Last year's progress report: 3 May 2005

Please review and, as appropriate, revise the information you have reported as your major **research and education activities**:

Monthly data had shown strong associations that we wanted to pursue with daily data (at leads and lags) to establish order of events, if not causality. We completed an initial sequence of observational studies with daily data. We added additional diaganostic tests as suggested by Brian Hoskins and by John (Mike) Wallace with whom the PI had extensive discussions at the 1st CLIVAR conference in Baltimore (June 04). Even the best of the raw daily observational results was inconclusive. We began to low-pass filter the data (using power spectra to guide our choice of cut-off frequency). This has begun to successfully reproduce our monthly associations whilst allowing some indication of the chain of events.
As promised, we have been able to implement locally a stationary wave model. In an effort to expedite that task, we started with a model developed by Grant Branstator many years ago. Unfortunately, the model was originally written in obsolete Fortran, relied on a NCAR-specific unsupported iftran preprocessor, relied on nearly obsolete NCAR library routines, and used double precision in a way that would not work on our Linux system. These and other hurdles were not expected and required a huge effort on our part to resolve. While the process was more challenging than expected, it was likely still shorter than developing such a model from scratch. Happily, by the end of the grant year we had developed a FORTRAN 95 version this program working successfully at UC Davis.

(Last) Please review and, as appropriate, revise the information you have reported as your major **findings**:

It is too early to report what we might call major findings. Some minor, tentative results are these.

First, to see strong behaviors found in monthly mean data it was necessary to filter the data. Individual frontal cyclones dominate the variability and do not have significant correlation in raw data. However, the aggregate variability does have interannual variation that we propose (amongst several mechanisms) to impact the Arctic surface climate. (The model has significant problems with the aggregate cyclone activity.) A minimum period to cut-off the low pass filter turned out to be 10 days. This is small enough that a significant signal appears which shows remote midlatitude and tropical forcings that precede or follow SLP changes at various locations in the Arctic. One surprise was that stronger SLP in the Barents and GIN seas leads (not follows) a storm track shift into the Iberian peninsula. This work is being analyzed at the present time for presentation by the time of the next June 2005 CCSM workshop.

Second, discussions with attendees at the July 2004 CCSM workshop suggested that we cannot simply use a linear stationary wave model to diagnose the impacts of storm tracks errors upon the Arctic surface climate. This conclusion was based on a somewhat related linear calculation had just been done independently by Eric deWeaver. However, the observations show an association as some level, and Eric's work has spurred us to focus on developing a nonlinear iterative calculation.

---- 5 April 2006 report

In the past 11 months (May 2005 – March 2006) we can report the following activities:
a. completed our initial 1-point correlation studies using filtered data with lags and leads.
b. investigated a possible link between the SLP bias and the Arctic Oscillation (AO)
c. continued work to implement Branstator's stationary wave model (SWM)
d. developed code to interpolate model and observational fields to SWM sigma levels
e. have nearly completed development of scheme to derive forcing from bias fields
f. made extensive tests with temperature (T) forcing of the SWM, based on the T bias
g. evaluated whether ERA-40 or NCEP RA2 fields were better for bias & verification
h. attended 9th CCSM workshop: presented results & met with collaborators
i. attended IAMAS2005: presented results and held discussions
j. submitted 2 papers, revised and resubmitted a 3rd.

Major findings are these:
This study seeks to understand the causes of the SLP bias in NCAR climate models.
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a. The SLP bias field has ring-like structure roughly centered near Novaya Zemlya. To some people, the bias looks like the AO. Since the AO is a strong internal mode of variability in the model, the AO could be stimulated by various means and therefore it would be difficult to identify primary cause(s) for the bias pattern. From CAM3 data we obtained the leading EOF of SLP (the model's form of the AO) and after interpolating to matching Gaussian grids projected that EOF onto the model SLP bias. We found that the bias was NOT like the AO. (Figure 1) The EOF was a small part of the bias, so internal variability cannot explain much of the bias field. Further, when the EOF was removed from the bias the resultant field looked more similar to the bias found in earlier model versions, recovering a positive maximum bias near Novaya Zemlya. This result is important because it means that it is reasonable to seek local and remote causes of the Arctic surface bias.
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b. The 1-point correlation studies, both with model output and in NCEP RA1 observations find a significant lagged correlation with Indian Ocean Precipitation (P) and outgoing longwave radiation (OLR). Filtered daily data find that ~5 days after P (or OLR) in the NE Indian Ocean SLP is correlated in the Novaya Zemlya region. The correlation flips sign as the location of P (or OLR) is moved latitudinally. (Figure 2) The P bias field has a dipole pattern in the NW Indian Ocean such that both poles contribute to positive correlation of SLP in the Novaya Zemlya region.
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c. Work by others (DeWeaver, 2004 CCSM workshop) seemed to imply that a linear model like the SWM might not be helpful in diagnosing the SLP bias. However, in our tests with very simple idealized heating anomalies, we can reproduce various parts of the SLP bias. (Figure 3) Cold and warm anomalies can be generated by anomalous cooling and heating forcing in the SWM. Nine such cooling/heating anomalies were tested to match prominent cold and warm anomalies in the lower free troposphere. Such anomalies generate wavetrains in SWM fields, which includes surface pressure (from which we developed a conversion to SLP). Tests of the nine anomalies singly and in combination

find that anomalous cooling over Saharan and Arabian deserts has the strongest link to positive SLP near the Novaya Zemlya maximum SLP bias. Other major cooling/heating forcing (biases) have lesser effect on the Novaya Zemlya region. Anomalous warming (to match a warm bias) in eastern Siberia has a prominent secondary effect on Arctic ocean region: contributing to the Novaya Zemlya SLP bias max and lower SLP over the Beaufort Sea (where the model has negative bias).

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d. We compared numerous large scale variables in the ERA-40 and NCEP/DOE reanalysis II datasets. The ERA-40 data seems to allow more interhemispheric transfer of information than the NCEP data. The ERA-40 data has more vigorous Hadley cells but evaporates less water in the subtropics so that both datasets have quite similar precipitation (!)We could not assess which dataset was 'more correct', however, the tropical Atlantic was largely missing the ICZ during DJF in NCEP data(!) However, the northern Indian Ocean (!) seemed more reasonable in NCEP data. While this study has been written up for a special journal issue on the general circulation, it suggests that we make comparisons (and bias calculations) with ERA-40 data as well as (or in place of) NCEP data.

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e. Our current work is directed to sorting out how these model results are consistent with our correlation studies. One tool is to run the SWM 'backwards'. Symbolically, the SWM can be written as: Ax = F where F is the forcing discussed above, x is the solution sought, and A is a very large square matrix dependent on the basic state (3-dimensional DJF fields of vorticity, divergence, temperature, and log_e surface pressure). To run the SWM 'backwards' we specify x and find the F. By specifying the bias fields as x, then we should obtain the important result of what forcing can cause the model's bias field. At this writing we need to resolve some software issues; we expect to have that result soon.

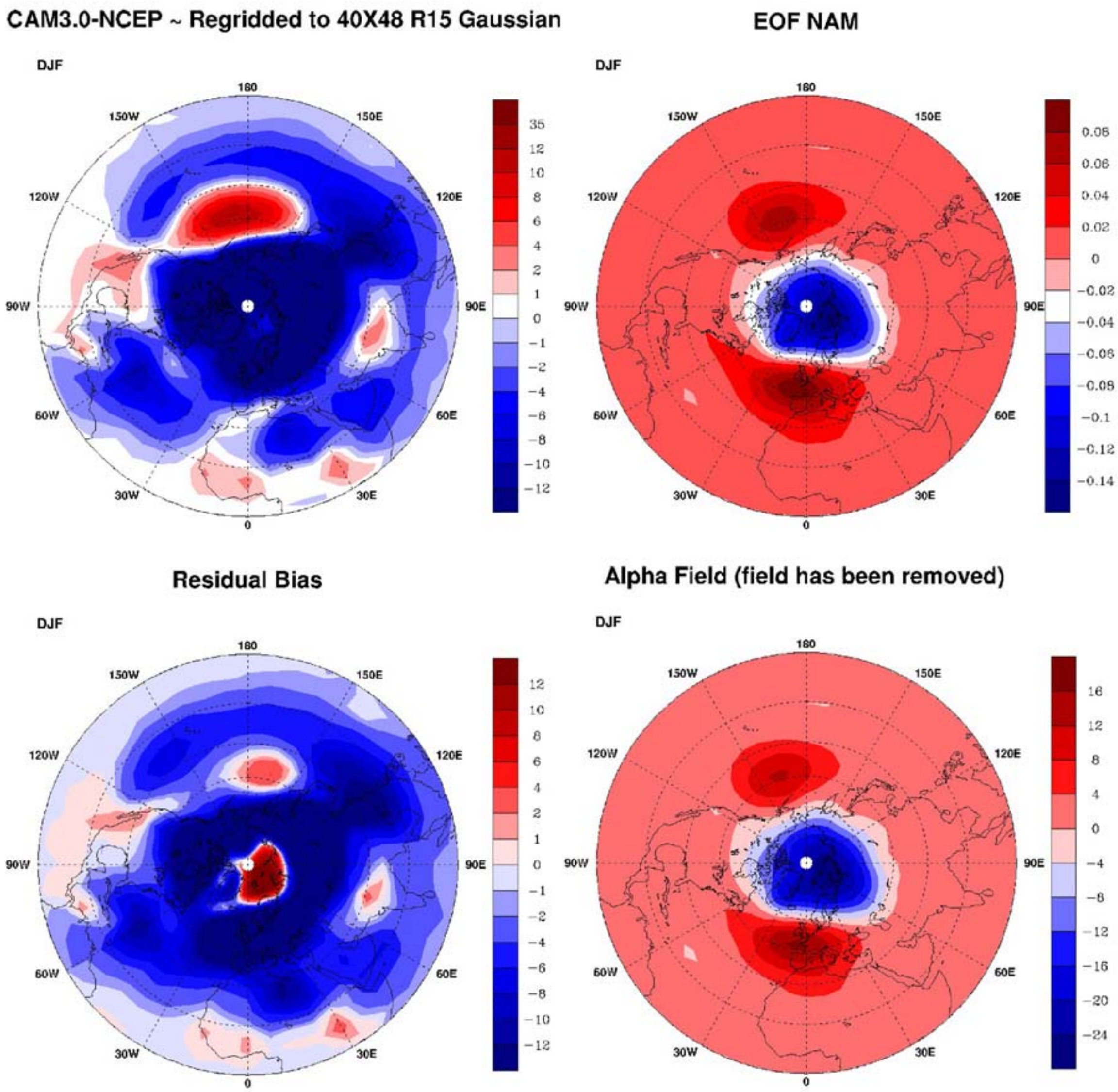

Figure 1. The SLP bias in CAM3 (and CCSM3) does ***not*** have a significant amount of the model's Arctic Oscillation (AO). Top left panel is CAM3 SLP bias (CAM3 minus NCEP RA I). Top right is leading EOF in CAM3, the model's form of the AO. Lower right panel is the projection of the bias onto the EOF. Lower left is the residual after removing that projection from the bias. Clearly the EOF is not a primary contributor to the SLP bias in the model. Removing the EOF produces a bias in CAM3 that more closely resembles the Arctic bias in earlier models (e.g. CCM3.6). This result is important because if the EOF was the main contributor then the SLP bias would be a natural mode of variability that could be excited by many different phenomena rather than a standing wave pattern that might be understood by distinct forcing, such as in a stationary wave model.

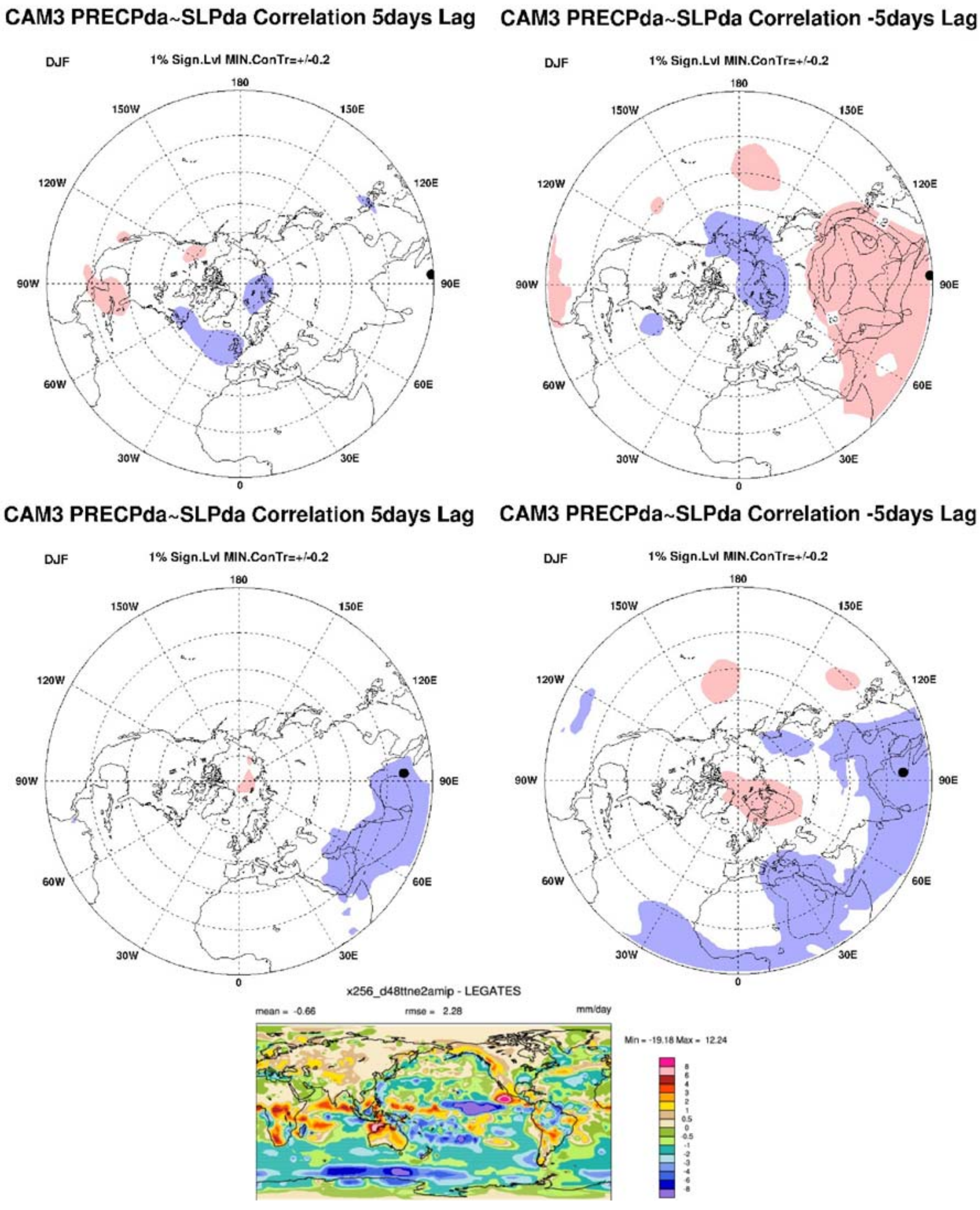

Figure 2. 1 point correlations of CAM3 precipitation (P at the black dot) and CAM3 SLP (2-Dimensional field). Left column, SLP correlation 5 days before value of P at black dot. Right column, SLP correlation 5 days after P at black dot. Data low pass filtered with 10d cut-off. Shaded areas pass a significance test at the 99% level. Bottom inset: CAM3 AMIP run (posted at NCAR-CGD website) which shows P bias dipole pattern in NE Indian Ocean: negative at equator (reverse sign of top row of plots) and positive at 10 N (middle row of plots). The dipoles in P bias both give SLP bias >0 near Novaya Zemlya. A similar connection is found in observed OLR and SLP.

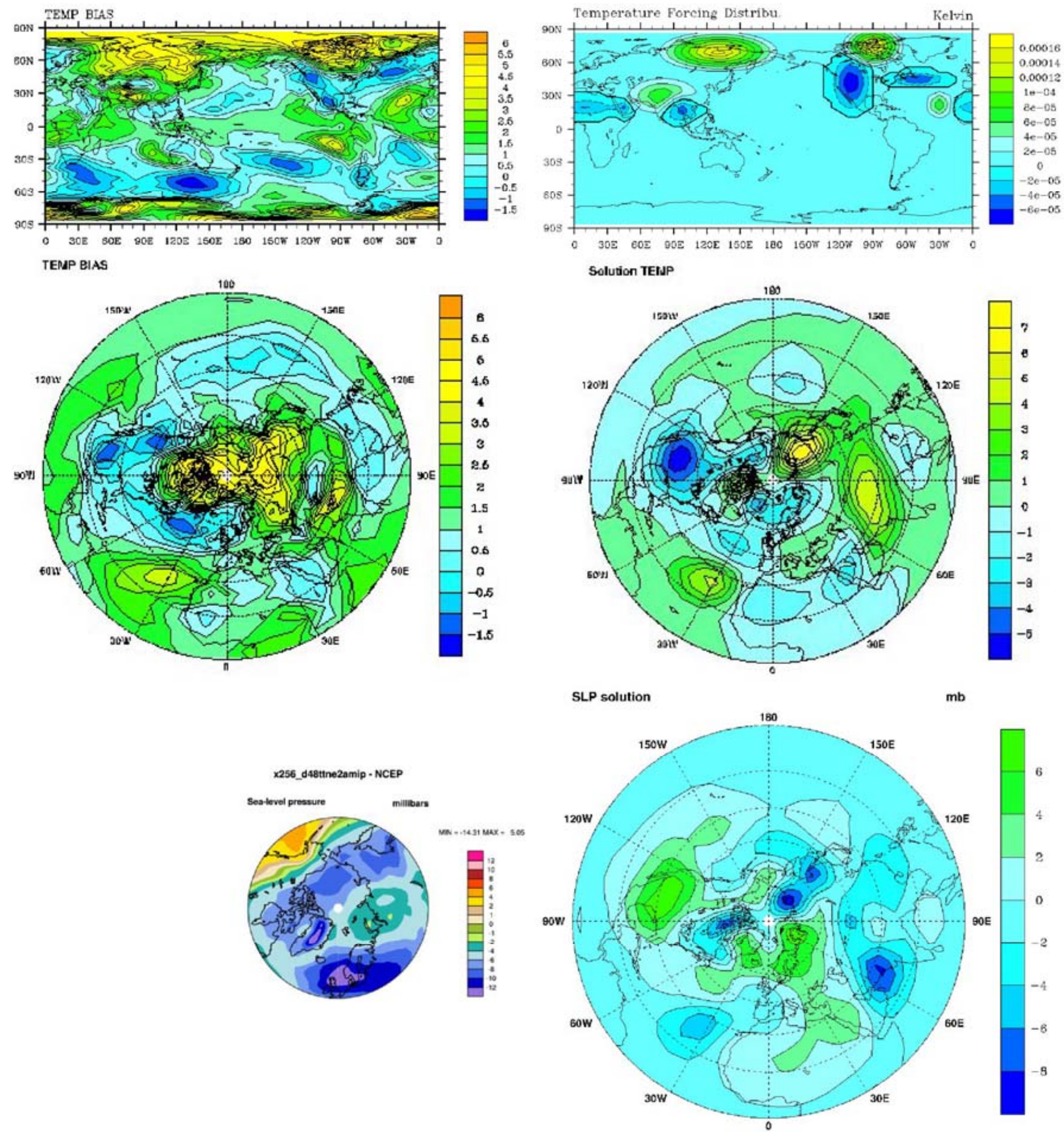

Figure 3. Example test calculation with anomalous T forcing in stationary wave model (SWM) of Branstator (1990) compared with bias fields. Top left, interpolated T bias at $\sigma = 0.811$ (CAM3 vs NCEP RA1, DJF); top right, 9 ellipses of T forcing input into SWM based on T bias. Middle right, SWM solution of T at $\sigma = 0.811$ for the input T forcing, Middle left, polar view of T bias for comparison. Lower right, SWM sea level pressure (SLP) solution. Lower left, SLP bias (CAM3 vs NCEP RA1, DJF; posted at NCAR-CGD website) for comparison, drawn to same scale as SWM SLP solution. The color bars vary between all panels. No tuning was done to improve the match in SLP, but extrema in T bias at 850mb guided forcing magnitudes. The key result is that the SLP bias is partly represented by a stationary wave related to T. Causes of the T forcing are diabatic and dynamic. For example, the SWM SLP max near Novaya Zemlya is most closely linked to the T forcing over the Saharan and Arabian deserts.