Evaluation of the Stratosphere in the Operational CFS and CFS-Next

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An evaluation of the operational Climate Forecast System (CFS, T62L64) and a test version of the model, which may be used as the next version of the CFS (CFS-Next), has been conducted over the past 12 months. The purpose of this evaluation was to assess if the CFS forecasts are producing the basic state of the stratosphere correctly. The evaluation of the operational CFS was based upon 23 year averages of the monthly mean forecasts from 1982 through 2005. The multiyear CFS averages were compared against the Reanalysis-2 (R2) and the Climate Prediction Center (CPC) height, temperature and ozone analyses whenever possible. The focus was upon the 50 hPa heights, total ozone, zonal winds, and particularly the Quasi-Biennial Oscillation (QBO).

Beginning with 50 hPa heights, in comparison with R2 and CPC heights, we want to see if there is a bias between the CFS and these two standards, if the bias is uniform at all latitudes, and if the bias changes with forecast lead time. No bias or a constant bias is preferable, a variable bias with time, latitude, and/or initiating season indicates problems with the model dynamics and parameterizations. Figure 1 presents the average zonal mean 50 hPa heights at various lead times validating during the DJF time period. The average zonal mean R2 50 hPa heights for this same time period are plotted as well. There is an initial bias between the 0-month lead and the R2 heights at all latitudes, with the bias being greater in the SH, which is the summer hemisphere. This bias continues to grow until the 2-month lead, then seems to stabilize in the Northern Hemisphere (NH), but continues to grow in the Southern Hemisphere (SH). An evaluation of height field on other levels indicates that a bias between R2 and the CFS forecasts is present even at 500 hPa. This bias increases in magnitude, as does in the high latitude, and spreads from 500 to 50 hPa. The largest increase in the height bias occurs between 200 and 100 hPa.

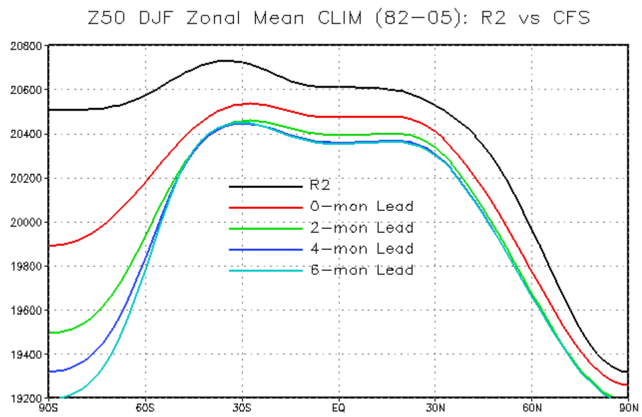

Figure 1 DJF climatology (1982-2005) of zonal mean 50 hPa height from Reanalysis 2 and CFS hindcasts at 0, 2, 4, and 6 months lead. (unit: m)

Next, we evaluate the ozone field forecasts to see whether the equator to pole Brewer-Dobson circulation is correct and also if the parameterized chemistry is correct. Figure 2 presents the average zonal mean total ozone from the CFS forecasts validating during DJF. The average zonal mean total ozone from the Solar Backscatter Ultraviolet spectrometer (SBUV/2) is also plotted. Two features are apparent, large surpluses of ozone in the high latitudes and a deficit of ozone in the tropics. This implies that either the Brewer-Dobson

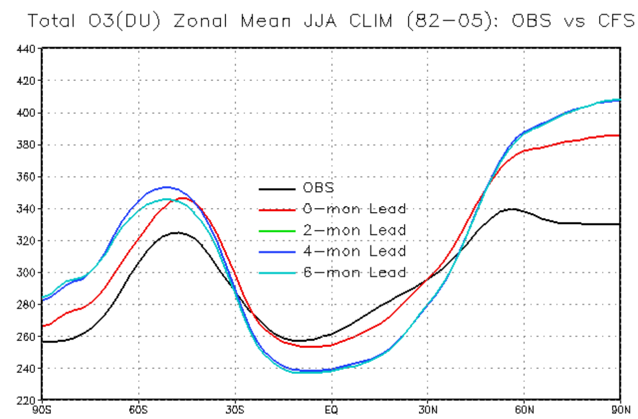

Figure 2 JJA climatology (1982-2005) of zonal mean total ozone from SBUV/2 and CFS hindcasts at 0, 2, 4, and 6 months lead. (unit: DU).

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circulation is too aggressive or that the model's ozone Production/Loss parameterization is in error. These same features are also present in the JJA forecasts.

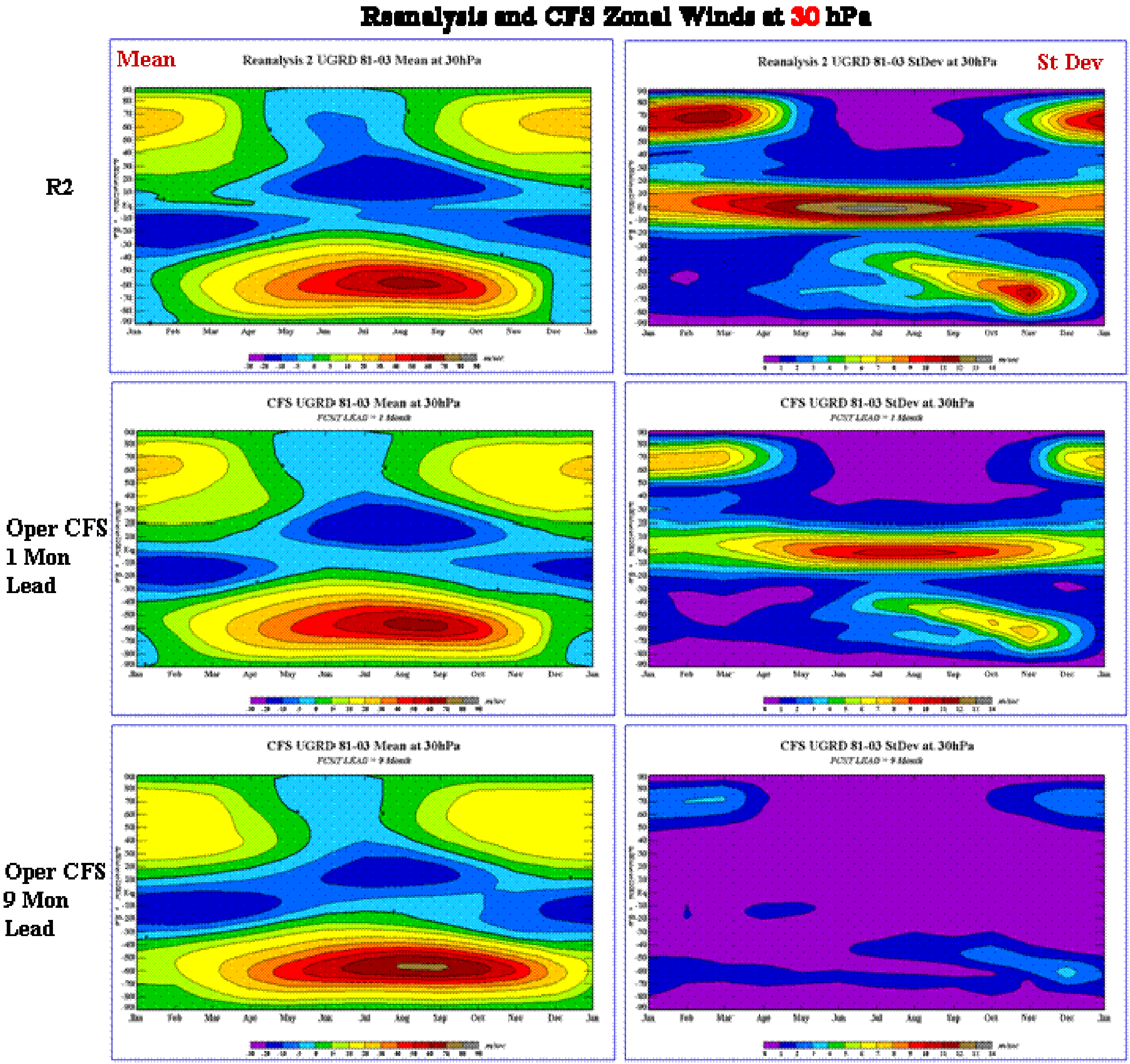

Figure 3 Annual cycle of 30 hPa zonal mean zonal winds (m/s) and their variability over the 1981-2003 period from Reanalysis 2 and CFS hindcasts at 1 month lead and 9 month lead.

If the height fields have an increasing bias, this must show up in the wind field differences. An evaluation of the CFS zonal mean wind fields from 100 hPa to 10 hPa and their variability from one year to the next (Figure 3) reveals that as the forecast time increases, the interannual variability decreases dramatically, particularly, for the equatorial winds and the SH polar jet. The winds in the SH also indicate that for longer forecasts there is no transition from winter to summer circulation, rather the circulation remains westerly, which is consistent with the strong height biases shown in Figure 1.

A closer look at the maintenance of the QBO revealed that the amplitude of the easterly and westerly zonal mean winds decreases with increasing forecast time (Figure 4). By the 5-month lead, the easterly winds are eliminated and by the 9-month lead the quasi-biennial nature of the winds has changed to a semiannual pattern.

The atmospheric component of the operational CFS uses the 2004 version of the Global Forecast System (GFS). Since then the operational GFS has had several modifications, of importance are changes to its long wave radiation code, the ozone production/loss scheme, its vertical coordinate system (from sigama to sigma-pressure hybrid), and now use of a Gridpoint Statistical Interpolation assimilation scheme. With these changes and improvements to what may be used for the CFS-Next, there were expectations of an improved basic state to the stratosphere. These expectations were assessed using output from a test experiment, which consists of 1 member runs initialized on May 15 for 25 years (from 1981-2006) using the T382L64 version of this model. This set of runs allows us to examine the model performance in the SH winter and spring period. Compared with the T62L64 15 member ensemble runs initialized in May for the same period (1981-2006), the bias in the JJA mean heights is greatly reduced at 50 hPa in the NH. However, there does not appear to be any improvement in the height bias in the SH. An examination of the JJA zonal mean temperatures (Figure 5) from the surface to 1 hPa reveals that the CFS and R2 agree with each other to within 1° C from the surface up to 200 hPa. Above 200 hPa the CFS is 6-9° C colder than R2 north of 30°S. While in the SH polar regions the bias between the CFS and R2 ranges from 6° C (at 70 hPa) to greater than 20° C above 5 hPa. The same is true for September-October (SO) temperatures except that the SH polar temperatures differ by 6° C at 150 hPa and the maximum cold bias has lowered to between 30 and 2 hPa. In the NH a warm bias shows up between 10 and 5 hPa poleward of 60° N.

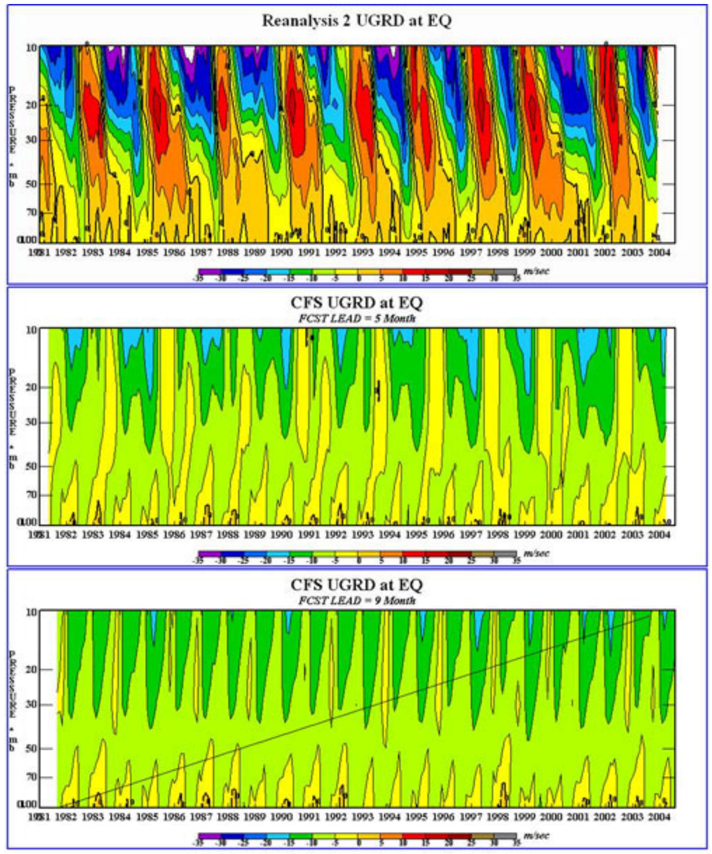

Figure 4 Pressure-time plots of the zonal wind (m/s) averaged between 10N and 10S from Reanalysis 2 (upper panel), CFS at 5 month lead (middle panel), and CFS at 9 month lead (lower panel).

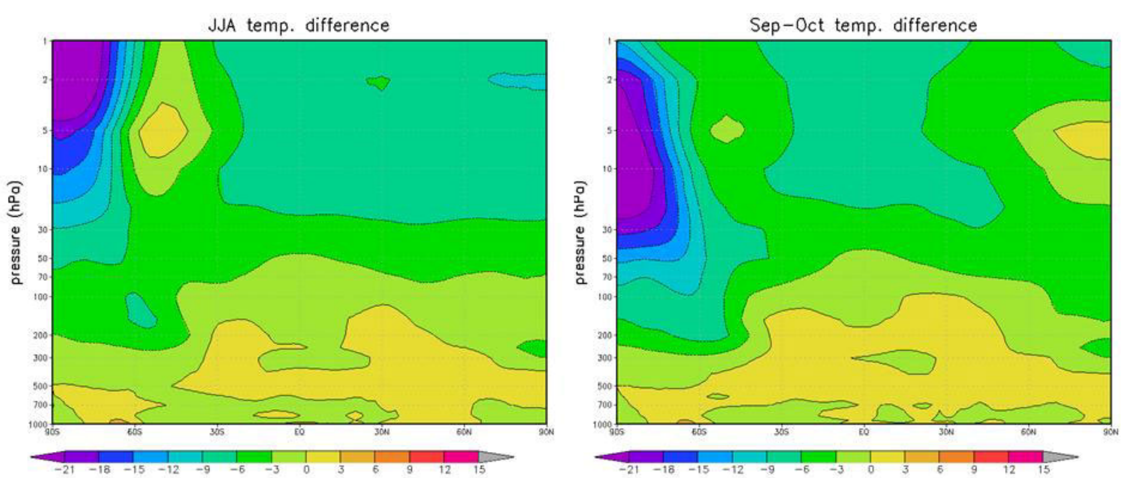

Figure 5 1000-1 hPa zonal mean temperature differences between CFS and R2 for JJA (left) and SO (right).

The impacts of the temperature bias upon the heights and consequently upon the wind fields reveal that the differences upon the wind fields occurs equatorward of the SH polar jet, beginning at 200 hPa and extending to lower pressures as forecast time increases.

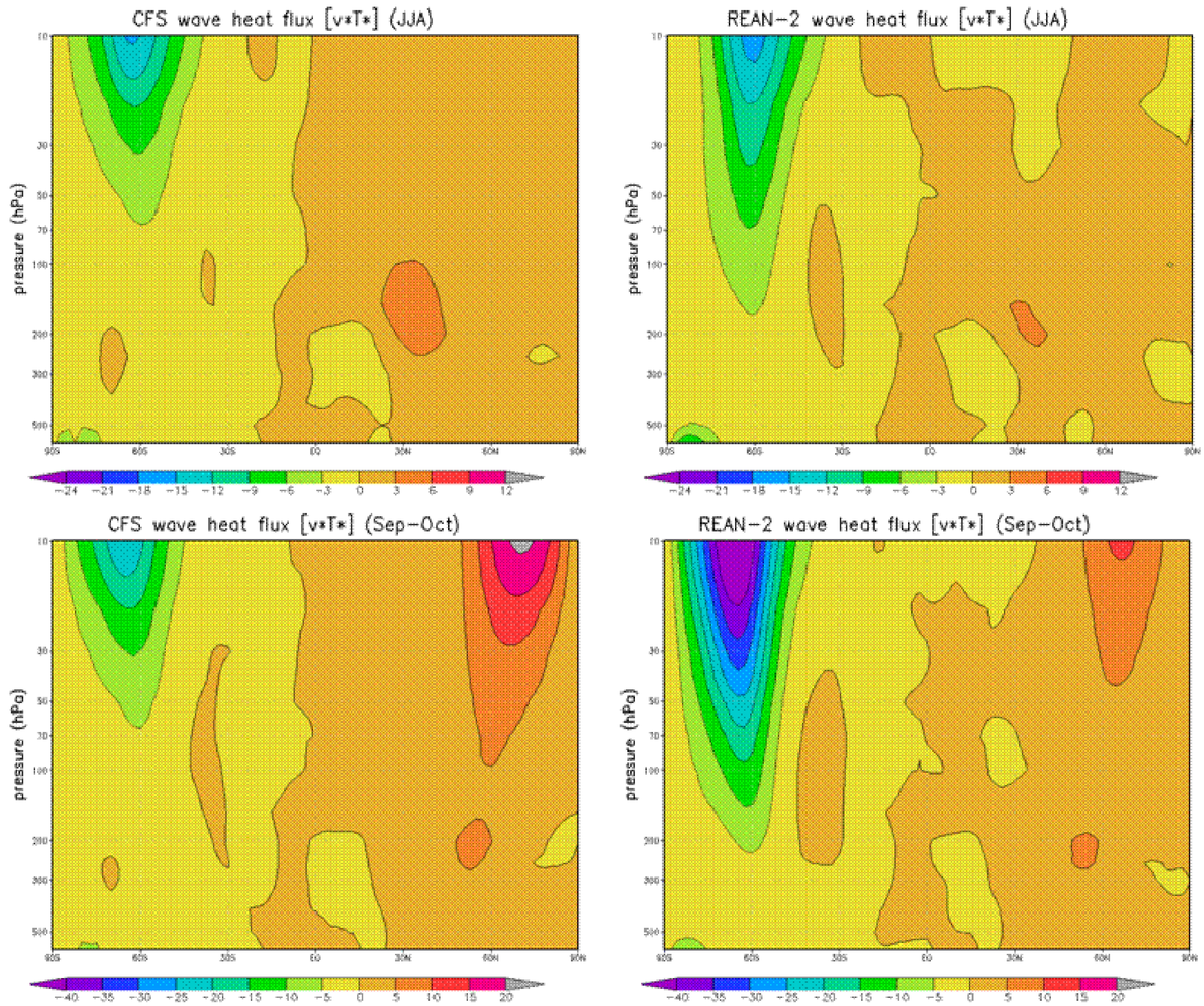

Figure 6 600-10 hPa zonal mean stationary wave heat flux (v*T*) (km/s). (a) CFS for JJA, (b) R2 for JJA , (c) CFS for SO, and (d) R2 for SO.

An examination of the poleward heat flux by stationary waves (v*T*) (Figure 6) indicates that in JJA the south poleward heat flux is weaker than R2 and does not extend towards the surface beyond 70 hPa. While the heat flux in R2 extends down to almost 200 hPa. In SO the CFS south polar heat flux is much less than R2 (-20 K m s-1 vs < -40 K m s-1). However, the CFS has a stronger northward north polar heat flux (>20 K m s-1 vs. 10 K m s-1). This would explain why the CFS has a positive temperature bias between 10 and 5 hPa poleward of 60 °N.

Vertical-longitudinal cross-sections of height anomalies are useful to detect the baroclinicity of the atmosphere. A westward tilt of the anomalies with height (decreasing in pressure) is indicative of poleward heat flux. Such a cross-section at 50° S was taken of the 25 year mean R2 and CFS (Figure 7). The R2 cross-section shows a negative tilt of the primary wave from 0°E at the surface to 60°W at 10 hPa. Besides having quite different wave structures, the CFS waves are vertically stacked, indicative of a barotropic atmosphere with weak polar heat flux.

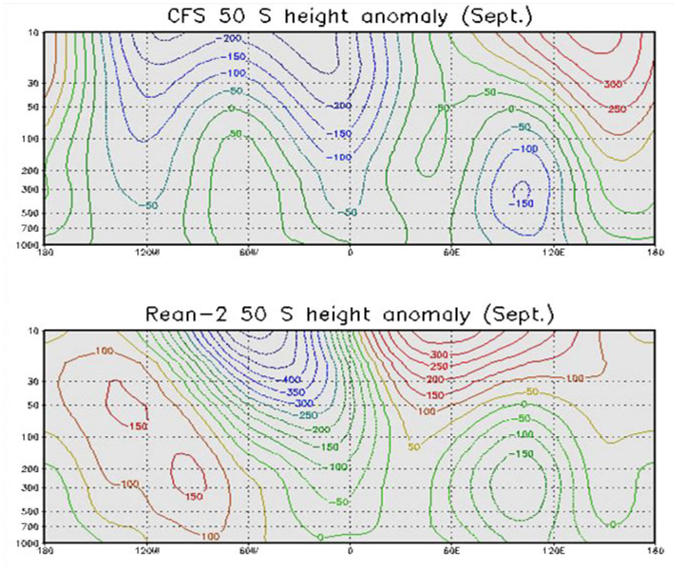

Figure 7 September mean height anomalies (m) from 1000-10 hPa at 50S. Top: CFS and bottom: R2.

The ozone in the T382 CFS runs was much improved over the T62 CFS. There is no evidence of equatorial deficits or large polar surpluses.

Finally, the variability and predictability of extreme SH polar temperatures was examined. The warm SO that occurred in 1986, 1988, and 2002 do not show up in the time-latitude plot.

Problems are revealed:

1. Too little SH poleward heat flux,
2. Too little interannual variability in temperature, heights and winds,
3. Height differences begin above 200 hPa and continue to grow,
4. Insufficient vertical wave propagation is suspected.

These evaluations indicate that a closer examination of the upper troposphere-lower stratosphere dynamics, wave propagation and parameterization need to be conducted. One thing that came out of this evaluation was that the horizontal resolution did not seem to make much of an improvement. Tests should be conducted to see if increasing the vertical resolution in the upper troposphere and lower stratosphere, raising the model top, or a combination of the two will make an improvement in the forecasts.