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

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CISESS Science Meeting, 12 November 2019
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.
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-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

Mie: narrow laser spectrum in red

Rayleigh: broad Gaussian spectrum in green

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

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

Rayleigh Clear - Before QC
- STDV: 4.6 m/s

Rayleigh Clear - After QC
- STDV: 4.1 m/s

Mie Cloudy - Before QC
- STDV: 3.4 m/s

Mie Cloudy - After QC
- STDV: 2.9 m/s
Bias Correction and Observation Errors

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

Dynamic Observation Errors

<table>
<thead>
<tr>
<th></th>
<th>Rayleigh clear</th>
<th>Mie cloudy</th>
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<tbody>
<tr>
<td>Ascending</td>
<td>$1.16 + 1.00 \times L2B_{\text{uncertainty}}$</td>
<td>$3 \text{ m/s}$</td>
</tr>
<tr>
<td>Descending</td>
<td>$1.25 + 0.94 \times L2B_{\text{uncertainty}}$</td>
<td>$3 \text{ m/s}$</td>
</tr>
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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

<table>
<thead>
<tr>
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<th>Control run (FV3CTL)</th>
<th>ADM Experiment (FV3ADM)</th>
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<tbody>
<tr>
<td>All operationally assimilated observations</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>ADM L2B HLOS</td>
<td>No</td>
<td>Yes (Rayleigh clear + Mie cloudy winds)</td>
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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

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

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

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

NH

SH

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