THE EUMETSAT AVHRR AND SLSTR AMV TROPICAL SPEED BIASES PATTERN EXPLAINED

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Abstract:
Since EUMETSAT started deriving Atmospheric Motion Vectors (AMVs) from the Advanced Very-High-Resolution Radiometer (AVHRR) on board the Metop satellites, AMVs from EUMETSAT's Low-Earth Orbit (LEO) platforms are known to have significant speed biases in the tropical band, when compared to the forecast model. LEO AMVs are noticeably too fast at most longitudes in the tropics, while being mostly unbiased in other areas. This problem is usually referred to as the tropical speed biases problem. Studies on this problem have mostly hypothesized physics-related causes, like convection, wrong height assignment for cirrus clouds, and gravitational waves, among others. In this work, however, we prove that the root cause of the tropical speed biases is algorithmic: a common misconception on the robustness of cross-correlation tracking, combined with an approximation made on the guess vector and the long temporal gap between consecutive images used from LEO satellites, is actually responsible not only for the positive biases observed in the tropics, but also for the negative biases at mid-latitudes. To demonstrate this, we will focus on the steps of the AMV tracking algorithm, including the use of the guess, the computation of the parallax correction and its effects depending on the wind direction and the relative position of the satellites at stake. As a consequence of this finding, EUMETSAT started to investigate new tracking algorithms independent of the wind guess to extract AMVs from LEO satellites.

What are tropical speed biases ?

AMVs from geostationary (GEO) and low-Earth-orbit (LEO) sensors are biased with respect to the ECMWF forecast model. In particular in the tropical latitude band (30ºS to 30ºN), AMVs tend to be significantly faster than the model. However, the GEO positive bias pattern is seasonal and geographically localised, while LEO speed biases can be observed all year long, and at all longitudes of the tropical band.

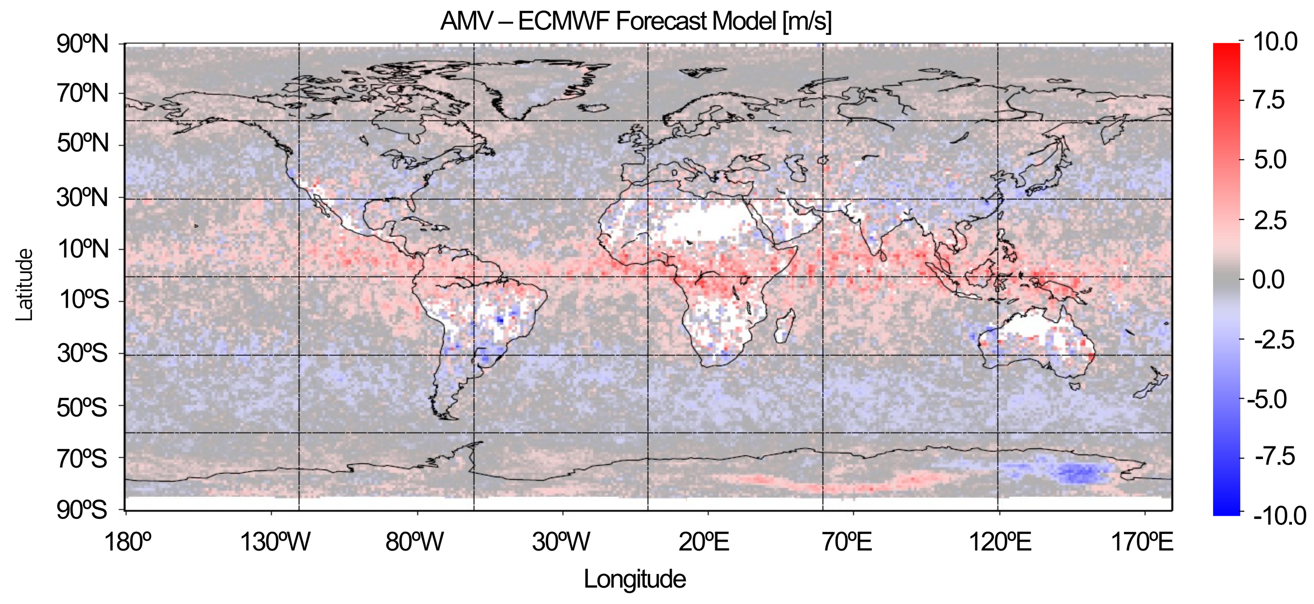


Figure 1: biases of S3A SLSTR AMVs against the ECMWF forecast model for the period 22 April 2021 to 21 May 2021. Only AMVs faster than 2.5 m/s and whose QIs are greater than 60 are used. Cells in which fewer than 5 fitting AMVs were derived are left blank.

Where could they come from ?

Errors can come either from wrong height assignment, or from the tracking.

The main source of height error is the difference between the guess height (computed from the ECMWF model, at the temperature corresponding to the 20% coldest target pixels) and the final height (obtained via CCC).

However, the biases between the AMVs and the guess vectors are similar.

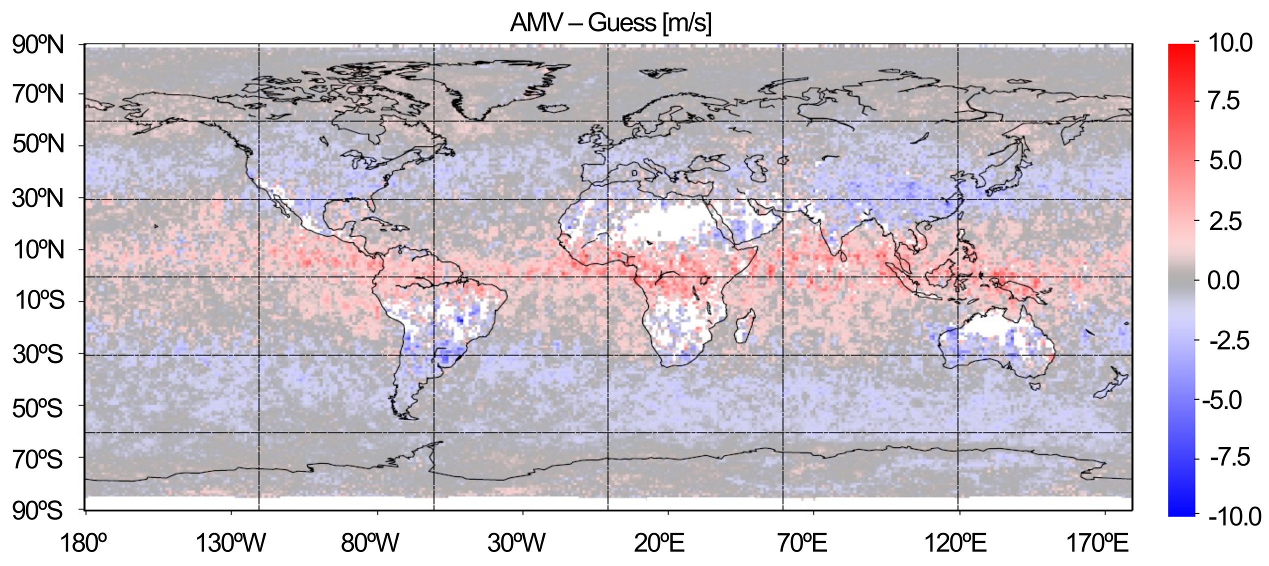


Figure 2: biases of S3A SLSTR AMVs against the guess vectors used in the derivation for the period 22 April 2021 to 21 May 2021. Only AMVs faster than 2.5 m/s and whose QIs are greater than 60 are used. Cells in which fewer than 5 fitting AMVs were derived are left blank.

Not from height errors

So it comes from the tracking. Let's see which steps could be problematic:

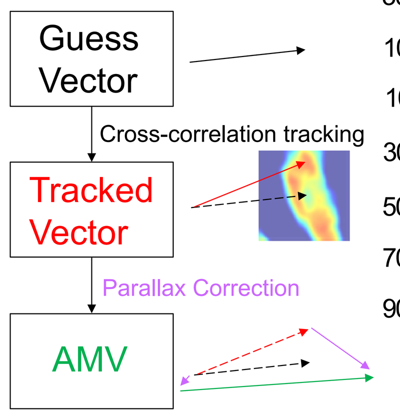


Figure 3: vectors and processing steps involved in the current LEO AMV derivation scheme. At each step, the vectors from the previous steps are drawn with dashed-lines.

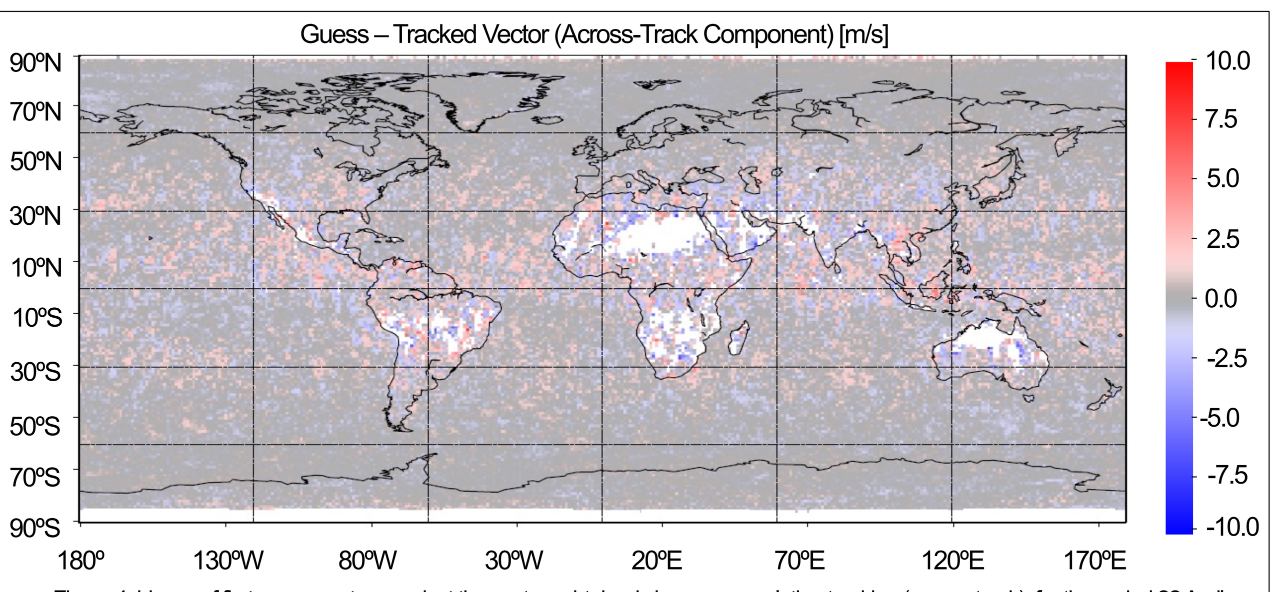


Figure 4: biases of first guess vectors against the vectors obtained via cross-correlation tracking (across-track), for the period 22 April 2021 to 21 May 2021. Only AMVs faster than 2.5 m/s and whose QIs are greater than 60 are used. Cells in which fewer than 5 fitting AMVs were derived are left blank.

Biases between the guess and the tracked vectors are small. Consequently, tropical speed biases are linked to the parallax correction.

The role of the parallax

The guess (as extracted from the model) is a physical quantity. To be rigorous, it should take into account the viewing geometry to be converted to an "apparent displacement vector", usable in an image.

This step, that we call "reverse parallax correction", is purposely overlooked because the resulting shift is so small that the tracking should be able to compensate for it. Or so we thought…

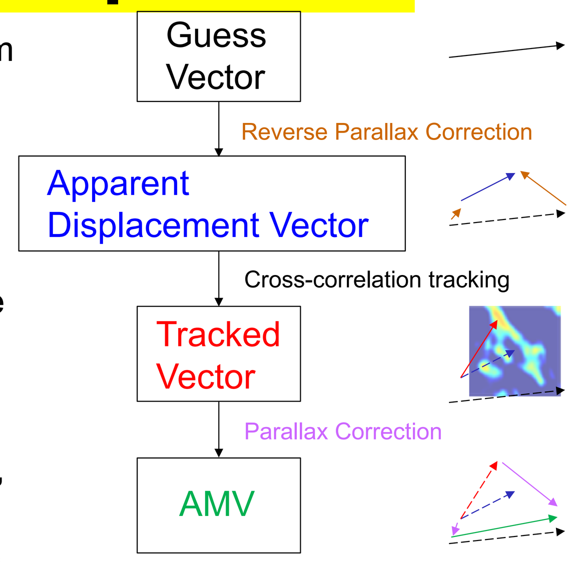


Figure 5: vectors and processing steps involved in a scheme including reverse parallax correction. At each step, the vectors from the previous steps are drawn with dashed-lines.

Considering a dual satellite setup (e.g., Metop-B/Metop-C, or Sentinel-3A (S3A)/Sentinel-3B (S3B), the reference satellite (sensing later in time) always has its trace west of that of the dual satellite (sensing earlier), see Figure 6.

In this context, the effect of the absence of reverse parallax correction is well understood: it lengthens the vectors going towards the West, and shortens the vectors going towards the East (see Figure 7). This effect is stronger the closer we are to the tropics. Indeed, the overlap area is then limited to pixels seen at very high zenith angles, resulting in a bigger parallax correction.

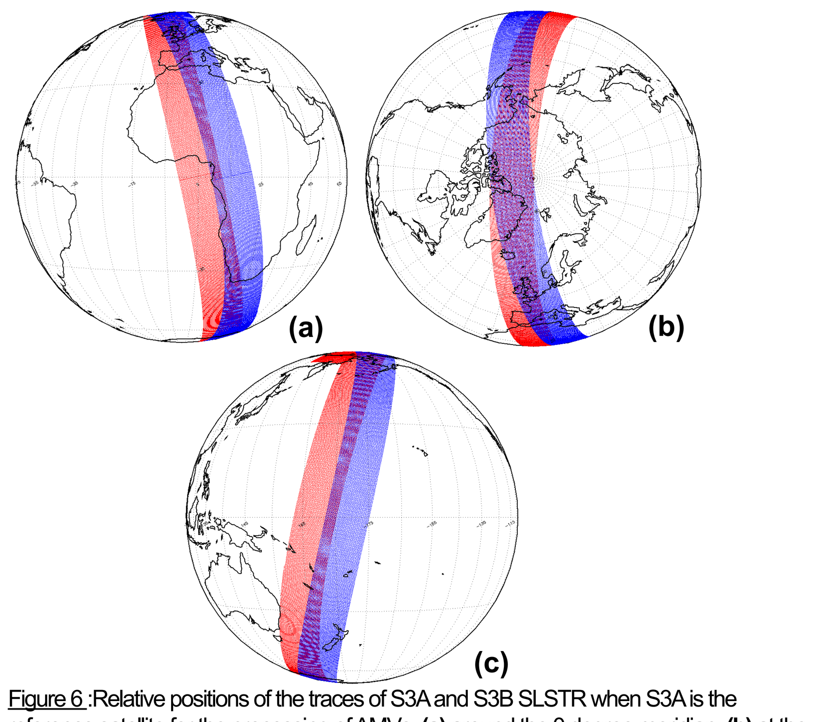


Figure 6: Relative positions of the traces of S3A and S3B SLSTR when S3A is the reference satellite for the processing of AMVs, **(a)** around the 0 degree meridian, **(b)** at the North Pole and **(c)** around the 180 degrees meridian.

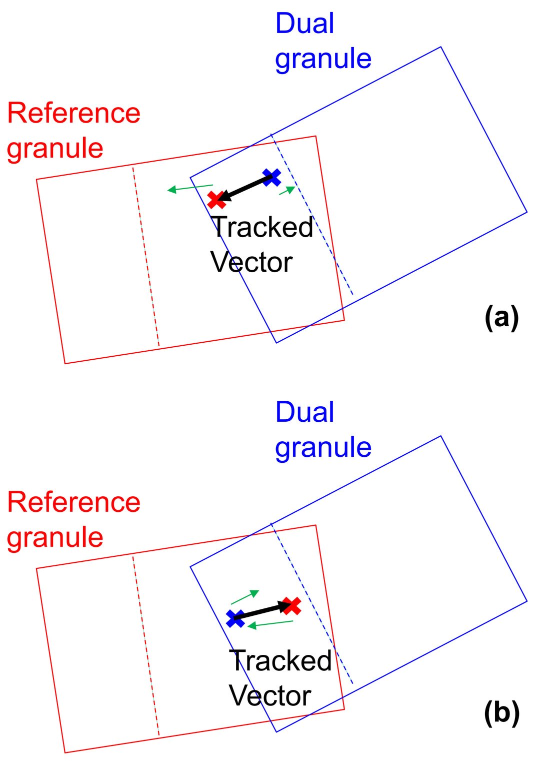


Figure 7: Illustration of the effect of the parallax correction on the tracked vector **(a)** for a wind with strong westward component and **(b)** for a wind with strong eastward component. The reference satellite is the satellite whose data is sensed later. The projection of the nadir of each satellite is plotted in dotted lines. The blue cross is the starting point in the dual image, and the red cross is the arrival point in the reference image. The parallax correction pulls each of the points towards the respective nadir projection, which effectively increases the size of vectors going West, and decreases the size of vectors going East.

So where DO they come from ?

Figure 8 shows the map of overall wind directions. Its correlation with the speed biases is 0.76 (P << 0.001). Following the reasoning developed above with Figure 7, the vectors derived in the tropics are very often lengthened because they mostly go westward. Similarly, the vectors derived at mid-latitudes are often shortened because they mostly go eastward. At the poles, satellite zenith angles are smaller, mitigating the impact of the parallax.

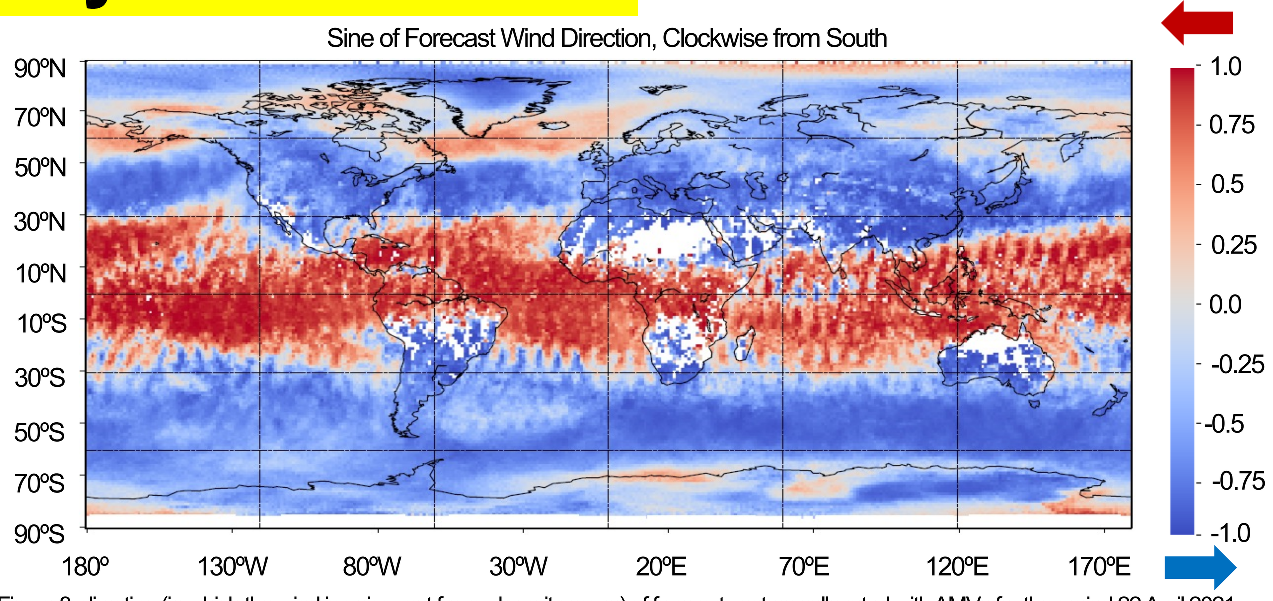


Figure 8: direction (in which the wind is going, not from where it comes) of forecast vectors collocated with AMVs for the period 22 April 2021 to 21 May 2021. The directions are shown as sine of the direction clockwise from South, meaning that values close to 1 (red) indicate winds with strong westward components, and values close to -1 (blue) indicate winds with strong eastward components. Only AMVs faster than 2.5 m/s and whose QIs are greater than 60 are used. Cells in which fewer than 5 fitting AMVs were derived are left blank.

When including the reverse parallax correction on the guess vectors (scheme proposed in Figure 5), the tropical speed biases, but also the negative biases at mid-latitudes, disappear (see Figure 9).

The tropical speed biases are an artefact caused by an approximation on the guess, that cross-correlation tracking is not robust enough to compensate in a context with high time gaps and low ground resolutions.

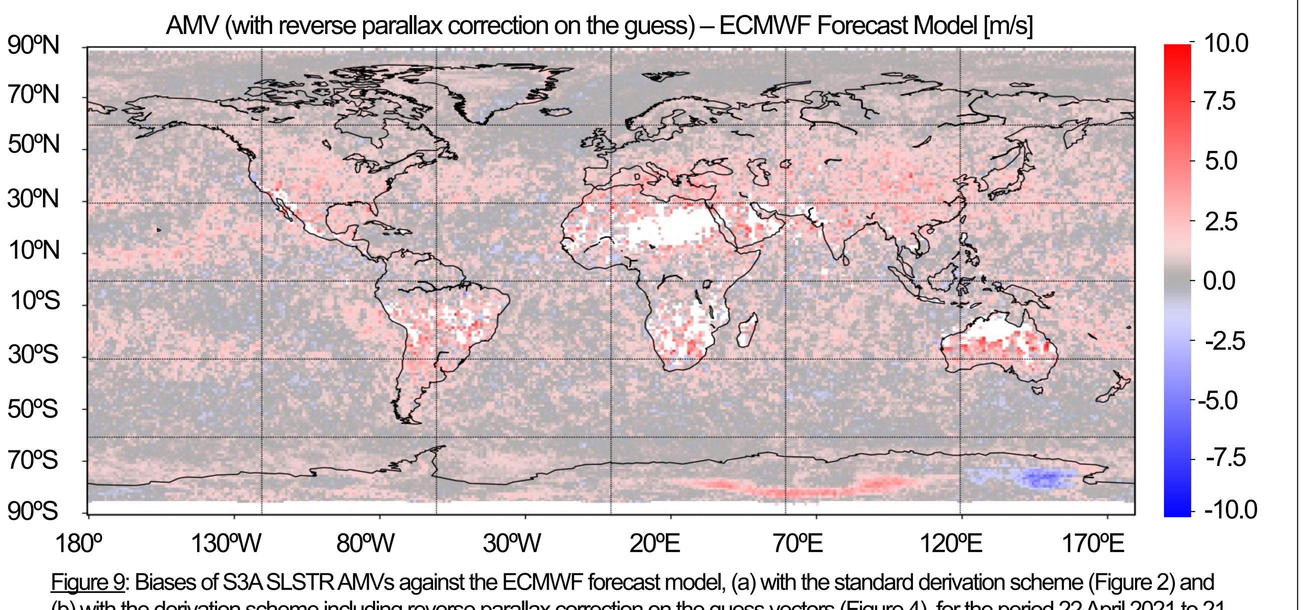
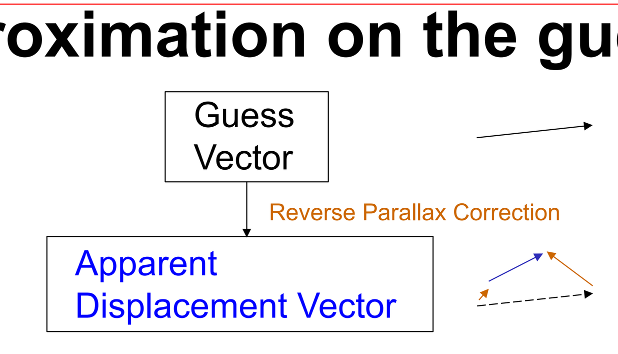
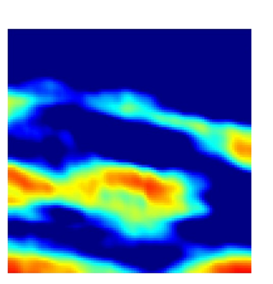


Figure 9: Biases of S3A SLSTR AMVs against the ECMWF forecast model, (a) with the standard derivation scheme (Figure 2) and (b) with the derivation scheme including reverse parallax correction on the guess vectors (Figure 4), for the period 22 April 2021 to 21 May 2021. Only AMVs faster than 2.5 m/s and whose QIs are greater than 60 are used. Cells in which fewer than 5 fitting AMVs were derived are left blank.

Conclusion

LEO Tropical speed biases = **Approximation on the guess** + **Lack of robustness of the tracking**





Shall we then just correct the guess ? No !

The tracking should be robust enough not to be sensitive to small shifts on the guess. This work proves that it is not the case for LEO sensors, where time gaps are large and resolutions are coarse. Correcting the guess would be masking the tracking problems instead of dealing with them. Need to explore new tracking methods, more robust than cross-correlation ! See: Barbieux and Borde, 'A New Paradigm for the Derivation of LEO AMVs Without Wind Guess', IWW16, 8-12 May 2023, Montréal, Canada.

References

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