# VarBC for AMVs: Can AEOLUS help?

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## Introduction

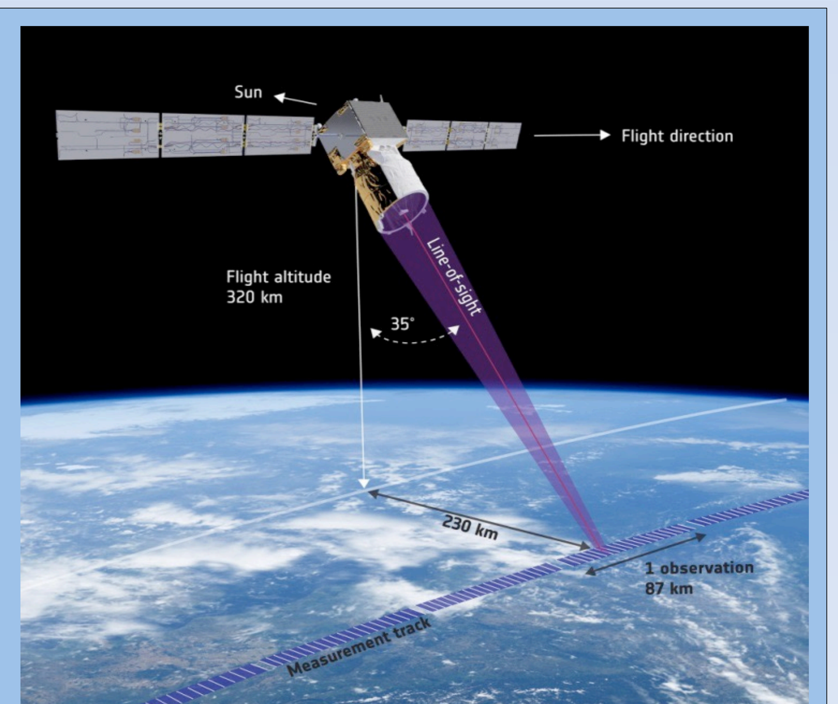
Wind observations are critical for environmental analysis and numerical weather prediction (NWP).

Wind observations used in NWP data assimilation are under-represented. Sources are mainly limited to 2D winds: Geo/Polar cloud track wind (CTW) and water vapor (WV) atmospheric motion vectors (AMVs), ocean surface winds (scatterometers, microwave imagers), in-situ (aircraft, mesonet, buoys); and sparse profiles of winds from rawinsondes and dropsondes. AMVs suffer from a variety of coherent error that induce error correlations. The most important errors for CTW AMVs may be due to height assignment errors.
The NRC decadal survey identifies 3D horizontal wind vector measurements as transformative to weather and air quality forecasts, and space-based Doppler wind lidar or combined approaches as a Targeted Observables.

A method to apply VarBC in an obs operator for AMVs is proposed. This VarBC has three degrees of freedom corresponding to a wind speed bias, a vertical height assignment bias, and the depth of the layer that contributes to the AMV.

In the same way that GNSS/RO observations have provided the highly accurate observations necessary to make VarBC of radiances successfully, it had been anticipated that Aeolus winds will do the same for the VarBC of AMVs, provided that the DWL observations are in fact very accurate and bias free. The parallels would be striking: GNSS/RO and Aeolus DWL observations have global but sparse coverage, are (or should be) extremely accurate, and have high vertical resolution. In the box on the right we describe a VarBC obs operator for AMVs that relies on whatever unbiased accurate winds are available as anchors in the DA system, mostly radiosonde and aircraft reports, and hopefully DWL observations. In any case, VarBC makes use of all information presented to the DA system, including all observations, the model forecast, and a priori constraints, not just the unbiased anchoring observations. It should be kept in mind that VarBC corrections are relative to the background (short-term forecast), so that the resulting corrections include any forecast model bias.

## Aeolus Status




The essential instrument on the Atmospheric Dynamics Mission (ADM), also know as Aeolus, is the Atmospheric LAser Doppler INstrument (ALADIN).

- Aeolus was launched on August 22, 2018, and the first wind lidar in space to obtain backscattering from molecules and particles (aerosols/clouds)
- ALADIN operates @ 355 nm (UV) with spectrometers for molecular Rayleigh and Mie (aerosol/cloud) backscatter; and
- Retrieves wind profiles projected onto the Horizontal Line-of-Sight (HLOS) up to 30 km (15 km for Mie channel) with vertical resolution from 250 m - 2 km and horizontal resolution of ~90 km. There are ~2000 HLOS wind profiles globally every day.

The current AEOLUS products have not yet attained the high quality that would make them a good candidate as anchors for an AMV VarBC. While there has been a more rapid than expected decrease in laser energy, there are also a number of known solvable issues that impact the Aeolus data quality. For example, very recently, a new fix was implemented to the star tracker to improve the corrections made due to space craft motion, which is expected to remove some of the observation bias. Further efforts are now being made in terms of additional calibration and enhancements to the AEOLUS L2 processing, and we expect that high quality observations will be available, at least for part of the mission.

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## Aeolus Sample Data

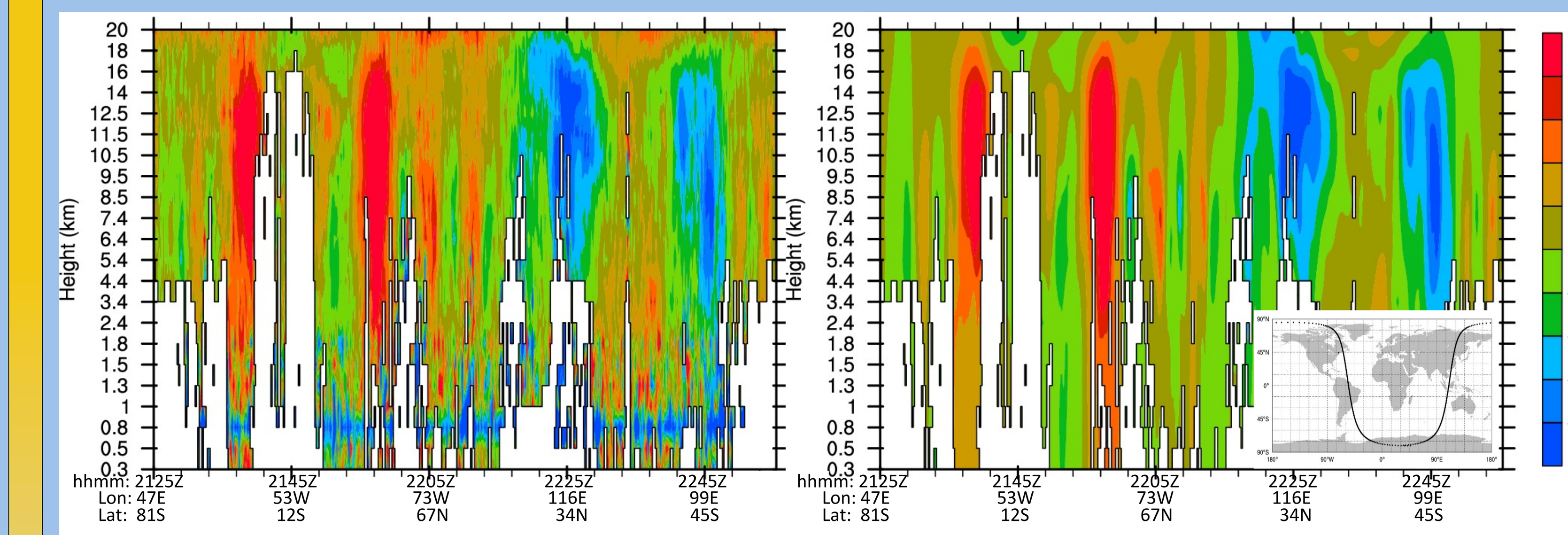
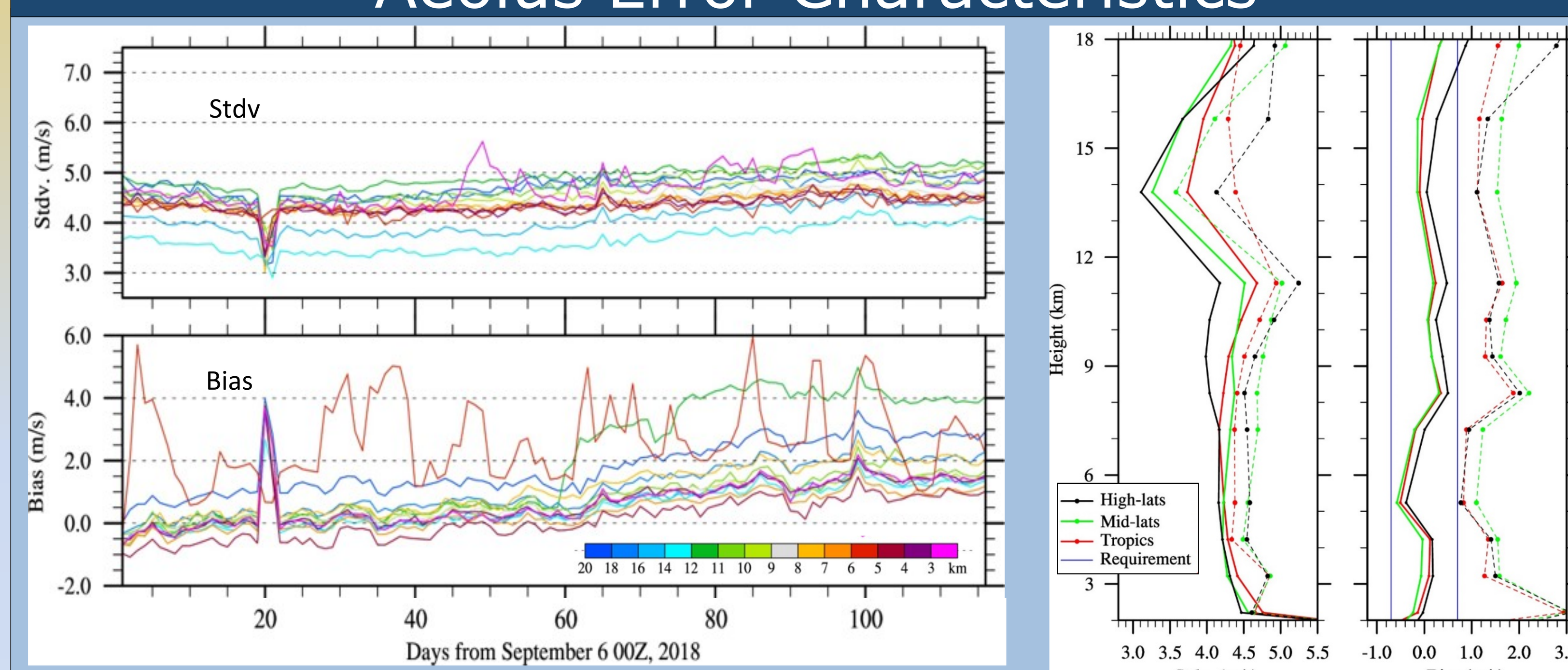



**Figure.** Sample L2B Rayleigh clear (left) and GFS background (right) HLOS wind speeds (m/s, color coded) for one orbit (25 Feb 2019, pictured in inset). The orbit starts in Antarctica, traverses Brazil, etc.

## Aeolus Error Characteristics




**Figures.** Error characteristics for Aeolus vary with time and height. (Left) Time evolution of standard deviation (m/s, top) and bias (m/s, bottom) of Rayleigh clear sky HLOS wind speeds compared to GFS for different levels (color lines) for the period 3 September to 31 December 2018. (Right) Time averaged statistics for 1-15 October (solid lines) and 16-31 December (dashed lines) for different domains (colors).

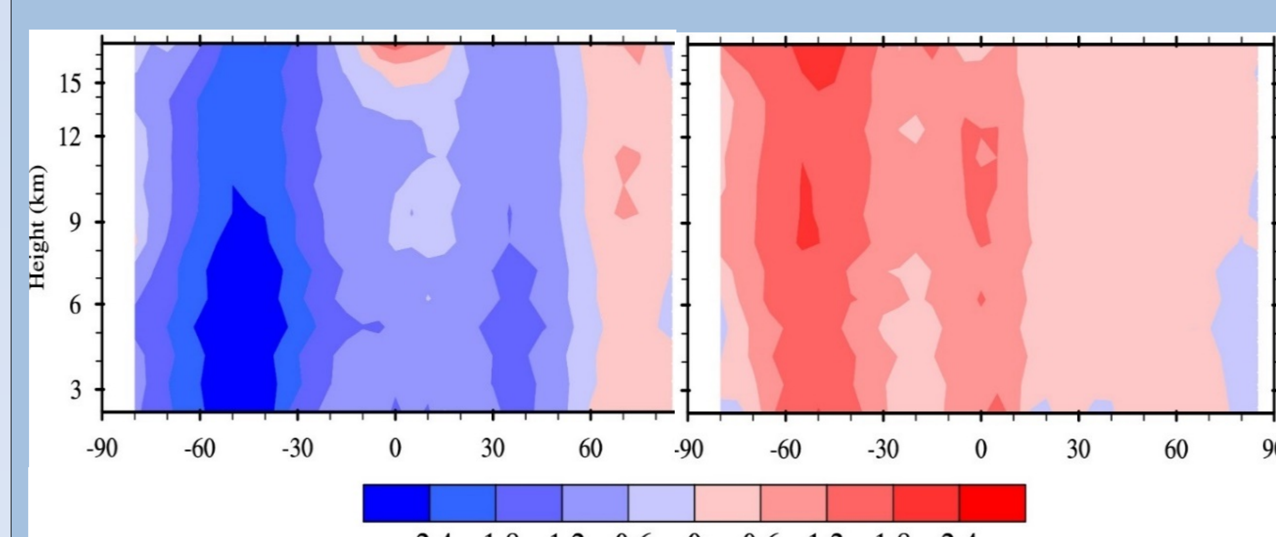



**Figure.** Latitude-height cross sections of L2B – ERA5 HLOS wind bias for 15-30 September 2018 for ascending (left) and descending (right) orbits.

## VarBC Obs Operator

The VarBC AMV obs operator is

$$\overline{\mathbf{V}} = (1+\gamma)\overline{W}^{-1}\int_{p_o+\delta p-h/2}^{p_o+\delta p+h/2} W(p)\mathbf{V}(p)dp$$

Here,

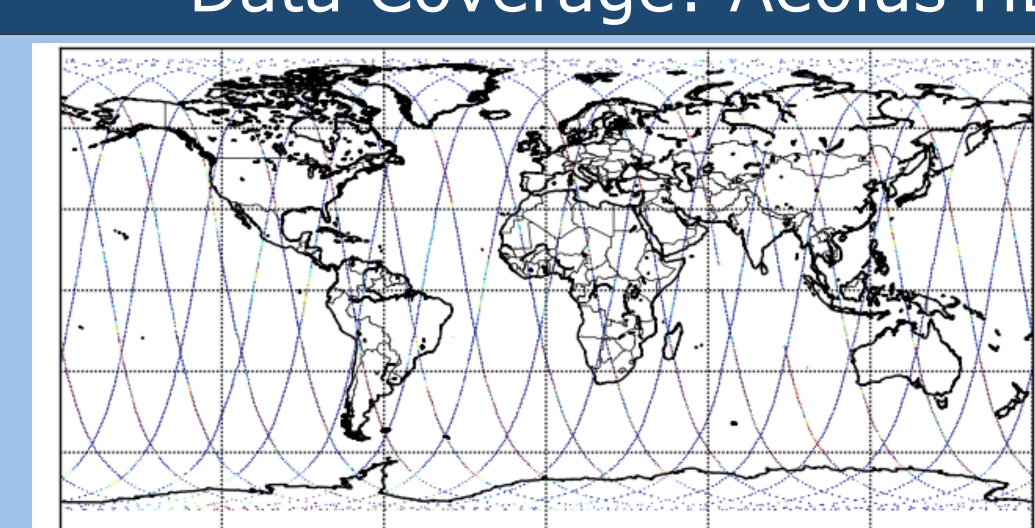
- $\delta p$ is the height bias (hPa);
- $\gamma$ is the speed bias (fraction);
- $h$ is the layer thickness (hPa);
- $p_o$ is the obs reported height (hPa);
- $\mathbf{V}$ is the vector wind ($u, v$, m/s);
- $W$ is the weighting function; and
- $\overline{W}$ is the integral of $W$ over the same bounds.

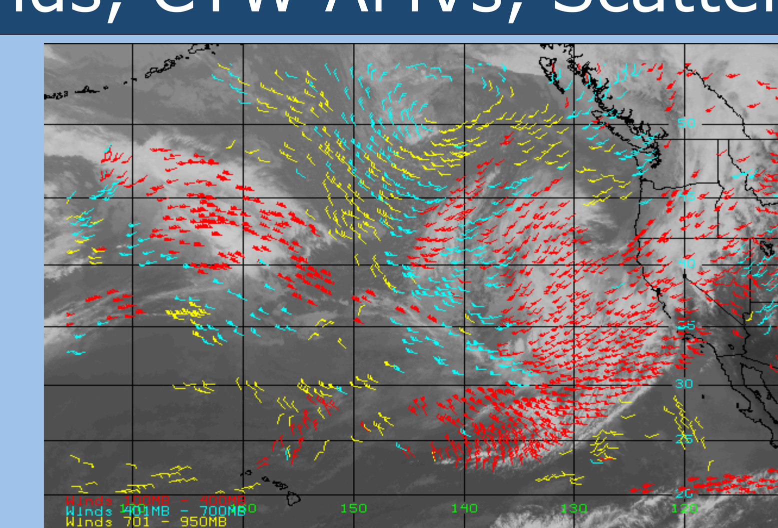
*Motivation*. First, it is thought that the most critical bias of AMVs is due to height assignment errors. Second, AMVs no doubt have additional wind speed biases once height assignments are corrected. Third, AMVs are representative of a layer, not a level, and the estimate of the layer depth may also be bias corrected.

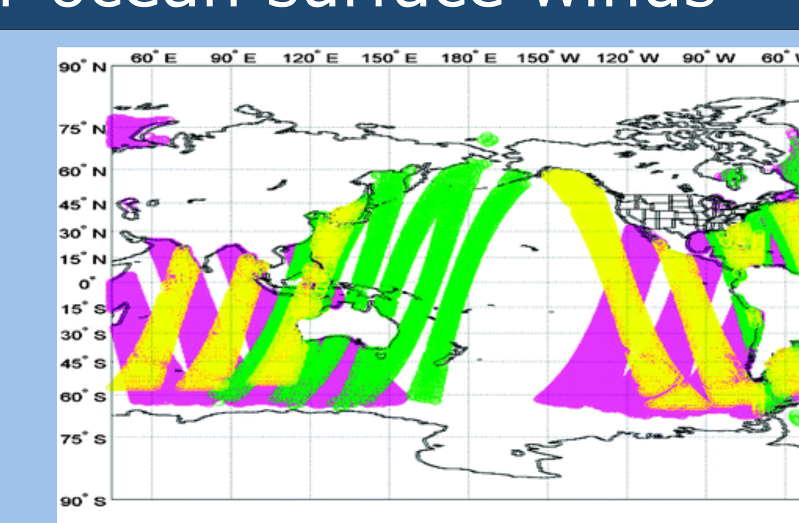
*Method*. The parameters, δp, γ, and $h$ are determined to get the best possible consistency between the observations and the simulated wind. These three parameters are constrained to be a function of some variables derived from the background (i.e., 6-h forecast) and a small number of fit "constants" that are determined by optimization. The fit "constants" depend on location of the observation, and the type of AMV.

*Considerations*. Different types of AMVs will require different corrections. For example, $h$ is likely small for window channel IR CTW AMVs compared to $h$ for hyperspectral clear-sky layer water vapor (WV) AMVs. On the other hand hyperspectral WV AMVs may have smaller height assignment errors than CTW AMVs because WV AMVs can use an internally consistent retrieved height based on the weighting function profiles while for CTW AMVs height assignments depend on an externally provided temperature profile. The weighting function might be any specified shape---box car, trapezoid, truncated Gaussian hill, etc.---and it could depend on cloud type or AMV product.

## Data Coverage: Aeolus HLOS winds, CTW AMVs, Scatterometer ocean surface winds








**Figures.** (Left) One day (10 January 2019) of Aeolus level 10 (~11 km AGL) HLOS wind speed (m/s, color coded). (Center) GOES-West hourly AMVs (one 6-h period), courtesy of www.ospo.nesdis.gov. (Right) Scatterometer ocean surface winds (one 6-h period) from Bi (2011, 10.1175/2011MWR3391.1, Fig. 2).