

Improving Boundary Layer Data Assimilation in the NASA GEOS System

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Abstract The Goddard Earth Observing System (GEOS) developed by the NASA Global Modeling and Assimilation Office assimilates a wide range of observations to support various NASA Earth Science missions. As Measurement of planetary boundary layer (PBL) was designated as an incubation program by the 2018 Decadal Survey, we have aimed to improve PBL thermodynamic structure using data from multiple observing systems. In particular, we have developed strategies and infrastructure to assimilate PBL height (PBLH) data derived from radiosondes, GNSS radio occultation, space-based lidar (CALIPSO, CATS, IceSat-2), ground-based lidar (MPLNET) and radar wind profilers to produce global PBL height analyses. We have also explored methods to better represent capping inversions by using PBLH data together with other observations in the GEOS to adjust background error covariance and enhance model PBL parameterization performance.

Motivations

- PBL is an important interface between the earth and atmosphere
- Measurement of PBL was designated as an incubation program by the 2018 Decadal Survey. “Better observations of **PBL temperature** and **water vapor profiles**, and of **PBL height** were selected as priorities by ESAS 2017, which recommended the PBL as an Incubation Targeted Observable (TO).” *
- Any single observing system can sample only a fraction of the global PBL space-time structure and physical aspects
- The GEOS data assimilation system provides the critical capability to assimilate a wide range of observations in producing a comprehensive PBL estimate consistent with model physics and observations

Objectives

- Develop data assimilation strategy and infrastructure in the NASA GEOS for global PBLH data analysis and monitoring for multiple observing systems
- Assess data impacts from PBLH, GNSS RO and radiances on PBL thermodynamic structure

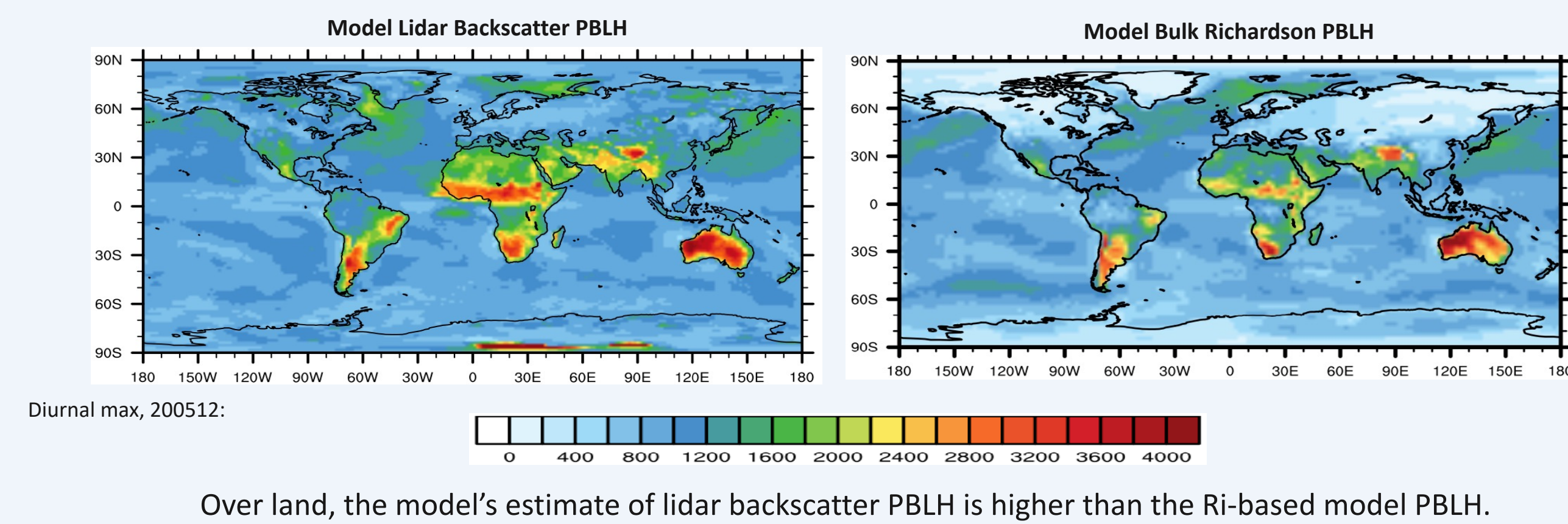
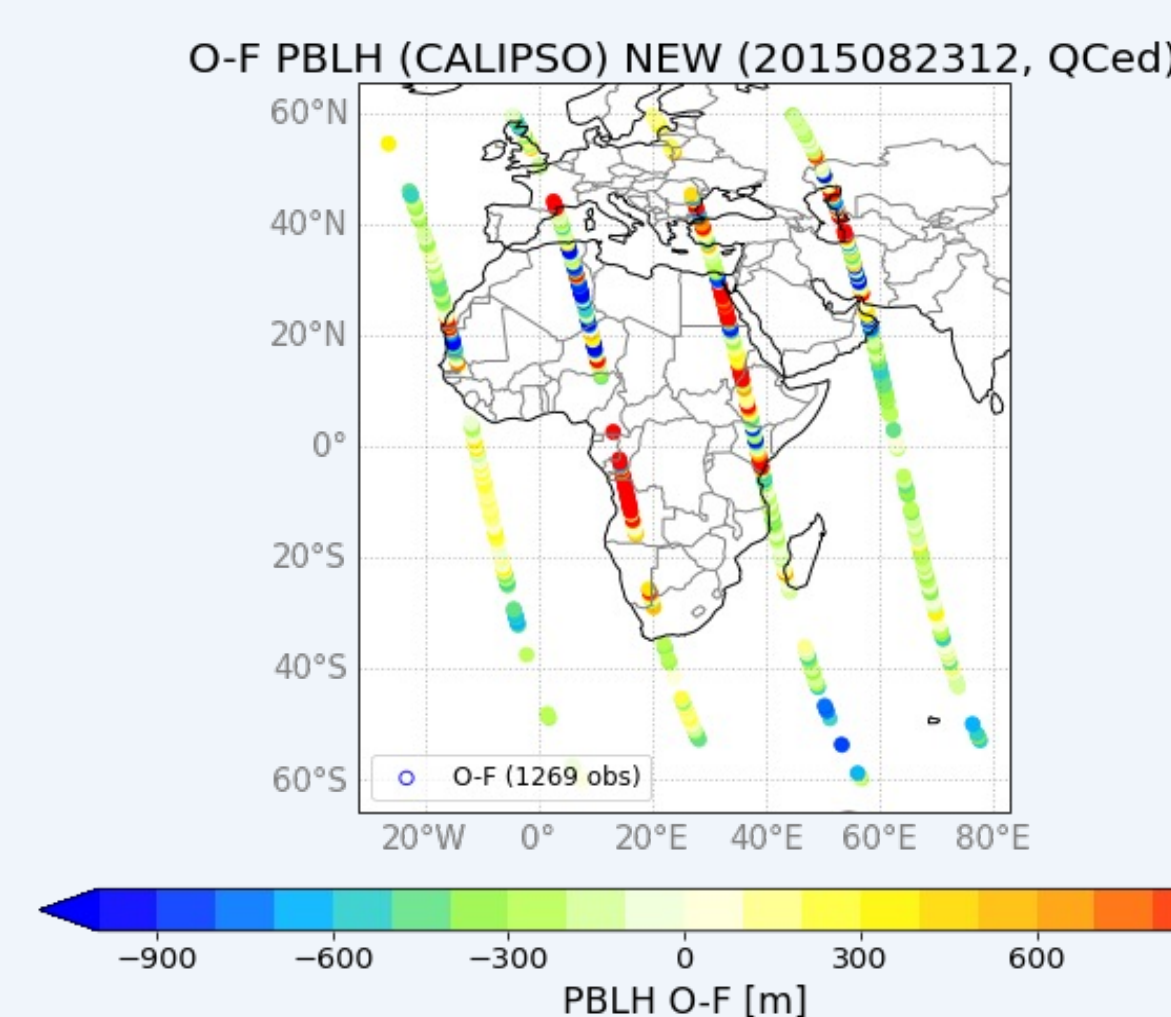
Consistent comparison between the observed and simulated PBLH

PBLH data

- PBLH data derived from multiple observing systems: **Radiosonde**, **Global radar wind profiler**, **Space-based lidars** (CALIPSO, CATS, ICESat-2), **Ground-based lidar MPLNET**, **GNSS RO**
- Instruments/retrievals of PBLH vary widely, can be sensitive to meteorology, aerosol content, and other atmospheric fields.

Corresponding model PBLH Definitions

- Bulk Richardson number**
 - Refractivity gradient**
 - Lidar total attenuated backscatter gradient**
 - Radar backscatter gradient**
- (Implemented, under validation, planned)

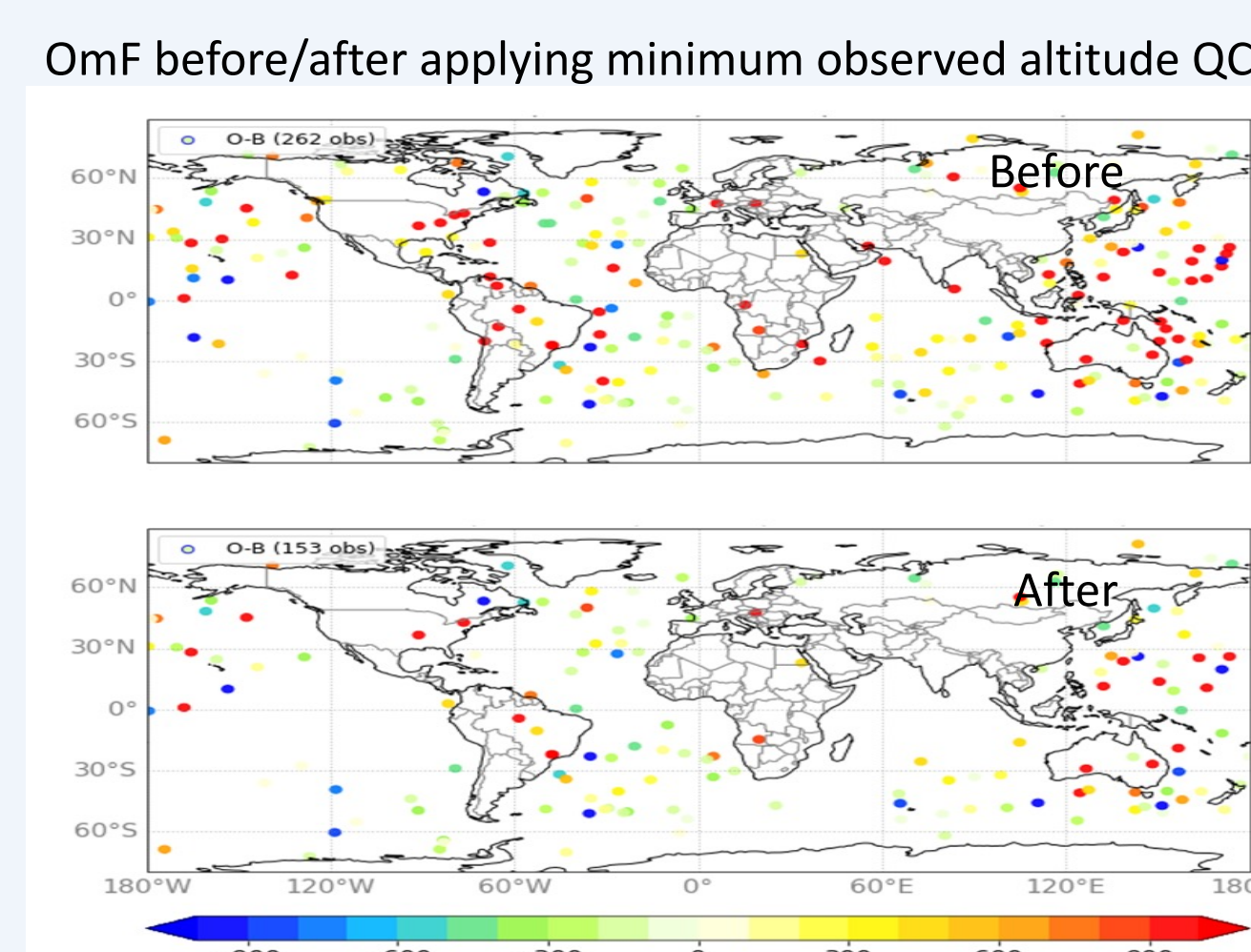


→ Large differences between CALIPSO (lidar based) observations and the model's Ri PBL height reflect the “mismatch” in PBLH definitions.
→ This mismatch will be eliminated by using the proper model PBLH definition for each observation type.

Quality control of PBLH data for data assimilation

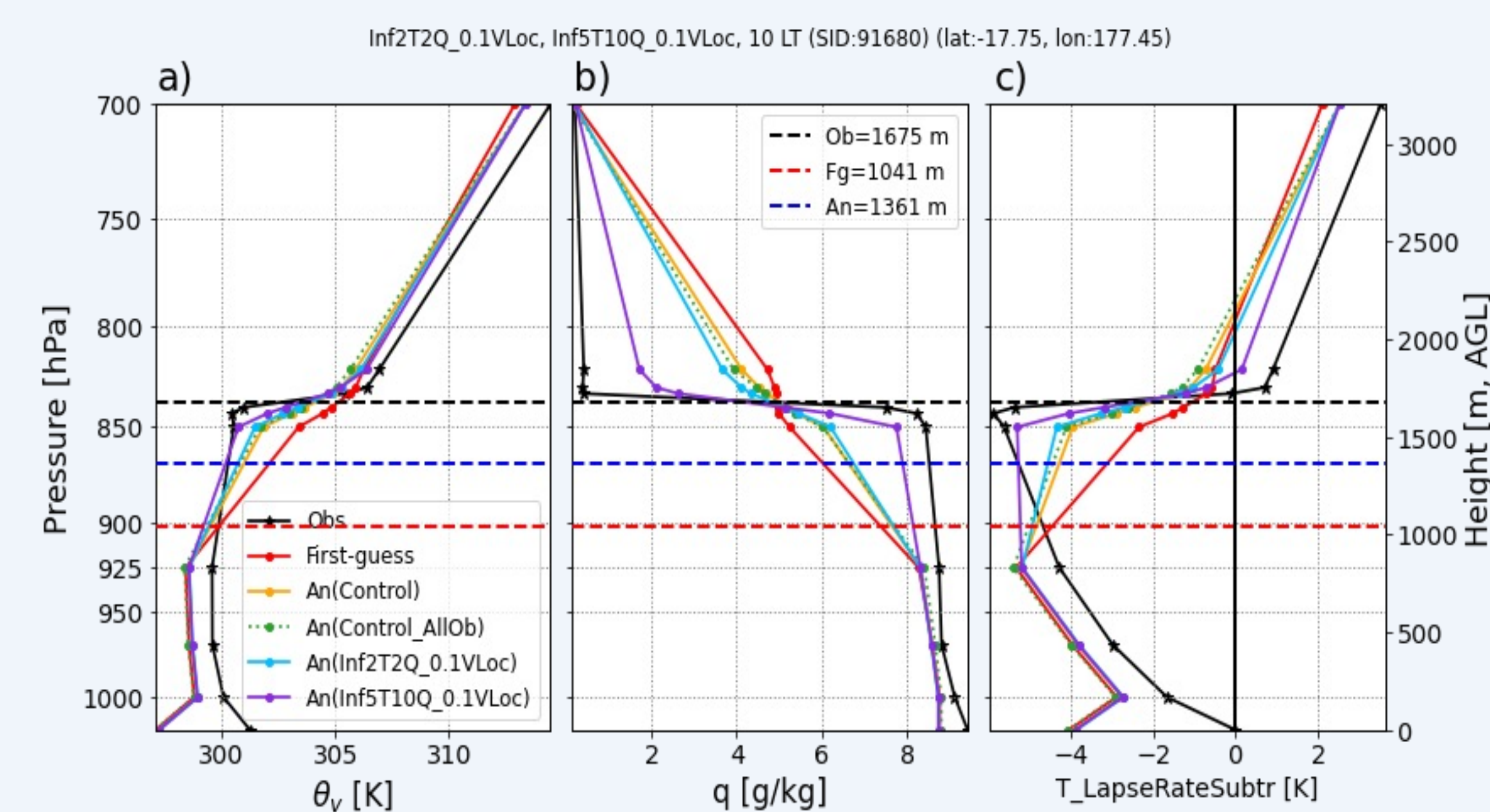
Quality control, an important step in data assimilation, has been developed for PBLH data used in this project. For example, GNSS-RO PBLH data are excluded in data assimilation if

- Mixed surface type
- Minimum observed altitude larger than 500m
- Sharp gradient terrain or rapidly varying orography: subgrid STDV of surface height > 200m
- Gross error check: absolute value of the ratio between OmF and observation error > 2.5

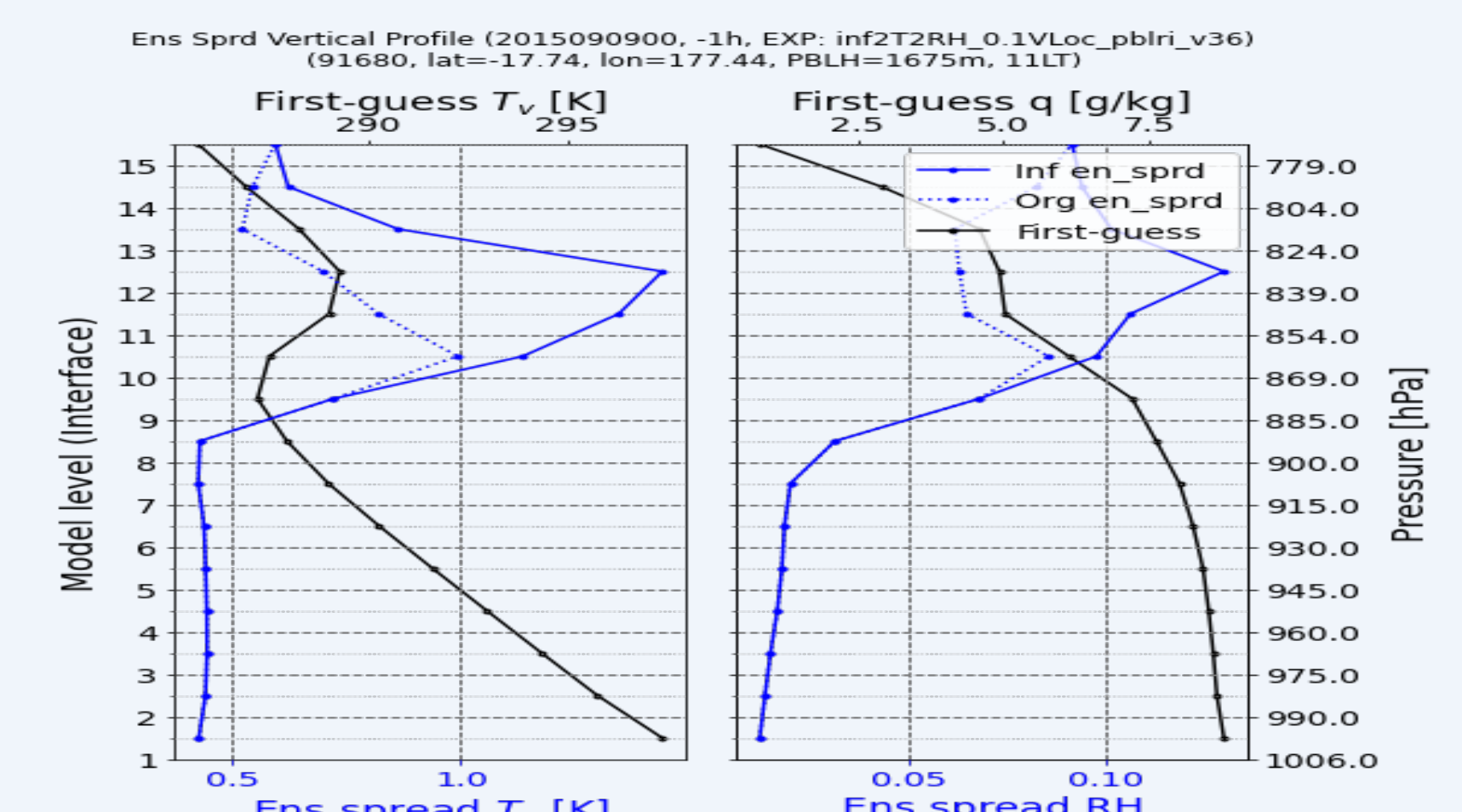


PBL height data assimilation: Capture a boundary layer capping inversion

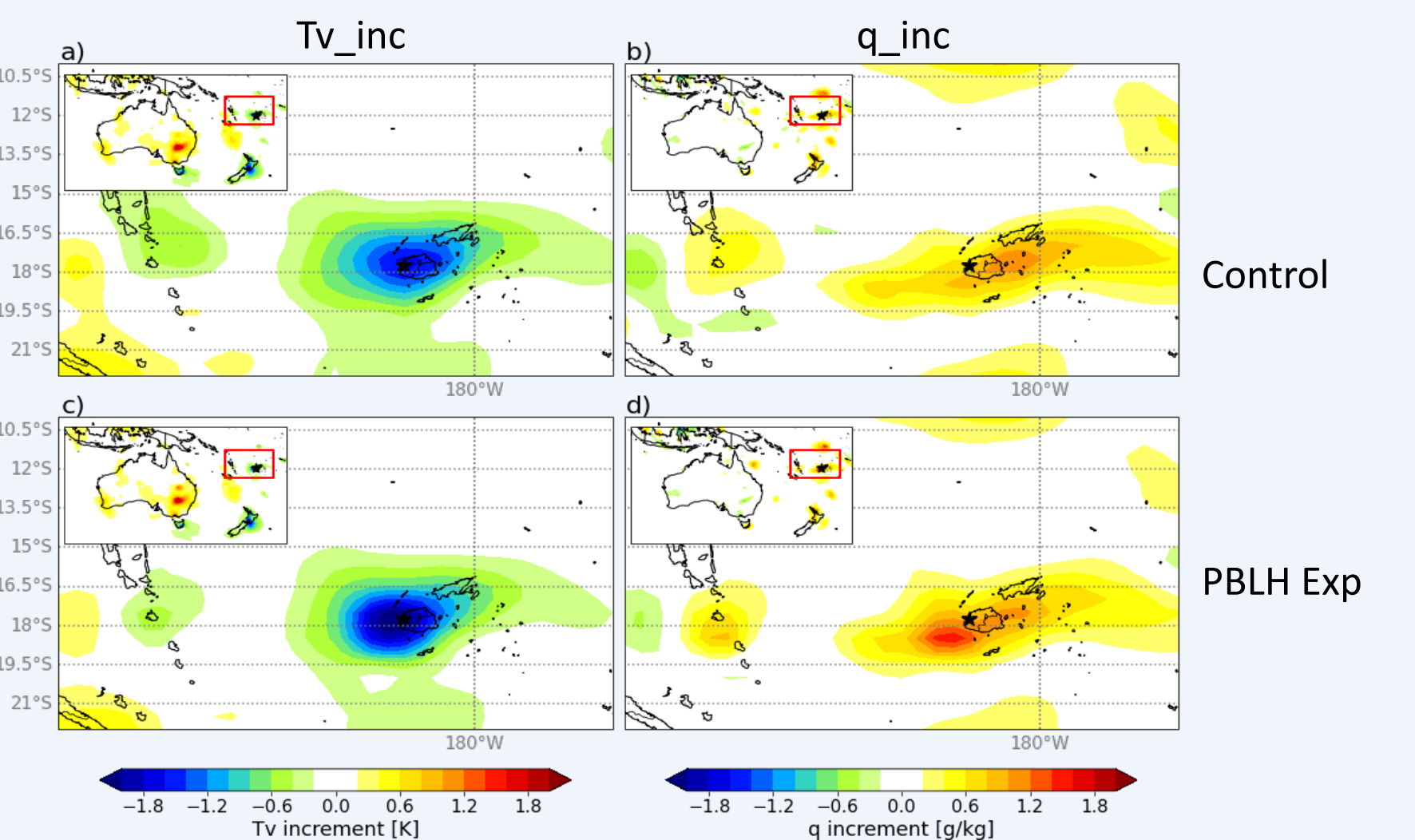
- Improve T/RH background error covariance around PBL top**
 - Model uncertainties: original ensemble spread too small in magnitude and peak at an incorrect level
 - Inflation of T/RH ensemble spread to ensure they are characterized by large ensemble spread around inversion height
 - Adjustment of vertical localization length scale to impose the decoupling between the errors in the PBL and in the above atmosphere



Assimilation of radiosonde PBLH data improved PBLH analysis (blue dashed). Inflation of ensemble spread and adjustment of vertical localization length scale (cyan and purple lines) help to capture the capping inversion. The larger the inflation, the better the representation of PBL inversion.



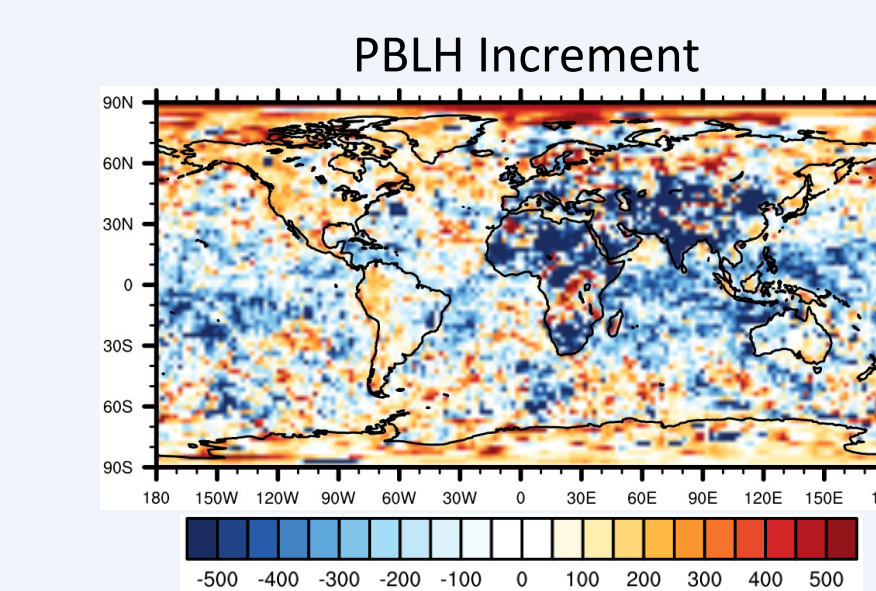
Original ensemble spread (dotted blue line) is too small in magnitude and the location of peak is too low. Ensemble spread is inflated around observed PBL top (solid blue line).



Compared with the control run, the increments become larger in magnitude and the q increment maximum location is shifted to west.

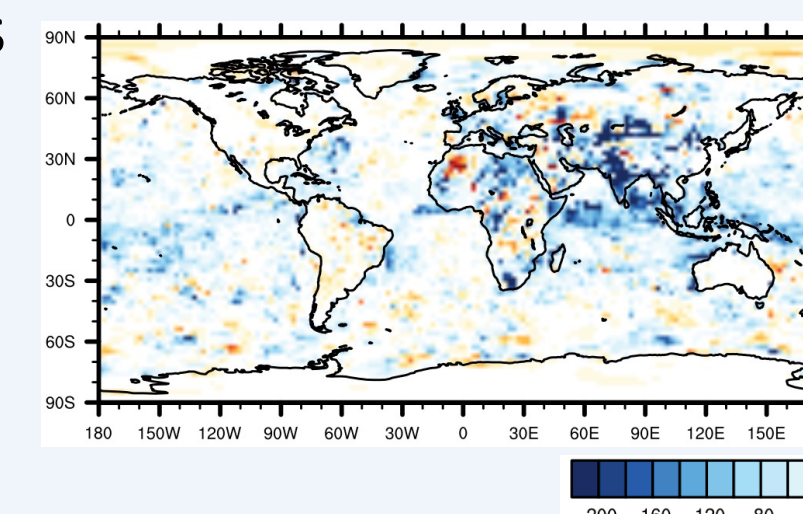
Reducing model PBL error with adaptive parameter adjustment

- TURB parameters TPFAC and BETA_SURF adjusted proportional to PBLH increment, up to +/-50% default
- Nudge model PBL depth into agreement with analysis
- Reduce model compensation of analysis tendencies

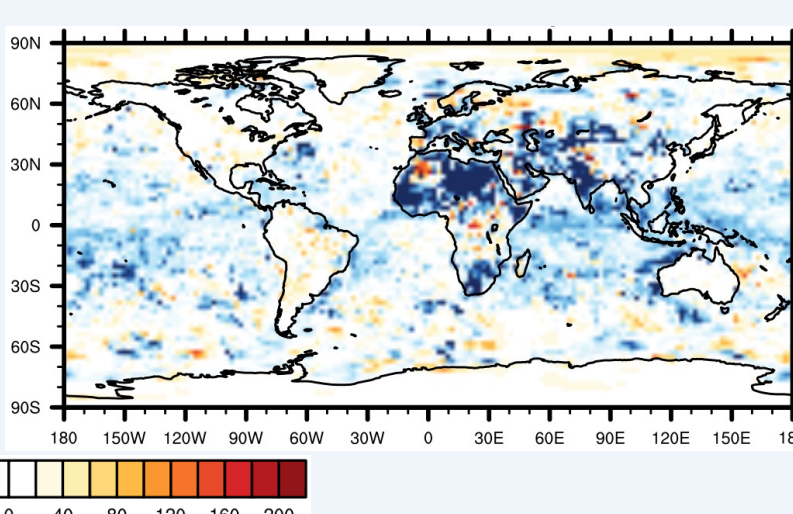


Model PBLH Corrector-predictor

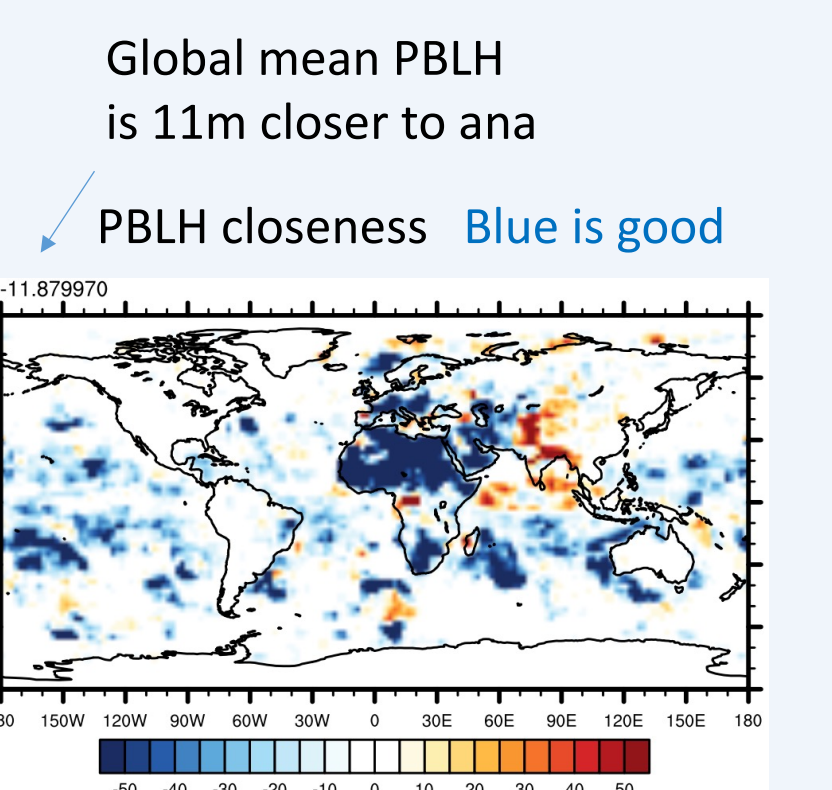
Model PBLH w/param adjust Corrector-predictor



This is the 'default' change in model PBLH due to the T/Q/U/V analysis tendencies.



Parameter adjustment using analysis PBLH results in a larger model PBLH change.



Global mean PBLH is 11m closer to ana

PBLH closeness Blue is good

The larger adjustment brings model PBLH closer to the analysis.

Ongoing and future work

- Continue to develop and validate model lidar- and radar-based PBLH definitions
- Optimize inflation coefficient of ensemble spread and vertical localization length scale and investigate PBLH data impact on PBL thermodynamic structure
- Further investigate model parameter adaptation in cycled runs for better retaining observation information in model forecast

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