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RESPONSE OF HYDROLOGICAL CYCLE TO TINY RANDOM SEA SURFACE TEMPERATURE DISTURBANCES

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1 INTRODUCTION

The linkage between the sea surface temperature (SST) field and the hydrological cycle has been studied for the past few decades. In these sensitivity studies, the SST anomalies were of recognizable scale and always treated as deterministic functions of time and space. One might ask such a question: What is the atmospheric response (or in turn the air-ocean fluxes) to stochastic and tiny SST anomalies? Solving this problem has a great practical implication. If the hydrological cycle is not sensitive to small random SST change, we might use low resolution (in space and time) SST input to run models. If the hydrological cycle is very sensitive to tiny and random SST anomaly, we need use high quality and high resolution SST data. In this paper, we use the most recent version of the well-developed NCAR Community Climate Model to explore the effects of tiny, random SST disturbance on the air-ocean surface fluxes.

2 EXPERIMENTAL DESIGN

2.1 MODEL DESCRIPTION

The model that we used in this study is the NCAR Community Climate Model Version 3 (CCM3), which has evolved from the Australian spectral model described by Bourke et al. (1977), and modified from the earlier version (Hack et al., 1993).

2.2 A TINY GAUSSIAN-TYPE SST ANOMALY

In contrast to traditional studies on atmospheric response to SST anomaly, we use a Gaussian-type random variable (δT) to represent SST anomalies. The probability distribution function is given by

$$F(\delta T) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(\delta T)^2}{2\sigma^2}\right]$$

where δT is a random variable with a zero mean and a standard deviation of σ. Since our interest is to see the response of atmosphere to tiny random SST anomalies, we set

$$\sigma = 0.05^\circ\mathrm{C} \tag{2}$$

in this study. This value (0.05°C) is less than the current instrumentation error and the climatic variability. The NMC SST data show that positive anomalies occupied vast area of the Atlantic Ocean with a value of 2°C in the Gulf Stream extension just off the coast of North America in January 1994 (Fig.1a) and even larger in July 1994 (Fig.1b). We used a random number generator (FORTRAN function, Ranf) to produce random disturbances for each grid point independently with mean value of zero and standard deviation of 0.05°C.

2.3 EXPERIMENTS

2.3.1 CONTROL RUN

The initial condition used in this study is 1 September's climatology of the atmospheric and surface fields, which was provided by the NCAR Climate and Global Dynamics (CGD) Division. The surface boundary conditions were monthly sea and land surface temperatures (also obtained from NCAR CGD Division) linearly interpolated onto each time step (20 min). We integrated CCM3 for 16 months from 1 September to 31 December of the next year, and used the data between 1 January to 31 December of the second year for comparison.

2.3.2 ANOMALY RUN

After three months of the control run, we added a tiny Gaussian-type random SST anomaly with zero mean and 0.05°C standard deviation (for example as shown in Fig.1) generated by the FORTRAN random number generator applied to monthly SST data (first year December to second year December), and then interpolated into each time step. The rest of the forcing was kept the same. The model were integrated from 1 December of the first year to 31 December of the second year (Fig.2). We compare the air-ocean interfacial moisture flux for the second year between the two runs, and call the difference between anomalous minus control runs as the anomaly response.

2.3.3 ROOT-MEAN-SQUARE DIFFERENCE (RMSD)

The difference of the two runs (anomaly run minus control run) of any surface variable ψ is a function of space (x, y), and time t ,

$$\Delta\psi(x_i, y_j, t) = \psi_a(x_i, y_j, t) - \psi_c(x_i, y_j, t).$$

where ψ_a and ψ_c are the variables from anomaly and control runs, respectively. We define RMSD for investigating the temporal variation of the global difference,

$$RMSD_\psi(t) = \sqrt{\frac{1}{M}\sum_i\sum_j|\Delta(x_i, y_j, t)|^2} \tag{3}$$

where M is the total number of horizontal grid points.

3 STATISTICAL TEST

The simulated fields in the two cases were analyzed in terms of monthly mean fields (near 30-day), from the second year January to December. For each grid point of CCM3 a normalized response

$$r(x, y, t) = \frac{|\Delta\psi(x, y, t)|}{S_\psi(x, y, t)} \tag{4}$$

is calculated for any variable (i.e., the tiny-random change response) at the grid point (x, y) and time period t, and $S_\psi(x, y, t)$ is the estimate of the standard deviation of monthly averages of the variable for the CCM3 control integration. This parameter, r, is proportional to t-statistic. Table 1 (from Chervin, 1976) shows the relationship between r and the significant level for two-sided t-tests. As pointed by Chervin et al. (1980), we can regard as significant those response patterns which are associated with extensive regions where $r \geq 4$ (*a priori* significance criterion.) For clarity, in subsequent figures of surface flux response, we present the corresponding geographical distribution of r-values.

4 MONTHLY-AVERAGED SURFACE MOISTURE FLUX OF THE RESPONSE

4.1 PRECIPITATION RATE

The precipitation rate anomaly (Δ Pr) response is shown in Fig.3a (for January) and 3c (for July), respectively,

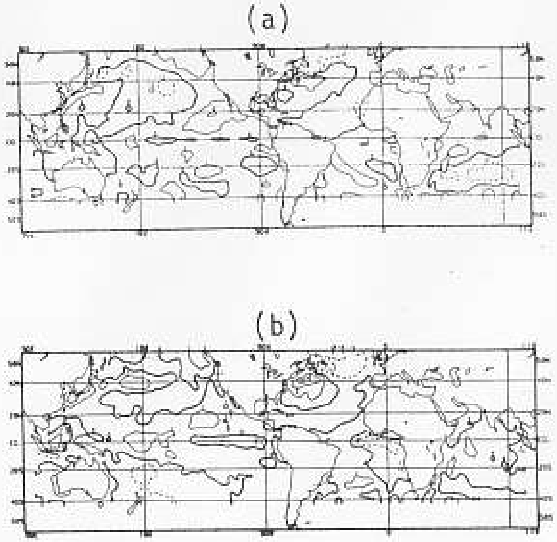

Figure 1 – Global SST anomaly from NMC Climate Center: (a) January 1994, and (b) July 1994.

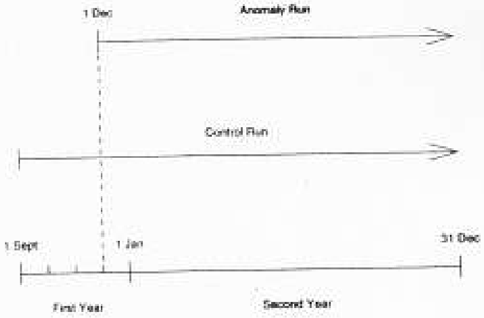

Figure 2 – Control and anomaly runs.

r	Significance level for two-sided t-test
1	0.5169
2	0.2286
3	0.1002
4	0.0469
5	0.0238
6	0.0131
7	0.0077
8	0.0047
9	0.0031

Table 1. Significance levels for a selection of values of r corresponding to four degrees of freedom and t=r/sqrt(2) (from Chervin, 1976).

with the corresponding maps of the r-values being shown in Fig.3b (for January) and 3d (for July). The evident anomaly response is found over land at the southwest of the United States, Tibetan Plateau, Lybian Desert, the South Africa, Northeast Australia, Queen Maud Land in both January and July. In January evident anomaly response is also found over the oceans.

4.2 SURFACE NET MOISTURE BUDGET

Evaporation rate minus precipitation rate is the net moisture flux from ocean to atmosphere (Fig.4). The evident anomaly response is found over land at the southwest of the United States, Tibetan Plateau, Lybian Desert, the South Africa, Northeast Australia, Queen Maud Land in both January and July. In January evident anomaly response is also found over the oceans.

4.3 TEMPORAL VARIATIONS OF RMSD FOR VARIOUS MOISTURE FLUXES

Temporal variation of RMSD for the net surface moisture flux is shown in Fig.5. The temporal Similar to the surface wind stress, two modes were found from Fig.5: (a) near-linearly growing mode and (b) oscillatory mode. During the near-linearly growing modes, $\mathrm{RMSD}_{M_{net}}$ increases from 0 to an evident value (5.7 mm/day) at around the 20-th day.

During the oscillatory modes, $\mathrm{RMSD}_{M_{net}}$ oscillates between 6.8 mm/day and 4.4 mm/day.

5 CONCLUSIONS

1. This study shows large responses of hydrological cycle to a tiny Gaussian-type random SST disturbance. After three months of the control run of the NCAR CCM3 model, we introduced a tiny Gaussian-type random SST anomaly (zero mean and 0.05°C standard deviation) generated by a FORTRAN random number generator to the SST data at each grid and ran the model for another 13 months (anomaly run). The rest of the forcing were kept the same as the control run. The monthly mean values for both the control and anomaly runs were used for comparison. It is quite surprising that the responses of surface fluxes were very strong, even in the monthly mean values.

2. Two modes of the global response were found in this study: (a) near-linearly growing mode and (b) oscillatory mode. During the near-linearly growing modes, the **difference of the root-mean-squares** (RMSDs) increase from 0 to evident values at around the 20-th day:

$$RMSD_{M_{net}} \simeq 5.7mm/day$$

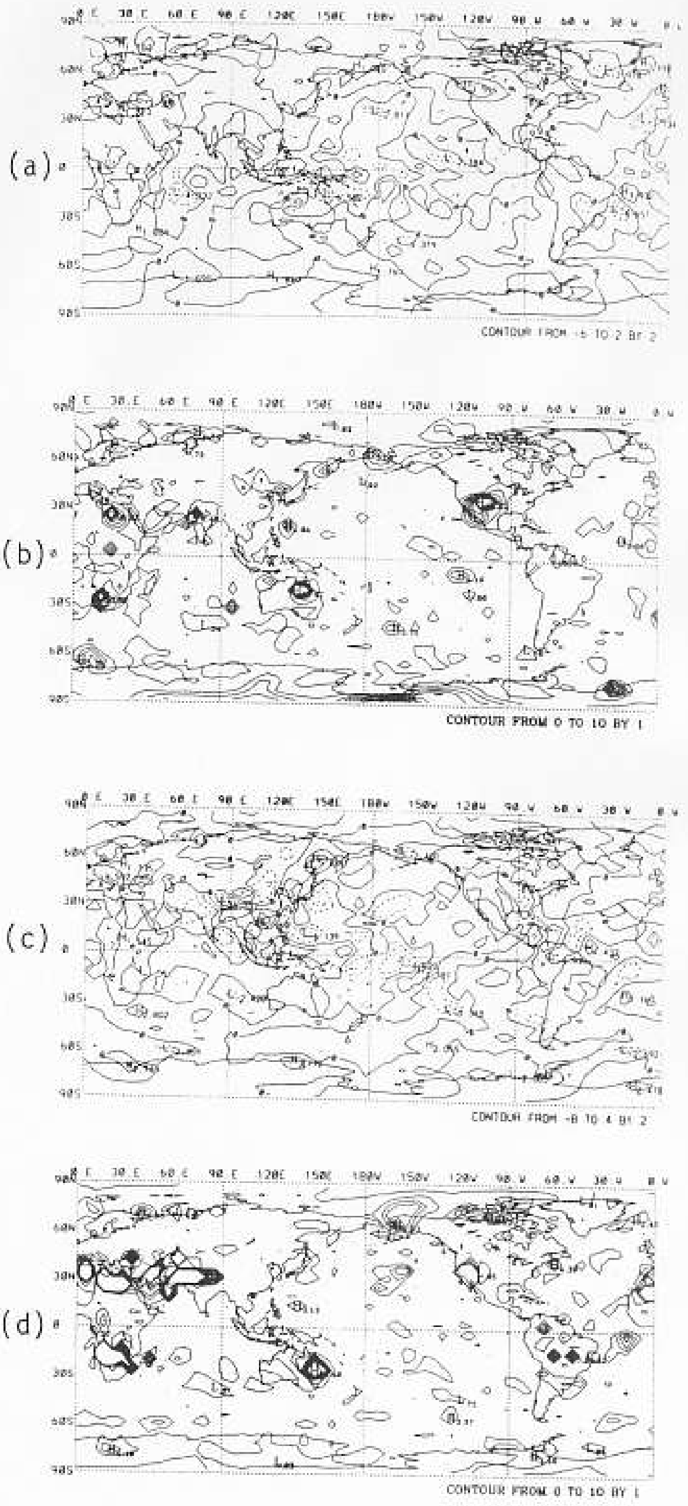

Figure 3 – **Response of monthly mean precipitation (mm/day) to a tiny ransom SST anomaly for: (a) January, and (c) July. The r-statistics are given in (b) January, and (d) July..**

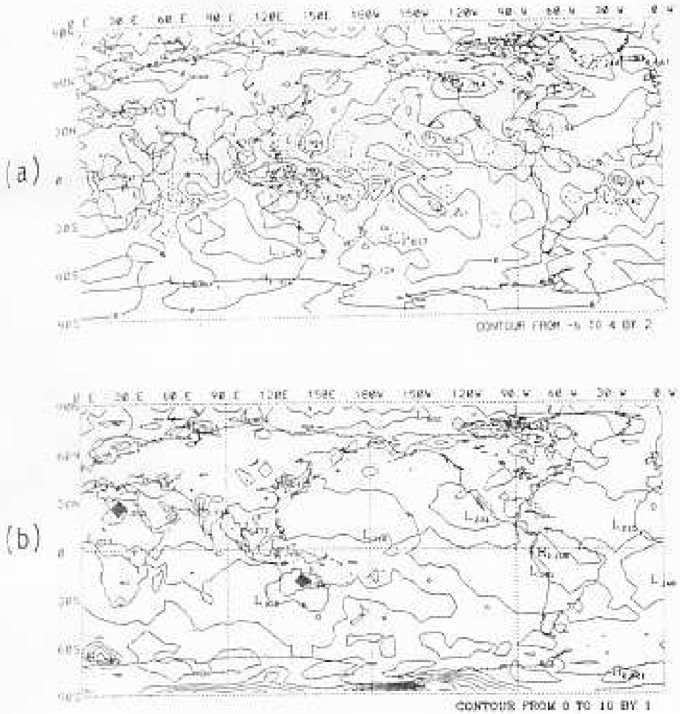

Figure 4 - Same as in Fig.3 except for monthly mean net moisture flux which is evaporation rate minus precipitation rate (mm/day).

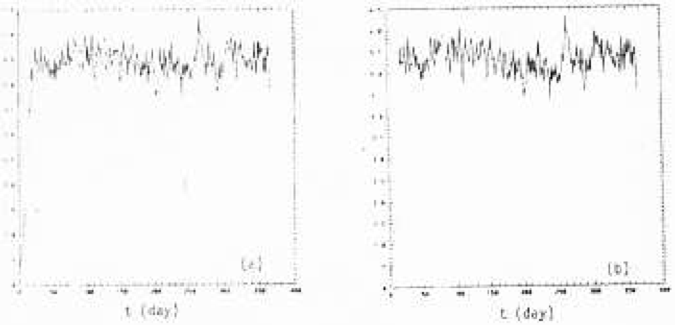

Figure 5 - Temporal variation of RMSD for varipus surface moisture fluxes (unit: mm/day): (a) precipitation, and (b) net surface moisture flux. The horizontal axis starts from the first day (t=0) when the tiny random SST anomaly was introduced.

During the oscillatory modes, RMSDs oscillates around these evident values.

3. Several geographic locations were found sensitive to the tiny-SST anomalies. Polar regions, Tibetan Plateau, Northeast Australia, North Africa, South tip of the Africa, and western Pacific.

4. Integration of atmospheric model needs accurate SST data. The noise in the SST data may bring drastic change in the model results.

5. From the RMSD values, we estimate that the uncertainty of 5.7 mm/day in the net moisture flux.

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