Numerical experiments using CCSR/NIES GCM in ISSI intercomparison project of Venus General Circulation Models

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Contents

1. Model setup
2. Result of control run
(For diffusions, standard values in our model are used)
3. Results of sensitivity experiments

Model(equations)

- T21L52 CCSR/NIES AGCM ver.5.6 (*Numaguti et al.* 1995)

(Tech. Rep. http://www-cger.nies.go.jp/cger-e/e_report/r_index-e.html I025-'97)

3D primitive equation in the sigma coordinate system

Continuity equation
Divergence equation
Vorticity equation
Thermodynamics equation
Mixing ratio of components (e.g, water)

Spectral space

Continuity equation
Advection
Rayleigh friction
Horizontal hyperdiffusion

Grid space

Heating/cooling
Surface drag
Vertical diffusion

Model(horizontal spacing)

Dynamical process

Spectral space of
0 to 21 wavenumbers

Spectral
transformation

Physical process

Grid space of 32 X 64
~ 5° lat X lon

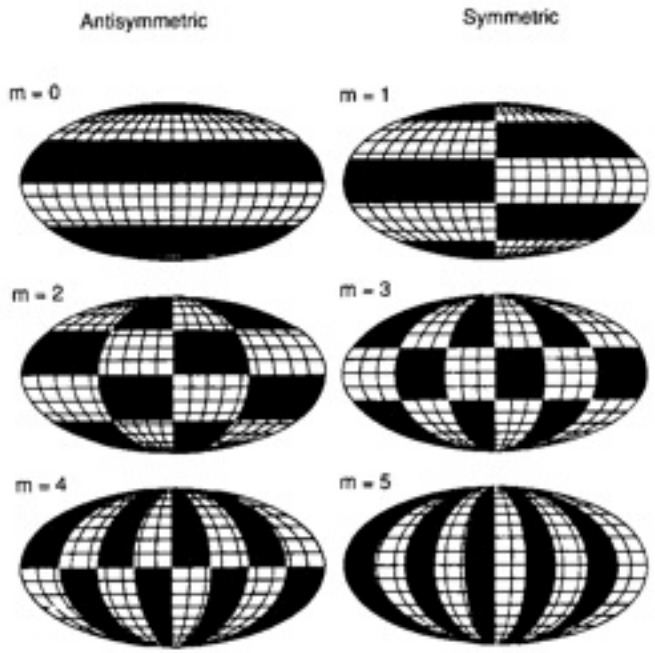
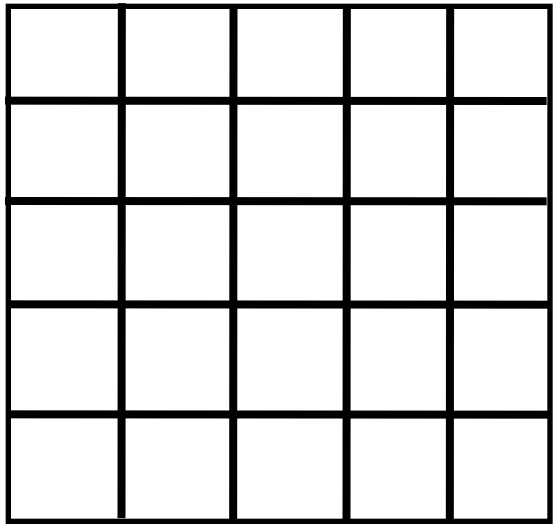
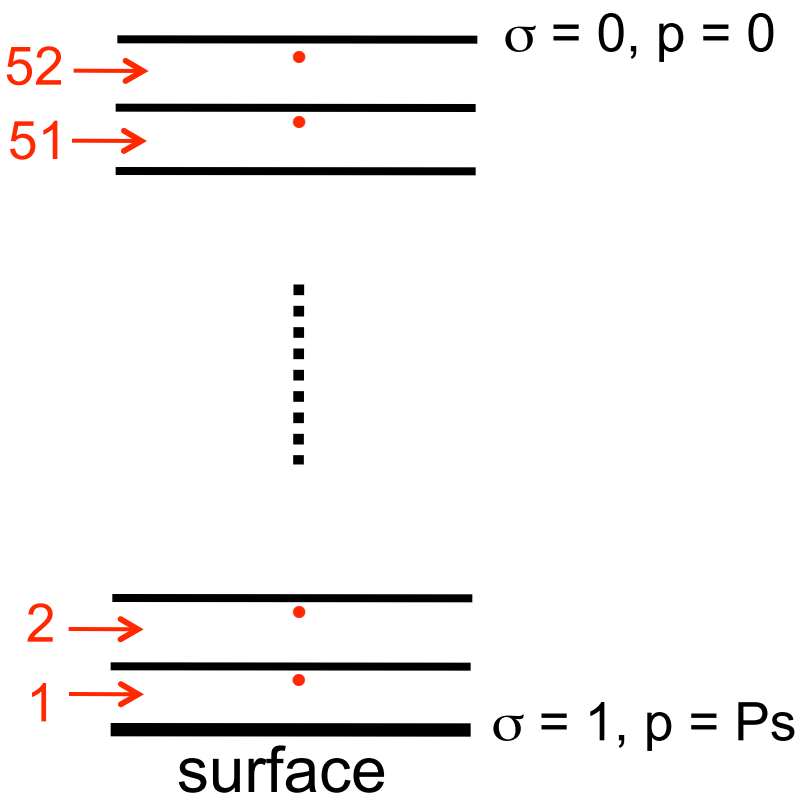


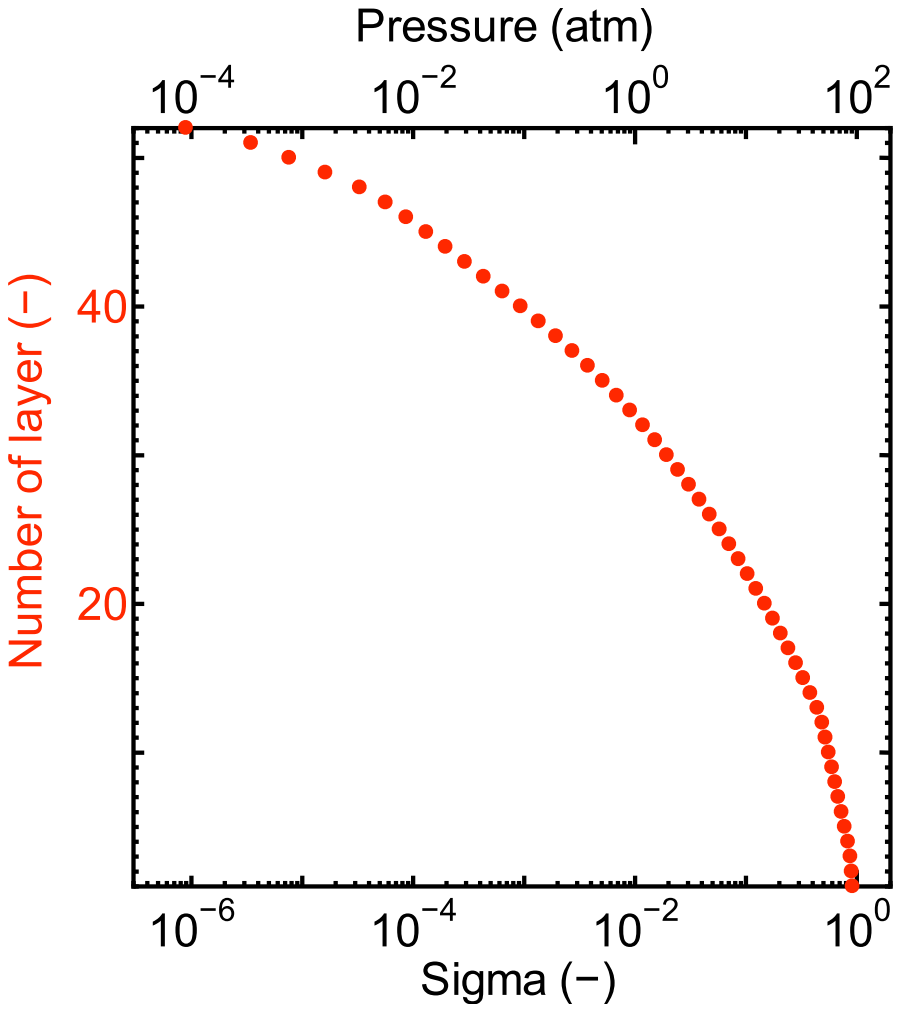
Fig. 13.3 Patterns of positive and negative regions for the spherical harmonic functions with $n = 5$ and $m = 0, 1, 2, 3, 4, 5$. (After Washington and Parkinson, 1986, adapted from Baer, 1972.)



Model(vertical spacing)

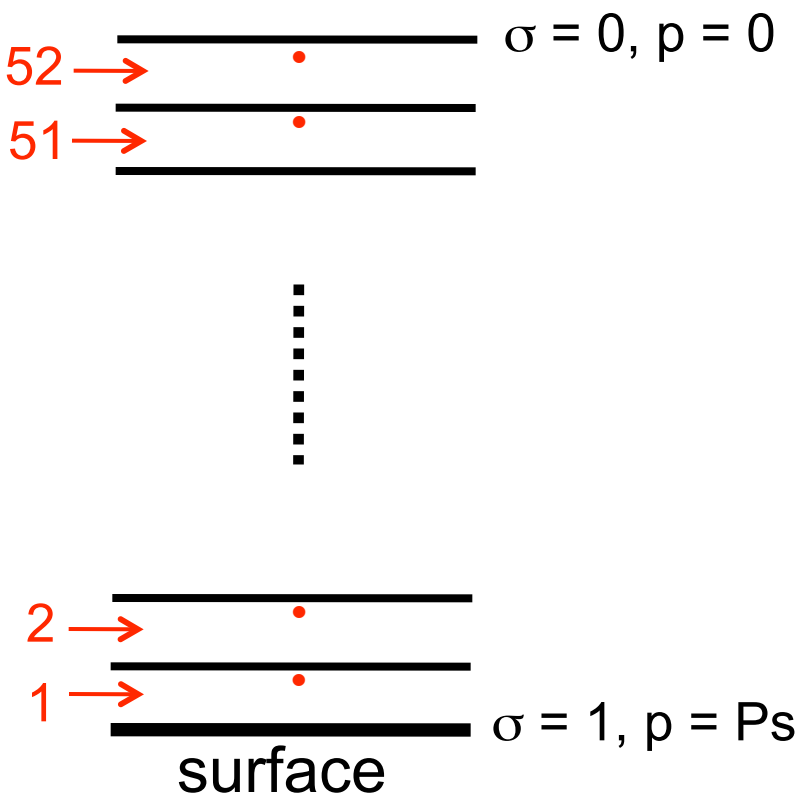
52 layers in a sigma coordinate system

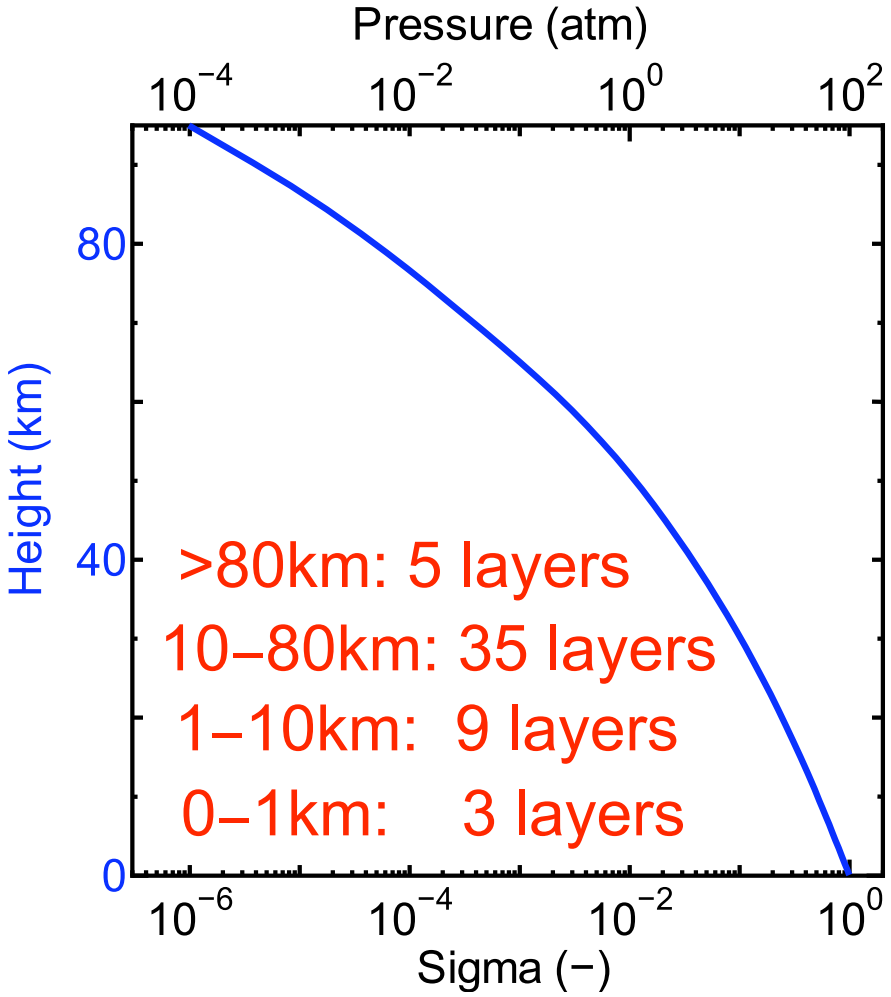




Model(vertical spacing)

52 layers in a sigma coordinate system





Model Setup

- T21L52 CCSR/NIES AGCM ver.5.6 (*Numaguti et al.* 1995)

(Tech. Rep. http://www-cger.nies.go.jp/cger-e/e_report/r_index-e.html I025-'97)

→Lebonnois' kick-off proposition on Oct 2008

LMD model configuration based on Lee's paper & PhD thesis

⬇ Differences in sub-grid diffusions and dissipation

4-th order horizontal diffusion of 4 days at the maximum wavenumber.
⇒Hyper viscosity formula in spectra space.

Constant vertical eddy diffusion of K_V = 0.15 m^2/s.

Surface drag coefficient of C_D= 4 X 10^{-3}. ⇒ Bulk formula

Rayleigh friction for horizontal flow (mean+eddy) near the top boundary.

$$\frac{1}{\tau_R} = \frac{1}{1000\ days}\left[1 - \tanh\left(\frac{z - z_T}{6\ km}\right)\right] \qquad z = -(5\ km)\ln\sigma \qquad z_T = -(5\ km)\ln\sigma_{top}$$

Rayleigh friction for eddy horizontal flow with time constant of $\sigma/10^{-6}$ (Earth days) for the top 3 layers.

Model Setup (phys. parameters)

(Lee et al. 2007)

Planetary rotation period : 243 Earth days

Venus solar day : 117 Earth days

Planetary Radius: 6,040,000 m

Gravity (g): 8.87 m s^{-2}

Const. pres. spec. heat (Cp) : 887.0 J kg^{-1} K^{-1}

Gas constant (R) : 191.4 J kg^{-1} K^{-1}

Topography and seasonal variation are not included
for the control run (CNTL).

Computer: HitachSR11000 (Hokkaido Univ.)

Model Setup (Temp. & Heat.)

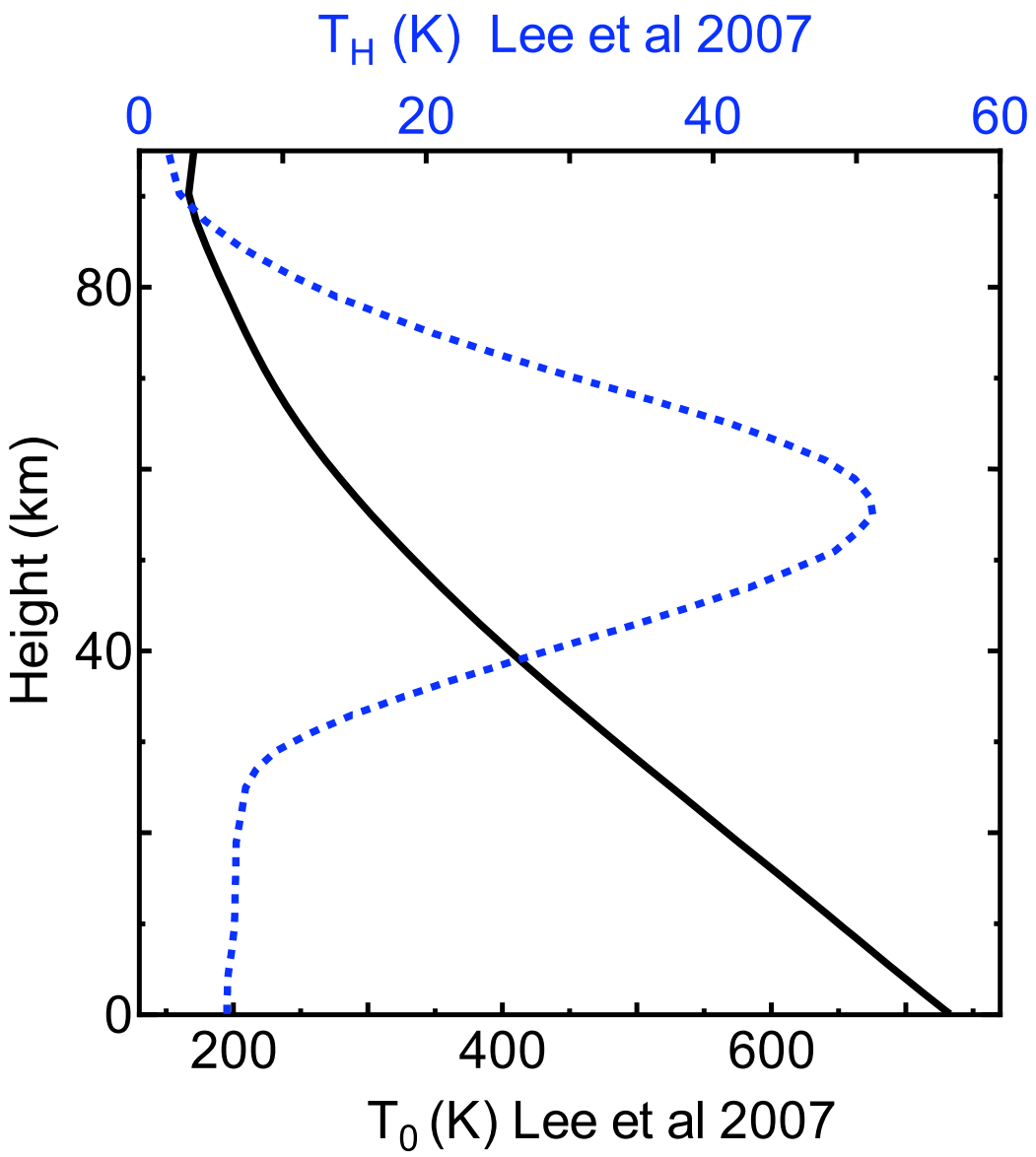
Heating rate

$$\left.\frac{dT}{dt}\right|_{heating} = -\frac{(T - T_R)}{\tau_N}$$

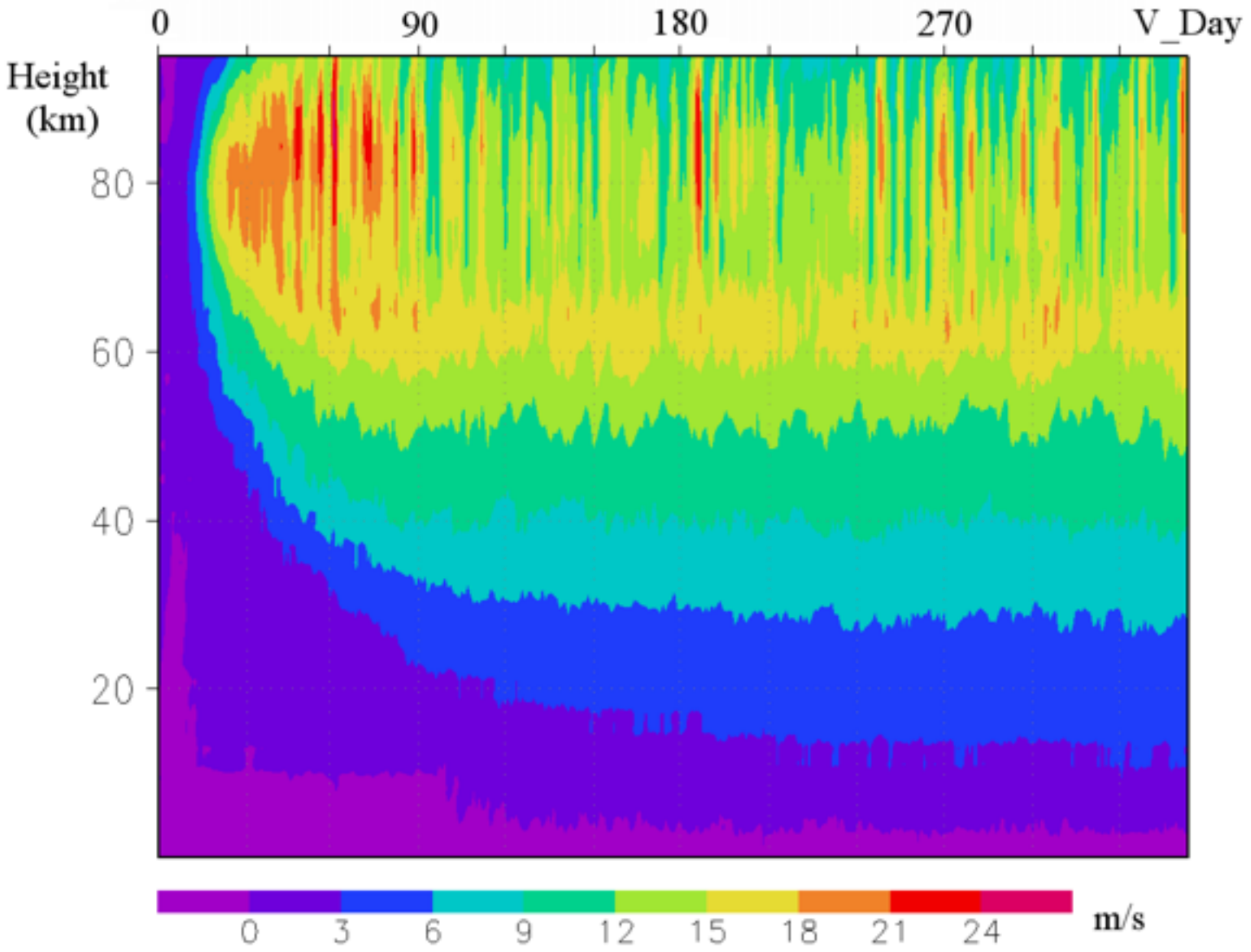
$$where\ T_R = T_0 + T_H \cos\phi,$$

$$\tau_N = 25\ Earth\ days$$

$(Lee\ et\ al.\ 2007)$



Time history (zonal flow, equator)



Analysis based on TEM (e.g. Andrews et al. 1987)

Sampling period: 6144 hours (~ 2 Venus days) after 360 Venus days
Sampling interval: 6 hours

Residual mean meridional circulation

$$V^* = \bar{v} - (\rho_0 \overline{v'\theta'} / \bar{\theta}_z)_z / \rho_0$$

$$W^* = \bar{w} + (\cos\phi \, \overline{v'\theta'} / \bar{\theta}_z)_\phi / a\cos\phi$$

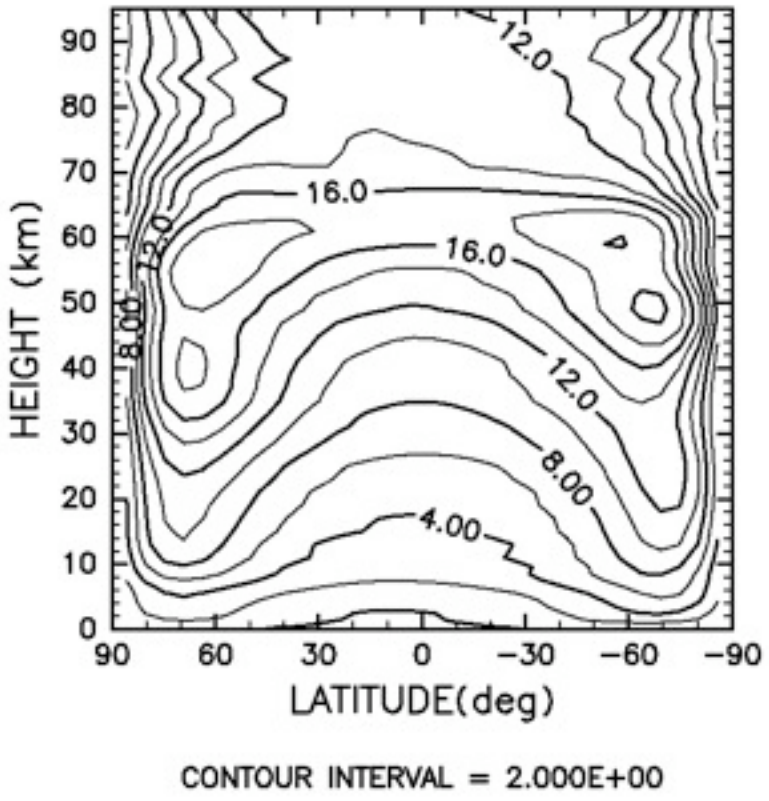
The Eliassen-Palm flux

$$F_{EP}^{\ z} = \rho_0 a \cos\phi \{\overline{u'w'} - [f - (\bar{u}\cos\phi)_\phi / a\cos\phi] \overline{v'\theta'} / \bar{\theta}_z\}$$

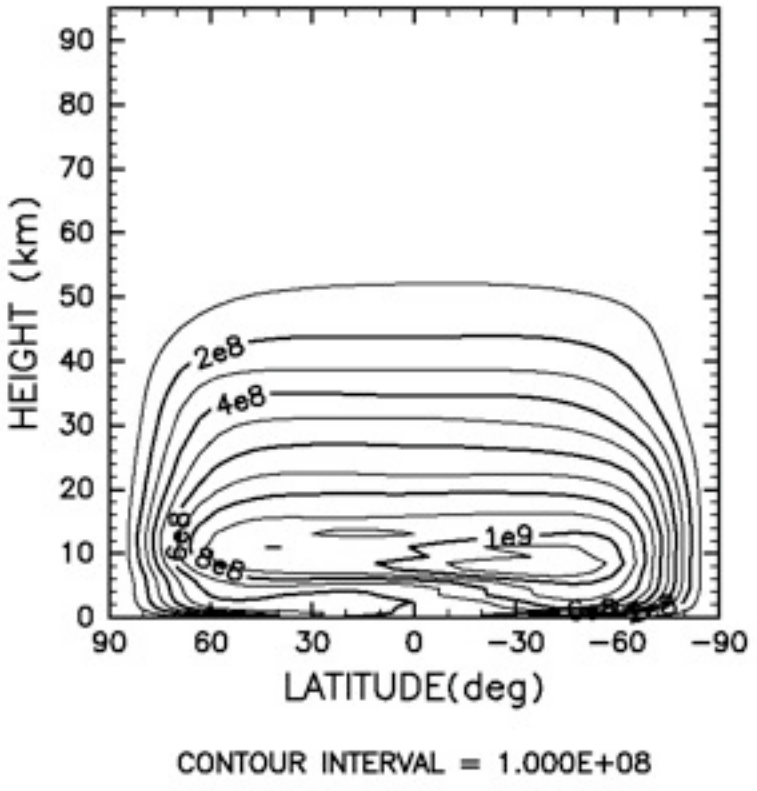
$$F_{EP}^{\ \phi} = \rho_0 a \cos\phi (\overline{u'v'} - \bar{u}_z \overline{v'\theta'} / \bar{\theta}_z)$$

Zonal mean components

Mean zonal flow (m/s)

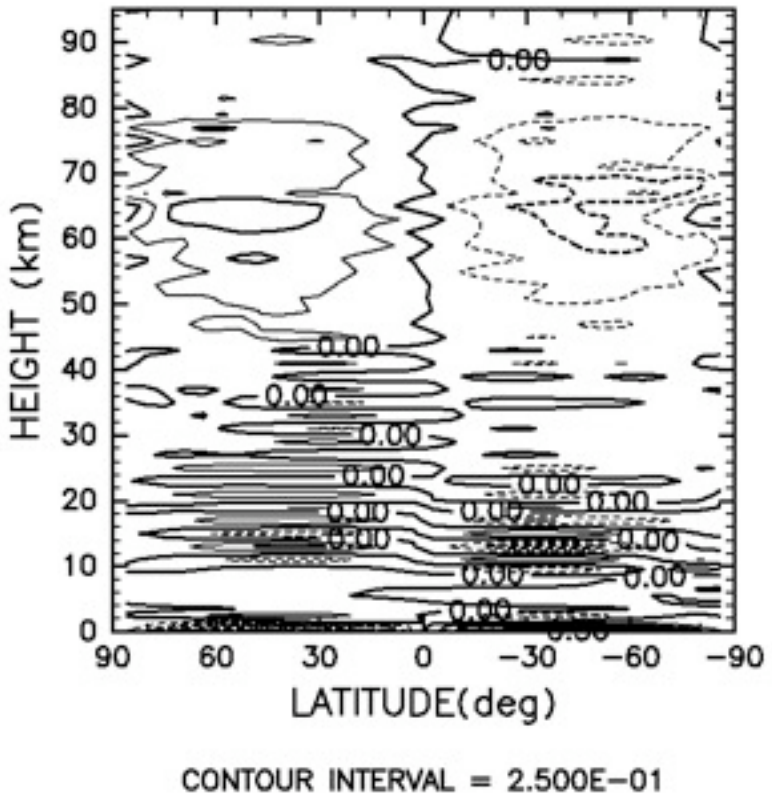


Angular. Momentum

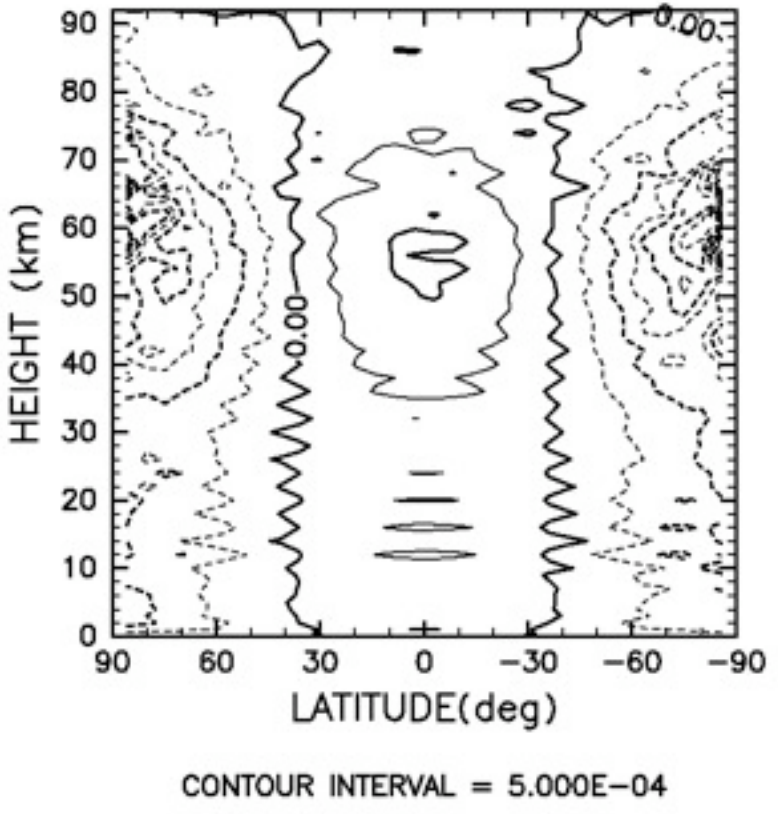


Zonal mean components

Mean meridional flow (m/s)

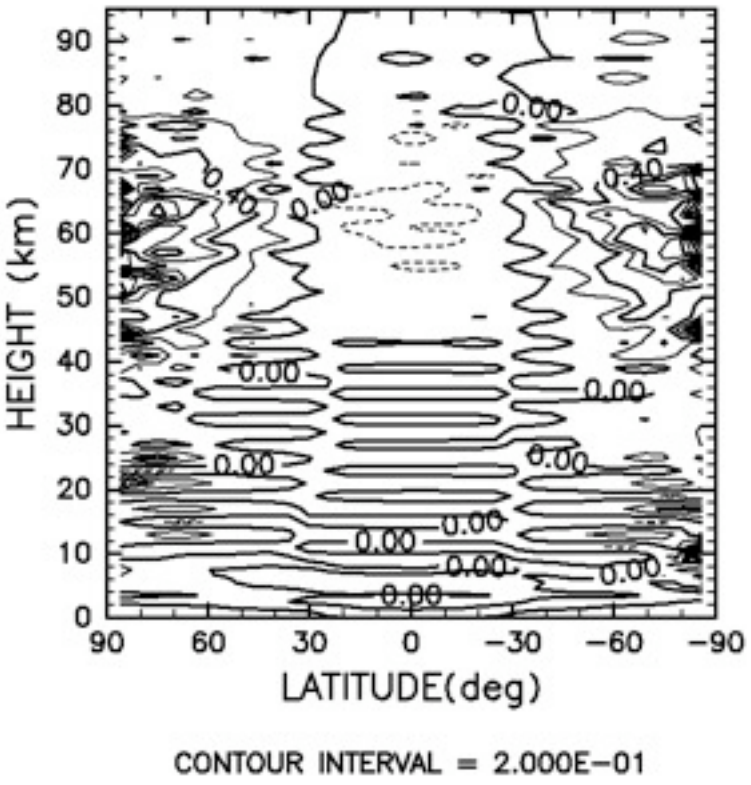


Mean vertical flow (m/s)

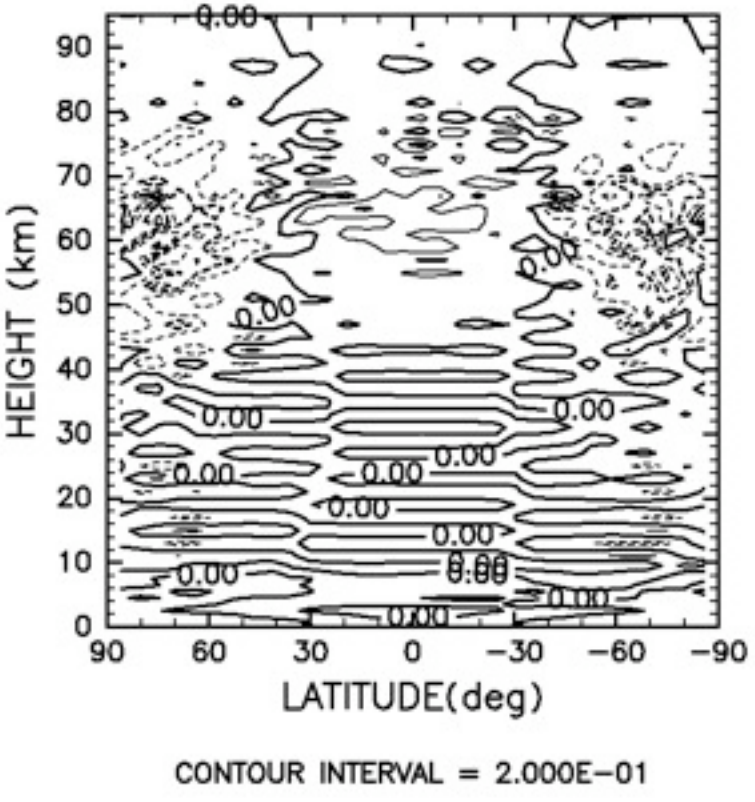


Zonal mean components

Acceleration due to horizontal advection

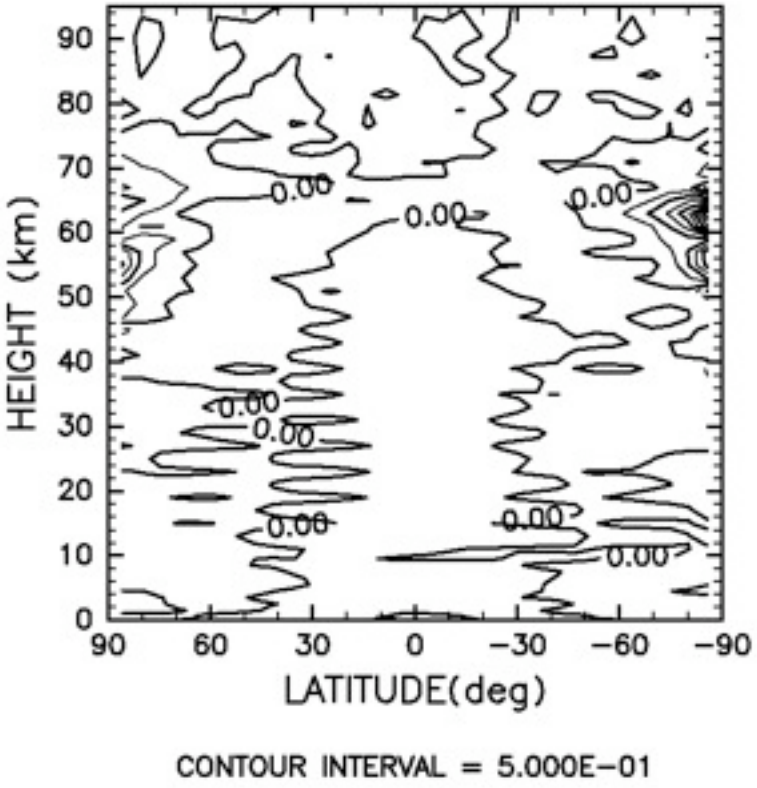


Acceleration due to vertical advection

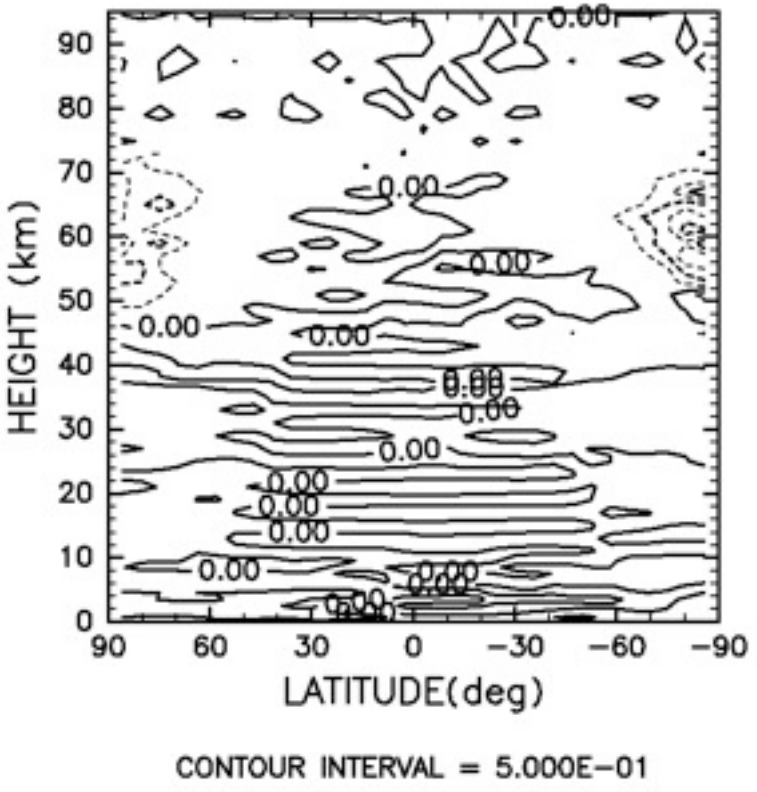


Eddy components

Acceleration due to horizontal EP flux

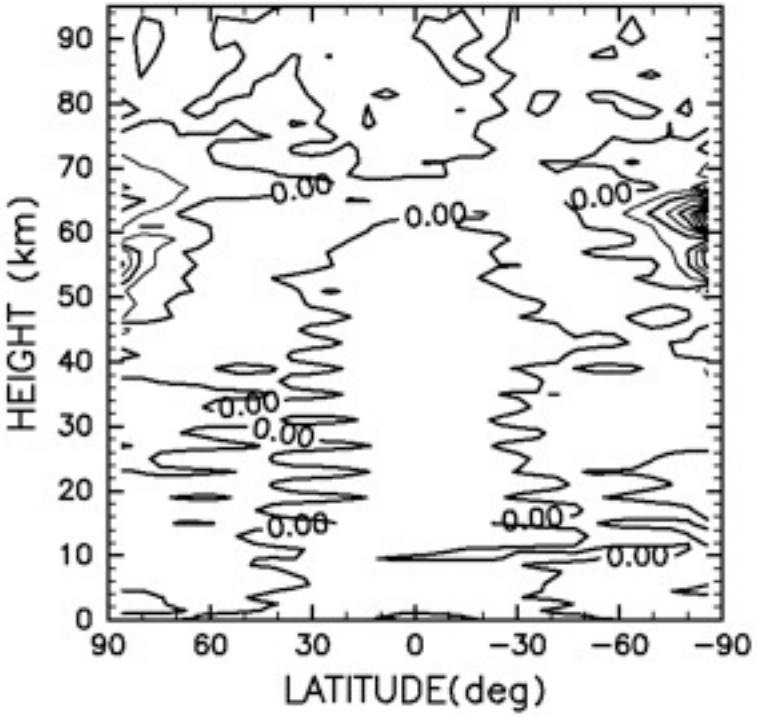


Acceleration due to vertical EP flux

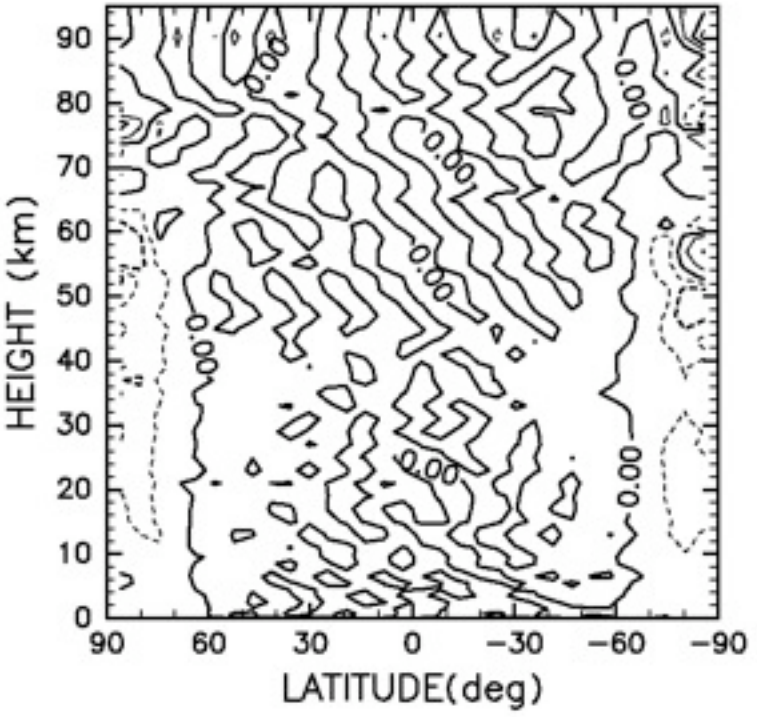


Eddy components

Acceleration due to horizontal EP flux



Acceleration due to Hyper diffusion



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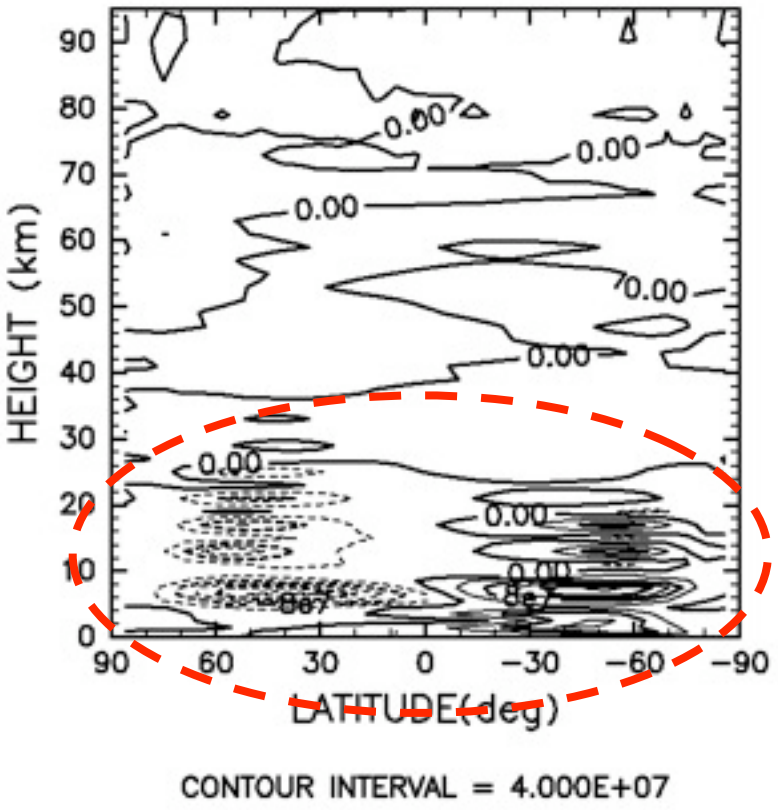
Very small hyper diffusion hardly accelerate SR.

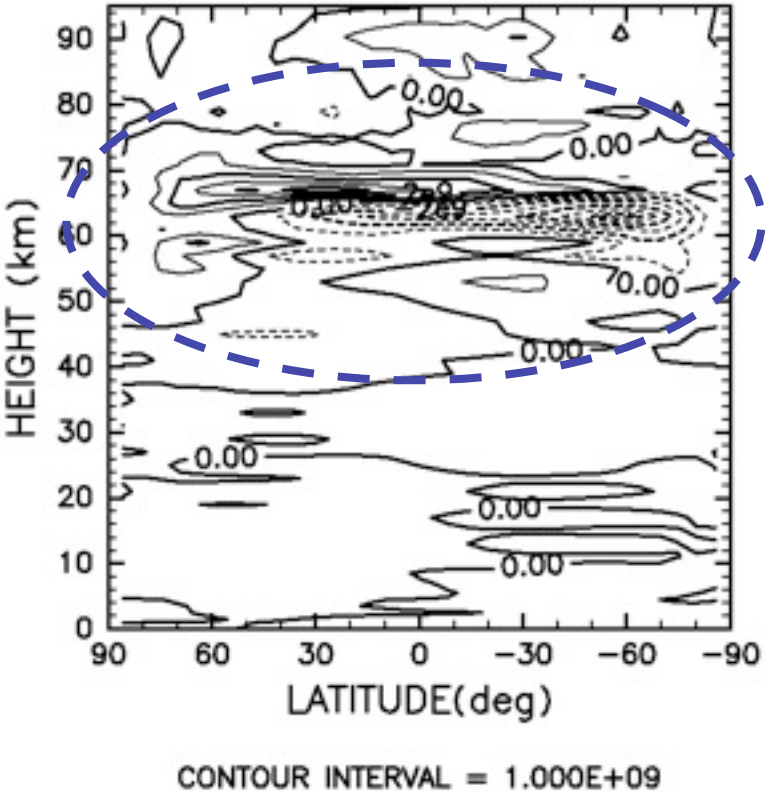
Eddy components

Horizontal EP flux



Equatorward

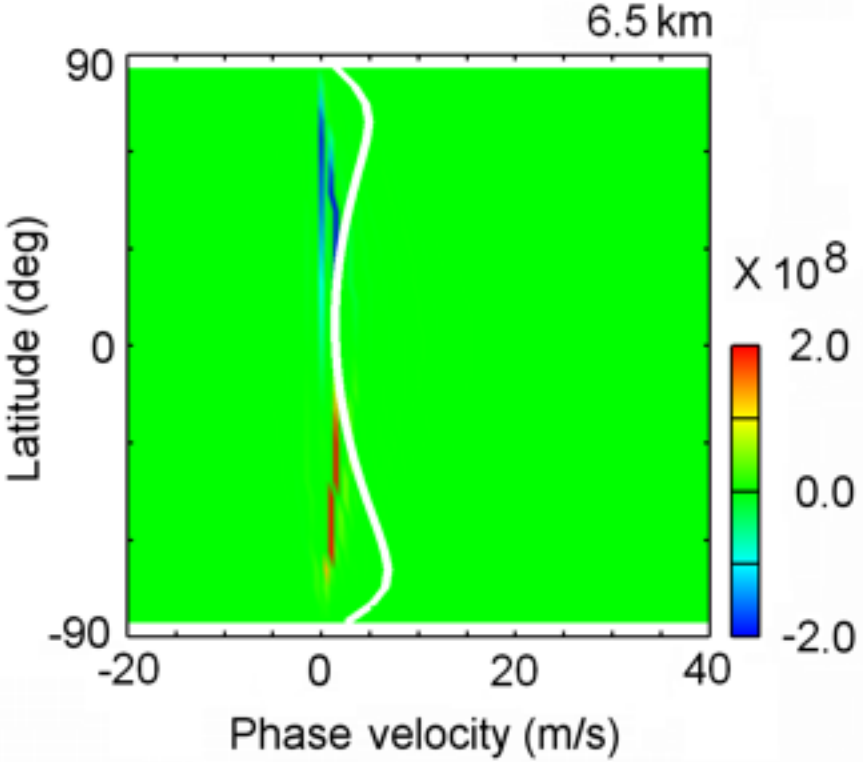
σ^{-1}-weighted horizontal EP flux

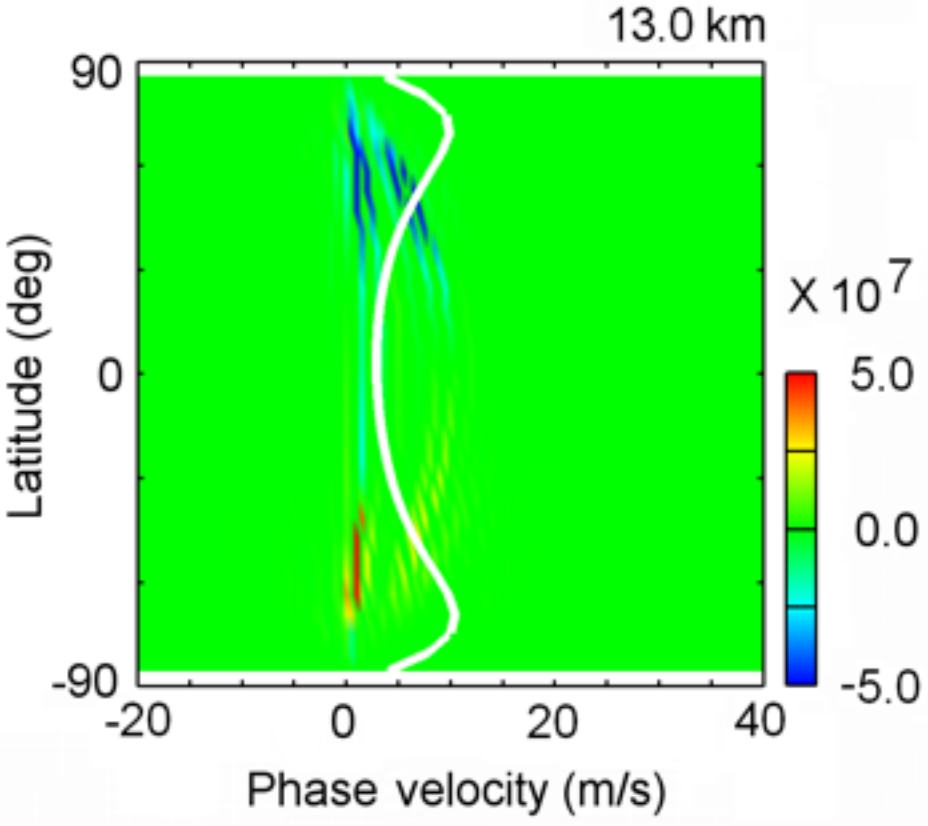


Poleward

Phase velocity – latitude distribution of horizontal EP flux

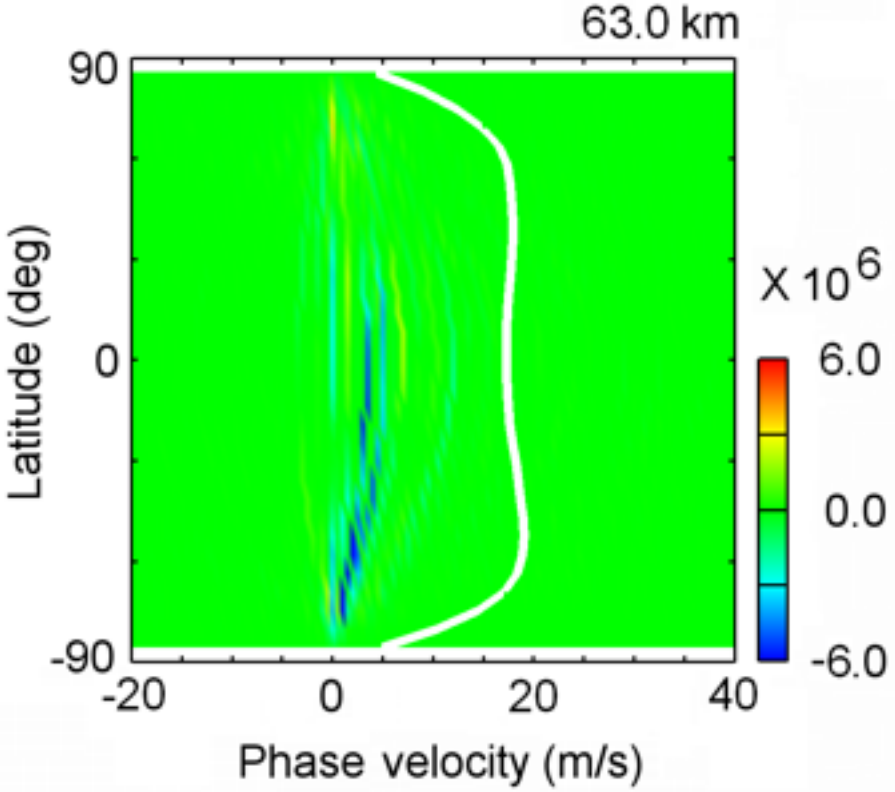
Equatorial acceleration

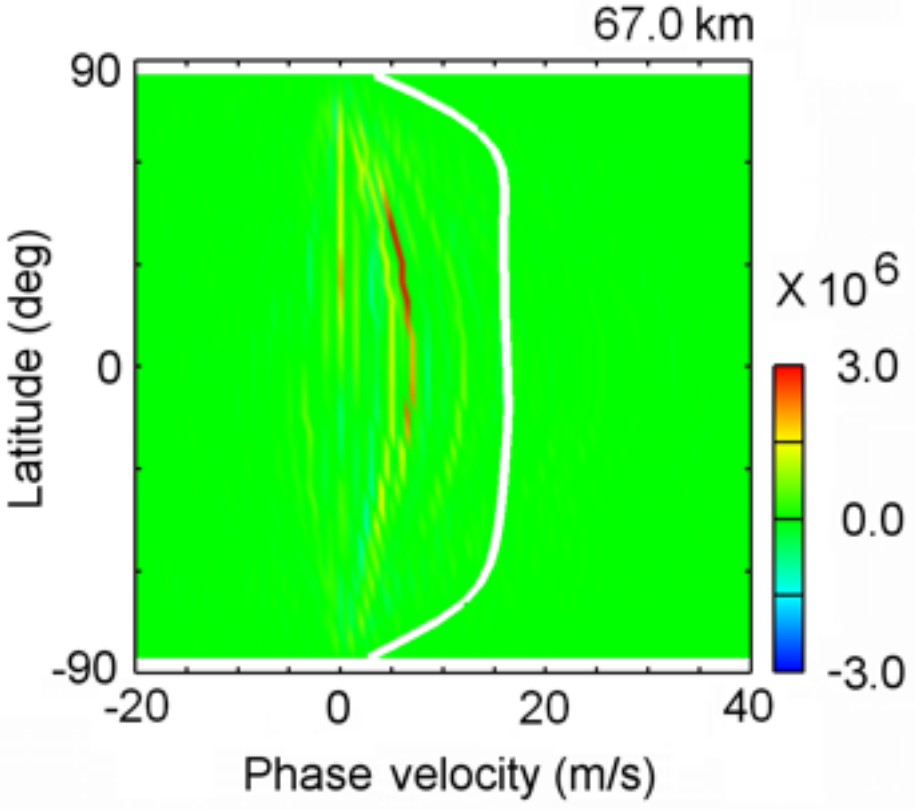




Phase velocity – latitude distribution of horizontal EP flux

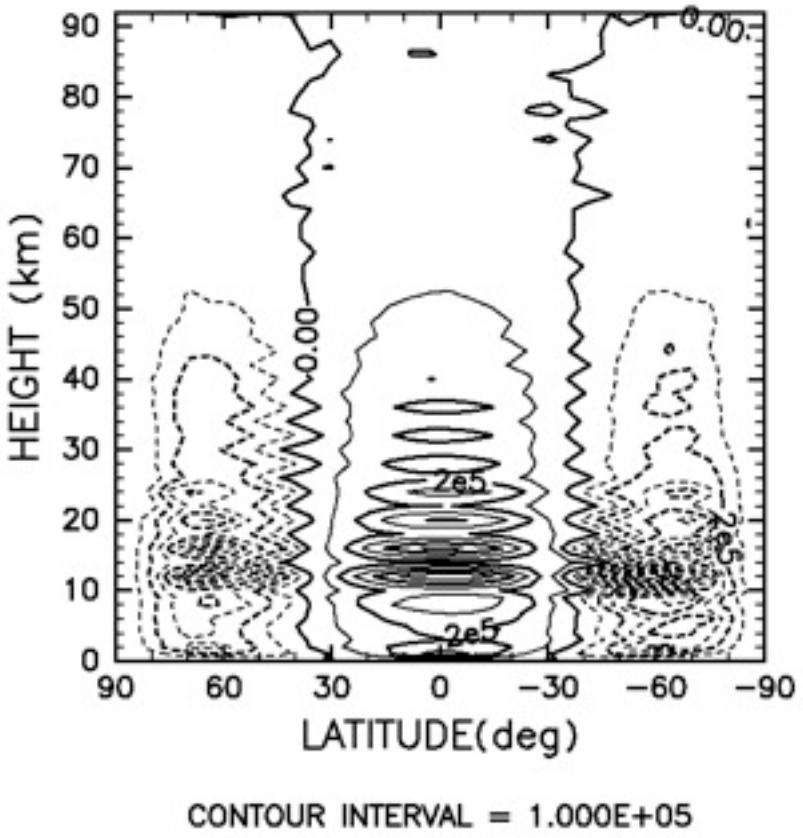
polar deceleration



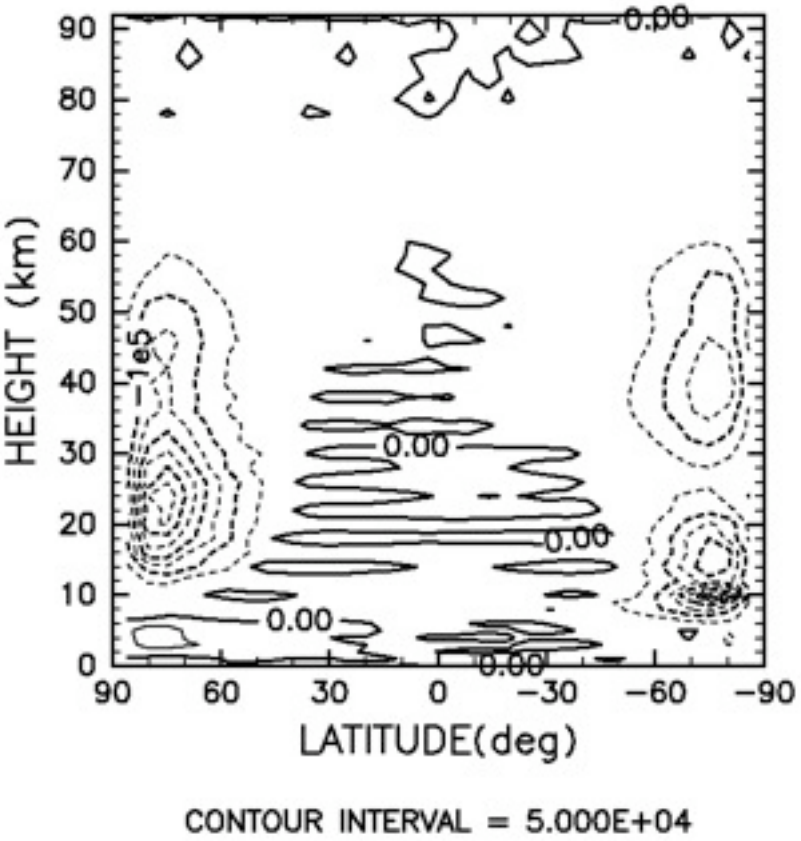


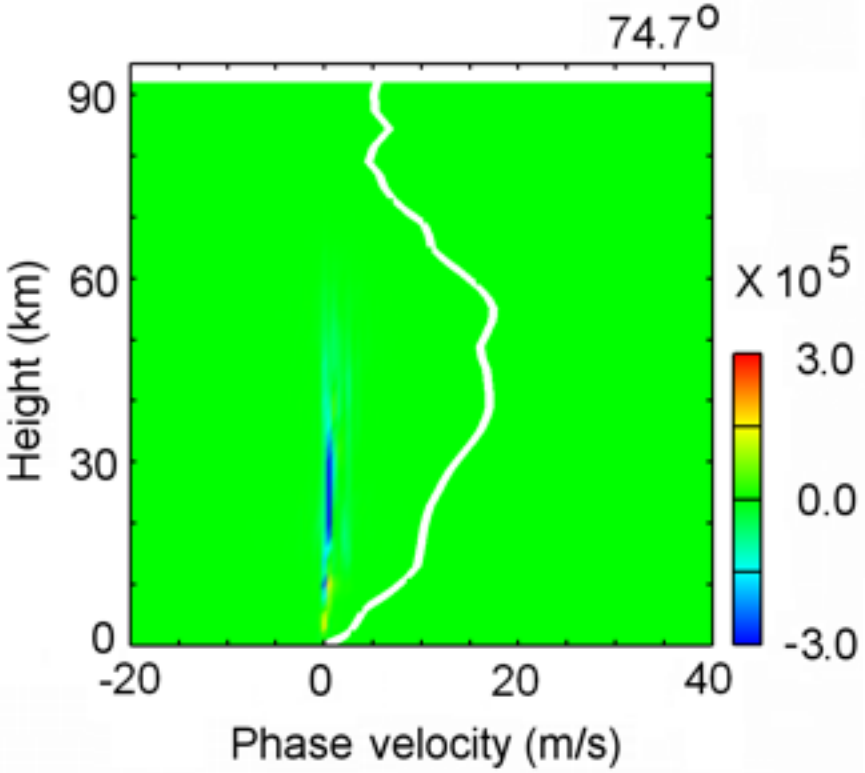
Eddy components

Vertical flux of ang. mom. due to mean vertical flow



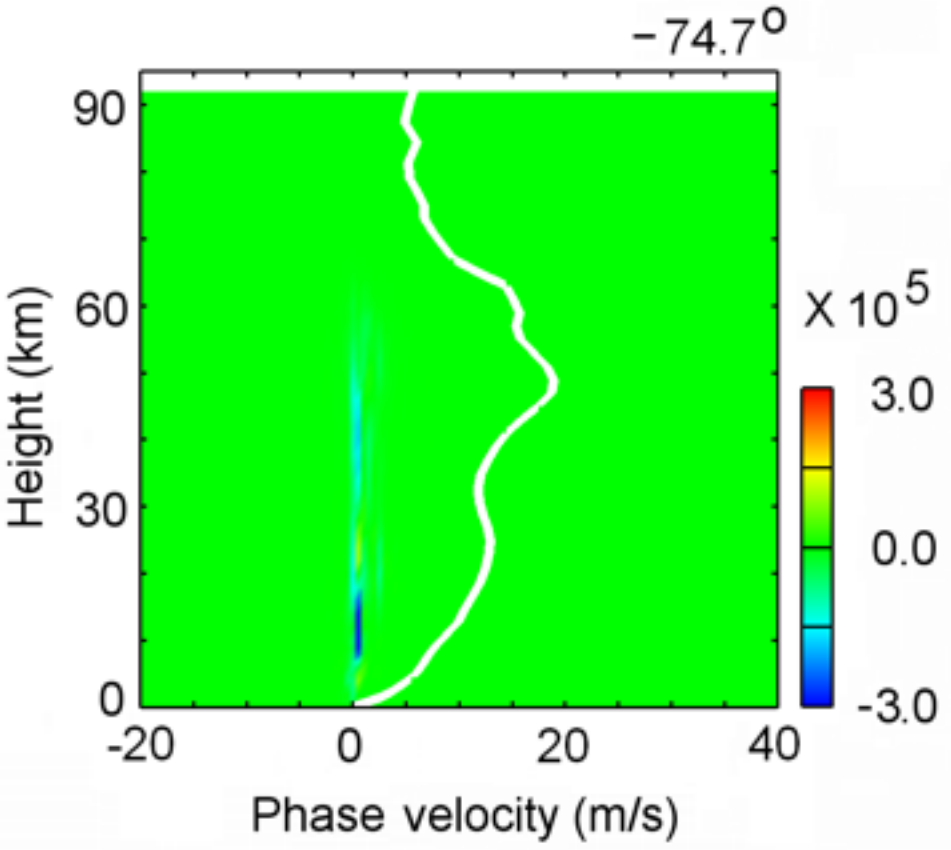
Vertical EP flux





Phase velocity – height distribution of vertical EP flux

slowly propagating waves

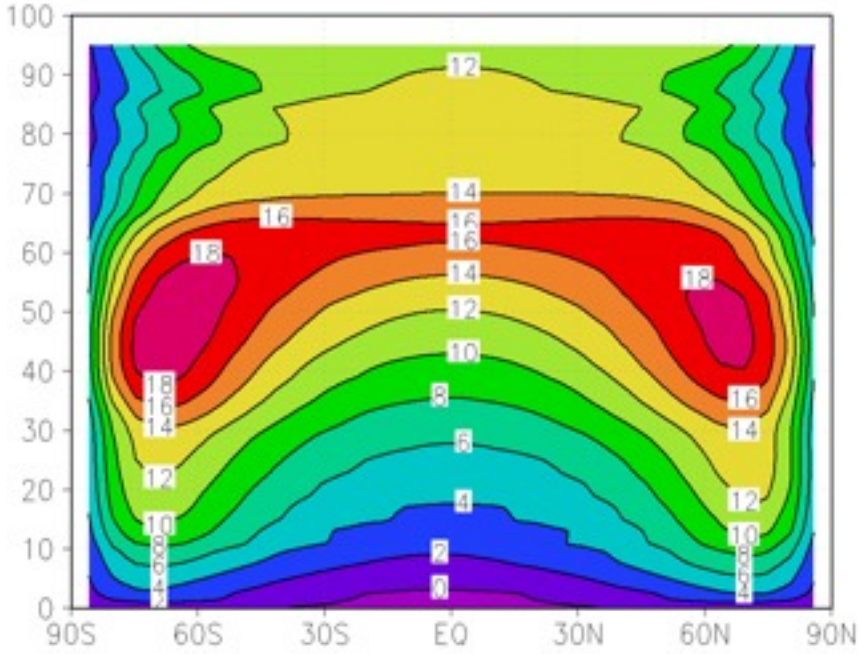


Sensitivity study (surface drag)

Expr. CNTL

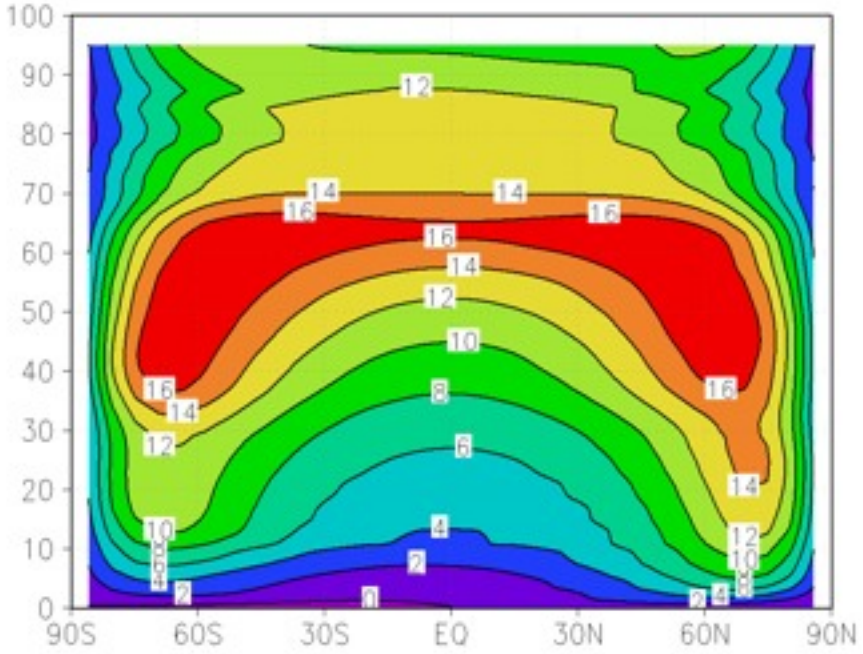
Bulk formula ($\rho C_D|u|u$)

$C_D = 4 \times 10^{-3}$



Rayleigh friction formula ($-u/\tau_D$)

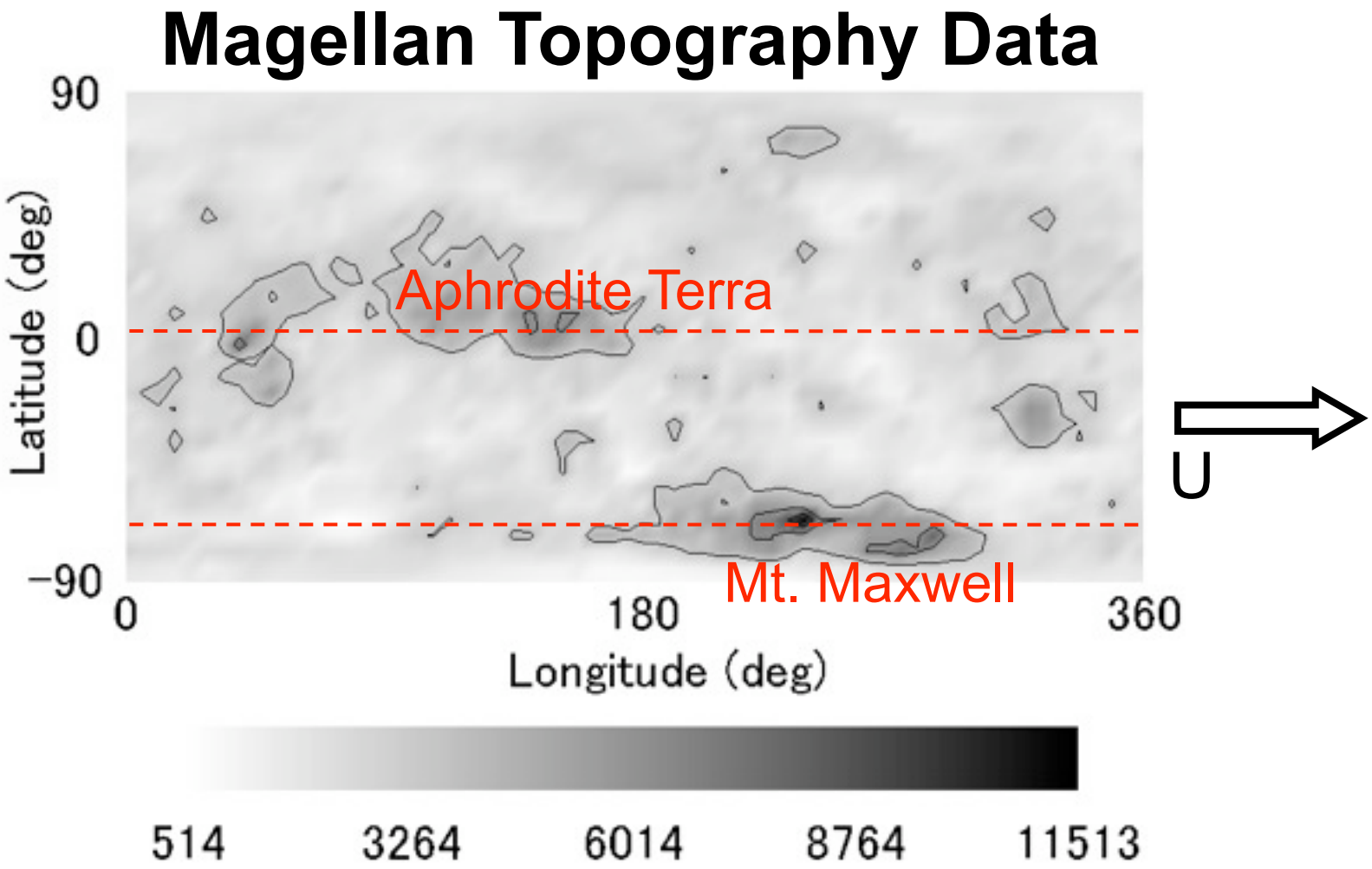
$\tau_D = 3$ Earth days



This result is similar as CNTL, although it is somewhat weak

long-term (30 Venus days) averages of zonal flows

Sensitivity study (topography)

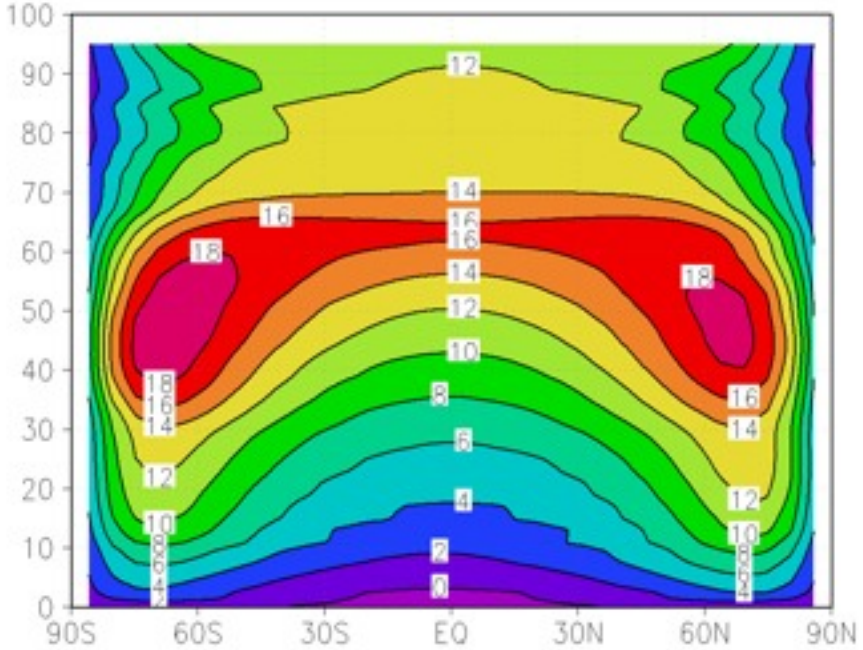


(Ford and Pettengill 1992)

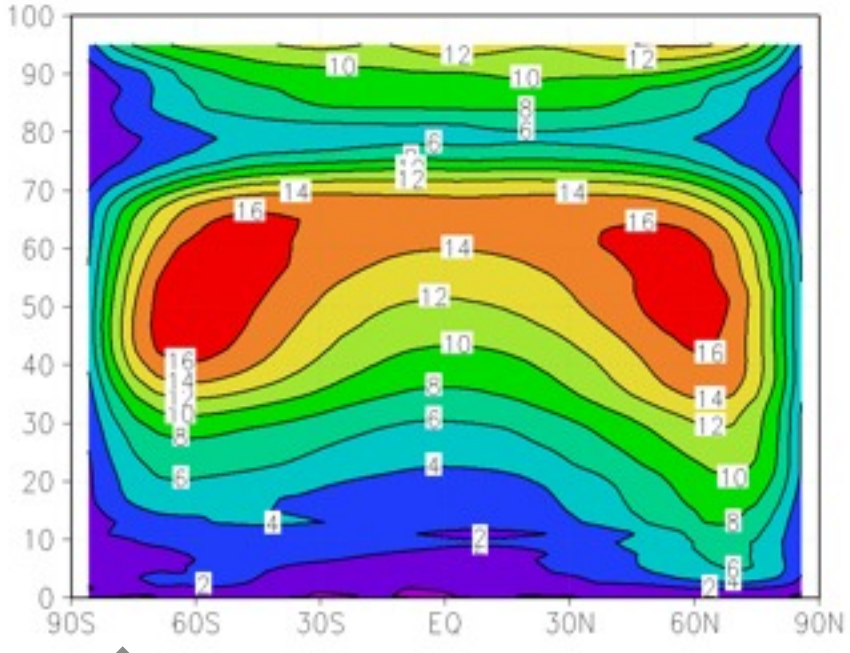
Sensitivity study (topography)

Expr. CNTL

Without topography



With topography



Mt. Maxwell

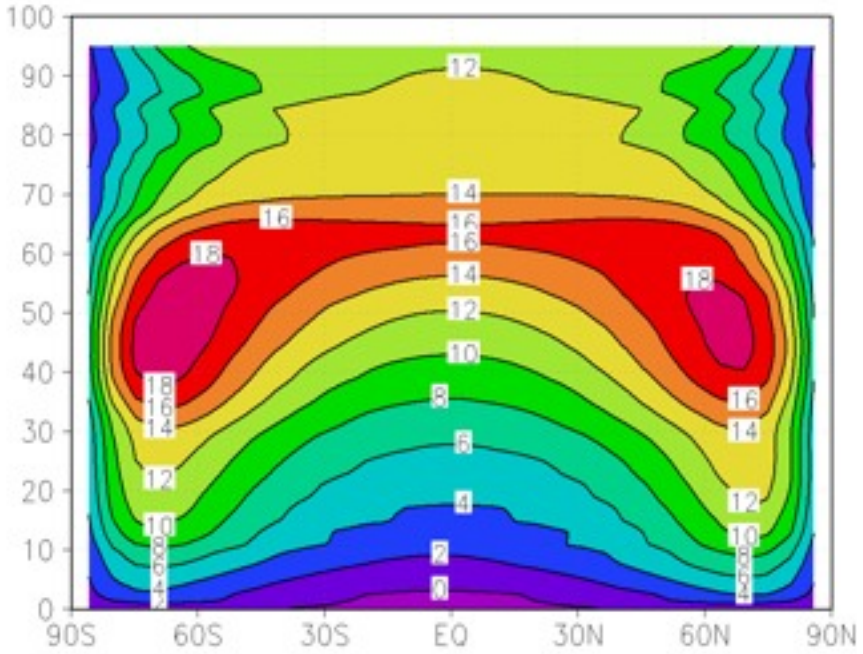
We can see the asymmetry between north and south hemispheres

long-term (30 Venus days) averages of zonal flows

Sensitivity study (hyper diffusion)

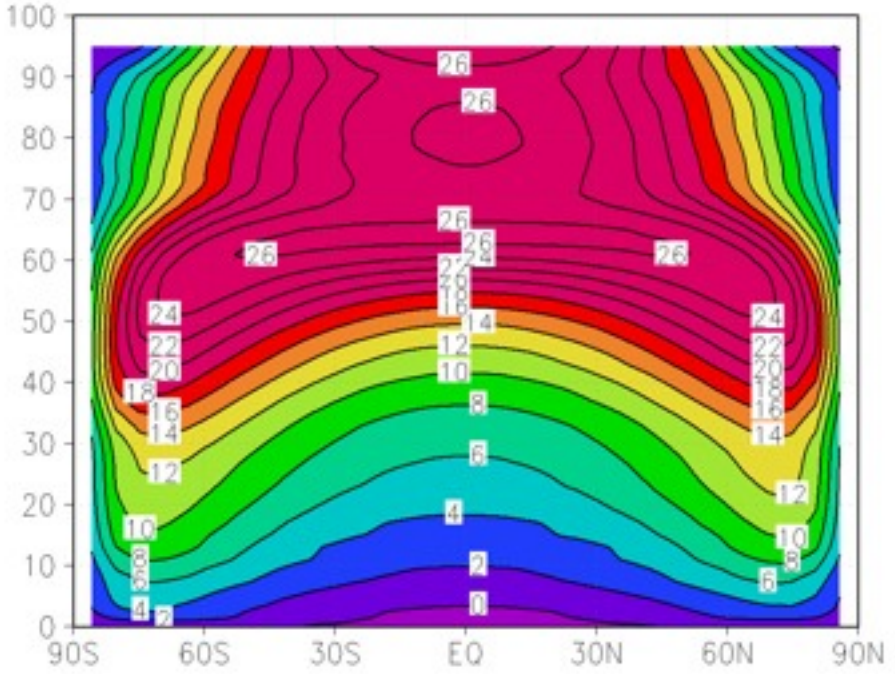
Expr. CNTL

Fourth order (4 days)



U is 1.4-times larger than CNTL

Sixth order (30 days)



However, for extremely-small diffusion, it may be difficult to suppress numerical instability in fully developed superrotation.

long-term (30 Venus days) averages of zonal flows

Summary (control run)

1. Superrotation of 16-18 m/s is formed in the cloud layer in the case of only a latitudinal temperature difference.

2. Gierasch mechanism is ineffective, since the zonal-flow acceleration is predominant in the polar regions.

Further tests

1. How do we set up spectral and grid-based GCMs under the same condition? In particular, model resolution, Hyper diffusion, vertical coordinate system…

2. Whether do we check the sensitivity for different model setup among GCMs? In particular, diffusion, surface process, …

Set up the same condition in a further intercomparison

Kh: Horizontal hyper diffusion

Sixth order (30 days for s_{max} ,Lee et al. 2007) or other appropriate value?

Kv: Vertical diffusion

Our value is Kv=0.15 m/s2.
I would like to set the same value as other groups.

Number of sigma layers

50 layers LDM or 52 layers (2 layers finer in PBL) CCSR.

Number of horizontal grids

32 X 64. we must set 2^n.

C_D: Surface drag coefficient

Vaule of C_D (4×10^{-3}) ?

Bulk formula or Rayleigh friction formula ?