The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2050-1

Targeted Training Activity: Predictability of Weather and Climate: Theory and Applications to Intraseasonal Variability

27 July - 7 August, 2009

The Global Atmospheric Circulation: Observations

David Straus

Center for Ocean-Land-Atmosphere Studies/Goerge Mason University (COLA-GMU)
Institute for Global Environment & Society (IGES)
Calverton, MD
USA

International Centre for Theoretical Physics

Targeted Training Activity:

Predictability of Weather and Climate

David M. Straus

1. **The Global Atmospheric Circulation: Observations**
2. Modeling the Weather and Climate
3. Errors in Forecasts: Roles of Initial States, Model Errors, and Chaos
4. Climate Predictability on Seasonal Time Scale: Role of Boundary Forcing
5. Seasonal Mean Predictability over the Pacific - North American Region

The Global Atmospheric Circulation:

Observations

Motivation:

Even if the focus is on tropical / monsoon related weather, an understanding of the large scale global circulation is important:

-**The large scale (background) flow provides the environment in which small scale weather disturbances grow**

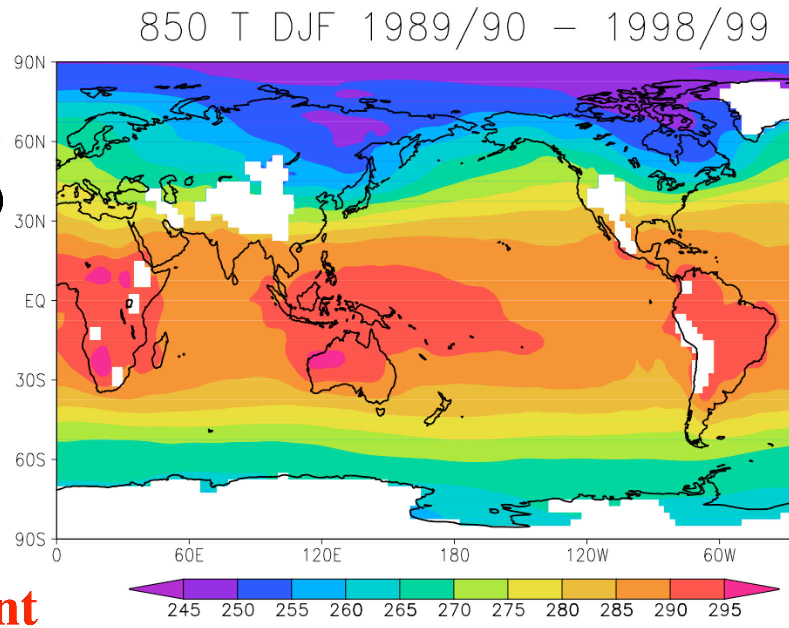
(Indian Monsoon rainfall occurs only during summer.)

- **Mid-latitudes can (and do) affect the tropics!!**

(Cold-air outbreaks trigger tropical Pacific convection.)

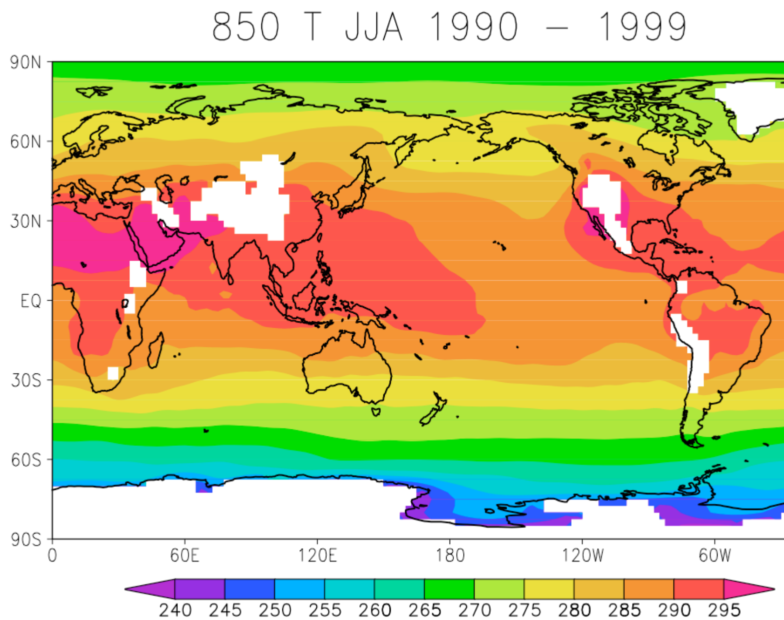
(Mid-latitude baroclinic disturbances feed tropical storms.)

Seasonal Mean Temperature at 850 hPa (just above the boundary layer) from NCEP Reanalysis



DJF

Meridional Temperature Gradient

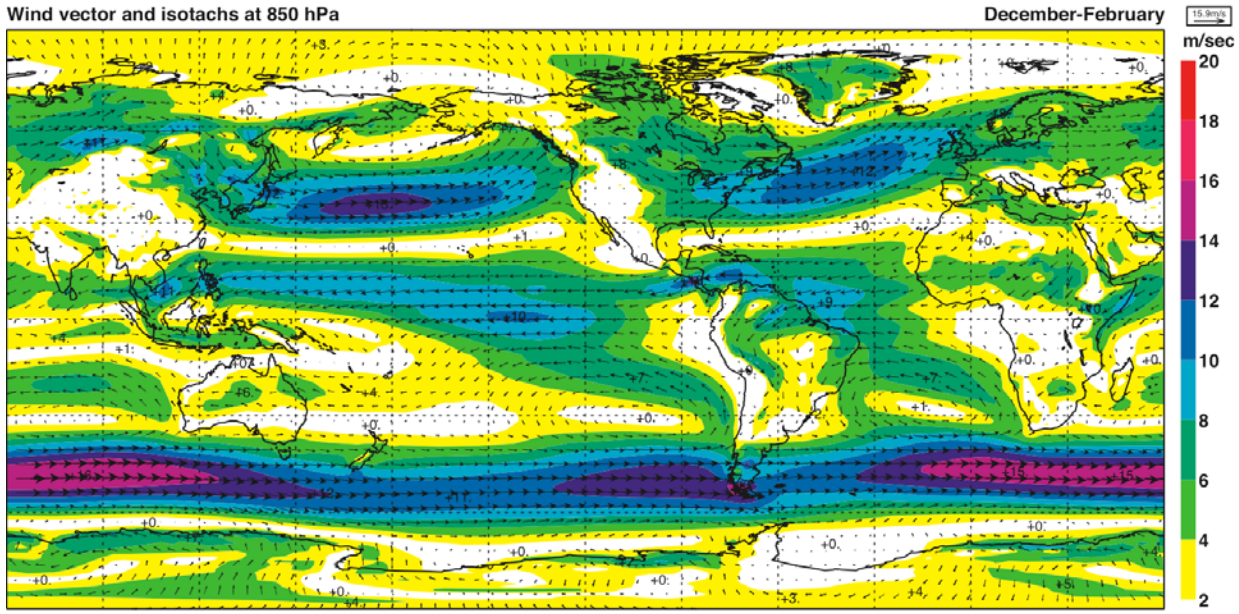


JJA

Although regional T depends on season (e.g. India), the main variation is with latitude.

T decreases towards poles strongly in both seasons

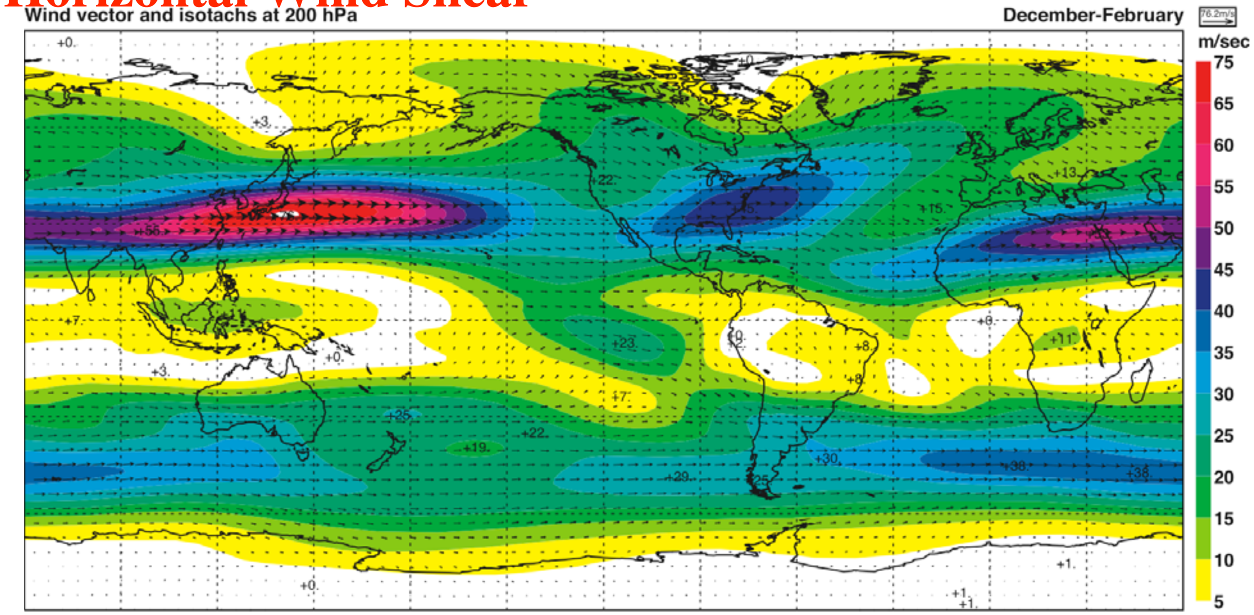
ECMWF
Reanalysis
Horizontal
Winds (u,v)



DJF 850 hPa

Horizontal shear (∂u/∂y) in both NH and SH

Vertical and Horizontal Wind Shear



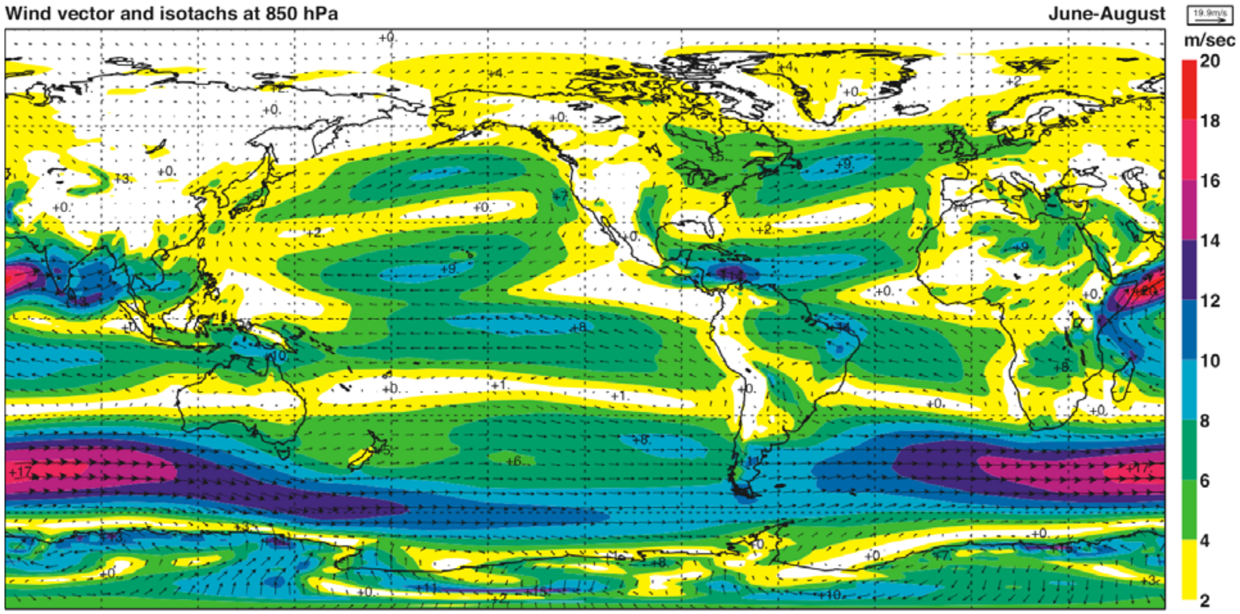
Note stronger vertical shear (∂u/∂z) in the North. Hemis.

DJF 200 hPa

∂u/∂z leads to Baroclinic Instability

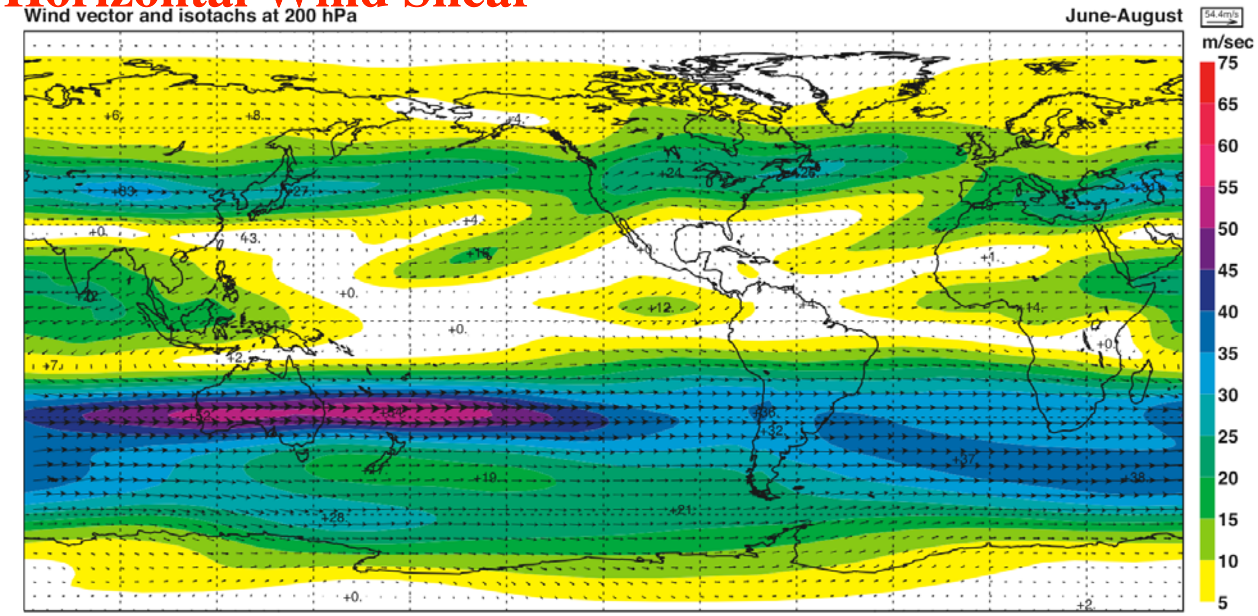
∂u/∂y leads to Barotropic Instability

ECMWF Reanalysis Horizontal Winds (u,v)



JJA 850 hPa

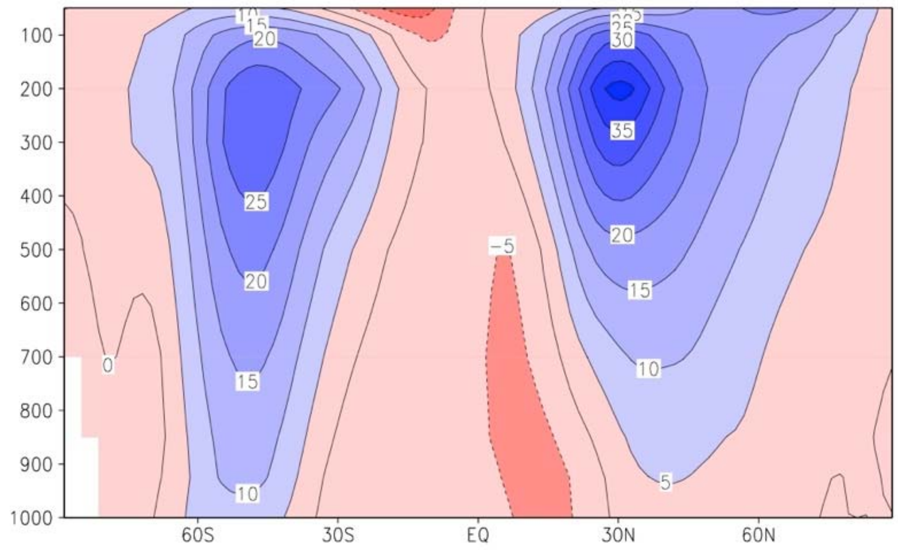
Vertical and Horizontal Wind Shear



JJA 200 hPa

Note stronger NH seasonal dependence

DJF Zonal Mean = average over all longitudes. Shows average vertical and horizontal shear:

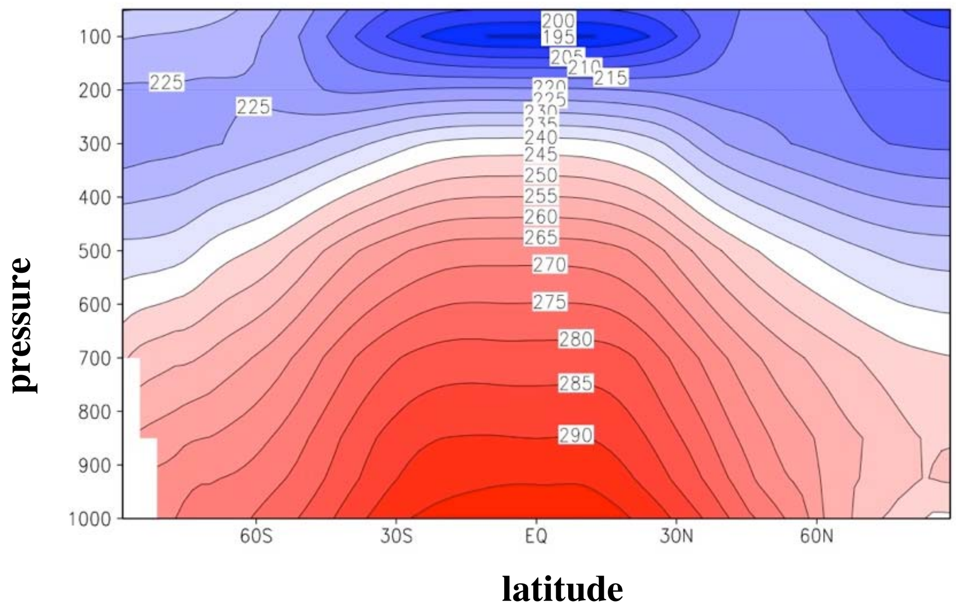


[u]

Thermal Wind Relation: Vertical wind shear ~ Horizontal Temperature Gradient

[∂u/∂z] leads to Baroclinic Instability

[∂u/∂y] would lead to Barotropic Instability



[T]

The thermal wind relationship between the zonal wind u and the meridional temperature gradient of temperature T can be written as:

$$\frac{\partial u}{\partial Z} = -\frac{R}{f H}\frac{\partial T}{\partial y} \tag{1}$$

where we have used the vertical coordinate Z based on pressure:

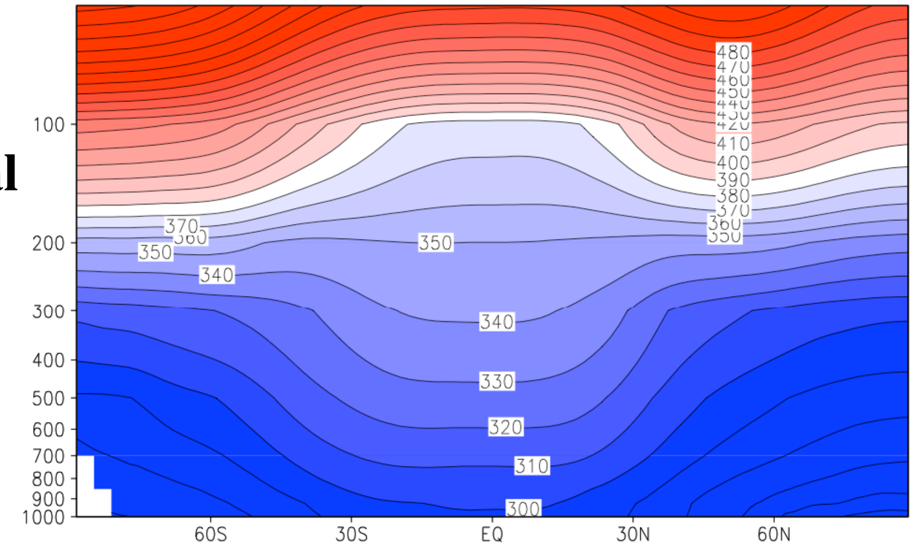
$$Z = H \ln\left(\frac{p_0}{p}\right) \tag{2}$$

Here H is a constant scale height, taken to be 10 km, p_0 is a constant pressure, taken to be 1000 hPa, $f = 2\Omega \sin(\phi)$ is the Coriolis parameter dependent on latitude ϕ, and $y = a\,\phi$ where a is the earth's radius.

Time and Zonal Mean of Potential Temperature Θ

$s = C_p \log(\Theta)$

$ds/dZ > 0$ (static stability)

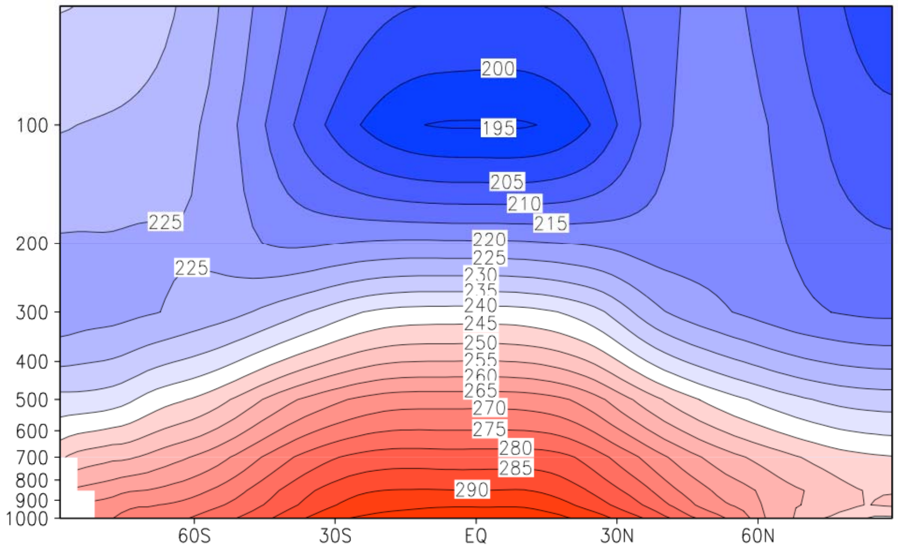


Adiabatic Flow is along surfaces of constant Θ

x-axis: Latitude
y-axis: $Z = H \log(p_0/p)$

Time and Zonal Mean of Temperature T

Note reversal of gradient of T in stratosphere

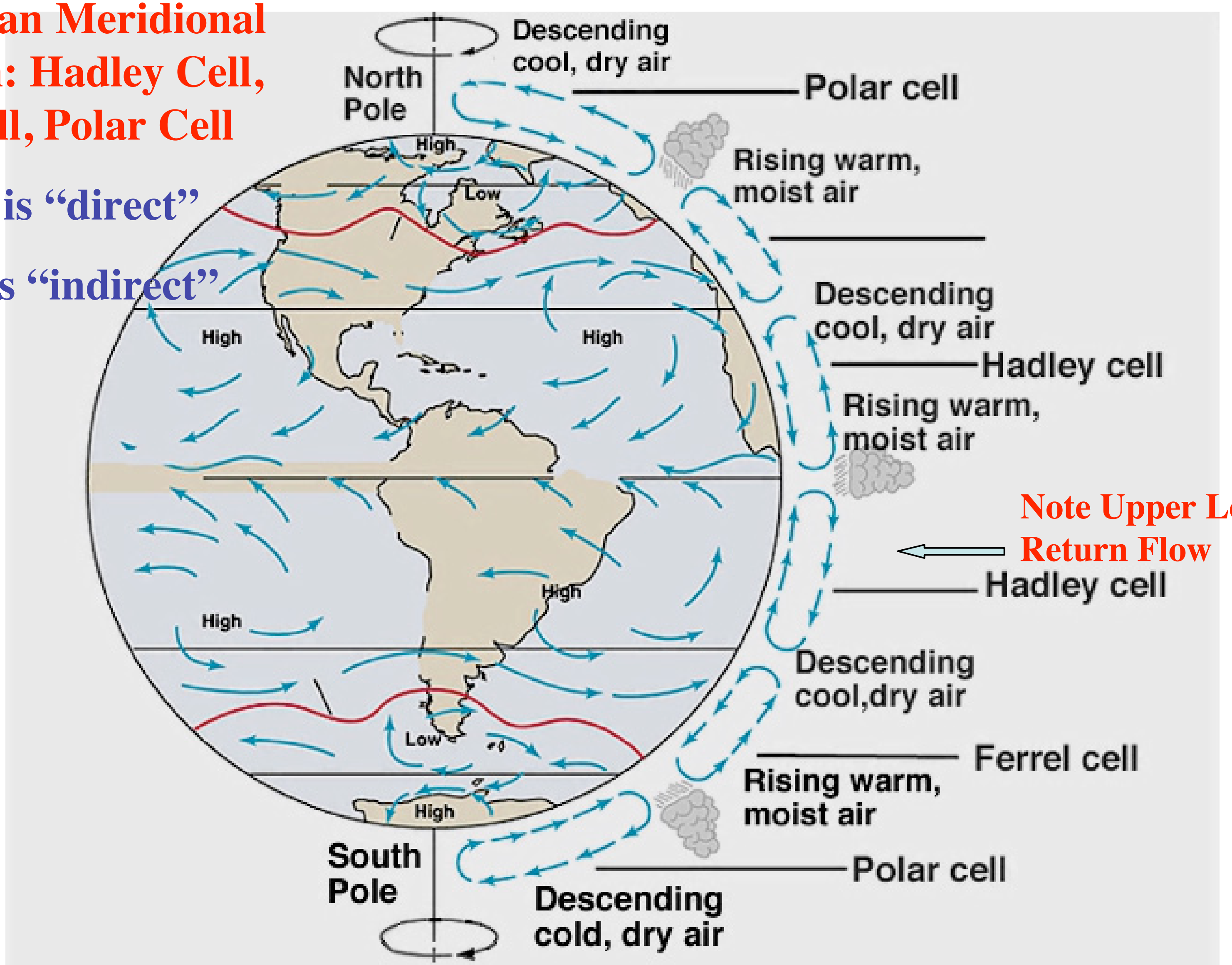


http://ess.geology.ufl.edu/ess/Notes/AtmosphericCirculation/atmoscell_big.jpeg

Annual Mean Meridional Circulation: Hadley Cell, Ferrel Cell, Polar Cell

Hadley cell is "direct"

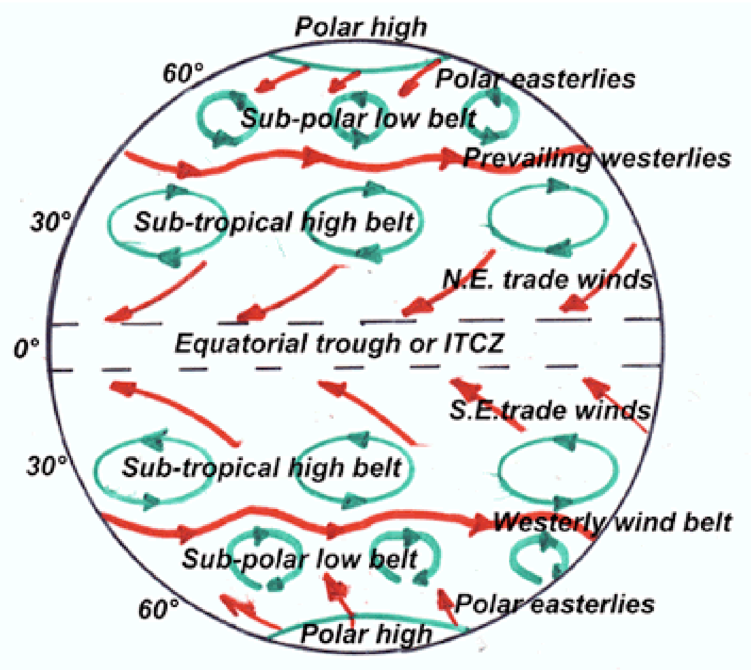
Ferrel cell is "indirect"



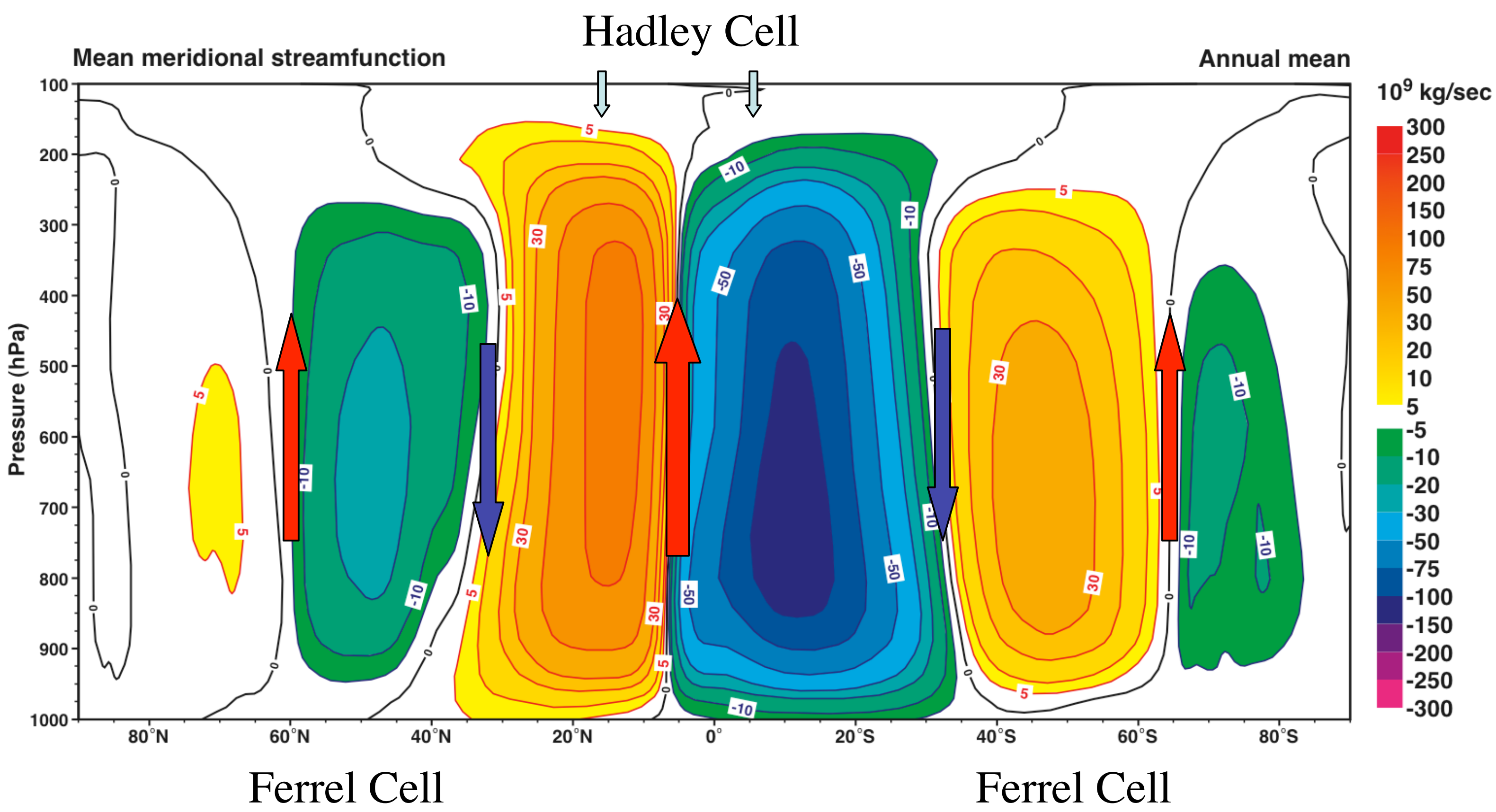
Note Upper Level Return Flow

http://www.pilotfriend.com/training/flight_training/met/images/26.gif

Idealized Schematic Diagram of Surface Circulation



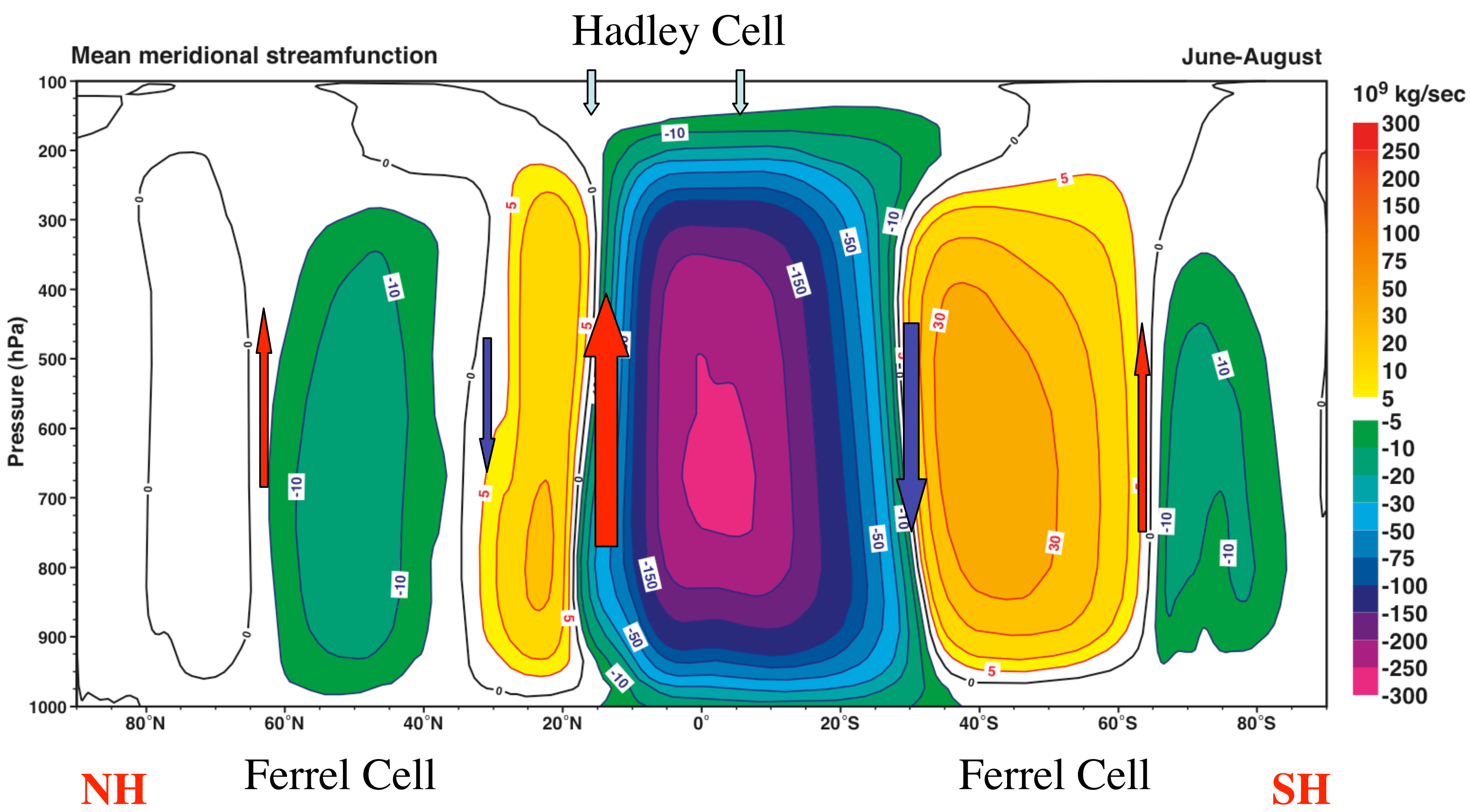
Annual Mean Hadley and Ferrel Cells



Closed Mass Circulations Defined ONLY by Taking Zonal Average !!!

http://www.ecmwf.int/research/era/ERA-40_Atlas/docs

NH Summer JJA Hadley and Ferrel Cells



Upper Level Return Flow mostly to Winter (Southern) Hemisphere

http://www.ecmwf.int/research/era/ERA-40_Atlas/docs

Transient Disturbances

Wide Range of Space and Time Scales of Atmospheric Motions

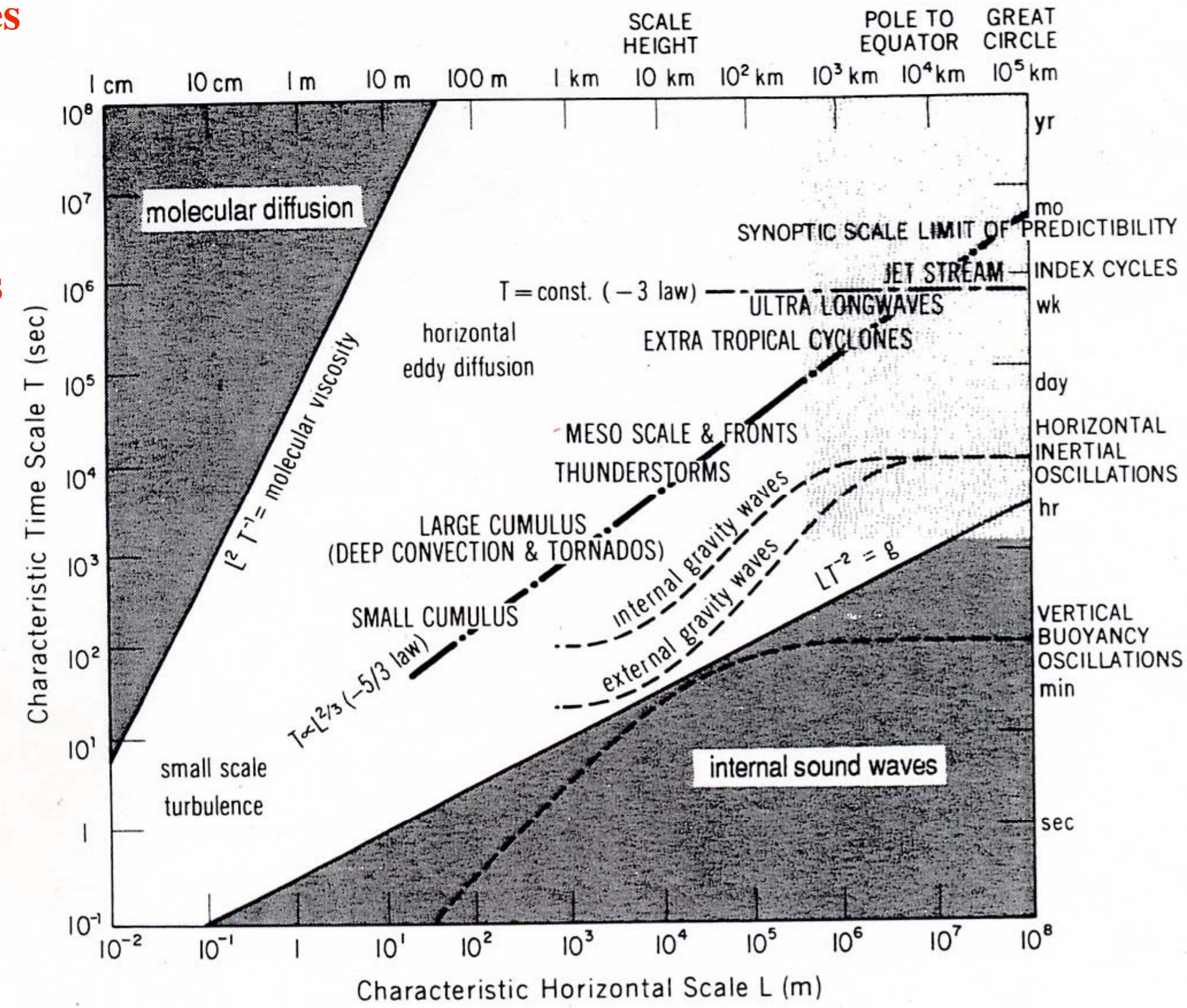


Fig. 6.2 Diagram showing the space and time scales of phenomena in the atmosphere. Light shading represents approximately scales that can be resolved in climate models. [From Smagorinsky (1974).]

Mid-Latitude Cyclone

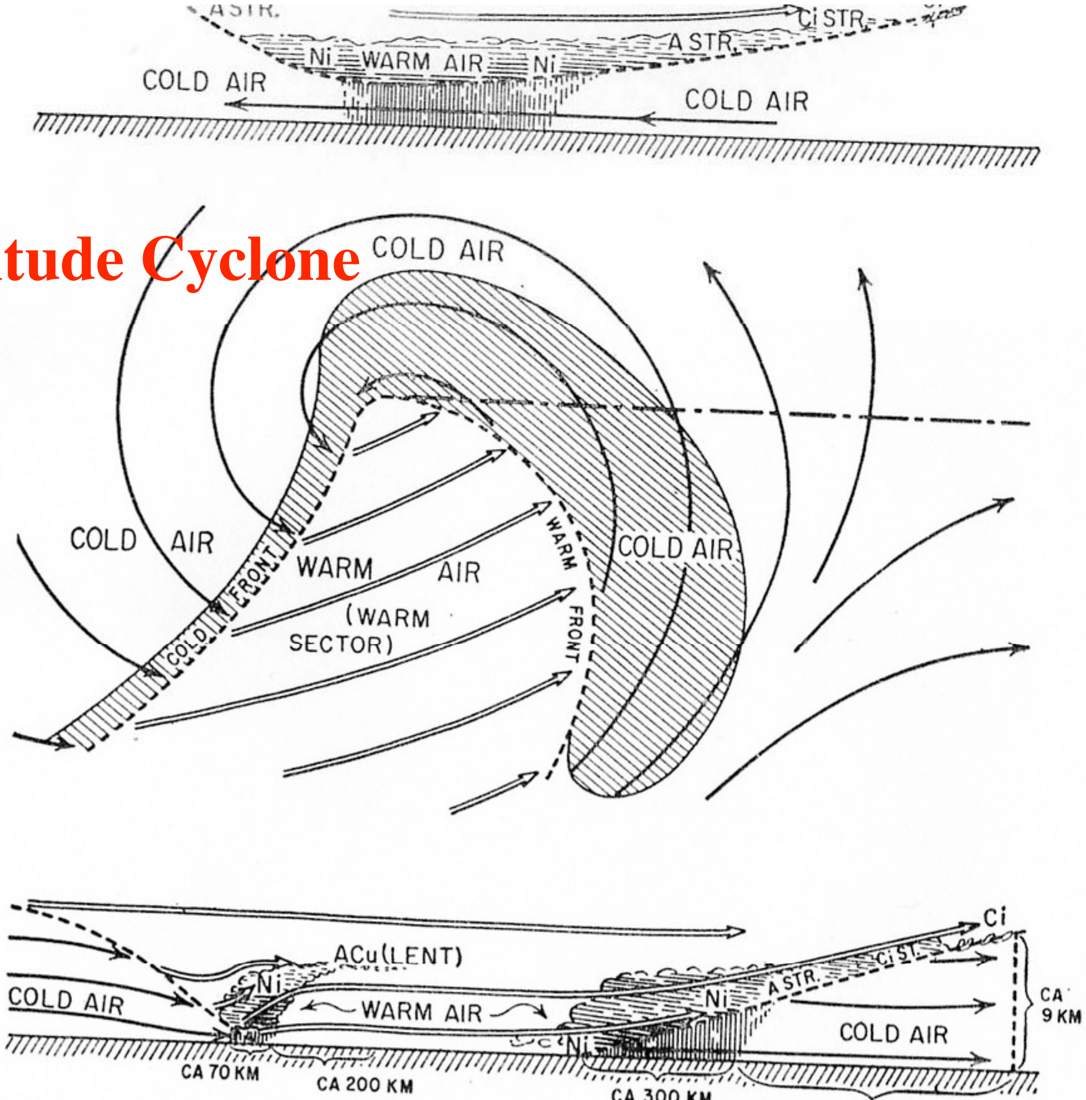
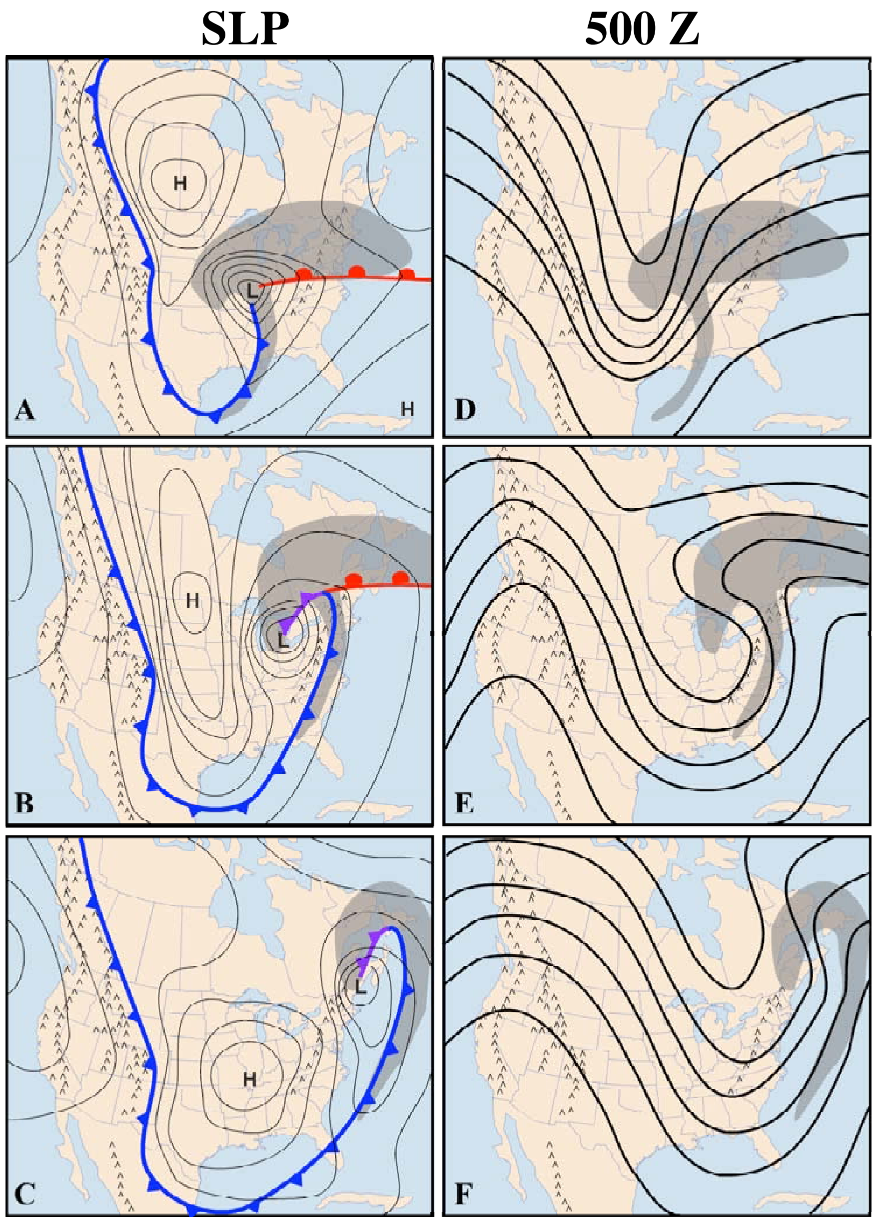


FIG. 12.1.4. Bjerknes' cyclone model. For convenience, this diagram has been reproduced from Bjerknes and Solberg (1921); it contains slight modifications as compared with the original model of J. Bjerknes, 1918.

Cold Fronts **Warm Fronts**

- Strong cyclones over the North Pacific & the central or eastern US can indirectly enhances the polar outbreaks by intensifying trough & ridge regions.
- Rocky mountains also favors intensification of trough & ridge
- Progression occurs over a period of 2-3 days.
- During this time eastern North America cools while western part warms.



Mid-Latitude Cyclones / Anti-cyclones and the Ferrel Cell

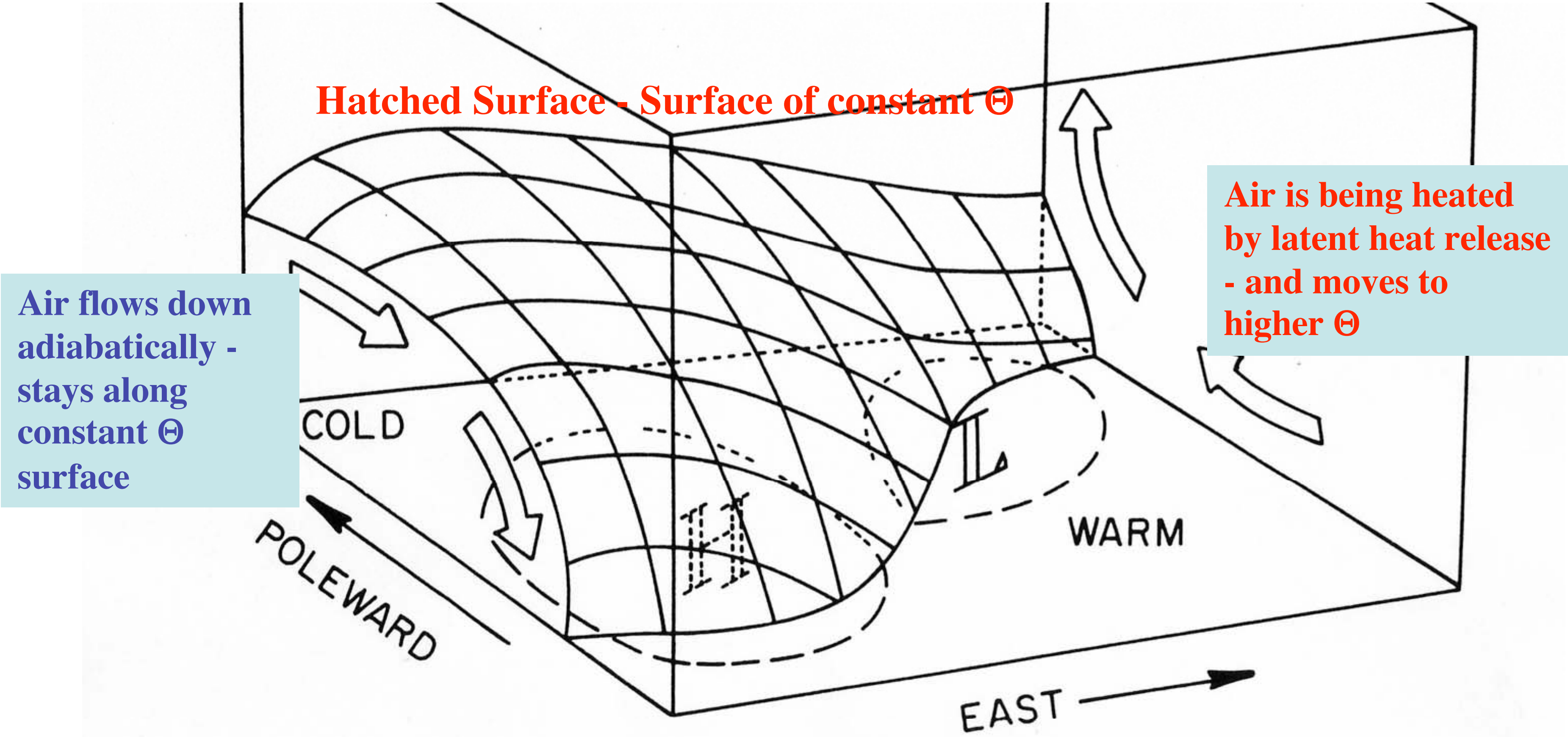


FIG. 3.18 Schematic diagram showing a sloping, three-dimensional isentropic surface and its relationship to developing high (H) and low (L) pressure centers. Schematic contours on the box bottom illustrate the surface pressure pattern. The double-shafted arrows show the meridional motion of air parcels in the warm and cold air sectors.

Mid-Latitude Disturbances Affect the Tropical Circulation !!!

AUGUST 1991 LANCE F. BOSART AND JOSEPH A. BARTLO

Tropical Storm Formation in a Baroclinic Environment

LANCE F. BOSART AND JOSEPH A. BARTLO

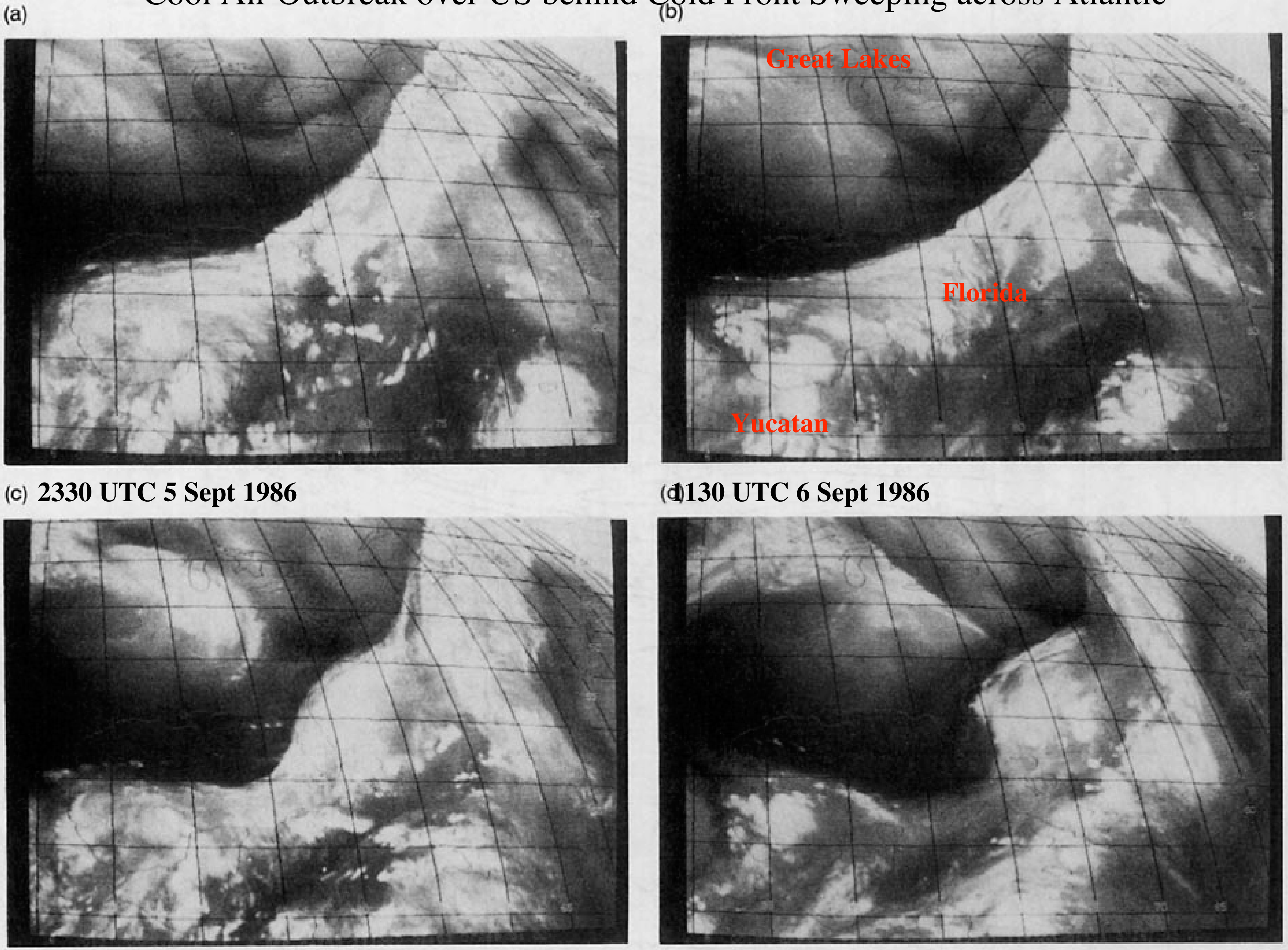
Department of Atmospheric Science, State University of New York at Albany, Albany, New York

(Manuscript received 22 August 1990, in final form 4 March 1991)

ABSTRACT

An analysis is presented of the large-scale conditions associated with the initial development of Tropical Storm Diana (September 1984) in a baroclinic environment. Ordinary extratropical wave cyclogenesis began along an old frontal boundary east of Florida after 0000 UTC 7 September and culminated in tropical cyclogenesis 48 h later. Water-vapor satellite imagery showed that the initial cyclogenesis and incipient tropical storm formation was nearly indistinguishable from a classical midlatitude development.

Cool Air Outbreak over US behind Cold Front Sweeping across Atlantic



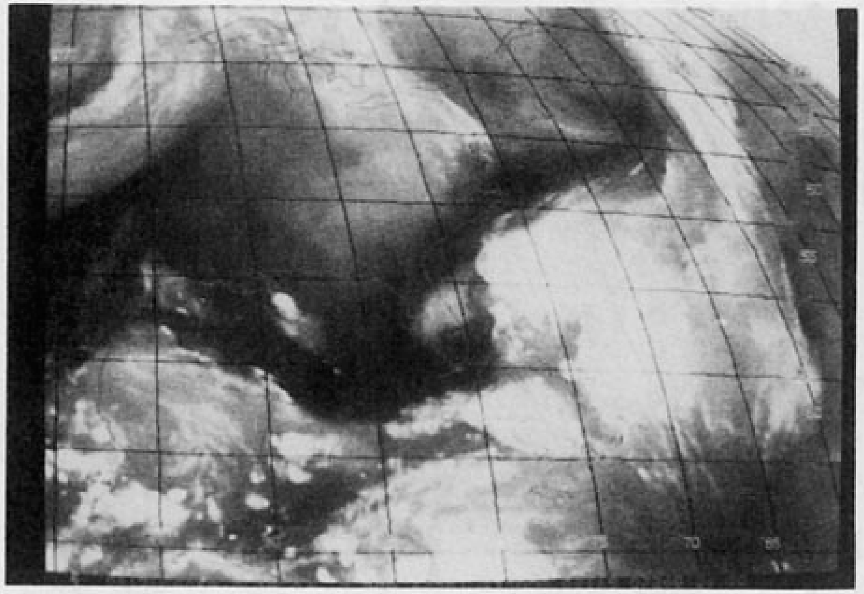
2330 UTC 5 Sept 1986

1130 UTC 6 Sept 1986

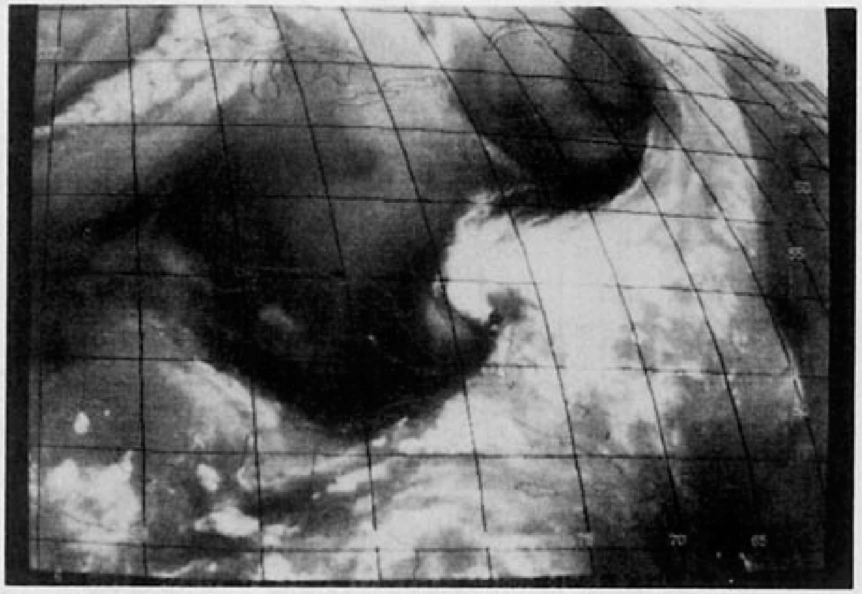
2330 UTC 6 Sept 1986

1130 UTC 7 Sept 1986

(e)

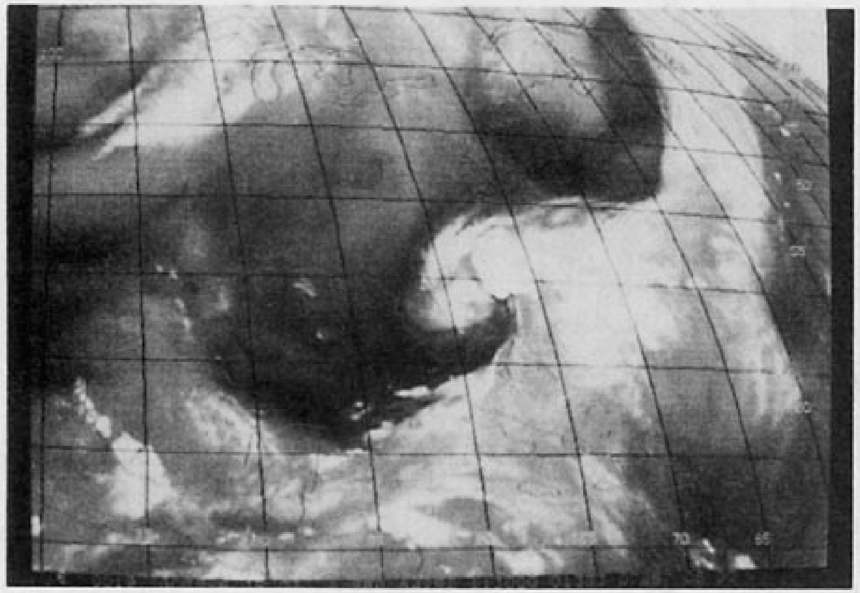


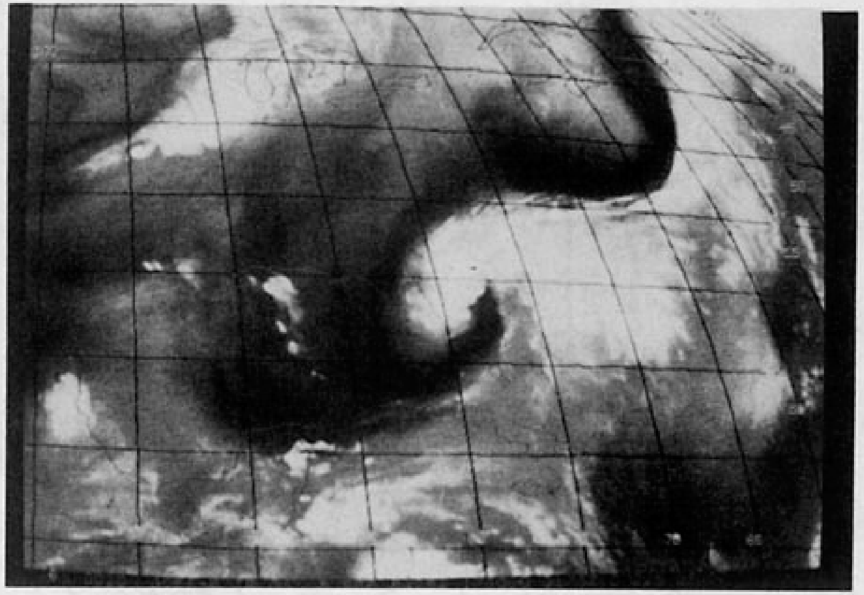
(f)



(g) **2330 UTC 7 Sept 1986**

(h) **530 UTC 8 Sept 1986**



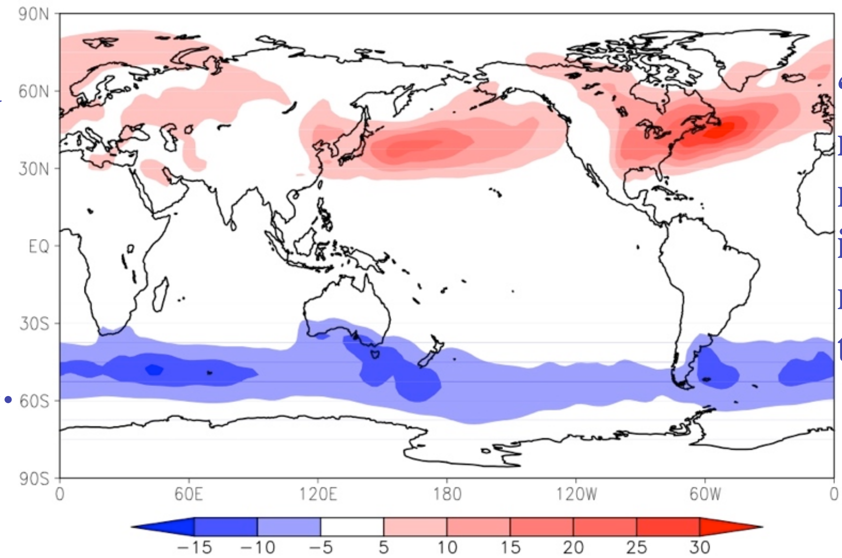


1130 UTC 8 Sept 1986

1730 UTC 8 Sept 1986

Poleward Heat Transport by (Anti) Cyclones

Measured by covariance of meridional velocity v and temperature T filtered to retain time scales of 2-8 days.

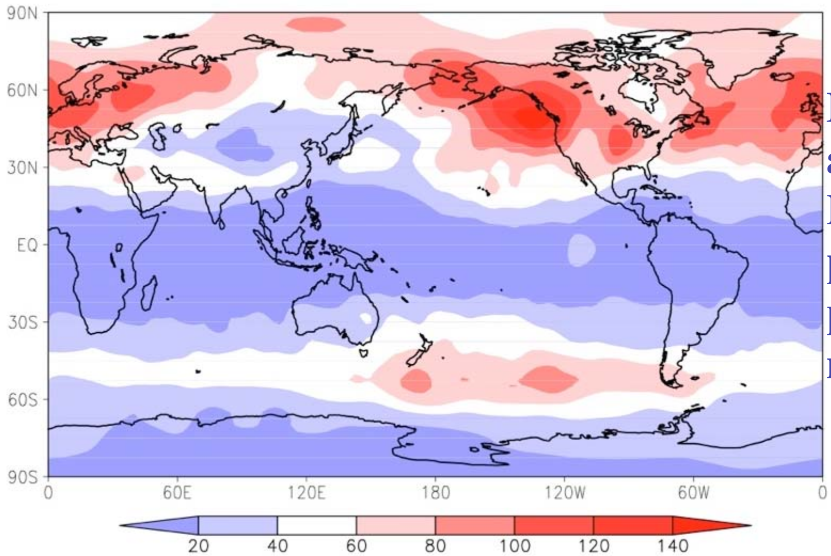


"Storm Tracks" aligned with maximum vertical shear - related to baroclinic instability. Synoptic scale motions attempt to decrease the gradient of Temperature

Transient Fluctuations and the General Circulation

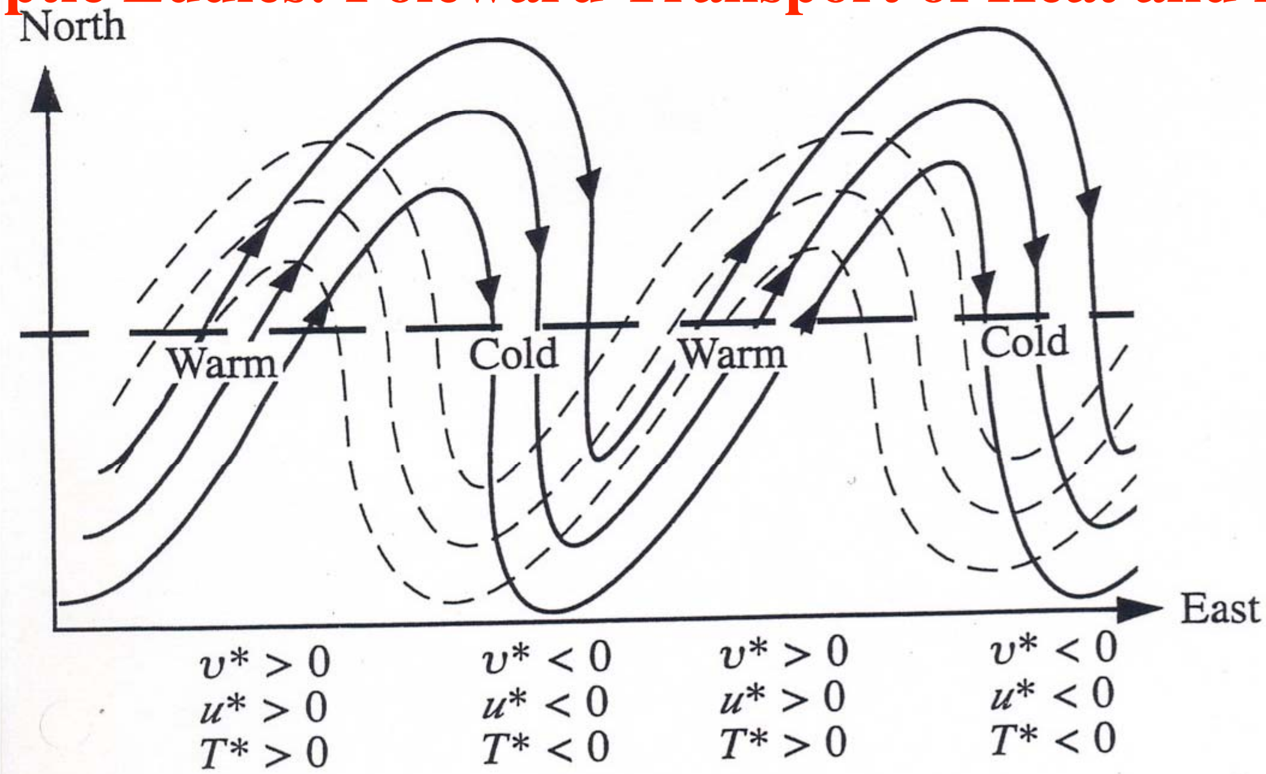
Variability on longer Intra-Seasonal time scales

Measured by variance of meridional velocity v and filtered to retain time scales of 10 - 90 days.



Maxima in variance associated with "Blocking Highs" - long-lived high pressure systems causing persistent weather regimes in the region

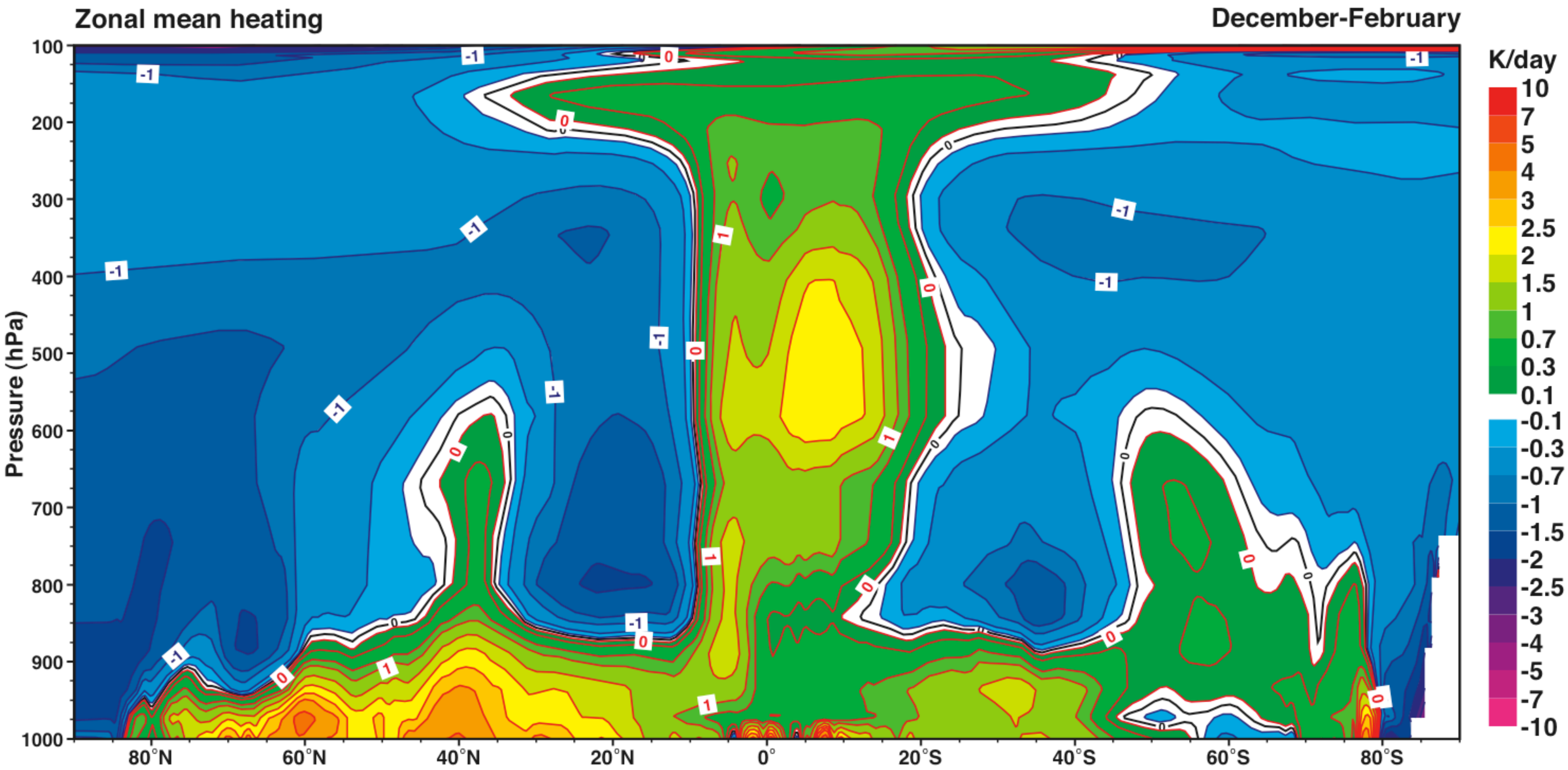
Synoptic Eddies: Poleward Transport of Heat and Momentum



Schematic of the streamlines (solid) and isotherms (dashed) associated with a large-scale .sturbance in midlatitudes of the Northern Hemisphere. Arrows along the streamline con- ıe direction of wind velocity. The streamlines correspond approximately to lines of constant the winds are nearly geostrophic. The signs of the deviations of the wind components from ·rage values are shown to illustrate that the NE–SW tilt of the streamlines indicates a north- ›mentum transport, and the westward phase shift of the temperature wave relative to the gives a northward heat transport.

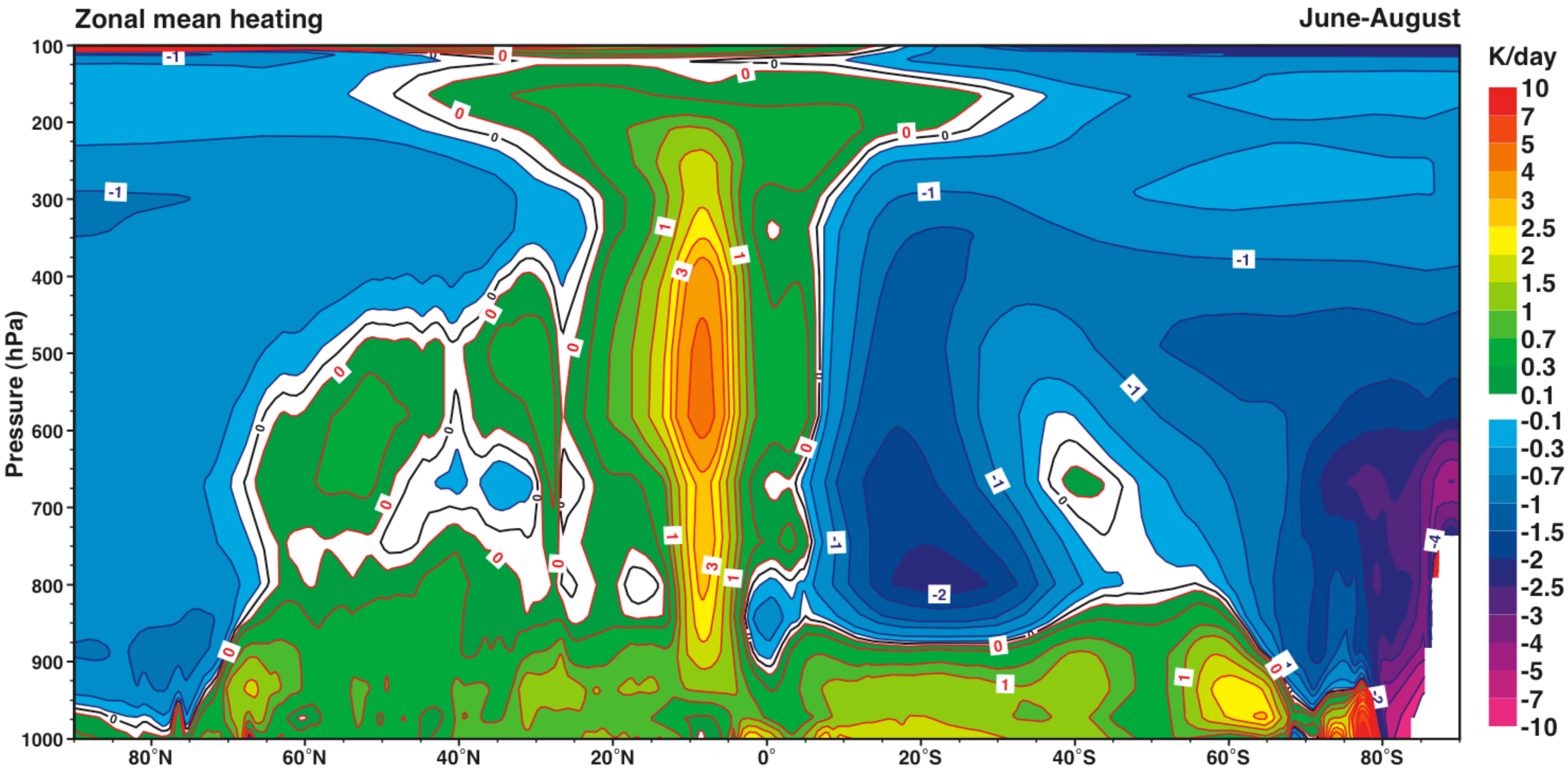
DJF Diabatic Heating

Due to Radiation, Latent Heat Release, Heating from Boundary, and Turbulence. We can ONLY get this from an Atmospheric General Circulation Model (AGM)



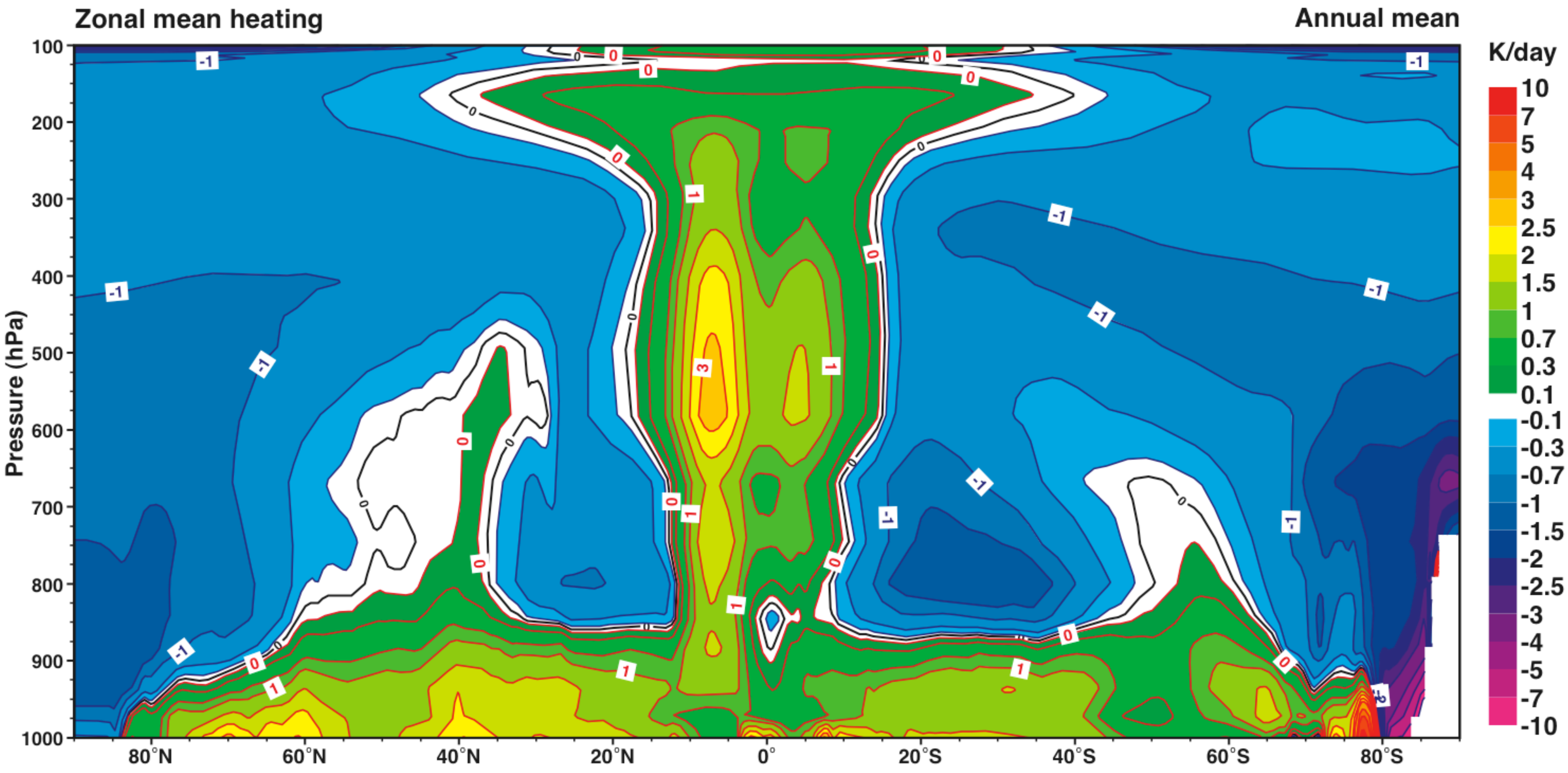
How is diabatic heating estimated from reanalyses?

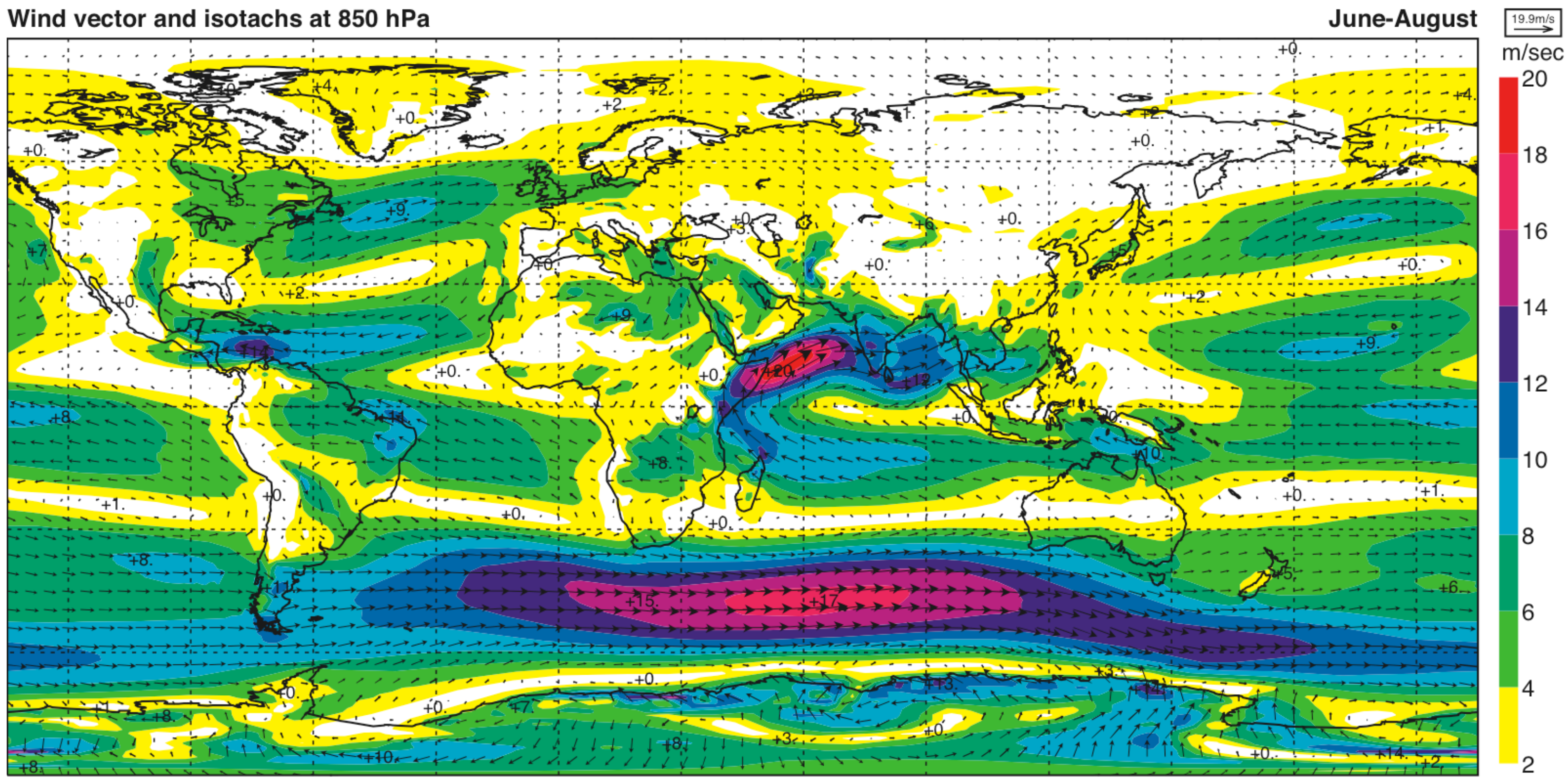
JJA Diabatic Heating



Large Northward Shift in Heating from DJF to JJA partially due to Indian Monsoon

Annual Mean Diabatic Heating




Wind vector and isotachs at 850 hPa
June-August
19.9m/s
m/sec
20
18
16
14
12
10
8
6
4
2

Indian Summer Monsoon: July-Sept Circulation from ERA-40