



Capturing capping inversion in PBL data assimilation in the GEOS

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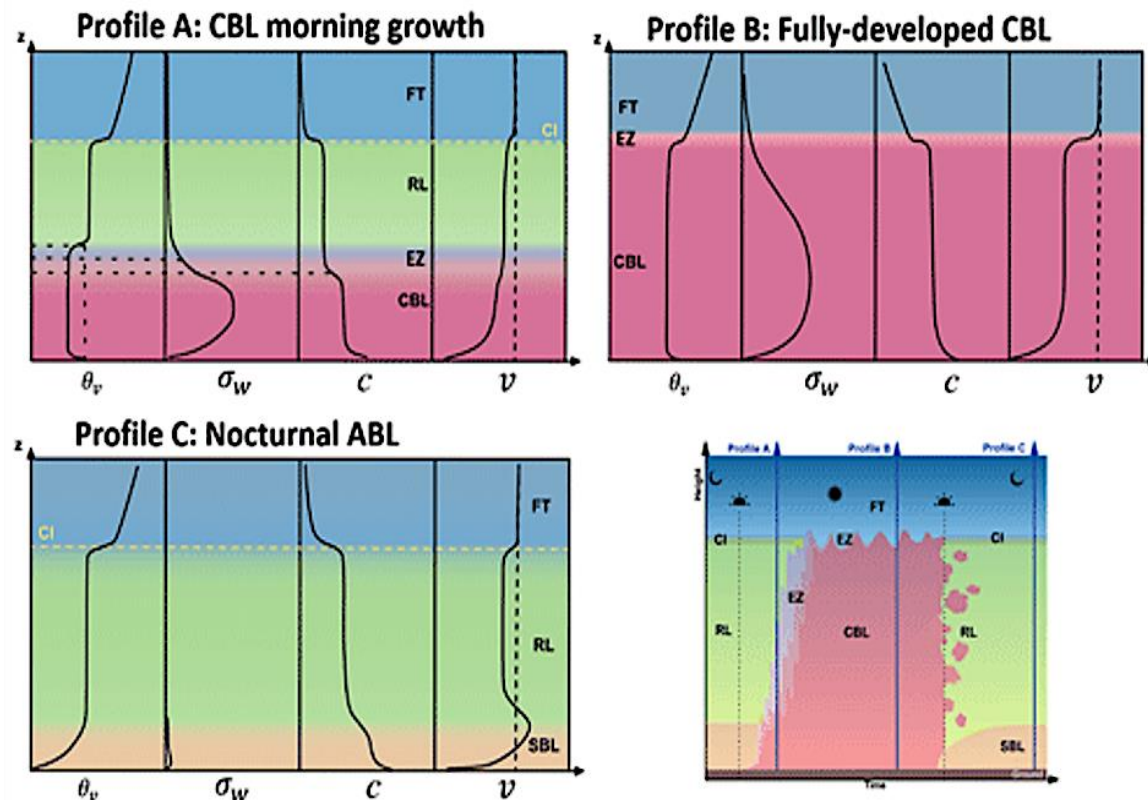
Science questions we'd like to address:

- ❑ Challenges of accurately representing PBL thermodynamic structure and PBL height (PBLH) in data assimilation
 - Unique feature of PBL: capping inversion

- ❑ Utilization of PBLH data in PBL data assimilation in the GEOS
 - Data assimilation strategy for different PBLH data, which represent different physical heights
 - Exploration of methods to capture PBL capping inversion
 - Adjustments of T/q ensemble spread & vertical localization length scale (AdjEnsVloc)
 - AdjEnsVloc vs. Multivariate aspects of background error covariances

θ_v mean virtual potential temperature
 σ_w vertical velocity variance
 c mean atmospheric constituent
 v mean horizontal wind speed

Unique feature of PBL -- often marked by the base of capping inversion



- A sharp vertical gradient of temperature or specific humidity profile
- Ensemble **B** is characterized by the decoupling between the errors in the PBL and the above atmosphere

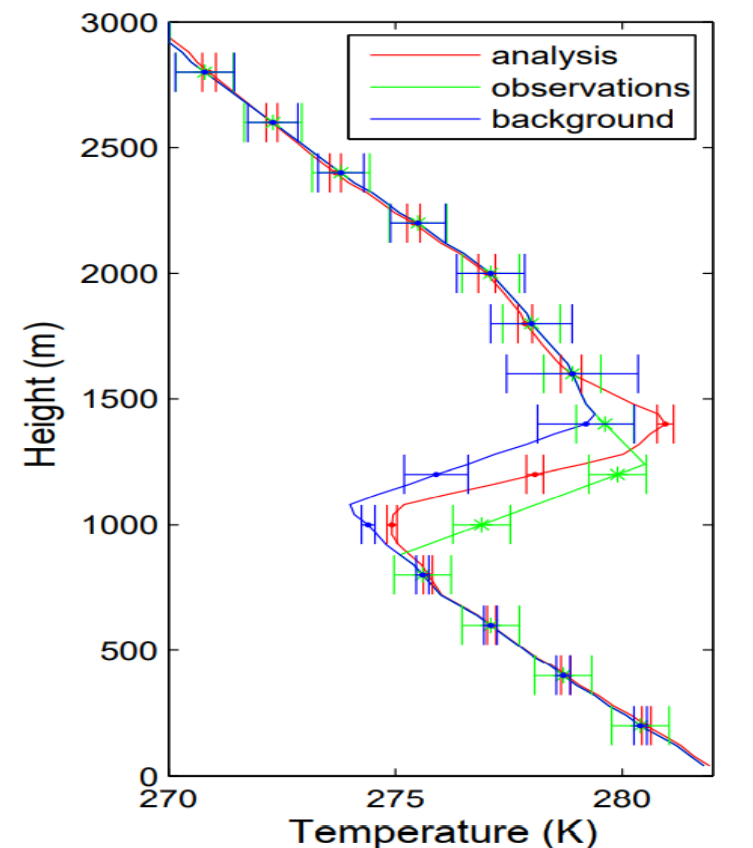
Both amplitude & displacement errors

Idealized vertical profiles of atmospheric variables during the idealized diurnal evolution of atmospheric boundary layer (Kotthaus et al. 2023)

- ❑ Displacement error in the background inversion will smear out the PBL structure and result in poor PBL analysis (Fowler et al. 2012)
- ❑ In general, **only where 1D-Var retrievals used numerical weather prediction (NWP) as input and already had an inversion could the retrieval have an inversion too** (Hilton et al 2020)
- ❑ Algorithms to account for positional error explicitly (e.g. Ravela et al 2007, Fowler et al 2012, etc), however,
 - complicated, nonlinear
 - sensitive to many factors

It is essential to improve background error covariances to capture capping inversions

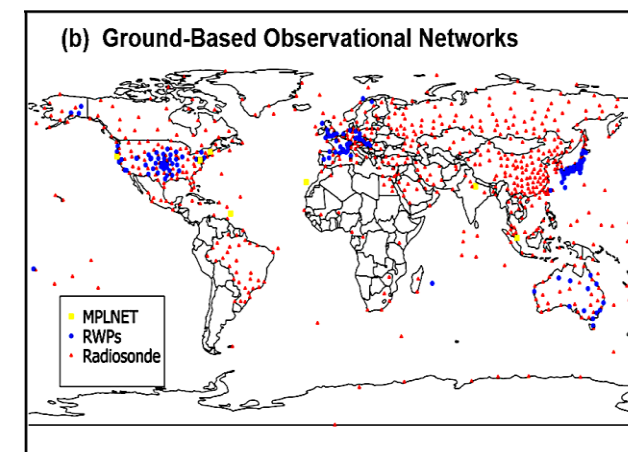
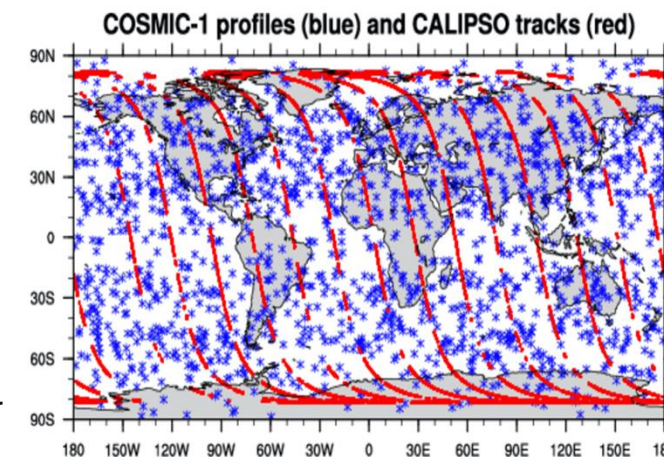
BKG inversion is 200m higher than observed



A simple demonstration of 1DVAR of using temperature observations (Fowler 2012)

Why PBL height data assimilation?

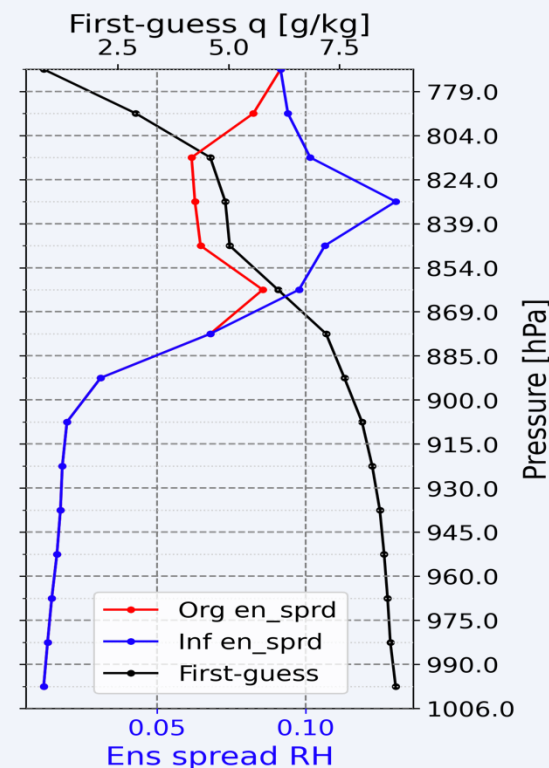
- ❑ **Generate global PBL height (PBLH) analysis & monitor various PBLH data online**
 - PBLH data are sensitive to observing method, retrieval algorithm.
 - Consistent model PBLH definitions with different PBLH data, e.g. refractivity gradient-based model PBLH for GNSS-RO PBLH data
 - PBLHs control variable augmentation
- ❑ **Capture the locations of capping inversions**
 - Benefit the use of all other observations in the lower troposphere
- ❑ **Provide additional info for thermodynamic variables through background error covariances**
 - Multivariate aspects



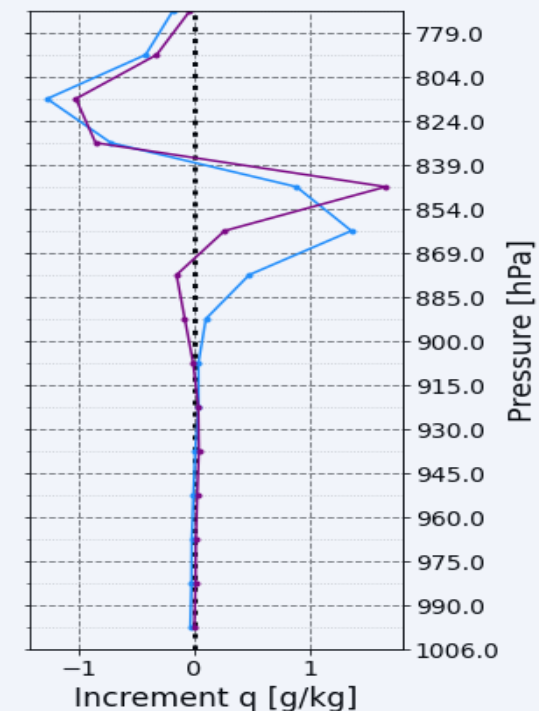
Capture capping inversions

- Improve T & RH Background Error Covariances around observed PBL top -- AdjEnsVloc

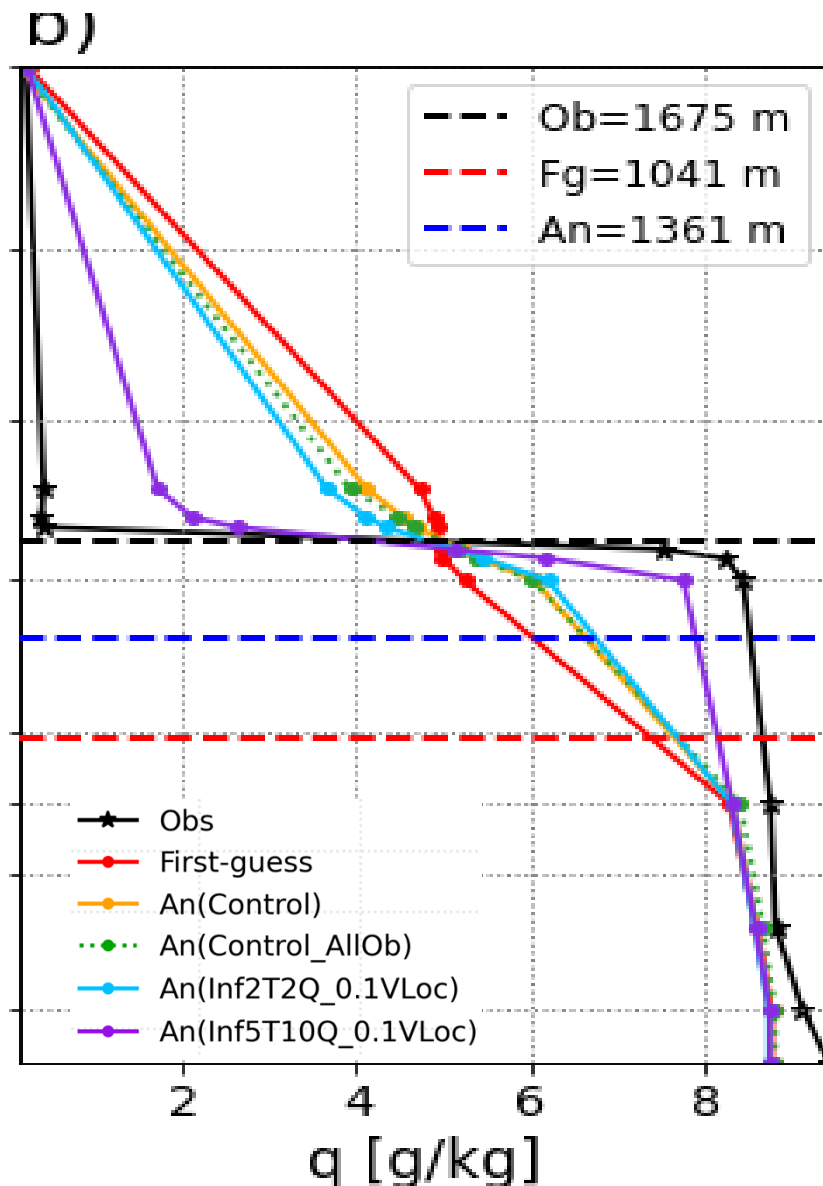
- Inflation of T & RH ensemble spread
- Adjustment of vertical localization length scale



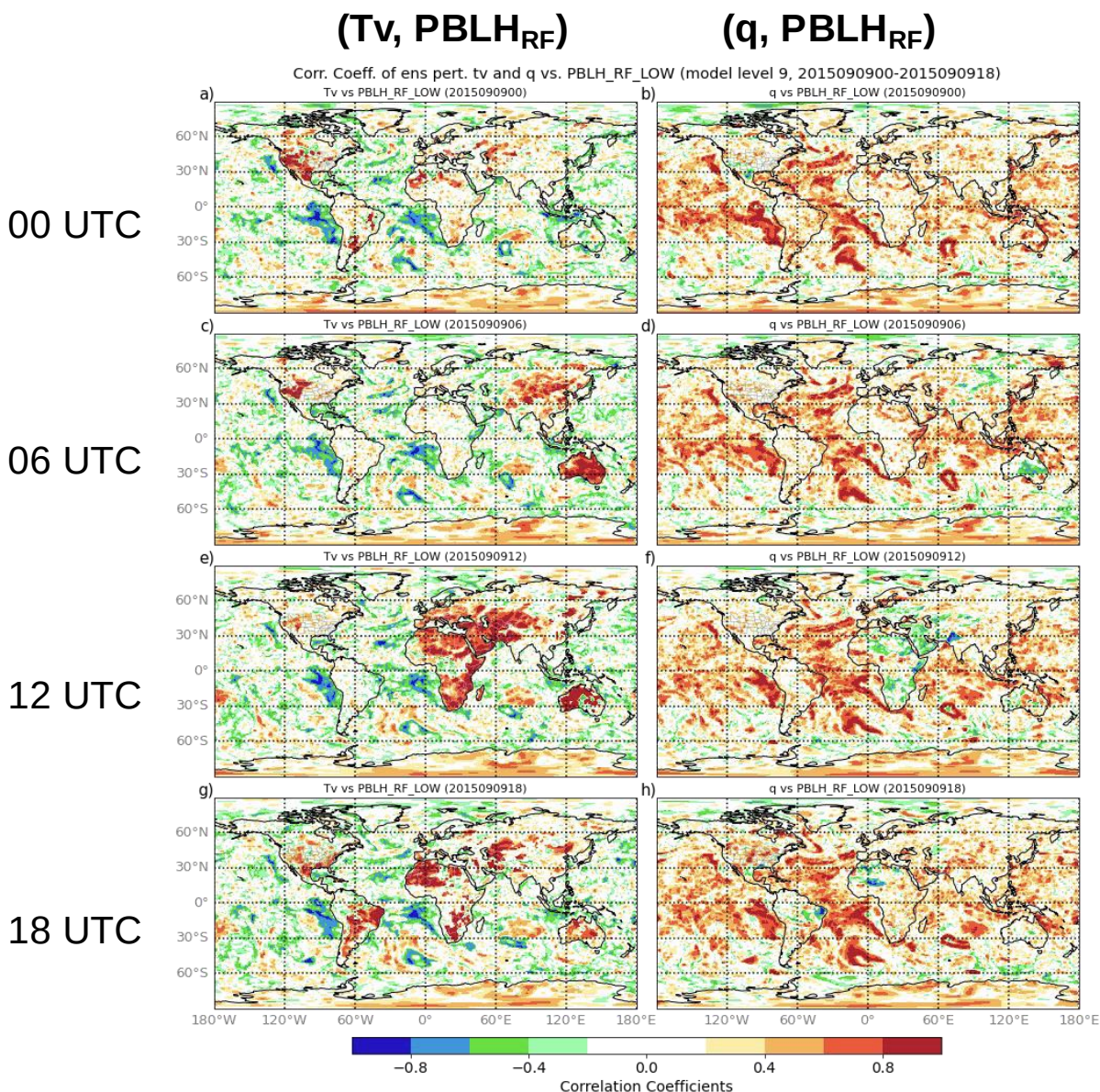
- Original ensemble spread:
- Too small in magnitude
 - Peak level too low
 - Inflate to correct level



- Smaller vertical localization length scale can better represent stronger inversions



- ❑ Model forecasts shallower PBL than the radiosonde observations
- ❑ Assimilating all observations doesn't help
- ❑ AdjEnsVloc improves PBL thermodynamic structure. The larger the ensemble spread inflation, the closer the analyses are drawn to observations



Multivariate aspects of background error covariances

- ❑ Like Bulk Richardson number-based model $PBLH_{Ri}$, refractivity gradient based model $PBLH_{RF}$ is also closely related to atmospheric states but more complicated
- ❑ Clear diurnal cycle accompanying the convective boundary layer
- ❑ Persistent relationship in marine stratocumulus regions

AdjEnsVloc vs. Multivariate aspects of background error covariances

Exp Name	PBLH _{RF} B	AdjEnsVloc
Exp1	Static	Off
Exp2	Static	On
Exp3	Hybrid	Off
Exp4	Hybrid	On

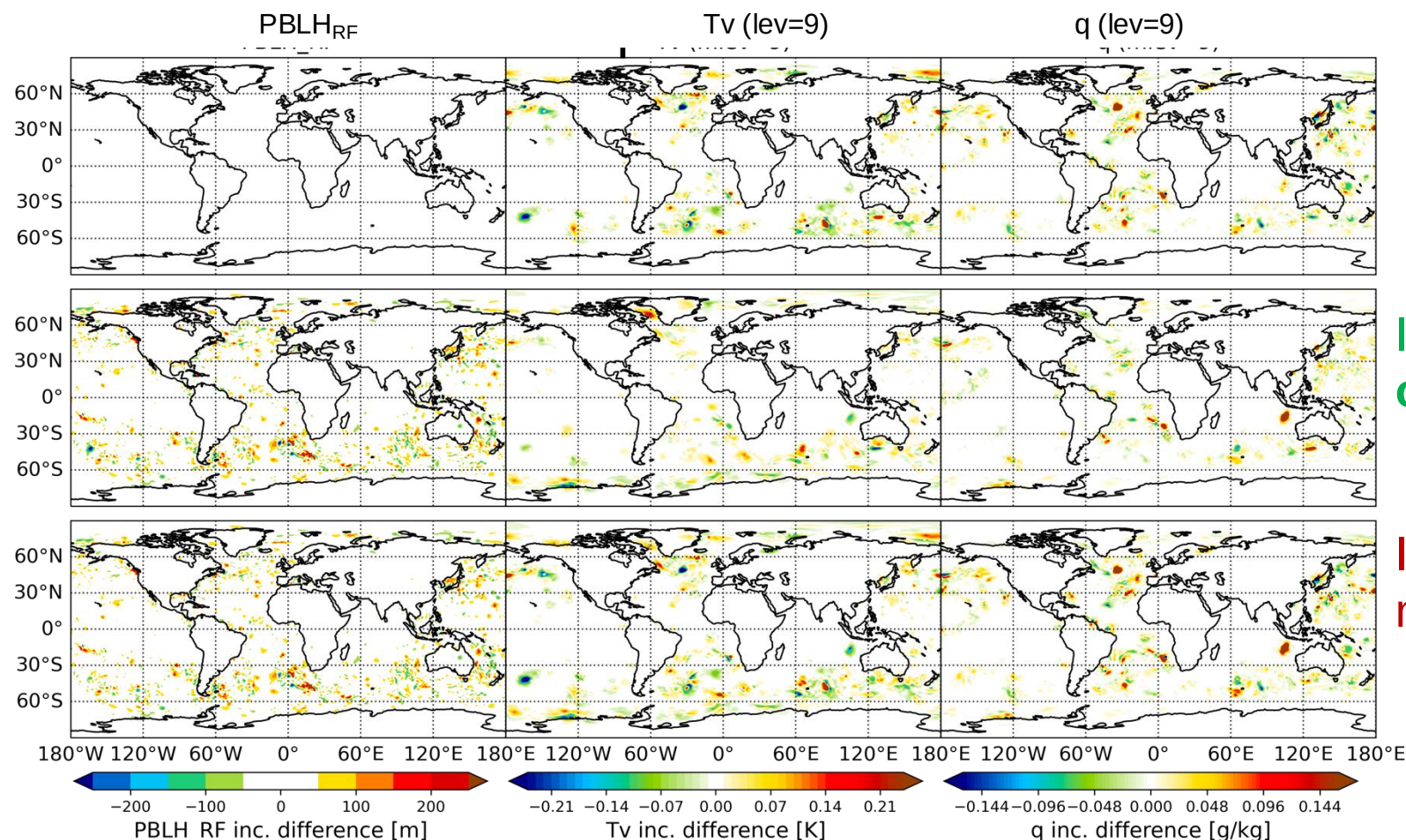
- ❑ Hybrid 4D EnVar configuration: all operational observations
- ❑ Additional data: GNSS-RO PBLH_{RF} data

Impact of AdjEnsVloc only

Impact of multivariate aspects of **original B**

Combined impact of AdjEnsVloc & multivariate aspects of **improved B**

An example of analysis increment differences between



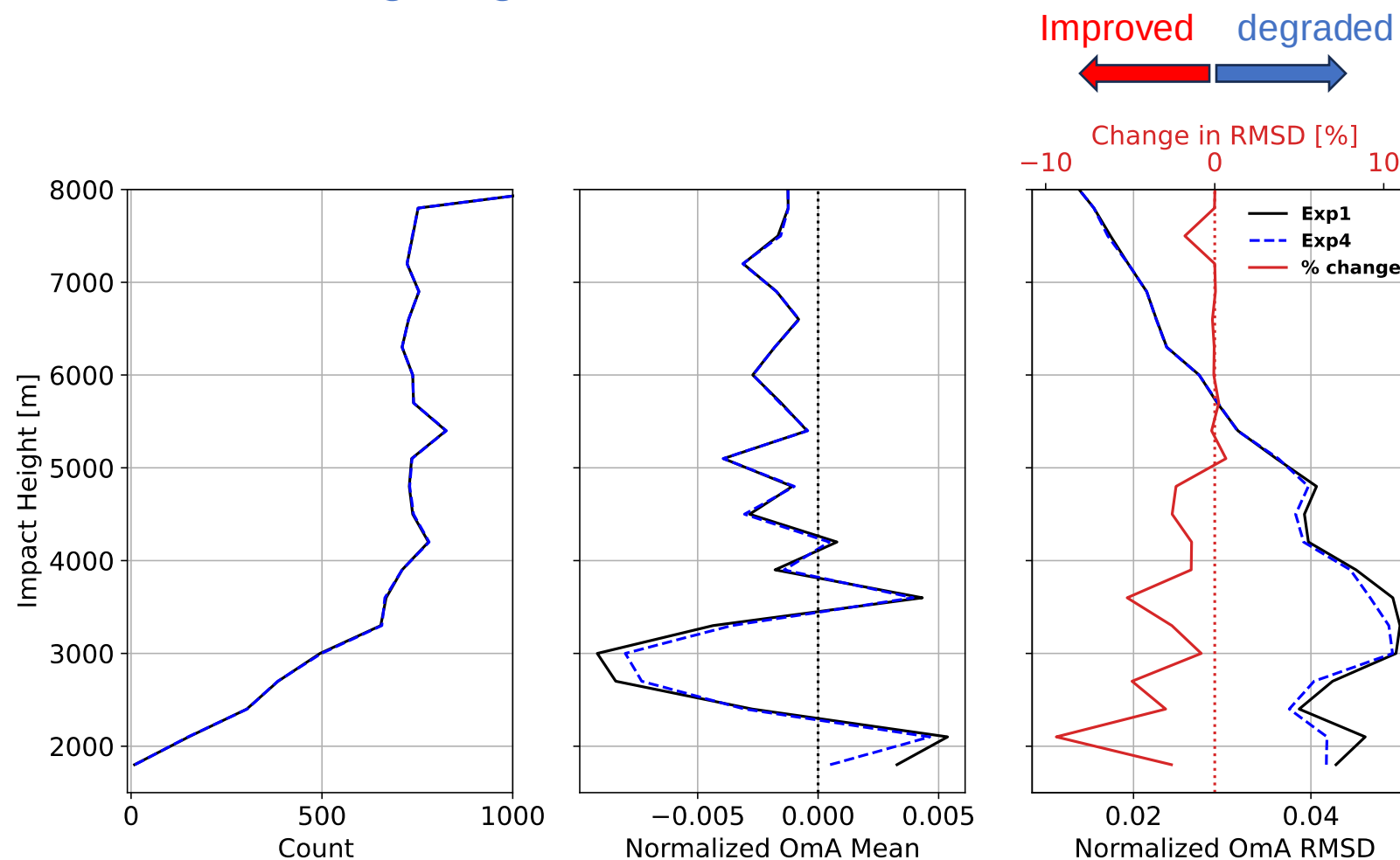
Impact of AdjEnsVloc only

Impact of multivariate aspects of original B

Impact of **combined** AdjEnsVloc & multivariate aspects of **improved** B

PBLH data impacts on T & q through **AdjEnsVloc** are quite different from those through **multivariate aspects of original B** in both magnitude and location

Combined impact of AdjEnsVloc & multivariate aspects of **improved B** on GNSS-RO bending angle OmFs





Conclusions and future work

- ❑ Developed the framework to evaluate existing and future PBLH data using proper model PBLH definitions and to assimilate PBLH data from multiple observing systems
- ❑ Developed AdjEnsVloc method, i.e. inflation of T & RH ensemble spread and adjustment of vertical localization length scale around observed PBL top, to help capture capping inversions
- ❑ PBLH data impacts on T & q through AdjEnsVloc are quite different from those through multivariate aspects of original B in both magnitude and location
- ❑ Further study is needed to generalize and optimize the AdjEnsVloc method
- ❑ Continue to investigate combined data impact from PBLH, conventional, GNSS RO, and radiance data on the PBL structure
- ❑ Further explore methods for better retaining observation information in model forecast
- ❑ Transition to the JEDI-based GEOS system



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