Large stationary gravity waves:

a game changer for Venus' science

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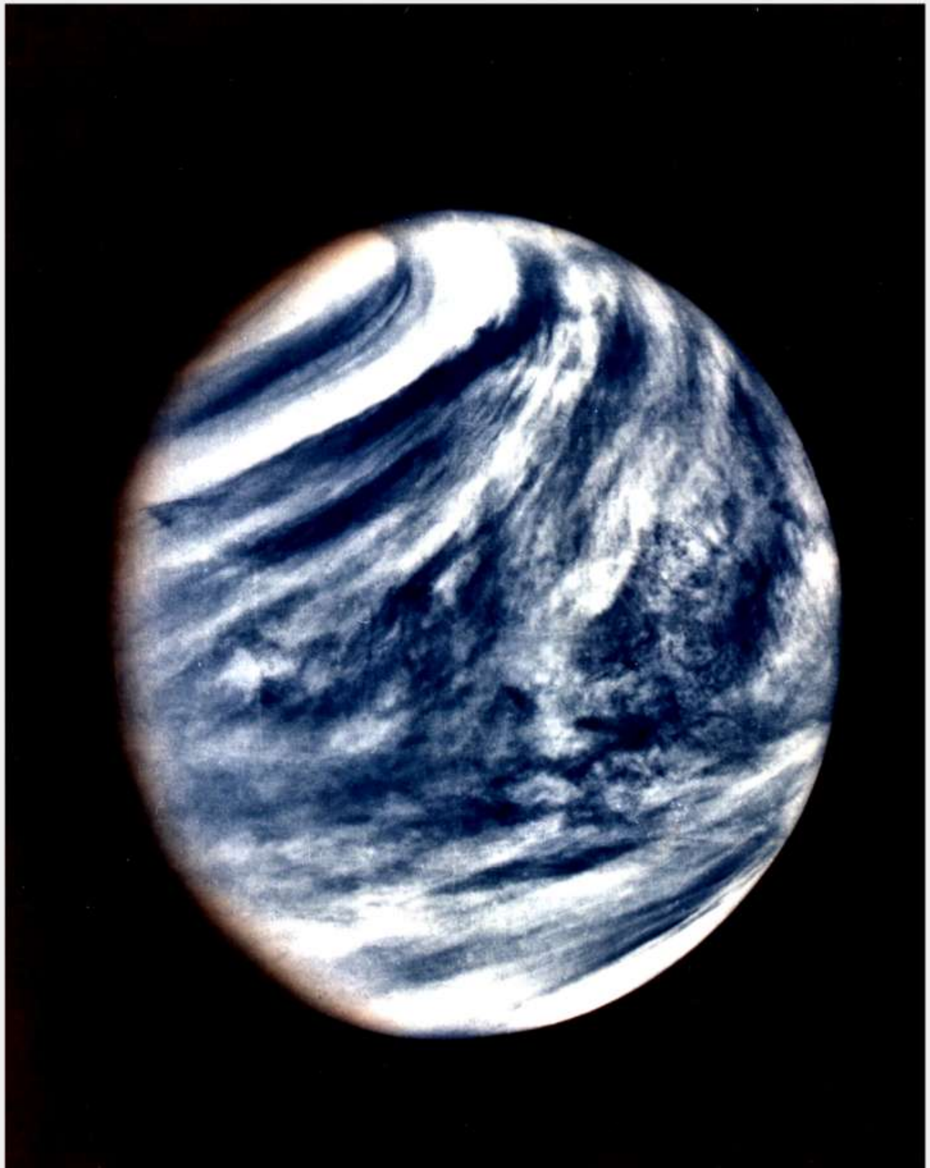
Venera-D workshop Moscow, October 2017

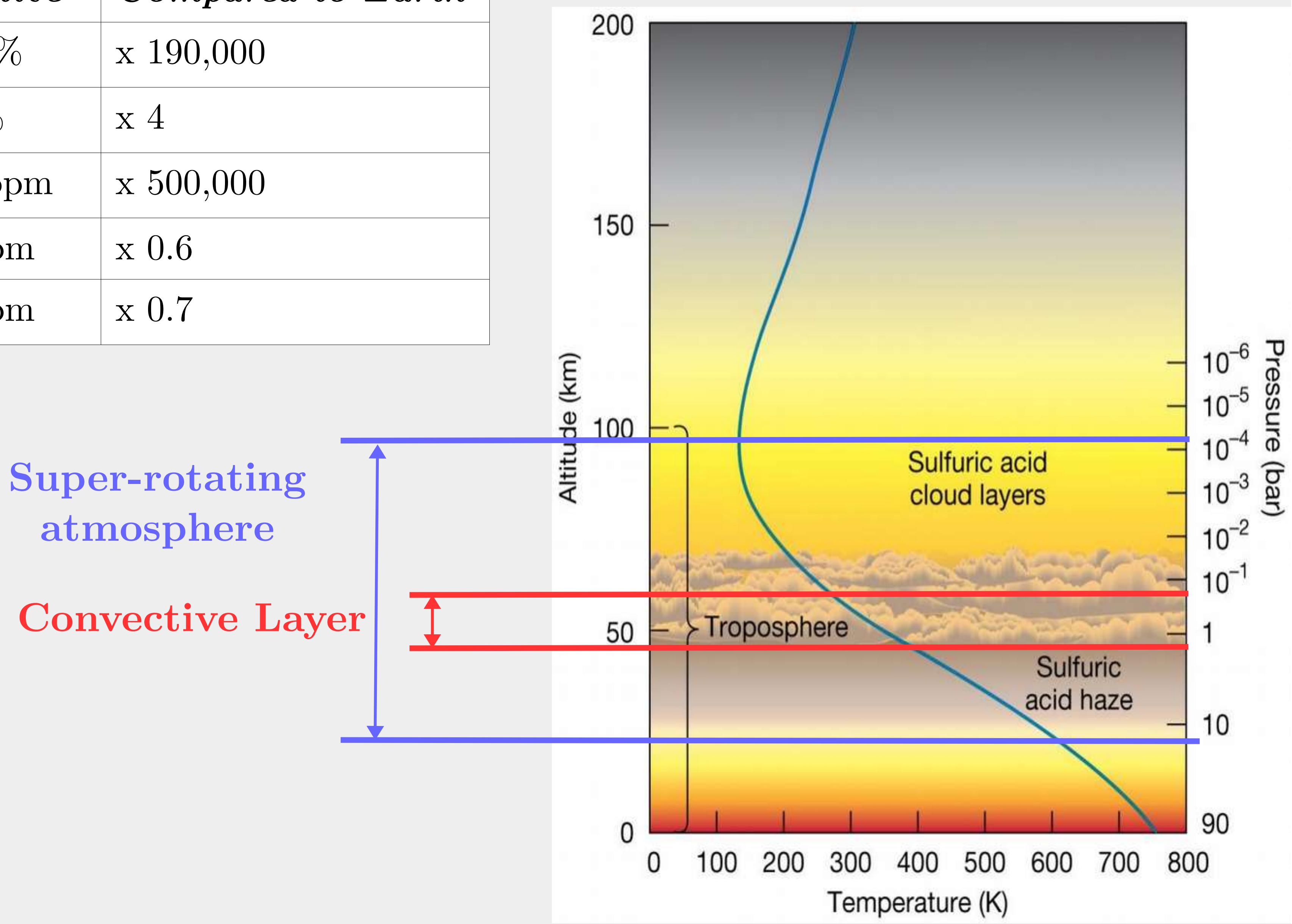


Credit: Mariner 10/NASA

VENUS FACTS	
Mass	0,815 $M_{\oplus}$
Radius	0,95 $R_{\oplus}$
Obliquity	177,4°
Year	224 days
Sidereal day	243 days
Solar Day	117 days
Super-rotation	4 days at 60 km
Interior	???

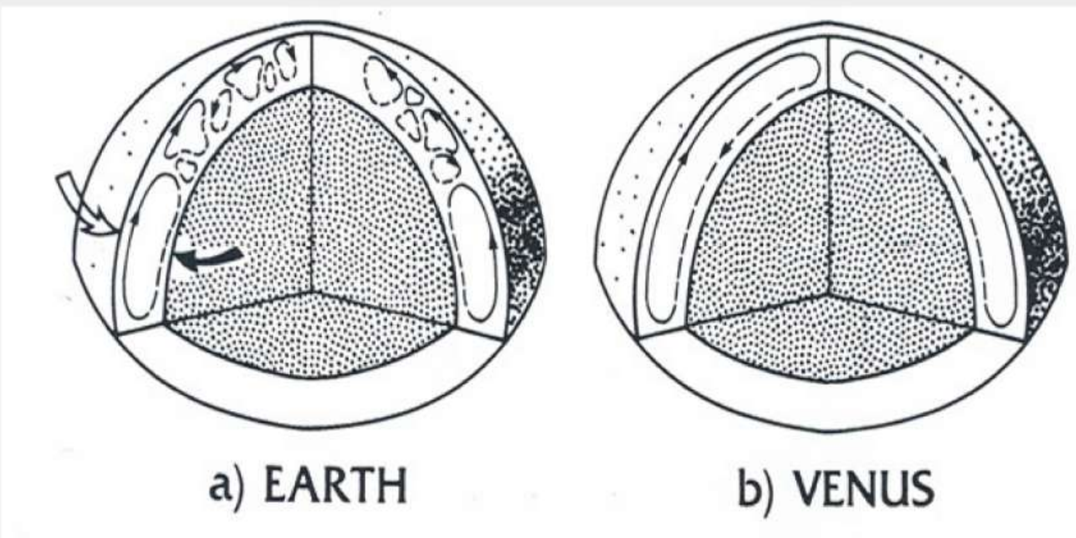
COMPOSITION		
Species	*Relative*	*Compared to Earth*
CO_2	96,5 %	x 190,000
N_2	3,5 %	x 4
SO_2	150 ppm	x 500,000
Ar	70 ppm	x 0.6
H_2O	20 ppm	x 0.7

Credit: Pearson Education

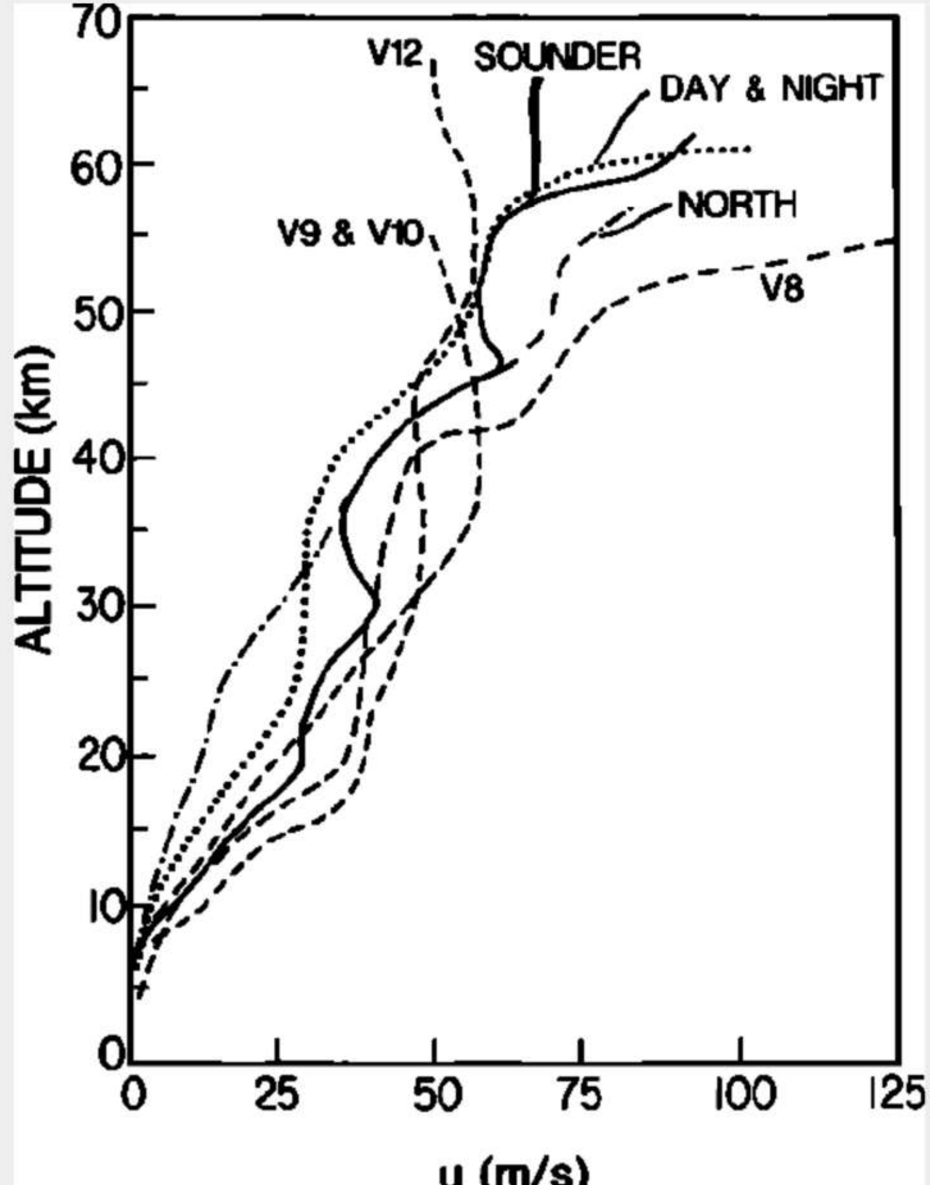


- Super-rotation :

  - General circulation



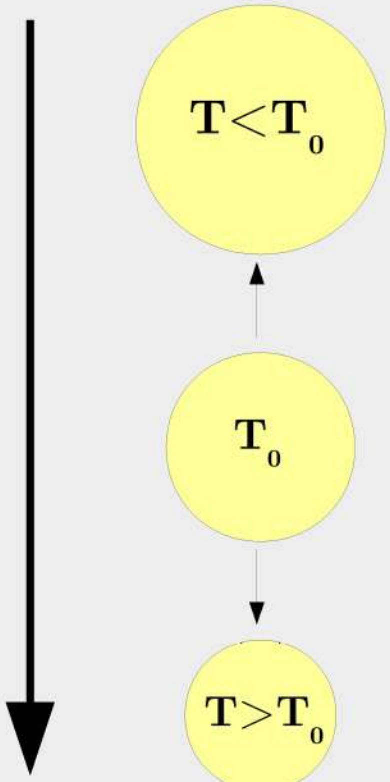
  - Diurnal tide



From Schubert et al., 1980

Stability of the atmosphere

Pressure, Temperature

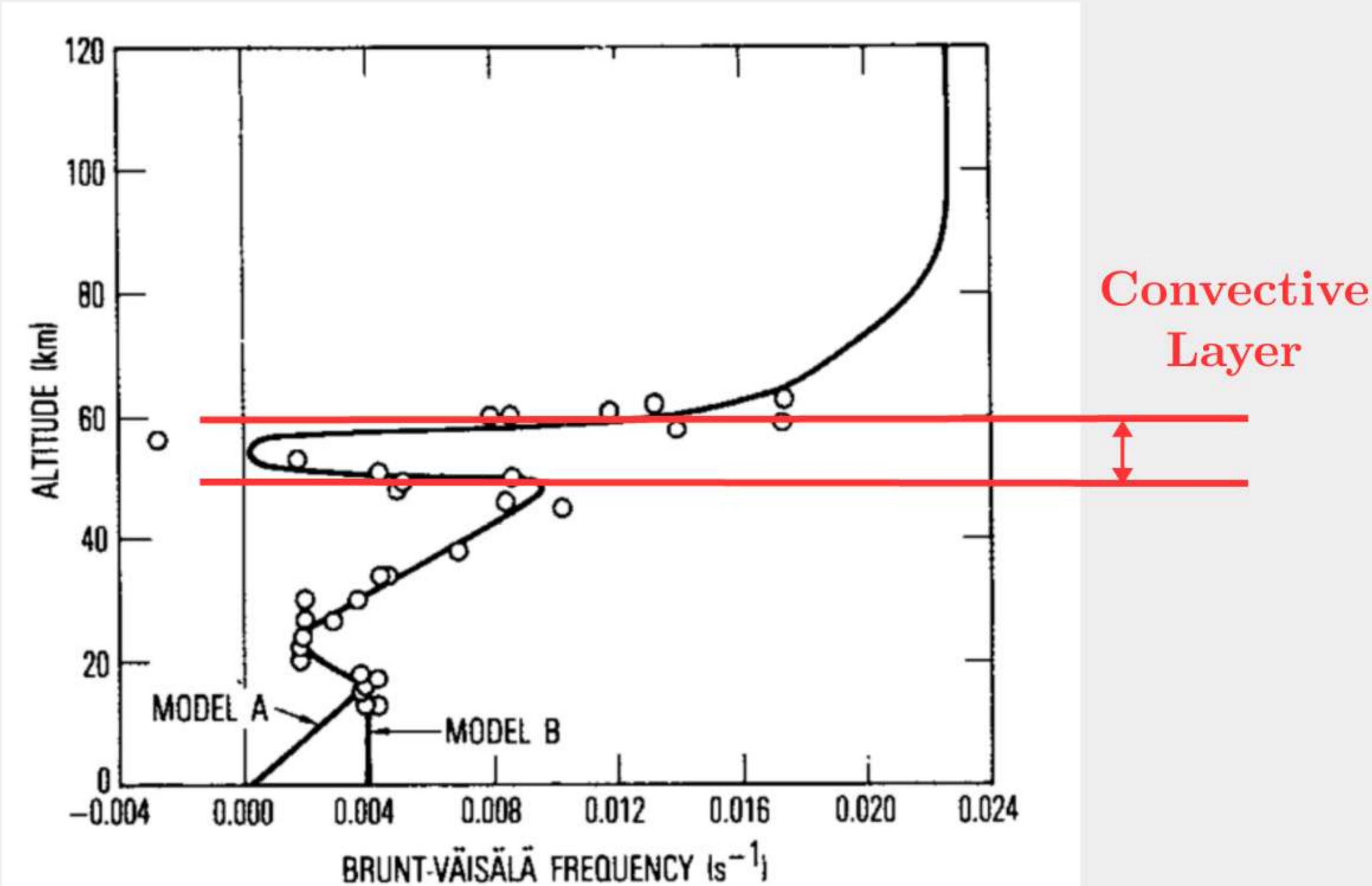


Potential Temperature

$$\theta = T\left(\frac{P_0}{P}\right)^{\frac{R}{C_p}}$$

Brunt-Vaisala Frequency

$$N^2 = \frac{g}{\theta}\frac{d\theta}{dz}$$

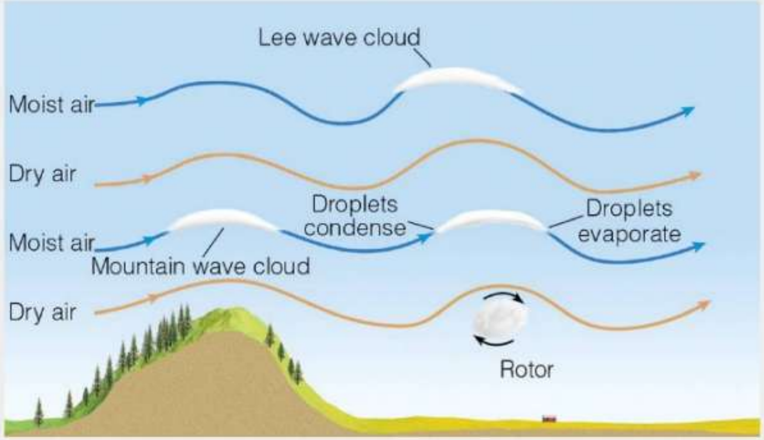


From Schubert et al., 1984

Gravity waves

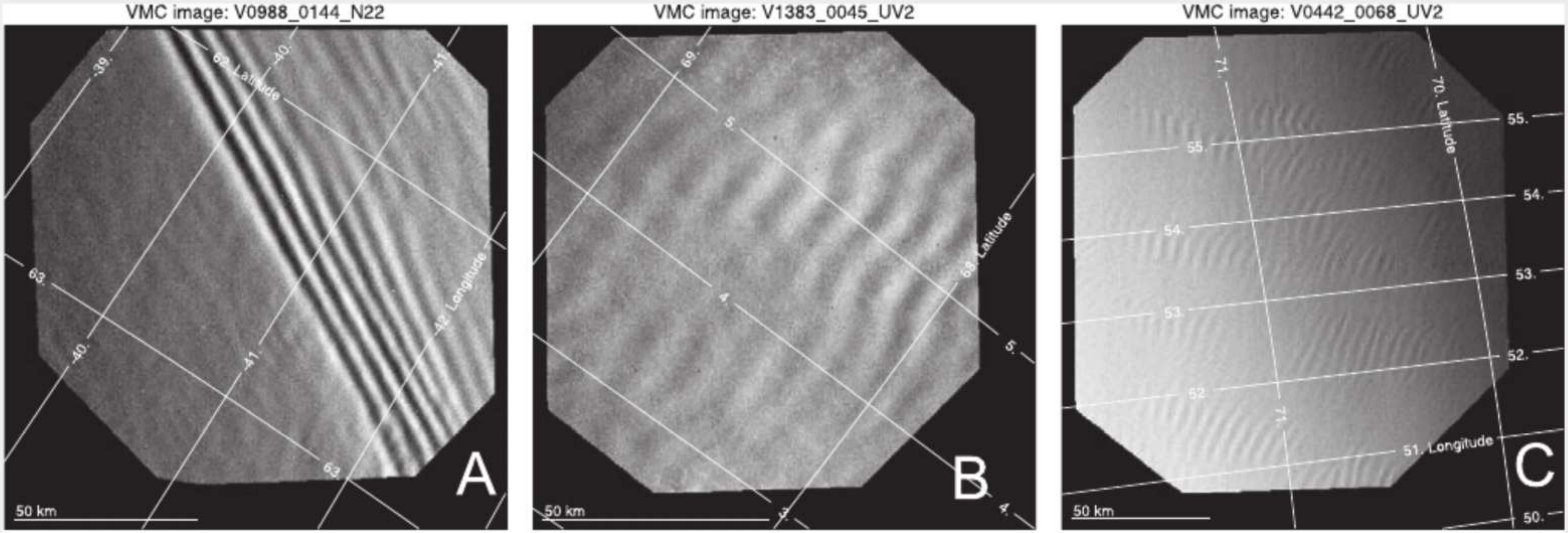
Credit: WeatherFlow

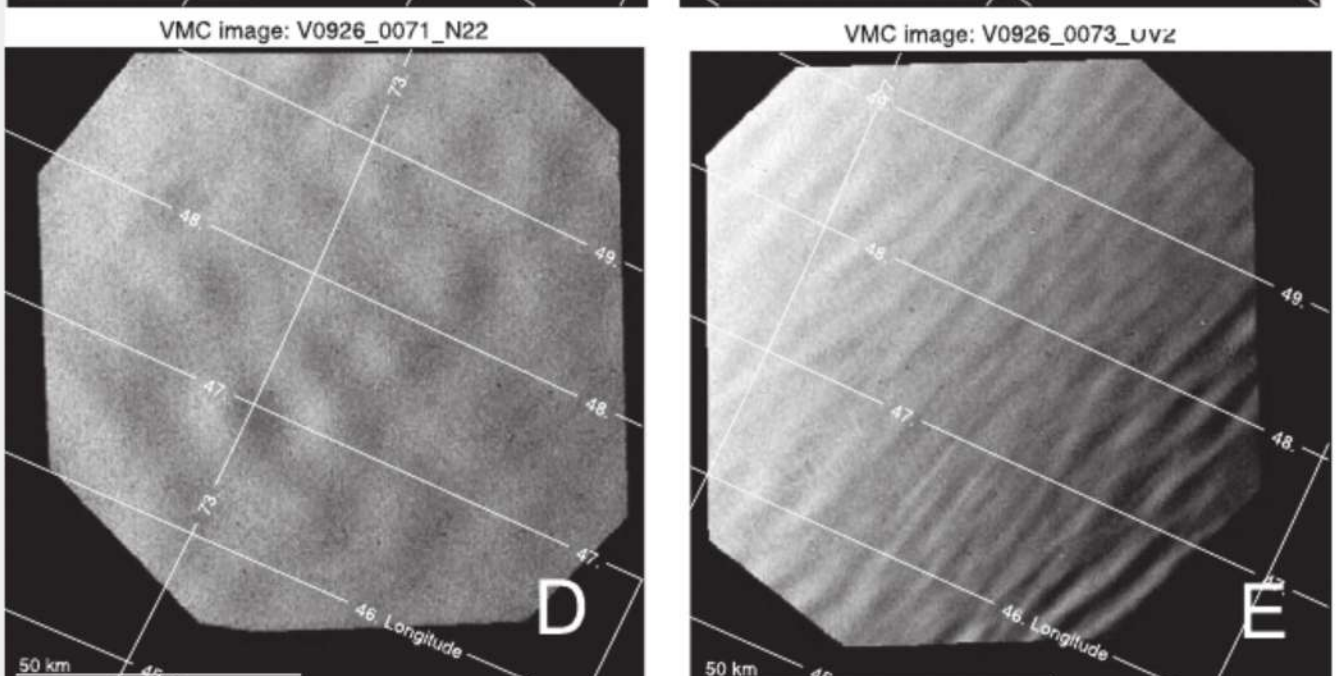
Credit: NASA Earth Observatory



Credit: Thomson Higher Education

Gravity waves



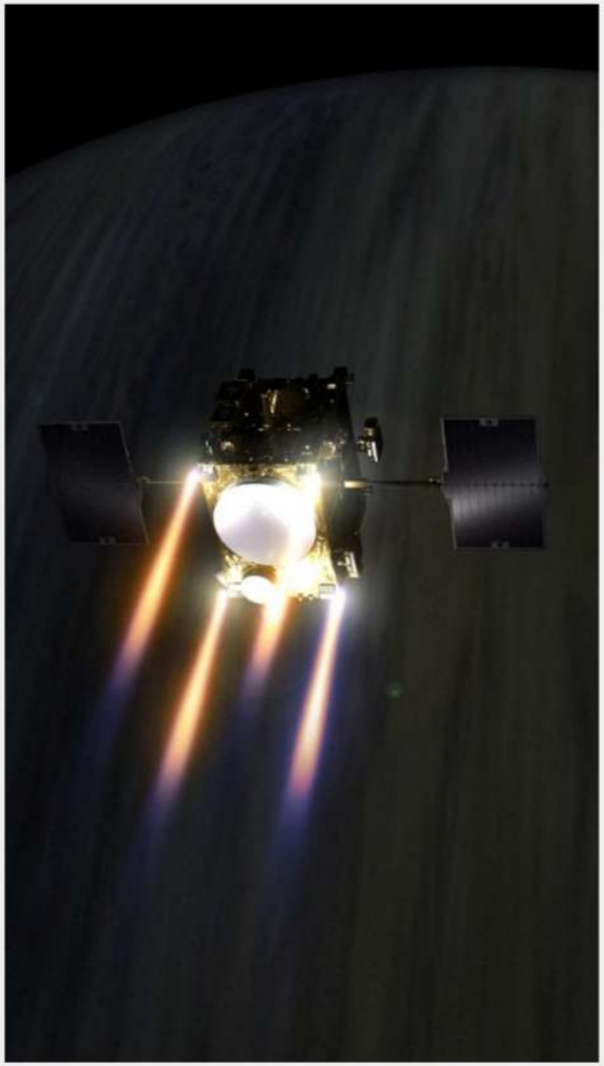


50 km

Venus Express observations from Piccialli et al., 2014

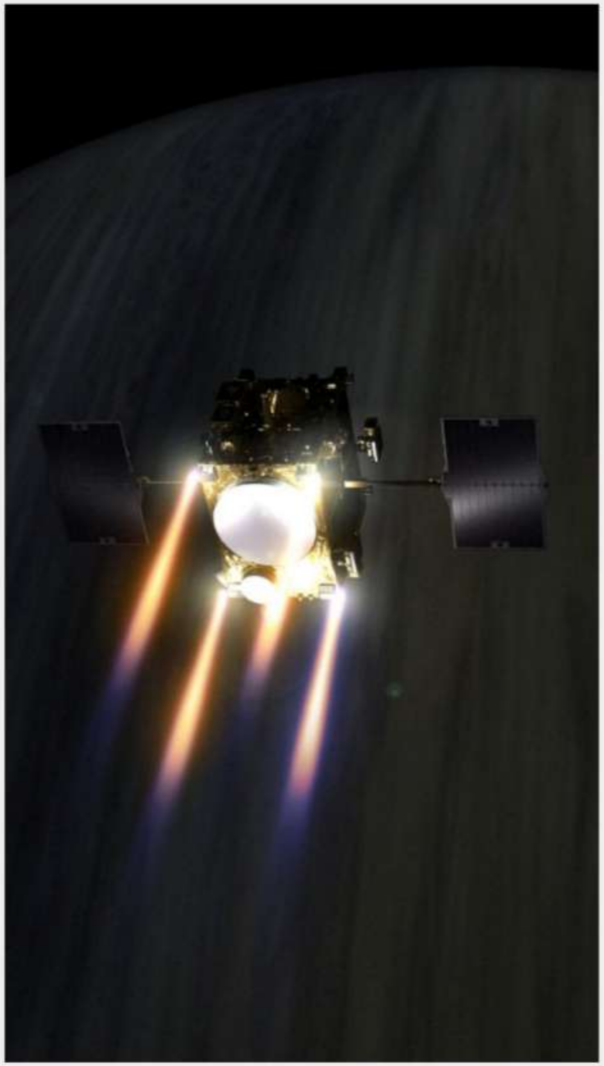
Credit: ESA

Akatsuki spacecraft



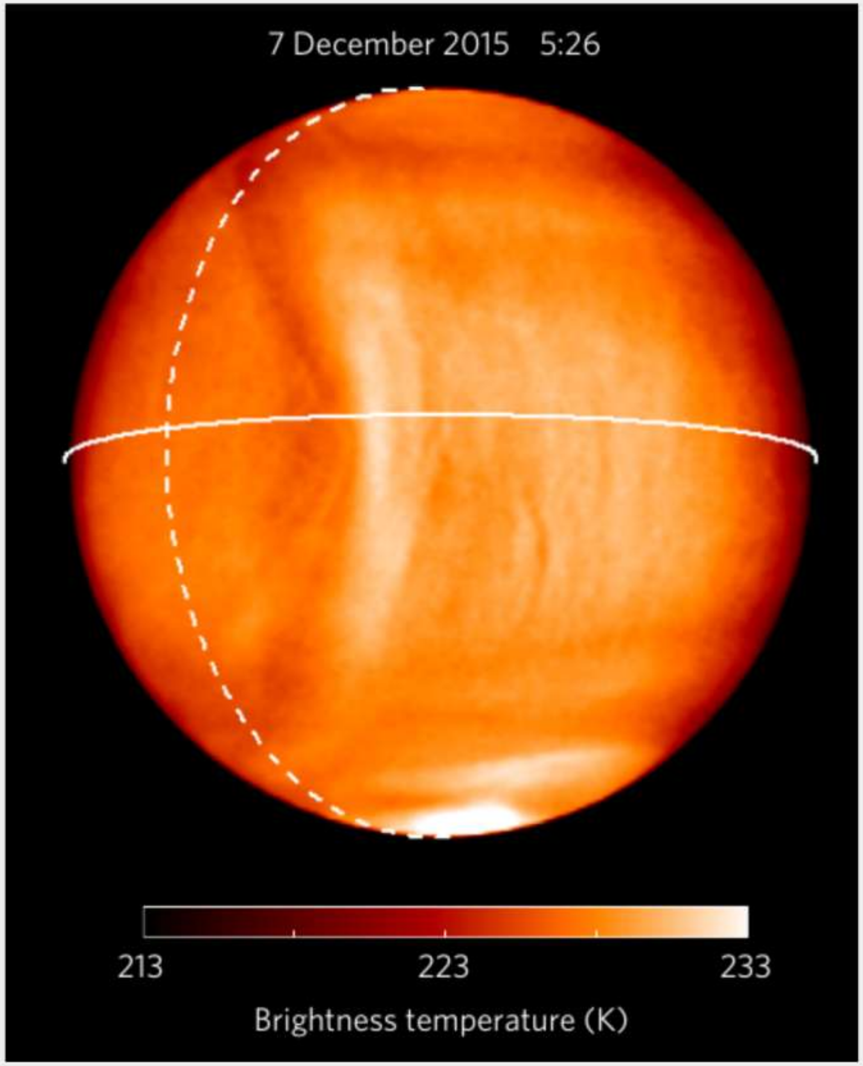
Credit: Go Miyazaki

Akatsuki spacecraft



Credit: Go Miyazaki

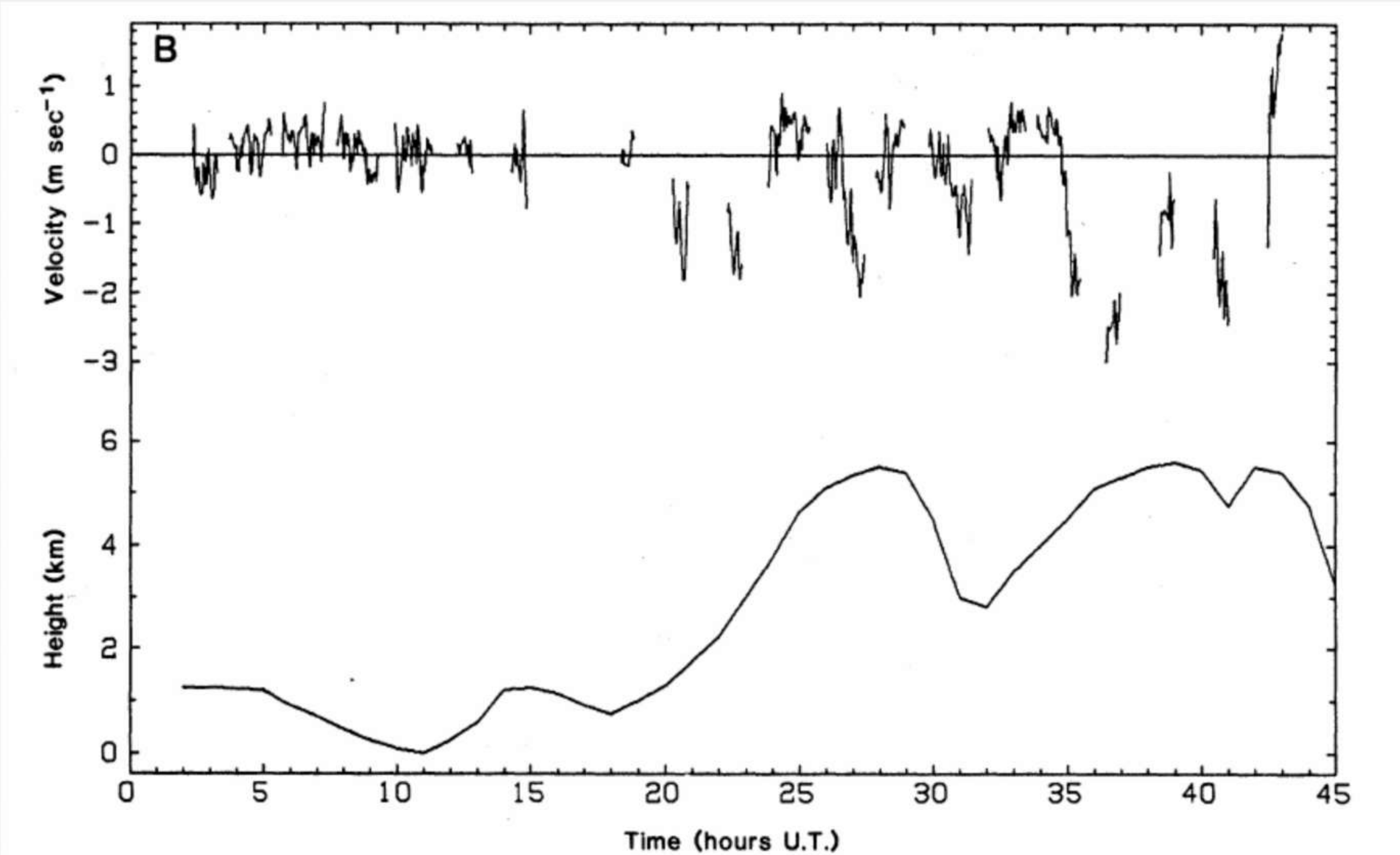
From Fukuhara et al., 2017



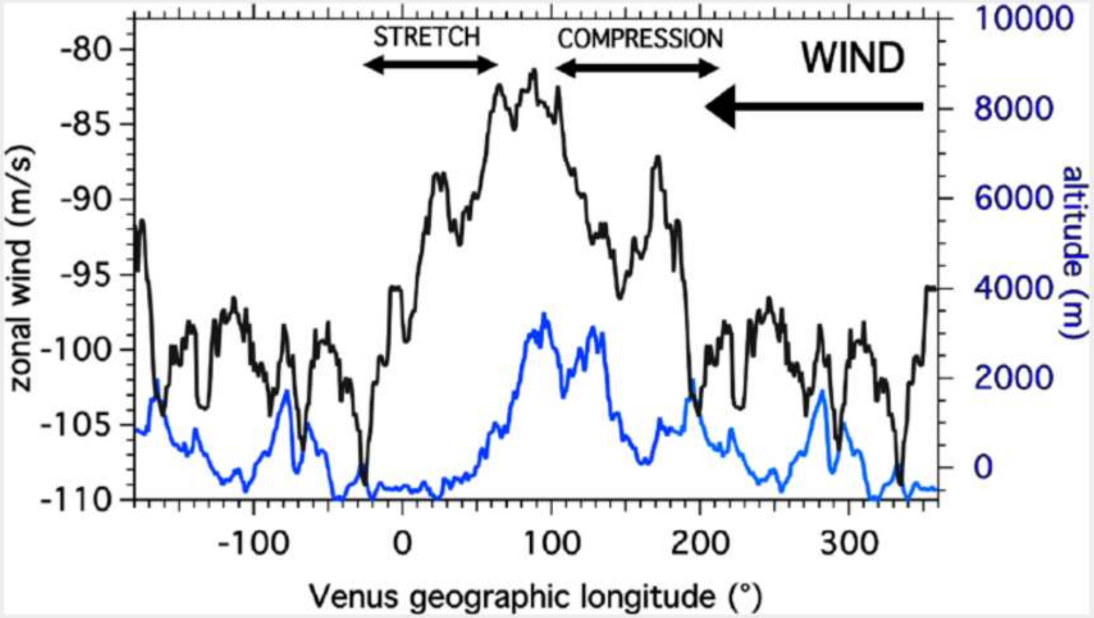
A stationary bow feature at 70 km altitude!

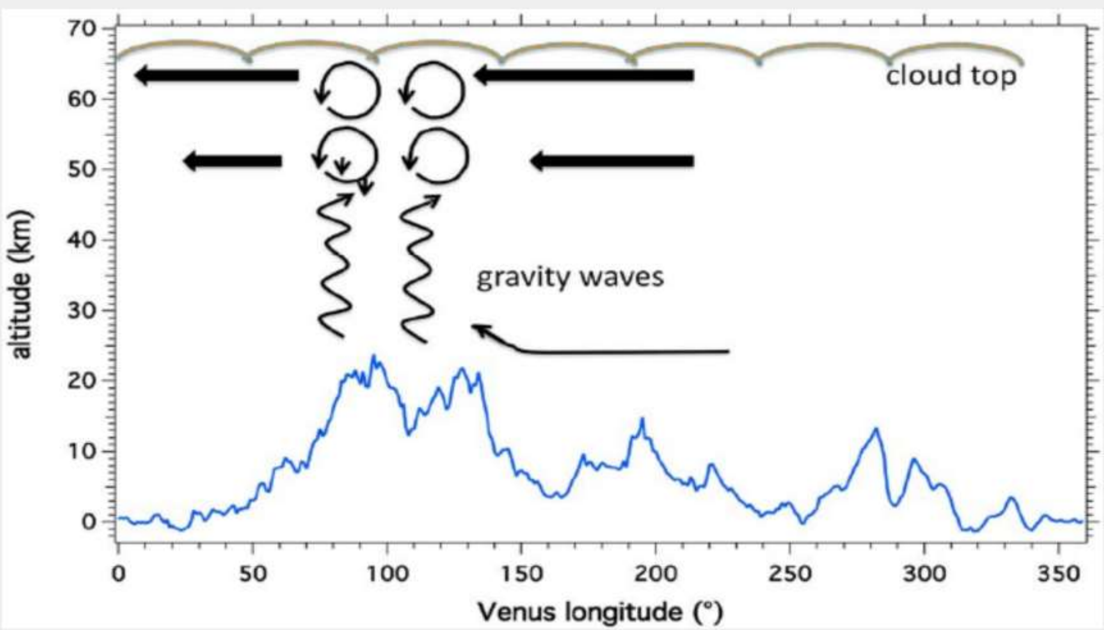
VEGA Balloon

Blamont et al., 1986



Venus Express winds



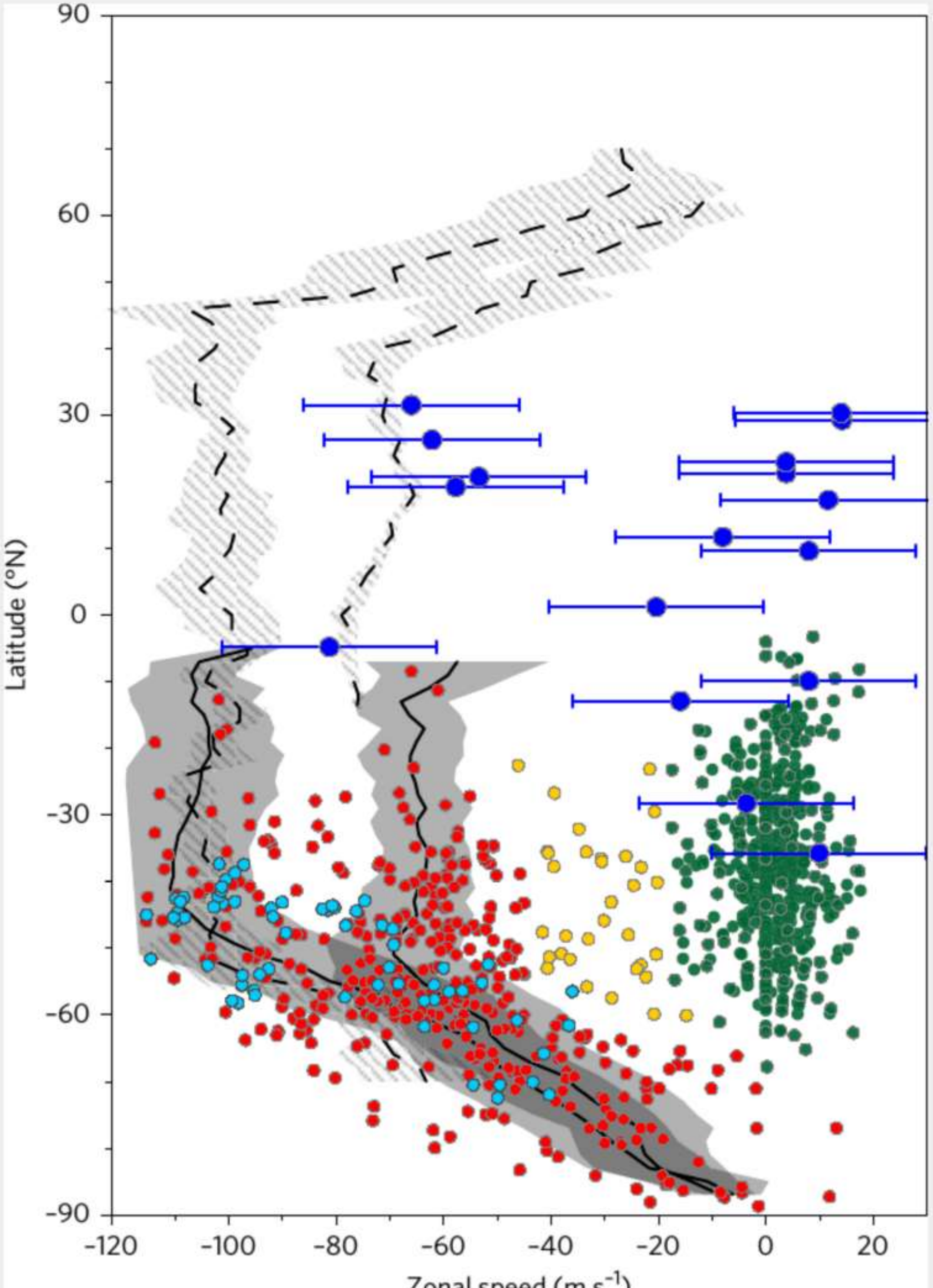


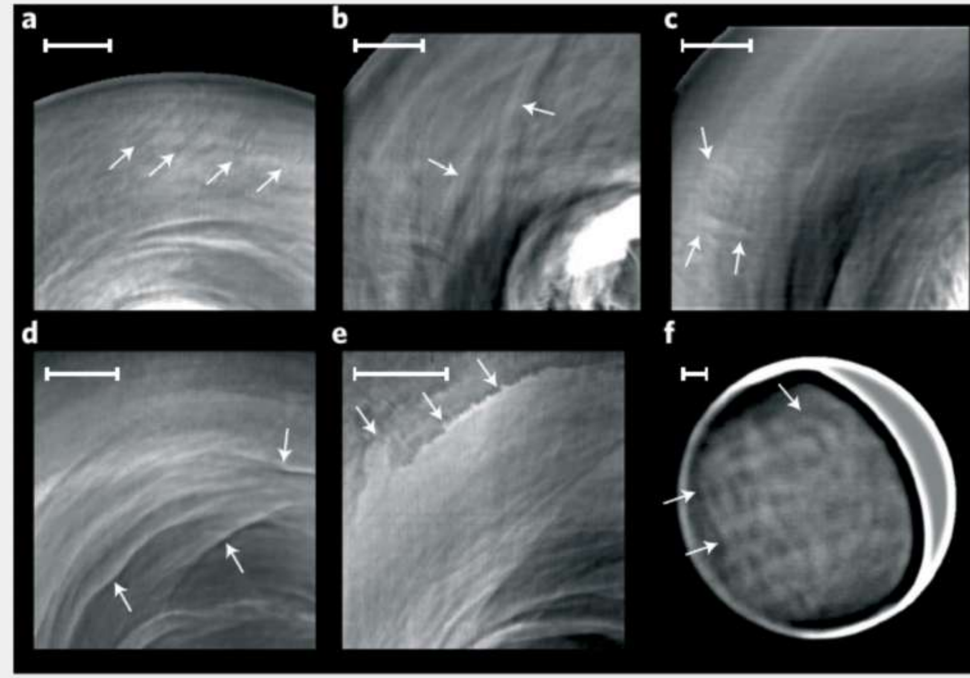
Bertaux et al., 2016

- Winds from tracking of UV images of the Venus Monitoring Camera

- There is a zonal anomaly in the averaged climatology of winds, above Aphrodite.

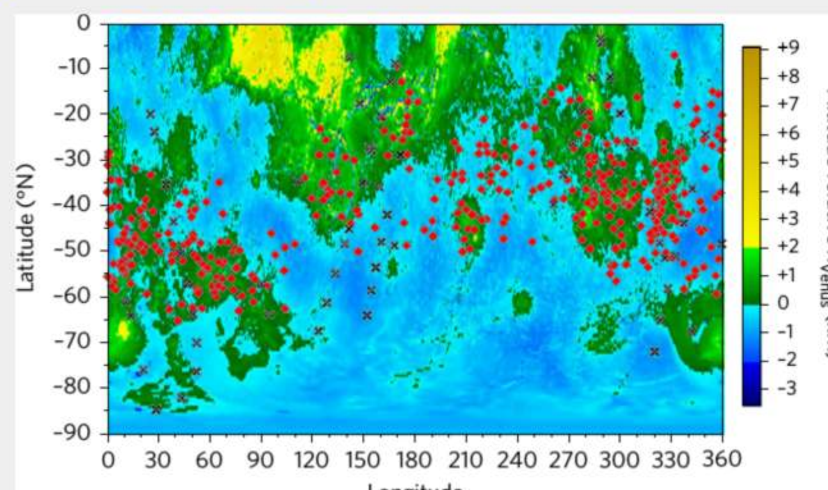
Venus Express features (Peralta et al. 2017)





(a) "Wavy patterns" from VIRTIS

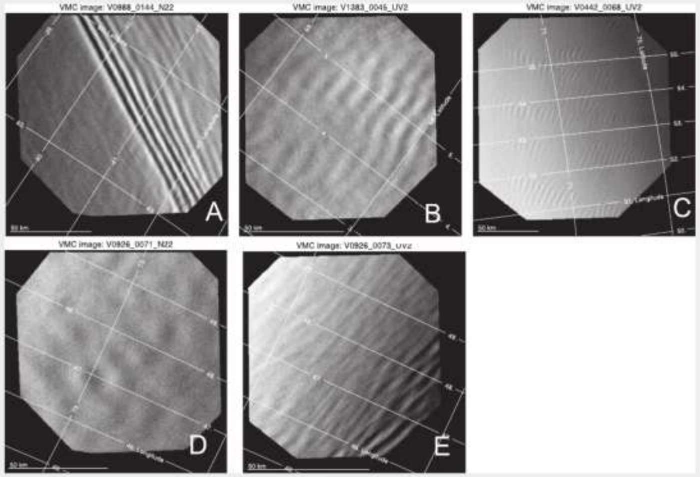
(f) "Bow-shaped" features from IRTF

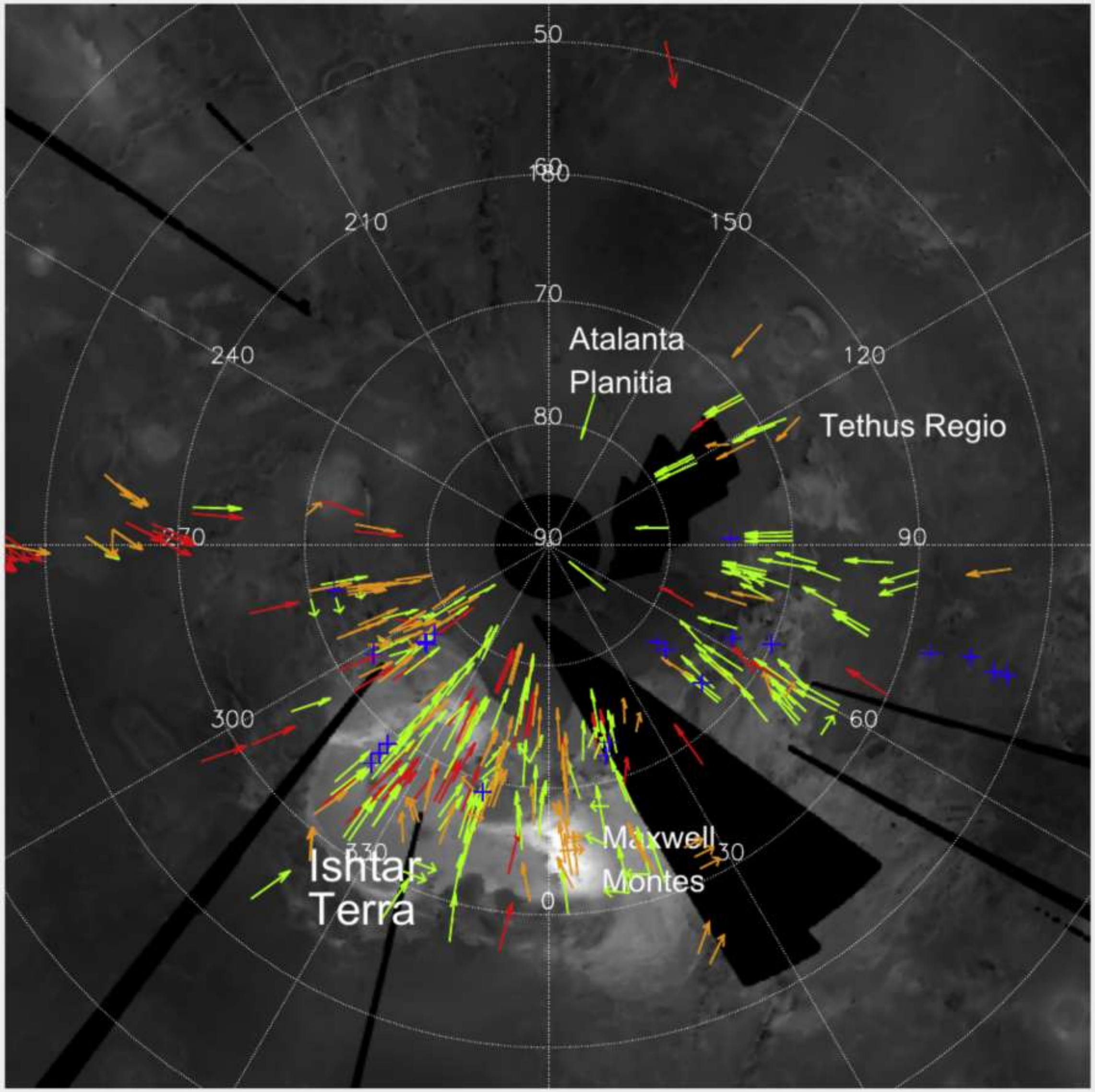


Venus Express features

Green: long waves

Red: short waves

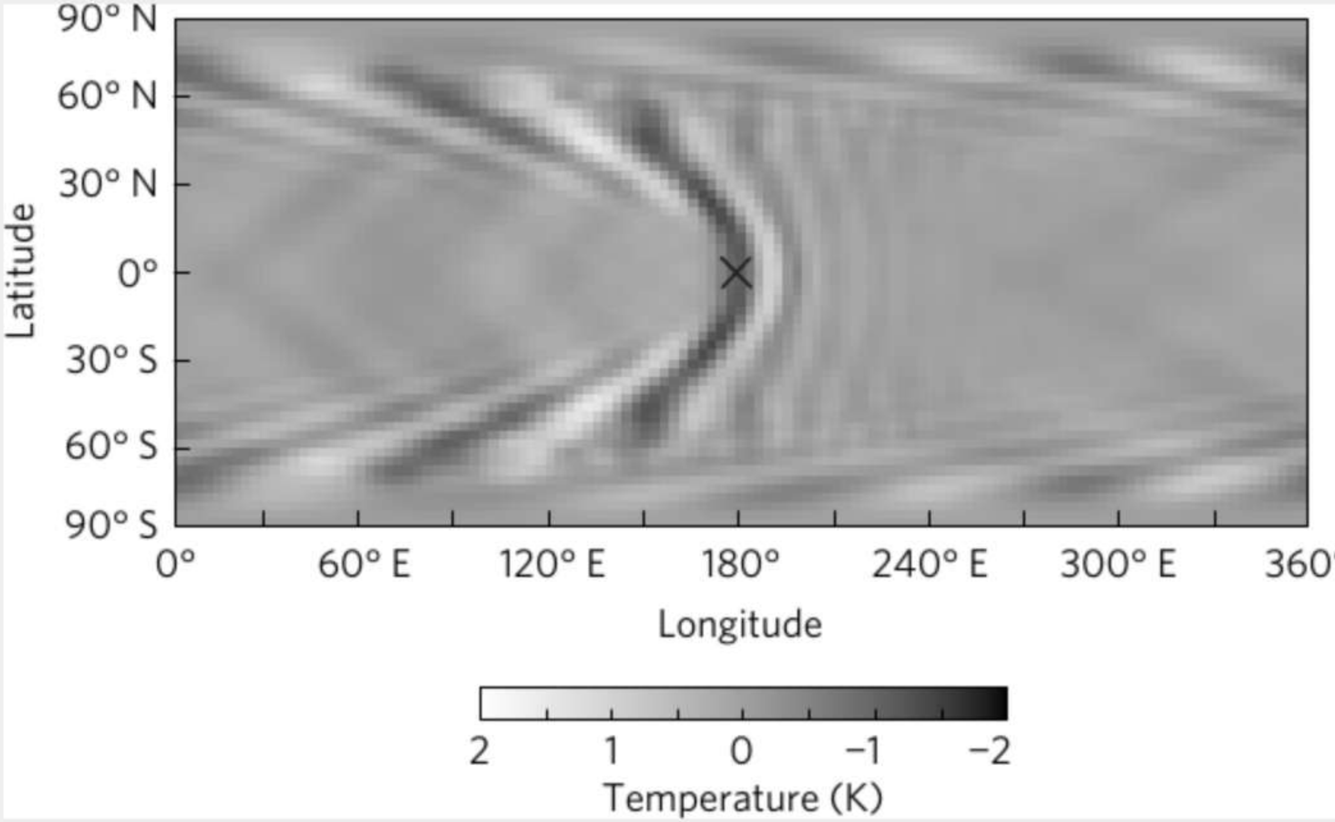




From Piccialli et al., 2014

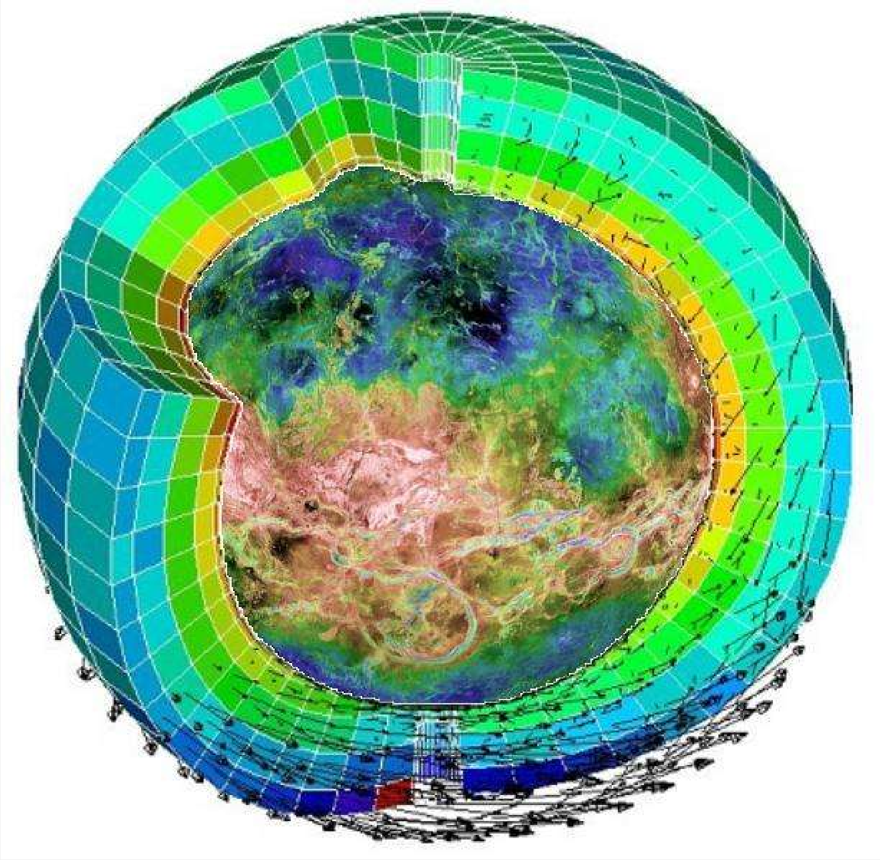
Numerical modelling

From Fukuhara et al., 2017



- Numerical simulation of the atmosphere with a perturbation at 10 km of altitude
- Very crude model: no diurnal cycle, imposed winds and temperature, no topography

LMD Model :
Building a virtual planet

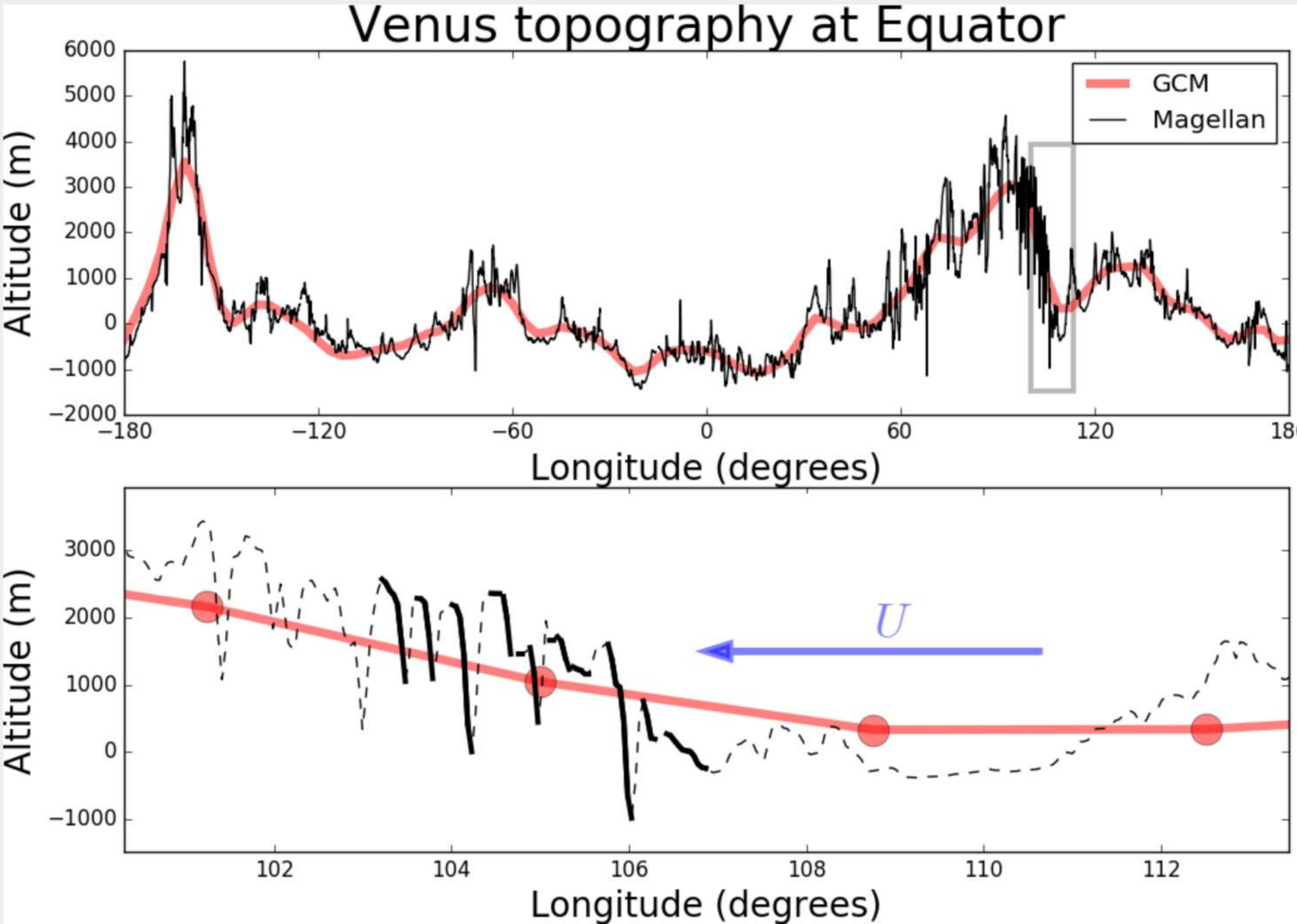


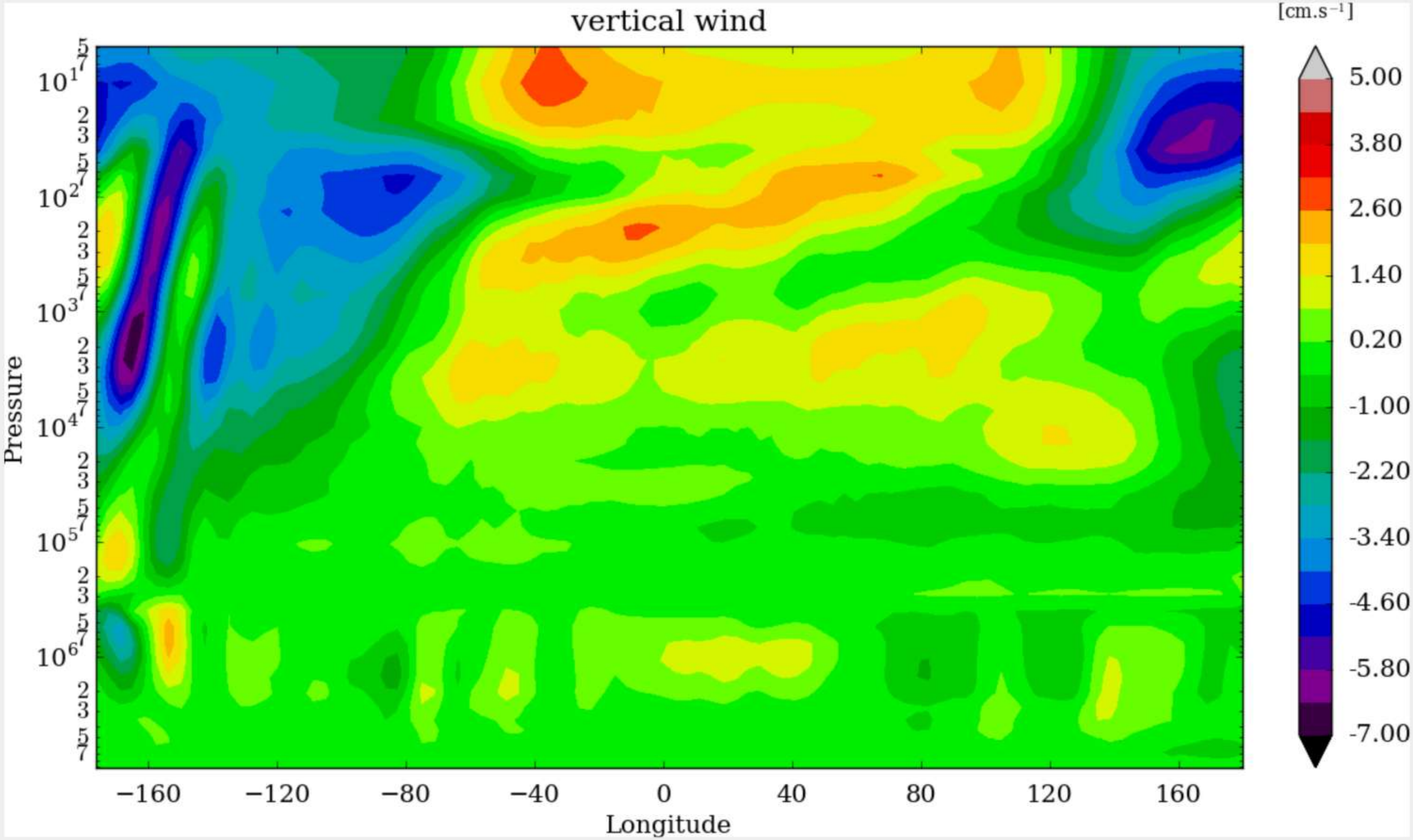
- Dynamical core
- Radiative transfer
- Convection
- [Aerosols & clouds]
- Interaction w/ surface

\+ Modeler's tricks:

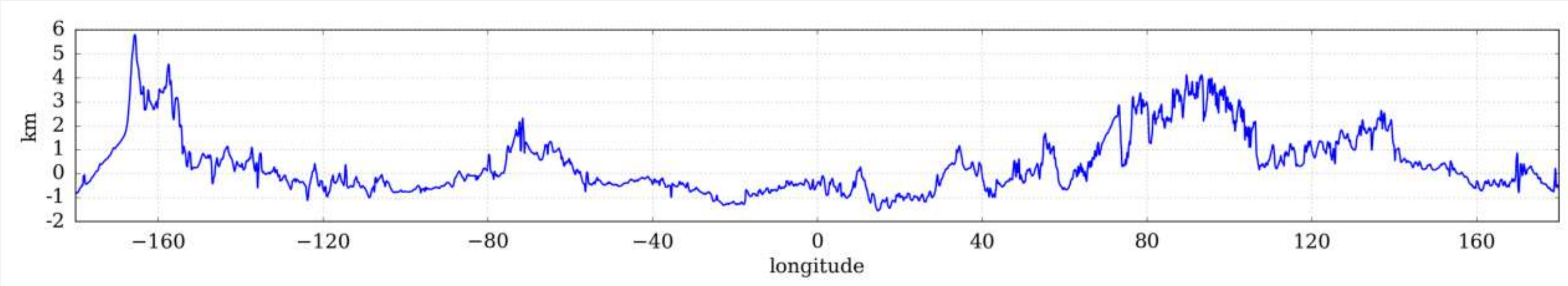
- Dissipation
- Sponge layer

Subgrid parameterization
(Lott et al. 97 for Earth)



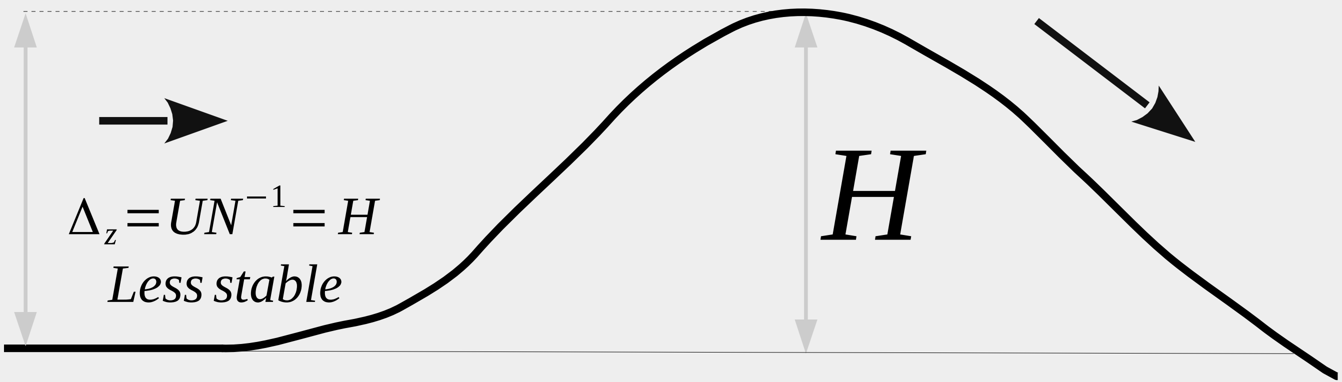


vertical wind
[cm.s⁻¹]
Pressure
Longitude
5.00
3.80
2.60
1.40
0.20
-1.00
-2.20
-3.40
-4.60
-5.80
-7.00

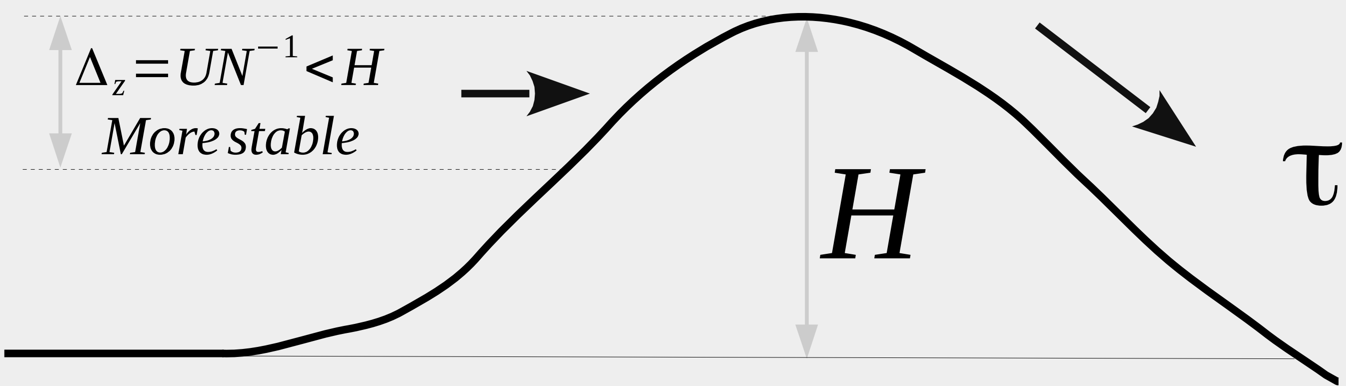


km
longitude

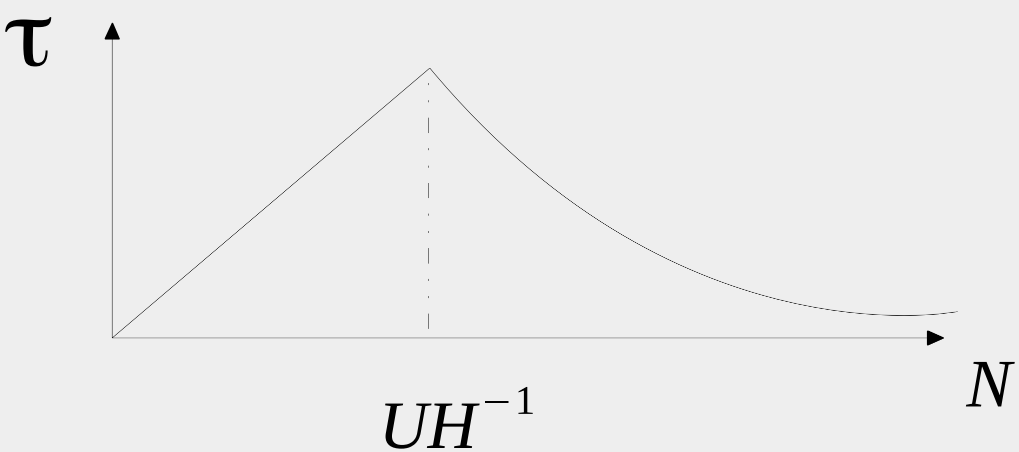
Mountain stress: $\tau = k\rho U N \Delta_z^2$



$$\tau = k\rho U N H^2$$

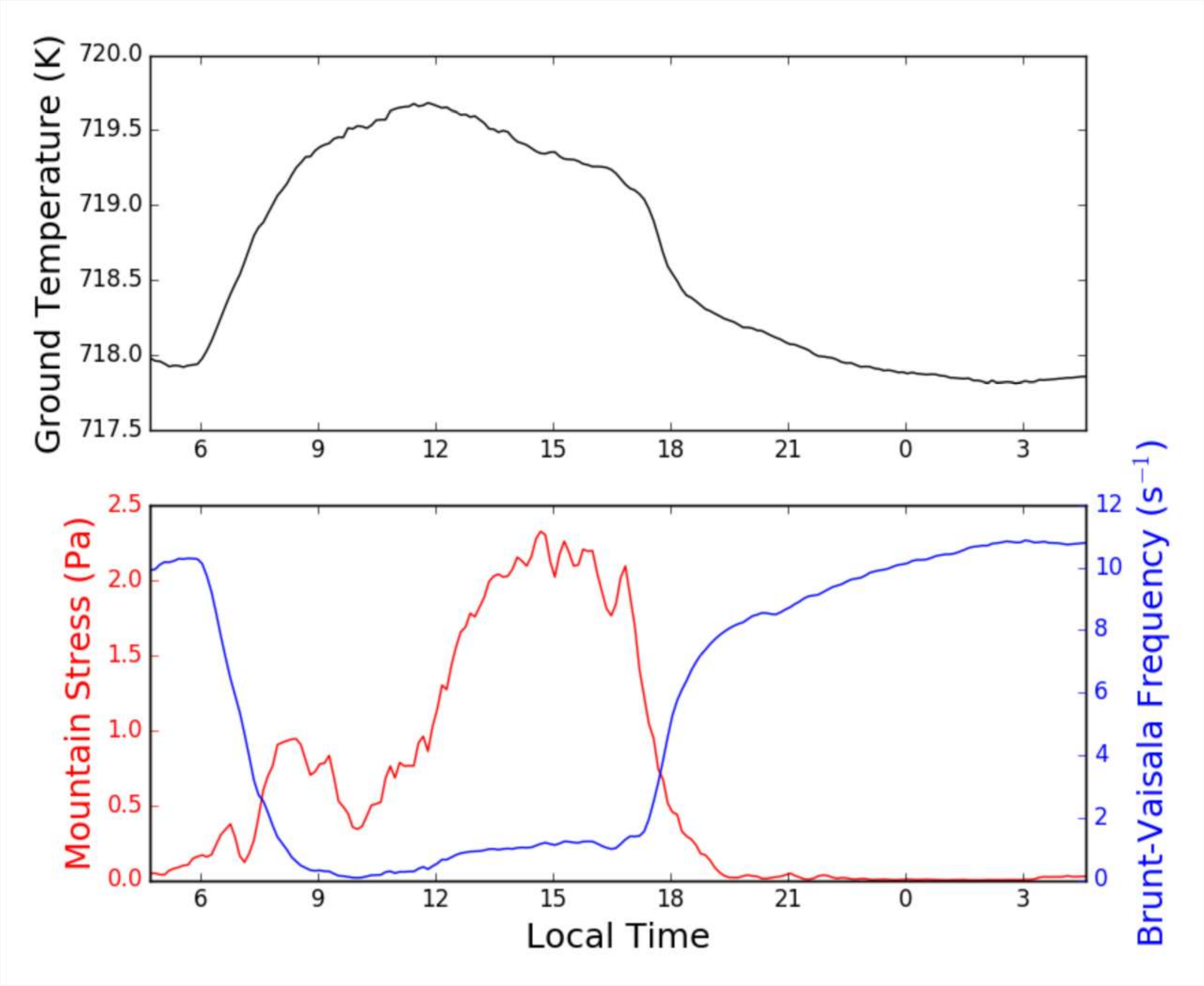


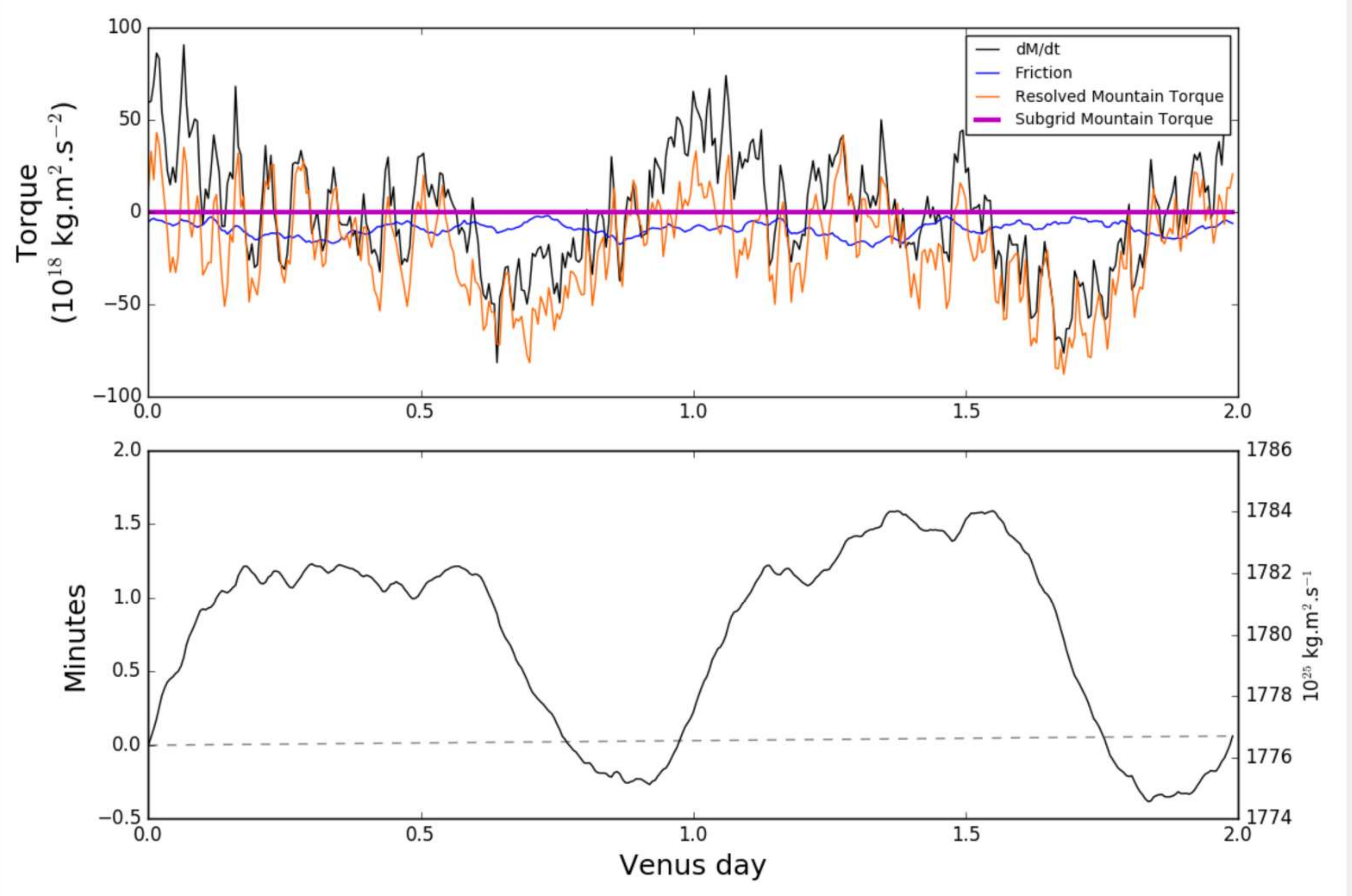
$$\tau = k\rho U^3 N^{-1}$$



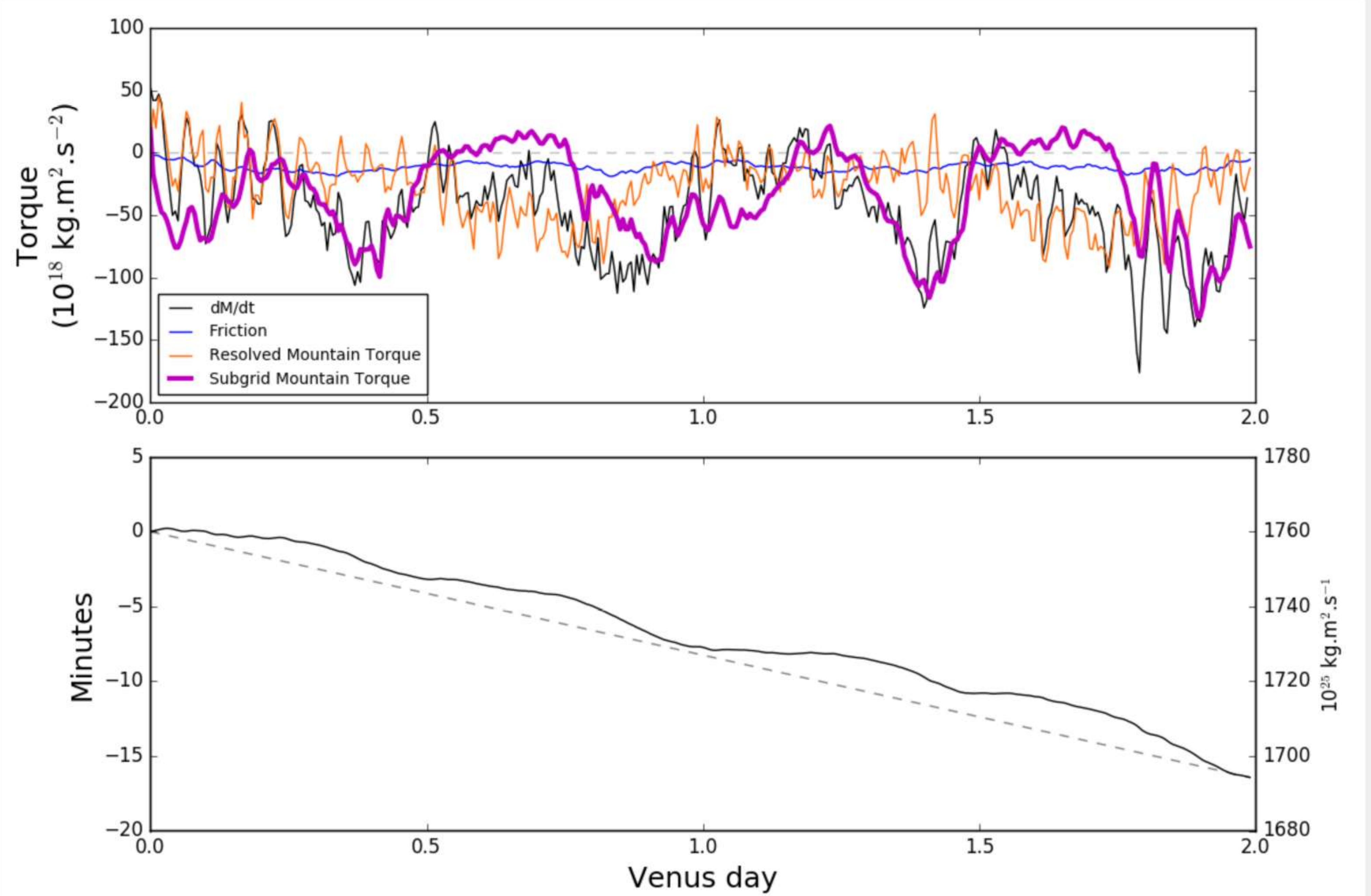
Mountain stress is maximal for $N = UH^{-1}$

Example over Aphrodite





dM/dt
Friction
Resolved Mountain Torque
Subgrid Mountain Torque
Torque
(10^{18} kg.m^2.s^{-2})
100
50
0
−50
−100
0.0
0.5
1.0
1.5
2.0
Minutes
2.0
1.5
1.0
0.5
0.0
−0.5
1786
1784
1782
1780
1778
1776
1774
10^{25} kg.m^2.s^{-1}
Venus day



Torque
$(10^{18}$ kg.m^2.s$^{-2})$
dM/dt
Friction
Resolved Mountain Torque
Subgrid Mountain Torque
Minutes
10^{25} kg.m^2.s^{-1}
Venus day

A fluctuating rotation rate

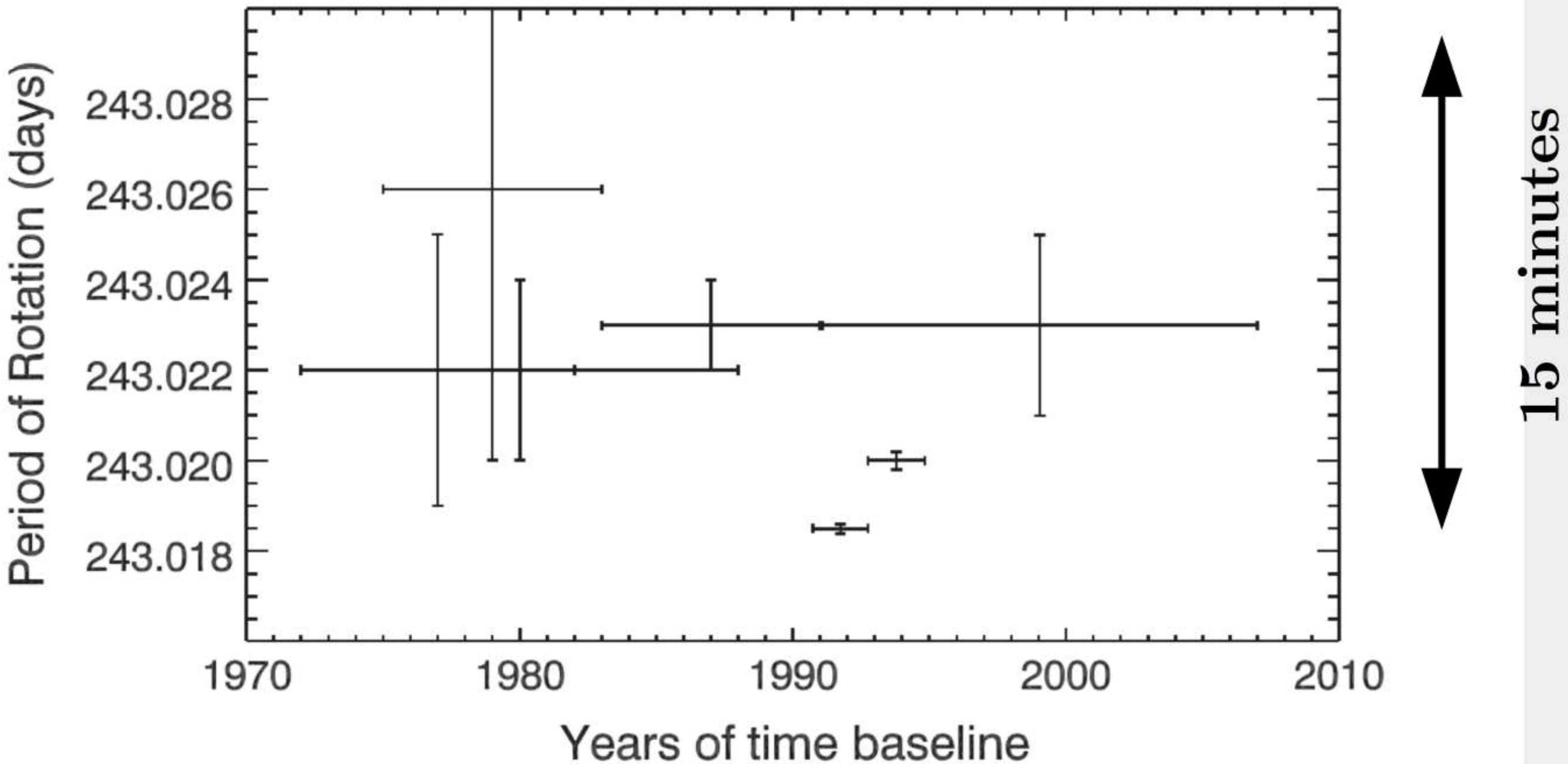


Fig. 4. The most recent estimates of the period of rotation and the time baseline of measurements. The full models and their sources are given in Table 3. The horizontal bars show the period over which the data for each estimate was acquired.

Mueller et al., 2011

A balanced rotation rate

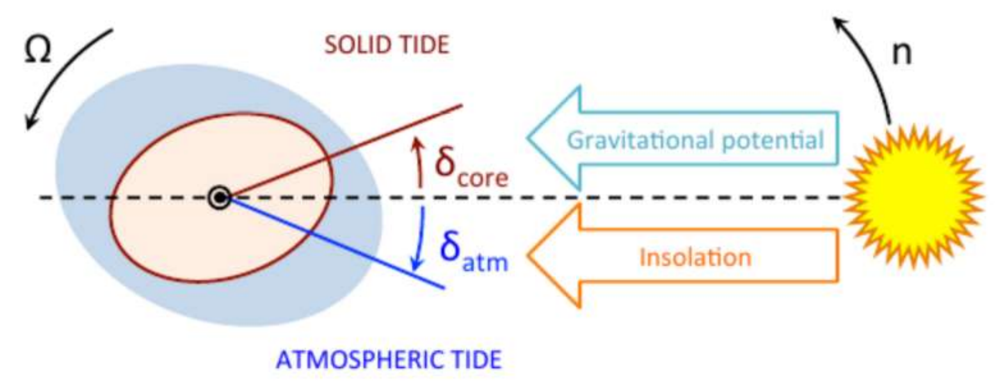
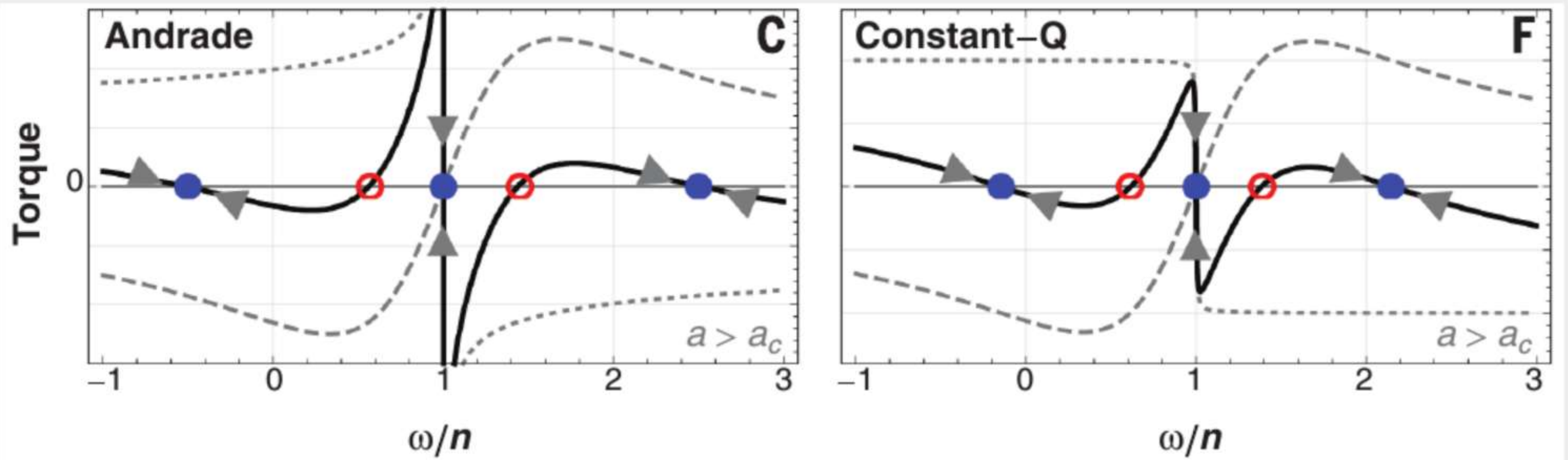


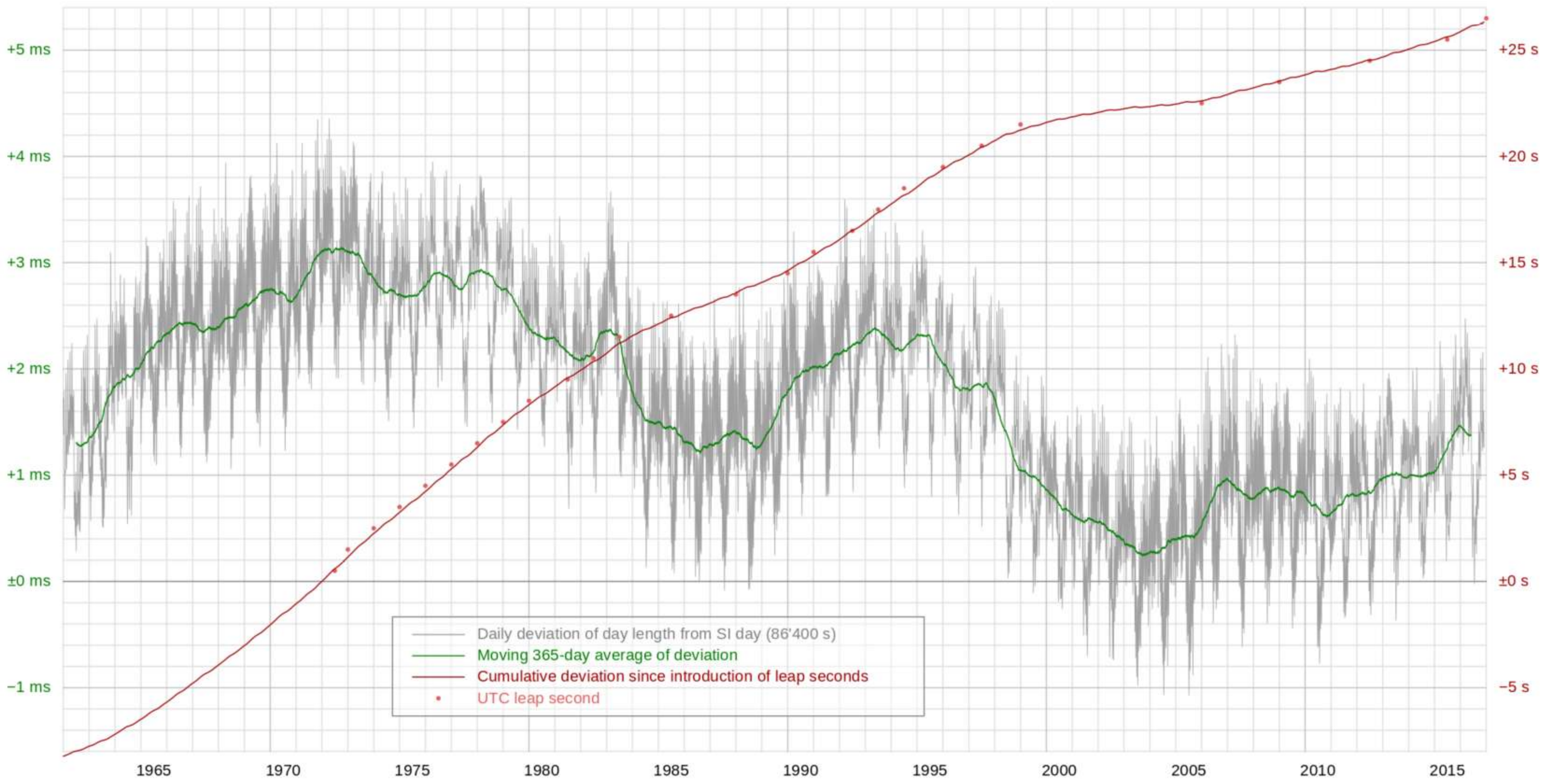
Fig. 1. Tidal elongation of a Venus-like rotating planet, composed of a solid core (brown) and a gaseous atmosphere (blue), and submitted to gravitational and thermal forcings.

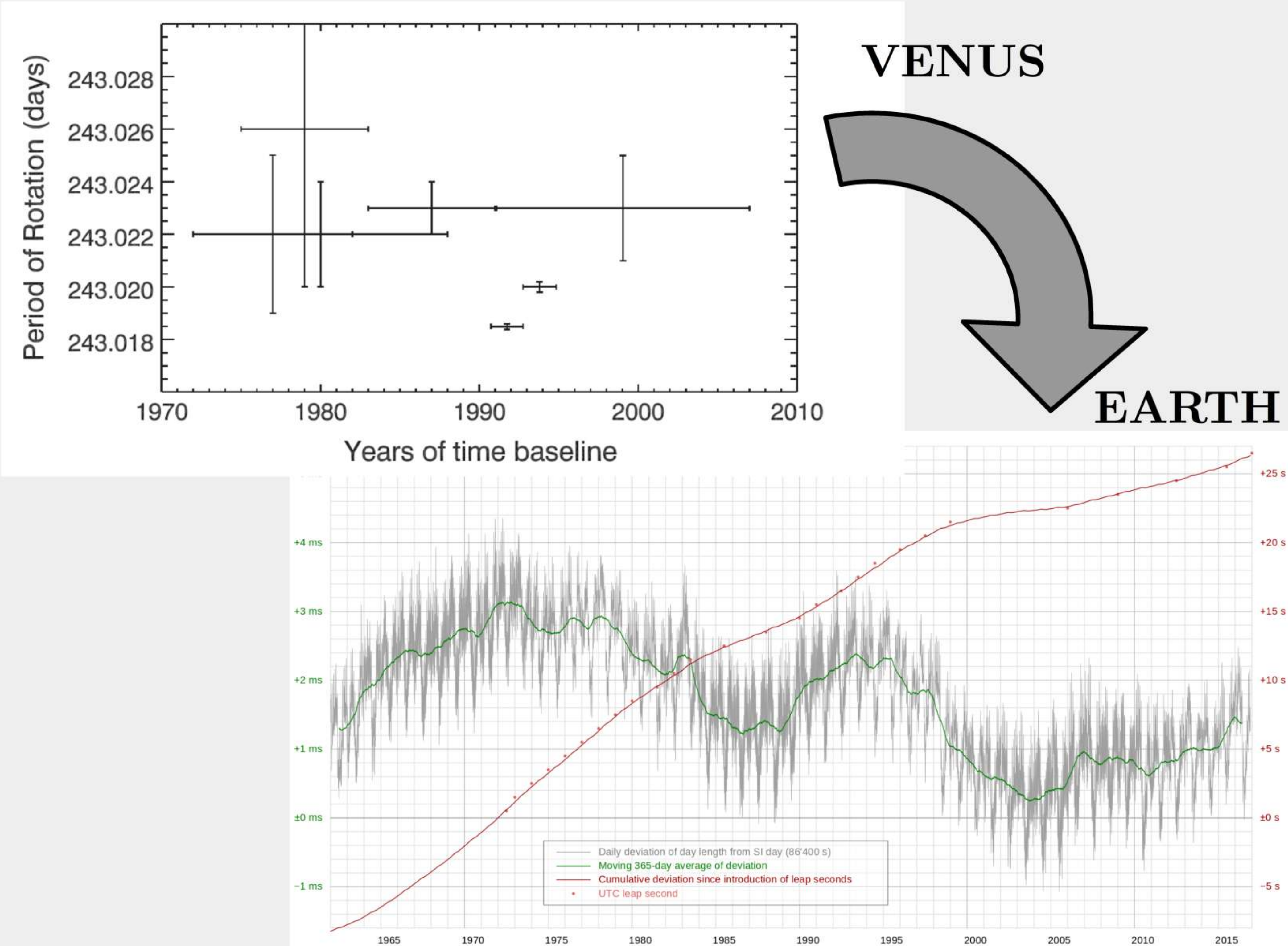
Auclair-Desrotour et al., 2016



Leconte et al., 2015

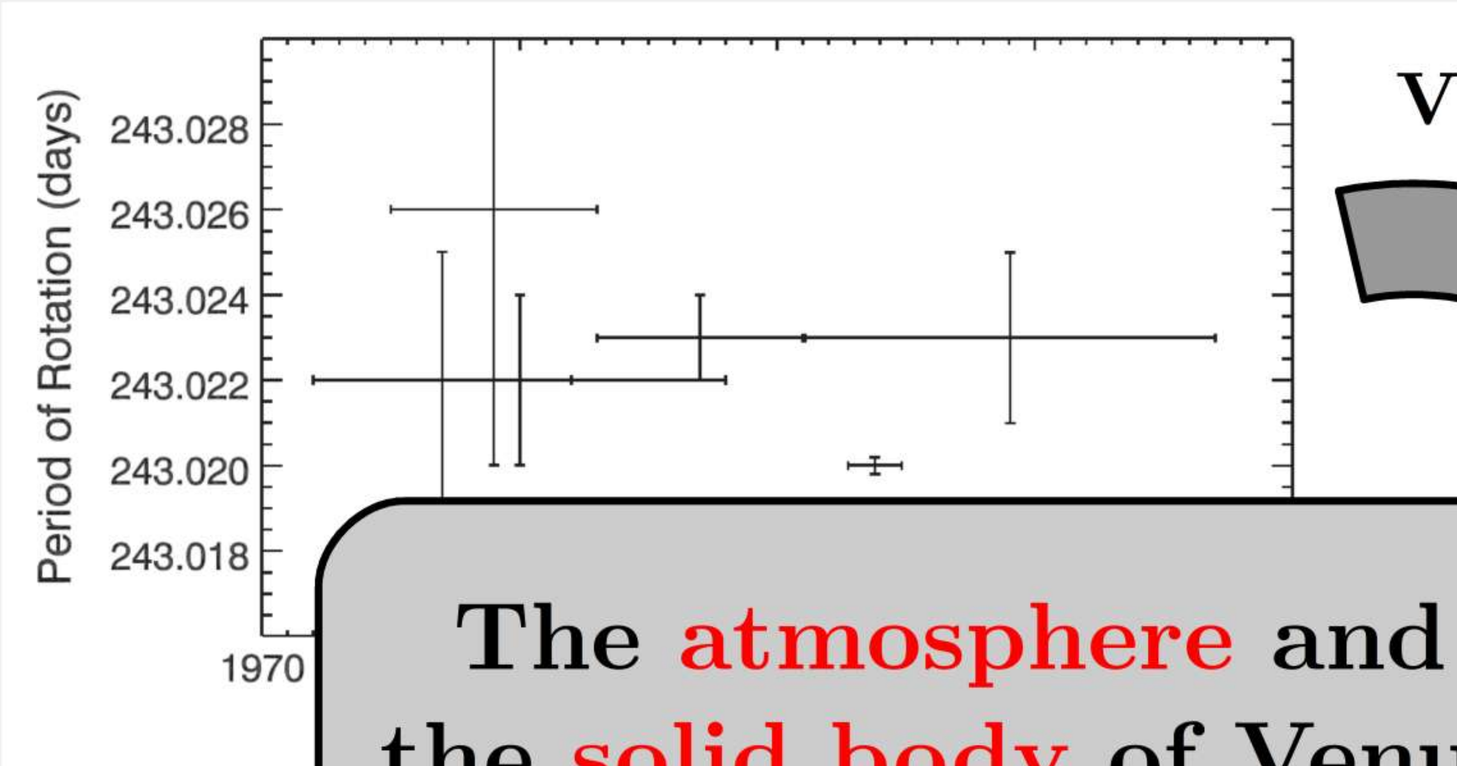
Length of day: Earth



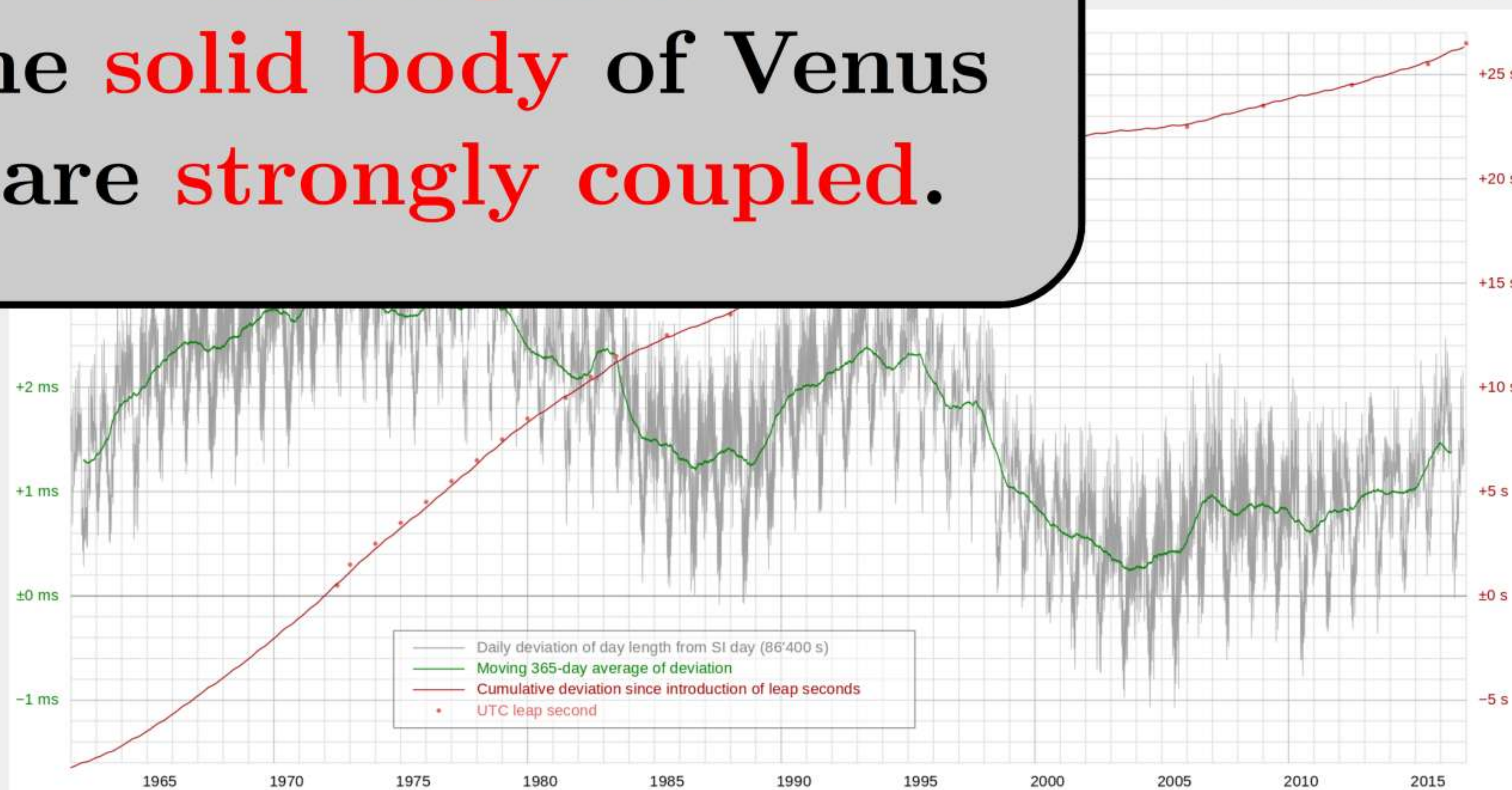


VENUS
EARTH
Period of Rotation (days)
243.028
243.026
243.024
243.022
243.020
243.018
1970
1980
1990
2000
2010
Years of time baseline
+4 ms
+3 ms
+2 ms
+1 ms
±0 ms
−1 ms
+25 s
+20 s
+15 s
+10 s
+5 s
±0 s
−5 s
Daily deviation of day length from SI day (86'400 s)
Moving 365-day average of deviation
Cumulative deviation since introduction of leap seconds
UTC leap second
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

VENUS



EARTH



The atmosphere and the solid body of Venus are strongly coupled.