NWC SAF Winds Intercomparison Study Report

Version 7

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1. Abstract

Previous Atmospheric Motion Vector (AMV) intercomparison studies, conducted from 2007 to 2009, compared the operational AMV algorithms of each of the satellite-derived wind producers using a common set of MSG/SEVIRI images and ancillary data. The studies assessed how the cloudy AMVs from the various wind producers compared in terms of coverage, speed, direction, and cloud height (Genkova et al. 2008; Genkova et al. 2010).

The goal of this study is to:

- Include the NWC SAF/HRW algorithm in the intercomparison studies, in order to quantify its performance, relative to the other AMV algorithms.
- Update the results of the previous AMV intercomparison studies because many of the operational AMV algorithms have changed since the last study.
- Perform follow up studies as identified in the previous intercomparison work, such as considering specific characteristics of the input data and AMV output.

2. Motivation

This project seeks to quantify the quality and identify unique attributes of the NWCSAF/HRW (High Resolution Winds) product with respect to AMVs provided by other operational centres. The results will guide new developments and enhancements for future updates to the HRW algorithm.

3. Case Study

The case study for the AMV experiments is a triplet of infrared (10.8μ) Meteosat-9, full–disk images from 17 September 2012 at 1200, 1215, 1230 UTC (Figure 1).

Additional 6.3μ, 7.2μ, 12.0μ and 13.4μ images for the same slots were also provided, in case AMV producers would like to use them for the AMV Height assignment procedure in Experiment 4.

Additional outputs from MPEF products “Scene Type and Quality” and “Cloud Analysis” for the same slots were also provided, also in case AMV producers would like to used for the AMV Height assignment procedure in Experiment 4.

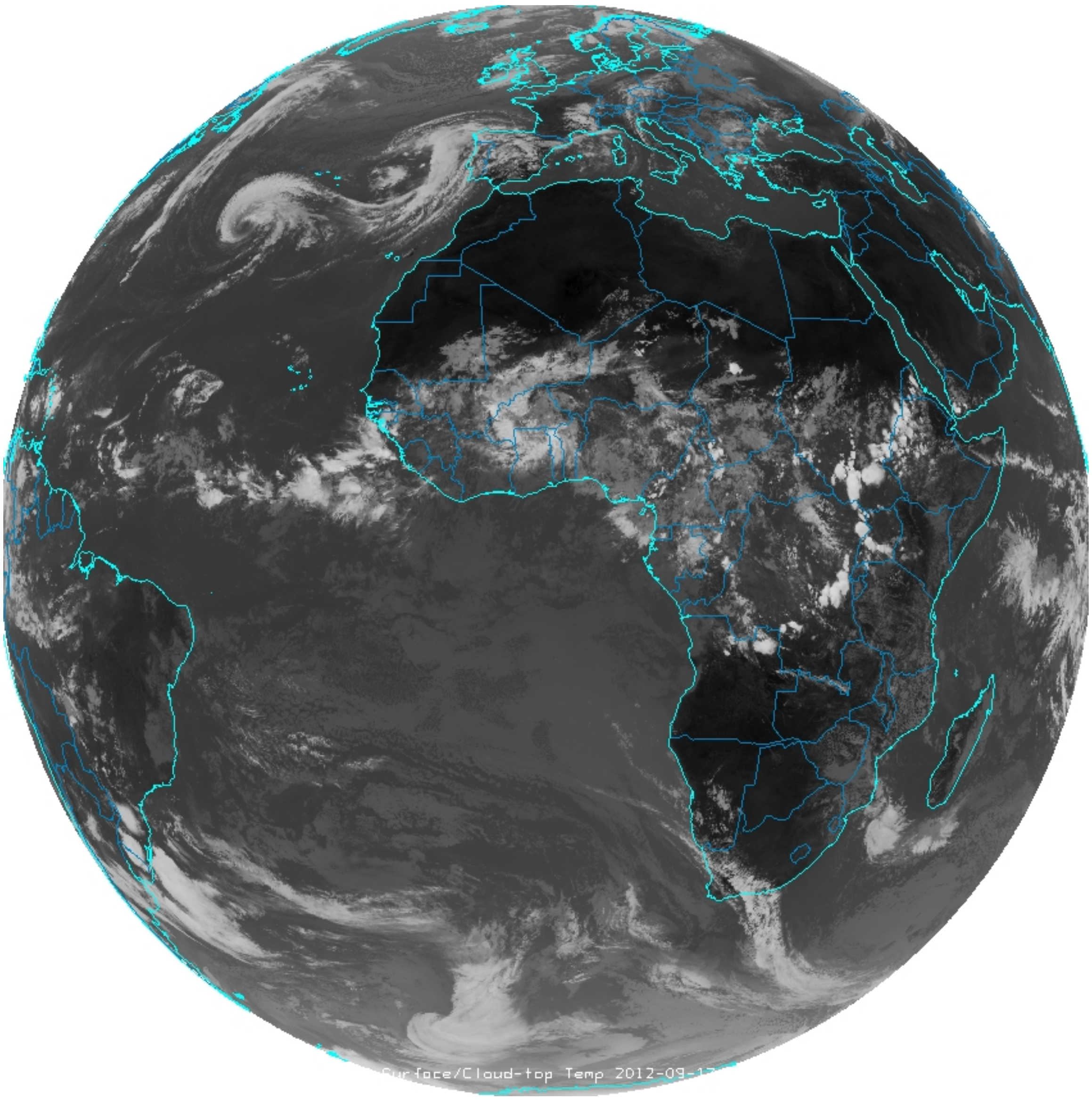

Figure 1: Meteosat-9 10.8 µm from 17 September 2012 at 1215 UTC.

4. Overview

Each of the four experiments is in a separate section, which include text from the proposal describing the experiment, the approach used in the analysis, highlights of the results, and figures, tables, and graphs supporting the results. Text that is in *italics* is extracted directly from the CIMSS proposal.

The approach taken began with the scripts used in the previous intercomparision studies (Genkova et al. 2008, 2010). This resulted in plots and statistics that can be compared and contrasted with the previous work.

In this new effort, an additional analysis was performed with a goal to quantify the differences in terms of statiscial significance. This was done using a paired t-test. While the Standard (Student's) t-test determines the likelihood a statistically significant difference exists between two data sets, a paired t-test assumes data points from the two different data sets are related. For example, a paired t-test is often used to compare before-and-after data sets because each "before" data point is paired with a specific "after" data point. In our case, each data point from center X was paired, by having both latitude and longitude coordinates within a specified distance, with its corresponding data point from center Y. For each of the comparisons, paired t-tests were calculated for several variables in each experiment in order to compare every combination of centers, with a 95% confidence setting.

5. Input Data Files

Each wind producer provided files containing the results of the experiments with the same parameters using a text file format. The text files contained semi-colon separated values, which were converted to 'space' separated values for easier reading by Matlab, Python, and bash scripts.

The wind producers are:

- EUM: EUMETSAT
- CMA: China Meteorological Administration
- JMA: Japan Meteorological Agency
- NOA: National Oceanic and Atmospheric Administration
- KMA: Korea Meteorological Administration
- NWC: Satellite Application Facility on Support to Nowcasting & Very Short Range Forecasting
- BRZ: Brazilian Meteorological Center

The three-letter abbreviations above are used throughout the remainder of this report.

The variables reported by the centres were the same, with these exceptions:

- BRZ did not report QI with forecast (QIWF)
- CMA did not report QI without forecast (QINF)
- JMA did not report speed for Experiment 1

The decimal precision of the values varied from centre to centre and is summarized in Table 1. Note: Even though the *precision* reported is not same for all centres, they should be within the expected *accuracy* in the measurements.

Table 1: The precision of values in the text files. The last column (Min.) is the minimum precision across all winds producers, for each parameter. This was updated 29 January 2014.

	BRZ	CMA	EUM	JMA	KMA	NOA	NWC	Min.
Latitude	2	2	4+	7+	5	2	4	2
Longitude	2	2	4+	7+	5	2	4	2
Speed	2	2	3+	6+	5	2	2	2
Direction	2	2	3+	6+	5	2	2	2
Height	2	0	3+	6+	5	2	2	0
Model speed	-	-	3	6+	5	2	2	2
Model direction	-	-	3	6+	5	2	2	2
Correlation	2	3	6	8	5	2	2	2
Height error	-	-	0+	-	-	2	2	0

The ancillary data consisted of two ECMWF forecast grids for the 12- and 18-hour forecast from 0000 UTC on 17 September 2012. It was subsected and reformatted by EUMETSAT to the Meteosat-9 domain with the following specifications:

- 135x135 grid centered at 0°N/0°E
- Domain: 67° S to 67° N; 67° E to 67° W
- 1° spatial resolution
- 40 vertical levels
- Parameters: pressure, geopotential height, temperature, water vapor mixing ratio, ozone mixing ratio, wind speed, wind direction, and dewpoint temperature.

Note: The NOAA AMV processing software requires additional parameters, so this background was not used. See the NOAA (NOA) section in the Summary of Wind Retrieval Algorithms for more details on the grids used.

6. Summary of Wind Retrieval Algorithms

The descriptions and configurations of the individual wind retrieval algorithms were extracted from information provided by each producer, in response to a questionnaire and follow up questions. This is incomplete at this time.

a) EUMETSAT (EUM)

EUM uses the first image as reference.

The 'standard' configuration (Exp. 2) and 'prescribed' configuration (Exp. 3) for EUMETSAT are identical.

b) China Meteorological Administration (CMA)

CMA uses the second image as reference.

Sub-pixel interpolation: *We activated the "subpixel tracking" in experiment 1. Our algorithm for the "subpixel tracking" is defined as: A pixel(col,row) which has maximum correlation coefficient in search box is found. In column direction of pixel(col,row), a parabolic fitting is calculated with five pixels,(col,row-2),(col,row-1),(col,row),(col,row+1),(col,row+2). The position of the parabola vertex is the "subpixel tracking" result of column. In row direction, five pixels, (col-2,row), (col-1,row), (col,row), (col+1,row), (col+2,row) are used to calculated.*[1]

c) Japan Meteorological Agency (JMA)

JMA uses the second image as reference.

Sub-pixel interpolation: This is done *by using polynomial fitting (f(x,y) = a x^2 + b y^2 + c x + d y + e) for sub-pixel estimation. Five cross-correlation values locating at center and 4 neighboring grid points are used for determining five coefficients.*[2]

d) NOAA (NOA)

NOA uses the second image as reference.

The new algorithm designed for GOES-R, Motion Cluster Tracking (MCtrack), was used to derive AMVs instead of the operational winds package that runs in the NOAA/National Environmental Satellite, Data, and Information Service

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[1] Provided by CMA 24 March 2014

[2] Provided by JMA 23 March 2014

(NESDIS) operations. MCtrack requires additional parameters over what was provided in the standard grid. Due to the required background grids for MCtrack, grids from ECMWF and NCEP's Global Forecast Syatem (GFS) were combined. The additional grids from the GFS were: surface snow, total ozone, tropopause temperature, tropopause pressure, and the depth of the Planetary Boundary Layer (PBL). The resulting grids were at 25 levels, instead of the 40 levels used by the other providers.

e) Korea Meteorological Administration (KMA)

KMA uses the second image as reference.

f) NWCSAF (NWC)

NWC uses the first image as reference.

Sub-pixel interpolation: *It is based on a quadratic (second order) interpolation in both lines and columns. In each one of the cases the correlation of three pìxels is taken into account:*

- *In the line fitting: (col,row-1),(col,row),(col,row+1) are taken into account.*
- *In the column fitting: (col-1,row),(col,row),(col+1,row) are taken into account.*[3]

g) Brazilian Meteorological Center (BRZ)

BRZ uses the second image as reference.

7. Experiment 1

AMV producers extract IR10.8 channel AMVs considering a triplet of images with a known displacement. This experiment will be used to test the Tracking step in all AMV algorithms.

Since the triplet of images is identical, this experiment will give insight to the behavior of the various tracking algorithms. Each AMV producer has unique code to pattern-match each feature in the target image with the same feature in the other two images. With all the images being identical, the pattern match will be perfect. However, the speed and direction of the feature may not be the same from the different AMV producers, for the following reasons:

[3] Provided by NWCSAF 26 March 2014

a) *The differing methods used to identify the target and subsequent best match in the other images. For example, are the target and search boxes even or odd dimensioned; how does that impact identifying the 'center' pixel?*
b) *The implementation of the image geolocation (line/element => latitude/longitude) may not be exactly the same and could introduce a small difference or bias in tracking.*
c) *Determining latitude/longitude displacements is usually done using a great circle computation, but some centers may use an approximation to the great circle. This may result in small differences in the speed and direction.*

For colocated targets, we will not only examine these 'artificial' AMVs to quantify differences in the tracking algorithms (a), but also attempt to identify differences due to factors (b) and (c).

<u>Experiment 1 Highlights</u>
A fixed displacement of four elements and two lines were applied to a single image in order to create an artificial triplet. This tests the tracking differences between the data producers.

There were two positive results:

- All AMV algorithms detected this shift correctly, generally with no more than 0.1 pixel error (with sub-pixel tracking turned on). See Figure 2 to Figure 8.
- There were 10876 colocated vectors using a distance threshold of 35 km. The differences of horizontal and vertical displacements between EUM and each of the other centres were not statistically significant (Table 2 and Table 3).

Two sites, BRZ and CMA, appear to have an AMV speed dependence on distance from satellite subpoint (Figure 11 and Figure 15), which may be due to an approximation of the great circle to compute distance. Both centres might be in the need to investigate the reasons for this behaviour.

a) Approach

The text files contain line and element displacements of the tracked features. Since the images were artificially displaced by a constant of four elements and two lines, it was expected that the text files will contain the constant shift. Generating histograms of the line and element displacements and computing the mean of the displacements from each producer would verify this. If the shift were not constant, that information would be communicated to the producer, since it indicates there may have been an issue with the tracking algorithm.

To further quantify, colocated AMVs were examined with the expectation that the speed and direction of the colocated AMVs would be nearly the same. Any differences noted would most likely have been due to (b) and (c) above, and/or how the final vector was determined (average of two intermediate vectors, second vector, etc.). Differences due to computing the distance from latitude/longitude displacements (c) can be explained if the producers use different methods (great circle vs. and approximation). Differences due to geolocation computation (b) would be difficult to determine, since we don't have the image line/element position corresponding to the latitude/longitude of the AMV.

A statistical analysis of the differences for colocated AMVs of pixel displacement, speed, direction, was performed to determine if the differences are significant. Any significant differences found here were used to explain findings in the subsequent experiments.

b) Pixel displacement distributions

Each center reported pixel displacement for tracking the artificially shifted images in terms of a horizontal and vertical displacement. This was done for each image pair of the triplet. In the following figures, HDISP1 and HDISP2 are the horizontal displacements for image pair one and two; VDISP1 and VDISP2 are the vertical displacements. The sign of the displacements are dependent on which image was used for targeting: first image vs. middle image.

The images were shifted by four elements and two lines, for a total displacement of eight elements and four lines between images one and three. Histograms of each displacement are shown in Figure 2 through Figure 8. Three centres (EUM, CMA, BRZ) reported all displacements exactly as shifted.

NOA and NWC also detected the shift correctly, however they had a very small percentage of outliers. For NOA, the outliers were due to a software error, which has since been corrected. For NWC, the outliers were due to the "Quick correlation method" used by HRW algorithm (Xu and Zhang 1996), in which the correlation is initially calculated for only one of every eight pixels, and later refined to all pixels around the correlation maxima. This method substantially reduces the algorithm running time, which is necessary for running in minimal computing environments, while only causing incorrect tracking for approximately 0.05% of all AMVs (i.e, 1 AMV of every 2000).

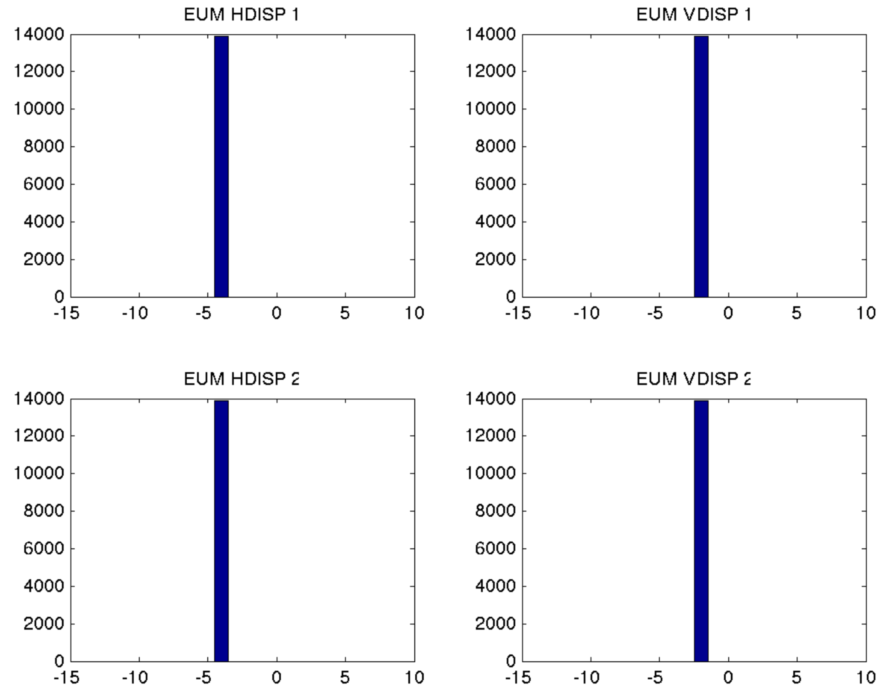

Figure 2: EUM: 13890 AMVs. Shift detected correctly for all.

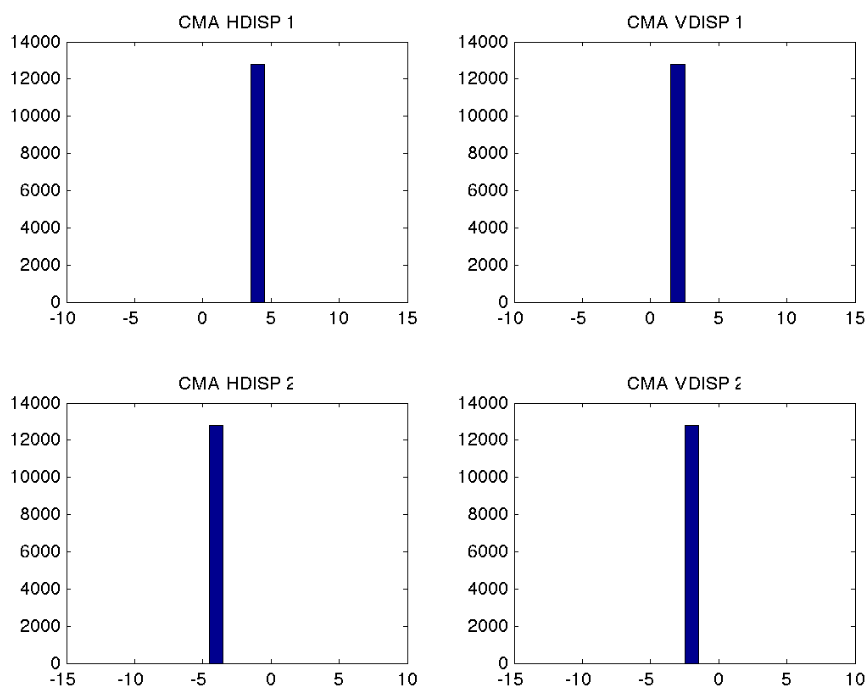

Figure 3: CMA: 12769 AMVs. Shift detected correctly for all.

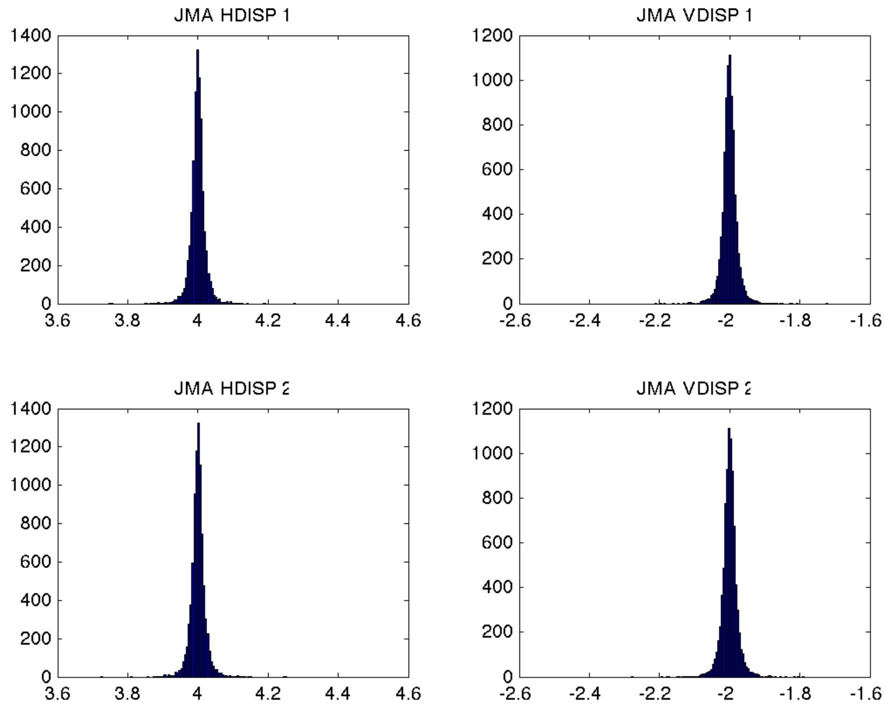

Figure 4: JMA: 8540 AMVs. Sub-pixel variations are nearly all within 0.1 pixels of the mean.

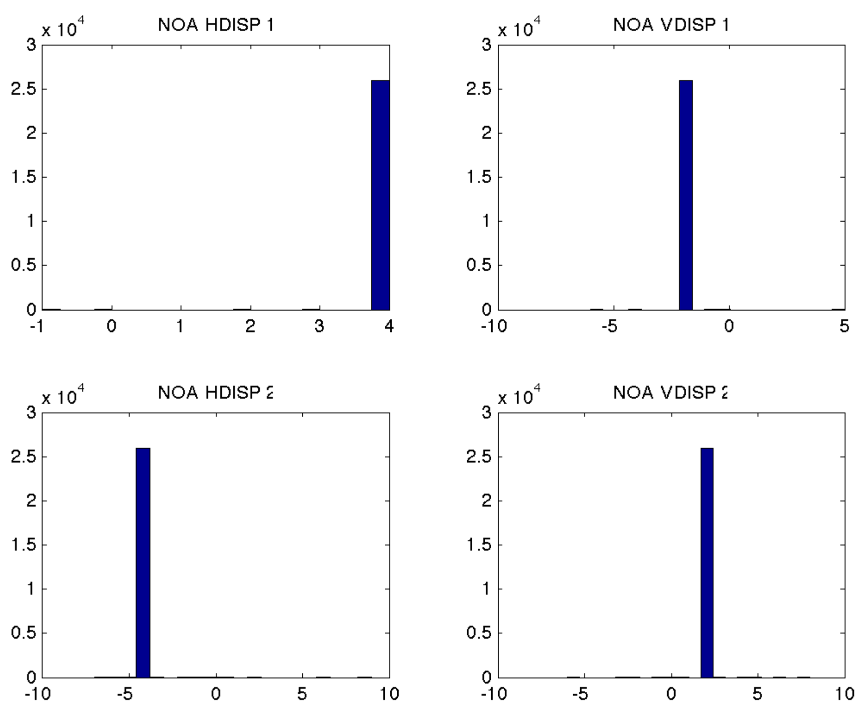

Figure 5: NOA: 25958 AMVs. Nearly all displacements are correct, however, there are some outliers.

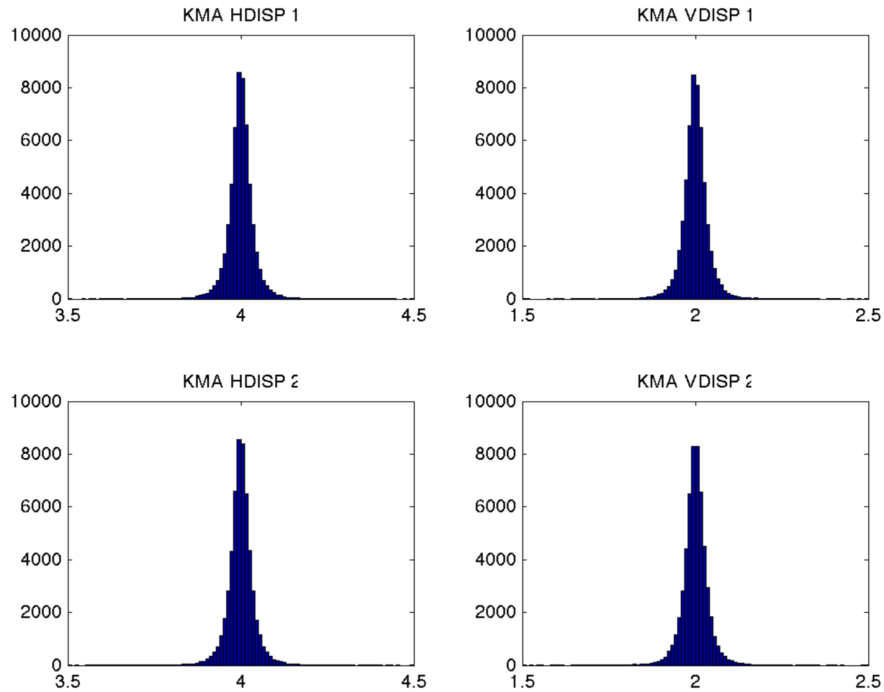

Figure 6: KMA: 55200 AMVs. Sub-pixel variations are all within 0.1 pixels of the mean.

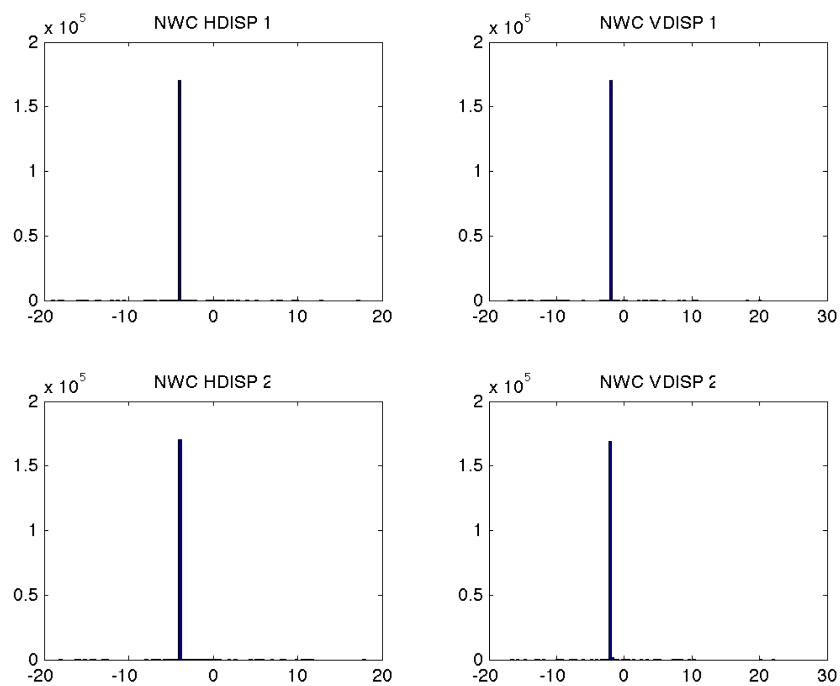

Figure 7: NWC: 170775 AMVs. Nearly all displacements are correct, however, there are some outliers.

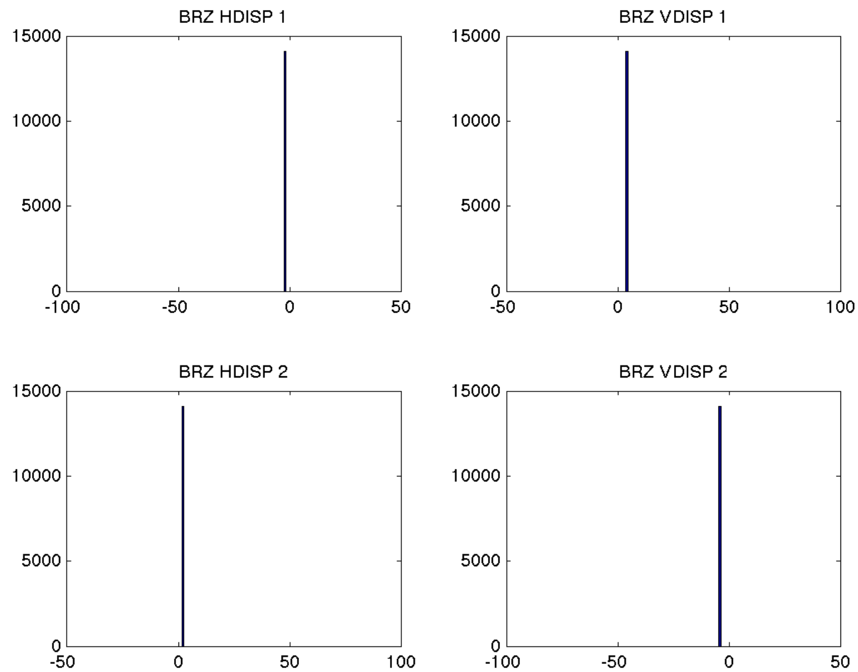

Figure 8: BRZ: 14116 AMVs. Shift detected correctly for all.

c) Colocation differences

The distribution of pixel displacements in the previous section found only very small deviations (generally less than 0.1 pixel) from the true displacement. But, how does a 0.1 pixel shift translate into velocity? For Meteosat-9, a one-pixel shift[4] at:

- The satellite subpoint is 3 km
- 50°N 50°W is 12 km
- 60°N 60°W is 33 km

To convert km/(15 minutes) to ms^{-1}, multiply by: 1.11. Therefore, a 0.1 pixel shift is:

- 0.3 ms^{-1} at the subpoint
- 1.3 ms^{-1} at 50°N 50°W
- 3.6 ms^{-1} at 60°N 60°W

This implies that precise tracking, accurate geolocation, and the computation of distance are essential as even 0.1 pixel error will result in a 0.3 to 3.6 ms^{-1} error in the wind speed, depending on the distance from the satellite subpoint.

Histograms of speed (Figure 9) and direction (Figure 10) differences (as compared to EUM) were generated for all centers, except JMA who did not report wind speed. Utilizing a distance threshold of 35 km to define colocation while not filter QI, resulted in 10876 AMVs.

Speed differences between EUM and NOA, KMA, NWC had a zero bias and a range within ±0.2 ms^{-1} (Figure 9). However, differences were noted between EUM with CMA and BRZ:

- CMA: There is a 0.5 ms^{-1} slow bias in the CMA AMV speed compared to EUM (upper-left Figure 9) and a broader wind direction difference (compared to the other centres) shown in the upper-left of Figure 10. Since EUM and CMA reported exactly the same pixel displacements, this speed bias may be due a truncation in the distance calculation.
- BRZ: The frequency plot of AMV speed difference of BRZ-EUM (lower-left Figure 9) shows a peak at 0.0 ms^{-1}, however there are two smaller peaks: at +2 ms^{-1} and -2.5 ms^{-1}. As with CMA, the pixel displacements for BRZ are the same as EUM, so this speed (and direction) difference implies an error in calculating distance.

[4] As measured using the Man computer Interactive Data Access System (McIDAS)

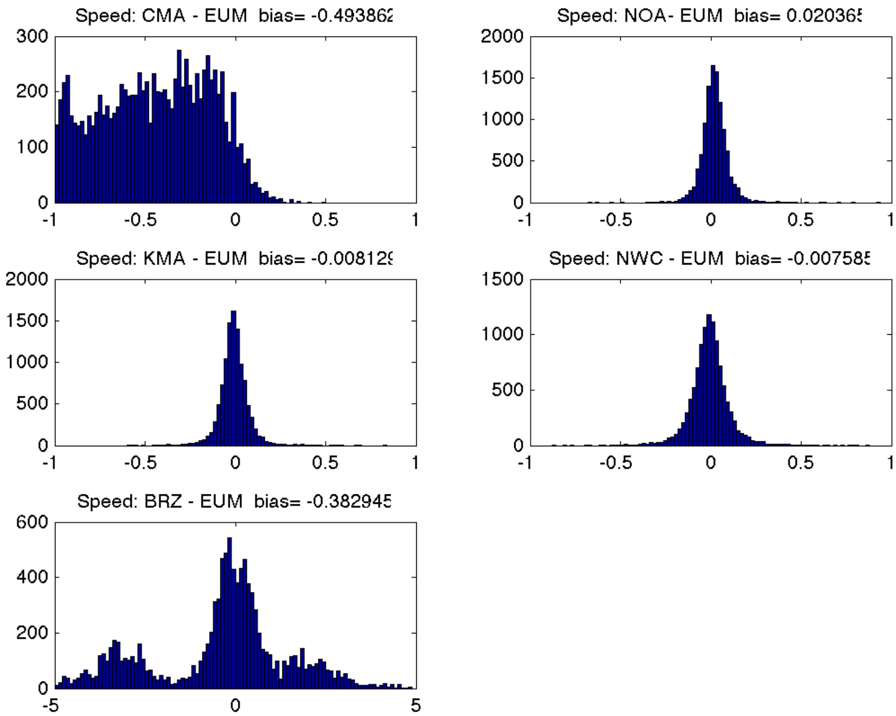

Figure 9: Experiment 1 speed difference distribution, as compared to EUM. JMA did not provide speed.

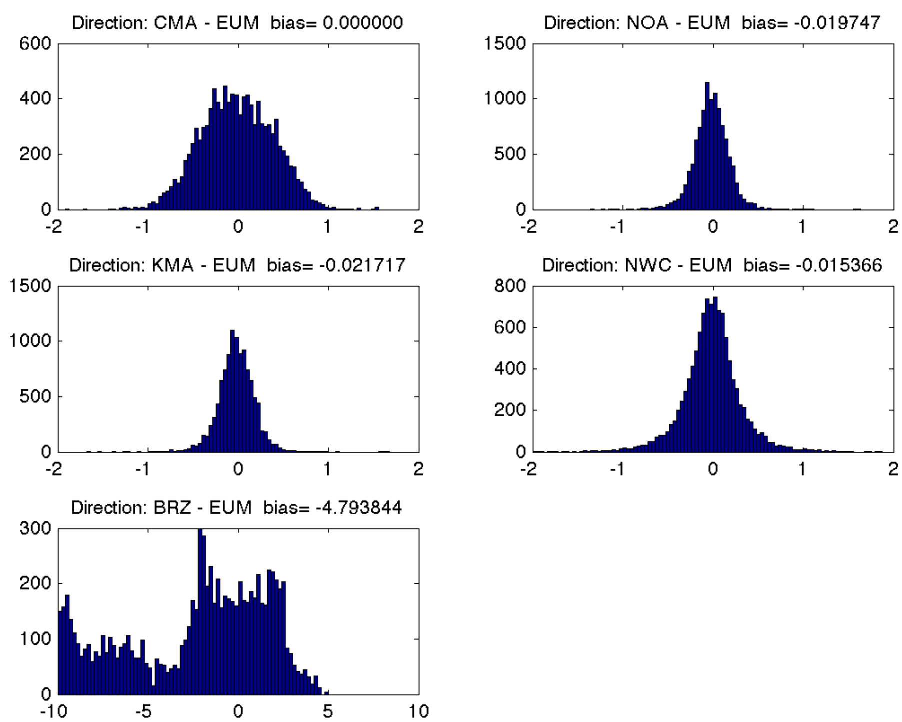

Figure 10: Experiment 1 distribution of direction difference as compared to EUM. JMA was not included.

To further investigate reasons for the differences in the speed for BRZ and CMA, scatter plots of the speed difference (*centre*-EUM) as a function of latitude and longitude were examined. There is no evidence of latitude or longitude dependency on the speed difference for NWC, NOA, KMA (Figure 12, Figure 13 and Figure 14). However, Figure 11 depicts a significant dependence of the speed difference on latitude and longitude between EUM and BRZ. AMV producers at BRZ centre might be in the need to investigate the cause of this behaviour. Also, the speed difference of CMA-EUM does show some relationship to latitude and longitude (Figure 15). Since, the difference is nearly all negative values, it may be due to truncation in the distance calculation.

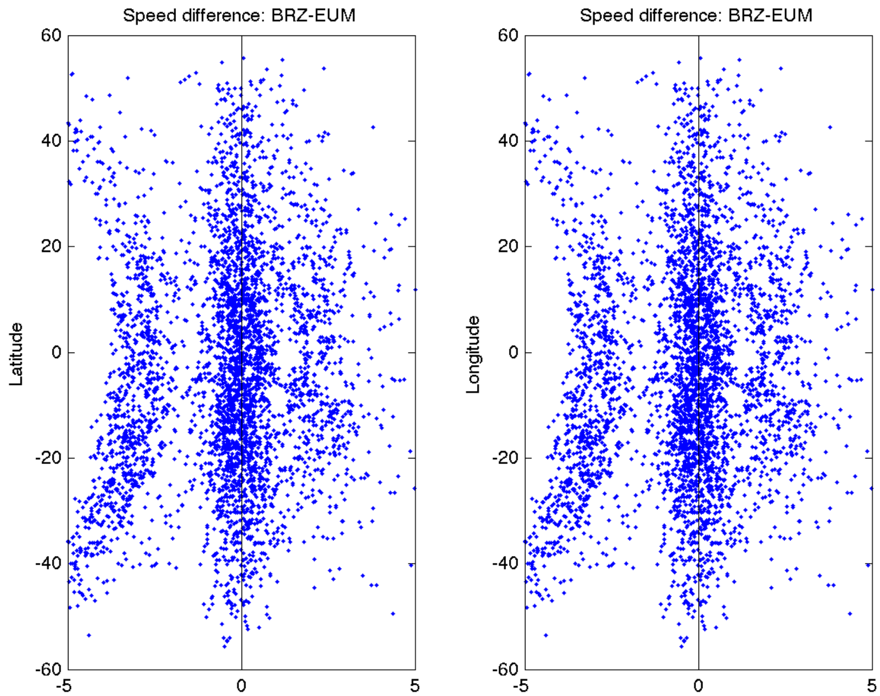

Figure 11: Experiment 1: Latitude vs. Speed difference BRZ-EUM (left); Longitude vs. Speed difference BRZ-EUM (right).

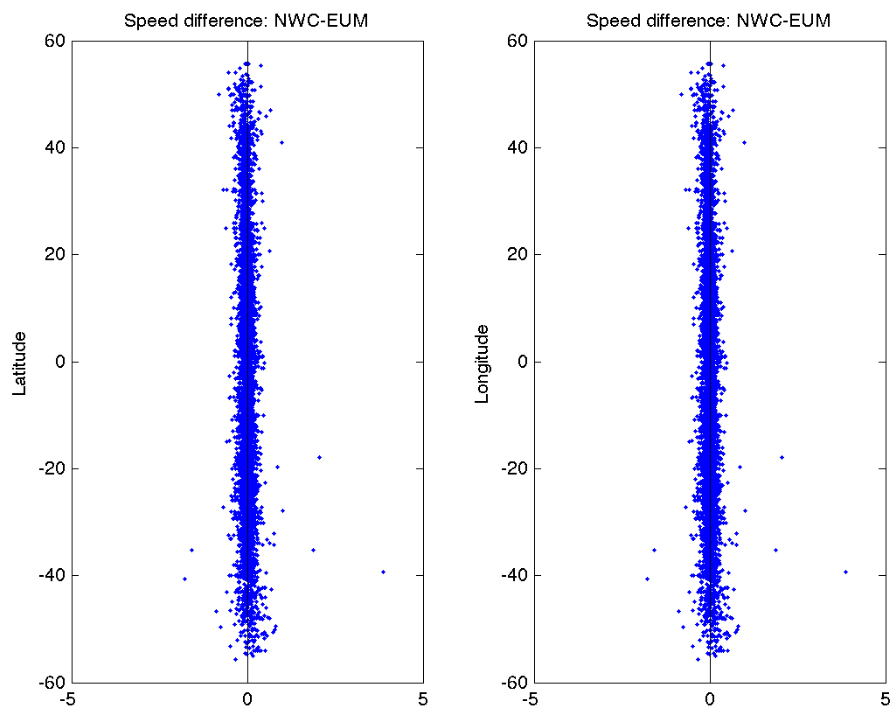

Figure 12: Experiment 1: Latitude vs. Speed difference NWC-EUM (latitude); Longitude vs. Speed difference NWC-EUM (longitude).

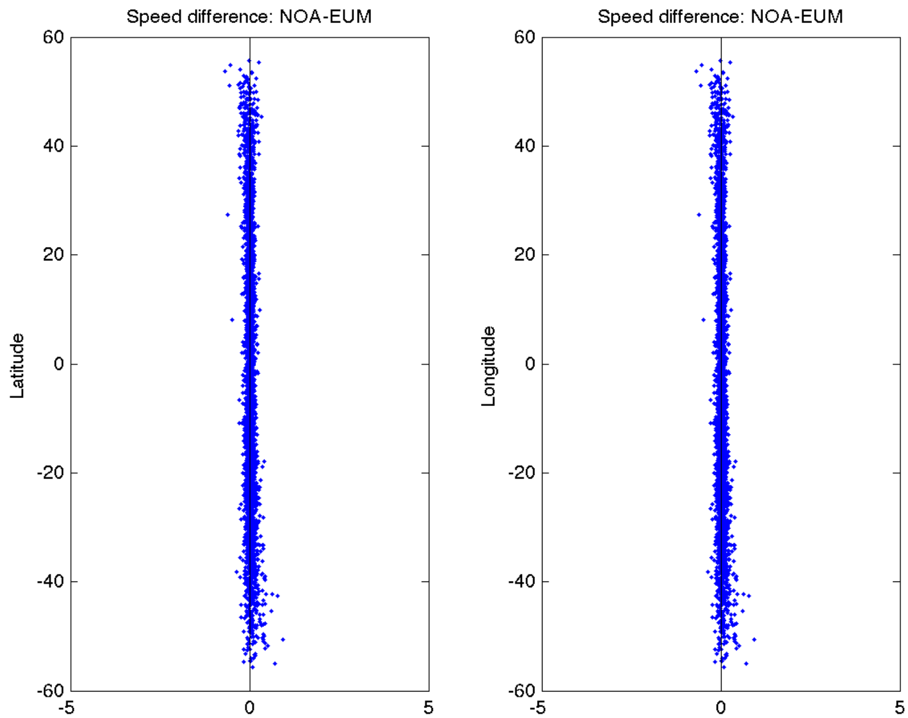

Figure 13: Experiment 1: Latitude vs. Speed difference NOA-EUM (left); Longitude vs. Speed difference NOA-EUM (right).

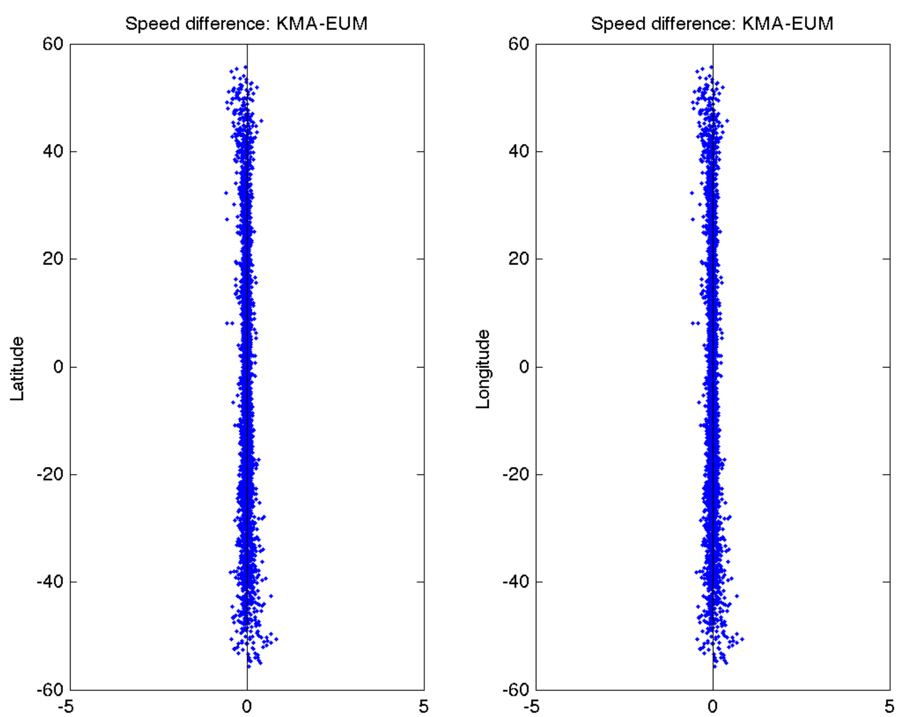

Figure 14: Experiment 1: Latitude vs. Speed difference KMA-EUM (left); Longitude vs. Speed difference KMA-EUM (right).

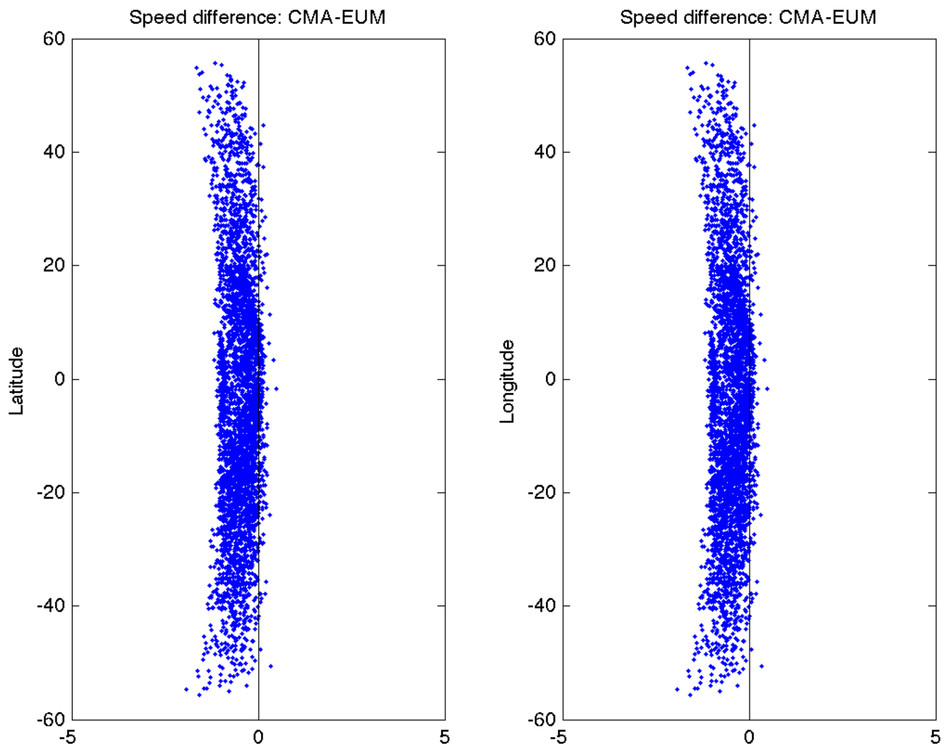

Figure 15: Experiment 1: Latitude vs. Speed difference CMA-EUM (left); Longitude vs. Speed difference CMA-EUM (right).

d) Statistical comparison

To quantify the observed differences in the previous plots, a paired t-test was used with all combinations of producers (and parameters) to determine if the differences are statistically significant for colocated AMVs. This was done using the Matlab *ttest* function, which performs a t-test of the hypothesis that the data come from a distribution with mean zero (see Appendix B: t-test Results for more details). The data in this case are differences between the parameters from each pair of data producers; therefore, a mean of zero is expected. In the following tables, green indicates no statistical difference between the centers at the 95% confidence level and red symbolizes a statistical difference.

All AMVs were considered; there was no filtering based on QI. The distance threshold is 35 km, resulting in 10876 colocated vectors.

For the horizontal and vertical displacements all the algorithms detected the shift correctly (Table 2 and Table 3): There is no statistical difference between the different centres.

The speed is statistically different between all centers, except for NWC compared to EUM and NOA (Table 4). Table 5 shows that direction is not statistically different between NWC with EUM, KMA, CMA, NOA and CMA with NOA. Complete output from the t-test can be found in Appendix B: t-test Results: Experiment 1 t-test Results.

Table 2: Experiment 1 horizontal displacement t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA	BRZ
EUM							
KMA							
CMA							
NOA							
NWC							
JMA							
BRZ							

Table 3: Experiment 1 vertical displacement t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA	BRZ
EUM							
KMA							
CMA							
NOA							
NWC							
JMA							
BRZ							

Table 4: Experiment 1 speed t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different. JMA did not report speed.

	EUM	KMA	CMA	NOA	NWC	JMA	BRZ
EUM							
KMA							
CMA							
NOA							
NWC							
JMA							
BRZ							

Table 5: Experiment 1 direction t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different. JMA was not included.

	EUM	KMA	CMA	NOA	NWC	JMA	BRZ
EUM							
KMA							
CMA							
NOA							
NWC							
JMA							
BRZ							

8. Experiment 2

AMV producers extract IR10.8 channel AMVs considering their standard AMV algorithm configuration, but only using the MSG/SEVIRI IR10.8 images and the ECMWF model data for the Height assignment. This experiment will be used to test the Target selection, Tracking and Quality control steps in all AMV algorithms.

The standard AMV configuration defines target scene size, search scene size, etc. to be the typical settings used by each AMV producers.

For each one of the AMV producer's datasets, a distribution of AMV speed, direction, vector height, and QI will be generated. Differences of these quantities between AMV producers will be made. Also, differences in AMV coverage and number of vectors will be presented as bulk statistics and geographic plots.

Colocated AMVs from the different algorithms will be used to measure the differences. Also, a comparison of the AMVs with the NWP model winds and height assignment investigations using NWP model best-fit pressure will be used for verification.

Experiment 2 Highlights

The bulk distribution of AMV height is highly variable among the different centres, which is surprising since they are required to use only the IR brightness temperature. This indicates the variability is probably due to how the representative T_B is determined.

There are 7050 colocated AMVs (QI no forecast > 50). EUM is not statistically different with NWC and JMA and differences among all other centres are usually 0.3 to 1.0 ms^{-1}. Assigned pressures are all statistically different; with differences ranging from 30 to 80 hPa. However, the largest difference appear when compared to EUM: up to 130 hPa.

When the AMVs are compared to rawinsondes, NWC has the lowest error while BRZ and EUM have the highest: Vector RMS ranges from 6 ms^{-1} (NWC) to 9 ms^{-1} (BRZ,EUM) and the speed RMS ranges from 4.5 ms^{-1} (NWC) to 7 ms^{-1} (EUM).

For EUM:
- The distribution of AMV heights (high-level winds are too low; low-level winds are too high),
- The large differences of heights compared to other centres, and
- Large errors compared to rawinsondes.

All point to the IR brightness temperature height assignment as not performing well.

a) Approach

This experiment tested the target selection and tracking from the different winds producers. The AMVs should have been the best in terms of speed and direction from each producer, as the standard configuration for target and search boxes is used. However, only a single channel was used for cloud height.

This test was similar to Study 1 (Genkova et al. 2008):
- Only used SEVIRI 10.8 μm channel
- Producers used their algorithm and operational settings
- Used ECMWF grids (although, in the first part of Study 1 the producers used their usual grids).
- Colocated AMVs in Study 1 were within 0.5° of latitude and longitude; in this study the distance is 55 km. Using distance provides a more precise colocation, especially in high latitudes.

The Genkova scripts, now including NWC, were used to do similar comparison and analysis as before.

In addition, two new analysis methods were used to quantify any observed differences between producers:

- Used the best fit analysis to further analyze differences in cloud heights,
- Computed paired t-test to determine if the observed differences in colocated AMVs are statistically significant.

b) Parameter distributions

The bulk statistics are presented in both tables and histograms, for QINF >= 50 and QIWF >= 50 (because not all centres reported both QINF and QIWF). Note: Since there are little differences in filtering based on QINF or QIWF, QINF >= 50 will be used for the following discussions (except for CMA which only reported QIWF).

Table 6 lists basic Experiment 2 statistics for the AMVs for each winds producer. Most of the values in this table are approximately the same, with the largest variation being in the number of AMVs, ranging from 6000 (JMA) to 90000 (NWC).

Table 6: Experiment 2 statistical summary of AMV datasets for QINF >= 50.

	EUM	BRZ	JMA	KMA	NOA	NWC
Total AMVs	12053	7126	6219	48046	11651	90816
QI>=50	9074	2170	5465	40823	10615	75888
SPD_min	2.51	3.06	2.51	2.50	3.00	2.50
SPD_max	78.59	63.00	74.22	60.59	67.30	75.12
SPD_mean	12.50	12.17	11.35	11.90	12.86	12.10
P_min	127.56	19.00	208.68	110.00	138.93	57.41
P_max	1015.02	1000.00	995.88	1000.00	998.35	995.92
P_mean	696.32	591.30	676.19	620.50	508.37	574.97
Low_winds	57.43	47.14	57.31	45.89	21.31	38.68
Mid_winds	32.35	19.12	24.96	32.29	44.58	34.45
High_winds	10.23	33.73	17.73	21.82	34.11	26.88
Low_SPD_min	2.51	3.06	2.51	2.50	3.00	2.50
Low_SPD_max	78.59	39.96	54.92	58.38	27.77	52.05
Low_SPD_mean	9.70	7.75	8.87	9.20	8.55	8.28
Low_P_min	700.04	700.16	850.00	700.01	700.09	700.00
Low_P_max	1015.02	1000.00	995.88	1000.00	998.35	995.92
Low_P_mean	846.41	813.13	866.68	825.78	778.17	785.40
Mid_SPD_min	2.51	3.27	2.51	2.50	3.01	2.50
Mid_SPD_max	77.62	42.78	74.22	60.59	58.15	70.63
Mid_SPD_mean	15.81	10.18	14.43	13.16	11.95	12.17
Mid_P_min	400.08	400.21	400.18	400.01	400.07	400.01
Mid_P_max	699.95	699.94	643.92	699.99	699.80	699.98
Mid_P_mean	546.02	601.94	489.21	552.15	529.06	570.45
High_SPD_min	2.55	3.46	2.51	2.50	3.02	2.50
High_SPD_max	71.68	63.00	60.07	56.96	67.30	75.12
High_SPD_mean	17.73	19.48	15.06	15.70	16.75	17.50
High_P_min	127.56	19.00	208.68	110.00	138.93	57.41
High_P_max	399.92	399.63	399.93	400.00	399.98	399.99
High_P_mean	328.90	275.26	323.72	289.91	312.80	277.99

The following bulk histograms show unique characteristics of the AMVs for each centre:

- BRZ (Figure 16): The wind direction (lower-left) is not a smooth distribution. Conversely, it has two very sharp peaks. The AMV pressure distribution (lower-right) has peaks at 300 and 770 hPa. Upper-level winds at 300 hPa is reasonable, but the 770 hPa peak is probably too high for low-level clouds.
- EUM (Figure 17): The AMV pressure distribution has a peak at 500 and 800 hPa. The upper level winds are too low, while the low-level winds are too high.
- JMA (Figure 18): The AMV pressure distribution has a peak at 500 and 850 hPa. The upper level winds are too low, while the low-level winds are placed well. There is also a noticeable gap in mid-level winds.

- KMA (Figure 19): The AMV pressure distribution has a peak at 450 and 800 hPa. The upper level winds are too low, while the low-level winds are too high.
- NOA (Figure 20): The AMV pressure distribution has a peak at 400 and 780 hPa. The upper level winds are too low, while the low-level winds are too high.
- NWC (Figure 21): The AMV pressure distribution has a peak at 400 and 780 hPa. The upper level winds are too low, while the low-level winds are too high.
- CMA (Figure 22): The AMV pressure distribution has a peak at 380 and 760 hPa. The upper level winds are too low, while the low level winds are too high. Also, there are many mid-level clouds compared to other centres.

Since only the IR brightness temperature is used in this experiment, the wide variation in cloud heights can be attributed to different techniques and thresholds in determining a representative T_B.

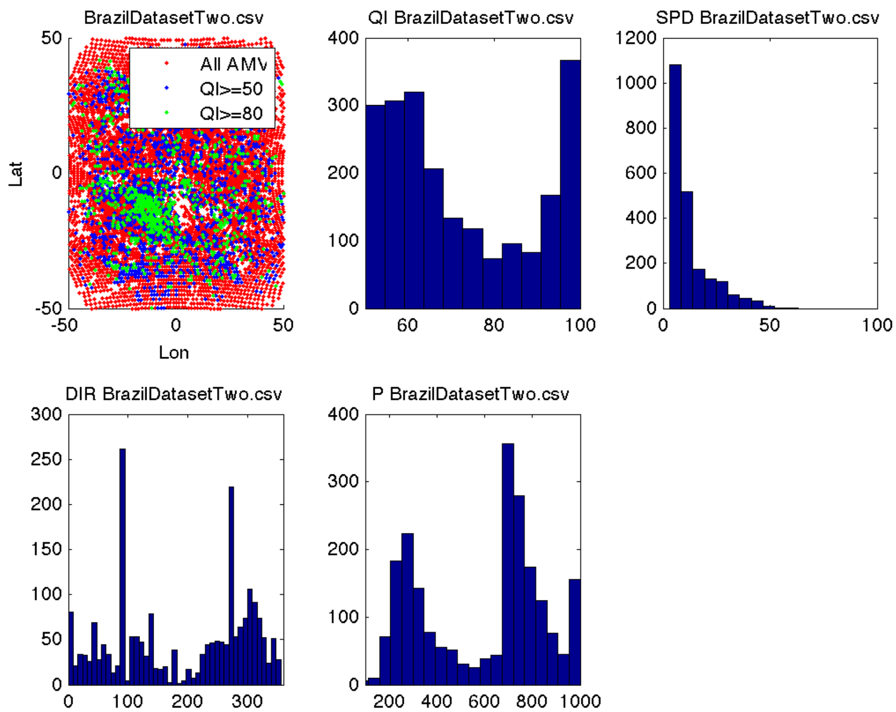

Figure 16: Experiment 2 parameter distributions for BRZ: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

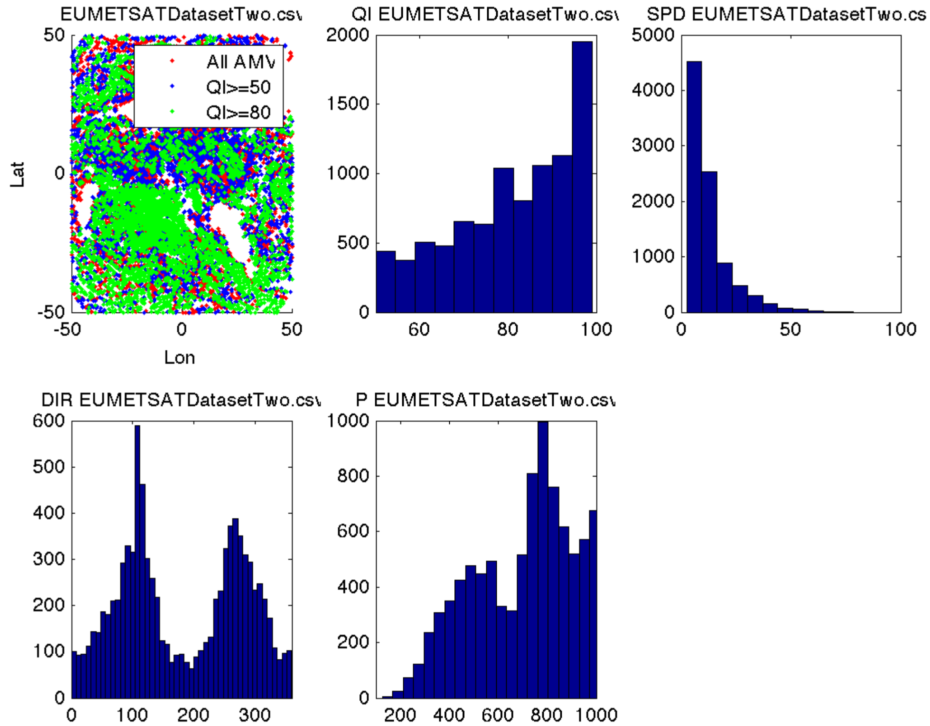

Figure 17: Experiment 2 parameter distributions for EUM: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

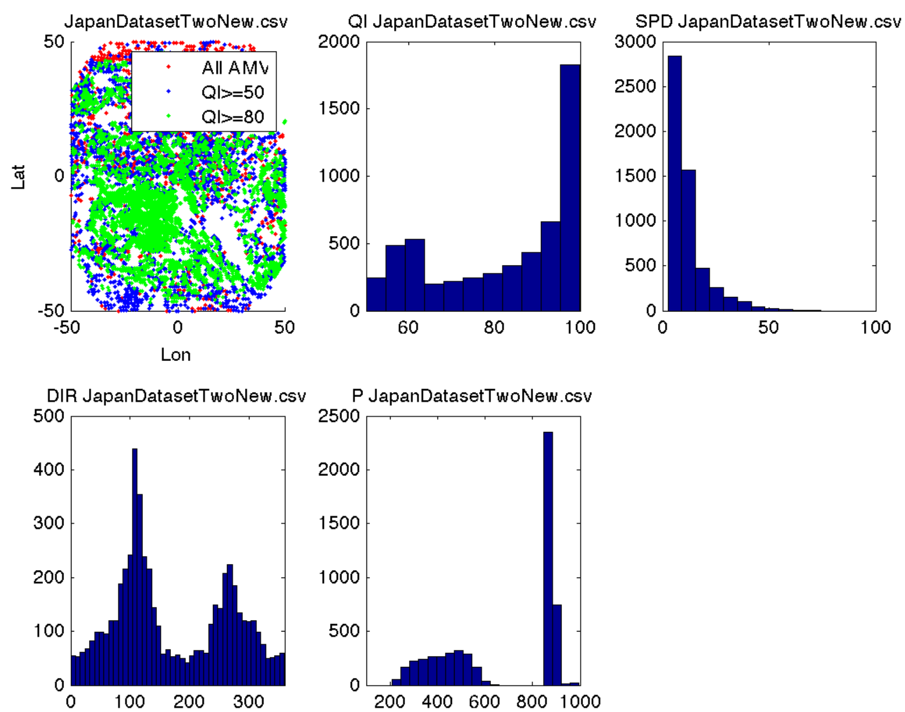

Figure 18: Experiment 2 parameter distributions for JMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

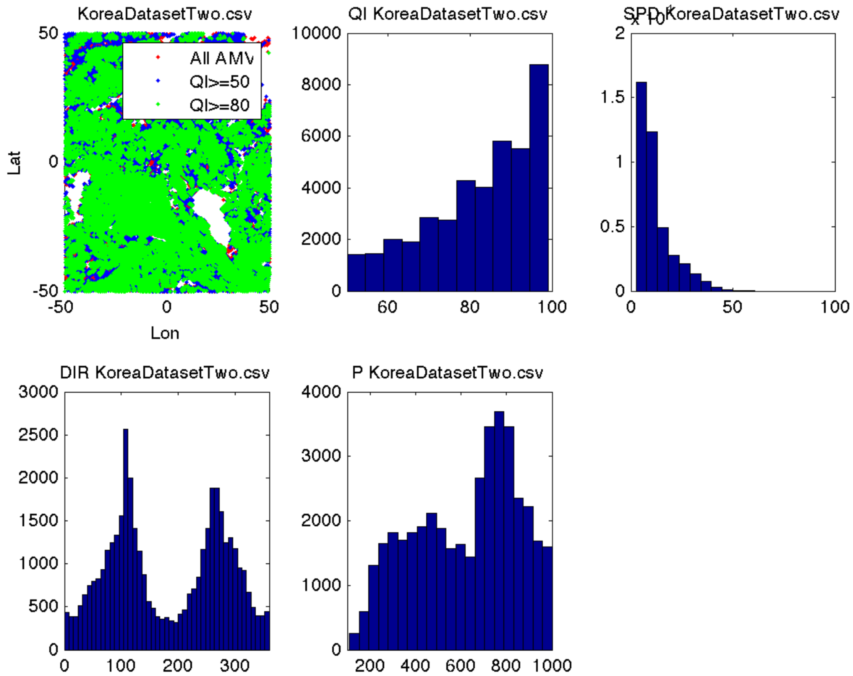

Figure 19: Experiment 2 parameter distributions for KMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

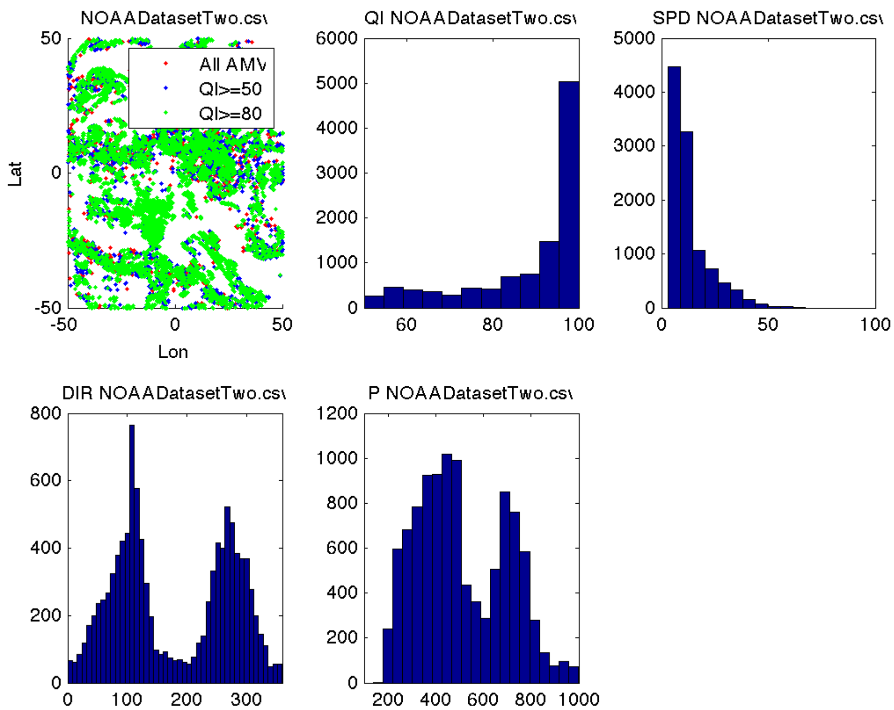

Figure 20: Experiment 2 parameter distributions for NOA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

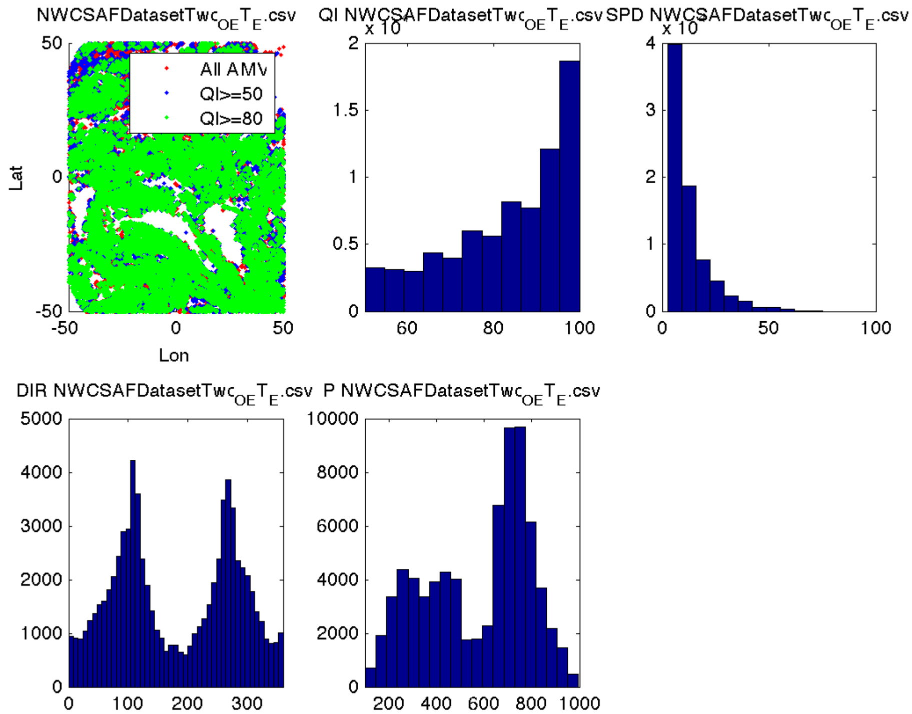

Figure 21: Experiment 2 parameter distributions for NWC: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

The following table and plots are for QIWF >= 50. These are very similar to the plots for QINF >= 50.

Table 7: Experiment 2 statistical summary of AMV datasets for QIWF >= 50.

	EUM	CMA	JMA	KMA	NOA	NWC
Total AMVs	12053	4920	6219	48046	11651	90816
QI>=50	9260	4915	5161	39215	10276	75055
SPD_min	2.51	3.19	2.51	2.50	3.00	2.50
SPD_max	78.59	76.58	74.22	60.59	67.30	75.12
SPD_mean	12.37	19.79	11.29	12.02	12.86	12.20
P_min	127.56	150.00	208.68	110.00	138.93	57.41
P_max	1015.02	949.00	995.12	1000.00	998.35	995.92
P_mean	695.49	477.82	680.19	620.83	510.56	574.35
Low_winds	57.22	14.73	58.52	45.90	21.78	38.66
Mid_winds	32.42	43.93	23.89	32.35	44.30	34.25
High_winds	10.36	41.34	17.59	21.75	33.92	27.09
Low_SPD_min	2.51	3.19	2.51	2.50	3.00	2.50
Low_SPD_max	78.59	28.51	54.92	42.63	27.77	52.05
Low_SPD_mean	9.65	8.98	8.75	9.24	8.54	8.32
Low_P_min	700.04	700.00	850.00	700.01	700.09	700.00
Low_P_max	1015.02	949.00	995.12	1000.00	998.35	995.92
Low_P_mean	846.30	787.30	866.28	825.61	777.38	786.49
Mid_SPD_min	2.51	3.19	2.51	2.50	3.01	2.50
Mid_SPD_max	77.62	76.58	74.22	60.59	55.56	70.63
Mid_SPD_mean	15.60	17.52	14.52	13.28	11.90	12.27
Mid_P_min	400.08	401.00	400.18	400.01	400.07	400.01
Mid_P_max	699.95	699.00	643.92	699.99	699.80	699.98
Mid_P_mean	546.69	546.19	487.68	551.93	530.59	569.12
High_SPD_min	2.54	3.31	2.51	2.50	3.02	2.50
High_SPD_max	71.68	75.48	60.07	56.96	67.30	75.12
High_SPD_mean	17.33	26.06	15.36	16.01	16.88	17.63
High_P_min	127.56	150.00	208.68	110.00	138.93	57.41
High_P_max	399.92	400.00	399.93	400.00	399.98	399.99
High_P_mean	327.97	294.91	322.69	291.22	313.12	278.18

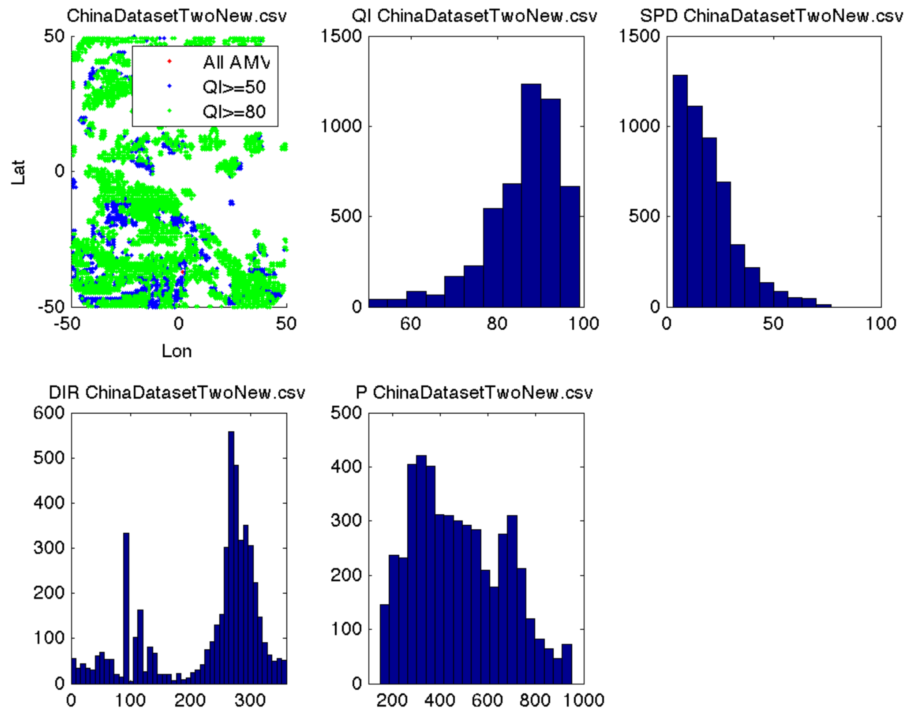

Figure 22: Experiment 2 parameter distributions for CMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

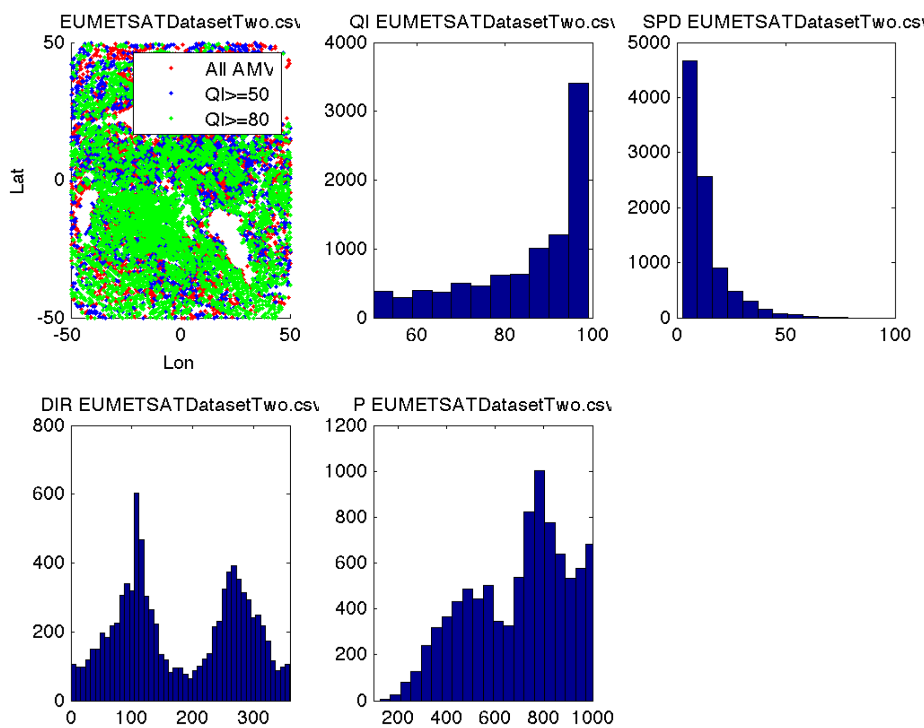

Figure 23: Experiment 2 parameter distributions for EUM: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

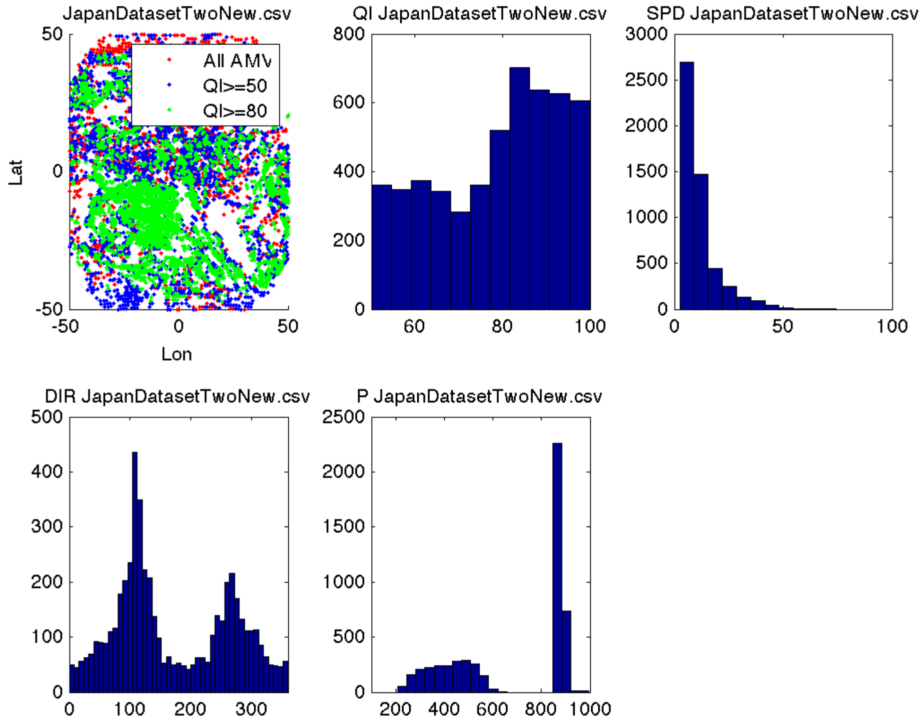

Figure 24: Experiment 2 parameter distributions for JMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

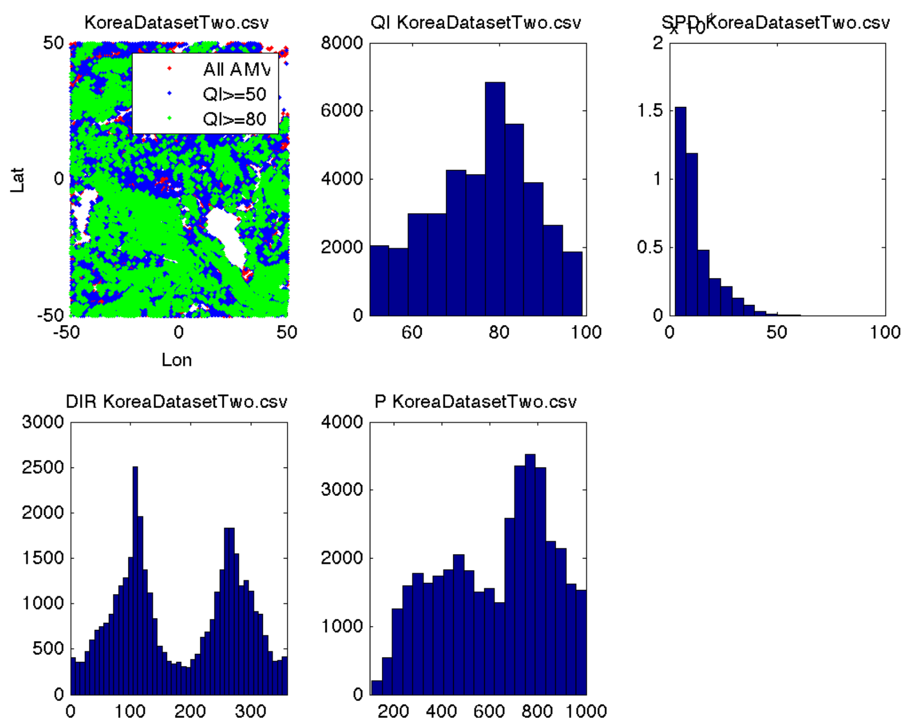

Figure 25: Experiment 2 parameter distributions for KMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

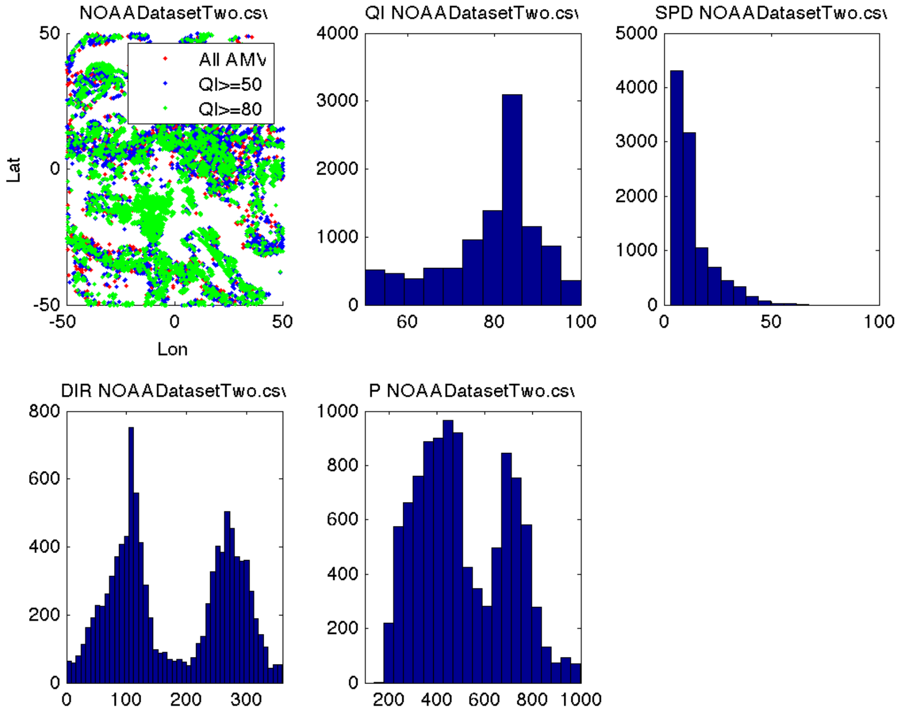

Figure 26: Experiment 2 parameter distributions for NOA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

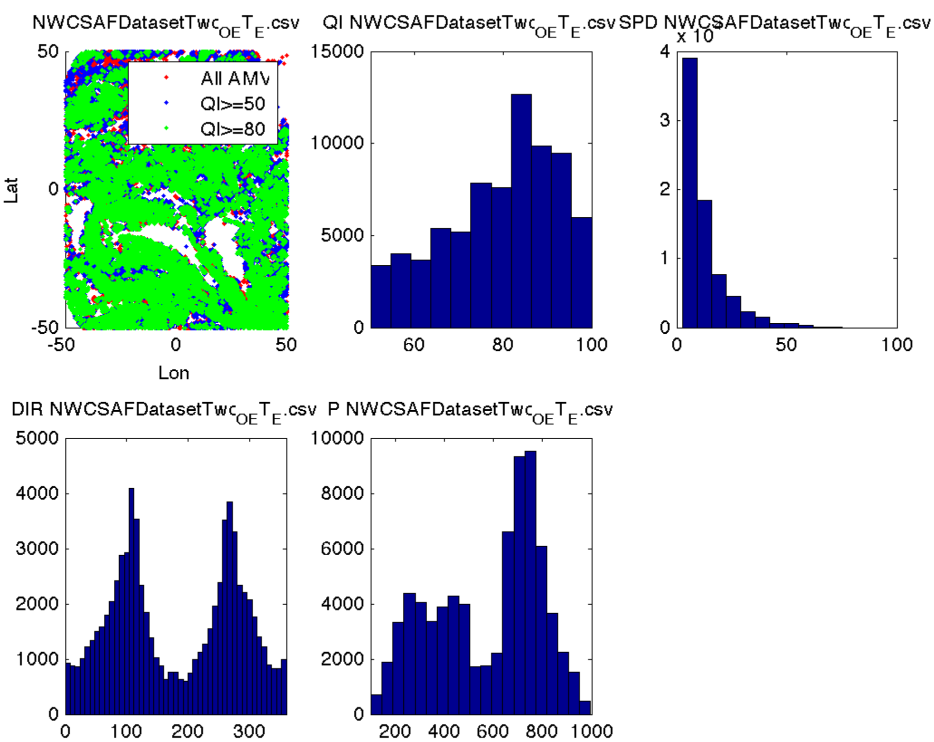

Figure 27: Experiment 2 parameter distributions for NWC: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

c) Colocation plots

AMVs are first quality controlled, retaining only those with a QINF >= 50. For colocation the distance threshold is 55 km, resulting in 7050 AMVs.

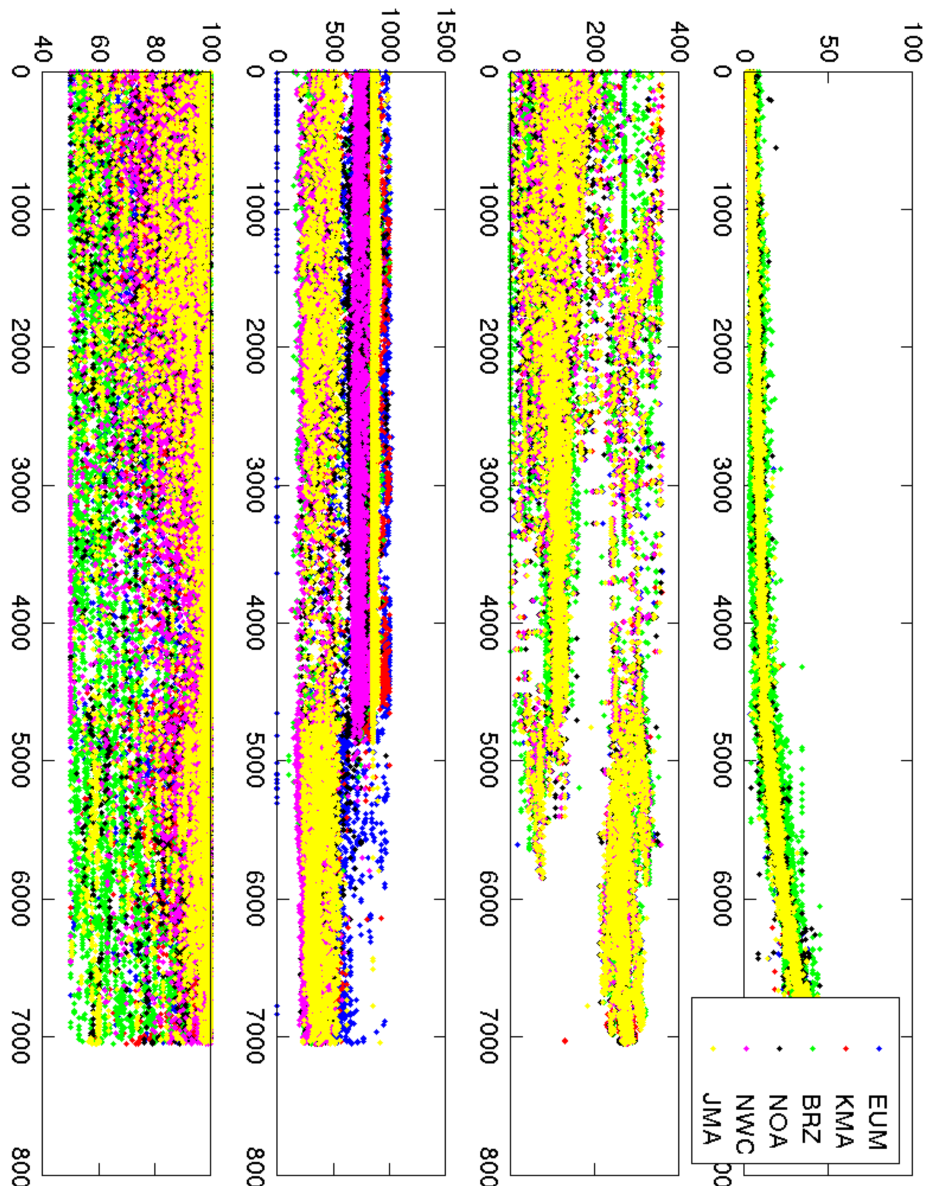

Figure 28: Plots of colocated AMVs of speed (top), direction (2nd), pressure (3rd), and QI (bottom) are color-coded based on legend in upper right. The x-axis is AMV number.

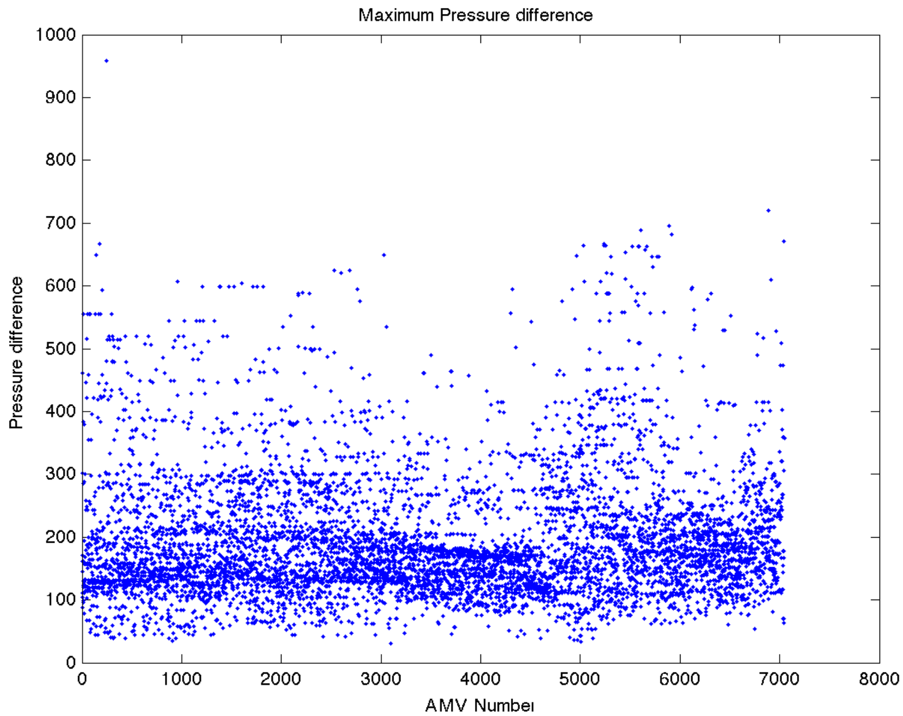

Figure 29: The maximum pressure difference between any two colocated AMVs.

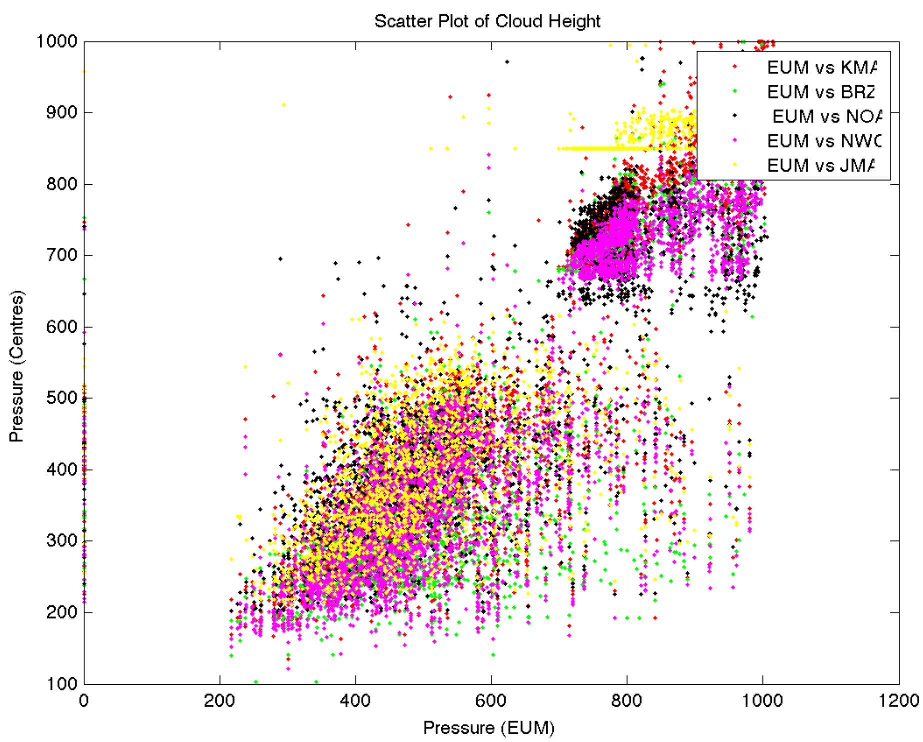

Figure 30: Scatter plot of AMV pressure for each center vs. EUM pressure.

A similar comparison is done for AMVs with QI with forecast, retaining only those with a QIWF >= 50. For colocation the distance threshold is 55 km, resulting in 7050 AMVs.

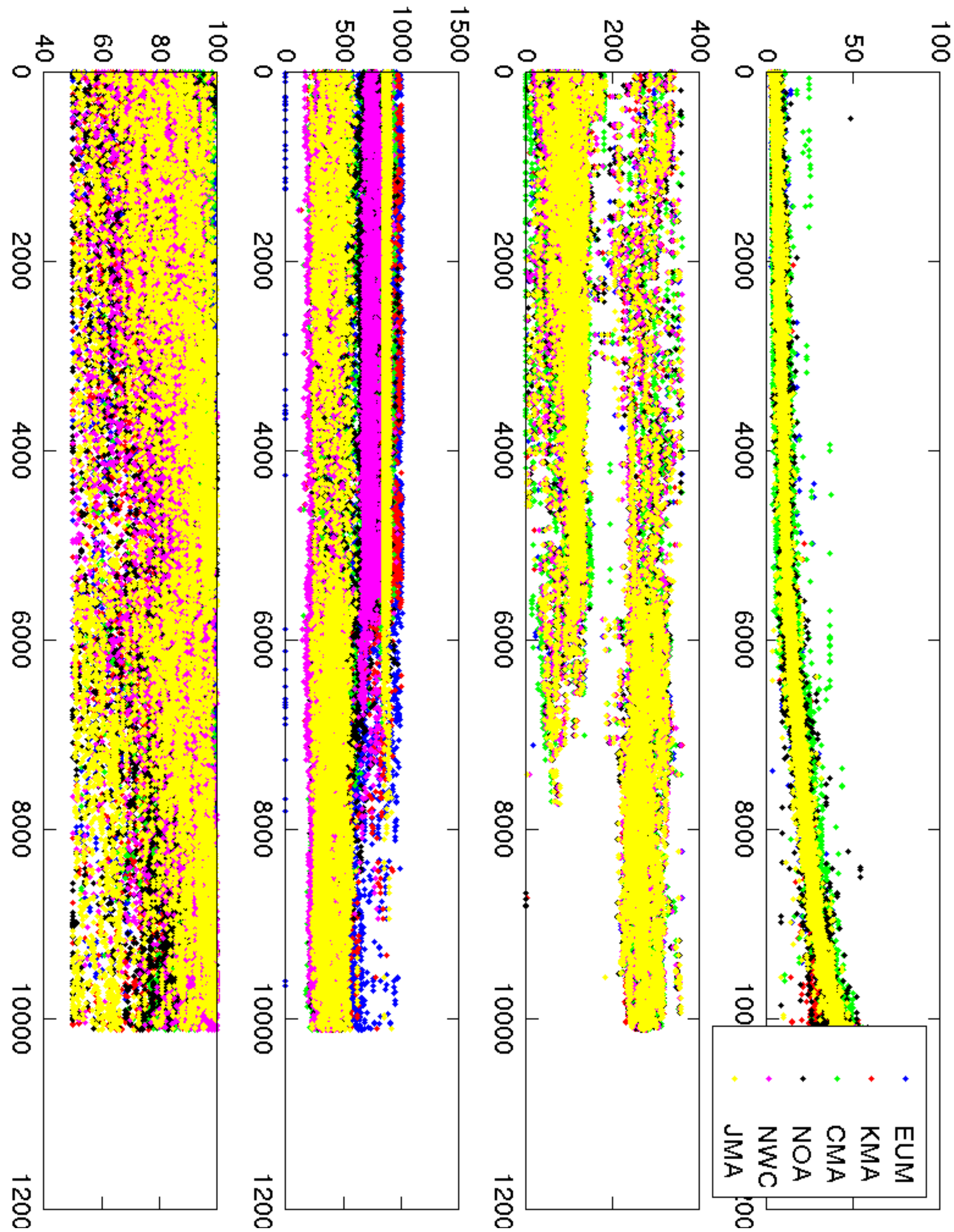

Figure 31: Plots of colocated AMVs of speed (top), direction (2nd), pressure (3rd), and QI (bottom) are color-coded based on legend in upper right. The x-axis is AMV number.

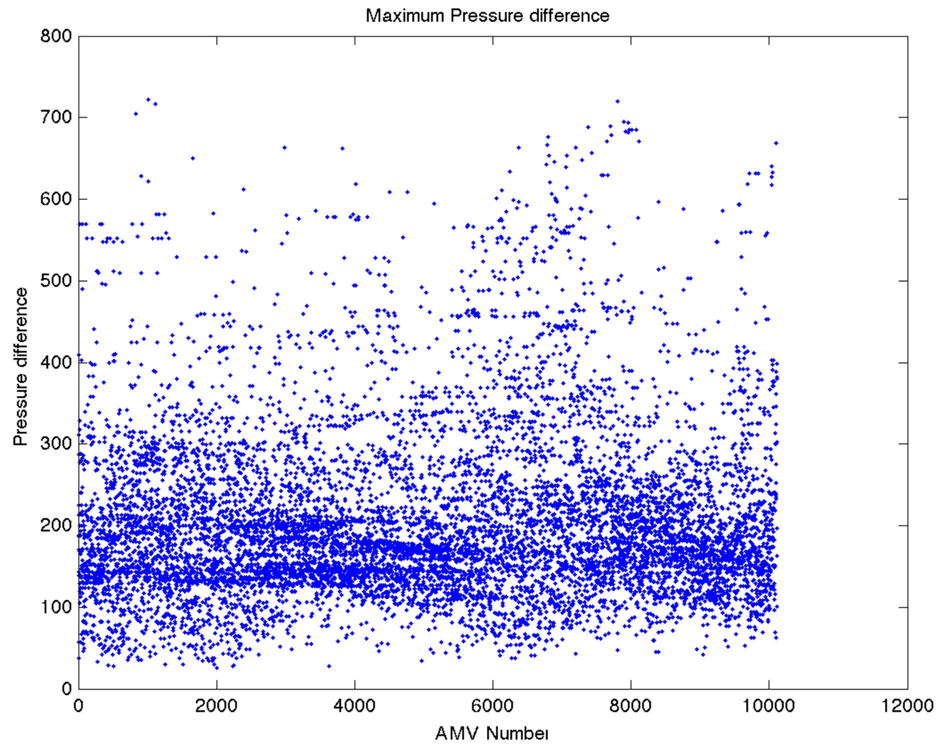

Figure 32: The maximum pressure difference between any two colocated AMVs.

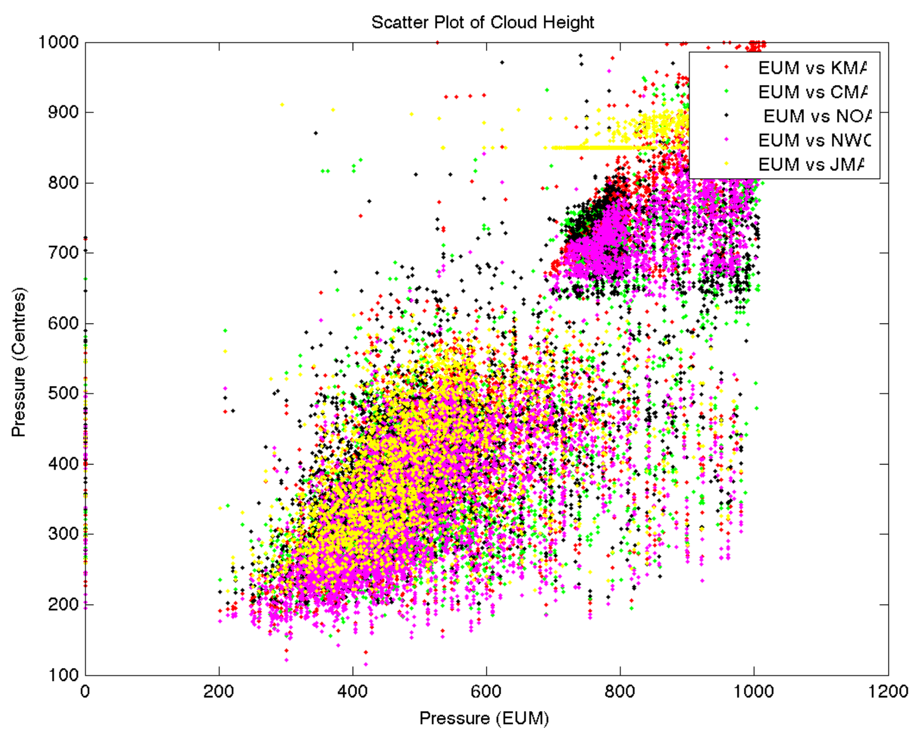

Figure 33: Scatter plot of AMV pressure for each center vs. EUM pressure.

d) Rawindsonde comparison

The comparison of AMVs to collocated rawinsondes is summarized in Table 8 (QINF >= 50) and Table 9 (QIWF >= 50). Note: The sample is rather small for some AMV producers (the range is from 60 to 2500 AMV matches to rawinsondes).

The vector RMS ranges from 6 ms^{-1} (NWC) to 9 ms^{-1} (BRZ, EUM); the speed RMS ranges from 4.5 ms^{-1} (NWC) to 7 ms^{-1} (EUM). Since the tracking differences in Experiment 1 were small, these large RMS differences are probably due to the substantial variation in height assignment (see Figure 29 and Figure 32).

Table 8: Experiment 2: AMVs (QI no forecast >= 50) comparison to rawinsondes within 150 km. N= number of matches; P bias = pressure bias; P RMS = pressure RMS; SpdBias = speed bias; SpdRMS= speed RMS; DirBias = wind direction bias; VecRMS = vector RMS. The extreme for each category is highlighted: Yellow = high value; cyan = low value.

Site	N	P bias	P RMS	SpdBias	SpdRMS	DirBias	VecRMS
BRZ	63	0.67	18.81	0.14	5.27	-11.12	9.59
EUM	268	-0.53	26.57	3.09	7.24	0.05	9.43
JMA	177	-2.20	26.26	0.36	6.04	6.07	8.04
KMA	1346	1.19	24.98	-0.02	5.94	9.04	7.91
NOA	361	-1.59	27.14	3.08	6.30	12.84	8.94
NWC	2410	-1.86	26.03	-0.78	4.75	1.53	6.14

Table 9: Experiment 2: AMVs (QI with forecast >= 50) comparison to rawinsondes within 150 km. N = number of matches; P bias = pressure bias; P RMS = pressure RMS; SpdBias = speed bias; SpdRMS = speed RMS; DirBias = wind direction bias; VecRMS = vector RMS. The extreme for each category is highlighted: Yellow = high value; cyan = low value.

SIte	N	P bias	P RMS	SpdBias	SpdRMS	DirBias	VecRMS
CMA	241	3.60	26.33	0.17	7.51	5.05	8.99
EUM	283	-0.71	26.15	2.74	7.07	0.57	9.46
JMA	169	-2.50	26.81	0.14	5.09	3.52	7.04
KMA	1266	1.24	24.92	0.18	5.81	8.35	7.79
NOA	342	-1.23	27.27	3.17	6.18	14.21	8.87
NWC	2410	-1.89	25.97	-0.72	4.68	1.52	6.06

e) Best fit height

The Best Fit height analysis was done for each wind producer according to the method described by Salonen et al. (2012). This technique finds the background model best-fit pressure associated with the AMV. The model best-fit pressure is the height (in pressure) where the vector difference between the observed AMV and model background is a minimum. The number of best-fit matches is generally less than 30% of the AMVs. See Appendix C: Best Fit Height Algorithm for implementation details.

Figure 34 to Figure 40 show the:

- Distribution of Best Fit minus AMV pressure differences, color-coded by low, medium, and high clouds (upper left),
- Spatial distribution with same color coding (upper right),
- Relationship between AMV pressure and latitude, color-coded to indicate if the Best fit moved the AMV higher (red) or lower (blue) (lower left),
- Relationship between AMV pressure and speed, color-coded to indicate if the Best fit moved the AMV higher (red) or lower (blue) (lower right).

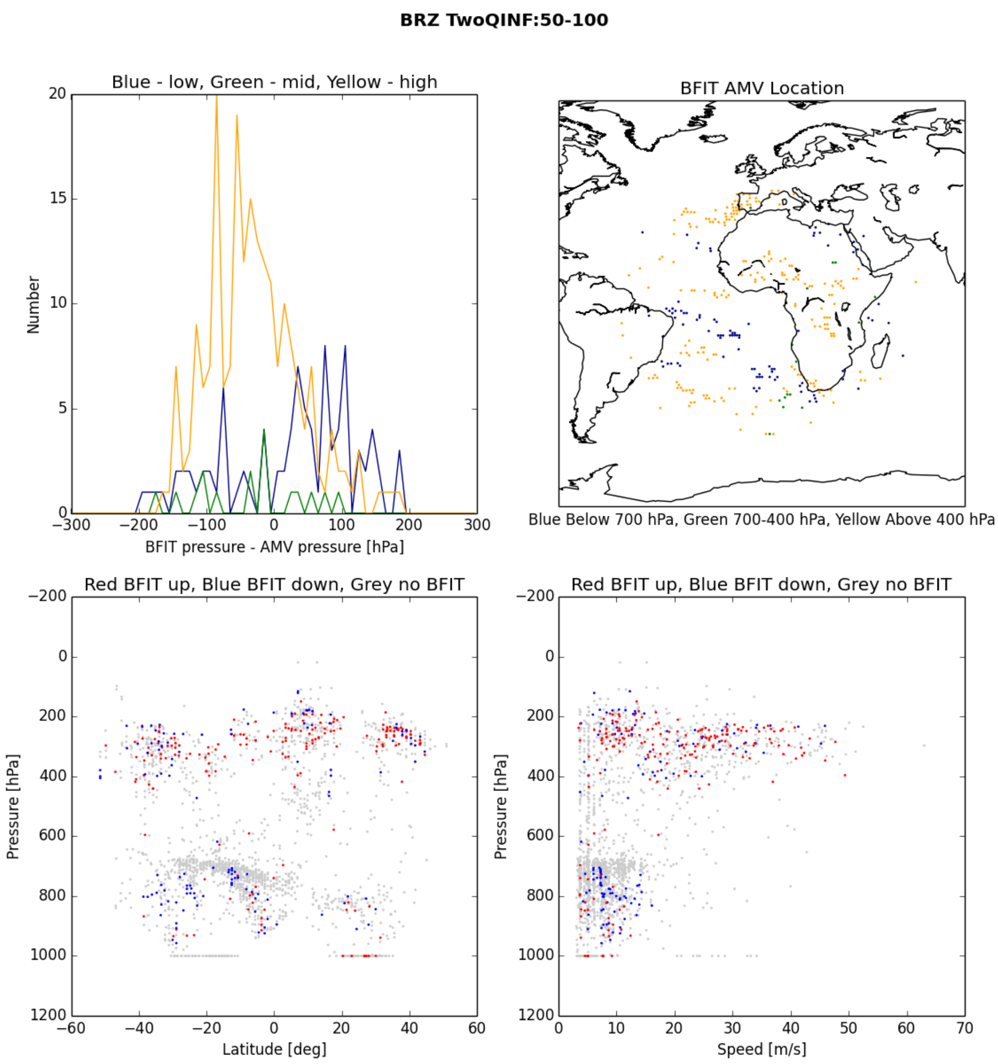

Figure 34: BRZ: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

CMA TwoQIWF:50-100

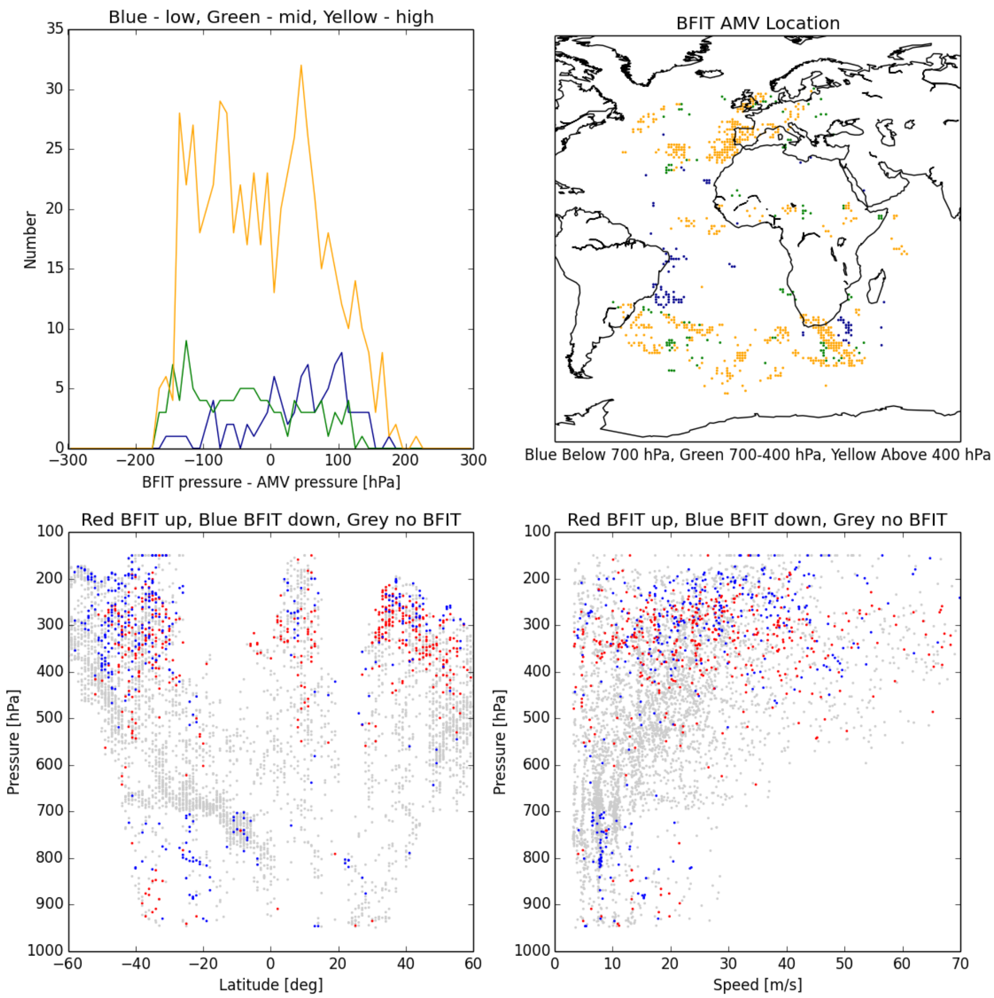

Figure 35: CMA: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

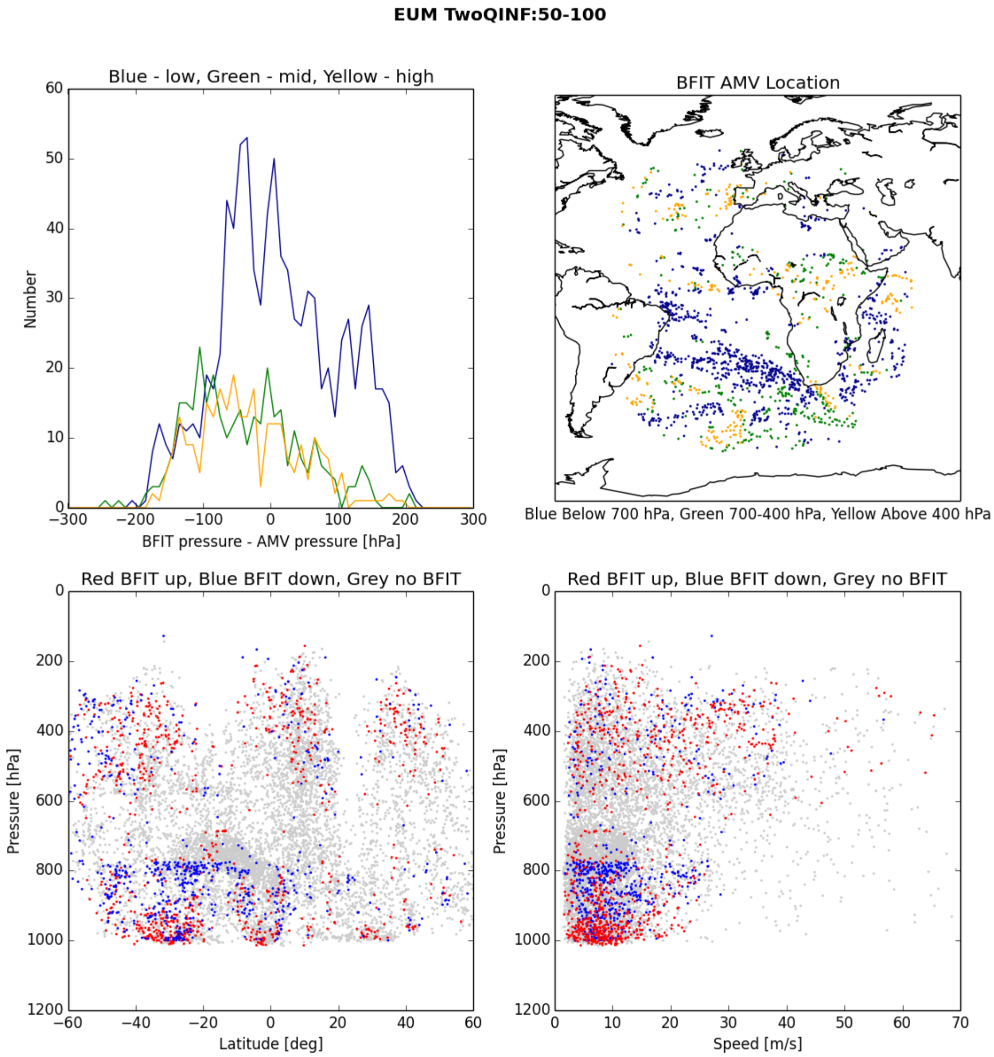

Figure 36: EUM: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

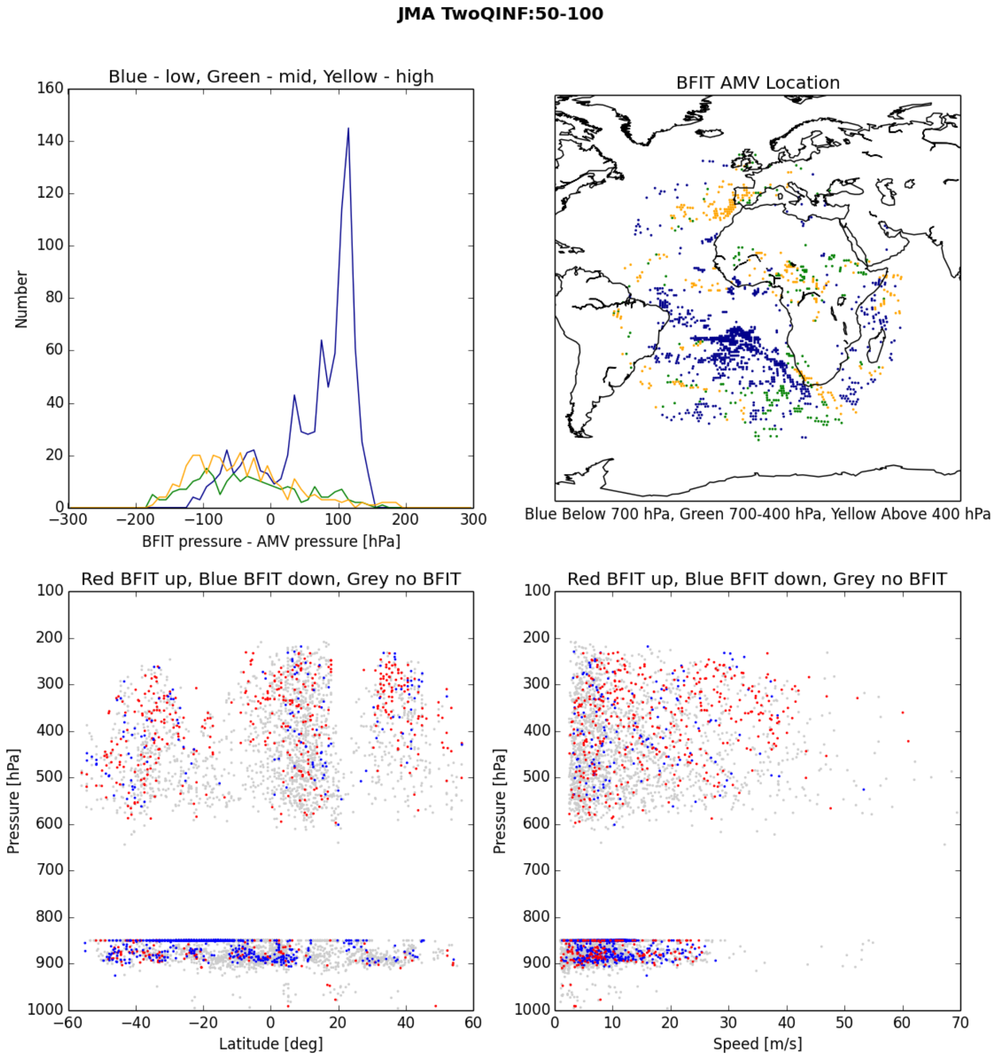

Figure 37: JMA: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

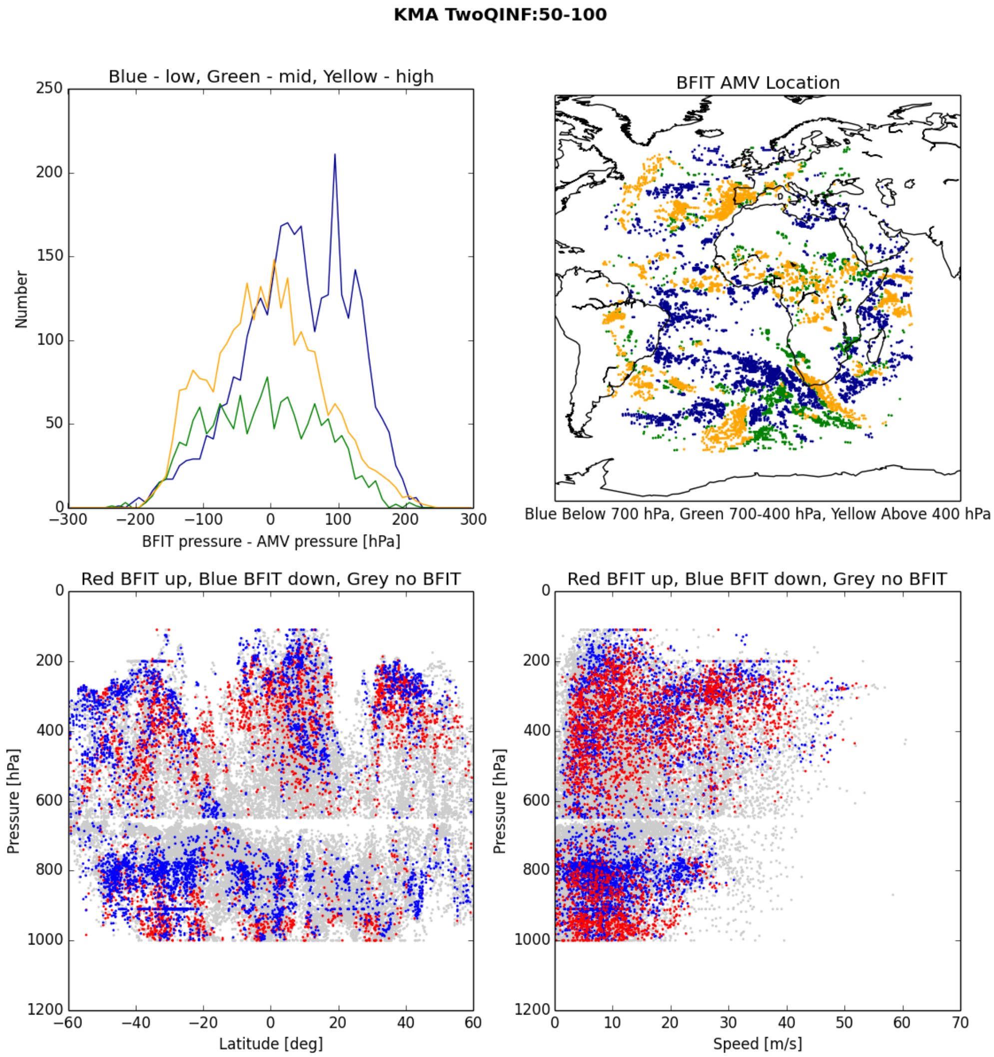

Figure 38: KMA: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

NOA TwoQINF:50-100

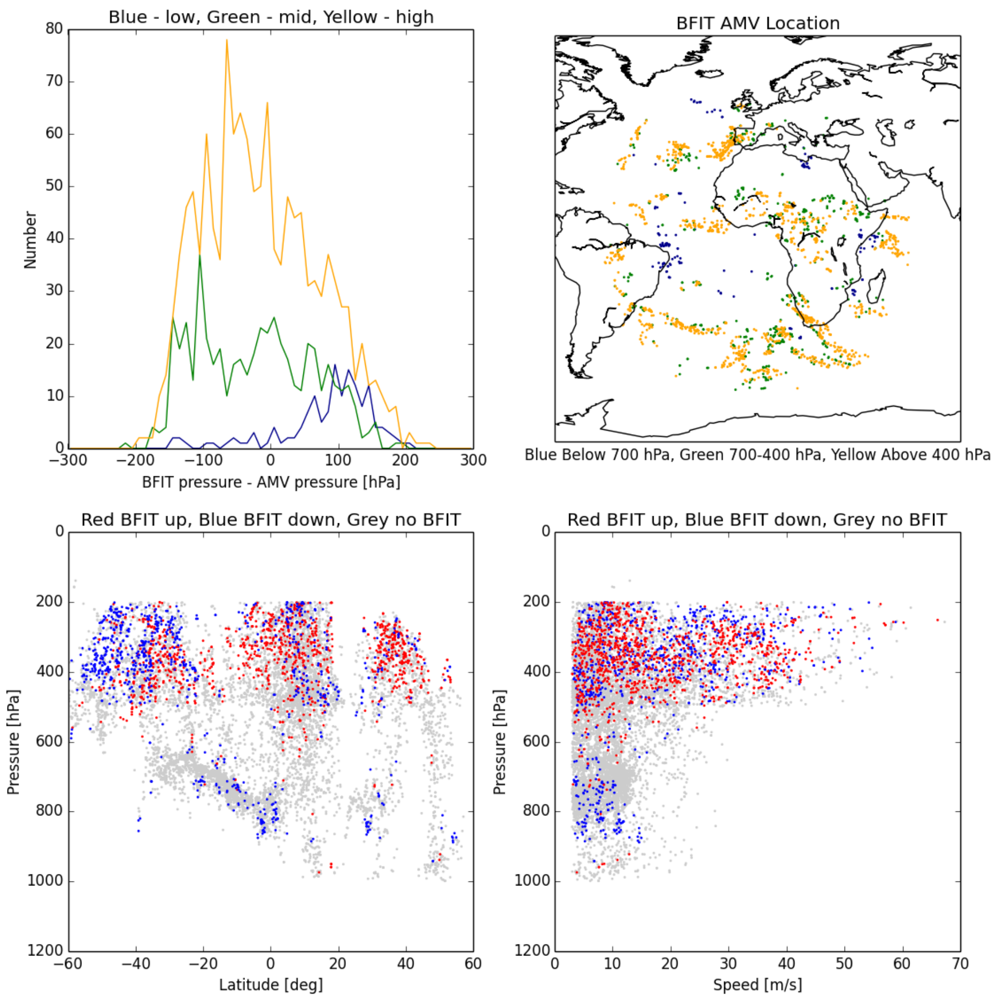

Figure 39: NOA: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

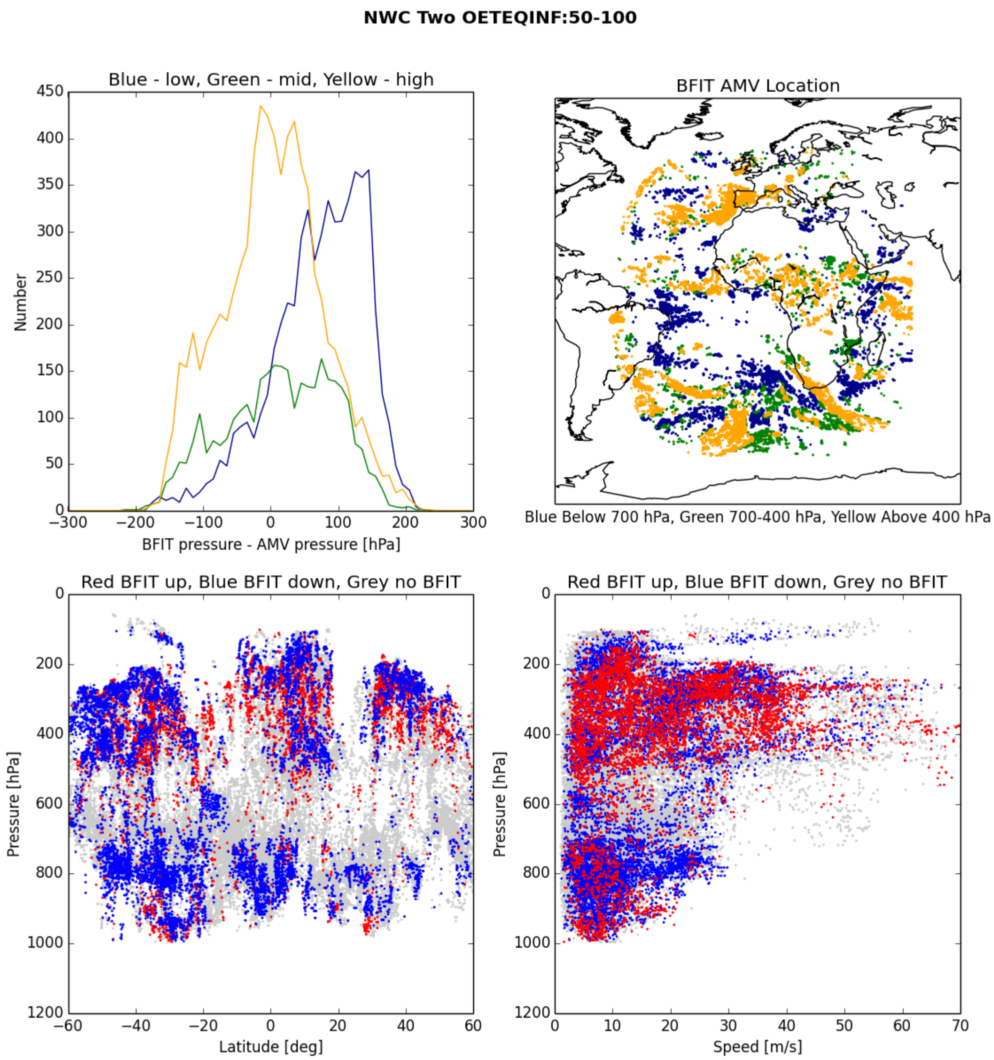

Figure 40: NWC: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

The depiction of the distribution of Best Fit statistics is in Figure 41 through Figure 47. Depending on the site, 16% to 24% (lower left in each figure) of the AMVs are adjusted to a Best Fit pressure. Results show an approximate Gaussian distribution of the pressure difference centered near zero (upper right plot in figures), extending ±200 hPa. There does not appear to be a relationship between latitude or longitude and adjusted pressure (upper left and middle left in figures).

In the upper-right corner of the figures, the distribution of the pressure difference (AMV Best Fit pressure minus the Original Pressure). For sites BRZ, CMA, EUM, NOA, and KMA the pressure difference is centered near zero. However, JMA has two peaks (-50 and +100) with a minimum near zero and for NWC it is slightly skewed to the right of zero. For experiment 2, since the AMV heights are assigned using only the IR brightness temperature, these offset and skewed distributions may be the result of the specific implementation of the IR brightness temperature height assignment, shown to be erroneous.

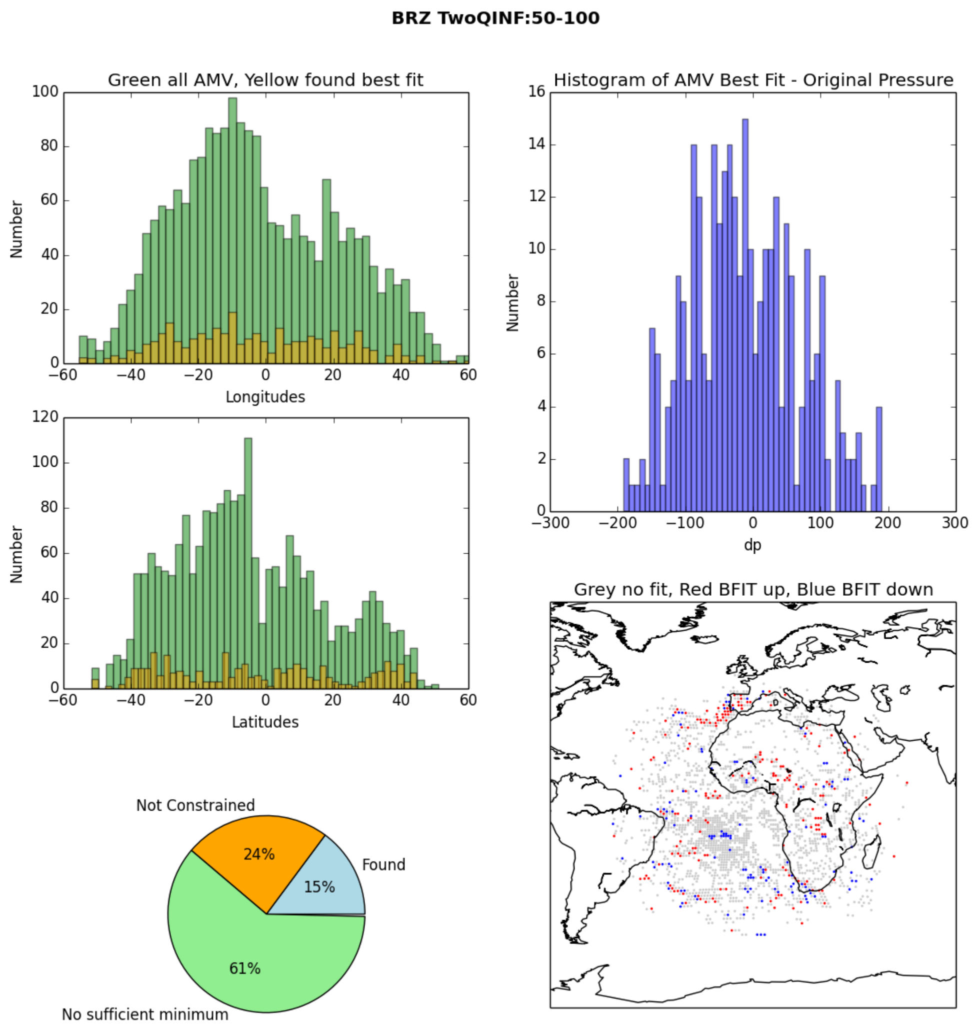

Figure 41: BRZ: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

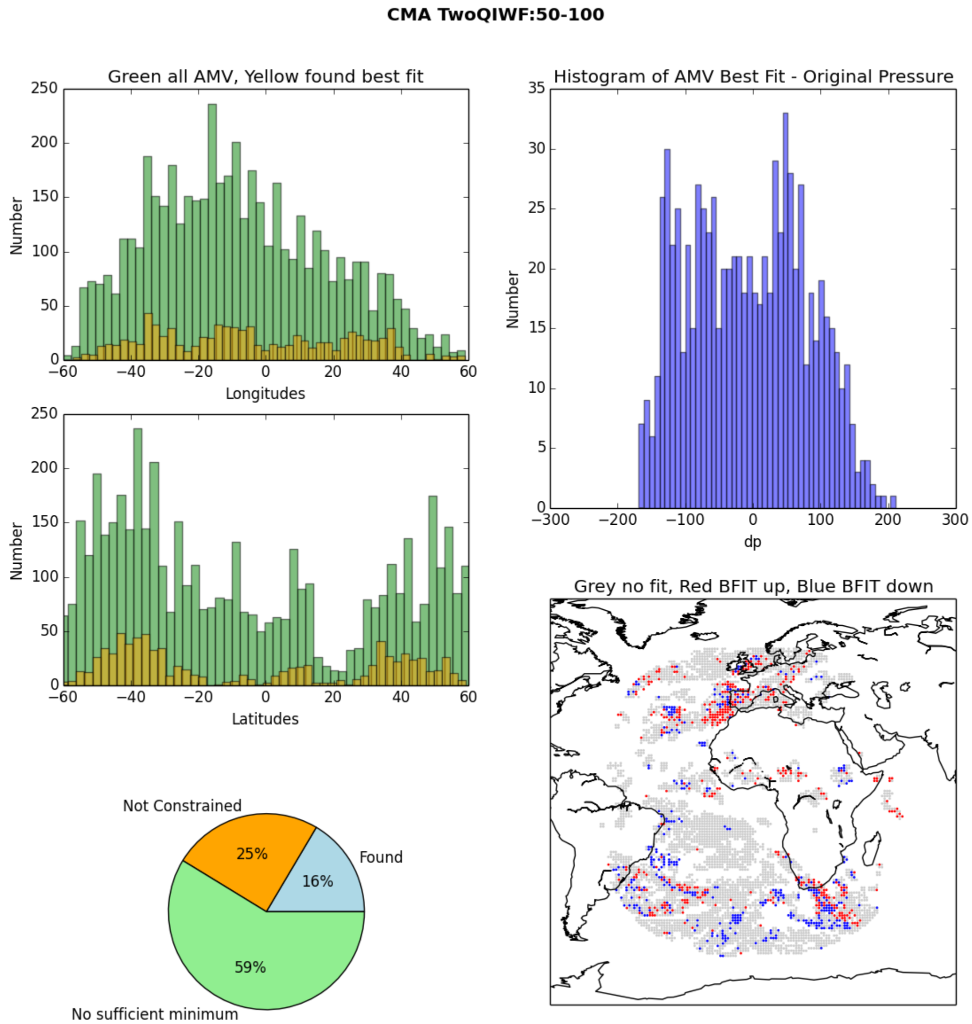

Figure 42: CMA: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

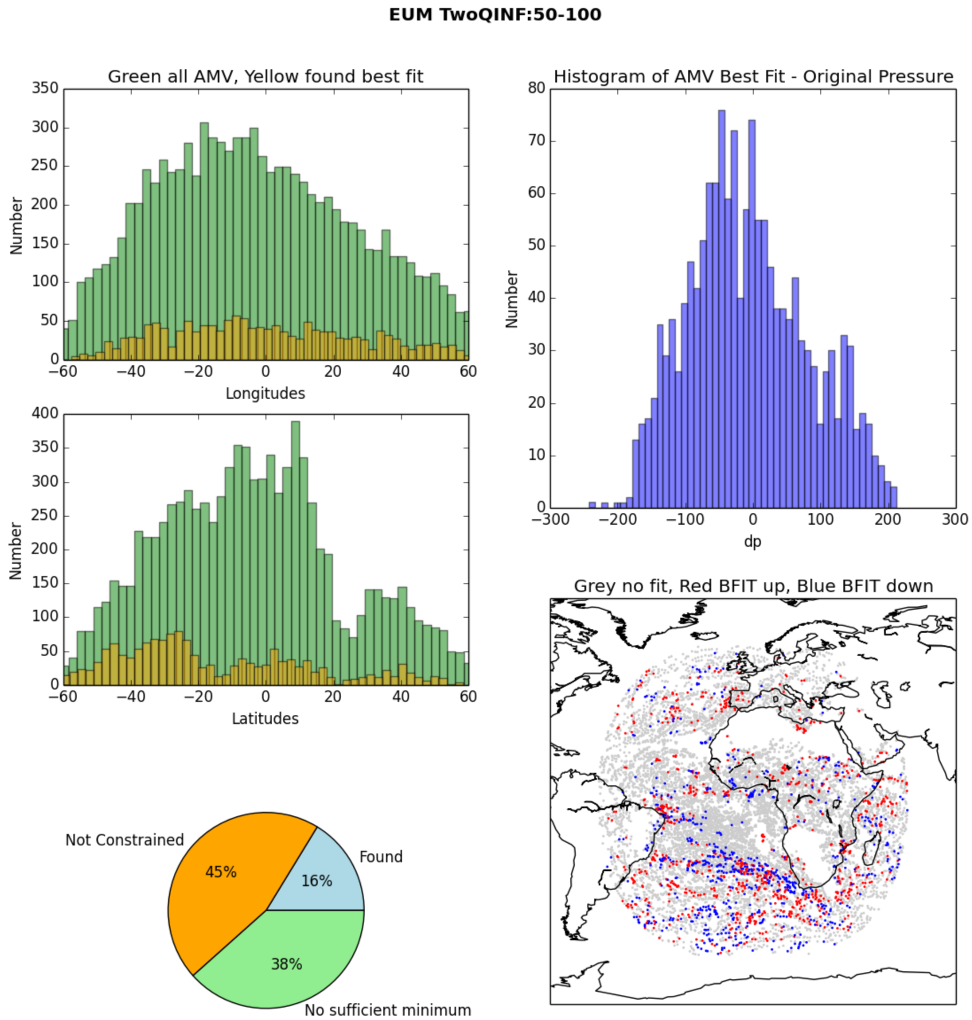

Figure 43: EUM: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

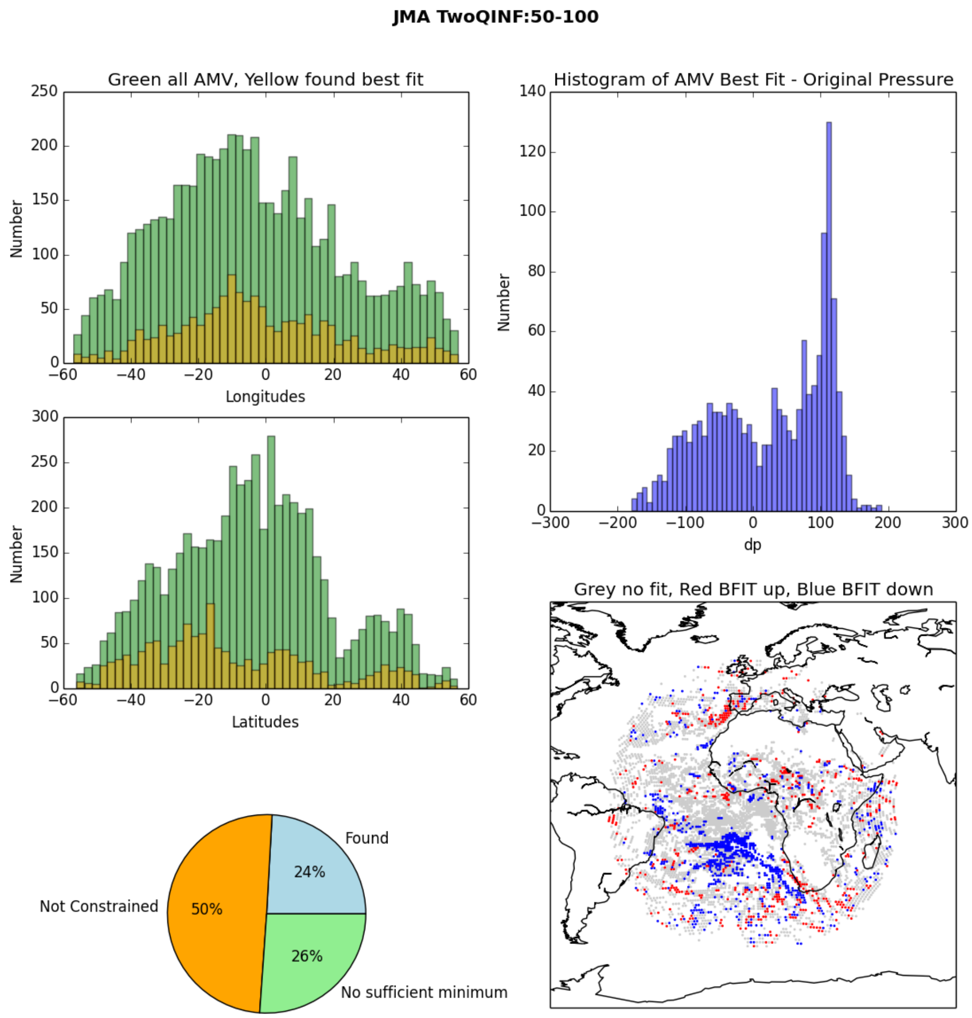

Figure 44: JMA: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

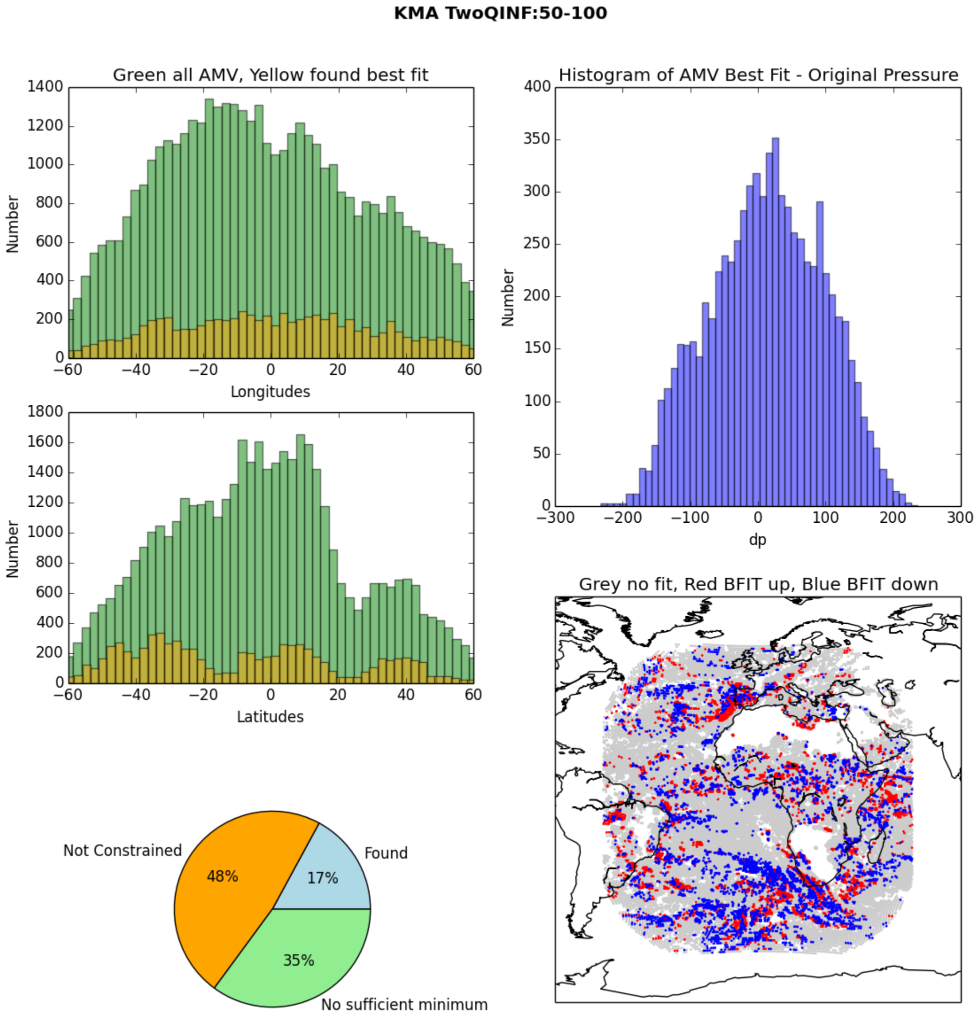

Figure 45: KMA: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

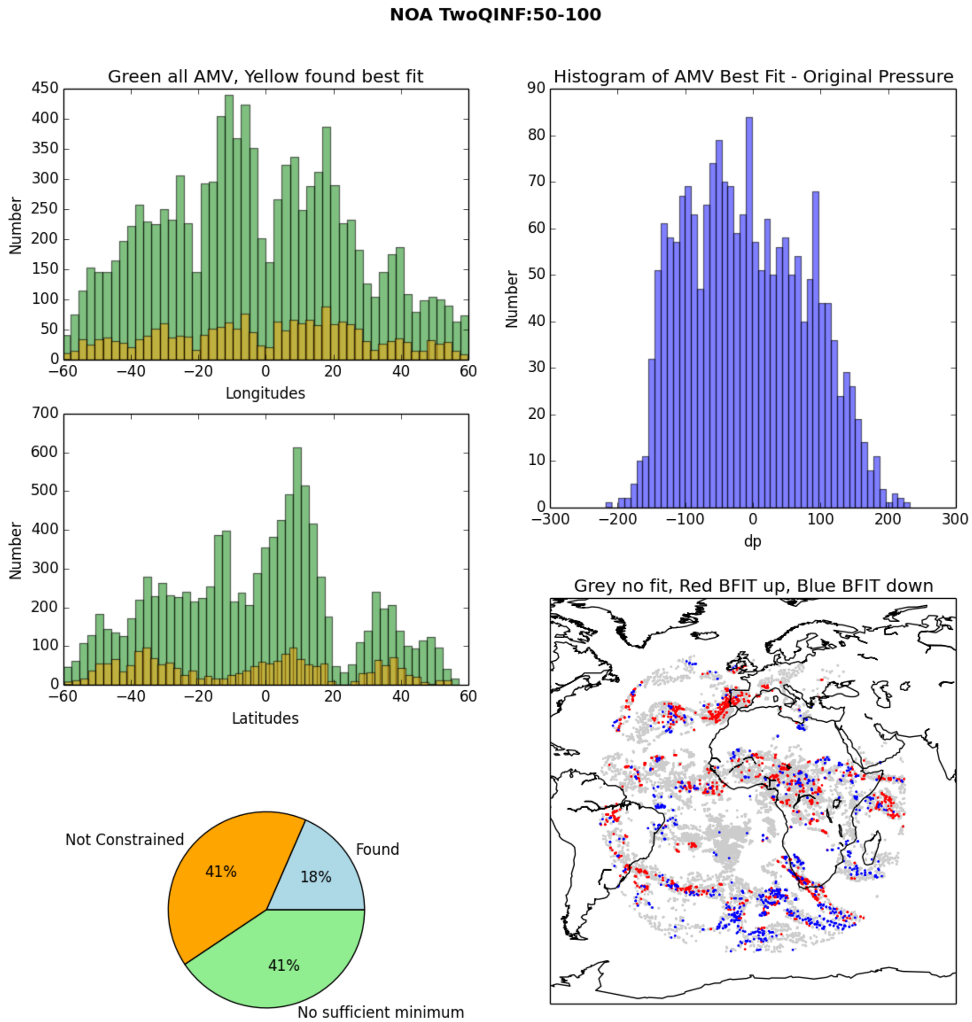

Figure 46: NOA: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

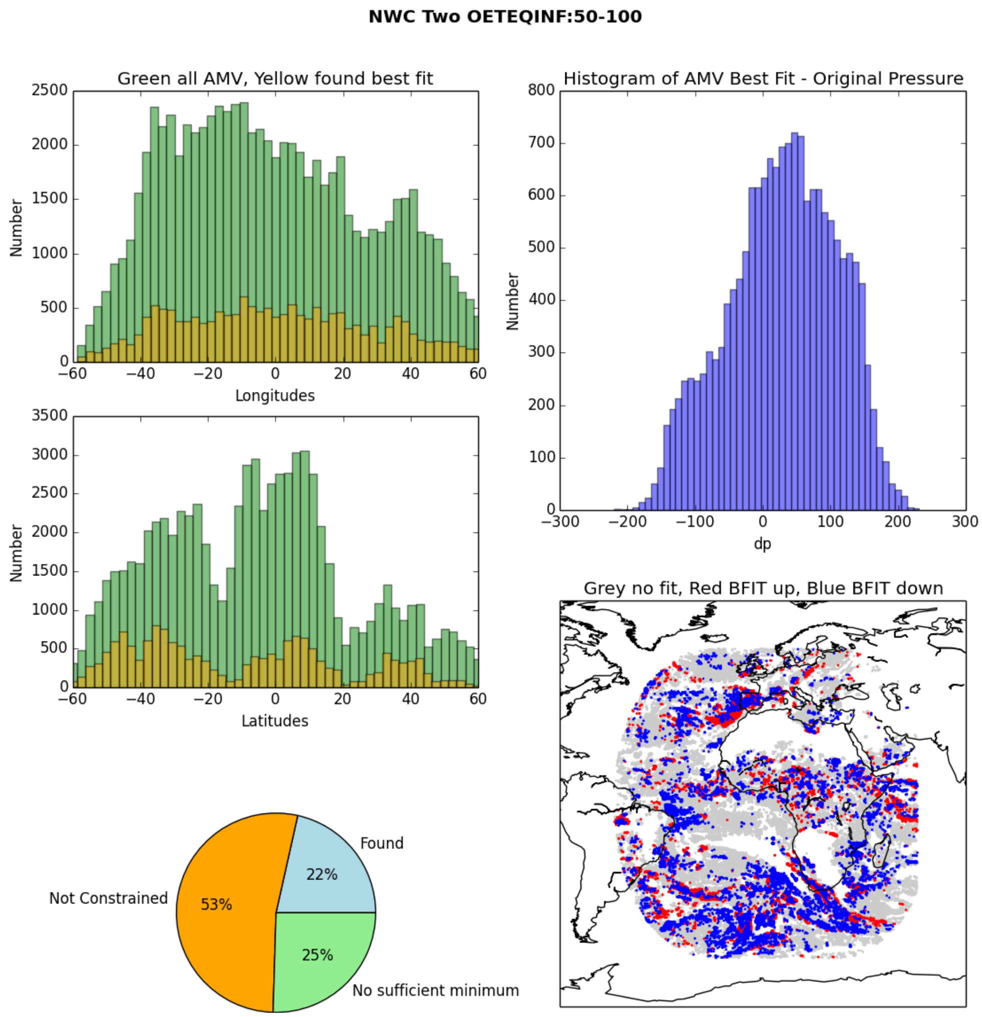

Figure 47: NWC: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

The lower half of Figure 129 to Figure 135 shows the change in the speed difference distribution before (left) and after (right) Best Fit adjustment. As expected, the speed bias is usually reduced, as is the standard deviation.

The lower half of Figure 136 to Figure 142 shows the change in the vector difference distribution before (left) and after (right) Best Fit adjustment. As expected, the vector difference is usually reduced, as is the standard deviation. BRZ and CMA had the largest deviation before the best fit, with a vector difference of over 7 ms^{-1} as compared to the background grid. NWC had the smallest desviation before the best fit, with a vector difference of less than 4 ms^{-1}.

f) Statistical comparison

To quantify the observed differences in the previous plots, a paired t-test is used with all combinations of producers (and parameters) to determine if the differences are statistically significant for colocated AMVs. This is done using the Matlab ttest function: Performs a t-test of the hypothesis that the data come from a distribution with mean zero (see Appendix A: Matlab t-test Documentation for more details). The data in this case are differences between the parameters from each pair of data producers; therefore, a mean of zero is what is expected. In the following tables, green indicates no statistical difference between the centers at the 95% confidence level; red is a statistical difference.

AMVs are first quality controlled, retaining only those with a QINF >= 50. For colocation the distance threshold is 35 km, resulting in 7050 AMVs.

NWCSAF and EUMETSAT are the only combinations which are very close in terms of both speed and direction, however with a cloud height bias of 130 hPa.

Table 10: Experiment 2 speed t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	BRZ	NOA	NWC	JMA
EUM						
KMA						
BRZ						
NOA						
NWC						
JMA						

Table 11: Experiment 2 direction t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	BRZ	NOA	NWC	JMA
EUM						
KMA						
BRZ						
NOA						
NWC						
JMA						

Table 12: Experiment 2 pressure t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	BRZ	NOA	NWC	JMA
EUM						
KMA						
BRZ						
NOA						
NWC						
JMA						

Table 13: Experiment 2 QI without forecast t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	BRZ	NOA	NWC	JMA
EUM						
KMA						
BRZ						
NOA						
NWC						
JMA						

A similar comparison is done for AMVs with QI with forecast, retaining only those with a QIWF >= 50. For colocation the distance threshold is 35 km, resulting in 10113 AMV

Table 14: Experiment 2 speed t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA
EUM						
KMA						
CMA						
NOA						
NWC						
JMA						

Table 15 : Experiment 2 direction t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA
EUM						
KMA						
CMA						
NOA						
NWC						
JMA						

Table 16: Experiment 2 pressure t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA
EUM						
KMA						
CMA						
NOA						
NWC						
JMA						

Table 17: Experiment 2 QI with forecast t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA
EUM						
KMA						
CMA						
NOA						
NWC						
JMA						

g) Model Grid comparison

Pythons scripts that find the Best Fit, also output comparison of all AMVs to the background grid. This comparison is based on 12-hour forecast using QINF >= 80. The results in Table 18 are similar to what was found with the rawinsonde comparisons: NWC and JMA have the lowest error, while BRZ and EUM have the highest errors.

Table 18: Experiment 2 AMV comparison to background grid: a 12-hour forecast. N = total number of AMVs; BFN = Best Fit number of AMVs; V_O = VD OMB mean; RAF = RMSE after Best Fit; VAF = Vector difference after Best Fit; RMSE = root mean square error.

Exp	QI	N	BFN	V_O	RAF	VAF	RMSE
BRZ	QINF:80–100	745	113	7.51	8.89	7.04	8.64
CMA	QIWF:80–100	3964	755	7.07	8.22	6.44	7.81
EUM	QINF:80–100	5378	1003	6.88	9.73	6.47	9.54
JMA	QINF:80–100	3498	955	4.50	6.05	3.71	5.52
KMA	QINF:80–100	26427	5189	5.95	7.88	5.49	7.61
NOA	QINF:80–100	8180	1640	6.87	8.79	6.22	8.37
NWC	QINF:80–100	49331	11963	4.62	5.52	4.05	5.06

9. Experiment 3

AMV producers extract IR10.8 channel AMVs considering a prescribed AMV algorithm configuration, but only using the MSG/SEVIRI IR10.8 images and the ECMWF model data for the height assignment. This experiment will be used to test the Tracking and Quality control steps in all AMV algorithms, considering similar targets.

The prescribed AMV configuration defines target scene size, search scene size, etc. to be the same for all AMV producers. Something similar was done in the 2nd study and it was found that:
"Winds data sets retrieved using common target and search box sizes revealed that each producer's algorithm is finely tuned to a specific imagery temporal and spatial resolution, as well as target and search box sizes (Genkova et al. 2010)."

Genkova, I., R. Borde, J. Schmetz, C. Velden, K. Holmlund, N. Bormann, P. Bauer (2010), Global atmospheric motion vector intercomparison study, 10th Int. Winds Workshop, Tokyo, Japan.

For each one of the AMV producer's datasets, a distribution of AMV speed, direction, vector height, and QI will be generated. Differences of these quantities between AMV producers will be made. Also, differences in AMV coverage and number of vectors will be presented as bulk statistics and geographic plots.

Colocated AMVs from the different algorithms will be used to measure the differences. Also, a comparison of the AMVs with the NWP model winds and height assignment investigations using NWP model best-fit pressure will be used for verification.

Experiment 3 Highlights
Graphs of bulk distributions are similar to Experiment 2, since the height assignment options are retricted to IR B_T.

Colocated vectors only number 370, due to the lower overall numbers of AMVs when using prescribed target and search box sizes. Speed and direction differences between the different centres are not statistically different. Although, pressure and QI values are significantly different.

a) Approach

By using a prescribed AMV configuration, we will be able to better quantify differences in AMV density between the producers. In cases with similar densities among producers, the QI can also be compared quantitatively.

This is similar to Study 2 by Genkova et al. (2010):

- Only use SEVIRI 10.8 µm channel
- Producers use their algorithm
- Prescribed target and search box sizes
- Use ECMWF grids
- Colocated AMVs in Study 2 were within 0.5°; in this study the distance is 55 km.

Genkova's scripts were used to do same comparison and analysis as done before, but now including NWCSAF.

In addition:

- The best fit analysis is used to further analyze differences in cloud heights
- The paired t-test are computed to determine if the observed differences in colocated AMVs are statistically significant.

This will also be an opportunity to compare AMVs from Exp. 2 and 3 from the same producer, to quantify differences in AMVs from the standard and prescribed configuration.

EUMETSAT 'standard' configuration is the same as the 'prescribed'.

b) Parameter distributions

The bulk statistics are presented in both tables and histograms, for QINF >= 50 and QIWF >= 50 (because not all centres reported both QINF and QIWF). Note: Since there are little differences in filtering based on QINF or QIWF, QINF >= 50 will be used for the following discussions (except for CMA which only reported QIWF).

Table 19 lists basic Experiment 3 statistics for the AMVs for each winds producer. Most of the values in this table are approximately the same, with the biggest difference is in the number of AMVs: Ranging from 3000 (NWC) to 12000 (EUM).

Table 19: Experiment 3 statistical summary of AMV datasets for QI without forecast >= 50.

	EUM	BRZ	JMA	KMA	NOA	NWC
Total AMVs	12053	11371	6219	11986	3881	3169
QI>=50	9074	4510	5465	9605	3169	2349
SPD_min	2.51	3.11	2.51	2.50	3.01	2.51
SPD_max	78.59	72.13	74.22	54.81	78.43	60.85
SPD_mean	12.50	13.41	11.35	12.11	13.77	12.31
P_min	127.56	19.00	208.68	110.00	190.78	83.47
P_max	1015.02	1000.00	995.88	1000.00	992.58	984.15
P_mean	696.32	633.51	676.19	620.92	505.92	553.03
Low_winds	57.43	48.80	57.31	46.00	21.77	38.10
Mid_winds	32.35	30.80	24.96	32.08	43.74	28.99
High_winds	10.23	20.40	17.73	21.93	34.49	32.91
Low_SPD_min	2.51	3.11	2.51	2.50	3.01	2.51
Low_SPD_max	78.59	43.61	54.92	41.09	29.02	28.36
Low_SPD_mean	9.70	8.73	8.87	9.32	8.87	8.74
Low_P_min	700.04	700.00	850.00	700.01	700.13	700.02
Low_P_max	1015.02	1000.00	995.88	1000.00	992.58	984.15
Low_P_mean	846.41	816.54	866.68	826.02	765.86	780.92
Mid_SPD_min	2.51	3.28	2.51	2.51	3.02	2.52
Mid_SPD_max	77.62	64.35	74.22	51.95	78.43	60.56
Mid_SPD_mean	15.81	15.98	14.43	13.48	12.89	10.80
Mid_P_min	400.08	400.01	400.18	400.01	400.01	400.17
Mid_P_max	699.95	699.94	643.92	699.99	699.91	699.97
Mid_P_mean	546.02	573.32	489.21	552.37	529.91	573.72
High_SPD_min	2.55	3.45	2.51	2.51	3.03	2.65
High_SPD_max	71.68	72.13	60.07	54.81	75.37	60.85
High_SPD_mean	17.73	20.74	15.06	15.97	17.99	17.80
High_P_min	127.56	19.00	208.68	110.00	190.78	83.47
High_P_max	399.92	399.38	399.93	399.94	399.91	399.76
High_P_mean	328.90	286.51	323.72	290.97	311.40	270.94

The following bulk histograms show unique characteristics of the AMVs for each centre, which are very similar to Experiment 2 since the height assignment method is unchanged:

- BRZ (Figure 48): The wind direction (lower-left) is not a smooth distribution, with two very sharp peaks. The AMV pressure distribution has peaks at 300 and 770 hPa. Upper level winds at 300 hPa is reasonable, but the 770 hPa peak is probably too high for low-level clouds.
- EUM (Figure 49): The AMV pressure distribution has a peak at 500 and 800 hPa. The upper level winds are too low, while the low-level winds are too high.
- JMA (Figure 50): The AMV pressure distribution has a peak at 500 and 850 hPa. The upper level winds are too low, while the low level winds are placed well. There is also a noticeable gap in mid-level winds.

- KMA (Figure 51): The AMV pressure distribution has a peak at 450 and 800 hPa. The upper level winds are too low, while the low level winds are too high.
- NOA (Figure 52): The AMV pressure distribution has a peak at 400 and 780 hPa. The upper level winds are too low, while the low level winds are too high.
- NWC (Figure 53): The AMV pressure distribution has a peak at 400 and 780 hPa. The upper level winds are too low, while the low level winds are too high.
- CMA (Figure 54): The AMV pressure distribution has a peak at 380 and 760 hPa. The upper level winds are too low, while the low level winds are too high. Also, there are many mid-level clouds compared to other centres.

Since only the IR brightness temperature is used in this experiment, the wide variation in cloud heights can be attributed to different techniques and thresholds in determining a representative T_B.

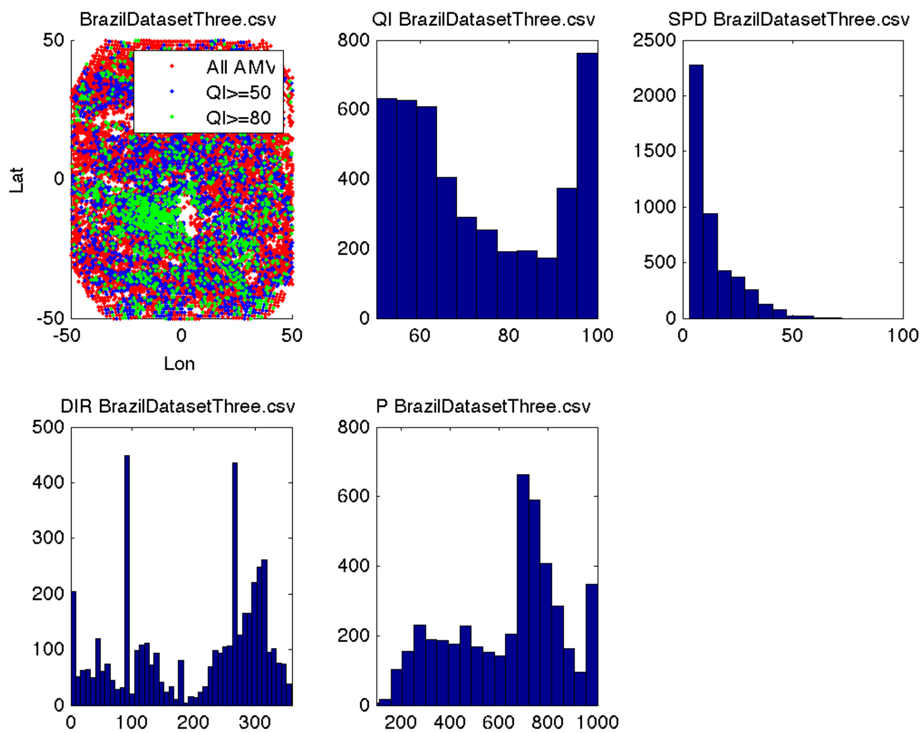

Figure 48: Experiment 3 parameter distributions for BRZ: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

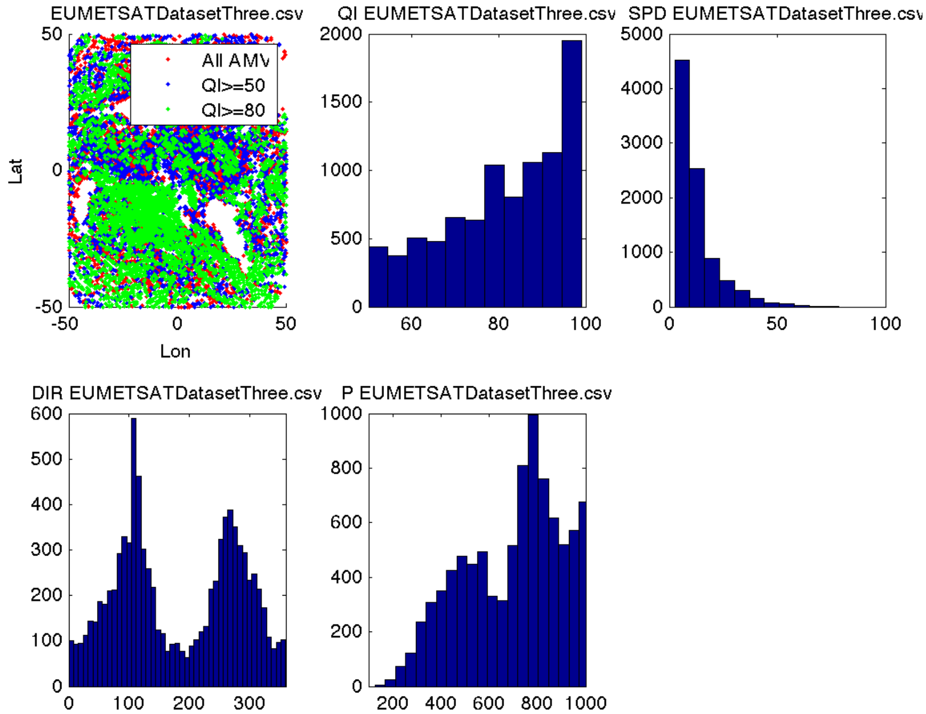

Figure 49: Experiment 3 parameter distributions for EUM: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

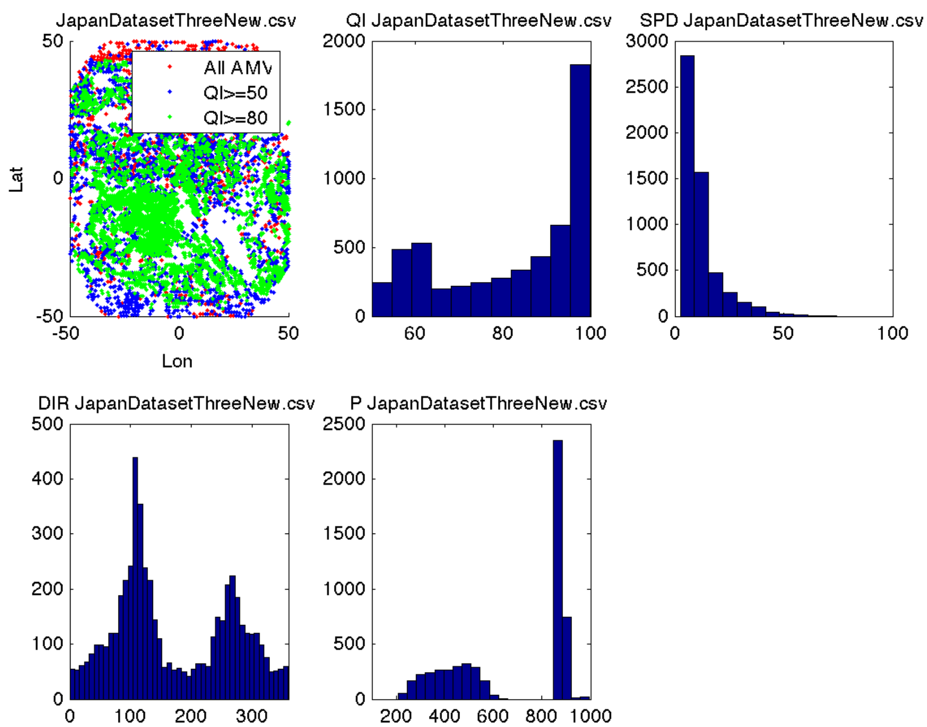

Figure 50: Experiment 3 parameter distributions for JMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

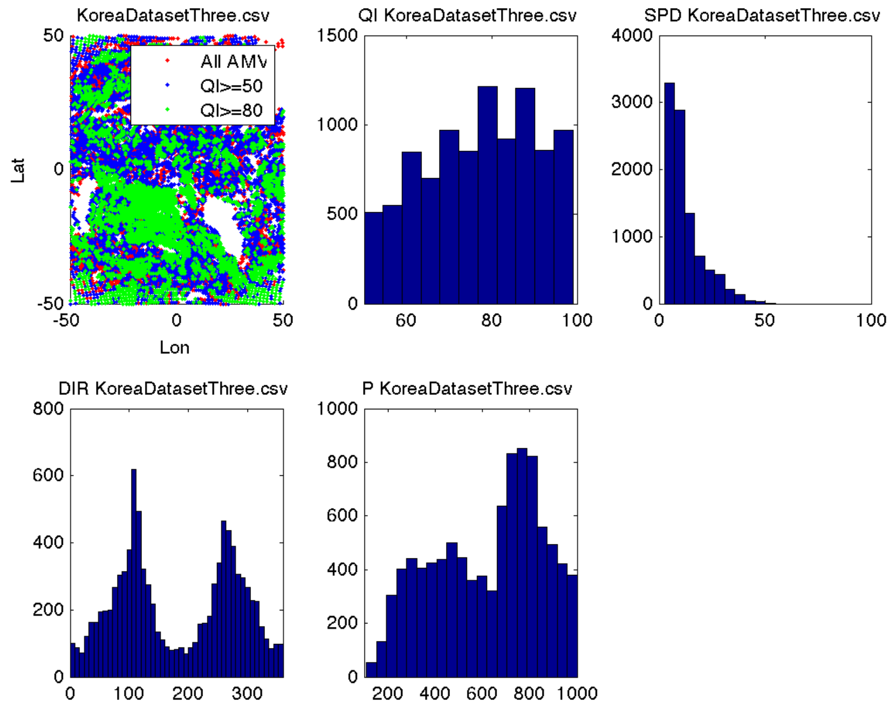

Figure 51: Experiment 3 parameter distributions for KMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

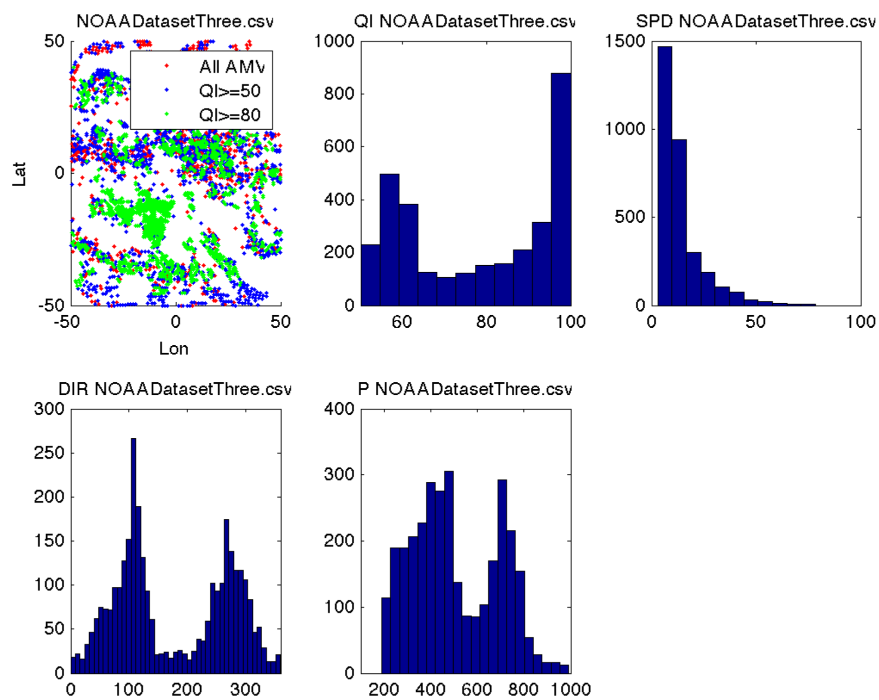

Figure 52: Experiment 3 parameter distributions for NOA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

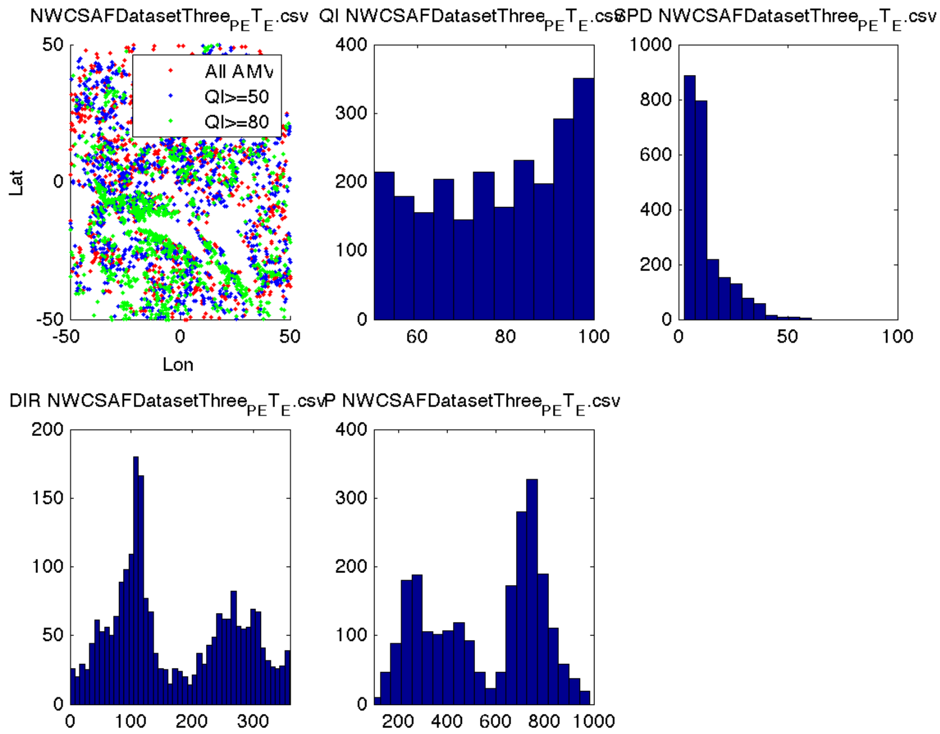

Figure 53: Experiment 3 parameter distributions for NWC: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

The following table and plots are for QIWF >= 50. These are very similar to the plots for QINF >= 50.

Table 20: Experiment 3 statistical summary of AMV datasets for QI with forecast >= 50.

	EUM	CMA	JMA	KMA	NOA	NWC
Total AMVs	12053	5331	6219	11986	3881	3169
QI>=50	9260	5328	5161	8965	2810	2297
SPD_min	2.51	3.16	2.51	2.50	3.01	2.51
SPD_max	78.59	82.64	74.22	54.81	78.43	60.85
SPD_mean	12.37	16.57	11.29	12.30	13.57	12.58
P_min	127.56	150.00	208.68	110.00	190.78	83.47
P_max	1015.02	947.00	995.12	1000.00	992.58	984.15
P_mean	695.49	516.77	680.19	620.65	514.56	550.90
Low_winds	57.22	21.98	58.52	46.11	23.24	37.48
Mid_winds	32.42	44.16	23.89	31.78	43.02	29.21
High_winds	10.36	33.86	17.59	22.11	33.74	33.30
Low_SPD_min	2.51	3.19	2.51	2.50	3.01	2.51
Low_SPD_max	78.59	33.87	54.92	41.09	29.02	28.36
Low_SPD_mean	9.65	8.34	8.75	9.32	8.81	8.86
Low_P_min	700.04	700.00	850.00	700.01	700.13	700.02
Low_P_max	1015.02	947.00	995.12	1000.00	992.58	984.15
Low_P_mean	846.30	778.34	866.28	825.48	764.66	783.50
Mid_SPD_min	2.51	3.16	2.51	2.52	3.02	2.52
Mid_SPD_max	77.62	72.97	74.22	48.37	78.43	60.56
Mid_SPD_mean	15.60	15.53	14.52	13.74	12.73	11.03
Mid_P_min	400.08	401.00	400.18	400.01	400.01	400.17
Mid_P_max	699.95	699.00	643.92	699.99	699.91	699.97
Mid_P_mean	546.69	559.62	487.68	552.48	538.24	571.60
High_SPD_min	2.54	3.19	2.51	2.51	3.03	2.69
High_SPD_max	71.68	82.64	60.07	54.81	75.37	60.85
High_SPD_mean	17.33	23.26	15.36	16.44	17.91	18.13
High_P_min	127.56	150.00	208.68	110.00	190.78	83.47
High_P_max	399.92	400.00	399.93	399.94	399.91	399.76
High_P_mean	327.97	291.08	322.69	291.43	312.08	270.95

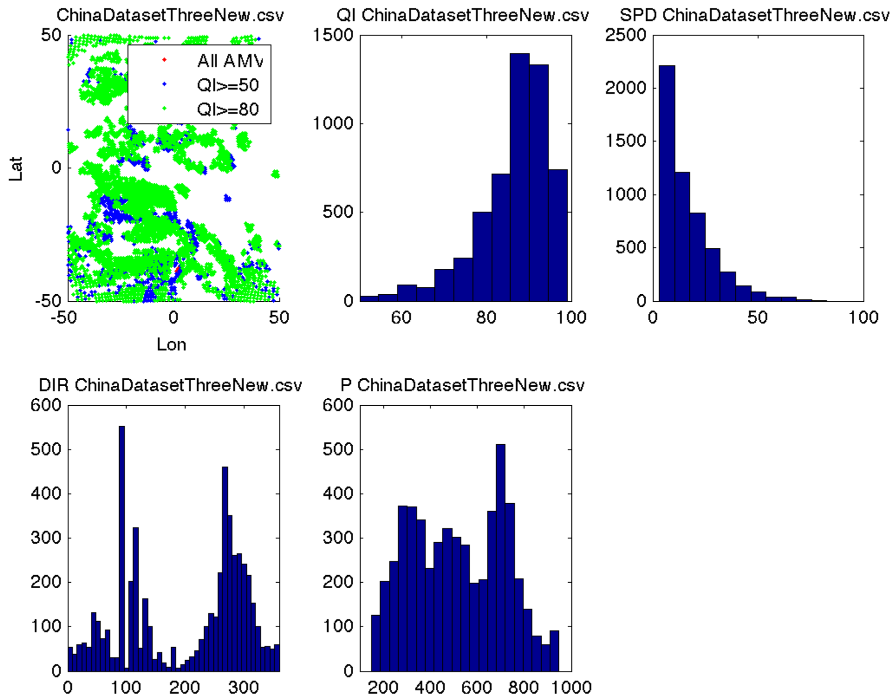

Figure 54: Experiment 3 parameter distributions for CMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

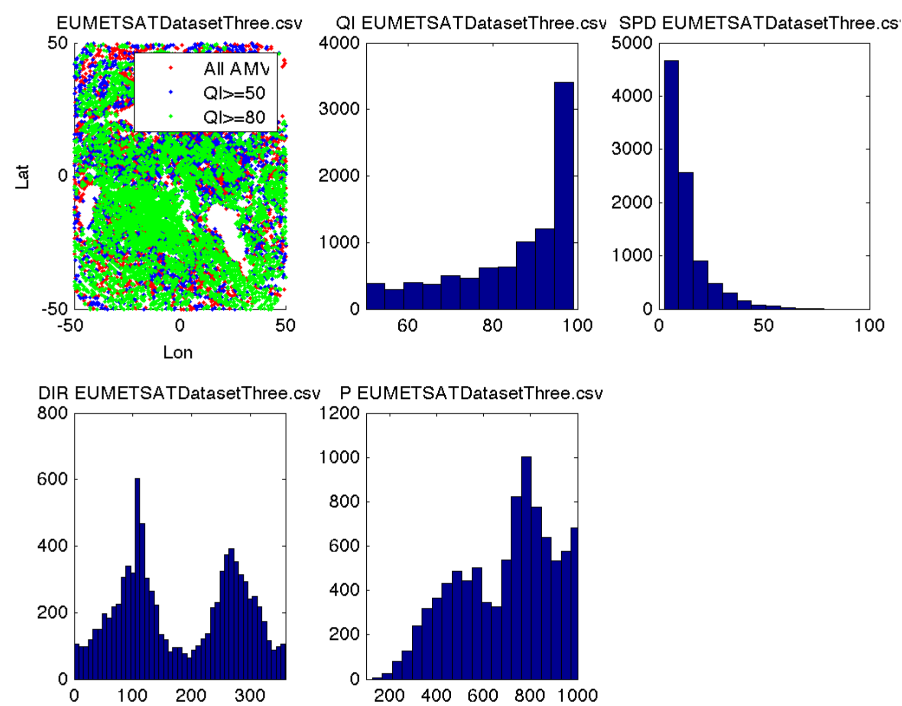

Figure 55: Experiment 3 parameter distributions for EUM: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

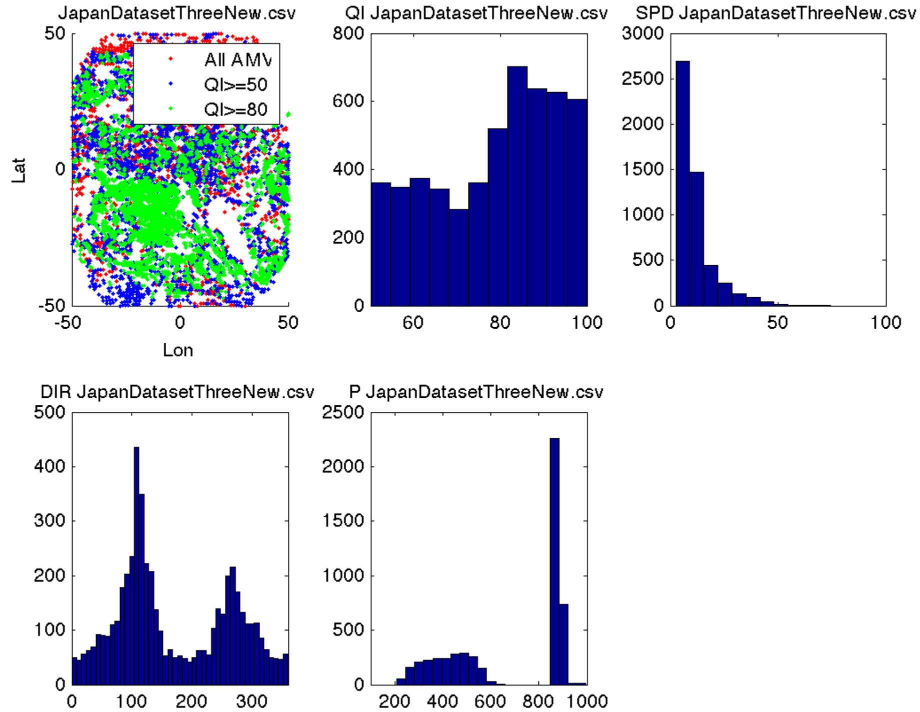

Figure 56: Experiment 3 parameter distributions for JMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

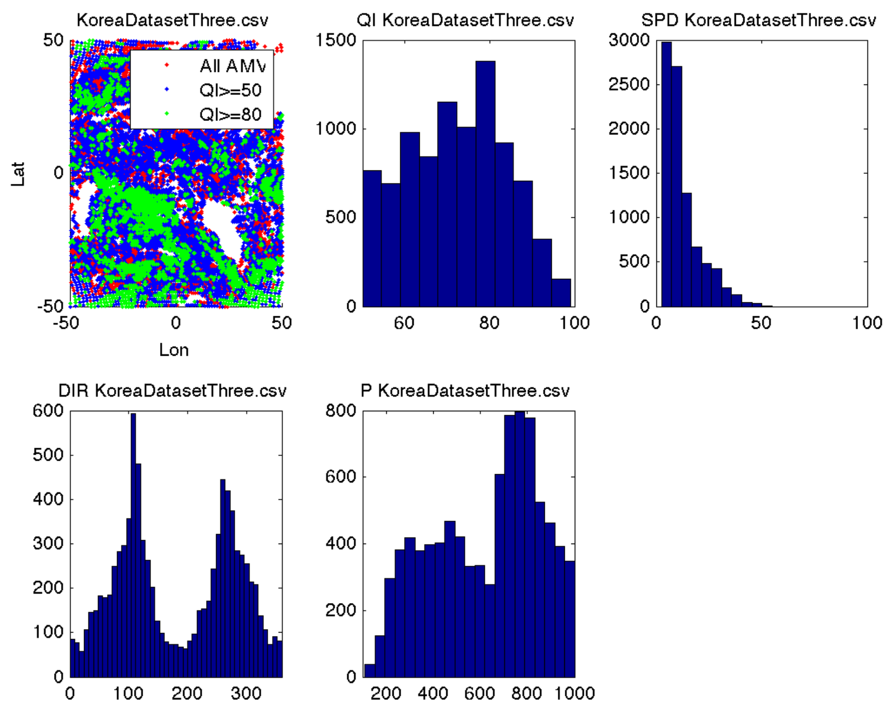

Figure 57: Experiment 3 parameter distributions for KMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

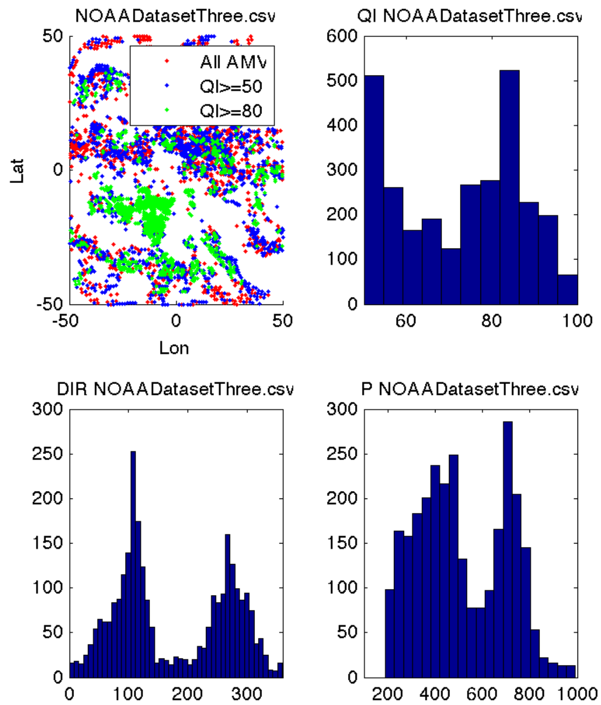

Figure 58: Experiment 3 parameter distributions for NOA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

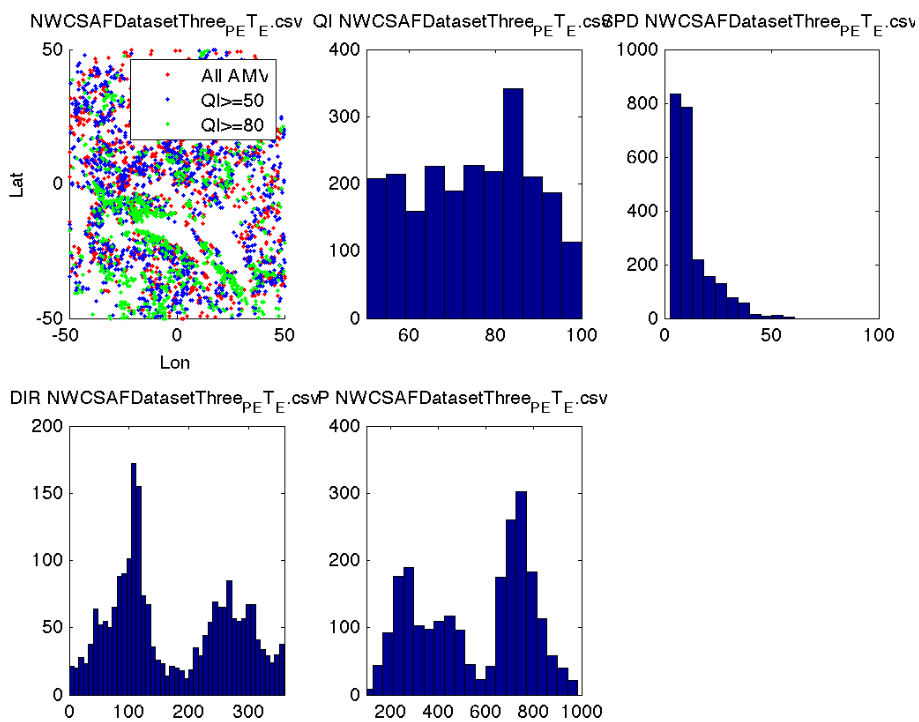

Figure 59: Experiment 3 parameter distributions for NWC: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

c) Colocation plots

AMVs are first quality controlled, retaining only those with a QINF >= 50. For colocation the distance threshold is 55 km, resulting in 370 AMVs.

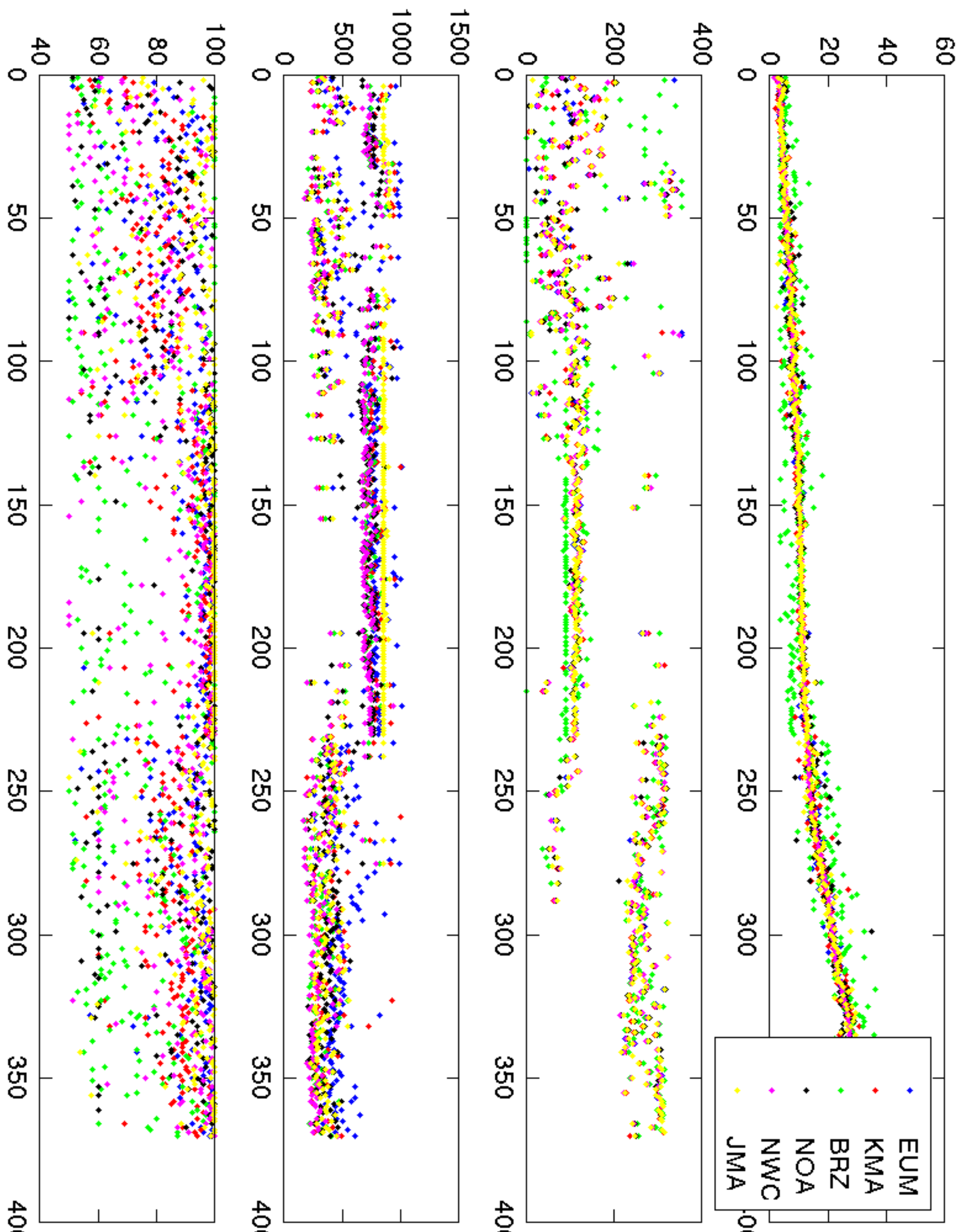

Figure 60: Plots of colocated AMVs of speed (top), direction (2nd), pressure (3rd), and QI (bottom) are color-coded based on legend in upper right. The x-axis is AMV number.

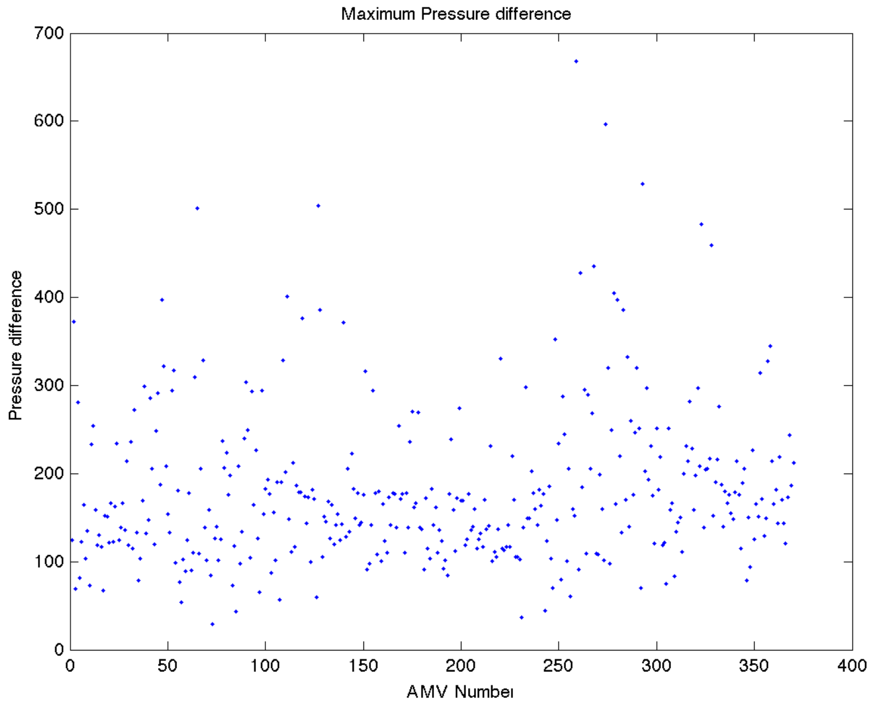

Figure 61: The maximum pressure difference between any two colocated AMVs.

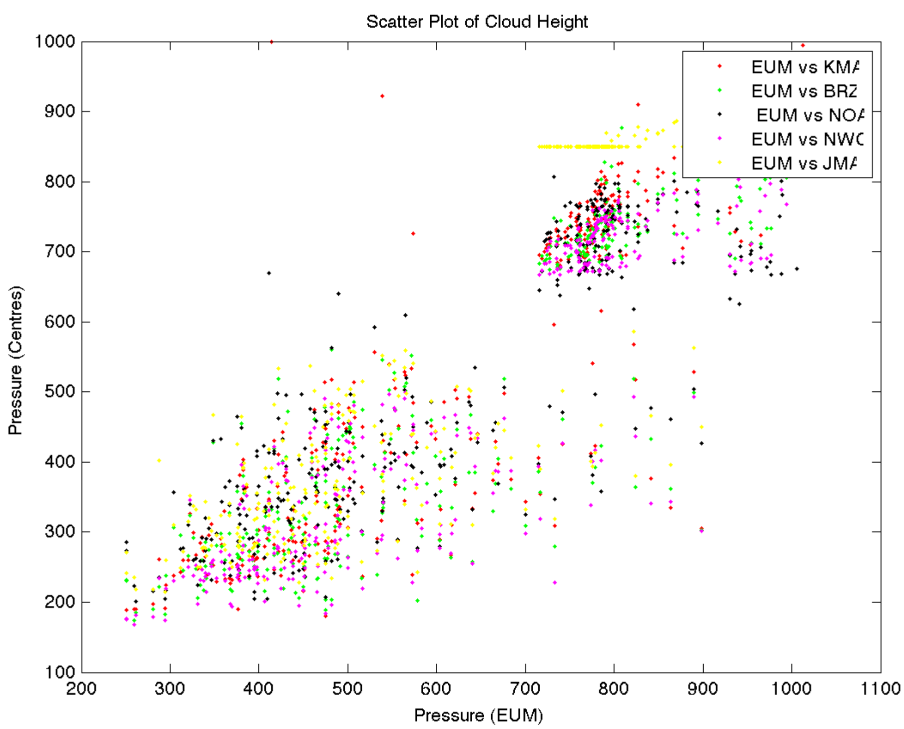

Figure 62: Scatter plot of AMV pressure for each center vs. EUM pressure.

A similar comparison is done for AMVs with QI with forecast, retaining only those with a QIWF >= 50. For colocation the distance threshold is 55 km, resulting in 409 AMVs.

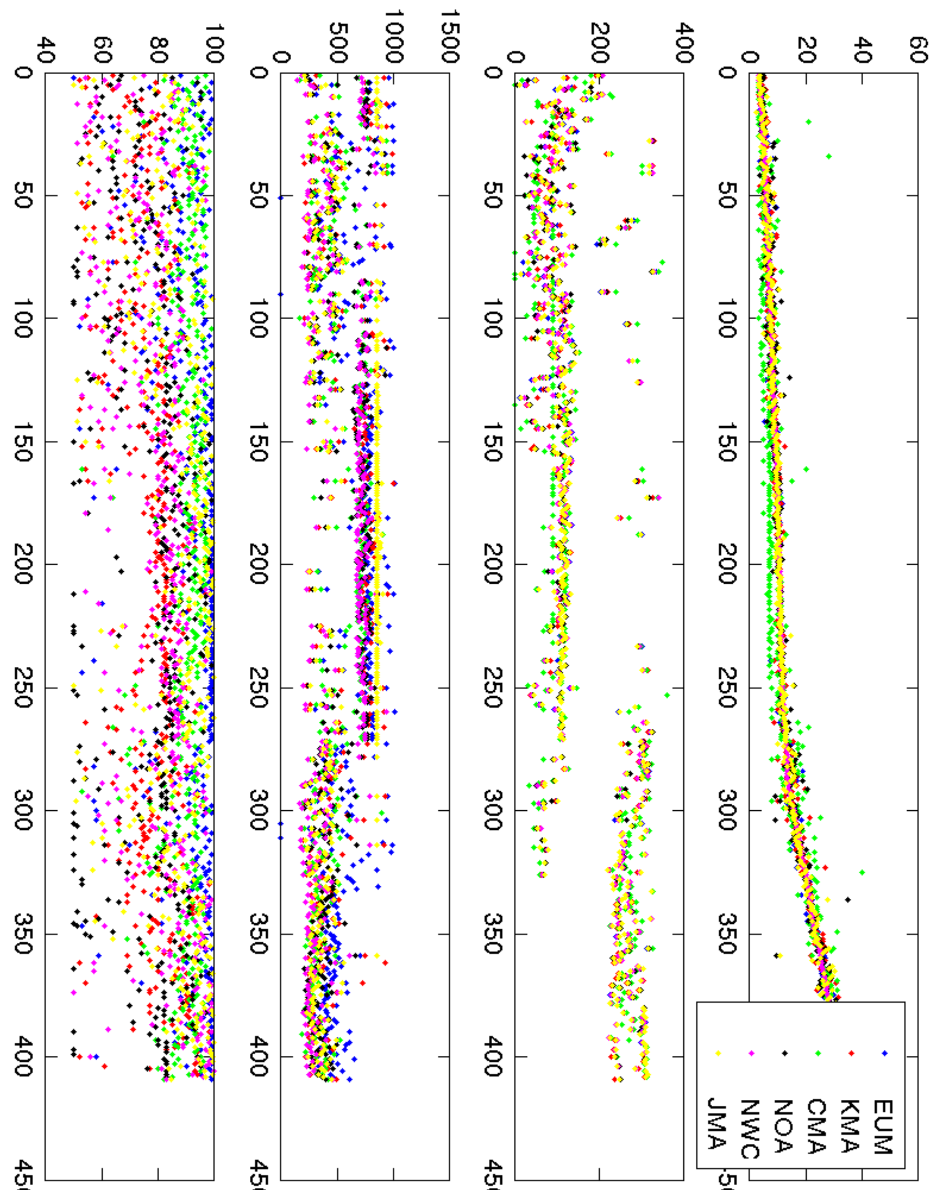

Figure 63: Plots of colocated AMVs of speed (top), direction (2nd), pressure (3rd), and QI (bottom) are color-coded based on legend in upper right. The x-axis is AMV number.

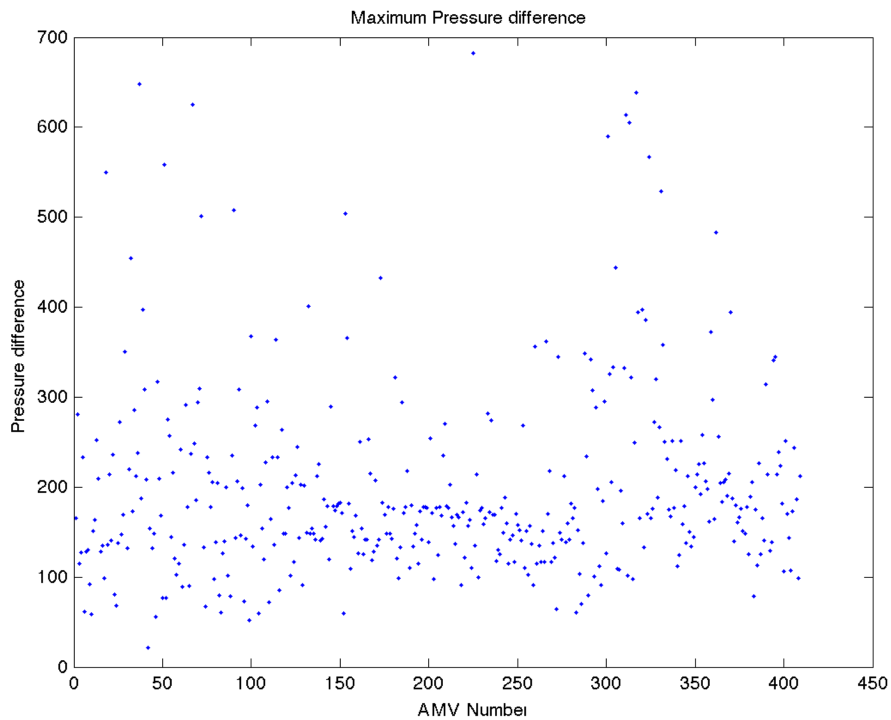

Figure 64: The maximum pressure difference between any two colocated AMVs.

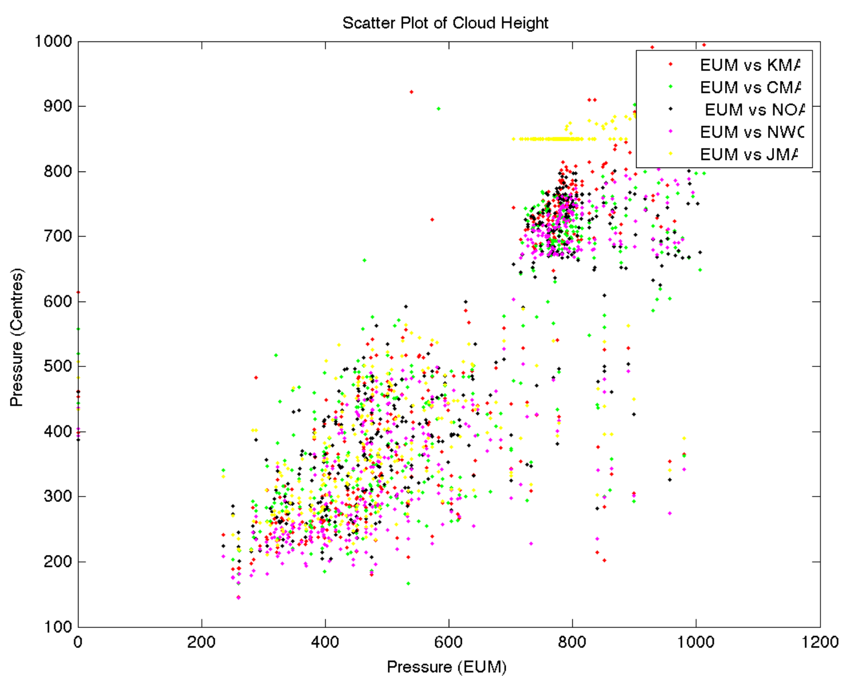

Figure 65: Scatter plot of AMV pressure for each center vs. EUM pressure.

d) Rawindsonde comparison

The comparison of Experiment 3 AMVs to collocated rawinsondes are summarized in Table 21 (QINF >= 50) and Table 22 (QIWF >= 50). Note: The sample is small (70 to 300 matches).

The vector RMS ranges from 6 ms^{-1} (NWC) to 9-10 ms^{-1} (BRZ, EUM); the speed RMS ranges from 5 ms^{-1} (NWC, JMA) to 7 ms^{-1} (BRZ, EUM). These results are very similar to Experiment 2, which is expected, as there was not a change in the cloud height assignment method.

Table 21: Experiment 3 AMVs (QI no forecast >= 50) comparison to rawinsondes within 150 km. N = number of matches; P bias = pressure bias; P RMS = pressure RMS; SpdBias = speed bias; SpdRMS = speed RMS; DirBias = wind direction bias; VecRMS = vector RMS. The extreme for each category is highlighted: Yellow = high value; cyan = low value.

SIte	N	P bias	P RMS	SpdBias	SpdRMS	DirBias	VecRMS
BRZ	144	0.03	23.90	1.61	6.32	-3.21	10.54
EUM	268	-0.53	26.57	3.09	7.24	0.05	9.43
JMA	177	-2.20	26.26	0.36	6.04	6.07	8.04
KMA	309	0.16	24.85	-0.02	5.36	4.25	7.13
NOA	101	5.13	24.19	2.37	5.57	22.25	9.32
NWC	75	-3.60	22.36	-1.81	5.13	-3.19	6.44

Table 22: Experiment 3 AMVs (QI with forecast >= 50) comparison to rawinsondes within 150 km. N = number of matches; P bias = pressure bias; P RMS = pressure RMS; SpdBias = speed bias; SpdRMS = speed RMS; DirBias = wind direction bias; VecRMS = vector RMS. The extreme for each category is highlighted: Yellow = high value; cyan = low value.

SIte	N	P bias	P RMS	SpdBias	SpdRMS	DirBias	VecRMS
CMA	201	0.97	28.15	1.25	7.30	5.50	9.12
EUM	283	-0.71	26.15	2.74	7.07	0.57	9.46
JMA	169	-2.50	26.81	0.14	5.09	3.52	7.04
KMA	287	0.80	24.72	0.12	5.07	6.05	6.73
NOA	96	4.89	24.10	2.28	5.57	25.82	9.30
NWC	73	-3.17	21.93	-1.95	5.16	0.44	6.29

e) Best fit height

The Best Fit height analysis was done for each wind producer according to the method described by Salonen et al. (2012). This technique finds the background model best-fit pressure associated with the AMV. The model best-fit pressure is the height (in pressure) where the vector difference between the observed AMV and model background is a minimum. The number of best-fit matches is generally less than 30% of the AMVs. See Appendix C: Best Fit Height Algorithm for implementation details.

Figure 66 to Figure 72 show the:

- Distribution of Best Fit minus AMV pressure differences, color-coded by low, medium, and high clouds (upper left),
- Spatial distribution with same color coding (upper right),
- Relationship between AMV pressure and latitude, color-coded to indicate if the Best fit moved the AMV higher (red) or lower (blue) (lower left),
- Relationship between AMV pressure and speed, color-coded to indicate if the Best fit moved the AMV higher (red) or lower (blue) (lower right).

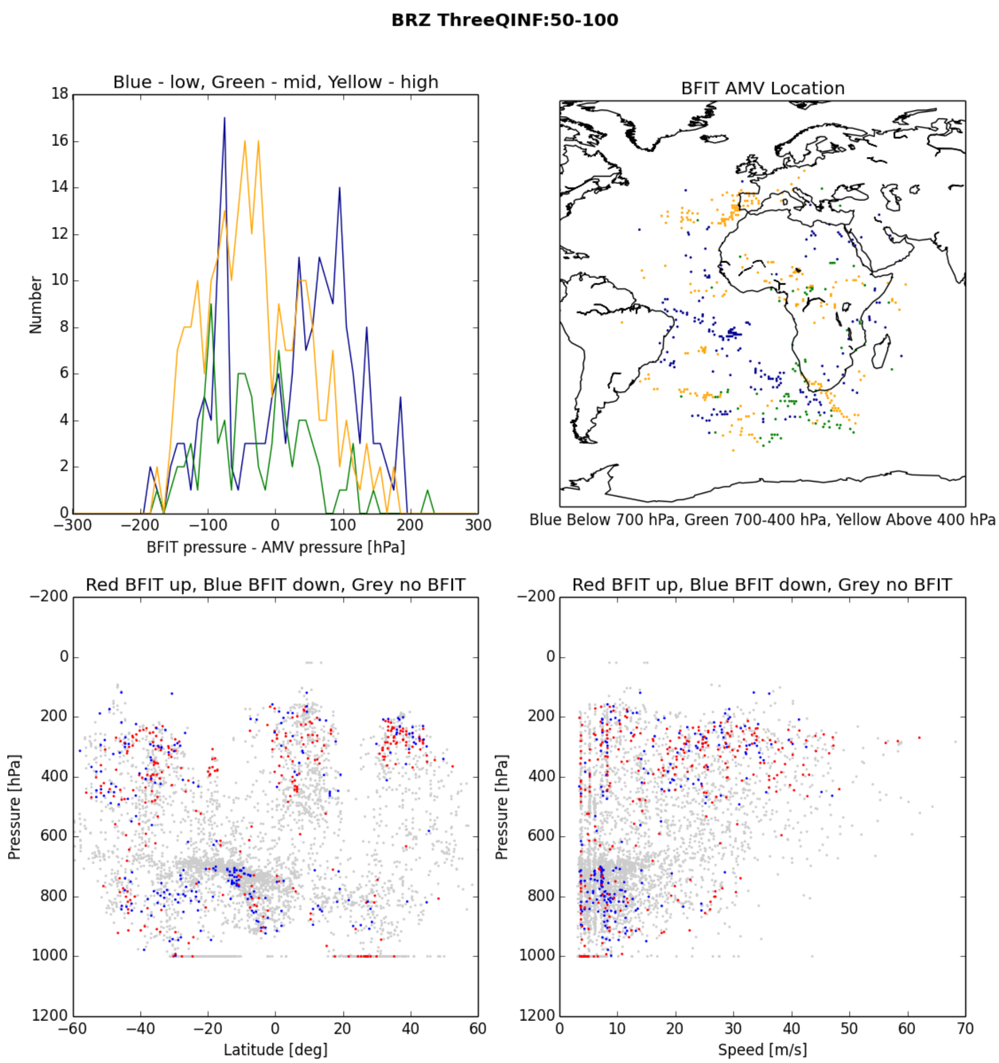

Figure 66: BRZ: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

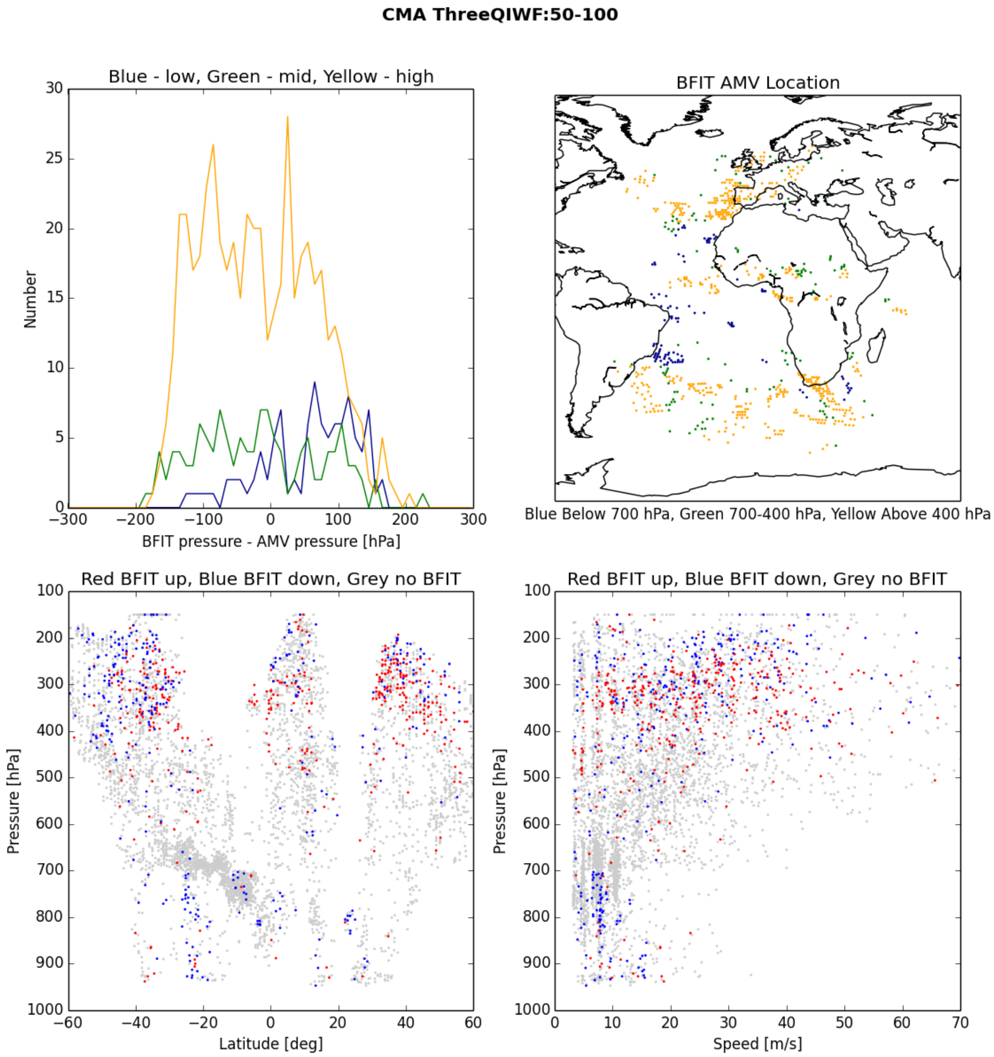

Figure 67: CMA: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

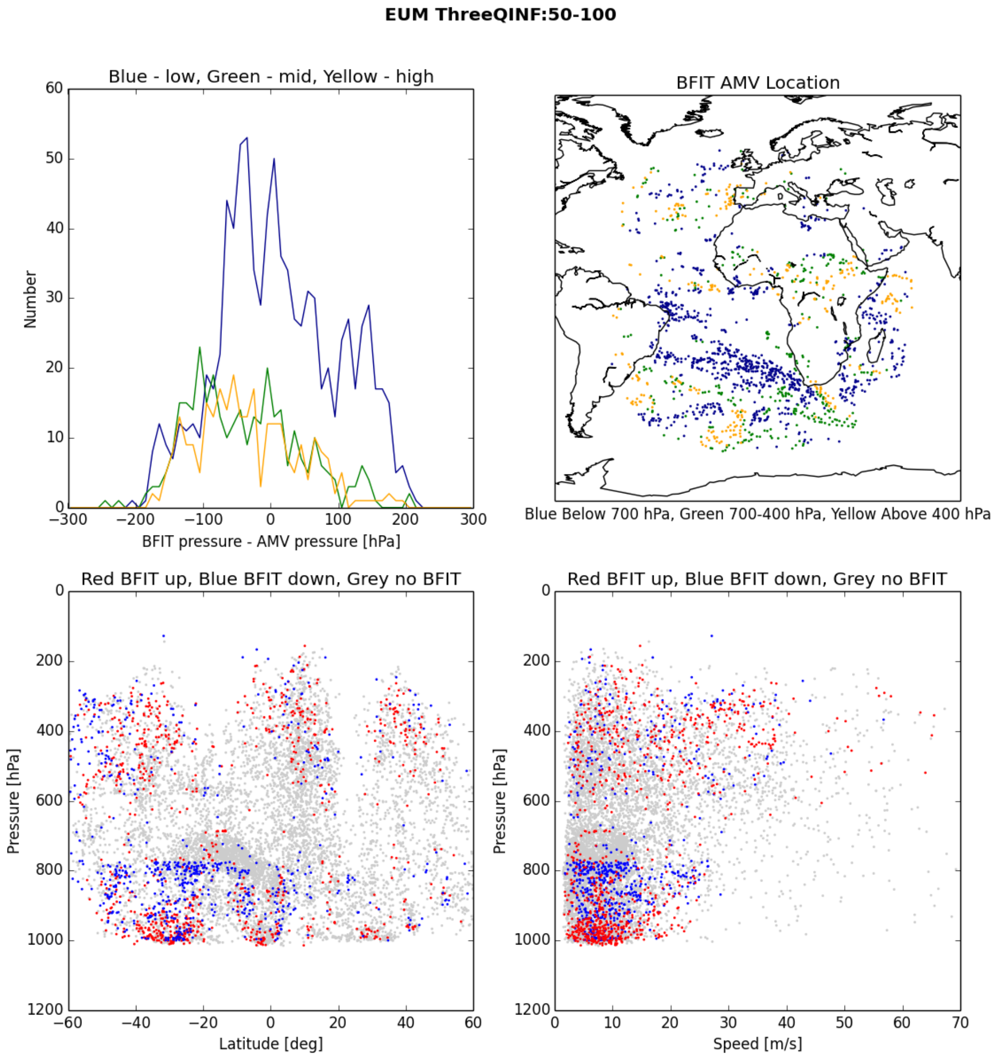

Figure 68: EUM: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

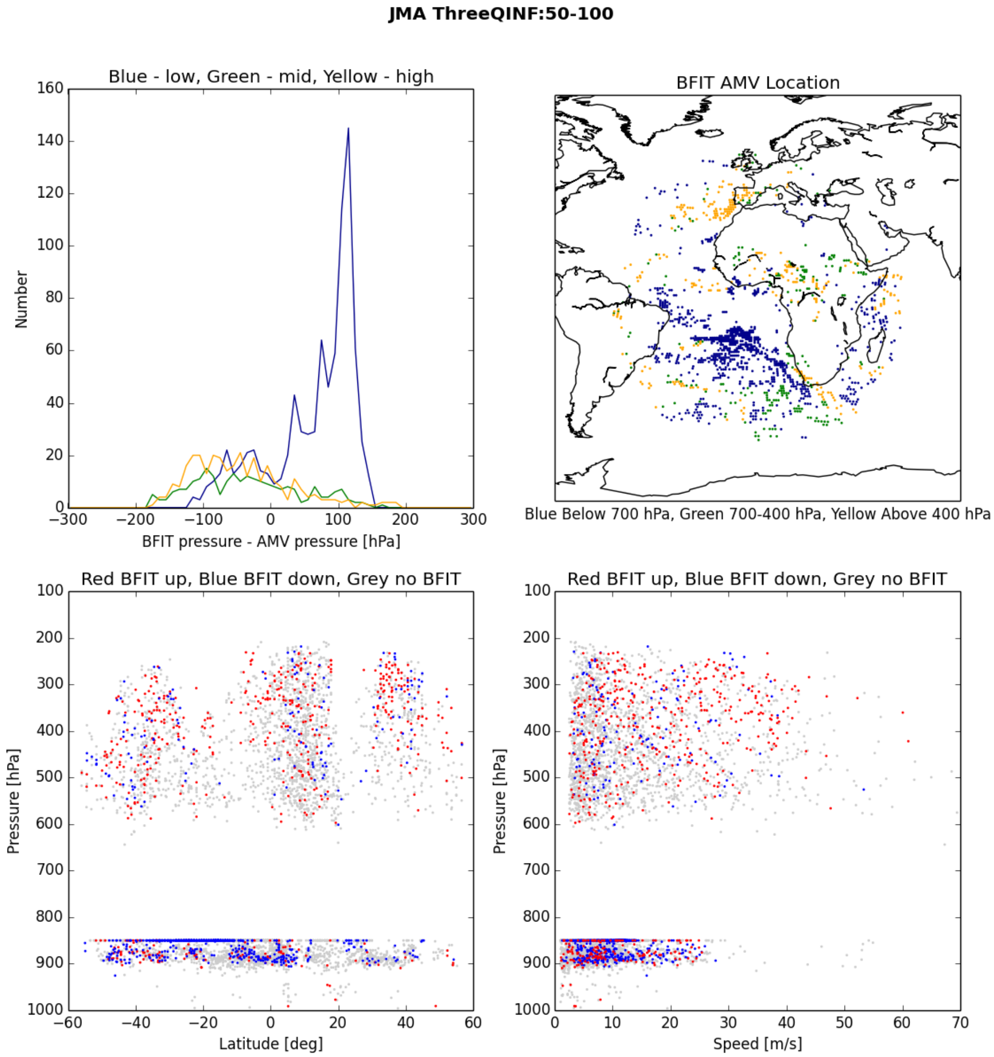

Figure 69: JMA: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

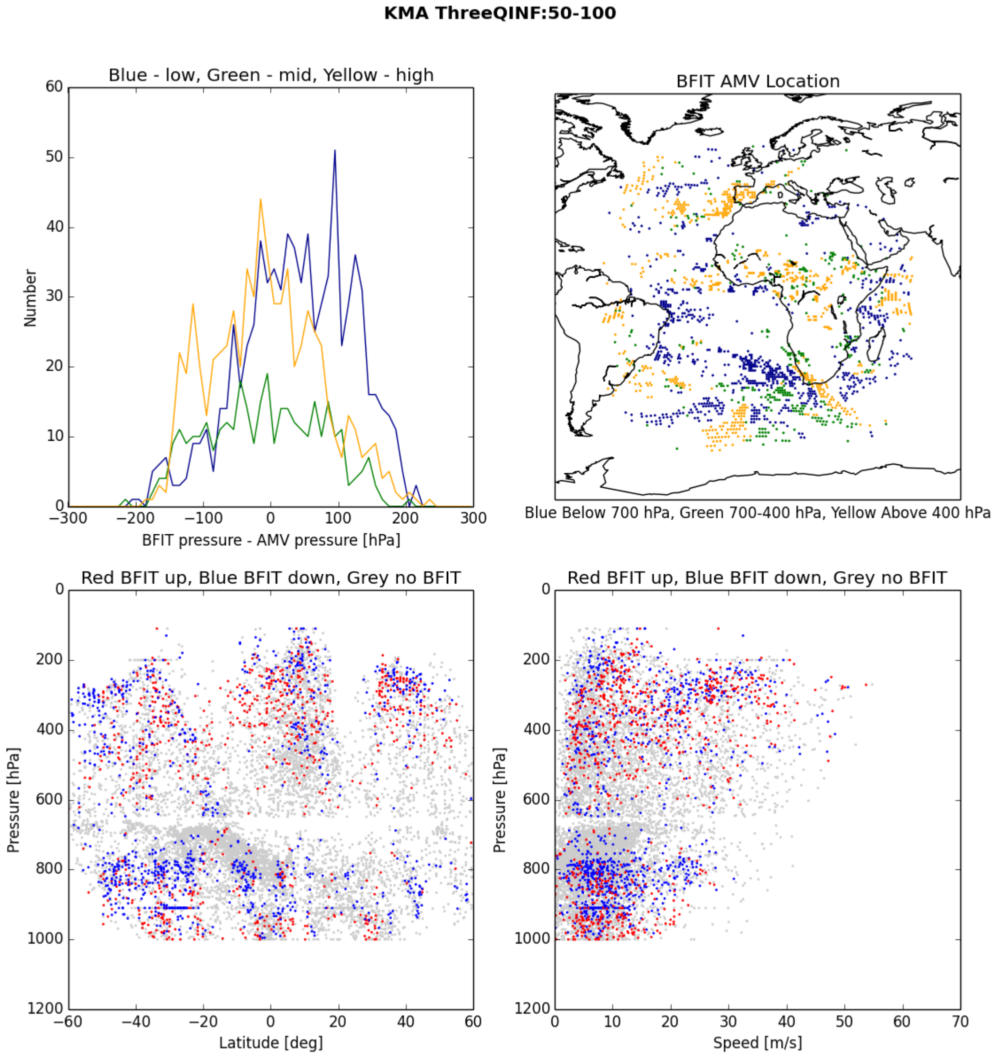

Figure 70: KMA: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

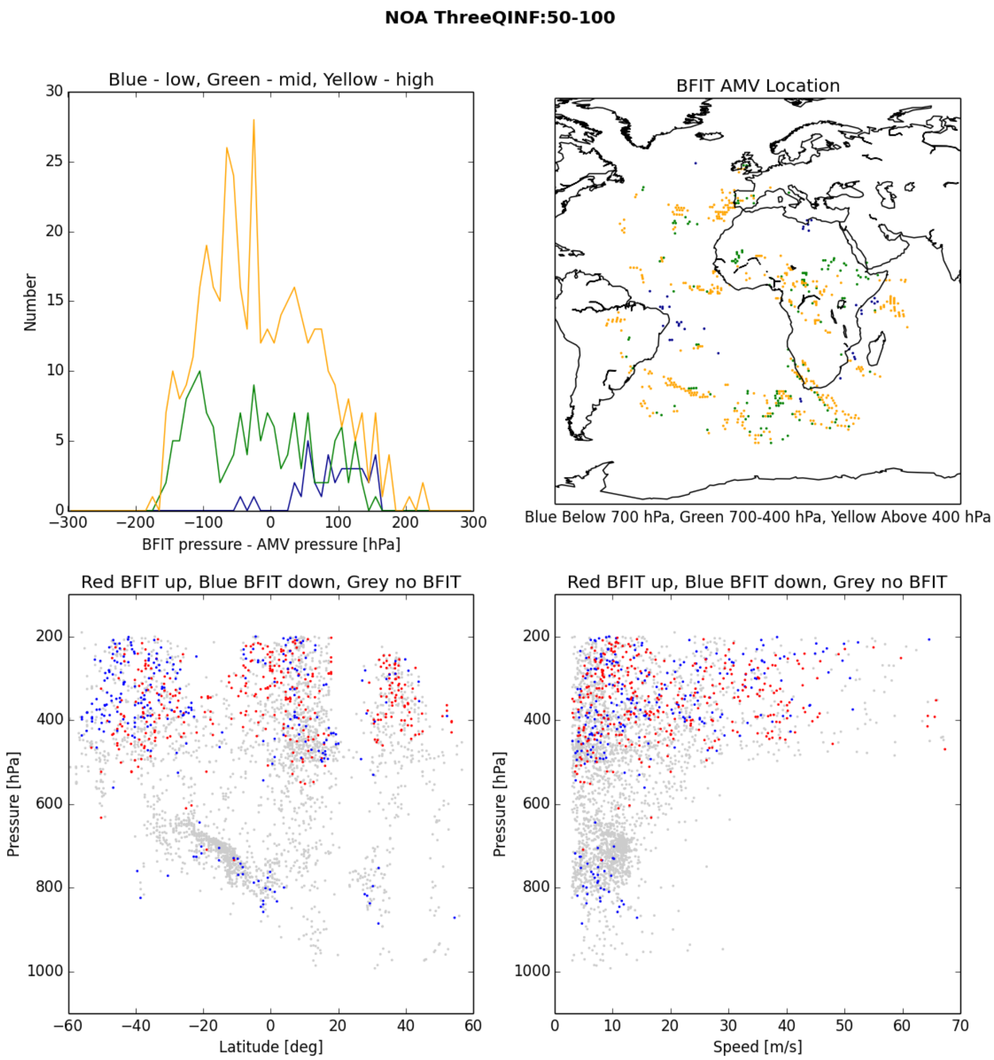

Figure 71: NOA: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

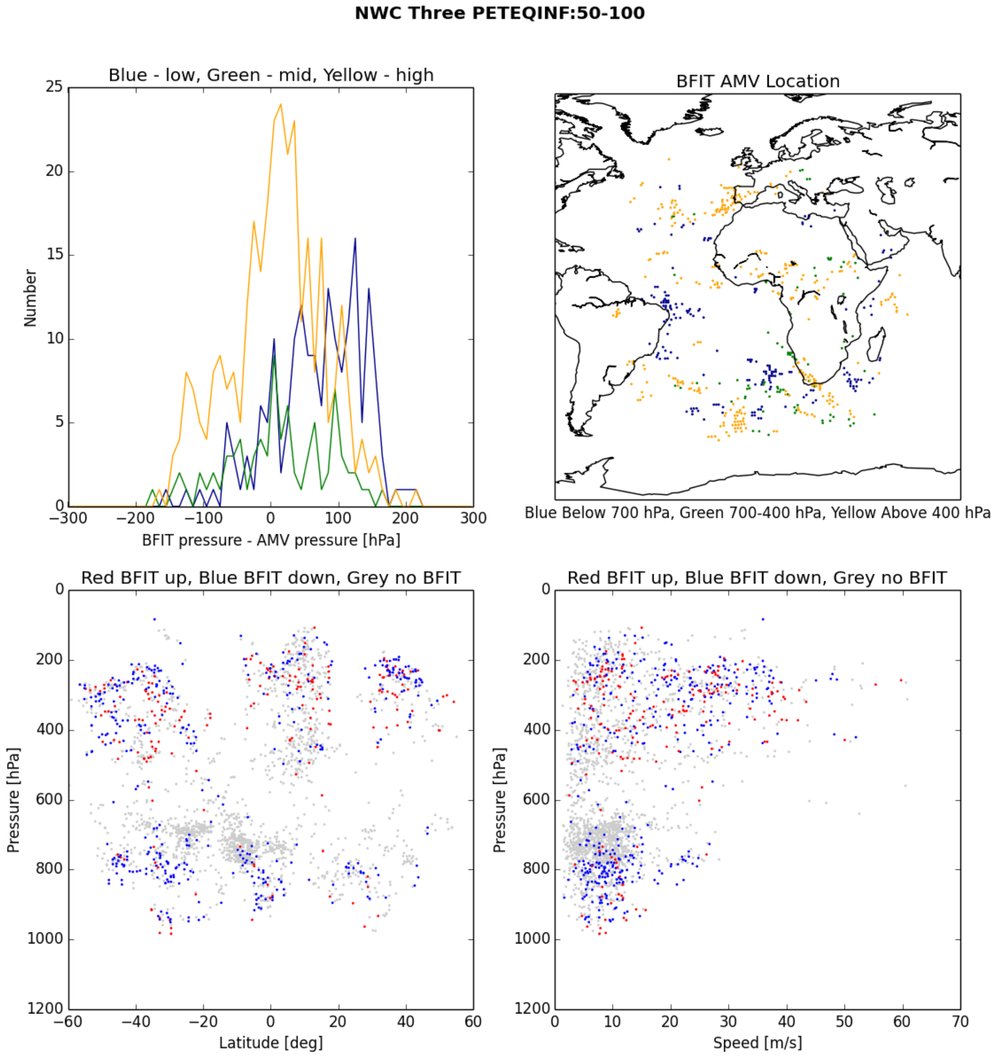

Figure 72: NWC: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

The depiction of the distribution of Best Fit statistics is in Figure 73 through Figure 79. Depending on the site, 12% to 28% (lower left in each figure) of the AMVs are adjusted to a Best Fit pressure. There does not appear to be a relationship between latitude or longitude and adjusted pressure (upper left and middle left in figures).
In the upper-right corner of the figures, the distribution of the pressure difference (AMV Best Fit pressure minus the Original Pressure). For sites BRZ, CMA, EUM, NOA, and KMA the pressure difference is centered near zero. However, JMA has two peaks (-50 and +100) with a minimum near zero and for NWC it is slightly skewed to the right of zero. For experiment 3, since the AMV heights are assigned using only the IR brightness temperature, these offset and skewed distributions may be the result of the specific implementation of the IR brightness temperature height assignment, shown to be erroneous.. These results are very similar to Experiment 2.

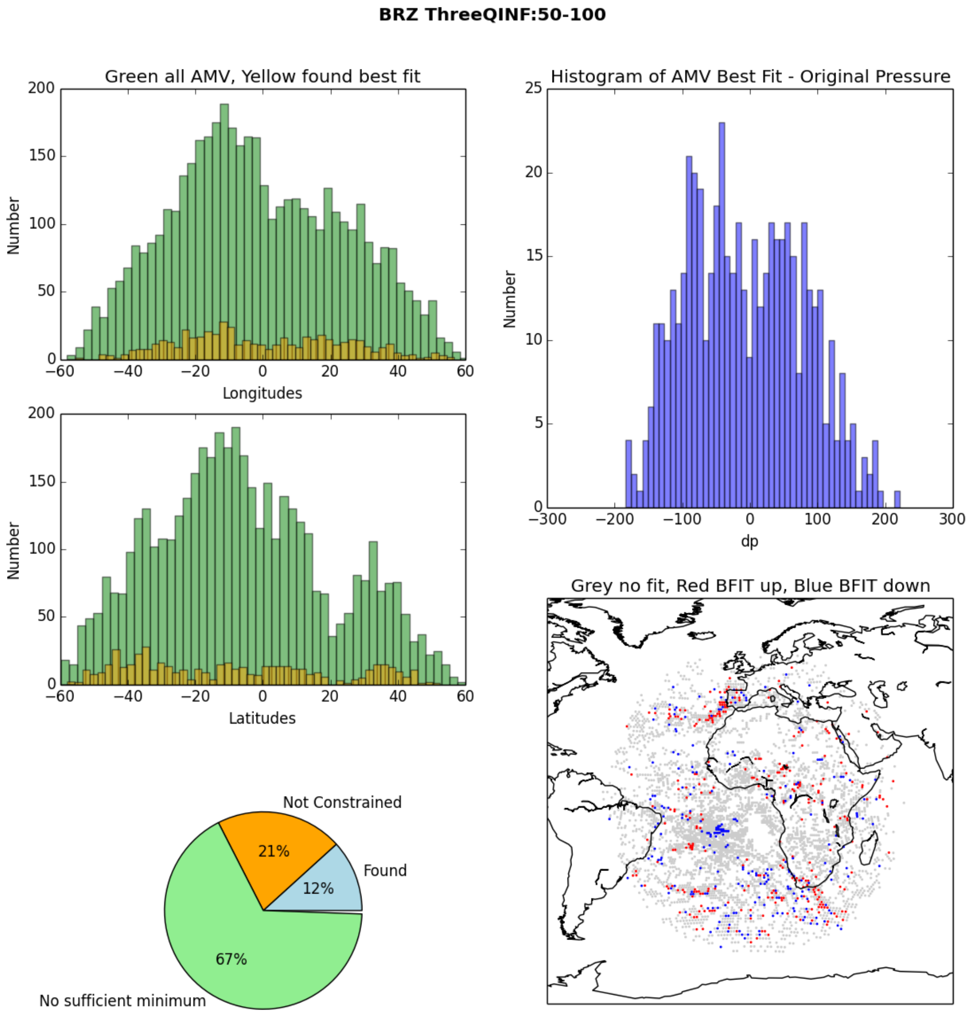

Figure 73: BRZ: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

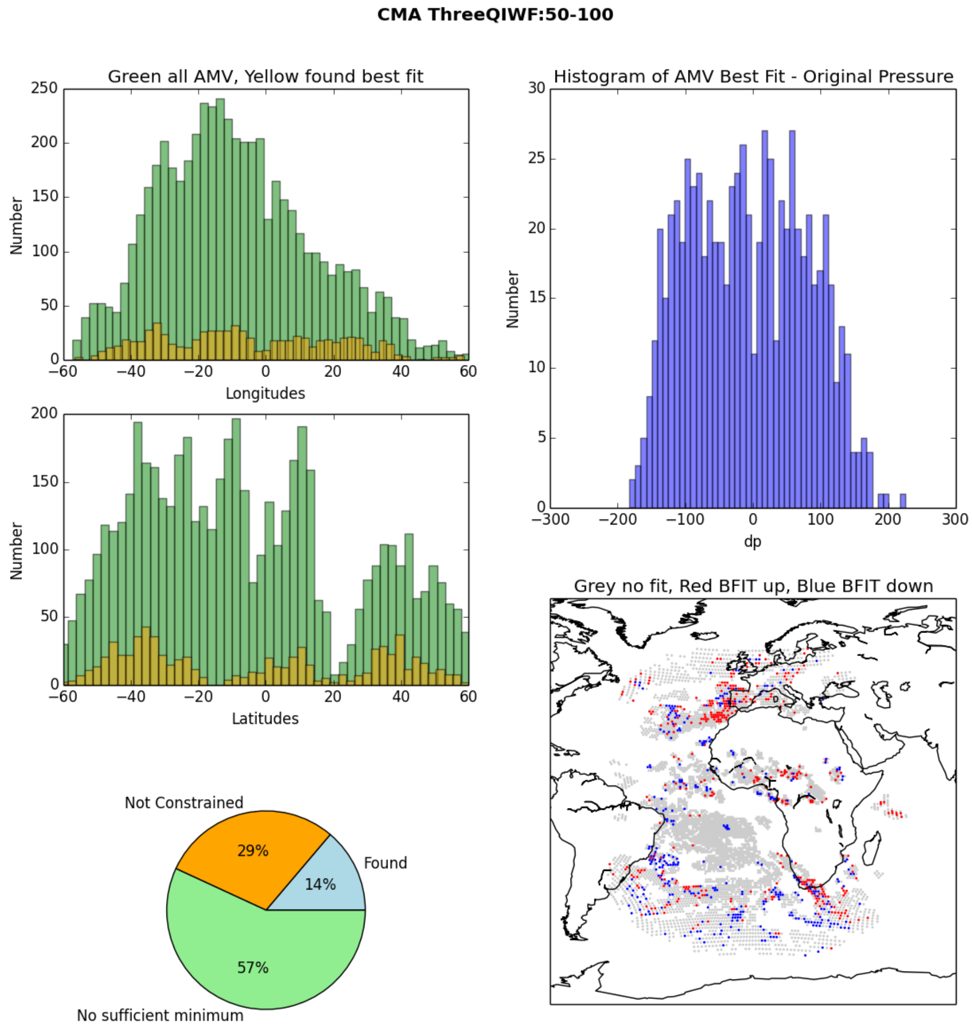

Figure 74: CMA: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

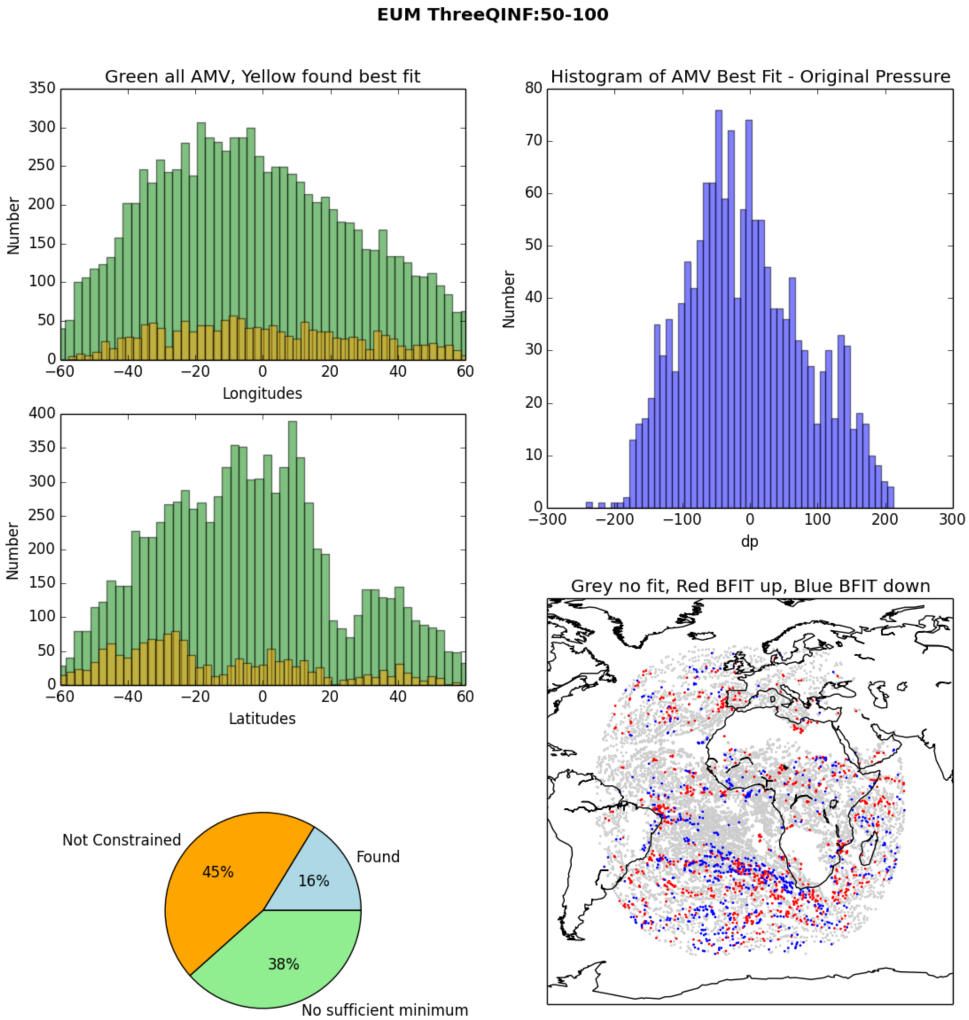

Figure 75: EUM: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

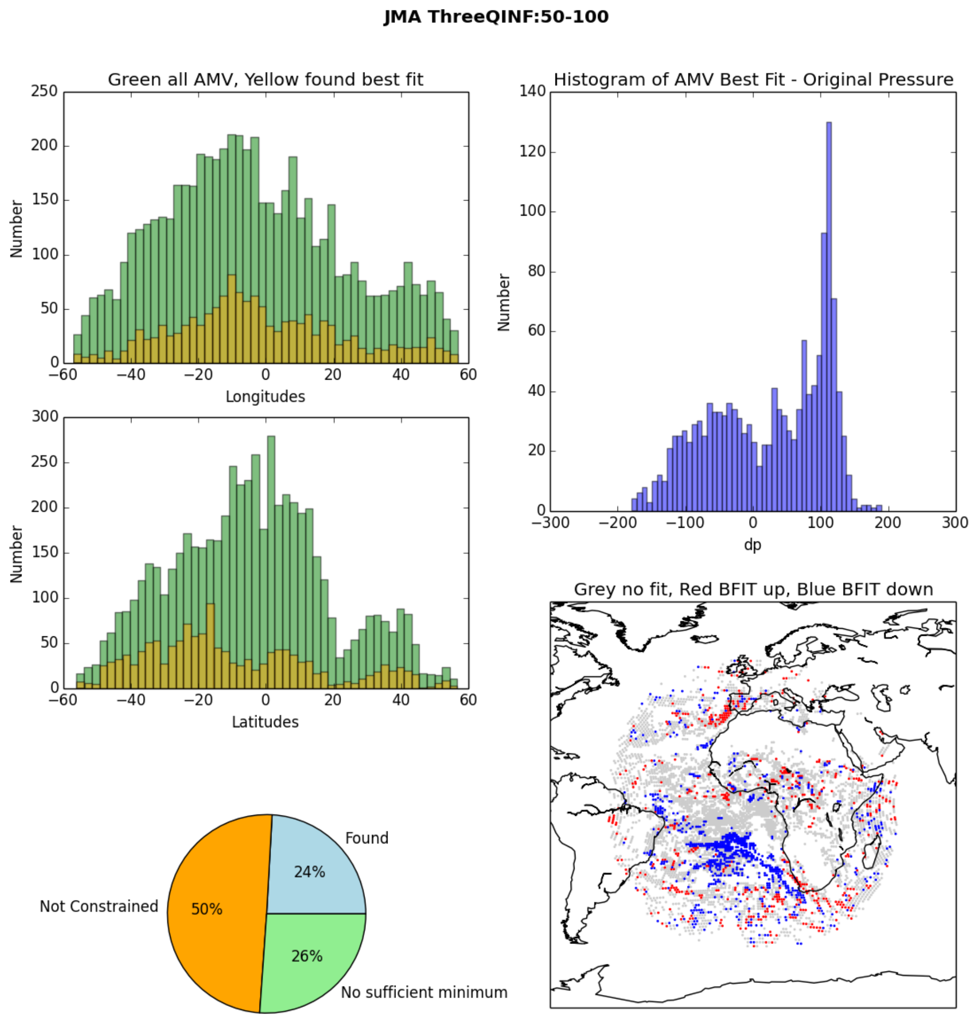

Figure 76: JMA: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

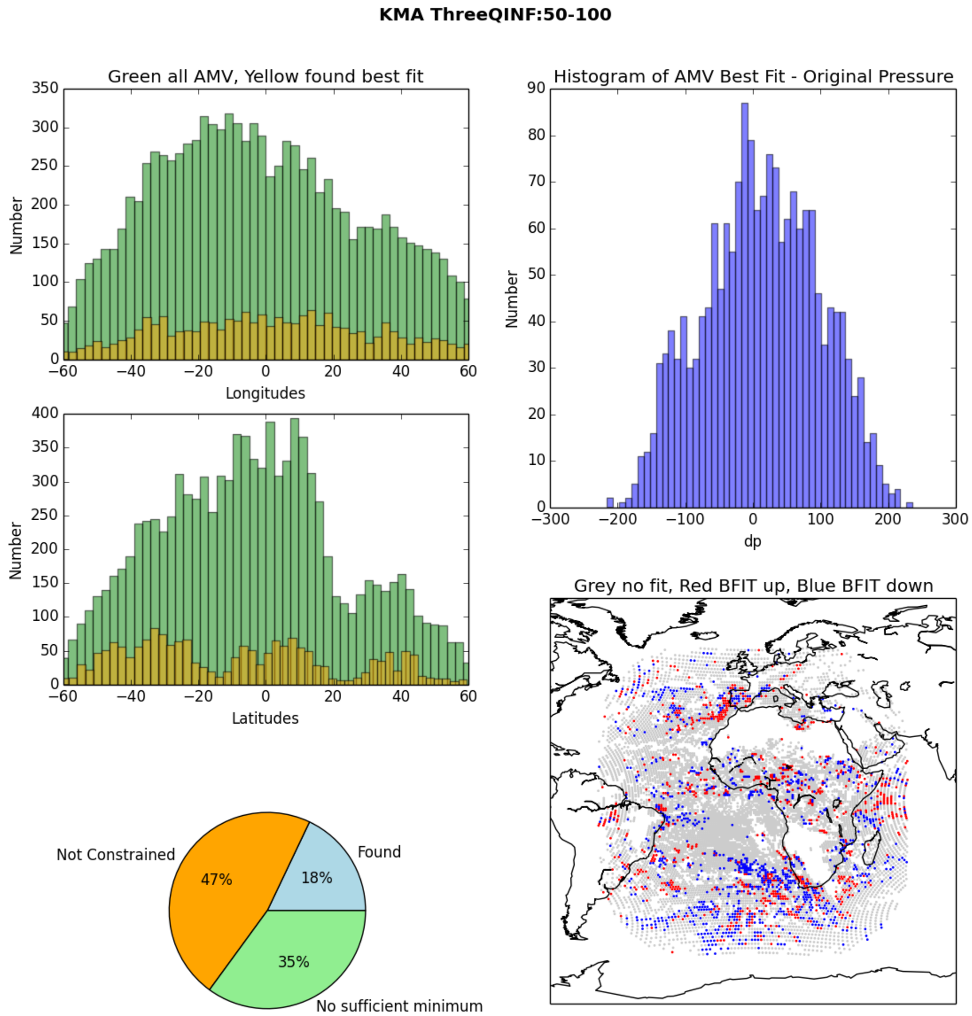

Figure 77: KMA: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

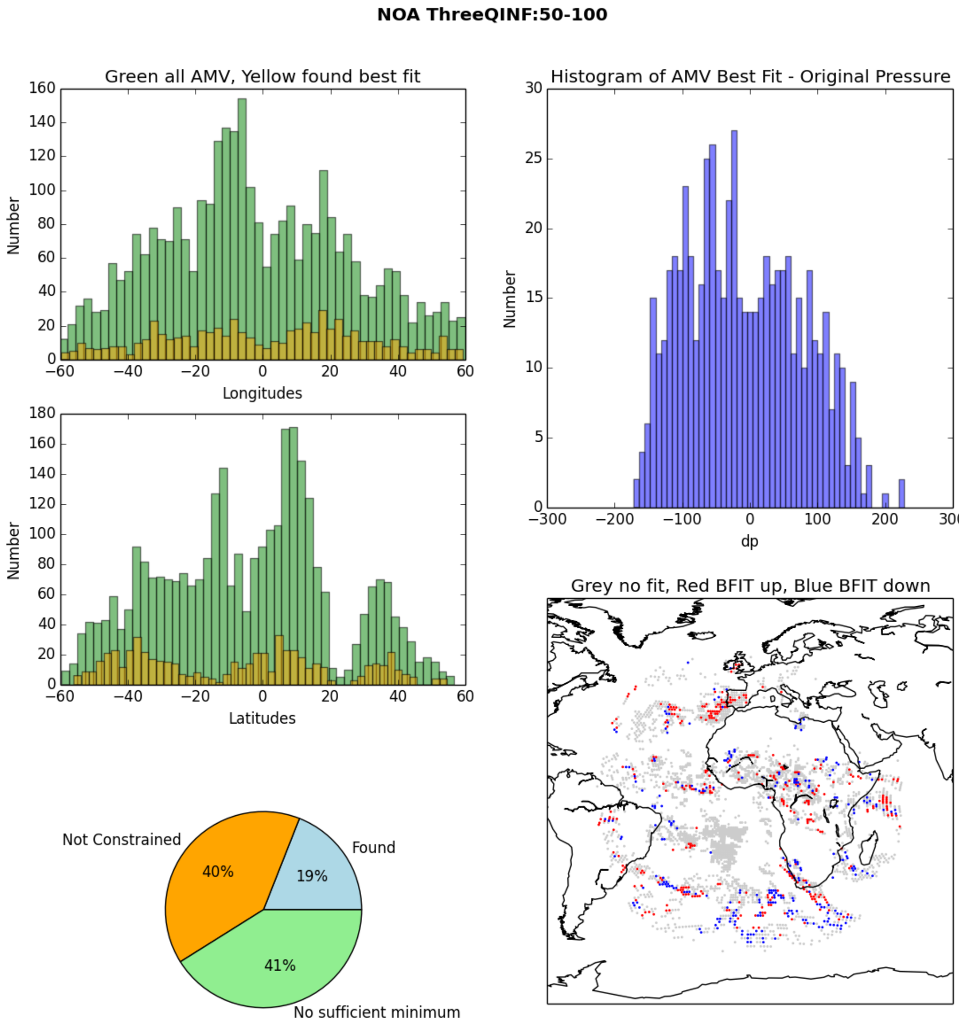

Figure 78: NOA: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

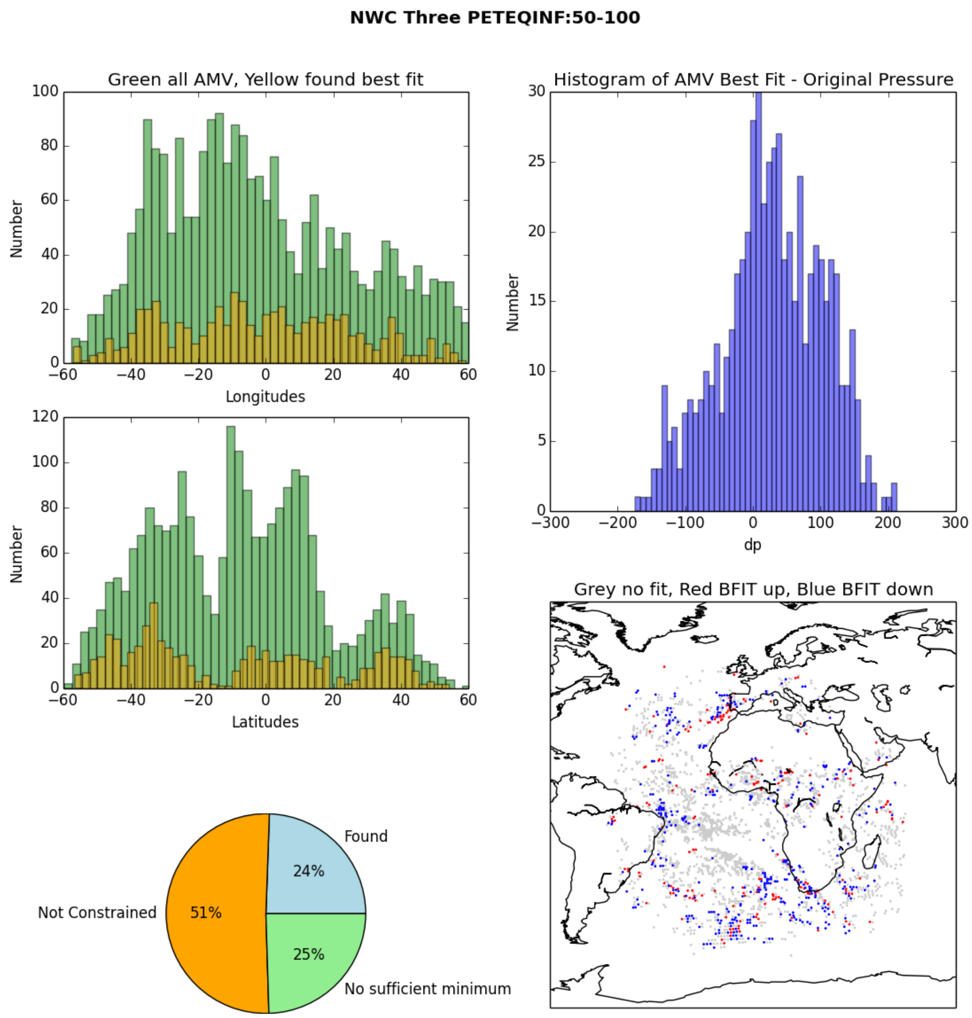

Figure 79: NWC: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

Ancillary figures were generated (Appendix D: Best Fit Speed and Vector Difference) to show how the statistics improve when the AMV height is adjusted to the Best Fit level. The lower half of Figure 143 to Figure 150 shows the change in the speed difference distribution before (left) and after (right) Best Fit adjustment. As expected, the speed bias is usually reduced, as is the standard deviation. These results are very similar to Experiment 2.

The lower half of Figure 150 to Figure 156 shows the change in the vector difference distribution before (left) and after (right) Best Fit adjustment. As expected, the vector difference is usually reduced, as is the standard deviation. BRZ and CMA had the largest deviation before the best fit, with a vector difference of about 8 ms^{-1} as compared to the background grid. NWC had the smallest deviation before the best fit, with a vector difference of about 4 ms^{-1} as compared to the background grid. These results are very similar to Experiment 2.

f) Statistical comparison

The paired t-test was used between all combinations of producers (and parameters) to determine if the differences are statistically significant in colocated AMVs. The number of matches is very low. QI no forecast >= 50; distance threshold 55 km. Number of co-locations is 370.

As compared to Experiment 2, there are many more instances of agreement between the winds producers in terms of wind speed (Figure 23) and wind direction (Figure 24). In fact for direction, differences between the centres are not statistically significant.

As with Experiment 2, there is no similarity in AMV pressure and QI values, at least as measured by the paired t-test.

The output from the paired t-test for this experiment can be found in Appendix B: t-test Results Experiment 3.

Table 23: Experiment 3 <u>speed</u> t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	BRZ	NOA	NWC	JMA
EUM						
KMA						
BRZ						
NOA						
NWC						
JMA						

Table 24: Experiment 3 <u>direction</u> t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	BRZ	NOA	NWC	JMA
EUM						
KMA						
BRZ						
NOA						
NWC						
JMA						

Table 25: Experiment 3 <u>pressure</u> t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	BRZ	NOA	NWC	JMA
EUM						
KMA						
BRZ						
NOA						
NWC						
JMA						

Table 26: Experiment 3 <u>QI without forecast</u> t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	BRZ	NOA	NWC	JMA
EUM						
KMA						
BRZ						
NOA						
NWC						
JMA						

The paired t-test was used between all combinations of producers (and parameters) to determine if the differences are statistically significant in colocated AMVs. The number of matches is very low. QIWF >= 50; distance threshold 55 km. Number of co-locations is 245.

There is no statistical difference in direction and many speed differences are also not statistically different (Table 27).

The output from the paired t-test for this experiment can be found in Appendix B: t-test Results Experiment 3.

Table 27: Experiment 3 speed t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA
EUM						
KMA						
CMA						
NOA						
NWC						
JMA						

Table 28: Experiment 3 direction t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA
EUM						
KMA						
CMA						
NOA						
NWC						
JMA						

Table 29: Experiment 3 pressure t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA
EUM						
KMA						
CMA						
NOA						
NWC						
JMA						

Table 30: Experiment 3 QI with forecast t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA
EUM						
KMA						
CMA						
NOA						
NWC						
JMA						

g) Model Grid comparison

Pythons scripts that find the Best Fit, also output comparison of all AMVs to the background grid. This comparison is based on 12-hour forecast. The results in Table 31 are similar to what was found in Experiment 2 since the cloud heights are not changed: NWC and JMA have the best fit to the background, while BRZ and EUM have the highest errors.

Table 31: Experiment 3 AMV comparison to background grid: a 12-hour forecast. N = total number of AMVs; BFN = Best Fit number of AMVs; V_O = VD OMB mean; RAF = RMSE after Best Fit; VAF = Vector difference after Best Fit; RMSE = root mean square error.

Exp	QI	N	BFN	V_O	RAF	VAF	RMSE
BRZ	QINF:80-100	1586	188	8.61	10.42	8.25	10.25
CMA	QIWF:80-100	4399	672	6.75	7.80	6.27	7.47
EUM	QINF:80-100	5378	1003	6.88	9.73	6.47	9.54
JMA	QINF:80-100	3498	955	4.50	6.05	3.71	5.52
KMA	QINF:80-100	4486	921	6.09	8.00	5.60	7.72
NOA	QINF:80-100	1639	312	6.74	8.26	6.16	7.89
NWC	QINF:80-100	1145	310	4.61	5.48	4.02	4.98

10. Experiment 4

AMV producers extract IR10.8 channel AMVs considering a <u>prescribed</u> AMV algorithm configuration, but using the <u>height assignment method of their choosing</u>. This experiment will be used to test the Height assignment and Quality control steps in all AMV algorithms, considering similar targets.

This is the same as Experiment 3, except the AMV producers can use additional height assignment methods, such as CO_2 slicing, H_2O-Intercept, Cloud Base, etc.

For each one of the AMV producer's datasets, a distribution of AMV speed, direction, vector height, and QI will be generated. Differences of these quantities between AMV producers will be made. Also, differences in AMV coverage and number of vectors will be presented as bulk statistics and geographic plots.

Colocated AMVs from the different algorithms will be used to measure the differences. Also, a comparison of the AMVs with the NWP model winds and height assignment investigations using NWP model best-fit pressure will be used for verification.

<u>Experiment 4 Highlights</u>

Using additional height assignments results in a shift in the distributions of AMV pressure, for both high- and low-level clouds. This was especially noted for EUM and NOA, which resulted in a substantial improvement in the vector RMS with rawinsonde comparisons for EUM (from 9.46 to 6.26 ms^{-1}) and NOA (from 9.30 to 7.36 ms^{-1}).

Other centres (BRZ, CMA, KMA, JMA) have very few AMVs shifted in height, accounting for only a few percent, with little change in the rawinsonde and model grid comparison RMS errors.

Colocated vectors number 9942. Nearly all speed, direction, pressure, and QI differences are significant between all centres. The only exception is direction for EUM, NOA, NWC, and JMA. Pressure differences are smaller than in Experiment 3, although the mean difference for colocated vectors has a range from 20 to 100 hPa.

a) Approach

Similar comparison and analysis as Experiment 3, but now more can be done with cloud heights: Determine if these cloud heights have improved best-fit statistics over just the B_T technique in Experiment 3.

b) Parameter distributions

The bulk statistics are presented in both tables and histograms, for QINF >= 50 and QIWF >= 50 (because not all centres reported both QINF and QIWF). Note: Since there are little differences in filtering based on QINF or QIWF, QINF >= 50 will be used for the following discussions (except for CMA which only reported QIWF).

Table 32 lists basic Experiment 4 statistics for the AMVs for each winds producer. Most of the values in this table are approximately the same, with the biggest difference is in the number of AMVs: Ranging from 4000 (NOA) to 92000 (NWC).

Table 32: Experiment 4 statistical summary of AMV datasets for QI without forecast >= 50.

	EUM	BRZ	JMA	KMA	NOA	NWC
Total AMVs	12182	11371	5648	11986	4449	92512
QI>=50	9147	4480	4996	9594	3773	79609
SPD_min	2.51	3.11	2.51	2.50	3.01	2.50
SPD_max	78.59	72.13	67.77	54.81	78.41	76.30
SPD_mean	12.46	13.38	10.69	12.10	14.28	11.73
P_min	123.86	19.00	100.49	105.05	110.17	123.00
P_max	995.20	1000.00	995.88	1000.00	999.47	998.94
P_mean	576.89	594.51	638.54	580.17	377.32	656.12
Low_winds	44.62	46.81	62.73	43.96	18.39	58.87
Mid_winds	17.82	19.80	4.82	23.92	11.90	12.40
High_winds	37.56	33.39	32.45	32.11	69.71	28.73
Low_SPD_min	2.51	3.11	2.51	2.50	3.02	2.50
Low_SPD_max	64.94	43.61	54.92	41.09	23.33	49.96
Low_SPD_mean	8.76	8.43	8.87	9.15	8.95	9.02
Low_P_min	700.11	700.00	707.57	700.04	700.02	700.00
Low_P_max	995.20	1000.00	995.88	1000.00	999.47	998.94
Low_P_mean	861.96	818.49	866.58	826.96	823.59	872.98
Mid_SPD_min	2.51	3.29	2.57	2.51	3.01	2.50
Mid_SPD_max	78.59	55.25	41.13	48.37	66.92	73.30
Mid_SPD_mean	12.69	12.63	10.90	12.22	12.34	13.61
Mid_P_min	400.02	400.05	400.37	400.16	400.41	400.03
Mid_P_max	699.90	699.94	672.61	699.99	699.76	699.95
Mid_P_mean	524.48	592.69	507.67	565.62	533.89	532.31
High_SPD_min	2.54	3.45	2.51	2.51	3.02	2.51
High_SPD_max	71.68	72.13	67.77	54.81	78.41	76.30
High_SPD_mean	16.75	20.76	14.18	16.06	16.02	16.48
High_P_min	123.86	19.00	100.49	105.05	110.17	123.00
High_P_max	399.81	399.58	399.55	399.94	399.54	399.93
High_P_mean	263.17	281.64	217.10	253.14	232.83	265.27

The following bulk histograms show unique characteristics of the AMVs for each centre:

- BRZ (Figure 80): The wind direction (lower-left) is not a smooth distribution, with two very sharp peaks. The AMV pressure distribution has peaks at 300 and 770 hPa. Upper level winds at 300 hPa are reasonable, but the 770 hPa peak is probably too high for low-level clouds.

- EUM (Figure 81): The AMV pressure distribution has a peak at 250 and 870 hPa. This distribution is much improved over Experiment 2 and 3.
- JMA (Figure 82): The AMV pressure distribution has a peak at 220 and 850 hPa. This distribution is much improved over Experiment 2 and 3.
- KMA (Figure 83): The AMV pressure distribution has a peak at 220 and 850 hPa. This distribution is much improved over Experiment 2 and 3.
- NOA (Figure 84): The AMV pressure distribution has a peak at 220 and 790 hPa. The upper level winds are placed well, while the low level winds are too high.
- NWC (Figure 85): The AMV pressure distribution has a peak at 220 and 860 hPa. This distribution is much improved over Experiment 2 and 3.
- CMA (Figure 86): The AMV pressure distribution has a peak at 220 and 780 hPa. The upper level winds are placed well, while the low level winds are too high.

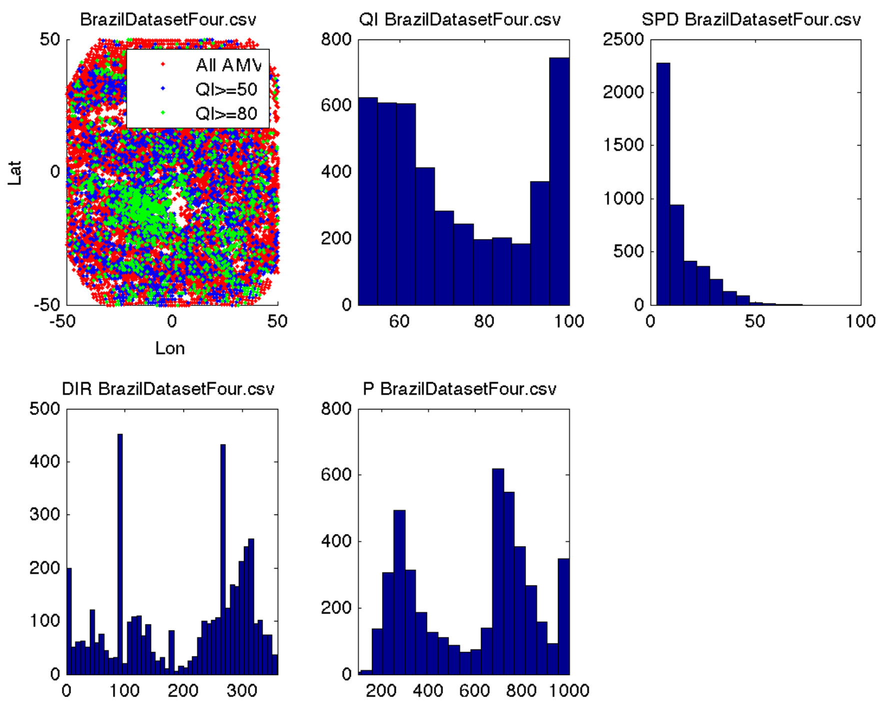

Figure 80: Experiment 4 parameter distributions for BRZ: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

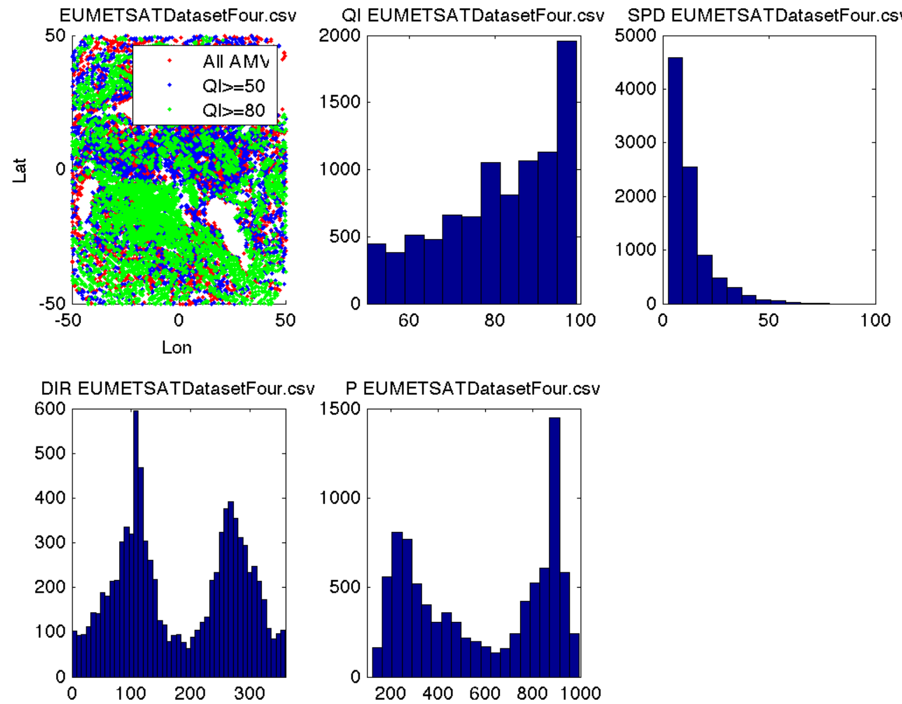

Figure 81: Experiment 4 parameter distributions for EUM: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

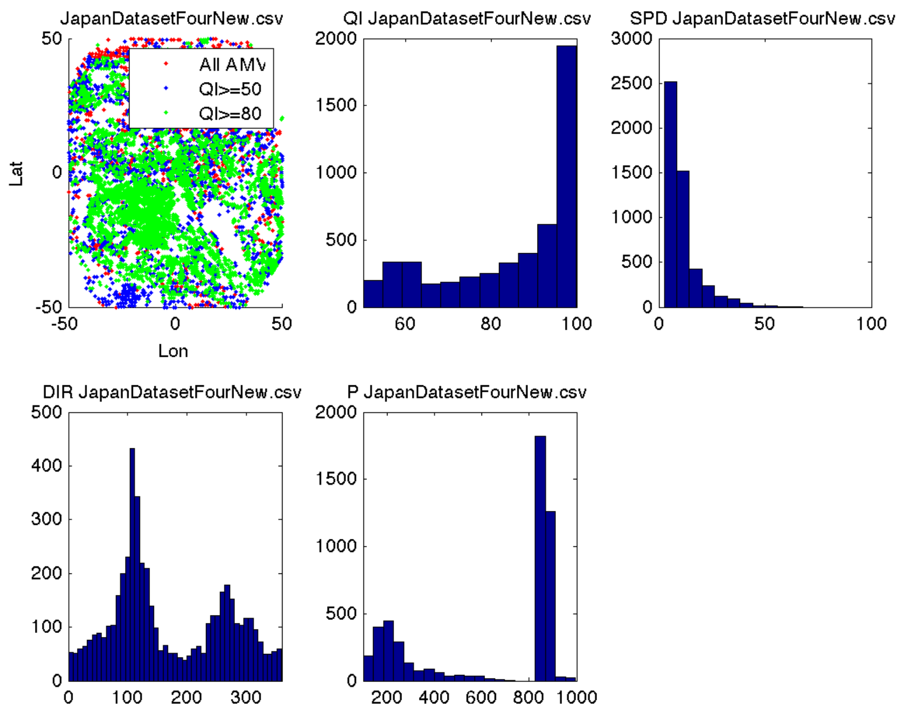

Figure 82: Experiment 4 parameter distributions for JMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

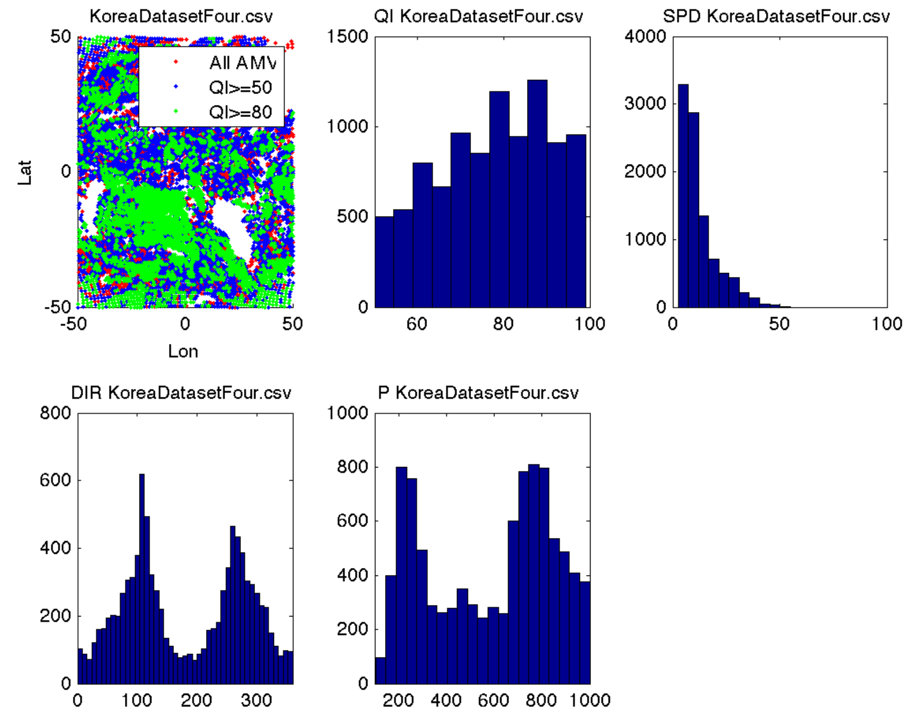

Figure 83: Experiment 4 parameter distributions for KMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

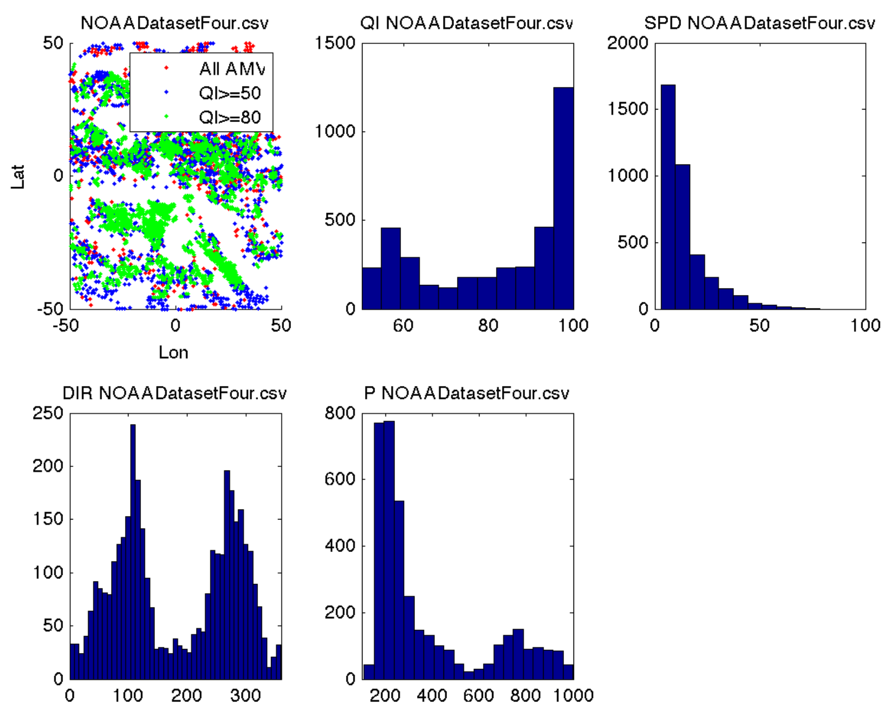

Figure 84: Experiment 4 parameter distributions for NOA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

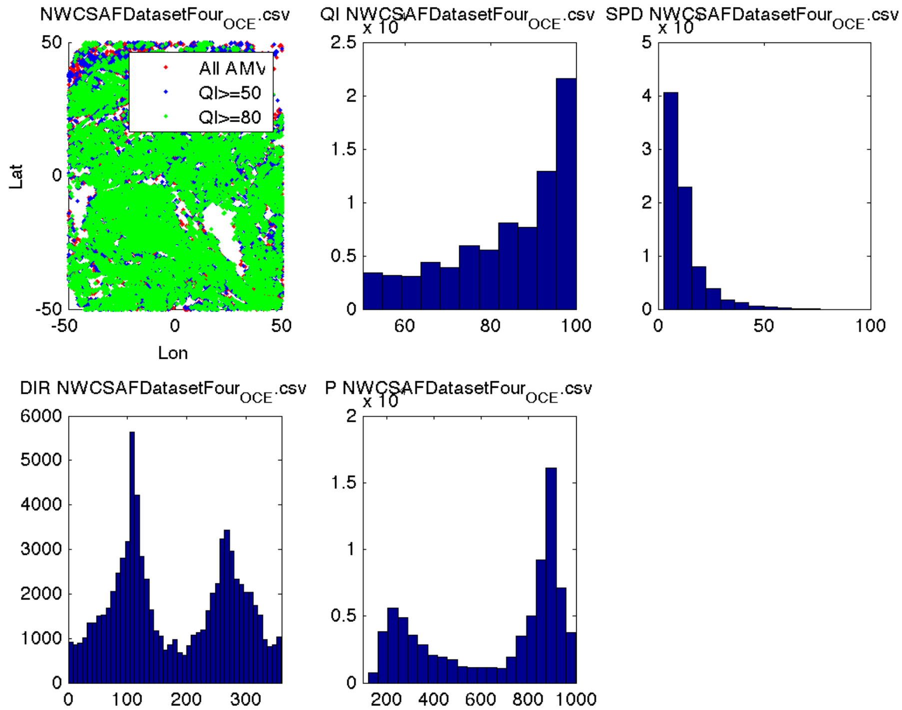

Figure 85: Experiment 4 parameter distributions for NWC: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

The following table and plots are for QIWF >= 50. These are very similar to the plots for QINF >= 50.

Table 33: Experiment 4 statistical summary of AMV datasets for QI with forecast >= 50.

	EUM	CMA	JMA	KMA	NOA	NWC
Total AMVs	12182	5498	5648	11986	4449	92512
QI>=50	9339	5496	4790	9008	3416	79839
SPD_min	2.51	3.16	2.51	2.50	3.02	2.50
SPD_max	78.59	82.64	67.77	54.81	78.41	76.30
SPD_mean	12.33	16.58	10.73	12.27	14.18	11.79
P_min	123.86	150.00	100.49	105.05	110.17	123.00
P_max	995.20	947.00	995.12	1000.00	999.47	998.94
P_mean	575.60	436.74	639.95	578.15	379.93	657.32
Low_winds	44.24	19.71	63.05	43.86	19.17	59.10
Mid_winds	18.19	24.07	4.72	23.56	11.62	12.26
High_winds	37.56	56.22	32.23	32.58	69.20	28.63
Low_SPD_min	2.51	3.19	2.51	2.50	3.03	2.50
Low_SPD_max	64.94	33.87	54.92	41.09	22.60	49.96
Low_SPD_mean	8.74	8.18	8.75	9.14	8.91	9.06
Low_P_min	700.11	700.00	850.00	700.04	700.02	700.00
Low_P_max	995.20	947.00	995.12	1000.00	999.47	998.94
Low_P_mean	861.85	780.36	866.28	826.30	819.85	873.26
Mid_SPD_min	2.51	3.19	2.57	2.52	3.02	2.50
Mid_SPD_max	78.59	71.49	45.11	48.37	66.92	73.30
Mid_SPD_mean	12.46	12.97	11.36	12.42	11.49	13.73
Mid_P_min	400.02	401.00	400.37	400.16	400.58	400.03
Mid_P_max	699.90	699.00	672.61	699.99	699.76	699.95
Mid_P_mean	526.21	583.12	505.20	566.15	538.71	531.70
High_SPD_min	2.54	3.16	2.51	2.51	3.02	2.51
High_SPD_max	71.68	82.64	67.77	54.81	78.41	76.30
High_SPD_mean	16.50	21.07	14.52	16.38	16.09	16.57
High_P_min	123.86	150.00	100.49	105.05	110.17	123.00
High_P_max	399.91	400.00	399.55	399.94	399.54	399.93
High_P_mean	262.37	253.62	216.98	252.76	231.38	265.40

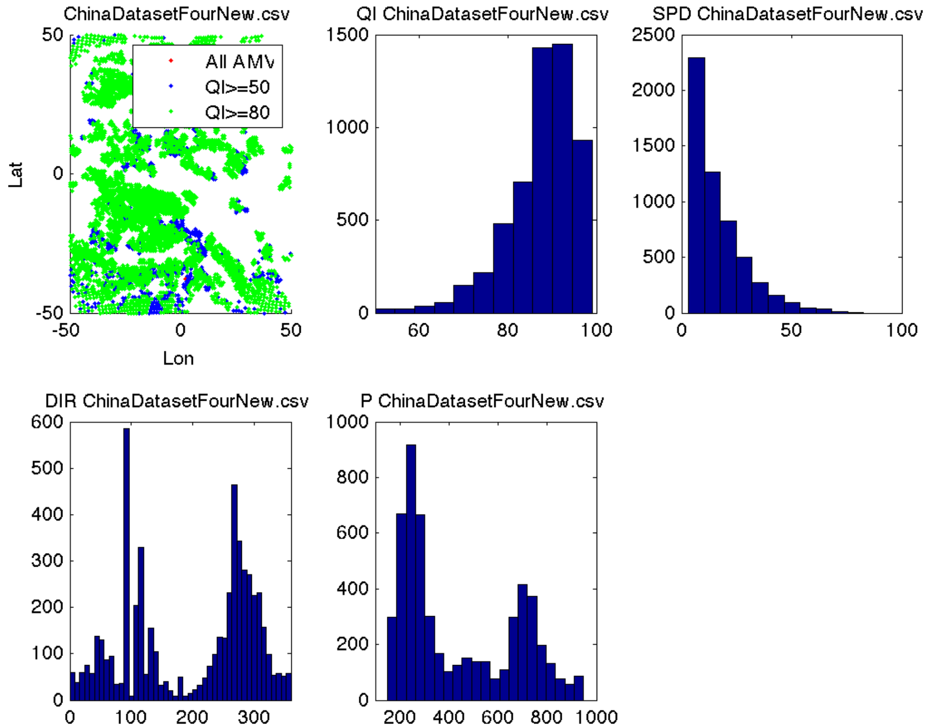

Figure 86: Experiment 4 parameter distributions for CMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

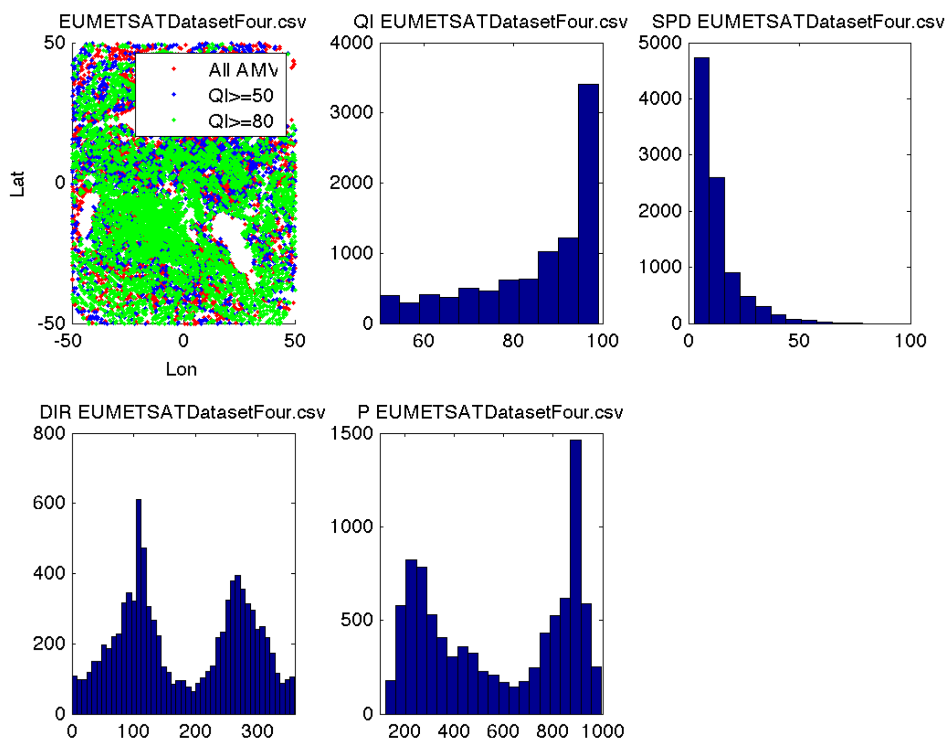

Figure 87: Experiment 4 parameter distributions for EUM: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

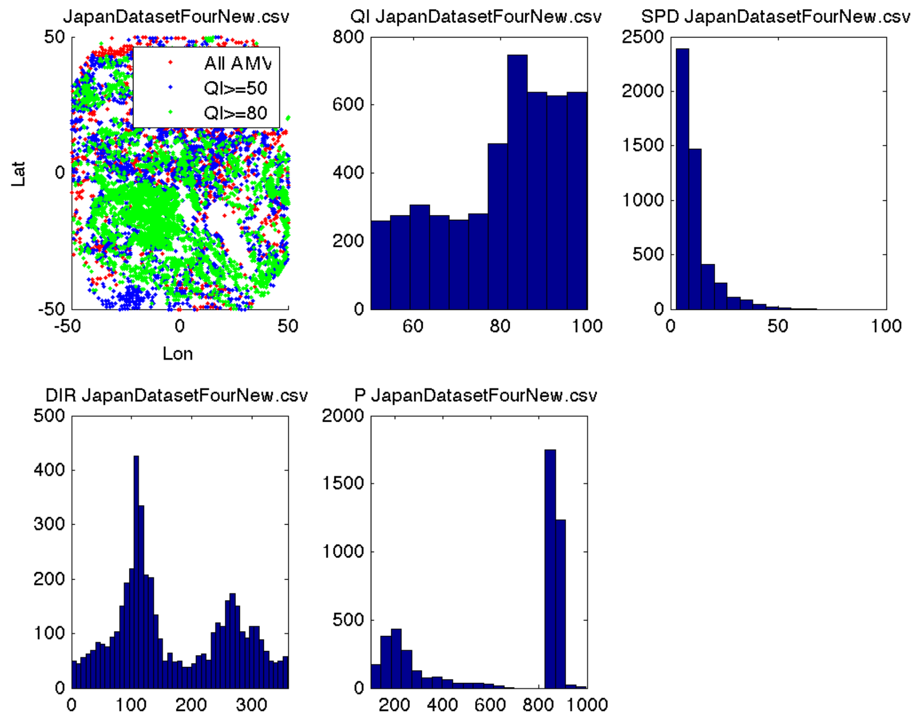

Figure 88: Experiment 4 parameter distributions for JMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

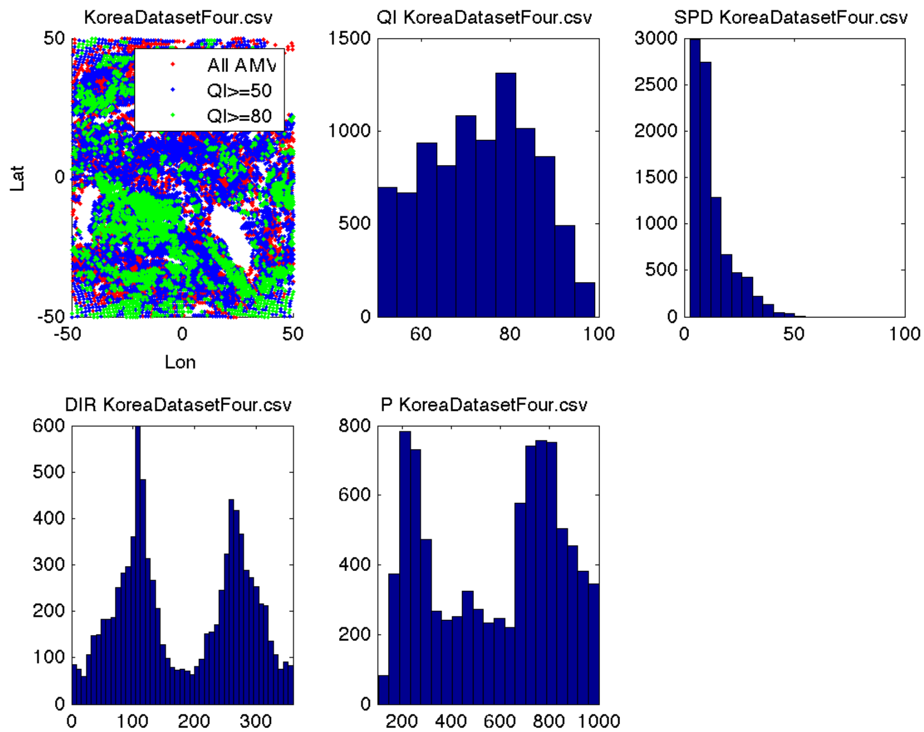

Figure 89: Experiment 4 parameter distributions for KMA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

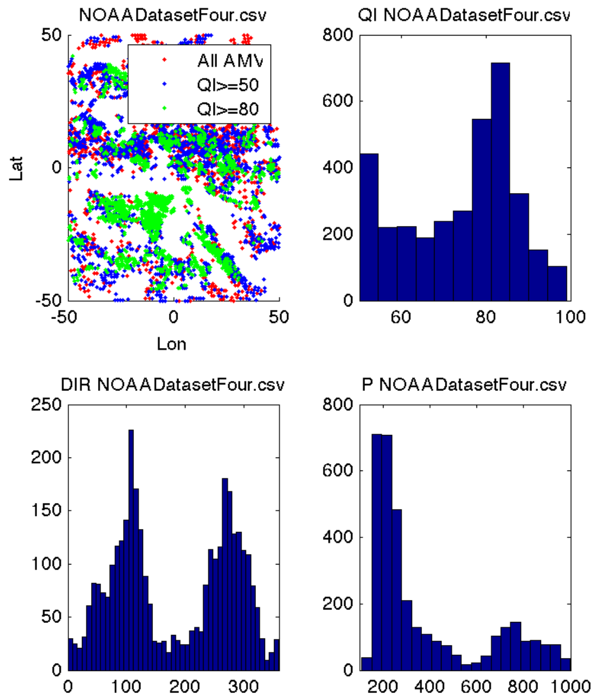

Figure 90: Experiment 4 parameter distributions for NOA: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

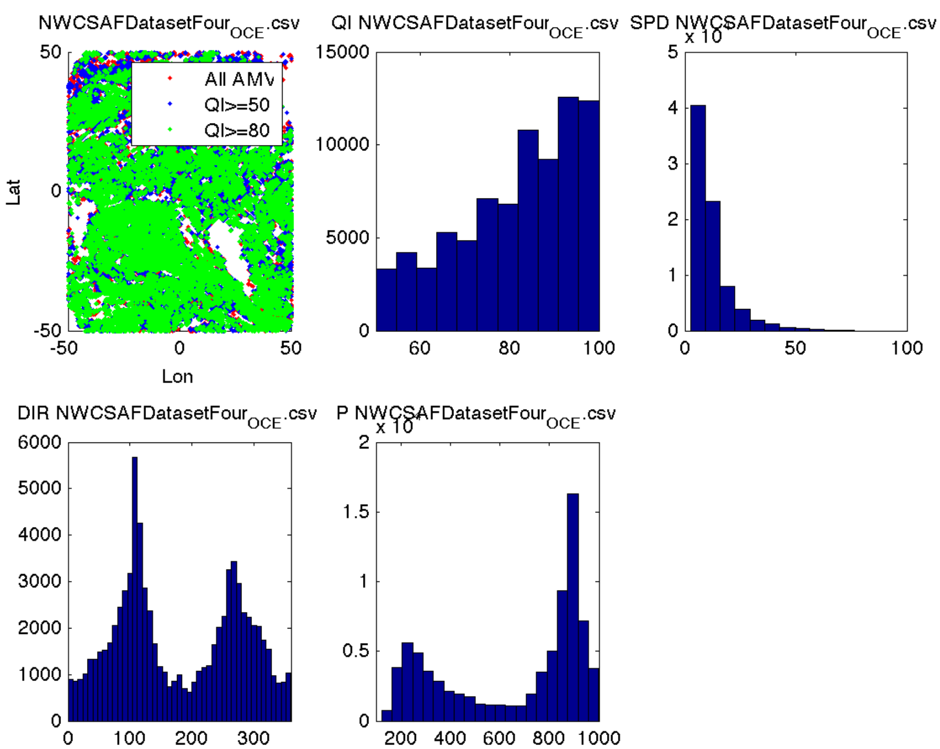

Figure 91: Experiment 4 parameter distributions for NWC: latitude/longitude spatial distribution and histograms of QI, wind speed, direction, and AMV pressure.

c) Colocation plots

AMVs are first quality controlled, retaining only those with a QINF >= 50. For colocation the distance threshold is 55 km, resulting in 9942 AMVs.

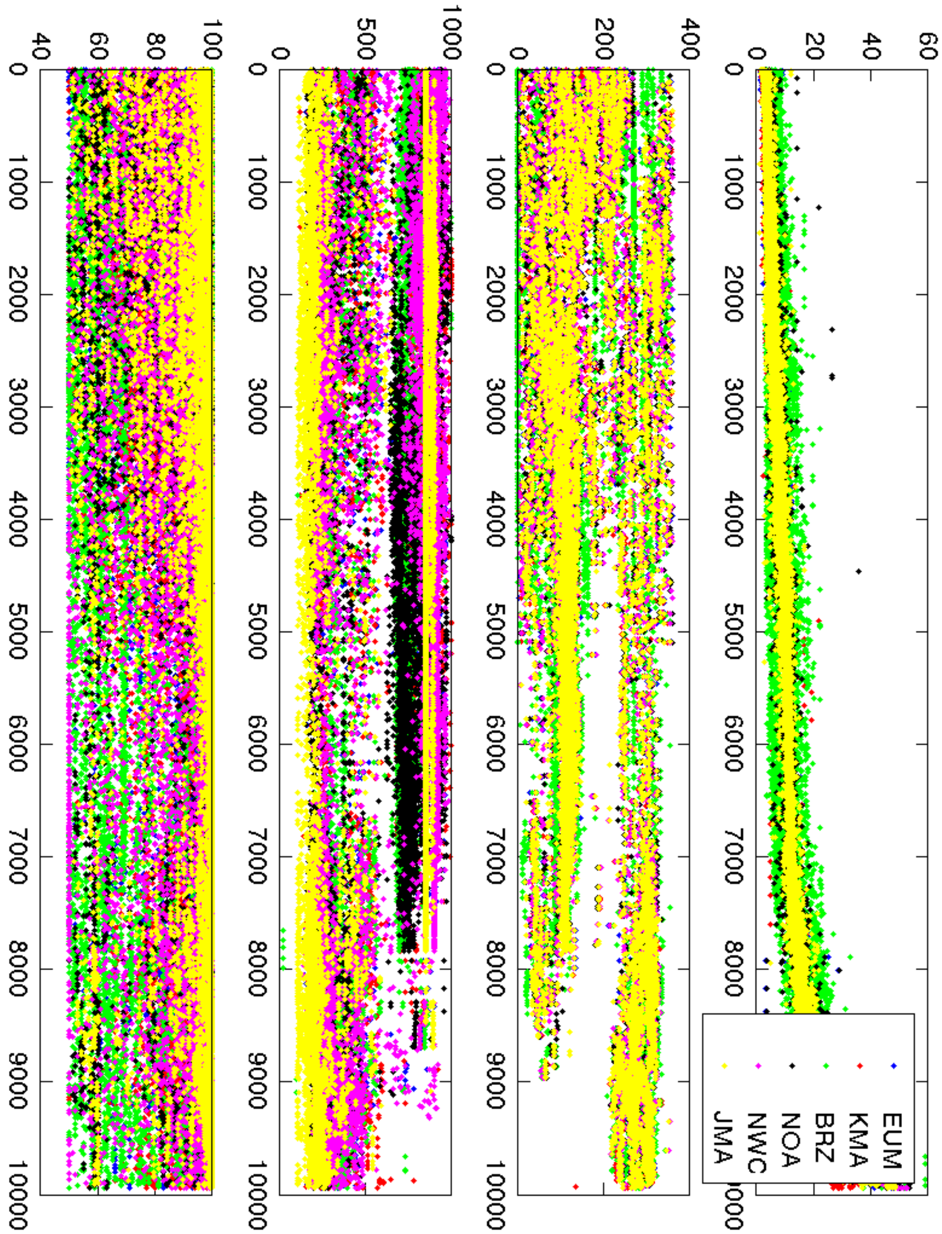

Figure 92: Plots of colocated AMVs of speed (top), direction (2nd), pressure (3rd), and QI (bottom) are color-coded based on legend in upper right. The x-axis is AMV number.

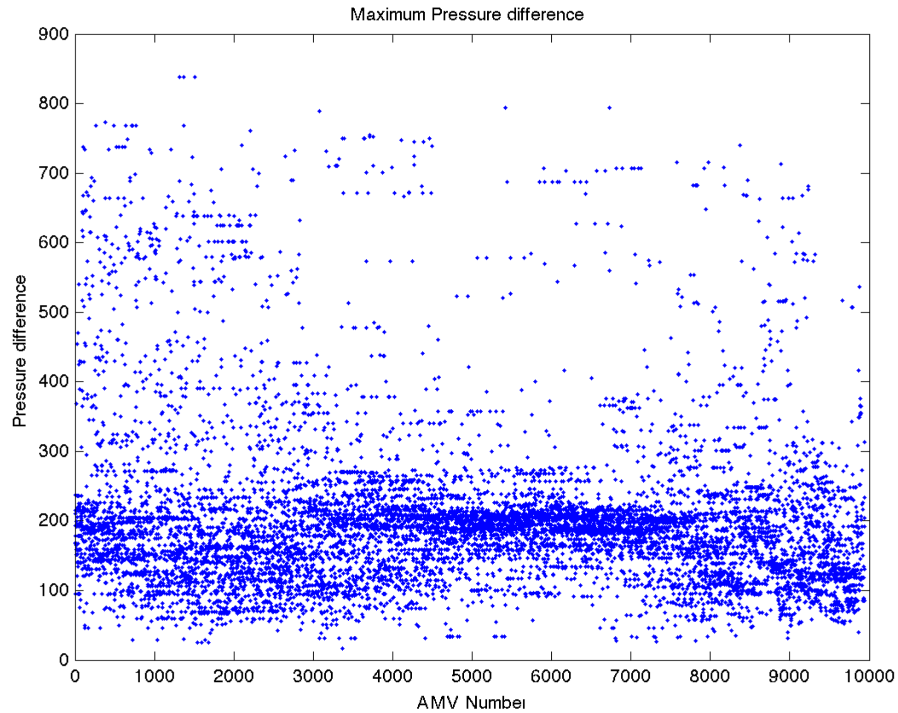

Figure 93: The maximum pressure difference between any two colocated AMVs.

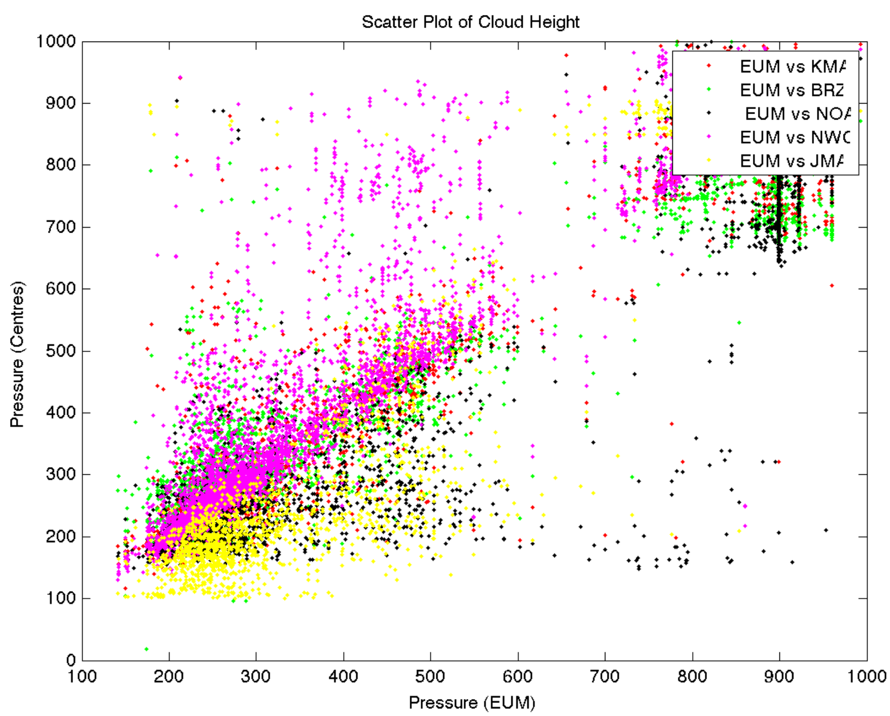

Figure 94: Scatter plot of AMV pressure for each center vs. EUM pressure.

A similar comparison is done for AMVs with QI with forecast, retaining only those with a QIWF >= 50. For colocation the distance threshold is 55 km, resulting in 10285 AMVs.

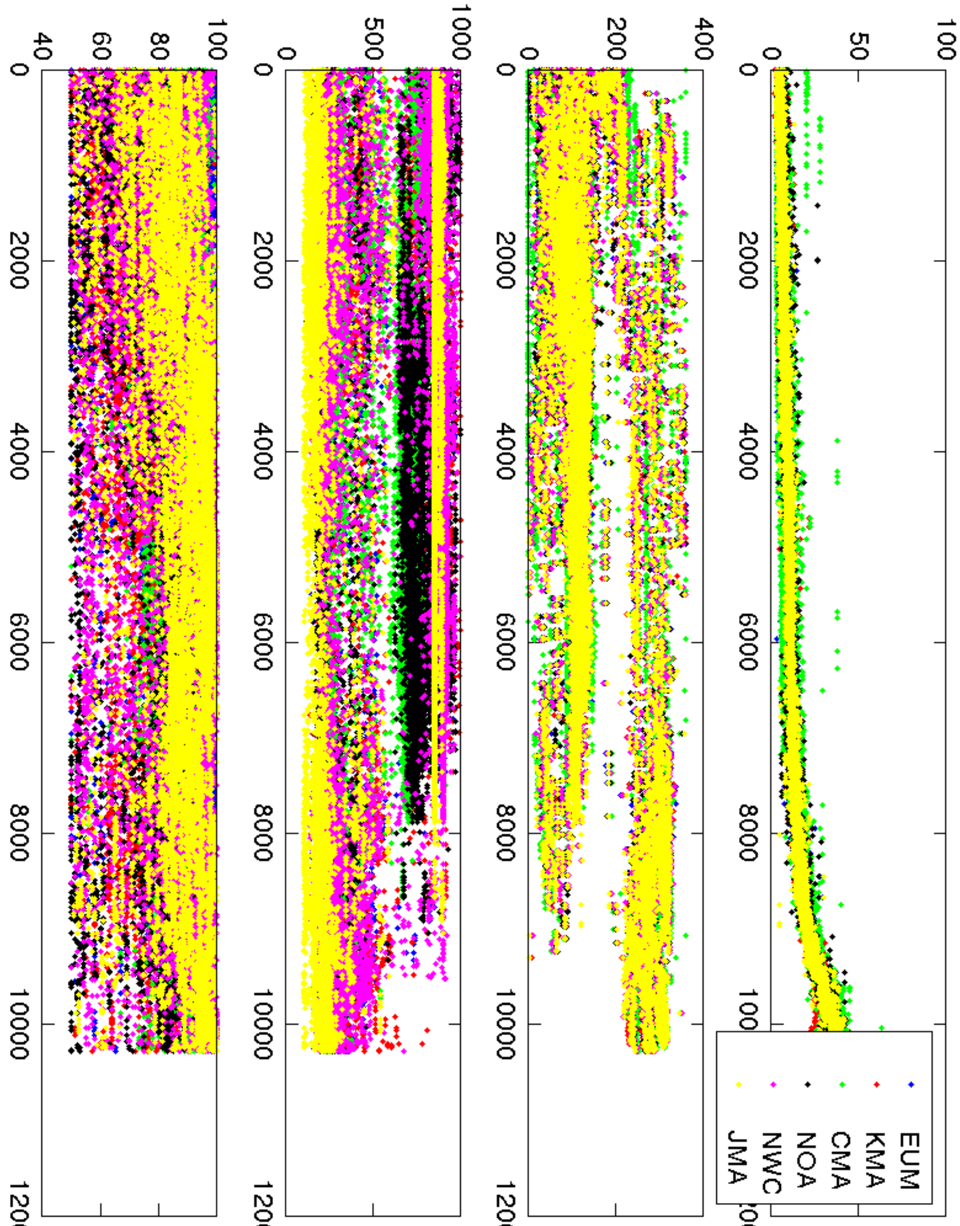

Figure 95: Plots of colocated AMVs of speed (top), direction (2nd), pressure (3rd), and QI (bottom) are color-coded based on legend in upper right. The x-axis is AMV number.

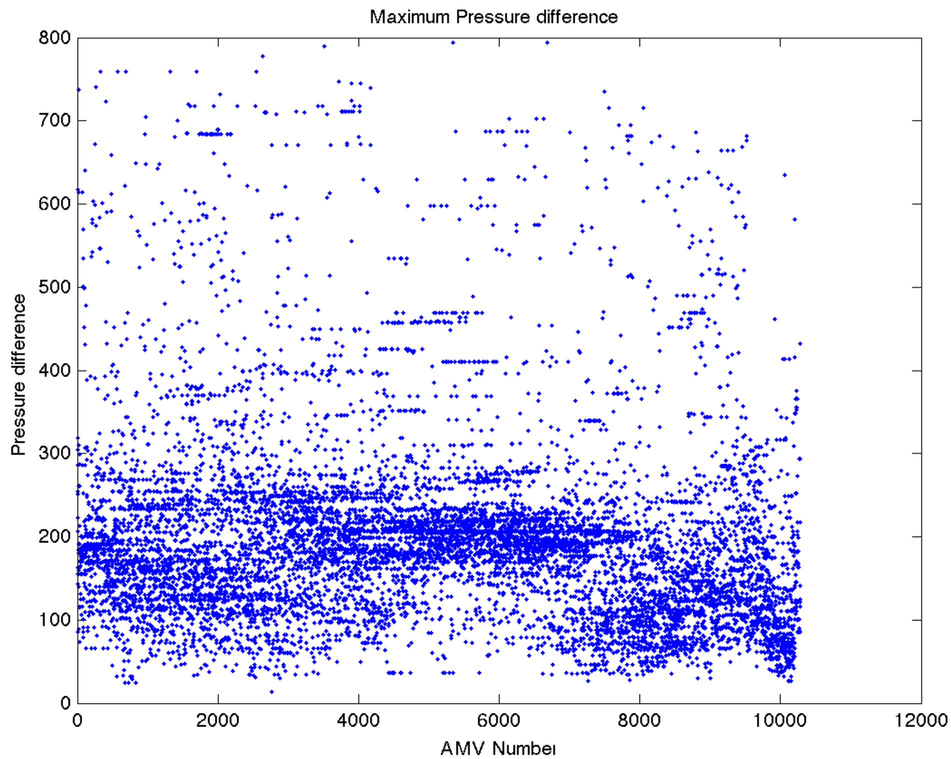

Figure 96: The maximum pressure difference between any two colocated AMVs.

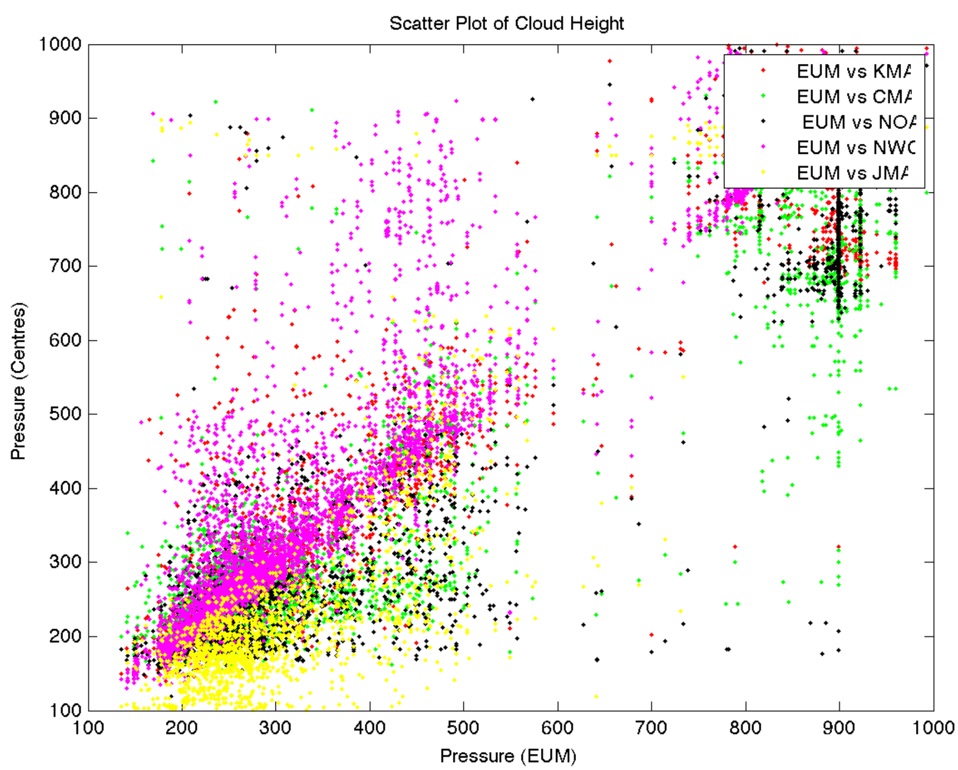

Figure 97: Scatter plot of AMV pressure for each center vs. EUM pressure.

The following figures have wind vectors from Experiment 4 overlayed on storm systems in the mid-Atlantic Ocean: EUM in magenta; the other centres in cyan (in individual figures).

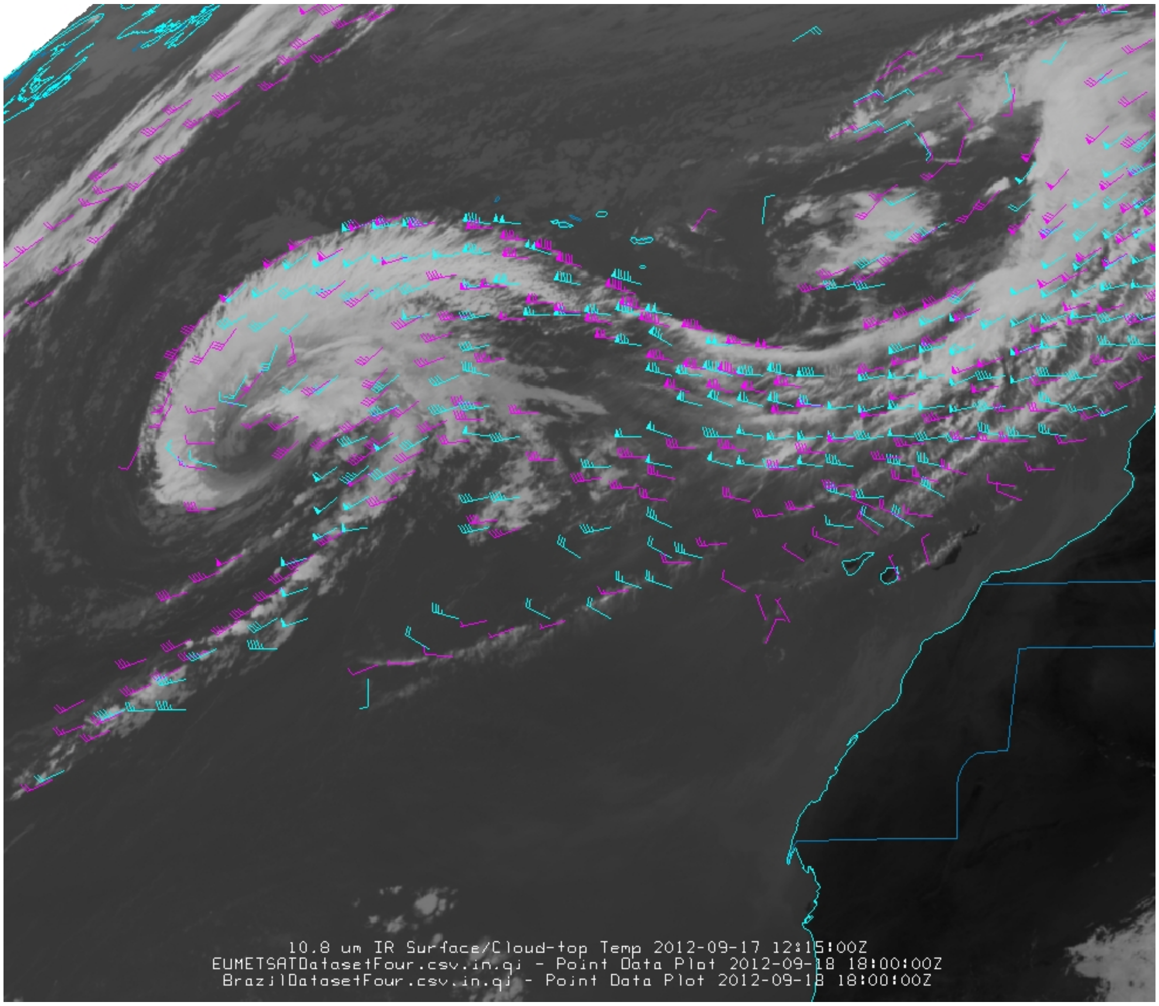

Figure 98: Experiment 4: EUM (magenta) and BRZ (cyan) AMVs over Central Atlantic (Africa in lower right). QI >= 50 and altitude above 7500 m.

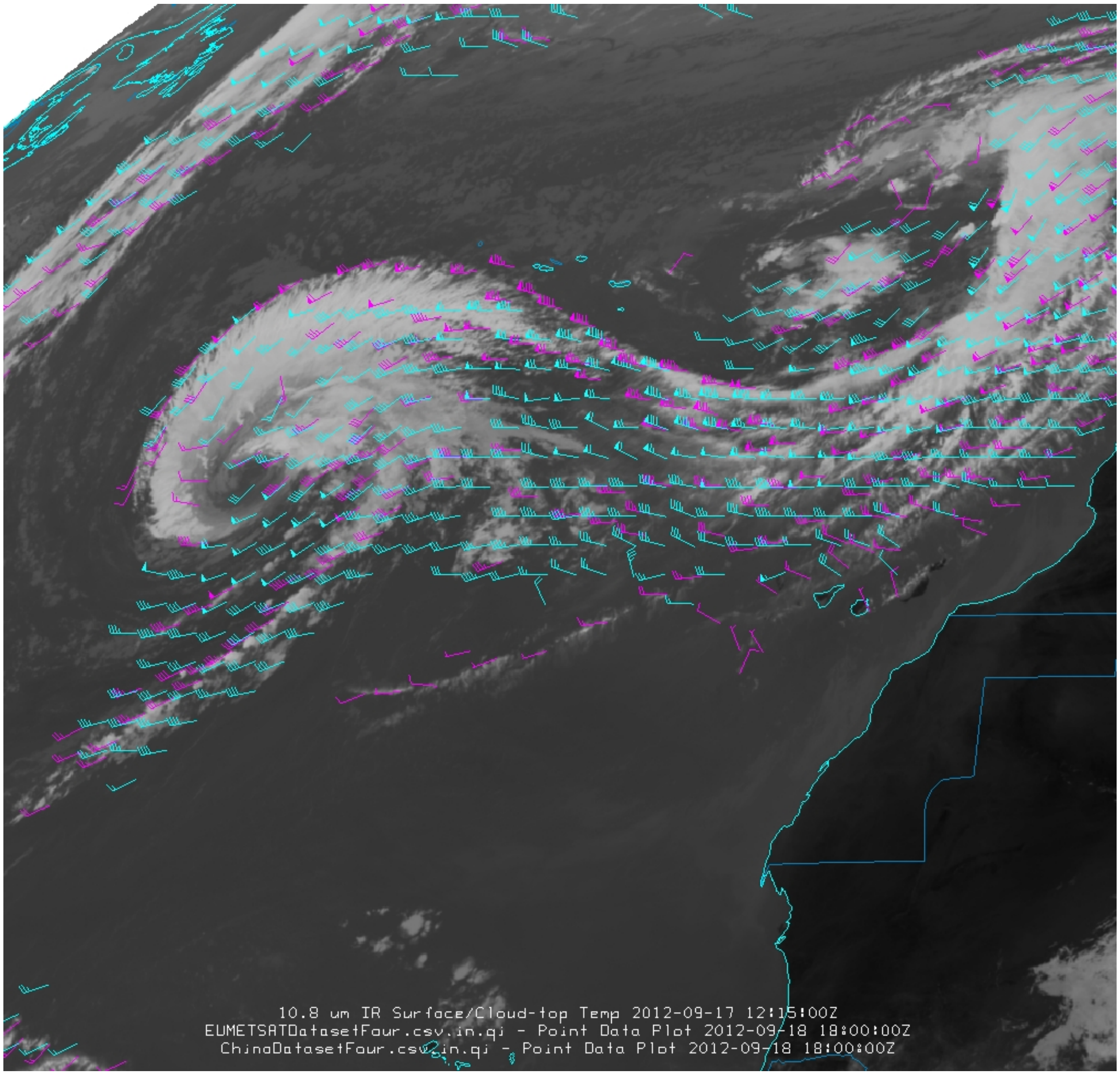

Figure 99: Experiment 4: EUM (magenta) and CMA (cyan) AMVs over Central Atlantic (Africa in lower right). QI >= 50 and altitude above 7500 m.

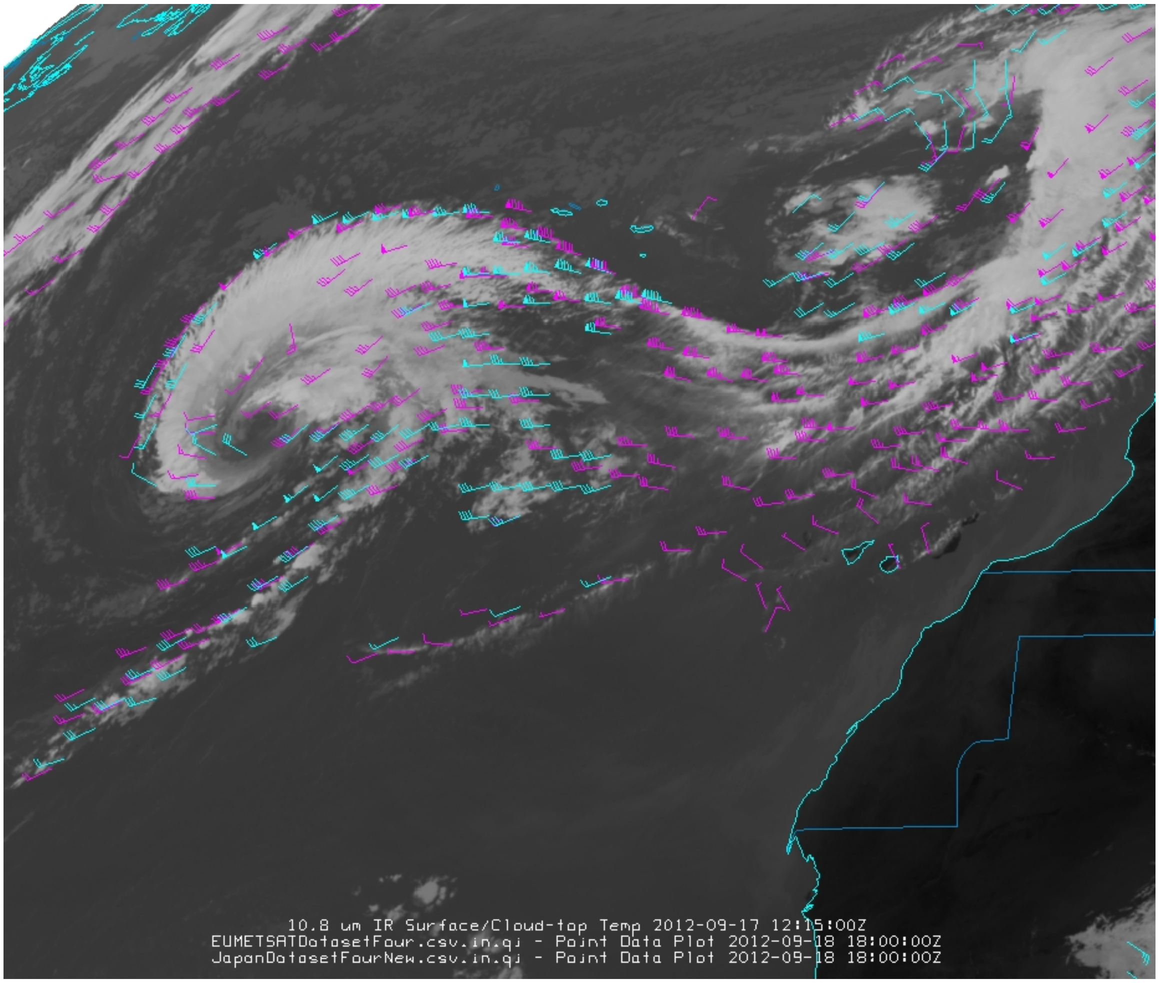

Figure 100: Experiment 4: EUM (magenta) and JMA (cyan) AMVs over Central Atlantic (Africa in lower right). QI >= 50 and altitude above 7500 m.

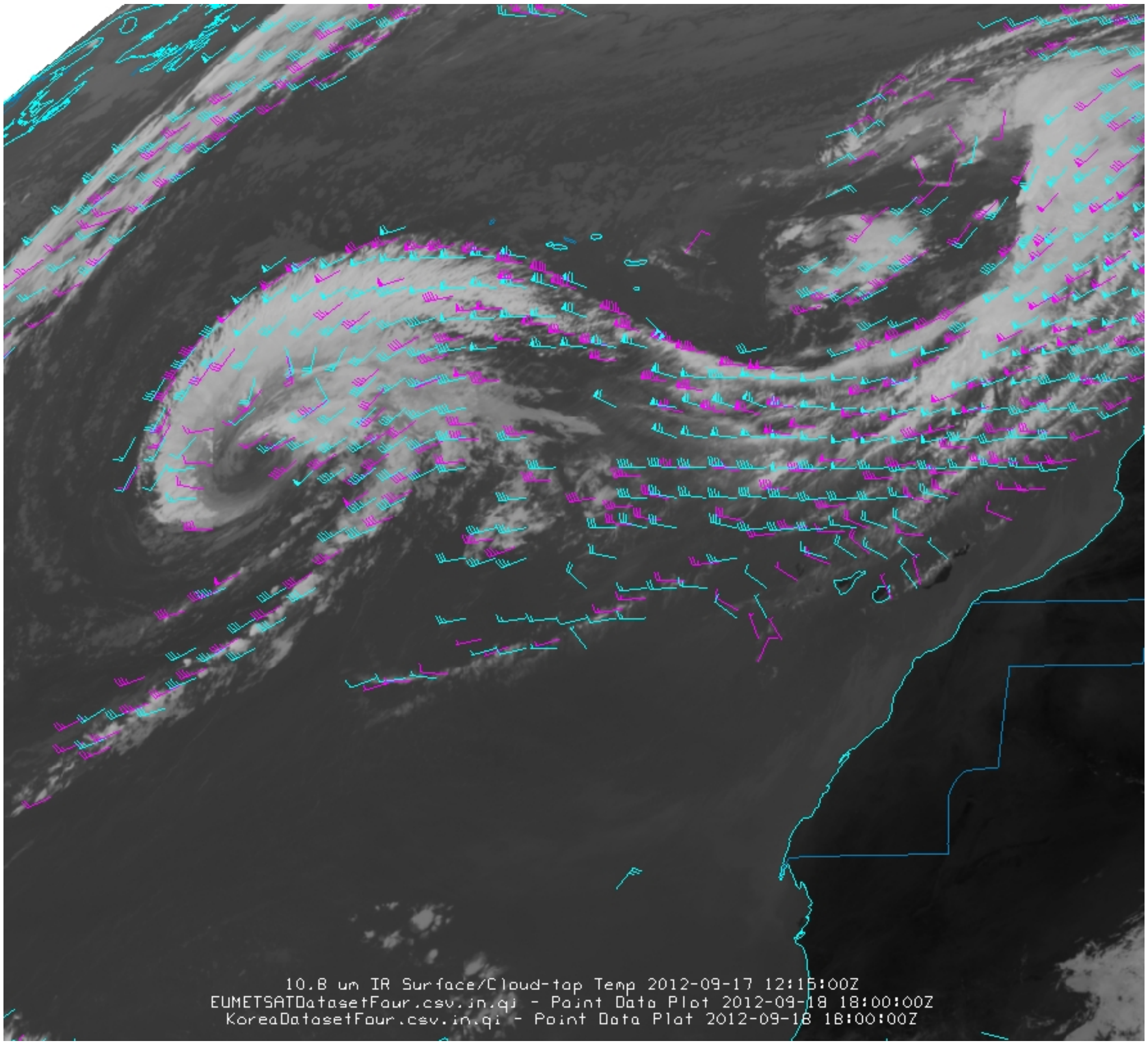

Figure 101: Experiment 4: EUM (magenta) and KMA (cyan) AMVs over Central Atlantic (Africa in lower right). QI >= 50 and altitude above 7500 m.

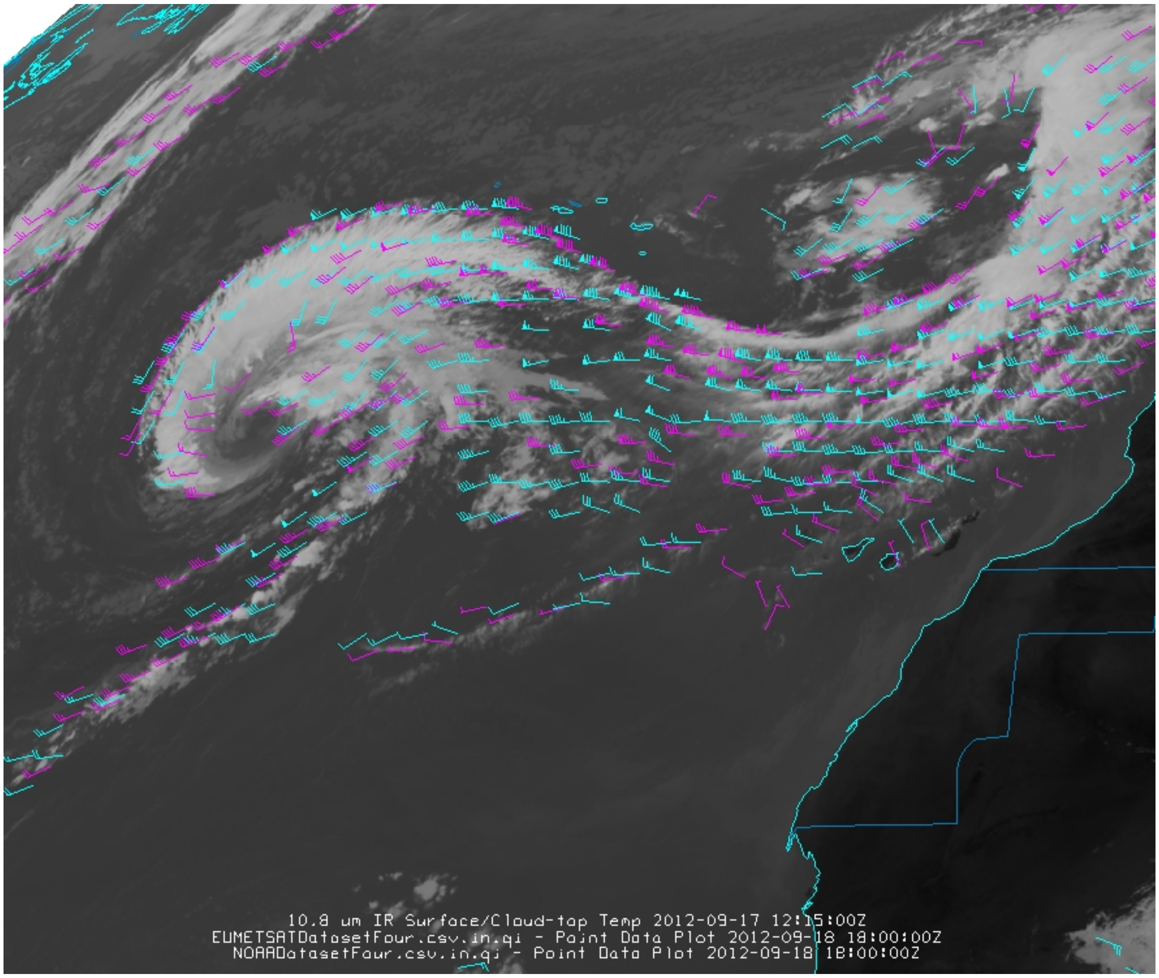

Figure 102: Experiment 4: EUM (magenta) and NOA (cyan) AMVs over Central Atlantic (Africa in lower right). QI >= 50 and altitude above 7500 m.

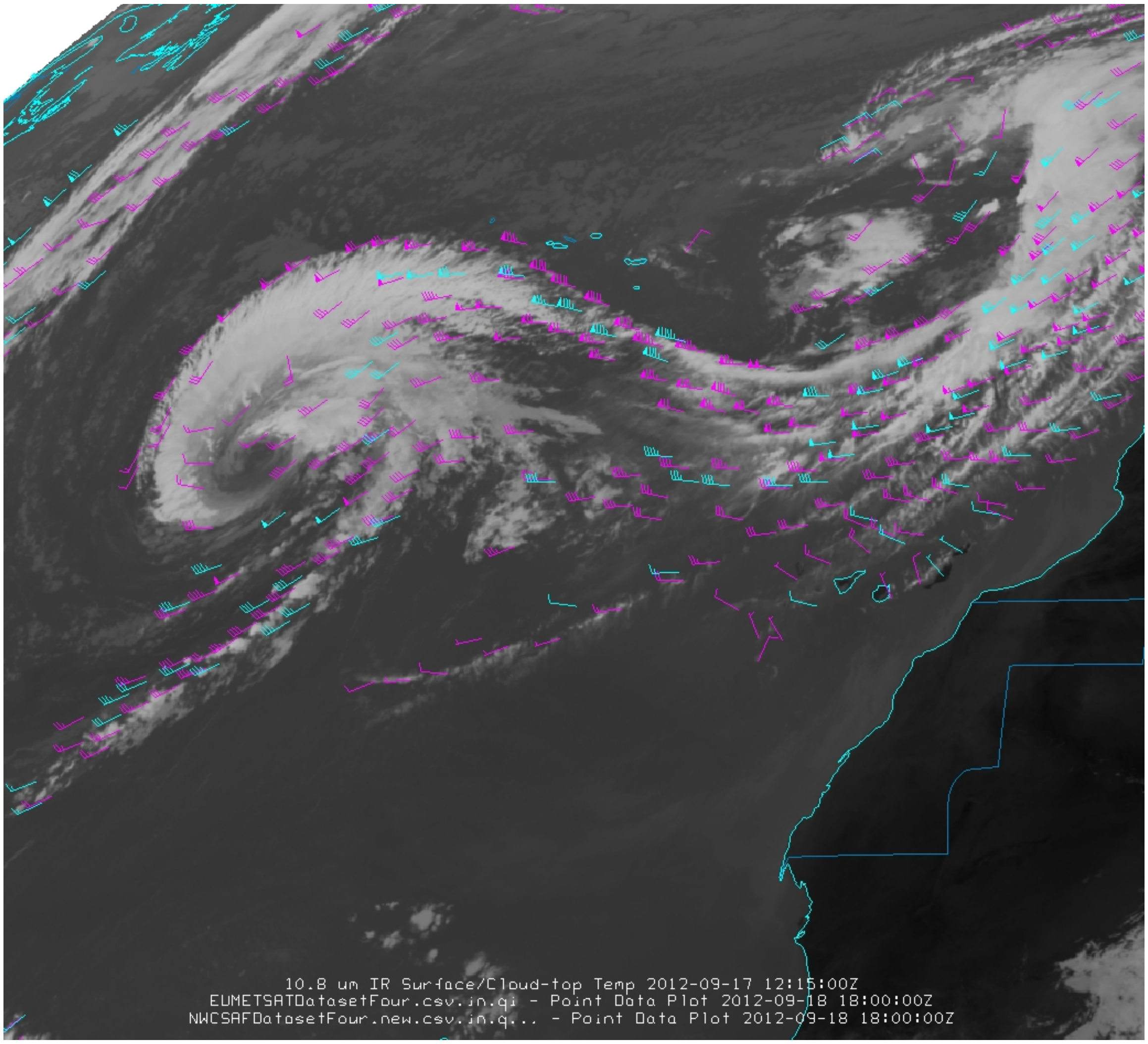

Figure 103: Experiment 4: EUM (magenta) and NWC (cyan) AMVs over Central Atlantic (Africa in lower right). QI >= 50 and altitude above 7500 m.

d) Rawinsonde comparison

The comparison of Experiment 4 AMVs to collocated rawinsondes are summarized in Table 34 (QINF >= 50) and Table 35 (QIWF >= 50). Note: The sample is small for some AMV producers (range from 60 to 2800 AMV matches to rawinsondes).

The vector RMS ranges from 4.5 ms^{-1} (NWC) to 9-10 ms^{-1} (BRZ, JMA); the speed RMS ranges from 3.5 ms^{-1} (NWC) to over 7 ms^{-1} (JMA). Sites such as EUM improved substantially over Experiment 3.

Table 34: Experiment 4 comparison to rawinsondes within 150 km. N = number of matches; P bias = pressure bias; P RMS = pressure RMS; SpdBias = speed bias; SpdRMS = speed RMS; DirBias = wind direction bias; VecRMS = vector RMS. The extreme for each category is highlighted: Yellow = high value; cyan = low value.

SIte	N	P bias	P RMS	SpdBias	SpdRMS	DirBias	VecRMS
BRZ	153	0.63	19.77	0.55	5.61	-3.07	10.05
EUM	307	0.22	22.87	-0.61	4.73	1.99	6.07
JMA	154	-3.00	21.50	-2.26	7.64	8.89	9.60
KMA	326	-0.63	21.91	-0.73	4.72	2.68	6.38
NOA	131	0.35	22.75	1.48	5.79	9.01	7.70
NWC (Operational conf., EUM Clouds)	2375	-1.06	22.79	-0.39	3.90	0.46	5.12
NWC (Operational conf., NWC Clouds)	2797	-0.65	21.64	-1.23	4.49	-1.55	5.67
NWC (Prescribed conf., EUM Clouds)	73	-0.76	17.53	-0.60	3.48	-3.74	4.67

Table 35: Experiment 4 comparison to rawinsondes within 150 km. N = number of matches; P bias = pressure bias; P RMS = pressure RMS; SpdBias = speed bias; SpdRMS = speed RMS; DirBias = wind direction bias; VecRMS = vector RMS. The extreme for each category is highlighted: Yellow = high value; cyan = low value.

SIte	N	P bias	P RMS	SpdBias	SpdRMS	DirBias	VecRMS
CMA	237	-1.11	18.58	-1.30	6.40	5.28	7.74
EUM	320	-0.05	22.85	-0.80	4.90	3.29	6.26
JMA	149	-3.40	21.98	-2.62	7.04	4.76	8.96
KMA	304	-0.59	21.67	-0.67	4.27	4.19	5.83
NOA	125	0.57	23.53	1.29	5.47	8.30	7.36
NWC (Operational conf., EUM Clouds)	2378	-0.74	22.76	-0.36	3.86	0.45	5.09
NWC (Operational conf., NWC Clouds)	2789	-0.53	21.65	-1.20	4.44	-1.64	5.61
NWC (Prescribed conf., EUM Clouds)	73	-0.00	17.42	-0.60	3.47	-2.27	4.56

e) Best fit height

The Best Fit height analysis was done for each wind producer according to the method described by Salonen et al. (2012). This technique finds the background model best-fit pressure associated with the AMV. The model best-fit pressure is the height (in pressure) where the vector difference between the observed AMV and model background is a minimum. The number of best-fit matches is generally less than 30% of the AMVs. See Appendix C: Best Fit Height Algorithm for implementation details.

Figure 104 to Figure 112 show the:

- Distribution of Best Fit minus AMV pressure differences, color-coded by low, medium, and high clouds (upper left),
- Spatial distribution with same color coding (upper right),
- Relationship between AMV pressure and latitude, color-coded to indicate if the Best fit moved the AMV higher (red) or lower (blue) (lower left),
- Relationship between AMV pressure and speed, color-coded to indicate if the Best fit moved the AMV higher (red) or lower (blue) (lower right).

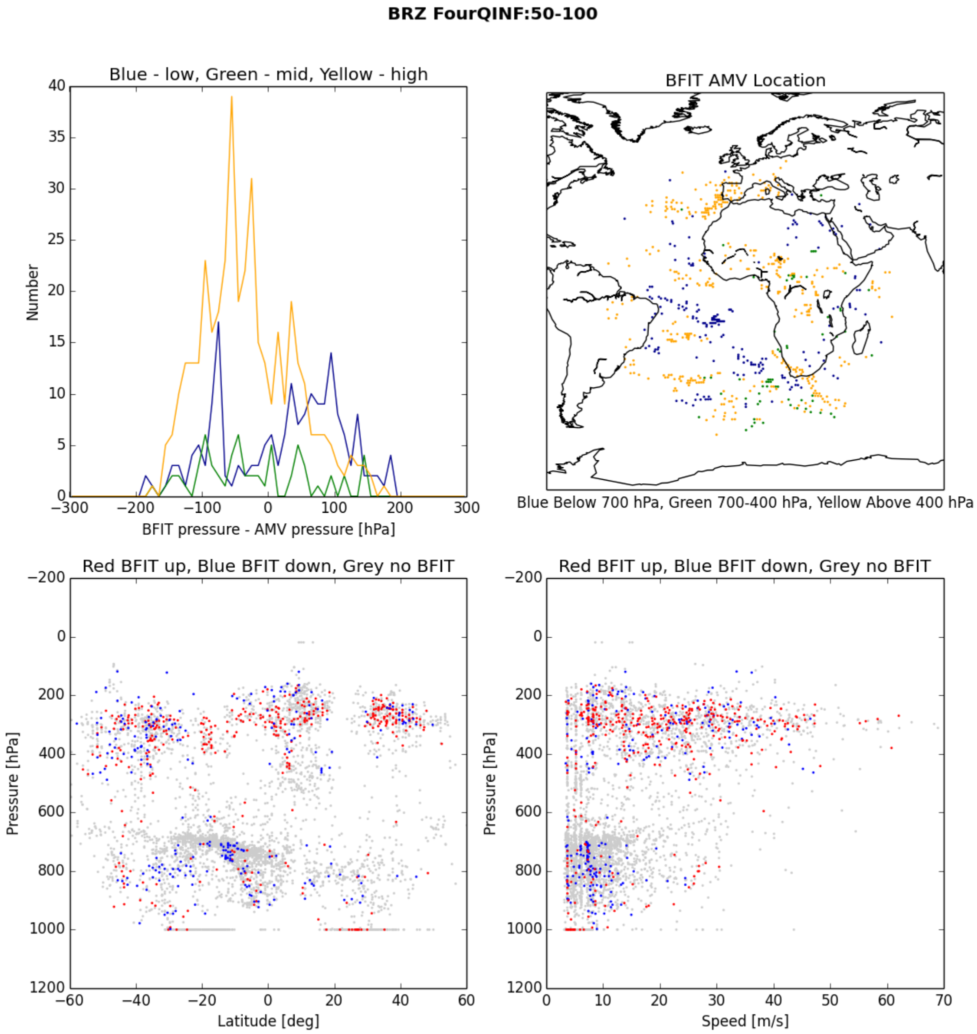

Figure 104: BRZ: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

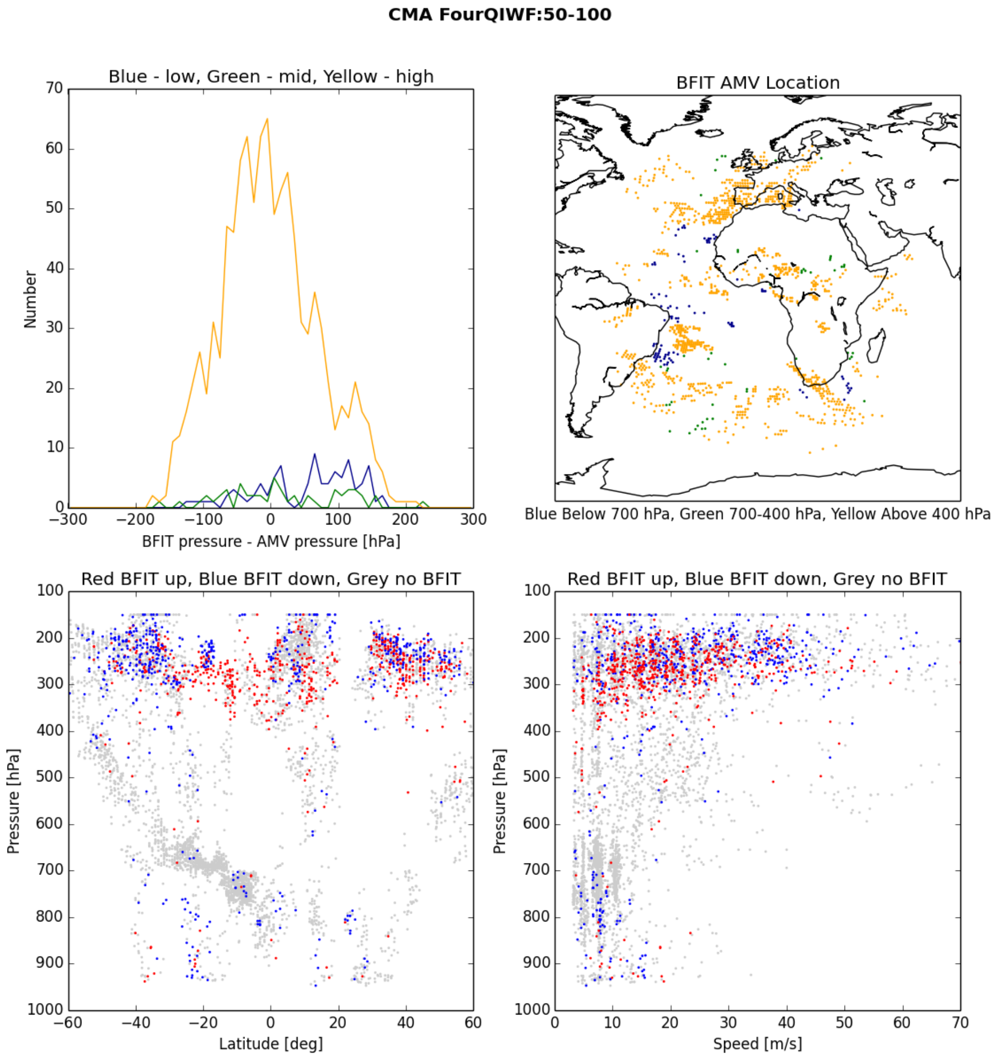

Figure 105: CMA: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

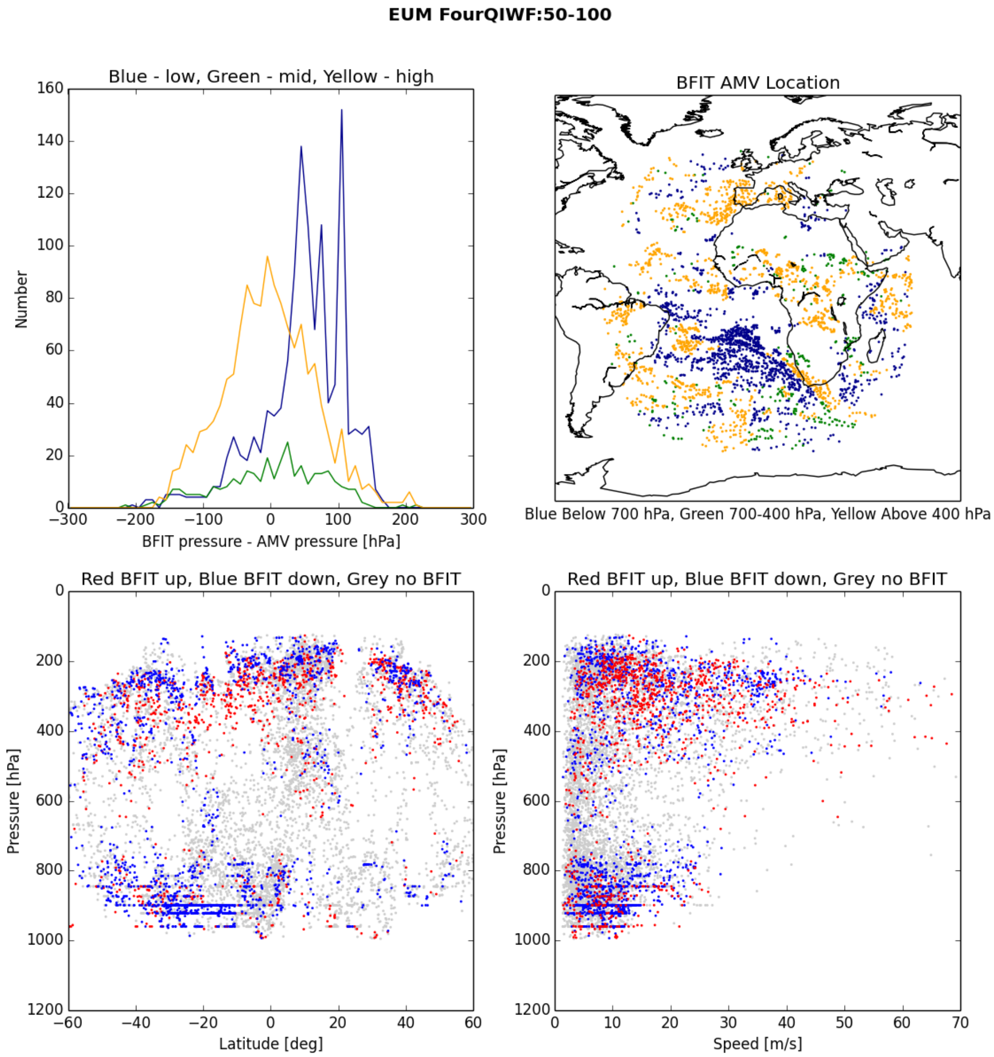

Figure 106: EUM: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

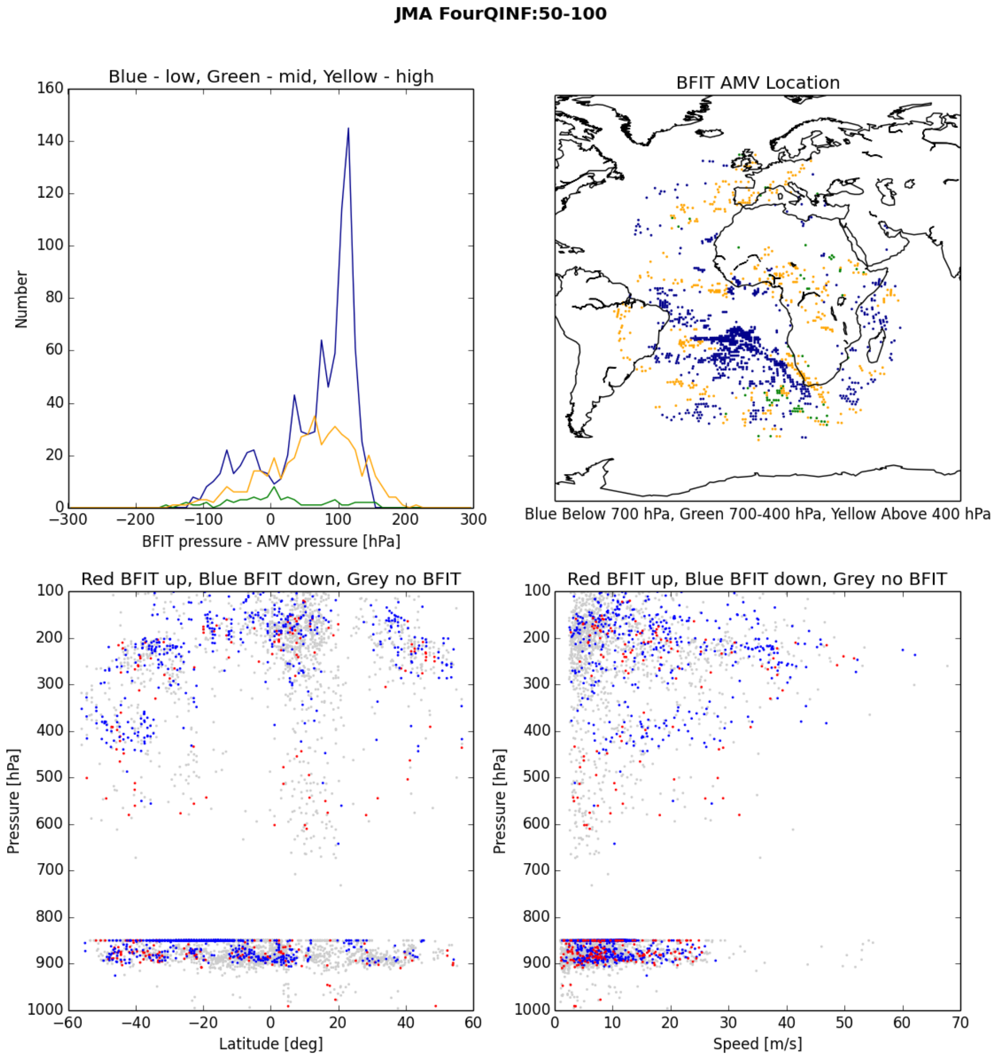

Figure 107: JMA: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

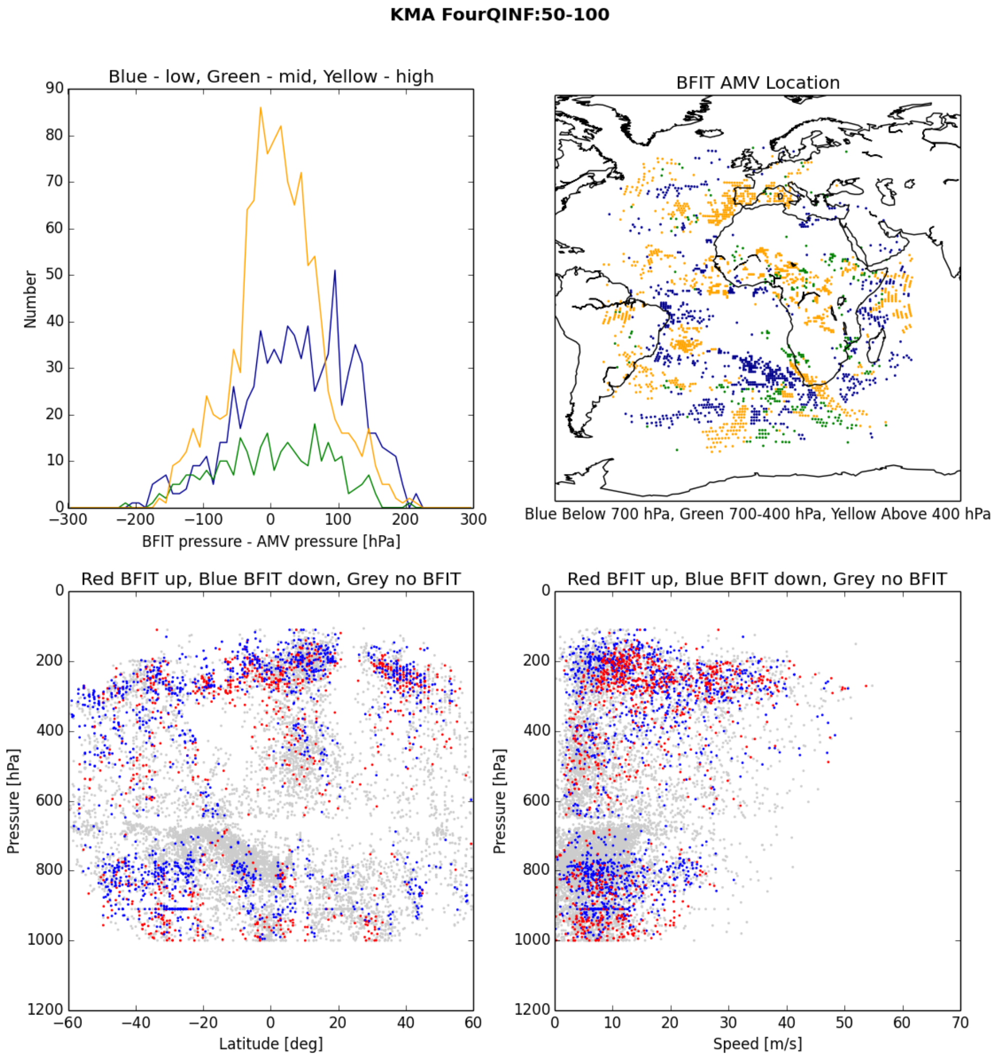

Figure 108: KMA: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

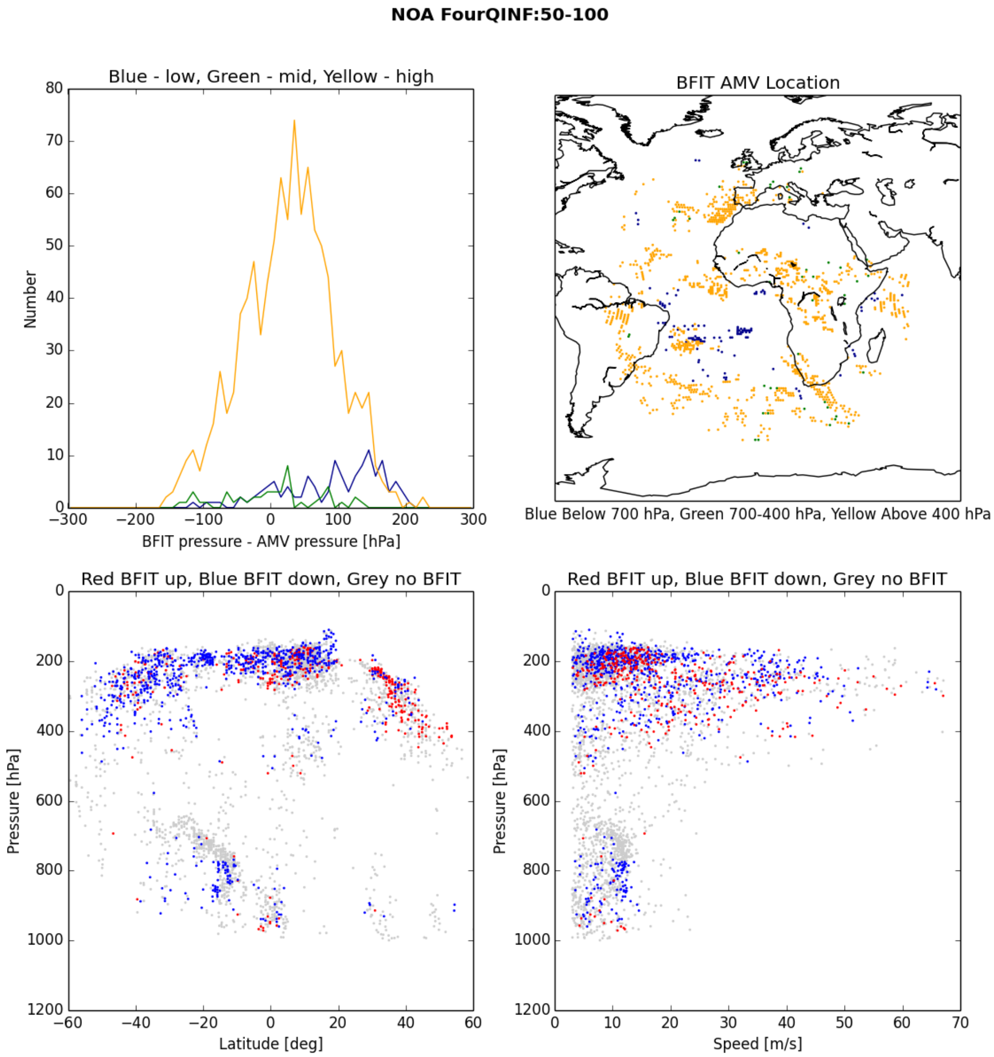

Figure 109: NOA: Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

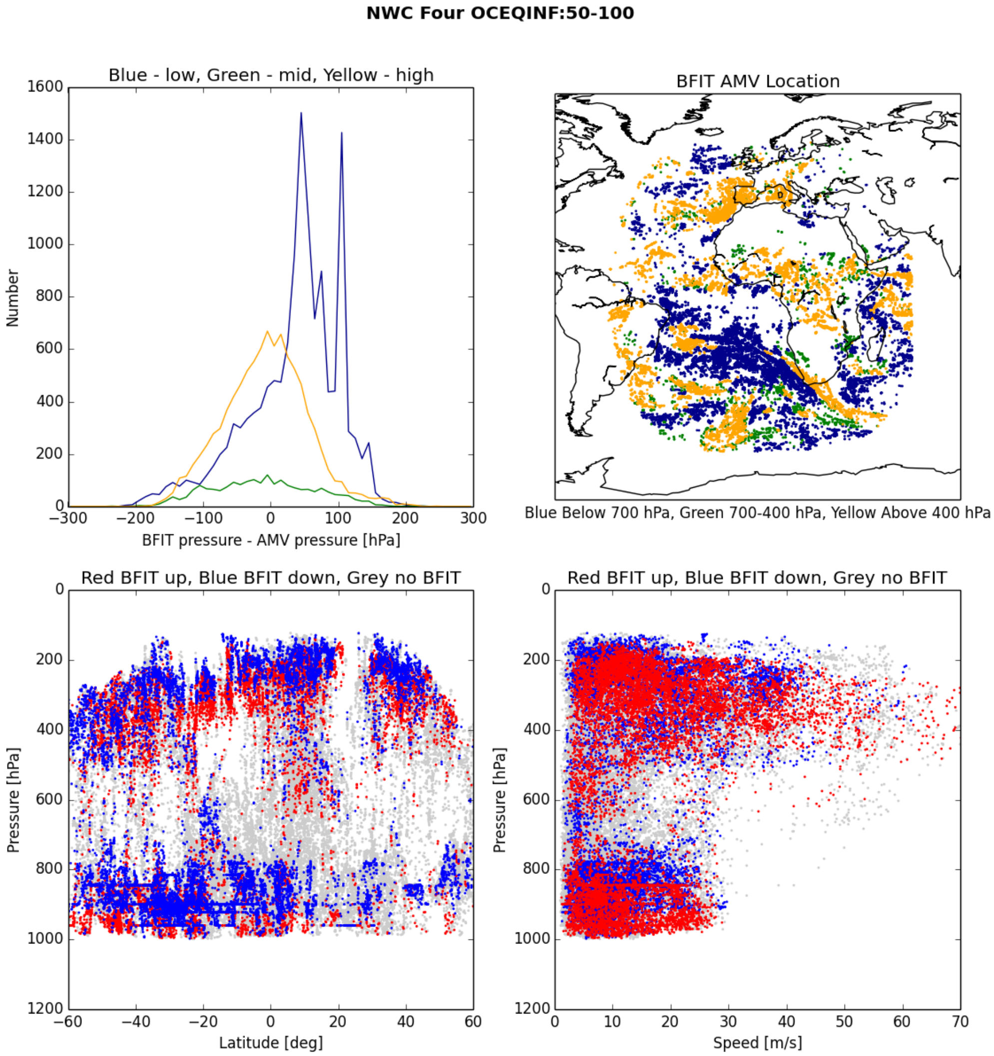

Figure 110: NWC (Operational conf., EUM Clouds): Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

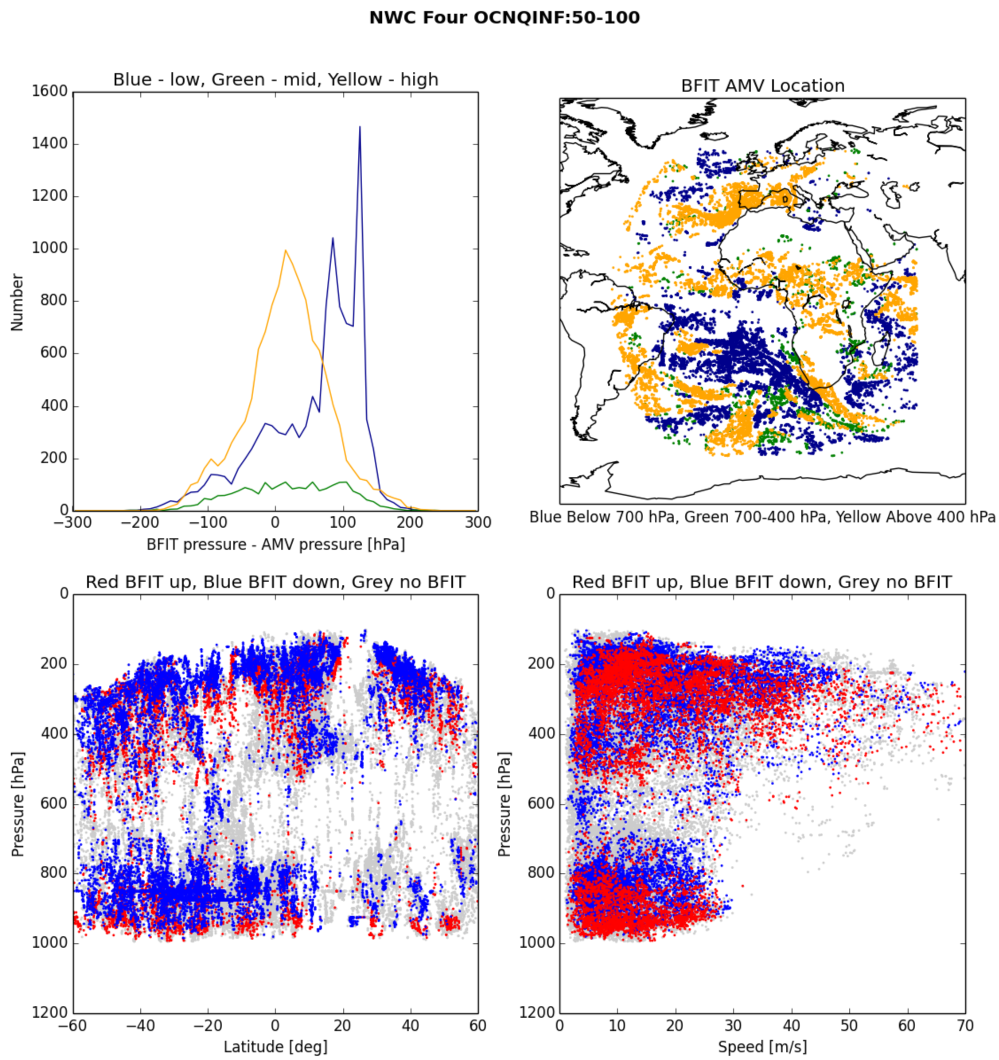

Figure 111: NWC (Operational conf., NWC Clouds): Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

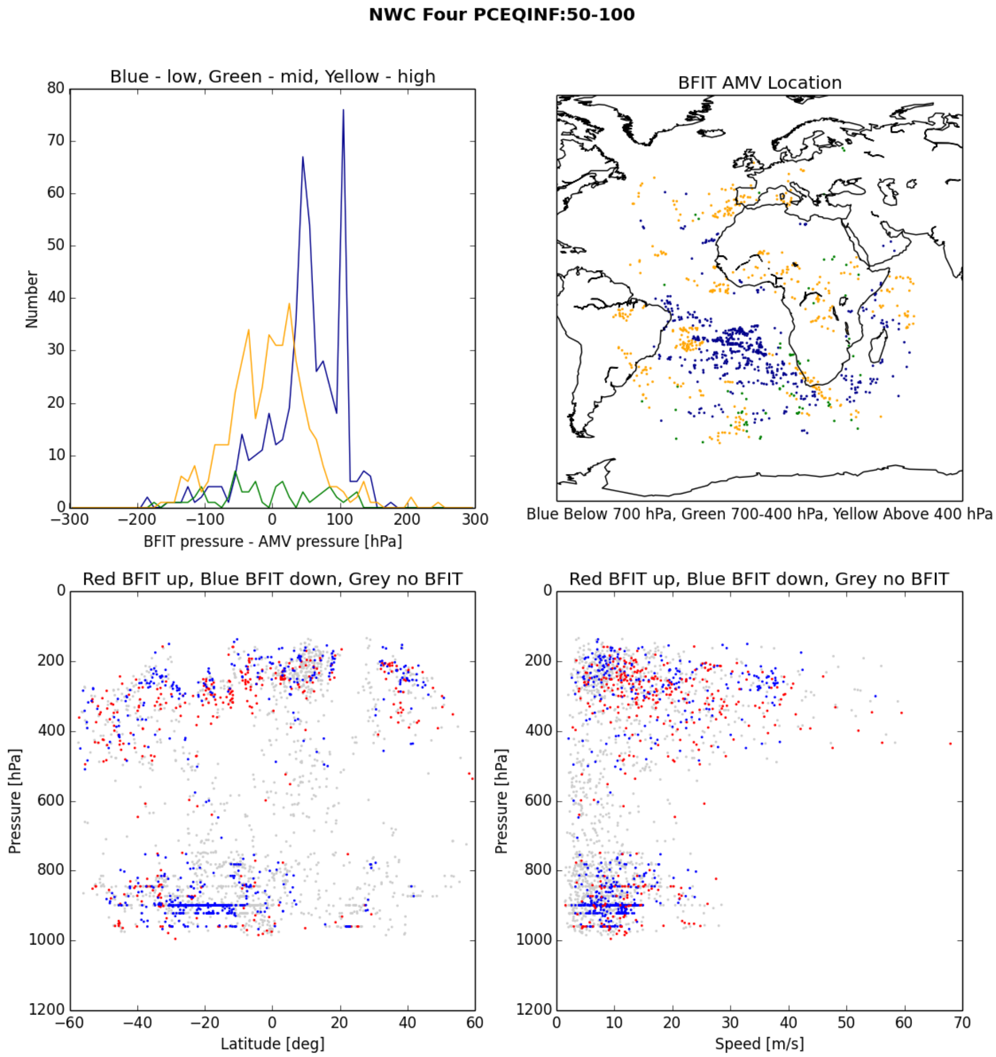

Figure 112: NWC (Prescribed conf., EUM Clouds): Distribution of Best Fit – AMV pressure by height (upper left); Best Fit AMV location (color coded by height); AMV pressure vs. Latitude (color coded by Best Fit height adjustment); AMV pressure vs. Speed (color coded by Best Fit height adjustment).

The depiction of the distribution of Best Fit statistics is in Figure 113 through Figure 121. Depending on the site, 14% to 31% (lower left in each figure) of the AMVs are adjusted to a Best Fit pressure. There does not appear to be a relationship between latitude or longitude and adjusted pressure (upper left and middle left in figures).
In the upper-right corner of the figures, the distribution of the pressure difference (AMV Best Fit pressure minus the Original Pressure).

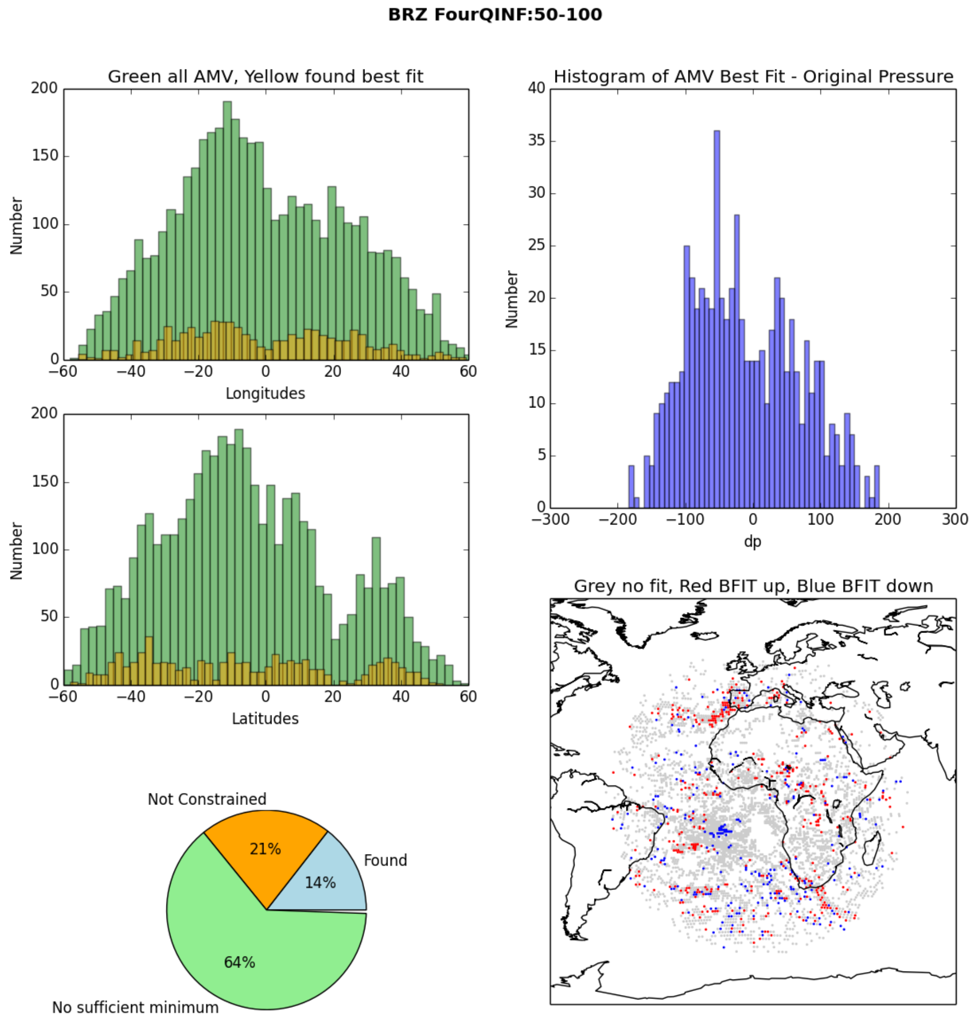

Figure 113: BRZ: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

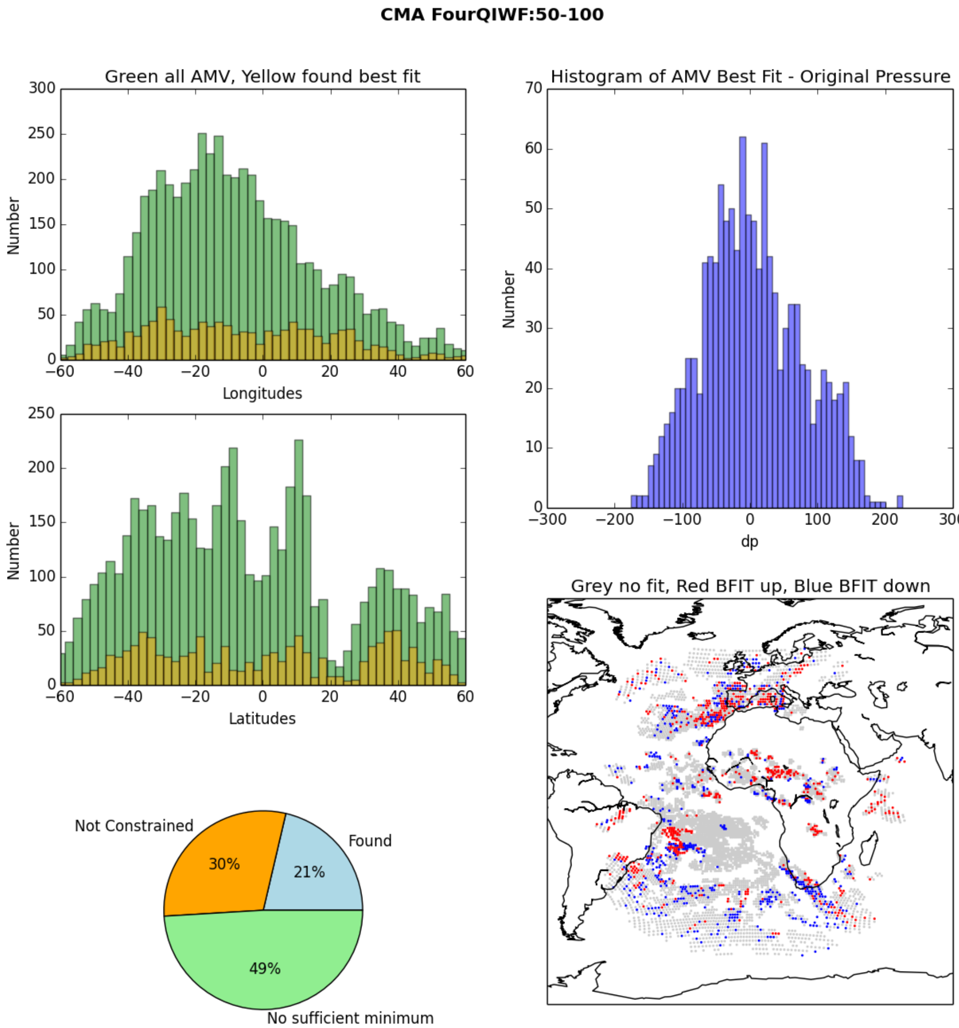

Figure 114: CMA: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

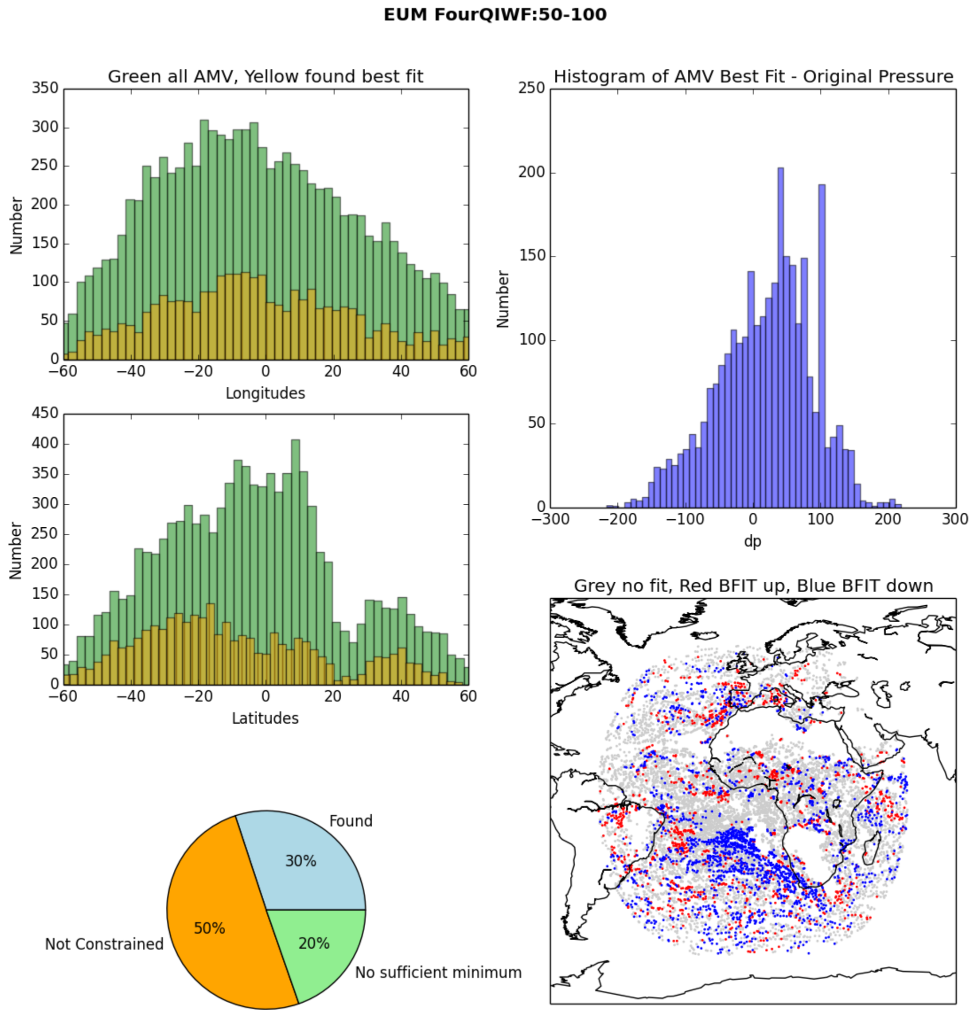

Figure 115: EUM: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

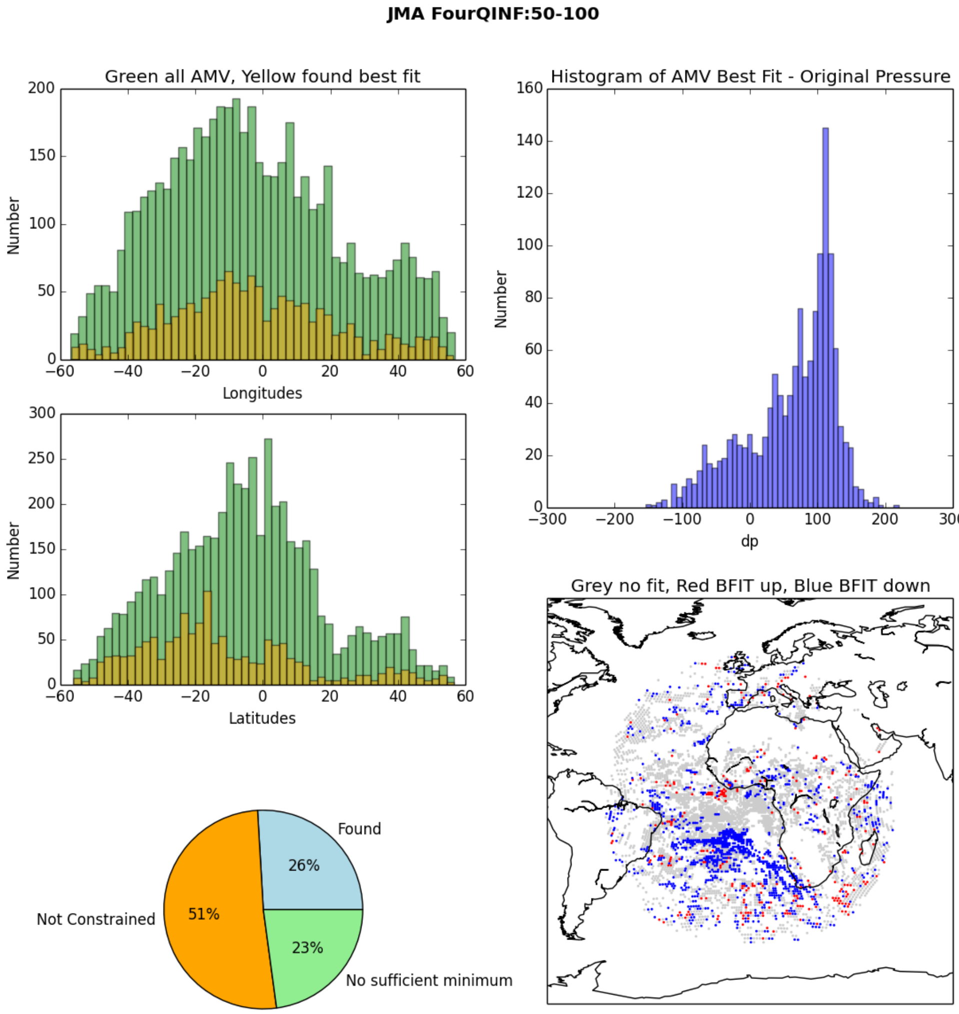

Figure 116: JMA: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

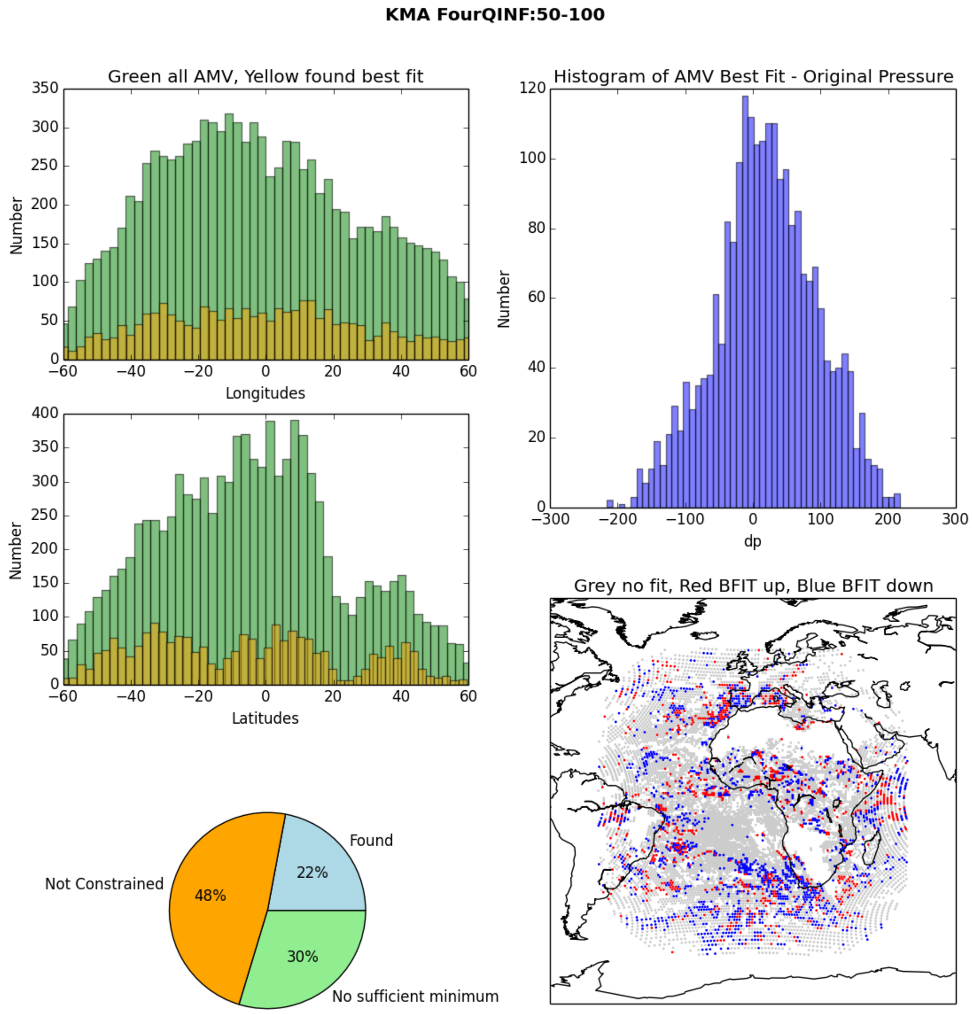

Figure 117: KMA: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

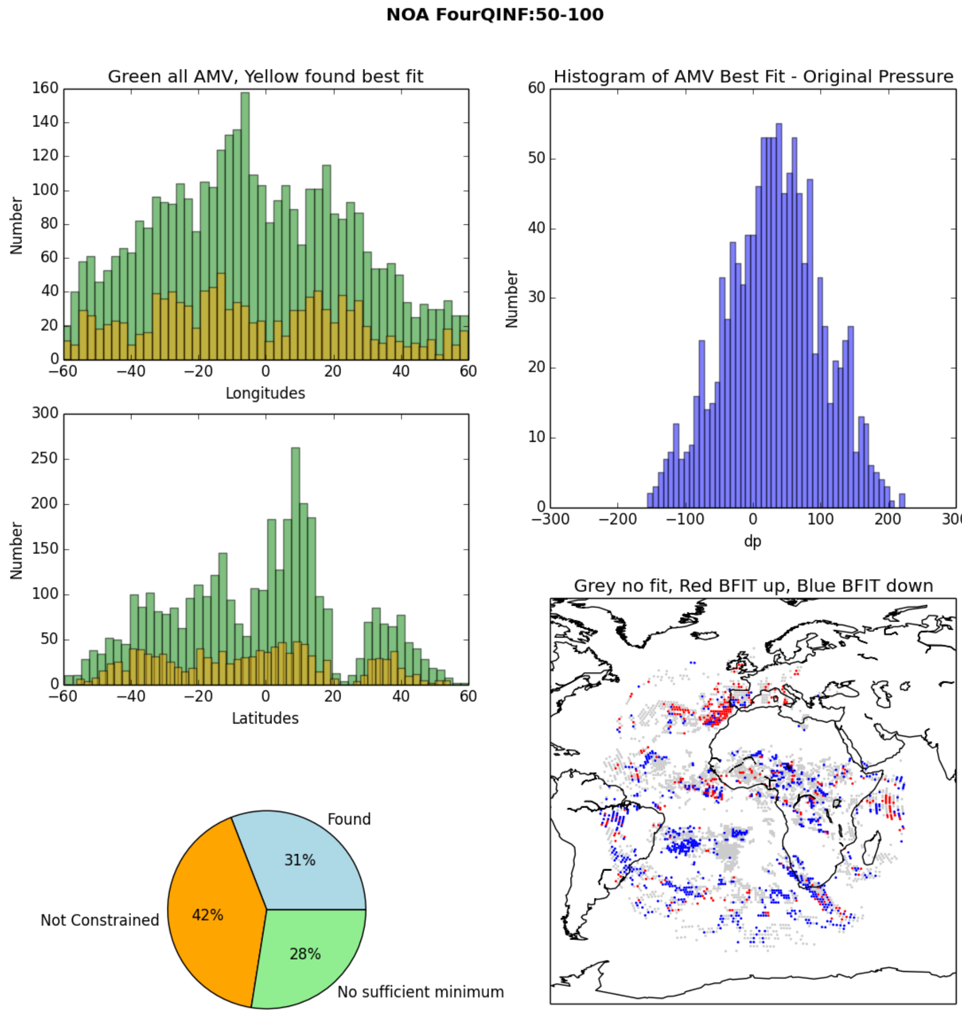

Figure 118: NOA: Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

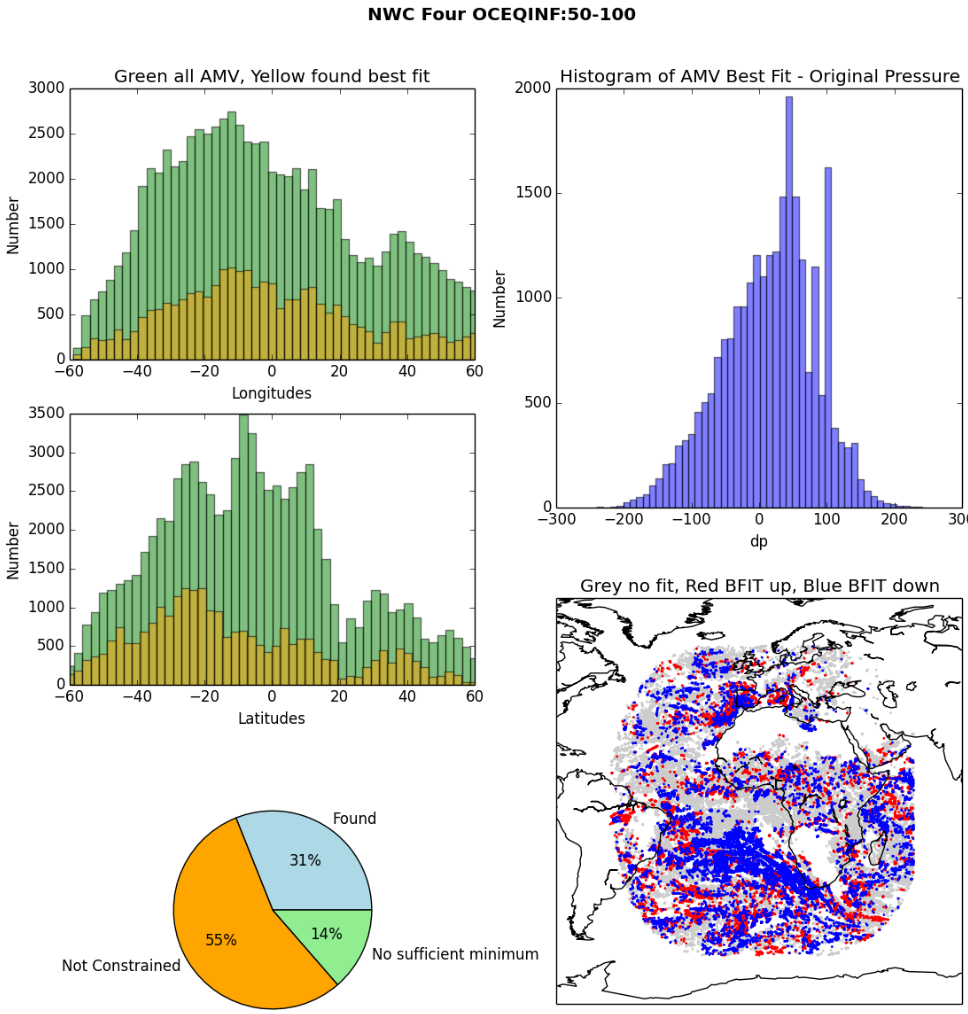

Figure 119: NWC (Operational conf., EUM Clouds): Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

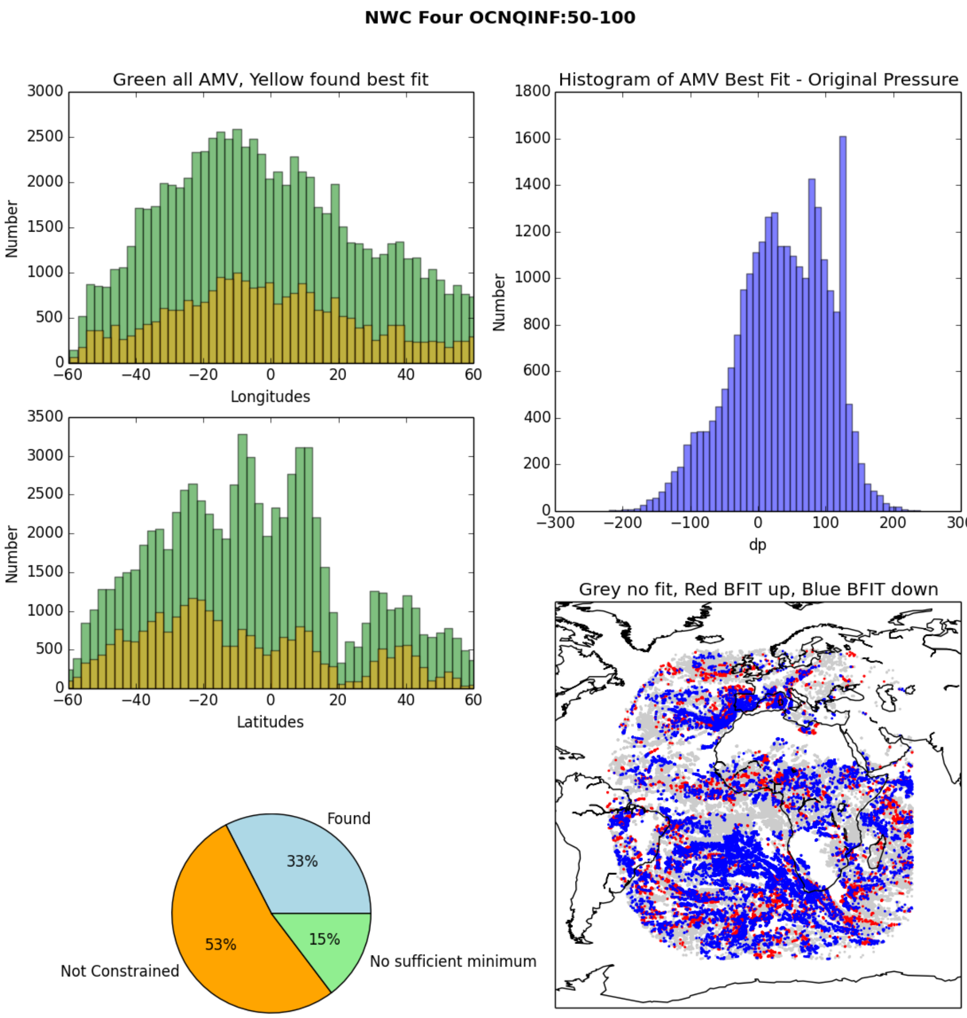

Figure 120: NWC (Operqtional conf, NWC Clouds): Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

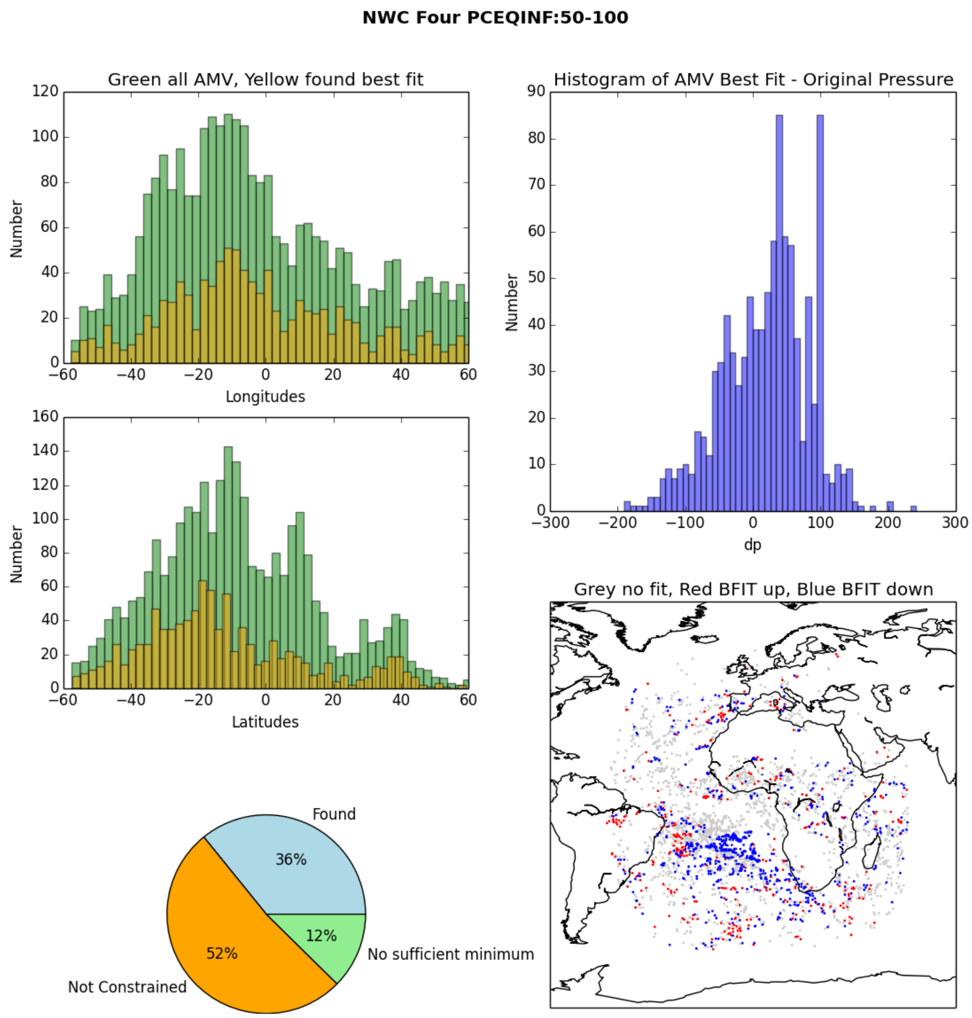

Figure 121: NWC (Prescribed conf., EUM Clouds): Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Latitude (upper left); Distribution of all AMVs (green) and Best Fit AMVs (gold) vs. Longitude (middle left); Percent of AMVs used in Best Fit (Found) and those that didn't meet criteria (Not Constrained, No sufficient minimum) (lower left). Frequency of pressure difference, Best Fit – original AMV pressure (upper right); spatial distribution of Best Fit modified AMVs (color code by Best Fit height adjustment (lower right).

f) Statistical comparison

Use the paired t-test between all combinations of producers (and parameters) to determine if the differences are statistically significant in colocated AMVs. QI without forecast >= 50; distance threshold 55 km. Number of co-locations is 9942. Only for a few combinations of directions the differences are statistically not significant.

Table 36: Experiment 4 <u>speed</u> t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	BRZ	NOA	NWC	JMA
EUM						
KMA						
BRZ						
NOA						
NWC						
JMA						

Table 37 : Experiment 4 <u>direction</u> t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	BRZ	NOA	NWC	JMA
EUM						
KMA						
BRZ						
NOA						
NWC						
JMA						

Table 38: Experiment 4 <u>pressure</u> t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	BRZ	NOA	NWC	JMA
EUM						
KMA						
BRZ						
NOA						
NWC						
JMA						

Table 39: Experiment 4 <u>QI without forecast</u> t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	BRZ	NOA	NWC	JMA
EUM						
KMA						
BRZ						
NOA						
NWC						
JMA						

QI with forecast >= 50; distance threshold 55 km. Number of co-locations is 10285

.

Table 40: Experiment 4 speed t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA
EUM						
KMA						
CMA						
NOA						
NWC						
JMA						

Table 41 : Experiment 4 direction t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA
EUM						
KMA						
CMA						
NOA						
NWC						
JMA						

Table 42: Experiment 4 pressure t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA
EUM						
KMA						
CMA						
NOA						
NWC						
JMA						

Table 43: Experiment 4 QI with forecast t-test for each paired combination of winds producers. Green indicates the parameter is not statistically different at the 95% level; red is statistically different.

	EUM	KMA	CMA	NOA	NWC	JMA
EUM						
KMA						
CMA						
NOA						
NWC						
JMA						

g) Model Grid comparison

Pythons scripts that find the Best Fit, also output comparison of all AMVs to the background grid. This comparison is based on 12-hour forecast. The results in Table 44 are similar as Experiment 2 and 3, with NWC fitting the background best, and BRZ having the largest deviation. EUM has improved significantly due to better height assignments.

Table 44: Experiment 4 AMV comparison to background grid: a 12-hour forecast. N = total number of AMVs; BFN = Best Fit number of AMVs; V_O = VD OMB mean; RAF = RMSE after Best Fit; VAF = Vector difference after Best Fit; RMSE = root mean square error.

Exp	QI	N	BFN	V_O	RAF	VAF	RMSE
BRZ	QINF:80-100	1590	220	8.01	9.67	7.54	9.43
CMA	QIWF:80-100	4743	1090	6.38	7.44	5.77	7.02
EUM	QIWF:80-100	6583	2301	3.91	5.36	3.29	4.84
JMA	QINF:80-100	3514	1056	4.91	6.59	3.94	5.88
KMA	QINF:80-100	4574	1221	5.16	6.83	4.66	6.52
NOA	QINF:80-100	2274	807	5.90	7.54	4.84	6.83
NWC (Oper.conf., EUM Clouds)	QINF:80-100	53010	18115	3.23	4.15	2.71	3.65
NWC (Oper.conf., NWC Clouds)	QINF:80-100	52464	18732	3.77	4.65	3.05	4.04
NWC (Pres.conf., EUM Clouds)	QINF:80-100	1419	605	3.05	4.01	2.45	3.40

h) IR height vs. best height method

The only difference between Experiment 3 and 4 is the option to use any height assignment method (4) over only the IR B_T (3). In the following figures, the change in AMV height between Experiment 3 and 4 is depicted: negative values indicate the AMV is placed to lower pressure (higher altitude); positive values are AMVs moved to higher pressure (lower altitude). Colocated AMVs are determined for each centre if the winds in the two experiments are with 2 km of each other; except for NWC where the distance threshold is 12 km.

The histogram of these height differences show that EUM (Figure 123), NOA (Figure 127), and NWC (Figure 128) have a significant change in AMV height when the algorithm uses the preferred height method over only IR B_T. The majority of the winds from EUM and NOA are shifted higher in altitude, which corresponds to observed shift in the height histogram from Figure 55 to Figure 81 (EUM). Also, there is a substantial improvement in the vector RMS with rawinsonde comparisons for EUM (from 9.46 to 6.26 ms^{-1}) and NOA (from 9.30 to 7.36 ms^{-1}).

The other centres (BRZ, CMA, KMA, JMA) have very few AMVs shifted in height, accounting for only a few percent, with little change in the rawinsonde and model grid comparisons RMS errors.

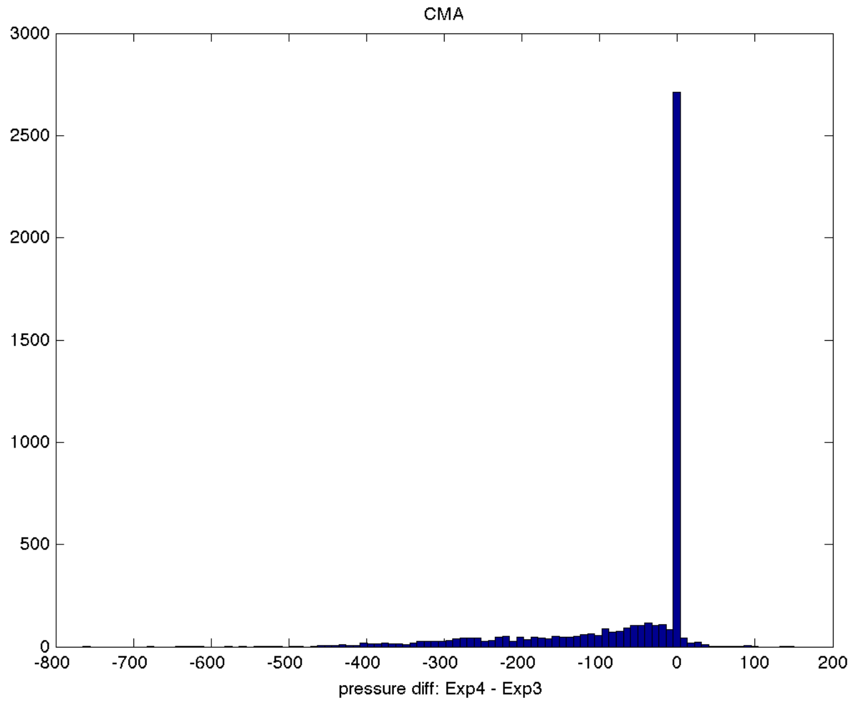

Figure 122: CMA colocated pressure differences between Exp. 4 and Exp. 3. 517 colocated matches.

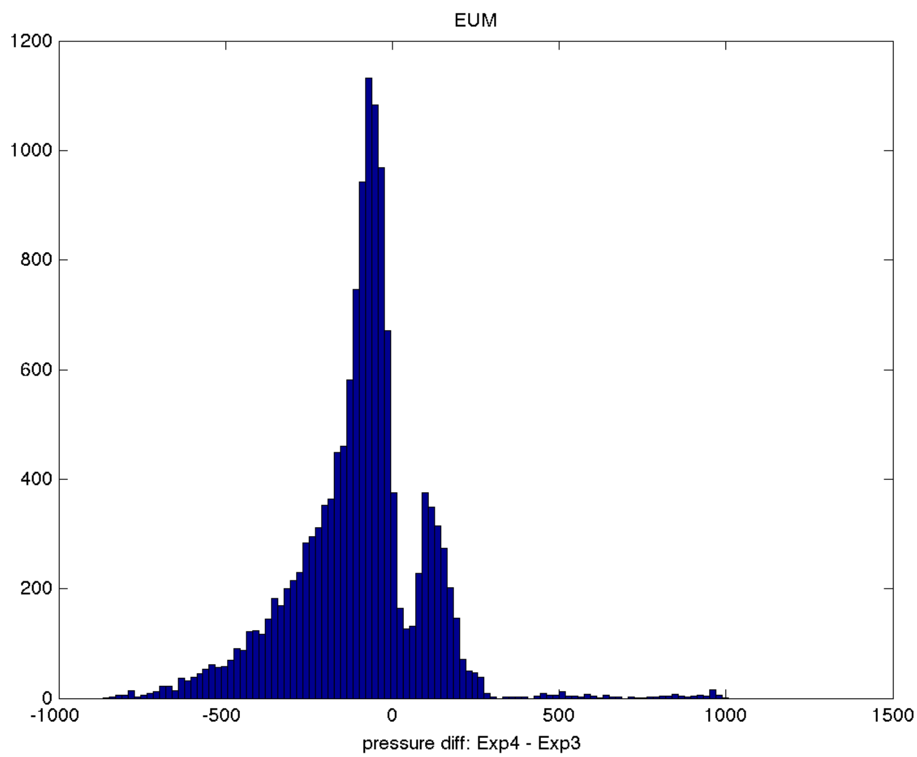

Figure 123: EUM colocated pressure differences between Exp. 4 and Exp. 3. 13947 matches

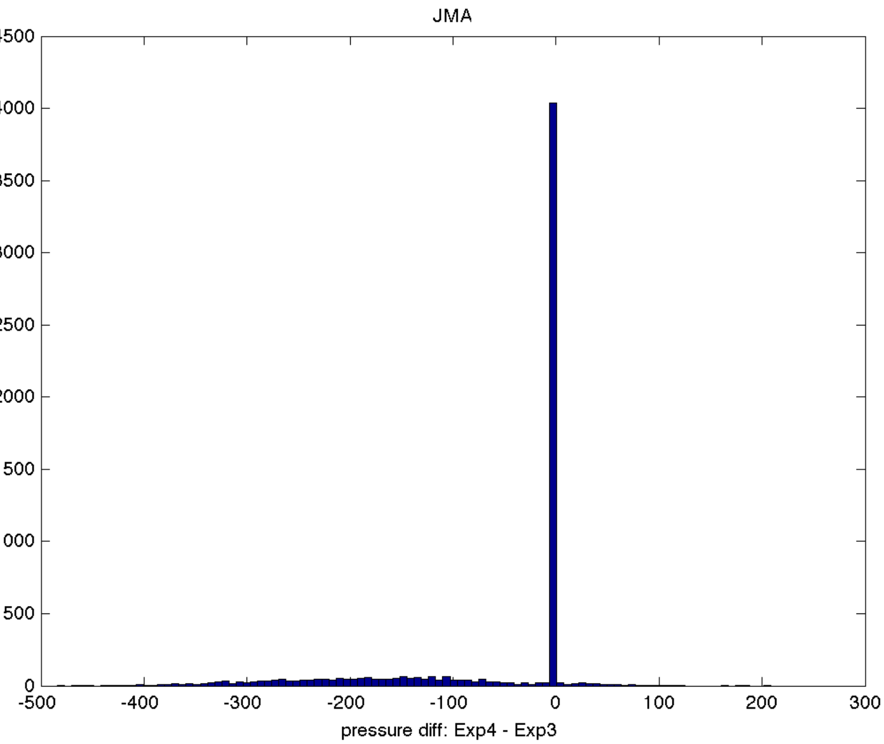

Figure 124: JMA colocated pressure differences between Exp. 4 and Exp. 3. 6129 matches

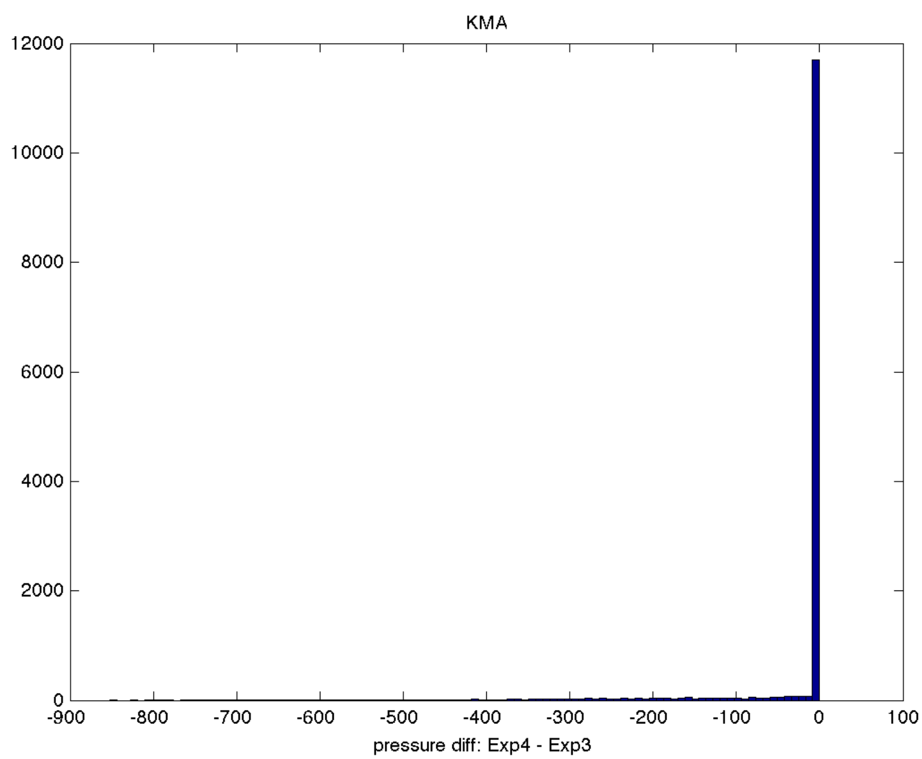

Figure 125: KMA colocated pressure differences between Exp. 4 and Exp. 3. 13718 matches

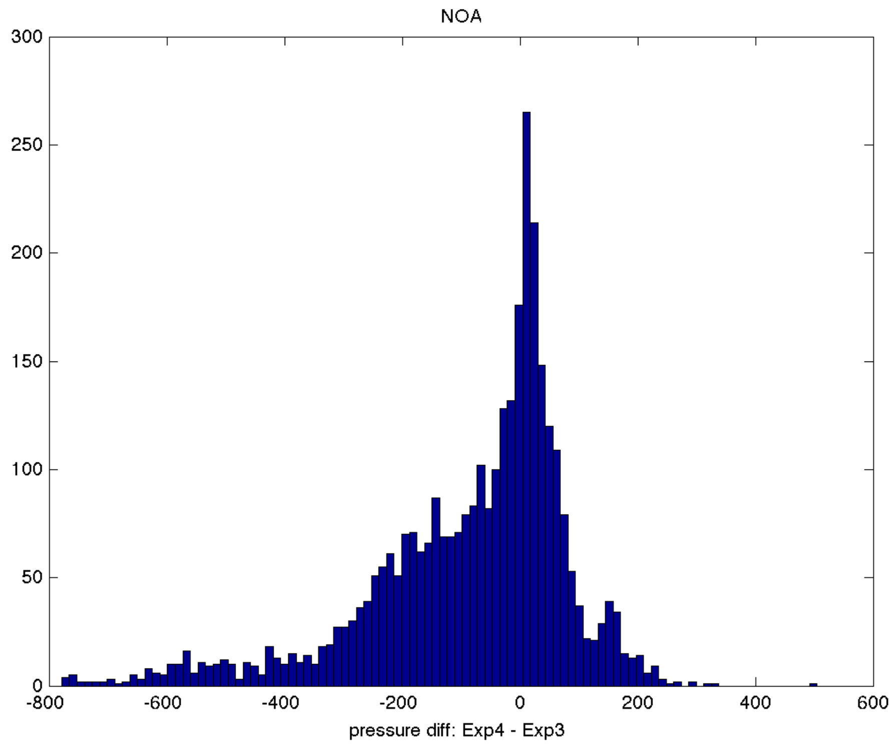

Figure 126: NOA colocated pressure differences between Exp. 4 and Exp. 3. 3362 collocated.

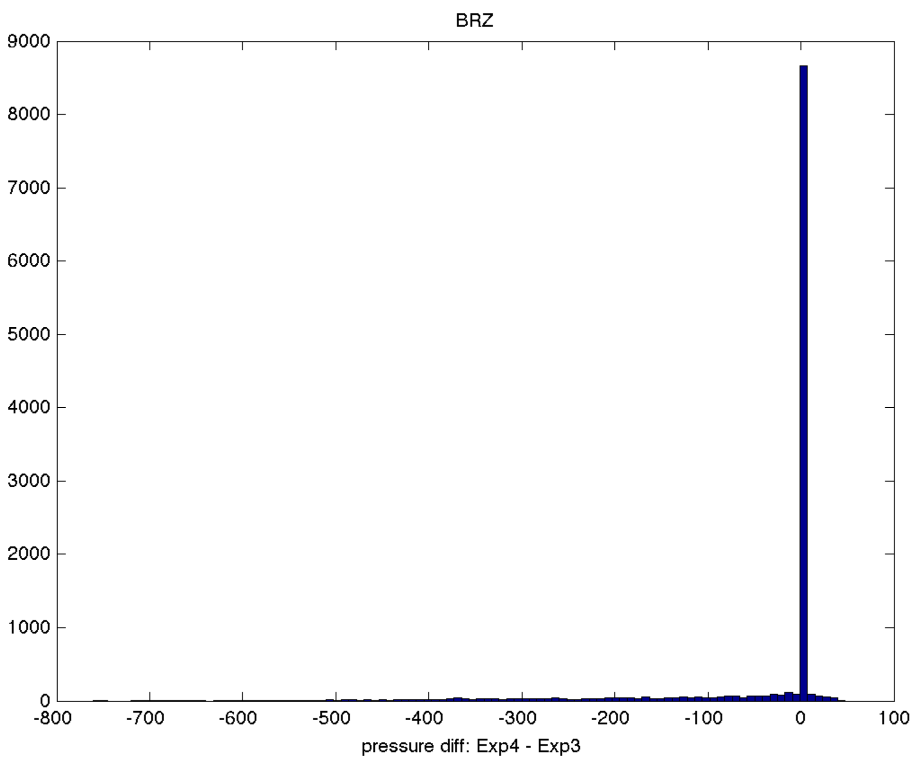

Figure 127: BRZ colocated pressure differences between Exp. 4 and Exp. 3. 11371 collocated.

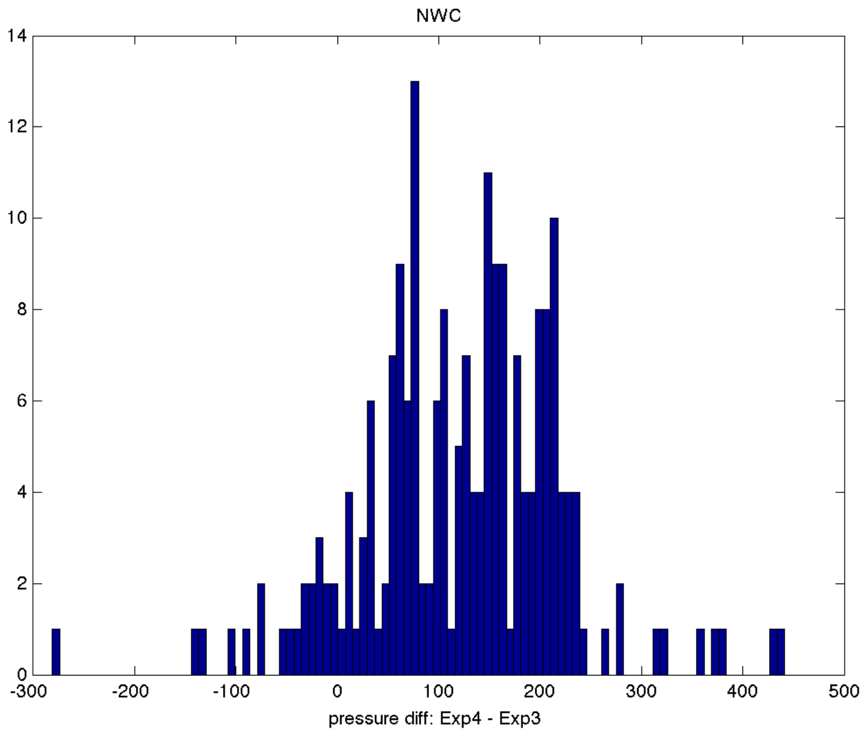

Figure 128: NWC colocated pressure differences between Exp. 4 and Exp. 3. 207 collocated.

11. Summary and Conclusions

Four experiments were conducted by each of the AMV producers:

1. AMV producers extracted IR 10.8 μ AMVs considering a triplet of images with a known displacement. This experiment tests the tracking step in all AMV algorithms.
2. AMV producers extract IR 10.8 μ AMVs considering their standard AMV algorithm configuration, but only using the MSG/SEVIRI IR 10.8 μ images and the ECMWF model data for the Height assignment. This experiment tests the target selection, tracking and quality control steps in all AMV algorithms.
3. Same as Exp. 2, except a prescribed AMV algorithm configuration is used. This experiment will be used to test the tracking and quality control steps in all AMV algorithms, considering similar targets.
4. Same as Exp. 3, except the AMV producer can use the height assignment method of their choosing. This experiment will be used to test the height assignment and quality control steps in all AMV algorithms, considering similar targets.

The following sections detail the findings from the experiments, in terms of each AMV producer, independently. This includes the strengths and weaknesses as determined from the results of the experiments.

a) EUMETSAT

In this study, the EUMETSAT AMVs were used as the comparison to all the other centres to detect differences in the datasets. The strengths of the algorithm were especially noted in Experiments 1 and 4. In Experiment 1, all vector displacements were correct. In Experiment 4, the statistical comparison of the EUM AMVs to rawinsondes and the background forecast wind field, was second only to NWCSAF. However, the use of only the IR B_T for cloud height (Experiment 3) resulted in AMVs being placed several hundred hPa different than when other techniques could be used (Experiment 4). This conclusion was confirmed with the high error in the rawinsonde comparison statistics.

b) China Meteorological Administration

The CMA algorithm preformed well in Experiment 1, detecting the correct displacement of the artificially moved features in all cases. In the other experiments, the AMV comparison to rawinsondes and the background wind field exhibited larger errors than other centres, which may be due to very extensive use of IR-only B_T in determing AMV heights. However, the Best Fit analysis indicates that there are good AMVs in this dataset as the Best Fit height adjustment and corresponding improvement in statistics (compared to the background) are very similar to other centres.

c) Japan Meteorological Agency

The results from Experiment 4 show that the JMA algorithm is in the middle (statistically) when measuring performance based on comparisons to rawinsondes and the background wind field. Moreover, JMA, KMA, and NOAA, had good intercomparison agreement.

d) NOAA

The strength of the NOAA algorithm is in its cloud height determination as evidenced in Experiment 4: A substantial number of heights were adjusted (as compared to IR-only B_T) resulting in a improvement in a statistical comparison to rawinsondes and the background forecast wind field. Unfortunately, they were not able to use a high vertical resolution background grid, to better detect temperature inversions and the height of low-level clouds.

e) Korea Meteorological Administration

The results from Experiment 4 show that the KMA algorithm is in the middle (statistically) when measuring performance based on comparisons to rawinsondes and the background wind field. Moreover, KMA, JMA, and NOAA, had good intercomparison agreement

f) NWCSAF

Among all the centres in this study, the NWCSAF/HRW algorithm had the best statistics as compared to rawinsondes and the background forecast wind field. This was the case for both Experiment 3 (IR B_T only cloud height) and Experiment 4 (any cloud height technique). Moreover, NWC AMVs with IR-only cloud height performed better than several other centres using other cloud height techniques.

g) Brazilian Meteorological Center

The performance of the BRZ AMV algorithm could not be evaluated because the results of Experiment 1 indicates an error in determining wind speed up to 10 ms^{-1} depending on the distance from the satellite subpoint. However, the Best Fit analysis indicates that there are good AMVs in this dataset as the Best Fit height adjustment and corresponding improvement in statistics (compared to the background) are very similar to other centres.

12. References

Genkova, I., R. Borde, J. Schmetz, J. Daniels, C. Velden, K. Holmlund, 2008: Global atmospheric motion vectors intercomparison study, *9th Int. Winds Workshop*, Annapolis, MD USA, April 2008.

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Xu J. and Q. Zhang, 1996: Calculation of Cloud motion wind with GMS-5 images in China. *Proceedings 3rd international winds workshop*, EUMETSAT Pub.18, pp.45-52.

13. Acknowledgements

We would like to thank EUMETSAT, the Satellite Application Facility on support to Nowcasting (NWCSAF) and Agencia Estatal de Meteorología (AEMET) for the funding and support of this project. Also, we appreciate the comments and suggestions from Régis Borde and the International Winds Working Group (IWWG) co-chairs, Jaime Daniels and Mary Forsythe.

14. Appendix A: Matlab t-test Documentation

```
ttest  One-sample and paired-sample t-test.
    H = ttest(X) performs a t-test of the hypothesis that the data in the
    vector X come from a distribution with mean zero, and returns the
    result of the test in H.  H=0 indicates that the null hypothesis
    ("mean is zero") cannot be rejected at the 5% significance level.  H=1
    indicates that the null hypothesis can be rejected at the 5% level.
    The data are assumed to come from a normal distribution with unknown
    variance.

    X can also be a matrix or an N-D array.   For matrices, ttest performs
    separate t-tests along each column of X, and returns a vector of
    results.  For N-D arrays, ttest works along the first non-singleton
    dimension of X.

    ttest treats NaNs as missing values, and ignores them.

    H = ttest(X,M) performs a t-test of the hypothesis that the data in
    X come from a distribution with mean M.  M must be a scalar.

    H = ttest(X,Y) performs a paired t-test of the hypothesis that two
    matched samples, in the vectors X and Y, come from distributions with
    equal means. The difference X-Y is assumed to come from a normal
    distribution with unknown variance.  X and Y must have the same length.
    X and Y can also be matrices or N-D arrays of the same size.

    [H,P] = ttest(...) returns the p-value, i.e., the probability of
    observing the given result, or one more extreme, by chance if the null
    hypothesis is true.  Small values of P cast doubt on the validity of
    the null hypothesis.

    [H,P,CI] = ttest(...) returns a 100*(1-ALPHA)% confidence interval for
    the true mean of X, or of X-Y for a paired test.

    [H,P,CI,STATS] = ttest(...) returns a structure with the following fields:
       'tstat' -- the value of the test statistic
       'df'    -- the degrees of freedom of the test
       'sd'    -- the estimated population standard deviation.  For a
                  paired test, this is the std. dev. of X-Y.
```

15. Appendix B: t-test Results

Text output from Matlab script Stats_QIF_One.m. Text files used as input:

EUM: EUMETSATDatasetOne.csv
CMA: ChinaDatasetOneNew.csv
JMA: JapanDatasetOneNew.csv
NOA: NOAADatasetOne.csv
KMA: KoreaDatasetOne.csv
NWC: NWCSAFDatasetOne_O_C_WO_N.csv
BRZ: BrazilDatasetOne.csv

All QI values are used; distance threshold = 35km; 10876 colocated matches.
Statistical confidence 95%.

See

Appendix A: Matlab t-test Documentation for description of h, p, ci, Mean.

Experiment 1 t-test Results

```
10876

EUMETSAT vs. Korea
  Speed:  h = 1, p = 0.00, ci = 0.01 0.02, Mean: 0.01
  Dir:    h = 1, p = 0.00, ci = 0.02 0.03, Mean: 0.03
  Hdisp1: h = 0, p = 0.54, ci = -0.00 0.00, Mean: 0.00
  Vdisp1: h = 0, p = 0.51, ci = -0 0.00, Mean: 0.00
  Hdisp2: h = 0, p = 0.54, ci = -0.00 0.00, Mean: -0.00
  Vdisp2: h = 0, p = 0.51, ci = -0.00 0.00, Mean: -0.00
EUMETSAT vs. China
  Speed:  h = 1, p = 0.00, ci = 0.49 0.51, Mean: 0.50
  Dir:    h = 1, p = 0.00, ci = 0.01 0.03, Mean: 0.02
  Hdisp1: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
  Vdisp1: h = NaN, p = NaN, ci = 0 0.00, Mean: 0.00
  Hdisp2: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
  Vdisp2: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
EUMETSAT vs. NOAA
  Speed:  h = 1, p = 0.00, ci = -0.02 -0.01, Mean: -0.01
  Dir:    h = 1, p = 0.00, ci = 0.02 0.03, Mean: 0.02
  Hdisp1: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
  Vdisp1: h = NaN, p = NaN, ci = 0 0.00, Mean: 0.00
  Hdisp2: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
  Vdisp2: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
EUMETSAT vs. NWCSAF
  Speed:  h = 0, p = 0.60, ci = -0.02 0.01, Mean: -0.00
  Dir:    h = 0, p = 0.85, ci = -0.06 0.05, Mean: -0.01
  Hdisp1: h = 0, p = 0.08, ci = -0.01 0.00, Mean: -0.00
  Vdisp1: h = 0, p = 0.50, ci = -0 0.01, Mean: 0.00
  Hdisp2: h = 0, p = 0.13, ci = -0.01 0.00, Mean: -0.00
  Vdisp2: h = 0, p = 0.52, ci = -0.00 0.01, Mean: 0.00
EUMETSAT vs. Japan
  Speed:  h = 1, p = 0.00, ci = 17.21 17.33, Mean: 17.27
  Dir:    h = 1, p = 0.00, ci = -0.12 -0.11, Mean: -0.11
  Hdisp1: h = 0, p = 0.10, ci = -0.00 0.00, Mean: 0.00
  Vdisp1: h = 0, p = 0.92, ci = -0 0.00, Mean: -0.00
  Hdisp2: h = 0, p = 0.10, ci = -0.00 0.00, Mean: -0.00
  Vdisp2: h = 0, p = 0.92, ci = -0.00 0.00, Mean: 0.00
EUMETSAT vs. Brazil
  Speed:  h = 1, p = 0.00, ci = 0.40 0.47, Mean: 0.43
  Dir:    h = 1, p = 0.00, ci = 4.72 4.96, Mean: 4.84
  Hdisp1: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
  Vdisp1: h = NaN, p = NaN, ci = 0 0.00, Mean: 0.00
  Hdisp2: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
  Vdisp2: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
Korea vs. China
  Speed:  h = 1, p = 0.00, ci = 0.48 0.49, Mean: 0.49
  Dir:    h = 1, p = 0.02, ci = -0.01 -0.00, Mean: -0.01
  Hdisp1: h = 0, p = 0.54, ci = -0.00 0.00, Mean: -0.00
  Vdisp1: h = 0, p = 0.51, ci = -0 0.00, Mean: -0.00
  Hdisp2: h = 0, p = 0.54, ci = -0.00 0.00, Mean: 0.00
  Vdisp2: h = 0, p = 0.51, ci = -0.00 0.00, Mean: 0.00
Korea vs. NOAA
  Speed:  h = 1, p = 0.00, ci = -0.03 -0.03, Mean: -0.03
  Dir:    h = 1, p = 0.01, ci = -0.00 -0.00, Mean: -0.00
  Hdisp1: h = 0, p = 0.54, ci = -0.00 0.00, Mean: -0.00
  Vdisp1: h = 0, p = 0.51, ci = -0 0.00, Mean: -0.00
  Hdisp2: h = 0, p = 0.54, ci = -0.00 0.00, Mean: 0.00
  Vdisp2: h = 0, p = 0.51, ci = -0.00 0.00, Mean: 0.00
```

```
Korea vs. NWCSAF
  Speed:  h = 1, p = 0.01, ci = -0.03 -0.00, Mean: -0.02
  Dir:    h = 0, p = 0.26, ci = -0.09 0.02, Mean: -0.03
  Hdisp1: h = 0, p = 0.07, ci = -0.01 0.00, Mean: -0.00
  Vdisp1: h = 0, p = 0.56, ci = -0 0.01, Mean: 0.00
  Hdisp2: h = 0, p = 0.14, ci = -0.01 0.00, Mean: -0.00
  Vdisp2: h = 0, p = 0.47, ci = -0.00 0.01, Mean: 0.00
Korea vs. Japan
  Speed:  h = 1, p = 0.00, ci = 17.20 17.31, Mean: 17.25
  Dir:    h = 1, p = 0.00, ci = -0.14 -0.13, Mean: -0.14
  Hdisp1: h = 0, p = 0.67, ci = -0.00 0.00, Mean: 0.00
  Vdisp1: h = 0, p = 0.51, ci = -0 0.00, Mean: -0.00
  Hdisp2: h = 0, p = 0.67, ci = -0.00 0.00, Mean: -0.00
  Vdisp2: h = 0, p = 0.51, ci = -0.00 0.00, Mean: 0.00
Korea vs. Brazil
  Speed:  h = 1, p = 0.00, ci = 0.38 0.46, Mean: 0.42
  Dir:    h = 1, p = 0.00, ci = 4.69 4.93, Mean: 4.81
  Hdisp1: h = 0, p = 0.54, ci = -0.00 0.00, Mean: -0.00
  Vdisp1: h = 0, p = 0.51, ci = -0 0.00, Mean: -0.00
  Hdisp2: h = 0, p = 0.54, ci = -0.00 0.00, Mean: 0.00
  Vdisp2: h = 0, p = 0.51, ci = -0.00 0.00, Mean: 0.00
China vs. NOAA
  Speed:  h = 1, p = 0.00, ci = -0.52 -0.51, Mean: -0.51
  Dir:    h = 0, p = 0.07, ci = -0.00 0.01, Mean: 0.01
  Hdisp1: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
  Vdisp1: h = NaN, p = NaN, ci = 0 0.00, Mean: 0.00
  Hdisp2: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
  Vdisp2: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
China vs. NWCSAF
  Speed:  h = 1, p = 0.00, ci = -0.52 -0.49, Mean: -0.50
  Dir:    h = 0, p = 0.41, ci = -0.08 0.03, Mean: -0.02
  Hdisp1: h = 0, p = 0.08, ci = -0.01 0.00, Mean: -0.00
  Vdisp1: h = 0, p = 0.50, ci = -0 0.01, Mean: 0.00
  Hdisp2: h = 0, p = 0.13, ci = -0.01 0.00, Mean: -0.00
  Vdisp2: h = 0, p = 0.52, ci = -0.00 0.01, Mean: 0.00
China vs. Japan
  Speed:  h = 1, p = 0.00, ci = 16.71 16.82, Mean: 16.77
  Dir:    h = 1, p = 0.00, ci = -0.14 -0.12, Mean: -0.13
  Hdisp1: h = 0, p = 0.10, ci = -0.00 0.00, Mean: 0.00
  Vdisp1: h = 0, p = 0.92, ci = -0 0.00, Mean: -0.00
  Hdisp2: h = 0, p = 0.10, ci = -0.00 0.00, Mean: -0.00
  Vdisp2: h = 0, p = 0.92, ci = -0.00 0.00, Mean: 0.00
China vs. Brazil
  Speed:  h = 1, p = 0.00, ci = -0.10 -0.03, Mean: -0.07
  Dir:    h = 1, p = 0.00, ci = 4.70 4.94, Mean: 4.82
  Hdisp1: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
  Vdisp1: h = NaN, p = NaN, ci = 0 0.00, Mean: 0.00
  Hdisp2: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
  Vdisp2: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
NOAA vs. NWCSAF
  Speed:  h = 0, p = 0.19, ci = -0.00 0.02, Mean: 0.01
  Dir:    h = 0, p = 0.29, ci = -0.09 0.03, Mean: -0.03
  Hdisp1: h = 0, p = 0.08, ci = -0.01 0.00, Mean: -0.00
  Vdisp1: h = 0, p = 0.50, ci = -0 0.01, Mean: 0.00
  Hdisp2: h = 0, p = 0.13, ci = -0.01 0.00, Mean: -0.00
  Vdisp2: h = 0, p = 0.52, ci = -0.00 0.01, Mean: 0.00
NOAA vs. Japan
  Speed:  h = 1, p = 0.00, ci = 17.23 17.34, Mean: 17.28
  Dir:    h = 1, p = 0.00, ci = -0.14 -0.13, Mean: -0.14
  Hdisp1: h = 0, p = 0.10, ci = -0.00 0.00, Mean: 0.00
  Vdisp1: h = 0, p = 0.92, ci = -0 0.00, Mean: -0.00
```

```
  Hdisp2: h = 0, p = 0.10, ci = -0.00 0.00, Mean: -0.00
  Vdisp2: h = 0, p = 0.92, ci = -0.00 0.00, Mean: 0.00
NOAA vs. Brazil
  Speed:  h = 1, p = 0.00, ci = 0.41 0.49, Mean: 0.45
  Dir:    h = 1, p = 0.00, ci = 4.70 4.94, Mean: 4.82
  Hdisp1: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
  Vdisp1: h = NaN, p = NaN, ci = 0 0.00, Mean: 0.00
  Hdisp2: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
  Vdisp2: h = NaN, p = NaN, ci = 0.00 0.00, Mean: 0.00
NWCSAF vs. Japan
  Speed:  h = 1, p = 0.00, ci = 17.22 17.33, Mean: 17.27
  Dir:    h = 1, p = 0.00, ci = -0.16 -0.05, Mean: -0.11
  Hdisp1: h = 0, p = 0.07, ci = -0.00 0.01, Mean: 0.00
  Vdisp1: h = 0, p = 0.50, ci = -0 0.00, Mean: -0.00
  Hdisp2: h = 0, p = 0.16, ci = -0.00 0.01, Mean: 0.00
  Vdisp2: h = 0, p = 0.52, ci = -0.01 0.00, Mean: -0.00
NWCSAF vs. Brazil
  Speed:  h = 1, p = 0.00, ci = 0.40 0.48, Mean: 0.44
  Dir:    h = 1, p = 0.00, ci = 4.71 4.98, Mean: 4.85
  Hdisp1: h = 0, p = 0.08, ci = -0.00 0.01, Mean: 0.00
  Vdisp1: h = 0, p = 0.50, ci = -0 0.00, Mean: -0.00
  Hdisp2: h = 0, p = 0.13, ci = -0.00 0.01, Mean: 0.00
  Vdisp2: h = 0, p = 0.52, ci = -0.01 0.00, Mean: -0.00
Japan vs. Brazil
  Speed:  h = 1, p = 0.00, ci = -16.90 -16.77, Mean: -16.83
  Dir:    h = 1, p = 0.00, ci = 4.83 5.07, Mean: 4.95
  Hdisp1: h = 0, p = 0.10, ci = -0.00 0.00, Mean: -0.00
  Vdisp1: h = 0, p = 0.92, ci = -0 0.00, Mean: 0.00
  Hdisp2: h = 0, p = 0.10, ci = -0.00 0.00, Mean: 0.00
  Vdisp2: h = 0, p = 0.92, ci = -0.00 0.00, Mean: -0.00
```

Experiment 2 t-test Results

QINF: 7050

```
EUMETSAT "VS" Korea
  Speed:     h = 1, p = 0.00, ci = 0.29 0.40, Mean: 0.34
  Direction: h = 1, p = 0.05, ci = -1.25 -0.01, Mean: -0.63
  Pressure:  h = 1, p = 0.00, ci = 86.92 92.06, Mean: 89.49
  QI:        h = 1, p = 0.00, ci = -2.46 -2.00, Mean: -2.23

EUMETSAT "VS" Brazil
  Speed:     h = 1, p = 0.00, ci = -0.82 -0.66, Mean: -0.74
  Direction: h = 1, p = 0.03, ci = -2.44 -0.12, Mean: -1.28
  Pressure:  h = 1, p = 0.00, ci = 128.58 134.20, Mean: 131.39
  QI:        h = 1, p = 0.00, ci = 12.91 13.79, Mean: 13.35

EUMETSAT "VS" NOAA
  Speed:     h = 1, p = 0.00, ci = -0.14 -0.05, Mean: -0.09
  Direction: h = 1, p = 0.00, ci = -1.76 -0.62, Mean: -1.19
  Pressure:  h = 1, p = 0.00, ci = 95.59 101.03, Mean: 98.31
  QI:        h = 1, p = 0.00, ci = -5.04 -4.43, Mean: -4.74

EUMETSAT "VS" NWCSAF
  Speed:     h = 0, p = 0.12, ci = -0.01 0.05, Mean: 0.02
  Direction: h = 0, p = 0.33, ci = -0.85 0.29, Mean: -0.28
  Pressure:  h = 1, p = 0.00, ci = 125.24 130.35, Mean: 127.80
  QI:        h = 1, p = 0.00, ci = -2.94 -2.29, Mean: -2.62

EUMETSAT "VS" Japan
  Speed:     h = 0, p = 0.40, ci = -0.02 0.06, Mean: 0.02
```

```
  Direction: h = 1, p = 0.00, ci = -1.78 -0.50, Mean: -1.14
  Pressure:  h = 1, p = 0.00, ci = 37.56 43.63, Mean: 40.59
  QI:        h = 1, p = 0.00, ci = -2.77 -2.13, Mean: -2.45

Korea "VS" Brazil
  Speed:     h = 1, p = 0.00, ci = -1.17 -0.99, Mean: -1.08
  Direction: h = 0, p = 0.29, ci = -1.87 0.56, Mean: -0.66
  Pressure:  h = 1, p = 0.00, ci = 40.46 43.34, Mean: 41.90
  QI:        h = 1, p = 0.00, ci = 15.17 16.00, Mean: 15.58

Korea "VS" NOAA
  Speed:     h = 1, p = 0.00, ci = -0.49 -0.38, Mean: -0.44
  Direction: h = 0, p = 0.07, ci = -1.16 0.04, Mean: -0.56
  Pressure:  h = 1, p = 0.00, ci = 7.04 10.60, Mean: 8.82
  QI:        h = 1, p = 0.00, ci = -2.79 -2.23, Mean: -2.51

Korea "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = -0.37 -0.27, Mean: -0.32
  Direction: h = 0, p = 0.14, ci = -0.11 0.80, Mean: 0.35
  Pressure:  h = 1, p = 0.00, ci = 37.37 39.25, Mean: 38.31
  QI:        h = 1, p = 0.01, ci = -0.68 -0.09, Mean: -0.39

Korea "VS" Japan
  Speed:     h = 1, p = 0.00, ci = -0.38 -0.27, Mean: -0.33
  Direction: h = 0, p = 0.07, ci = -1.07 0.05, Mean: -0.51
  Pressure:  h = 1, p = 0.00, ci = -50.48 -47.31, Mean: -48.89
  QI:        h = 0, p = 0.14, ci = -0.51 0.07, Mean: -0.22

Brazil "VS" NOAA
  Speed:     h = 1, p = 0.00, ci = 0.56 0.74, Mean: 0.65
  Direction: h = 0, p = 0.87, ci = -1.09 1.28, Mean: 0.10
  Pressure:  h = 1, p = 0.00, ci = -35.07 -31.09, Mean: -33.08
  QI:        h = 1, p = 0.00, ci = -18.55 -17.63, Mean: -18.09

Brazil "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = 0.68 0.84, Mean: 0.76
  Direction: h = 0, p = 0.10, ci = -0.19 2.19, Mean: 1.00
  Pressure:  h = 1, p = 0.00, ci = -4.93 -2.26, Mean: -3.59
  QI:        h = 1, p = 0.00, ci = -16.44 -15.50, Mean: -15.97

Brazil "VS" Japan
  Speed:     h = 1, p = 0.00, ci = 0.67 0.84, Mean: 0.76
  Direction: h = 0, p = 0.81, ci = -1.05 1.34, Mean: 0.14
  Pressure:  h = 1, p = 0.00, ci = -92.39 -89.20, Mean: -90.80
  QI:        h = 1, p = 0.00, ci = -16.27 -15.33, Mean: -15.80

NOAA "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = 0.07 0.16, Mean: 0.12
  Direction: h = 1, p = 0.00, ci = 0.32 1.50, Mean: 0.91
  Pressure:  h = 1, p = 0.00, ci = 27.99 30.99, Mean: 29.49
  QI:        h = 1, p = 0.00, ci = 1.77 2.47, Mean: 2.12

NOAA "VS" Japan
  Speed:     h = 1, p = 0.00, ci = 0.06 0.16, Mean: 0.11
  Direction: h = 0, p = 0.89, ci = -0.63 0.72, Mean: 0.05
  Pressure:  h = 1, p = 0.00, ci = -59.84 -55.58, Mean: -57.71
  QI:        h = 1, p = 0.00, ci = 1.94 2.64, Mean: 2.29

NWCSAF "VS" Japan
  Speed:     h = 0, p = 0.76, ci = -0.04 0.03, Mean: -0.01
  Direction: h = 1, p = 0.00, ci = -1.44 -0.28, Mean: -0.86
```

```
  Pressure:  h = 1, p = 0.00, ci = -88.67 -85.74, Mean: -87.20
  QI:        h = 0, p = 0.39, ci = -0.21 0.54, Mean: 0.17
```

QI with forecast: 10113

```
EUMETSAT "VS" Korea
  Speed:     h = 1, p = 0.00, ci = 0.36 0.47, Mean: 0.42
  Direction: h = 0, p = 0.60, ci = -0.23 0.40, Mean: 0.08
  Pressure:  h = 1, p = 0.00, ci = 95.55 99.81, Mean: 97.68
  QI:        h = 1, p = 0.00, ci = 7.38 7.84, Mean: 7.61

EUMETSAT "VS" China
  Speed:     h = 1, p = 0.00, ci = -0.32 -0.19, Mean: -0.26
  Direction: h = 0, p = 0.35, ci = -0.25 0.70, Mean: 0.23
  Pressure:  h = 1, p = 0.00, ci = 134.12 139.11, Mean: 136.61
  QI:        h = 1, p = 0.00, ci = 0.15 0.67, Mean: 0.41

EUMETSAT "VS" NOAA
  Speed:     h = 0, p = 0.09, ci = -0.09 0.01, Mean: -0.04
  Direction: h = 1, p = 0.04, ci = -0.75 -0.01, Mean: -0.38
  Pressure:  h = 1, p = 0.00, ci = 109.33 113.99, Mean: 111.66
  QI:        h = 1, p = 0.00, ci = 9.19 9.69, Mean: 9.44

EUMETSAT "VS" NWCSAF
  Speed:     h = 0, p = 0.60, ci = -0.02 0.04, Mean: 0.01
  Direction: h = 0, p = 0.82, ci = -0.24 0.30, Mean: 0.03
  Pressure:  h = 1, p = 0.00, ci = 135.30 139.49, Mean: 137.39
  QI:        h = 1, p = 0.00, ci = 4.56 5.06, Mean: 4.81

EUMETSAT "VS" Japan
  Speed:     h = 1, p = 0.00, ci = 0.02 0.09, Mean: 0.06
  Direction: h = 0, p = 0.06, ci = -0.61 0.01, Mean: -0.30
  Pressure:  h = 1, p = 0.00, ci = 55.76 60.57, Mean: 58.17
  QI:        h = 1, p = 0.00, ci = 7.25 7.85, Mean: 7.55

Korea "VS" China
  Speed:     h = 1, p = 0.00, ci = -0.75 -0.60, Mean: -0.67
  Direction: h = 0, p = 0.53, ci = -0.30 0.59, Mean: 0.14
  Pressure:  h = 1, p = 0.00, ci = 37.00 40.87, Mean: 38.93
  QI:        h = 1, p = 0.00, ci = -7.42 -6.99, Mean: -7.21

Korea "VS" NOAA
  Speed:     h = 1, p = 0.00, ci = -0.51 -0.40, Mean: -0.46
  Direction: h = 1, p = 0.01, ci = -0.83 -0.09, Mean: -0.46
  Pressure:  h = 1, p = 0.00, ci = 12.18 15.78, Mean: 13.98
  QI:        h = 1, p = 0.00, ci = 1.59 2.06, Mean: 1.83

Korea "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = -0.46 -0.36, Mean: -0.41
  Direction: h = 0, p = 0.65, ci = -0.27 0.17, Mean: -0.05
  Pressure:  h = 1, p = 0.00, ci = 38.88 40.55, Mean: 39.72
  QI:        h = 1, p = 0.00, ci = -3.01 -2.60, Mean: -2.80

Korea "VS" Japan
  Speed:     h = 1, p = 0.00, ci = -0.42 -0.31, Mean: -0.36
  Direction: h = 1, p = 0.01, ci = -0.66 -0.11, Mean: -0.38
  Pressure:  h = 1, p = 0.00, ci = -40.82 -38.20, Mean: -39.51
  QI:        h = 0, p = 0.66, ci = -0.34 0.22, Mean: -0.06

China "VS" NOAA
  Speed:     h = 1, p = 0.00, ci = 0.14 0.29, Mean: 0.22
```

```
  Direction: h = 1, p = 0.02, ci = -1.13 -0.08, Mean: -0.61
  Pressure:  h = 1, p = 0.00, ci = -26.62 -23.29, Mean: -24.95
  QI:        h = 1, p = 0.00, ci = 8.80 9.27, Mean: 9.03

China "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = 0.20 0.33, Mean: 0.27
  Direction: h = 0, p = 0.38, ci = -0.63 0.24, Mean: -0.19
  Pressure:  h = 0, p = 0.39, ci = -0.98 2.55, Mean: 0.78
  QI:        h = 1, p = 0.00, ci = 4.16 4.64, Mean: 4.40

China "VS" Japan
  Speed:     h = 1, p = 0.00, ci = 0.25 0.38, Mean: 0.31
  Direction: h = 1, p = 0.02, ci = -0.98 -0.07, Mean: -0.53
  Pressure:  h = 1, p = 0.00, ci = -80.46 -76.43, Mean: -78.45
  QI:        h = 1, p = 0.00, ci = 6.86 7.42, Mean: 7.14

NOAA "VS" NWCSAF
  Speed:     h = 1, p = 0.04, ci = 0.00 0.10, Mean: 0.05
  Direction: h = 1, p = 0.02, ci = 0.08 0.75, Mean: 0.41
  Pressure:  h = 1, p = 0.00, ci = 24.19 27.27, Mean: 25.73
  QI:        h = 1, p = 0.00, ci = -4.88 -4.38, Mean: -4.63

NOAA "VS" Japan
  Speed:     h = 1, p = 0.00, ci = 0.05 0.15, Mean: 0.10
  Direction: h = 0, p = 0.69, ci = -0.31 0.48, Mean: 0.08
  Pressure:  h = 1, p = 0.00, ci = -55.47 -51.52, Mean: -53.49
  QI:        h = 1, p = 0.00, ci = -2.18 -1.60, Mean: -1.89

NWCSAF "VS" Japan
  Speed:     h = 1, p = 0.01, ci = 0.01 0.08, Mean: 0.05
  Direction: h = 1, p = 0.02, ci = -0.60 -0.06, Mean: -0.33
  Pressure:  h = 1, p = 0.00, ci = -80.46 -78.00, Mean: -79.23
  QI:        h = 1, p = 0.00, ci = 2.43 3.05, Mean: 2.74
```

Experiment 3 t-test Results

QI no forecast: 370

```
EUMETSAT "VS" Korea
  Speed:     h = 0, p = 0.84, ci = -0.15 0.19, Mean: 0.02
  Direction: h = 0, p = 0.17, ci = -0.79 4.46, Mean: 1.83
  Pressure:  h = 1, p = 0.00, ci = 82.56 104.22, Mean: 93.39
  QI:        h = 1, p = 0.00, ci = 2.92 4.90, Mean: 3.91

EUMETSAT "VS" Brazil
  Speed:     h = 1, p = 0.00, ci = -1.07 -0.32, Mean: -0.69
  Direction: h = 0, p = 0.70, ci = -4.19 6.25, Mean: 1.03
  Pressure:  h = 1, p = 0.00, ci = 106.27 126.87, Mean: 116.57
  QI:        h = 1, p = 0.00, ci = 10.85 14.55, Mean: 12.70

EUMETSAT "VS" NOAA
  Speed:     h = 0, p = 0.37, ci = -0.24 0.09, Mean: -0.08
  Direction: h = 0, p = 0.08, ci = -0.32 5.68, Mean: 2.68
  Pressure:  h = 1, p = 0.00, ci = 91.46 112.30, Mean: 101.88
  QI:        h = 1, p = 0.02, ci = 0.28 3.35, Mean: 1.81

EUMETSAT "VS" NWCSAF
  Speed:     h = 1, p = 0.01, ci = 0.03 0.23, Mean: 0.13
  Direction: h = 0, p = 0.14, ci = -0.45 3.17, Mean: 1.36
  Pressure:  h = 1, p = 0.00, ci = 122.95 142.70, Mean: 132.82
  QI:        h = 1, p = 0.00, ci = 2.49 5.38, Mean: 3.94
```

```
EUMETSAT "VS" Japan
  Speed:     h = 0, p = 0.83, ci = -0.12 0.14, Mean: 0.01
  Direction: h = 0, p = 0.09, ci = -0.39 5.98, Mean: 2.79
  Pressure:  h = 1, p = 0.00, ci = 36.05 60.81, Mean: 48.43
  QI:        h = 1, p = 0.00, ci = -3.47 -0.99, Mean: -2.23

Korea "VS" Brazil
  Speed:     h = 1, p = 0.00, ci = -1.11 -0.32, Mean: -0.71
  Direction: h = 0, p = 0.75, ci = -5.82 4.21, Mean: -0.80
  Pressure:  h = 1, p = 0.00, ci = 16.50 29.87, Mean: 23.18
  QI:        h = 1, p = 0.00, ci = 6.97 10.60, Mean: 8.79

Korea "VS" NOAA
  Speed:     h = 0, p = 0.35, ci = -0.29 0.10, Mean: -0.09
  Direction: h = 0, p = 0.37, ci = -1.01 2.71, Mean: 0.85
  Pressure:  h = 0, p = 0.08, ci = -1.00 17.98, Mean: 8.49
  QI:        h = 1, p = 0.01, ci = -3.64 -0.56, Mean: -2.10

Korea "VS" NWCSAF
  Speed:     h = 0, p = 0.16, ci = -0.05 0.27, Mean: 0.11
  Direction: h = 0, p = 0.63, ci = -2.39 1.45, Mean: -0.47
  Pressure:  h = 1, p = 0.00, ci = 33.70 45.17, Mean: 39.43
  QI:        h = 0, p = 0.97, ci = -1.38 1.43, Mean: 0.02

Korea "VS" Japan
  Speed:     h = 0, p = 0.98, ci = -0.19 0.19, Mean: -0.00
  Direction: h = 0, p = 0.30, ci = -0.85 2.77, Mean: 0.96
  Pressure:  h = 1, p = 0.00, ci = -52.99 -36.93, Mean: -44.96
  QI:        h = 1, p = 0.00, ci = -7.37 -4.91, Mean: -6.14

Brazil "VS" NOAA
  Speed:     h = 1, p = 0.00, ci = 0.25 0.99, Mean: 0.62
  Direction: h = 0, p = 0.48, ci = -2.92 6.23, Mean: 1.65
  Pressure:  h = 1, p = 0.00, ci = -21.13 -8.26, Mean: -14.69
  QI:        h = 1, p = 0.00, ci = -12.90 -8.87, Mean: -10.88

Brazil "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = 0.45 1.20, Mean: 0.82
  Direction: h = 0, p = 0.90, ci = -5.05 5.72, Mean: 0.34
  Pressure:  h = 1, p = 0.00, ci = 12.56 19.95, Mean: 16.25
  QI:        h = 1, p = 0.00, ci = -10.80 -6.72, Mean: -8.76

Brazil "VS" Japan
  Speed:     h = 1, p = 0.00, ci = 0.35 1.07, Mean: 0.71
  Direction: h = 0, p = 0.47, ci = -3.02 6.55, Mean: 1.77
  Pressure:  h = 1, p = 0.00, ci = -73.57 -62.71, Mean: -68.14
  QI:        h = 1, p = 0.00, ci = -16.82 -13.04, Mean: -14.93

NOAA "VS" NWCSAF
  Speed:     h = 1, p = 0.01, ci = 0.05 0.36, Mean: 0.21
  Direction: h = 0, p = 0.33, ci = -3.95 1.31, Mean: -1.32
  Pressure:  h = 1, p = 0.00, ci = 24.00 37.89, Mean: 30.94
  QI:        h = 1, p = 0.02, ci = 0.32 3.93, Mean: 2.12

NOAA "VS" Japan
  Speed:     h = 0, p = 0.20, ci = -0.05 0.23, Mean: 0.09
  Direction: h = 0, p = 0.79, ci = -0.72 0.95, Mean: 0.11
  Pressure:  h = 1, p = 0.00, ci = -62.14 -44.76, Mean: -53.45
  QI:        h = 1, p = 0.00, ci = -5.46 -2.63, Mean: -4.04
```

```
NWCSAF "VS" Japan
  Speed:     h = 1, p = 0.05, ci = -0.23 -0.00, Mean: -0.12
  Direction: h = 0, p = 0.28, ci = -1.15 4.01, Mean: 1.43
  Pressure:  h = 1, p = 0.00, ci = -90.21 -78.57, Mean: -84.39
  QI:        h = 1, p = 0.00, ci = -7.72 -4.61, Mean: -6.17
```

QI with forecast: 409

```
EUMETSAT "VS" Korea
  Speed:     h = 0, p = 0.79, ci = -0.25 0.32, Mean: 0.04
  Direction: h = 0, p = 0.58, ci = -0.81 1.44, Mean: 0.32
  Pressure:  h = 1, p = 0.00, ci = 103.89 142.39, Mean: 123.14
  QI:        h = 1, p = 0.00, ci = 12.31 15.24, Mean: 13.77

EUMETSAT "VS" China
  Speed:     h = 1, p = 0.01, ci = -1.04 -0.13, Mean: -0.58
  Direction: h = 0, p = 0.69, ci = -5.09 3.37, Mean: -0.86
  Pressure:  h = 1, p = 0.00, ci = 90.82 129.52, Mean: 110.17
  QI:        h = 0, p = 0.52, ci = -1.15 2.25, Mean: 0.55

EUMETSAT "VS" NOAA
  Speed:     h = 1, p = 0.00, ci = -0.58 -0.12, Mean: -0.35
  Direction: h = 0, p = 0.82, ci = -1.01 1.27, Mean: 0.13
  Pressure:  h = 1, p = 0.00, ci = 93.31 127.06, Mean: 110.19
  QI:        h = 1, p = 0.00, ci = 14.32 18.16, Mean: 16.24

EUMETSAT "VS" NWCSAF
  Speed:     h = 0, p = 0.39, ci = -0.09 0.23, Mean: 0.07
  Direction: h = 0, p = 0.31, ci = -0.44 1.38, Mean: 0.47
  Pressure:  h = 1, p = 0.00, ci = 140.12 174.84, Mean: 157.48
  QI:        h = 1, p = 0.00, ci = 6.61 10.02, Mean: 8.32

EUMETSAT "VS" Japan
  Speed:     h = 0, p = 0.08, ci = -0.38 0.02, Mean: -0.18
  Direction: h = 0, p = 0.46, ci = -1.49 0.67, Mean: -0.41
  Pressure:  h = 1, p = 0.00, ci = 88.86 124.32, Mean: 106.59
  QI:        h = 1, p = 0.00, ci = 5.83 9.44, Mean: 7.64

Korea "VS" China
  Speed:     h = 1, p = 0.01, ci = -1.09 -0.15, Mean: -0.62
  Direction: h = 0, p = 0.59, ci = -5.45 3.10, Mean: -1.18
  Pressure:  h = 0, p = 0.05, ci = -26.03 0.09, Mean: -12.97
  QI:        h = 1, p = 0.00, ci = -14.86 -11.58, Mean: -13.22

Korea "VS" NOAA
  Speed:     h = 1, p = 0.01, ci = -0.70 -0.08, Mean: -0.39
  Direction: h = 0, p = 0.78, ci = -1.50 1.12, Mean: -0.19
  Pressure:  h = 1, p = 0.03, ci = -24.42 -1.49, Mean: -12.96
  QI:        h = 1, p = 0.01, ci = 0.54 4.40, Mean: 2.47

Korea "VS" NWCSAF
  Speed:     h = 0, p = 0.80, ci = -0.22 0.28, Mean: 0.03
  Direction: h = 0, p = 0.72, ci = -0.70 1.00, Mean: 0.15
  Pressure:  h = 1, p = 0.00, ci = 26.99 41.68, Mean: 34.34
  QI:        h = 1, p = 0.00, ci = -7.03 -3.88, Mean: -5.45

Korea "VS" Japan
  Speed:     h = 0, p = 0.15, ci = -0.51 0.08, Mean: -0.22
  Direction: h = 0, p = 0.24, ci = -1.95 0.49, Mean: -0.73
  Pressure:  h = 1, p = 0.00, ci = -25.09 -8.02, Mean: -16.55
  QI:        h = 1, p = 0.00, ci = -7.66 -4.61, Mean: -6.14
```

```
China "VS" NOAA
  Speed:     h = 0, p = 0.37, ci = -0.28 0.74, Mean: 0.23
  Direction: h = 0, p = 0.64, ci = -3.15 5.13, Mean: 0.99
  Pressure:  h = 0, p = 1.00, ci = -11.71 11.74, Mean: 0.02
  QI:        h = 1, p = 0.00, ci = 13.66 17.72, Mean: 15.69

China "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = 0.20 1.11, Mean: 0.65
  Direction: h = 0, p = 0.54, ci = -2.90 5.56, Mean: 1.33
  Pressure:  h = 1, p = 0.00, ci = 35.86 58.75, Mean: 47.31
  QI:        h = 1, p = 0.00, ci = 5.94 9.59, Mean: 7.77

China "VS" Japan
  Speed:     h = 0, p = 0.10, ci = -0.08 0.88, Mean: 0.40
  Direction: h = 0, p = 0.84, ci = -3.90 4.80, Mean: 0.45
  Pressure:  h = 0, p = 0.54, ci = -15.16 8.00, Mean: -3.58
  QI:        h = 1, p = 0.00, ci = 5.25 8.92, Mean: 7.08

NOAA "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = 0.21 0.63, Mean: 0.42
  Direction: h = 0, p = 0.54, ci = -0.76 1.45, Mean: 0.34
  Pressure:  h = 1, p = 0.00, ci = 39.10 55.48, Mean: 47.29
  QI:        h = 1, p = 0.00, ci = -10.04 -5.80, Mean: -7.92

NOAA "VS" Japan
  Speed:     h = 0, p = 0.08, ci = -0.02 0.36, Mean: 0.17
  Direction: h = 0, p = 0.34, ci = -1.64 0.57, Mean: -0.54
  Pressure:  h = 0, p = 0.36, ci = -11.31 4.12, Mean: -3.60
  QI:        h = 1, p = 0.00, ci = -10.39 -6.82, Mean: -8.61

NWCSAF "VS" Japan
  Speed:     h = 1, p = 0.00, ci = -0.41 -0.09, Mean: -0.25
  Direction: h = 0, p = 0.08, ci = -1.87 0.11, Mean: -0.88
  Pressure:  h = 1, p = 0.00, ci = -56.25 -45.53, Mean: -50.89
  QI:        h = 0, p = 0.45, ci = -2.45 1.08, Mean: -0.68
```

Experiment 4 t-test Results

QI without forecast: 9942

```
EUMETSAT "VS" Korea
  Speed:     h = 1, p = 0.00, ci = 0.15 0.22, Mean: 0.18
  Direction: h = 0, p = 0.09, ci = -0.06 0.80, Mean: 0.37
  Pressure:  h = 1, p = 0.00, ci = 53.18 57.50, Mean: 55.34
  QI:        h = 1, p = 0.00, ci = 2.09 2.48, Mean: 2.28

EUMETSAT "VS" Brazil
  Speed:     h = 1, p = 0.00, ci = -0.76 -0.63, Mean: -0.70
  Direction: h = 1, p = 0.00, ci = -4.33 -2.08, Mean: -3.20
  Pressure:  h = 1, p = 0.00, ci = 57.07 61.79, Mean: 59.43
  QI:        h = 1, p = 0.00, ci = 11.61 12.36, Mean: 11.99

EUMETSAT "VS" NOAA
  Speed:     h = 1, p = 0.00, ci = -0.20 -0.14, Mean: -0.17
  Direction: h = 0, p = 0.10, ci = -1.04 0.09, Mean: -0.47
  Pressure:  h = 1, p = 0.00, ci = 77.83 82.45, Mean: 80.14
  QI:        h = 1, p = 0.00, ci = -1.76 -1.21, Mean: -1.49

EUMETSAT "VS" NWCSAF
```

```
  Speed:     h = 1, p = 0.04, ci = -0.05 -0.00, Mean: -0.02
  Direction: h = 0, p = 0.20, ci = -0.76 0.16, Mean: -0.30
  Pressure:  h = 1, p = 0.00, ci = -23.16 -20.38, Mean: -21.77
  QI:        h = 1, p = 0.01, ci = -0.69 -0.10, Mean: -0.39

EUMETSAT "VS" Japan
  Speed:     h = 1, p = 0.01, ci = 0.01 0.06, Mean: 0.03
  Direction: h = 0, p = 0.18, ci = -0.85 0.16, Mean: -0.34
  Pressure:  h = 1, p = 0.00, ci = 50.07 53.34, Mean: 51.71
  QI:        h = 1, p = 0.00, ci = -4.52 -4.04, Mean: -4.28

Korea "VS" Brazil
  Speed:     h = 1, p = 0.00, ci = -0.95 -0.81, Mean: -0.88
  Direction: h = 1, p = 0.00, ci = -4.68 -2.47, Mean: -3.57
  Pressure:  h = 1, p = 0.00, ci = 2.54 5.65, Mean: 4.10
  QI:        h = 1, p = 0.00, ci = 9.34 10.06, Mean: 9.70

Korea "VS" NOAA
  Speed:     h = 1, p = 0.00, ci = -0.40 -0.31, Mean: -0.36
  Direction: h = 1, p = 0.01, ci = -1.50 -0.19, Mean: -0.84
  Pressure:  h = 1, p = 0.00, ci = 22.37 27.23, Mean: 24.80
  QI:        h = 1, p = 0.00, ci = -4.03 -3.51, Mean: -3.77

Korea "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = -0.24 -0.17, Mean: -0.21
  Direction: h = 1, p = 0.01, ci = -1.17 -0.17, Mean: -0.67
  Pressure:  h = 1, p = 0.00, ci = -79.39 -74.84, Mean: -77.11
  QI:        h = 1, p = 0.00, ci = -2.97 -2.39, Mean: -2.68

Korea "VS" Japan
  Speed:     h = 1, p = 0.00, ci = -0.19 -0.11, Mean: -0.15
  Direction: h = 1, p = 0.01, ci = -1.27 -0.16, Mean: -0.72
  Pressure:  h = 1, p = 0.00, ci = -6.09 -1.17, Mean: -3.63
  QI:        h = 1, p = 0.00, ci = -6.80 -6.33, Mean: -6.57

Brazil "VS" NOAA
  Speed:     h = 1, p = 0.00, ci = 0.45 0.59, Mean: 0.52
  Direction: h = 1, p = 0.00, ci = 1.53 3.93, Mean: 2.73
  Pressure:  h = 1, p = 0.00, ci = 18.14 23.26, Mean: 20.70
  QI:        h = 1, p = 0.00, ci = -13.88 -13.06, Mean: -13.47

Brazil "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = 0.60 0.74, Mean: 0.67
  Direction: h = 1, p = 0.00, ci = 1.75 4.06, Mean: 2.90
  Pressure:  h = 1, p = 0.00, ci = -83.74 -78.67, Mean: -81.21
  QI:        h = 1, p = 0.00, ci = -12.79 -11.97, Mean: -12.38

Brazil "VS" Japan
  Speed:     h = 1, p = 0.00, ci = 0.66 0.80, Mean: 0.73
  Direction: h = 1, p = 0.00, ci = 1.67 4.05, Mean: 2.86
  Pressure:  h = 1, p = 0.00, ci = -10.40 -5.06, Mean: -7.73
  QI:        h = 1, p = 0.00, ci = -16.66 -15.88, Mean: -16.27

NOAA "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = 0.12 0.18, Mean: 0.15
  Direction: h = 0, p = 0.55, ci = -0.39 0.73, Mean: 0.17
  Pressure:  h = 1, p = 0.00, ci = -104.51 -99.31, Mean: -101.91
  QI:        h = 1, p = 0.00, ci = 0.75 1.43, Mean: 1.09

NOAA "VS" Japan
  Speed:     h = 1, p = 0.00, ci = 0.17 0.23, Mean: 0.20
```

```
  Direction: h = 0, p = 0.55, ci = -0.29 0.55, Mean: 0.13
  Pressure:  h = 1, p = 0.00, ci = -31.08 -25.78, Mean: -28.43
  QI:        h = 1, p = 0.00, ci = -3.07 -2.52, Mean: -2.80

NWCSAF "VS" Japan
  Speed:     h = 1, p = 0.00, ci = 0.03 0.08, Mean: 0.06
  Direction: h = 0, p = 0.87, ci = -0.55 0.47, Mean: -0.04
  Pressure:  h = 1, p = 0.00, ci = 71.22 75.73, Mean: 73.48
  QI:        h = 1, p = 0.00, ci = -4.19 -3.58, Mean: -3.89
```

QI with forecast: 10285

```
EUMETSAT "VS" Korea
  Speed:     h = 1, p = 0.00, ci = 0.17 0.24, Mean: 0.20
  Direction: h = 0, p = 0.40, ci = -0.43 0.17, Mean: -0.13
  Pressure:  h = 1, p = 0.00, ci = 52.03 56.22, Mean: 54.12
  QI:        h = 1, p = 0.00, ci = 13.20 13.62, Mean: 13.41

EUMETSAT "VS" China
  Speed:     h = 1, p = 0.00, ci = 0.26 0.38, Mean: 0.32
  Direction: h = 1, p = 0.00, ci = 0.84 2.05, Mean: 1.44
  Pressure:  h = 1, p = 0.00, ci = 87.20 92.25, Mean: 89.73
  QI:        h = 1, p = 0.00, ci = 3.01 3.46, Mean: 3.24

EUMETSAT "VS" NOAA
  Speed:     h = 1, p = 0.00, ci = -0.14 -0.08, Mean: -0.11
  Direction: h = 0, p = 0.19, ci = -0.12 0.62, Mean: 0.25
  Pressure:  h = 1, p = 0.00, ci = 70.03 74.09, Mean: 72.06
  QI:        h = 1, p = 0.00, ci = 12.50 12.97, Mean: 12.73

EUMETSAT "VS" NWCSAF
  Speed:     h = 0, p = 0.34, ci = -0.01 0.03, Mean: 0.01
  Direction: h = 1, p = 0.01, ci = 0.09 0.68, Mean: 0.39
  Pressure:  h = 1, p = 0.00, ci = -21.86 -19.23, Mean: -20.54
  QI:        h = 1, p = 0.00, ci = 5.67 6.19, Mean: 5.93

EUMETSAT "VS" Japan
  Speed:     h = 1, p = 0.00, ci = 0.04 0.09, Mean: 0.06
  Direction: h = 0, p = 0.42, ci = -0.44 0.18, Mean: -0.13
  Pressure:  h = 1, p = 0.00, ci = 52.30 55.44, Mean: 53.87
  QI:        h = 1, p = 0.00, ci = 5.45 5.89, Mean: 5.67

Korea "VS" China
  Speed:     h = 1, p = 0.00, ci = 0.05 0.18, Mean: 0.12
  Direction: h = 1, p = 0.00, ci = 1.00 2.14, Mean: 1.57
  Pressure:  h = 1, p = 0.00, ci = 33.69 37.52, Mean: 35.61
  QI:        h = 1, p = 0.00, ci = -10.38 -9.96, Mean: -10.17

Korea "VS" NOAA
  Speed:     h = 1, p = 0.00, ci = -0.35 -0.27, Mean: -0.31
  Direction: h = 0, p = 0.05, ci = -0.00 0.76, Mean: 0.38
  Pressure:  h = 1, p = 0.00, ci = 15.92 19.95, Mean: 17.94
  QI:        h = 1, p = 0.00, ci = -0.91 -0.43, Mean: -0.67

Korea "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = -0.23 -0.16, Mean: -0.19
  Direction: h = 1, p = 0.00, ci = 0.21 0.82, Mean: 0.51
  Pressure:  h = 1, p = 0.00, ci = -76.87 -72.46, Mean: -74.67
  QI:        h = 1, p = 0.00, ci = -7.73 -7.22, Mean: -7.48

Korea "VS" Japan
```

```
  Speed:     h = 1, p = 0.00, ci = -0.18 -0.10, Mean: -0.14
  Direction: h = 0, p = 0.99, ci = -0.34 0.34, Mean: 0.00
  Pressure:  h = 0, p = 0.84, ci = -2.74 2.24, Mean: -0.25
  QI:        h = 1, p = 0.00, ci = -7.96 -7.52, Mean: -7.74

China "VS" NOAA
  Speed:     h = 1, p = 0.00, ci = -0.49 -0.37, Mean: -0.43
  Direction: h = 1, p = 0.00, ci = -1.83 -0.56, Mean: -1.19
  Pressure:  h = 1, p = 0.00, ci = -19.94 -15.40, Mean: -17.67
  QI:        h = 1, p = 0.00, ci = 9.25 9.75, Mean: 9.50

China "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = -0.37 -0.25, Mean: -0.31
  Direction: h = 1, p = 0.00, ci = -1.64 -0.48, Mean: -1.06
  Pressure:  h = 1, p = 0.00, ci = -112.87 -107.67, Mean: -110.27
  QI:        h = 1, p = 0.00, ci = 2.43 2.96, Mean: 2.69

China "VS" Japan
  Speed:     h = 1, p = 0.00, ci = -0.32 -0.20, Mean: -0.26
  Direction: h = 1, p = 0.00, ci = -2.18 -0.96, Mean: -1.57
  Pressure:  h = 1, p = 0.00, ci = -38.63 -33.08, Mean: -35.86
  QI:        h = 1, p = 0.00, ci = 2.21 2.66, Mean: 2.44

NOAA "VS" NWCSAF
  Speed:     h = 1, p = 0.00, ci = 0.09 0.15, Mean: 0.12
  Direction: h = 0, p = 0.39, ci = -0.17 0.44, Mean: 0.14
  Pressure:  h = 1, p = 0.00, ci = -94.89 -90.31, Mean: -92.60
  QI:        h = 1, p = 0.00, ci = -7.08 -6.53, Mean: -6.80

NOAA "VS" Japan
  Speed:     h = 1, p = 0.00, ci = 0.14 0.19, Mean: 0.17
  Direction: h = 1, p = 0.00, ci = -0.62 -0.13, Mean: -0.38
  Pressure:  h = 1, p = 0.00, ci = -20.52 -15.85, Mean: -18.19
  QI:        h = 1, p = 0.00, ci = -7.29 -6.84, Mean: -7.06

NWCSAF "VS" Japan
  Speed:     h = 1, p = 0.00, ci = 0.02 0.08, Mean: 0.05
  Direction: h = 1, p = 0.00, ci = -0.75 -0.28, Mean: -0.51
  Pressure:  h = 1, p = 0.00, ci = 72.35 76.48, Mean: 74.42
  QI:        h = 0, p = 0.05, ci = -0.52 0.01, Mean: -0.26
```

16. Appendix C: Best Fit Height Algorithm

Histogram of pressure differences (AMV – model background) for each producer. Additional plots may include histograms of the number of best-fit heights by latitude, by longitude and a geographic distribution of the pressure differences to depict regions where the heights are generally higher or lower.

Finds the background model best-fit pressure associated with the AMV. The model best-fit pressure is the height (in pressure units) where the vector difference between the observed AMV and model background is a minimum. This calculation may only work approximately 1/3 of the time (Salonen et al. 2012).

The code logic:

a) Look for the model pressure levels within the troposphere up to 150 hPa (tunable parameter) above and below the AMV.
b) Using a parabolic fit, find the model pressure level with the minimum vector difference within vertical search limits in (a).
c) The minimum vector difference must be less than or equal to 4 ms^{-1}
d) The minimum vector difference must be at least 2 ms^{-1} smaller than the vector difference +/- 100 hPa from the best-fit pressure level. This is therefore dependent on the model vertical resolution. More resolution maybe 2 ms^{-1} is too demanding.

Histogram distribution binned by longitude, latitude, pressure difference, and a geographic plot. Interesting, but not too surprising, there is a pattern in the geographic distribution. We are looking more into regions where lower best fits are adjacent to higher best fits (for example, south of Africa for CMA). Pie chart shows fraction of AMV with found best-fit, not constrained (another min was found close by), or did not meet minimum vector difference limits (which is 4).

17. Appendix D: Best Fit Speed and Vector Difference

Experiment 2 Best Fit speed difference

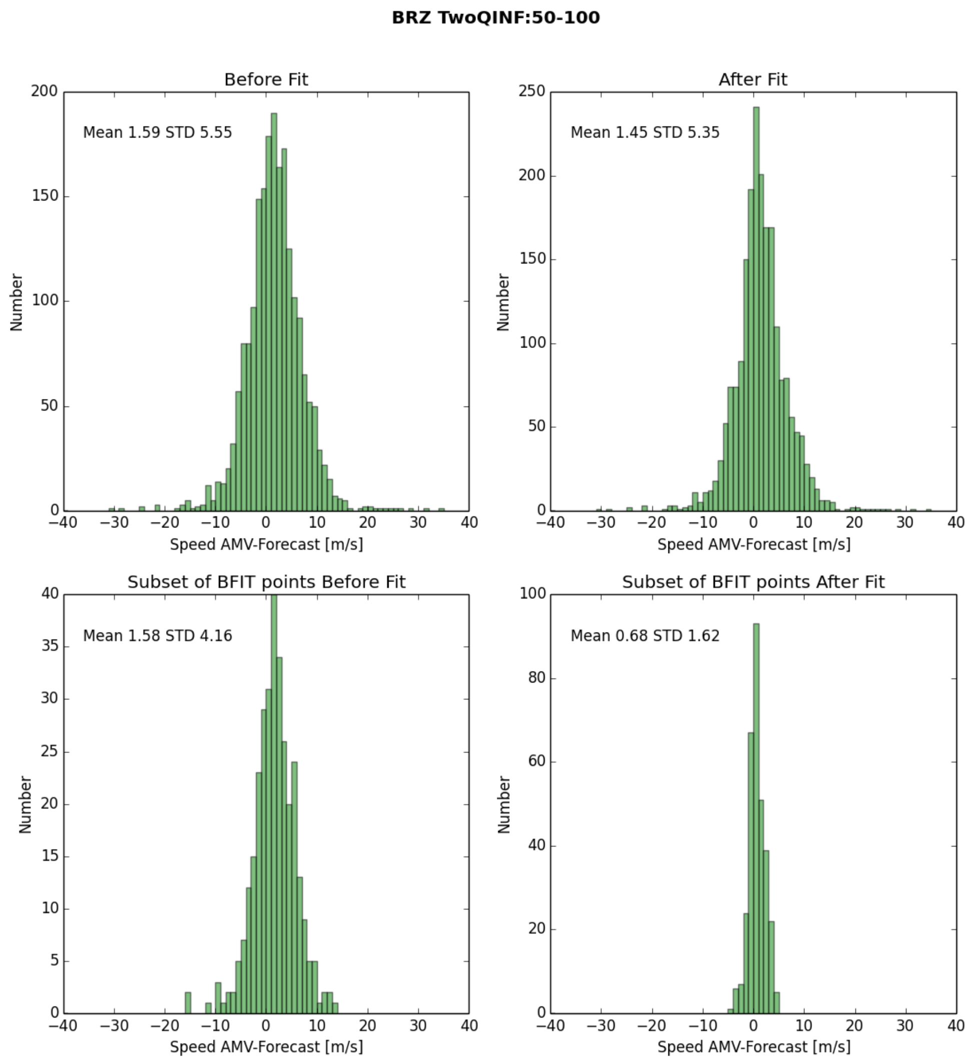

Figure 129: BRZ: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

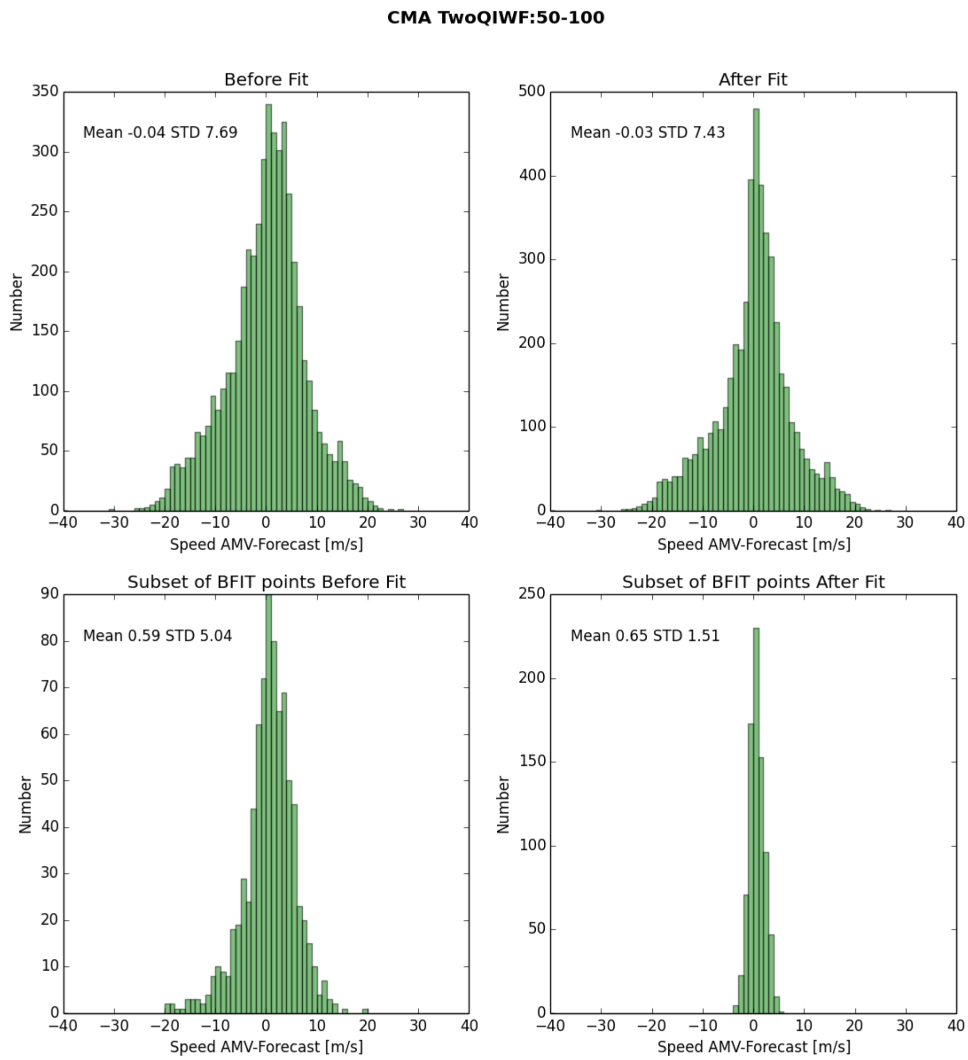

Figure 130: CMA: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

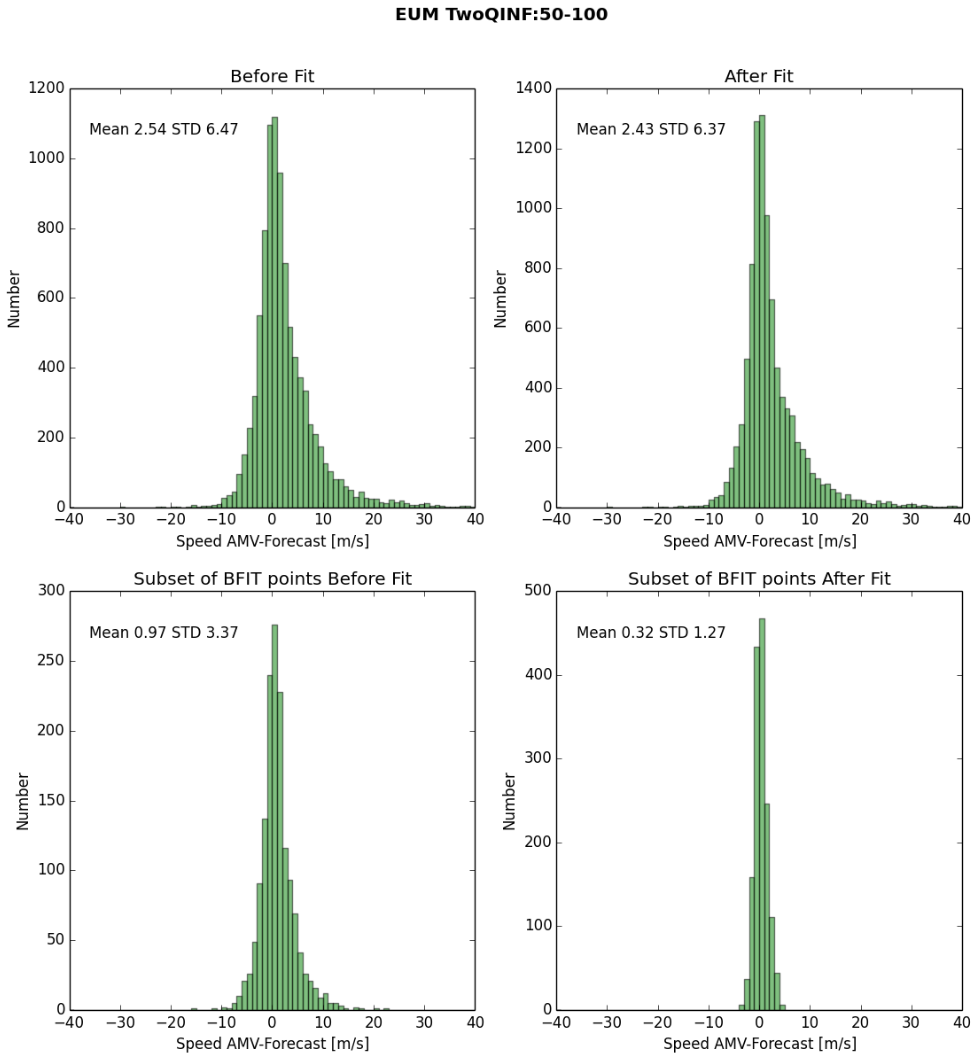

Figure 131: EUM: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

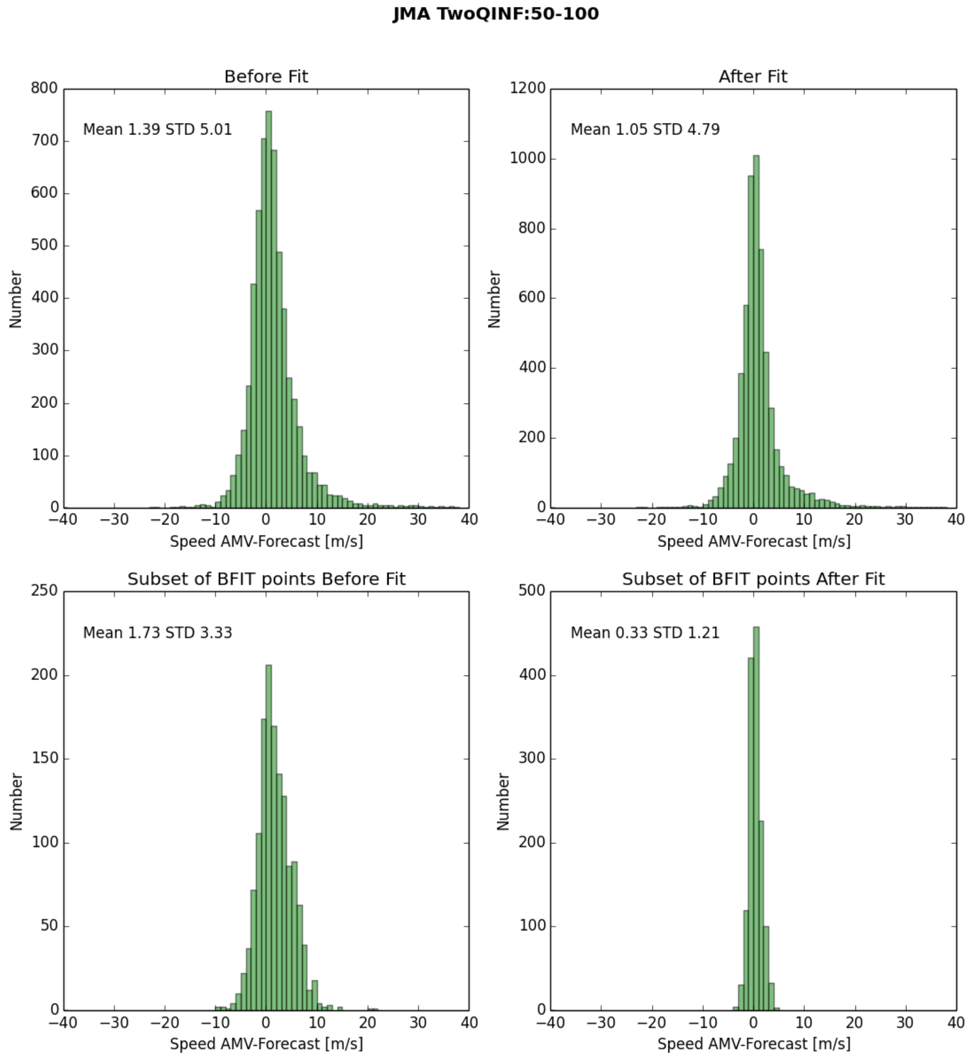

Figure 132: JMA: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

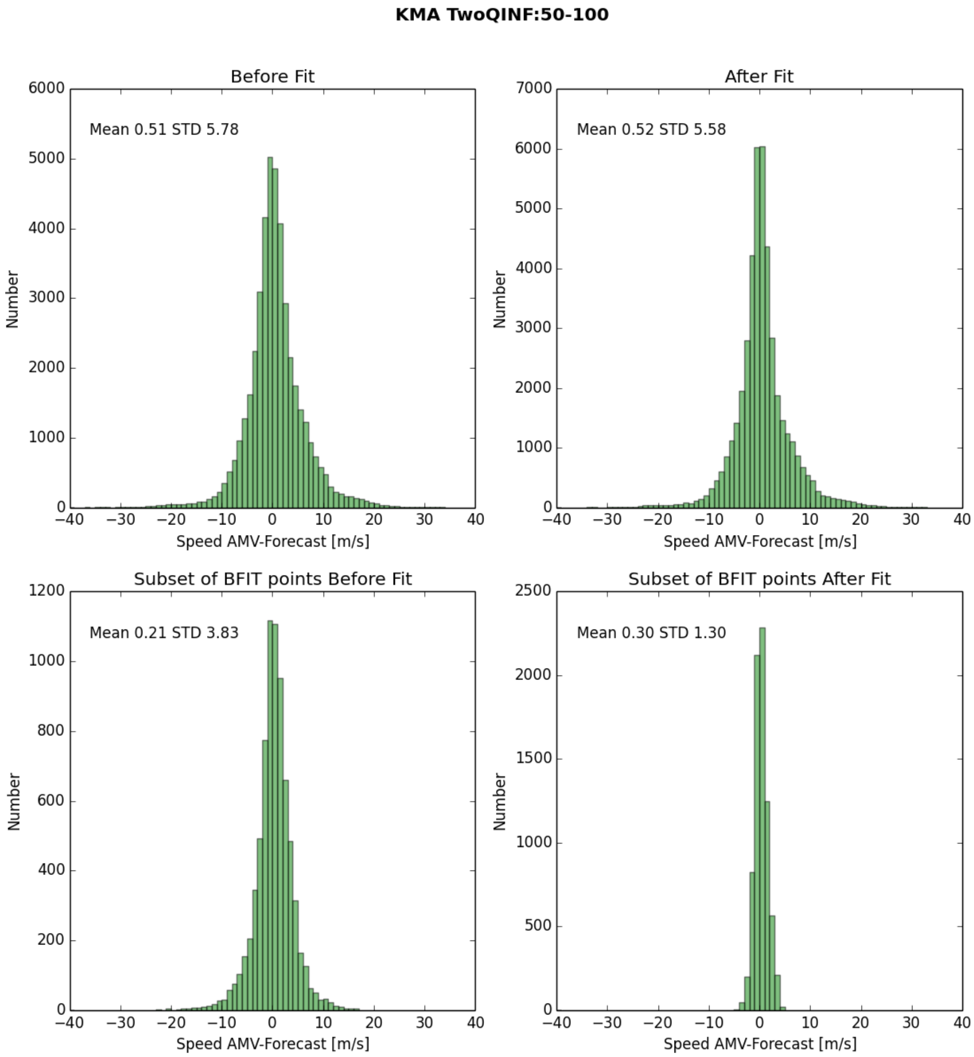

Figure 133: KMA: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

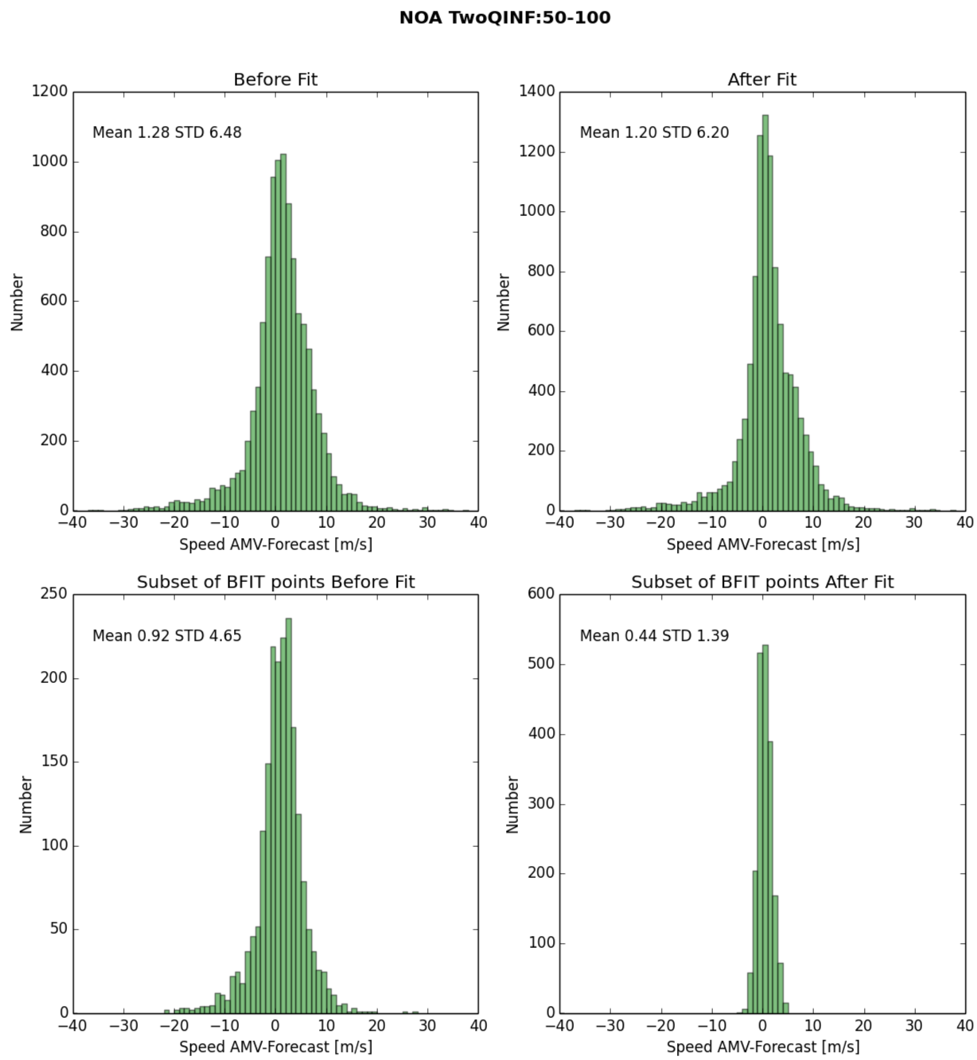

Figure 134: NOA: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

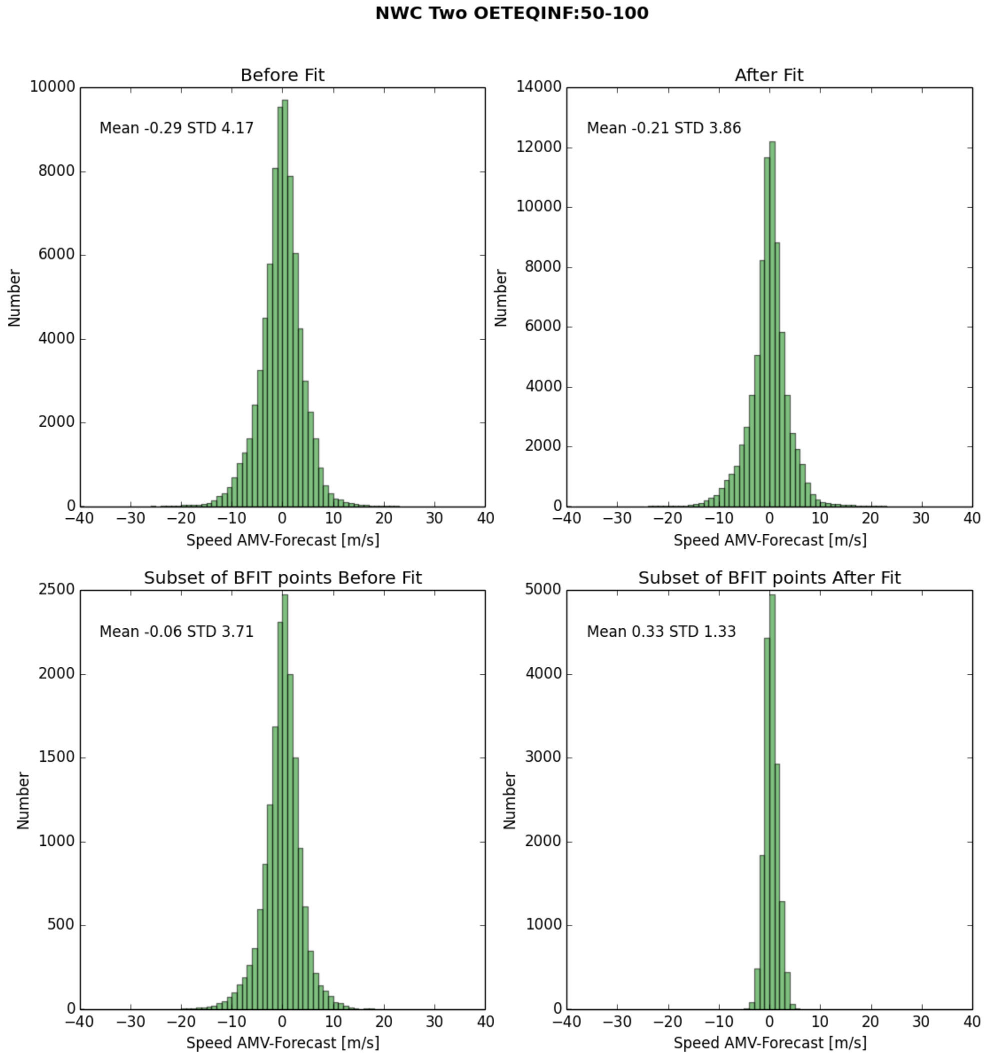

Figure 135: NWC: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

Experiment 2 Best Fit vector difference

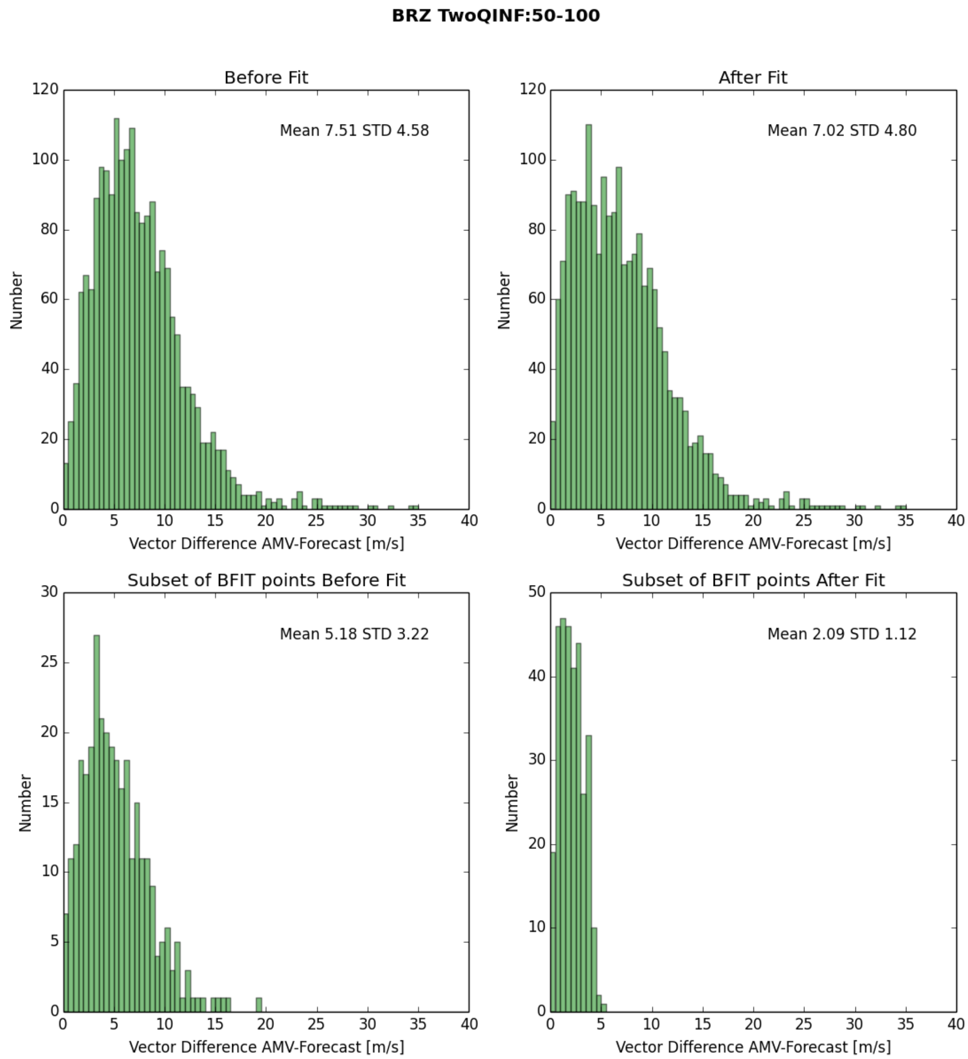

Figure 136: BRZ: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

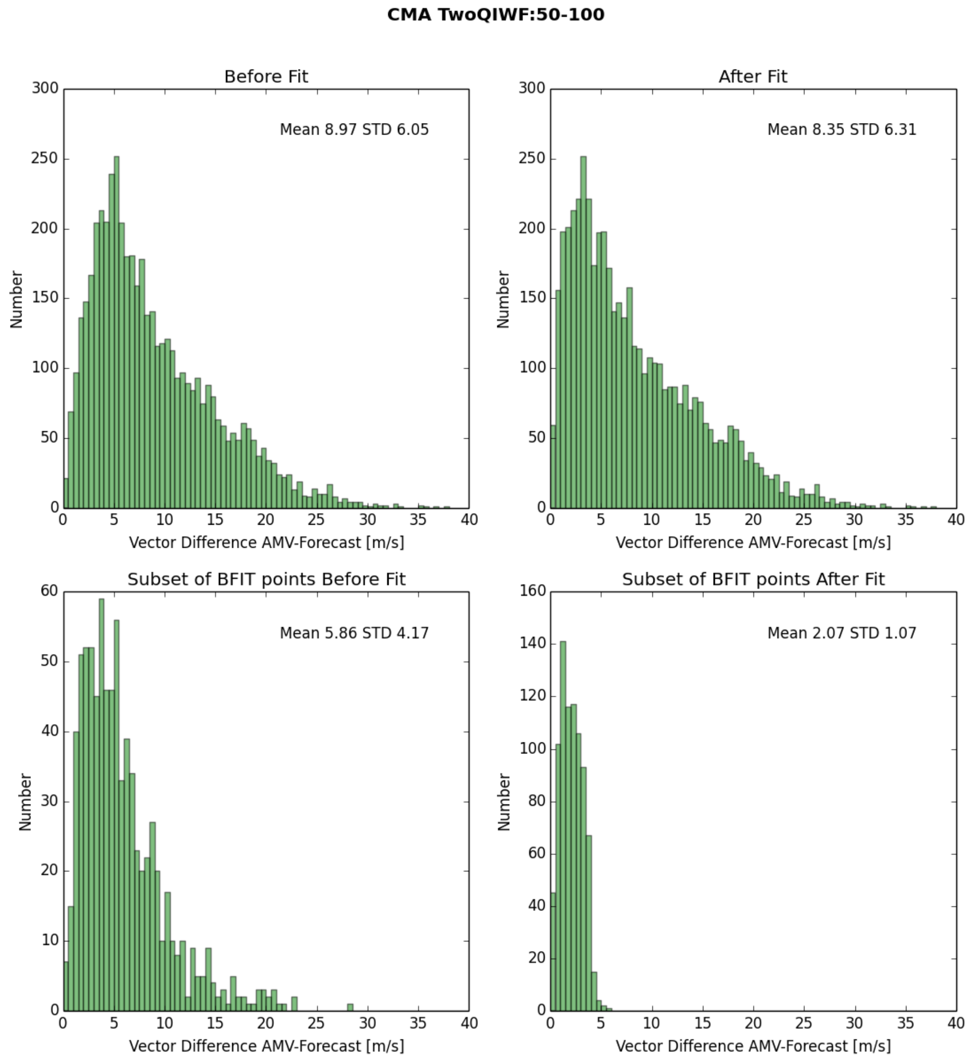

Figure 137: CMA: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

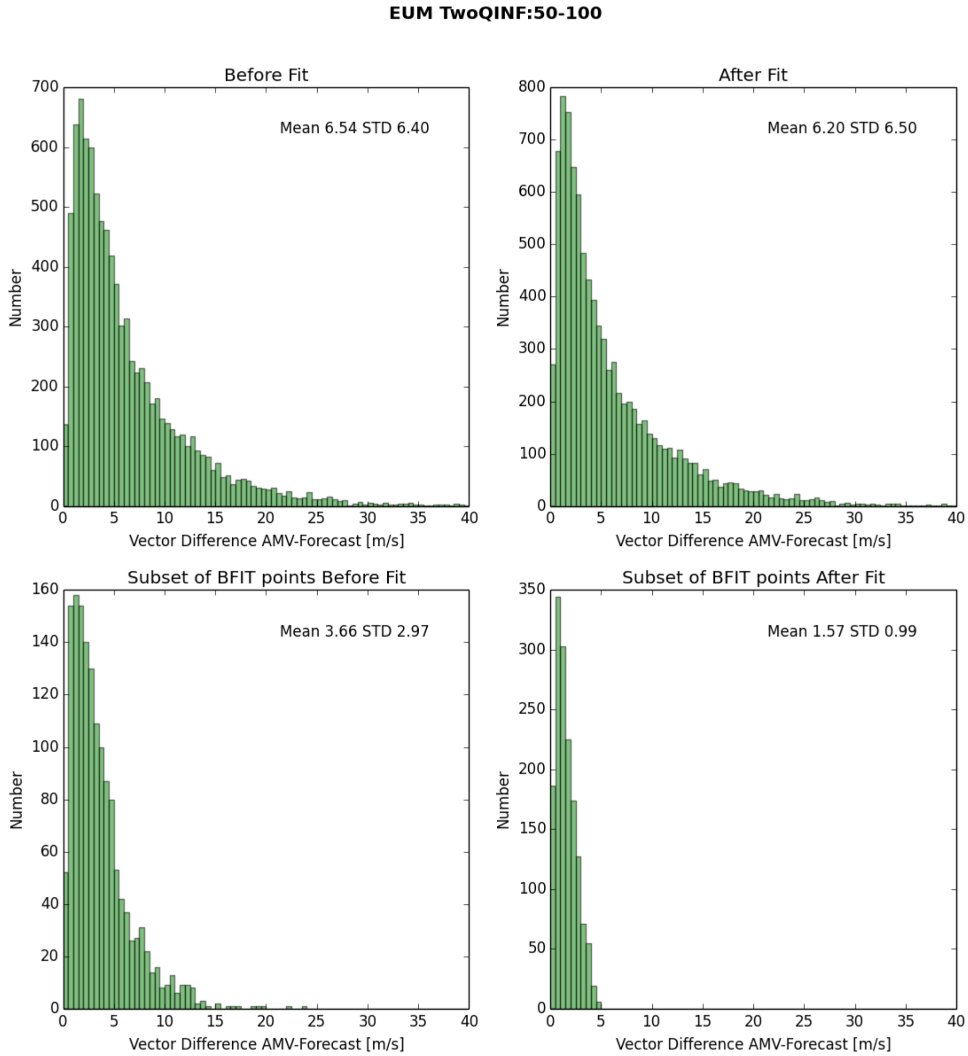

Figure 138: EUM: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

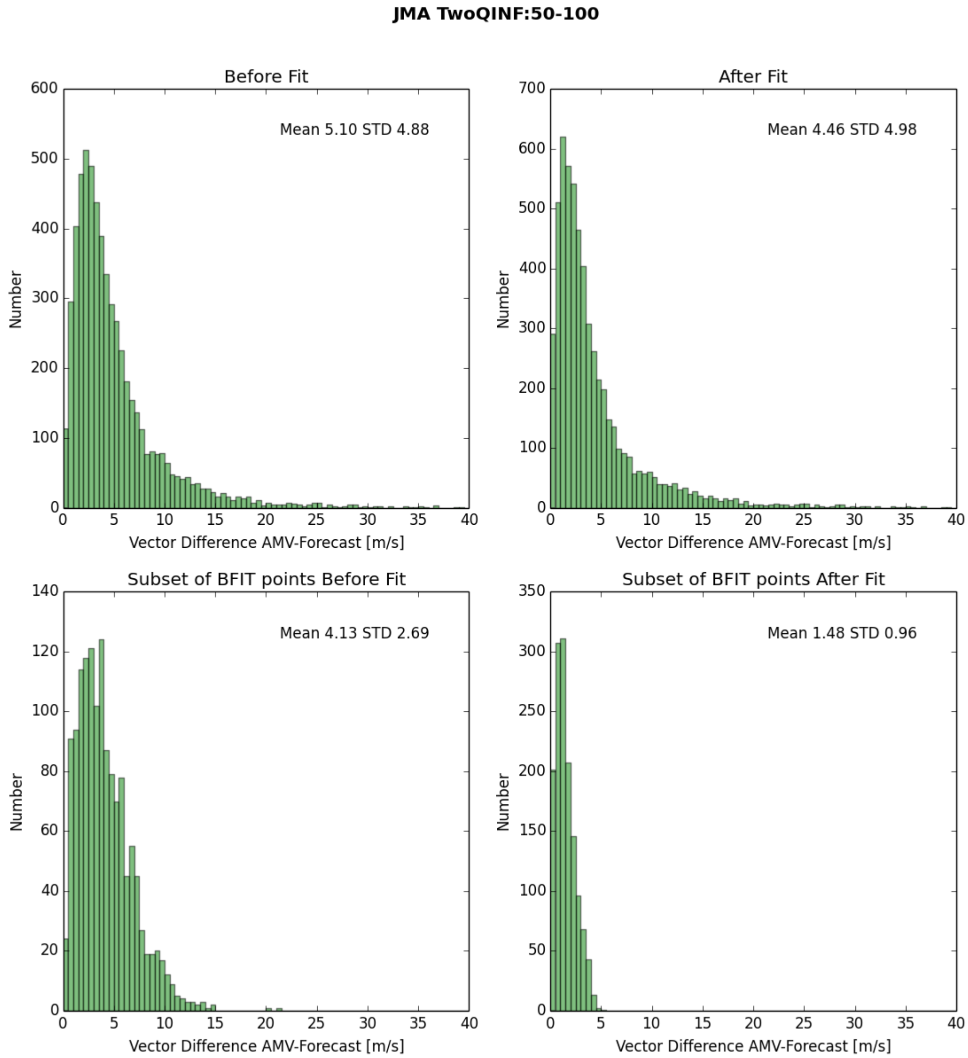

Figure 139: JMA: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

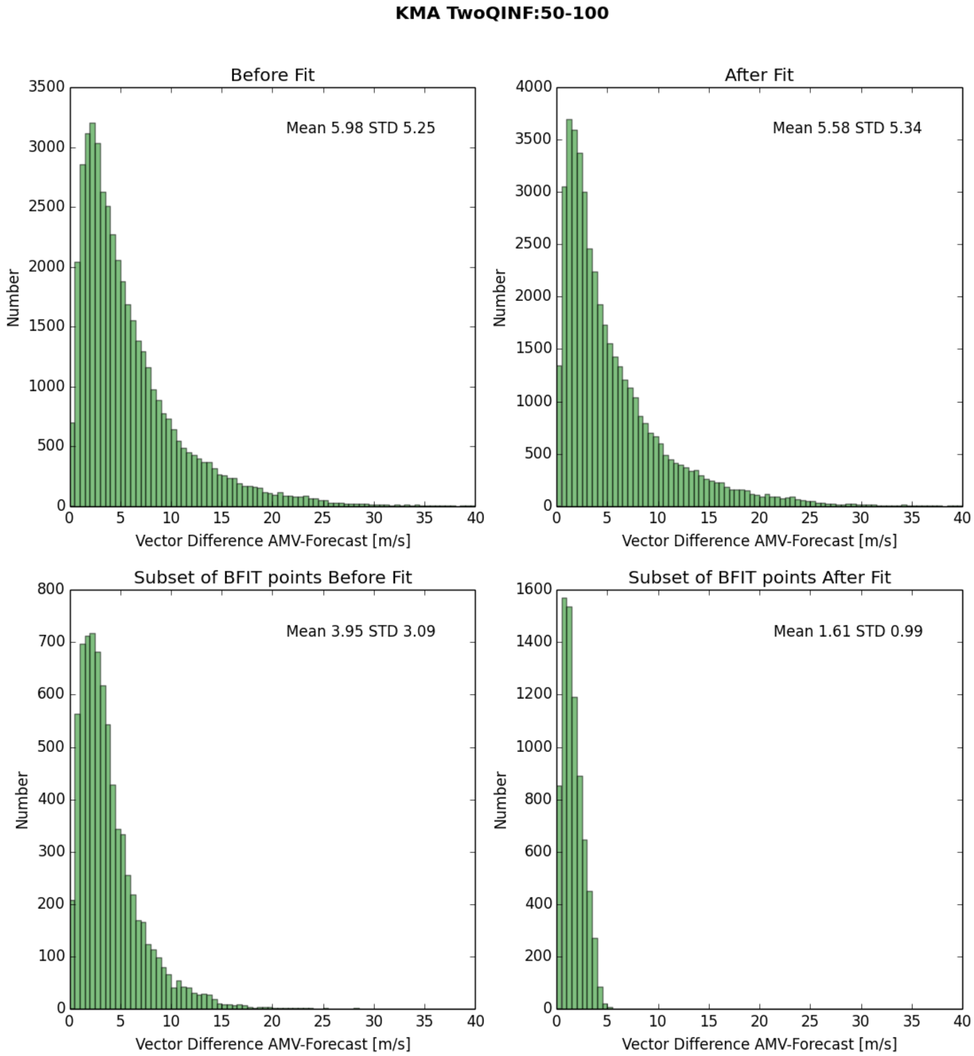

Figure 140: KMA: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

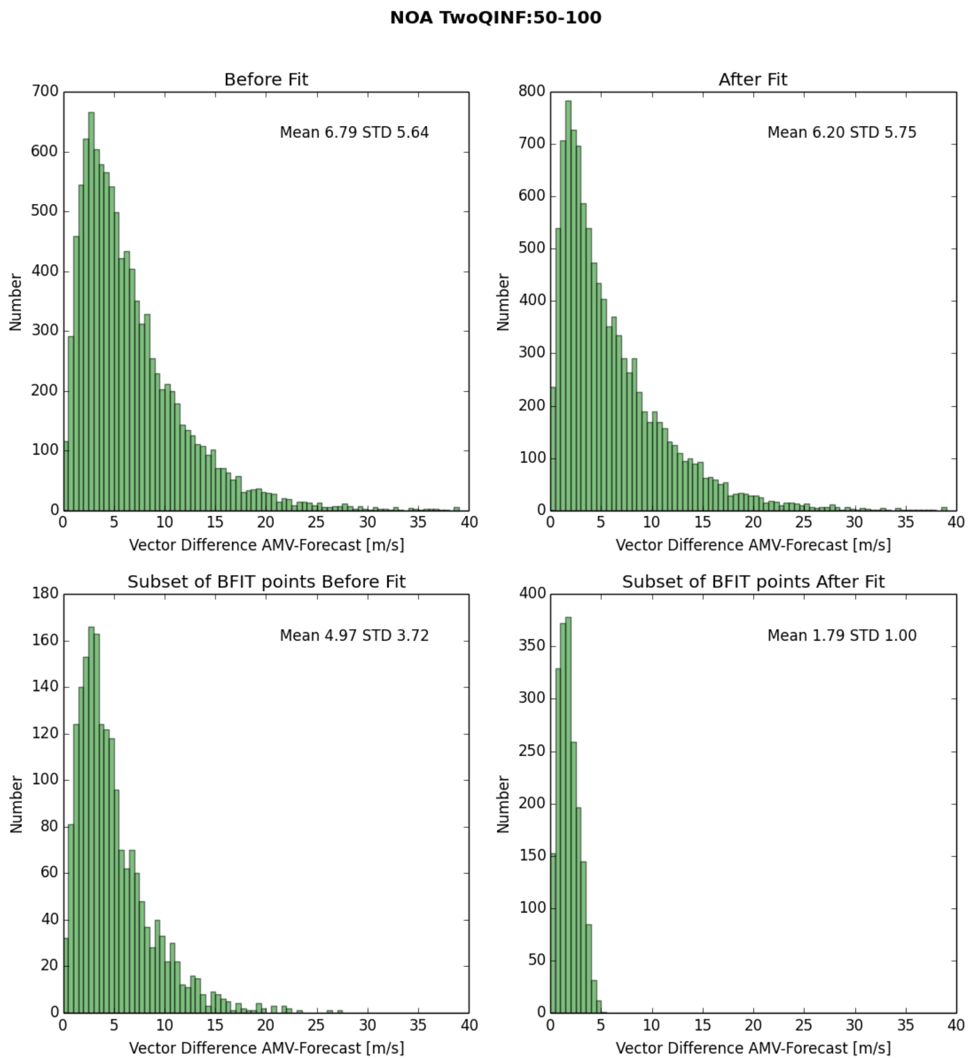

Figure 141: NOA: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

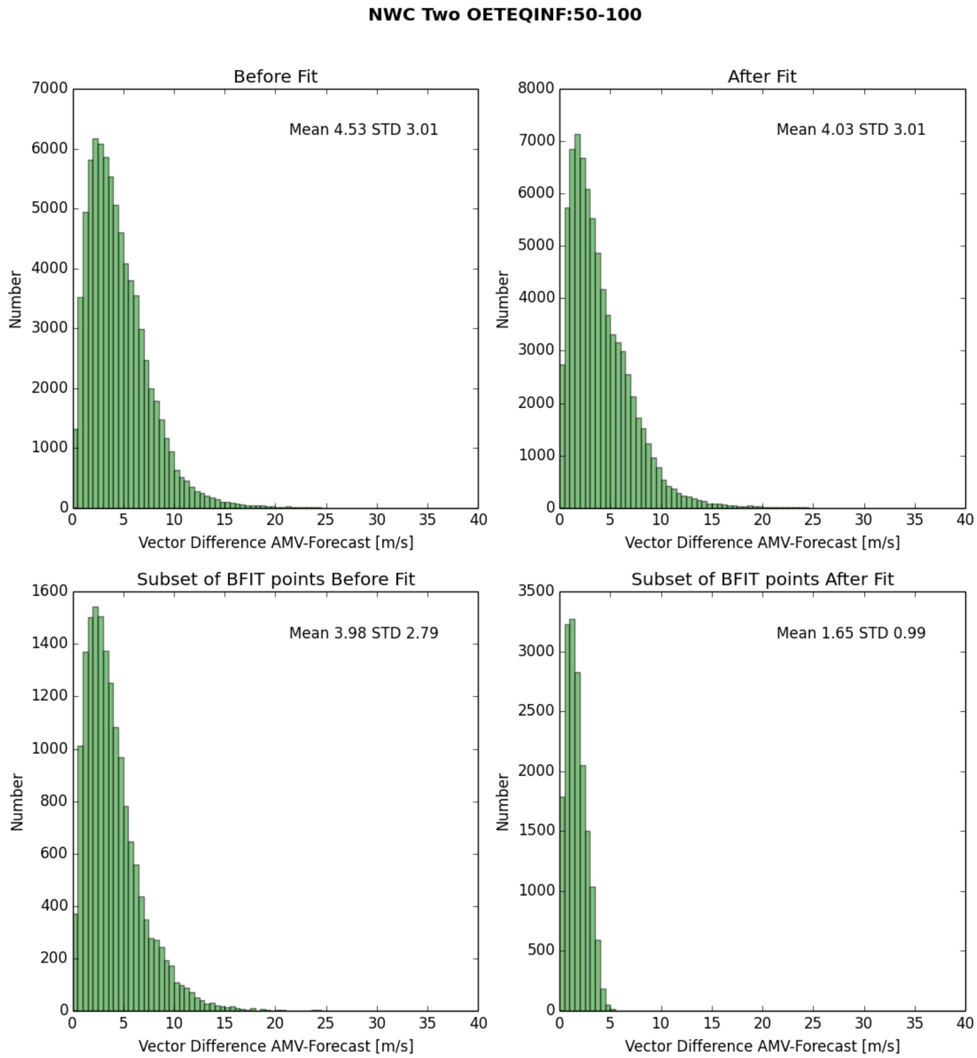

Figure 142: NWC: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

Experiment 3 Best Fit speed difference

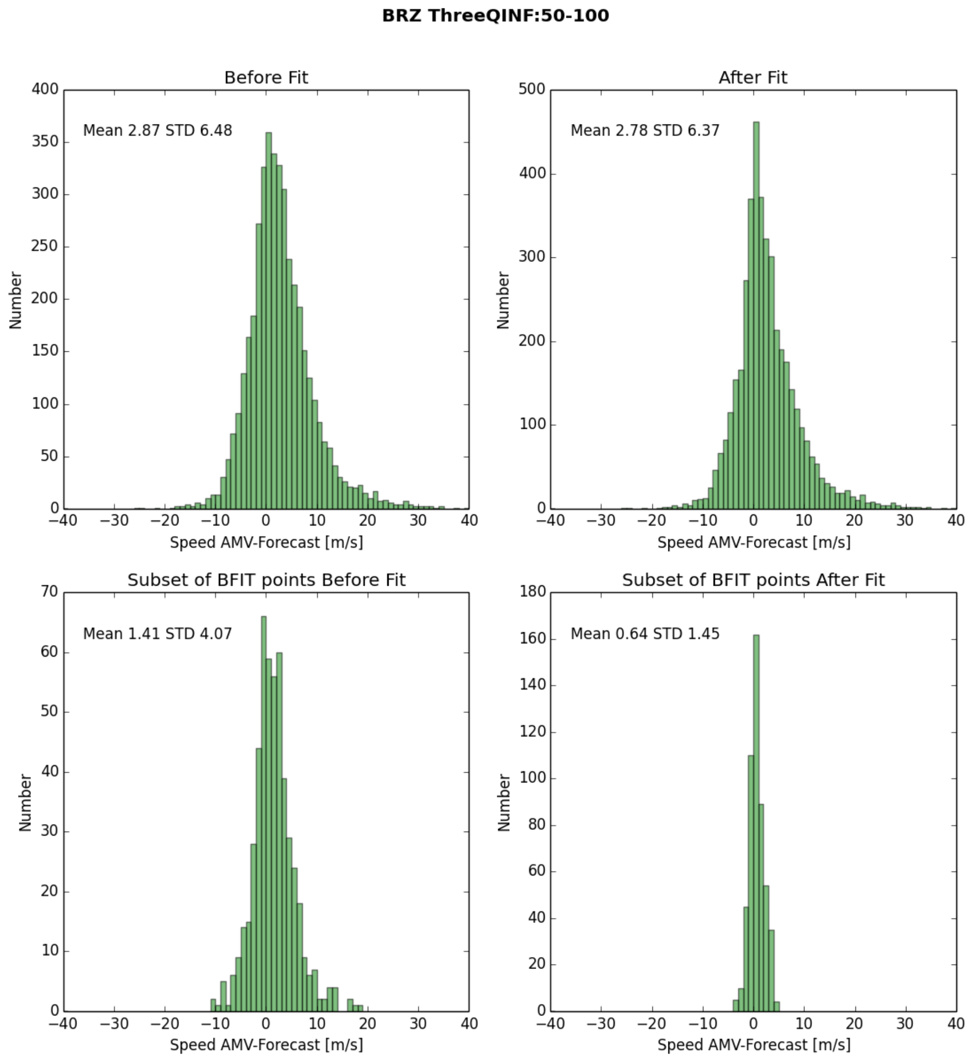

Figure 143: BRZ: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

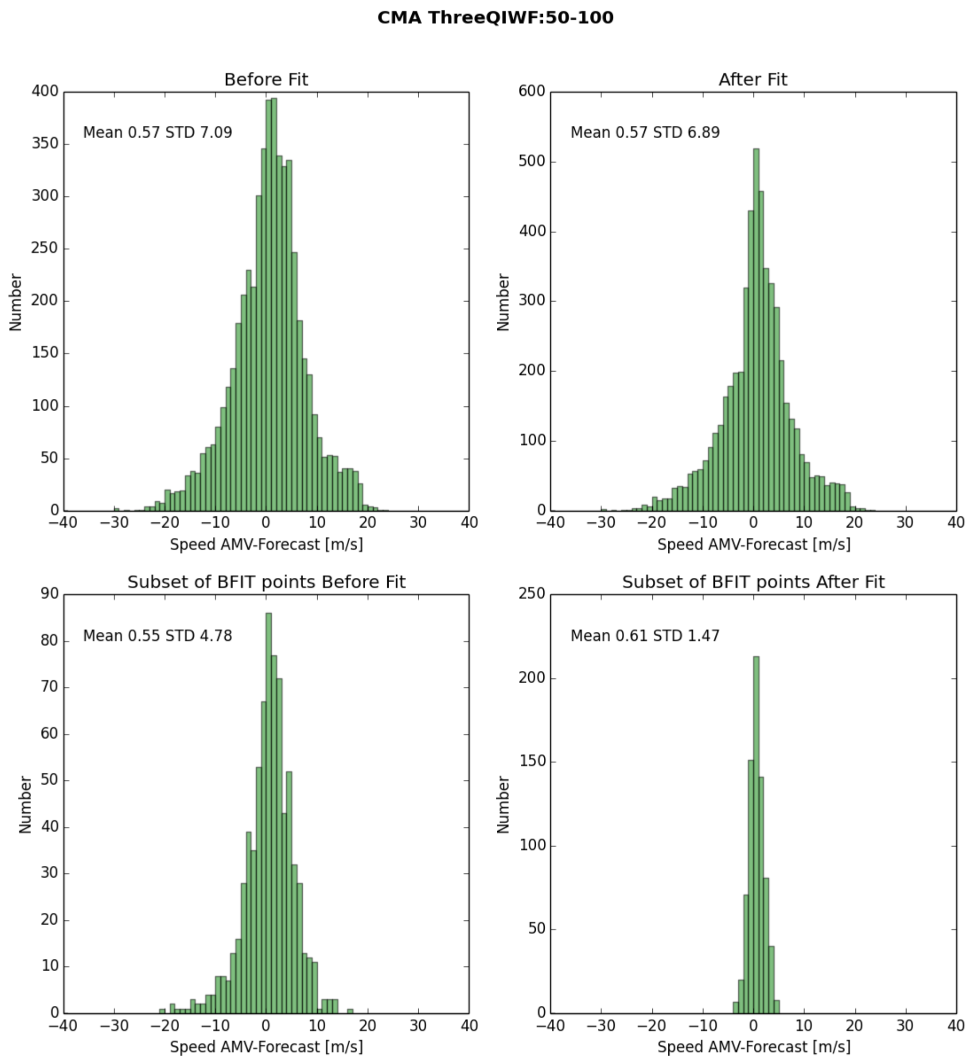

Figure 144: BRZ: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

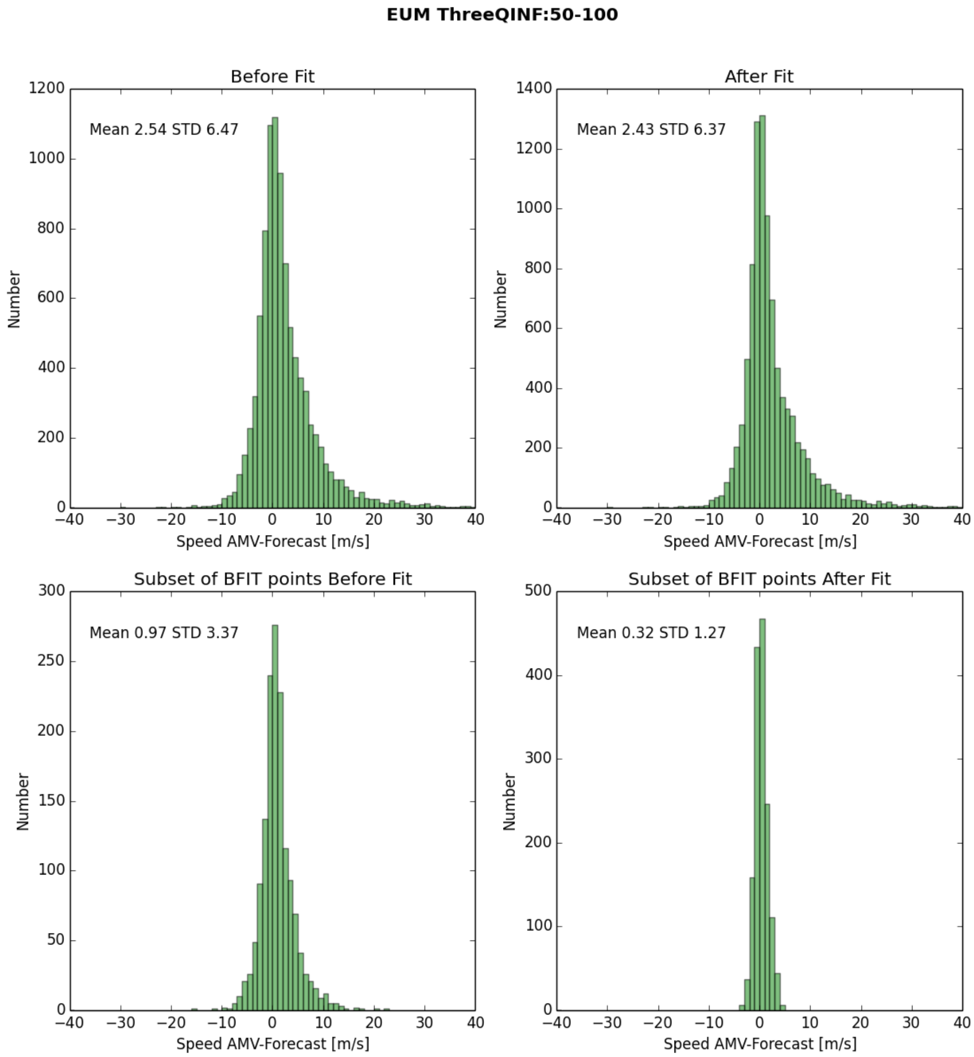

Figure 145: EUM: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

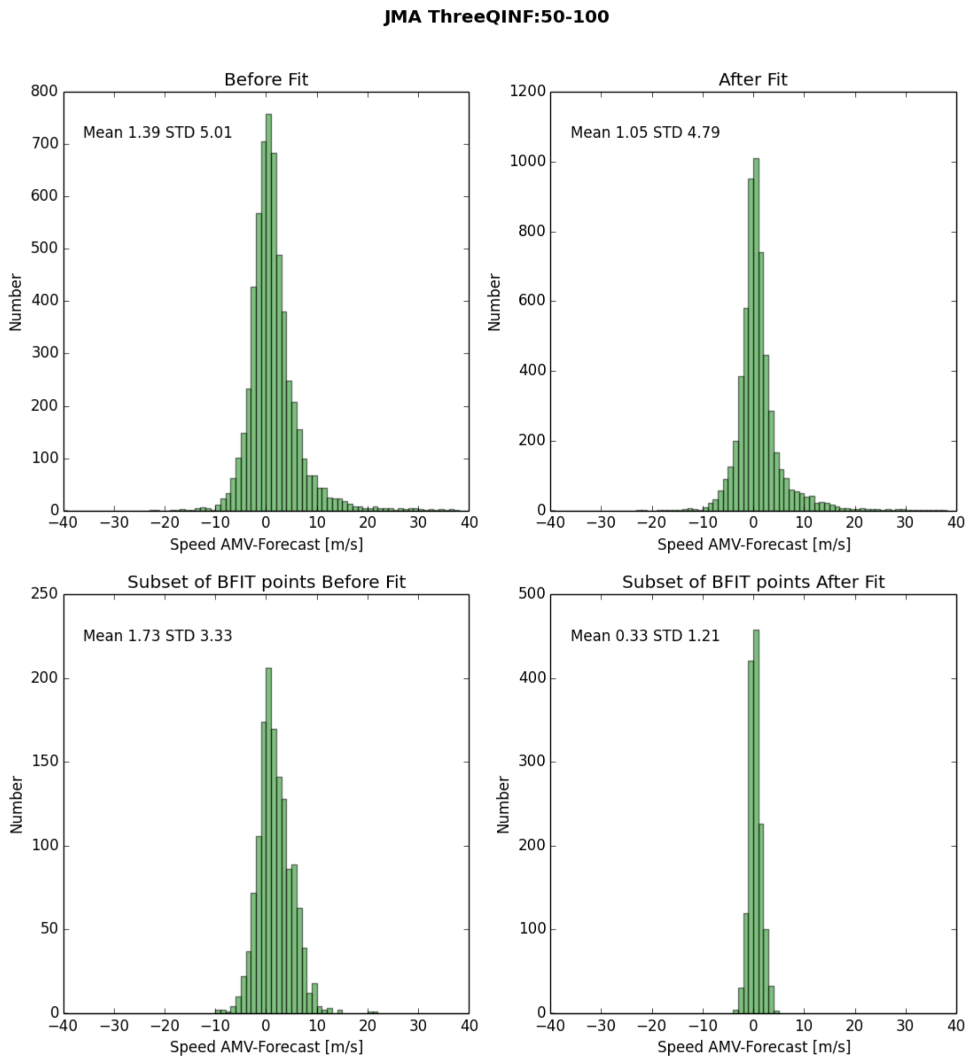

Figure 146: JMA: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

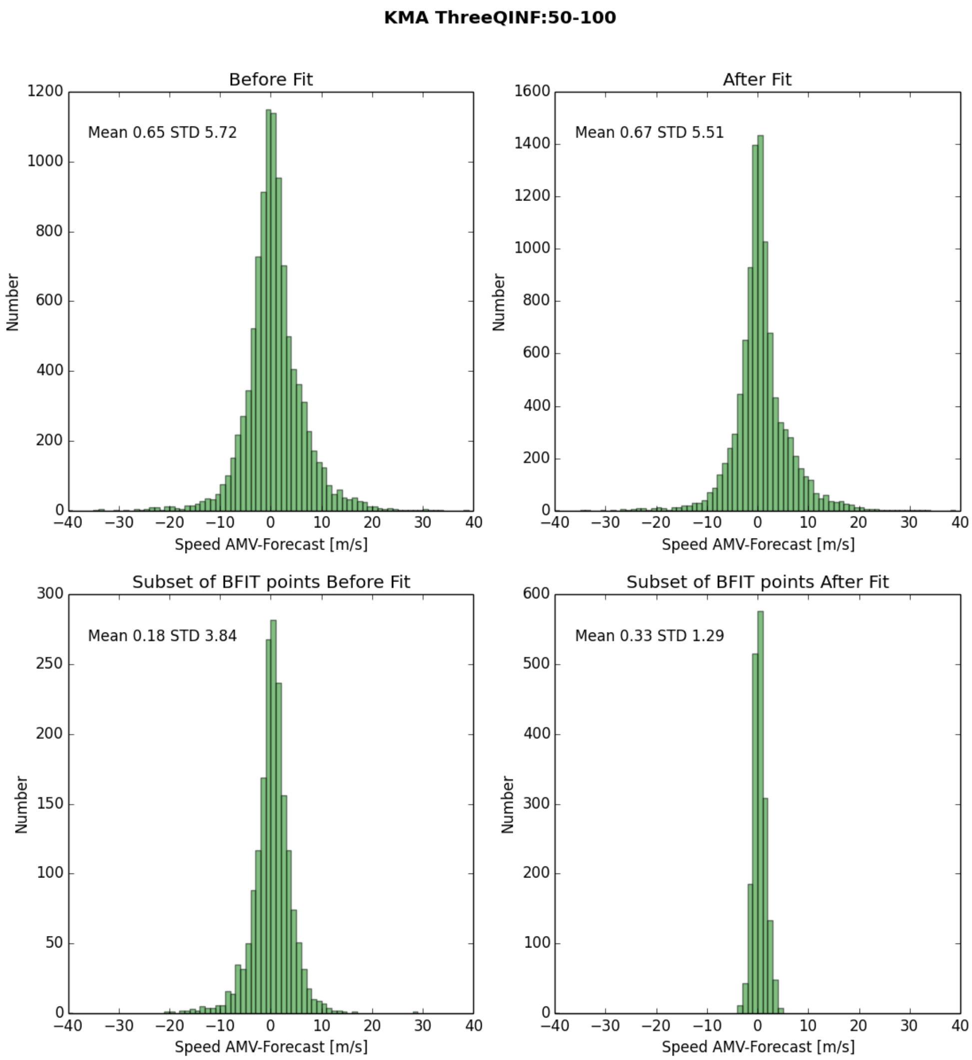

Figure 147: KMA: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

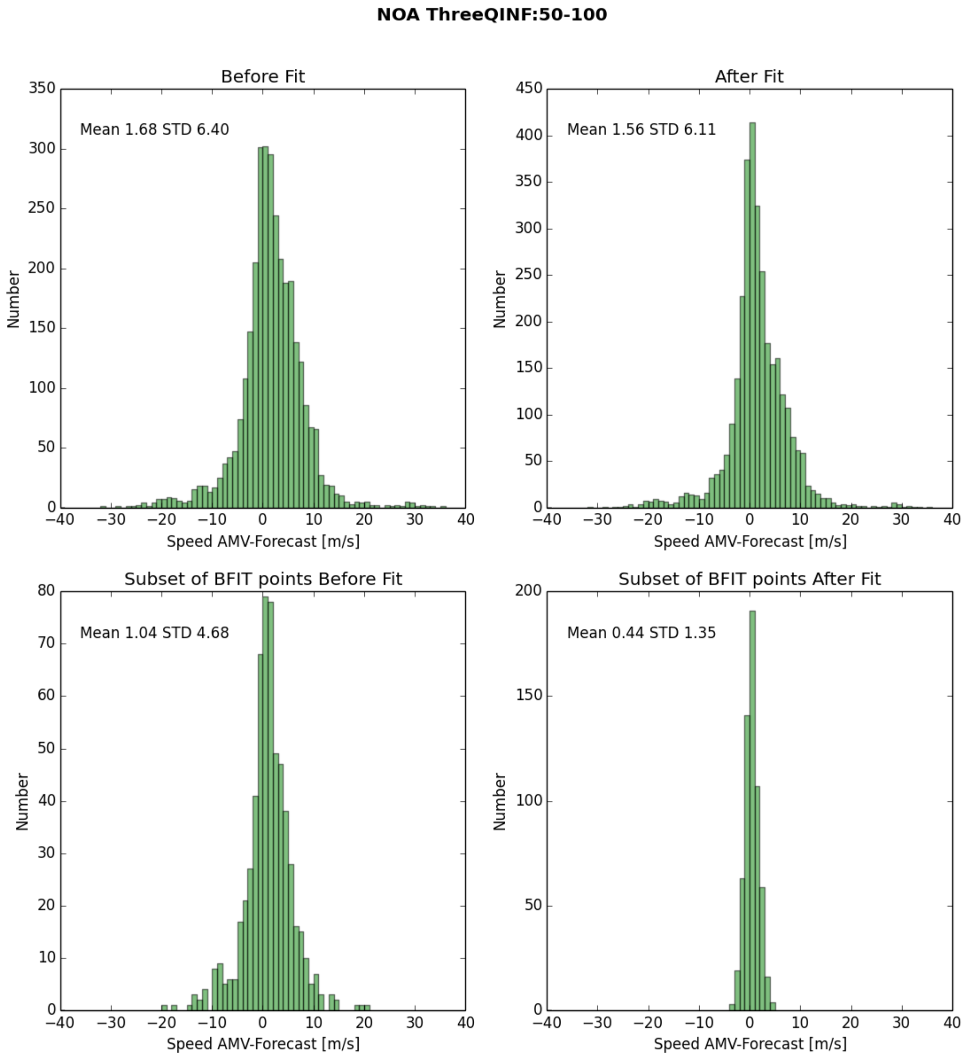

Figure 148: NOA: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

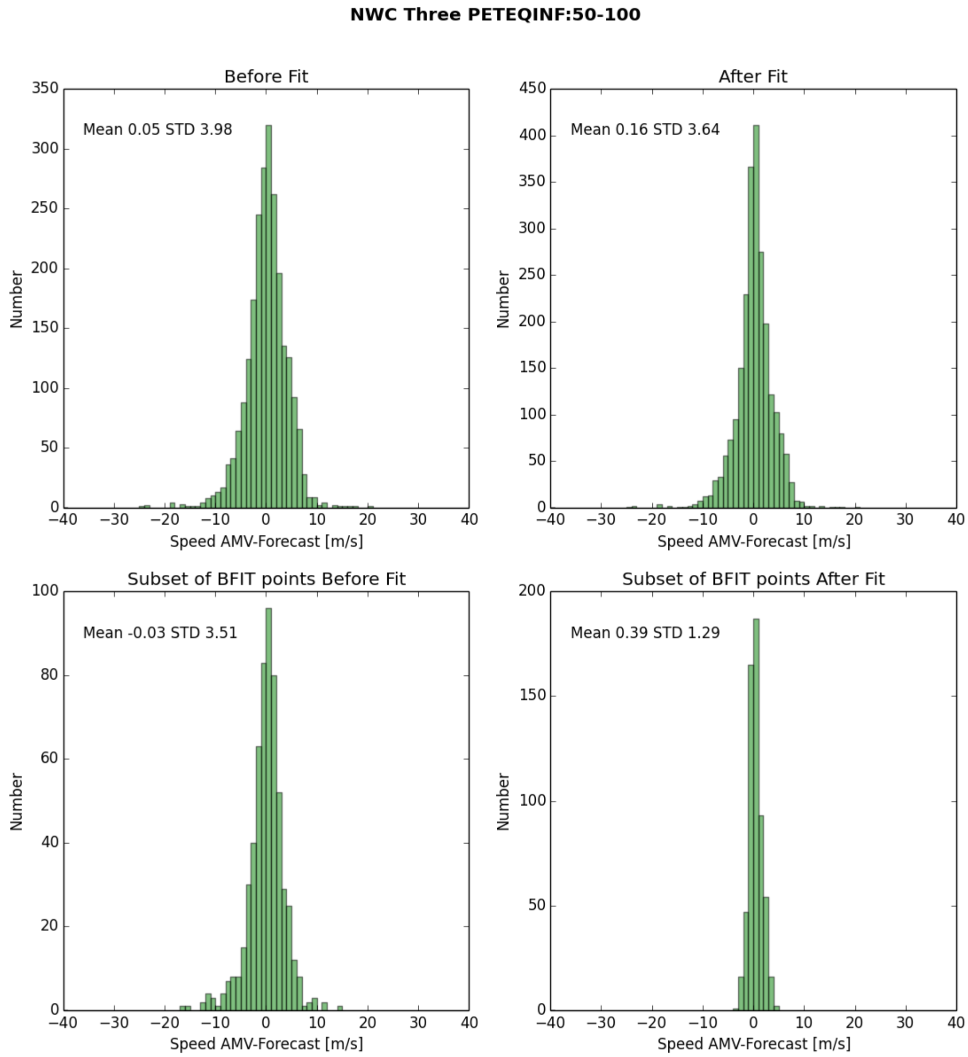

Figure 149: NWC: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

Experiment 3 Best Fit vector difference

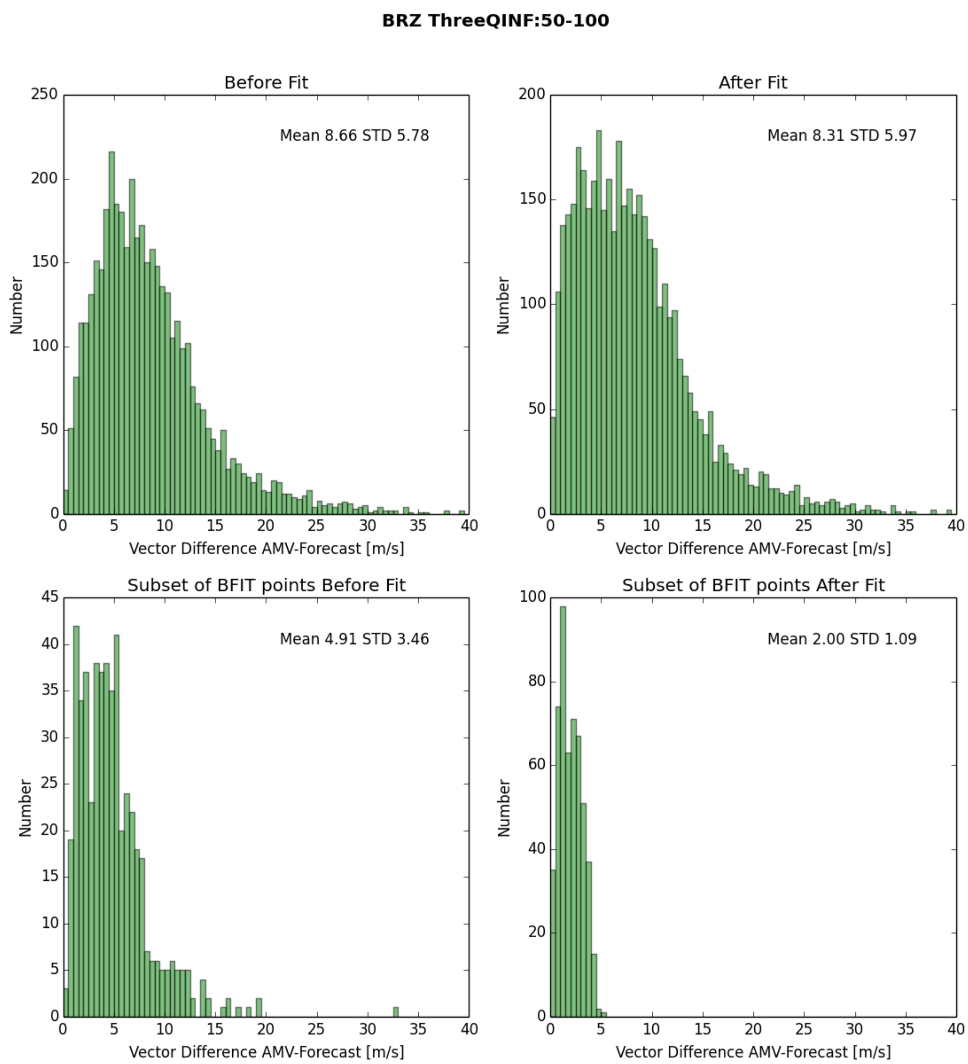

Figure 150: BRZ: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

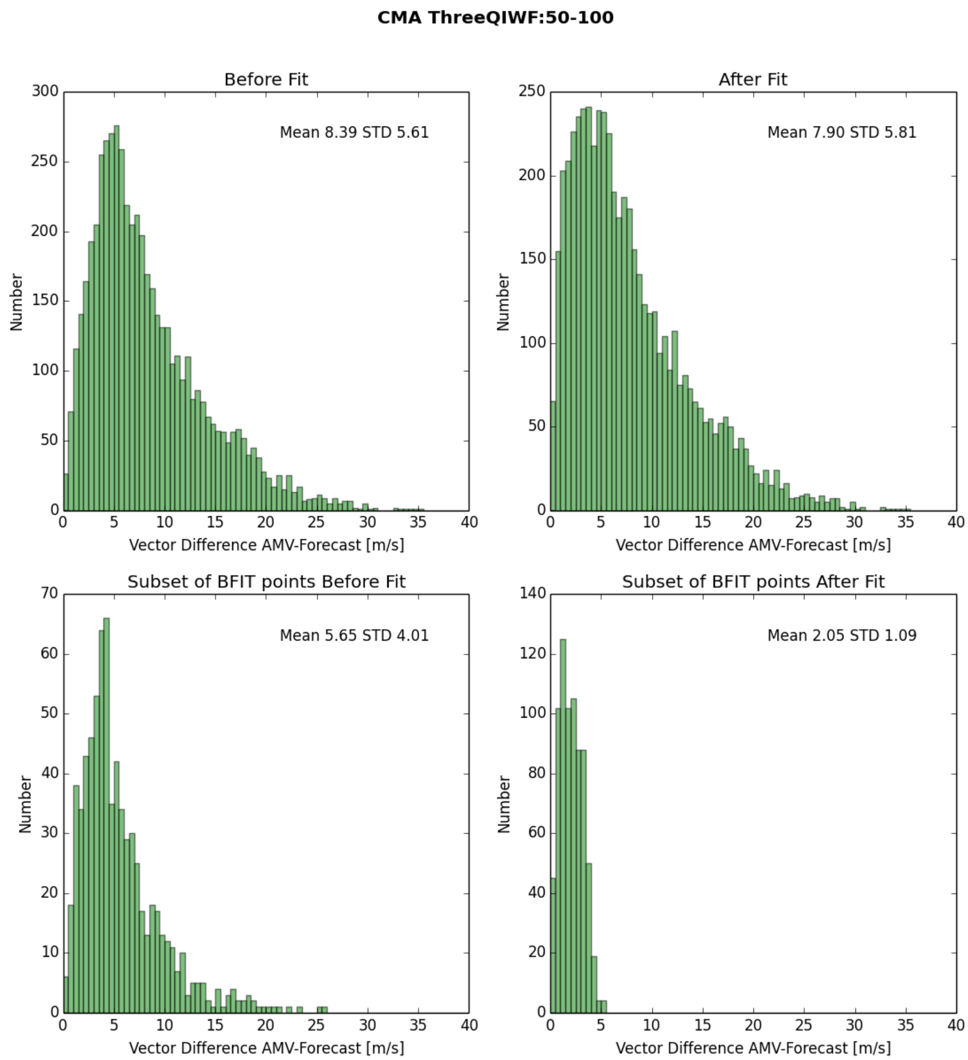

Figure 151: CMA: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

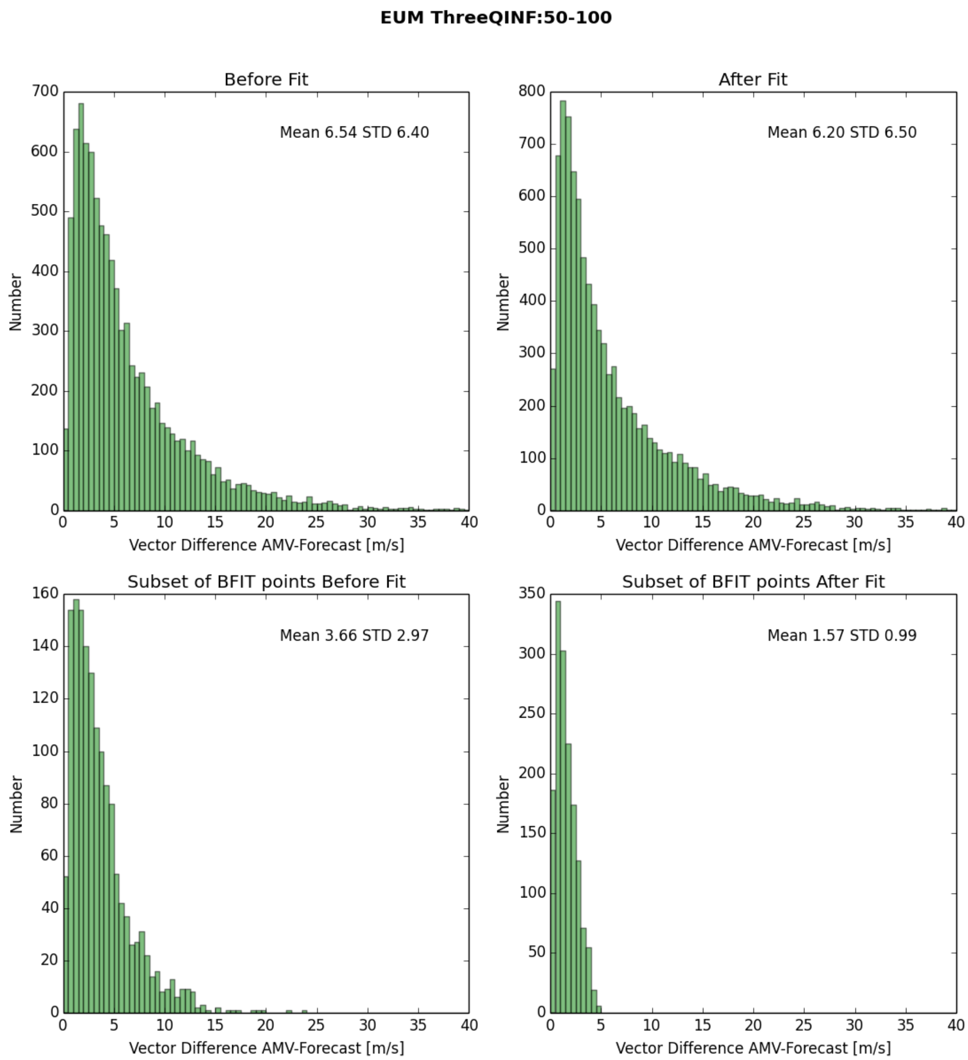

Figure 152: EUM: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

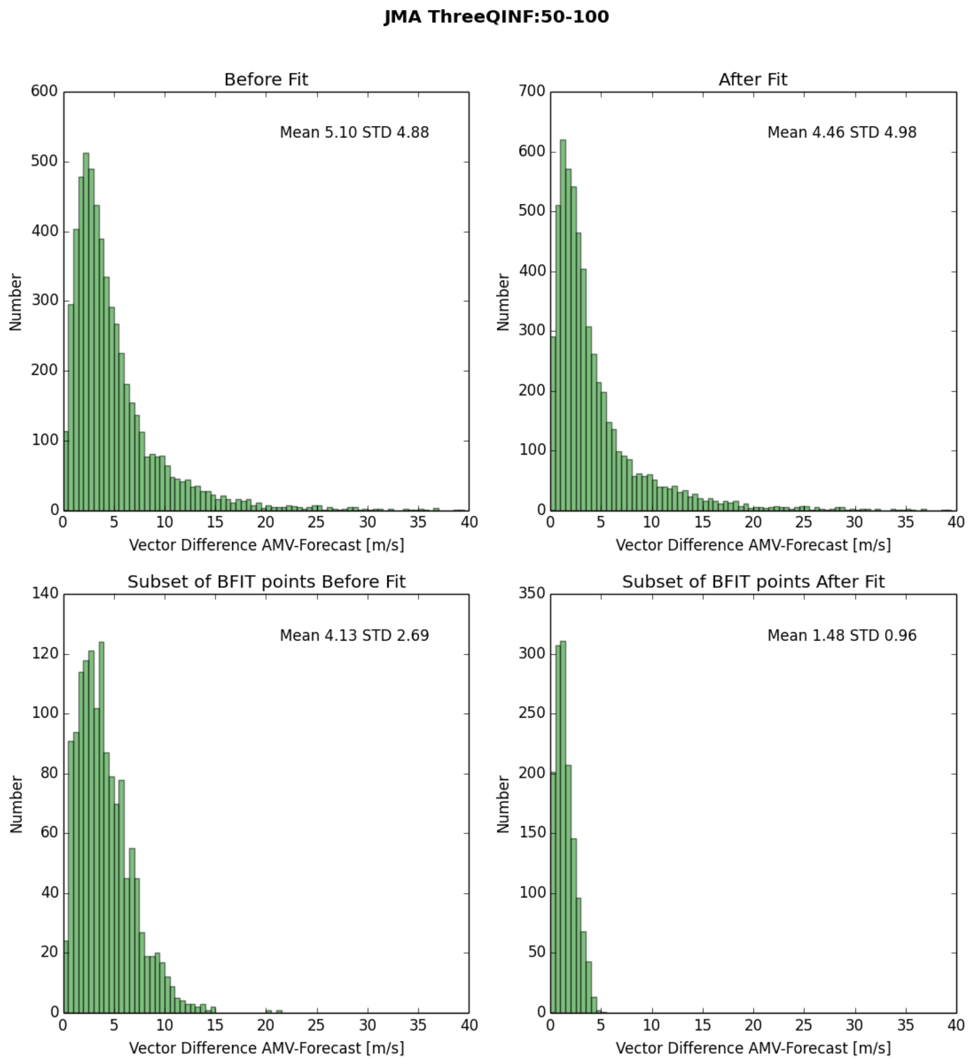

Figure 153: JMA: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

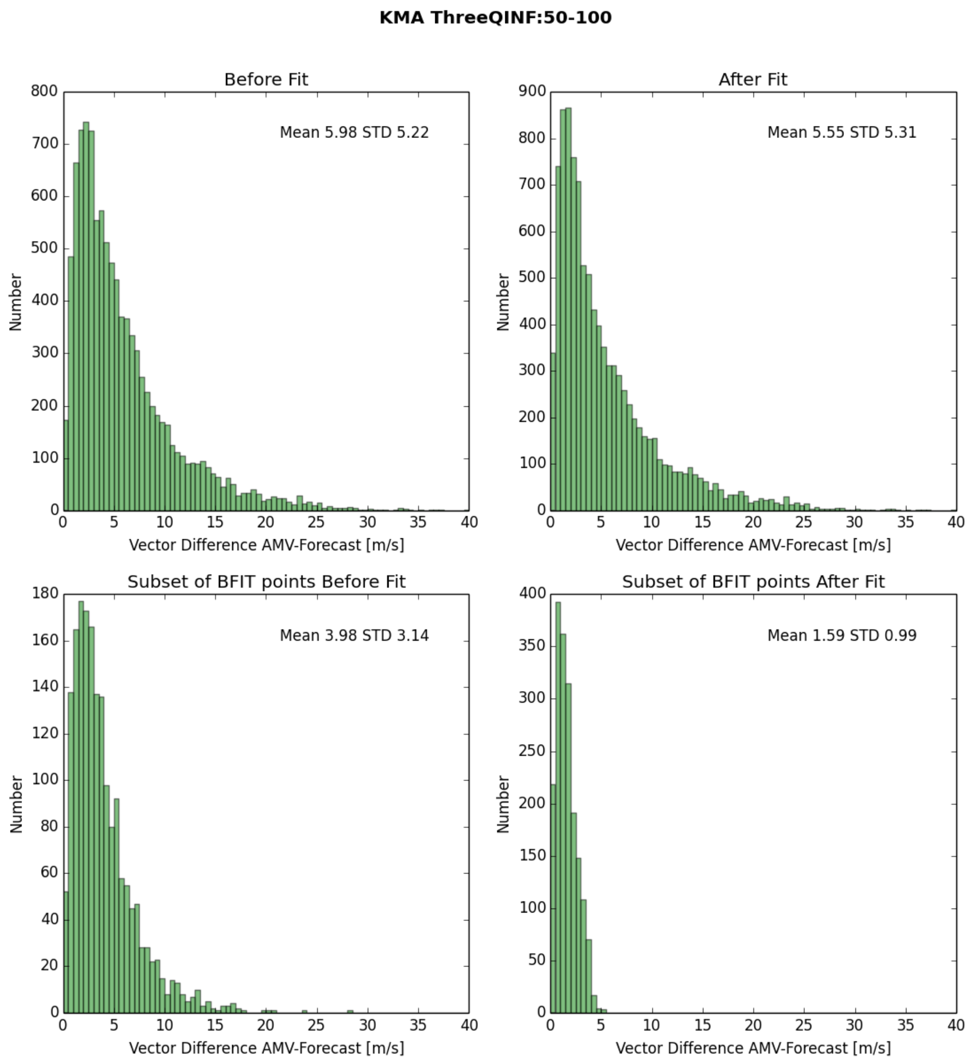

Figure 154: KMA: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

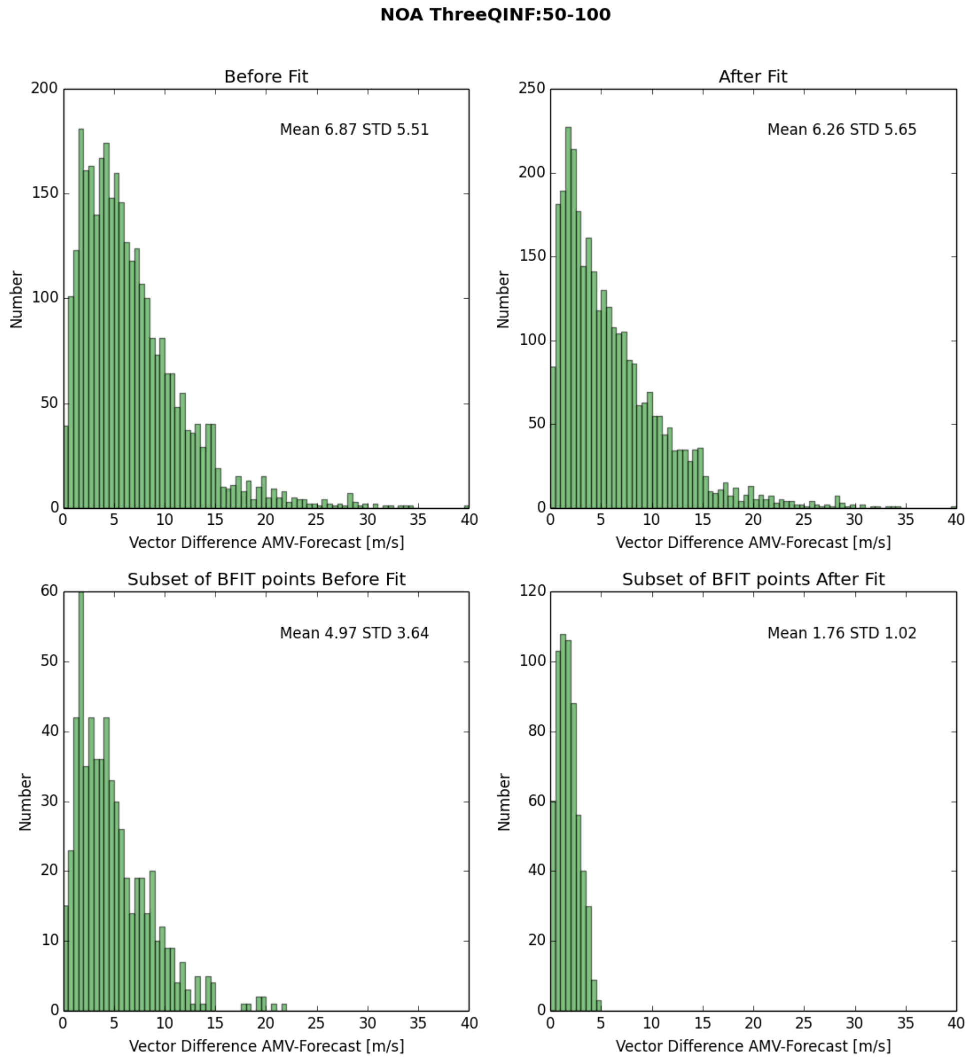

Figure 155: NOA: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

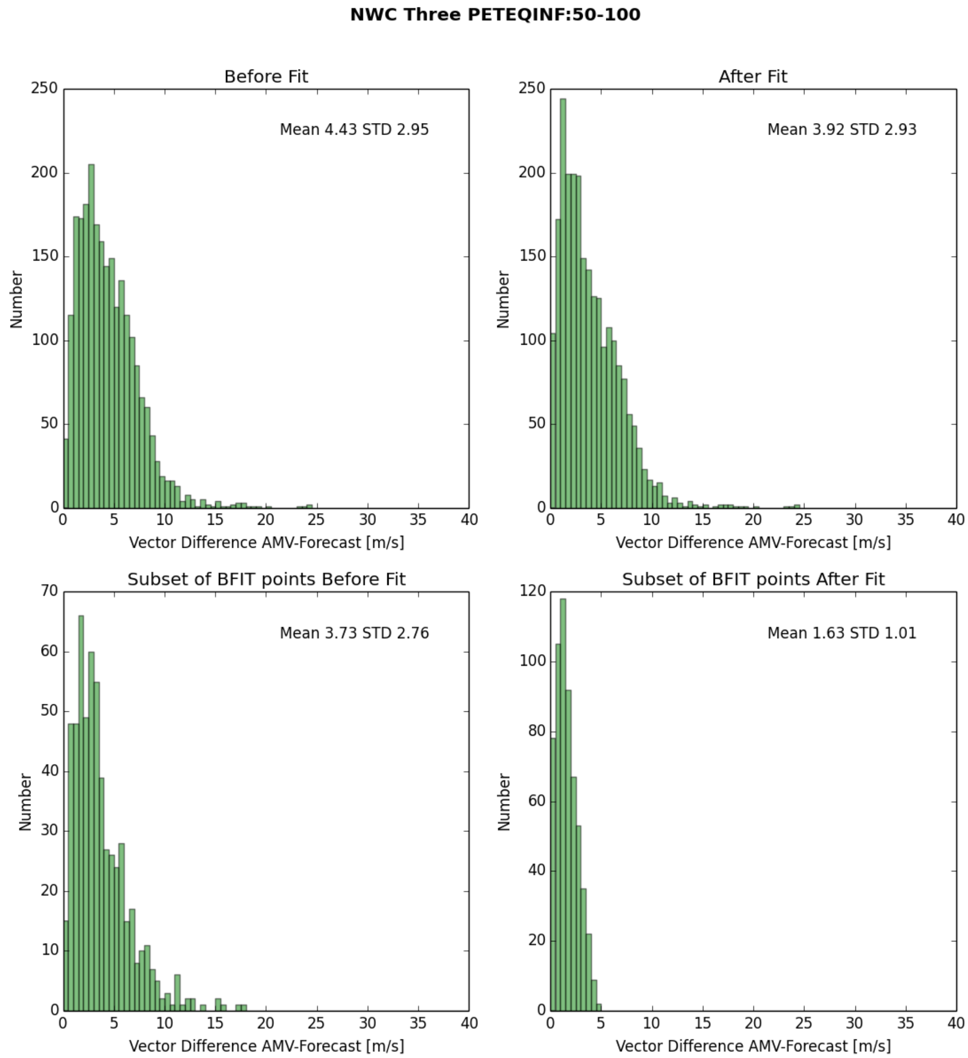

Figure 156: NWC: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

Experiment 4 Best Fit speed difference

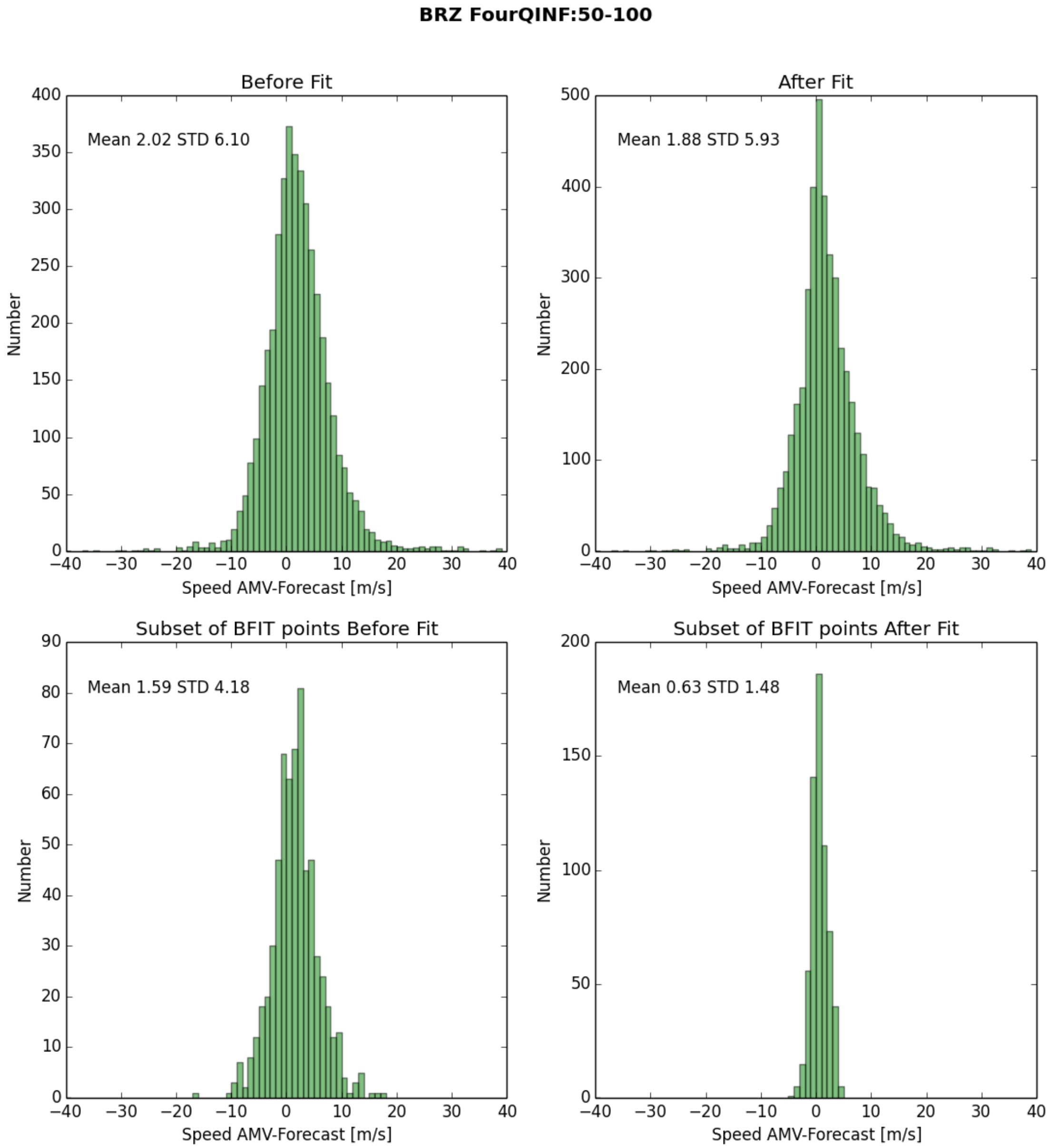

Figure 157: BRZ: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

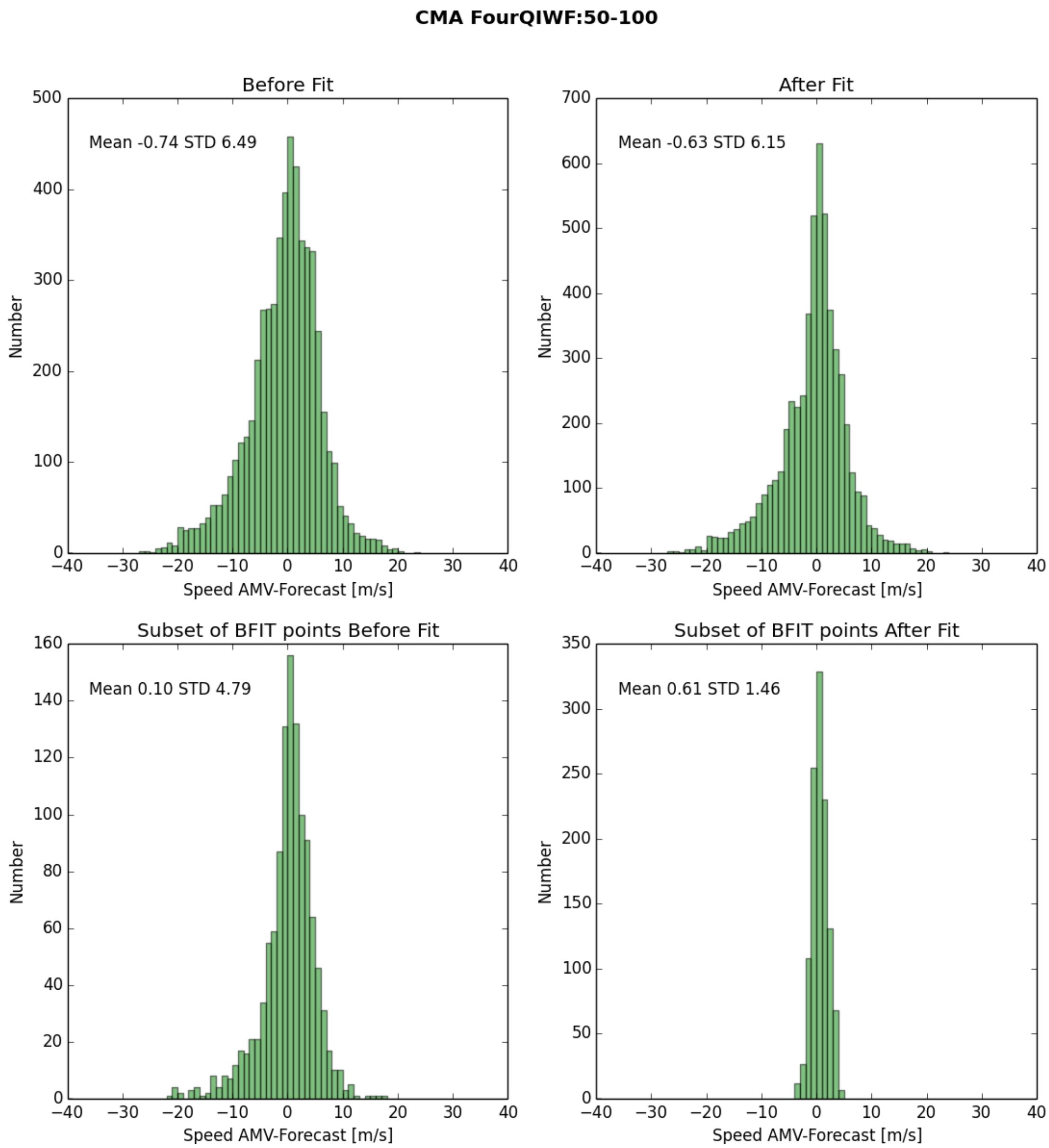

Figure 158: CMA: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

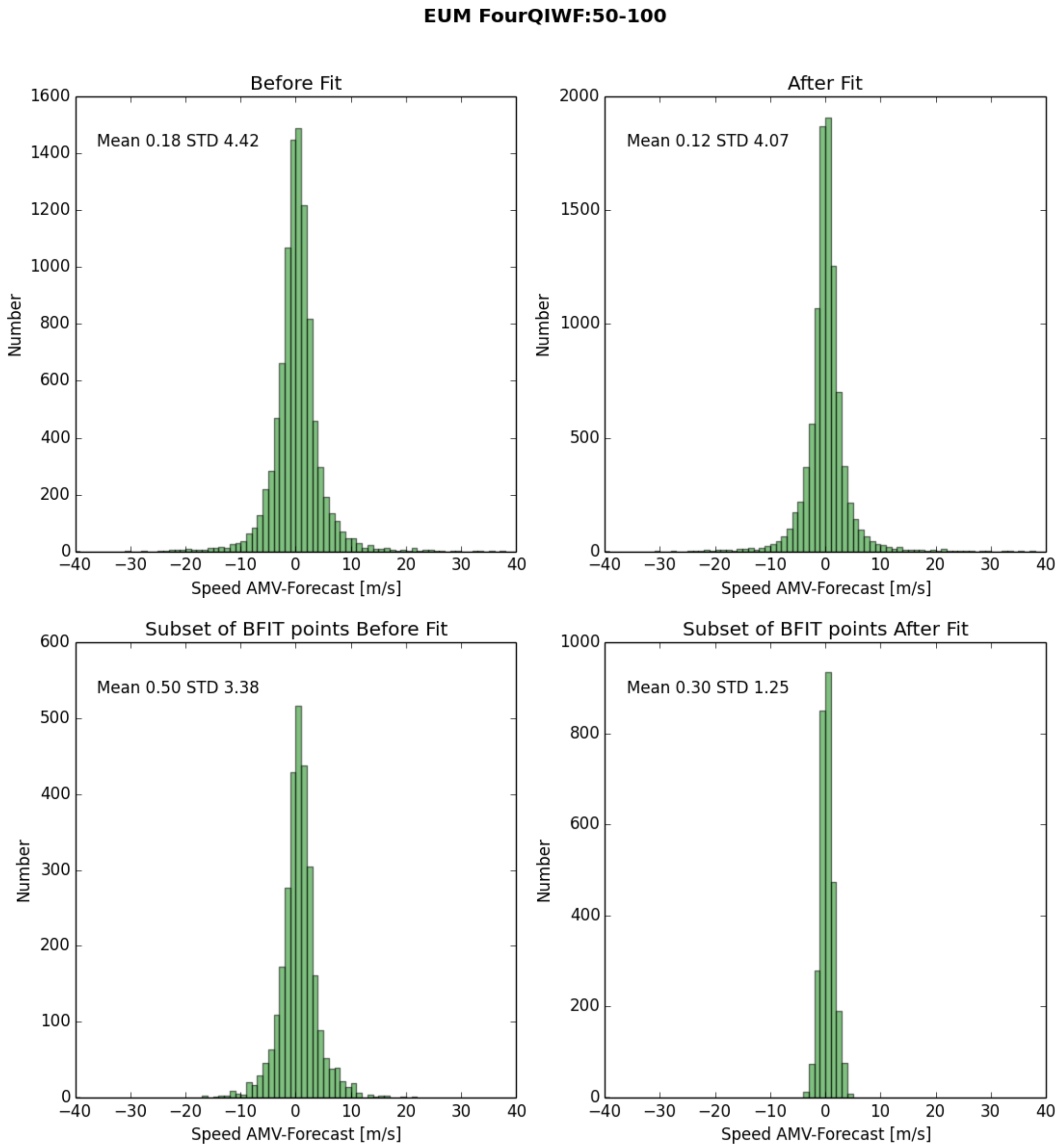

Figure 159: EUM: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

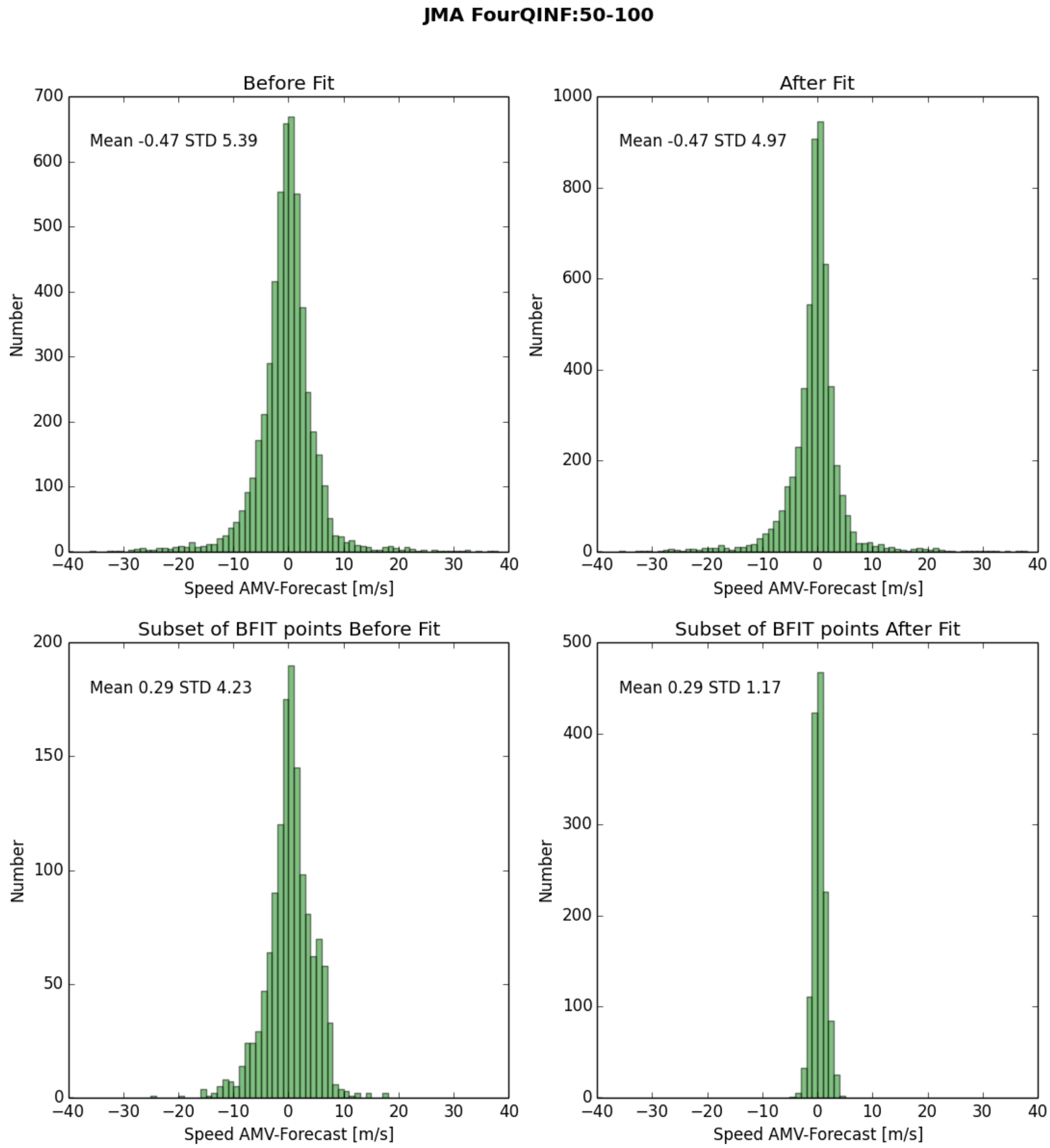

Figure 160: JMA: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

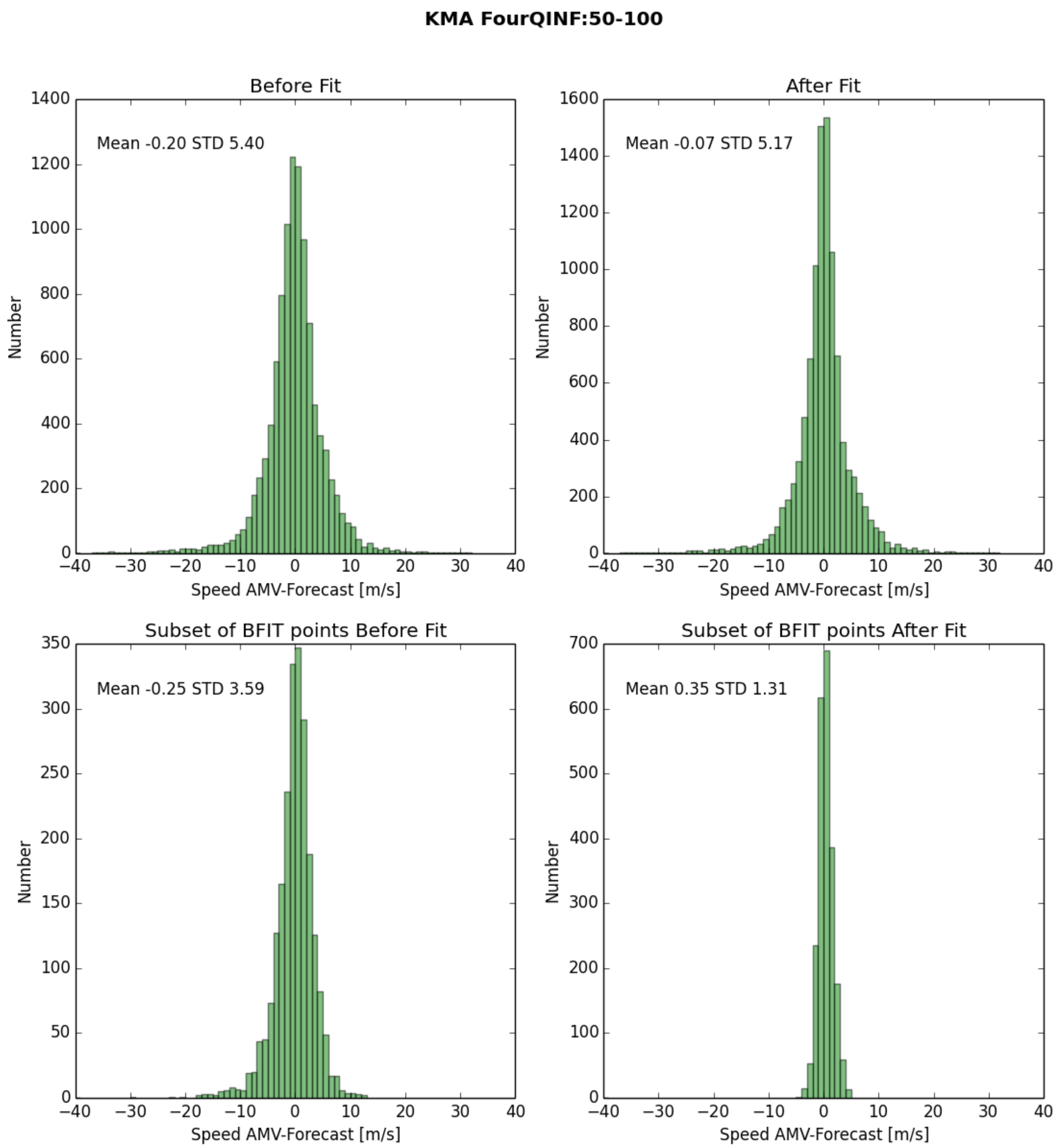

Figure 161: KMA: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

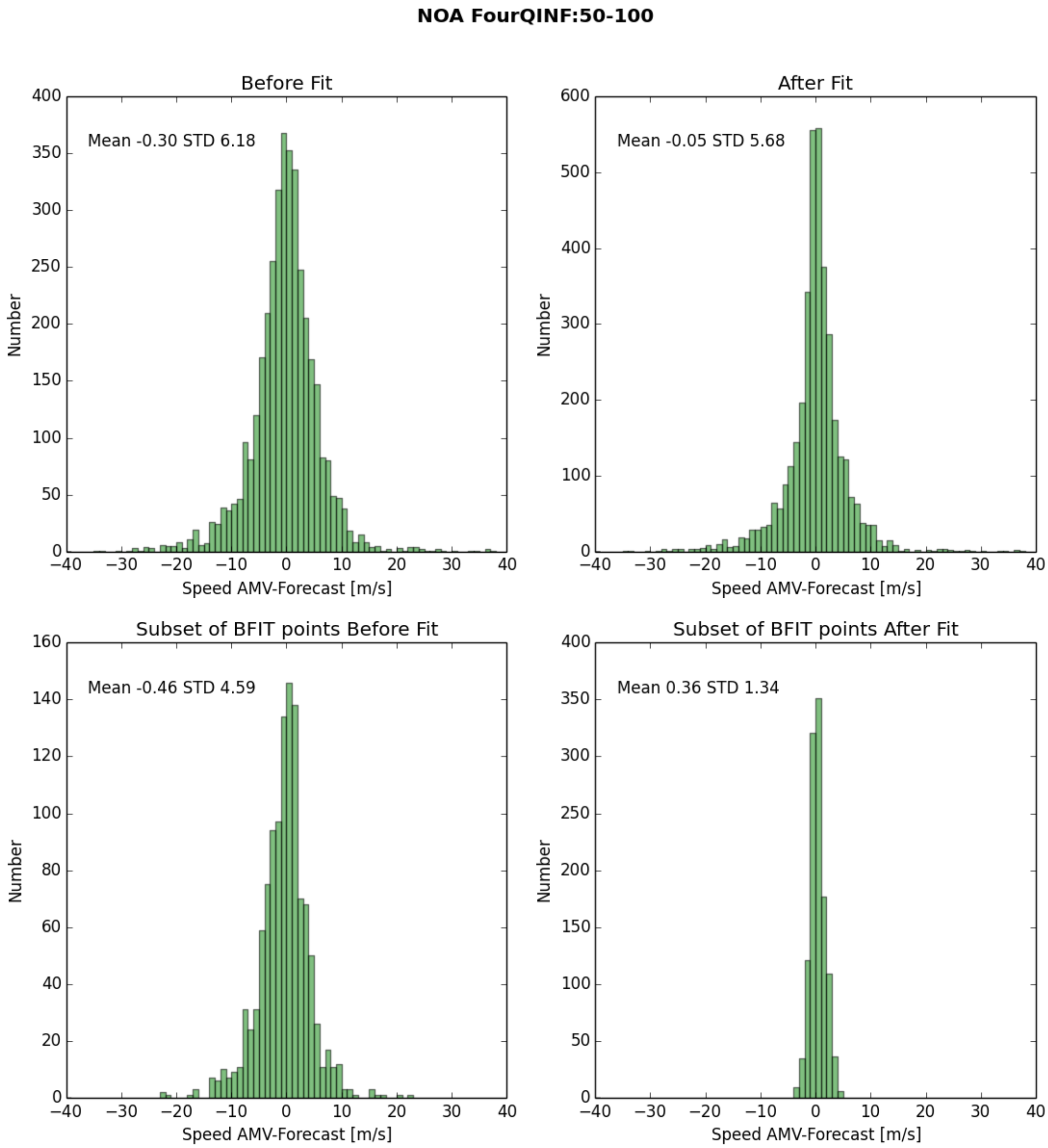

Figure 162: NOA: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

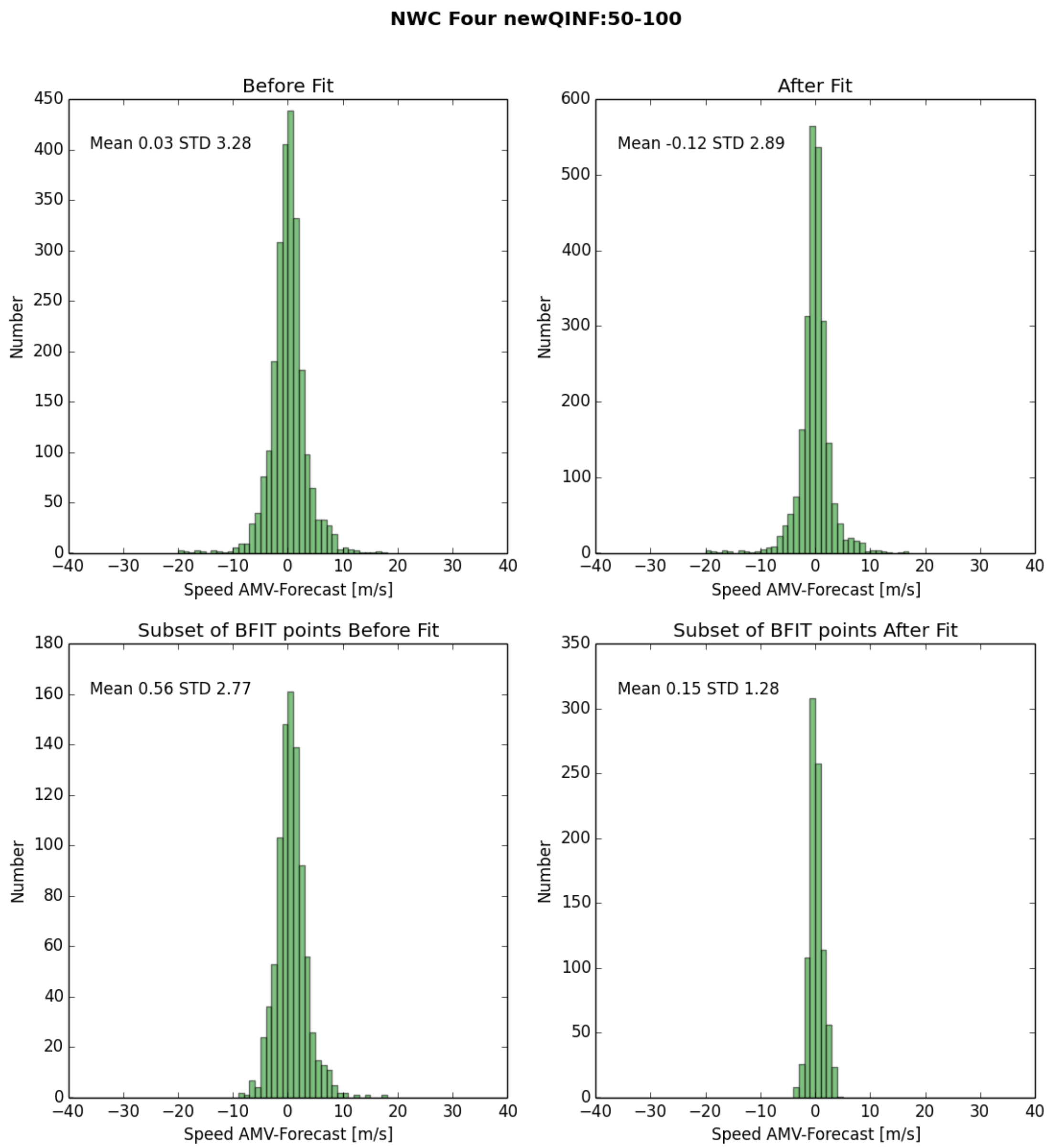

Figure 163: NWC: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

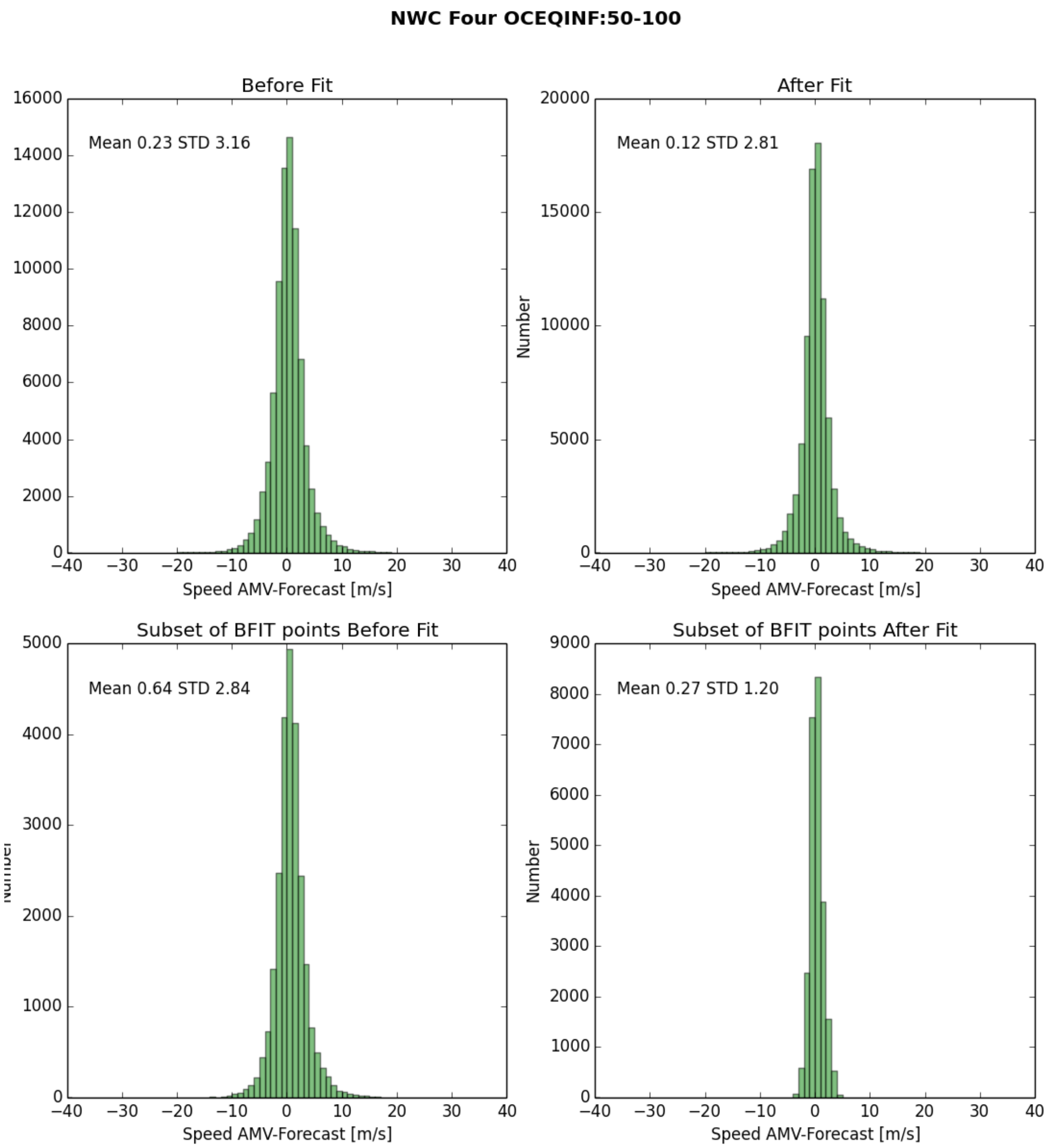

Figure 164: NWC: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

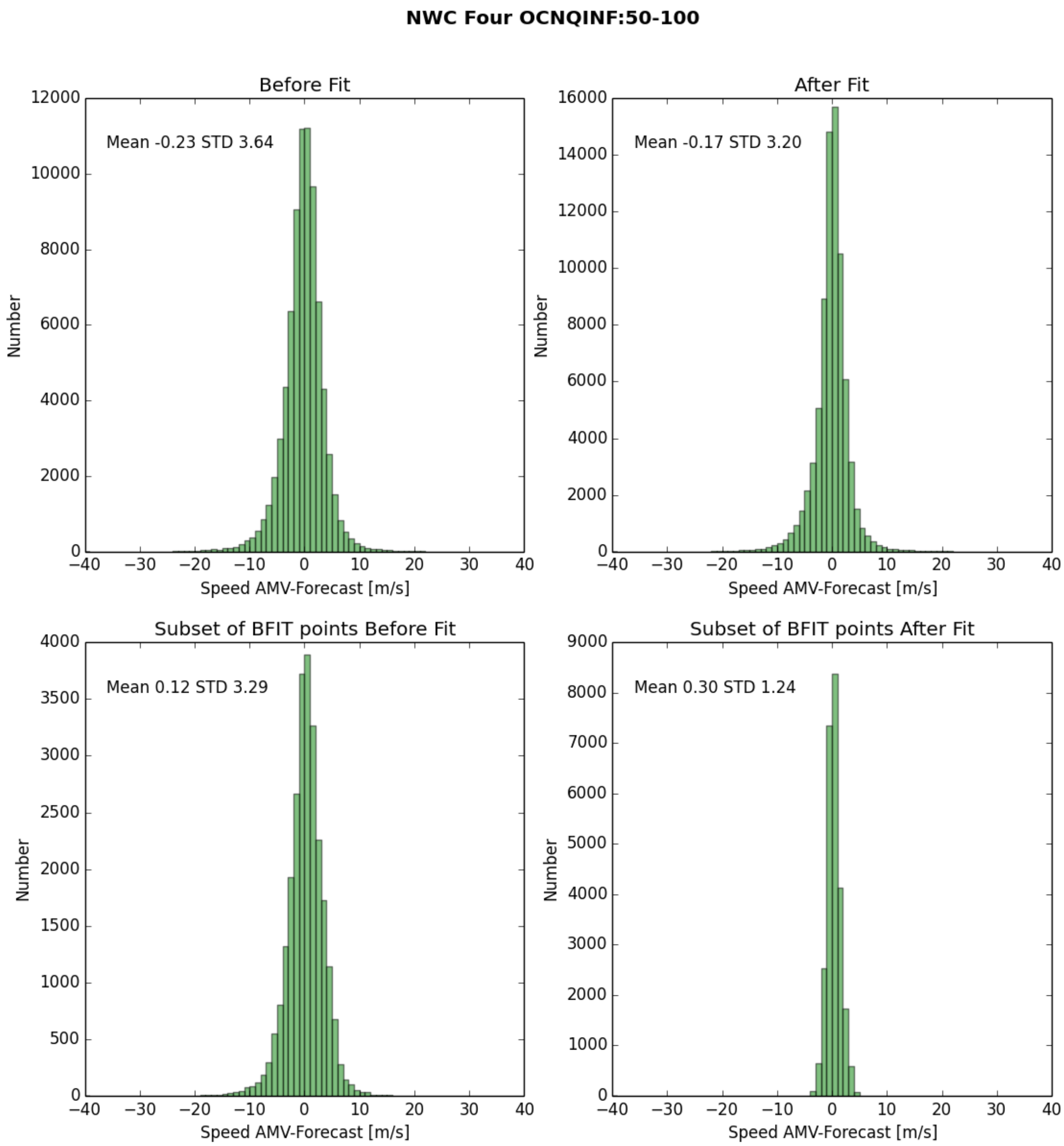

Figure 165: NWC: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

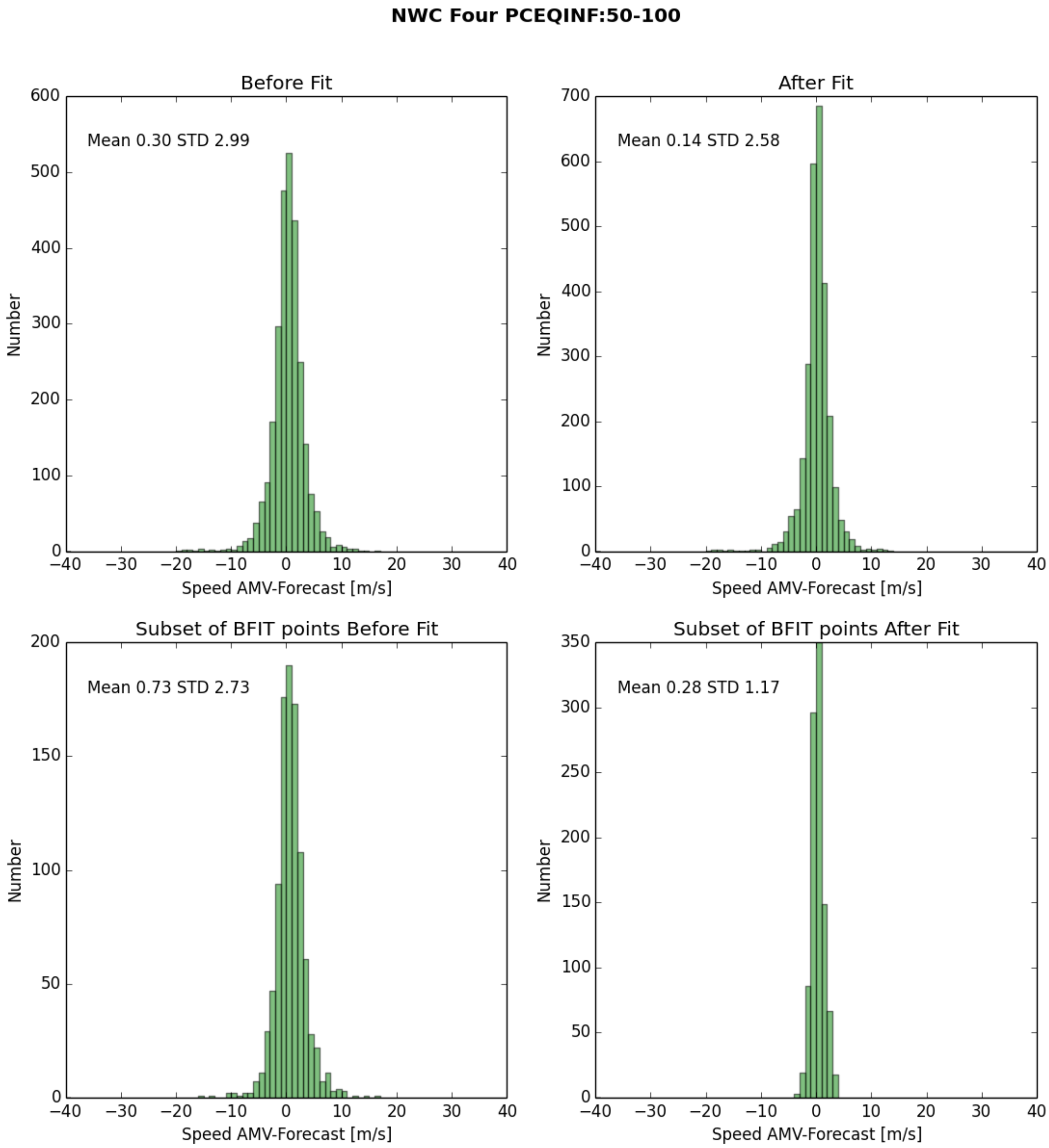

Figure 166: NWC: AMV – background speed distribution of all AMVs (upper left); AMV – background speed distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background speed distribution of Best Fit AMVs (lower left); AMV – background speed distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

Experiment 4 Best Fit vector difference

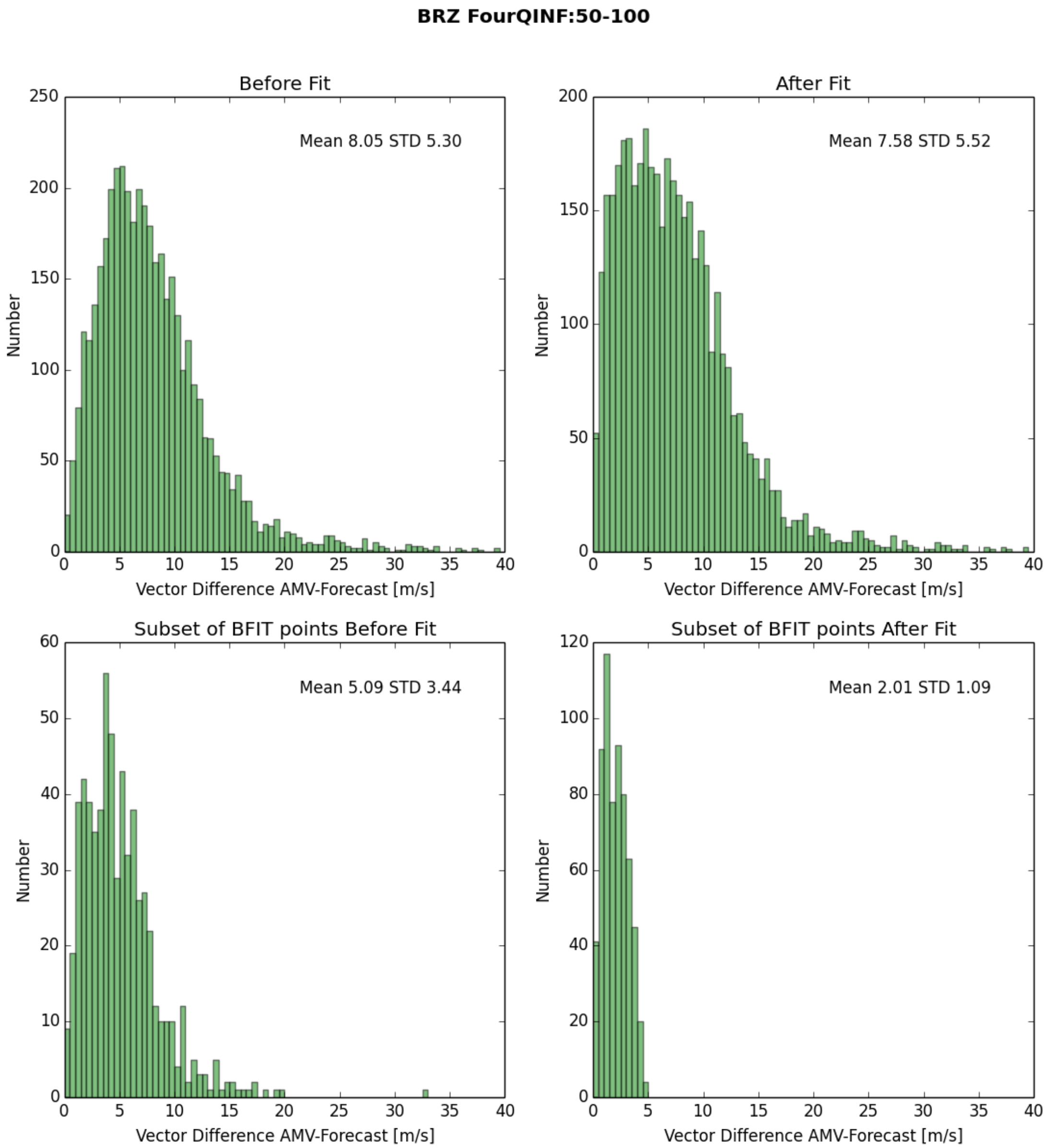

Figure 167: BRZ: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

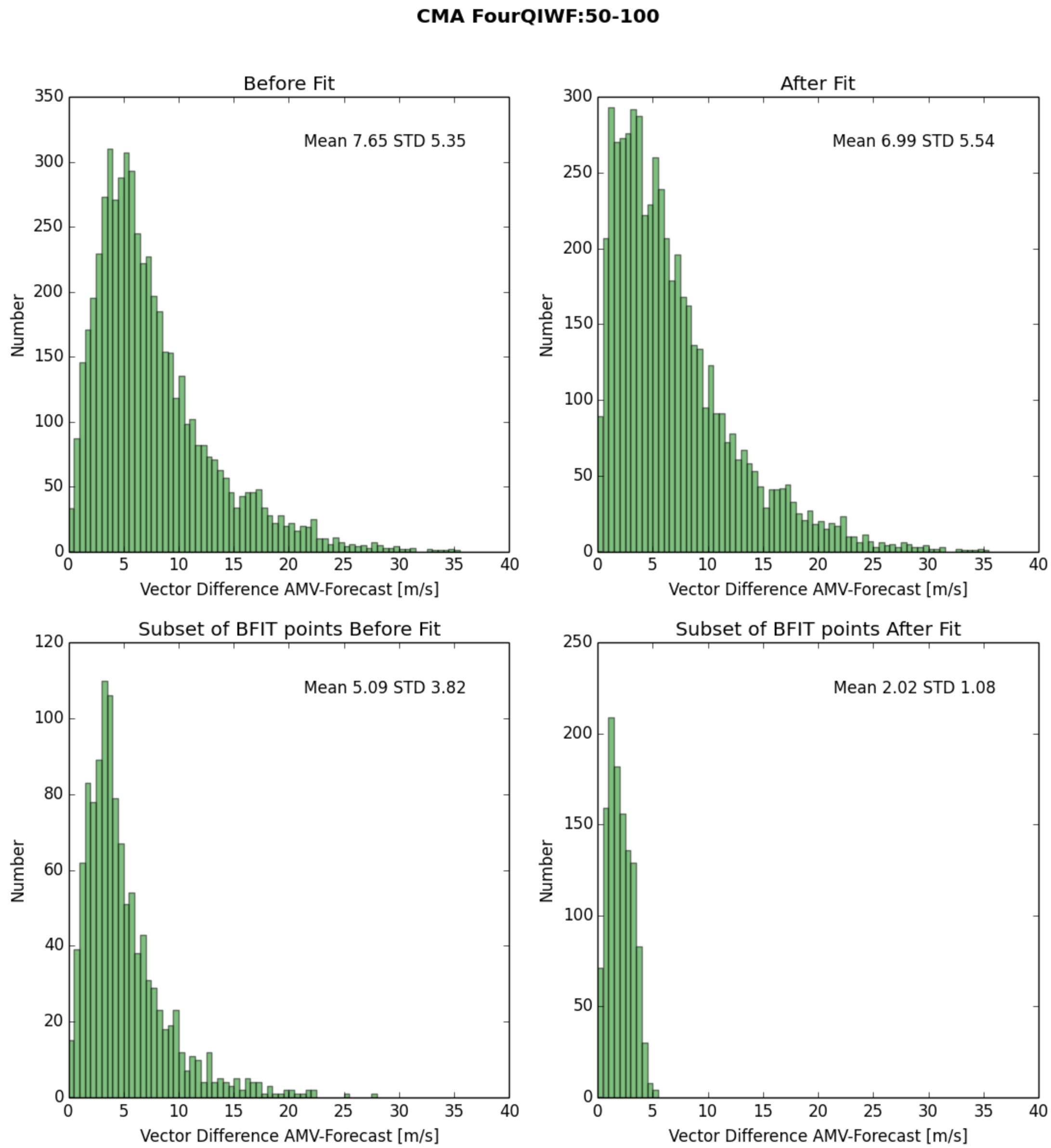

Figure 168: CMA: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

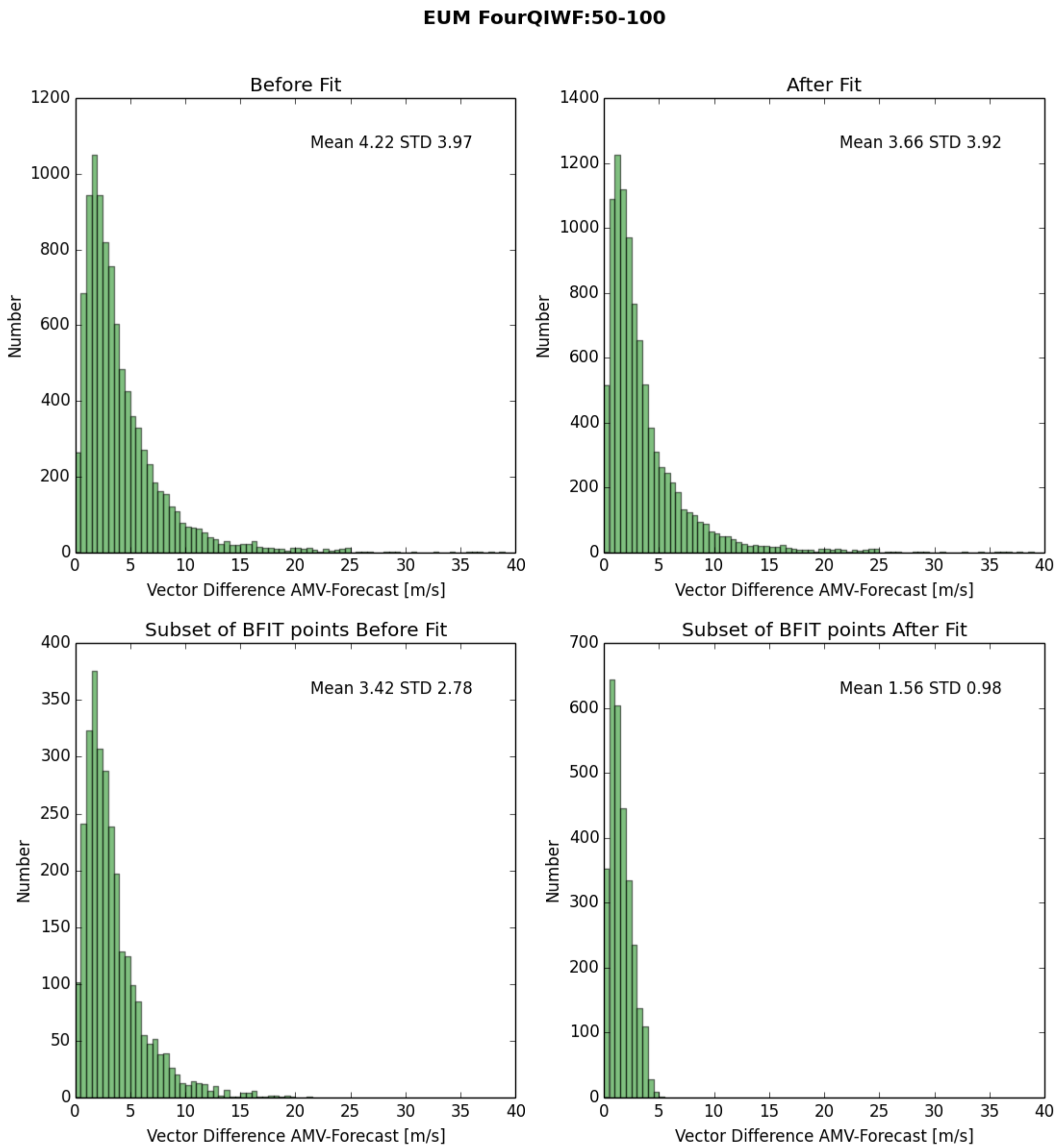

Figure 169: EUM: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

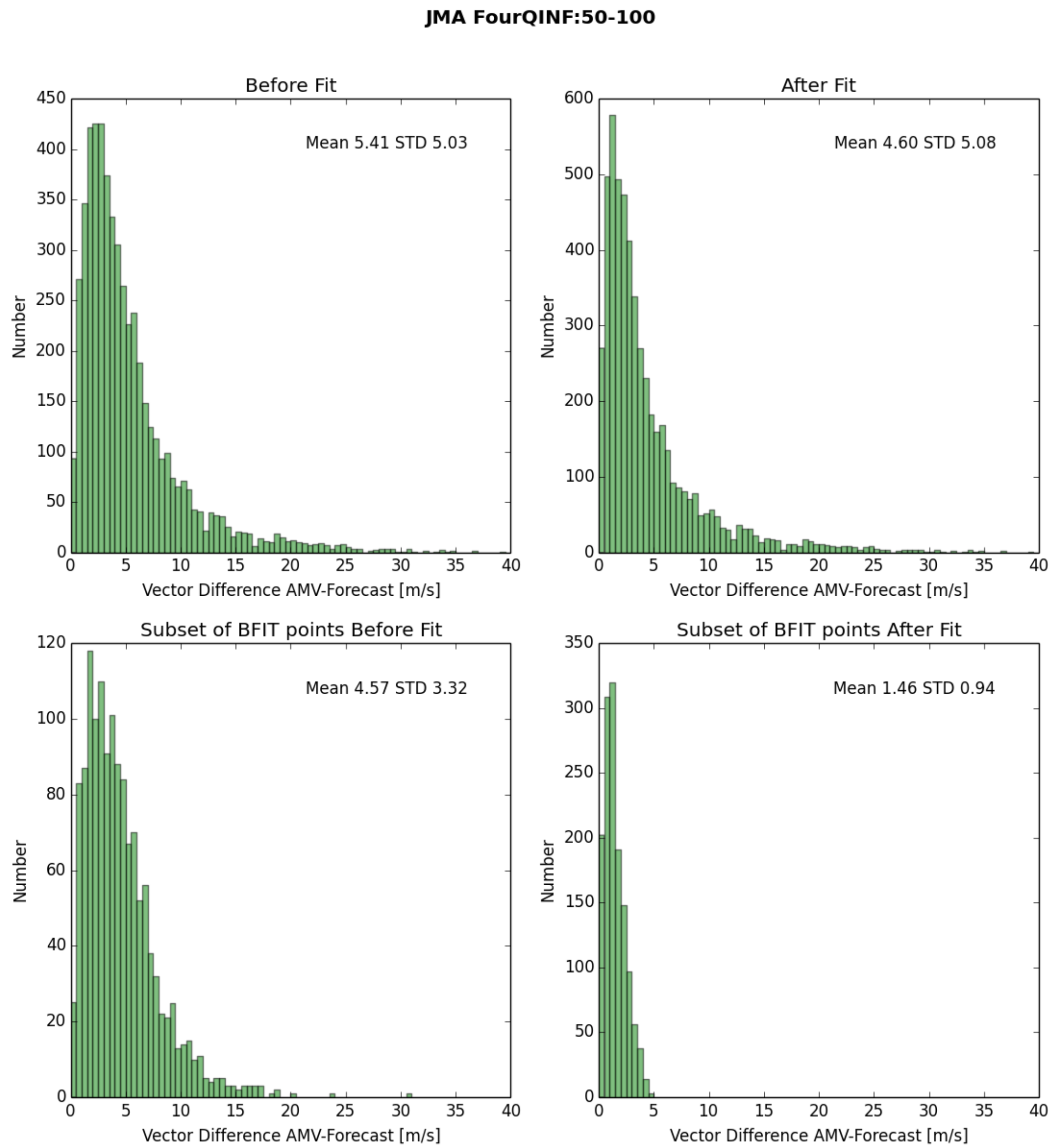

Figure 170: JMA: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

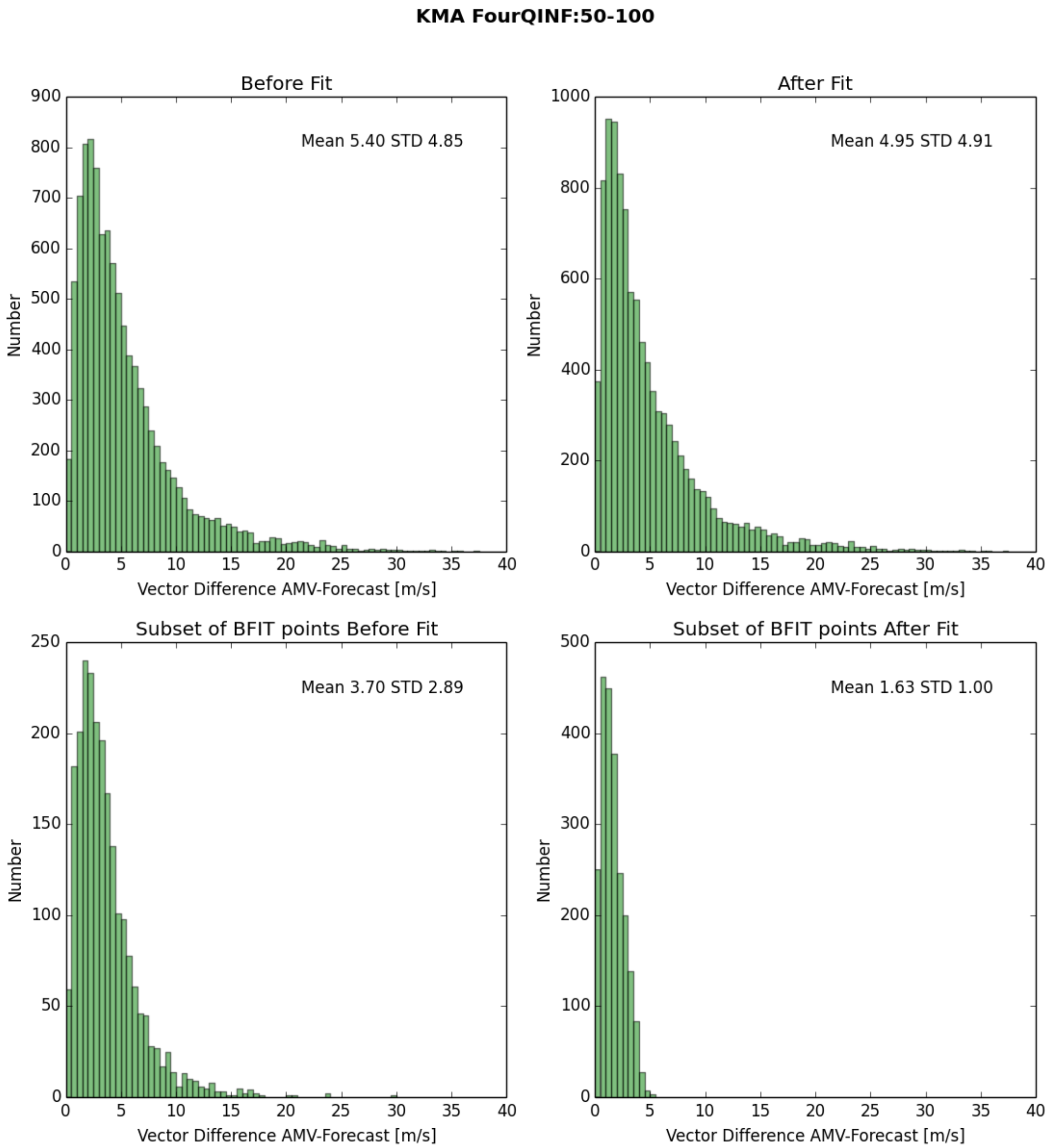

Figure 171: KMA: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

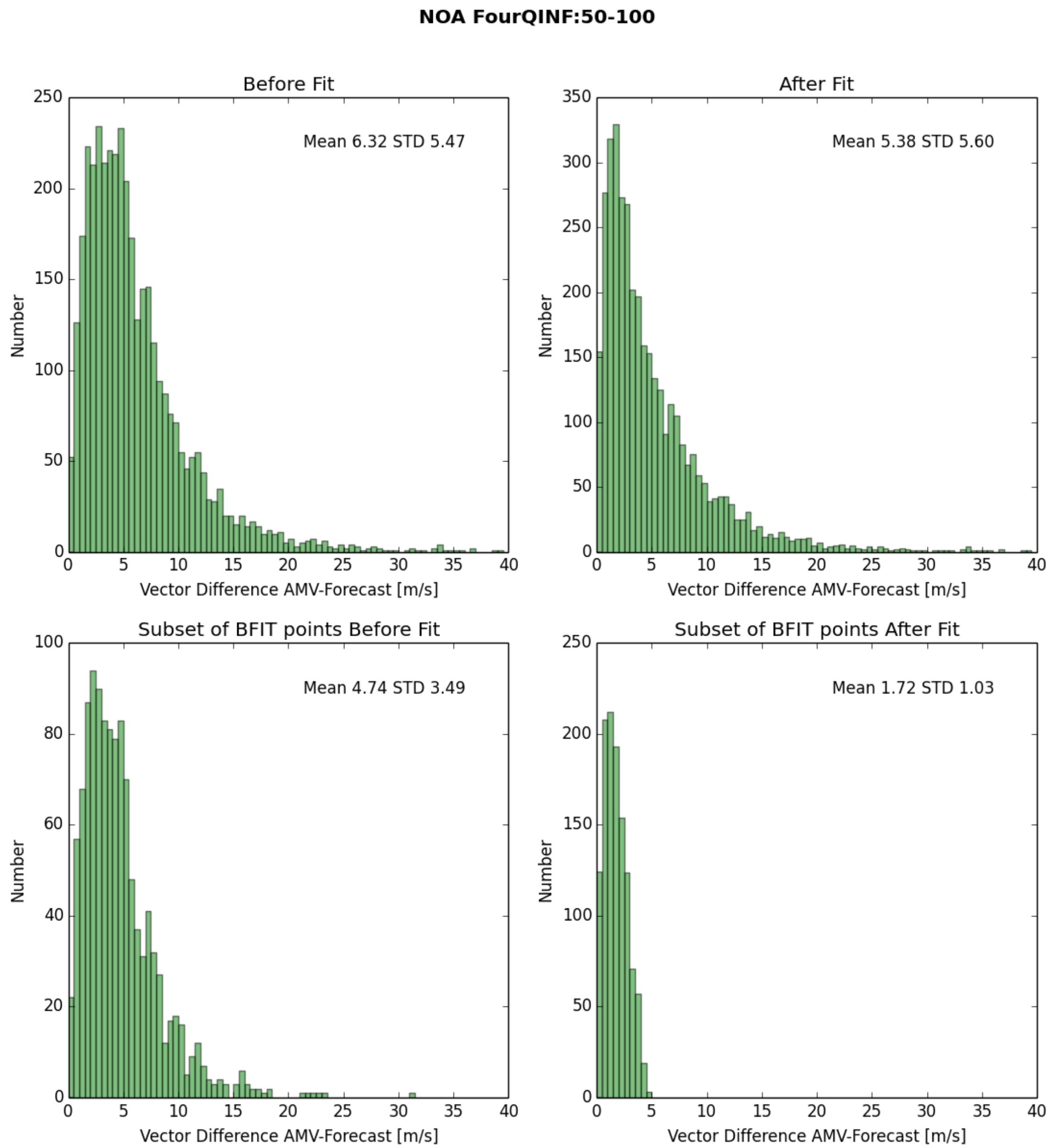

Figure 172: NOA: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

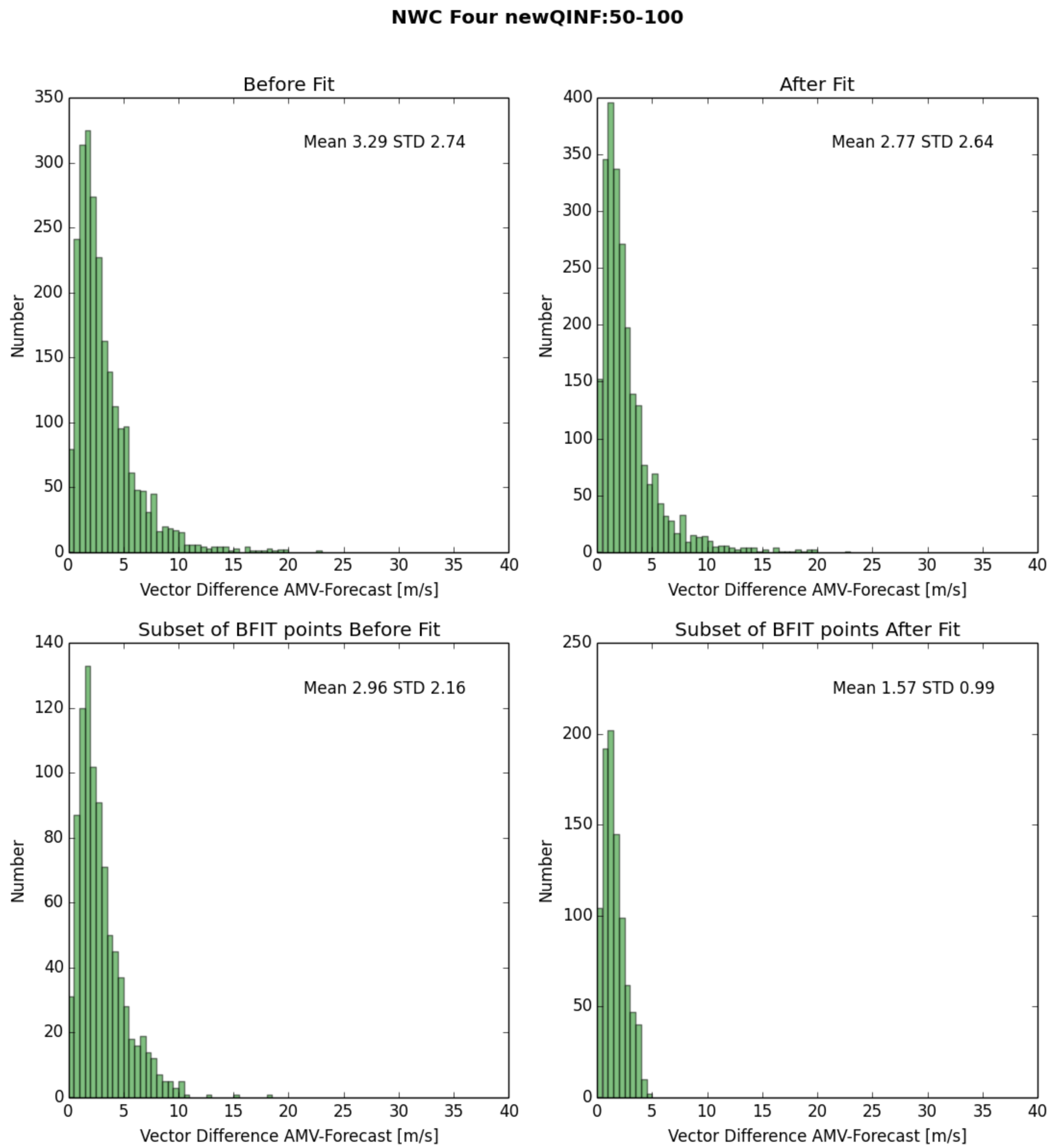

Figure 173: NWC: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

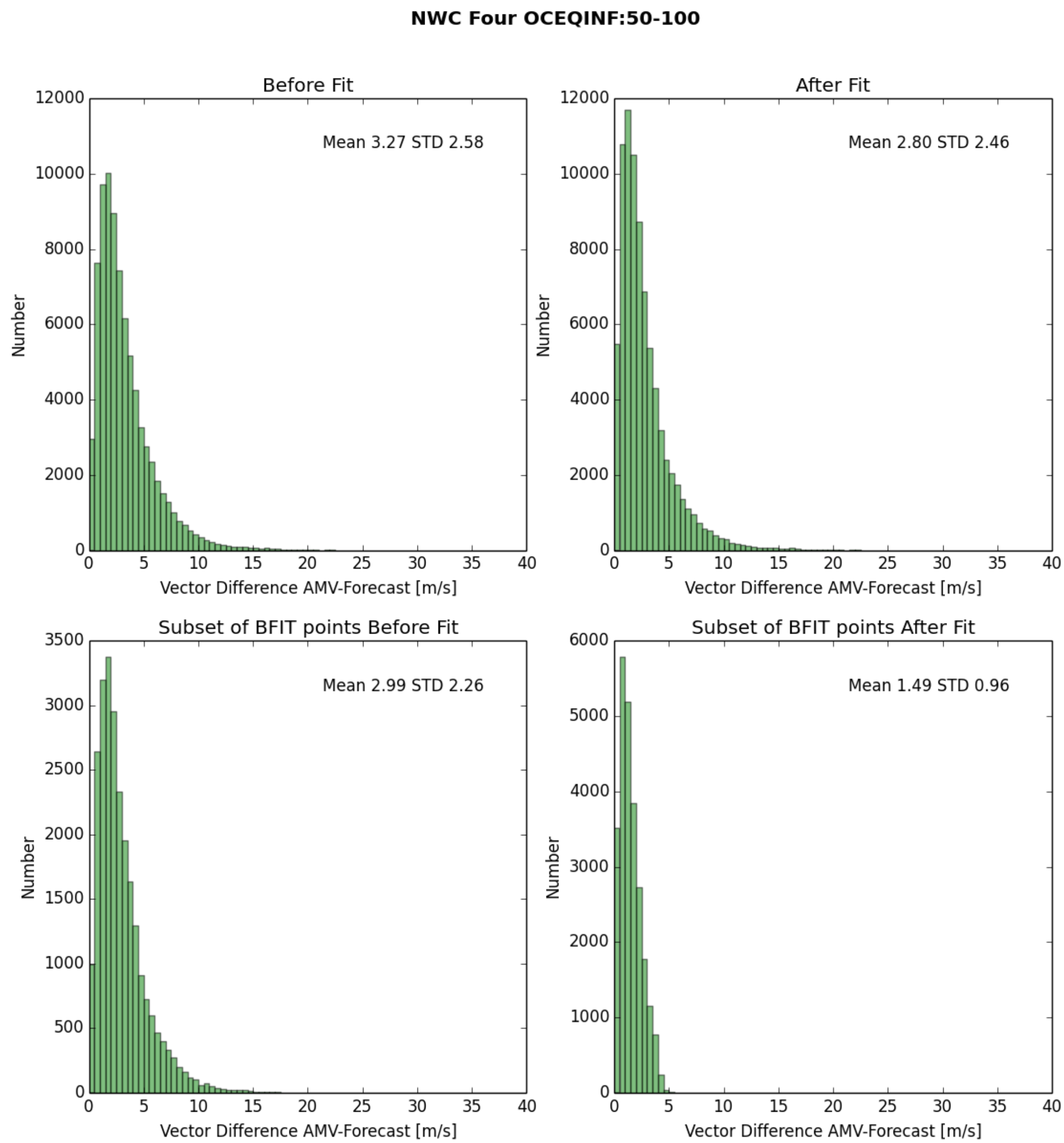

Figure 174: NWC: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

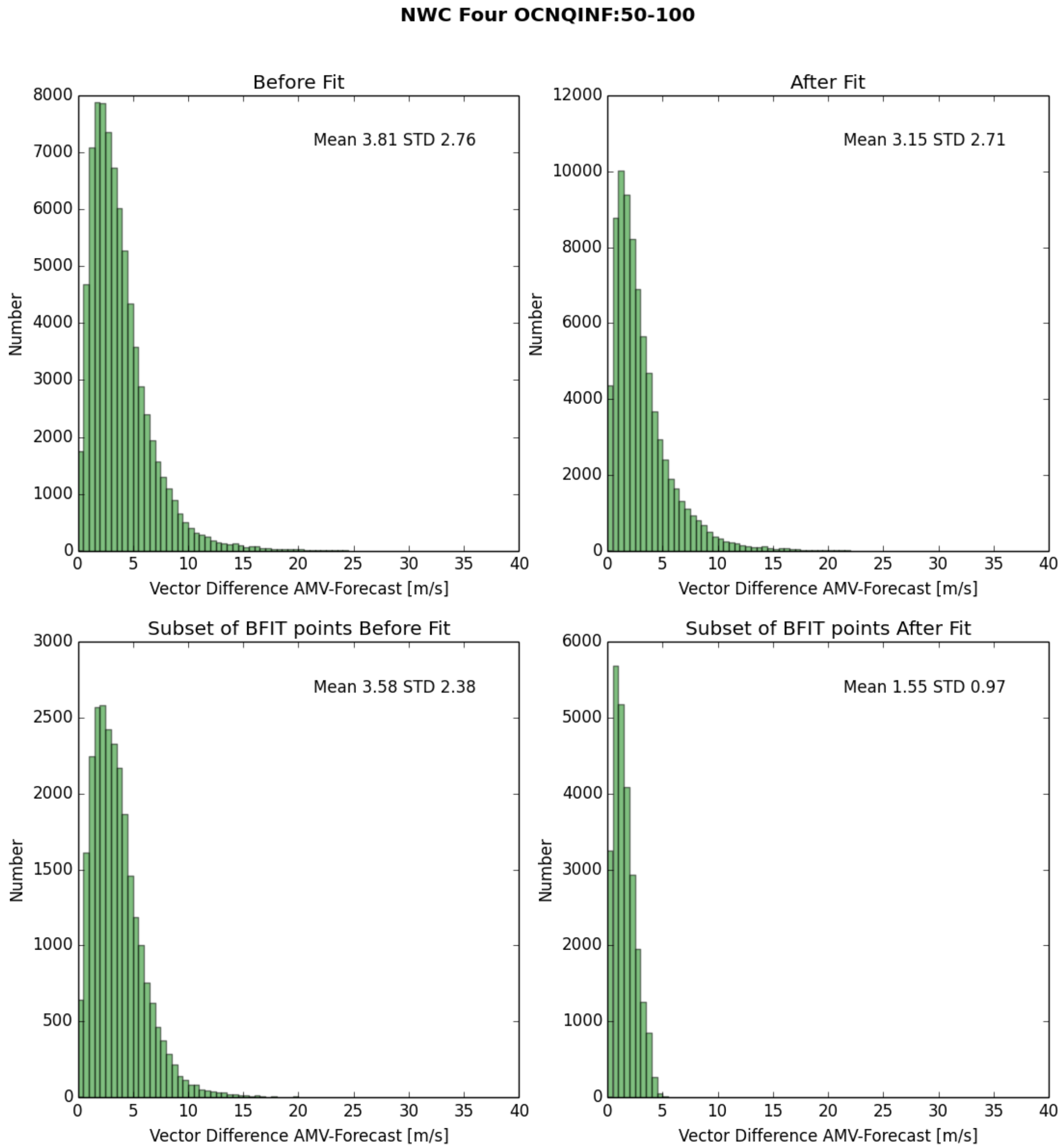

Figure 175: NWC: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

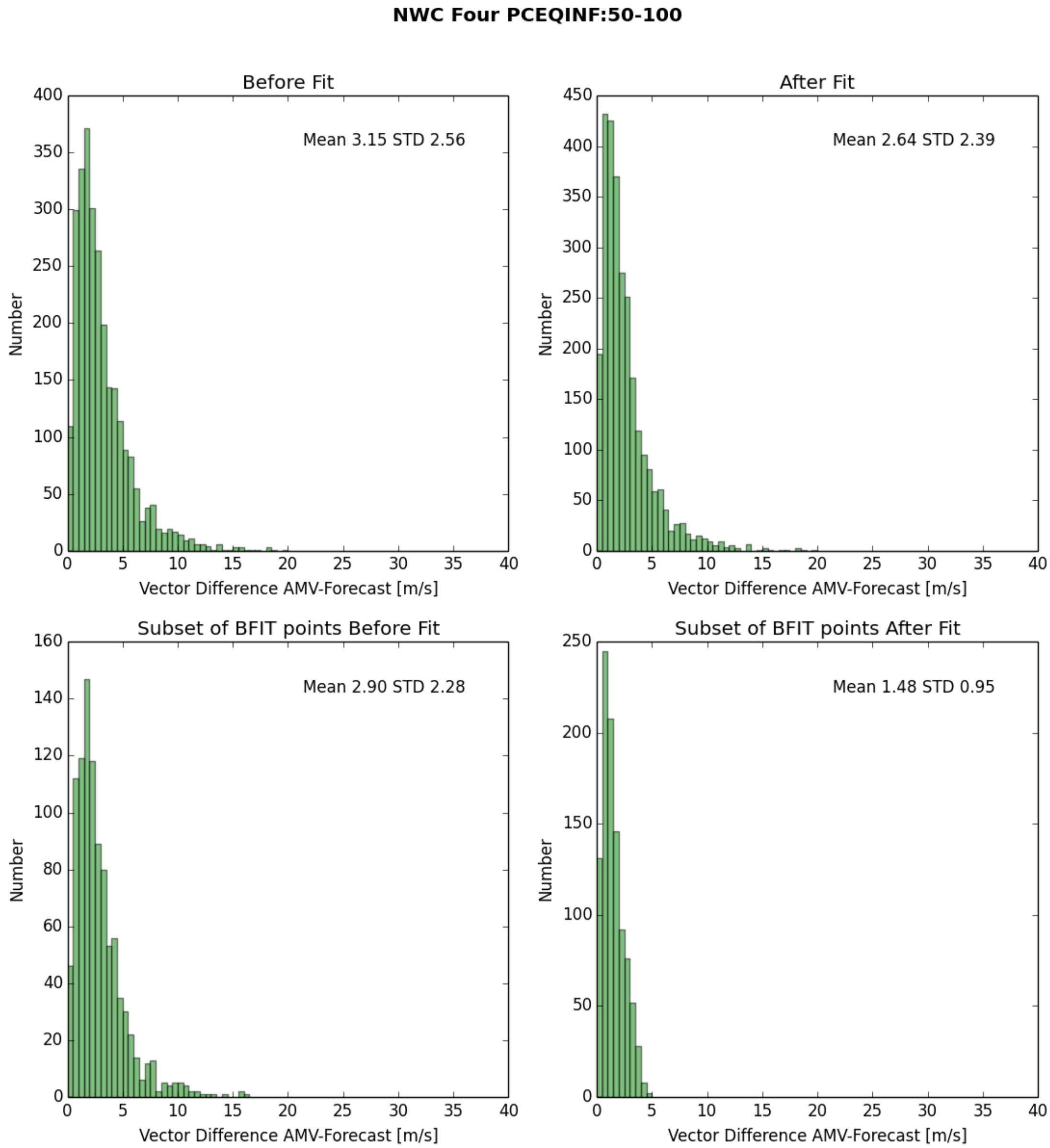

Figure 176: NWC: AMV – background vector difference distribution of all AMVs (upper left); AMV – background vector difference distribution of all AMVs, including those that are Best Fit adjusted. (upper right); AMV – background vector difference distribution of Best Fit AMVs (lower left); AMV – background vector difference distribution of Best Fit AMVs, after Best Fit adjustment (lower right).

18. Appendix E: Shell Scripts

These scripts were used to preprocess the text files.

input_fix.sh

input_fix.sh replaces semi-colons with 5 spaces in the text files.

This script ran on 'granite'. A copy is stored on 'tinman' 1 Oct 2013:
/Users/daves/Desktop/Intercomparison/Max_Mindock/AMVIntercomparisonFinalData16Apr2013/ZMiscellaneous/

```
#**********************************************************************
# input_fix.sh
# This script does a recursive, case sensitive directory search and replace of
files
# To make a case insensitive search replace, use the -i switch in the grep call
# uses a startdirectory parameter so that you can run it outside of specified
directory - else this script will modify itself!
#**********************************************************************

!/bin/bash
# **************** Change Variables Here ************
startdirectory="/Users/mmindock/Desktop/AMVIntercomparisonFinalData16Apr2013/Ja
pan/GoodData/*.csv"
searchterm="N/A"
replaceterm="0"
# **********************************************************

echo "******************************************"
echo "* Search and Replace in Files Version .1 *"
echo "******************************************"

        for file in $(grep -l -R $searchterm $startdirectory)
          do
           sed 's/;/     /g' $file > output.txt
           mv output.txt $file
           echo "Modified: " $file
        done

echo " *** Yay! All Done! *** "
```

19. Appendix F: Best-Fit Python Scripts

These scripts compute the Best-Fit pressure.

test_amv.py

Determines AMV best-fit pressure with respect to model background.

On ‘verdandi’ 16 Jan 2014: /home/snebuda/icomp/python/save/
On tinman 21 Jan 2014: /Users/daves/Desktop/Intercomparison/BestFit

```
#!/usr/bin/env python

import os, os.path
import sys

import numpy as np
import amv as amv

import matplotlib as mpl
import matplotlib.pyplot as plt
from mpl_toolkits.basemap import Basemap

from matplotlib.colors import LogNorm
from pylab import *

undef = -9999.

# European data
file_amv='EUMETSATDatasetTwo.csv'
file_fig='amv.europe.png'
fig_title='European AMV Data'

# Chinese data
file_amv='ChinaDatasetTwo.csv'
file_fig='amv.china.png'
fig_title='Chinese AMV Data'

print "Reading amv data file: "  + file_amv
amv_data = amv.read_txt(file_amv)

print "Reading forecast file"
file_fcst = 
'/home/daves/intercomparison/nominal/DecodedForecast_20120917070613Z_2012091712
0000Z_12_O_MPFS03'
fcst_data = amv.read_DecodedForecast_MSG(file_fcst)

print "Finding grid location"
grid_i,grid_j = amv.locate(amv_data,fcst_data)

print "Finding best fit"
amv_num = amv_data.shape[1]
amv_bfit=np.empty(amv_num)
bfit_flag=np.empty(amv_num)

print 'Number of AMV {0}'.format(amv_num)

n = 0
while (n < amv_num):
    amv_single = amv_data[:,n]
    fcst_profile = fcst_data[grid_i[n],grid_j[n],:,:]
    amv_bfit[n],bfit_flag[n] = amv.bestfit(amv_single,fcst_profile)
    n += 1

amv_prs = amv_data[4,:]
amv_lat = amv_data[2,:]
amv_lon = amv_data[3,:]
```

```
#Compute change in pressure for AMV best fit
dp = amv_bfit[amv_bfit !=undef] - amv_prs[amv_bfit !=undef]
dp_x = amv_lon[amv_bfit != undef]
dp_y = amv_lat[amv_bfit != undef]
dp_x_none = amv_lon[amv_bfit == undef]
dp_y_none = amv_lat[amv_bfit == undef]
dp_x_down = amv_lon[amv_bfit > amv_prs]
dp_y_down = amv_lat[amv_bfit > amv_prs]
dp_x_up = amv_lon[(amv_bfit != undef) & (amv_bfit < amv_prs)]
dp_y_up = amv_lat[(amv_bfit != undef) & (amv_bfit < amv_prs)]

frac = np.empty(4)
flag_title=['Found','Not Constrained','No sufficient minimum','No forecast
pressure match']
for f in range (4):
    frac[f] = float((bfit_flag == f).sum()) / float(amv_num)

x=amv_data[3,:]
y=amv_data[2,:]

fig = plt.figure(figsize=(12,12))

plt.subplot(3,2,1)
num_bins=50
n,bins,patches = plt.hist(x,num_bins,facecolor='green',alpha=0.5)
n,bins,patches = plt.hist(dp_x,num_bins,facecolor='orange',alpha=0.5)
plt.xlim(-60.,60.)
plt.ylim(0.,600.)
plt.xlabel('Longitudes')
plt.ylabel('Number')
plt.title(r'Green all AMV, Yellow found best fit')

plt.subplot(3,2,3)
num_bins=50
n,bins,patches = plt.hist(y,num_bins,facecolor='green',alpha=0.5)
n,bins,patches = plt.hist(dp_y,num_bins,facecolor='orange',alpha=0.5)
plt.xlim(-60.,60.)
plt.ylim(0.,600.)
plt.xlabel('Latitudes')
plt.ylabel('Number')
#plt.title(r'Green all AMV, Yellow found best fit')

plt.subplot(4,2,7)
#not enough flag=3 to plot for these test cases
labels=flag_title[0:3]
sizes=frac[0:3]
colors=['lightblue','orange','lightgreen','red']
plt.pie(sizes,labels=labels,colors=colors,autopct='%.0f%%')
plt.axis('equal')

plt.subplot(2,2,2)
num_bins=50
n,bins,patches = plt.hist(dp,num_bins,facecolor='blue',alpha=0.5)
plt.xlim(-300.,300.)
plt.ylim(0.,100.)
plt.xlabel('dp')
plt.ylabel('Number')
plt.title(r'Histogram of AMV Best Fit - Original Pressure')

plt.subplot(2,2,4)
```

```
plt.scatter(dp_x_none,dp_y_none,s=1,color='0.8')
plt.scatter(dp_x_up,dp_y_up,s=1,color='r')
plt.scatter(dp_x_down,dp_y_down,s=1,color='b')
m = Basemap(projection='cyl',llcrnrlat=-80.,urcrnrlat=80.,llcrnrlon=-
80.,urcrnrlon=80.,resolution='c')
m.drawcoastlines()
plt.title(r'Grey no fit, Red higher, Blue lower ')

plt.figtext(0.5,0.96,fig_title,ha='center',color='black',weight='bold',size='la
rge')

#plt.show()
plt.gcf().set_size_inches(13, 13)
plt.savefig(file_fig)
plt.clf()

print "wrote figure file: "  + file_fig
```

amv.py

```
#!/usr/bin/env python

import os, os.path
import sys
import numpy as np
import math

def read_txt(file):

    undef = -9999.0

# count the valid AMV
    amv_num = 0
    with open(file,'r') as f:
        for line in f:
            try:
                amv_list=parse_amv(line)
                if (amv_list[0] != undef):
                    amv_num +=1
            except:
                continue
    f.closed

# allocate np arrays
    amv_spd = np.empty(amv_num)
    amv_dir = np.empty(amv_num)
    amv_prs = np.empty(amv_num)
    amv_lat = np.empty(amv_num)
    amv_lon = np.empty(amv_num)

# read again to fill np arrays
    count = 0
    with open(file,'r') as f:
        for line in f:
            try:
                amv_list=parse_amv(line)
                if (amv_list[0] != undef):
                    amv_spd[count] = amv_list[0]
                    amv_dir[count] = amv_list[1]
```

```
                    amv_lat[count] = amv_list[2]
                    amv_lon[count] = amv_list[3]
                    amv_prs[count] = amv_list[4]
                    count +=1
            except:
                continue
    f.closed

# place in one variable for convenience
    amv_data = np.vstack((amv_spd,amv_dir,amv_lat,amv_lon,amv_prs))

    return amv_data



def parse_amv(line):

# contain format of text file and data checking in one function

    undef = -9999.0

    tlat = 1 ; vlat=[-61.,61.]
    tlon = 2 ; vlon=[-61.,61.]
    tspd = 5 ; vspd=[0.,150.]
    tdir = 6 ; vdir=[0.,361.]
    tprs = 7 ; vprs=[10.,1020.]

    token=line.split()

    lat=undef
    lon=undef
    spd=undef
    dir=undef
    prs=undef
    #print 'lat {0} lon {1} spd {2} dir {3} prs
{4}'.format(token[tlat],token[tlon],token[tspd],token[tdir],token[tprs])

# basic valid data check, could add QI or other flag check here
    valid=True
    if (float(token[tlat]) < vlat[0]) or (float(token[tlat]) > vlat[1]):
        valid=False
    if (float(token[tlon]) < vlon[0]) or (float(token[tlon]) > vlon[1]):
        valid=False
    if (float(token[tspd]) < vspd[0]) or (float(token[tspd]) > vspd[1]):
        valid=False
    if (float(token[tdir]) < vdir[0]) or (float(token[tdir]) > vdir[1]):
        valid=False
    if (float(token[tprs]) < vprs[0]) or (float(token[tprs]) > vprs[1]):
        valid=False

    if (valid):
        lat = float(token[tlat])
        lon = float(token[tlon])
        spd = float(token[tspd])
        dir = float(token[tdir])
        prs = float(token[tprs])

    amv_list = [spd,dir,lat,lon,prs]

    return amv_list
```

```
def write_txt(file,amv_data):

    amv_num  = np.size(amv_data,axis=1)

    with open(file,'w') as f:
        out_string=file+" spd,dir,lat,lon,prs"
        f.write(out_string)
        f.write("\n")
        i = 0
        while (i<amv_num):
            out_string="{0} {1} {2} {3}
{4}".format(amv_data[0,i],amv_data[1,i],amv_data[2,i],amv_data[3,i],amv_data[4,
i])
            f.write(out_string)
            f.write("\n")

            i +=1
    f.closed

    return

def read_DecodedForecast_MSG(file):

    """Usage: DecFcst = read_DecodedForecast_MSG(file)
    where, e.g.:
    file = '[...]/DecodedForecast_20120503070606Z_20120503120000Z_12_V_MPFS07'
    """

#     Decoded forecast header (4,776 bytes)
#     Decoded_Forecast_Header = BYTARR(4776)

#     Decoded forecast data point (40 bytes)
#     Decoded_Forecast_Point = {Latitude      : FLOAT(0), $
#                              Longitude     : FLOAT(0), $
#                              Pressure      : FLOAT(0), $
#                              Geopotential  : FLOAT(0), $
#                              Temperature   : FLOAT(0), $
#                              WVMixingRatio : FLOAT(0), $
#                              O3MixingRatio : FLOAT(0), $
#                              WindSpeed     : FLOAT(0), $
#                              WindDirection : FLOAT(0), $
#                              DewPointTemp  : FLOAT(0)}
#   Decoded forecast data array (29,160,000 bytes)
#   Decoded_Forecast_Array = REPLICATE(Decoded_Forecast_Point, 40L * 135L *
135L)

# This could input defined
    num_x = 135
    num_y = 135
    num_var = 10
    num_lev = 40
    num_pt = num_x * num_y
    arrout = np.zeros((num_x,num_y,10,40))

#   Open file and skip header
    fo = open(file)
    fo.seek(4776)

    print "Program is reading decoded forecast data:" + file
```

```
#   '>f4' is float which is big-endian
    forecast=np.fromfile(fo,dtype=('>f4'))
    fo.close()
    fore=np.reshape(forecast,(num_pt,num_lev,num_var))

    latitude      = fore[:,:,0]
    longitude     = fore[:,:,1]
    pressure      = fore[:,:,2]
    geopotential  = fore[:,:,3]
    temperature   = fore[:,:,4]
    wvmixingratio = fore[:,:,5]
    o3mixingratio = fore[:,:,6]
    windspeed     = fore[:,:,7]
    winddirection = fore[:,:,8]
    dewpointtemp  = fore[:,:,9]

    for j in range(num_pt):

#hardwired for this input file
        x = np.floor(longitude[j,0] + 67)
        y = np.floor(latitude[j,0] + 67)

        arrout[x,y,0,:] = pressure[j,:]
        arrout[x,y,1,:] = geopotential[j,:]
        arrout[x,y,2,:] = temperature[j,:]
        arrout[x,y,3,:] = wvmixingratio[j,:]
        arrout[x,y,4,:] = o3mixingratio[j,:]
        arrout[x,y,5,:] = windspeed[j,:]
        arrout[x,y,6,:] = winddirection[j,:]
        arrout[x,y,7,:] = dewpointtemp[j,:]
        arrout[x,y,8,:] = latitude[j,:]
        arrout[x,y,9,:] = longitude[j,:]

    return arrout


def locate(amv_data,fcst_data):

    amv_num  = np.size(amv_data,axis=1)
    grid_i = np.zeros(amv_num)
    grid_j = np.zeros(amv_num)
    fcst_lat  = fcst_data[:,:,8,0]
    fcst_lon  = fcst_data[:,:,9,0]
    numx = np.size(fcst_data,axis=0)
    numy = np.size(fcst_data,axis=1)

    n = 0
    while (n<amv_num):
        amv_lat  = amv_data[2,n]
        amv_lon  = amv_data[3,n]
        grid_diff = (amv_lat-fcst_lat)**2 + (amv_lon-fcst_lon)**2
        indx= np.argmin(grid_diff)
        indx_2d=np.unravel_index(indx,(numx,numy))
        grid_i[n] = indx_2d[0]
        grid_j[n] = indx_2d[1]
        n +=1

    return grid_i,grid_j
```

```
def bestfit(amv_data,fcst_data):

    """Finds the background model best fit pressure associated with the AMV.
       The model best-fit pressure is the height (in pressure units) where the
       vector difference between the observed AMV and model background is a
       minimum.  This calculation may only work approximately 1/3 of the time.

       Reference:
       Salonen et al (2012), "Characterising AMV height assignment error by
       comparing best-fit pressure statistics from the Met Office and ECMWF
       System."  Proceedings of the 11th International Winds Workshop,
       Auckland, New Zealand, 20-24 February 2012.

       Input contained in amv_data and fcst_data:
       amv_spd -  AMV speed m/s
       amv_dir -  AMV direction deg
       amv_prs -  AMV pressure hPa
       fcst_spd - (level) forecast speed m/s
       fcst_dir - (level) forecast direction (deg)
       fcst_prs - (level) forecast pressure (hPa)

       Output:
       amv_bfit - AMV best fit pressure m/s, unconstrained value is undef
       flag - 0 found, 1 not contrained, 2 vec diff minimum not met, 3 failed
to find suitable fcst pressure match

       History:
       10/2012 - Steve Wanzong - Created in Fortran
       10/2013 - Sharon Nebuda - rewritten for python
    """
    undef = -9999.0

    amv_spd = amv_data[0]
    amv_dir = amv_data[1]
    amv_prs = amv_data[4]
    amv_lat = amv_data[2]
    amv_lon = amv_data[3]

    fcst_spd = fcst_data[5,:]
    fcst_dir = fcst_data[6,:]
    fcst_prs = fcst_data[0,:]
    fcst_lat = fcst_data[8,0]
    fcst_lon = fcst_data[9,0]

    fcst_num_levels = fcst_spd.shape[0]

#   verbose = True
    verbose = False

    SatwindBestFitPress = undef
    SatwindBestFitU = undef
    SatwindBestFitV = undef

    PressDiff = 150.                      # pressure above and below AMV to
look for fit
    TopPress = 50.                        # highest level to allow search

    flag = 3

    #print " AMV location lat,lon,prs
```

```
({0},{1},{2})".format(amv_lat,amv_lon,amv_prs)

    if (amv_prs<TopPress):
        if (verbose):
            print " AMV location lat,lon,prs ({0},{1},{2}) is higher than
pressure {3}".format(amv_lat,amv_lon,amv_prs,TopPress)
        return undef

#Calculate the pressure +/- 150 hPa from the AMV pressure.
    PressMax = amv_prs + PressDiff
    PressMin = max((amv_prs-PressDiff),TopPress)

#1d array of indicies to consider for best fit location
    kk = np.where((fcst_prs<PressMax) & (fcst_prs>PressMin))
    if (len(kk[0]) ==0):
        if (verbose):
            print " AMV location lat,lon,prs ({0},{1},{2}) failed to find fcst
prs around AMV".format(amv_lat,amv_lon,amv_prs)
        return undef

#Diagnostic field: Find the model minimum speed and maximum speed within
PressDiff of the AMV.
    if (verbose):
        SatwindMinSpeed = min(fcst_spd[kk])
        SatwindMaxSpeed = max(fcst_spd[kk])

#Compute U anv V for both AMVs and forecast
# fix this
    amv_uwind = -amv_spd * np.sin(math.radians(amv_dir))
    amv_vwind = -amv_spd * np.cos(math.radians(amv_dir))
#   fcst_uwind = -fcst_spd[:] * np.sin(math.radians(fcst_dir[:]))
#   fcst_vwind = -fcst_spd[:] * np.cos(math.radians(fcst_dir[:]))
    dr=0.017453
    fcst_uwind = -fcst_spd * np.sin(dr*fcst_dir)
    fcst_vwind = -fcst_spd * np.cos(dr*fcst_dir)

#Calculate the vector difference between the AMV and model background at all
levels.
    VecDiff = np.sqrt((amv_uwind - fcst_uwind) ** 2 + (amv_vwind - fcst_vwind)
** 2)

#Find the model level of best-fit pressure, from the minimum vector difference.
    MinVecDiff = min(VecDiff[kk])
    imin=-1
    for i, item in enumerate(VecDiff):
        if MinVecDiff == VecDiff[i]:
            if i in kk[0]:
                imin = i

    if (imin ==-1 ):
        if (verbose):
            print " AMV location lat,lon,prs ({0},{1},{2}) failed to find min
vector difference in layers around AMV".format(amv_lat,amv_lon,amv_prs)

        return undef


#Use a parabolic fit to find the best-fit pressure.
#p2 - Minimized model pressure at level imin (hPa)
#v2 - Minimized vector difference at level imin (m/s)
#p1 - 1 pressure level lower in atmosphere than p2
```

```
#p3 - 1 pressure level above in atmosphere than p2
#v1 - Vector difference 1 pressure level lower than p2
#v3 - Vector difference 1 pressure level above than p2

    p2 = fcst_prs[imin]
    v2 = VecDiff[imin]

# assumes fcst data level 0 at surface and (fcst_num_levels-1) at model top
#if bottom model level
    if imin == 0:
        SatwindBestFitPress = p2
    else:
        p3 = fcst_prs[imin+1]
        p1 = fcst_prs[imin-1]
        v3 = VecDiff[imin+1]
        v1 = VecDiff[imin-1]

#if top of allowed region
        if p3 < TopPress:
            SatwindBestFitPress = p2

#check not collinear
        elif (v1 != v2 and v2 != v3):
            SatwindBestFitPress = p2 - (0.5 *
            ((((p2 - p1) * (p2 - p1) * (v2 - v3)) - ((p2 - p3) * (p2 - p3) *
(v2 - v1))) /
            (((p2 - p1) * (v2 - v3)) - ((p2 - p3) * (v2 - v1)))))
            if (SatwindBestFitPress < p3) or (SatwindBestFitPress > p1):
                if (verbose):
                    print " Best Fit not found between two pressure layers"
                    print " SatwindBestFitPress {0} p1 {1} p2 {2} p3 {3} imin
{4} ".format(SatwindBestFitPress,p1,p2,p3,imin)
                SatwindBestFitPress = p2
        else:
            SatwindBestFitPress = p2

#Find best fit U and V by linear interpolation.
    if (verbose):
        if p2 == SatwindBestFitPress:
            SatwindBestFitU = fcst_uwind[imin]
            SatwindBestFitV = fcst_vwind[imin]
        else:
            if p2 < SatwindBestFitPress:
                LevBelow = imin - 1
                LevAbove = imin
                Prop = (SatwindBestFitPress - p1) / (p2 - p1)
            else:
                LevBelow = imin
                LevAbove = imin + 1
                Prop = (SatwindBestFitPress - p2) / (p3 - p2)

            SatwindBestFitU = fcst_uwind[LevBelow] * (1.0 - Prop) +
fcst_vwind[LevAbove] * Prop
            SatwindBestFitV = fcst_uwind[LevBelow] * (1.0 - Prop) +
fcst_vwind[LevAbove] * Prop


# Check to see if the best fit pressure is constrained.

    SatwindGoodConstraint = 0
    flag = 2
```

```
    if MinVecDiff <= 4.0:

        SatwindGoodConstraint = 1
        flag = 1

        for ilev in range(fcst_num_levels):
            if fcst_prs[ilev] >= TopPress:

                if ((fcst_prs[ilev] < (SatwindBestFitPress - 100.)) or  \
                   (fcst_prs[ilev] > (SatwindBestFitPress + 100.))) and  \
                   (VecDiff[ilev] <= (MinVecDiff + 2.0)):
                   SatwindGoodConstraint = 0

    if SatwindGoodConstraint == 1:
        amv_bfit = SatwindBestFitPress
        flag = 0
    else:
        amv_bfit = undef

    if (verbose):
        print "*** AMV best-fit ***"
        print "AMV -> p/minspd/maxspd: {0} {1}
{2}".format(amv_prs,SatwindMinSpeed,SatwindMaxSpeed)
        print "Bestfit -> p1,p2,p3,v1,v2,v3: {0} {1} {2} {3} {4}
{5}".format(p1,p2,p3,v1,v2,v3)
        print "Bestfit -> pbest,bfu,bfv,obu,obv,bgu,bgv: {0} {1} {2} {3} {4}
{5} {6}".format(

SatwindBestFitPress,SatwindBestFitU,SatwindBestFitV,amv_uwind,amv_vwind,fcst_uw
ind[imin],fcst_vwind[imin])
        print "Good Constraint: {0}".format(SatwindGoodConstraint)
        print "Minimum Vector Difference: {0}".format(VecDiff[imin])
        print "Vector Difference Profile: "
        print VecDiff
        print "Pressure Profile: "
        print fcst_prs

        if (abs(SatwindBestFitU - amv_uwind) > 4.0) or  (abs(SatwindBestFitV -
amv_vwind) > 4.0):
            print 'U Diff: {0}'.format(abs(SatwindBestFitU - amv_uwind))
            print 'V Diff: {0}'.format(abs(SatwindBestFitV - amv_vwind))

    return amv_bfit,flag
```

20. Appendix G: Matlab Scripts

The Matlab scripts are similar to the ones used by Iliana Genkova in the earlier AMV intercomparison studies, but were modified to:

- Use distance in kilometers instead of degrees of latitude and longitude for determining colocated AMVs.
- Truncate or round values for better comparison if producers reported values with differing precision.

Winds_Bulk_QINF.m

On ‘tinman’ 11 March Dec 2014:
/Users/daves/Documents/MATLAB/Intercomparison

```
% old data colums - see email to Dave Stettner
% doublecheck.... test with new data, sent away!


% new data columns
% 1. IDN
% 2. LAT[DEG]
% 3. LONG[DEG]
% 4. TBOX[PIX]
% 5. SBOX[PIX]
% 6. SPD[MPS]
% 7. DIR[DEG]
% 8. P[HPA]
% 9. LOWL
% 10.MSPD[MPS]
% 11.MDIR[DEG]
% 12.ALB[%]
% 13.CORR[%]
% 14.TMET
% 15.PERR[HPA]
% 16.HMET
% 17.QINF[%]
% 18.QIF[%]

clear;

% Set exp: 2,3,4
exp=4

qitype=17  % QI with forecast (18) or without (17)

if (exp == 2 )
    fall= {'BrazilDatasetTwo.csv',  'EUMETSATDatasetTwo.csv',
'JapanDatasetTwoNew.csv', 'KoreaDatasetTwo.csv', 'NOAADatasetTwo.csv',
'NWCSAFDatasetTwo_O_ET_E.csv',};
    fsym= {'b.'                 , 'ro'                    , 'y'
, 'g^'                  , 'k+'                , 'ms'};
    tbsize=[32 24 24 24 19 24];
end

if (exp == 3 )
   fall= {'BrazilDatasetThree.csv', 'EUMETSATDatasetThree.csv',
'JapanDatasetThreeNew.csv', 'KoreaDatasetThree.csv', 'NOAADatasetThree.csv',
'NWCSAFDatasetThree_P_ET_E.csv',};
   fsym= {'b.'                    , 'ro'                      ,  'y'
, 'g^'                    , 'k+'                  , 'ms'};
   tbsize=[24 24 24 24 24 24];
end

if (exp == 4 )
    fall= {'BrazilDatasetFour.csv', 'EUMETSATDatasetFour.csv',
'JapanDatasetFourNew.csv', 'KoreaDatasetFour.csv', 'NOAADatasetFour.csv',
'NWCSAFDatasetFour_O_C_E.csv',};
```

```
    fsym= {'b.'                   , 'ro'                    , 'y'
, 'g^'                  , 'k+'                 , 'ms'};
    tbsize=[24 24 24 24 24 24];
end

%    figure;
for i=1:6
    fname=fall{i};
    a=load(fname);

    %Remove records with invalid pressure
    abad=find(a(:,8)==0);
    a(abad,:)=[];

    %Remove records with invalid latitude
    abad=find(a(:,2) >  90);
    a(abad,:)=[];
    abad=find(a(:,2) < -90);
    a(abad,:)=[];

    spd25=find(a(:,6)>=2.5);
    a=a(spd25,:);
    good_50=find(a(:,qitype)>=50);
    good_80=find(a(:,qitype)>=80);
    figure;
    subplot(2,3,1);
    hold on;
    plot(a(:,3),a(:,2),'r.');
    plot(a(good_50,3),a(good_50,2),'b.');
    plot(a(good_80,3),a(good_80,2),'g.');
    legend('All AMV','QI>=50','QI>=80');
    xlabel('Lon');
    ylabel('Lat');
    title(fname);
%     plot(a(good_80,3),a(good_80,2),fsym{i});
     xlim([-50  50])
     ylim([-50  50])
%     hold on;
    disp('*************************');
    disp(fname);
    fprintf('Target box size in pixels: %d \n',tbsize(i));
    fprintf('Total num winds: %d \n',length(a(:,1)));
    fprintf('Winds QI>=50: %d \n',length(good_50));
    fprintf('Winds QI>=80: %d \n',length(good_80));

    fprintf('Lat min: %6.2f \n', min(a(:,2)));
    fprintf('Lat max: %6.2f \n', max(a(:,2)));
    fprintf('Lon min: %6.2f \n', min(a(:,3)));
    fprintf('Lon max: %6.2f \n', max(a(:,3)));

    fprintf(' \n');
    fprintf('*** For AMV with QI>=50 ***\n');

    alow=find(a(good_50,8)>=700);
    amid=find(a(good_50,8)<700 & a(good_50,8)>400);
    ahigh=find(a(good_50,8)<=400);

    fprintf('SPD min: %6.2f \n', min(a(good_50,6)));
    fprintf('SPD max: %6.2f \n', max(a(good_50,6)));
    fprintf('SPD mean: %6.2f \n', mean(a(good_50,6)));
```

```
fprintf('P min: %6.2f \n', min(a(good_50,8)));
fprintf('P max: %6.2f \n', max(a(good_50,8)));
fprintf('P mean: %6.2f \n', mean(a(good_50,8)));

fprintf('Low winds: %6.2f \n', 100*length(alow)/length(good_50) );
fprintf('Mid winds: %6.2f \n', 100*length(amid)/length(good_50) );
fprintf('High winds: %6.2f \n', 100*length(ahigh)/length(good_50) );

aa=a(good_50,:);
fprintf('Low SPD min: %6.2f \n', min(aa(alow,6)));
fprintf('Low SPD max: %6.2f \n', max(aa(alow,6)));
fprintf('Low SPD mean: %6.2f \n', mean(aa(alow,6)));

fprintf('Low P min: %6.2f \n', min(aa(alow,8)));
fprintf('Low P max: %6.2f \n', max(aa(alow,8)));
fprintf('Low P mean: %6.2f \n', mean(aa(alow,8)));

fprintf('Mid SPD min: %6.2f \n', min(aa(amid,6)));
fprintf('Mid SPD max: %6.2f \n', max(aa(amid,6)));
fprintf('Mid SPD mean: %6.2f \n', mean(aa(amid,6)));

fprintf('Mid P min: %6.2f \n', min(aa(amid,8)));
fprintf('Mid P max: %6.2f \n', max(aa(amid,8)));
fprintf('Mid P mean: %6.2f \n', mean(aa(amid,8)));

fprintf('High SPD min: %6.2f \n', min(aa(ahigh,6)));
fprintf('High SPD max: %6.2f \n', max(aa(ahigh,6)));
fprintf('High SPD mean: %6.2f \n', mean(aa(ahigh,6)));

fprintf('High P min: %6.2f \n', min(aa(ahigh,8)));
fprintf('High P max: %6.2f \n', max(aa(ahigh,8)));
fprintf('High P mean: %6.2f \n', mean(aa(ahigh,8)));

subplot(2,3,2);
hist(a(good_50,qitype)); % QI
title(['QI' ' ' fname]);

subplot(2,3,3);
hist(a(good_50,6)); % SPD
title(['SPD' ' ' fname]);

subplot(2,3,4);
hist(a(good_50,7)); % DIR
title(['DIR' ' ' fname]);

subplot(2,3,5);
hist(a(good_50,8)); % H
title(['P' ' ' fname]);

if ( exp == 2)
    saveas(gcf, ['Exp_2_QINF_' fname(1:6)], 'tif');
end

if ( exp == 3)
    saveas(gcf, ['Exp_3_QINF_' fname(1:6)], 'tif');
end

if ( exp == 4)
    saveas(gcf, ['Exp_4_QINF_' fname(1:6)], 'tif');
end
```

```
% THIS section doesn't make sense with the new data sets, as they don't have
Height Assignment Method. Best to be deleted.
% %     subplot(2,3,6);
% %     aa=a(good_50,:);
% %     if i==1
% %         ind_0=find( a(good_50,26)==1 );
% %         aa(ind_0,26)=0;
% %         ind_1=find( a(good_50,26)==14 );
% %         aa(ind_1,26)=1;
% %         ind_2=find( a(good_50,26)==2 |  a(good_50,26)==3 |
a(good_50,26)==4 |  a(good_50,26)==5 );
% %         aa(ind_2,26)=2;
% %     end;
% %     hist(aa(:,26),0:3); % HAM
% %     title(['HAM' ' ' fname]);

      %saveas(gcf,['bulk_' fname(1:3) '.tif'],'tif');

%     figure;
%     hist(a(good_50,2)); % Lat (zonal distribution)
%     title(['Lat' ' ' fname]);
%     saveas(gcf,['hist_lat_' fname(1:3) '.tif'],'tif');
%
%     figure;
%     hist(a(good_50,3)); % Lon
%     title(['Lon' ' ' fname]);
%     saveas(gcf,['hist_lon_' fname(1:3) '.tif'],'tif');
%

%     pause;
%     keyboard;

end;
```

Winds_Bulk_QIF.m

On 'tinman' 22 March Dec 2014:
/Users/daves/Documents/MATLAB/Intercomparison

```
% old data colums - see email to Dave Stettner
% doublecheck.... test with new data, sent away!


% new data columns
% 1. IDN
% 2. LAT[DEG]
% 3. LONG[DEG]
% 4. TBOX[PIX]
% 5. SBOX[PIX]
% 6. SPD[MPS]
% 7. DIR[DEG]
% 8. P[HPA]
% 9. LOWL
% 10.MSPD[MPS]
% 11.MDIR[DEG]
% 12.ALB[%]
```

```
% 13.CORR[%]
% 14.TMET
% 15.PERR[HPA]
% 16.HMET
% 17.QINF[%]
% 18.QIF[%]

clear;

% Set exp: 2,3,4
exp=4

qitype=18  % QI with forecast (18) or without (17)

if (exp == 2 )
    fall= {'ChinaDatasetTwo.csv',  'EUMETSATDatasetTwo.csv',
'JapanDatasetTwoNew.csv', 'KoreaDatasetTwo.csv', 'NOAADatasetTwo.csv',
'NWCSAFDatasetTwo_O_ET_E.csv',};
    fsym= {'b.'                 , 'ro'                    , 'y'
, 'g^'                 , 'k+'                , 'ms'};
    tbsize=[32 24 24 24 19 24];
end

if (exp == 3 )
   fall= {'ChinaDatasetThree.csv', 'EUMETSATDatasetThree.csv',
'JapanDatasetThreeNew.csv', 'KoreaDatasetThree.csv', 'NOAADatasetThree.csv',
'NWCSAFDatasetThree_P_ET_E.csv',};
   fsym= {'b.'                    , 'ro'                      ,  'y'
, 'g^'                     , 'k+'                   , 'ms'};
   tbsize=[24 24 24 24 24 24];
end

if (exp == 4 )
    fall= {'ChinaDatasetFour.csv', 'EUMETSATDatasetFour.csv',
'JapanDatasetFourNew.csv', 'KoreaDatasetFour.csv', 'NOAADatasetFour.csv',
'NWCSAFDatasetFour_O_C_E.csv',};
    fsym= {'b.'                   , 'ro'                     , 'y'
, 'g^'                   , 'k+'                 , 'ms'};
    tbsize=[24 24 24 24 24 24];
end

%    figure;
for i=1:6
    fname=fall{i};
    a=load(fname);

    %Remove records with invalid pressure
    abad=find(a(:,8)==0);
    a(abad,:)=[];

    %Remove records with invalid latitude
    abad=find(a(:,2) >  90);
    a(abad,:)=[];
    abad=find(a(:,2) < -90);
    a(abad,:)=[];

    spd25=find(a(:,6)>=2.5);
    a=a(spd25,:);
    good_50=find(a(:,qitype)>=50);
    good_80=find(a(:,qitype)>=80);
    figure;
```

```
    subplot(2,3,1);
    hold on;
    plot(a(:,3),a(:,2),'r.');
    plot(a(good_50,3),a(good_50,2),'b.');
    plot(a(good_80,3),a(good_80,2),'g.');
    legend('All AMV','QI>=50','QI>=80');
    xlabel('Lon');
    ylabel('Lat');
    title(fname);
%     plot(a(good_80,3),a(good_80,2),fsym{i});
     xlim([-50  50])
     ylim([-50  50])
%     hold on;
    disp('*************************');
    disp(fname);
    fprintf('Target box size in pixels: %d \n',tbsize(i));
    fprintf('Total num winds: %d \n',length(a(:,1)));
    fprintf('Winds QI>=50: %d \n',length(good_50));
    fprintf('Winds QI>=80: %d \n',length(good_80));

    fprintf('Lat min: %6.2f \n', min(a(:,2)));
    fprintf('Lat max: %6.2f \n', max(a(:,2)));
    fprintf('Lon min: %6.2f \n', min(a(:,3)));
    fprintf('Lon max: %6.2f \n', max(a(:,3)));

    fprintf(' \n');
    fprintf('*** For AMV with QI>=50 ***\n');

    alow=find(a(good_50,8)>=700);
    amid=find(a(good_50,8)<700 & a(good_50,8)>400);
    ahigh=find(a(good_50,8)<=400);

    fprintf('SPD min: %6.2f \n', min(a(good_50,6)));
    fprintf('SPD max: %6.2f \n', max(a(good_50,6)));
    fprintf('SPD mean: %6.2f \n', mean(a(good_50,6)));

    fprintf('P min: %6.2f \n', min(a(good_50,8)));
    fprintf('P max: %6.2f \n', max(a(good_50,8)));
    fprintf('P mean: %6.2f \n', mean(a(good_50,8)));

    fprintf('Low winds: %6.2f \n', 100*length(alow)/length(good_50) );
    fprintf('Mid winds: %6.2f \n', 100*length(amid)/length(good_50) );
    fprintf('High winds: %6.2f \n', 100*length(ahigh)/length(good_50) );

    aa=a(good_50,:);
    fprintf('Low SPD min: %6.2f \n', min(aa(alow,6)));
    fprintf('Low SPD max: %6.2f \n', max(aa(alow,6)));
    fprintf('Low SPD mean: %6.2f \n', mean(aa(alow,6)));

    fprintf('Low P min: %6.2f \n', min(aa(alow,8)));
    fprintf('Low P max: %6.2f \n', max(aa(alow,8)));
    fprintf('Low P mean: %6.2f \n', mean(aa(alow,8)));

    fprintf('Mid SPD min: %6.2f \n', min(aa(amid,6)));
    fprintf('Mid SPD max: %6.2f \n', max(aa(amid,6)));
    fprintf('Mid SPD mean: %6.2f \n', mean(aa(amid,6)));

    fprintf('Mid P min: %6.2f \n', min(aa(amid,8)));
    fprintf('Mid P max: %6.2f \n', max(aa(amid,8)));
    fprintf('Mid P mean: %6.2f \n', mean(aa(amid,8)));
```

```
    fprintf('High SPD min: %6.2f \n', min(aa(ahigh,6)));
    fprintf('High SPD max: %6.2f \n', max(aa(ahigh,6)));
    fprintf('High SPD mean: %6.2f \n', mean(aa(ahigh,6)));

    fprintf('High P min: %6.2f \n', min(aa(ahigh,8)));
    fprintf('High P max: %6.2f \n', max(aa(ahigh,8)));
    fprintf('High P mean: %6.2f \n', mean(aa(ahigh,8)));

    subplot(2,3,2);
    hist(a(good_50,qitype)); % QI
    title(['QI' ' ' fname]);

    subplot(2,3,3);
    hist(a(good_50,6)); % SPD
    title(['SPD' ' ' fname]);

    subplot(2,3,4);
    hist(a(good_50,7)); % DIR
    title(['DIR' ' ' fname]);

    subplot(2,3,5);
    hist(a(good_50,8)); % H
    title(['P' ' ' fname]);

    if ( exp == 2)
        saveas(gcf, ['Exp_2_QIF_' fname(1:6)], 'tif');
    end

    if ( exp == 3)
        saveas(gcf, ['Exp_3_QIF_' fname(1:6)], 'tif');
    end

    if ( exp == 4)
        saveas(gcf, ['Exp_4_QIF_' fname(1:6)], 'tif');
    end

% THIS section doesn't make sense with the new data sets, as they don't have
Height Assignment Method. Best to be deleted.
% %     subplot(2,3,6);
% %     aa=a(good_50,:);
% %     if i==1
% %         ind_0=find( a(good_50,26)==1 );
% %         aa(ind_0,26)=0;
% %         ind_1=find( a(good_50,26)==14 );
% %         aa(ind_1,26)=1;
% %         ind_2=find( a(good_50,26)==2 |  a(good_50,26)==3 |
a(good_50,26)==4 |  a(good_50,26)==5 );
% %         aa(ind_2,26)=2;
% %     end;
% %     hist(aa(:,26),0:3); % HAM
% %     title(['HAM' ' ' fname]);

      %saveas(gcf,['bulk_' fname(1:3) '.tif'],'tif');

%     figure;
%     hist(a(good_50,2)); % Lat (zonal distribution)
%     title(['Lat' ' ' fname]);
%     saveas(gcf,['hist_lat_' fname(1:3) '.tif'],'tif');
%
%     figure;
%     hist(a(good_50,3)); % Lon
```

```
%     title(['Lon' ' ' fname]);
%     saveas(gcf,['hist_lon_' fname(1:3) '.tif'],'tif');
%

%     pause;
%     keyboard;

end;
```

Winds_Match_QIF.m

On 'tinman' 22 March Dec 2014:
/Users/daves/Documents/MATLAB/Intercomparison

```
% collocation of the cgms study datastes - search for a spatial match
% within less than a specified distance

clear;

% Set exp: 2,3,4
exp=4

qitype=18  % QI with forecast (18) or without (17)
dist=55    % Distance in km
qi=50      % QI threshold

if (exp == 2 )
   fall= {'EUMETSATDatasetTwo.csv',  'ChinaDatasetTwo.csv',
'JapanDatasetTwoNew.csv', 'NOAADatasetTwo.csv' , 'KoreaDatasetTwo.csv',
'NWCSAFDatasetTwo_O_ET_E.csv'};
   tbsize=[24 32 24 19 24 24];
end

if (exp == 3 )
   fall= {'EUMETSATDatasetThree.csv', 'ChinaDatasetThree.csv',
'JapanDatasetThreeNew.csv', 'NOAADatasetThree.csv' , 'KoreaDatasetThree.csv',
'NWCSAFDatasetThree_P_ET_E.csv'};
   tbsize=[24 32 24 19 24 24];
end

if (exp == 4 )
   fall= {'EUMETSATDatasetFour.csv', 'ChinaDatasetFour.csv',
'JapanDatasetFourNew.csv', 'NOAADatasetFour.csv' , 'KoreaDatasetFour.csv',
'NWCSAFDatasetFour_O_C_E.csv'};
   tbsize=[24 24 24 24 24 24];
end

fsym= {'b.'                    ,  'r.'                   , 'g.'
, 'k.'                 , 'm.'                 , 'y.' };

set_eum=load(fall{1});
set_cma=load(fall{2});
set_jma=load(fall{3});
set_noa=load(fall{4});
set_kma=load(fall{5});
```

```
set_nwc_temp=load(fall{6});

set_nwc=sortrows(set_nwc_temp,6);

qivar=[];
qivar=find(set_eum(:,qitype)>=qi);
set_eum=set_eum(qivar,:);
qivar=[];
qivar=find(set_kma(:,qitype)>=qi);
set_kma=set_kma(qivar,:);
qivar=[];
qivar=find(set_cma(:,qitype)>=qi);
set_cma=set_cma(qivar,:);
qivar=[];
qivar=find(set_noa(:,qitype)>=qi);
set_noa=set_noa(qivar,:);
qivar=[];
qivar=find(set_nwc(:,qitype)>=qi);
set_nwc=set_nwc(qivar,:);
qivar=[];
qivar=find(set_jma(:,qitype)>=qi);
set_jma=set_jma(qivar,:);


i_out=0;

for i_amv=1:length(set_nwc(:,1))
%   disp(i_amv)

    [val1, loc1]=min( deg2km(distance(set_eum(:,2), set_eum(:,3),
set_nwc(i_amv,2), set_nwc(i_amv,3)))); % lat/lon metrics

    if val1 < dist

            [val2, loc2]=min( deg2km(distance(set_cma(:,2), set_cma(:,3),
set_nwc(i_amv,2), set_nwc(i_amv,3)))); % lat/lon metrics

            if val2 < dist

                [val3, loc3]=min( deg2km(distance(set_jma(:,2), set_jma(:,3),
set_nwc(i_amv,2), set_nwc(i_amv,3)))); % lat/lon metrics

                if val3 < dist

                    [val4, loc4]=min( deg2km(distance(set_noa(:,2),
set_noa(:,3), set_nwc(i_amv,2), set_nwc(i_amv,3)))); % lat/lon metrics

                    if val4 < dist

                        [val5, loc5]=min( deg2km(distance(set_kma(:,2),
set_kma(:,3), set_nwc(i_amv,2), set_nwc(i_amv,3)))); % lat/lon metrics

                        if val5 < dist

                    i_out=i_out+1;
                    set_out_lat(i_out,:) =[ set_eum(loc1,02) set_kma(loc5,02)
set_cma(loc2,02)  set_noa(loc4,02) set_nwc(i_amv,02) set_jma(loc3,02) ];
                    set_out_lon(i_out,:) =[ set_eum(loc1,03) set_kma(loc5,03)
set_cma(loc2,03)  set_noa(loc4,03) set_nwc(i_amv,03) set_jma(loc3,03) ];
                    set_out_spd(i_out,:) =[ set_eum(loc1,06) set_kma(loc5,06)
set_cma(loc2,06)  set_noa(loc4,06) set_nwc(i_amv,06) set_jma(loc3,06) ];
```

```
                    set_out_dir(i_out,:) =[ set_eum(loc1,07) set_kma(loc5,07)
set_cma(loc2,07)  set_noa(loc4,07) set_nwc(i_amv,07) set_jma(loc3,07) ];
                    set_out_pres(i_out,:)=[ set_eum(loc1,08) set_kma(loc5,08)
set_cma(loc2,08)  set_noa(loc4,08) set_nwc(i_amv,08) set_jma(loc3,08) ];
                    set_out_ham(i_out,:) =[ set_eum(loc1,16) set_kma(loc5,16)
set_cma(loc2,16)  set_noa(loc4,16) set_nwc(i_amv,16) set_jma(loc3,16) ];
                    set_out_qi(i_out,:)  =[ set_eum(loc1,qitype)
set_kma(loc5,qitype) set_cma(loc2,qitype)  set_noa(loc4,qitype)
set_nwc(i_amv,qitype) set_jma(loc3,qitype) ];

                    end;
                end;
            end;
        end
    end;
end;

disp('**************');
disp(i_out);

figure;
x=1:i_out;
subplot(4,1,1);
plot(x,set_out_spd(:,1),fsym{1},x,set_out_spd(:,2),fsym{2},x,
set_out_spd(:,3),fsym{3},x,set_out_spd(:,4),fsym{4},x,set_out_spd(:,5),fsym{5},
x, set_out_spd(:,6), fsym{6} );
legend('EUM', 'KMA', 'CMA', 'NOA', 'NWC', 'JMA');
subplot(4,1,2);
plot(x,set_out_dir(:,1),fsym{1},x,set_out_dir(:,2),fsym{2},x,
set_out_dir(:,3),fsym{3},x,set_out_dir(:,4),fsym{4},x,set_out_dir(:,5),fsym{5},
x, set_out_dir(:,6),fsym{6} );
subplot(4,1,3);
plot(x,set_out_pres(:,1),fsym{1},x,set_out_pres(:,2),fsym{2},x,
set_out_pres(:,3),fsym{3},x,set_out_pres(:,4),fsym{4},x,set_out_pres(:,5),fsym{
5},x, set_out_pres(:,6),fsym{6} );
subplot(4,1,4);
plot(x,set_out_qi(:,1),fsym{1},x,set_out_qi(:,2),fsym{2},x,
set_out_qi(:,3),fsym{3},x,set_out_qi(:,4),fsym{4},x,set_out_qi(:,5),fsym{5},x,s
et_out_qi(:,6),fsym{6} );

if ( exp == 2)
   saveas(gcf,'Exp_2_qif_all.tif','tif');
end

if ( exp == 3)
   saveas(gcf,'Exp_3_qif_all.tif','tif');
end

if ( exp == 4)
   saveas(gcf,'Exp_4_qif_all.tif','tif');
end

figure;
plot(set_out_pres(:,1),set_out_pres(:,2),'r.',set_out_pres(:,1),
set_out_pres(:,3),'g.', set_out_pres(:,1), set_out_pres(:,4),'k.',
set_out_pres(:,1), set_out_pres(:,5),'m.', set_out_pres(:,1),
set_out_pres(:,6),'y.');
legend('EUM vs KMA','EUM vs CMA',' EUM vs NOA','EUM vs NWC', 'EUM vs JMA');
xlabel('Pressure (EUM)');
ylabel('Pressure (Centres)');
title('Scatter Plot of Cloud Height');
```

```
if ( exp == 2)
   saveas(gcf,'Exp_2_qif_pres_scat.tif','tif');
end

if ( exp == 3)
   saveas(gcf,'Exp_3_qif_pres_scat.tif','tif');
end

if ( exp == 4)
   saveas(gcf,'Exp_4_qif_pres_scat.tif','tif');
end

figure;
plot(x,abs(max(set_out_pres')-min(set_out_pres')),'.');
xlabel('AMV Number');
ylabel('Pressure difference');
title('Maximum Pressure difference');

if ( exp == 2)
   saveas(gcf,'Exp_2_qif_pres_hist.tif','tif');
end

if ( exp == 3)
   saveas(gcf,'Exp_3_qif_pres_hist.tif','tif');
end

if ( exp == 4)
   saveas(gcf,'Exp_4_qif_pres_hist.tif','tif');
end

set_out_names = {'EUMETSAT', 'Korea', 'China', 'NOAA', 'NWCSAF', 'Japan'}

set_out_spd1 = [set_out_spd(:,1), set_out_spd(:,2), set_out_spd(:,3),
set_out_spd(:,4), set_out_spd(:,5), set_out_spd(:,6),
((set_out_spd(:,1)+set_out_spd(:,6)+set_out_spd(:,2))/3)];
fall1 = {'EUMETSAT', 'Korea', 'China', 'NOAA', 'NWCSAF', 'Japan', 'Correct'}

set_out_qi1 = [set_out_qi(:,1), set_out_qi(:,2), set_out_qi(:,3),
set_out_qi(:,4), set_out_qi(:,5), set_out_qi(:,6),
((set_out_qi(:,3)+set_out_qi(:,5))/2)];

for i=1:5
    for n=i:5
        fprintf('%s "VS" %s \n', set_out_names{i}, set_out_names{n+1});
        [h,p,ci,stats]=ttest(set_out_spd(:,i),set_out_spd(:,n+1));
        fprintf('  Speed:     h = %d, p = %.2f, ci = %.2f %.2f, Mean: %.2f \n',
h, p, ci(1), ci(2), (ci(1)+ci(2))/2);
        [h,p,ci,stats]=ttest(set_out_dir(:,i),set_out_dir(:,n+1));
        fprintf('  Direction: h = %d, p = %.2f, ci = %.2f %.2f, Mean: %.2f \n',
h, p, ci(1), ci(2), (ci(1)+ci(2))/2);
        [h,p,ci,stats]=ttest(set_out_pres(:,i),set_out_pres(:,n+1));
        fprintf('  Pressure:  h = %d, p = %.2f, ci = %.2f %.2f, Mean: %.2f \n',
h, p, ci(1), ci(2), (ci(1)+ci(2))/2);
        [h,p,ci,stats]=ttest(set_out_qi(:,i),set_out_qi(:,n+1));
        fprintf('  QI:        h = %d, p = %.2f, ci = %.2f %.2f, Mean: %.2f
\n\n', h, p, ci(1), ci(2), (ci(1)+ci(2))/2);
    end;
end;
```

```
%
% %"Correct" Speed Comparison
% for i=1:6
%     fprintf('%s %s \n', 'Speed Correct VS.', fall1{i});
%     [h,p,ci,stats]=ttest(set_out_spd1(:,7),set_out_spd1(:,i));
%     fprintf('Speed "Correct": h = %d, p = %f, ci = %f %f, Mean: %f \n', h, p,
ci(1), ci(2), mean(set_out_spd1(:,7)-set_out_spd1(:,i)));
% end;
% fprintf('\n');



% "Correct" QI Comparision
for i=1:6
    fprintf('%s %s \n', 'QI Correct VS.', fall1{i});
    [h,p,ci,stats]=ttest(set_out_qi1(:,7),set_out_qi1(:,i));
    fprintf('Speed "Correct": h = %d, p = %.2f, ci = %.2f %.2f, Mean: %.2f \n',
h, p, ci(1), ci(2), mean(set_out_qi1(:,7)-set_out_qi1(:,i)));
end;
```

Winds_Match_QINF.m

On 'tinman' 22 March Dec 2014:
/Users/daves/Documents/MATLAB/Intercomparison

```
% collocation of the cgms study datastes - search for a spatial match
% within less than a specified distance

clear;

% Set exp: 2,3,4
exp=2

qitype=17  % QI with forecast (18) or without (17)
dist=55    % Distance in km
qi=50      % QI threshold

if (exp == 2 )
   fall= {'EUMETSATDatasetTwo.csv',  'BrazilDatasetTwo.csv',
'JapanDatasetTwoNew.csv', 'NOAADatasetTwo.csv' , 'KoreaDatasetTwo.csv',
'NWCSAFDatasetTwo_O_ET_E.csv'};
   tbsize=[24 32 24 19 24 24];
end

if (exp == 3 )
   fall= {'EUMETSATDatasetThree.csv', 'BrazilDatasetThree.csv',
'JapanDatasetThreeNew.csv', 'NOAADatasetThree.csv' , 'KoreaDatasetThree.csv',
'NWCSAFDatasetThree_P_ET_E.csv'};
   tbsize=[24 32 24 19 24 24];
end

if (exp == 4 )
   fall= {'EUMETSATDatasetFour.csv', 'BrazilDatasetFour.csv',
'JapanDatasetFourNew.csv', 'NOAADatasetFour.csv' , 'KoreaDatasetFour.csv',
'NWCSAFDatasetFour_O_C_E.csv'};
```

```
   tbsize=[24 24 24 24 24 24];
end

fsym= {'b.'                    ,  'r.'                   , 'g.'
, 'k.'                 , 'm.'                 , 'y.' };

set_eum=load(fall{1});
set_brz=load(fall{2});
set_jma=load(fall{3});
set_noa=load(fall{4});
set_kma=load(fall{5});
set_nwc_temp=load(fall{6});

set_nwc=sortrows(set_nwc_temp,6);

qivar=[];
qivar=find(set_eum(:,qitype)>=qi);
set_eum=set_eum(qivar,:);
qivar=[];
qivar=find(set_kma(:,qitype)>=qi);
set_kma=set_kma(qivar,:);
qivar=[];
qivar=find(set_brz(:,qitype)>=qi);
set_brz=set_brz(qivar,:);
qivar=[];
qivar=find(set_noa(:,qitype)>=qi);
set_noa=set_noa(qivar,:);
qivar=[];
qivar=find(set_nwc(:,qitype)>=qi);
set_nwc=set_nwc(qivar,:);
qivar=[];
qivar=find(set_jma(:,qitype)>=qi);
set_jma=set_jma(qivar,:);


i_out=0;

for i_amv=1:length(set_nwc(:,1))
%   disp(i_amv)

    [val1, loc1]=min( deg2km(distance(set_eum(:,2), set_eum(:,3),
set_nwc(i_amv,2), set_nwc(i_amv,3)))); % lat/lon metrics

    if val1 < dist

            [val2, loc2]=min( deg2km(distance(set_brz(:,2), set_brz(:,3),
set_nwc(i_amv,2), set_nwc(i_amv,3)))); % lat/lon metrics

            if val2 < dist

                [val3, loc3]=min( deg2km(distance(set_jma(:,2), set_jma(:,3),
set_nwc(i_amv,2), set_nwc(i_amv,3)))); % lat/lon metrics

                if val3 < dist

                    [val4, loc4]=min( deg2km(distance(set_noa(:,2),
set_noa(:,3), set_nwc(i_amv,2), set_nwc(i_amv,3)))); % lat/lon metrics

                    if val4 < dist
```

```
                        [val5, loc5]=min( deg2km(distance(set_kma(:,2),
set_kma(:,3), set_nwc(i_amv,2), set_nwc(i_amv,3)))); % lat/lon metrics

                        if val5 < dist

                    i_out=i_out+1;
                    set_out_lat(i_out,:) =[ set_eum(loc1,02) set_kma(loc5,02)
set_brz(loc2,02)  set_noa(loc4,02) set_nwc(i_amv,02) set_jma(loc3,02) ];
                    set_out_lon(i_out,:) =[ set_eum(loc1,03) set_kma(loc5,03)
set_brz(loc2,03)  set_noa(loc4,03) set_nwc(i_amv,03) set_jma(loc3,03) ];
                    set_out_spd(i_out,:) =[ set_eum(loc1,06) set_kma(loc5,06)
set_brz(loc2,06)  set_noa(loc4,06) set_nwc(i_amv,06) set_jma(loc3,06) ];
                    set_out_dir(i_out,:) =[ set_eum(loc1,07) set_kma(loc5,07)
set_brz(loc2,07)  set_noa(loc4,07) set_nwc(i_amv,07) set_jma(loc3,07) ];
                    set_out_pres(i_out,:)=[ set_eum(loc1,08) set_kma(loc5,08)
set_brz(loc2,08)  set_noa(loc4,08) set_nwc(i_amv,08) set_jma(loc3,08) ];
                    set_out_ham(i_out,:) =[ set_eum(loc1,16) set_kma(loc5,16)
set_brz(loc2,16)  set_noa(loc4,16) set_nwc(i_amv,16) set_jma(loc3,16) ];
                    set_out_qi(i_out,:)  =[ set_eum(loc1,qitype)
set_kma(loc5,qitype) set_brz(loc2,qitype)  set_noa(loc4,qitype)
set_nwc(i_amv,qitype) set_jma(loc3,qitype) ];

                    end;
                end;
            end;
        end
    end;
end;

disp('**************');
disp(i_out);

figure;
x=1:i_out;
subplot(4,1,1);
plot(x,set_out_spd(:,1),fsym{1},x,set_out_spd(:,2),fsym{2},x,
set_out_spd(:,3),fsym{3},x,set_out_spd(:,4),fsym{4},x,set_out_spd(:,5),fsym{5},
x, set_out_spd(:,6), fsym{6} );
legend('EUM', 'KMA', 'BRZ', 'NOA', 'NWC', 'JMA');
subplot(4,1,2);
plot(x,set_out_dir(:,1),fsym{1},x,set_out_dir(:,2),fsym{2},x,
set_out_dir(:,3),fsym{3},x,set_out_dir(:,4),fsym{4},x,set_out_dir(:,5),fsym{5},
x, set_out_dir(:,6),fsym{6} );
subplot(4,1,3);
plot(x,set_out_pres(:,1),fsym{1},x,set_out_pres(:,2),fsym{2},x,
set_out_pres(:,3),fsym{3},x,set_out_pres(:,4),fsym{4},x,set_out_pres(:,5),fsym{
5},x, set_out_pres(:,6),fsym{6} );
subplot(4,1,4);
plot(x,set_out_qi(:,1),fsym{1},x,set_out_qi(:,2),fsym{2},x,
set_out_qi(:,3),fsym{3},x,set_out_qi(:,4),fsym{4},x,set_out_qi(:,5),fsym{5},x,s
et_out_qi(:,6),fsym{6} );

if ( exp == 2)
   saveas(gcf,'Exp_2_qinf_all.tif','tif');
end

if ( exp == 3)
   saveas(gcf,'Exp_3_qinf_all.tif','tif');
end

if ( exp == 4)
```

```
   saveas(gcf,'Exp_4_qinf_all.tif','tif');
end

figure;
plot(set_out_pres(:,1),set_out_pres(:,2),'r.',set_out_pres(:,1),
set_out_pres(:,3),'g.', set_out_pres(:,1), set_out_pres(:,4),'k.',
set_out_pres(:,1), set_out_pres(:,5),'m.', set_out_pres(:,1),
set_out_pres(:,6),'y.');
legend('EUM vs KMA','EUM vs BRZ',' EUM vs NOA','EUM vs NWC', 'EUM vs JMA');
xlabel('Pressure (EUM)');
ylabel('Pressure (Centres)');
title('Scatter Plot of Cloud Height');

if ( exp == 2)
   saveas(gcf,'Exp_2_qinf_pres_scat.tif','tif');
end

if ( exp == 3)
   saveas(gcf,'Exp_3_qinf_pres_scat.tif','tif');
end

if ( exp == 4)
   saveas(gcf,'Exp_4_qinf_pres_scat.tif','tif');
end

figure;
plot(x,abs(max(set_out_pres')-min(set_out_pres')),'.');
xlabel('AMV Number');
ylabel('Pressure difference');
title('Maximum Pressure difference');

if ( exp == 2)
   saveas(gcf,'Exp_2_qinf_pres_hist.tif','tif');
end

if ( exp == 3)
   saveas(gcf,'Exp_3_qinf_pres_hist.tif','tif');
end

if ( exp == 4)
   saveas(gcf,'Exp_4_qinf_pres_hist.tif','tif');
end

set_out_names = {'EUMETSAT', 'Korea', 'Brazil', 'NOAA', 'NWCSAF', 'Japan'}

set_out_spd1 = [set_out_spd(:,1), set_out_spd(:,2), set_out_spd(:,3),
set_out_spd(:,4), set_out_spd(:,5), set_out_spd(:,6),
((set_out_spd(:,1)+set_out_spd(:,2))/2)];
fall1 = {'EUMETSAT', 'Korea', 'Brazil', 'NOAA', 'NWCSAF', 'Japan', 'Correct'};



for i=1:5
    for n=i:5
        fprintf('%s "VS" %s \n', set_out_names{i}, set_out_names{n+1});
        [h,p,ci,stats]=ttest(set_out_spd(:,i),set_out_spd(:,n+1));
        fprintf('  Speed:     h = %d, p = %.2f, ci = %.2f %.2f, Mean: %.2f \n',
h, p, ci(1), ci(2), (ci(1)+ci(2))/2);
        [h,p,ci,stats]=ttest(set_out_dir(:,i),set_out_dir(:,n+1));
        fprintf('  Direction: h = %d, p = %.2f, ci = %.2f %.2f, Mean: %.2f \n',
h, p, ci(1), ci(2), (ci(1)+ci(2))/2);
```

```
        [h,p,ci,stats]=ttest(set_out_pres(:,i),set_out_pres(:,n+1));
        fprintf('  Pressure:  h = %d, p = %.2f, ci = %.2f %.2f, Mean: %.2f \n',
h, p, ci(1), ci(2), (ci(1)+ci(2))/2);
        [h,p,ci,stats]=ttest(set_out_qi(:,i),set_out_qi(:,n+1));
        fprintf('  QI:        h = %d, p = %.2f, ci = %.2f %.2f, Mean: %.2f
\n\n', h, p, ci(1), ci(2), (ci(1)+ci(2))/2);
    end;
end;
fprintf('\n')
%
%
%"Correct" Speed Comparison
for i=1:6
    fprintf('%s %s \n', 'Speed Correct VS.', fall1{i});
    [h,p,ci,stats]=ttest(set_out_spd1(:,7),set_out_spd1(:,i));
    fprintf('Speed "Correct": h = %d, p = %.2f, ci = %.2f %.2f, Mean: %.2f \n',
h, p, ci(1), ci(2), mean(set_out_spd1(:,7)-set_out_spd1(:,i)));
end;
```