



NASA's GMAO Atmospheric Motion Vectors Simulator

Description and Application to the MISTiC Winds Concept

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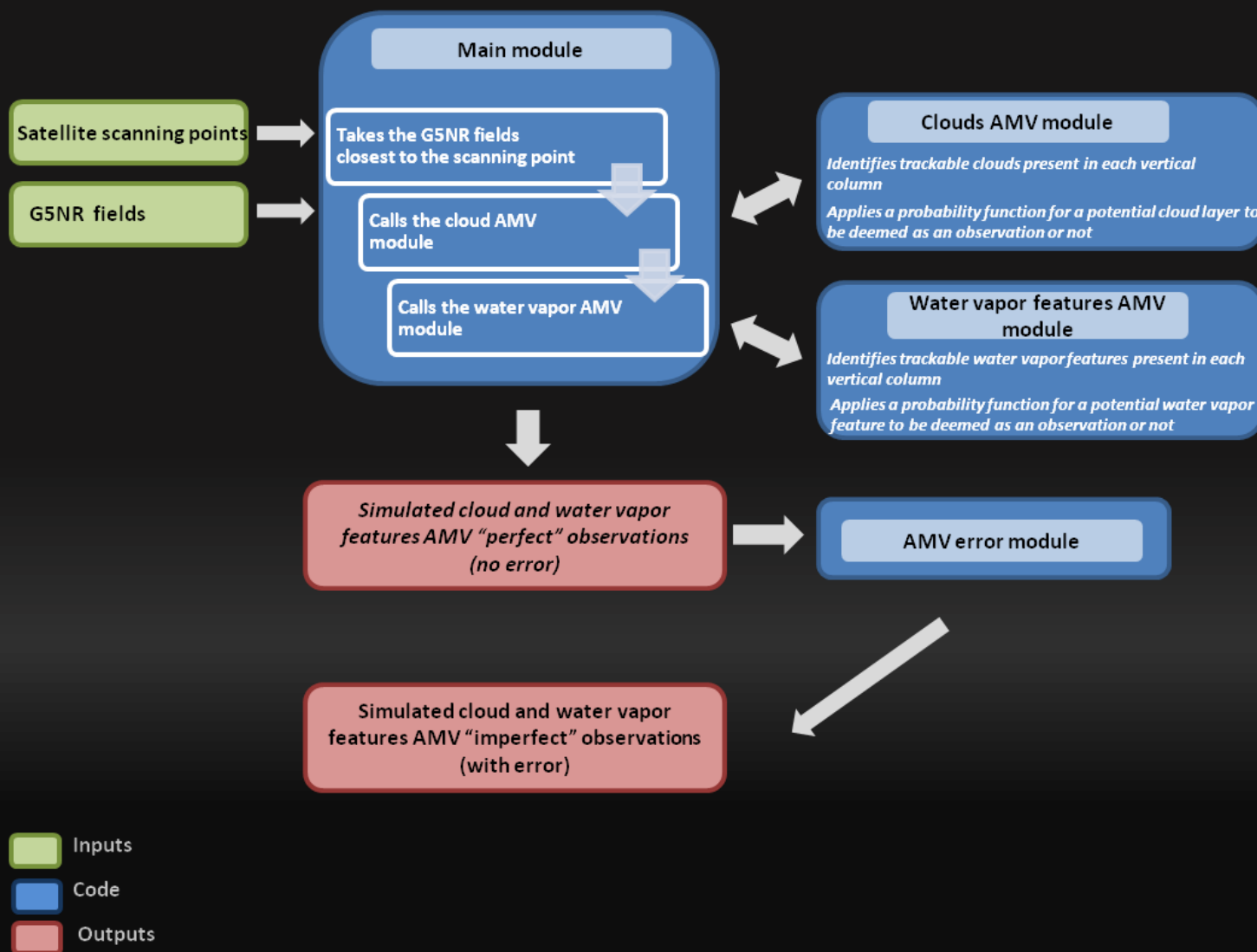
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Why simulate AMVs?

- In the recent past, efforts have been made to estimate the potential added value of new observations to the present Earth observing system by quantifying their expected impact on the current weather forecasting skills.
- Observing System Simulation Experiments (OSSEs) are an essential tool to perform this. A key aspect is that the envisioned observations are realistically simulated for the DAS to show a similar behavior when applied to real observations (mainly **spatial and temporal distributions, and errors**).
- However, feature tracking on a model grid such as the G5NR is not a reasonable option...
 - Coarse spatial resolution compared to satellite imagery (7 km vs. ~1-2 km)
 - Temporal resolution is also insufficient (30 mins vs. 10 mins)
 - G5NR does not have clouds and water vapor fields, but cloud fractions and humidity fields (ratios and not amounts, not exactly the same...)
- A code was designed to simulate cloud and water vapor features tracking AMVs using as an atmosphere the GEOS-5 Nature Run (G5NR), to be later on used as simulated AMVs in OSSEs. The simulated wind observations are taken at G5NR gridpoints where clouds and water vapor gradients exist.

GMAO AMV simulator





Cloud-tracking AMVs simulation

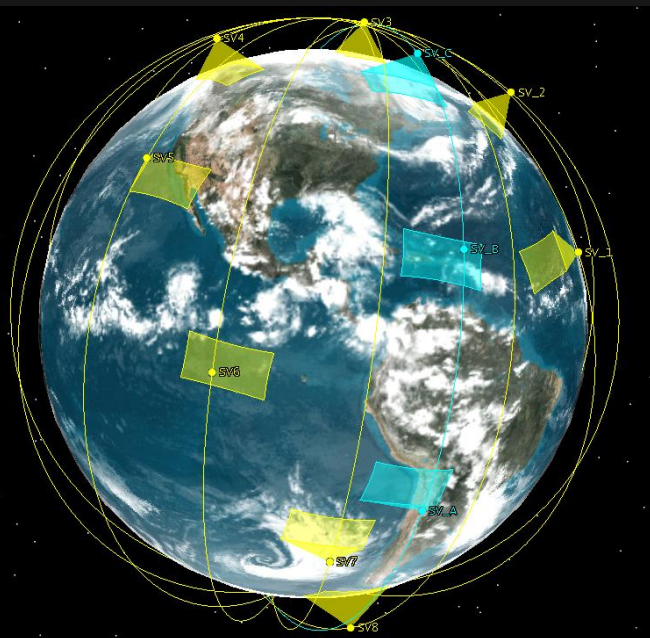
- **Trackable clouds** are identified in the G5NR cloud fraction fields:
 - For each scanning point of the instrument (lat, lon, time), the closest G5NR point (lat, lon, time) vertical column is determined.
 - Search for cloud layers in the vertical column: Starting from the highest model level down, when the cloud fraction of a given vertical level is higher than 10% a new cloud layer is “open”. Going further down, when the cloud fraction of a lower vertical level is less than 10% the cloud is “closed”. Process repeated if more vertical levels with the same characteristics are found below.
 - The cloud fraction of each cloud is computed assuming a maximum random overlap (the cloud fractions of each level within a single cloud maximally overlap, while independent clouds within the column, if present, randomly overlap)
 - For mid-high level clouds (cloud top located lower than 700 hPa), the cloud pressure height is defined as the pressure height of the cloud top, while for low level cloud layers the cloud pressure height is defined as the pressure height of the cloud bottom (following EUMETSAT methodology).
 - **Trackable cloud**: cloud layer located below the tropopause, with cloud fractions in the range of 20-80%, not stationary (with wind speeds at their location higher than $3 \text{ m}\cdot\text{s}^{-1}$) and that are able to potentially be seen by the satellite instrument - not substantially covered by higher clouds above (assuming a random overlap between independent cloud layers)
- A **probability function** was included to determine which of the identified trackable clouds will be effectively selected as observations



Water vapor AMVs simulation

- **Trackable water vapor features** are identified in the G5NR relative humidity fields:
 - For each scanning point of the instrument (lat, lon, time), the closest G5NR point (lat, lon, time) vertical column is determined, but now only for some predetermined fixed vertical levels (the levels envisioned to be resolved by MISTiC): 150, 200, 250, 300, 400, 500, 600 and 700 hPa.
 - For each vertical level the RH “gradient” was computed (not the mathematical gradient, a vector, but rather a scalar approximation defined as the difference between the maximum and minimum RH value within a 35 km² horizontal box).
 - **Trackable water vapor feature**: Points where the RH gradient is higher than 65%, not stationary (with wind speeds at their location higher than 3 m.s⁻¹), not significantly covered by clouds above (the cloud fraction above is less than 85% assuming a vertical random overlap) and that are located below the tropopause height.
- A **probability function** was included to determine which of the trackable water vapor features found in the G5NR will be effectively selected as observations. This probability function favors (gives higher probabilities to) trackable water vapor features with higher RH gradients and shallower (if none) clouds located above.

MISTiC Winds concept: a case study

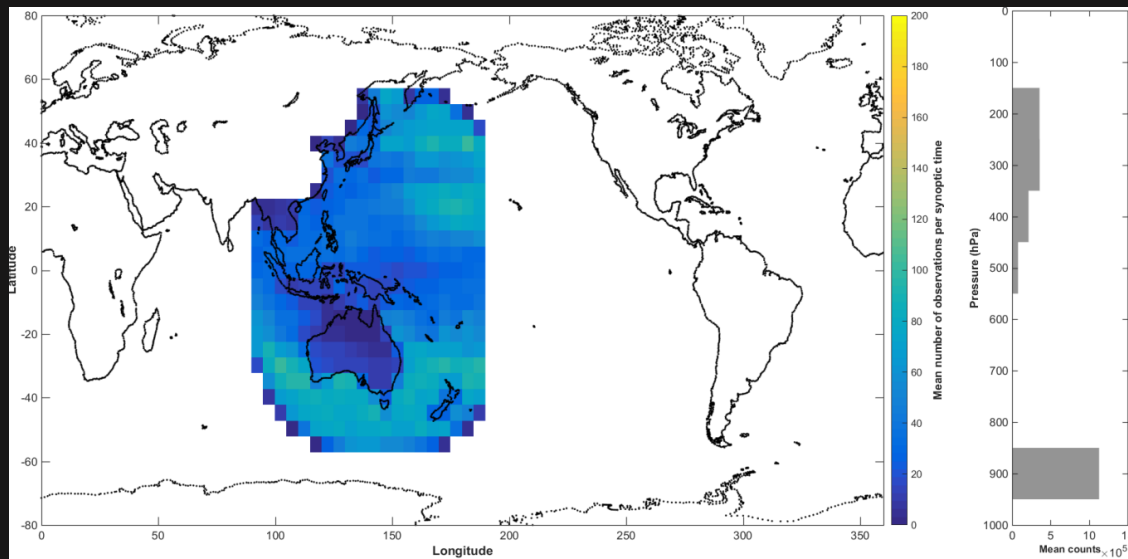


- NASA mission concept that consists of a low Earth orbit (LEO) constellation of MicroSats.
- High spatio-temporal resolution temperature and humidity soundings of the troposphere.
- Besides radiances (IR spectrometer sampling the midwave), temporally subsequent sets of retrievals can be used to perform cloud and water vapor feature tracking and retrieve AMVs.
- The GMAO AMVs simulator was used to simulate the AMVs expected to be derived from MISTiC Winds instruments, to be later used in OSSEs to assess if these new observations can improve the forecasts skill.

➤ Since there are no real MISTiC AMV observations to quantify how many AMVs the instruments will collect, an instrument that is currently part of the Earth Observing System has to be used as proxy:

- ❑ The Himawari-8 geostationary satellite Advanced Himawari Imager (AHI) was considered as a proxy instrument to tune and validate the AMVs simulator code when applied to MISTiC. AHI is a 16 channel multispectral imager that operates in the visible and infrared, and it has a similar horizontal resolution to that of MISTiC Winds.

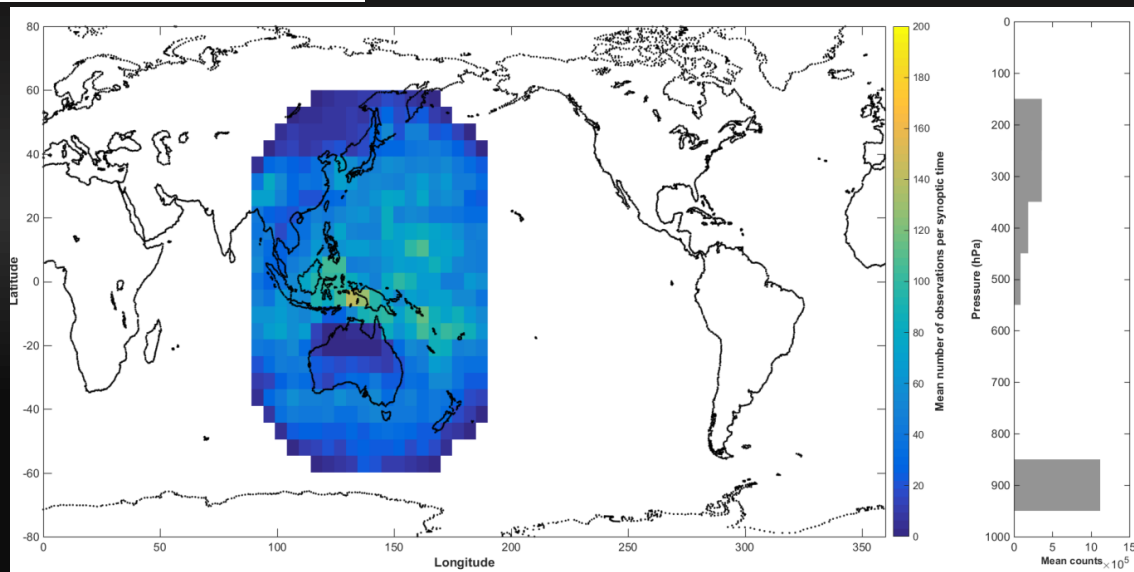
MISTiC Winds: simulated and real AHI AMVs



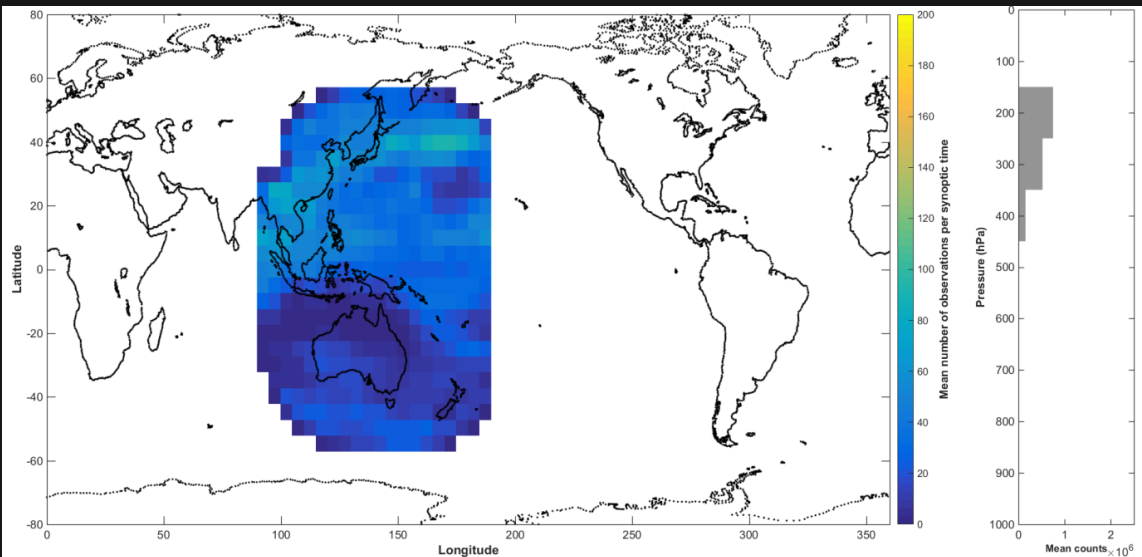
- ❑ Simulated Himawari-8 AHI cloud AMVs vertical distribution and number of obs perfectly match the real ones (~17,400 simulated vs. ~17,300 real average counts per synoptic time)
- ❑ Horizontal distribution not so much... Differences between the real and G5NR meteorology and cloud fields for this month (?)

❑ Real AHI cloud AMVs tend to be scarcer over land, maybe related to malfunctions and/or data blacklisting's over land (eg., AHI AMVs below 400 hPa over land are usually blacklisted or given a low quality index).

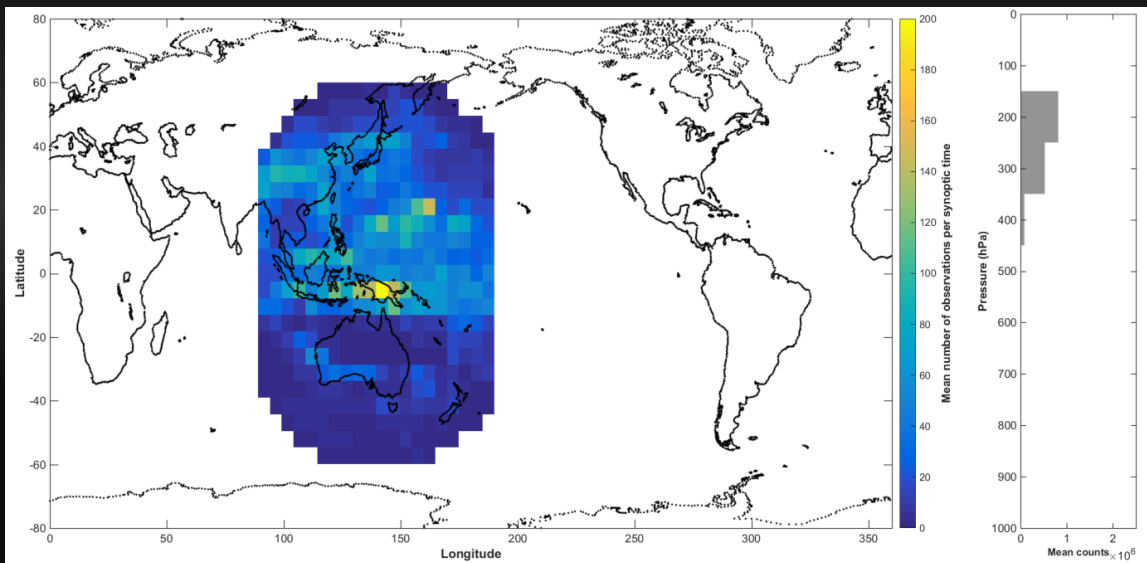
❑ This was not mimicked by the cloud AMV simulator since it is not expected that MISTiC cloud-tracking AMVs will show this behavior.



MISTiC Winds: simulated and real AHI AMVs



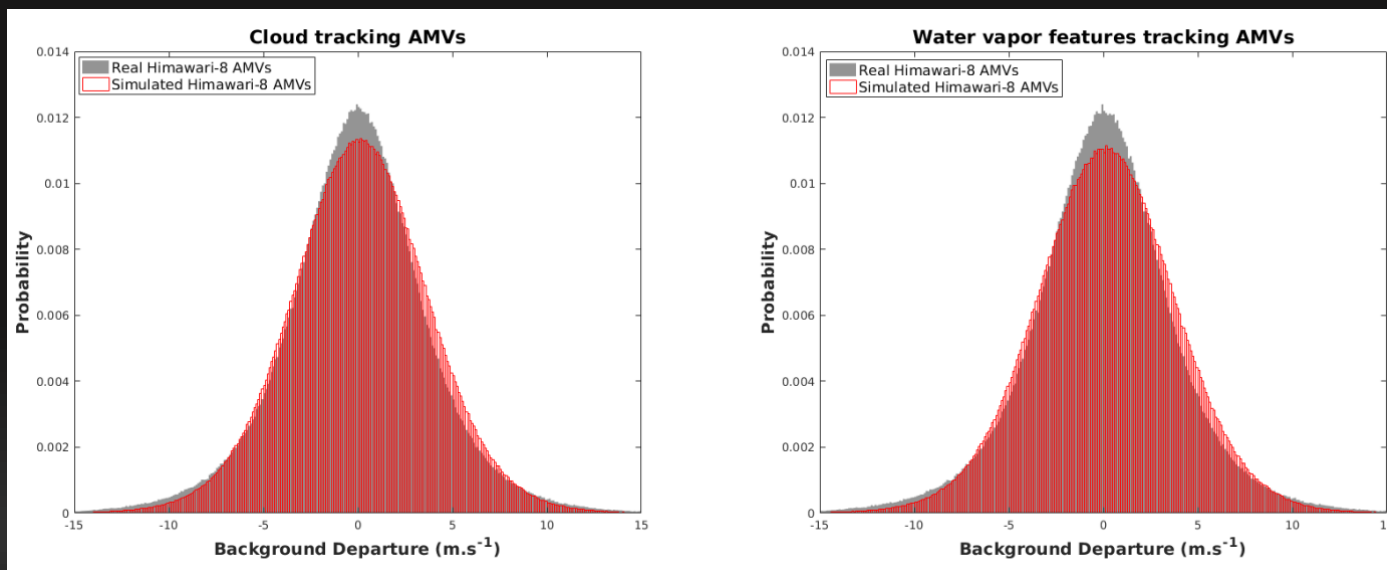
- ❑ Simulated Himawari-8 AHI water vapor AMVs vertical distribution and number of obs perfectly match the real ones (~11,450 simulated vs. ~11,500 real average counts per synoptic time)
- ❑ Again, horizontal distribution not so much... Differences between the real and G5NR meteorology and relative humidity fields for this month (?)



✓ Despite these differences, it is clear that the simulated AMVs show a high degree of realism in terms of number and spatial distributions

MISTiC Winds: simulated and real AHI AMVs

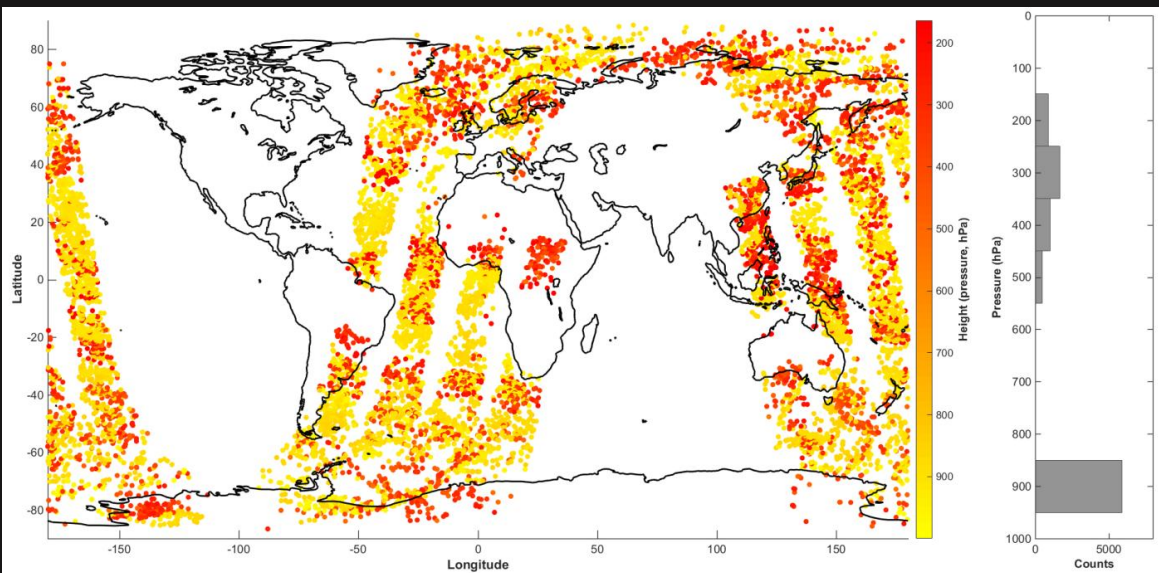
- For the DAS system to show the same behavior when applied to simulated observations, the latter need to show also a realistic distribution of the differences between the observations and the backgroundfields (OMFs).
- Observational error was added to the simulated AMVs (**random and correlated error**). Himawari-8 AHI AMV error values simulated by the GMAO OSSE code used as proxy (see Errico et al., 2016 for details about the errors).



- Although the MISTiC cloud AMVs errors are expected to be very similar to the Himawari-8 AHI ones (similar instruments), the water vapor AMV errors are not readily/easily quantified...

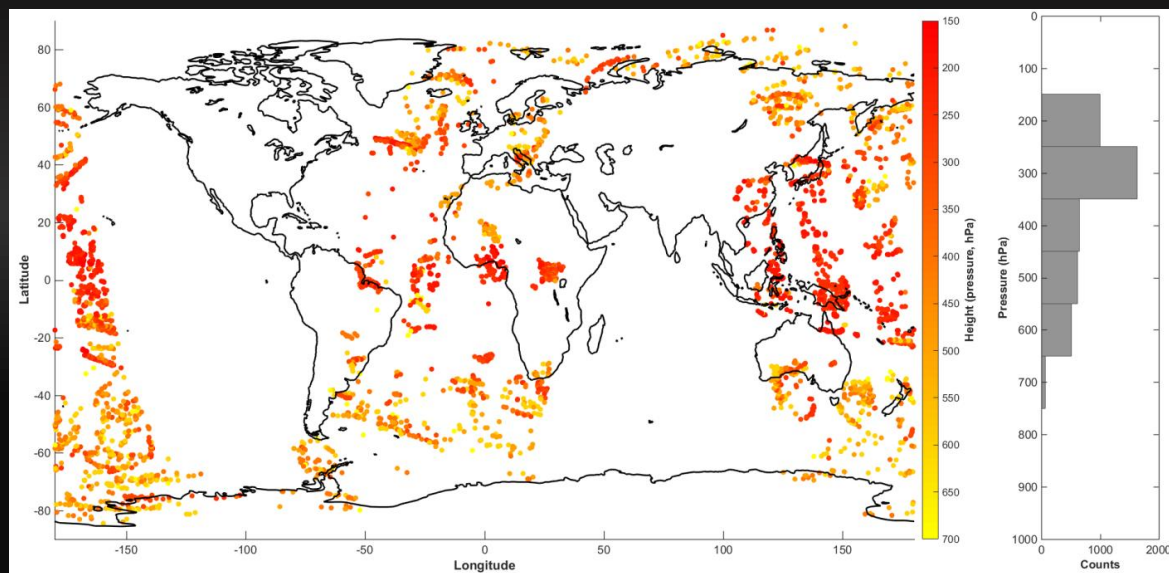
- ❑ Traditional AMVs are performed in radiance space (Large uncertainty in height assignment).
- ❑ MISTiC approach is to retrieve wind on retrieved WV on constant pressure surfaces (Height assignment error now translated into retrieval error).
- ❑ As best (and first) guess, we kept the correlated vertical scales the same and assume that the Himawari-8 Ahi water vapor AMVs error are a decent approximation to the MISTiC water vapor AMVs.

MISTiC Winds: simulated MISTiC AMVs



- Considering only one orbital plane (3 satellites), MISTiC Winds is able to collect approximately **13,000 cloud AMV observations** and **5,000 water vapor AMVs every 6 hours**.
- If 4 orbital planes are considered, a **full global coverage could be obtained every 6 hours**, collecting **~ 73,500 AMV observations**.

- The simulated water vapor AMVs vertical distribution reflect the expected added-value of MISTiC Winds in terms of increased vertical resolution, being able to derive AMVs below 500-400 hPa, a unique feature among the water vapor AMVs derived from the current Earth observing system.





Conclusions

- ✓ An AMVs simulator was developed to simulate AMV observations from future satellite constellation concepts, which can be later used in OSSEs to estimate the potential added value of new observations to the present Earth observing system.
- ✓ The designed code identifies trackable clouds and water vapor features in the G5NR and employs a probabilistic function to draw a subset of the identified trackable features.
- ✓ As a case study and application example, NASA's GMAO AMV simulator was used to simulate AMVs expected to be collected by a NASA mission concept – MISTiC Winds, a constellation of satellites equipped with infrared spectral midwave spectrometers.
- ✓ A calibration and validation considering a proxy instrument to MISTiC Winds (Himawari-8 Advanced Imager) showed that the GMAO AMVs simulator synthesizes AMVs observations with enough quality and realism to produce a response from the DAS equivalent to the one produced with real observations (the main goal of an OSSE).
- ✓ When applied to MISTiC Winds, it can be expected that the MISTiC Winds will be able to collect approximately 60,000 wind observations every 6 hours, if considering a constellation composed of 12 satellites (4 orbital planes).
- ✓ The GMAO AMV simulator is a tunable and flexible computer code that can be easily adapted and applied to AMVs simulation expected to be derived from different instruments and satellite orbit configurations.