On the predictability of a blocking occurred on 15th December 2005

Mio MATSUEDA[1,2](mimatsue@mri-jma.go.jp), Masayuki KYOUDA[3], Zoltan TOTH[4], Takemasa MIYOSHI[5], Hiroshi L. TANAKA[6], and Tadashi TSUYUKI[2]

1: Advanced Earth Science and Technology Organization, Tsukuba, Japan
2: Meteorological Research Institute, Tsukuba, Japan
3: Numerical Prediction Division, Japan Meteorological Agency, Tokyo, Japan
4: National Centers for Environmental Prediction, National Oceanic and Atmospheric Administration, USA
5: Department of Atmospheric and Oceanic Science, University of Maryland, College Park, USA
6: Center for Computational Sciences, University of Tsukuba, Tsukuba, Japan

Abstract: An atmospheric blocking occurred over the Rocky Mountains on 15th December 2005. Medium-range ensemble forecast initialized at 12UTC on 10th December 2005 was very interesting. All the NCEP members could not predict a correct location of the blocking, whereas almost all the JMA members and most of the CMC members could predict it.

Multi-analysis ensemble forecasts and ensemble-based simple sensitivity analysis were conducted to investigate causes of the collective mis-prediction of the NCEP EPS. JMA-GSM runs were conducted using the NCEP control and perturbed analyses. The control and perturbed members also could not predict the correct location of the blocking. Ensemble-based sensitivity analysis detected a sensitivity area over the central North Pacific at 12UTC on 10th December. In this area, there was a cut-off cyclone. The difference between the JMA and the NCEP control analyses around the cyclone was relatively larger than the other areas. In addition, there were no effective initial perturbations in the NCEP members. These seem to have led to the collective mis-prediction. In fact, the JMA-GSM runs using the NCEP analyses amplified only over the sensitivity area tended to show a decrease in the RMSE over the blocking region without a degradation of the forecast skill over the Northern Hemisphere. In contrast, global amplification of initial perturbations tended to lead to not only a decrease in the RMSE over the blocking region but also an increase of the RMSE over the Northern Hemisphere. These results suggested that excessive amplification of initial perturbation over non-sensitivity area is undesirable, and that the regional amplification technique can lead to a better forecast without a degradation of forecast over the other areas. Such a case dependent estimates may really have value as compared to climatologically based rescaling that is used widely.

1. Introduction

Recently, the ensemble forecast has become a major component of the operational global weather prediction systems, and has drawn more attention in various timescales, such as short-, medium-, and long-ranges for both operational and research purposes.

The World Meteorological Organization (WMO) began The Observing System Research and Predictability Experiment (THORPEX; WMO 2005) project in 2005 in order to accelerate improvements in the accuracy of one-day to two-week high-impact weather forecasts for the benefit of society, the economy, and the environment. At the heart of the THORPEX is the research needed for the design and demonstration of a global interactive forecasting system that allows information exchange between the forecast users, numerical forecast models, data assimilation systems, and observations. The THORPEX Interactive Grand Global Ensemble (TIGGE; Richardson et al. 2005), which is a key component of the THORPEX, has enabled us to get operational medium-range ensemble forecast data near real time, to compare the medium-range ensemble forecasts, to construct the new types of ensemble forecast, and to analyze extreme events.

Prior to the TIGGE project, Matsueda et al. (2007) constructed the Multi-Center Grand Ensemble (MCGE), consisting of three operational medium-range ensemble forecasts by the CMC, JMA, and NCEP, on a quasi-operational basis, and showed an advantage of the MCGE against a single-center ensemble. Matsueda et al. (2007) also introduced an interesting example of the ensemble forecast of an atmospheric blocking occurred over the Rocky Mountains on 15th December 2005. All the NCEP members could not predict a correct location of the blocking, whereas almost all the JMA members and most of the CMC members could predict it.

In this study, multi-analysis ensemble forecasts and ensemble-based simple sensitivity analysis were conducted to investigate causes of the collective mis-prediction of the NCEP EPS.

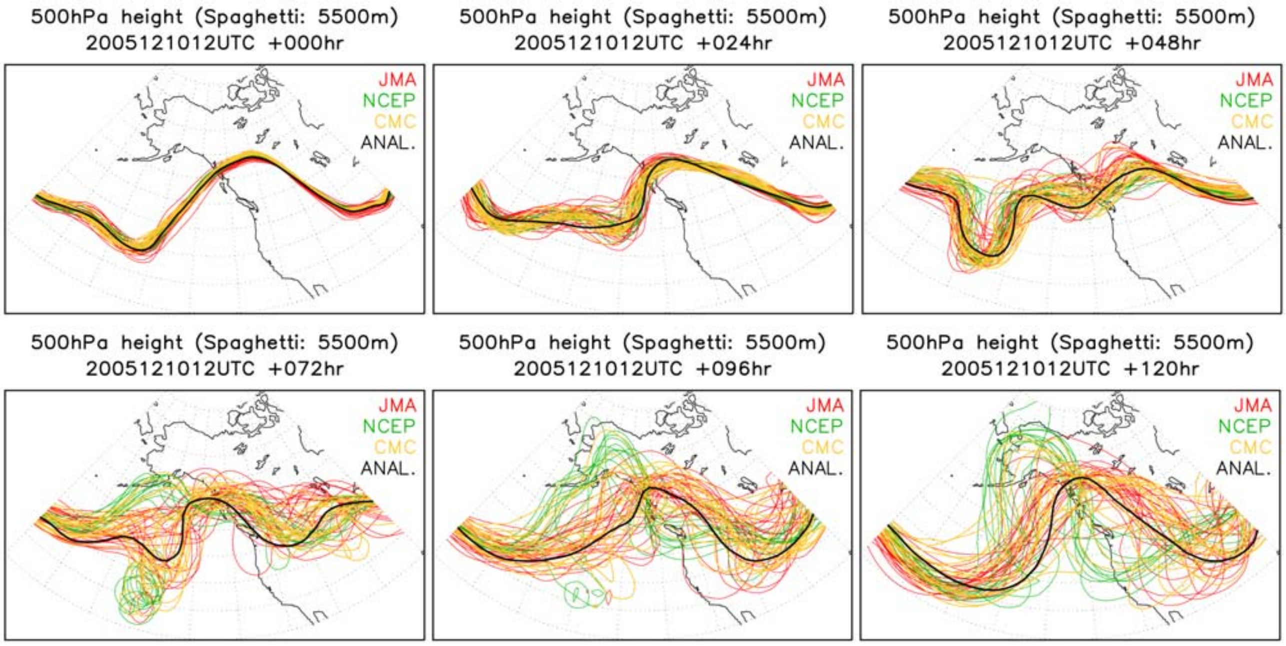

Figure 1. Spaghetti diagrams of 500hPa height (5500m) for ensemble members of CMC (yellow), JMA (red), and NCEP (green), initialized at 00 UTC (CMC) or 12 UTC (JMA and NCEP) on 10th December 2005, valid 12 UTC on 15th December 2005. Thin solid line is for each ensemble member forecast and thick solid line for JMA analysis at the valid time.

Table 1. Operational medium-range ensemble prediction system (EPS) at CMC, JMA, and NCEP as of December 2005.

	Model Resolution	Initial Perturba-tion	Ensemble Size (Initial UTC)
CMC	TL149L23-41 1.2degL28	EnKF	17x1 (00)
JMA	T106L28	BVs	51x1 (12)
NCEP	T126L28	BVs	11x4 (00,06,12,18)

2. Data and method

2.1 Ensemble forecast data

Three operational medium-range ensemble forecast data: CMC, JMA, and NCEP, are used. The details of these EPS as of December 2005 are summarized in Table 1. The horizontal resolution of the forecast model is comparable to each other. The JMA and the NCEP EPSs used the BV method as the initial perturbation, and the CMC EPS used the Ensemble Kalman Filter (EnKF) method.

2.2 Ensemble-based sensitivity analysis

Enomoto et al. (2007) proposed a SV-like simple sensitivity analysis using ensemble forecast data. This method does not need numerical prediction model and adjoint code, and needs only ensemble forecast data that has already been calculated. Using this technique, the sensitivity area in the prediction of atmospheric phenomenon can be identified.
The detail is also written in Matsueda (2008).

2.3 Multi-analysis ensemble forecasts

Based on the ensemble-based simple sensitivity analysis, multi-analysis ensemble forecasts were performed using the operational JMA Global Spectral Model (JMA-GSM; JMA 2007). The horizontal and vertical resolutions of the JMA-GSM are TL159L40. The JMA-GSM used in this study is a semi-Lagrangian model, whereas the operational JMA-GSM as of December 2005 was not.

3. Target blocking

The blocking occurred over the Rocky Mountains at 12 UTC on 15th December 2005. The mature time of the blocking was 18th December 2005. This blocking did not persist for a long time, and decayed within several days. Ensemble forecasts initialized at 12 UTC on 10th December 2005 was very interesting. Figure 1 illustrates the spaghetti diagrams of the Z500 for the CMC, JMA, and NCEP ensemble forecasts and JMA analysis, at 0-hr to 120-hr lead times. The initial times are 12 UTC on 10th December 2005 for the JMA and the NCEP, and 00 UTC on 10th December 2005 for the CMC. Until 48-hr lead time, it is found that each ensemble member captured the analysis well. However, at 72-hr lead time, the NCEP members started to mis-predict the blocking. At 96-hr lead time, the NCEP members predicted the ridge of the blocking more upstream than the analysis. At 120-hr lead time, all the NCEP members predicted the wrong location of the blocking with a large negative

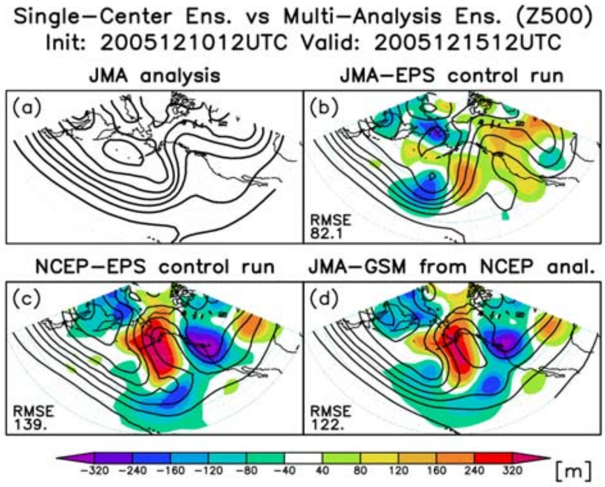

Figure 2. 500hPa height (contour) and its forecast error (shaded) for (a) JMA analysis, the control runs of (b) JMA and (c) NCEP, and (d) JMA-GSM run from NCEP control analysis, initialized at 12 UTC on 10th December 2005, valid 12 UTC on 15th December 2005.

error over the Rocky Mountains, whereas the JMA members and most of the CMC members predicted the correct location of the blocking. Interestingly, most of the CMC members initialized at 00 UTC on 11th December 2005 and a half of the JMA members initialized at 12 UTC on 11th December 2005 predicted the wrong location of the blocking (not shown), as in the NCEP members initialized at 12 UTC on 10th December 2005. In order to identify causes of the collective mis-prediction of the NCEP initialized at 12 TUC on 10th December 2005, multi-analysis ensemble forecasts and simple sensitivity analysis and were performed.

4. Results

4.1 Multi-analysis ensemble forecasts with NCEP analyses

First, the multi-analysis ensemble forecasts were conducted with the JMA-GSM (TL159L40) using the NCEP control and perturbed analyses. If the NCEP members on the JMA-GSM cannot predict the correct location of the blocking, it can be concluded that a main cause of the collective mis-prediction of the NCEP was due to the initial condition of the NCEP EPS.

The time evolution of the JMA-GSM run with the NCEP control analysis is similar to that of the NCEP control run (Fig. 2). Despite a change of the numerical model, the NCEP control analysis on the JMA-GSM led to a wrong prediction of the location of the blocking (Fig. 2d). It can be concluded that one of the causes of the collective mis-prediction of the blocking is due to the NCEP control analysis at the initial time. It is, however, interesting that

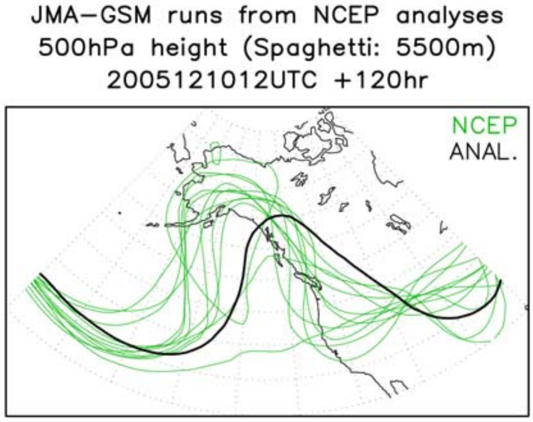

Figure 3. Spaghetti diagrams of 500hPa height (5500m) for JMA-GSM runs from NCEP control and perturbed analyses initialized at 12 UTC on 10th December 2005, valid 12 UTC on 15th December 2005. Thin and thick solid lines are for each ensemble member and NCEP analysis at the valid time, respectively.

the 120-hr RMSE of the JMA-GSM run with the NCEP control analysis (Fig. 2d) is smaller than that of the NCEP control run (Fig. 2c). This might indicate decreases of imperfection of the model formulation by introduction of other numerical models.

For the JMA-GSM runs with the NCEP perturbed analyses, it is found that all of them were not able to predict the correct location of the blocking (Fig. 3), as in the original NCEP perturbed runs. However, the JMA-GSM runs with the NCEP analyses predicted the location of the blocking somewhat accurately than the original NCEP runs, but more inaccurately than the JMA members. In fact, as shown in Table 2, the JMA-GSM runs with the NCEP analyses, except for 02m, 03m, and 05p (m and p indicate ensemble member in which the initial perturbation is subtracted from and added to the control run, respectively), had a better forecast skill over the blocking region than the original NCEP members. This result also might indicate decreases of imperfection of the model formulation.

4.2 Ensemble-based sensitivity analysis

In the previous subsection, it was found that the collective mis-prediction resulted from initial value of the NCEP members. In order to detect the sensitivity area against the blocking, the ensemble-based sensitivity analysis was performed. In this study, the dry total energy norm (Ehrendorfer and Errico 1995) was used:

$$\mathrm{TE} = \frac{1}{2}\iint_A u'^2 + v'^2 + \frac{c_p}{T_r}T'^2 + RT_r\left(\frac{p'_s}{p_r}\right)^2 dA\,dp,$$

where u', v', T', and p'_s are perturbed components of zonal and meridional velocity, temperature, and surface pressure, respectively, c_p

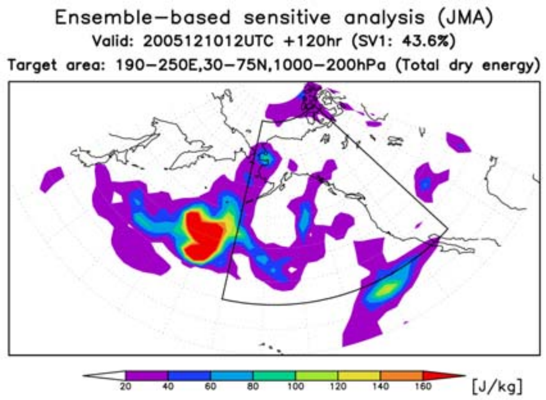

Figure 4. Sensitivity area obtained from JMA ensemble forecast initialized at 12 UTC on 10th December 2005. The target time is 12 UTC on 15th December 2005, that is, 120-hr lead time. The target area is surrounded by black line.

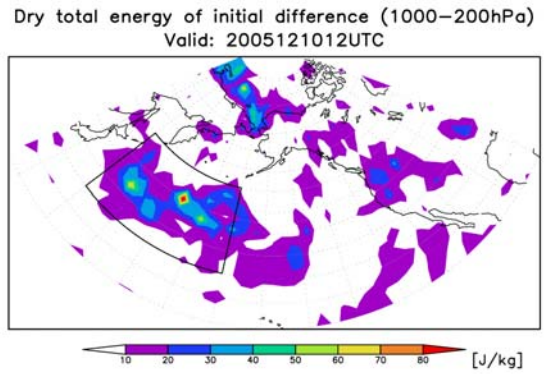

Figure 5. Initial difference between JMA and NCEP analyses at 12 UTC on 10th December 2005, measured by dry total energy. The sensitivity area is surrounded by black line.

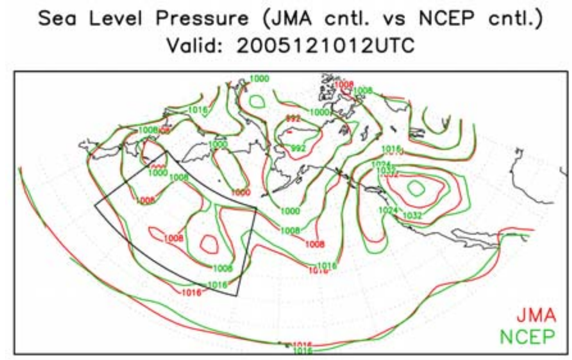

Figure 6. Sea level pressure of JMA (red) and NCEP (green) control analysis at 12 UTC on 10th December 2005. The sensitivity area is surrounded by black line.

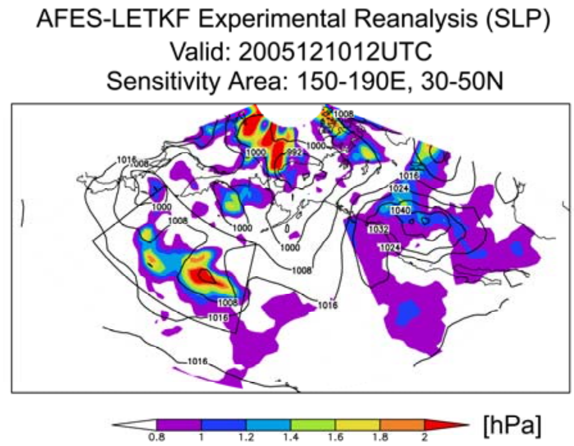

Figure 7. Sea level pressure (contour) and its analysis error (shaded) based on AFES-LETKF Experimental Re-Analysis (ALERA) at 12 UTC on 10th December 2005.

the specific heat at constant pressure, R the gas constant for dry air, T_r (=300K) and p_r (=800hPa) are the reference temperature and pressure. The target area is set to 190E-250E, 30N-75N, and 1000-200hPa (black line in Fig. 4). The target time is set to 12 UTC on 15th December 2005, that is, 120-hr lead time.

Figure 4 illustrates the sensitivity area measured by the vertically integrated dry total energy norm obtained from the JMA ensemble data. There are well-defined signals over the central north Pacific. These signals exist at each pressure level for each component, u, v, T, and p_s (not shown). This region, 150E-190E, 30N-50N, is defined as a sensitivity area. In the sensitivity area, it is found that the difference between the JMA and the NCEP control analyses at 12 UTC on 10th December 2005 measured by the the vertically integrated dry total energy norm is relatively larger than the other areas (Fig. 5). In other words, the sensitive area had a large uncertainty. The difference seems to be due to a cut-off cyclone (Fig. 6). The difference between the JMA and the NCEP control analyses at the center of the cut-off cyclone (180E, 40N) was about 4 hPa at 12UTC on 10th December. The difference reached about 8 hPa at 48-hr lead time. After 72-hr lead time, the cut-off cyclone traveled quite different direction from each other. The cut-off cyclone simulated by the NCEP control run traveled toward the southeast, whereas that simulated by the JMA control run traveled toward the northeast (not shown). The southeast travel of the cyclone predicted by the NCEP control run can be detected in the Z500 field (Fig. 2c). It might be considered that the synoptic field around the cyclone over the central north Pacific at 12 UTC on 10th December affected the blocking formation. In fact, the AFES-LETKF Experimental Re-Analysis (ALERA; Miyoshi et al. 2007) shows a large analysis error, that is, a large uncertainty around the cyclone (Fig. 7).

4.3 Multi-analysis ensemble forecasts with amplified initial perturbations

It was suggested in the previous subsection that the NCEP control analysis had a weaker cyclone than the JMA control analysis, and the cyclone affected the blocking formation. However, even if the control analysis has a large initial uncertainty, initial perturbations in the

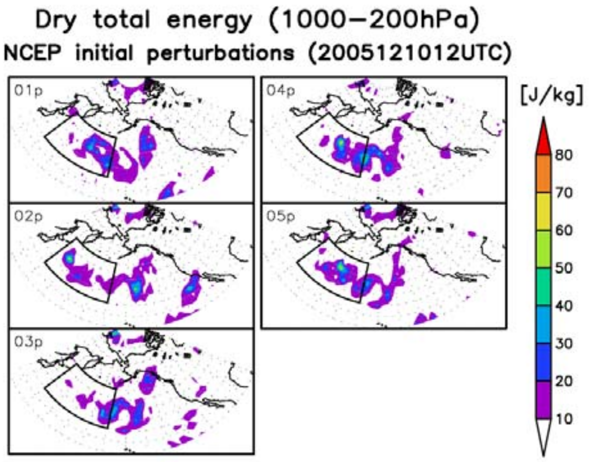

Figure 8. Dry total energy for NCEP initial perturbations at 12 UTC on 10th December 2005. The sensitivity area is surrounded by black line.

ensemble forecast can reduce it. Figure 8 illustrates the vertically integrated dry total energy for the NCEP initial perturbations at 12 UTC on 10th December 2005. It is found that the initial perturbations: 02 and 03, did not have well-defined signals around the cyclone. Also, even if there are any signals around the cyclone (perturbations 01, 04 and 05), the amplitude of the initial perturbation seems to be small compared with the analysis difference shown in Fig. 5. Base on the fact that there is a large uncertainty in the sensitivity area, these results might suggest that the NCEP ensemble did not have effective initial perturbations to predict the blocking formation more accurately. The NCEP EPS tend to have a smaller ensemble spread than the other EPSs. There is a possibility that amplification of the initial perturbation leads to improvement of the forecast skill at least in this case.

Based on the ensemble-based sensitivity analysis, the multi-analysis ensemble forecasts using initial perturbations amplified were performed. First, the amplitude of the NCEP initial perturbations was globally increased by a factor of 1.5. The fourth column in Table 2 shows the 120-hr RMSE for the Z500 over the blocking region (170E-260E, 20N-80N). Compared with the third column in Table 2, it is found that for most of runs the global amplification led to an improvement in the RMSE over the blocking region. However, the global amplification of initial perturbations led to a degradation of the forecast over the Northern Hemisphere (Table 3). Compared with the third and fourth columns in Table 3, it is found that the global amplification led to a worse skill, on the hemispherical scale, than the JMA- GSM runs with the original amplitude, except for 04p and 05p.

Based on these results, the additional multi-

Table 2. 120-hr RMSEs of NCEP EPS and JMA-GSM runs from NCEP analyses for 500hPa height over the blocking region (170E-260E, 20N-80N).

20051210 12UTC +120hr	NCEP EPS	JMA-GSM runs from NCEP analyses		
		Amp: 1.0	Amp: 1.5	Amp: 1.5area
00	139	122	-	-
01p	143	95.6	84.1	81.9
01m	123	115	136	128
02p	131	71.7	71.3	61.9
02m	103	111	101	110
03p	143	127	141	134
03m	100	140	151	138
04p	148	102	89.5	93.7
04m	88.3	73.9	68	56.5
05p	116	125	98.4	101
05m	128	68.9	63.7	63.1
Ens. Mean	117	91.1	78.0	79.6

JMA ensemble mean: 61.6m

Table 3. 120-hr RMSEs of NCEP EPS and JMA-GSM runs from NCEP analyses for 500hPa height over the Northern Hemisphere (20N-90N).

20051210 12UTC +120hr	NCEP EPS	JMA-GSM runs from NCEP analyses		
		Amp: 1.0	Amp: 1.5	Amp: 1.5area
00	96.9	87.1	-	-
01p	104	79.0	82.6	75.8
01m	90.8	104	122	109
02p	102	69.0	88.3	66.5
02m	82.7	97.0	104	97.4
03p	110	105	117	108
03m	79.1	87.5	95.5	86.8
04p	99.3	79.9	78.3	78.6
04m	81.2	67.0	72.9	63.1
05p	96.3	87.6	76.4	80.2
05m	98.5	78.4	85.7	76.2
Ens. Mean	85.8	72.5	70.7	69.1

JMA ensemble mean: 57.1m

analysis ensemble forecasts with regionally amplified initial perturbations were per formed. The amplitude of the NCEP initial perturbation was increased by a factor of 1.5 only over the sensitivity area. If the regional amplification led to an improvement of the forecast over the blocking region, it can be concluded that the sensitivity area is a key component of the prediction of the blocking. For many members, the regional amplification reduced forecast error over the blocking region without a degradation of the forecast skill over the Northern Hemisphere (fifth columns in Tabs. 2 and 3). This indicates that the regional amplification of the perturbations over the sensitivity area was essential for the improvement of the prediction of the blocking. The perturbed members: 01p, 02p, 04m, and 05m, with the regionally amplified

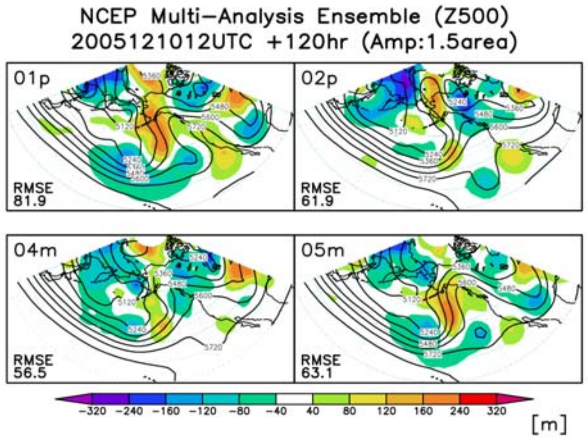

Figure 9. 500hPa height (contour) and its forecast error (shaded) for JMA-GSM runs from NCEP perturbed analyses with regionally amplified initial perturbations, initialized at 12 UTC on 10th December 2005, valid 12 UTC on 15th December 2005.

perturbations have the lowest RMSE over the blocking region (Tab. 2). It is found the location of the blocking predicted by these members was closer to the analysis than that by the original NCEP ones (Fig. 9). These members did not have a well-defined large negative forecast error over the Rocky Mountains shown in the original NCEP EPS. The absence of the negative error seems to enable the blocking ridge to shift somewhat eastward. In terms of the ensemble mean, the improvement of the forecast by the regional amplification is also obvious (bottom line in Tabs. 2 and 3). These results indicate that the sensitivity area was a key component of the prediction of the blocking. They also indicate that excessive amplification of the initial perturbation over non-sensitivity area is undesirable, and that the regional amplification technique can lead to a better forecast without a degradation of the forecast over the other area.

5. Conclusion

An atmospheric blocking occurred over the Rocky Mountains on 15th December 2005. Medium-range ensemble forecast initialized at 12UTC on 10th December 2005 was very interesting. All NCEP members could not predict a correct location of the blocking, whereas almost all the JMA members and most of the CMC members could predict it.

Multi-analysis ensemble forecasts and ensemble-based simple sensitivity analysis were conducted to investigate causes of the collective mis-prediction of the NCEP EPS. JMA-GSM runs were conducted using the NCEP control and perturbed analyses. The control and perturbed members also could not predict the correct location of the blocking. Ensemble-based sensitivity analysis detected a sensitivity area over the central North Pacific at 12UTC on 10th December. In this area, there was a cut-off cyclone. The difference between the JMA and the NCEP control analyses around the cyclone was relatively larger than the other areas. In addition, there were no effective initial perturbations in the NCEP members. These seem to have led to the collective mis-prediction. In fact, the JMA-GSM runs using the NCEP analyses amplified only over the sensitivity area tended to show a decrease in the RMSE over the blocking region without a degradation of the forecast skill over the Northern Hemisphere. In contrast, global amplification of initial perturbations tended to lead to not only a decrease in the RMSE over the blocking region but also an increase of the RMSE over the Northern Hemisphere. These results suggested that excessive amplification of initial perturbation over non-sensitivity area is undesirable, and that the regional amplification technique can lead to a better forecast without a degradation of forecast over the other areas. Such a case dependent estimates may really have value as compared to climatologically based rescaling that is used widely.

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