Analysis of Propagating Modes in the Tropics in Short AMIP runs.

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1. Introduction and summary.

NCEP has produced in early 2002 a large set of 1-year AMIP runs of candidate next generation NWP models that may become operational, see companion paper in this volume by Saha and Van den Dool. A total of about fifteen 1-year AMIP runs were made with variation in horizontal and vertical resolution, and aspects of the physics, such as the convection scheme. The initial condition was Dec 15, 2000, and the 1 year we studied, discarding the 1st two weeks of the runs, covers Jan, 1 to Dec, 31 of 2001. A few runs were extended to 5 years, and two runs all the way out to 25 years. We here analyze the behavior of these models in the large scale tropical troposphere, primarily the MJO, the tides and the zonal mean zonal wind. Tides are studied in terms of surface pressure, while MJO is gauged by 200mb velocity potential (χ). An analysis technique, named Empirical Wave Propagation (EWP), explained in section 2, is applied to model data and the results in terms of amplitude and phase speed of χ anomalies are compared to observations (~analyses from CDAS). Depending on the physical packages and the resolution, there are clear differences in strength and phase speed of large scale tropical disturbances in the models. Compared to AMIP I, when we and most other researchers concluded that the MJO was very weak in amplitude and much too fast, the current global NCEP model is better in producing stronger divergence anomalies which move in the right direction, but too slow. Model versions with better χ anomalies also tend to be better in the streamfunction ψ. With regards to the tides in the tropics - they are much too strong in all model runs. There are worrisome changes in the systematic error in the mean and the variance of the zonal mean zonal wind in response to changing convection scheme, but the path to model improvement, given such large sensitivity, is not clear.

2. Empirical Wave Propagation

Given is a data set X, for instance 200 mb velocity potential, once daily 0Z, on a 2.5 by 2.5 lat/lon grid, denoted as $X(\lambda, \phi, t)$. Remove a suitable climatology (a function of day of the year and hour of the day) and retain anomaly data X'. For any given time t : project X' along a latitude circle onto the sin $m\lambda$ / cos $m\lambda$ orthogonal pair. This yields two coefficients (a and b), or, alternatively, amplitude (A) and phase (ϵ) for each zonal wavenumber m, m=0 to 72, i.e.

$$X'(\lambda, t) = A_0 + \sum_m A_m \cos m(\lambda - \epsilon_m) \quad (1)$$

(1) is just an ordinary Fourier transform. First a few comments about the amplitude A.

Note that the space-time variance $= \sum_t \sum_s X'^2 = \frac{1}{2} \sum_t \sum_m A^2_m$

$$= \frac{1}{2} \left(\sum_m \langle A_m \rangle^2 + \sum_m \langle A'^2_m \rangle \right), \text{ where } \langle\,\rangle \text{ is the time mean.}$$

$$\approx \frac{1}{2} \left(\sum_m \langle A_m \rangle^2 \right)$$

To about 75% accuracy the variance in the atmosphere can be thought of as being associated with anomaly waves with a constant time mean amplitude ($\langle A_m \rangle$). The amplitude of anomaly waves, thus defined, is surprisingly constant.

These waves move! Now a few comment about the phase speed.

Take a single wave m_0 . Question: will wave m_0 on average move east or west???

At time t: $A \cos m_0(\lambda - \epsilon) = a \cos m_0\lambda + b \sin m_0\lambda$ (2)

At time t+1: $A_1 \cos m_0(\lambda - \epsilon_1) = a_1 \cos m_0\lambda + b_1 \sin m_0\lambda$ (2a)

Move the crest of the wave on the leading day (t) to a reference longitude (like Greenwich), this is done by phase shifting over $+\epsilon$. Move the wave on the next day (t+1) over the exact same ϵ - this maintains the relative positioning, but in a new framework. This yields:

At time t: $A \cos m_0\lambda = A \cos m_0\lambda + 0 \sin m_0\lambda$ (3)

At time t+1: $A_1 \cos m_0(\lambda - (\epsilon_1 - \epsilon)) = c_1 \cos m_0\lambda + d_1 \sin m_0\lambda$ (3a)

Now do this for all pairs t/t+1!! The r.h.s. coefficients A, c_1 and d_1 are a function of time, with time means $\langle A \rangle$, $\langle c_1 \rangle$ and $\langle d_1 \rangle$.{ The time mean of coefficients a and b would be zero.} The amplitudes of time averaged phase shifted wave at the leading time is simply $\langle A \rangle$, while the phase angle difference t vs t+1 is given by $\epsilon_{p1} = \arctan(\langle d_1 \rangle / \langle c_1 \rangle)$, and the phase speed by:

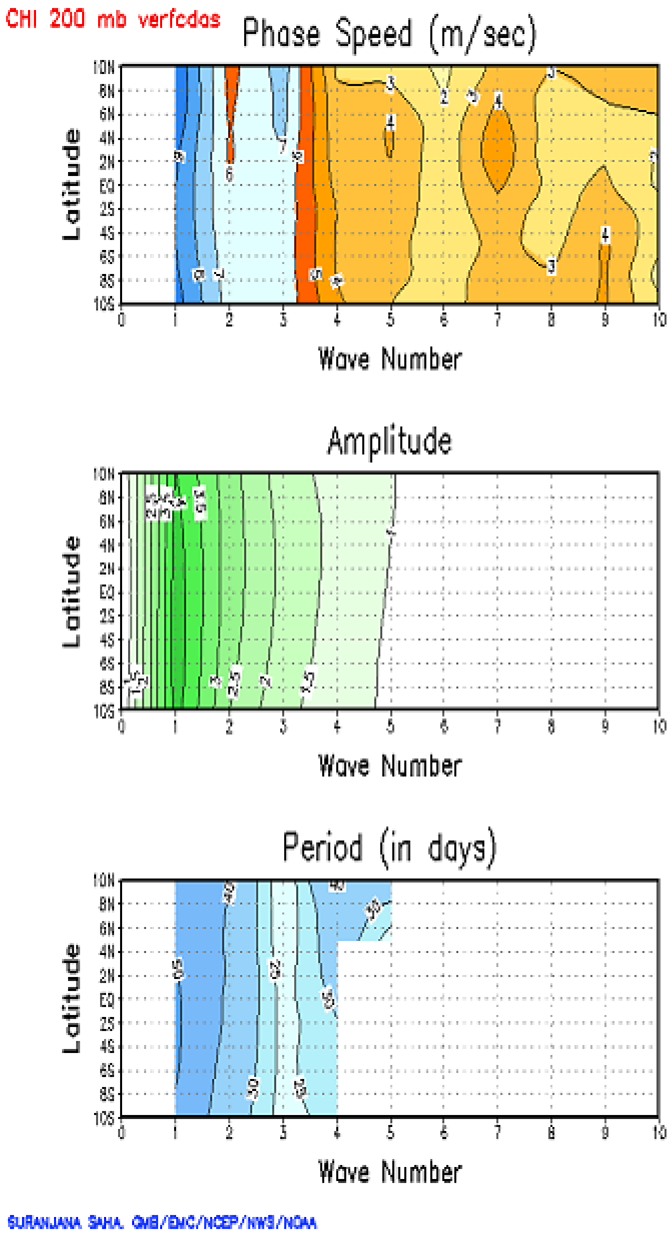
$$c(\phi, m_0) = \epsilon_{p1}(\phi, m_0) \cdot 6375000 \cdot \cos(\phi) / 86400 / m_0 \quad (4)$$

EWP is related to spectral analysis but uses only 1-day lagged data to determine wave speeds (and amplitude) under quasi linear conditions.

3. Results

We applied the above EWP analysis to χ anomalies for the year 2001, and show in Fig 1 the phase speed (top), amplitude (middle), and period (bottom), as a function of latitude and zonal wavenumber in the tropical strip. Clearly, χ anomalies propagate eastward, with considerable dispersion as shorter waves have little phase speed. Maximum speed and amplitude is seen for wavenumber 1. The period is the amount of time for wave m to travel 360/m degrees of longitude. So a speed of 9 to 10 m/s for wave 1 yields the familiar MJO period of about 45 days. Fig.1 is as observed according to CDAS. Similar diagrams were made for some 15 model AMIP runs for 2001. They are not shown for lack of space, but can be viewed in http://wwwt.emc.ncep.noaa.gov/gmb/ssaha/exps/chi/spd/ . The results show the current NCEP model and its perturbation in terms of resolution etc have decent amplitude but a too low phase speed. Only the model versions with RAS convection have reasonable speed, both in χ and in ψ.

In October 2002, a model was selected to be the new operational model. A 23 year AMIP run was made that allows us to discuss seasonality of χ anomaly behavior in that new model. In this case a 23 year climatology was removed month by month and the EWP analysis was done for each month separately. Focusing only on wave #1 along the equator, Fig 2. shows the phase speed and amplitude of zonal wave #1 as a function of month. In the analyses, CDAS (top), the phase speed is seen to vary twice a year with a maximum (~10-11 m/s) in May and November, and minima near 6 m/s in February and August-September. The amplitude has a single maximum in March and a single minimum in December. The middle (phase speed) and lower panel (amplitude) of Fig.2 show that the model (labeled prx_28/64) has little reality in its annual cycle, neither in T62L28 nor in T62L64 resolution. Waves are progressive in all seasons, but the speed is too low, especially from Oct to Jan. The amplitude may be too strong in the model, especially with 64 levels. On the whole the current model is better than at the time of AMIP I, when the amplitude was much too weak and the phase speed much too fast. Still, there is much room for improvement.



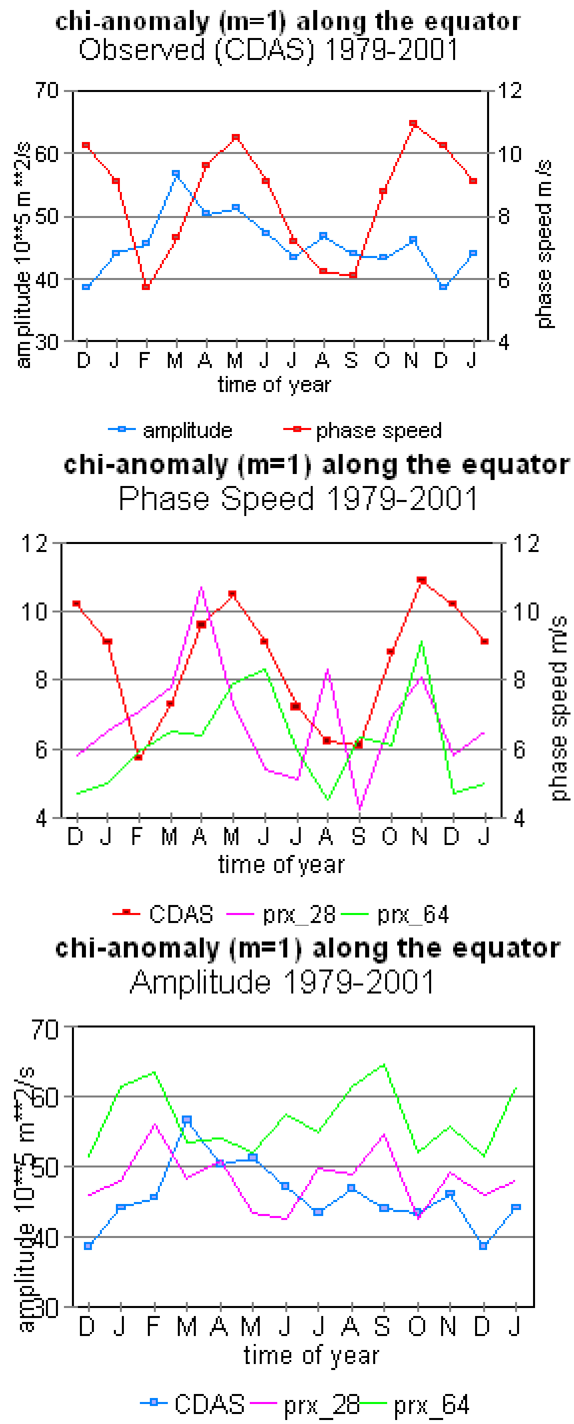


Fig. 1. The phase speed (top, m/s), amplitude (middle, 10**6 m**2/s) and period (days) of χ anomalies at 200mb as a function of latitude and zonal wavenumber. Calculations done with verifying analyses during 2001.

Fig.2 The phase speed (m/s), and amplitude of χ anomaly wave # 1 at 200mb along the equator as a function of month during 1979-2001. Top for CDAS (observed), middle and bottom the phase speed and amplitude in two model runs compared to CDAS.