Intraseasonal Variability - A Critical Component of ENSO ?

Stephen E. ZEBIAK

Lamont-Doherty Geological Observatory
Palisades, NY 10964 - U.S.A.

ABSTRACT

The impact of intraseasonal variability on ENSO is studied in the context of the Zebiak and Cane (1987) coupled atmosphere-ocean model, and an idealized representation intraseasonal forcing. The effects of the parameterized forcing are examined in both simulation and forecast experiments, with similar results: the intraseasonal variability generally plays a minor role in altering the model behavior. Despite the uncertainties inherent in both the coupled model and the specified forcing, the results clearly suggest that intraseasonal variability is not an essential component of ENSO. At the same time, they present evidence of occasional sensitive periods or states of the coupled system in which intraseasonal forcing (and possibly other forcings) can indeed disrupt the future course of events.

1. Introduction

Since the pioneering work of Madden and Julian (1971,1972), the so-called 40-50 day oscillation (also known as the 30-60 day oscillation, or Madden-Julian oscillation) has been the subject of intense study. It is a prominent mode of variability on intraseasonal timescales throughout most of the tropics, with clear signatures in upper and lower level tropospheric zonal wind, and convective activity (Madden and Julian 1971,1972; Lau and Chan 1985,1986a; Knutson and Weickmann 1987; Chen and Murakami 1988). Its significance is further heightened by suggested relationships with a number of other phenomena; among them, fluctuations of the Indian monsoon (Krishnamurti and Subrahmanyan 1982; Murakami et al. 1984,1986; Cadet and Greco 1987), fluctuations of the Southeast Asian monsoon (Chen et al. 1988), westerly wind bursts in the western Pacific (Lau et al. 1988), and the onset of El Niño (Lau and Chan 1986b,1988). The latter two are related inasmuch as westerly wind episodes typically characterize the early stages of El Niño events (Luther et al. 1983). The proposed relationship between 30-60 day activity (hereafter referred to as intraseasonal variability or ISV) and El Niño is the subject of this study. Specifically, we will assess the impact of ISV on the Zebiak and Cane (1987) coupled model in both simulation mode and forecast mode.

One can easily imagine, following the authors cited above, that the energetic ISV forcing, if not an essential element of ENSO, is often influential in the timing of events. On the other hand, the theory emerging from simple coupled models points to an essentially deterministic interannual cycle. If one accepts this theory, then the role of ISV would seem to be secondary; or more correctly, the role of that component of ISV not controlled by the slower, ENSO-mode variability would seem secondary. Whereas one perspective treats El Niño occurrences as individual events, dependent on some triggering mechanism(s), the other views warm (and cold) events as the inevitable consequence of a systematic preconditioning process, and part of an ongoing, self-sustaining cycle. Of course, there is the possibility that both viewpoints are partially correct. A

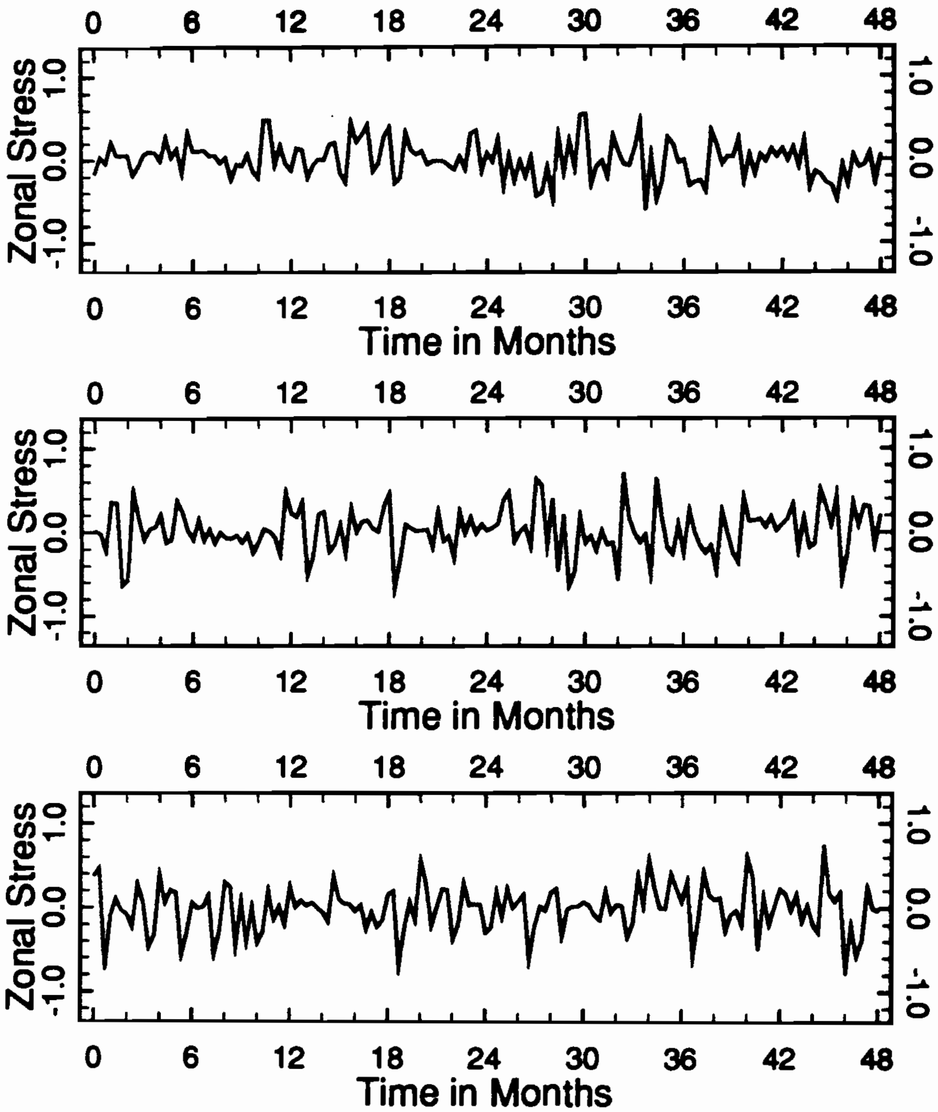

Fig. 1. Three 48-month realizations of the stochastic ISV model defined by Eq. (1).

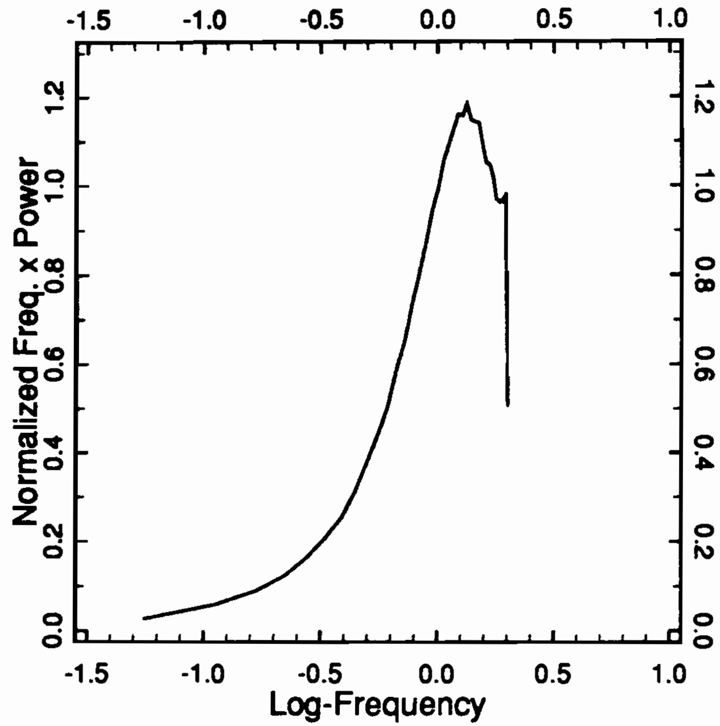

Fig. 2. Spectrum of model ISV. Abscissa has been scaled so that zero represents a 40-day period (logarithms are in base 10).

deterministic, but chaotic, ENSO cycle likely would be characterized by periods of lesser and greater susceptibility to various external forcing factors, including ISV. Even if this forcing were not usually sufficient to disrupt the cycle, at particular times or in extreme instances it might well do so. It is the purpose of this paper to determine which of these scenarios obtains in the context of the ZC model.

2. A Model of Intraseasonal Forcing

Intraseasonal variability appears naturally in atmospheric models with time-dependent dynamics, and reasonable representations of convective heating (e.g., Lau and Lau,1986; Chang and Lim,1988; Hendon,1988; Sui and Lau,1989). It does not occur in the simpler, steady-state models such as that of ZC. Thus, for the present purposes it is necessary to specify the intraseasonal variability in some fashion. To do this, several observational results are utilized: (i) the low-level wind signal is dominantly zonal in the equatorial region, (ii) the 30-60 day period band contains most of the power, and (iii) the disturbances are energetic in the west Pacific, but weaker (at the surface) in the eastern Pacific. In the model to be constructed here the spatial structure of the imposed anomalies is fixed in time, and positioned in the western Pacific at the equator. The eastward propagation aspect is not included as it is considered relatively unimportant in terms of the ocean response (especially the remote response to the east of the forcing region). Specifically, the following form is chosen for fluctuations in zonal wind stress:

$$\tau^{(x)}(t) = A\Big[R(t) + 2R(t-\Delta t) + R(t-2\Delta t)\Big] \cos(\omega_0 t + t_0) \exp\left[\frac{y}{10^\circ}\right]^2 \exp\left[\frac{x-x_0}{30^\circ}\right]^2, \qquad (1)$$

where R is a normal random variable with zero mean and unit variance, and t_0 represents a uniform random variable on $(0,2\pi)$. This forcing is evaluated at time intervals of Δt, which for the ZC model is 10 days. The parameters ω_0 and x_0 were taken to be $2\pi/40 days$ and $146°E$, respectively, and the amplitude A was set at $.015\,N/m^2$.

Fig. 1 shows three 48-month realizations of this forcing function. Anomalies as large as the climatological mean stress (about $.05\,N/m^2$) occur frequently; the model forcing is at least as strong, and probably stronger, than what is observed (Madden, personal communication). A spectrum of the forcing (Fig. 2) shows that, like the real ISV, most of the total power resides in the 20-60 day band. Subsequent coupled model runs incorporate this forcing with one exception: the amplitude A is reduced during simulated warm episodes. We reduce A in proportion to $(\mathrm{NINO3})^{1/2}$ for NINO3 >1, where NINO3 is the area averaged SST anomalies for the region $(90°W-150°W, 5°S-5°N)$. The rationale behind this is that convective activity is generally observed to decrease in the west Pacific during El Niño events. The reduction in model forcing is modest (always less than a factor of two), so that the simulated ISV is still energetic by observed standards.

3. Model Simulations/Forecasts with Imposed ISV

Two 1000-year simulations were done, one with and one without ISV forcing, for the standard physics case as described in ZC. Such a lengthy simulation reveals a wide range of behavior in the unperturbed coupled model (Fig. 3), including periods of large, regular warm events, periods of more irregular cycles, and even periods of almost no variability. How much can a powerful ISV forcing alter this pattern? Given this range of behavior in the basic model, it is perhaps not surprising to find that there is little effect (Fig. 4). The favored 4 year period, and transitions between regimes of larger and smaller amplitude variability all occur analogously. A more quantitative comparison is shown in Fig. 5. The two time series were divided into segments of 24 years duration, Fourier analyzed (with a Welch window applied to minimize aliasing effects), and then averaged to form a mean spectrum. The two spectra are nearly identical; only

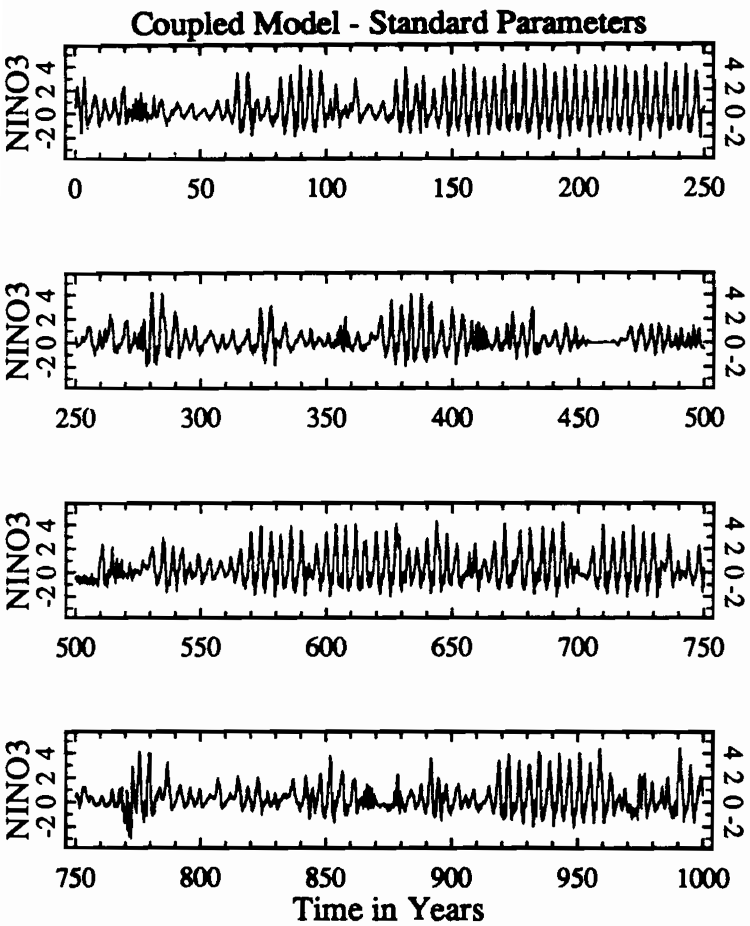

Fig. 3. NINO3 index from a 1000-year run of the coupled model with no ISV forcing.

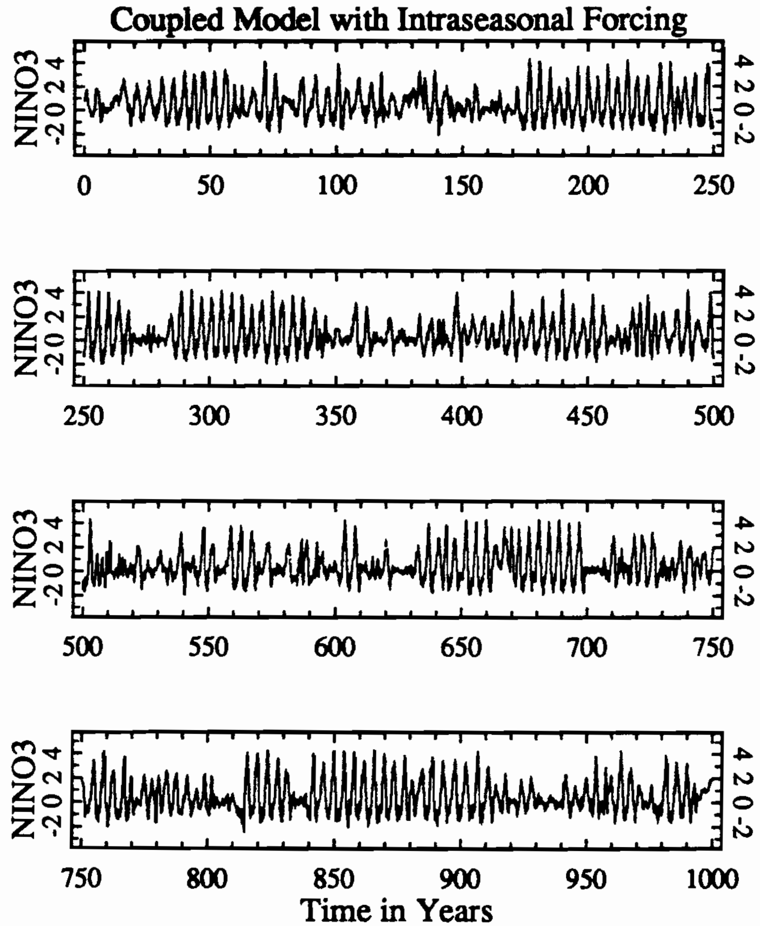

Fig. 4. As Fig. 3, except with added ISV forcing.

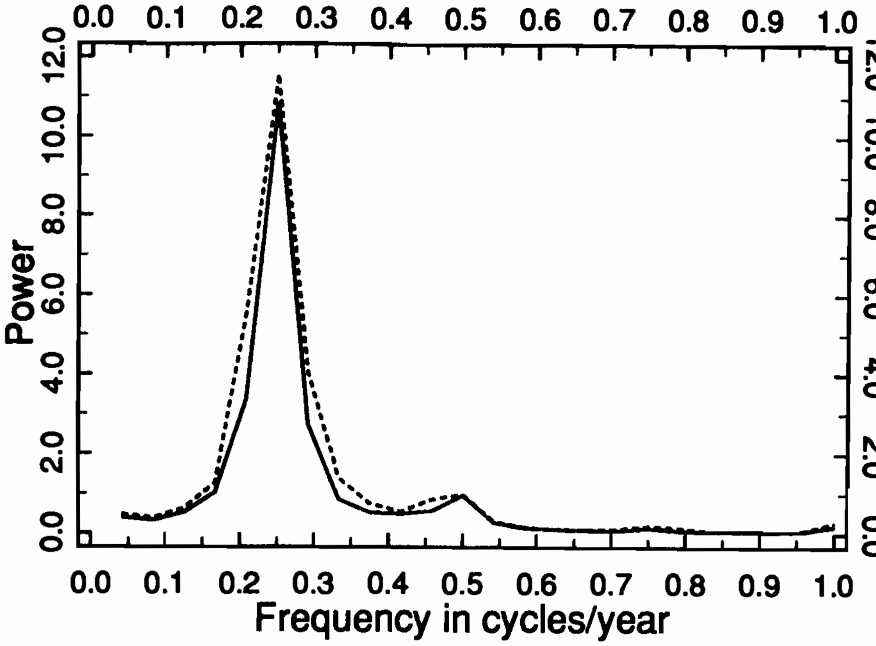

Fig. 5. Spectra of the time series in Figs. 3 and 4, for the period range 1-24 years.

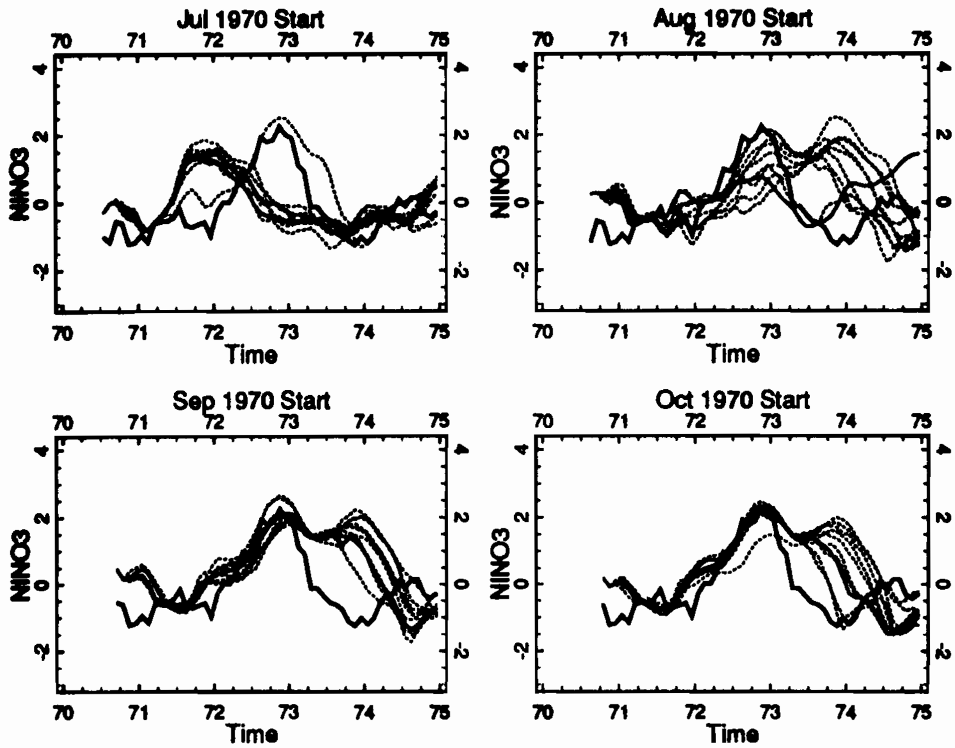

Fig. 6. Observed NINO3 (heavy solid line), and forecasts of NINO3 made with the coupled model alone (light solid line) and with added ISV forcing (dashed lines), starting from July 1970 through October 1970.

a minute spreading about the central period of four years is detectable in the ISV-forced case.

Previously, we have used the ZC model to make predictions of tropical Pacific SST during the period 1970 to 1988. (The experimental forecast procedure is described in detail in Cane et al., 1986.) Forecasts were made starting from each month of the period, with the initial conditions determined as follows: a detrended and smoothed version of the FSU pseudo-stress fields (Goldenberg and O'Brien, 1981) was used as a forcing for the ocean component of the coupled model. The result is a sequence of simulated ocean states for the entire period (mid-1960's to the present). The SST from this simulation was then used as a forcing for the atmospheric component, resulting in a corresponding sequence of simulated atmospheric states for the same period consistent with the coupled model physics.

The fact that ISV has little effect on the overall statistics of the coupled model does not guarantee that it is unimportant for prediction purposes. Indeed, some have speculated that ISV is a major factor in the onset or termination of warm events. To test this, all of the previous forecasts were rerun with 9 separate realizations of ISV forcing. A small but representative sample of the results is shown in Figs. 6-9. The NINO3 index from the original forecasts (no ISV), from each of the perturbed forecasts, and from observations is presented for sequences originating in four consecutive months.

The July-October 1970 sequence (Fig. 6) represents a transitional time between incorrect and correct predictions of the 1971-1972 period in the unperturbed forecasts. All but one of the perturbed forecasts from July follow the original in producing a warming in 1971, and moreover all from August follow the original in producing no warming in that year, despite rapid spreading thereafter. Another period showing large month-to-month differences in the original forecasts is September-December 1975 (Fig. 7). Once again, it is evident that the entire envelope of ISV forecasts is tending to follow the unperturbed ones, with apparently greater spreading at times when the month-to-month stability of unperturbed forecasts is small. In contrast to other times, the 1977-1978 period is remarkable in that almost none of the original forecasts produced any warm events over a three year period. The addition of ISV for February-May 1978 (Fig. 8) hardly alters this pattern at all, resulting in only a weak warming in the third year or beyond in about 10% of the cases. If anything, the periods just prior to or during warm events are even more stable with respect to ISV forcing. A typical example is September-December 1986 (Fig. 9), where the envelopes tightly bracket the original forecasts throughout the extended warm episode, and subsequent cooling in 1988.

The picture emerging from these results is that ISV forcing can be important at particular times, but that on average, it does little to alter the evolution as predetermined by the initial conditions. In fact, the sensitivity to consecutive monthly changes in initial conditions appears greater than that associated with ISV. This can be quantified by a calculation in the spirit of predictability studies.

The usual predictability experiment consists of a series of model integrations with small changes in initial conditions. A measure of predictability is obtained from calculating the spread among individual "predictions", compared with the expected differences among randomly chosen states of the model or observed variables. While the theoretical limit of predictability is a function of the governing physics alone, an analogous predictability can be defined on the basis of any method of perturbing the system, whether it be in the initial conditions, or some external forcing. In this case, the rate at which the envelope spreads is a function not only of the model physics, but also the form and size of perturbations. The rate of spreading provides a means for evaluating the dynamical significance of a particular type of initial condition perturbation or external forcing. For example, if perturbations to which the system is very insensitive are introduced, the rate of spreading will approach the theoretical one - only model physics matter. On the other hand, if sizeable or otherwise dynamically significant perturbations are introduced, the rate of spreading

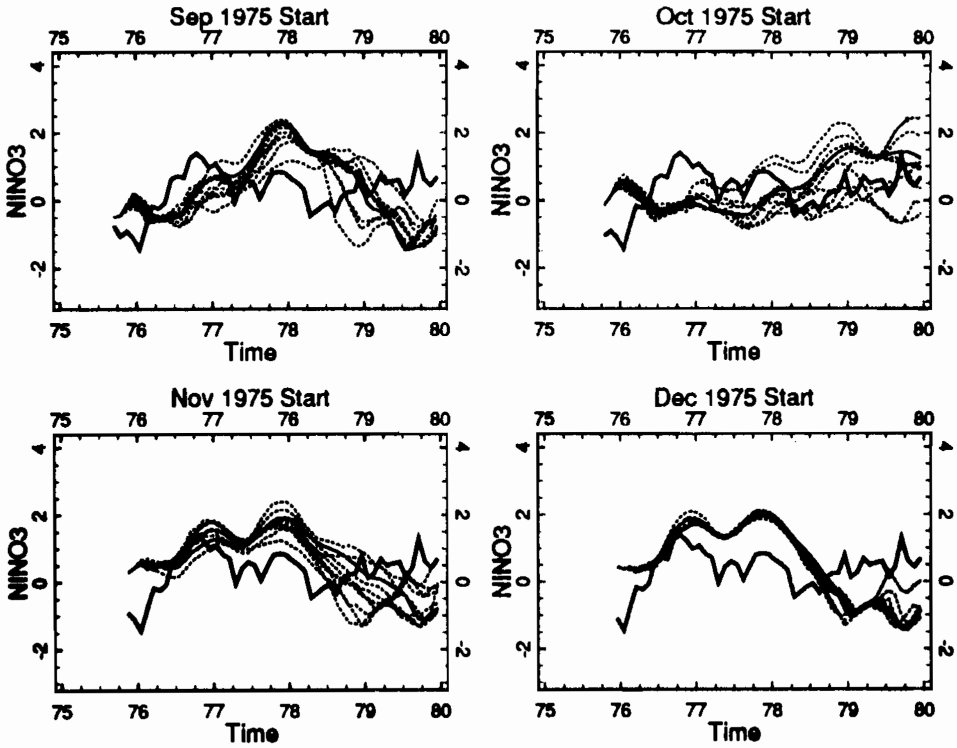

Fig. 7. As Fig. 6, except for September 1975 through December 1975.

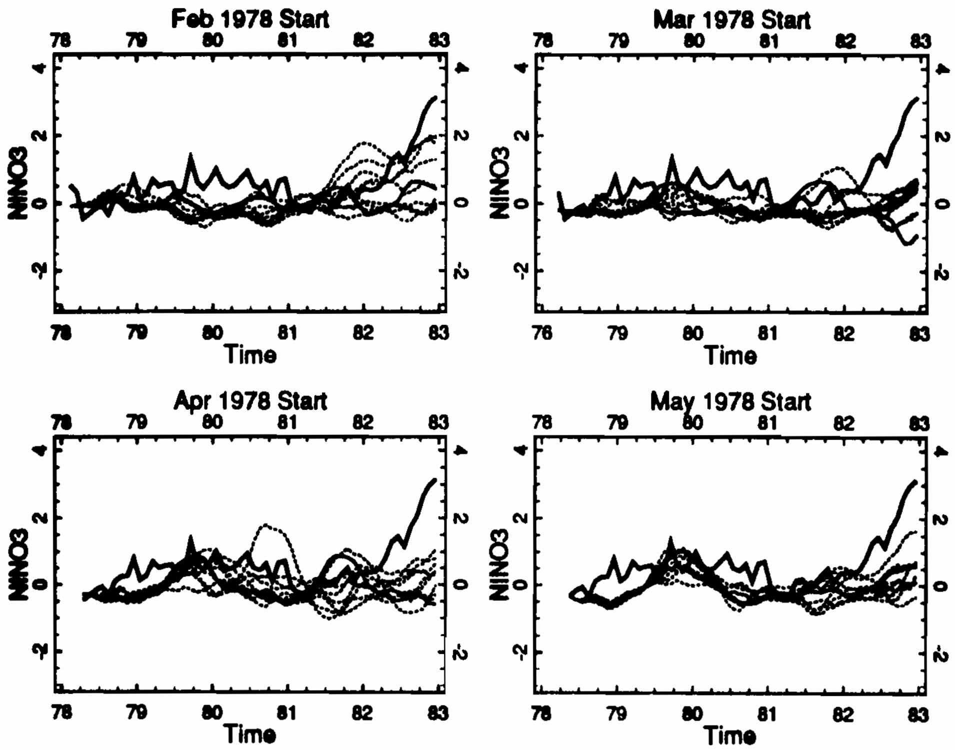

Fig. 8. As Fig. 6, except for February 1978 through May 1978.

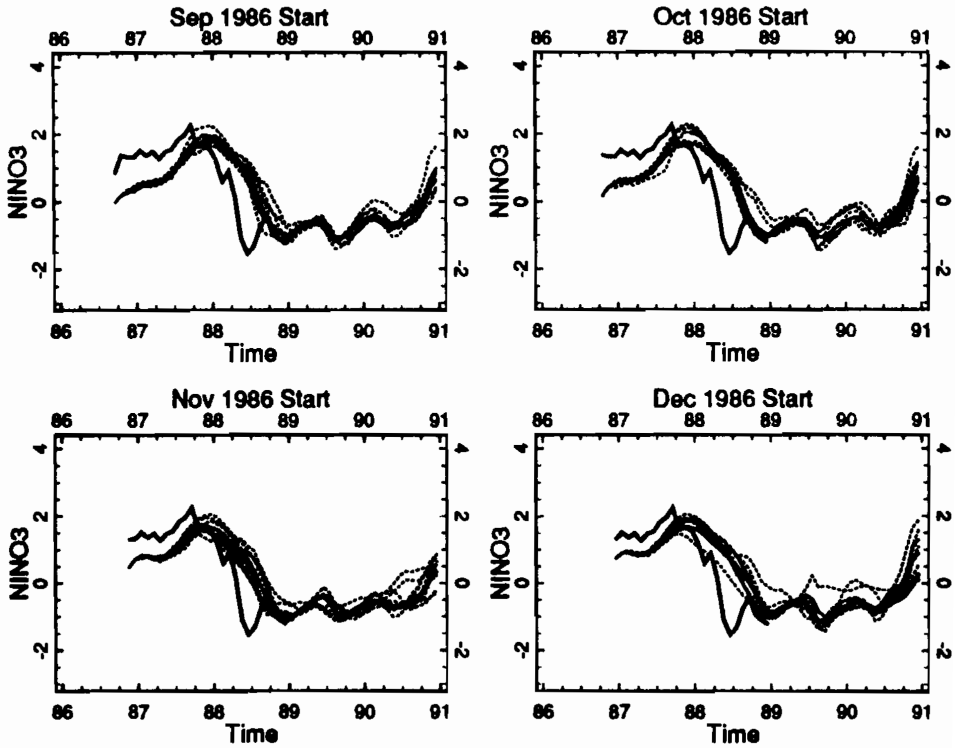

Fig. 9. As Fig. 6, except for September 1986 through December 1986.

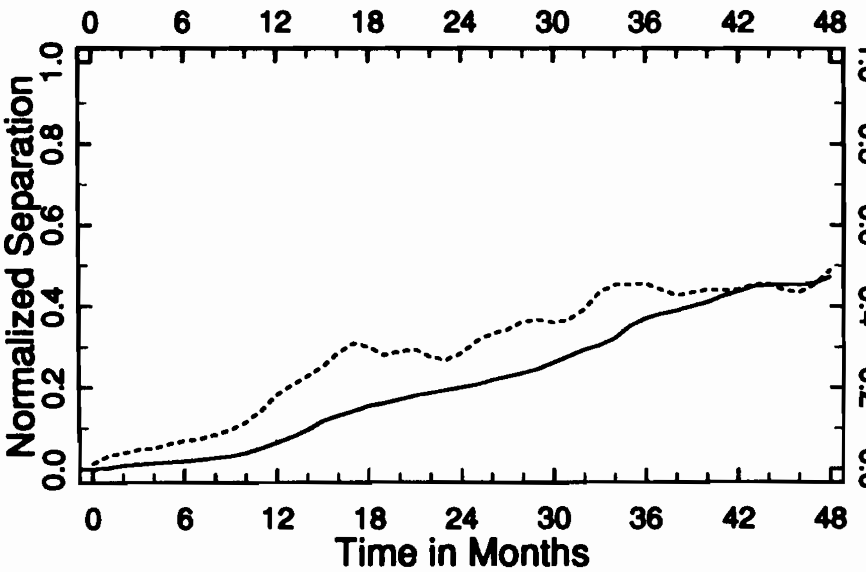

Fig. 10. Root mean square separation among all pairs of forecasts starting from the same initial conditions, but with different realizations of ISV (dashed line), compared with the same quantity computed from pairs of forecasts without ISV beginning one month apart (solid line).

will be much larger, and the predictability limit will be reached sooner.

For the present purposes we wish to compare the spreading rates associated with ISV forcing and one-month differences in start time. The former is determined by computing the mean square difference among all pairs of forecasts starting from the same initial conditions, but with different realizations of intraseasonal forcing. Similarly, the latter is determined from the mean square difference between forecasts starting one month apart, and with no ISV (only the overlapping time period enters for this calculation). Both are shown in Fig. 10. The results confirm what was suggested in the sets of individual forecasts: the ISV forcing has less overall effect on the forecasts than does moving the start time by one month.

4. Discussion

The question of intraseasonal variability and its impact on ENSO has been addressed in the context of the Zebiak and Cane (1987) coupled model and an idealized representation of ISV. From several different analyses, the results are unambiguous: ISV has only a marginal effect on ENSO. Lengthy integrations of the model with and without ISV yield nearly identical statistics. The majority of individual forecast experiments show little spreading over a two year period as a result of this forcing. Predictability calculations show that, even relative to the differences among forecasts starting one month apart, the ISV influence is small. (The comparison with forecasts starting two months or more apart is more dramatic.)

It is worth noting that the initial conditions in our forecast experiments are generated with a filtered (and detrended) version of the FSU pseudo-stress fields. This involves a temporal 1-2-1 smoothing of monthly averages, and therefore has nearly all intraseasonal variability removed. Thus the changes in initial conditions from month to month in the forecasts do not simply reflect ISV, but rather reflect somewhat lower frequency wind changes at varying preceeding times depending on position. The results show that the sensitivity to these lower frequency components of the wind field (whether real or spurious) supersedes the effects of ISV.

Despite the consistency of the results, conclusions should be considered tentative for two reasons. Our ISV model, though motivated by observations, is highly idealized in many respects and may not represent the real phenomenon faithfully. Also, the ZC model has systematic biases, and quite possibly is overly insensitive to the imposed west Pacific forcing. Both of these potential problems in principle can be reduced with better or more complete models. Awaiting such further studies, the present results can be regarded as suggestive of a secondary role for ISV in relation to ENSO.

Finally, it is interesting to consider the relatively infrequent periods where the imposed intraseasonal forcing *did* have an important effect on forecasts. This leads to question: what characteristics of the coupled system determine whether or not the future is well determined? Is there some feature symptomatic of an uncertain future evolution, beyond our imperfect knowledge of the state of the system at any given time? In general, can we know when predictability is more and less limited? It seems certain that a careful study of these issues will give new insight into the model dynamics, but may also contribute to a better understanding of the real climate system.

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