Initial Impact Assessment of ADM-Aeolus Satellite Lidar Winds on NOAA global NWP

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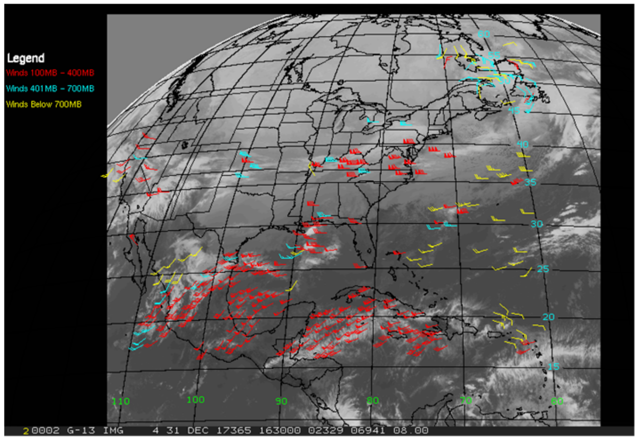
Outline

- Introduction of ADM-Aeolus Satellite Lidar Winds
- Comparison of ADM Level-2B winds to GFS background
- Impact of ADM winds on NOAA FV3GFS forecast
- Conclusions

Introduction

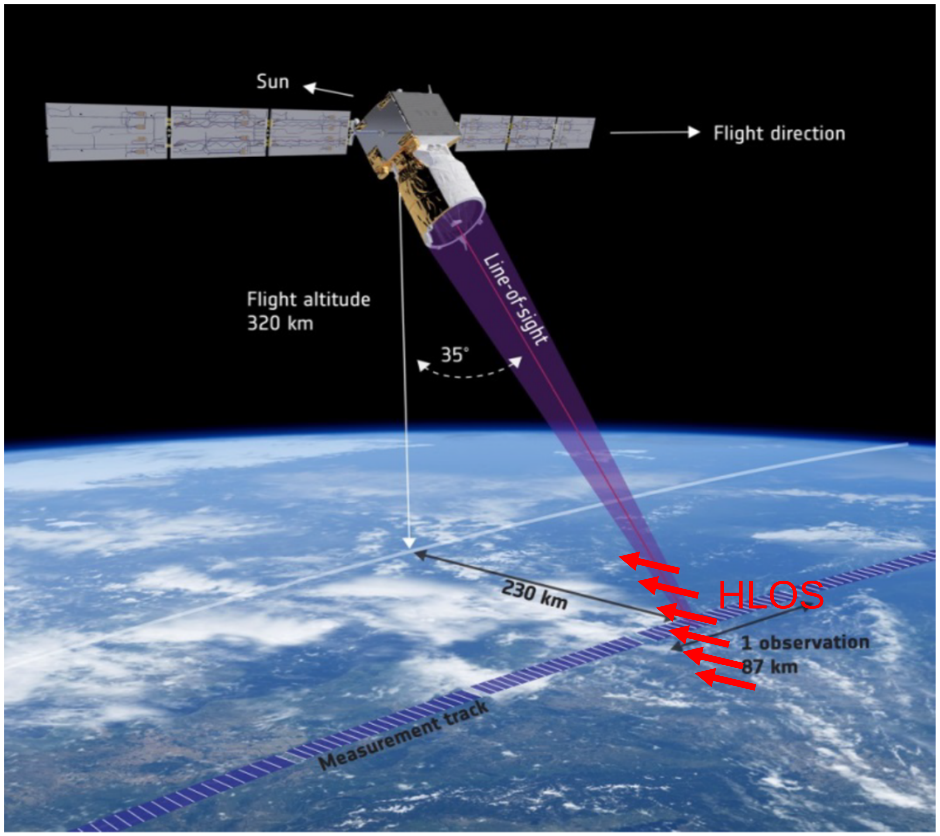
Wind observations are critical for operational forecasting (e.g. Nowcasting) and numerical weather prediction (NWP).

- Winds throughout the atmosphere describe general flow, shear, strength of cyclones, location of jets, etc. critical in environmental analysis and prediction
- Current sources are mainly limited to 2D view of winds at various, disconnected levels: AMVs (cloud/water vapor tracked), ocean surface winds (scatter-meters, microwave imagers), in-situ (aircraft, mesonet, buoys), with exception of sparse rawinsonde and dropsonde.
- **Motivation:** Availability of 3D wind profiles (with adequate spatial/temporal coverage) would improve atmospheric analyses /forecast particularly in ageostrophic situations (e.g. tropics, mesoscale systems), and improve characterization/use of other satellite-based winds.

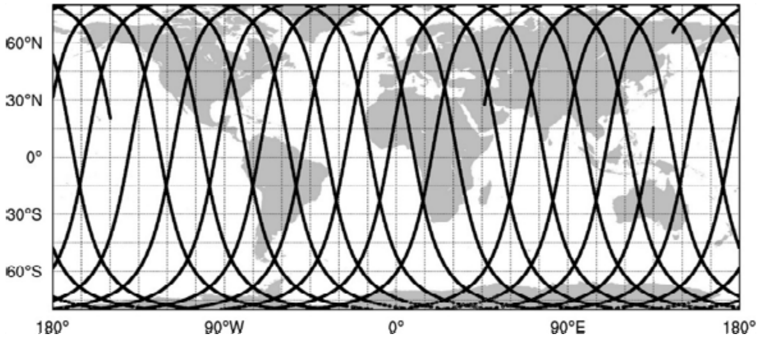


Example of GOES-based Atmospheric Motion Vectors (AMVs). Colors represent wind barbs at different atmospheric layers.

3D Wind from Atmospheric Dynamic Mission (ADM)

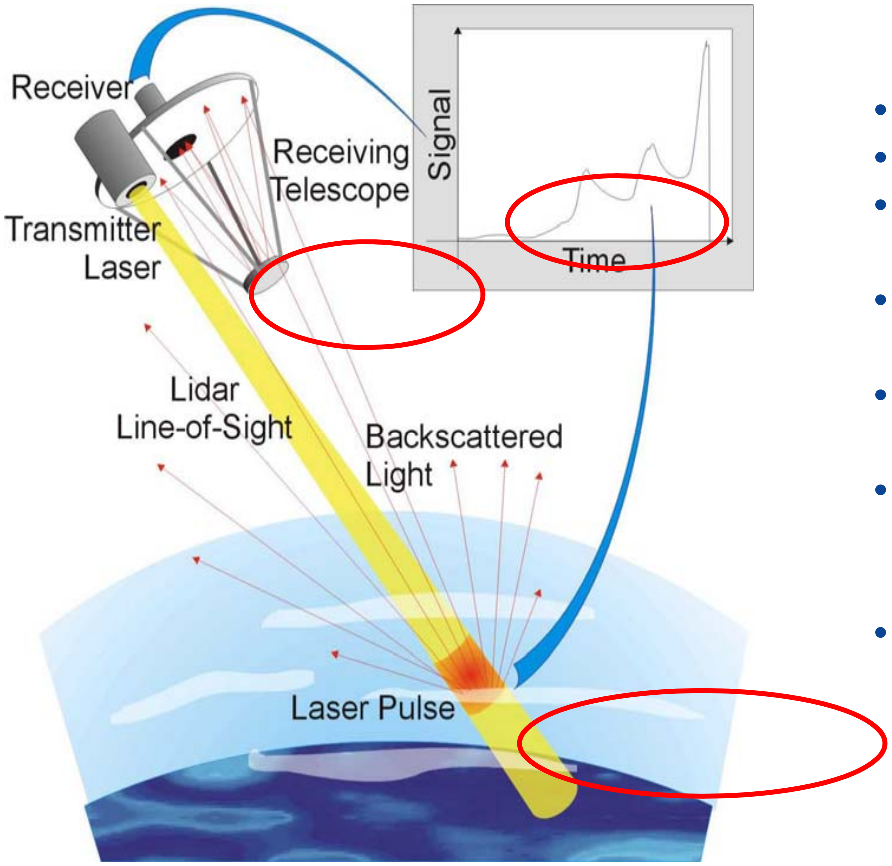


- Launched on August 22, 2018
- First polar orbit satellite wind lidar of European Space Agency to provide 3D global wind profiles
- Wind retrievals along Horizontal Line-of-Sight (HLOS) **up to 24 km** altitude with **vertical resolution from 250 m - 2 km**
- Horizontal resolution is ~ **90 km**
- ~2000 profiles every day



ADM profile locations, Oct 16 2018

ADM-Aeolus Lidar Principal



- Emitting laser frequency at 355 nm (UV)
- The receivers obtain:
- Rayleigh backscattering from molecular of clear sky
- Mie backscattering from aerosol/clouds particles
- both in the troposphere and lower stratosphere

- Doppler frequency shift due to movement of the scatters although tiny in magnitude

- Wind component along lidar line-of-sight derived from Doppler shift, and averaged in a volume of air (90km in horizontal by 1-2km in vertical)

Rayleigh and Mie Backscattering Spectrum

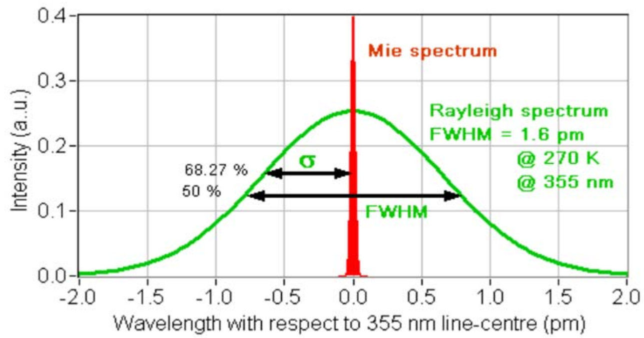


Figure 3-4: Wavelength spectra for the backscatter signals from aerosols (Mie spectrum, red) and from molecules (Rayleigh spectrum, green) illustrating the different spectral widths (σ, Full Width Half Maximum FWHM=$2\sqrt{2ln2}\sigma$) at a laser wavelength of 355 nm for 0 ms^{-1} wind speed.

Mie: narrow laser spectrum in red

Rayleigh: broad Gaussian spectrum in green

$$\sigma = \frac{2\lambda}{c}\sqrt{\frac{kT}{m}}$$

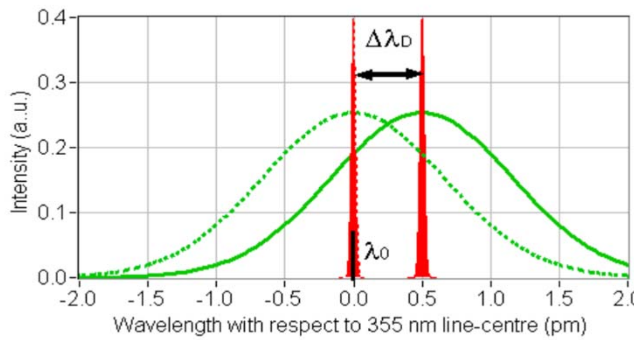


Figure 3-5: Wavelength spectra for the backscattered Mie (red) and Rayleigh (green) signal for a 355 nm source at λ_0 (dotted lines) and a Doppler shift $\Delta\lambda_D$ (bold lines); the indicated Doppler shift of 0.5 pm corresponds to a LOS wind speed of ~ 200 ms^{-1}.

Rayleigh & Mie spectrum can move (separately) due to Doppler shifts from movement of clouds/aerosol and/or molecules

Challenge is to measure the Doppler shift accurately given its tiny magnitude

Objectives of NOAA

Exploitation and assessment of ADM-Aeolus space lidar horizontal line-of sight (HLOS) winds in NOAA applications.

- Implement near-real time data flow of ADM-Aeolus L2B HLOS winds
- Characterize error of L2B winds by comparing to NWP analyses and forecast
- Develop QCs, bias correction, and observational error specification for assimilation
- Assess impact of assimilating L2B winds on NOAA's global forecast

Comparison of ADM Winds to GFS Background

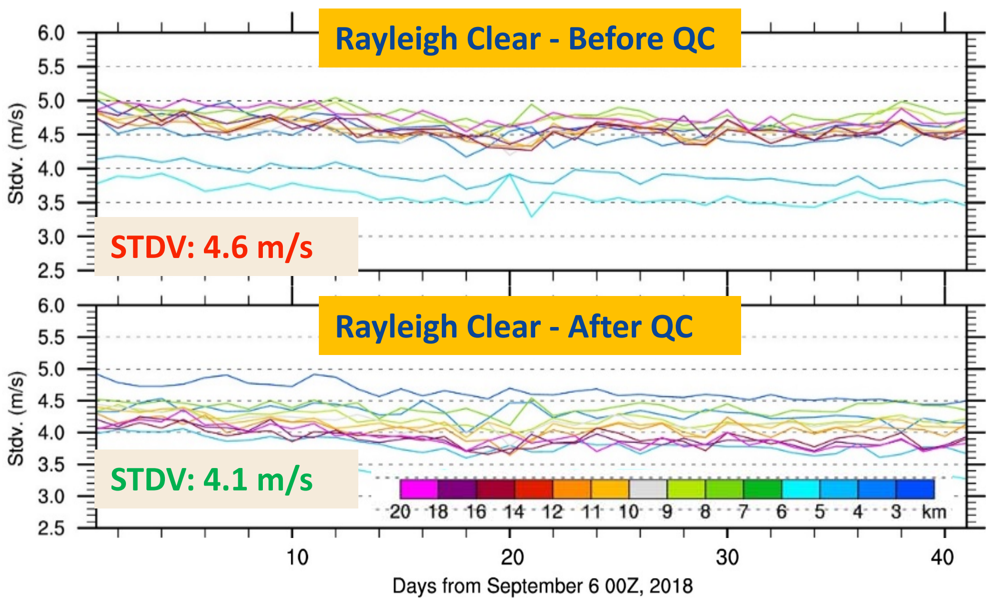
- ADM Level-2B HLOS winds considered:
  - September 6 – October 16, 2018
  - Resolutions: 1-2km in vertical, and 90km in horizontal
  - L2B uncertainty: < 8 m/s (Rayleigh clear-sky) and 3 m/s (Mie cloudy-sky)
- GFS 6-hour forecast:
  - 0.25 degree horizontal resolution
  - 64 levels (0-60km) for GFS
- Comparison to GFS forecast (forward operator):
  - NWP wind profiles are linearly interpolated horizontally to the center of L2B wind volume, and transformed to the HLOS wind component

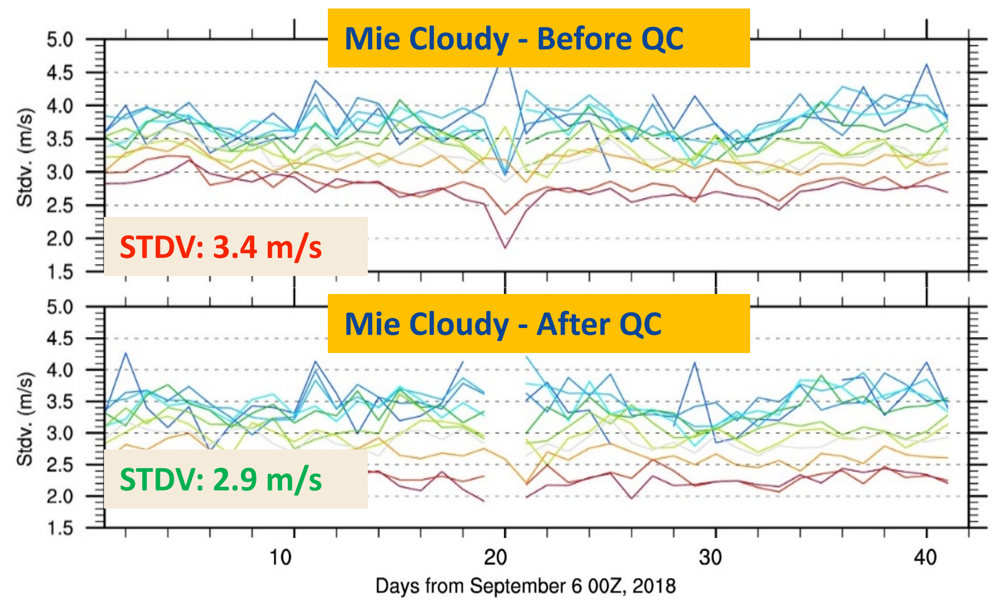
QCs of ADM Winds

QC 1 Check — Remove Blacklisted Data

QC 2 Remove
- Mie wind: > 1.5 m/s uncertainty
- Rayleigh wind: > 4.0 m/s uncertainty

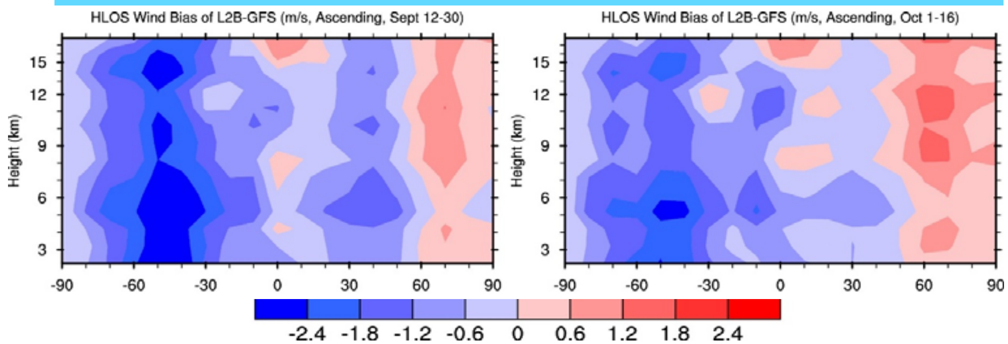
QC 3 Shear — Remove: GFS vertical shear of HLOS wind > 5 m/s/km

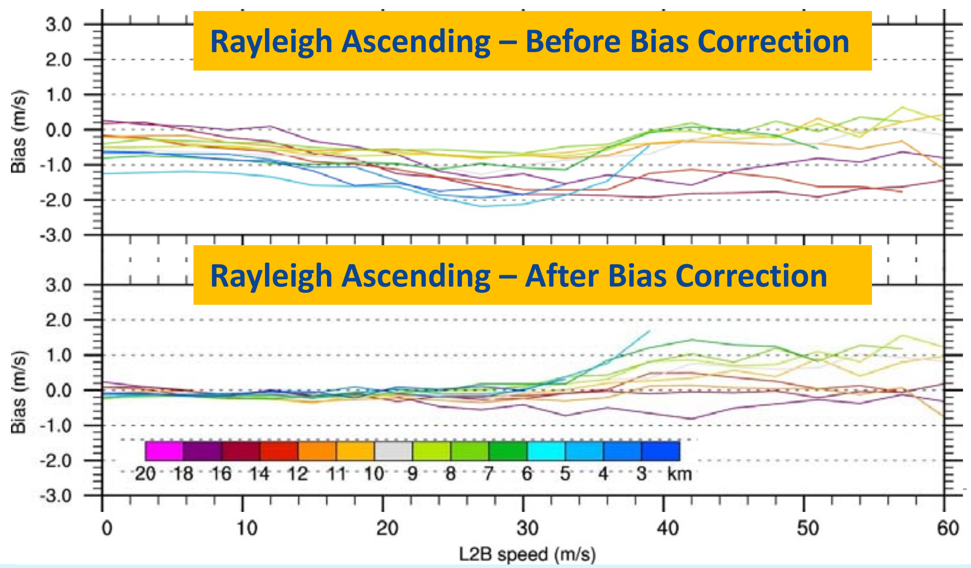




Bias Correction and Observation Errors

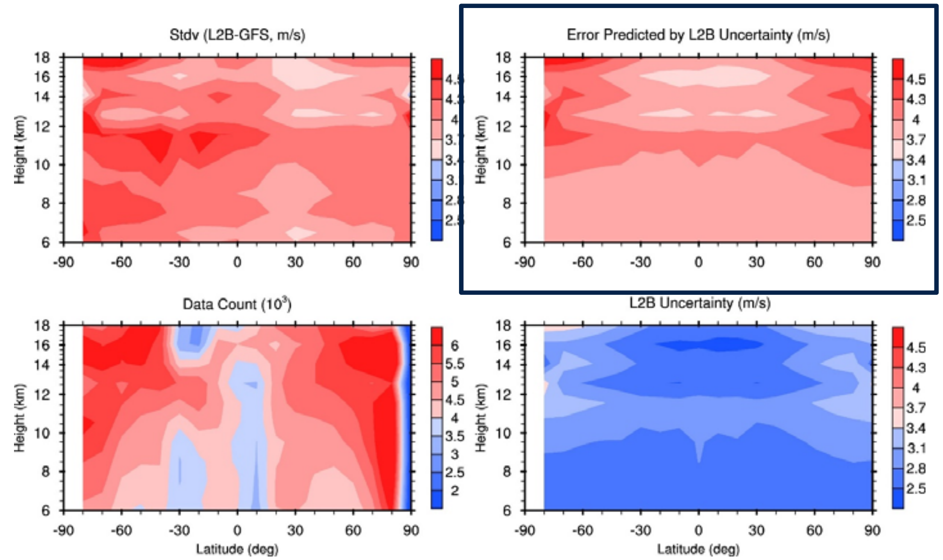
Offline bias correction for Rayleigh. *B(y, z, t)*





Dynamic Observation Errors

	Rayleigh clear	Mie cloudy
Ascending	1.16 + 1.00 * L2Buncertainty	3 m/s
Descending	1.25 + 0.94 * L2Buncertainty	3 m/s



Forecast Impact Assessment of ADM Winds

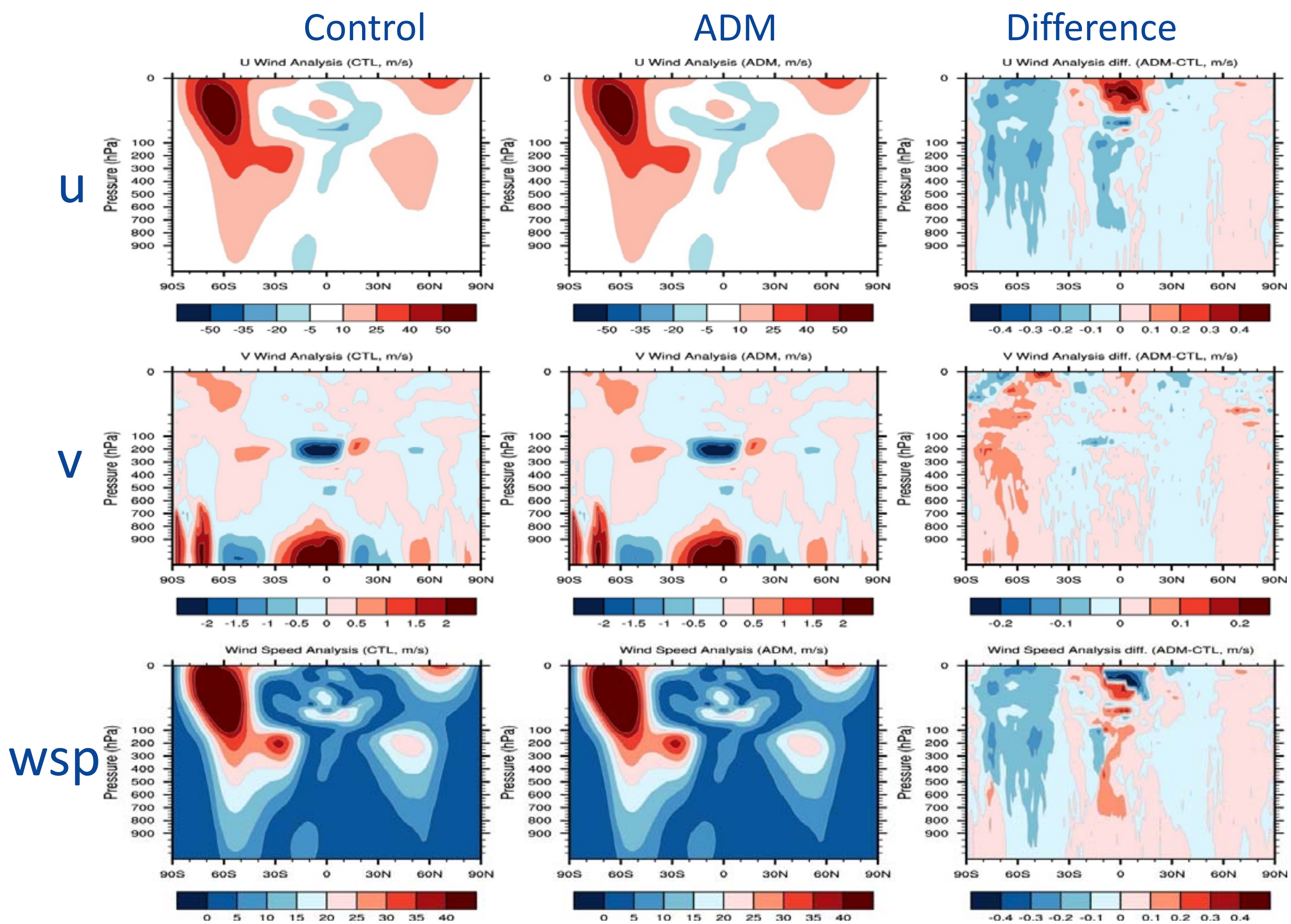
- Integrate and assimilate L2B HLOS winds into NOAA FV3GFS 4DEnVar
- Experiments at C384/C192/L64 resolution (25 km)
- Initialized at Sep 5 00Z, 2018
- Assessment period is Sep 12 – Oct 16, 2018

- Impact on Analysis (zonal mean)
- Impact on 6-hour to 5-day forecast by fit to independent observations and ECMWF analysis
- Summary score of forecast verification to ECMWF analysis and anomaly correlations

Experiment setup

	Control run (FV3CTL)	ADM Experiment (FV3ADM)
All operationally assimilated observations	Yes	Yes
ADM L2B HLOS	No	Yes (Rayleigh clear + Mie cloudy winds)

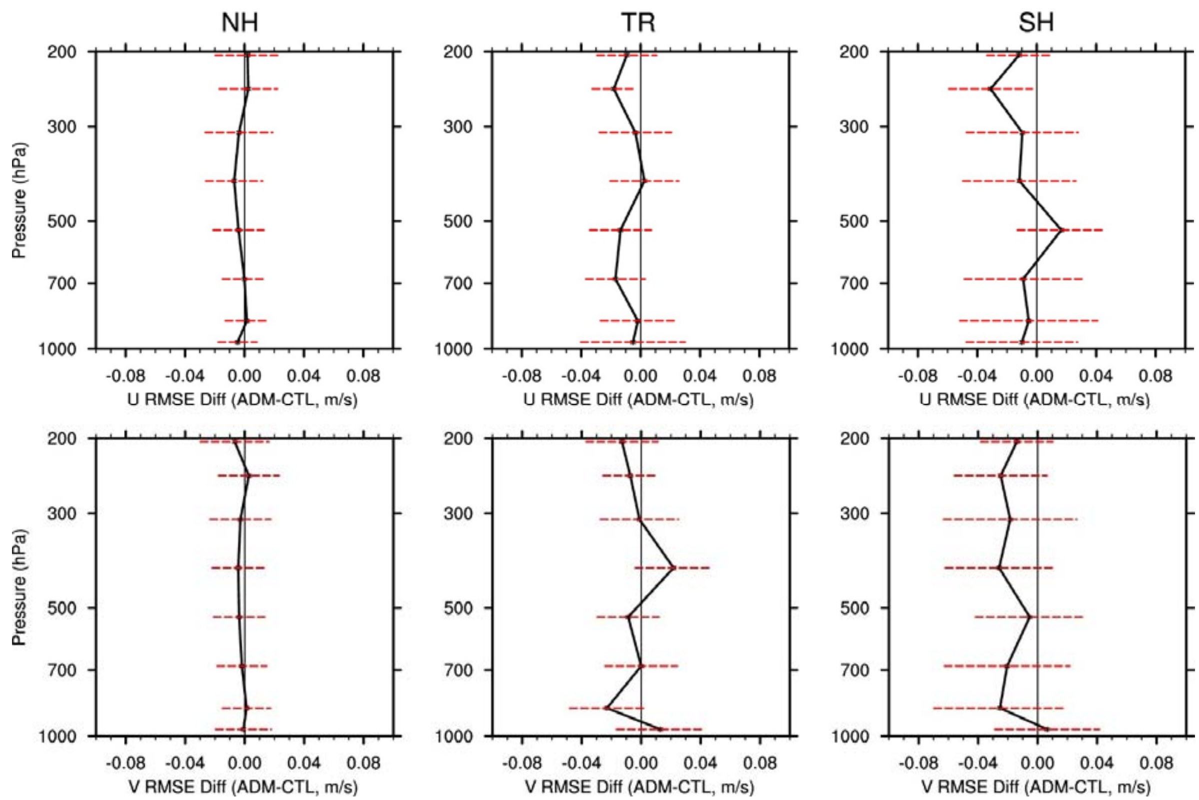
Zonal Mean of Wind Analyses (Sep 12–Oct 16, 2018)



Wind differences due to ADM data are evident mainly in SH and TR regions

RMSE of 6-hour Forecast vs. Aircraft Winds
(Sep 12–Oct 16, 2018)

ADM Experiment shows some improvement to background when compared to Aircraft flight level winds in SH and TR.

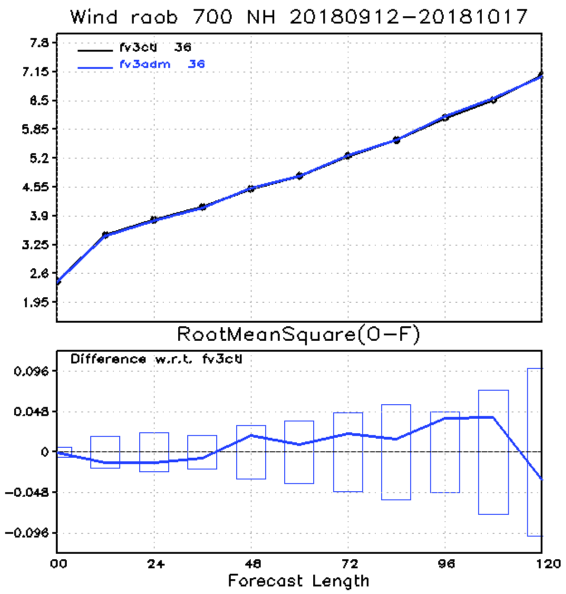


U and V RMSE difference (ADM-CTL) of 6-hour forecast vs. Aircraft. Red lines indicate significance.

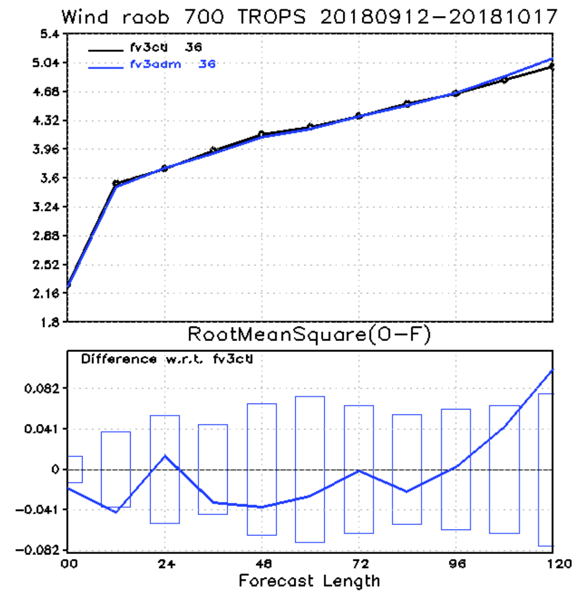
RMSE of 5-Day Forecast vs. Radiosonde Winds

700 hPa, Sep 12-Oct 16, 2018

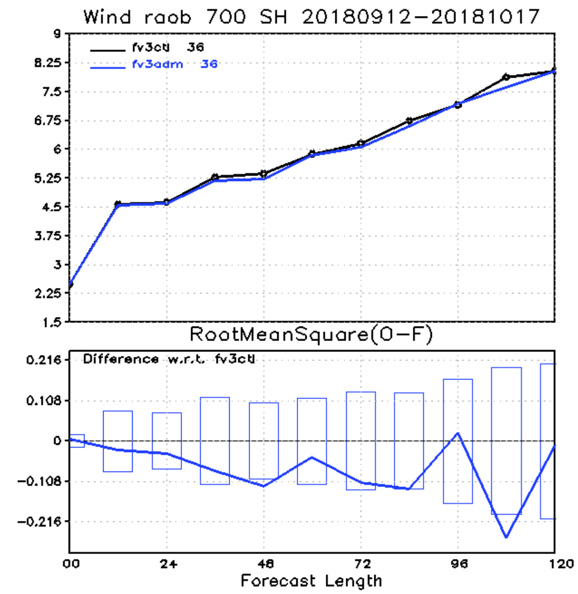
NH



TRO



SH

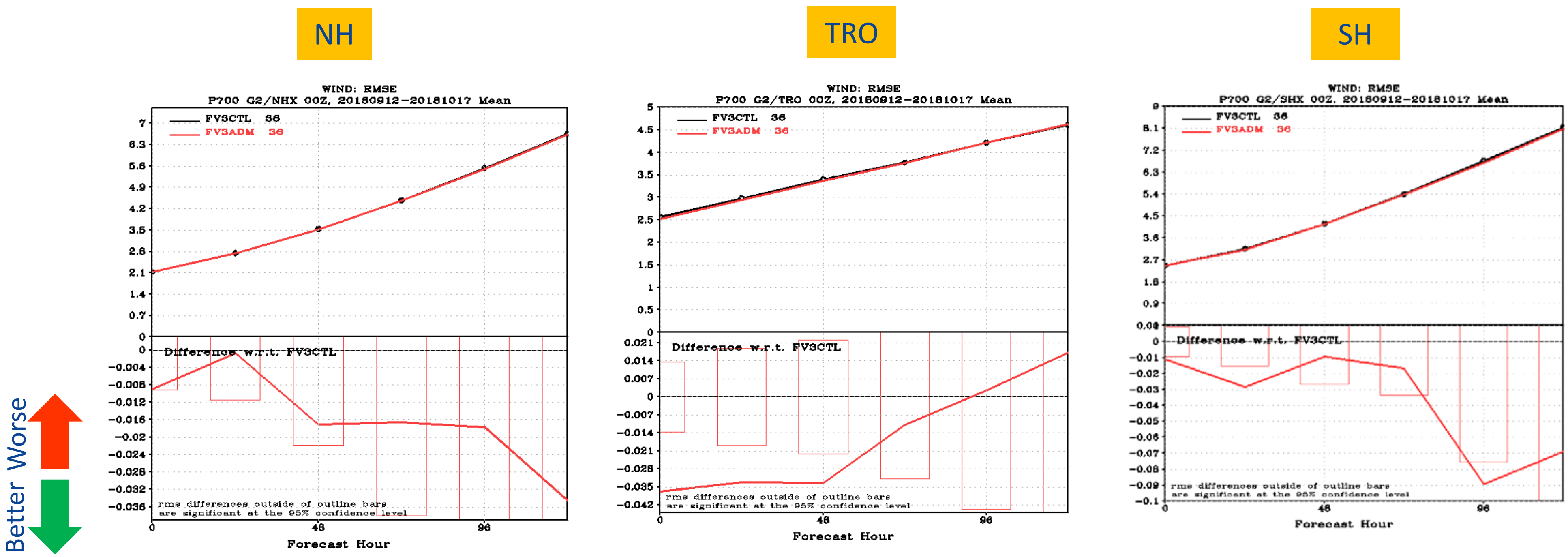


Better Worse

Vector wind RMSE vs. Forecast Length (top); Difference of ADM Exp w.r.t. Control forecast (Bottom). Bars represent significance at the 95%.

RMSE of 5-Day Forecast vs. ECMWF Wind Analysis

700 hPa, Sep 12-Oct 16 2018

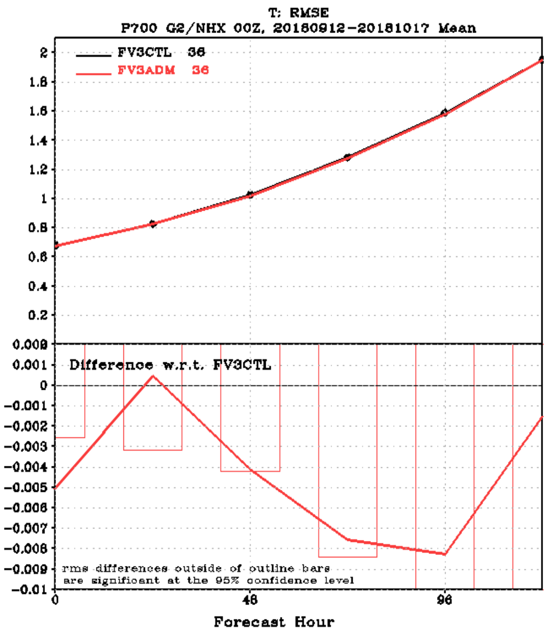


Vector wind RMSE vs. Forecast Length (top); Difference of ADM Exp w.r.t. Control forecast (Bottom). Bars represent significance at the 95%.

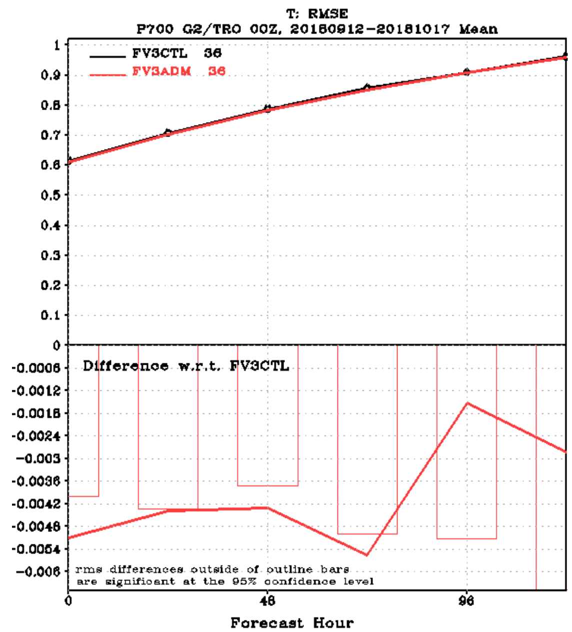
RMSE of 5-Day Temp Forecast vs. ECMWF Analysis

700 hPa, Sep 12-Oct 16, 2018

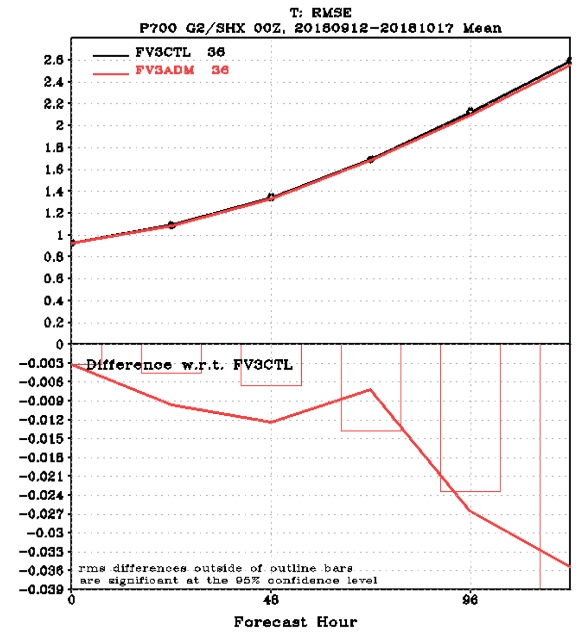
NH



TR



SH



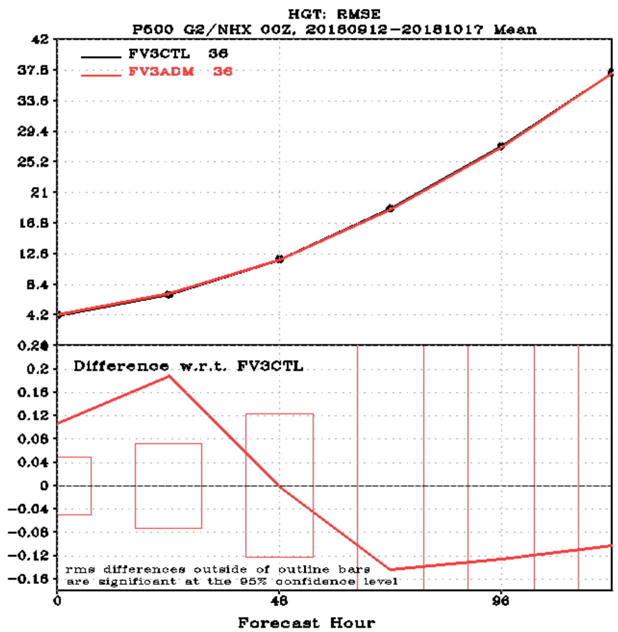
Better Worse

Biases vs. Forecast Length (top); Difference of ADM Exp w.r.t. Control forecast (Bottom).
Bars represent significance at the 95%.

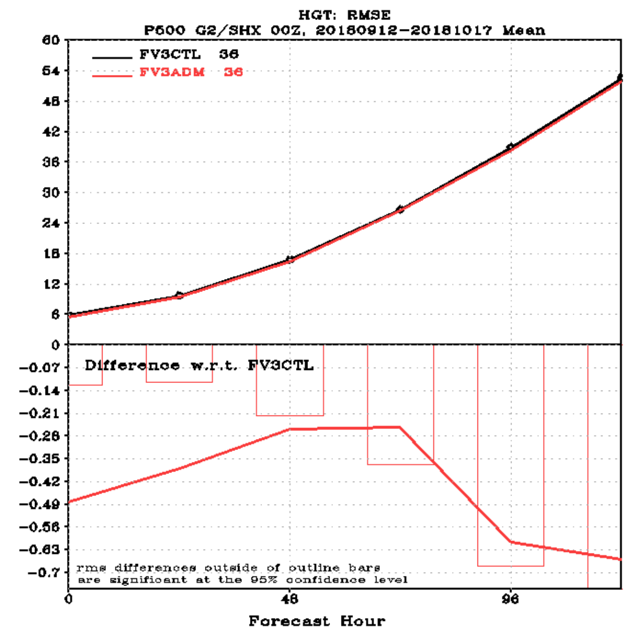
RMSE of 500 hPa Height Forecast vs. ECMWF Analysis

Sep 12-Oct 16, 2018

NH



SH



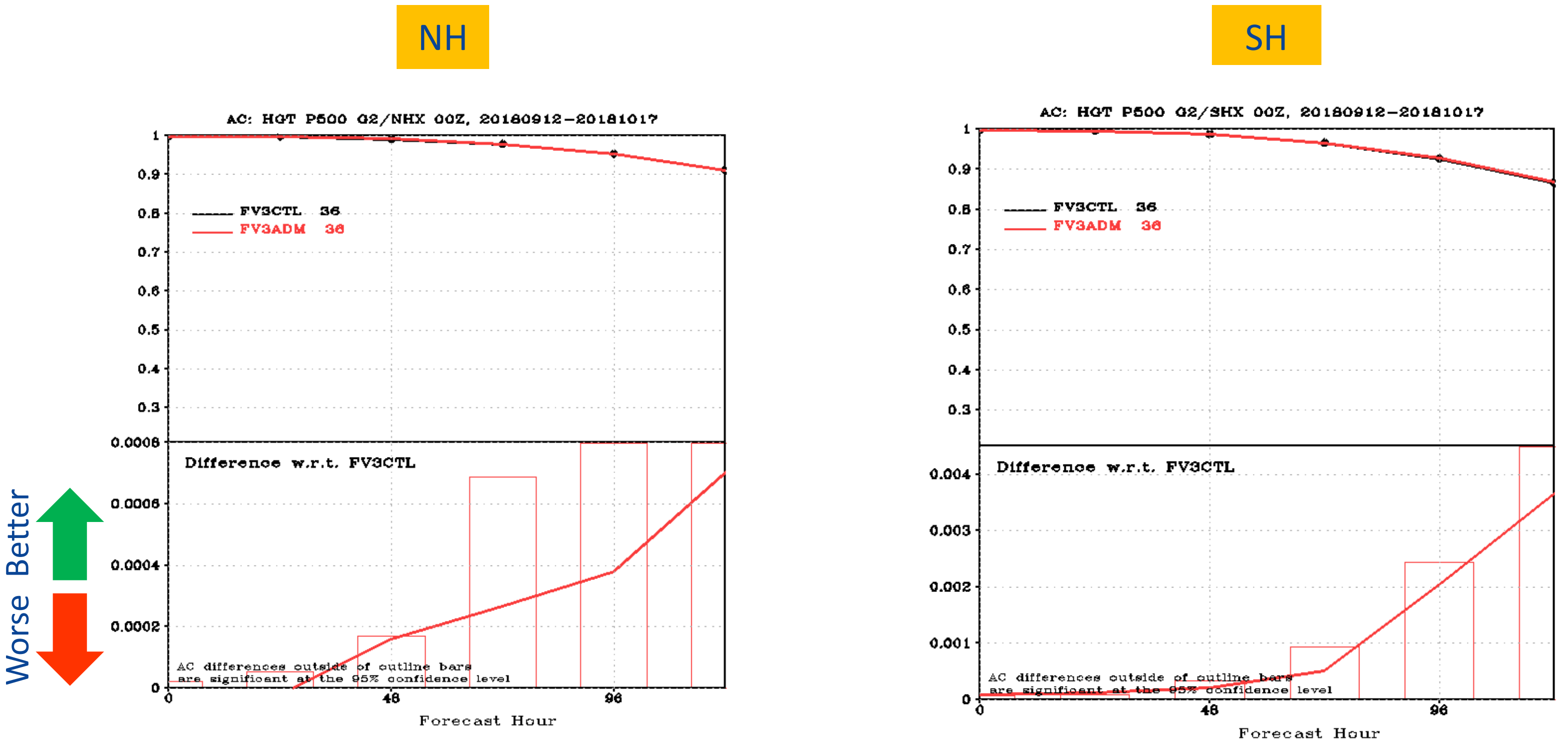
Worse

Better

AC vs. Forecast Length (top); Difference of ADM Exp w.r.t. Control forecast (Bottom).
Bars represent significance at the 95%.

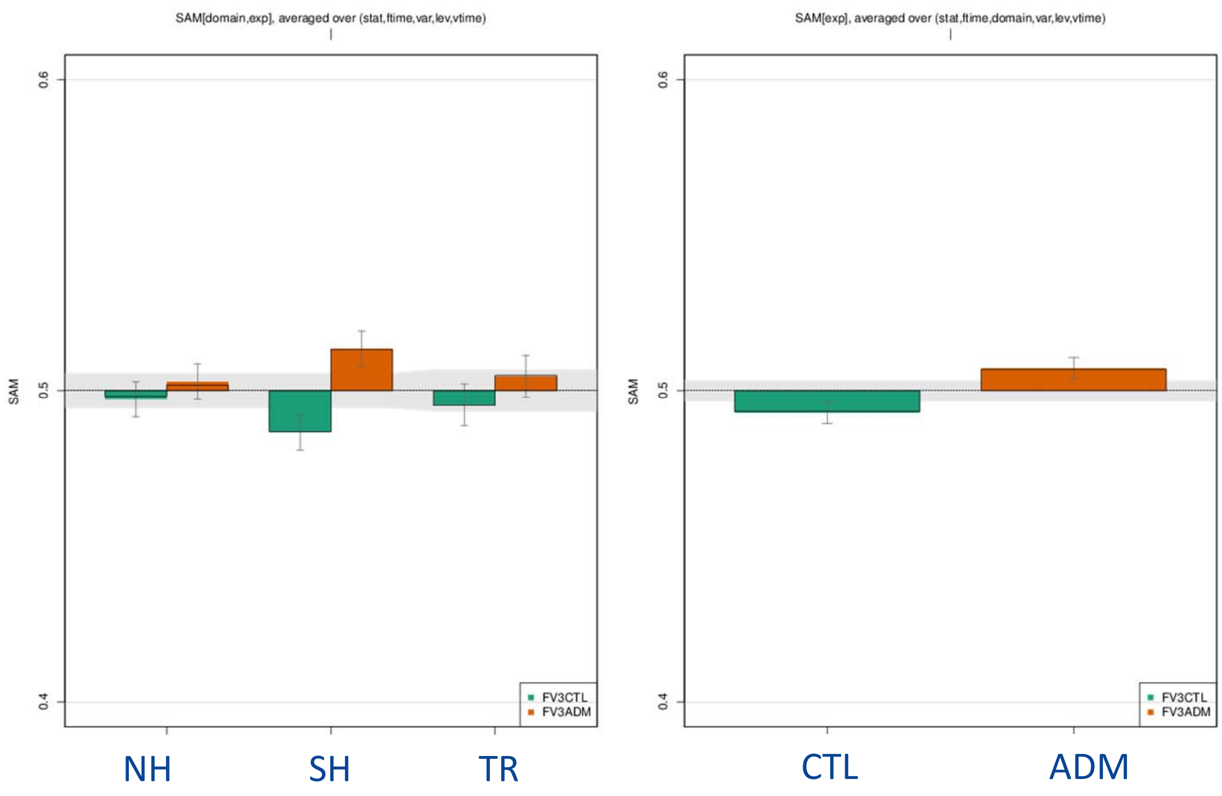
Anomaly Correlation of 500 hPa Height Forecast

Sep 12-Oct 16, 2018



AC vs. Forecast Length (top); Difference of ADM Exp w.r.t. Control forecast (Bottom). Bars represent significance at the 95%.

Overall Impact of ADM Data on 0-5 Day Forecast
(Sep 12–Oct 16, 2018)



A summary score composited of forecast verifications of U/V, T, Z, RH to ECMWF analysis at all levels and lead times (Hoffman et al., 2018):

> 0.5 = improvement

< 0.5 = degradation

Conclusions

- ADM HLOS winds have been integrated into NOAA global FV3GFS 4DEnVar system
- Preliminary results are encouraging (w/o any optimization):
  - Positive impact on forecast in the Southern Hemisphere and Tropics
  - Neutral impact in the Northern Hemisphere
- Future optimizations in:
  - QCs of ADM wind data
  - Dynamic bias correction
  - Dynamic observational error specification