The 9th CCFD

CFD Applications in Hydraulics and Meteorology

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Outline

(1) CFD Applications
- Hydraulics
- Meteorology

(2) Research Activities in REEL

(3) On the Climate System
- Introduction
- Physical Processes
- Important Events
  - Global Warming
  - El Nino
  - Indian Summer Monsoon

CFD Applications in hydraulics

- Water quality prediction of Mid-Route of South-to-North Water Transfer Project.
- Dam-break simulation of Miyun Reservoir
- Anisotrpoic Buoyant Turbulence model and applications in pollutant discharge into rivers

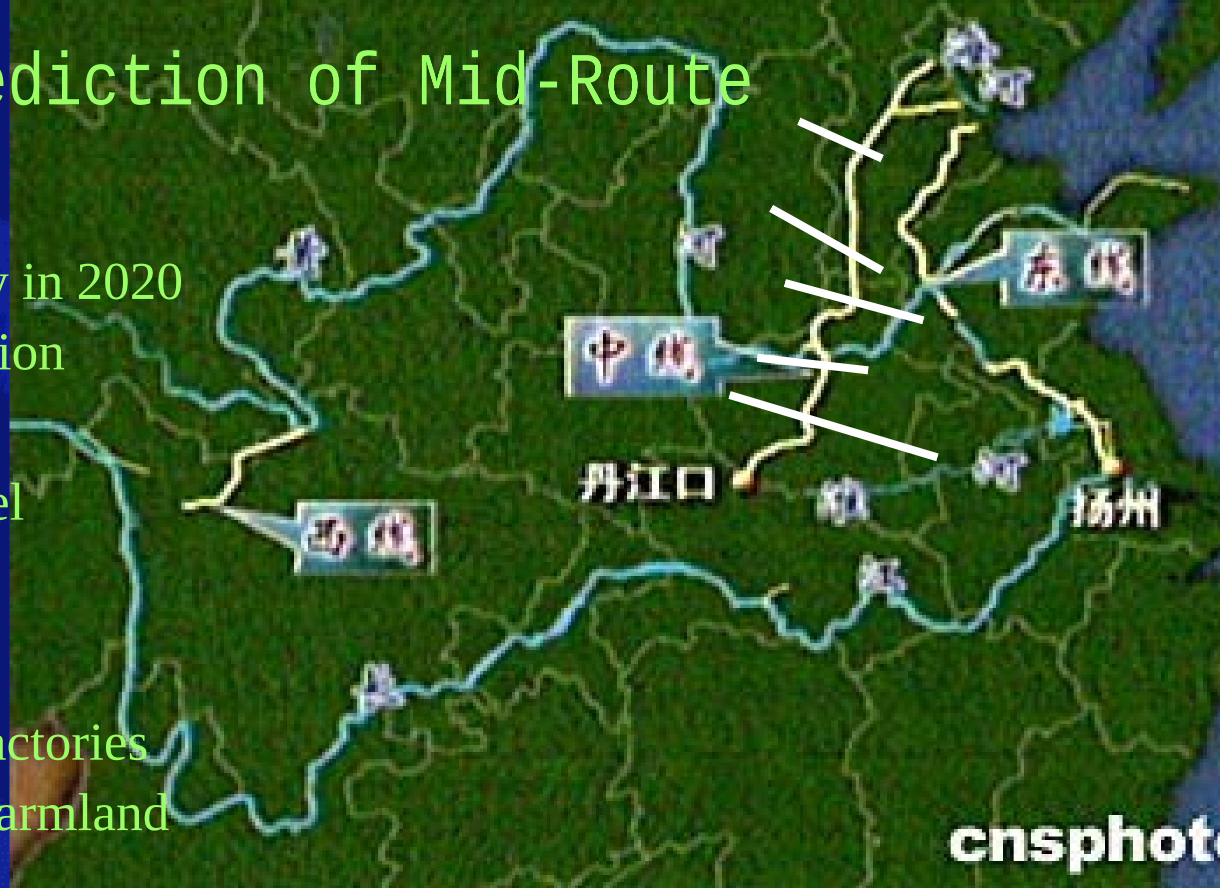
South-to-North Water Transfer Project

Water transfer along Mid-Route:

Pump water from Danjangkou of Hanjiang River;

Supply for west and mid- plain of Huang-Huai-Hai Riverbasin, Beijing and Tianjing

Water quality prediction of Mid-Route



Objectives

- Predict water quality in 2020
- Control water pollution

Background

Rivers crossing the channel may pollute water

Pollutant sources

(1) Point source from factories

(2) Area sources from farmland

Equations

(1) Continuity: Qout = Qin + qin-qout

(2) Energy: Eout = Ein – friction loss – local loss

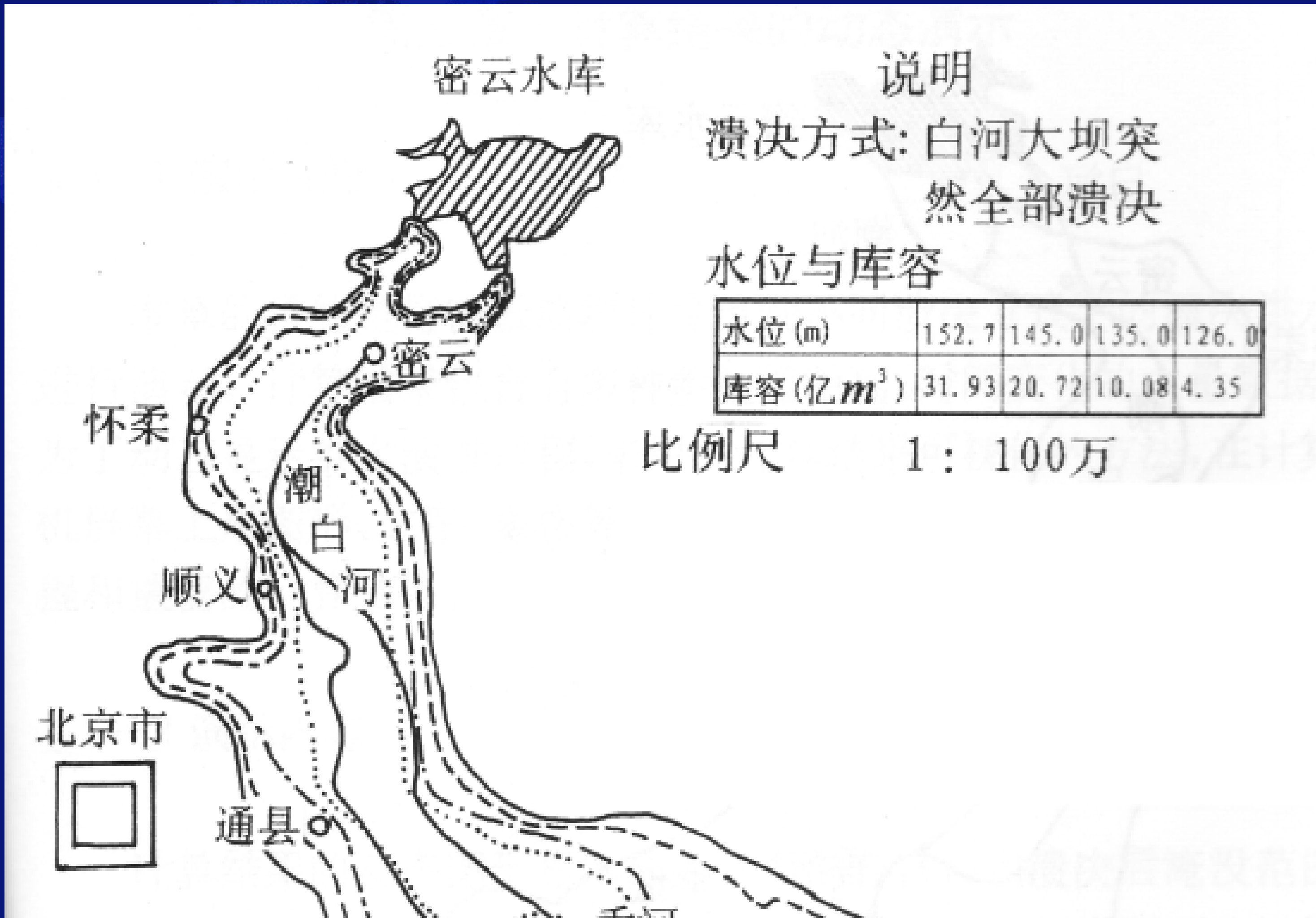
(3) Pollutant: Local = Adv + Dif + source - sink

Conclusions

(1) Avoid mixing of rivers and channel water as many as possible

(2) Pollution is severe in flooding season

Miyun Reservoir



Dam-break simulation

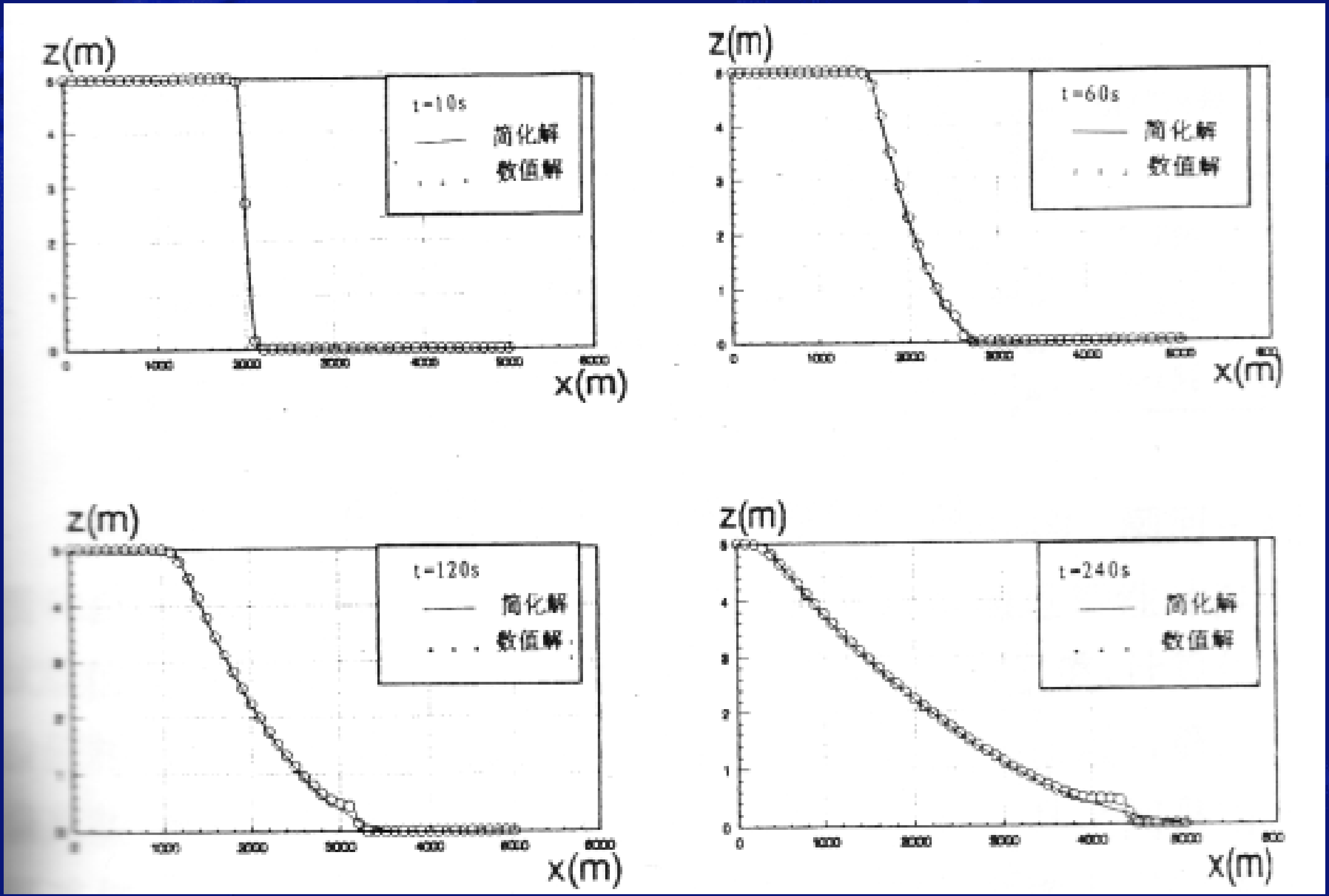
- Background
  - Constructed in 1958-1960, the biggest reservoir in north China （capacity: 43.75m^3，about 1/3~1/4 of the Three- gorge Reservoir；Area: 224km^2)，major water resource of Beijing. Two major dams: Baihe and Chaohe
  - 1976: Land sliding in Baihe dam due to Tangshan earthquake.
  - Big dams should be checked every 5-10 years.
  - Due to lack of water resources, Miyun reservoir may be operated at high water levels
  - The downstream Beijing, Tanjing and Tangshan may be flooded one dams are broken
- Difficulties
  - Topography information
- Dam-break simulation
  - Equations

$$\partial A/\partial t + \partial Q/\partial x = 0$$

$$\partial Q/\partial t + \partial (Q^2 / A)/\partial x = -gA(\partial z/\partial x + Q^2 / K^2)$$

  - TVD (total variation diminishing):Computationally stable, and shock-wave capturing

Validation I: Analytical solution



Anisotrpoic Buoyant Turbulence model

- *k*-ε model
  - Very good for planar jet but bad for axis jet
- Buoyant models
  - Reynolds stress model → too complicated
  - Algebraic stress model (Rodi)
    - Implicit (linear assumption or local equilibrium) (Launder et al., 1979)
    - Explicit (Gatski and Speziale, 1993)
    - Numerical singularity if strain >>
- Nonlinear models
  - Speziale (1987) → No buoyancy
- Nonlinear buoyant models

Anisotrpoic Buoyant Turbulence model

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho U}{\partial x}+\frac{\partial \rho V}{\partial y}=0 \qquad (1)$$

$$\frac{\partial \rho U}{\partial t}+\frac{\partial}{\partial x}\left(\rho UU-\mu\frac{\partial U}{\partial x}\right)+\frac{\partial}{\partial y}\left(\rho UV-\mu\frac{\partial U}{\partial y}\right)=-\frac{\partial P}{\partial x}-\frac{\partial \overline{\rho uu}}{\partial x}-\frac{\partial \overline{\rho uv}}{\partial y} \qquad (2)$$

$$\frac{\partial \rho V}{\partial t}+\frac{\partial}{\partial x}\left(\rho UV-\mu\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial y}\left(\rho VV-\mu\frac{\partial V}{\partial y}\right)=-\frac{\partial P}{\partial y}-\frac{\partial \overline{\rho uv}}{\partial x}-\frac{\partial \overline{\rho vv}}{\partial y}-\alpha\Delta C\rho_a g \qquad (3)$$

$$\frac{\partial \rho C}{\partial t}+\frac{\partial}{\partial x}\left(\rho UC-D\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(\rho VC-D\frac{\partial C}{\partial y}\right)=-\frac{\partial \overline{\rho uc}}{\partial x}-\frac{\partial \overline{\rho vc}}{\partial y} \qquad (4)$$

$$\frac{\partial \rho k}{\partial t}+\frac{\partial}{\partial x}\left[\rho Uk\right]+\frac{\partial}{\partial y}\left[\rho Vk\right]=\frac{\partial}{\partial x_l}\left[\rho C_k\frac{k^2}{\varepsilon}\frac{\partial k}{\partial x_l}\right]+\rho P_k+\rho G_k-\rho\varepsilon \qquad (5)$$

$$\frac{\partial \rho \varepsilon}{\partial t}+\frac{\partial}{\partial x}\left[\rho U\varepsilon\right]+\frac{\partial}{\partial y}\left[\rho V\varepsilon\right]=\frac{\partial}{\partial x_l}\left[\rho C_\varepsilon\frac{k^2}{\varepsilon}\frac{\partial \varepsilon}{\partial x_i}\right]+$$

$$c_{\varepsilon 1}\rho\frac{\varepsilon}{k}\left(P_k+G_k\right)\left(1+C_{\varepsilon 3}R_f\right)-C_{\varepsilon 2}\rho\frac{\varepsilon^2}{k} \qquad (6)$$

$$\rho=\rho_a(1+\alpha\Delta C) \qquad (7)$$

$$\overline{u_i u_j}=\overline{u_i u_j}(strain, nonlinear)+\overline{u_i u_j}(buoyancy, ASM)$$

Validation in pure jets

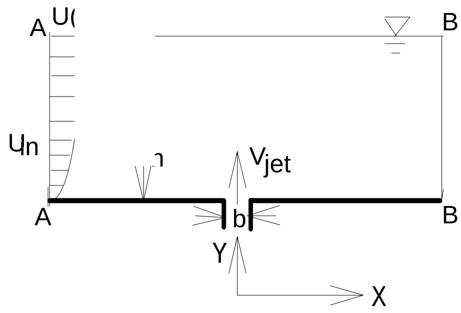
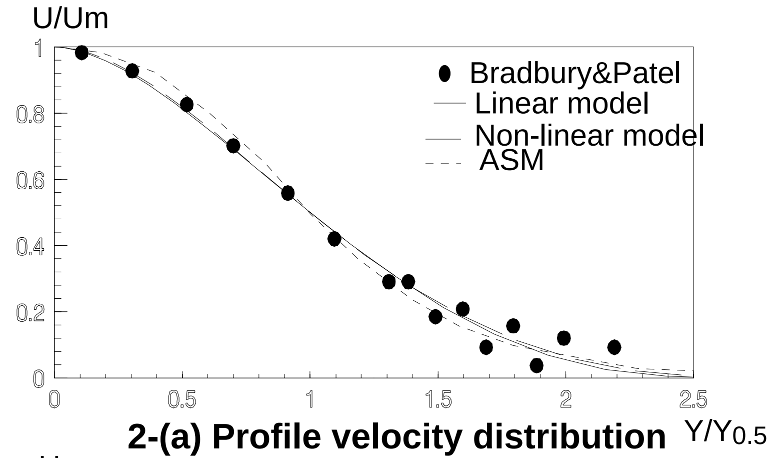
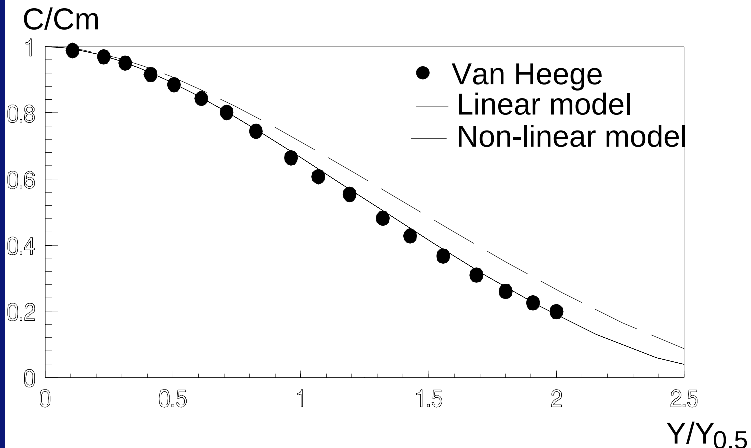


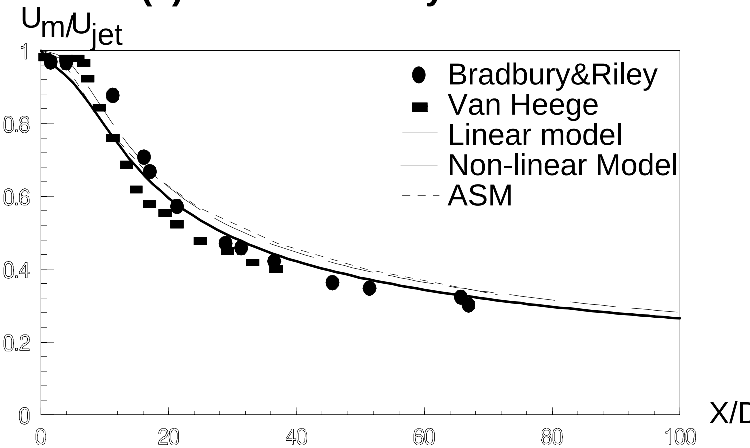
Fig.1 Jet in tidal flow



2-(a) Profile velocity distribution



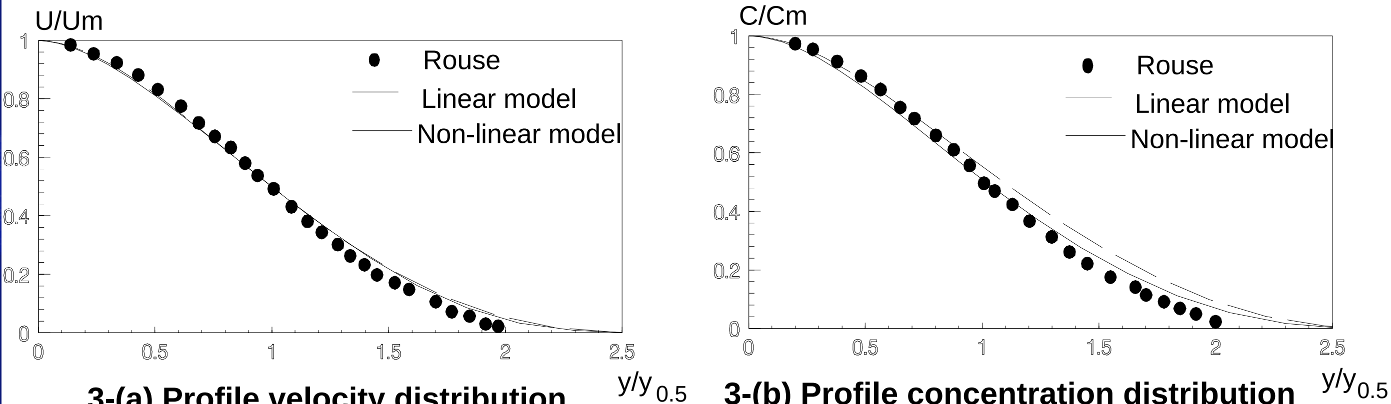
2-(b) Profile concentration Distribution



2-(c) Axial velocity distribution

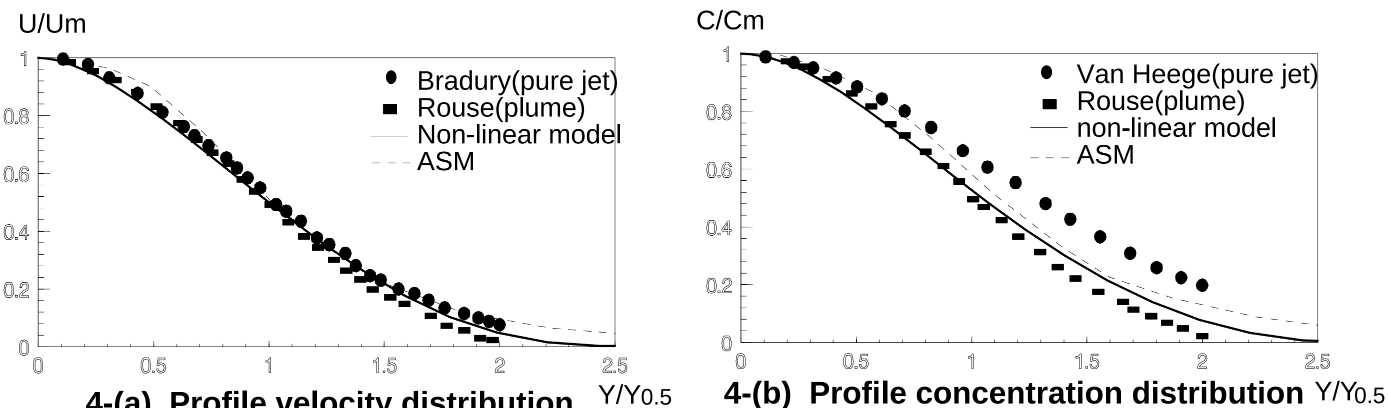
Fig. 2 Experimental and Computational result of pure jet in stagnant ambient

Validation in plume jets



3-(a) Profile velocity distribution **3-(b) Profile concentration distribution**

Fig. 3 Experimental and computational result of plume in stagnant ambient



4-(a) Profile velocity distribution **4-(b) Profile concentration distribution**

Fig.4 Computational results of buoyant jet in stagnant ambient ($F_d = 24$)

Pollutant discharge into tidal Yangtze River

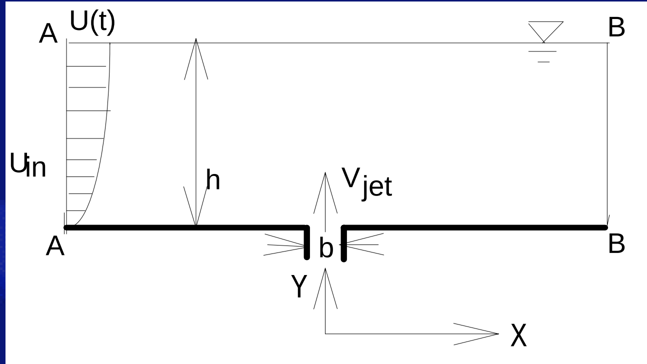


Fig.4 Jet in tidal flow

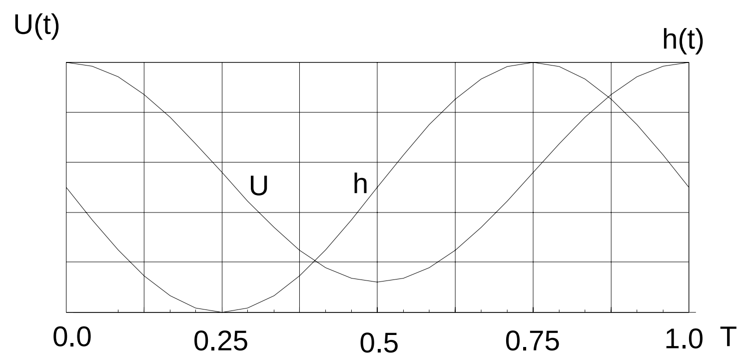


Fig.5 Depth and velocity of tidal flow

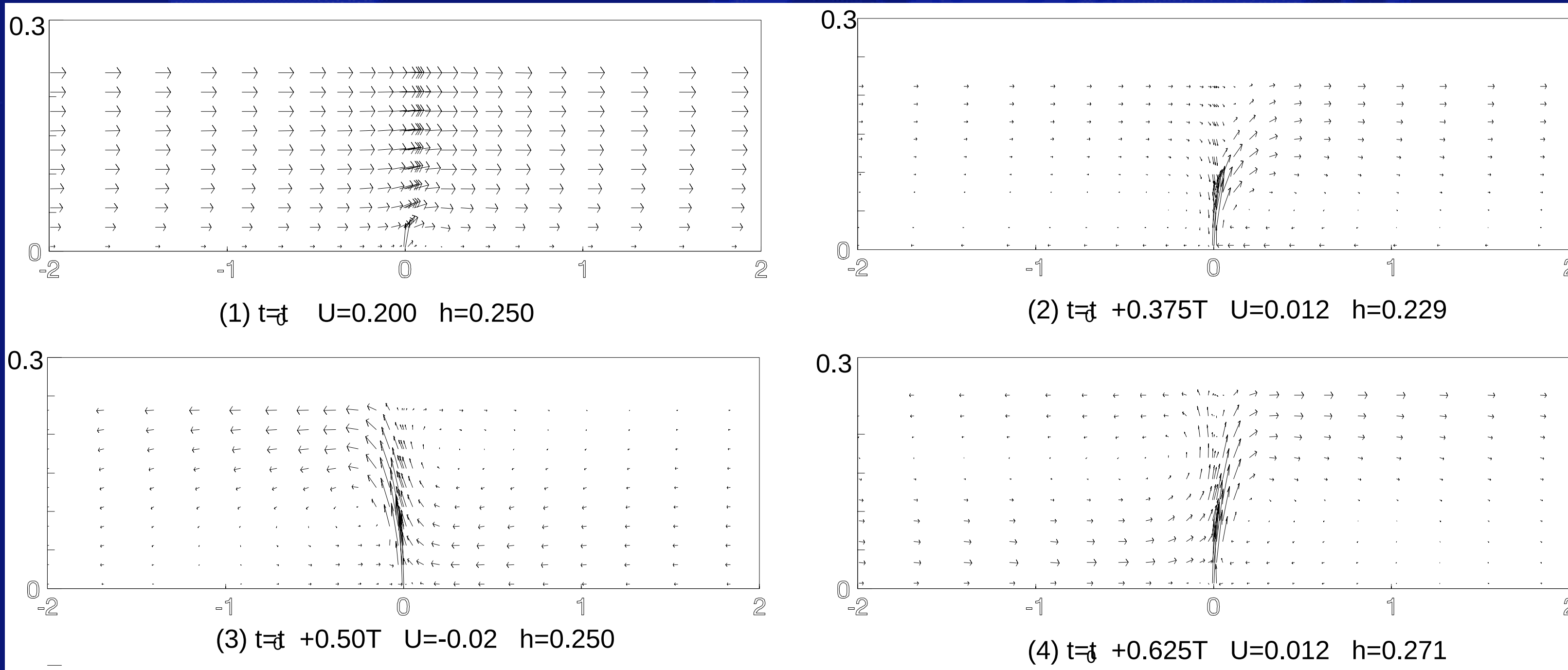
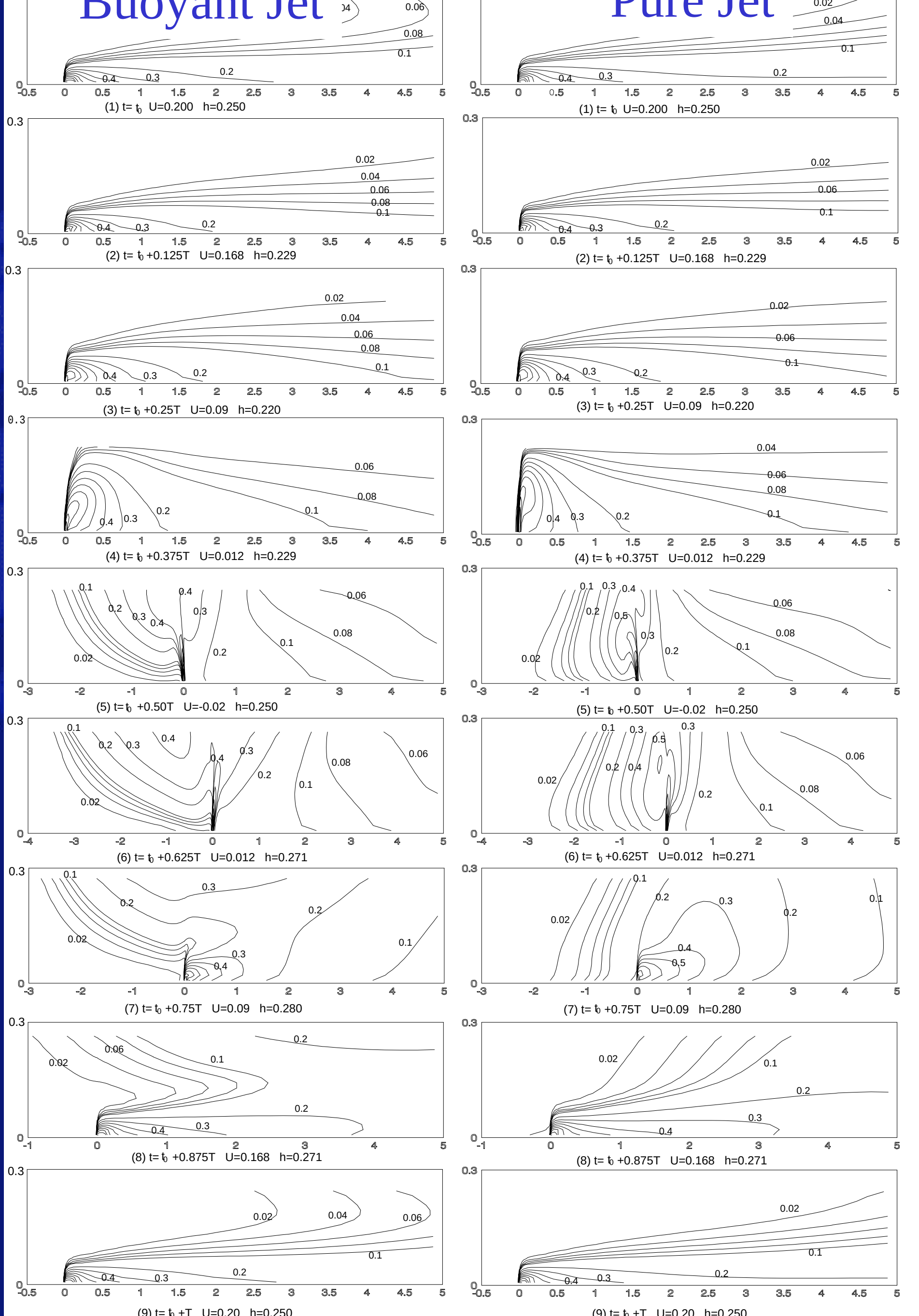


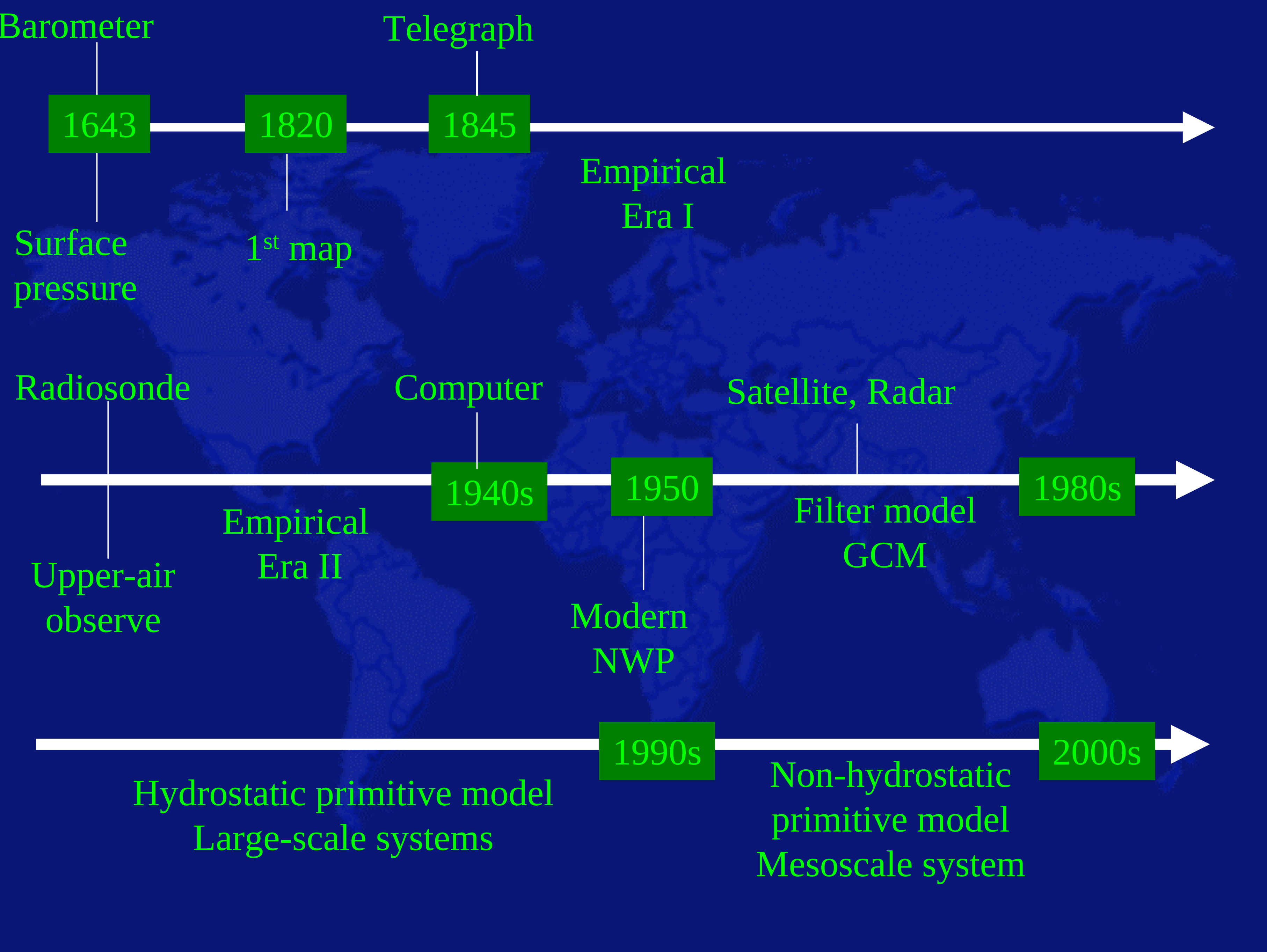
Fig.6 Velocity vectograph of buoyant jet in tidal flow

- $t=t_0$
- $t=t_0+1/8T$
- $t=t_0+1/4T$
- $t=t_0+3/8T$
- $t=t_0+1/2T$
- $t=t_0+5/8T$
- $t=t_0+3/4T$
- $t=t_0+7/8T$
- $t=t_0+T$



CFD Applications in meteorology

- History of Numerical weather prediction (NWP)
- Governing equations and Numerical methods
- Plateau boundary layer simulation


Barometer
Telegraph
1643
1820
1845
Empirical Era I
Surface pressure
1st map
Radiosonde
Computer
Satellite, Radar
1940s
1950
1980s
Empirical Era II
Filter model GCM
Upper-air observe
Modern NWP
1990s
2000s
Hydrostatic primitive model
Large-scale systems
Non-hydrostatic primitive model
Mesoscale system

Important events in the history of NWP

- 1904, V. Bjerknes: weather prediction is an initial value-problem
- 1922:L. F. Richardson: apply FDM to predicting the weather
  - produce first inaccurate six-hour forecast (25x5)
  - published his *Weather Prediction by Numerical Process*
  - Foundations for present day weather forecasting.
- 1948: Jule Charney: derived simplified mathematical models of the atmospheric motions
- 1950: von Neumann and Jule Charney: applied the computer to weather forecasting
- 1962: US launched the first operational quasi-geostrophic baroclinic model
- 1966: The first global primitive equations model began operating at NMC Washington,
- Data assimilation technique for initialization
- Land-atmosphere –ocean coupled model

Richardson's weather forecasting (B. Hayes, 2001)

Figure 2. Data for Richardson's forecast included measurements of winds (*M*), barometric pressure (*P*) and temperature (*T*). Initial data were recorded in 25 squares, each 200 kilometers on a side, but conditions were forecast only for the two central squares outlined in red.

Pressure increased 140mb!!!

(1) Staggered discretization
(2) Leapfrog integration
(3) Land and biological factors
(4) Primitive equations

(1) CFL condition
(2) Initial errors

What is data assimilation?

Observation data for the Earth system are obtained from a variety of sources, including satellites.

The data are of different types (eg. temperature, wind, ozone), and to get the maximum benefit from this data for both climate research and weather forecasting we need to find a method to combine this mixture of data.

Data assimilation is such a method. It is a technique in which the data are combined with output (forecasts) from a model of the evolving atmosphere (for example) to produce an optimal representation of the evolving state of the atmosphere.

One benefit of data assimilation is that it produces a sequence of three-dimensional states consistent with our knowledge of the way in which the whole Earth system evolves.

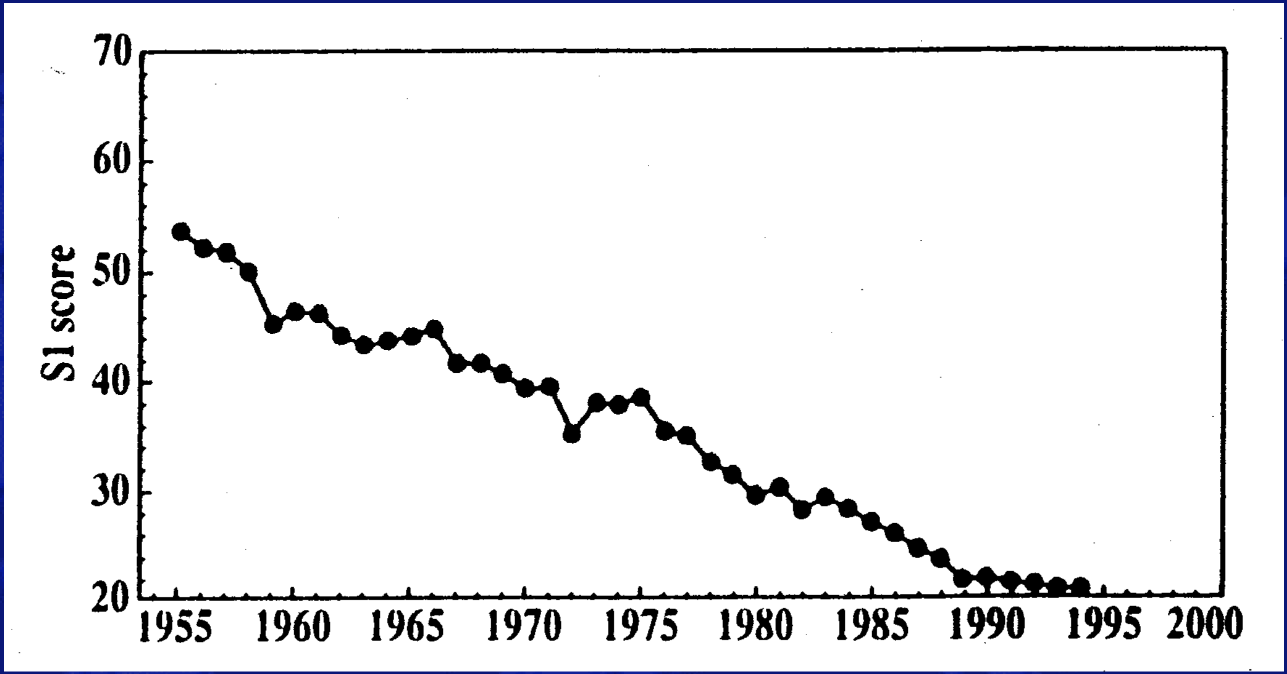
The benefits of data assimilation

Research scientists need the three-dimensional time sequences produced by data assimilation in order to understand how the different components of the Earth system work, and how they interact with each other.

Without data assimilation, they would be faced with observations from a wide range of instruments with different errors, unevenly distributed in space and time, often including large data gaps.

By combining (and comparing) model forecasts and observational data, data assimilation can enable scientists to determine possible problems with both the data and their model – thereby leading to improvements in both data quality and model forecasts.

Prediction skill



Evolution of the SI skill score for the 500-hPa 36-h forecast over North America. The SI score measures the relative error in the forecast of pressure gradient. Values of 70% and 20% are considered useless and essentially perfect forecasts, respectively (Kalnay, 1995).

Atmospheric dynamics

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho U_i}{\partial x_i} = 0$$

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + F_{ci} + (Buoy - g)\delta_{i3} - \frac{\partial \overline{u_i u_j}}{\partial x_j}$$

$$\frac{\partial K}{\partial t} + U_j \frac{\partial K}{\partial x_j} = -\frac{\partial \overline{k u_j}}{\partial x_j} + P_{buoy} + P_{mech} - D_{diss}$$

$$P = \frac{\rho R_d T(\varepsilon + q_v)}{\varepsilon(1 + q_v + q_{liquid+ice\ water})}$$

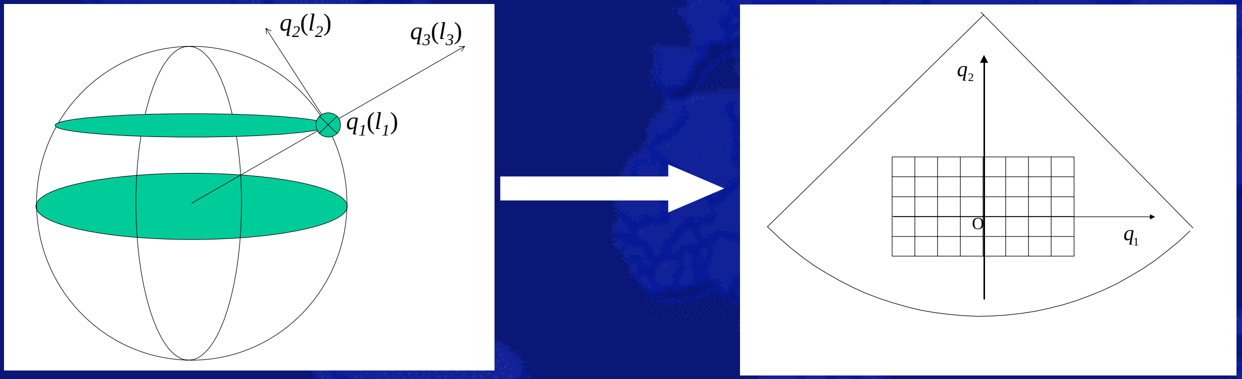
$$\frac{\partial q_\psi}{\partial t} + U_j \frac{\partial q_\psi}{\partial x_j} = \frac{S_{q_\psi}}{\rho} - \frac{\partial \overline{q'_\psi u_j}}{\partial x_j} + \frac{\partial q_\psi V_{q_\psi}}{\partial x_3}$$

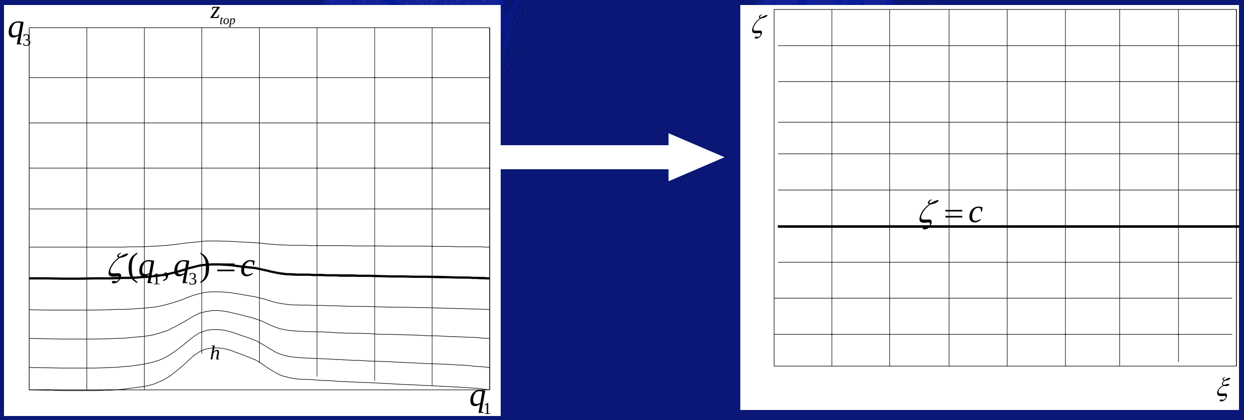
$$\frac{\partial \Theta}{\partial t} + U_j \frac{\partial \Theta}{\partial x_j} = \frac{(S_{TR} + S_{Tq})\pi}{\rho C_p} - \frac{\partial \overline{\theta u_j}}{\partial x_j}$$

- Compressible (sound waves and gravity waves)
- Earth’s rotation → Coriolis force
- Barotropic → Baroclinic
- Thermodynamics

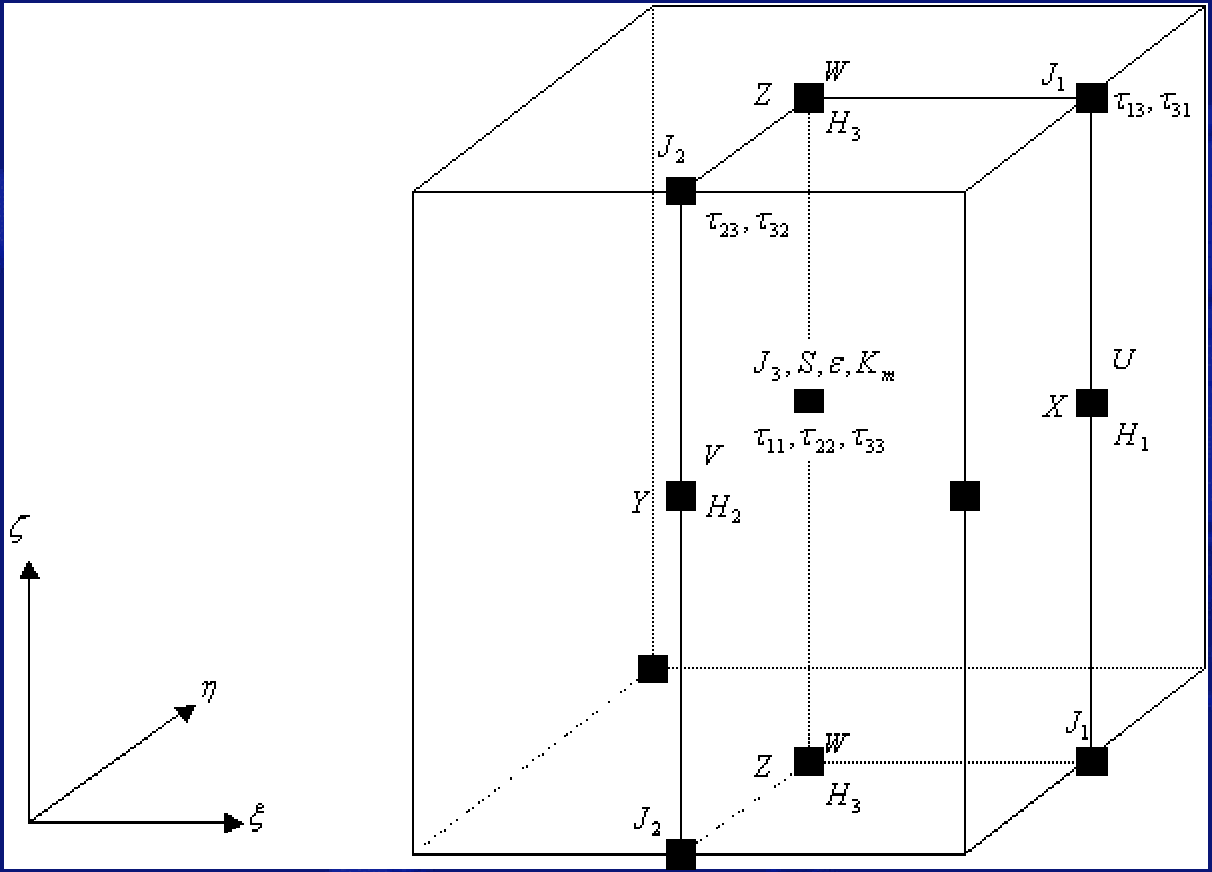
Numerical method

- Convert from sphere to Cartesian coordinate
- Convert from complex terrain to flat plain





Arakawa C Grid



Some techniques

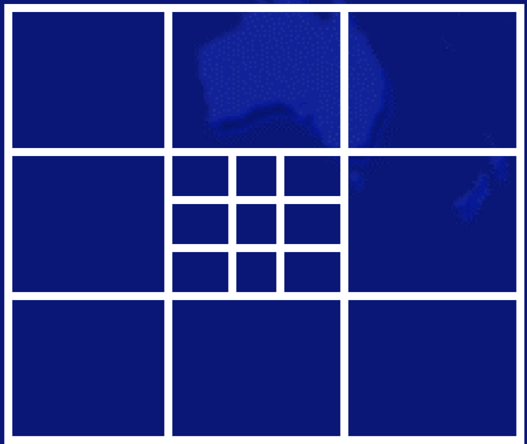
- Filter → hydrostatic approximation

$$\frac{\partial p}{\partial z} = -\rho g$$

- Mode-splitting time integration → integrate fast wave using small time step while slow wave using big time step.

$$\frac{y^{\tau+\Delta\tau} - y^{\tau}}{\Delta\tau} = f^{\tau} + g^{t}$$

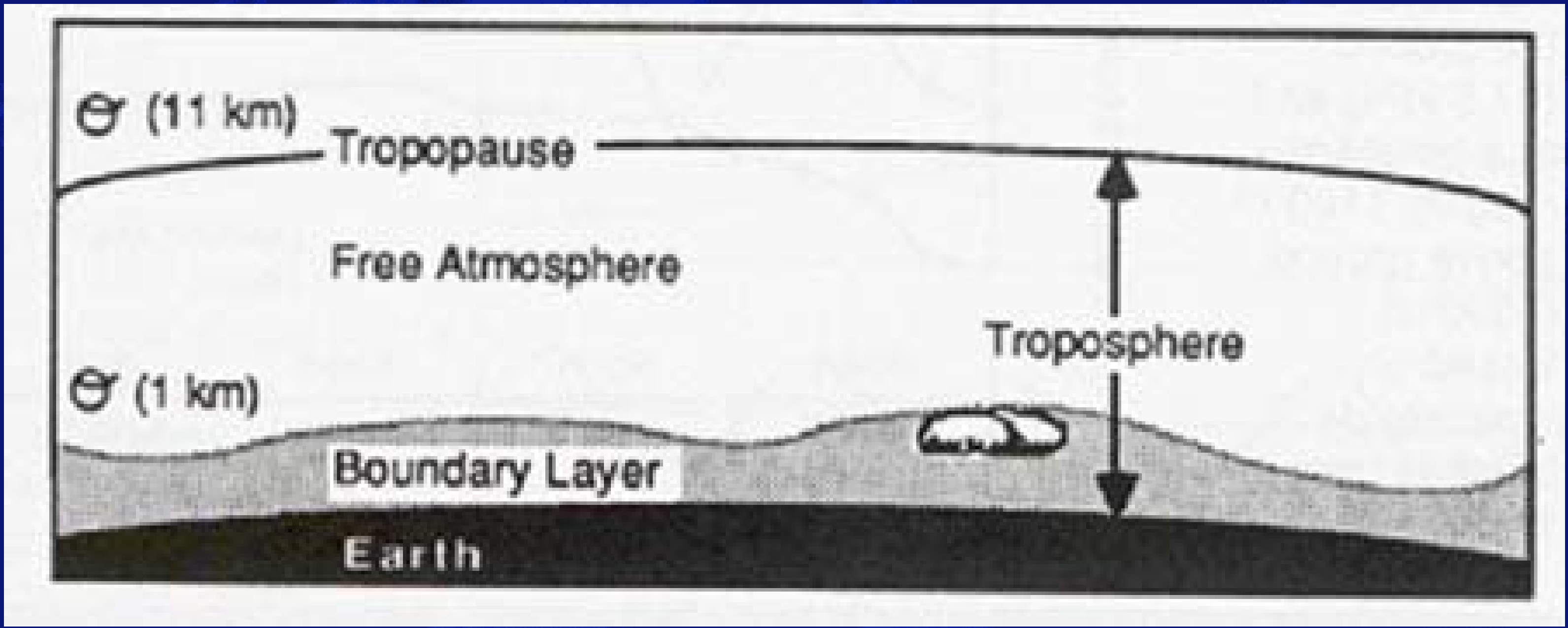
- Nesting → refine simulation



- Downscaling

Example: Plateau boundary layer simulation

The Daytime Evolution of the Atmospheric Boundary Layer, Convection and Mountain-Valley Circulations over the Tibetan Plateau: Observations and Simulations


(11 km)
Tropopause
Free Atmosphere
Troposphere
(1 km)
Boundary Layer
Earth

Background

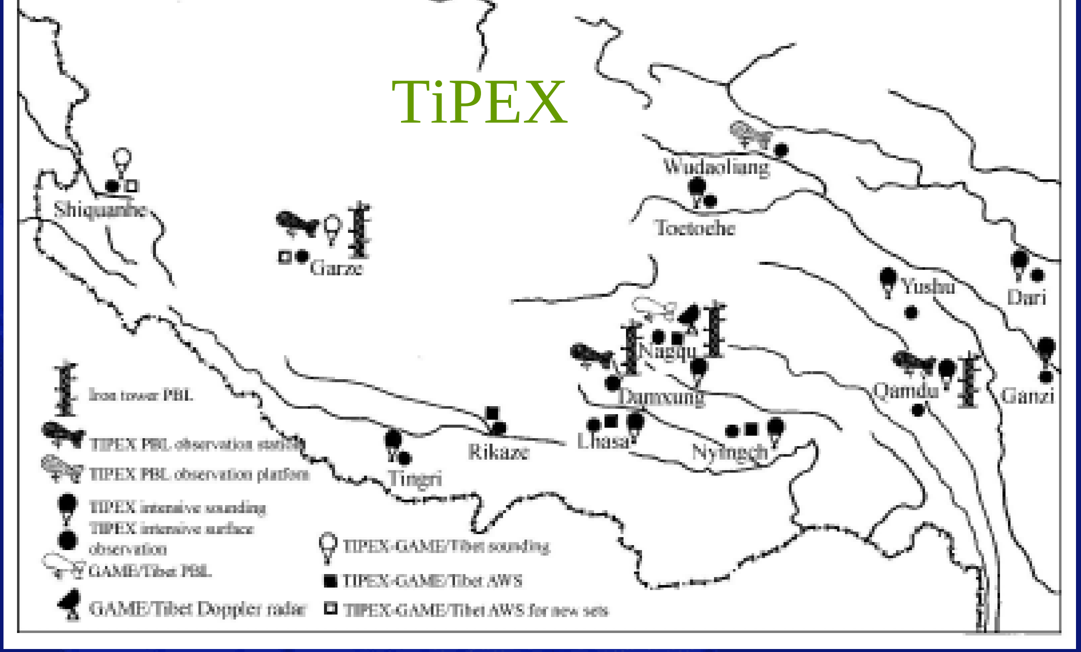
- The plateau is a huge elevated heat source during the summer (Ye et al. 1979). It exerts profound thermal and orographic effects on atmospheric circulation patterns on all temporal and spatial scales (Gao et al. 1981). The onset of the Asian summer monsoon is an interactive process between the plateau–induced circulation and the circulation associated with the principal rainbelt migrating northward (Yanai et al. 1992; Wu and Zhang, 1998).

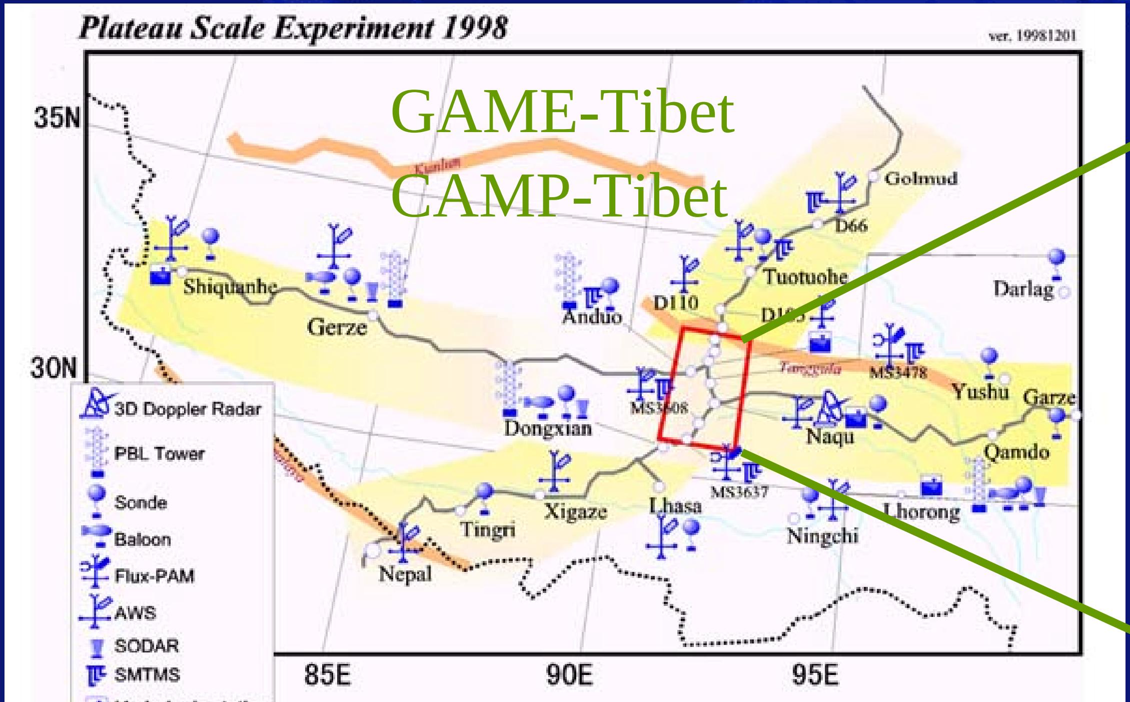
- The Plateau ABL has the most frequent synoptic-scale and mesoscale pressure systems. Many synoptic systems that cause the rainfall in East China plain have their origin in the boundary layer over the plateau and its surroundings (Gao *et al*. 1981; Tao and Ding 1981). The drought-flood in East China is sensitive to the thermal anomaly of the plateau underlying surface (Xu *et al*. 2000; Huang and Yao, 2004).

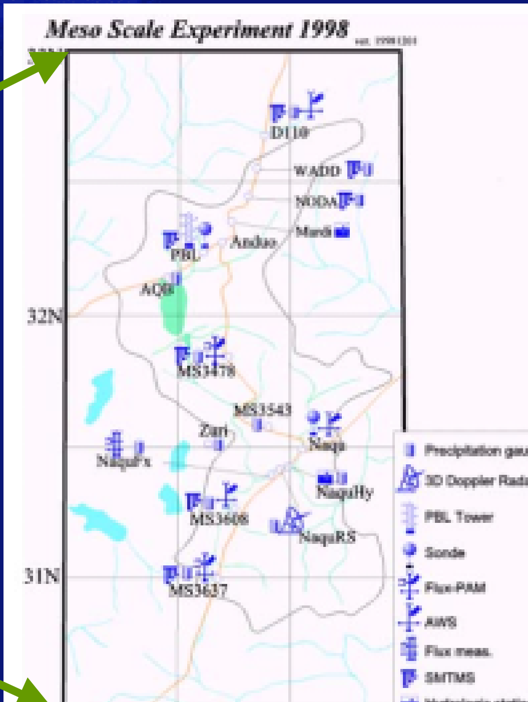
Problem statement

- The plateau ABL is usually high, particularly in pre-monsoon period. What is the mechanism of ABL evolution or the energy budget in the ABL?
- The Plateau has low air density, are the convection and mountain-valley circulations different from that of lowlands?

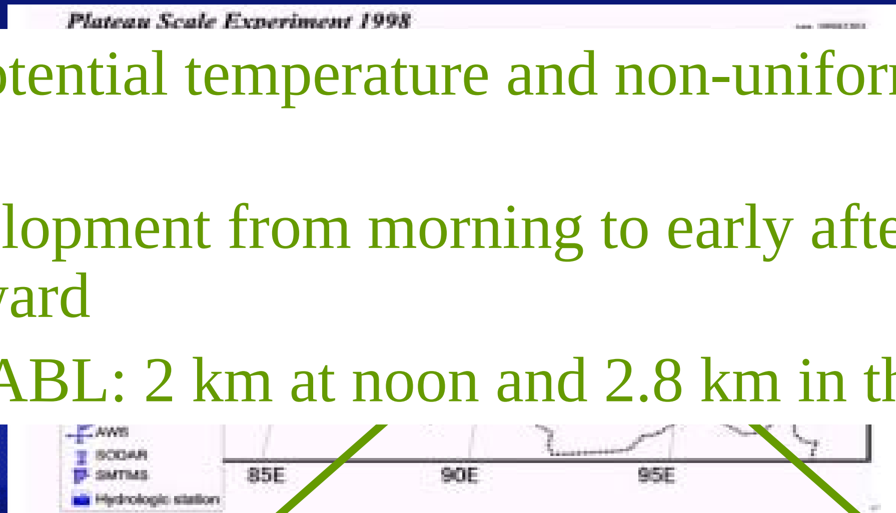
Experiments







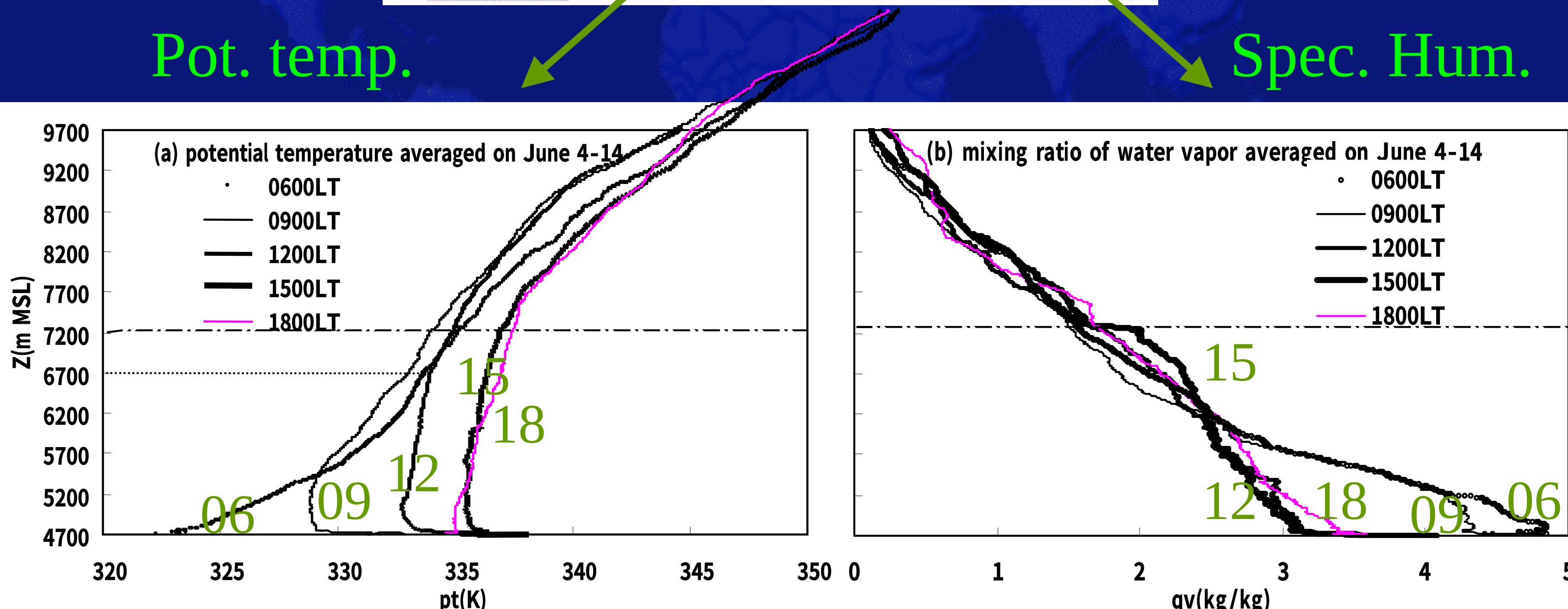
ABL (Amdo, 4700MSL)



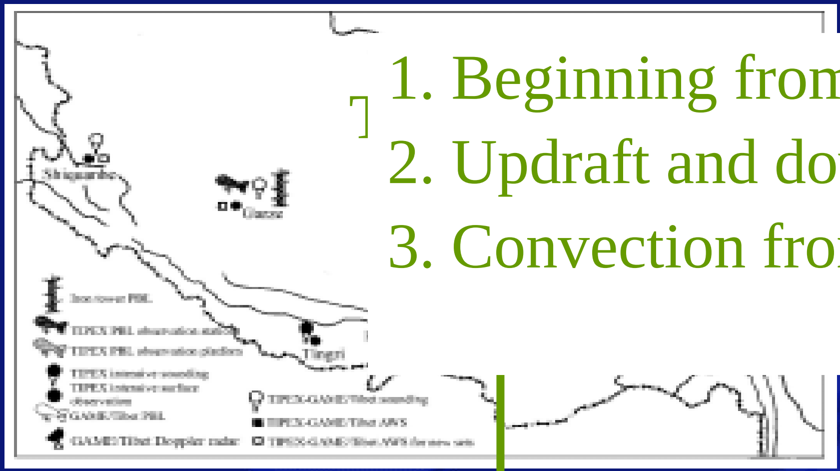
1. Uniform potential temperature and non-uniform specific humidity
2. Quick development from morning to early afternoon while slow afterward
3. Very high ABL: 2 km at noon and 2.8 km in the afternon

Pot. temp.

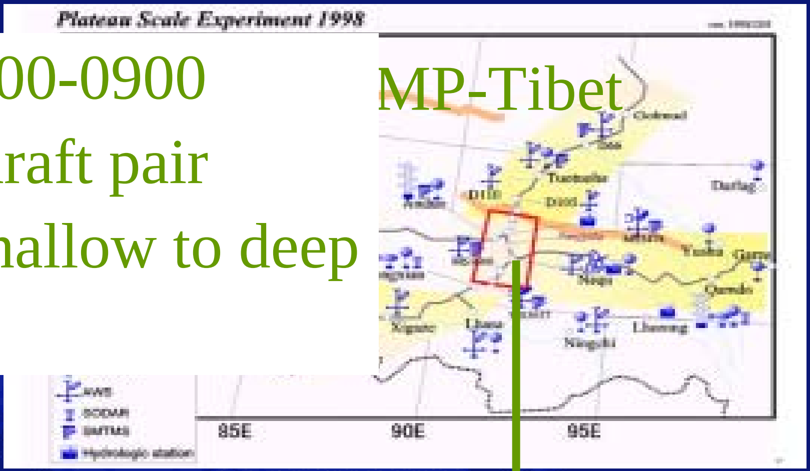
Spec. Hum.



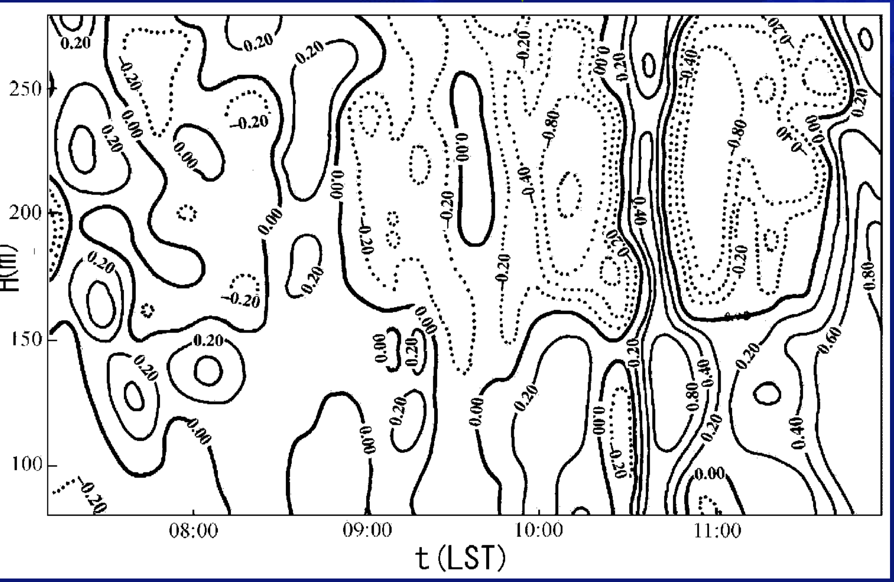
Observed vertical velocity



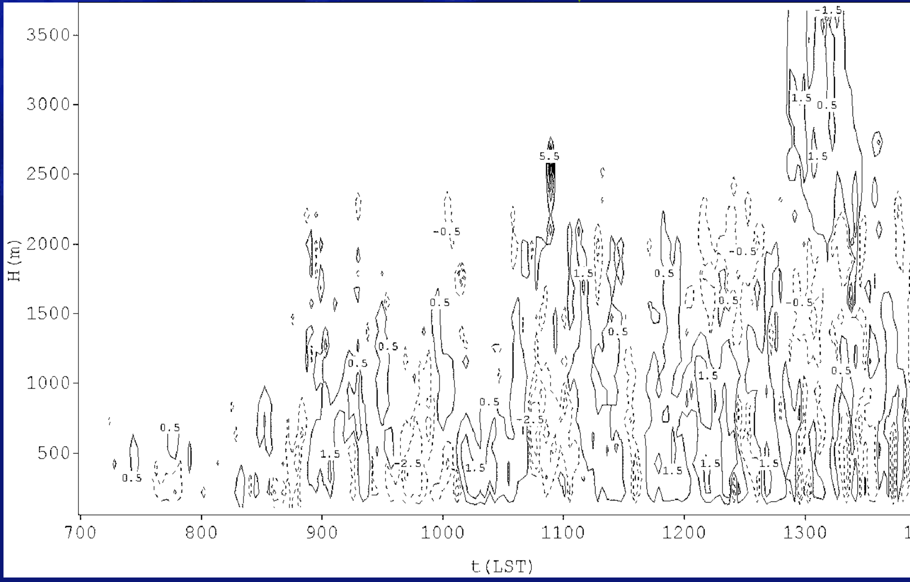
1. Beginning from 0800-0900
2. Updraft and downdraft pair
3. Convection from shallow to deep



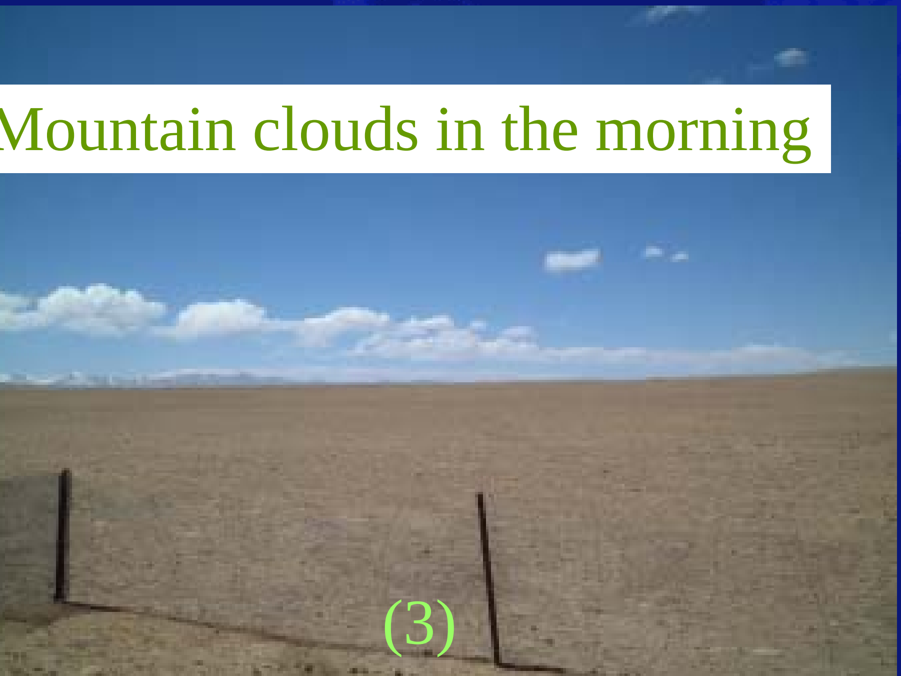
Damxung



Naqu



Diurnal variation



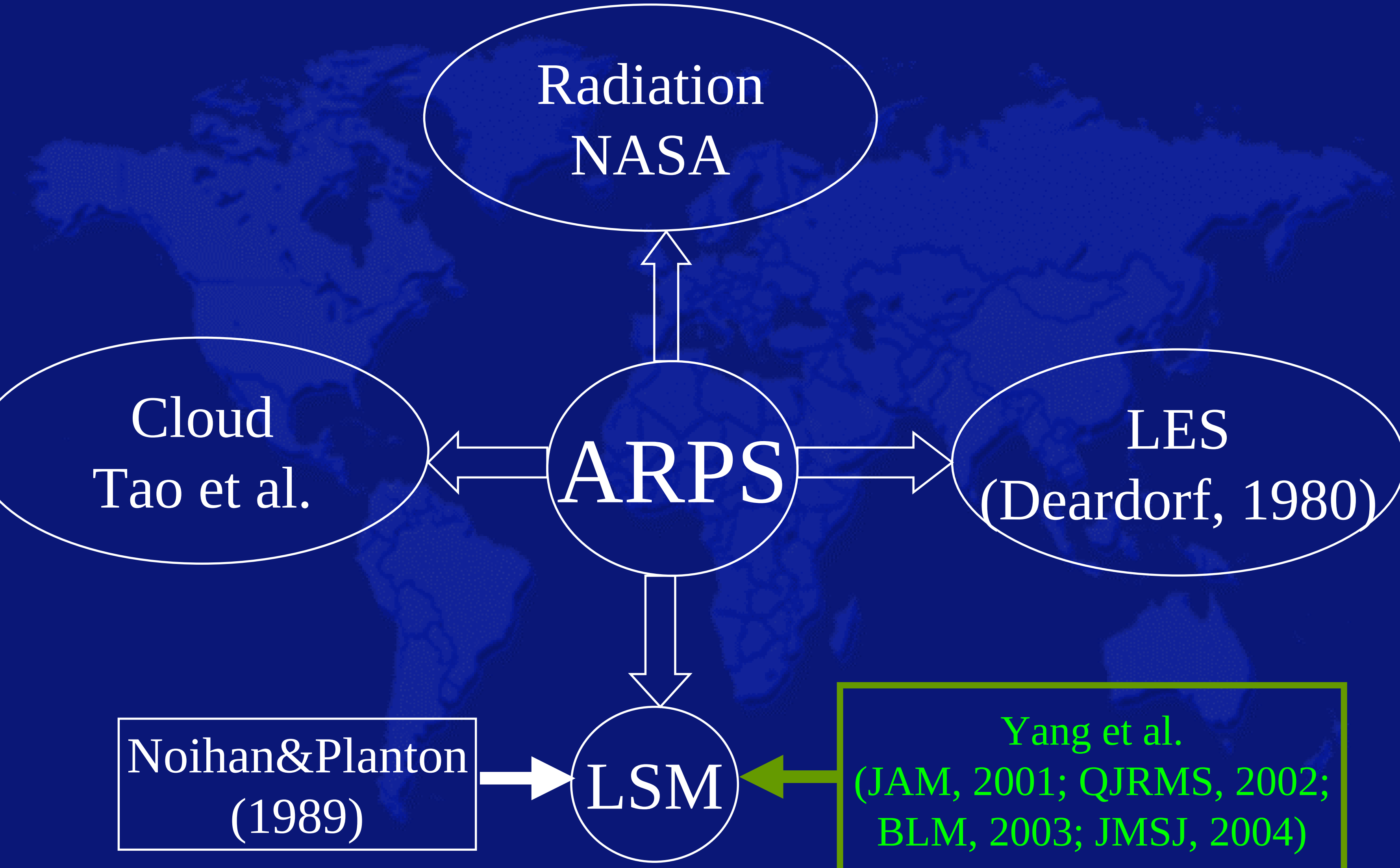
Observations

(1) Deep ABL(>2.5km) characterized by uniform potential temperature and non-uniform specific humidity;
(2) Shallow convection→ deep convection;
(3) The sky has a typical diurnal variation: fine in the morning while full of convective clouds in the afternoon.

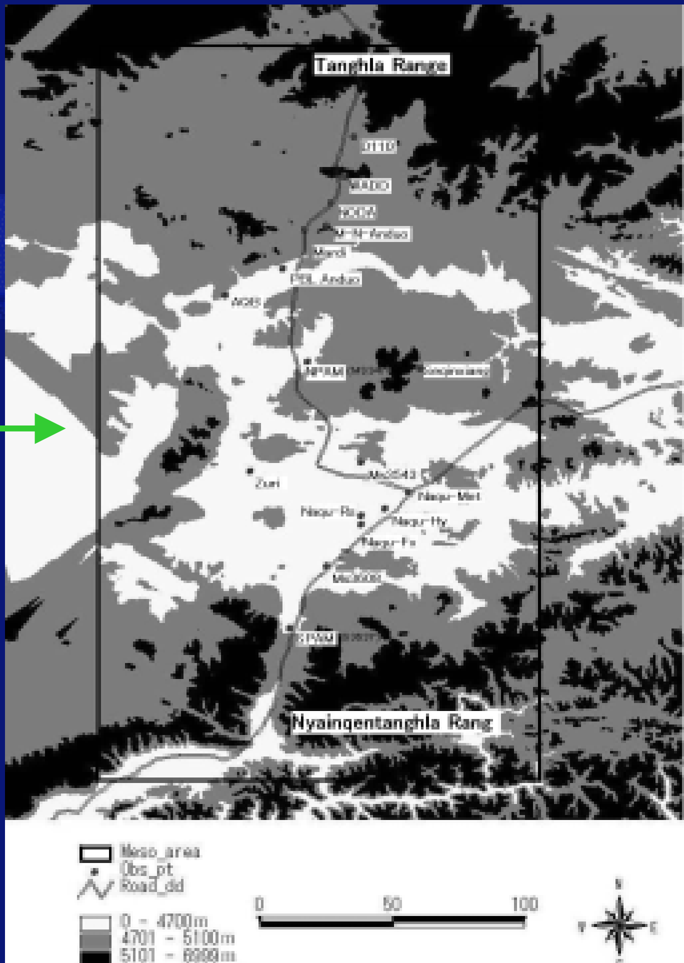
Questions:

(1) Mechanism of ABL development;
(2) Spatial features of convection;
(3) The role of convection in ABL evolution;
(4) The role of terrain variability

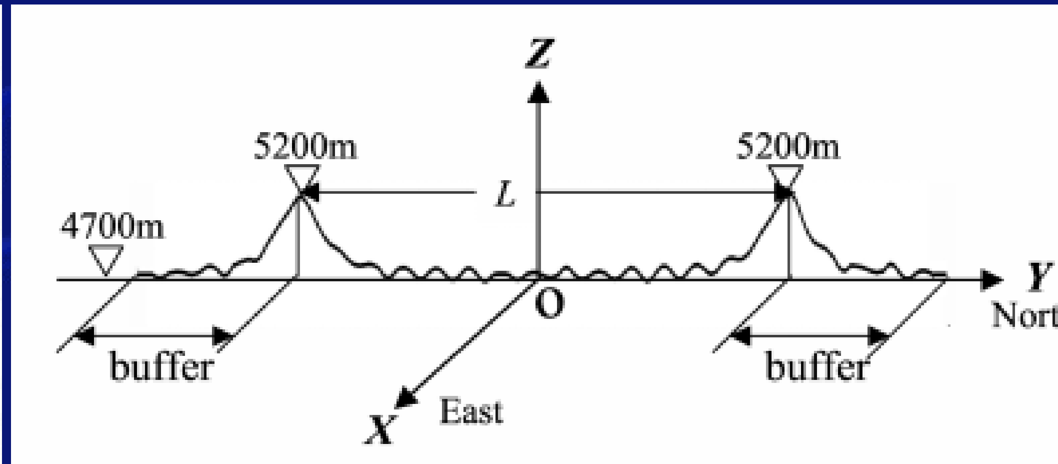
Model:Advanced regional prediction system



2D simulation domain



(a)



$$dy = 125\text{m}$$

$$dz_{\min} = 100\text{m}$$

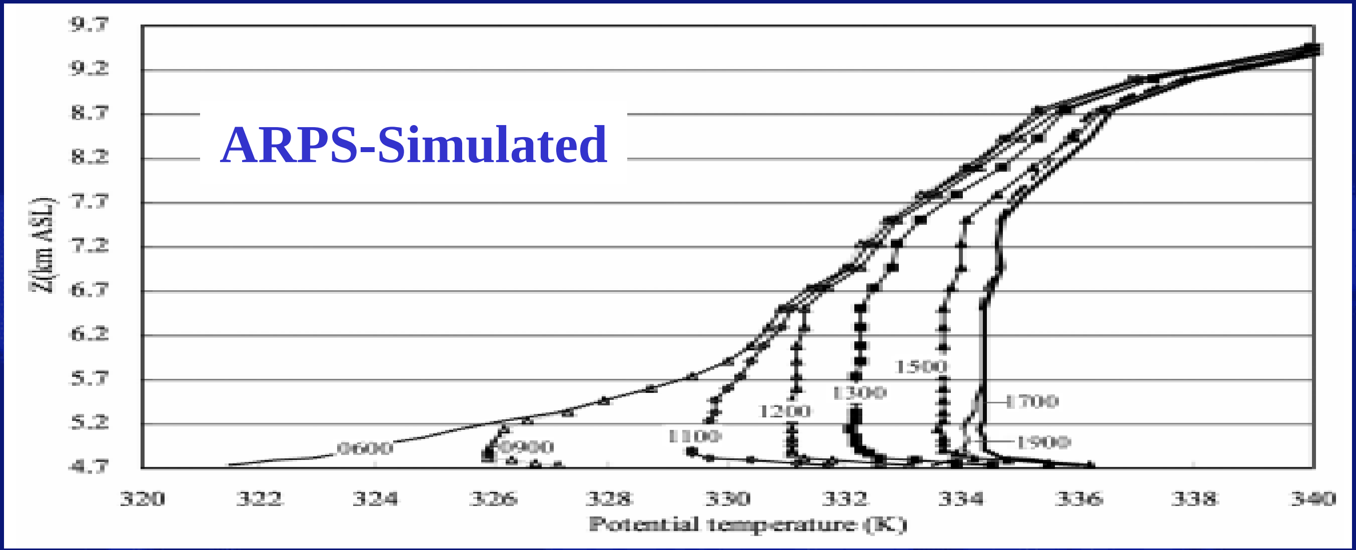
$$dt_{big} = 3s$$

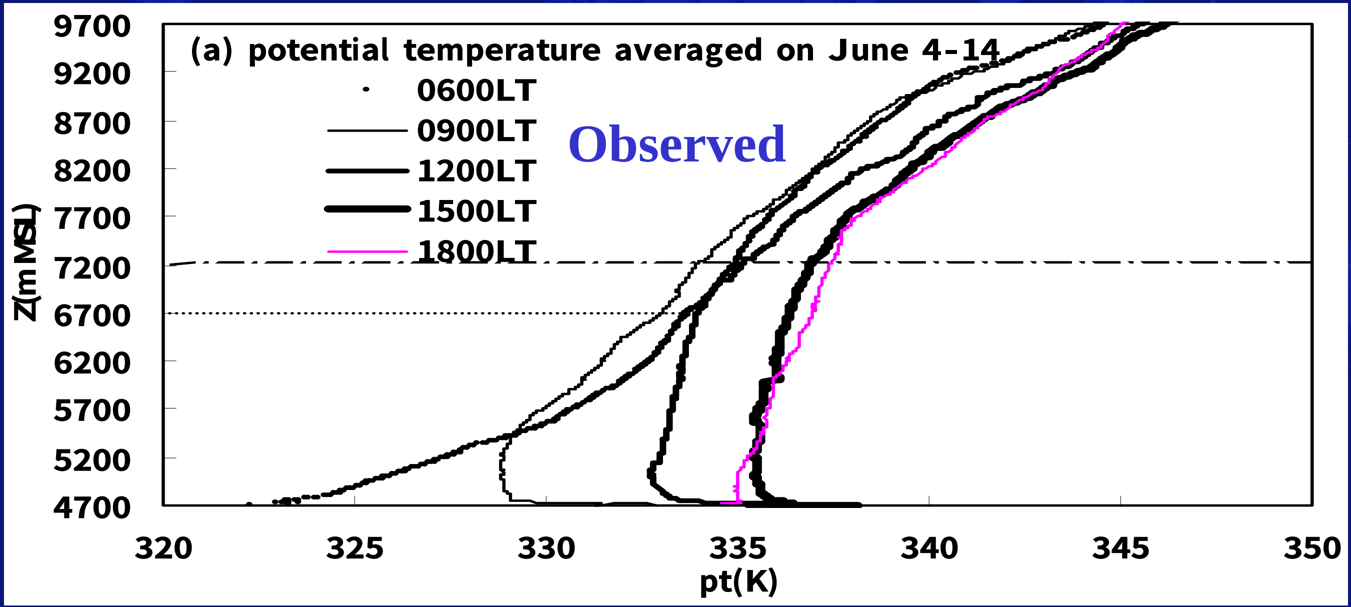
$$dt_{small} = 0.3s$$

I.C.: Sonde Sounding, SMTMS

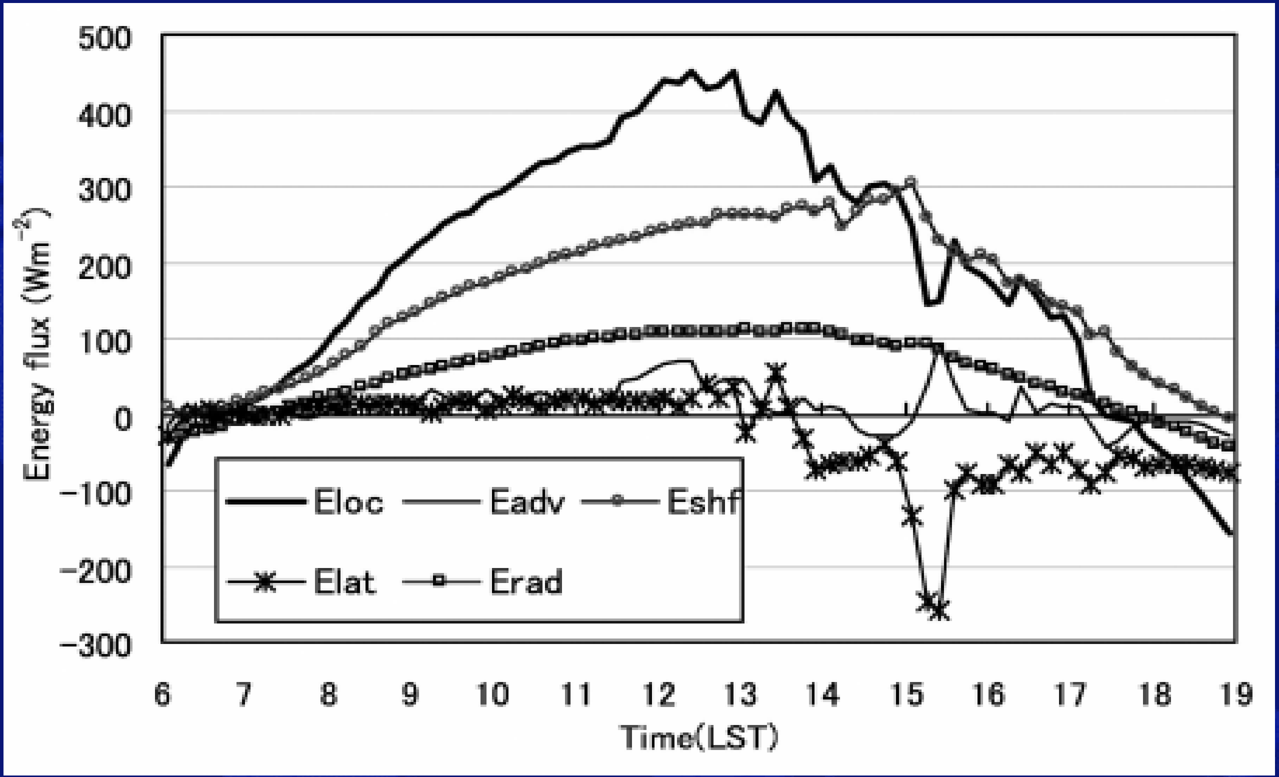
B.C.: Periodic.

Result 1a：Simulated ABL evolution



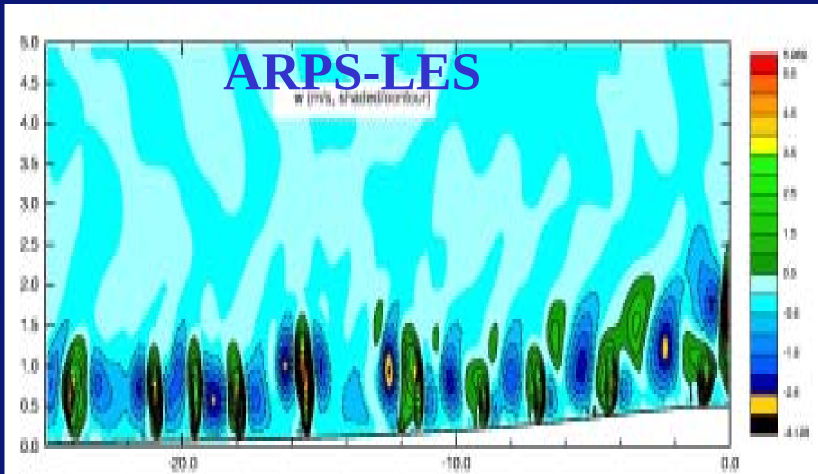


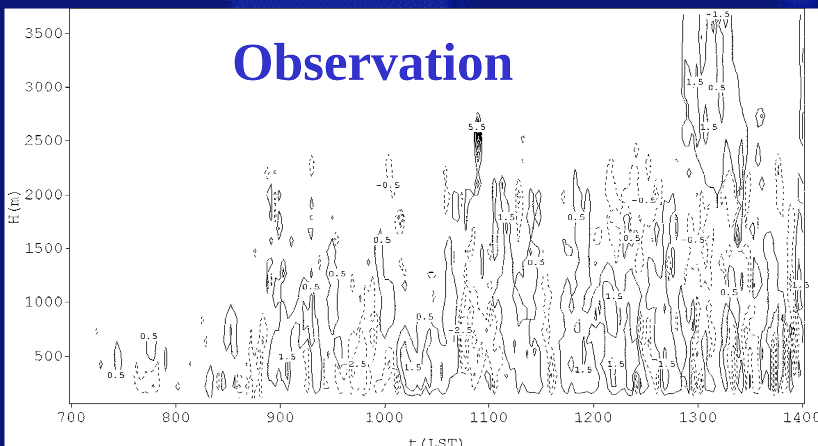
Result 1b：energy budget in the lower 3km

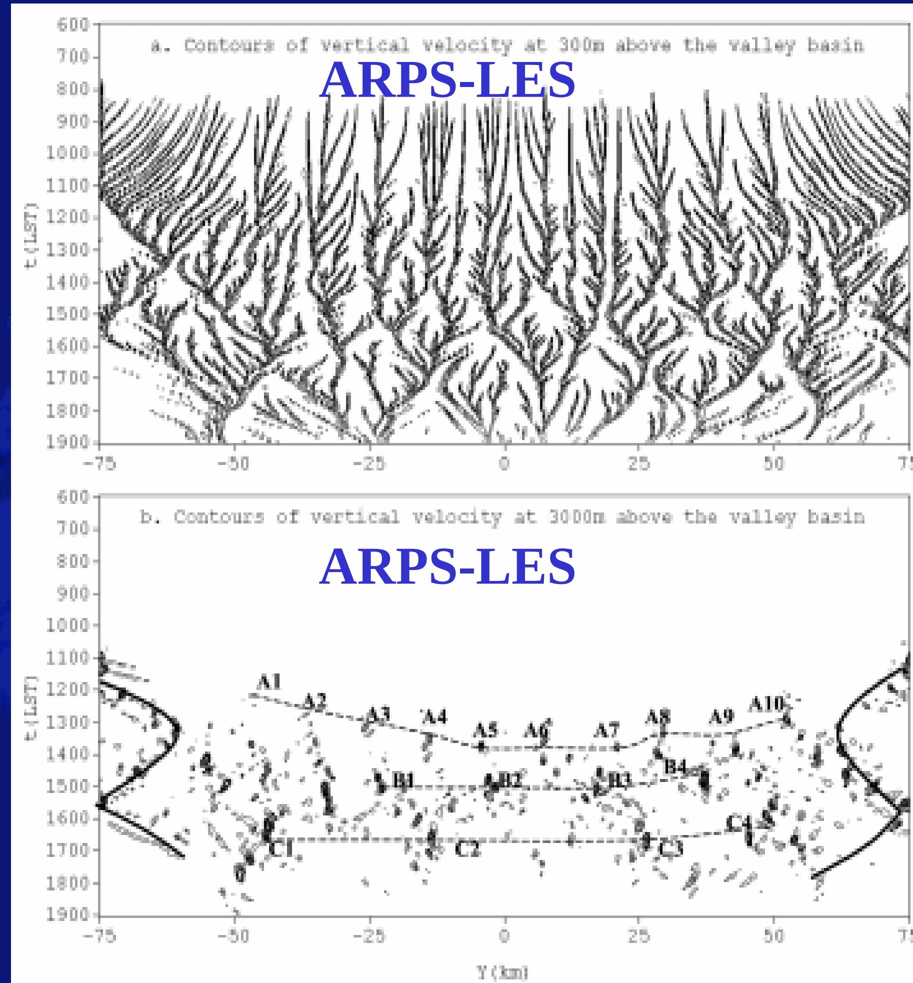


The **sensible heat** is the most important energy to sustain the PBL growth, and the **radiative force** also significantly contributes to it. In the afternoon, **evaporative cooling** suppresses the PBL development.

Result 2a：Simulated convection

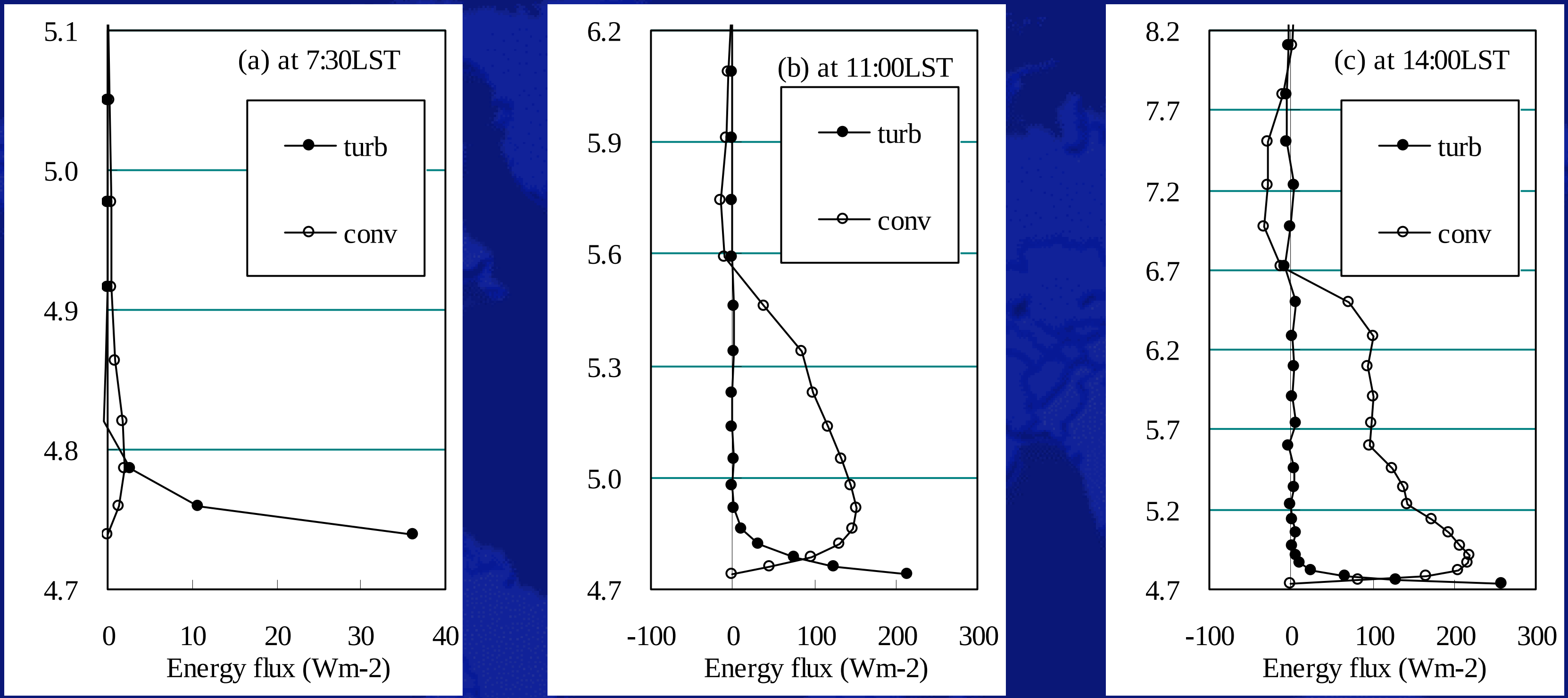






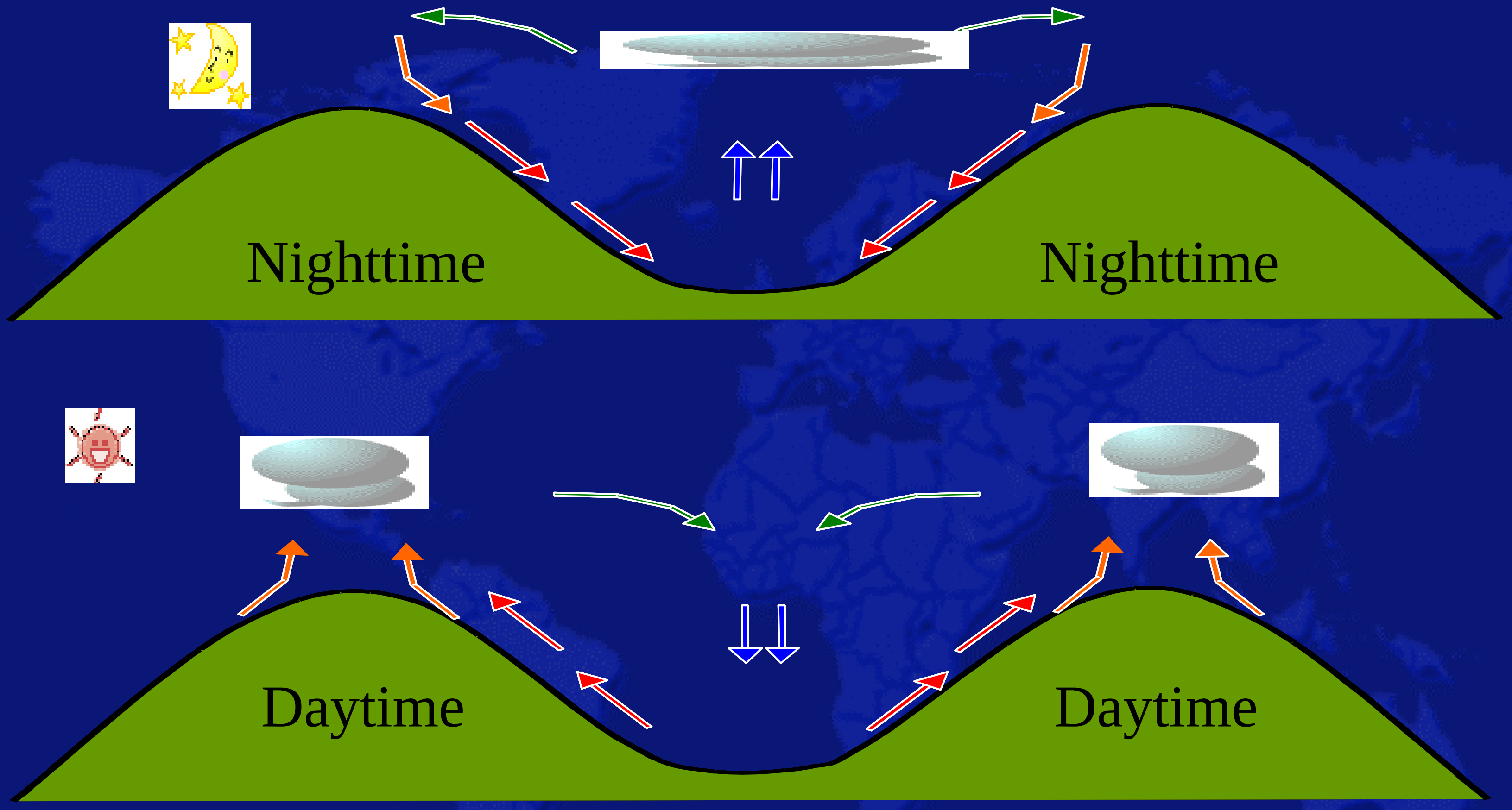
(1) There are numerous convection cells over the TP.
(2) They evolves from shallow convection in the morning to deep convection in the afternoon.

Result 2b：The role of convection

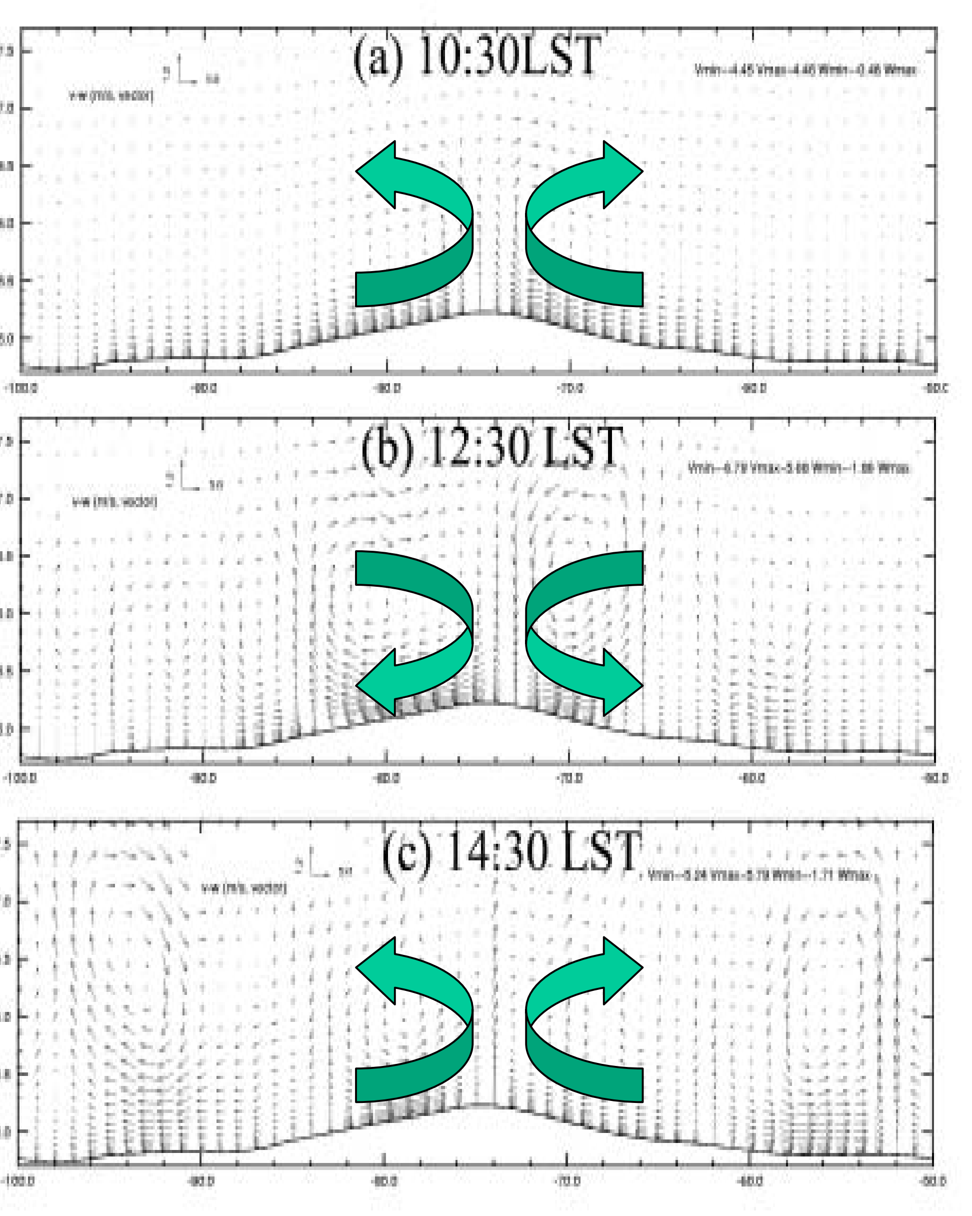


- The **convective mixing is the dominant means** to exchange the quantities between the ground surface and the atmosphere aloft, and speeds up the ABL development.

Result 3: MVC--general view



Result 3：Simulated M-V circulation

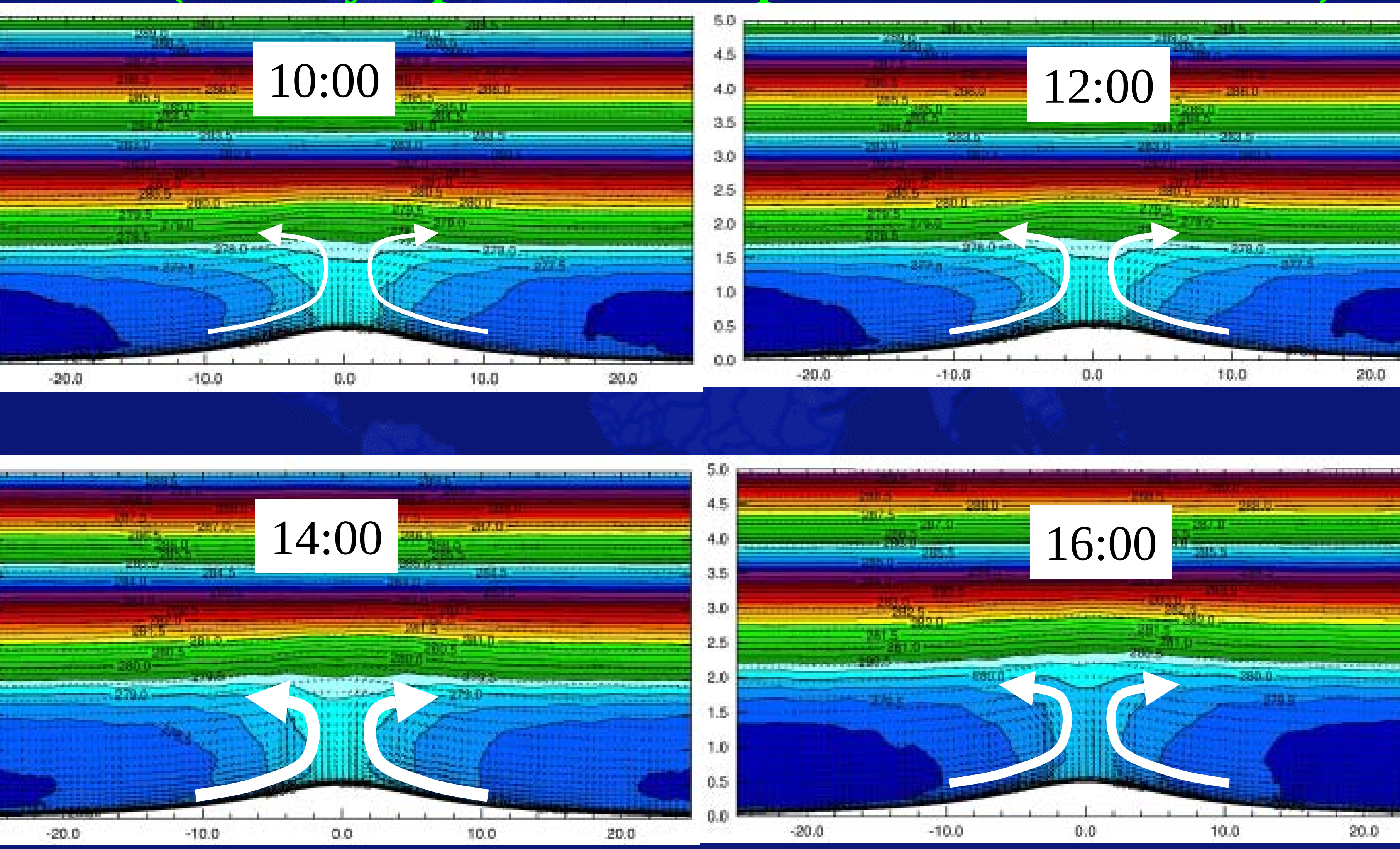


Exp 1: lowlands+cloud

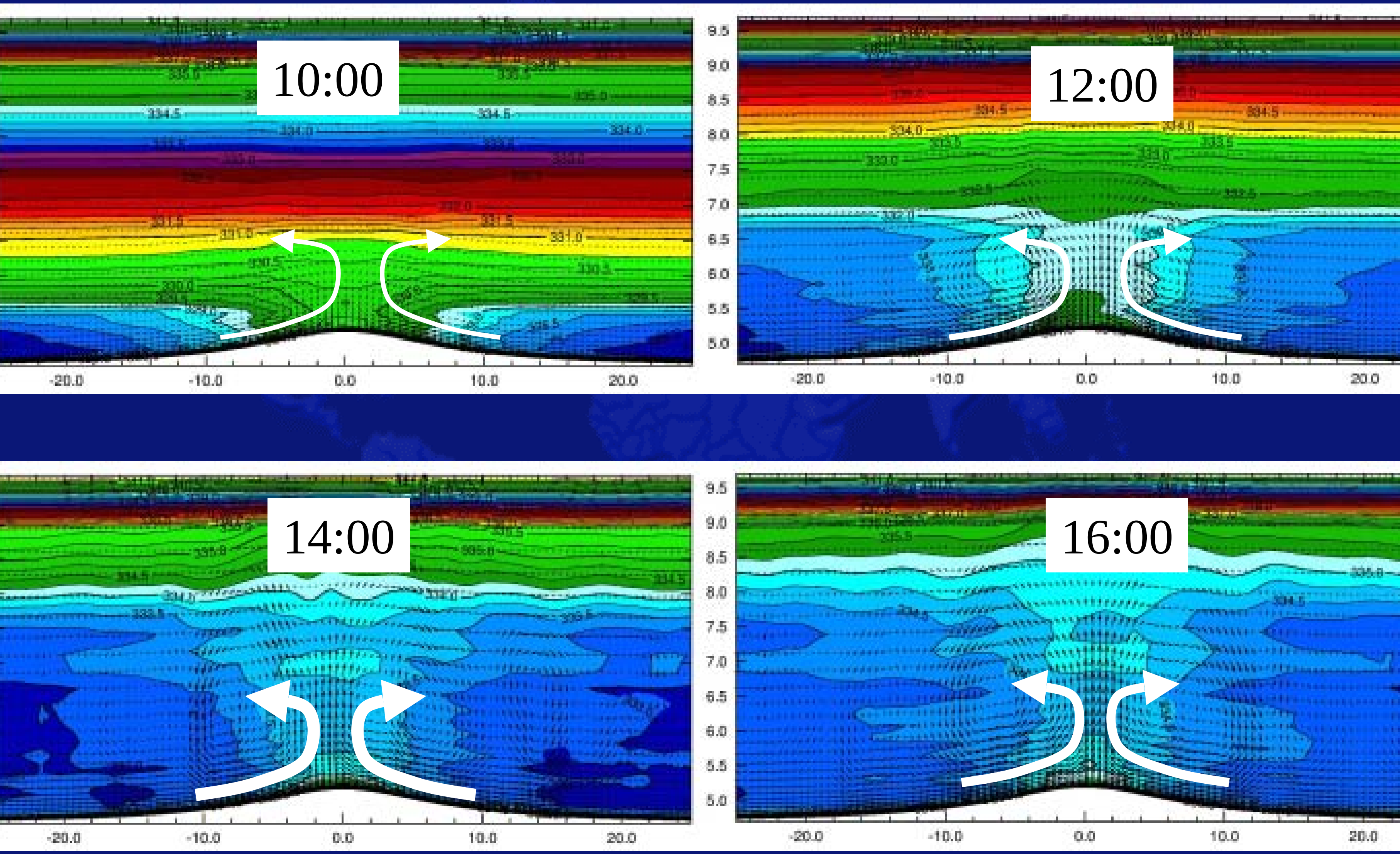
Exp 2: highlands+dry ru

Exp 3: highlands+cloud

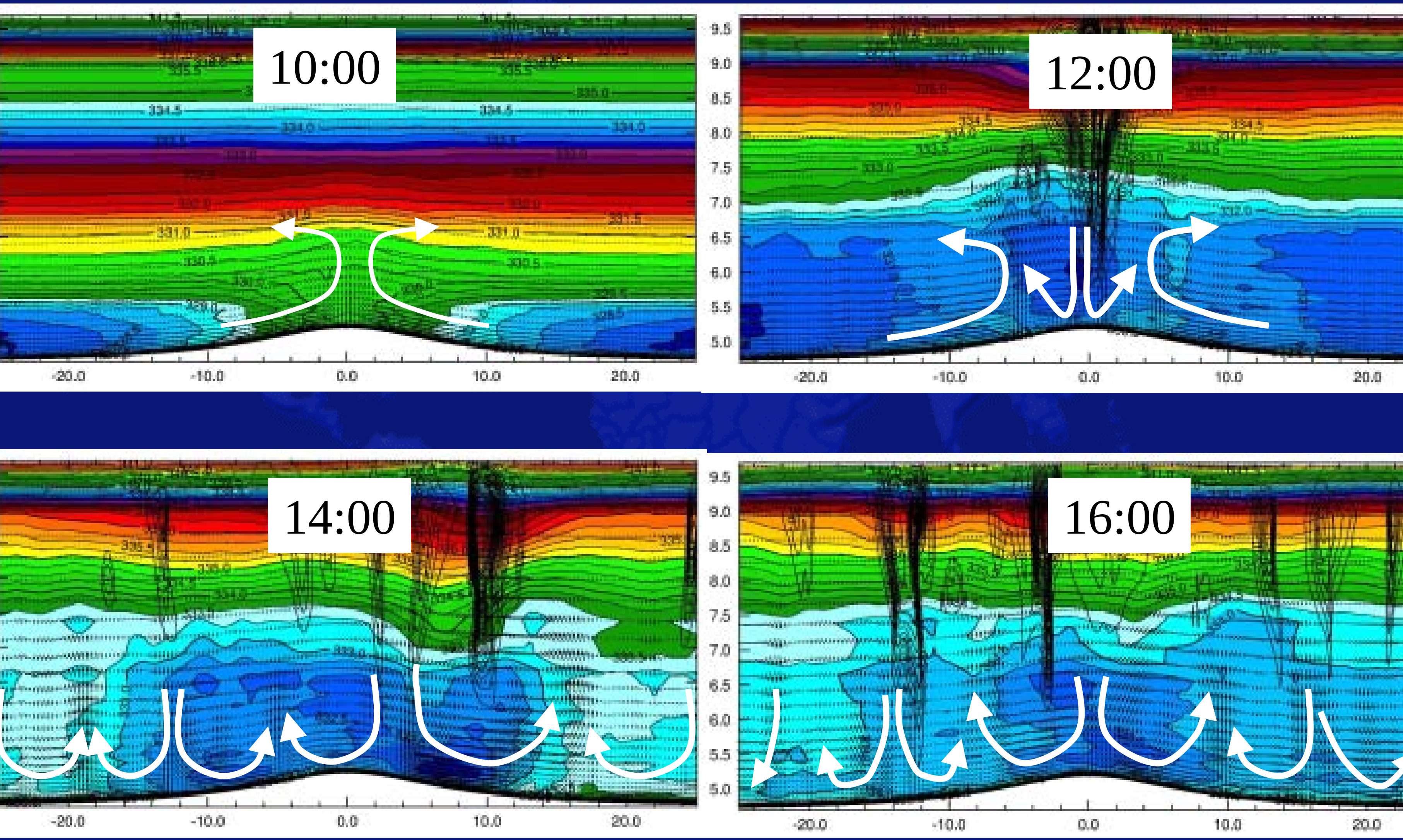
Experiment 1: lowlands+cloud
(velocity，potential temperature，cloud water)



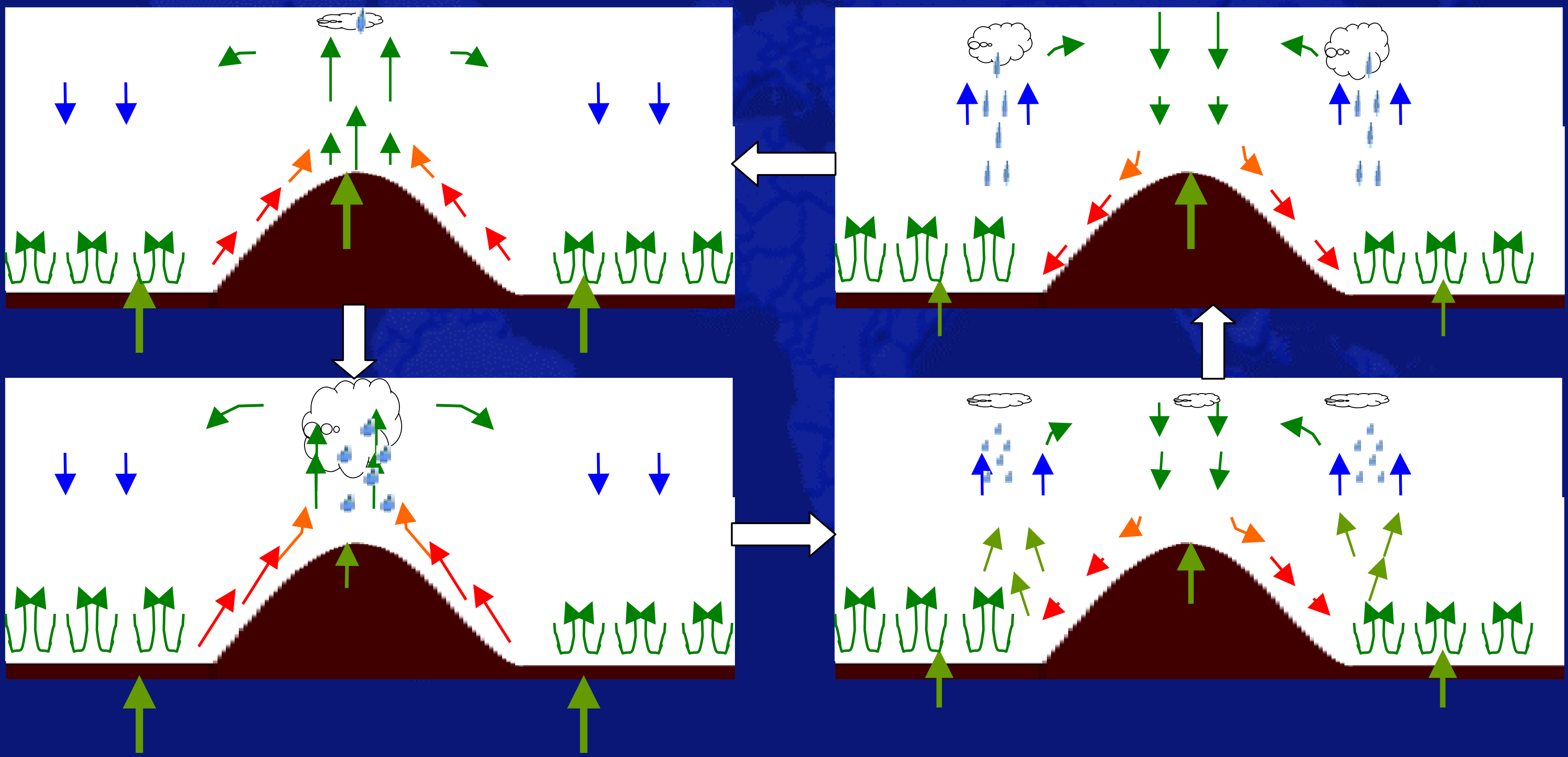
Experiment 2: highlands + dry run



Experiment 3: highlands + cloud



Proposed Mechanism: an interactive process between mountain-valley circulations and <u>convective clouds</u> over <u>highlands</u>



Outline

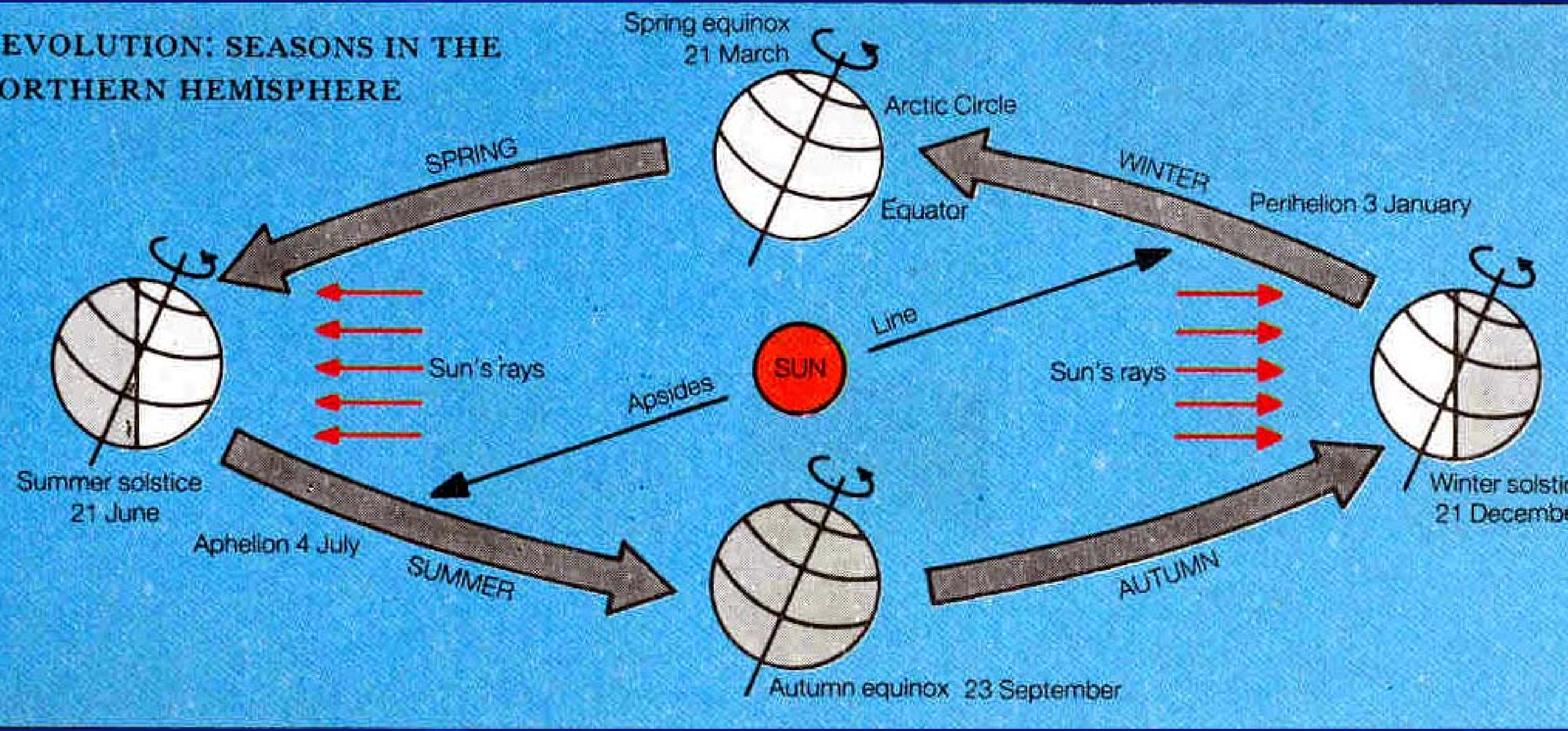
(1) CFD Applications

- Hydraulics
- Meteorology

(2) Research Activities in REEL

(3) On the Climate System

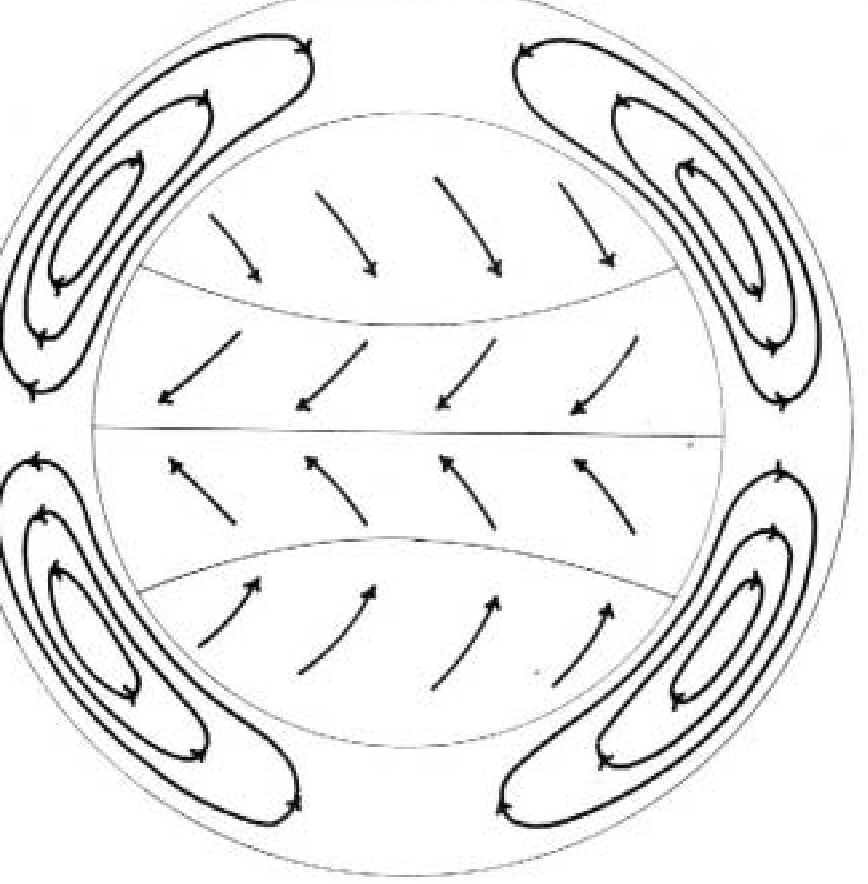
- Introduction
- Physical Processes
- Important Events
  - Global Warming
  - El Nino
  - Indian Summer Monsoon



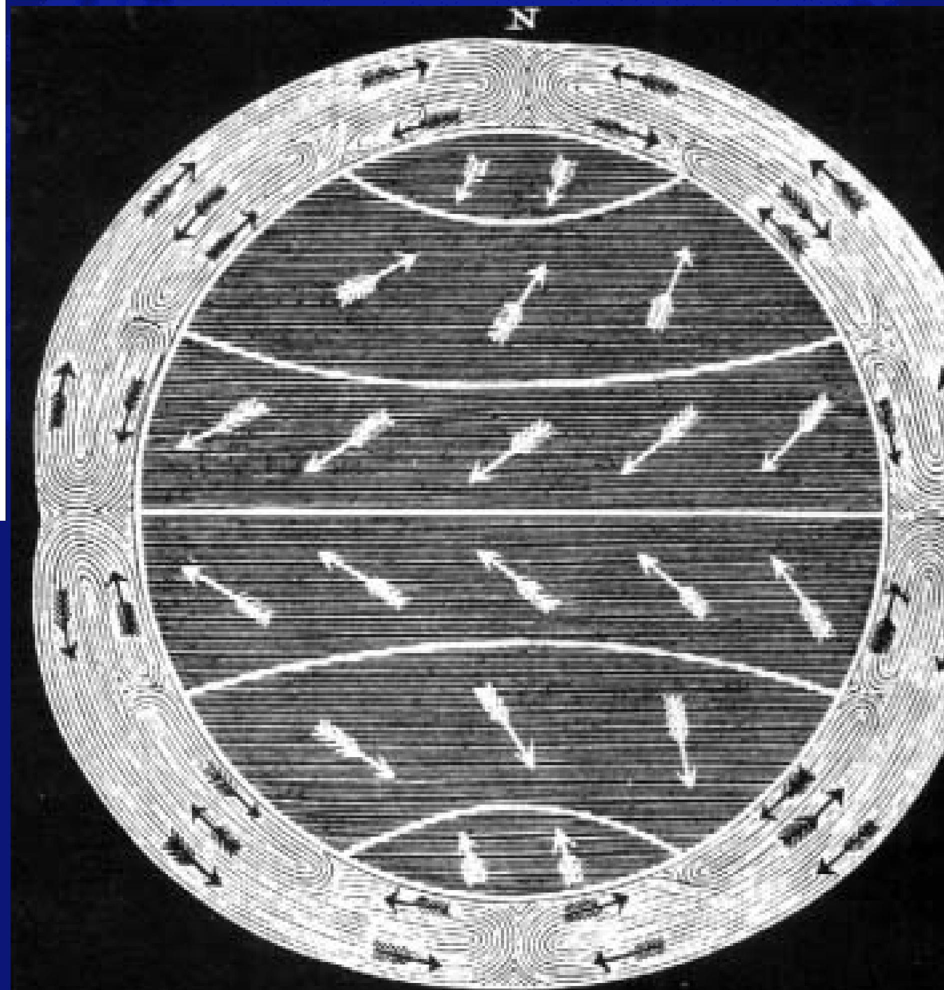
Oxford School Atlas

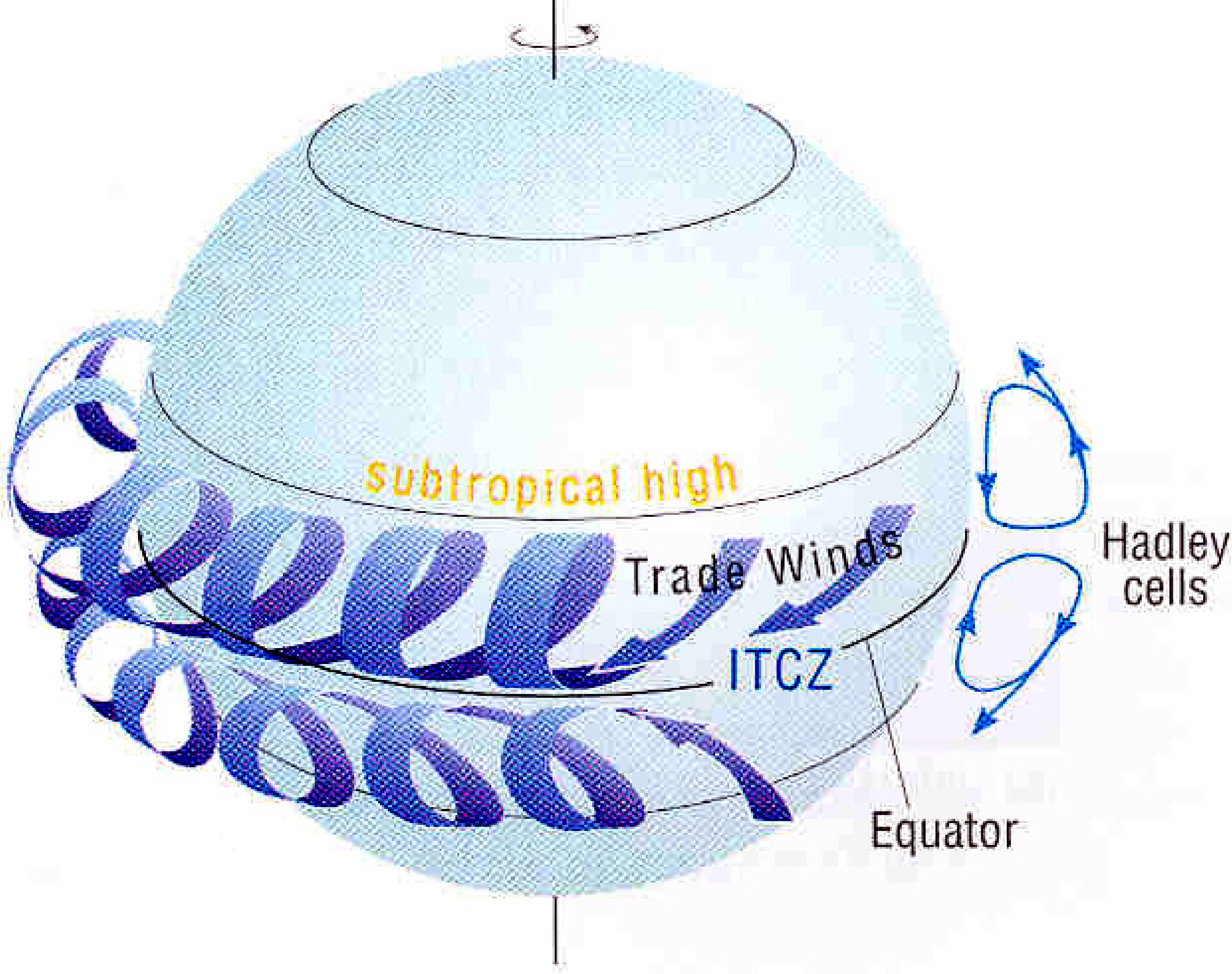
George Hadley (1735)

North-south circulation

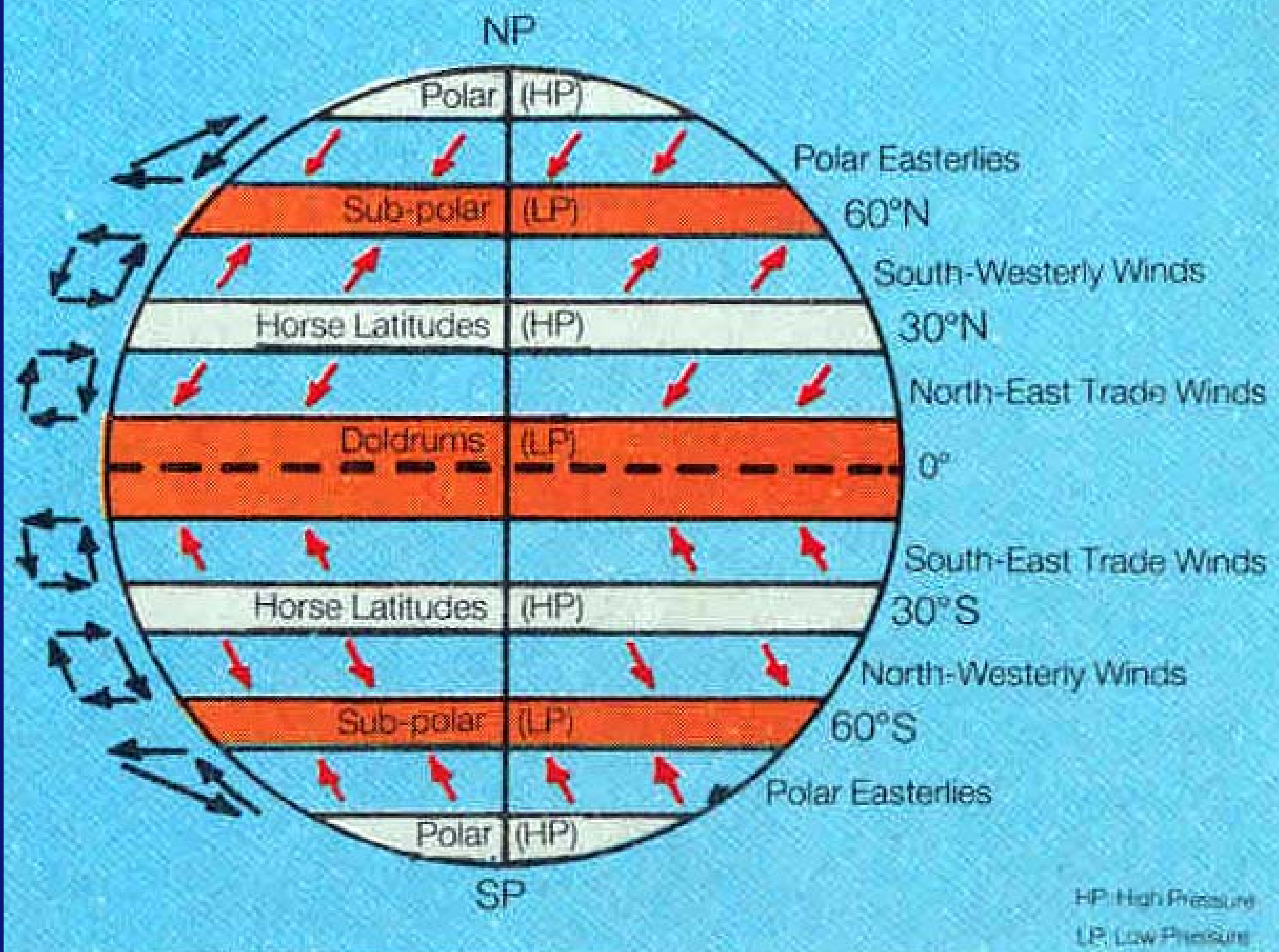


William Ferrel (1859)



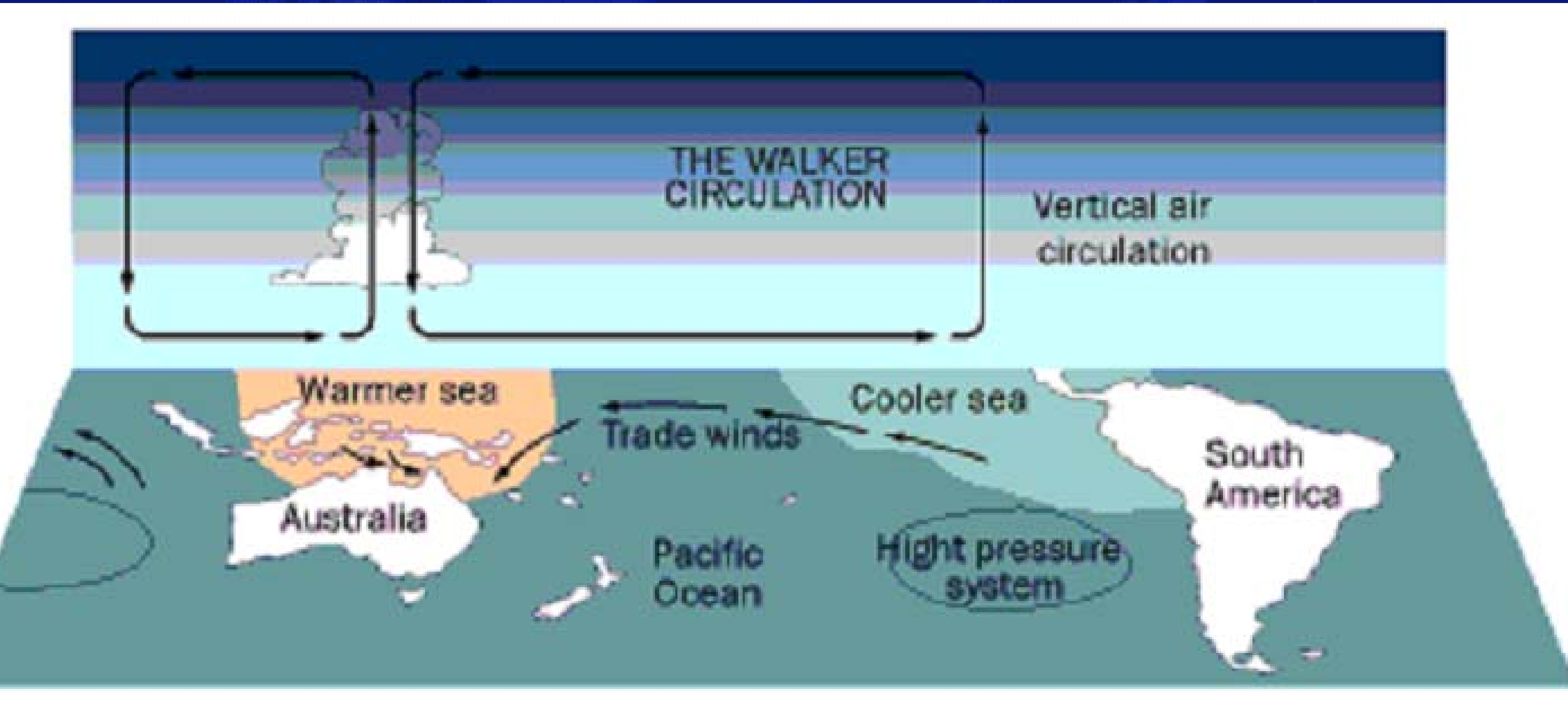

subtropical high
Trade Winds
ITCZ
Hadley
cells
Equator

PRESSURE BELTS AND WINDS

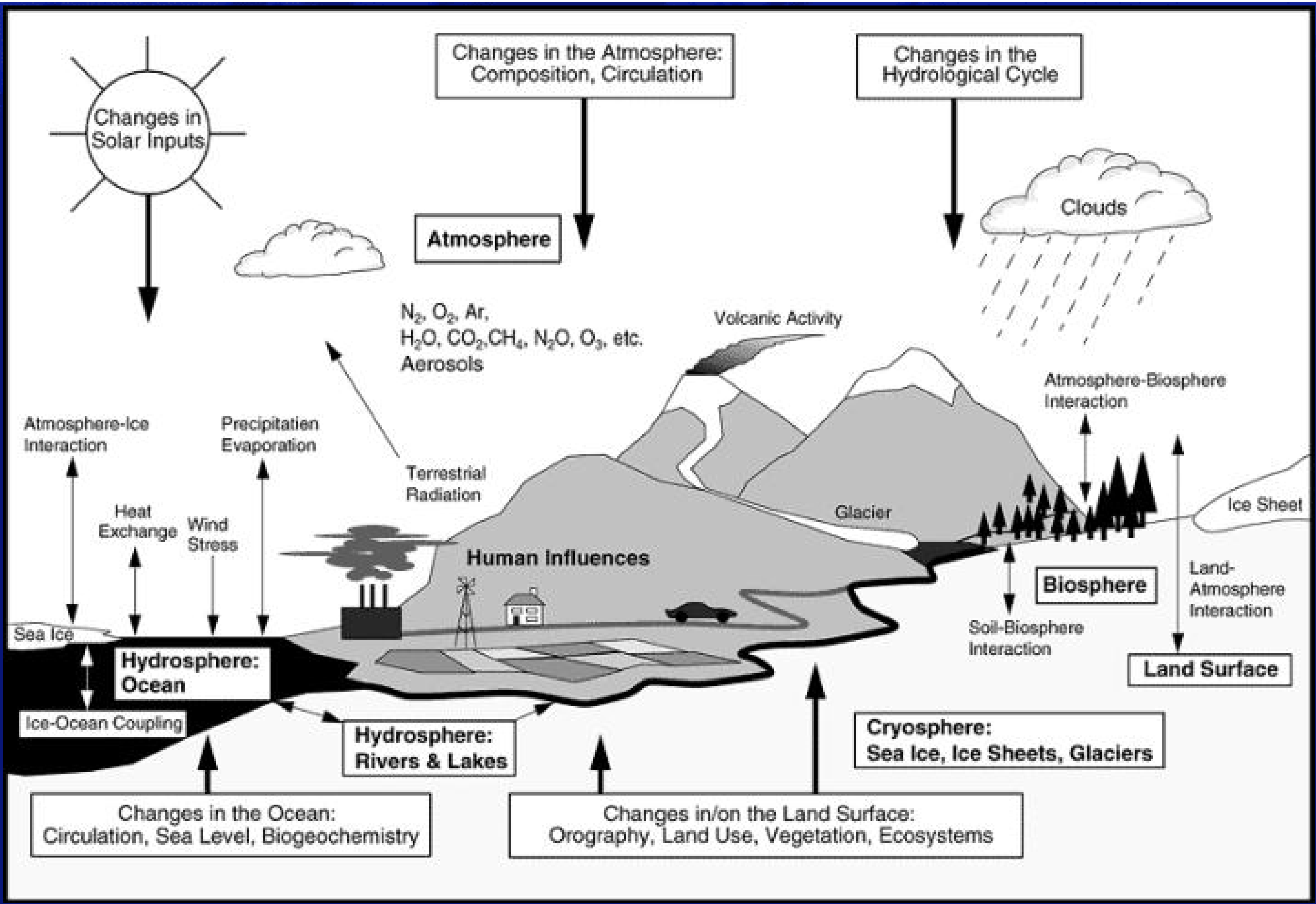


Oxford School Atlas

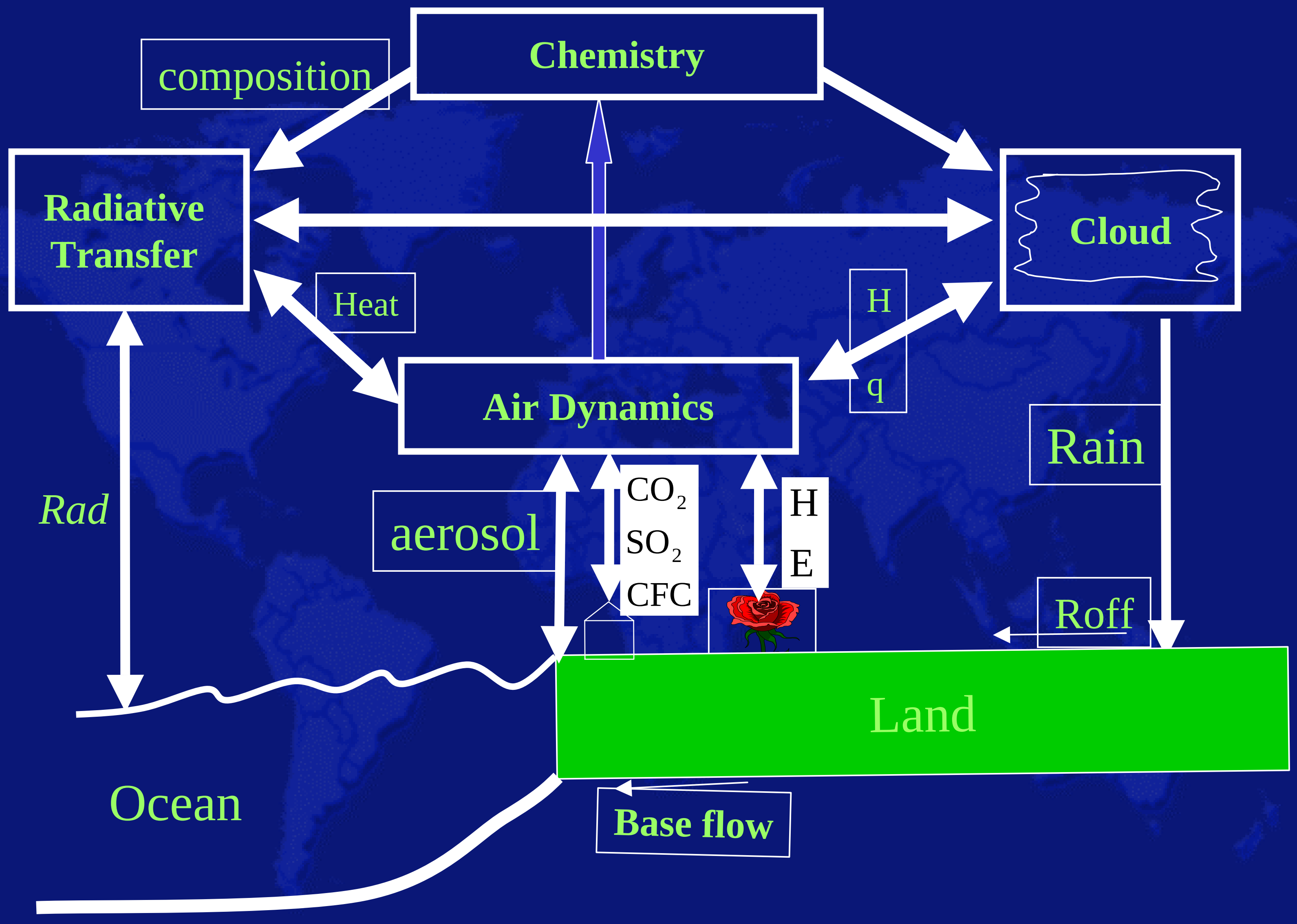
East-west circulation



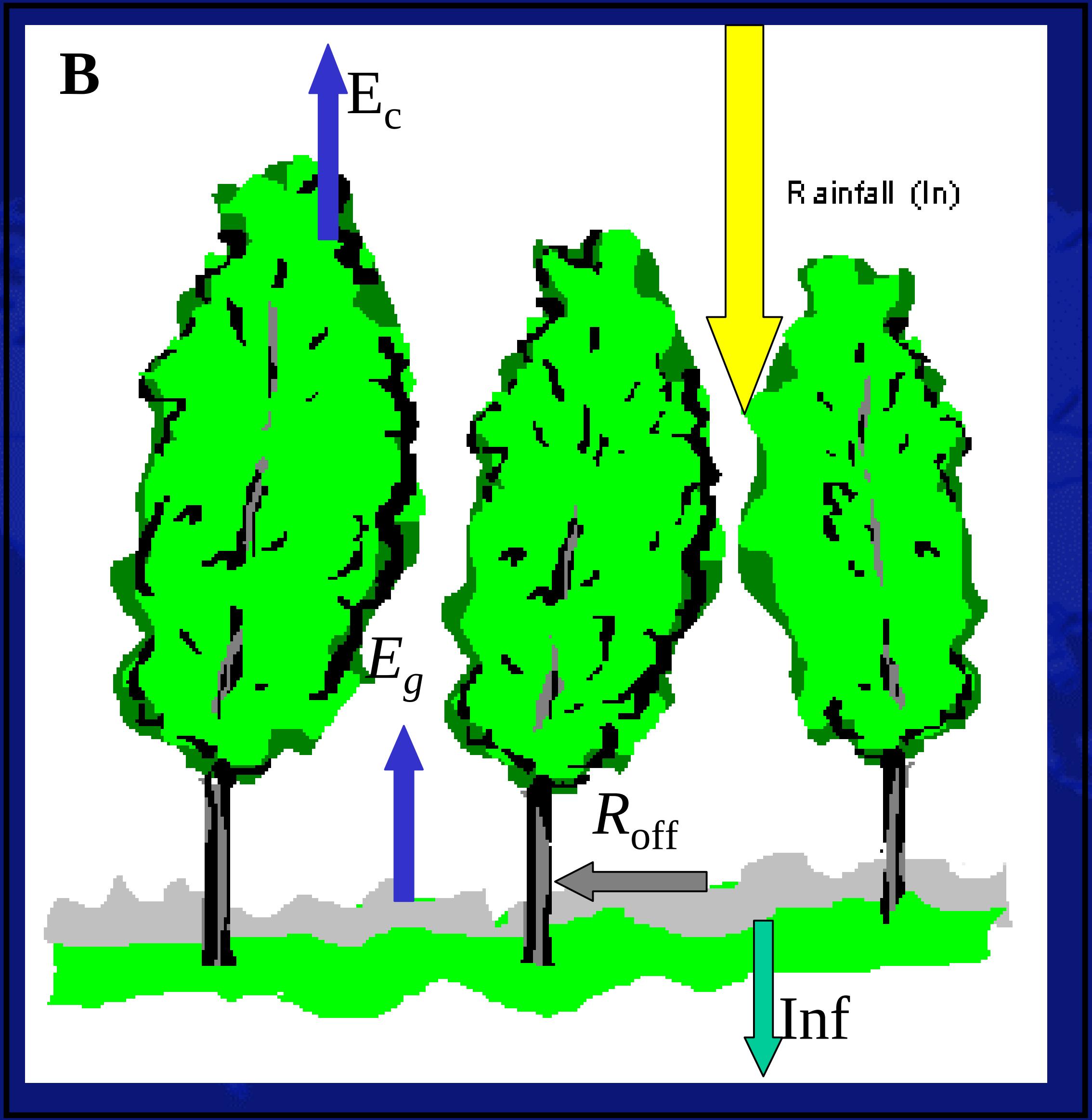
The climate system is an interactive system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere, forced or influenced by various external forcing mechanisms such as solar variability, volcano eruption, and human activities



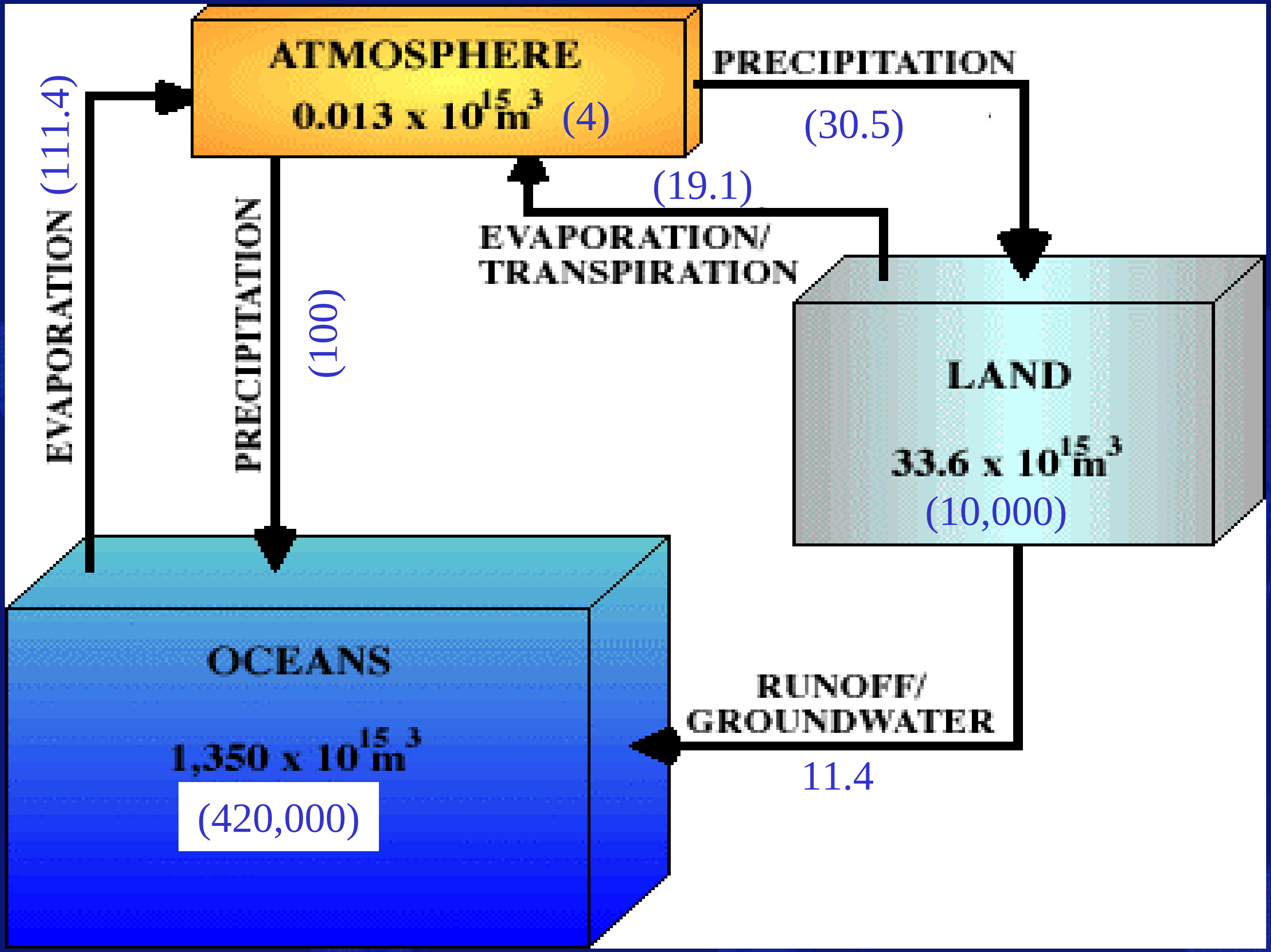
Physical processes



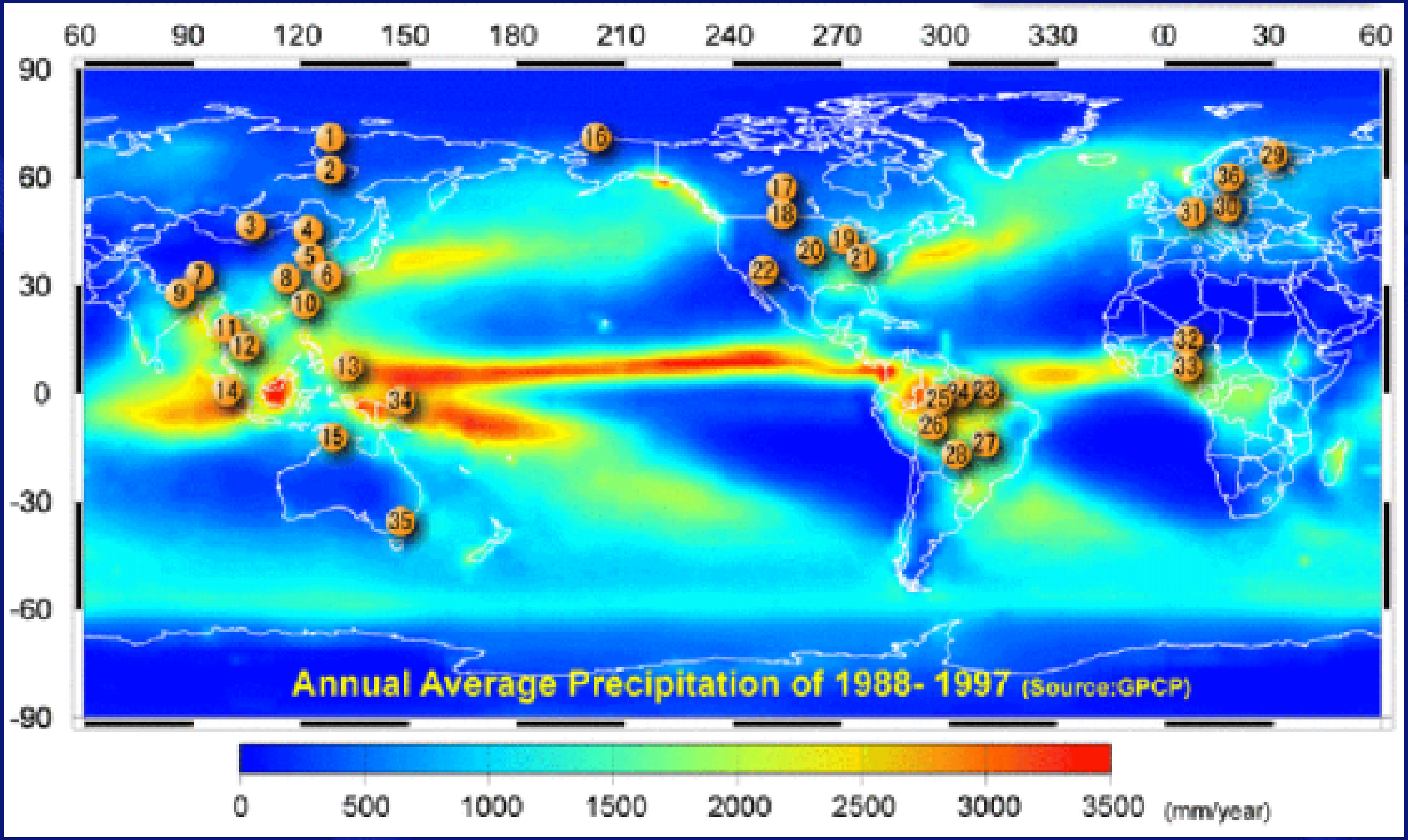
Schematic diagram of a climate modeling system



Surface Water Budget (from AgriMet system)



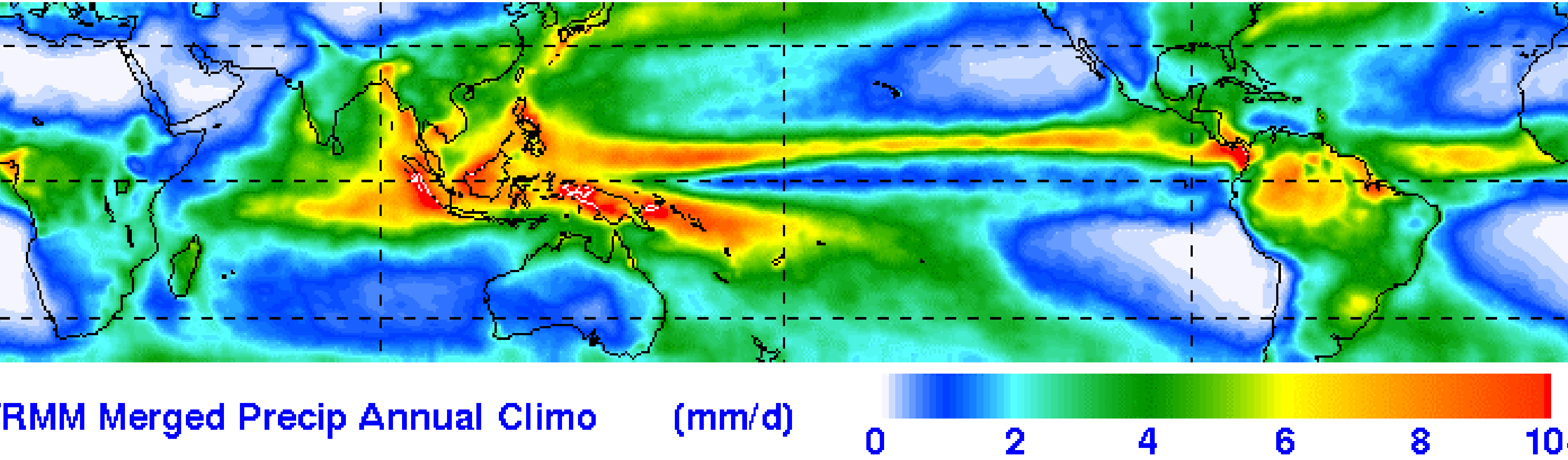
Long-term mean global water cycles. The number in the parenthesis is the percentage of water amount relative to precipitation over ocean



(CEOP newsletter)

Tropical Rainfall Measuring Mission (TRMM)

Three–Year TRMM Climatology



January 1998 – December 2000

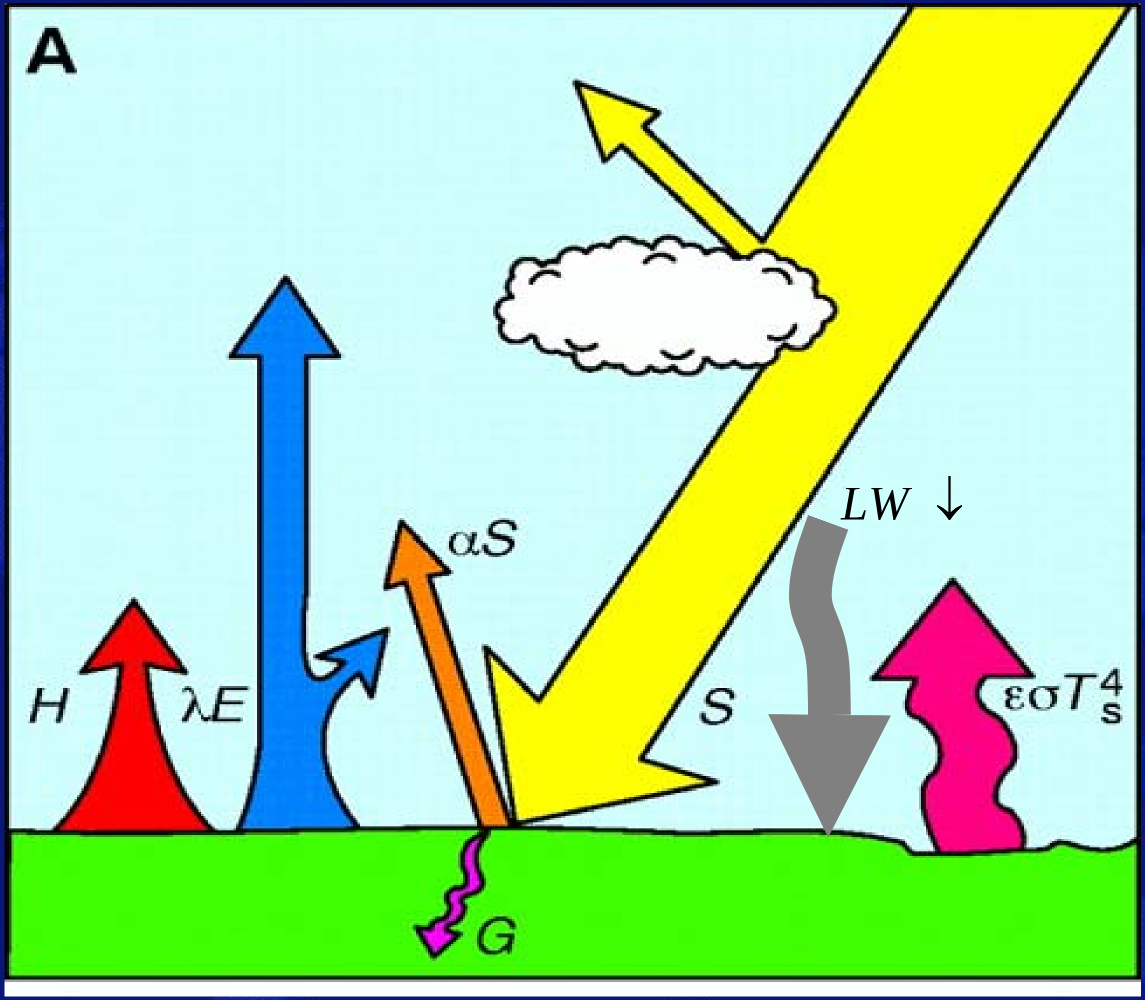
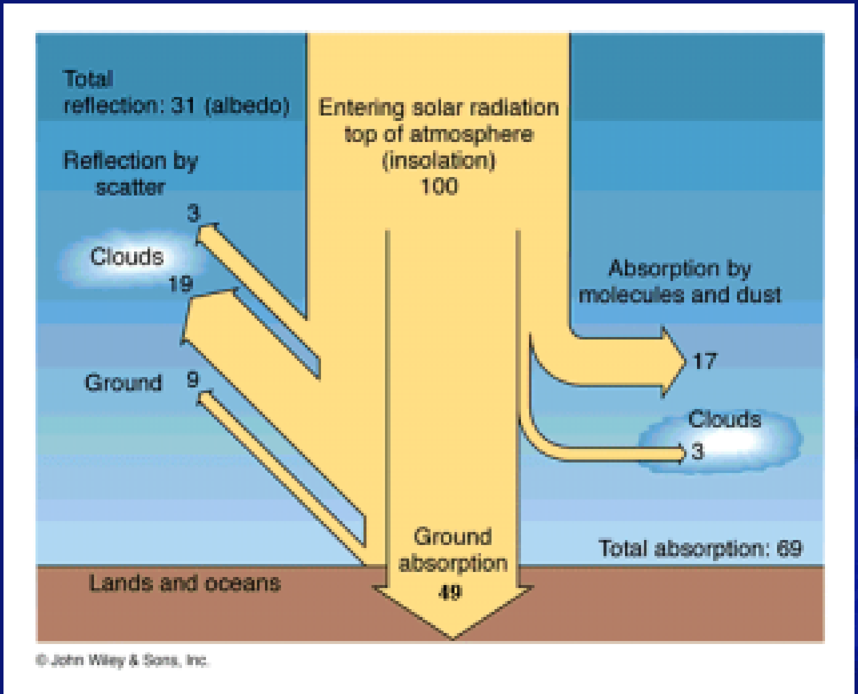
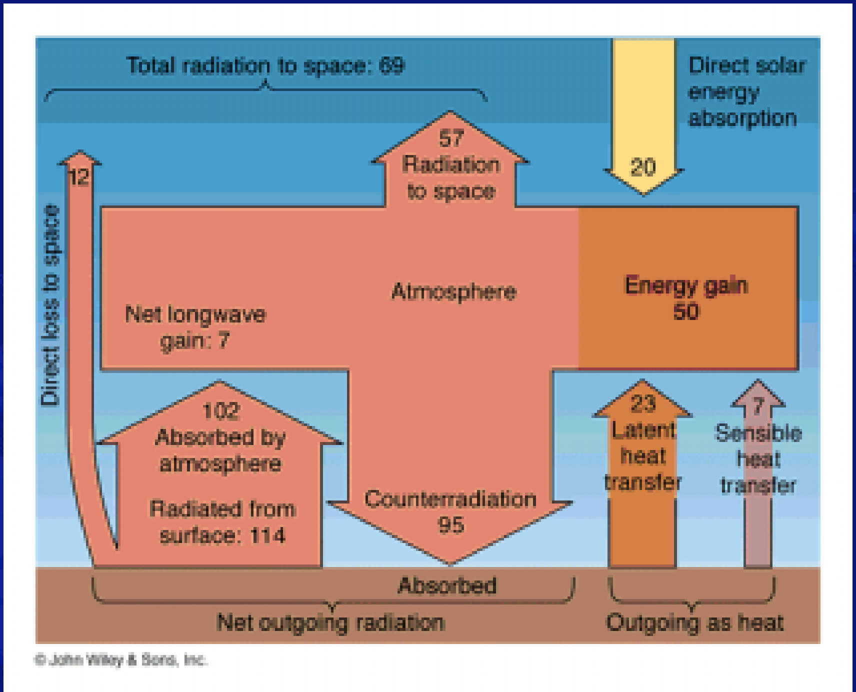


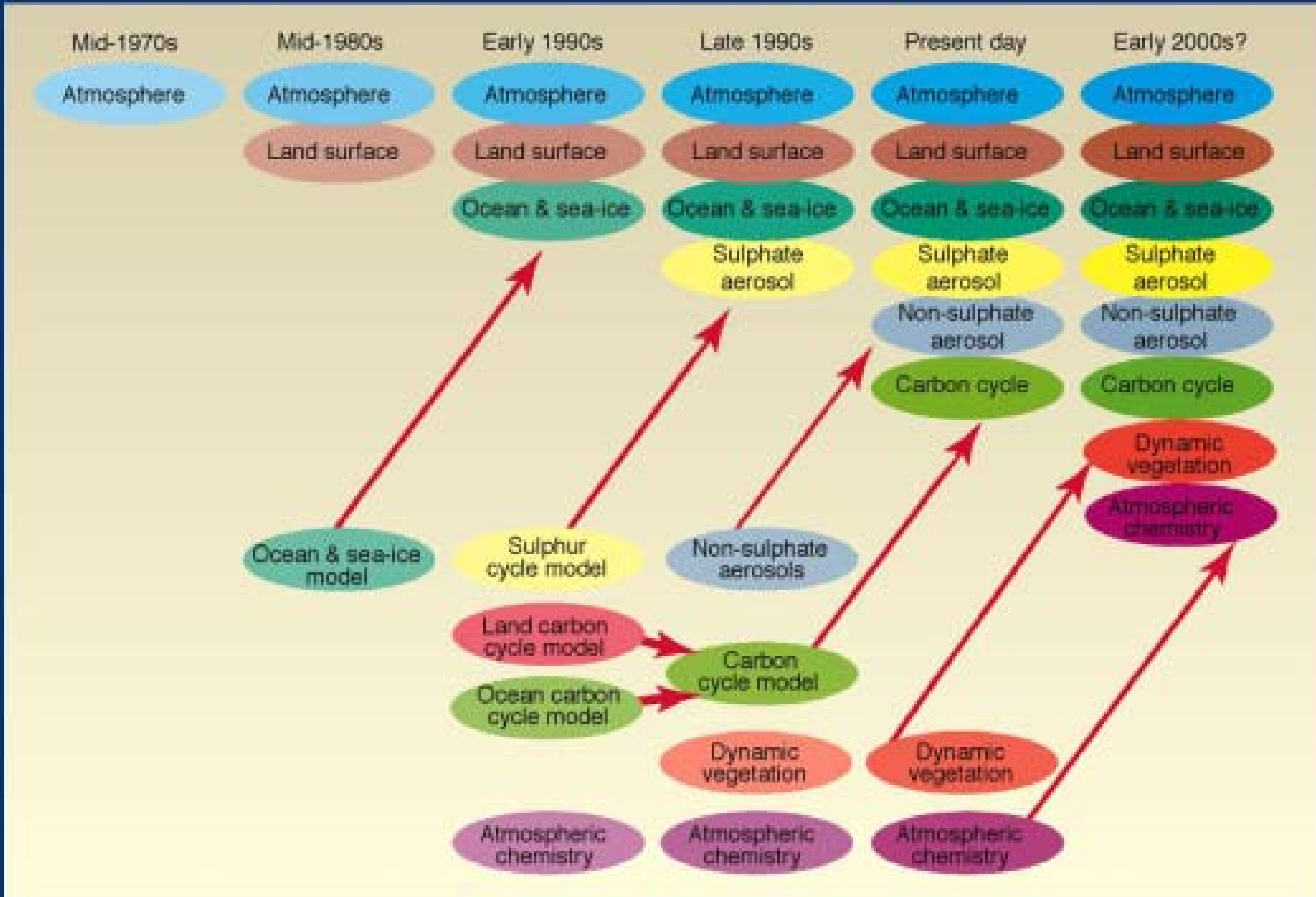
Figure 3: Surface energy budget (Sellers et al, 1997)





Long-term mean energy budget in earth-atmosphere system (Strahler and Strahler, 1997)

The development of climate models, past, present and future

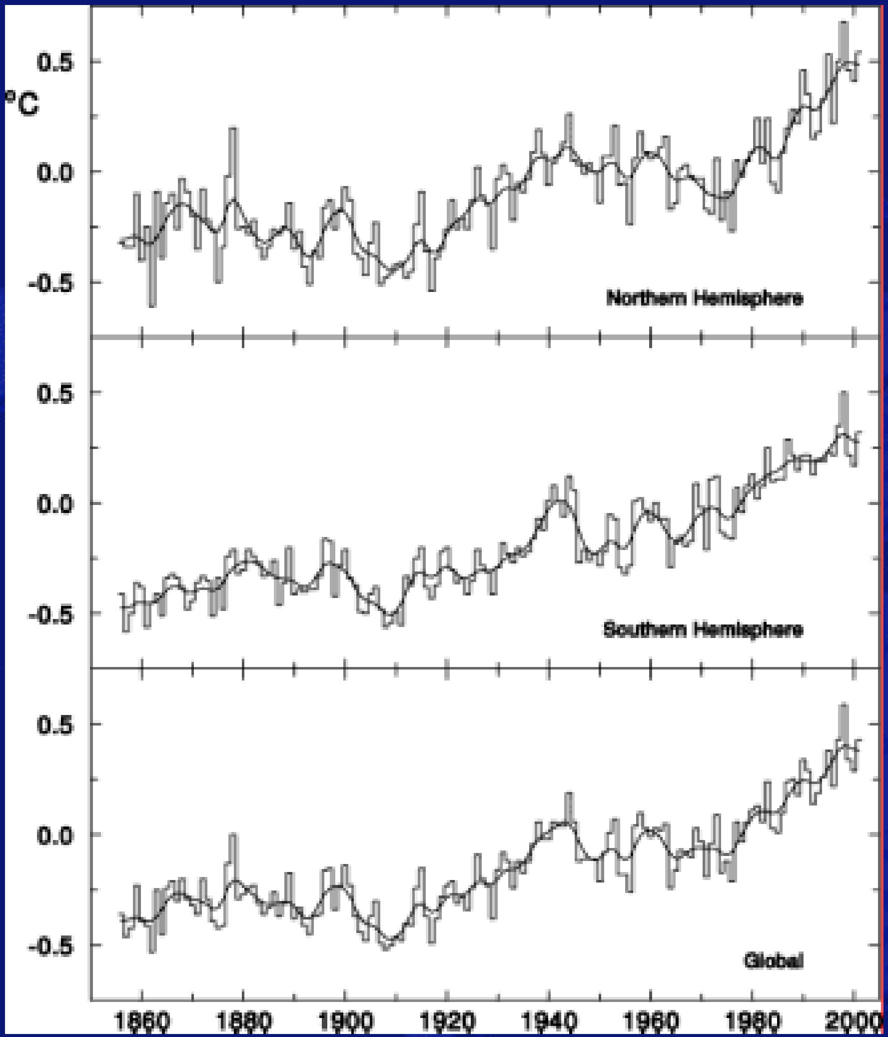


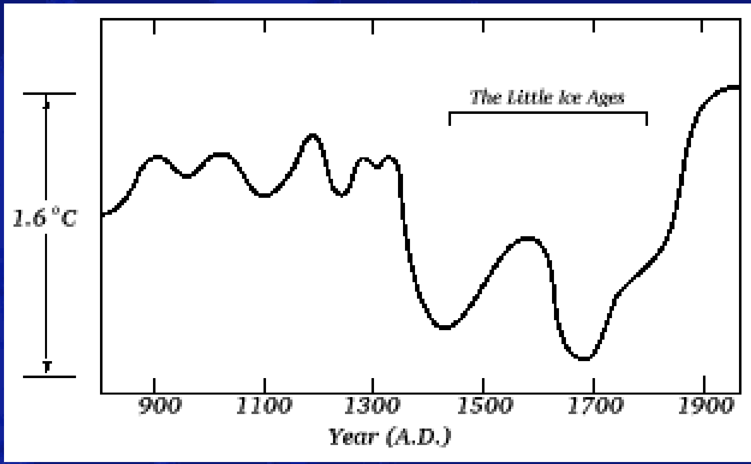
WG1 - TS BOX 3
FIGURE 1

Several Important events in climate system

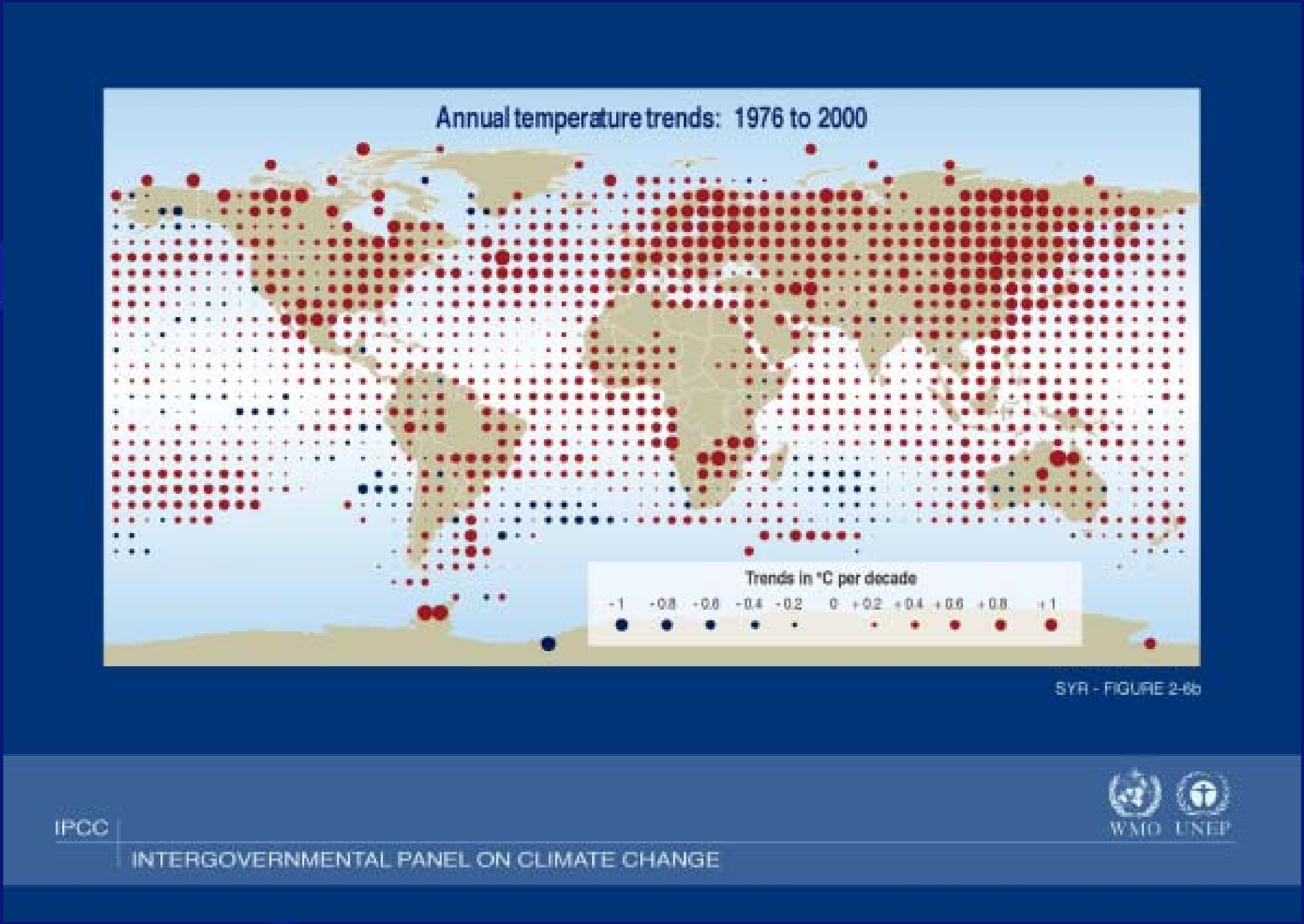
- Global warming
- El Nino and southern Oscillation (ENSO)
- Indian summer monsoon and Arabian dry

Global warming

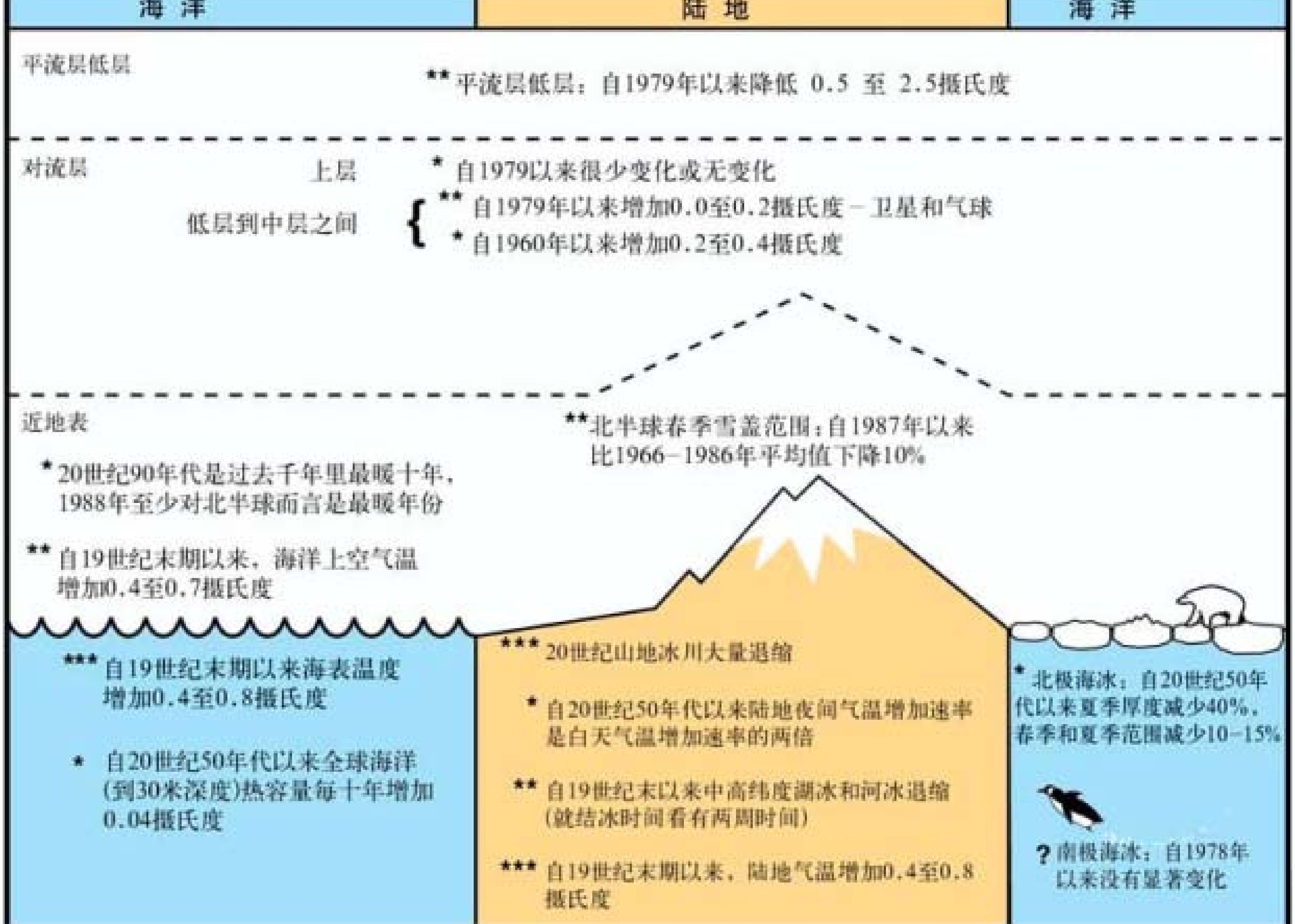




Globally mean temperature increase from the industrial era (IPCC, third assessment, 2001)

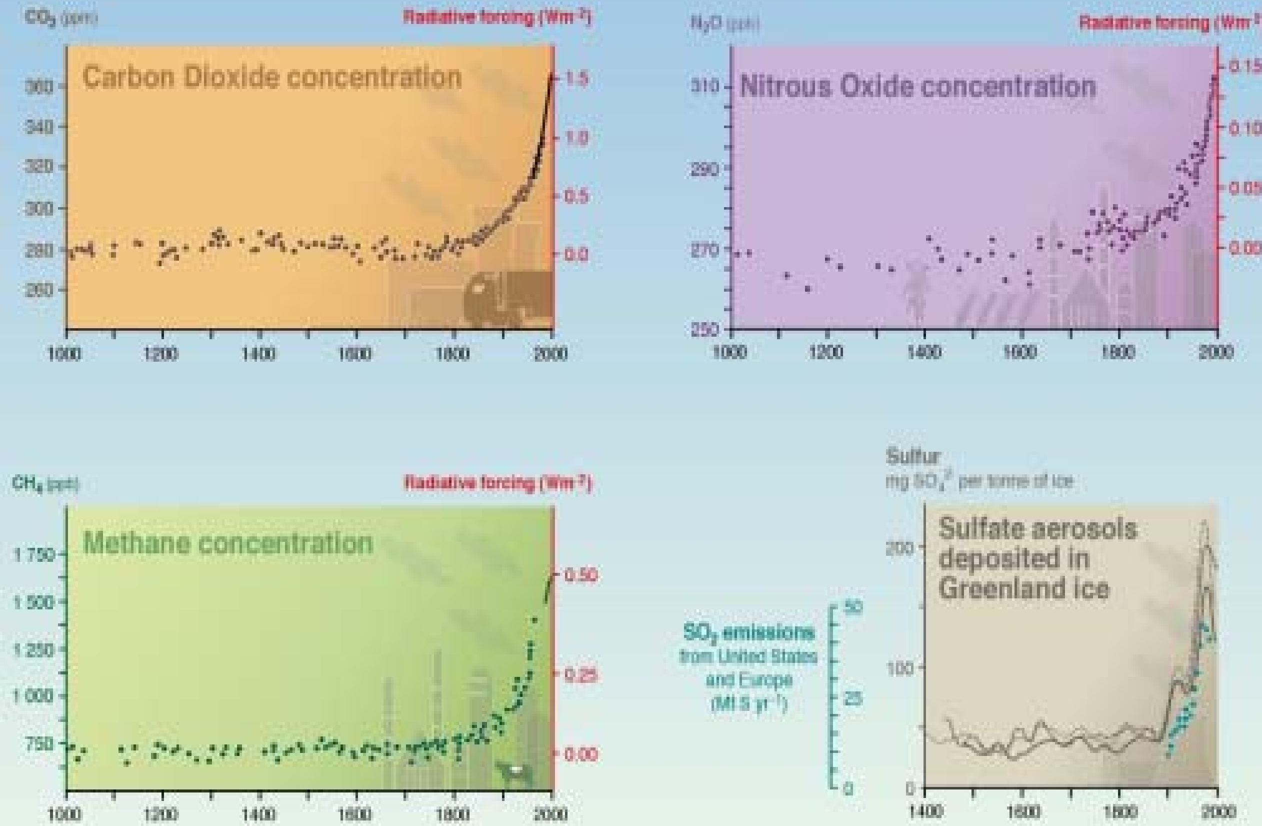


Temperature increase all over the world from 1976 to 2001

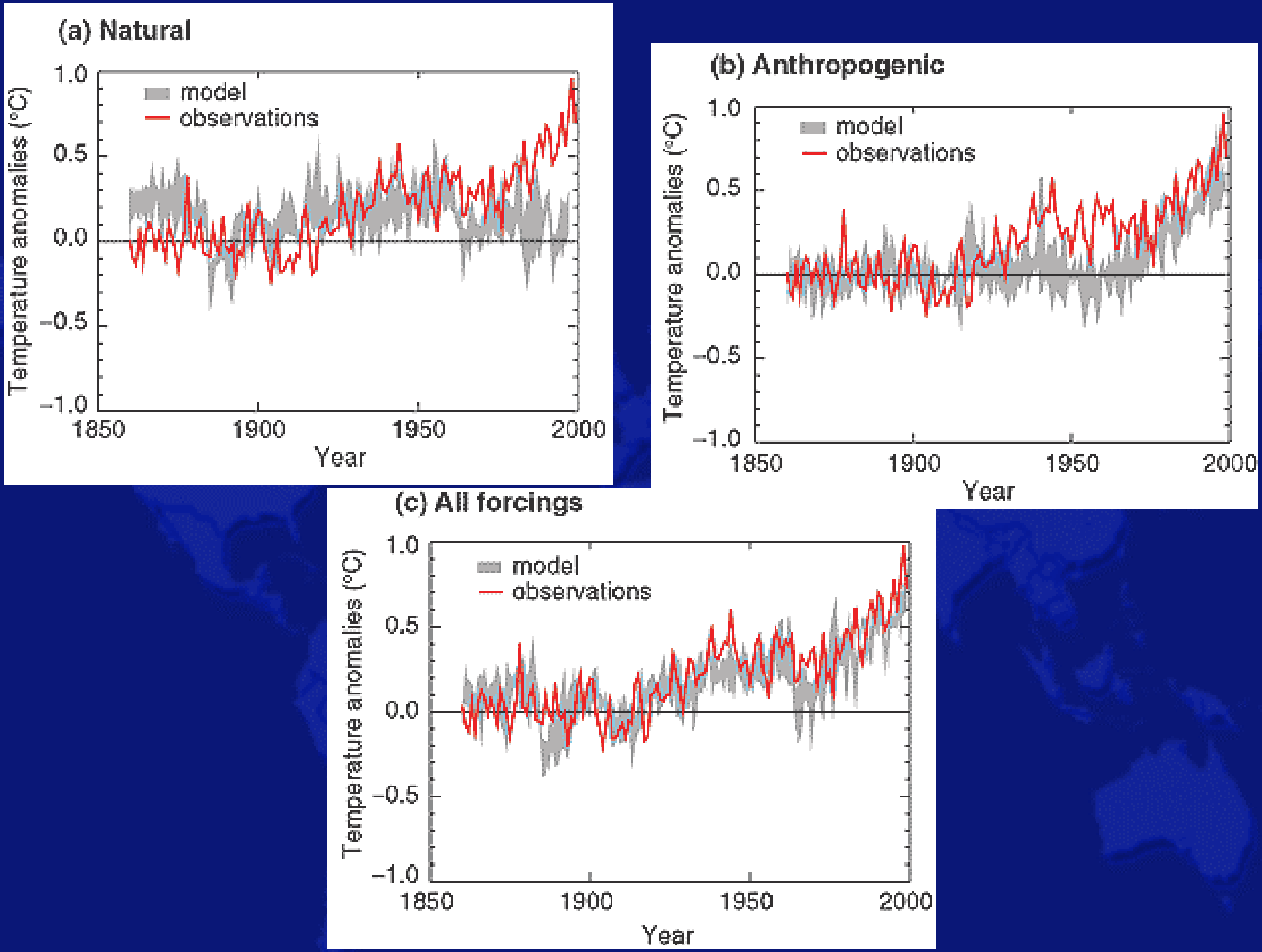


可能性：
- *** 基本肯定(几率大于99%)
- ** 很可能(几率大于90%但小于99%)
- * 可能(几率大于66%但小于90)
- ? 中度可能性(几率大于33%但小于66%)

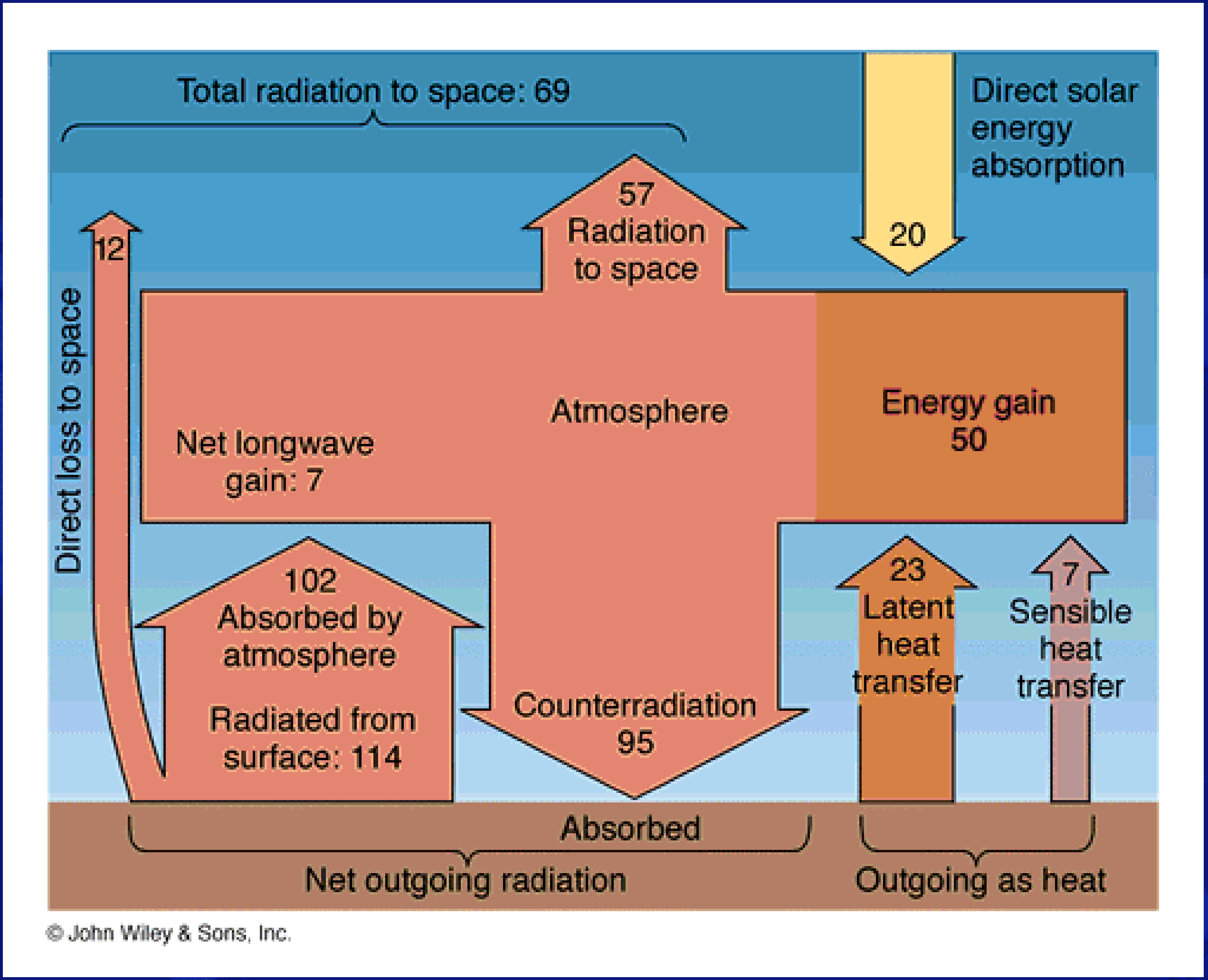
Indicators of the human influence on the atmosphere during the Industrial era



SYR - FIGURE 2-1
WG1 FIGURE SPM



The natural and human-effect components in the recent global warming (IPCC, third assessment, 2001)



Long-term mean energy budget in earth-atmosphere system (Strahler and Strahler, 1997)

Indicates the contribution of each greenhouse gas.

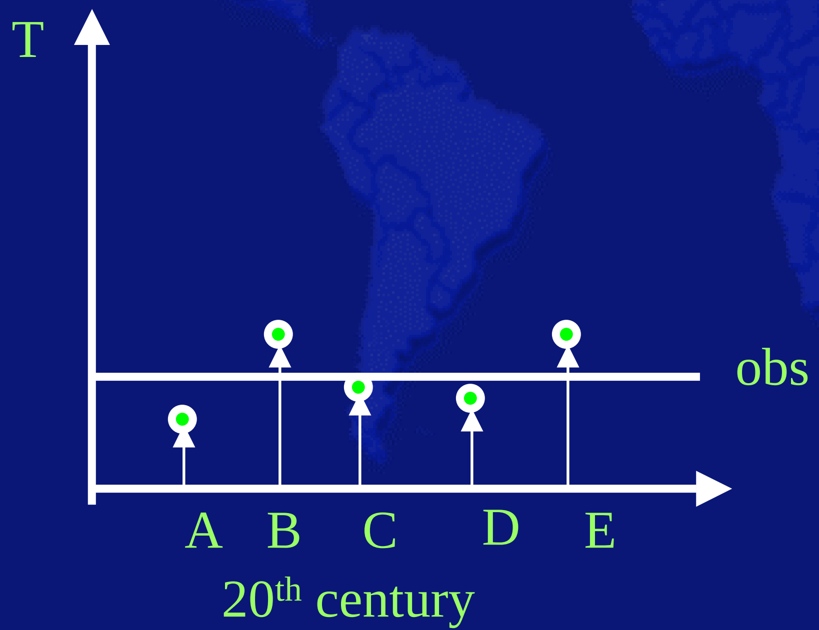
Gas and Effects	Relative Percentage
CO_2: Burning of Fossil Fuels, Deforestation	60 %
Methane (CH_4): Coal Mines, Wetlands, Rice Patties, Cattle, Subpolar Soil	15 %
CFC's: Refrigeration, Fire Extinguishers, Industrial Solvents.	12 %
Near-Surface Ozone: Unburned hydrocarbons from internal combustion engines reacting with sunlight	8%

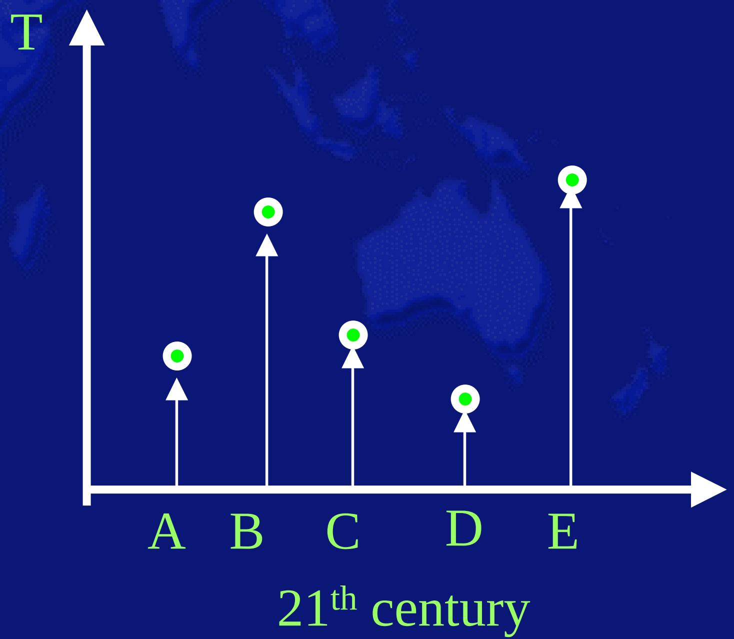
Table 2: Consequence of Global warming

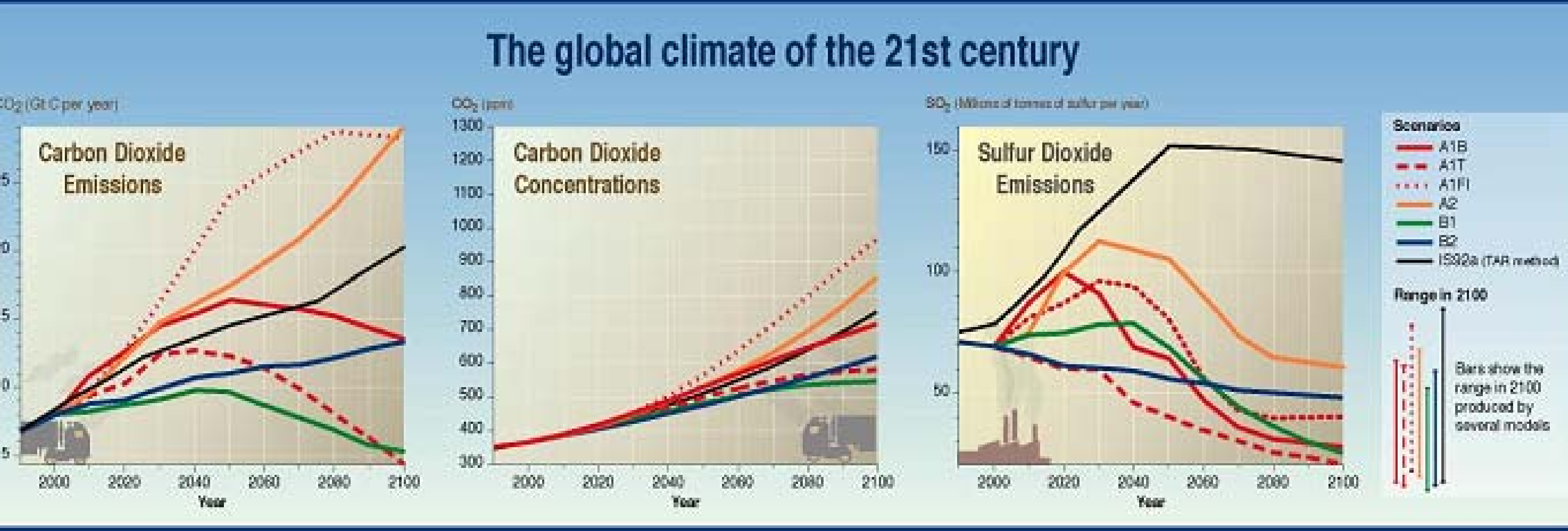
- Increase in warming:
  - Least effect in tropics.
  - Greatest towards poles
- Change in rain or snowfall:
  - Wandering weather patterns.
  - Increased Precipitation.
  - Less rain in the summer in the U.S. midwest.
  - Wetter in former Soviet Union.
  - An increase in monsoon rains in India.
  - Drier in Africa, China & Brazil.
  - The intensity and number of storms will increase
- The ocean currents may be modified, resulting in changes in temperature over land areas.
- Inadequate water for irrigation and human use in dryer areas
- sea level rise 1-3 feet by 2100
  - Expansion of water due heating
  - Melting of glaciers.
  - Will result in coastal flooding
- Natural habitats will be destroye
  - Forests will start dying off.
  - Wild animals in these regions will be unable to migrate to a more suitable climate. This is because of development and isolation.
- Agriculture may be helped or hurt.
  - Depends on area - Siberia will be helped. Midwest U.S. will be hurt.
  - Also depends on the ability of farmers to react fast enough to changing climate conditions.
- Diseases common to warm regions will be able to expand to

Ensemble projection of Global warming

- Uncertainties
  - Emission Uncertainties
  - Model uncertainties (Allen et al, 2000; Murphy et al, 2004, Nature)

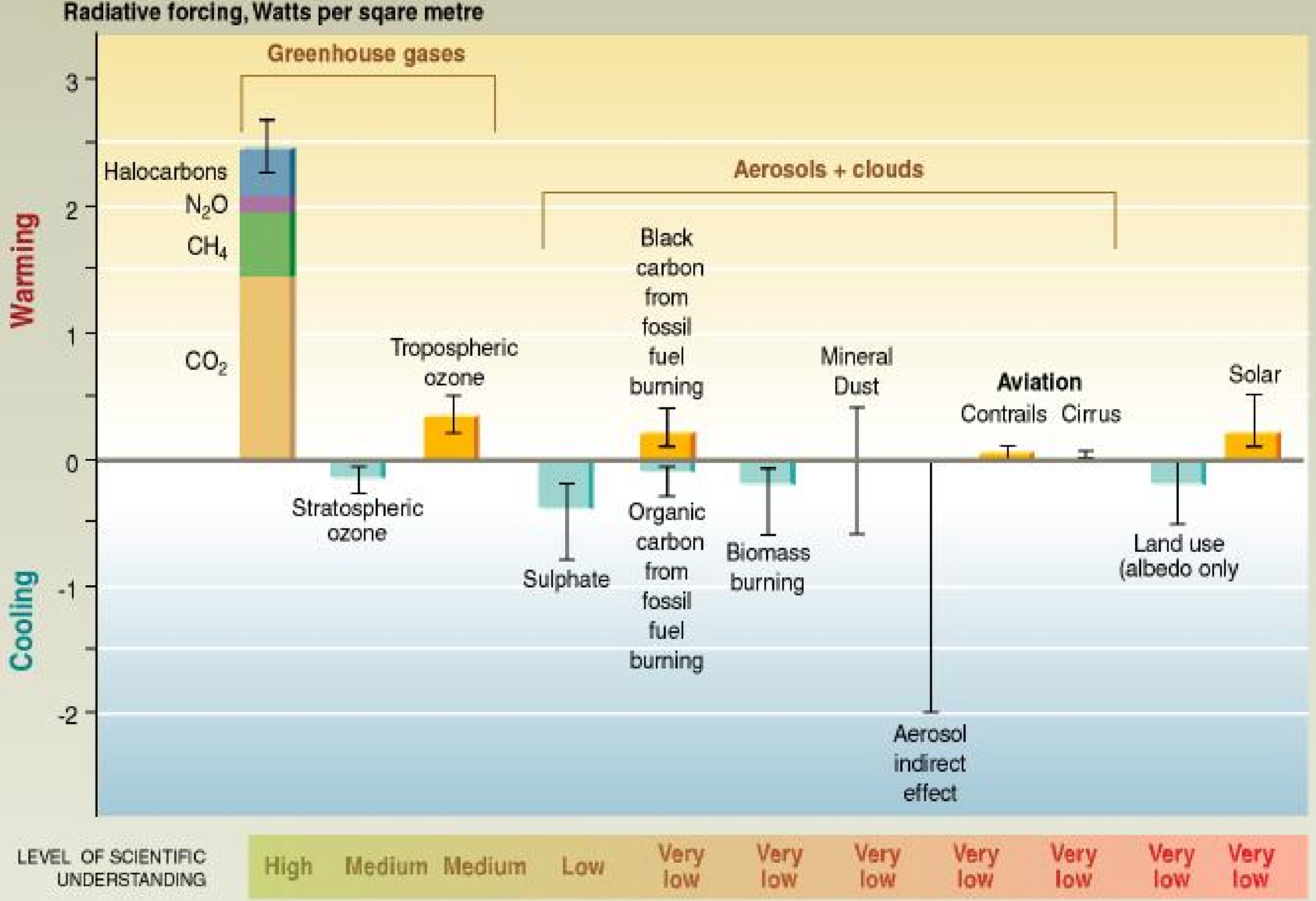




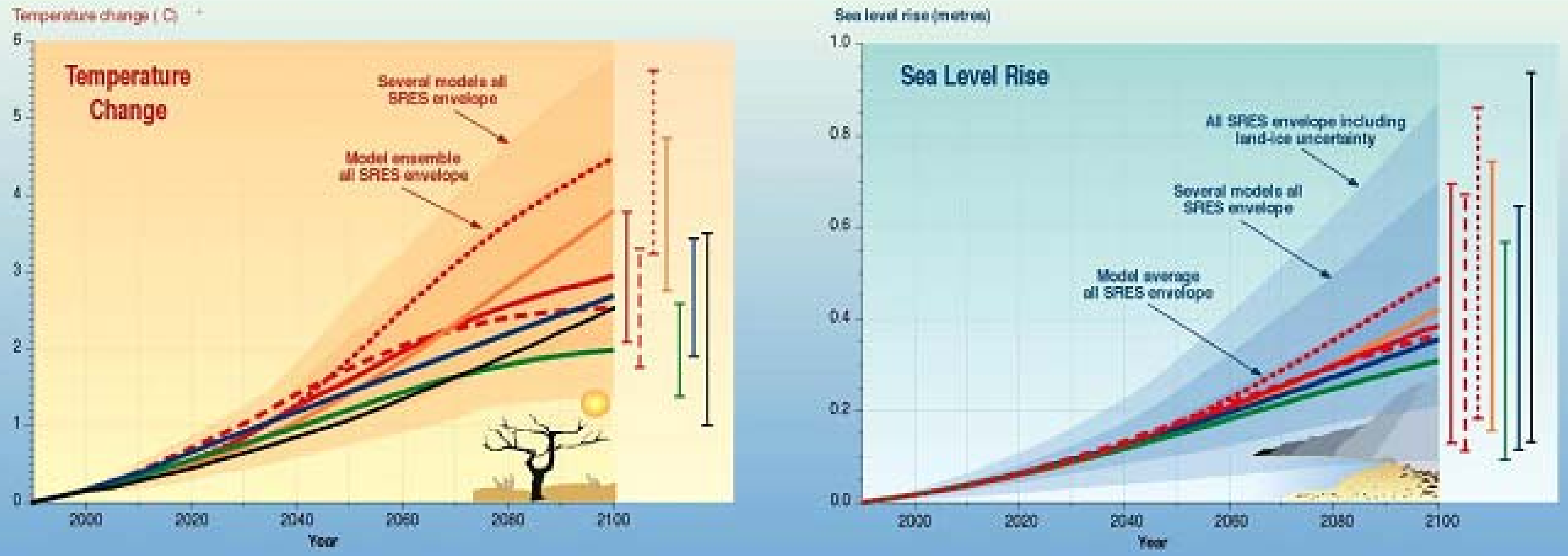


Special Report on Emissions Scenarios (SRES)

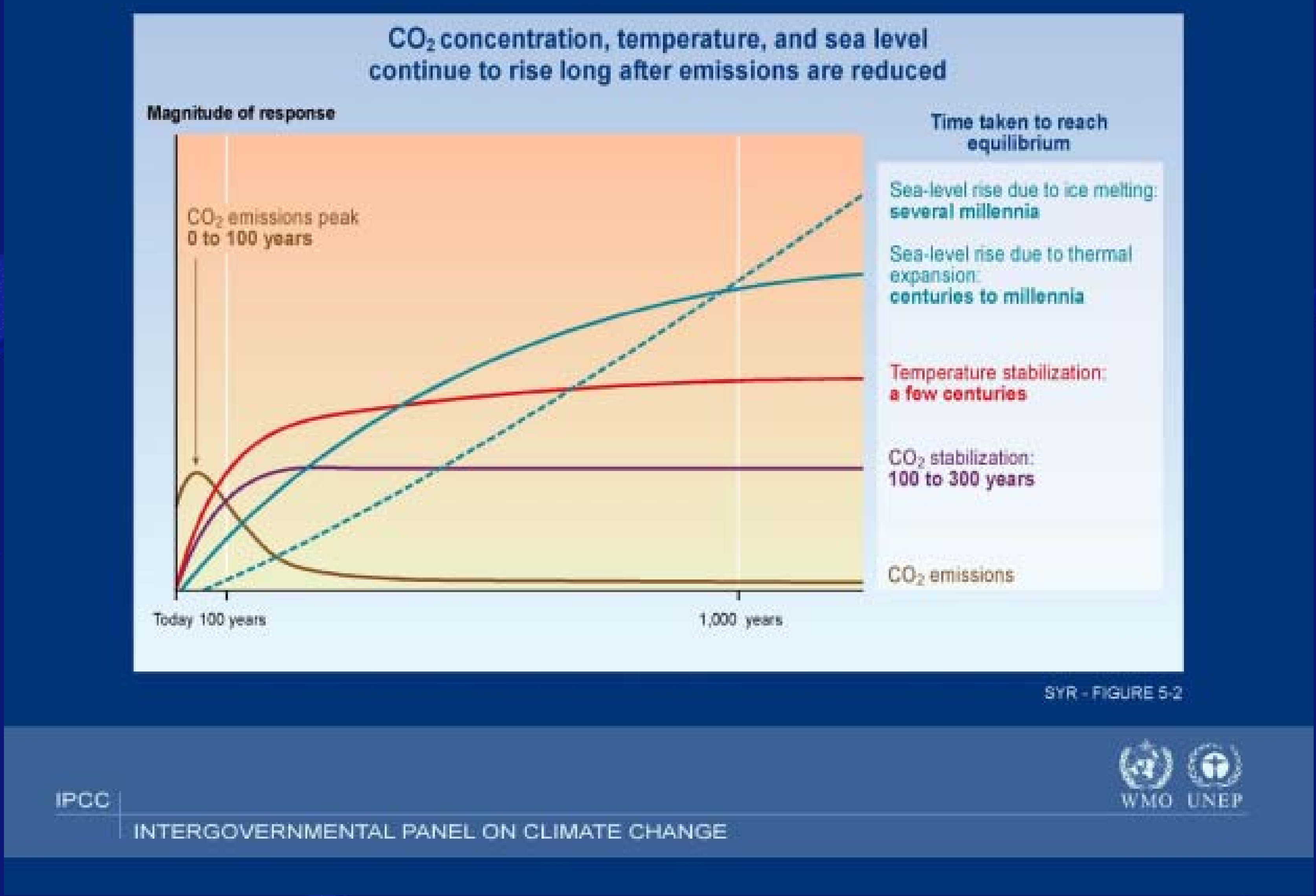
The global mean anthropogenic radiative forcing of the climate system for the year 2000, relative to 1750



The height of the bar indicates a mid-range estimate of the forcing and the bars show the possible range of values.

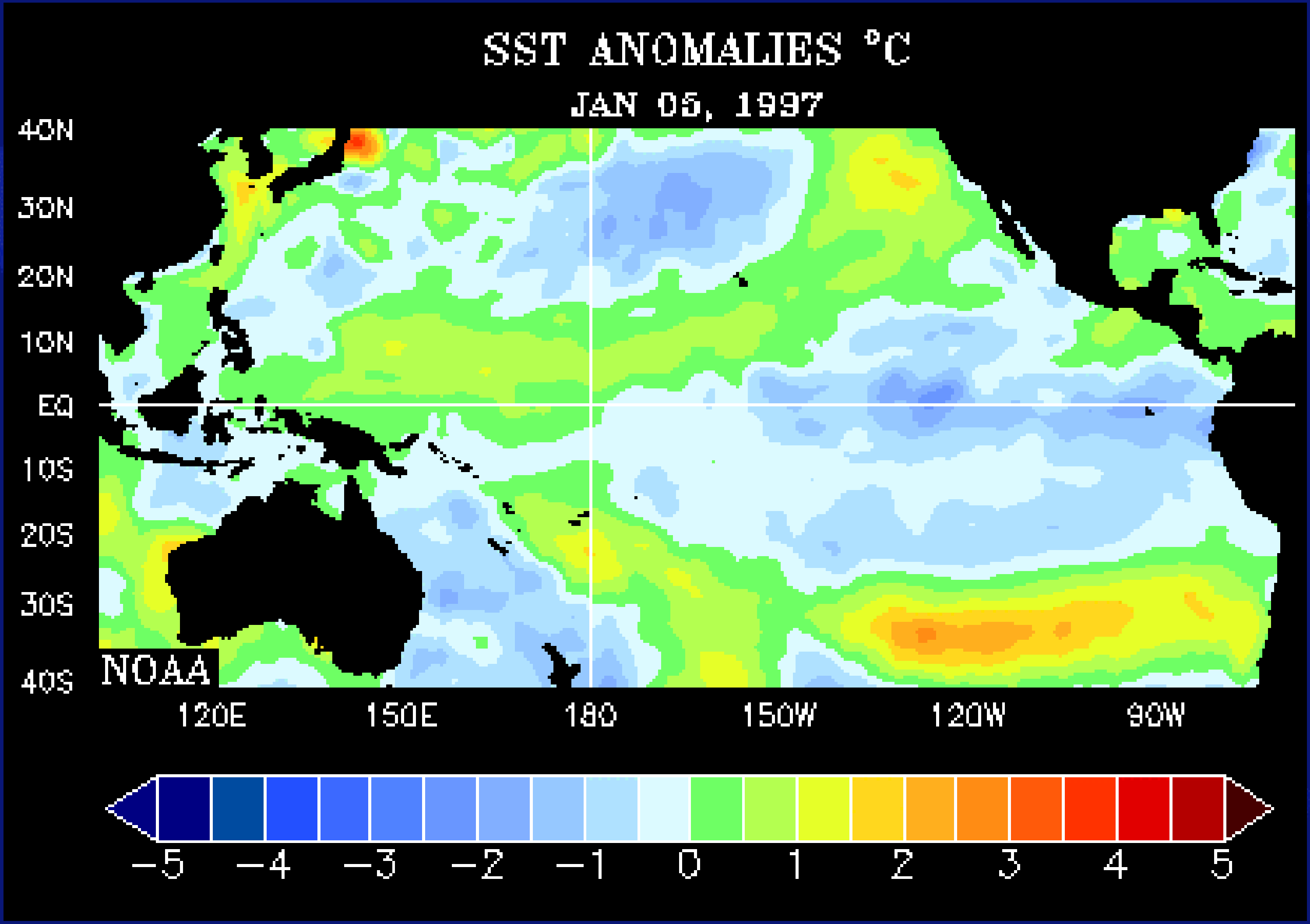


Projection of global warming



Time taken to reach equilibrium for CO2, temperature and sea level

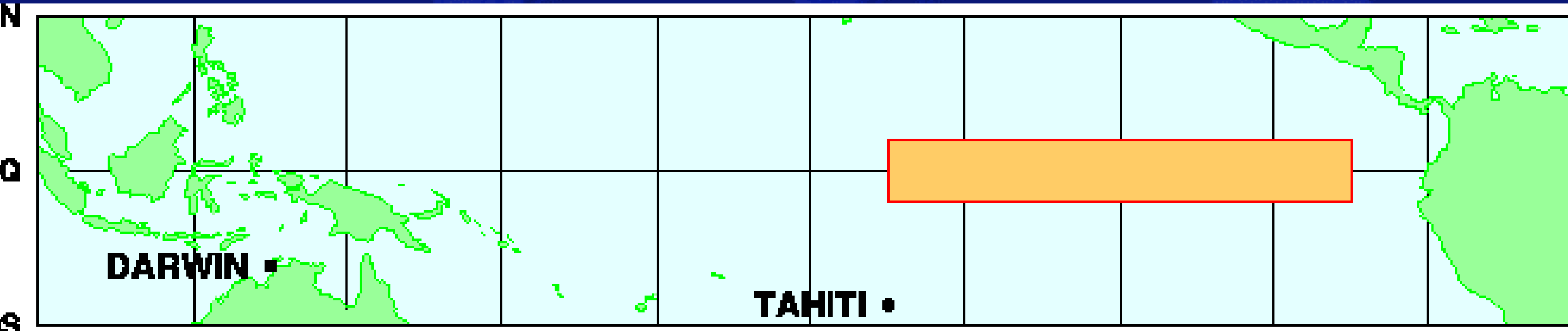
El Nino and southern Oscillation (ENSO)



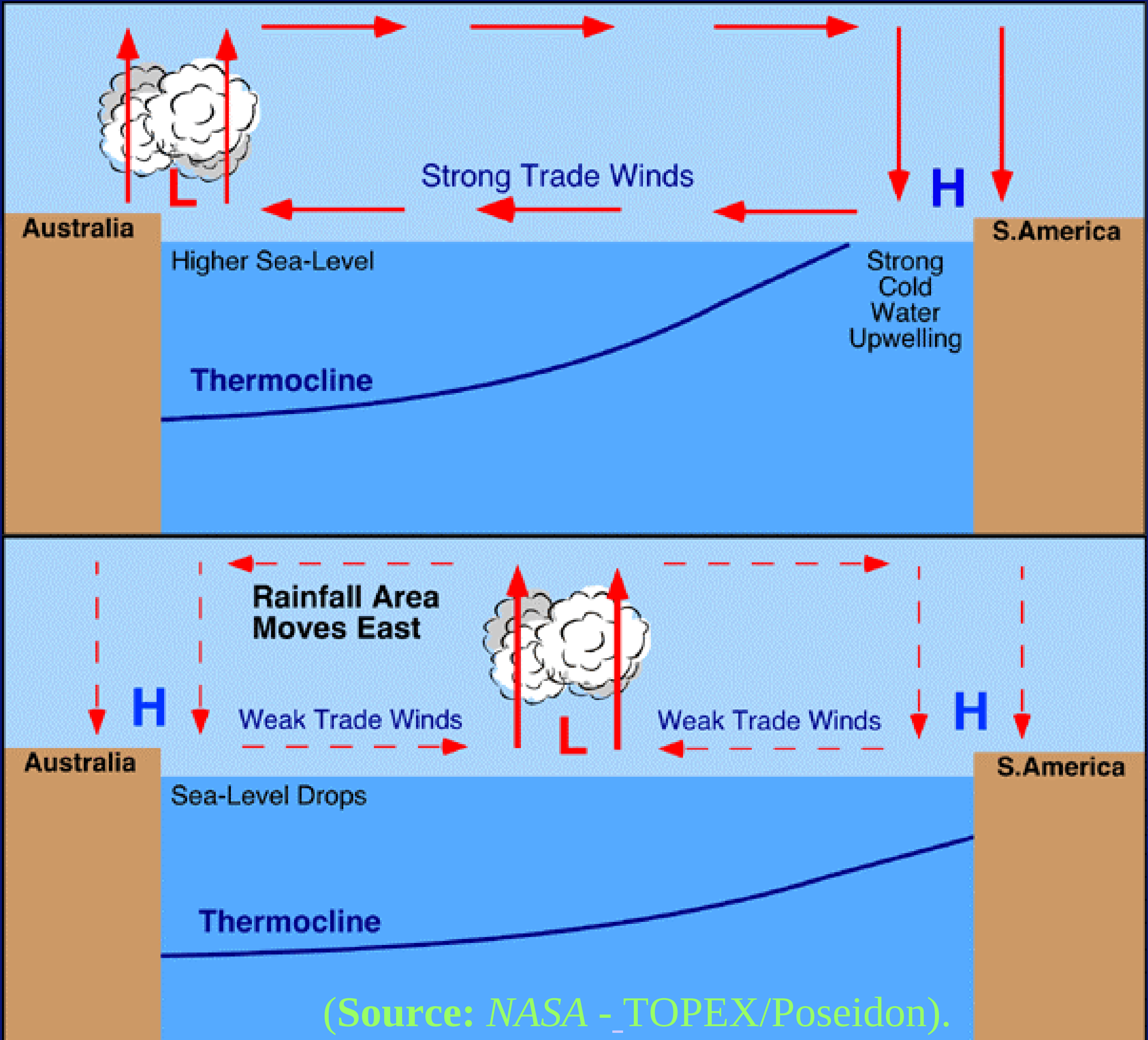
NOAA's Climate Diagnostics Center

History of El Nino

- Normally the waters in east Pacific were cold and flowed from south to north. But in certain years the waters would reverse their flow and become very warm.→ a local phenomenon?
- Sir Gilbert Walker : seesaw of pressure between EP and (WP) → South Oscillation
- 1957 IUGG → (1) El Nino is not a local phenomenon (2) trade wind died.
- 1966 Jacob Bjerknes connected El Nino and SO → to be confirmed
- 1982 The Conrad vessel sailed eastwards along the equator in the Pacific → too warm SST; easterly wind
- 1985 Tropical Ocean Global Atmosphere (TOGA)
- 1986 O-A GCM predicted El Nino



El Nino

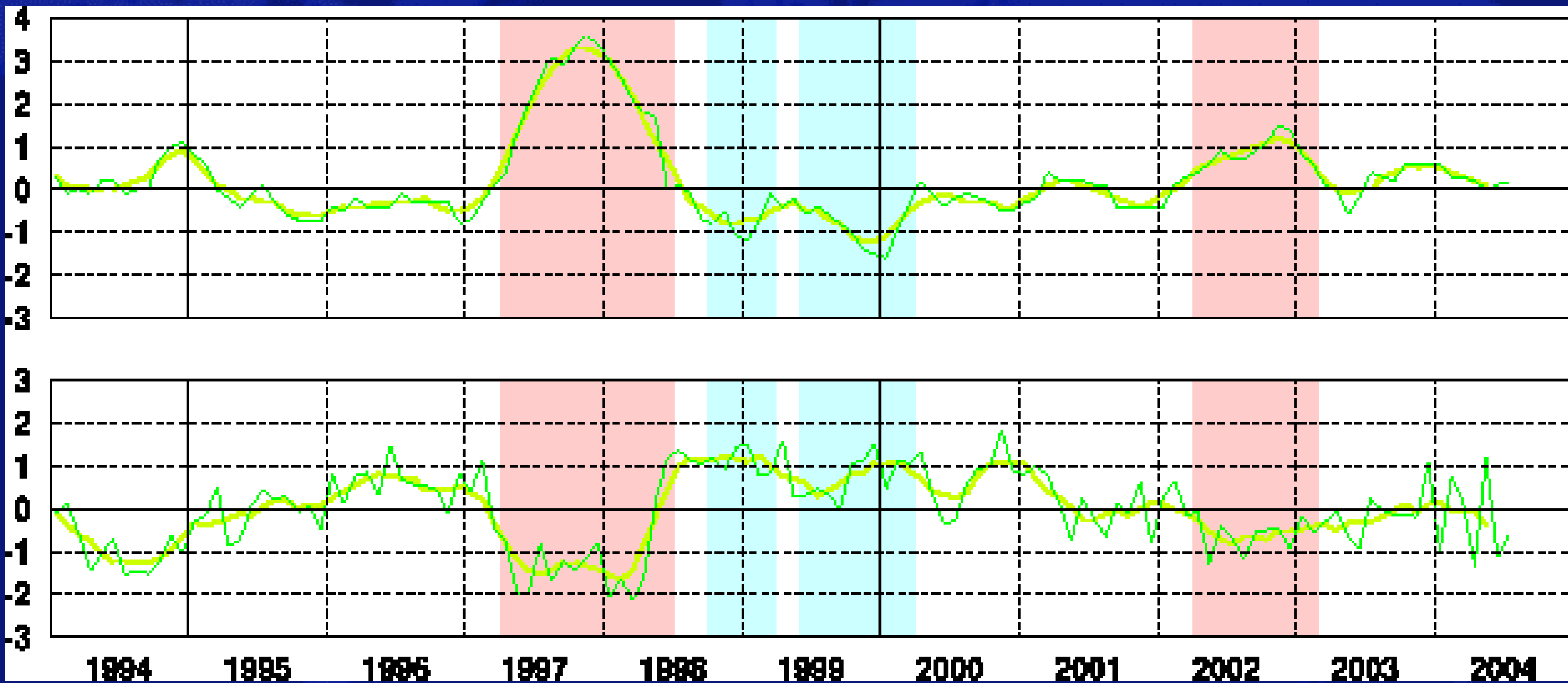


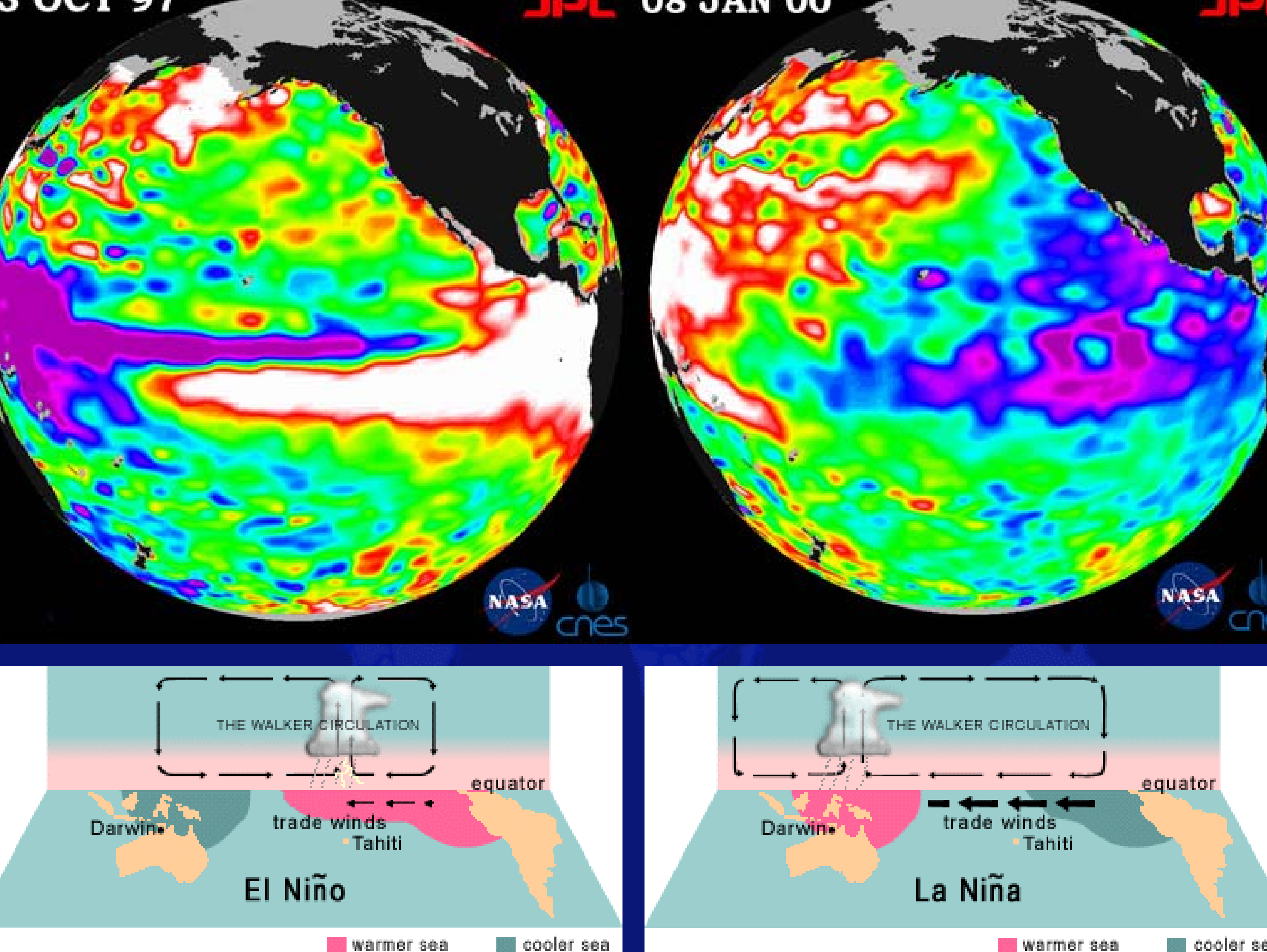
(**Source:** *NASA* - TOPEX/Poseidon).

El Nino/Southern Oscillation (ENSO)

SST

SOI




3 OCT 97
08 JAN 00
THE WALKER CIRCULATION
equator
Darwin
trade winds
Tahiti
El Niño
warmer sea
cooler sea
THE WALKER CIRCULATION
equator
Darwin
trade winds
Tahiti
La Niña
warmer sea


60
Warmer Winters
Warmer Winters
Winter Storms
30
Winter Storms
Hurricanes
Drought
Increased Precipitation
Increased Precipitation
Drought
0
Drought
Drought
Warmer Winters
Drought
Hurricanes
Drought
Drought
Drought
30
60
Robinson Projection

1.Australia - Drought and devastating brush fires
2.Indonesia, Philippines - Crops fail, starvation follows
3.India, Sri Lanka - Drought,fresh water shortages
4.Tahiti - 6 tropical cyclones
5.South America - Fish industry devastated
6.Across the Pacific - Coral reefs die
7.Colorado River basin - Flooding, mud slides
8.Gulf states - Downpours cause death, property damage
9.Peru, Ecuador - Floods, landslides
10.Southern Africa - Drought, disease, malnutrition

Predictability of El Nino

- Predictability is largely limited by the effects of high-frequency atmospheric 'noise'
- **Limitations arising from the growth of initial errors in model simulations**

Predictability of El Niño over the past 148 years

Dake Chen[1,2], Mark A. Cane[1], Alexey Kaplan[1], Stephen E. Zebiak[1] & Daji Huang[2]

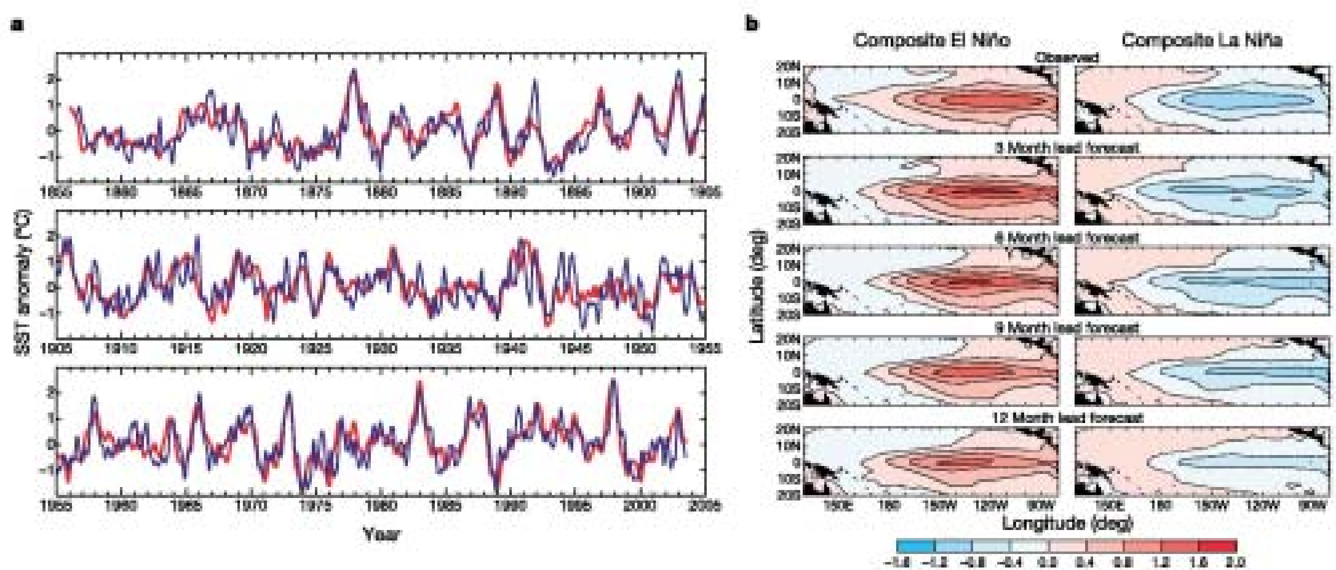


Figure 1 Retrospective predictions of El Niño and La Niña in the past 148 yr. **a,** Time series of SST anomalies averaged in the NINO3.4 region (5° S–5° N, 120–170° W). The 6-month lead. **b,** Composite El Niño and La Niña from 24 warm events and 23 cold events. Top panels are observations, and the rest are predictions at different lead times. The

Indian summer monsoon and Arabian dry

Joint AOGS 1st Annual Meeting & 2nd APHW Conference, 5-9 July, Singapore
Outreach & Public Lecture
Suntec Singapore International Convention & Exhibition Centre, 7 July 2004

Climate of South Asia: Role of the Ocean

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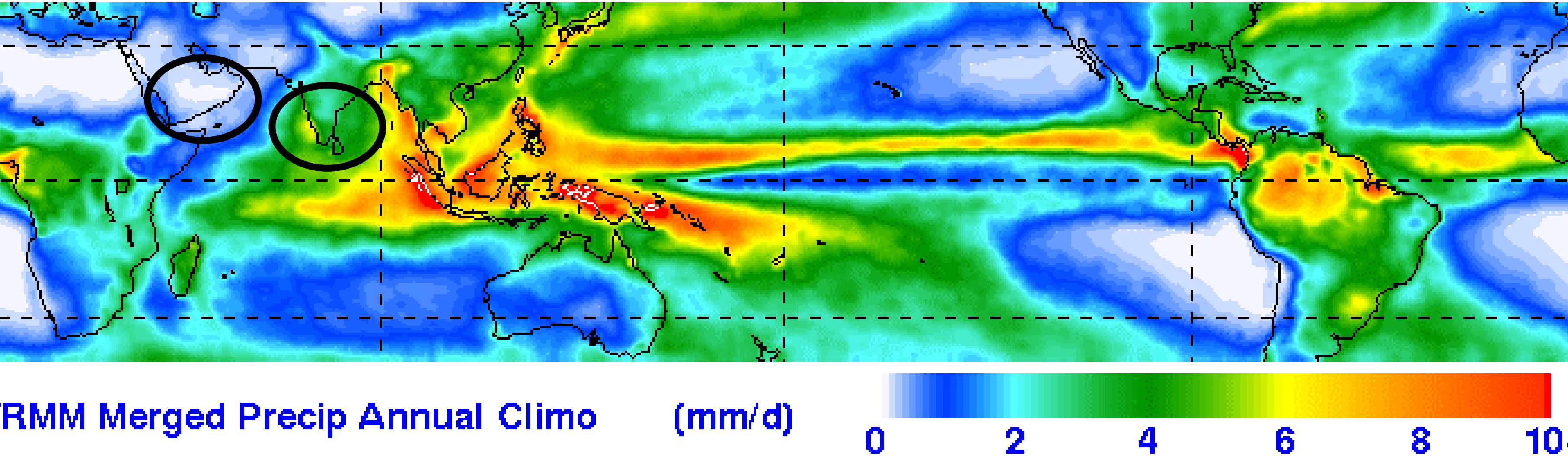
Dona Paula, Goa 403 004, India
shetye@darya.nio.org

Tropical Rainfall Measuring Mission (TRMM)

Three–Year TRMM Climatology



January 1998 – December 2000

- Largest rainy area: northern Bay of Bengal.

- Distinct northwest-ward elongation of the above area: the excess or below normal rain over this area determines whether the country as a whole will have flood or drought conditions.

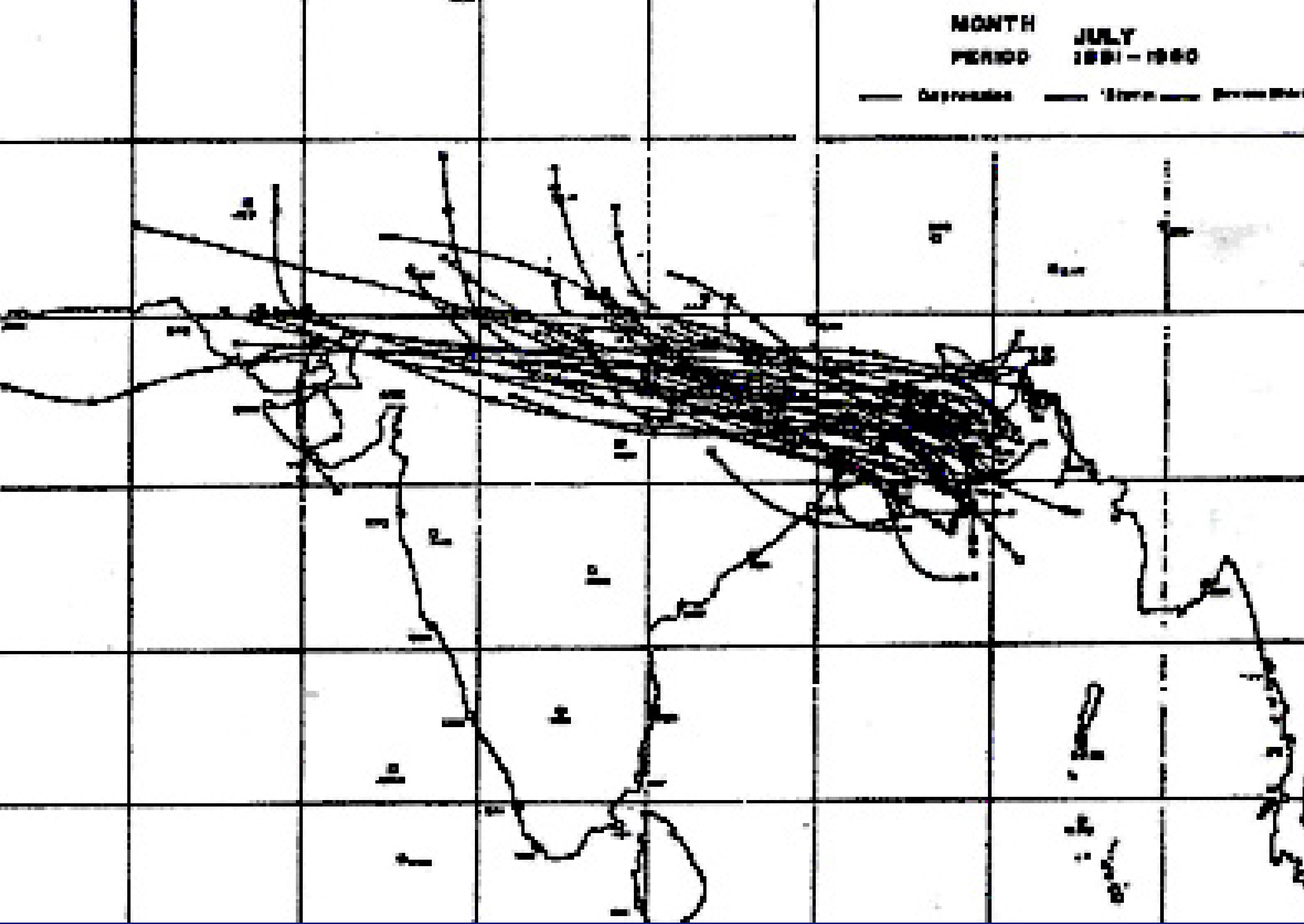
- High precipitation is along the west coast of India: topographic effect.

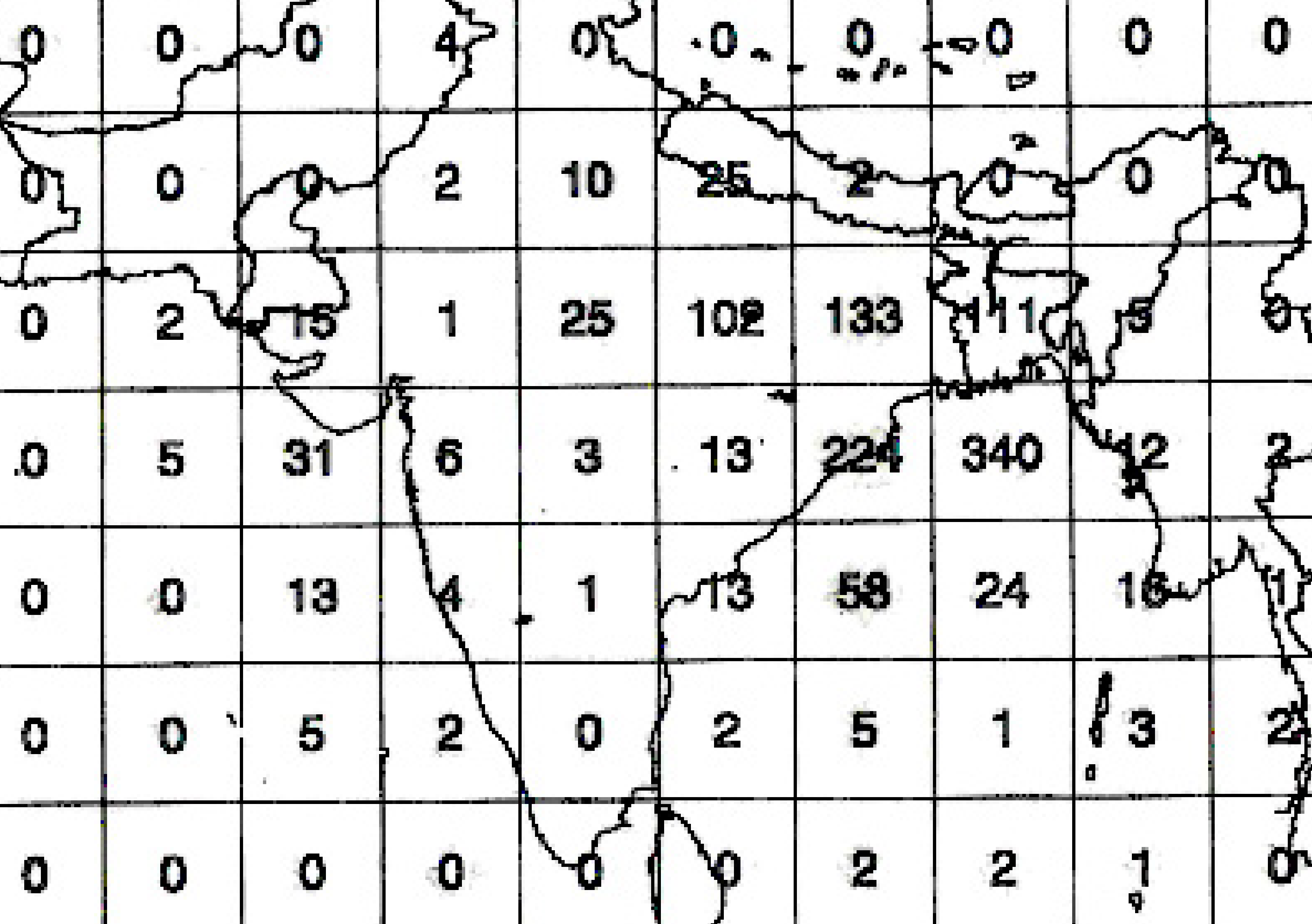
- Very low precipitation over the western Arabian Sea.

Conditions that need to be satisfied for rainfall to occur over the North Indian Ocean:

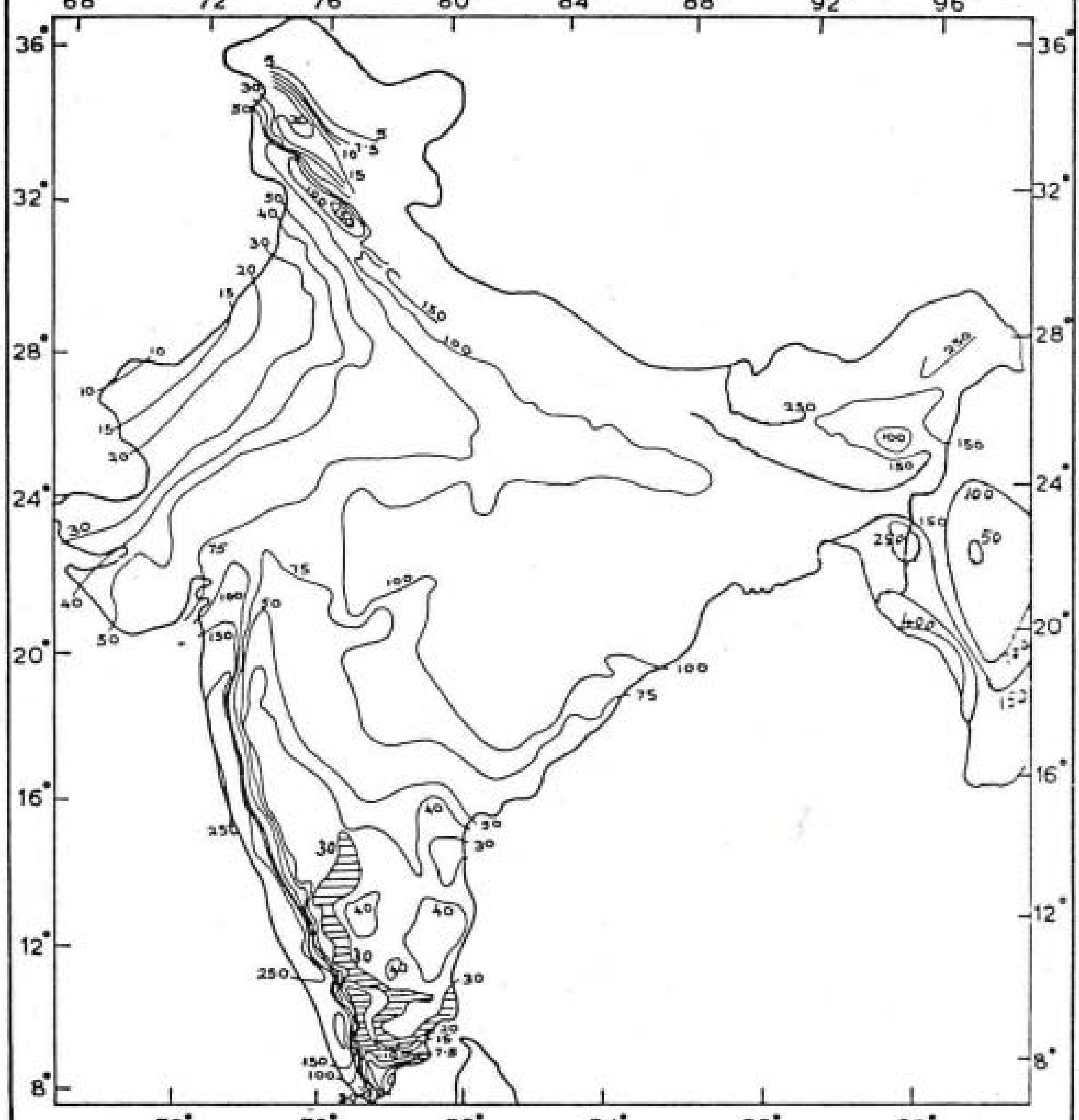
- ITCZ should have moved over the region, i.e. there should be large-scale convergence of air followed by uplift.

- Sea Surface Temperature should exceed a critical value of ~ 28 C: known earlier for tropical regions, but has been shown explicitly to be true for the Indian monsoon region. This is a necessary condition, but not sufficient.


MONTH
JULY
PERIOD



umber of LPS formed in June-September over 4 x 4 deg. Sq. during 1888-1983


36°
32°
28°
24°
20°
16°
12°
8°

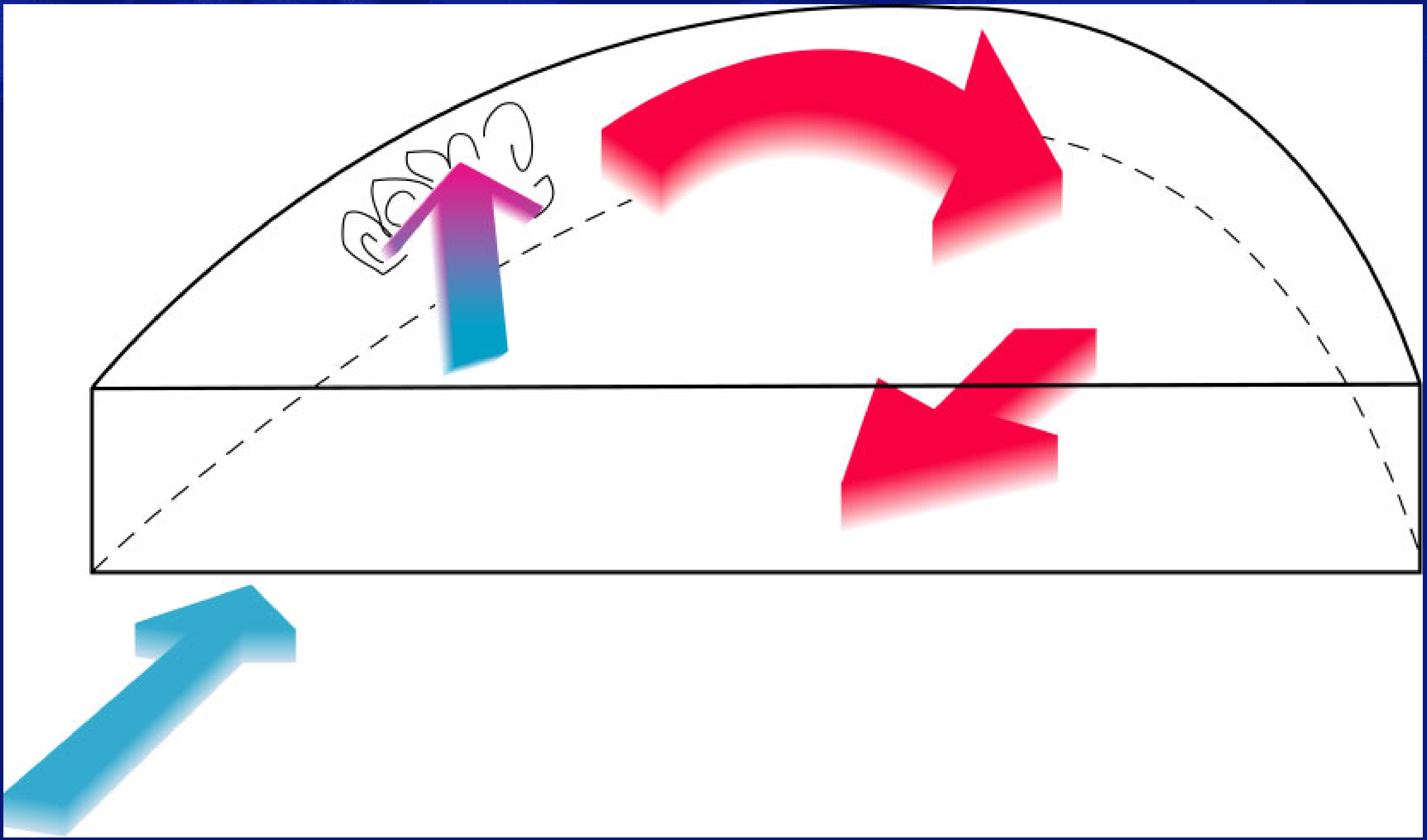
- By staying warm during the monsoon season (i.e. when the ITCZ is over the region) the Bay of Bengal makes it possible for a large area of the peninsular India to receive rainfall.

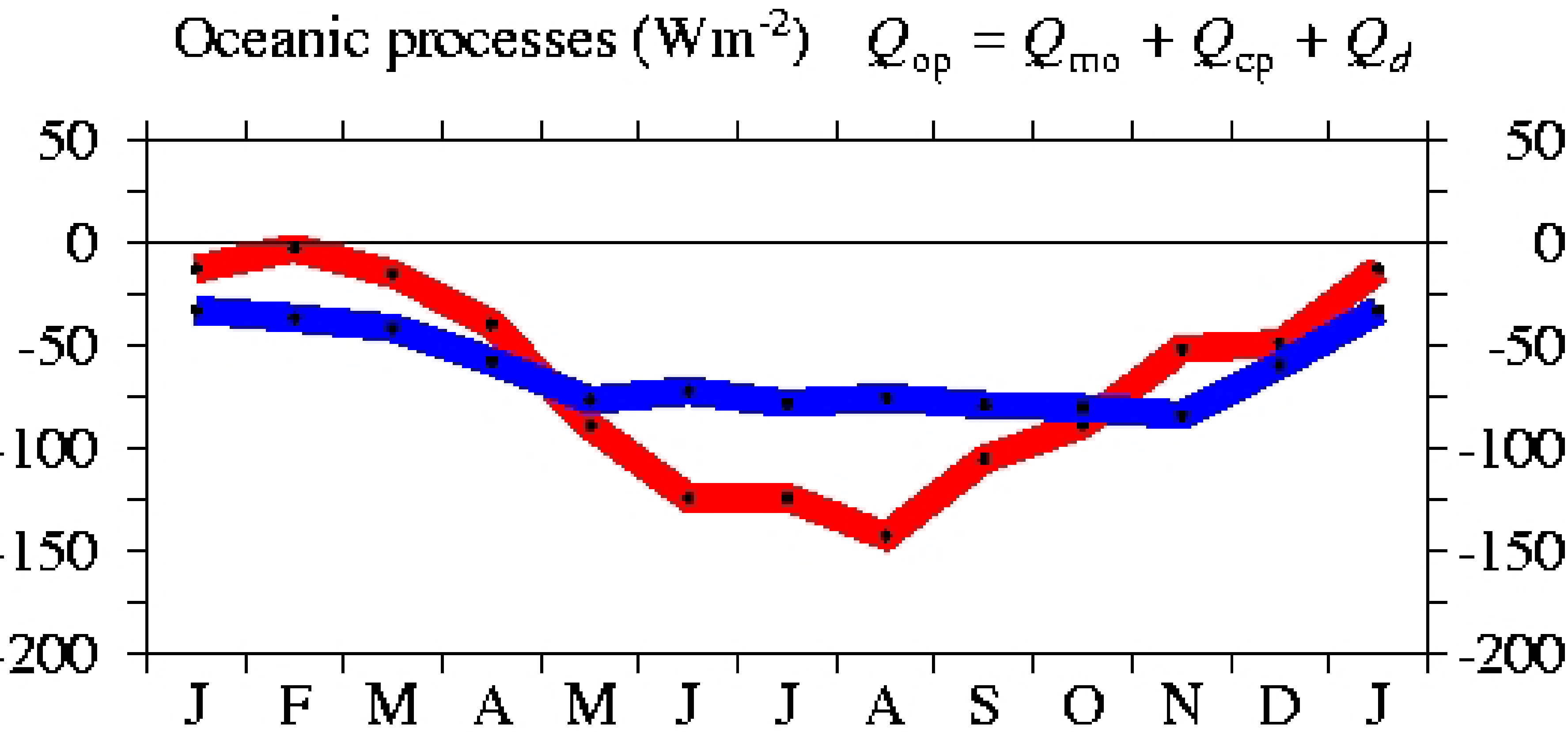
- Arabian Sea is much too cool to play such a role.

- What is the most critical factor that leads to the difference in SST?

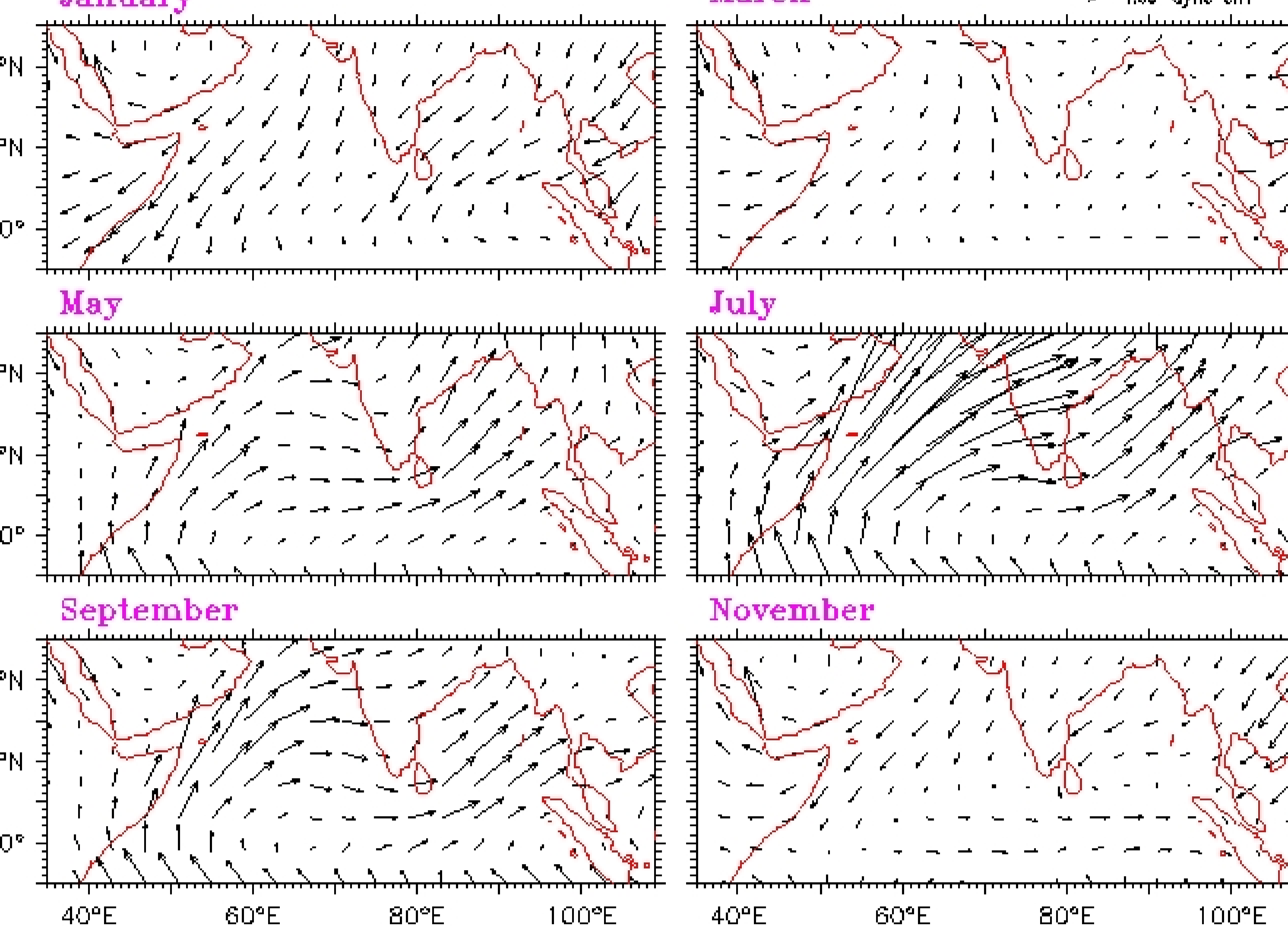
  2 reasons

- Cooler (deeper) northward moving waters upwell, mix with surface waters, turn eastward, then southward. The net result: cooling of the upper layer.





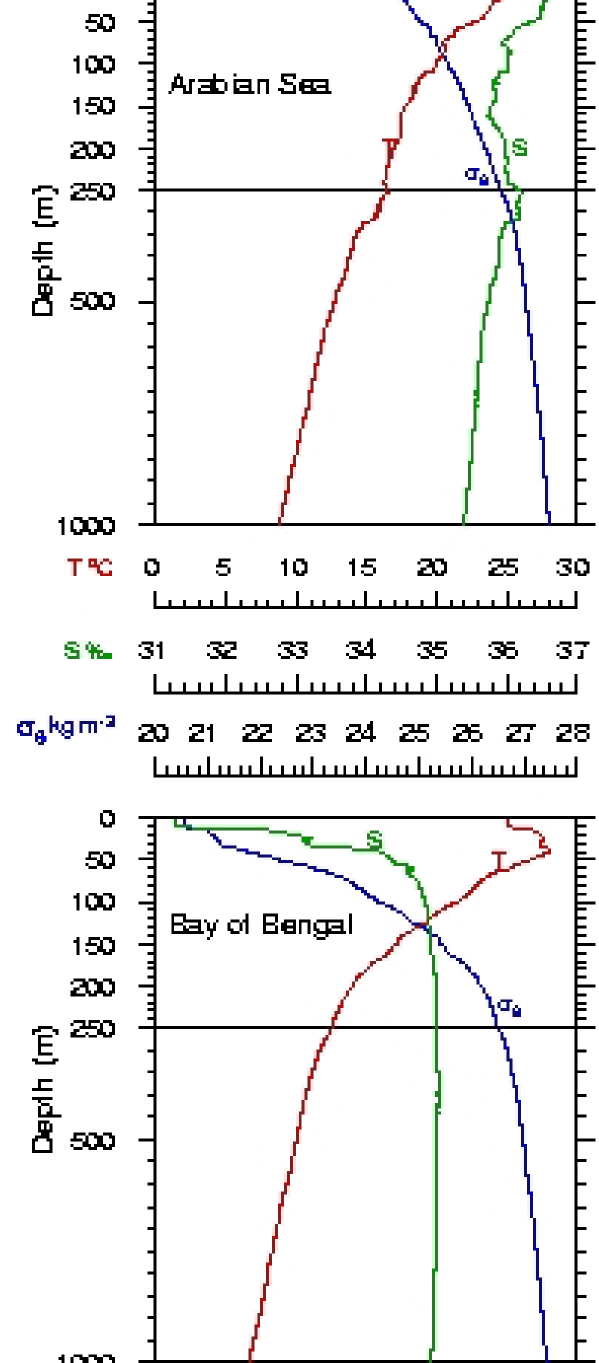
- The process is most active during the ISM
- Why is the process much more active in the Arabian Sea than in the Bay of Bengal during ISM?


May
July
September
November
40°E
60°E
80°E
100°E
40°E
60°E
80°E
100°E

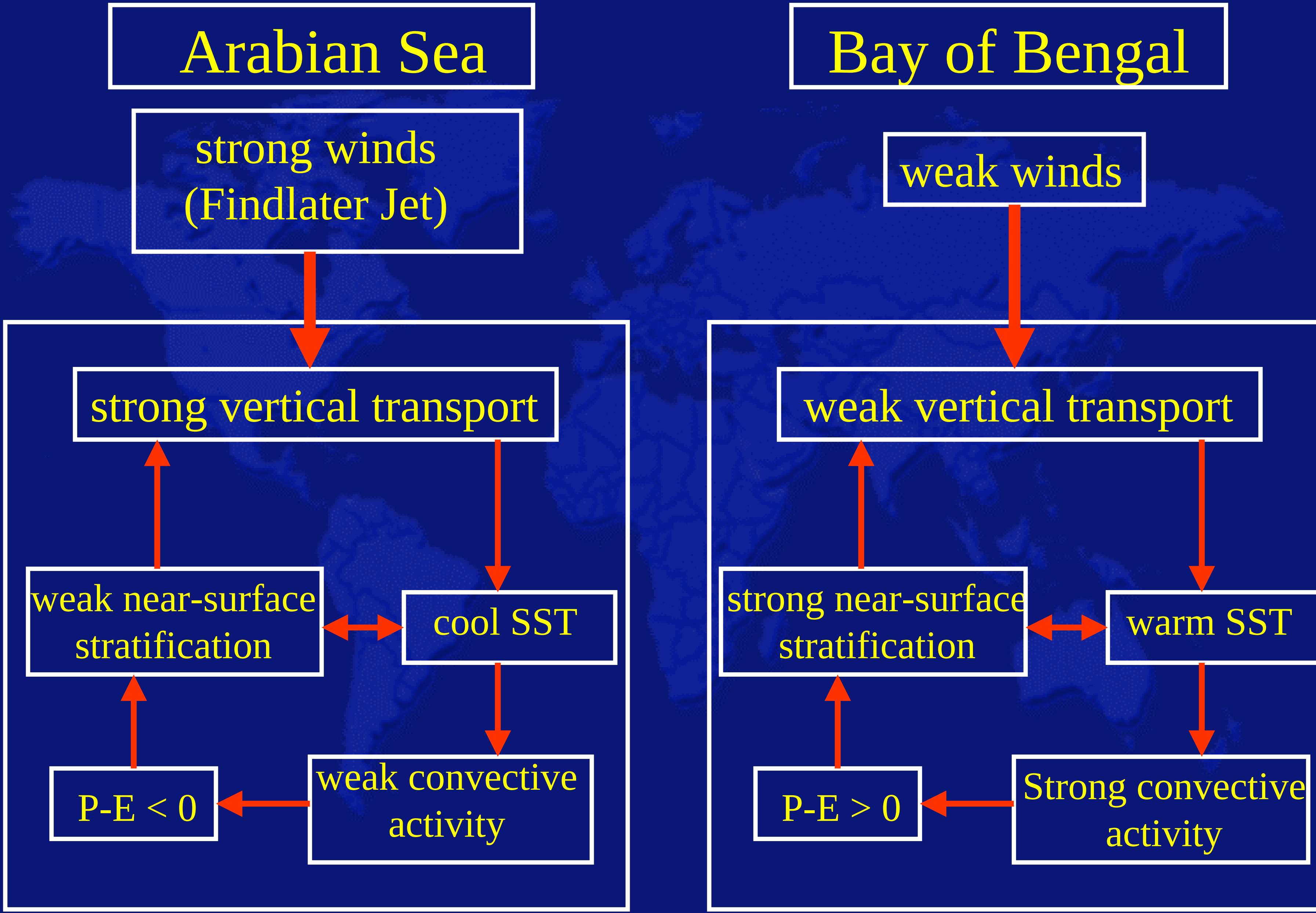
While the main difference between the budgets arises from difference in wind forcing, stratification too is expected to play a role

~19 N, 65 E , March

~19 N, 85 E , December



A schematic of feedback cycles



Summary

- Ocean processes over the Bay of Bengal help to sustain the southwest monsoon over the Indian subcontinent and surroundings.

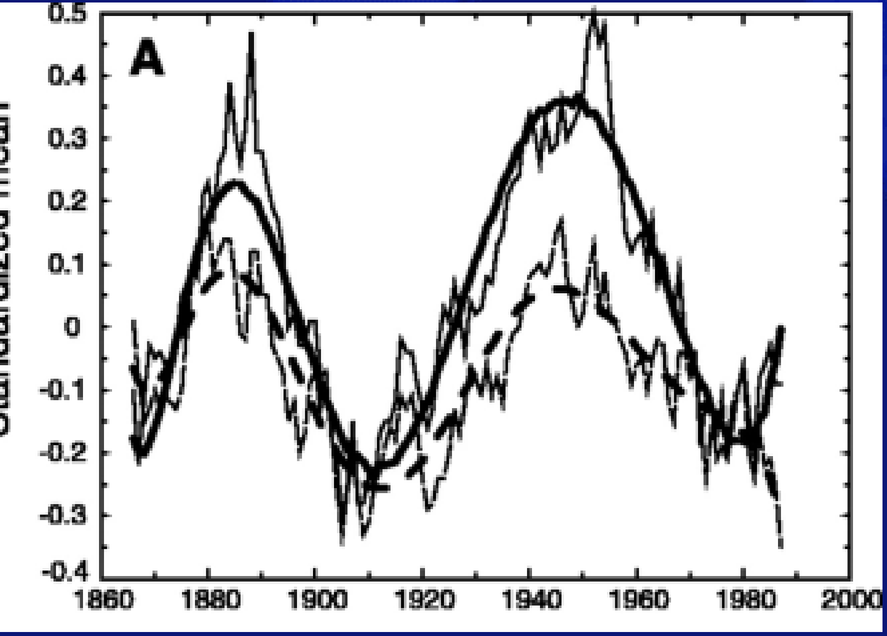
- Processes in the Arabian Sea limit the westward extent of the monsoonal climate.

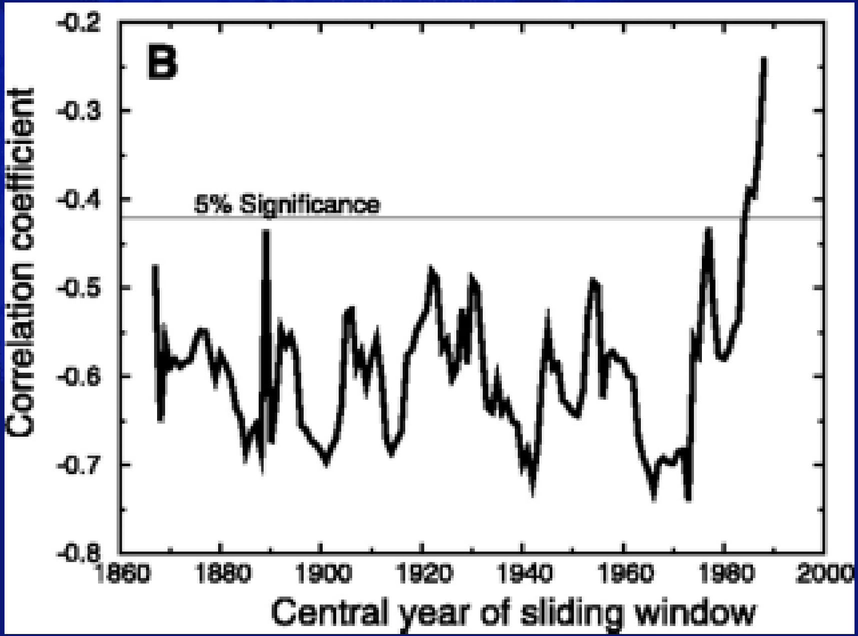
- Ocean processes are expected to be important in defining monsoon variability.

- Tibetan Plateau ~ Arabia Circulation

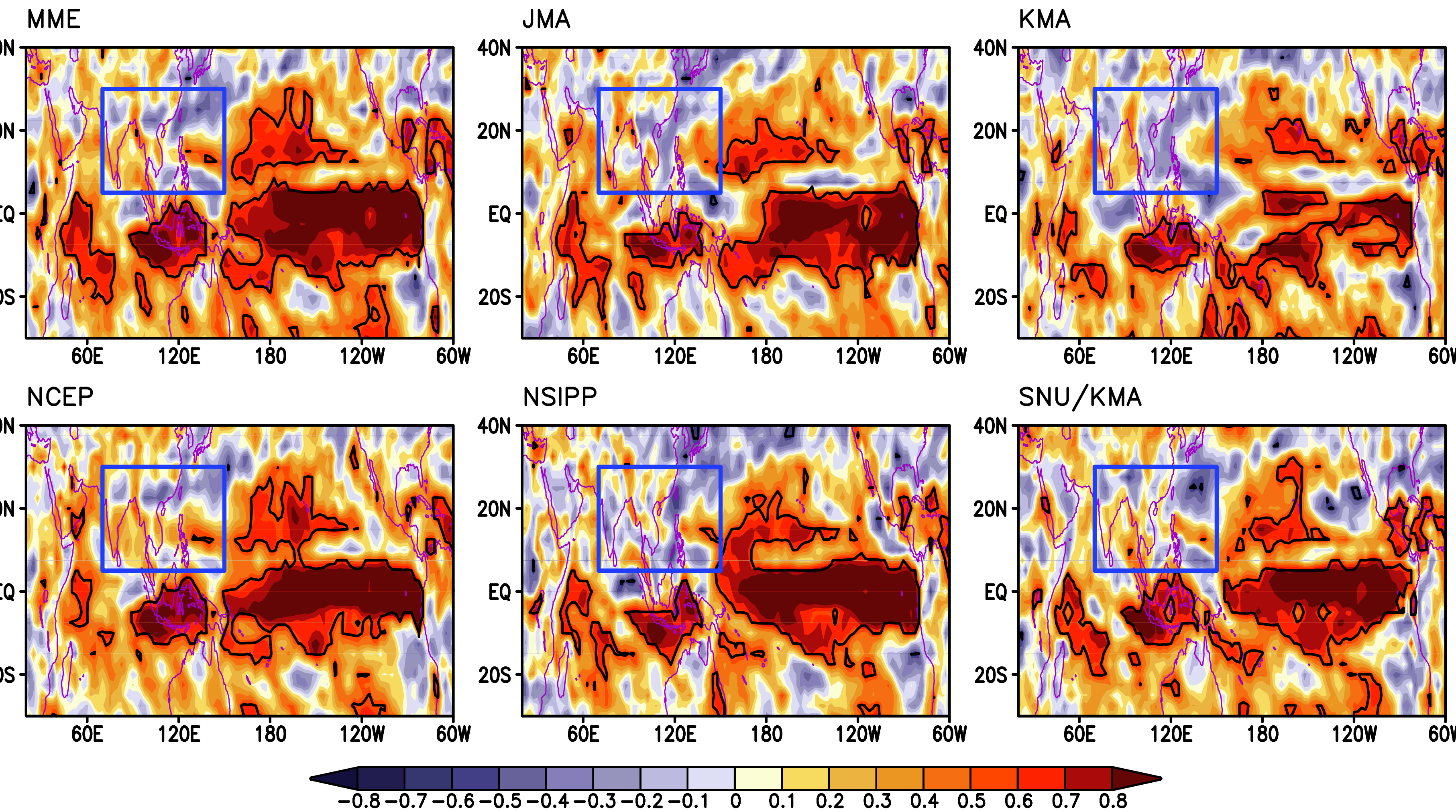
Recent Advance

- **ENSO is unusually correlated with weak Indian summer monsoon. However, since 1980s, the correlation between Indian Summer Monsoon and ENSO is becoming weak**
    - The subsidence area during ENSO shift southward
    - The Eurasian warming enhances the indian summer monsoon.





Obs ~ Model correlation



All models' hindcasts of monsoon rainfall variability failed
(Wang, 2004)

Time scale associated with climate change is ~ decades, not days

A scene from *The Day After Tomorrow*