Assimilation of total ozone using a local ensemble transform Kalman filter

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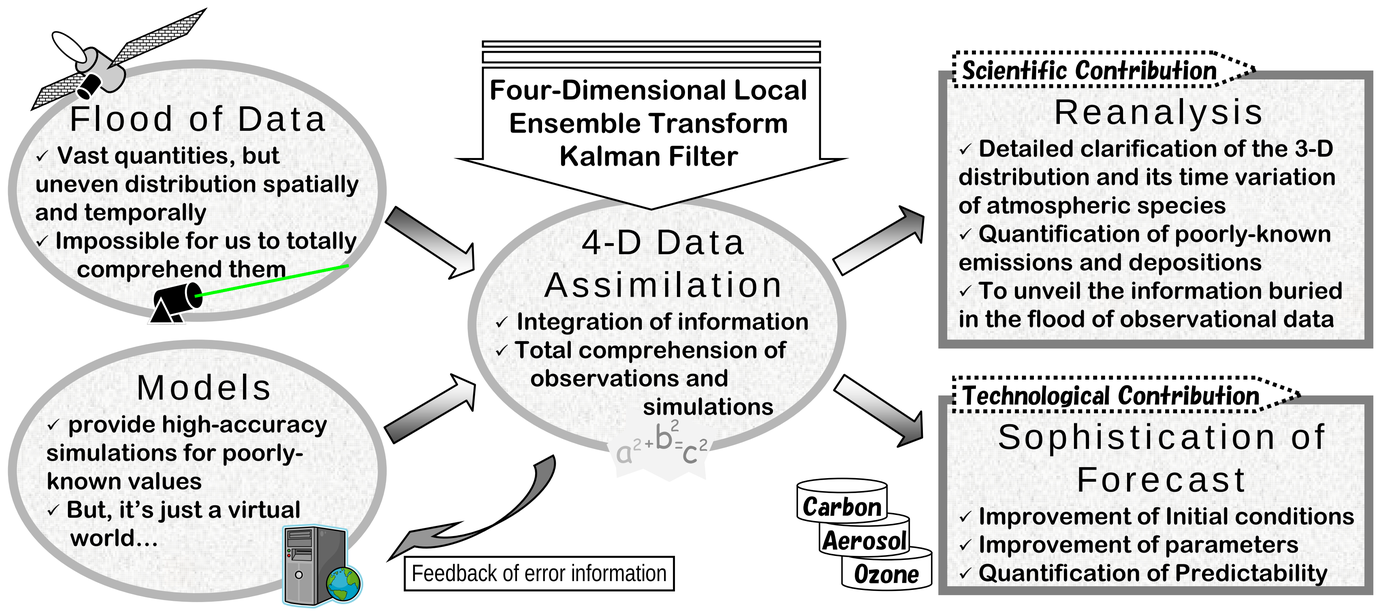
Abstract

A four-dimensional local ensemble transform Kalman filter (4D-LETKF, cf. Miyoshi et al., 2007) is applied to MRI-CTM (Chemistry Transport Model developed by the Meteorological Research Institute of Japan, cf. Sekiyama et al., 2005, Shibata et al., 2005) to assimilate total ozone columns which are observed by satellite instruments – such as TOMS or OMI.

The 4D-LETKF data assimilation system, which is based on the scheme originally developed by the Japan Meteorological Agency (JMA) for routine weather forecasts, (1) provides analysis for the detailed global distribution of stratospheric ozone, and (2) supplies the initial conditions of total ozone distribution to forecast high-accuracy ultraviolet (UV) irradiance at the earth surface.

The assimilation results are compared with ground-based observations including vertical ozone profiles - such as Brewer Umkehr and Ozonesonde observations operated by JMA.

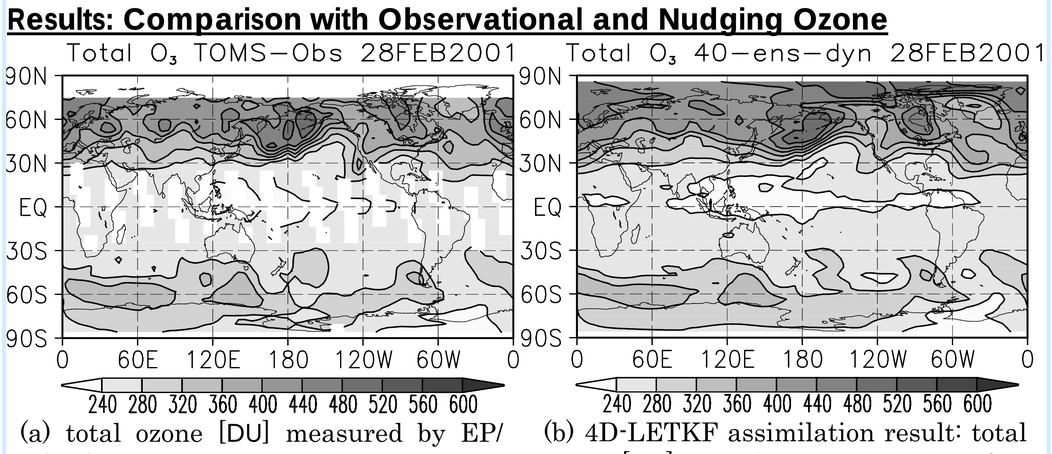
We present the advantages of this assimilation system by comparison with another simpler assimilation process for total ozone, that is to say, the Newtonian relaxation (= Nudging method) which has been used by JMA for its daily UV index forecast.



Experiment 1

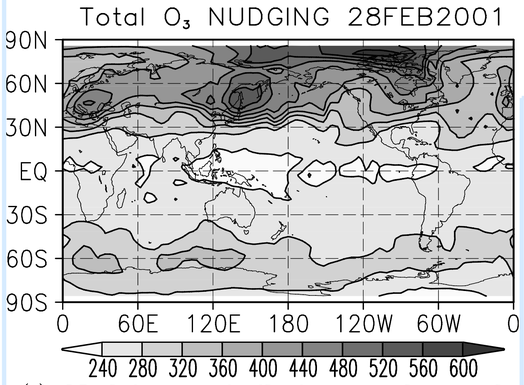
- 4D-LETKF assimilation of total ozone measured by EP/TOMS
- Model resolution: 5° latitude × 5° longitude grid (T21) with 45 vertical layers (from surface to mesopause)
- Meteorological field: nudged into ERA-40/ECMWF
- Initial condition: only meteorology-nudged, but non ozone-assimilated chemical field as of January 01, 2001
- Number of ensemble members: 10, 20, or 40

Results: Comparison with Observational and Nudging Ozone



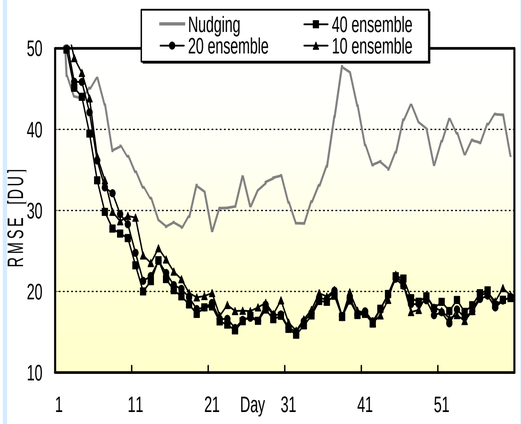
(a) total ozone [DU] measured by EP/TOMS on February 28, 2001.

(b) 4D-LETKF assimilation result: total ozone [DU] on February 28, 2001; after 58 days since the assimilation experiment started; using 40 ensemble members. *GOOD PERFORMANCE!*



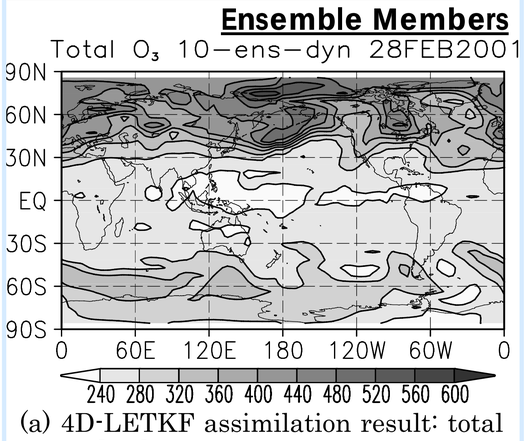
(c) Nudging assimilation result: total ozone [DU] on February 28, 2001 simulated by MRI-CTM with EP/TOMS.

Results: Root Mean Square Error in the middle latitudes of the Northern Hemisphere

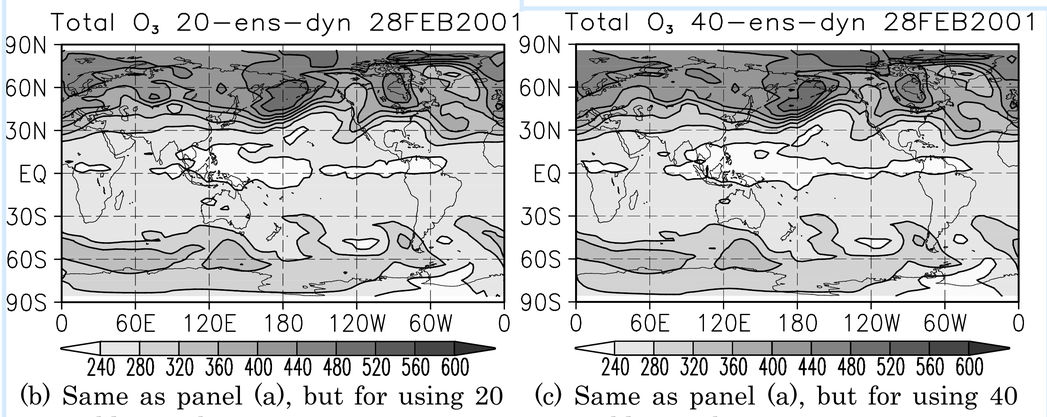


Time sequence of root mean square errors (RMSE) between EP/TOMS measurements and data-assimilated total ozone (4D-LETKF and Nudging results) in the middle latitudes of the Northern Hemisphere (averaged over 19°N ~ 53° N). X-axis indicates the elapsed days since the beginning of the assimilation on January 01, 2001.

Results: Effect of the Number of Ensemble Members



(a) 4D-LETKF assimilation result: total ozone [DU] on February 28, 2001; using 10 ensemble members.



(b) Same as panel (a), but for using 20 ensemble members.

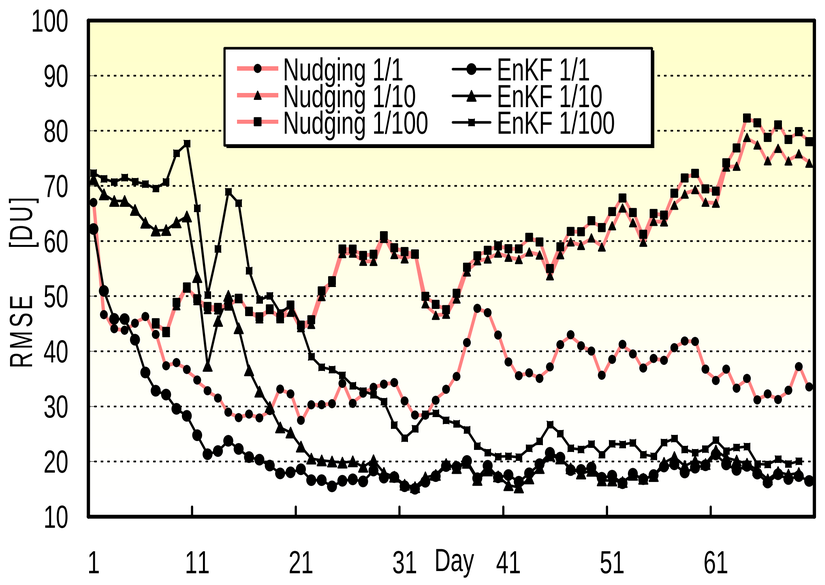
(c) Same as panel (a), but for using 40 ensemble members.

Experiment 2

- Thin out randomly and reduce the number of the observational data-points (1/10 and 1/100) which are used for 4D-LETKF and nudging assimilations.
- The same experimental conditions as 20-ensemble **Experiment 1**, but for the number of EP/TOMS measurements used for assimilation.

Results

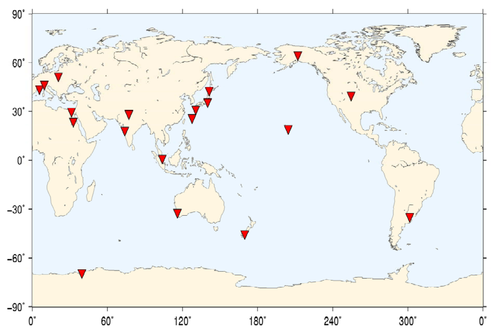
- Although the decrease in observational data-points deteriorates the performance of nudging assimilation results seriously, LETKF assimilation results are hardly disturbed by the decrease.



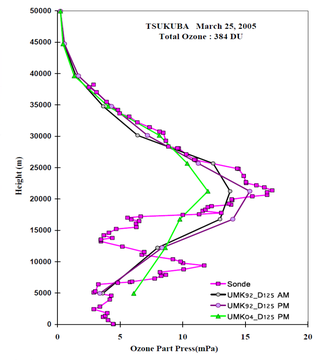
Time sequence of RMSE between EP/TOMS measurements and data-assimilated total ozone in the Northern Hemisphere middle latitudes (19°N ~ 53°N). Black (red) lines show 4D-LETKF (Nudging) assimilation results with 1/1, 1/10 or 1/100 observational data-points used. X-axis indicates the elapsed days since the beginning of the assimilation on January 01, 2001.

Experiment 3

- 4D-LETKF Assimilation of Dobson Umkehr observations (vertical ozone profiles), adding simultaneously EP/TOMS total ozone assimilation (as with Experiment 1).
- Dobson Umkehr observations: more frequent (e.g., in 2001, 2.24 times/week at one site) than Ozone sondes (less than 1 time/week at one site); but lower vertical resolution (10 levels from surface to stratopause) than Ozone sondes.



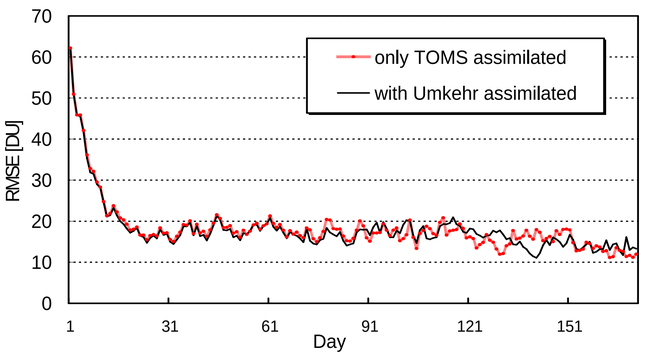
(a) All of the Dobson Umkehr observatory sites used for assimilation Experiment 3. The dataset provided by WOUDC (Canada) includes 2199 ozone-profiles from 19 observatory sites around the world in 2001.

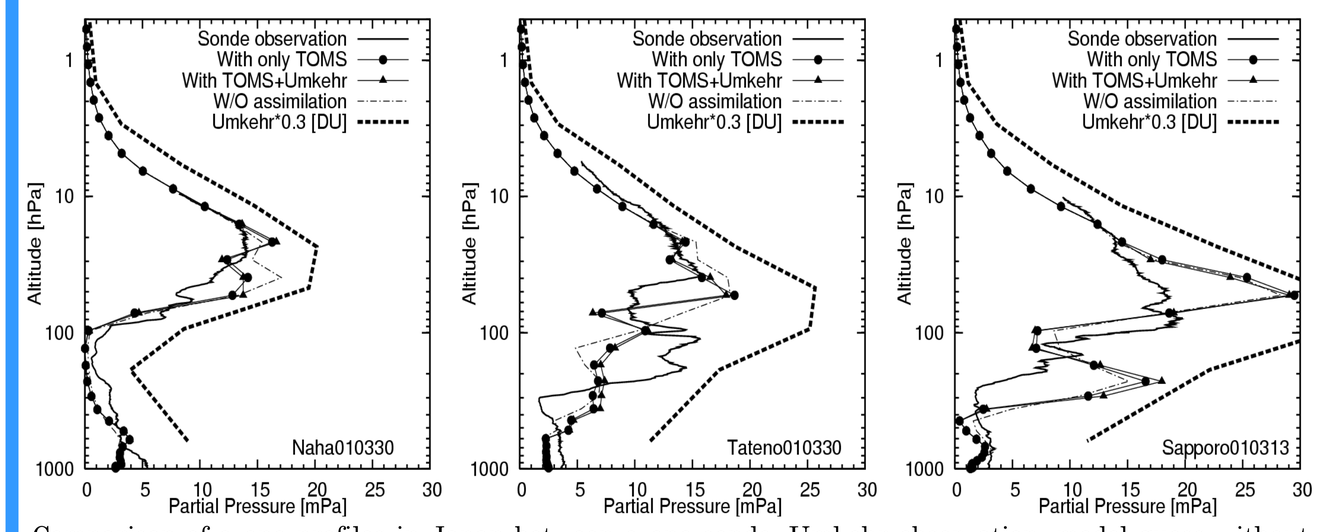


(b) Comparison of ozone profiles between Umkehr observations and a Ozone sonde (Miyagawa, 2006). The Umkehr unit is converted to partial pressure.

Results

- (Right panel) Time sequence of RMSE in the Northern Hemisphere middle latitudes; Experiment 1(red line, only TOMS assimilated) and 3 (black line, TOMS + Umkehr assimilated).
- Little influence of Umkehr assimilation on the synoptic-scale RMSE of total ozone...





Comparison of ozone profiles in Japan between ozone sonde, Umkehr observation, model guess without assimilation, and 4D-LETKF assimilation results of Experiment 1 (●: only TOMS assimilation) and 3 (▲: TOMS + Umkehr assimilation), (Left) at Naha [in Okinawa, 26°N] on March 30, (Middle) at Tateno [in Tsukuba, 36°N] on March 30, (Right) at Sapporo [43°N] on March 13 in 2001. Note that only Umkehr observation unit is the column amount of each layer (DU), and others are partial pressure (mPa).