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

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Introduction

Recent studies suggest the presence of an interhemispheric coupling. 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.

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.

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

| Parameter                                      | Details                                                                 |
|-----------------------------------------------|-------------------------------------------------------------------------|
| 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 O₂/O₃ heating                                               |
| GW parameterization                           | Orographic: McFarlane (1987)                                            |
|                                               | Non-Orographic: Hines (1997)                                            |
|                                               | (the wave source was given following Watanabe, 2008)                   |

**Observation:**

| 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 O₂ and 234-GHz O¹⁸O        |
| 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 → Applied 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 |
| L7 L25 | 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 |

← ← ← ← ← ← ← ← ← ←

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

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

\[ \sim 50 \text{ km} \rightarrow \sim 40 \text{ km (\sim 250 K)} \]

Zonal wind in the stratosphere in the northern hemisphere:

\[ \sim 40 \text{ m/s} \rightarrow \sim -20 \text{ m/s} \]

- 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.