Seasonal Surrogate for Climate

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1 February 1994 and 26 October 1994

In attempting to verify model predictions and parameterizations, it would be immensely helpful to have natural climate surrogates in the existing instrumental record. Certain primitive attempts in this direction assumed that local temperature or regional seasonal variability might serve in this regard (Raval and Ramanathan 1989; Rind et al. 1991). Unfortunately, regional climate is not locally determined. Typically, subsiding air originating from horizontally distant regions determines tropospheric properties above the boundary layer, and the winter and summer tropical regions are part of a single Hadley circulation that couples both hemispheres (Lindzen and Hou 1988). A surrogate for global climate change must, at the least, consider climate change averaged over major circulation systems. In this connection, the seasonal variation of *global averages* does meet this condition, and as shown in Fig. 1, the *globally averaged* surface temperature shows a strong seasonal cycle. The data cover the period January 1982 to December 1992. The size of this variation (almost 3°C) is, by the standards of climate change, huge. This seasonal variation in *globally averaged* surface temperature arises from the asymmetry between the Northern and Southern Hemispheres and the changing distance of the earth from the sun in the course of a year. The relative importance of these factors may be estimated with the use of a GCM; such an estimate will be presented later in this note.

While it is necessary for variations to occur in averages over large-scale circulation systems in order for such variations to be surrogates for climate, it is by no means clear that this is sufficient. Nor is it clear that all climate variations are surrogates for climate change resulting from increasing CO_2. The purpose of this note is to suggest and investigate an additional physically based condition. It was noted by Sun and Lindzen (1993), based on the work of Williams et al. (1992), that an important source of upper-tropospheric water vapor [and, hence, an important component of the all-important water vapor feedback (Lindzen 1994)] was the ice crystals detrained from cumulonimbus towers, and that this detrainment depended critically on the convective available potential energy (CAPE). Thus, one might reasonably ask that the variations in CAPE for different forms of global change be the same in order for one change to be a surrogate for the other. Now, the determination of CAPE in GCMs is a somewhat delicate matter in view of the sensitivity of CAPE to small changes in temperature, among other things (Williams and Renno 1993). However, a much less ambiguous quantity is the ratio of the temperature change at 500 mb to the change at the surface. This is by no means the CAPE; however, it is extremely unlikely that two modes of climate change for which this quantity differs will have the same CAPE. Comparisons of this quantity, therefore, allow us to ascertain whether two modes might be surrogates for each other. As is the case with CAPE, itself, this is simply another necessary but not sufficient condition. The remainder of this note consists in comparing this quantity for a variety of cases based variously on analyzed data and model output. This comparison is readily done for a

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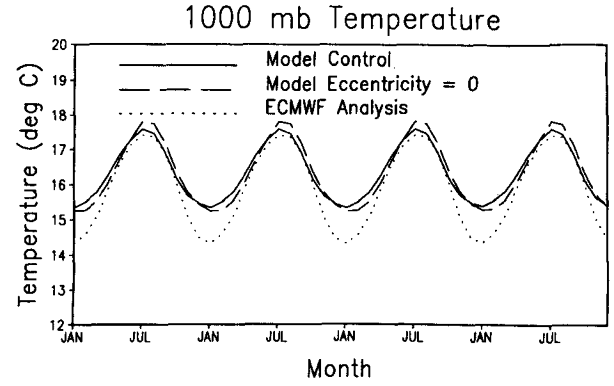

FIG. 1. Annual cycle of globally averaged, monthly mean 1000-mb temperature for the COLA model and ECMWF analysis. Also shown are model results with fixed solar distance. Points where the annual mean surface pressure is less than 950 mb are not included in the averaging.

model, and our results show that the seasonal cycle is not a surrogate for CO_2-induced climate change *in the model examined.* However, we do not know what the signal of doubling CO_2 is in the data, and hence, we cannot perform a similar comparison for the data alone. Nonetheless, we will compare the model and observed seasonal cycles. This will allow us to determine whether the model comparisons are likely to be a reliable indicator of the real situation. We find significant and revealing differences between the observed and model seasonal cycles. While, our results may be of some interest in themselves, they are primarily presented as an example of the application of the suggested test.

We begin by comparing a climate GCM's seasonal behavior in globally averaged surface temperature with analyzed observations from the European Centre for Medium-Range Weather Forecasts (ECMWF). The GCM used is a global spectral model being used for climate modeling at the Center for Ocean–Land–Atmosphere studies (COLA). The atmospheric model is based on the NMC medium-range forecast model. Details are provided in Schneider and Kinter (1994) and references therein. For studying seasonal cycle effects, we use a simple 50-m mixed-layer ocean model with no ocean heat flux and no sea ice. We see in Fig. 1 that the model and observed globally averaged annual cycle amplitudes are in good agreement at the surface. However, as we shall see, this agreement is, in some measure, due to the cancellation of various errors. The model annual mean is somewhat warmer due to the neglect of ocean heat transports. The neglect of ocean heat transports causes the model climate to differ significantly from the observed climate in many ways. Especially, the tropical sea surface temperatures and global mean surface and 500-mb temperatures are up to several degrees warmer. The atmospheric model simulation is much closer to nature when sea surface temperatures are specified or determined by a coupled dynamical ocean general circulation model. However, the simpler model used here should be adequate to illustrate the application of the suggested test. With reference to the question of whether north–south variations in land surface proportions or variations in distance from the sun are of primary importance in producing the annual cycle in globally averaged temperature, we also show the model annual cycle for a run where the distance from the sun was kept constant. The results show that the effect of removing the seasonal variations in earth–sun distance is to increase the magnitude of the annual cycle in surface temperature slightly, because the Northern Hemisphere would receive more solar radiation in the summer and less in the winter with constant earth–sun distance. Thus, the major source of the annual cycle in global mean surface temperature is the land–sea distribution.

We next examine model behavior at 500 mb. Figure 2 shows the model seasonal behavior of globally averaged 500-mb temperature. We see that the amplitude of the cycle is about 60% smaller than at the surface. This is only half of the amplitude of the observed annual cycle at 500 mb. However, this figure also shows the sensitivity to the annual cycle of earth–sun distance is larger at 500 mb than at the surface, with the annual cycle amplitude comparable to the observed when there is no annual cycle in earth–sun distance. We finally compare the 500-mb seasonal behavior with the behavior of the same model for a doubling of CO_2. Figure 3 shows the vertical profile of globally averaged, equilibrium model response to a doubling of CO_2. In contrast to the seasonal cycle simulation, the perturbation at 500 mb is somewhat larger than that at the surface. This suggests that, at least in the context of the COLA model, the annual cycle in globally averaged surface temperature is not a surrogate for long-term climate change. The reason for this behavior of the model seasonal cycle is unclear. A comparison, in Fig. 4, of the model power spectrum for temperature variations at

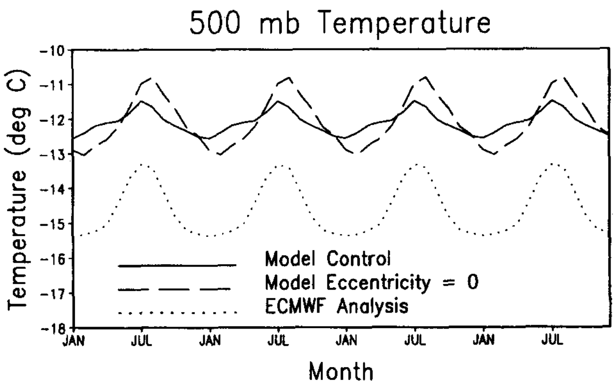

FIG. 2. Time history of globally averaged, monthly mean 500-mb temperature for both the COLA model and ECMWF data analyses. Also shown are model results with fixed solar distance.

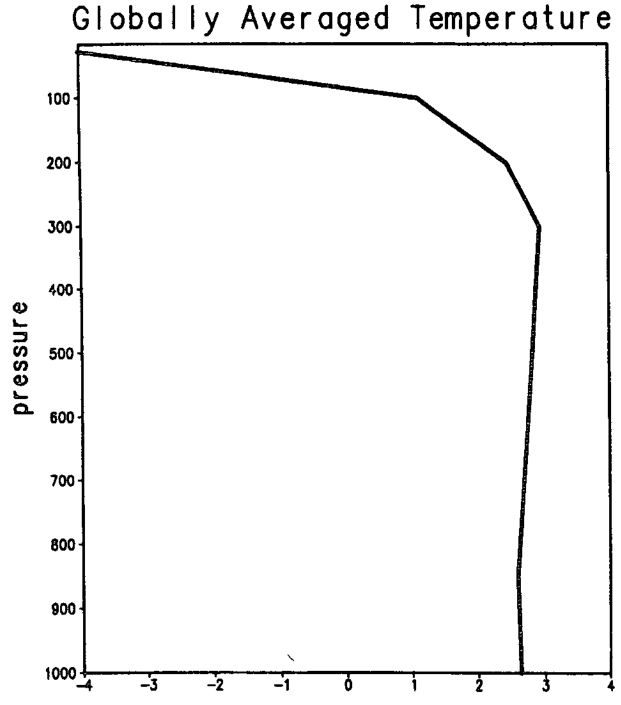

FIG. 3. Vertical profile of globally averaged equilibrium model perturbation temperature arising from a doubling of CO_2.

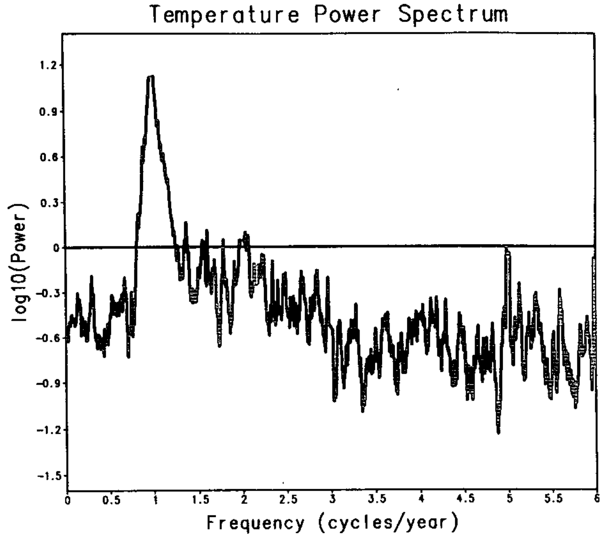

FIG. 4. Log10 of the ratio of the power spectrum for temperature at surface to that at 500 mb.

500 mb and at the surface [obtained from a 400-yr model run using a more realistic dynamical ocean model by Schneider and Kinter (1994)] shows that at all frequencies except that of the annual cycle, power is at least as great at 500 mb as at the surface. However, it is also clear that the ratio of power at 500 mb to that at the surface does not reach a constant until very low frequencies.

It is, of course, not necessarily the case that the model result will carry over to the natural climate system. The absence of any observational test of the climate's response to increased CO_2 makes it difficult to perform a complete test of the model results. However, we may at least see if the model seasonal behavior at 500 mb is compatible with observations. In Fig. 2 we see that the analyzed ECMWF seasonal cycle in globally averaged 500-mb temperature is larger than what is obtained from the COLA model with the observed annual cycle in the earth–sun distance, though it is still smaller than the cycle in globally averaged surface temperature. The ECMWF results are entirely compatible with the annual cycle of globally averaged 500-mb temperature derived directly from raw radiosonde data obtained from the National Center for Atmospheric Research. Thus, there is no reason to suspect that the ECMWF analysis may be an artifact of the analysis scheme itself. It is evident that the model behavior may not be the same as that found in nature. It is also worth noting that the observational results also suggest a difference between the ratio of the magnitude of 500-mb seasonal behavior to that at the surface, and what the model shows for the ratio of magnitudes of warming at 500 mb and at the surface for 2 × CO_2 experiments.

Finally, to gain some insight into the nature of the difference between the model and observed annual cycle, we consider averages over the Tropics (30°S–30°N) instead of global averages. The results are shown in Figs. 5 and 6. In Fig. 5 we see that model and observed tropically averaged annual cycles are similar at the surface though the model Tropics are about 1°C warmer than observed consistent with results for the globally averaged surface temperature. In Fig. 6 we see that there is no clear observed seasonal cycle in tropically averaged 500-mb temperature. Evidently, the observed

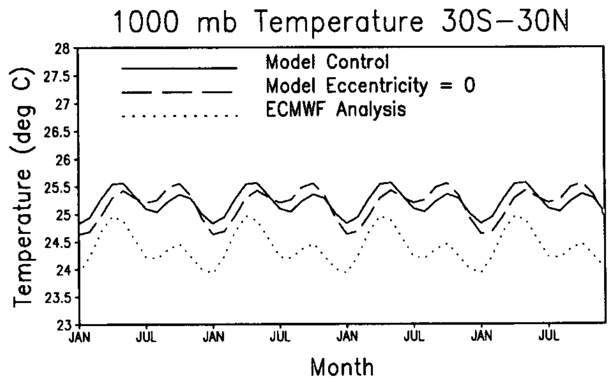

FIG. 5. Annual cycle of monthly mean 1000-mb temperature for the COLA model and ECMWF analysis averaged between 30°S and 30°N. Also shown are model results with fixed solar distance. Points where the annual mean surface pressure is less than 950 mb are not included in the averaging.

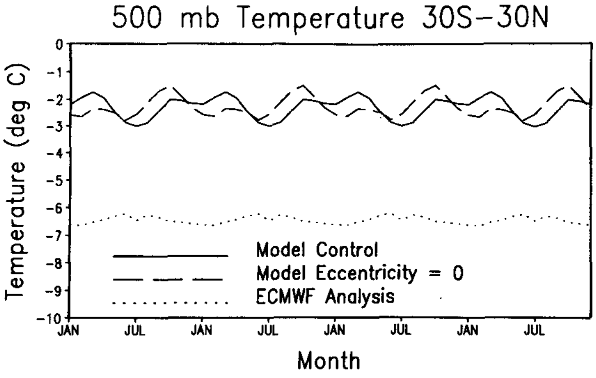

FIG. 6. Time history of tropically averaged, monthly mean 500-mb temperature for both the COLA model and ECMWF data analyses. Also shown are model results with fixed solar distance.

globally averaged 500-mb cycle is primarily due to extratropical contributions. In the COLA model, the extratropical oscillation is very close to the observed. The difference in the global mean between model and nature is due to differences in the low latitudes. The model difference from analysis at 500 mb in the low-latitude area mean annual cycle results from local differences that are much larger in magnitude, but which cancel in the areal mean. Despite the apparently large change in the models's low-latitude mean annual cycle at 500 mb when the solar forcing is changed, the local annual cycles are very similar, indicating that the difference in the low-latitude areal mean annual cycles at 500 mb may not be physically significant. Both simulations are equally unrealistic. However, the large differences in the local annual cycle between model and observations are likely to indicate important departure from reality. Also, the model at 500 mb in the Tropics is about 4°C warmer than observed, implying a very substantial difference in static stability. When observed sea surface temperatures are used as the lower boundary condition, the simulated 500-mb tropical temperature is slightly cooler than the observed.

The primary point of this note is to illustrate a simple necessary condition for a short-term event serving as a surrogate for climate for purposes of evaluating model performance. The condition, of course, is not sufficient. However, it is likely to be a useful addition to the collection of tests for climate studies. *For the COLA model,* seasonal variations of global means are not a surrogate for longer-term changes and in particular for changes associated with increased CO_2. However, differences in the ratio of 500 mb to surface change for the seasonal cycle as described by ECMWF-analyzed data also differ from model results for this quantity. It is probably necessary to correctly model ocean heat fluxes to obtain results relevant to the real climate system.

Acknowledgments. This work was supported by Grant 914441-ATM from the National Science Foundation, and Grant NAGW 525 from the National Aeronautics and Space Administration, all at M.I.T., and by NSF Grants ATM-9342469 and ATM-9101628, and Grant DE-FG02-93ER61722 from the Department of Energy at COLA. Ten percent of this research was funded by the U.S. Department of Energy's (DOE) National Institute of Global Environmental Change (NIGEC) through the NIGEC Northeast Regional Center at Harvard University (DOE Cooperative Agreement DE-FC03-90ER61010). Financial support does not constitute an endorsement by DOE of the views expressed in this article.

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