18-21 Nov. 2019. Workshop: Stratospheric predictability and impact on the troposphere, ECMWF, Reading

Evaluation of revised gravity wave parametrizations using statistics of first-guess departures

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Introduction

✓ Background:

- The effects of unresolved gravity waves which play a crucial role for accurate numerical weather prediction (NWP) are parametrized as subgrid-scale orography (SSO) parametrization and non-orographic gravity waves (NGW) parametrization in global models.
- These parametrizations are known for large uncertainties due to lack of direct observations of momentum flux. However, it is still possible to indirectly evaluate these parametrizations using a massive volume of various kinds of observation which is available through data assimilation in an NWP system.

✓ What we did:

- The performance of the new SSO and revised NGW parametrizations in the Japan Meteorological Agency Global Spectral Model (JMA GSM; JMA 2019) is individually examined in terms of the statistics of fit between first guess (FG) and observation processed in data assimilation.

Overview of Parametrizations and Evaluations

☐ Parametrizations ◆ Evaluations using statistics of FG departure (Pros/Cons)

1. Non-orographic Gravity Waves (NGW)

☐ In order to improve the representation of the quasi-biennial oscillation (QBO), a latitudinal dependent function F is introduced into the source momentum flux in an NGW scheme (Scinocca 2003) and vertical diffusion coefficient is damped with a cubic function of pressure above the diagnosed tropopause in stable conditions in a turbulent diffusion scheme, and F is given by

$$F(lat) = 1-(1-A)\exp\left(-\left(\frac{lat}{2w}\right)^2\right)$$

where A and w are tunable parameters (ECMWF 2014; $A = 0.55, w = 10$ [deg]; hereafter LATD+VDAMP).

◆ Compared to old parametrization (i.e. uniform source momentum flux; hereafter UNIFORM), LATD+VDAMP significantly decreases the standard deviation of FG departures (observation minus first guess (3h-9h forecasts)) in the tropical stratosphere, especially for microwave sounders, GNSS radio occultation and radiosonde, which indicates positive impacts also on short-range forecasts in data assimilation.

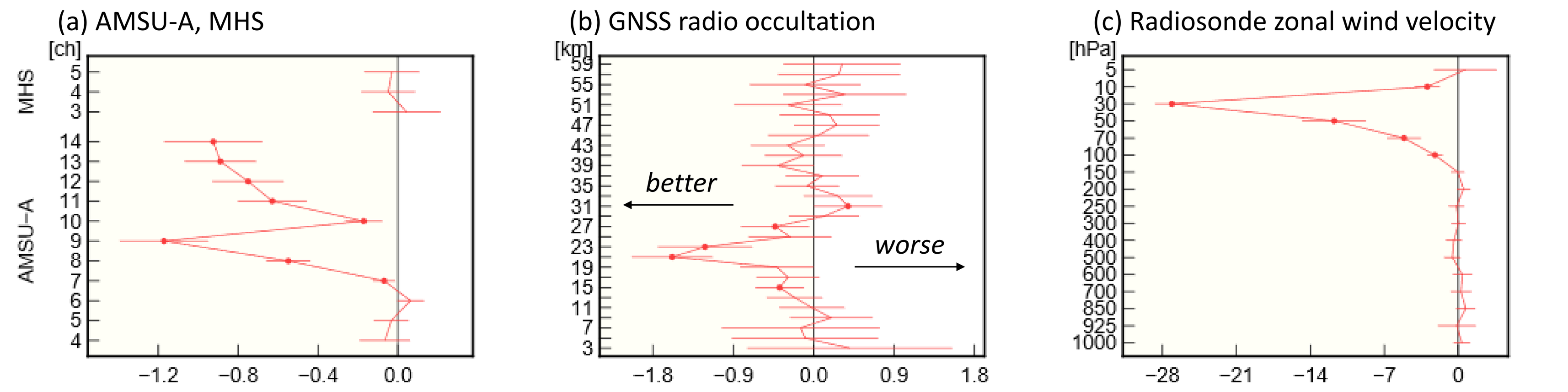


Figure. Normalized changes [%] in standard deviation of the FG departures in the tropics (20˚N-20˚S) for (a) microwave temperature sounders, humidity sounders (AMSU-A, MHS), (b) GNSS radio occultation, (c) radiosonde zonal wind velocity. The period is from Jul. 21 to Sep. 11 2017. Error bars and dots indicate 95% confidence interval and statistically significant change, respectively. Negative values show improvement.

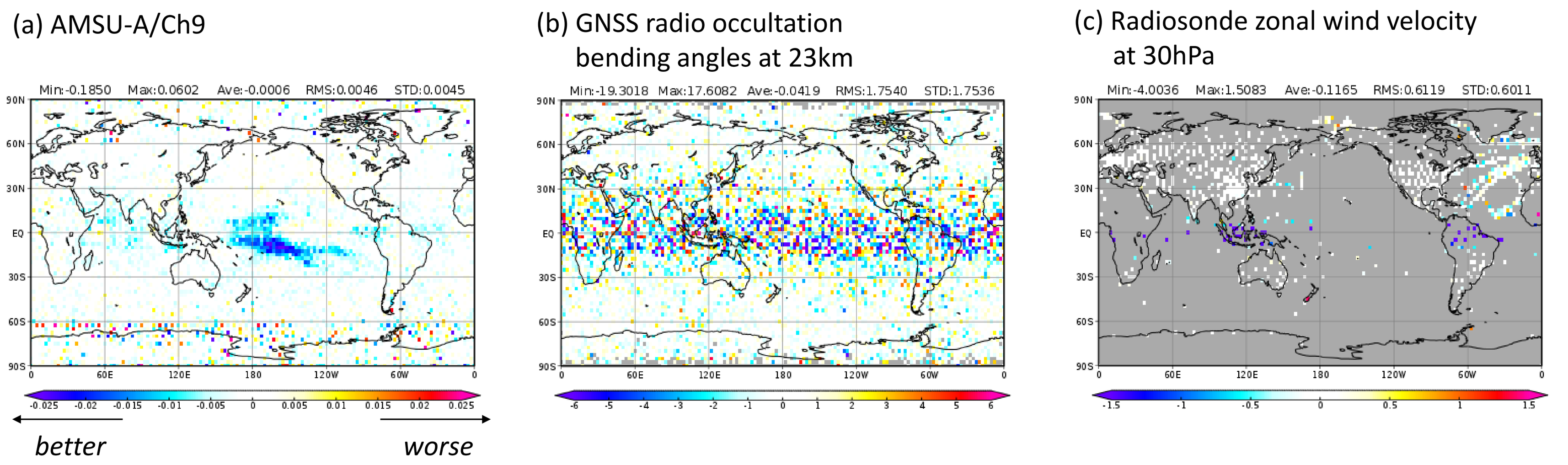


Figure. Differences in root mean square FG departures between LATD+VDAMP and UNIFORM for (a) AMSU-A/Ch9 [K], (b) GNSS radio occultation bending angles at a height of 23km [μrad], (c) radiosonde zonal wind velocity at 30hPa [m/s]. The period is from Jul. 21 to Sep. 11 2017.

2. Subgrid-Scale Orography (SSO)

☐ A new set of parametrizations (hereafter LMTOFD) representing sub-grid scale orographic drag including the effects of low-level flow blocking and orographic gravity wave drag (OGWD) by Lott and Miller (1997), and the turbulent orographic form drag by Beljaars et al. (2004) is implemented.

☐ The performance of this set of parametrizations is compared with the OGWD scheme by Iwasaki et al. (1989) (hereafter IW), which is currently used in the GSM and incorporates two different types of gravity wave drag affecting on upper troposphere to lower stratosphere, and surface to lower troposphere. Note that no parametrization scheme accounting for the form drag is used in IW runs with OGWD scheme.

◆ LMTOFD runs remarkably improve medium-range forecasts skills in the NH winter in the troposphere, and the improvement especially manifests itself in mitigation of the positive geopotential height bias around the East Asia, which has been one of the major issues to be addressed in the GSM for a long time. This positive impact can also be seen clearly in the standard deviations of FG departures, for instance for radiosonde zonal wind velocity.

◆ However, in the stratosphere the deterioration of the root mean square FG departures for microwave sounding channels and radiosonde spreads out over the downstream of the steep orography (e.g. Himalayas, Southern Andes and Antarctic Peninsula) in the winter hemisphere.

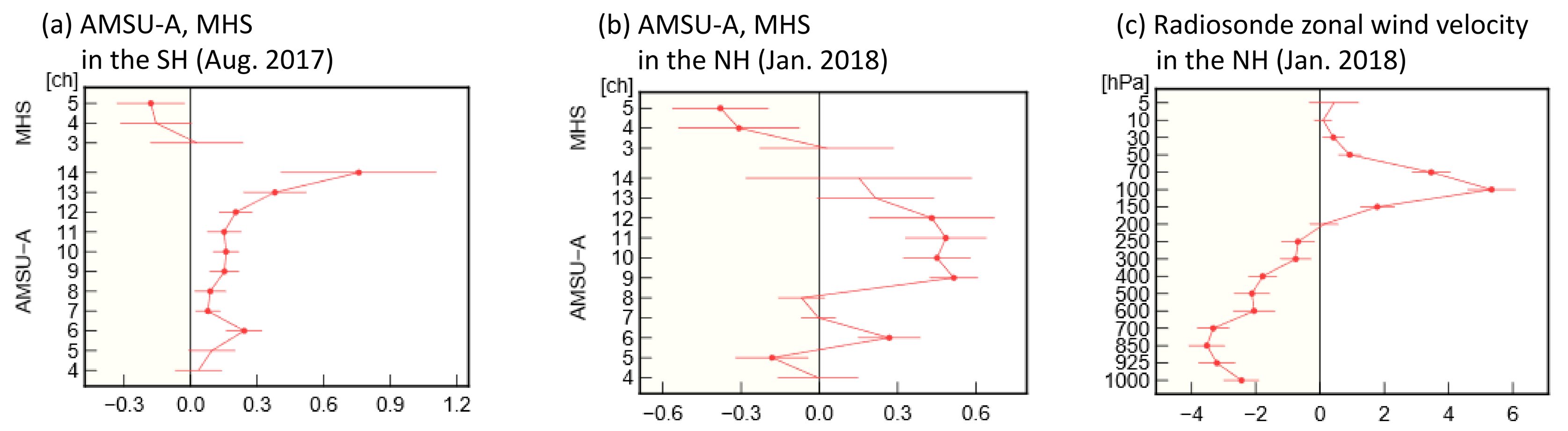


Figure. Normalized changes [%] in standard deviation of the FG departures for (a) microwave temperature sounders, humidity sounders (AMSU-A, MHS) in the Southern Hemisphere (90˚S-20˚S) from Jul. 21 to Sep. 11 2017, (b) AMSU-A, MHS in the Northern Hemisphere (20˚N-90˚N) from Dec. 21 2017 to Feb. 11 2018, (c) radiosonde zonal wind velocity in the Northern Hemisphere from Dec. 21 2017 to Feb. 11 2018. Error bars and dots indicate 95% confidence interval and statistically significant change, respectively. Negative values show improvement.

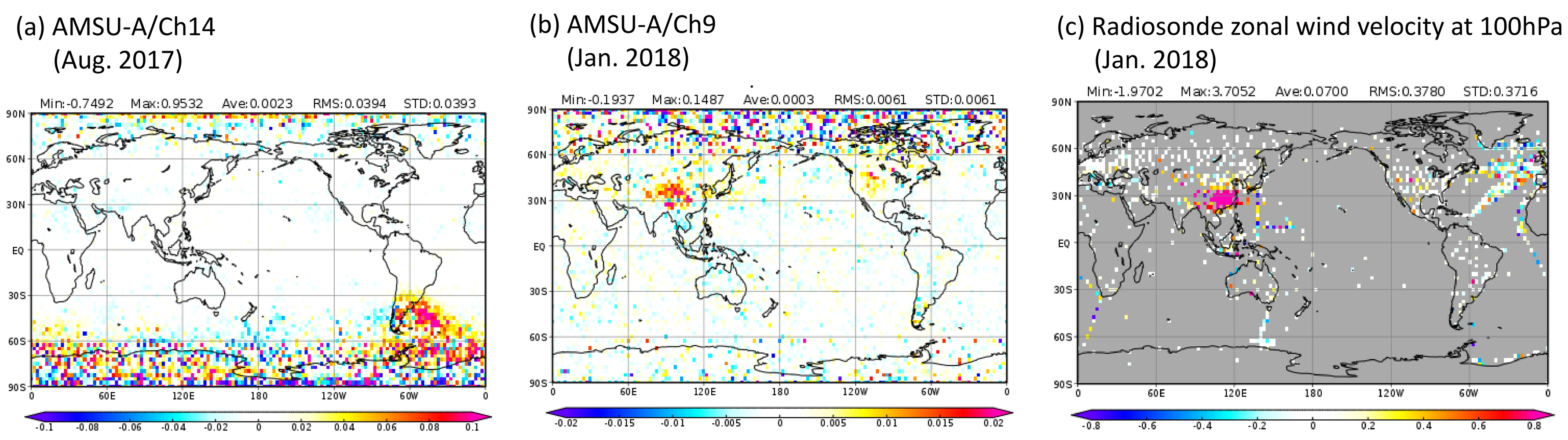


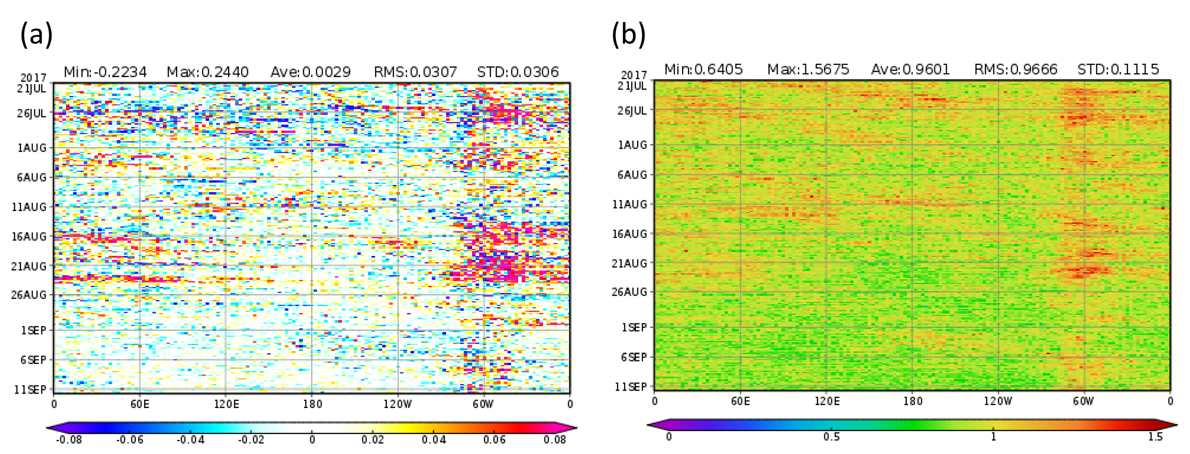
Figure. Differences in root mean square FG departures between LMTOFD and IW for (a) AMSU-A/Ch14 [K] from Jul. 21 to Sep. 11 2017, (b) AMSU-A/Ch9 [K] from Dec. 21 2017 to Feb. 11 2018, (c) radiosonde zonal wind velocity at 100hPa [m/s] from Dec. 21 2017 to Feb. 11 2018.

✓ Further investigation toward improvement of FG departures in the stratosphere

◆ The worse fit of FG with observations in LMTOFD described above occurs intermittently along with generation of large orographic gravity wave momentum flux (not shown), and IW also indicates relatively large root mean square FG departures in the upper stratosphere around the Southern Andes.

◆ The mean FG departures for AMSU-A/Ch14 shows overall negative departures over the Southern Andes in IW, and these departures become larger in LMTOFD.

- The additional experiment with the new OGWD but configured to show similar profiles of parametrized gravity wave flux resulting in weaker orographic gravity wave drag to IW leads to better fit with observations in the stratosphere than LMTOFD; however, it results in counteraction of the improvement of medium-range forecasts in the mid-latitude troposphere (not shown).
- These suggest that further improvements of the gravity wave momentum flux generation and vertical profile of orographic gravity wave breaking are required particularly in the regions with larger FG departures.



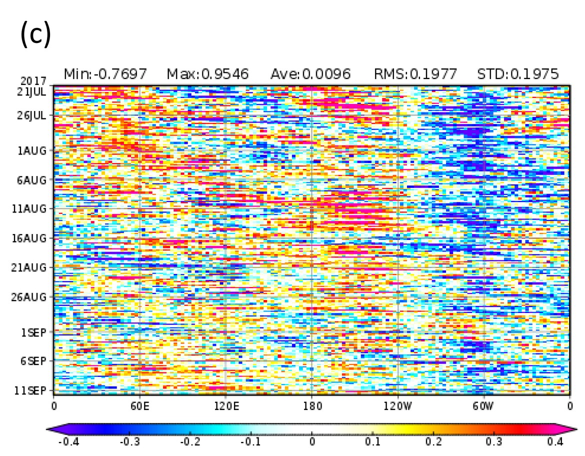


Figure. Hovmöller (x-t) diagrams of the meridional mean of (a) difference in root mean square FG departures for AMSU-A/Ch14 [K] between LMTOFD and IW, (b) root mean square FG departures for AMSU-A/Ch14 [K] in IW, (c) mean FG departures for AMSU-A/Ch14 [K] in IW. The period is from Jul. 21 to Sep. 11 2017.

Future Plans

- Improving stratospheric representation in orographic gravity wave parametrization particularly over the regions, where LMTOFD shows worse fit of the FG departures with observations than IW, through the evaluation using the statistics of FG departures
- Evaluating gravity wave parametrizations using direct/indirect observations and partitioning into orographic and non-orographic gravity wave drag, blocked flow drag, and turbulent orographic form drag parametrizations

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