Aeolus wind LiDAR data exploitation to improve hurricane numerical weather analyses and forecasts at NOAA

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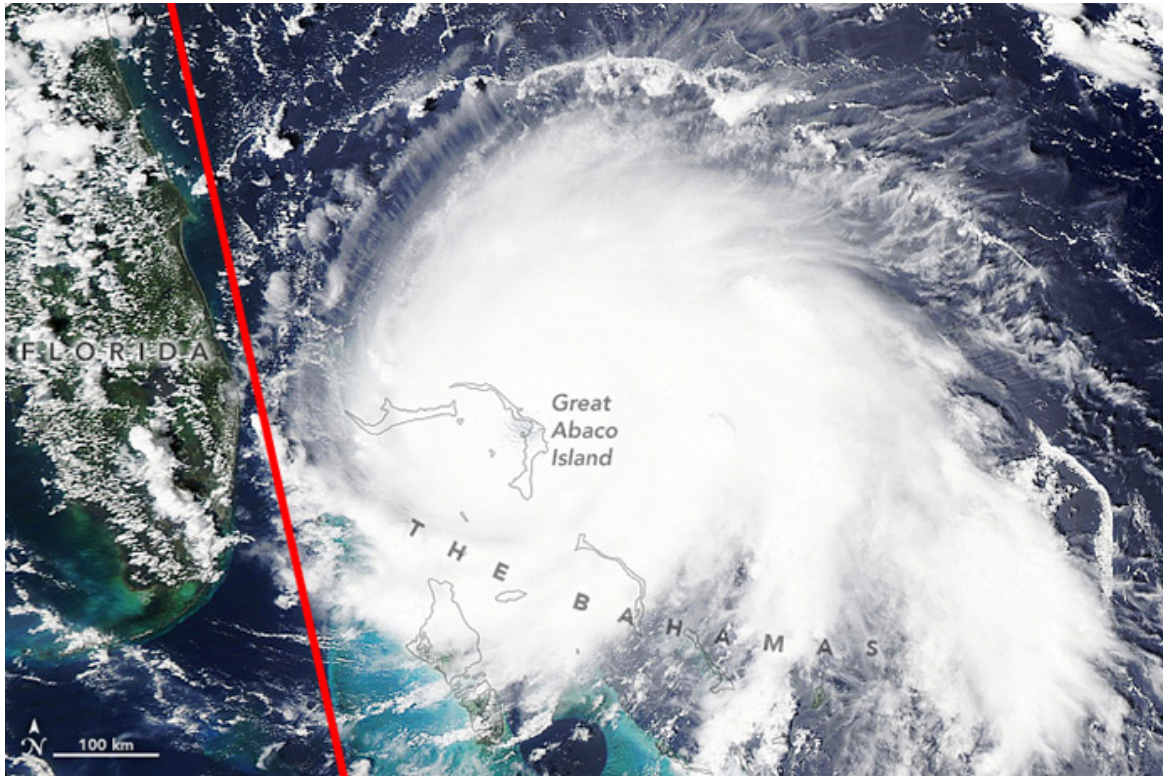
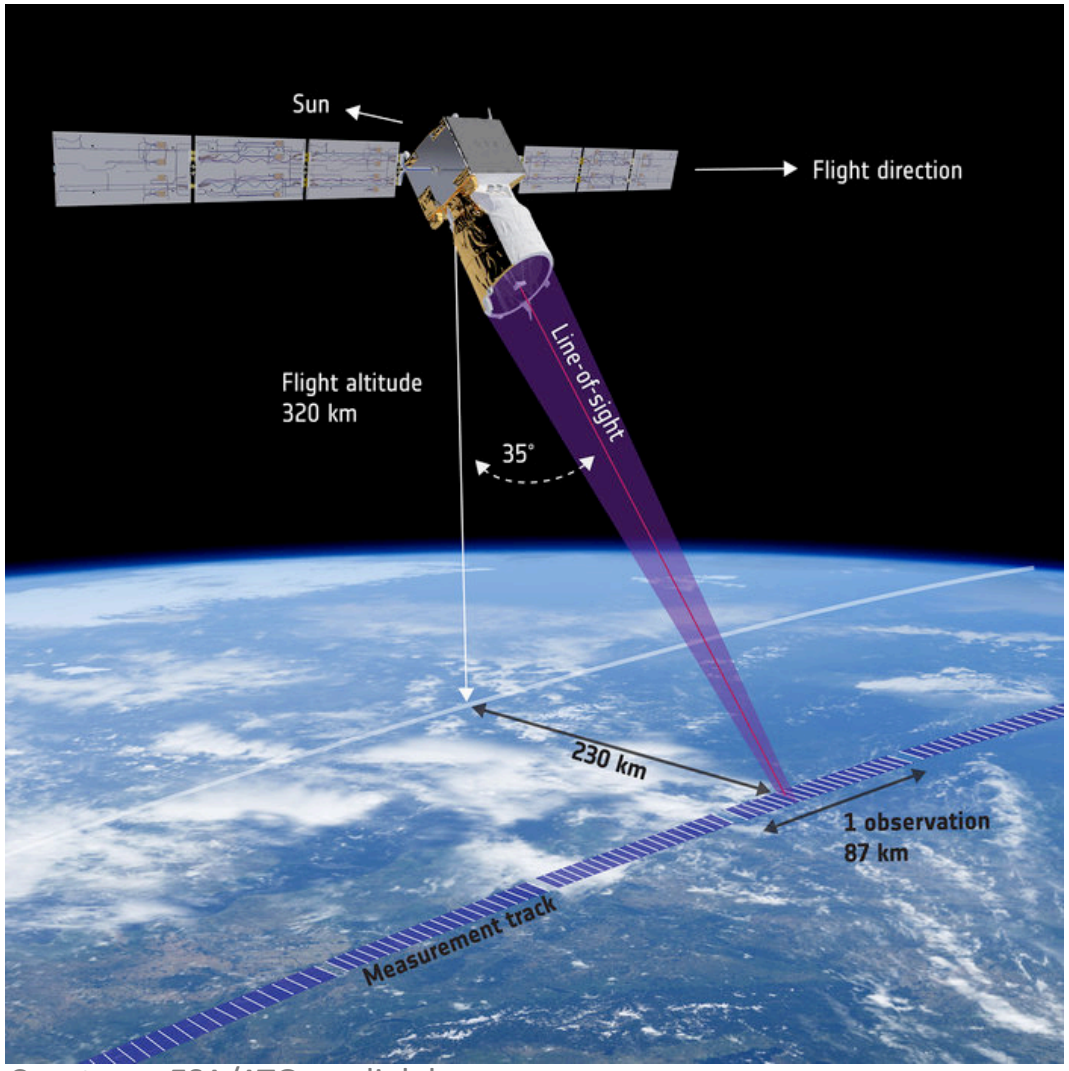


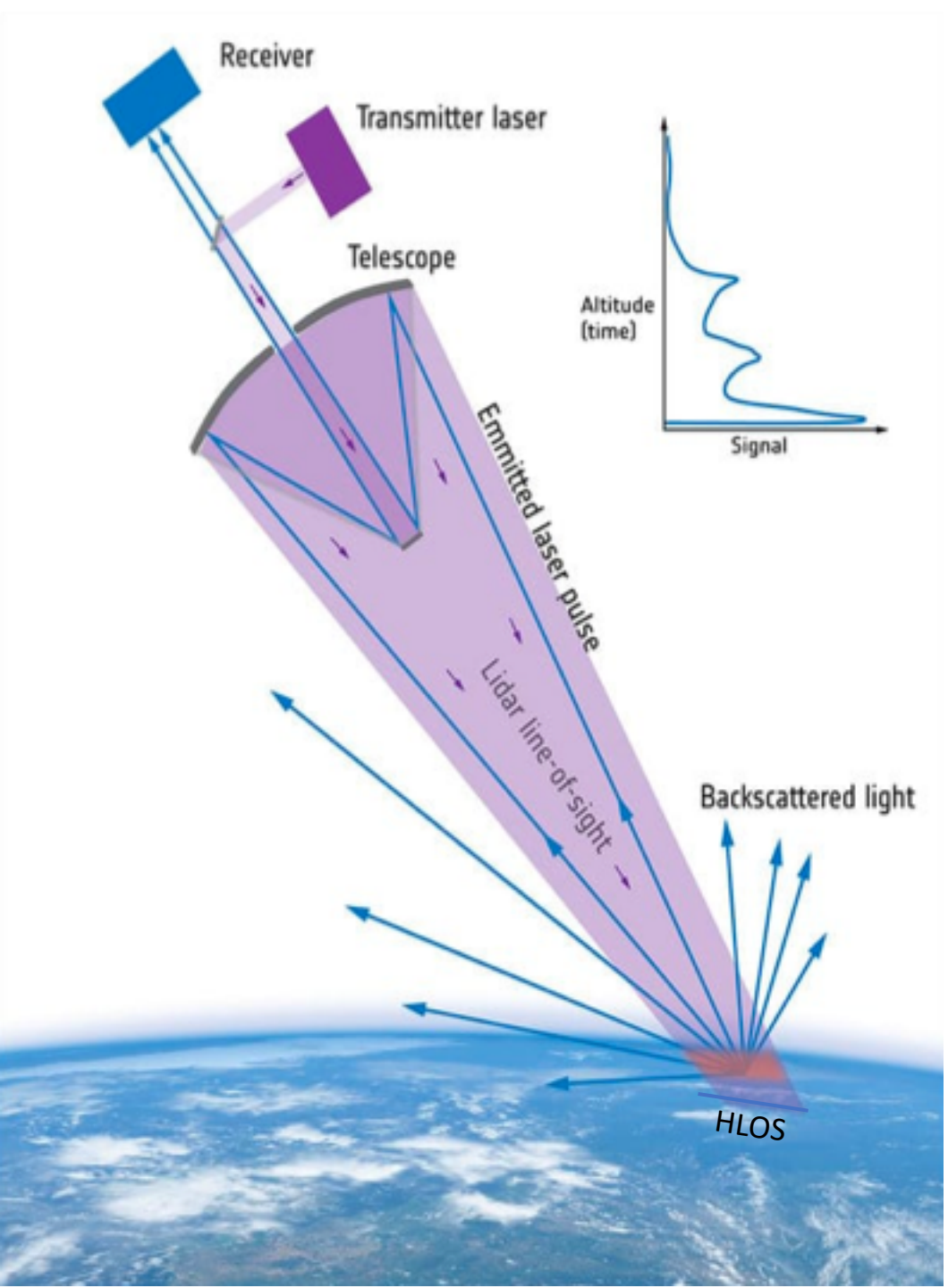
Aeolus satellite track overlaid on a NASA Aqua's satellite image of hurricane Dorian at 1805 UTC on September 1, 2019. (Satellite image: NASA)

Motivation: Aeolus benefits to tropical cyclone(TC) prediction

- AEOLUS can provide valuable wind profiles in the peripheral TC environment
- Horizontal Line of Sight (HLOS) observations can be measured from outside the TC inner core to the radius of tropical storm force winds
- However, complex synoptic features in TC's with regions of strong gradients in fields near the TC environment may benefit from advanced DA strategies



Courtesy: ESA/ATG medialab



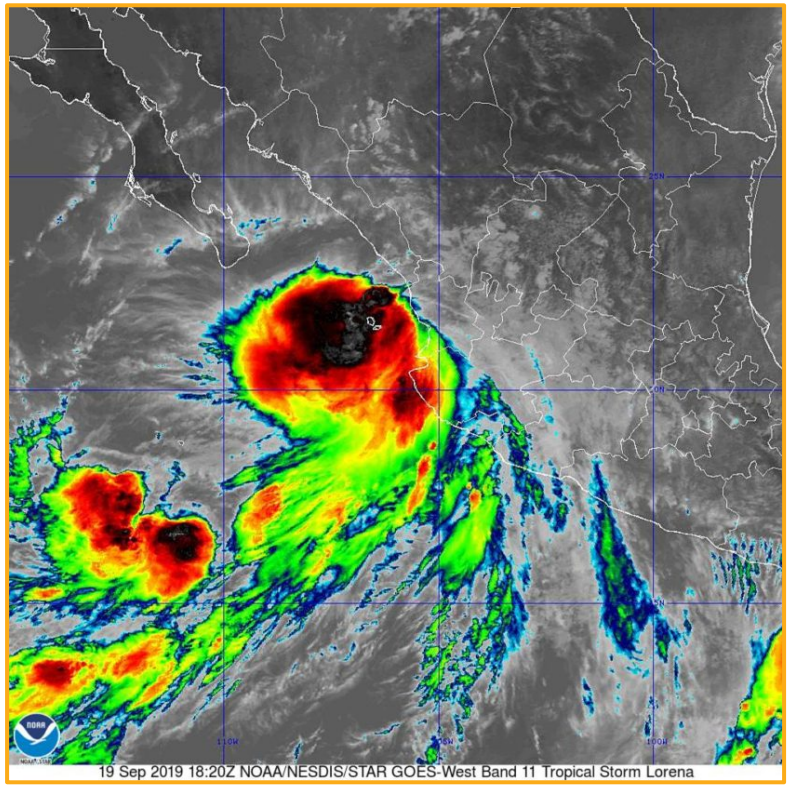
Objective: Optimize Aeolus assimilation for hurricane analysis and forecast in NOAA NWP systems

- Improve the assimilation of Aeolus HLOS retrievals in global (FV3GFS) and storm-scale (HWRF) NWP to improve TC analysis and prediction
- DA refinements in collaboration with NECEP/EMC (e.g. addressing suboptimal observation weight assignment by implementing new Variational QC)
- All DA developments done in FV3GFS to improve hurricane prediction are to be ported to HWRF to quantify the impact of regional hurricane forecasts

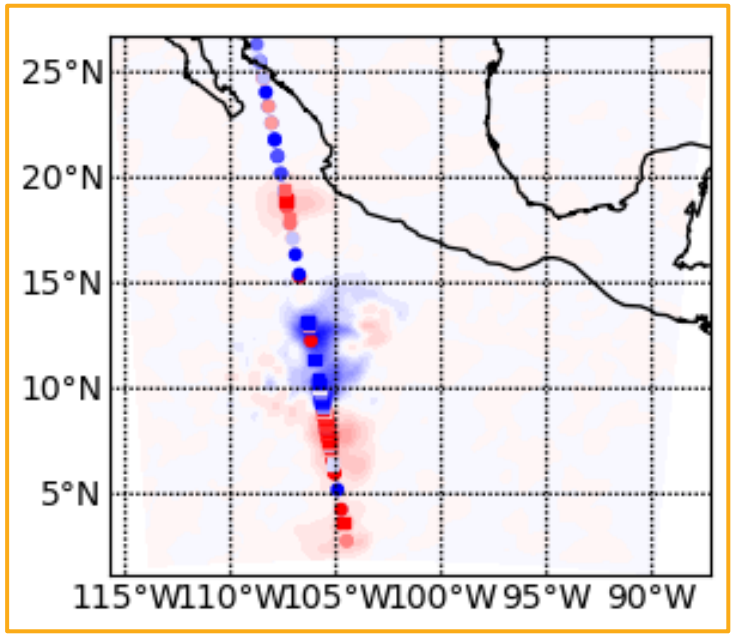
Global NWP impacts: Aeolus wind profiles assimilation in FV3GFS

Assimilation of Aeolus HLOS in FV3GFS during hurricane Lorena, 2019

TC Lorena - GOES-W IR



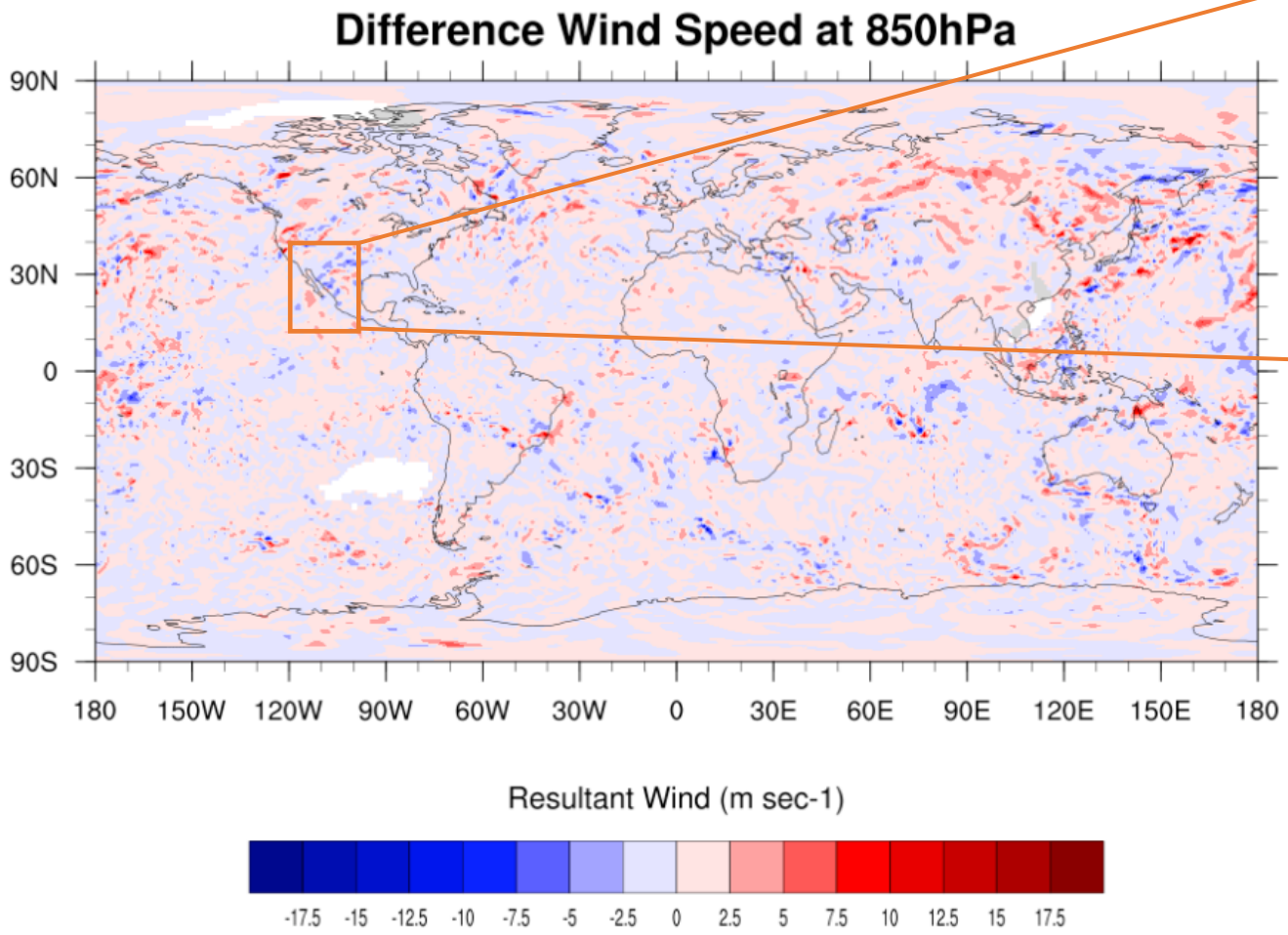
Assimilated Aeolus HLOS swath Mie-cloudy+Ray-clear during Hurricane Lorena



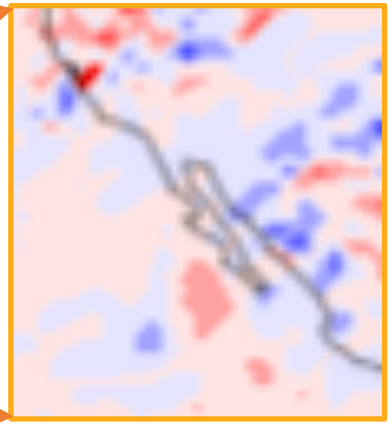
- Lorena was a category 1 hurricane (on the Saffir-Simpson Hurricane Wind Scale)
- Made landfall off the coast of Jalisco, and a second landfall in Baja California Sur (70-kt winds at 00 UTC 19 September)
- Lorena then weakened and reached the coast of mainland Mexico just north of Guaymas as a broad area of low pressure and dissipated over land
- N. East Pacific basin storm – less observed ocean region

Aircraft reconnaissance observations may may not be readily available for these TC systems and Aeolus can help fill the gap!

FV3GFS Analysis - TC Lorena: Sep. 17-22, 2019



AEOLUS_DA–CNTL



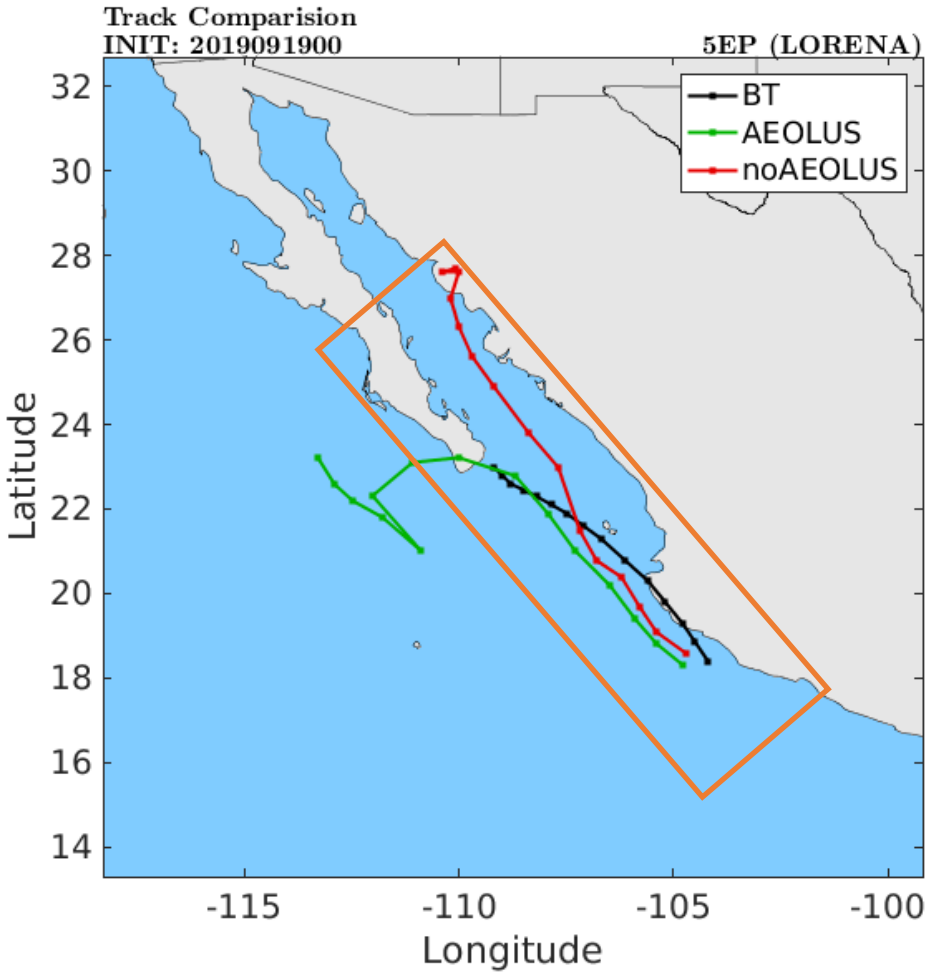
NWP specs with ECMWF recommended static QC and HLOS OE + Static BC

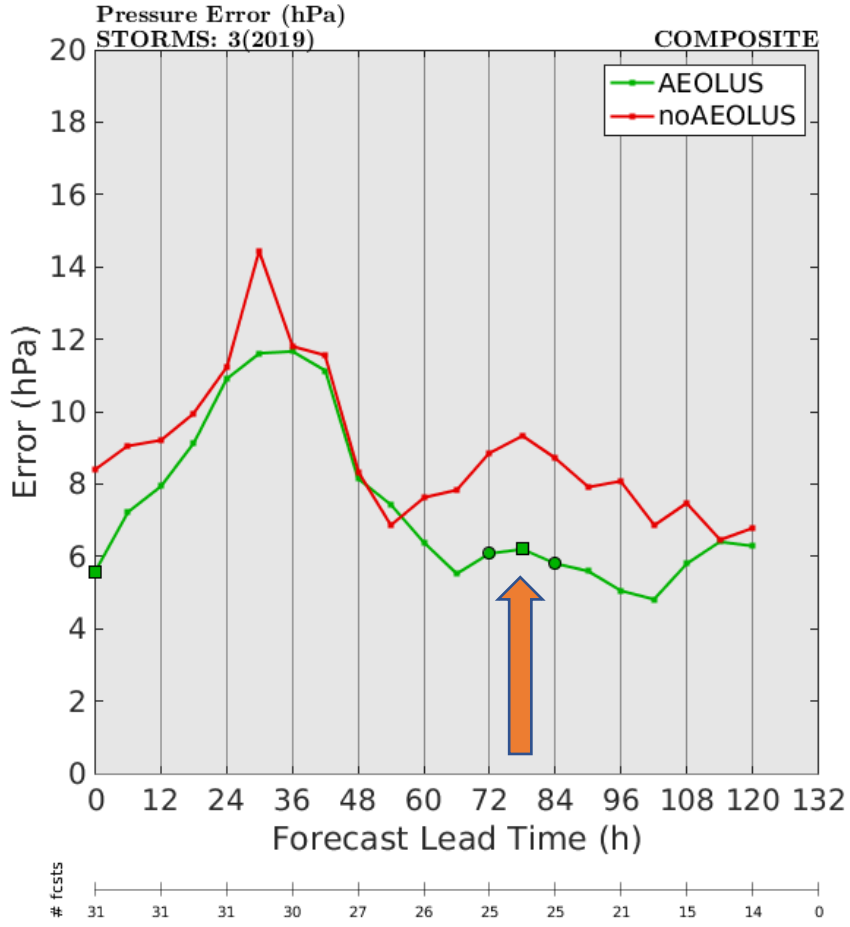
- Analysis difference plot in resultant wind speed
- Noticeable dipole structures, also near the Aeolus swath close to the TC
- Evidence of impacts to the synoptic environment

TC verification metrics under the assimilation of Aeolus wind profiles in FV3GFS

NHC TC verification for Lorena case study: Track, Pressure, Intensity

Green: Aeolus – Red: CNTL – Black: NHC Best





- Initialized: 2019091900
- 6-hour cycling and assessment, like in the operational HWRF (0Z, 06Z, 12Z, 18Z)
- Left: Initial degradation on track in the first 42 hours
- Near by a near perfect agreement on TC track close to it's second landfall up to 72- forecast hour
- Consistent Error reduction in Pressure forecast, significant after the 72-forecast hour

NHC TC verification for Lorena case study: Track, Pressure, Intensity

Green: Aeolus – Red: CNTL – Black: NHC Best

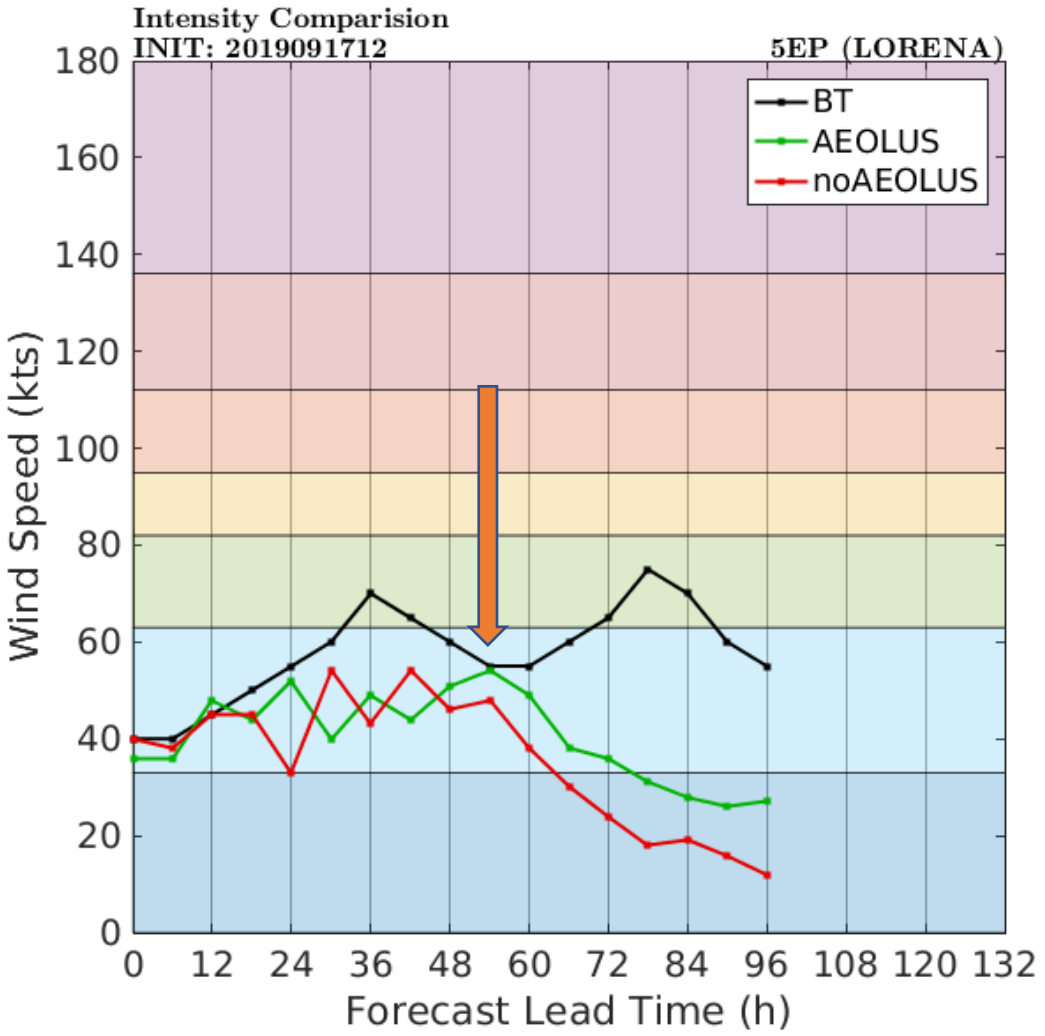
Composite wind speed 3 storms: Aeolus closer to NHC actual intensity forecast after the 52-forecast hour

but… High case-to-case variability in FM-A/FM-B TC assessment

Outliers or good quality data near the TC?

Suboptimal observational weight assignment prior to minimization:

Rejecting GOOD/assimilating BAD obs near the TC where they have a better chance at impacting the synoptic environment and influence steering or shearing!



Adopting VarQC for Aeolus in FV3GFS

New NCEP Variational Quality Control

Assimilate what you can, reject what you must!

Power of Assimilation: St. John Henry Newman

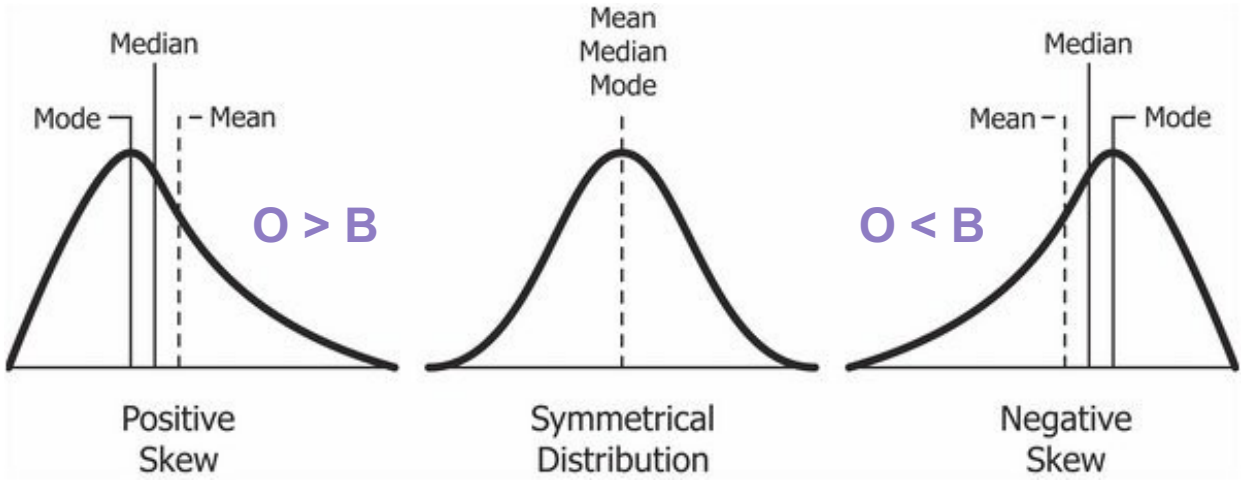
- Even good quality data show significant departures from the pure Gaussian form
- Current Gaussian-based operational data assimilation may not be sufficient
- New VarQC scheme in NOAA/NCEP/FV3GFS extended to the Aeolus DW observation operator
- Based on Chevron-family or Huber probability density functions
- Suited for unimodal and leptokurtic distributions (taller peaks and broader tails than a pure Gaussian)
- Currently at VarQC parameter tuning stage

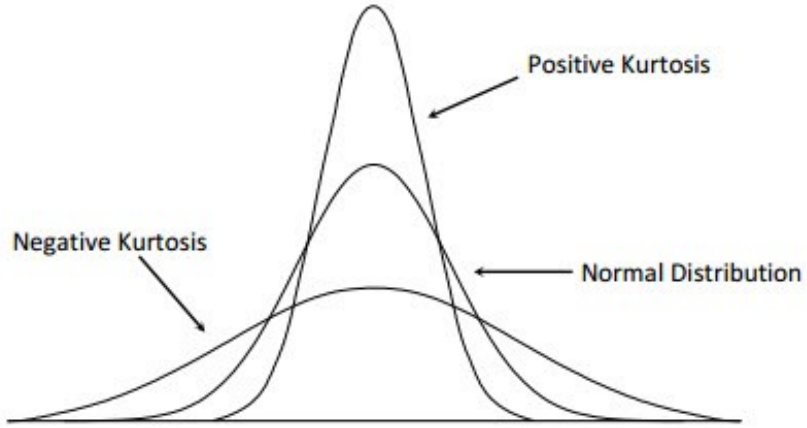
We hope that by assigning adaptive weights to AEOLUS observations near the TC inner and outer cores, minimization can achieve synergy between HLOS OE, observational weights, the background, and the analysis!

Variational Quality Control

- Adopted NCEP new VarQC for the Aeolus DW observation operator in GSI
- Assessment of normality departures
- Pure Gaussian (normal) form: Skewness=0
- coincidental mean, median, mode

- **Need 3 moments of the Aeolus O-B, O-A PDF's:**
- **2nd central moment: variance (σ spread)**
- **3rd standardized moment: skewness**
- **4th standardized moment: Kurtosis, wide vs. narrow tails**

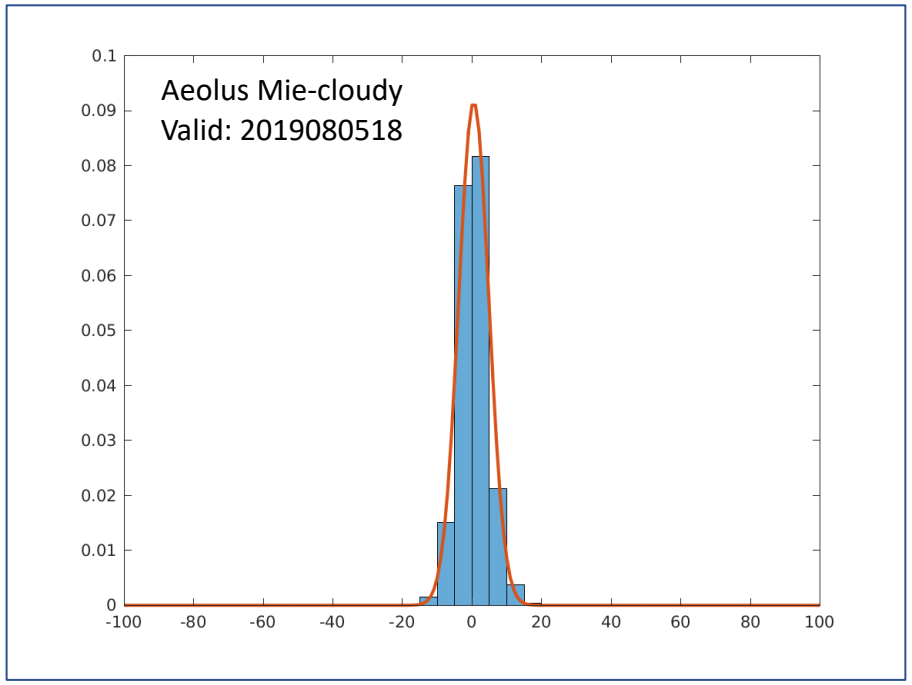


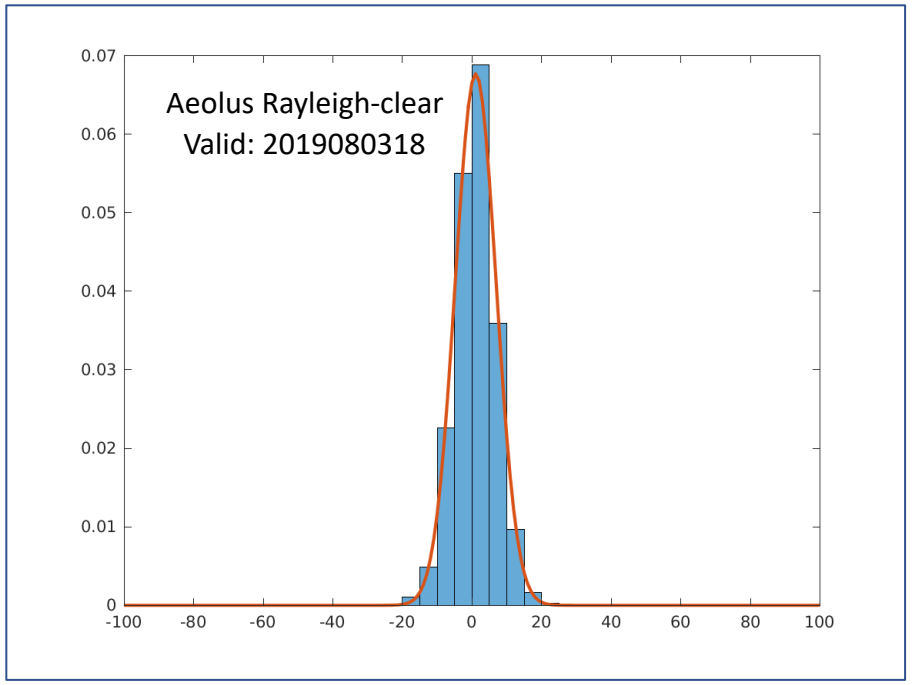


(O-B) Statistical Assessment and non-Gaussianity

Accurate probability model for the Aeolus observation errors (Mie-cloudy and Rayleigh-clear)

1-month Statistical Assessment Experiment
O-B PDF's after static QC+BC

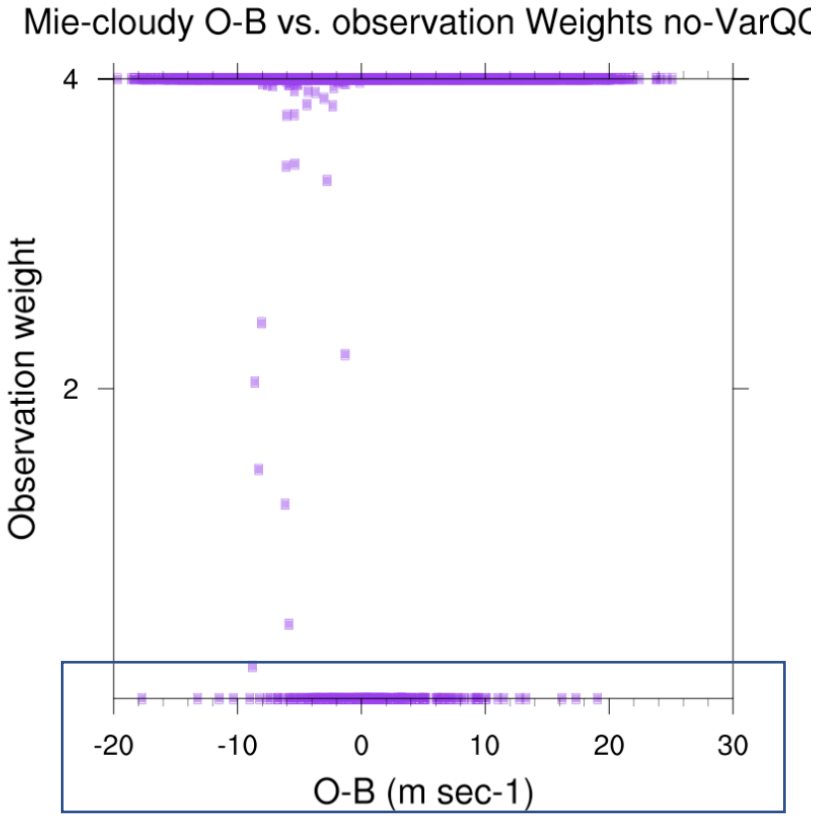


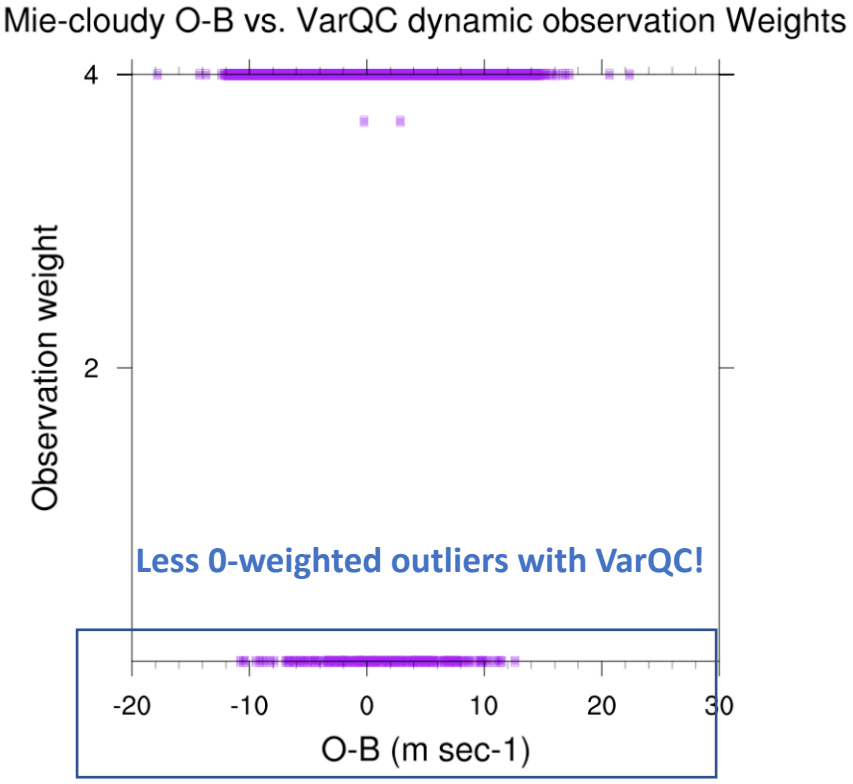


- Innovation statistics indicate departures from the pure Gaussian form
- Unimodal and leptokurtic distributions, with asymmetry
- Aeolus assimilation may benefit from advanced QC by assigning adaptive weights to observation outliers

Dynamical Weight Assignment for Observation Outliers

β parameter tuning experiment at variance=~24
valid 2019080306, mid obs. rejection limit





- For minimization, the penalty and weight for each observation depends on broadness (β), convexity (κ), asymmetry (α) of the PDF, and observation error
- Calculated the 2nd, 3rd and 4th moments (variance, asymmetry, and kurtosis) from 1-month stats experiment
- Less outliers given a zero weight by using VarQC for Aeolus

Also need to check weights as a function of obs error, other variance values, penalties (minimization)
Not tuning Kurtosis yet, set to 0 in VarQC

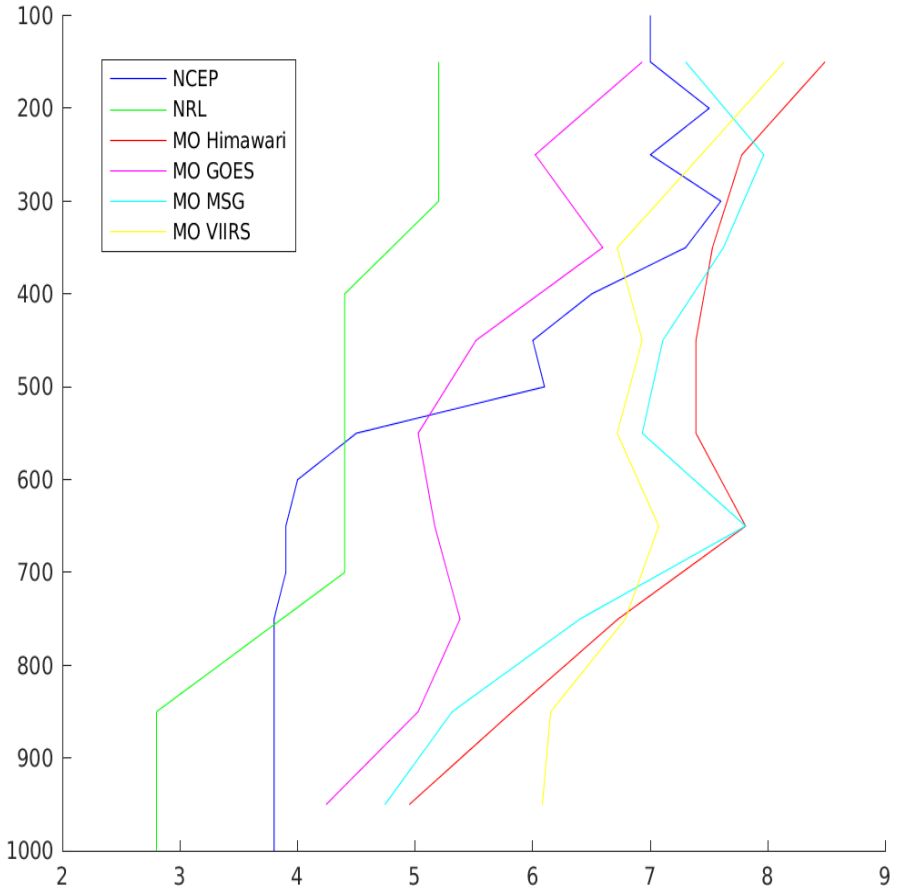
Observation error assessment for VarQC

- Observation errors are very important for VarQC tuning
- Optimal synergy between OE, OW, the background, and the analysis
- Inventory in NWP centers show a wide variability range

MetOffice:
OE_Mie=0.7*HLOSEE+2.9
OE_Pay=2.0*HLOSEE+1.4
Soon:
OE_Mie=1.4*HLOSEE+1.7

AOML/NCEP (ECMWF)
OE_Mie=2*HLOSEE
OE_Ray=1.4*HLOSEE

IR AMVs - NCEP, NRL, MetOffice



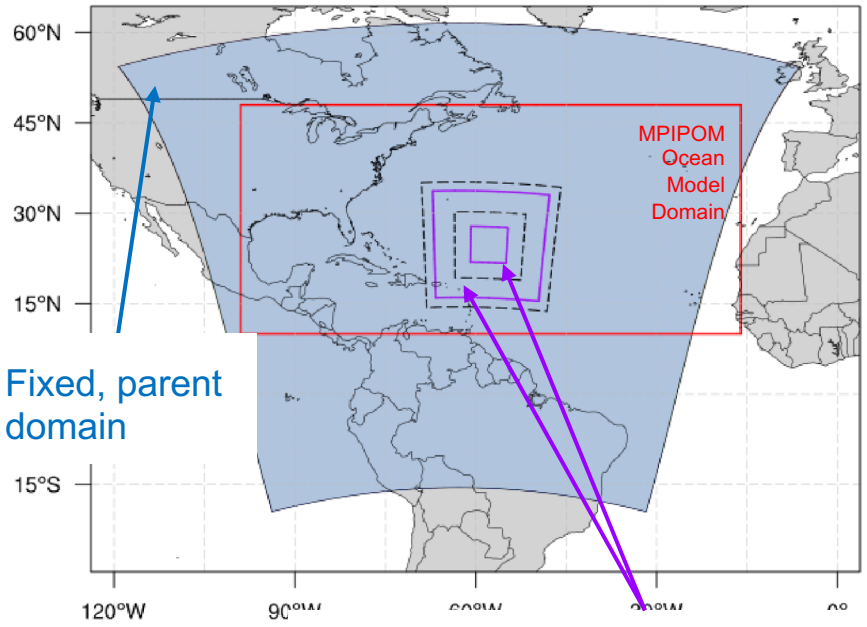
Regional NWP impacts: Aeolus wind profiles assimilation in HWRF

Regional Modelling and Assimilation for Tropical Cyclones

- Hurricane Weather Research and Forecasting Model (HWRF)
  (Tallapragada et al., 2014; Biswas et al., 2018)
  - NOAA's operational, regional hurricane prediction model
  - 3 nested grids (horizontal resolution of 13.5, 4.5 and 1.5 km, respectively)
  - GSI hybrid 3D-EnVAR data assimilation system
    (Kleist et al. 2009)
  - Initial and boundary conditions from NOAA global model

- 2019 Hurricane season
  - Current sample: 3 storms / 68 forecasts
  - Hurricanes Dorian, Humberto (Atlantic) and Lorena (E.P.)

- Two Initial Experiments
  - CTL (2020 Operational)
  - AEO-NOBC (CTL + Aeolus without Bias Correction)

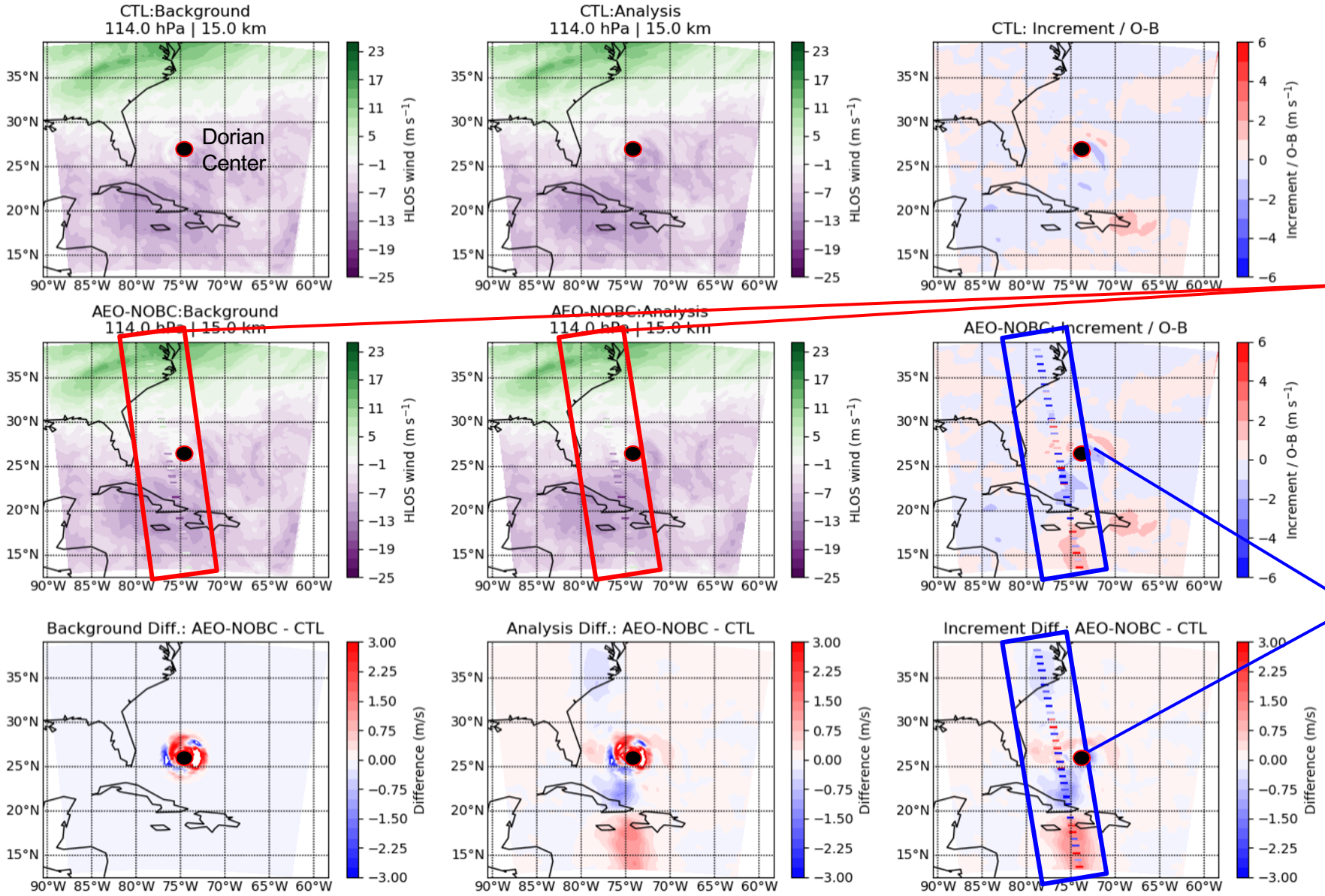


Example of Aeolus Assimilation: Hurricane Dorian (09/01 00Z, 114 hPa)

CTL

AEO-NOBC

Diff.



HLOS wind (similar to U wind)

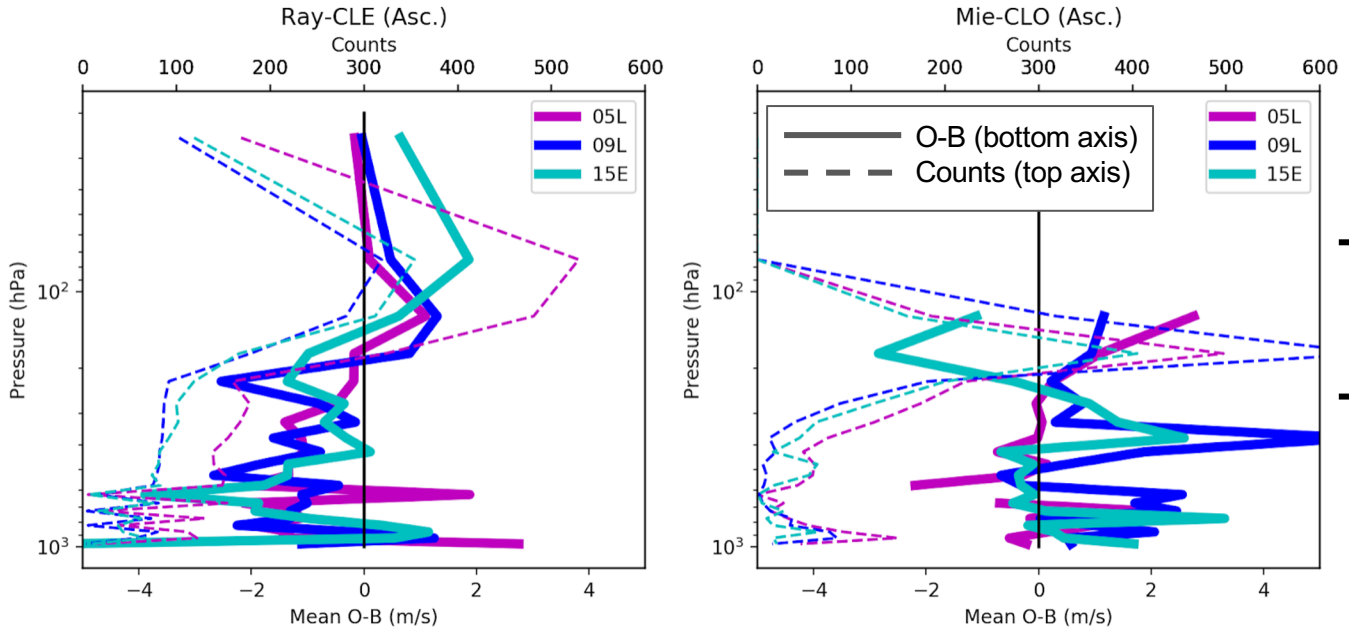
Typically, one swath of Aeolus observations within HWRF DA domains

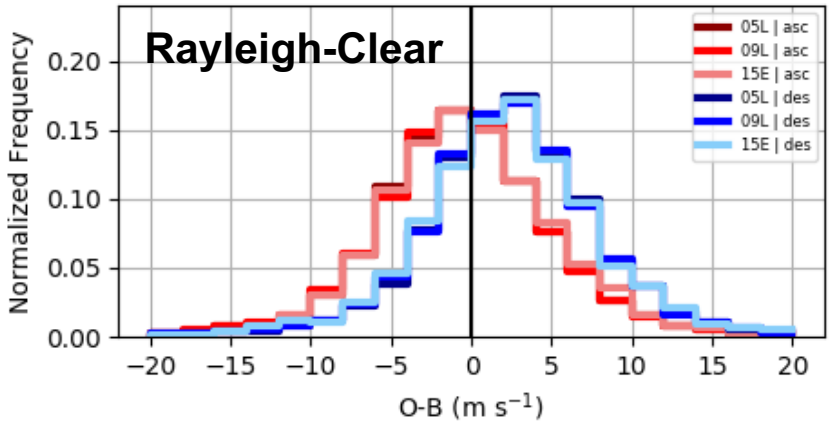
Aeolus HLOS wind observations can lead to significant changes in HWRF initialization state, as compared to other observations

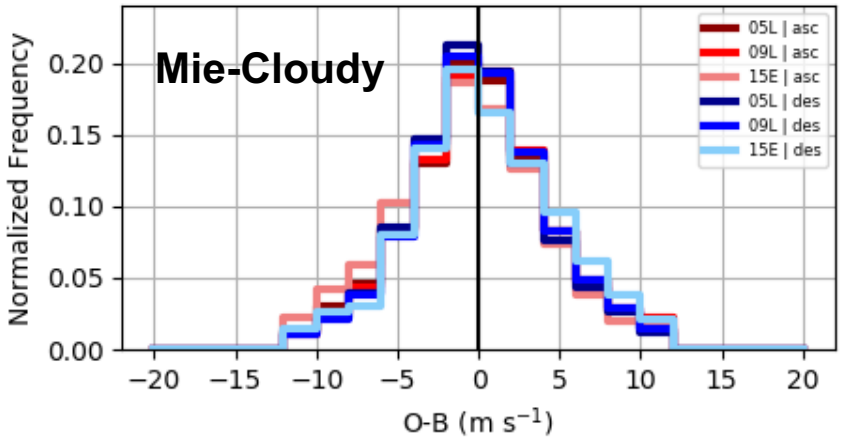
HWRF Assimilation Statistics

- Observation-Background (O-B) Statistics
  - Consistent among the 3 tropical cyclones
  - Rayleigh-Clear statistics depend on orbit

- O-B statistics also vary based on height (below) and wind speed (not shown)



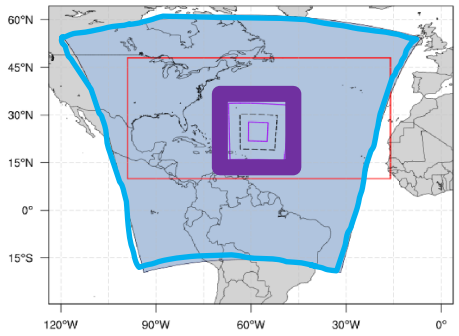


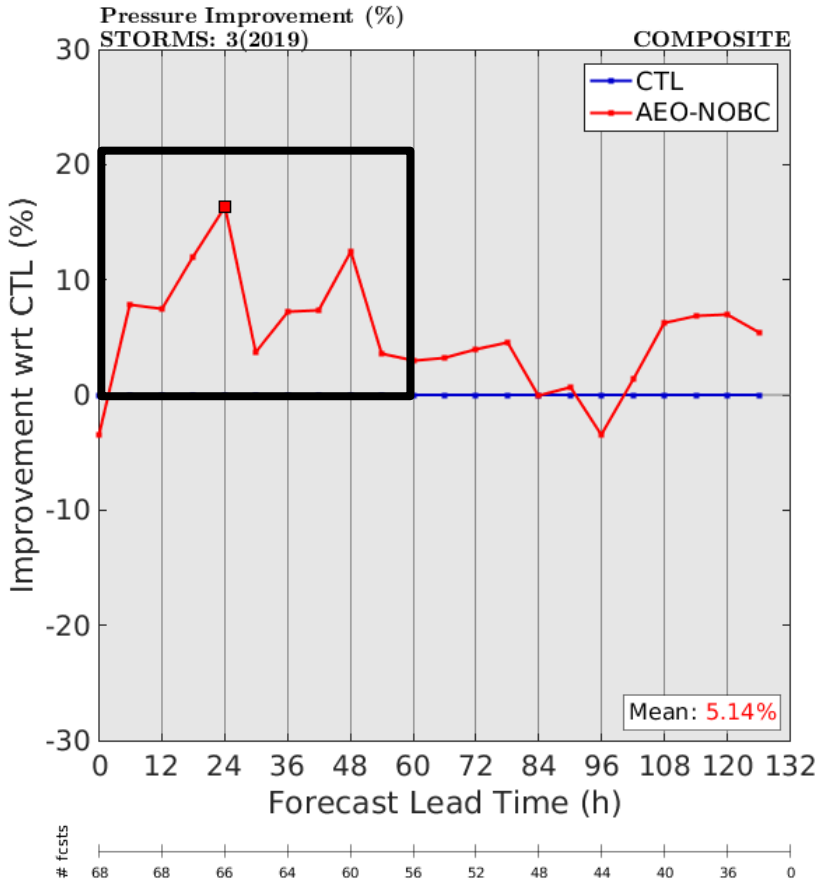


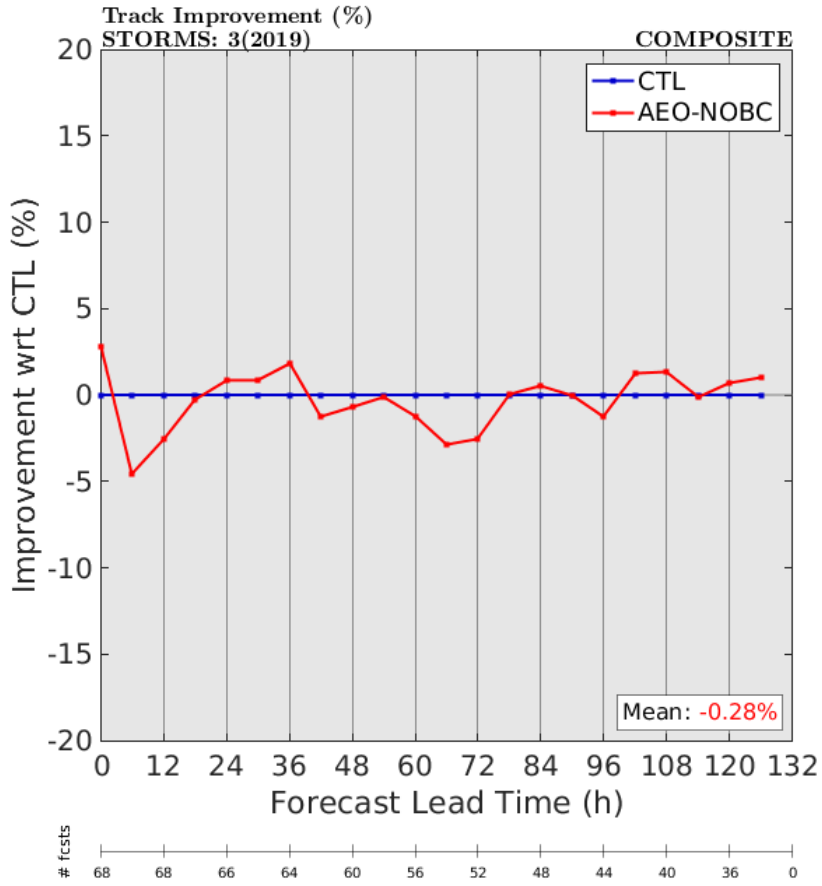
Most Aeolus observations within HWRF D02/D03 Domains above 300 hPa

Preliminary Results: Intensity Improved / Track Unchanged

- Improvements to near-term (0-48 hr) intensity forecasts
- Minimal impacts to track forecasts
  - Likely due to lack of Aeolus data in parent domain







Next Steps

Global NWP (FV3GFS)

Use M1-BC corrected data for long-term TC impact assessment experiments

Add scaling parameters to observation errors

Complete VarQC tuning

Conduct VarQC impact assessment experiments

Regional NWP (HWRF)

Rerun analyses with re-processed data

Include more storms

Incorporate IC/BC with FV3GFS model that includes Aeolus assimilation

Thank you for your attention!

Questions?