Changes in the Probability Density Function of 500-hPa Geopotential Heights during El Niño and La Niña events

By

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Abstract

This study addresses the changes in the probability density function (PDF) of the 500-hPa geopotential heights during El Niño and La Niña events using the dynamical seasonal hindcasts made at the National Center for Environmental Prediction. First, two-way layout analysis of variance (ANOVA) is applied to the hindcasts to assess the effects of lead time on the simulated climatological mean and variance. Results demonstrate that there is no statistically significant effect of lead time in DJF. However, there is a significant effect of lead time on the climatological mean for JJA over northeastern China, due to the initial soil wetness. This effect on anomalies can be eliminated by using the climatological mean with different lead times.

Based on this analysis, we combined four 10-member ensembles with different lead times to increase the ensemble members to 40, which allows us to examine the statistical significance of the change in the PDF. We applied non-parametric Kolmogorov-Smirnov tests to the changes for the El Niño and La Niña events. Results indicate that the changes in the PDF are significant during these events over most of the globe and have unique features for each event, but the major factor is the change in the mean.

1. Introduction

The ensemble method is essential for dynamical seasonal prediction since the seasonal time scale exceeds the limit within which the dynamical forecast is deterministic. Large ensemble members are required to obtain reliable mean states, which provide a meaningful signal. The required ensemble size depends on the regions. Brankovic and Palmer (1997) argued that about 25 members are required to obtain a statistically significant signal in 2-m temperature and precipitation prediction in the extratropics, while Wehner (2000) demonstrated that more than 50 members are necessary for the significant seasonal means of the ground temperatures in mid- and high latitudes, like eastern Europe. In some operational institutions, ensemble prediction with a reasonably large ensemble number has been performed: 20 at the National Center for Environmental Prediction (NCEP), 31 at the Japan Meteorological Agency, and 40 at the U.K. Meteorological Office.

One method to increase the number of ensemble members is to combine different lead time predictions into an ensemble. When a seven-month seasonal prediction is routinely performed every month, as has been done at NCEP (Kanamitsu et al., 2002b), four different lead time predictions are available for any three-month period, where first month data is not available. However, it is not always possible to combine different lead time predictions, since each of them may have a different climatology. The atmospheric initial conditions affect the predictions for three to six weeks (Reichler and Roads, 2005), while the initial soil wetness conditions affect predictions for a couple of months (Kanamitsu et al., 2002b) since soil wetness has a long memory (Vinnikov et al., 1996). Therefore, the dataset from different lead time predictions must have the same statistical characteristics, verified by using a statistical test, before they can be combined to form a larger dataset. The combination method has been used in previous studies (Chen, 2004; Phelps et al., 2004; Peng and Kumar, 2005), but the verification has not yet been fully performed.

The large ensemble enables us to investigate the change in the probability density distribution (PDF; Sardeshmukh et al., 2000; Compo et al., 2001) and the change in the variance during El Niño and La Niña events.
Prediction (Barnston et al., 2003). Though reliable probabilistic forecasts are based on the detectability of the change in the shape of the PDF, the detection requires very many ensemble members, such as 180 (Sardeshmukh et al., 2000). However, 24 members at T42 at the International Research Institute of Climate Prediction (Barnston et al., 2005) and 12 members at T63 at the Experimental Climate Prediction Center (Roads et al., 2003) are feasible as experimental predictions. It is important to investigate the detectability of the change in PDF using the combination method constructed from a small ensemble.

In this study, the statistics for different lead time predictions of the 500-hPa geopotential height fields for December-January-February (DJF) and for June-July-August (JJA) are compared, and the statistical characteristics are examined using the two-way layout analysis of variance (ANOVA). Moreover, the detectability of the change in the PDF during El Niño or La Niña events is investigated from a small ensemble. The paper is organized as follows. Section 2 describes the model and data used. Section 3 discusses the statistical tests for the combinations and for the change in the PDF. Section 4 compares the model climatological values with the observed ones. Section 5 presents the results of the combinations and the change in the PDF. Section 6 contains a discussion, and Section 7 presents concluding remarks.

2. Model and data

The atmospheric general circulation model data used are the seasonal ensemble hindcasts for DJF and JJA performed by NCEP Climate Prediction Center (Kanamitsu et al., 2002b). The model used in this hindcast experiment is the dynamical seasonal forecast model (SFM), 28-level, T62 reduced-grid version of the NCEP Global Spectral Model (GSM). The physics of the SFM was modified further from the Reanalysis-2 (R-2) version (Kanamitsu et al., 2002a). For a more detailed comparison of the model physics between the NCEP models, refer to Kanamitsu et al. (2002b).

The hindcast experiment consists of the 10-member ensemble, seven-month integrations available for every month of the 21-year period (1979 to 1999). The lagged initial conditions were used for producing the 10-member ensemble. Each member hindcast starts from the first five days of the beginning of each month, 12 hours apart. The sea surface temperatures (SSTs) used in the hindcasts were from NCEP weekly SST analysis (Reynolds and Smith, 1994). Climatological soil wetness and snow from R-2 were used as initial conditions in this hindcast experiment. These products were obtained from the National Weather Service anonymous FTP site. For a more detailed experiment design, refer to Kanamitsu et al. (2002b). Forty-member seasonal mean hindcasts with four lead times (a month apart) for each season of each year are available by combining the monthly mean hindcasts from month two to month seven forecasts. Four ensembles with different lead times are available for each three-month season. Table 1 presents the schematic representation of the four ensembles with different lead times.

For comparison, the observed DJF and JJA 500-hPa height fields are derived from the 21-year (1979-1999) NCEP-Department of Energy Reanalysis-2 (R-2) dataset (Kanamitsu et al., 2002a). Niño 3.4 (5.5°S - 5.5°N, 170°W - 120°W) SST was used as an El Niño Southern Oscillation (ENSO) index computed from the optimal interpolated SST (OISST) (Reynolds and Smith, 1994).

3. Analysis

a. Two-way layout analysis of variance

The two-way layout analysis of variance (ANOVA) is applied to investigate the possibility of the combination between the hindcast ensembles with the different lead times. The climatological mean and variance for each lead time are compared. One-way ANOVA was used for estimating the potential predictability (e.g. Rowell, 1998; Nakaegawa et al., 2003), and the factor is the year; in other words, the interannual variability of SST as a lower boundary condition. The two-way layout ANOVA is the two-factor version of the ANOVA, and the factors are lead time and year in this paper. This analysis was used to quantify the effects of SST and different initial flow regimes on the modes of mid-latitude variability (Shabbar et al., 2003). The detailed formulations can be found in textbooks, such as Rice (1995), and Turner and Thayer (2001).

By assuming that \( M \) members (the ensemble size; 10 in this study) are available at each combination of \( N \) levels (the number of the years of the hindcast experiment; 21) of the year factor and \( I \) levels (the number of the different lead times; 4) of the lead time factor, then the two-way layout with an equation of the form is written as

\[
x_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ijk},
\]

which means that the \( k \)-th data value for the \( j \)-th level of the lead time factor and the \( i \)-th level of the year factor is the

| Table 1 Combination of the hindcast outputs with different lead times for DJF and JJA. Bold months represent the combined data, and italicized months represent the initialization months. |
|---|---|---|---|---|
| DJF | JJA | DJF | JJA |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
| Mar Apr May | Sep | Mar Apr May | Sep |
sum of five components: the grand mean (climatological mean \( \mu \)), the level effect for the year factor (\( \alpha \)), the level effect for the lead time factor (\( \beta \)), the interaction effect ((\( \alpha \beta \))), and the residual (\( e \): internal variability).

The total squares \( S_T \) is expressed by a summation of the squares for the year \( S_{\alpha} \), the squares for the lead time \( S_{\beta} \), the squares for the interaction between the lead time and the year \( S_{\alpha \beta} \), and the squares for the internal variability \( S_e \).

\[
S_T = S_{\alpha} + S_{\beta} + S_{\alpha \beta} + S_e.
\]  

(2)

The degrees of freedom of the total squares and the four squares on the right-hand side of Eq. (2) are \( v_T = NMI-I \), \( v_\alpha = N-I \), \( v_\beta = M-I \), \( v_{\alpha \beta} = (N-I)(M-I) \), and \( v_e = (N-1)(I-1) \). The variance \( V_y \) is,

\[
V_y = S_T / v_T ,
\]

(3)

where \( y = T, \alpha, \beta, e, \) or \( \alpha \beta \).

The F-test tests the null hypothesis: there is no difference in the population means of the different levels of the factors. The hypothesis for the three effects is expressed as follows:

\( a \): \( H_0: (\alpha \beta)_{ij} = 0 \) \( (F_{(\alpha \beta)} = V_{(\alpha \beta)} / V_e) \)

The ensemble mean for each year is not influenced by the lead time.

\( b \): \( H_0: (\alpha) = 0 \) \( (F_{\alpha} = V_{\alpha} / V_e) \)

The year factor has no effect on the climatological mean.

\( c \): \( H_0: (\beta) = 0 \) \( (F_{\beta} = V_{\beta} / V_e) \)

The lead time factor has no effect on the climatological mean.

\( F \) is the F-statistics used for each test of the hypothesis. The climatological means of the ensembles with different lead times are equal to one another if the hypothesis is not rejected.

The same two-way layout ANOVA is used to quantify the effect of the two factors on the internal variability. Since unique internal variability is available for each pair of the two factors in this case, this analysis cannot separate the square of the internal variability from that of the interaction (let \( k \) be omitted in Eq. (1)). If the effect of the interaction on the mean is not statistically significant, the effect of the interaction on the variance is assumed to be negligible, that is, \( S_{(\alpha \beta)} = 0 \).

b. Change in the probability distribution function

The non-parametric two-sample Kolmogorov-Smirnov (KS) measure \( D_{KS} \) was used to assess the change in distributions for each event. This measure is defined as the maximum difference between two cumulative distribution functions, lying between 0 and 1, and indicating different distributions with larger values. The power of the change detection between 10-member and 40-member ensembles is compared using Monte Carlo simulation. Since each ENSO event is compared to the composite of five normal events in the change in the PDF subsection below, the detectabilities for 10 and 50 (5-event, 10-member ensemble) data points and for 40 and 200 (5-event, 40-member ensemble) data points are computed. The expectation of \( D_{KS} \) is obtained from the 50,000 samples of \( D_{KS} \) that are simulated by assuming that a variable is distributed according to the normal distributions \( N(\mu_0, \sigma^2_0) \) and \( N(\mu, \sigma^2) \), where \( \mu \) is the mean and \( \sigma^2 \) is the variance. Figure 1 plots the contour line of the expected values of \( D_{KS} \), where \( \mu \) is converted to \( (\mu - \mu_0) / \sigma_0 \) and \( \sigma \) is converted to \( \sigma / \sigma_0 \). It is difficult to detect the change from a 10-member ensemble when \( \mu_0 \) (mean shift) is smaller than \( \sigma_0 \) except for the very small variance. However, it is possible to detect the change from a 40-member ensemble as long as the mean shift exceeds 0.5 \( \sigma_0 \). The change is not detectable when the mean shift is small.

4. Comparison between the model and the observation

Previous studies (Kanamitsu et al., 2002b; Chen, 2004; Nakaegawa and Kanamitsu, 2006) verified that the SFM accurately reproduced the climatological mean and the interannual variability of the 500-hPa height fields in the hindcast experiment. The reproducibility of the climatological standard deviations was investigated here.

The contour lines of Fig. 2 depict the climatological standard deviations of the 500-hPa height fields of DJF and

![Fig. 1 Expected Kolmogorov-Smirnov measure \( (D_{KS}) \) between the normal distributions \( N(\mu_0, \sigma_0^2) \) and \( N(\mu, \sigma^2) \).](image1)

![Fig. 2 Climatological standard deviations of the 500-hPa height fields of DJF and JJA.](image2)
JJA both for the observation and the model result. The standard deviations were computed from a 21-year, 40-member (total 820) ensemble using different climatology for different lead times. The basic global patterns are accurately reproduced for both seasons. The northern hemisphere (NH) for DJF includes the following features. The model correctly reproduces the standard deviations in the eastern part of the north Pacific Ocean with large standard deviation, but significantly overestimates the standard deviation in the northern Atlantic Ocean and the Arctic Ocean along the Siberian coast. The southern hemisphere (SH) for DJF includes the following features. The standard deviations in the model are generally smaller than in the observation, especially in the Antarctic. However, for JJA, the model’s standard deviations are slightly smaller than those of the observation, and the global pattern around the Antarctic in the model is shifted to the east. The resemblance of the spatial pattern with the observation allows us to analyze this dataset further.

5. Results

a. Effects of the two factors on the climatological mean

ANOVA requires the assumption that a variable is distributed according to the normal distribution when the significance of the difference in the variance due to the level of the factors is tested. The KS test was used to test the goodness-of-fit of the normal distribution, and the results confirmed that the 21-year 500-hPa geopotential heights for both DJF and JJA were distributed according to the normal distributions across most of the globe, as in Sardeshmukh et al. (2000) and Shabbar et al. (2003), which enables us to apply the ANOVA to the dataset.

Figure 3 illustrates the results of 500-hPa height fields for DJF obtained from the two-way layout ANOVA. Figure 3c illustrates the F-statistics for the interaction effect, and indicates that the interaction effect is not statistically significant, and the change in the climatological mean due to one factor does not have any effect on that of the other factor; therefore, the total variance can be defined as the summation of the variances for the two factors. Figure 3a presents the geographical distribution of the F-statistics for the lead time. Though the values exceed 0.2 in the tropics and Antarctica, and 0.5 in the central tropical Pacific, they are not statistically significant. Therefore, the factor lead time does not have a significant effect on the climatological means for DJF. Figure 3b exhibits the same as Fig. 3a, but for the factor year. The areas with a 10% significance level are surrounded by thick lines. The global pattern generally is symmetric to the equator, and the values are slightly higher in the NH than in the SH. The F-statistics exceeds 2 in the tropics and the mid-latitudes of the eastern Pacific.

Figure 4 illustrates the same as Fig. 3, but for JJA. Figure 4c indicates that the interaction effect is negligible, and the two factors can be independently treated. Figure 4a illustrates the geographical distribution of the F-statistics for the factor lead time. The large values are seen in the land areas of the NH mid- and high latitudes, especially in far
eastern Eurasia. Large areas with a 10% significance level are confined to northeastern China. Figure 4b indicates that the F-statistics are high in the tropics and low in the mid- and high latitudes, and that they are higher in the winter hemisphere (SH) than in the summer hemisphere (NH). The unique feature in JJA is that the factor lead time has a significant effect on the climatological means.

Following the same procedure for the climatological means, the two-way layout ANOVA was used to test the change in the climatological variance, where the different climatological means with lead times were used. Though multiple samples or ensemble members are not available for each level of each factor, the variances are computed from the internal variabilities of the ensemble members, so the interaction is assumed to be negligible because the interaction between the two factors has little effect on the climatological means mentioned above. The value of F-distribution for the lead time is $F(3, 60) = 2.758$ at the upper 10% significance level. No area has larger F-statistics than the values (figure not shown); therefore, the lead time does not have a statistically significant effect on the climatological variance.

No statistically significant difference in the climatologies for DJF due to the lead time was found, but a difference in northeastern China for JJA was found. This effect on the anomalies can be removed by using different climatological means for each lead time. The difference in the variance due to the lead times is not statistically significant for either DJF or JJA. Hence, the four ensembles are treated as one combined ensemble.

b. Change in the PDF

This subsection investigates the change in the PDF during the ENSO events for DJF. Table 2 presents the warm, normal, and cold events in this study based on the Niño 3.4 SST for DJF. Each of the ENSO events is compared to the composite of the five normal events. Figure 5 displays the geographical distribution of the KS measure for DJF of each event. Statistically significant changes in the PDF for each El Niño event are found, but the global patterns for each event have unique features. The teleconnection patterns from the eastern Pacific to both North and South America and the western Pacific of the NH, formed by Rossby wave propagation, are distinct in El Niño events of 1991/92 and 1997/98. The very large values of the KS measure in the Pacific North America (PNA) sector for the largest 1997/98 El Niño event in the twentieth century are consistent with the very high skill in seasonal forecast (Barnston et al., 1999).

The KS measure exceeding 0.8 is confined to the
The variance for the year; the interannual variabilities of the atmosphere, and the interactions between the atmosphere and the ocean or the land. The variance ratio $V_y/V_T$ is an index of the potential predictability, which is the same in previous studies (Rowell, 1998; Nakaegawa et al., 2003). Note that the potential predictability means that the maximum values can be reached under the framework of the ensemble mean forecast with the “perfect model” assumption that a numerical model can use perfectly predicted SST as well as perfectly reproduce the climatological means, the interannual variabilities of the atmosphere, and the interactions between the atmosphere and the ocean or the land. The variance ratio $V_y/V_T$ is an index of the effect of the initial conditions consisting of both the atmospheric conditions and the land-surface conditions.

Figure 3d depicts the geographical distribution of the variance ratio for lead time. No contour line in Fig. 3d appears since the ratio does not exceed 0.2 anywhere, and different lead times or initial conditions have little effect on the potential predictability, as expected. Figure 3e presents the variance ratio of interannual variability. In addition to the areas relevant to Fig. 3b, the ratio exceeds 0.2 in North and South America, as well as the Asian monsoon region, including southern Japan. The patterns of the eastern Pacific in the mid- and high latitudes with high ratios are formed by Rossby wave propagation excited by the adiabatic heating due to convective activities in the eastern tropical Pacific. The areas with high ratios in the southern Atlantic and central China are also formed by the same process. Figure 3f displays the same as Fig. 3d, but for the total effect, or the summation of Figs. 3d and 3e. The variance ratio is overestimated throughout the entire globe, especially in the southern hemisphere. These increases from the ratio in Fig. 3e stem from artificial differences in the climatological means with different lead times, which suggests that the lead time has a substantial effect on the variance ratio, though it has few effects on the climatological mean.

Figure 4d presents the same as Fig. 3d, but for JJA. The areas with high ratios are extended in the mid- and high latitudes of the NH. Figure 4e presents the same as Fig. 3e, but for JJA. The variance ratio in the summer NH is generally lower than in the winter SH. This asymmetric pattern is formed by the same tropical diabatic heating sources, since the Rossby wave propagates into the winter hemisphere more easily than into the summer one. Figure 4f presents the same as Fig. 3f, but for JJA. The areas with ratios exceeding 0.2 cover most of the globe, and the ratio exceeds 0.6 in the NH Pacific. The global pattern of the variance ratio in previous studies (Rowell, 1998; Sugi et al., 1997; Nakaegawa et al., 2003) resembles that of Fig. 4e rather than that of Fig. 4f. Soil wetness can significantly affect the atmosphere during the NH summer (Kanamitsu et al., 2003; Koster et al., 2003). These results suggest that the large variance ratio in Fig. 4d is due to the initial soil wetness.

The $F$-statistics over the area with statistically significant signals decrease with the increase of altitude (figure not shown). Since soil wetness is a key factor of the predictability of the ground air temperature in seasonal

Figure 7 Twelve regions for which the time evolutions of the soil wetness were examined.

6. Discussion

a. Two-way Layout ANOVA

The variance ratio is defined as $V_y$ divided by the total variance $V_T$, where $y = a$ (the variance for the year; the interannual variabilities) or $\beta$ (the variance for the lead time). The variance ratio $V_y/V_T$ is an index of the potential predictability, which is the same in previous studies (Rowell, 1998; Nakaegawa et al., 2003). Note that the potential predictability means that the maximum values can be reached under the framework of the ensemble mean forecast with the “perfect model” assumption that a numerical model can use perfectly predicted SST as well as perfectly reproduce the climatological means, the interannual variabilities of the atmosphere, and the interactions between the atmosphere and the ocean or the land. The variance ratio $V_y/V_T$ is an index of the effect of the initial conditions consisting of both the atmospheric conditions and the
forecasts (Hong and Kalney, 2003; Kanamitsu et al., 2003), the initial soil wetness may be a possible cause of the large $F$-statistics in Fig. 4a and the large variance ratio in Fig. 4d. Figure 8 depicts the time evolutions of the climatological ensemble mean of the soil wetness at the bottom layer for each lead time in twelve domains depicted in Fig. 7. The error bars in the figure represent ±1σ of the interannual variability of the soil wetness. The differences in the soil wetness between different lead times are small in Brazil (the number in Figs. 7 and 8 is 3), southeastern Asia (7), and Australia (8). The differences remain large in the other regions in the entire seven-month integration period, since the climatological mean of the R-2 soil wetness is substantially different from that of the SFM soil wetness and the soil wetness persists for a long time.

However, though the climatological soil wetness with different lead times is different, the $F$-statistics are large in Fig. 4a and lie out of the interval of ±1σ. However, though the climatological soil wetness with different lead times is different, the $F$-statistics are small in low latitudes: Argentina (4), India (9), and South Africa (12). Figures 4a and 4b demonstrate that the interannual SST variability controls the geopotential heights in these areas more than the soil wetness; therefore, the effect of the initial soil wetness on the heights is negligible there. In addition, the two-way layout ANOVA is applied to the soil wetness and the ground air temperature, and the results obtained are consistent with Fig. 4a (see Fig. 9 that is same as in Fig. 4 but for top soil wetness). Therefore, we can confirm that the statistically significant $F$-statistics in Fig. 4a are due to the difference in the climatological soil wetness between R-2 and SFM, and that the variance ratios in Figs. 4d and 4f are overestimated.

b. Change in the PDF

The results in Figs. 5 and 6 raise the question of whether significant change in the PDF is due to the change in the mean or the shape. The KS test is applied to assess the change in the shape of the two PDFs (the PDF of the internal variability of the 5-normal-event 40-member (5x40=200) ensemble, and that of the 40-member ensemble for each ENSO event), and shows no statistically significant difference in the internal variability between ENSO events and normal events. However, it does not mean that the internal variability changes at all, but a larger ensemble size is required for detecting statistically significant change since the power of the test is weak in this case, as illustrated in Fig. 1b.

Kumar et al. (2000) investigated this question and demonstrated that the change in the mean is the dominant contribution to the change in PDF, and the change in the variance is a secondary contribution. However, the effect of
El Niño and La Niña events on the internal variability is not generally agreed upon (e.g. Schubert et al., 2001; Sardeshmukh et al., 2000; Kumar et al., 2000; Chen, 2004; Peng and Kumar, 2005). Further studies need to address this difference.

7. Conclusion

This paper examined the seasonal mean fields of 500-hPa geopotential heights of the hindcast experiment of the NCEP SFM, using two-way layout ANOVA and the non-parametric KS test. The statistical differences in the seasonal mean fields of 500-hPa geopotential heights between four different lead times and those between years were examined using the two-way layout ANOVA. Significant differences in the climatological means for JJA are found in northeastern China, while DJF did not exhibit significant differences in climatological means anywhere. This difference for JJA stems from the difference in climatological soil wetness means between NCEP SFM and R-2. The variance ratio can be overestimated due to the differences in the climatological means for DJF, though they are not statistically significant. However, this effect on the anomalies can be eliminated by using the climatological means for different lead times. No significant differences in the variance for DJF and JJA between different lead times are found anywhere. Therefore, NCEP SFM ensemble members with different lead times for both seasons can be treated as a combined ensemble if climatological means for different lead times are used.

The changes in the PDF during ENSO events for DJF were examined using the combined ensemble. The non-parametric KS test identified the changes in most of the globe, especially the tropics, eastern Pacific, and North and South America. Each ENSO event has individual features in mid- and high latitudes as investigated by Hoerling and Kumar (1997). There are two factors responsible for the change in the PDF: changes in the mean and changes in the shape. No significant change in the variance for any event is found with the KS test due to the low power of the test. The global pattern of the large KS measure resembled that of the change in the mean displayed in Fig. 3e. Therefore, the changes in the PDF are primarily due to the change in the mean, but are also due to the change in the variance, as demonstrated by Kumar et al. (2000).

The combination of the ensembles with different lead times enables us to analyze a relatively large member ensemble at institutions that routinely perform the seasonal forecast with small ensembles, and even provide an opportunity for them to demonstrate the probabilistic forecast at such institutions. Combined ensembles at operational institutions consist of about 120 to 160 members, and bring more reliable probabilistic forecasts and detection of the changes in the PDF. The influences of initial soil wetness on climatological means suggest that correct soil wetness significantly improves the model’s climatological means in summer, if available, which encourages one to work for land data assimilation.

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References


**エルニーニョ・ラニーニイベント時の500-hPaジオポテンシャル高度場の確率密度関数の変化**

仲江川敏之・金光正郎

本研究では、米国環境予測センターで実施された力学的季節予報ハイドキャスト実験の結果を用いて、エルニーニョ・ラニーニイベント時の500-hPaジオポテンシャル高度場の確率密度関数の変化について調べた。初めに、リードタイムが気候学的平均と分散に与える影響を評価するために、2元分散分析を実験結果に適用した。その結果、個々の月平均については、リードタイムの違いは統計的に有意な影響を与えないと示された。しかし、個々の月平均については、中国東北部において、リードタイムは気候学的平均に有意な差異を与えることが示され、この差異は初期土壌水分量によるものと結論付けられる。気候学的のアノマリーに対する、リードタイム影響はリードタイム毎の気候学的平均を用いることによって、除去することができる。この結果を基に、pptのリードタイムの異なるpptメンバー・アンサンブルを一つのpptメンバー・アンサンブルに合成した。このことにより、pptの変化が統計的に有意かどうか調べる検定力を高めることができる。平年とエルニーニョ・ラニーニイベント時のpptの比較のためにノンパラメトリックな検定を実施したところ、多くの領域でpptの変化は有意であり、その主因は平均値の変化によるものであった。また、イベント毎に特有の全球分布が見られた。