Dynamic meteorology without tears

Part A:

Rossby's planetary waves

What “is” a Rossby wave?

Lunch discussion at ECMWF around 1995:

Scientist: -What about the weekend weather?

AP: -Oh, Fine!

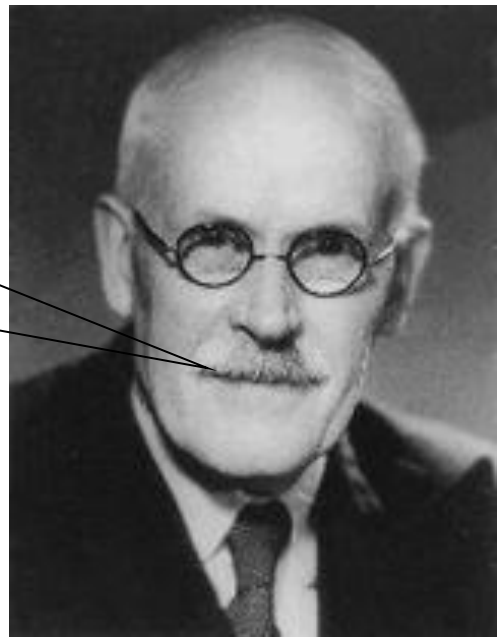
Scientist: -How can you be so sure?

AP: -A big Rossby wave is seen coming in!

Scientist: -But can you *see* a Rossby wave??

What is a Rossby wave?

I never understood what a Rossby wave was…



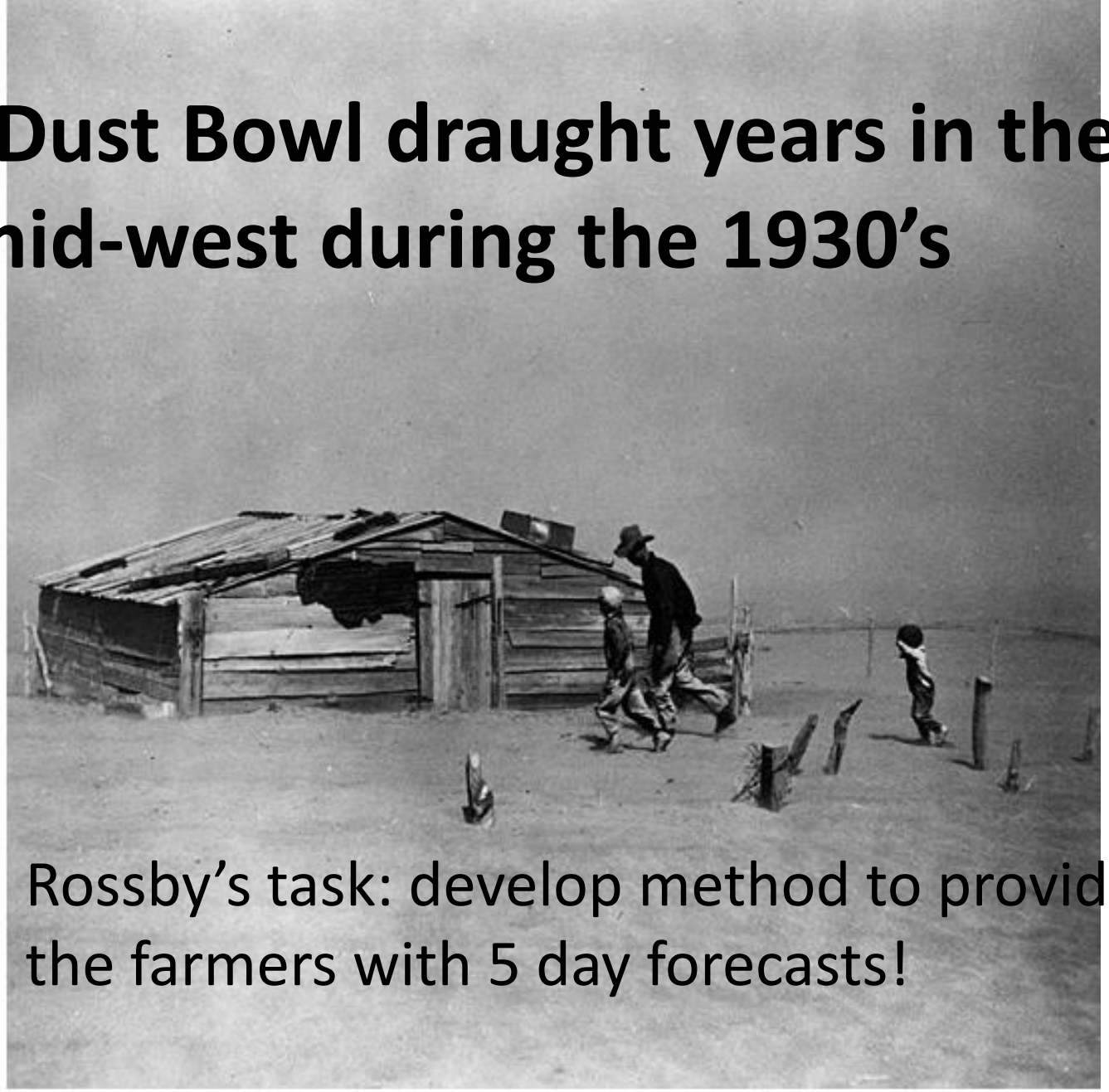
Sir Harold Jeffreys 1891-1989

Carl Gustaf Rossby (1898-1957)

Carl Gustaf Rossby (1898-1957)

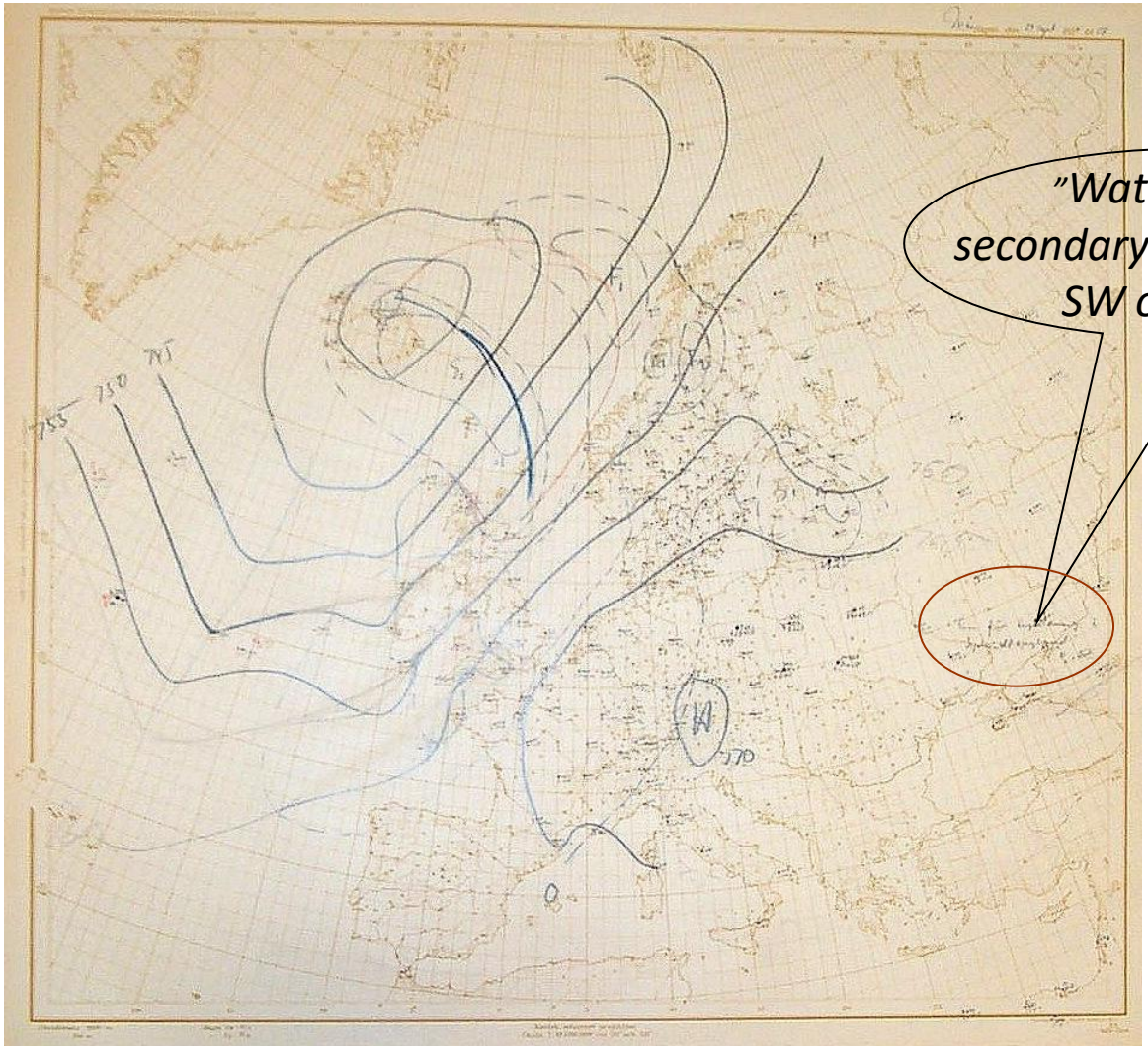
1898	Born in Stockholm, Sweden
1919-20	Bjerknes group in Bergen
1921	Studying aerology in Germany
1922-25	Weather forecaster at SMHI
1926	Moves to the United States of America to spread the Bergen school concept
1936-38	Works on geostrophic adjustment problems
1938-39	Discovers and explains “his” wave

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

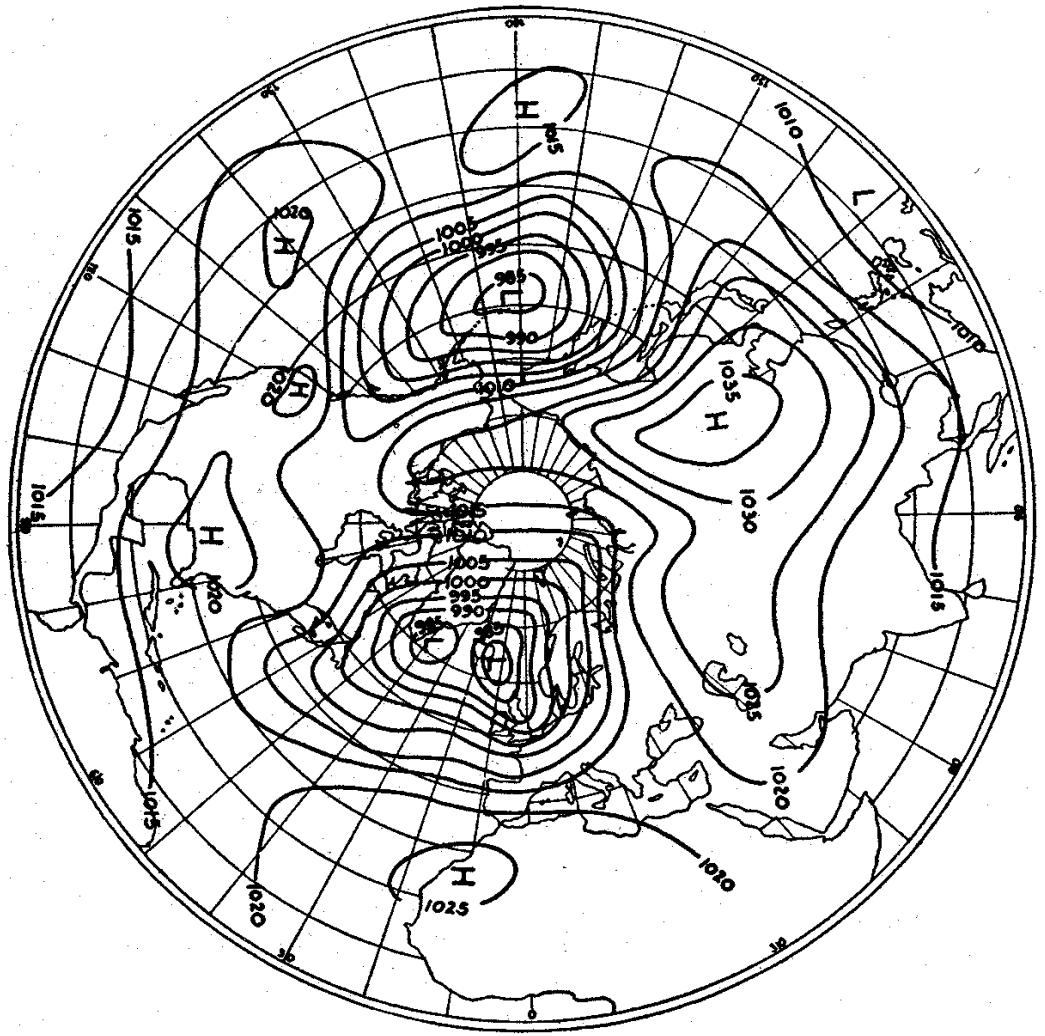


Rossby's task: develop method to provide the farmers with 5 day forecasts!

A routine weather map drawn by Carl-Gustaf Rossby 1924



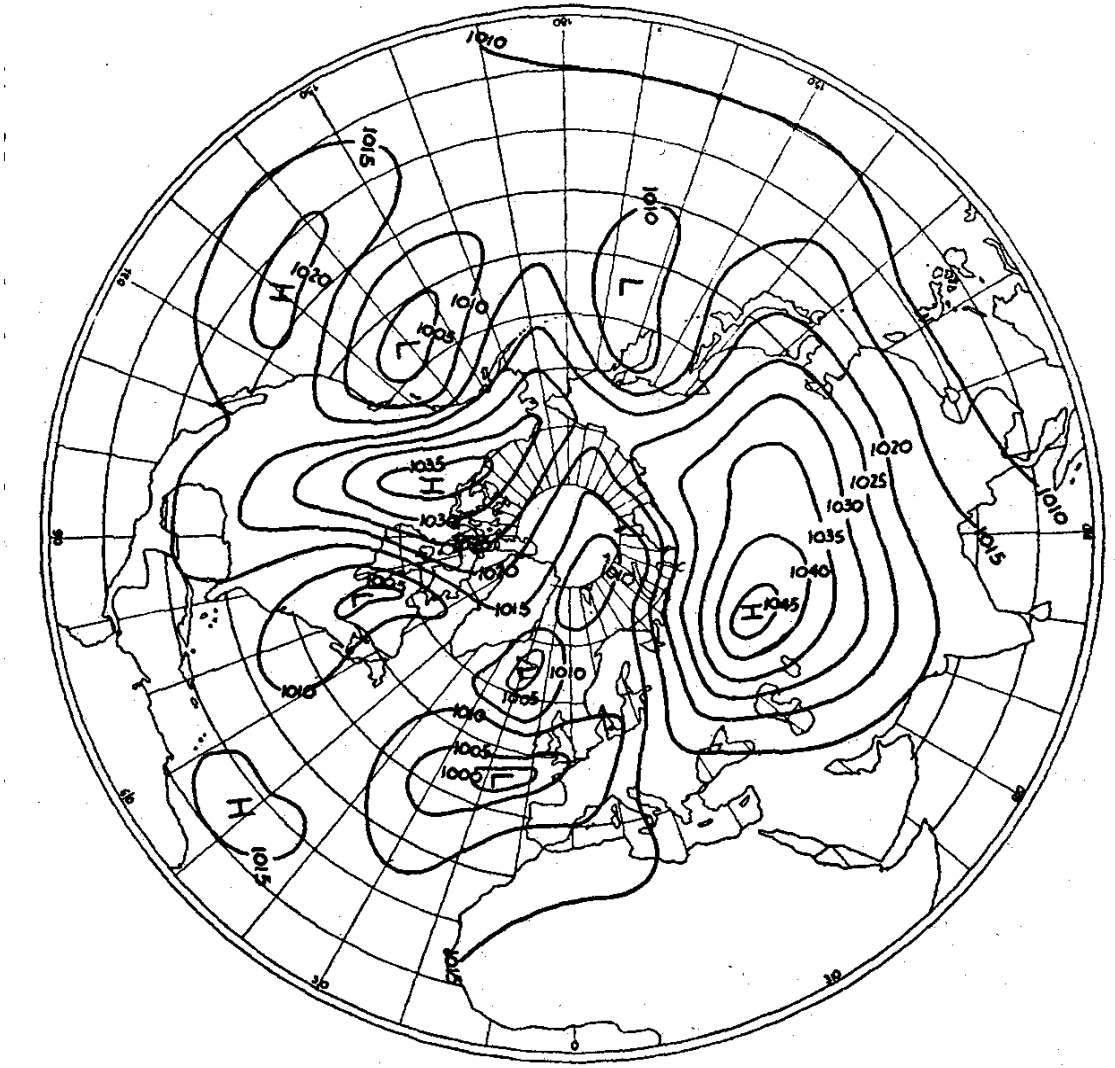
”Grosswetterlage” depicted though five or seven day average maps



High Index Circulation
9-15 Jan
1938

Zonal Flow

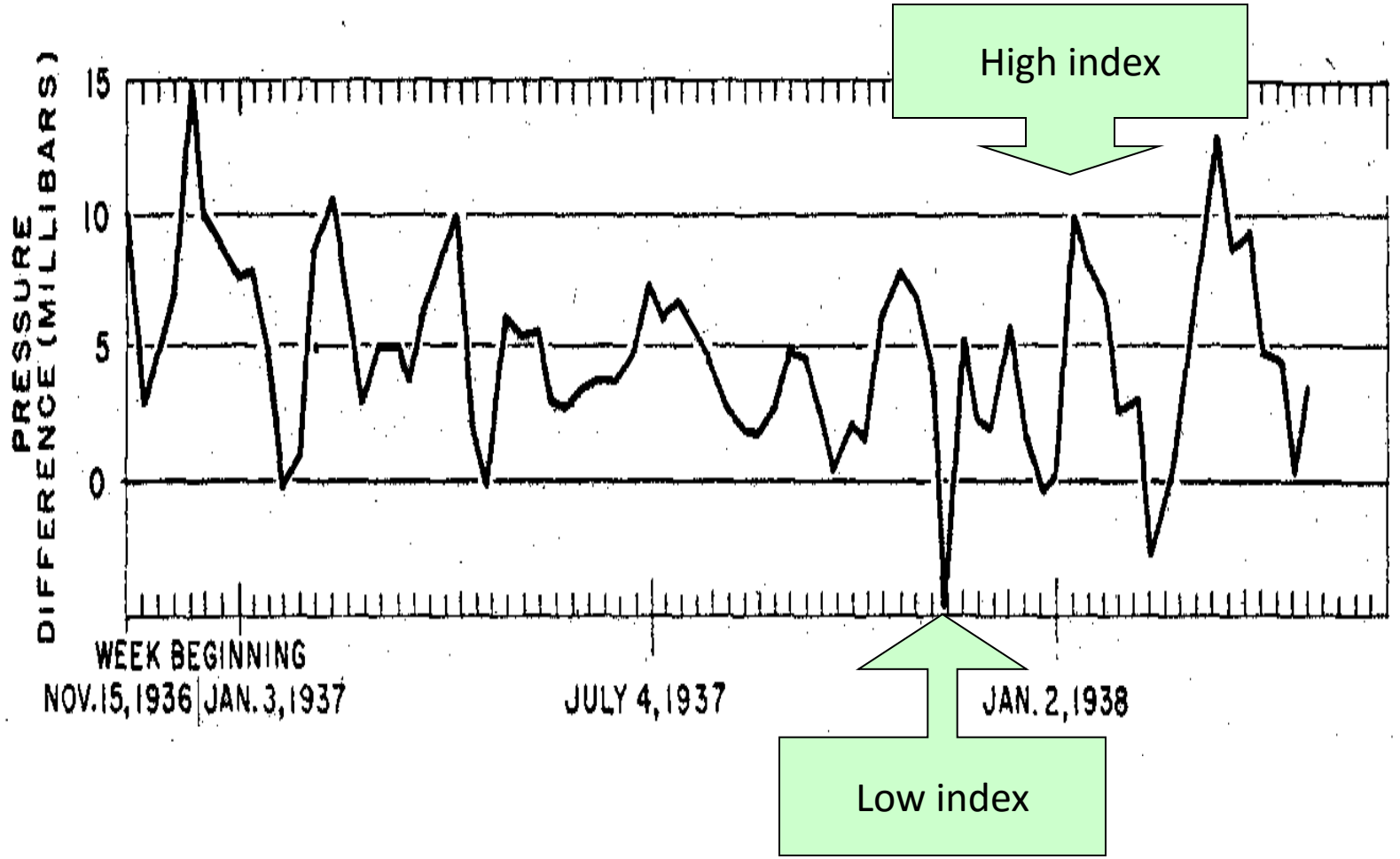
”Grosswetterlage” depicted though five or seven day average maps



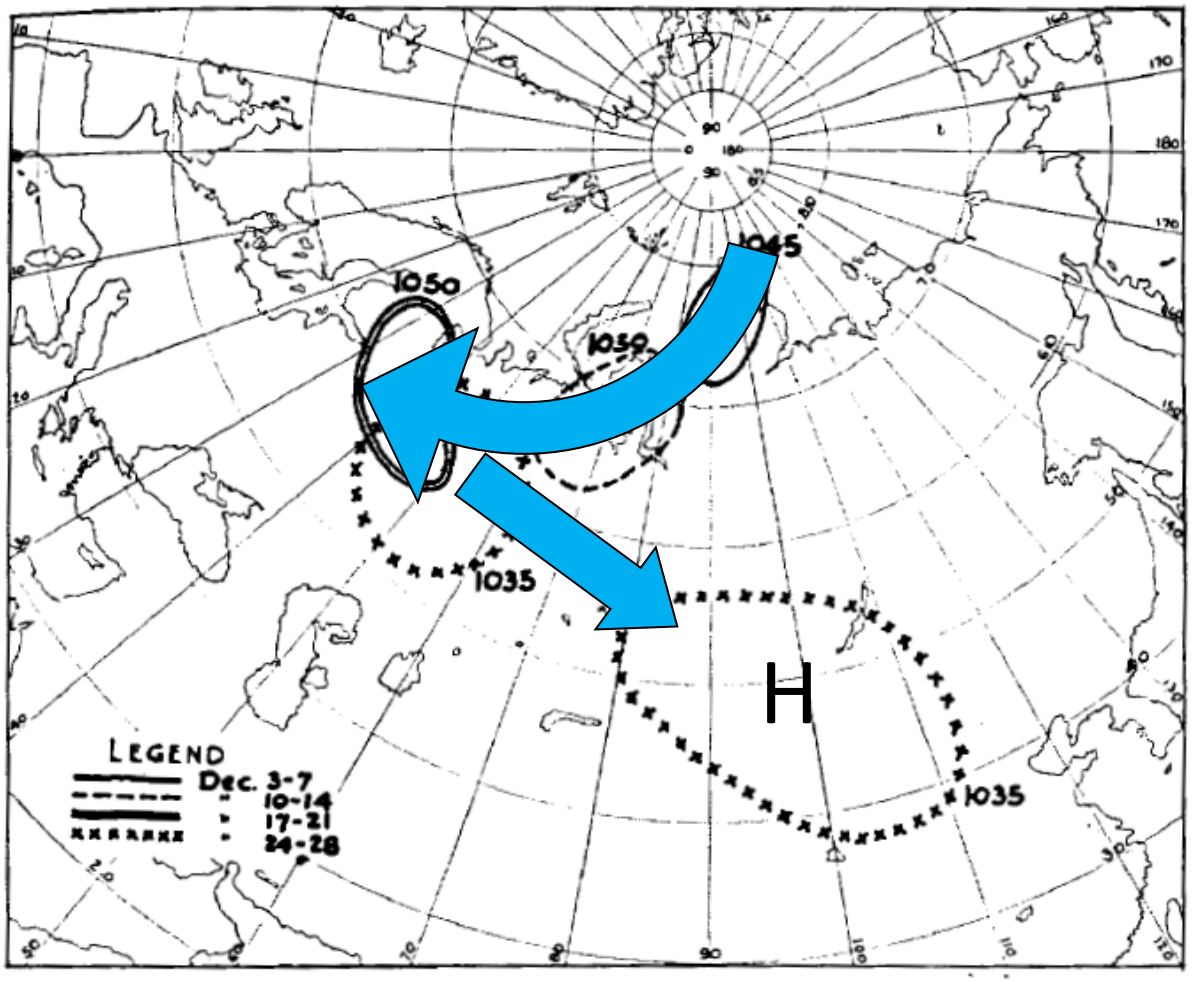
Low Index Circulation
14-20 Nov
1937

Blocked Flow

Pressure contrast between 35º and 55º latitude is a measure of the westerly, zonal flow



Motions of the Siberian high Dec 1938



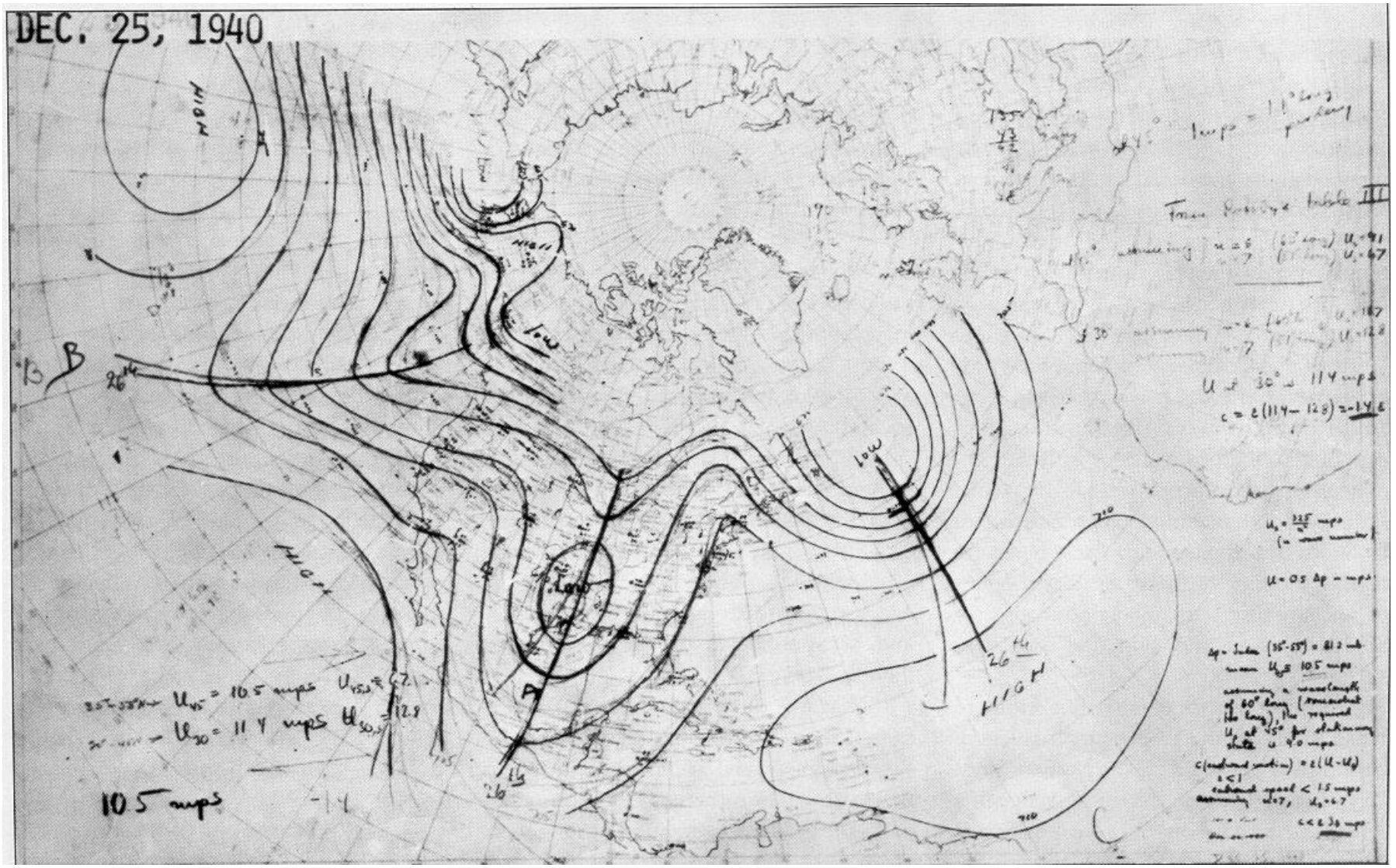
Rossby's wave formula
(inspired by Ekman, 1932)

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

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

Rossby and his team discovered the large scale planetary waves



Five-day forecasts from August 1940

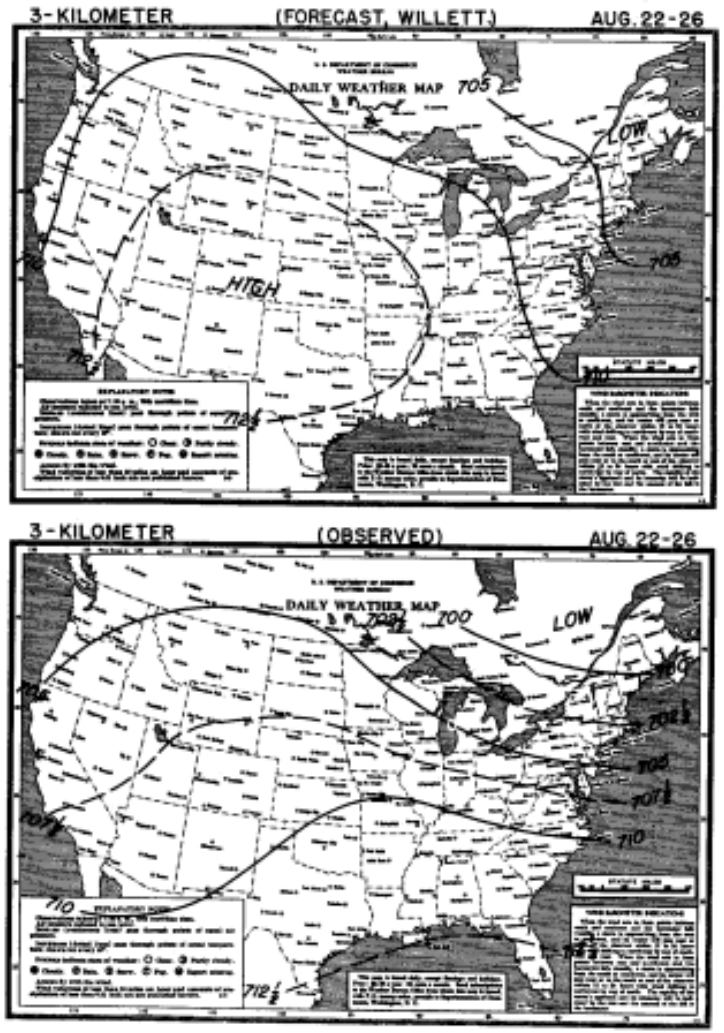


FIGURE 35.—Forecast and verification charts of mean 3-kilometer-pressure distribution (millibars) over the United States for the period August 21–25, 1940.

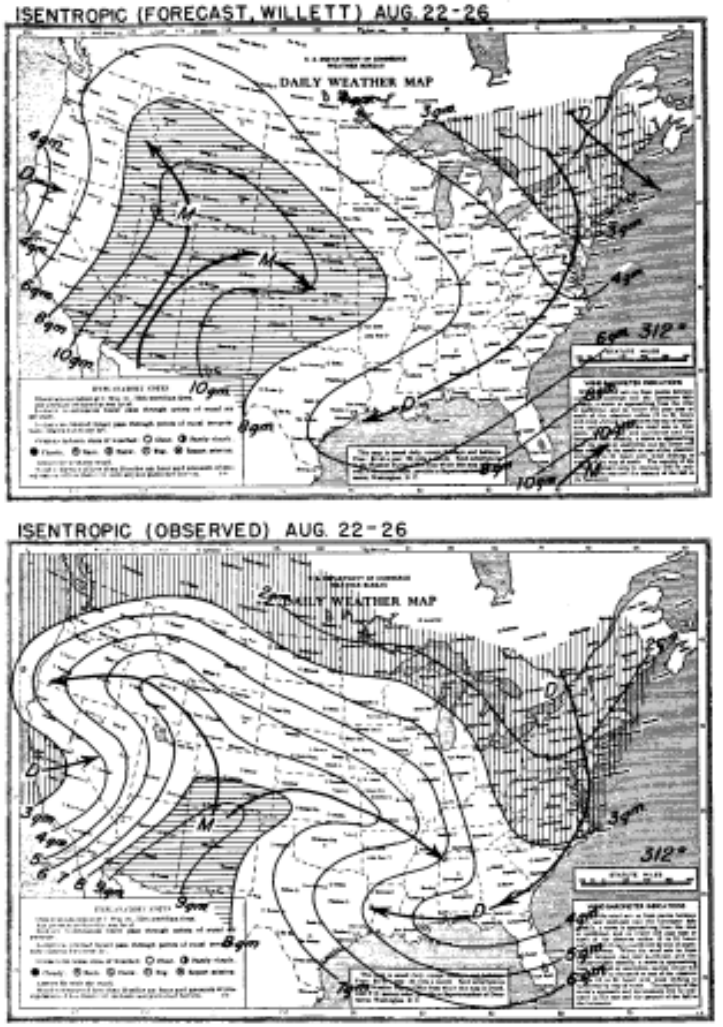
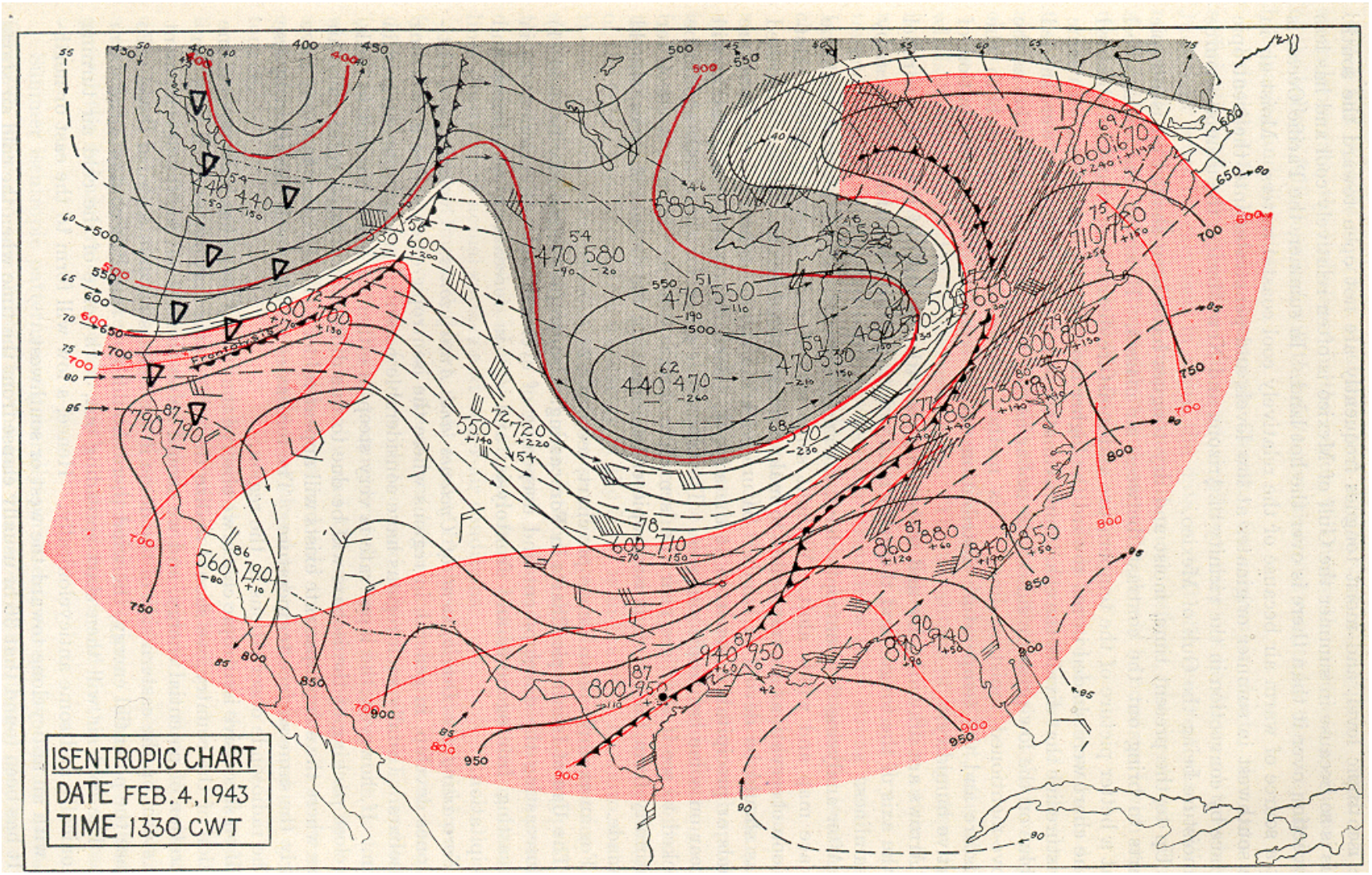
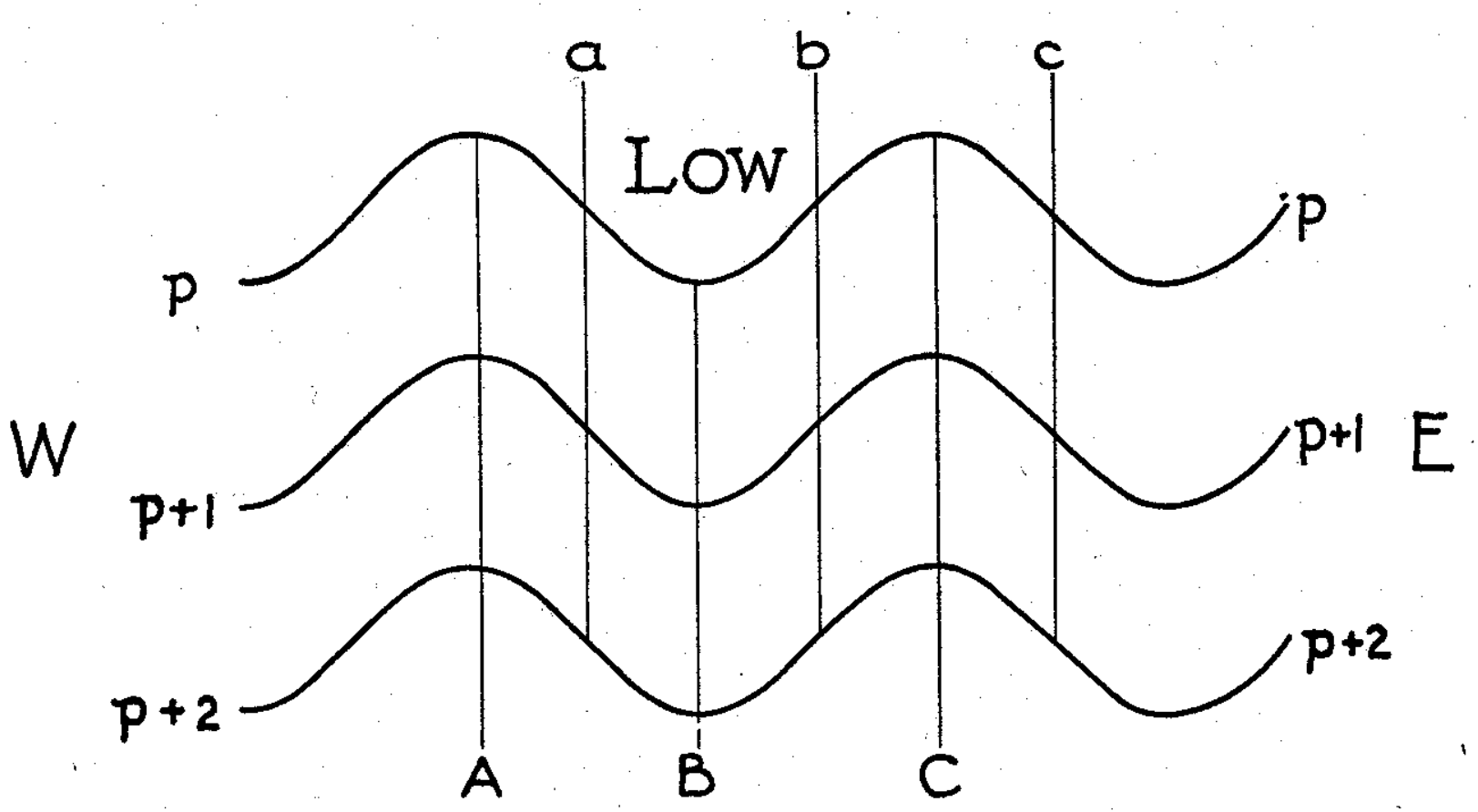


FIGURE 36.—Forecast and verification charts of the mean isentropic-moisture distribution over the United States for the period August 21–25, 1940.

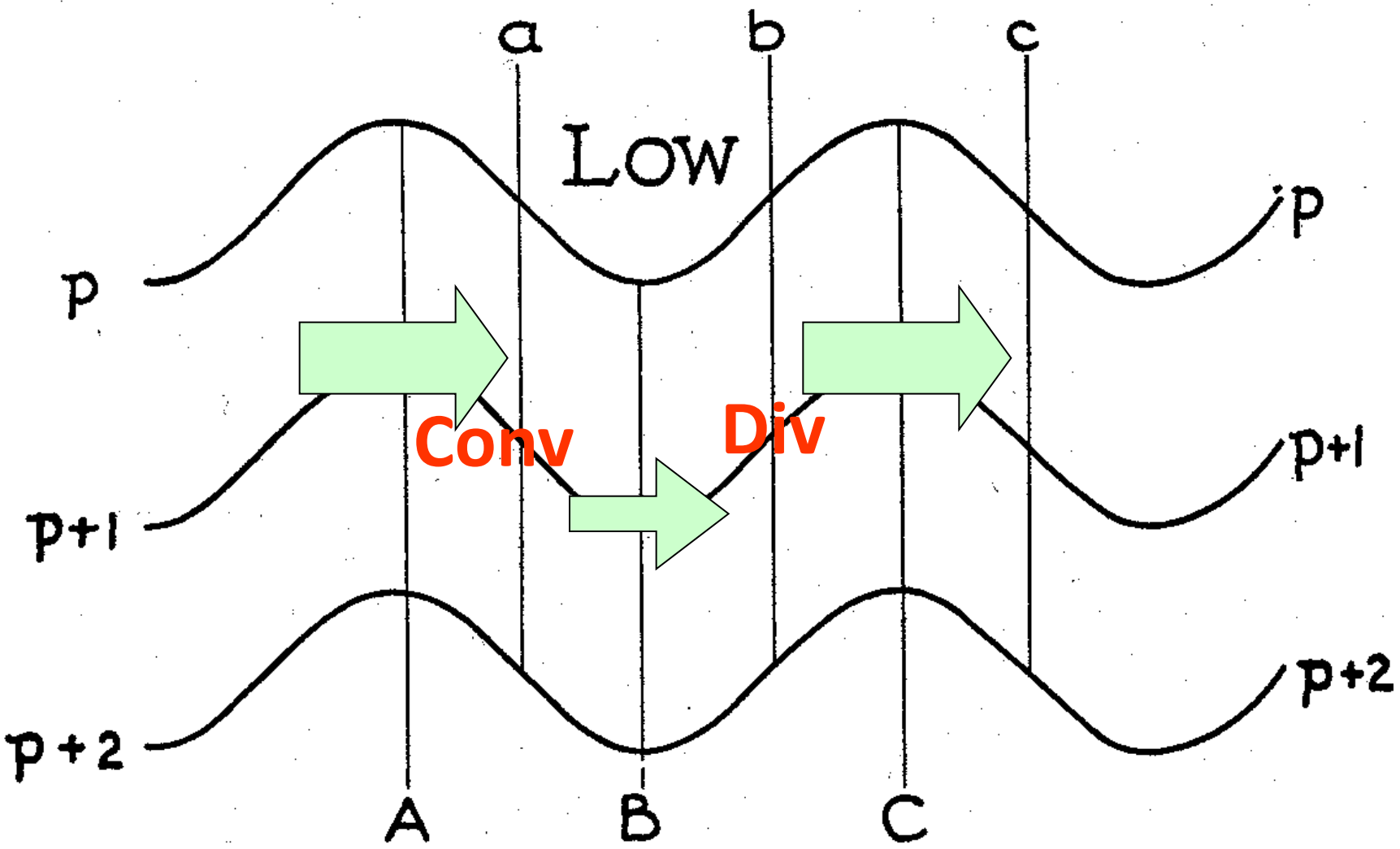

ISENTROPIC CHART
DATE FEB. 4, 1943
TIME 1330 GWT

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

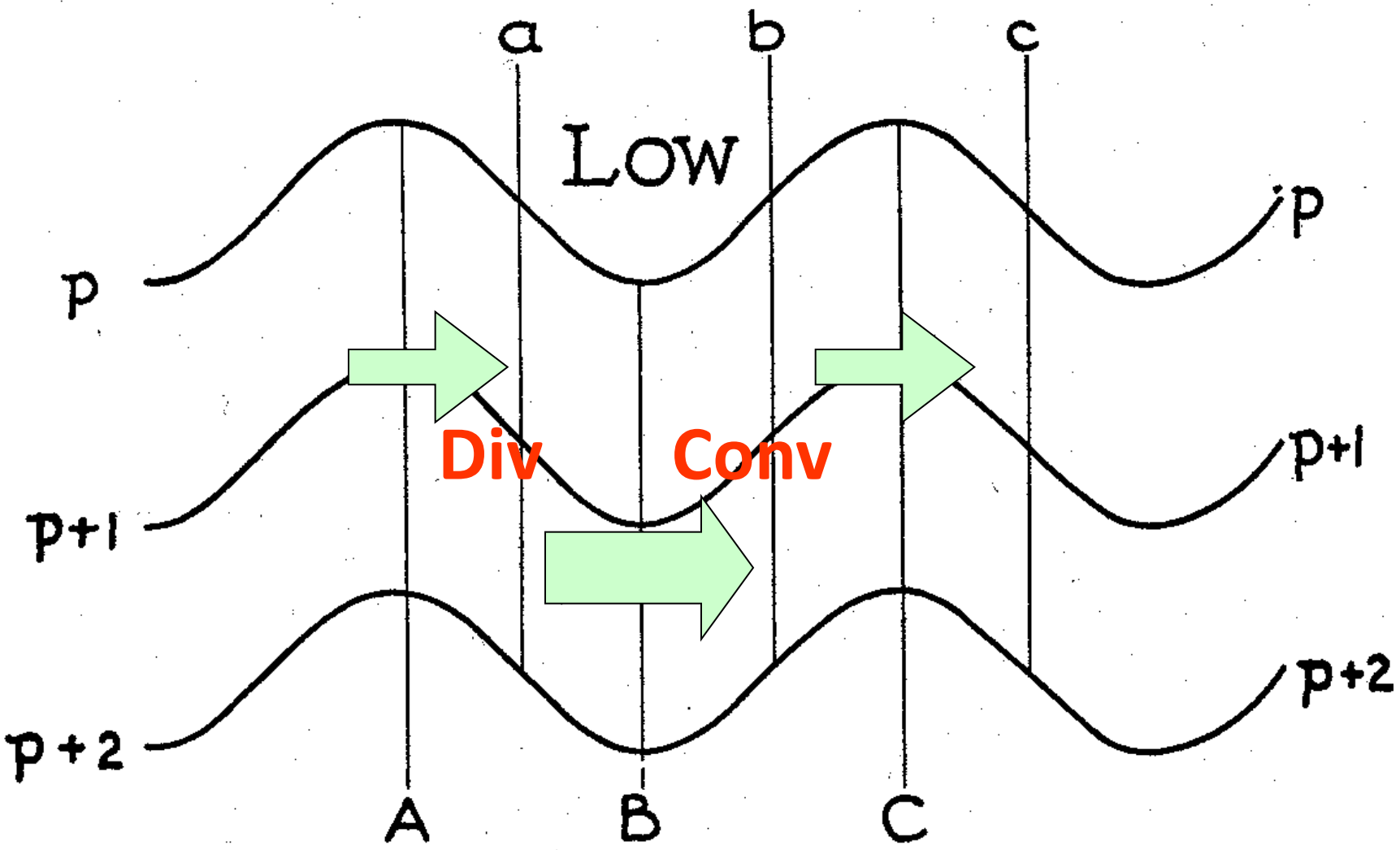


…to which he applied the gradient wind equation

Considering only the curvature effect on the gradient wind which is relevant for shorter waves – makes them move east



Considering only the latitude effect on the gradient wind which is relevant for longer waves – makes them move west

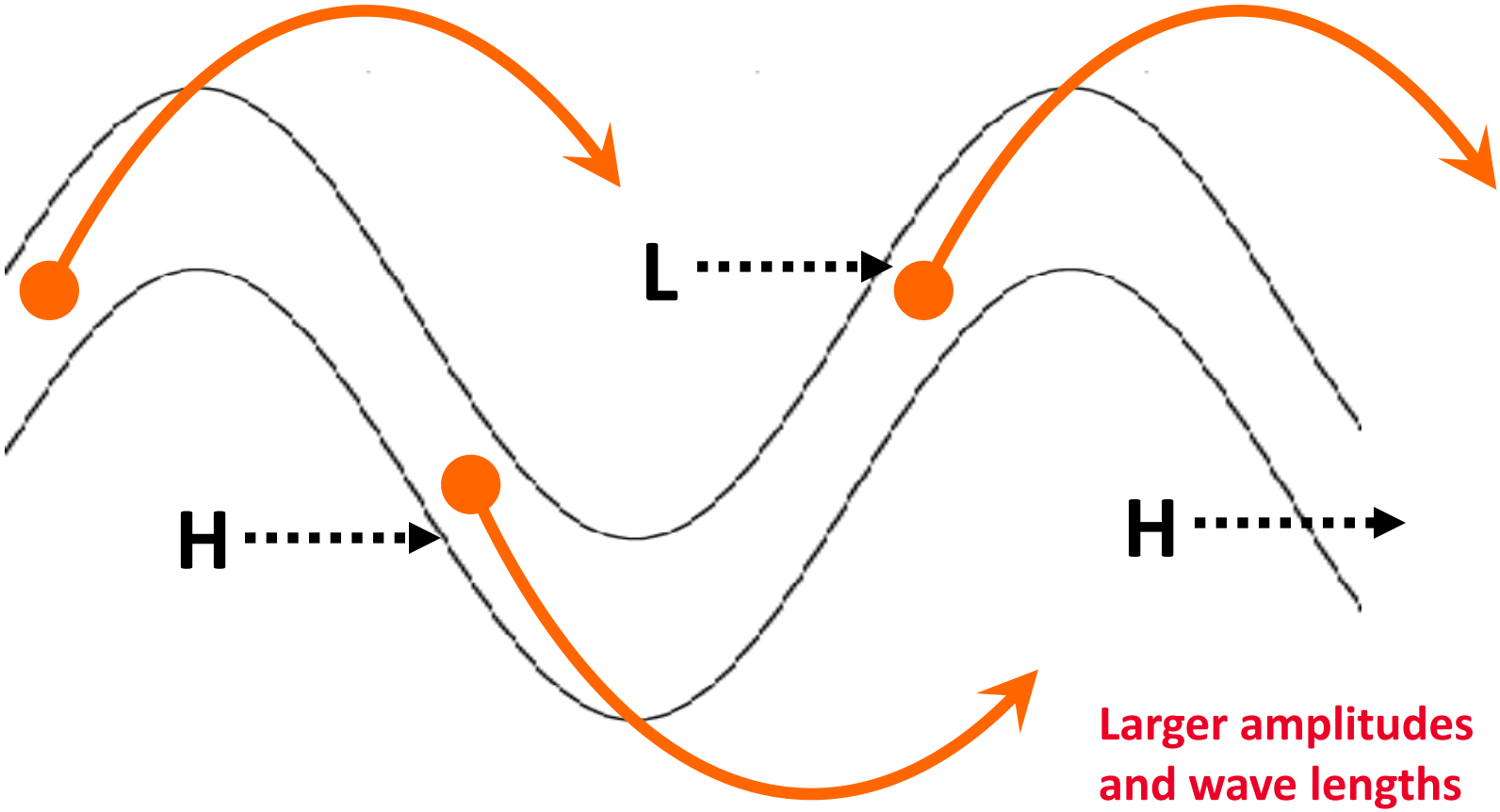


Only when the paper was published in 1939 did Rossby realize that he could not use the gradient wind balance - it is only applicable on stationary patterns

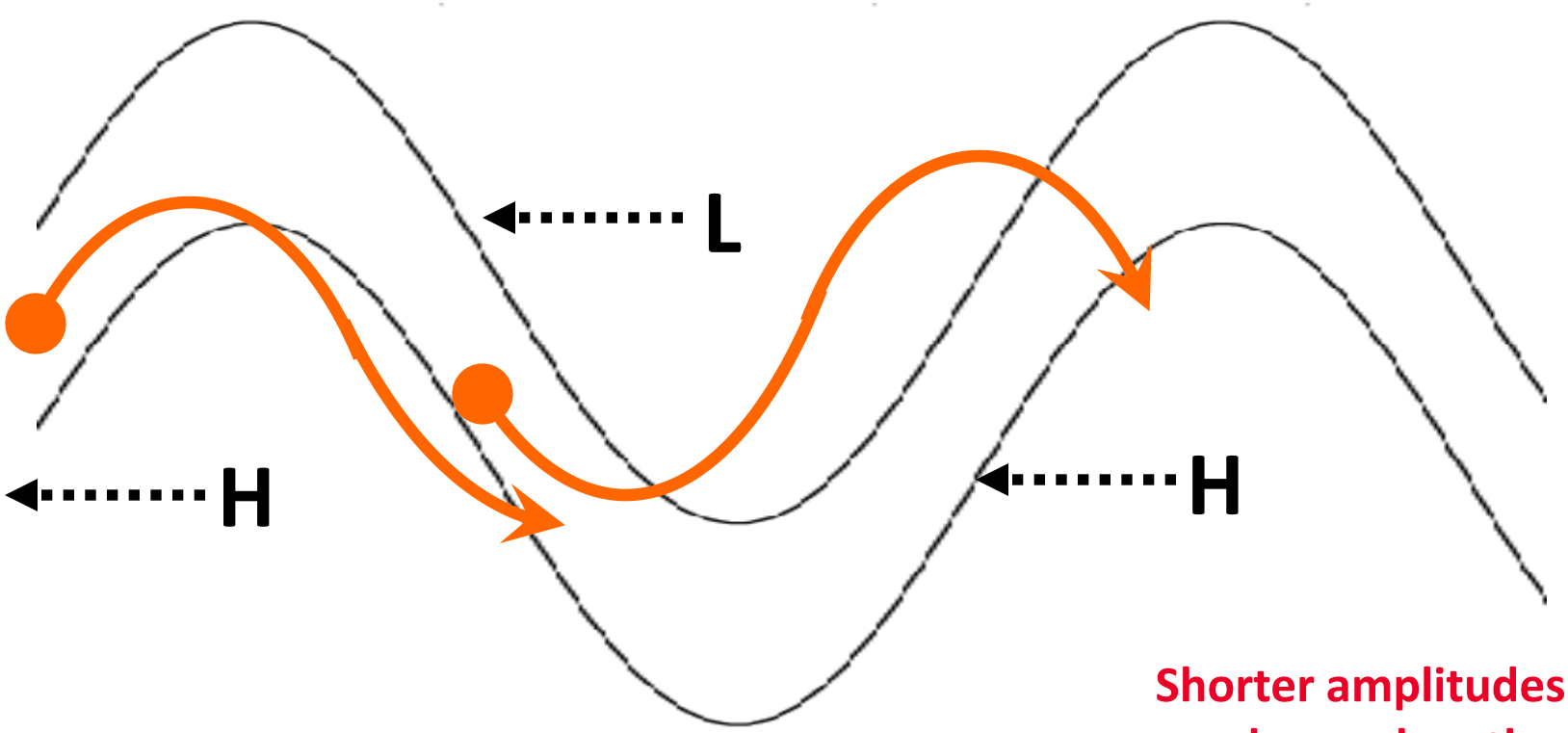
So he published a new version in the Canadian edition of QJRMS

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

Relation between stream lines and trajectories in a *progressive* flow

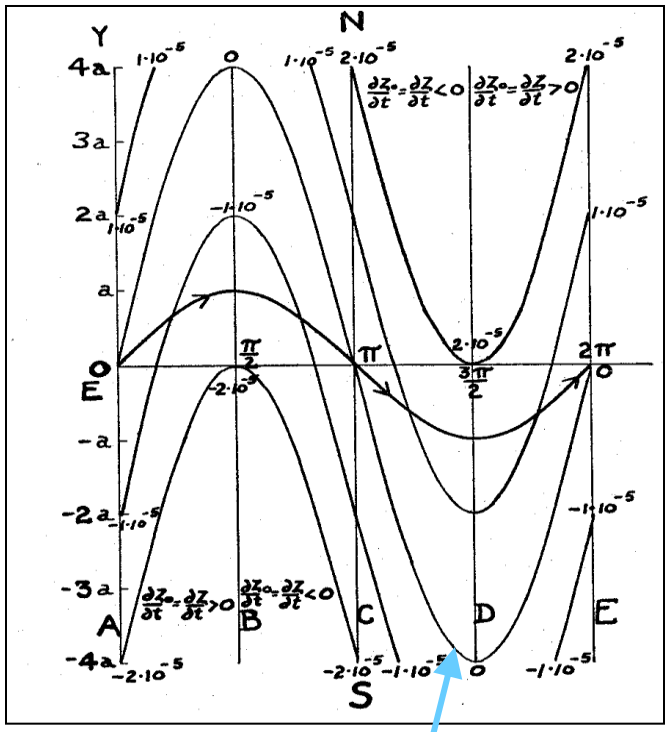


Relation between stream lines and trajectories in a *retrogressive* flow



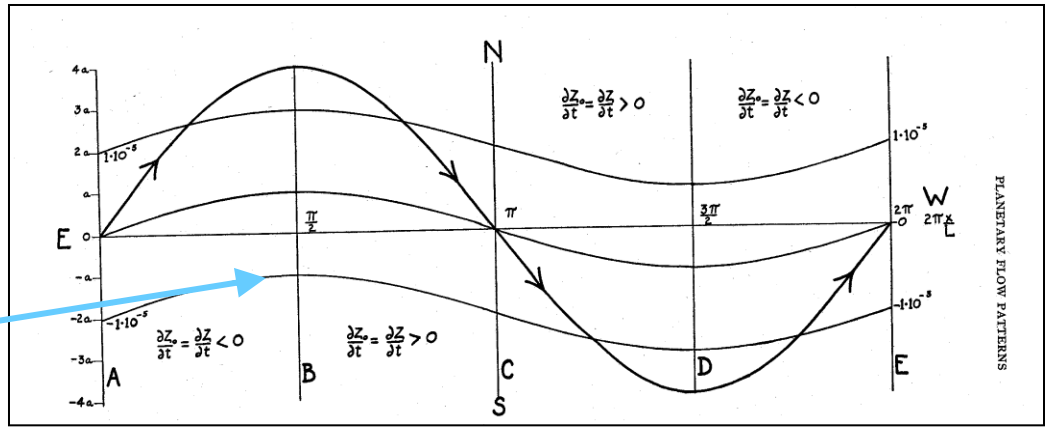
Shorter amplitudes and wave lengths

In 1940 a new article is published by C-G Rossby, the war time edition of Quarterly Journal issued by the Canadian branch of the Royal Meteorological Society



Very few seem to have taken notice of a Rossby (1940) correction - and even fewer understood what he meant

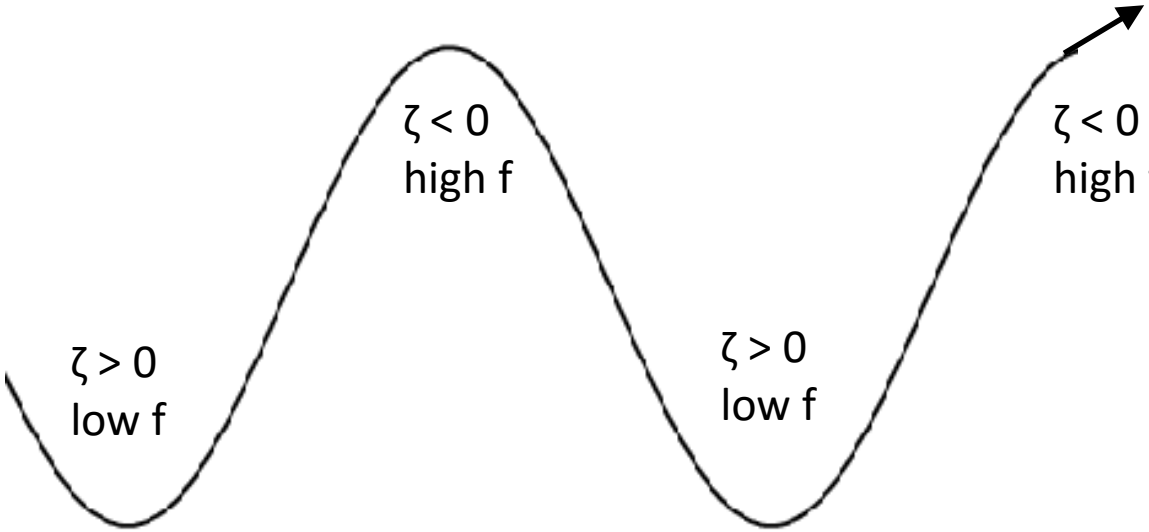
(Trajectories represented by PV isolines)



This is NOT a Rossby wave - as is often taught!

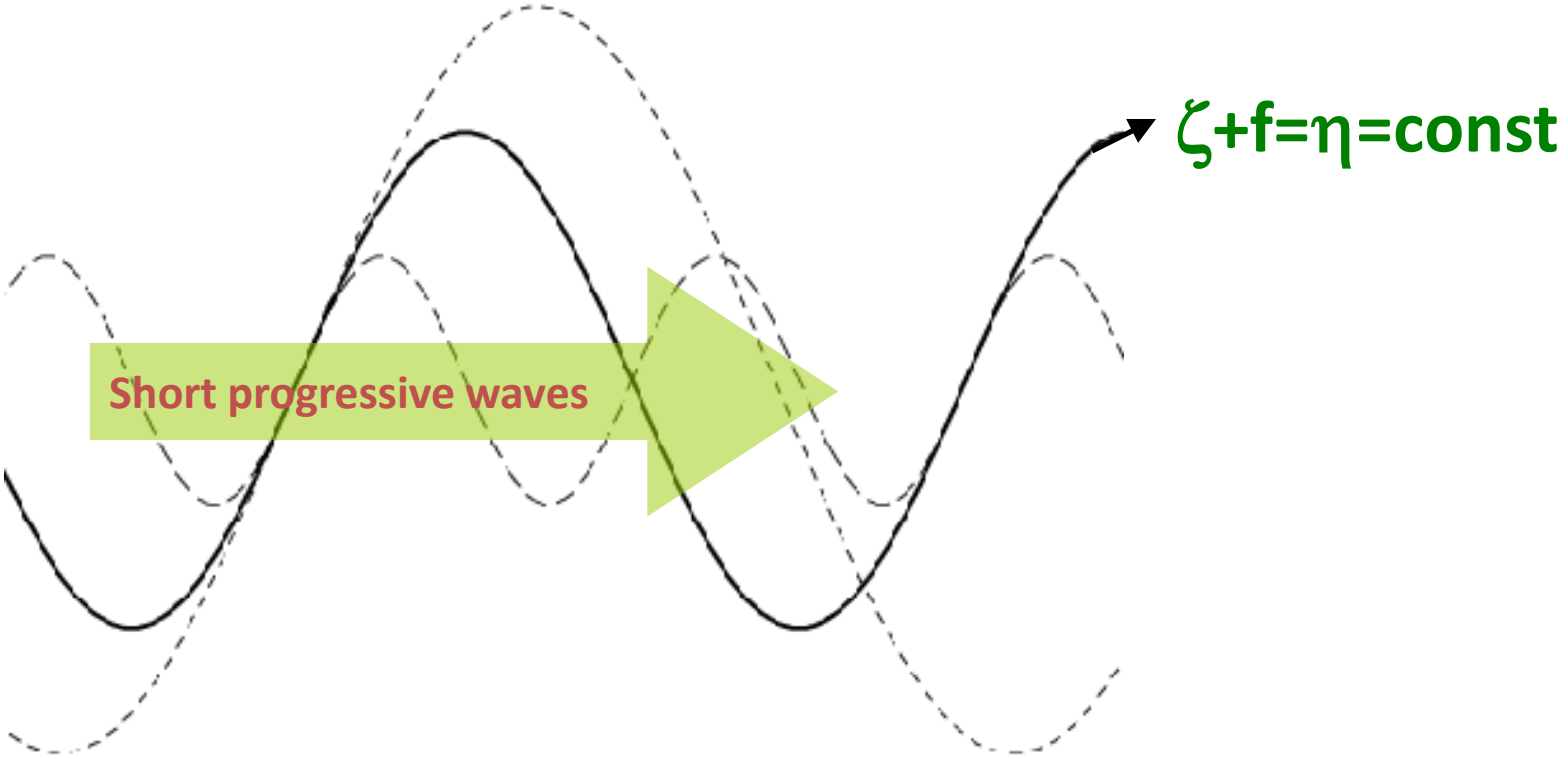
Conservation of absolute vorticity

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



…but a Constant Absolute Vorticity Trajectory!

-Rossby (1940) showed that one and the same CAV trajectory satisfies two types of streamlines (waves)



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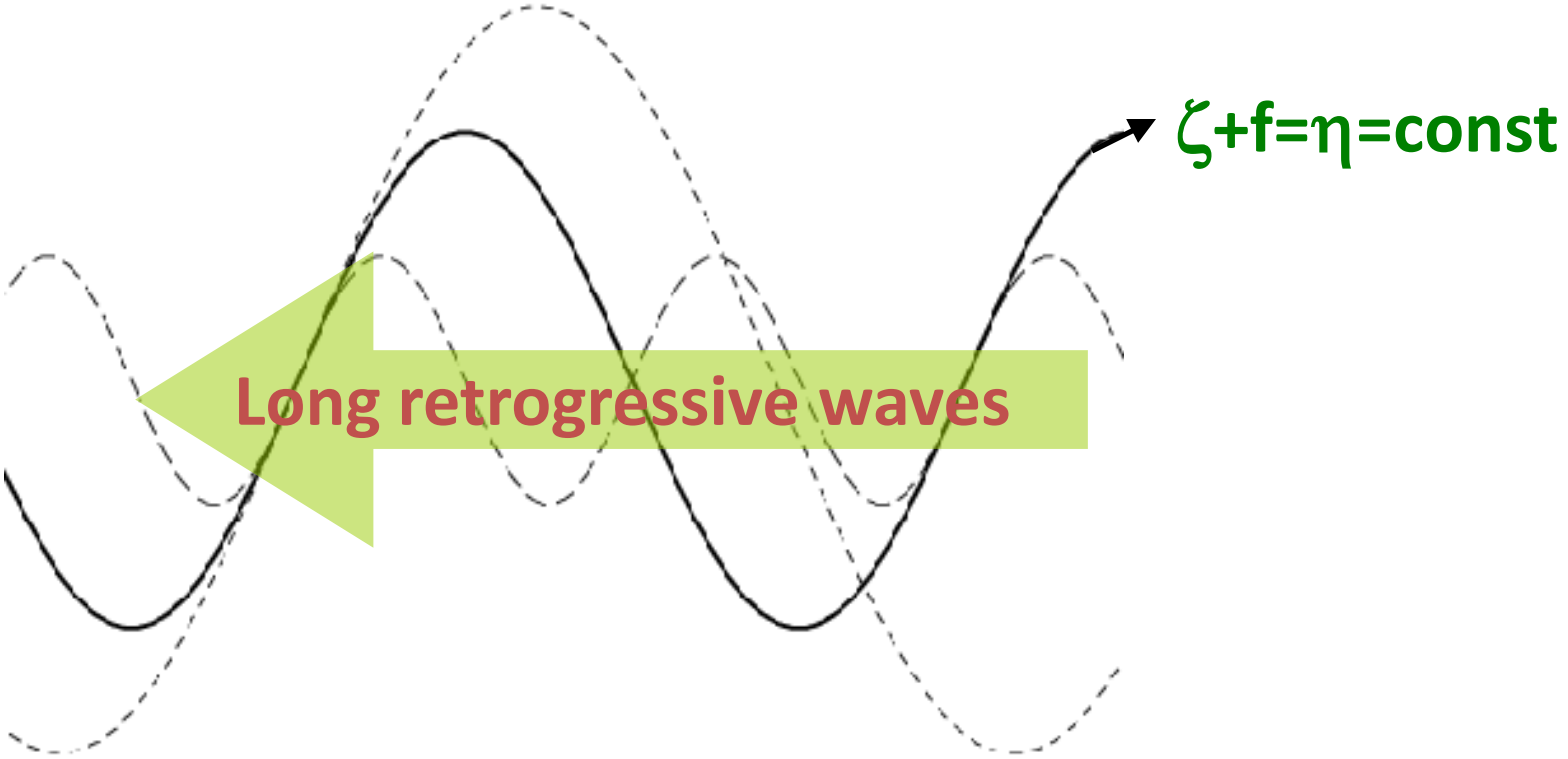


The meteorological $E=mc^2$

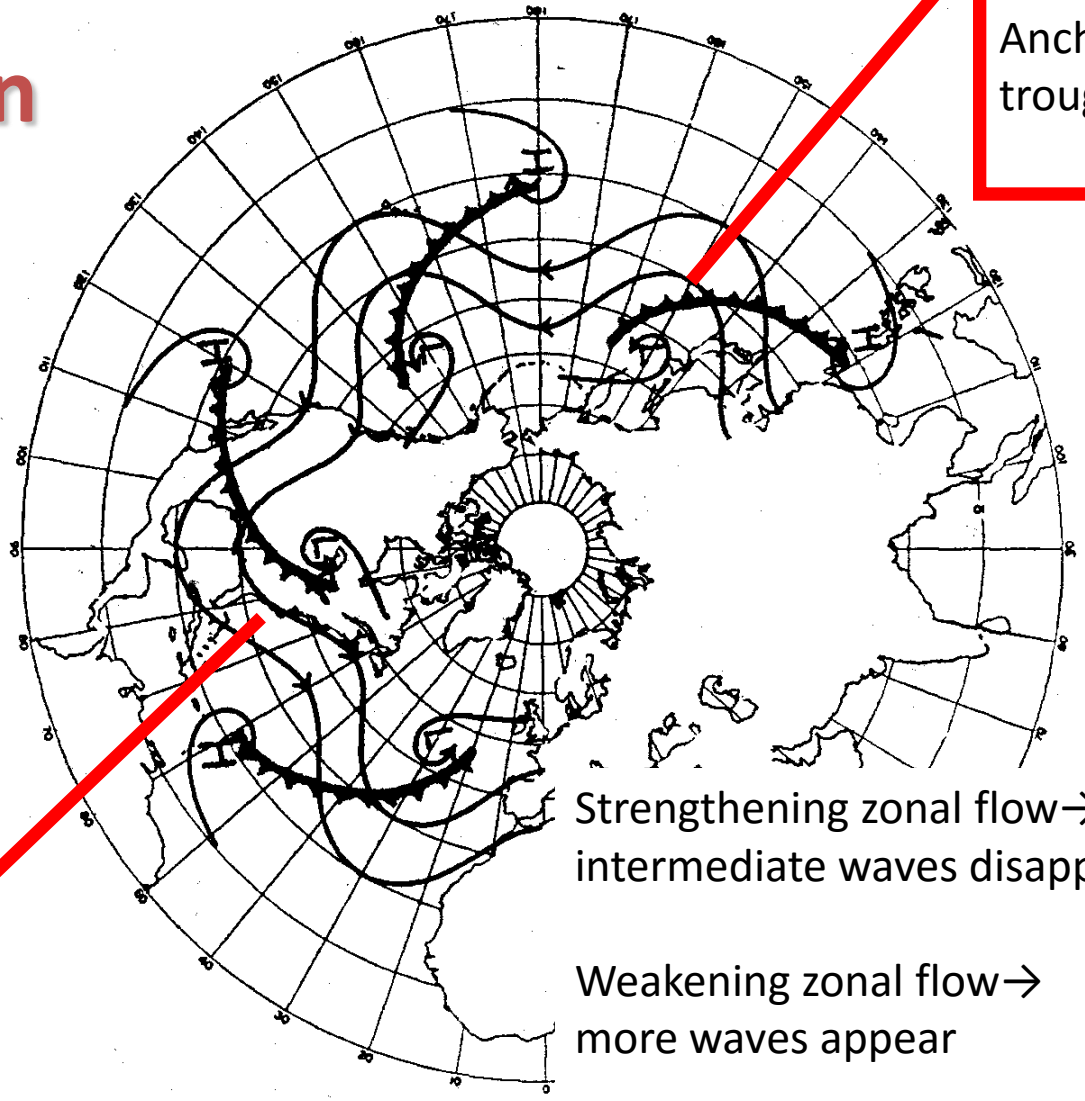
$$c = U - \frac{\beta L^2}{4\pi^2}$$

c = phase speed, U= zonal flow at 5-6 km, L=wave length, β=df/dy

Going west for large L, going east for small L

How Rossby's wave equation was used in practical forecasting

Quantum mechanical approach



Anchor trough

Anchor trough

Strengthening zonal flow→ intermediate waves disappear

Weakening zonal flow→ more waves appear

For c=0 Rossby derived the stationary wave length

$$L_S = 2\pi\sqrt{\frac{U}{\beta}}$$

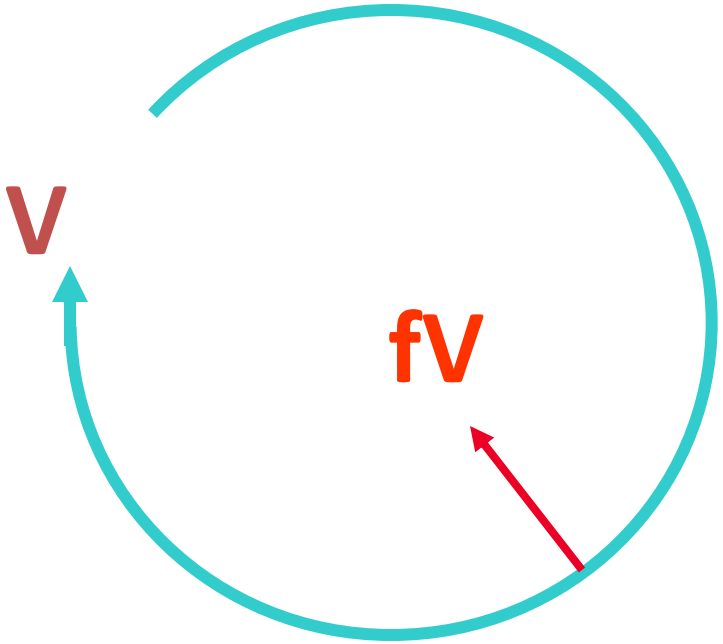
Differences between the current wave length and the stationary gave indications about re-positions

$$c = U\left(1 - \frac{L^2}{L_S^{\ 2}}\right)$$

But what ”is” it?

The “inertia circle” motion

$$-2\Omega \times V$$



The Coriolis parameter
$f = 2\Omega\sin\varphi$

The radius of the inertia circle
$R=V/f$

The ”beta-effect”

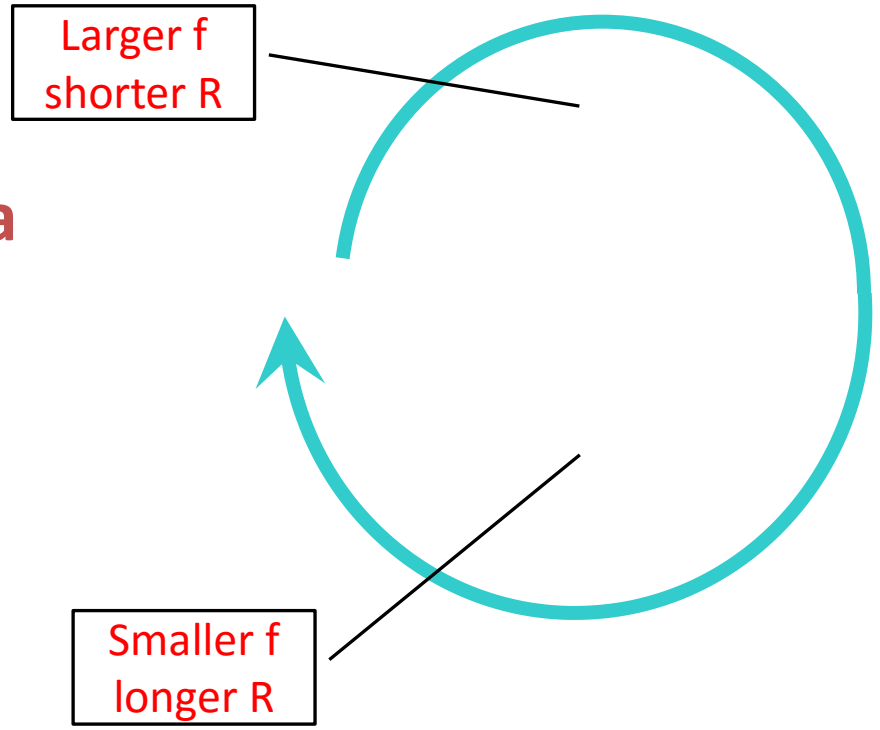
The Coriolis parameter $f = 2\Omega\sin\varphi$

depends on latitude

$\therefore$ the radius of the inertia circle

$R=V/f$

depends on latitude



The ”beta-effect”

The Coriolis parameter
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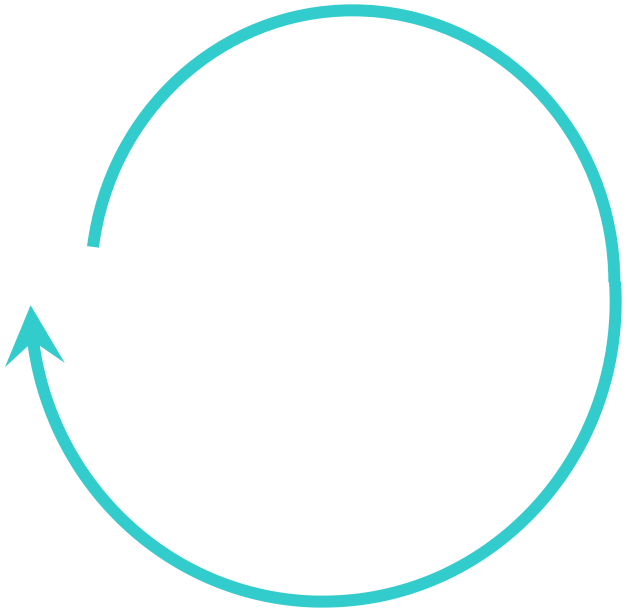
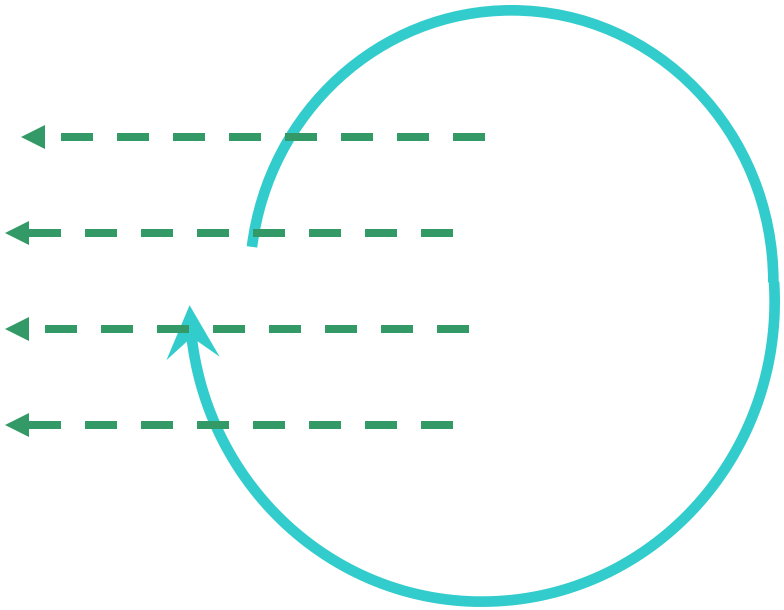
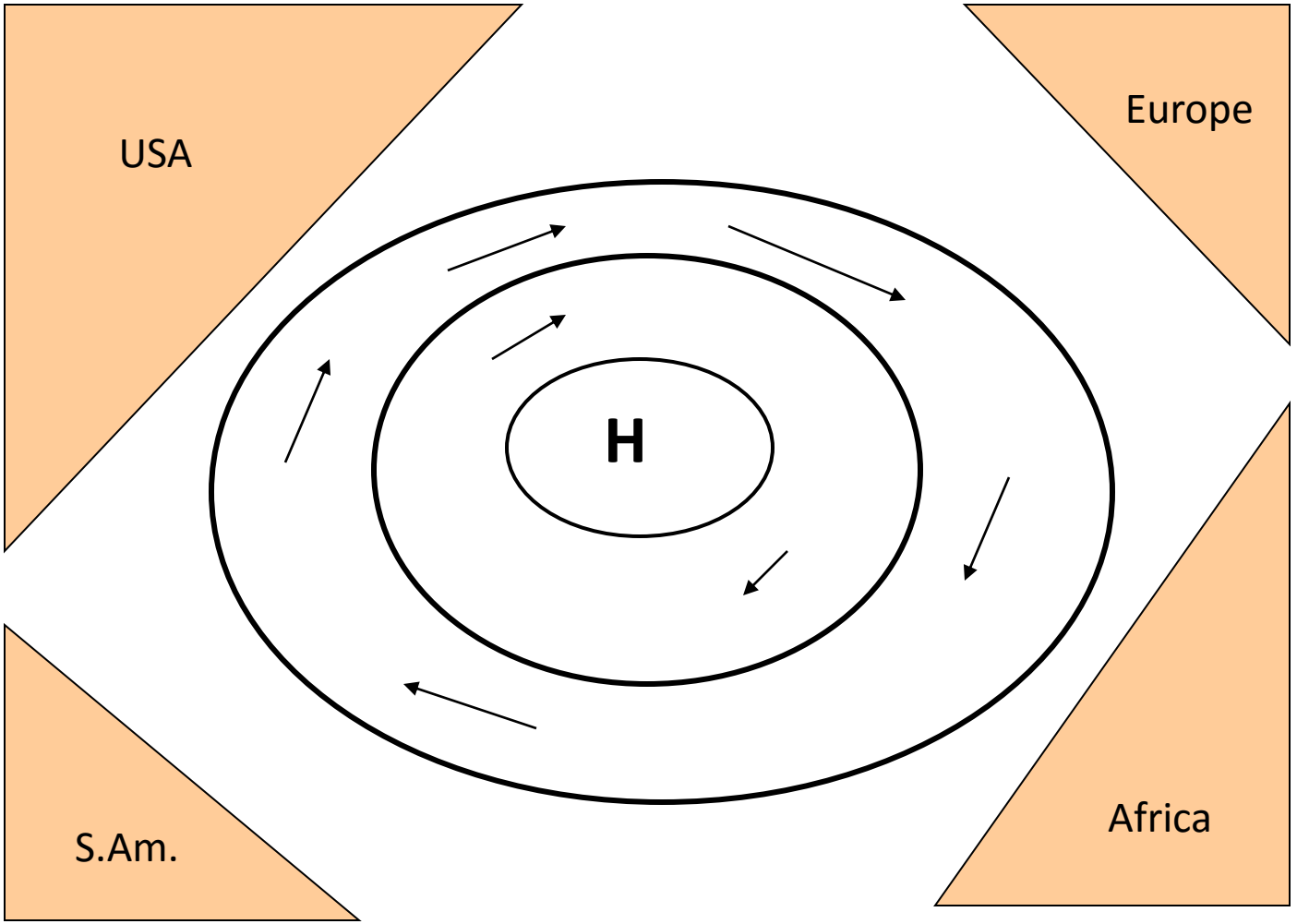


$\therefore$ the radius of
the inertia circle
$R=V/f$
depends on latitude

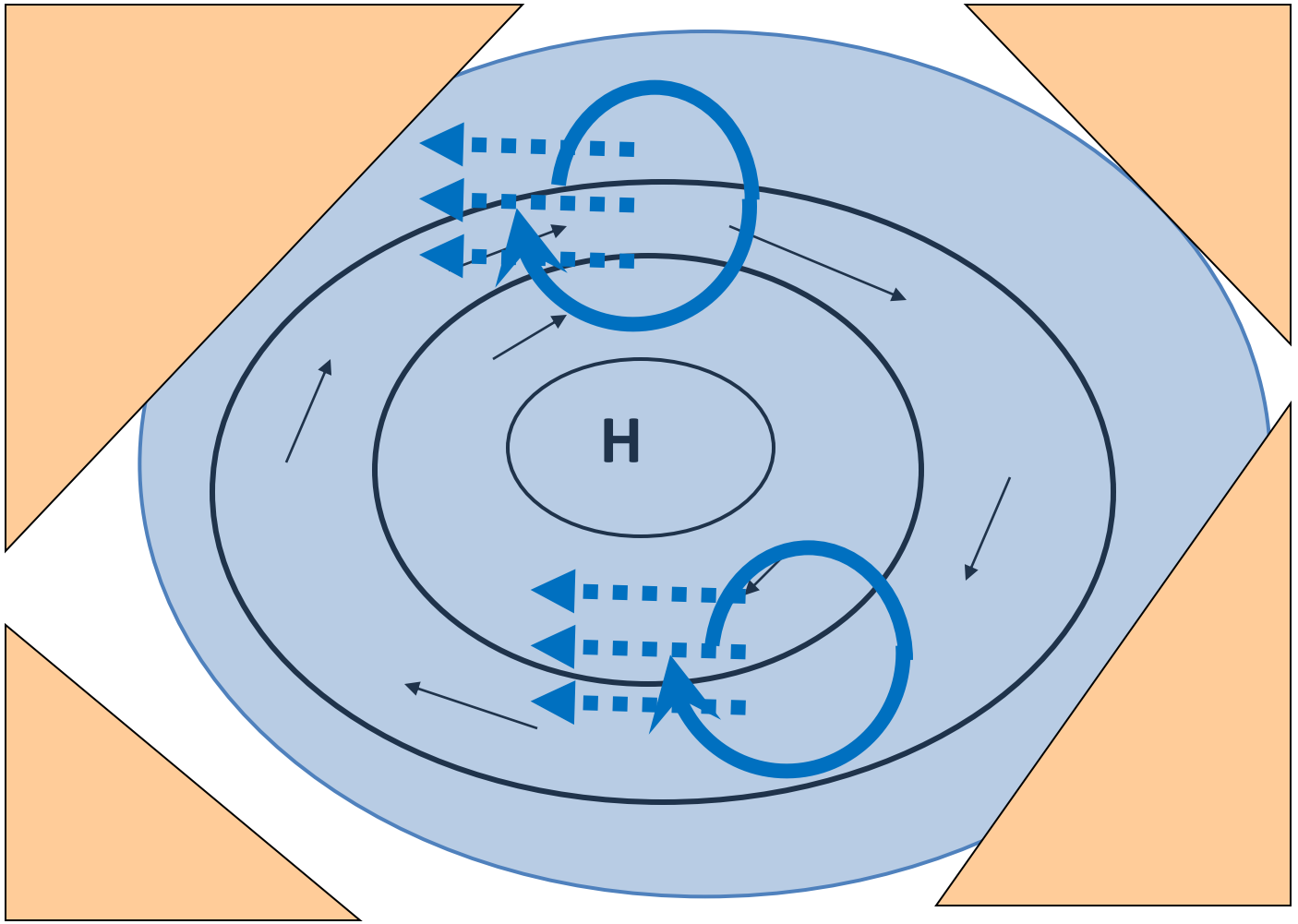
The ”beta-effect” gives rise to a slow westward propagation of mass



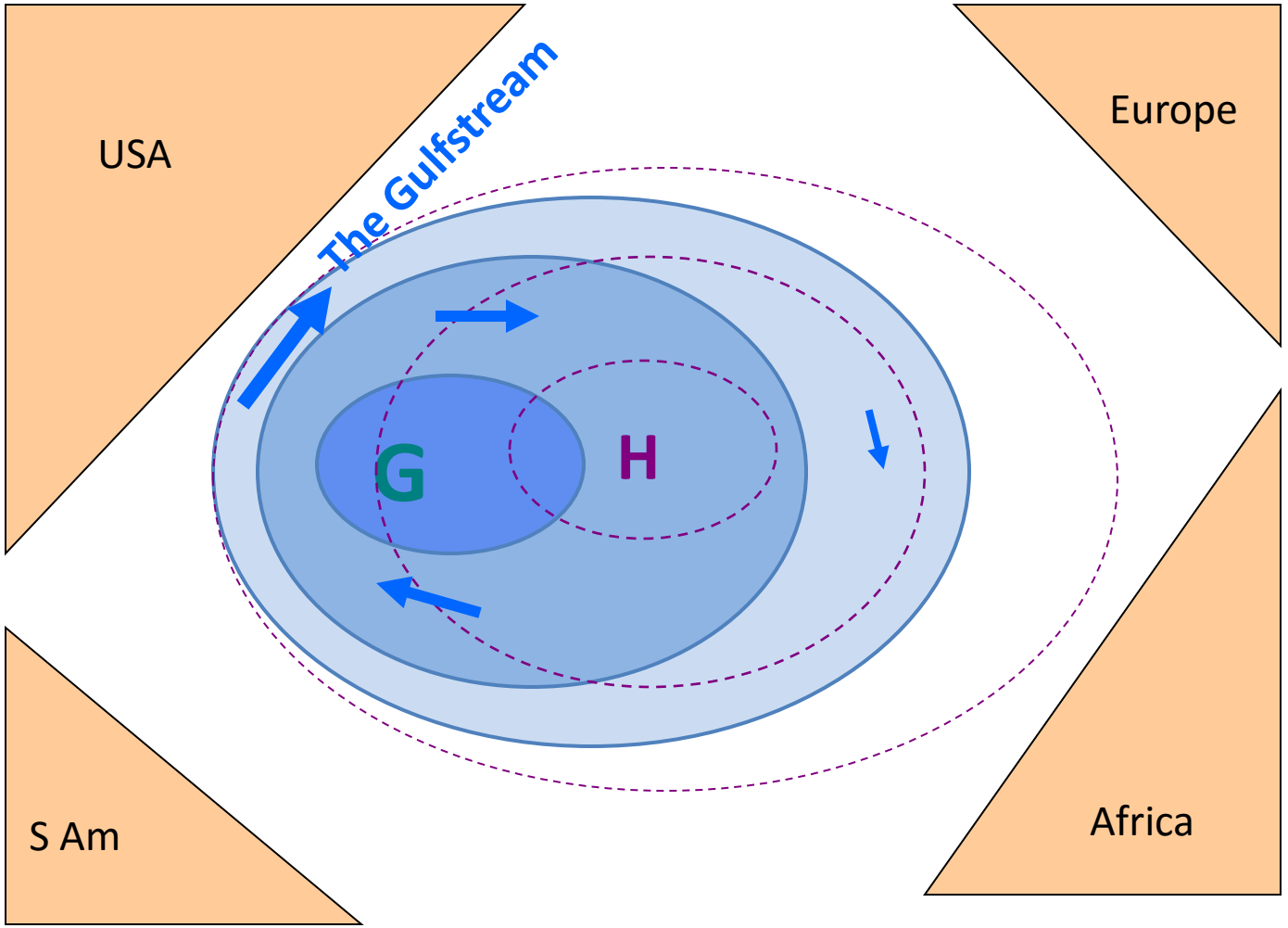
The subtropical high pressure area ("The Azores High")



The beta effect would drive the water westward



Instead we get an asymmetric Gulf Stream circulation



End