第一章:

大气环流概述

授课教师：张洋
第一章:

大气环流概述

Reference reading:
PO Chapter 5.1-5.2; James Chapter 2.2, 2.4
大气环流概述

- 历史回顾
- 内容简介
- 观测资料
- 资料处理与分析
- 再分析资料
- 分析方法
大气环流概述 - 历史简介

1735年 Hadley 信风理论

1832年 Coriolis

1856年 Ferrel

20世纪前二三十年

role of eddies

1939年 Rossby 长波理论

1947, 1949年 Charney, Eady 斜压不稳定性理论

1950-59年 Lorenz 能量循环

1960年 气象卫星 (TIROS-1)

1961年 Eliassen-Palm 通量

波流相互作用

20世纪六七十年代

气候模式

1975年 Wally Broecker in Science

1970年代

海气模式

1980年 Held-Hou 模型

1988年 James Hansen in US Congress

1985年 Kyoto Protocol

2005年 Kyoto Protocol into action

21世纪

Global Warming

2014年 5th IPCC

2021年 6th IPCC

至今

全球变暖

1990年 1st IPCC

2007年 4th IPCC

2016年 Paris Agreement

授课教师：张洋
大气环流概述 — 历史简介

1735年 Hadley 信风理论
1832年 1857年 Coriolis Thomson
1856年 Ferrel
1939年 Rossby 长波理论
1947, 1949年 Charney, Eady 斜压不稳定性理论
1950-59年 Lorenz 能量循环
1960年 气象卫星 (TIROS-1)
1961年 Eliassen-Palm 通量波流相互作用
1960年
1975年 Wally Broecker in Science
1980年 Held-Hou 模型
1988年 James Hansen in US Congress
1997年 Kyoto Protocol
2005年 held-Hou 模型
2007年 4th IPCC
2014年 5th IPCC
2016年 Paris Agreement
2021年 6th IPCC

授课教师：张洋
1735年，Hadley 信风理论

- **Motivation**: explain the easterly (northeasterly) trade winds of the tropics and the prevailing westerly (northwesterly) of midlatitudes.

- **Single cell**: solar heating in low latitudes lead to rising motion near the equator and sinking near the poles, with equatorward motion at low levels and poleward motion aloft.

- Conservation of **absolute velocity**: the equatorward motion at low levels turns westerly when arriving at high latitudes and forms the trade wind.

1735年，Hadley 信风理论

**Motivation**: explain the easterly (northeasterly) trade winds of the tropics and the prevailing westerly (northwesterly) of midlatitudes.

**Single cell**: solar heating in low latitudes lead to rising motion near the equator and sinking near the poles, with equatorward motion at low levels and poleward motion aloft.

**Conservation of absolute velocity**: the equatorward motion at low levels turns westerly when arriving at high latitudes and forms the trade wind.

Understanding the effect of earth’s rotation!


Gaspard-Gustave de Coriolis
1792-1843
1856年, Ferrel’s view

- Observed *southwesterly* challenged Hadley’s theory;
- **Three-cell circulation**, close to current views of earth’s general circulation.
1857年，Thomson’s view

Still a single direct cell in the upper troposphere;

In the lower levels of middle and higher latitudes, a shallow indirect cell with poleward flow near ground and equatorward flow in the intermediate levels.
1859年, Ferrel’s second view

Close to Thomson’s view, except for a polar cell in high latitudes.
The role of eddies?

- **Bigelow (1902)**, the effect of cyclones should be taken into account.
- **Defant (1912)**, eddies transport heat to higher latitudes.
- **Jeffreys (1926)**, eddies transfer angular momentum.
- **V. Bjerknes (1937)**, Ferrel-Thomson’s circulation is unstable to eddies.

BY

C.-G. ROSSBY AND COLLABORATORS

Massachusetts Institute of Technology

This paper attempts to interpret, from a single point of view, several at first sight independent phenomena brought into focus through the synoptic investigations carried on at the Massachusetts Institute of Technology during the last few years. Since this interpretation is very largely based on a consideration of the changes in vorticity which must occur in vertical air columns which are displaced from one latitude to another and since such vorticity changes play a fundamental role also in Ekman’s general ocean current theory (1932), the results would appear to be of enough interest to physical oceanographers to warrant their publication in this journal. The particular phenomena brought out in the course of our studies are listed below.
Currently most-accepted view
大气环流概述 — 内容简介

The British Atmospheric Data Centre (BADC)
www.badc.nerc.ac.uk/data/claus (infra-red)
Observations

-Zonal mean fields

- Stream function (流函数)
Observed features

great amount of convective cloud in the western pacific
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 Nin˜o and the Southern Oscillation: Observation (0148)). 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 Nin˜o 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
Features of monsoonal circulation: - an Indian monsoon example

- High temperature
Non-zonal circulations
Storm tracks

The storm zones occur in association with the jet streams;

The storm zones are most intense near the longitude of the jet exits.
大气环流概述 - 内容简介

- 外部强迫：
  - 辐射强迫
  - 下界面过程

- 经向环流系统（纬向平均环流, zonally averaged circulations）：
  - Hadley 环流
  - Ferrel 环流、急流、波流相互作用

- 纬向环流系统：
  - Storm tracks
  - Monsoon
  - ENSO and Walker circulation

- 不同复杂度的大气环流模式
大气环流概述 - 内容简介

- 外部强迫：
  - 辐射强迫
  - 下界面过程

- 经向环流系统（纬向平均环流, zonally averaged circulations）：
  - Hadley 环流
  - Ferrel 环流、急流、波流相互作用

- 纬向环流系统：
  - Storm tracks
  - Monsoon
  - ENSO and Walker circulation

- 不同复杂度的大气环流模式
- 全球暖化背景下的大气环流
Currently most-accepted view
大气环流概述

- 历史回顾
- 内容简介
- 观测资料
- 资料处理与分析
- 再分析资料
- 分析方法
大气环流概述 - 历史简介

1735年 Hadley 信风理论

高空探测资料 二十世纪三四十年代

气象卫星 (TIROS-1) 1960年

NCEP/NCAR ECMWF，再分析 二十世纪九十年代

至今 全球变暖 Global Warming
大气环流概述—观测资料

- 地面资料（陆地，航船）
- 探空资料
- 卫星资料
- Aircraft report (AI REP)
- 海洋资料
Measurements include: pressure, temperature, specific humidity, cloud cover, precipitation...

Number of land-based surface stations is at least one order of magnitude greater than the number of upper air stations.
Measurements include: pressure, temperature, specific humidity, cloud cover, precipitation...

Number of land-based surface stations is at least one order of magnitude greater than the number of upper air stations.

Station distribution is highly inhomogeneous.
大气环流概述 – 观测资料

- 地面资料（航）
  - Measurements include: sea surface temperature, salinity...
  - Also include: atmospheric temperature, pressure, humidity, wind direction, wind speed.
  - Most observations were taken by commercial ship.
大气环流概述 - 观测资料

探空资料
Radiosonde (无线电探空仪)
探空资料

Radiosonde (无线电探空仪)

感应元件（传感器）、转换装置、发射机、电源
大气环流概述 - 观测资料

探空资料

Radiosonde (无线电探空仪)
探空资料

Radiosonde (无线电探空仪)

- Measurements include: temperature (~1K), relative humidity (~10%), winds (~3-5 m/s).
- Relatively high vertical resolution (‘standard’ levels: 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 50, 30 hPa.), but errors becomes larger at higher levels.
- Most stations (800/1000) are located in the Northern hemisphere.
- **Poorer accuracy** than conventional measurements
- **High** horizontal resolution, relatively **poor** vertical resolution. Typical vertical resolution is several km.
- Sounding ceases at the cloud top, no data taken within the vigorous weather.
- Typical orbital period is 90 mins, so it takes several hours before the entire globe is covered.
- Even though, still important data source over oceans.

*Compared to temperature and humidity sounding from radiosonde*

(First meteorological satellite, 1960)
First reliable measurements of incoming and outgoing radiative fluxes at TOA.

Multiple spectral band: e.g. microwave band-liquid water content of the atmosphere, wind stress over the oceans, distribution of sea ice, height of sea level, distribution of pollutants...
大气环流概述 - 观测资料

卫星资料

风云3- A / C、B：2008-2014
风云4- A：2016.12
First reliable measurements of incoming and outgoing radiative fluxes at TOA

Multiple spectral band: e.g. microwave band-liquid water content of the atmosphere, wind stress over the oceans, distribution of sea ice, height of sea level, distribution of pollutants...

The A-Train satellite formation currently consists of five satellites flying in close proximity: Aqua, CloudSat, CALIPSO, PARASOL and Aura. (from NASA website.)
AIREP资料

- Reports of temperature and pressure taken by airlines
- Taken at the flight level of the aircraft
- Most of the AIREP are seen in the air lanes of North Atlantic and North pacific
大气环流概述 - 观测资料

- AIREP资料

(B) Aircraft Locations

2004年(NCEP)
海洋资料

- Research vessels: temperature, salinity, oxygen content, concentrations of various nutrients.
- Shorter time coverage.
- Still limited knowledge on the dynamical structure of the oceans.
海洋资料: Argo

- 覆盖全球海洋，提供实时海洋上层观测数据。
- Consist of almost 4000 drifting, profiling float: temperature, salinity and currents.
- Coverage since 2000s.
- Drift at 1000m, every 10 days, dive to 2000m then move to surface.
海洋资料: Argo

- 覆盖全球海洋，提供实时海洋上层观测数据。
- Consist of almost 4000 drifting, profiling float: temperature, salinity and currents.
- Coverage since 2000s.
- Drift at 1000m, every 10 days, dive to 2000m then move to surface.