EXPERIMENTAL WEEKLY TO SEASONAL U.S. FORECASTS WITH THE REGIONAL SPECTRAL MODEL

BY J. ROADS

Since 1997, the Scripps Experimental Climate Prediction Center (ECPC) has been routinely making near-real-time experimental global and regional dynamical weekly to seasonal forecasts of many pertinent geophysical variables.

As described previously Roads et al. 2001a, hereafter RCF), the Scripps Experimental Climate Prediction Center (ECPC) has been making routine, near-real-time, long-range experimental global and regional dynamical forecasts since 27 September 1997. The global spectral model (GSM) used for these forecasts is that of National Centers for Environmental Prediction's (NCEP; Kalnay et al. 1996; see also Roads et al. 1999) used for the NCEP–National Center for Atmospheric Research (NCAR) reanalysis. The initial conditions and SST boundary conditions for these experimental GSM forecasts come from the NCEP Global Data Assimilation (GDAS) 0000 UTC operational analysis, which is available to interested researchers, almost without fail, every day in near–real time on NCEP rotating disk archives. Transforming NCEP's higher-resolution operational global analyses to lower (vertical and horizontal) resolution initial conditions for the GSM, 7-day global forecasts are made every day, and every weekend these GSM forecasts are extended to 16 weeks. RCF (see also Roads et al. 2001b; Chen et al. 2001; Roads and Brenner 2002; Roads and Chen 2003) provided a preliminary evaluation of the 12-week forecast capability of the GSM for many regions for the first 2 yr and indicated that there were places and times when the GSM 12-week forecasts of many relevant geophysical variables were skillful.

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Utilizing these GSM forecasts as lateral boundary conditions, the ECPC also routinely makes higher-resolution regional spectral model (RSM; Juang and Kanamitsu 1994; Juang et al. 1997) forecasts for various regions (United States, the Southwest, California, Brazil). Several papers have described the RSM regional simulation capability (Chen et al. 1999; Anderson et al. 2000a,b, 2001; Anderson and Roads 2002; Han and Roads 2004; Roads and Chen 2000; Roads et al. 2003a,b,c; Takle et al. 1999). These papers have shown that the RSM is certainly useful for simulating and understanding regional climates. The RSM, like other regional models, provides increased focus for specific regions, can be more constrained by realistic large-scale conditions, and can make use of higher-resolution regional datasets for validation.

However, except for a few notable cases (e.g., Anderson et al. 2000a,b, 2001; Leung et al. 2003) the RSM has not yet unambiguously indicated that it provides a better regional simulation capability than the bounding global analyses. This has been somewhat surprising, since it is commonly assumed that the interactions of a regional model with its associated higher-resolution landscape should provide better regional simulations and predictions. We do already know that increased resolution alone is not sufficient to achieve better global simulations. In global models, physical parameterization improvements are sometimes much more important (see, e.g., Marshall et al. 1997). Also, increased skill of regional models can sometimes be more easily attributed to regional model physical parameterization improvements than to increased resolution (see, e.g., Chen 2002; Roads et al. 2003a; Han and Roads 2004). In addition to further improving the RSM parameterizations, we are now beginning to understand that if the regional simulations are to be significantly better than the bounding global analysis, then additional regional observations will probably have to be included. For example, the pending regional reanalysis (Mesinger et al. 2002) makes use of regional precipitation and other observations, along with improved land surface and other parameterizations, in order to develop an improved regional analysis.

What about long-range forecasts with regional models? Do regional models in general and our version of the RSM in particular make useful regional forecasts when bounded by global forecasts instead of global analyses? This question is especially important when considering global change projections that need to be downscaled for regional applications (see, e.g., Chen et al. 2003; Han and Roads 2004), but also is relevant to current seasonal global forecasts. Roads et al. (2004) and Roads (2004) examined the seasonal forecast capability of fire danger and precipitation and found that the RSM was perfectly capable of providing significant forecast skill at weekly to seasonal time scales for many U.S. regions, but for at least the case of precipitation forecasts, it was not clear that the regional forecast skill was significantly better than the global forecast skill.

This regional forecast examination is continued in this paper by analyzing various forecast variables from the global and regional forecasts that may be especially relevant to various hydrology, fire danger, and atmospheric pollution communities. Accurate forecasts of precipitation, temperature (2 m), and soil moisture would be useful to the hydrologic community; precipitation, temperature (2 m), relative humidity (2 m), and wind speed to the fire community; and wind speed (10 m) and planetary boundary layer height to the air pollution community. This ability to provide a diverse set of consistent geophysical outputs is one of the reasons that dynamical models are potentially more useful than statistical forecasting methodologies, which focus in on only one or two variables, such as, for instance, temperature and precipitation, which must have adequate observational data.

The next section provides an overview of our methodology (models, observations, error measures), followed by an examination of geographic, temporal, and forecast lag characteristics of the experimental regional forecasts. The article concludes with a summary of the evaluations. In short, our current regional forecasts have significant skill, but this forecast skill is not significantly better than that obtained from the driving GSM.

METHODOLOGY. *GSM forecasts.* The GSM forecasts used for this study were previously described in many papers (e.g., RCF; Roads 2004). Again, the GSM is based upon the medium-range forecast (MRF) model used for the NCEP–NCAR reanalyses (Kalnay et al. 1996; Kanamitsu et al. 2002). The GSM has a triangular truncation of T62 (192×94 global Gaussian grid) and 18 irregularly spaced vertical levels (18LT62). Seven-day GSM forecasts, initialized every day from the 0000 UTC NCEP GDAS operational analysis, and 16-week GSM forecasts made every weekend provide the basic large-scale driving data for the RSM. During the weekly 16-week (and also daily 7-day) forecasts, it is assumed that the initial SST anomaly is constant (persistent). The GDAS initial conditions have been accessed almost every day from 0000 UTC 27 September 1997 to the present (28LT126 NCEP global analyses were available from 0000 UTC 27 September 1997 to 1800 UTC 14 March 2000; 42LT170 were available from 0000 UTC 15 March 2000 to 1800 UTC 14 July 2002; 62LT256 became available 0000 UTC 15 July 2002). These higher-resolution analyses are transformed to lower-resolution initial conditions (18LT62) by linearly interpolating between vertical sigma levels, spectrally truncating the spectral components, and bilinearly interpolating the higher-resolution surface grids to our lower-resolution grids (and land mask).

RSM. The RSM was initially developed by Juang and Kanamitsu (1994; see also Juang et al. 1997) to provide a regional extension to the GSM, and thus in principle provides an almost seamless transition between the RSM and the GSM or the associated NCEP–NCAR reanalyses (Kalnay et al. 1996; Kanamitsu et al. 2002) and the higher-resolution region of interest. An intrinsic advantage, according to Hong and Leetma (1999), is that the RSM has relatively less restriction on nesting size in comparison to other regional climate models, and smaller nests can be easily embedded within the large-scale reanalysis or GSM forecasts with noticeable errors or influences. For this experiment, the grid spacing was chosen to be 60 km at the central point. This horizontal resolution (and 18 vertical levels) is sufficient to resolve many features of interest, although eventually even higher-resolution simulations and forecasts need to be attempted for the U.S. West, where the topography exerts a strong control on near-surface features.

Both the GSM and RSM use the same primitive hydrostatic system of virtual temperature, humidity, surface pressure, and mass continuity prognostic equations on terrain-following sigma (sigma is defined as the ratio of the ambient pressure to surface pressure) coordinates. Therefore, in the absence of any regional forcing (and intrinsic internal dynamics, any significant physical parameterization differences, and significant spatial resolution) the total RSM solution should be identical to the GSM solution. A minor structural difference is that the GSM utilizes vorticity and divergence equations, whereas the RSM utilizes momentum equations in order to have simpler lateral boundary conditions. The GSM and RSM horizontal basis functions are also different. The GSM uses spherical harmonics with a triangular truncation of 62 (T62) whereas the RSM uses cosine or sine waves to represent regional perturbations about the imposed global-scale base fields on the regional grids. The double Fourier spectral representations are carefully chosen so that the normal wind perturbations are antisymmetric about the lateral boundary. Other model scalar variables (i.e., virtual temperature, specific humidity, and surface log pressure) use symmetric perturbations.

Except for the scale-dependent horizontal diffusion, the GSM and RSM physically are, in principle, identical. However, there are some notable parameterization differences between the NCEP GSM and this RSM, which has an upgraded physics package comparable to what was used for the NCEP Reanalysis II (see Kanamitsu et al. 2002). Solar radiation is calculated from Chou and Suarez (1996) and the infrared radiation is calculated according to Schwartzkopf and Fels (1991). As modified by Hong and Pan (1996), the RSM now allows convection to occur when the convective available potential energy (CAPE) is large. There are some other important differences in the boundary layer. In the GSM boundary layer, vertical transfer is related to eddy diffusion coefficients dependent upon a Richardson number–dependent diffusion process (Kanamitsu 1989). In the RSM, a nonlocal diffusion concept is used for the mixed layer (diffusion coefficients are still applied above the boundary layer). Briefly, in the mixed layer, the turbulent diffusion coefficients are calculated from a prescribed profile shape as a function of boundary layer height and scale parameters derived from similarity requirements (Troen and Mahrt 1986). It should be noted that the RSM output planetary boundary layer height is actually the height of the inversion layer, which can be a few tens of meters higher than the commonly defined height corresponding to the level of maximum negative heat flux, and the minimum height is the height of the lowest model level (50 m), but nonetheless this PBL may have some influence upon smoke and other pollutant dispersal.

The RSM can be initialized directly from the GSM, analysis or reanalysis, or it can use a previous integration to initialize itself. Roads et al. (2003a) showed that it was best to initialize the RSM every day from the global analysis, since continuous runs adversely affected the regional solution. The first part of an RSM forecast or simulation involves the integration of the GSM for a nesting period based upon the large-scale output. Here, the RSM predicts regional deviations from the large-scale atmosphere base fields, which are linearly interpolated in time between two output periods (6 h). The nonlinear advection is first computed at the model grid points by transforming the global and regional spectral components to the regional grid. The global quantities are transformed to the global grid and then bilinearly interpolated to the regional grid; the regional quantities are exactly transformed. These calculations are almost exact (except for the interpolation error for the global quantities) and thus, like the global model, the regional model is free of aliasing and phase error. The linearly interpolated global-scale tendency is then removed, so that, in effect, only the portion affecting the regional perturbation is retained. At the horizontal boundaries, the perturbation amplitude approaches zero by a damping function increasing rapidly toward the lateral boundary, which ensures that the boundary tendencies are similar to the original GSM tendencies and features. A semi-implicit time integration scheme is employed to suppress computational modes and also to allow the use of longer time integration steps.

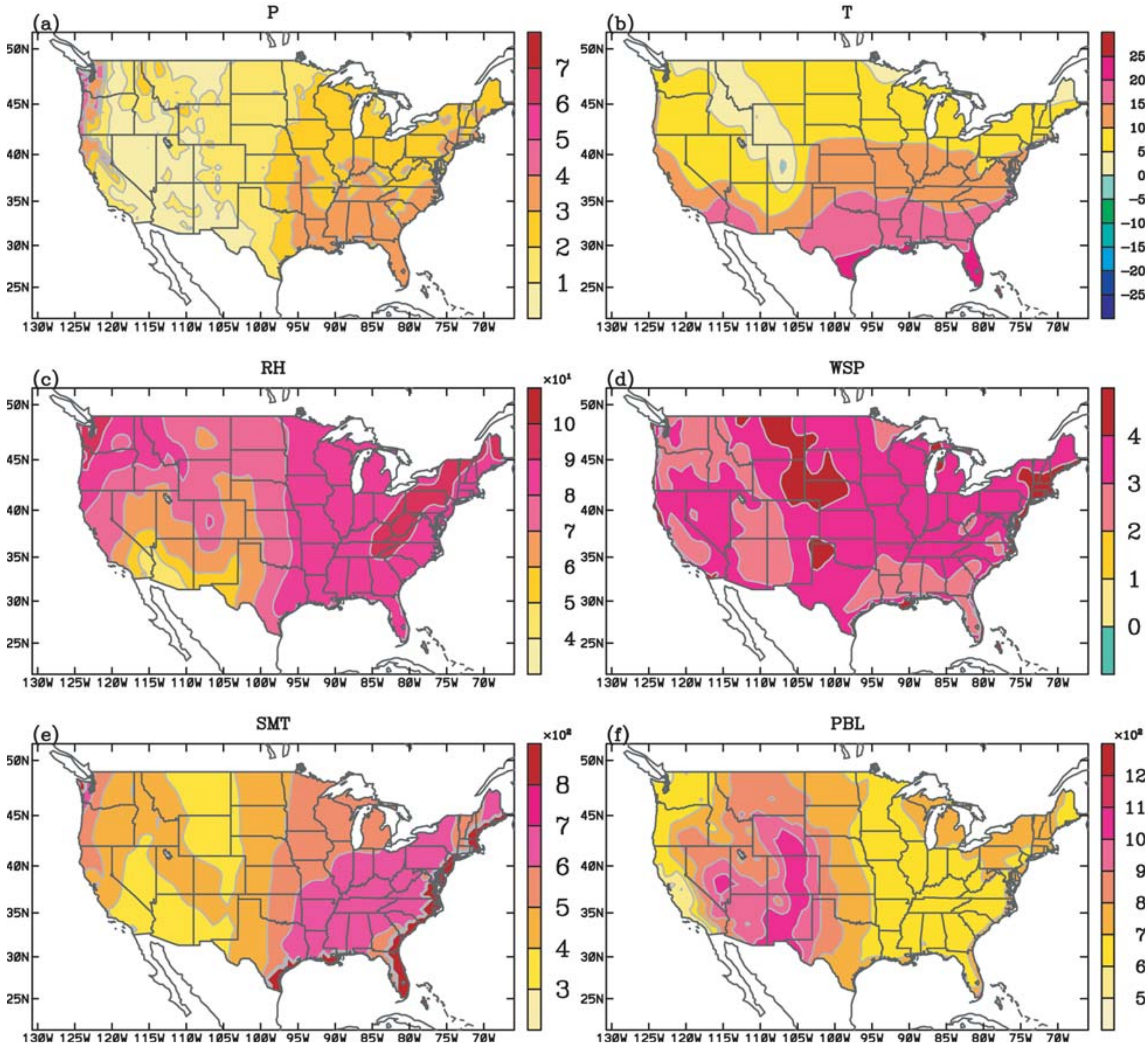

Fig. 1. Validating RSM annual means: (a) precipitation (*P*; mm day^{-1}), (b) temperature (*T*; °C), (c) relative humidity (RH; %), (d) wind speed (WSP; m s^{-1}), (e) soil moisture (SMT; mm); and (f) planetary boundary layer height (PBL; m).

Validations. We evaluated our 16-week GSM/RSM U.S. forecasts, made starting every Saturday (0000 UTC) since 27 September 1997. Again, an extensive validation effort was previously undertaken for the GSM. Here we focus on the RSM forecasts, although some comparison to the coarser-scale GSM forecasts is also provided. The main validation data for the weekly to 12-week forecasts was the weekly average of the 1-day RSM forecasts (output 4 times daily), initialized every day from 0000 UTC analysis initial conditions and bounded by the GSM 1-day forecasts (every 6 h). These 1-day RSM forecasts (also output 4 times daily) are not exactly the same as the operational analysis, which is based upon 4 times daily 6-h global forecasts from the latest high-resolution global model, or the reanalysis, which is based upon 4 times daily 6-h forecasts with the GSM, or the GSM 1-day forecasts (also output 4 times daily) we previously used to validate the global model, but they do form a useful approximation that can at least be used to estimate forecast skill. There were very few (three) missing 0000 UTC initial states for the 5+ yr we have now run this experimental system and for these periods we used a previous 2-day forecast to generate the associated daily (actually 4 times daily) GSM forcings.

Although the 1-day (output 4 times daily) RSM forecast validation set is certainly useful in the absence of actual observations, at least there are better approxi-

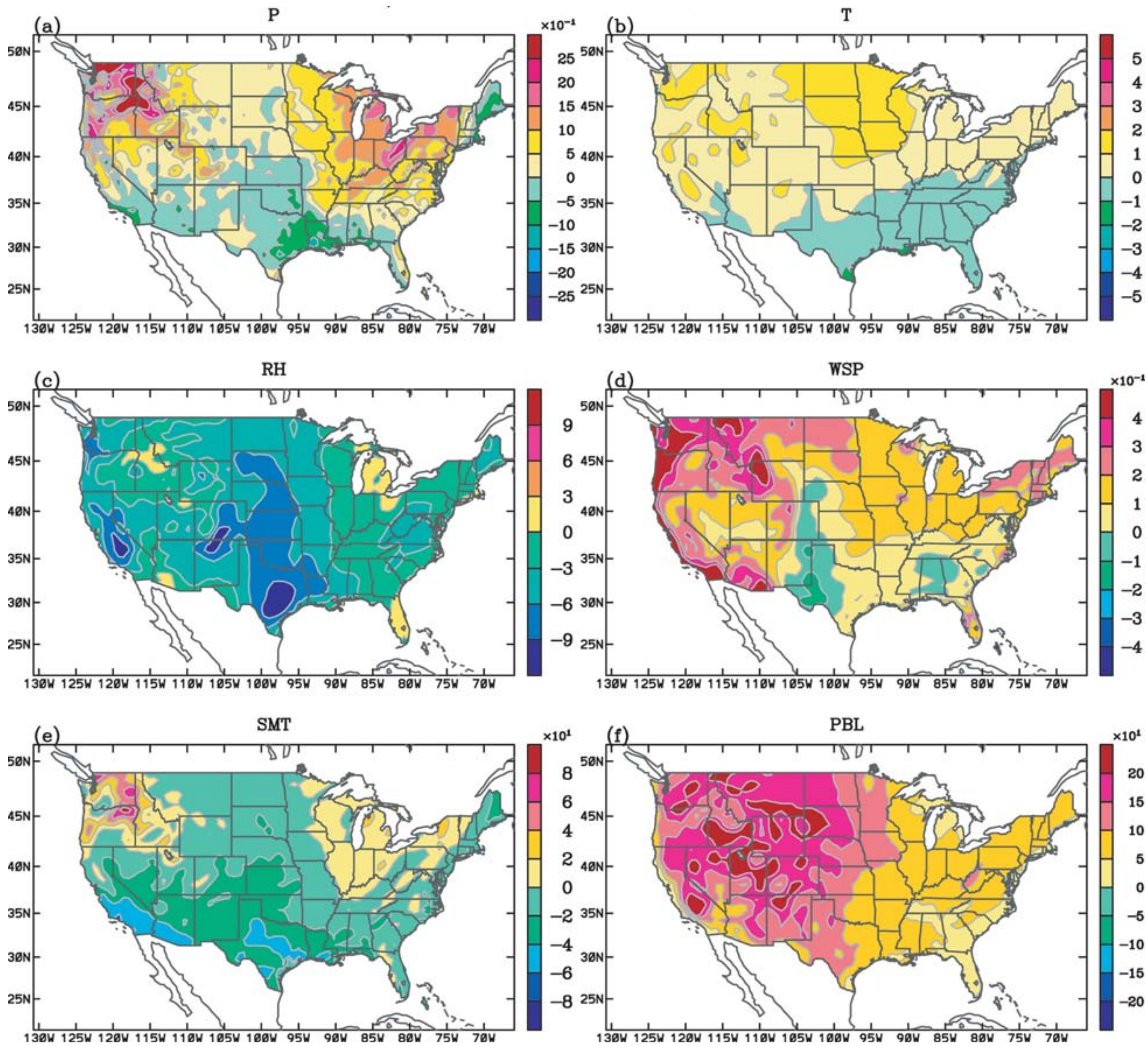

Fig. 2. RSM 12-week forecast systematic errors: (a) *P* (mm day⁻¹), (b) *T* (°C), (c) RH (%), (d) WSP (m s⁻¹), (e) SMT (mm), and (f) PBL (m).

mations to the U.S. precipitation from independent observations. For example, the National Climatic Data Center (NCDC) and first-order station network along with the precipitation network of the River Forecast Centers were utilized by Higgins et al. (2000) to develop gridded (25 km) daily precipitation. Maximum and minimum temperature observations (Janowiak et al. 1999) were only available through September 2001, which would have limited our evaluation period to only 3 yr; however, as shown by Roads et al. (2003c), the GSM and RSM surface temperature closely mimicked these observations and we thus feel confident that our 1-day RSM simulations provide an adequate substitute, for at least 2-m temperature. However, we are certainly much less confident about other geophysical variables (2-m RH, 10-m wind speed, total soil moisture in upper 2 m, and planetary boundary layer, or more precisely height of inversion layer above lowest model level). In that regard, the pending NCEP regional reanalysis (Mesinger 2002) should eventually provide a better validation for these kinds of regional model evaluations. In any event, the basic evaluation of these forecasts occurred for initial periods of 27 September 1997 (since we also compared persistence forecasts, the first dynamical forecast actually began 4 October 1997) with the ending validation day for the 16-week forecast ranging from 24 January 1998–12 January 2002.

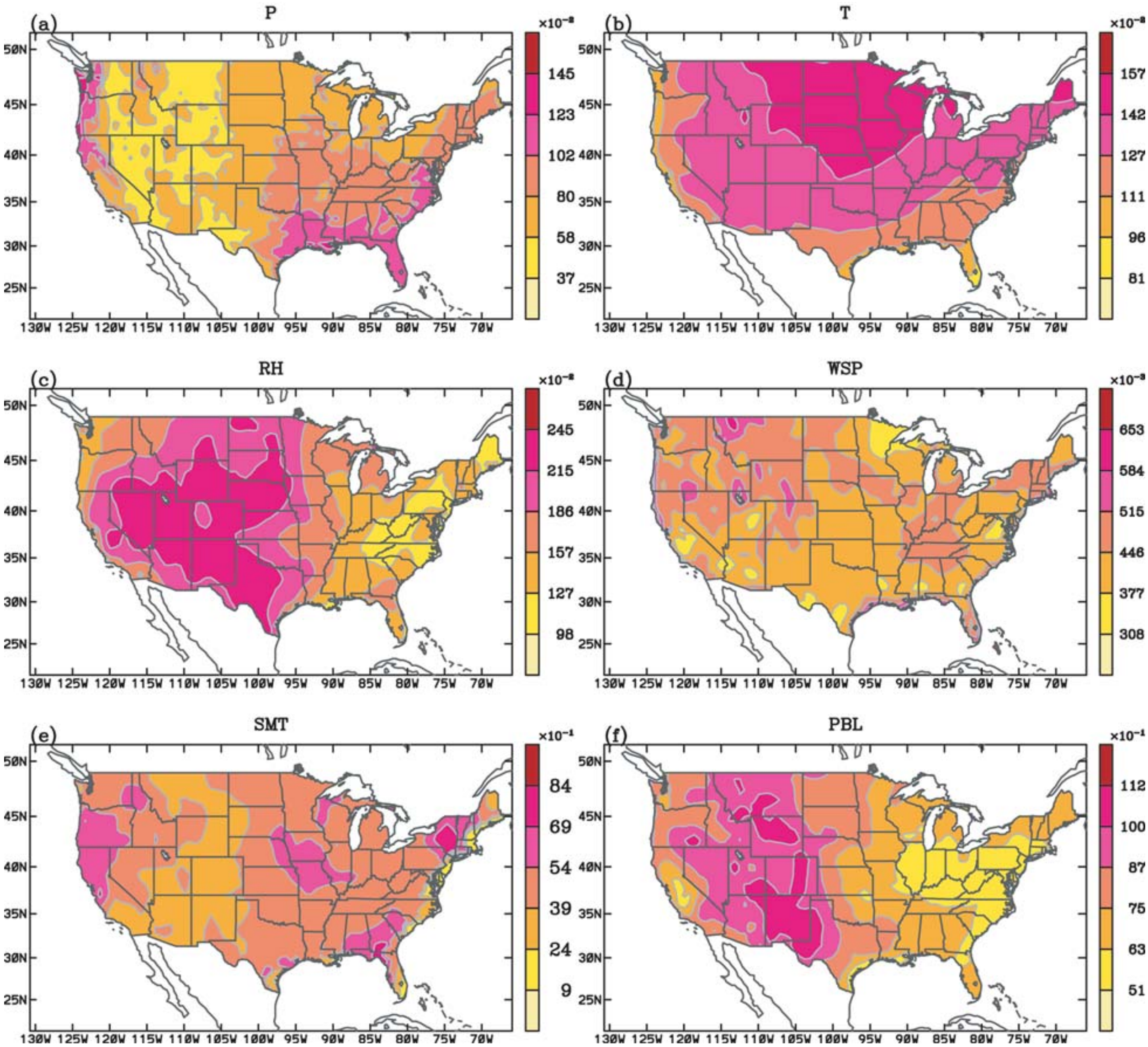

Fig. 3. Validating RSM 12-week standard deviations: (a) *P* (mm day^{-1}), (b) *T* (°C), (c) RH (%), (d) WSP (m s^{-1}), (e) SMT (mm), and (f) PBL (m).

Skill measures. The skill measures used here were previously used to describe the GSM forecast skill (e.g., see RCF). Briefly they are

1) systematic error, which measures the average difference between forecasts and observations;
2) standard deviations, which compares the level of variation about the individual forecast and validation climatologies;
3) correlation, which compares the correlation between the forecast and validation anomalies: both temporal and average correlations were computed and as pointed out by RCF, because there are times when the entire domain is anomalously high or low, the average of the temporal correlations is smaller than the average correlation. For this reason, a normalized covariance was used instead of the temporal spatial correlation when examining temporal variations in the correlation; the average of the normalized covariances was then closer to the average correlation calculated over time and space.

GEOGRAPHICAL VARIATIONS. Figure 1 shows the annual means of the RSM validation data, which again consists of the average of 1-day RSM forecasts along with observed (Higgins et al. 2000) precipitation. Note that precipitation (*P*) is greatest over the northwest coastal regions and U.S. southeast, in contrast to

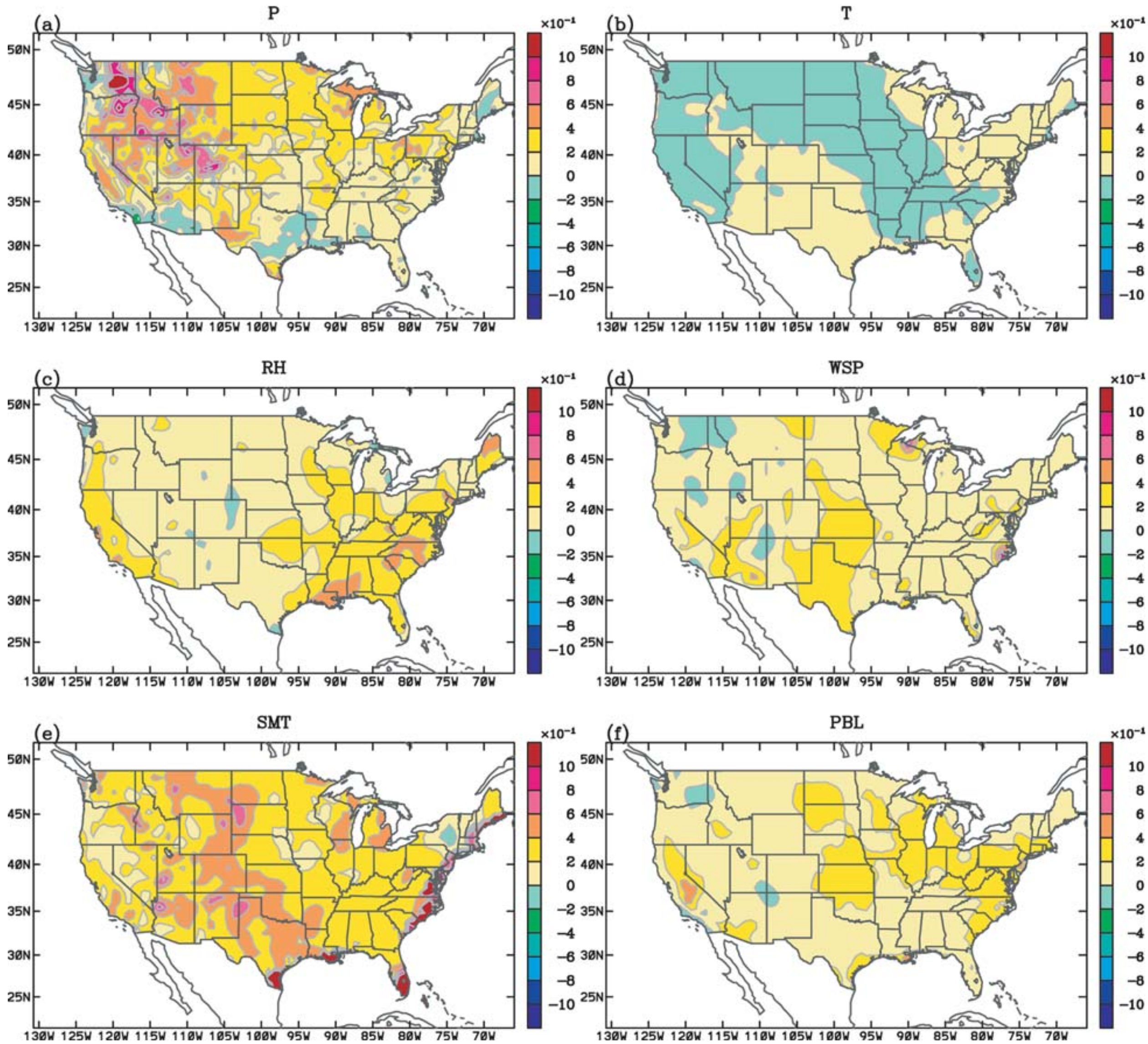

Fig. 4. RSM 12-week forecast std dev in comparison to validating 12-week std dev. (a) *P,* (b) *T,* (c) RH, (d) WSP, (e) SMT, and (f) PBL.

the drier central region of the Great Plains and U.S. Southwest. Precipitation variations were quite similar to relative humidity (RH) and soil moisture (SMT) variations, although RH and SMT were relatively higher in the colder northern regions. In contrast to precipitation, relative humidity, and soil moisture, 2-m temperature (*T*) decreased with latitude and elevation and had a more east–west orientation. Wind speed (WSP) was strongest over the coastal regions in the lee of the Rocky Mountains. The planetary boundary layer height was a maximum over the dry mountainous regions of the United States [again the RSM had a diagnostic PBL, whereas the general circulation model (GCM) did not]. Finally, it should be noted that these general climatological features were quite similar in the GSM validation data (not shown).

There were a number of noticeable systematic errors (Fig. 2) in the RSM 12-week forecasts of the RSM validation dataset. The precipitation was relatively large in the north and relatively weak in the south. The 12-week temperature forecast was too high in the north central and too low in the south. Wind speed (10 m) had a strong systematic low bias in the Rocky Mountain Front Range. For the most part, forecast soil moisture was relatively dry just about everywhere but became especially dry in the southwest in the RSM and especially dry throughout the intermountain region of the West. Finally, the forecast PBL was relatively high,

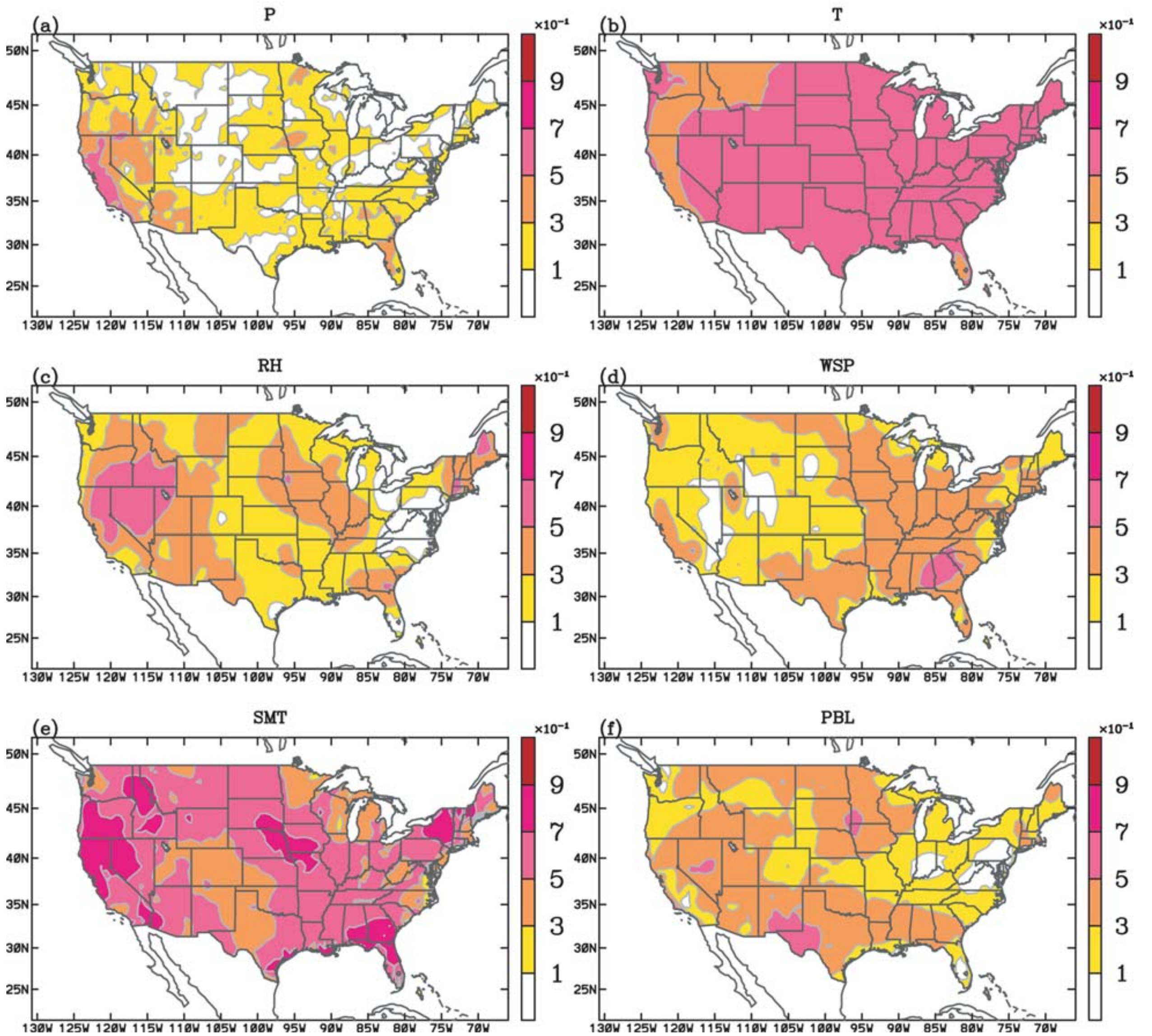

Fig. 5. RSM 12-week forecast correlations: (a) *P*, (b) *T*, (c) RH, (d) WSP, (e) SMT, and (f) PBL.

especially over the western mountains, where it had a local maximum; this is somewhat consistent with the soil moisture forecasts, which were drier than the initial state. The systematic errors in the GSM were somewhat comparable to the RSM and will be discussed later for the U.S. averages as a whole.

The validation standard deviations of 12-week means are shown in Fig. 3. Precipitation, soil moisture, and PBL variability were a maximum in the region where they had maximum climatological values, namely the northwest and southeast. Relative humidity, on the other hand, was greatest in the southwest, presumably because this is a dry region; in the moist regions, relative humidity is limited by the saturation value. Temperature variability was greatest in the central part of the country, where the land has a dominant influence and the moderating ocean influences are smallest. Wind speed variability was strongest in the Northwest and northern prairies.

Figure 4 shows that the forecast variations were relatively stronger than the validating analysis for almost all variables except temperature. As noted by Roads (2004), the precipitation variability was especially strong over the U.S. West, in agreement with the overly strong GSM precipitation variability in this region (not shown). This variability also showed up in the soil moisture variability, although interestingly, the variability was even stronger further to the east and south. The relative humidity variations were a bit strong in the Gulf Coast and Atlantic Seaboard and the wind speed variations were a bit strong in the region of the low-level jet, where the climatological values were relatively weak by comparison. PBL variations were slightly strong everywhere, although the greatest excess variability occurred in the central part of the country.

Figure 5 shows the correlations between the 12-week forecasts and the validating observations. Assuming 208 independent 12-week forecasts, correlations above 0.1 might be considered to be significant at the 99% level (e.g., Von Storch and Zwiers 1999). Of course, given the serial dependence of these forecasts, the significance is likely to be lower. Anyway, temperature forecasts were most skillful in the eastern part of the country where they were correlated with the RSM validations at greater than 60%; however, correlations were also greater than 0.4 for the western part of the country. On the other hand, precipitation forecast correlations were greater than 0.1 only in the southern and California regions of the country, where the ENSO cycle dominates, and surprisingly has a north–south band centered over the Great Plains. The correlations were especially strong over California, indicating that this is one region where we can make the best precipitation forecasts, at least during the wintertime. However, even more skillful forecasts were made for the relative humidity, especially over the U.S. West, which has some implication for long-range forecasts of fire danger. Regions where the relative humidity forecasts were less skillful, that is, over the U.S. East, were regions where the wind speed was forecast best, which again could help to provide some skill to forecasts of fire danger, which depend on both wind and relative humidity (Roads et al. 1991). Soil moisture was forecast well everywhere (presumably because this is a highly persistent variable), with perhaps the dry regions of New Mexico and west Texas being the most difficult to accurately predict. Finally the planetary boundary layer height was forecast best across the southern tier of states; it was more difficult to forecast this variable to the north, although there was some indication of skill in the northern prairies.

TEMPORAL VARIATIONS. Figure 6 shows the temporal variations of the U.S. 12-week RSM forecast means (coterminous 48 states, cosine-weighted) in comparison to the RSM validating data. For these and subsequent plots, individual 12-week means are plotted at the midpoint of the 12-week mean (e.g., the 12-week mean from 27 September 1997–19 December 1997 is centered at 7 November 1997 on the plot abscissa). Despite obvious systematic errors, the forecasts and validations have similar seasonal and intraseasonal behavior. Temperature was a maximum during the summer, in contrast to relative humidity, which was a maximum during the winter. Wind speed was a maximum during the winter–spring and a minimum during the summer–fall. Soil moisture was a maximum during the spring and a minimum during the fall. PBL was a maximum during the summer and a minimum during the fall.

Again, the mean or systematic errors were not insignificant in either the GSM or RSM (Fig. 7). Although the average RSM (solid lines) precipitation tends to follow the validating observations, there was a tendency for forecast precipitation to peak somewhat earlier, as was noted previously by Roads et al. (2003a) and Roads (2004). The GSM (dashed lines) precipitation bias had a stronger seasonal cycle. Temperature errors were relatively smaller although there was certainly a decrease in error during the winter months, presumably in the southern tier of the United States. The GSM had a stronger positive bias during the wintertime. The rela-

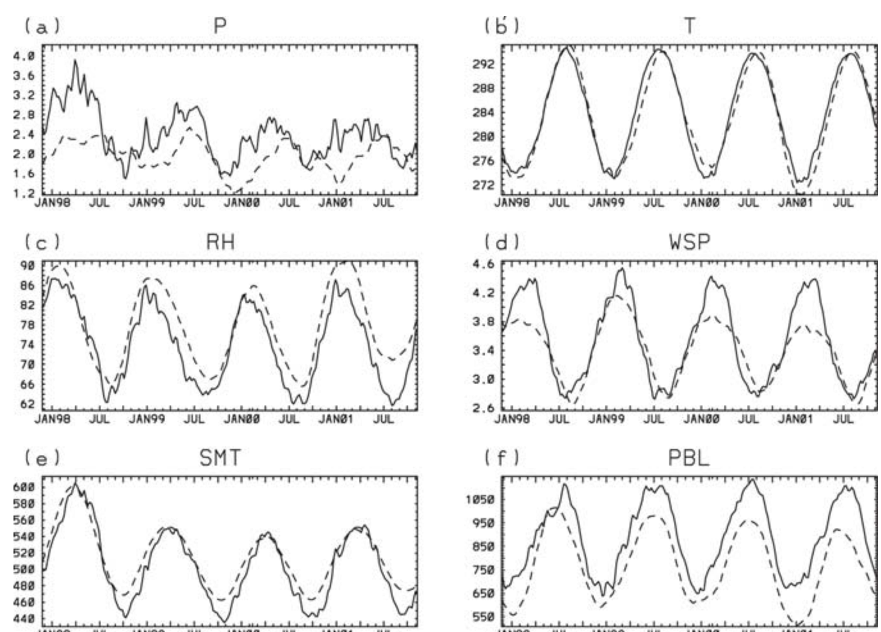

FIG. 6. RSM 12-week forecast (solid lines) and validation (dashed lines) U.S. averages: (a) *P*, (mm day^{-1}), (b) *T* (°C), (c) RH (%), (d) WSP (m s^{-1}), (e) SMT (mm), and (f) PBL (m).

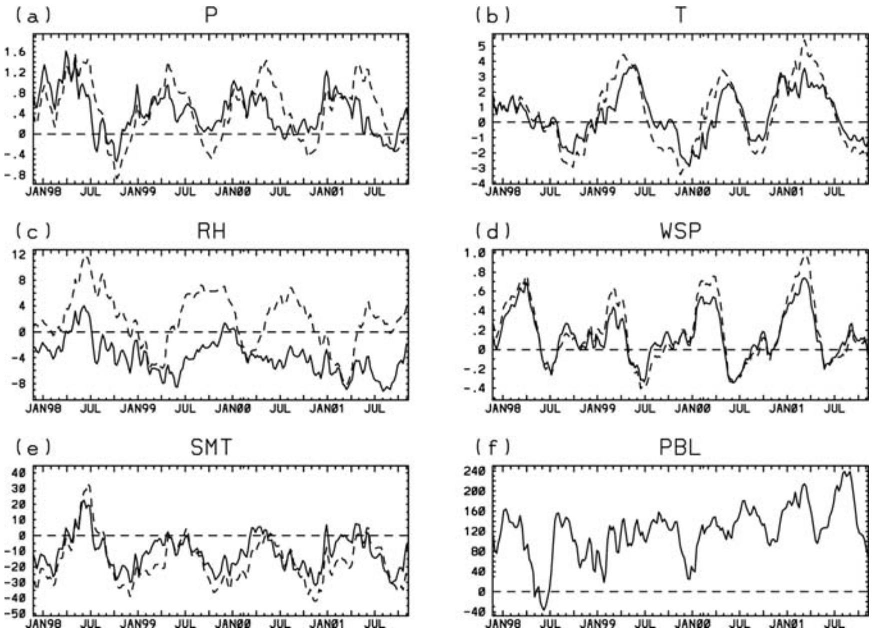

FIG. 7. RSM (solid lines) and GSM (dashed lines) 12-week forecast mean errors (U.S. average): (a) *P* (mm day^{-1}), (b) *T* (°C), (c) RH (%), (d) WSP (m s^{-1}), (e) SMT (mm), and (f) PBL (m).

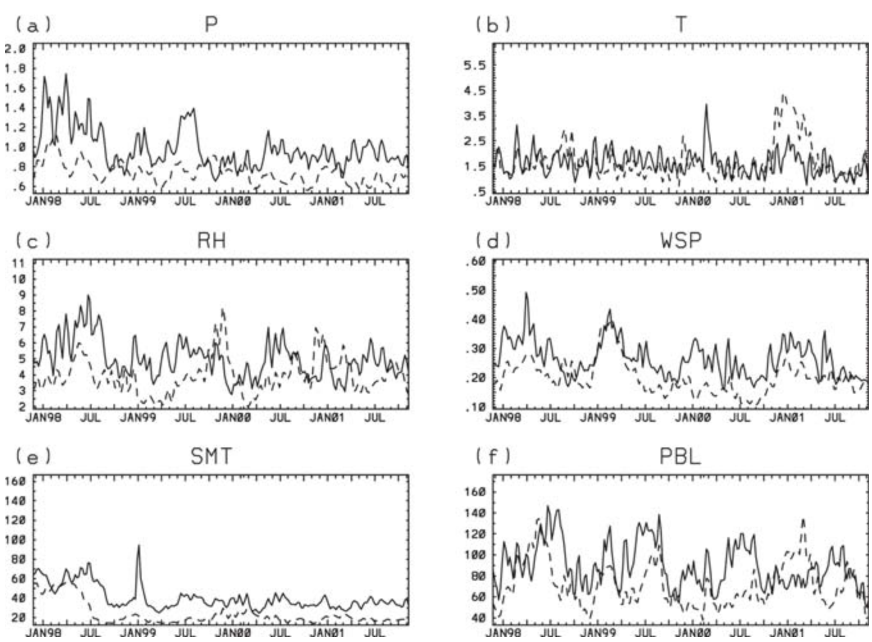

FIG. 8. RSM 12-week forecast (solid lines) and validation (dashed lines) U.S. std dev: (a) *P* (mm day^{-1}), (b) *T* (°C), (c) RH (%), (d) WSP (m s^{-1}), (e) SMT (mm), and (f) PBL (m).

tive humidity was relatively low in the RSM and relatively high in the GSM although both showed somewhat similar seasonal variations. The wind speed biases were only slightly reduced in the RSM and both the GSM and RSM had too-strong winds during the winter to summer transition. Soil moisture variations were quite similar in both the RSM and GSM. Basically, the 12-week forecasts were too dry, especially during the late summer to fall. Twelve-week forecast planetary boundary layer heights were too high almost all of the time, which was consistent with the overall soil moisture bias and at least the positive summertime temperature bias.

Figure 8 shows that the magnitude of the temporal variations of the U.S. standard deviations were comparable to the magnitude of the systematic errors, which is the main reason why one has to compute separate climatologies for different lagged forecasts. That is, comparisons of the absolute differences would be larger than the standard deviations; by taking into account the climatologies at different lags, we can focus on the anomalous behavior, which does have some forecast skill. However, note that variations in the 12-week forecasts were much larger than the variations in the validation dataset, especially in the precipitation, relative humidity, soil moisture, and planetary boundary layer height. Temperature and wind speed had a better correspondence between the forecasts and validating data.

Figure 9 shows the temporal variations of the correlations for the RSM (solid lines) and GSM (dashed lines) 12-week forecasts with the RSM validations. Of interest here is how close the RSM and GSM forecast correlations were for all fields. For some of the variables there was a clear seasonal variation in skill. For example, precipitation and soil moisture forecast skill were strongest during the winter and smallest during the summer. Of special interest is the slight decrease in skill for many variables. RCF (see also Reichler and Roads 2003) hypothesized that part of the initial forecast skill could probably be attributed to the strong El Niño–Southern Oscillation (ENSO) cycle at the beginning of the period.

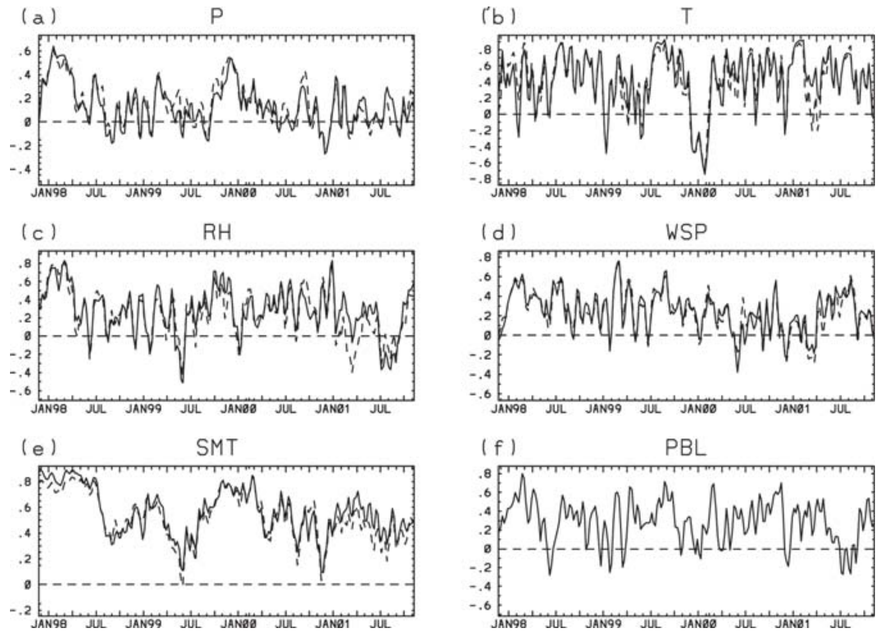

Fig. 9. RSM (solid lines) and GSM (dashed lines) 12-week forecast correlations (U.S. average): (a) *P* (mm day^{-1}), (b) *T* (°C), (c) RH (%), (d) WSP (m s^{-1}), (e) SMT (mm), and (f) PBL (m).

FORECAST LAGS. Figure 10 shows the U.S. average systematic errors (in comparison to the RSM validation) as a function of forecast lead for both the RSM (solid lines) and GSM (dashed lines). RSM (and GSM) precipitation were excessive initially, but became closer to the observations at long forecast lead times. In a similar manner, the temperature bias increased over time. GSM RH had a positive bias initially and then decreased toward a small bias at long lead times, whereas the RSM RH bias was small initially and then became a relatively large negative basis at long lead times. The soil moisture also decreased with increasing forecast time, which had been noted previously by Roads and Chen (2000). This decrease in soil moisture is consistent with the increasing bias in the PBL height, although, as shown previously, is not wholly geographically consistent. Finally the wind speed had a slight negative bias in the RSM but a small positive bias in the GSM.

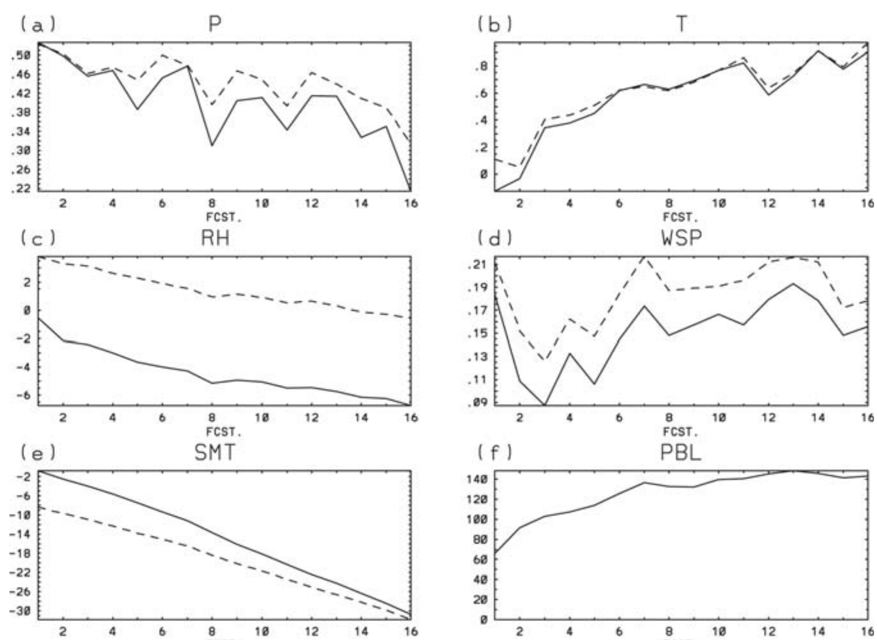

Fig. 10. U.S. RSM weekly (solid line) and GSM weekly (dashed) mean errors as a function of forecast lead time (weeks): (a) *P*, (b) *T*, (c) RH, (d) WSP, (e) SMT, and (f) PBL.

Figure 11 shows the RSM (solid lines) and GSM (dashed lines) correlations with the RSM validation as a function of forecast lead. Also shown are RSM monthly (O) and 12-week forecast correlations (*), and GSM monthly (+) and 12-week (×) forecast correlations. Note that there is remarkable agreement between the GSM and RSM. The skill was especially high for the temperature and soil moisture (although, as shown below, it is actually quite difficult to diagnose this model-based quantity). Precipitation appeared to be the most difficult variable to forecast although wind speed and rela-

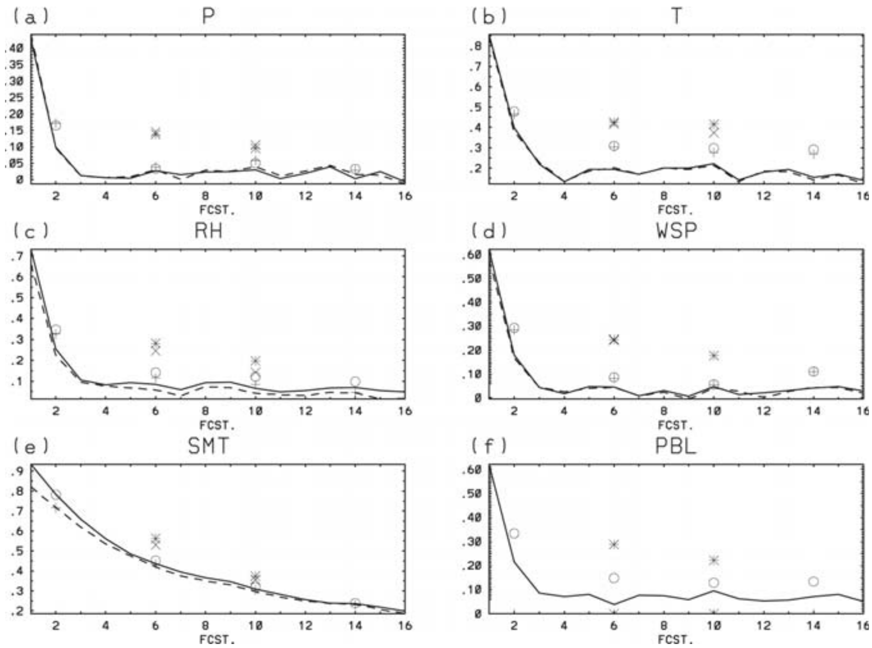

FIG. 11. U.S. RSM weekly (solid line), monthly (o), 12-week (*), and GSM weekly (dashed line), monthly (+), 12-week (x) forecast correlations: (a) *P*, (b) *T*, (c) RH, (d) WSP, (e) SMT, and (f) PBL.

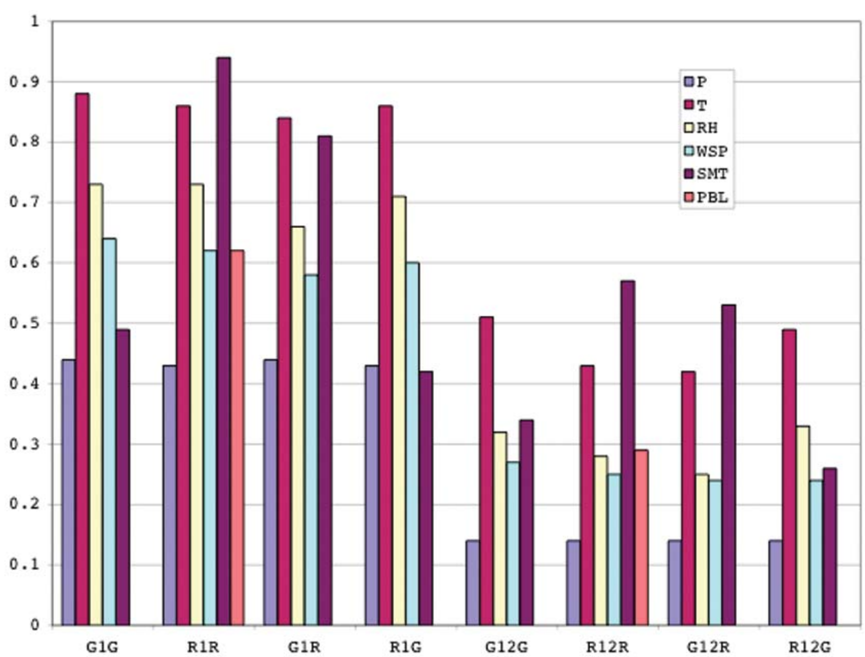

FIG. 12. GSM and RSM 1- and 12-week forecast correlations. G1G indicates 1-week forecasts made by the global model and validated by the global model validations. R1R indicates 1-week forecasts made by the regional model and validated by the regional model validations. G1R indicates 1-week forecasts made by the global model and validated by the regional model validations. R1G indicates 1-week forecasts made by the regional model and validated by the global model validations. Similar notation is applicable to the G12G, R12R, G12R, and R12G labels, except 12 denotes that these are 12-week forecasts.

tive humidity were also relatively difficult to forecast. Except for soil moisture, all variables show the positive influence of time averaging, indicating that forecasts of time averages, even for lags of 2 months, still show significant skill. Note that 12-week forecast skill at zero lag is also almost as good as 4-week forecasts at zero lag and only slightly better than 12-week averages at 1-month lag, indicating the usefulness of dynamical models (in a time-averaged sense) for seasonal forecasts.

SUMMARY. Figure 12 summarizes the GSM and RSM 1- and 12-week forecast correlations using both the GSM and RSM validation datasets (observed precipitation was used in place of daily forecast precipitation in both datasets). Note that the weekly forecast skill, as measured by correlation, is quite high in comparison to seasonal forecast skill, which is especially low for precipitation. Soil moisture has fairly high skill due to its remarkable persistence, but there are obviously problems in describing it; for example, the global forecasts were better able to forecast the regional soil moisture than the global soil moisture. There does appear to be somewhat of a scale problem since the global model predictions of the regional validating set were generally slightly lower than the regional model predictions of the global validating set (excepting soil moisture). In any event, despite the significant skill of these seasonal forecasts by the regional model of many geophysical variables, this skill is certainly not significantly greater than what might be achieved by a global forecast model.

Although this paper emphasized the evaluation of the RSM forecasts (since a number of previous papers had evaluated the GSM forecast skill), it has now become clear (see Tables 1 and 2) that the RSM has only comparable but clearly not superior forecast capability over the corresponding driving GSM. There were many similarities. The 12-week GSM and RSM precipitation was too high over the northern United States and deficient over the southern United States. By contrast the soil moisture was too low just about everywhere, except perhaps the northwest, where the 12-week precipitation forecasts were exceedingly wet. This dry soil moisture was consistent with an excessively high U.S. West planetary boundary layer (at least in the RSM). Forecast temperature was too low over the southern Gulf Coast states. Wind speeds were too low in the southern entrance region of the low-level jet. The 12-week variations were comparable to these 12-week forecast biases, indicating that they must be removed, either empirically or through the development of better models. It should also be mentioned that the RSM appears to have somewhat greater variance, especially in the precipitation forecasts (see also Roads 2004) than either the GSM or the validation dataset.

Thus, we have to conclude that the RSM is not yet capable of producing quantitatively better weekly to seasonal forecasts than the GSM. If we can find ways to improve these RSM forecasts, perhaps by developing better regional land surface initial conditions or better regional parameterizations, we may eventually be able to show a clear advantage to using a regional model for seasonal forecasts. This challenge is being met by the RSM community of modelers, which has

Table 1. RSM and GSM U.S. 1-week forecast means; forecast systematic errors (SE); forecast std dev (SD); ratio of forecast standard deviations to validating standard deviations (SD/SDv); forecast correlations, using either the GSM or RSM validation datasets. G1G indicates 1-week forecasts made by the global model and validated by the global model validations. R1R indicates 1-week forecasts made by the regional model and validated by the regional model validations. G1R indicates 1-week forecasts made by the global model and validated by the regional model validations. R1G indicates 1-week forecasts made by the regional model and validated by the global model validations.

G1G	Mean	SE	SD	SD/SDv	Correlation
P, mm day^{-1}	2.49	0.52	2.10	0.91	0.44
T, K	283.31	−0.30	3.10	1.01	0.88
RH, %	81.83	2.97	7.42	0.92	0.73
WSP, m s^{-1}	3.61	0.05	0.70	1.07	0.64
SMT, mm	480.18	−36.92	28.95	0.42	0.49
PBL, m					
R1R	**Mean**	**SE**	**SD**	**SD/SDv**	**Correlation**
P, mm day^{-1}	2.50	0.53	2.73	1.18	0.43
T, K	283.08	−0.12	3.14	0.98	0.86
RH, %	77.43	−0.56	7.74	1.01	0.73
WSP, m s^{-1}	3.58	0.18	0.66	1.12	0.62
SMT, mm	488.17	−0.73	30.52	1.11	0.94
PBL, m	833.87	65.67	176.41	1.07	0.62
G1R	**Mean**	**SE**	**SD**	**SD/SDv**	**Correlation**
P, mm day^{-1}	2.49	0.52	2.10	0.91	0.44
T, K	283.31	0.11	3.10	0.97	0.84
RH, %	81.83	3.84	7.42	0.97	0.66
WSP, m s^{-1}	3.61	0.21	0.70	1.18	0.58
SMT, mm	480.18	−8.72	28.95	1.06	0.81
PBL, m					
R1G	**Mean**	**SE**	**SD**	**SD/SDv**	**Correlation**
P, mm day^{-1}	2.50	0.53	2.73	1.18	0.43
T, K	283.08	−0.53	3.14	1.02	0.86
RH, %	77.43	−1.43	7.74	0.96	0.71
WSP, m s^{-1}	3.58	0.02	0.66	1.02	0.60
SMT, mm	488.17	−28.93	30.52	0.44	0.42
PBL, m					

TABLE 2. RSM and GSM U.S. 12-week forecast means; forecast systematic errors (SE); forecast std dev (SD); ratio of forecast standard deviations to validating standard deviations (SD/SDv); forecast correlations, using GSM or RSM validation. G12G indicates 12-week forecasts made by the global model and validated by the global model validations. R12R indicates 12-week forecasts made by the regional model and validated by the regional model validations. G12R indicates 12-week forecasts made by the global model and validated by the regional model validations. R12G indicates 12-week forecasts made by the regional model and validated by the global model validations.

G12G	Mean	SE	SD	SD/SDv	Correlation
P, mm day^{-1}	2.42	0.46	0.81	1.09	0.14
T, K	283.82	0.12	1.62	0.98	0.51
RH, %	79.83	1.10	4.74	1.08	0.32
WSP, m s^{-1}	3.57	0.02	0.29	1.32	0.27
SMT, mm	471.56	−44.03	35.17	0.84	0.34
PBL, m					
R12R	**Mean**	**SE**	**SD**	**SD/SDv**	**Correlation**
P, mm day^{-1}	2.39	0.43	0.99	1.33	0.14
T, K	283.78	0.48	1.65	0.98	0.43
RH, %	74.08	−3.84	5.01	1.28	0.28
WSP, m s^{-1}	3.54	0.15	0.26	1.32	0.25
SMT, mm	477.58	−10.90	39.06	1.75	0.57
PBL, m	886.91	119.56	89.70	1.26	0.29
G12R	**Mean**	**SE**	**SD**	**SD/SDv**	**Correlation**
P, mm day^{-1}	2.42	0.46	0.81	1.09	0.14
T, K	283.82	0.53	1.62	0.97	0.42
RH, %	79.83	1.90	4.74	1.21	0.25
WSP, m s^{-1}	3.57	0.18	0.29	1.46	0.24
SMT, mm	471.56	−16.92	35.17	1.57	0.53
PBL, m					
R12G	**Mean**	**SE**	**SD**	**SD/SDv**	**Correlation**
P, mm day^{-1}	2.39	0.43	0.99	1.33	0.14
T, K	283.78	0.08	1.65	1.00	0.49
RH, %	74.08	−4.64	5.01	1.15	0.33
WSP, m s^{-1}	74.08	−4.64	5.01	1.15	0.33
SMT, mm	3.54	−0.02	0.26	1.19	0.24
PBL, m	477.58	−38.01	39.06	0.94	0.26

shown steady growth for a number of years (e.g., Roads 2000). In addition to the overall RSM model development, which takes place as the GSM is developed, increasing focus is being paid to further improving RSM characteristics, which could then potentially influence further GSM development. In that regard, it should be mentioned that the evaluations described here were developed from a somewhat older version of the RSM (RSM96) and our goal is to begin transitioning to the newer version of the model (RSM), which is beginning to show increased skill in some regions.

Finally, the RSM continues to provide a potential outreach to the application community, which is interested in not only the long forecast horizons and ensembles currently obtainable from global models, but also the higher geographic resolution obtainable from regional models. Again, besides possible influences upon regional skill, another value of regional model simulations and forecasts is the increased scrutiny brought to bear for a specific region. It is now possible to use a small amount of global or regional analysis data to initialize and drive a regional model on short to long time scales. We can then use these regional models to provide comprehensive regional output and to examine various physical parameterizations and test various scientific hypotheses under highly controlled boundary conditions. Regional models thus continue to provide a valuable analysis tool, even if they are not yet able to provide a superior long-range forecast tool. Our challenge is still to show that the RSM and other regional models can significantly contribute to global seasonal forecast ensembles and global change experiments.

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