Developing an early warning system to mitigate temperature stress on rice production

Yoshiji Yokote, Director, Climate Prediction Division, Global Environment and Marine Department, Japan Meteorological Agency

A recent pilot project jointly conducted by the Japan Meteorological Agency and the National Agriculture and Food Research Organization's Tohoku Agricultural Research Center saw the development of climate information services for the agricultural sector in the Tohoku region.

The accuracy of seasonal forecasts issued by the Japan Meteorological Agency (JMA) has increased thanks to improved prediction techniques and advances in understanding regarding the predictability of climate-related phenomena. However, seasonal forecasts have not been effectively deployed in some user sectors. One reason for this is that JMA's seasonal forecast is probabilistic in three categories (below-normal, near-normal and above-normal) on a regional scale, meaning that it is not necessarily easy to use or comprehend. Against such a background, JMA sought ways to develop easy-to-use information tailored to users' requirements in order to support their decision-making activities in various sectors. As part of such efforts, JMA began issuing Early Warning Information on Extreme Weather (EWIEW) in March 2008. EWIEW indicates the possibility of very high or low temperatures up to two weeks ahead, and contributes to the implementation of farming measures against damage caused by extreme weather phenomena such as very cold conditions.

The National Agriculture and Food Research Organization (NARO) is Japan's largest research organization addressing agriculture, food and rural communities. Its Tohoku Agricultural Research Center (TARC) is one of the leading institutions in the field of studies on the use of weather and climate information for the agricultural sector and provides such data to end users (farmers). NARO/TARC's recent activities have included consideration of how to supply improved information with a greater level of tailoring to end users. In addition, there have been good long-term relationships between NARO/TARC and local JMA observatories in the Tohoku region (in the northern part of Japan's mainland).

In July 2009, JMA hosted an international event titled The Tokyo Climate Conference: Better Climate Information for a Safe and Sustainable Society. The aims of the conference were:

- To identify actions and methods for the development of an effective framework involving users and providers in order to create user-oriented products and promote their utilization with a focus on the Asia-Pacific region
- To contribute to the World Climate Conference-3, which initiated the establishment of the Global Framework for Climate Services.

Building on the favourable long-term relationships between NARO/TARC and local JMA observatories in the Tohoku region, the conference provided an ideal opportunity for the two organizations to discuss how the use of climate information in the agricultural sector could be enhanced, and this exchange led to the idea of a pilot project that would benefit both JMA and NARO/TARC in their service and research activities.

As a result, the two organizations initiated a pilot project to promote the effective use of seasonal forecast data in Japan. The aims of the initiative were to develop climate information applicable to agriculture in the Tohoku region, which tends to be greatly affected by cold conditions, to provide customized climate information to end users (farmers) via a website, and to evaluate the information's effectiveness using a questionnaire survey. Future goals include enhancing the use of climate prediction information in various user sectors through lessons learned from the pilot project.

Dialogue and development

In the first stage of the project, JMA and NARO/TARC engaged in dialogue to determine related requirements and to exchange knowledge and information. JMA considered how to promote the better use of predictions covering the period up to two weeks ahead in user sectors, based on recent improvements in prediction skill. NARO/TARC also sought to improve the customized information it provides to end users so that better countermeasures could be taken to protect rice crops against the adverse effects of extreme temperatures, especially in the occasional cold summer conditions affecting its area of responsibility. As a result of this dialogue, the two organizations decided to target climate information towards the development of the pilot project for the farming of rice crops in the Tohoku region in summer. There were three key reasons for this choice:

- The Tohoku region is frequently affected in summer by cold north-easterly winds (known as Yamase winds), which have a great impact on rice crops
- Controlling water temperatures in rice fields by adjusting water levels is an effective countermeasure to combat the adverse effects of extreme temperatures on rice crops – for example, farmers

may increase the quantity of water to reduce the sterility effect that low temperatures can cause
- Climate prediction information is considered useful for water temperature control, as farmers require one to two weeks to prepare for the water level adjustment countermeasure mentioned above.

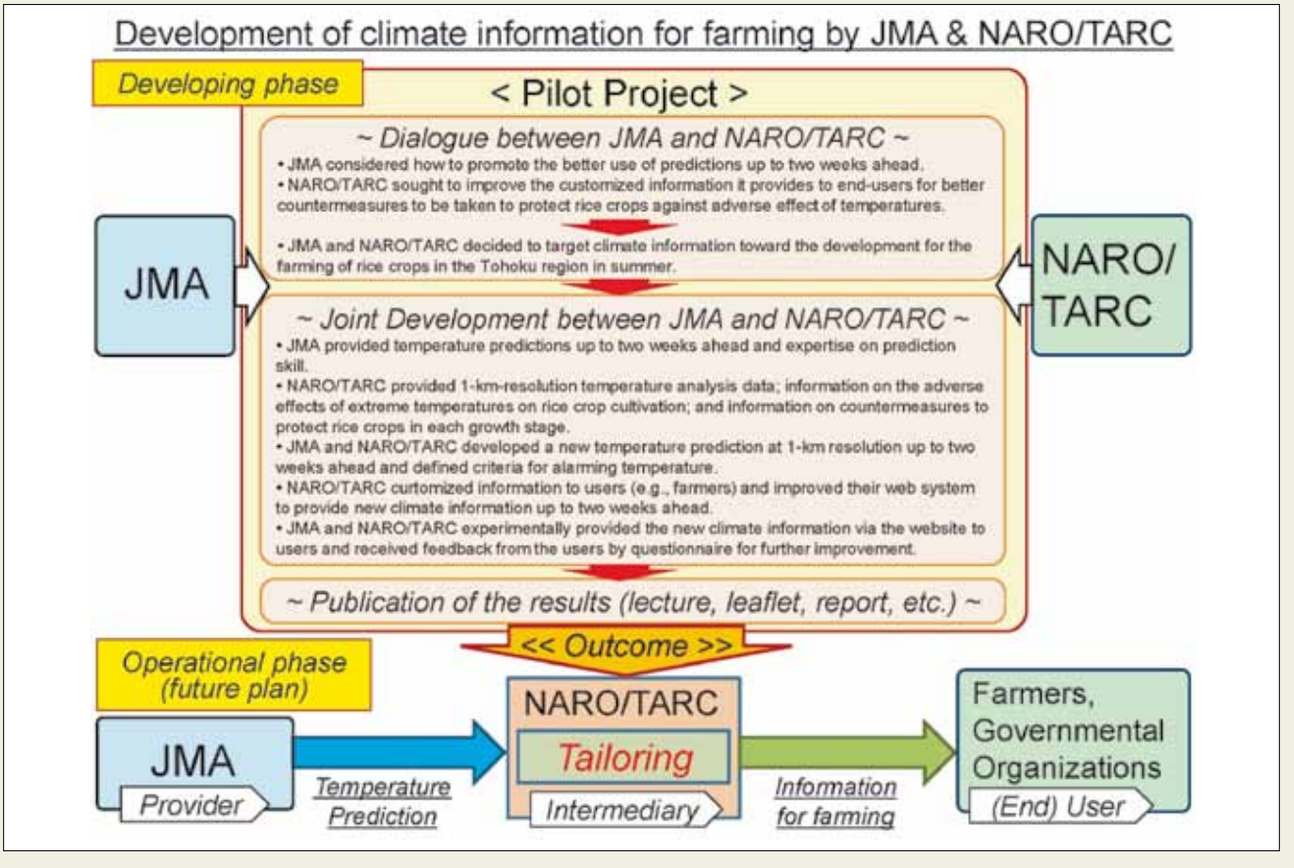
In the development phase, JMA and NARO/TARC first discussed the content of new climate prediction information suitable for the purposes at hand. JMA provided temperature predictions covering the period up to two weeks ahead and expertise on prediction skill. NARO/TARC provided:
- 1 km-resolution temperature analysis data formulated using JMA observation and local geographical data
- Information on the adverse effects of extreme temperatures on rice crop cultivation
- Information on countermeasures to protect rice crops in each growth stage.

Based on these exchanges of information and expertise, JMA and NARO/TARC developed a method to predict probability density functions (PDFs) of seven-day mean temperatures (T7d) at a resolution of 1 km for the Tohoku region covering the period up to two weeks ahead. The T7d prediction was based on a combination of two data sets: the climatological normal of T7d with a 1 km resolution covering the 30-year period from 1981 to 2010 (produced by NARO/TARC), and the PDF prediction for regional-scale T7d anomalies on the Sea of Japan side and the Pacific Ocean side of the Tohoku region (produced by JMA).

JMA and NARO/TARC then discussed criteria for alarming temperatures at which countermeasures should be taken in consideration of related issues such as the various growth stages of paddy rice, impacts on its development and countermeasures to be taken. The discussions in this phase were based on NARO/TARC's expertise and experience in agro-meteorology. As a result, two criteria were defined: temperatures of 20° C or below from the middle of July to the beginning of August, which increase the risk of sterility in rice crops; and temperatures of 27° C or above in August, which increase the risk of poor grain filling in rice crops.

To evaluate the effectiveness of this new prediction approach, JMA verified T7d prediction skill at a 1 km resolution using hindcast experiment (re-forecast) data for the 30-year period from 1981 to 2010. The predicted values were compared to actual temperatures recorded at 17 surface stations in the Tohoku region, and the results confirmed that the mean of the T7d predictions indicated

Key processes of the JMA NARO/TARC pilot project



Source: JMA

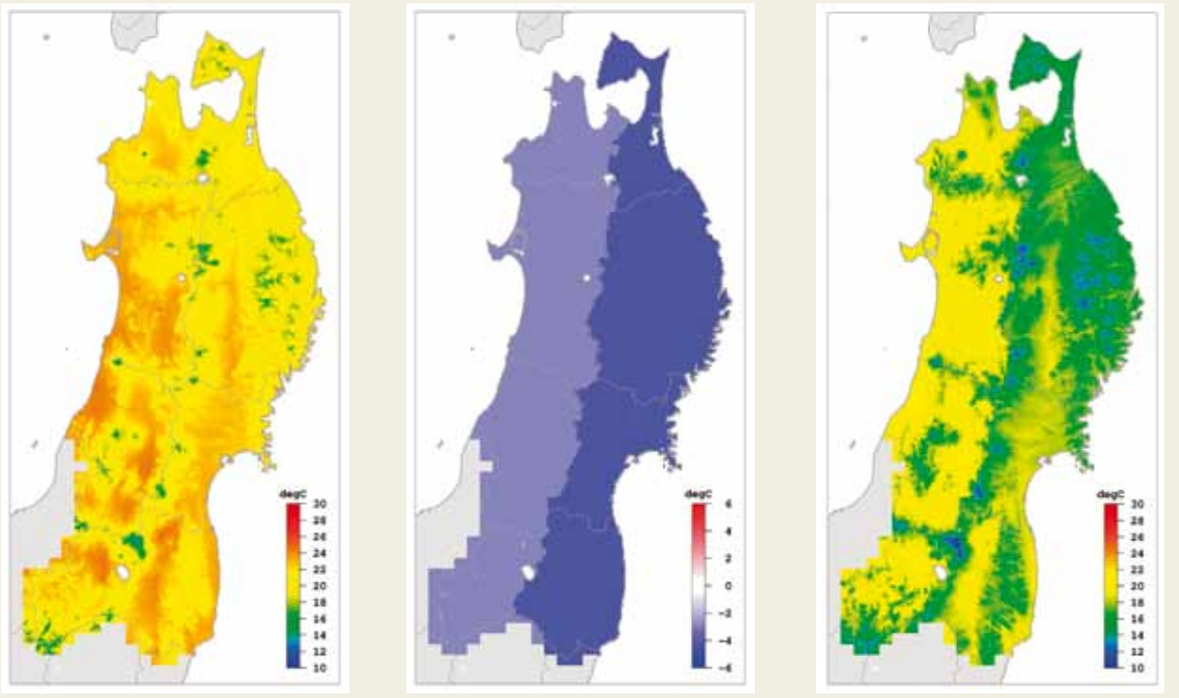
a higher level of skill than the climatological value of T7d for the period up to two weeks ahead. It was also found that the prediction skill for the probability of T7d values, at 20° C or below and 27° C or above, was reasonable. JMA verified this in relation to past extreme events, including the very high temperatures seen in 1994 and the very low temperatures seen in 2003, and found realistic temperature distributions and variations of the prediction comparable to actually observed values.

Experimental provision of climate information

During summer 2011, JMA and NARO/TARC experimentally provided the new climate information through a website to registered users (see map image on next page). In fact, NARO/TARC, in collaboration with the Faculty of Software and Information Science at Iwate Prefectural University (IPU) had operated a website providing weather and related tailored information aimed at reducing rice crop damage even before the pilot project was implemented. Under the project, NARO/TARC further customized information to users and improved the web system to provide new climate information covering the period up to two weeks ahead. The data included mean T7d predictions and the predicted probability of T7d values at 20° C or below and 27° C or above for each 1 km grid, covering the period from one to two weeks ahead. On the website, users could also view time-sequence information for specific registered points, including predicted T7d values and their variability (standard deviation) and the predicted probability of T7d values at the levels described above. The site also included maps showing the climatological occurrence of the high and low temperatures and related interpretation. When the predicted probability of T7d reaching the alarming temperature was high at a registered point, an alert was automatically sent to users' e-mail terminals and mobile phones. For example, if the possibility of temperatures at or below 20° C was high, users received an alert so that they could increase water levels in rice fields to protect against low-temperature-related damage.

After the experiment of July 2011, NARO/TARC and the IPU conducted an e-mail questionnaire survey. The questionnaire was distributed to the 154 users who participated in the experiment, and 89 replies were received. Unfortunately (as far as the experiment is concerned), no remarkably high or low temperatures occurred during the trial period, meaning that few alert messages were sent. Nonetheless, a number of respondents clearly indicated the usefulness of the information provided during the experimental period. Others underlined the need for climate information covering the period up to two weeks ahead. The results of the survey indicated that the experimental provision was fruitful, in that it highlighted agricultural users' need for longer-range forecasts in the Tohoku region and clarified that the provision of tailored climate information offers potential benefits to farmers. These findings were an important outcome of the pilot project. However, as no extremely cold conditions were seen during the experimental period in 2011, it is prema-

Seven-day mean temperature (T7d) prediction at a 1 km resolution in the Tohoku region of Japan



(a) Climatological normal of T7d at a 1 km resolution

(b) Mean value of predicted regional-scale T7d anomalies

(c) Mean value of predicted T7d at a 1 km resolution (= (a) + (b))

Source: JMA

ture to conclude the effectiveness of the new climate information services and identify possible related problems. JMA and NARO/TARC will continue to supply the new information on a trial basis in summer 2012 towards its operational provision in the near future.

Success factors

The pilot project was successful both for JMA and for NARO/TARC. In particular, JMA gained significant expertise on developing better climate information services. Some keys to the initiative's success and lessons learnt from it are summarized below:

- It is critical for climate information users and providers to engage in close and productive dialogue and to share knowledge due to the nature and difficulty of climate prediction and information. JMA and NARO/TARC frequently shared relevant information both by e-mail and at face-to-face meetings, which supported the success of the project.
- Intermediaries linking providers and end users of climate information are very important in promoting its use. In the pilot project, NARO/TARC and its researchers acted as intermediaries between JMA and end users in the agricultural sector.
- Effective use of existing systems, as well as support from partners, contributes to the smooth and successful launch of new services. In the project, experimental provision of the new information was effectively carried out using existing systems operated by NARO/TARC in collaboration with the IPU, which offered useful support as it specializes in information technology. Making the most of its experience to implement the pilot project, NARO/TARC took steps to improve its agro-meteorology information based on user feedback.

Future plans and expectations

Based on the success of the pilot project with NARO/TARC, JMA held discussions with NARO (the higher authority of NARO/TARC) with a view to efficiently expanding such collaboration to initiate similar projects in other regions. Currently, JMA is involved in four pilot projects in conjunction with four regional agricultural research centres under NARO. In addition, recognizing the effectiveness of tailored climate information in the agricultural sector, JMA has begun discussions with Japan's Ministry of Agriculture, Forestry and Fisheries (which oversees and connects all stakeholders in the agricultural sector, including those within local governments) to develop better partnerships with the sector and promote further development and effective use of climate information services beneficial to various agricultural activities.

JMA is further seeking opportunities to collaborate with operators in other fields, including the energy sector, in order to provide greater levels of usefulness and tailoring in its climate information services. Such collaboration is expected to promote efficient climate information services that are beneficial in a variety of socioeconomic activities.

A map for the experimental provision of temperature prediction to specific users (in Japanese)

Users can select mean values of the seven-day mean temperature (T7d) and the predicted probability of T7d values at or below (above) 20 (27)° C at a 1 km resolution for the period from one to two weeks ahead of 27 July, 2011, on the website

Source: JMA

Temperature prediction at a 1 km resolution

T7d prediction at a 1 km resolution was made based on a combination of two data sets: NARO/TARC provided climatological normals of T7d at a 1 km resolution covering the 30-year period from 1981 to 2010, while JMA provided PDF prediction data for regional-scale T7d anomalies for the Sea of Japan side and the Pacific Ocean side of the Tohoku region.

The climatological normals of T7d in more than 70,000 1 km grids in the Tohoku region were calculated from historical records of daily mean temperatures (T1d), which were statistically estimated using surface observation data of T1d and geographical information at a 1 km resolution. These observation data were obtained from a network of automated weather stations operated by JMA, known as the Automated Meteorological Data Acquisition System (AMeDAS).

JMA provided predicted PDFs of regional-scale T7d anomalies that are made twice a week for EWIEW. The PDFs were calculated using both numerical prediction data from JMA's operational one-month Ensemble Prediction System (EPS) and regression coefficients estimated from hindcast experiments (re-forecasts) for 1981-2010, which were carried out with the same system as that in operational use. To calculate the predicted PDFs of T7d at a 1 km resolution with respect to actual temperatures (rather than in three operational categories), two steps must be completed: statistical downscaling for predicted PDFs of T7d anomalies from a regional scale to a 1 km resolution, and addition of the PDFs to the climatological normal.

When the predicted PDFs were changed from a regional scale to a 1 km resolution, the mean values were assumed to be uniform and equal to that in each region. However, PDF variances are thought to differ for each 1 km grid even in the same region. Accordingly, differences in variances caused by the different spatial scale were estimated using historical records of temperature at a 1 km resolution provided by NARO/TARC. Based on this estimation, PDFs of the T7d anomaly at a 1 km resolution were calculated from the regional-scale values. After this process, the PDFs were added to the climatological normals for each 1 km grid so that users could use the PDFs in view of actual temperatures rather than anomalies. This facilitated user understanding and supported use in decision-making.