12.810 Dynamics of the Atmosphere

Course description: Discusses the dynamics of the atmosphere, with emphasis on the large scale.

Instructor:
Paul O'Gorman
Email: pog@mit.edu
Office: 54-1712

Questions: Drop by, email, and office hour (Wednesday?)

Logistics

Course Webpage
http://www.mit.edu/~pog/810.html

Class times
Tuesday and Thursday 10:30-12

Classroom
54-1623

Prerequisite
Fluid dynamics of the atmosphere & ocean (12.800)
or instructors permission

Assessment: Problem sets and Project

Grading:

1. Problem sets (4 in total, 60%)
2. Project:
   - writeup ($\leq$12 pages+references, 20%)
   - class presentations (~15 mins, 20%)

Problem Sets Policy:

Collaboration is allowed, but students must write up the problem set on their own.

Project topics:

Project topics should be decided at midterm. I will give out topics, or you can come up with a topic yourself in consultation with me.

Schedule (will send out google calendar)

Projects:

Project presentations will be in class in the last one or two weeks of semester

Project reports are due on the last day of class (May 12th)

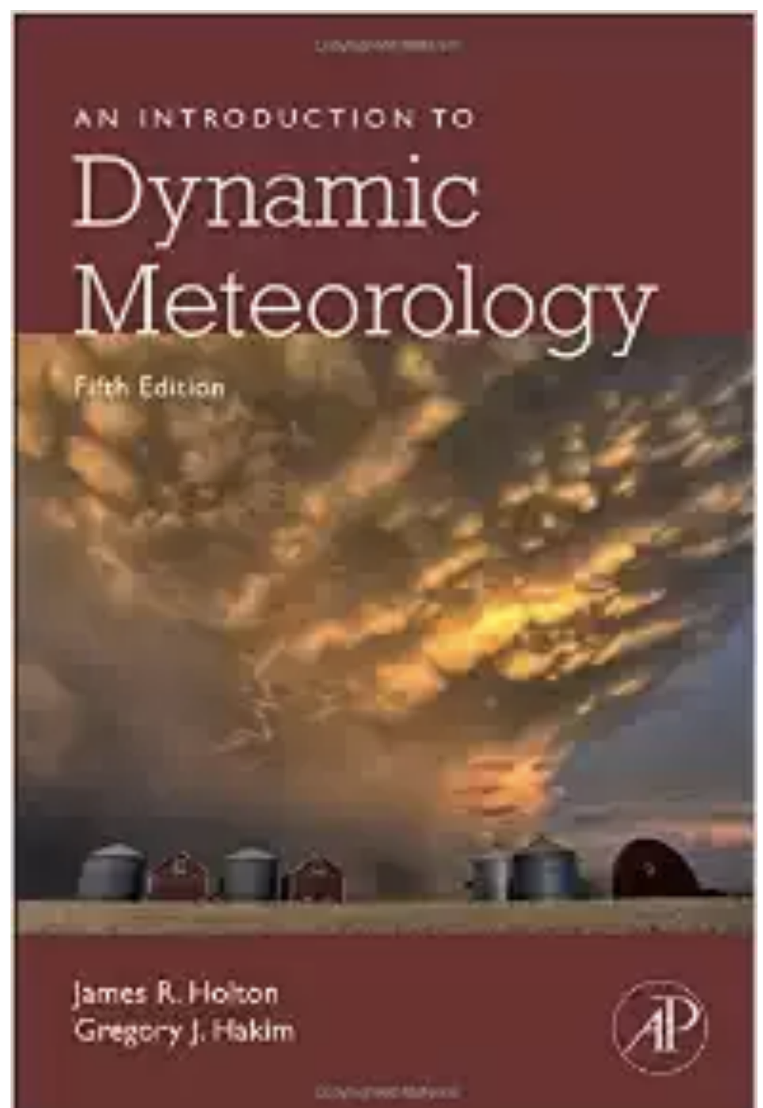
Problem sets:

Problem set 1 (out Mar 3rd; due Mar 17th)
Problem set 2 (out Mar 17th; due Mar 31st)
Problem set 3 (out Mar 31st; due Apr 14th)
Problem set 4 (out Apr 14th; due May 5th) (longer problem set)

Textbooks and other resources

Primary Textbook

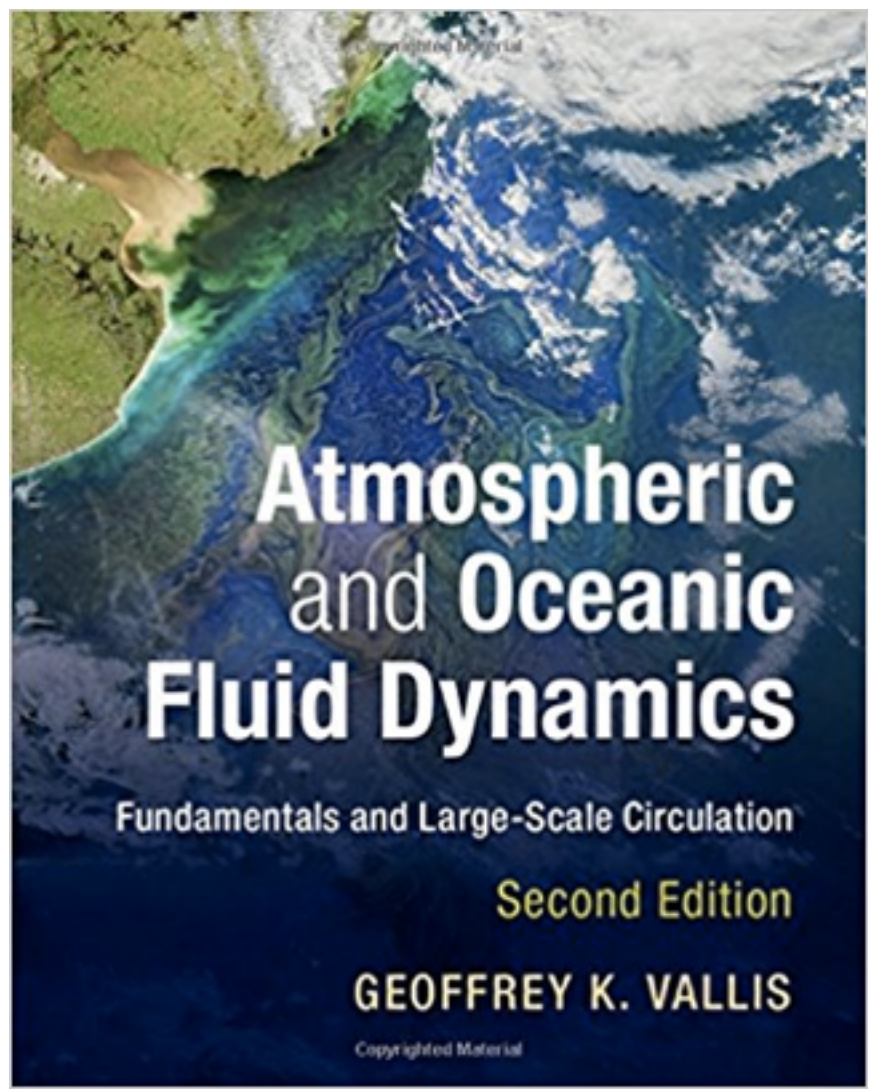
An Introduction to Dynamic Meteorology, Holton and Hakim (5th edition)



Textbooks and other resources

Secondary Textbook

Atmospheric and Oceanic Fluid Dynamics, Vallis (2nd edition)



Textbooks and other resources

Other references:

Physics of Climate, Peixoto and Oort

Interactive plotting website:
http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl

Gridded datasets: www.cdc.noaa.gov/data/gridded/

Course topics

1. **Hadley-cell dynamics** for a zonally symmetric atmosphere (the role of eddies is discussed later in the course)
2. **Internal gravity waves:** propagation, effect on mean flow, forcing by mountains
3. **Potential vorticity, quasigeostrophic dynamics, and Rossby waves** includes omega equation for vertical motion
4. **Growth of disturbances**: wave activity and E-P fluxes, Charney-Stern condition, Eady model, non-modal growth
5. **Energetics:** concept of available potential energy
6. **The general circulation**: the role of eddies, transformed Eulerian mean, downward control

Plan for the remainder of this introduction

- Sources of observations
- Basic aspects of observed circulations and thermal structure
- Some motivating questions

Sources of observations

Observational data for studies of large-scale atmospheric dynamics

- Data sparseness in space and time is a major issue

- Often combine the data with an atmospheric general circulation model (GCM) using data assimilation (includes analysis and initialization)

- Goal is minimization of discrepancy between observations and model variables (e.g., 3D or 4D var)

We will often refer to reanalysis products

- Reanalysis (e.g., NCEP, NCEP2, ERA40, ERA interim, ERA5, MERRA, NCEP CFSR, 20CR) means that GCM is held fixed over long time period, but observational inputs vary

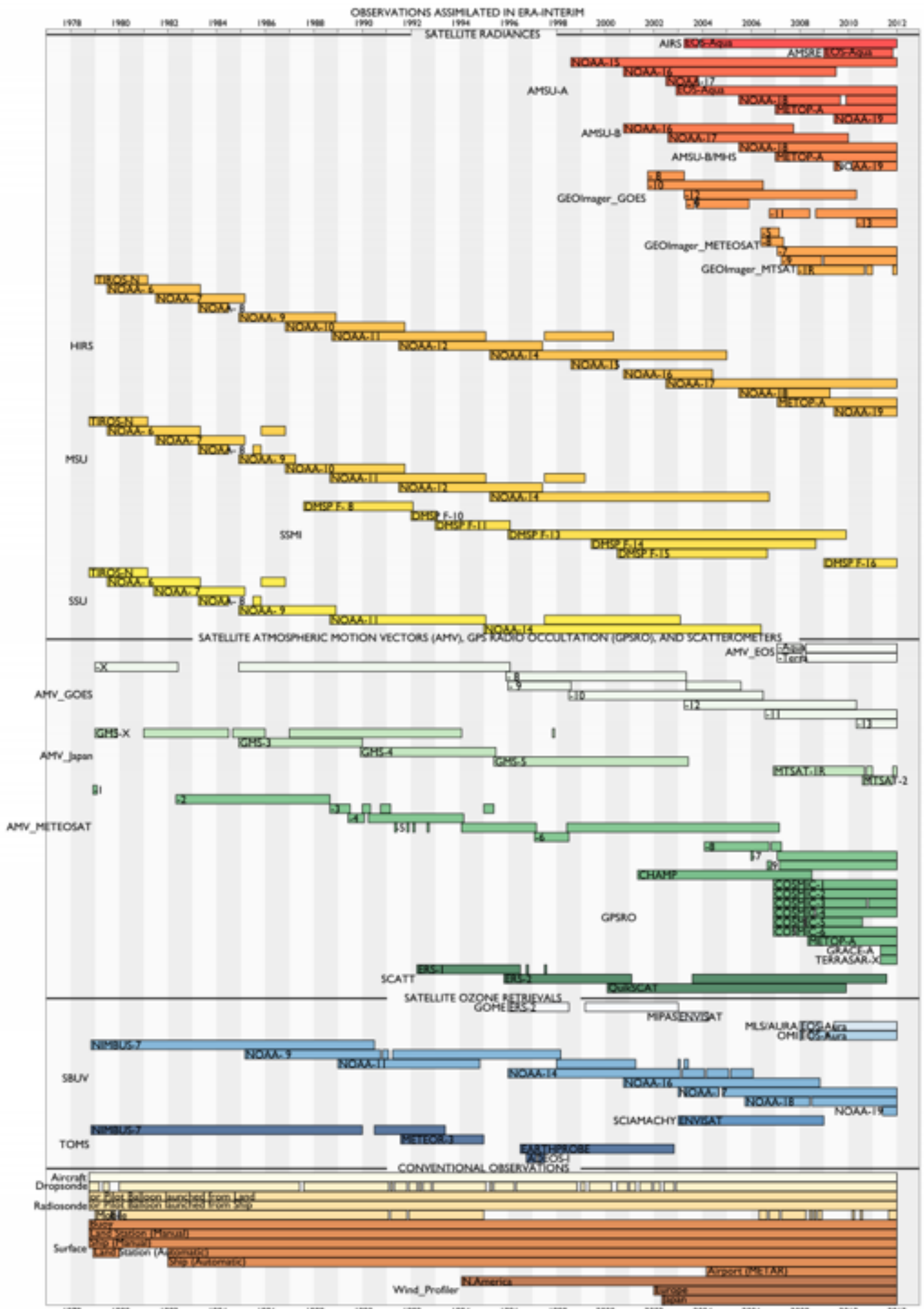
- Very popular!

[HTML] The **ERA-Interim** reanalysis: Configuration and performance of the data assimilation system

DP **Dee**, SM Uppala, AJ Simmons… - Quarterly Journal of …, 2011 - Wiley Online Library

Abstract ERA-Interim is the latest global atmospheric reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). The ERA-Interim project was conducted in part to prepare for a new atmospheric reanalysis to replace ERA-40, which will

Cited by 9611 Related articles All 18 versions Import into BibTeX



Timeline of observations assimilated in ERA interim

Climate data guide

Timeline of observations assimilated in ERA40

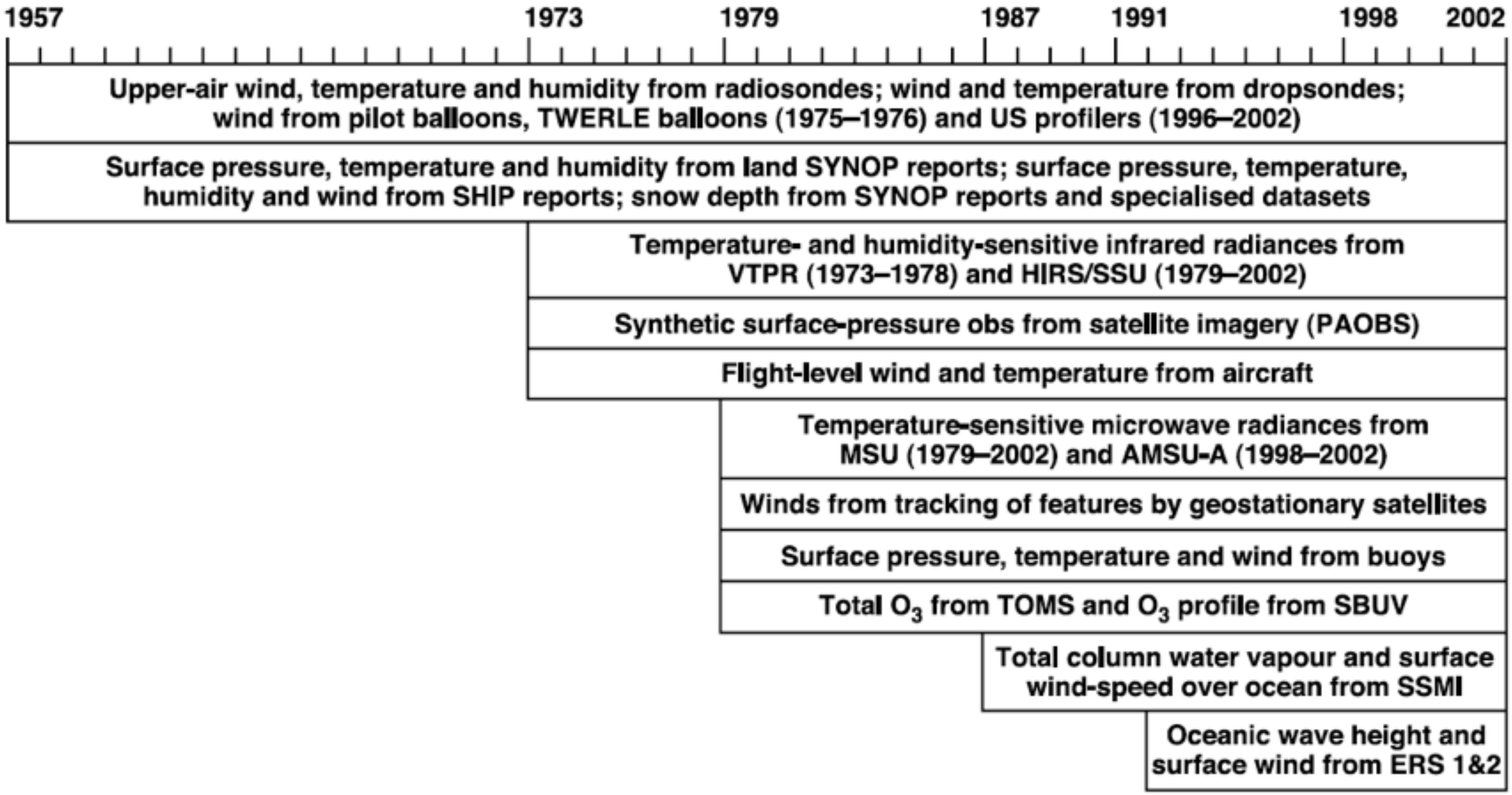


Figure 1. Chronology of types of observations assimilated in ERA-40 from 1957 to 2002. (See appendix A for acronyms.)

Uppala et al, QJRM 2005

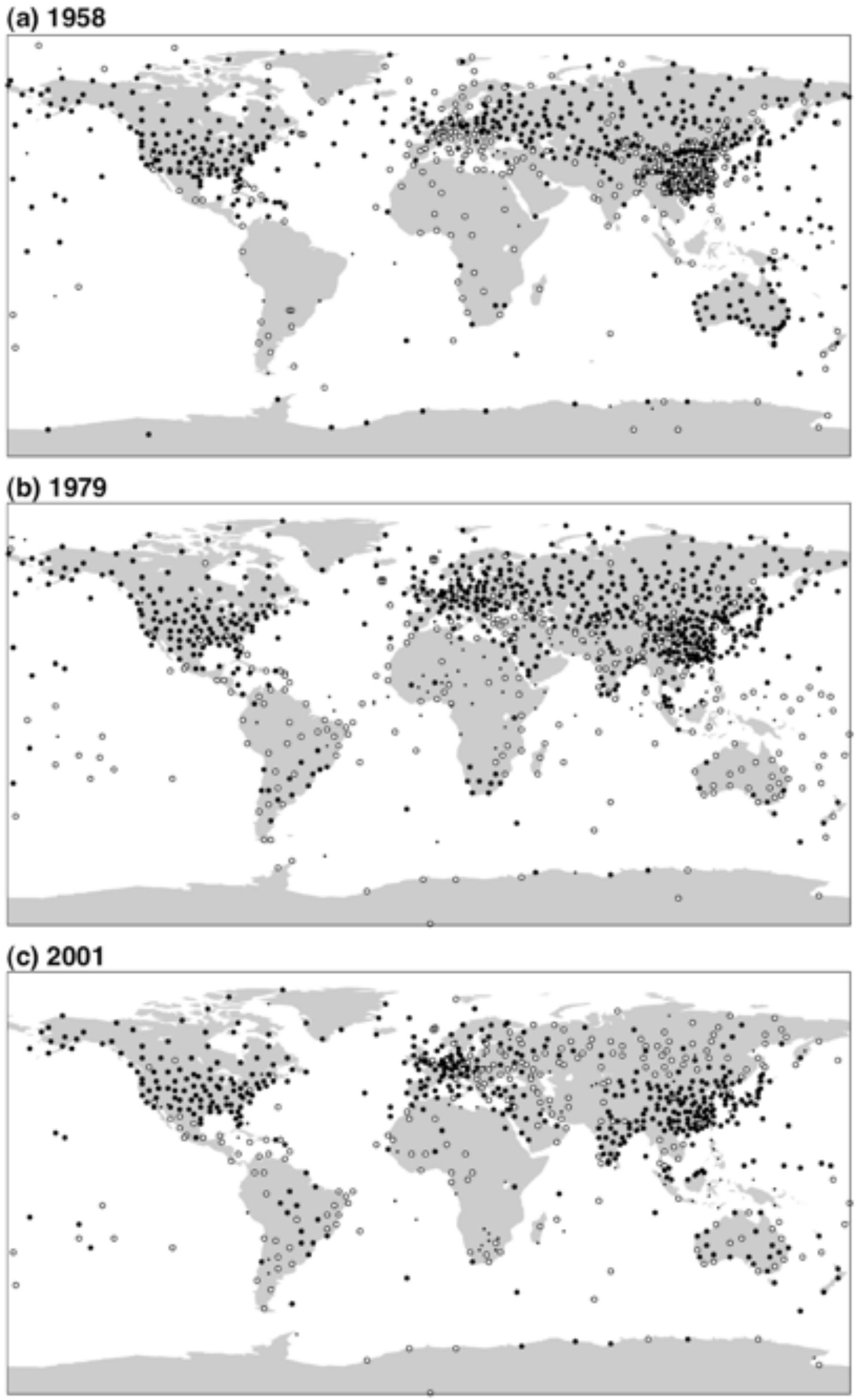


Figure 2. Frequency of radiosonde reports for: (a) 1958, (b) 1979 and (c) 2001. Solid circles denote stations from which at least three reports are available every 2 days on average, open circles denote other stations reporting at least once every 2 days, and small dots represent stations reporting at least once per week.

Frequency of radiosonde reports

Uppala et al, QJRM 2005

TABLE 1. AVERAGE DAILY COUNTS OF VARIOUS TYPES OF OBSERVATION SUPPLIED TO THE ERA-40 DATA ASSIMILATION, FOR FIVE SELECTED PERIODS

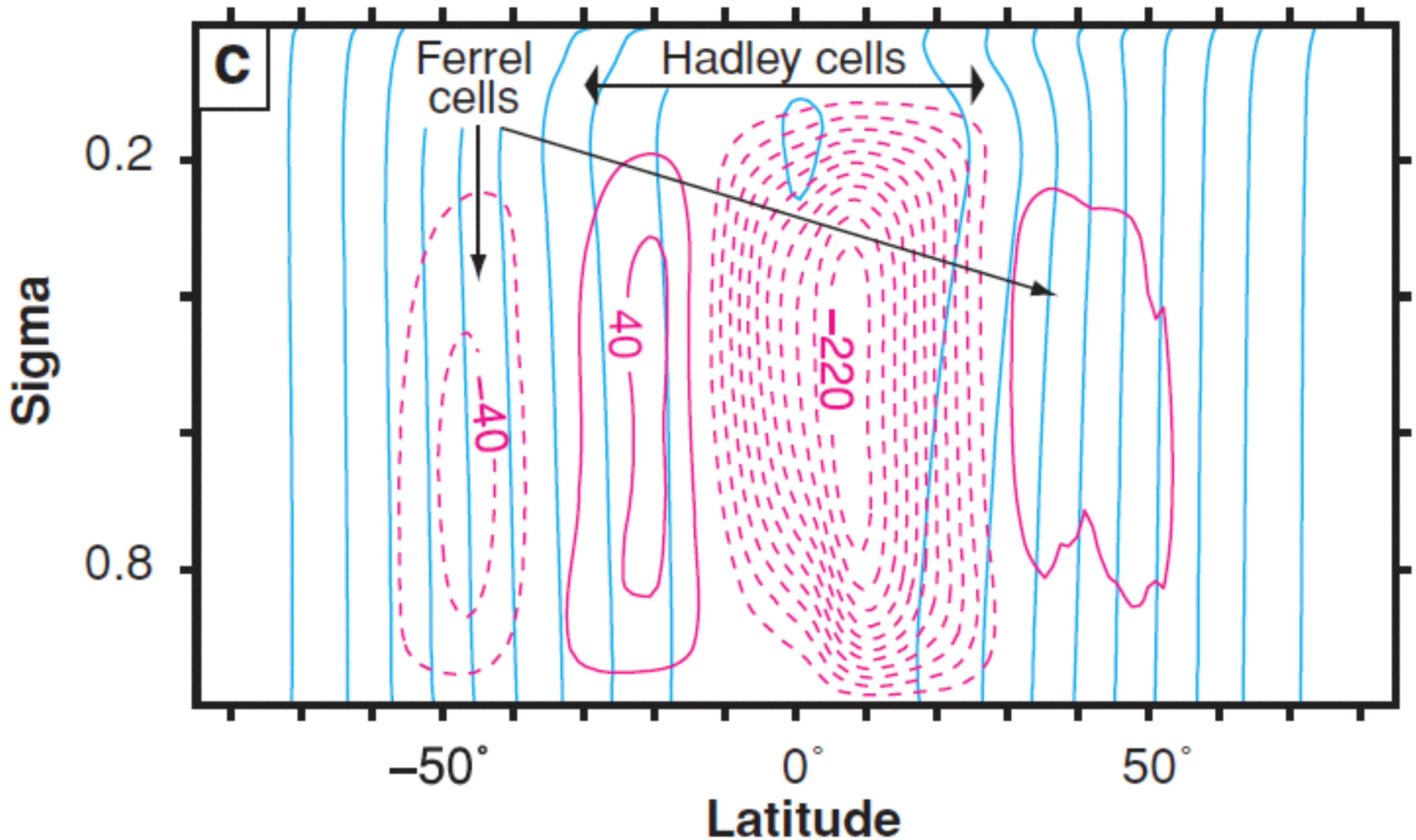
Observation type	1958–66	1967–72	1973–78	1979–90	1991–2001
SYNOP/SHIP	15 313	26 615	28 187	33 902	37 049
Radiosondes	1 821	2 605	3 341	2 274	1 456
Pilot balloons	679	164	1 721	606	676
Aircraft	58	79	1 544	4 085	26 341
Buoys	0	1	69	1 462	3 991
Satellite radiances	0	6	35 069	131 209	181 214
Satellite winds	0	0	61	6 598	45 671
Scatterometer	0	0	0	0	7 575
PAOBs	0	14	1 031	297	277

Uppala et al, QJRM 2005

Basic aspects of observed circulations and thermal structure with some motivating questions

Hadley cells, and subtropical and eddy-driven jets

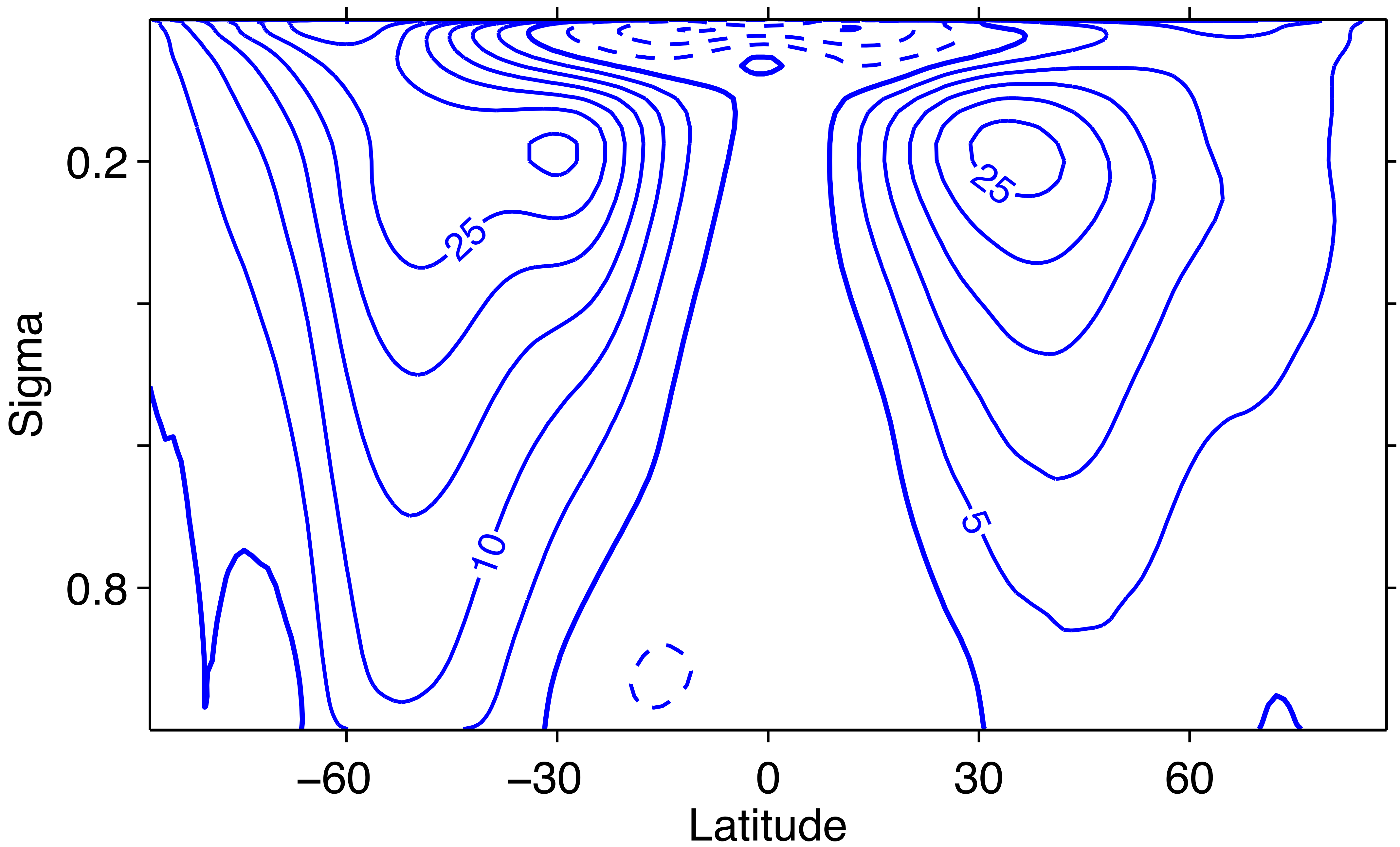
Mean meridional circulation and contours of angular momentum per unit mass (January; ERA40)



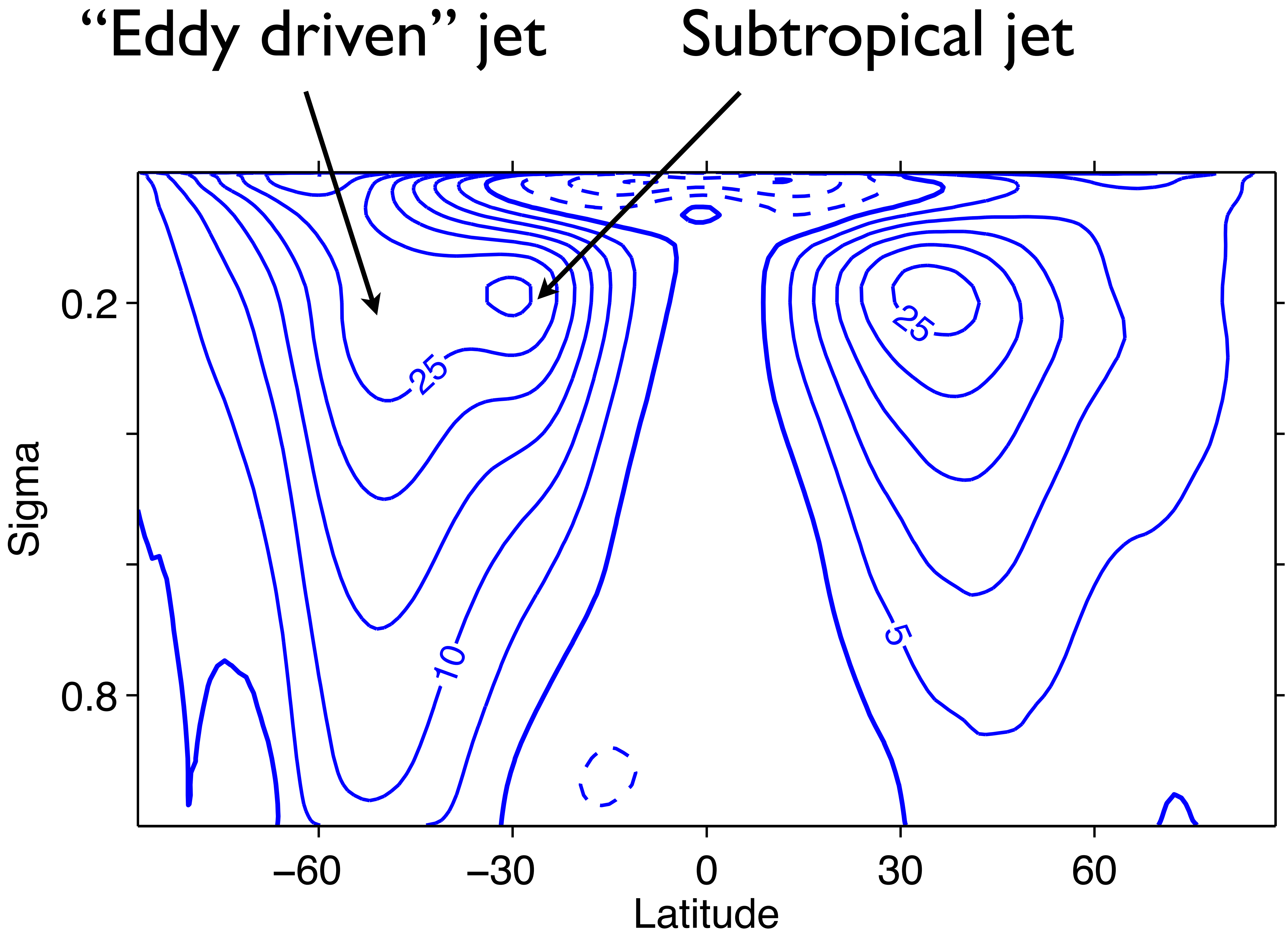
(c) Eulerian mass flux streamfunction (*magenta*) and angular momentum (*light blue*). Contour intervals are 20×10^9 kg s^{-1} for streamfunction and $0.1\Omega a^2$ for angular momentum, with angular momentum decreasing monotonically from the equator to the poles.

(T. Schneider, Fig. 1, Ann. Rev. Earth Planet. Sci. 2006)

Zonal- and time-mean zonal wind (m/s)

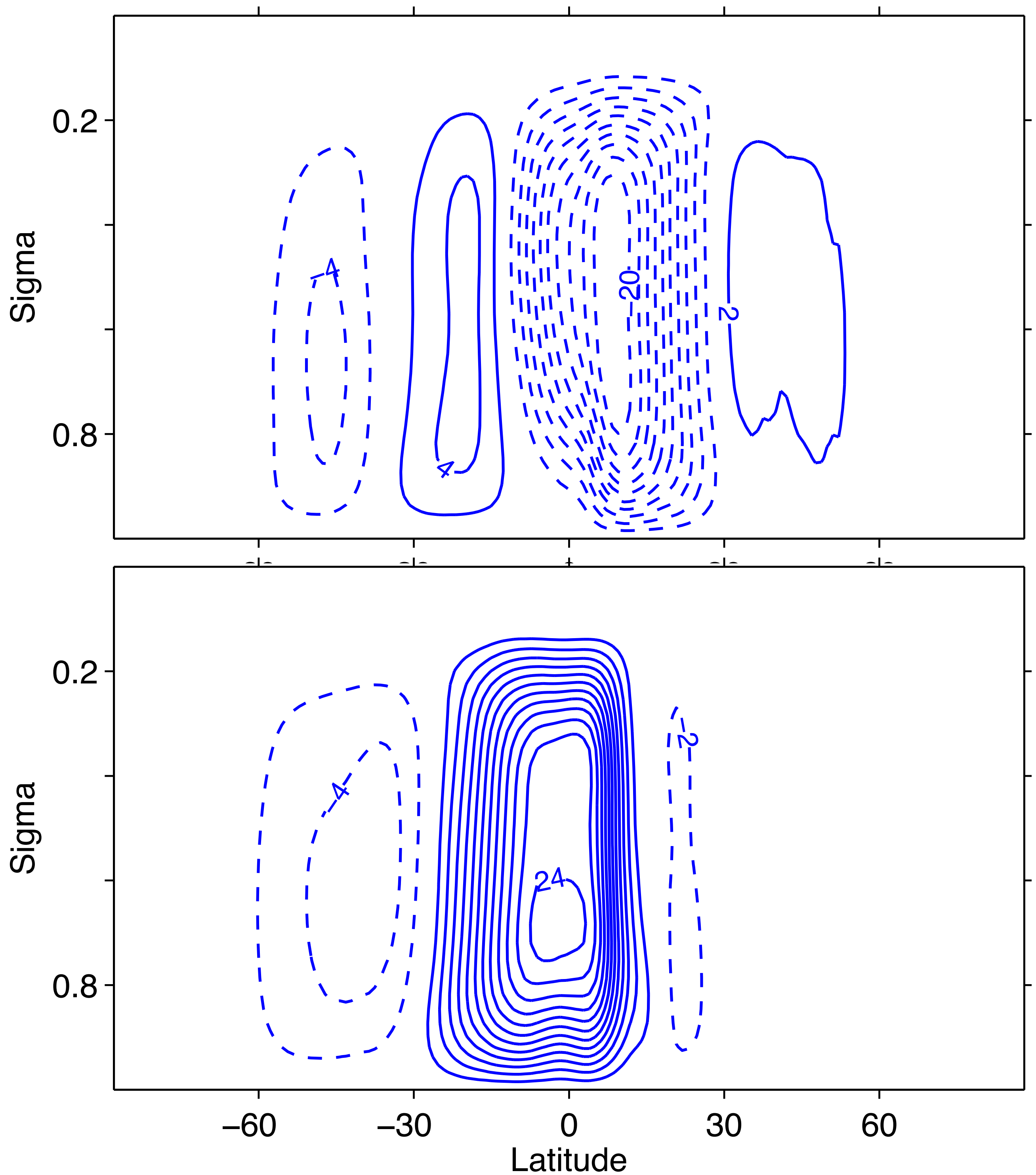


(ERA40 reanalysis 1980-2001)



(ERA40 reanalysis 1980-2001)

Mean meridional streamfunction (10^{10} kg s^{-1}): different seasons



December-January-February
(DJF)

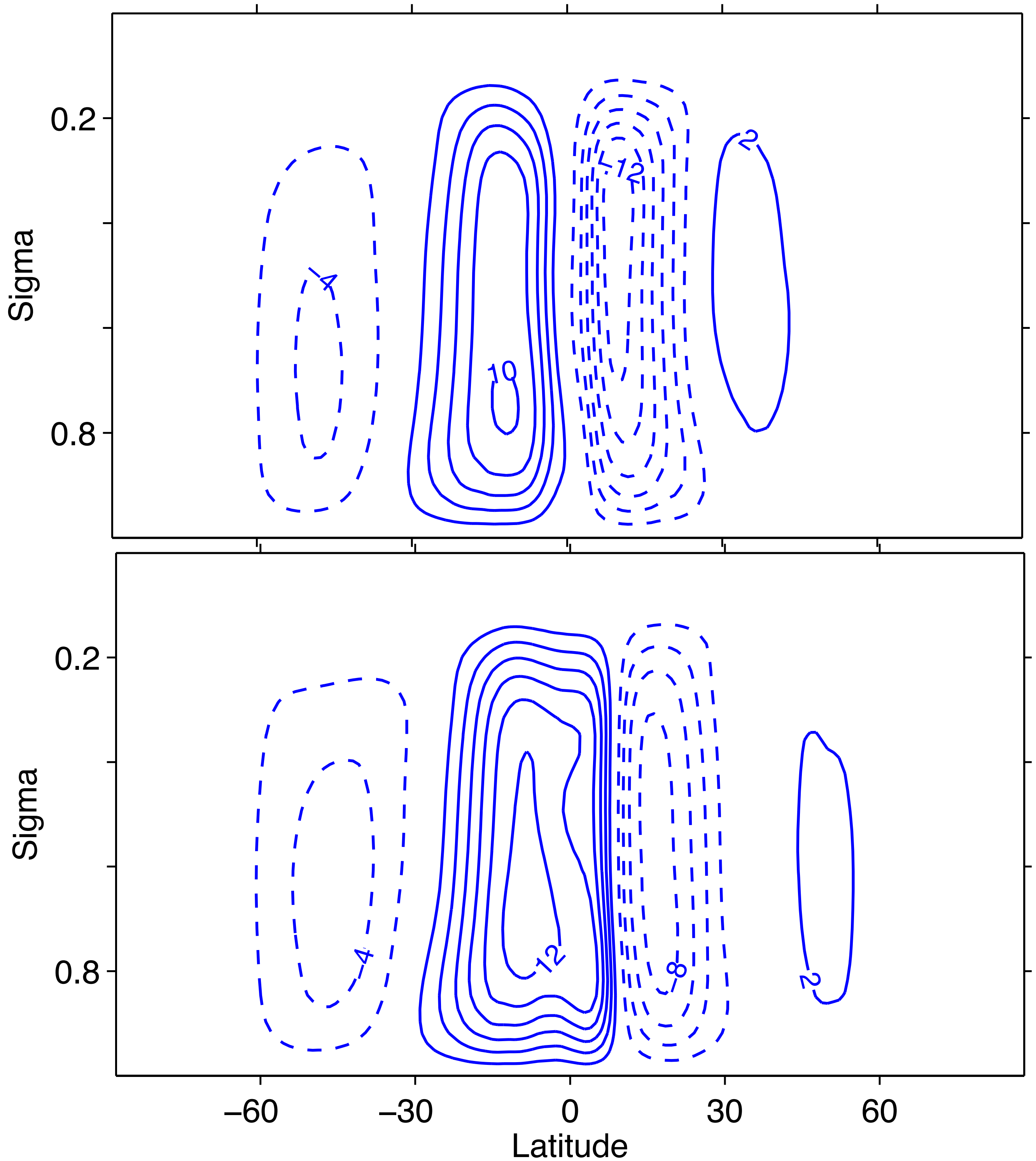
June-July-August
(JJA)

(ERA40 reanalysis 1980-2001)

Mean meridional streamfunction (10^{10} kg s^{-1}): different seasons

MAM

SON

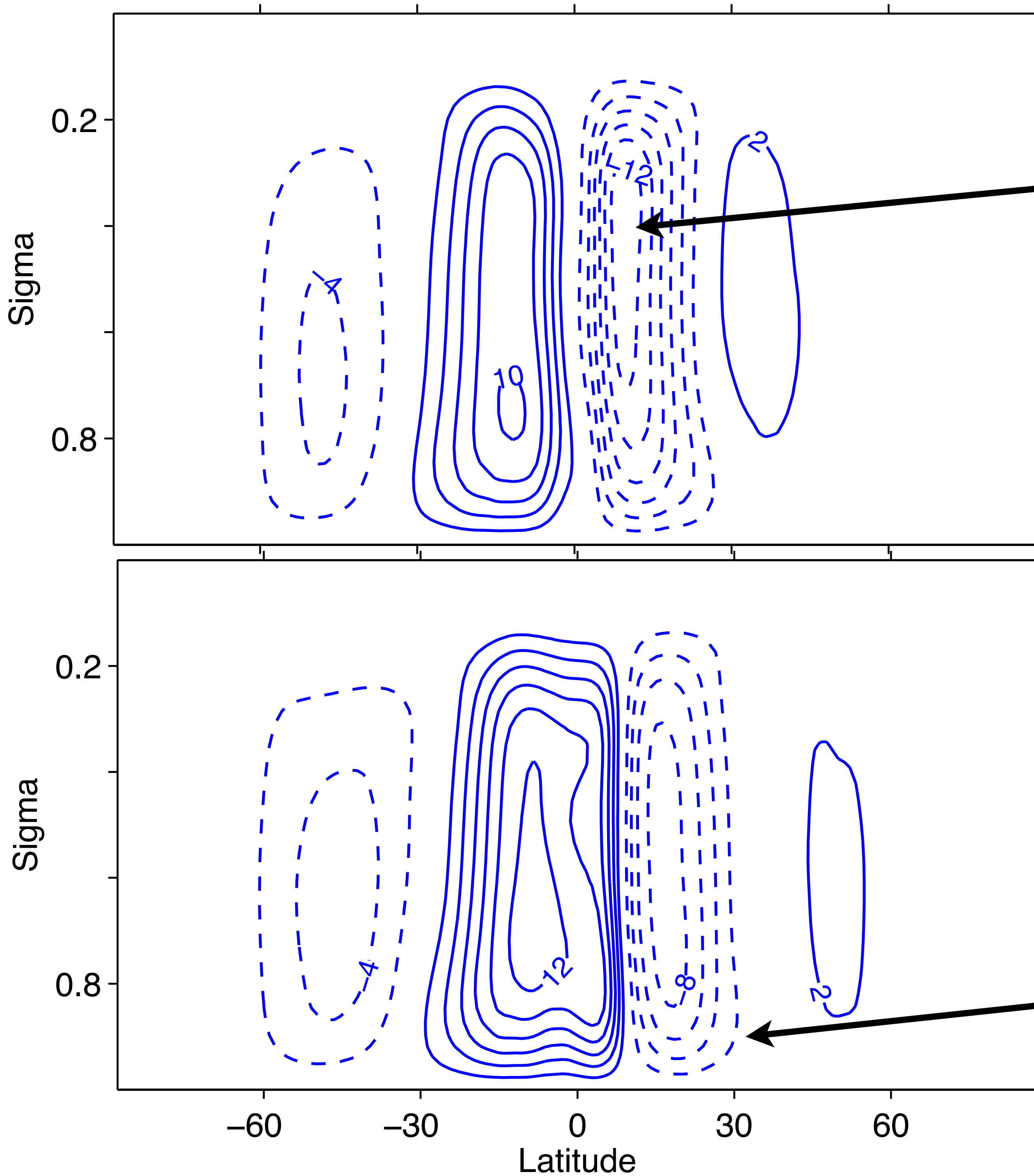


(ERA40 reanalysis 1980-2001)

Mean meridional streamfunction (10^{10} kg s^{-1}): different seasons

MAM

SON



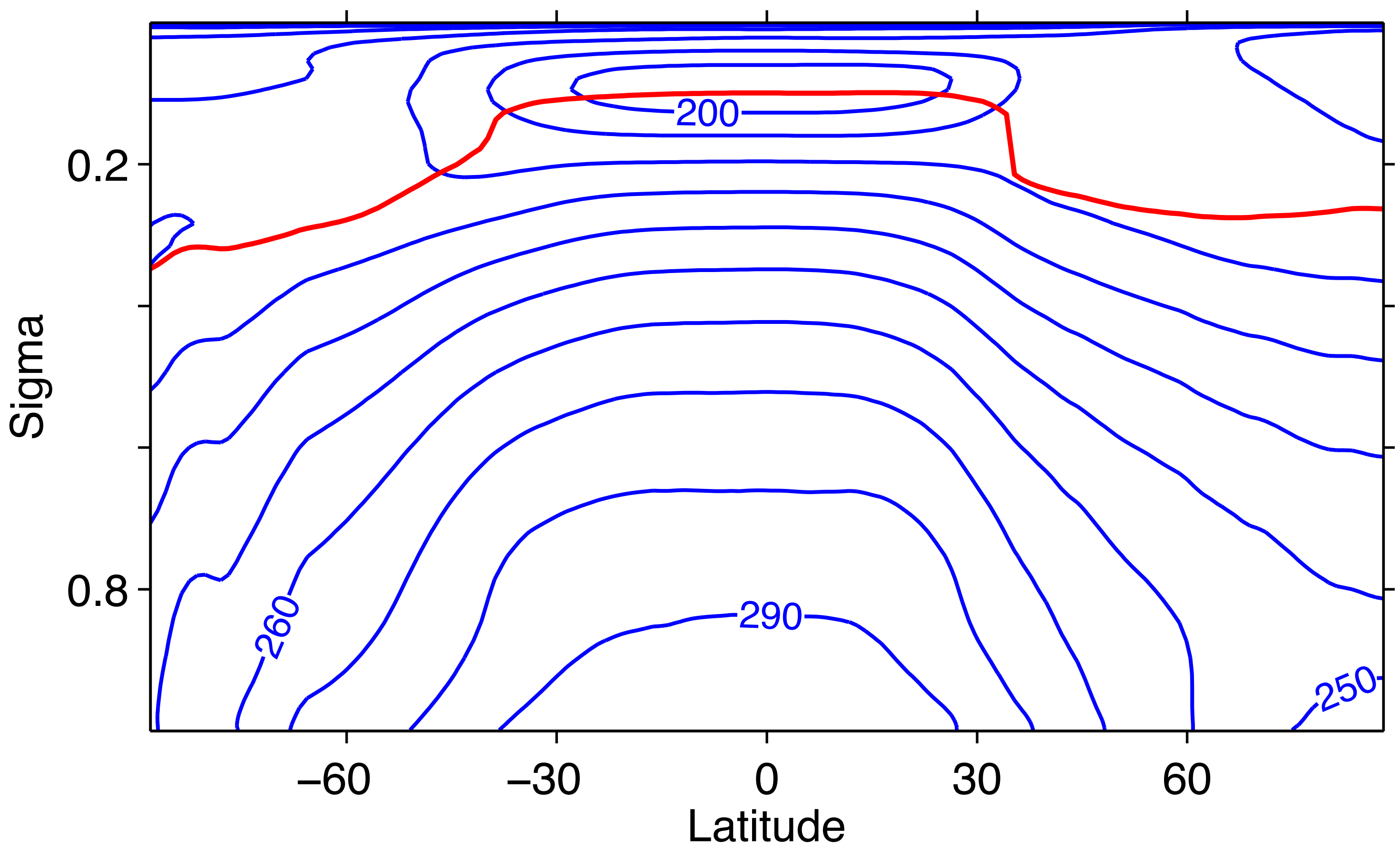
1. What determines strength of Hadley cells?

2. What determines extent of Hadley cells?

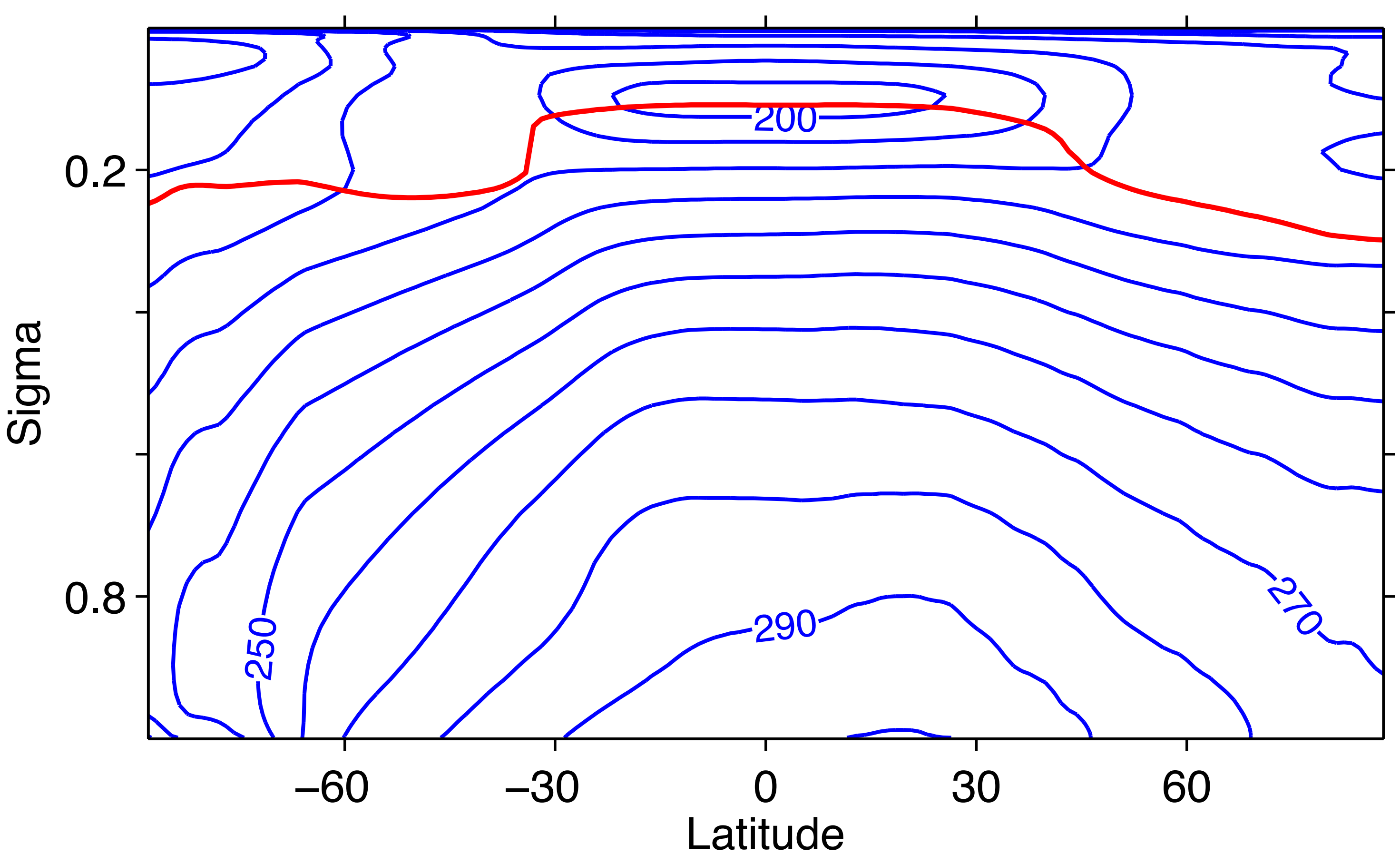
(ERA40 reanalysis 1980-2001)

Observed thermal structure and gravity wave dynamics

Zonal and time mean temperature (K)

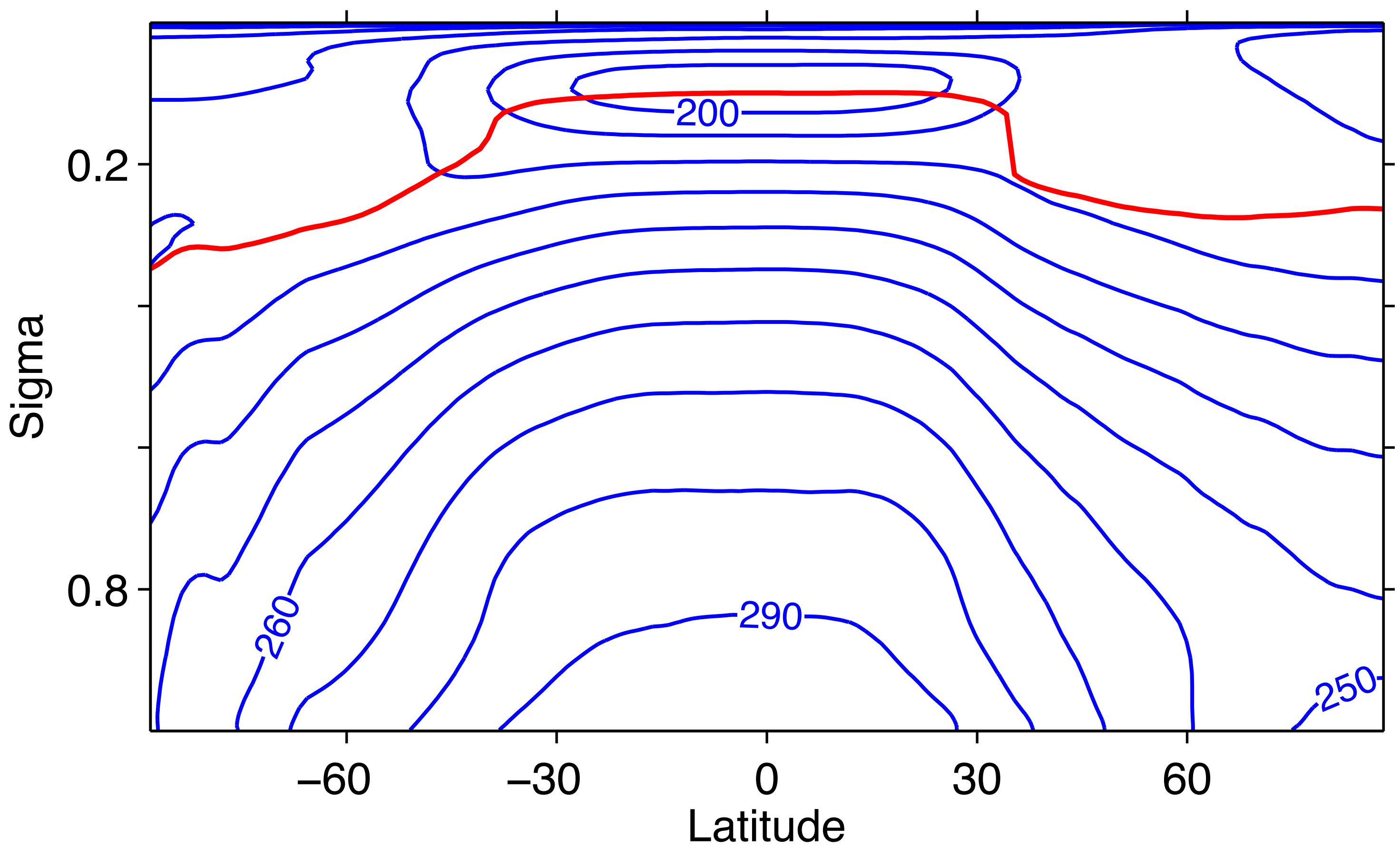


December-January-February (DJF)



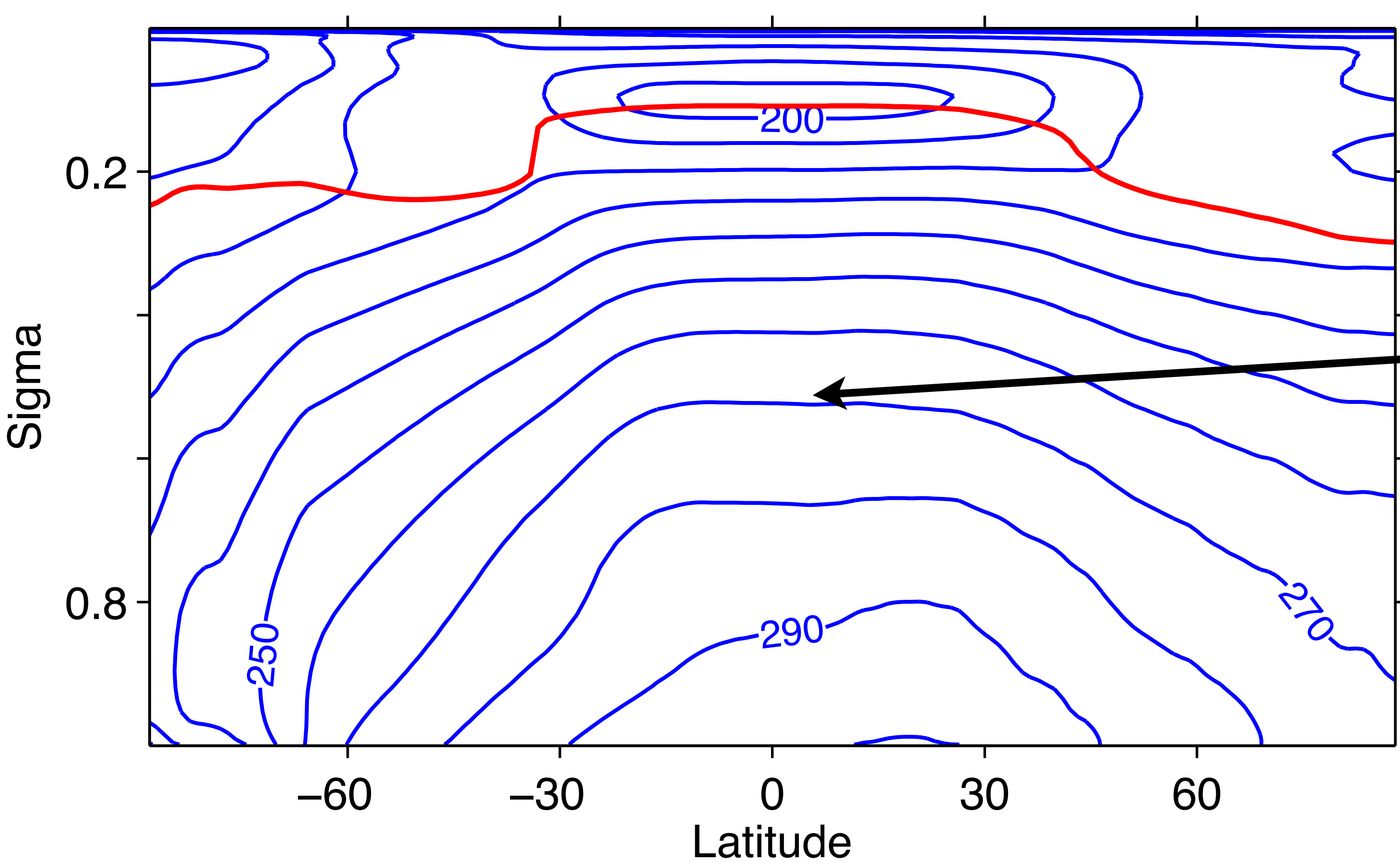
June-July-August (JJA)

(ERA40 reanalysis data 1980-2001)



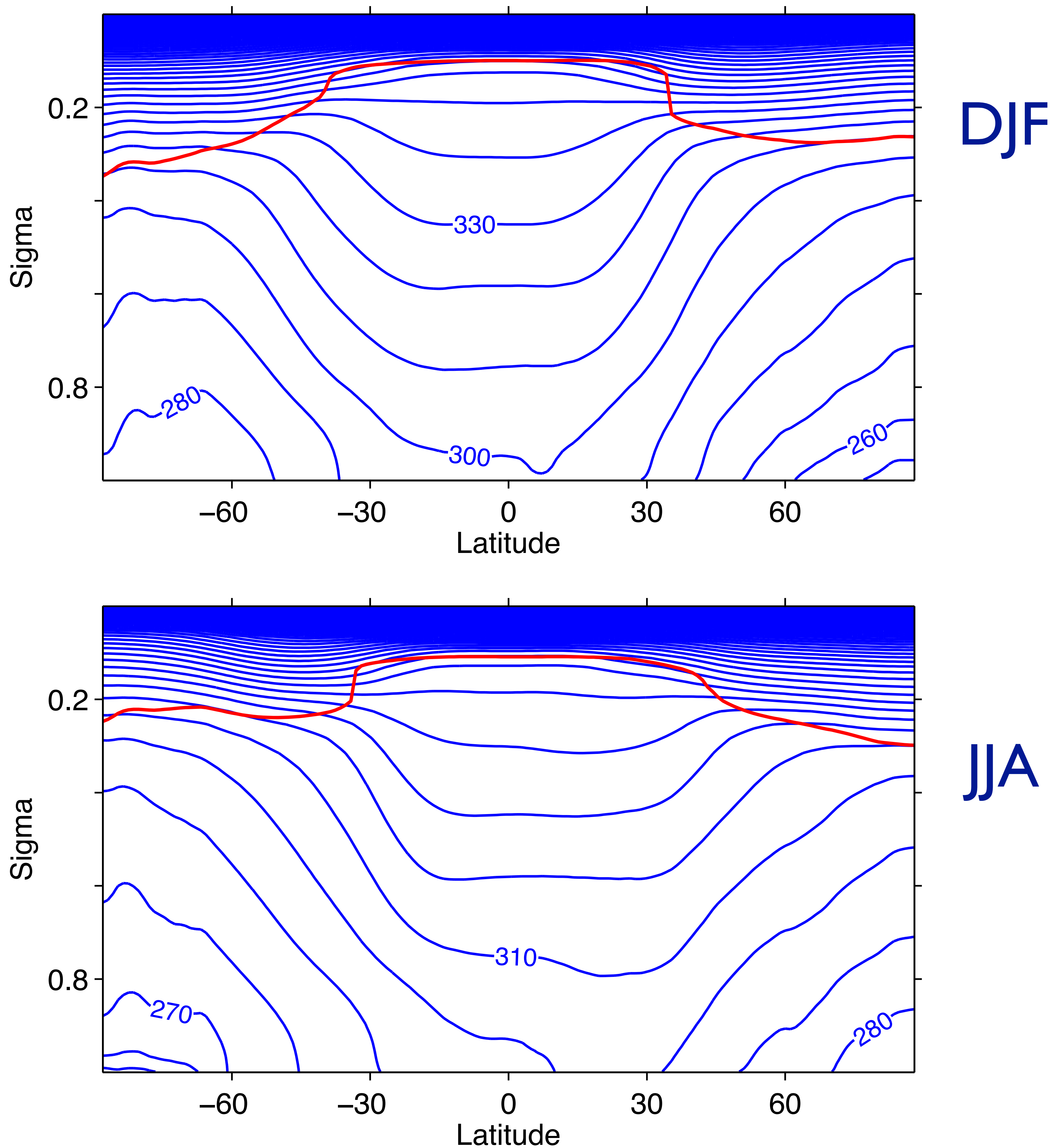
Zonal and time mean temperature (K)

December-January-February (DJF)



Note flat isotherms in tropics

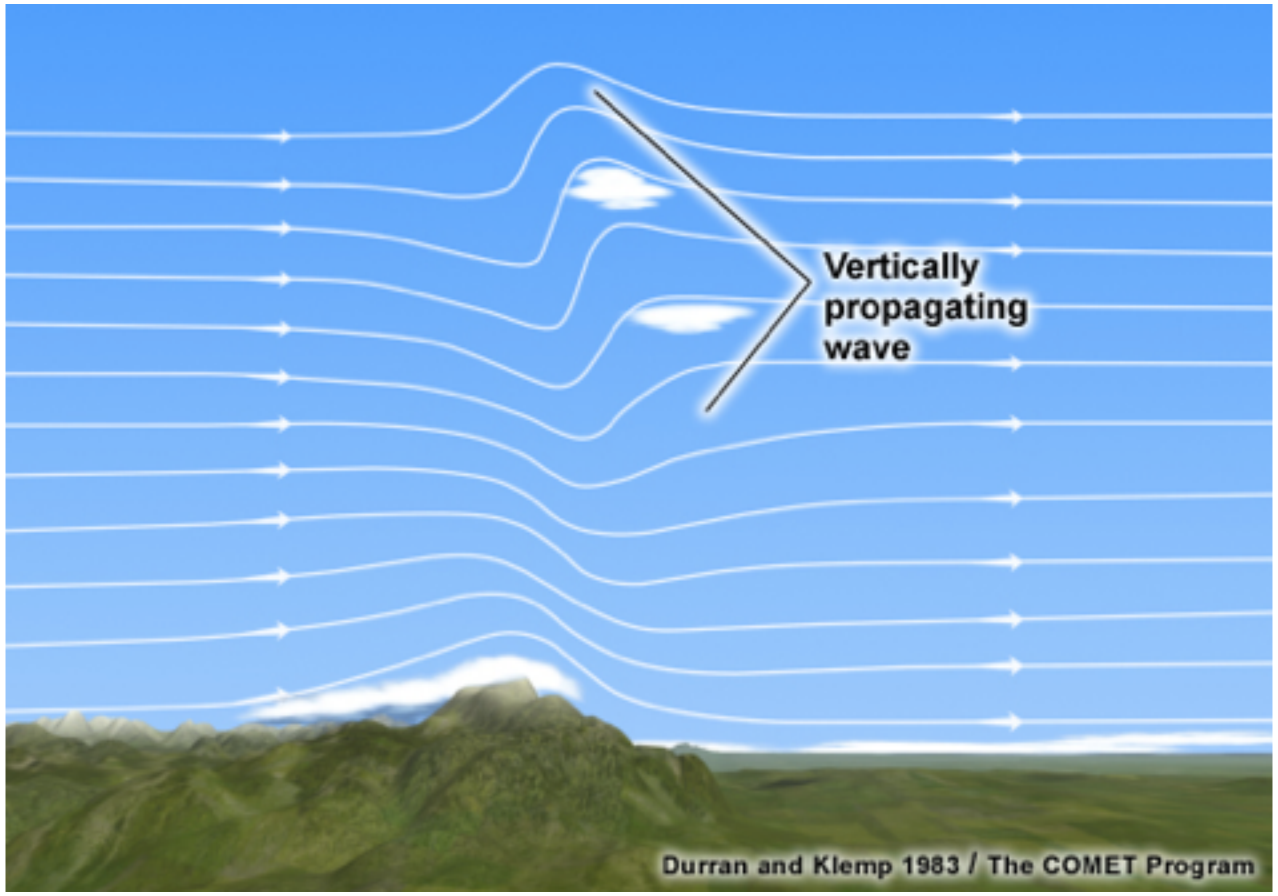
(ERA40 reanalysis data 1980-2001)



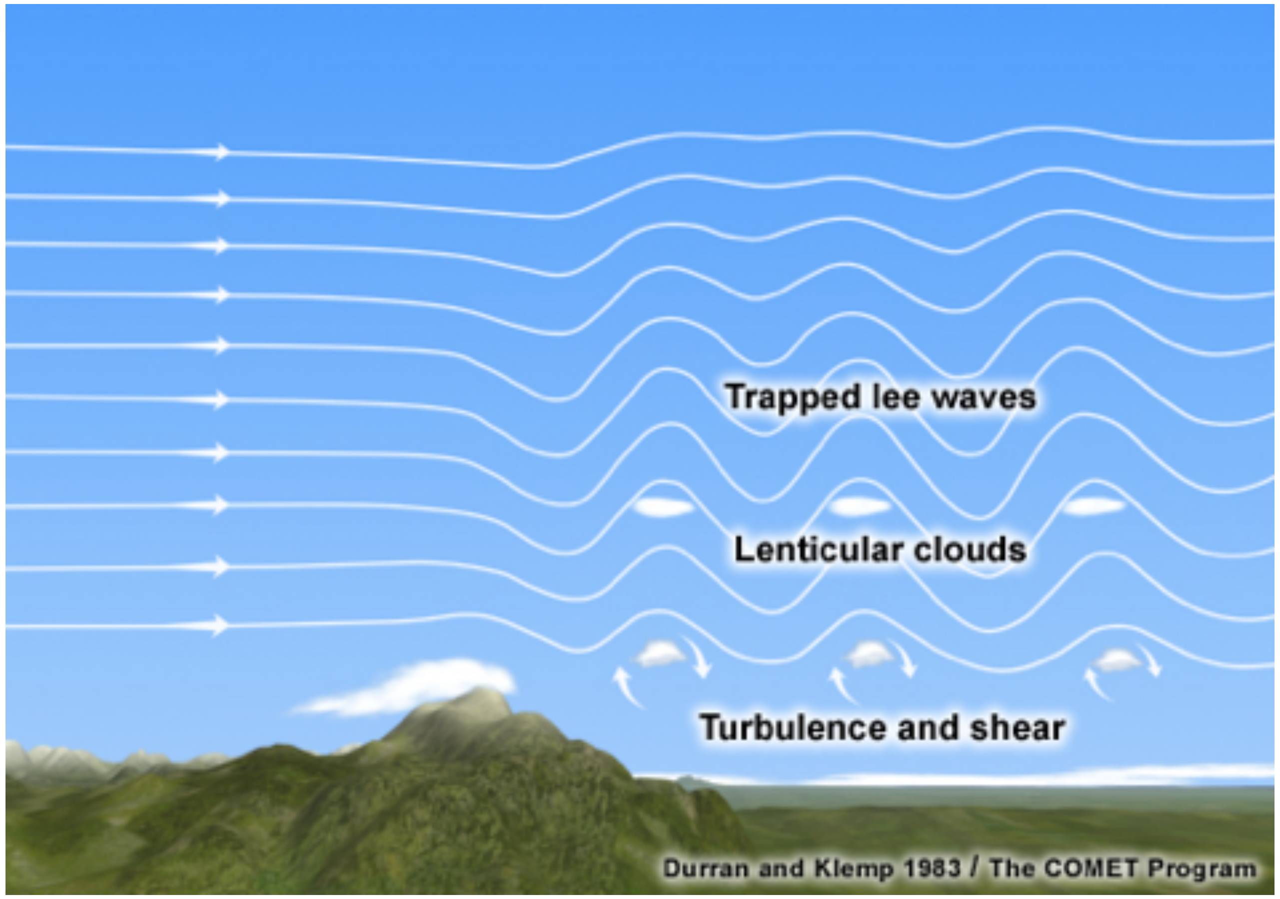
Potential temperature (K)

Increase with height (implies dry static stability)

(ERA40 reanalysis data 1980-2001)

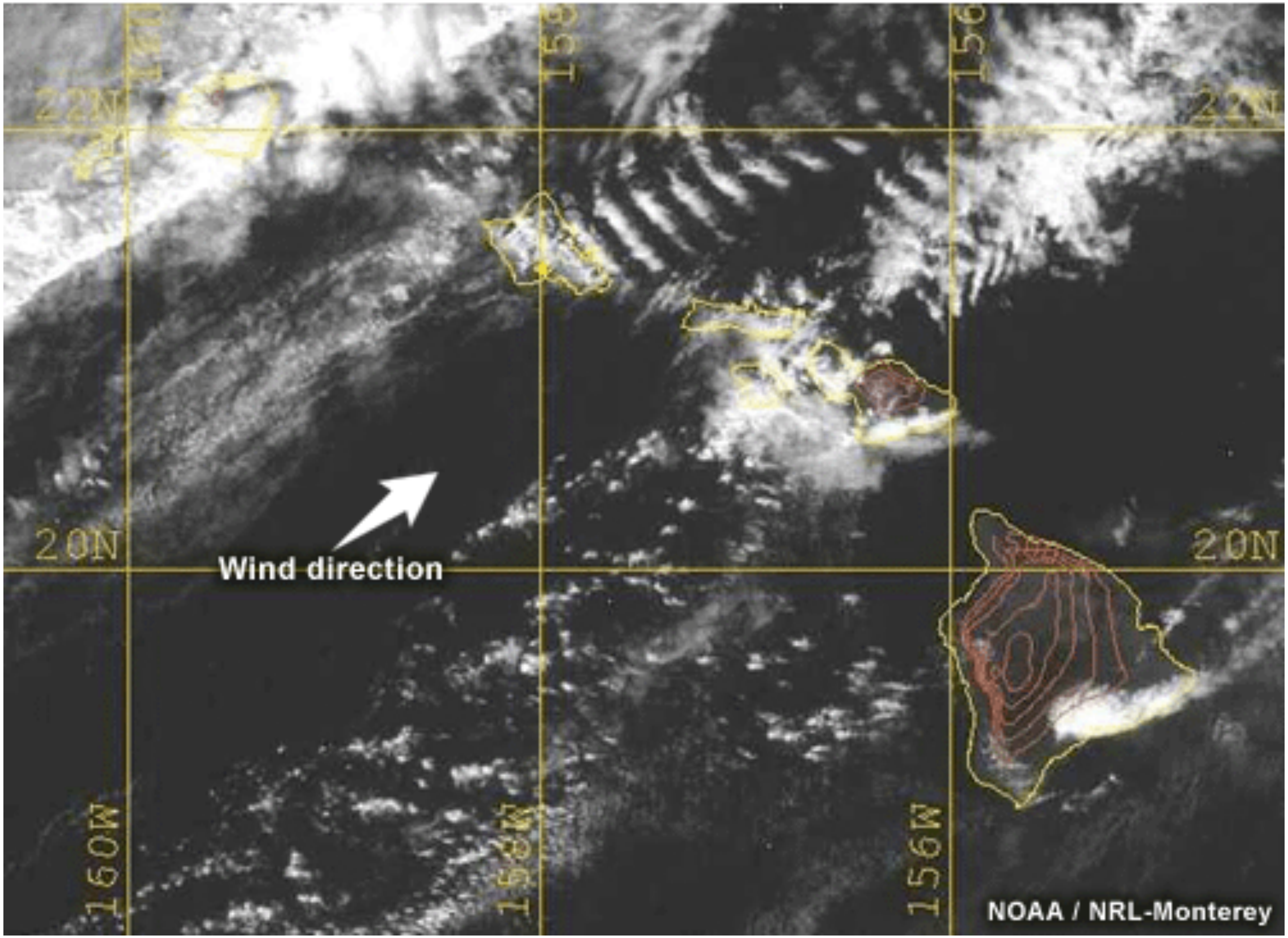


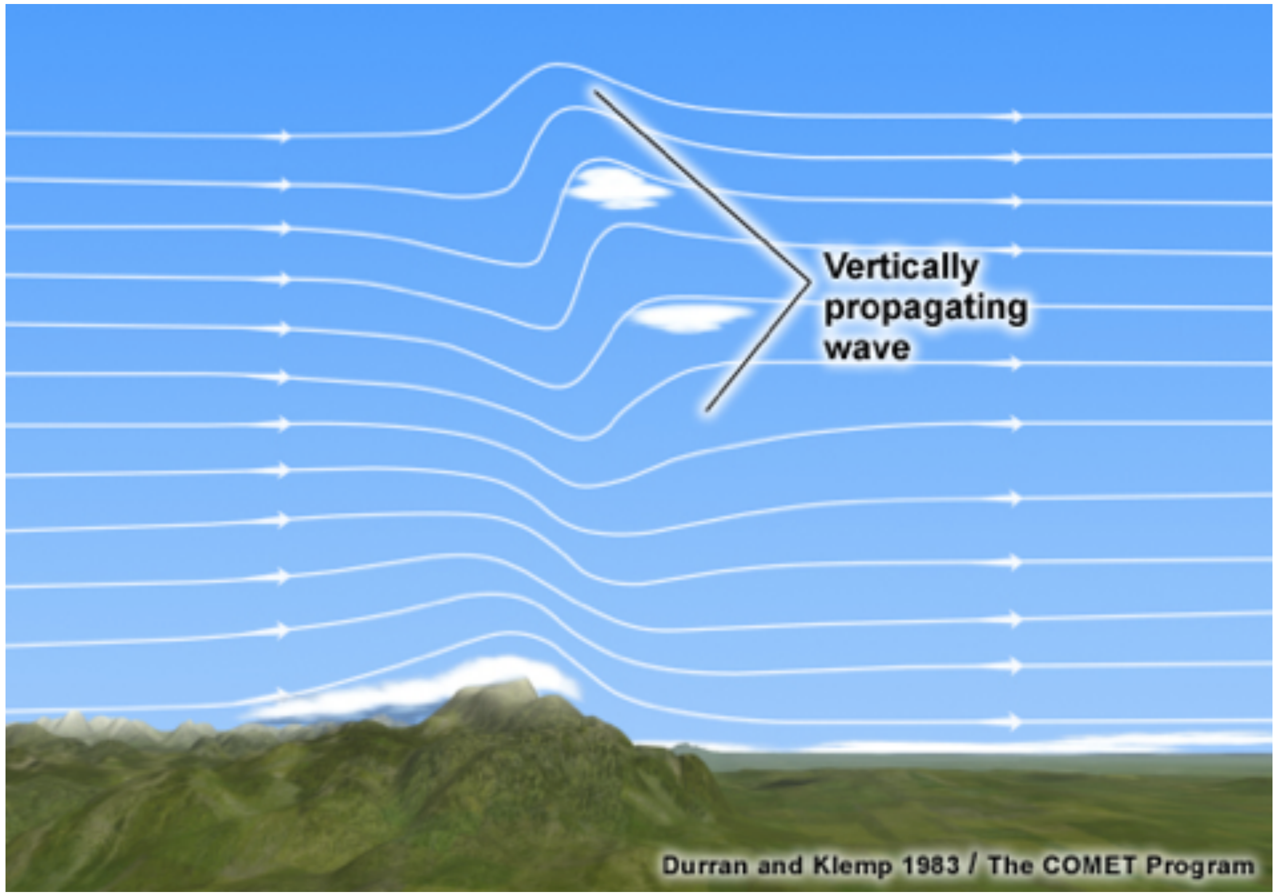
Static stability allows for internal gravity waves: here forced by mountain

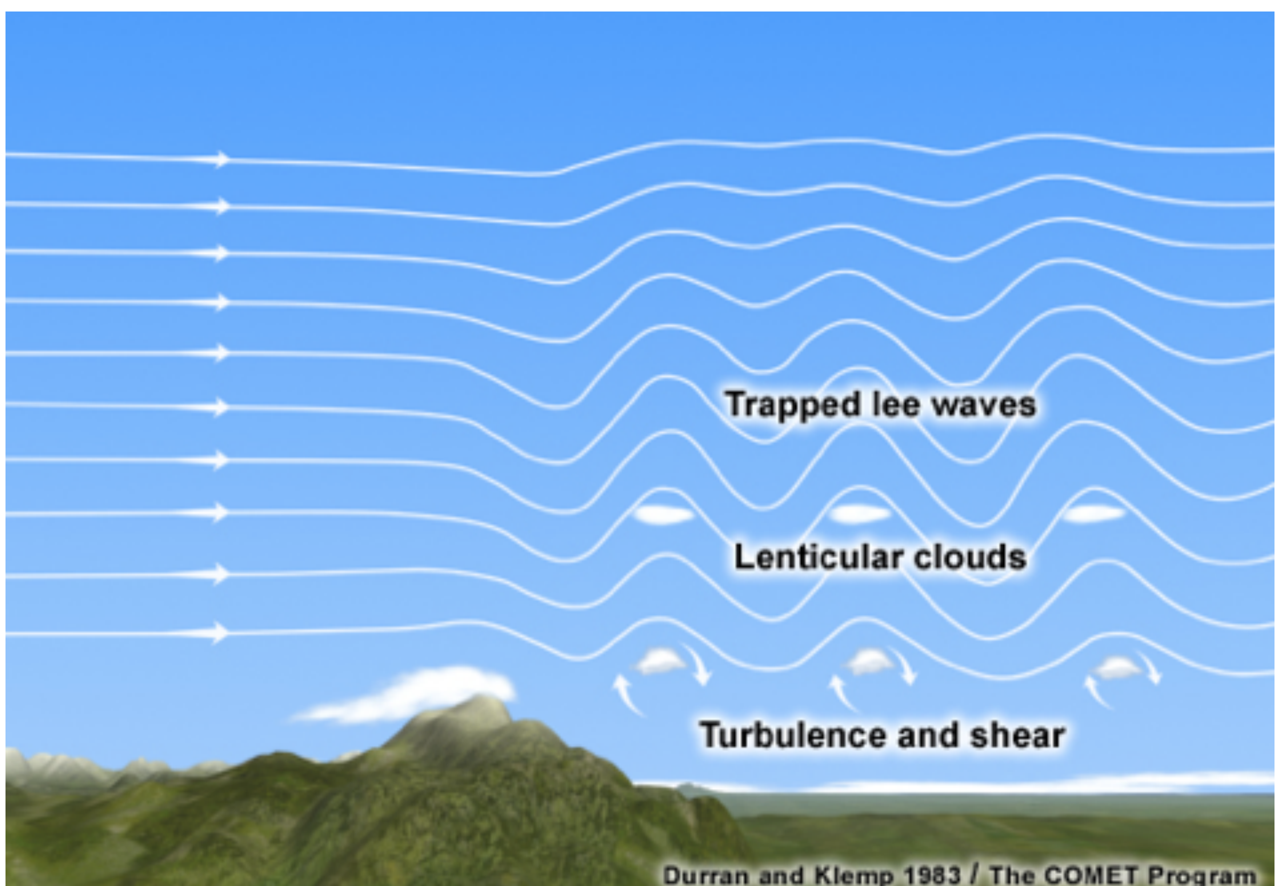


Trapped lee waves downwind from Hawaiian Islands

GOES-10 VIS Image 2000 UTC 24 Jan 2003







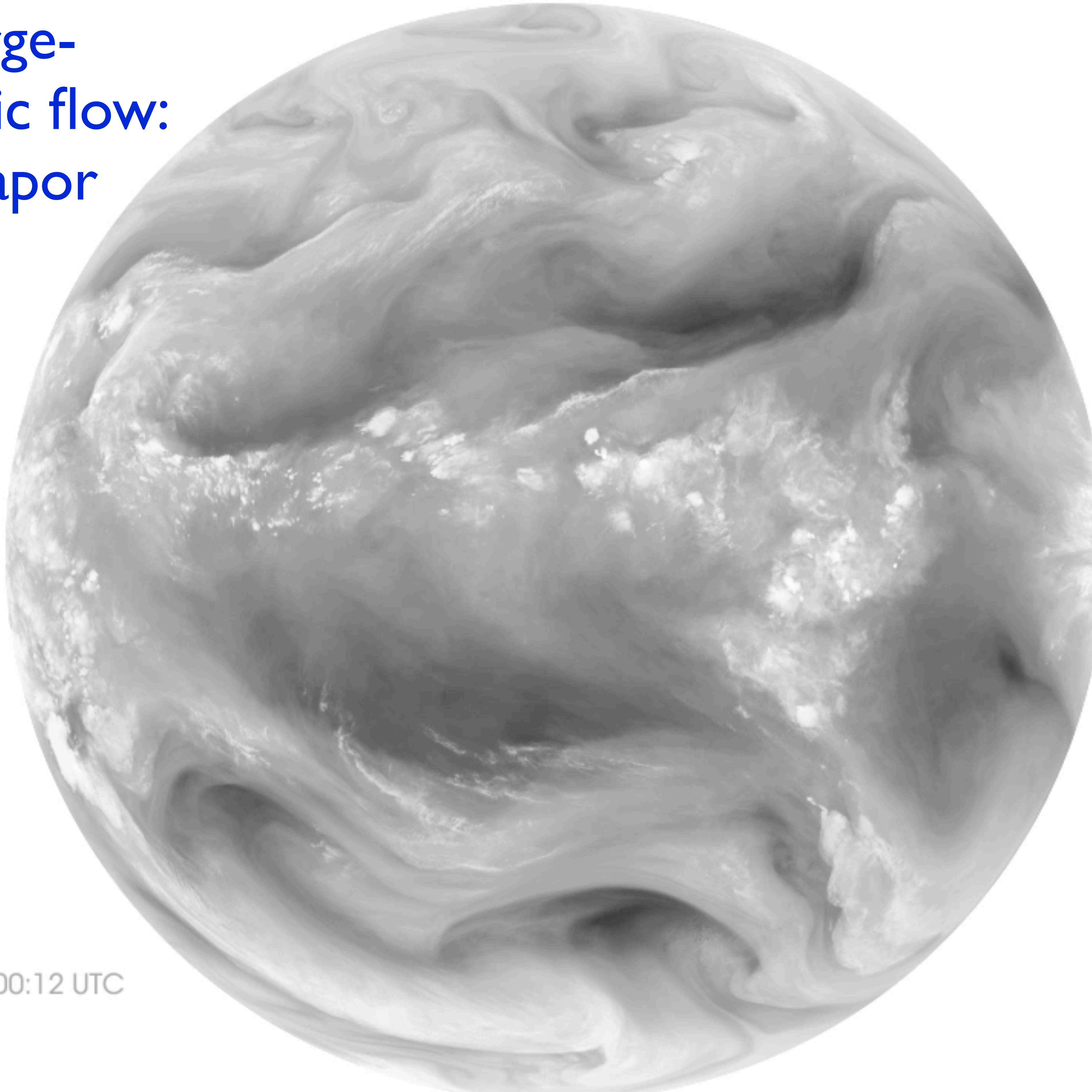
Questions:

1. What determines whether internal gravity waves are vertically propagating or trapped?

2. How do the waves affect the mean flow?

Large-scale eddies:
Growth of baroclinic eddies, propagation of planetary waves, forcing of vertical motions

Illustration of large-scale atmospheric flow: satellite water vapor imagery



October 7, 2007 00:12 UTC

Animation: Robert Simmon,NASA
Data: Seviri water vapor (IR)

Transient (<1 week) eddies in midlatitudes in observations

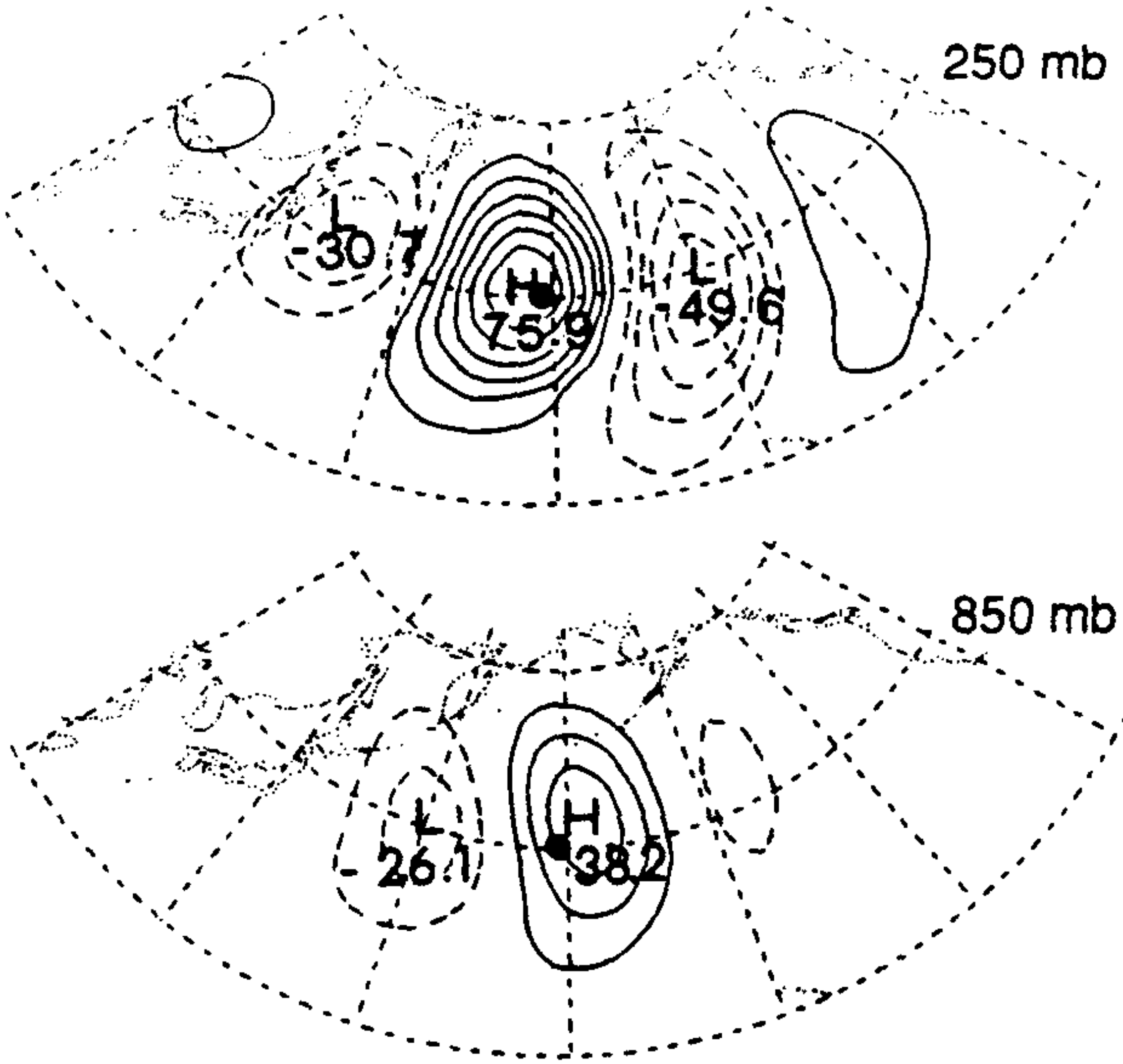


FIG. 1. The 250-mb (upper) and 850-mb (lower) geopotential height regression maps based on highpass filtered, normalized 500-mb height at the reference grid point marked with a solid circle. Each map covers from 140°E through the date line to 140°W in longitude and 20°N to 60°N. The interval between latitude and longitude lines is 20°. Negative contours are dashed and the zero contour is omitted. Contour interval: 10 m.

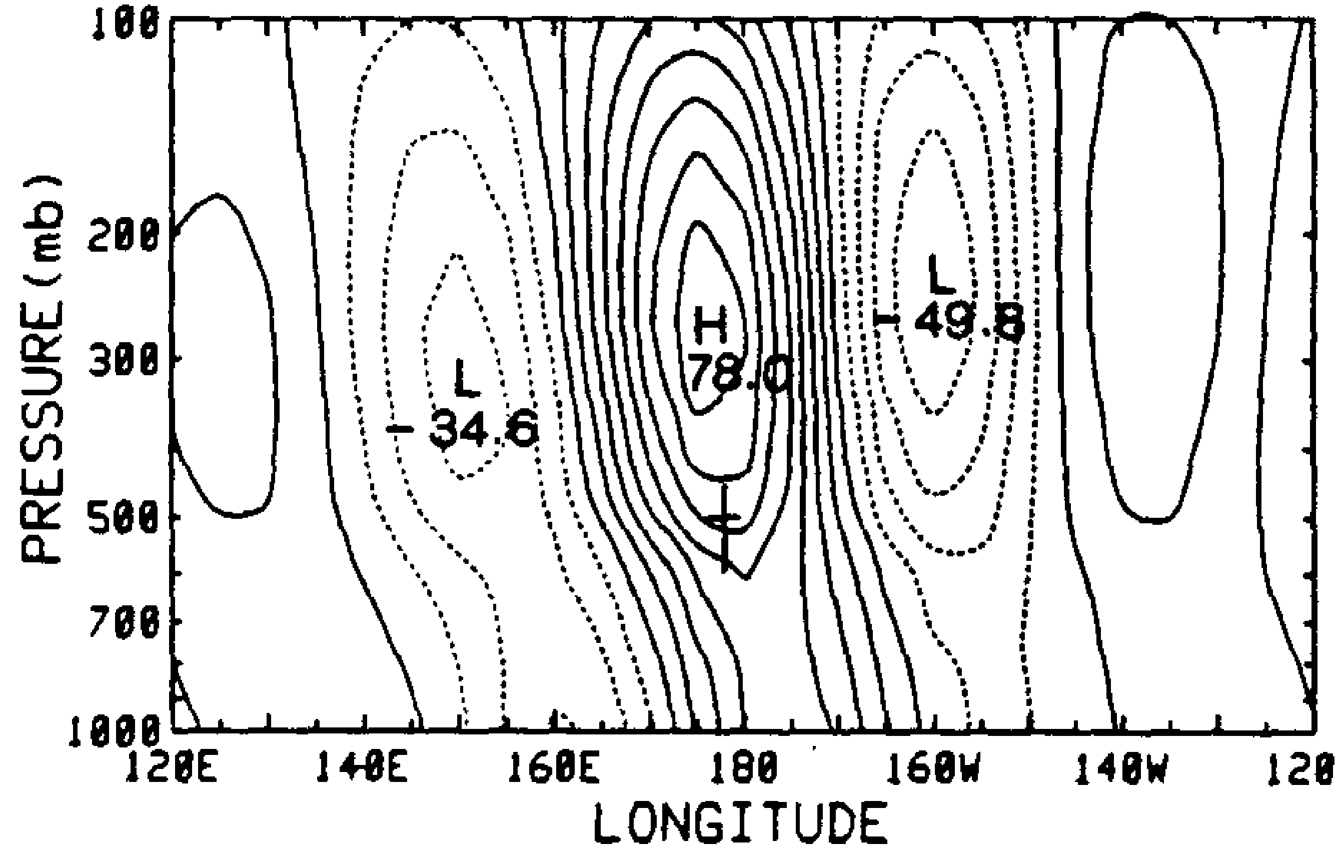
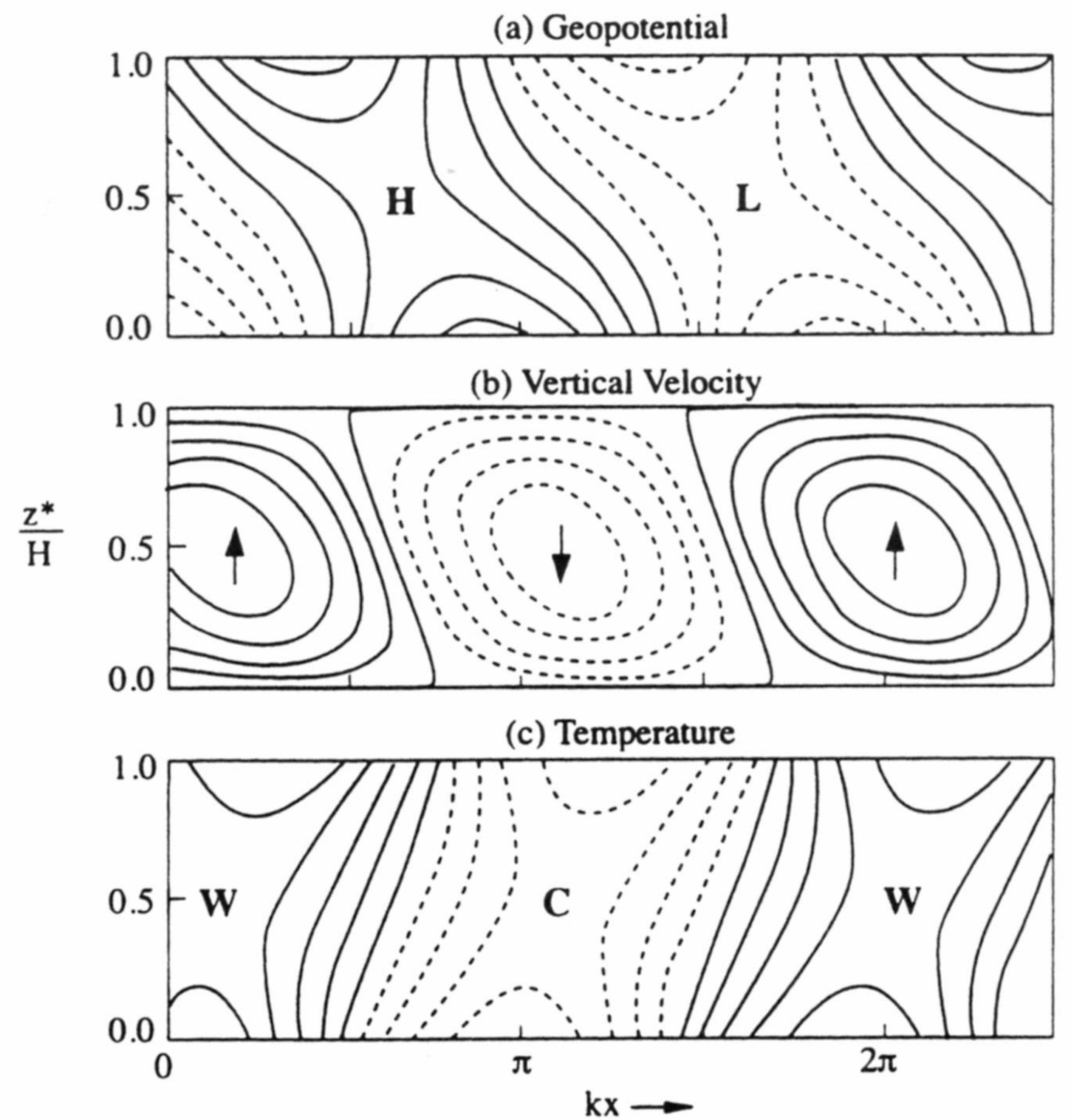


FIG. 3. Geopotential height regression cross section along 40°N for the same reference time series as in Fig. 1, assembled from one-point regression maps of geopotential height at ten standard pressure levels. Negative contours are dashed. Contour interval: 10 m.

Lim and Wallace 1991

Why do eddies grow in midlatitudes?

Most unstable wave in the Eady model



Why do eddies grow in midlatitudes?

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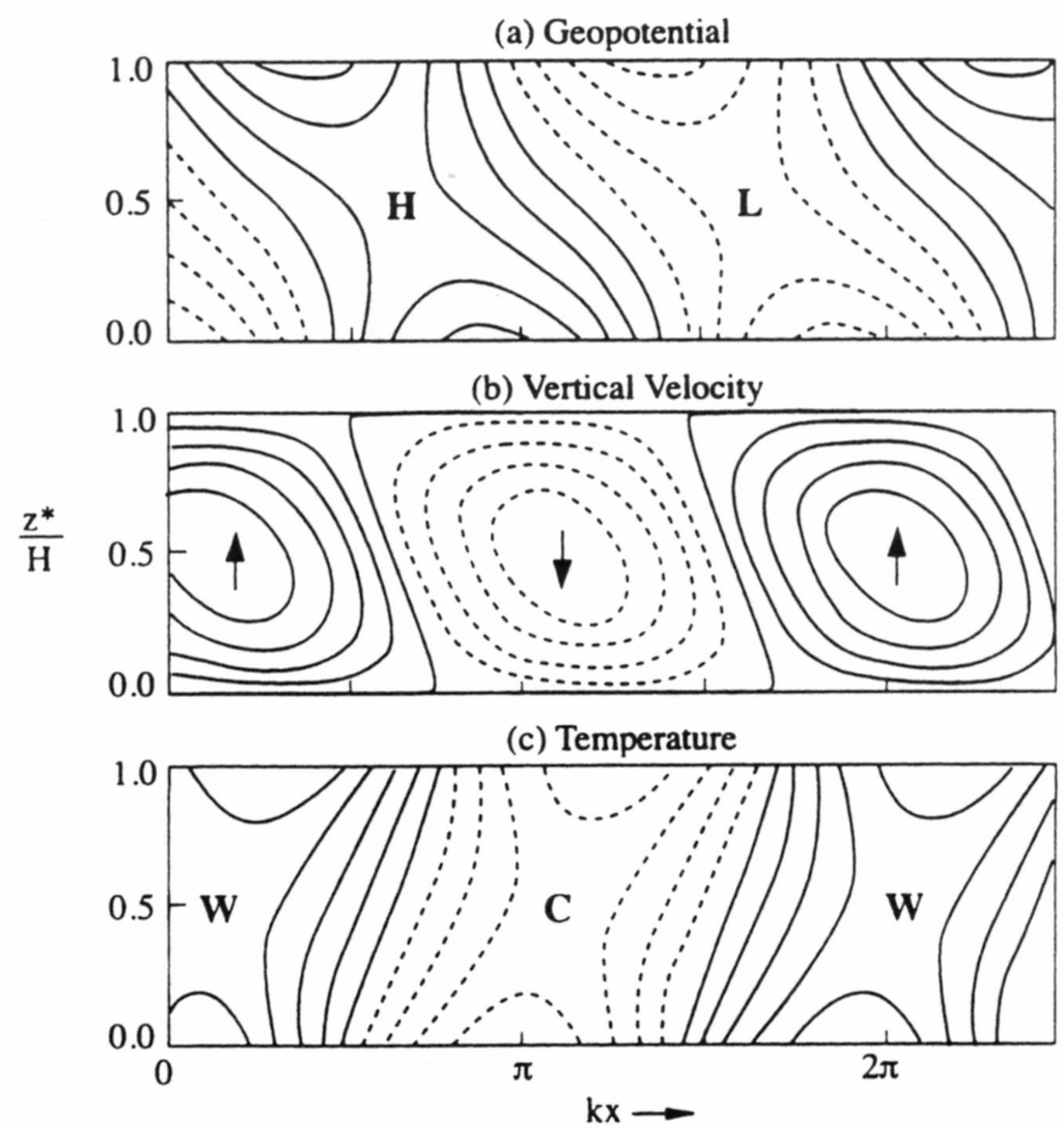


And what controls the magnitude of the vertical velocity?

How can we understand individual cyclogenesis events? (using potential vorticity!)

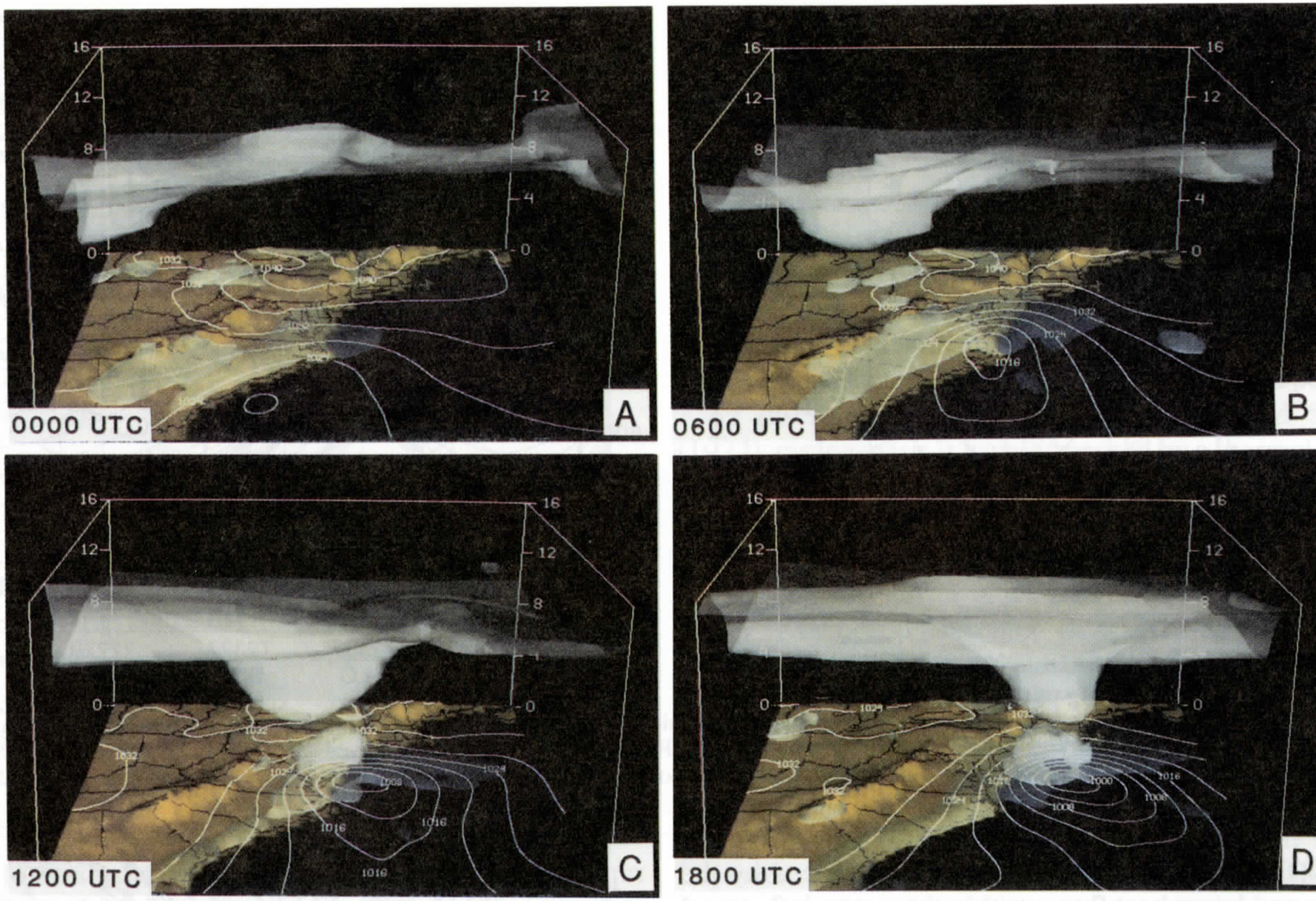
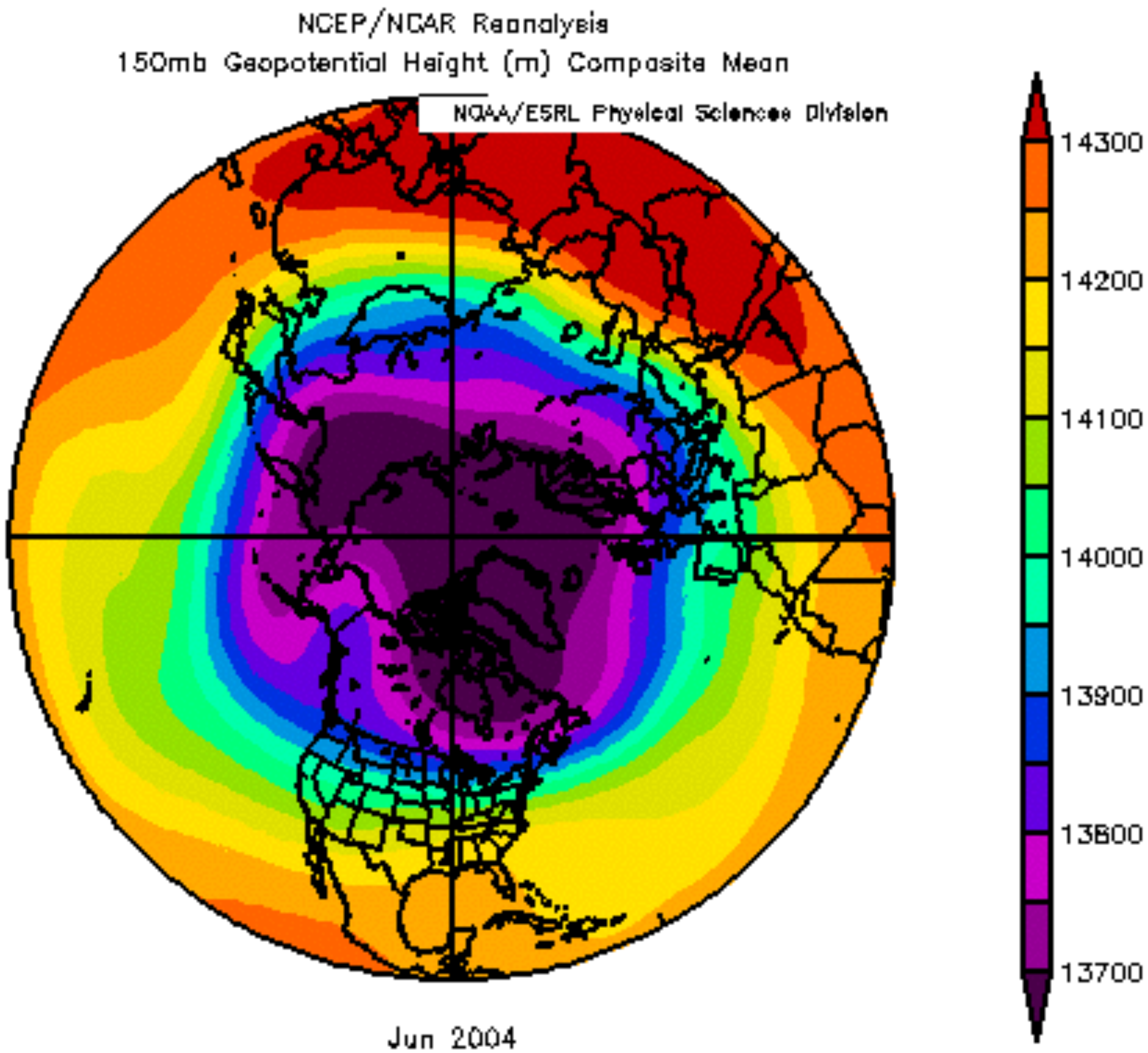


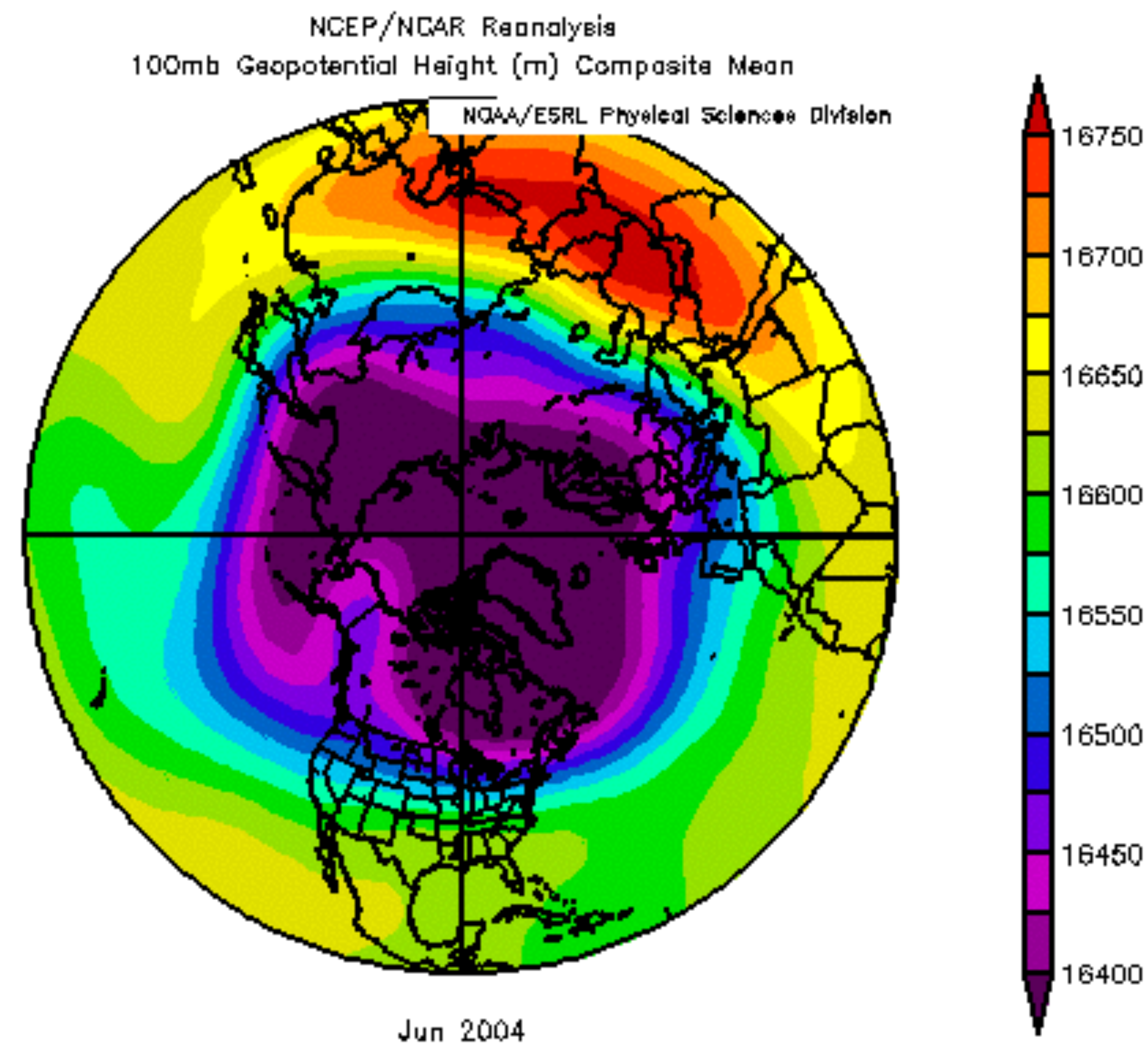
FIG. 6.12. Three-dimensional perspectives, as viewed from the south, of the 2×10^{-5} K mb^{-1} s^{-1} IPV surface, and sea-level pressure isobar pattern (mb) derived from the numerical simulation of the Presidents' Day cyclone of Whitaker et al. (1988) for (a) 00 UTC, (b) 06 UTC, (c) 12 UTC and (d) 18 UTC 19 February 1979. The three-dimensional perspectives were derived by William Hibbard using the University of Wisconsin, Space Science and Engineering Center, three-dimensional McIDAS system.

Ucellini chapter

How does the zonal wind control the vertical propagation of Rossby waves into the stratosphere?



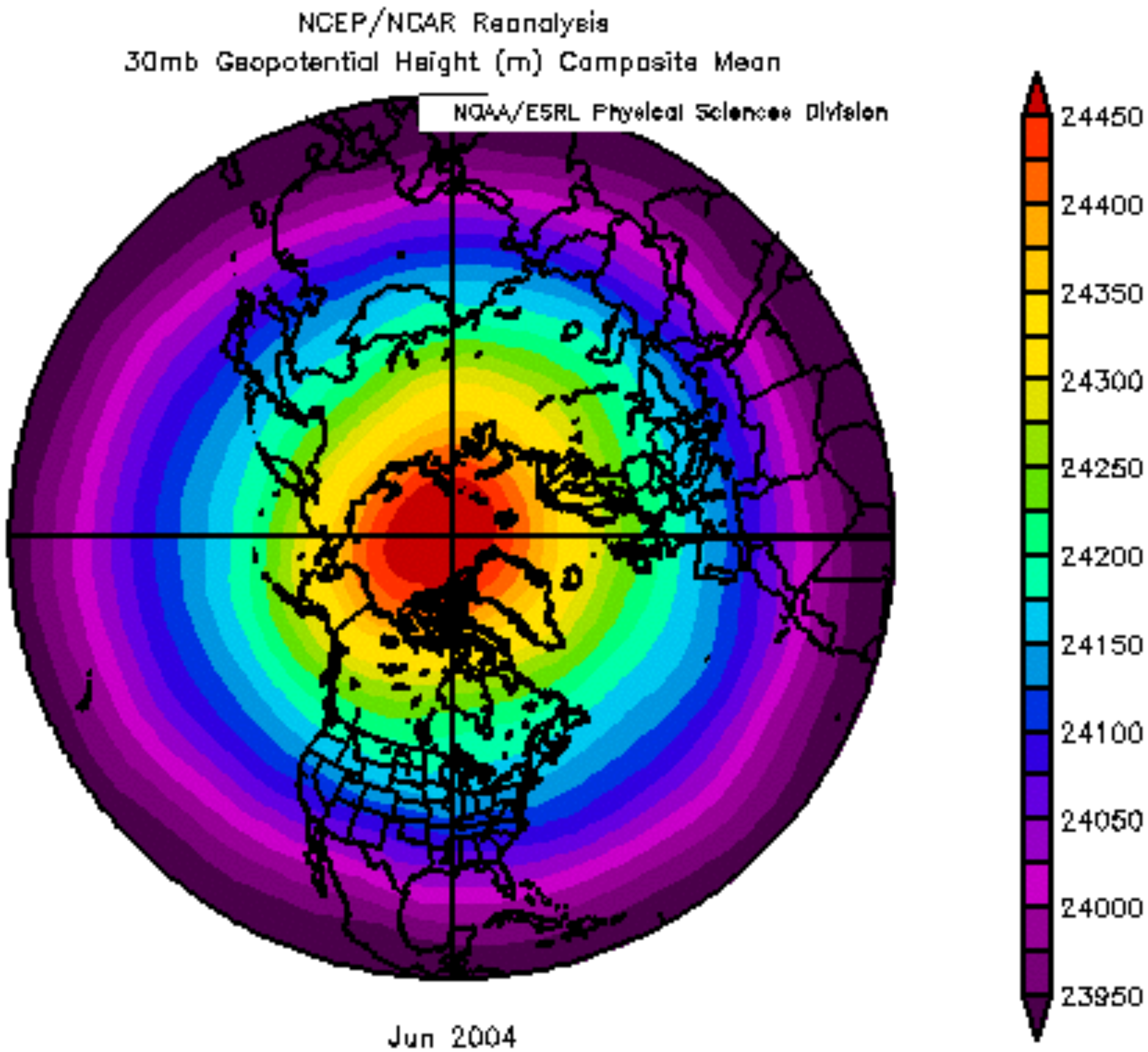
150hPa



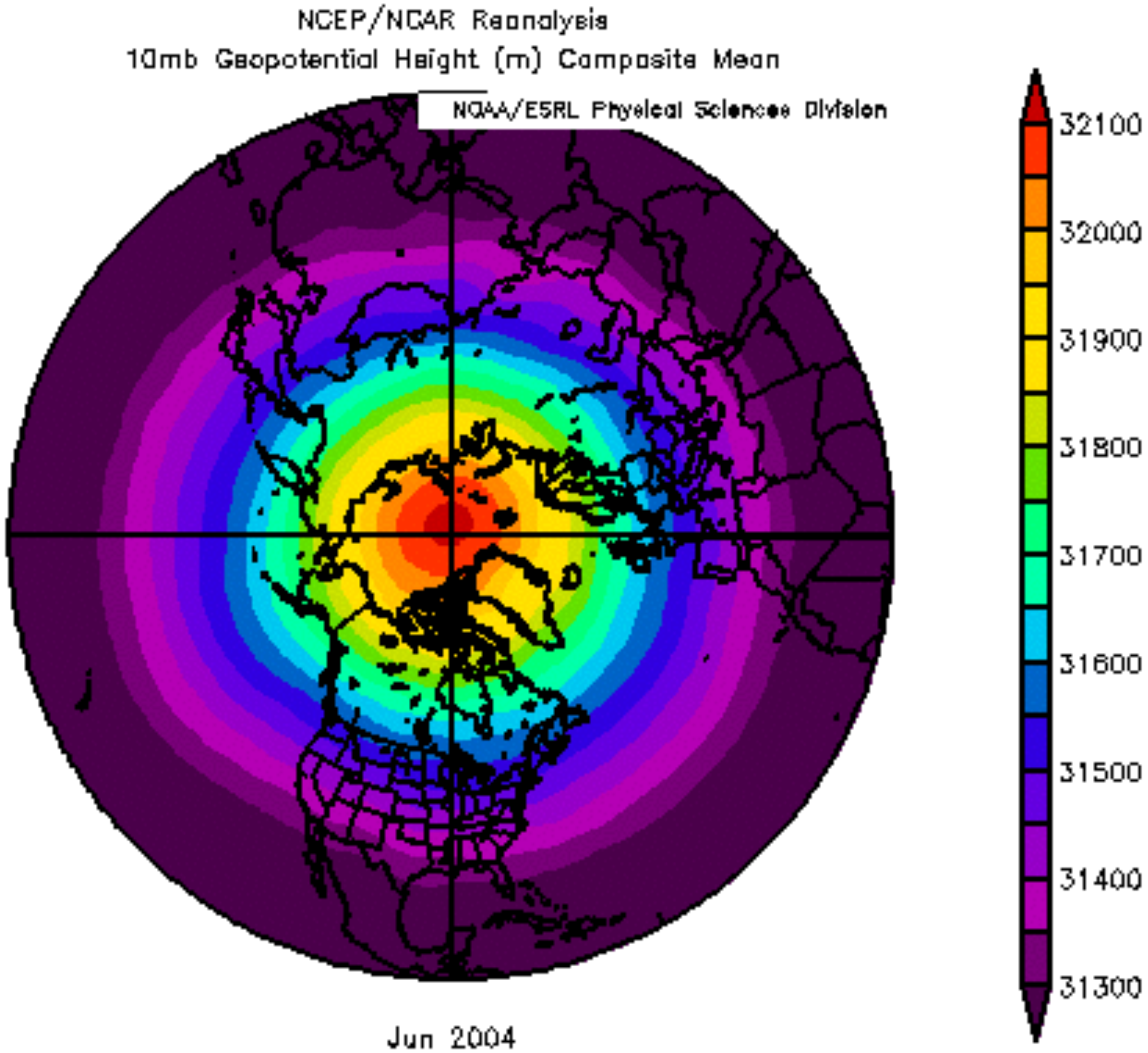
100hPa

Planetary waves in June 2004

No planetary waves in the stratosphere at that time

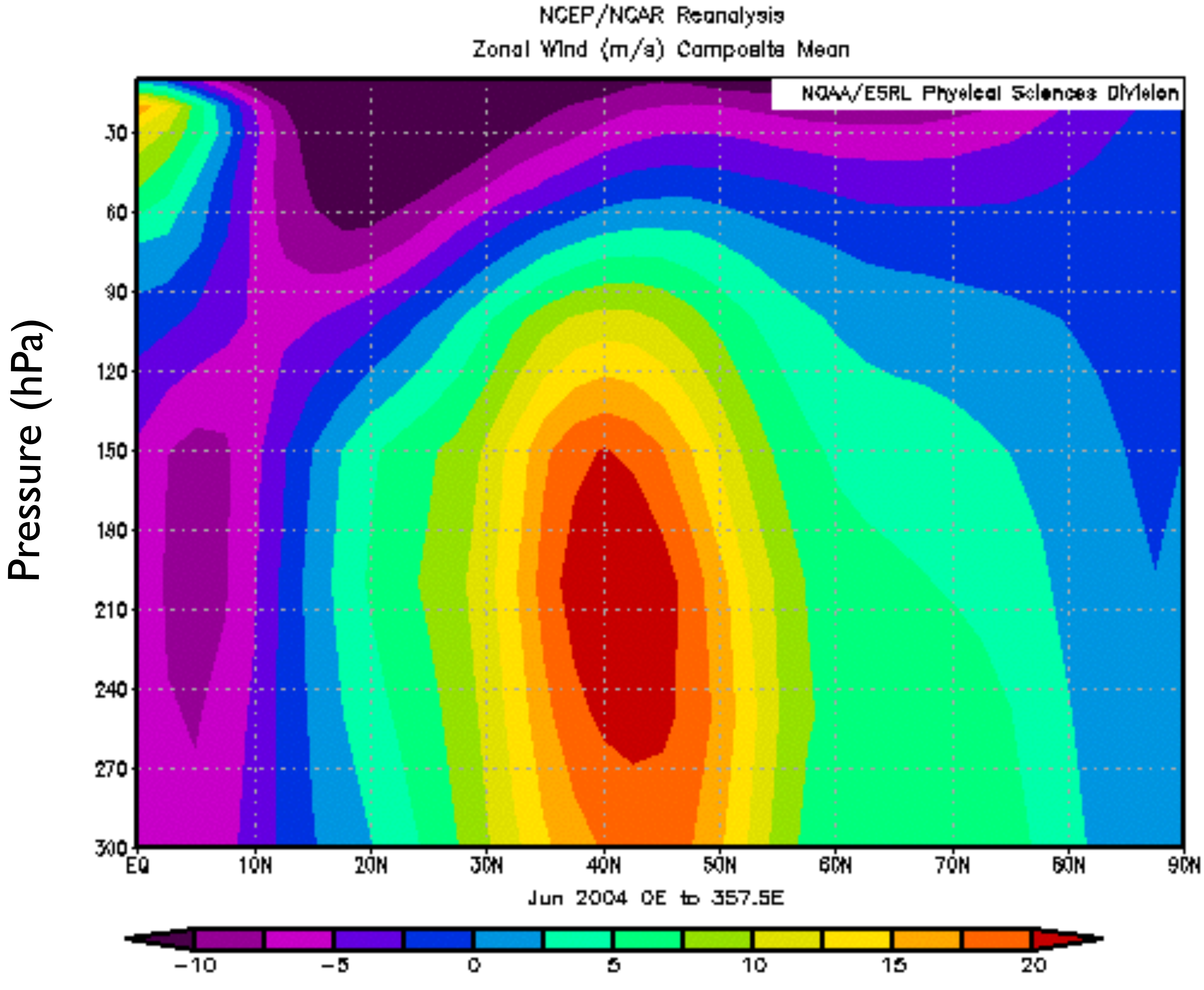


30hPa



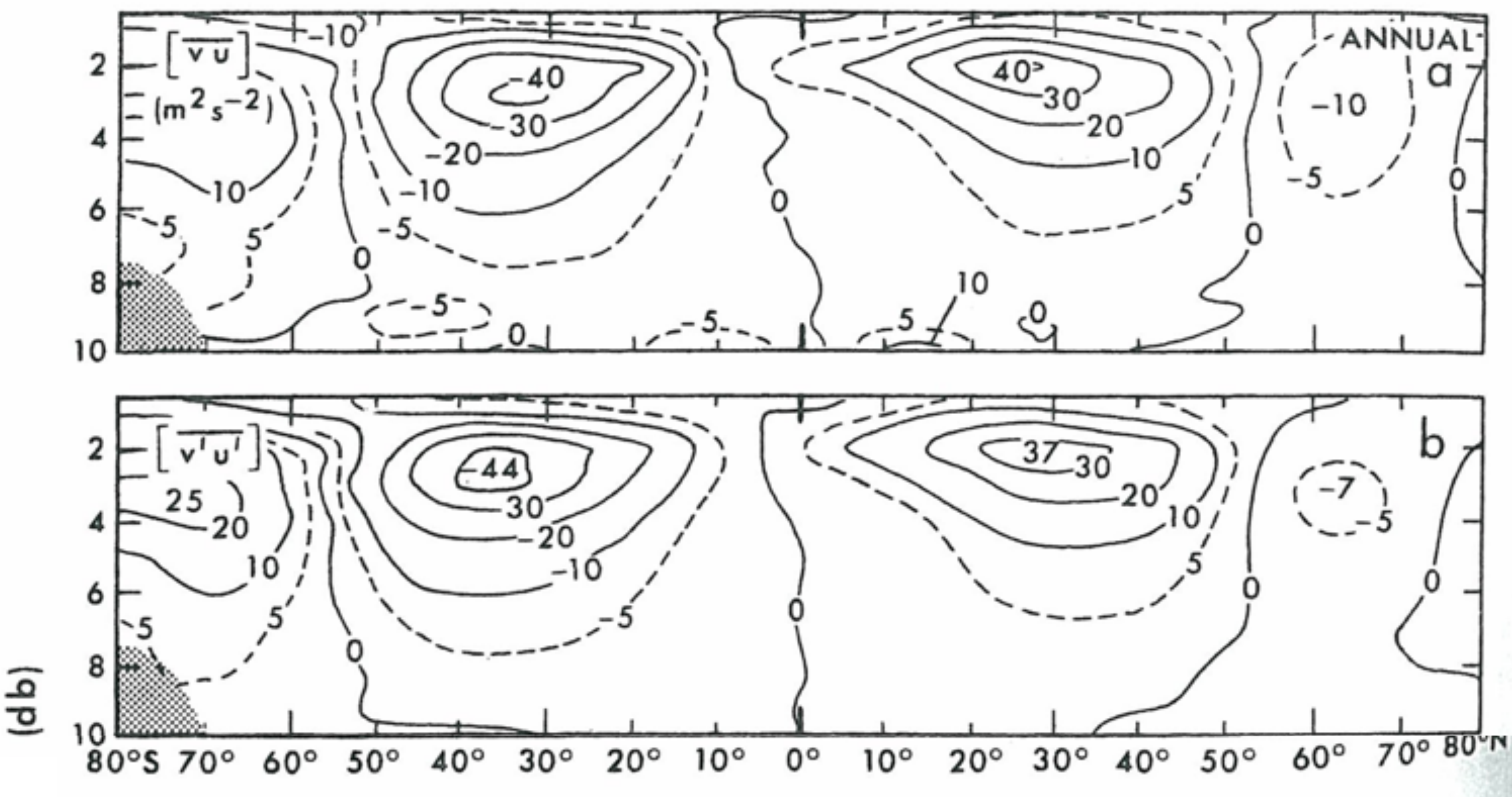
10hPa

Zonal-mean zonal wind (Jun 2004): transition from westerly to easterly flow at 60hPa



Role of eddies in the general circulation

Eddies transport momentum: How does this determine the surface westerlies and affect the Hadley cells?



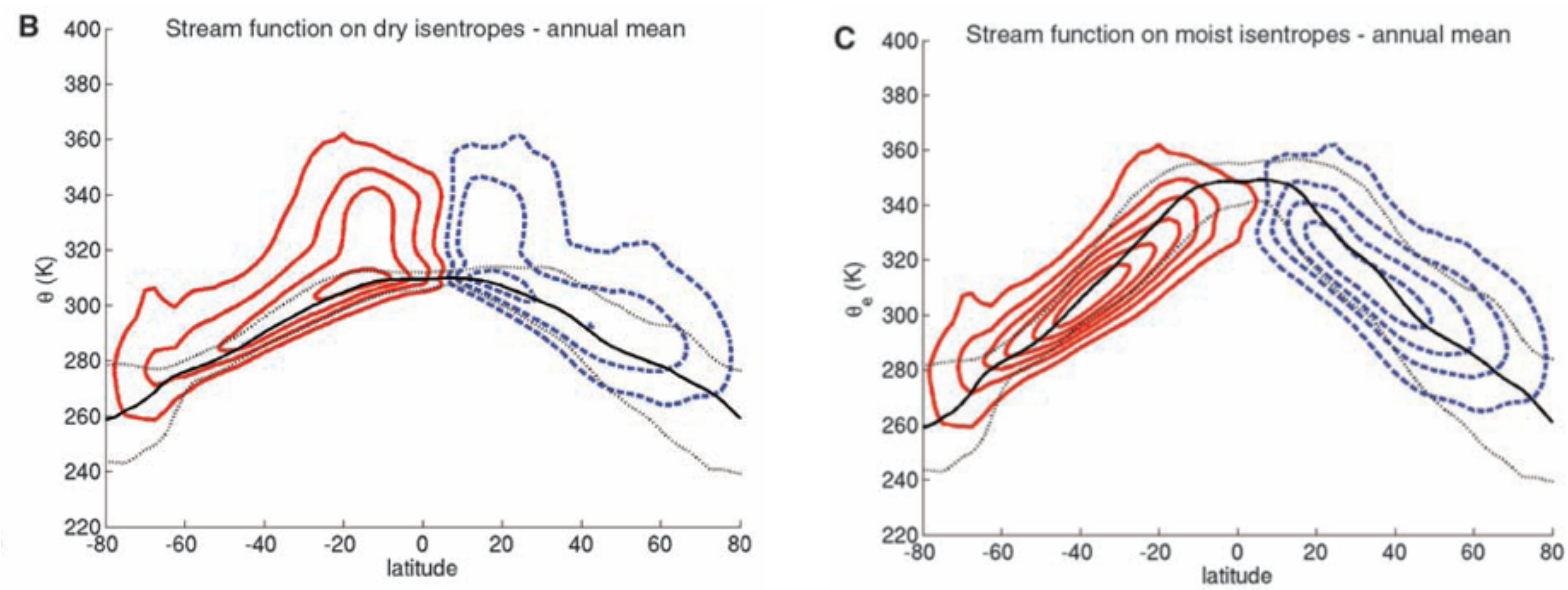
Total

Transient eddies

Northward flux of momentum (m^2/s^2)

Peixoto and Oort, Fig 11.7

Why is the mean circulation very different when potential temperature is used as a vertical coordinate?



(Pauluis et al, Science, 2008)

We will explore the closely related
Transformed Eulerian Mean (TEM) framework