The tropical Atlantic influence on boreal summer rainfall in the Western Hemisphere

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Abstract: The Western Hemisphere warm pool (WHWP) has a large annual variation (Fig. 1), largest in summer when tropical storms affect the tropical North Atlantic (TNA) and the rising node of the Walker Circulation migrates from tropical South America to the WHWP. Both ENSO and tropical Atlantic SST indices (including the WHWP) correlate in similar ways with Western Hemisphere summer rainfall (Fig. 2). The similarity of the correlation patterns is probably related to the fact that ENSO often forces a delayed SST response in the Atlantic (Fig. 3). This results in the inter-correlation of the Pacific and Atlantic SST indices, and makes a definitive attribution difficult. In this paper we show that a strong TNA warming and associated large WHWP occur in the late spring and early summer following about half of the recognized El Niño events (1950-1999), but that this fails to occur after the other half of the El Niños (Fig. 4,5). One can thus construct composite-averaged summer rainfall maps for both subsets of El Niño events (Fig. 6a,b). Even though both sets follow El Niño, they are opposite in character depending on whether a warm Atlantic (and large warm pool) resulted, or not. This provides further evidence that the tropical North Atlantic and/or the warm pool are probably the direct source of the observed, and more nearly contemporaneous summer climate associations.

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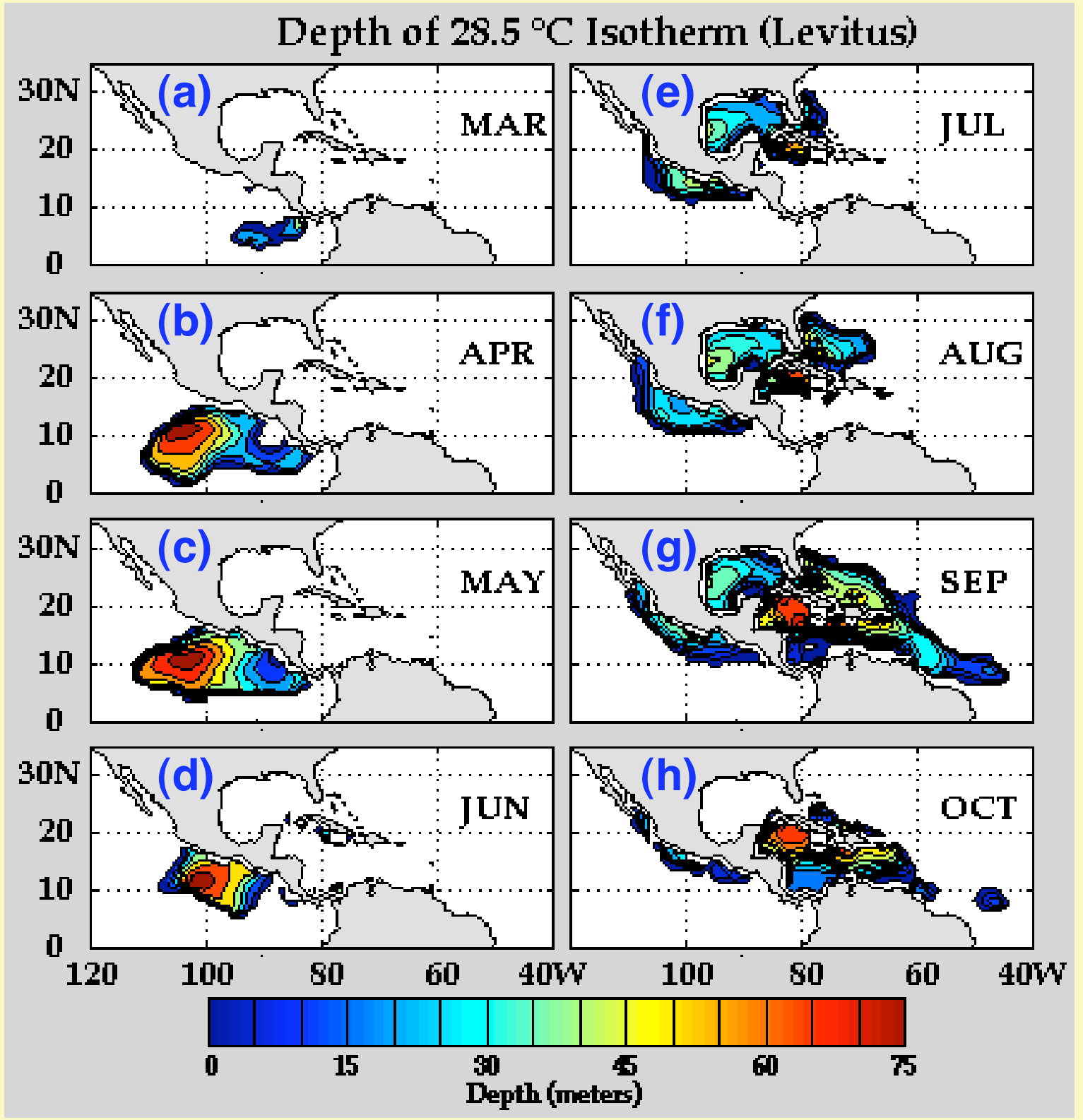

Fig. 1 -- The Western Hemisphere warm pool (WHWP) is the region of very warm (>28.5°C) SSTs that develops first in the eastern North Pacific in the spring, then expands to the Gulf of Mexico in July-August and finally encompasses the entire Intra-Americas Sea (IAS) and into the tropical North Atlantic (TNA) east of the Lesser Antilles, in September-October (*Enfield & Wang,* 2001, 2002). The depth of the 28.5°C "bubble" is usually close to the Levitus mixed layer depth. It is thickest to the west of the Costa Rica Dome in the Pacific **(b,c)** and in the northern Caribbean **(g,h)**.

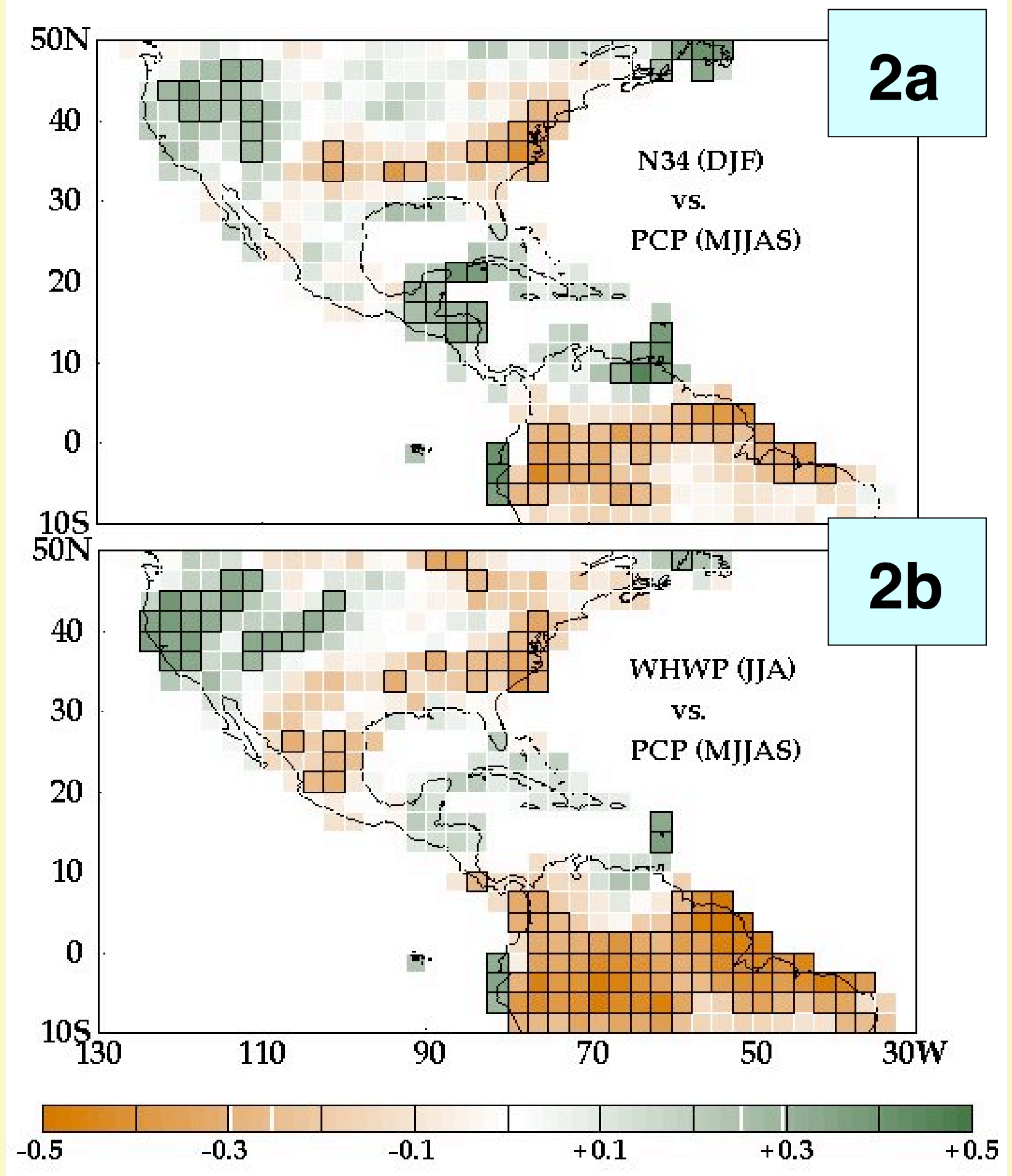

Fig. 2 -- Western Hemisphere maps of the correlation of May-October (MJJAS) rainfall anomaly with **(a)** prior winter N34 (DJF) and **(b)** concurrent summer WHWP (JJA). Here we see the difficulty of discriminating between the various indices and lags, because the patterns are very similar, either one more intense in certain regions and less intense in others. (black bevels ==> 90%)

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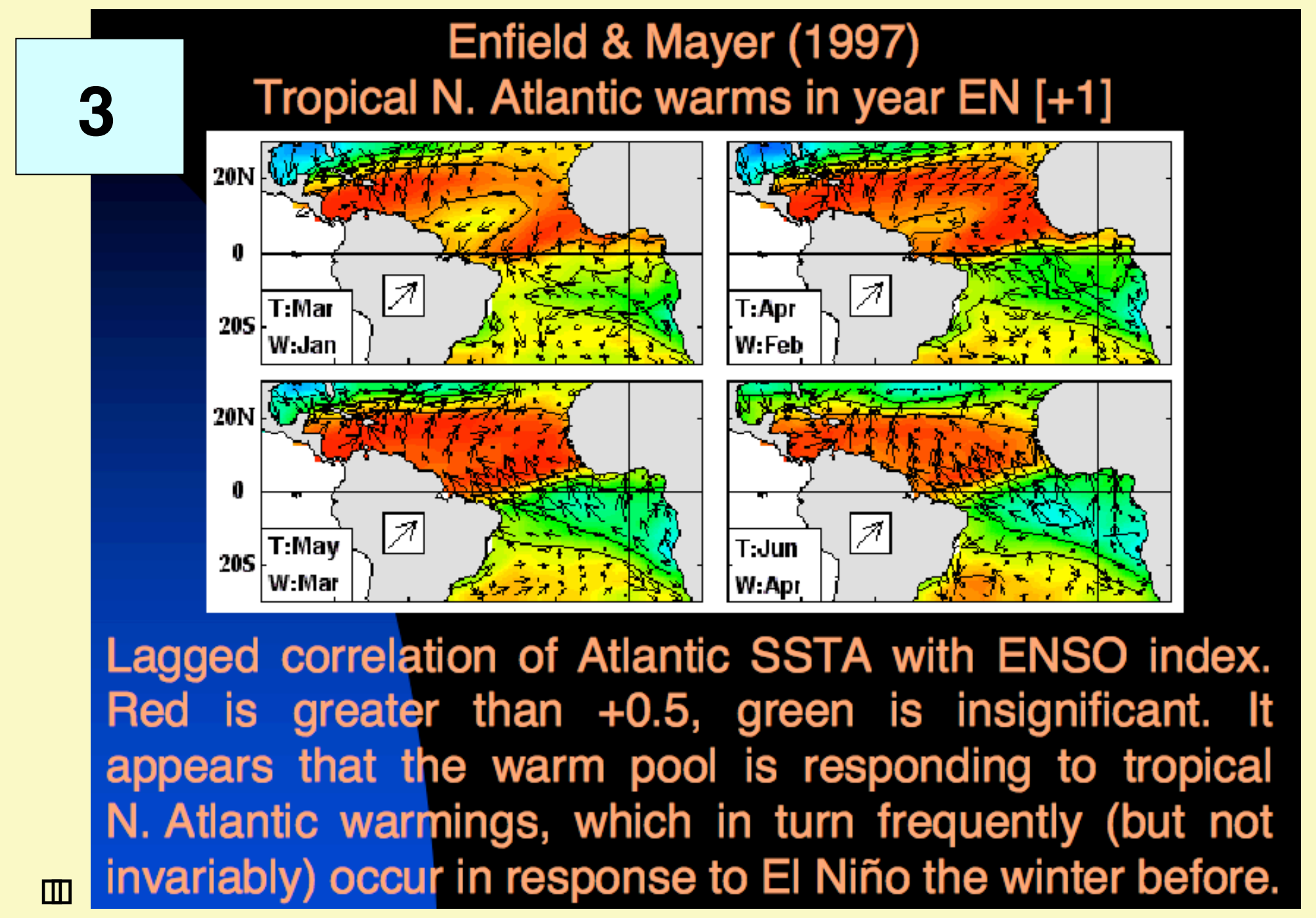
Enfield & Mayer (1997)
Tropical N. Atlantic warms in year EN [+1]



Lagged correlation of Atlantic SSTA with ENSO index. Red is greater than +0.5, green is insignificant. It appears that the warm pool is responding to tropical N. Atlantic warmings, which in turn frequently (but not invariably) occur in response to El Niño the winter before.

Fig. 3 -- Boreal winter ENSO peaks are associated with TNA warmings (or coolings) 4-6 months later in the boreal spring. This figure from Enfield and Mayer (1997) shows how the TNA SST anomalies tend to develop following El Niño peaks, with wind anomalies from two months prior superimposed. A "tropospheric bridge" from the Pacific results in weaker NE trades and heating due mainly to reduced evaporation.

Note, in particular, that the spring warming extends into the warm pool region. This must be related to anomalous warm pool growth and explains the high correlation between the WHWP and TNA indices (see Fig. 5).

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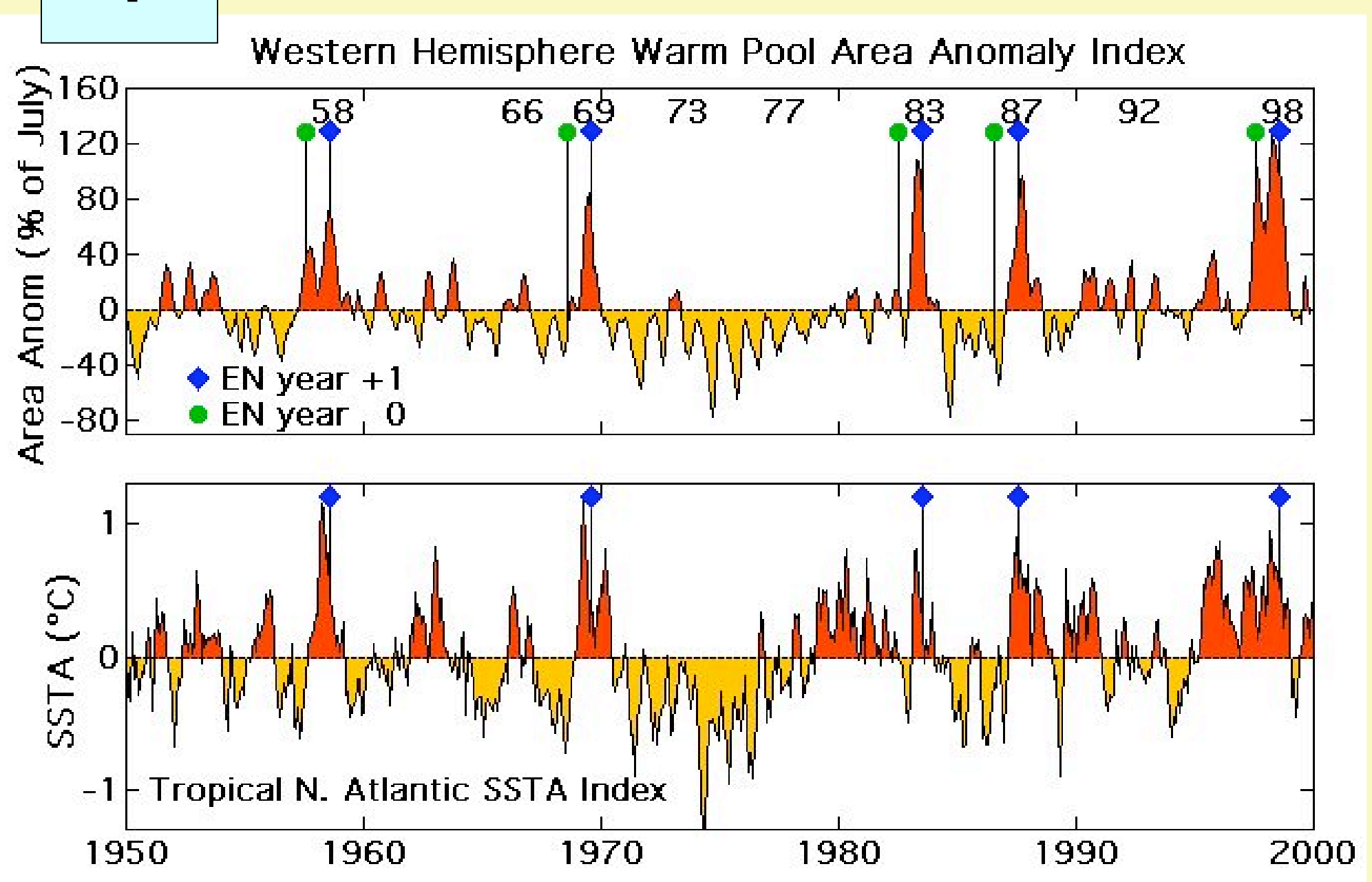
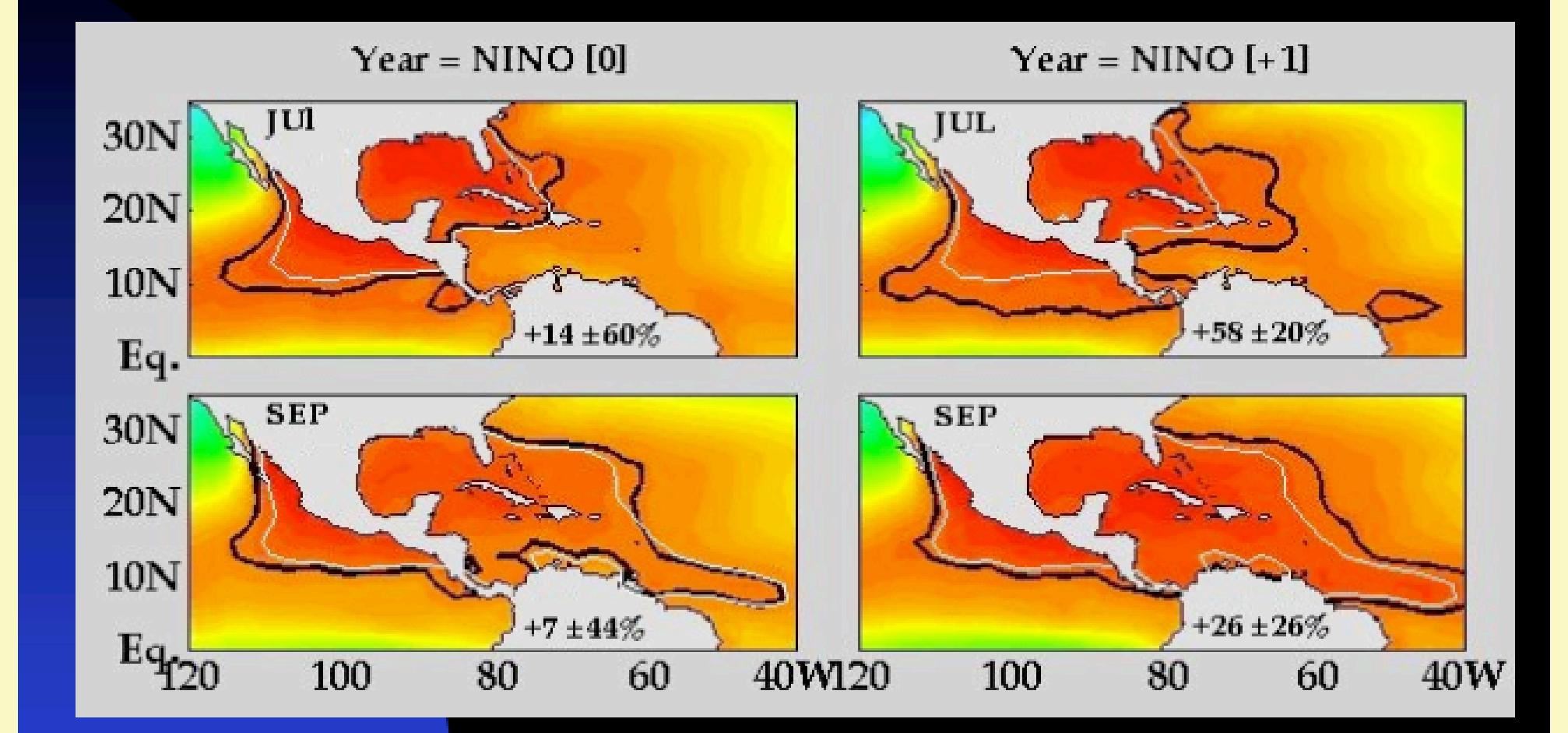


Fig. 4 -- **(a)** Time series of the WHWP area index anomaly. Numbers indicate Niño(+1) years. Blue diamonds (◆) highlight the upper decile, or five largest warm pools, which on average reached their maximum anomaly in July.

All five occurred in the summer following recognized El Niño events. These warm pools are about twice as large as the climatological average for July. They also coincide with strong warmings of the highly correlated TNA (r=0.54)* **(b)**. Note that four of the historically recognized El Niños were not followed by Atlantic warmings and large warm pools.

*Note: There is some overlap between the WHWP and TNA domains, but only when the eastern limits of the largest WPs extend east of the 50°W meridian. The correlation results because both respond to the "tropospheric bridge" (Fig. 3).

The 5 largest WPs occur in year EN [+1] and are significantly greater than the mean (90% significance)



However, occurrence of El Niño is no guarantee of a very large warm pool

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Fig. 5 -- Dark contours: Warm pools of the onset years (*EN[0],* left) and year following (*EN[+1],* right) five El Niños that engendered subsequent large warm pools (1957-58, 1968-69, 1982-83, 1986-87, and 1997-98). White contours: climatology.

Onset years tend to be near-normal in size, consistent with the years signaled by green circles (●) in Fig. 4a. The large warm pools are most anomalous in July. While the actual size continues to grow into the late summer, the anomalous excess decreases. This is consistent with Fig. 4. It is also consistent with the observation that Caribbean rainfall responds to Atlantic SSTA in the early summer more than the late summer (Taylor et al., 2002).

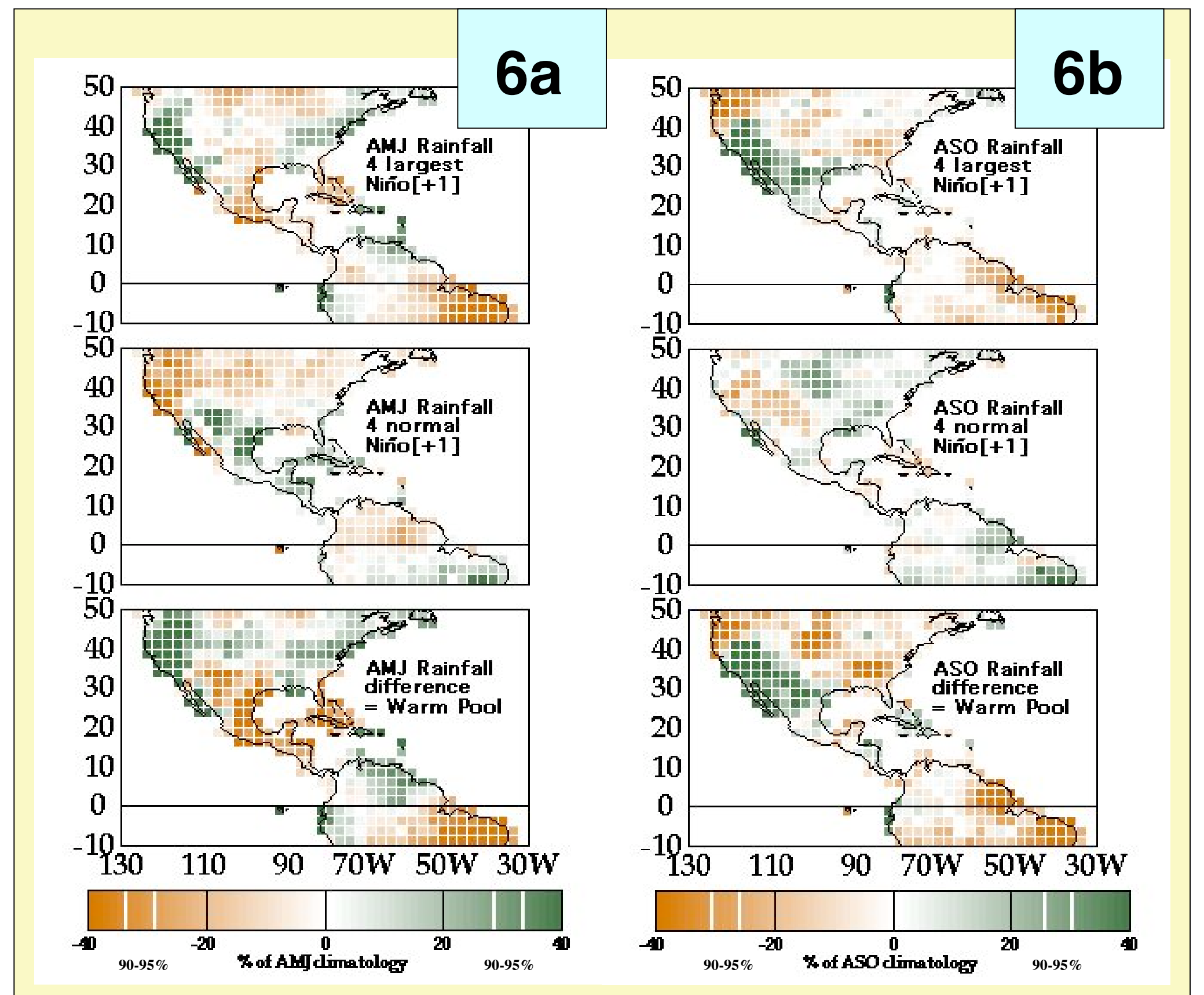

Fig. 6 -- Composite average precipitation patterns based on contrasting subsets of early **(6a)** and late **(6b)** summers following El Niño events: four with large warm pools (top: 1958, 1983, 1987, 1998) and four in which large warm pools failed to develop (Middle: 1966, 1973, 1977, 1992). The bottom maps are the difference between the top & middle composites. They highlight the effect of large warm pools on rainfall as contrasted with the effect of a prior El Niño.

Even though both sets follow El Niño, they are opposite in character depending on whether a warm Atlantic and large warm pool resulted, or not. This suggests that the tropical North Atlantic and/or the warm pool are probably the more direct source of the observed associations than the Pacific.

Discussion: Because only about half of the El Niño events result in very large warm pools, invariably in the year following the El Niño peak (Fig. 4), it is possible to construct composite averaged rainfall maps stratified on warm pool size but not on ENSO phase (Fig. 6). This approach minimizes the indeterminacy noted for correlations.

The composites show nearly opposite rainfall patterns depending on whether the warm pool is large or not. This suggests that it is not the prior occurrence of El Niño that most directly influences the summer rainfall pattern, but the occurrence (or not) of a warm TNA and a large warm pool.

The existence (or not) of large warm pools seems to have a modifying influence on how the northern monsoons respond to a prior El Niño maximum in the equatorial Pacific. In early summer, the Mexican Monsoon region is dryer for years when large warm pools develop. As the Monsoon develops into the late summer, the southwestern states (U.S.) become wetter than in years without a large warm pool.

Because of the small sample sizes, the influence of warm pool variability is not conclusive from this analysis. It suggests, however, that research should increasingly focus observations and modeling on the Atlantic and the warm pool as modulating influences on monsoon development. In particular, improved summer predictability should result from understanding why Atlantic warm pool growth occurs following some El Niño peaks and not others, and in developing coupled models that correctly emulate that process and predict the Atlantic warmings.