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ENSO and Atmospheric Circulation Cells[1]

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1. Introduction

Bjerknes (1969) first visualized a close relation among the Southern Oscillation, east-west SST contrast in the equatorial Pacific Ocean, and the thermally driven zonal Walker circulation. Since then, the Walker circulation has been recognized to be associated with the interannual phenomenon of ENSO and schematic diagrams of the Walker circulation cell during ENSO have been well-known (e.g., Webster and Chang, 1988; McPhaden et al., 1998). However, how the Walker circulation cell evolves during ENSO from data has not been well studied, probably because of a lack of observational data. The atmosphere also has meridional circulation cells: the Hadley cell and the Ferrel cell (e.g., Trenberth et al., 2000; and references there). Little is known about how these atmospheric meridional cells vary during the evolution of ENSO. The recently available data of the NCEP-NCAR reanalysis field provide an opportunity to study the atmospheric circulation associated with ENSO. This note also reports an atmospheric mid-latitude zonal cell (MZC) over the North Pacific. Additionally, it shows how the Pacific El Niño affects the tropical North Atlantic through the Walker and Hadley cells.

2. Mean and interannual atmospheric cells

This note briefly summarizes mean and interannual atmospheric circulation cells over the Pacific that are analysed from the NCEP-NCAR reanalysis field from 1950-1999. Detailed data analyses are available in Wang (2002a, b). Atmospheric circulation cells are identified by atmospheric vertical motion and the divergent component of the wind.

Based on the data analysed from the NCEP-NCAR reanalysis, the mean state and anomaly of the equatorial zonal Walker cell, the tropical meridional Hadley cell, the extratropical meridional Ferrel cell, and the MZC are summarized in Fig. 1.

The mean Walker circulation cell is characterized as the air ascending in the equatorial western Pacific, flowing eastward in the upper troposphere, sinking in the equatorial eastern Pacific, and returning toward the equatorial western Pacific in the lower troposphere (Fig. 1a). The western Pacific shows a single mean Hadley cell, with the air rising in the tropical region, flowing poleward in the upper troposphere, and returning to the tropics in the lower troposphere. In the eastern Pacific, the tropical circulation has two meridional cells with moist air rising in the intertropical convergence zone (ITCZ), then diverging northward and southward in the

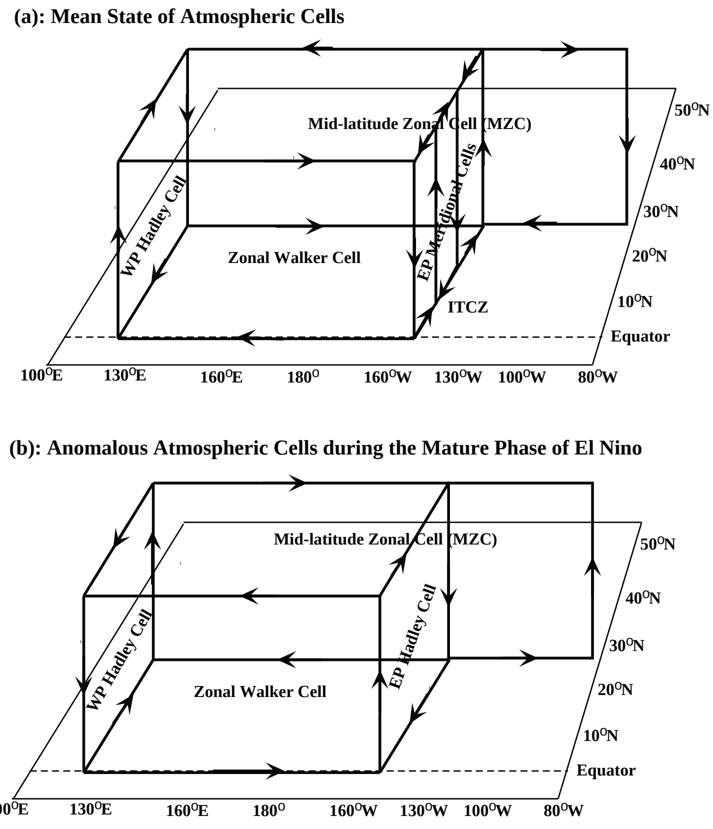

Fig. 1: Schematic diagrams summarizing (a) mean state of atmospheric circulation cells and (b) anomalous atmospheric cells during the mature phase of El Niño. Shown are the equatorial zonal Walker cell, the merdional Hadley cell in the western Pacific (WP), the meridional Hadley and Ferrel cells in the eastern Pacific (EP), and the mid-latitude zonal cell (MZC). The schematic diagrams are drawn, based on the data analyzed from the NCEP-NCAR reanalysis field (Wang, 2002a).

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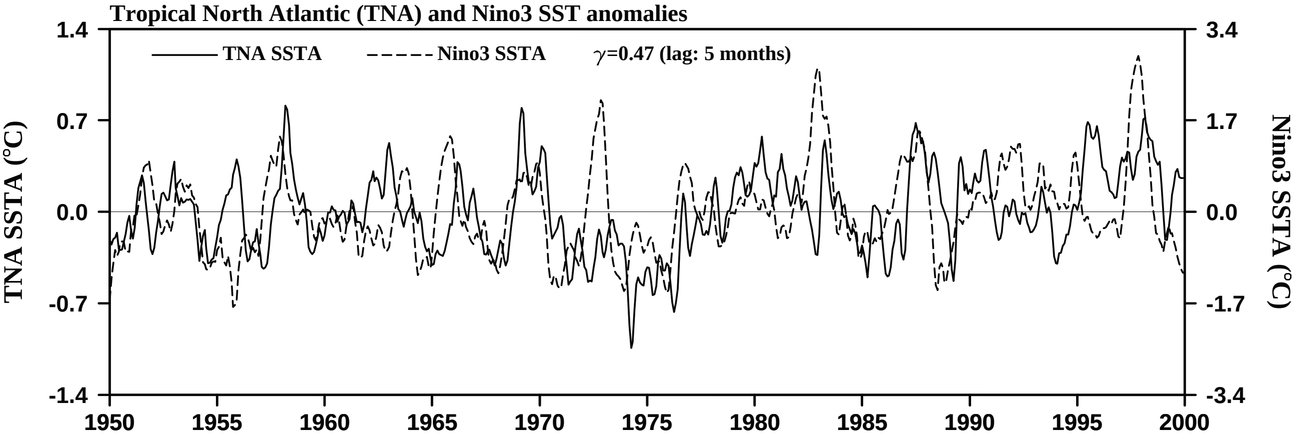

Fig. 2: Three-month running means of SST anomalies in the tropical North Atlantic (TNA) region (5°N-25°N, 55°W-15°W) and SST anomalies in the Nino3 region (5°S-5°N, 150°W-90°W). The γ represents correlation coefficient. The data are from the NCEP SST.

upper troposphere, and descending over the regions of the subtropical high and the equatorial eastern Pacific cold tongue. The extratropics shows a classical Ferrel cell, with upward motion in the mid-latitudes and downward motion in the southern extratropics.

The mean MZC shows that the air rises in the central North Pacific, diverges eastward and westward in the upper troposphere, descends over regions of the west coast of North America and the east coast of Asia, then flows back to the central North Pacific in the lower troposphere. As in the Walker and Hadley cells, the MZC is identified by the divergent wind and the pressure vertical velocity. If we also consider the rotational wind, the MZC is not a closed cell (Wang, 2002a).

The atmospheric cells also vary with the interannual phenomenon of ENSO. Figure 1b shows the anomalous atmospheric cells for the mature phase of El Niño. During the mature phase of El Niño, both the Walker cell and the MZC are weakened. The anomalous Hadley cell in the eastern Pacific during the mature phase of El Niño shows the air rising in the tropical region, flowing northward in the upper troposphere, descending in the mid-latitude, and returning to the tropics in the lower troposphere. The anomalous Hadley cell in the western Pacific has an opposite rotation as that of the anomalous Hadley cell in the eastern Pacific.

3. Influence of the Pacific El Niño on the tropical North Atlantic

The SST anomalies in the tropical North Atlantic (TNA) and in the Niño3 region are shown in Fig. 2. The maximum positive correlation of 0.47 occurs when the TNA SST anomalies lag the Nino3 SST anomalies by five months, consistent with previous studies (e.g., Curtis and Hastenrath, 1995; Enfield and Mayer, 1997). Since the mature phase of the Pacific El Niño occurs around December of the Pacific El Niño year, the TNA SST anomalies thus tend to peak around subsequent May of the Pacific El Niño year. Previous studies have suggested that the Pacific El Niño affects TNA northeast (NE) trade winds that reduce latent heat flux and then increase the TNA SST. The question is: how does the Pacific El Niño affect the TNA trade winds? Herein, the Walker and Hadley circulations are emphasized for linking the Pacific El Niño with the TNA.

The anomalous Walker and Hadley cells during the mature phase of El Niño, analysed from the NCEP-NCAR reanalysis field (Wang, 2002b; Wang and Enfield, 2002), are summarized in Fig. 3. The air anomalously ascends in the far equatorial eastern Pacific, diverges eastward in the upper troposphere, and then descends over the equatorial Atlantic. Associated with this anomalous Atlantic Walker circulation is an anomalous Hadley circulation cell in the Atlantic. The Hadley cell shows anomalous ascending motion in the region of the subtropical high. The anomalous ascending motion weakens subsidence in the region of the subtropical high pressure system. This corresponds to a weakening of the subtropical high and the associated NE trade winds over its southern limb in the TNA region. The weaker NE trades reduce evaporation, leading to warm SST anomalies over the TNA in the subsequent spring of the Pacific El Niño year. When the warm TNA SST anomalies are established in spring, the TNA region shows anomalous ascending motion (Wang, 2002b).

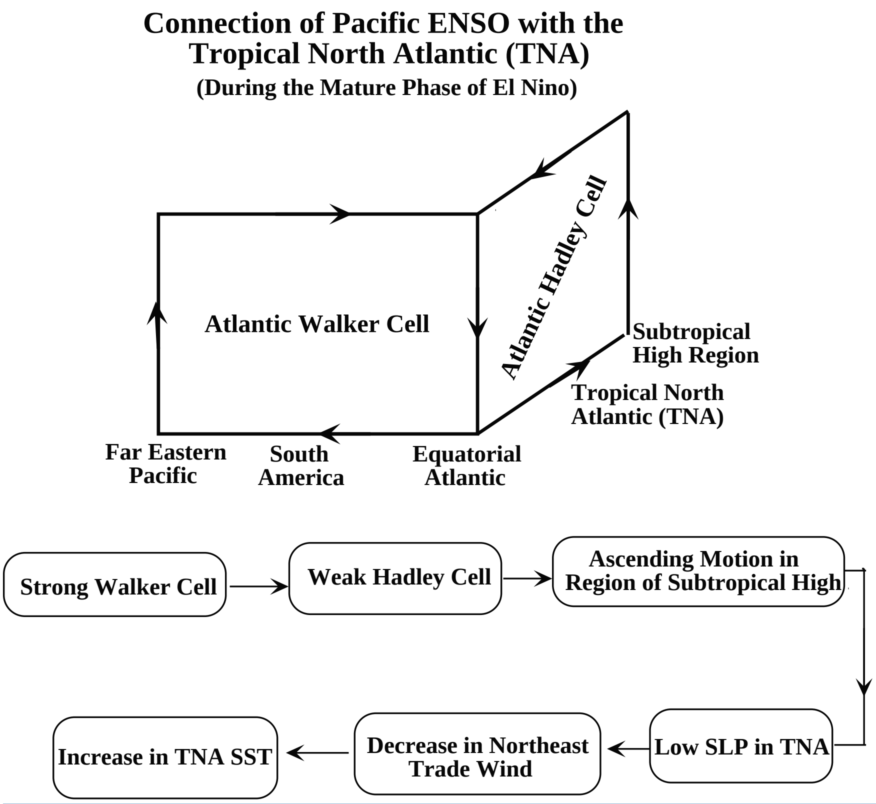

Fig. 3: Schematic diagrams showing linkage of the Pacific El Niño with the tropical North Atlantic (TNA). The anomalous Atlantic Walker and Hadley circulation cells are drawn, based on the data analyzed from the NCEP-NCAR reanalysis field (Wang 2002b).

4. Summary

The NCEP-NCAR reanalysis field shows interannual variations of atmospheric circulation cells. During El Niño, the equatorial zonal Walker cell is weakened. The anomalous meridional Hadley circulation cell in the eastern Pacific shows the air rising in the tropics, flowing poleward in the upper troposphere, sinking in the subtropics, and returning to the tropics in the lower troposphere. The anomalous Hadley cell in the western Pacific is opposite to that in the eastern Pacific. The divergent wind and vertical velocity also show a MZC over the North Pacific. The mean MZC is characterized by the air rising in the central North Pacific, flowing westward and eastward in the upper troposphere, descending in the east coast of Asia and the west coast of North America, then returning back to the central North Pacific in the lower troposphere. The anomalous MZC during the mature phase of El Niño shows an opposite rotation to the mean MZC, indicating a weakening of the MZC. During the boreal winter a strong Hadley cell emanates northward from the Amazon heat source with subsidence over the subtropical North Atlantic, sustaining a strong North Atlantic anticyclone and associated NE trade winds over its southern limb in the TNA. This circulation, including the NE trades, is weakened during Pacific El Niño winters and results in a spring warming of the TNA.

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