論 文 内 容 要 旨

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学位論文の 題　　目	Application of ensemble dynamical downscaling to medium-range forecast of surface air temperature over northeastern Japan during summer. (夏季の東北地方における地上気温を対象とした中期予報へのアンサンブルダウンスケールの適用)		

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The surface air temperature has large impacts on crops in their quality and quantity. In decision to reduce the damage of crops, high-resolution medium-range probabilistic forecasts of surface air temperature fields should be helpful. In northeastern Japan, a northeasterly wind called Yamase sometimes brings anomalously cool and cloudy weather during summer, and causes serious damage to crops. The anomalous temperature fields are largely influenced by complex terrain, while Yamase itself is considered as a part of large-scale flow. Therefore, it is necessary to consider effects of smaller-scale phenomena as well as large-scale phenomena. Meanwhile, since the growth of forecast errors generally depends on the state of the atmosphere, it is also important to predict the reliability of forecasts.

Even operational global models for medium-range ensemble forecasts are still too coarse to realistically represent both temporal and spatial variability of the surface air temperature. Although ensemble dynamical downscaling forecasts are expected to be an alternative, its validity for medium-range surface air temperature forecast has not been fully investigated. The purpose of this study is to assess ensemble downscaling for medium-range forecasts of the detailed spatial distributions of surface air temperature.

First, to evaluate the surface air temperature simulated by dynamical downscaling model itself, a perfect boundary experiment was conducted. In this experiment, the Japan Meteorological Agency (JMA) nonhydrostatic models (NHMs) with horizontal resolution of 25 km, 5 km, and 1.5 km were used as dynamical downscaling models. Japanese 55-year Reanalysis data were adopted as the initial and lateral boundary conditions. The experimental periods were set to July 2003 and 2004. In July 2003, a cool summer is brought by Yamase, while a hot summer is brought due to no influence of Yamase in July 2004.

The bias of diurnal temperature range is found to be reduced with dynamical downscaling in both July 2003 and July 2004. This is the results from the improvement in the reproduction of local circulations and clouds with dynamical downscaling. In particular, the reduction of the bias in July 2003 is attributed to the improvement in the reproduction of clouds accompanied by Yamase, whose distributions are largely influenced by terrain. On the other hand, the downscaled daily mean air temperature has warm bias and the bias accounts for about 60 % of the RMSEs in both July 2003 and 2004. This implies that bias correction is helpful to extract effective signals from dynamical downscaling results. Meanwhile, the warm bias of the

daily mean temperature is enhanced with dynamical downscaling in July 2004. The features are not found in July 2003. These results suggest that the dynamical downscaling model have some deficiency in clear days and the effects of errors are larger than those of enhancement of the horizontal resolution.

Second, to assess medium-range forecasts of the detailed spatial distribution of the daily mean surface air temperature, an ensemble downscaling forecast experiment was conducted using NHMs with horizontal resolutions of 25 km and 5 km. In this experiment, the JMA's one-month ensemble hindcast data, which consist of 9 ensemble members, were adopted as the initial and lateral boundary conditions. The initial times were set to 20 June, 30 June, 10 July, and 20 July from 2000 to 2009. The bias was corrected at each forecast time and at each position against the surface air temperatures observed by the Automated Meteorological Data Acquisition System (AMeDAS).

Single dynamical downscaling forecasts enhance the temporal and spatial variability of surface air temperature which is underestimated with the coarse global model. As an effect of the increase of the variability, single dynamical downscaling forecasts amplify the errors in lateral boundary conditions. The ensemble means of downscaling forecasts have 15 % smaller RMSEs compared with the single downscaling forecasts, and still have larger variability than the coarse global forecasts have. The ensemble means of downscaling forecasts can successfully extract reliable signals with information of local circulations. Moreover, the ensemble downscaling forecasts have 80 % larger spreads than the global forecasts. This is because ensemble downscaling forecasts can add the uncertainty including effects of smaller-scale phenomena. The result suggests that ensemble downscaling forecasts can provide the probabilistic forecasts considering the effects of local-scale phenomena that cannot be reproduced with coarse global models.

An empirical orthogonal function (EOF) analysis is conducted. The analysis clarified that the predictability depends on the EOF modes. The predictable periods are 8 days for the homogeneous mode over northeastern Japan, 5 days for the Yamase mode (east-west mode), 2 days for the north-south mode. The dynamical downscaling can properly predict amplitudes of the EOF modes. Particularly regarding the Yamase mode, the dynamical downscaling can predict 90 %, though the global model can do only 20 %. This result indicates that the validity of ensemble downscaling for medium-range forecast of surface air temperature field induced by Yamase.

This study shows the validity of ensemble downscaling for medium-range forecasts of the detailed spatial distributions of surface air temperature. The ensemble downscaling is useful to estimate realistic features including effects of small-scale phenomena such as spatial variability, temporal variability, and probabilistic distribution. Therefore, results of the ensemble downscaling have a potential in use as inputs of models such as agricultural models that need realistic surface variables. It is also possible to estimate the reliability of the forecasts with contribution rates of the predictable modes in the ensemble mean forecasts. In addition, this study suggests that even the state of the art dynamical downscaling model have some deficiency in terms of the reproduction of surface air temperature. Further improvements in the model are needed.

論文審査の結果の要旨

福井真は、夏季の東北地方の地上気温を対象とした中期予報について、全球アンサンブル予報のダウンスケール数値シミュレーション(アンサンブルダウンスケール)の適用可能性を調べた。

農業では、一週間程度先の気温の中期予報に関する要望が強い。現在の週間予報では比較的解像度の低い数値モデルが用いられており、時空間の自然変動度が小さく、地域の情報を得ることは難しい。地域予測を行うためにダウンスケールという手法が考えられる。しかし、中期予報の予測可能性は全球予測モデルの予測性能で決まっており、単純にダウンスケールしても有益な情報は得られない。そこで、本研究ではアンサンブルダウンスケールを利用し、夏季の東北地方の地上気温の中期予報について、有効な情報を抽出できるかどうか調べた。

まず、現状のダウンスケールモデルの気温について再現性能を調べた。側面境界条件には解析値を用い、解像度が 25 ㎞、5 ㎞、1 ㎞の多重格子モデルでダウンスケールし、その結果をアメダス観測データと比較した。気温の日較差の再現精度は、解像度を増すに従い向上した。しかし日平均気温の再現は難しく、モデルの改良とアメダスデータの代表性について検討が必要であることを示唆した。地域の気温予測ではバイアス修正したアノマリー予測が適当であることを示した。

次に、気象庁の気候情報課の協力を得て、アンサンブルダウンスケール中期予報実験を行った。単独のダウンスケール予報は、自然変動度の大きさは適切に再現するが、大規模場の予測誤差を増幅し、実用には不向きである。アンサンブル予報を行いその平均をとることにより、自然変動度を保ちつつ、予測誤差を抑えることに成功した。また、アンサンブルダウンスケール予報は、メソスケールに関連した不確実性の情報を含み、メソスケール確率予報の有効性を示唆した。予測結果を経験的直行関数の固有関数で展開すると、モード毎に予測可能期間が異なることを示し、ヤマセを代表するモードは、予測可能期間 5〜6 日であった。

アンサンブルダウンスケール法は地域の気温の中期予測に有効である。全球予報モデルやダウンスケールモデルの性能が向上すれば、一層の効果が期待できる。本研究は、自立して研究活動を行うに必要な高度の研究能力と学識を有することを示している。したがって，福井真提出の博士論文は，博士（理学）の学位論文として合格と認める。