Refining the assimilation of Aeolus Doppler wind LiDAR observations in NOAA/FV3GFS by adopting VarQC

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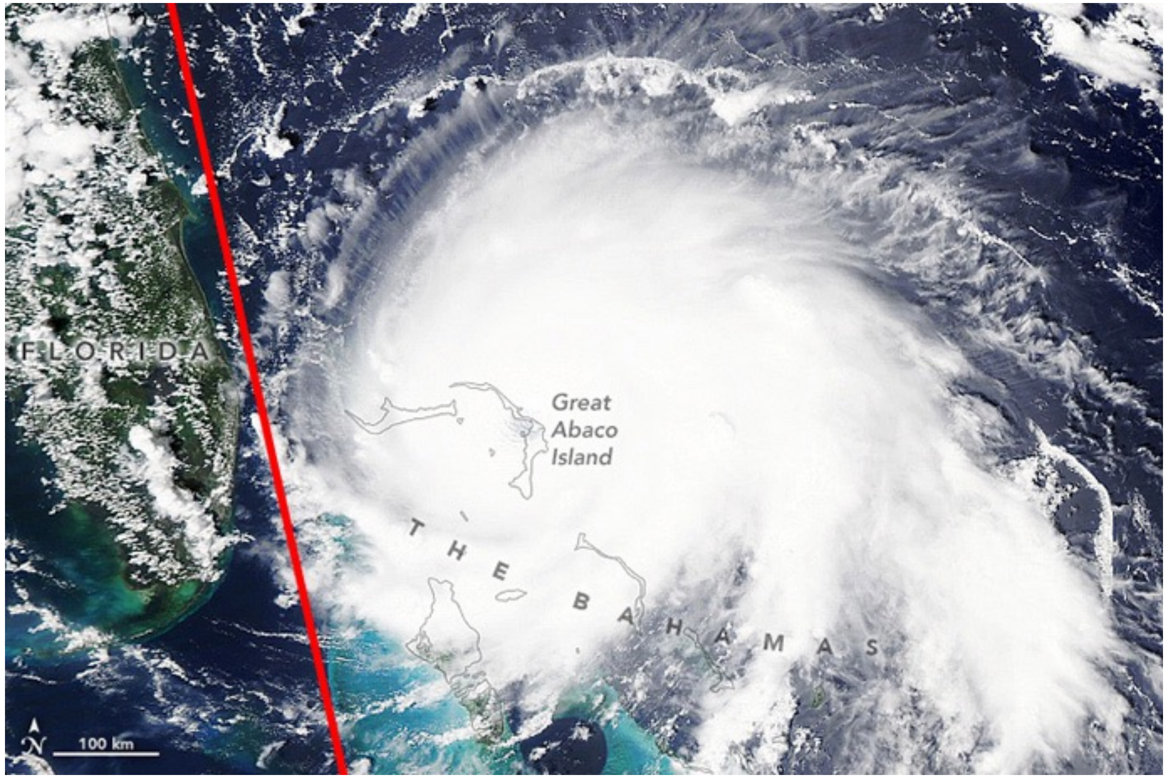
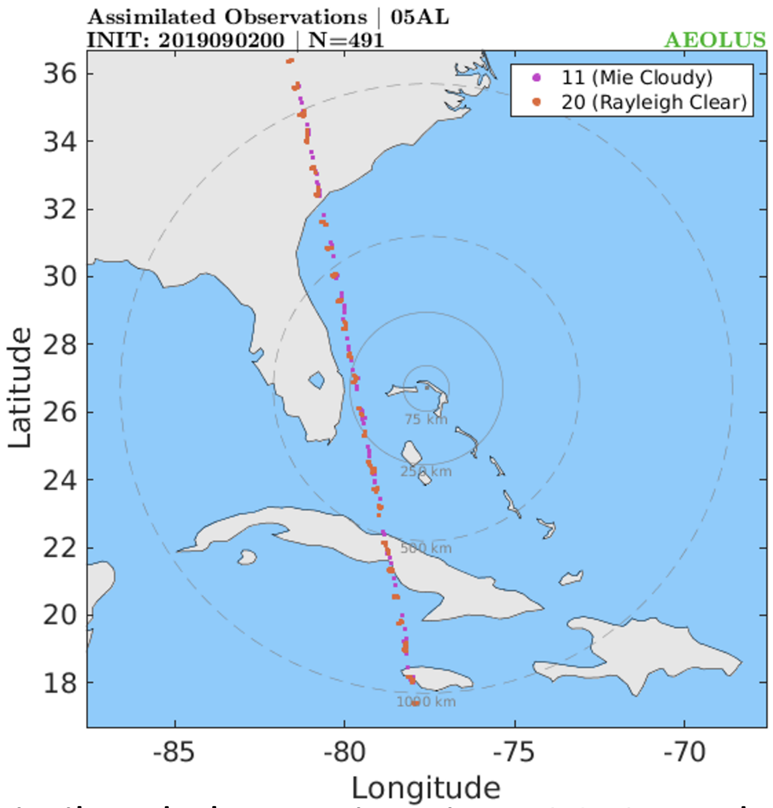


Aeolus satellite track overlaid on a NASA Aqua's satellite image of hurricane Dorian at 1805 UTC on September 1, 2019. (Image credit: NASA)

Motivation: QC of Aeolus HLOS and use in tropical cyclone (TC) prediction

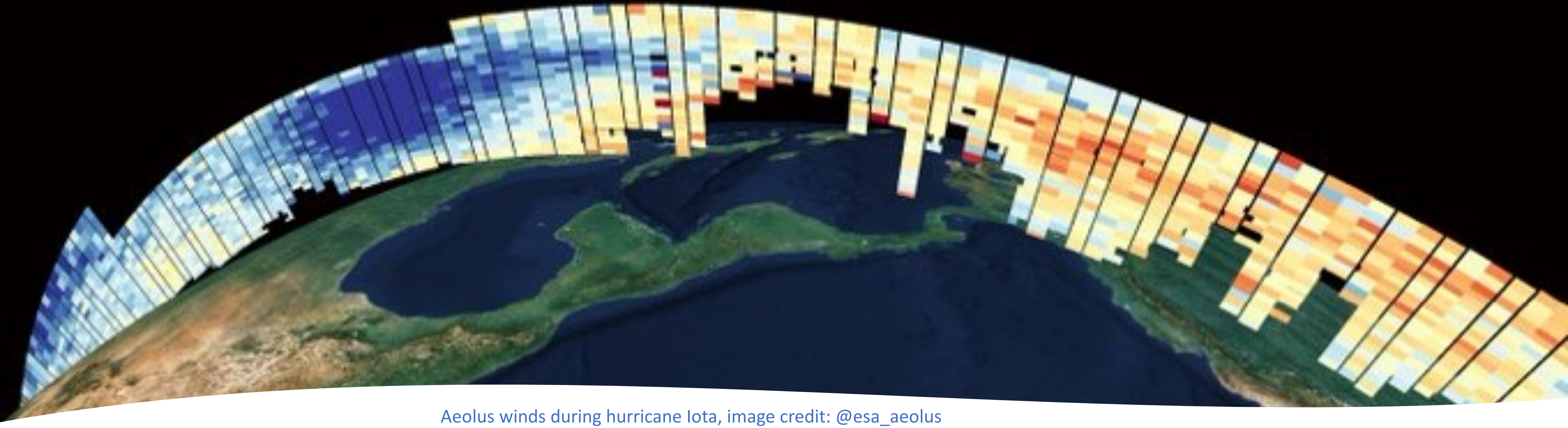
- Current experiments assimilating Aeolus observations in FV3GFS have shown promise, with evidence of impacts to the synoptic environment
- A TC impact assessment yielded a high case-to-case variability in the results, prompting us to ponder… Are we rejecting observation outliers or good quality data?
- Implications for TC's: Large (O-B) departures in the TC environment can have detrimental impacts on the analysis leading to obs. rejection, even though some obs. are correct

Valid: 20190902, during Hurricane Dorian, 2019



Assimilated observations in FV3GFS at edge of the Dorian's outer core (258 km radius)

DA in the presence of complex synoptic features in TC's with regions of strong gradients may benefit from adaptive QC



Aeolus winds during hurricane Iota, image credit: @esa_aeolus

Objective: Optimize Aeolus assimilation with an emphasis on 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

New NCEP Variational Quality Control

Assimilate what you can, reject what you must!

The 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
- Adopted a new VarQC scheme implemented in the 2021 operational NCEP/GFS (Purser et al., 2019) to improve the assimilation of Aeolus
- For observations, whose departures fall into super-logistic (Chevron-type) family, their probability density function (PDF) is shaped by modulating parameters
- The VarQC scheme can assign adaptive weights to observations

Mathematical formalism of VarQC

- The VarQC component of the incremental VAR observational cost function in GSI is given by:

$$J_o = \sum_i -g(\alpha_i, \beta_i, \kappa_i; z_i)$$

- where α, β, κ are PDF modulating parameters (asymmetry, broadness, convexity) and z is the probability of gross error

- The modulating parameters are based on skewness, variance, and kurtosis of the PDF of innovations

- $z_i = \frac{x}{\sigma}$, the z PDF is a non-dimensional error variable, x is the observation error, σ is the nominal standard error when x is small

Mathematical formalism of VarQC

- Thus, the weight $W_i(z_i)$ given to an observation by the VarQC algorithm is related to the probability of the shaping parameters of the innovation PDF and the probability of the gross error
- $W_i(z_i)$ is obtained during the inner minimization loop when taking the gradient of J_o
- VarQC assigns adaptive weights as a function of observation increment and the probability of gross error:

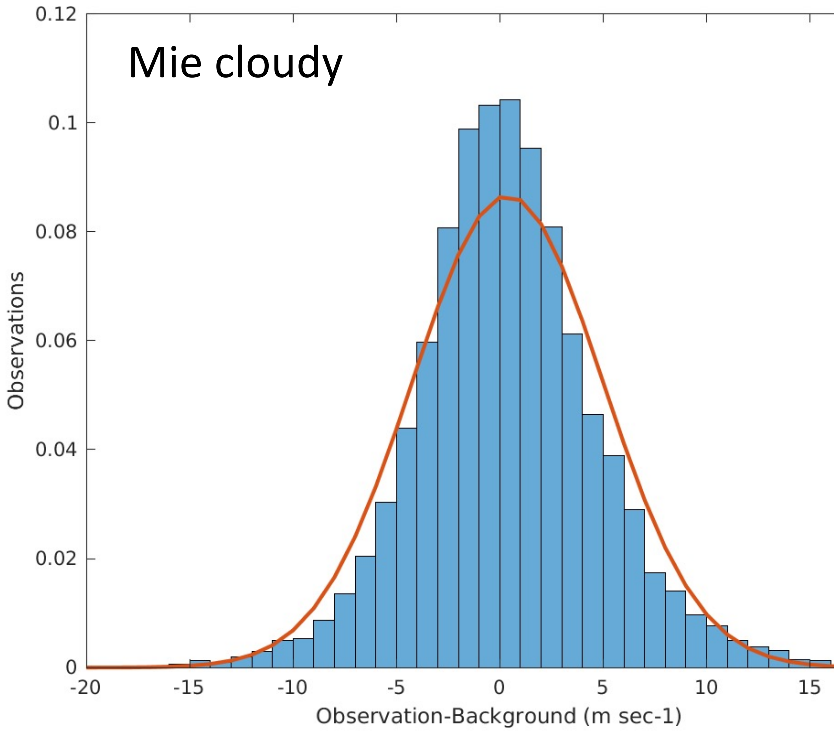
$$W_i(z_i) = \left\{ \begin{array}{l|l} 1 & : z_i = 0 \\ \hline \frac{-1}{z_i} \frac{dg_i(\alpha_i,\beta_i,\kappa_i;z_i)}{dz_i} & : z_i \neq 0 \end{array} \right\}$$

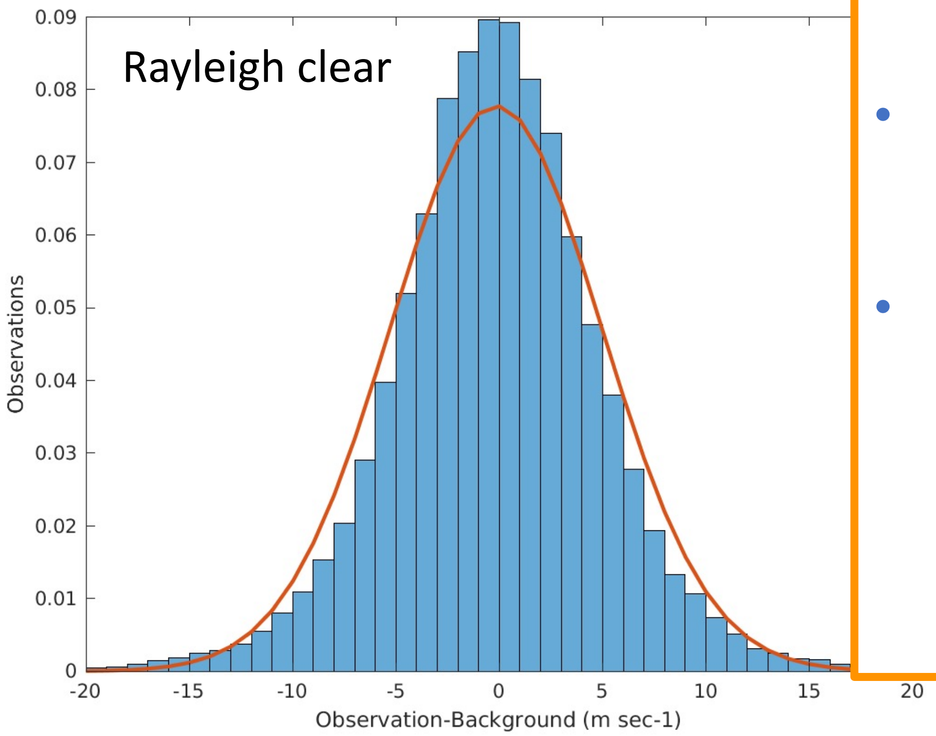
- For the symmetric PDF case–or within the Gaussian realm, the modulating weight goes to unity since $\alpha = 0$

(O-B) Statistical assessment and non-Gaussianity

Probability model for the Aeolus observation errors (Mie-cloudy and Rayleigh-clear) after strict static QC checks recommended by ESA and a lower bound of ECMWF observation error inflation (Desroziers' method –Michael Rennie)

Innovation Statistics: valid: 2019082018

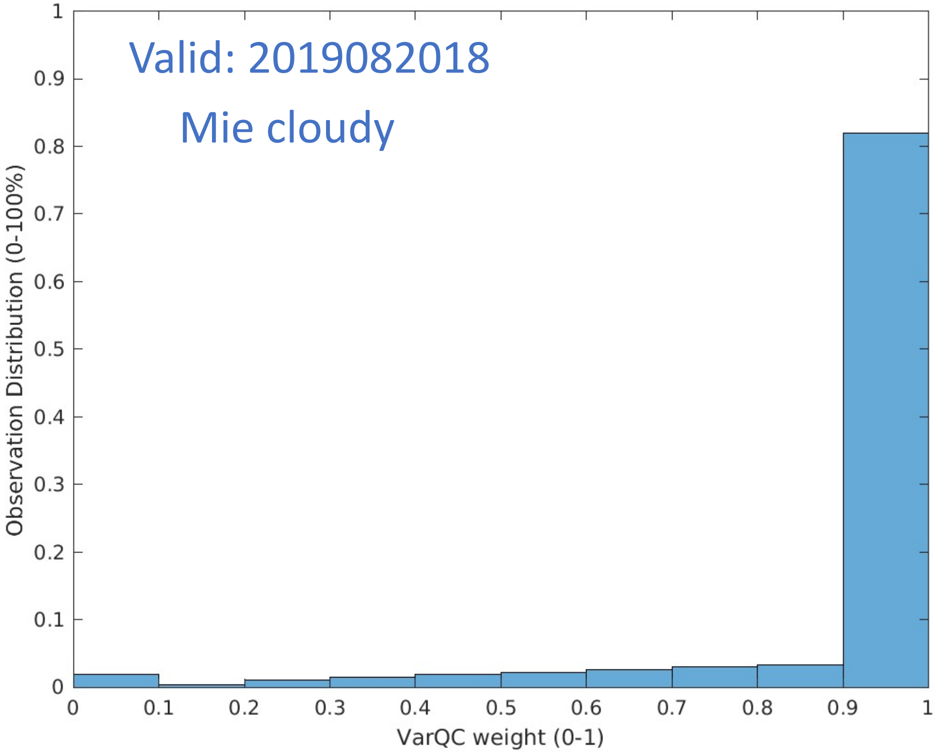


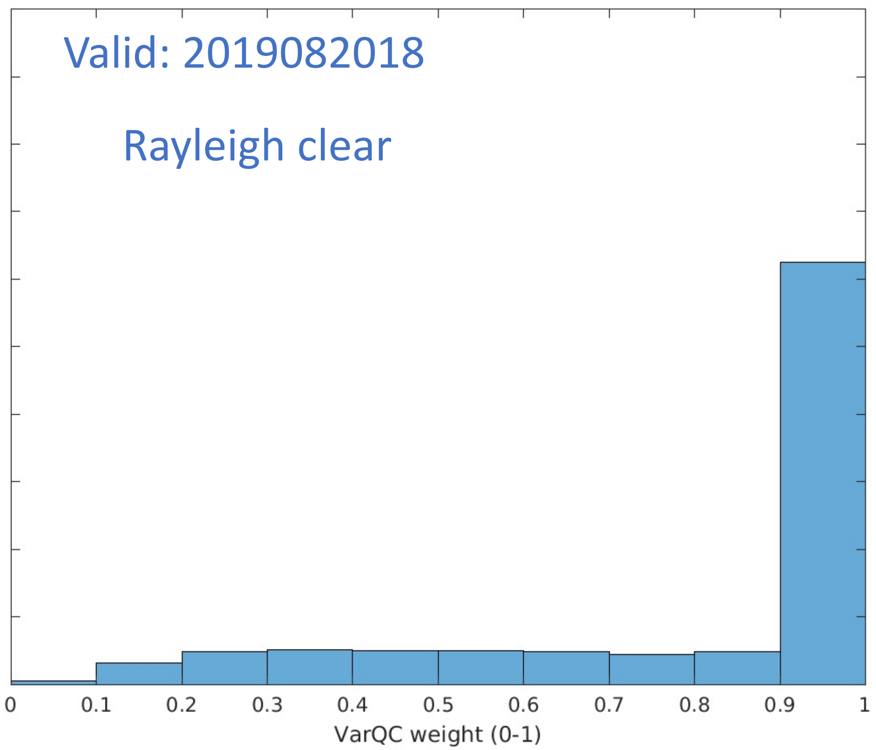


- Innovation statistics (1-month) indicate departures from the pure Gaussian form
- Unimodal and leptokurtic distributions, with some asymmetry
- Aeolus assimilation may benefit from advanced QC by assigning adaptive weights to observation outliers and not rejecting them

Adaptive weight distribution for Aeolus after VarQC

- VarQC deals with rejection limits outside of the Gaussian form
- Not discarding observations with large departures, but assigning less weight during the final analysis (~20% for Mie_cloudy and ~40% for Rayleigh_clear)

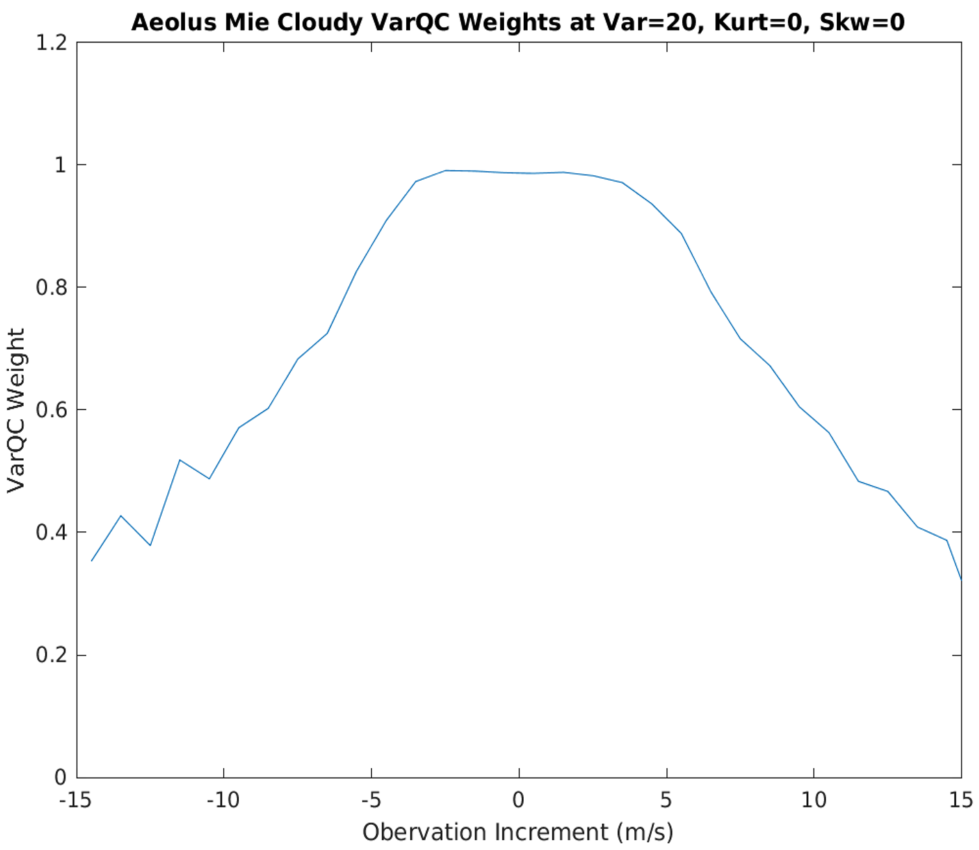


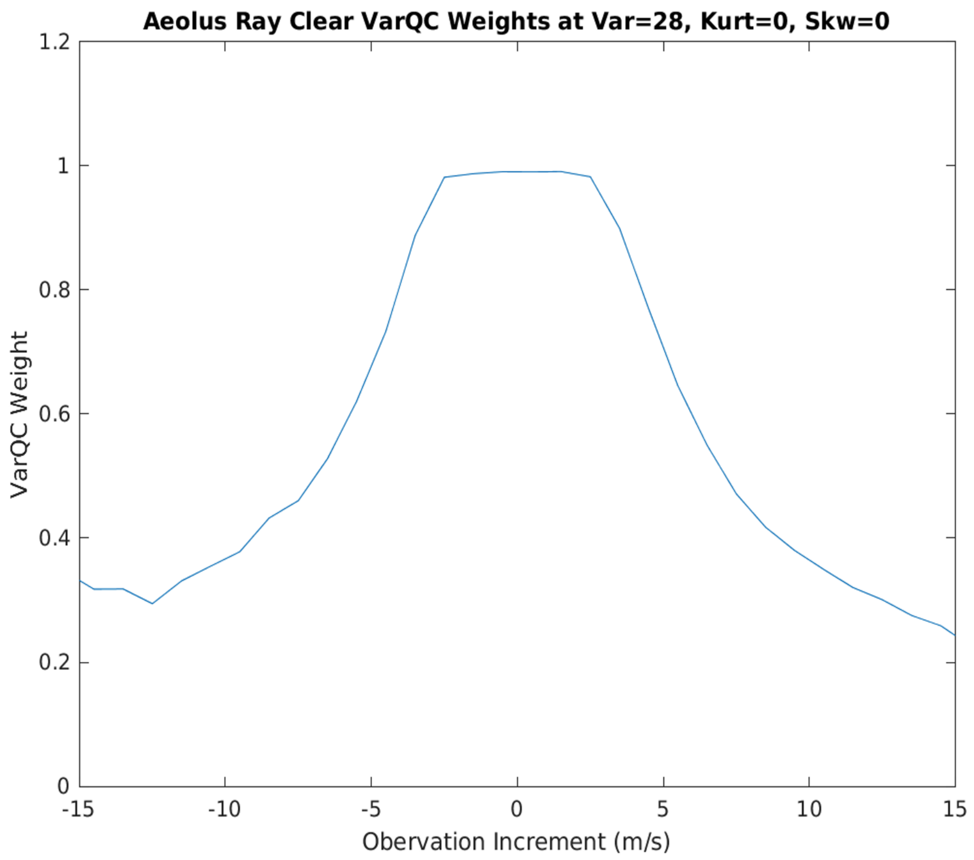


VarQC adaptive weights 0 to 1 range

- 0 least impact to the analysis
- 1 most impact to the analysis

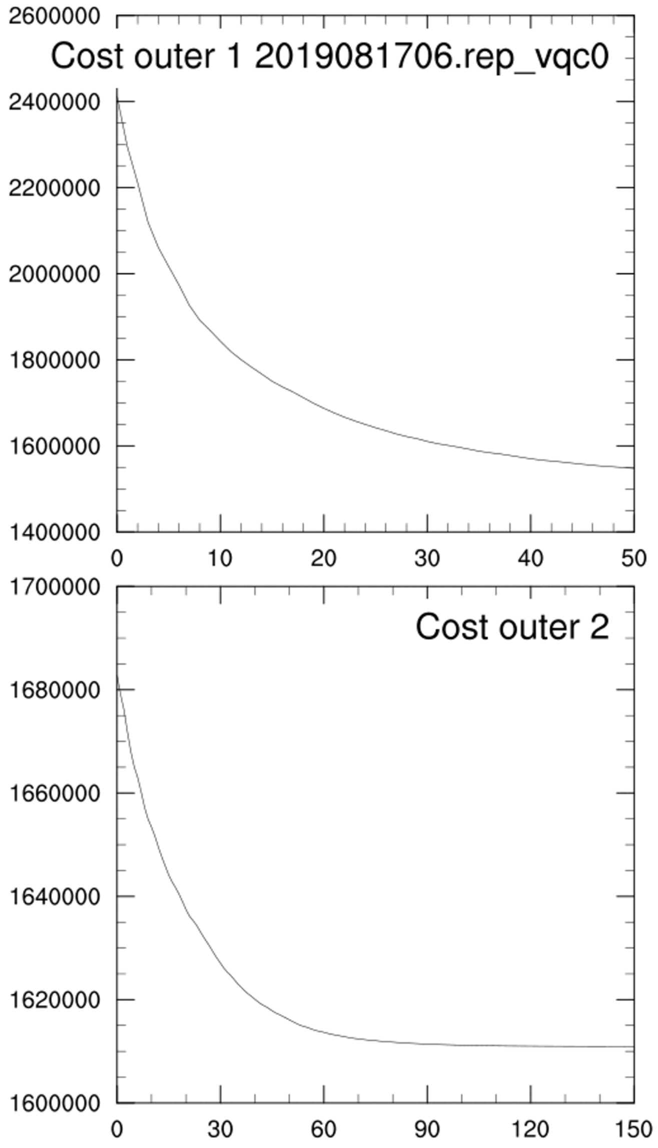
Adaptive weight assignment for Aeolus observations



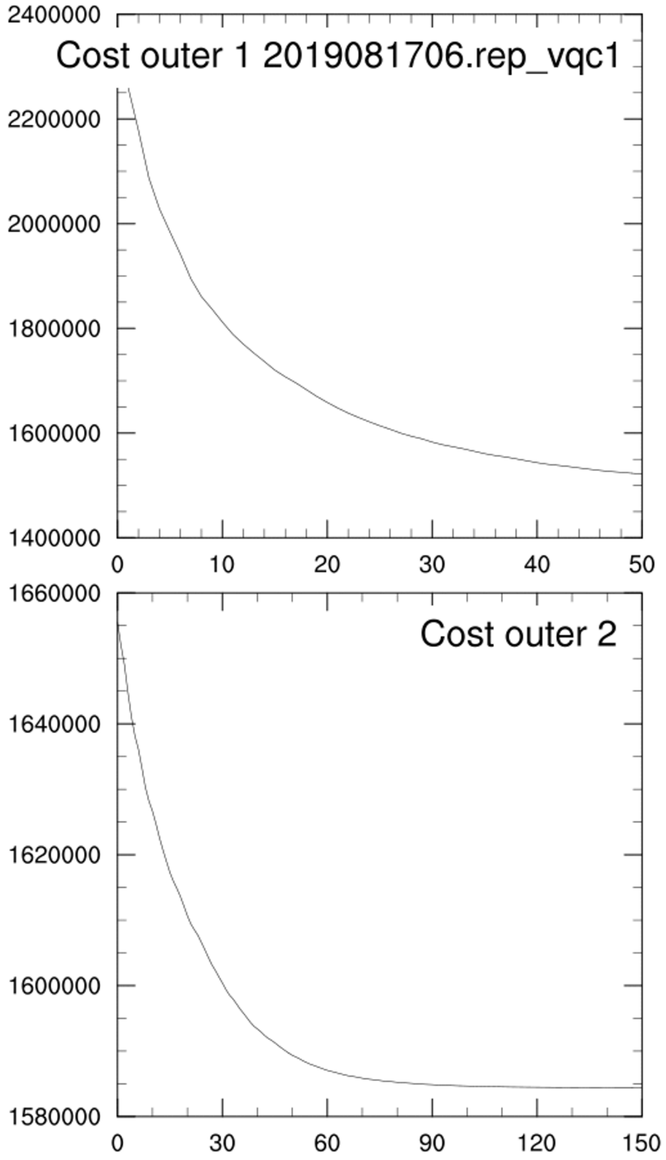


- More weight in the middle of the distribution
- Non-zero weight in the tails (places with large departures)
- More influence of data with large departures in the analysis

Aeolus DA No VarQC



Aeolus DA with VarQC



Minimization statistics

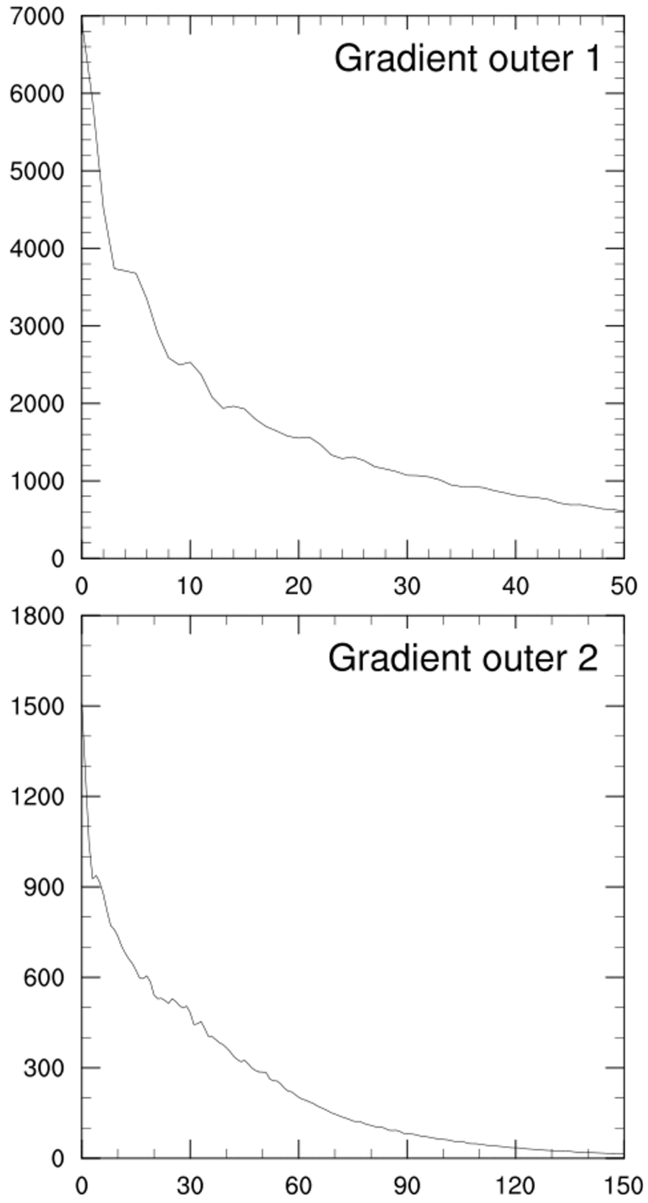
valid: 2019081706-2019082018

Further cost function reduction after second outer loop minimization for Aeolus with VarQC (left)

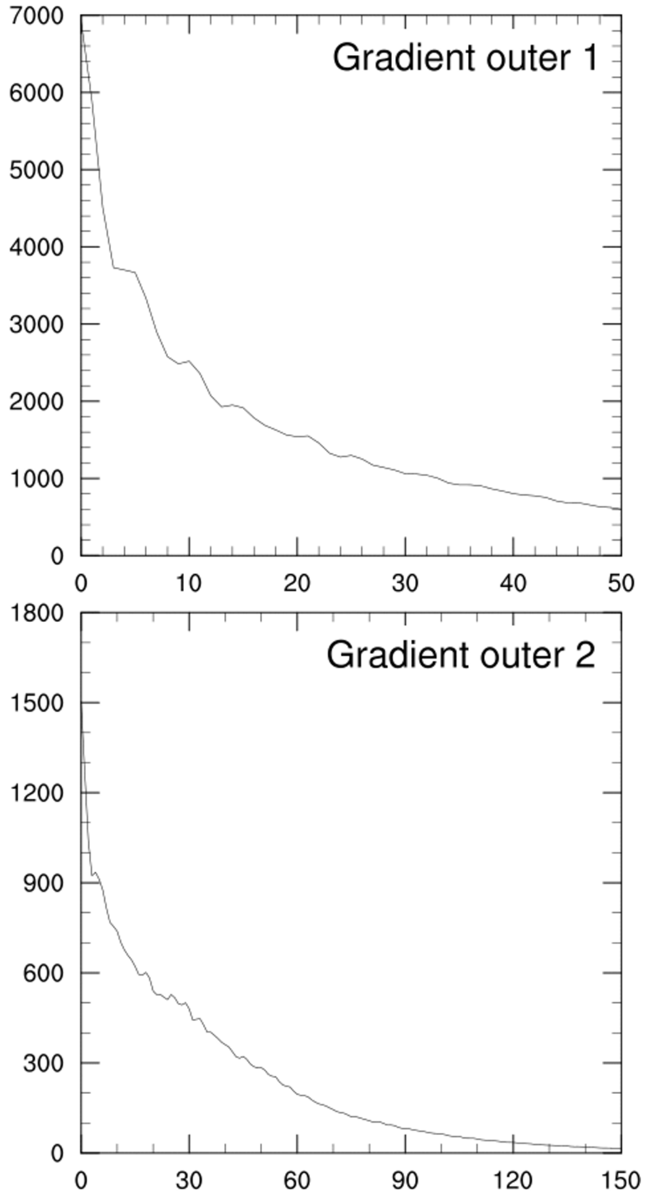
Gradient statistics

valid: 2019081706-2019082018

Aeolus DA No VarQC



Aeolus DA with VarQC

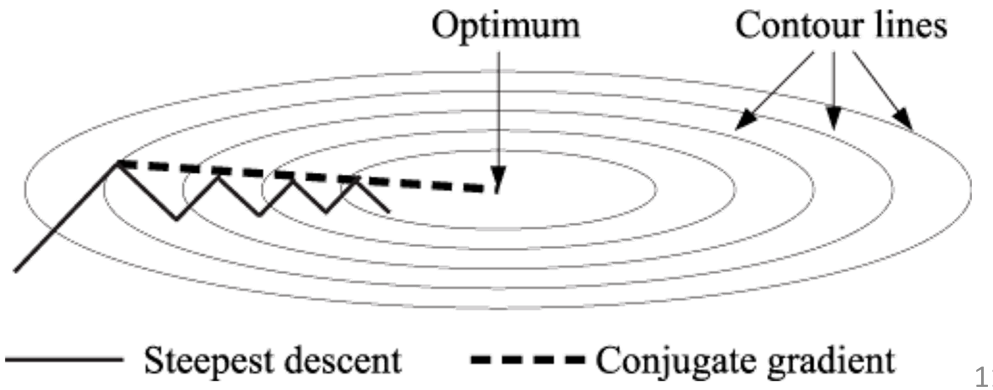


-More zigzagging using VarQC, but reaches convergence in the end

- VarQC runs on top of steepest descent algorithm within the conjugate gradient minimization method

- Treatment of large innovations results in large gradient norm spikes

Minimization in GSI



Summary and next steps

- More Aeolus (Mie-cloudy and Rayleigh_clear) observations are assimilated through adaptive weight assignment by using VarQC
- Initial tuning tests have shown that observations with large departures are included in the analysis, but with lesser weight
- Conduct a TC impact assessment with FV3GFS of Aeolus DA with adaptive weights
- Provide initial and lateral boundary conditions from FV3GFS_v16 with Aeolus DA + VarQC to initialize regional hurricane forecasts (NCEP/HWRF)

Thank you for your attention!

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