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Atmospheric general circulation and waves simulated by a Venus AORI GCM with topographical and radiative forcings

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Our research goal is to elucidate atmospheric general circulation and waves using AORI GCM

○General circulation and long-period waves (stationary wave and thermal tide) in geographic and solar-locked coordinates of Venus AORI GCM (Yamamoto et al. 2019, 2021 Icarus)

○Short-period waves in Venus AORI GCM (focused in this presentation)

This work is conducted under the cooperative research activities for climate system research of the Atmosphere and Ocean Research Institute (AORI) at the University of Tokyo (Prof. M. Satoh).

Model(CCSR/NIES AGCM ver.5.6, Ikeda 2011)

Radiative transfer model

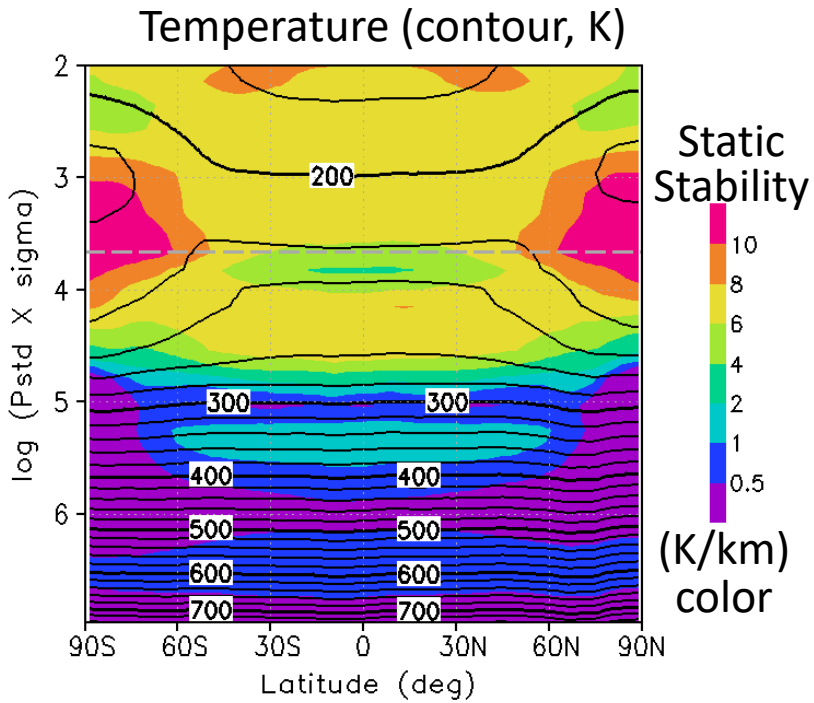
Discrete-Ordinate/Adding, 2-stream (Ikeda 2011)

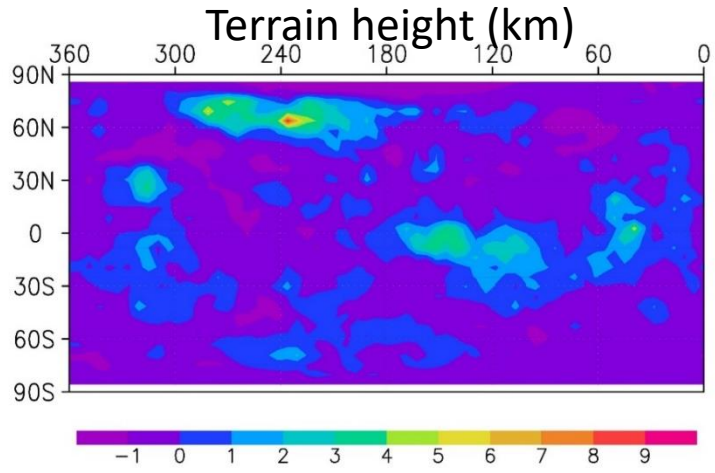
- **IR and Solar: 28 bands**
- **Gas absorption**
  - Correlated k-distribution method
  - CO_2: CDSD-1000, sub-Lorentz lineshape (Fukabori et al., 1986)
  - H_2O, SO_2, OCS, CO: HITRAN2004, Voigt lineshape
  - Collision-induced absorption by CO_2 (Moskalencko et al., 1979)
- **Cloud**
  - 75% H_2SO_4 (refractive index: Palmer and Williams, 1975)
  - log-normal 3 mode (Pollack et al., 1980)
  - Unknown UV absorber (Crisp, 1986)

⇒ Thermal structures similar to the observations

Topography

Magellan topography height data (Ford & Pettengill 1992)





(Yamamoto et al. 2019, 2021)

Model setup

Temperature $T(p)$

Initial: VIRA (Seiff et al. 1985)

Zonal wind $U(p)$

Nudging run <u>until equilibrium</u>

Vday 0 – 10: *U* is nudged to Uref
with a time constant of 3 Edays.

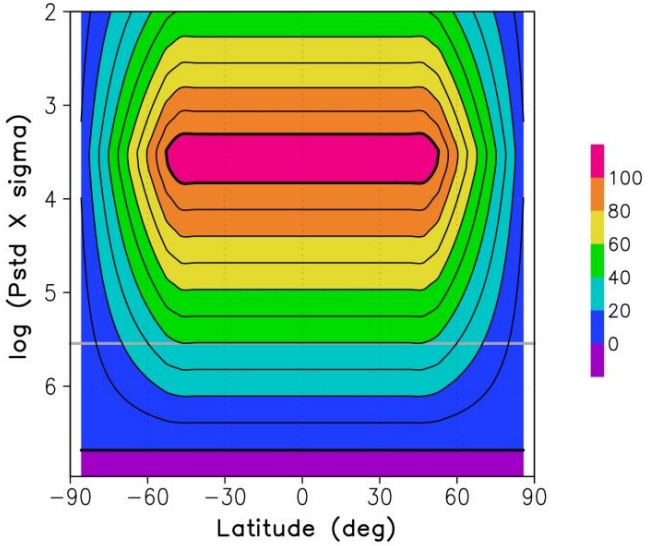
Vday10 – 90: Zonal-mean component
of U below 40 km is nudged to Uref
with a time const. of 3 Edays.

Nudging-free T63L52 run
using Vday 90 of Nudging run

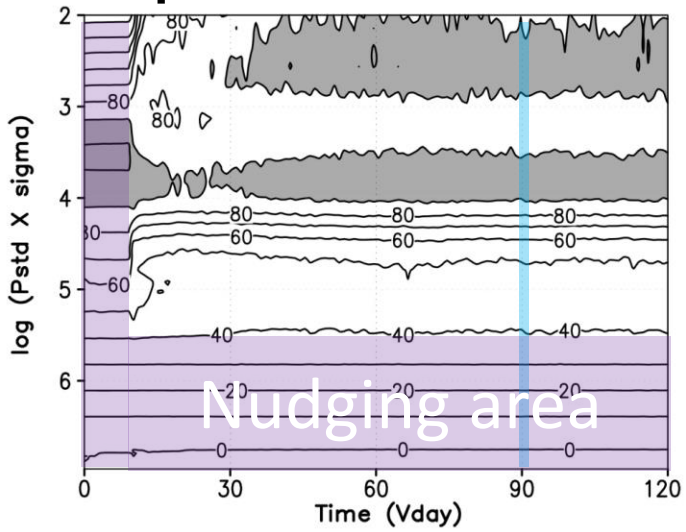
10th Vdays from the restart

⇒ *Data analysis (3024 h)*

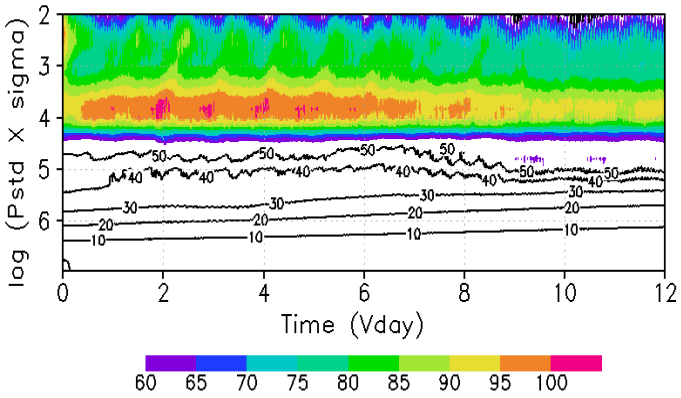
Reference zonal flow Uref

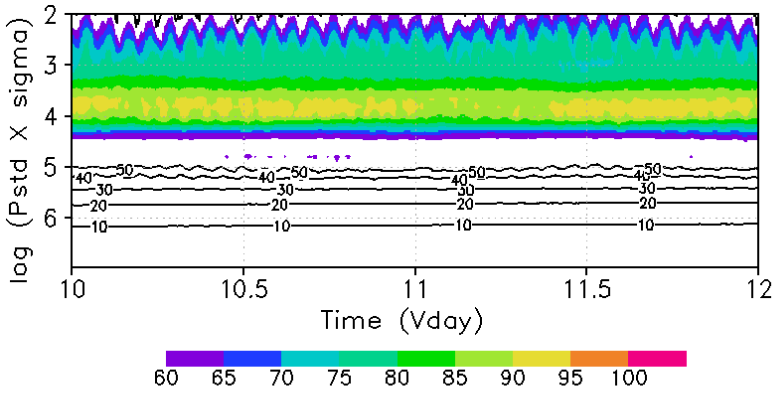


Nudging T21L52 run
Equatorial zonal wind



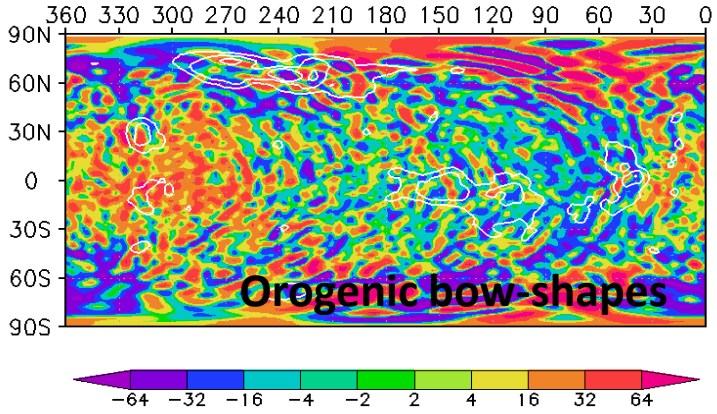
***Nudging-free T63L52 run,* Equatorial zonal wind**





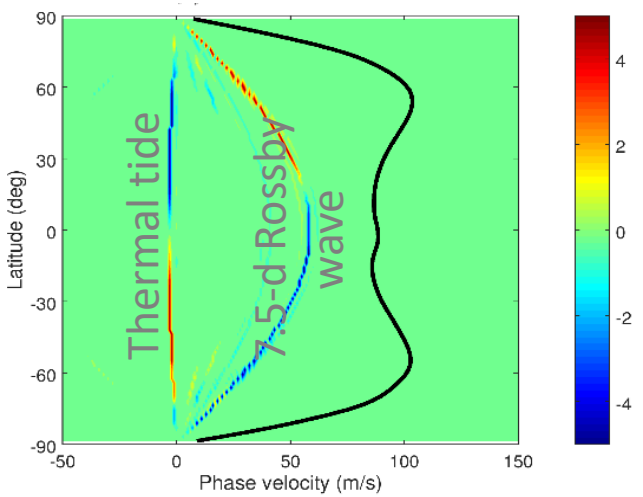
Characteristics of waves
~ cloud top ~

Vertical wind (mm/s) at the cloud top

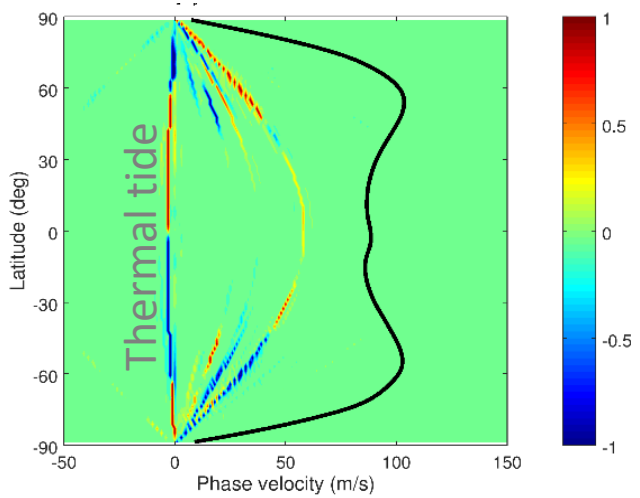


Fine-scale bow-shapes

Spectrum of u'v' at the cloud top



Spectrum of T'v' at the cloud top



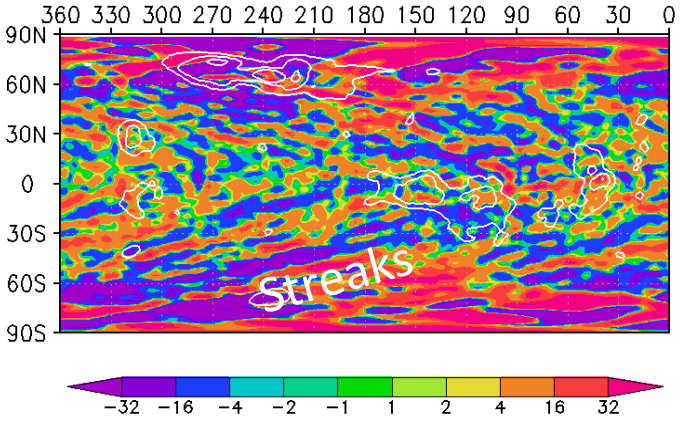
Fine-scale vertical flows are enhanced over equatorial high lands around the morning and evening terminators

Thermal tides transport momentum equatorward and heat poleward

7.5-day Rossby wave transports heat & momentum poleward

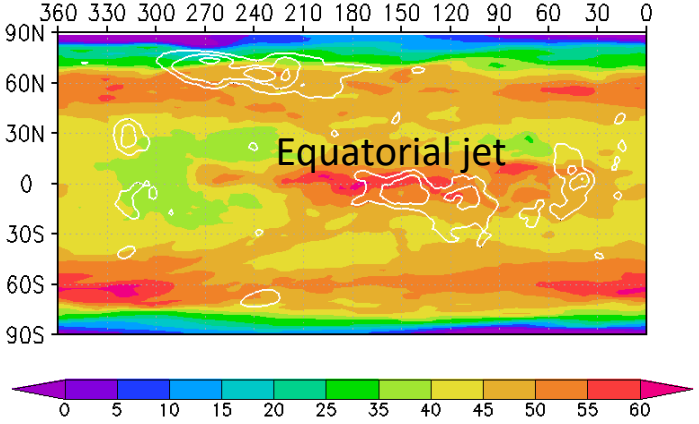
Characteristics of waves
~ cloud bottom ~

Vertical wind (mm/s) at the cloud bottom



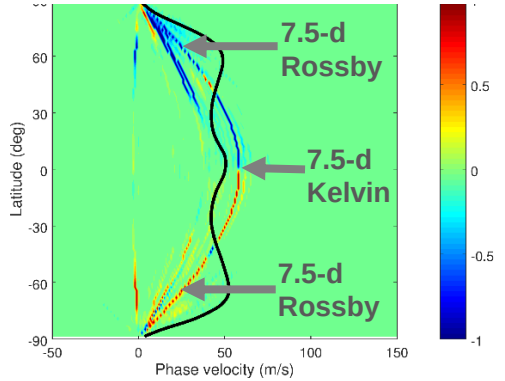
V-shaped streaks

Zonal wind (m/s) at the cloud bottom



Equatorial jet-like, Kelvin-like wave

Spectrum of u'v' at the cloud bottom



Zonal mean flow has an equatorial maximum (black line).

7.5-d Kelvin-like and Rossby-like waves with equatorward momentum fluxes are predominant.

The wave period of 7.5 Earth days is longer than the observed one (5.5 Earth days), because zonal mean wind speed is slower than the observed wind.

Eddy heat and momentum fluxes

$\overline{T'v'}$ (K m s^{-1}, shade)

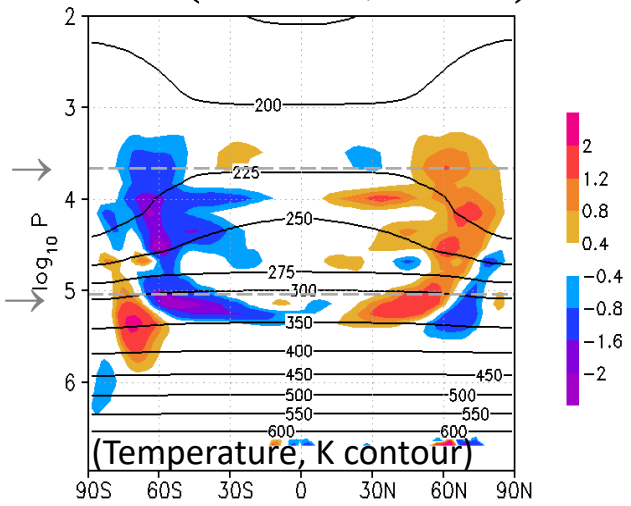
$\overline{u'v'}$ (m^2 s^{-2}, shade)

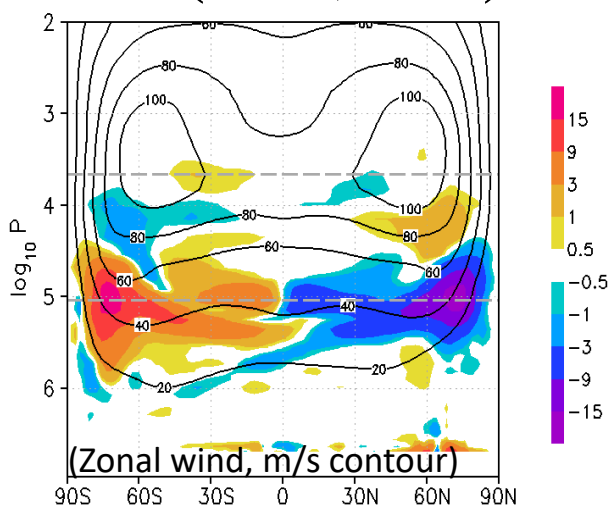
$\overline{u'w'}$ (m^2 s^{-2}, shade)

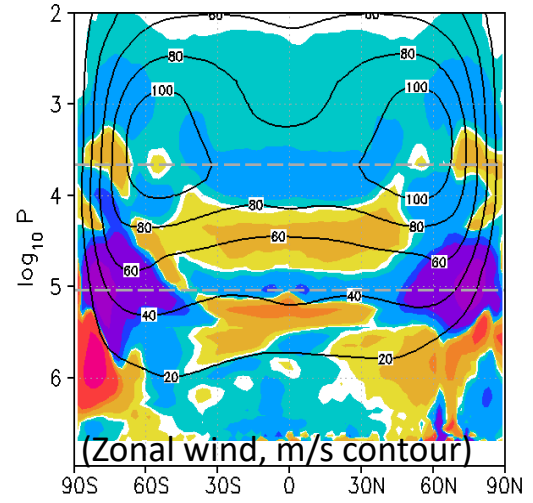
Total waves

Cloud top →

Cloud bottom →

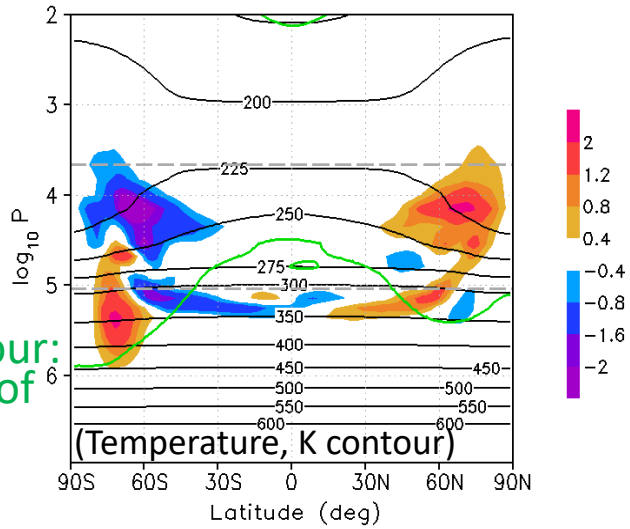


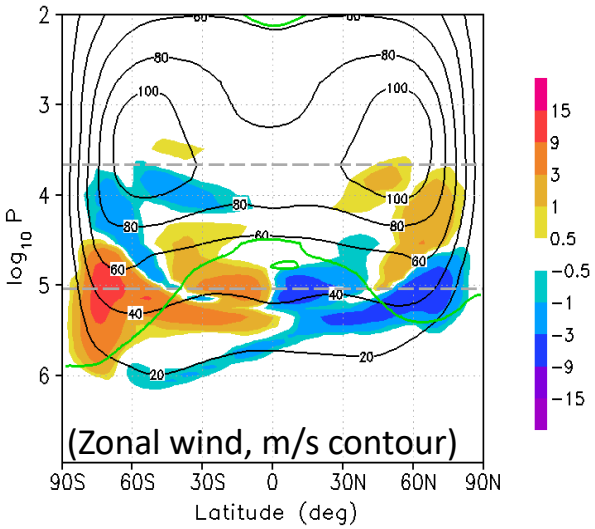


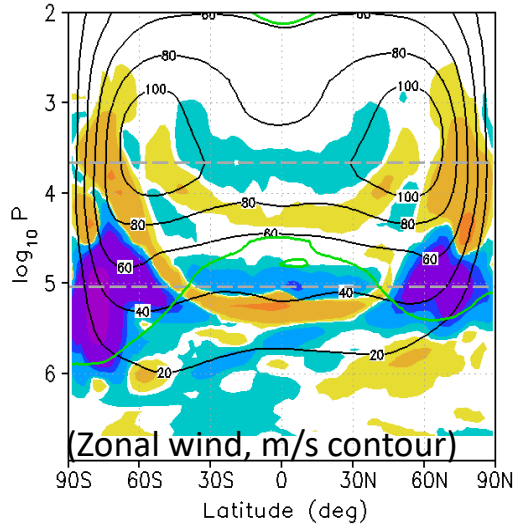


Zonal wave-number 1 7.5-day wave

green contour: critical line of 7.5-d wave



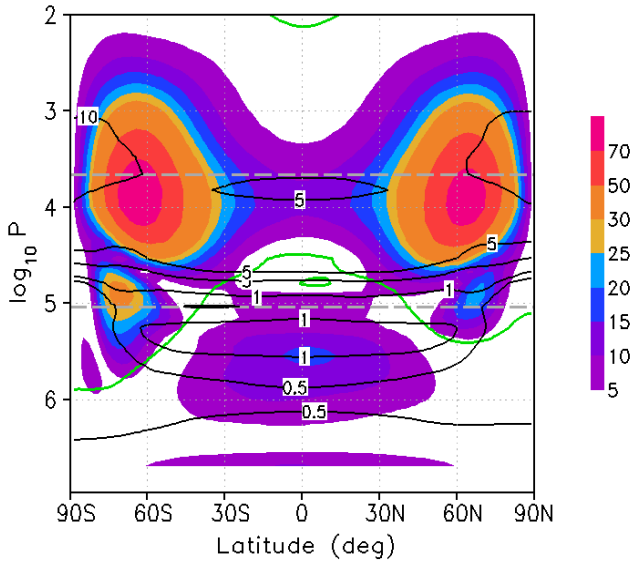




The 7.5-d wave is a predominant transporter of heat and momentum around the cloud bottom

7.5-day wave structures

Amplitude of 7.5-d wave (shade) and static stability (contour)

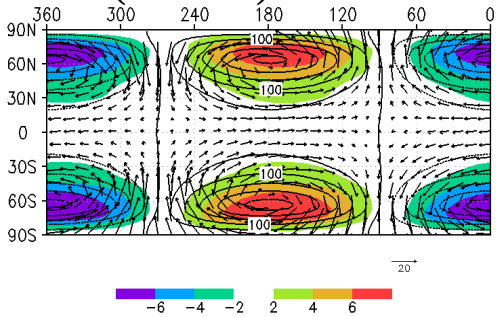


(green contour, critical line of 7.5-d wave)

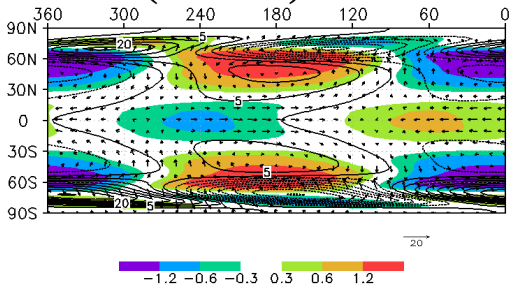
- Rossby wave in upper clouds
- Tropopause-trapped Rossby wave in strong wind shear region
- Equatorial Kelvin wave in a weakly stable region below the cloud bottom

Geopotenital height (m, contour) & temperature (K, shade)

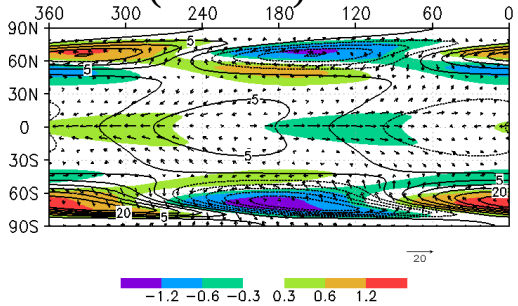
9.74×10^3 Pa(~65 km)

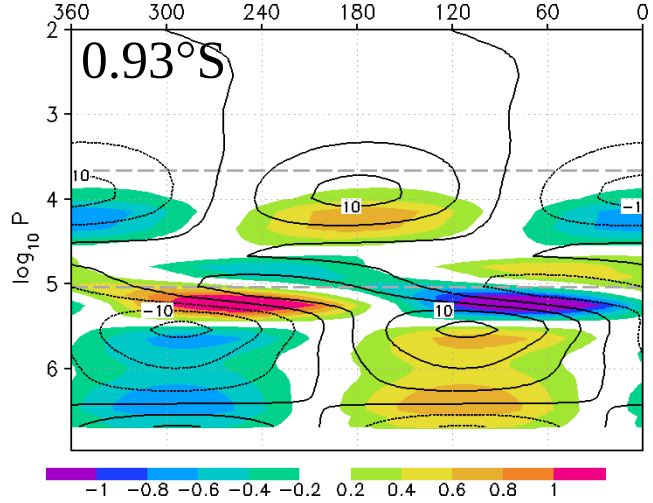


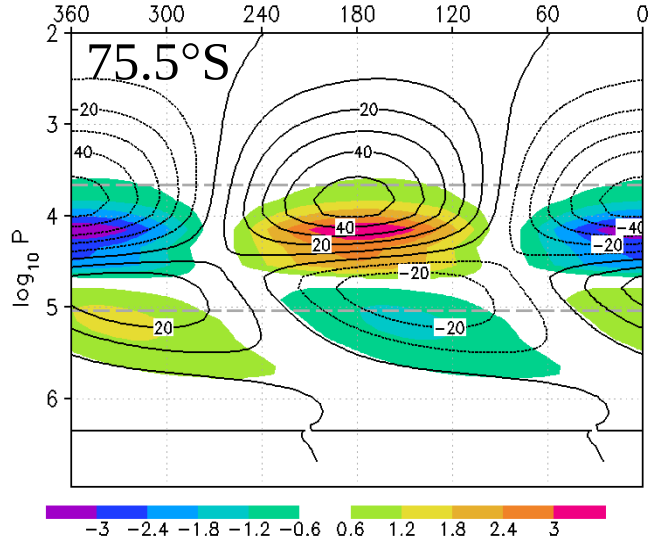
6.19×10^4 Pa (~54 km)



1.07×10^5 Pa (~50 km)

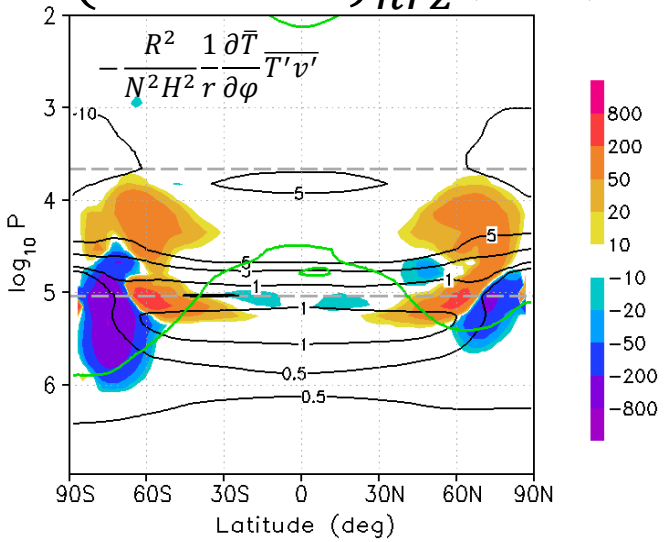




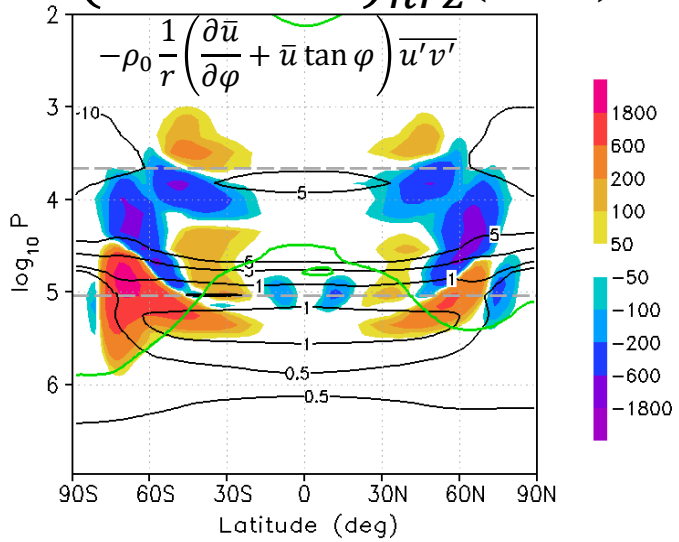


7.5-day wave energy conversion

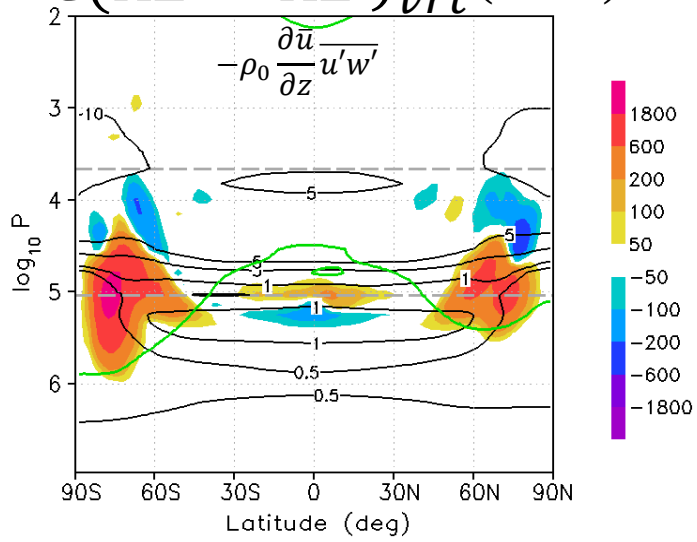
$C(\overline{PE} \rightarrow PE')_{hrz}$ (shade)



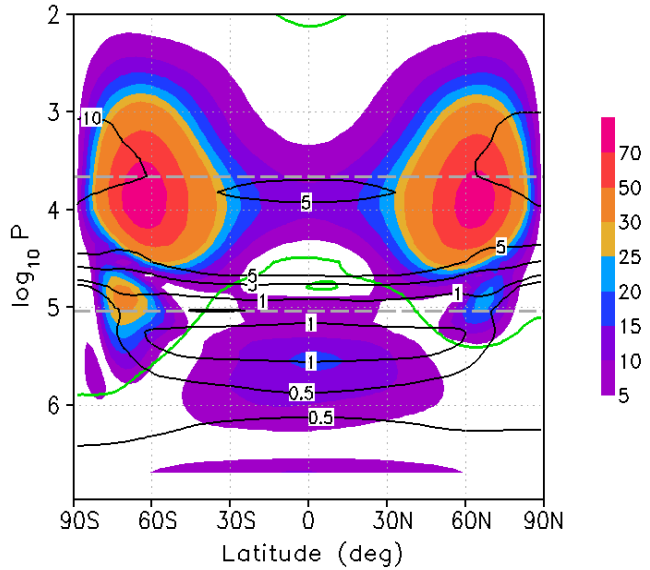
$C(\overline{KE} \rightarrow KE')_{hrz}$ (shade)



$C(\overline{KE} \rightarrow KE')_{vrt}$ (shade)



(Black contour, static stability K/km) (Green contour, critical line of 7.5-d wave)



- Rossby wave in upper clouds

↔ Available potential energy conversion *via poleward heat flux*

- Tropopause-enhased Rossby wave in strong wind shear region
- Equatorial Kelvin wave in a weakly stable region below the cloud

↔ These two waves couple horizontally

Kinetic & available potential energy conversions across the critical line and Kinetic energy conversion via horizontal and vertical momentum fluxes

Summary 1

＜Cloud Top＞ (Yamamoto et al. 2019, 2021 Icarus)

- Thermal tides are equatorward momentum transporters producing locally the superrotation around the cloud heating maximum, together with the vertical momentum flux (Yamamoto & Takahashi 2004, 2006; Horinouchi et al. 2020)
- **7.5-d Rossby wave** is a poleward heat & momentum transporter

＜Cloud Bottom＞

- Large-scale streaks of the vertical flow, different from the cloud-top bow shapes
- Equatorial jet-like structure (superposition of Kelvin-like wave & zonal-mean equatorial jet)
- ***7.5-d equatorial Kelvin-like* wave** & ***7.5-d high-latitude Rossby-like wave*** are equatorward momentum transporters

Summary 2

3 waves of *7.5 days* are predominant in a whole atmosphere

- **Rossby wave** at the cloud top and in the upper clouds

↔ *Available potential energy conversion via poleward heat flux*

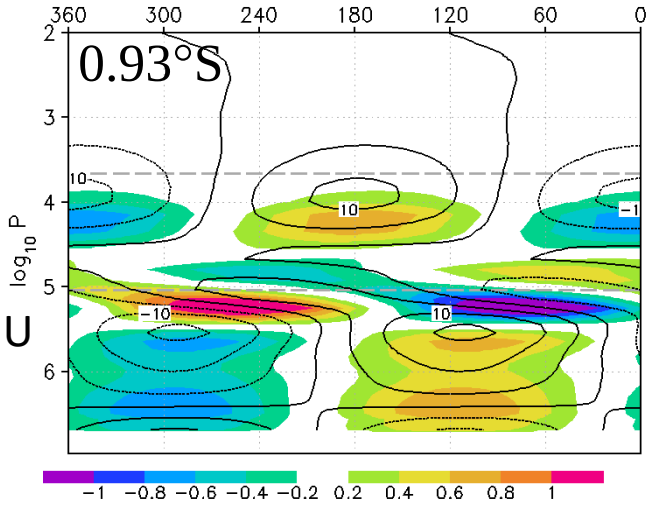
- ***Equatorial Kelvin wave*** around the cloud bottom
- ***High-latitude Rossby wave*** enhanced at the tropopause

} Coupled pair similar to Iga & Matsuda 2005, Yamamoto & Takahashi 2004, 2006

↔ *Kinetic & available potential energy conversions across the critical line*

Kinetic energy conversions via horizontal and vertical momentum fluxes

Eddy geopotential height (m, contour)



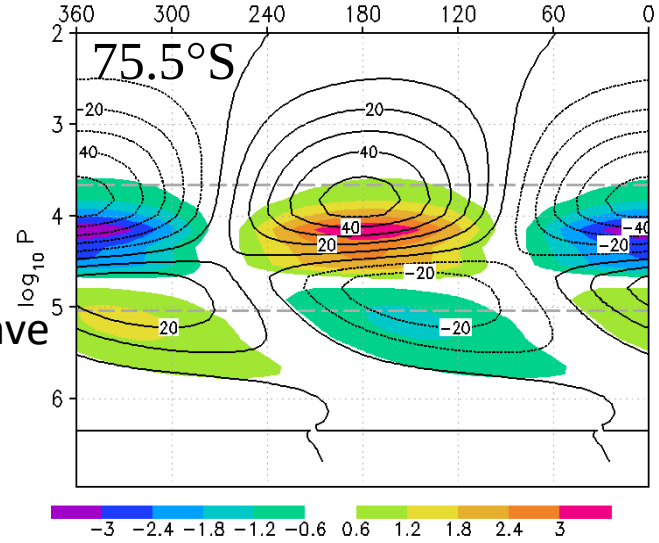
Eddy temperature (K, shade)

Horiz. shear of U

Kelvin wave ⟷ Rossby wave

Coupling via horizontal momentum & heat fluxes across the critical line

Eddy geopotential height (m, contour)



Eddy temperature (K, shade)

Horiz. T grad

Horiz. & vert. shears of U