

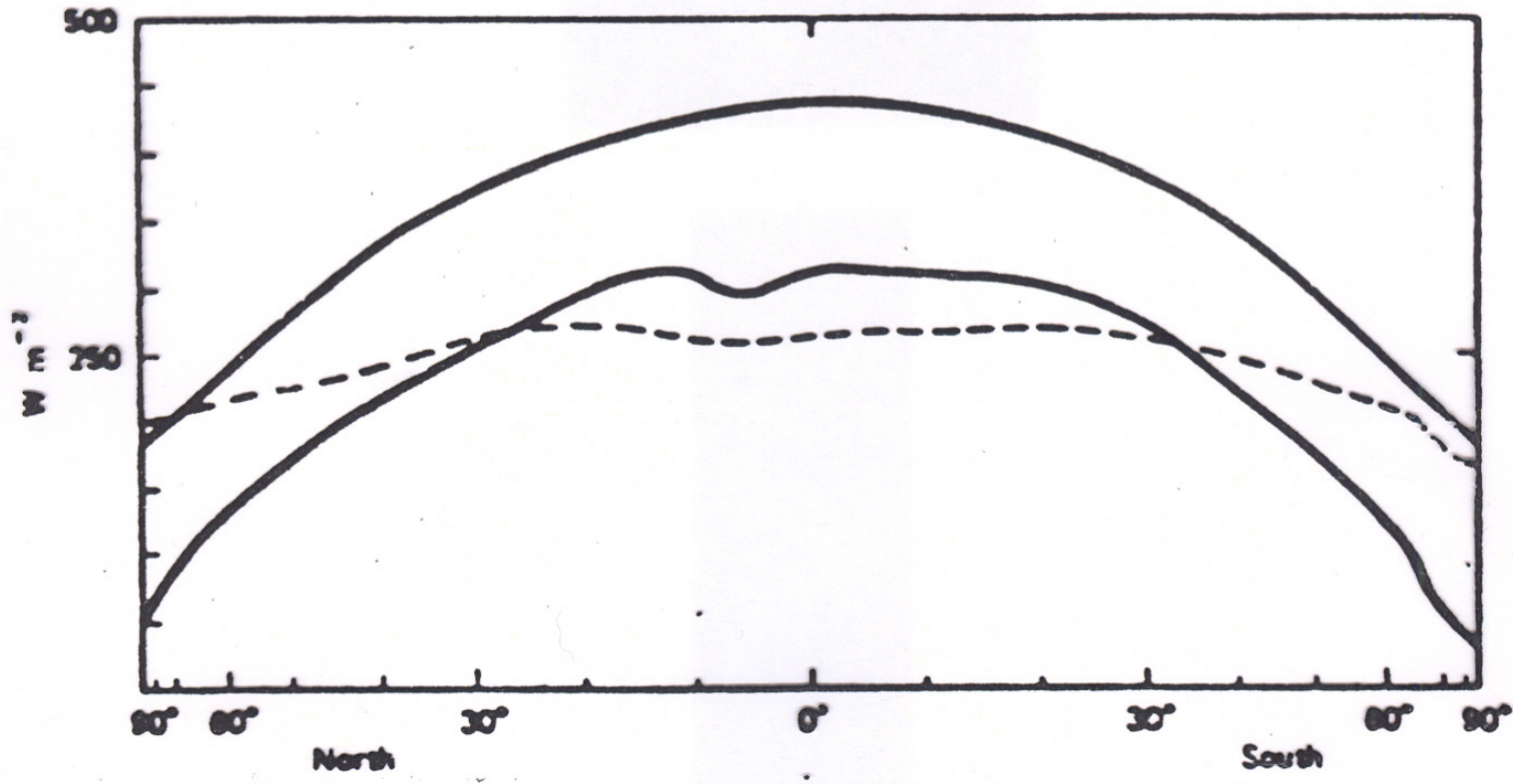
École Doctorale des Sciences de l'Environnement d'Île-de-France

Année Universitaire 2012-2013

Modélisation Numérique  
de l'Écoulement Atmosphérique  
et Assimilation de Données

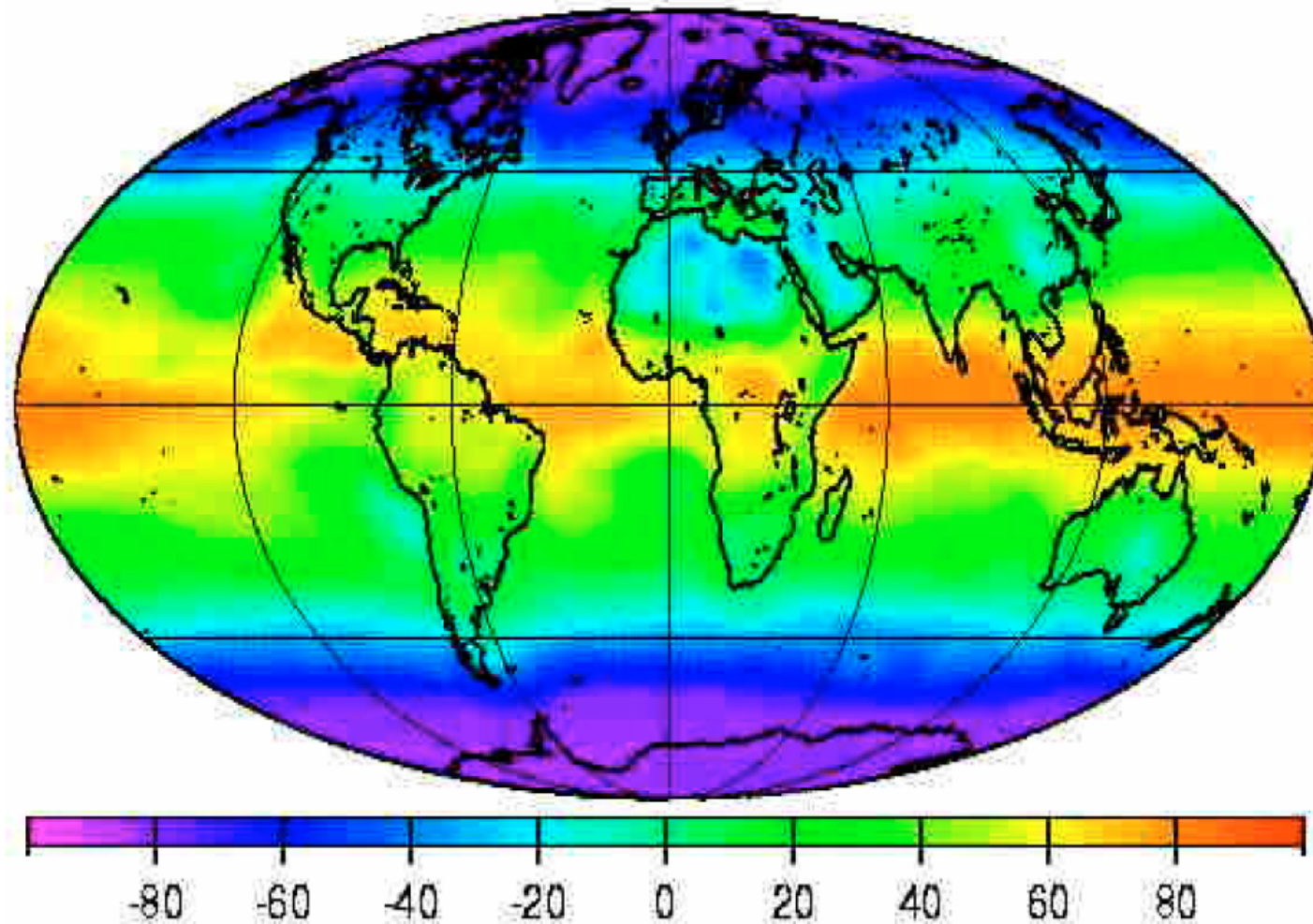
Olivier Talagrand  
Cours 1

15 Mars 2013

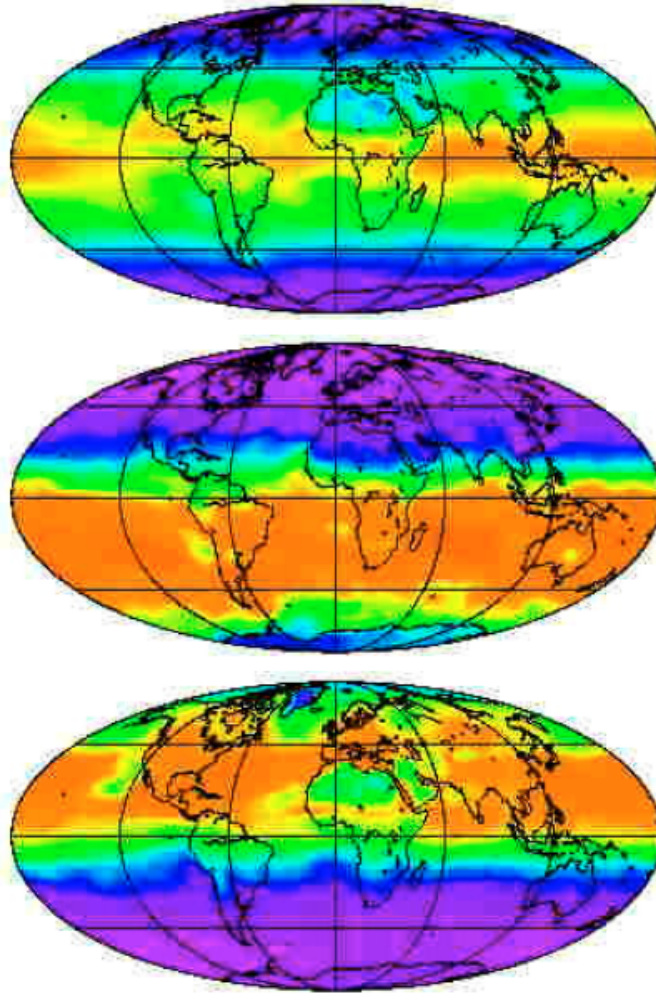


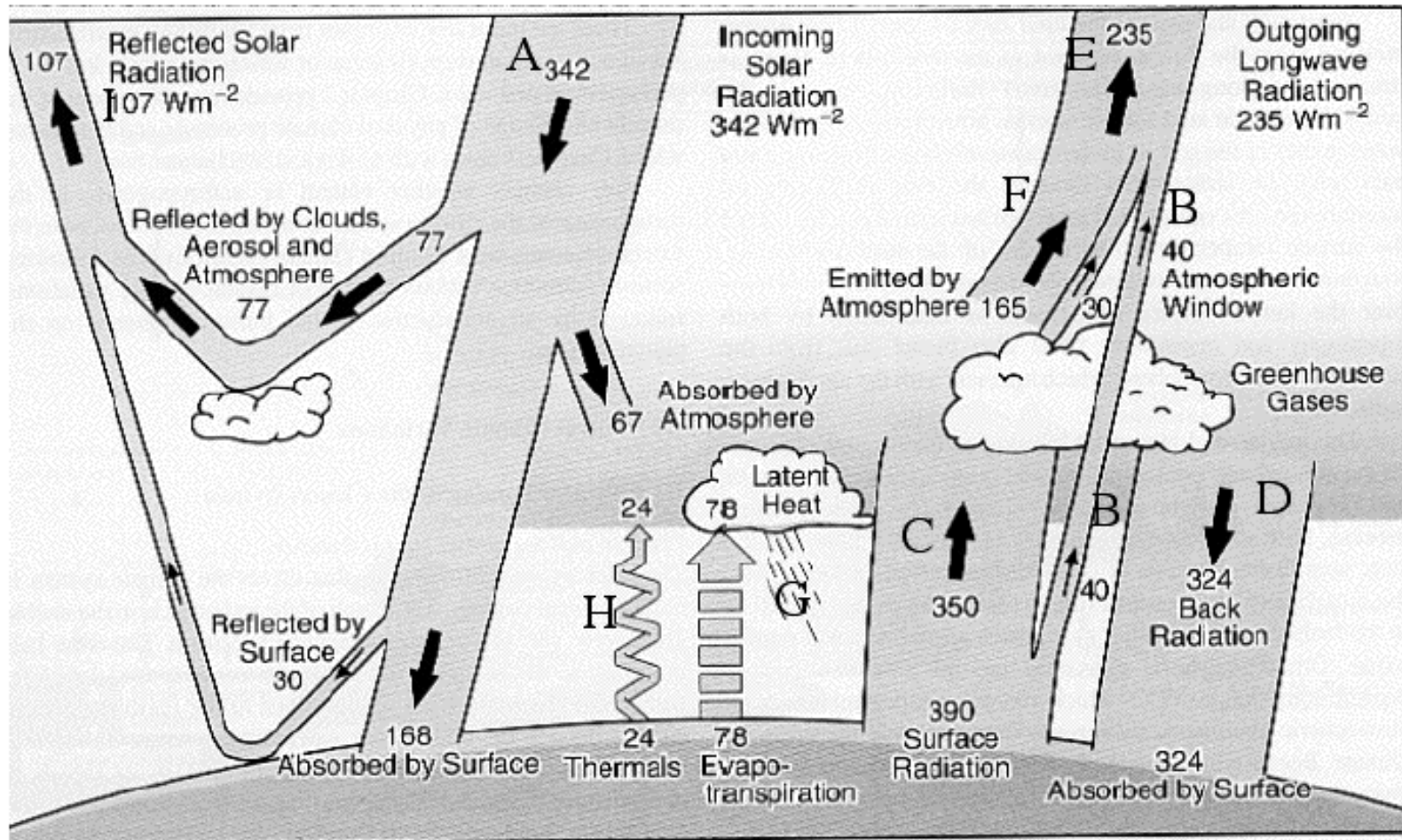
Bilan radiatif de la Terre, moyenné sur un an

## Bilan radiatif au sommet de l'atmosphère (en $\text{W m}^{-2}$ )



# Variations saisonnières du bilan radiatif





D'après K. Trenberth

Particle moves on sphere with radius  $R$   
under the action of a force lying  
in meridian plane of the particle

→ Angular momentum wrt axis of rotation conserved.

$$(u + \Omega R \cos\varphi) R \cos\varphi = \text{Cst}$$

On Earth,  $\Omega \approx 2\pi \cdot 10^{-5} \text{ s}^{-1}$ ,  $R \approx 6.4 \cdot 10^6 \text{ m}$ .

If  $u = 0$  at equator,  $u = 329 \text{ ms}^{-1}$  at latitude  $\varphi = 45^\circ$ . If  $u = 0$  at  $45^\circ$ ,  $u = -232 \text{ ms}^{-1}$  at equator.

Hadley, G., 1735, Concerning the cause of the general trade winds, *Philosophical Transactions of the Royal Society*

*The general circulation*

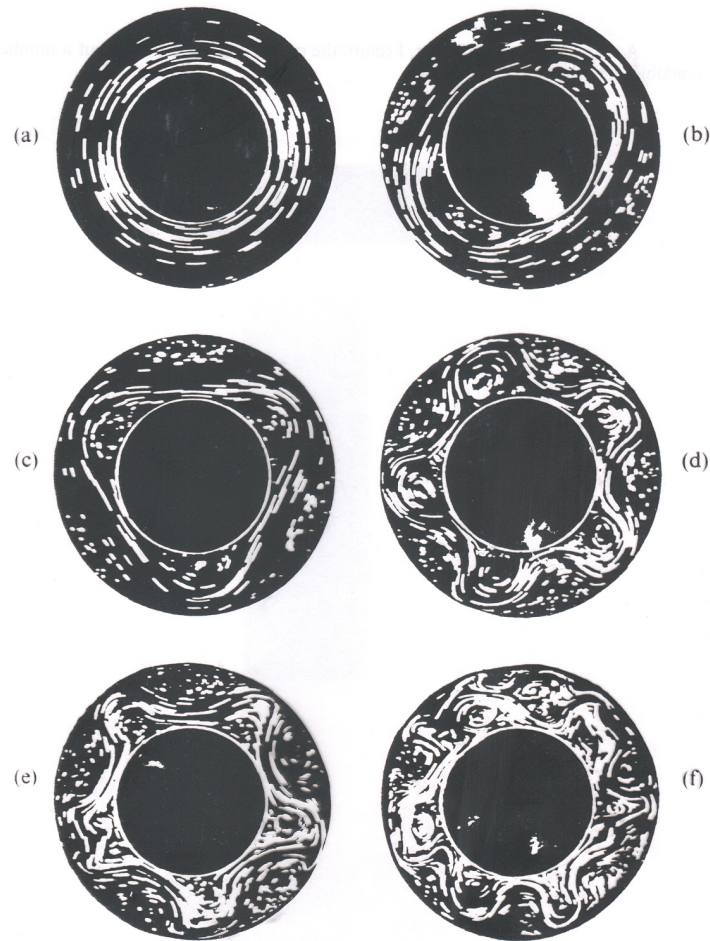


Fig. 10.1. Streak photographs illustrating the dependence of the flow type on rotation rate  $\Omega$  for a laboratory 'dishpan' experiment. The values of  $\Omega$  in  $\text{rad s}^{-1}$  are (a) 0.41; (b) 1.07; (c) 1.21; (d) 3.22; (e) 3.91; (f) 6.4. Working fluid was a water-glycerol solution of mean density  $1.037 \text{ g cm}^{-3}$  and kinematic viscosity  $1.56 \times 10^{-2} \text{ cm}^2 \text{ s}^{-1}$ . The streak photographs show the flow at a depth of 0.5 cm below the free upper surface (see also problem 10.1.) (From Hide & Mason, 1975)

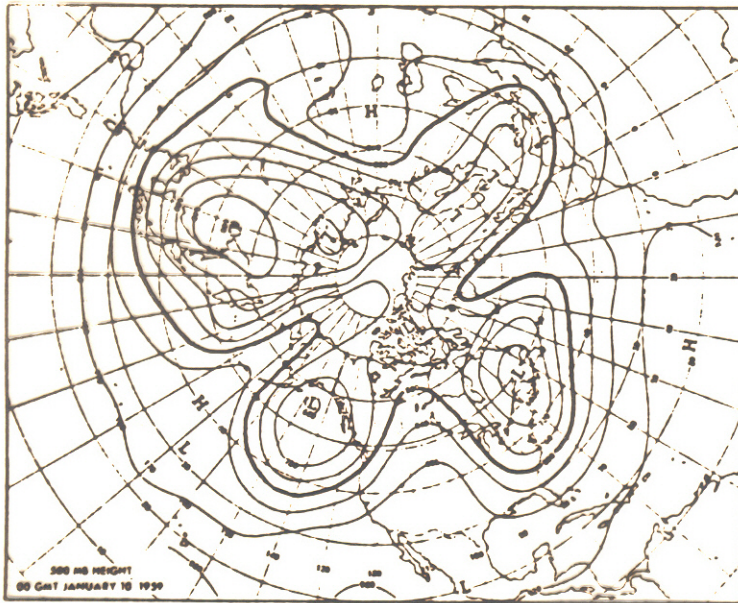


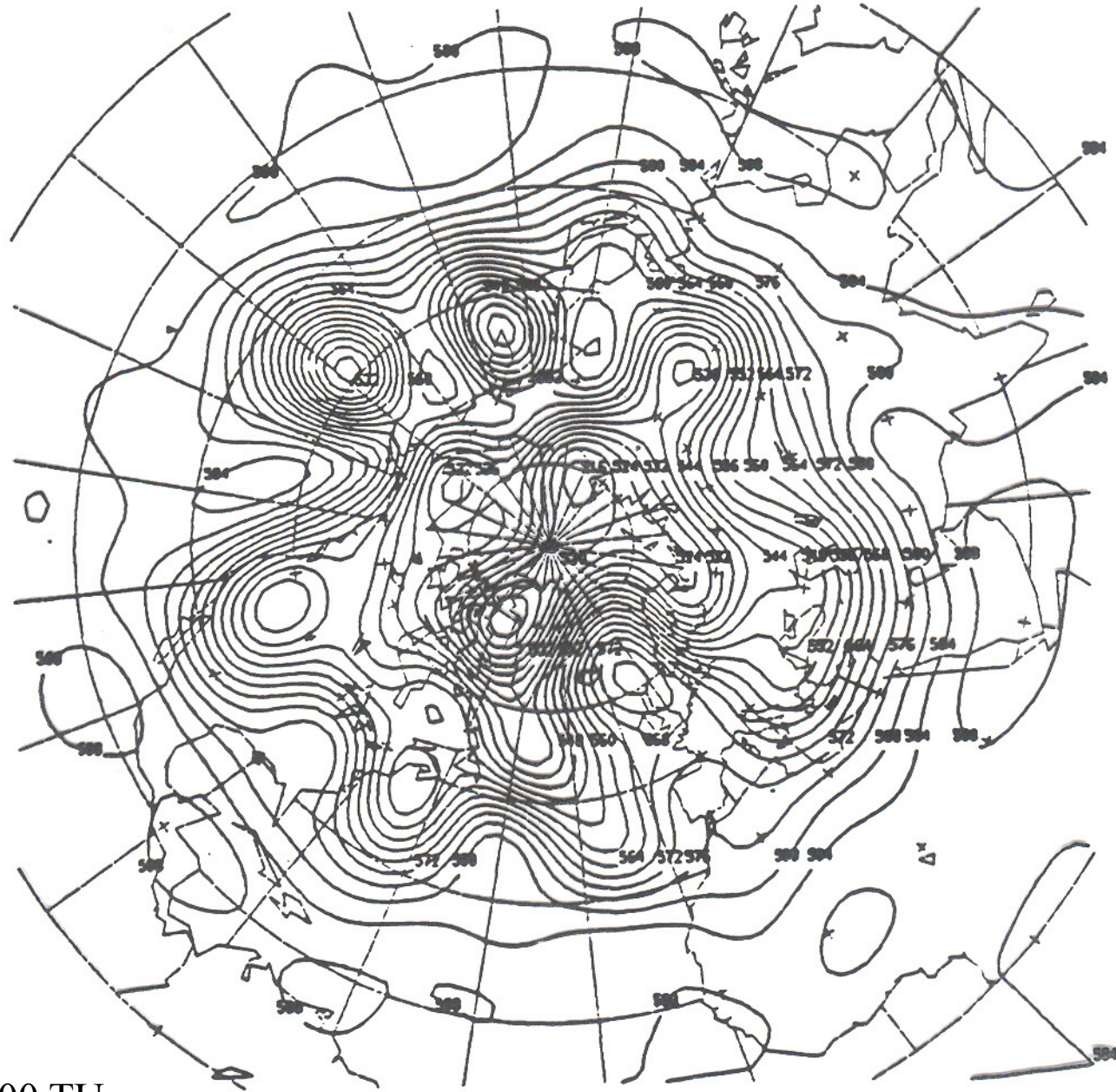
Figure 2. Comparison shows similarities between the global 500 mb pressure pattern in the upper atmosphere of the Northern Hemisphere and a four-wave pattern in the laboratory.

(Laboratory flow conditions were similar to those in Fig. 1, except  $\Omega = 1.95$  radians per sec.) In the atmosphere the flow is approximately parallel to the isobars (the flow is to the right,

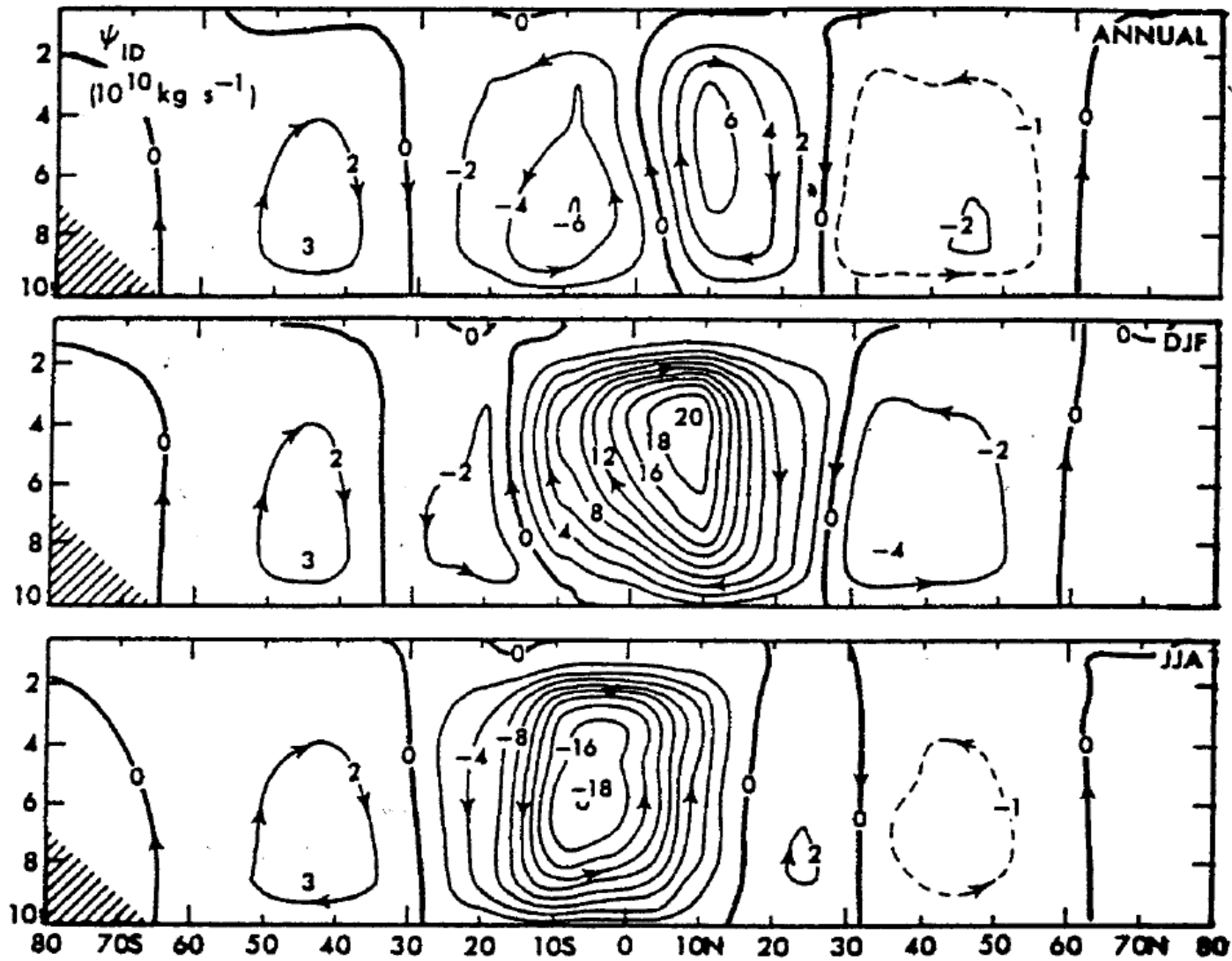


from high to low pressure), with speed inversely proportional to the spacing. Changes in the wave pattern have a significant effect on large-scale weather and climate.

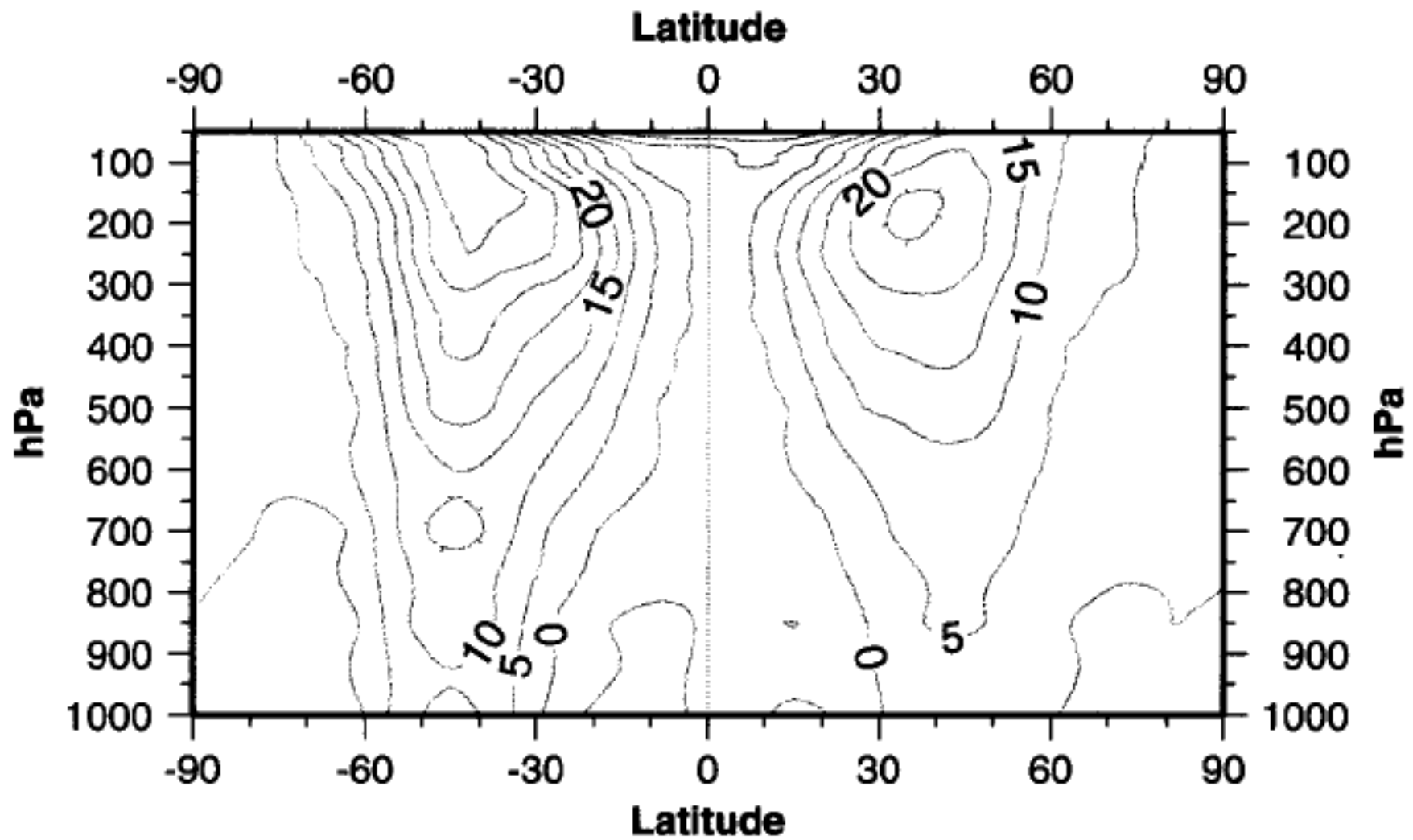




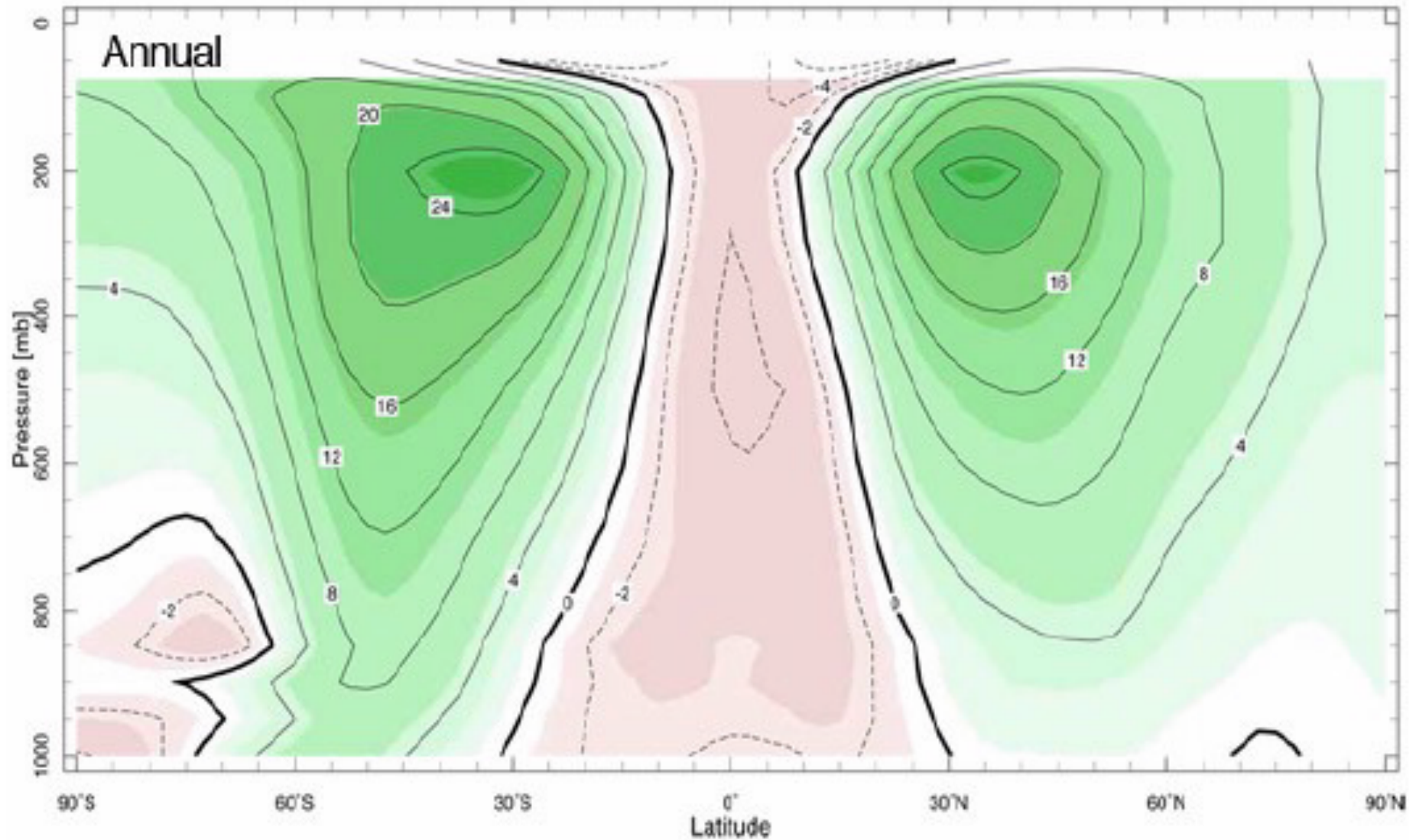
26/04/1984, 00/00 TU



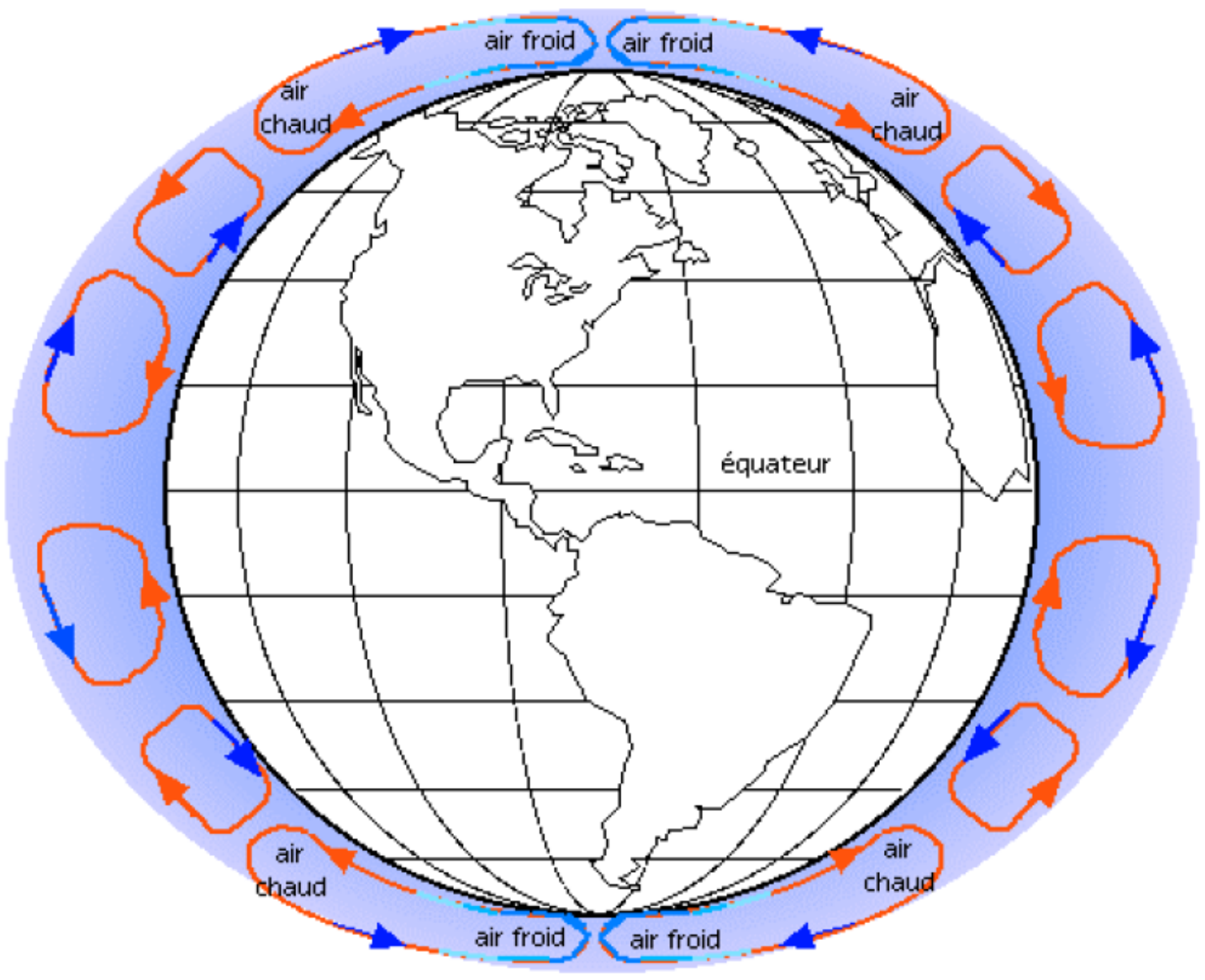
Peixoto and Oort, 1992, *The Physics of Climate*, Springer-Verlag



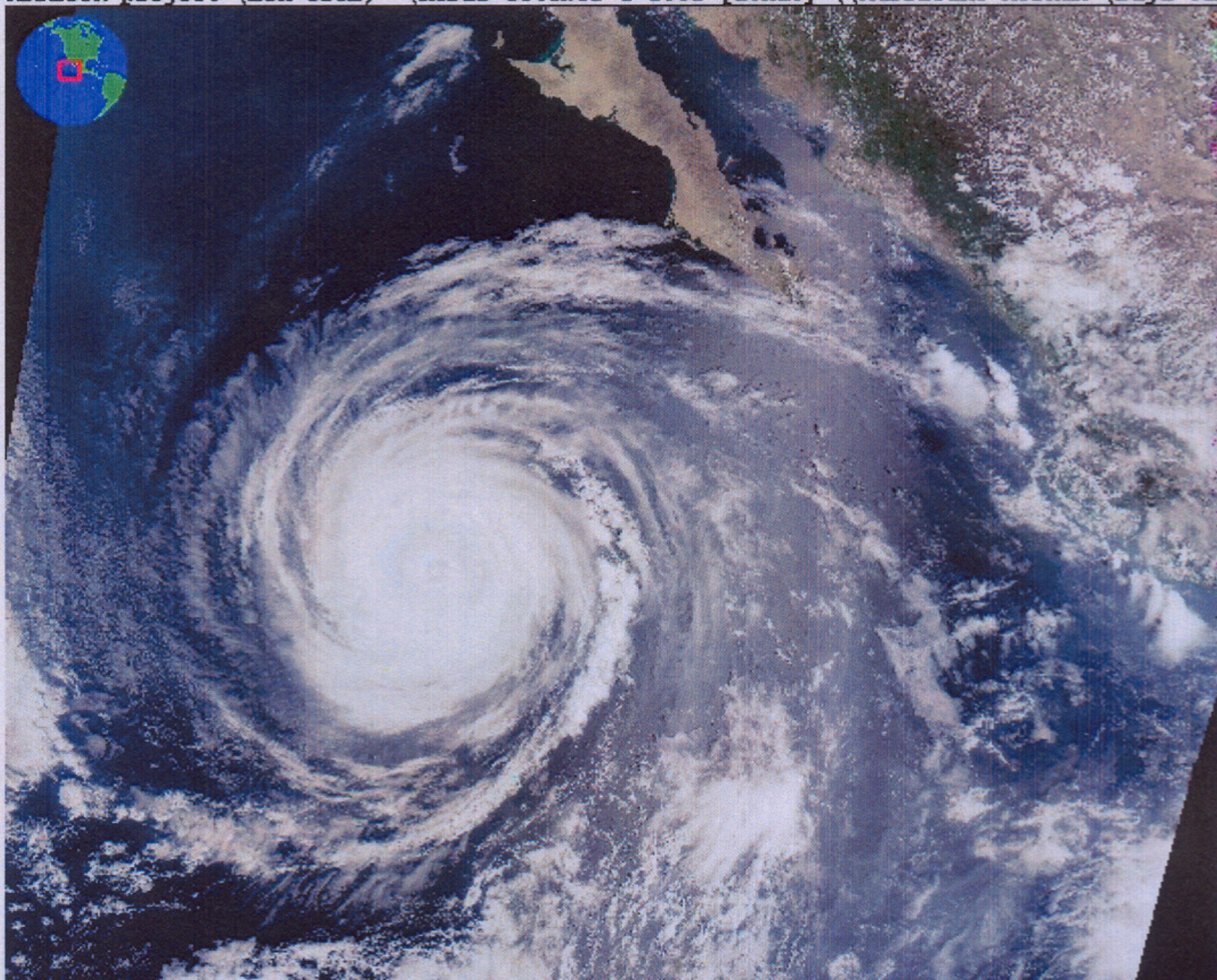
Distribution moyenne latitude-altitude du vent zonal (m.s<sup>-1</sup>, simulation)  
(cours H. Le Treut)



Vent zonal; moyenne longitudinale annuelle ( $\text{m.s}^{-1}$ ,  
<http://paoc.mit.edu/labweb/notes/chap5.pdf>,  
Atmosphere, Ocean and Climate Dynamics, by J. Marshall and R. A. Plumb,  
International Geophysics, Elsevier)



HDFLook project (LOA-USTL) (MODIS October 2 2002 [18h10] (Hurricane Hernan (Baja Cali



## Lois physiques régissant l'écoulement

- Conservation de la masse

$$D\rho/Dt + \rho \operatorname{div}\underline{U} = 0$$

- Conservation de l'énergie

$$De/Dt - (p/\rho^2) D\rho/Dt = Q$$

- Conservation de la quantité de mouvement

$$D\underline{U}/Dt + (1/\rho) \operatorname{grad}p - \underline{g} + 2 \underline{\Omega} \wedge \underline{U} = \underline{F}$$

- Equation d'état

$$f(p, \rho, e) = 0 \quad (p/\rho = rT, e = C_v T)$$

- Conservation de la masse de composants secondaires (eau pour l'atmosphère, sel pour l'océan, ...)

$$Dq/Dt + q \operatorname{div}\underline{U} = S$$

Les modèles utilisés pour la prévision météorologique de grande échelle et la simulation climatologique couvrent la totalité du volume de l'atmosphère. Ils sont, jusqu'à présent au moins, construits sur l'hypothèse *hydrostatique*

Dans la direction verticale :

$$\partial p / \partial z + \rho g = 0$$

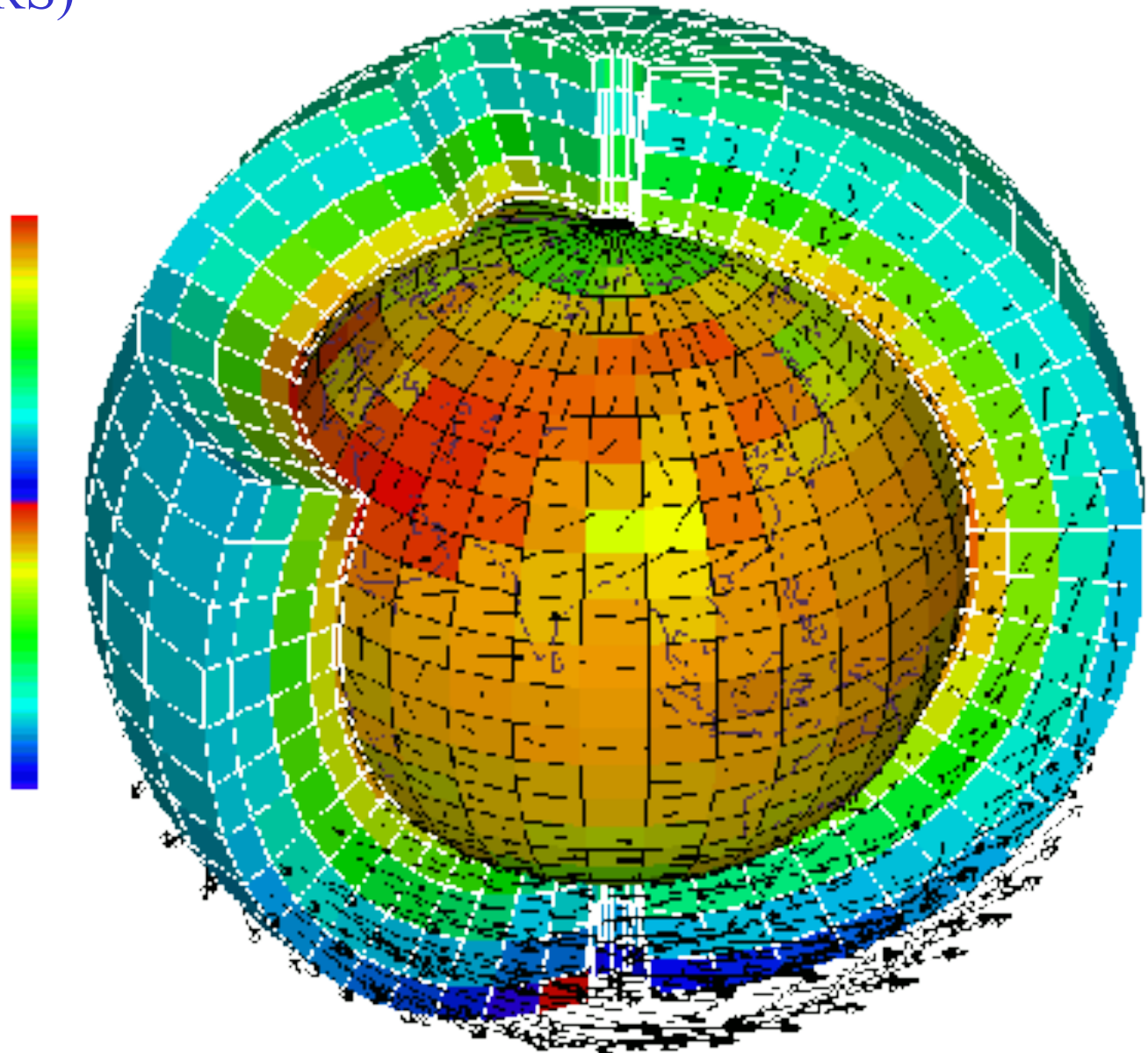
Élimine l'équation du mouvement pour la direction verticale; en outre, l'écoulement est incompressible dans les coordonnées  $(x, y, p)$   $\Rightarrow$  nombre d'équations diminué de deux unités.

Approximation hydrostatique valide pour échelles horizontales  $> 20-30$  km

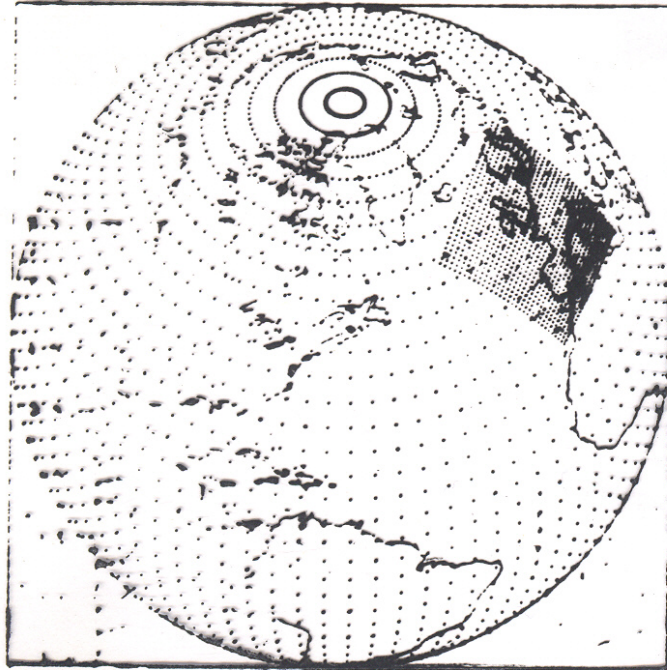
Modèles non-hydrostatiques, plus coûteux, sont utilisés pour la météorologie de petite échelle.



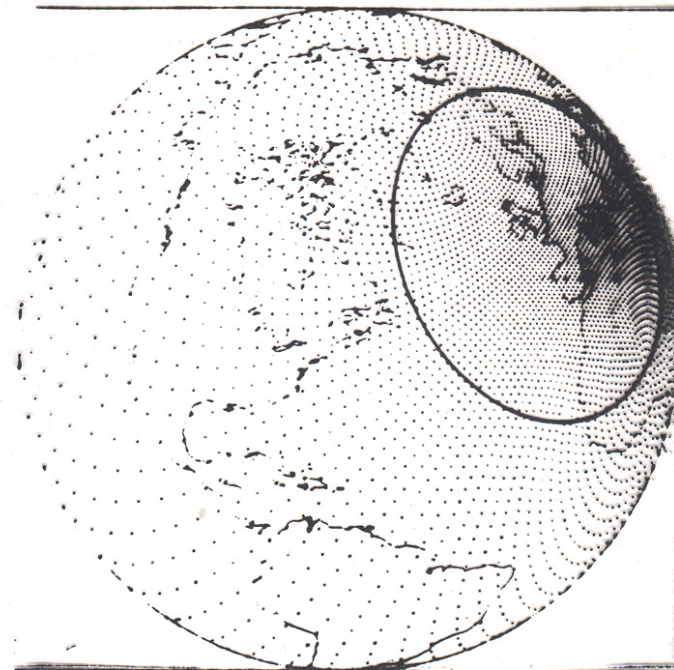
A schematic of an Atmospheric General Circulation Model (L. Fairhead /LMD-CNRS)



Grille Emerald-Péridot



Grille Arpège



Grilles de modèles de Météo-France (*La Météorologie*)