Influence of Gravity Waves on the Atmospheric Climate

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1)Dynamical impact of mountains on atmospheric flows

2)Representations of mountains in General Circulation Models

3)Non-orographic gravity waves sources and breaking

4)Impact of gravity waves on the middle atmosphere dynamics

Influence of Gravity Waves on the Atmospheric Climate

4) Impacts of Gravity waves on the middle atmosphere dynamics

a) Basic climatologies

b) Interpretation of the dynamics with a heuristic models

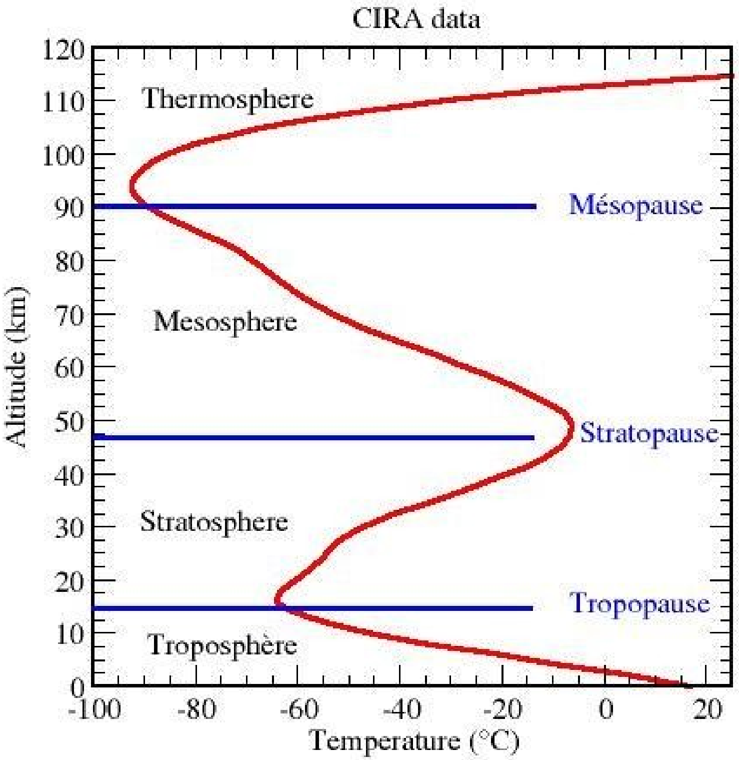
c) Brewer Dobson circulation

d) Middle latitudes dynamics
    Stratospheric sudden warmings

e) Equatorial dynamics
    Semi annual and quasi-biennal oscillations

4) Impact of gravity waves on the middle atmopshere
a) Basic climatologies

Global average of Temperature as a function of altitude



4) Impact of gravity waves on the middle atmopshere
a) Basic climatologies

Vertical distribution of Water vapor
The middle atmosphere is very dry

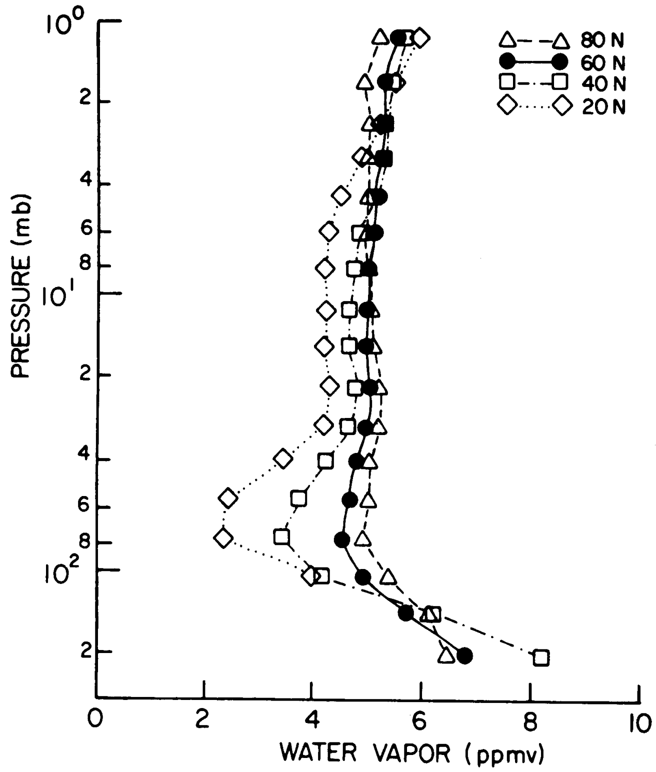


Fig. 1.5. Vertical profiles of water vapor mixing ratio at several latitudes measured by the LIMS instrument on the *Nimbus* 7 satellite for May 1–26, 1979. [From Remsberg *et al.* (1984b). American Meteorological Society.]

Vertical distribution of Ozone

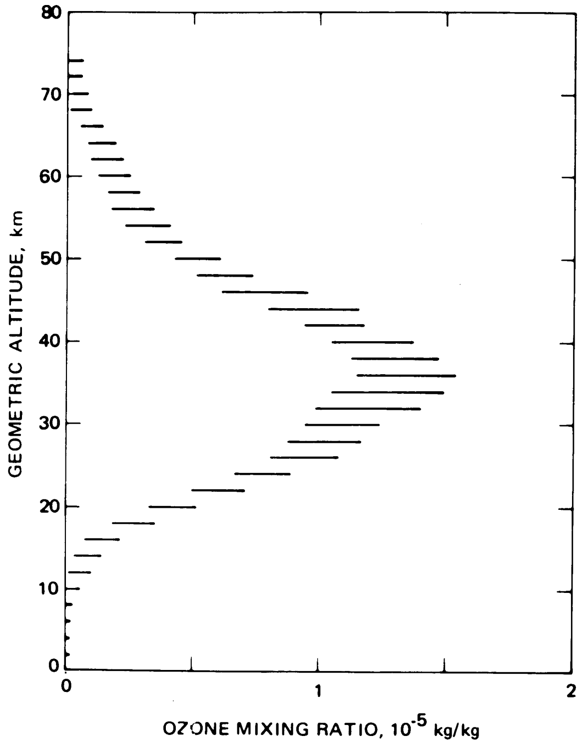
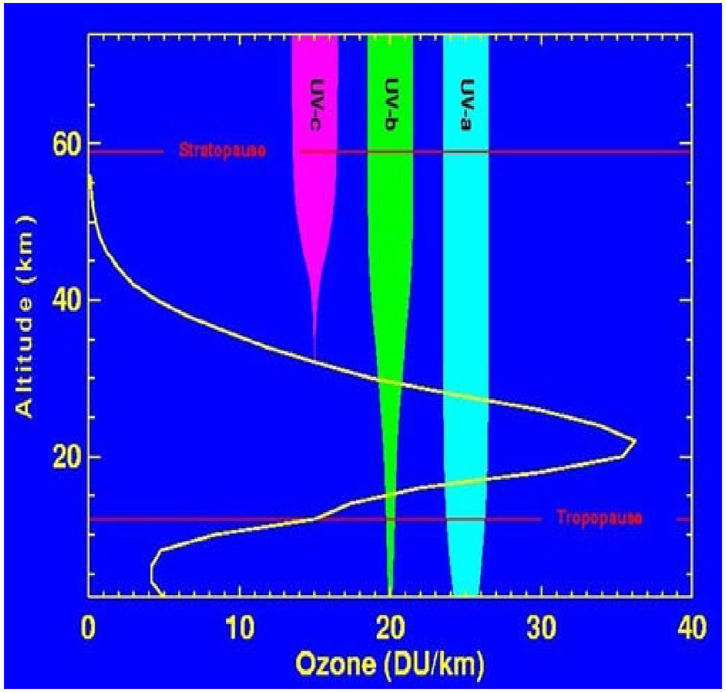


Fig. 1.7. The standard ozone profile of Fig. 1.6 plotted in terms of the mass mixing ratio. [From the *U.S. Standard Atmosphere* (1976).]

4) Impact of gravity waves on the middle atmopshere
a) Basic climatologies

- Absorption of the UV-b by 03 is driving the middle atmosphere



Profil d'Ozone aux moyennes latitude et Altitude de pénétration des UV-a, UV-b, UV-c

4) Impact of gravity waves on the middle atmopshere
a) Basic climatologies

Heating by ozone build-up the stratosphere above the stratosphere

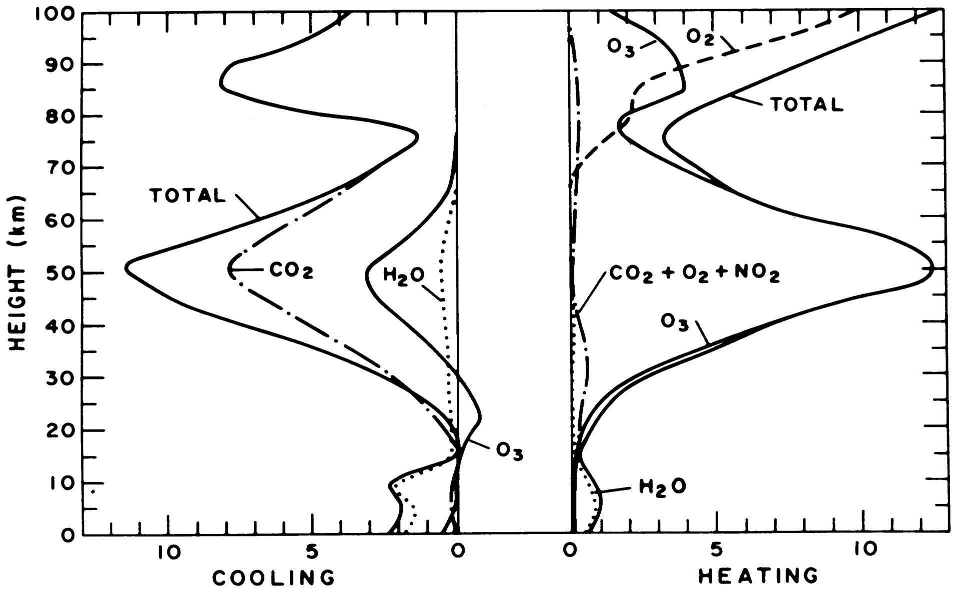


Fig. 2.1. Vertical distribution of heating due to absorption of solar radiation (right) and cooling due to emission of infrared radiation (left). [From London (1980), with permission.]

Vertical distribution of the direct solar heating, and of the infrared cooling (essentially due to the green house gas CO2).

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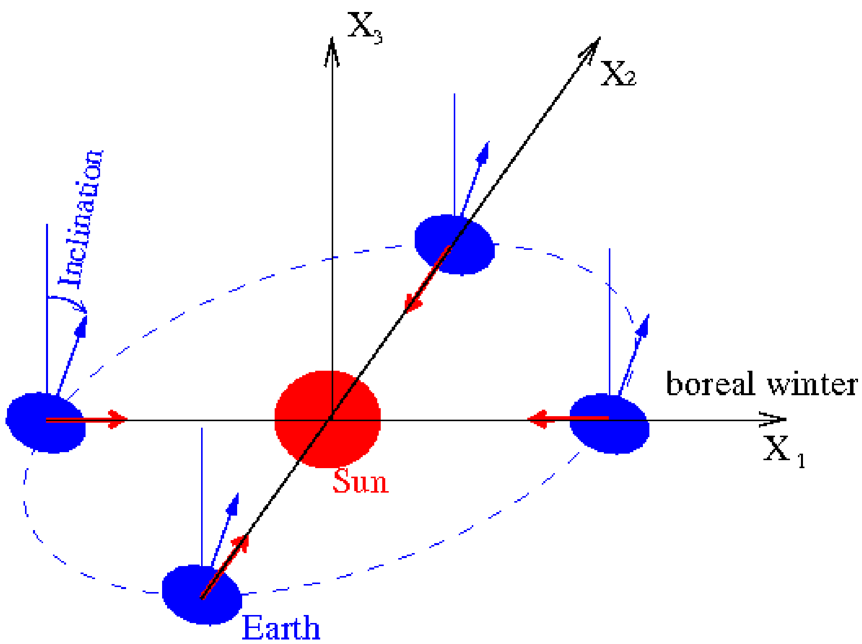
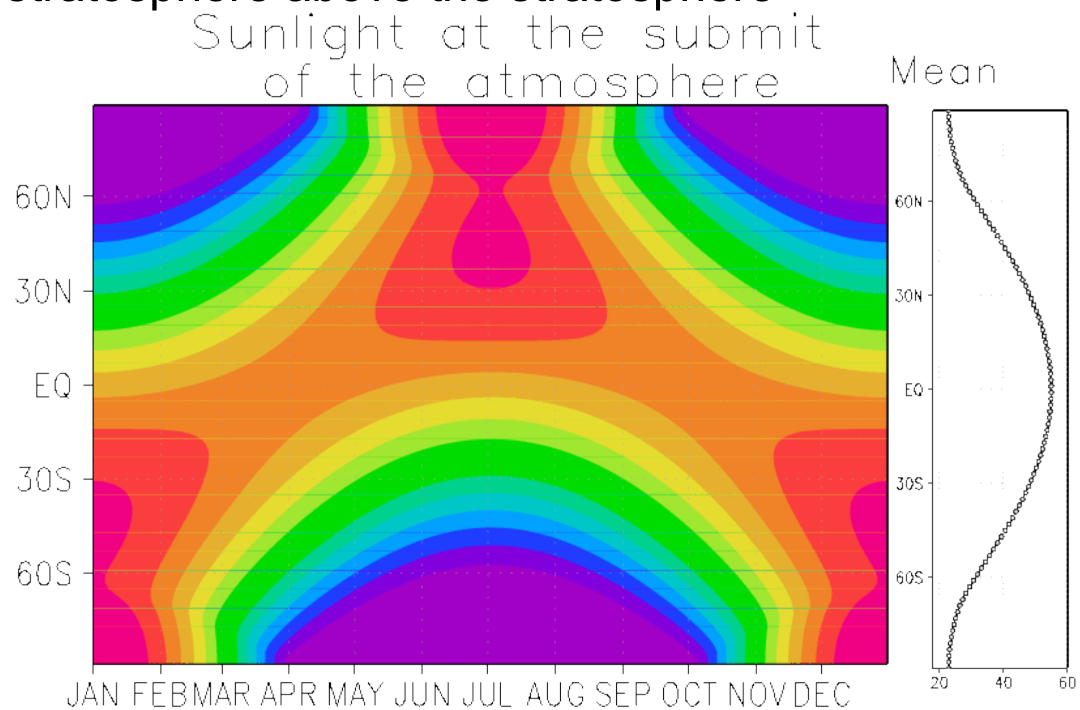




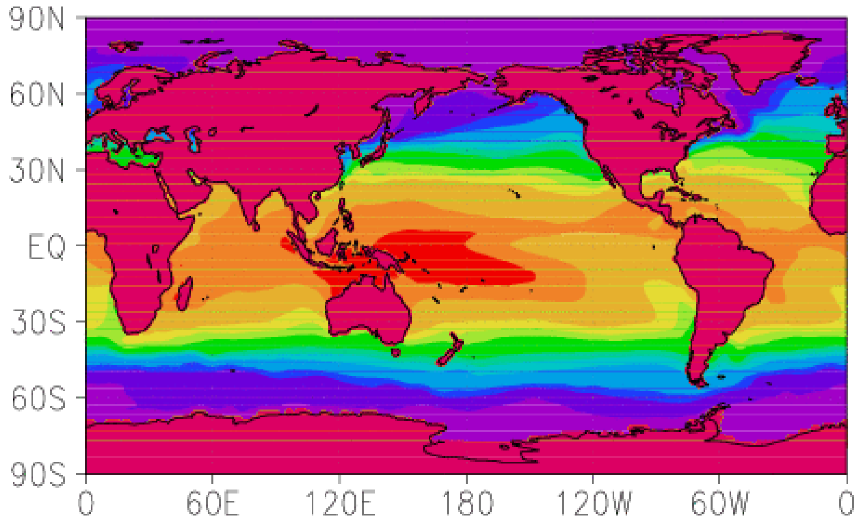
Ozone re-emit quasi immediatly, and through chemical heating the UV-radiation it absorbs (O+O2-->O3)

The daily average sunlight is maximum at the pole in summer

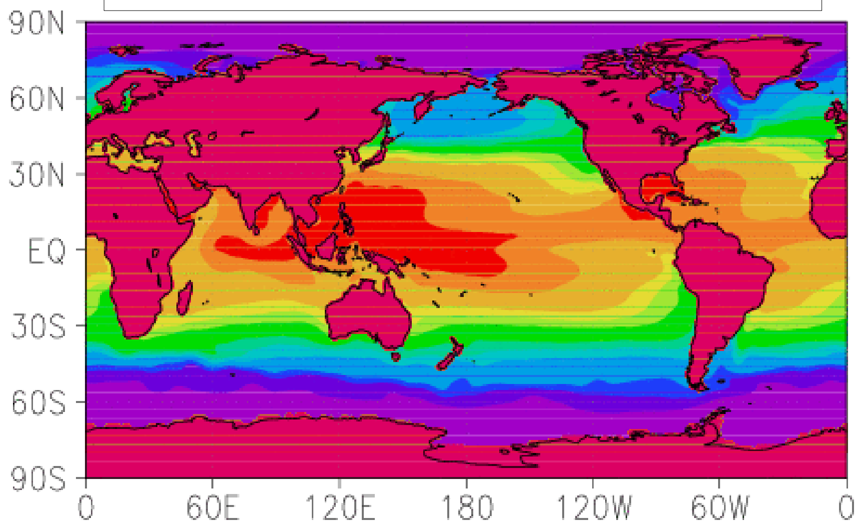
Its mean over the year the sunlight is maximum at the Equator

4) Impact of gravity waves on the middle atmosphere
a) Basic climatologies

Sea surface T in January
ECMWF (1993-1997)



July



SST is always warmer in the tropical regions

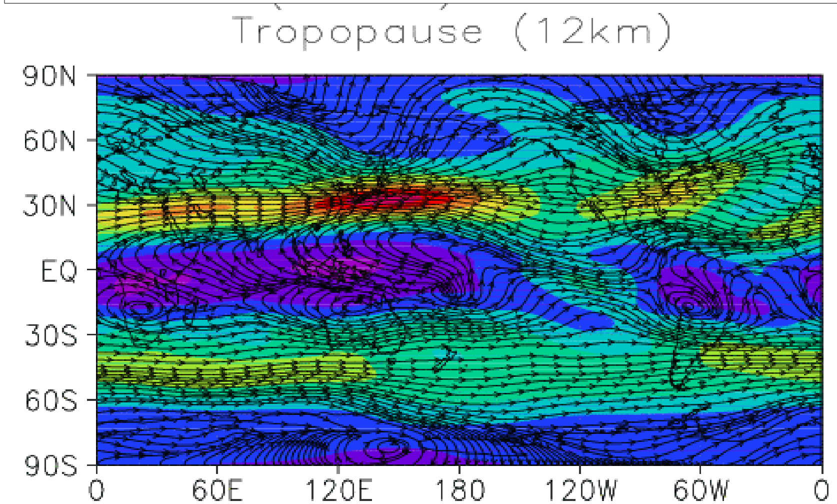
It also maintain a high rate of humidity and therefore a strong greenhouse effect in the tropical regions

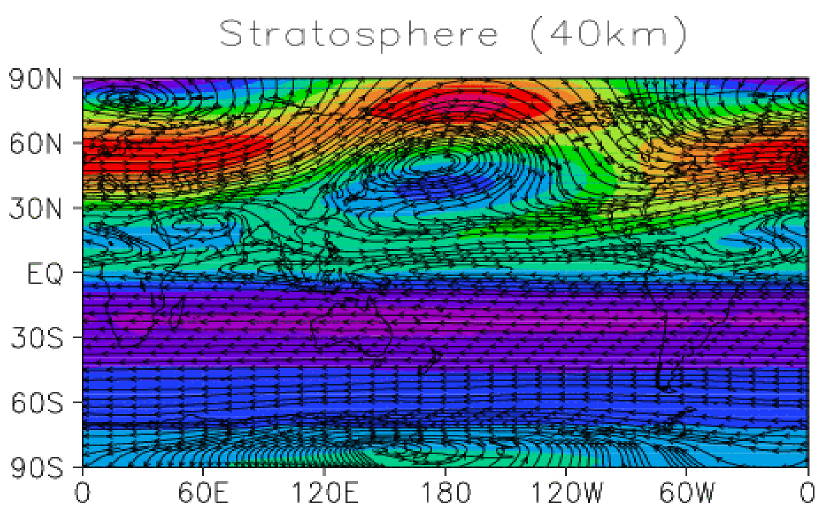
The troposphere is in first place forced by the bottom, and will therefore have an annual cycle much less dramatic than the middle atmosphere

4) Impact of gravity waves on the middle atmopshere
a) Basic climatologies

An illustration of the difference between the general Circulations in the troposphere and in the stratosphere

ECMWF (93-97) winter wind





4) Impact of gravity waves on the middle atmopshere
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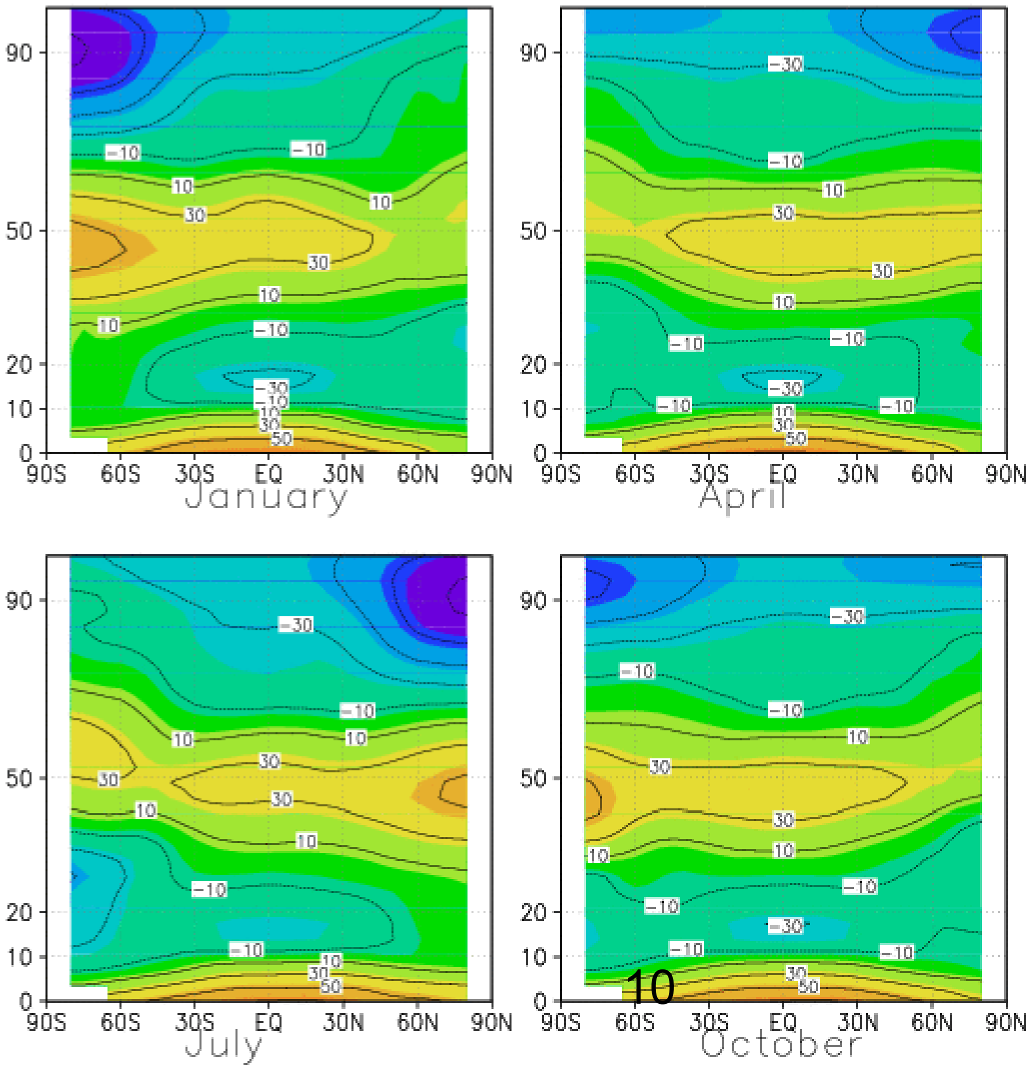
The zonal mean of theTemperature in the troposphere and in the middle atmosphere

T-230 (K)

Solstices Equinoxes



4) Impact of gravity waves on the middle atmopshere
b) Interpretation of the dynamics with heuristic models

Equations

$$\left(\frac{\partial}{\partial t}+\frac{v}{a}\frac{\partial}{\partial \phi}\right)u-\left(2\Omega+\frac{u}{a\cos\phi}\right)v\sin\phi=0$$

$$\left(\frac{\partial}{\partial t}+\frac{v}{a}\frac{\partial}{\partial \phi}\right)v+\left(2\Omega+\frac{u}{a\cos\phi}\right)u\sin\phi=-\frac{1}{a}\frac{\partial \Phi}{\partial \phi}$$

$$\frac{\partial \Phi}{\partial t}+\frac{1}{a\cos\phi}\frac{\partial \Phi v\cos\phi}{\partial \phi}=Q_{0_3}-\overline{Q}_{0_3}^{\phi}-\alpha\left(\Phi-\Phi_0\right)$$

Angular momentum conservation:

$$\left(\frac{\partial}{\partial t}+\frac{v}{a}\frac{\partial}{\partial \phi}\right)\left(u\cos\phi+a\Omega\cos^2\phi\right)=0$$

Donne pour des mouvements de petite amplitude (initialement):

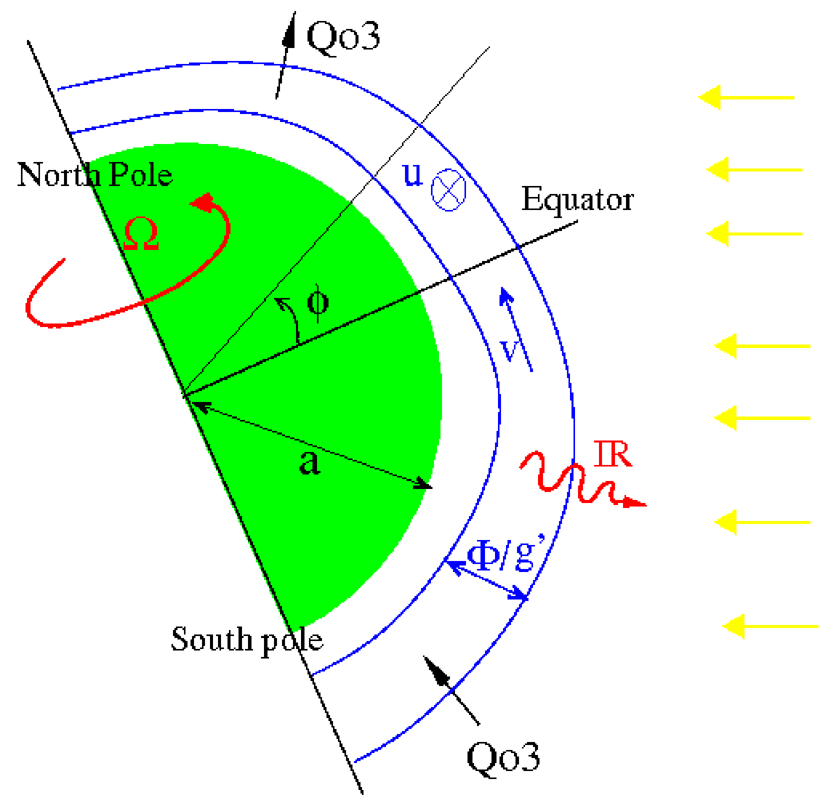
Geostrophic Equilibrium:

$$2\Omega\sin\phi\, u=-\frac{1}{a}\frac{\partial \Phi}{\partial \phi}$$

Thermal equilibrium

(propre à ce modèle et pour $t \to \infty$)

$$Q_{0_3}-\overline{Q}_{0_3}^{\phi}=\alpha\left(\Phi-\Phi_0\right)$$



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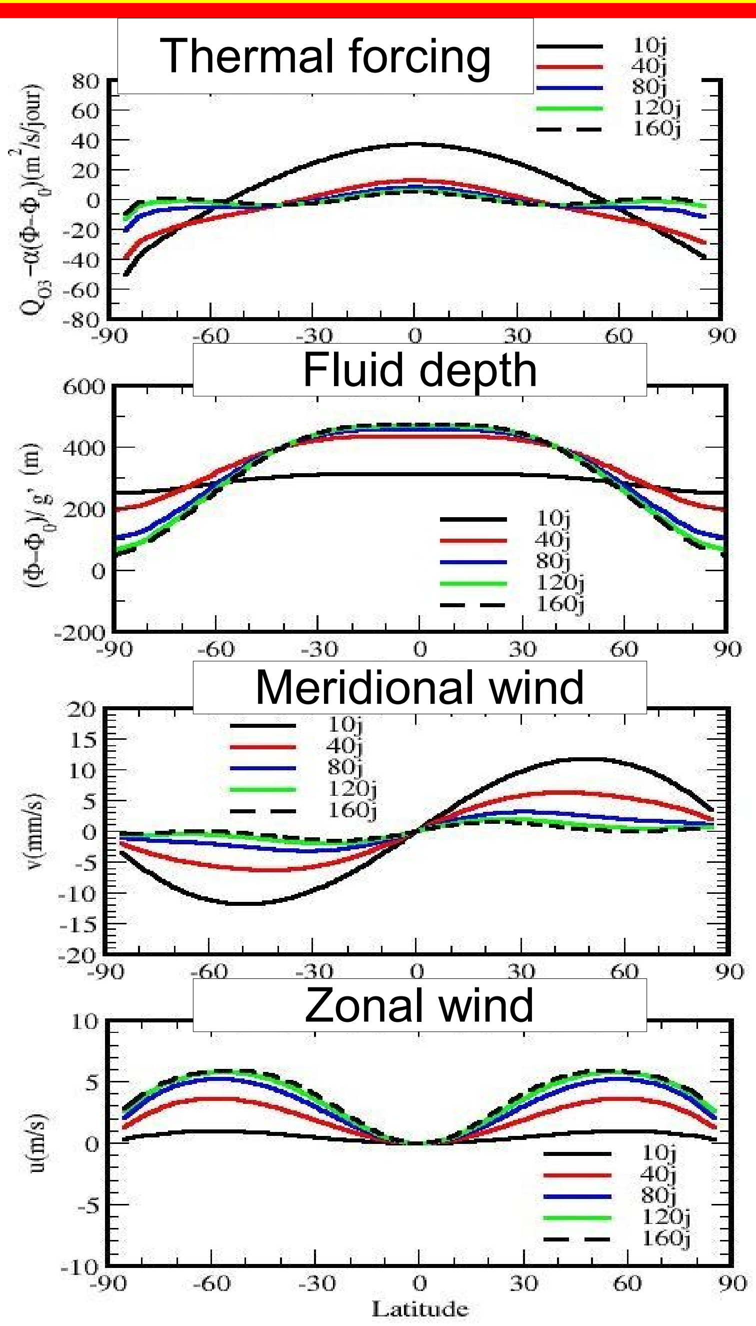

Results for Equinoxes

4) Impact of gravity waves on the middle atmopshere
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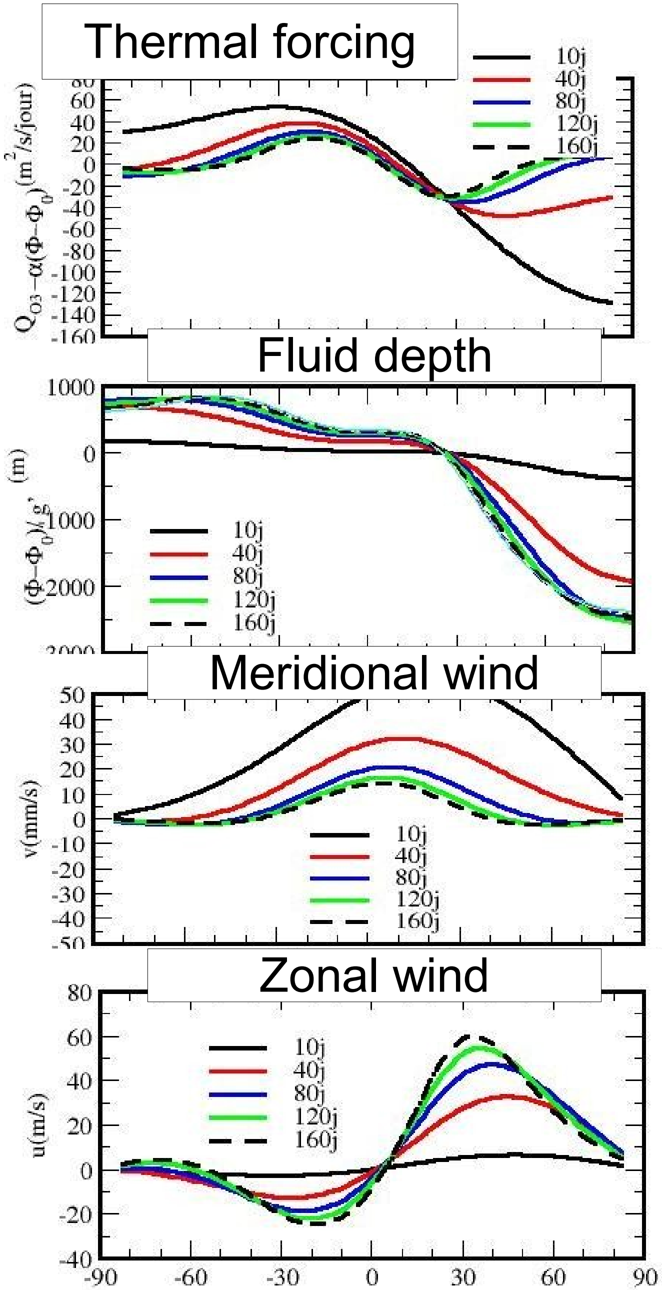

Results for January

4) Impact of gravity waves on the middle atmopshere
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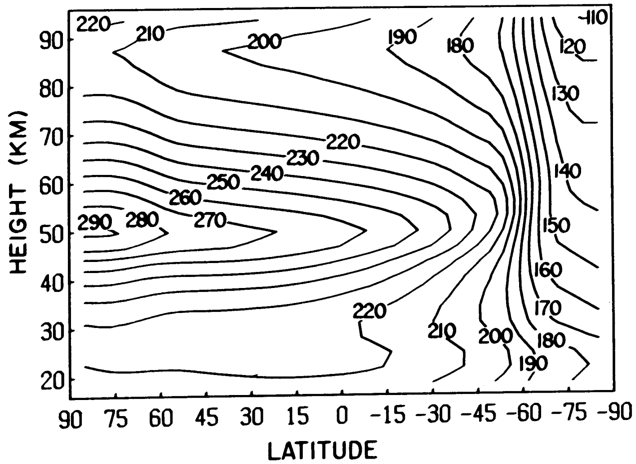

Fig. 2.34. Radiative equilibrium temperature distribution for northern (left) summer solstice. [From Wehrbein and Leovy (1982), with permission.]

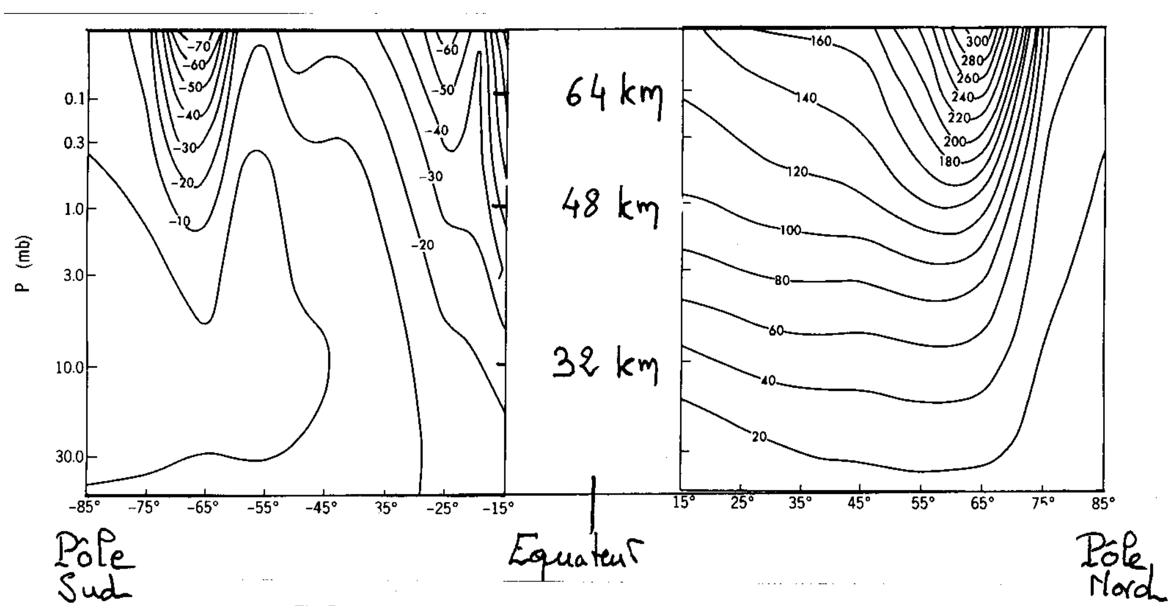

Fig. 7.1. Zonal gradient wind u_{gr} that is in thermal-wind balance with the temperature field T_r of Fig. 1.2 and equals the observed climatological zonal wind at 100 mb. (a) Northern Hemisphere (winter), (b) Southern Hemisphere (summer). (Courtesy of Dr. S. B. Fels.)

The middle atmosphere is not in thermal equilibrium

Result here from a radiative code alone,

The zonal wind is evaluated from the T field via the thermal wind balance

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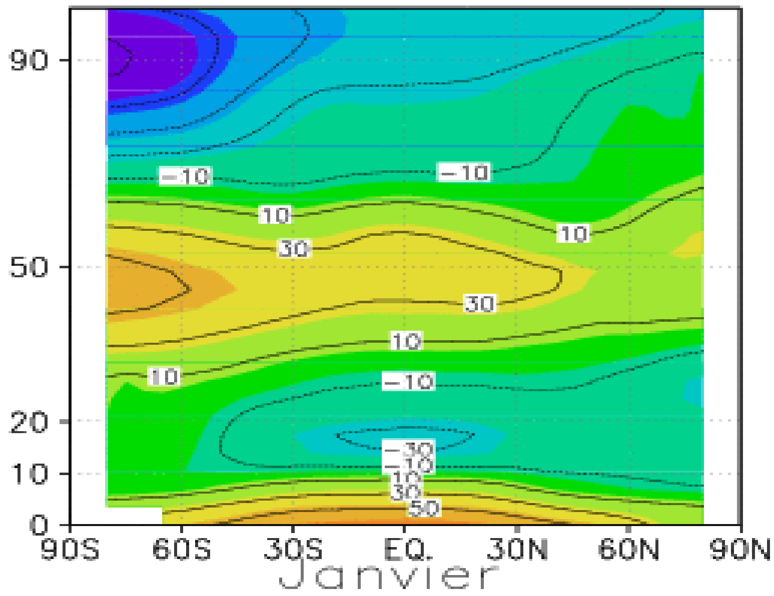
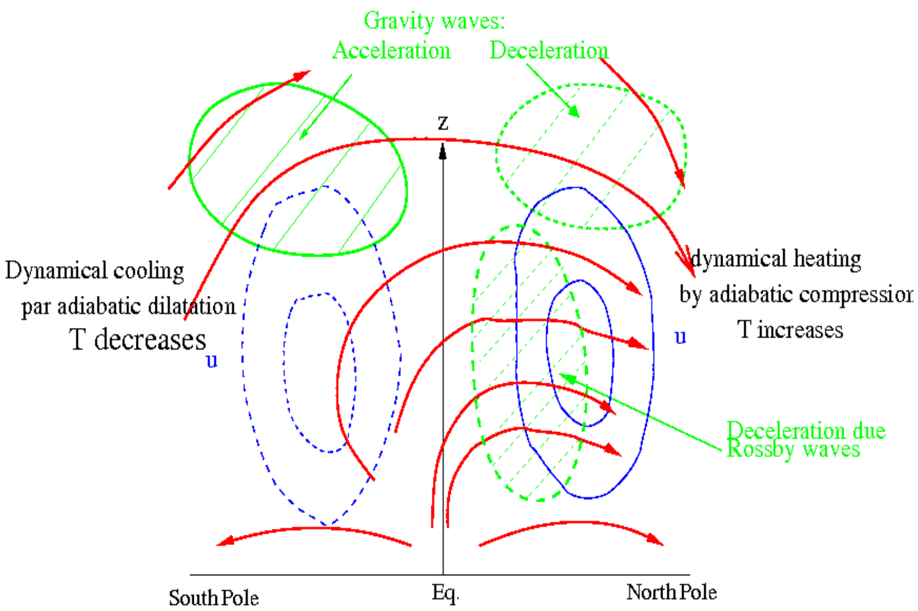
January Temperatures



The meridional circulation driven by waves and the « downward control »



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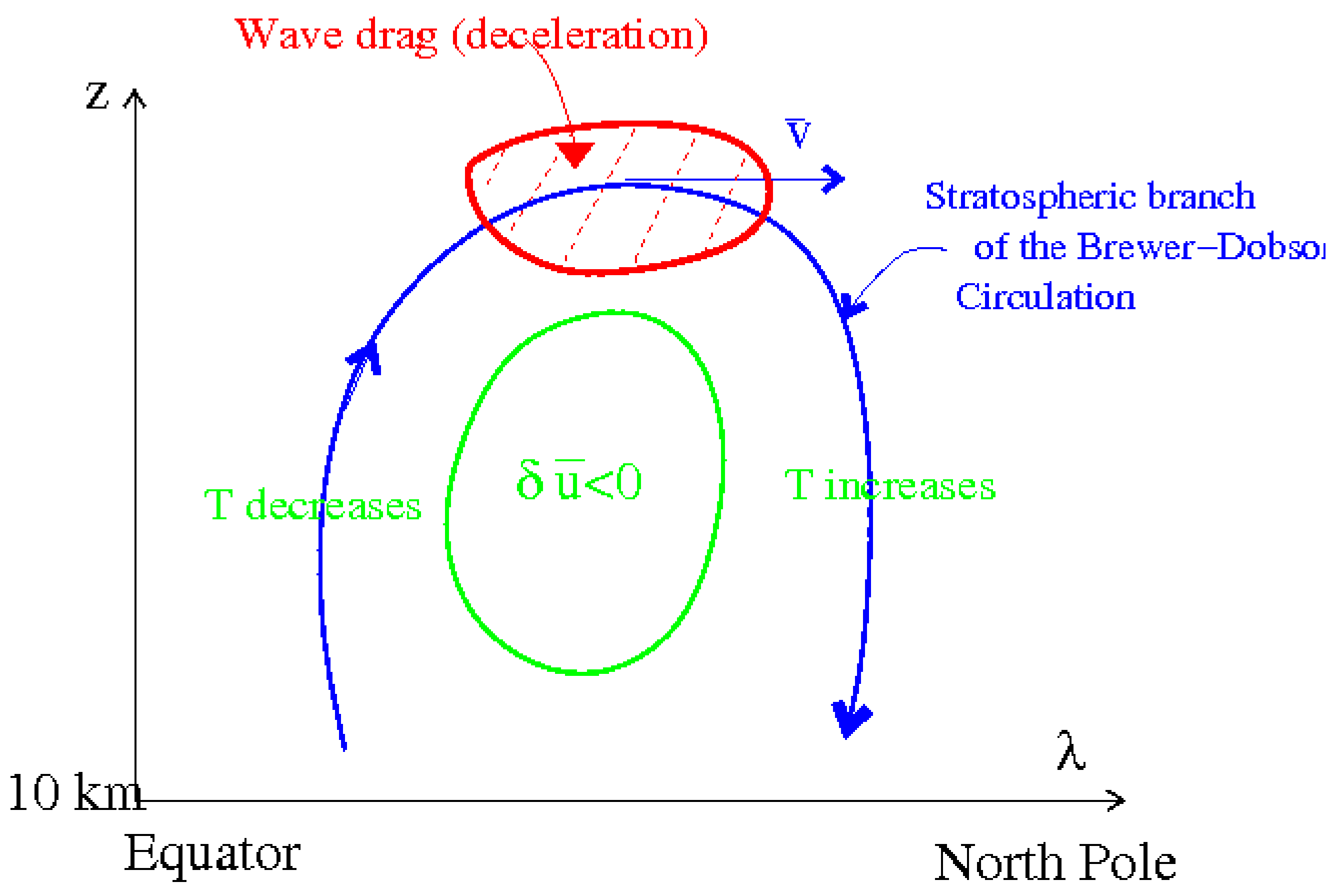
More about the downward control, or how to decelerate a rapidly rotating fluid on a sphere!



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$$\left(\frac{\partial}{\partial t}+\frac{v}{a}\frac{\partial}{\partial\phi}\right)u-\left(2\Omega+\frac{u}{a\cos\phi}\right)v\sin\phi = X$$

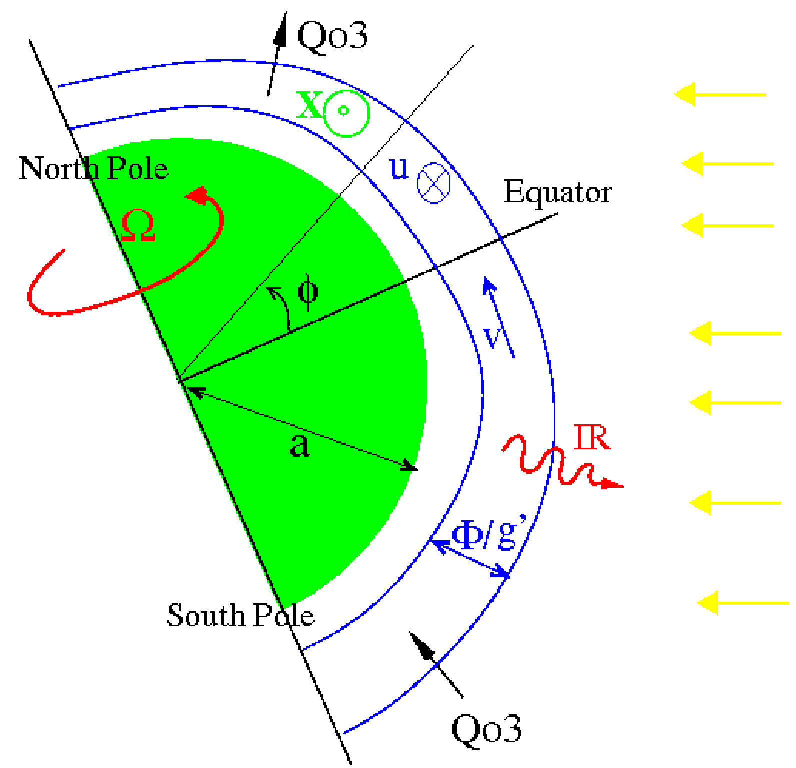
$$\left(\frac{\partial}{\partial t}+\frac{v}{a}\frac{\partial}{\partial\phi}\right)v+\left(2\Omega+\frac{u}{a\cos\phi}\right)u\sin\phi = -\frac{1}{a}\frac{\partial\Phi}{\partial\phi}$$

$$\frac{\partial\Phi}{\partial t}+\frac{1}{a\cos\phi}\frac{\partial\Phi v\cos\phi}{\partial\phi} = Q_{0_3}-\overline{Q}^{\phi}_{0_3}-\alpha\left(\Phi-\Phi_0\right)$$

« Forced » meridional circulation:

$$-2\Omega\sin\phi v \approx X$$

Our Saint-Venant model can produce a persistent meridional circulation if it includes a mechanical forcing



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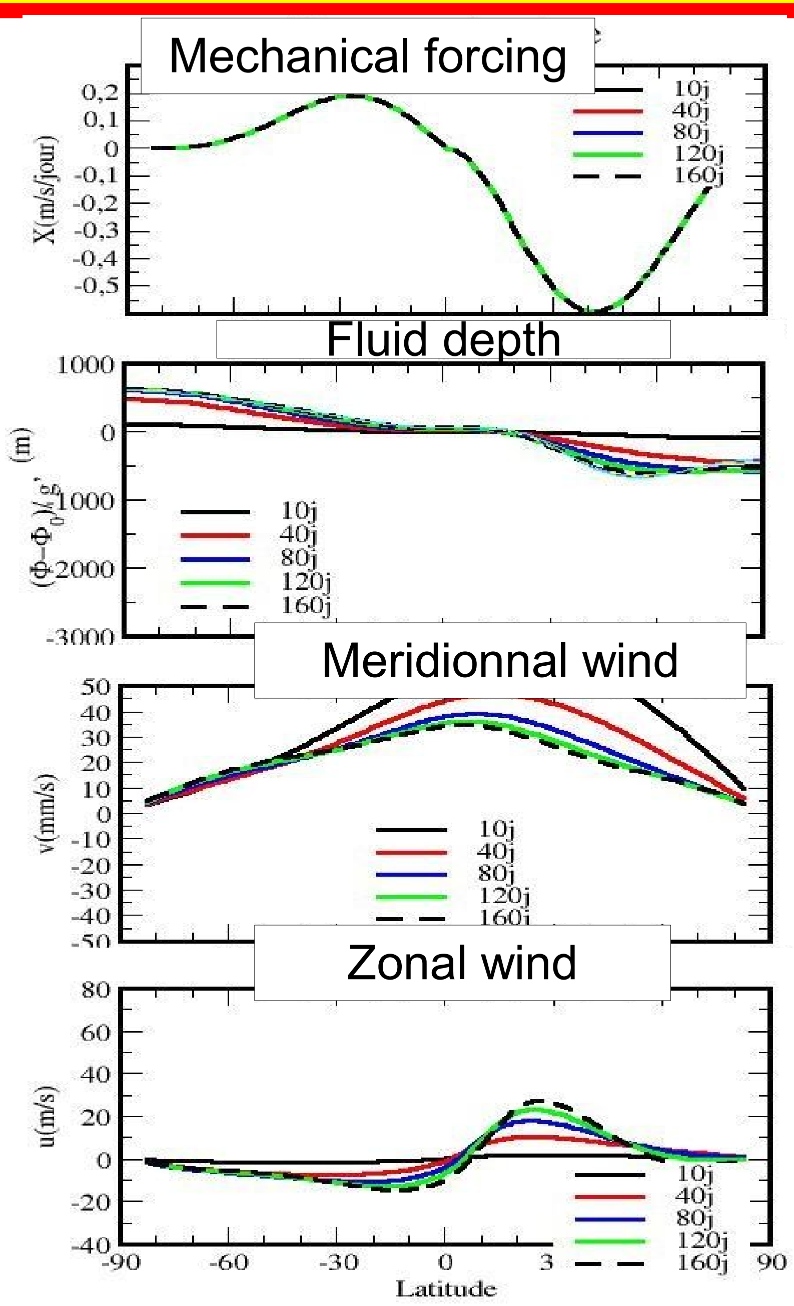
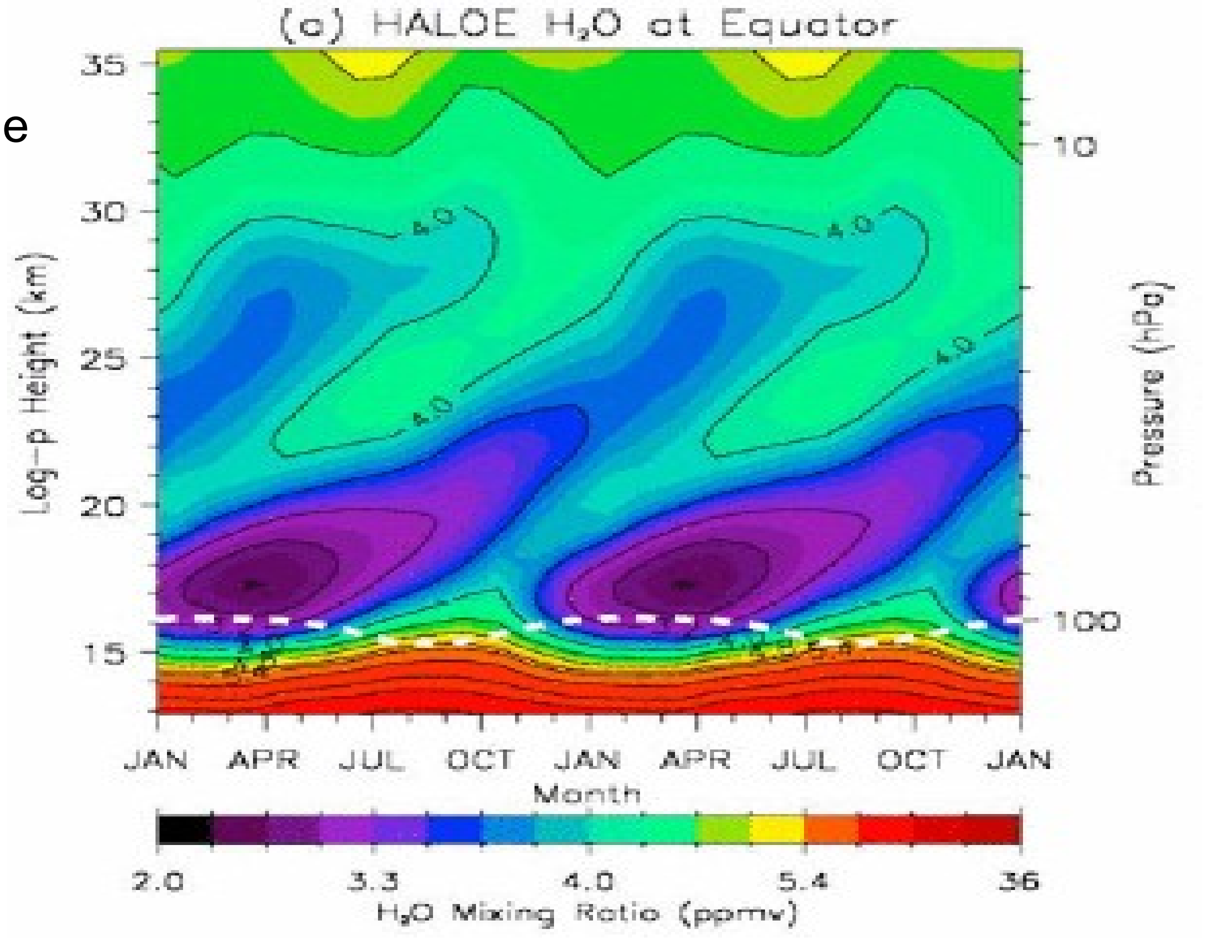


January month, case of the gravity waves around the mesopause

4) Impact of gravity waves on the middle atmopshere
c) The Brewer Dobson circulation

The water vapor enters in the stratosphere around the tropical tropopause, a very cold place!

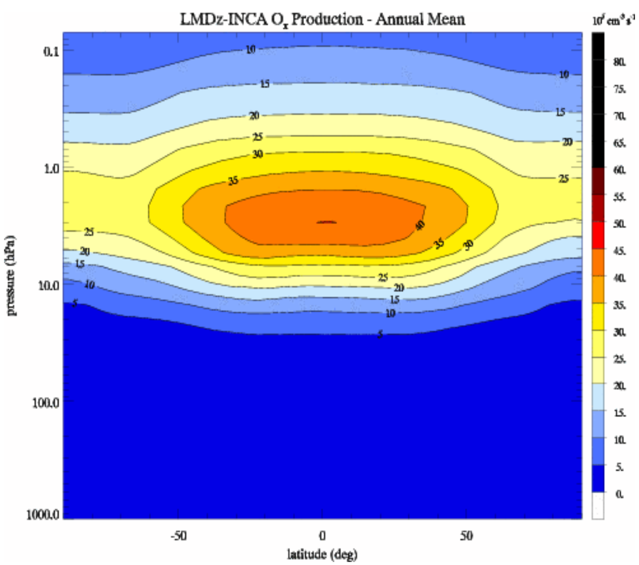
HALOE satellites observations of the « Tape recorder »



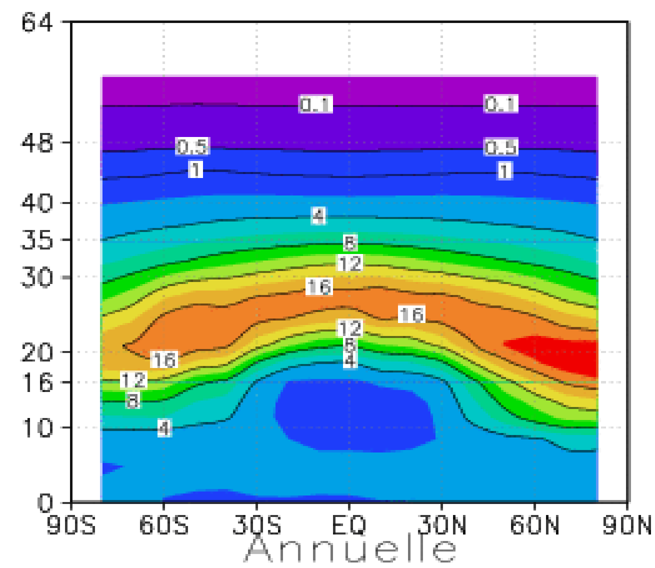
4) Impact of gravity waves on the middle atmopshere
c) The Brewer Dobson circulation

The ozone is produced in majority around
the equatorial trpopause, but accumulates up at much
lower altitudes and latitudes!

Annual mean production
Of Ox



Annual mean of O3



4) Impact of gravity waves on the middle atmopshere
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The ozone is produced in majority around
the equatorial trpopause, but accumulates up at much
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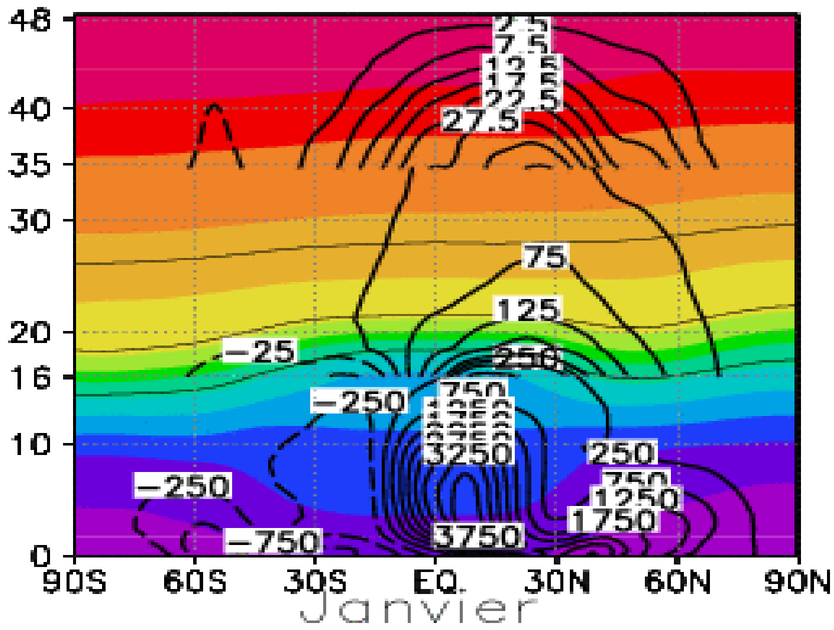
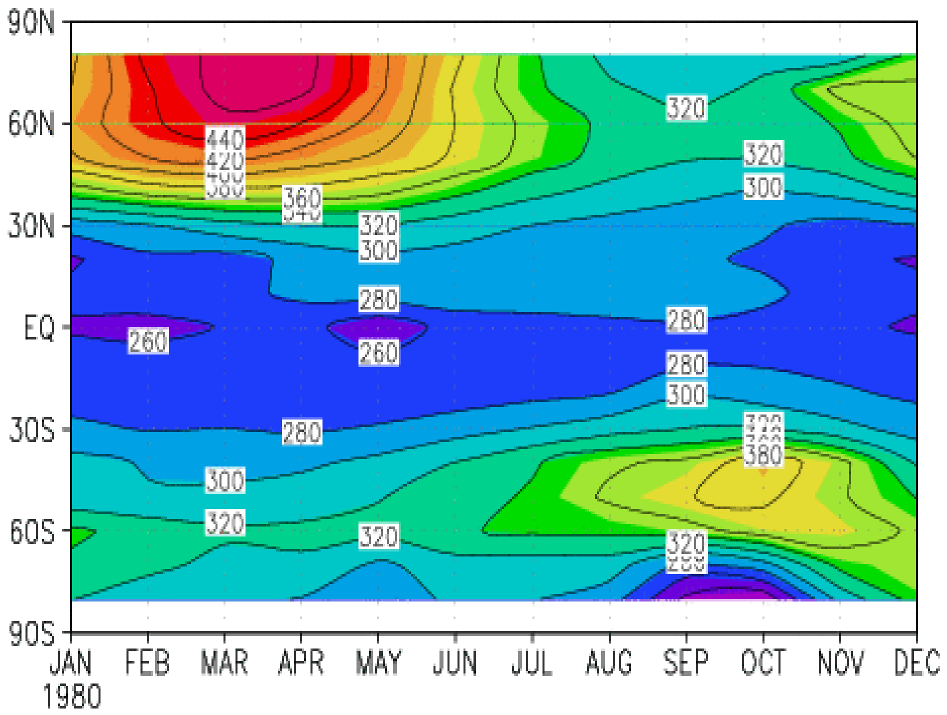
Streamfunction of the meridional
circulation, January
(TEM formalism)



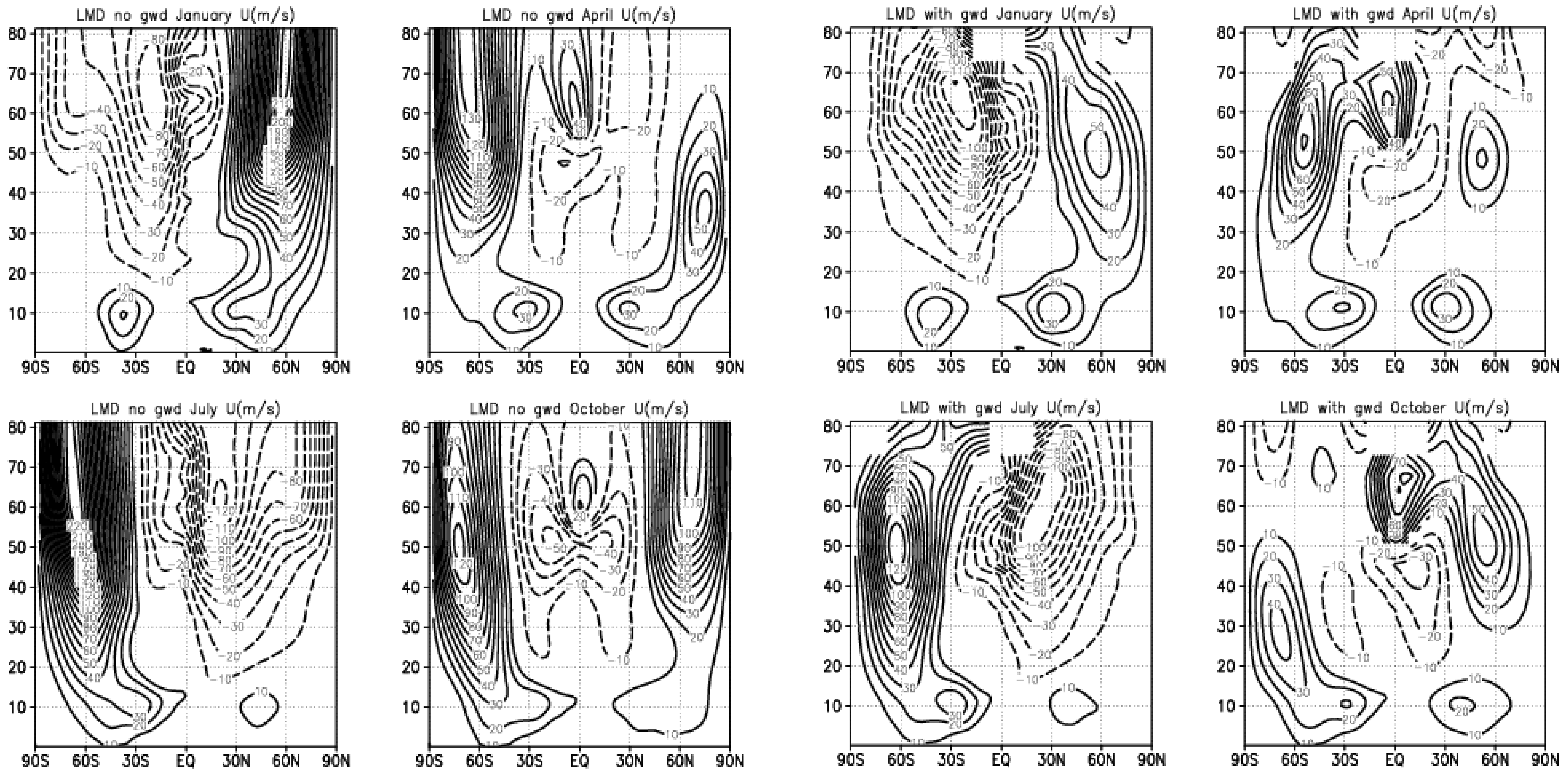
Annual Cycle of O3



4) Impact of gravity waves on the middle atmopshere
d) Middle latitude dynamics

The effect of gravity waves can be well seen in the mesosphere
if we compare simulations with and without parameterization LMDz
(Lott et al. 2005, Lott Millet 2010):

without with



4) Impact of gravity waves on the middle atmopshere
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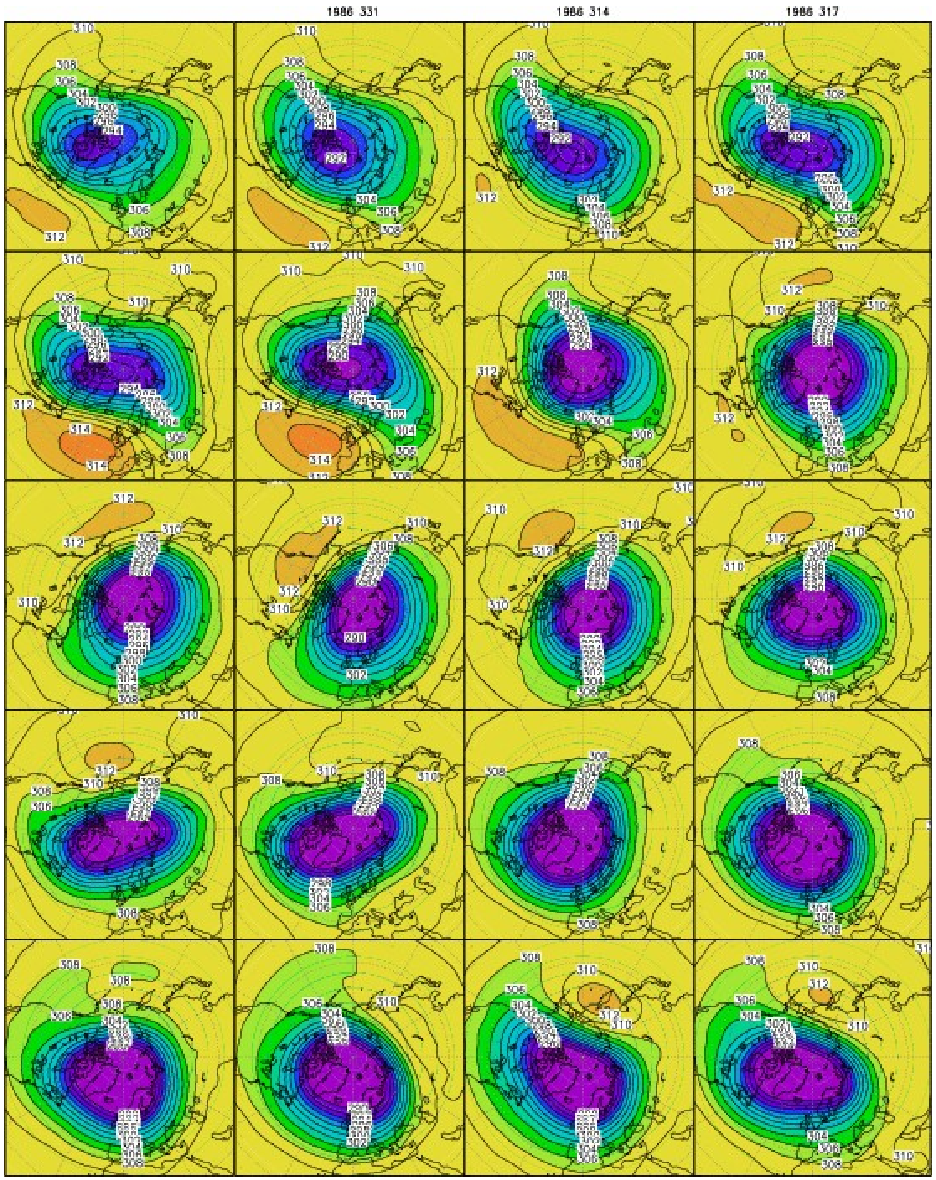
But in the stratosphere the Rossby waves play a very large rôle on the mean climate and variability

(here evolution of a geopotentiel map at z=32km every 3 days)



4) Impact of gravity waves on the middle atmopshere
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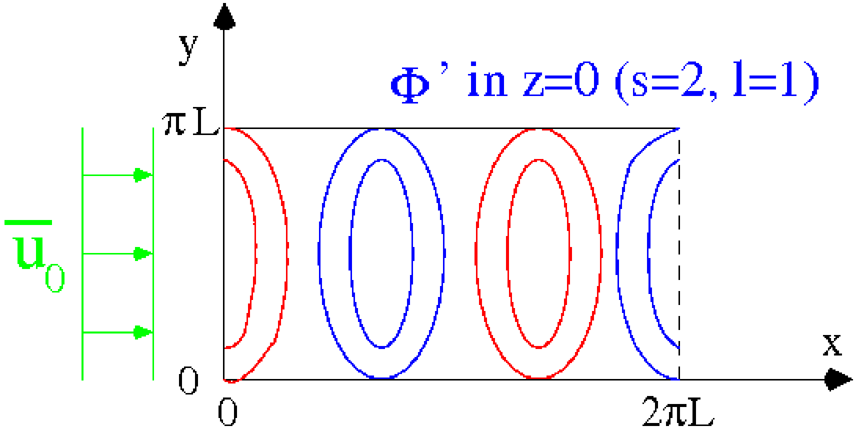
These Rossby waves are very slow, they are quite intermittent and are forced by the low frequency variability of the tropospheric weather.

Vertical structure equation of a quasi-steady Rossby wave on a laterally bounded beta plane. Quasi-Geostrophic approximation is made.



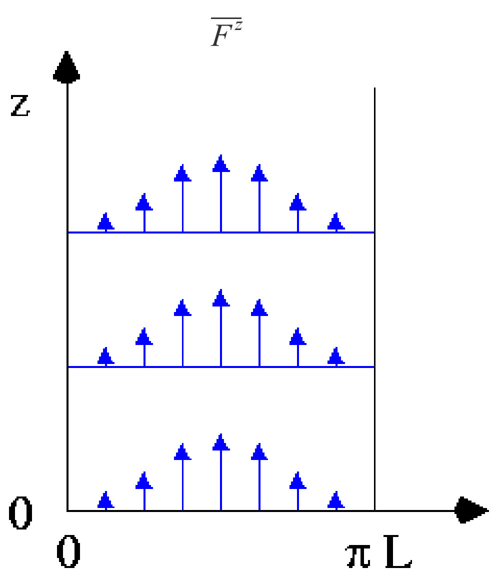
$$\hat{\Phi}_{zz} + \left(\frac{N^2}{f^2} \left(\frac{\beta}{\overline{u}_0} - k^2 - l^2 \right) - \frac{1}{4H^2} \right) \hat{\Phi} = 0$$

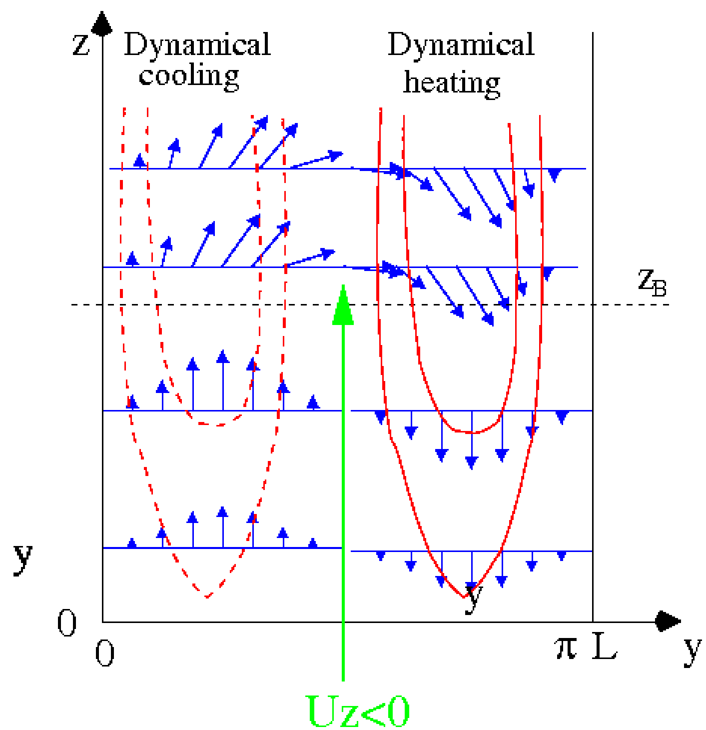
Only vertical propagation if the mean wind is >0 (in winter)

Only the very long modes can propagate vertically

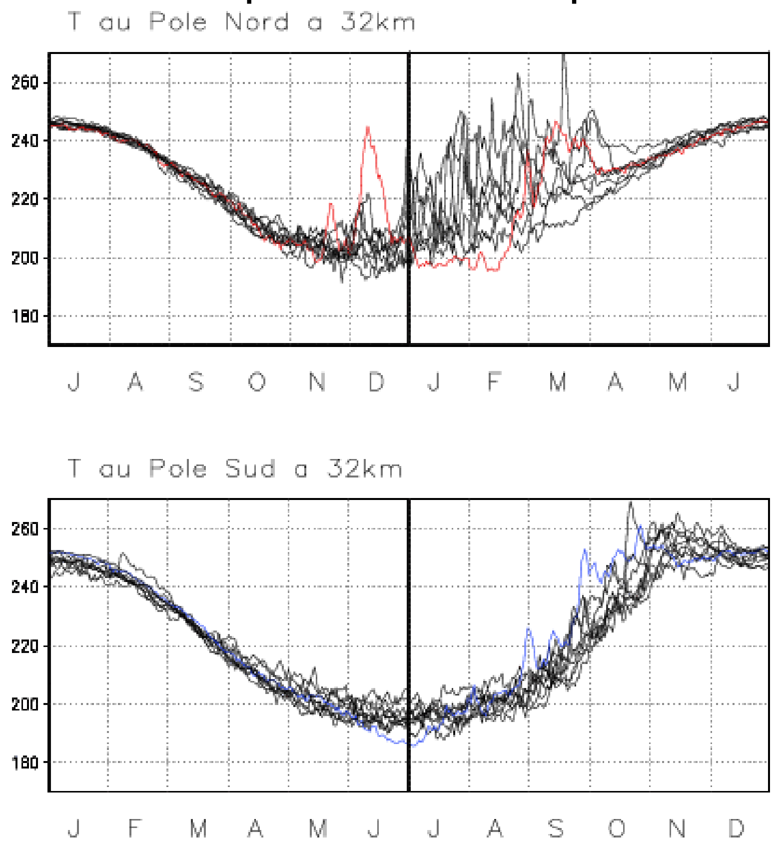
4) Impact of gravity waves on the middle atmopshere
d) Middle latitude dynamics

These Rossby waves as well break (in this case via barotropic instabilities rather than by convective instability for the Gws). This yields to the Stratospheric warmings





Temperature at the poles



4) Impact of gravity waves on the middle atmopshere
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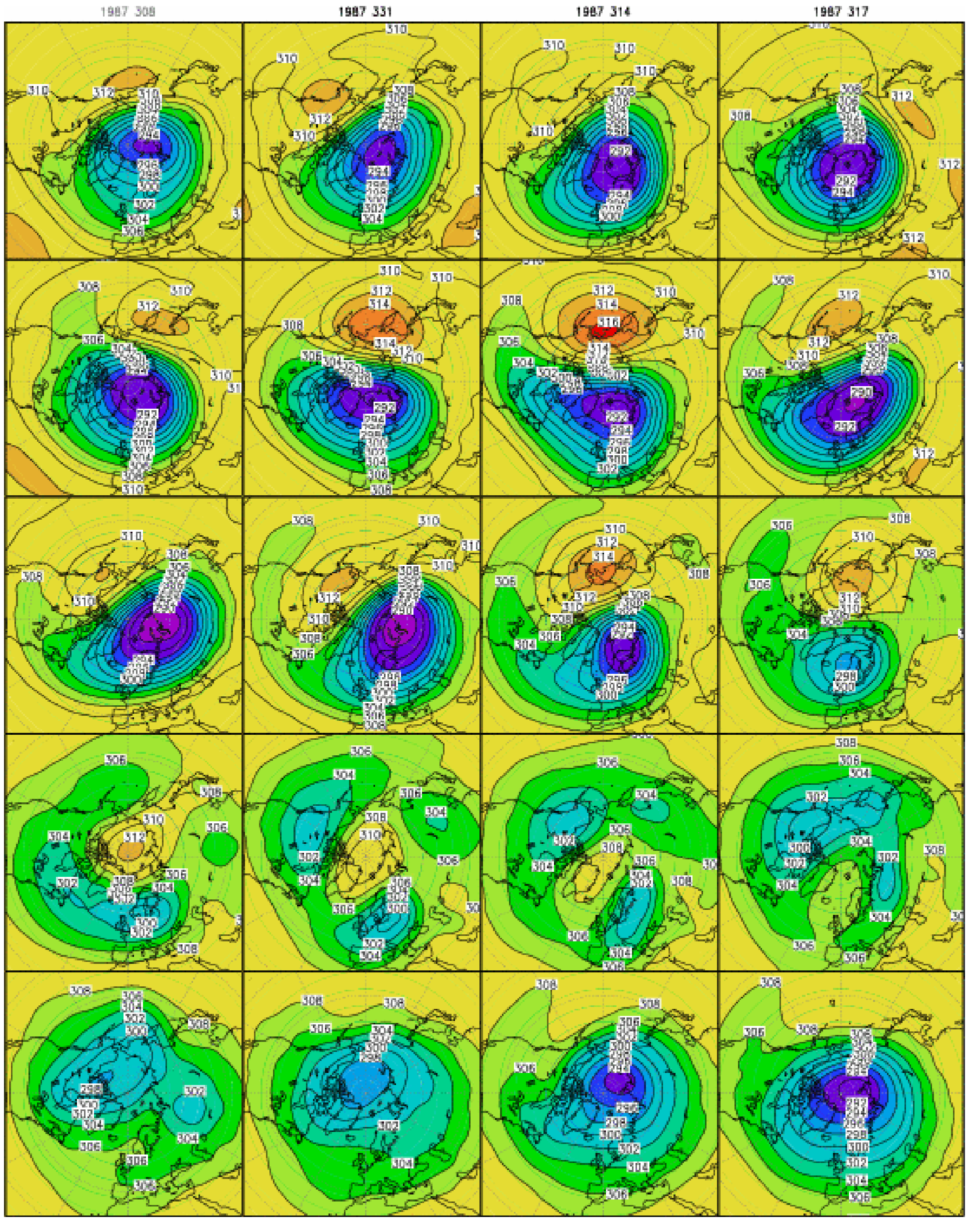
Note that during the life cycle of the warming, shorter waves enter into the stratosphere

$$\hat{\Phi}_{zz}+\left(\frac{N^2}{f^2}\left(\frac{\beta}{\overline{u}_0}-k^2-l^2\right)-\frac{1}{4H^2}\right)\hat{\Phi}=0$$

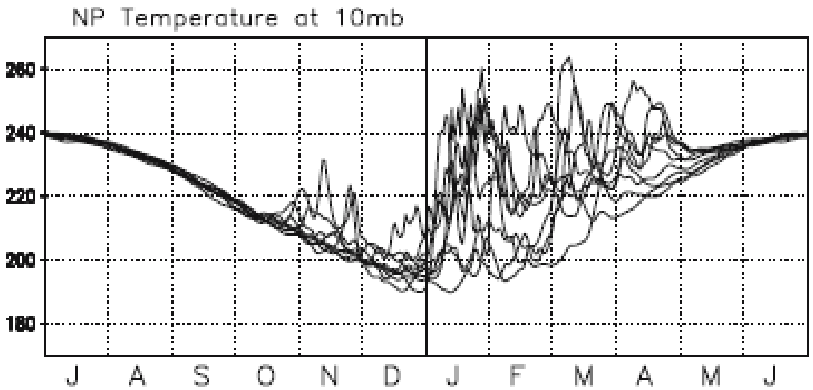


4) Impact of gravity waves on the middle atmopshere
d) Middle latitude dynamics

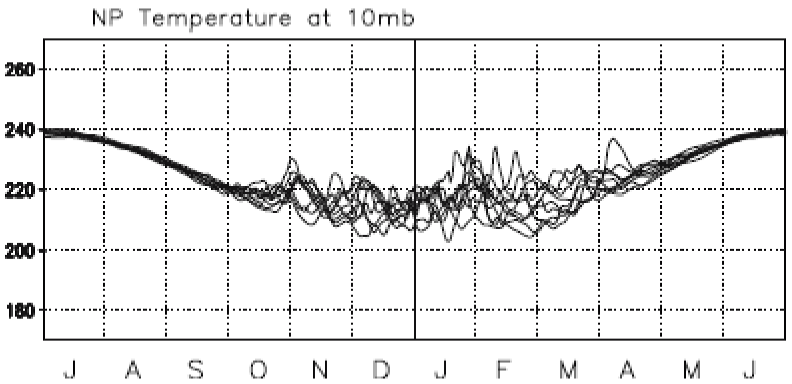
The gravity waves, and particularly the mountain waves can easily reduce the zonal mean wind and affect the Rossby waves propagation.

$$\hat{\Phi}_{zz} + \left(\frac{N^2}{f^2}\left(\frac{\beta}{\bar{u}_0} - k^2 - l^2\right) - \frac{1}{4H^2}\right)\hat{\Phi} = 0$$

Weak oro GWs



Strong oro GWs

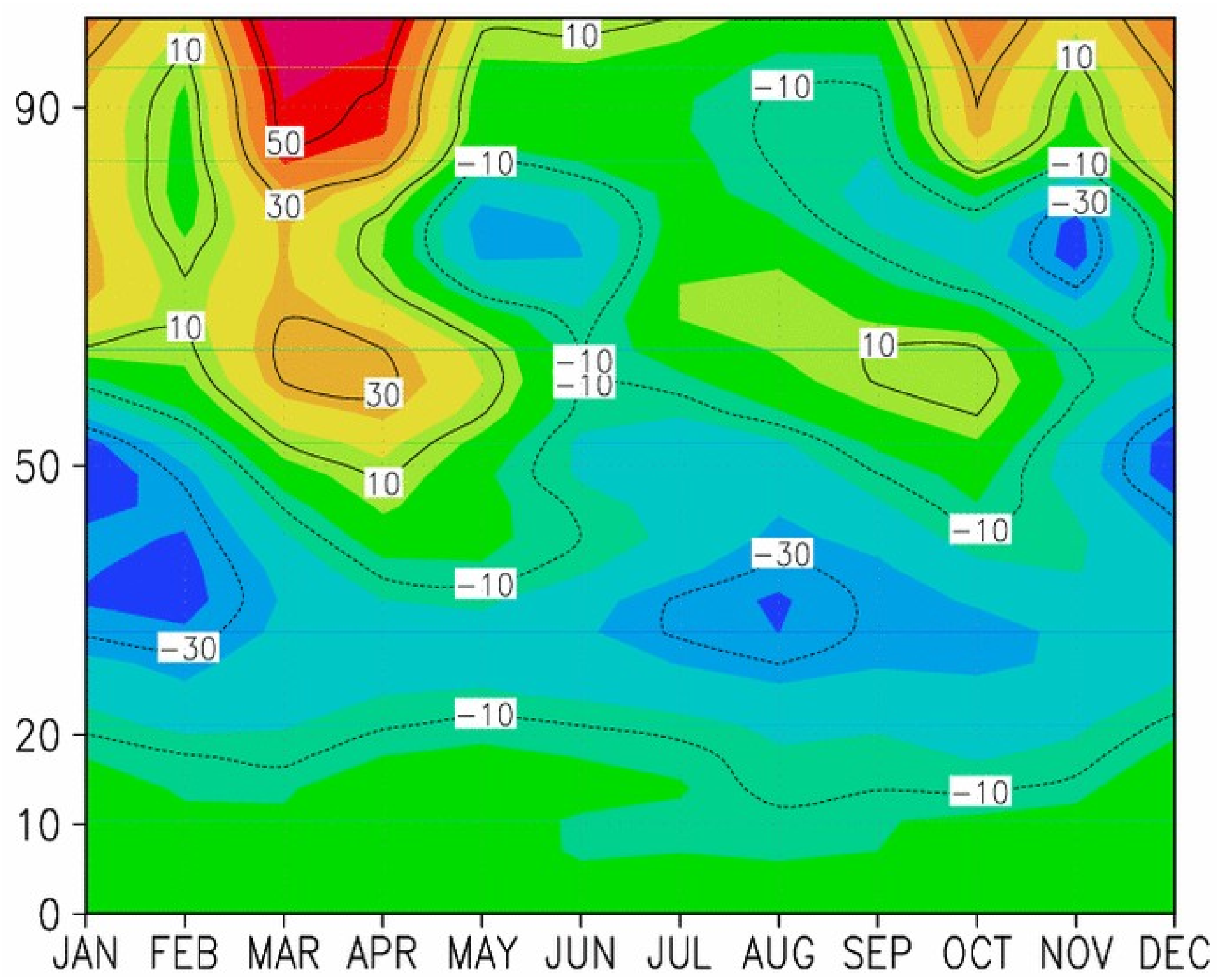


Lott et al (2005)

These changes also impact the persistence of the Arctic Oscillation at the surface!

4) Impact of gravity waves on the middle atmopshere
d) Equatorial dynamics

Zonal wind at the Equator, seasonnal man.
Semi annual oscillation



4) Impact of gravity waves on the middle atmopshere
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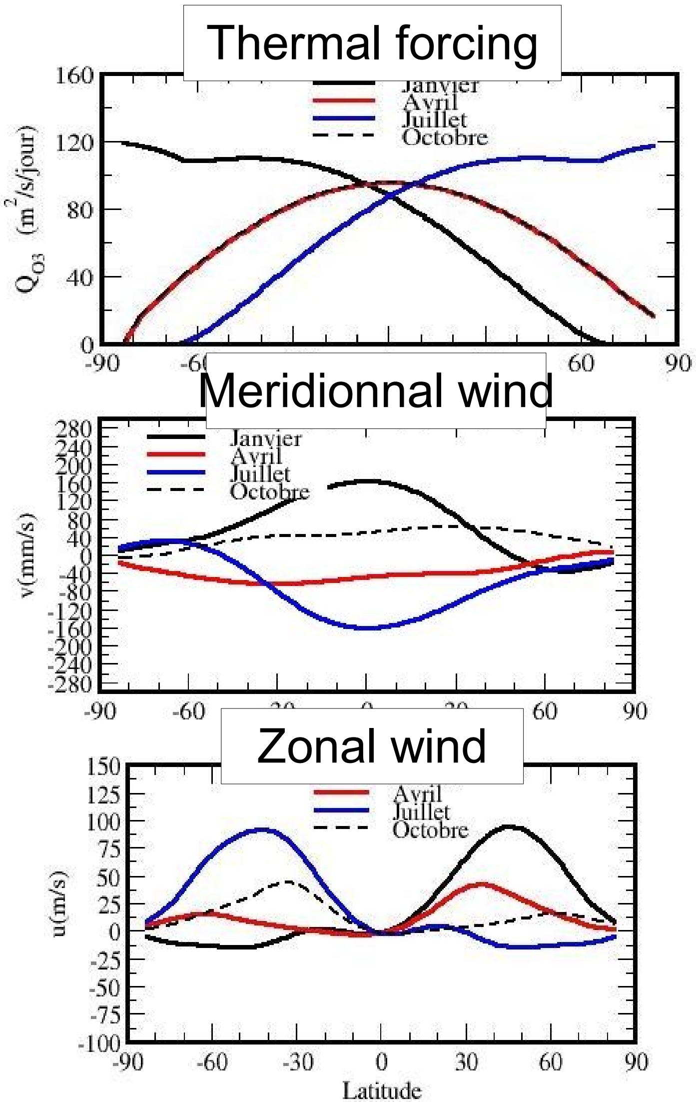
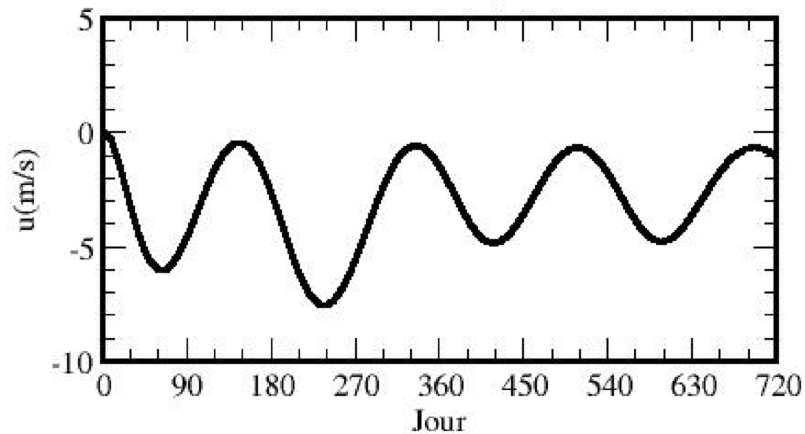
Can we interpret this oscillation as a signature of the inter-hemispheric Brewer Dobson circulation? Response with the shallow water model.



Also we produce a semi-annual Oscillation, the equatorial wind is never positive. Lack a positive acceleration likely to be due to fast Kelvin waves

Zonal wind at the Equator



4) Impact of gravity waves on the middle atmopshere
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Zonal wind at the Equator: semi annual and quasi biennal oscillation

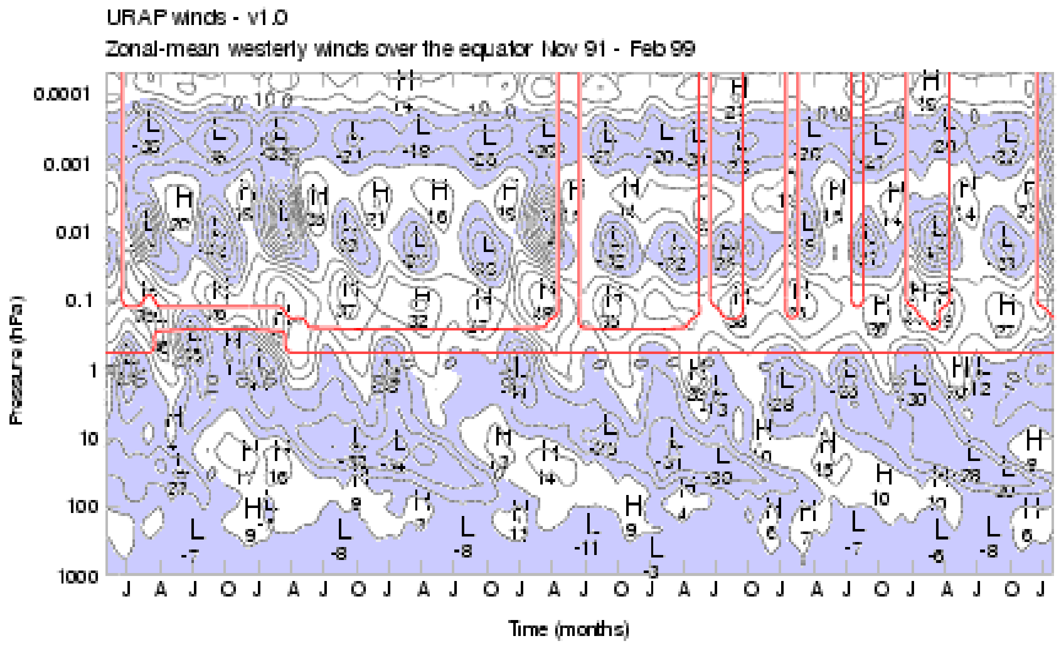


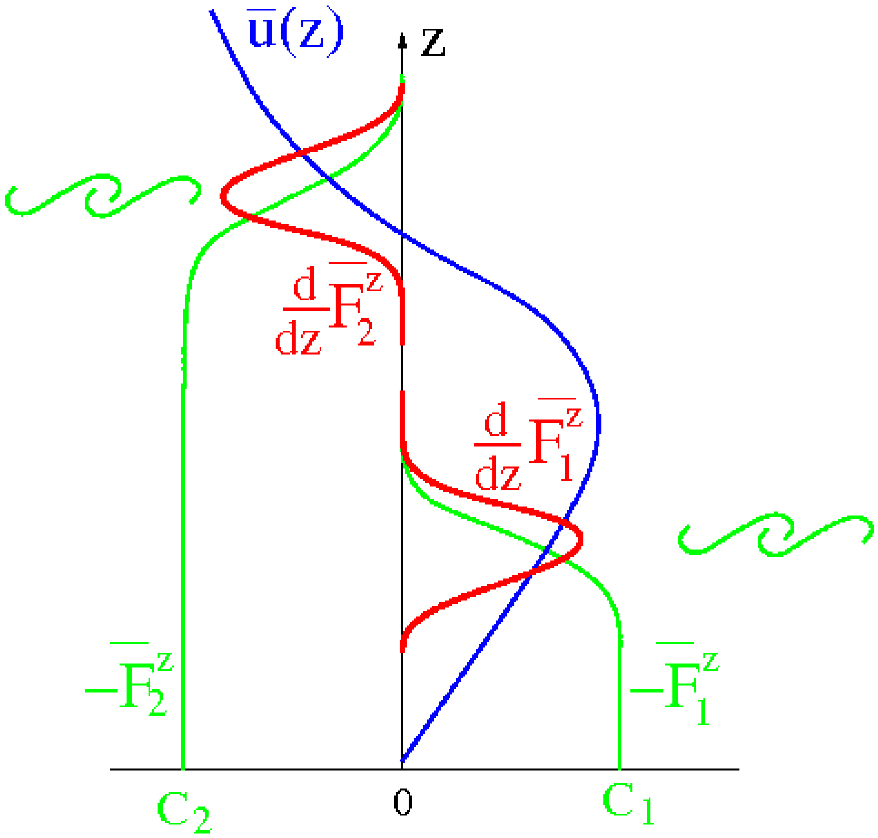
Figure 6. Time series of zonal-mean westerly winds over the equator, from November 1991 to February 1999. The tick marks along the x-axis mark each January, April, July and October. The additional lines show where the values are mainly derived from interpolated or climatogical data.

(UARS observations, Swinbank and Ortland, 1997)

4) Impact of gravity waves on the middle atmopshere
d) Equatorial dynamics

The Plumb (1981) model for a quasi-biennal oscillation driven by two gravity waves

$$\rho_0 \frac{\partial \bar{u}}{\partial t} = \sum_{i=1}^{2} \frac{\partial \bar{F}_i^z}{\partial z} + \frac{\partial}{\partial z} \nu \frac{\partial \bar{u}}{\partial z}$$



4) Impact of gravity waves on the middle atmopshere
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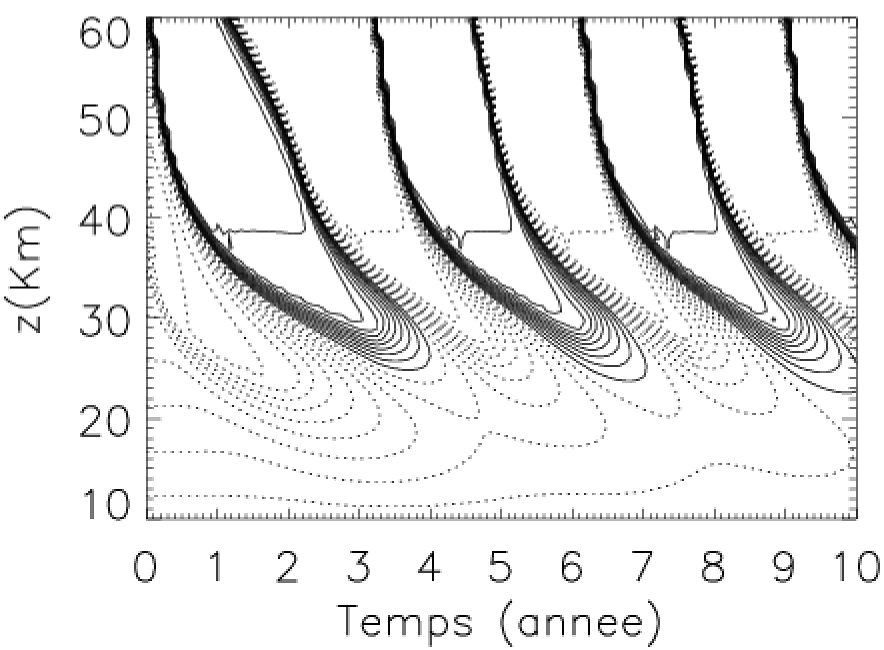
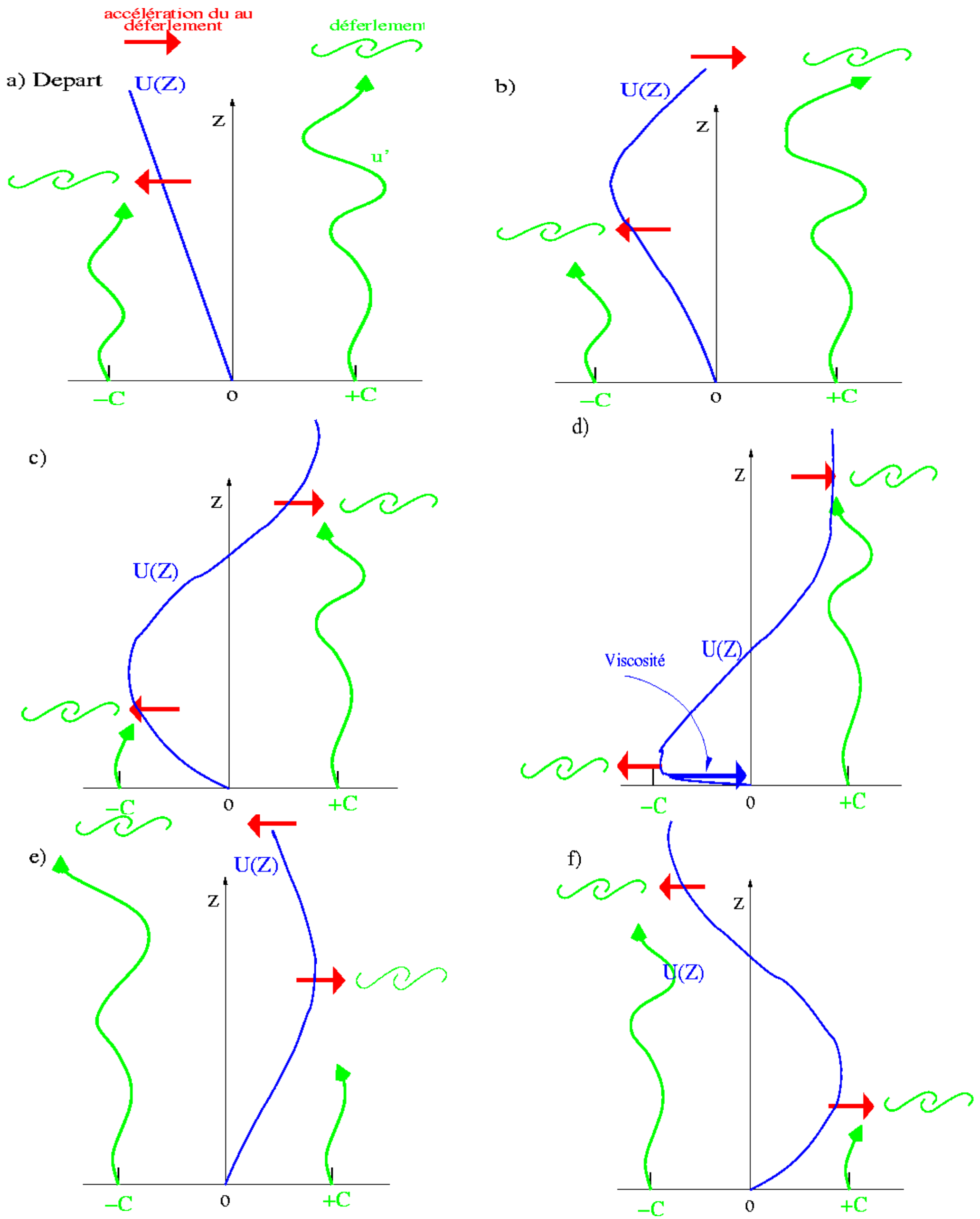
<u>Results from the model:</u>

$\bar{u}(z,t)$

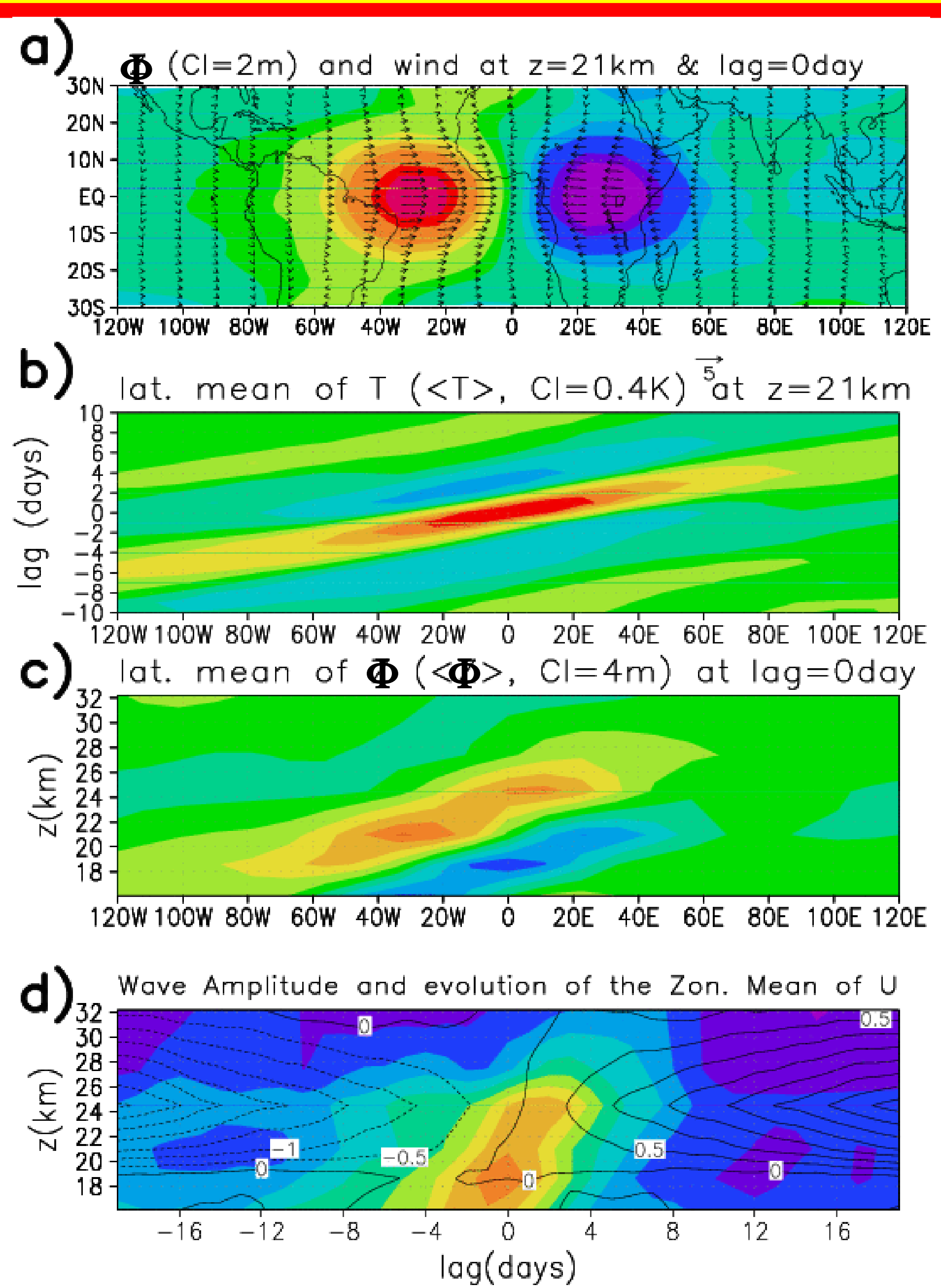




4) Impact of gravity waves on the middle atmopshere
d) Equatorial dynamics

In reality, the QBO really need parameterized gravity waves to be well represented. But again these waves interact with the planetary scale waves that also enter in the QBO dynamics.

Here an Eastward propagating Kelvin wave
(Lott et al. 2010)



4) Impact of gravity waves on the middle atmopshere
d) Equatorial dynamics

In reality, the QBO really need parameterized gravity waves to be well represented. But again these waves interact with the planetary scale waves that also enter in the QBO dynamics.

Here a westward propagating Rossby-Gravity wave (Lott et al. 2010)