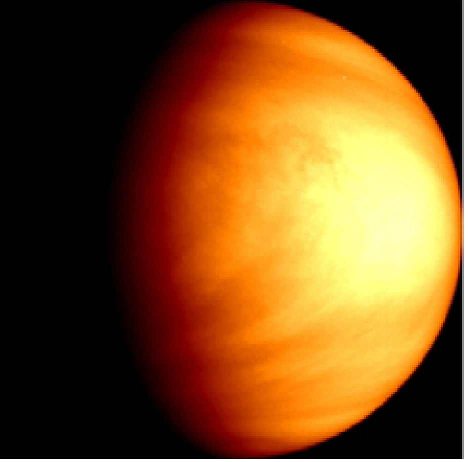
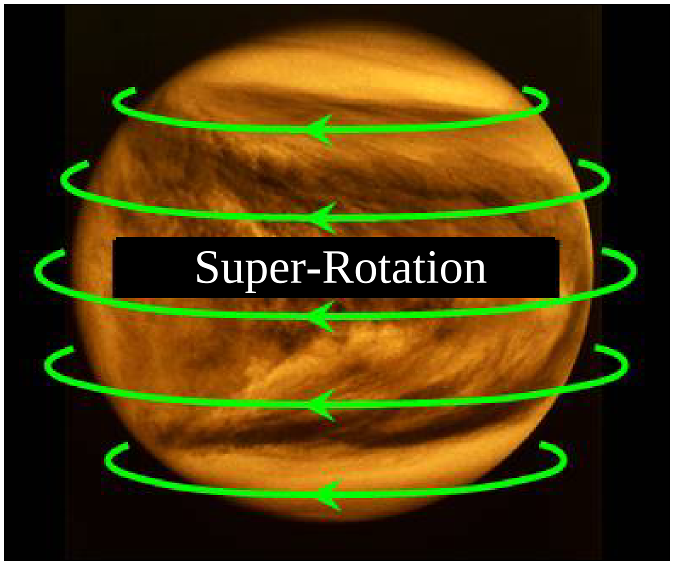


Horizontal structures of planetary-scale waves at the cloud top deduced from Venus cloud images

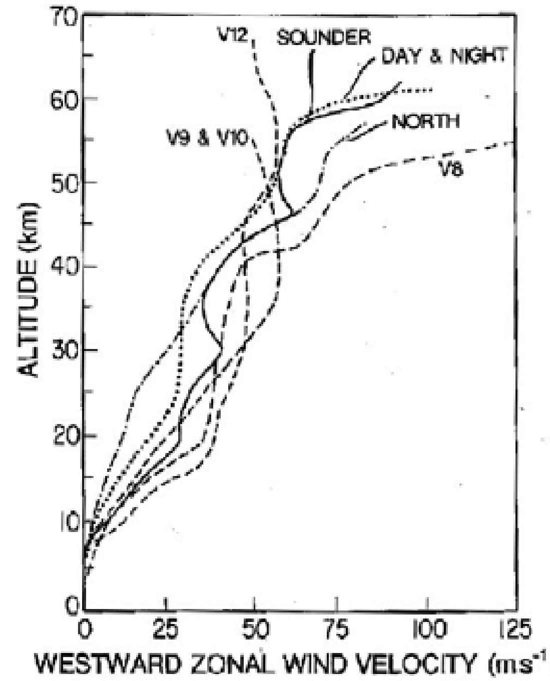
T.Kouyama[1] M.Nakamura[2], T.Satoh[2],
T.Imamura[2], Y.Futaana[3]

[1]:University of Tokyo, [2]:ISAS/JAXA,[3]:IRF

Super-Rotation on Venus



http://www.stp.isas.jaxa.jp/venus/



[Schubert, 1983]

At the top of the Venus cloud, the atmosphere moves rapidly with a period of about 4 days (100 m/s at 70 km height), called the *super-rotation*. It is not completely clear why the cloud moves much faster than the surface rotation (the rotational period of 243 days 1.8 m/s), although several mechanisms for the super-rotation have been proposed.

Atmospheric Waves on Venus

Thermal Tides

Equatorial Kelvin wave

Transport momentum upward

Accumulate momentum
at upper layers

Super-Rotation

Previous Study

Simulations

Thermal tides
can maintain the super-rotation.
[Takagi and Matsuda, 2006]

Equatorial Kelvin wave
can maintain the super-rotation,
and excite Rossby wave in mid-latitude region.
[Yamamoto and Takahashi, 1997]

Observations

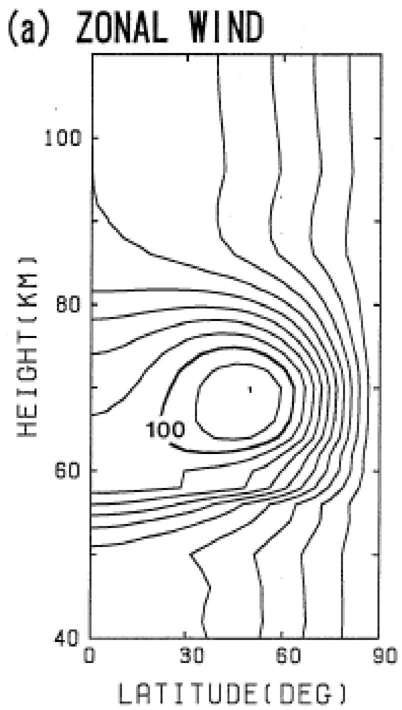
Structures though to be thermal tides are deduced from wind speed fields.

- Pioneer Venus observations [Rossow et al 1990]
- Galileo observation [Our results]
- Venus Express observations [Moissl et al., 2009]

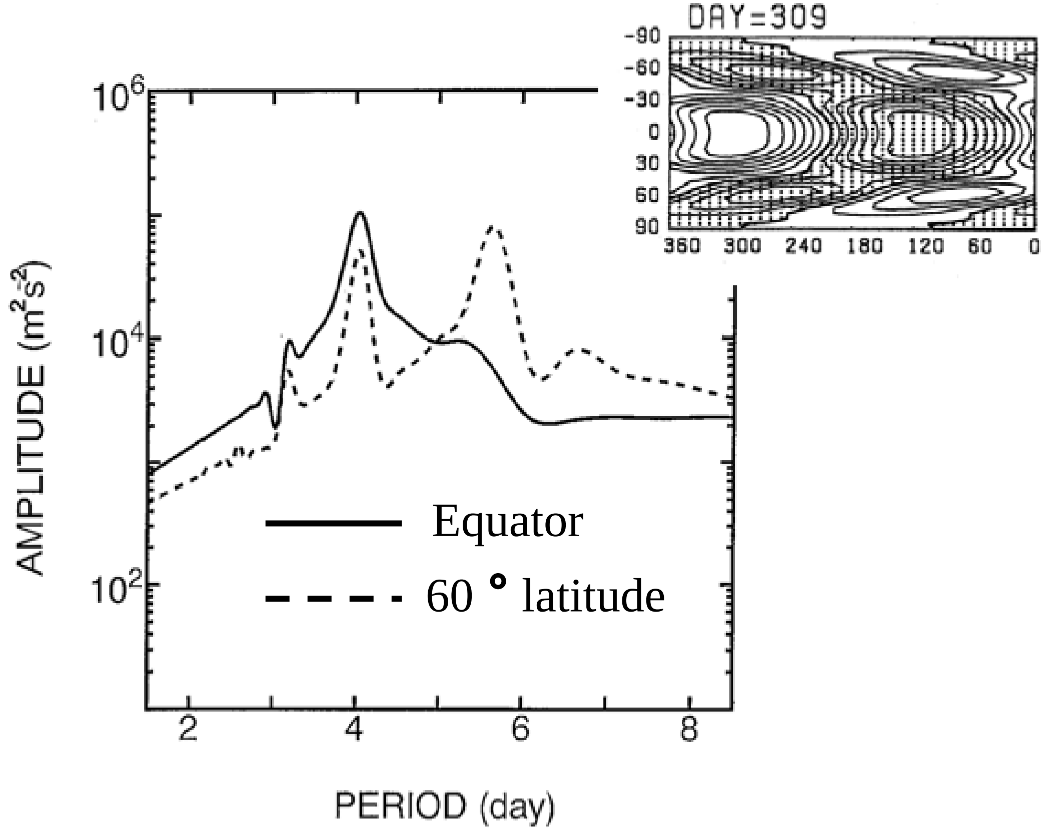
Equatorial Kelvin wave & Rossby wave

Simulations

Induced 4-day wave forcing in the equatorial region at 40 km height.
[Yamamoto and Takahashi, 1997]



Meridional distributions of the longitudinally averaged wind (contour interval of 10 m/s)



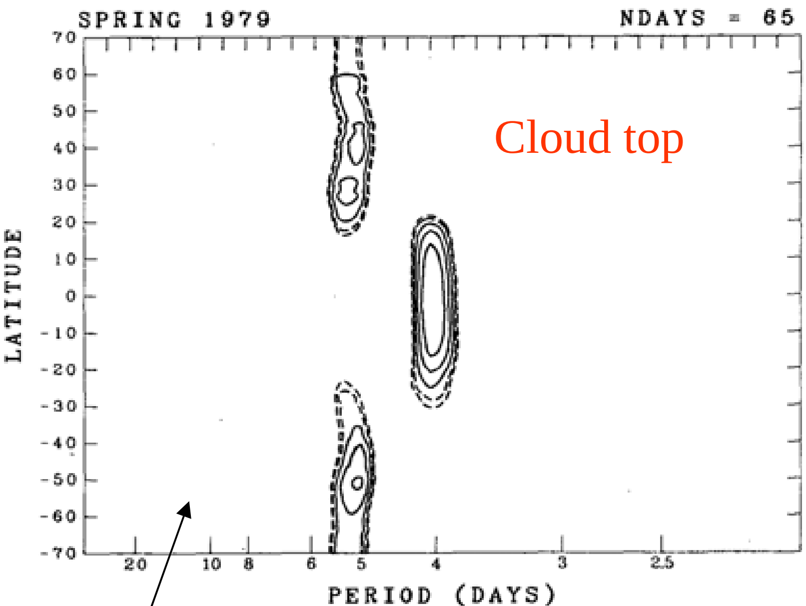
Diagrams of the Fourier coefficients of the geopotential perturbations vs period at the 62-km altitude.

Equatorial Kelvin wave & Rossby wave

Observations

There are some evidences of existence of
the equatorial Kelvin wave and the Rossby wave.

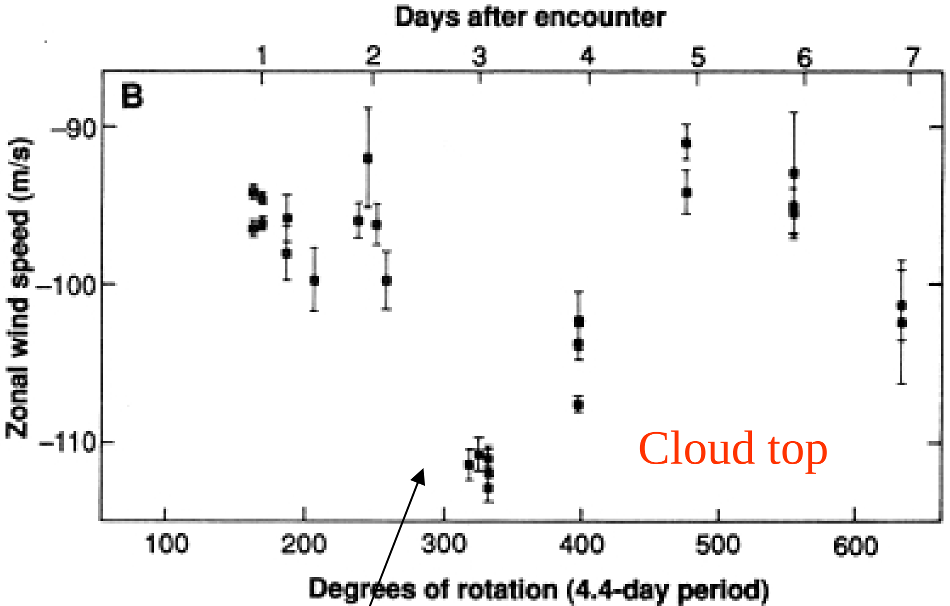
Brightness fluctuations (UV images)
- Pioneer Venus / OCPP : 1979 Spring



[Del Genio et al., 1989]

Equator : 4-day perturbation
Mid-latitude : 5.3-day perturbation

Time variation of Zonal wind speeds
- Galileo / SSI : 1990 Feb



[Belton et al., 1991]

About 4-day variation ?

Purpose

In this study, we focused

- Equatorial Kelvin Wave
- Rossby Waves.

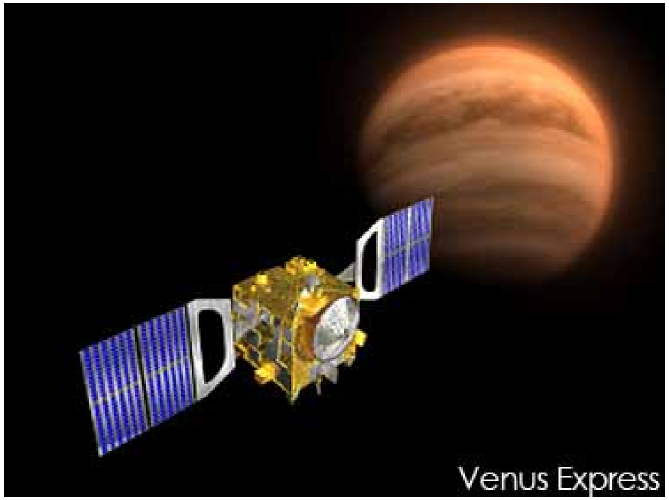
These waves are thought to be important to maintain the super-rotation on Venus as well as thermal tides.

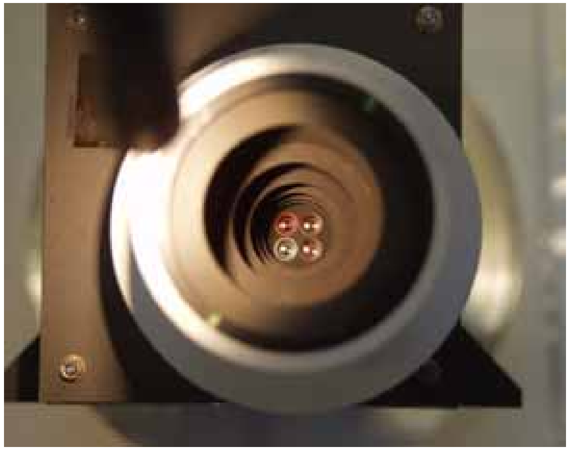
Purpose :

To verify structures of these atmospheric waves using observations.

<Venus Cloud images>

Data used in this study





http://www.mps.mpg.de/projects/venus-express/vmc/

Venus Express / Venus Monitoring Camera (VMC)

- 2007 Jan 25 – Feb 13 (#279 – #298)
- Wave Length : 315 nm
- Cloud Height : Cloud Top (~ 70 km)

[Moissl et al 2008]

All data used in this study are from http://www.planetary.org/data/vex/

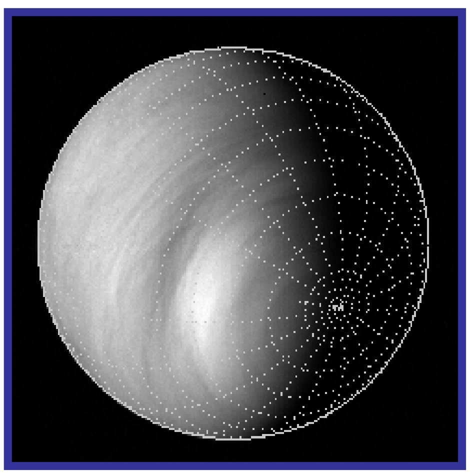
<u>Method</u>

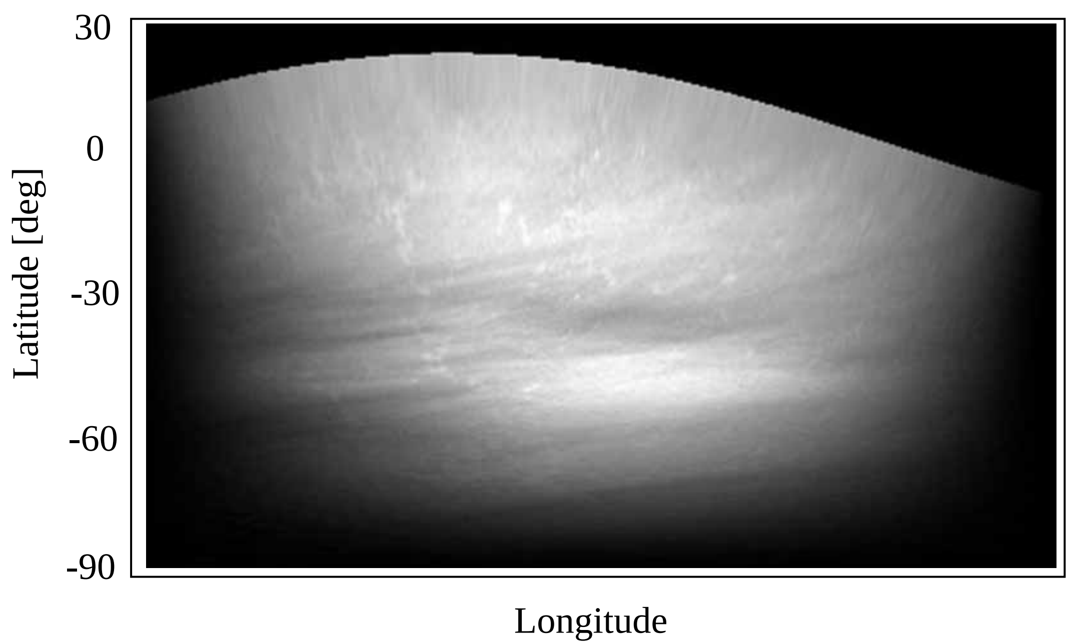
Image Analysis

Cloud Images → Wind speed

1.Projection

Venus Images → longitude-latitude coordinate





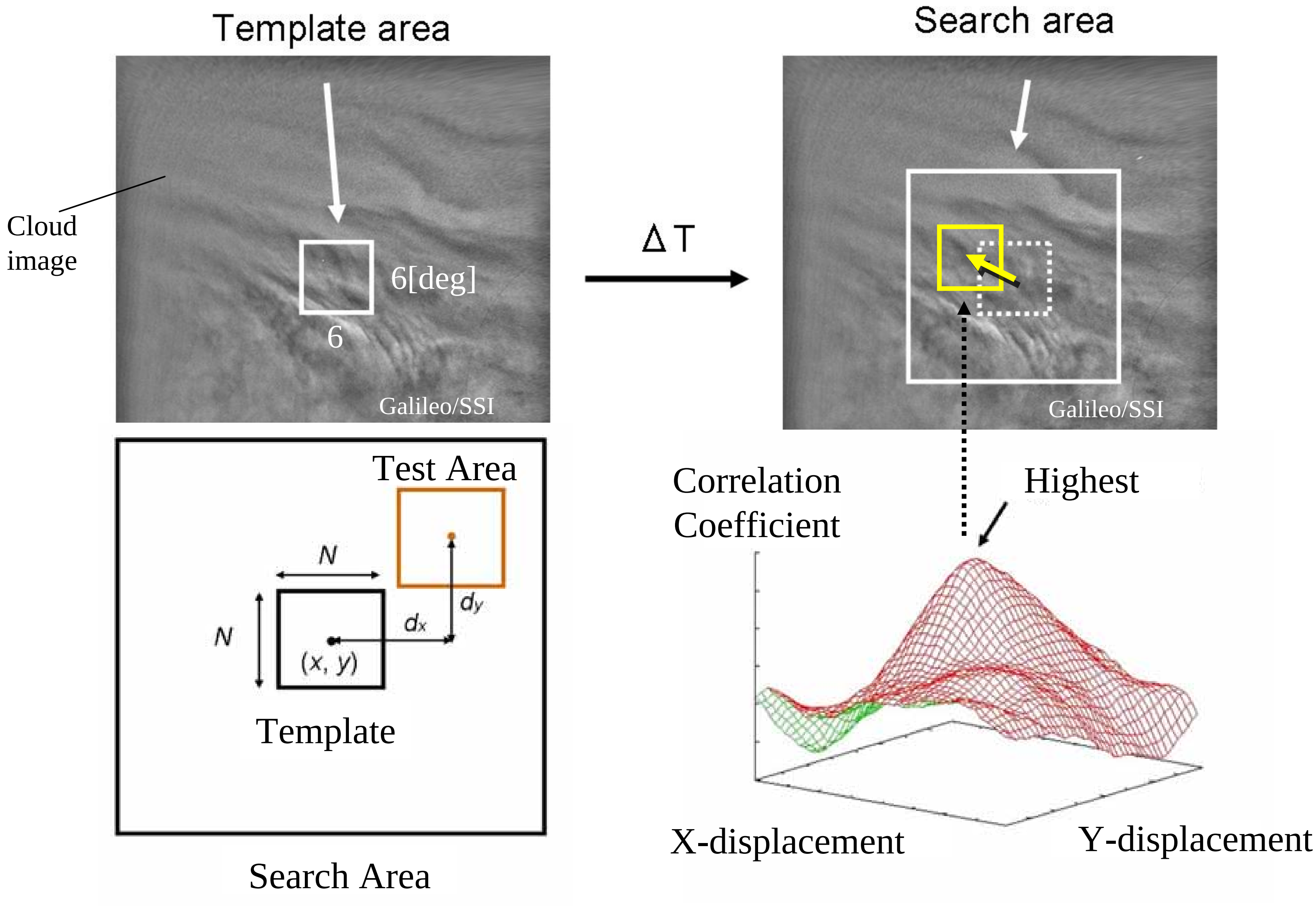
Orbit #30 UV

2.Cloud Tracking

Cloud motion → Wind speed

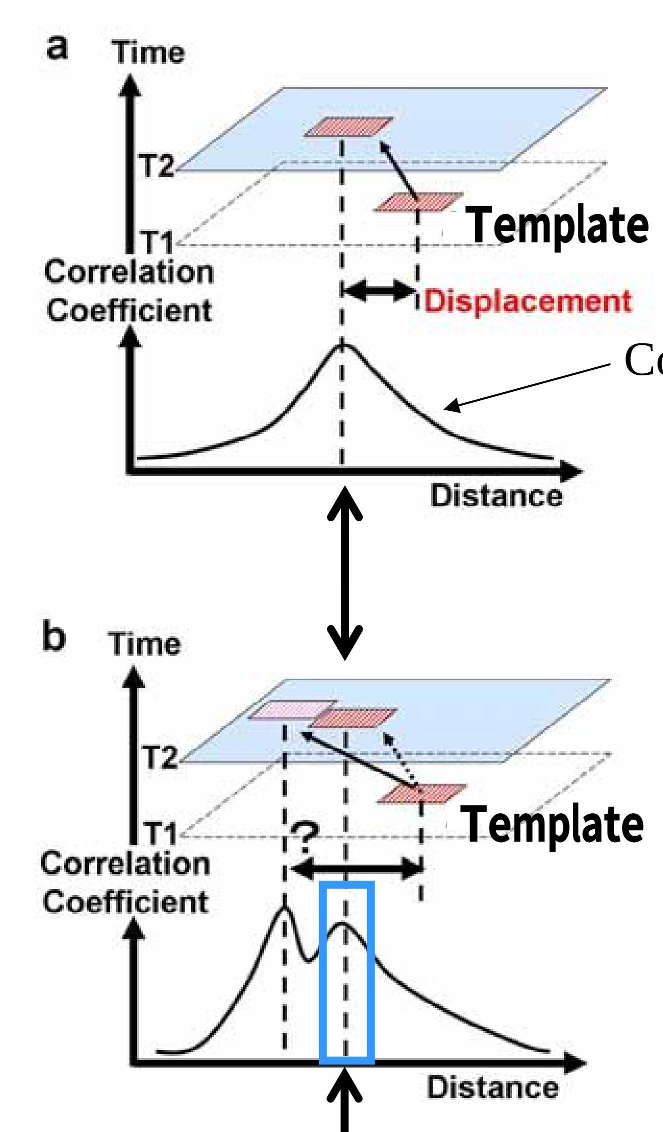
Method

Cloud Tracking Technique



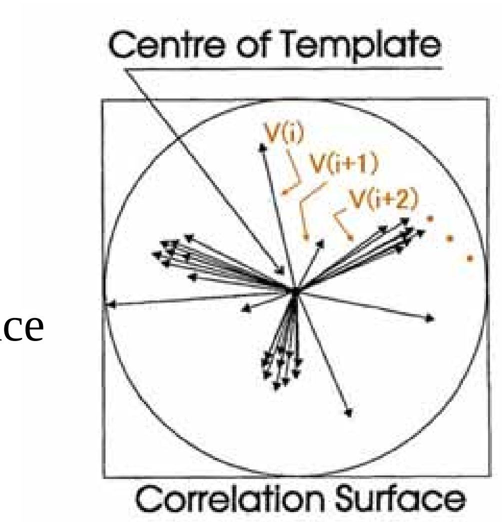
Correction of incorrect Vectors

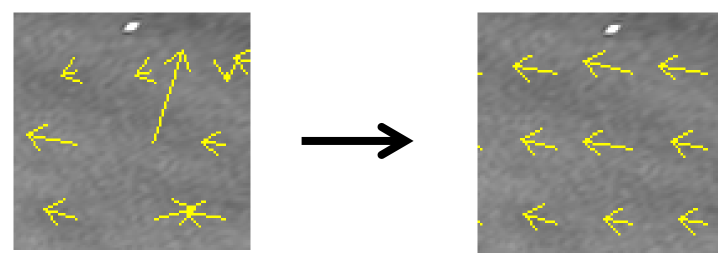
[Qing, 1995, Evans, A. N., 2000]



Correlation surface

More plausible direction

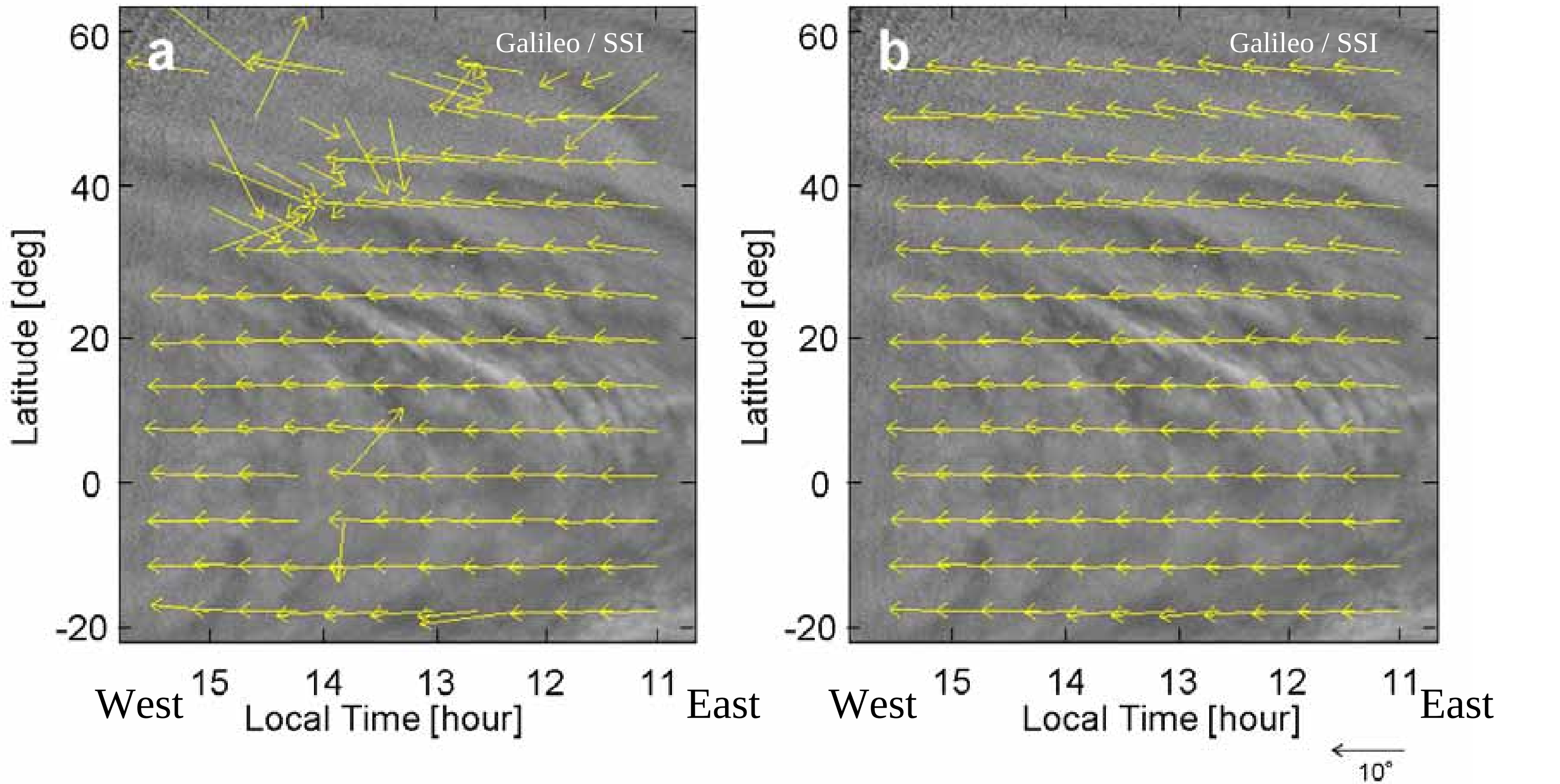




Correction of incorrect Vectors

Using Vectors with Highest correlations

Using corrected Vectors



Cloud Tracking Technique

Error evaluation

Error sources :

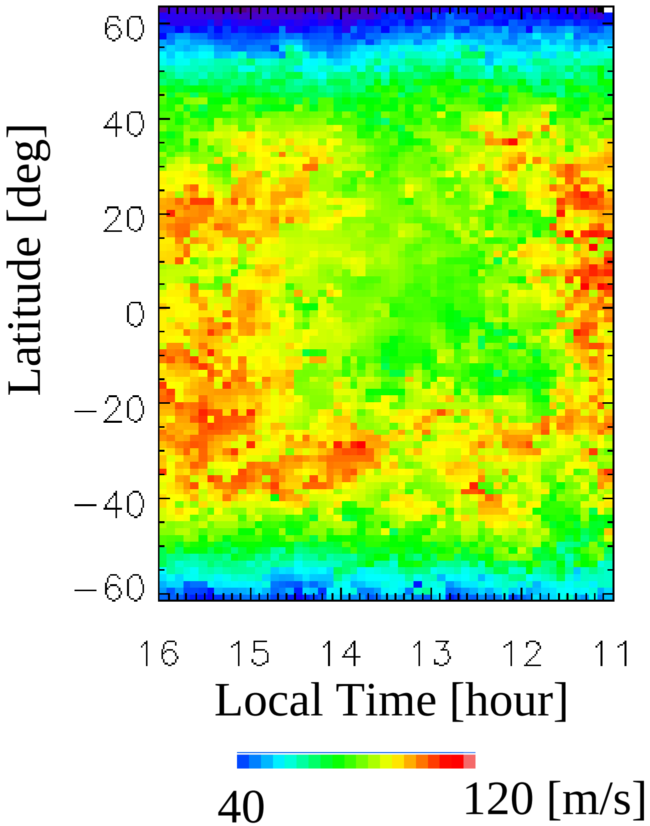
1. Pointing and mapping inaccuracies
2. Pixelation and noise
3. Morphology and morphological evolution of clouds
4. Systematic and random error from measurement method

[Moissl et al.,2008]

Currently under discussion…

Standard deviation 10 m/s

Example:
Zonal wind speed
(Template size = 3 x 3 deg)

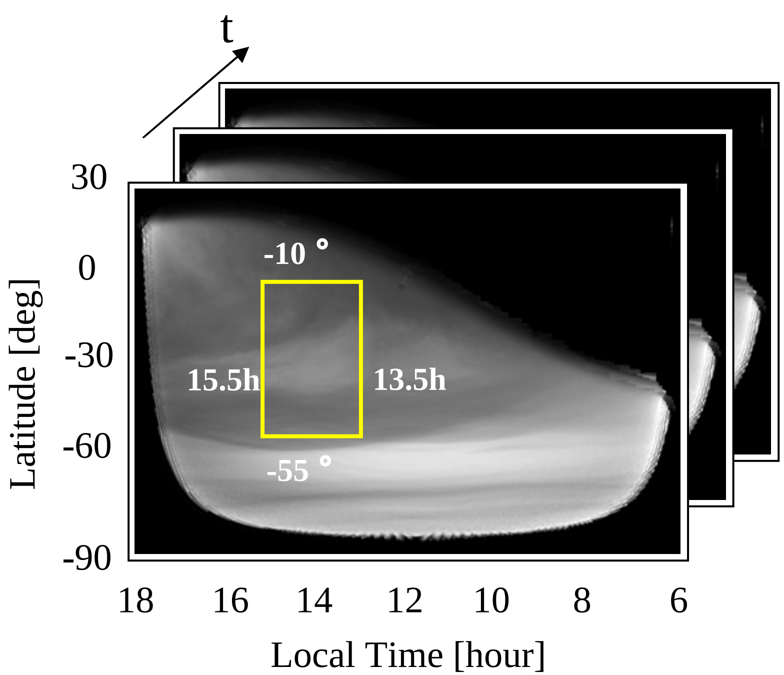


Galileo Observation (1990 Feb.16)

<u>Results</u>

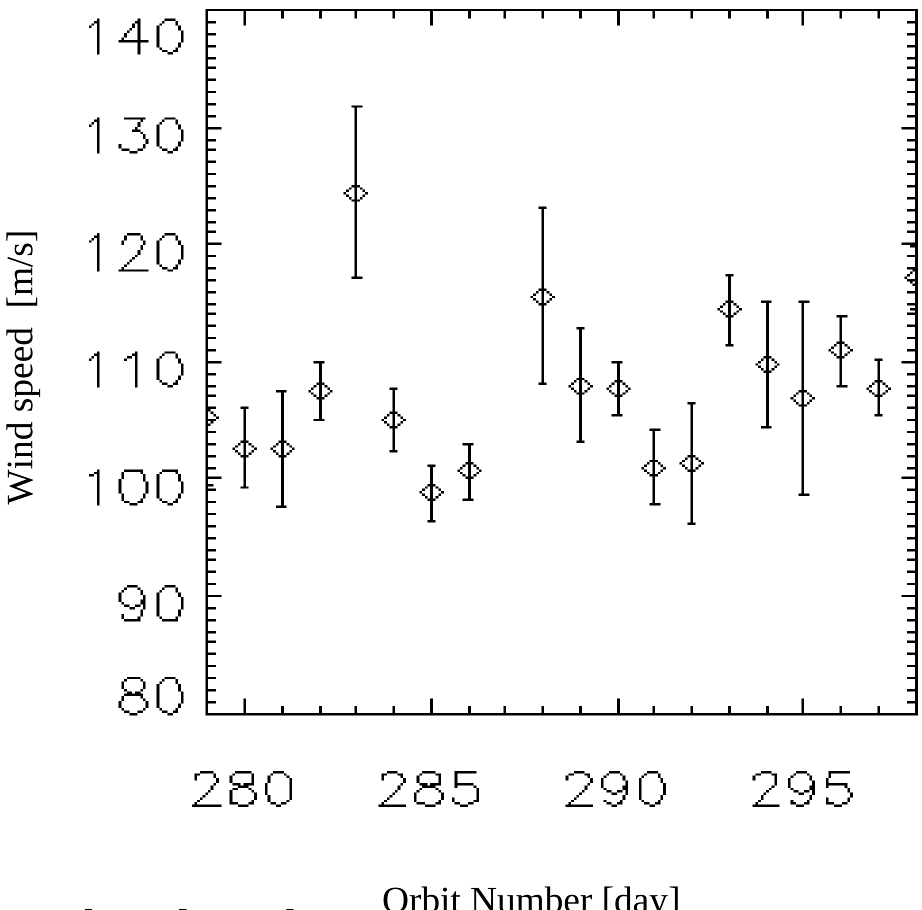
To deduce Kelvin wave and Rossby wave

We analyzed time variations of wind speeds from -10 ° to -55 ° of latitude because both waves rotate with the super-rotation.



Example :

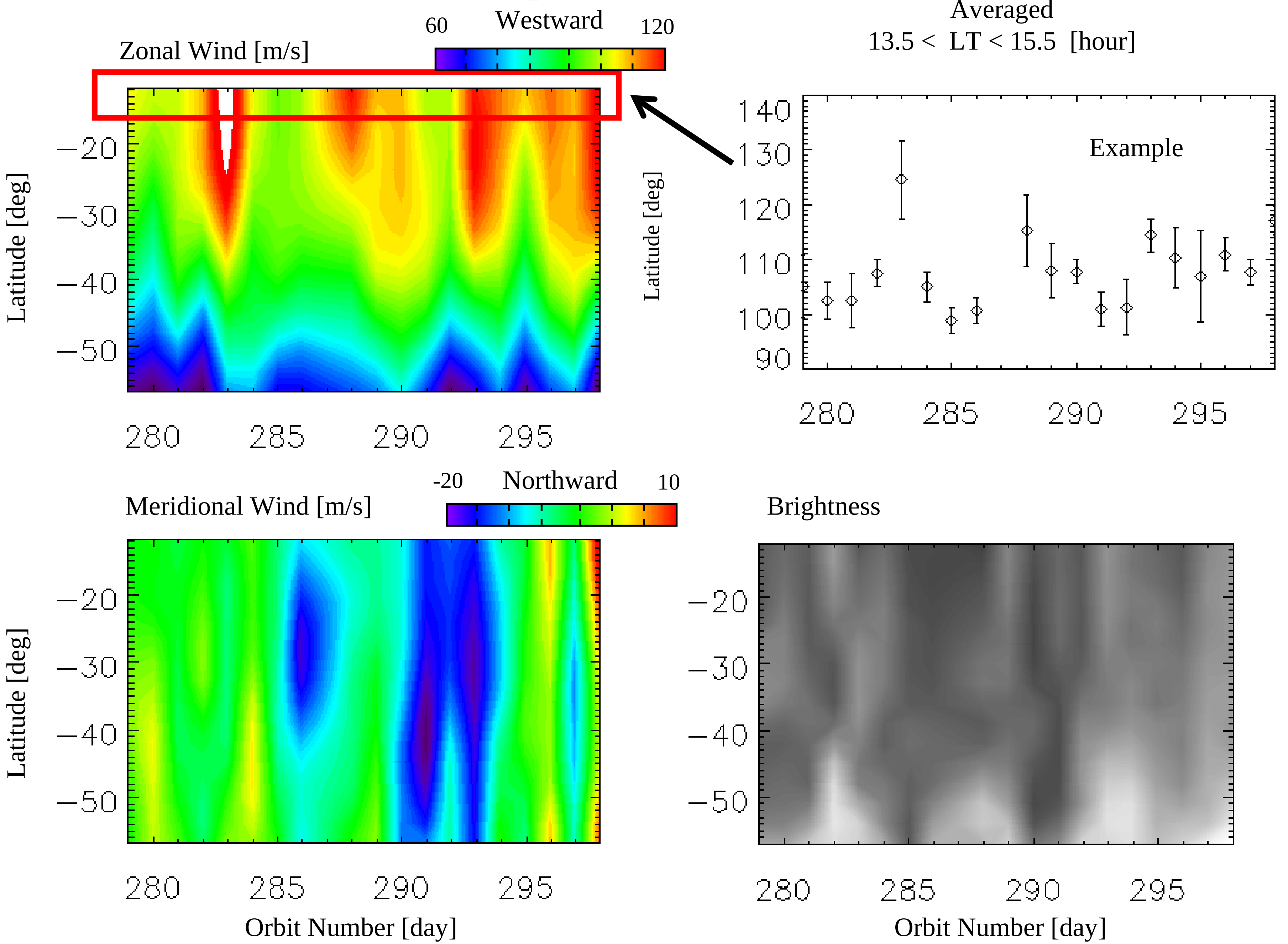
Time variations of zonal winds (m/s) at -10 ° of latitude



Wind speeds were averaged in the between LT 13.5h and 15.5h

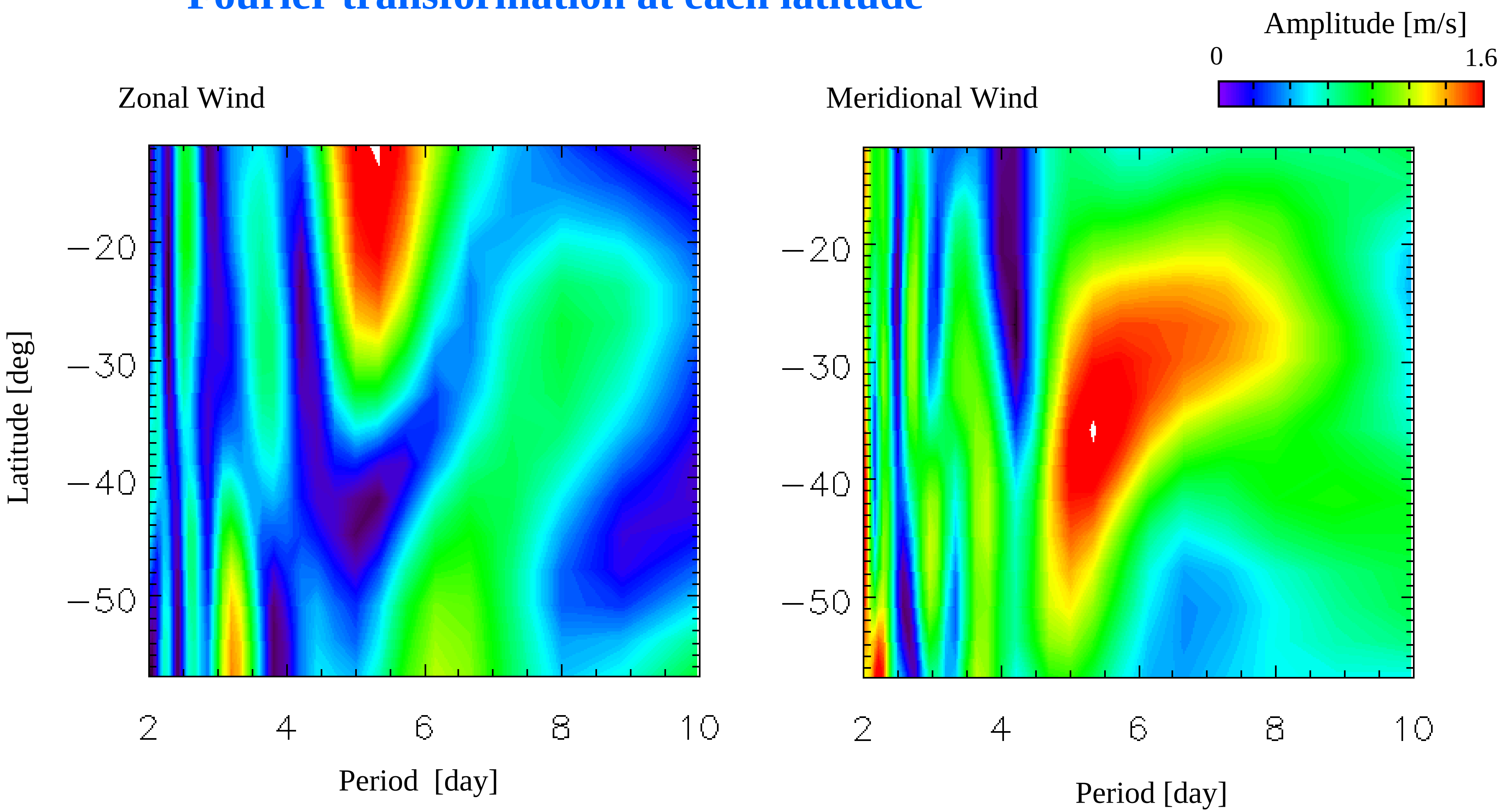
Results

Time variations of wind speeds



Results

Fourier transformation at each latitude



Lat > -35 °

Large amplitude at 5.5-day period (~ 6 m/s at -10 °)

Small amplitude at 3.5-day period (~ 2 m/s at -20 °)

Lat < -35 °

Large Amplitude at 3.3-day period (~ 4 m/s)

↑ Integration value

-20 ° > Lat > -50 °

Large Amplitude at 5.5-day period (~ 4 m/s at -35 °)

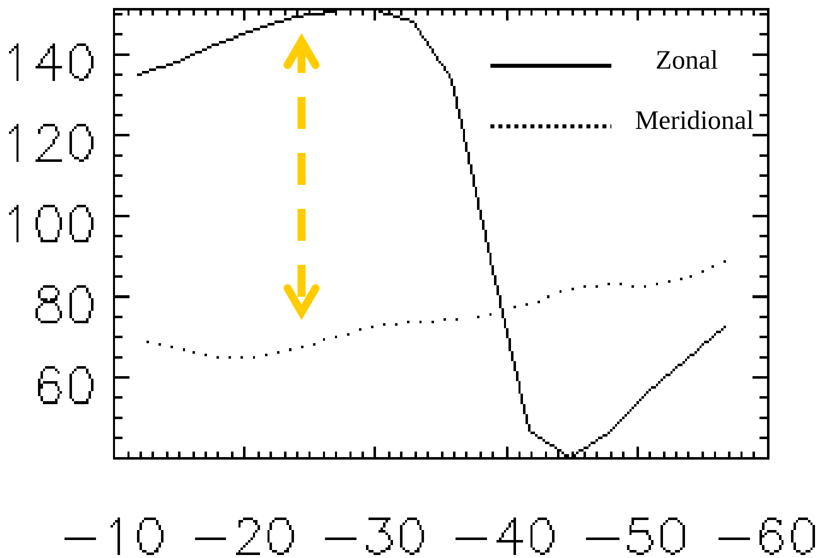
Results

Structure of 5.5-day period fluctuation

$$f_{5.5}(t) = F_{5.5} \exp [\, i \, (2 \pi/5.5 \, t + \theta_{5.5}) \,]$$

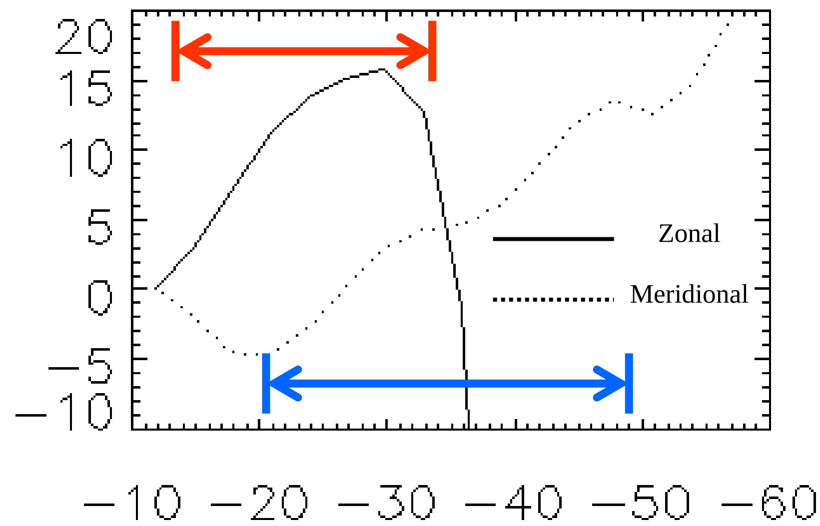
f: Observed Value, F: Amplitude,
θ:Initial Phase、t:Time [day]

Initial Phase [deg]



Latitude [deg]

$\Delta\theta$ [deg] $\Delta\theta = \theta$(Lat) $-$ θ(-10°)



Latitude [deg]

90° difference between the initial phases of Zonal and Meridional wind speeds

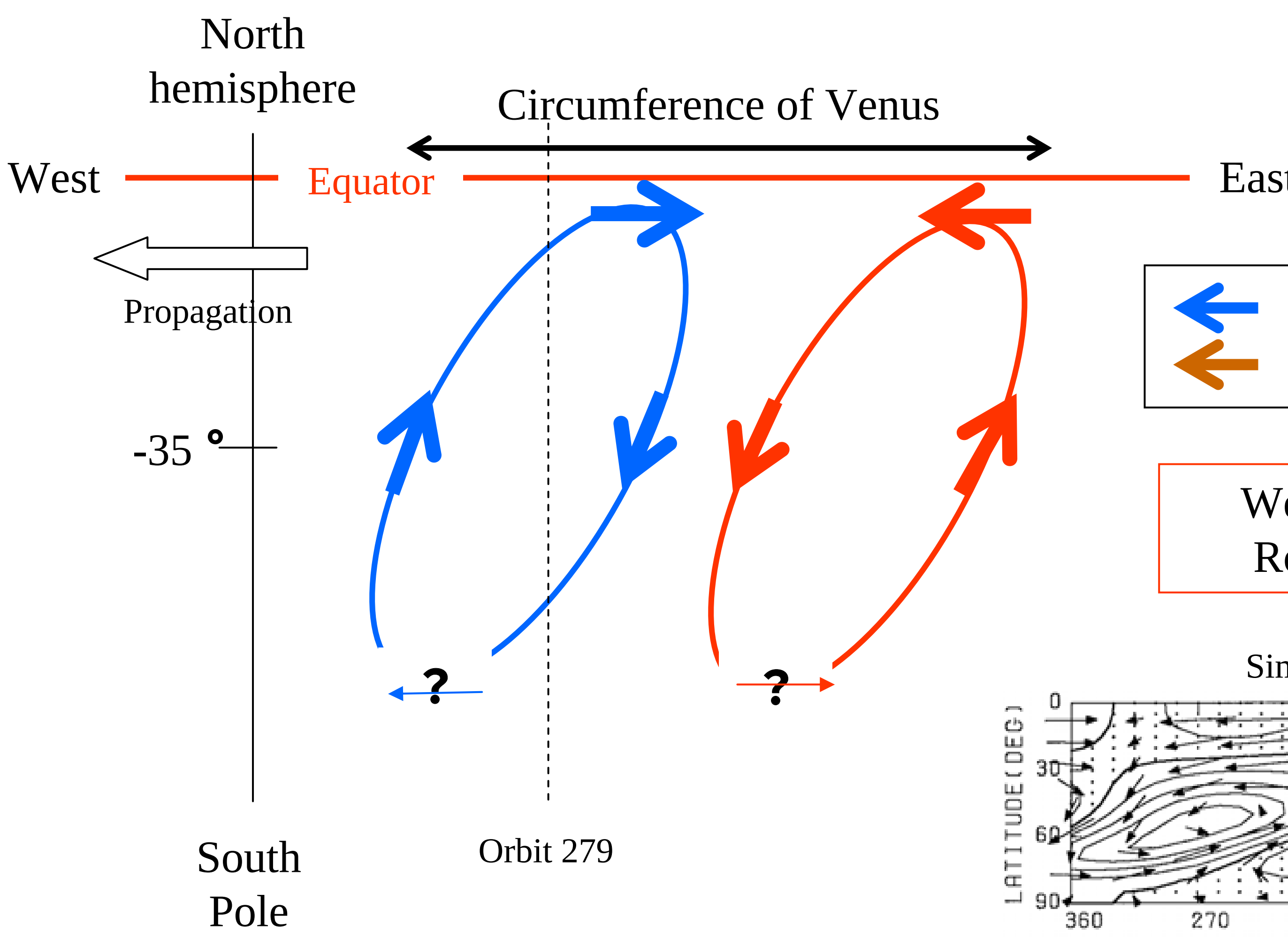
Both initial phases of zonal and meridional wind speeds increase at where large amplitudes exist.

Results

Structure of 5.5-day period fluctuation

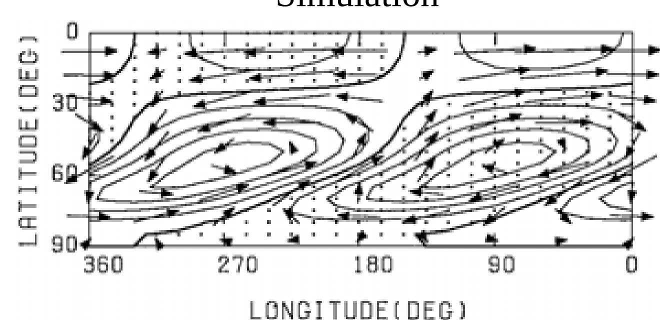
$$f_{5.5}(t) = F_{5.5} \exp\left[\, i \left(2\pi/5.5\, t + \theta_{5.5}\right) \right]$$

f: Observed Value, F: Amplitude,
θ:Initial Phase、t:Time [day]



Westward-tilting
Rossby Wave ?

Simulation



[Yamamoto and Takahashi, 1997]

Discussion

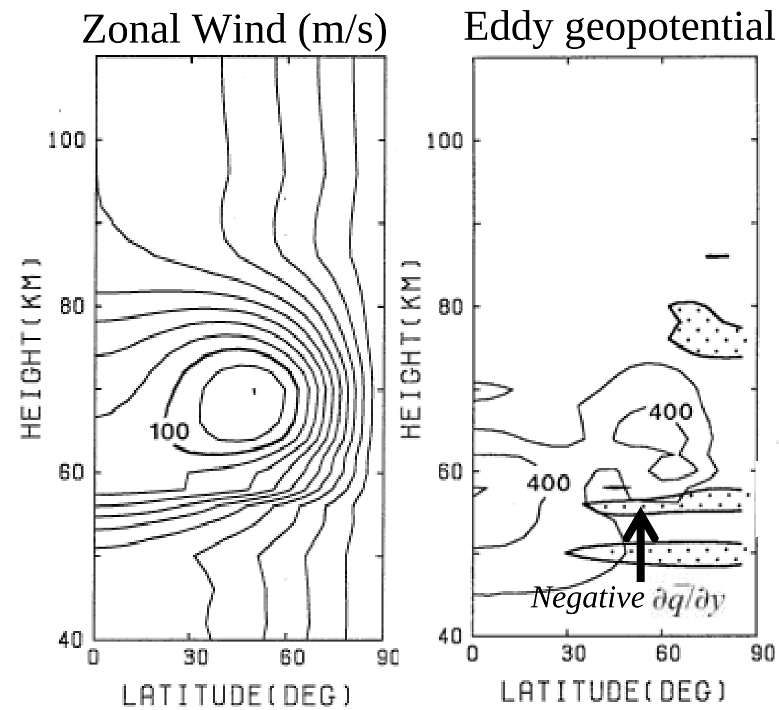
Rossby wave at low latitude

Expectation from simulations [Yamamoto et al 1998]

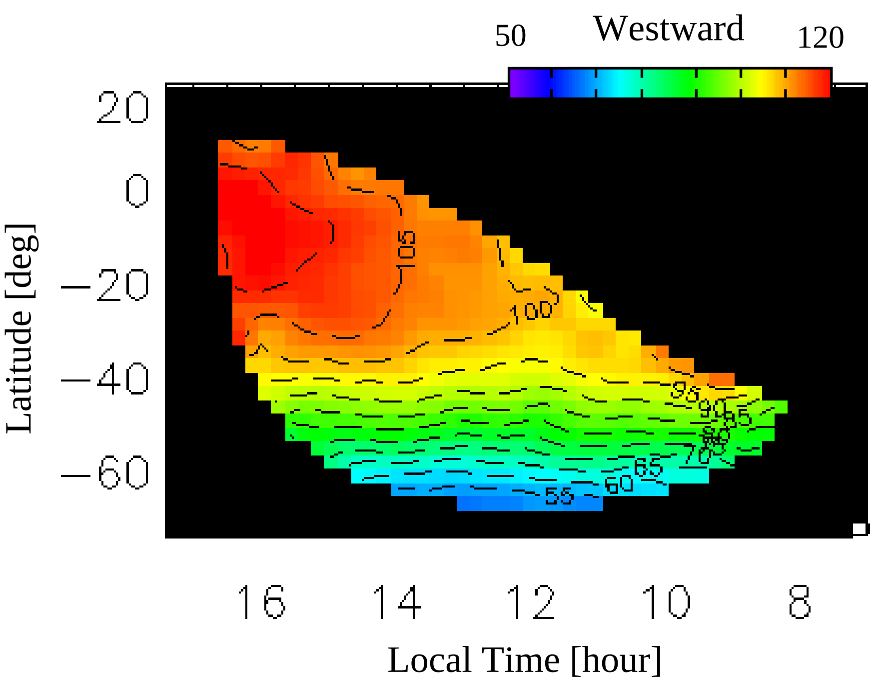
Strong wind shear of zonal winds can excite baroclinic instability.

→ Rossby wave

(This wave contributes to dissipation of the instability)



[Yamamoto, M. and H. Tanaka, 1997]



Observed time-mean zonal winds [m/s]
(from #279 to #298)

Observation :

Local maximum (= jet) in low latitude

↓

This jet may excite Rossby wave centered at -35 ° latitude.

Summary

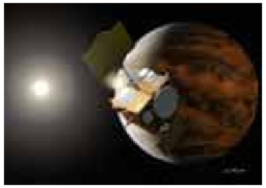
We are now constructing a suitable cloud tracking method to Venus cloud images with correction of wind vectors which indicate incorrect directions.

We deduced a large 5.5 day perturbation and a small 3.5 day perturbation in low latitude.

From the analysis of initial phase, the 5.5 day perturbation had a westward-titling Rossby wave structure that consisted with a simulation inducing 4-day wave forcing.

Future work

- Evaluate quantitatively contribution of atmospheric waves to maintain the super-rotation,
- Analyze time variations of the Rossby wave (and the equatorial Kelvin wave),
- Deduce the vertical wind shear in zonal winds using VIRTIS data and VCO data.



Launch : 2010 May

References

- Belton, M. J. S.,et al., (1991): Images from Galileo of the Venus cloud deck. *Science*, **253**, 1531-1536.
- Del Genio, A. D., et al., 1989: Planetary-Scale Waves and the Cyclic Nature of Cloud Top Dynamics of Venus. *J. Atmos. Sci.*, **47**, 293-318.
- Qing X. Wu., 1995: A Correlation-Relaxation-Labeling Framework for Computing Optical Flow - Template Matching from a New Perspective, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, **17**, 843-853
- Evans, A. N., 2000. Glacier surface motion computation from digital image sequences. *IEEE Transactions on Geoscience and Remote Sensing*, **38** (2), pp. 1064-1072.
- Rossow, W. B., et al., 1990: Cloud-tracked winds from Pioneer Venus OCPP images. *J. Atmos. Sci.*, **47**, 2053-2084.
- Takagi, M., and Y. Matsuda (2007), Effects of thermal tides on the Venus atmospheric superrotation, J. Geophys. Res., **112**, D09112
- Yamamoto, M., and H. Tanaka, 1997: Formation and maintenance of the 4-day circulation in the Venus middle atmosphere. *J. Atmos. Sci.*, **54**, 1472-1489.

Acknowledgements..

All data used in this study are from http://www.planetary.org/data/vex/