第一章:

大气环流概述

授课教师：张洋

2022. 9. 15

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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

1990年
1st IPCC

2007年
4th IPCC

2014年
5th IPCC

2021年
6th IPCC

Eliassen-Palm通量
波流相互作用
1961年

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

Coriolis　Thomson
1832年　1857年

1735年
Hadley
信风理论

1856年
Ferrel

二十世纪
前二三十年
role of eddies

二十世纪
五十年代
数值模式

六七十年代
气候模式

七八十年代
海气模式

2005年
Kyoto Protocol
into action

至今
全球变暖
Global
Warming

1988年
James Hansen
in US Congress

1975年
Wally Broecker
in *Science*

1997年
Kyoto Protocol

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

1980年
Held-Hou模型

2016 年
Paris Agreement

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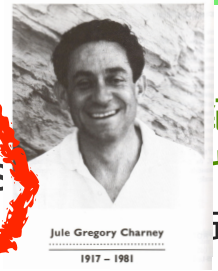

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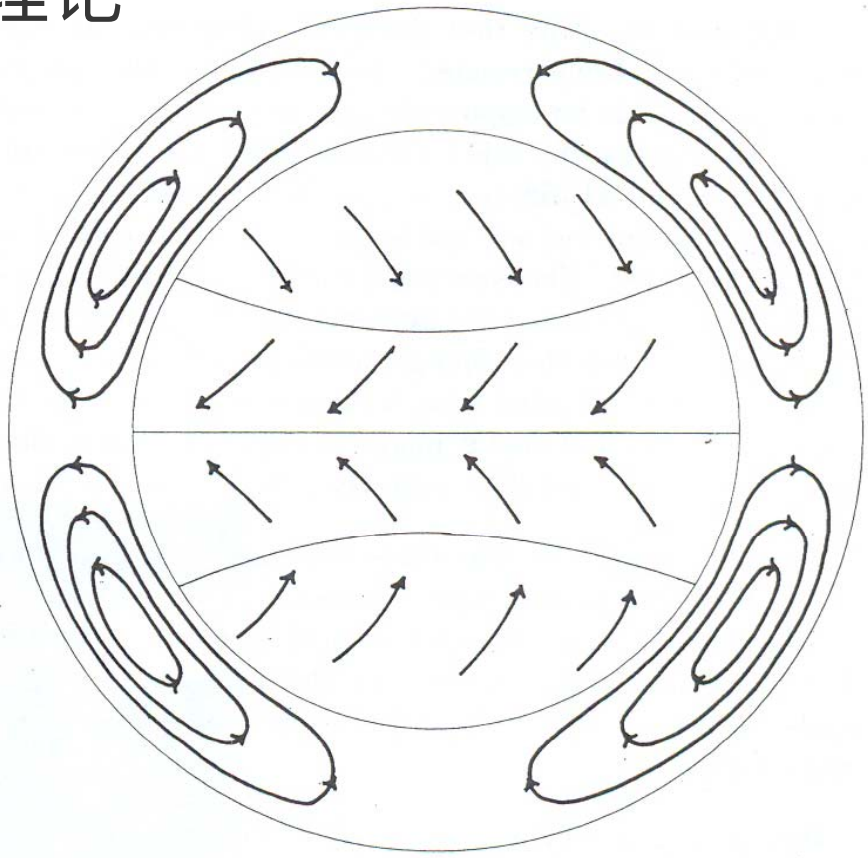
大气环流概述－历史简介

Review

"On the Cause of the General Trade Winds," in the *Philosophical Transactions of the Royal Society.*

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.



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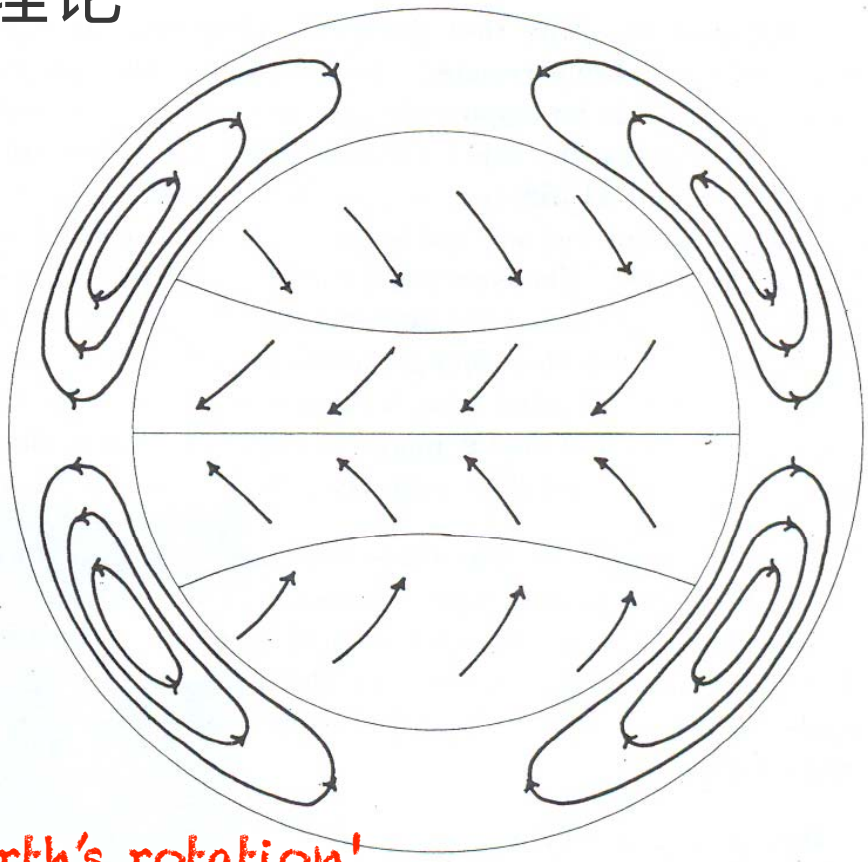


Understanding the effect of earth's rotation!

大气环流概述－历史简介

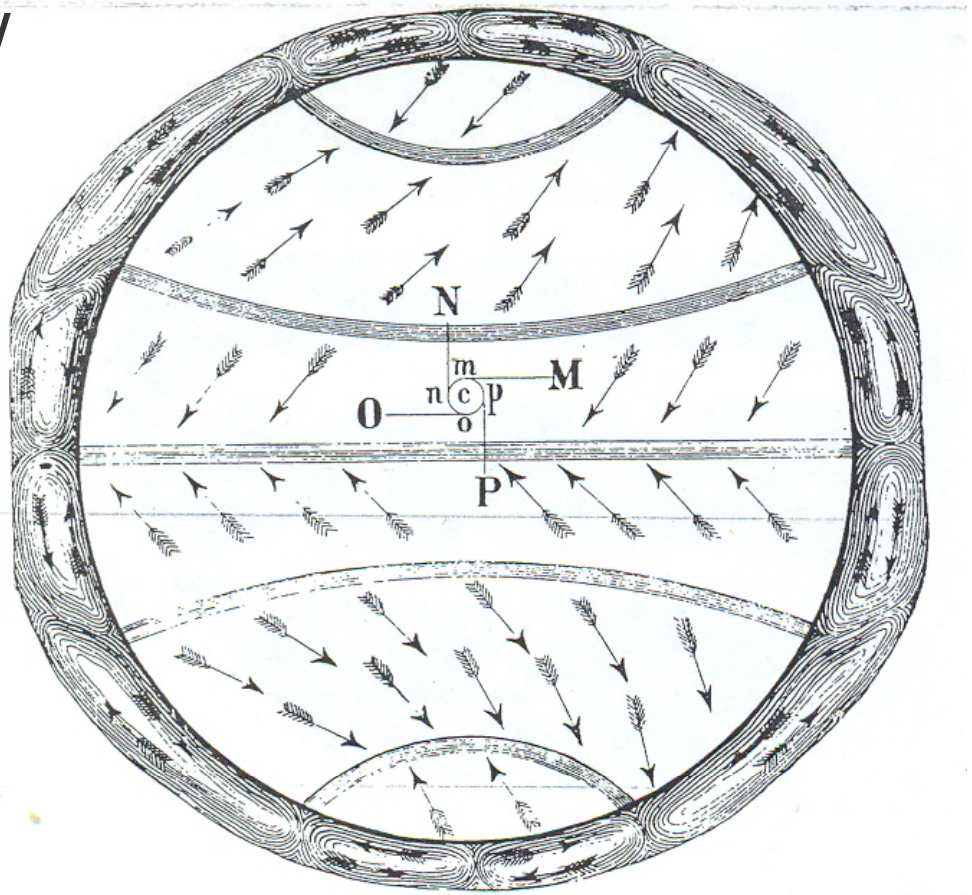
- **Coriolis 1832.** Memoire sur le principe des forces vives dans les mouvements relatifs des machines. (On the principle of kinetic energy in the relative movement of machines.) *J. Ec. Polytech,* 13, 268-301.
- **Coriolis 1835.** Memoire sur les equations du mouvement relatif des syst\`emes de corps. (On the equations of relative motion of a system of bodies. *J. Ec. Polytech.,* 15, 142-154.

Gaspard-Gustave de Coriolis
1792-1843

大气环流概述－历史简介

- 1856年, Ferrel’s view

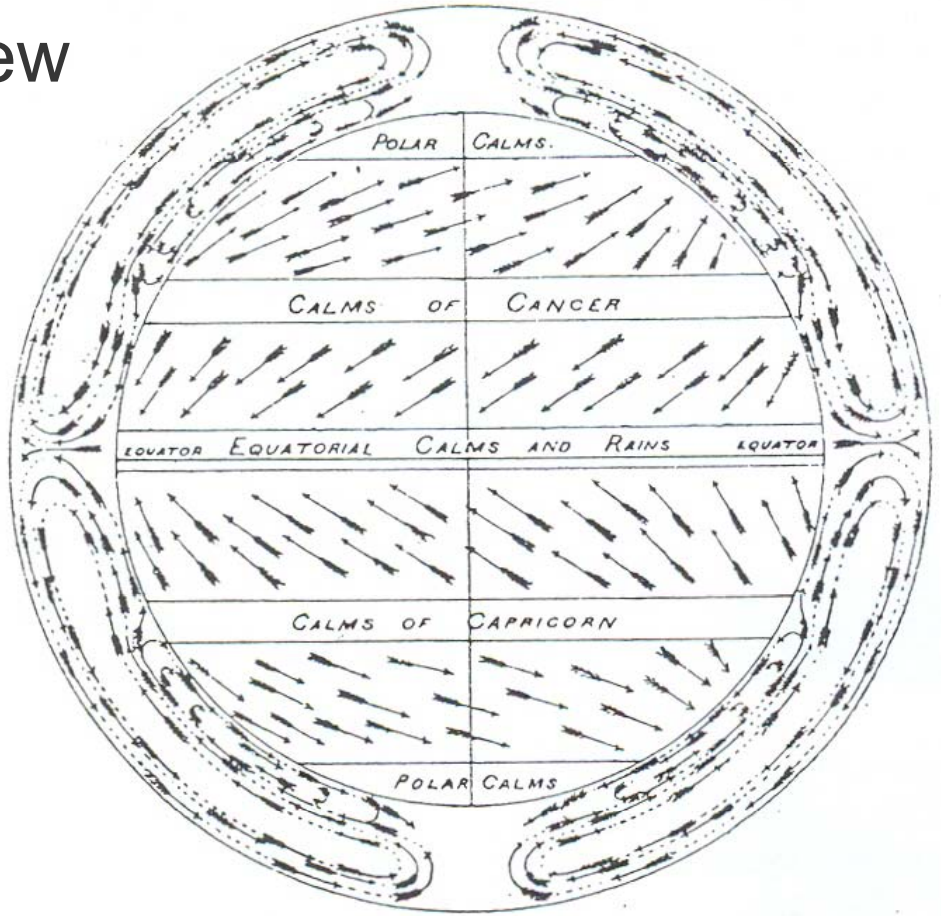
- Observed **southwesterly** challenged Hadley’s theory;
- **Three-cell circulation,** close to current views of earth’s general circulation.



大气环流概述－历史简介

- 1857年, Thomson’s view

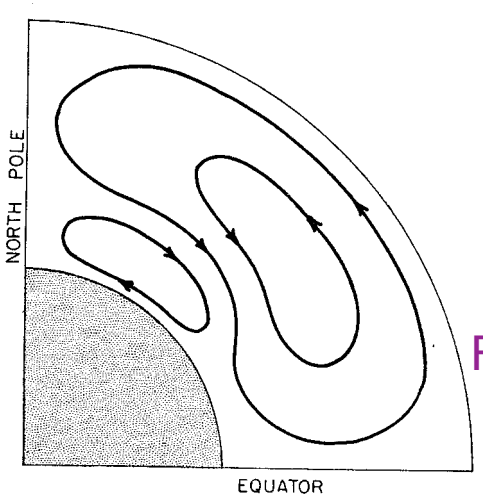
- Still **a single direct cell** in the upper troposphere;
- In the lower levels of middle and higher latitudes, **a shallow indirect cell** with poleward flow near ground and equatorward flow in the intermediate levels.



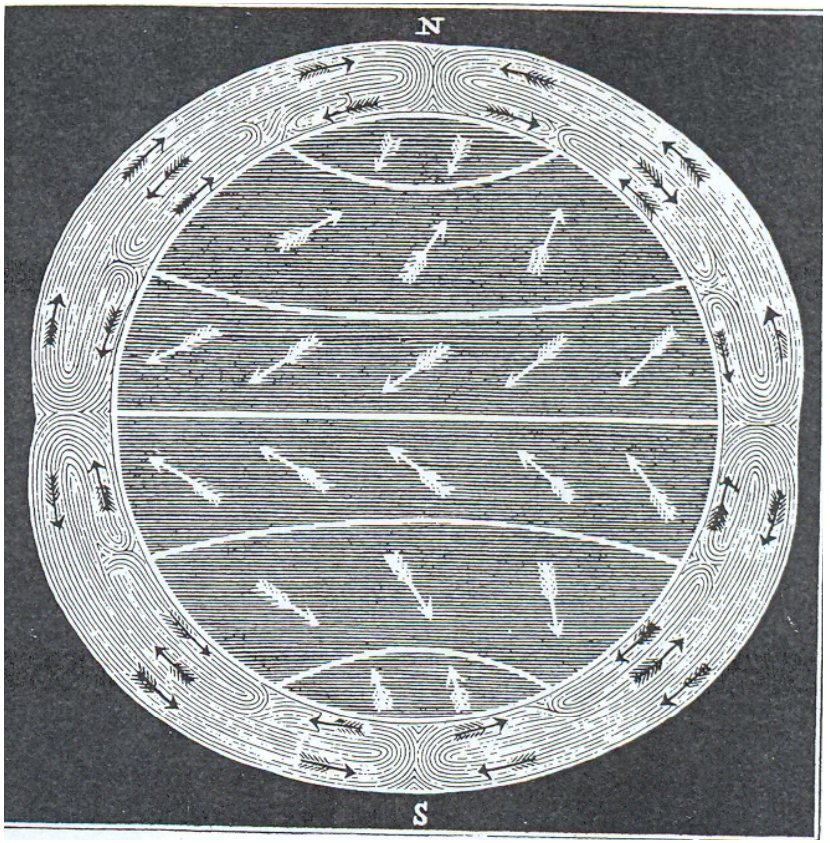
大气环流概述－历史简介

- 1859年, Ferrel’s second view

Close to Thomson’s view, except for a polar cell in high latitudes.

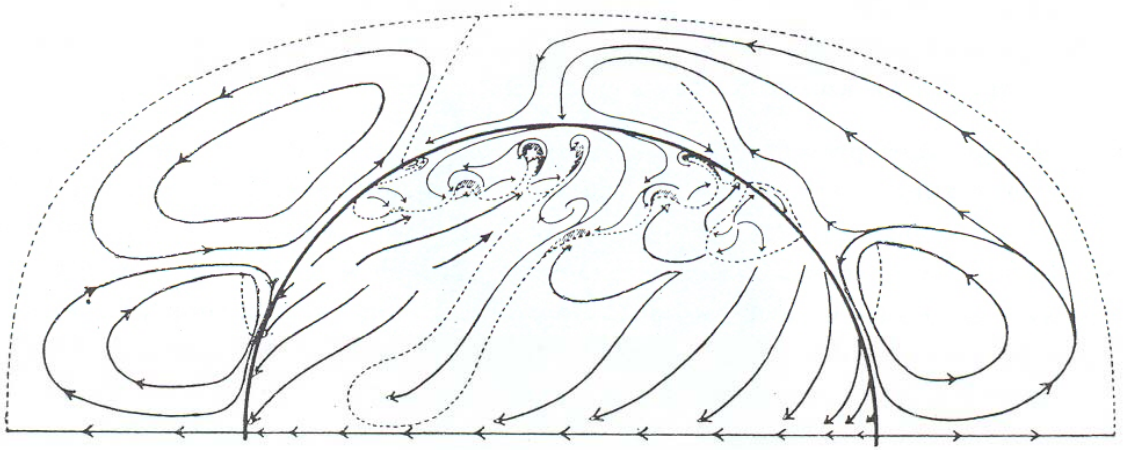


Ferrel-Thomson’s circulation



大气环流概述－历史简介

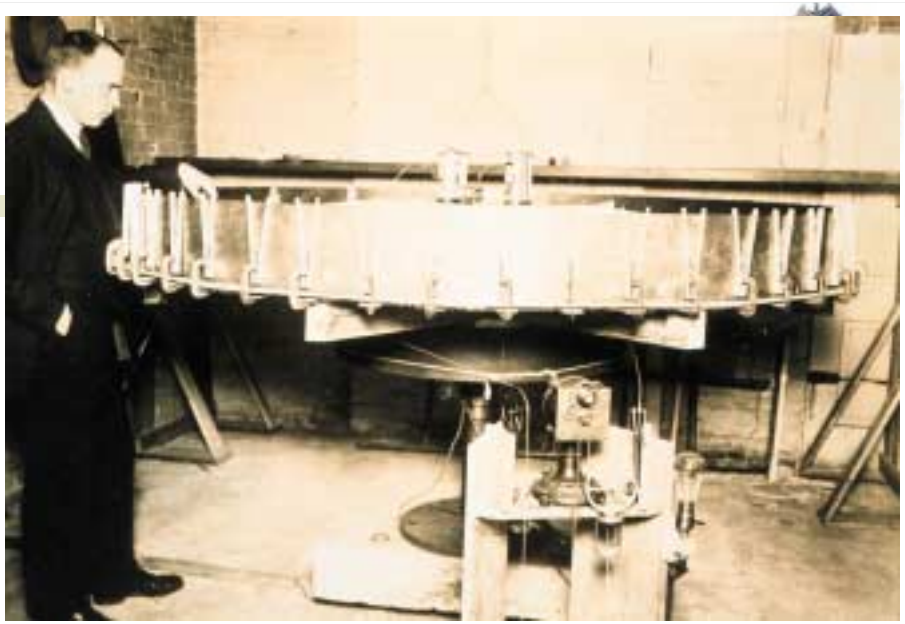
- The role of eddies?
  - **Bigelow(1902)**, the effect of cyclones should be taken into account.
  - **Defant (1912)**, eddies transport heat to higher latitudes.
  - **Jeffreys (1926)**, eddies transfer angular momentum.
  - **V. Bjerknes (1937)**, Ferrel-Thomson's circulation is unstable to eddies.



Rossby 波

Carl-Gustaf Arvid Rossby

1898 – 1957



RELATION BETWEEN VARIATIONS IN THE INTENSITY OF THE ZONAL CIRCULATION OF THE ATMOSPHERE AND THE DISPLACEMENTS OF THE SEMI-PERMANENT CENTERS OF ACTION*

By

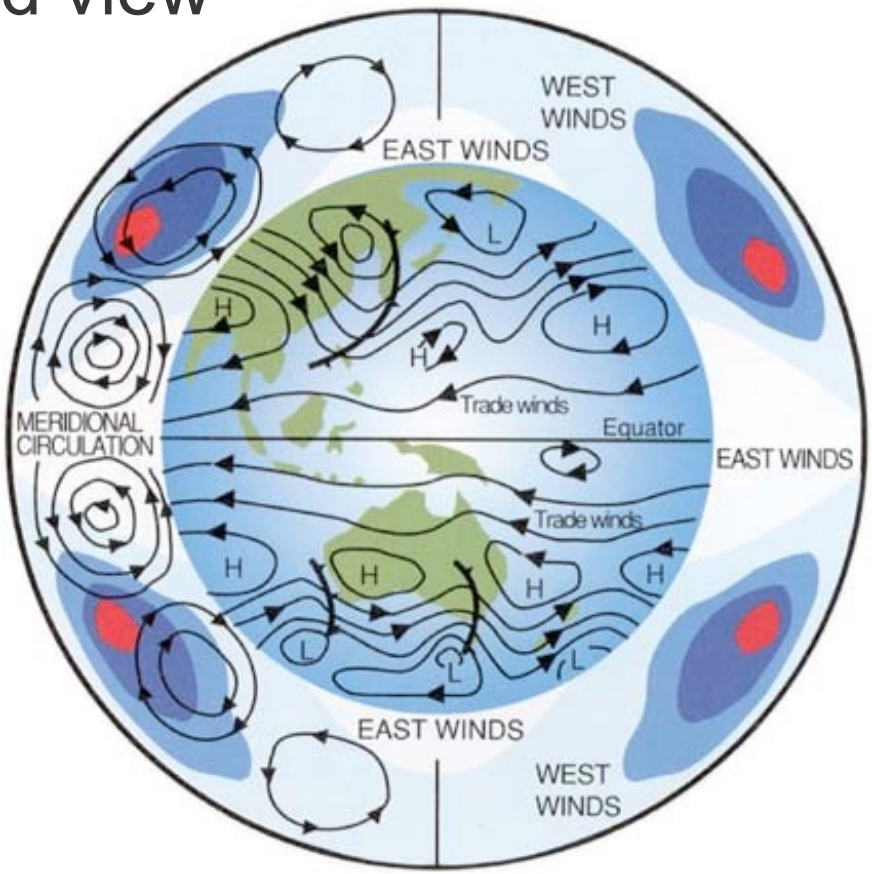
C.-G. ROSSBY AND COLLABORATORS

Massachusetts Institute of Technology

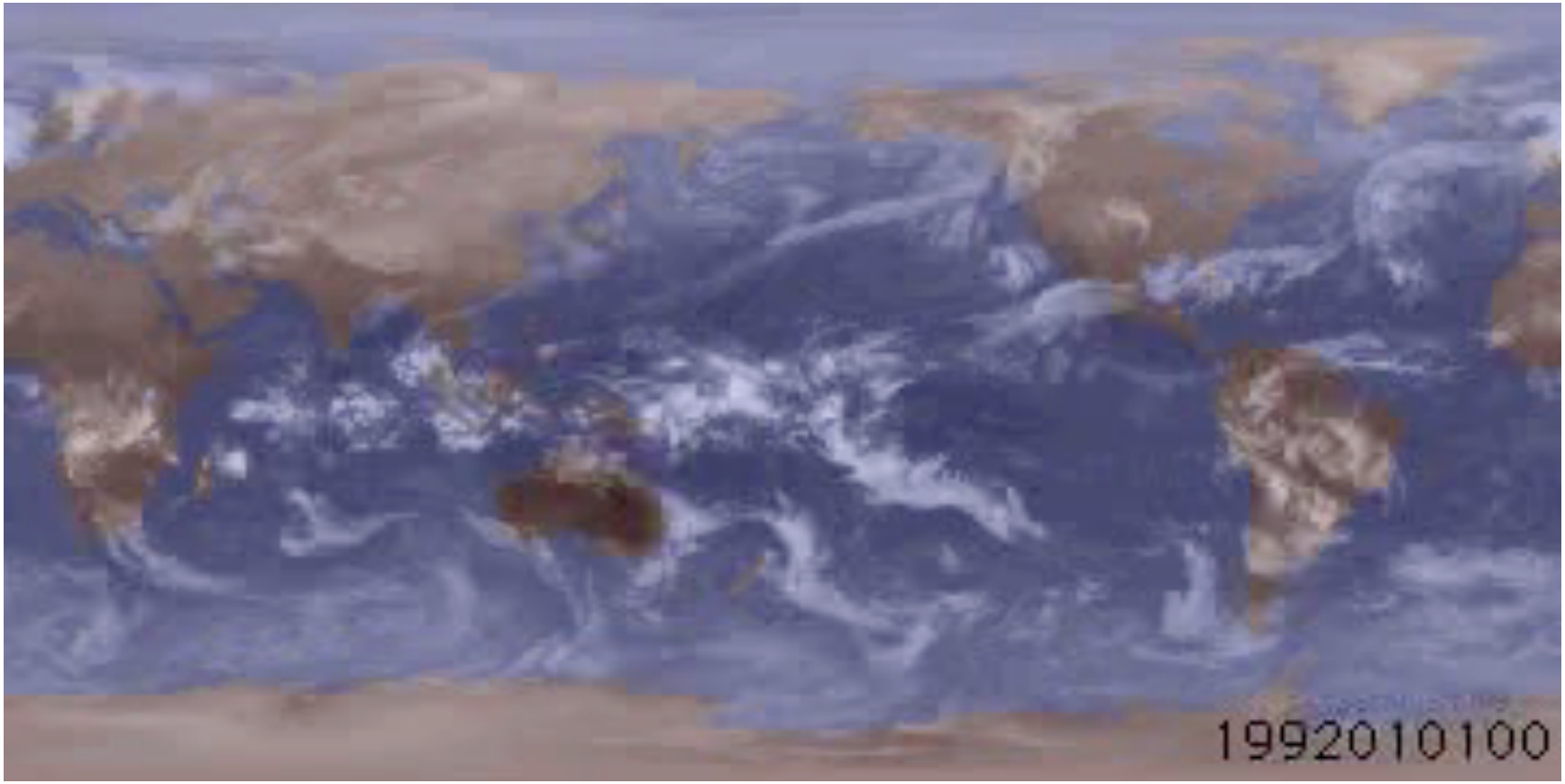
This paper attempts to interpret, from a single point of view, several at first sight independent phenomena brought into focus through the synoptic investigations carried on at the Massachusetts Institute of Technology during the last few years. Since this interpretation is very largely based on a consideration 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.

大气环流概述－历史简介

- Currently most-accepted view



大气环流概述－内容简介

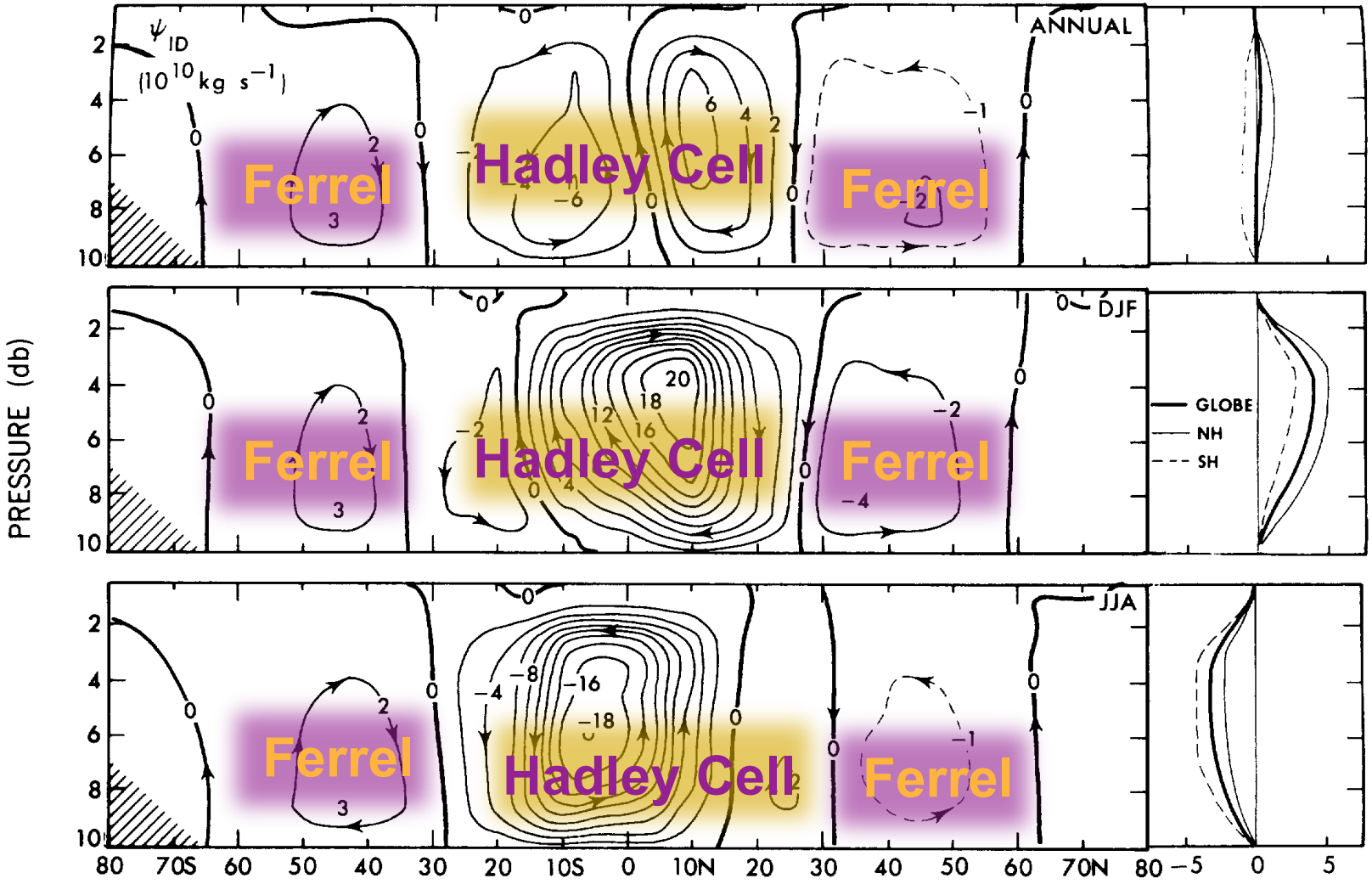


The British Atmospheric Data Centre (BADC)
www.badc.nerc.ac.uk/data/claus (infra-red)

Observations

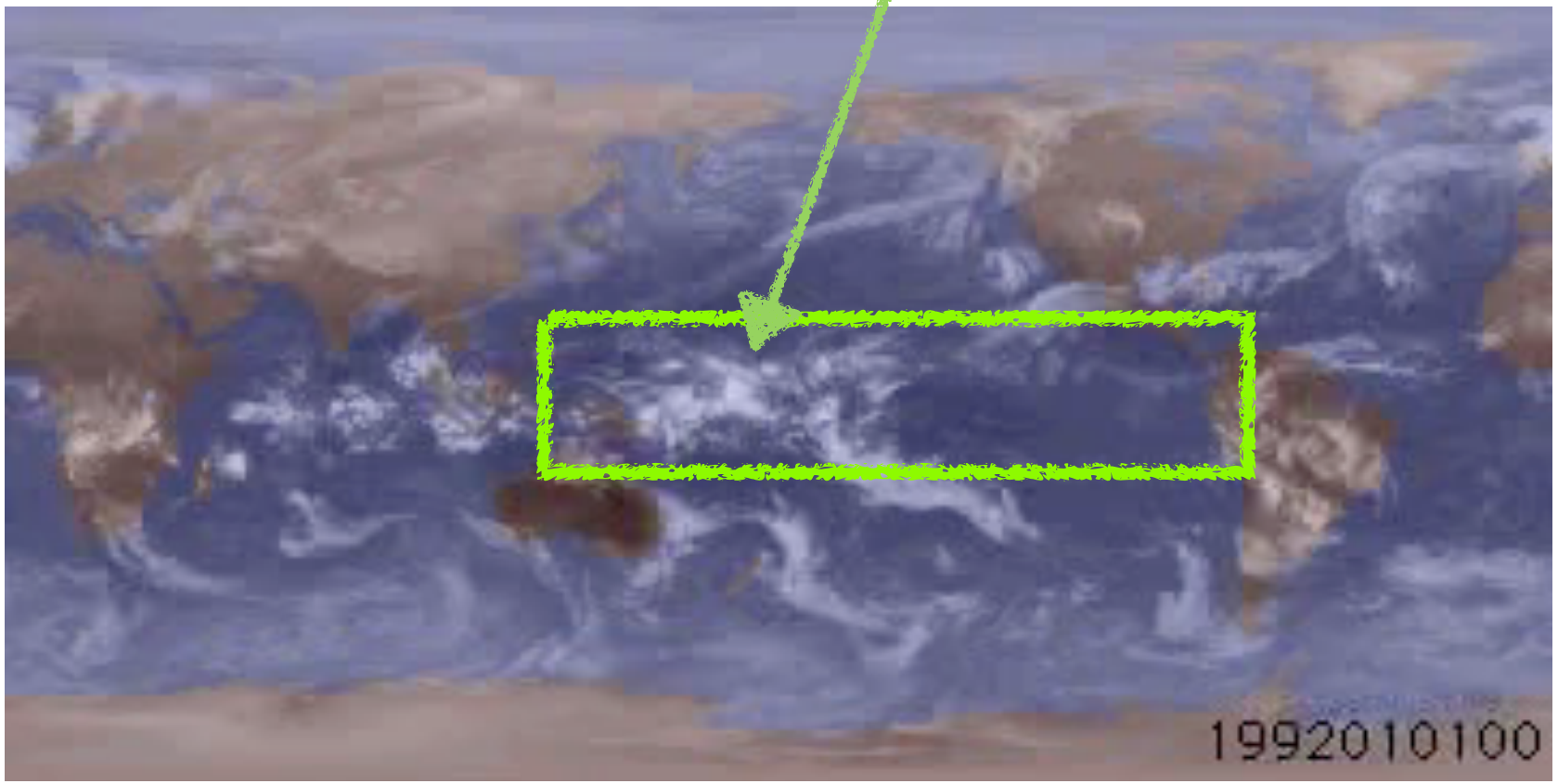
-Zonal mean fields

- Stream function (流函数)

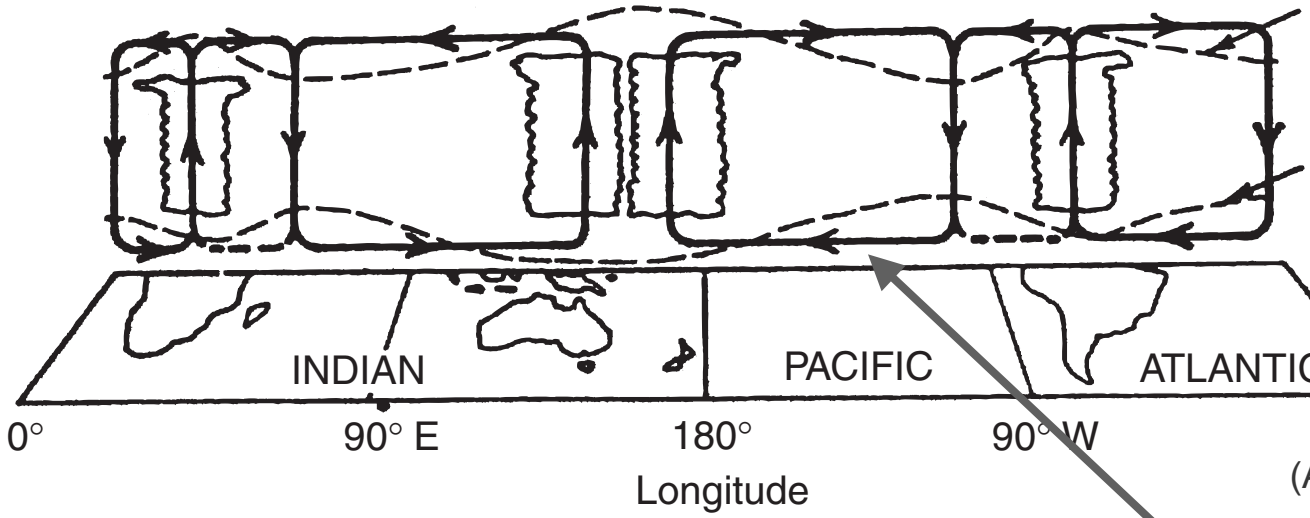


Observed features

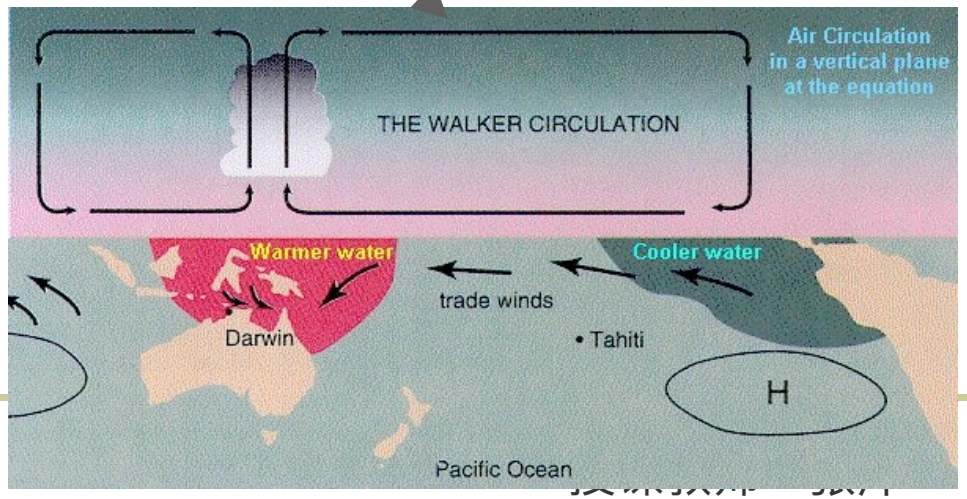
great amount of convective cloud in the western pacific



Walker Circulation



(Adapted from Webster 1983)



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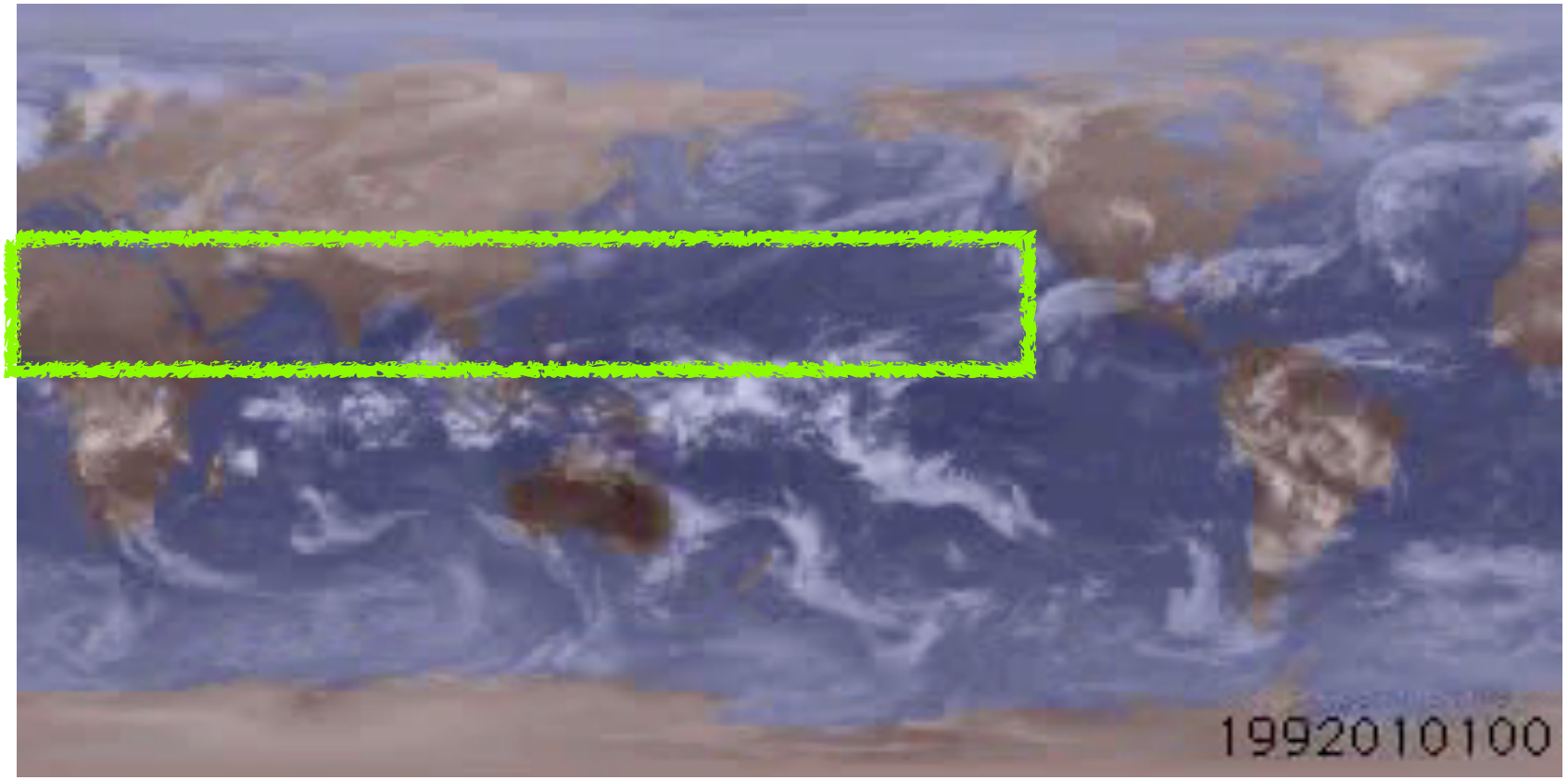
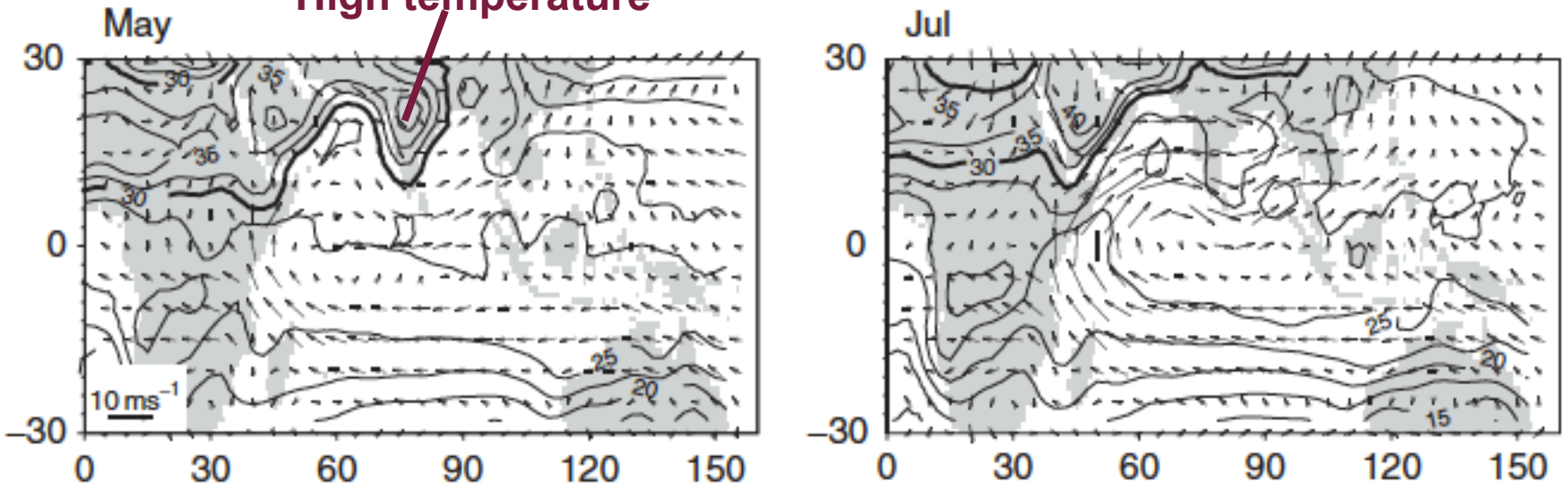
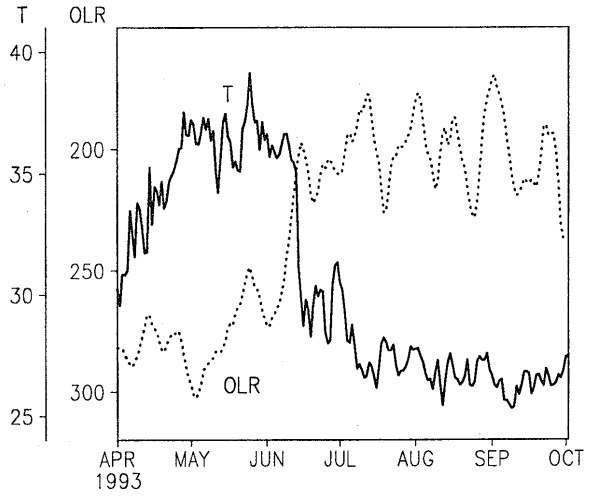


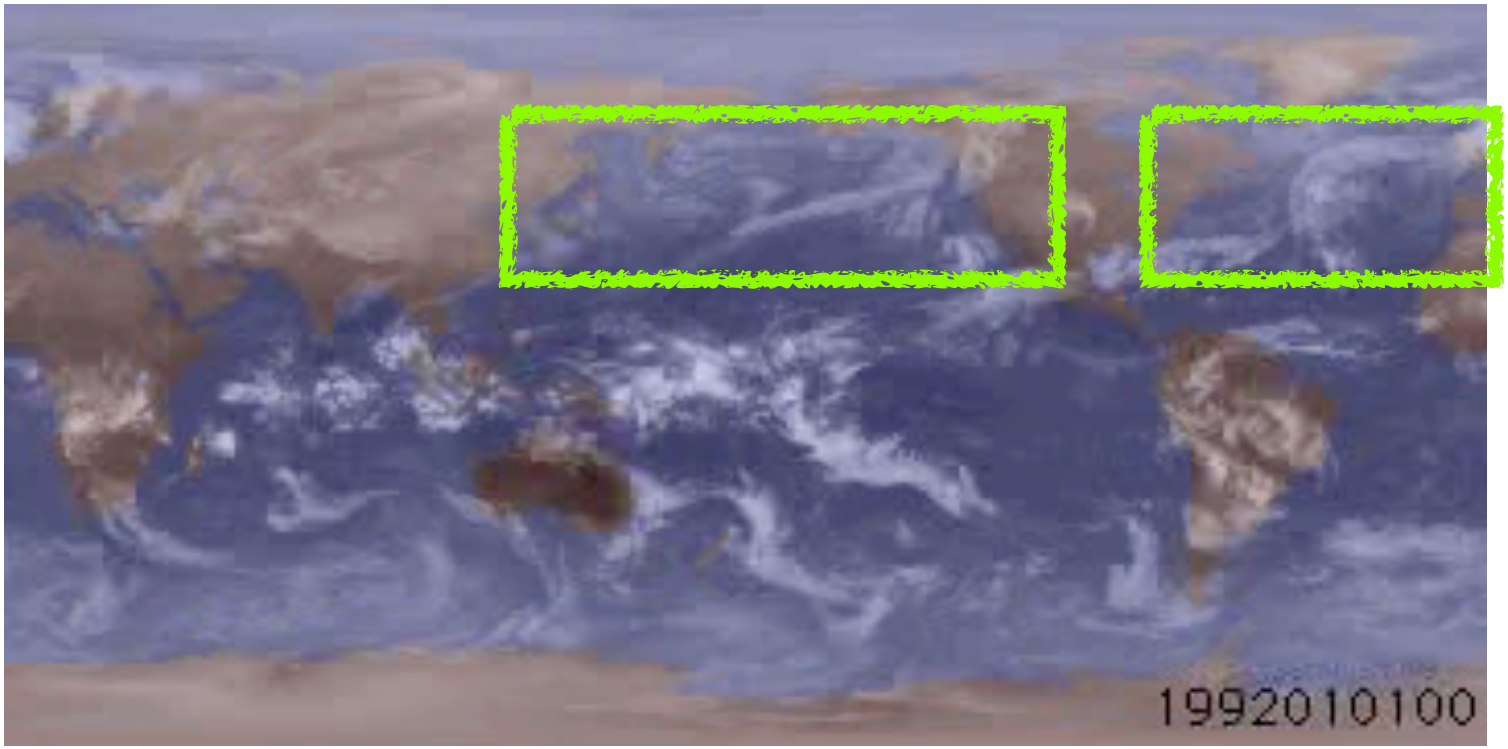
Features of monsoonal circulation:
-an Indian monsoon example

High temperature

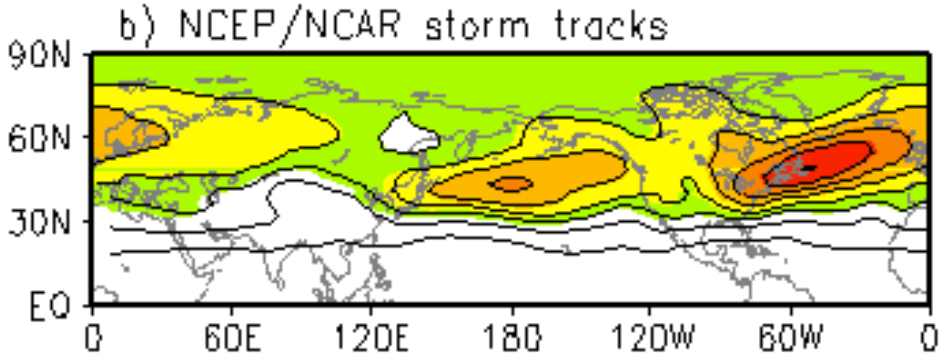


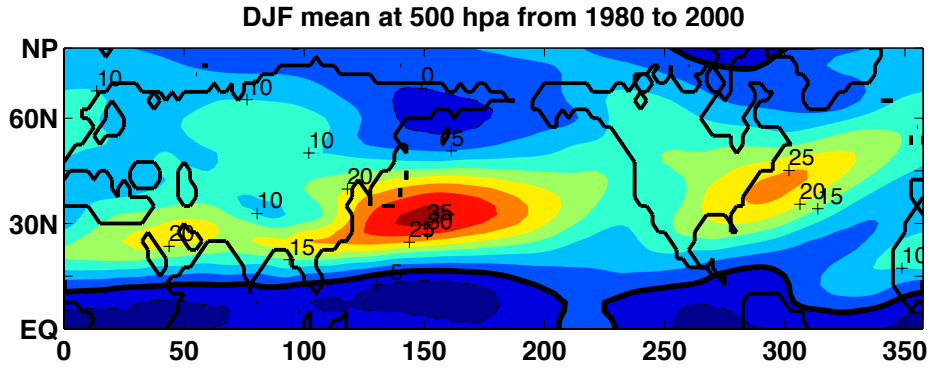


Non-zonal circulations



Storm tracks





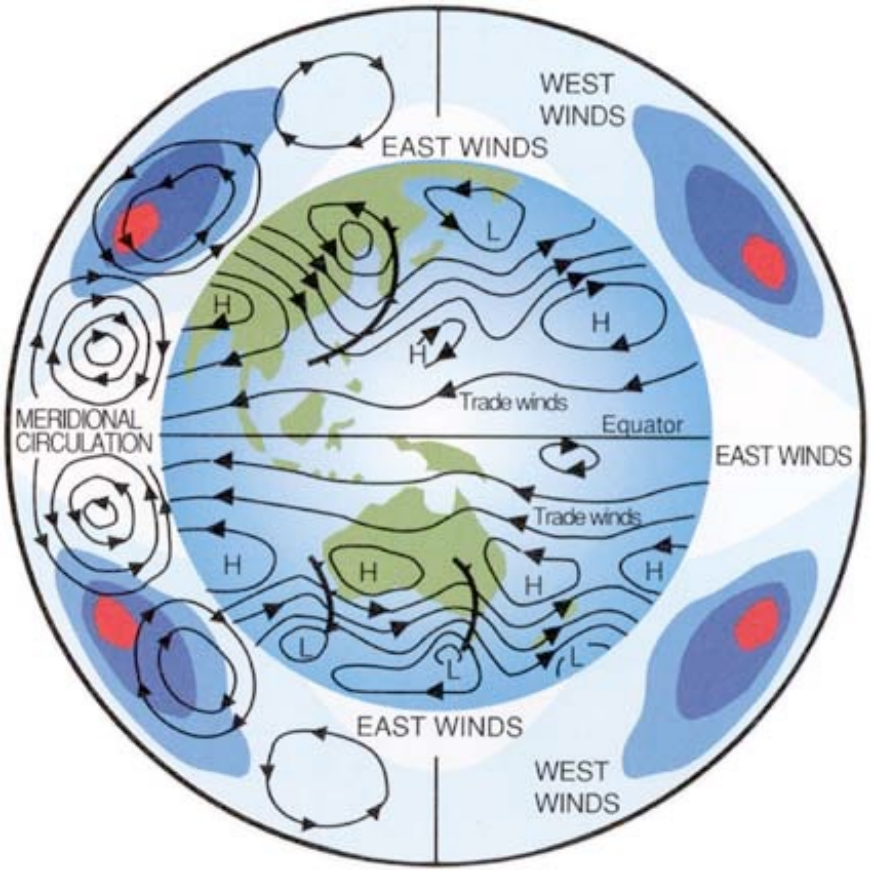
Zonal wind from NCEP/NCAR data

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（non-zonal circulations）：
  - Storm tracks
  - Monsoon
  - ENSO and Walker circulation



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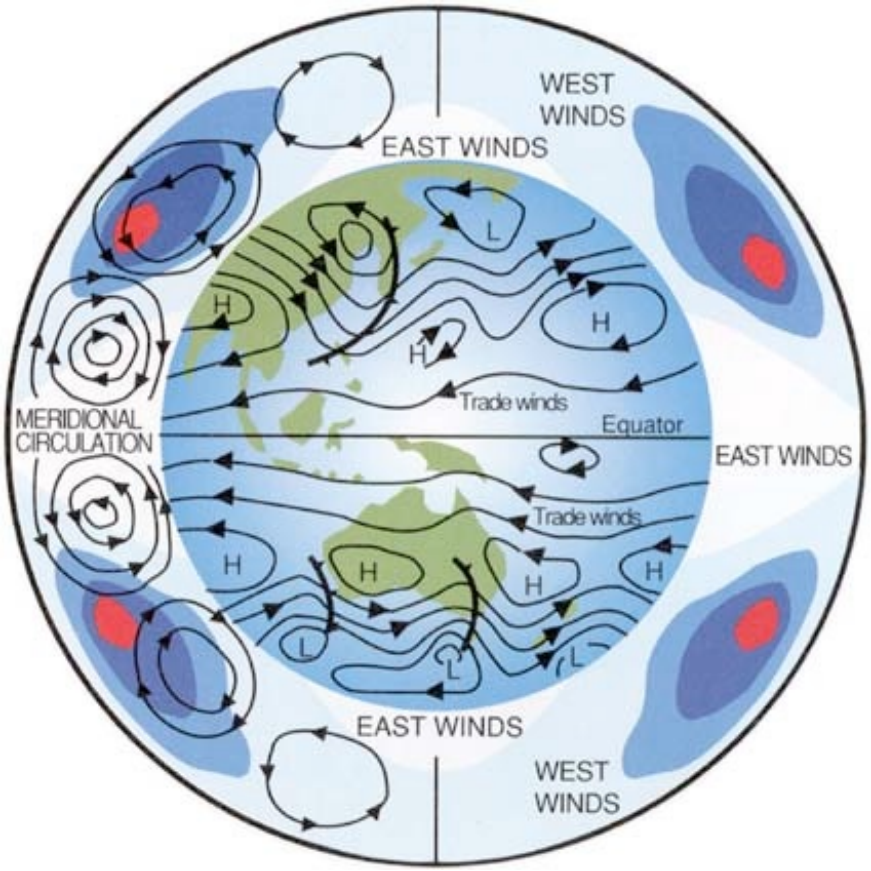
- 不同复杂度的大气环流模式
- 全球暖化背景下的大气环流



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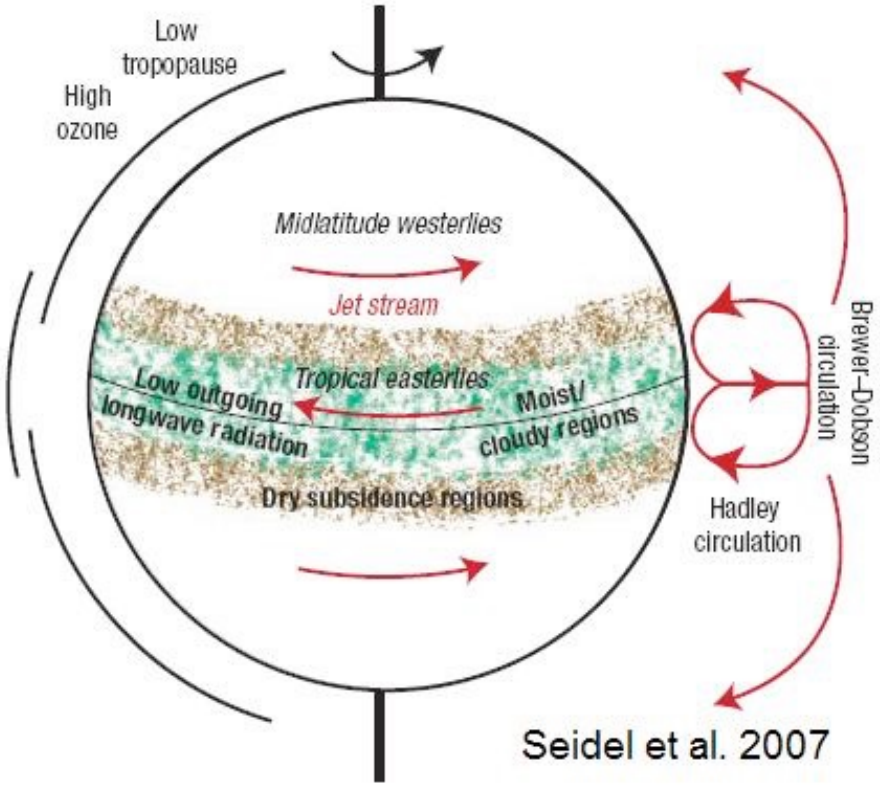

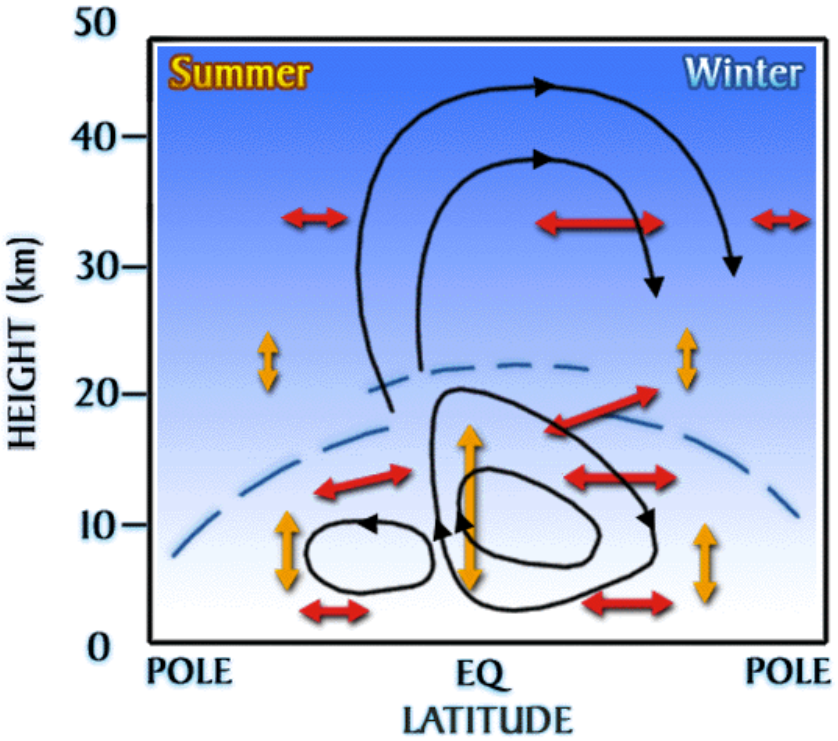

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Warming

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 (AIREP)
- 海洋资料

大气环流概述－观测资料

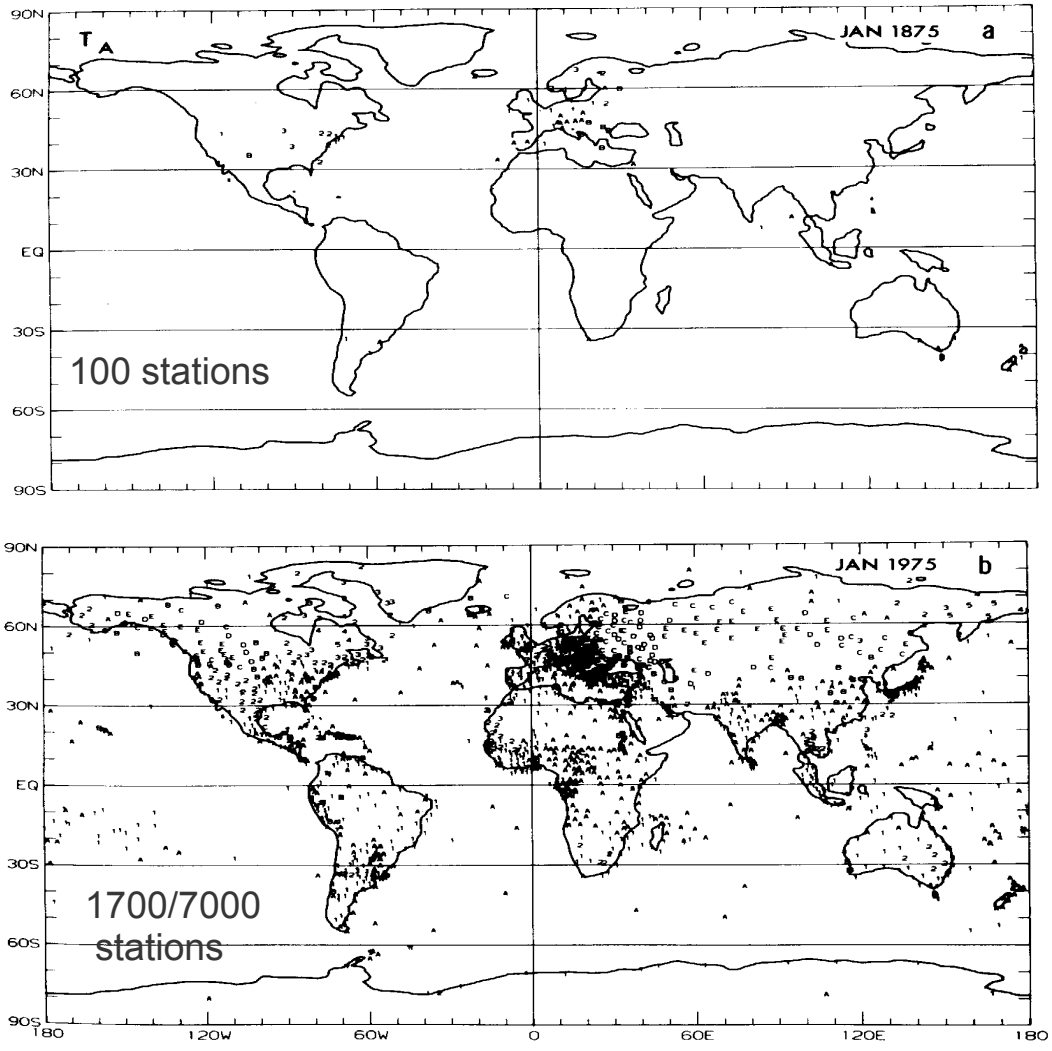
地面资料（陆地）

- 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.

大气环流概述－观测资料

- 地面资料（陆地

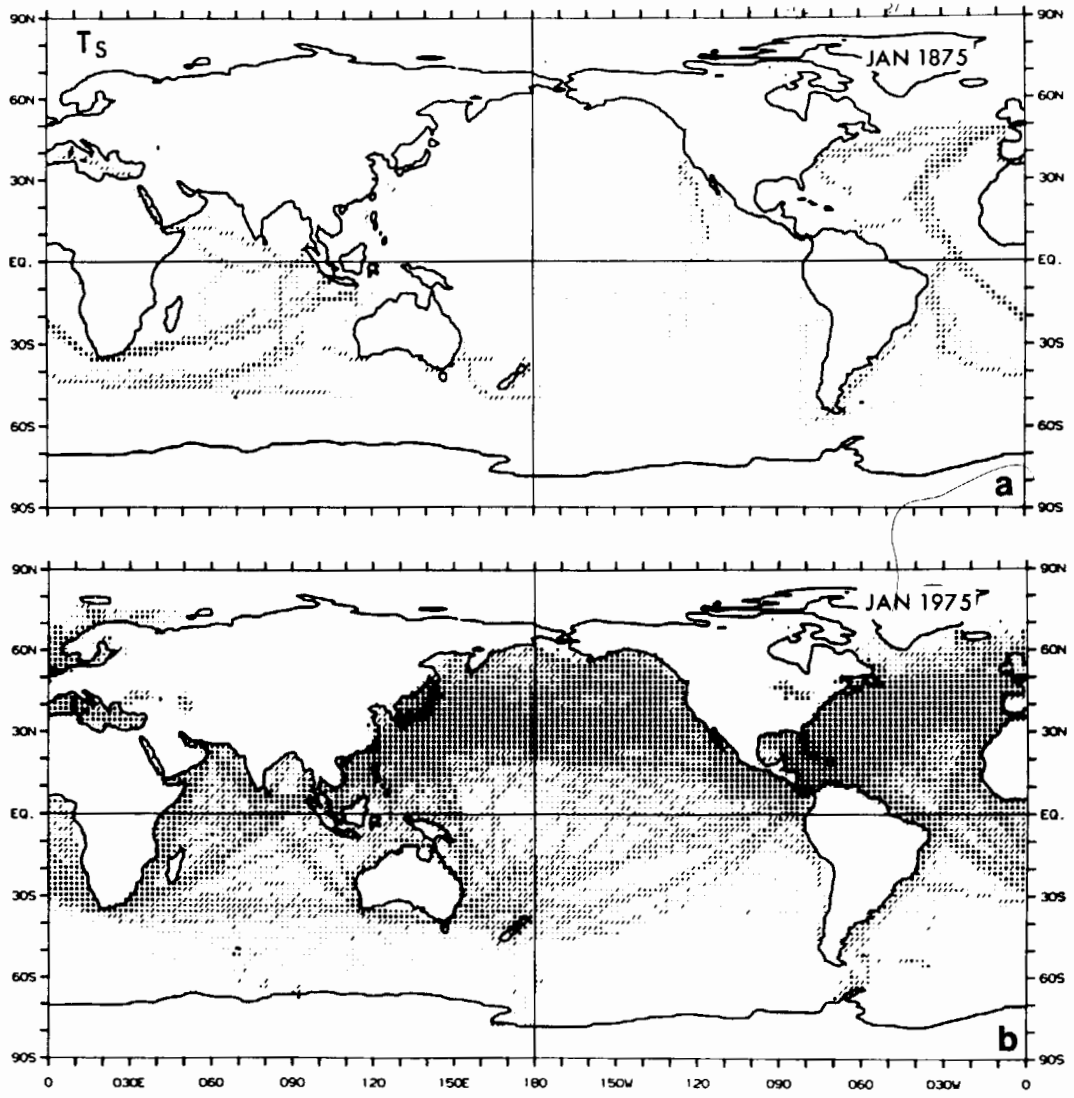
- Measurements include: pressure, temperature, specific humidity, cloud cover, precipitation...
- Number of land-based surface stations is at least one order of magnitude greater than the number of upper air stations.
- Station distribution is highly inhomogeneous.



大气环流概述－观测资料

- 地面资料（航

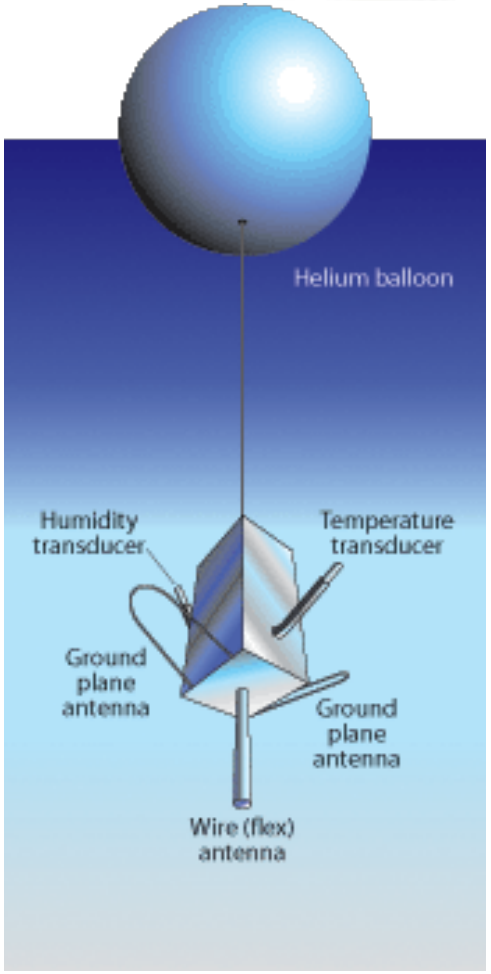
- Measurements include: sea surface temperature, salinity...
- Also include: atmospheric temperature, pressure, humidity, wind direction, wind speed.
- Most observations were taken by commercial ship.



大气环流概述－观测资料

- 探空资料

Radiosonde (无线电探空仪)

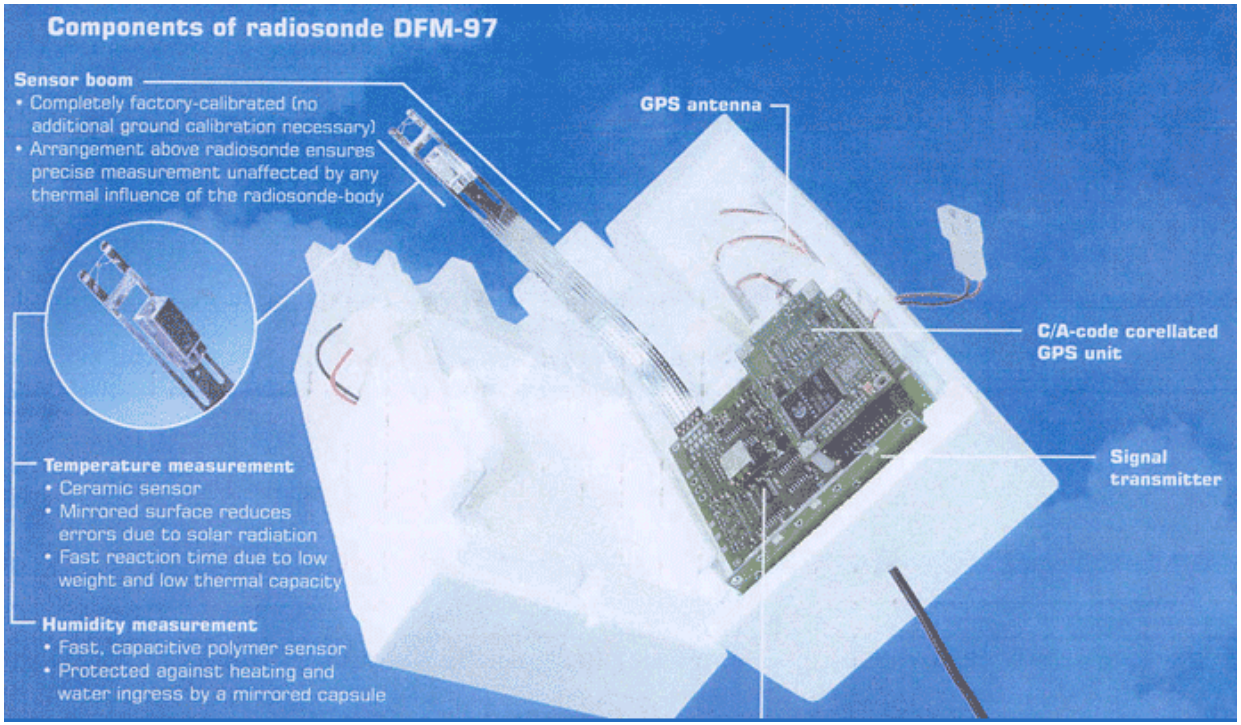


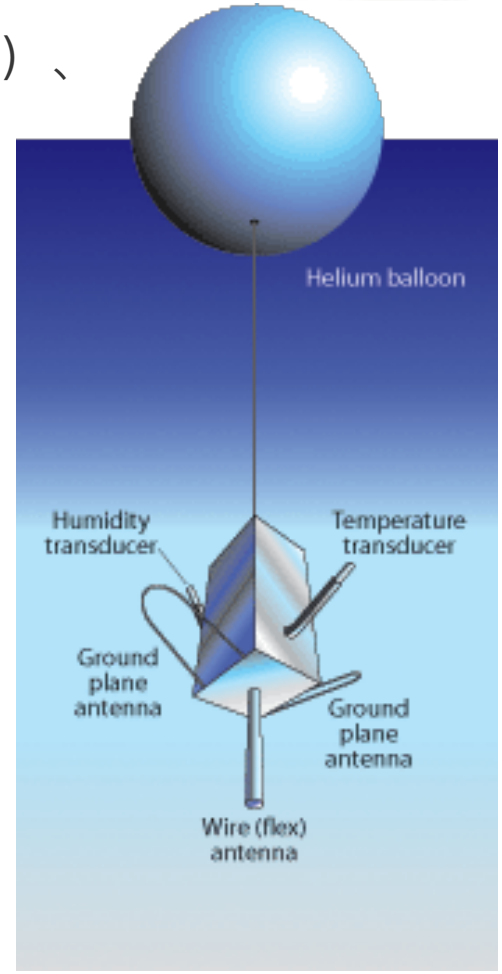
大气环流概述－观测资料

- 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

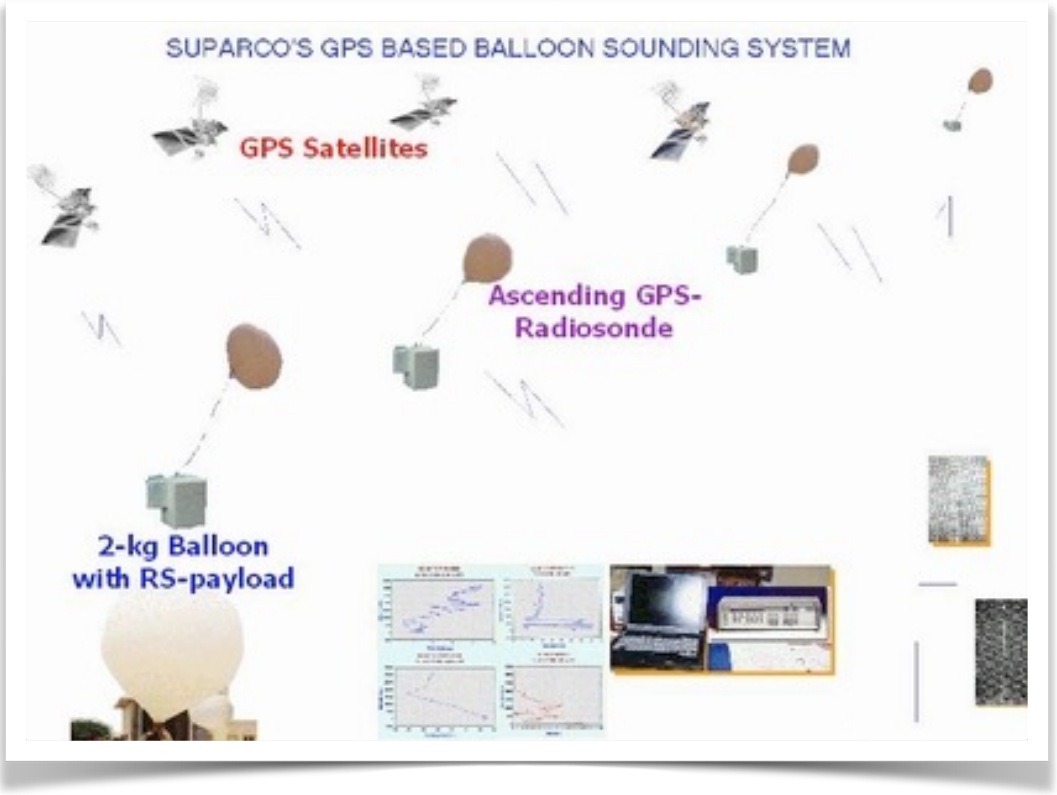




大气环流概述－观测资料

- 探空资料

Radiosonde (无线电探空仪)

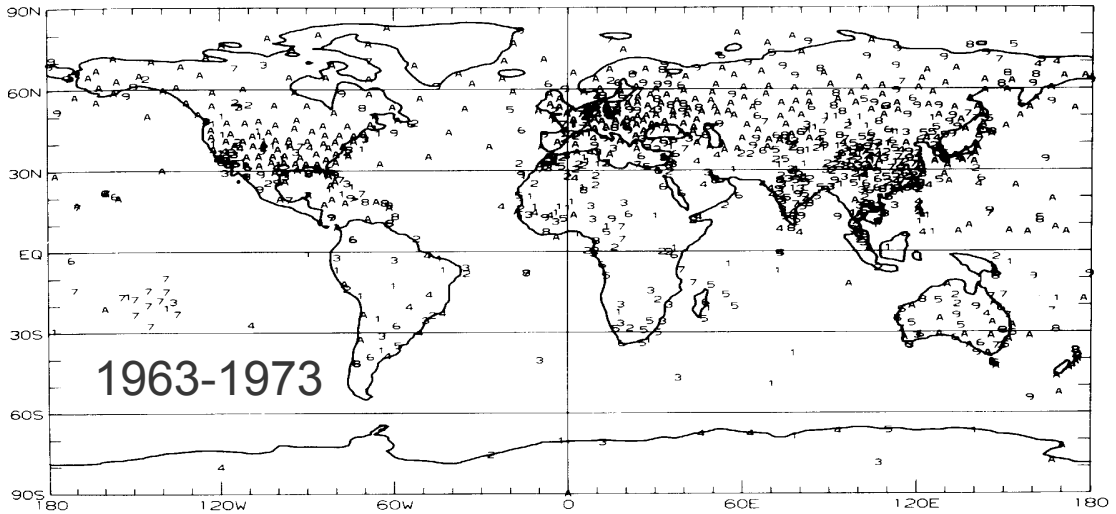


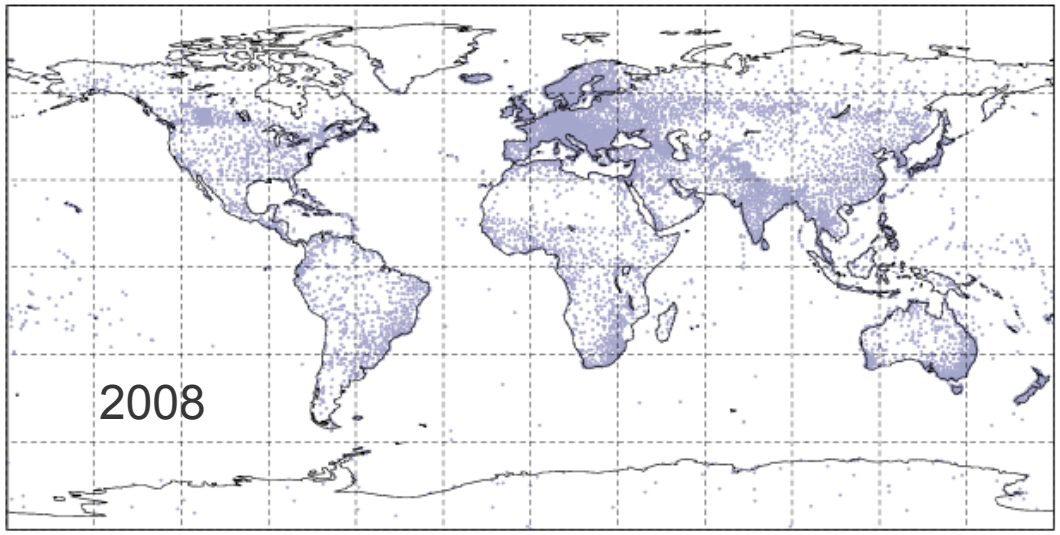
大气环流概述－观测资料

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.



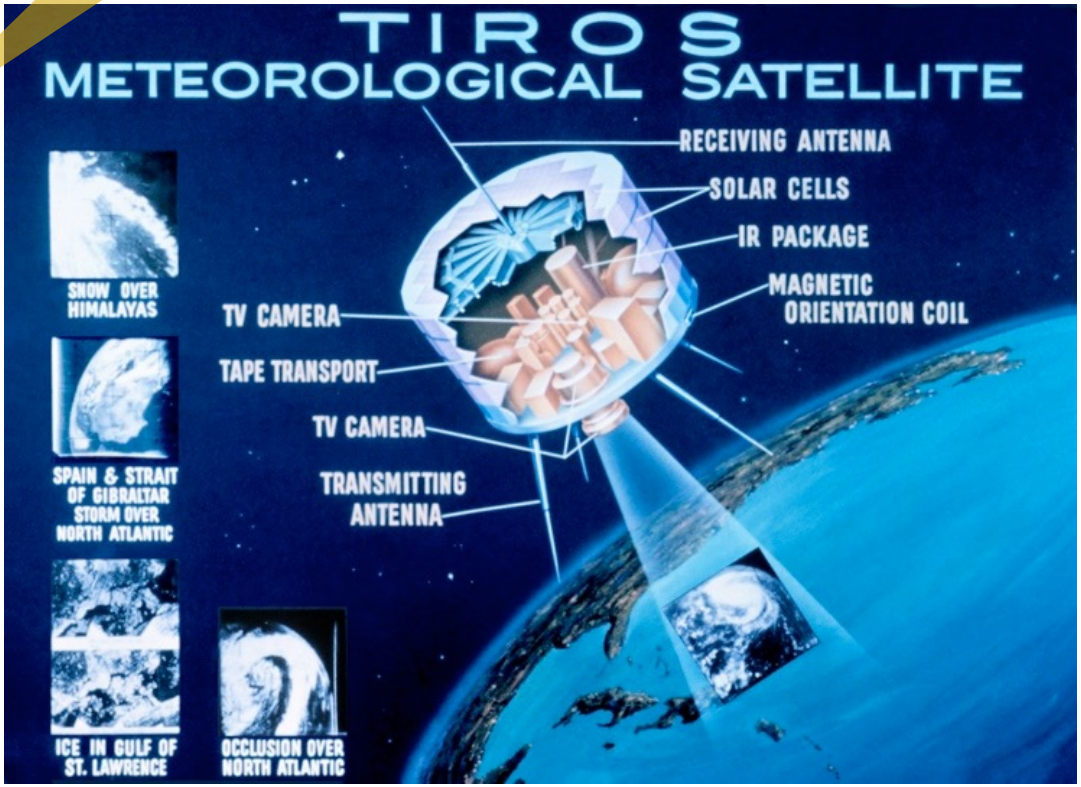


大气环流概述－观测资料

Compared to temperature and humidity sounding from radiosonde

卫星资料

- 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.

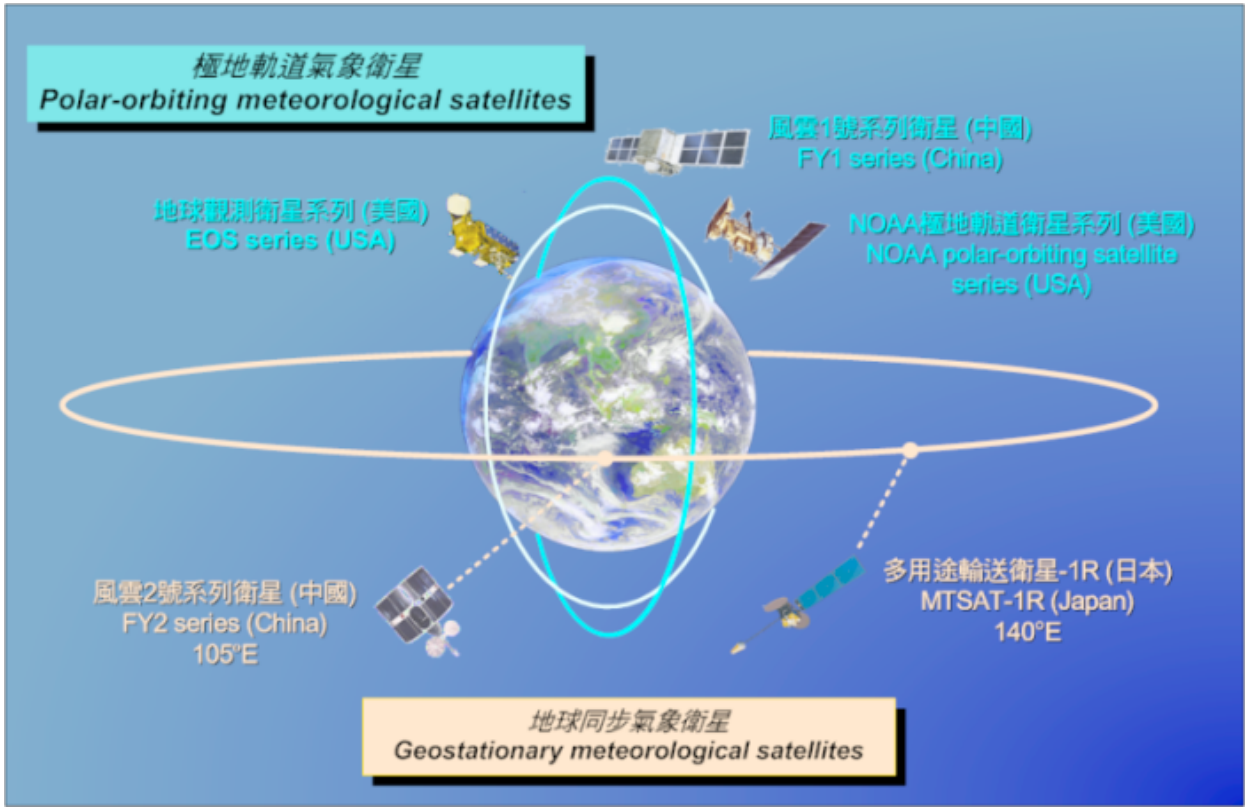


(First meteorological satellite, 1960)

大气环流概述－观测资料

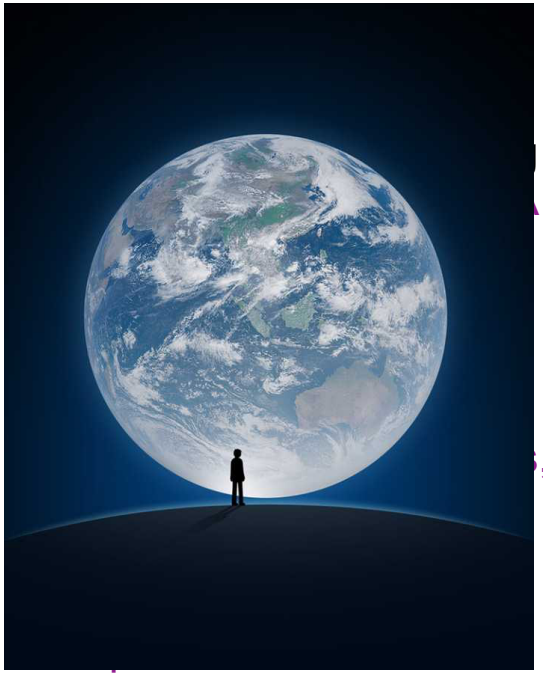
卫星资料

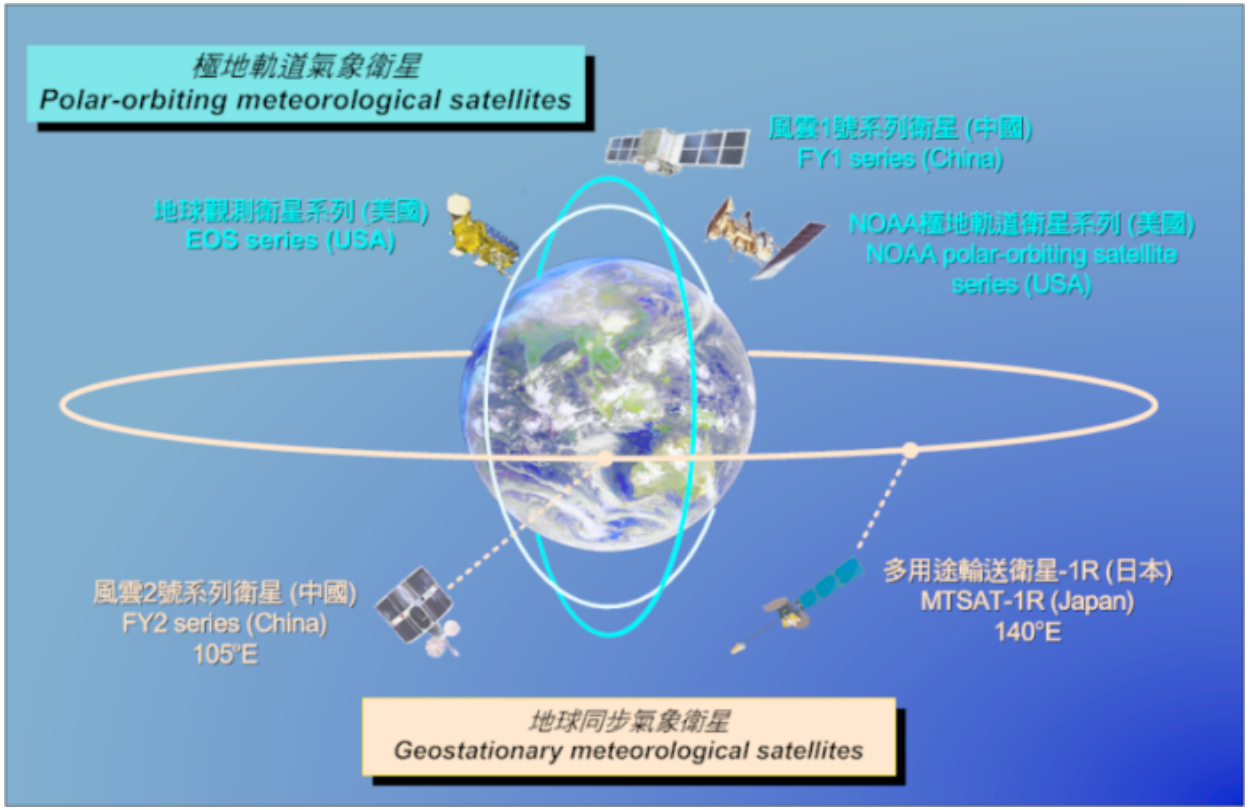
- First reliable measurements of incoming and outgoing radiative fluxes at TOA
- Multiple spectral band: e.g. microwave band- liquid water content of the atmosphere, wind stress over the oceans, distribution of sea ice, height of sea level, distribution of pollutants...



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

大气环流概述－观测资料

卫星资料

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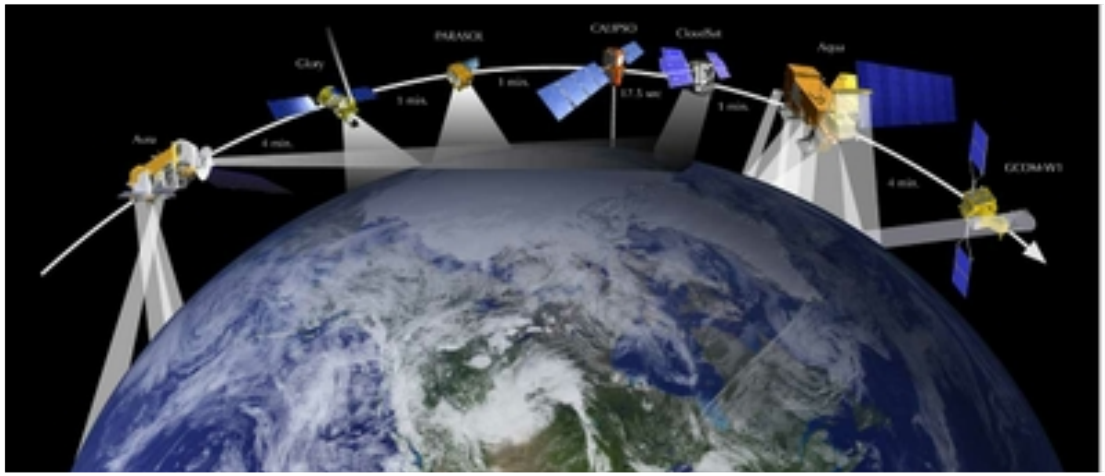
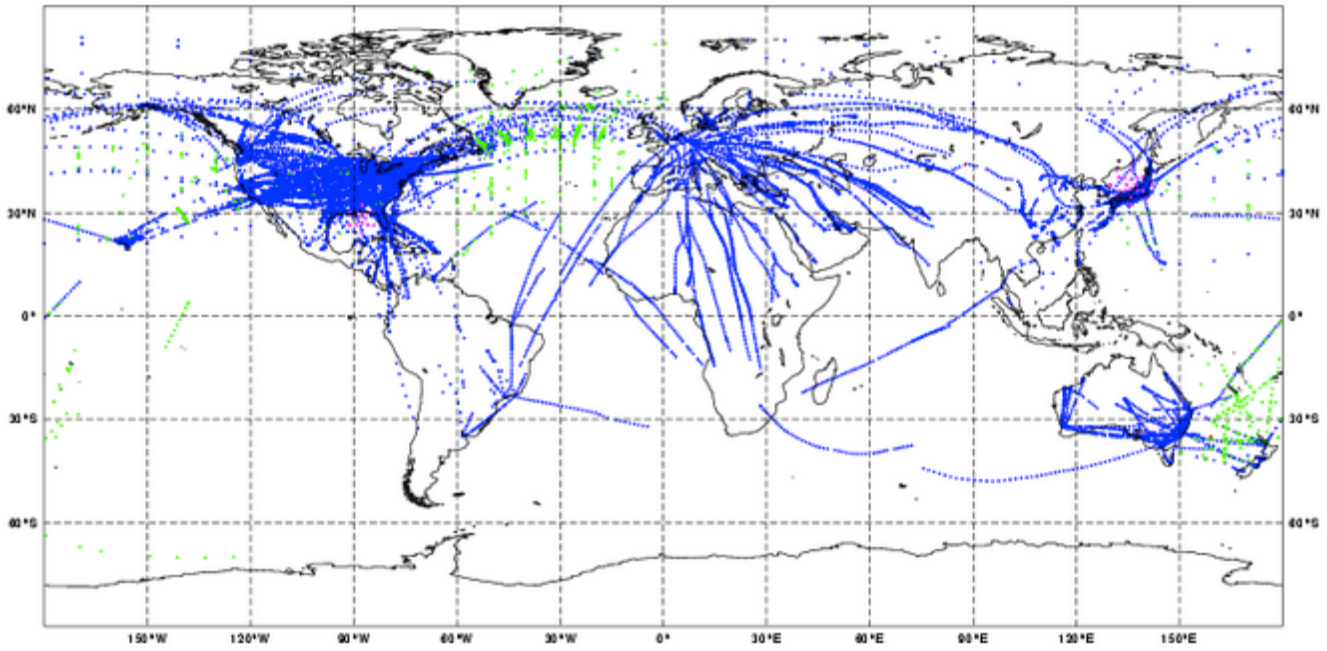


The A-Train satellite formation currently consists of five satellites flying in close proximity: Aqua, CloudSat, CALIPSO, PARASOL and Aura. (from NASA website.)

大气环流概述－观测资料

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

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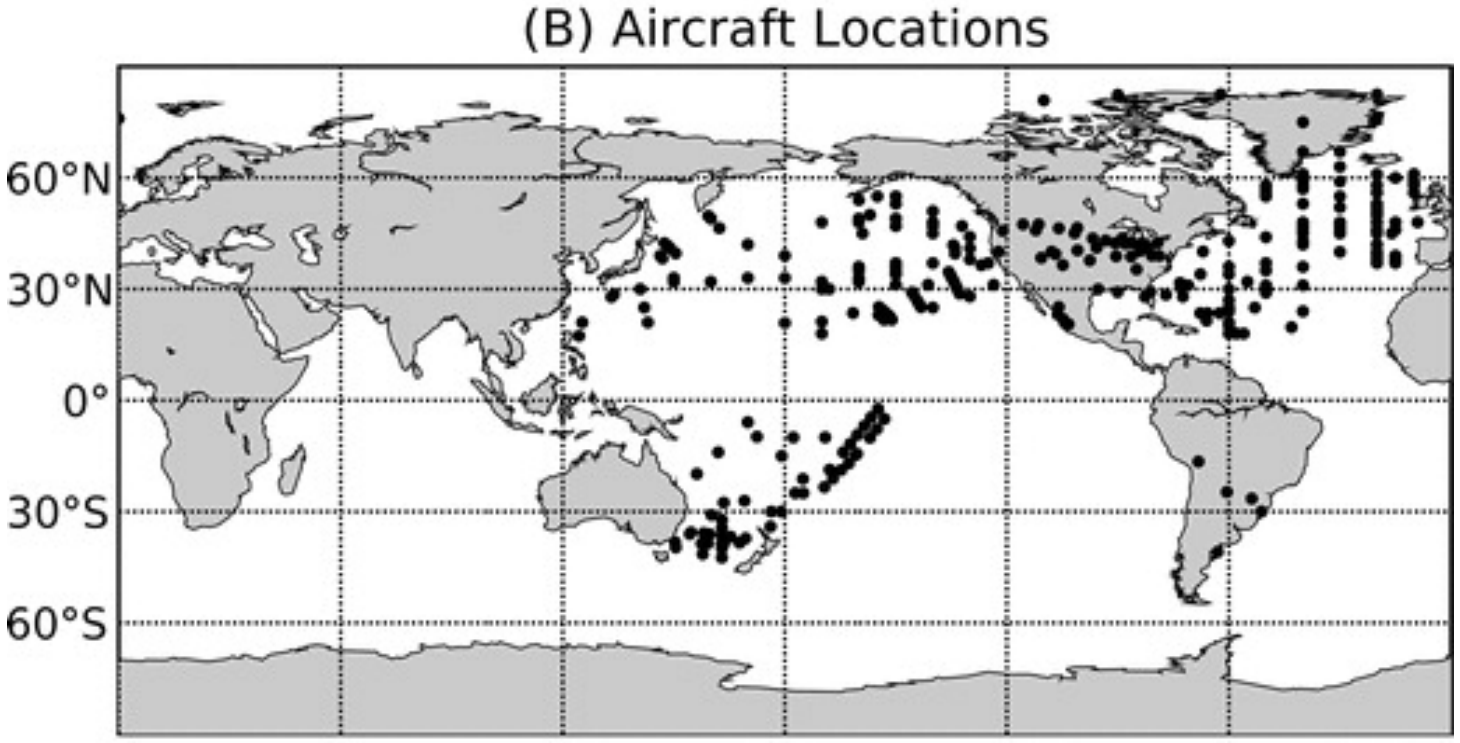
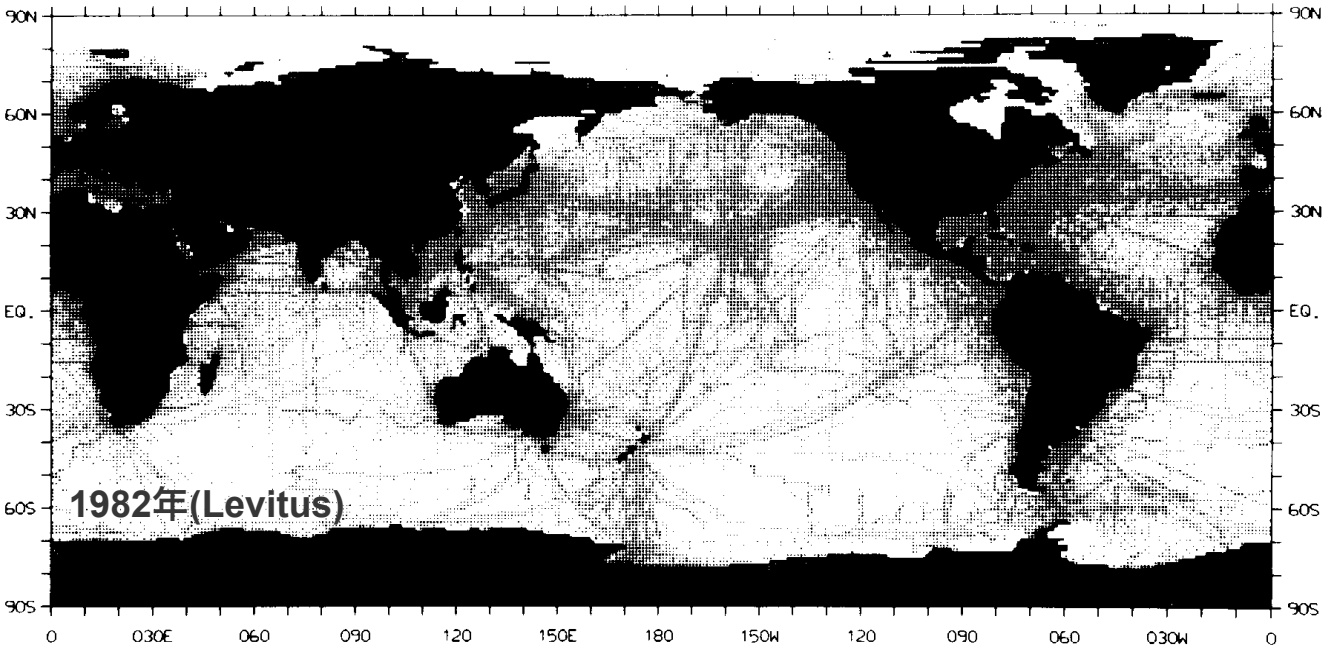


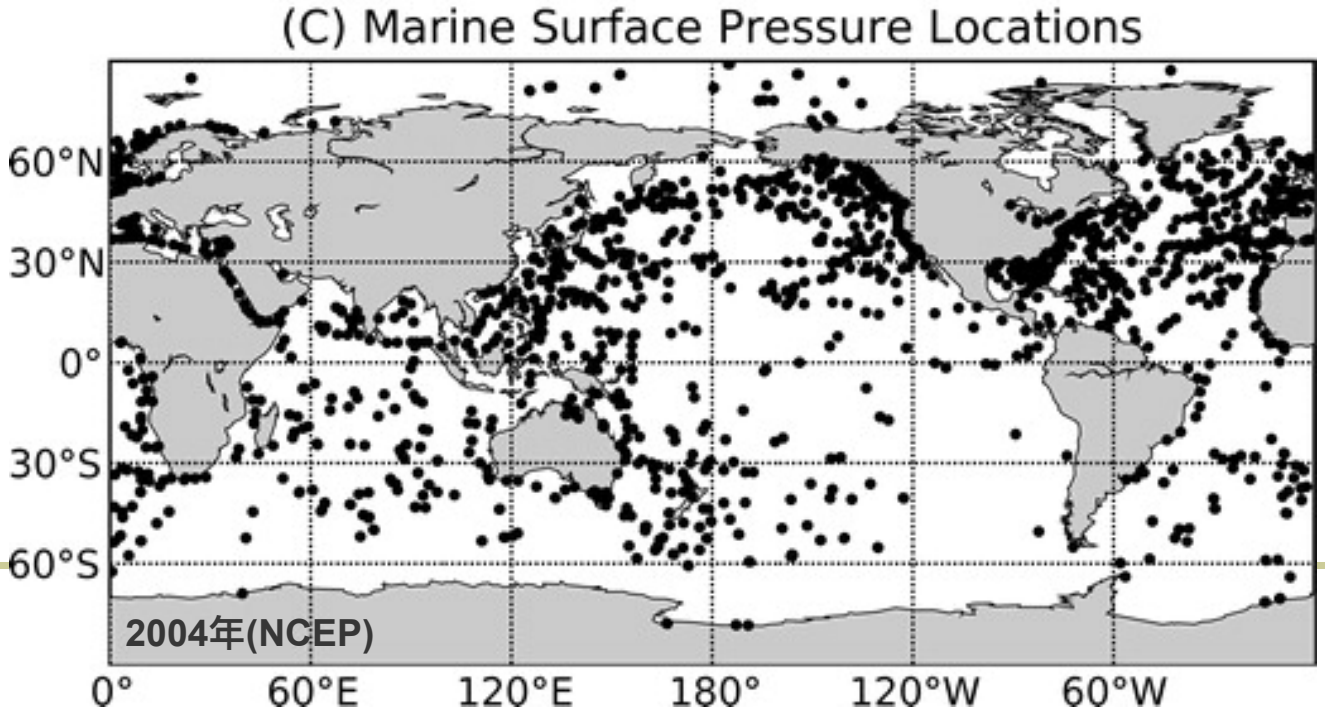
2004年(NCEP)

大气环

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.

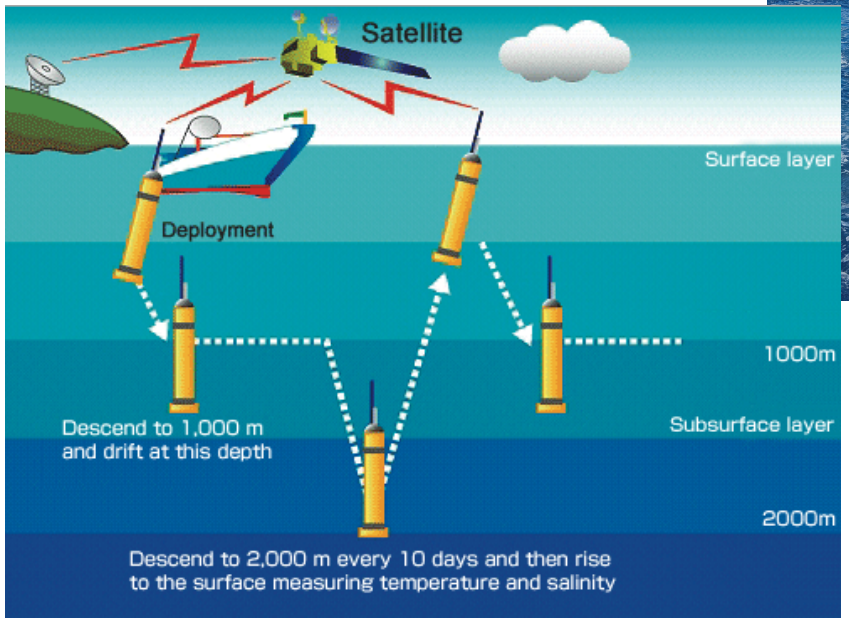




大气环流概述－观测资料

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.



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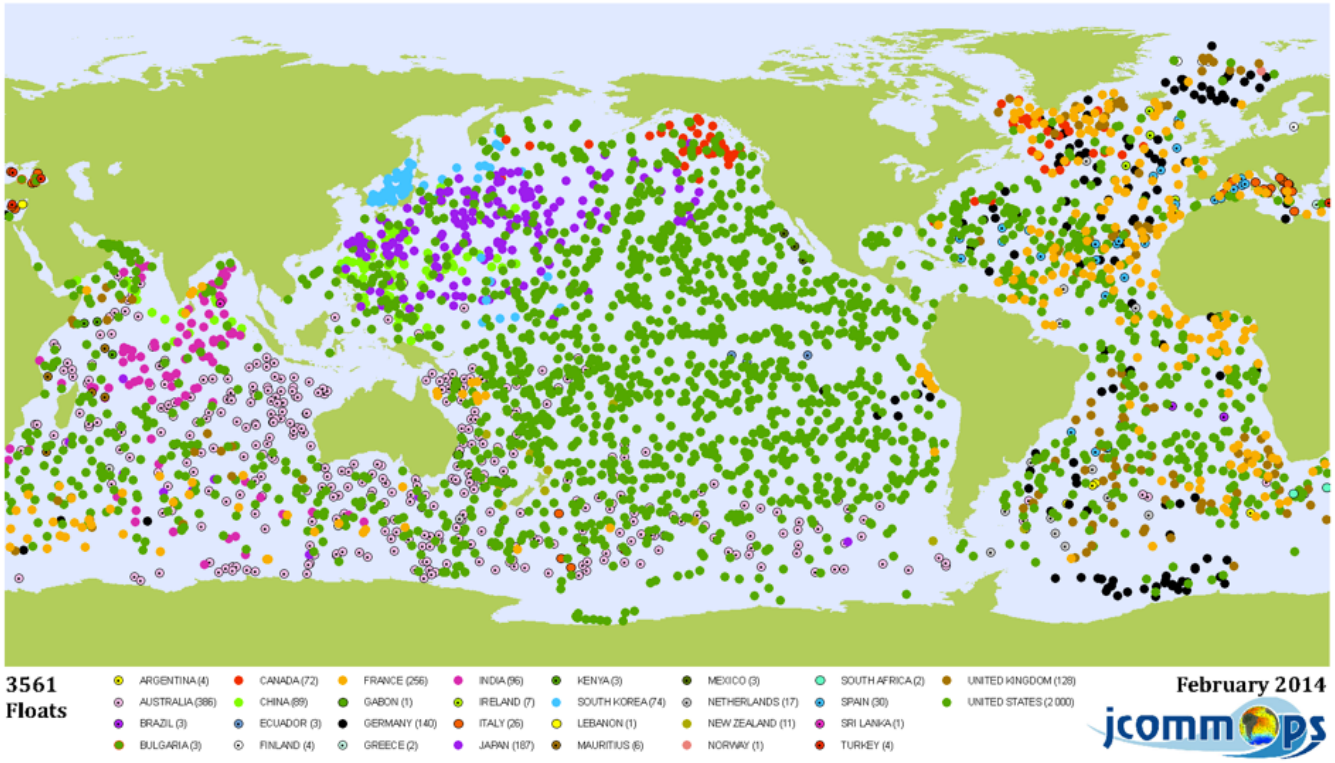
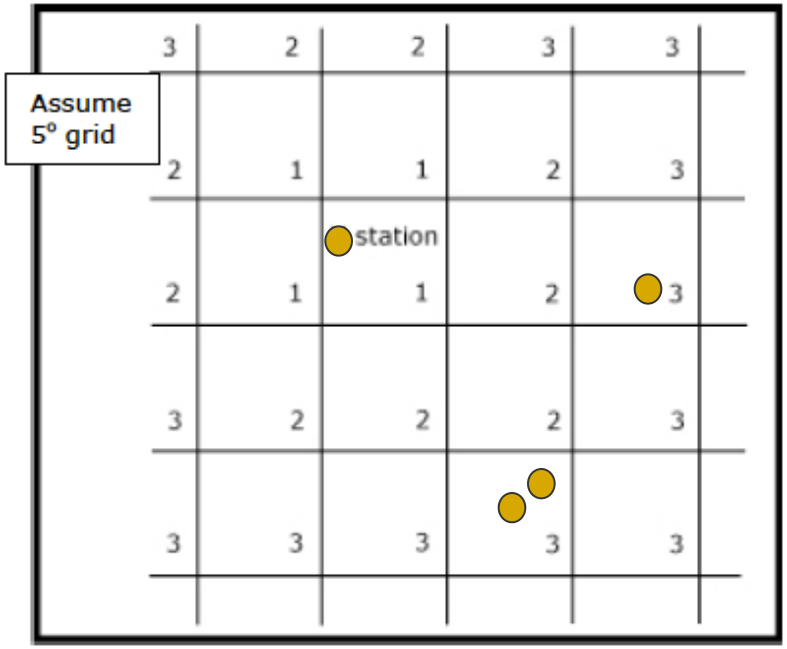


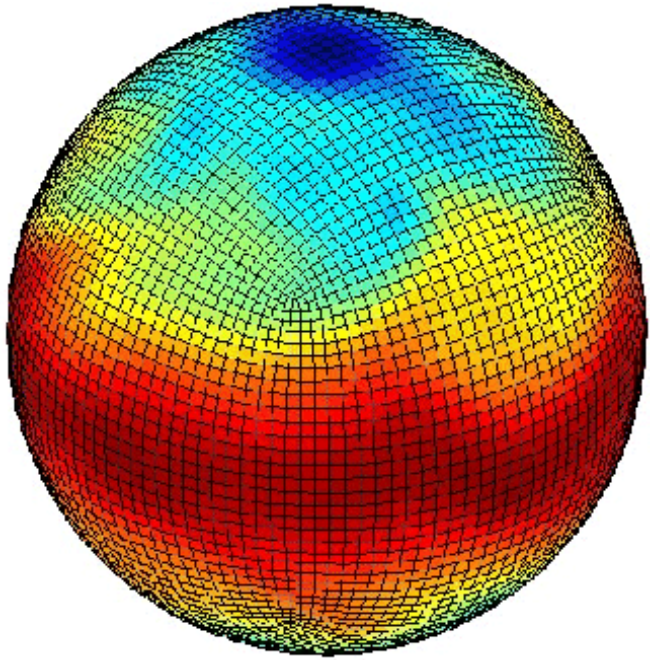
大气环流概述

- 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－资料处理与分析

- 举例: 从站点资料到格点资料

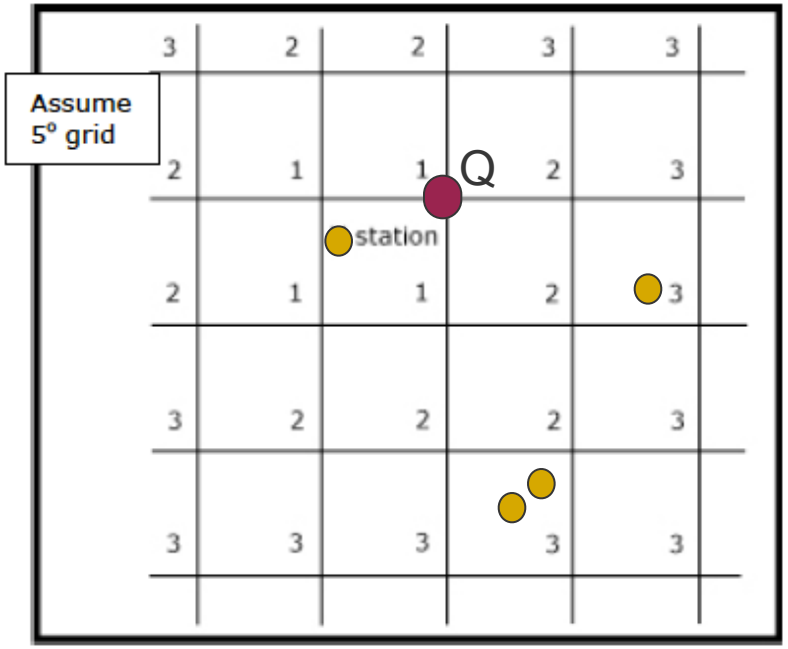




From Stone, 2005

大气环流概述－资料处理与分析

- 举例: 从站点资料到格点资料 (radiosonde based)



From Stone, 2005

- Initial guess Q_g for the actual field Q.
- Refine Q_g from any observations within a certain distance of each grid point:

$$Q_r = (1 - \sum_i W_i) Q_g + \sum_i W_i Q_i$$

The heart of the method is the appropriate choice of the weights W_i. In general, it depends on the distance of the observation from grid points. More sophisticated schemes might also consider the balance condition between variables.

- 举例: 从站点资料到格点资料 (**data assimilation**)

- Data assimilation:
  - process by which **observations** are incorporated into a **computer model** of a real system;
  - In each analysis cycle, **observations** of the current (and possibly past) state of a system are combined with the results from a numerical weather **prediction model** (the forecast) to produce an *analysis*, which is considered as 'the best' estimate of the current state of the system;
  - Data assimilation tries to balance the uncertainty in the **data** and in the **forecast**.

大气环流概述－资料处理与分析

data assimilation → “froze” analysis technique

technique always in development, e.g. using models with higher resolution, better parameterization

reanalysis data

ERA　　NCEP/NCAR

大气环流概述－再分析资料

- 再分析资料：ERA-40和NCEP/NCAR
  - NCEP(National Centers for Environmental Prediction)/ NCAR(National Center for Atmospheric Research)
    - Dataset Product:
      - 1948.01.01-present, global grids
      - 4-times daily and monthly
      - Horizontal: 2.5 X 2.5 degree (Basic)
      - Vertical: 17 pressure levels (Basic)
    - Model for data assimilation: T62 with 28 levels
    - Reference: Kalnay et al.,1996: The NCEP/NCAR 40-year reanalysis project, *Bull. Amer. Meteor. Soc.*, 77, 437-470.
    - http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html

大气环流概述－资料处理

- NCEP/NCAR 再分析资料
  - 物理量及分类
    - **A** (strongly influenced by *observed data*, hence, in the most reliable class): geopotential height, T, u, v...
    - **B** (although there are *observational data* directly affecting the value of the variable, the *model* also has a strong influence): relative humidity, w(vertical velocity), lowest level u and v...
    - **C** (*no observations* directly affecting the variable, so that it is derived *solely from the model* forced by the data assimilation): radiation fluxes, surface heat fluxes, cloud forcing, precipitation rate...
    - **D** (*fixed* from climatological values and does *NOT depend on models*): surface roughness, surface geopotential height...