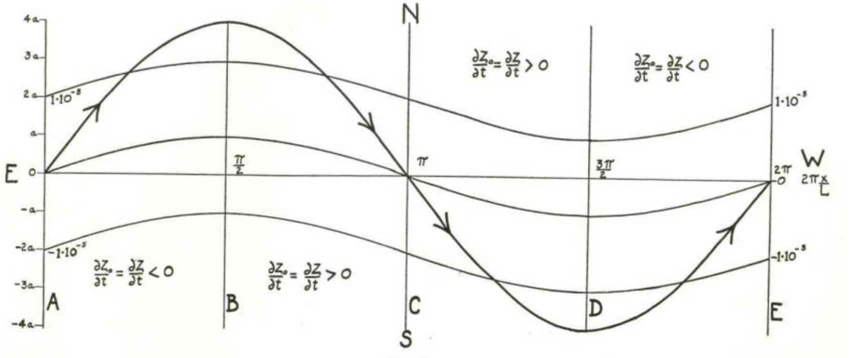
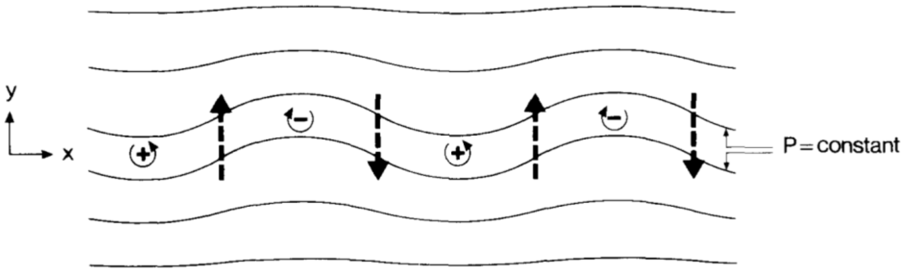
QUARTERLY JOURNAL
OF THE
ROYAL METEOROLOGICAL SOCIETY

UNIVERSITY OF OXFORD

# Rossby waves in the Quarterly Journal

**Tim Woollings**
*Dept. of Physics, University of Oxford*



# Intro to Rossby waves

BULLETIN AMERICAN METEOROLOGICAL SOCIETY [Vol. 28

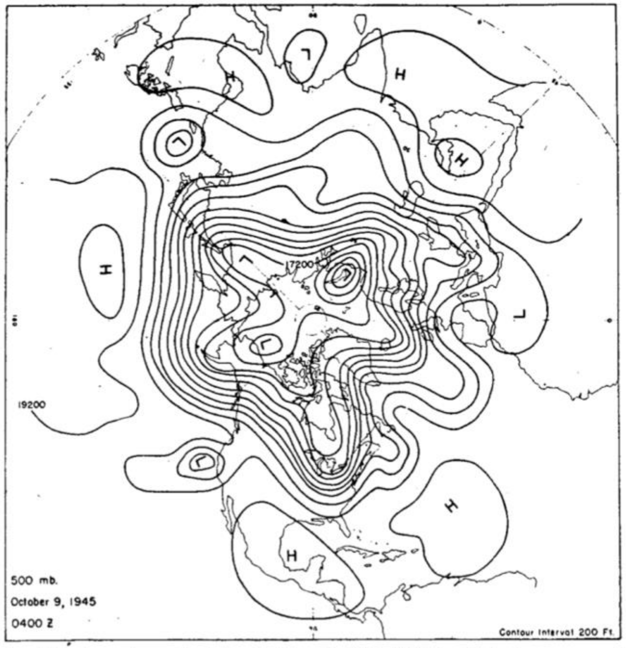
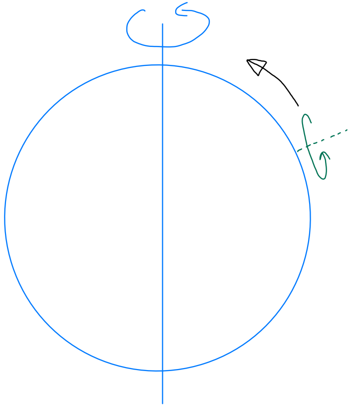



FIG. 4. 500-mb contour chart for October 9, 1945, 0400Z. Note long-wave pattern, with five major waves. Note deep trough in region of Azores.

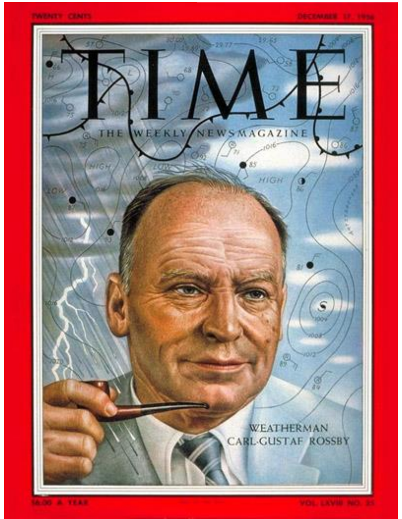
*Staff Members paper (1947)*

Planetary vorticity –
due to rotation of Earth



Relative vorticity –
air spinning with
respect to Earth

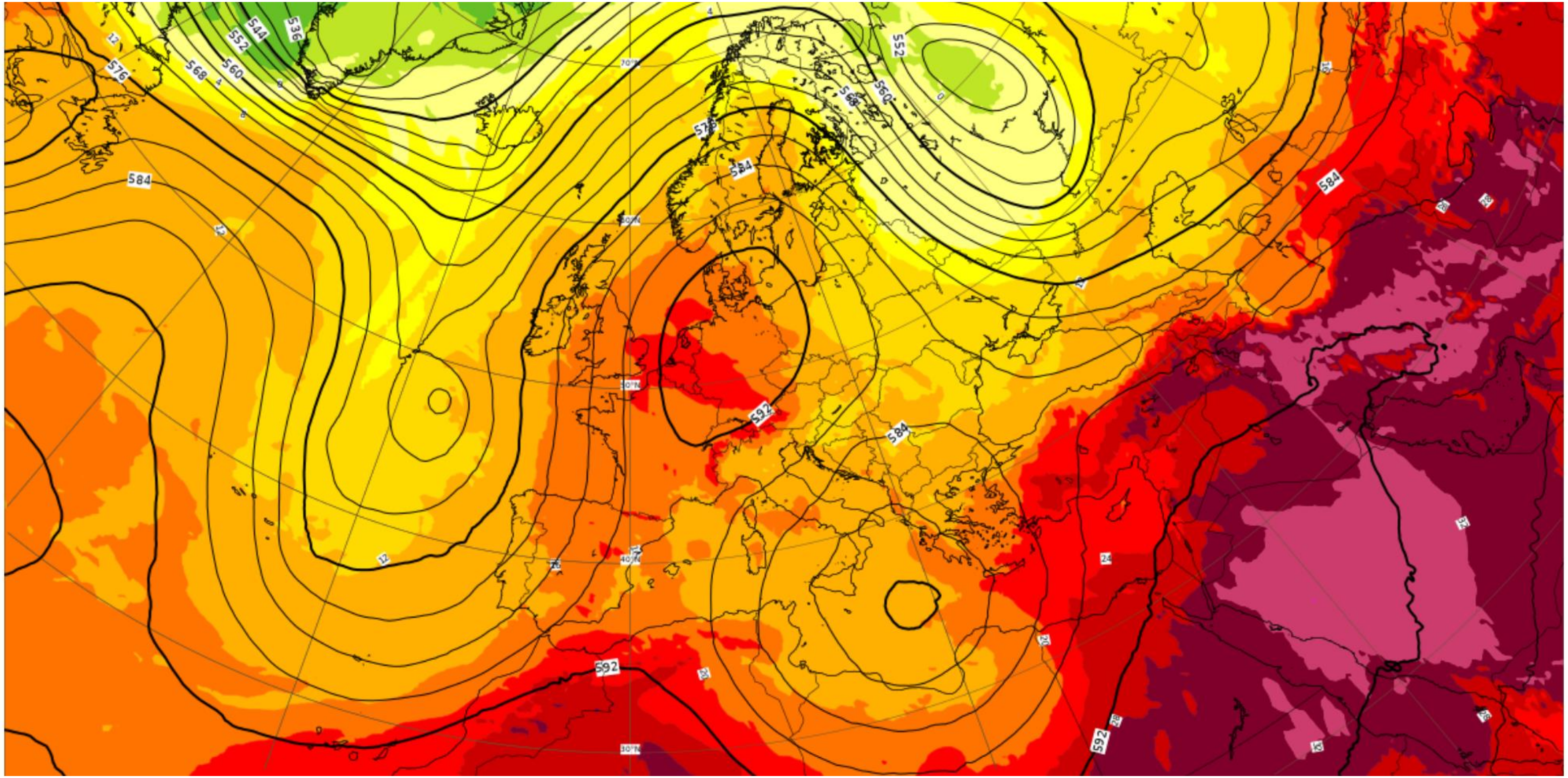
Total vorticity
is conserved




Rossby pioneered observation as well as theory, e.g. in coordinated balloon observations to give first global flow maps

## Intro to Rossby waves

Still a key research focus, especially in relation to stationarity



# Rossby's theory

Rossby and collaborators (1939)
Journal of Marine Research

- followed Bjerknes' circulation theorem
- described beta effect
- considered uniform westerly flow
- derived propagation of barotropic waves, including phase speed
- started to consider change in depth of column…

RELATION BETWEEN VARIATIONS IN THE INTENSITY OF THE ZONAL CIRCULATION OF THE ATMOSPHERE AND THE DISPLACEMENTS OF THE SEMI-PERMANENT CENTERS OF ACTION*

By

C.-G. ROSSBY AND COLLABORATORS

*Massachusetts Institute of Technology*

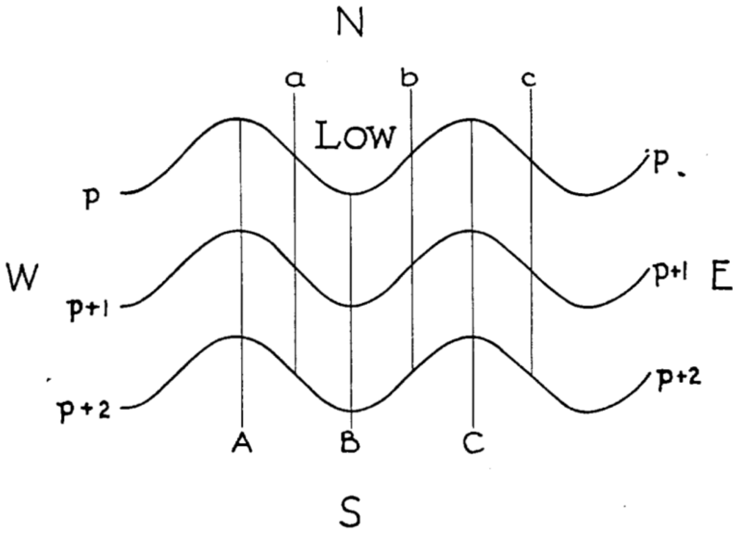



Figure 11. Sinusoidal Perturbation on Zonal Motion.

# Rossby (1940) Planetary flow patterns in the atmosphere, QJ

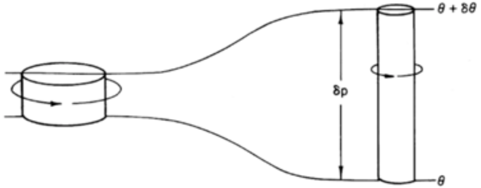
**QJ@150**

Focused on a new quantity which is conserved following the flow:

Shallow water case: $$\frac{d}{dt}\left(\frac{f+\zeta}{D}\right)=0$$

For an isentropic layer: $$\frac{d}{dt}\left(\frac{f+\zeta}{\Delta}\right)=0$$

*This quantity, which may be called the potential vorticity, represents the vorticity the air column would have if it were brought, isopycnically or isentropically, to a standard latitude ($f_0$) and stretched or shrunk vertically to a standard depth $D_0$ or weight $\Delta_0$.*




*Holton & Hakim*

"Rossby took a step further"
"simplest version of the modern concept of `potential vorticity'"
"ingenious mathematical device of great simplifying power"

**QJ@150**

*Hoskins, McIntyre & Robertson (1985, QJ)*

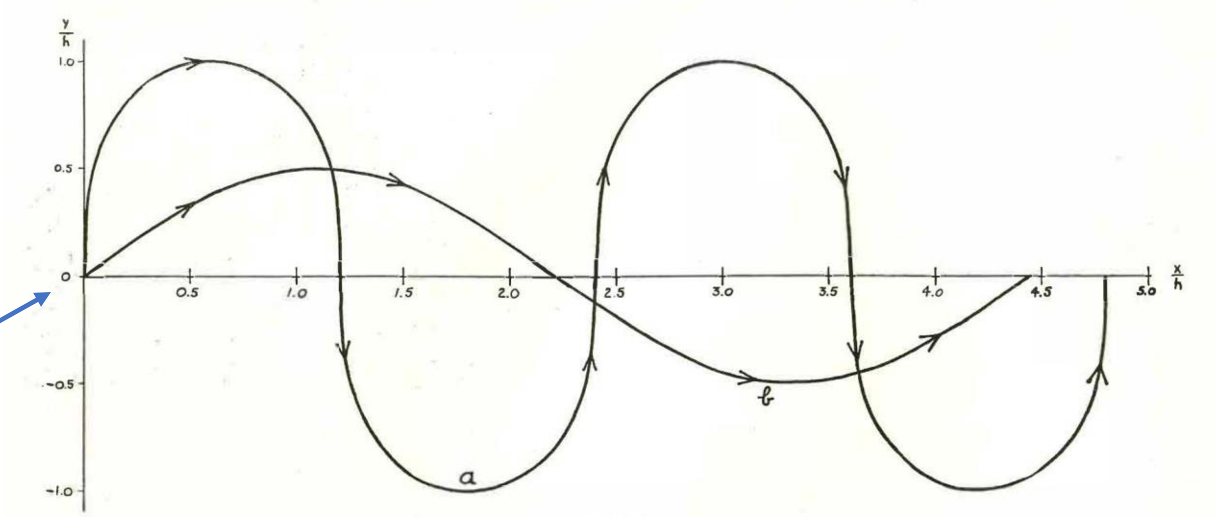
# Waves on a narrow westerly jet

Vorticity transport along jet:

$$fV + \frac{M}{R} = (f_0 + \beta y)V + \frac{M}{R} > f_0 V.$$

Initial — Later

Jet has cyclonic curvature (R>0) where it is displaced north



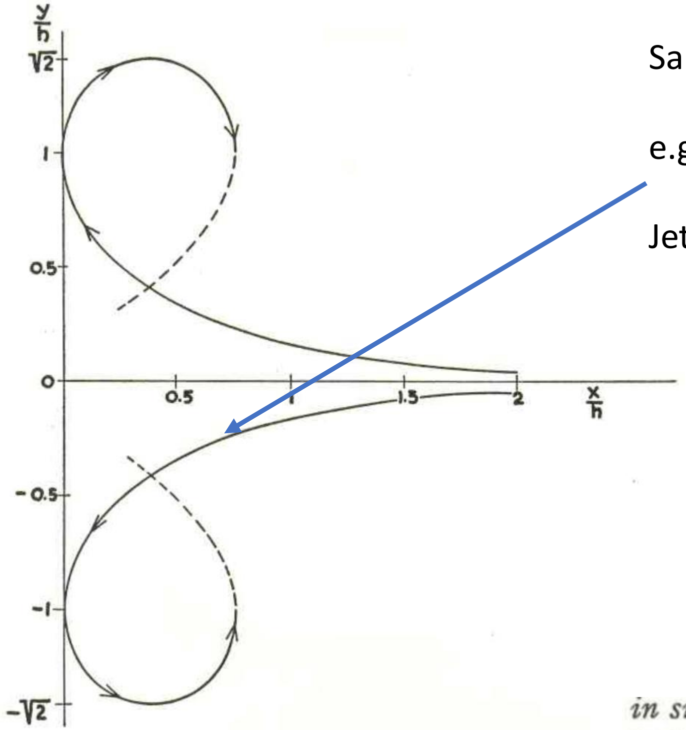

As y increases, R must increase – curvature weakens then reverses

➔ Jet bends back south

➔ **Jet stable and a Rossby wave forms**

Stationarity was a key focus even in these early papers

# Unstable easterly jets




Same argument for easterly jets results in eddy trajectories…

e.g. $fV + M/R$ constant along this trajectory

Jet moves further south

- -> $f$ decreases
- -> $R$ decreases further
- -> tighter curvature

It would thus appear justifiable to state that *easterly wind currents in such a barotropic atmosphere are unstable and* must break up into intermittently re-established cyclonic or anticyclonic vortices as a result of very small impressed forces.

# Physical arguments for propagation

Interpretation via the alignment of streamlines (**bold**) and PV contours

A consequence of the scale effect of PV inversion (HMR85)

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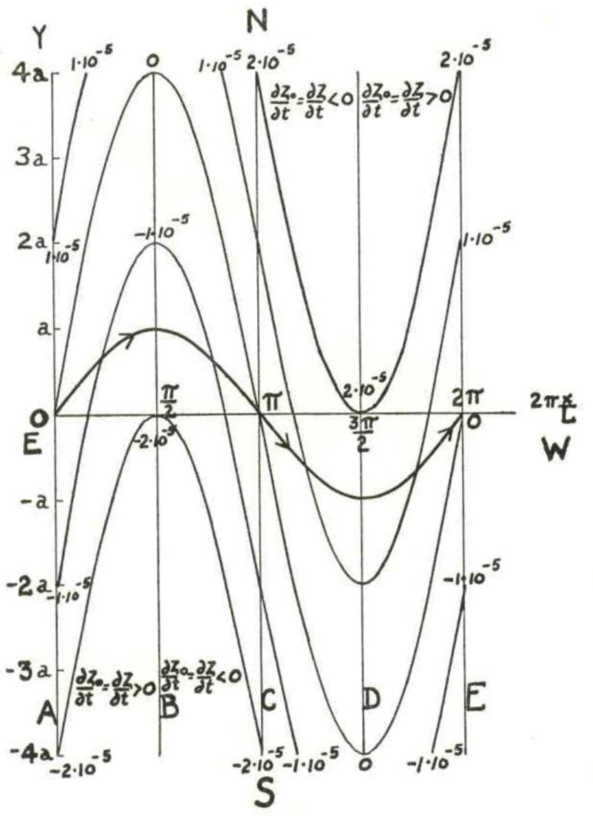
**Short waves**

- streamline meanders have *weaker* amplitude than PV contours

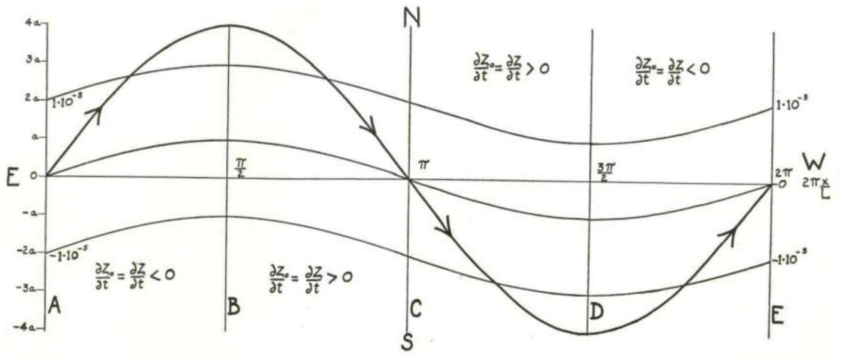
- zero PV line is advected *east*




**Long waves**

- streamline meanders have *greater* amplitude than PV contours

- zero PV line is advected *west*



# Wider interpretation

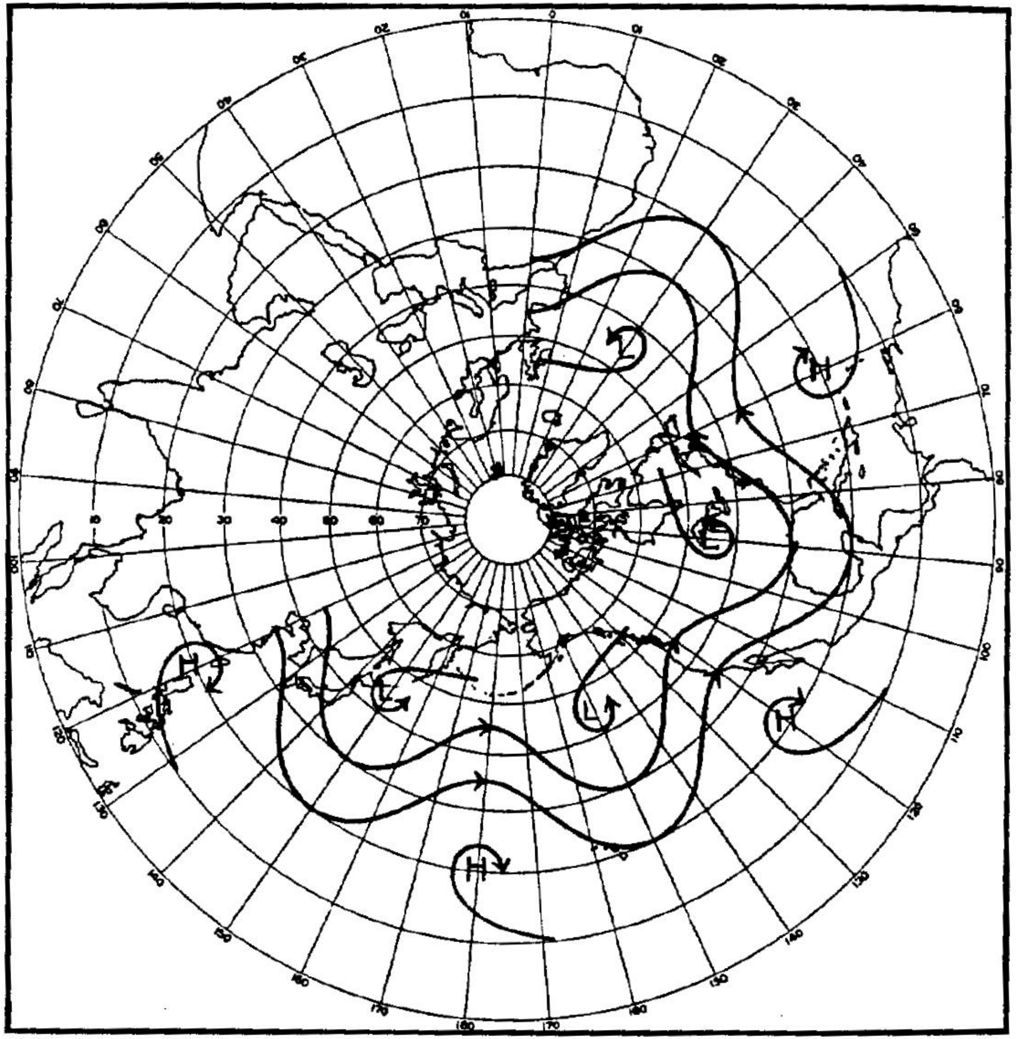
Theory predicted reasonable wavelengths of stationary waves on the westerlies

Inspired Rossby to draw this cartoon:

- A wavy westerly jet in mid-latitudes

- Eddies in the unstable easterly regions to north and south

**But what was Rossby missing…?**

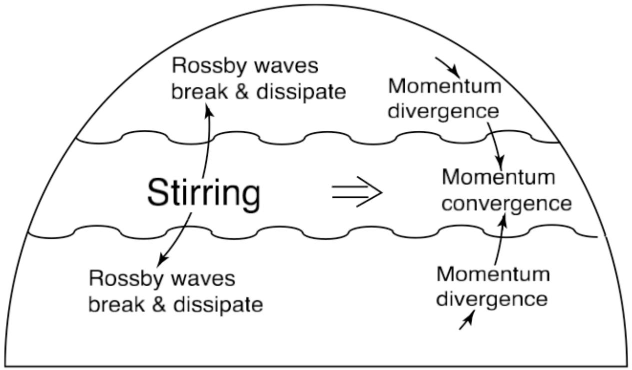


# Instability

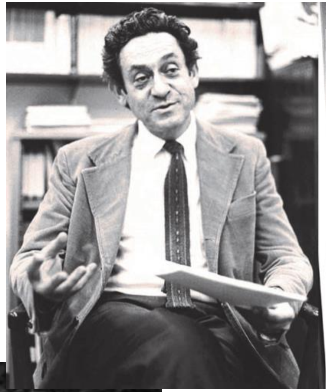
- westerlies are *baroclinically unstable*

- waves are generated there in the process of poleward heat transport

- propagation out of the westerly region linked to momentum fluxes inward to maintain the jet




*Vallis*



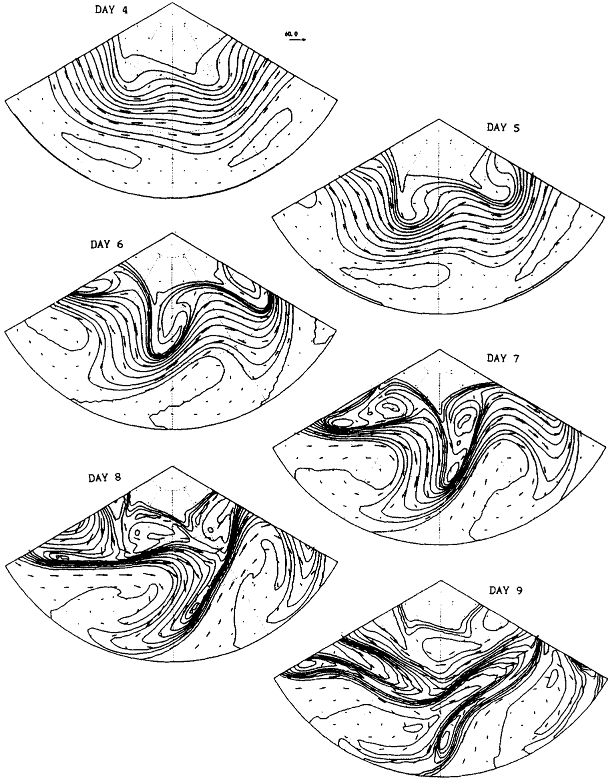



Figure 7. Potential temperature on the PV = 2 PVU surface in LC1 between days 4 and 9. Contours are drawn every 5 K from 290 K to 350 K going equatorward. Wind vectors are included; for days 4 to 7 these have had the phase speed of the normal mode removed to give the relative flow. The arrow scale is as in Fig. 11 (with allowance for the different figure dimensions). Sectors are shown for two wavelengths between latitude 20°N and the pole. Lines of constant latitude and longitude are drawn every 20 and 30 degrees, respectively.

*Thorncroft et al (1993, QJ)*

# Green (1970)

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*Quart. J. R. Met. Soc.* (1970), **96**, pp. 157-185

551.511.3 : 551.515

Transfer properties of the large-scale eddies and the general circulation of the atmosphere

By J. S. A. GREEN
*Imperial College, London*

Rossby took background flow as a given and worked out how the waves would propagate.

Green instead started from the observed variation of energy and used baroclinic theory to predict the eddy fluxes of PV, momentum and heat, and ultimately the large-scale flow.

Explained basic features of surface westerlies in dishpan experiments and the Gulf Stream as well as in the troposphere

TRANSFER BY LARGE-SCALE EDDIES

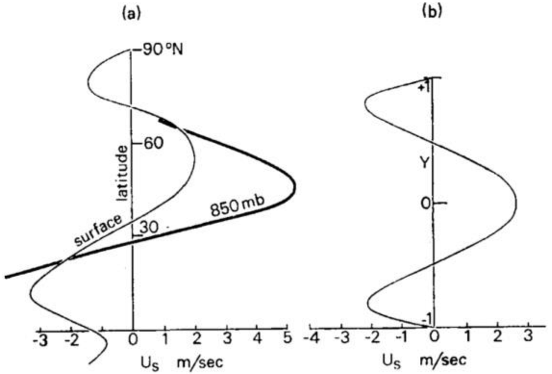


Figure 12. Variation of mean zonal component of wind with latitude in the winter season,
(a) at anemometer level (Mintz) thin, at 850 mb (Buch) thick.
(b) from theoretical solution with $Y$-scale such that $Y = \pm 1$ corresponds to $\pm$ 3,000 km.

# QJ Rossby wave papers over the years

Lots of activity since Rossby's first study of the stable jets and the unstable spirals:

1940 → 2023

Rossby (1940)

Green (1970)
Platzman (1968)

Hoskins, McIntyre & Robertson (1985)
Simmons (1982)
James (1988)

Ambrizzi and Hoskins (1997)
Bishop (1993)

Methven et al (2005)
Ndara & Waugh (2010)
Glatt & Virth (2013)
Li et al (2019)
Saffin et al (2021)

No sign of a death spiral here…

**Conclusion:**

The Quarterly Journal is **stable** and welcomes papers on Rossby waves!