Venusian Upper Mesosphere and Lower Thermosphere GCMs Intercomparison Project

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- **Introduction:**

Several Venusian Global Climate Models (GCMs) are currently developed around the world. To explore the robustness of these Venus GCM results in the thermosphere, an inter comparison project has been set up, to explore the similarities and main differences between the USA VTGCM developed by S. Bougher and A. Brecht (VTGCM; [1]), the Japanese VTGCM developed at Tohoku University (TUGCM; [2]), and the IPSL Venus GCM (LMDZ; [3]). Although the GCMs describe the same environment, they are different in many ways, especially because of the characteristics of the model or the parameterization of the physical processes. This study should lead to a better understanding of the importance of parameterization in physical processes as well as a better understanding of the controls of these processes.

This study will focus on the upper mesosphere and the lower thermosphere, which corresponds to a pressure between 100 Pa and 10-6 Pa, and the simulations will all have the same solar conditions (Extreme Ultraviolet) of 70 solar flux unit (s.f.u) and 200 s.f.u. Here, we will focus on the thermal and composition structure.

Data (used for VEXAG): Temperature (Venus Express, Pioneer Venus, ground-based instruments), Composition (PV, VEX),

[1] Brecht et al., (2021). *Journal of Geophysical Research: Planets*, 126, doi: 10.1029/2020JE006587.
[2] Hoshino et al., (2012), *Icarus*, *217*, 818–830, doi: 10.1016/j.icarus.2011.06.039.
[3] Gilli et al., (2017), Icarus, Vol 281, 2017, 55-72, 0019-1035, https://doi.org/10.1016/j.icarus.2016.09.016.

Brief presentation of the GCMs

	Venus Thermospheric GCM (VTGCM)	LMD-GCM	TU-GCM
References	Bougher et al., 1999 Brecht et al., 2011, Brecht et al., 2020	Based upon Lebonnois et al., 2010. Gilli et al., 2017; 2021	Based upon Hoshino et al., 2012. Hoshino et al., 2013
Fields	T, U, V, W, O, CO, N2, CO2, Z, N(4S), N(2D), NO, O2, SO, SO2, PCE ions	T, U, V, W, O, CO, CO2 + photochemical model fully coupled (Stolzenbach, 2016)	T, U, V, W, O, CO, CO2, Z
Altitude	70-200/300 km : 69 levels	0 – 200/250 km : 90 levels $9.2 \cdot 10^6\ Pa$ to $8.9 \cdot 10^{-9}\ Pa$	80-150/180 km : 38 levels 356 Pa to 6×10^{-7} Pa
Horizontal Resolution	5 lat vs 5 lon	1.875 lat vs 3.75 lon	10 lat vs 5 lon
Lower Boundary	"Varying" - FMS Venus GCM : T, U, V, Z, five day averaged output	Topography	Constant T, U, V, Z, O, CO, CO2
Non-orographic Gravity Wave prescription	Rayleigh Friction Zhang and Bougher 1996; Zalucha et al., 2013	Lott et al., 2012 Lott and Guez, 2012,2013	Medvedev and Klassen, 2000
Temporal discretization	Leapfrog scheme Time step: 20 s (to satisfy the Courant-Friedrichs-Lewy (CFL) stability criterion.)	Leapfrog-Matsuno scheme Time step: 210 s	Leapfrog scheme Time step: 4s

Brief presentation of the GCMs

	Venus Thermospheric GCM (VTGCM)	LMD-GCM	TU-GCM
15 microns cooling rates	Measurement of laboratories on Earth: $k = (1-6) \cdot 10^{-12}\ cm^3 s^{-1}$	Based upon Roldàn et al., 2000 CO2-O deactivation rate: $k = 3 \cdot 10^{-12} cm^3 . s^{-1}$ (at 300 K)	
	$k = 3 \cdot 10^{-12}\ cm^3 s^{-1}$	$k = 7 \cdot 10^{-12}\ cm^3 s^{-1}$	$k = 3 \cdot 10^{-12}\ cm^3 s^{-1}$
EUV heating	**EUV heating efficiencies in agreement with detailed on-line calculations provided by Fox (1988)**		**Bougher et al., 1988**
	EUV_EFF = 20 % & EUV index: F10.7	EUV_EFF = 17 % & EUV index: E10.7	EUV_EFF = [10] % & EUV index: F10.7
NIR and Solar heating	Both models follow Roldàn et al., 2000 for the 4.3 microns heating		**Bougher et al., 1986**
	NLTE: tabulated heating rates from line-by-line model results in Roldan et al. 2000	NLTE: NIR heating rate formula from Forget et al., 1999 Multiband fitted adjusted on Roldan et al., 2000	NLTE: ratios between non-LTE and LTE heating rate calculated by the GCM (Lopez-Valverde et al., 1998)
	Below 100 km: Solar heating rates from Crisp (1986)	Below 100 km: Solar heating rate based upon Haus et al. 2016	-

Vertical profile of temperature / Dayside

GCMs vs Temperature measurements

- Venus Express (VEx) observations revealed that VIRA is not representative of the atmosphere of Venus above 100 km
- VTGCM, LMDZ and TUGCM are consistent compared to averaged temperature profiles observed by Venus Express and ground-based instruments.
- Daytime temperature shift of about 5-10 km above 130 km altitude.

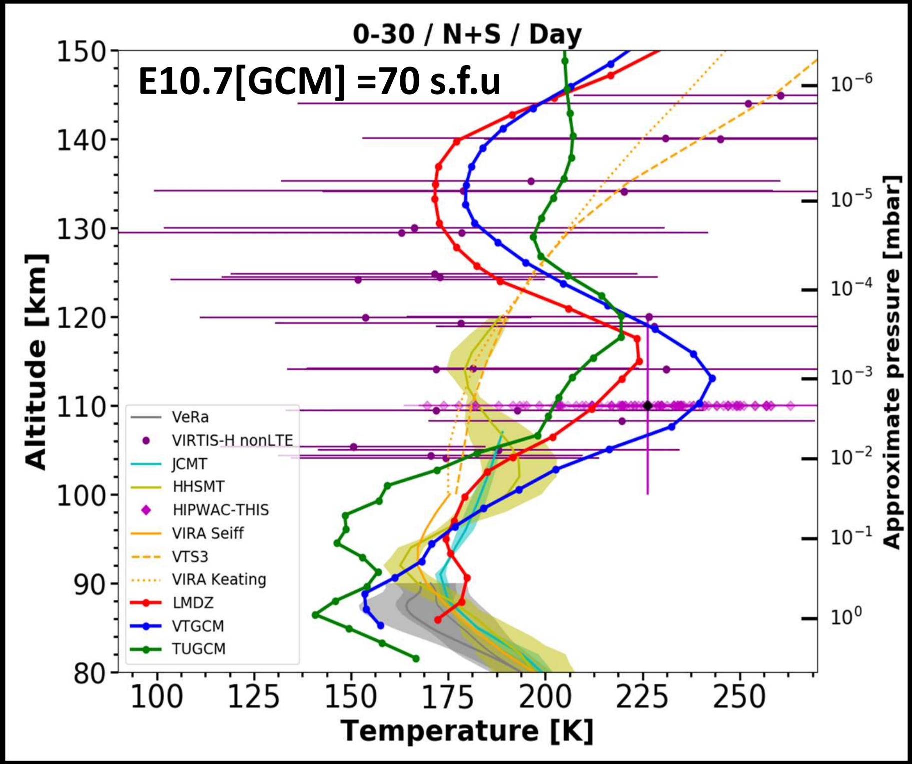

Figure: LMDZ (IPSL Venus GCM; red), VTGCM (USA VTGCM; blue) and TUGCM (Japanese VTGCM; green) temperature profiles compared to averaged temperature profiles observed by Venus Express and ground-based instruments in the dayside.

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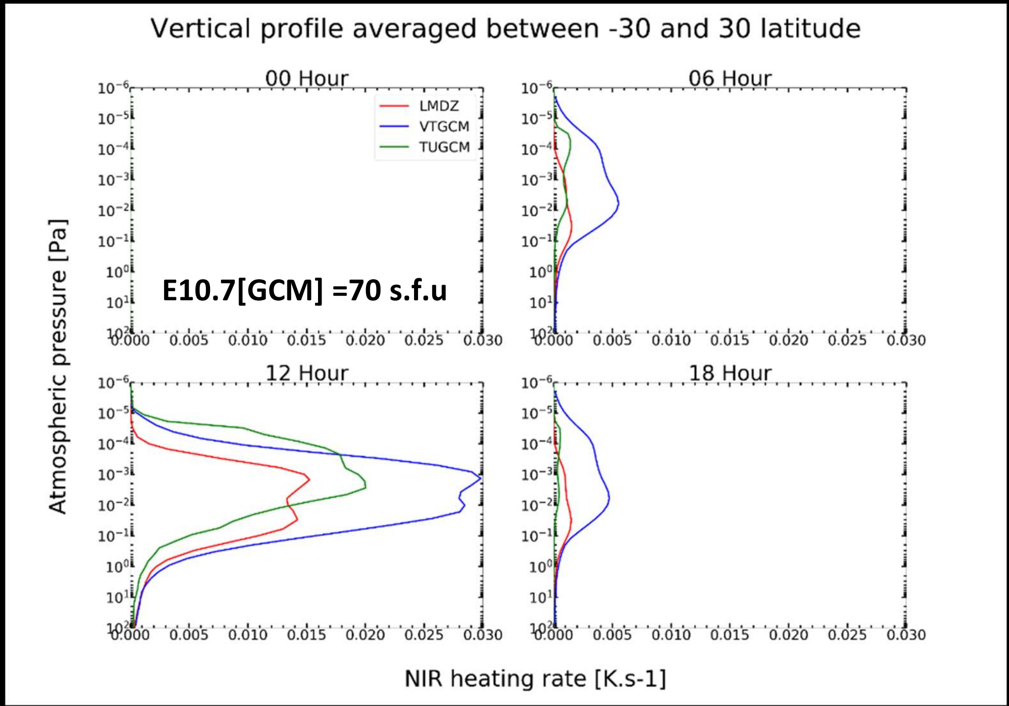
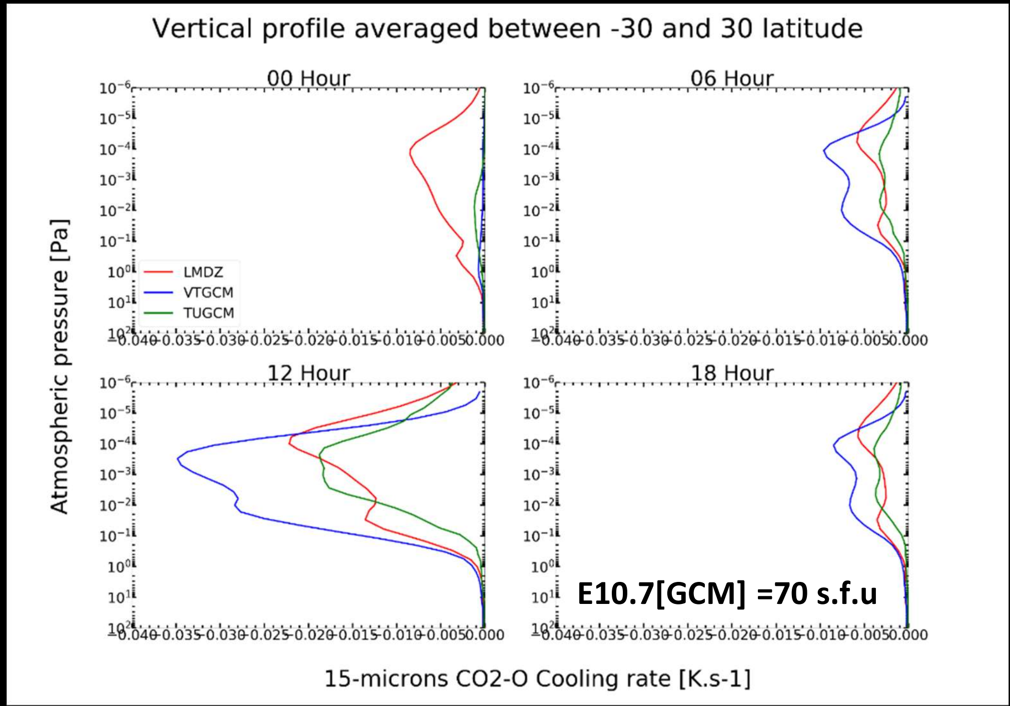
NIR heating rate and 15 microns radiative cooling rate





Vertical profile of the NIR heating rate and the 15 microns CO2-O cooling rate for several local time.

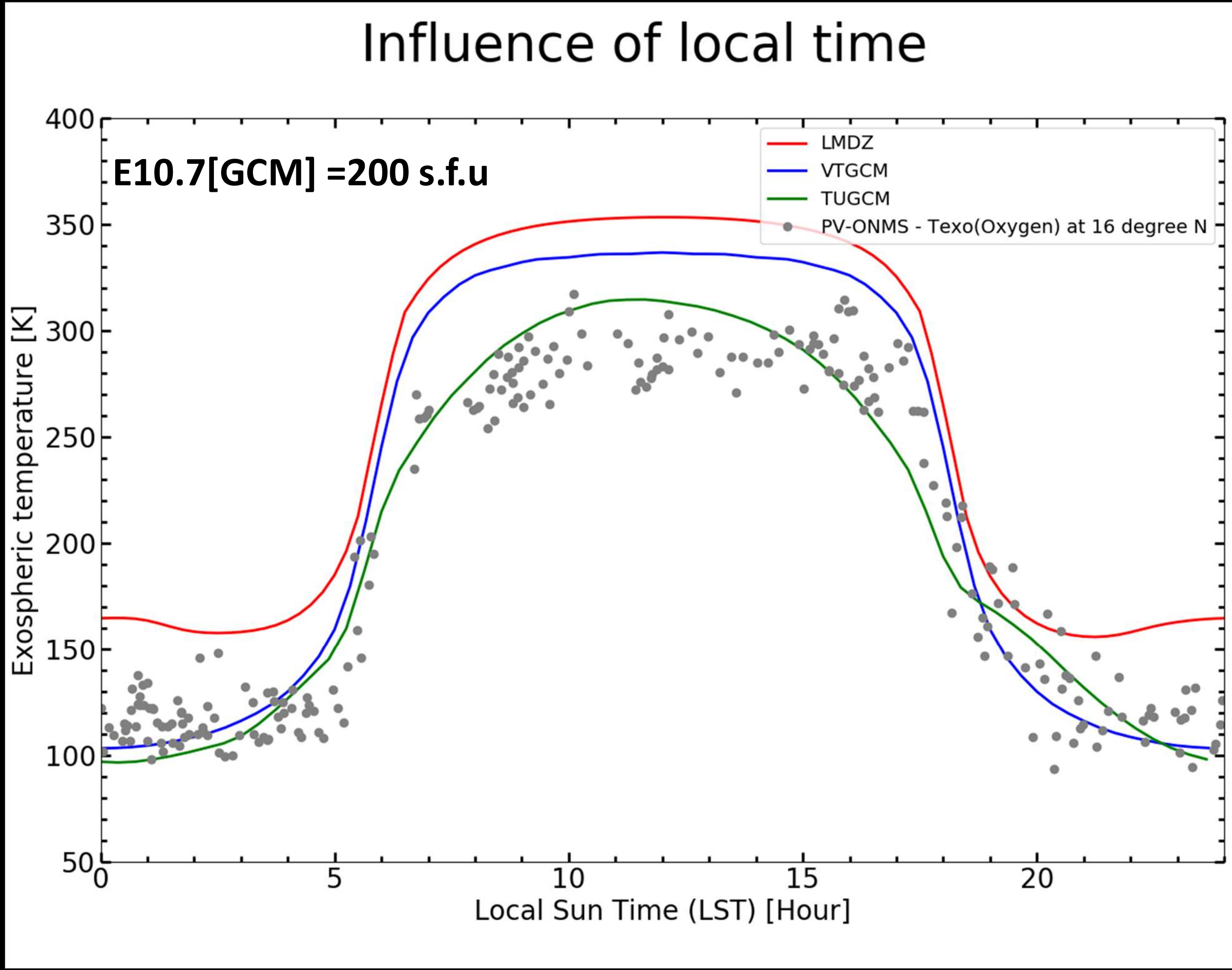
The differences in the dayside temperature profile between the different models are mainly due to differences in the NIR heating rate and the cooling rate. Although both VTGCM and LMDZ are based on Roldan et al. 2000, the cooling efficiency of LMDZ appears to be lower than for VTGCM, forcing a reduction in the NIR heating rate in compensation.

Exospheric temperature at $\boldsymbol{P = 10^{-6}\ Pa}$

GCMs vs Retrieved Temperature

- PV-ONMS: (Pioneer Venus Orbiter Neutral Mass spectrometer) Retrieved temperature from the height scale of the Oxygen density.

- Good agreement of VTGCM and TUGCM with temperatures at night.



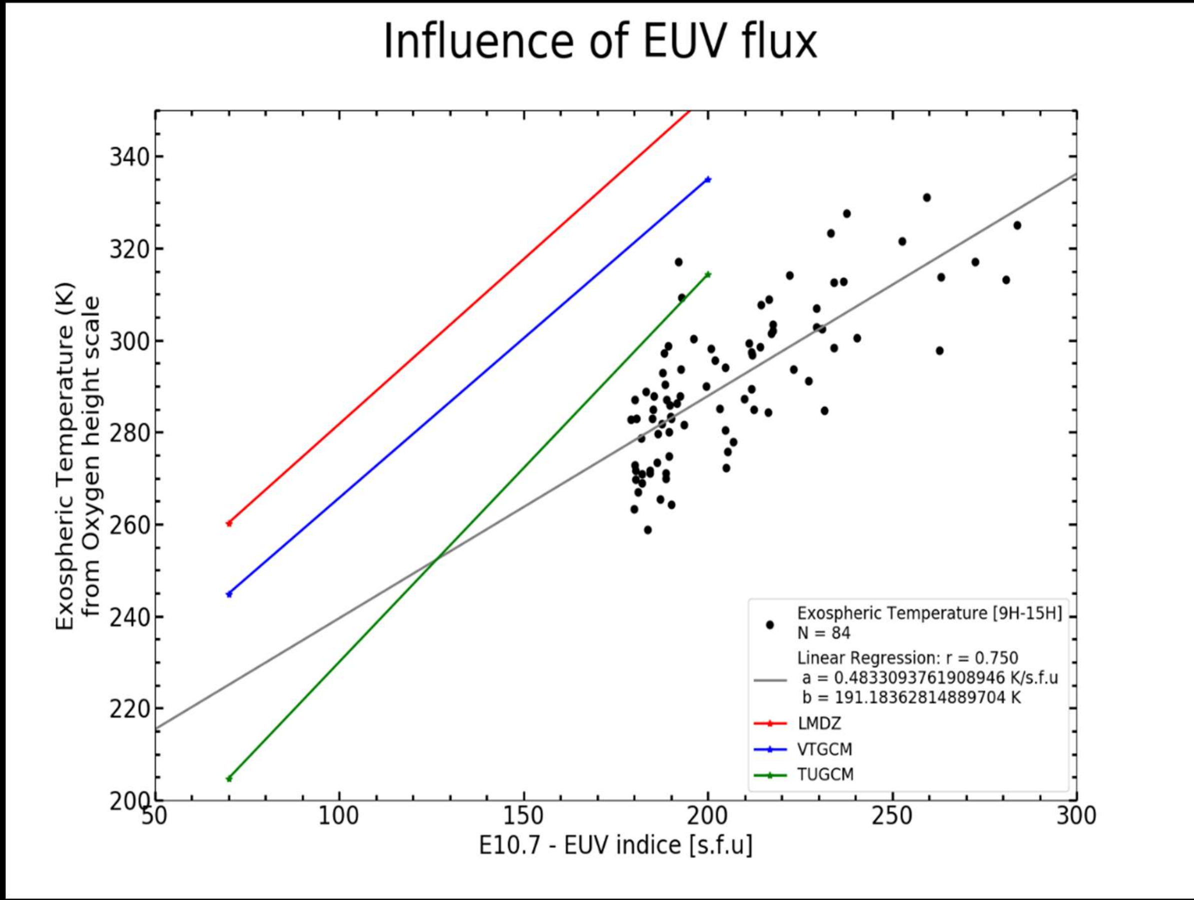
Influence of EUV flux on exospheric temperature

GCMs vs Retrieved Temperature

- PV-ONMS: (Pioneer Venus Orbiter Neutral Mass spectrometer) Retrieved temperature from the height scale of the Oxygen density.

- E10.7 : Solar Irradiance Plateform (formely SOLAR2000; Tobiska et al., 2000.)

  - $\frac{dT}{dEUV}[PV - ONMS] = 0.48\ K.sfu^{-1}$
  - $\frac{dT}{dEUV}[LMDZ] = 0.71\ K.sfu^{-1}$
  - $\frac{dT}{dEUV}[VTGCM] = 0.69\ K.sfu^{-1}$
  - $\frac{dT}{dEUV}[TUGCM] = 0.84\ K.sfu^{-1}$

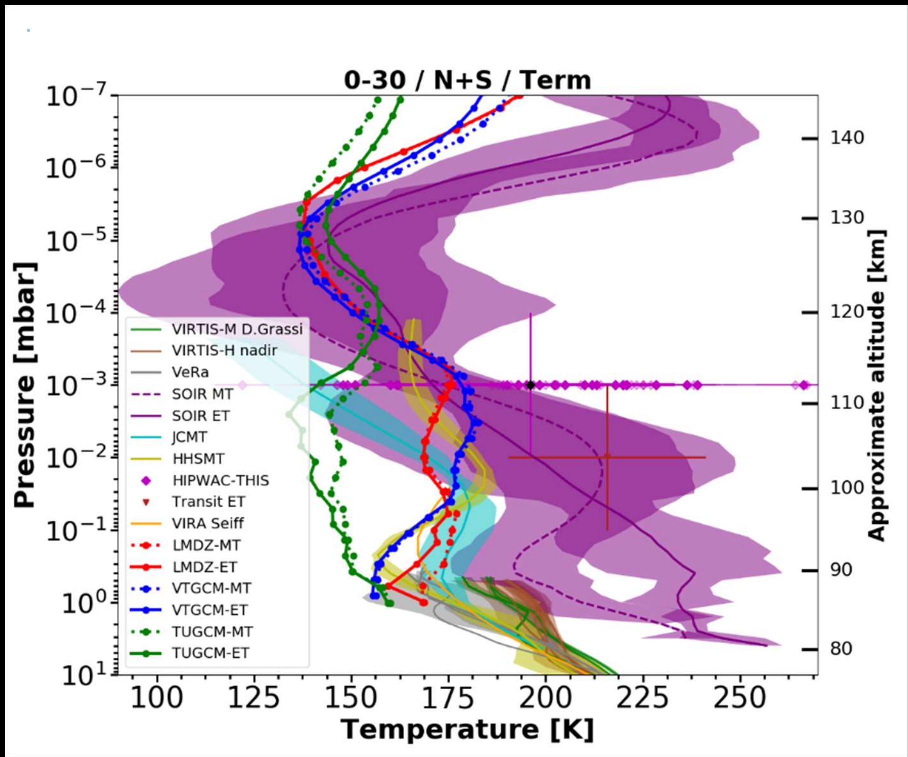


Tobiska et al., 2000. J. Atmos. Solar-Terres. Phys. 62 (14), 1233–1250. https://doi.org/10.1016/S1364-6826(00)00070-5

Vertical profile of temperature / Nightside and Terminator

GCMs vs Temperature measurements

Figure: LMDZ (IPSL Venus GCM; red), VTGCM (USA VTGCM; blue) and TUGCM (Japanese VTGCM; green) temperature profiles compared to averaged temperature profiles observed by Venus Express and ground-based instruments in the terminator.



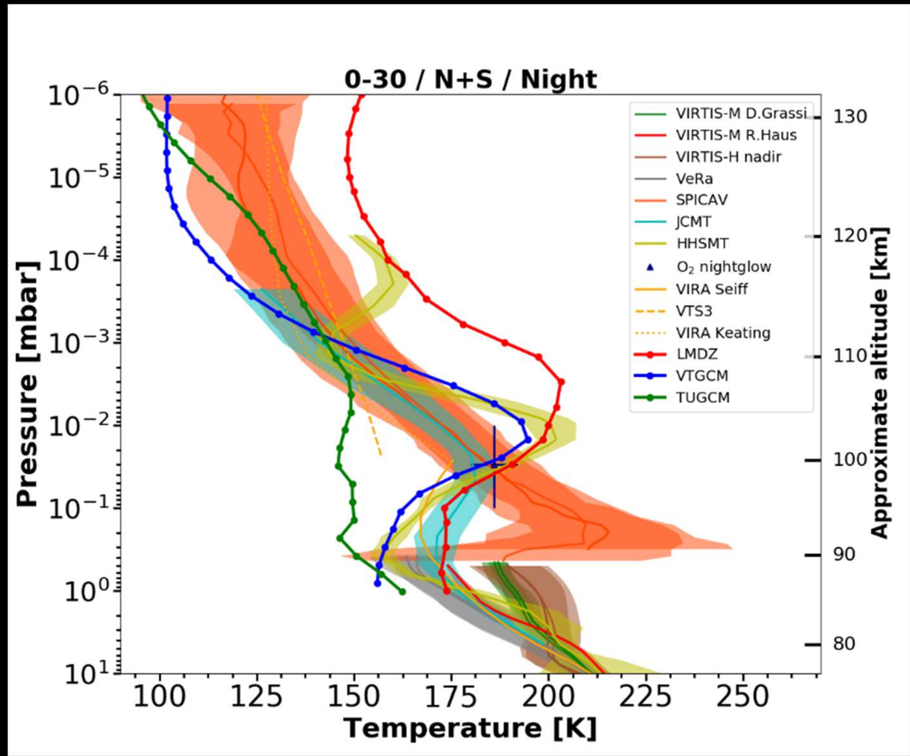


Figure: LMDZ (IPSL Venus GCM; red), VTGCM (USA VTGCM; blue) and TUGCM (Japanese VTGCM; green) temperature profiles compared to averaged temperature profiles observed by Venus Express and ground-based instruments in the nightside.

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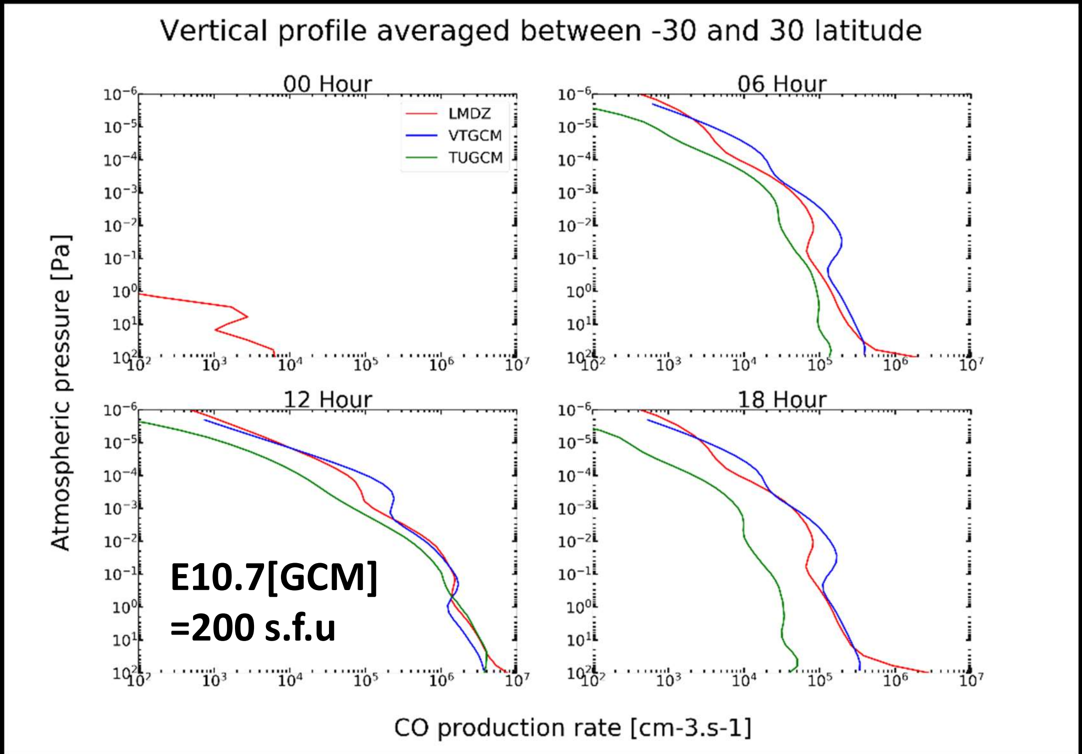
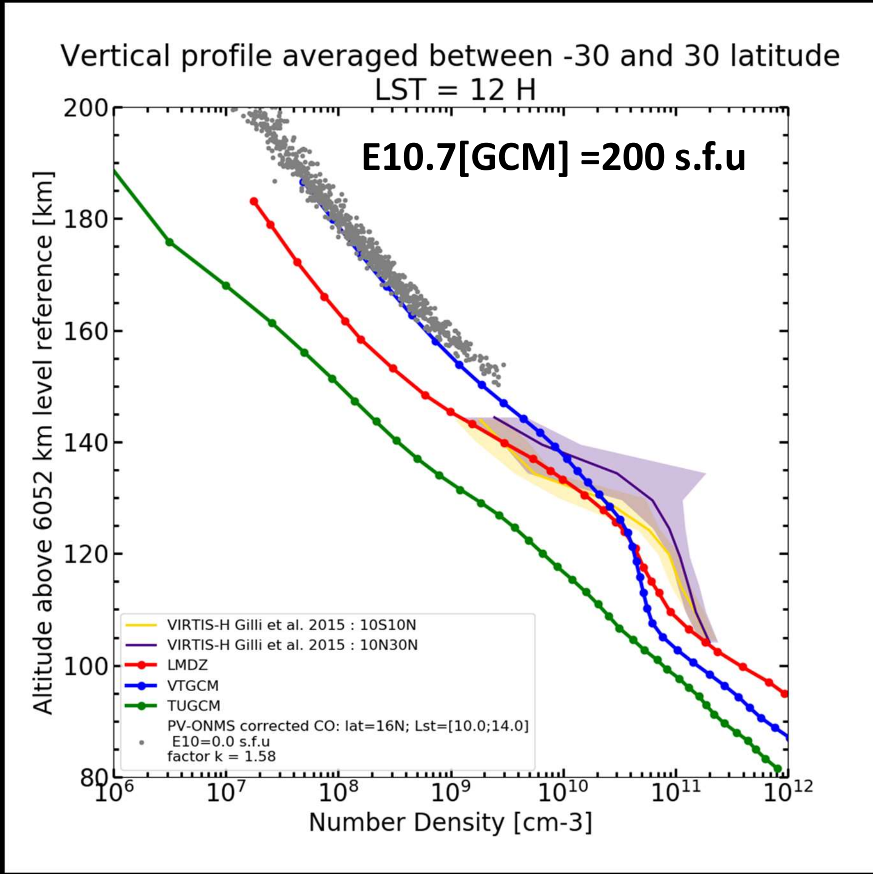
CO density & CO production rate

- Good agreement between VTGCM CO density and PV-ONMS CO density at noon.
- Difference between the three GCM CO density may be explained by the CO production rate in the dayside.





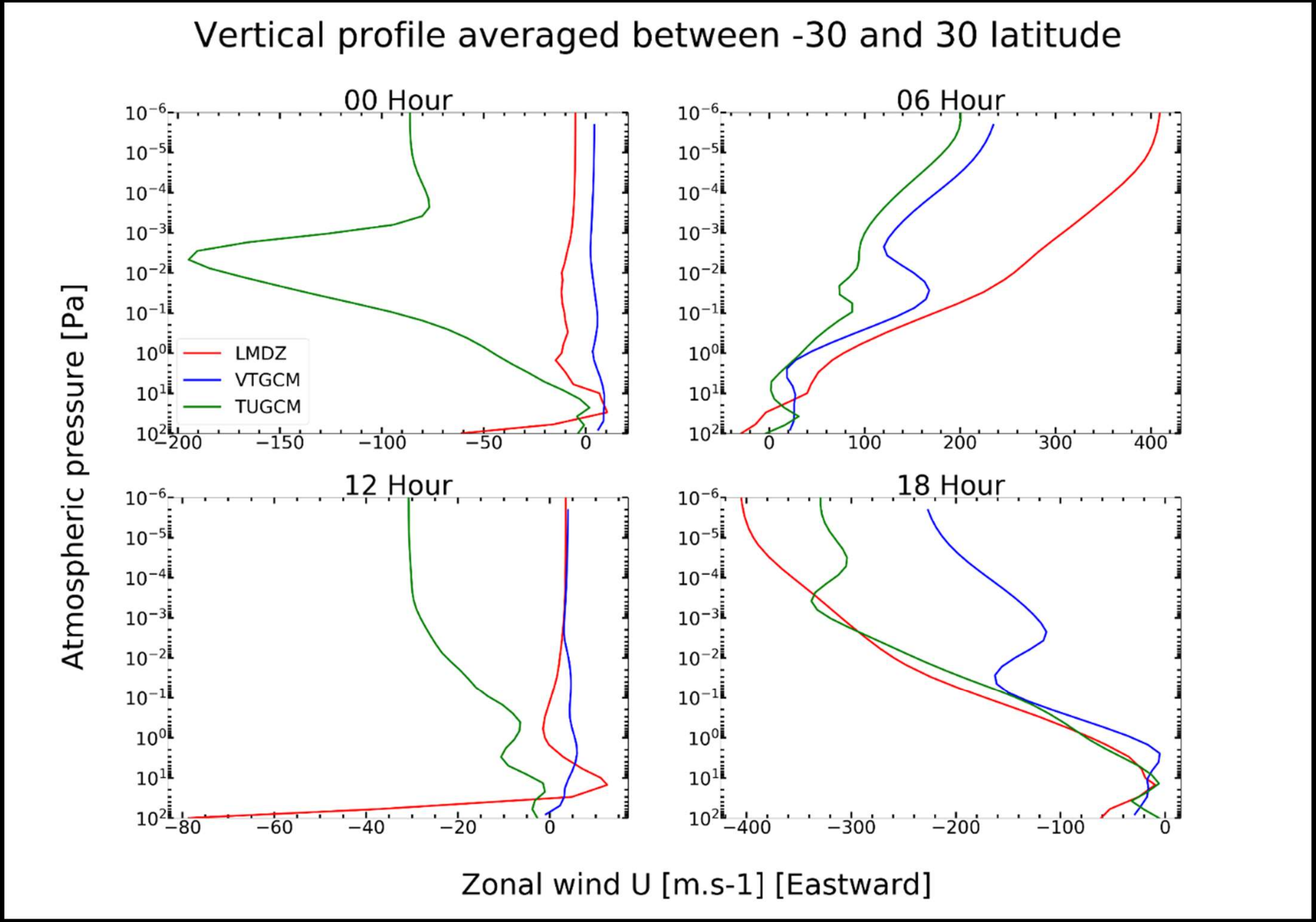
VIRTIS-H : Venus Express (~70-120 s.f.u)
ONMS: Pioneer Venus (~180-250 s.f.u)

Vertical profile of Zonal Wind

GCMs Comparison

- Longitudinal symmetry (asymmetry) of zonal wind intensity for LMDZ and VTGCM (TUGCM).

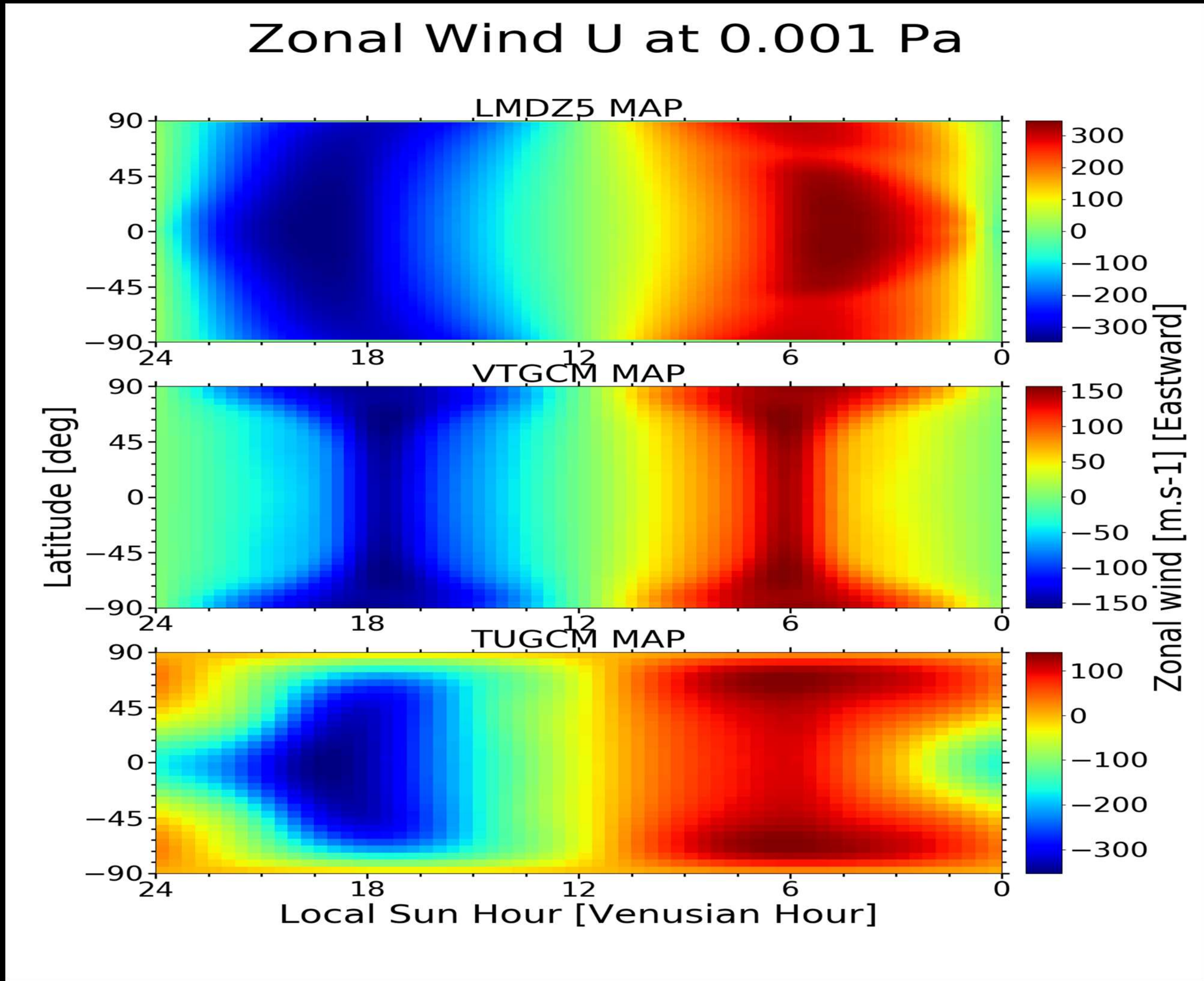
- Zonal winds at terminals twice as much for LMDZ as VTGCM in the thermosphere.



Zonal Wind U at $P = 10^{-3}\ Pa$

GCMs Comparison

- Different wind coverage according to GCMs
- Longitudinal symmetry (asymmetry) of zonal wind intensity for LMDZ and VTGCM (TUGCM).
- Zonal winds at terminals twice as much for LMDZ as VTGCM in the thermosphere.



Vertical profile of wind acceleration due to Non-Orographic Gravity Waves or Rayleigh friction

GCMs Comparison

- Here, VTGCM utilizes Rayleigh Friction (so no gravity waves parametrization). It is prescribed as [exp((p-po)/2)]*1e-4, where po=zp=-1.5. This is applied on zonal and meridional winds, fixed in time, and varies horizontally by cos(latitude).
- The low wind deceleration is probably a cause of the high wind intensity for LMDZ.
- The lack of wind deceleration in the thermosphere for LMDZ can lead to a temperature increase on the night side via dynamic processes.