Improved Representation of Satellite-Derived Atmospheric Motion Vectors (AMVs) by Attributing Assigned Heights to Tropospheric Layers

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Introduction and Motivation

- The proper analysis of tropospheric winds is an important prerequisite to accurate numerical model forecasts

- Improved data assimilation methods emerging from the NWP community are challenging AMV researchers and providers to advance the quality of their products

- AMVs are typically treated as single-level data within current NWP model assimilation

    - AMV wind speed and direction are assigned by the data providers to a pressure height, and these are used by NWP data assimilation systems as point wind observations

Introduction and Motivation (continued)

- Although AMVs have mostly positive impacts on NWP, vector height assignments have long been suspected as a significant source of error

  - Satellites actually sense radiation emitted from a finite layer of the atmosphere, especially in clear-sky WV situations, rather than just one specific pressure level

- Various approaches to minimize the height-assignment problem in NWP have been investigated, such as spreading the AMV information over more than one level (Rao, Velden and Braun, *JAM*, 2002)

- The optimal approach to this AMV "information spreading" in NWP data assimilation is still relatively unknown because the vertical representivity of AMVs has not been thoroughly examined and provided by the data producers

Introduction and Motivation (continued)

• **In this study we investigate large samples of multispectral AMV data, through comparison with co-located rawinsondes, to determine the depth (layer) of troposphere over which the vectors may be most representative**

Data and Methodology

• The AMV datasets were produced by the UW-CIMSS automated algorithm (Velden et al., BAMS, 2005), nearly identical to the code used to produce operational AMVs at NOAA/NESDIS (Daniels et al. 2002)

• The AMV datasets are compared to rawinsonde wind observations collected by the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) program at three supersites

ARM Site	Primary Sonde Launch Location(s)	Satellite Instrument(s) Used	Study Time Period	# of AMV Matches
Southern Great Plains	Lamont, OK (36.6 N 97.5 W)	GOES-12	Jan. 03-Jun. 06	6017
Tropical Western Pacific	Darwin, Australia (12.4 S, 130.9 E) Manus Island, Papua New Guinea (2.1 S, 147.4 E) Nauru Island (0.5 S, 166.9 E)	GMS-5, GOES-9, MTSAT	Jan. 03-Jun. 06	4018
North Slope of Alaska	Barrow, AK (71.3 N, 156.6 W)	Aqua and Terra MODIS	Feb. 04, Sept. 04, Oct. 04, Jul. 05, Aug. 05, May-Nov. 06	2342

Match criteria: AMV location must be 50 km and 1 hour from sonde launch time/sites

Data and Methodology (continued)

• AMVs are initially assigned heights by the UW-CIMSS algorithm based on radiative properties of the tracked cloud or WV features using the following methods:
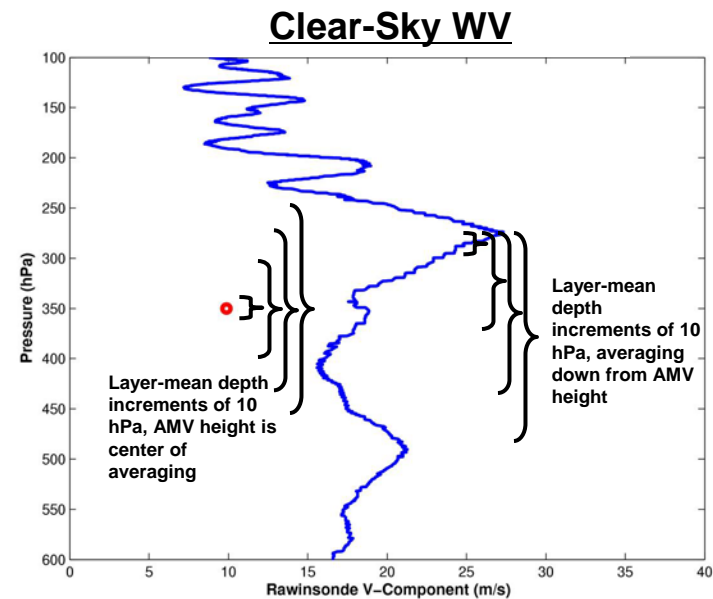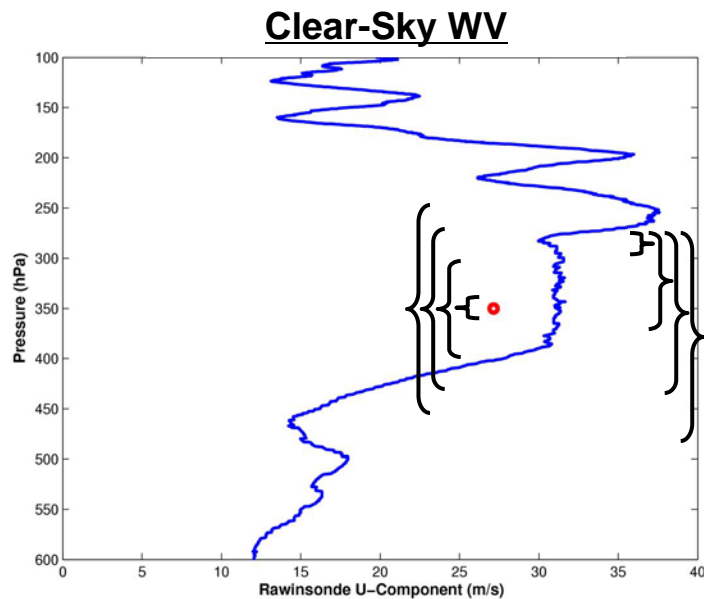
    1) IR window

    2) Cloud base method

    3) CO_2 Slicing

    4) Water Vapor Absorption

    5) Histogram method

• AMVs are then passed through a series of post-processing steps that edit or assign quality flags. Initially assigned heights may also be adjusted slightly based upon better fit to a local 3-D analysis of all nearby vectors.

    - The adjusted heights yielded a closer AMV-sonde VRMS agreement in our sample, so results based on these heights are used in this study

Data and Methodology (continued)

• Vaisala RS-92 sonde wind data is recorded every 2 seconds during sonde flight, providing obs at very high vertical resolution

• AMVs are first compared to the closest vertical sonde data point to evaluate the quality of the "level-based" height assignment

• Sonde wind component data are then averaged over increasingly deep layers VRMS stats are computed between mean sonde and AMV values.

 - Exact method of averaging depends if targets are clear vs. cloudy

Clear-Sky WV

Clear-Sky WV

Results: Level of Best Fit Height Assignment

GOES–12 vs. Western Pacific Improvment By Level BF Assignment

~20 % of AMV-sonde vector differences would improve by > 5 ms⁻¹

~50 % of AMV-sonde vector differences would improve by at least 2.5 ms⁻¹ by AMV assignment to its "level of best fit"

Legend: Western Pacific, GOES–12

Y-axis: **Percent Obs. Greater Than X-Value**
X-axis: **Actual–Best Fit Vector Difference (m/s)**
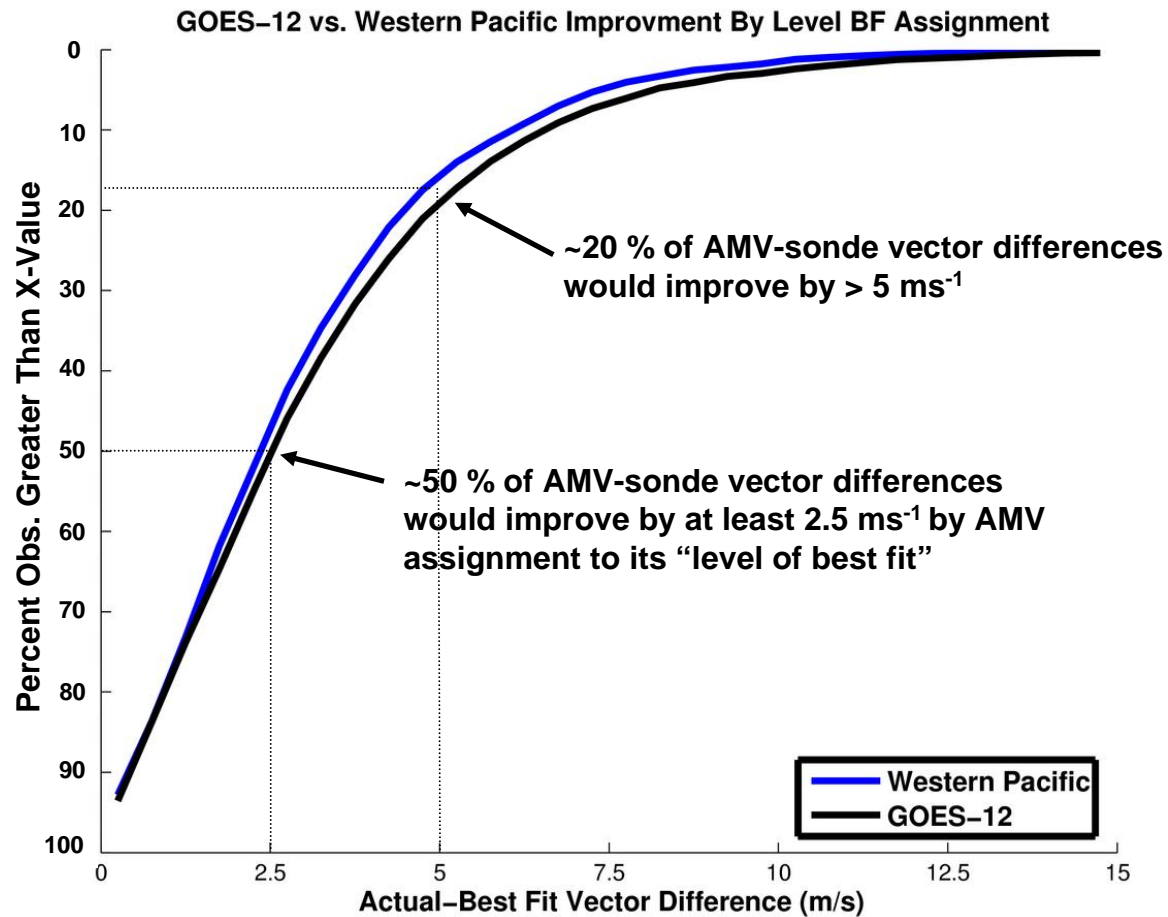
Level of Best Fit: Sonde level within +/- 100 hPa of AMV height assignment where AMV-sonde vector difference is minimized

Results: Level of Best Fit Height Assignment
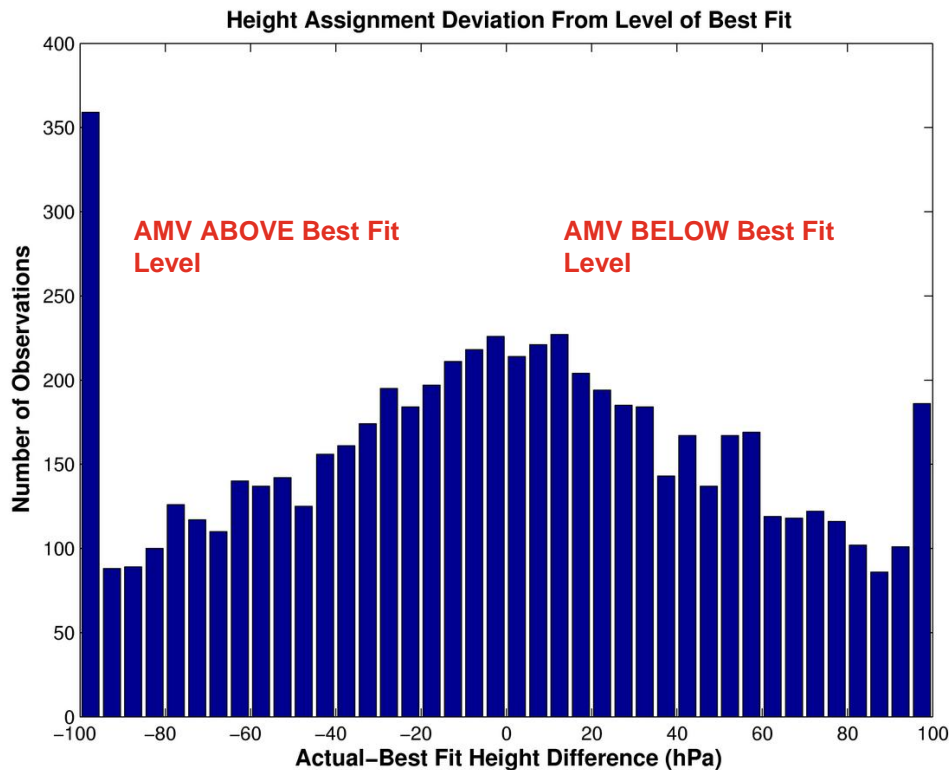
GOES-12

Western Pacific
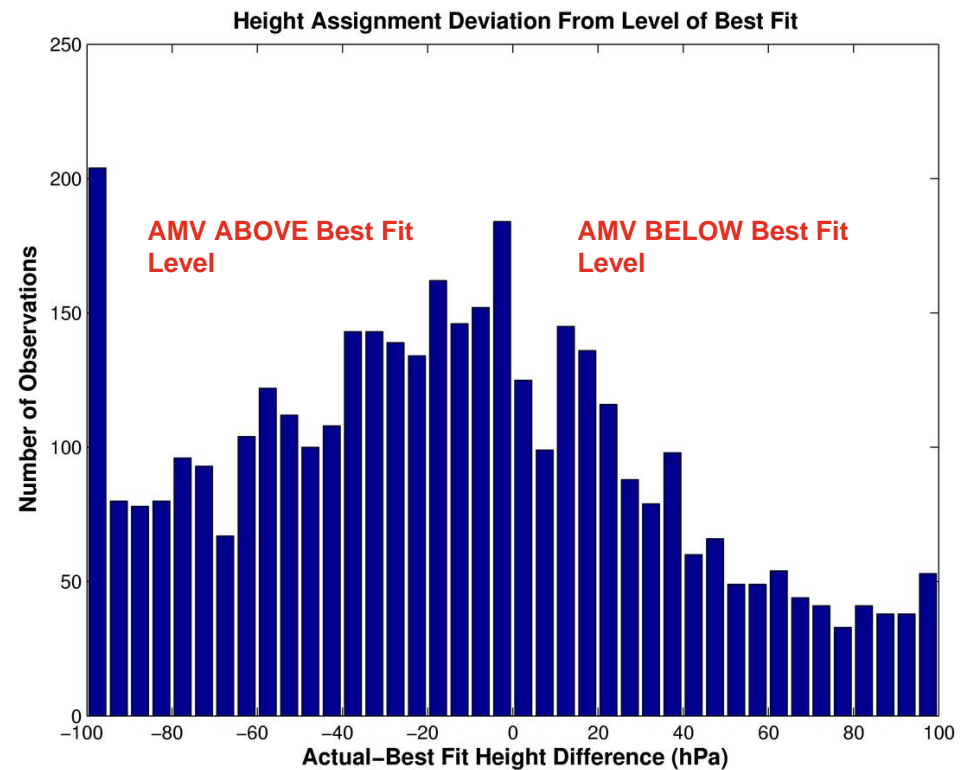
- Height assignment to an apriori "level of best fit" could significantly improve AMV-sonde agreement

- **This clearly demonstrates the importance of the height assignment to level-based AMV-sonde agreement**

Results: GOES-12 AMVs - *Layer* of Best Fit

- **GOES-12 low-level AMVs (1000-600 hPa) best correspond to a 70-100 hPa tropospheric layer**

-More difficult to evaluate low level vectors due to complex boundary layer and surface flows

- **Upper-level cloudy IR and WV AMVs (above 600 hPa) agree best with a shallower layer, ~30-50 hPa in depth**

- **Clear-sky WV AMVs best relate to a much deeper layer, 150-200 hPa.**

- Rao et al. (2002) show upper-level moisture content and/or gradients can modulate the layer of best fit depth for CSWV
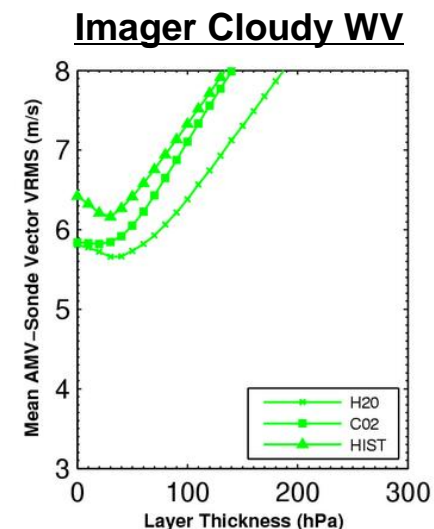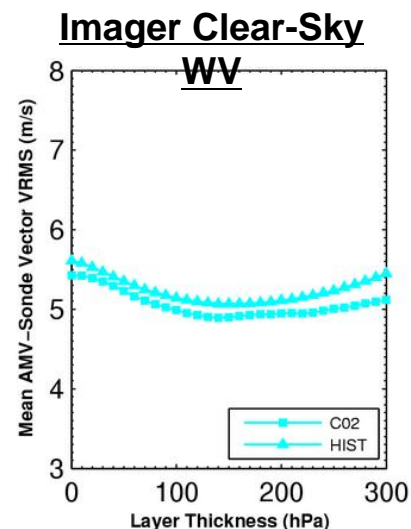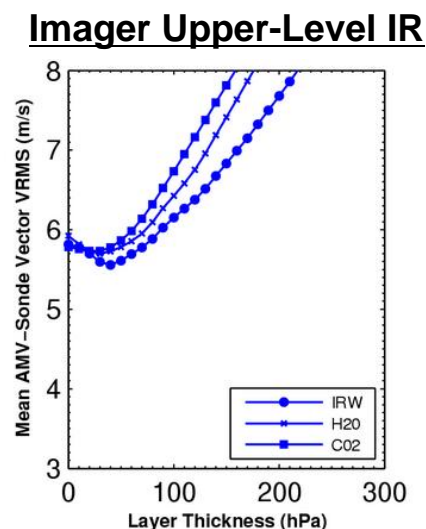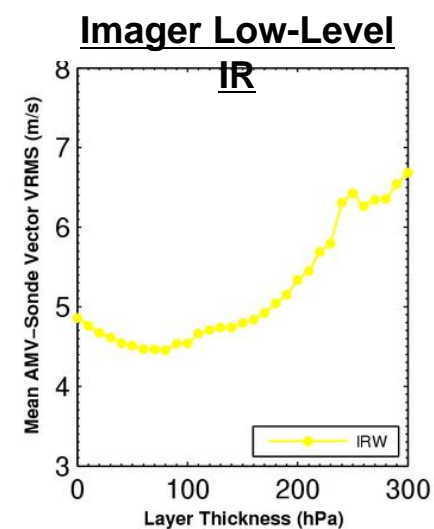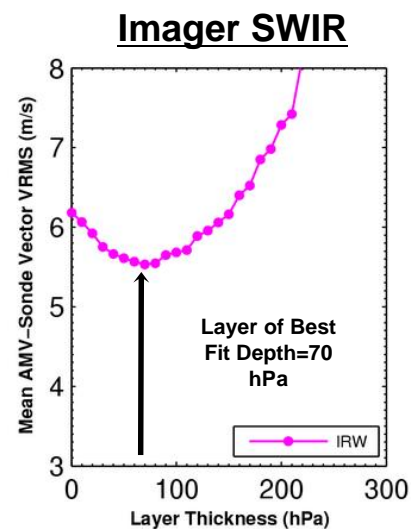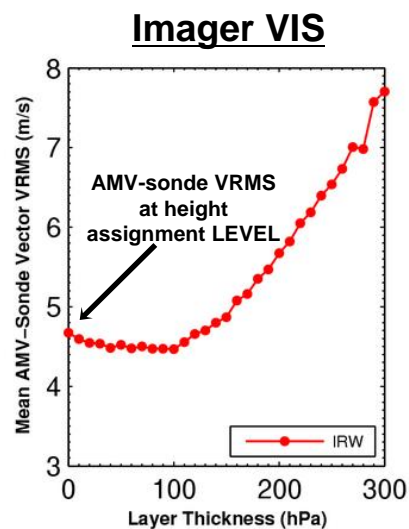
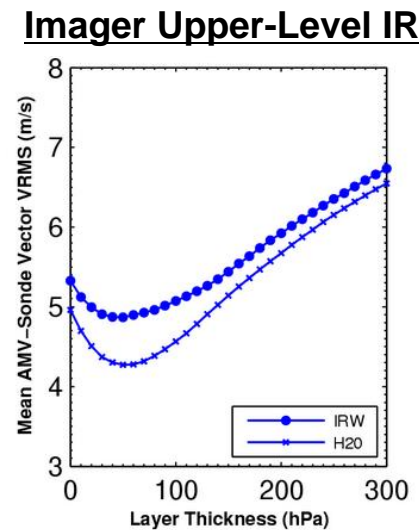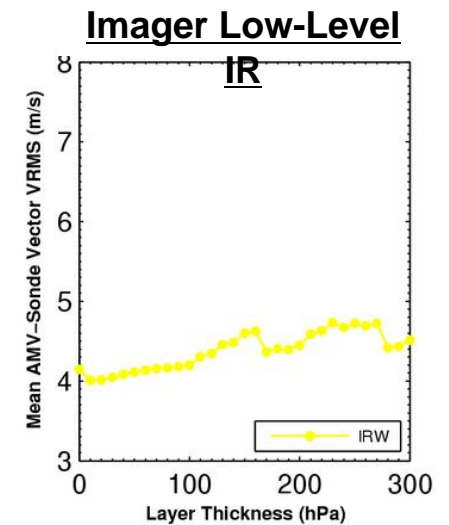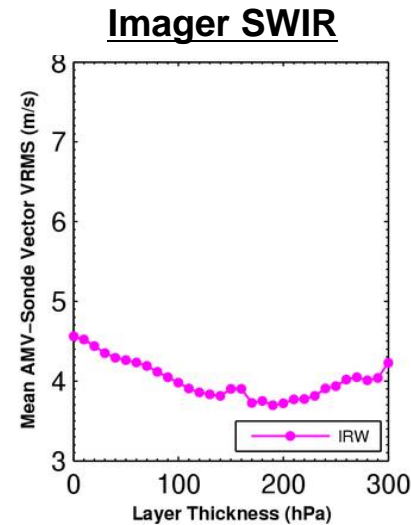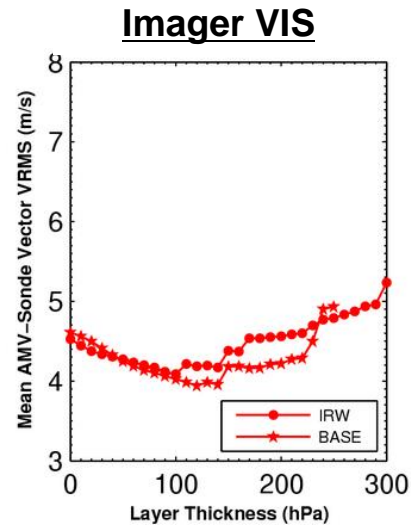# Results: Western Pacific AMVs (GMS-5, GOES-9, MTSAT)

- **West Pac. AMV-sonde agreements generally closer than GOES-12, except for clear-sky WV**

- **Low-level AMV relationships less clear**

- **Upper-level cloudy IR and WV AMV layer depths similar to, but more pronounced than GOES**

-Layer of best fit improves agreement by .5-.8 ms^{-1}

- **Clear-sky WV results similar to GOES-12**

Imager VIS

Imager SWIR

Imager Low-Level IR

Imager Upper-Level IR

Imager Clear-Sky WV

Imager Cloudy WV
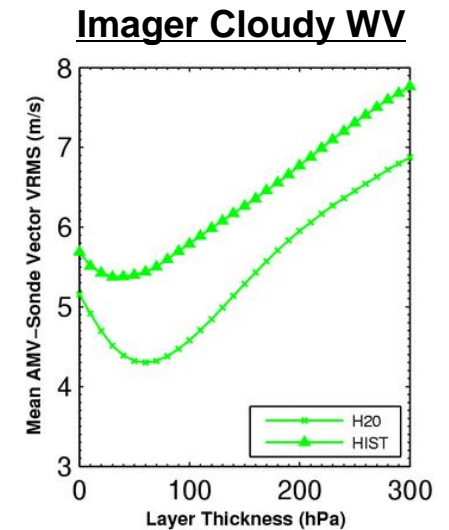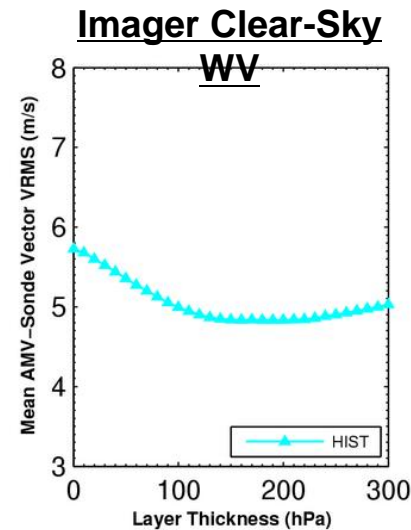
Results: Polar AMVs (Aqua and Terra MODIS)

• Layer mean relationships are still suggested, however they are less clear in the north Alaskan region validation of MODIS polar AMVs. The characteristics of Arctic clouds, together with the extreme variability in flow regimes at higher latitudes, may be damping more definitive signals.
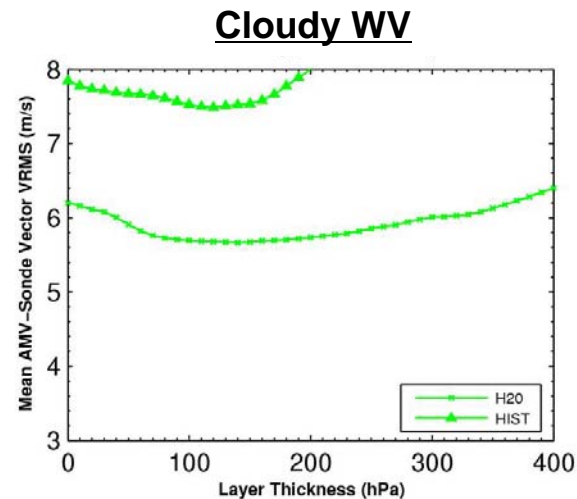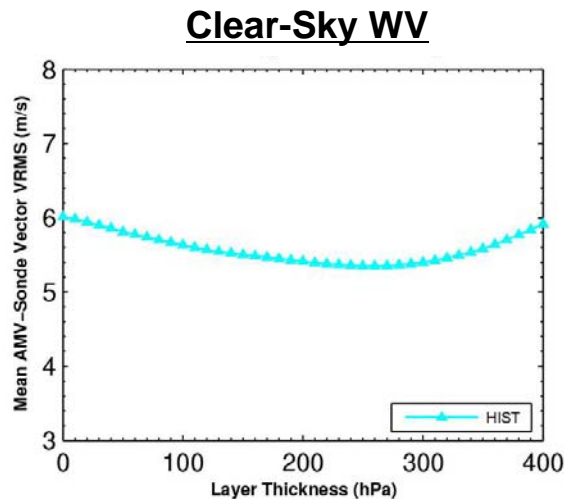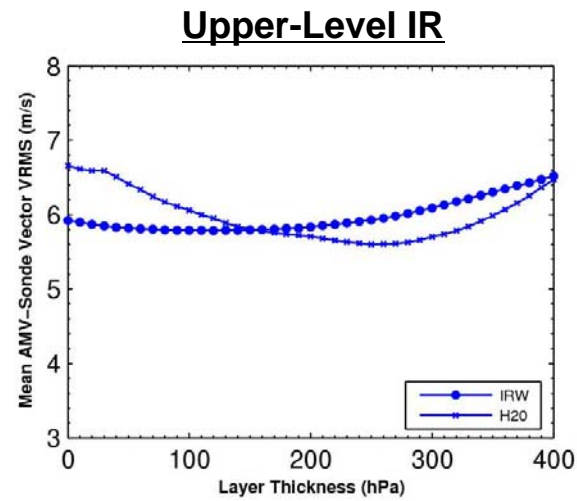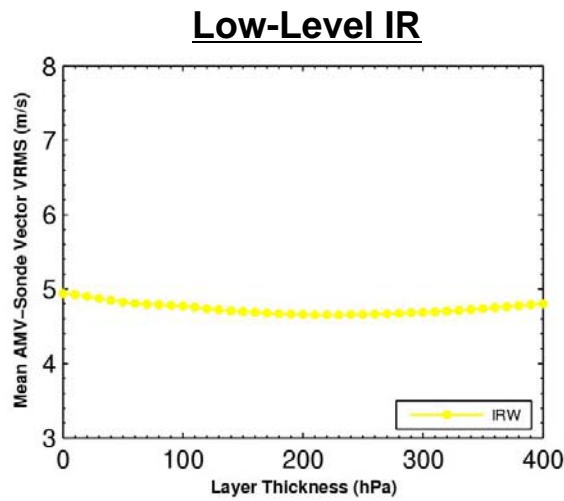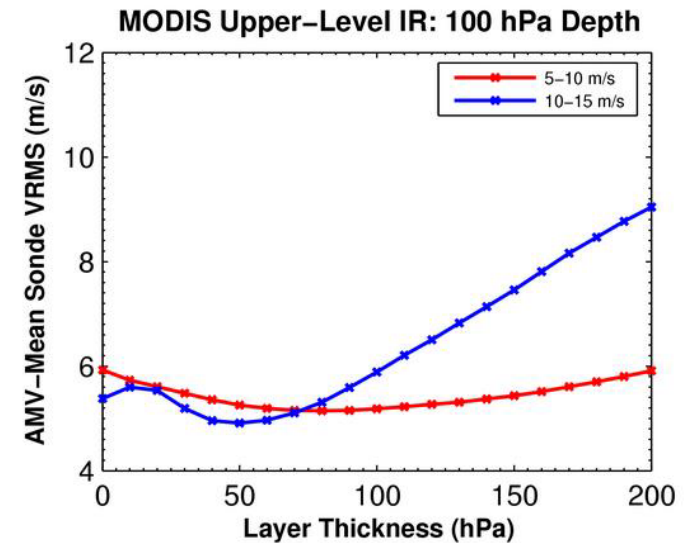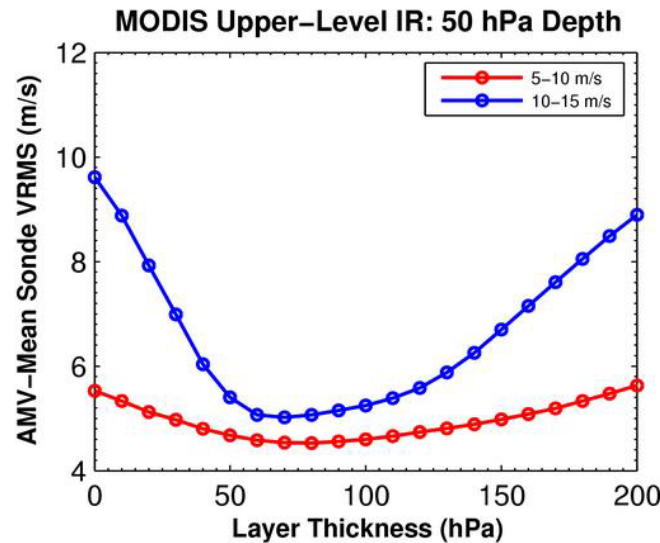
Results: Influence of Vertical Wind Shear, MODIS

MODIS Upper-level IR AMVs show a layer-mean flow relationship in high shear situations

Clear-sky and low-level AMV-wind shear relationships are less evident (not shown)

**Need more matches to evaluate effect of higher shear values in cloudy WV**

INSUFFICIENT NUMBER OF HIGH SHEAR CLOUDY WV MATCHES

Results: Influence of Vertical Wind Shear, GEO

Higher vertical wind shear has several impacts on the layer depth relationships:

1) Increased AMV-sonde VRMS at AMV height assignment level

2) Layer-mean flow representation has very pronounced impact over level-based assignment
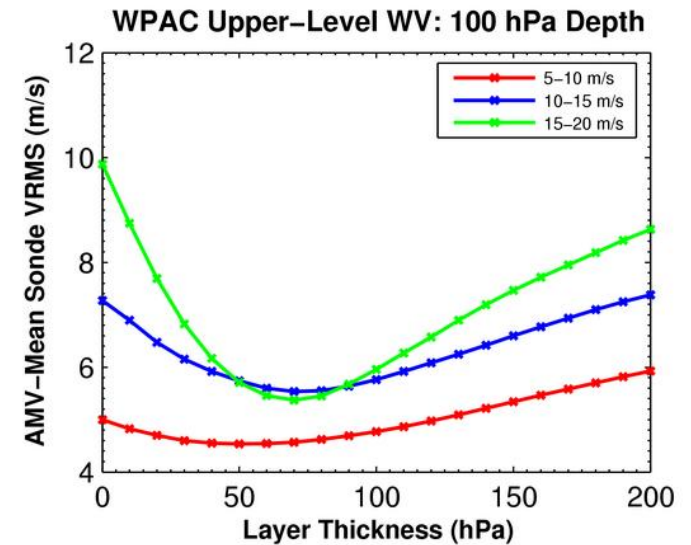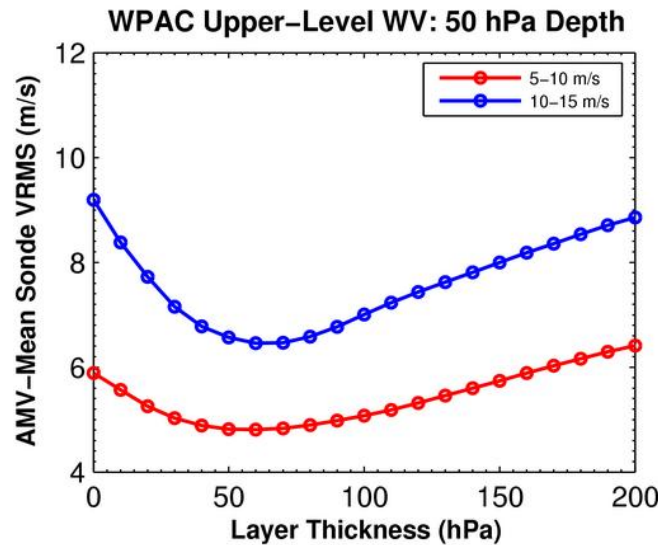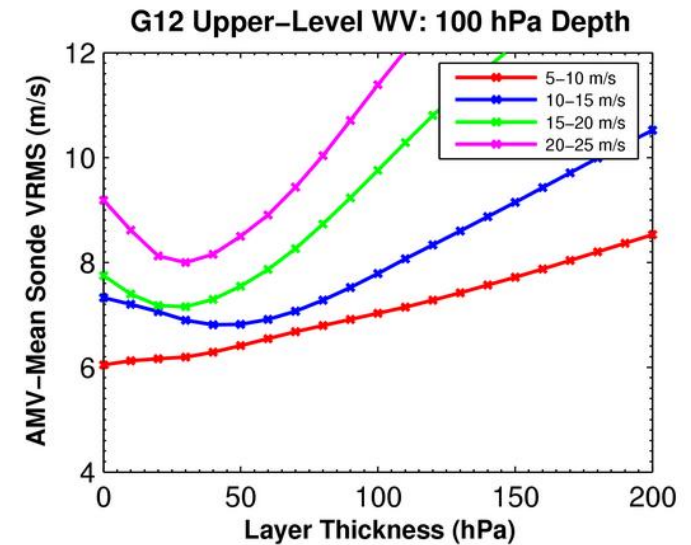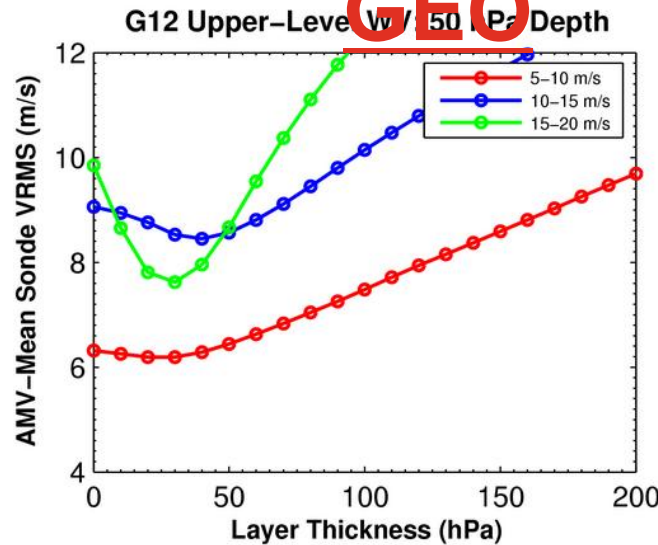
Wind Shear=Vector Difference Between Sonde Wind at Layer Top and Bottom (50 or 100hPa depths)

Conclusions

• The findings in this study clearly show quantitatively what has been believed for quite some time with respect to the representativeness of satellite-derived AMVs; that the data best represent finite *layers* of tropospheric flow, the depth of which are dependent on many factors:

    1) Original vector height

    2) Spectral channel used

    3) Vertical wind shear magnitude

    4) Scene type (i.e. clear vs. cloudy)

    5) Upper-tropospheric moisture content/gradients (Rao et al. 2002)

    6) Geographic region

• Attribution of AMV information to a specified layer improves upon AMV-sonde agreement by ~0.3-1 ms^{-1} over traditional level-based assignment, with larger improvements in high wind shear situations

    - An accurate as possible level-based height assignment is still necessary to place the AMV in the vicinity of its layer of best fit

Implications

- These results could be very relevant to data assimilation as AMVs have traditionally not been well represented in numerical model analyses due in part to the treatment as single-level observations

- While more sophisticated objective analysis systems include vertical spread functions of various data inputs, these have not been well known or understood with respect to AMVs

  - AMV data influence can be typically constrained in the vertical and thus have less chance of making an impact on the initial analysis

- The results in this study should next be tested in NWP to assess the potential impact on the analysis and subsequent model forecasts, especially in data sparse and dynamically active regimes

Velden, C. S., and K. M. Bedka, 2007: Improved representation of satellite-derived atmospheric motion vectors by attributing the assigned heights to tropospheric layers. To be submitted to *J. Appl. Meteor.*