RESEARCH REPORT 2015-06

APEC CLIMATE CENTER

Improvement of the Real-time Forecast System on the BSISO (I): Verification for the BSISO Forecast

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Preface

As increasing international attention on subseasonal to seasonal (S2S) prediction, the APEC Climate Center (APCC) has provided the world's first operational forecast service on the boreal summer intraseasonal oscillation (BSISO), one of the important potential source for predictability within S2S timescale, in cooperation with the Working Group on Numerical Experimentation (WGNE) MJO Task Force from 2013.

Since the BSISO forecast can provide critical information for predicting hydrometeorological extreme events and related disasters, screening high-quality BSISO forecast and releasing its information are essential. In 2014, APCC has expanded BSISO service to include verification information along with its forecast on the APCC website (http://www.apcc21.org/eng/service/bsiso/fore/japcc030601.jpg). The APCC's expanded BSISO forecasting services are ultimately expected to promote its high uptake in various application areas and create socio-economic benefits.

The metrics used for producing BSISO verification information and disscusion for BSISO skill assessment is mainly provided in this report. Especially, Chapter 3 describes the real-time verification system of BSISO indices and examines the performance produced by each model and intercomparison between models in predicting BSISO. With advance knowledge of the BSISO forecast characteristics of each model, we can ensure more reliable multi-model ensemble forecasts of the BSISO in operational uses later.

Finally, I am pleased to publish this report on forecasting activities of the BSISO, with a special emphasis on verification, as one of APCC's research outcome in 2014. This report is intended to be a reference book for researchers who need to utilize more accurate BSISO forecast as well as for researchers in charge of the BSISO operational system. I welcome any feedback on this report. APCC will continuously strive to improve the BSISO forecast system and maintain its world-leading position in climate prediction. I also acknowledge the dedicated work of Dr. Hae-Jeong Kim and the support from Ms. Hye-In Jeong, Ms. Yoorim Jung and colleagues at APCC.

Dr. Chin-Seung Chung

Director / APEC Climate Cente

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ABSTRACT

The APEC Climate Center (APCC) has provided the real-time Boreal Summer Intraseasonal Oscillation (BSISO) forecast service because of the prominent role of BSISO in subseasonal to seasonal predictions (S2S) predictions. This study focuses on in terms of the improvement of the real-time BSISO forecast system through additional forecast contents and the construction of the BSISO real-time verification system at APCC. The added forecast content, a 5-day mean of Outgoing Longwave Radiation anomalies for 20-day forecasts, demystifies the BSISO activity and makes it more intuitive. The real-time verification system at the APCC produces verification information about BSISO indices using five skill metrics such as correlation, root-mean-square-error, phase error, and amplitude error and releases this information on the APCC website.

In addition, the ability of five operational models to predict BSISO indices is evaluated using information from the previous two years, 2013–2014. BSISO forecasting performance indicates that BSISO indices are generally predictable from 1 week to over 20-day forecast lead time, and the predictability of BSISO 2 is better than that of BSISO 1 in the many phases. ECMWF yields the best performance in most skill metrics, but it is worse than the other models in representing BSISO phase amplitude. Predictability increases somewhat for forecasts with well-developed BSISO at the initial time. This suggests that a more skillful forecast for the BSISO may be associated with a stronger initial amplitude. According to the performance at each phase, phases 7 and 8 are more predictable for most of the models. The potential BSISO predictability in each model far exceeds the actual skill while the upper bound for predictability varies across the models. That means the BSISO forecast skill can be improved by using better initial conditions and model physics. In conclusion, the models' performance in predicting the BSISO varies with the initial phase and amplitude of BSISO. A multi-model ensemble system is therefore advantageous in BSISO predictions.

Contents

Improvement of the Real-time Forecast System on the BSISO(I): Verification for the BSISO Forecast

1. INTRODUCTION

The Boreal Summer Intraseasonal Oscillation (BSISO), the largest convective variability over the Asian summer monsoon region, is a well-known potential source of subseasonal to seasonal predictions (S2S) (Vitart, 2013; Lee et al., 2010; Wang et al., 2009). Given the prominent role of BSISO in climate, weather and hydrological extreme events over the monsoon area (Moon et al., 2012; Kikuchi and Wang, 2010), it is a critical component of S2S predictions.

As the occurrence of and concern over extreme climate events rise, providing real-time forecasts of BSISO is becoming increasingly important. Therefore, the APEC Climate Center (APCC) has recently begun to provide the BSISO forecast information service at http://www.apcc21.org/eng/service/bsiso/fore/japcc030601.jsp, with contributions from the Bureau of Meteorology, Australia (BOM); the National Centers for Environmental Prediction, United States (US NCEP); the European Center for Medium-range Weather Forecasts, United Kingdom (ECMWF); and the United Kingdom Meteorological Office (UKMO) in cooperation with the Commission for Atmospheric Sciences (CAS)/The World Climate Research Program (WCRP) Working Group on Numerical Experimentation Madden Julian Oscillation Task Force (Kim, 2013). Interest and curiosity about the real activity of BSISO also led the APCC to construct the BSISO monitoring system (http://www.apcc21.org/eng/service/bsiso/moni/japcc030602.jsp). Accumulating available forecasts and constructing a monitoring system allow for the possibility of future uses and applications of these forecasts. As forecasts from operational models increase, it is important to confirm which model has the ability to predict more reliable BSISO indices.

As of yet, there have been only a small number of BSISO forecast studies using operational forecast models (Lee et al., 2014, unpublished manuscript; Sooraj and Seo, 2012). However, predictability studies for BSISO using different operation models are necessary to understand the level of capability of the models and to improve forecast skill from an operational perspective. Thus, the objectives of this study are to construct a real-time BSISO forecast system and to evaluate models' BSISO indices forecast in comparison with observation.

The operational forecast model, the datasets are briefly described in section 2. The section following will introduce the real-time verification system of BSISO indices and examine the performance of each model as well as the intercomparison between these models. Section 4 gives a summary and a discussion about future plans.

2. Data and Methodology

2.1. Data

2.1.1 Forecast Data

Table 1 summarizes the five dynamical forecast systems from four operational centers: BOM, NCEP, ECMWF, and UKMO. The ensemble forecasts initialized at boreal summer season from 1 May to 31 October for 2013 and 2014 are analyzed in this study. All supplied data include a 2.5-degree grid over the Asian summer monsoon region (10°S-40°N, 40°-160°E) as ASCII data.

2.1.2 Reanalysis Data

To calculate daily BSISO indices, daily averaged values of zonal wind at 850-hPa (U850) from the National Centers for Environmental Prediction/Department of Energy (NCEP/DOE) Global Reanalysis 2 (R2) (Kanamitsu et al., 2002) and Advanced Very High Resolution Radiometer (AVHRR) Outgoing Longwave Radiation (OLR) from the National Oceanic and Atmospheric Administration (NOAA) polar-orbiting series of satellites (Liebmann and Smith, 1996) are used. All the datasets have a resolution of 2.5° longitude X 2.5° latitude. Using the daily data from 1981 to 2010, the analysis of two variables on boreal summer season from 1 May to 31 October is calculated.

2.2. Methodology

2.2.1. Real-time BSISO indices

In order to facilitate real-time monitoring and forecast of the BSISO, new indices

(BSISO1 and BSISO2) are proposed by Lee et al. (2013), which were based on multivariate empirical orthogonal function (MV-EOF) analysis of daily mean OLR and U850 anomalies. The observed and predicted anomalies are obtained from subtracting the climatological seasonal cycle as well as interannual variability by removing the running mean of the last 120 days. The BSISO indices for the forecast and observation are produced by a projection of forecast anomalies onto the observed EOF structures as derived using the NCEP/DOE R2. In this study, BSISO indices are identified following the procedure described in Lee et al. (2013).

2.2.2. Verification Metrics for BSISO Forecasts

The five verification scores for BSISO real-time forecasts used in this study are correlation, root-mean-square-error (RMSE), amplitude error, phase error and mean square skill score (MSSS) following Lin et al. (2008) and Rashid et al. (2010). The details of the verification equations are summarized in the auxiliary material as an operational manual. Correlation of 0.5 and RMSE of $\sqrt{2}$ are used as an indication of the limit of a skillful forecast as discussed in Rashid et al (2010).

3. RESEARCH RESULTS

3.1. Supplement of forecast contents

As a part of improving the real-time forecast system of the BSISO, 5 day-mean OLR anomalies in forms of a latitude-longitude frame (Figure 1) are plotted for 20 days forecast in order to offer more variety of BSISO forecast service. Blue shades indicate enhanced convection, and red shades indicate suppressed convection in units of W m^{-2}.

Figure 2, available on the APCC BSISO forecast webpage, shows the spatial OLR anomalies of a forecast from each model. The added forecast contents help to make the BSISO activity more intuitive and therefore, easier to understand.

3.2. Construction of real-time verification system

This section describes the construction of the BSISO real-time verification system, and assesses the ability of five operational models to predict BSISO indices.

3.2.1 Procedure for the skill assessment of BSISO prediction

In this report, forecast data is made and evaluated based on the BSISO indices from Lee et al. (2013). As mentioned in section 2, five metrics are used to perform skill assessment of predicted BSISO indices. The real-time verification system is constructed by linking to the forecast and monitoring system. The verification system consists of two kinds of content, a real-time verification system done by setting a target date for a verification and a total verification system done by averaging skills for all available forecasts. These two types of verification information of BSISO indices have been released at the APCC website. More detailed information of the procedure for skill assessment is shown in the operational manual located in the auxiliary material.

3.2.2. Skill Assessment

3.2.2.1 Individual model

First, the bivariate scores of BSISO forecast from the individual participant models for not only the ensemble mean but also all ensemble members are computed. The scores, including correlation, RMSE, amplitude error, phase error, and MSSS, are calculated using all available forecast from 2013 and 2014.

a) BOM

Figure 3 shows the BSISO forecast skills from BOM, as measured by correlation, RMSE, amplitude error, phase error, and MSSS, as a function of lead time. In general, all predictive skills except for phase error of BSISO 1 and BSISO 2 drop as forecast time increases. The ensemble mean is more predictable than the individual members, which shows the usefulness of the ensemble prediction over the single member predictions. For BSISO 1, BOM produces skillful forecasts for up to 6–13 days (8–13.5 days) in terms of correlation (RMSE). The amplitude error of ensemble members is close to zero up to a lead time of 12 days, whereas the ensemble mean has a smaller amplitude than that observed of up to 16 days lead time. However, after a while, the amplitude of the ensemble members and ensemble mean become larger. The phase error predicted by BOM is slower than that observed by up to 7 days lead time, but then become faster after a lead time of 12 days. For BSISO 2, the skillful forecast days in correlation, RMSE, and MSSS are relatively short compared to those of BSISO 1. The skillful forecast days vary from 3.2 to 7 days in the RMSE and from 6 to 8 days in the correlation. Additionally, the scores of the ensemble mean outperform all ensemble members within the skillful prediction lead time. The phase errors of both the ensemble members and ensemble mean increase as a function of lead time, and the ensemble mean has lower error than the ensemble members. With respect to MSSS, the forecasts for ensemble members up to 7 ~ 11 days and 3 ~ 5 days are meaningful for BSISO 1 and BSISO 2, respectively. The ensemble mean for both BSISO indices extends the length of useful forecast days by about 1 day.

In order to evaluate the dependence of the forecast skill on the BSISO amplitude in the initial condition, correlations for strong, weak, and all cases are calculated (Figure 4). The cases of strong and weak BSISO forecasts are determined on the basis of the observed BSISO amplitude in the initial condition being greater than 1.0 and smaller than 1.0, respectively. The amplitude of the BSISO 1 and BSISO 2 is defined as $\sqrt{PC1^2 + PC2^2}$ and $\sqrt{PC3^2 + PC4^2}$, respectively. For both BSISO 1 and BSISO 2, the strong case has better forecast skill than all cases as well as the weak case at most lead times. According to a correlation with 0.5 as the minimum for useful skill, there is one day improvement of skillful forecast from 11 to 12 days between weak and strong BSISO 1. For BSISO 2, the skill drops to 0.5 by about 7 days lead time regardless of initial amplitude of the BSISO.

In order to demonstrate the sensitivity of the initial phase of the BSISO, the correlation and RMSE of the BSISO indices for forecasts initialized at four phase groups are shown in Figure 5 and Figure 6, respectively. In Figure 5, for the ensemble mean of BSISO 1, the BOM model has the best skill with 13 and 18 days for P78 (convection in Western North Pacific) and P34 (convection in Maritime continent and India), respectively, and the lowest skill (10 days) for P12 with active convection over Indian ocean. For the BSISO 2, the BOM model has the best skill of 9 days for P12 and P34 (convection in India and Philippine with subsequent propagation toward the South China Sea) and the lowest skill of 5 days for P56 (with convection over South East Asia). In the P78 of BSISO 1, the BOM model has a large ensemble spread, and the difference of the skillful forecast time between individual members is about 9 days. The skills of some ensemble members are higher than that of the ensemble mean after a certain time for the BSISO 2.

The results of the RMSE, as shown in Figure 6, are different with those of correlation. The lead time of the ensemble mean, which has the RMSE of $\sqrt{2}$, is longer than that of the ensemble members from 2.5 days (P34 in BSISO 2) to 11 days (P34 in BSISO 1). For the ensemble mean, BSISO 1 is the most skillful when the initial phase group of the BSISO contains phases 3 and 4, or P34 (18 days), and has the worst skill when the BSISO occurs in phases 7 and 8, or P78 (11 days); while the skill of BSISO 2 is the best in the initial phases 1 and 2, or P12 (8.5 days), and the lowest in phases 3 and 4, or P34 (5 days). The BSISO 1 forecast with regard to the phase speed predicted by the BOM model (Figure 7), is slower than the observation up to 7 and 13 days lead time for P34 and P56, respectively, and faster after that. The errors from P12 and P78 have similar tendencies characterized by different error sizes for different lead times. The forecast of BSISO 2 shows slow phase speed at the beginning in P34 and P56, and faster phase speed by lead time at about 10 days. Figure 8 summarizes the phase-space evolution of forecast and observed BSISO indices composited for initial dates. The spirals of the observed BSISO indices only have a slight counter-clockwise progression due to the small sample size in each case. The forecasts of BSISO 1 are close to reality, but those of BSISO 2 display different evolutions from the observation sometimes. Figure 9 shows the estimation of an approximate upper bound for BSISO predictability by depicting potential predictability following the method detailed in Rashid et al. (2010). There are substantial differences between the actual predictability and potential predictability in both BSISO 1 and 2. The correlation coefficients of the potential predictabilities are still high by the lead time of 20 days, whereas actual skills drop below 0.5 by 12 (BSISO 1) and 7.5 days (BSISO 2). Even though the BOM model has some limitation in predicting BSISO, we can confirm that there is the potential for improvement through better initial conditions and reduced model error.

b) CFS

Forecast skills from the CFS model are shown in Figure 10. In general, the ensemble spread is very small. Skills between members are very similar at the beginning of the lead time and gradually increase with time. The predictability from the ensemble mean is better than those from the ensemble members in every metric. In terms of predictive lead time based on the correlation, RMSE, and MSSS, BSISO 1 and BSISO 2 forecasts have a similar period of about 10 days. The CFS model can simulate the amplitude of the BSISO well up to 9 days, after which it has a large amplitude with small error. The phase predicted by the CFS model is slower than that of the observed at less than 10 days lead time and becomes faster after that in BSISO 1. The error in BSISO 2 is negative across all lead times.

Figure 11 shows the forecast skill based on the initial strength of BSISO. In BSISO 1, the first, second and third performances are strong, all and weak cases respectively. However, the scores of these three cases are hardly different, meaning the initial amplitude of BSISO does not influence the whole forecast skill in the CFS model. In BSISO2, the change of all and strong cases with time is similar. The correlation of the weak cases intermittently exceeds that of the strong cases because of its wide variation. A comparison of each phase in Figures 12 and 13 shows that the BSISO 1 forecast is very skillful in P56 and P78 since the correlation coefficient remains above 0.5 and the RMSE stays below 1.4 at 20-day lead time. The forecast skill from best to worst in BSISO 2 is P34, P56, P78 and P12. Figure 14 indicates the phase error of each phase. The phase of the predicted BSISO 1 is faster than that of the observation after about 10 days of lead time in every phase except for P12, corresponding to Figure 10. The CFS model simulates slower phase speed of the BSISO 2 over the entire lead time range in almost every phase. The index evolution of each phase is plotted in Figure 15. For BSISO 1, forecasts can capture the progression of the observation at every phase. However, the difference of angle between observation and forecast grows with time in P34. For BSISO 2, the curve of the forecast in P34 looks similar with that of the observation. Figure 16 shows that the potential predictability is very high and that the predictability for BSISO 1 is better than that of BSISO 2.

c) GFS

The GFS model has only one ensemble member. Figure 17 shows that GFS produces skillful forecasts of BSISO 1 up to 9 (MSSS), 9.5 (RMSE) and 10.5 (correlation) days with those of BSISO 2 up to 8 (RMSE, MSSS) and 10 (correlation) days. The skill of BSISO

1 is slightly higher than that of BSISO 2. Amplitude and phase error are a little small for both indices. For BSISO 1, forecast amplitude increases and phase gains speed after 5 days lead time. For BSISO 2, forecast amplitude is larger than the observation over the whole lead time range. The BSISO 2 phase predicted by the GFS model is faster than that observed at all lead times except for the period from 2 to 9 days. For both modes of BSISO, the correlation difference between strong and weak cases at the initial state is large and decreases with increasing lead time as shown in Figure 18. The correlation skill of all cases is worse than that of the strong cases but better than the weak cases in BSISO 1 (Figure 18). Additionally, there is a 2.5 day difference between when the strong and the weak BSISO 1 cases reach correlation coefficients of 0.5. In BSISO 2, the lead time of 8 days is the turning point in the skill when the correlation value for the strong case become smaller than that of the weak case. The skills according to each phase in BSISO 1(Figures 19 and 20) arranged by highest value are P78, P12, P56, P34. For BSISO 2, the phases listed in order of highest skill are as follows: P12, P56, P78 and P34. However, the score in P34 shows the best skill in terms of correlation for the first five days. The phase error in BSISO 1 (Figure 21) shows that the GFS model is faster than the observation for all lead times in P56, and the predicted phase speed changes from slower to faster than the observation at 8 around days for P34 and 10 days for P12. The forecasts of P34 and P78 are close to the observation. The predicted phase speed changes from faster to slower than the observed in P12 and vice versa in P56. The total phase error of BSISO 2 in Figure 17 appears small at the initial stage since the phase errors of P12 and P56 cancel each other out. Figure 22 shows that GFS can reasonably capture the moving of BSISO, as a whole.

d) UKM

Figure 23 illustrates a small ensemble spread of BSISO indices from the UKMO model with time. Through correlation, RMSE and MSSS, the predictive skill of the UKMO model normally reaches about 15 days and 14 days for BSISO 1 and BSISO 2, respectively. The skillful forecast lead time of BSISO 2 (~8 days) produced by this model is unexpectedly longer than that of BSISO 1 (~14 days) in terms of MSSS and correlation, whereas in general, the predictability of BSISO 2 is relatively low compared to that of BSISO 1. With regard to RMSE, the difference of skillful lead time between the lowest of the ensemble members and the ensemble mean (over 6 days) is longer than that of other models. That means the effect of ensemble mean can be maximized in predicting BSISO indices. The amplitude errors of BSISO 1 and 2 are near zero, but the predicted amplitude of BSISO 2 is slightly faster than the observed amplitude for the entire period. The phase error of BSISO reveals that the UKMO model has a consistent tendency to propagate the BSISO 1 (BSISO 2) slightly slower (faster) than the observed.

In Figure 24, the strong amplitude of BSISO 1 in the initial condition leads to better predictability for entire lead time compared to the weak case. The skill of the UKMO model to predict BSISO 1 can be improved with a gain of about 1 day when the BSISO 1 has strong initial conditions compared to weak initial conditions. For BSISO 2, the correlation coefficient of the strong case is higher than that of other cases early in the lead time but falls below the value of the weak case on day 9.5. The weak case is considerably more skillful than the strong case with regard to the lead time when the correlation skill reaches 0.5.

In Figure 25, the forecast skill as a correlation for some ensemble members is superior to that for the ensemble mean by about 1 day. For BSISO 1, when the BSISO is in phase 5 and 6, the predictability sharply decreases at early lead times, while when the BSISO is in phase 3 and 4 the skill is high. For BSISO 2, BSISO initiated from P34 and P78 is skillful. Most of phases of BSISO 2 have a lead time of above 10 days in producing reliable forecast. This is not the case for BSISO 1. Figure 25 illustrates the reason BSISO 2 has longer period than BSISO 1 in terms of useful lead time in predicting BSISO index in Figure 23. Unlike the correlation according to phase, the result from RMSE analysis shows that BSISO in most phases is skillful (Figure 26). However, BSISO 1 in phase 5 and 6 is not simulated well with the UKMO model, even for RMSE.

In Figure 27, in comparison with observations, the predicted BSISO 1 tends to diminish in speed when located in phase 1 and 2 regions. For P34 and P78, BSISO 1 forecast has low phase errors at small lead times that become faster than the observation after 6 or 7 days. For P56, the UKMO model calculates the speed of BSISO 1 to be faster and then slower than the actual convective cell. The predicted BSISO 2 propagates faster than the observed one in most phases and most of the periods. In Figure 28, the forecast of BSISO captures the tendency and initial amplitude of the observed, but there are some discrepancies in simulating the position of the initial point and the propagating speed. The UKMO model has very high potential predictability. Similar to the results of the ensemble mean, the potential predictability of BSISO 1 is inferior to that of BSISO 2. The actual forecast skill in BSISO 1 drastically drops with time, but that in BSISO 2 declines at a similar rate as its potential predictability.

e) ECM

Figure 30 shows that the ECMWF model has a high performance in predicting the BSISO 1 and BSISO 2 over 20 days through correlation, RMSE and MSSS, even though the model has a few ensemble spreads. The ensemble mean is also more skillful than the ensemble members in this model. The predicted BSISO 1, regarding the amplitude error, has a smaller amplitude than the observation from the first day of lead time. For BSISO 2, the amplitude of forecast is almost equal to that of observation up to 5 days of lead time, after which the error has a small negative value. For both BSISO 1 and BSISO 2, the phase error is small but grows as lead time increases. The ECMWF model tends to predict the progression of the BSISO slowly rather than rapidly. According to the initial strength of the BSISO, the period having predictive skill is over 20 days when the BSISO 1 initiates with a strong amplitude, but the correlation skill of the weak case is slightly higher than that of the strong case from 7 to 15 days of lead time (Figure 31). For BSISO 2, in general, the ECMWF model predicts the BSISO activity with the strong initial condition slightly better compared to that with the weak initial condition. Figures 32 and 33 show that the correlation coefficient is high in most of the phases without the distinction of BSISO mode. For BSISO 1, the skill in P78 is good enough to exceed 0.5 for the whole lead time range. For BSISO 2, the skill in P56 is best. From Figure 34, we can see a broad range of phase errors depending on the phase in addition to complicated variability of errors over the whole lead time. In Figure 35, the predicted track seems to follow the observed one well for both modes and each phase of the BSISO. Figure 36 shows that the potential predictability from the ECMWF model is outstanding and the actual forecast skill is as high as the potential predictability.

3.2.2.2. Intercomparison

The aim of this section is to understand which model has the most advantages in predicting BSISO by comparing operation models. Five scores using all available forecasts from the summers of 2013 and 2014 are shown in Figure 37. The ECMWF model shows the best performance of all of the models in predicting both BSISO modes in terms of correlation, RMSE, and MSSS over the entire lead time, while the GFS and the UKM (BOM) models have the worst skill in predicting BSISO 1 (BSISO 2). The models achieve about 9 days' (6 days') skill in BSISO 1 (BSISO 2) and display slightly greater skill in BSISO 1 than in BSISO 2. Three models (BOM, ECM, and UKM) have a smaller amplitude error than that of the observed for BSISO 1, whereas the GFS model and the CFS model show a larger amplitude error than the observed for most lead times. Most of the models, except the ECMWF model, predict stronger amplitude error for BSISO 2 than the observation for entire lead time. The CFS model shows the smallest error in representing the amplitude of both BSISO indices, whereas the skill shown by the ECMWF model is worse than the other models. In general, BSISO propagates slowly in all models except the GFS in representing BSISO 1 and the UKM in BSISO 2. The assessment of skill for well-developed BSISO at the initial time indicates that the predictability for BSISO indices improves slightly in most of the models in terms of correlation and RMSE (Figure 38). The ECMWF model also has superior skill for the BSISO with strong initial amplitude. Regarding amplitude error of predicted BSISO indices initialized with strong initial condition, there are no significant differences in result between Figure 39 and Figure 37. However, the models have a weaker amplitude of BSISO 1 at up to 4 days, and the variability of error is larger than that for all available forecasts in BSISO 2. Figure 40 and 41 show forecasts initialized at phase 7 and 8 (convection in Western North Pacific) have a higher skill in most of the models and that ECMWF is the best model in predicting BSISO in every phase. In terms of correlation (Figure 40), the models have a better performance in simulating BSISO 2 at phase 34 with active convection over Bay of Bengal and South China Sea at the start of the lead time. But the models have little ability and large diversity in predicting BSISO 1 at phase 56 (with convection across maritime continent), well known for the so-called Maritime continent predictability barrier. Considerable diversity between models is shown in BSISO 2 compared to that in BSISO 1 with regard to RMSE in Figure 40.

4. CONCLUDING REMARKS

This report aims to improve real-time forecast system of the BSISO. First, 5 day-mean OLR anomalies in the forms of latitude-longitude frames are plotted for 20 days forecast in order to add more variety to the BSISO forecast service. The added forecast contents help to make understanding the BSISO activity more intuitive and therefore easier to decipher and interpret.

Second, we have described the construction of the BSISO real-time verification system and assessed the ability of five operational models to predict BSISO indices.

In setting up the verification system, five metrics are used to perform skill assessments of predicted BSISO indices and a link is created to the forecast and monitoring system from the verification system. As a result, real-time verification information of BSISO indices has been released at the APCC website.

In addition, the ability of five operational models to predict BSISO indices is evaluated over the summers of 2013 and 2014. In terms of BSISO forecasting performance, in general, BSISO indices are predictable from 1 week to over 20 days forecast lead time, although the skill varies between models, strength, and phase of the BSISO in the initial state. The predictability of BSISO 2 is better than that of BSISO 1 in many of the phases. The ECMWF model shows the best performance overall, but it is the worst in representing BSISO phase amplitude. The BOM and ECM models have relatively large ensemble spreads, whereas the CFS and UKM models do not. For forecasts with well-developed BSISO at the initial time, the predictability increases somewhat. This suggests that a more skillful forecast for the BSISO may be attributed to a higher skill associated with a stronger initial amplitude. Phase error in predicting the BSISO also varies depending on the model. Based on the performance at each phase, phase 7 and 8 are most predictable for the majority of the models. In the composite of track for BSISO indices, the models can capture the tendency and initial amplitude of the observed BSISO indices but there are some discrepancies in simulating the position of the initial point and propagating speed, even if the observed BSISO tends to decay quickly due to small sample size. The potential predictability of models for the BSISO far exceeds the actual skill while the upper bound for BSISO predictability varies by model. That means it is possible for models to improve the BSISO forecast skill using better initial conditions and model physics. The models' performance in predicting the BSISO varies with the initial amplitude and phase of BSISO. Consequently, using a multi-model ensemble system is advantageous. With advance knowledge of the forecast characteristics of each model, we can ensure more reliable multi-model ensemble forecasts of the BSISO for operational uses. In addition, we can confirm more reliable predictability for BSISO indices once sufficient sample sizes of forecasts are obtained.

Recently, user requests for BSISO information have rapidly increased in support of risk management and decision making. Therefore, further studies will be required to regularly utilize BSISO forecasts for a number of applications such as energy, financial, agricultural, and water resources sectors.

REFERENCES

Kanamitsu, M., W. Ebisuzaki, J. Woollen, S.K. Yang, J.J. Hnilo, M. Fiorino, G.L. Potter, 2002: NCEP-DEO AMIP-II Reanalysis (R-2). *Bull. Amer. Meteor. Soc.*, **83**(11), 1631-1643.

Kikuchi, K., and B. Wang, 2010: Formation of tropical cyclones in thenorthern Indian Ocean associated with two types of tropical intraseasonal oscillation modes. *J. Meteor. Soc.Japan*, **88**, 3, 475–496.

Kim, H.-J., 2013: construction of BSISO Forecast System and Application to Summer Monsoon Prediction, *APCC Research Report 2013*, **2**, 3-32

Liebmann, B., and C. A. Smith, 1996: Description of a complete (interpolated) outgoing longwave radiation dataset. *Bull. Amer. Meteor. Soc.*, **77**, 1275–1277.

Lin, H., G. Brunet and J. Derome. 2008: Forecast skill of the Madden-Julian Oscillation in two Canadian atmospheric models. *Mon. Wea. Rev.*, **136**, 4130-4149.

Lee, J.Y., B. Wang, I.S. Kang and J. Shukla et al., 2010: How are seasonal prediction skills related to models' performance on mean state and annual cycle? *Climate Dyn.*, **35**, 267–283.

Lee, J.-Y., B. Wang, M. C. Wheeler, X. Fu, D. E. Waliser, and I.-S. Kang, 2012: Real-time multivariate indices for the boreal summer intraseasonal oscillation over the Asian summer monsoon region. *Climate Dyn.*, **40**, 493-509, DOI:10.1007/s00382-012-1588-5

Marshall, A. G., D. Hudson, M. C. Wheeler, H. H. Hendon, O. Alves, 2011: Assessing the simulation and prediction of rainfall associated with the MJO in the POAMA seasonal forecast system. *Climate Dyn.*, **37**, 2129-2141, DOI: 10.1007/s00382-010-0948-2

Moon, J.-Y., B. Wang, K.-J.Ha, and J.-Y. Lee, 2012: Teleconnections associated with Northern Hemisphere summer monsoon intraseasonal oscillation. *Climate Dyn.*, DOI:10.1007/s00382-012-1394-0.

Sooraj, K. P., and K.-H. Seo, 2013: Boreal summer intraseasonal variability simulated in the NCEP climate forecast system: insights from moist static energy budget and sensitivity to convective moistening. *Climate Dyn.*, DOI 10.1007/s00382-012-1631-6.

Vitart, F., 2013: Evolution of ECMWF sub-seasonal forecast skill scores. *Quart. J. Roy. Meteor. Soc.*, DOI: 10.1002/qj.2256.

Wang, B., J.Y. Lee, J. Shukla, and I.S. Kang et al., 2009: Advance and prospectus of seasonal prediction: assessment of APCC/CliPAS 14-modelensemble retrospective seasonal prediction (1980–2004). *Climate Dyn.*, **33**, 93–117.

FIGURE CAPTIONS

Figure 1. Snapshot of 5-day mean anomalies for 20 days forecast initialized from 4th of May in 2014 by CFS.

Figure 2. Web service for spatial OLR forecast anomalies.

Figure 3. Five skill measurements for BSISO1 and BSISO2 as a function of lead time for BOM forecasts initialized during 2013–2014; ensemble members (dashed orange line) and an ensemble mean (solid red line).

Figure 4. Correlation coefficients of the BSISO indices for strong (dashed orange line), weak (dashed red lines) and all (solid gray line) MJO cases.

Figure 5. As in Figure 4, except for initial phase of BSISO.

Figure 6. As shown in Figure 5, except for RMSE.

Figure 7. As in Figure 6, except for phase error of ensemble mean.

Figure 8. Phase-space evolution of observation and forecast for BSISO indices composited for initial phase, P12 (red curve), P34 (blue curve), P56 (green curve), P78 (magenta curve). The big marker indicates initial point of each track. The progression is shown for 20 days.

Figure 9. An estimated potential predictability (dashed orange line) and actual forecast skill (solid red line) of BSISO indices from BOM model for the last two summer.

Figure 10. As in Figure 3, except for CFS.

Figure 11. As in Figure 4, except for CFS.

Figure 12. As in Figure 5, except for CFS.

Figure 13. As in Figure 6, except for CFS.

Figure 14. As in Figure 7, except for CFS.

Figure 15. As in Figure 8, except for CFS.

Figure 16. As in Figure 9, except for CFS.

Figure 17. As in Figure 3, except for GFS.

Figure 18. As in Figure 4, except for GFS.

Figure 19. As in Figure 5, except for GFS.

Figure 20. As in Figure 6, except for GFS.

Figure 21. As in Figure 7, except for GFS.

Figure 22. As in Figure 8, except for GFS.

Figure 23. As in Figure 3, except for UKM.

Figure 24. As in Figure 4, except for UKM.

Figure 25. As in Figure 5, except for UKM.

Figure 26. As in Figure 6, except for UKM.

Figure 27. As in Figure 7, except for UKM.

Figure 28. As in Figure 8, except for UKM.

Figure 29. As in Figure 9, except for UKM.

Figure 30. As in Figure 3, except for ECM.

Figure 31. As in Figure 4, except for ECM.

Figure 32. As in Figure 5, except for ECM.

Figure 33. As in Figure 6, except for ECM.

Figure 34. As in Figure 7, except for ECM.

Figure 35. As in Figure 8, except for ECM.

Figure 36. As in Figure 9, except for ECM.

Figure 37. Five skill metrics of BSISO indices forecasts by BOM (red curve), CFS (orange curve), GFS (blue curve), UKM (magenta curve) and ECM (green curve) for the last two summers.

Figure 38. Same as Figure 37, except for correlation and RMSE of BSISO forecasts with initial amplitude greater than 1.0.

Figure 39. As in Figure 38, except for amplitude error.

Figure 40. As in Figure 5, except for ensemble mean of five models.

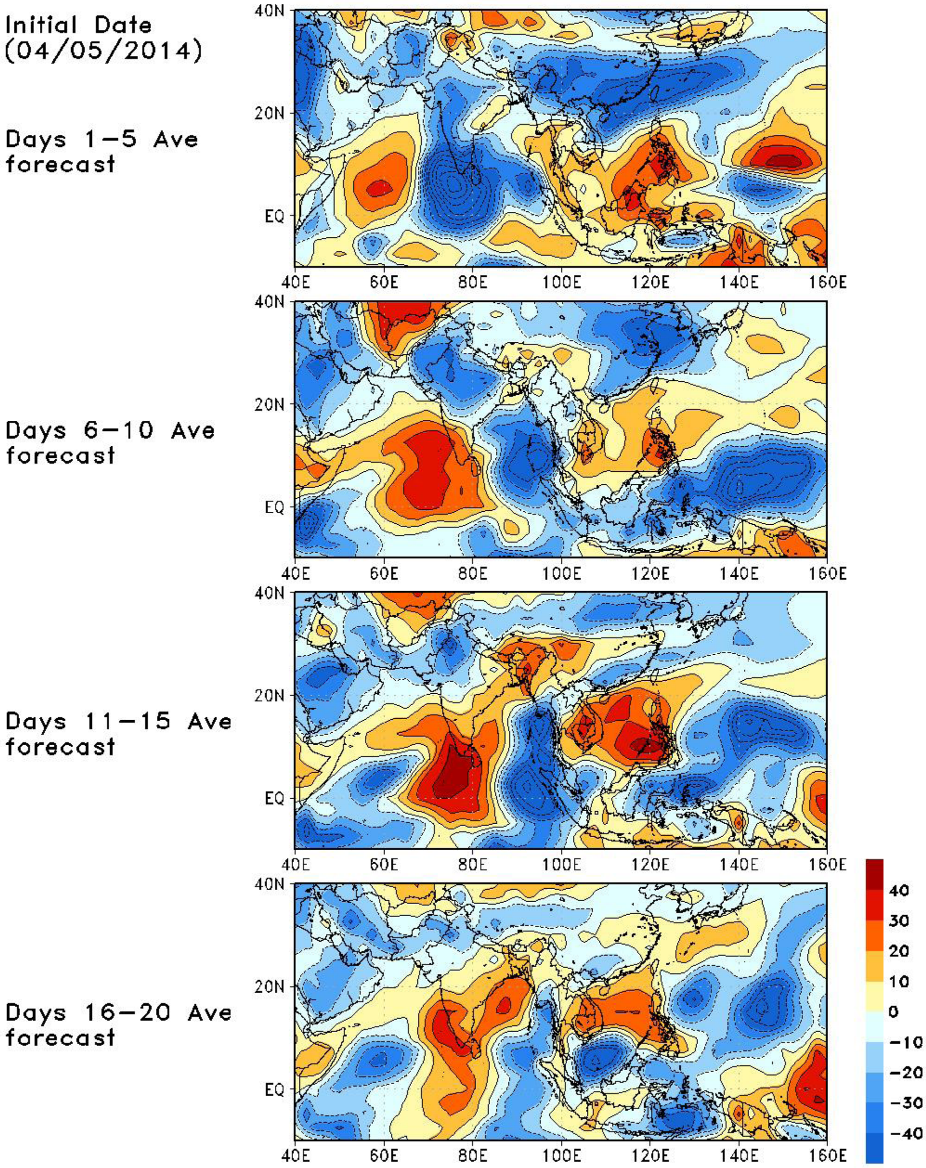
Figure 41. As in Figure 6, except for ensemble mean of five models.

TABLES

Table 1. Specific information for each of the current and planned data streams

Institute	Model	Ensemble Size	Forecast Period	Update Frequency	Resolution
NCEP	Climate Forecast System	4	40 days	Once per day	T126 L64
	Global Forecast System	1	16 days	Once per day	T574, T190 L64
BOM	POAMA 2.4 multi-week model	33	40 days	Twice per week	T47 L17
ECMWF	ECMWF Ensemble Prediction System	51	32 days	Twice per week	T639, T319 L62
UKMO	MOGREPS-15	24	15 days	Once per day	60 km L70

FIGURES



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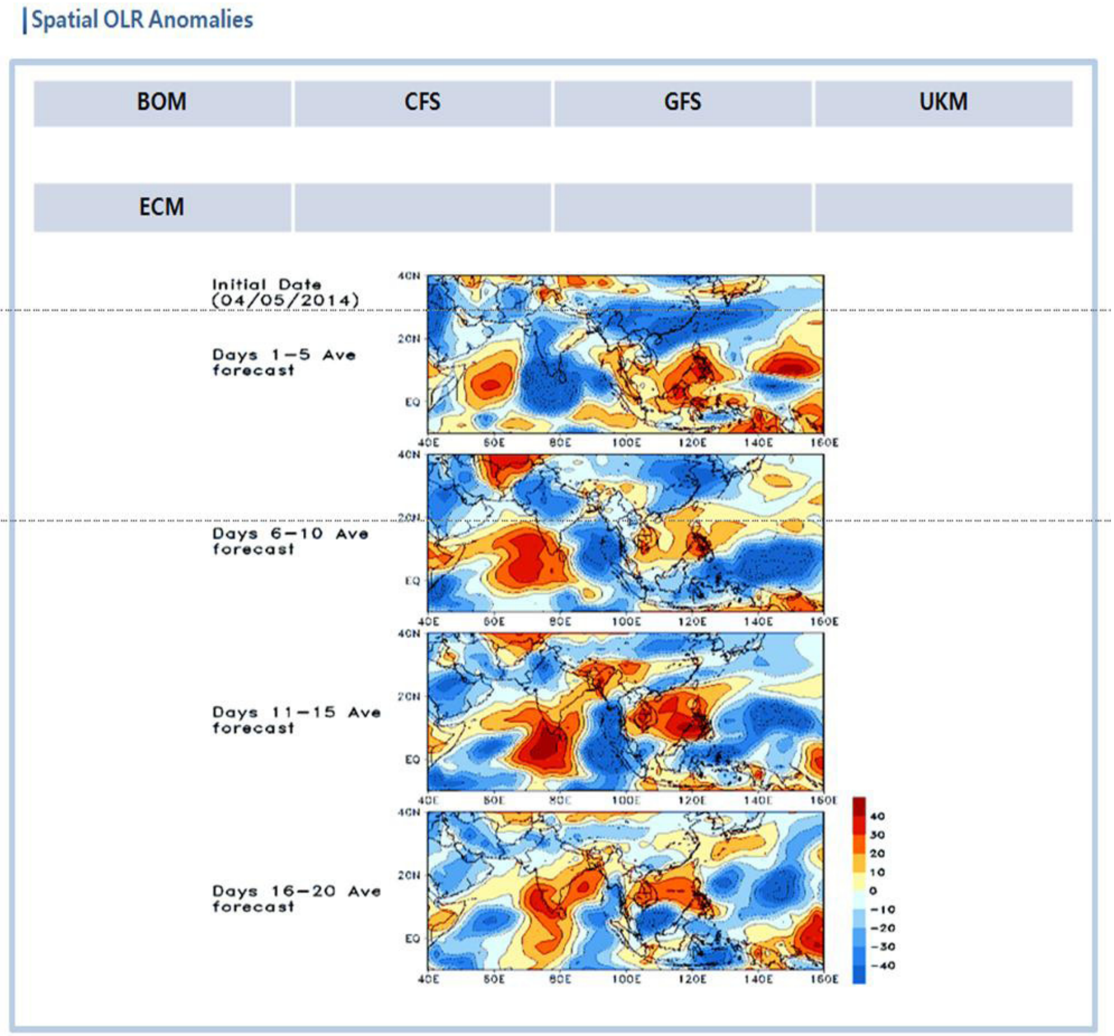

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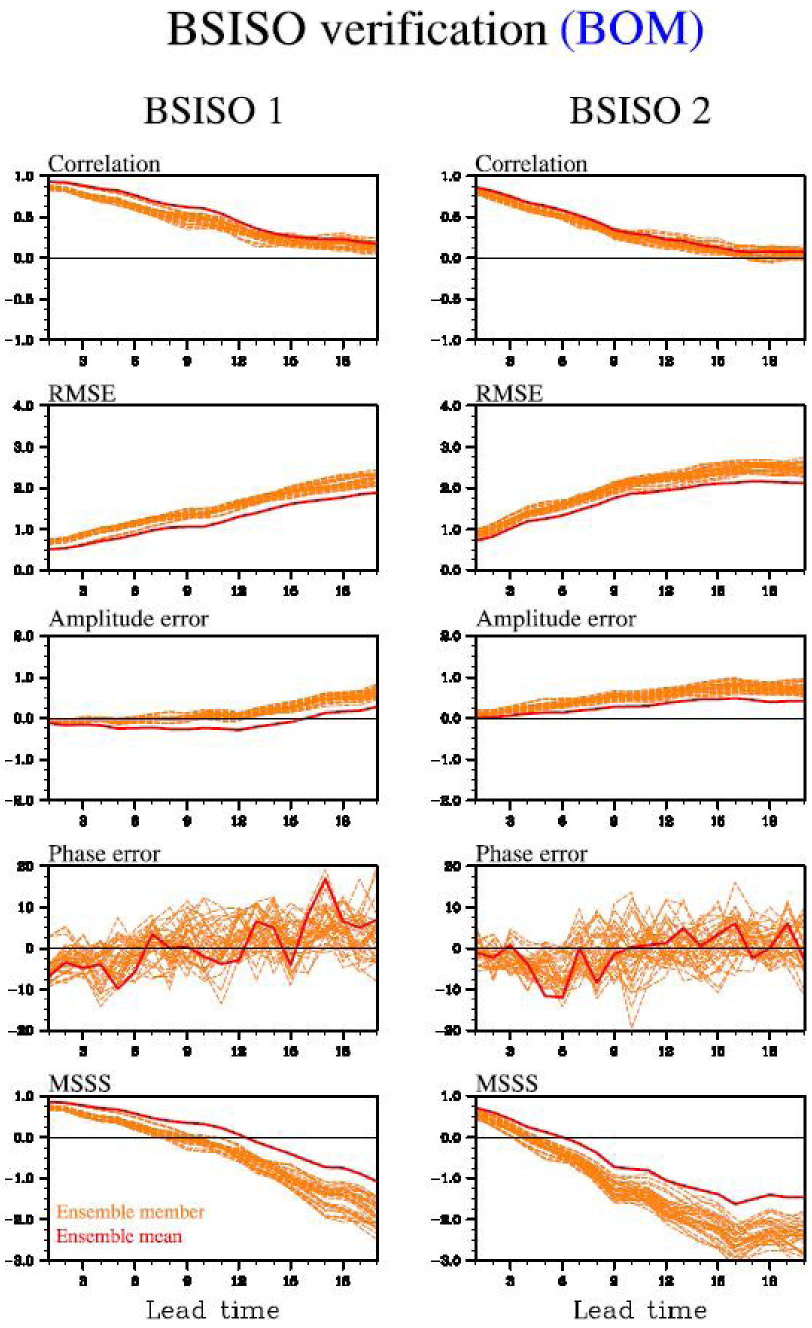

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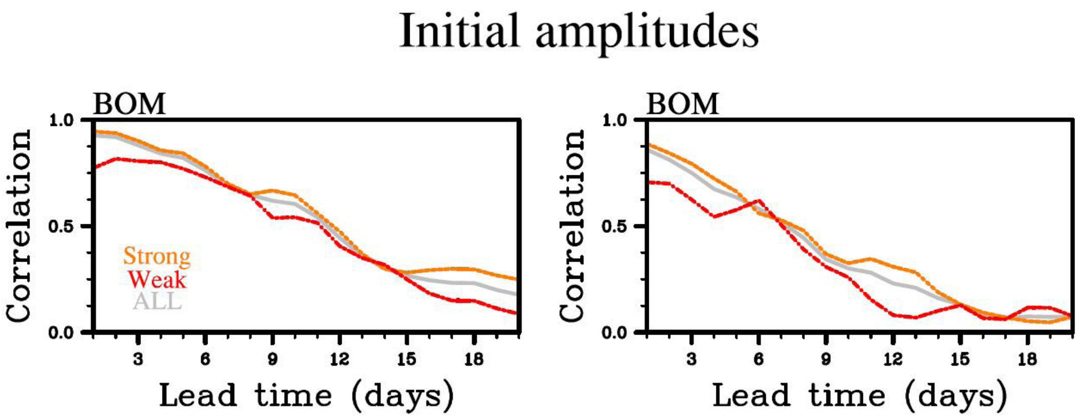

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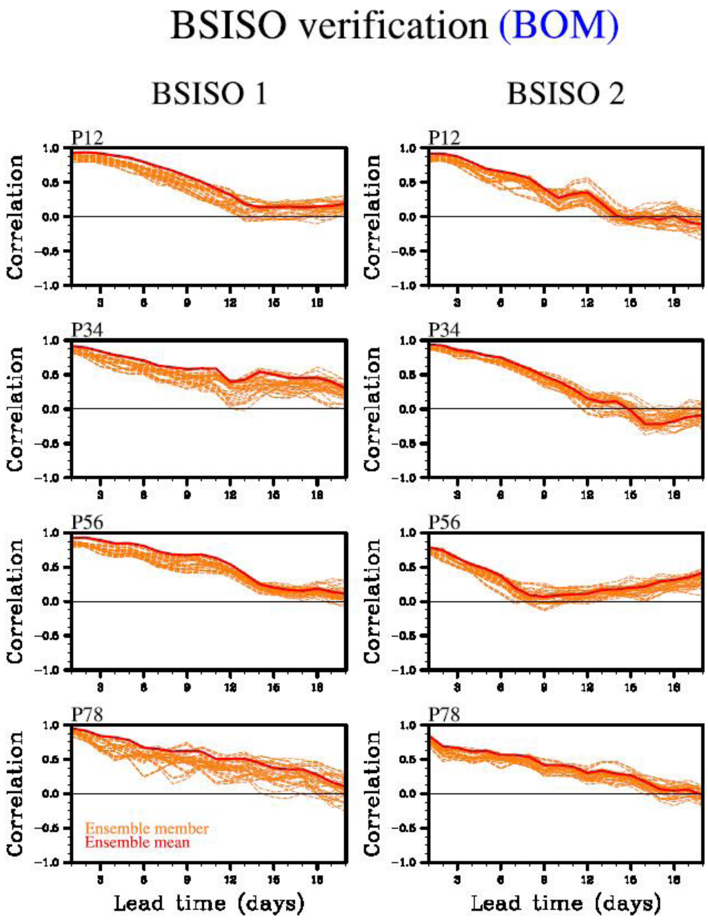


Figure 5. As in Figure 4, except for initial phase of BSISO.

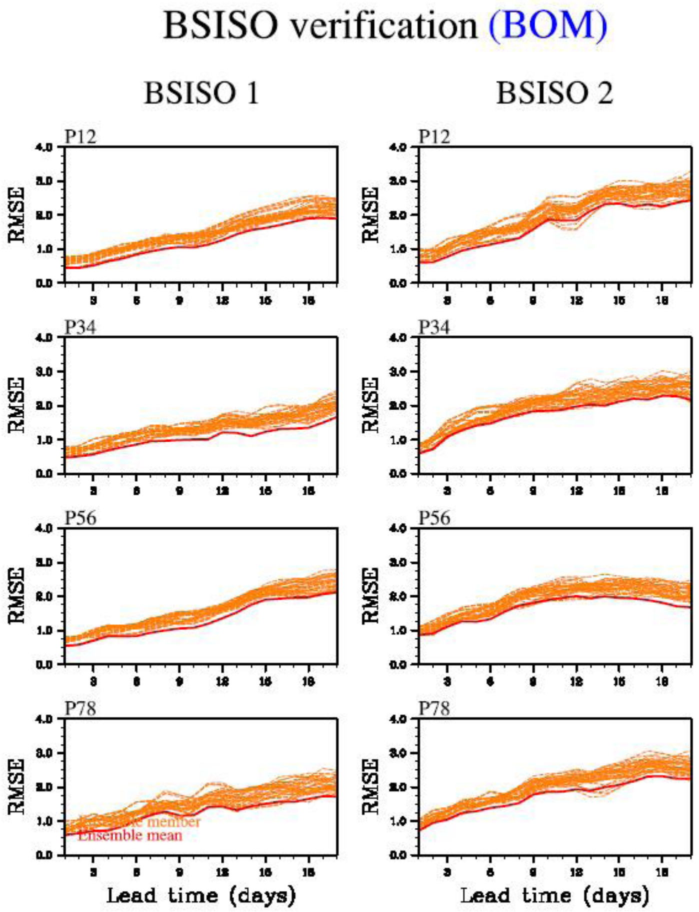


Figure 6. As shown in Figure 5, except for RMSE.

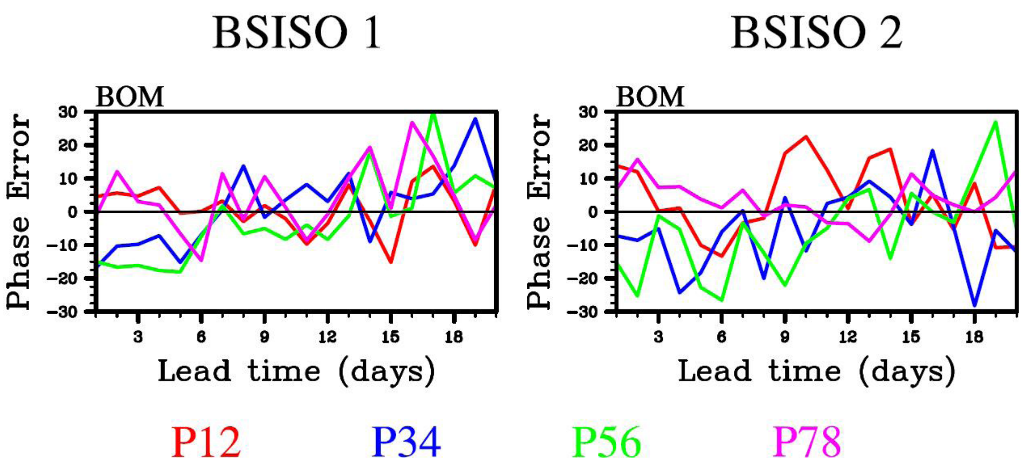
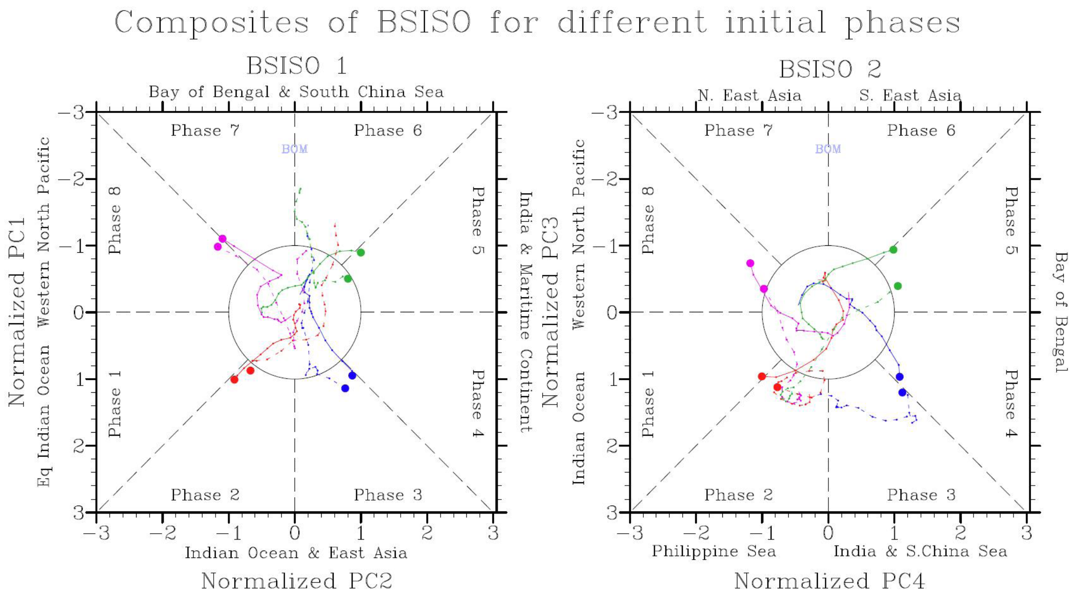


Figure 7. As in Figure 6, except for phase error of ensemble mean.



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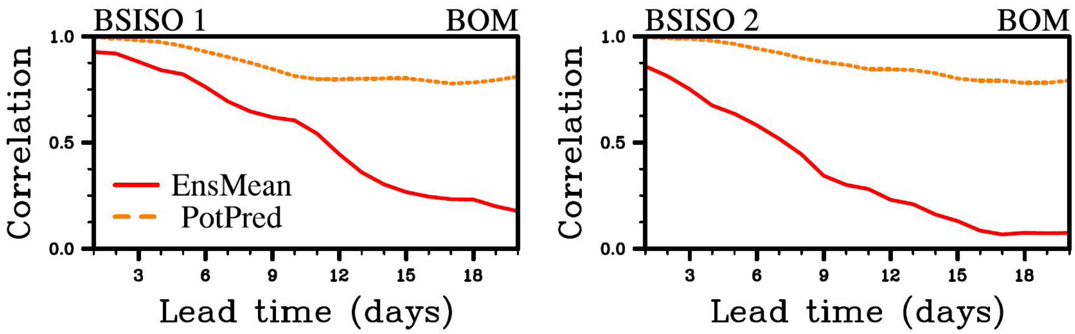

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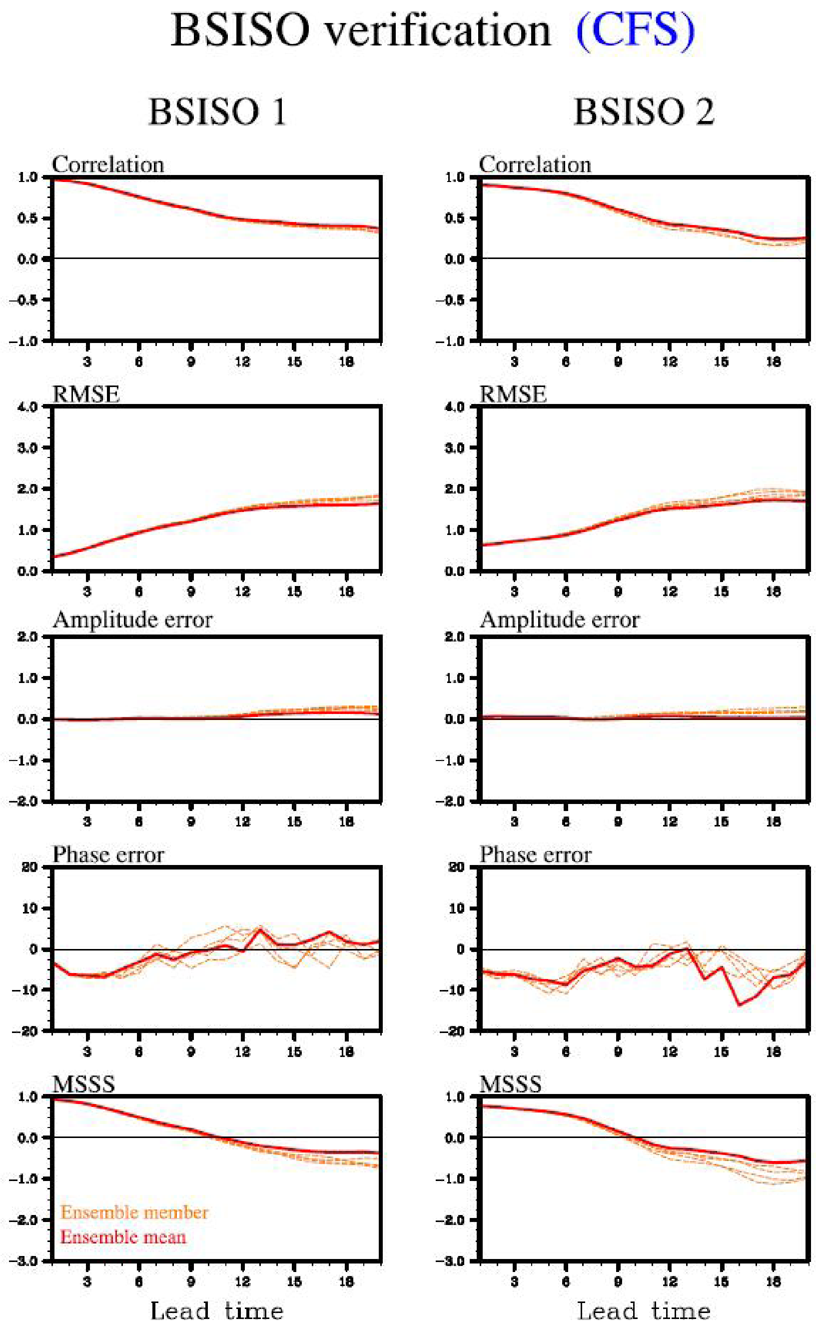


Figure 10. As in Figure 3, except for CFS.

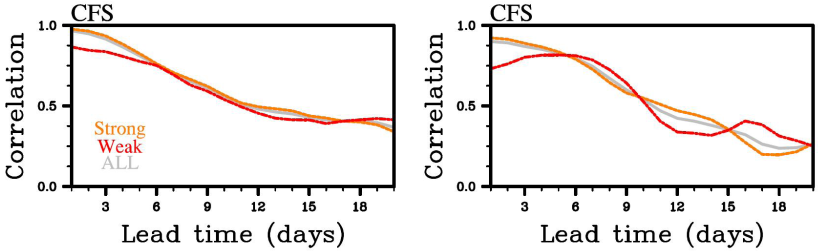


Figure 11. As in Figure 4, except for CFS.

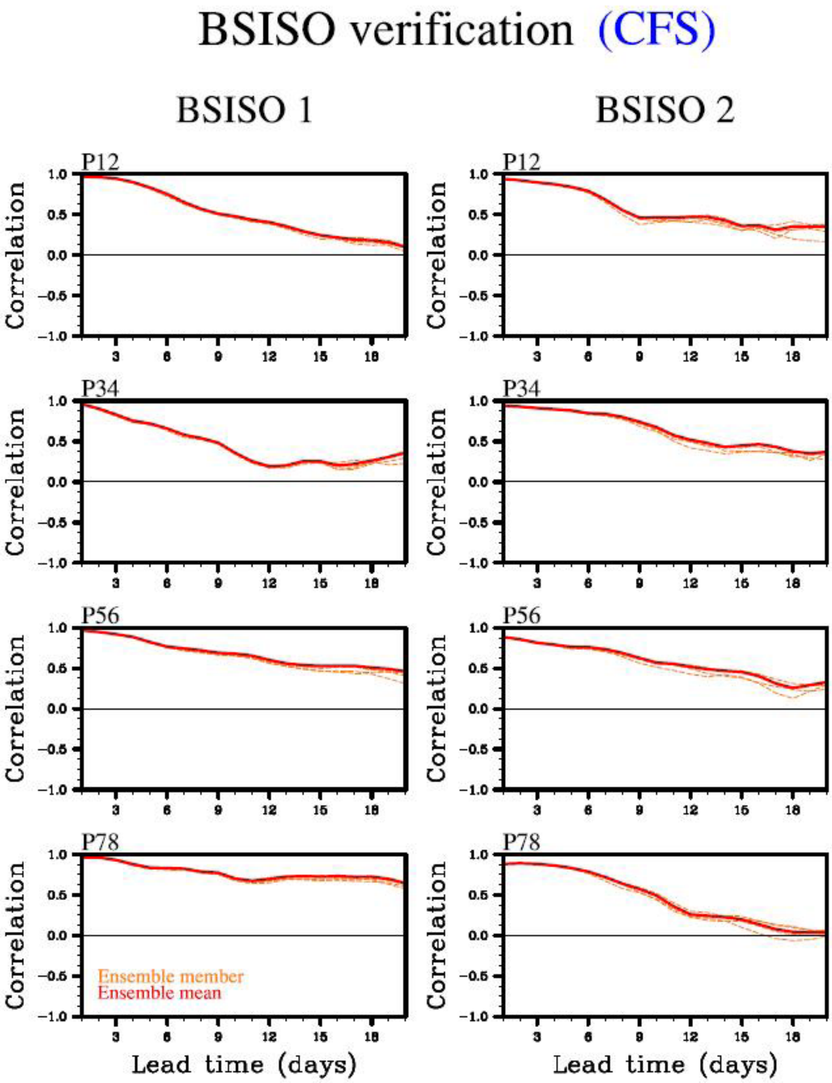


Figure 12. As in Figure 5, except for CFS.

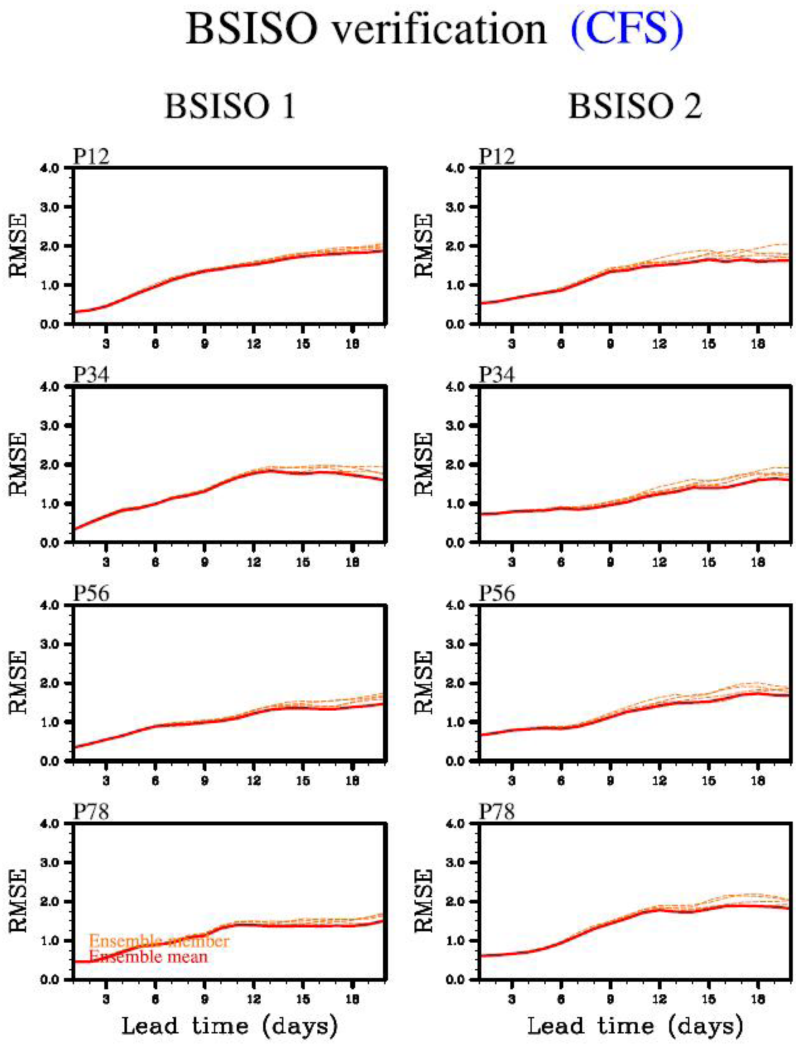
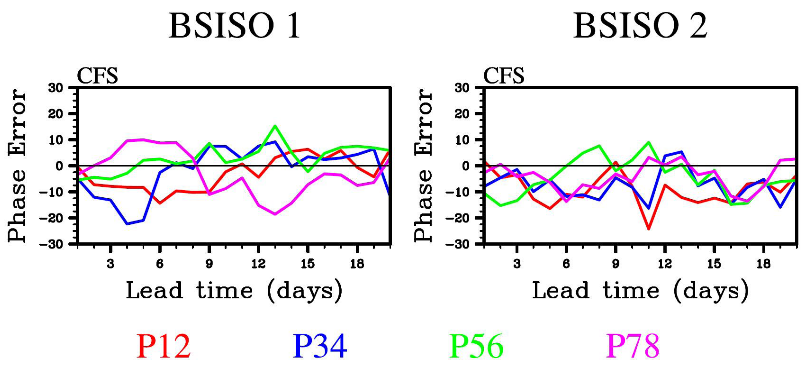


Figure 13. As in Figure 6, except for CFS.



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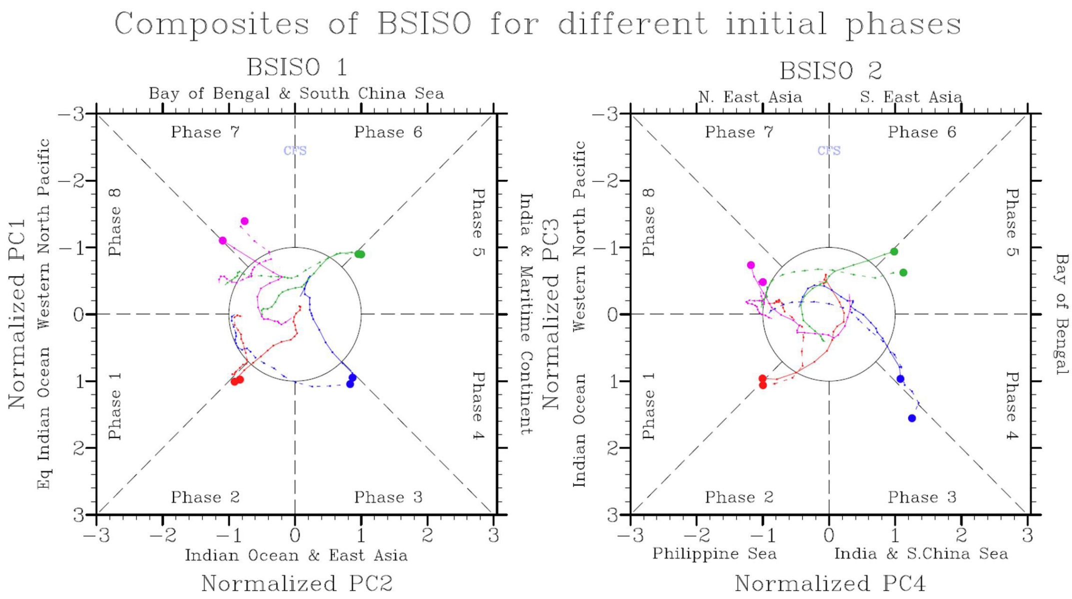

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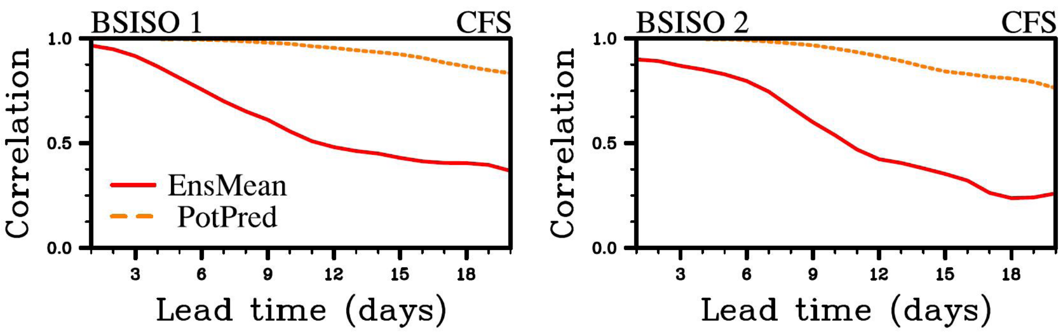


Figure 16. As in Figure 9, except for CFS.

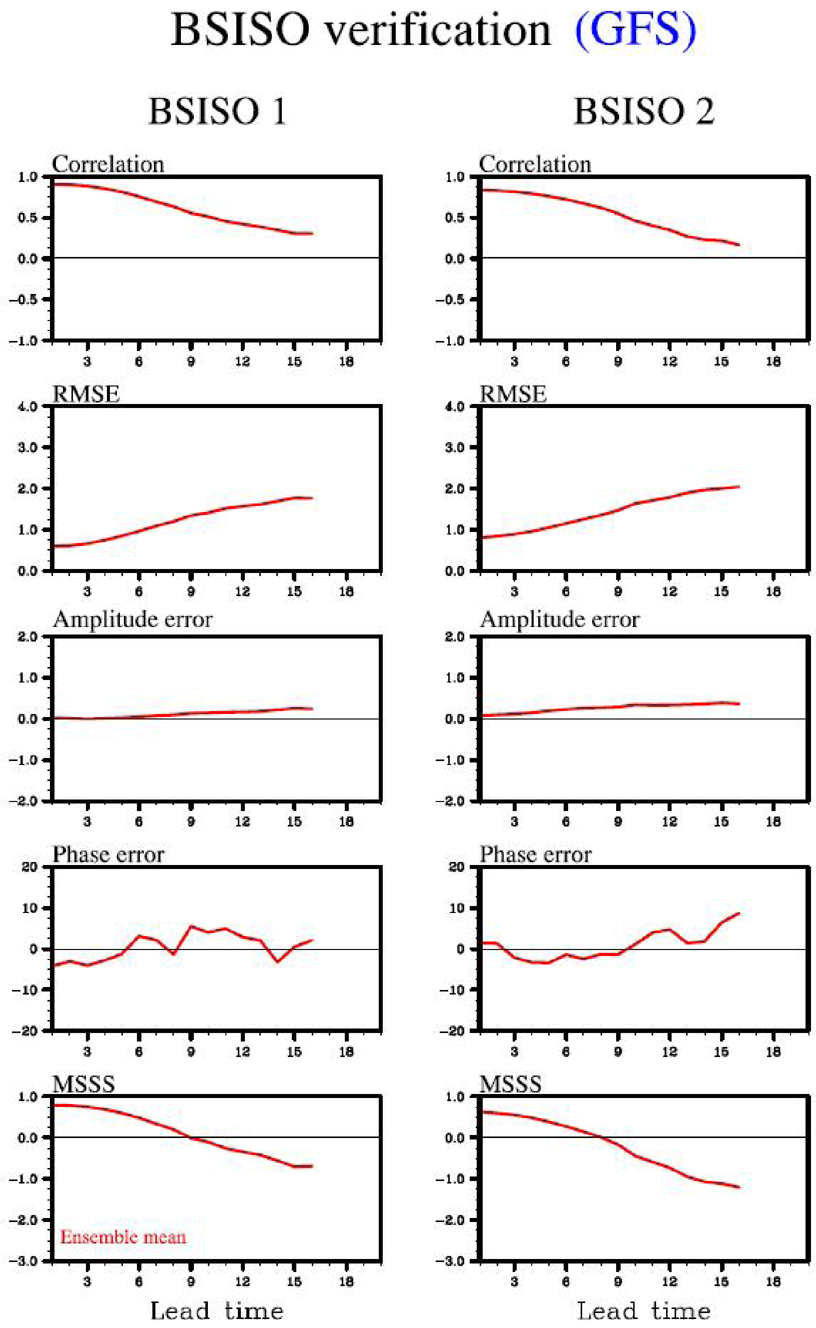


Figure 17. As in Figure 3, except for GFS.

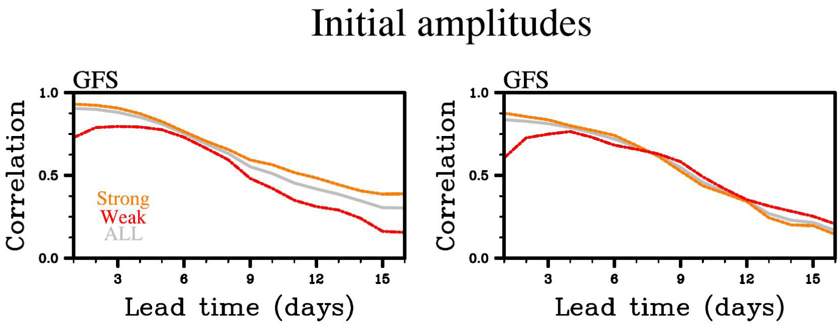


Figure 18. As in Figure 4, except for GFS.

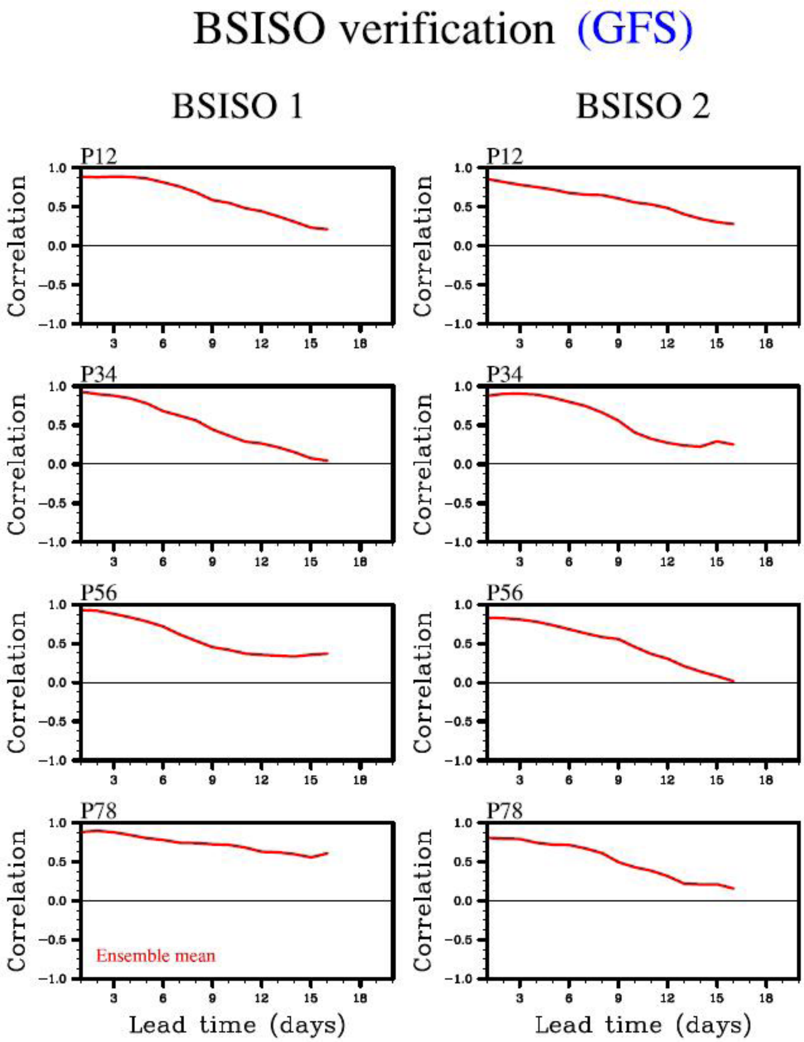
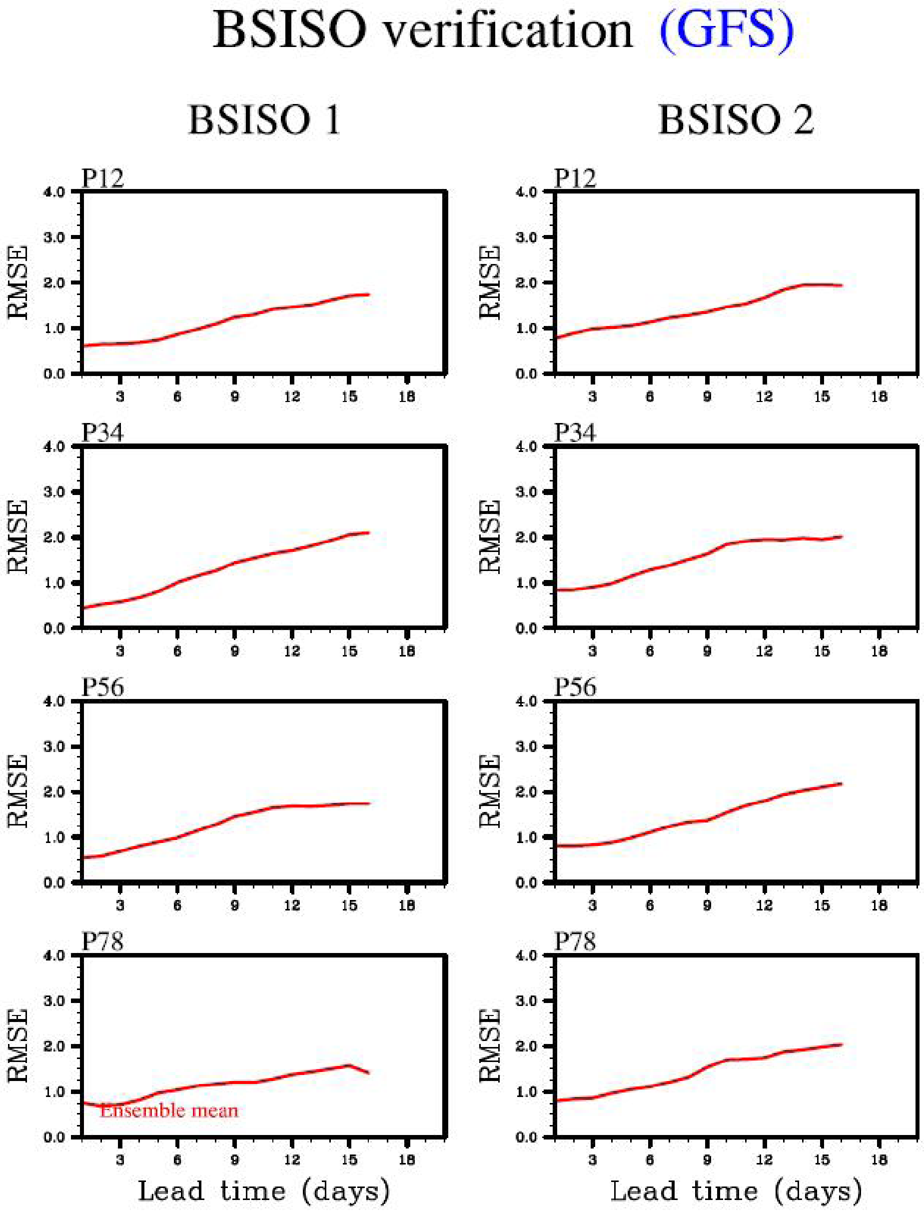


Figure 19. As in Figure 5, except for GFS.



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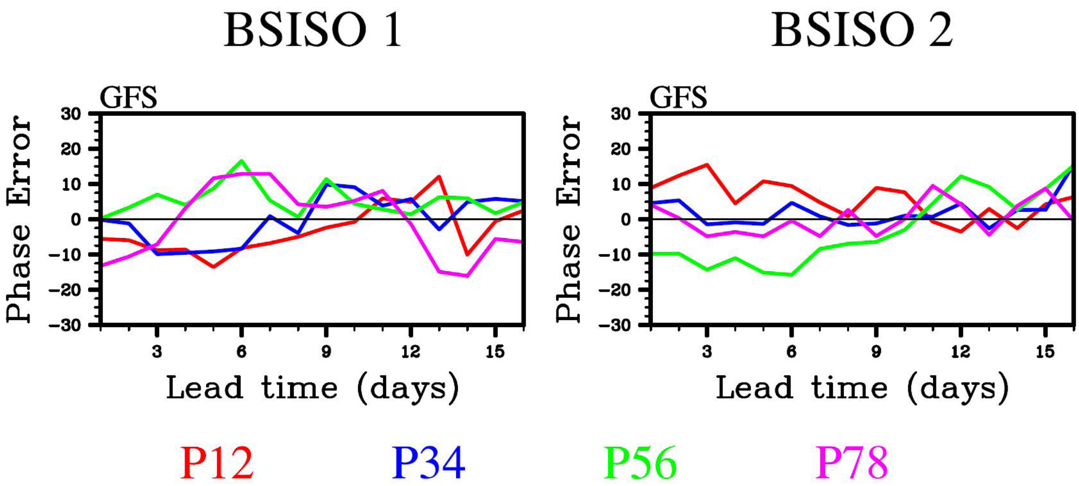


Figure 21. As in Figure 7, except for GFS.

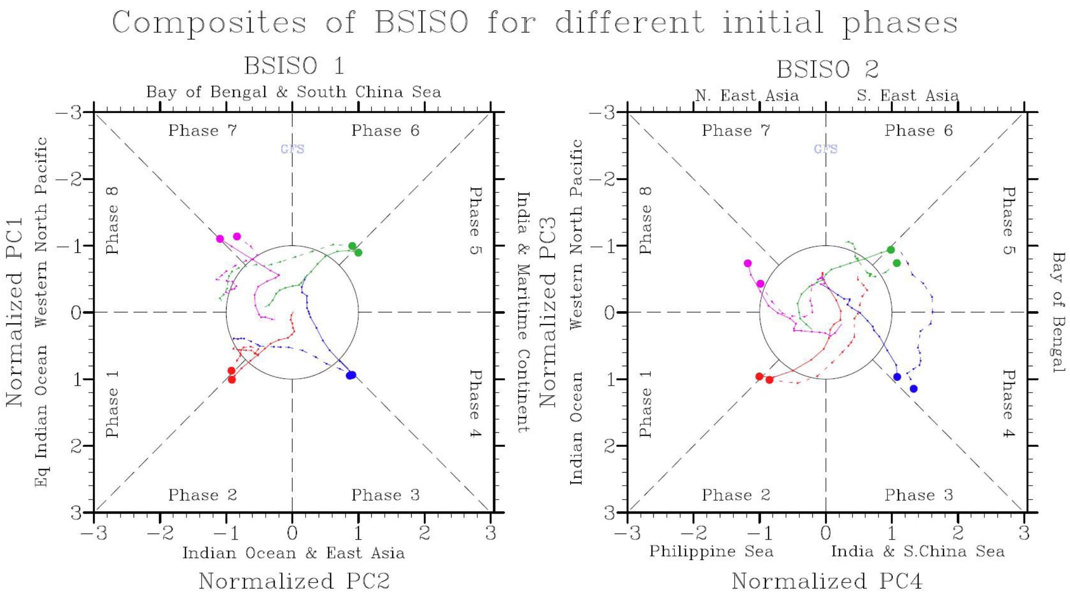


Figure 22. As in Figure 8, except for GFS.

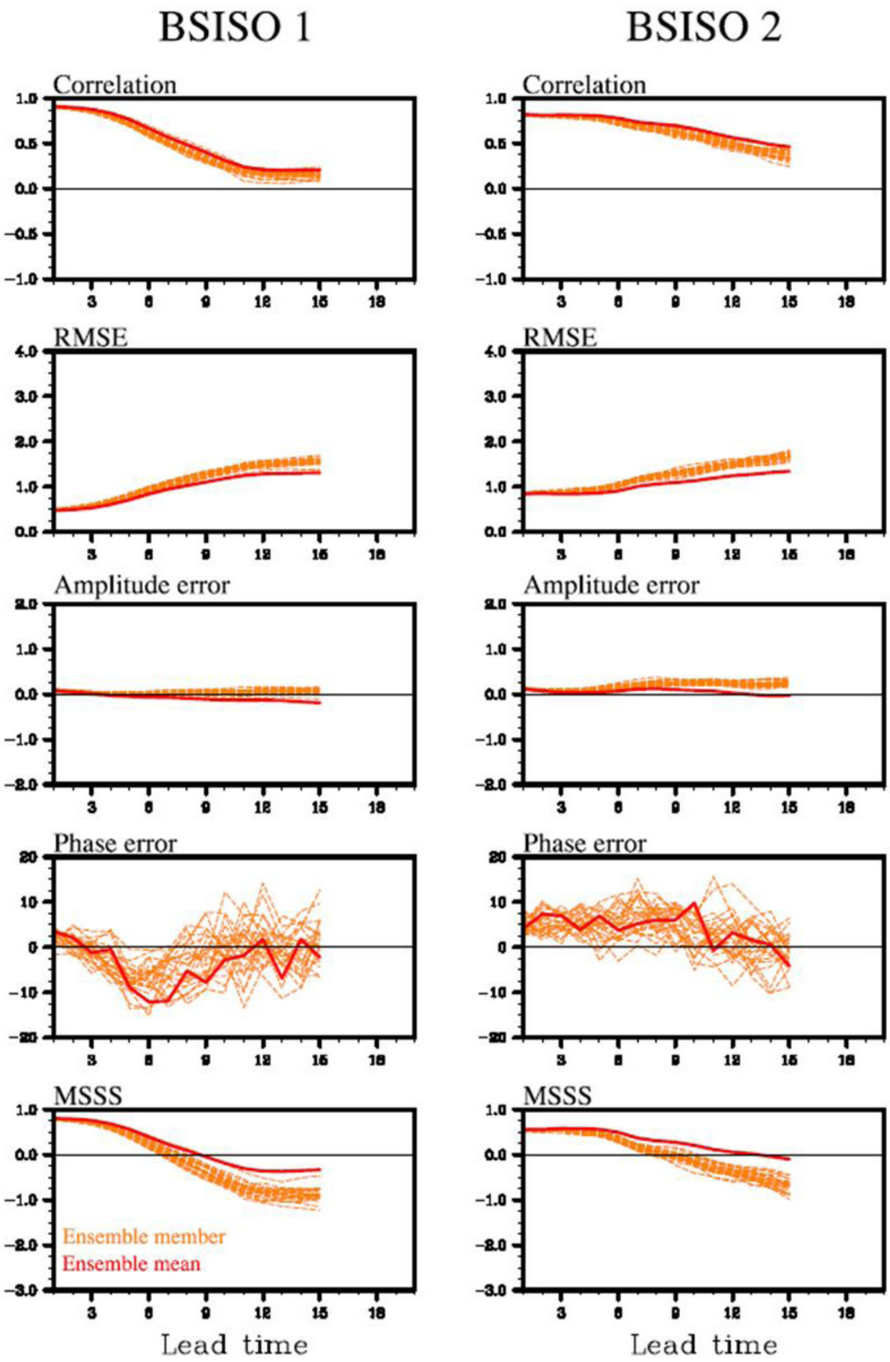


Figure 23. As in Figure 3, except for UKM.

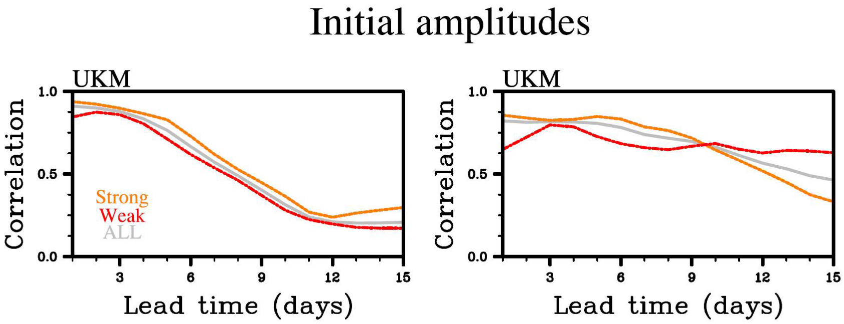


Figure 24. As in Figure 4, except for UKM.

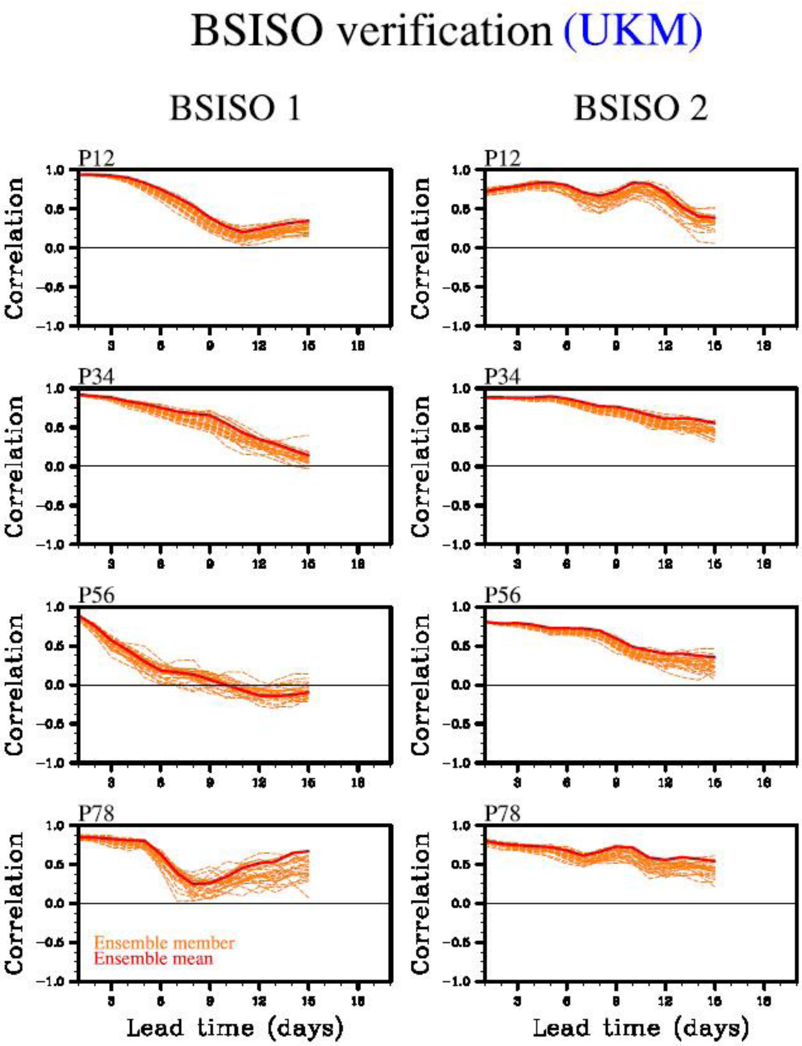


Figure 25. As in Figure 5, except for UKM.

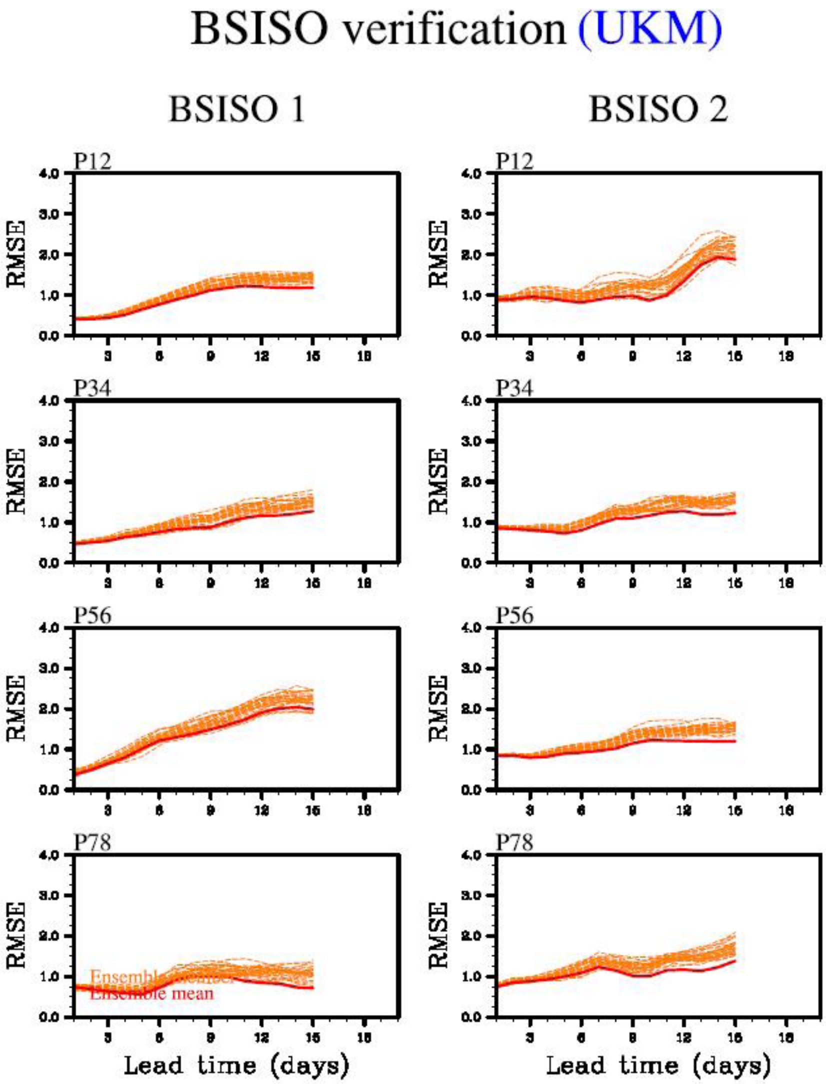


Figure 26. As in Figure 6, except for UKM.

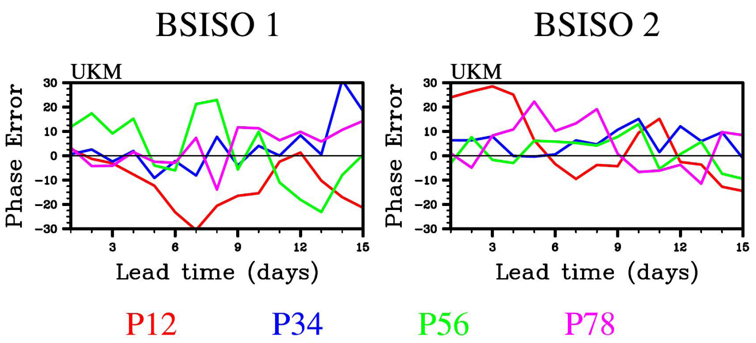


Figure 27. As in Figure 7, except for UKM.

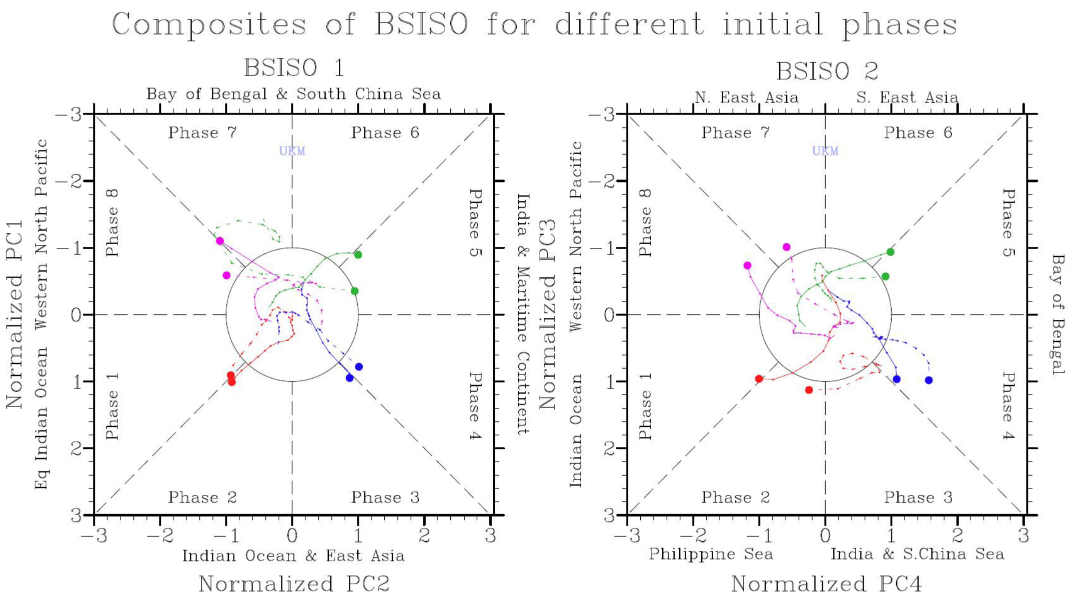


Figure 28. As in Figure 8, except for UKM.

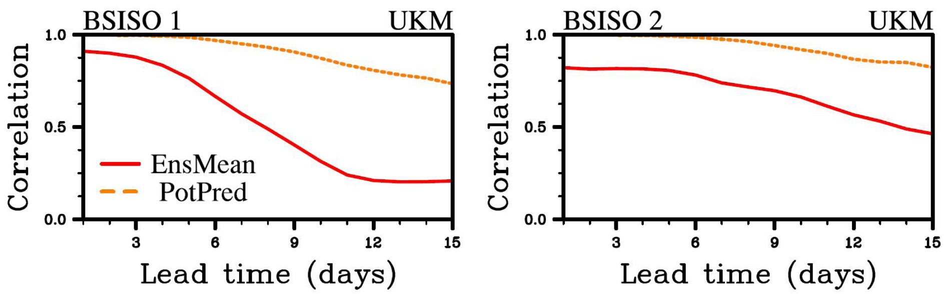


Figure 29. As in Figure 9, except for UKM.

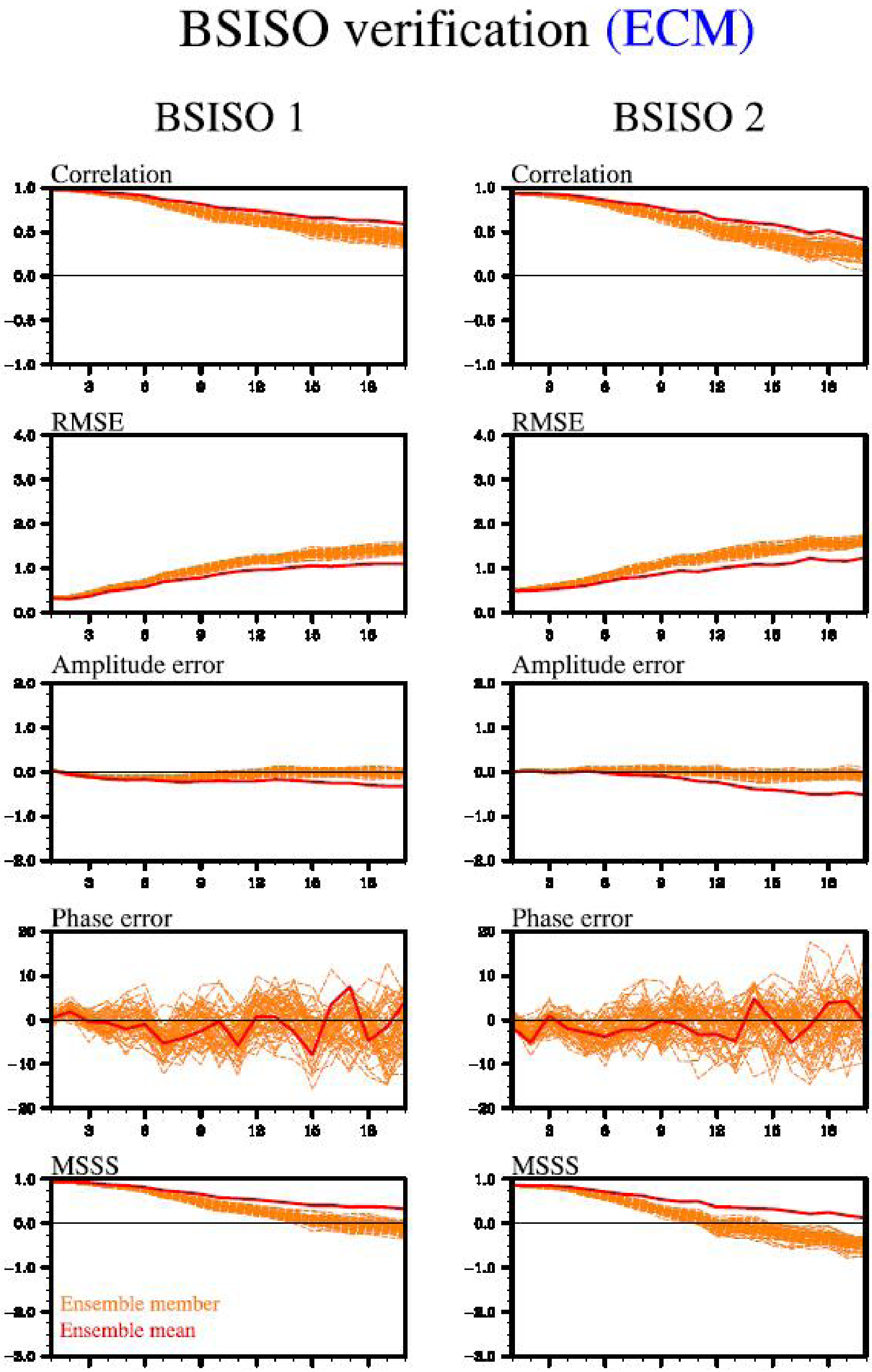
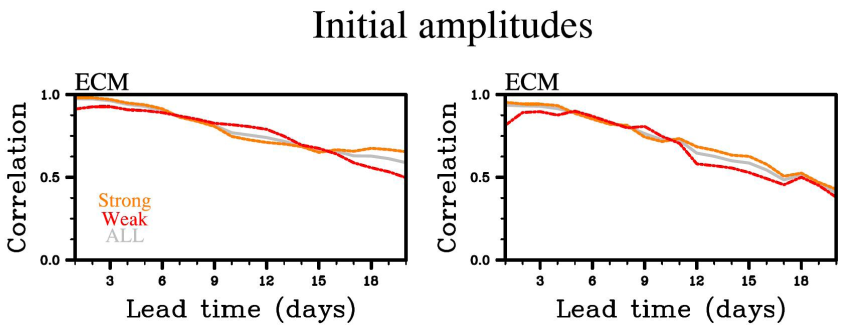


Figure 30. As in Figure 3, except for ECM.



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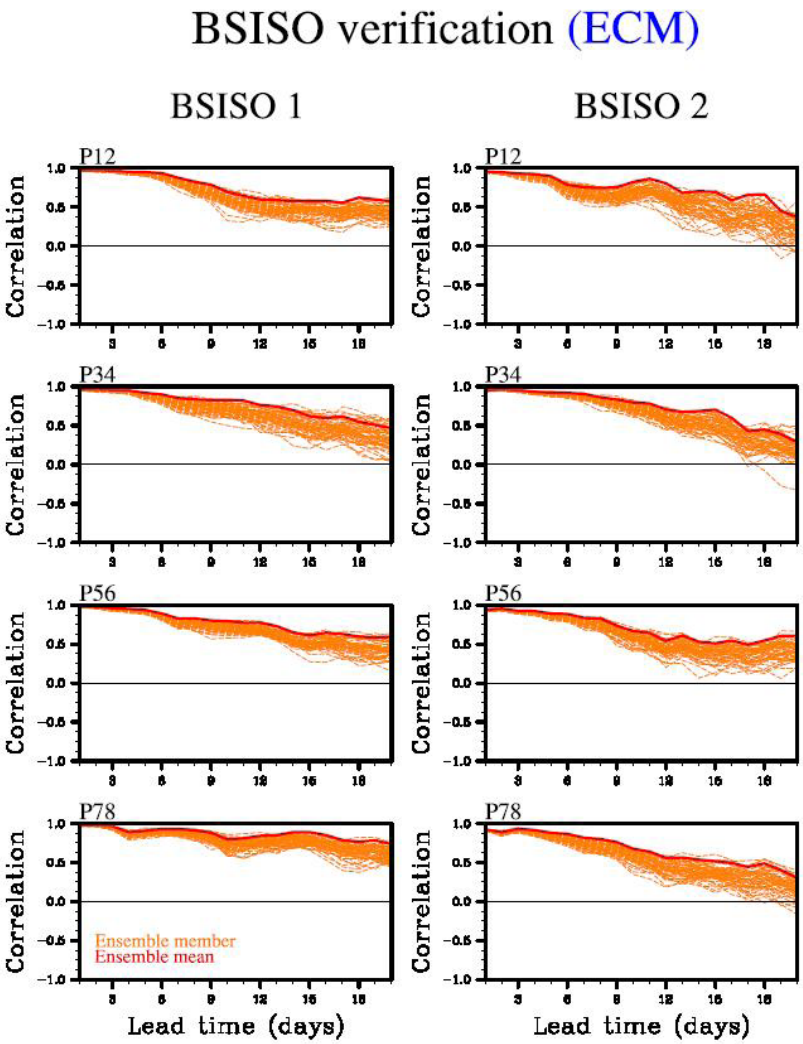


Figure 32. As in Figure 5, except for ECM.

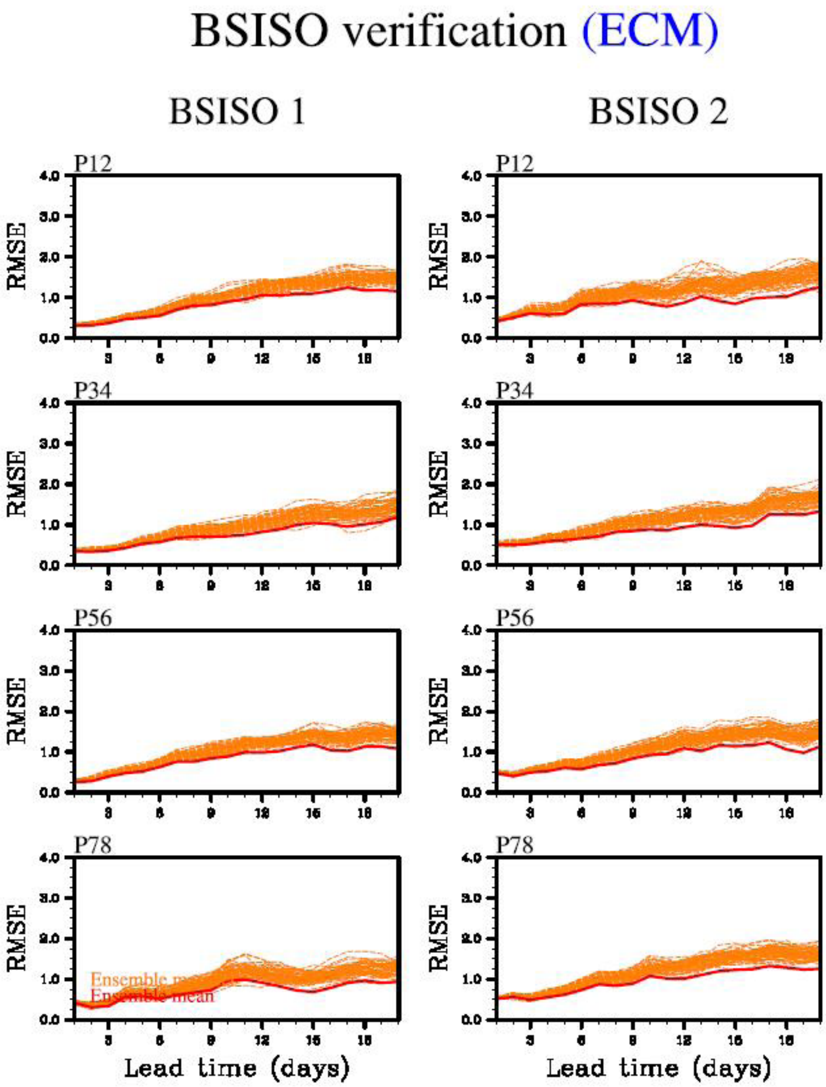


Figure 33. As in Figure 6, except for ECM.

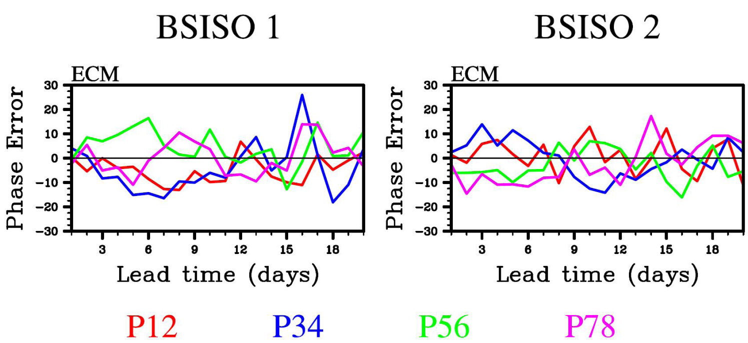
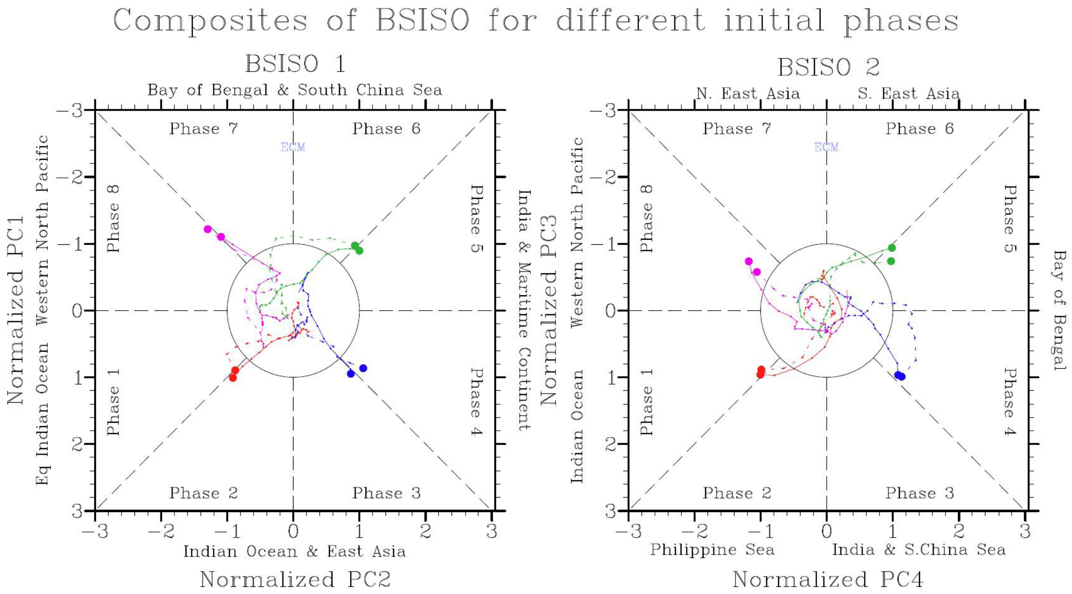


Figure 34. As in Figure 7, except for ECM.



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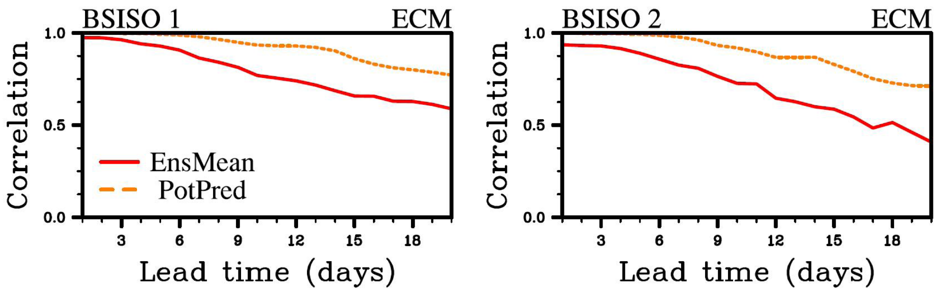

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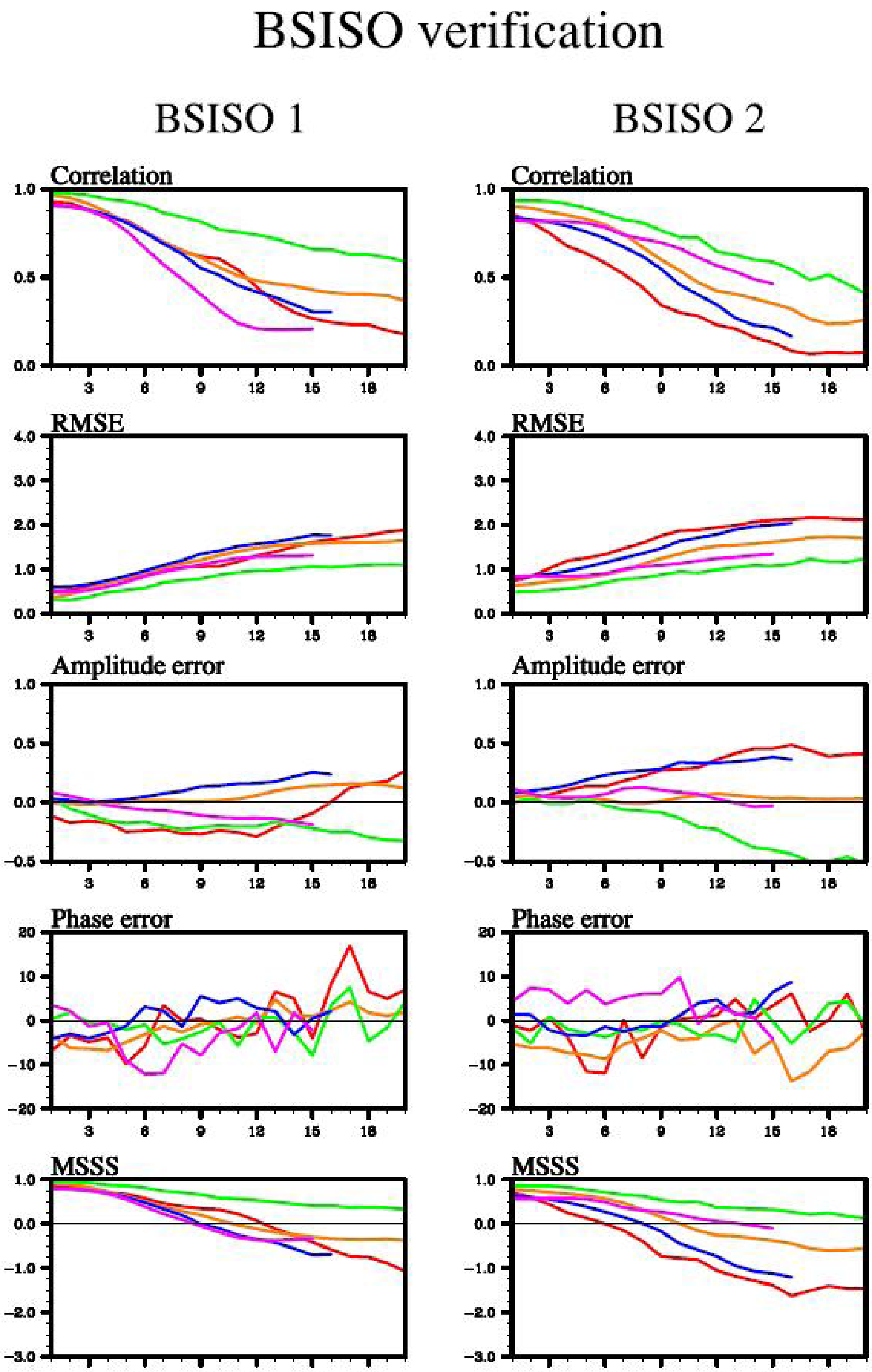

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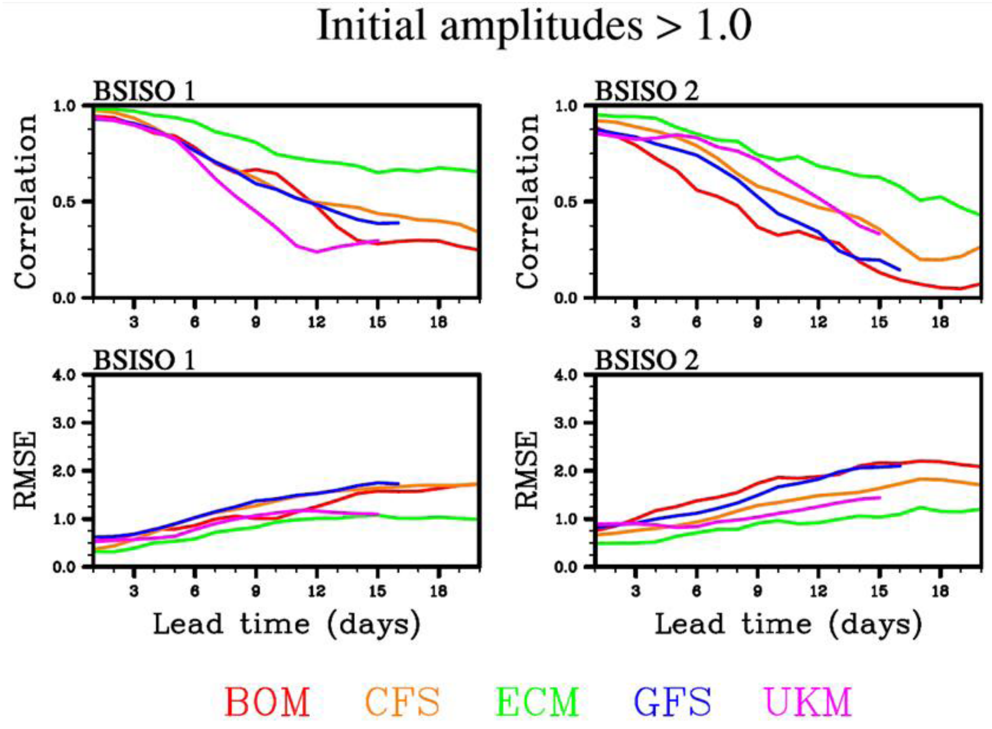

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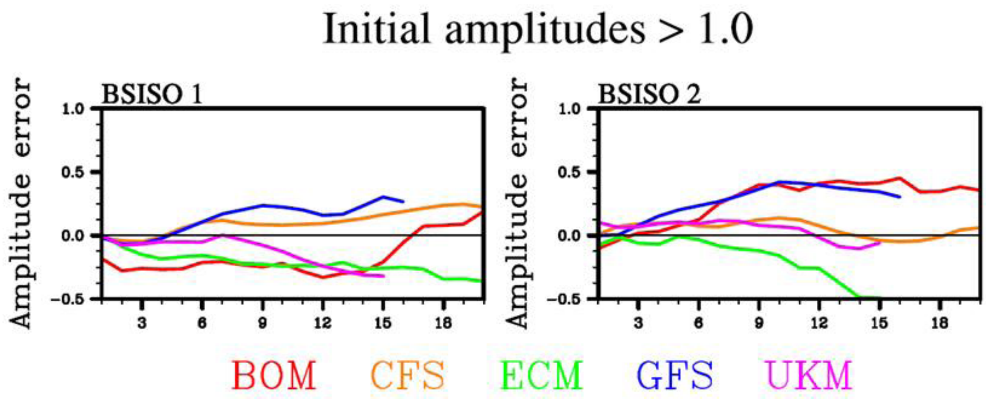

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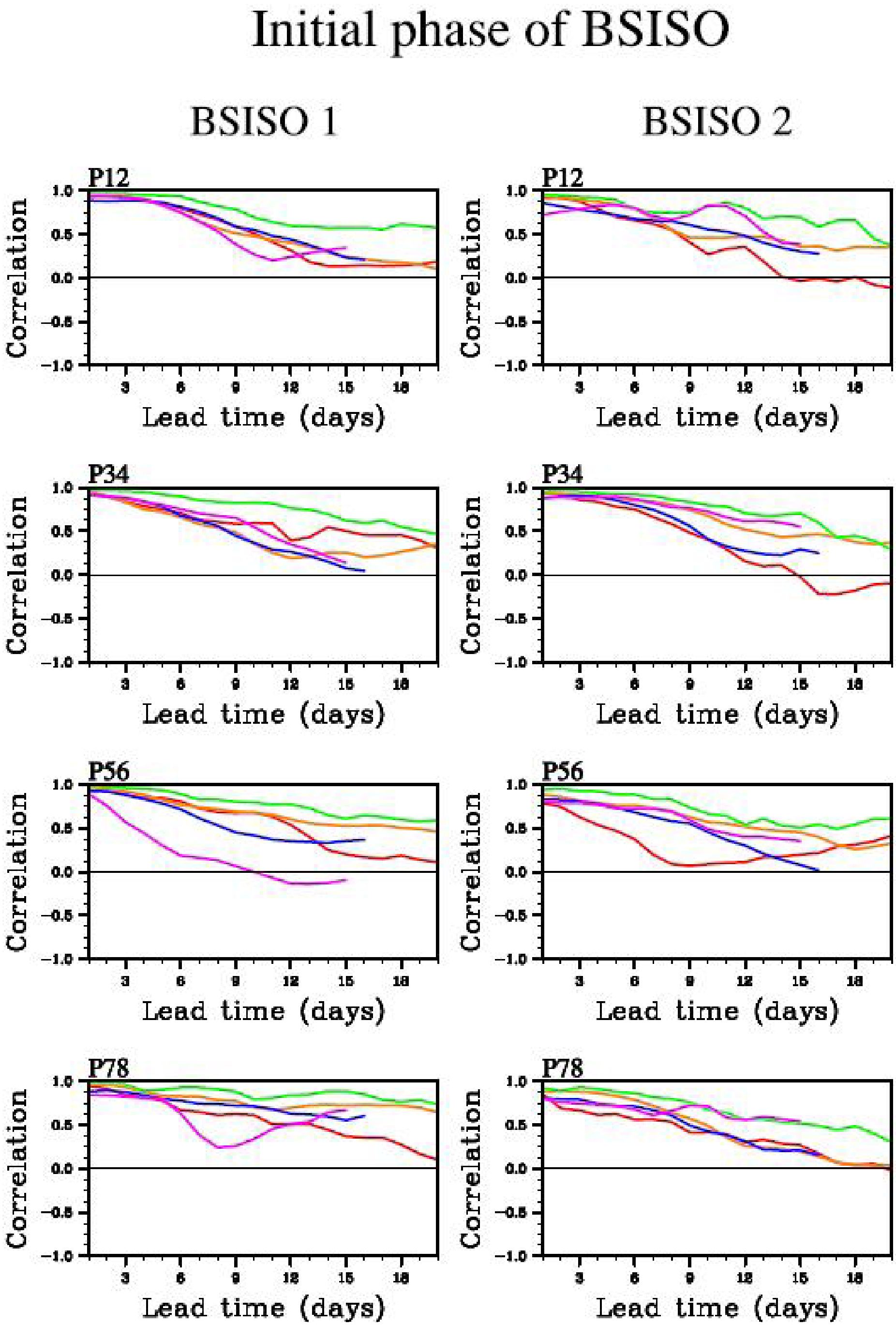

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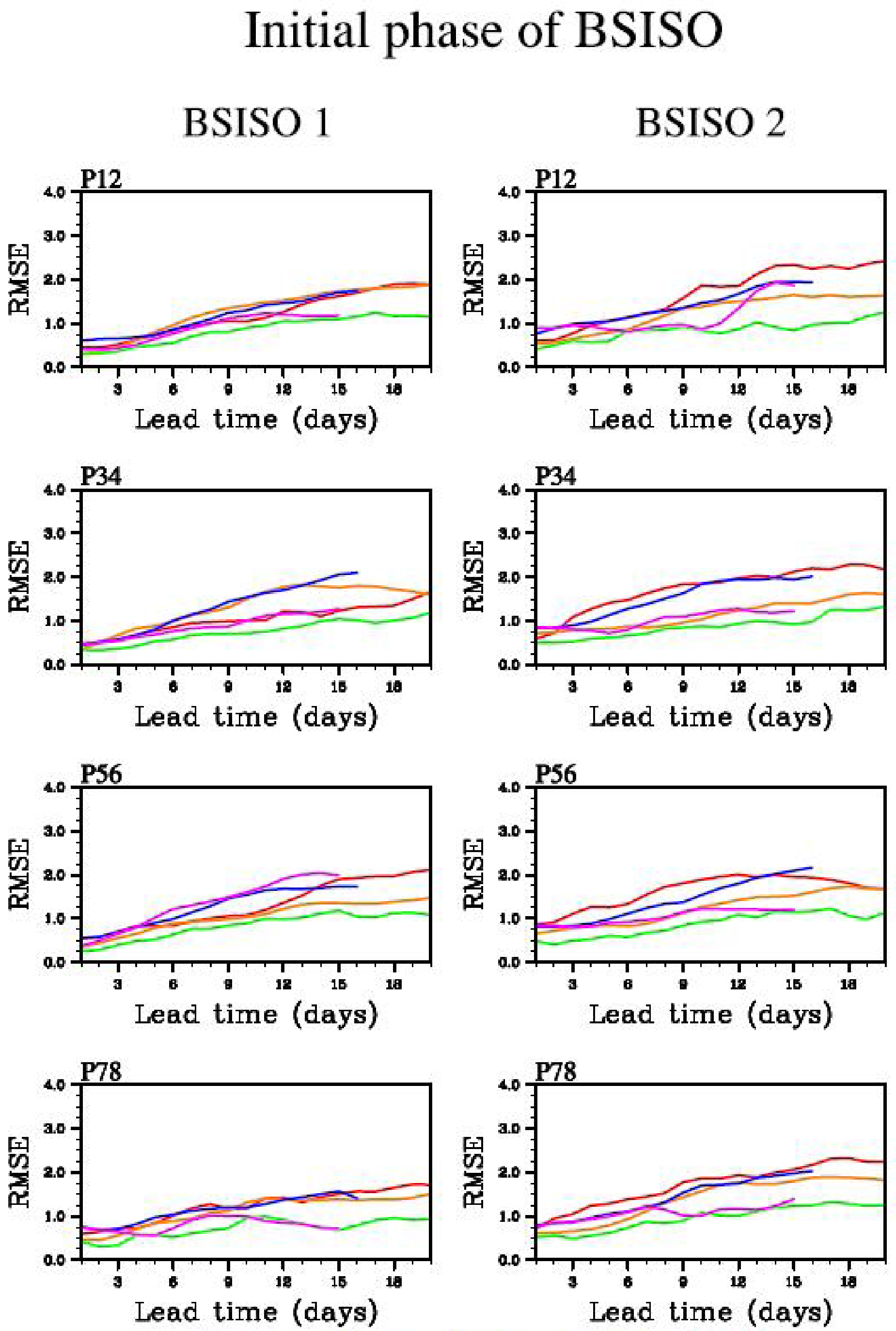


Figure 41. As in Figure 6, except for ensemble mean of five models.

OPERATIONAL MANUAL

Real-time Verification for Boreal Summer Intraseasonal Oscillation (BSISO) forecast

Hye-In Jeong
Climate Analysis Team

Summary and Purpose of Document

This document contains an overview of the verification system for the APCC BSISO forecast with not only real-time skills but also skills for all available days in 2013.

1. Overview

The APEC (Asia-Pacific Economic Cooperation) Climate Center (APCC) has developed an **automated verification system for Boreal Summer Intraseasonal Oscillation (BSISO) forecasts** to monitor its quality daily and provide verification information through the APCC website.

2. BSISO Verification Scores

Five verification skill scores are used in this system. They are bivariate correlation coefficient (CORR), root mean square error (RMSE), Phase error, Amplitude error, and mean square skill score (MSSS). The equations used were derived from Lin et al. (2008) and Rashid et al. (2010). We provide the verification skills for not only the real-time aspect but also the total skill scores, the skill for all available BSISO forecasts.

2.1 Correlation Coefficients

- **Definition (Real-time):**

$$COR(\tau) = \frac{a_1 b_1(\tau) + a_2 b_2(\tau)}{\sqrt{a_1^2 + a_2^2}\sqrt{b_1^2(\tau) + b_2^2(\tau)}}$$

- **Definition (Total):**

$$COR(\tau) = \frac{\sum_{t=1}^{N}[a_1(t)b_1(t,\tau) + a_2(t)b_2(t,\tau)]}{\sqrt{\sum_{t=1}^{N}[a_1^2(t) + a_2^2(t)]}\sqrt{\sum_{t=1}^{N}[b_1^2(t,\tau) + b_2^2(t,\tau)]}}$$

where a_1 = observed BSISO1 index, a_2 = observed BSISO2 index,
b_1 = forecasted BSISO1 index, b_2 = forecasted BSISO2 index,
τ is forecast lead time, t is time, N is the number of forecasts.

- **Range:** -1 to 1
- **Perfect score:** 1
- **Characteristics:** Correlation measures the skill in forecasting the phase of the BSISO, which is insensitive to amplitude errors. Correlation is equivalent to a spatial pattern correlation between the observations and the forecasts when they are expressed by the two leading combined EOFs. Following the discussion of Hollingsworth et al. (1980), we also use COR = 0.5 as an indication of the limit of a skillful forecast.

2.2 Root Mean Square Error

- **Definition (Real-time):**

$$RMSE(\tau) = \sqrt{(a_1 - b_1(\tau))^2 + (a_2 - b_2(\tau))^2}$$

- **Definition (Total):**

$$RMSE(\tau) = \sqrt{\frac{1}{N}\sum_{t=1}^{N}([a_1(t) - b_1(t,\tau)]^2 + [a_2(t) - b_2(t,\tau)]^2)}$$

- **Range:** 0 to plus infinity
- **Perfect score:** 0
- **Characteristics:** RMSE takes into account errors in both phase and amplitude and is equivalent to the spatially averaged root-mean-square difference between the observations and the forecasts when expressed by the two leading combined EOFs. As BSISO1 and BSISO2 are normalized to their observed standard deviations, the saturated value of RMSE when τ is so big that the forecast and observation are no longer correlated is 2, assuming the forecast BSISOs have the same

standard deviations as the observations. Similarly, for a climatological forecast (BSISO1=0 and BSISO2=0), the RMSE is $\sqrt{2}$.

2.3 Phase Amplitude

- **Definition (Real-time):**

$$ERR_{amp}(\tau) = RMMA_{for}(\tau) - RMMA_{obs}$$

$$RMMA_{for}(\tau) = \sqrt{b_1(\tau)^2 + b_2(\tau)^2}$$; amplitude of forecast

$$RMMA_{obs} = \sqrt{a_1^{\ 2} + a_2^{\ 2}}$$; amplitude of observation

- **Definition (Total):**

$$ERR_{amp}(\tau) = \frac{1}{N}\sum_{t=1}^{N}(RMMA_{for}(t,\tau) - RMMA_{obs}(t))$$

$$RMMA_{for}(t,\tau) = \sqrt{b_1(t,\tau)^2 + b_2(t,\tau)^2}$$; amplitude of forecast

$$RMMA_{obs}(t) = \sqrt{a_1^{\ 2}(t) + a_2^{\ 2}(t)}$$; amplitude of observation

- **Range:** minus infinity to plus infinity
- **Perfect score:** 0
- **Characteristics:** Relative amplitude difference between observation and forecast. A positive value means that the forecasted amplitude is relatively larger than that of observation. A negative value indicates that the forecast amplitude is relatively smaller than that of observation.

2.4 Phase Error

- **Definition (Real-time):**

$$ERR_{phs}(\tau) = \tan^{-1}\left(\frac{a_1 b_2(\tau) - a_2 b_1(\tau)}{a_1 b_1(\tau) + a_2 b_2(\tau)}\right)$$

- **Definition (Total):**

$$ERR_{phs}(\tau) = \frac{1}{N}\sum_{t=1}^{N} \tan^{-1}\left(\frac{a_1(t) b_2(t,\tau) - a_2(t) b_1(t,\tau)}{a_1(t) b_1(t,\tau) + a_2(t) b_2(t,\tau)}\right)$$

- **Range:**
- **Perfect score:** 0
- **Characteristics:** ERR_{phs} is equivalent to the phase angle difference between the forecasts and observations. If this angle is positive, the phase speed of the forecast is faster than that of the observation, whereas a negative angle indicates the phase speed of the forecast is slower than that of the observation.

2.5 Mean Square Skill Score (MSSS; Murphy 1988)

- **Definition (Real-time):**

$$MSSS(\tau) = [1 - \frac{MSE_f(\tau)}{MSE_c}]$$

$$MSE_f(\tau) = (a_1 - b_1(\tau))^2 + (a_2 - b_2(\tau))^2$$; error of the model forecast

$$MSE_c = (a_1^2 + a_2^2)$$; climatological variance

- **Definition (Total):**

$$MSSS(\tau) = [1 - \frac{MSE_f(\tau)}{MSE_c}]$$

$$MSE_f(\tau) = \frac{1}{N}\sum_{t=1}^{N}\{(a_1(t) - b_1(t,\tau))^2 + (a_2(t) - b_2(t,\tau))^2\}$$

; error of the model forecast

$$MSE_c = \frac{1}{N}\sum_{t=1}^{N}[a_1^2(t) + a_2^2(t)]$$; climatological variance

- **Range:** minus infinity to 1
- **Perfect score:** 1
- **Characteristics:** MSSS provides a relative level of skill for the BSISO forecast compared to a climatological forecast that predicts no BSISO signal. A perfect forecast ($MSE_f(\tau) = 0$) has an MSSS of 1, a forecast with an error as big as the climatological variance ($MSE_f(\tau) = MSE_c$) has a zero MSSS, and when a forecast is doing worse than the climatological forecast, a negative MSSS is obtained.

3. Verification Data Base

3.1 Observational Data

To verify the BSISO forecast, we need the observed real-time BSISO indices that are automatically generated at our BSISO server daily. We can find the observed BSISO indices under the /data21/BSISO/MONI/09.STEP9/text, named BSISO.YYYYMMDD.INDEX.NORM.data. To retrieve basic information, please write as follows.

As an example;

```
> vi BSISO.20140711.INDEX.NORM.data
```

You can find following information.

YEAR	DAY	BSISO1-1	BSISO1-2	BSISO2-1	BSISO2-2	BSISO1	BSISO2
2014	1	0.809	0.490	-0.679	0.494	0.946	0.839
2014	2	0.643	0.541	-0.797	0.697	0.840	1.058
2014	3	0.401	0.279	-0.430	0.795	0.489	0.904
2014	4	0.126	-0.035	-0.282	1.246	0.130	1.278
2014	5	-0.014	-0.441	-0.090	0.713	0.441	0.719
2014	6	-0.072	-0.320	0.311	0.336	0.328	0.458
2014	7	-0.037	0.088	-0.019	-0.409	0.096	0.409
2014	8	0.043	0.345	-0.272	-0.457	0.348	0.532
(continued)							
2014	186	0.023	-0.028	1.502	-0.969	0.036	1.787
2014	187	-0.289	0.022	1.229	-0.740	0.290	1.435
2014	188	-0.316	0.325	1.555	0.411	0.453	1.608
2014	189	-0.253	0.518	1.784	0.865	0.577	1.983
2014	190	0.161	0.556	0.775	0.758	0.579	1.084
2014	191	0.525	0.932	0.202	0.785	1.070	0.810
2014	192	0.669	1.489	0.230	0.127	1.632	0.263

- This file has an ASCII format.
- X-axis means; Year, Julian day, index of BSISO1-1, 1-2, 2-1, 2-2, BSISO1 and BSISO2.

BSISO1 means $\sqrt{BSISO1-1^2 + BSISO1-2^2}$

BSISO2 indicates $\sqrt{BSISO2-1^2 + BSISO2-2^2}$

- All *BSISO.YYYYMMDD.INDEX.NORM.data* file has started from January 1st of the relevant year.

3.2 Forecasted Data

The predicted BSISO indices for the upcoming 20 days are updated after the BSISO forecast runs at each model directory under the /data21/BSISO/FCST/11.BINAR. Currently, 5 Global Circulation Models provide us with their BSISO forecast. Detailed information for model forecast is as follows

Table 1. Summary of BSISO forecast data

Model	CFS	GFS	BOM	ECM	UKM
Forecast Period	20 day	16 day	20 day	20 day	15 day
Ensemble member	4	1	33	51	24
Updating Frequency	1/day	1/day	1/3−4 days	1/3−4 days	1/day

Each of the forecasted BSISO are located under

/data21/BSISO/FCST/11.BINAR/

There are 5 GCM directories

/data21/BSISO/FCST/11.BINAR/BOM/

/data21/BSISO/FCST/11.BINAR/CFS/

/data21/BSISO/FCST/11.BINAR/ECM/

/data21/BSISO/FCST/11.BINAR/GFS/

/data21/BSISO/FCST/11.BINAR/UKM/

Each model directories has sub-directories. For example;

/data21/BSISO/FCST/11.BINAR/BOM/2013

/data21/BSISO/FCST/11.BINAR/BOM/2014

There are many files in each model directory. Among them, we use the "YYYYMMDD_BOMC_BSISO.20d.INDEX" file.

※ Reading Format of Forecasted BSISO index file

```
Do YEAR
Do ENSEMBLE
Do DAY
     YEAR ENSEMBLE DAY BSISO1-1 BSISO1-2 BSISO2-1 BSISO2-2 BSISO1 BSISO2

End Do
End Do
End Do
```

As an example;

```
> vi 20140713_BOMC_BSISO.20d.INDEX
```

Returns the following information.

YEAR	ENSEMBLE	DAY	BSISO1-1	BSISO1-2	BSISO2-1	BSISO2-2	BSISO1	BSISO2
2014	1	194	0.907	1.908	0.673	-0.019	2.112	0.673
2014	1	195	0.752	1.691	1.186	-0.377	1.851	1.245
2014	1	196	0.385	1.467	1.094	-0.925	1.517	1.432
2014	1	197	0.179	1.716	0.948	-0.996	1.726	1.376
2014	1	198	0.057	1.818	0.473	-0.684	1.819	0.831
2014	1	199	-0.455	2.031	0.505	-0.301	2.081	0.588

(continued)

2014	34	207	-1.711	0.818	1.055	-0.235	1.897	1.081
2014	34	208	-1.809	0.690	1.561	-0.226	1.936	1.577
2014	34	209	-1.834	0.411	1.953	-0.138	1.879	1.958
2014	34	210	-1.939	0.078	2.103	0.110	1.941	2.106
2014	34	211	-1.959	-0.165	2.146	0.378	1.966	2.180
2014	34	212	-1.928	-0.247	2.121	0.615	1.943	2.209
2014	34	213	-1.876	-0.141	2.072	0.780	1.881	2.214

4. APCC BSISO Verification System

4.1 Operating Verification System

To run the verification system for the BSISO forecast, no action is necessary as it is carried out automatically every day.

```
> crontab -l
```

The following message is returned:

```
#<<<<<<<<<<<<<<<<<<<< BSISO >>>>>>>>>>>>>>>>>>>>

#Download updated GFS and CFS forecast files (2014.04.15 Koh)
20  09  *  *  *  csh  /data21/BSISO/FCST/00.PREPR/00.FTP.csh  >>
/data21/BSISO/FCST/99.RUN/LOG/cron.log

#Monitoring Run (2014.04.15 Koh)
30  10  *  *  *  csh  /data21/BSISO/MONI/99.RUN/MONI_RUN.CSH  >>
/data21/BSISO/MONI/99.RUN/LOG/cron.log
```

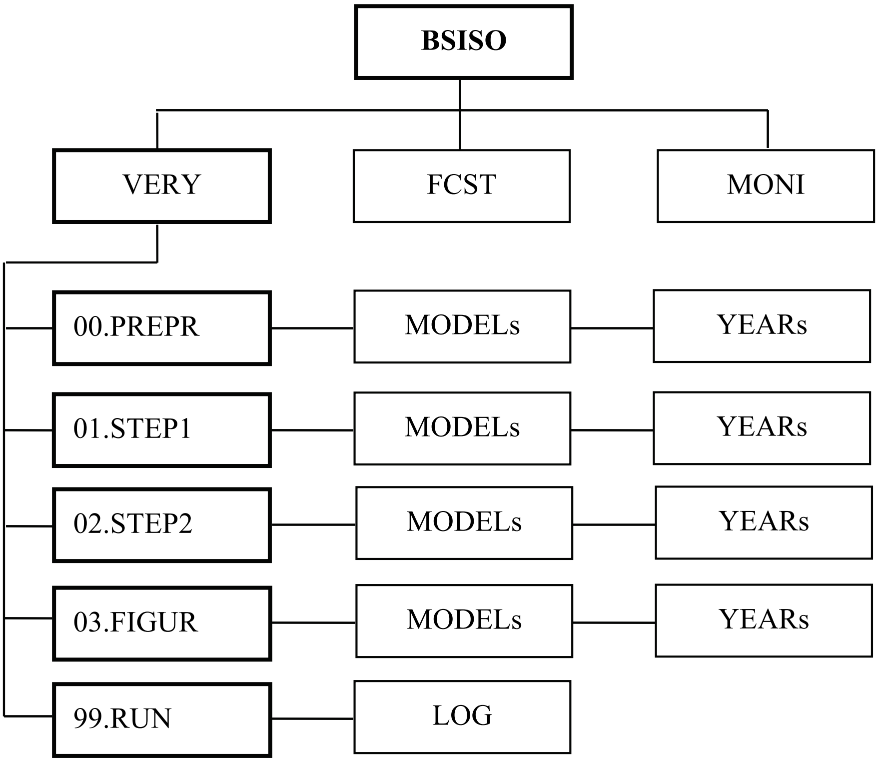
```
#Forecasting Run (2014.04.15 Koh)
40   10   *   *   *   csh   /data21/BSISO/FCST/99.RUN/FCST_RUN.csh   >>
/data21/BSISO/FCST/99.RUN/LOG/cron.log

#Verification Run (2014.04.15 Koh)
15   12   *   *   *   csh   /data21/BSISO/VERI/99.RUN/UPDATE.csh   >>
/data21/BSISO/VERI/99.RUN/LOG/cron.log
```

The final line indicates the verification run part. It is executed at 12:15 every day throughout the year. The main shell script of the BSISO verification system is “UPDATE.csh”.

The main directory of the BSISO verification system is : /data21/BSISO/VERI/

4.2 Directory Structure



※ FCST: BSISO Forecast System

※ MONI: BSISO Monitoring System

※ VERI: BSISO Verification System

※ 00.PREPR: Collects forecasted and observed BSISO indices

※ 01.STEP1: Rearranges the forecasted and observed BSISO indices by target day

※ 02.STEP2: Stores the verification scores of all individual models

※ 03.FIGUR: Stores the verification figures of all individual models

※ 99.RUN: Runs the verification system and contains all source code

※ MODELs: BOM, CFS, ECM, GFS, UKM

※ YEARs: 2013, 2014 (as of now)

4.3 Managing System

The control files and source code files for the BSISO verification can be found under /data21/BSISO/VERI/99.RUN. Details for each file are discussed in Section 5, separately.

- UPDATE.csh : controls the verification system
- UPDATE.VERI.csh : controls the real-time BSISO verification
- UPDATE.VERI.TOTA.csh : controls the total BSISO verification
- Regarding the real-time BSISO verification :

  - 00. PREPR_MDL.ncl
  - 01.STEP1_MDL.ncl
  - 01.STEP1_OBS.ncl
  - 02.STEP2.ncl
  - 03.FIGUR_LINE.ncl
  - 03.FIGUR_MARK.ncl
  - 03.FIGUR_ALL.ncl
  - 03.FIGUR_CHECK.ncl
  - 03.FIGUR_CHECK_ALL.ncl

- Regarding the Total BSISO verification :

  - 10.PREPR_OBS.ncl
  - 12.STEP2_TOTA.ncl
  - 13.FIGUR_TOTA.ncl
  - 13.FIGUR_ALL_TOTA.ncl

5. Verification System Codes

5.1 Control the Verification System

The BSISO verification system is controlled by main shell script. You can find the main shell script under /data21/BSISO/VERI/99.RUN/. **There is no need to modify this script**.

```
> vi UPDATE.csh
```

[UPDATE.csh]

```
#!/bin/csh

echo 'VERIFICATION start: ' `date +%c`

set YEAR = `date  –u +'%Y'`
set MONTH = `date -u +'%m'`
set DAY    = `date -u +'%d'`

echo "YEAR MON DAY" $YEAR $MONTH $DAY

##############################################################

cd /data21/BSISO/VERI/99.RUN

  sed -e s/toyear/${YEAR}/g UPDATE.VERI.csh > a0.csh
  sed -e s/tomon/${MONTH}/g          a0.csh > a1.csh
  sed -e s/today/${DAY}/g            a1.csh > a2.csh

  csh a2.csh > ./LOG/$YEAR/$YEAR$MONTH$DAY.log

  rm -rf a?.csh
```

```
##############################################################

  sed -e s/toyear/${YEAR}/g UPDATE.VERI.TOTA.csh > a0.csh

  csh a0.csh > ./LOG/$YEAR/T$YEAR$MONTH$DAY.log

  rm -rf a?.csh

echo 'VERIFICATION end: ' `date +%c`
```

- First, the date is set to today.
- Second, the date information of *UPDATE.VERI.csh* is modified, and the script is run.
- Finally, the date in *UPDATE.VERI.TOTA.csh* is updated, and the script is run.

5.2 Control the real-time Verification System

To implement the real-time BSISO verification, the *UPDATE.VERI.csh* shell script is controlled. The *UPDATE.VERI.csh* shell script consists mainly of five parts:

I. Setting time information
II. Changing the forecasted BSISO index file's name
III. Rearranging the BSISO index file into the verification target day
(This process is for real-time verification)
IV. Calculating and writing the five verification skill scores
V. Making verification figures and sending them to a web server

[UPDATE.VERI.csh]

```
#!/bin/csh
#-----------------------------------------------------------------------------------------#
```

```
#                                          Date: 17Mar, 2014
#                                          By Ms. Hyein Jeong
#
# BSISO Realtime verification system
#
# 00.PREPR -> Change file name of 20d INDEX from each Model and OBS
# 01.STEP1 -> Rearrange 20d INDEX file to verification day
# 02.STEP2 -> Writing 5 skill scores
# 03.STEP3 -> Graphics
#----------------------------------------------------------------------#
# Set directory
#----------------------------------------------------------------------#
setenv FIGUR /data21/BSISO/VERI/03.FIGUR
                                          …  (Continued)….
```

- Information of developed date and developer
- Structure of real-time BSISO verification run
- Setting the FIGUR directory

I. Setting time information

```
#----------------------------------------------------------------------#
# Set time
#----------------------------------------------------------------------#
set YEAR = 'toyear'
set MONTH = 'tomon'
set DAY    = 'today'

#TDAY indicates target day for verification #arakoh
set MONDIR = '/data21/BSISO/MONI/00.PREPR/U850/ORG'
```

```
set ITIME = `ls -al ${MONDIR}/pgb.anl.????????18.grib | tail -1 | cut -c 92-99`

set    VYEAR = `date -d ${ITIME} +'%Y'`
set    VMONTH = `date -d ${ITIME} +'%m'`
set    VDAY    = `date -d ${ITIME} +'%d'`

#--------------------------------------------------------------------#

echo '------------------------------ '
echo '      BSISO Verification         '
echo ' Date            : YYYY MM DD '
echo ' Today           : ' $YEAR $MONTH $DAY
echo ' Veri. Day       : ' $VYEAR $VMONTH $VDAY
echo '------------------------------ '
echo '                              '
                                        …  (Continued)….
```

- Setting the date of Today (Verification implementing date)
- The verification date is retrieved from the Monitoring directory and set. The verification date is the recent observed date. In general, the observation is updated every day with the date of 4 or 5 days prior. However, due to reliability issues, we use the date of the most recent observation file.
- Information about the real-time verification date is written in a log file

II. Change the forecasted BSISO index file's name

```
#--------------------------------------------------------------------#
#      00.PREPR MDL
#--------------------------------------------------------------------#
```

```
foreach MDL ( BOM CFS ECM GFS UKM )
echo '                              '
echo ' 00.PREPR        : ' $MDL
echo '                              '

  sed -e s/mld/${MDL}/g    00.PREPR_MDL.ncl > a0.ncl
  sed -e s/yyyy/${VYEAR}/g           a0.ncl > a1.ncl
  ncl < a1.ncl
  rm -rf a?.ncl

end
                    …..(Continued)…….
```

- This sets the model information. Currently, we use five GCMs.
- Here we modify the model and verification year of *00.PREPR_MDL.ncl*
- We implement the modified NCL file and remove it
- Detailed information of *00.PREPR_MDL.ncl* can be found in **section 5.2.1**

III. Rearrange the observed and forecasted BSISO index file into verification target day

```
#--------------------------------------------------------------------#
#     01.STEP1 OBS
#--------------------------------------------------------------------#
foreach MDL ( OBS )
echo '                              '
echo ' 01.STEP1        : ' $MDL
echo '                              '

    if ($MDL == 'OBS' ) then
```

```
      set TDD = '20'
      set TEN = '0'
    endif

  sed -e s/yyyy/${VYEAR}/g    01.STEP1_OBS.ncl > a0.ncl
  sed -e s/mmmm/${VMONTH}/g          a0.ncl > a1.ncl
  sed -e s/dddd/${VDAY}/g               a1.ncl > a2.ncl
  sed -e s/mld/${MDL}/g                 a2.ncl > a3.ncl
  sed -e s/ttt/${TDD}/g                 a3.ncl > a4.ncl
  ncl < a4.ncl
  rm -rf a?.ncl

end

#-----------------------------------------------------------------------#
#      01.STEP1 MDL
#-----------------------------------------------------------------------#
foreach MDL ( BOM CFS ECM GFS UKM )
echo '                              '
echo ' 01.STEP1         : ' $MDL
echo '                              '
    if ( $MDL == 'BOM' ) then
      set TDD = '20'
      set TEN = '33'
    else if ( $MDL == 'CFS' ) then
      set TDD = '20'
      set TEN = '4'
    else if ( $MDL == 'ECM' ) then
      set TDD = '20'
      set TEN = '51'
    else if ( $MDL == 'GFS' ) then
```

```
     set TDD = '16'
     set TEN = '1'
    else if ( $MDL == 'UKM' ) then
     set TDD = '15'
     set TEN = '24'
    endif

  sed -e s/yyyy/${VYEAR}/g 01.STEP1_MDL.ncl > a0.ncl
  sed -e s/mmmm/${VMONTH}/g        a0.ncl > a1.ncl
  sed -e s/dddd/${VDAY}/g          a1.ncl > a2.ncl
  sed -e s/mld/${MDL}/g            a2.ncl > a3.ncl
  sed -e s/ten/${TEN}/g            a3.ncl > a4.ncl
  sed -e s/ttt/${TDD}/g            a4.ncl > a5.ncl
  ncl < a5.ncl
  rm -rf a?.ncl

end
              ……(Continued)……
```

- In this script, we rearrange the observed and forecasted BSISO index files from the forecast starting date to the verification date (This is for real-time verification).
- We modify *01.STEP1_OBS.ncl* and implement it
- We modify the model name, verification date, ensemble member, and forecast period of *01.STEP1_MDL.ncl*
- Then we implement the modified NCL file and remove them
- The detailed information of *01.STEP1_OBS.ncl* and *01.STEP1_MDL.ncl* is located in **sections 5.2.2 and 5.2.3.**

IV. Calculating and Writing the five verification skill scores

```
#--------------------------------------------------------------------#
#     02.STEP2 MDL
#--------------------------------------------------------------------#
foreach MDL ( BOM CFS ECM GFS UKM )
echo '                              '
echo ' 02.STEP2        : ' $MDL
echo '                              '

    if ( $MDL == 'BOM' ) then
      set TDD = '20'
      set TEN = '33'
    else if ( $MDL == 'CFS' ) then
      set TDD = '20'
      set TEN = '4'
    else if ( $MDL == 'ECM' ) then
      set TDD = '20'
      set TEN = '51'
    else if ( $MDL == 'GFS' ) then
      set TDD = '16'
      set TEN = '1'
    else if ( $MDL == 'UKM' ) then
      set TDD = '15'
      set TEN = '24'
    endif

  sed -e s/yyyy/${VYEAR}/g    02.STEP2.ncl > a0.ncl
  sed -e s/mmmm/${VMONTH}/g      a0.ncl > a1.ncl
  sed -e s/dddd/${VDAY}/g            a1.ncl > a2.ncl
  sed -e s/mld/${MDL}/g              a2.ncl > a3.ncl
```

```
  sed -e s/ten/${TEN}/g              a3.ncl > a4.ncl
  sed -e s/ttt/${TDD}/g               a4.ncl > a5.ncl
  ncl < a5.ncl
  rm -rf a?.ncl

end
                    ……(Continued)……
```

- Here we calculate the verification skill scores with the forecasted and observed BSISO indices
- We modify the model name, verification date, ensemble member, and forecast period of *02.STEP2.ncl*
- Then we implement the modified NCL file and remove them
- The detailed information of *02.STEP2.ncl* is located in **section 5.2.4.**

V. Graphics of verification figures and transmission to web server

```
#----------------------------------------------------------------------#
#     03.FIGUR for Each Model
#----------------------------------------------------------------------#
foreach MDL ( BOM CFS ECM GFS UKM )
echo '                              '
echo ' 03.FIGUR        : ' $MDL
echo '                              '

  if ( $MDL == 'CFS' || $MDL == 'GFS' || $MDL == 'UKM' ) then

     sed -e s/yyyy/${VYEAR}/g    03.FIGUR_LINE.ncl > a0.ncl
     sed -e s/mmmm/${VMONTH}/g           a0.ncl > a1.ncl
```

```
     sed -e s/dddd/${VDAY}/g                  a1.ncl > a2.ncl
     sed -e s/mld/${MDL}/g                    a2.ncl > a3.ncl
     ncl < a3.ncl
     rm -rf a?.ncl

  else if ( $MDL == 'BOM' || $MDL == 'ECM' ) then

     sed -e s/yyyy/${VYEAR}/g    03.FIGUR_MARK.ncl > a0.ncl
     sed -e s/mmmm/${VMONTH}/g              a0.ncl > a1.ncl
     sed -e s/dddd/${VDAY}/g                  a1.ncl > a2.ncl
     sed -e s/mld/${MDL}/g                    a2.ncl > a3.ncl
     ncl < a3.ncl
     rm -rf a?.ncl

  endif
convert -density 150x150 -trim
          ${FIGUR}/${MDL}/${VYEAR}/
            BSISO.VERI.${MDL}C.${VYEAR}${VMONTH}${VDAY}.pdf
          ${FIGUR}/${MDL}/${VYEAR}/
            BSISO.VERI.${MDL}C.${VYEAR}${VMONTH}${VDAY}.png

#--------------------------------------------------------------------#
#      03.FIGUR Check for Individual Models
#--------------------------------------------------------------------#
     sed -e s/yyyy/${VYEAR}/g    03.FIGUR_CHECK.ncl > a0.ncl
     sed -e s/mmmm/${VMONTH}/g              a0.ncl > a1.ncl
     sed -e s/dddd/${VDAY}/g                  a1.ncl > a2.ncl
     sed -e s/mld/${MDL}/g                    a2.ncl > a3.ncl
     ncl < a3.ncl
     rm -rf a?.ncl
```

```
scp
    ${FIGUR}/WEB/BSISO.VERI.${MDL}.png
    apcc21@210.98.49.32:/data/apcc_images/BSISO/VERI/BSISO.VERI.${MDL}.png

#--------------------------------------------------------------------#
#     03.FIGUR for ALL
#--------------------------------------------------------------------#
   sed -e s/yyyy/${VYEAR}/g    03.FIGUR_ALL.ncl > a0.ncl
  sed -e s/mmmm/${VMONTH}/g          a0.ncl > a1.ncl
   sed -e s/dddd/${VDAY}/g              a1.ncl > a2.ncl
                  ……(Continued)…….
#--------------------------------------------------------------------#
#     03.FIGUR Check for ALL
#--------------------------------------------------------------------#
   sed -e s/yyyy/${VYEAR}/g    03.FIGUR_CHECK_ALL.ncl > a0.ncl
   sed -e s/mmmm/${VMONTH}/g                a0.ncl > a1.ncl
   sed -e s/dddd/${VDAY}/g                  a1.ncl > a2.ncl
                                  ……(Continued)…….
end
```

- This script makes verification figures for the individual models with all ensemble members and figures with each model's ensemble mean (For comparison between models).
- It then modifies the model name and verification date of *03.FIGUR_LINE.ncl or 03.FIGUR_MARK.ncl*
- Note that the CFS, GFS, and UKM models predict the BSISO forecast daily (See Table 1). Therefore, we can draw the skill scores with the type of LINE. However, the BOM

and ECM models predict the BSISO forecast every 3 or 4 days. For these models, we use the MARK type graphics tool.

- Before sending graphics to the web server, we check the file of the verification skill scores. If the skill score is whole missing a value during the 20 days, the verification figure will not be sent to the web server. *03.FIGUR_CHECK.ncl* or *03.FIGUR_CHECK_ALL.ncl* files check for missing values.
- The detailed information of *03.FIGUR_LINE.ncl* can found at **section 5.2.5.** *03.FIGUR_MARK.ncl* can found at **section 5.2.6.** *03.FIGUR_ALL.ncl* is located in **section 5.2.7.** *03.FIGUR_CHECK.ncl* is found in **section 5.2.8.** *03.FIGUR_CHECK_ALL.ncl* is outlined in **section 5.2.9.**

5.2.1 Preparing the forecasted BSISO index file

[00.PREPR_MDL.ncl]

```
;**********************************************************
;                    00.PREPR
;                      MDL
; Forecasted BSISO 20d INDEX -> Change File name [Julian]
;**********************************************************'
begin
;==============================================================
   MOD = "mld"
   YYYY = yyyy
;==============================================================
                                        …..(Continued)……
f1=/data21/BSISO/FCST/11.BINAR/"+MOD+"/"+YYYY+"/"+YYYY+"0"+MM+"0"+DD+"_
"+MOD+"C_BSISO.20d.INDEX"

if (isfilepresent(f1))
```

```
  f      = readAsciiTable(f1,9,"float",1)
  JDAY = f(0,2)
  opt    = True
  opt@fout = "/data21/BSISO/VERI/00.PREPR/"+MOD+"/"+
                    YYYY+"/"+YYYY+"_"+JDAY+"_"+MOD+"C_BSISO.20d.INDEX"
  opt@title = "Year    ENSEMBLE Day     PC1      PC2      PC3      PC4 BSISO1    BSISO2"
  write_matrix(f,"1x,f5.0,3x,f4.0,5x,f4.0,3x,f6.3,3x,f6.3,3x,f6.3,3x,f6.3,3x,f6.3,3x,f6.3", opt)
end if
                                   .....(Continued)......
```

- Input files : /data21/BSISO/FCST/11.BINAR/+each model directory + each year +/YYYY MMDD_MODC_BSISO.20d.INDEX
- Output files : /data21/BSISO/VERI/00.PREPR/+each model directory + each year +/YYYY _JDAY_MODC_BSISO.20d.INDEX
- Main functions: Read the third column (Julian Day; JDAY) at the first line of forecasted the BSISO index file and rewrite it with the file name of Julian day.
- Reason: This process is creates a common format between forecasted index files.
- Major NCL functions: **isfilepresent, readAsciiTable, write_matrix** (Detailed descriptions of each function are located in Appendix F)

5.2.2 Rearrangement of observed BSISO index files to the verification date

[01.STEP1_OBS.ncl]

```
;*******************************************************
;                    01.STEP1
;                       OBS
; Rearrange BSISO 20d INDEX -> Target Day [Julian]
;*******************************************************
```

```
begin
;=================================================================
   YYYY = yyyy
   MM    = mmmm
   DD    = dddd
   MOD = "mld"
   TDD = ttt
   TDAY = TDD
;=================================================================
JDAY    = day_of_year(YYYY,MM,DD)
;=================================================================
  iTGDAY = JDAY(0)    ; consider leap year
  newf = new((/TDAY,8/),"float")
  f1 = "/data21/BSISO/MONI/09.STEP9/text/BSISO."+YYYY+".INDEX.NORM.data"
  if (isfilepresent(f1))
   f       = readAsciiTable(f1,8,"float",1)
   oldDAY = f(:,1)
   ndims = dimsizes(oldDAY)
   do i=0,ndims - 1
      if oldDAY(i).eq.iTGDAY
        do j=0,TDD-1
          newf(j,:) = f(i,:)
        end do
          newf(:,1) = ispan(iTGDAYs,iTGDAY,1)
     end if
   end do
  end if
;**********************************************************
  opt = True
  opt@fout="/data21/BSISO/VERI/01.STEP1/"+MOD+"/"+YYYY+"/"+YYYY+"_"+
            iTGDAY+"_"+MOD+"C_BSISO.20d.INDEX"
```

```
  opt@title = "Year Day    PC1    PC2    PC3    PC4    BSISO1 BSISO2"
  write_matrix (newf, "1x,f5.0,3x,f4.0,3x,f6.3,3x,f6.3,3x,f6.3,3x,f6.3,3x,f6.3,3x,f6.3", opt)

end
```

- Input files: /data21/BSISO/MONI/09.STEP9/text/BSISO.YYYY.INDEX.NORM. data

  - This file has observed BSISO indices from January 1st of relevant the year.

- Output files: /data21/BSISO/VERI/01.STEP1/+each model directory + each year +/YYYY _JDAY_MODC_BSISO.20d.INDEX
- Main functions: Read the observed BSISO index file and rewrite the BSISO indices for the target date (verification date). The output file has the same BSISO indices during 20 days.
- Reason: This is to verify the forecasted BSISO with 20 days lead time.
- Major NCL functions: **day_of_year, ispan** (You can find a detailed description of each function at Appendix)

5.2.3. Rearrangement of forecasted BSISO index files from forecast starting date to verification date

[01.STEP1_MDL.ncl]

```
;*********************************************************
;                    01.STEP1
;                       MDL
; Rearrange BSISO 20d INDEX -> Target Day [Julian]
;*********************************************************
begin
;===========================================================
   MOD = "mld"
```

```
    YYYY = yyyy
    MM    = mmmm
    DD    = dddd
    ENS = ten
    TDD = ttt
    TDAY = (ENS+1)*TDD
;==============================================================
JDAY    = day_of_year(YYYY,MM,DD)
;==============================================================
  iTGDAY = JDAY(0)    ; consider leap year
     if MOD.eq."GFS"
     iTGDAYs = iTGDAY - 15
    end if
    if MOD.eq."CFS"
     iTGDAYs = iTGDAY - 19
    end if
    if MOD.eq."BOM"
     iTGDAYs = iTGDAY - 19
    end if
    if MOD.eq."ECM"
     iTGDAYs = iTGDAY - 19
    end if
    if MOD.eq."UKM"
     iTGDAYs = iTGDAY - 14
    end if
     newf = new((/TDAY,9/),"float")
    newDAY=0
do ee=0,ENS
  do DAY =iTGDAYs,iTGDAY
    f1="/data21/BSISO/VERI/00.PREPR/"+MOD+"/"+YYYY+"/"+YYYY+"_"+
           DAY+"_"+MOD+"C_BSISO.20d.INDEX"
```

```
  if (isfilepresent(f1))
    f    = readAsciiTable(f1,9,"float",1)
    oldDAY = f(:,2)
    iStart    =ee*TDD
    iEnd    =ee*TDD+(TDD-1)

    do i=iStart,iEnd
        if oldDAY(i).eq.iTGDAY
          newf(newDAY,:) = f(i,:)
          newf(newDAY,2) = DAY
        end if
      end do
  else
          newf(newDAY,0) = YYYY
          newf(newDAY,1) = ee+1
          newf(newDAY,2) = DAY
          newf(newDAY,3) = 99.999
          newf(newDAY,4) = 99.999
          newf(newDAY,5) = 99.999
          newf(newDAY,6) = 99.999
          newf(newDAY,7) = 99.999
          newf(newDAY,8) = 99.999
  end if
  newDAY = newDAY+1
  end do
 end do
;***********************************************************
 opt      = True
 opt@fout="/data21/BSISO/VERI/01.STEP1/"+MOD+"/"+YYYY+"/"+YYYY+"_"+
                  iTGDAY+"_"+MOD+"C_BSISO.20d.INDEX"
 opt@title = "Year ENSEMBLE Day PC1 PC2 PC3 PC4 BSISO1 BSISO2"
```

```
 write_matrix (newf, "1x, f5.0, 3x, f4.0, 5x, f4.0, 3x, f6.3, 3x, f6.3, 3x, f6.3, 3x, f6.3, 3x,
f6.3, 3x, f6.3", opt)

end
```

- Input files : /data21/BSISO/VERI/00.PREPR/+each model directory + each year +/YYYY_JDAY_MODC_BSISO.20d.INDEX
- Output files: /data21/BSISO/VERI/01.STEP1/+each model directory + each year +/YYYY_JDAY_MODC_BSISO.20d.INDEX
- Main functions: Read the forecasted BSISO index file and rewrite them for the target date (verification date). If there is not a forecasted index file, a number representing a missing value (99.999) will be written in the output file. The BOM, CFS, and ECM models have 20 days forecast lead time. However, the GFS model has 16 days, and the UKM model has 15 days forecast lead time (See Table 1). Each model has a different ensemble member. Therefore, we should consider each ensemble member individually.
- Reason: This process is for verifying the forecasted BSISO with the maximum 20 days lead time.

5.2.4 Calculating and writing five verification skill scores

[02.STEP2.ncl]

```
;*******************************************************
;                    02.STEP2
;                      MDL
;          Calculating and Writing 5 Skill Scores
;*******************************************************
begin
;=======================================================
```

```
  MOD = "mld"
  YYYY = yyyy
  MM   = mmmm
  DD   = dddd
  ENS = ten
  TDD = ttt
;==================================================================
JDAY   = day_of_year(YYYY,MM,DD)
;==================================================================
 iTGDAY = JDAY(0)   ; consider leap year

 cor12 = new((/ENS+1,TDD/),"float",99.999)
 cor12!0 = "ENS+1"
 cor12!1 = "leadtime"
 cor34 = cor12
                                        …..(Continued)……
if(isfilepresent("/data21/BSISO/VERI/01.STEP1/"+MOD+"/"+YYYY+"/"+YYYY+"_"+
                 iTGDAY+"_"+MOD+"C_BSISO.20d.INDEX"))
  f1="/data21/BSISO/VERI/01.STEP1/"+MOD+"/"+YYYY+"/"+YYYY+"_"+
          iTGDAY+"_"+MOD+"C_BSISO.20d.INDEX"
  o1="/data21/BSISO/VERI/01.STEP1/OBS/"+YYYY+"/"+YYYY+"_"+
          iTGDAY+"_OBSC_BSISO.20d.INDEX"

        f = readAsciiTable(f1,9,"float",1)

                                        …..(Continued)……
;*******************************************************
; Read the data for the desired period
;*******************************************************

 fpc1 = new((/ENS+1,TDD/),"float")
```

```
  fpc2 = new((/ENS+1,TDD/),"float")
  fpc3 = new((/ENS+1,TDD/),"float")
  fpc4 = new((/ENS+1,TDD/),"float")

  opc1 = new((/1,TDD/),"float")
  opc2 = new((/1,TDD/),"float")
  opc3 = new((/1,TDD/),"float")
  opc4 = new((/1,TDD/),"float")

  do ee=0,ENS
    iStrt    = ee*TDD + 0
    iLast    = ee*TDD + TDD - 1
    fpc1(ee,:)      = f(iStrt:iLast,3)
    fpc2(ee,:)      = f(iStrt:iLast,4)
    fpc3(ee,:)      = f(iStrt:iLast,5)
    fpc4(ee,:)      = f(iStrt:iLast,6)
  end do

    opc1(0,:)      = o(:,2)
    opc2(0,:)      = o(:,3)
    opc3(0,:)      = o(:,4)
    opc4(0,:)      = o(:,5)
;**********************************************************
; 1. Calc CORR
;**********************************************************
do ee=0,ENS
  do itime = 0, TDD - 1

    if fpc1(ee,itime).eq.99.999
      of12(ee,itime)    = 99.999
      oo12(ee,itime)    = 99.999
```

```
   ff12(ee,itime)    = 99.999
   of34(ee,itime)    = 99.999
   oo34(ee,itime)    = 99.999
   ff34(ee,itime)    = 99.999
  else
   of12(ee,itime)=of12(ee,itime)+(opc1(0,itime)*fpc1(ee,itime)+opc2(0,itime)*fpc2(ee,itime))
oo12(ee,itime)=oo12(ee,itime)+(opc1(0,itime)*opc1(0,itime)+opc2(0,itime)*opc2(0,itime))
ff12(ee,itime)=ff12(ee,itime)+(fpc1(ee,itime)*fpc1(ee,itime)+fpc2(ee,itime)*fpc2(ee,itime))
              ….(Continued)…..
 end do
end do
;*******************************************************
; 2. Calc RMSE
;*******************************************************
               ….(Continued)…..
sdif1(ee,itime)=(opc1(0,itime)-fpc1(ee,itime))*(opc1(0,itime)-fpc1(ee,itime))
sdif2(ee,itime)=(opc2(0,itime)-fpc2(ee,itime))*(opc2(0,itime)-fpc2(ee,itime))
rms12(ee,itime)=rms12(ee,itime) + (sdif1(ee,itime)+sdif2(ee,itime))
                               ….(Continued)…..
;*******************************************************
; 3. Calc ERRamp
;*******************************************************
                               ….(Continued)…..
 o12(ee,itime)    = sqrt(opc1(0,itime)*opc1(0,itime)+opc2(0,itime)*opc2(0,itime))
 f12(ee,itime)    = sqrt(fpc1(ee,itime)*fpc1(ee,itime)+fpc2(ee,itime)*fpc2(ee,itime))
 Eamp12(ee,itime) = Eamp12(ee,itime) + (f12(ee,itime) - o12(ee,itime))
                               ….(Continued)…..
;*******************************************************
; 4. Calc ERRphs
;*******************************************************
                               ….(Continued)…..
```

```
 o1f2(ee,itime)    = opc1(0,itime)*fpc2(ee,itime)
 o2f1(ee,itime)    = opc2(0,itime)*fpc1(ee,itime)
 o1f1(ee,itime)    = opc1(0,itime)*fpc1(ee,itime)
 o2f2(ee,itime)    = opc2(0,itime)*fpc2(ee,itime)
 Ephs12(ee,itime)=Ephs12(ee,itime)+(atan((o1f2(ee,itime)-
                        o2f1(ee,itime))/(o1f1(ee,itime)+o2f2(ee,itime))))
                                                ….(Continued)…..
;*********************************************************
CNT    = CNT + 1
end if ; ispresent
;*********************************************************
; 5. Calc MSSS
;*********************************************************
   MSE_f12(:,:) = rms12(:,:)/CNT
   MSE_f34(:,:) = rms34(:,:)/CNT
   MSE_c12(:,:) = oo12(:,:)/CNT
   MSE_c34(:,:) = oo34(:,:)/CNT
;*********************************************************
;*********************************************************
      cor12(:,:) = of12(:,:)/sqrt(oo12(:,:)*(ff12(:,:)))
   cor34(:,:) = of34(:,:)/sqrt(oo34(:,:)*(ff34(:,:)))

   rms12(:,:) = sqrt(rms12(:,:)/CNT)
   rms34(:,:) = sqrt(rms34(:,:)/CNT)

   Eamp12(:,:) = Eamp12(:,:)/CNT
   Eamp34(:,:) = Eamp34(:,:)/CNT

   Ephs12(:,:) = Ephs12(:,:)/CNT
   Ephs34(:,:) = Ephs34(:,:)/CNT
```

```
   MSSS12(:,:) = 1.0 - (MSE_f12(:,:)/MSE_c12(:,:))
   MSSS34(:,:) = 1.0 - (MSE_f34(:,:)/MSE_c34(:,:))
;*******************************************************
;    WRITING OUTPUT FILE
;*******************************************************
      DAY = iTGDAY
   DAY@calendar = "julian"
   DAY@calendar = "noleap"
   DAY@units = "days since "+YYYY+"-1 -1"
   DAY = DAY - 1
   utc_date=cd_calendar(DAY,0)
   year=tointeger(utc_date(:,0))
   imon=tointeger(utc_date(:,1))
   iday=tointeger(utc_date(:,2))

   namMonth = (/ "Jan","Feb","Mar","Apr","May","Jun",\
              "Jul","Aug","Sep","Oct","Nov","Dec"/)

System ("rm-rf/data21/BSISO/VERI/02.STEP2/"+MOD+"/"+YYYY+"/"+MOD+"C_"+
            YYYY+"_"+iTGDAY+"_0"+iday(0)+namMonth(imon(0)-1)+"_SKILL.nc")
fout=addfile("/data21/BSISO/VERI/02.STEP2/"+MOD+"/"+YYYY+"/"+MOD+"C_"+
            YYYY+"_"+iTGDAY+"_0"+iday(0)+namMonth(imon(0)-1)+"_SKILL.nc","c")
fout->cor12=cor12
fout->cor34=cor34
fout->rms12=rms12
fout->rms34=rms34
fout->Eamp12=Eamp12
fout->Eamp34=Eamp34
fout->Ephs12=Ephs12
fout->Ephs34=Ephs34
fout->MSSS12=MSSS12
```

```
fout->MSSS34=MSSS34
end
```

- Input file (f) : /data21/BSISO/VERI/01.STEP1/+each model directory + each year +/YYYY _JDAY_MODC_BSISO.20d.INDEX
- Input file (o) : /data21/BSISO/VERI/01.STEP1/OBS/+each year+/YYYY_+JDAY_OBSC _BSISO.20d.INDEX
- Output files: /data21/BSISO/VERI/01.STEP2/+each model directory + each year +/+MODC _YYYY_JDAY_DD_MM_SKILL.nc
- Main functions: Calculating BSISO verification skill scores such as COR, RMSE, Amplitude Error, Phase Error, and MSSS. BSISO1 (using PC1 and PC2) as well as BSISO2 (using PC3 and PC4) are calculated. If there are missing values in the forecasted or observed BSISO indices, the verification skill score also has missing values.

5.2.5 Making figures for the CFS, GFS, and UKM models

[03.FIGUR_LINE.ncl]

```
;**********************************************************
;                    03.STEP3
;                      MDL
; Graphic for "CFS","GFS",or "UKM" [They provide BSISO index everyday]
;**********************************************************
Begin
;============================================================
   MOD = "mld"
   YYYY = yyyy
   MM    = mmmm
```

```
   DD    = dddd
;==============================================================
pltDir = "/data21/BSISO/VERI/03.FIGUR/"+MOD+"/"+YYYY+"/"
pltType = "pdf"
;==============================================================
                   ……(Continued)……..
fin=addfile("/data21/BSISO/VERI/02.STEP2/"+MOD+"/"+YYYY+"/"+MOD+"C_"+
                 YYYY+"_"+iTGDAY+"_0"+iday(0)+namMonth(imon(0)-1)+"_SKILL.nc","r")
cor12 = fin->cor12(:,::-1)
cor34 = fin->cor34(:,::-1)
rms12 = fin->rms12(:,::-1)
rms34 = fin->rms34(:,::-1)
                                      ……(Continued)……..
     pltName = "BSISO.VERI."+MOD+"C."+YYYY+MM+DD
     pltPath = pltDir+pltName
;*******************************************************
; Graphic
;*******************************************************
wks                  = gsn_open_wks(pltType,pltPath)
                                      ……(Continued)……..
res1@xyDashPatterns    = (/"Dash"/)
res1@xyLineThicknessF = 1
res1@xyLineColors      = (/"Orange"/)

res2@xyDashPatterns    = (/"solid"/)
res2@xyLineThicknessF = 2
res2@xyLineColors      = (/"Red"/)
                                      ……(Continued)……..
       do i=0,nens-2
       plot=gsn_csm_xy(wks,leadtime,cor12(i,:),res1)
   end do
```

```
            plot=gsn_csm_xy(wks,leadtime,cor12(nens-1,:),res2)
                                  ……(Continued)……..

end
```

- Input file : /data21/BSISO/VERI/02.STEP2/+each model directory + each year +/+MODC_YYYY_JDAY_DD_MM_SKILL.nc
- Output files: /data21/BSISO/VERI/03.FIGUR/+each model directory + each year +/+BSISO.VERI.MODC.YYYYMMDD.pdf
- Main functions: Produce verification figures for skill scores such as COR, RMSE, Amplitude Error, Phase Error, and MSSS.
- All ensemble members are indicated by orange dashed lines with line thickness 1. The ensemble mean is indicated by a red solid line with line thickness 2.
- Appendix A contains an example figure.

5.2.6 Making figures for the BOM and ECM models

[03.FIGUR_MARK.ncl]

```
;*******************************************************
;                    03.STEP3
;                       MDL
; Graphic for "BOM" or "ECM"
;*******************************************************
begin
                                  ……(Continued)……..

;*******************************************************
; Graphic
```

```
;*********************************************************
                              ……(Continued)……..
res1@xyMarkLineMode    = (/"Markers"/)
res1@xyMarkerColors      = (/"Orange"/)

res2@xyMarkLineMode    = (/"Markers"/)
res2@xyMarkerColors      = (/"Red"/)
                              ……(Continued)……..

end
```

- Input file: /data21/BSISO/VERI/02.STEP2/+each model directory + each year +/+MODC _YYYY_JDAY_DD_MM_SKILL.nc
- Output files: /data21/BSISO/VERI/03.FIGUR/+each model directory + each year +/BSISO. VERI.MODC.YYYYMMDD.pdf
- Main functions: Making verification figures for skill scores such as COR, RMSE, Amplitude Error, Phase Error, and MSSS.
- Same as *03.FIGUR_LINE.ncl* except for the graphic part. All ensemble members are indicated by closed orange circles, and the ensemble mean is indicated by a closed red circle.
- An example is located in Appendix B.

5.2.7 Making figures for the ensemble mean of each model

[03.FIGUR_ALL.ncl]

```
;*********************************************************
;                 03.STEP3
;                    MDL
```

```
;           Graphic for Each Models' Ensemble Mean
;*******************************************************
begin
;==============================================================
YYYY = yyyy
MM    = mmmm
DD    = dddd
;==============================================================
JDAY    = day_of_year(YYYY,MM,DD)
iTGDAY = JDAY(0)

pltDir = "/data21/BSISO/VERI/03.FIGUR/ALL/"+YYYY+"/"
pltType = "pdf"
;==============================================================
fin1 =addfile ("/data21/BSISO/VERI/02.STEP2/BOM/"+YYYY+"/BOMC_"+
                  YYYY+"_"+iTGDAY+"_"+iday(0)+namMonth(imon(0)-1)+"_SKILL.nc","r")
fin2=addfile ("/data21/BSISO/VERI/02.STEP2/CFS/"+YYYY+"/CFSC_"+
                  YYYY+"_"+iTGDAY+"_"+iday(0)+namMonth(imon(0)-1)+"_SKILL.nc","r")
fin3=addfile ("/data21/BSISO/VERI/02.STEP2/ECM/"+YYYY+"/ECMC_"+
                  YYYY+"_"+iTGDAY+"_"+iday(0)+namMonth(imon(0)-1)+"_SKILL.nc","r")
fin4=addfile ("/data21/BSISO/VERI/02.STEP2/GFS/"+YYYY+"/GFSC_"+
                  YYYY+"_"+iTGDAY+"_"+iday(0)+namMonth(imon(0)-1)+"_SKILL.nc","r")
fin5=addfile ("/data21/BSISO/VERI/02.STEP2/UKM/"+YYYY+"/UKMC_"+
                  YYYY+"_"+iTGDAY+"_"+iday(0)+namMonth(imon(0))+"_SKILL.nc","r")

bom_cor12 = fin1->cor12(::-1,::-1)
bom_cor34 = fin1->cor34(::-1,::-1)

                  ……(Continued)……..

pltName = "BSISO.VERI.ALL."+YYYY+MM+DD
```

```
pltPath = pltDir+pltName

;*********************************************************
; Graphic
;*********************************************************
   res1@xyMarkerColors    = (/"Red"/)
  res1@xyMarkLineMode    = (/"Markers"/)
  res1@xyMarkerSizeF      = 0.004

   plot=gsn_csm_xy(wks,leadtime,cor12(0,:),res1)

  res1@xyLineColors      = (/"Orange"/)
  res1@xyMarkLineMode    = (/"Lines"/)

   plot=gsn_csm_xy(wks,leadtime,cor12(1,:),res1)

  res1@xyMarkerColors    = (/"Green"/)
  res1@xyMarkLineMode    = (/"Markers"/)
  res1@xyMarkerSizeF      = 0.004

   plot=gsn_csm_xy(wks,leadtime,cor12(2,:),res1)

  res1@xyLineColors      = (/"Blue"/)
  res1@xyMarkLineMode    = (/"Lines"/)

   plot=gsn_csm_xy(wks,leadtime,cor12(3,:),res1)

  res1@xyLineColors      = (/"magenta"/)
  res1@xyMarkLineMode    = (/"Lines"/)

      plot=gsn_csm_xy(wks,leadtime,cor12(4,:),res1)
```

```
……(Continued)……..

end
```

- Input file: /data21/BSISO/VERI/02.STEP2/+each model directory + each year +/+MODC_YYYY_JDAY_DD_MM_SKILL.nc
- Output files: /data21/BSISO/VERI/03.FIGUR/ALL/+each year +/BSISO.VERI.ALL.YYYYMMDD.pdf
- Main functions: Making verification figures for skill scores of each model's ensemble mean
- The CFS, GFS, and UKM models are indicated by an orange, a blue, and a pink line, respectively. The BOM and ECM models are indicated by red and green marks.
- You can find an example figure in Appendix C.

5.2.8 Checking for missing values for all individual models

[03.FIGUR_CHECK.ncl]

```
;**********************************************************
;                    03.STEP3
;                       MDL
;           Graphic check for ALL individual models
;**********************************************************
begin
;==========================================================
MOD = "mld"
YYYY = yyyy
MM    = mmmm
```

```
DD    = dddd
;===========================================================
JDAY    = day_of_year(YYYY,MM,DD)
iTGDAY = JDAY(0)
;===========================================================
fin =addfile ("/data21/BSISO/VERI/02.STEP2/MOD/"+YYYY+"/MODC_"+
                YYYY+"_"+iTGDAY+"_"+iday(0)+namMonth(imon(0)-1)+"_SKILL.nc","r")
cor12 = fin->cor12(:,::-1)
if (.not.all(ismissing(cor12)))
   system("scp /data21/BSISO/VERI/03.FIGUR/"+MOD+"/"+YYYY+"/"+"
                    BSISO.VERI."+MOD+"C."+YYYY+"0"+MM+"0"+DD+".png
                    /data21/BSISO/VERI/03.FIGUR/WEB/BSISO.VERI."+MOD+".png")

if (all(ismissing(cor12)))
  print("Data is all missing. Can't copy to WEB directory.")
end if
end
```

- Input file: /data21/BSISO/VERI/02.STEP2/+each model directory + each year +/+MODC _YYYY_JDAY_DD_MM_SKILL.nc
- Output file: Nothing
- Main functions: Checking for missing values in all individual models
- If there are not missing values, the graphic file will be sent to /data21/BSISO/VERI/03. FIGUR/WEB/. If there is a missing value, the graphic file will not be sent to the above directory and will return a message saying “Data is all missing. Can’t copy to WEB directory.”.

5.2.9 Checking for missing values in the ensemble mean of each model

[03.FIGUR_CHECK_ALL.ncl]

```
;*******************************************************
;                    03.STEP3
;                      MDL
;           Graphic for Each Models' Ensemble Mean
;*******************************************************
begin
;==================================================================
YYYY = yyyy
MM    = mmmm
DD    = dddd
;==================================================================
JDAY    = day_of_year(YYYY,MM,DD)
iTGDAY = JDAY(0)
;==================================================================
fin1 =addfile ("/data21/BSISO/VERI/02.STEP2/BOM/"+YYYY+"/BOMC_"+
                 YYYY+"_"+iTGDAY+"_"+iday(0)+namMonth(imon(0)-1)+"_SKILL.nc","r")
fin2=addfile ("/data21/BSISO/VERI/02.STEP2/CFS/"+YYYY+"/CFSC_"+
                 YYYY+"_"+iTGDAY+"_"+iday(0)+namMonth(imon(0)-1)+"_SKILL.nc","r")
fin3=addfile ("/data21/BSISO/VERI/02.STEP2/ECM/"+YYYY+"/ECMC_"+
                 YYYY+"_"+iTGDAY+"_"+iday(0)+namMonth(imon(0)-1)+"_SKILL.nc","r")
fin4=addfile ("/data21/BSISO/VERI/02.STEP2/GFS/"+YYYY+"/GFSC_"+
                 YYYY+"_"+iTGDAY+"_"+iday(0)+namMonth(imon(0)-1)+"_SKILL.nc","r")
fin5=addfile ("/data21/BSISO/VERI/02.STEP2/UKM/"+YYYY+"/UKMC_"+
                 YYYY+"_"+iTGDAY+"_"+iday(0)+namMonth(imon(0))+"_SKILL.nc","r")
bom_cor12 = fin1->cor12(::-1,::-1)
cfs_cor12 = fin2->cor12(::-1,::-1)
ecm_cor12 = fin3->cor12(::-1,::-1)
gfs_cor12 = fin4->cor12(::-1,::-1)
```

```
ukm_cor12 = fin5->cor12(::-1,::-1)

cor12(0,:)      = bom_cor12(0,:)
cor12(1,:)      = cfs_cor12(0,:)
cor12(2,:)      = ecm_cor12(0,:)
cor12(3,0:15)   = gfs_cor12(0,:)
cor12(4,0:14)   = ukm_cor12(0,:)

if (.not.all(ismissing(cor12)))
   system("scp /data21/BSISO/VERI/03.FIGUR/ALL/+YYYY+"/"+"
                   BSISO.VERI.ALL."+YYYY+"0"+MM+"0"+DD+".png
                   /data21/BSISO/VERI/03.FIGUR/WEB/BSISO.VERI.ALL.png")
end if
if (all(ismissing(cor12)))
  print("Data is all missing. Can't copy to WEB directory.")
end if
end
```

- Input file: /data21/BSISO/VERI/02.STEP2/+each model directory + each year +/+MODC _YYYY_JDAY_DD_MM_SKILL.nc
- Output file: Nothing
- Main functions: Checking for missing values in each model’s ensemble mean
- Similar to *03.FIGUR_CHECK.ncl.*

5.3 Control the Total Verification System

To implement the total BSISO verification, the *UPDATE.VERI.TOTA.csh* shell script is controlled and consists of four main parts.

I. Setting time information

II. Changing the observed BSISO index filename

III. Calculating and writing the five verification skill scores

IV. Making verification figures and sending them to a web server

[UPDATE.VERI.TOTA.csh]

```
#!/bin/csh
#-----------------------------------------------------------------------------------------------------------#
#                                   Date: 17Mar, 2014
#                                   By Ms. Hyein Jeong
#
# BSISO Total verification system
#
# 10.PREPR -> Change file name of 20d INDEX from each Model and OBS
# 12.STEP2 -> Writing 5 skill scores
# 13.STEP3 -> Graphics
#-------------------------------------------------------------------------#
# Set directory
#-------------------------------------------------------------------------#
setenv FIGUR /data21/BSISO/VERI/03.FIGUR


                                    … (Continued)….
```

- Information about developed date and developer
- Structure of real-time BSISO verification run
- Setting the FIGUR directory

I. Setting time information

```
#----------------------------------------------------------------------#
# Set time
#----------------------------------------------------------------------#
set SYEAR = ‘2013’
set EYEAR = ‘toyear’

echo '------------------------------------------- '
echo '    BSISO TOTAL Verification    '
echo ' Start Year        : ' $SYEAR
echo ' End    Year       : ' $EYEAR
echo '------------------------------------------- '
echo '                              '
                                        …  (Continued)….
```

- Setting the end year (information about current year)
- The APCC BSISO forecasts started in 2013. That’s why we have the forecast data from 2013.

II. Changing the name of the Observed BSISO index file

```
#----------------------------------------------------------------------#
#      10.PREPR OBS
#----------------------------------------------------------------------#
```

```
echo '                              '
echo ' 10.PREPR        : OBS          '
echo '                              '

  sed -e s/ssss/${SYEAR}/g    10.PREPR_OBS.ncl > a0.ncl
  sed -e s/eeee/${EYEAR}/g              a0.ncl > a1.ncl
  ncl < a1.ncl
    rm -rf a?.ncl
```
…..(Continued)…….

- Modifying the verification year of *10.PREPR_OBS.ncl*
- Implementing the modified NCL file and removing it
- Detailed information about *10.PREPR_OBS.ncl* can be found at **section 5.3.1**

III. Calculating and Writing the 5 verification skill scores

```
#-------------------------------------------------------------------#
#      12.STEP2 MDL
#-------------------------------------------------------------------#
foreach MDL ( BOM CFS ECM GFS UKM )
echo '                              '
echo ' 12.STEP2        : ' $MDL
echo '                              '

      if ( $MDL == 'BOM' ) then
        set TDD = '20'
        set TEN = '33'
      else if ( $MDL == 'CFS' ) then
        set TDD = '20'
        set TEN = '4'
```

```
    else if ( $MDL == 'ECM' ) then
      set TDD = '20'
      set TEN = '51'
    else if ( $MDL == 'GFS' ) then
      set TDD = '16'
      set TEN = '1'
    else if ( $MDL == 'UKM' ) then
      set TDD = '15'
      set TEN = '24'
    endif

  sed -e s/ssss/${SYEAR}/g    12.STEP2_TOTA.ncl > a0.ncl
  sed -e s/eeee/${EYEAR}/g                a0.ncl > a1.ncl
  sed -e s/mld/${MDL}/g                 a1.ncl > a2.ncl
  sed -e s/ten/${TEN}/g                 a2.ncl > a3.ncl
  sed -e s/ttt/${TDD}/g                 a3.ncl > a4.ncl
  ncl < a4.ncl
  rm -rf a?.ncl

end
                    ……(Continued)……
```

- Calculating verification skill scores with forecasted and observed BSISO indices
- Modifying the model name, verification date, ensemble member, and forecast period of *12.STEP2_TOTA.ncl*
- Implementing the modified NCL file and removing it
- The detailed information of *12.STEP2_TOTA.ncl* is located in **section 5.3.2.**

IV. Creating verification figures and sending to web server

```
#-------------------------------------------------------------------#
#     13.FIGUR for Each Model
#-------------------------------------------------------------------#
foreach MDL ( BOM CFS ECM GFS UKM )
echo '                              '
echo ' 13.FIGUR        : ' $MDL
echo '                              '

     sed -e s/ssss/${SYEAR}/g    13.FIGUR_TOTA.ncl > a0.ncl
     sed -e s/eeee/${EYEAR}/g               a0.ncl > a1.ncl
     sed -e s/mld/${MDL}/g                  a1.ncl > a2.ncl
     ncl < a2.ncl
     rm -rf a?.ncl

convert -density 150x150 -trim
            ${FIGUR}/${MDL}/TOTA/
              BSISO.VERI.${MDL}C.${SYEAR}.${EYEAR}.pdf
             ${FIGUR}/${MDL}/TOTA/
              BSISO.VERI.${MDL}C.${SYEAR}.${EYEAR}.png

scp     ${FIGUR}/${MDL}/TOTA/
              BSISO.VERI.${MDL}C.${SYEAR}.${EYEAR}.png
             ${FIGUR}/WEB/
              BSISO.VERI.TOTA.${MDL}.png
scp     ${FIGUR}/WEB/BSISO.VERI.TOTA.${MDL}.png
              apcc21@210.98.49.32:/data/apcc_images/BSISO/VERI/
              BSISO.VERI.TOTA.${MDL}.png

end
```

```
#---------------------------------------------------------------------#
#     13.FIGUR for ALL
#---------------------------------------------------------------------#
echo '                              '
echo ' 13.FIGUR for ALL             '
echo '                              '

  sed -e s/ssss/${SYEAR}/g    13.FIGUR_ALL_TOTA.ncl > a0.ncl
  sed -e s/eeee/${EYEAR}/g                    a0.ncl > a1.ncl
  ncl < a1.ncl
  rm -rf a?.ncl

convert -density 150x150 -trim
           ${FIGUR}/ALL/TOTA/
             BSISO.VERI.ALL.${SYEAR}.${EYEAR}.pdf
            ${FIGUR}/ALL/TOTA/
             BSISO.VERI.ALL.${SYEAR}.${EYEAR}.png

scp     ${FIGUR}/ALL/TOTA/
             BSISO.VERI.ALL.${SYEAR}.${EYEAR}.png
            ${FIGUR}/WEB/
             BSISO.VERI.TOTA.ALL.png
scp     ${FIGUR}/WEB/BSISO.VERI.TOTA.ALL.png
             apcc21@210.98.49.32:/data/apcc_images/BSISO/VERI/
             BSISO.VERI.TOTA.ALL.png
```

- Making verification figures for the individual models with all ensemble members and figures for each model's ensemble mean (For comparison between models).
- Modifying the model name and verification date of *13.FIGUR_TOTA.ncl or 13.FIGUR_ALL_TOTA.ncl*

- More detailed information of *13.FIGUR_TOTA.ncl* can found in **section 5.3.3.** and in **section 5.3.4** for*13.FIGUR_ALL_TOTA.*

5.3.1 Changing the name of observed BSISO index file

[10.PREPR_OBS.ncl]

```
;*****************************************************
;                  10.PREPR
;                     OBS
;   Observed BSISO 20d INDEX -> Change File name [Julian]
;*****************************************************
begin
;=============================================================
YYYY1 = ssss
YYYY2 = eeee
;=============================================================
do YYYY = YYYY1, YYYY2
;==========================================================
;   Read original OBS BSISO INDEX
;==========================================================
o_org = "/data21/BSISO/MONI/09.STEP9/text/BSISO."+YYYY+".INDEX.NORM.data"
o      = readAsciiTable(o_org,8,"float",1)
NJDAY = dimsizes(o(:,1))

  do iTGDAYs=1,346
      jTGDAYs=iTGDAYs+19
    if jTGDAYs.le.NJDAY
      o20      = new((/20,8/),"float")
      o20(:,:) = o(iTGDAYs-1:iTGDAYs+18,:)
;==========================================================
```

```
;      Write OBS BSISO 20d INDEX
;=============================================================
opt = True
opt@fout="/data21/BSISO/VERI/00.PREPR/OBS/"+YYYY+"/"+YYYY+"_"+iTGDAYs+
                "_OBSC_BSISO.20d.INDEX"
opt@title = "Year Day    PC1    PC2    PC3    PC4    BSISO1    BSISO2"
write_matrix (o20, "1x,f5.0,3x,f4.0,3x,f6.3,3x,f6.3,3x,f6.3,3x,f6.3,3x,f6.3,3x,f6.3", opt)
    delete(o20)
    end if ; jTGDAYs
  end do ; iTGDAYs

  delete(o_org)
    delete(o)

end do ; YYYY
end
```

- Input file : /data21/BSISO/MONI/09.STEP9/text/BSISO. each year .INDEX.NORM.data
- Output file: /data21/BSISO/VERI/00.PREPR/OBS/each year directory/each year_JDAY _OBSC_BSISO.20d.INDEX
- Main functions: Read the original observed BSISO indices file which contains the BSISO indices from January 1st. Rewrite the new observed BSISO index file which has BSISO indices for only 20 days.

5.3.2 Calculating and writing BSISO verification skill scores

[12.STEP2_TOTA.ncl]

```
;*******************************************************
;                   12.STEP2 TOTA
;                       MDL
;         Calculating and Writing 5 Skill Scores
;*******************************************************
begin
;===========================================================
MOD    = "mld"
YYYY1 = ssss
YYYY2 = eeee
ENS    = ten
TDD    = ttt
;===========================================================
CNT    = 0
do YYYY = YYYY1, YYYY2

   do iTGDAY=121,334    ; From 1Apr To 31Oct
   if (isfilepresent("/data21/BSISO/VERI/00.PREPR/"+MOD+"/"+YYYY+"/"+
                         YYYY+"_"+iTGDAY+"_"+MOD+"C_BSISO.20d.INDEX"))
      .and.
      (isfilepresent("/data21/BSISO/VERI/00.PREPR/OBS/"+YYYY+"/"+
                         YYYY+"_"+iTGDAY+"_OBSC_BSISO.20d.INDEX"))

      f1      = "/data21/BSISO/VERI/00.PREPR/"+MOD+"/"+YYYY+"/"+
                         YYYY+"_"+iTGDAY+"_"+MOD+"C_BSISO.20d.INDEX"
      f       = readAsciiTable(f1,9,"float",1)
      o1      = "/data21/BSISO/VERI/00.PREPR/OBS/"+YYYY+"/"+
                         YYYY+"_"+iTGDAY+"_OBSC_BSISO.20d.INDEX"
```

```
                        ……. Similar to 02.STEP2.ncl……..
    end if
    end do ; iTGDAY
end do    ; YYYY

;=============================================================
; WRITING OUTPUT FILE
;=============================================================
system("rm -rf /data21/BSISO/VERI/02.STEP2/"+MOD+"/TOTA/"+MOD+"C_"+
            YYYY1+"_"+YYYY2+"_SKILL.nc")
fout= addfile ("/data21/BSISO/VERI/02.STEP2/"+MOD+"/TOTA/"+MOD+"C_"+
            YYYY1+"_"+YYYY2+"_SKILL.nc","c")
fout->cor12=cor12
fout->cor34=cor34
fout->rms12=rms12
fout->rms34=rms34
fout->Eamp12=Eamp12
fout->Eamp34=Eamp34
fout->Ephs12=Ephs12
fout->Ephs34=Ephs34
fout->MSSS12=MSSS12
fout->MSSS34=MSSS34
end
```

- Input file (f) : /data21/BSISO/VERI/00.PREPR/model directory/year directory/Each year _JDAY_MODC_BSISO.20d.INDEX
- Input file (o): /data21/BSISO/VERI/00.PREPR/OBS/each year directory/each year _JDAY _OBSC_BSISO.20d.INDEX

- Output file : /data21/BSISO/VERI/02.STEP2/model directory/TOTA/MODC_Starting Year_Ending Year_SKILL.nc
- Main functions: Calculating the BSISO verification skill scores. Unlike real-time verification codes, this one calculates the skill scores with all available BSISO forecasts from 2013. You can find the verification equations in **Section 2**.

5.3.3 Making TOTAL verification figures of all individual models

[13.FIGUR_TOTA.ncl]

```
;************************************************************
;                 13.STEP3 TOTA
;                       MDL
;               Graphics for ALL Models
;************************************************************
begin
;=============================================================
MOD    = "mld"
YYYY1 = ssss
YYYY2 = eeee
;=============================================================
pltDir = "/data21/BSISO/VERI/03.FIGUR/"+MOD+"/TOTA/"
pltType = "pdf"

fin    = addfile ("/data21/BSISO/VERI/02.STEP2/"+MOD+"/TOTA/"+MOD+"C_"+
                         YYYY1+"_"+YYYY2+"_SKILL.nc","r")
                                    ……(Continued)……
pltName = "BSISO.VERI."+MOD+"C."+YYYY1+"."+YYYY2
pltPath = pltDir+pltName
                                    ……(Continued)……
end
```

- Input file : /data21/BSISO/VERI/02.STEP2/model directory/TOTA/MODC_
  Starting Year_Ending Year_SKILL.nc
- Output file : /data21/BSISO/VERI/03.FIGUR/model directory/TOTA/
  BSISO.VERI.MODC.Starting Year.Ending Year
- Main functions: Making verification figures for the ensemble mean and each ensemble member for each individual model. Each ensemble member is indicated by a dashed orange line The ensemble mean is indicated by a solid red line. Note that this TOTAL figure does not need to separate the figure type of LINE and MARK.
- You can find an example figure in Appendix D.

5.3.4 Making TOTAL verification figures for the ensemble mean of each model

[13.FIGUR_ALL_TOTA.ncl]

```
;*********************************************************
;                 13.STEP3 ALL TOTA
;                      MDL
;         Graphics for Each Models Ensemble Mean
;*********************************************************
begin
;============================================================
YYYY1 = ssss
YYYY2 = eeee
;============================================================
pltDir = "/data21/BSISO/VERI/03.FIGUR/ALL/TOTA/"
pltType = "pdf"

fin1 = addfile ("/data21/BSISO/VERI/02.STEP2/BOM/TOTA/BOMC_"+YYYY1+"_"+
                   YYYY2+"_SKILL.nc","r")
```

```
fin2 = addfile ("/data21/BSISO/VERI/02.STEP2/CFS/TOTA/CFSC_"+YYYY1+"_"+
              YYYY2+"_SKILL.nc","r")
fin3 = addfile ("/data21/BSISO/VERI/02.STEP2/ECM/TOTA/ECMC_"+YYYY1+"_"+
              YYYY2+"_SKILL.nc","r")
fin4 = addfile ("/data21/BSISO/VERI/02.STEP2/GFS/TOTA/GFSC_"+YYYY1+"_"+
              YYYY2+"_SKILL.nc","r")
fin5 = addfile ("/data21/BSISO/VERI/02.STEP2/UKM/TOTA/UKMC_"+YYYY1+"_"+
              YYYY2+"_SKILL.nc","r")
                        ……(Continued)……

pltName = "BSISO.VERI.ALL.”+YYYY1+"."+YYYY2
pltPath = pltDir+pltName
                        ……(Continued)……

 res1@xyLineColors    = (/"Red"/)
  plot=gsn_csm_xy(wks,leadtime,cor12(0,:),res1)

 res1@xyLineColors    = (/"Orange"/)
  plot=gsn_csm_xy(wks,leadtime,cor12(1,:),res1)

 res1@xyLineColors    = (/"Green"/)
  plot=gsn_csm_xy(wks,leadtime,cor12(2,:),res1)

 res1@xyLineColors    = (/"Blue"/)
  plot=gsn_csm_xy(wks,leadtime,cor12(3,:),res1)

 res1@xyLineColors    = (/"magenta"/)
  plot=gsn_csm_xy(wks,leadtime,cor12(4,:),res1)
                        ……(Continued)……
end
```

- Input file : /data21/BSISO/VERI/02.STEP2/model directory/TOTA/MODC_Starting Year _Ending Year_SKILL.nc
- Output file : /data21/BSISO/VERI/03.FIGUR/ALL/TOTA/BSISO.VERI.ALL.Starting Year. Ending Year
- Main functions: Making verification figures for each model's ensemble mean. Similar to 03.FIGUR_ALL.ncl except that all skill scores are indicated by solid lines.
- An example is located in Appendix E.

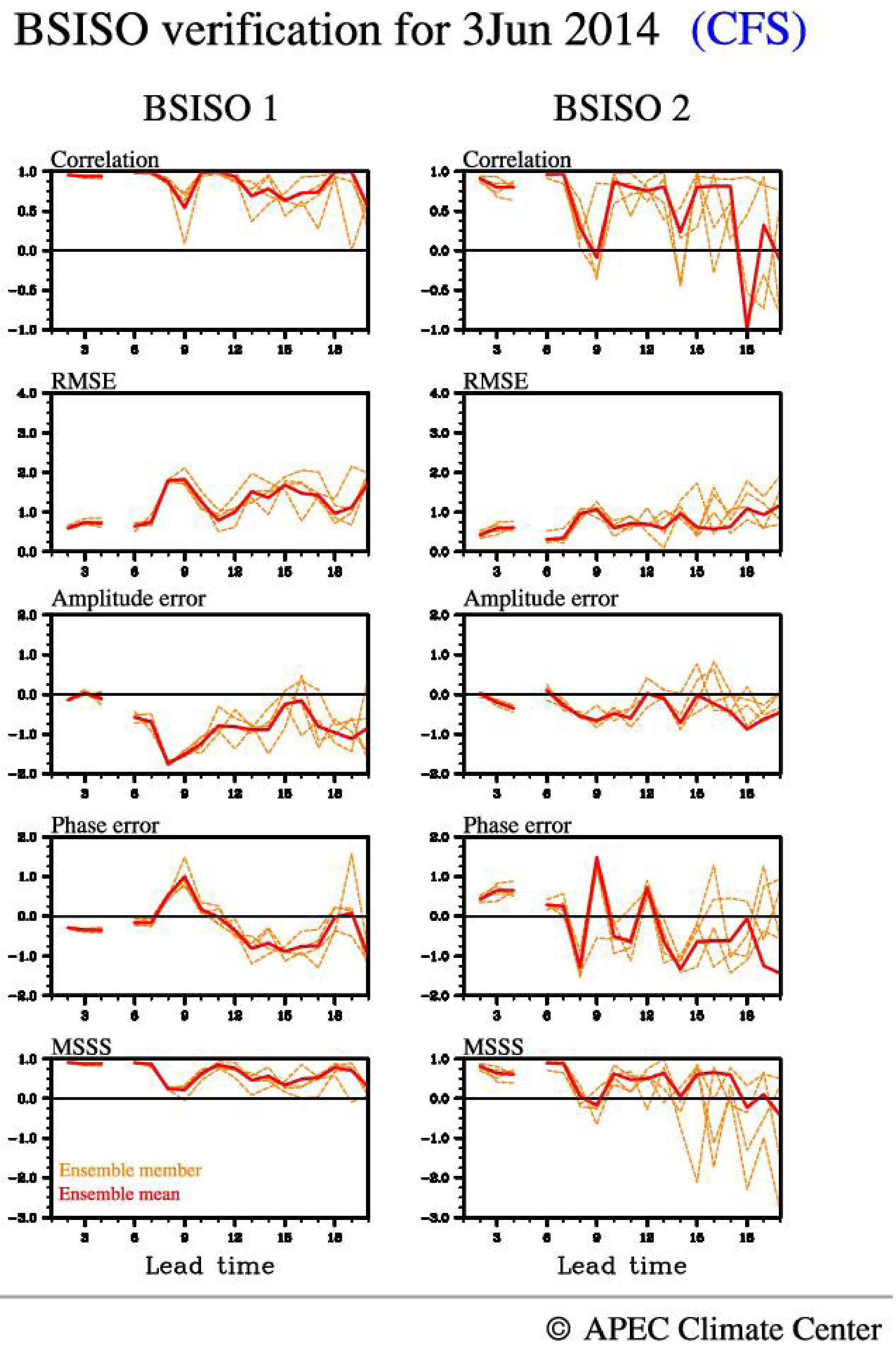
REFERENCES

Hollingsworth A, Arpe K, Tiedtke M, Capaldo M, Savija¨rvi H (1980) The performance of a medium-range forecast model in winter impact of physical parameterizations. Mon Weather Rev 108:1736–1773

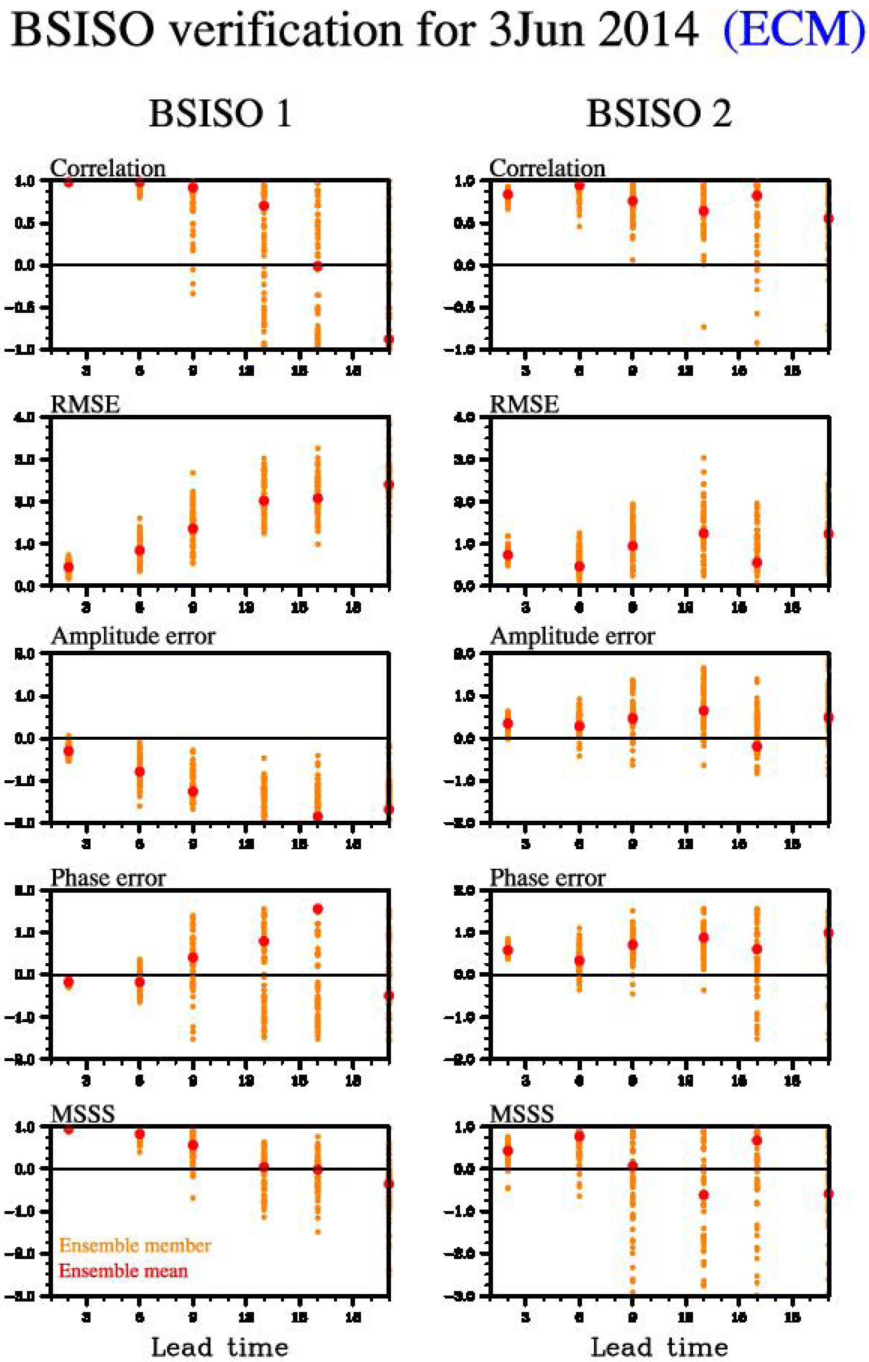
Lin H, Brunet G, Derome J (2008) Forecast skill of the Madden–Julian oscillation in two Canadian atmospheric models. Mon Weather Rev 136:4130–4149

Rashid H, Hendon HH, Wheeler M, Alves O (2010) Prediction of the Madden–Julian oscillation with the POAMA dynamical seasonal prediction system. Clim. Dyn. doi:10.1007/s00382-010-0754-x

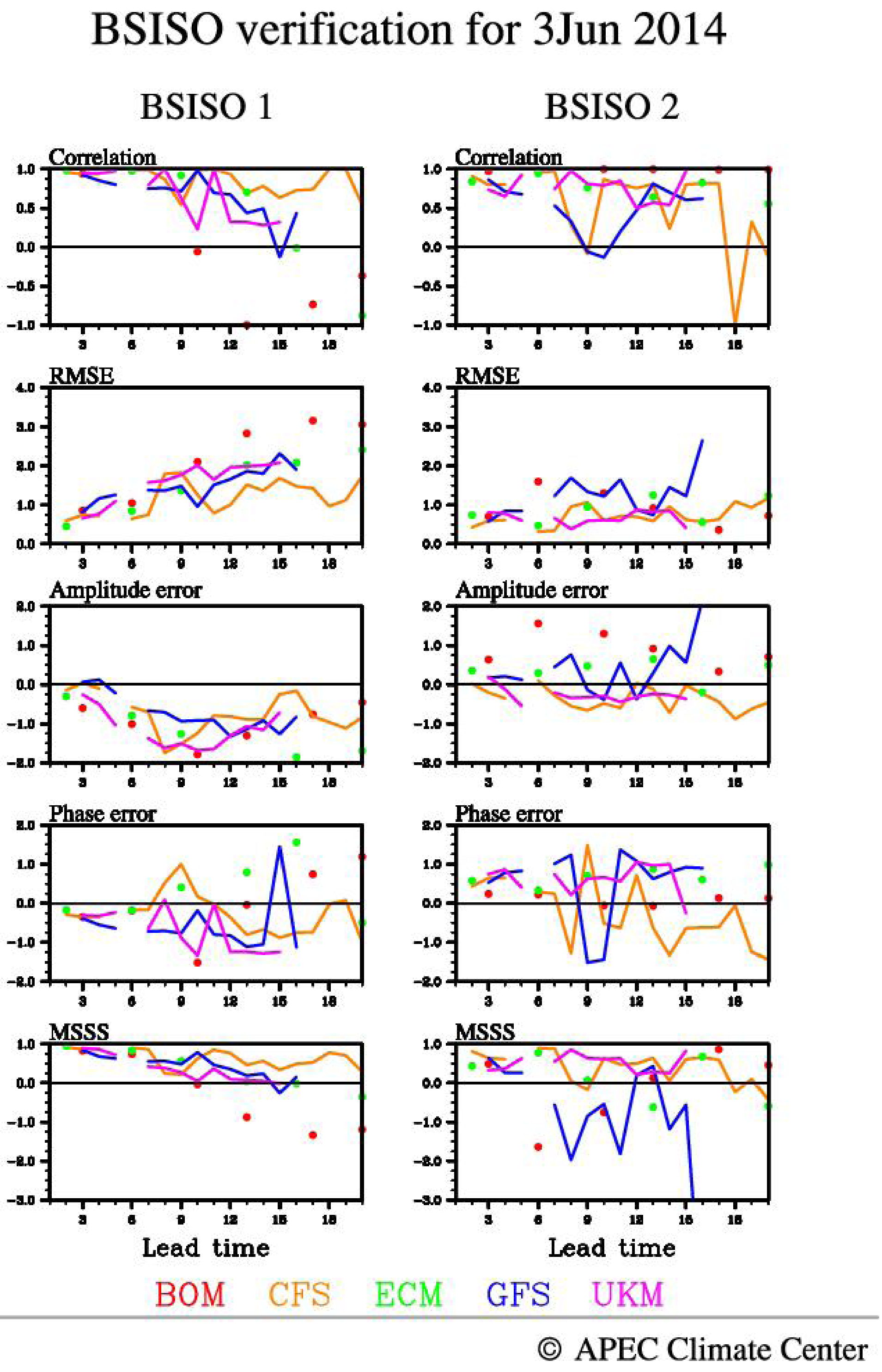
Appendix A. Figure of Real-Time Verification (Line)



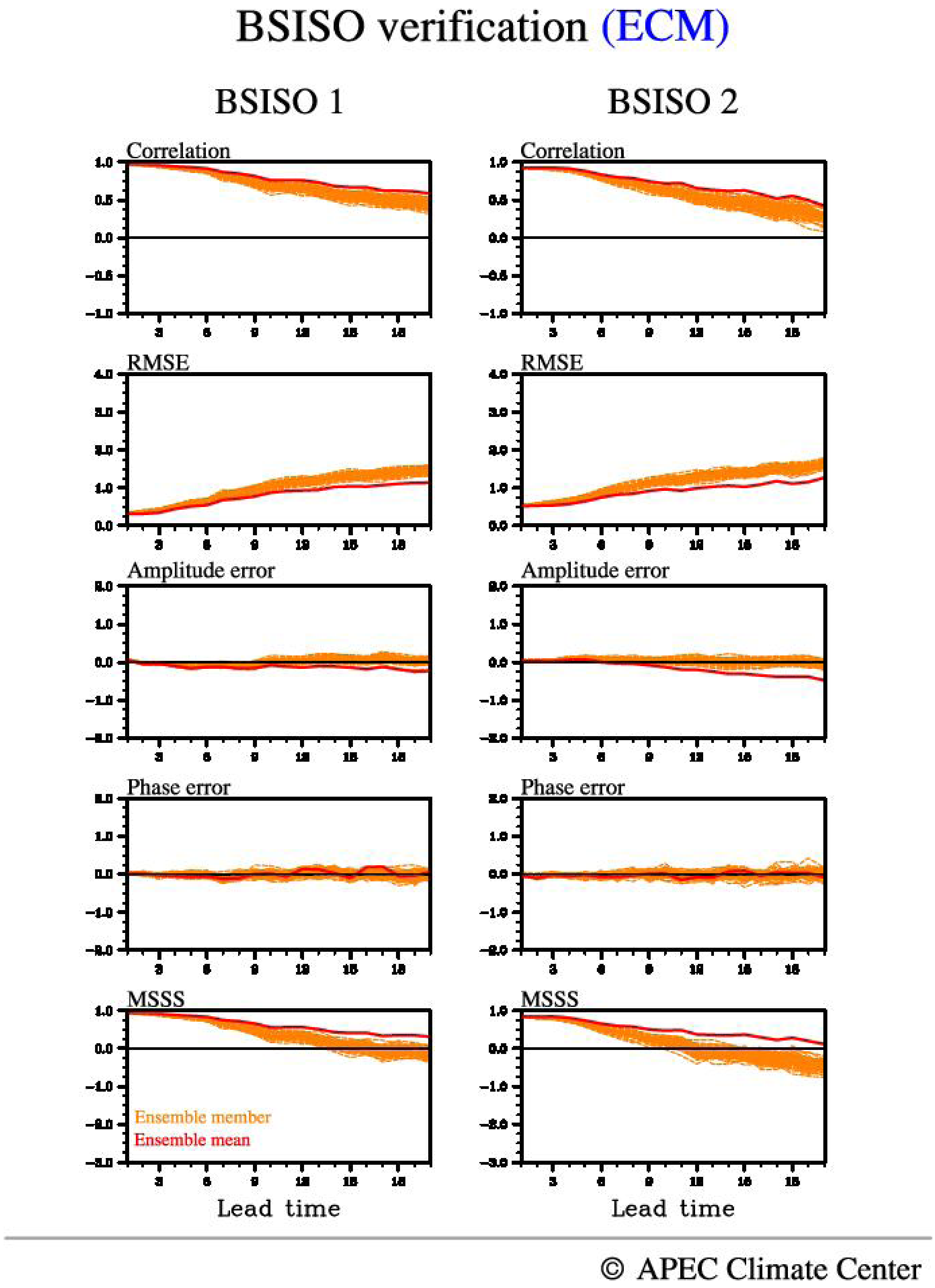
Appendix B. Figure of Real-Time Verification (Mark)



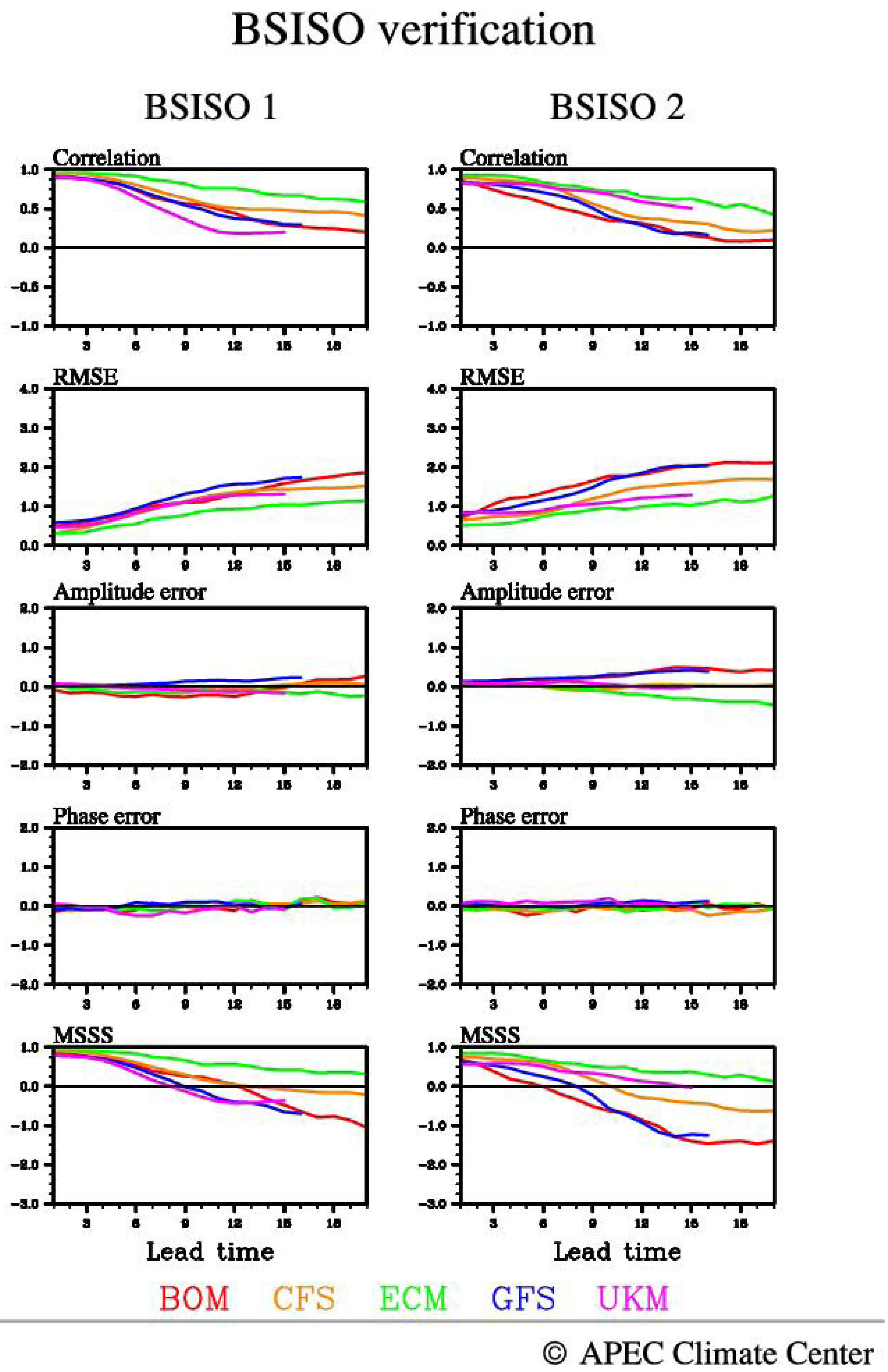
Appendix C. Figure of Real-Time Verification (Ensemble Mean)



Appendix D. Figure of Total Verification (Each Model)



Appendix E. Figure of Total Verification (Each Model Mean)



Appendix F. Major NCL functions used in Verification System

isfilepresent (A)	This function returns True if file A is present. If there is not A, False will returns. (More details: http://www.ncl.ucar.edu/Document/Functions/Built-in/isfilepresent.shtml)
readAsciiTable (File name, ncol, data_type, opt)	This function reads an ASCII file and returns the table data after the header portion, and before the footer portion (if specified). (More details: http://www.ncl.ucar.edu/Document/Functions/Contributed/readAsciiTable.shtml)
write_matrix (data, fmtf, option)	This function can make the 2D array. This procedure does not have the ability to print individual row and column text labels. (More details: http://www.ncl.ucar.edu/Document/Functions/Built-in/write_matrix.shtml)
day_of_year (year, month, day)	This function calculates the day of the year given month, day, and year. This function considers leap year. (More details: http://www.ncl.ucar.edu/Document/Functions/Built-in/day_of_year.shtml)
ispan (start, finish, stride)	This function returns an array of values beginning at start and ending at finish. Each element will be separated by the value of stride. The stride must be positive, and start and finish can be any valid integers. (More details: http://www.ncl.ucar.edu/Document/Functions/Built-in/ispan.shtml)

RESEARCH REPORT 2015-06

Improvement of the Real-time Forecast System on the BSISO (I): Verification for the BSISO Forecas

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