Dynamic meteorology without tears

Part III a:

Rossby's planetary waves

3rd Pskov lecture A
Anders Persson, Uppsala

Can we *see* Rossby waves?

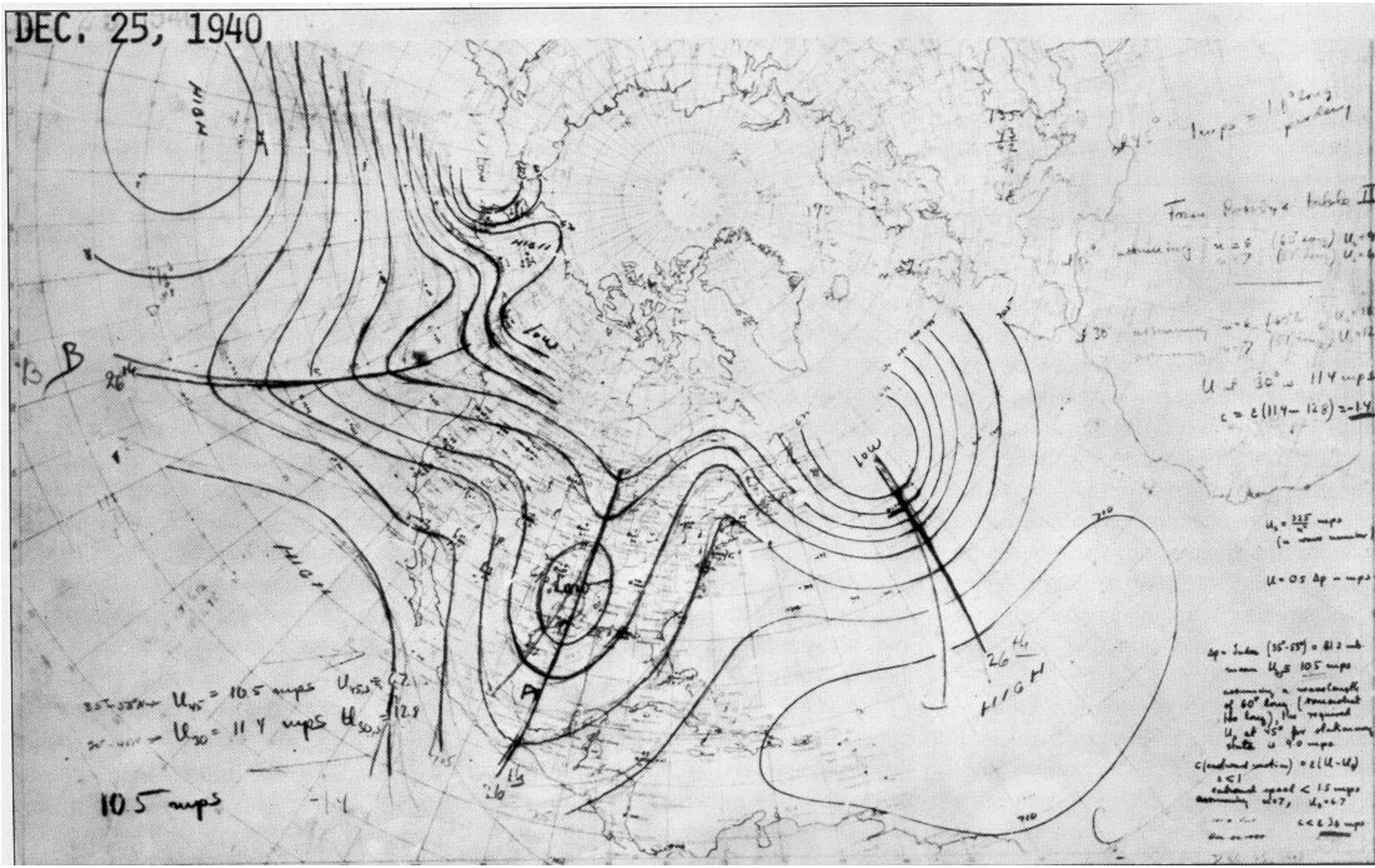
Lunch discussion at ECMWF 1995:

Scientist: -How is the weekend going to be?

AP: -Fine, a Rossby wave is seen coming in!

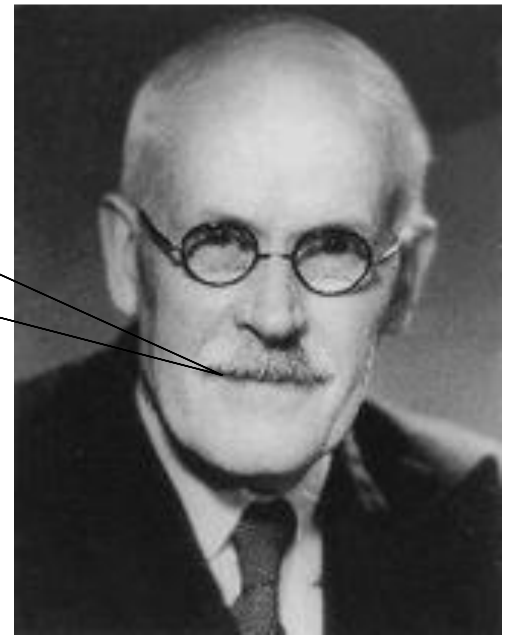
Scientist: -But can you *see* Rossby waves??

-Well, Rossby could see them - at least on Christmas Day 1940



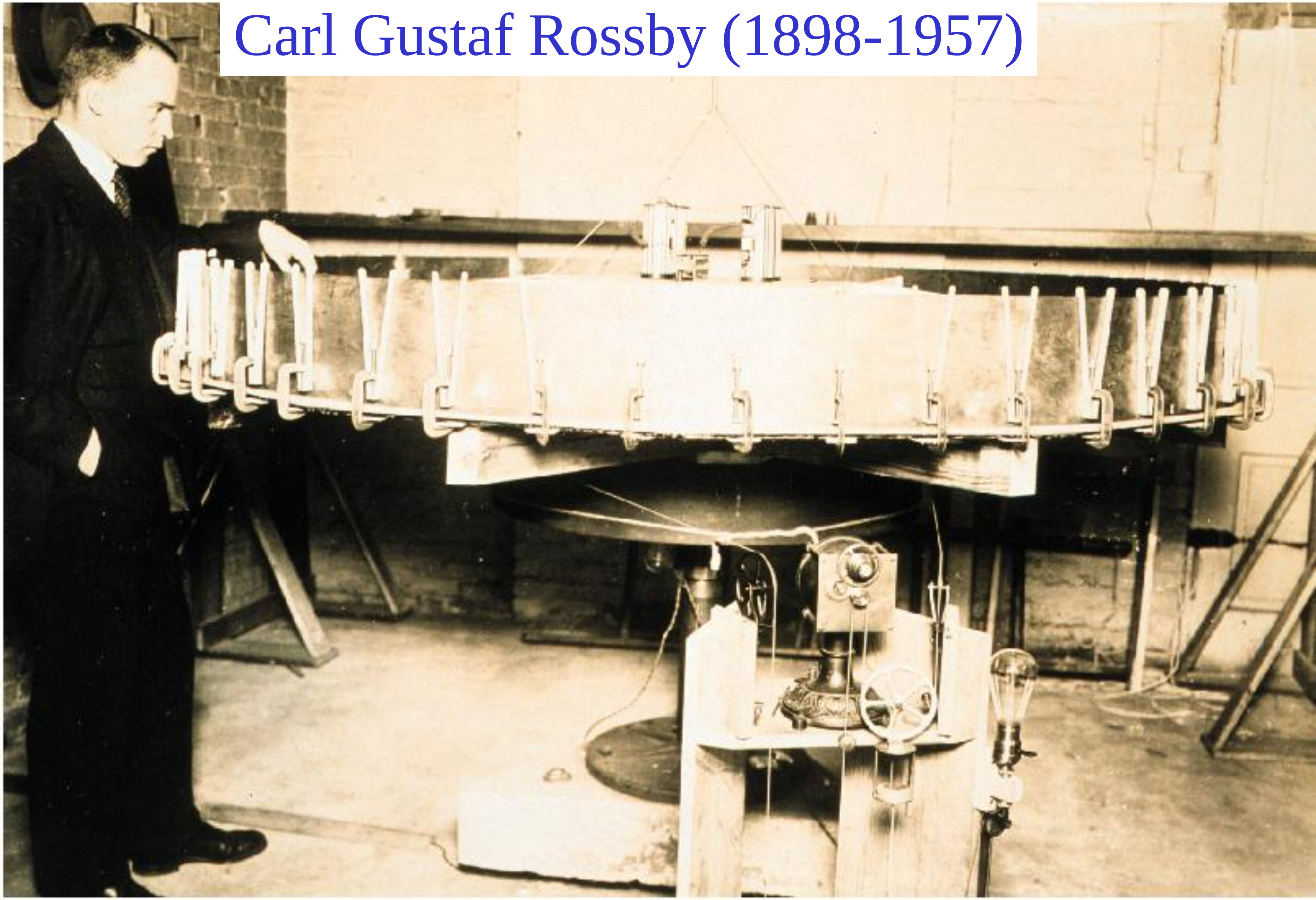
What is a Rossby wave?

I never understood what a Rossby wave was…



Sir Harold Jeffreys 1891-1989

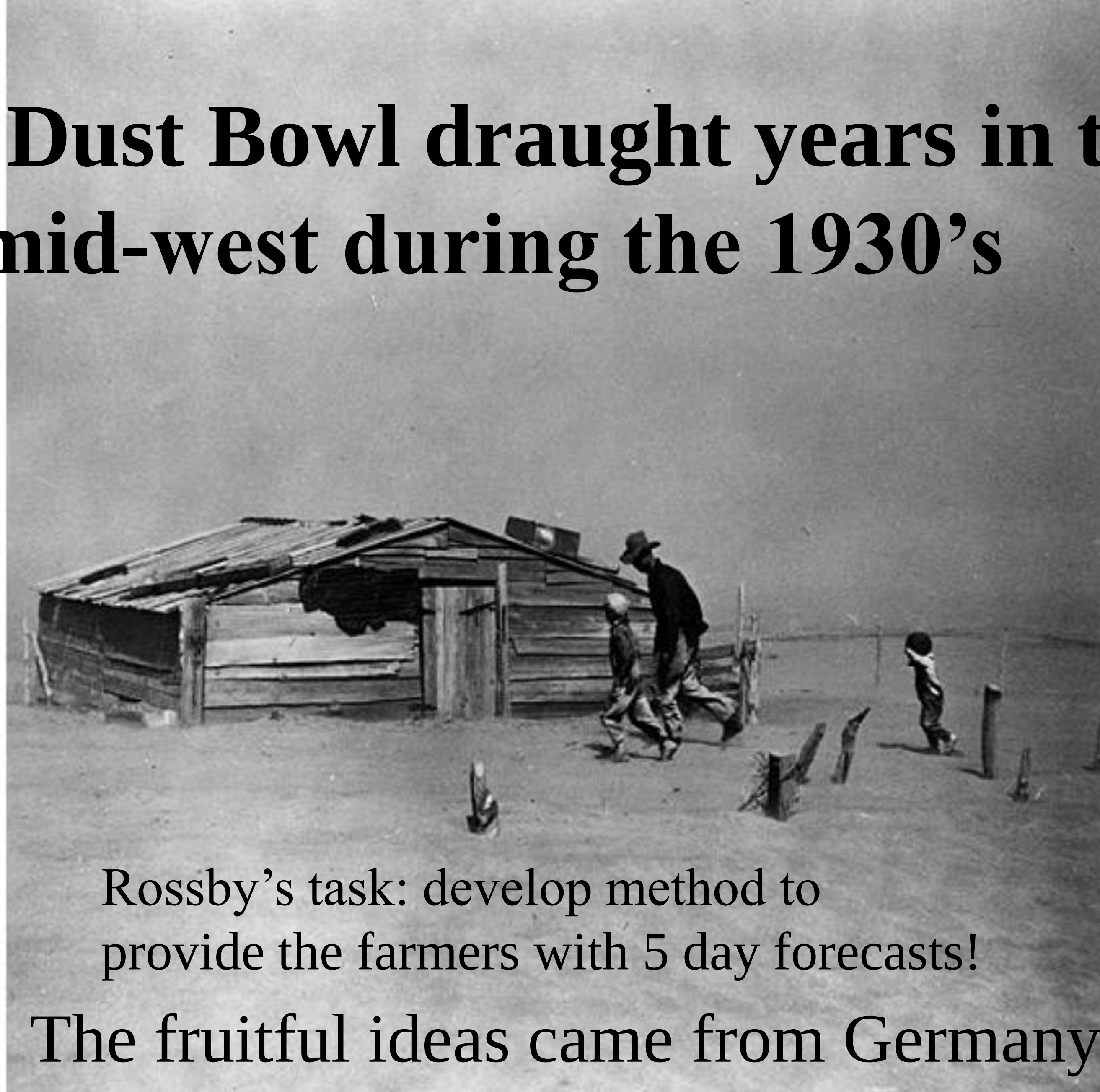
Carl Gustaf Rossby (1898-1957)



Carl Gustaf Rossby (1898-1957)

1898	Born in Stockholm, Sweden
1919-20	Bjerknes group in Bergen
1921	Studying aerology in Germany
1922-25	Weather forecaster at SMHI
1926	Moves to the United States of America to spread the Bergen school concept
1936-38	Works on geostrophic adjustment problems
1938-39	Discovers and explains “his” wave

The Dust Bowl draught years in the US mid-west during the 1930’s



Rossby’s task: develop method to provide the farmers with 5 day forecasts!

The fruitful ideas came from Germany

Five-day forecasts from August 1940

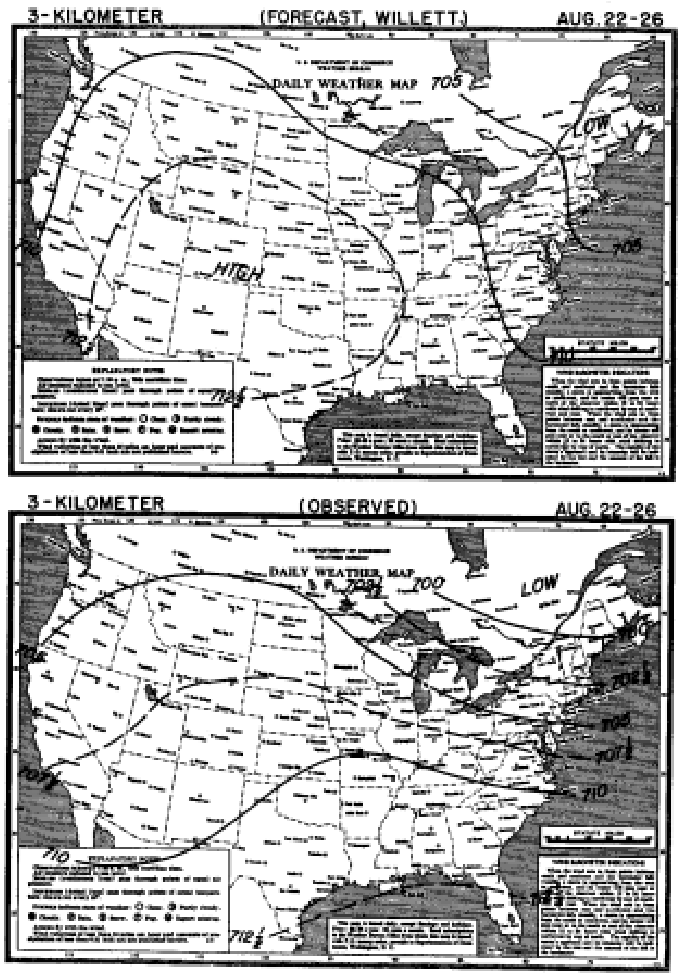


FIGURE 35.—Forecast and verification charts of mean 3-kilometer-pressure distribution (millibars) over the United States for the period August 21–25, 1940.

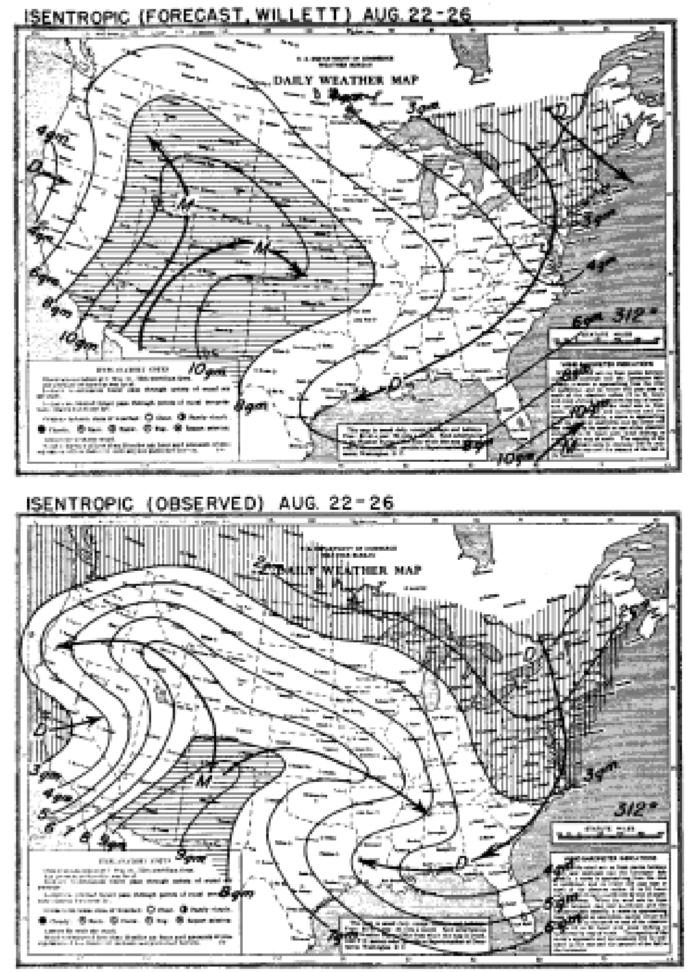
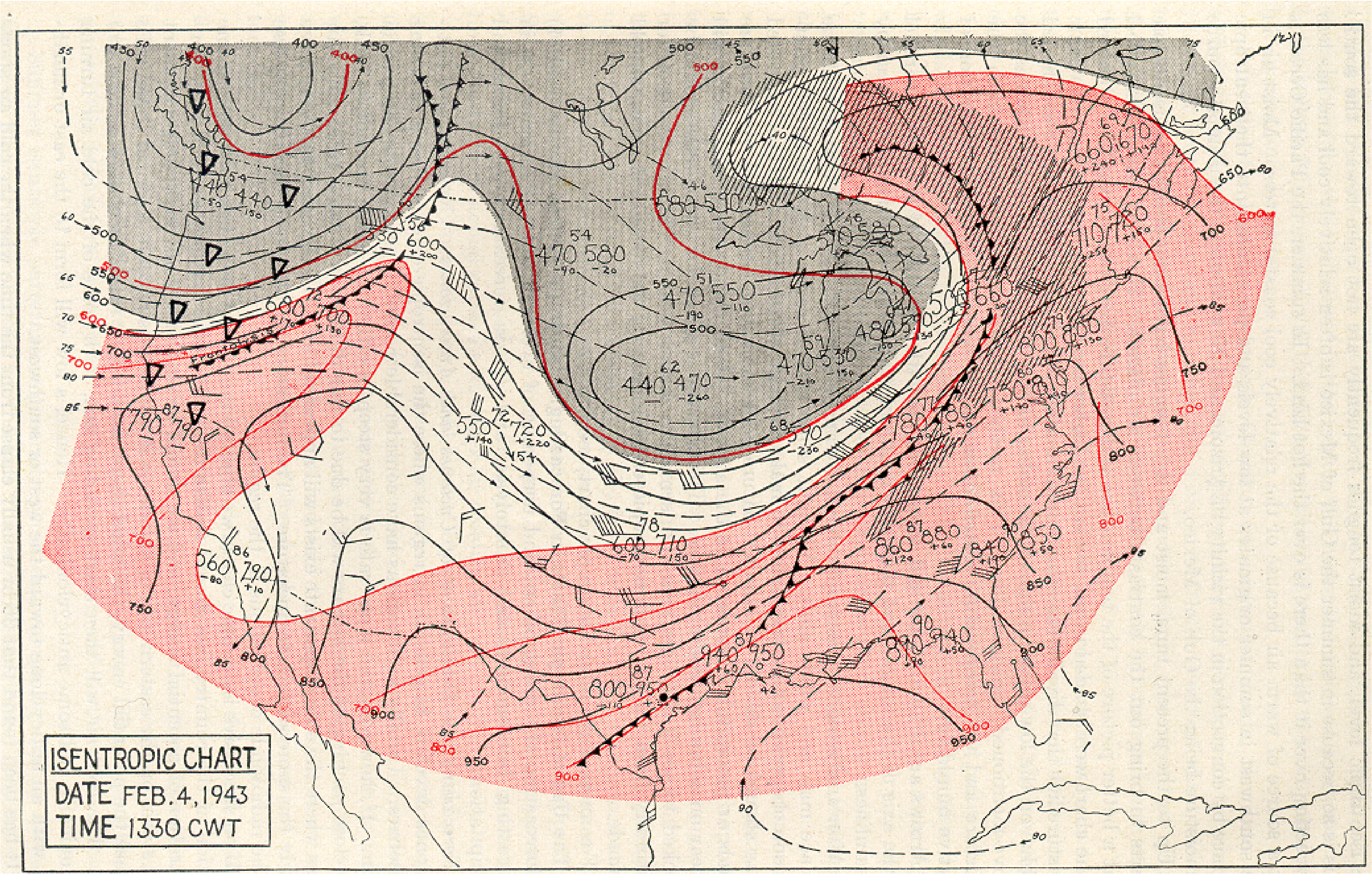
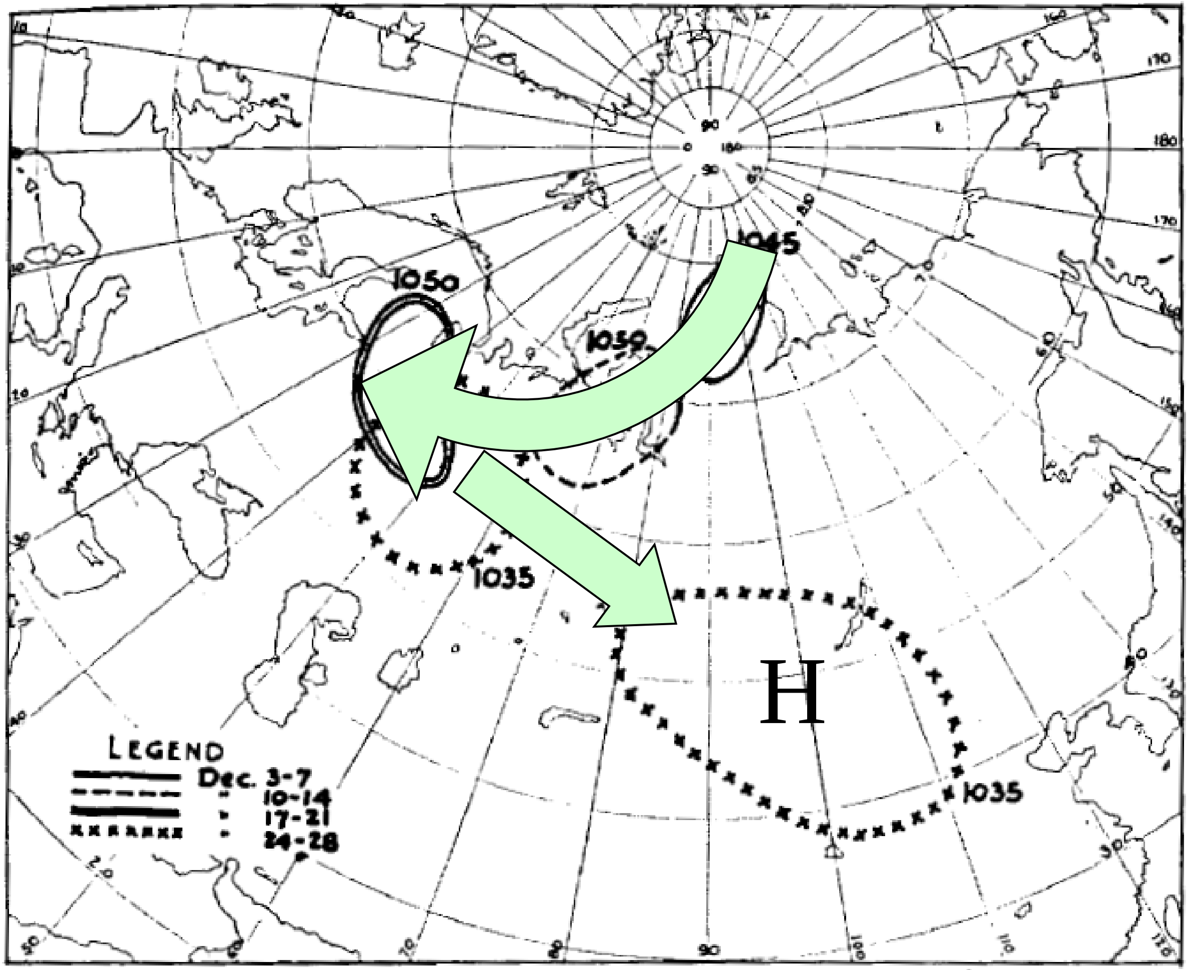


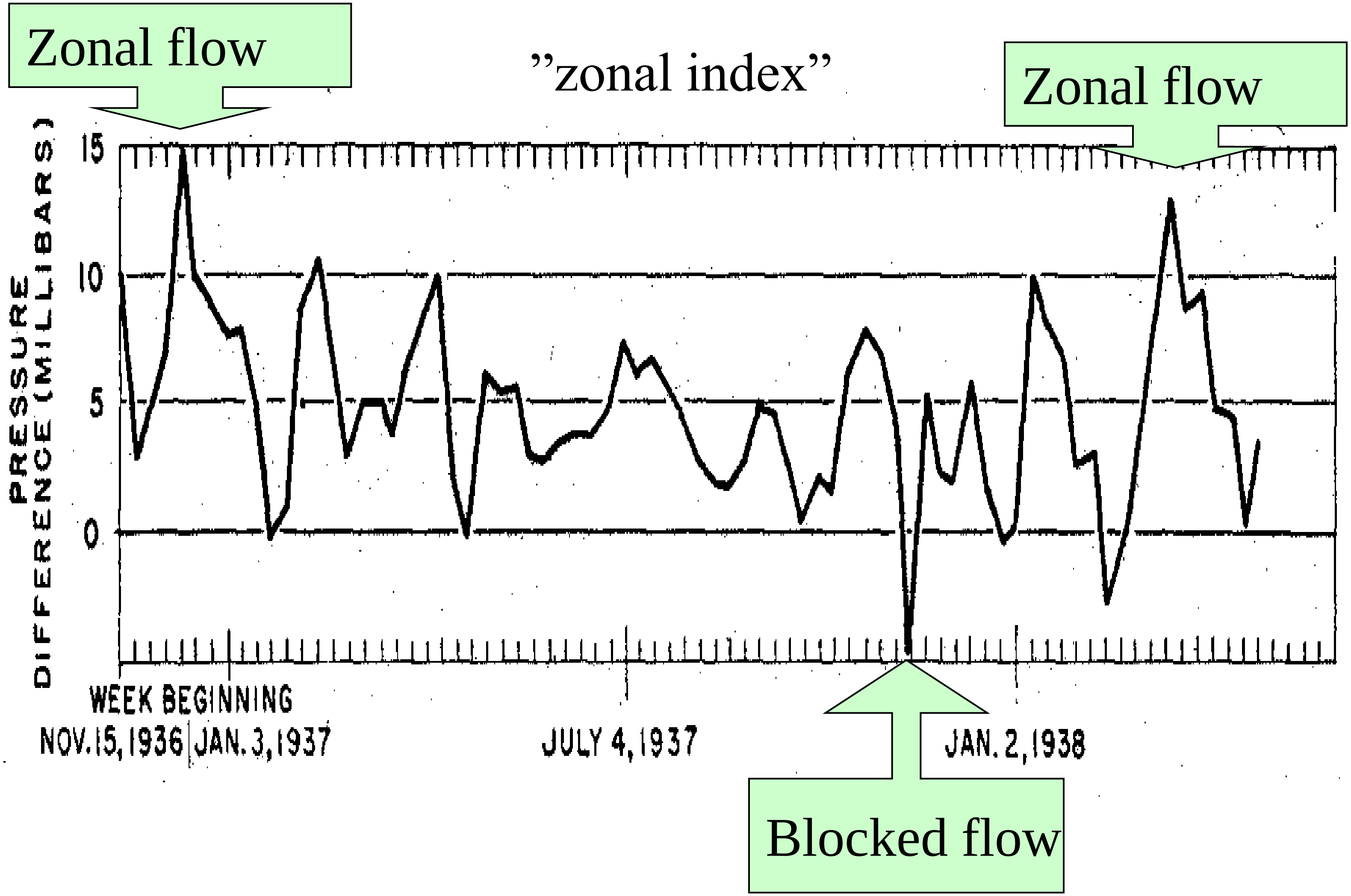
FIGURE 36.—Forecast and verification charts of the mean isentropic-moisture distribution over the United States for the period August 21–25, 1940.

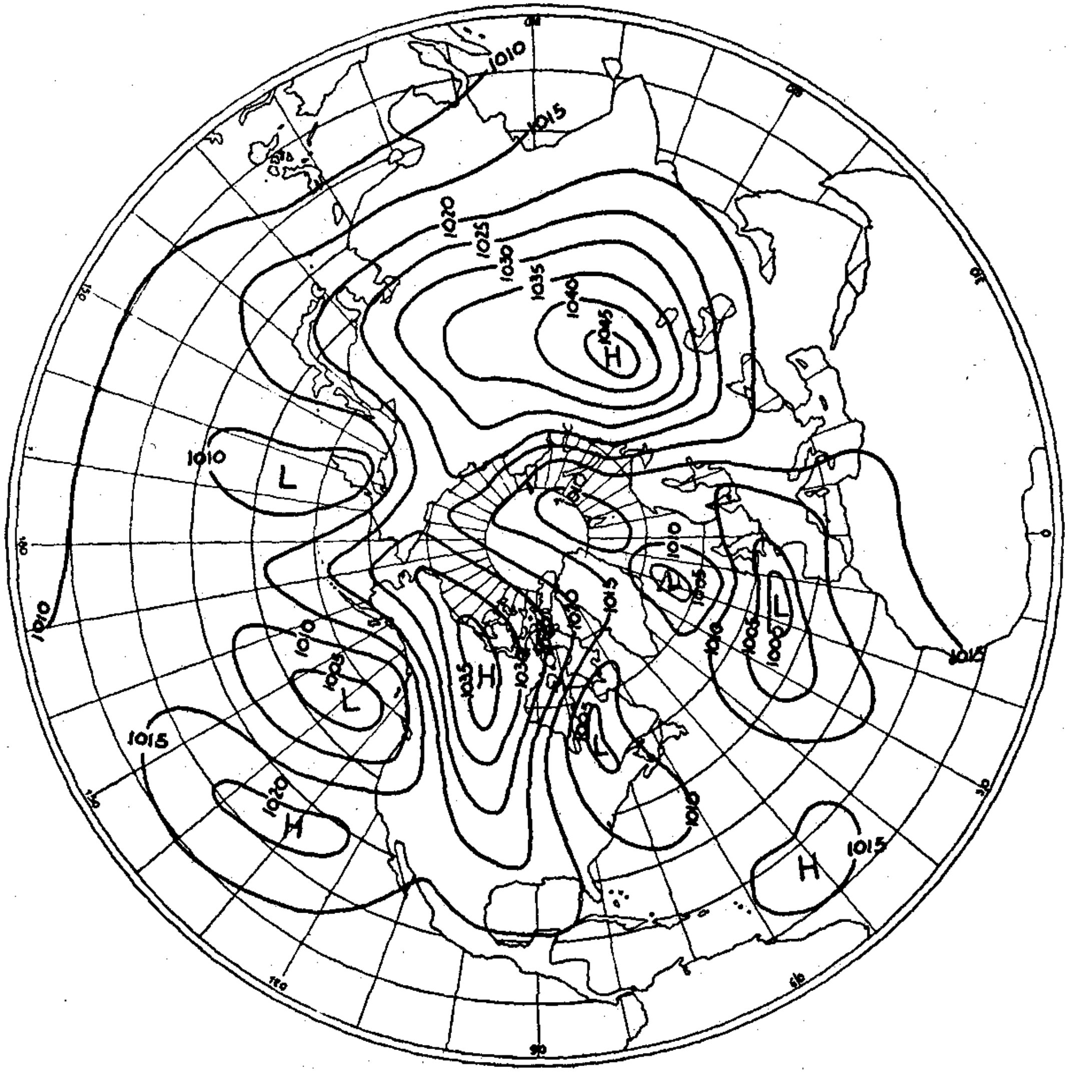

ISENTROPIC CHART
DATE FEB. 4, 1943
TIME 1330 CWT

Motions of the Siberian high Dec 1938



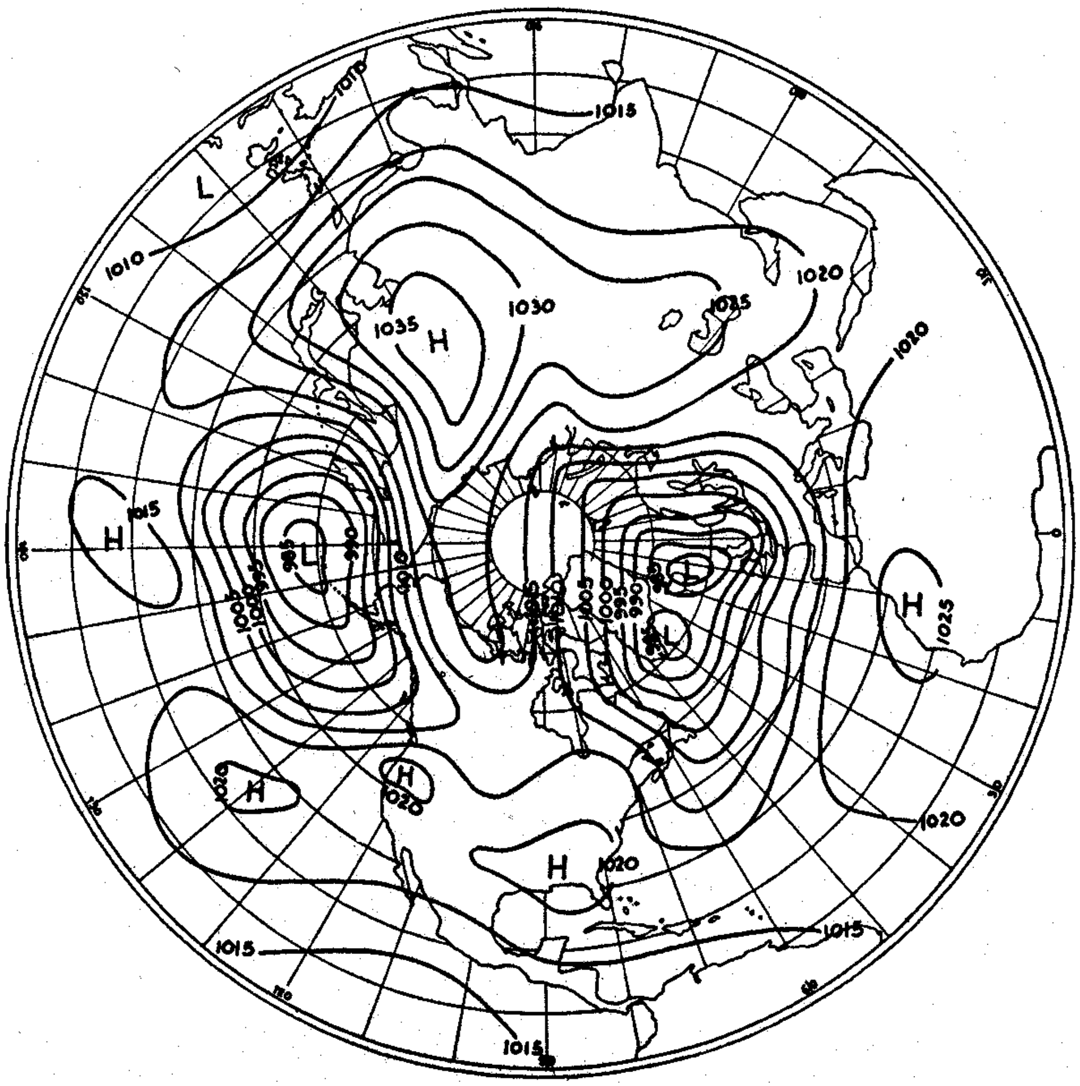
Pressure difference between 35º and 55º latitude





Low Index Circulation 14-20 Nov 1937

Blocked Flow



High Index Circulation 9-15 Jan 1938

Zonal Flow

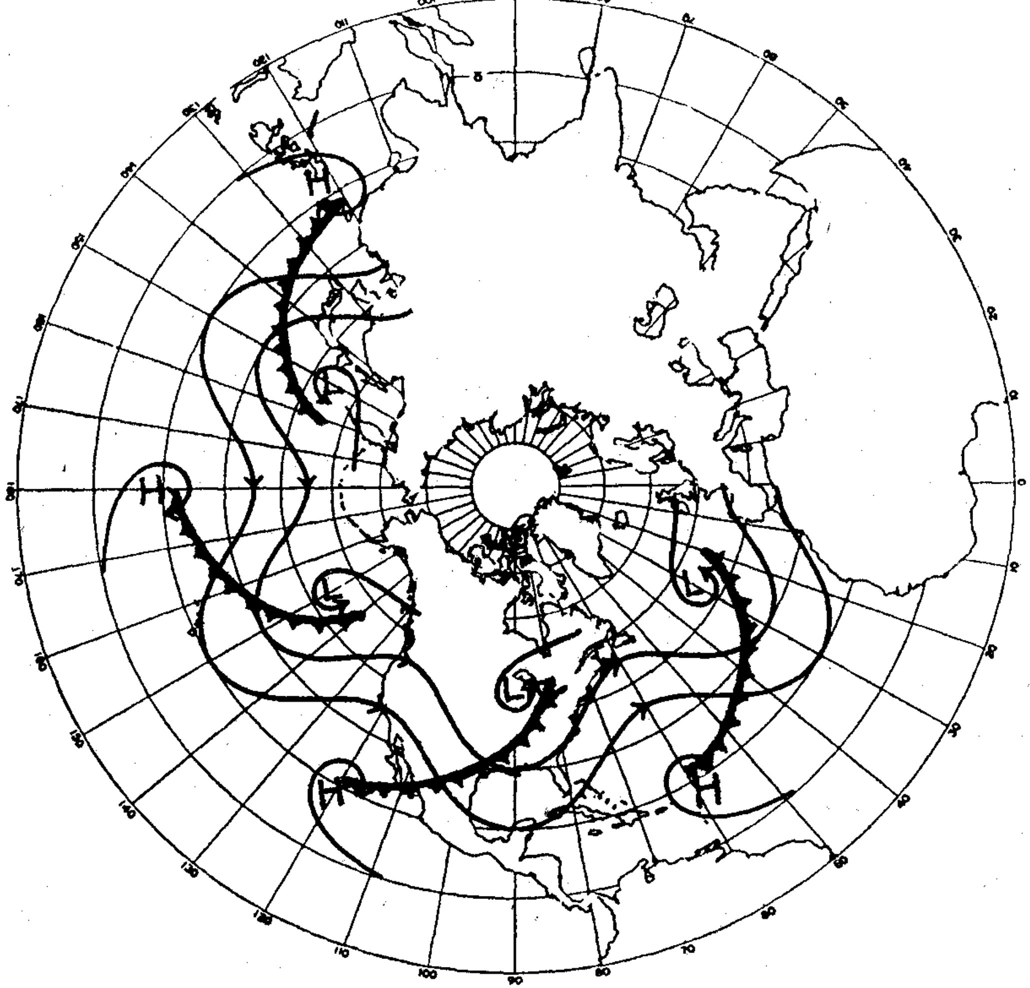
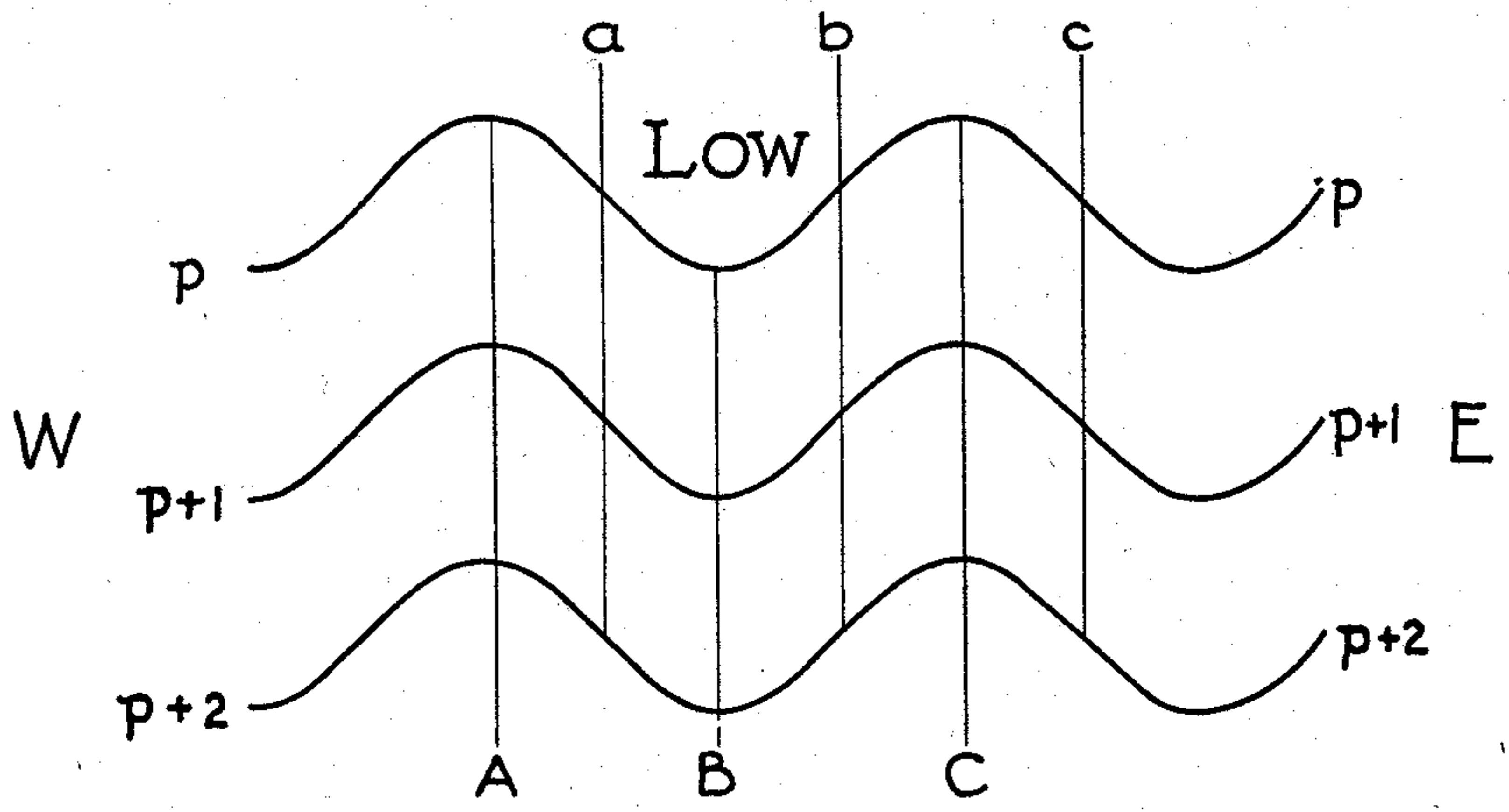


FIGURE 15.—An example of the theoretical planetary flow pattern for weak zonal circulation. Compare this diagram with figure 14 and note the presence in both of a split Aleutian low and a split Icelandic low, with one branch centered over eastern North America. In comparing the two diagrams it should be remembered that the wave pattern of the westerlies indicated here is in reality (fig. 14) obscured by shallow cold-air anticyclones but that it would appear clearly on a corresponding chart for the 3-kilometer level.

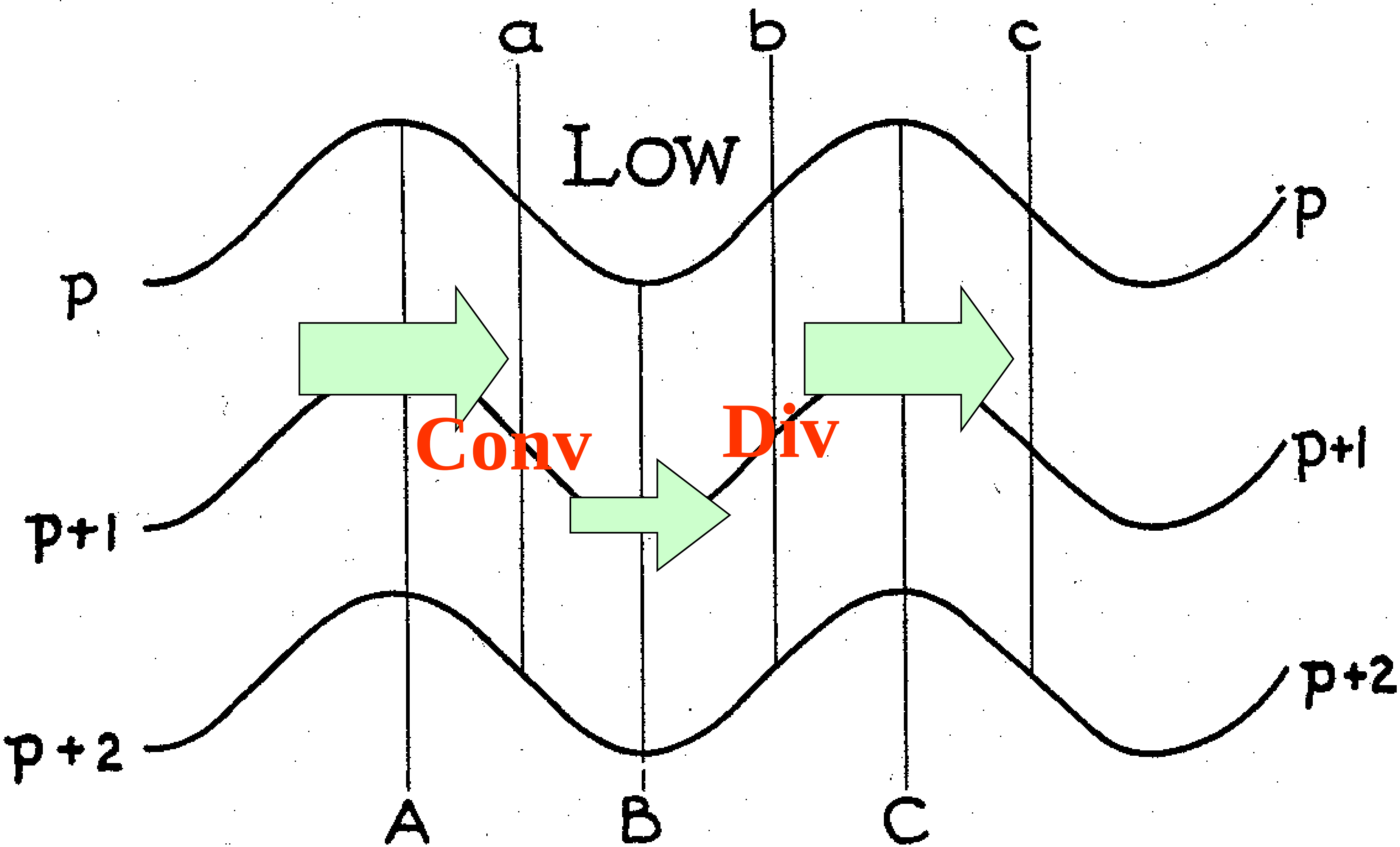
But what ”is” it?

The isobaric channel illustration used by Rossby et al (1939)

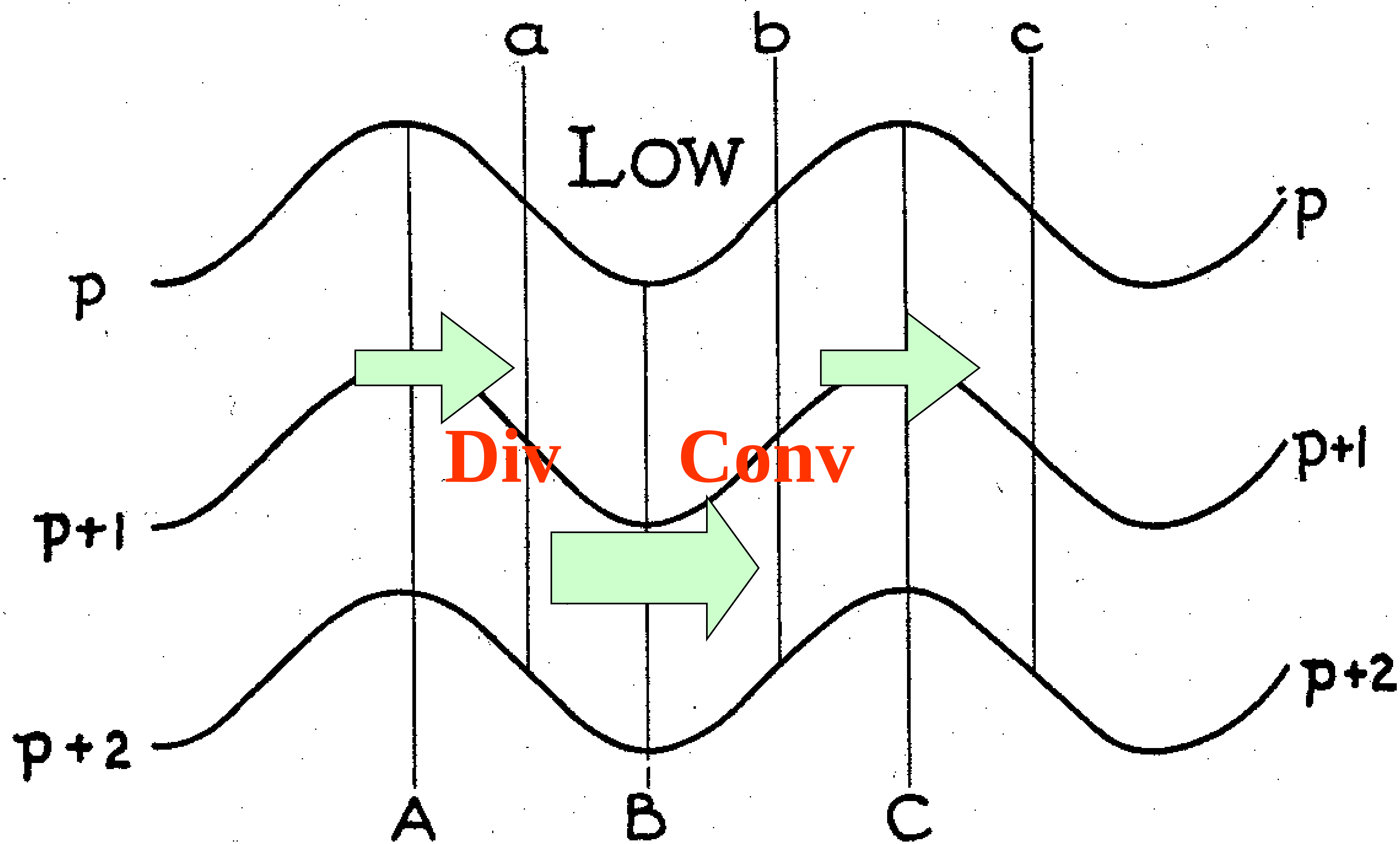


…to which he applied the gradient wind equation

Considering only the curvature effect on the gradient wind which is relevant for shorter waves



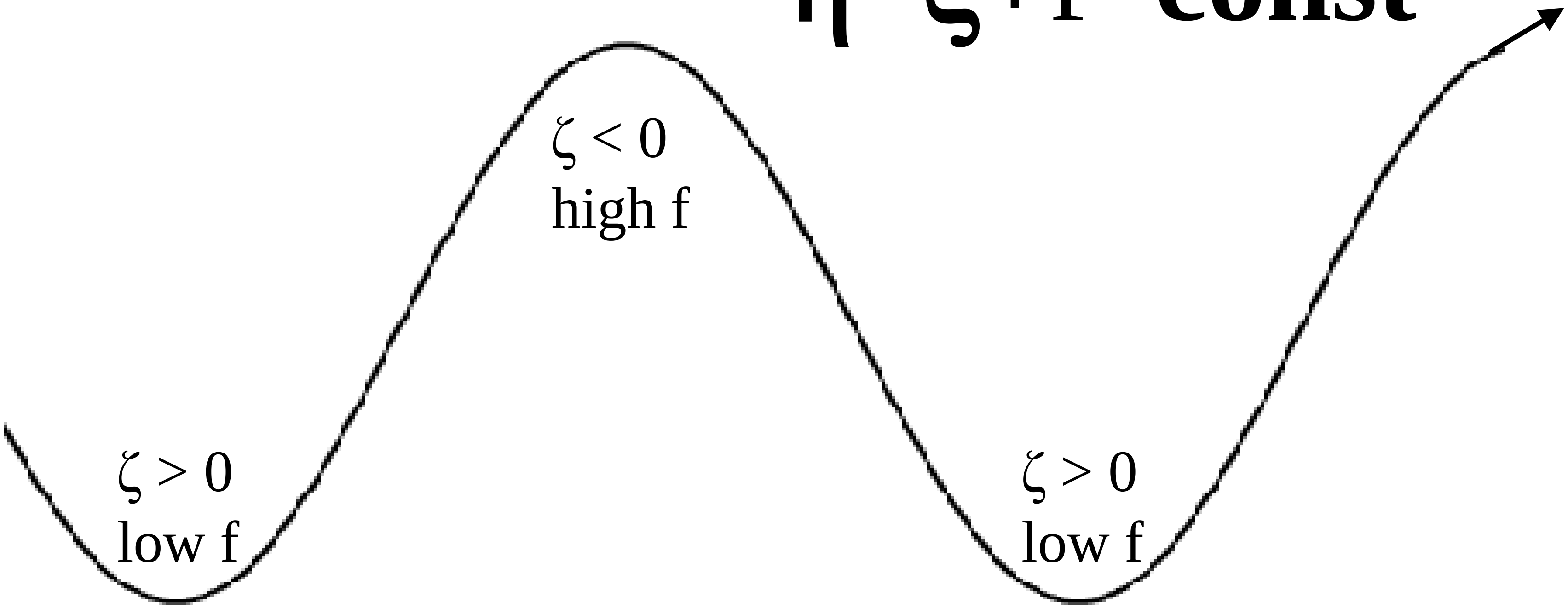
Considering only the latitude effect on the gradient wind which is relevant for longer waves



Only when the paper was published did Rossby realize that he could not use gradient wind balance - it is only applicable on stationary patterns

In his mathematics Rossby made use of Constant Absolute Vorticity Trajectory *(which is NOT a Rossby wave)*

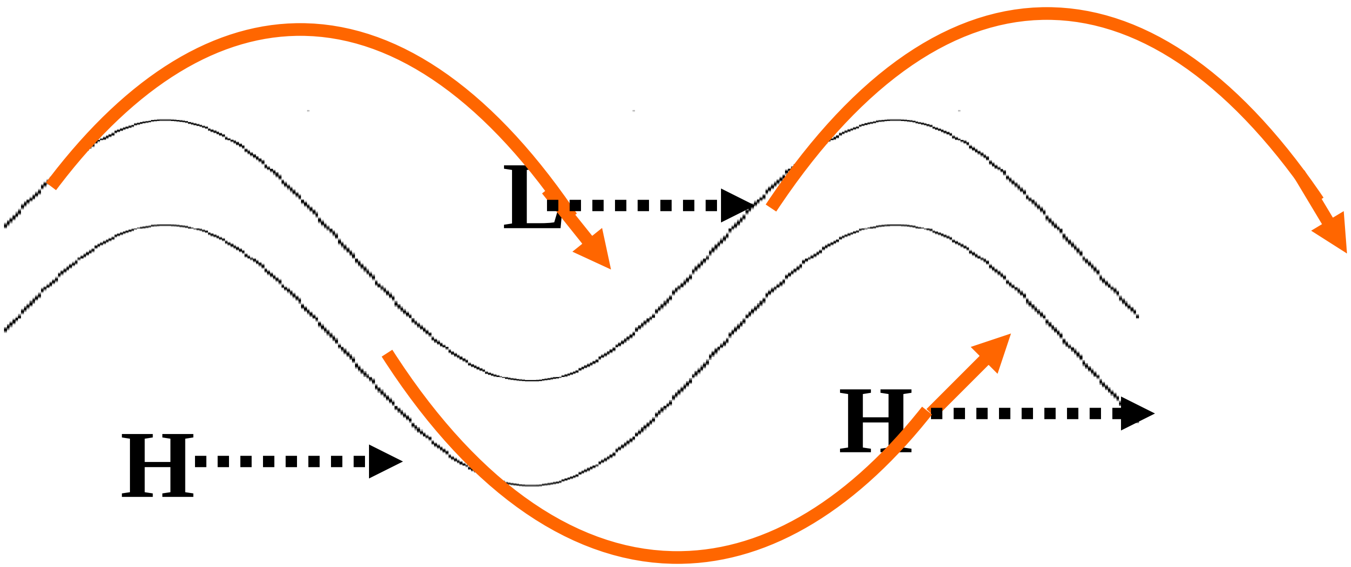
$$\eta=\zeta+f=\mathbf{const}$$



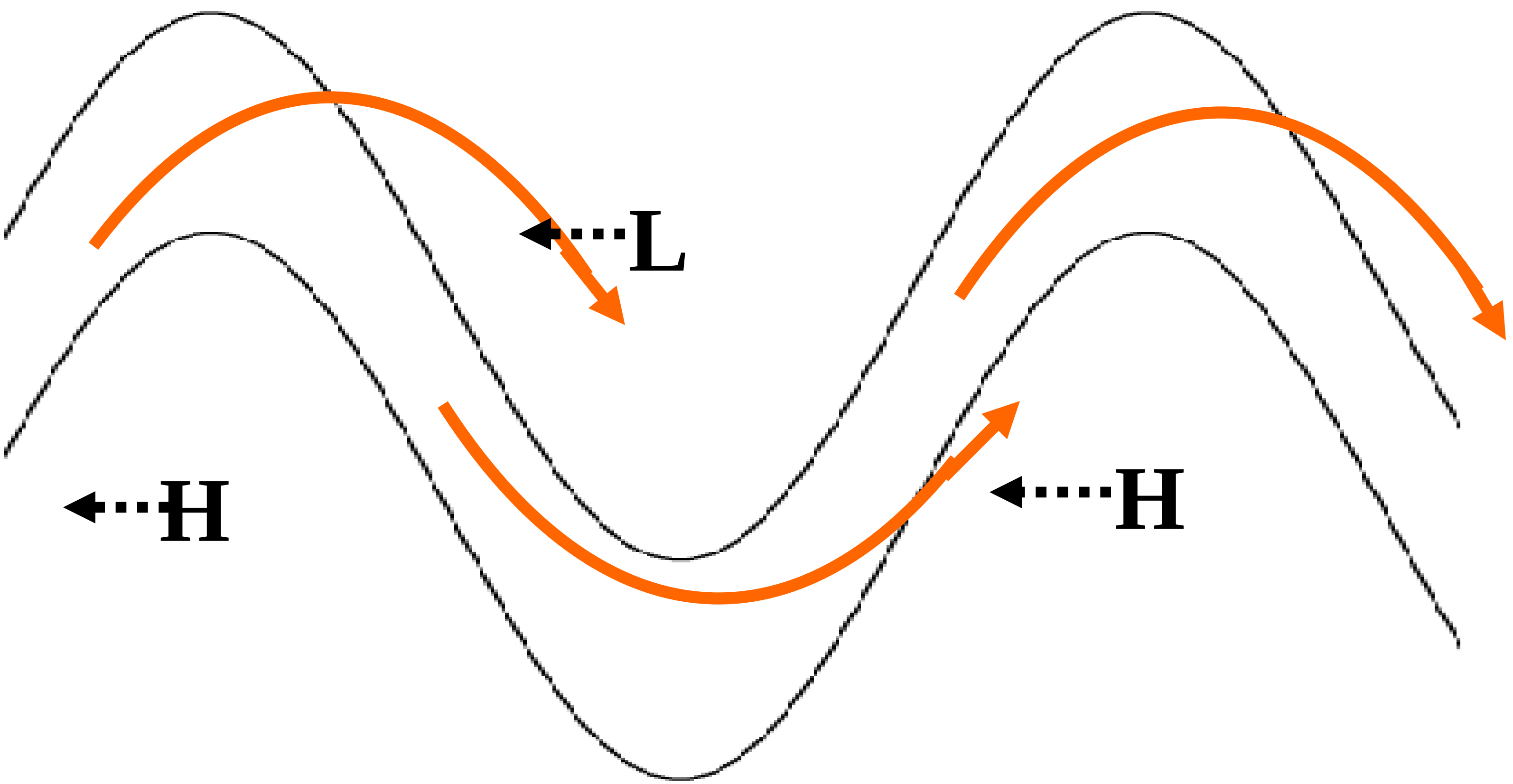
…from which he derived his famous wave formula →

Confusion between streamlines (waves) and trajectories has always been one of the main roots of confusion in dynamic and synoptic meteorology

Trajectories associated with low amplitude, short wave length stream lines in a *progressive* flow



Trajectories associated with high amplitude, long wave length stream lines in a *retrogressive* flow



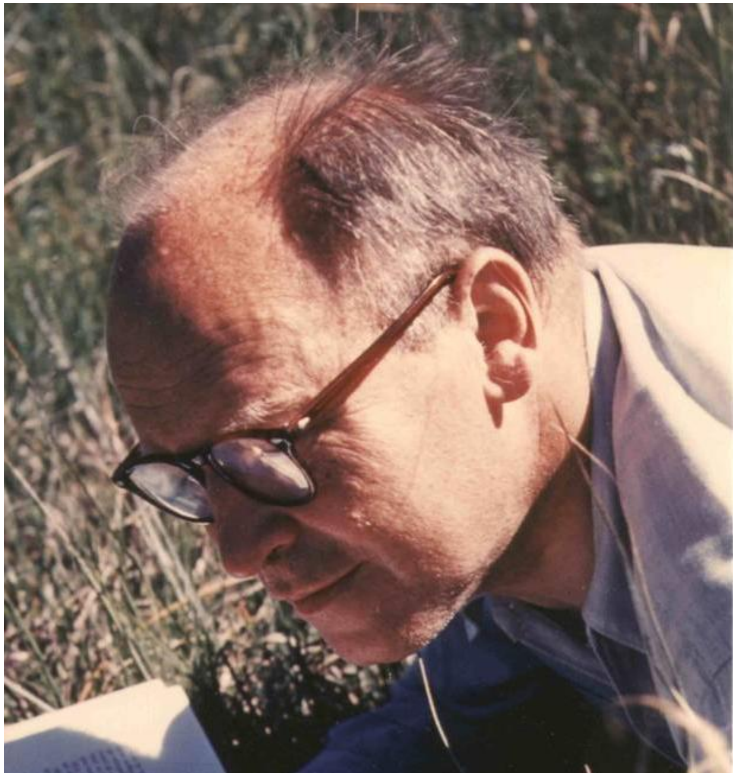
Dynamic meteorology without tears

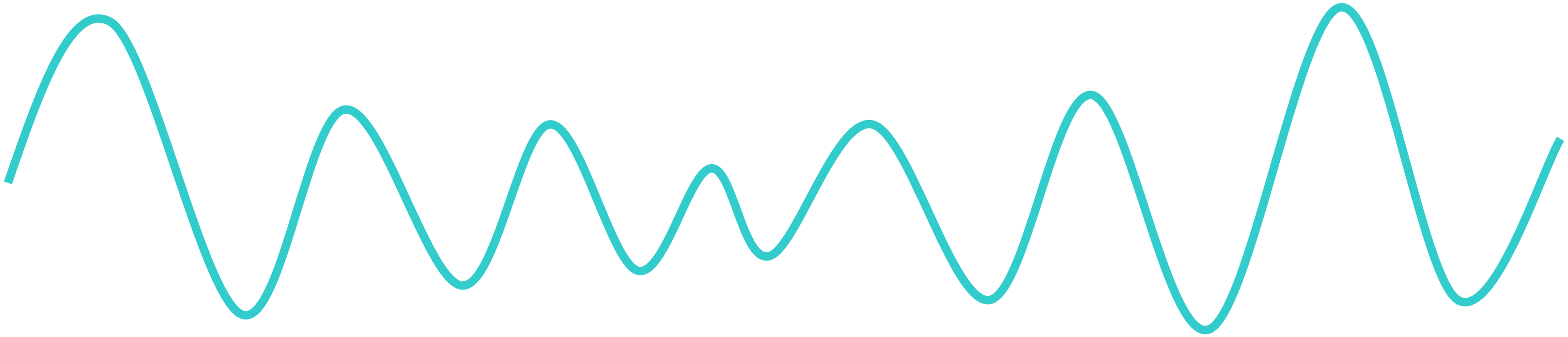
Part III b:

Group velocity

In summer 1944 Carl Gustaf Rossby, chief meteorological advisor to the US war government, took a well-deserved vacation in the oceanographic research centre La Jolla in southern California

Resting on the beech he could listen to the sound of the incoming waves, their rhythm with a peculiar periodicity, **"The Seventh Wave"**

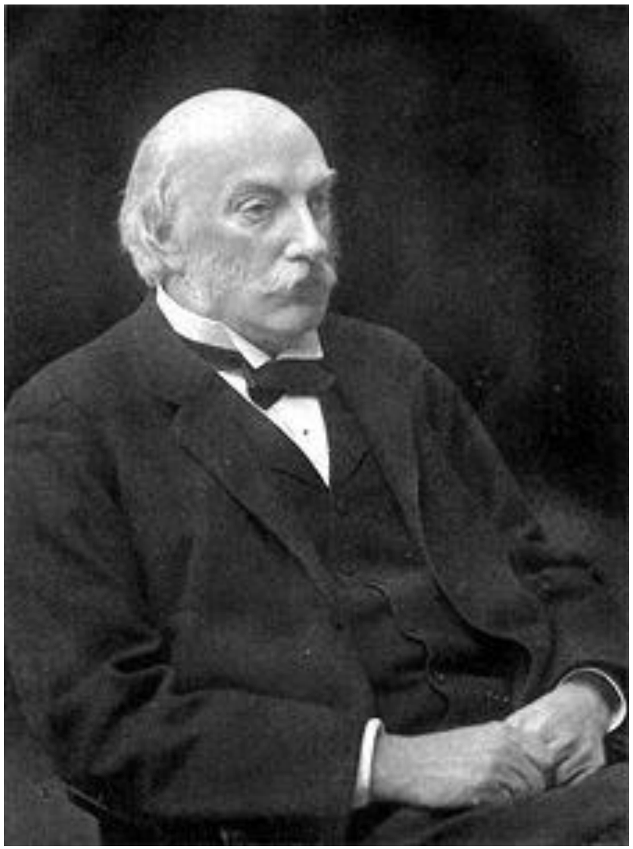


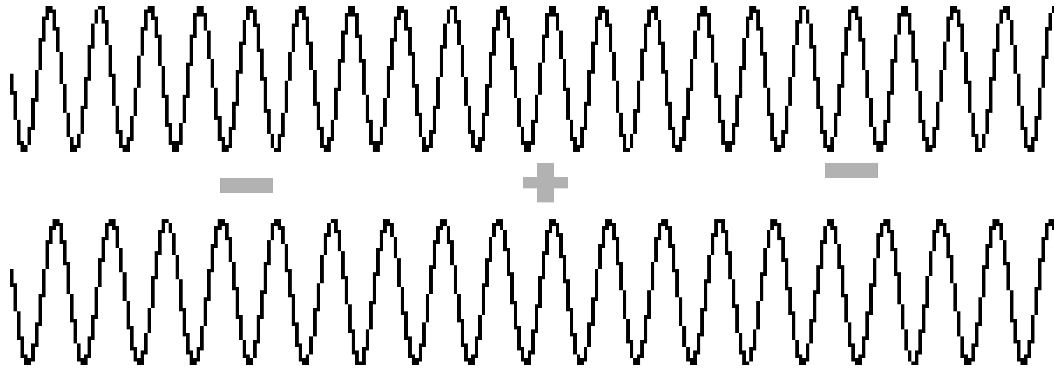


Group velocity

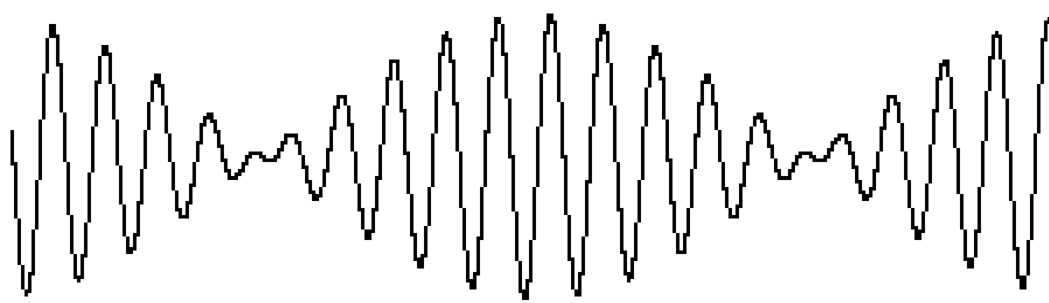
MADE IN BRITAIN

Discovered by Lord Rayleigh

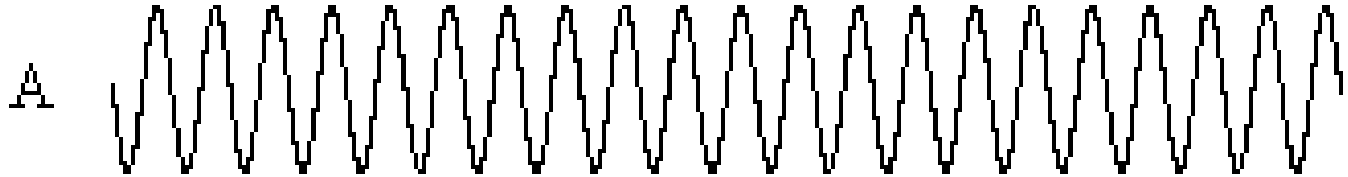




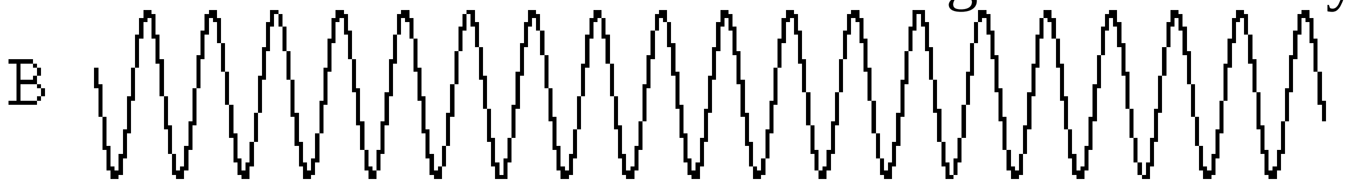
The modulated electromagnetic wave can be decomposed into a sum of non-modulated waves of different



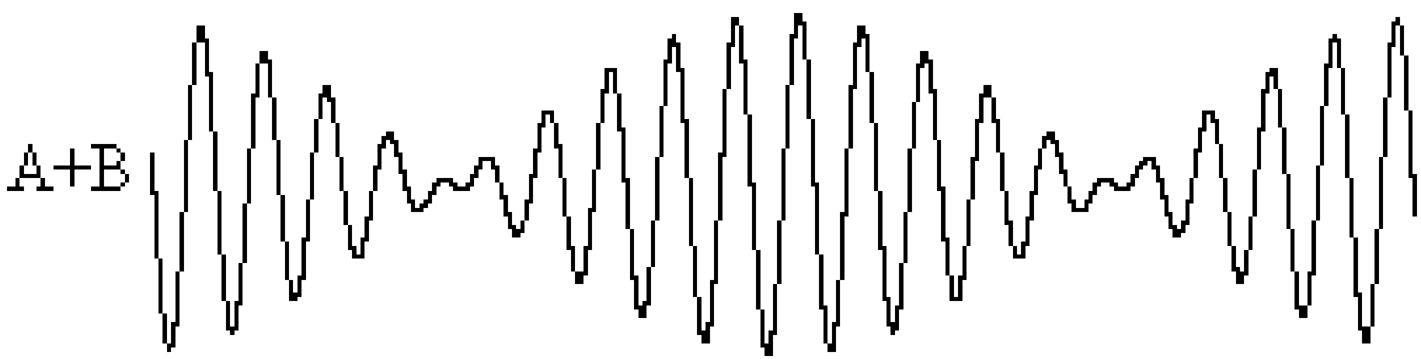
If the waves' phase speed depend on wave length they are dispersive



Waves A and B differ in wave length and velocity



The interference wave pattern moves with different velocity to A and B



Suddenly Rossby realised that also "his" newly found wave equation was dispersive

Phase speed

$$c = U - \frac{\beta L^2}{4\pi^2}$$

Wave length

What is the corresponding group velocity?

Rossby began to derive the group velocity
- in the sand on the beach!

$$c = U - \frac{\beta L^2}{4\pi^2} \Rightarrow c_g = U + \frac{\beta L^2}{4\pi^2}$$

Phase velocity

Group velocity

Rossby’s wave formula (inspired by Ekman, 1932)

$$c = U - \frac{\beta L^2}{4\pi^2}$$

C= phase speed, U= zonal flow at 500 hPa, L=wave length, β=df/dy

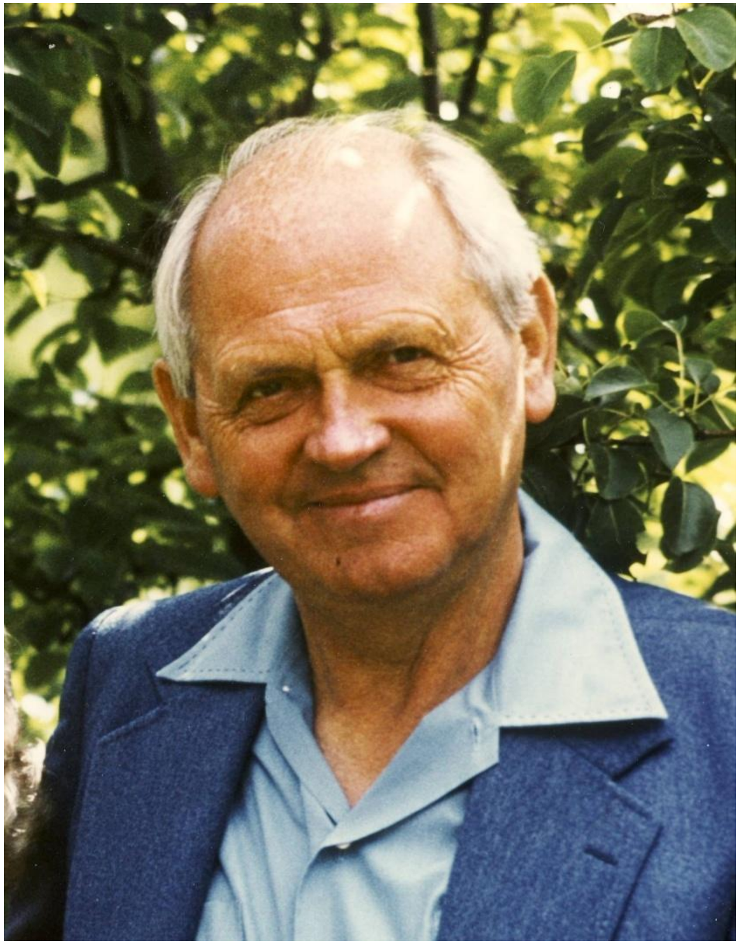
c < 0 for large L   c >0 for small L

But what did it *mean*?

$$c_g = U + \frac{\beta L^2}{4\pi^2}$$

Obviously "something" (the energy) was running rapidly downstream, ahead of synoptic weather systems

Ernest Hovmöller (1912-2006)

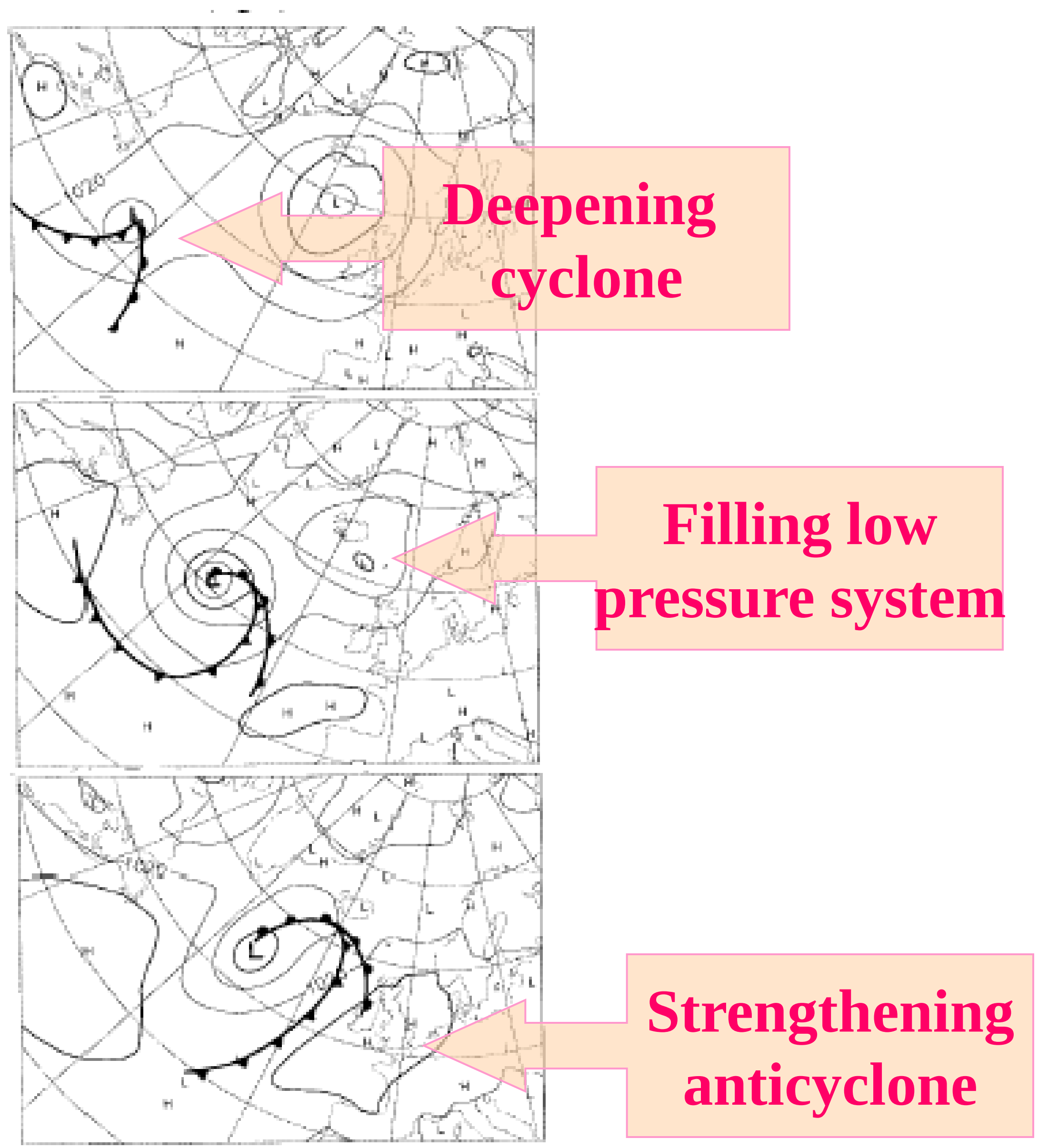


Here the matter could have rested

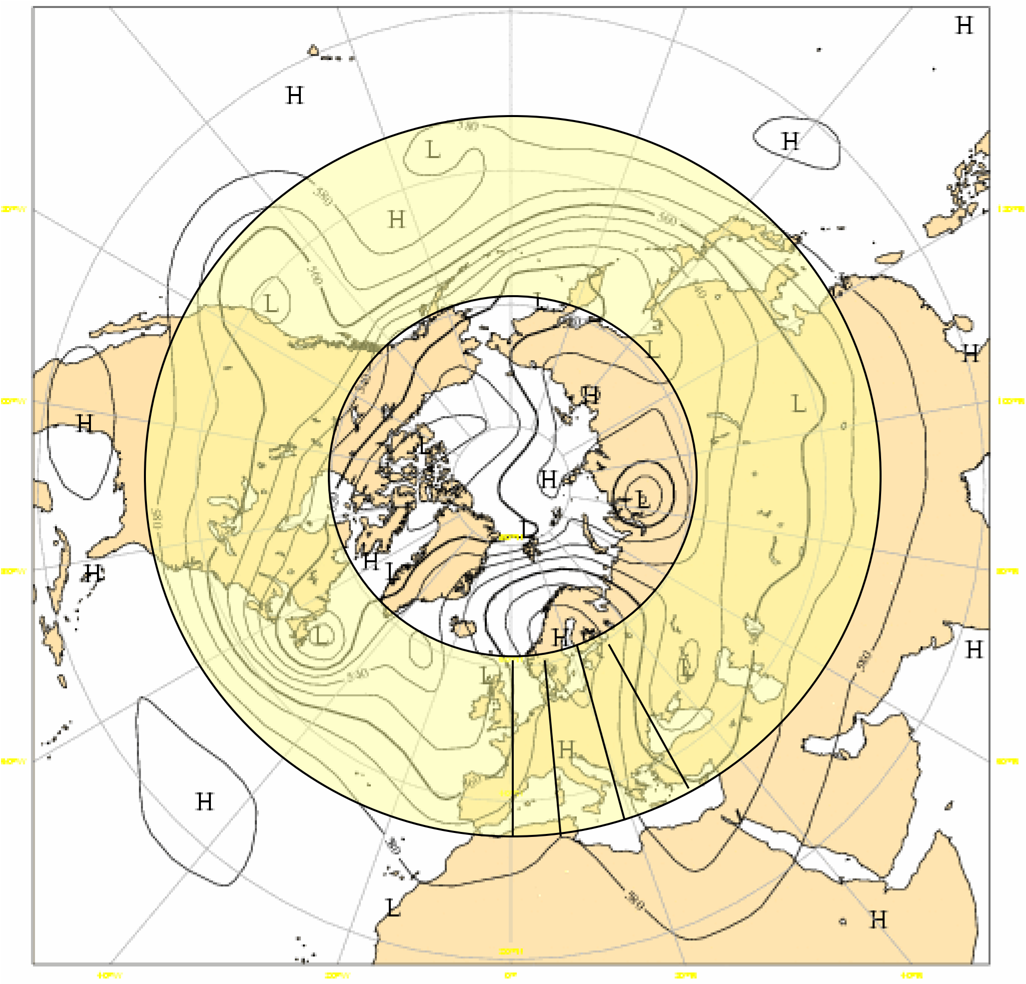
... if it hadn’t been for this man:

…and his Hovmöller diagram

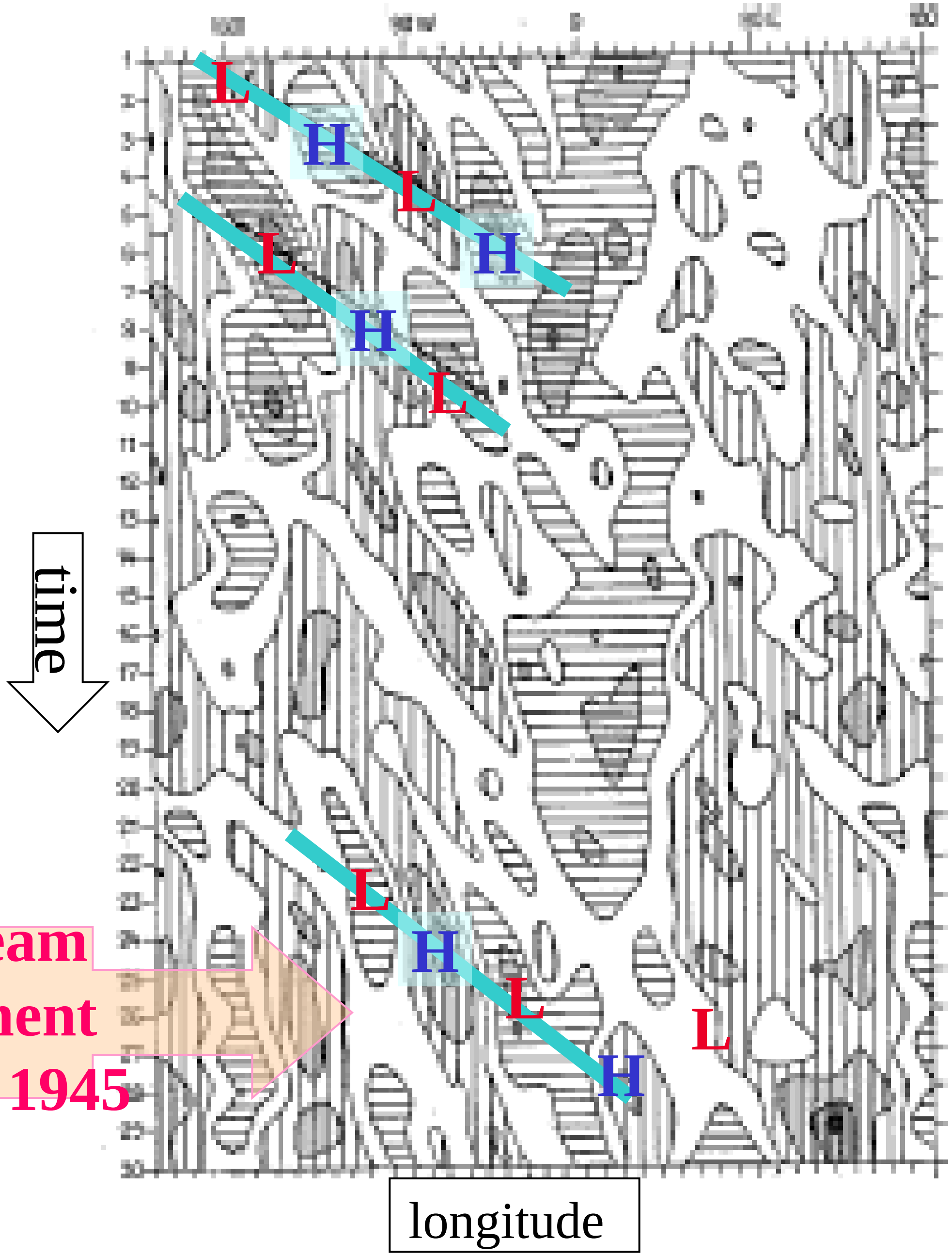
An old forecast rule about downstream development (Evjen, MetZ, 1936)



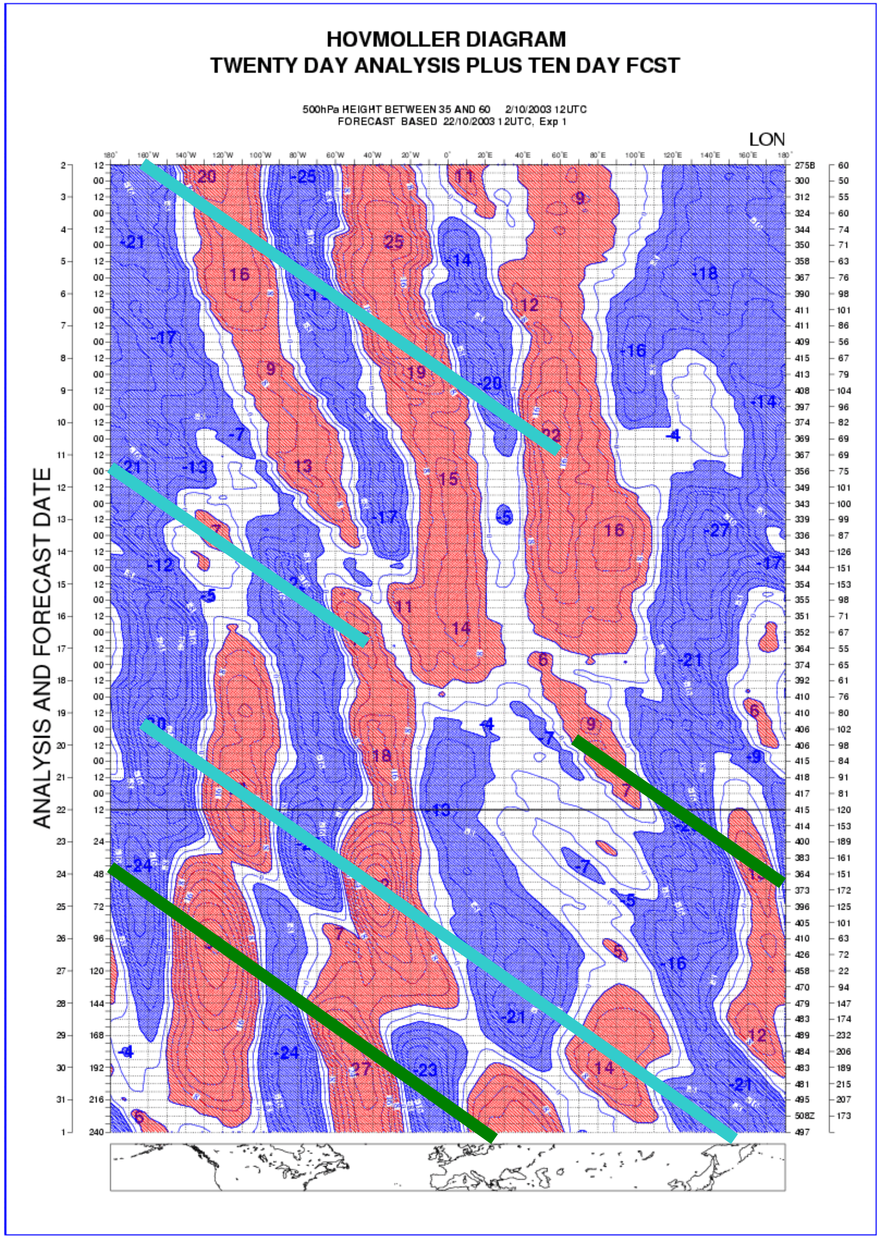
The traditional Hovmoller diagram - meridional means of 500 hPa heights



Hovmöller (1949) made time-*longitudinal* diagrams of the 500 hPa height



A routine Hovmöller diagram from ECMEF



Group velocity in water surface waves

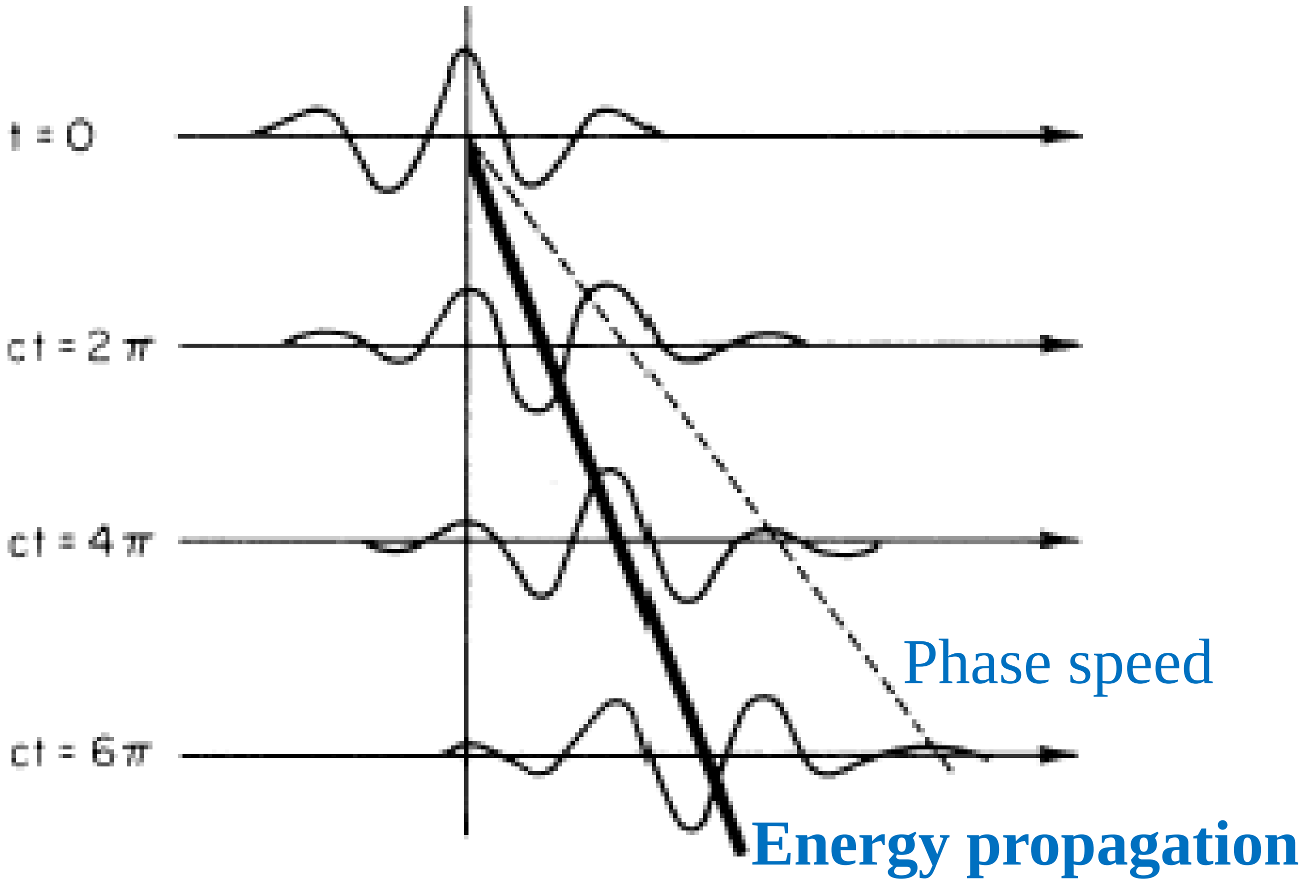
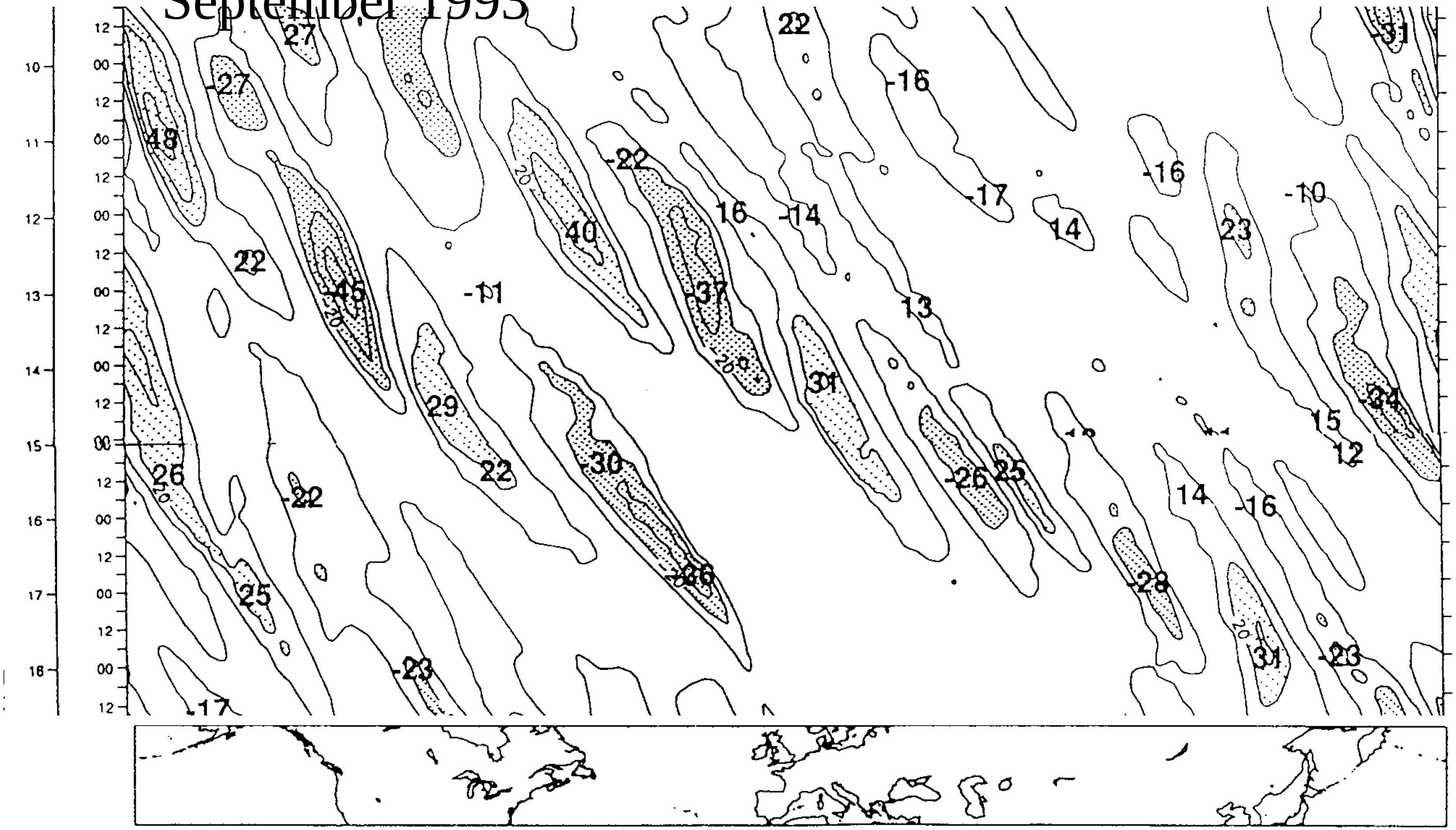


Fig.1 The successive progression of water wave packages. The crest in the centre moves rapidly out, weakens and leaves behind the main energy, into which upstream waves enter and amplify (from Holton, 1992).

Trough-ridge (Hovmöller) Diagram

of 250 hPa meridional wind component 10-18 September 1993



Trough-ridge (Hovmöller) Diagram

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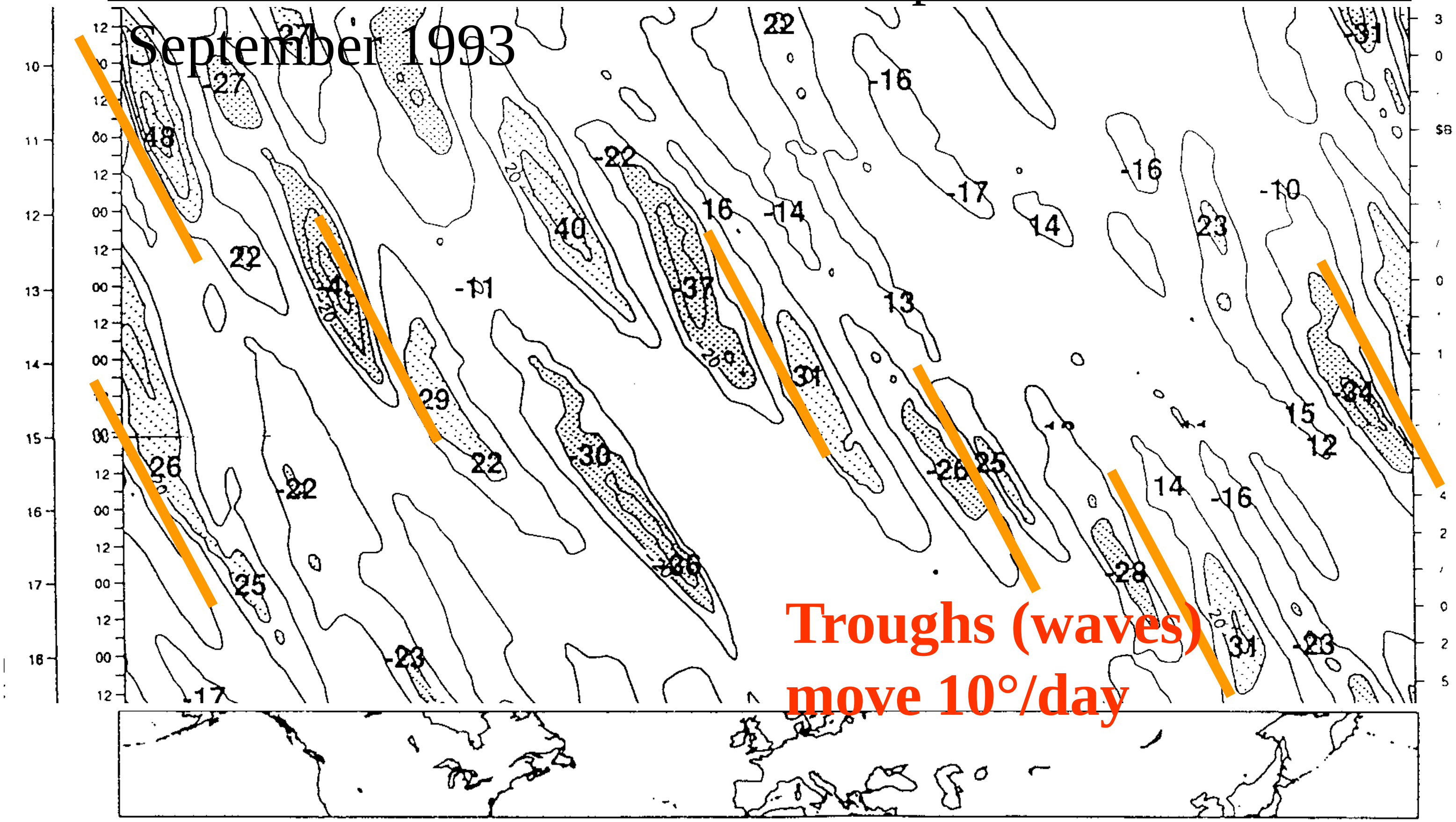

Trough-ridge (Hovmöller) Diagram

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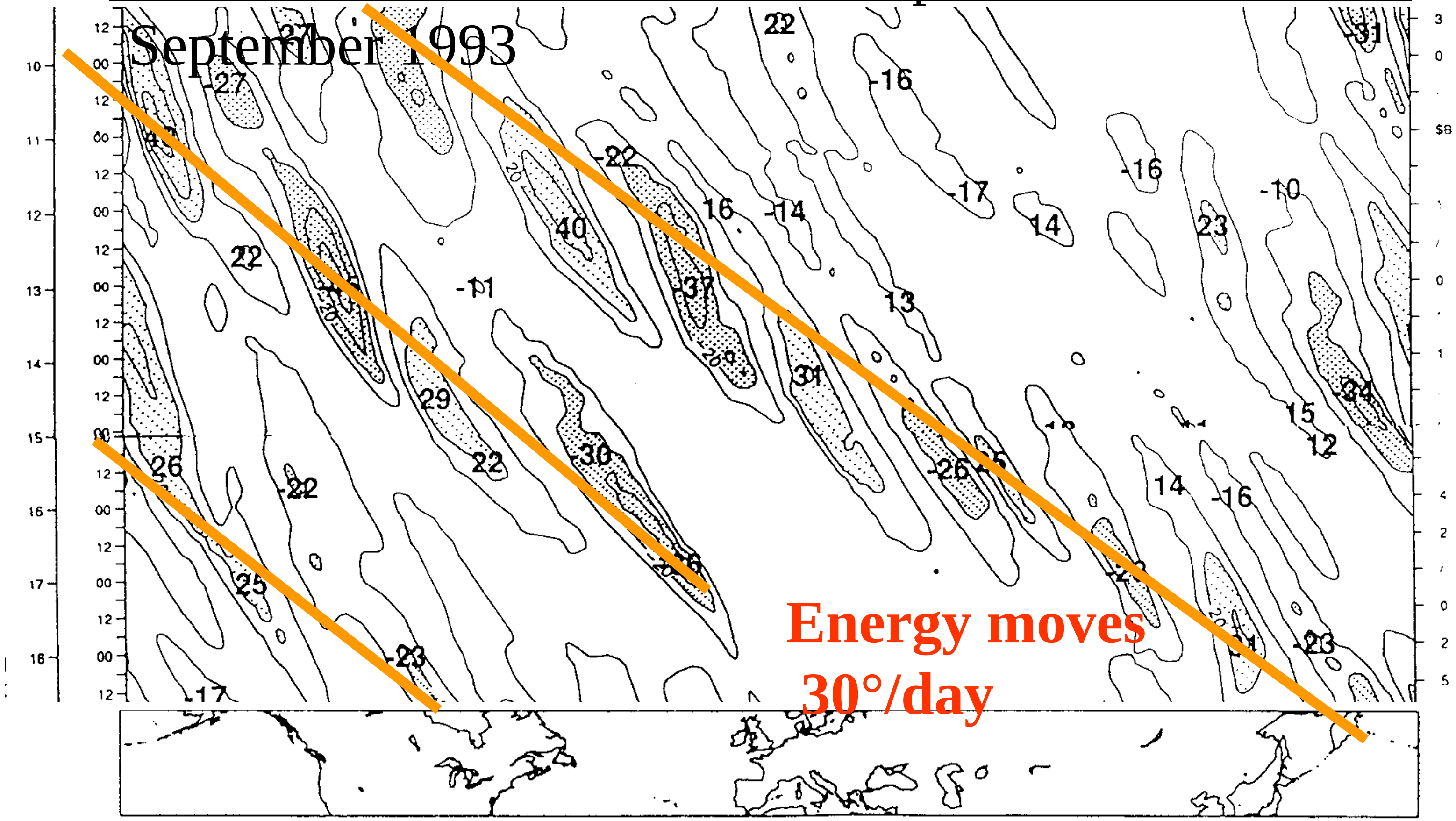


From an upstream baroclinic development the released kinetic energy is transported, through the upper-tropospheric flow, to the next downstream cyclone

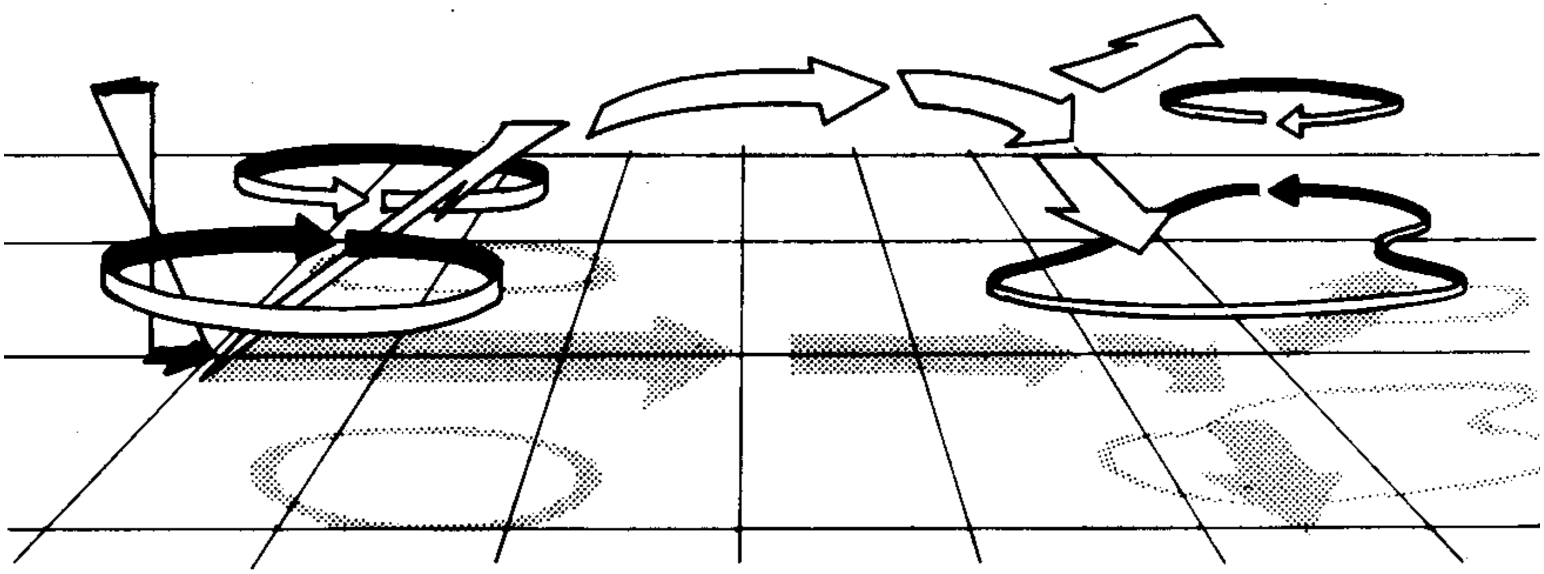


Illustration from Hoskins, James and White (JAS, 1983)

Group velocity in the atmosphere (Persson, 1993)

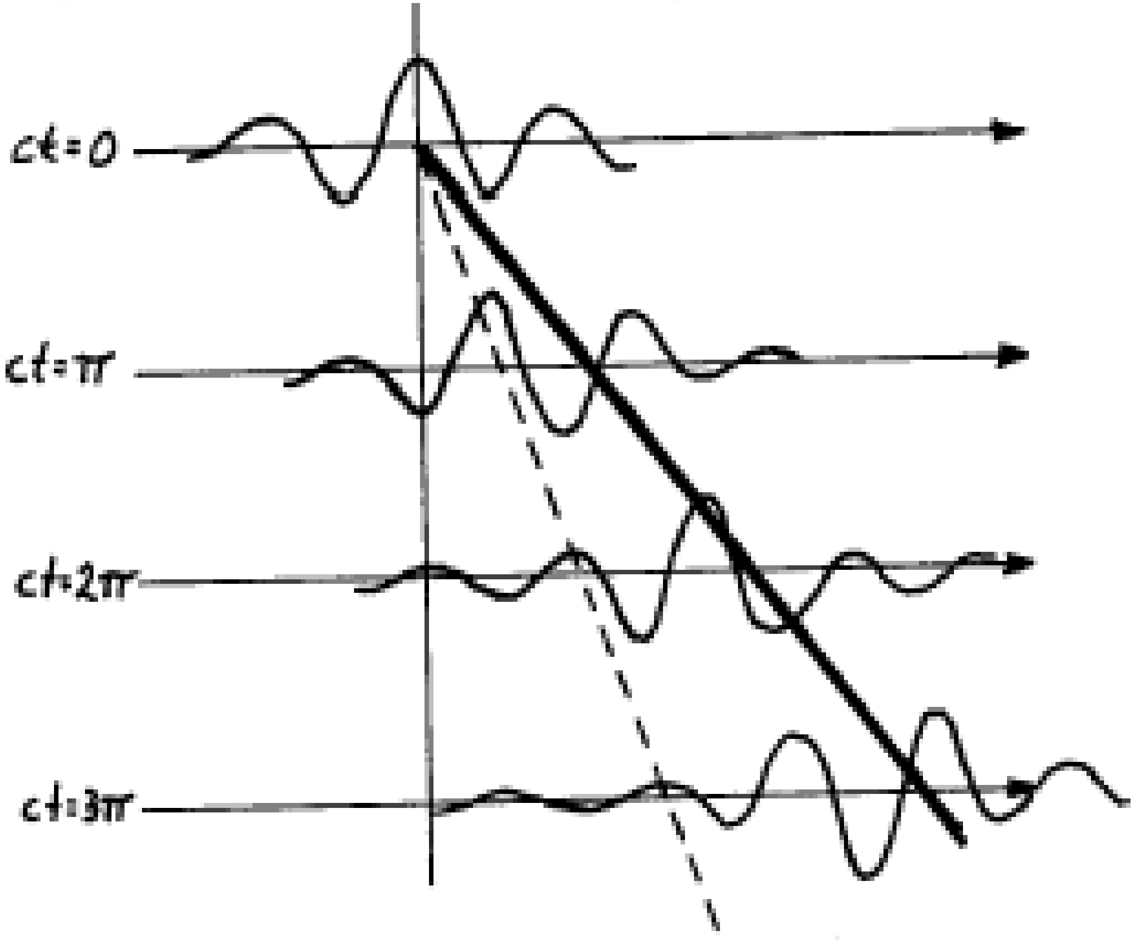


Fig. 2: The corresponding mechanism in the atmosphere: the central wave moves more slowly than the bulk of the energy which propagates downstream amplifying waves on its arrival.

A relevant image at last made it into the 4th edition of James R. Holton's textbook in 2004

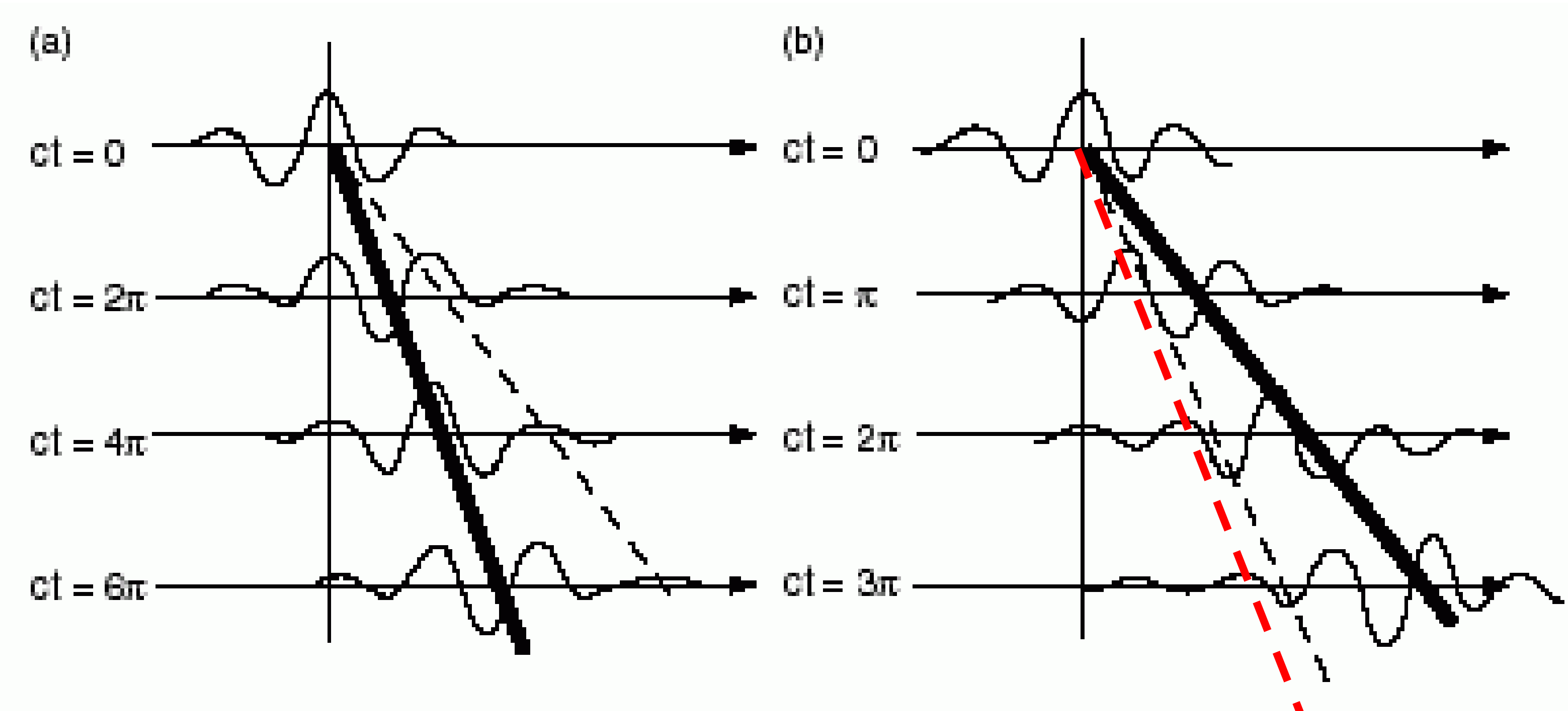
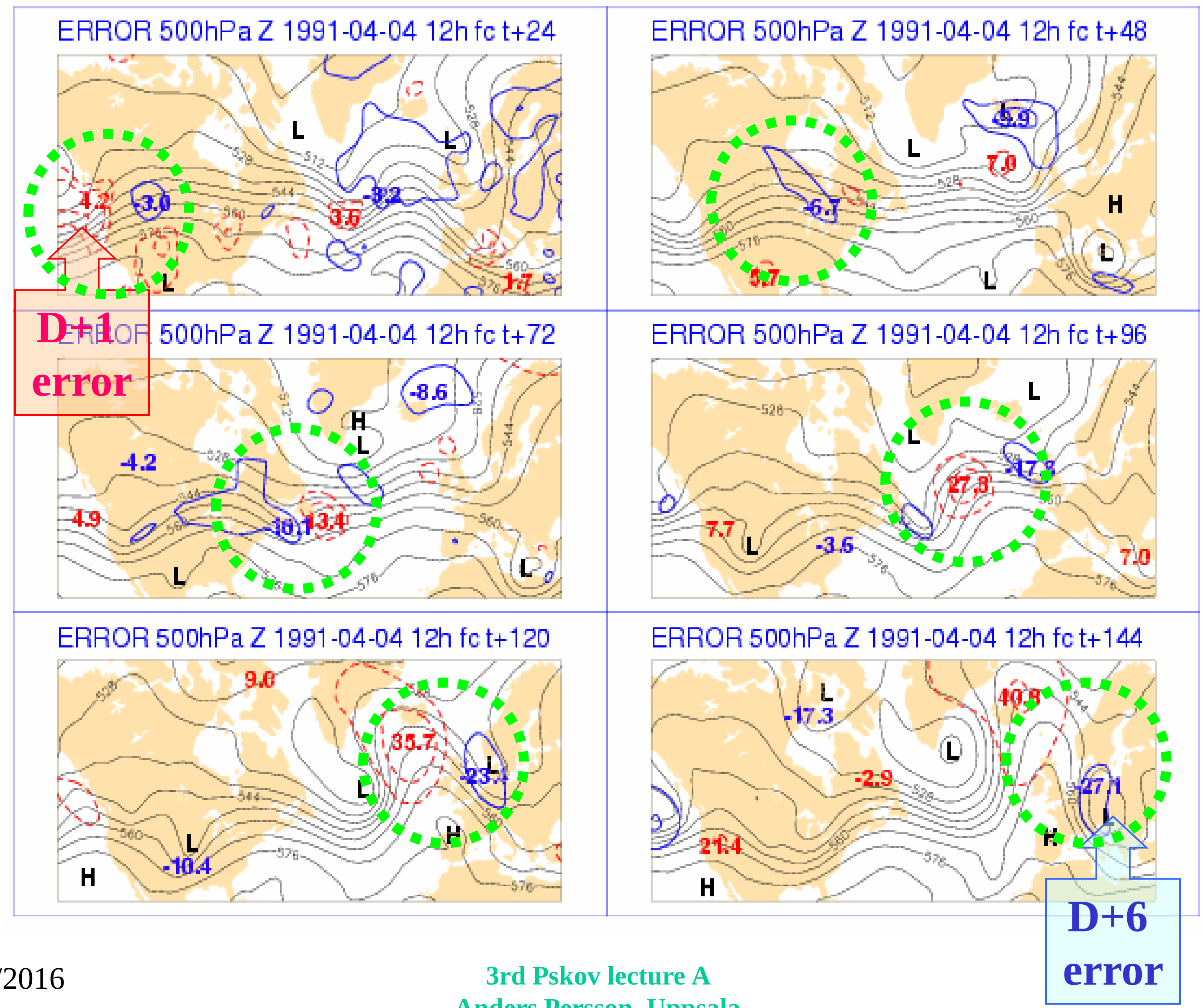
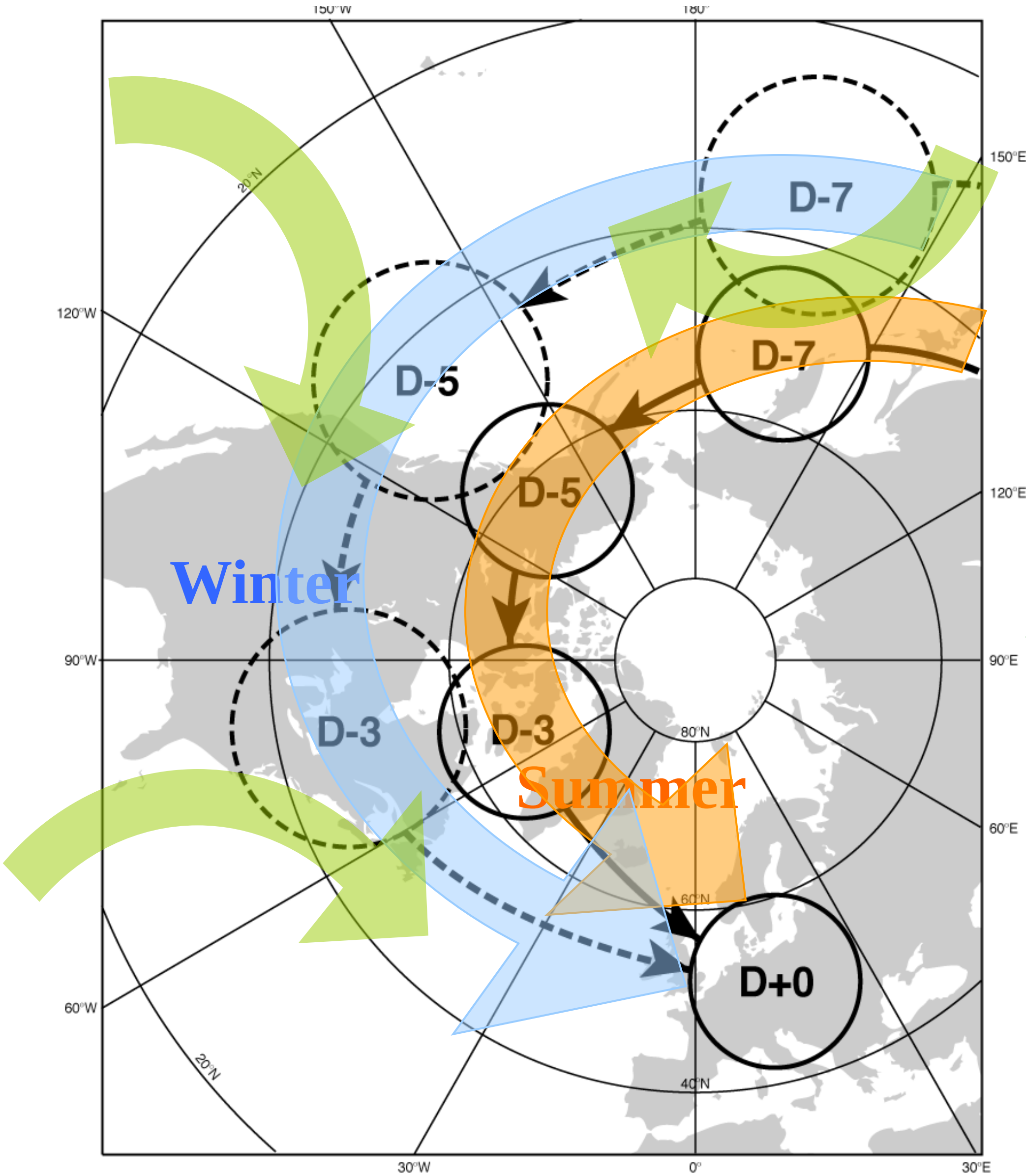


Fig. 7.4 Schematic showing propagation of wave groups: (a) group velocity less than phase speed and (b) group velocity greater than phase speed. Heavy lines show group velocity, and light lines show phase speed.

Error tracking from the NE Pacific to Europe in 6 days



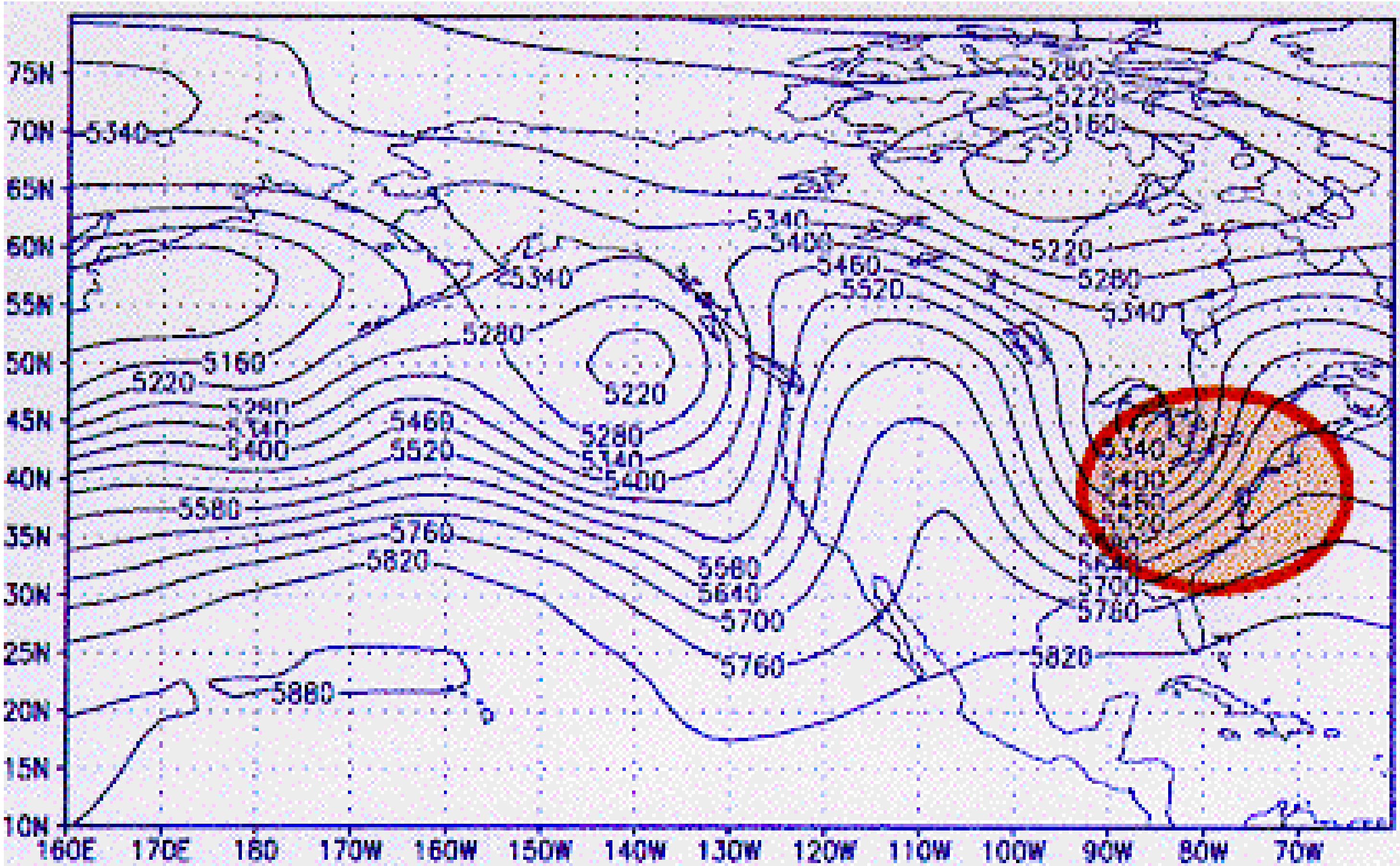
Error influence over Europa



Influences of good and bad information move 3 times faster than the weather systems themselves

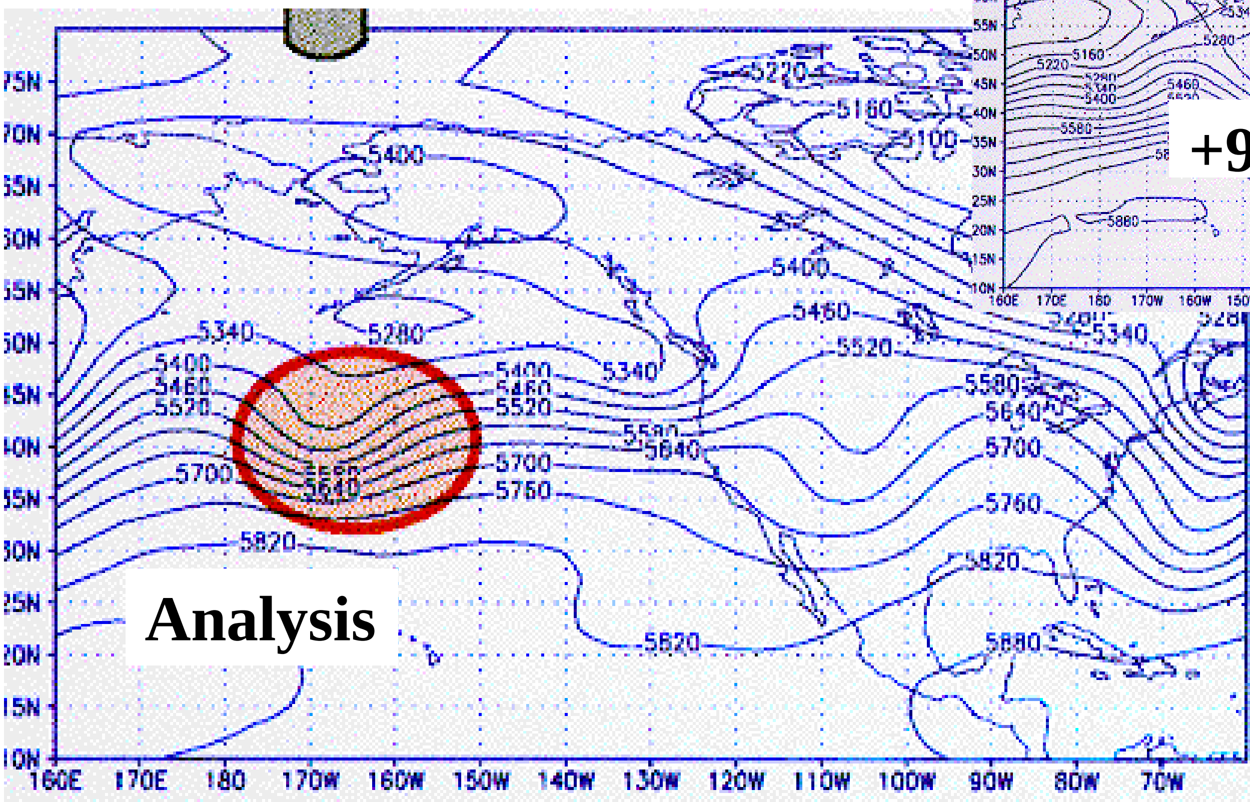
Add to that **tropical cyclones** which occasionally move to higher latitudes and radically affect the dynamic developments

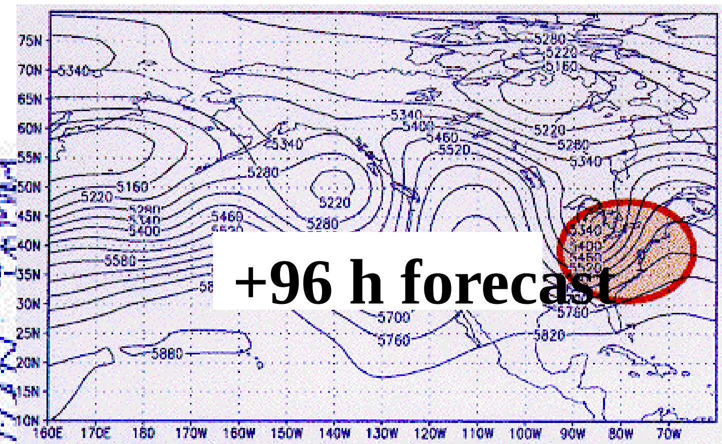
An example from the NCEP by Zoltan Toht



A numerical +96 h forecast indicates a storm over eastern USA in four days time

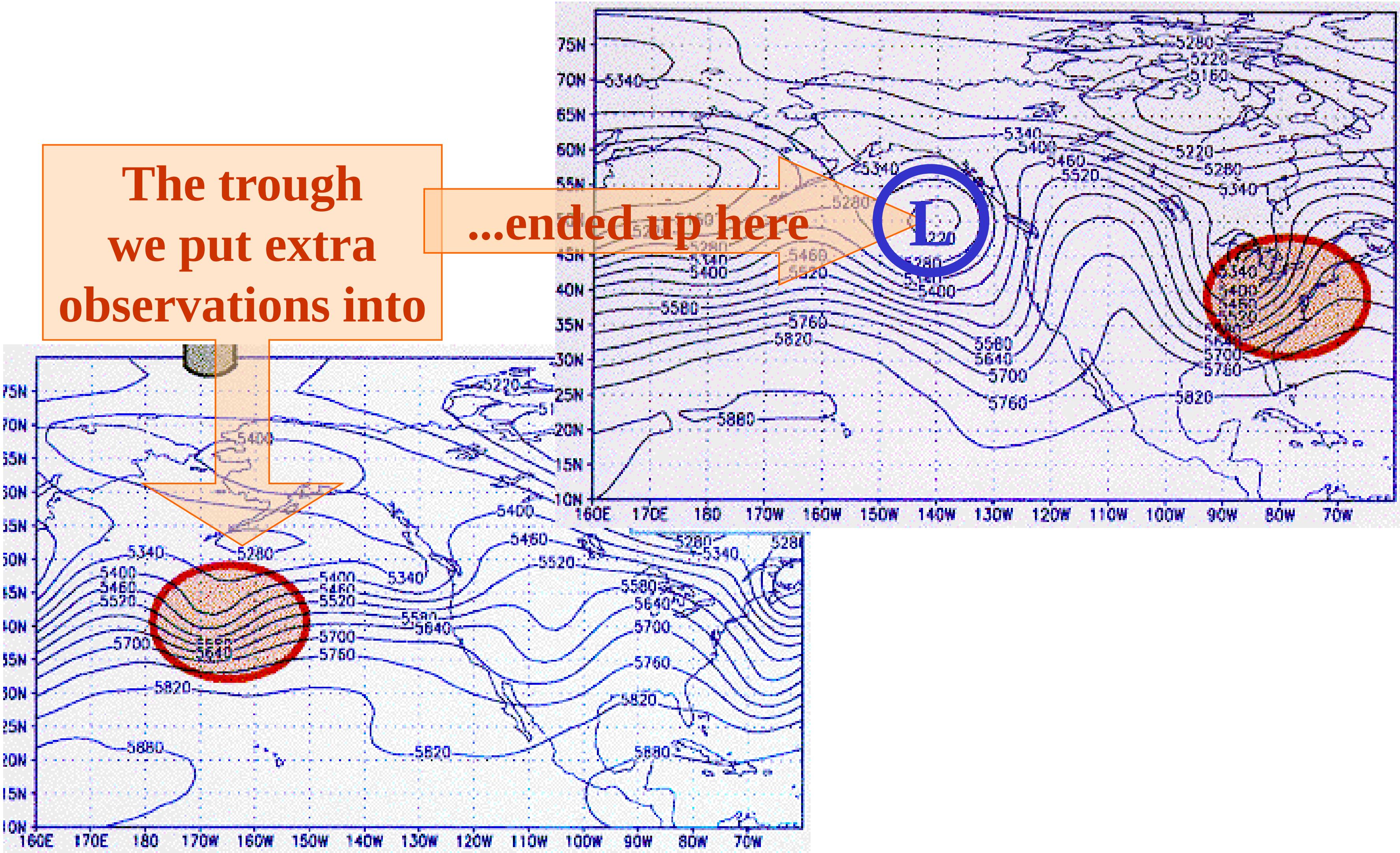
Mathematical (adjoint or sensitivity) analyses point out a trough in the mid-Pacific as the likely target for extra observations. More and better observation here will improve the forecast.

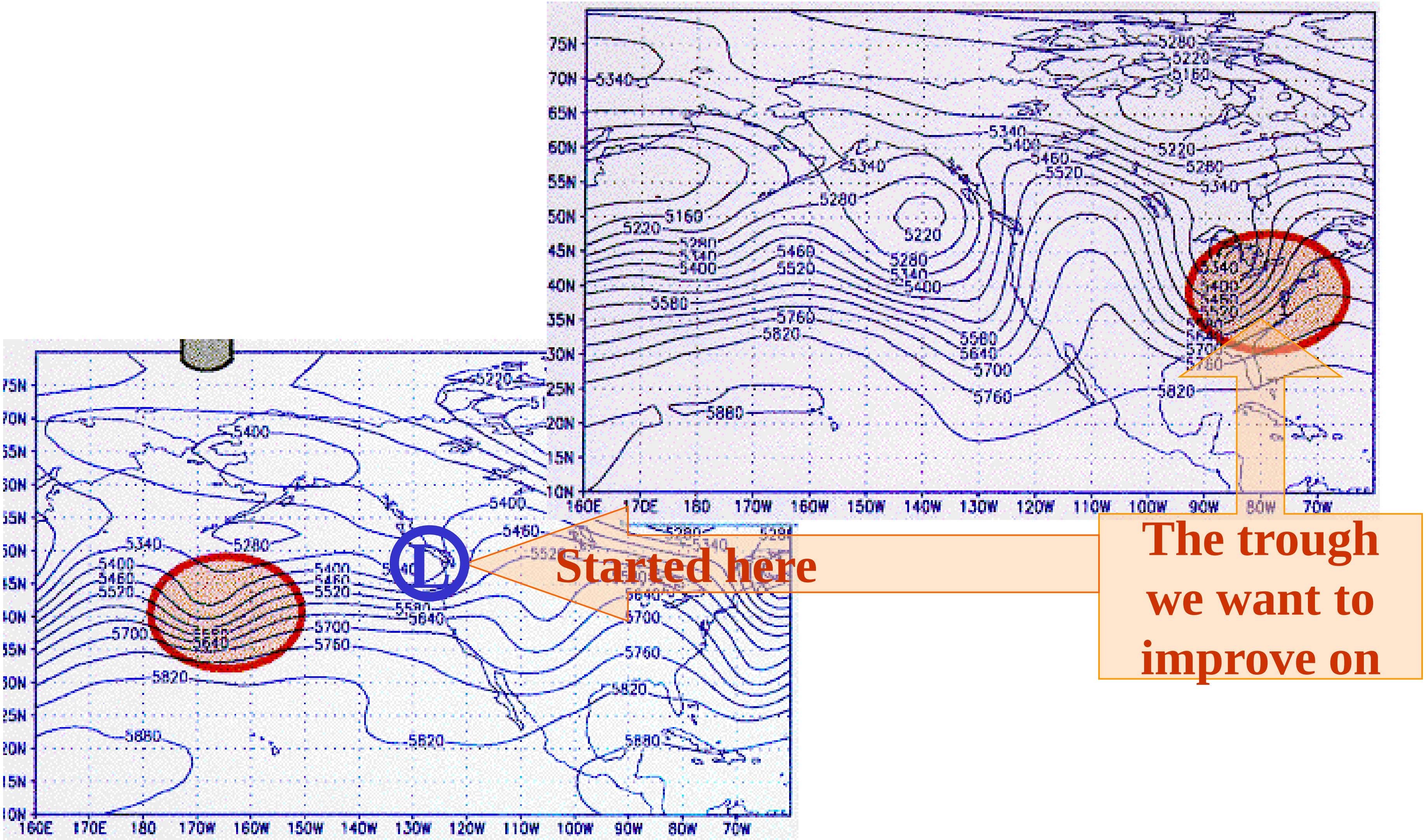




But are we looking at the same system?

The answer is NO




L
Started here
The trough we want to improve on

Break