Atmospheric Circulation Cells Associated with ENSO and Atlantic Climate Variability

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Using the NCEP-NCAR reanalysis field, this paper describes and examines the regional atmospheric circulation cells over the Pacific and Atlantic. The mean Pacific and Atlantic Walker circulation cells are characterized as the air ascending in the west equatorial region, flowing eastward in the upper troposphere, sinking in the east, and returning toward the west equatorial region. The mean Hadley circulation cells in the western Pacific and Atlantic show 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 and Atlantic, the Hadley circulation has two meridional cells with moist air rising in the intertropical convergence zone (ITCZ), then diverging northward and southward in the upper troposphere, and descending over the regions of the subtropical high and the equatorial cold tongue region. The divergent wind and vertical motion of the NCEP-NCAR reanalysis field show an atmospheric mid-latitude zonal cell (MZC) in the North Pacific. The mean MZC is characterized by the air rising in the central North Pacific, diverging westward and eastward in the upper troposphere, descending over the regions of the east coast of Asia and the west coast of North America, then flowing back to the central North Pacific in the lower troposphere.

Atmospheric circulation cells vary with the interannual phenomenon of ENSO. 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.

Our analyses show that atmospheric circulation cells can serve as a tropospheric bridge for transferring Pacific El Niño effects to the Atlantic sector. As the El Niño warming culminates near the end of the calendar year, an alteration of the low-latitude direct circulation occurs, featuring (1) an anomalous weakening of the convection over northern South America, (2) Walker circulation anomalies along the equatorial strip to the east and west, and (3) a weakened northward Atlantic Hadley flow aloft. The Hadley weakening results in less subsidence over the subtropical North Atlantic, an associated breakdown of the anticyclone and a weakening of the northeast trade winds in the tropical North Atlantic (TNA). The wind weakening leads to less evaporative surface cooling and entrainment of colder water from below the shallow oceanic mixed layer, resulting in warming of the TNA. The TNA anomalies expand area of the Western Hemisphere warm pool (WHWP). The WHWP SST anomalies, aided by a positive ocean-atmosphere feedback operating through longwave radiation and associated cloudiness, peak around the summer following Pacific El Niño. Once a large WHWP is formed, the atmosphere shows an altered circulation with the increased Hadley flow into the subtropical South Pacific that reinforces the South Pacific anticyclone and trade winds, probably playing a role in the transition back to the cool phase of ENSO.

Atmospheric circulation cells also vary with the Atlantic El Niño, the tropical Atlantic meridional gradient mode, and the North Atlantic Oscillation (NAO). During the warm phase of the Atlantic El Niño, the Atlantic Walker circulation weakens and extends eastward, which results in equatorial surface westerly wind anomalies in the western Atlantic. These westerly wind anomalies are partly responsible for warming in the equatorial eastern Atlantic that occurs in the second half of the year. The Atlantic El Niño thus seems to involve a positive ocean-atmosphere feedback associated with the Atlantic Walker circulation, similar to the Pacific El Niño. The tropical Atlantic meridional gradient mode is characterized by a strong SST gradient between the tropical North Atlantic and the tropical South Atlantic. Corresponding to the meridional gradient mode is an atmospheric meridional circulation cell in which the air rises over the warm SST anomaly region, flows toward the cold SST anomaly region aloft, sinks in the cold SST anomaly region, then crosses the equator toward the warm SST region in the lower troposphere. During the high NAO index, the atmospheric Ferrel and Hadley cells are strengthened, consistent with surface westerly and easterly wind anomalies in the North Atlantic and in the middle-to-tropical Atlantic, respectively. These winds are responsible for an alternating warm and cold SST anomaly tripole pattern observed during the high NAO index.