General Circulation:
Ideas & Controversies: 1735 – early 1950s

ISU Mt 590
Daryl Herzmann
2 Dec 2003

In the beginning...

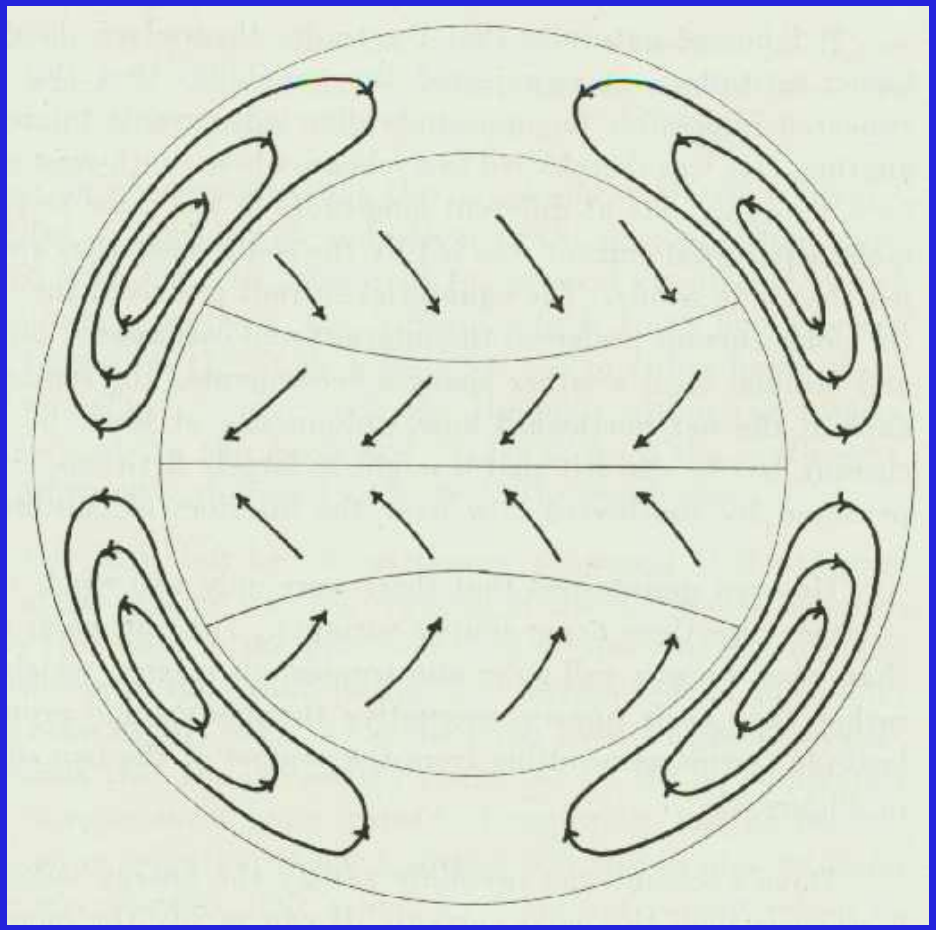


Figure 30. Lorenz, 1979

- George Hadley, 1735
  - British physicist
  - Tried to explain the trade winds at low latitudes
  - Thermally direct cell, “warm air rises, cold air sinks”
  - First conceptual model

Problems with Hadley's model

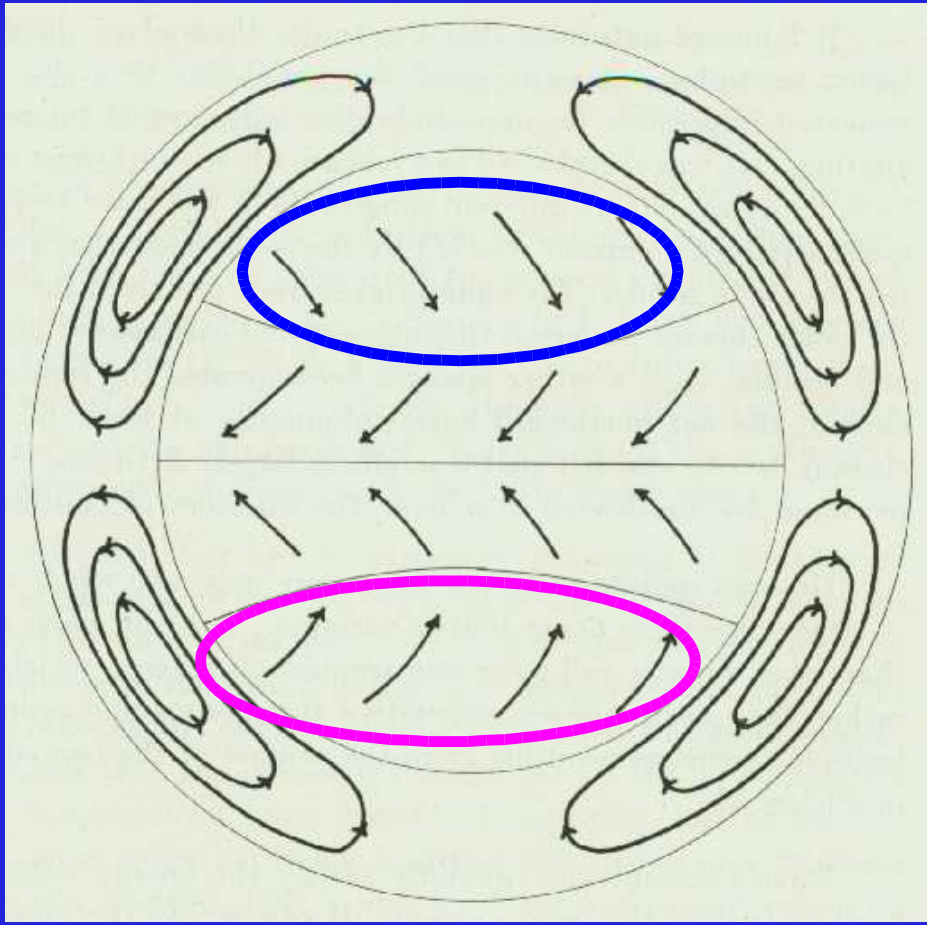


Figure 30. Lorenz, 1979

- Hadley's model depicts westerlies blowing from north of west instead of the observed south of west.
- Winds do not vary along latitude circle, this creates a near impossible air pressure scenario
- The long trek of air parcels from the equator to the poles would create tremendous westerly velocities

And 50 years later

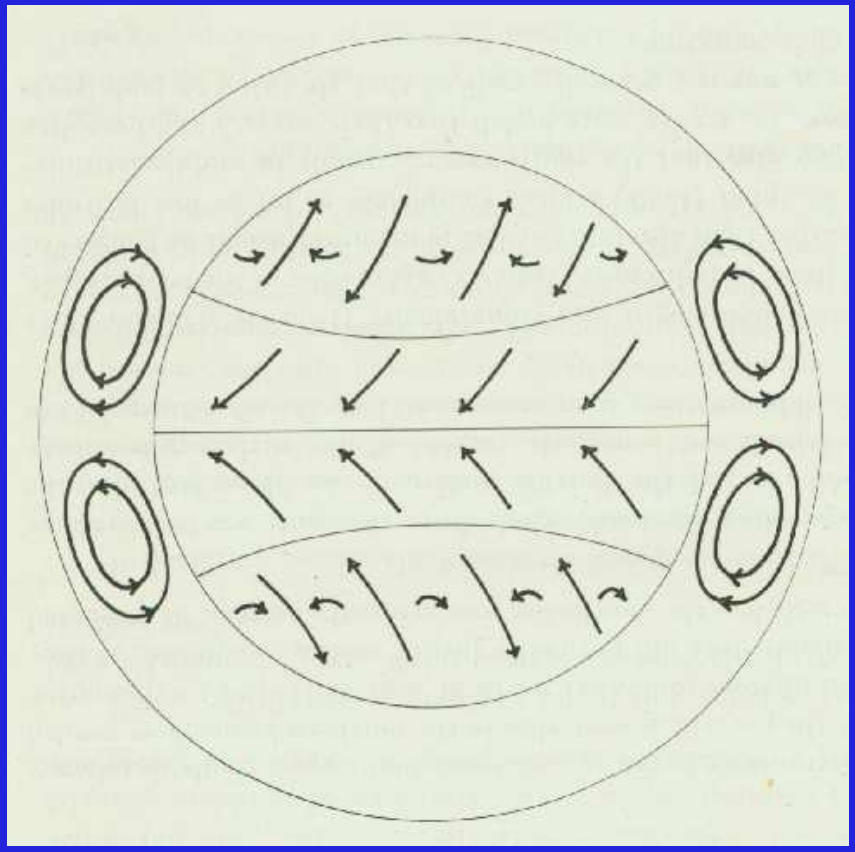


Figure 31. Lorenz, 1979

- Dove (1837) proposes that NE and SW winds alternate around a latitude circle
- Can satisfy the energy, momentum and water balance requirements.
- Big problem, all motions were adiabatic!

Matthew Maury, 1855: Indirect Cell

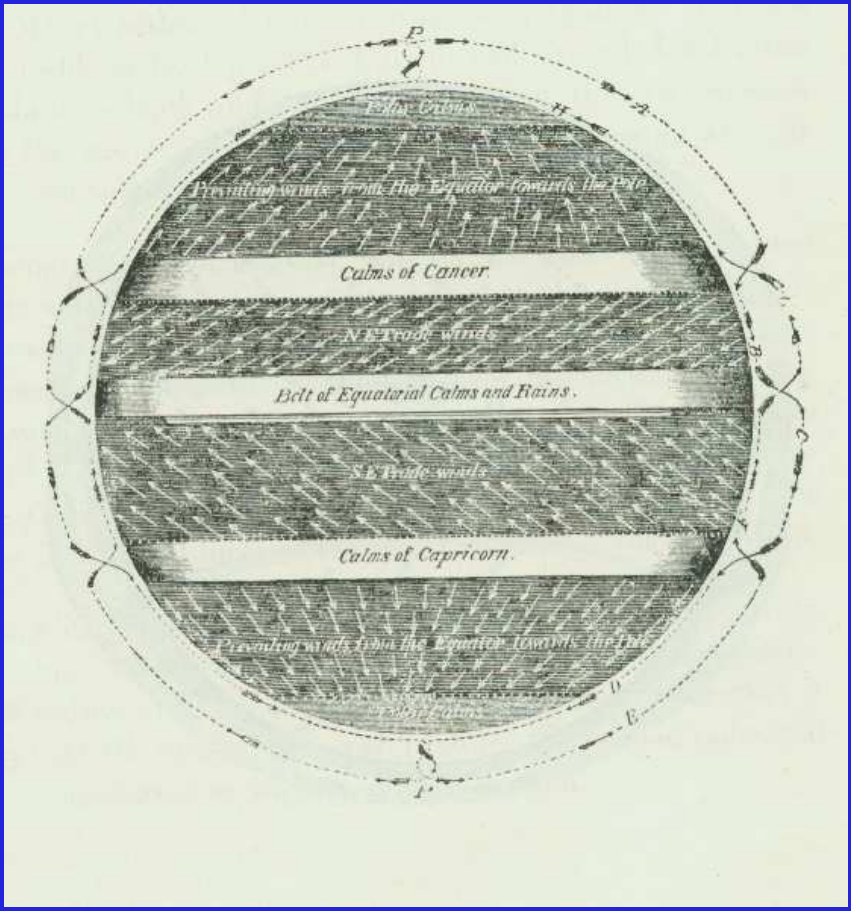


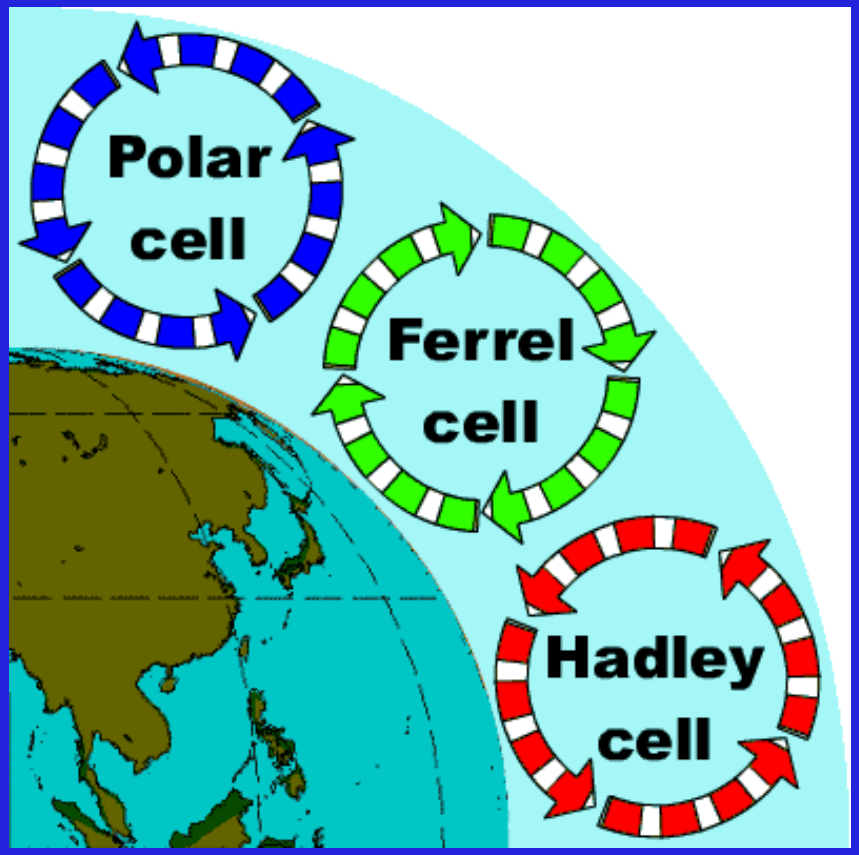
Figure 32. Lorenz, 1979

- Proposes the indirect cell north of the horse latitudes.
- Air would be transferred between the cells in an organized fashion.
- Maury could not explain the physical mechanism supporting the indirect cell, but hypothesized about it from all of the naval observations he had taken.

William Ferrel

- School teacher trying to pay his way through college. Eventually made it to Nashville were he was able to 'live'
- Around 1850 Ferrel came across the a copy of Newton's Principia which had been ordered by a resident of Liberty, MO but then never collected
- He hypothesized that the moon and the sun retard the Earth's rotation.
- Later, he read Muary's book and became immediately interested

Three cells are better than one



- Based this on his observations of surface pressure.
- Agreed with Hadley's direct equator cell.
- Importance of his paper
  - Introduced the north-south component of the Coriolis Force
  - Description of Geostropic wind
  - Pressure field adjusting the wind, instead of vice-versa

Big Problems with the Ferrel Cell

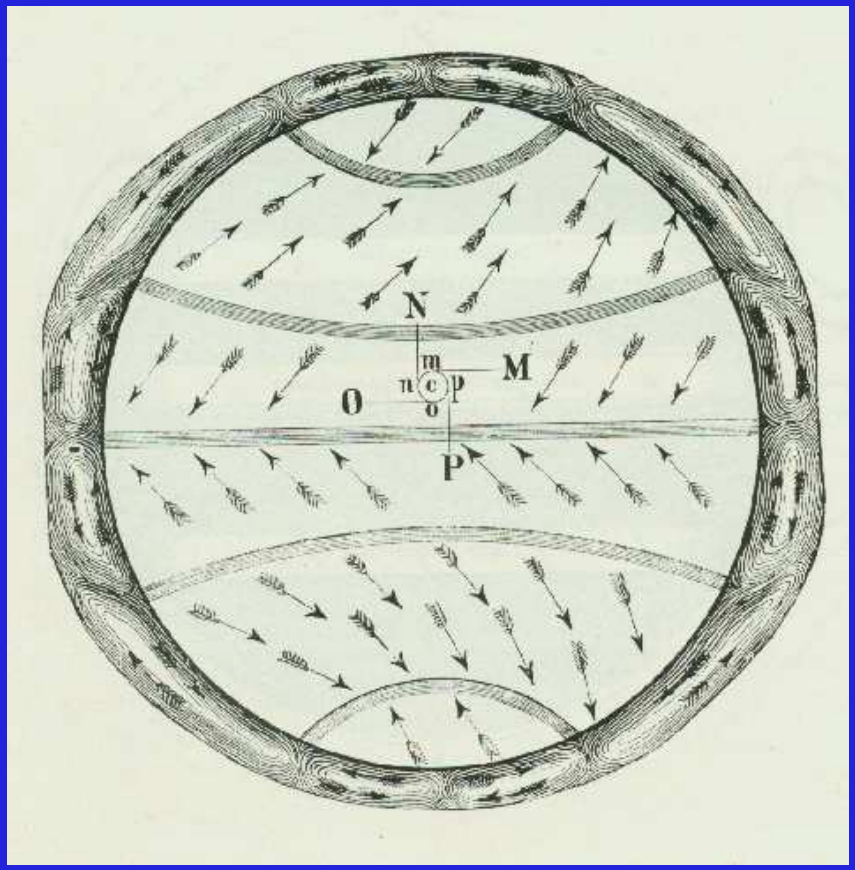


Figure 33. Lorenz, 1979

- Angular momentum and energy must be transferred to the equator which is opposite to what needs to happen due to differential solar heating and the Earth's spin.
- The upper-level mid-latitude westerlies are in a Ferrel cell which would indicate easterlies.

Having it both ways!

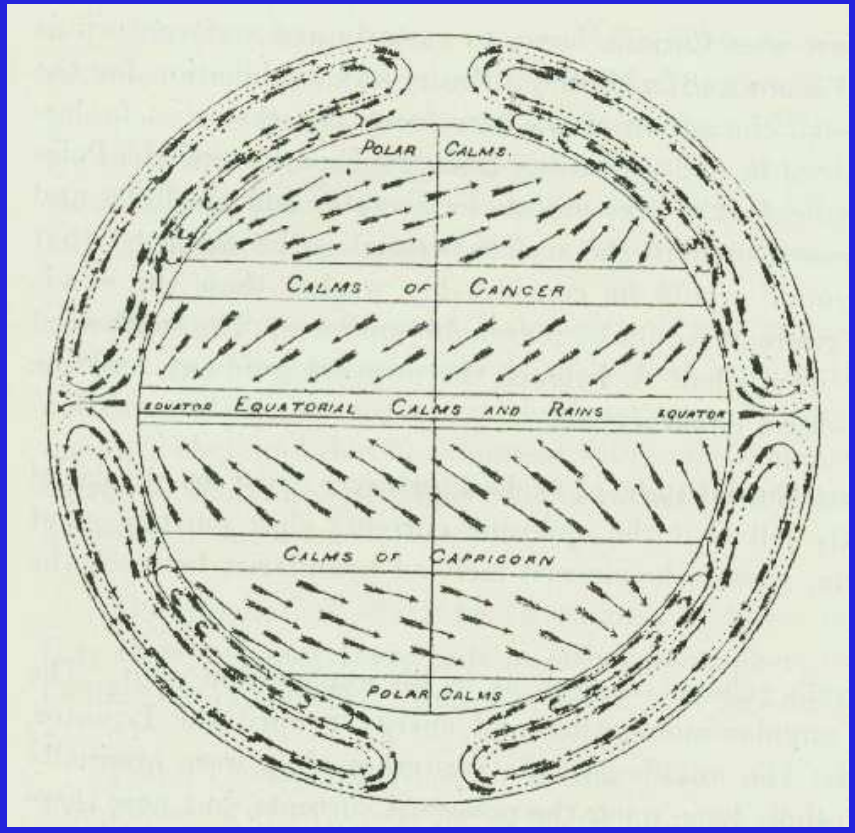
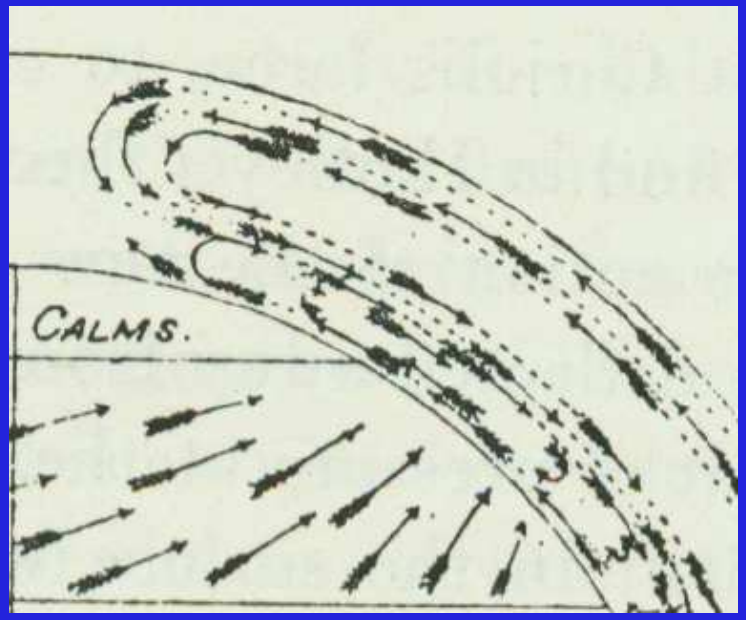


Figure 34. Lorenz, 1979

- James Thomson (1857)



Ferrel revised his model (1859)

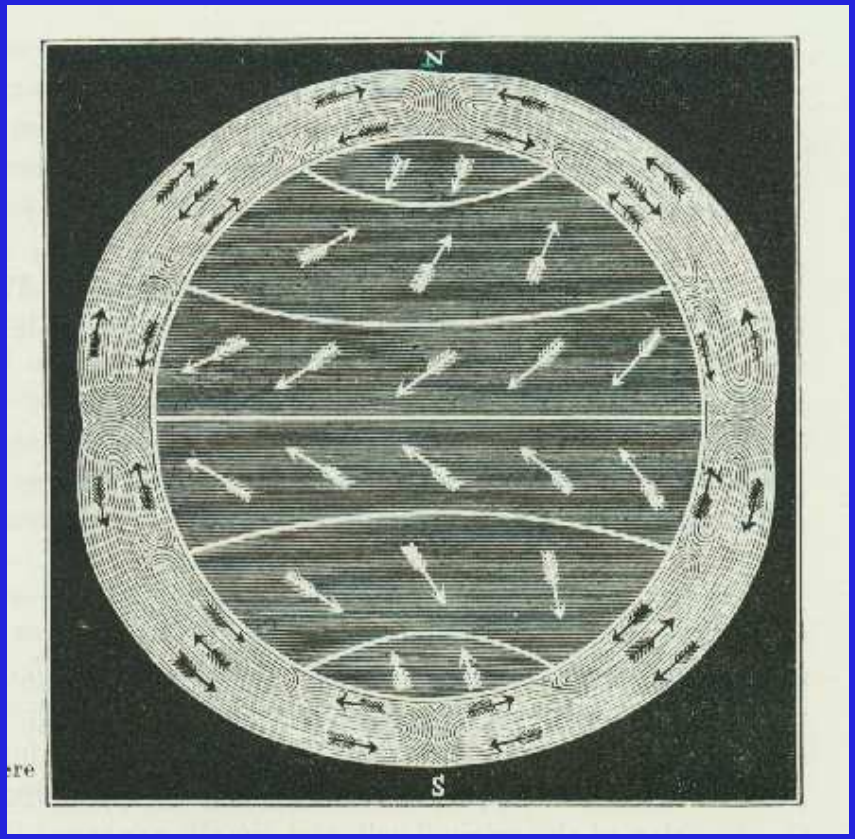


Figure 35. Lorenz, 1979

- He was intrigued about applying equations to represent general circulation, but thought that the frictional forces could not be properly formulated.

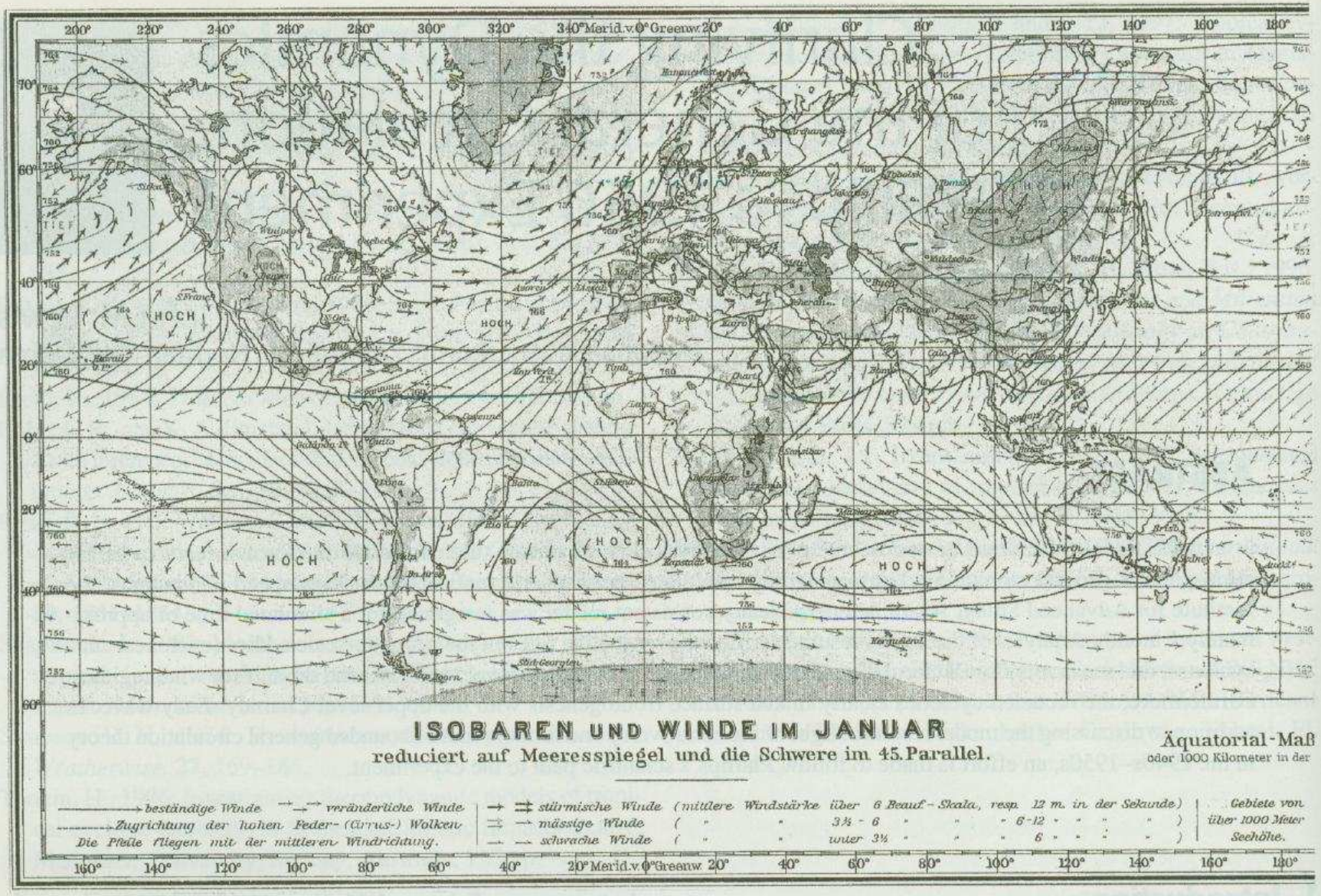
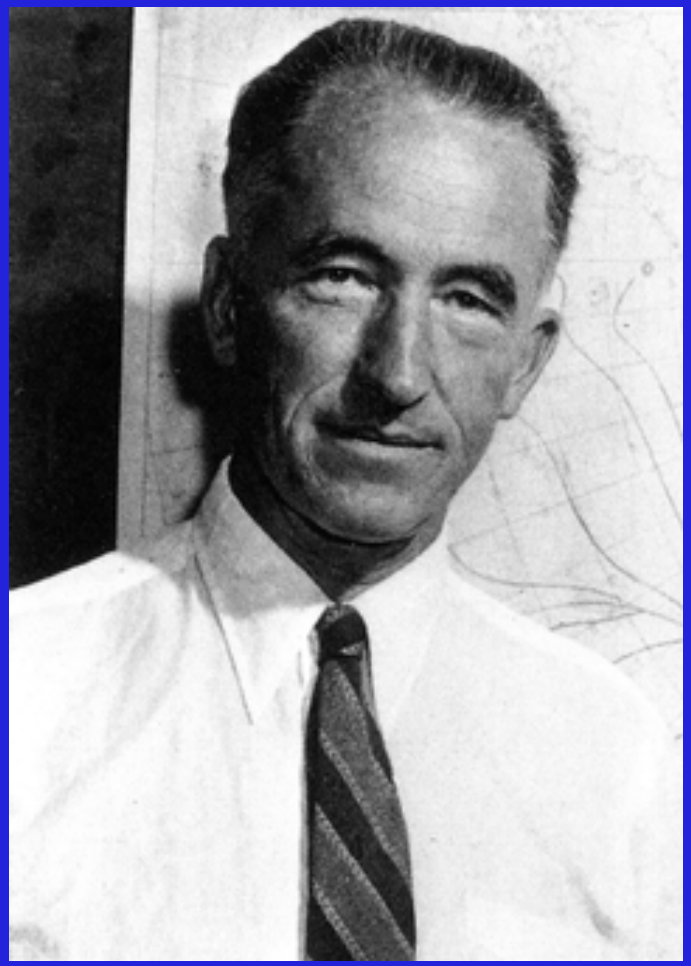


FIG. 1. Global wind and pressure patterns derived from late nineteenth-century charts constructed at Seewarte ("Sea Watch"). Isobars are labeled in mm (Hg) and the wind vectors combine both steadiness and strength. The steadier the wind, the longer the vector, and the stronger the wind (Beaufort scale), the thicker the shaft. Key words in the legend are *beständige* (steady), *veränderliche* (variable), *stürmische* (stormy), *mässige* (moderate), *schwäche* (weak), and *windstärke* (wind force/Beaufort scale). (Courtesy of Deutsche Seewarte, Hamburg, Germany.)

Skipping ahead, 1926 Jeffreys

- Stated that asymetric eddies (cyclones/anti-cyclones) were an essential component of the atmospheric circulation
- Symetric meridional circulations were not possible due to friction
- Paper was ahead of its time

1930s: Bjerknes & Palmén



- 120 radiosondes to investigate cyclone for 2 day period over 11 countries in Europe
- Found sloping frontal zone
- Bifurcation in the tropopause

1944: Brunt

- "It has been pointed out by many writers that it is impossible to derive a theory of the general circulation based on the known value of the solar constant, the constitution of the atmosphere, and the distribution of land and sea . . . It is only possible to begin by assuming the known temperature distribution, then deriving the corresponding pressure distribution, and finally the corresponding wind circulation"

Victor Starr 1947

"...up to the present time no rational theory approaching any degree of completeness has been devised to explain what we may call the general circulation."

1957: Eady

- "If from this incomplete survey, the reader has gained the impression that general circulation problems are complicated, this is as it should be. The point is that mere complication does not prevent their being solved. Much of the complication shows itself when we attempt to give precise answers instead of vague ones . . . To answer problems in any branch of geophysics we need vast quantities of observations but we also need precise, consistent, mathematical theory to make proper use of them"

Carl-Gustav Rossby

- Swedish
- Came to America in 1926
- Credited with assigning red to warm fronts and blue to cold fronts (1919)

Institute of Meteorology, U of Chicago

- Established on 1 Oct 1940 by Rossby & Byers
- Rossby wanted a midwest location to study storms before they effected the east coast.
  - Wrote letters encouraging the foundation of a Met program at U of Chicago, funding was a problem
  - Wanted Jacob Bjerknes to lecture to generate interest
- Horace Byers was "bored with the Weather Bureau folks, pleasant and cordial as they where", felt he needed a "higher intellectual plane" (sorry Grams!)

Avery provided start-up funds

- Sewell Avery
  - provided $15,000 (~ $180,000 today)
- Institute of Meteorology founded
  - Rossby, in charge
  - Byers, executive Secretary
  - Victor Starr, Henry Wexler, Michael Ference, Henry Leppard, and Oliver Wurf were hired on as faculty
  - Vincent Oliver was the first student

WWII Training

- Roosevelt stated that 50,000 military aircraft should be built, which would require 10,000 officers with Met training
- Rossby was in charge of the training by the "Big Five" programs
  - MIT, NYU, Cal Tech, U of California, Chicago
  - 1700 students were trained in 9 month courses at the U of Chicago. 9,000 total by all institutions.

Fight, Fight, Fight!

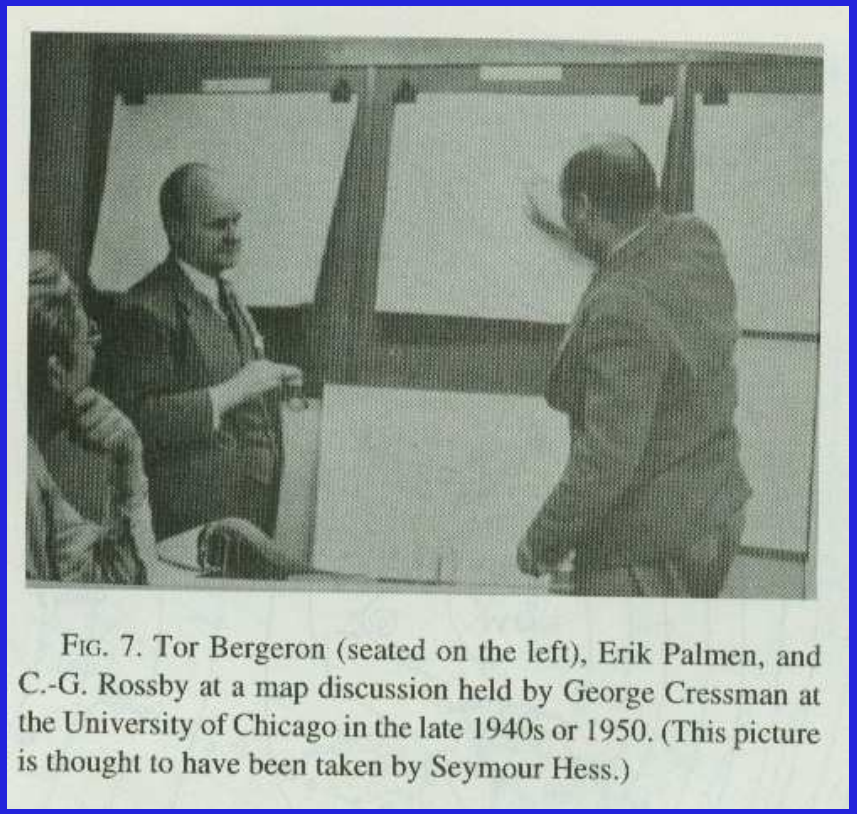


FIG. 7. Tor Bergeron (seated on the left), Erik Palmen, and C.-G. Rossby at a map discussion held by George Cressman at the University of Chicago in the late 1940s or 1950. (This picture is thought to have been taken by Seymour Hess.)

- George Cressman would lead a daily map discussion which would often provoke heated debates between Palmén and Rossby.

After WWII...

- Upper air observations were now available
- Research and Analysis techniques were developed to use this data
- The U of Chicago folks spread out

Notable U of Chicago PhDs

Victor Starr 1946
Dave Fultz 1947
Herbert Reihl 1947
George Platzman 1948
George Cressman 1949
Seymour Hess 1949
Norman Phillips 1951
William Gray 1964

15 went on to be presidents of the AMS

Victor Starr

- Second to get PhD at U of Chicago (1946)
- Went to MIT afterwards

Sidetrack: JoAnne Malkus-Starr-Simpson

- Married Victor Starr and was subsequently fired from U of Chicago
- Worked at Illinois Tech and took classes on the side.
- Rossby leaving to Sweden opened the door for her.
- 1949 PhD U of Chicago under Hebert Riehl

Simpson's Struggles

- "No woman has ever earned a PhD in Meteorology. No women ever will. Even if you did, no one would give you a job"
  – *Grad student advisor, U of Chicago 1946*
- "Cumulus clouds compose a fine line for a 'little girl' to work on, because it wasn't important enough to interest real meteorologists, and so you could stand out like a sore thumb."
  - *MIT Professor 1949*

Ahhh, true love!

Joanne and Victor Starr
1945
Chicago

And then came Bob Simpson

Joanne and Bob
after wedding

1965

Bob's 50th Birthday

Ingrid Perrson, Bob, Joanne, Herb Riehl, Karen (age 4)

Bob's 50th Birthday

1972

Lunch with the Fujitas!

Ted Fujita and his wife Susie
Bob and Joanne
1973
Chicago (Ted's back yard)

“Staff Members”, 1947: On the General Circulation of the Atmosphere in Middle Latitudes

- Authors: T.C. Yeh, Jule Charney, George Cressman, Dave Fultz, Seymour Hess, Alf Nyberg, Erik Palmén, Carl-Gustav Rossby, Zdenek Sekera, Victor Starr
- Rossby's views of global circulation dominated
- Tried to explain the NH winter circulation
- Noted uniform vorticity north of the jet, and sharp decrease south of the jet. This was attributed to strong lateral mixing north of the jet.

Starr, 1948: An Essay on the General Circulation of the Earth's Atmosphere, JofM

- Landmark paper.
  - 5 pages, 3 figures, 5 references, **0 EQUATIONS**
- Starr referred to his essay as “a further extension of the approach to the problem initiated by Jeffreys”
- Angular momentum is transferred from the earth to atmosphere in equatorial easterlies.
- Mid-latitude westerlies transfer momentum back to the earth.
- Source (equator) and the sink (mid-latitudes) need a transport mechanism to maintain the balance!

Starr's NE-SW tilted trough

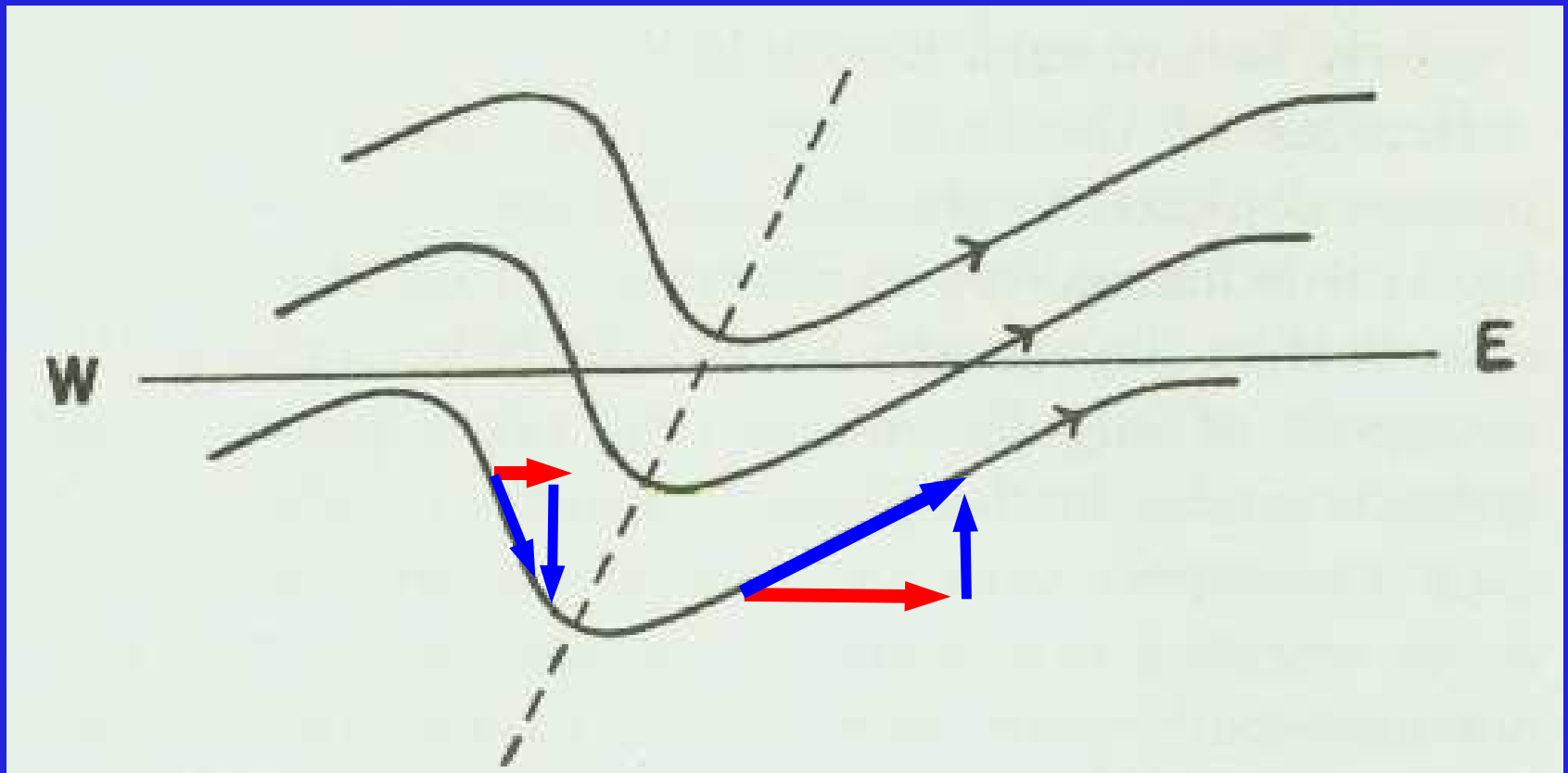


FIG. 1. Schematic picture of horizontal streamlines in a typical middle-latitude flow pattern in the upper westerlies.

Starr, 1948: An Essay on the General Circulation of the Earth's Atmosphere, JofM

- Starr felt an introduction of the concepts introduced was needed, hence zero equations, but he notes
  - "the reader who is mathematically inclined can easily supply such presentations where they are of obvious application"
- This paper sparked a heated debate with one of the former 'Staff Members'

Namias & Clapp, 1949: Confluence theory of the high tropospheric jetstream, J. Meteor.

- Jermone Namias and Philip Clapp were among the few non "Staff Members" dynamical meteorologists
- Proposed the confluence theory of jets involving a thermally direct meridional circulation at the entrance of the jet and thermally indirect circulation at the exit of the jet
- While interesting, did not explain the existence of the jet in the first place

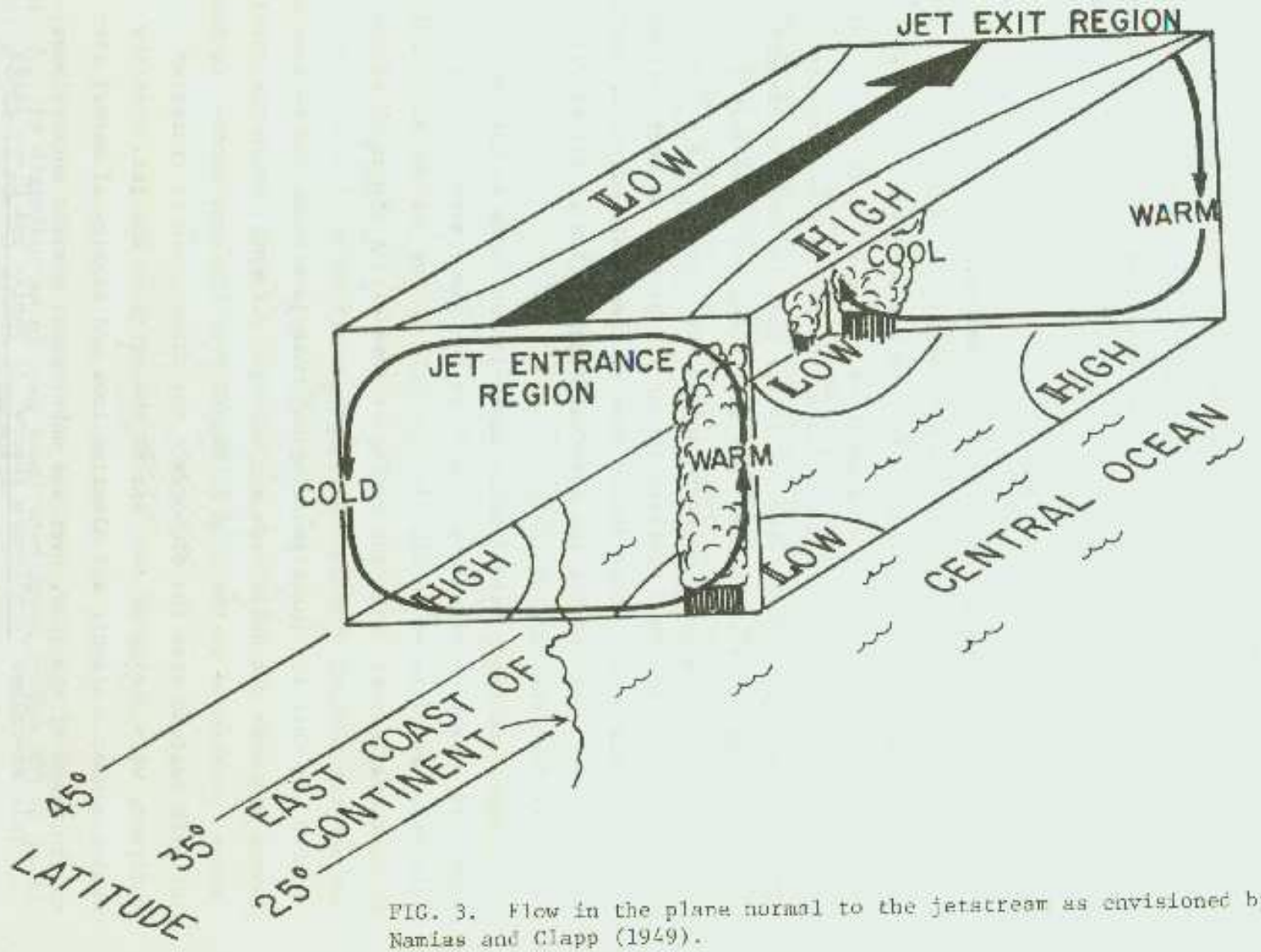


FIG. 3. Flow in the plane normal to the jetstream as envisioned by Namias and Clapp (1949).

Dave Fultz, 1949:

- Independently verified the importance of the NW-SE tilt in hydrodynamical experiments
- It gave credibility to Starr's argument.

Rossby & Starr, 1949:

- Elaborated on and formalized the balance requirement that Starr presented in 1947
- Palmén was not happy about the omission of mean meridional circulations in the angular momentum balance. So he wrote a critical letter in Dec of 1949 in Journal of Meteorology

Palmén's Letter

"It is not clear whether the authors intended to question the necessity of meridional circulations for the maintenance of the kinetic energy of the atmosphere. Such an intention would mean a complete change of the whole foundation of dynamic meteorology, and I doubt strongly that the genius of the authors, recognized by all meteorologists, will be sufficient for that goal."

Starr's Response

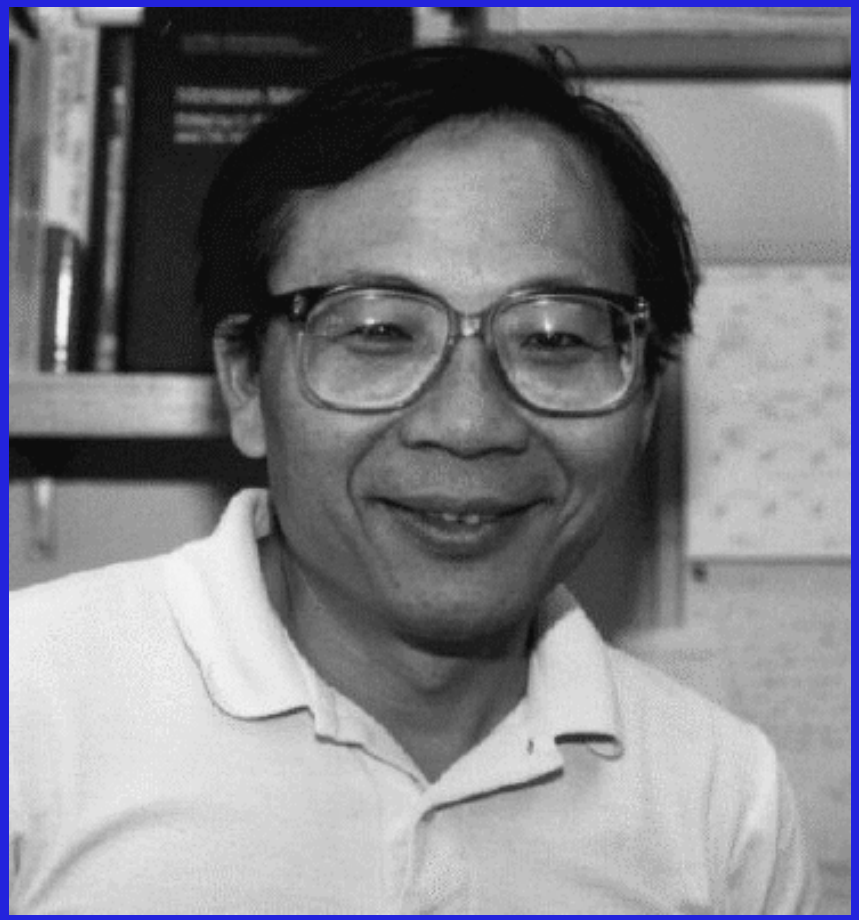
"Apparently Palmén suspects me of highest heresy... Indeed if such are the fruits of heresy, then I say let us have more heresy"

"We must encourage free experimentation with various hypotheses and proposals in order to see which ones lead to the discovery of new observationally verifiable facts, since definitive criteria for acceptance or rejection are lacking."

Palmén & Starr debate resolved?

- Palmén eventually accepted the primacy of the transient eddies
- Starr eventually accepted the role of the meridional circulations in the vertical transport of angular momentum and that they serve as important sources and sinks of zonal kinectic energy.

Acknowledgments



- Dr Chen for correcting all my errors while I gave this talk.

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