Dynamics of the Pacific Equatorial Dry Zone

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With 6 Figures

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Summary

The circulation mechanisms instrumental in the origin of the Pacific equatorial dry zone are studied from a combination of data sources. A triple structure of convergence zones enclosing a near-equatorial zone of surface divergence is well developed only in March-April. Over the eastern Pacific the divergence band is centered to the north of the equator. Downstream acceleration and meridional divergence in the cross-equatorial flow from the southern hemisphere result from the rightward directed and northward increasing Coriolis acceleration. Upper-tropospheric convergence and subsidence along the equator is compensated by divergence in the realm of the Equatorial Mid-Tropospheric Easterly Jet. While not feeding the divergence near the surface, the subsidence throughout the mid troposphere is unconducive to deep convection and may thus also contribute to the scarcity of cloudiness. Proceeding from the eastern towards the central Pacific, the mid-tropospheric jet vanishes, the cross-equatorial surface airflow fades out, and concordant with the axis of smallest upward motion the divergence maximum and cloudiness minimum shift to south of the equator.

1. Introduction

In the planetary perspective, the very low latitudes excel by the most abundant rainfall. Astounding in this context is the existence of a dry zone along the equator across much of the eastern and central Pacific. This has caught the curiosity of pioneering climatologists more than a century ago (Woeikoff, 1880; Hann, 1880; Koeppen, 1895; Deutsche Seewarte, 1886–97), and has been substantiated in subsequent decades (Schott, 1933a,b, 1938; U.S. Weather Bureau, 1938). Experience during WWII stimulated hypotheses on the vertical circulation in the free atmosphere (Fletcher, 1945; Rossby, 1949; review in Asnani, 1993, pp. 117–120).

An unprecedented synopsis of the cloudiness patterns over the entire Pacific basin was afforded by the launch of meteorological satellites in the 1960’s. With the motivation of providing ground truth for the satellite, the Line Islands Experiment (LIE) was conducted in the boreal spring 1967 (Zipser and Taylor, 1968). Satellite imagery showed during March-April 1967 a clear zone near the Equator enclosed by bands of cloudiness in either hemisphere. From the evaluation of the atmospheric heat budget subsidence was inferred near the equator, and from the compilation of historical ship observations (U.S. Weather Bureau, 1938) it was concluded that the surface divergence was prevalingly associated with the meridional wind component (Hastenrath, 1971).

In recent decades, much attention has been given to the zonal-vertical circulation along the Pacific equator (Walker cell) as proposed by Bjerknes (1966, 1969) and its role in the functioning of the Southern Oscillation (review in Hastenrath, 1995, p. 181, 198–201, 264–291). In the light of the dynamics of the zonal circulation envisioned by Bjerknes (1966, 1969) and appropriate to the vicinity of the equator...
only, and the longitude domain of the scarcest cloudiness, it appears tempting to interpret the Pacific equatorial dry zone as a subsiding portion of the Walker cell.

Such conjectures on the origin of the Pacific equatorial dry zone remain to be ascertained from comprehensive observational evidence including of the upper-air flow. Indeed, data sources that have since become available invite an expansion on the earlier study of the Pacific equatorial dry zone (Hastenrath, 1971). Earlier analyses for the equatorial Atlantic and eastern Pacific (Hastenrath and Lamb, 1977, 1978) will also be pertinent. Section 2 describes the data and analysis procedures, Sects. 3 to 5 discuss the recent results, and a synopsis is offered in the closing Sect. 6.

2. Data and Analysis

The data sources used in this study comprise global upper-air analyses and surface ship observations.

The National Center for Environmental Prediction—National Center for Atmospheric Research (NCEP-NCAR) Reanalysis (Kalnay et al., 1996; Kousky and Ropelewski, 1997) at a 2.5 degree latitude-longitude resolution and with an “origin” gridpoint at zero latitude and longitude was acquired for the years 1958–97. Data were processed into individual monthly mean fields and these were then averaged over the entire period of record. Elements of interest here are the fields of wind and vertical velocity for the levels surface (10 m), 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200 and 100 mb.

The ECMWF global upper-air analyses at a 2.5 degree latitude-longitude spatial resolution were acquired for the years 1980–93, but the fields of divergent wind component are regarded as reliable only from 1985 onward (Palmer et al., 1992). The quality of the ECMWF dataset has been considered by Palmer et al. (1992) and others.

Surface ship observations stemming from the same TDF-11 dataset as used in our atlases (Hastenrath and Lamb, 1977) were available in the COADS collection, with spatial resolutions of two and one degree squares (Woodruff et al., 1987, 1993). For the documentation of the surface wind field the ship observations of COADS are deemed superior to either the NCEP-NCAR or ECMWF 1000 mb maps.

From the total wind field at selected levels velocity potential and streamfunction were computed as described in Mancuso (1967), Krishnamurti (1971), and Krishnamurti et al. (1973), with full coverage from 75° N to 75° S and a grid spacing of 2.5 degrees. An inner sub-domain from these near-global fields is used here. From the fields of velocity potential maps were then constructed of divergent wind component and divergence.

The data sources described above were evaluated in a diversity of ways. Considering that the observational input to the NCEP-NCAR assimilation varied over the decades, analyses were carried out for the intervals 1958–78 and 1979–97, as well as 1958–97, with similar results. A limited comparison with the ECMWF dataset indicates that major characteristics of the large-scale circulation are reliably captured. Only the 1958–97 analyses of the NCEP-NCAR set are presented here. Maps of indicative atmospheric fields for the domain 15° N–15° S and 180–70° W are complemented by the meridional profiles for the strip 120–90° W and vertical cross sections. It is recognized that the NCEP-NCAR dataset stems from model-assimilation of observations and thus may not represent straightforward atmospheric reality. The present application to a definite meteorological problem may thus also serve to explore the potential and limitations of the NCEP-NCAR dataset.

3. Seasonal Evolution

Figure 1 illustrates the seasonal evolution of the surface circulation for the sector 120–90° W, where the triple structure of convergence zones enclosing a near-equatorial zone of divergence during boreal spring is particularly pronounced (Fig. 2a). The meridional profiles of sea level pressure (Fig. 1a) show in the progression from February to March and April a low pressure trough centered around 0–5° N displacing northward and becoming broader and flatter. From may onward the South Pacific high expands equatorward, in such a way that the steepest meridional pressure gradient changes from a location near 10–8° S in February-March-April