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WWRP Beijing Olympics 2008 Forecast Demonstration/ Research and Development Project (B08FDP/RDP)

BY

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気象研究所技術報告

第 62 号

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齊藤和雄、國井勝、原昌弘、瀬古弘
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The *Technical Reports of the Meteorological Research Institute* has been issued at irregular intervals by the Meteorological Research Institute (MRI) since 1978 as a medium for the publication of technical report including methods, data and results of research, or comprehensive report compiled from published papers. The works described in the *Technical Reports of the MRI* have been performed as part of the research programs of MRI.

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WWRP Beijing 2008 Olympics Forecast Demonstration/ Research and Development Project (B08FDP/RDP)

by

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Contents

序

世界気象機関（WMO）は、社会･経済への影響の大きな天気現象に対して費用対効果の高い予報技術を開発し、それを加盟国等へ普及することを使命とする「世界天気研究計画（WWRP）」を、1998 年に立ち上げた。WWRP のもとで実施される国際プロジェクトは、予報改善のために必要な科学的理解を深め、技術開発を推進する研究開発プロジェクト（RDP）と、それらの利益を具体的に示すために、利用者へのリアルタイムの情報伝達まで含んで実施される予報実証プロジェクト（FDP）に区分された。今回の技術報告のテーマである「北京オリンピック 2008 予報実証／研究開発プロジェクト（B08FDP/RDP）」は、2008 年北京オリンピックの天気予報を対象として実施された WWRP の国際プロジェクトである。本プロジェクトは、中国気象局による 2002 年の当初提案の段階から気象庁の参加が期待されていたが、結局、気象研究所が気象庁予報部の協力を得て B08RDP のコンポーネントに参加することになった。

気象庁の現業メソ数値予報モデルの予測精度は、高解像度化や物理過程の改善などのモデルの改良と、4 次元変分法などデータ同化手法の高度化と新規データ利用の進展による初期値の改善により、近年着実に向上している。しかしながら、災害につながる豪雨を場所と時間を特定して予測することには、現在でも多くの困難がある。不安定な大気状態で発生する局地的な大雨は特に予測が難しく、現象のスケールが小さいこと、僅かな初期値や計算条件の違いで結果が大きく変わる場合があること、などがその原因になっている。このように決定論的な予測が困難な場合に有効な予測手法としてアンサンブル予報があり、すでに週間天気予報や季節予報などで実用化されている。アンサンブル予報を短期予報に応用しようとする取り組みが国内外で始まっているが、メソ現象、特に顕著現象を対象とするアンサンブル予報については課題が多い。B08RDP は、メソ現象を対象とするアンサンブル予報の国際比較実験であり、米国やカナダなどこの分野で先行する国を含む 5 ヶ国 7 機関が参加した。オリンピックを対象に実施されたリアルタイム比較実験として社会的にも注目され、新聞やテレビなどでも報道された。

本技術報告では、プロジェクトの参加を通じて開発された、メソアンサンブル予報に関わるさまざまな摂動手法や検証手法などについての記述されている。この中には、将来の有力なデータ同化手法と注目されている局所アンサンブル変換カルマンフィルタをメソアンサンブル予報に適用した試みも含まれている。また、メソ 4 次元変分法の中国域への適用や、雲解像モデルによる実験、香港天文台が参加したナウキャストプロジェクト（B08FDP）へのサポートについても報告している。これらの技術開発は、気象研究所融合型経常研究「非静力学モデルによるメソ現象の予測と解明に関する研究」の副課題「メソ現象予測のための初期値解析技術の高度化」と「メソ現象の予測可能性に関する研究」の一環として行われ、平成 21 年度からは融合型経常研究「メソスケールデータ同化とアンサンブル予報に関する研究」に引き継がれている。このプロジェクトへの参加を通じて得られた知見や開発成果が今後さらに発展し、将来の実用化につながることを期待したい。

2010 年 4 月

予報研究部長
露木　義

WWRP 北京オリンピック 2008 予報実証/研究開発プロジェクト

斉藤和雄*・國井勝†・原昌弘*・瀬古弘*
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WWRP 北京オリンピック 2008 予報実証/研究開発プロジェクト(B08FDP/RDP)は，2008 年北京オリンピックに合わせて行われた短期予報に関する国際比較実験で、世界気象機関世界天気研究計画（WMO WWRP）傘下の研究計画として行われた。B08FDP/RDP は、2000 年にシドニーオリンピックに合わせて行われた国際予報実証実験 Sydney 2000FDP（日本は不参加）に引き続く研究計画として 2003 年 9 月オスロでの第 6 回 WWRP 科学運営委員会において中国気象局から正式提案され、2004 年 10 月ボルダーでの第 7 回 WWRP 科学運営委員会において承認された。ナウキャストに基づく 6 時間先までの予報実証実験(FDP)コンポーネントと 36 時間先までの予報についての研究開発プロジェクト（RDP）コンポーネントに分けて実施された。この技術報告は、気象研究所が気象庁予報部数値予報課の協力を得て参加した B08RDP プロジェクトに関連した数値モデリング活動の内容と、B08FDP プロジェクトにおける香港天文台の参加と気象研究所の協力について記述した。

B08RDP の実質的な活動は 2005 年に始まり、第 1 回ワークショップが 2005 年 3 月に北京で行われ、日本が RDP コンポーネントへの参加を表明した。データ転送を兼ねた予備実験は 2006 年から始まり、2006 年と 2007 年の予備実験の結果を受けて第 2 回ワークショップが 2006 年 8 月に北京で、第 3 回ワークショップが 2007 年 9 月に青島で開催された。

RDP コンポーネントは，Tier-1 と呼ばれる水平解像度 15 km の領域モデルによるメソアンサンブル予報の比較実験と，Tier-2 と呼ばれる水平解像度 4km 以下の雲解像モデルによるケーススタディに分けられている。気象研究所では、Tier-1 比較実験にあたり、メソアンサンブル予報のための初期値・境界値摂動手法の開発、メソ 4 次元変分データ同化手法の中国域への適用と中国での降水情報の同化、非静力学メソ数値予報モデルの調整などを行った。初期値摂動手法に関しては、週間アンサンブル予報のダウンスケール法、全球ターゲット特異ベクトル法，メソ特異ベクトル法, メソブリーディング法、局所アンサンブル変換カルマンフィルタによるアンサンブル変換を用いる方法、の 5 つの手法を開発・比較した。本実験に先立って、初期値摂動手法を選択するため、予報誤差に対するスプレッドの比と予報時間に対するスプレッドの変化傾向、アンサンブル平均の対初期値 RMSE の大きさ、降水のアンサンブル平均のスコアとブライアスコア、等を客観的に比較した。また境界値摂動に関しては、週間アンサンブル予報から与える手法と、全球ターゲット特異ベクトル法からの全球予報から与える 2 つの方法を開発し、領域アンサンブル予報における境界値摂動の重要性を示した。

B08FDP/RDP の本実験は, 2008 年 8 月 8 日～24 日の北京オリンピックに合わせて, 2008 年 7 月下旬から約 1 ヵ月間実施された。主な参加国（機関）は、FDP が中国(中国気象局国家気象センターと中国気象科学院)、米国(国立シビアストーム研究所)、カナダ(カナダ大気環境サービス)，香港（香港天文台），オーストラリア(オーストラリア気象局)、RDP が，中国((中国気象局国家気象センターと中国気象科学院), 米国(国立環境予測センターと国立大気研究センター)，カナダ(カナダ気象局)，日本（気象庁気象研究所），オーストリア&フランス(ZAMG & Meteo France)である．このうち，RDP の Tier-1 アンサンブル実験では、北京周辺の 105~125E, 30~45N の領域を共通検証領域と位置づけ、7 月 24 日～8 月 24 日の毎日、

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12UTC を初期値とする 36 時間予報のアンサンブル予報の各メンバーの 3 時間おきの予報値データを, 0.15 度の共通格子に GRIB2 フォーマットにより 2230UTC までに CMA の ftp サーバーに準リアルタイム送信した。これらの結果は B08RDP プロジェクトのウェブサイトにリアルタイム表示され，北京市気象局（BMB）によるオリンピック会場の当日予報の参考にも用いられた。

2008 年の本実験の成果については、2009 年 4 月に広州で開催された第 4 回ワークショップで報告されている。気象研究所の予報は、降水・気温の予測とも、コントロールランでは、参加 6 機関中トップクラスで、アンサンブル予報でも気温のアンサンブル平均や降水のブライアスコアで良好な成績だったが、地表要素のアンサンブルスプレッドが予報誤差に比べてまだ小さいことや、強い雨の確率予報や降水有無の捕捉率が十分ではないなどでは課題を残した。物理過程摂動を考慮していなかったことやアンサンブルメンバー数が 11 と少なめであったこと等が原因として考えられる他、摂動手法にも改善の余地があったと思われる。本報告では、比較実験終了後に行った、再実験による結果も一部紹介している。

B08RDP 本実験期間終了後は 9 月下旬までの 1 ヶ月、WWRP 傘下の研究計画でもある観測システム予報可能性実験（THORPEX）の太平洋アジア地域キャンペーン(T-PARC)への支援を兼ねて、領域を日本に移して準リアルタイムでメソアンサンブル予報実験を行った。この期間中、メソ特異ベクトル法に基づく感度解析も準リアルタイムで実行した。

本プロジェクトを遂行するにあたり、多くの方々の協力・助力を頂いた。中国気象局 Gong Jiandong 博士、Deng Guo 博士をはじめとする B08RDP 国際科学運営委員会事務局の労を多とするとともに、Li Yingling 氏、Li Li 氏などによる検証結果の一部を本報告に引用させて頂いた。メソ 4 次元変分法解析で同化した FDP による北京周辺の解析雨量（STEPS）は、オーストラリア気象局の Alan Seed 博士が作成したものである。また気象研究所電計管理班からは、B08RDP と T-PARC 支援準リアルタイム実験期間中の特別ジョブクラスを設定頂いた。本田有機、経田正幸、藤田匡、酒井亮太、佐藤清富、の各位をはじめとする気象庁予報部数値予報課の方々には、中国域を対象とする全球予報値の気象研究所への転送や NHM-LETKF の改良について、様々な力添えを頂いた。また本稿の原稿について、上記の方々や気象研究所の露木義、中村誠臣、数値予報課の小泉耕、石田純一、小野耕介、小森拓也の各位よりコメントを頂いた。これらの方々に深く感謝するものである。

本報告の構成は以下のようになっている。B 章で B08FDP/RDP プロジェクトについて、C 章と D 章で 2006 年と 2007 年 Tier-1 予備実験のシステムと結果を簡単に記述した。2007 年実験は、3km 解像度による Tier-2 実験の結果も含んでいる。E 章では、2008 年本実験でのモデル、初期・境界条件と摂動、実験システム、検証結果を示した。香港天文台が参加した FDP 実験に関して、気象研究所のサポートと香港天文台の短時間予測システム SWIRLS について香港天文台の黄偉健氏より寄稿頂いた。F 章では、プロジェクトの技術的なベースとしての週間アンサンブル予報や局所アンサンブル変換カルマンフィルタ、乱流クロージャモデルなどについて記述した。G 章では、T-PARC 支援のための日本域実験やいくつかのアンサンブル予報の応用事例について紹介した。本報告は、D-4-3, D-6-1, E-3-1, E-3-2, E-3-3, E-3-4, E-4-3, E-6, E-7-1, E-7-2, E-8-1, G-1, G-2-1 を主に國井が、D-4-2, E-4-2, E-5-1 を主に原昌弘が、D-5, D-6-2, D-6-3, D-7-1, D-8, E-4-5, E-4-6c, G-2-2, G-3 を主に瀬古が、F-1, F-2 を山口が、E-2-2, F-4, F-5 を原旅人が、F-3 を三好が、E-8-2 を黄（香港天文台）が、それ以外を主に斉藤が書いた。

A. Preface

This technical report describes modeling activities by the Meteorological Research Institute (MRI) for the WWRP Beijing 2008 Olympics Forecast Demonstration Project/Research and Development Project (B08FDP/RDP). MRI participated in B08RDP in collaboration with the Numerical Prediction Division (NPD) of the Japan Meteorological Agency (NPD/JMA). The main part of the B08RDP project, called Tier-1, is an intercomparison of mesoscale ensemble prediction systems (EPSs). MRI applied the JMA nonhydrostatic model (NHM) with a horizontal resolution of 15 km to the ensemble prediction and developed five initial perturbation methods; one-week EPS downscaling, the targeted global singular vector (SV) method, the mesoscale SV method, the breeding growing mode (BGM) method and a local ensemble transform (LET) method based on the local ensemble transform Kalman filter (LETKF). Prior to the 2008 intercomparison, the five methods were compared objectively by evaluating ensemble spreads, the root mean square error (RMSE) of the ensemble mean against the analysis, the quantitative precipitation scores for the ensemble mean and probabilistic forecasts. To improve the initial conditions, the JMA mesoscale four-dimensional variational assimilation (Meso 4D-Var) system was applied to the Beijing area, and precipitation information over China was assimilated. In addition, two lateral boundary perturbation methods were developed, and their impacts on the ensemble forecast were examined. Importance of lateral boundary perturbations in the BGM and LETKF cycles was also shown.

Six international participants conducted the intercomparison for a one-month period, from 24 July to 23 August, in 2008, and they reported their results at the fourth B08RDP workshop, held at Guangzhou in April 2009. Generally speaking, the MRI EPS performed well, both in the control run and also in ensemble forecasts of weak to moderate precipitation and of surface temperature. During the period of the Beijing Olympic Games, MRI also collaborated with the Hong Kong Observatory (HKO) in the application of their nowcasting system, called SWIRLS, as part of B08FDP.

After the 2008 intercomparison, the EPS domain was shifted from China to Japan, and mesoscale ensemble predictions were performed for another month in support of the THORPEX Pacific Asian Regional Campaign. During this period, sensitivity analyses based on the mesoscale singular vector method were also conducted in near real time.

The authors of this technical report thank many people for their help in making possible our participation in the B08FDP/RDP. In particular, we are grateful to Dr. Gong Jiandong, Dr. Yihong Duan, Dr. Deng Guo, Dr. Li Xiali and Dr. Li Yinglin of the China Meteorological Administration (CMA), whose efforts were indispensable, and we also acknowledge the CMA for supporting this international project. We appreciate CMA's courtesy for giving us permission to quote their verification results in this technical report. We also thank members of the International Science Steering Committees (ISSC) and the International Technical Supporting Team (ITeST) of B08RDP/FDP, especially Dr. Jun Du of the National Centers for Environmental Prediction, Dr. Martin Charron of the Meteorological Service of Canada, Dr. Yong Wang of the Zentral Anstalt fur Meterologie und Geodynamik, Dr. Dehui Chen of the Chinese Academy of Meteorological Sciences and Dr. Bill Kuo of the National Center for Atmospheric Research (NCAR). Dr. Alan Seed of the Australian Bureau of Meteorology provided the precipitation analysis data for the Beijing area that we assimilated with the Meso 4D-Var system. Dr. Juanzhen Sun of NCAR provided us a figure of radar reflectivity distribution over China quoted in Section D-8. We also thank the staff of MRI for supporting our modeling work, especially for the use of MRI's SX-6 super computer system. We are also grateful to Yuki Honda, Masayuki Kyouda, Tadashi Fujita, Ryouta Sakai, Kiyotomi Sato and other staff members of NPD/JMA for their help with the transfer of near-real-time data from NPD to MRI and for improving the EPS. Comments by Tadashi Tsuyuki and Masaomi Nakamura of MRI, and by Ko Koizumi, Jun-ichi Ishida, Kosuke Ono and Takuya Komori of NPD on the manuscript improved this report.

The report is organized as follows. Section B presents an overview of the B08FDP/RDP project. Sections C and D report MRI's preliminary EPS results obtained in experiments conducted in 2006 and 2007, respectively. The Tier 2 cloud-resolving ensemble forecast results are also reported in Section D. Section E describes the 2008 forecast model, the initial and boundary conditions and their perturbations, the experimental system, and verification results. The application of the HKO's SWIRLS nowcasting system in B08FDP and MRI's role in support of this application are also introduced in Section E. In Section F, the scientific bases of JMA's one-week EPS, the nonhydrostatic model–LETKF, and the Mellor-Yamada-Nakanishi-Niino (MYNN3) turbulent closure model are described. In Section G, mesoscale ensemble prediction results for Japan, conducted as part of the THORPEX Pacific Asian Regional Campaign (T-PARC), and other examples of the application of the mesoscale EPS developed in B08RDP are presented.

Sections D-4-3, D-6-1, E-3-1, E-3-2, E-3-3, E-3-4, E-4-3, E-6, E-7-1, E-7-2, E-8-1, G-1 and G-2-1 were written mainly by M. Kunii; sections D-4-2, E-4-2 and E-5-1 by M. Hara; and D-5, D-6-2, D-6-3, D-7-1, D-8, E-4-5, E-4-6c, G-2-2 and G-3 by H. Seko. F-1 and F-2 were written by M. Yamaguchi; E-2-2, F-4 and F-5 by T. Hara; F-3 by T. Miyoshi; and E-8-2 by W.K. Wong (HKO). Other sections were written mainly by K. Saito.

B. Overview of the B08FDP/RDP project and participation of MRI

The WWRP Beijing 2008 Olympics Forecast Demonstration / Research and Development Project (B08FDP/RDP), which was conducted in conjunction with the Beijing 2008 Olympic Games, was an international research project of the World Weather Research Programme (WWRP) of the World Meteorological Organization (WMO) for short range weather forecasting. This research project, which succeeded the Sydney 2000 Forecast Demonstration Project (Sydney 2000FDP; Keenan et al., 2003), was proposed by CMA in September 2003 at the sixth session of the WWRP Science Steering Committee, held in Oslo, Norway, and was officially approved in October 2004 at the seventh session, held in Boulder, Colorado, in the United States.

The B08FDP/RDP was divided into two components; the FDP component for a very short range forecast up to 6 hours based on the nowcasting, and the RDP component for a short range forecast up to 36 hours based on the mesoscale ensemble prediction system (MEPS). The first WWRP B08FDP/RDP workshop was held in 2005 in Beijing. There, the Meteorological Research Institute proposed to participate in the RDP component in collaboration with the Numerical Prediction Division of JMA. The RDP component was further divided into two parts; Tier-1, consisting of mesoscale ensemble prediction by regional models with a horizontal resolution of 15 km; and Tier-2, case studies using cloud resolving models with horizontal resolutions of less than 3 km. Prior to the intercomparison performed in summer 2008, preliminary experiments testing the data transfer and the EPSs of the six participants were carried out in summer 2006 and summer 2007. The second and third workshops were held after completion of the preliminary experiments, in August 2006 in Beijing and in September 2007 in Qindao, China, respectively.

The 2008 B08FDP/RDP experiment was conducted for about one month in summer 2008 to coincide with the period of the Beijing Olympic Games, which took place from 8 to 24 August 2008. The major FDP participants were the National Meteorological Center of CMA (NMC/CMA), the Atmospheric Environmental Service of Canada (AES), the United States National Severe Storm Laboratory (NSSL), the Hong Kong Observatory (HKO) and the Australian Bureau of Meteorology (BOM). The Tier-1 RDP participants were NMC/CMA, the Chinese Academy of Meteorological Sciences (CAMS/CMA), the U.S. National Centers for Environmental Prediction (NCEP), the Meteorological Service of Canada (MSC), the Zentral Anstalt fur Meterologie und Geodynamik (ZAMG) of Austria and Meteo-France, and MRI/JMA. The U.S. National Center for Atmospheric Research (NCAR), NMC and MRI/JMA conducted the Tier-2 case studies. In the Tier-1 ensemble experiment, participants were requested to run their ensemble predictions for a forecast time of up to 36 hours, starting every day at 12 UTC. The results were interpolated into common verification grids with a resolution of 0.15° over a common verification domain (105~125°E, 30~45°N). The grid point values (GPVs) were converted into GRIB2 format and transferred to the CMA's data server by 2230 UTC each day. The participants' ensemble predictions products were displayed by CMA on the B08RDP project website in near real time and were also utilized as reference information for the Beijing Meteorological Bureau's daily forecasts for the Olympic Games' venues. The project's achievements and other project-related subjects were discussed at the fourth workshop, held in Guangzhou in April 2009. A summary report (Duan et al., 2009) was submitted to the WWRP joint scientific committee in August 2009.

C. 2006 Preliminary Experiment

C-1. Overview of the 2006 preliminary experiment

A preliminary test for B08RDP was performed from 8 to 24 August 2006 by the five participating forecast centers; MRI/JMA, NCEP, MSC, NMC/CMA and CAMS/CMA. Main purposes of the 2006 experiment were construction of each participant's mesoscale ensemble prediction system (MEPS) and test of the data transfer. In the Tier-1 experiment, MEPs with a horizontal resolution of 15 km were conducted. Specifications of Tier-1 EPSs of 5 participants are listed in Table C-1-1.

Table C-1-1. Specifications of Tier-1 EPS of five participating centers in the 2006 experiment.

Participants	Model (number of ensemble member)	Initial Condition (IC)	IC perturbation	Physical perturbation	LBC
NCEP	WRF-NMM (5) WRF-ARW (5)	NCEP Global 3D-VAR	Breeding	Multi-model	Global EPS
MRI/JMA	JMA-NHM (11)	JMA Regional 4DVAR	Downscale of Global EPS (WEP)	non	JMA Regional Forecast
MSC	GEM (16)	MSC Global 3D-VAR	Targeted Global SV	Markov chain	MSC Global EPS
NMC/CMA	WRF-ARW (15)	WRF-3DVAR	Breeding	non	Global Forecast
CAMS/CMA	GRAPES (11)	GRAPES-3DVAR	Breeding	Multi-physics	Global Forecast

C-2. Numerical model for the 2006 experiment

MRI/JMA conducted 11 member mesoscale ensemble predictions with the JMA nonhydrostatic model (NHM; Saito et al., 2006a) which covers a domain of 3300 km x 3000 km (Fig. C-2-1). This domain was slightly smaller than the recommended area in B08RDP (3500 km x 3000 km) due to the coverage of the lateral boundary condition given by the Regional Spectral Model (RSM) of JMA (see C-3). In Fig. C-2-1, a fan-shaped sector over east China indicates the domain of the common verification area (105~125°E, 30~45°N). Note that the southwestern corner of the verification domain was embedded in the lateral boundary relaxation layers of NHM (24 grids = 360 km). Except the horizontal resolution and the domain size, most of them are the same as in the JMA operational mesoscale model (MSM) as of September 2004. That is, vertically, 40 levels with variable grid intervals of Δz = 40 m to 1180 m were employed, where the model top and the lowest level were located at 22060 m and 20 m, respectively. An explicit three-ice bulk microphysics scheme was incorporated, while the subgrid convection was parameterized by the Kain-Fritsch schemes. Details of physical processes and the operational application are given in Saito et al. (2006a).

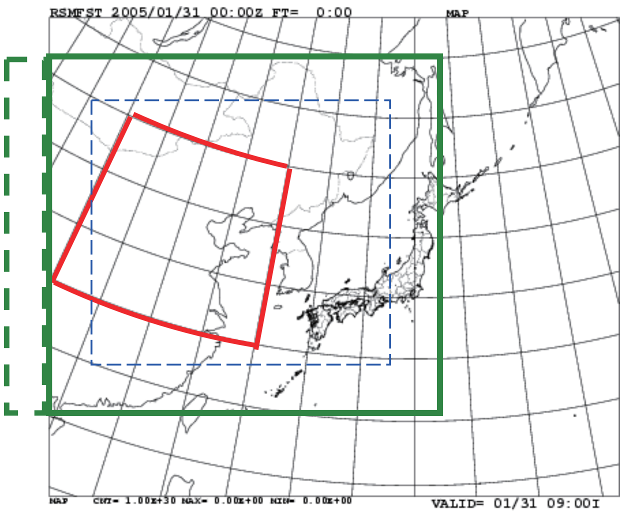

Fig. C-2-1. Domain of the MRI/JMA 2006 preliminary experiment (solid rectangle). Fan-shaped sector over east China indicates the domain of 0.15 degree common verification grids (105~125°E, 30~45°N). Broken lines show the boundary relaxation area. Broken rectangle left of the model domain shows the size of the recommended domain. Whole domain of this figure corresponds with the area that the RSM forecast was transferred to MRI as the lateral boundary conditions.

C-3. Initial and boundary conditions for the control run

In the 2006 experiment, the unperturbed initial conditions for MRI's EPS were given by interpolation of the initial conditions of the JMA operational Regional spectral model (RSM; 20 km L40). The initial condition of RSM was produced by the JMA operational regional analysis (RA), which employed a 4 dimensional variational method (Regional 4D-VAR; Shimbori and Koizumi, 2004). Horizontal resolution of the analysis was 20 km, while the inner loop model for data assimilation window (6 hours from 09 UTC to 15 UTC) was 40 km resolution. The boundary conditions were given by the forecast of RSM three hourly. These data were transferred from NPD/JMA to MRI through an exclusive line when the forecast of RSM at 12 UTC was finished. The original domain of RSM covered the East Asia domain of 6500 km x 5140 km, but data only over the domain of Fig. C-2-1, inside of the lateral boundary relaxation layers, were transferred to MRI as the boundary conditions. Thus, western edge of EPS model domain was inevitably limited as shown by a broken rectangle in Fig. C-2-1.

C-4. Initial perturbation method

As for the initial perturbations for MRI's EPS, perturbations from the JMA operational one week global EPS were employed in the 2006 experiment. The one week EPS at JMA was conducted with 51 members by the global spectral model (GSM) of JMA, whose initial perturbations were given by a global breeding method until October 2007 (see F-1). Initial perturbations in global model plane were transferred from NPD daily through the exclusive line between JMA and MRI.

The simplest way to prepare initial conditions of the mesoscale ensemble forecast may be the interpolation of one week global EPS's initial conditions to a higher resolution mesoscale model. However, we did not take this simple downscaling option because the JMA's one week EPS was conducted with a TL319L40 GSM, whose horizontal resolution (120 km) seemed insufficient to supply initial conditions to the 15 km resolution mesoscale model.

To make the initial conditions of ensemble runs in the 2006 experiment at MRI, initial conditions of the JMA's one week EPS were first interpolated to the 15kmL40 NHM model planes and five positive perturbations are extracted by subtracting the interpolated field of the control run from perturbed runs. Then, the perturbations are normalized and added to the initial condition of the control run of the 15 km NHM given by JMA's regional 4DVAR. Additionally, the normalized perturbations are subtracted from the initial condition of the control run of 15 km NHM to make five negative members.

In the normalization of the perturbation, normalization coefficients are determined so that root mean square values of the perturbations at each level do not exceed prescribed upper limits of standard error of analysis (0.7 hPa for MSL pressure, 1.8 m/s for horizontal winds (U and V), 0.7 K for potential temperature and 15 % for relative humidity, respectively). These values are based on 70 % of magnitudes of the JMA's operational Meso 4DVAR's (Koizumi et al., 2005) statistical background errors, and are the same as used in the mesoscale ensemble experiments by Saito et al. (2006b) and Seko et al. (2009).

Specifications of the 2006 preliminary MEP experiment of MRI/JMA are listed in Table. C-2-1.

Table C-2-1. Specifications of the 2006 preliminary MEP experiment of MRI/JMA.

Forecast time (number of members)	36 hours (11 members)
Horizontal resolution (grid size)	Δx=15km (221×201) with the Lambert conformal projection
Vertical levels	40 levels, Δz=40-1180 m
Initial condition for control run	JMA operational Regional analysis
Initial perturbation	JMA operational one week global EPS（normalized）
Lateral boundary condition	JMA operational Regional model 3 hourly (no perturbation)
Dynamics	HE-VI scheme, Δt=60 sec, Δτ=17 sec
Cloud microphysics	3 ice bulk method
Convective parameterization	Modified Kain-Fritsch scheme
Turbulence	Diagnostic TKE
Ground temperature	Prognostic 4 soil levels (no initial perturbations)

C-5. Products

Surface level data (2m temperature, 2m relative humidity, 10m winds, MSL pressure and 3 hour accumulated rain) at uniform 0.15° grids for a common verification domain (105~125°E, 30~45°N) were transferred to CMA in GRIB2 format (for details of GRIB2 transformation, see D-6-3). Examples of the ensemble forecasts for a case of 15 August 2006 are shown in Fig. C-5-1.

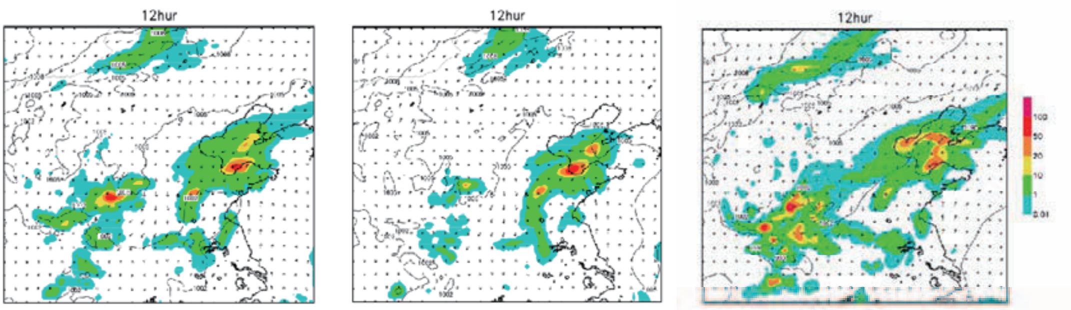

Fig. C-5-1. 3 hour accumulated rain for 12 hour forecast of NHM with the control run (Left), member M02p (center), and member M02m (Right). Initial time is 12 UTC 14 August 2006.

C-6. Verification

C-6-1. Verification by MRI

Figure C-6-1 shows 24 hour forecasts' RMSEs of the control runs and the ensemble means against the initial condition over the common verification domain. In all cases for 18 days from 2 to 19 August 2006, RMSEs of the ensemble mean forecasts are smaller than those of control runs in 10 m wind (Left). Similar tendencies are seen in 2m temperatures (Right), relative humidity and precipitation (figures not shown).

Figure C-6-2 indicates time sequences of the ensemble spreads of surface forecast during the verification period. Spreads of horizontal winds (U and V) increase up to FT=27, while the spread of U gradually decreases after that. Spread of the mean sea level (MSL) pressure reaches its maximum at FT=7 and then slightly decreases. Spread of relative humidity (RH) is almost constant for most simulation period but decreases after FT=34. These tendencies are attributable to the fixed lateral boundary condition without perturbations. Compared with the forecast errors in Fig. C-6-1 (about 1.2 m/s for U and about 1 C for temperature), the ensemble spreads are insufficient.

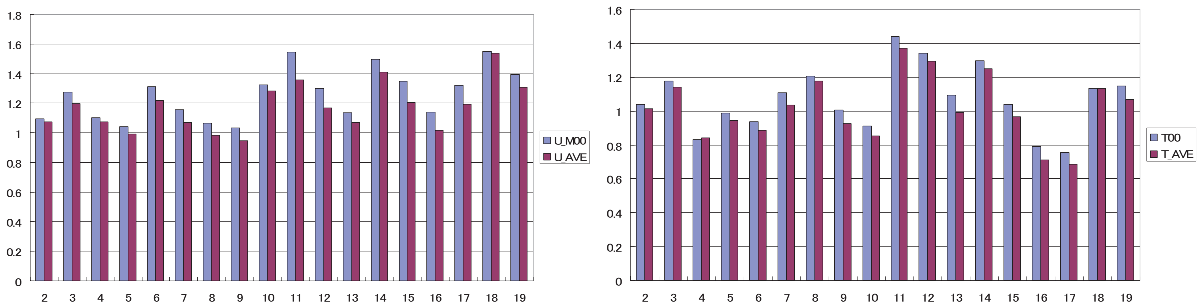

Fig. C-6-1. RMSEs of the control run (blue bars) and the ensemble mean (purple bars) over the verification domain at FT=24 against the initial conditions. Verification period is 18 days from 2 to 19 August. Left) 10 m wind (U). Right) 2 m temperature.

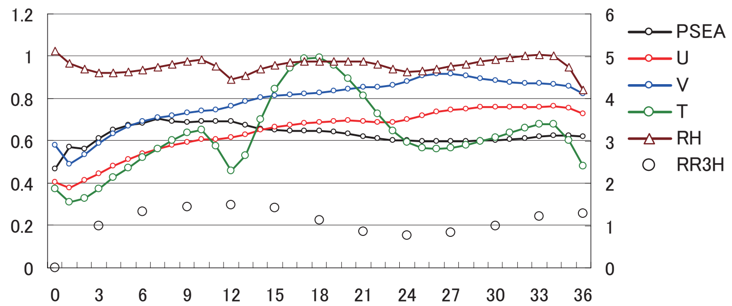

Fig. C-6-2. Time sequences of the ensemble spreads. Unit of the left vertical axis is 'hPa' for MSL pressure (PSEA), 'm/s' for horizontal winds (U and V), 'K' for 2m temperature (T), respectively. Unit of the right vertical axis is '%' for relative humidity (RH) and 'mm' for 3 hour accumulated rain (RR3H), respectively.

C-6-2. Verification by CMA

Preliminary verification of the 2006 experiment was performed by CMA (Li and Li, 2006). Forecast results in the common verification grids with a resolution of 0.15° (105~125°E, 30~45°N; Fig. C-2-1) were compared with the 400 synoptic observation stations and 722 dense auto observation stations (Fig. C-6-3). At every verification point, the domain with the radius of 0.075 degree was scanned and observation values were interpolated to the verification grid; if there was no station belonging to the 400 stations subset, a nearest auto station to the grid point was chosen.

Talagrand diagram for surface (2m) temperature at FT=24 of the MRI/JMA ensemble forecast is given in Fig. C-6-4. Every member has a similar contribution to EPS but many of the observations exceed the forecast range. As seen in Fig. C-6-5, ensemble spread is too small compared with the forecast errors (2-3 °C).

Similar tendencies were seen in EPS results by other participating centers (NCEP, MSC, NMC and CAMS). RMSE in the ensemble mean and the threat score of precipitation by MRI/JMA's EPS were relatively better than other participants (figures not shown).

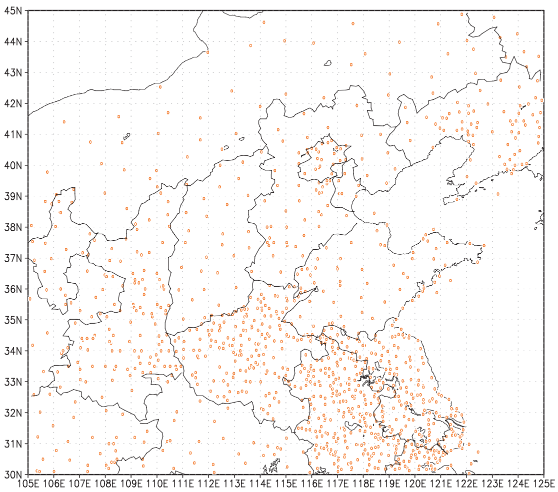

Fig. C-6-3. Surface observation points used for verification in B08 RDP. After Li and Li (2006). Courtesy of NMC/CMA.

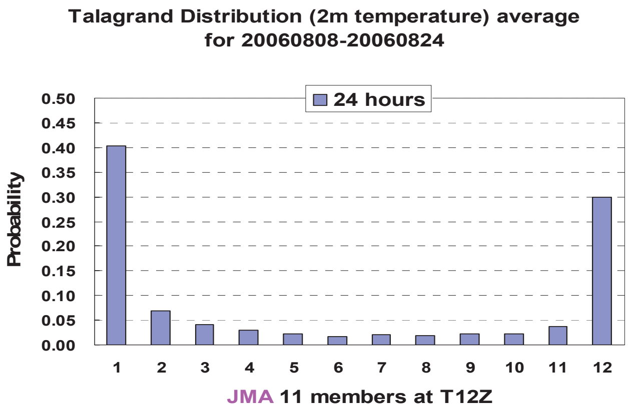

Fig. C-6-4. Talagrand diagram on surface (2m) temperature at FT=24 of MRI/JMA ensemble forecast. Period is 17 days from 8 August to 24 August 2006. After Li and Li (2006). Courtesy of NMC/CMA.

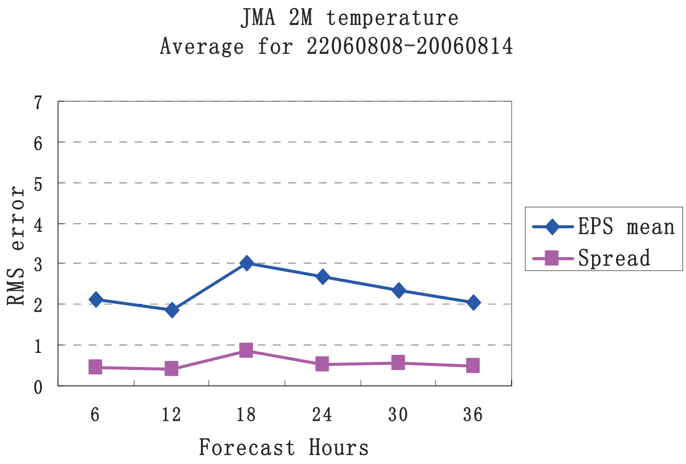

Fig. C-6-5. Ensemble spread and RMSE of the ensemble mean for surface (2m) temperatures by the MRI/JMA ensemble forecast. Period is 17 days from 8 August to 24 August 2006. After Li and Li (2006). Courtesy of NMC/CMA.