An update on the 4D-LETKF data assimilation system for the whole neutral atmosphere

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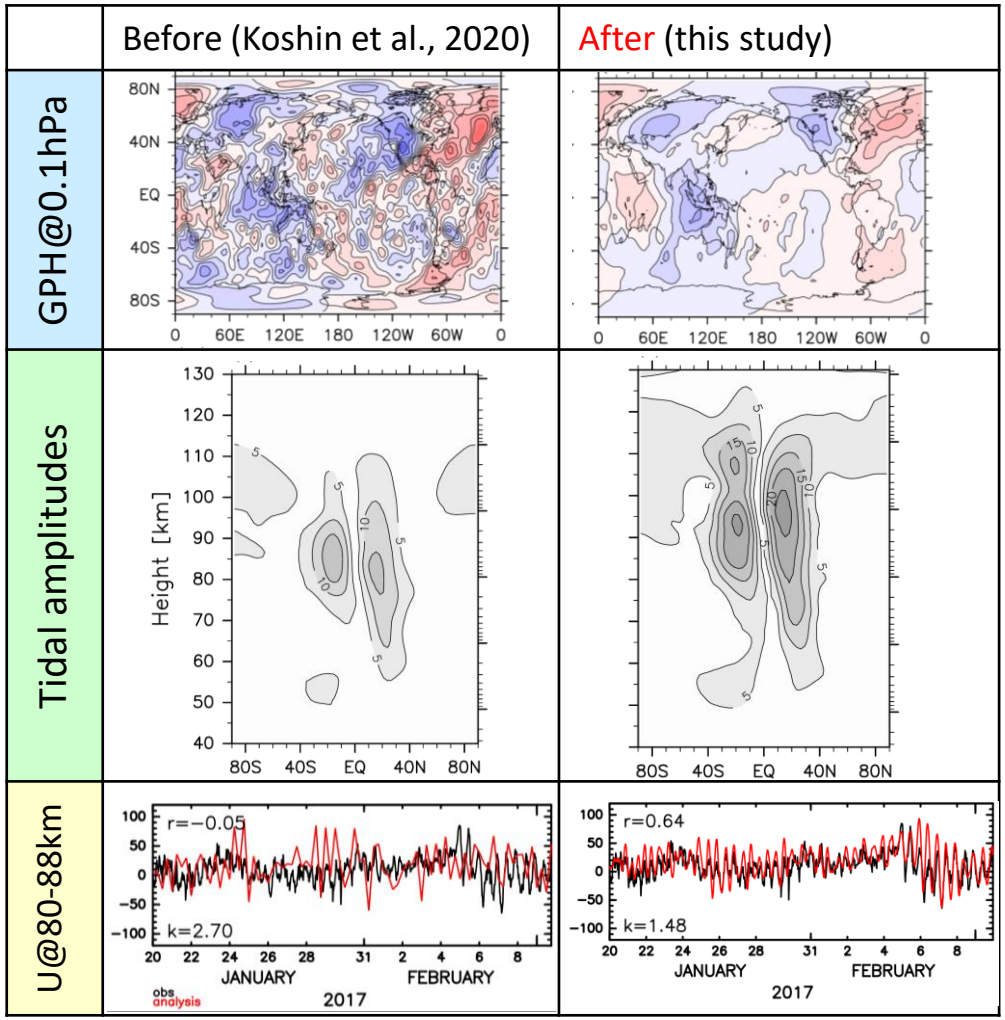
Dai. Koshin, Kaoru. Sato, Masashi. Kohma (UTokyo), and Shingo. Watanabe (JAMSTEC)

The 4-D ensemble Kalman filter data assimilation system for the whole neutral atmosphere (Koshin et al., 2020) is updated to better represent disturbances with wave periods shorter than 1 day in the mesosphere and lower thermosphere region. The improved points are:

1. The **incremental analysis update** (IAU) **filtering** is introduced to reduce the generation of **spurious waves** arising from the assimilation increments.
2. The **horizontal diffusion** in the forecast model is modified to reproduce more **realistic tidal amplitudes.**
3. The TIMED **SABER** and DMSP **SSMIS** observations in the stratosphere and mesosphere **are also assimilated**.

As a result, assimilation products are greatly improved not only for the zonal mean field and Rossby waves but also for tides.

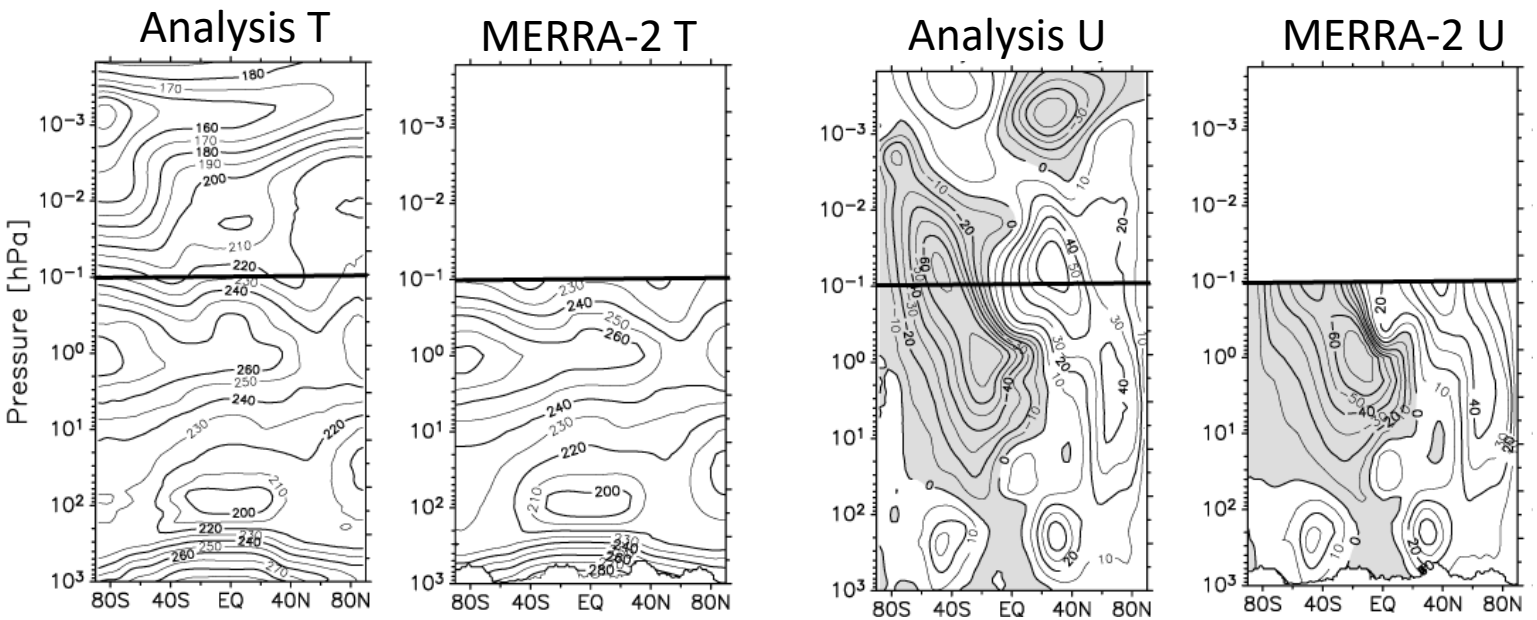


Koshin, D., Sato, K., Kohma, M., and Watanabe, S.: An update on the 4D-LETKF data assimilation system for the whole neutral atmosphere, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2020-381, in review, 2021.

1. Introduction

Global analysis data including the mesosphere and lower thermosphere (MLT) region, are currently made by only a few projects (NAVGEM-HA, WACCM-DART). Most reanalysis products cover the pressure levels up to 0.1 hPa.

Koshin et al. (2020) developed a data assimilation system (JAGUAR-DAS) with a 4D Local Ensemble Transform Kalman Filter (4D-LETKF) using the forecast model called JAGUAR. The first version of JAGUAR-DAS assimilated satellite temperature data from the Aura MLS.



(Koshin et al., 2020; averaged for 21-25 Jan. 2017)

In this study, we update the JAGUAR-DAS, particularly to better reproduce diurnal and semi-diurnal atmospheric tides.

2. Methodology

Forecast Model: Japanese Atmospheric GCM for Upper Atmosphere Research (JAGUAR) Watanabe and Miyahara (2009)	
Model top	≈150km
Resolutions	Horizontal: T42 (Δx=Δy≈300km) Vertical: L124 (Δz≈1km)
Radiation process for MLT region	Non-LTE and O_2/O_3 heating
GW parameterizations	Orographic: McFarlane (1987) Non-orographic: Hines (1997) (with GW source from Watanabe, 2008)

Observation	PrepBUFR	Aura MLS	TIMED SABER	DMSP SSMIS
Height range	≈0-30km (1000-1hPa)	≈10-100km (261-0.001hPa)	≈15-110km (100-0.0001hPa)	≈30-80km (10-0.01hPa)
Variables	T, U, V, RH, and Ps	T (retrieval)	T (retrieval)	Brightness T
Remarks	Conventional dataset	Sun-synchronous orbit	Non-sun-synchronous orbit	Dense horizontal distribution

Data assimilation: 4D LETKF (Miyoshi and Yamane, 2007)	
Number of ensembles	30
Target period	January to February, 2017 (First 10 days for spin-up)

3. Impacts of improvements

To examine the impacts of each improvement in the assimilation system, several assimilation experiments for the whole neutral atmosphere are performed.

Experiment	IAU	Diffusion	SABER	SSMIS	
Ctrl (Koshin et al., 2020)		Fourth order			
Expt. I	**x**	Fourth order			→ Result 3.1
Expt. II	x	**Eighth order**			→ Result 3.2
Expt. III	x	Eighth order	**x**		→ Result 3.3
Expt. IV (Final updated ver.)	x	Eighth order	x	**x**	

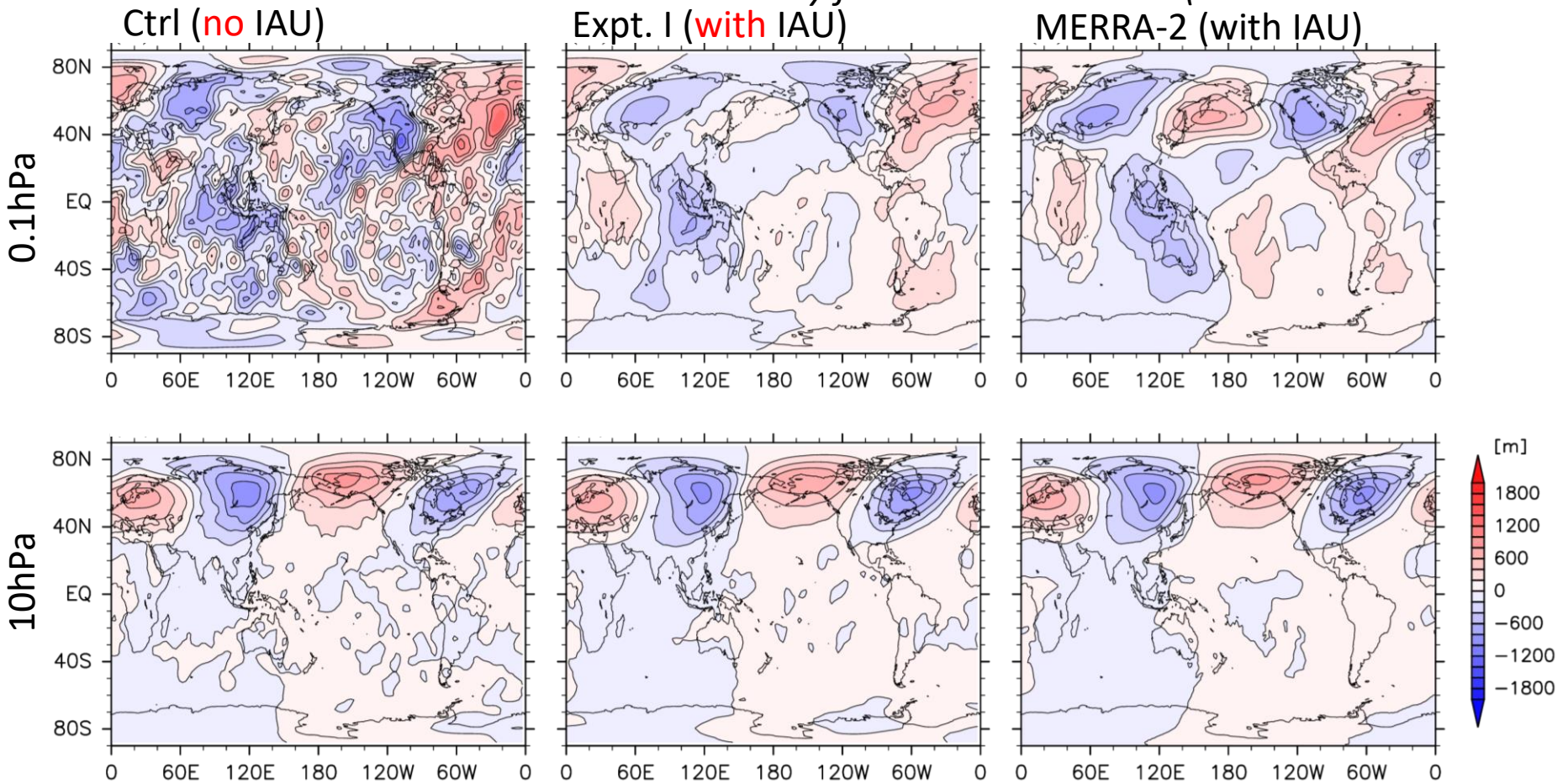
3.1 Introducing IAU

Analysis products by Koshin et al. (2020)

- Disturbances with scales of about 1000 km are conspicuous in the original analysis.
- The small-scale disturbances have larger amplitudes at higher altitudes.

→ These spurious disturbances are significantly reduced through the **IAU** and the resultant analysis product is consistent to the MERRA-2 reanalysis.

GPH anomaly from the zonal mean (00UTC on 20 Jan. 2017)

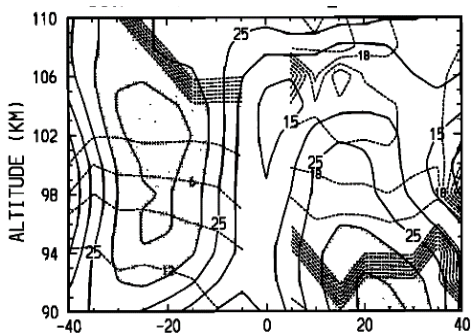


3.2 Tuning of the horizontal diffusion in the GCM

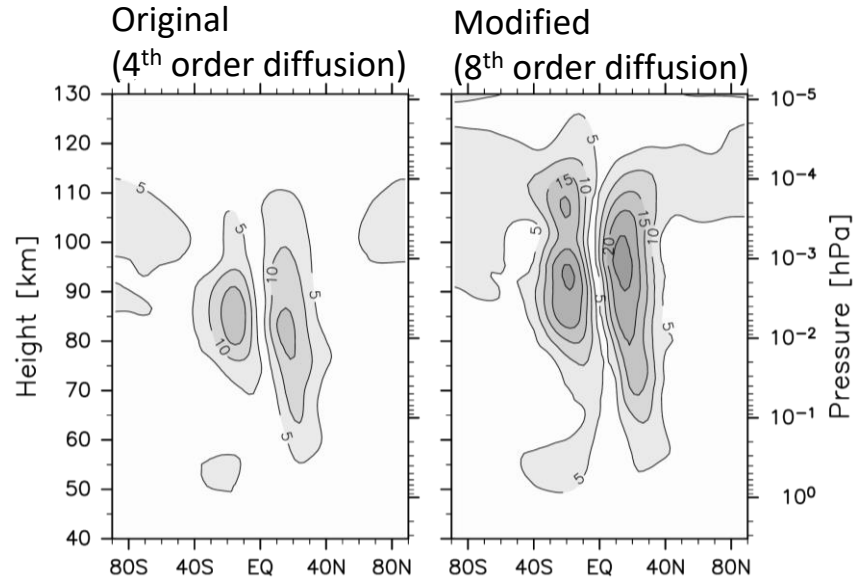
Analysis produced by Koshin et al. (2020)

- The analysis shows good agreement with the radar observations for fluctuations with periods longer than several days. However, there are some discrepancies in amplitudes and phases for fluctuations with periods shorter than one day.
- The **tidal amplitudes** in free run by the forecast model are **smaller** than that of the observation.

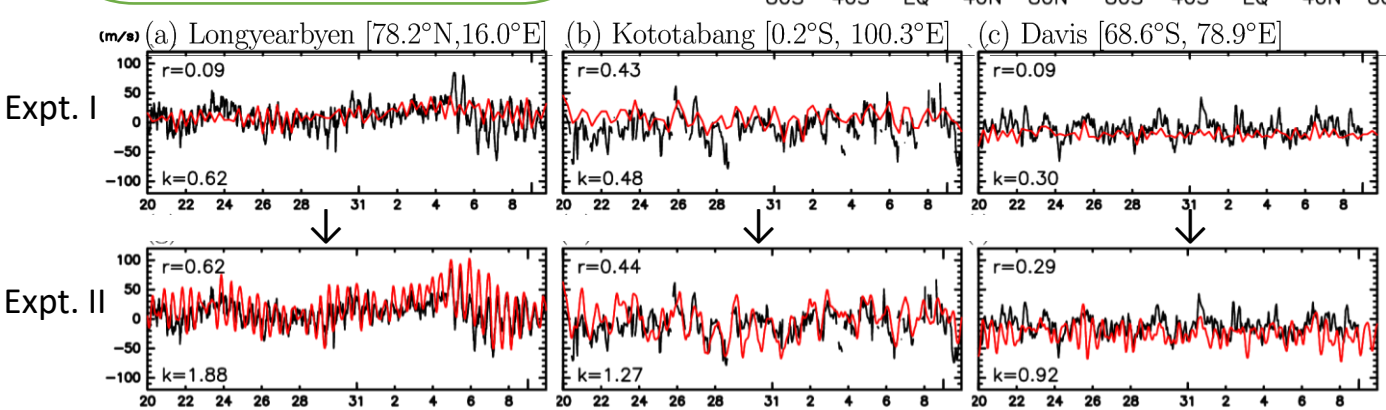
→ To obtain realistic tidal amplitudes, a horizontal hyper diffusion of the 8th order was introduced so that larger-scale fluctuations were not diffused.



The amplitude of the DW1 from the WINDII observations (McLandress et al., 1996)



Amplitudes of the DW1 from the free-run by JAGUAR (15 Jan.-20 Feb. 2017)

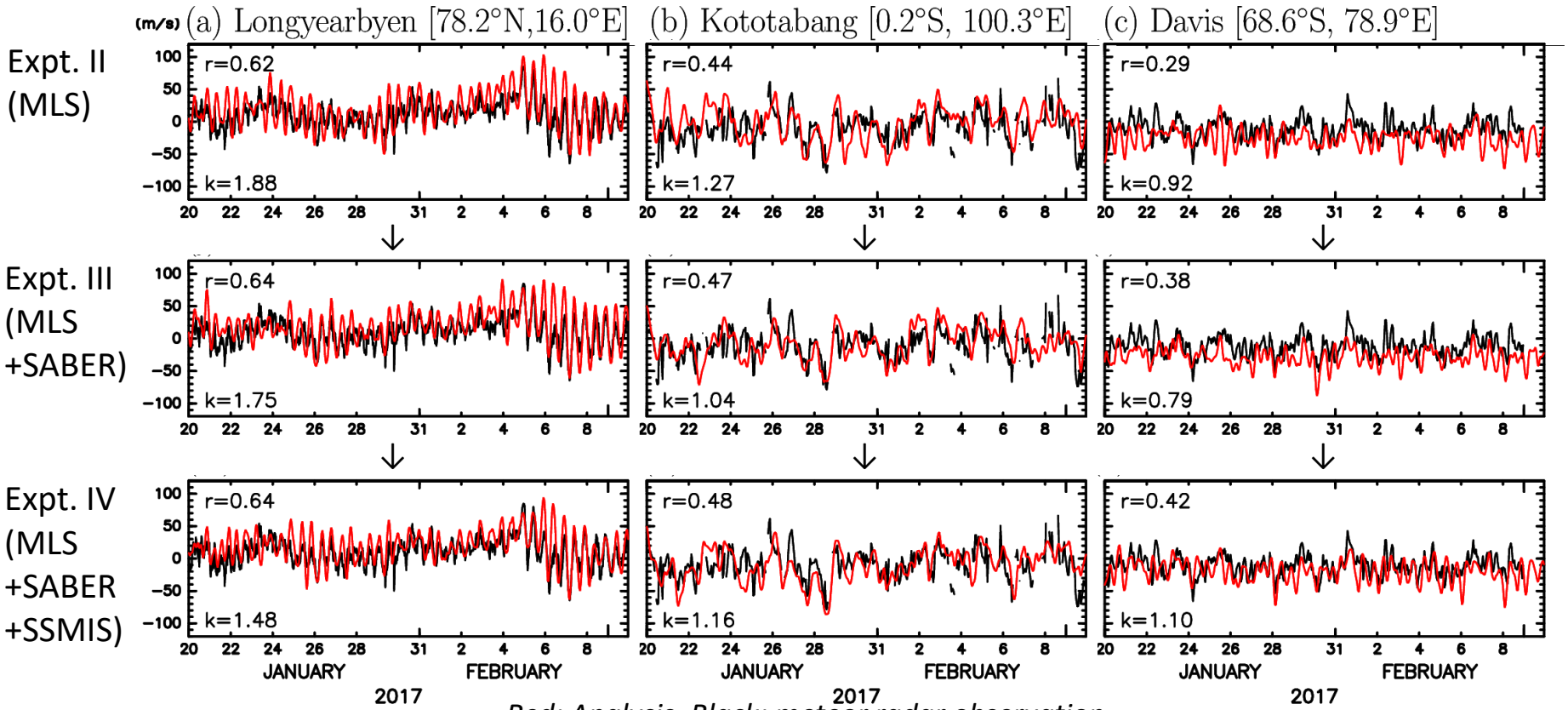


Time series of U (z=80-88km)

The Expt. II analysis (red) show similar time variations to the radar observations (black), particularly for the periods shorter than one day.

3.3 Assimilating SABER and SSMIS observations

Time series of U (z=80-88km)



Red: Analysis, Black: meteor radar observation

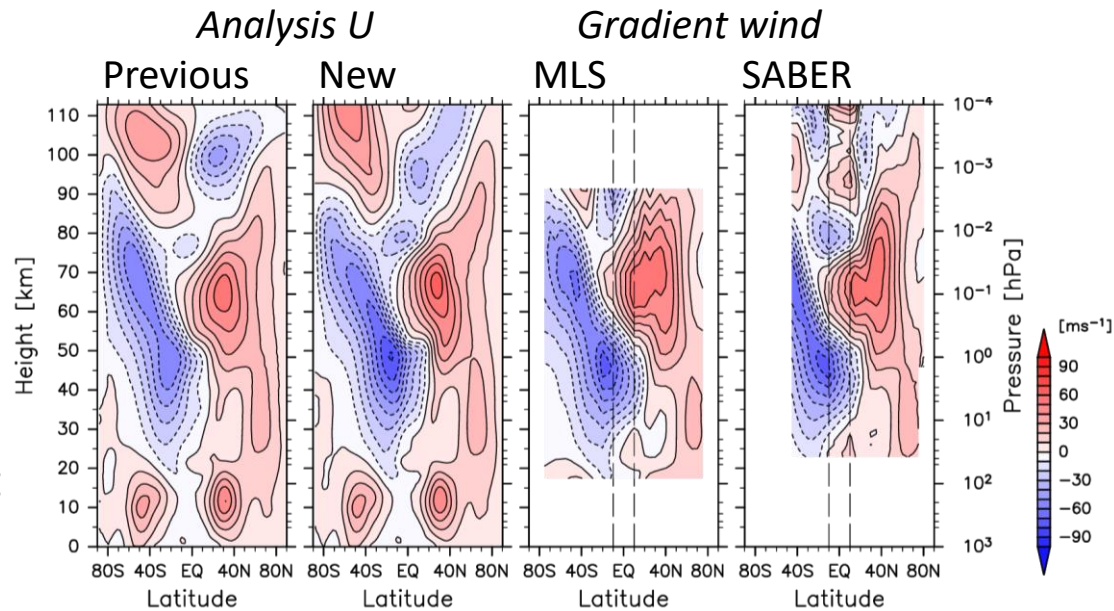
r: correlation coefficient, k: ratio of the variance between the analysis and observation

- The assimilation of the additional observations (i.e., SABER & SSMIS) **increases the correlation coefficients** at all stations.
- The wave **amplitudes** of the wind products in the upper mesosphere are also **closer to radar observations**.

↑ **The** constraint by observations at different **local times is crucial for reproducing realistic variation of tides**.

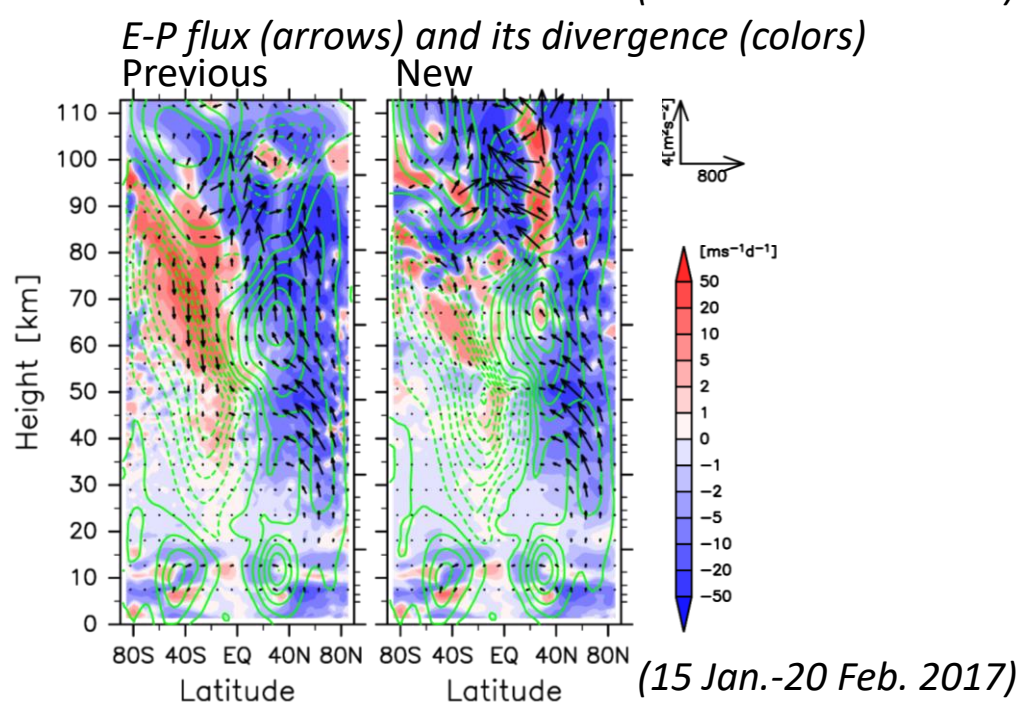
3.4 Comparison to the Koshin et al. (2020)'s analysis

- In the new analysis (final updated ver., Expt. IV), the easterly jet in the summer upper stratosphere and mesosphere is strong and its core shifts equatorward.
  → This is **close to the gradient wind estimated from the SABER**.



(15 Jan.-20 Feb. 2017)

- The zonal mean **zonal wind is similar for old and new analyses,** although the wave forcing properties have been largely **modified**.
  → The wave forcing represented by the assimilation increment has been expressed by the forecast model itself.



(15 Jan.-20 Feb. 2017)

4. Summary

The **data assimilation system** for the height region from the surface to the lower thermosphere developed by Koshin et al. (2020) **was updated to better represent atmospheric tides with wave periods shorter than one day,** which have large amplitudes and can induce significant wave forcing in the MLT region.

1. The **IAU filtering** was introduced. This could efficiently **reduce spurious waves** with small horizontal scales of about 1000 km in the MLT region.
2. **A horizontal hyper diffusion of the eighth order** was introduced. This allows realistic tidal wave amplitudes in the MLT region.
3. The **SABER** temperature retrieval and **SSMIS** brightness temperature retrieval were also assimilated. Assimilation of data at different local times is crucial for better product of atmospheric tides.

✓ The wave amplitudes of the winds in the upper mesosphere became closer to those from the radar observations.

✓ We plan to carry out a **long-period analysis** using the updated assimilation system, over ~16 years from the start of the Aura MLS observations to the present.