第五章:

大气环流中的纬向环流系统

5.3 Walker Circulation

授课教师：张洋

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Outline

- Introduction
- Features of Walker circulation
- Seasonal variation of walker circulation
- ENSO and Walker circulation (inter-annual variation)
- The two-box model of Walker circulation
- Summary
Introduction

**Walker Circulation** was first introduced in 1966 by Prof. Jacob Bjerknes, referring to the large scale atmospheric circulation along the *longitude-height plane* over the *equatorial Pacific Ocean*.

Named after Gilbert Walker, a key contributor to Southern Oscillation.
Introduction

The term Walker Circulation was first introduced in 1969 by Professor Jacob Bjerknes, referring to the large-scale atmospheric circulation along the longitude–height plane over the equatorial Pacific Ocean. The Walker Circulation features low-level winds blowing from east to west across the central Pacific, rising motion over the warm water of the western Pacific, returning flow from west to east in the upper troposphere, and sinking motion over the cold water of the eastern Pacific. Since Bjerknes’s introduction of the Walker Circulation, there have been reports of similar east–west circulation cells spanning different longitudinal sectors along the Equator. Today, the Walker Circulation generally refers to the totality of the circulation cells as shown in Figure 1.

Bjerknes originally named the Pacific east–west circulation the Walker Circulation because he considered it the key part of Sir Gilbert Walker’s Southern Oscillation (see El Nino and the Southern Oscillation: Observation). He interpreted the Walker Circulation as an atmospheric circulation driven by the gradient of sea surface temperature along the Equator and suggested that the characteristics of the Walker Circulation were largely determined by the coupling between the tropical atmosphere and oceans. Bjerknes’s work on the Walker Circulation marked an important milestone toward our basic understanding of the dynamics of zonal atmosphere–ocean coupling along the equatorial Pacific Ocean. Although his results were based on very limited data, Bjerknes’s original conjecture that the year-to-year variation of the Walker Circulation is closely tied to that of the Southern Oscillation and El Niño has been confirmed by a large number of observational and modeling studies during the several decades since his first report.

Climatology and Variability

Annual Mean

Thanks to the advance in satellite observations and improved assimilation of observations into global general circulation models, we have now a much more detailed and quantitative description of the Walker Circulation. We know that the tropical wind is made up of rotational and divergent components. The former is directly related to the effects of the rotation of the Earth and the latter to the overturning circulation, driven by atmospheric heating processes. The Walker Circulation and associated overturnings in the equatorial plane should refer only to the divergent component of the wind. Figure 2A shows the annual climatology (the mean state of all months) of the overturning circulations along the equatorial plane as streamlines constructed from the divergent zonal and vertical winds. It can be seen that the major rising...
Observed features
Observed features

Adapted from Emanuel, 2005
Observed features

great amount of convective cloud in the western pacific
**Observed features**

Walker Circulation viewed as an air-sea coupled, self-maintained system

![Diagram of Walker Circulation](image)

Adapted from NOAA
El Niño is defined by prolonged differences in tropical Pacific Ocean SST when compared with the average value. The accepted definition is a warming or cooling of at least 0.5 °C averaged over the east-central tropical Pacific Ocean. Typically, this anomaly happens at irregular intervals of 2–7 years and lasts nine months to two years.

The Southern Oscillation is the atmospheric component of El Niño. This component is an oscillation in surface air pressure between the tropical eastern and the western Pacific Ocean waters. The strength of the Southern Oscillation is measured by the Southern Oscillation Index (SOI). The SOI is computed from fluctuations in the surface air pressure difference between Tahiti and Darwin, Australia.
ENSO and Walker Circulation

Adapted from NOAA
ENSO and

Walker Circulation

La Niña Conditions

Equator

Thermocline

120°E

80°W

Adapted from NOAA
ENSO and Walker Circulation

El Nino years:

Raising motion prevailed at almost all longitudes with a peak in central pacific.

La Nina years:

An enhanced Walker Circulation.

Adapted from Lau et al, 2002
ENSO and Walker Circulation

Jan-Mar 1998 Precipitation (mm)

Total

Departures (x100)

El Nino years

Adapted from NOAA
ENSO and Walker Circulation

Jan-Mar 1989 Precipitation (mm)

Total

Departures (x100)

La Nina years

Adapted from NOAA
ENSO and Walker Circulation

Adapted from NOAA
ENSO and Walker Circulation

Adapted from NOAA
ENSO and Walker Circulation

Adapted from NOAA
ENSO and Walker Circulation

COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY

Adapted from NOAA
ENSO and Walker Circulation

COLD EPISODE RELATIONSHIPS JUNE - AUGUST

Adapted from NOAA
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Two-box model

Walker Circulation

Interaction between convection and large-scale circulation

Two-Box Model:

- **Weak circulation**: Deep convection in both boxes
- **Strong circulation**: Deep convection only in warm box

Adapted from Emanuel, 2005
Two-box model

Walker Circulation

\[ s \equiv c_p(T_s - \bar{T}) \ln(\theta_e^*) \]

\( \theta_e^* \) -- saturation equivalent potential temperature

- \( s_{oc} \) - entropy on the cold ocean surface
- \( s_{bc} \) - entropy in the boundary layer over the cold ocean surface

\( s^* \) - entropy in the free troposphere, recall the weak temperature gradient in the tropics

Assume:
Quasi-equilibrium of the entropy in the boundary layer

Mass continuity

**Strong circulation**: Deep convection only in warm box

Adapted from Emanuel, 2005
**Two-box model**

**Walker Circulation**

**IN EACH BOX:**

- **Updraft**
- **Downdraft**
- **Entrainment**

Mass continuity:

\[ M_u - M_d - (1 - \sigma)w_d = w_b = \gamma w \]

In the boundary layer of the convecting zone, assume equilibrium:

\[ h \frac{\partial S_b}{\partial t} \approx 0 = F_s - (M_d + (1 - \sigma)w_d)(s_b - s_m) \]

Adapted from Emanuel, 2005
Two-box model

Walker Circulation

Two-Box Model:

Weak circulation: Deep convection in both boxes

Strong circulation: Deep convection only in warm box

Adapted from Emanuel, 2005
Walker circulation is the large-scale atmospheric overturning circulation along the longitude-height plane over the equatorial Pacific Ocean.

Walker circulation is a zonal temperature gradient driven, air-sea coupled phenomena.

Walker circulation shows seasonal migration in its location.

Walker circulation is strongly affected by the ENSO events, with broad impact on the climate in the tropical and extratropical regions.

The two-box model: the strength of walker circulation is determined by the entropy difference between the warm pool and the cold tongue, and the precipitation efficiency in the convective zone.