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An ensemble Kalman filter data assimilation system for the whole neutral atmosphere

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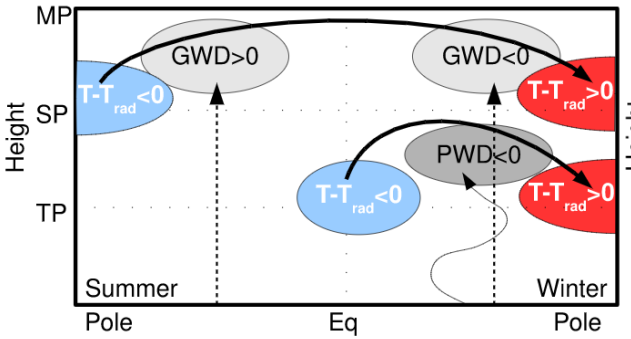
Koshin, D., Sato, K., Miyazaki, K., and Watanabe, S.: An ensemble Kalman filter data assimilation system for the whole neutral atmosphere, Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2019-252, under second review.

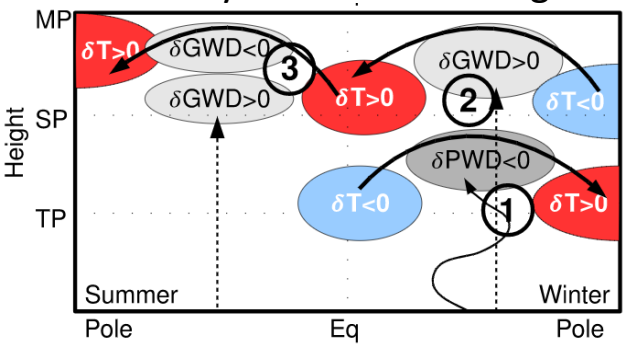
Introduction

Recent studies suggest the presence of an interhemispheric coupling.

Climatological Lagrangian circulation



Anomaly circulation during SSW



The relationship between the warming in the winter stratosphere and the warming in the summer mesosphere. (Körnich and Becker, 2010)

- A key may be a **modulation of gravity wave (GW) propagation** on a global scale.

→ However, there are few **observational evidences** of the modulation including the mesosphere.

- **An interplay of Rossby waves and GW** is important in the mesosphere (Sato and Nomoto 2015, Sato et al., 2018). → **High resolution grid data** for the whole neutral atmosphere is required.

Data assimilation studies for the mesosphere and lower thermosphere (MLT) region are made by a few research centers but the data are generally not open to the public.

CMAM	Polavarapu et al. (2005)	3D-Var	T47: 7×10^{-4} hPa	:10^{-3} hPa
NAVGEM	Hoppel et al. (2013)	4D-Var (hybrid)	L74: 6×10^{-5} hPa	:95 km
WACCMX-DART	Pedatella et al. (2018)	EAKF	L126: 4.1×10^{-10} hPa	:10^{-4} hPa

We developed a **new data assimilation system using the 4D-LETKF for the atmosphere up to the MLT region**.

Methodology

Forecast model: Japanese Atmospheric GCM for Upper Atmosphere Research (Watanabe and Miyahara, 2009)	
Model top	≈150km
Horizontal truncation wavenumber	T42 (≈300km resolution)
Number of vertical levels	124 (Δz≈1km)
Radiation process for the MLT region	Non-LTE and O_2/O_3 heating
GW parameterization	Orographic: McFarlane (1987) Non-Orographic: Hines (1997) (the wave source was given following Watanabe, 2008)

Observation:	**PREPBUFR**	**Aura MLS (Liversey et al., 2017)**
Variable	T, u, v, RH, and Ps	T (retrieval version 4.2)
Method	radiosondes, wind profilers, etc.	Limb observations from radiation of 118-GHz O_2 and 234-GHz $O^{18}O$
Height range	From the ground to the lower stratosphere (≈30km)	≈10–100km (261–0.001hPa; 42 vertical levels)
Horizontal distribution	Denser in the northern hemisphere, and sparser in the southern hemisphere	14 polar orbits per day

Data assimilation: 4D-LETKF (4 Dimensional Local Ensemble Transform Kalman Filter; Miyoshi and Yamane, 2007)

- ✓ High parallel calculation is possible by localization.
- ✓ Model independent → Applicated to many kinds of dynamical models (e.g. AFES, GSM, NICSM, SPEEDY, WRF)

Examined time period: January–February, 2017

- ✓ An international observation campaign for the mesosphere was performed from 22 Jan. to 28 Feb. 2017.
- ✓ The SSW onset is 1 February.

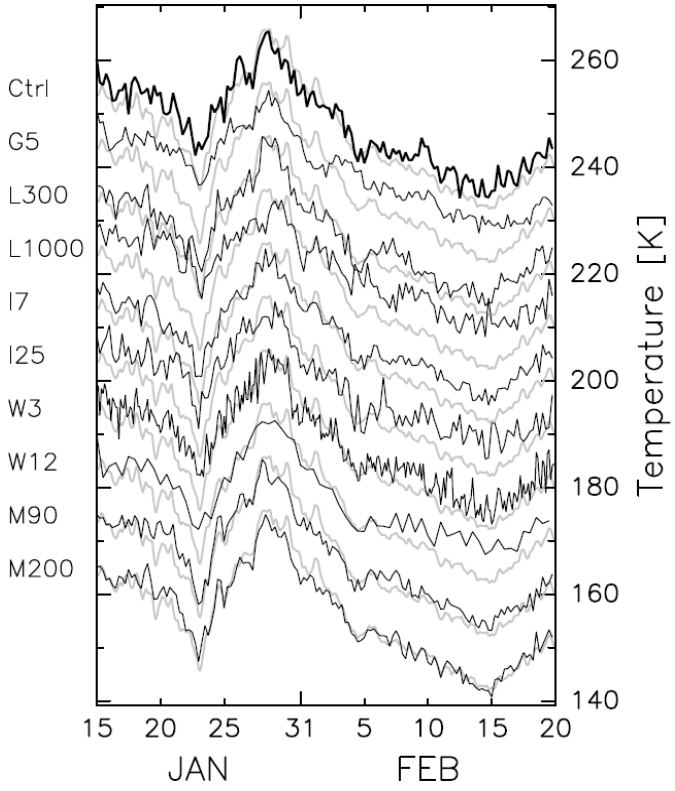
Results

As a result of sensitivity tests, a set of parameters that seems to be **optimal in the MLT** data assimilation is obtained. It is shown as “Ctrl”.

The result of Ctrl setting is comparable to the results with 90 and 200 ensembles.

Parameter settings for sensitivity tests.

	Gross error coefficient	Localization length	Inflation coefficient	Assimilation Window length	# of ensemble member
Ctrl	**20 for MLS (5 for others)**	**600km**	**15%**	**6h**	**30**
G5	**5**	600km	15%	6h	30
L300 L1000	20 for MLS	**300km** **1000km**	15%	6h	30
I7 I25	20 for MLS	600km	**7%** **25%**	6h	30
W3 W12	20 for MLS	600km	15%	**3h** **12h**	30
M90 M200	20 for MLS	600km	15%	6h	**90** **200**



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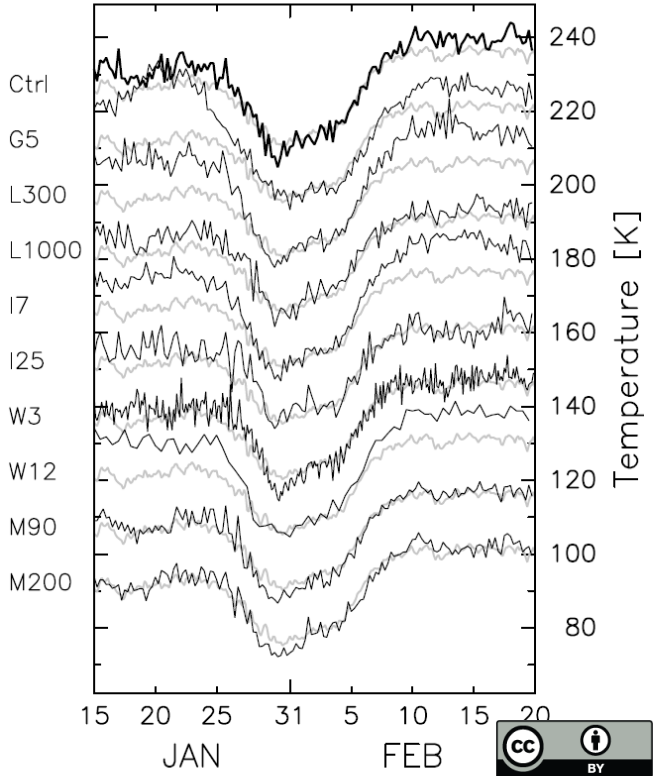
T at **1.0hPa**, 70°N for each parameter setting.
(The right axis is given for the Ctrl, and other curves are vertically shifted by 10 K.)

→ → → → → → → → → → →

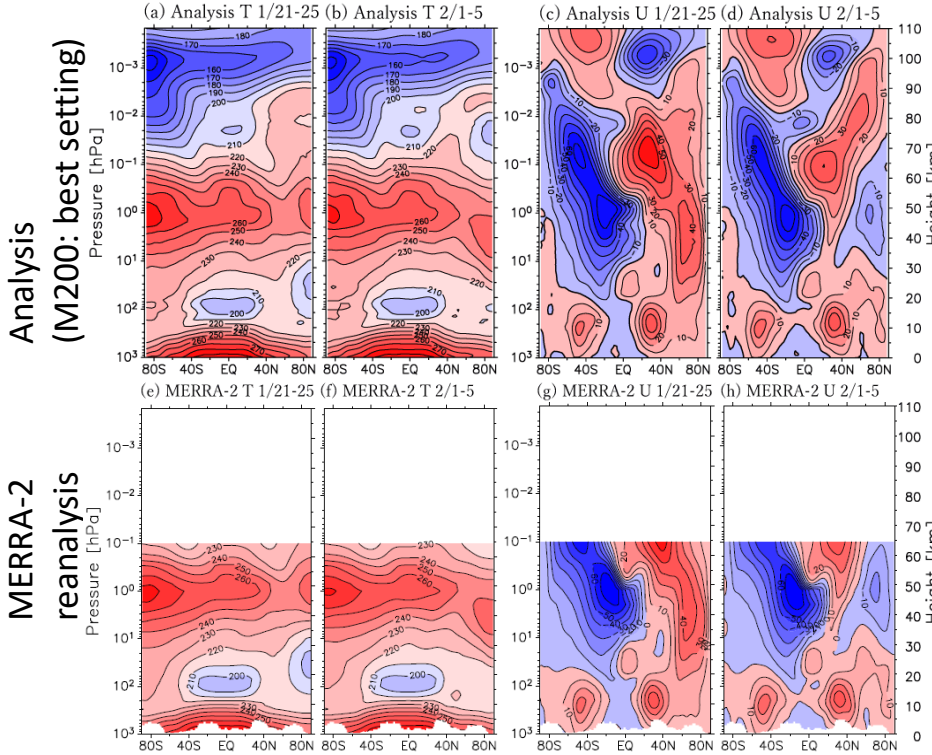
T at **0.1hPa**, 70°N for each parameter setting.
(The right axis is given for the Ctrl, and other curves are vertically shifted by 15 K.)

Black: analysis, Gray: MERRA-2

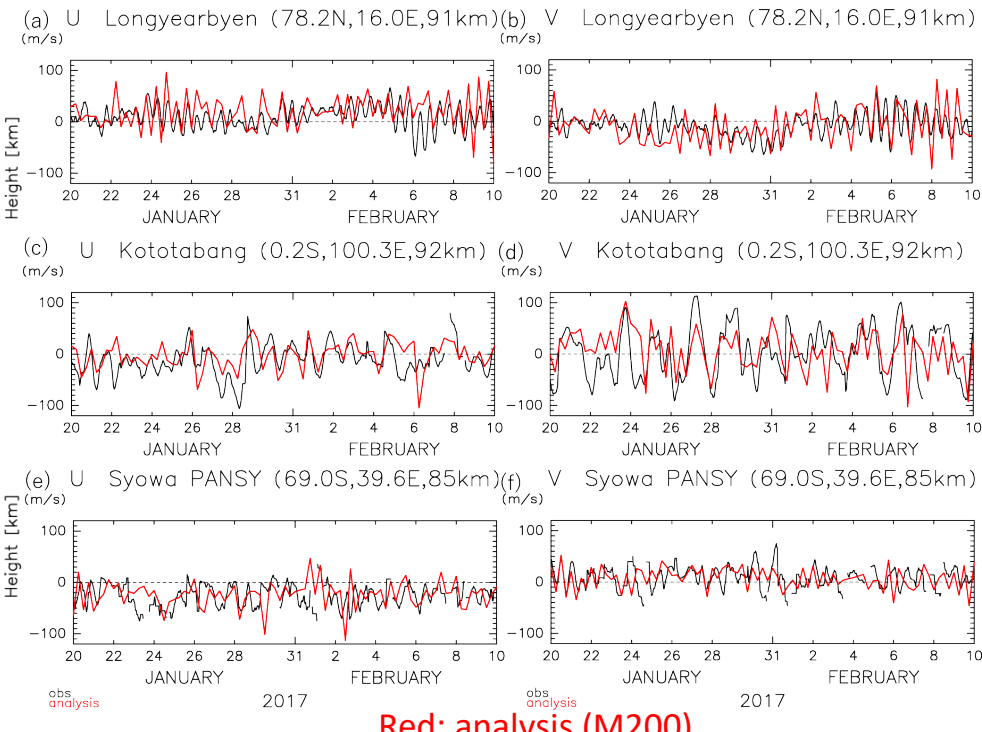


Validation of the assimilation

Comparison with MERRA-2



Comparison with Meteor radar observations



Red: analysis (M200)

Black: observation (6-h running mean)

- The stratopause in the northern polar region before and after the SSW:

  ~50 km → ~40 km (~250 K)

- Zonal wind in the stratosphere in the northern hemisphere:

  ~40 m/s → ~ -20 m/s

- **Fluctuations with a timescale longer than several days** are consistent with radar observations.
- Some discrepancies are observed for **diurnal and semidiurnal characteristics**.

(The reasons are the resolution of model and observation, sun-synchronous MLS orbit, etc.)

Summary

An **ensemble-based data assimilation system for the whole neutral atmosphere** (= from the troposphere to lower thermosphere) has been developed.

- ✓ The tuning parameters of the forecast model were **optimized** before the assimilation. (not shown in this presentation)
- ✓ The **set of parameters for the middle atmosphere** data assimilation system was optimized for 30 ensemble members through the series of sensitivity experiments. In addition, the **minimum optimal number of ensemble members** was estimated based on the result with 200 ensembles.
- ✓ The time series of horizontal winds were consistent with radar observations in the mesosphere for the timescale **longer than several days.**

Plan ongoing

- More observations in the middle atmosphere (e.g. SABER, SSMIS, GNSS, and radar wind observations) will be assimilated to create a better analysis.
- A simulation by a **high-resolution GCM** using the analysis data made by this study as an **initial condition** is proceeding.
  ⇒ To investigate global gravity-wave modulation initiated by the SSW.
- A long-period analysis for the whole neutral atmosphere is being produced, which covers 2005-2020.