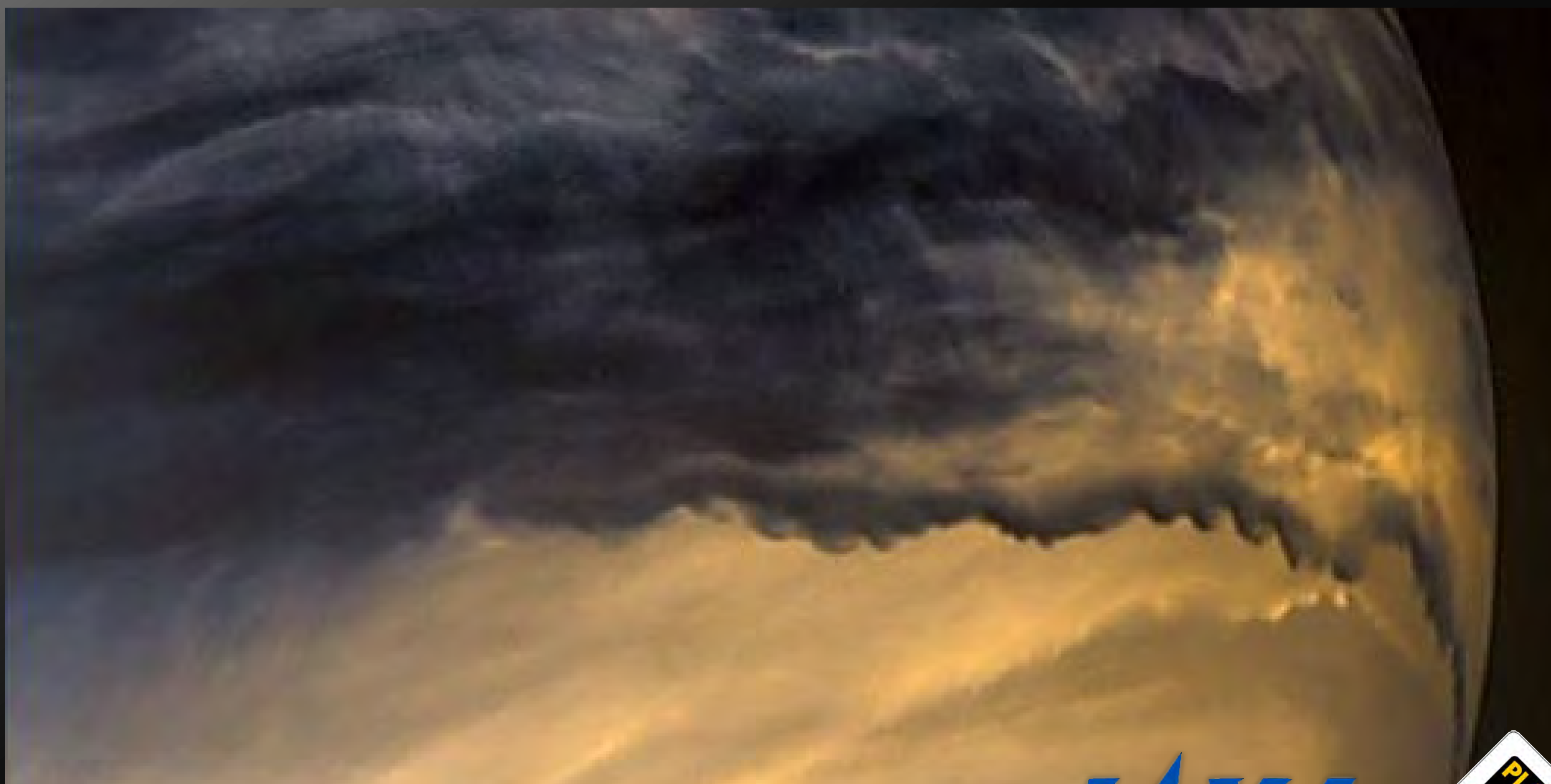
Atmospheric Phenomena and Cloud Dynamics of Venus: an update



Javier Peralta (University of Sevilla)
NASA Decadal Survey "Venus panel", 05 of May 2021

Atmospheric Phenomena and Cloud Dynamics on Venus: an update

Scope of this presentation

Our current understanding and characterization of:

- The zonal superrotation at the level of the clouds (zonally-averaged, local hour dependence, longitude dependence, time variability,...)
- The cloud phenomena (known and new).
- Planetary-scale/mesoscale Waves (known and new).
- Shear Instabilities (KH billows, shear waves, vortices...)

Major tools used to explore these topics

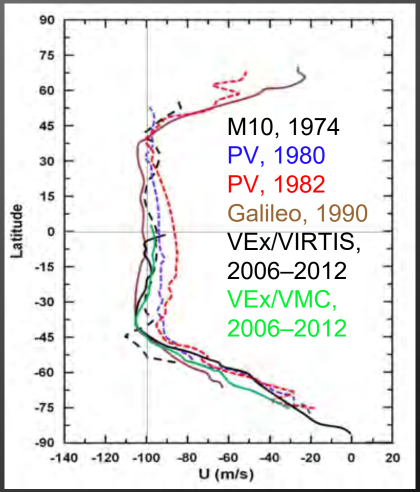
- Images from VIRTIS onboard ESA's Venus Express (h.a. VEx).
- Images from UVI, IR1, IR2 and LIR onboard JAXA's Akatsuki (h.a. VCO).
- Images from NASA's Infrared Telescope Facility (h.a. IRTF).

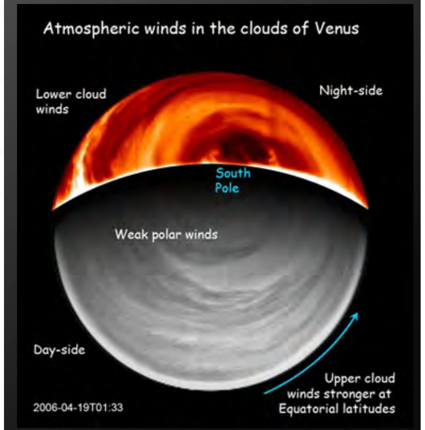
Wind results from papers before 2016

DAY SIDE OF VENUS

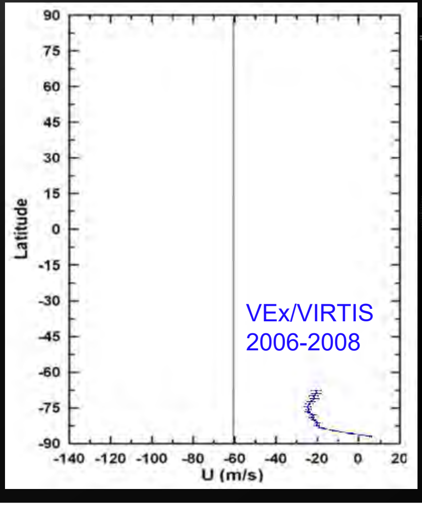
NIGHT SIDE OF VENUS

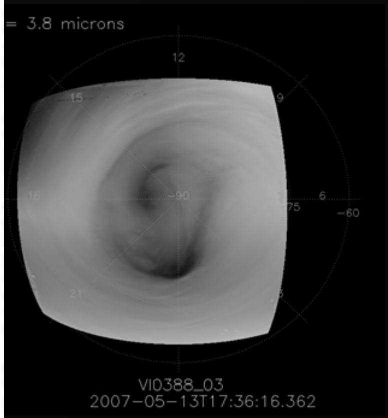
UPPER CLOUDS





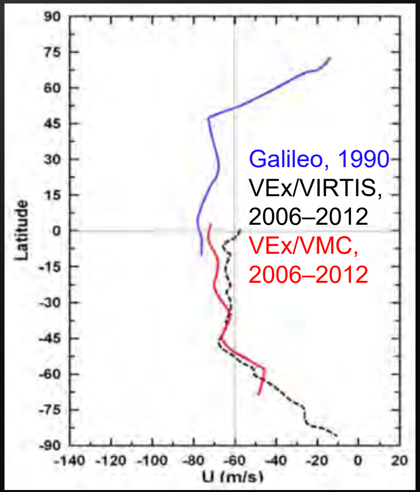
Sánchez-Lavega (2017)



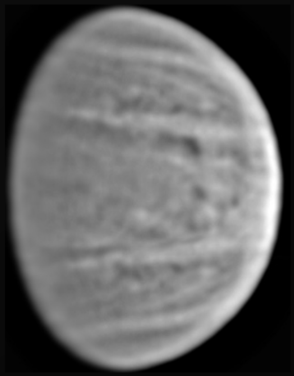


Luz (2011); Peralta (2012)

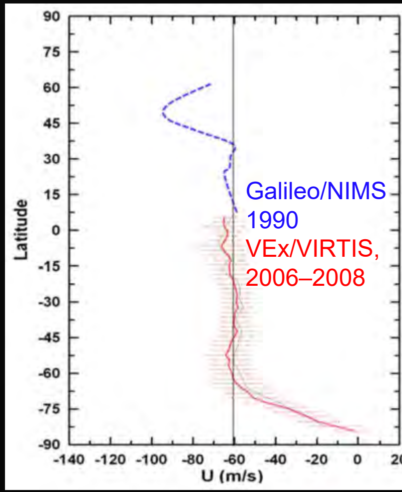
MID-LOW CLOUDS

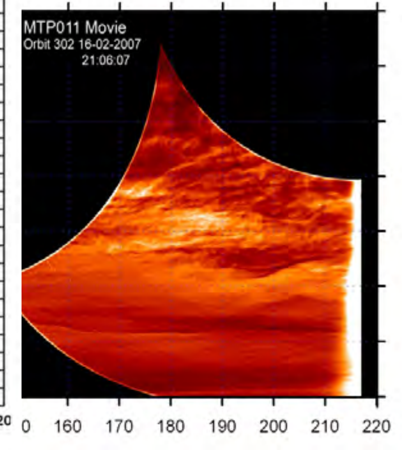


Galileo-SSI 986 nm



Peralta (2007); Hueso (2015); Khatuntsev (2017)





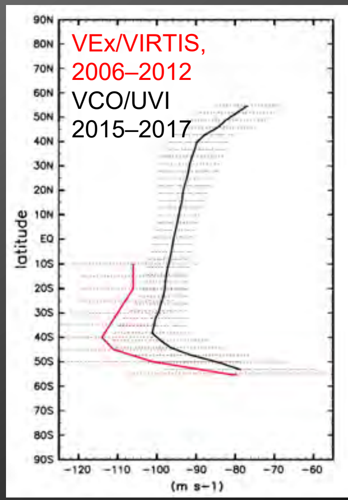
Carlson (1991); Hueso (2012)

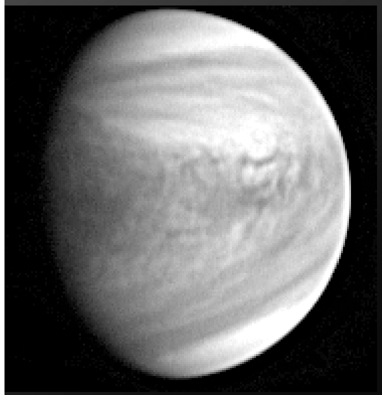
Wind results from papers after 2016

DAY SIDE OF VENUS

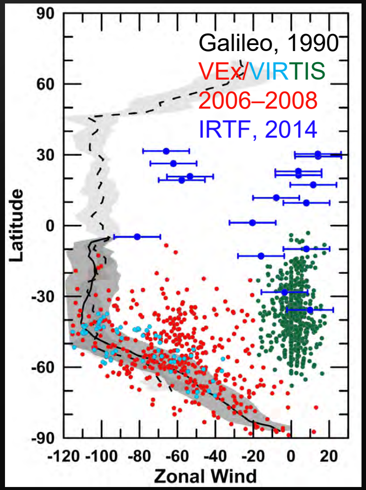
NIGHT SIDE OF VENUS

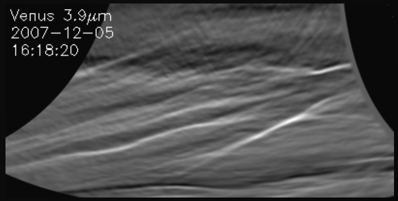
UPPER CLOUDS





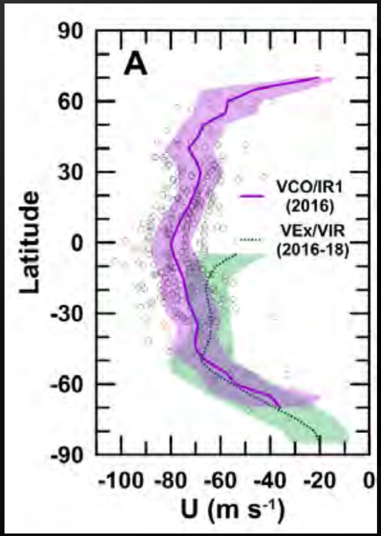
Horinouchi (2018)

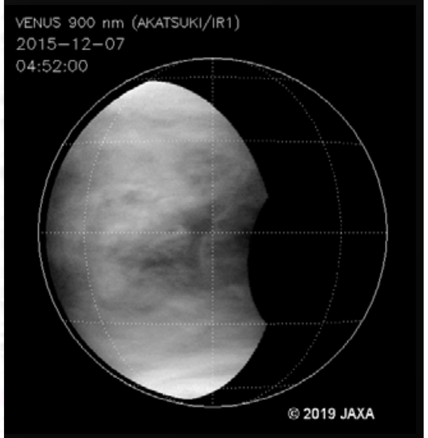




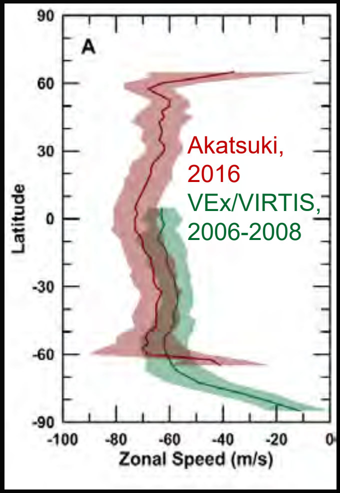
Peralta (2017)

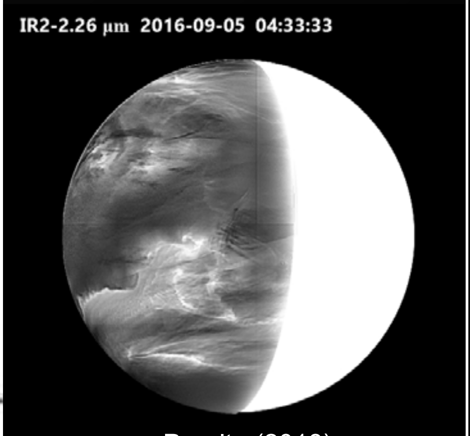
MID-LOW CLOUDS





Peralta (2019)

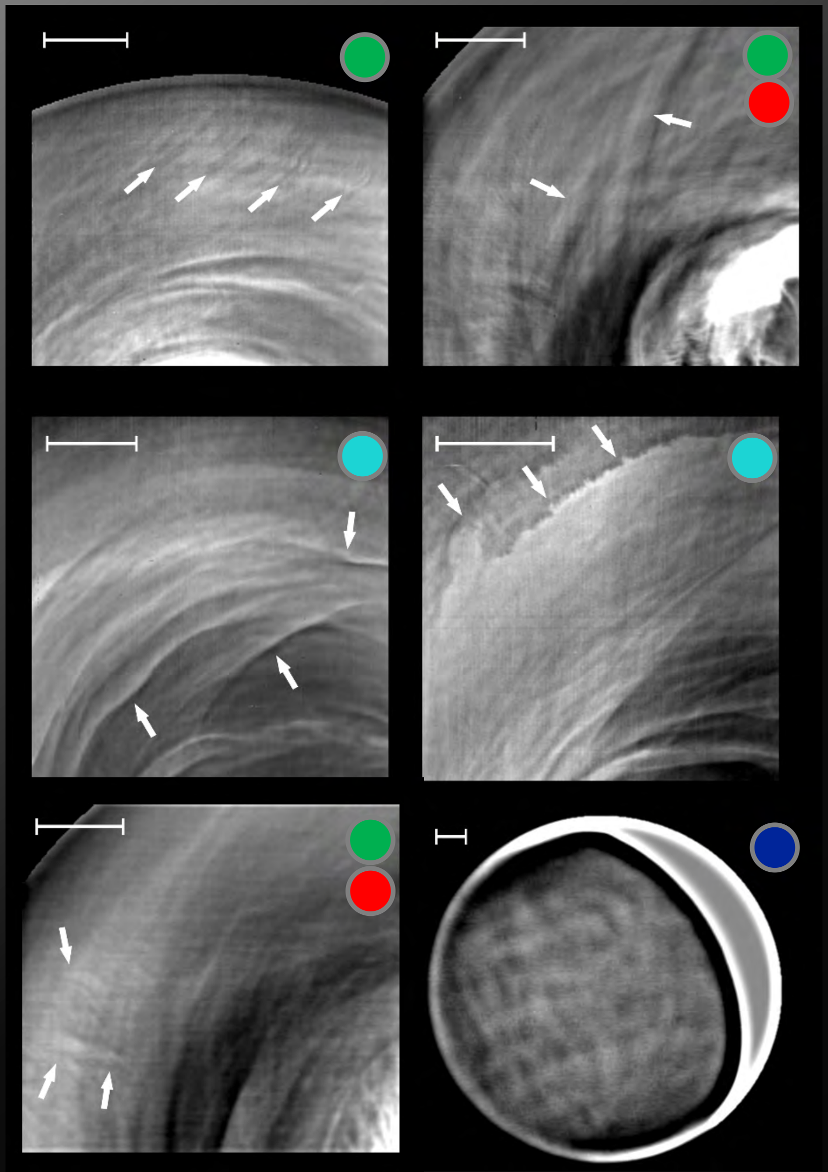


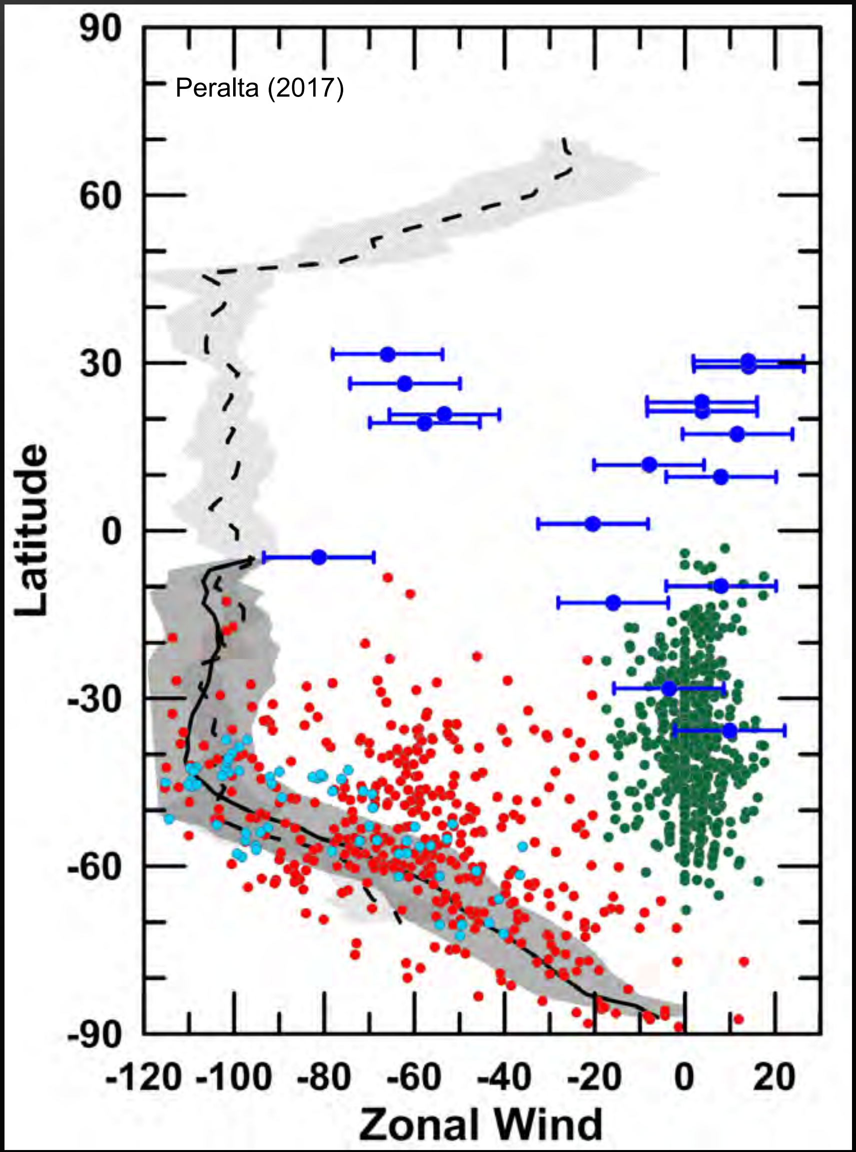


Peralta (2018)

Javier Peralta (Universidad de Sevilla, SPAIN)

Patterns and motions at the Night Upper Clouds





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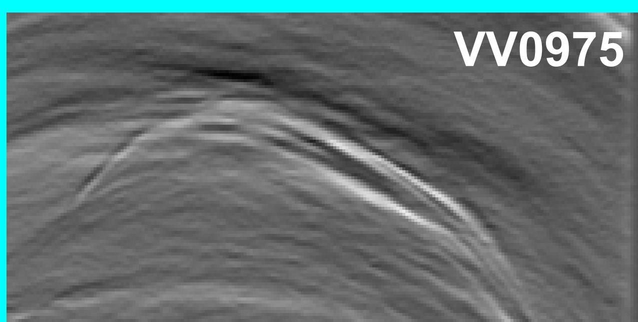
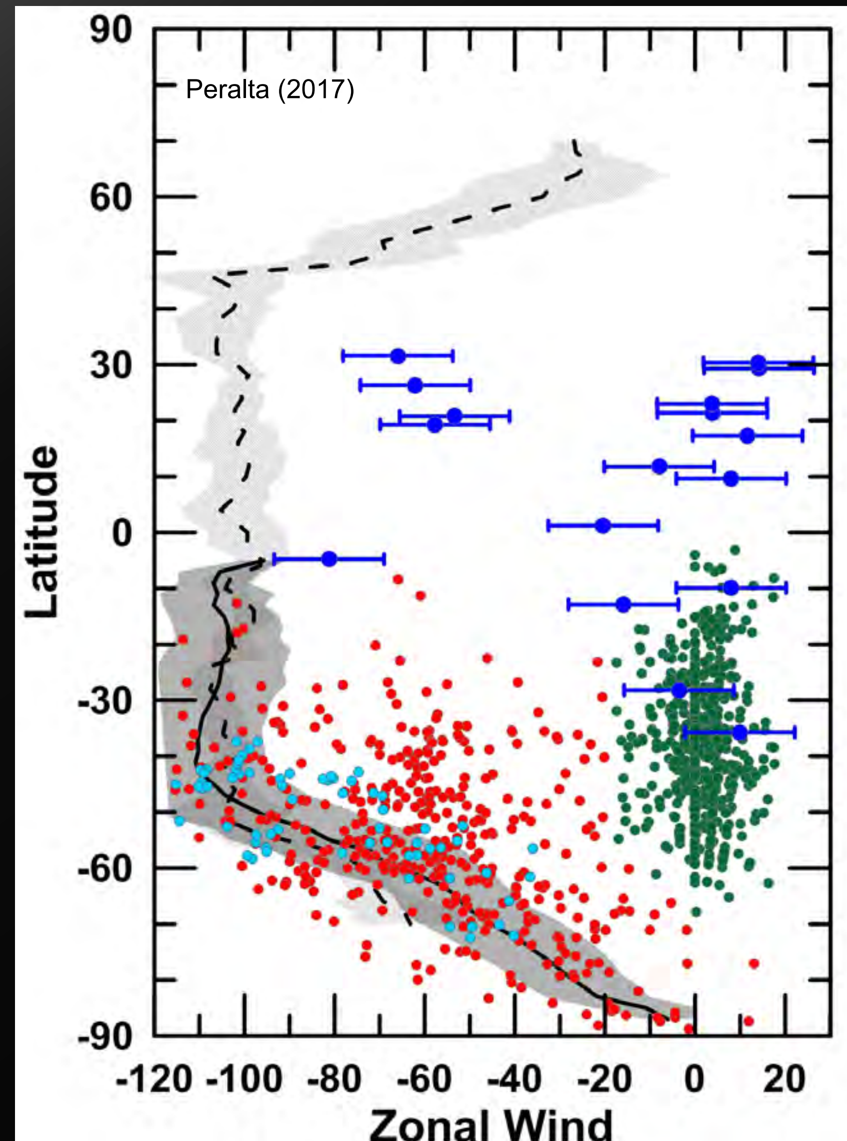
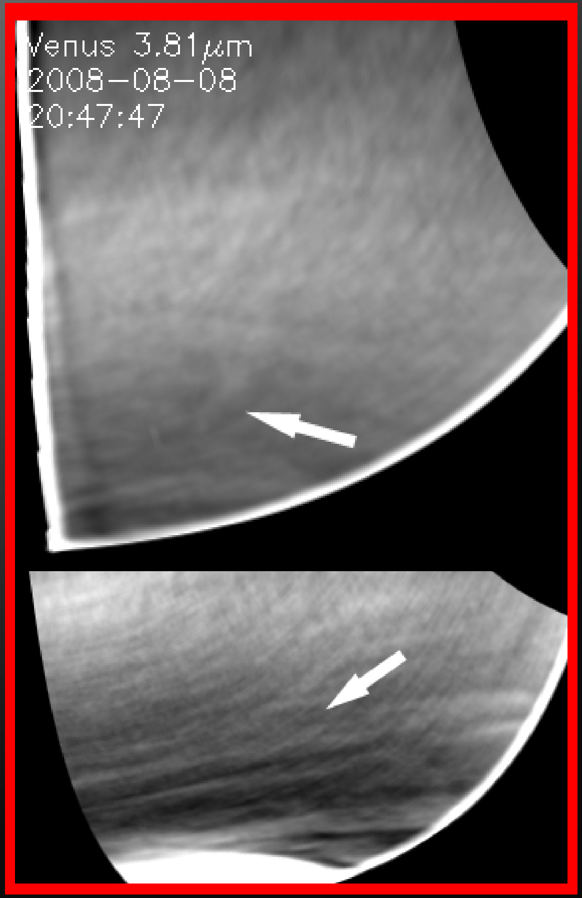
Patterns and motions at the Night Upper Clouds

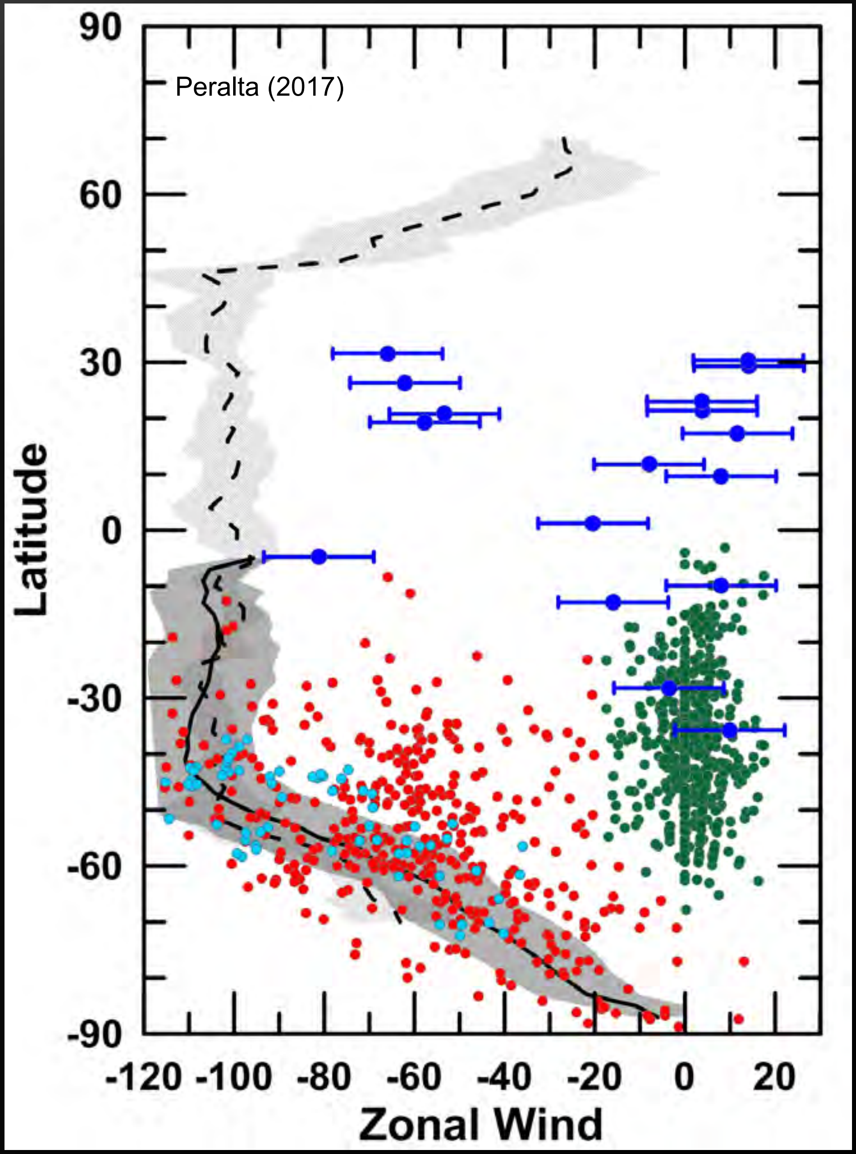
Fast bright filaments similar to the bright streamers in UV images (Titov, 2012).



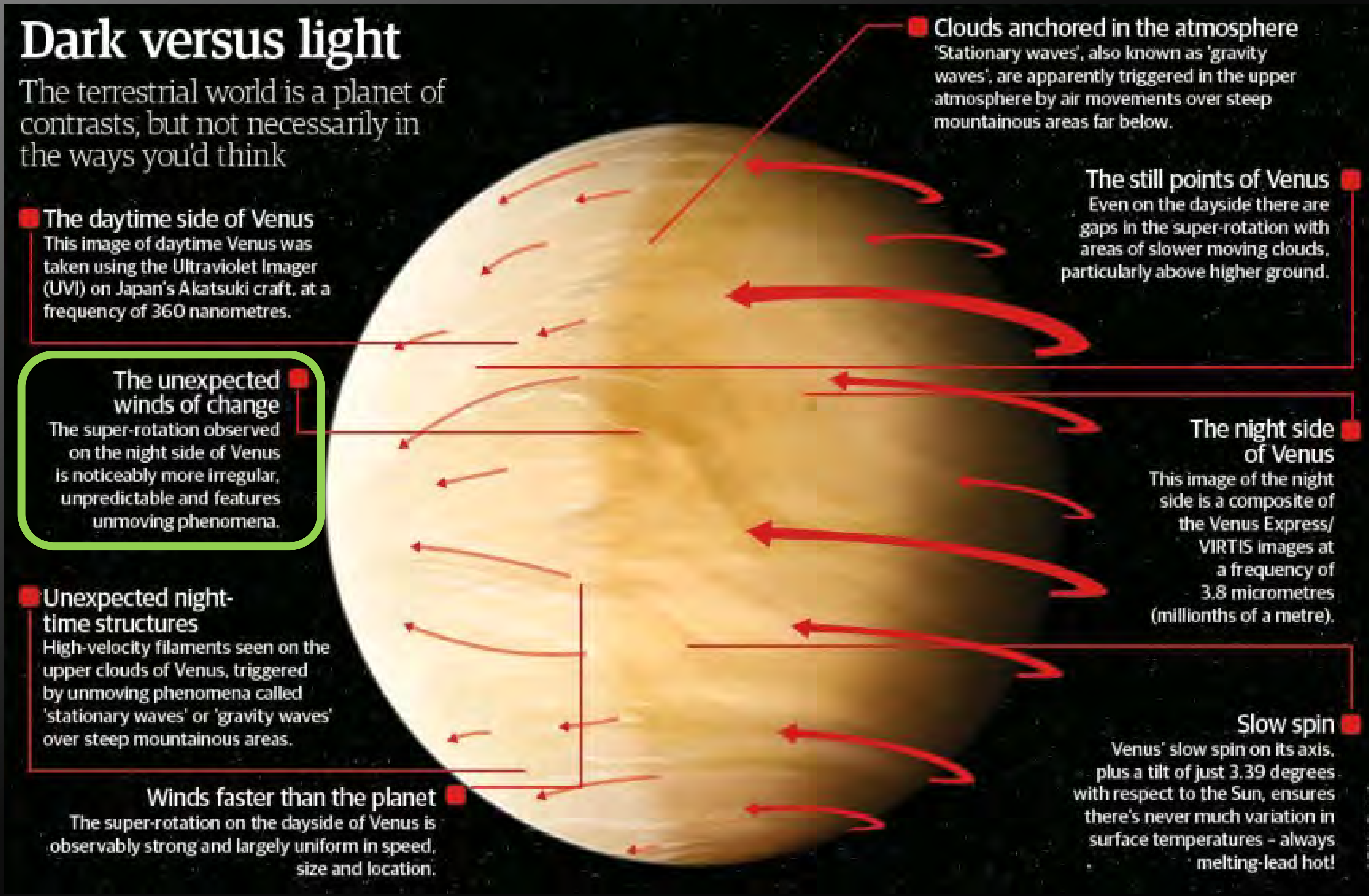


Patterns and motions at the Night Upper Clouds

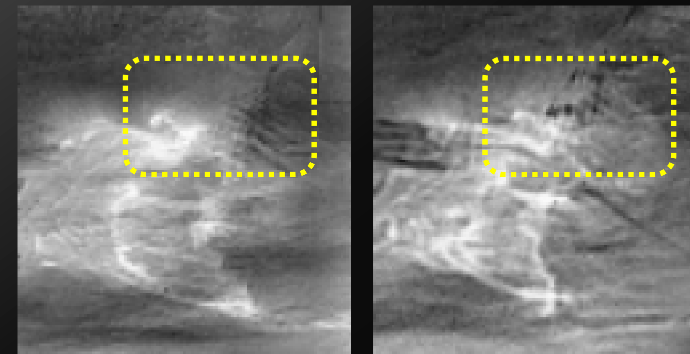




Chaotic Superrotation at the Night Upper Clouds?

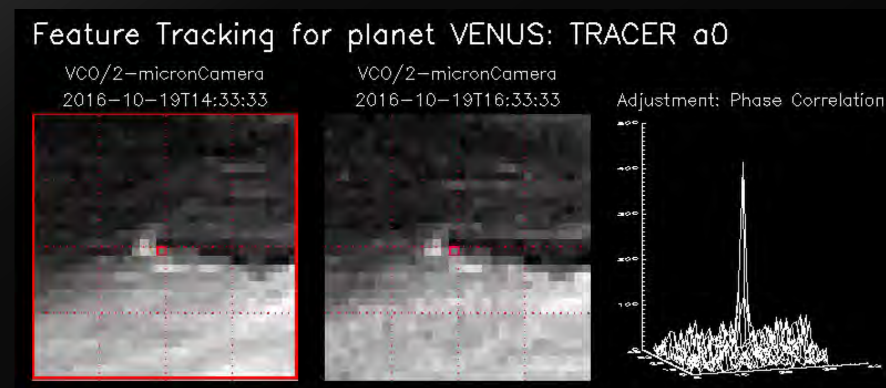


A jet at the night lower clouds

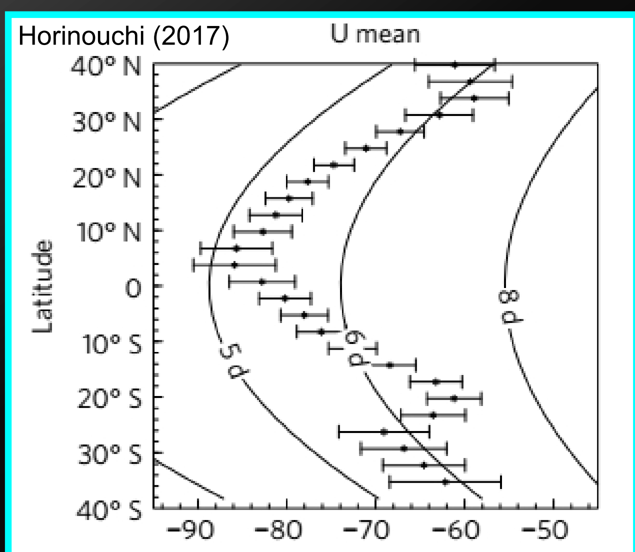


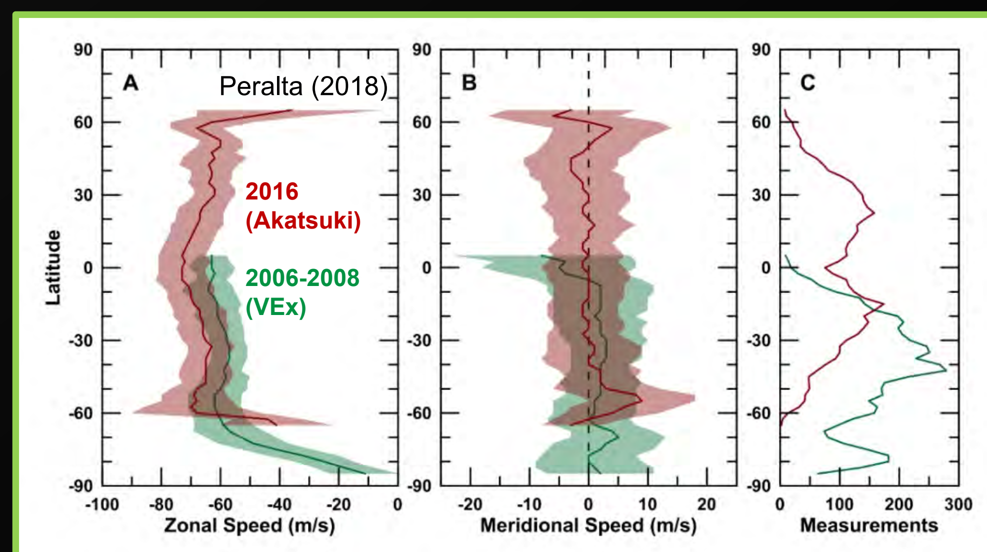
Procedure of Manual Tracking:
1. Cloud match with "Phase Correlation".
2. Visual Validation (discard waves).

A total of 2,947 wind measurements obtained with Manual Tracking (Peralta & Muto), and >149,000 have measured automatically (Horinouchi et al.)



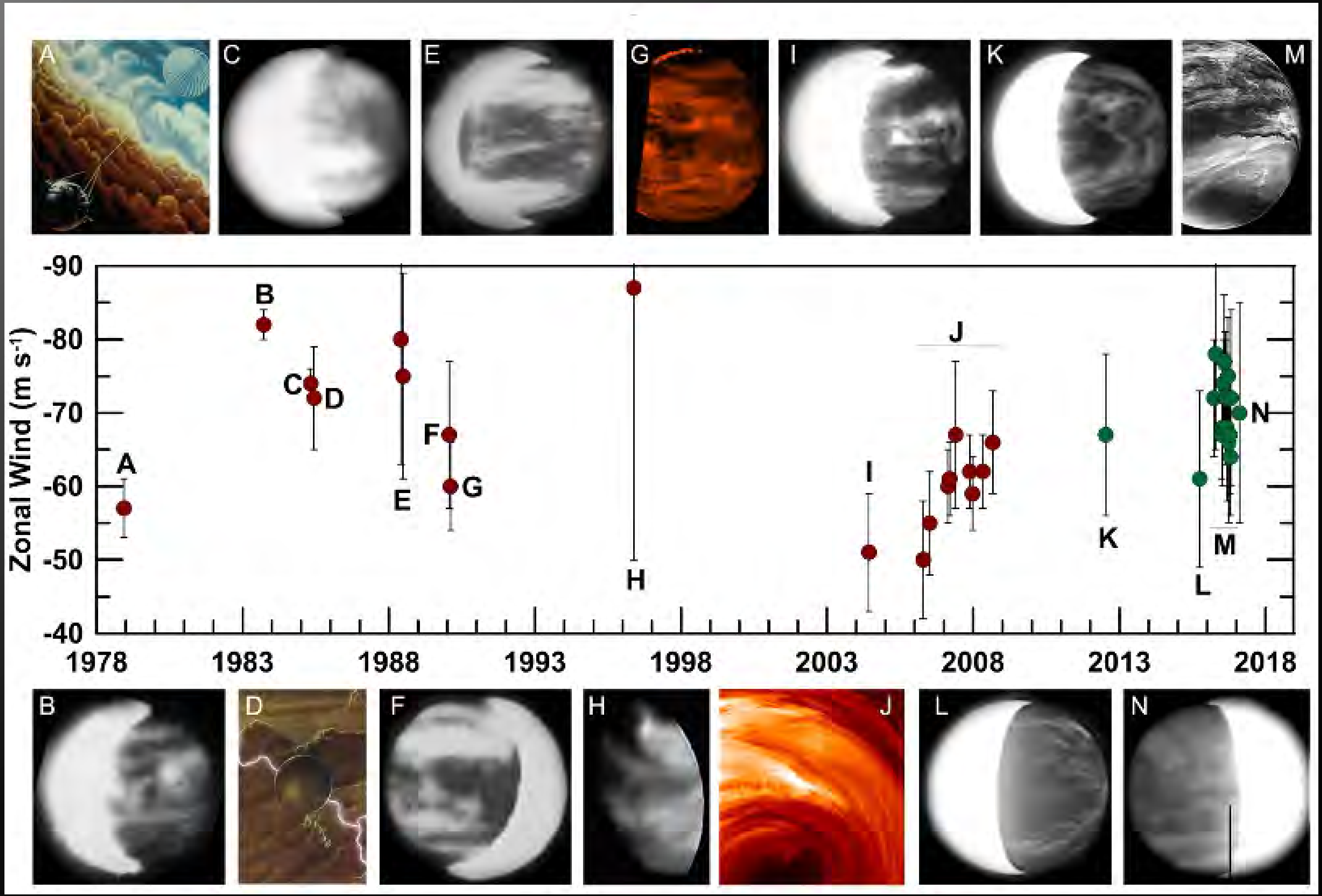
- Horinouchi (2017) discovered a JET at equator of Venus.
- Faster wind speeds than Venus Express (VEx). We also confirmed the recurrence of equatorial jets.





Decadal Changes (~30 m/s) on Winds 30ºN-30ºS

Peralta (2018)



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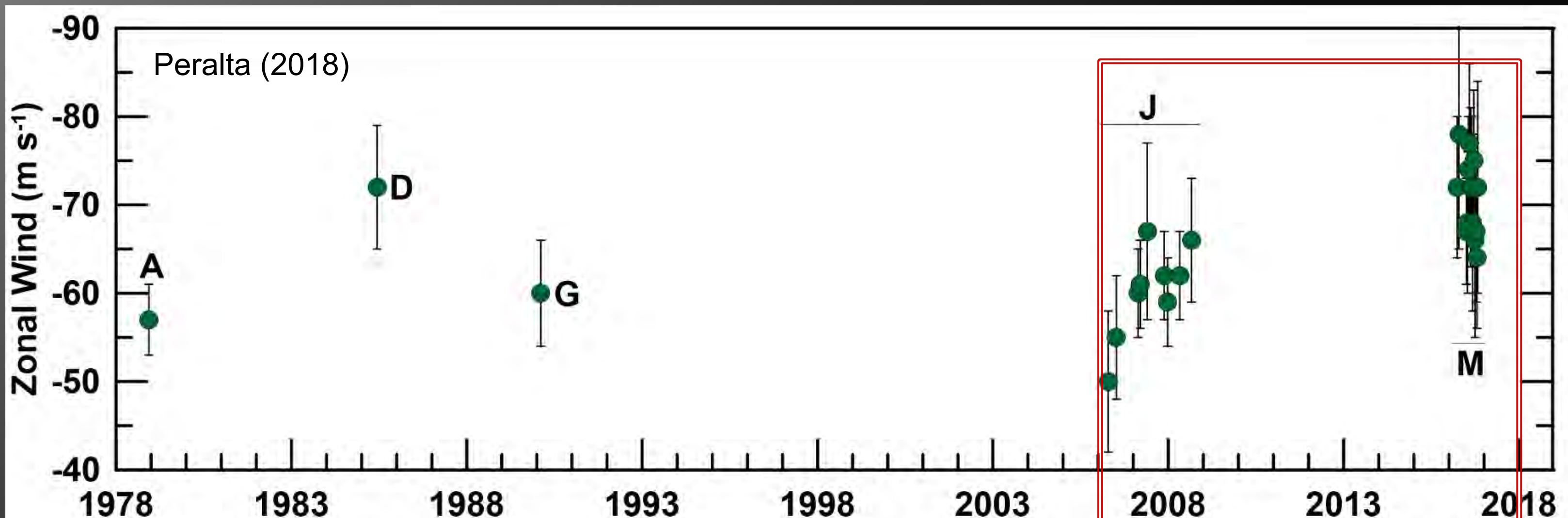
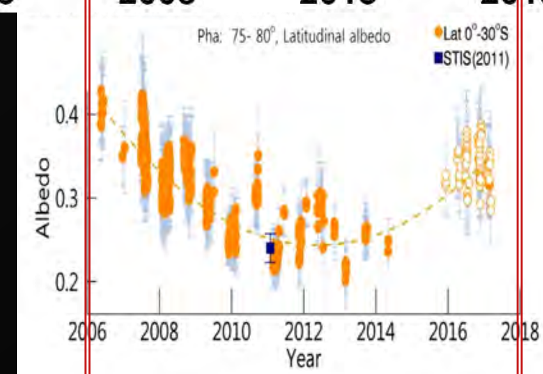
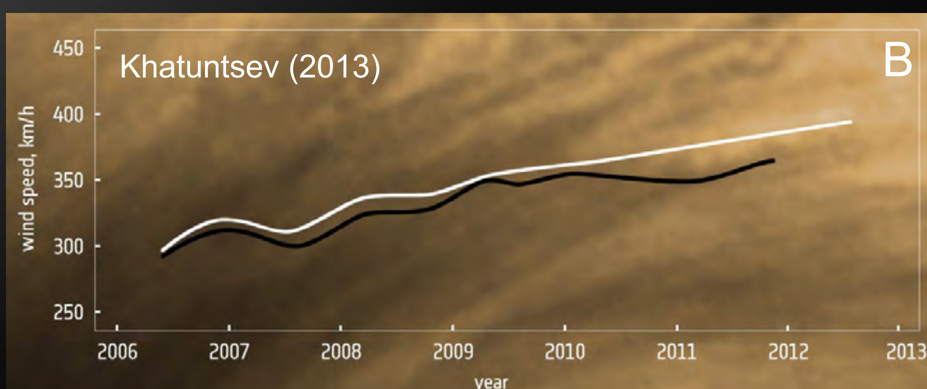
Decadal Changes (~30 m/s) on Winds 30ºN-30ºS

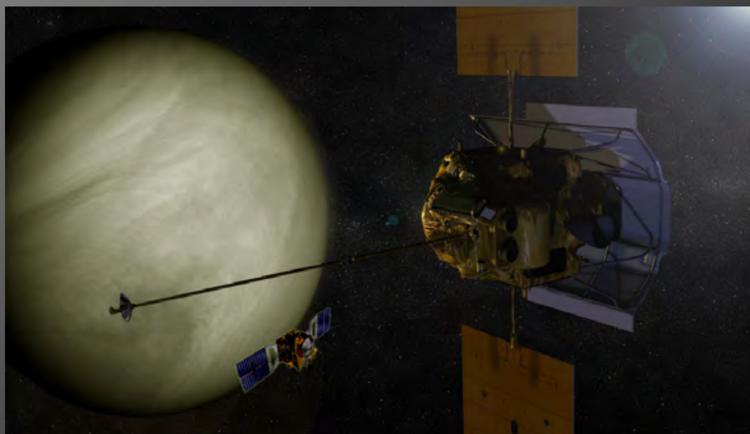


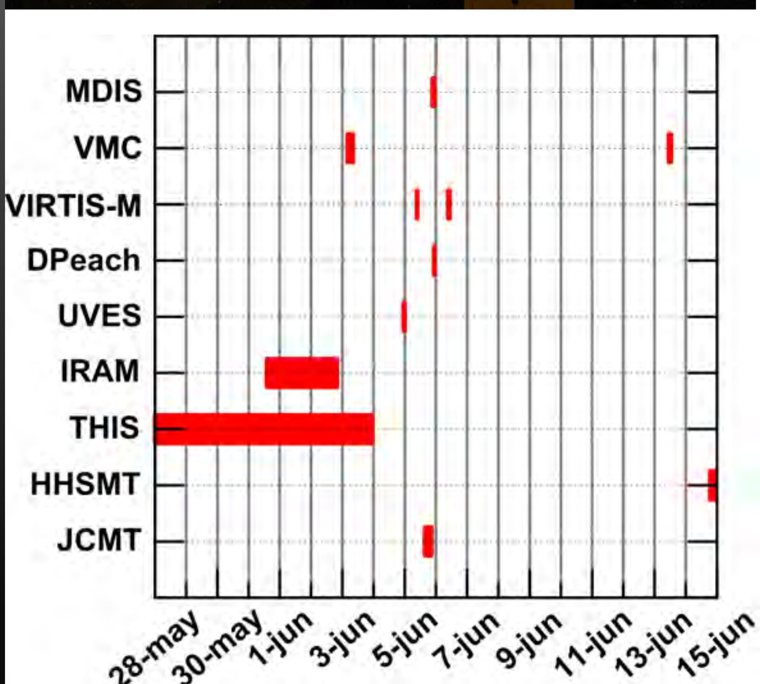


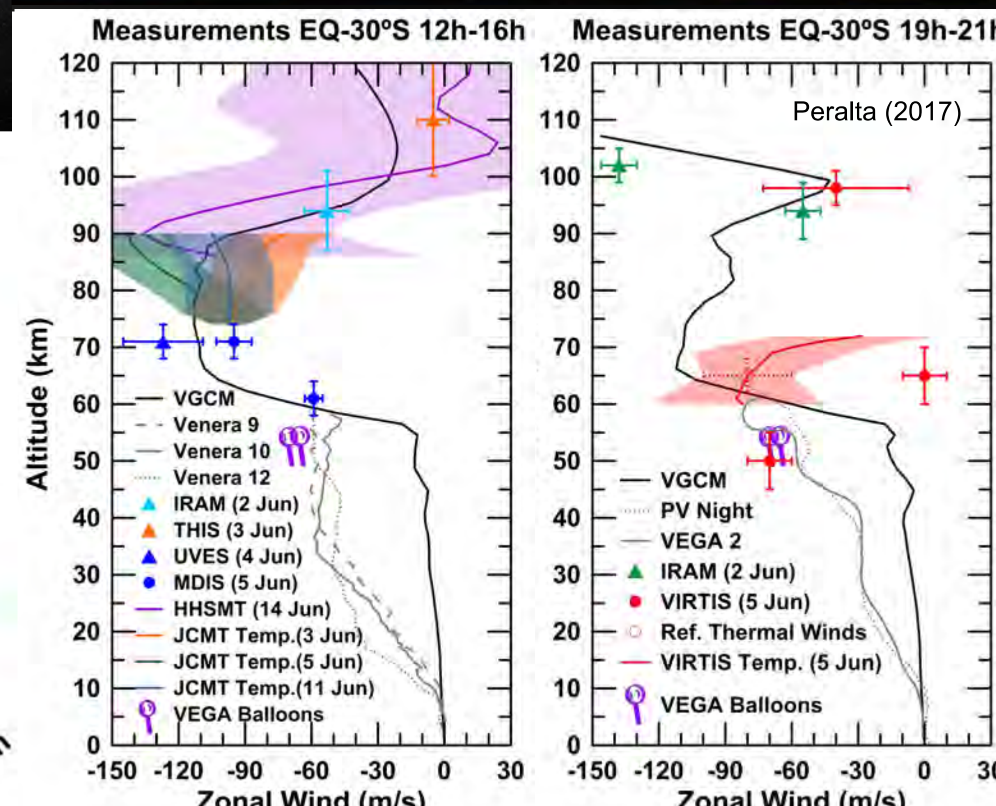


- Lee (2019) reported a decadal variation in the albedo of Venus's clouds.
- Variable solar absorption may modulate Thermal Tides (and also Wind Speeds).

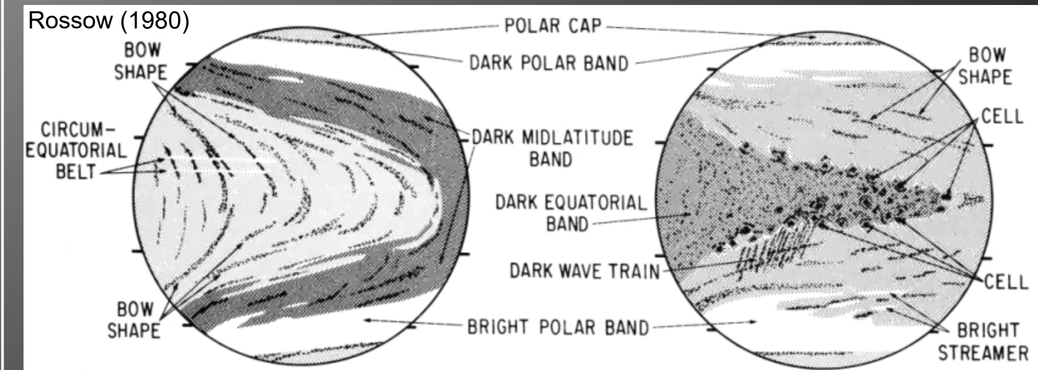
MESSENGER flyby: a complete 3D wind profile



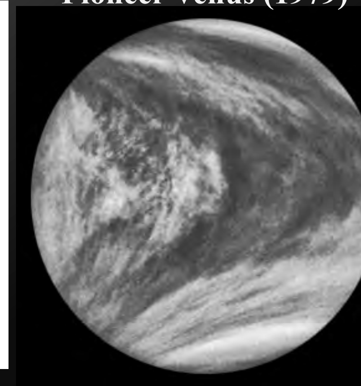




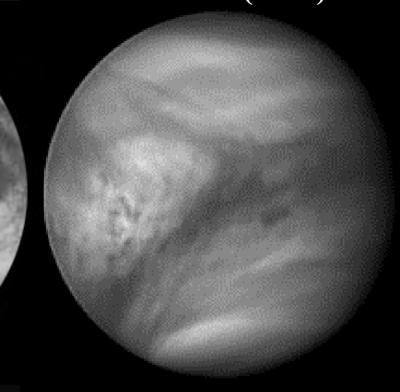
DAY Upper Clouds at ~70 km (~350-460 nm)

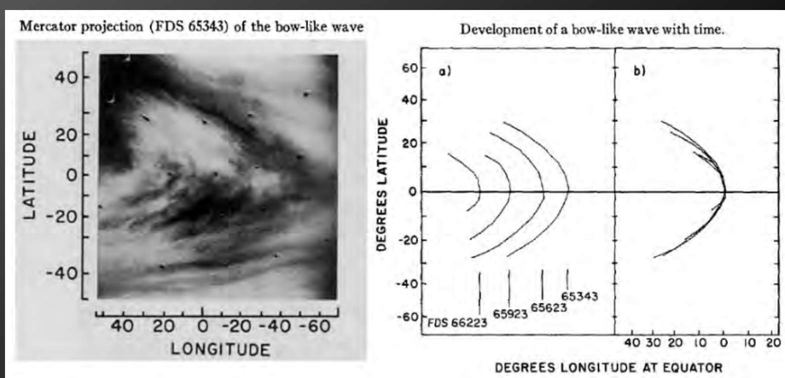


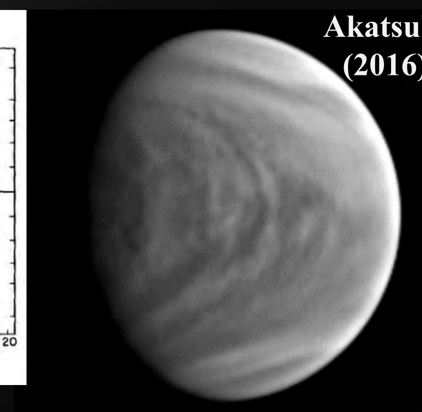
Pioneer Venus (1979)

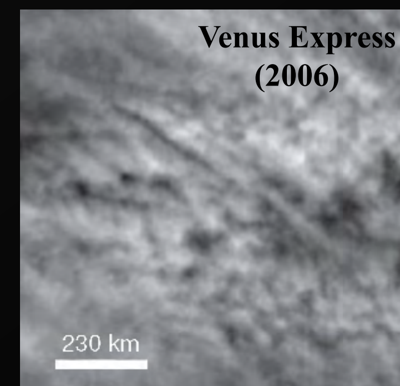


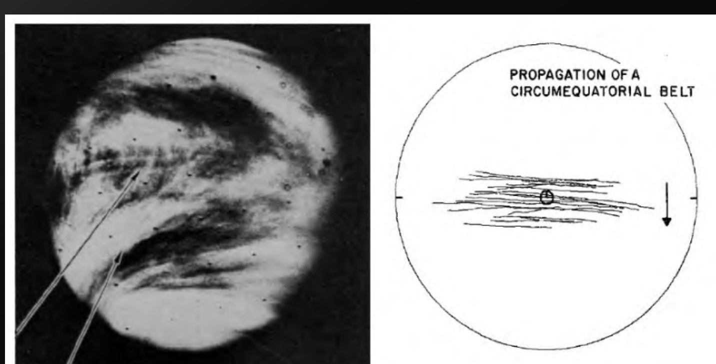
Akatsuki (2016)

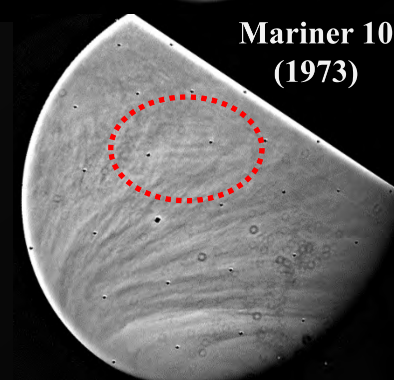


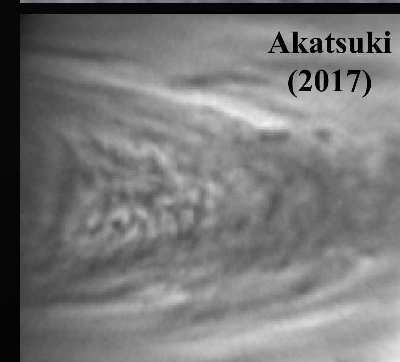






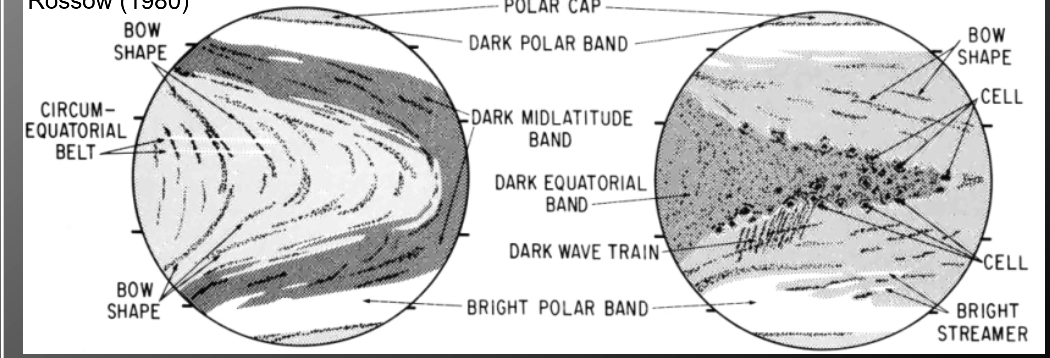






DAY Upper Clouds at ~70 km (~350-460 nm)

Rossow (1980)



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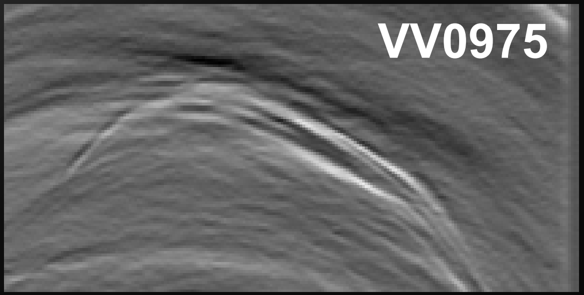
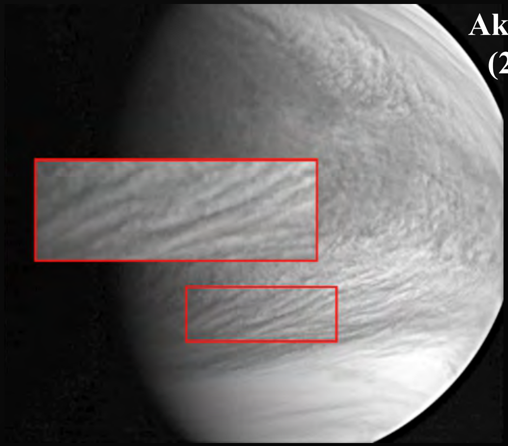
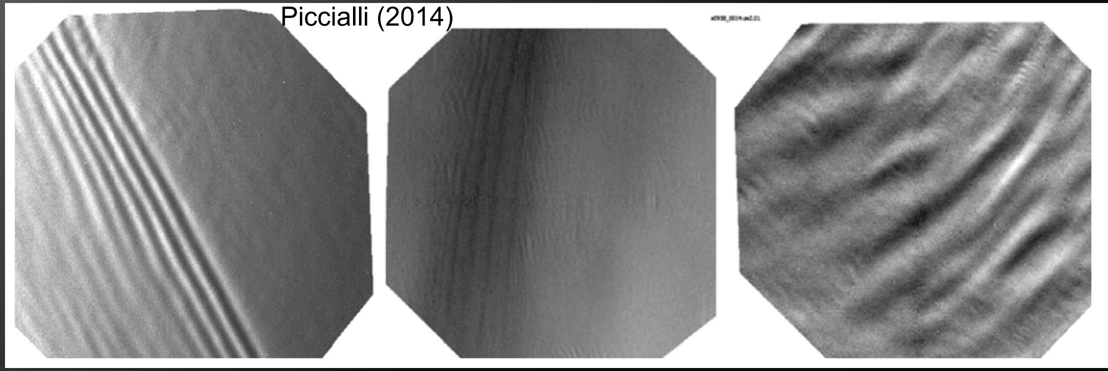


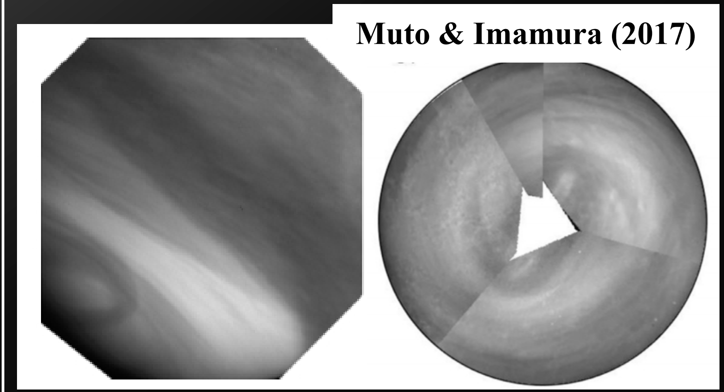
Akatsuki (2017)

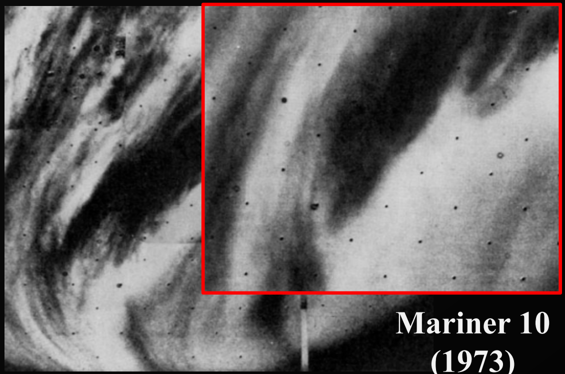


Picciali (2014)



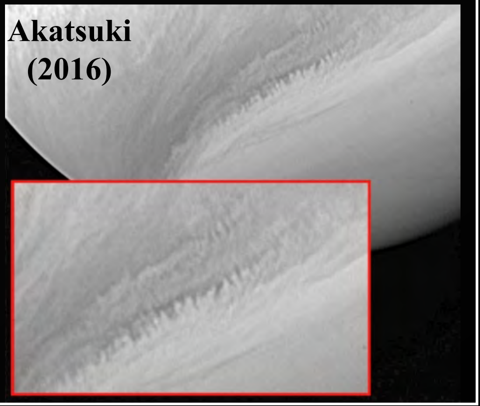
Muto & Imamura (2017)



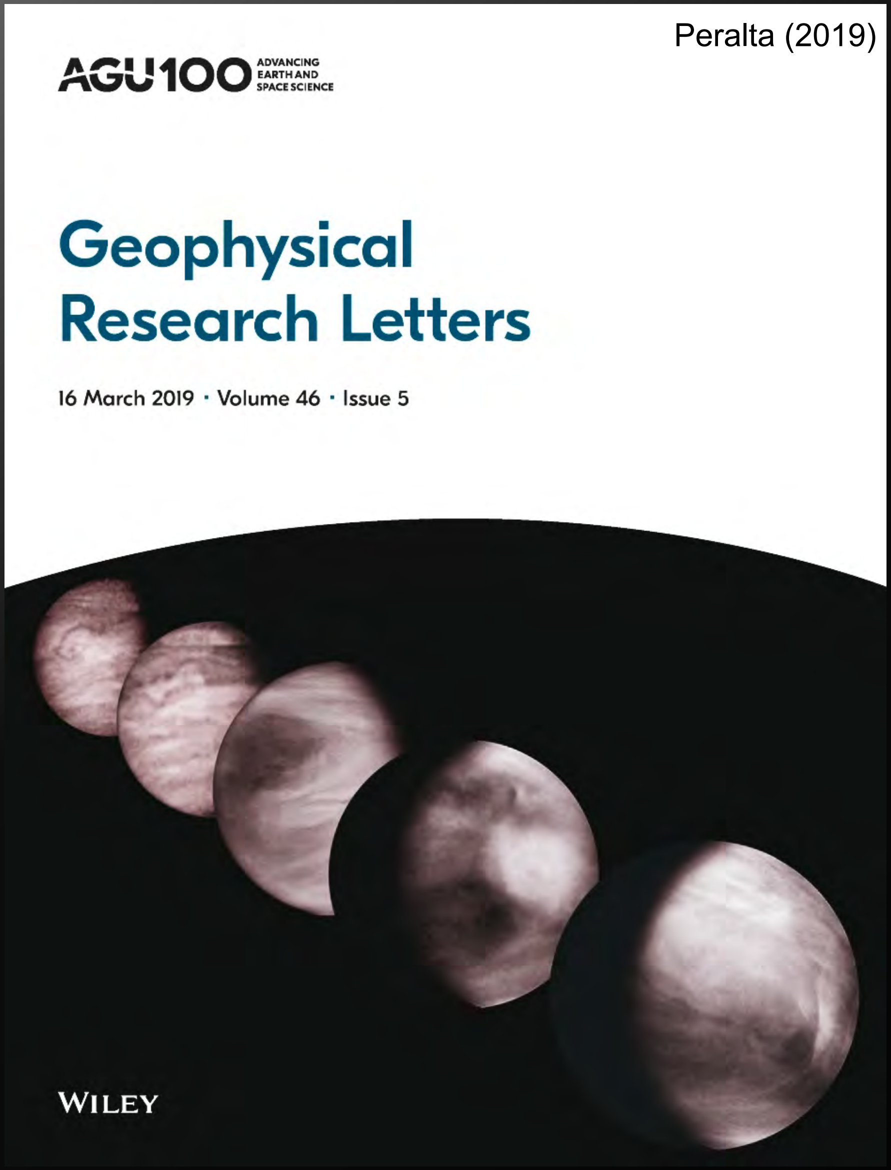


Mariner 10 (1973)

Akatsuki (2016)



DAY Middle Clouds at ~50-55 km (~800-950 nm)



DAY Middle Clouds at ~50-55 km (~800-950 nm)

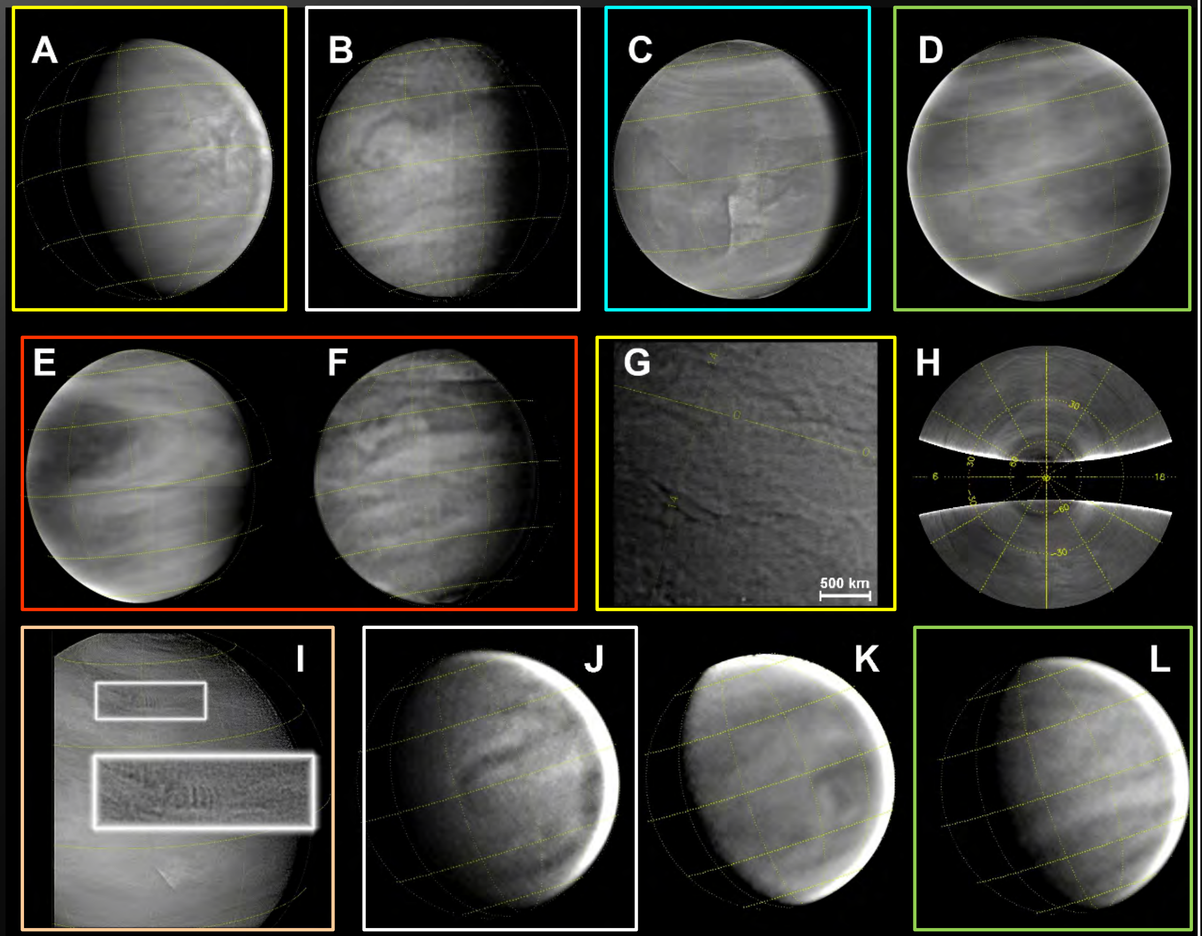
Images display a slightly darker band normally invaded by bright clouds, sometimes with swirl-shape and mottled aspect (A-C and G).

Turbulent regime seems to evolve to a laminar one, with clouds beco-ming homogeneously bright and/or featureless, with stripes with quasi-zonal orientation (D-F).

April–May 2016: north hemisphere up to 45ºN became periodically darkened (radiance decrease of ~ 5%) every 4-5 days (E-F).

The sharp albedo changes (C) involve a 1%-4% decrease in the photometrically-corrected radiance.

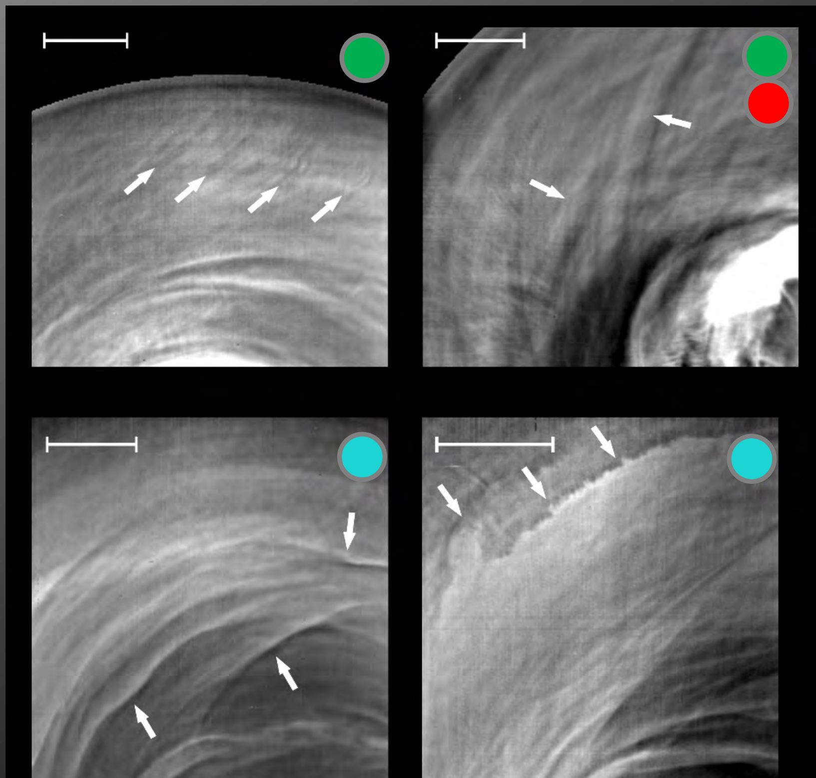
Hook-like dark filament on the north hemisphere appeared in May 2 (B) and October 5 (J), suggesting the development of shear instabilities.

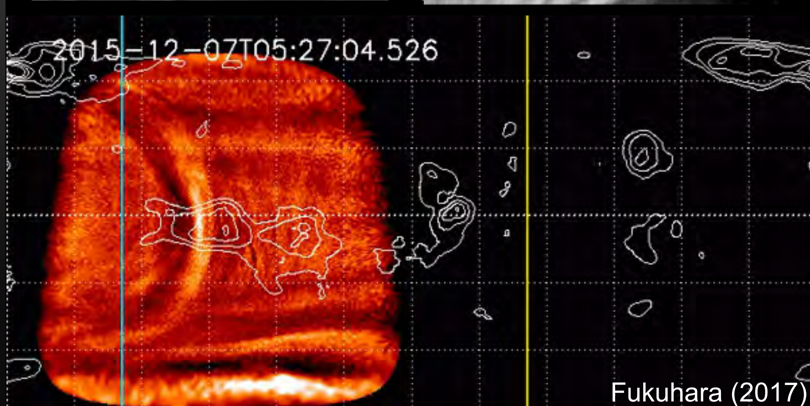


Peralta (2019)

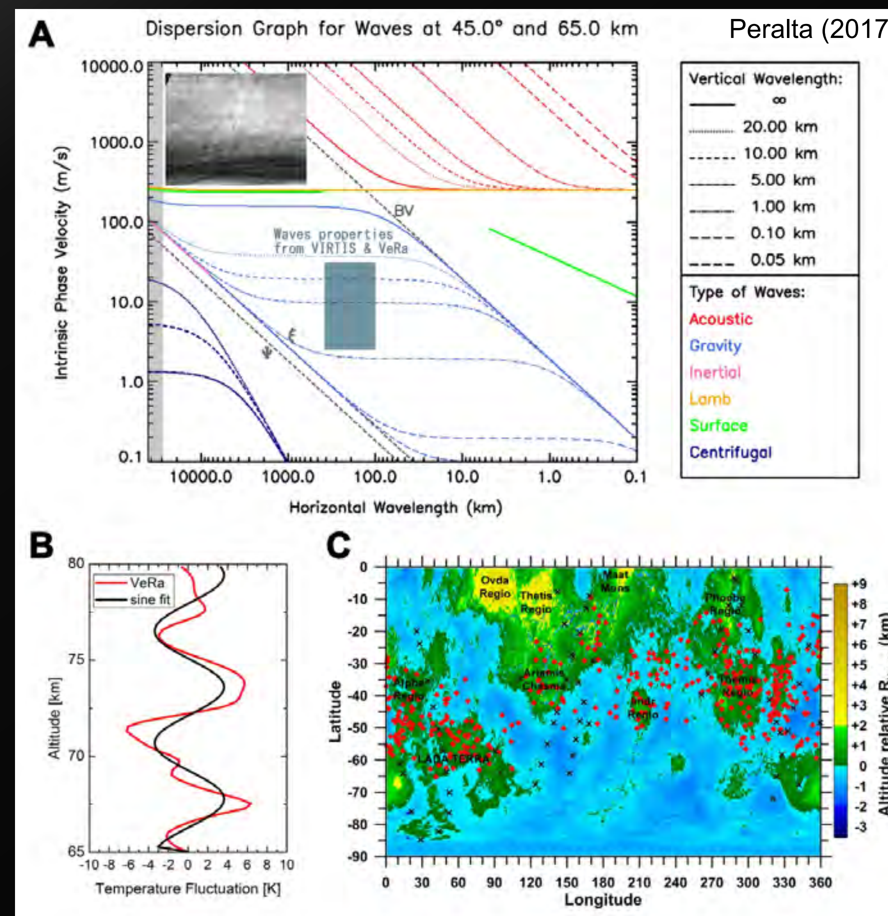
Gravity waves (I) are rare on NIR images and Kelvin-type waves like the Y-feature are also missing. This suggests that NIR images may be sensing altitudes where the static stability is low.

DAY/NIGHT Upper Clouds at ~60-75 km (3.8, 5,10 µm)





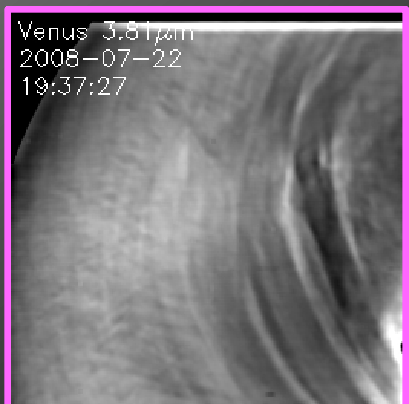
When we observe the thermal emission of the upper clouds, planetary and mesoscale stationary (Lee) waves are dominant along with new nocturnal phenomena.

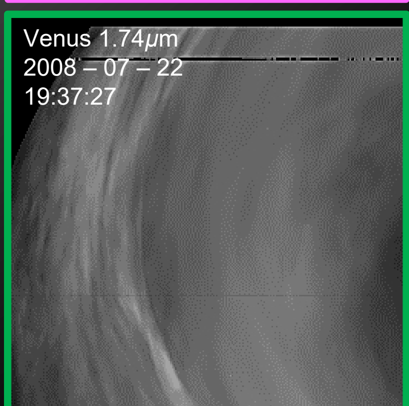


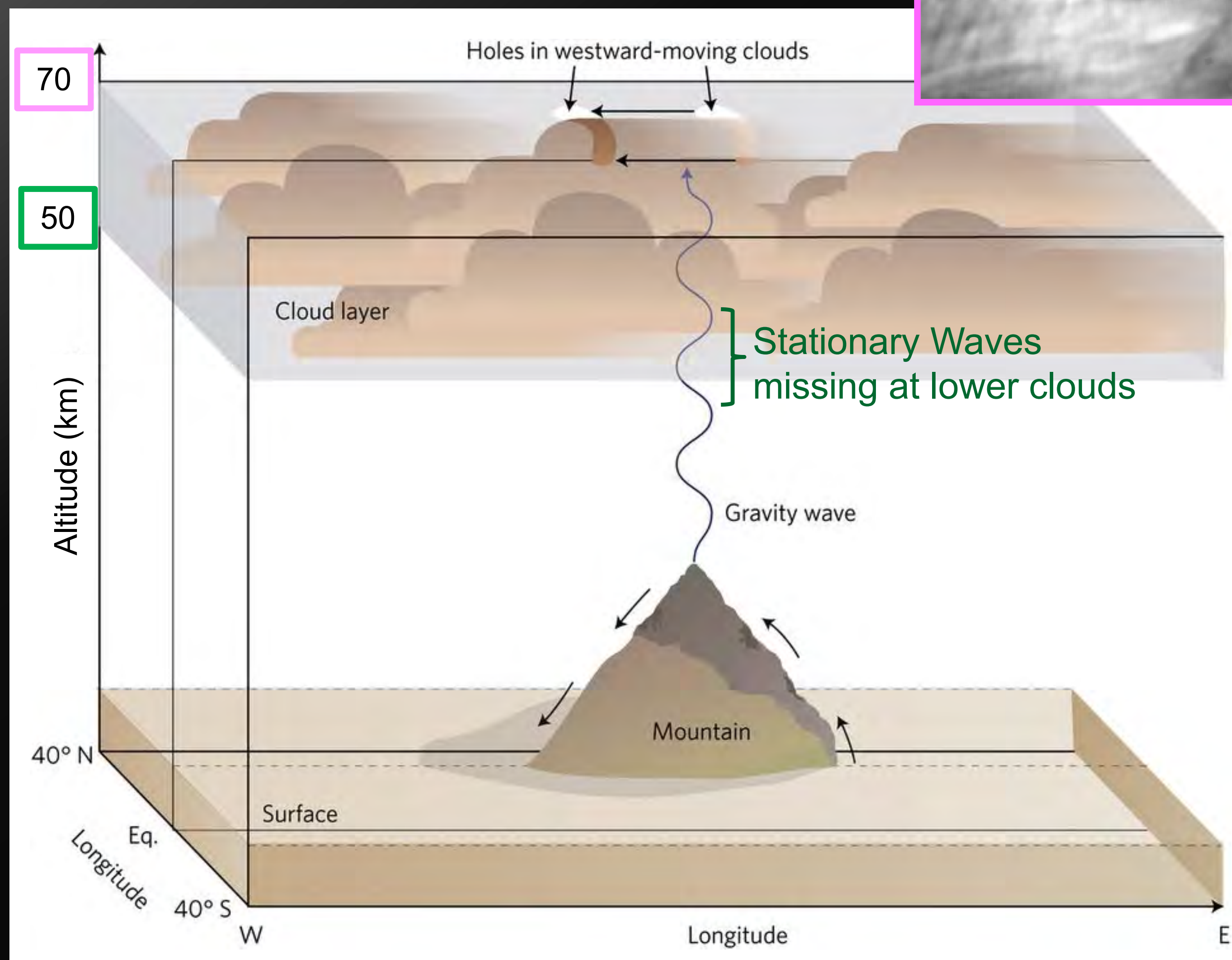
But wait… no Stationary Waves at Lower Clouds?

ESA's Venus Express nightside images at 3.8 and 5.0 μm frequently display between 20ºS-60ºS abundant stationary waves the upper clouds. These are **MISSING at INTERMEDIATE LEVELS.**

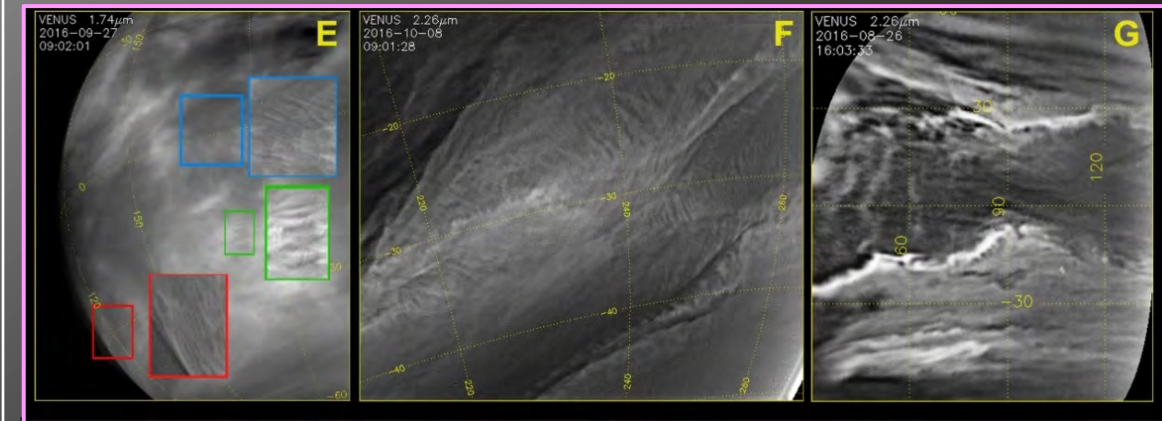
Peralta (2017)







NIGHT Lower Clouds at ~48-60 km (1.74, ~2.3 µm)



Mesoscale Waves

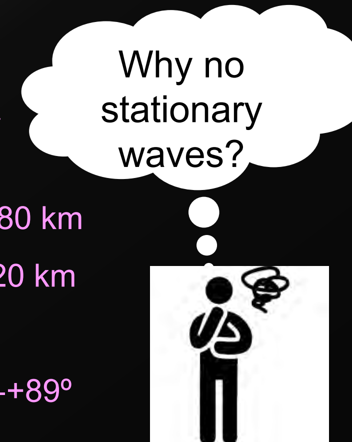
Cases: 13

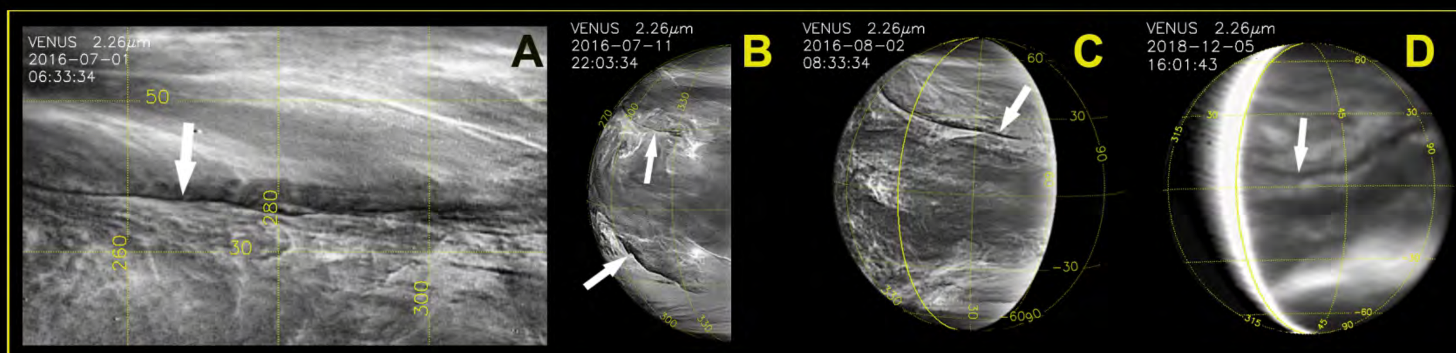
Length: 356 —1,380 km

Width: 166 — 3,320 km

λ: 66—335 km

Orientation: -87º—+89º





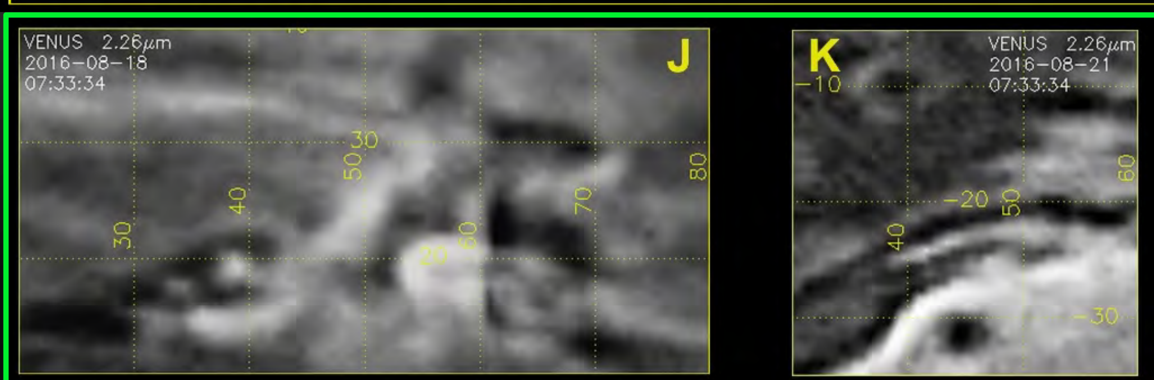
Dark Spirals

Cases: 8

Length: >8,500 km

Width: 35 — 300 km

Orientation: -38º



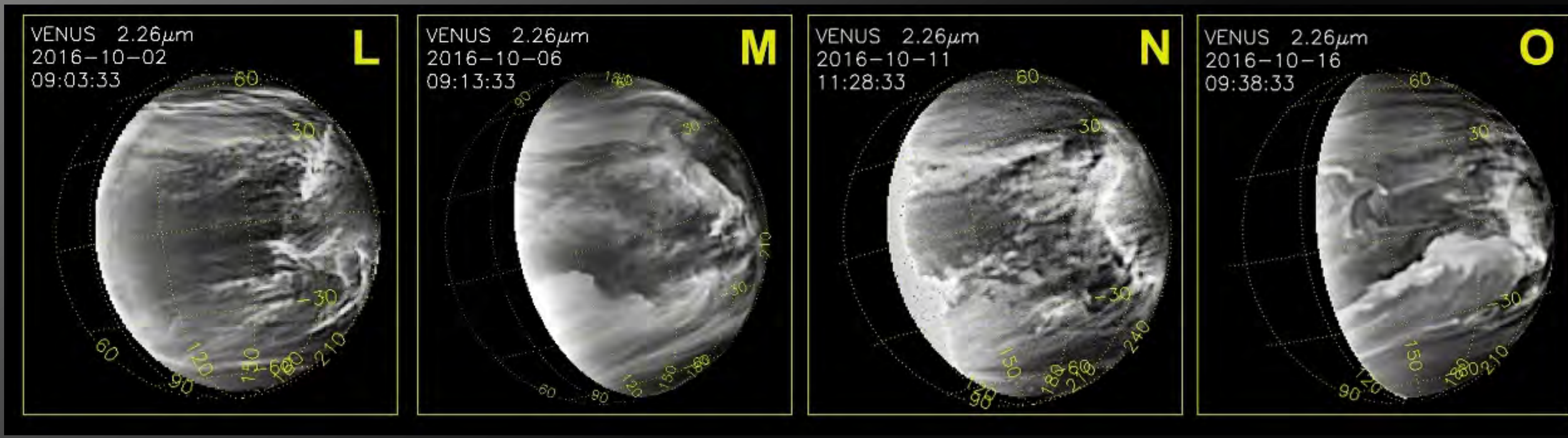
Dark Spots

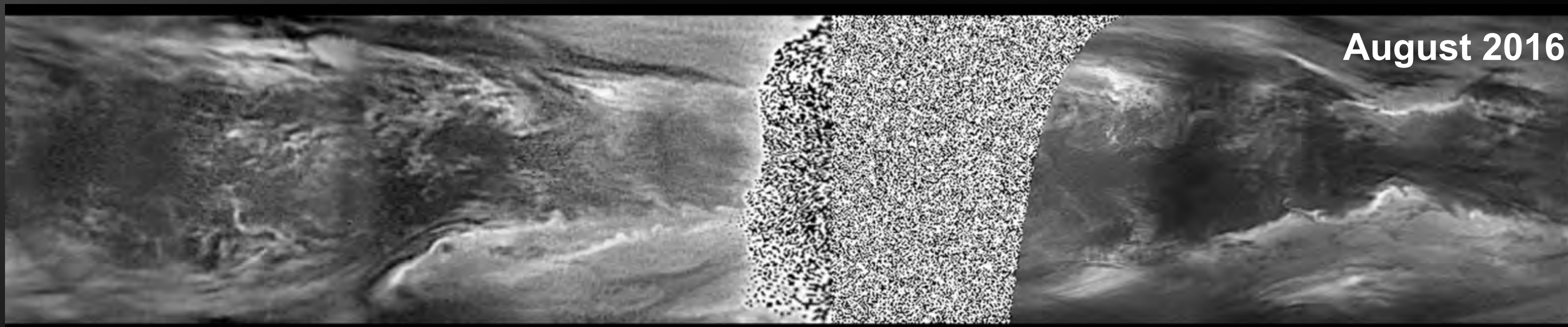
Cases: 46

Length: 280 — 1,430 km

Peralta (2019)
"New cloud morphologies discovered on the Venus's night during Akatsuki"

NIGHT Lower Clouds: a Bright Trough in 2016



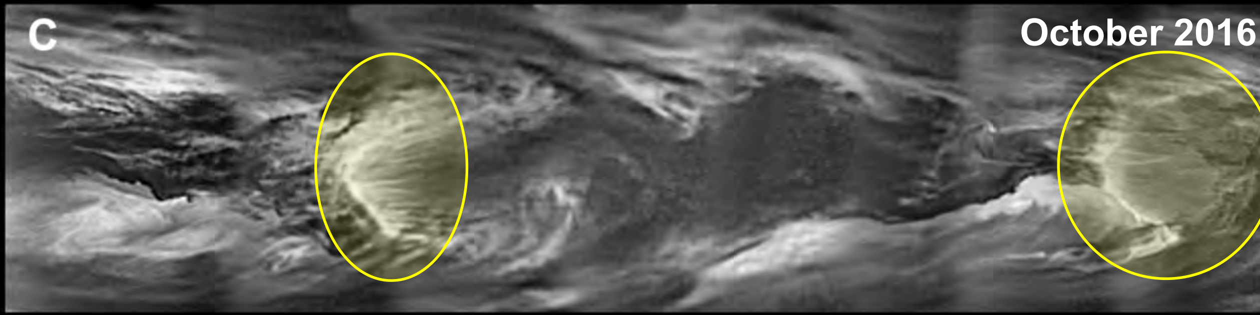


Bright Trough

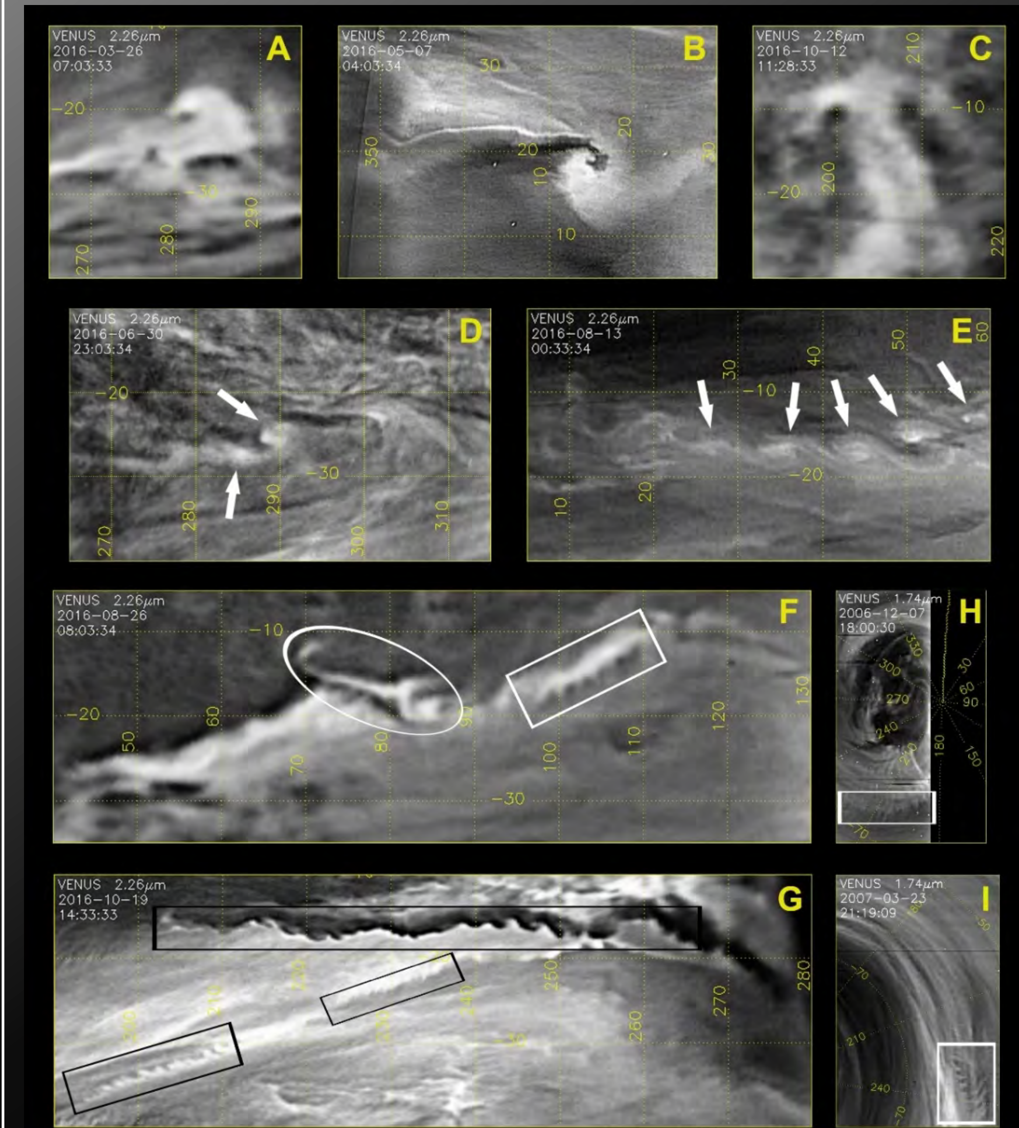
Length: 3,580 km —
8,600 km

Width: 260 km —
1,300 km

Orient: +42º(N) -45º(S)



NIGHT Lower Clouds: Vortices and Shear Waves



KH Billows & Vortices

Cases: 31

Length: 90 -2,540 km

Wavelength: N/A

Orientation: N/A

Shear Waves

Cases: 22

Length: 950-6,580 km

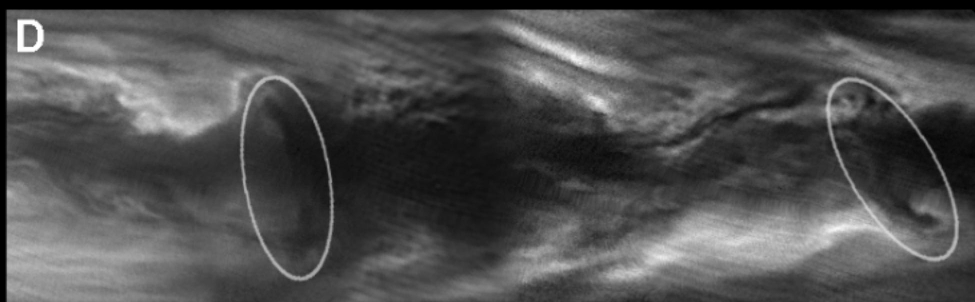
Wavelength: 100-2,575 km

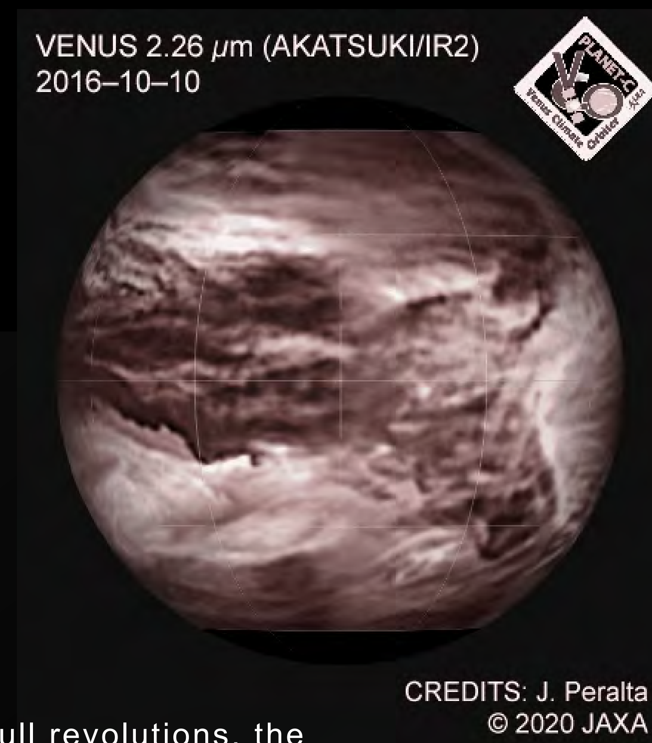
Orientation: -40º-+30º

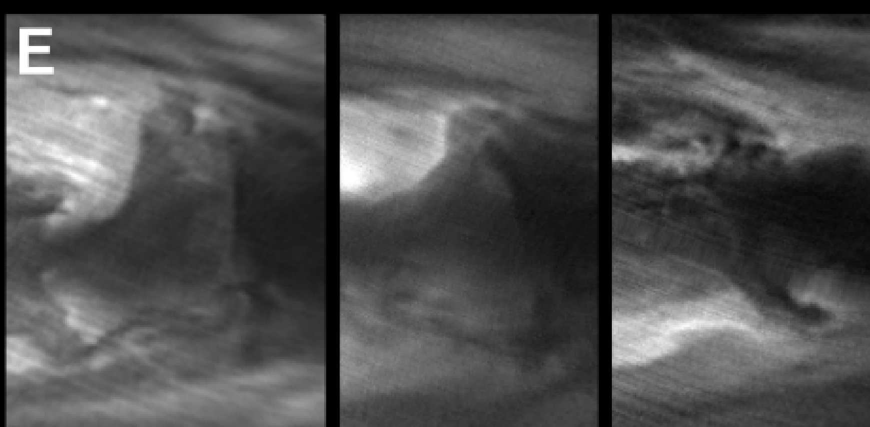
NIGHT Lower Clouds: a Disruption missing for years

During October 2016 mid-latitude bands merged at equator and gave birth to a bright through.

In December 2018 the disruption had become intense again.





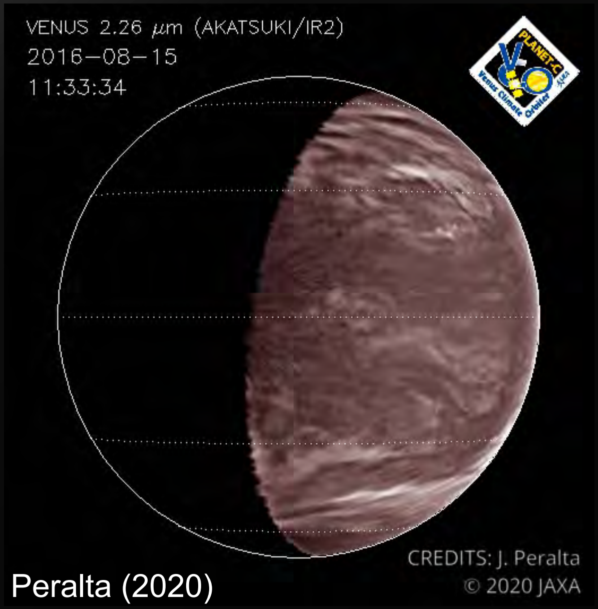


After 3 full revolutions, the disruption clearly overpass the other clouds: KELVIN WAVE??

NIGHT Lower Clouds: a Disruption missing for years

DISRUPTION ACCORDING TO OBSERVATIONS:

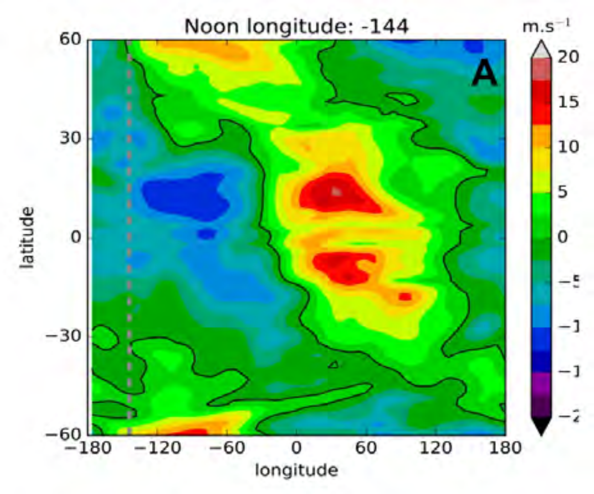
- The night lower clouds follow a cycle dominated by a recurrent cloud discontinuity of disruption.
- It propagates faster than wind at 30ºN-40ºS with a period of ~4.8 days, keeping coherent for weeks.
- The discontinuity importantly alter clouds' properties and, sometimes, even aerosols' distribution.
- Quasi-permanent phenomenon: on Venus since 1983.
- Its absence at upper clouds and rotation period suggests a Kelvin wave that dissipates before arriving upper clouds.



Peralta (2020)

DISRUPTION ACCORDING TO IPSL VENUS CGM:

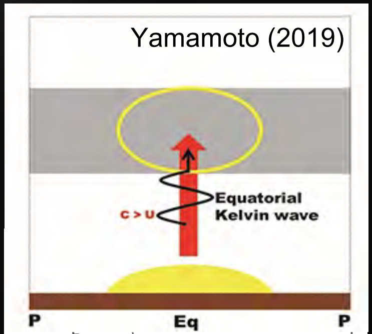
- A nonlinear Kelvin Wave reproduces many of its properties.
- Generated below the clouds. It appears even when surface topography is "switched off" in the GCM.
- Wave amplitude peaking at ~57 km and rotation period is sensitive to zonal winds below the clouds.
- Dynamic feedback between cloud properties and circulation yet to be implemented in IPSL GCM: long work ahead!

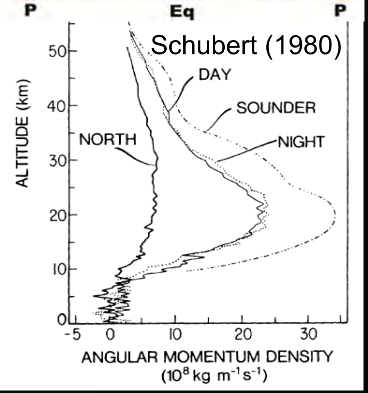


Elements of Strategy for the Future

Pending Questions:

1) Below the Clouds: HOW TO measure winds? How is the circulation below & momentum transported?
2) Above the Clouds: HOW TO increase wind vectors? How is the transition between the Super-rotation and the Solar-to-AntiSolar Circulation?
3) Inside the Clouds: HOW TO measure the amplitude of the mesoscale Waves? How are they excited and dissipated? Which is the role of dynamic instabilities? HOW TO obtain windspeeds with higher precision and Vertical Winds?
4) Disruption: Where is it generated/dissipated? Which is its role in the momentum budget, energy balance and chemistry?
5) Is there a long-term change in the climate of Venus?





Elements of Strategy for the Future:

- Motions Below the Clouds: new spectral windows, Doppler winds, track minor gases below clouds...
- Motions Above the Clouds: Doppler winds with remote sensing, new spectral windows...
- Vertical Winds: Dynamic and Adiabatic methods, time variation cloud top altitude (CO_2 bands).
- Focus on Long-term studies: increase ground-based monitoring, past data restoration/revision.

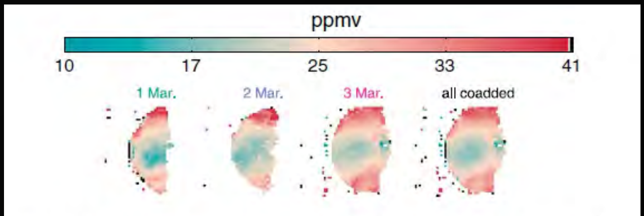


Figure 20. CO measurements in 2009. We see evidence of more CO in the northern hemisphere than the southern hemisphere.

Arney (2014)