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EVALUATING GCMS USING DIURNAL VARIABILITY

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1. Introduction

The diurnal cycle is one of the most obvious variations of the climate. Because of its large amplitude and short time scale, the diurnal cycle provides an excellent test bed for evaluating numerical weather forecast and climate models (e.g., Lin et al. 2000). Some of the atmospheric general circulation models (GCMs) designed before the 1990s did not have the diurnal cycle in order to save computer time and focus on the long-term climate. It has been shown, however, that excluding the diurnal cycle in GCMs results in degraded model performance (Wilson and Mitchell 1986). This is because many non-linear processes, such as surface evaporation, atmospheric radiation and atmospheric convection, have strong diurnal variations and can not be simulated adequately using daily mean fields.

One problem in evaluating model diurnal variability is a lack of global data sets with high temporal resolution. Here we analyze 3-hourly synoptic observations from over 15,000 stations and from many marine platforms for 1976-1997, and compare the observed diurnal variations with those in the NCAR Community Climate Model Version 3 (CCM3) (from a 1983-1988 AMIP2-type run at T42 or $\sim 2.8^o$ resolution) (Dai et al. 2001). We focus on diurnal variations in June-August (JJA) surface air temperature, surface pressure (Dai and Wang 1999), cloudiness (Hahn and Warren 1999), and convective precipitation (Dai 2001).

2. Results

Fig. 1a shows the diurnal (24 hr) harmonic (S_1) in observed and simulated JJA surface air temperature. The daytime bias in ship temperature records due to local radiative heating was corrected based on Kent et al.(1993). The S_1 dominates the sub-daily variation and accounts for most (>80% over land) of its variance. The observed S_1 peaks around 14–16 (or 2–4 PM) LST and varies little over land and ocean. The amplitude is much larger over land (1–6^{o}C) than over ocean ($\sim 0.5^o$). The CCM3 simulates these broad features fairly well. Over the oceans, however, the amplitude in the model ($\leq 0.2^o$C) is too small (this is also true when compared with the NCEP/NCAR reanalysis) and the phase is $\sim$2 hr late. The small temperature amplitude in the CCM3 does not appear to be a result of specifying SSTs without diurnal cycles, since this bias also exists when the CCM3 coupled to an ocean GCM.

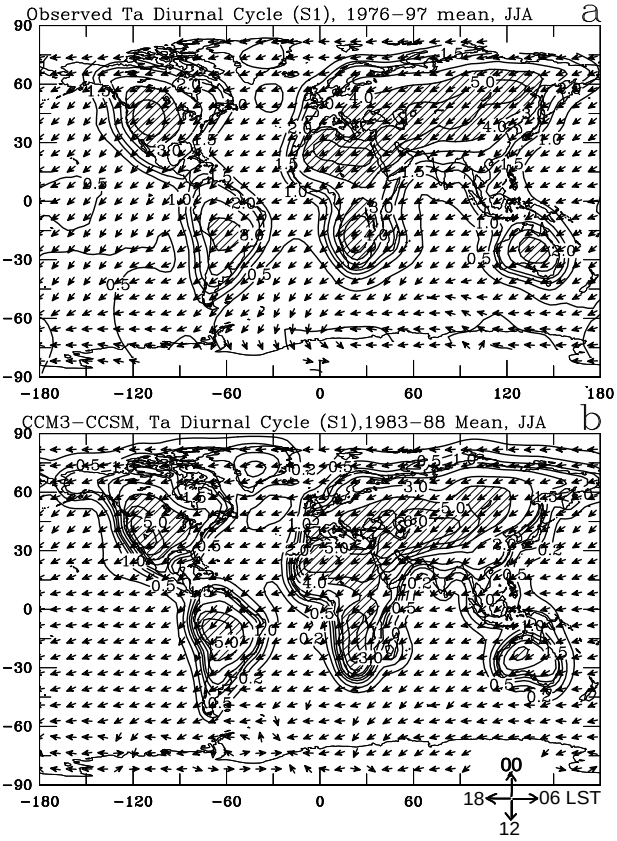

Figure 1: Amplitude (contours, ^{o}C) and local solar time at the maximum (arrows, bottom phase clock) of the diurnal harmonic of JJA surface air temperature from observations (a) and the model, CCM3 (b). Values over 4.0 are hatched.

Another well-known sub-daily variation is the surface pressure tide. Fig. 2 shows the diurnal pressure tide for JJA from observations and the CCM3. While the overall patterns [e.g., larger amplitude over land (0.4–1.4 mb) than over ocean (0.4–0.6 mb)] are simulated well, the model overestimates the diurnal amplitude (by 20–50%) over low-latitude land areas and underestimates the amplitude over the Rockies and other northern midlatitude land areas and most oceans. The simulated diurnal phase agrees with the observed over most oceans and midlatitude land areas. At low latitudes, the phase is around 06 LST

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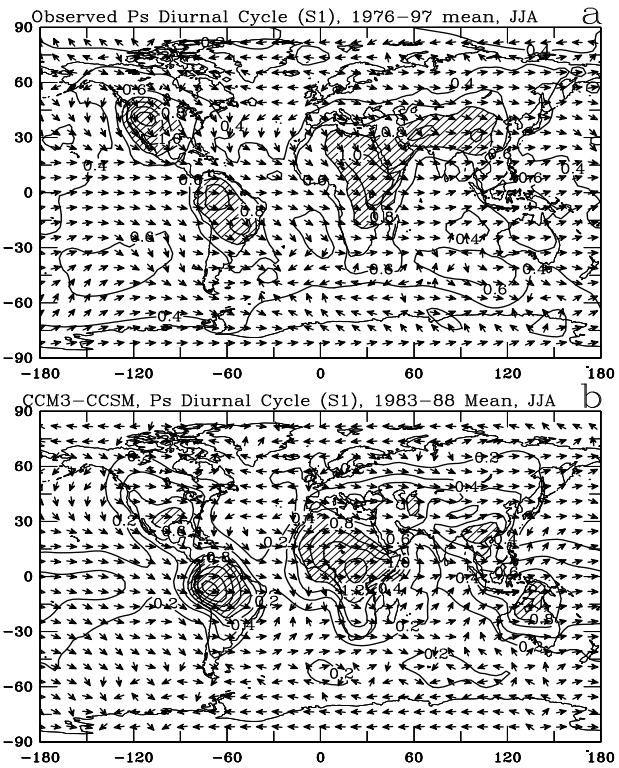

Figure 2: Same as Fig. 1 but for surface pressure diurnal harmonic (amplitude in mb, values over 0.8 are hatched).

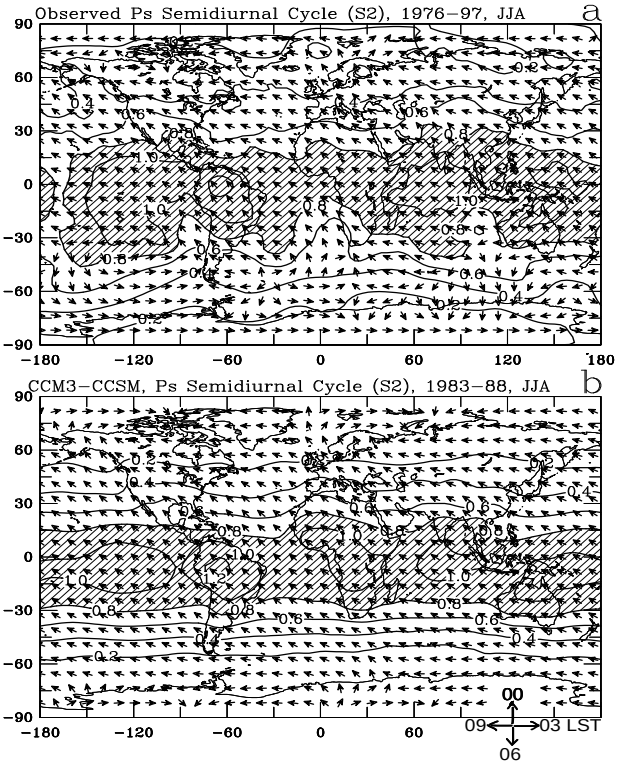

Figure 3: Same as Fig. 2 but for the semidiurnal (12 hr) harmonic.

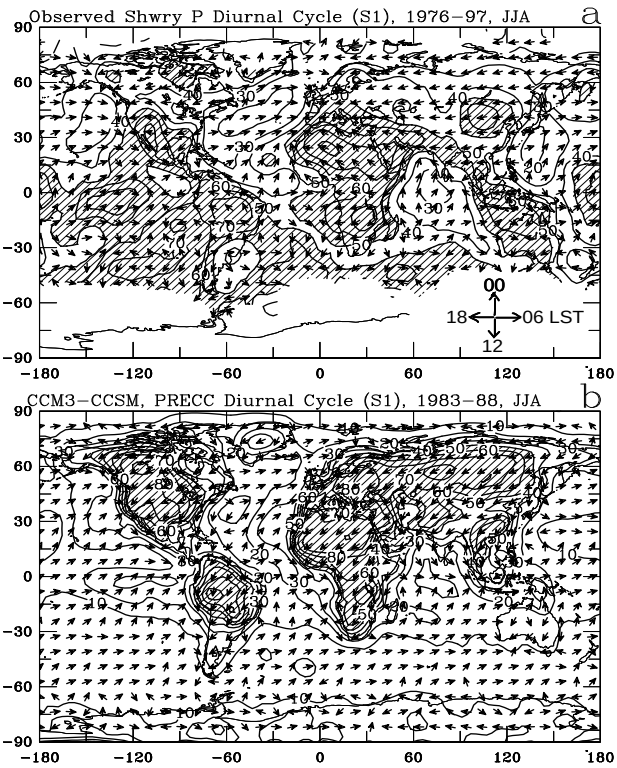

Figure 4: Same as Fig. 1 but for JJA observed showery precipitation frequency (a) and convective precipitation in CCM3 (b). Values (in % of the daily mean) over 50% are hatched.

over both land and ocean in the model, whereas land lags ocean by ∼2 hr in the observations.

The semidiurnal pressure tide is simulated well by the CCM3 in terms of both the amplitude and phase (Fig. 3). The model exhibits slightly less zonal variation of the amplitude than in the observations.

Fig. 4 compares the diurnal cycle (normalized by the daily mean) of JJA convective precipitation in the CCM3 with that of showery precipitation frequency from weather reports (Dai 2001; note that precipitation intensity has little diurnal variation). The normalized diurnal cycle is stronger in the model (amplitude=40–80% of the mean) than in the observations (30–70%) over most continents (except Australia), especially at northern midlatitudes, whereas over ocean it is weaker in the model (∼10%) than in the observations (20–60%). The observed precipitation diurnal cycle peaks in the late afternoon to evening over most land and in the early morning over most ocean. The CCM3 reproduces this broad pattern, but quantitative differences (e.g., over South America and Africa) exist.

A more challenging task is to simulate the diurnal cycle of clouds, which greatly affect solar and infrared

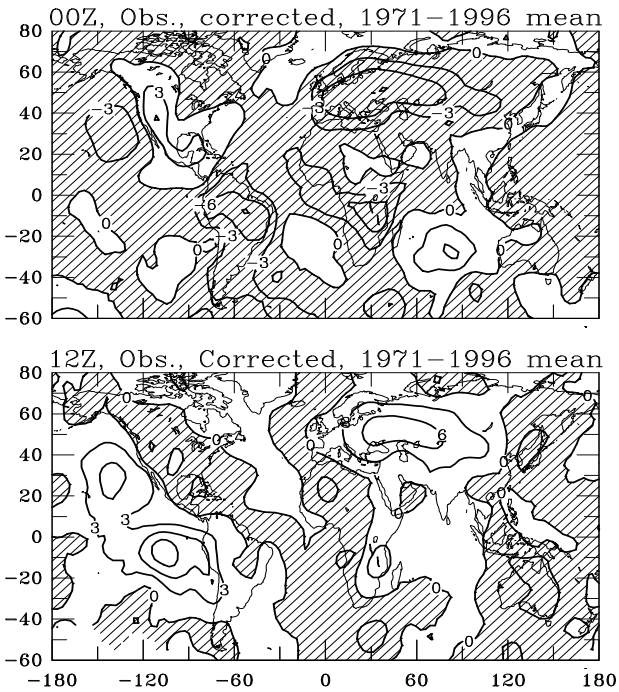

Figure 5: Diurnal anomalies of total cloud cover (%) at 00 and 12 UTC from surface observations. Hatched is negative.

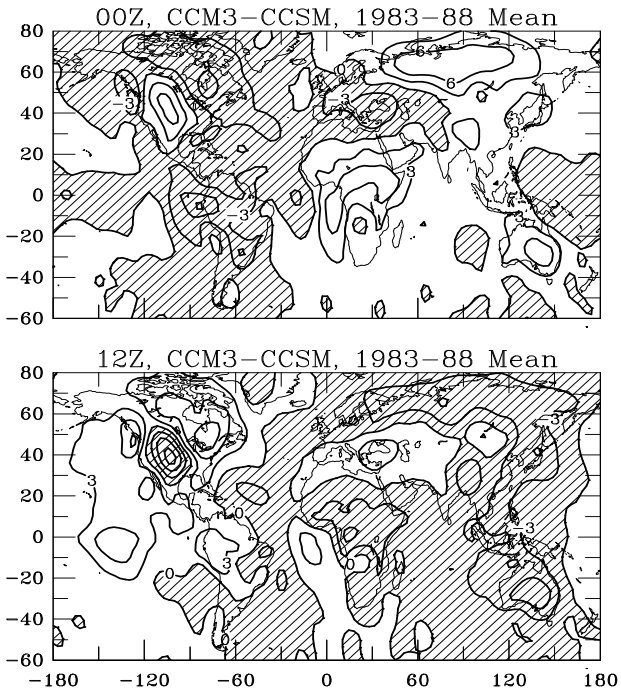

Figure 6: Same as Fig. 5 but from the CCM3.

radiation. The surface observed total cloud cover (excluding dark night conditions) roughly shows a wave number 2 mode with peak cloud cover in the afternoon and early morning (cf Fig. 5). In the CCM3, a wave number 1 mode for cloud anomalies is more evident (cf Fig. 6). In particular, the diurnal cycle of subtropical marine stratus clouds west to North and South Americas and Africa is not simulated well by the CCM3.

In summary, the CCM3 reproduces the diurnal cycles of land surface air temperature and pressure, and the semidiurnal pressure tides over the globe; but it has weak diurnal cycles for marine air temperature and pressure. The diurnal phase of convective precipitation in the CCM3 roughly agrees with that in observed showery precipitation, but the normalized amplitude is too strong (weak) over land (ocean) in the model. Simulations of the diurnal cycle of cloud cover in the CCM3 need to be improved considerably, especially since cloud diurnal variations greatly affect the solar and infrared radiation. Comparisons between the simulated and NCEP/NCAR reanalysis upper air winds revealed remarkable agreements even on regional scales. These results suggest that the surface energy balance over land and solar absorptions by ozone and water vapor seem to be represented well in the CCM3, while the diurnal cycle over ocean in general needs to be improved.

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