Proc. IAHS, 369, 7–11, 2015
proc-iahs.net/369/7/2015/
doi:10.5194/piahs-369-7-2015

Downscaling medium-range ensemble forecasts using a neural network approach

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Received: 15 April 2015 – Accepted: 15 April 2015 – Published: 11 June 2015

Abstract. In this study, we present an application of self-organizing maps (SOMs) to downscaling weekly ensemble forecasts for probabilistic prediction of local precipitation in Japan. SOM is simultaneously employed on four elemental variables derived from the JRA55 reanalysis over area of study (Southwestern Japan), whereby a two-dimensional lattice of weather patterns (WPs) dominated during the 1958–2008 period is obtained. Downscaling weekly ensemble forecasts to local precipitation are conducted by using the obtained SOM lattice based on the WPs of the global model ensemble forecast. A probabilistic local precipitation is easily and quickly obtained from the ensemble forecast. The predictability skill of the ensemble forecasts for the precipitation is significantly improved under the downscaling technique.

1 Introduction

Medium-range (3–10 days) ensemble forecasts can be crucial for reducing an impact of extreme events such as floods by increasing the capability of earlier weather warnings with more confidence than deterministic forecasts. However, in generally, spatial resolution of global models is low and therefore they are not suitable for surface variables that are of greatest relevance to users. Empirical/dynamical downscaling methods (e.g. Maraun et al., 2010) are often used to produce output at the smaller spatial scales required by the end users. In empirical downscaling, local climate is assumed to be a function of the large-scale climatic state and physical features of the local environment. Due to the huge amount of data given in medium-range ensemble forecasts, efficient analysis and downscaling tools are required to extract useful features, providing more simple and manageable information. Attempts to overcome the problem of downscaling for large number of ensemble forecast, recent some studies (Gutiérrez et al., 2005) propose the usage of self-organizing map (SOM; Kohonen, 1982)-based analogue technique for precipitation downscaling of forecast. The scope of this study is to evaluate a precipitation prediction which uses atmospheric forecasts from the JMA (Japan Meteorological Agency) Ensemble Prediction System (EPS) and verify the ability of the SOM-based downscaling technique at forecasting probabilities of local precipitation for medium-range lead times.

2 Data and downscaling method

2.1 Data

Atmospheric data for the period 1958–2008 used in this study were taken from the Japanese 55-year Reanalysis (JRA-55; horizontal resolution 1.25°; Ebita et al., 2011). We use historical high-resolution (0.05°) daily precipitation data over the Japanese land from the product in APHRODITE project, which is referred to as "APHRO_JP" (Kamiguchi et al., 2010). As atmospheric ensemble forecasts, a TL319, 60-level version of JMA-EPS from 2009 to 2011 was used. The EPS constructs 51 ensemble members every day (12:00 UTC) by perturbing initial conditions based on the singular vectors identifying the most unstable directions of the phase space. The boreal early summer (from 1 June to 31 July) and late summer (from 1 August to 30 September) are targeted in this study because it is the period of most hazardous weather season in Japan.

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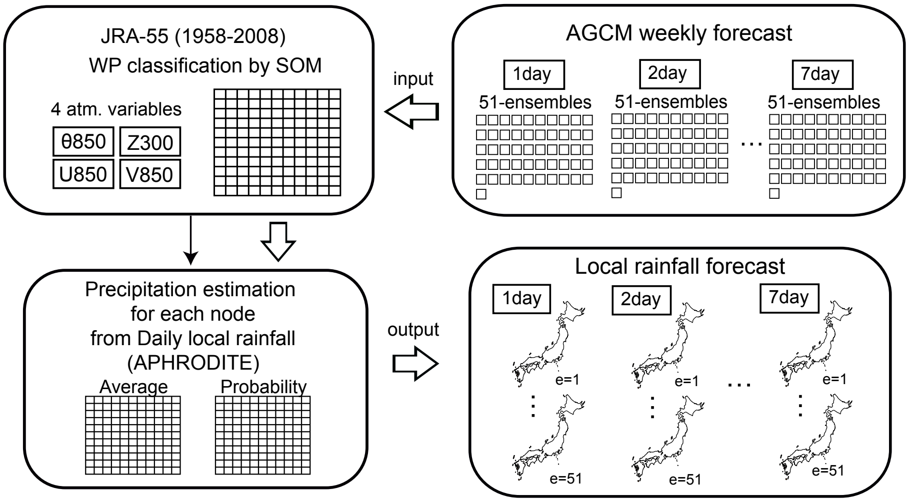

Figure 1. Schematic diagram of the SOM-based downscaling method.

2.2 SOM technique

We apply SOM for clustering a space of daily weather patterns (WPs) over the western Japan during the period 1958–2008 and linking it to the local precipitation. We use the four input fields of standardized anomalies for each day that are concatenated into a vector as input vector of SOM. Each of the arrays on the SOM is denoted as a node, which has one reference vector. SOM classifies input data into a two-dimensional plane utilizing similarities with the extracted patterns (reference vectors) on the map (e.g. Hewitson and Crane, 2002; Ohba et al., 2015). In this study, we use torus-SOM that has no difference of neighborhood sets and no edge in map. The SOM map adopted in this study consists of 20×20 neurons (i.e. 400 WPs). We selected four observed variables as input for SOM: 850 hPa equivalent-potential temperature (θ_e), zonal and meridional wind and 300 hPa geopotential height (GH) anomalies. Anomalies were identified by removing a mean climatological cycle and normalized with respect to each variable. For each SOM node, we also take the subset of the related daily precipitation to estimate the mean local precipitation and develop a precipitation PDF for each SOM node.

2.3 Rainfall downscaling method based on SOM

The schematic diagram of the algorithm of downscaling technique is represented in Fig. 1. Based on the link between the SOM derived WPs (represented by a reference vector) and related local precipitation, we obtain a forecast for a daily precipitation prediction from the EPS. This is an alternative to conventional analogue techniques (e.g. Lorenz, 1963). We take the same atmospheric window (region) and variables that we used to train the SOM and extract these from the EPS. Each WP of the ensemble forecast is assigned to its winner node, according to its distance from the reference vectors. Thus, the search of WP is conducted in the space of reference vectors which reducing significantly the computational cost compared with the conventional analogue method. For each season (JJ and AS), 51 forecast patterns are daily available. The composited PDF of the local forecast is finally obtained from the PDF which is assigning the local precipitation to each node and each of the grids. The locations of the precipitation data grid cells define the locations of the downscaling targets. This downscaling technique is applied to western Japan for early and late summer, respectively.

3 Rainfall downscaling of weekly ensemble forecast

Figure 2 shows the precipitation for observation (left panel), and downscaled precipitation (center panel) and raw precipitation (right panel) of ensemble mean of EPS for the mean of forecast one day during August–September 2011. As expected, because of the relatively low spatial resolution of the EPS, the precipitation response in the EPS raw cannot capture both the spatial distribution and intensity of local precipitations. However, by using the SOM-based empirical downscaling, the predicted precipitation relatively well captures the overall features found in the observed precipitation.

A heavy rainstorm caused by a stationary front (Baiu front) attacked northern Kyushu region (western edge of Japan) in late July 2009 (from 19 to 26 July 2009). Figure 3a shows the footprint of 51-weekly ensembles on the SOM lattice predicted from 19 July 2009. The solid box represents the actual state (most close WP). It is worth mention here that the top (right) edge of the SOM lattice is connected to bottom (left) edge since we use the torus-type SOM. The WP frequencies of the ensemble forecast extend gradually on the SOM while keeping the aggregation in some extent. In this case, it could be conceivable that the medium-range ensemble forecast relatively well capture the atmospheric condition of the actual

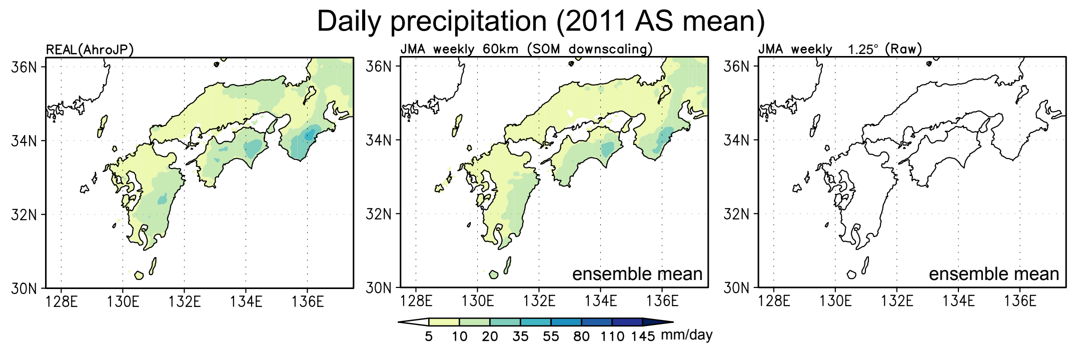

Figure 2. **(a)** Daily mean precipitation (mm day^{-1}) for observed, downscaled EPS (ensemble mean), 60 km EPS raw (ensemble mean).

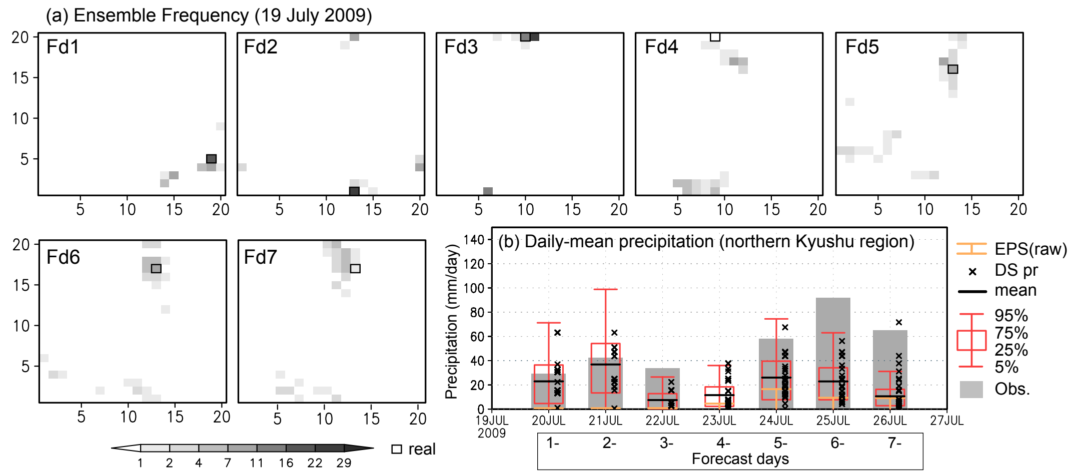

Figure 3. **(a)** SOM frequency (best matched) of the 51-ensemble members on the SOM lattice for the forecast day 1–7. Solid black box represents the actual state. **(b)** Daily-mean precipitation obtained from the downscaling for the forecast day 1–7. The spread of the ensemble for GSM raw is presented by orange box. The node-mean downscaled precipitation and its ensemble mean are represented by black × mark and horizontal bar, respectively. Composited PDFs of downscaled precipitation obtained from the SOM are represented by red error bar. Observational precipitation (actual state) is represented by the gray bar.

state (except for forecast day 4). This analysis provides an effective way to visually grasp the broadening of ensembles.

We also show the daily-mean precipitation averaged over the northern Kyushu region for this case (Fig. 3b), obtained from the precipitation downscaling of ensemble forecast. Orange error bars represent the ensemble spread of the raw precipitation output obtained from the EPS, while the red error bars with box plots represent the PDF obtained from the downscaling. By using the downscaling of precipitation, the precipitation of EPS is significantly improved. In the first and second day of the period, the PDF and mean of downscaled precipitations are almost agrees with the observational result. While the precipitation for the 4-day forecast is significantly overestimated, it may be comes from the failure to capture the actual WP. However, the signal of atmosphere which can potentially bring a heavy precipitation is relatively well captured by the downscaled EPS, implying that it would be worthwhile to use the information at the medium-range. As for the second half of the period, the empirical downscaling relatively well capture the high-risk of heavy rainfall in some extent, while not in EPS direct rainfall. Since the ensemble forecast extend gradually, the PDF get up close to the climatological PDF.

Next, we evaluate the predictability of local precipitation obtained from the downscaling of the ensemble forecast. As for the example, the precipitation averaged over the Kyushu region is evaluated for 2009–2011. Figure 4a show the results of the downscaling for the western Japan during the early summer for each forecast days (1, 3, 5 and 7 day lead times). In this region, the ensemble mean of the model relatively well predicts the precipitations during the early summer (especially for the forecast day 1), while the amounts are relatively smaller than the observation (gray shade bar) in the most of the wet day. The prediction skill is gradually decreased (and the extent of the spread is increased) with respect to the increase of the forecast days that could be result in the close of the PDF to climatological PDF. While the forecast uncertainty is much different day by day around the

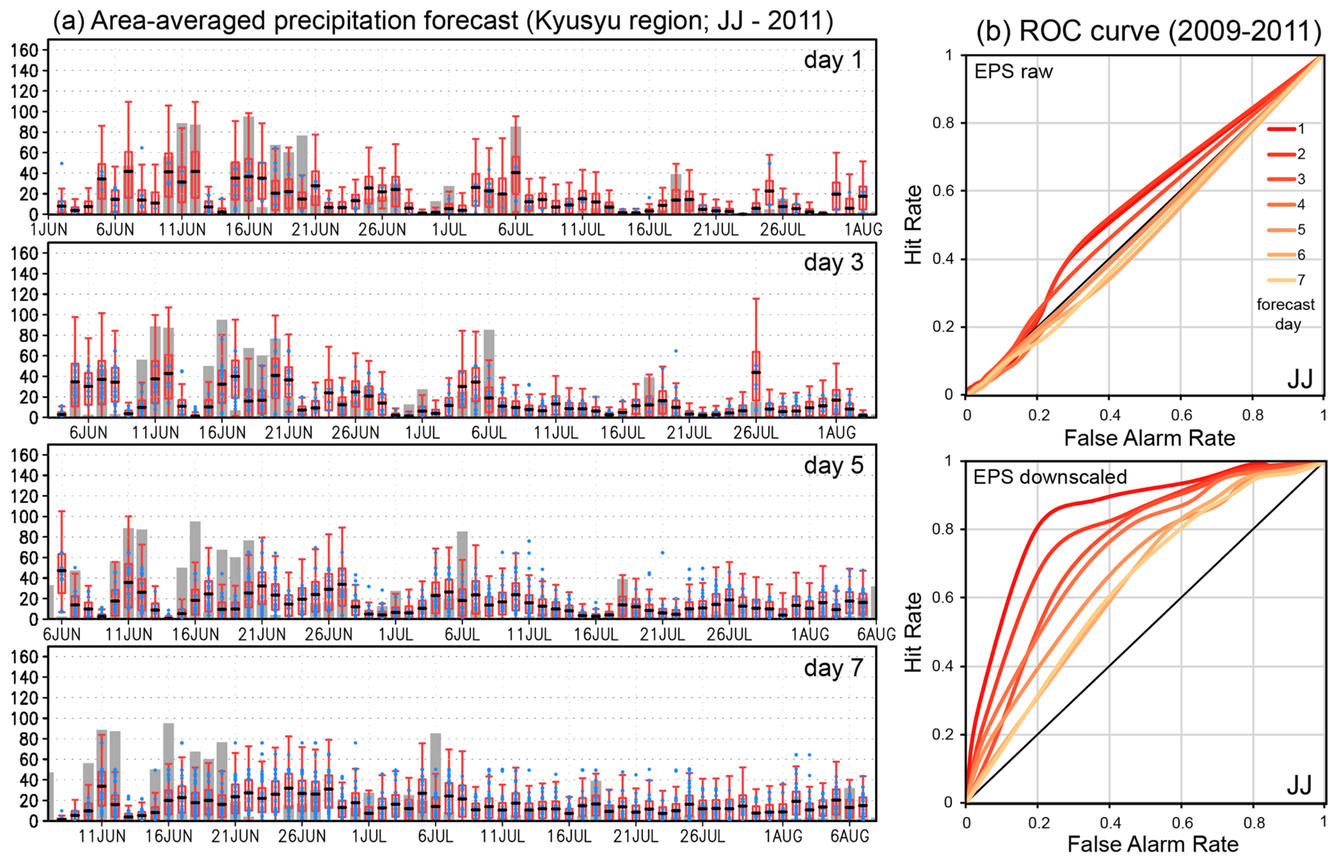

Figure 4. **(a)** Daily-mean precipitation obtained from the downscaling for the forecast day 1, 3, 5 and 7 during June–July. Composited PDFs of downscaled precipitation obtained from the SOM are represented by red error bar. The node-mean downscaled precipitation and its ensemble mean are represented by blue dots and horizontal bars, respectively. Observational precipitation (actual state) is represented by the gray bar. **(b)** ROC curves for the forecast days 1–7 for the precipitation of EPS raw and SOM downscaling during June–July at the periods 2009–2011.

forecast day 3–5, that in the forecast day 7 is almost similar through the days.

This downscaling technique can also be evaluated in probabilistic form, computing the probability of exceeding a given threshold. A standard verification methodology for probabilistic forecasting is relative operating characteristics (ROCs). The derivation of ROCs is based on contingency tables for the number of observed occurrences and non-occurrences of an event as a function of the forecast occurrences and non-occurrences. In order to check the skill of the downscaled forecasts for different lead times, we show the ROC curves obtained for the period 2009–2011 (Fig. 4b). As expected, the precipitations in the EPS direct output has basically no predictability skill. However, the predictability skill of the precipitation is significantly improved by the downscaling. Again, the prediction skill is gradually decreased with respect to the increase of the forecast days.

4 Conclusions

In this study we have illustrated the use of SOMs for analysis and downscaling of the medium-range forecasts produced by the EPS, to confirm the availability of regional mean precipitation for hydrological forecast. Via the downscaling, the precipitations associated with WPs can be predicted some days in advance and therefore the predictability skill of the precipitation is significantly improved. From the results, we conclude that the SOM-based downscaling can be an effective technique when we use very large number of ensemble forecasts. However, the downscaling approach underestimates the rainfall, particularly when heavier rainfall amounts have been observed. This point could be related with the use of old rainfall data, observed before AMeDAS observation network system established in the mid-1970s. We are now preparing to add statistical model to overcome this point, and a quantitative assessment will be done in future to more comprehensibly analyze performance of the approach.

The methodology presented in this study offers an inexpensive solution that may be quickly employed with a broad range of multi-model ensemble forecast outputs while we use the single model EPS. We will try the use of the multi-model data in the future study and the application of multi-model medium-range forecasts in different sectors, such as dam-management, hydroelectric power generation, and disaster prevention.

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