Predictabilities of a Blocking Anticyclone and a Explosive Cyclone

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In order to investigate the mechanisms of high-impact weather and seasonal variations of predictability, 10-day ensemble forecast experiments were conducted with the initial conditions on every day in a month in each season in 2010. This report describes the settings and preliminary results of the ensemble forecast experiments. Predictability studies are conducted on the Euro-Russian blocking anticyclone in the boreal summer and an explosive cyclone in the northwestern Pacific in the boreal winter among high-impact weather events occurred in 2010. Our preliminary investigation suggests that the Euro-Russian blocking anticyclone is maintained by the selective absorption of synoptic anticyclones and the predictability of the blocking anticyclone is strongly influenced by the storm-track activity in the north Atlantic. Our ensemble forecasts reproduced the rapid development of the explosive cyclone but with a 6–12 h delay in the forecast longer than 3 days. The forecast ensemble spread in our experiments share common features with those in operational ensemble forecasts from some centres, but not in those from other centres.

Keywords: Blocking Anticyclone, Explosive Cyclone, High-Impact Weather, Atmospheric General Circulation Model, Data Assimilation, Ensemble Forecast, Forecast Skill

1. Introduction

The aim of this project is to enhance knowledge on mechanisms of high-impact weather such as typhoons, explosive mid-latitude cyclones, blocking anticyclones and stratospheric sudden warmings and to clarify predictability variation associated with high-impact weather. Through the understandings on high-impact weather, we attempt to develop better data assimilation techniques and general circulation models to improve accuracy of numerical weather prediction.

In FY2013 10-day ensemble forecast experiments were conducted from every day in a month in each season at the Earth Simulator Center (ESC). Multi-model experiments were either postponed or conducted on other supercomputers. Instead ensemble forecast experiments for boreal spring and autumn planned for FY2014 were conducted in advance in FY2013 in addition to those for boreal winter and summer scheduled in FY2013. Almost all of the allocated computational resource was required to conduct these ensemble forecast experiments.

Case studies are conducted for the Euro-Russian blocking anticyclone in the boreal summer and an explosive cyclone in the northwestern Pacific in the boreal winter. The Euro-Russian blocking anticyclone lasted from July to August caused a number of disasters such as large-scale forest fires in Russia and floods in Pakistan and influenced remotely the heat wave in Japan. The explosive cyclone in the northwestern Pacific in early January caused severe meteorological and oceanic phenomena to highly impact Japan.

The present paper describes the experimental setting in section 2, the preliminary outcomes in section 3 along with the summary and some remarks in section 4.

2. Experimental Settings

In order to investigate the seasonal variations of predictability, ensemble forecast experiments were conducted using the Atmospheric General Circulation Model (AGCM) for the Earth Simulator (AFES) [1,2,3,4]. The spatial resolution of AFES is T119L48 (1° horizontally and 48 levels vertically) and the ensemble size is 64 (including the forecast from the ensemble mean), matching that of ALERA2 (AFES–LETKF experimental ensemble reanalysis version 2, where LETKF stands for the local ensemble transform Kalman filter [5,6,7,8]) [9] used as the initial conditions. This ensemble forecast system, called ALEPS2 (AFES–LETKF ensemble prediction system version 2), was prepared in FY24 [10] and used in this study. The ensemble forecasts for 10 days were conducted from 1200 UTC every day in each month in January, April, July and October 2010, representing the boreal winter, spring, summer and autumn seasons, respectively. Produced ensemble forecast variables include the 6 hourly winds, temperature, specific humidity, surface and sea-level pressure, geopotential height, precipitation, snow, radiative and surface fluxes and soil moisture. Preliminary results on two case studies are described in the following section.

3. Results

3.1 Predictability Variation of the Euro-Russian Blocking Maintenance

A Euro-Russian blocking anticyclone (simply *blocking or block*, hereafter) occurred in early July and maintained until early August in 2010. This block stayed the same position over western Russia and caused an extreme heat wave in western Russia and flooding in Pakistan and northwestern India [11, 12]. Accurate medium-range forecasts of the Euro-Russian block would be useful to mitigate such disasters. Matsueda (2011) [13] showed that the predictability of the block maintenance varied through the blocking period. Fujii (2013) [14] pointed that the upstream trough influenced the predictability drop in late July and that the blocking was maintained by the generation of anticyclonic vorticity due to the low-frequency divergence. In the present study, daily predictability variation of the block was revisited with the ensemble forecast experiments.

The selective absorption mechanism (SAM) [15] has been proposed to explain the maintenance of the block by the interaction between synoptic eddies and blocking. In the SAM, a blocking anticyclone absorbs synoptic anticyclones in a Lagrangian sense to maintain its intensity. The SAM successfully explains a positive feedback between blocking and synoptic eddies. Our separate study shows that the SAM is effective for the maintenance of the Euro-Russian blocking (not discussed here). Provided that the SAM is the most effective mechanism of the maintenance of the Euro-Russian blocking, the following hypothesis may be suggested:

- Predictability variation of the Euro-Russian blocking is affected by the activity of synoptic eddies (storm tracks), and
- an inactive (active) storm track leads to low (high) blocking predictability.

The Atlantic storm track region, off the east coast of North America, is the major origin of synoptic eddies that interact with the block (Fig. 1). Despite over the ocean, observations are relatively dense and thus the initial errors are assumed to be small. Then if the storm track is active, we expect high predictability of the block because the major source of air parcels absorbed into the Euro-Russian blocking originates from the storm-track region with small initial errors. The hypothesis is verified with the ensemble forecast experiments.

The relationships between predictability variations of the Euro-Russian block and the activity of synoptic eddies in the

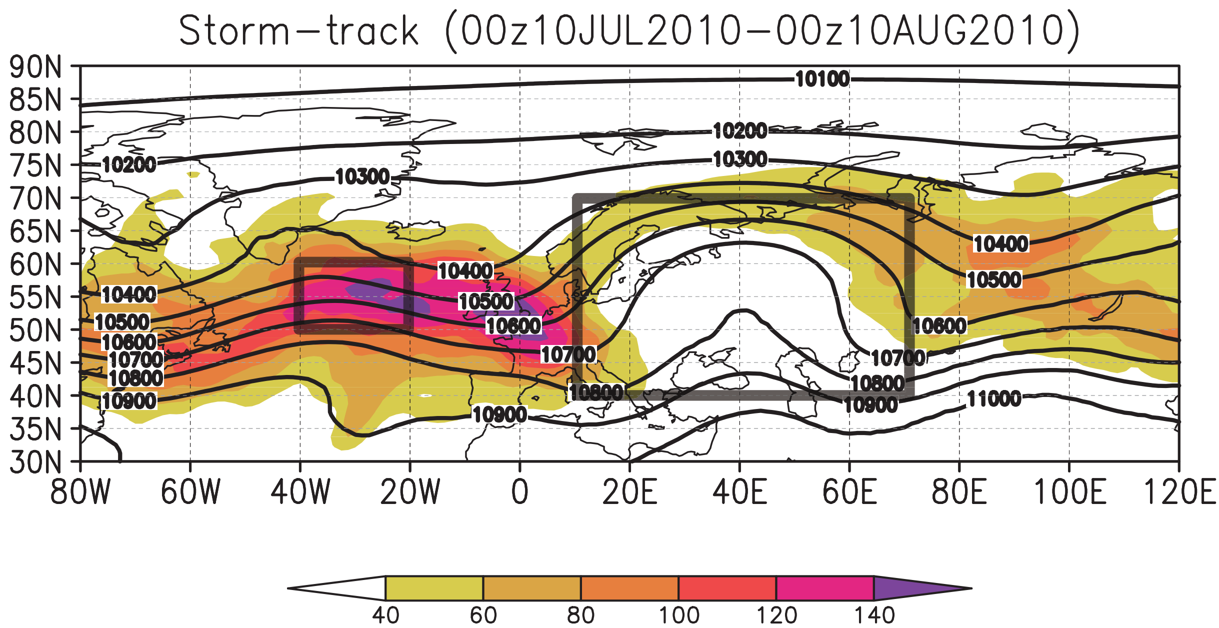

Fig. 1 The 2–8 days band-pass-filtered (eddy) kinetic energy (shade, m^2s^{-2}) and geopotential height (contour, m) at 250 hPa averaged over 0000 UTC 10 July–0000 UTC 10 August 2010. The former indicates the storm-track activity and the latter the Euro-Russian block. Small and large squares indicate frames of the storm-track and the blocking regions, respectively. Prepared from ALERA2.

storm-track region are investigated with the following two indices. To quantify the blocking predictability the forecast error index is defined by the root-mean-square difference (RMSD) of the 250-hPa geopotential height between the 5-day ensemble mean forecast and the ensemble mean analysis in ALERA2 at the valid time averaged over the blocking area defined in Fig. 1. The storm-track activity index is defined by the 2–8 days band-pass filtered eddy kinetic energy at 250 hPa obtained from the ALERA2 (Fig. 1), which has been conventionally used as an indicator of storm tracks in previous studies.

Figure 2 shows daily variation of the forecast error index (red line) and the storm-track activity index (black line). The forecast error index is negatively correlated with the storm-track activity index, during the period 19–31 July in particular. The largest forecast error on 20 July coincides with the inactive period

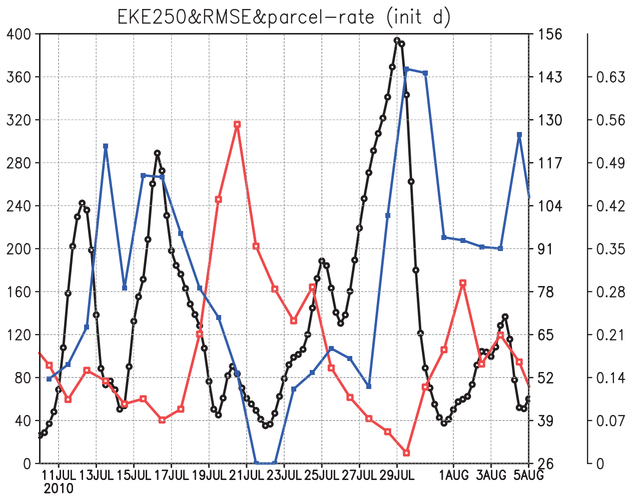

Fig. 2 The eddy kinetic energy (black, m^2s^{-2}) in the storm-track region and the 5-day forecast root-mean square difference (RMSD, red, m) in the blocking region and the absorption rate (blue). See text for the details. The three vertical axes are for black, red and blue lines from left to right, respectively. The horizontal axis indicates dates. Note that for the red line the dates correspond to the valid time of 5-day forecast.

of the storm-track activity. Conversely, the smallest forecast error on 29 July occurs simultaneously with the largest storm-track index. Note that the decrease of predictive skill for the blocking around 20 July occurred in other operational forecast models [13, 14]. This negative correlation, consistent with our hypothesis, suggests large influence of the storm-track activity on predictability variation of the blocking.

Additional evidence for the hypothesis is obtained from the backward trajectory analysis. The strength of the positive feedback between the storm-track activity and the blocking is quantified by the rate of synoptic anticyclones originating from the storm-track region absorbed into the blocking anticyclone due to the SAM. The absorption rate is defined by the ratio of parcels that cross the storm-track region to those initially placed in the blocking in the backward trajectory for 5 days. The winds on the 330 K isentropic surface from the JRA25/JCDAS reanalysis dataset [16] are used to advect the parcels (see Yamazaki and Itoh (2013) [15] for the details). In Fig. 2 the absorption rate (blue line) takes the minimum and maximum on 22 July and 30 July, respectively. The both dates are about 1–2 days after the extrema of the forecast error. This can be interpreted as variation of the connection between the storm-track activity and the maintenance of the block due to the SAM. Daily backward trajectories indicate that the parcels cross the storm-track region with meandered westerlies when the absorption rate is high and the parcels pass the region to the south of the storm track when the absorption rate is low (Fig. 3).

3.2 Predictability of Explosive Cyclones in the Northwestern Pacific

A synoptic cyclone rapidly developed on 13 January to the east of Japan and the central pressure dropped to 978.3 hPa at (151.2E, 41.2N) on 14 January. With the enhanced westward pressure gradient, a typical pressure pattern near Japan in the winter, the explosive cyclone caused meteorological and oceanic

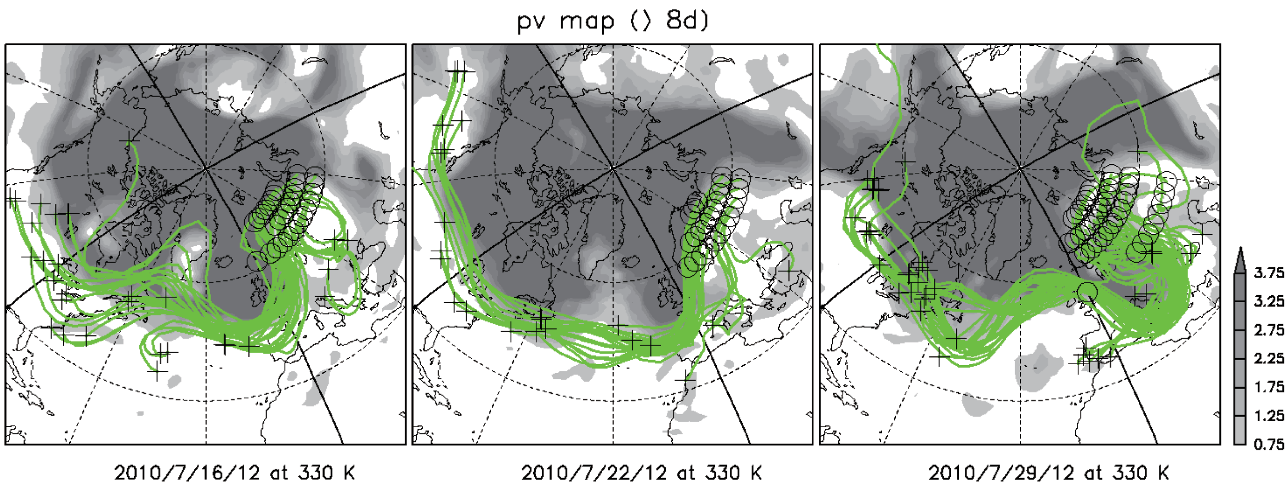

Fig. 3 The 6-day backward trajectories (green) from 1200 UTC 16, 1200 UTC 22 and 1200 UTC 29 July 2010, and the 8 days low-pass filtered Ertel's potential vorticity (PV PVU, shades) on the 330 K surface at these dates from left to right, respectively. The circles and + signs indicate the initial and end points of the backward trajectories, respectively. The PV is calculated from the JRA25/JCDAS on isentropic surfaces.

disasters such as wind burst, cold surge, heavy snow and rain and 5-m oceanic waves. The predictability of this explosive cyclone over the northwestern Pacific region was investigated using the 10-day ensemble forecasts at the ESC and operational forecasts from ECMWF, NCEP, JMA and UKMO in TIGGE database.

In the ESC forecasts using ALEPS2 longer than 3-day the development of the cyclone lags by 6–12 h, but the deepening of the cyclone is predicted well (Fig. 4). The operational forecasts can predict the rapid deepening timing even in the forecasts longer than 3 days. This is probably due to low quality of the ALERA2 over the ocean caused by the lack of satellite data assimilation.

The ensemble spreads for 3.5-day forecast are very different one another. In the ECMWF and JMA forecasts the ensemble spreads is large over the north of the cyclone, while in the NCEP, UKMO and ESC forecasts the ensemble spreads is large along frontal structures in the cyclone (Fig. 5). In addition the amplitudes are much larger in the ECMWF and JMA than those in the NCEP, UKMO and ESC forecasts. The difference could be attributed to the perturbation generation techniques: the singular vector (SV) method at ECMWF and at JMA and

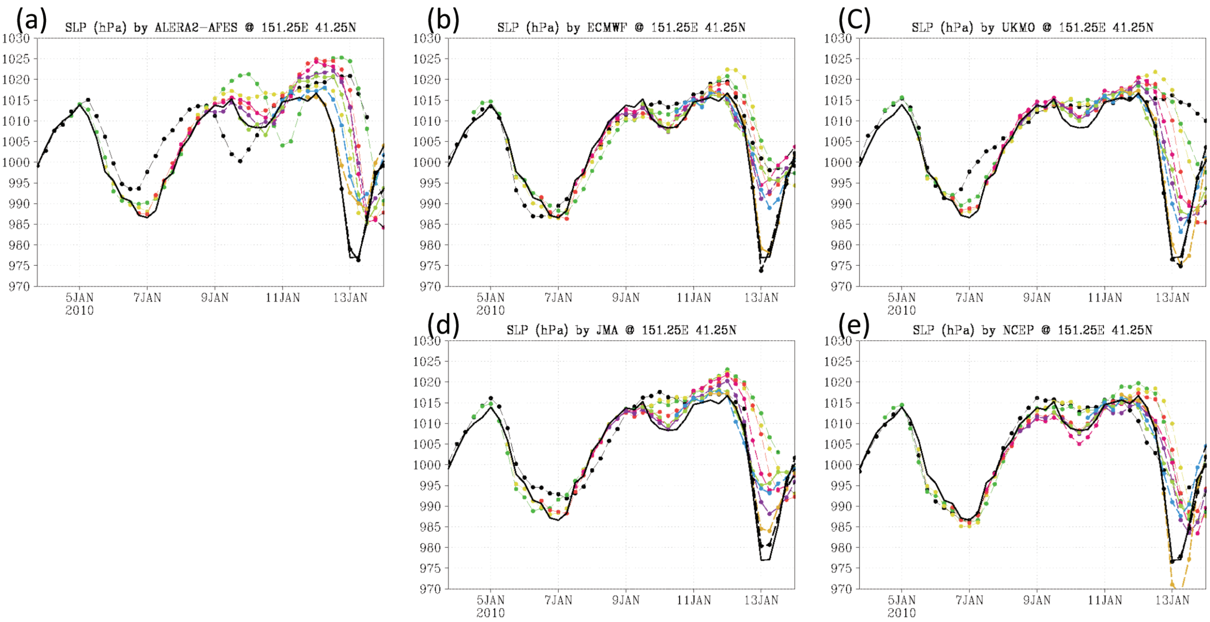

Fig. 4 The ensemble means of the SLP forecasts at 151.25E, 41.25N from every 1200 UTC 3–9 January (broken lines in black, green, yellow, red, magenta, purple, yellow-green, light blue, orange, black) of (a) ALEPS2, (b) ECMWF, (c) UKMO, (d) JMA and (e) NCEP. The solid black curve represents the SLP of ALERA2.

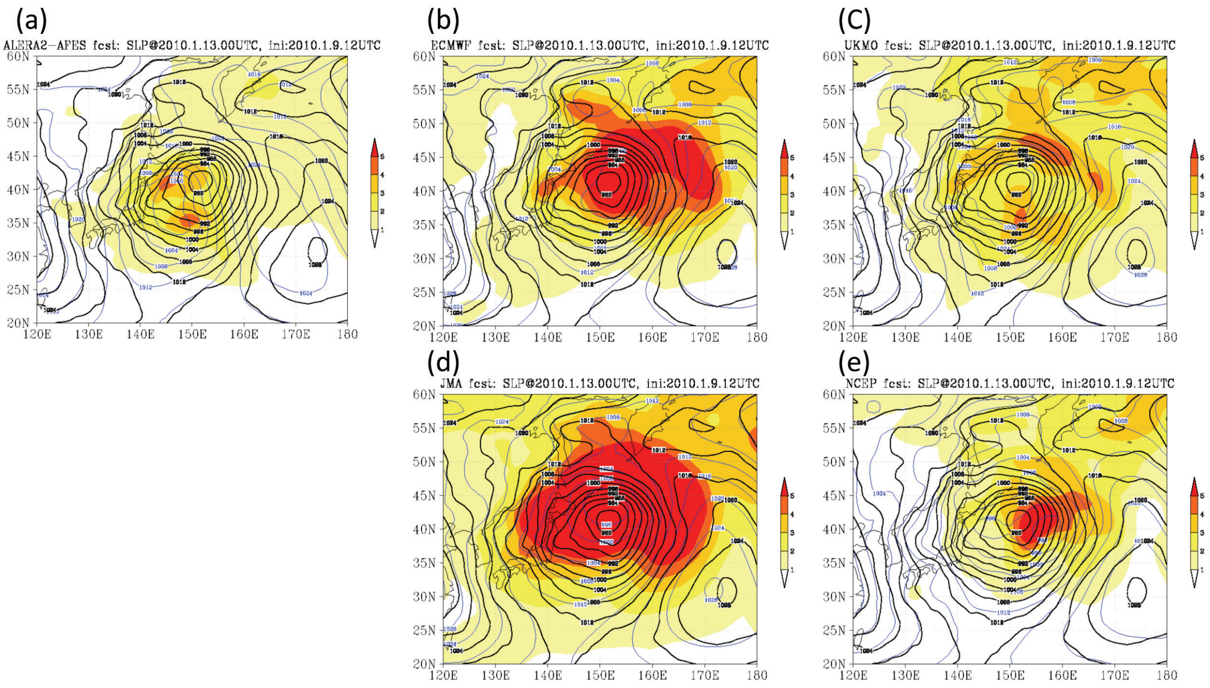

Fig. 5 The SLP forecasts at 0000 UTC 13 January from 1200 UTC 9 January. Ensemble mean (hPa, blue contour) and ensemble spread (colour shade). (a) ESC, (b) ECMWF, (c) UKMO, (d) JMA and (e) NCEP. The black contour represents the SLP of ALERA2.

the breeding vector (BV) method at NCEP and the ensemble Kalman filter (EnKF) method at UKMO and at ESC. Note that the both BV and EnKF perturbations are generated from the previous ensemble forecast and in this respect these methods are similar.

4. Summary and Final Remarks

Ensemble forecast experiments were conducted on the Earth Simulator and two case studies were conducted for the Euro-Russian blocking anticyclone in the boreal summer and an explosive cyclone in the northwestern Pacific in the boreal winter in 2010.

Our investigation indicates that the predictability variation of the Euro-Russian blocking is related to the activity of synoptic eddies in the western Atlantic storm track. This strong relationship between the blocking and the storm track offers evidence for the hypothesis that the Euro-Russian blocking was mainly maintained by the selective absorption of synoptic cyclones. In order to validate the SAM, we plan to conduct some sensitivity experiments to the storm track for the Euro-Russian blocking and investigation on other blocking events in the ensemble experiments.

The explosive cyclone in January 2010 is reproduced in our ensemble forecast experiments but with a delay of 6–12 h in forecasts longer than 3 days. The forecast ensemble spread in ALEPS2 is similar to those in the operational ensemble forecasts using the BV (NCEP) or EnKF (UKMO) as a perturbation generation method. We plan to conduct ensemble forecasts from the exchanged initial conditions to clarify the cause in the difference in the structure of the forecast ensemble spread.

In the future we wish to conduct observing system experiments for a future observation network design and sensitivity experiments with different parametrization schemes for model development in order to improve forecasts of high-impact weather.

List of Acronyms

AFES
AGCM for the Earth Simulator
AGCM
Atmospheric General Circulation Model
ALEPS2
AFES–LETKF ensemble prediction system version 2
ALERA2
AFES–LETKF experimental ensemble reanalysis version 2
BV
Breeding Vector
ECMWF
European Centre for Medium-range Weather Forecasts
ESC
The Earth Simulator Center
GrADS
Grid Analysis and Display System
JMA
The Japan Meteorological Agency
JRA25/JCDAS
The Japanese 25-year Reanalysis/JMA Climate Data Assimilation System
LETKF
Local Ensemble Transform Kalman Filter
NCEP
National Centers for Environmental Prediction, USA
PV
Potential Vorticity
RMSD
Root-mean square difference
SAM
Selective Absorption Mechanism
SLP
Sea-Level Pressure
SV
Singular Vector
UKMO
United Kingdom Met Office

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ブロッキング高気圧と急速に発達する低気圧の予測可能性

課題責任者

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影響の大きな気象のメカニズムを調べ、予測可能性の季節変動を調べるため、2010 年の各季節それぞれ 1 か月間の日々の初期値から 10 日間のアンサンブル予報実験を行った。本報告では、アンサンブル予報実験の設定と初期解析結果を示す。2010 年に発生した影響の大きな気象のうち、予測可能性研究を北半球夏季の欧露ブロッキング高気圧及び北半球冬季の北西太平洋における急速に発達する低気圧に対して行った。初期的な解析結果から、欧露ブロッキング高気圧は選択的に移動性高気圧を吸収することにより維持されており、ブロッキング高気圧の予測可能性は北西大西洋のストームトラックの活動度に大きな影響を受けていることが示唆された。急速に発達する低気圧はアンサンブル予報実験で再現されたが、3 日間を超える予報では 6 ～ 12 時間の遅れを伴っていた。予報アンサンブル・スプレッドは、いくつかの現業アンサンブル予報のものと共通の特徴を持つが、別の現業アンサンブル予報とは大きく異なっていた。

キーワード: ブロッキング高気圧, 急速に発達する低気圧, 顕著現象, 大気大循環モデル, データ同化, アンサンブル予報, 予報精度