Ensemble-based Variational Assimilation for a Cloud-Resolving Model

Kazumasa AONASHI
Meteorological Research Institute/ JAMSTEC
aonashi@mri-jma.go.jp
OUTLINE

• Introduction: Satellite microwave imager
• Ensemble-based variational assimilation method
• Experiment results using simulated MWI TBs
• Summary
Satellite Observation (TRMM)

- Infrared Imager
- SST, Winds
- Cloud Particles
- Frozen Precip.
- Snow Aggregates
- Melting Layer
- Rain Drops
- Cloud Top Temp.
- Radiation
- Scattering

3 mm-3 cm (100–10 GHz)

Microwave Radiometer
- Radiation from Rain
- Scattering by Frozen Particles
- Cloud Top Temp.

10 μm

Radar
- 19 GHz
- 85 GHz
- 2 cm

Back scattering from Precip.

SST, Winds
GPM (Global Precipitation Measurement)

Core Satellite
- Dual frequency Precipitation Radar
- GPM Microwave Imager

Constellation Satellites
- Microwave radiometers
  - NOAA AMSU-B

Concept of GPM
Goal: Data assimilation of MWI TBs into CRMs

Ensemble-based Variational Assim System

JMANHM (Saito et al, 2001)
• Resolution: 5 km
• Grids: 400 x 400 x 38

MWI TBs (PR)

Precip.
EnVA: min. cost function in the Ensemble forecast error subspace

- Minimize the cost function with non-linear Obs. term.

\[ J_x = \frac{1}{2} (\bar{X} - \bar{X}_f) P_f^{-1} (\bar{X} - \bar{X}_f) + \frac{1}{2} (Y - H(\bar{X})) R^{-1} (Y - H(\bar{X})) \]

- Assume the analysis error belongs to the space spanned by dual-scale NE vertical SVD mode:

\[ \bar{X} - \bar{X}_f = U_{NE}^f \circ \Omega^a = \begin{pmatrix} U_G \circ \Omega_G \\ U_g \circ \Omega_g \end{pmatrix} \]

\[ P^f = P_{U,NE}^f \circ S = \begin{pmatrix} (U_G U_G^t) \circ S_G \\ (U_g U_g^t) \circ S_g \end{pmatrix} \]

- Horizontal pattern of S is adaptively determined.
Why Ensemble-based method?:

To estimate the flow-dependency of the error covariance

Ensemble forecast error corr. of PT (04/6/9/22 UTC)
Why Variational Method?

To address the non-linearity of TBs

MWI TBs are non-linear function of various CRM variables.

- TB becomes saturated as optical thickness increases:
  \[ T - TB \approx (1 - \varepsilon_s)T e^{-2\tau/\mu}, \]
  when \( T \approx T_s \)

- TB depression mainly due to frozen precipitation becomes dominant after saturation.
Neighboring ensemble

- Hypothesis of Buehner and Charron (2007)
  Correlations in spectral space decreases as the difference in wave number increases.
- Spectral Localization
  \[
  \hat{C}_{sl}(k1, k2) = \hat{C}(k1, k2) \hat{L}_{sl}(k1, k2)
  \]
- When transformed into spatial domain
  \[
  C_{sl}(x1, x2) = \int C(x1 + s, x2 + s) \hat{L}_{sl}(s) ds
  \]
  Spectral-Localized correlation is a weighted, spatially-shifted average of correlation over the neighboring points.
- we approximated the forecast error correlation using neighboring ensemble (NE) members of the target points (5 x 5 grids).
To reduce degree of freedom, we use SVD modes of vertical cross correlation of NE forecast error. Separation of NE into large-scale modes (65 km ave.) and local modes (derivation).

Horizontal correlation cal. from the SVD modes

No separation

Separation

Precip

U

500 km

500 km

500 km

500 km
EnVA: min. cost function in the Ensemble forecast error subspace

- Minimize the cost function with non-linear Obs. term.

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- Assume the analysis error belongs to the space spanned by dual-scale NE vertical SVD mode:

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\[ P_f = P_{U,NE}^{f} \circ S = \begin{pmatrix} (U_G U_G^t) \circ S_G \\ (U_g U_g^t) \circ S_g \end{pmatrix} \]

- Horizontal pattern of S is adaptively determined.
Cloud-Resolving Model used

**JMANHM** (Saito et al, 2001)
- Resolution: 5 km
- Grids: 400 x 400 x 38
- Time interval: 15 s

Explicitly forecasts 6 species of water substances
Ensemble Forecasts

- 100 members started with perturbed initial data
- Geostrophically-balanced perturbation plus Humidity
- Random perturbation with various horizontal and vertical scales (Mitchell et al. 2002)

Extra-tropical Low (Jan. 27, 2003)

Typhoon CONSON (June 9, 2004)

Baiu case (June 1, 2004)
OSSE design

Typhoon Conson (04/6/9/22 UTC)

JMANHM (Saito et al, 2005) 5 km res.

Ensemble forecast (04/6/9/15): 100 members started with perturbed initial data

Regard one member as the “truth”
Sim. Observation for TMI TBs

TB10v

TB19v

TB21v

TB37v

TB85v
Procedures for assimilating simulated MWI TBs(OSSE)

1. Assimilate MWI TBs assuming no precipitation
2. Detect precipitation areas:
   - Use innovation and post-fit residuals
3. Assimilate MWI TBs in precipitation areas:
   - Non-linear iterative minimization
CRM control variables (no Precip)
(1st guess: Ensemble mean)
TBc calculated from 1st guess (no Precip)
Sim. Observation for TMI TBs

- B10v
- TB19v
- TB21v
- TB37v
- TB85v
Detection of Precipitation areas

- Thresholds
  - Innovation: $|Y - H(X^f)| > \beta \cdot \sigma_{H(X^f)}$ (+1)
  - Cloud water content: $q_c > q_{cth}$ (+2)
  - Cloud ice content: $q_{ci} > q_{cith}$ (+4)
  - Post fit residual: $\sum (Y - H(X^a))^2 / \sigma_a^2 > \chi_{th}^2$ (+8)
TBc sensitivity to control variables
Assimilation of no-precip Tb & detection of precip areas (Typhoon: 04/6/9/22 UTC)
Analysis increments for sim. MWI TBs

Assimilation rain-free TBs

Truth-XFAVE

SWS increment

XAAVE.it2-XFAVE

RHW2@1460m increment
Sim. MWI Tbo
(Typhoon: 04/6/9/22 UTC)
TBc NE+EnVA_1022 EXP140204.it3
(Typhoon: 04/6/9/22 UTC)
Assimilation of Sim. Precip. Retrieval  
(Typhoon: 04/6/9/22 UTC)
Analysis increments of hydrometers (EXP140204.it9) (Sim. MWI TB, Typhoon: 04/6/9/22 UTC)

Rain water @1460m

Graupel @5910m

Snow @5910m
Analysis increments of hydrometers (Sim. Precip, Typhoon: 04/6/9/22 UTC)

- Precip.
- Rain water @1460m
- Graupel @5910m
- Snow @5910m
Analysis increments of hydrometers
(Sim. MWI TB, Typhoon: 04/6/9/22 UTC)
Summary

• Satellite microwave imager
• Ensemble-based variational assimilation method
• Experiment results using simulated data
• Future directions (real data, FA cycle)