Mesoscale Ensemble Forecast Experiment and Sensitivity Analysis over Japan area

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Background

• Mesoscale Ensemble Prediction
  – Provide objective and valid information for a local severe weather.
  – SREF(NCEP), MOGREPS(Met Office)

• Development at MRI
  – Participate the B08RDP project.
    • The Beijing 2008 Olympics Research and Development Project
    • MRI/JMA, NCEP, MSC, ZAMG, NMC, CAMS
  – Compare initial perturbation methods.
    • Global singular vector method (downscaled)
    • Meso singular vector method (Regional)
    • Meso breeding method
    • Meso LETKF
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  – System overview
  – Technical issues
  – Application to short-range ensemble predictions over Japan
  – Comparison with global singular vector method

• Sensitivity Analysis using MSV
  – Calculation of the sensitivity area for T-PARC (Sep. 2008)
  – Data denial experiment

• Summary
Singular Vector Method (1/2)

SVs (x) can be determined by solving an eigenvalue problem.

\[ \hat{x} = \hat{x}(t = t_0) = E_i^{1/2} x(t = t_0) \]

\[ E_i^{-1/2} M^* E_r M E_i^{-1/2} \hat{x} = \sigma \hat{x} \]

SVs calculation needs tangent linear model and its adjoint.

The eigenvalue problem is solved by the Lanczos method with Gram-Schmidt reorthogonalization.

The norm for SV calculation is based on a total energy norm (Barkmeijer 2001) considering a moisture term.

\[ \|x\|^2 = \int_0^{Z_{wp}} \int_s \frac{1}{2} \rho \left( u'^2 + v'^2 + w'^2 + w_t \frac{C_p (\theta')^2}{\Theta_r} + R_T \left( \frac{p'}{p_r} \right)^2 + w_q \frac{L^2}{C_p T_r} q'^2 \right) dSdz \]

- \( C_p \) : specific heat of dry air at constant pressure
- \( L_c \) : latent heat of condensation
- \( R_d \) : gas constant for dry air
Singular Vector Method (2/2)

A singular vector method is developed at JMA to make initial conditions in the meso-ensemble prediction system.

The linearized model and its adjoint version are derived from the JNoVA 4D-Var analysis system (Honda et al., 2005).

JNoVA: the JMA NHM-based Variational Data Assimilation system (in operation since April 2009)

<table>
<thead>
<tr>
<th>Step Model</th>
<th>TLM and ADM</th>
</tr>
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<tr>
<td>Horizontal advection</td>
<td>Flux form 4th order</td>
</tr>
<tr>
<td>Gravity/sound waves</td>
<td>Time-splitting/HEVI</td>
</tr>
<tr>
<td>Moist physics</td>
<td>Large-scale condensation</td>
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<td>Convection</td>
<td>Moist convective adjustment</td>
</tr>
<tr>
<td>Turbulence</td>
<td>Deardorff(1980) diagnostic formula</td>
</tr>
<tr>
<td>Surface flux</td>
<td>Kondo(sea) and Louis(land)</td>
</tr>
<tr>
<td>Radiation</td>
<td>Not considered</td>
</tr>
</tbody>
</table>

TABLE. Specifications of the linearized model employed in the SV calculation.
Application to short-range EPS

Description of the system details

<table>
<thead>
<tr>
<th>Grid Type</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Grid</td>
<td>(91 \times 73) ((\Delta x = 40) km, (\Delta t = 120) s), LMN</td>
</tr>
<tr>
<td>Vertical Grid</td>
<td>40 levels ((\Delta z = 40 \text{–} 1180) m), (Z_{\text{top}} = 22) km ((\approx 40) hPa)</td>
</tr>
<tr>
<td>Norm</td>
<td>Total Energy Norm ((w_t = 1.0), (w_q = 0.3))</td>
</tr>
<tr>
<td>Optimization time</td>
<td>15 hour</td>
</tr>
<tr>
<td>Lanczos Iteration</td>
<td>20 times (use leading 5 SVs for ensemble prediction)</td>
</tr>
<tr>
<td>Target area</td>
<td>Japan area ((27.5\text{–}42.5)N, 125\text{–}145E)</td>
</tr>
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</table>

**Configuration of initial perturbations**

- Scale of initial perturbations
  - Rescaled with respect to the statistical analysis error (=\(\sigma\))
  - Limitation of \(3\sigma\) to remove local maxima
- Adjustment of supersaturation
- Correspondence for the hybrid vertical coordinate are adopted in the forecast model.
Example of ensemble forecasting

Initial time: 12 UTC 28 August 2008

Surface weather map at 00 UTC on 28 August 2008.

3-hour accumulated rainfall chart at 18 UTC on August 2008, (a) analyzed rainfall, (b) predicted by a control forecast.

Maximum predicted precipitation amount was 20 mm / 3 hours

<table>
<thead>
<tr>
<th>TABLE. Specifications of the MEPS</th>
<th>JMANHM (as of July 2008)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Member</td>
<td>11 (1 control run and 10 perturbed runs)</td>
</tr>
<tr>
<td>Horizontal grid</td>
<td>$239 \times 191, \Delta x = 15\text{km}, \text{LMN}$</td>
</tr>
<tr>
<td>Vertical levels</td>
<td>40 levels, $\Delta z = 40$-1180m, hybrid coordinate</td>
</tr>
<tr>
<td>Initial PTB</td>
<td>Mesoscale singular vectors (MSV, $\Delta x = 40 \text{ km}$, L40)</td>
</tr>
<tr>
<td></td>
<td>Global singular vector (GSV, T63L40)</td>
</tr>
<tr>
<td>Boundary PTB</td>
<td>None (MSV), Forecast of global model initiated by targeted SV (GSV)</td>
</tr>
</tbody>
</table>
Horizontal distributions of TE

Horizontal distributions of vertically integrated total energy of MSV

SV02, SV03 and SV05 had high sensitivity over Tokai district, where severe rainfall was observed 6 hours later from the initial time.
CNTL

OBS

SPREAD

MSV

FT=06

POP01 : >=1.0mm/3hour Prob.
POP02 : >=5.0mm/3hour Prob.
POP03 : >=10.0mm/3hour Prob.
POP04 : >=20.0mm/3hour Prob.
POP05 : >=50.0mm/3hour Prob.
More than 30% probability of precipitation is estimated even with a threshold of 50 mm 3-hour, where the control forecast could predict approximately 20 mm.

When singular vectors are used as initial perturbations in ensemble predictions, a pair of perturbations with opposite signs needs to be both included. So, the probability that a specific phenomena happens can seldom exceed 50% when a control forecast fails to capture an occurrence of the phenomena.
Comparison with global SV method

Ensemble forecast with MSVs has a special feature that the spread of precipitation grows rapidly, which is suitable for short-range ensemble predictions.

Variation of ensemble spreads of surface variables

Due to neglect of boundary PTB, ensemble spreads of MSV did not increase after FT=15.

ROC area skill score for the period 27 – 29 August 2008 (3-hour accumulated precipitation)

GSV: weak and moderate rain
MSV: intense rain
Sensitivity analysis over Japan area

<table>
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<th>Specification of the MSVs</th>
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<tbody>
<tr>
<td>Model</td>
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<tr>
<td>Resolution</td>
</tr>
<tr>
<td>Optimization Time</td>
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<td>Target Region</td>
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<tr>
<td>Norm</td>
</tr>
<tr>
<td>Initial Condition</td>
</tr>
<tr>
<td>Lead - time</td>
</tr>
<tr>
<td>Model</td>
</tr>
<tr>
<td>Resolution</td>
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</table>

For near real time operation, the 24-hour forecast of the JMA Global model (GSM; TL959L60) is used for the initial condition to calculate MSV.

$\rightarrow$ 14 hours lead time prior to the OBS time.

Target Area of MSVs (independent of a typhoon position)

FIGURE. Forecast domain

Period : Sep. 2008
Frequency : 1/day (12UTC init)
Case: T0813 (SINLAKU)

Init: 12UTC 18 Sep
Sensitivity area for T0813 (MSV)

**MSV**
- **Initial time**: 12UTC 17 Sep 2008
- **Observation time**: 12UTC 18 Sep 2008
- **Verification time**: 00UTC 19 Sep 2008
- **Optimization time**: 12-hour

Vertically integrated energy norm (initial)

Vertically integrated energy norm (final)

Non-linear model forecast (FT12)
Data denial experiment

Data assimilation was performed using JMA Meso-4DVar

00UTC  03UTC  06UTC  09UTC  12UTC

3-hour assimilation window

Remove data over sensitivity area

NHM (Δx = 15km) forecast

JMA Meso-4DVar : 3-hour cycle, Δx = 20km, L40
JMANHM : 36-hour forecast, Δx = 15km, L40

Assimilated observation data
Denial experiment changed the water vapor fields over sensitivity area, which resulted in the dry increment in the inflow region.
The increment had small impact on the tracks of the typhoon, whereas the central pressure was somewhat weakened.
Forecast fields (FT=12)

SLP and 3-hour accumulated rainfall

This discrepancy is probably attributable to the track error (about 100 km) in the GSM 24-hour forecast used as the initial condition to calculate MSVs.
Conclusions

- Mesoscale singular vector method was applied to short-range EPS experiment and the usefulness of this method was shown.

- Ensemble forecast with MSVs has a special feature that the spread of precipitation grows rapidly, which is suitable for short range ensemble predictions.

- MSVs-based sensitivity areas for TY0813 were located in the right side to the moving direction of the typhoon, which was dominated by the potential energy components in the mid-lower troposphere.

- The data denial experiment shows that the exclusion of observations over the sensitivity region has impact on forecast fields, however deterioration of forecast accuracy was not large because the differences of analyzed moisture fields with and without the data was small in this case.

- The difference of forecast fields at FT=12 in data denial experiments is conspicuous near the typhoon center, which does not necessarily consistent with the locations of final MSVs. This discrepancy is probably attributable to the track error (about 100 km) in the GSM 24-hour forecast used as the initial condition to calculate MSVs.

- To further assess the propriety of the MSV-based sensitivity region, OSSE on water vapor fields around typhoon center is necessary.