Time Spectral Analysis for the Natural Variability of the Barotropic Model Atmosphere with Annual Cycle Forcing

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1 Introduction

This is a continuation of our previous study of natural variability of a simple barotropic model atmosphere. Climate variation in nature is composed of two components: one is caused by unusual external forcing and the other is the inherent natural variability which occurs even under the fixed boundary conditions. A detailed analysis of climate variability is an important research subject to understand the issue in the global change. The first step to assess the recent climate variation is to separate the variability into the forced trend due to the anthropogenic greenhouse gases and a natural variability of the atmosphere.

The process to determine the magnitude of the natural variability depends highly on the complexity of the model. However, it is not clear how the natural variability depends on the complexity and the internal nonlinear structure of the model. Even a simple barotropic model with an energy source and sink can show its characteristic natural variability. Hence, it is interesting to evaluate the magnitude of the natural variability for different climate models and find some rules between the model complexity and the induced natural variability.

In our former report (Tanaka and Kimura 1993) we showed a typical magnitude of the natural variability of a model atmosphere by a long term integration (1000 years) of a simple barotropic model under a fixed boundary condition. It was found by this long term simulation that the atmospheric variability is characterized by a clear red noise frequency spectrum for the period less than 50 days and a clear white noise spectrum for the period longer than 50 days. The results was compared with the natural variability of other climate models (James and James 1989). Since our former model had no annual cycle, the next step of the study for natural variability is to introduce the fundamental atmospheric periodicity of the annual cycle. It is an interesting subject to know if the imposed forcing of the annual cycle could generate its harmonics and subharmonics over the rest of the frequency domain. Semiannual and biennial oscillations or the interseasonal and interannual variabilities might be excited as the nonlinear modulation of the strong annual cycle.

2 Objective

The objective of this study is to find out to what extent the forced annual cycle can generate the semiannual and biennial oscillations or the interseasonal and interannual variabilities as its harmonics and subharmonics over the frequency domain.

The results will be compared with our former study of the 1000 years run without the annual forcing to assess the role of the forced annual cycle on the low-frequency natural variabilities.

3 Model description

The model description is detailed in Tanaka (1991) and Tanaka and Kimura (1994). Here, we describe only how the annual cycle is forced in the simple barotropic model. The rest of the model description is identical to Tanaka and Kimura (1994). As is discussed in Tanaka and Kimura (1994) the unique energy input into the barotropic atmosphere is the parameterized baroclinic instability:

$$(BC)_i = -i\nu(\tau)a(\tau)\xi_i.$$

Here,

$$\nu(\tau) = (0.8 + 0.2\cos(\frac{2\pi\tau}{T}))\nu_0.$$

The growth rate due to the baroclinic instability ν is controlled in this study to oscillate at one year period over the range of 60-100% of the referenced magnitude ν_0 of the winter growth rate condition.

4 Results

We integrated the simple spectral barotropic model for 100 years under a fixed boundary condition with the forced annual cycle. Figures 1a and 1b illustrate the time series of the total energy of the model atmosphere for the first 10 and 100 years, respectively. The model output is stored for every 24 hours. Those time series are the plots of 10-day and 100-day means for 10 and 100 years, respectively. Namely, every panel of the time series contains 365 points of data.

Figure 1a shows random variations of energy level around the equilibrium about 15×10^5 Jm^{-2}. This time series contains low-frequency interseasonal variabilities superimposed on the annual cycle.

Figure 1b is for the 100-day mean time series during 100 years. Although the 100-day mean filters out most of the dominant oscillations, the annual cycle still remains showing sharp 100 peaks in the time series. Evidently, there is no clear trend nor interdecadal variations.

Figure 2a illustrates the power spectrum of the time series of the total energy for the 1000-year integration without the annual cycle after Tanaka and Kimura (1994). Figure 2b illustrates that for the 100-year integration with the annual cycle in this study. The power spectrum is estimated by the FFT routines and is smoothed by averaging 64 and 8 terms of the original power spectrum for the 1000- and 100-year runs, respectively. The frequency resolution of the spectrum is about 1/(10-years) which is still fine enough to argue the detailed spectral properties.

The result clearly separates the two characteristic spectral slopes of the model atmosphere. The spectrum is white for the period beyond 50 days. In other word, the random variable has no memory of the past for the variation beyond the 50-day period. In contrast, the spectrum is red for the period shorter than 50 days. Namely, the random variable remembers its own past to some extent for the variation shorter than 50-day period. Interestingly, the spectral slope for the red noise obeys approximately the -3 power of the frequency. There is an energy source into the system at the frequency range near 1/(5-day) due to the parameterized baroclinic instability. These features are identical to our former results.

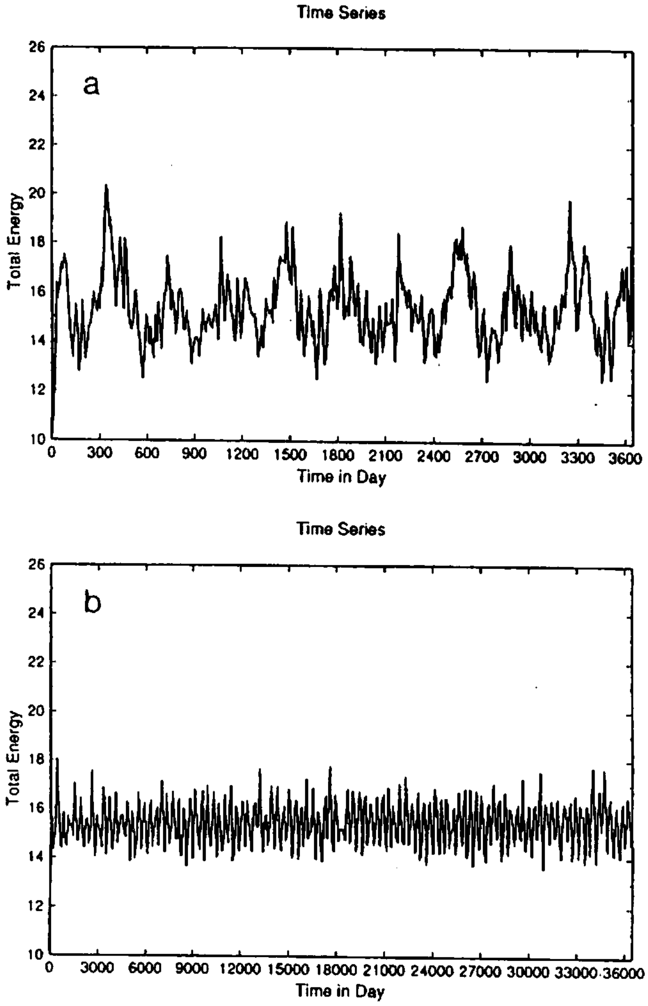

Figure 1. Time variations of (a) 10-day mean total energy during the first 10 years and (b) 100-day mean total energy during 100 years.

Now, the main difference between these two runs with and without the forced annual cycle is the sharp spectral peak at the one year period in present study. We find from the result that there is no obvious harmonics nor subharmonics corresponding to the forced annual spectral peak.

5 Summary

The results of the 100 year time integration of a simple barotropic model with forced annual cycle are summarized as the following three points:

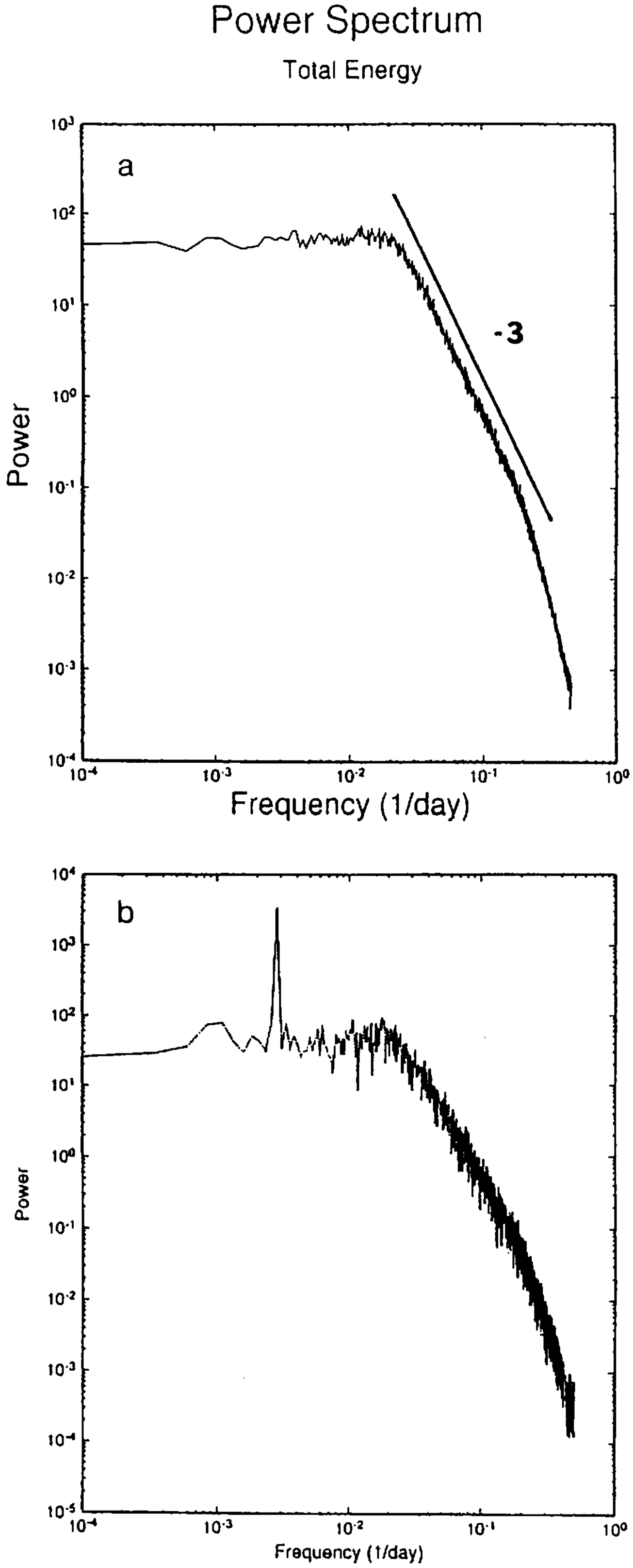

Figure 2. Power spectrum of the time series of the total energy for (a) the 1000-year integration without the annual cycle (after Tanaka and Kimura 1994) and (b) the 100-year integration with the annual cycle in this study.

1. By changing the growth rates of the parameterized baroclinic instability by 60-100% of the referenced magnitude of the winter growth rate condition, we find that the total energy oscillates over the range from 12 to 20 $\times$ 10^{5} Jm^{-2}. A clear spectral peak occurs at the one year period as expected.
2. The frequency spectrum is characterized as white for the period beyond 50 days. In contrast, the spectrum is red for the period shorter than 50 days. This feature is not altered by the introduced annual cycle.
3. Both the interseasonal and interannual oscillations are detectable in the original time series. However, the spectral peaks of the harmonics and subharmonics of the forced annual cycle appear to be insignificant in this study.

In this study, we find that the semiannual and biennial oscillations are not excited by the forced annual cycle for the 100 year statistics of the FFT spectral analysis. However, there are still chances of these modulations to occur in a temporal base, if an occurrence in positive phase offsets the other occurrence in negative phase. As the future research subject, it may be interesting to apply the orthogonal and continuous wavelet transform to identify the temporal appearance of the modulated annual cycle (e.g., Weng and Lau 1994).

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7 References

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