Intercomparison between Venus Thermospheric Models

Preliminary study with Venus PCM, TUGCM, VTGCM

Three General Climate Model

- IGCMP (Intercomparison General Climate model Project)
  - Created at the end of 2021
  - Collaboration between Three "Thermospheric" GCMs:
    - Venus PCM (LMD and IAA)
    - TUGCM (Japan)
    - VTGCM (American: Amanda Brecht)

Objectives of the project:

- Testing the robustness of the mesosphere and thermosphere temperature distribution and characteristics
- Same for wind distribution
- Assessing the most sensitive parameters controlling these structures
- Comparing the Gravity Wave scheme and their sensitive parameters

General Climate Model
- Summary -

	Venus Thermospheric GCM (VTGCM)	Venus PCM	TUGCM
References	Bougher et al., 1999 Brecht et al., 2011, 2012, Brecht et al., 2021	Based upon Lebonnois et al., 2010. Gilli et al., 2017; 2021; Martinez et al., 2023, 2024	Hoshino et al. (2012; 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, N2 + photochemical model fully coupled (Stolzenbach, 2016; 2023)	T, U, V, W, O, CO, CO2
Composition	90% of CO2 10% of N2	96.5% of CO2 3.5% of N2	100% of CO2
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 level 356 Pa to $6 \cdot 10^{-7}\ Pa$
Horizontal Resolution	5 lat vs 5 lon	1.875 lat vs 3.75 lon	5.5378 lat vs 5.625 lon
Lower Boundary	"Moving" – Oxford Venus GCM: T, U, V, Z, five day averaged output	Topography	Fixed conditions at 80 km (Hoshino et al. 2012)
Non-orographic Gravity Wave prescription	~~Yiğit et al., 2008 (previous schemes - Zhang and Bougher 1996; Zalucha et al., 2013)~~	Lott et al., 2012 Lott and Guez, 2012,2013	Medvedev and Klaassen (2000) Zhang et al. (1996)
Temporal discretization	Leapfrog scheme Time step: 20 s (to satisfy the Courant-Friedrichs-Lewy (CFL) stability criterion.)	Leapfrog-Matsuno scheme Physical Time step: 210 s	Leapfrog scheme Physical Time step: 4 s

General Climate Model
- Thermal/Cooling processes -

	Venus Thermospheric GCM (VTGCM)	VPCM	TUGCM
15 microns cooling rates	**Based upon Roldàn et al., 2000 but with different scheme CO2-O deactivation rate:**		**Parameterization: Bougher et al. (1986) Dickinson and Bougher (1986) Roldàn et al., 2000**
	$k = 3 \cdot 10^{-12} cm^3 . s^{-1}$ (at 300 K)	$k = 5 \cdot 10^{-12} cm^3 . s^{-1}$ (at 300 K)	$k = 3 \cdot 10^{-12} cm^3 . s^{-1}$ (at 300 K)
EUV heating	**EUV heating efficiencies in agreement with detailed on-line calculations provided by Fox (1988) But three different solar spectrum reference**		
	EUV_EFF = [20-22] % & EUV index: F10.7	EUV_EFF = 19.5 % & EUV index: E10.7	EUV_EFF = 10 % & EUV index: E10.7
NIR and Solar heating	Both models follow Roldàn et al., 2000 for the 4.3 microns heating		
	NLTE: look-up table from non-LTE radiative transfert line-by-line model results as Roldàn et al., 2000	NLTE: NIR heating rate formula from Forget et al., 1999 & Gonzalez-Galindo et al., 2009. Current version: Martinez et al. 2023	(Hoshino et al. 2013) Matched the reference NIR heating (Roldan et al. 2000)
	Below 100 km: Solar heating rates from Crisp (1986)	Below 100 km: Solar heating rate based upon Haus et al. 2016	--
Eddy processes	Constrained: K = K0 * (P_0/P)^0.5	Unconstrained	Constrained K = 1000 > K0 * (N_0/N)^0.5 > 100.

Three General Climate Model

- IGCMP (Intercomparison General Climate model Project)
  - Created at the end of 2021
  - Collaboration between Three GCMs:
    - LMDZ (LMD and us)
    - TUGCM (Japan)
    - VTGCM (American: Amanda Brecht)
  - Current data:
    - Two simulation « 70 s.f.u » and « 200 s.f.u » for Venus Express-MAGELLAN and Pioneer Venus comparison
    - Magellan, Venus Express, PV data (Martinez et al. 2023)
    - Mesospheric data from Limaye et al. 2017
  - Altitude range: from 80 to 200 km

Objectives of the project:

- Testing the robustness of the mesosphere and thermosphere temperature distribution and characteristics
- Same for wind distribution
- Assessing the most sensitive parameters controlling these structures
- Comparing the Gravity Wave scheme and their sensitive parameters

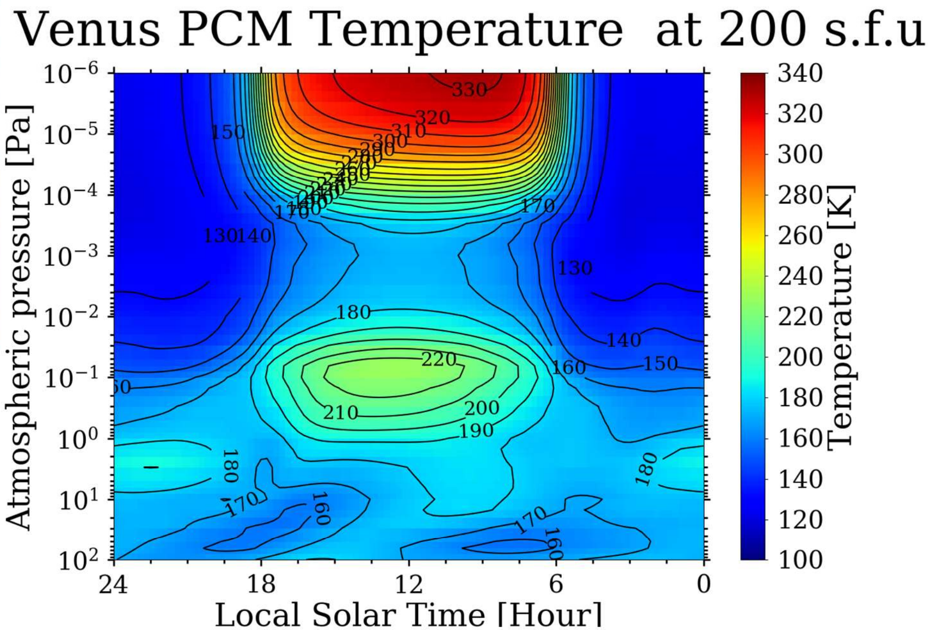
A Case study

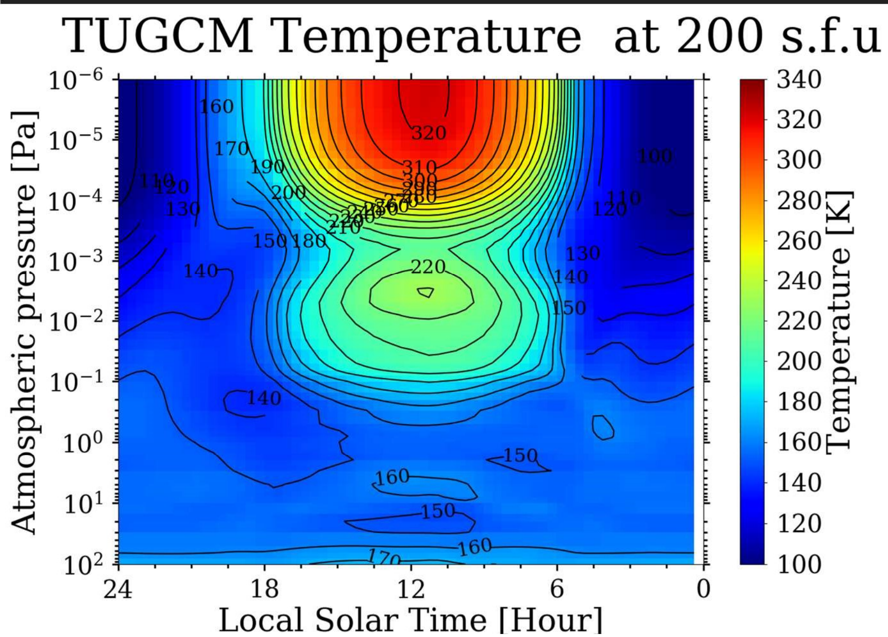
== Thermospheric Temperature structure at high solar activity ==

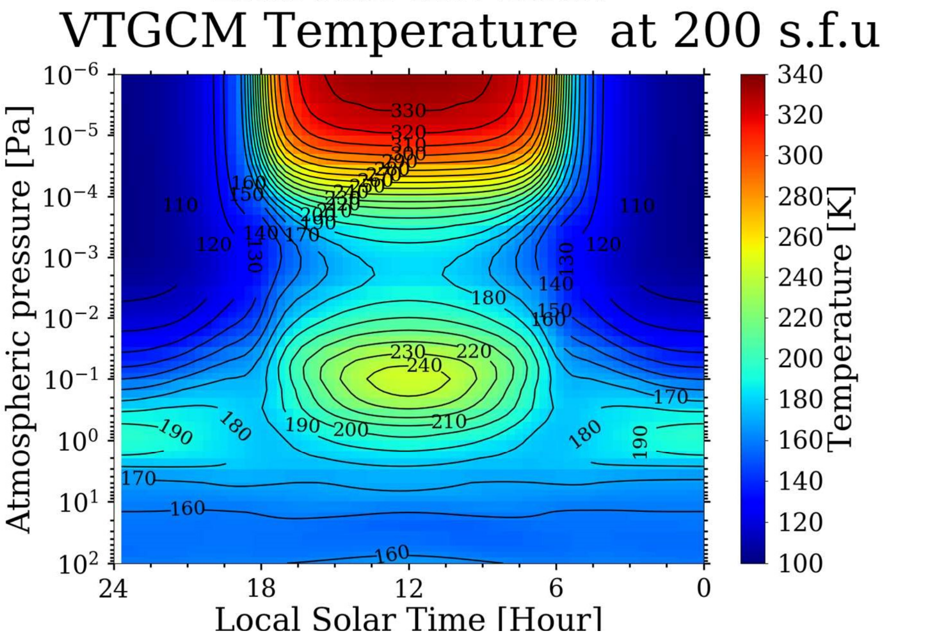
Objective: to understand the origin of the differences in the temperature structure of the Venusian thermosphere.

- Equatorial Temperature –
- High solar activity -

- Similar horizontal and vertical variation of the temperature but different absolute value.
- Different position of the temperature peak







Exospheric temperature

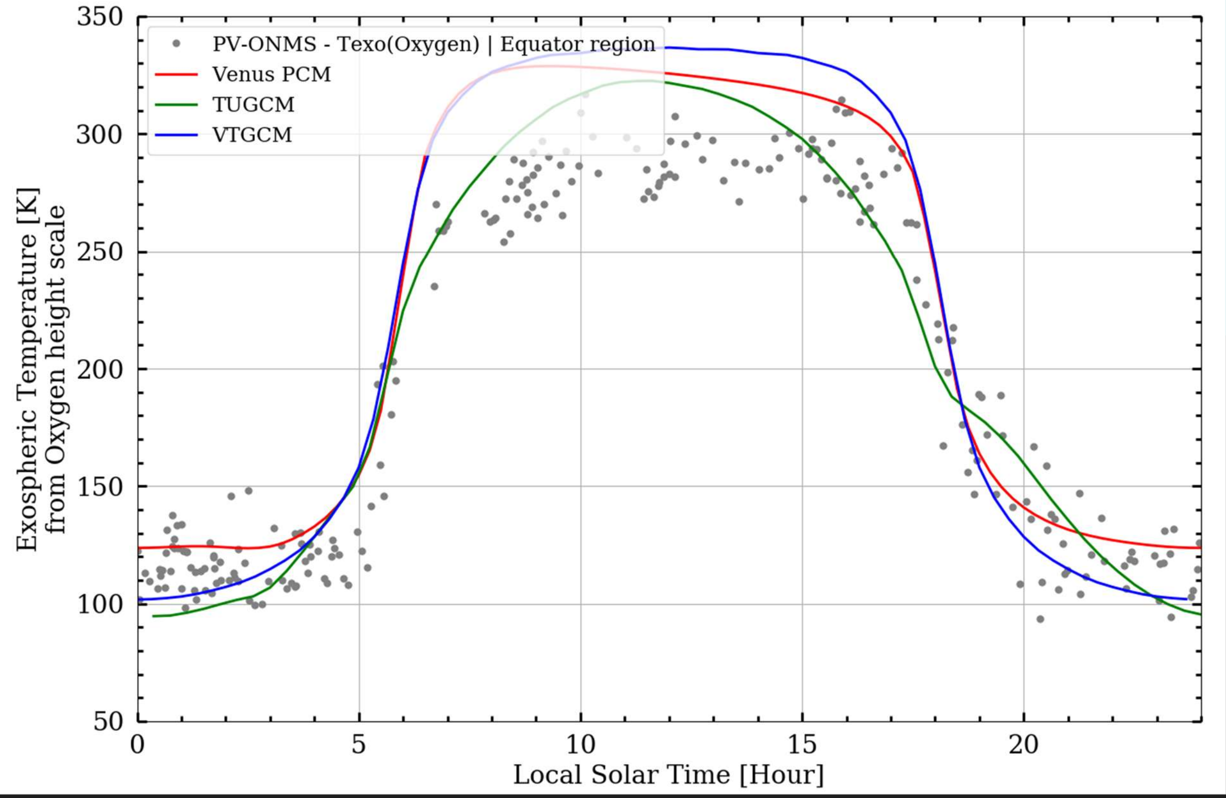
- High solar activity -

Dayside (200 s.f.u):

- VPCM: T = 325 K
- TUGCM: T = 300-320 K
- VTGVM: T = 335 K
- Pioneer Venus: T = 290K +/- 5 K

Nightside:

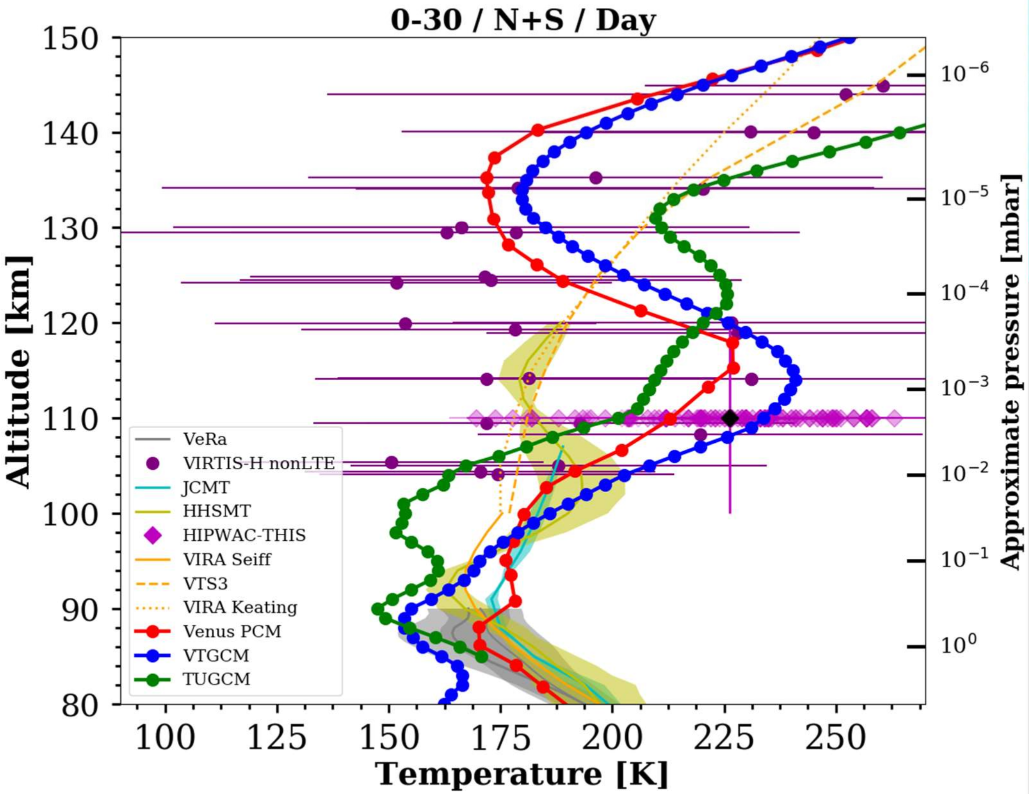
- VPCM: T = 125 K
- TUGCM: T = 95 K
- VTGVM: T = 100-105K
- Pioneer Venus: T = 116 K +/- 5 K

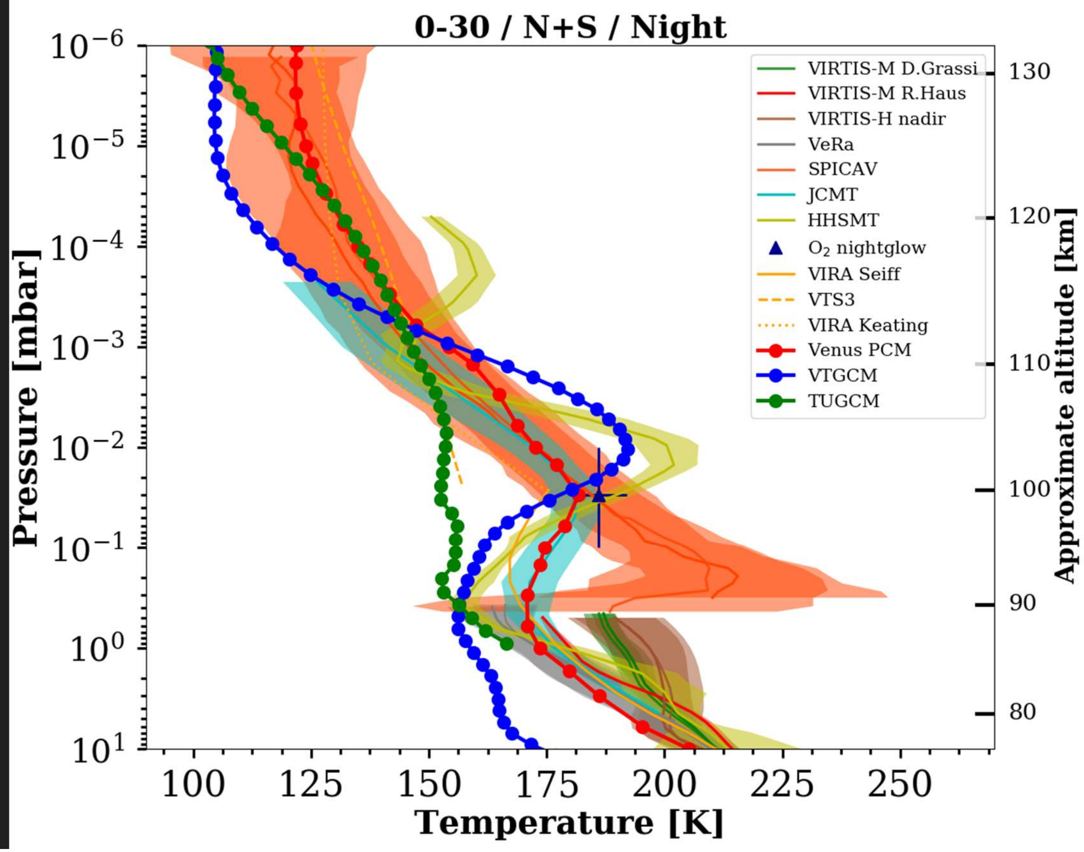


Over-estimation of the Dayside upper-thermosphere/exosphere temperature due to the lack of atomic oxygen which limits the cooling by O-CO2 15 microns radiation.

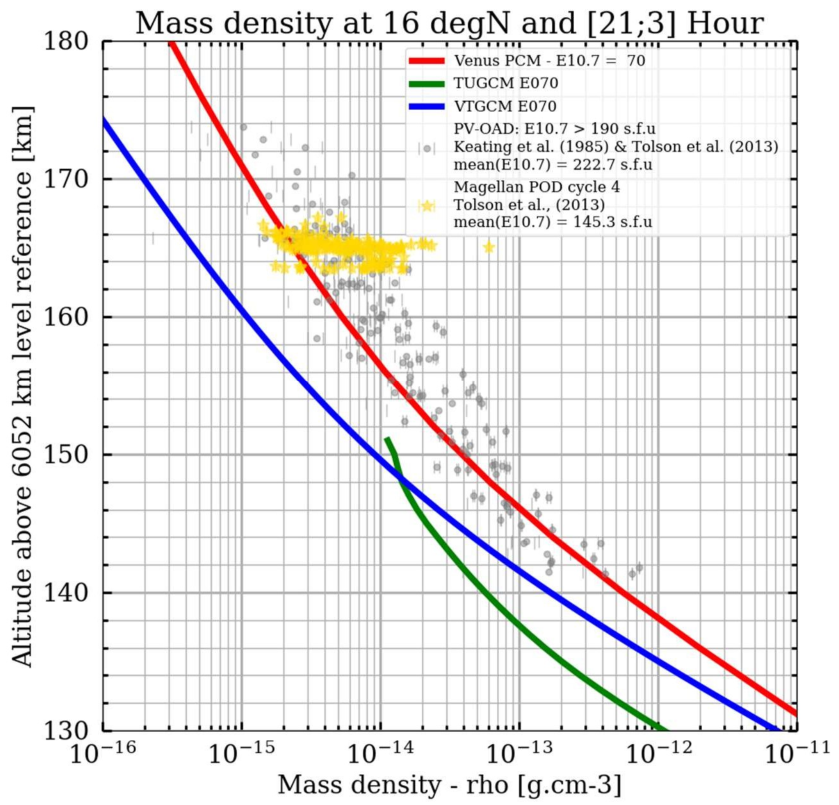
... But more on that later.

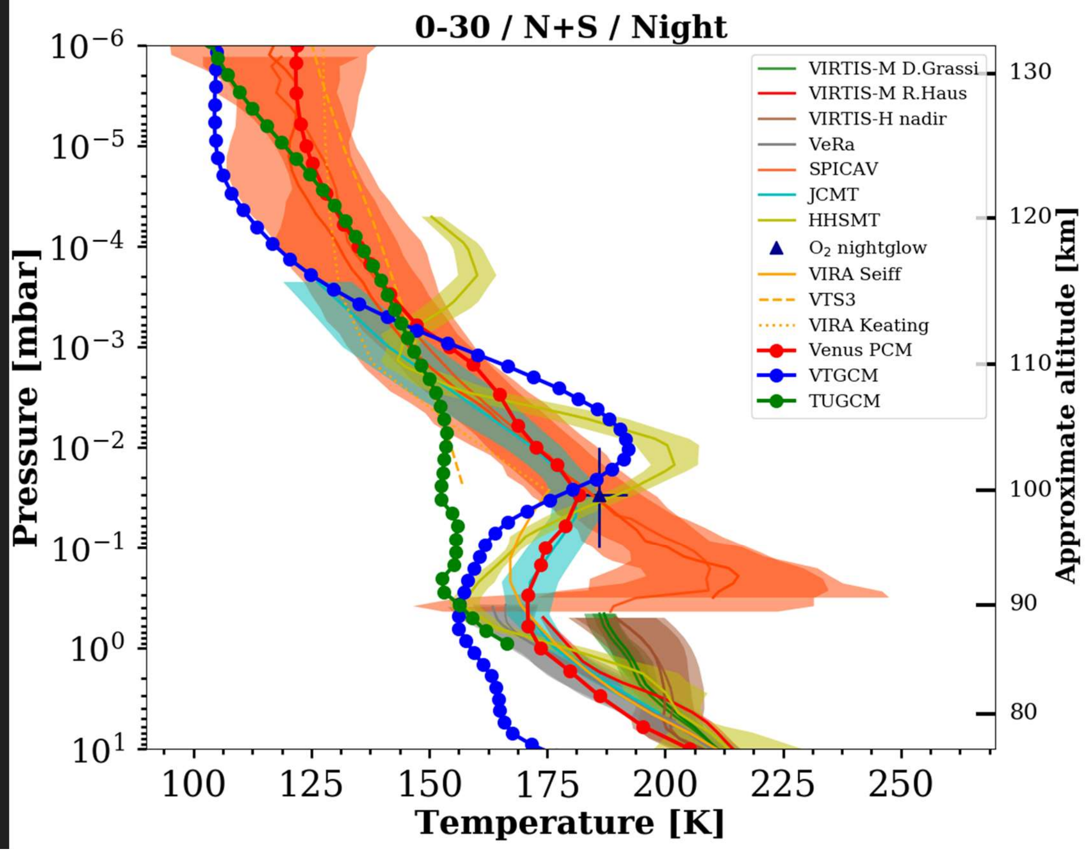
Vertical profile of temperature





Vertical profile of temperature and mass density - nightside



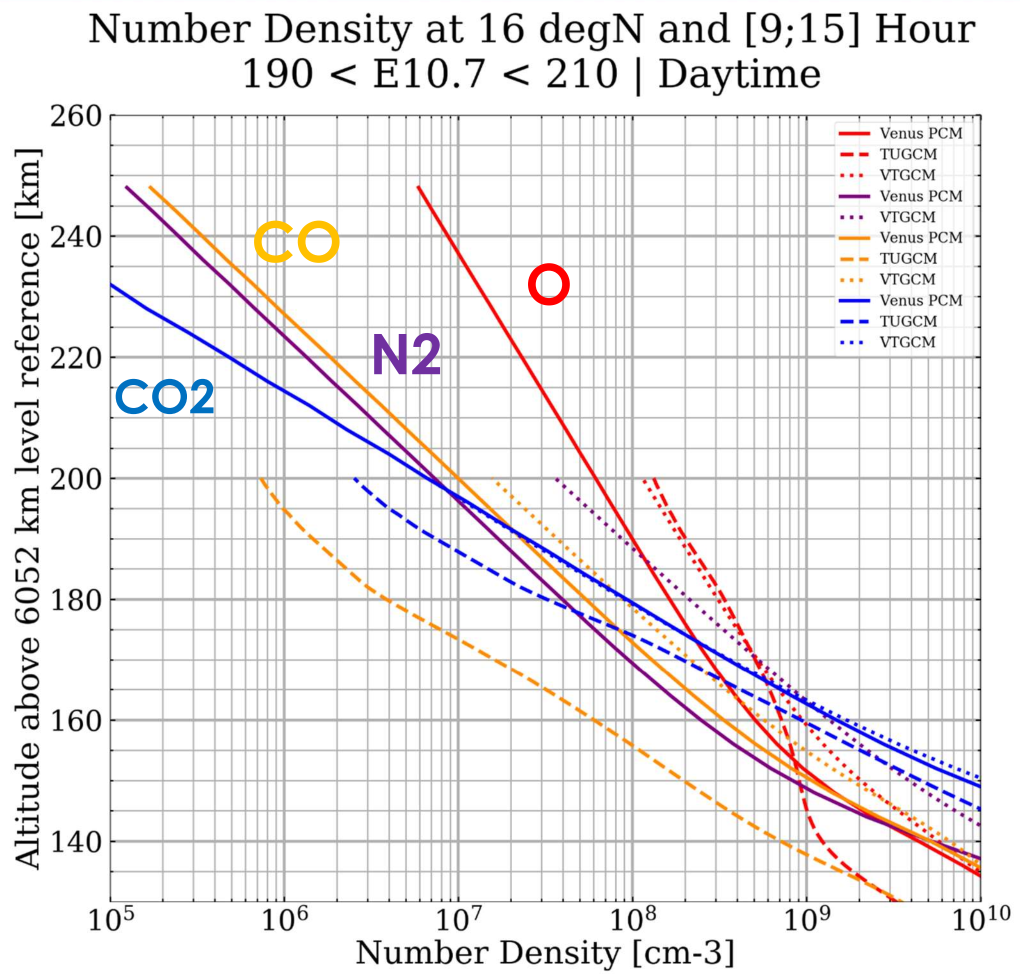


Underestimation of the mass density for VTGCM and TUGCM due to a too low temperature which shrinks the atmosphere.

Venusian thermosphere Composition

Composition at the bottom of the Model:

- **VPCM:** 96.5% and 3.5 % (CO2, N2)
- **TUGVM:** 100% of CO2
- **VTGCM:** 90% of CO2 and 10% of N2



Reminder: Pioneer Venus: 96.5% and 3.5% (CO2, N2)

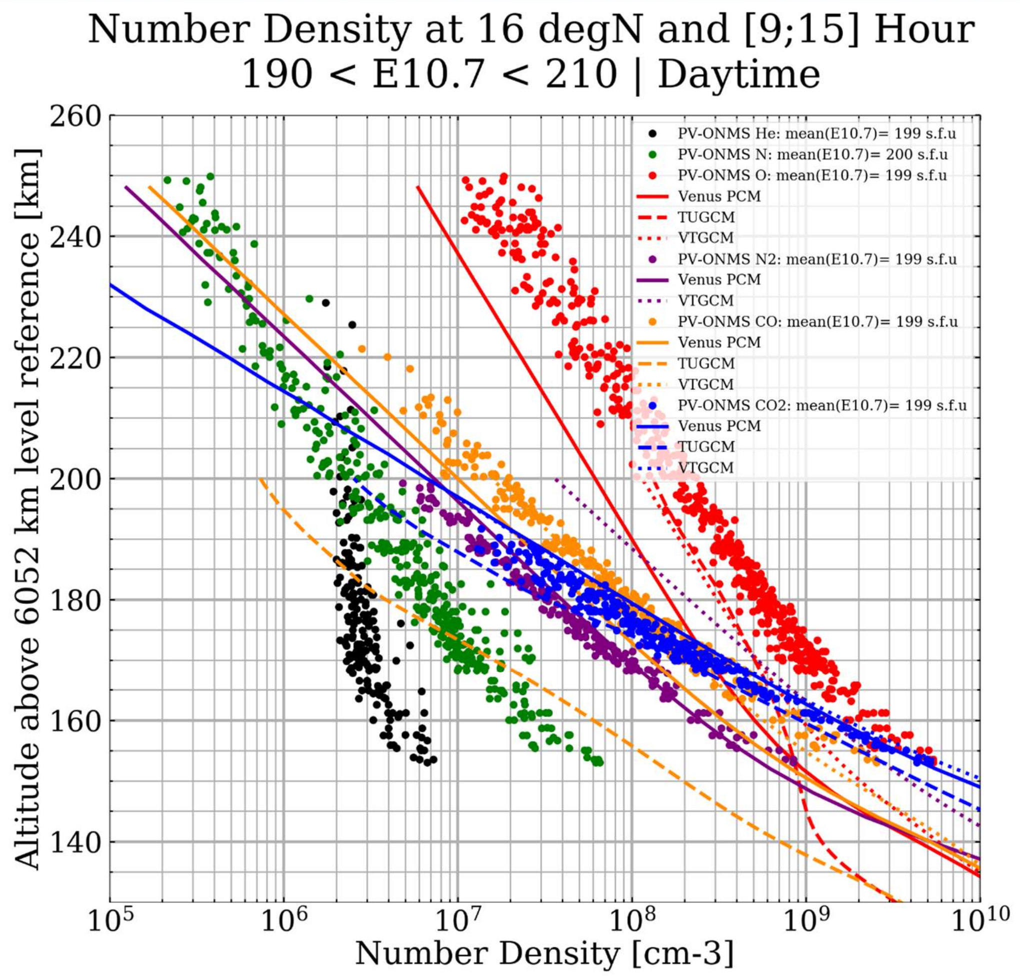
Venusian thermosphere Composition

Composition at the bottom of the Model:

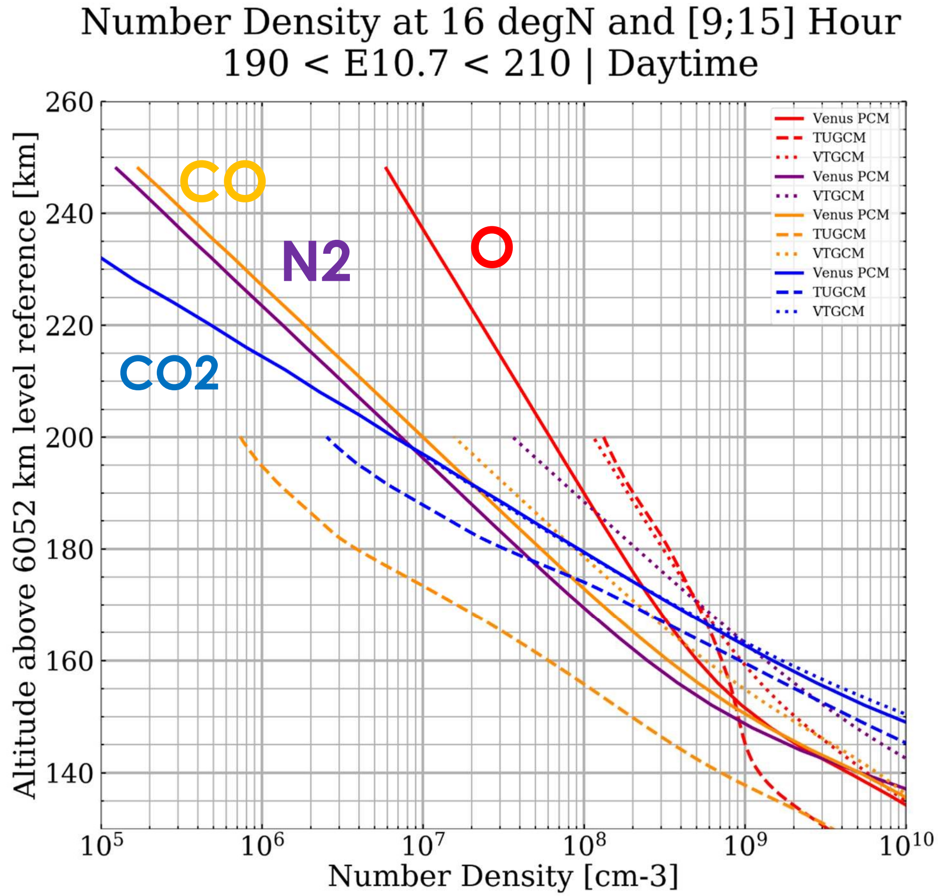
- **VPCM:** 96.5% and 3.5 % (CO2, N2)
- **TUGVM:** 100% of CO2
- **VTGCM:** 90% of CO2 and 10% of N2

Important under-estimation of the atomic oxygen amount in the thermosphere

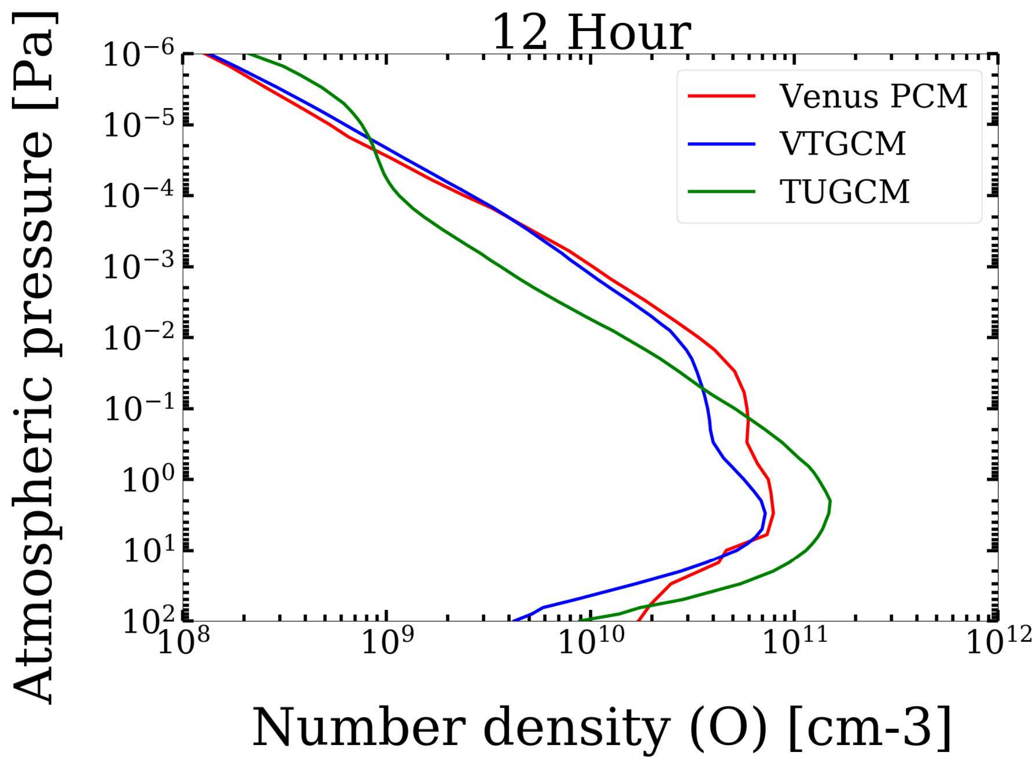
Reminder: Pioneer Venus: 96.5% and 3.5% (CO2, N2)



Atomic Oxygen underestimation and altitude shift



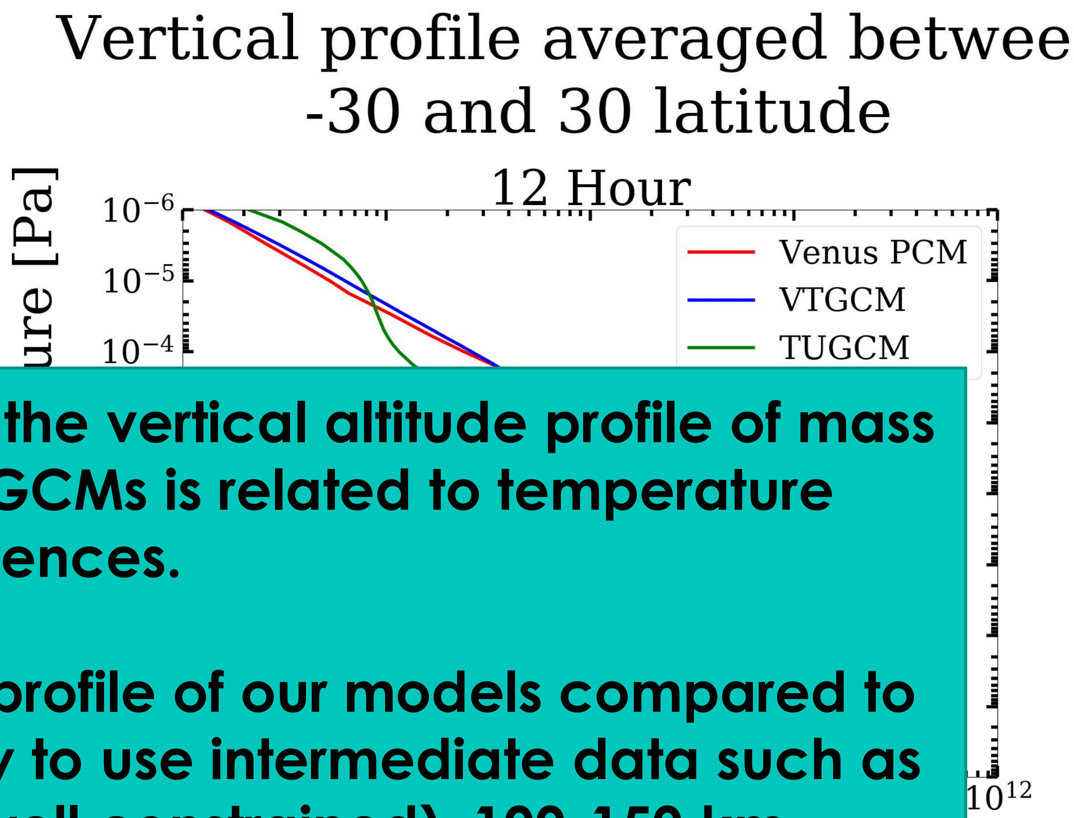
Vertical profile averaged between -30 and 30 latitude

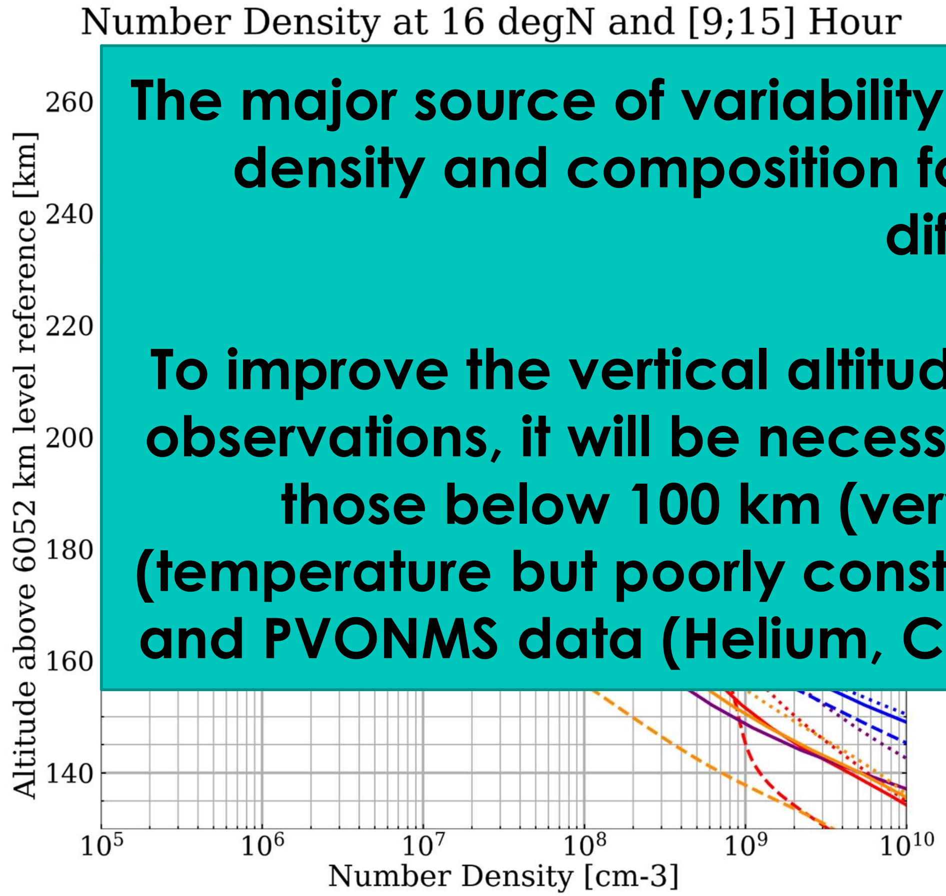


Despite a similar pressure for 2E+8 cm-3 of O between VTGCM and VPCM, there is a difference in altitude of 10 km.

Strange vertical variation of O for TUGCM, molecular diffusion is suspected [without evidence].

Atomic Oxygen underestimation and altitude shift





The major source of variability in the vertical altitude profile of mass density and composition for GCMs is related to temperature differences.

To improve the vertical altitude profile of our models compared to observations, it will be necessary to use intermediate data such as those below 100 km (very well constrained), 100-150 km (temperature but poorly constrained), Magellan data (130-140 km) and PVONMS data (Helium, CO2, N2). **[It won't be treated here, bonus time if you want]**

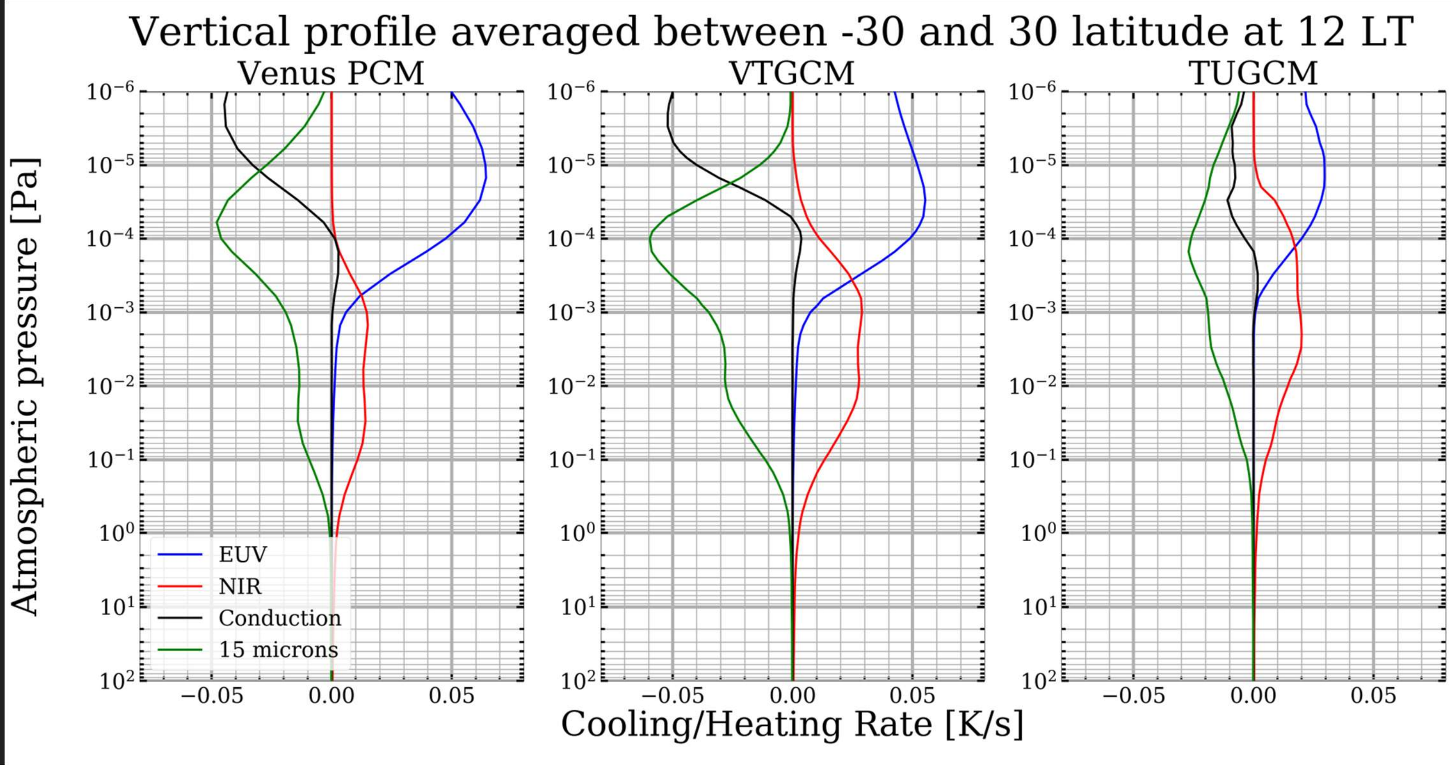
between VTGCM and VPCM, there is a difference in altitude of 15 km.

Strange vertical variation of O for TUGCM, molecular diffusion is suspected [without evidence].

Heating/cooling process of the thermosphere

- **Radiative**
  - EUV heating (Blue)
  - Near Infrared Heating (Red)
  - 15 microns CO_2 cooling (Green)

- **Transport:**
  - Conduction (Black)
  - Dynamic
  - Molecular & Eddy Diffusion

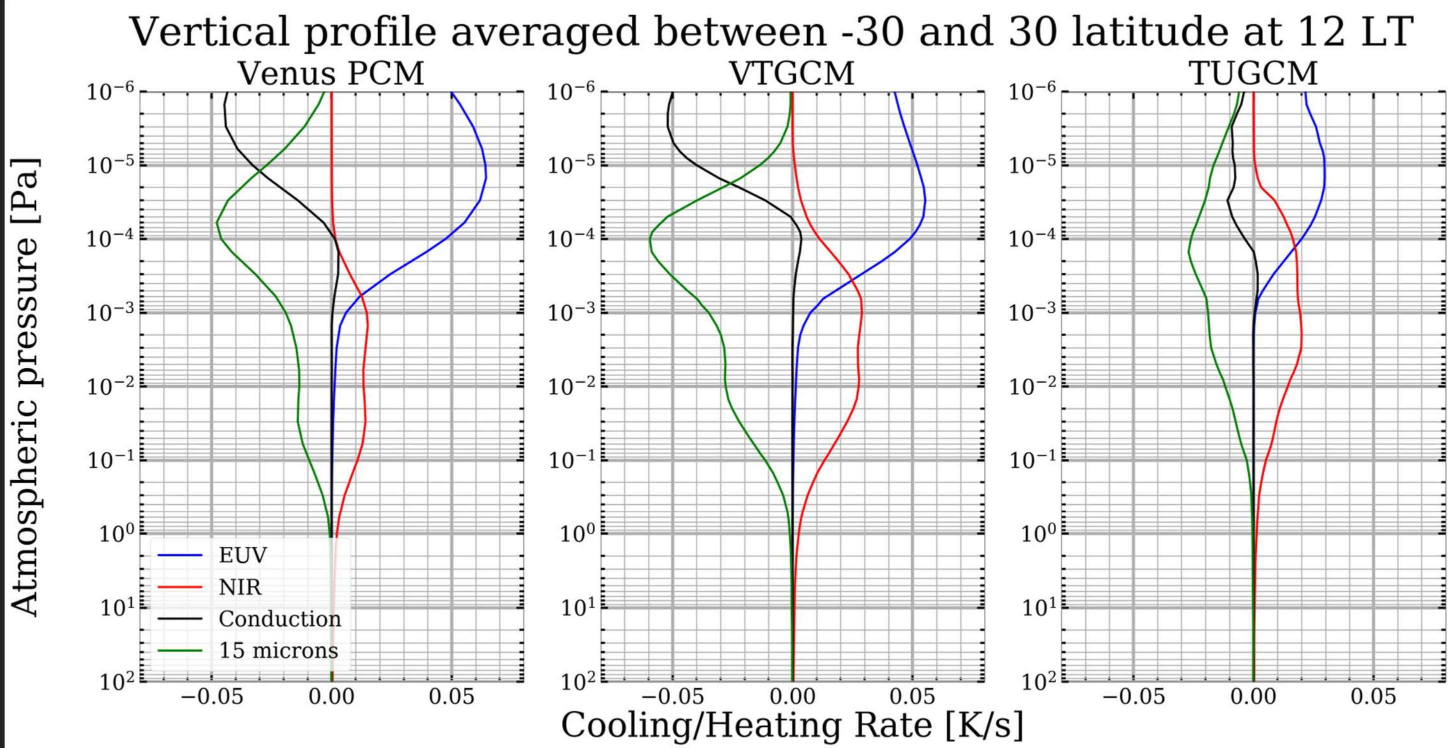


Importance of atomic oxygen in the thermosphere

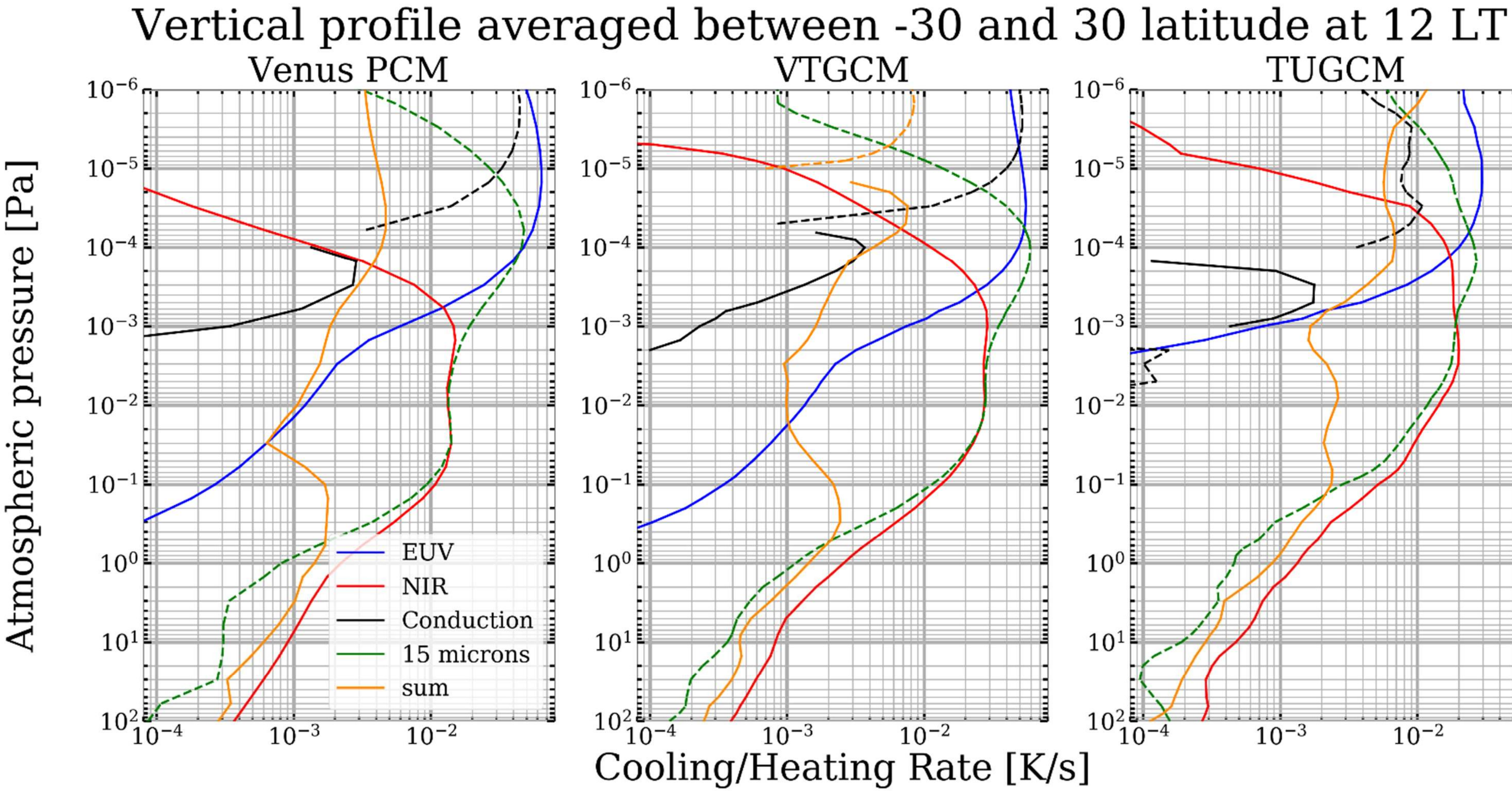
- 2E-5 Pa > P: Conduction cooling dominates & EUV heating dominates
- 2E-5 Pa < P: 15 microns cooling dominates (NLTE below 1.E-2 Pa – LTE above 1.E-2 Pa)
- 5E-4 Pa < P: NIR heating dominates

Conduction cools the top by transporting heat downwards, where 15 microns dominate.

The more atomic oxygen you have, the more NLTE cooling there is by 15 microns.



Heating/cooling process of the thermosphere



EUV heating difference

EUV range: <120 nm

UV range:
| 100 – 400 | nm

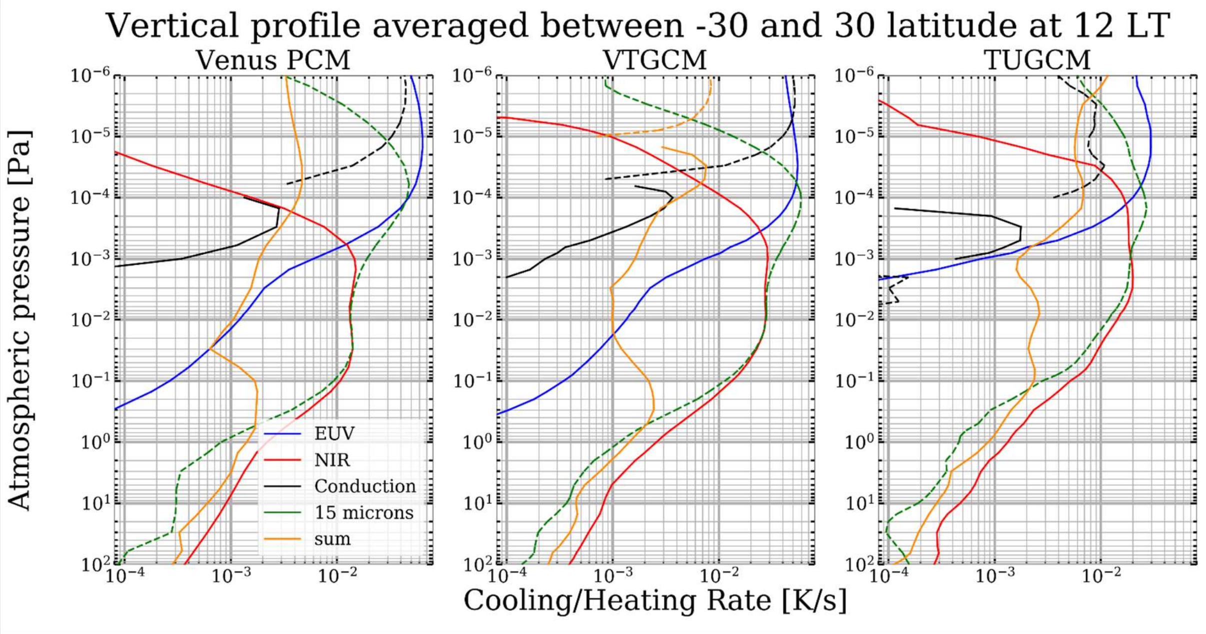
Main difference explained by:

- **P > 10^(-3) Pa (lower thermosphere):**

- Lack of EUV heating rate for TUGCM because of their solar spectrum reference (Torr et al. 1979) which doesn't have photon below 5 nm and above 105 nm contrary to VPCM and VTGCM. These photons can reach pressure above 10^(-3) Pa.

EUV Efficiency: Recommanded values: (16-25)%

19.5% 20% (EUV) - 22% (UV) 10%



EUV heating difference

<u>EUV range:</u> <120 nm

<u>UV range:</u>
| 100 – 400 | nm

<u>Main difference explained by:</u>

- **<u>P > 10^(-3) Pa (lower thermosphere):</u>**

- Lack of EUV heating rate for TUGCM because of their solar spectrum reference (Torr et al. 1979) which doesn't have photon below 5 nm and above 105 nm contrary to VPCM and VTGCM. These photons can reach pressure above 10^(-3) Pa.

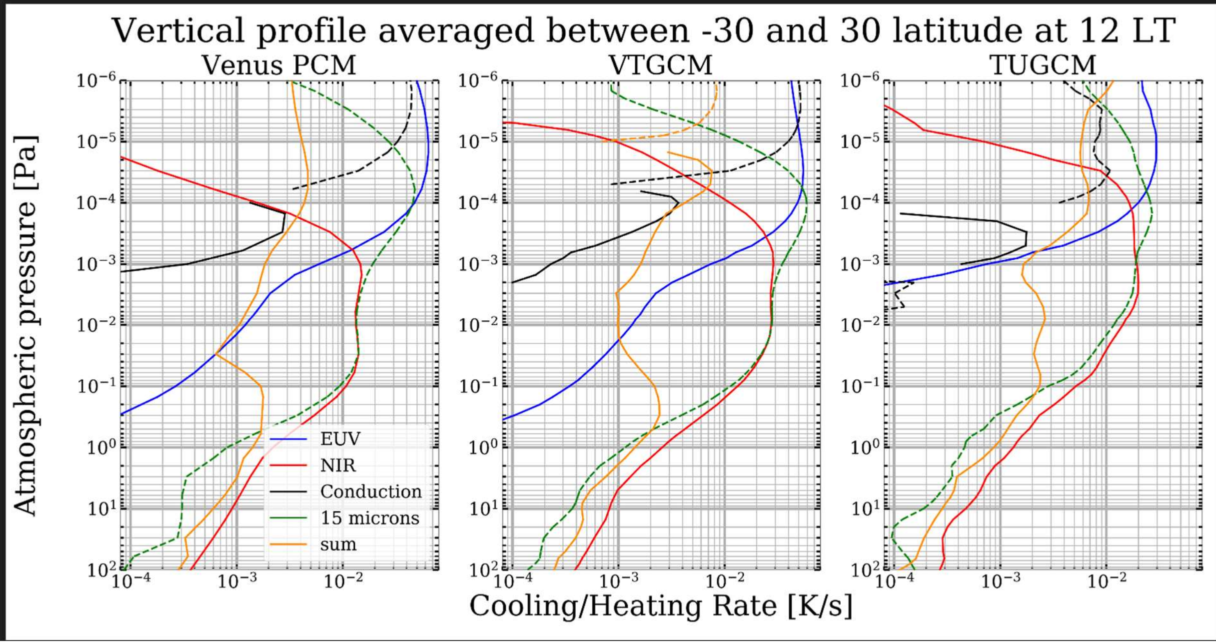
- **<u>P < 10^(-3) Pa (upper thermosphere)</u>**

- EUV efficiency twice lower for TUGCM (caused by the underestimation of the TUGCM conduction **[BONUS if we have the time]**

- Composition, EUV efficiency and spectrum reference for VTGCM/VPCM (small difference)

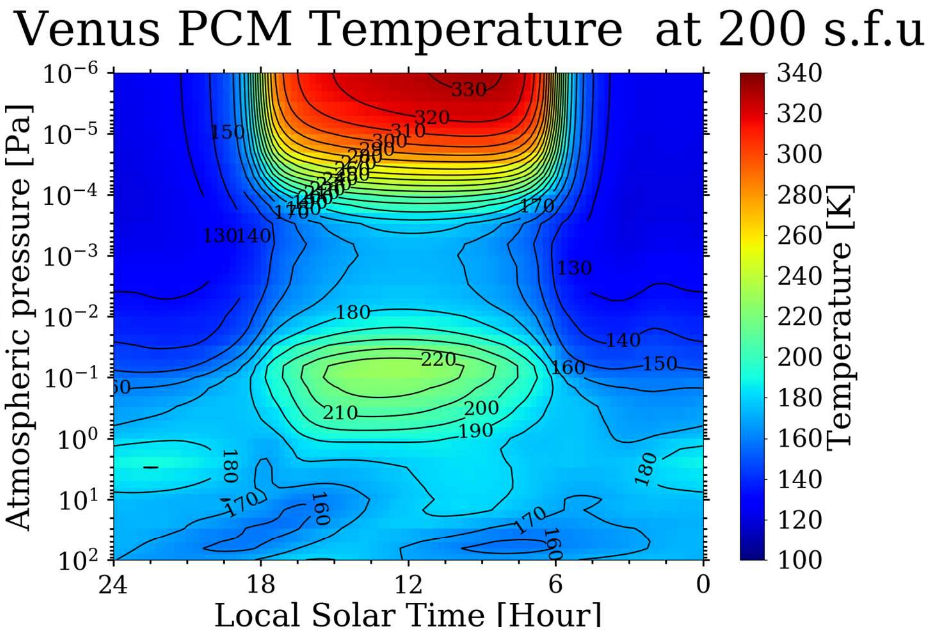
EUV Efficiency: Recommanded values: (16-25)%

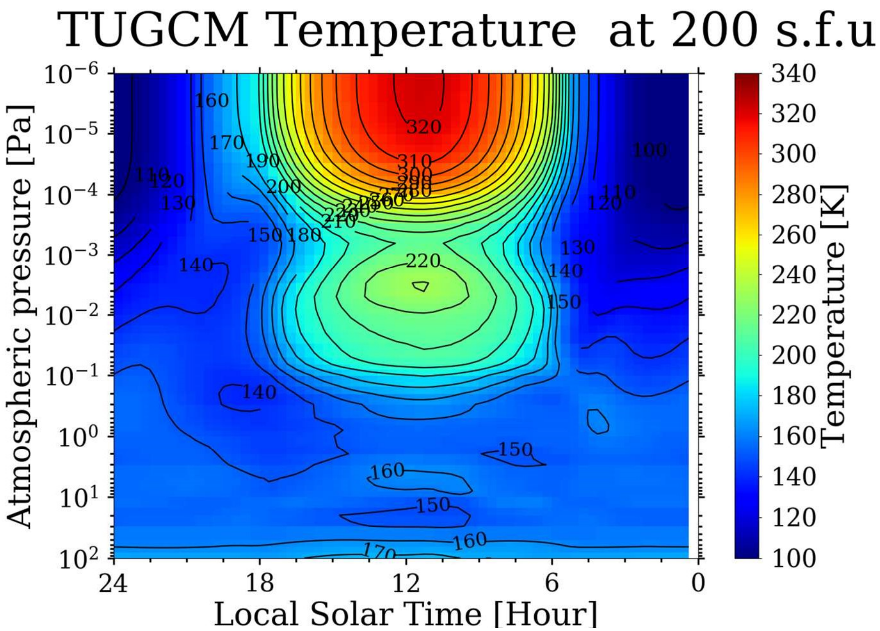
19.5% 20% (EUV) - 22% (UV) 10%

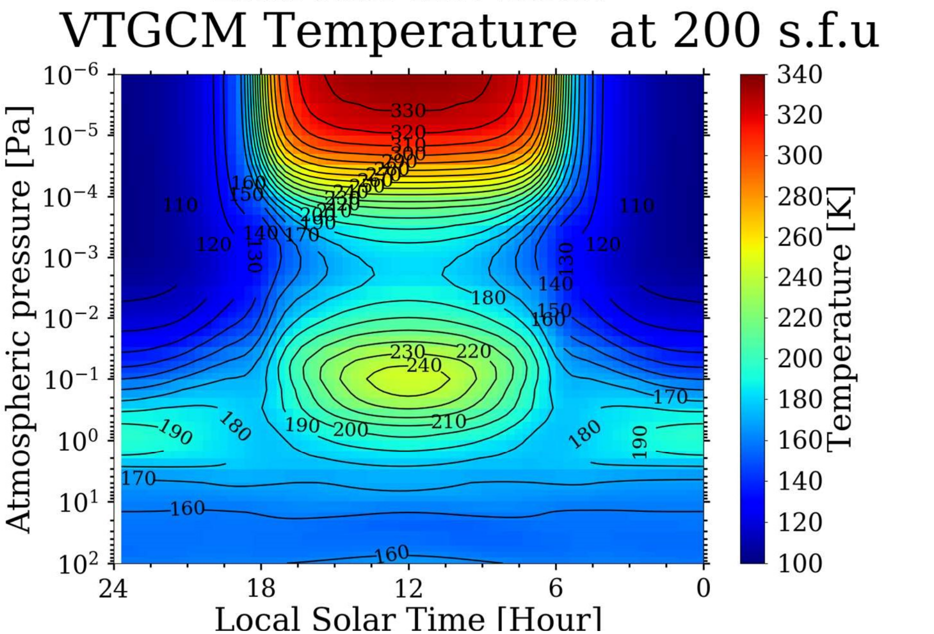


- Equatorial Temperature –
- High solar activity -

- **First temperature peak at noon:**
  - TUGCM : ~4.E-3 Pa (T = 230 K)
  - VTGCM : ~1.E-1 Pa (T = 245 K)
  - VPCM : ~1.E-1 Pa (T = 225 K)







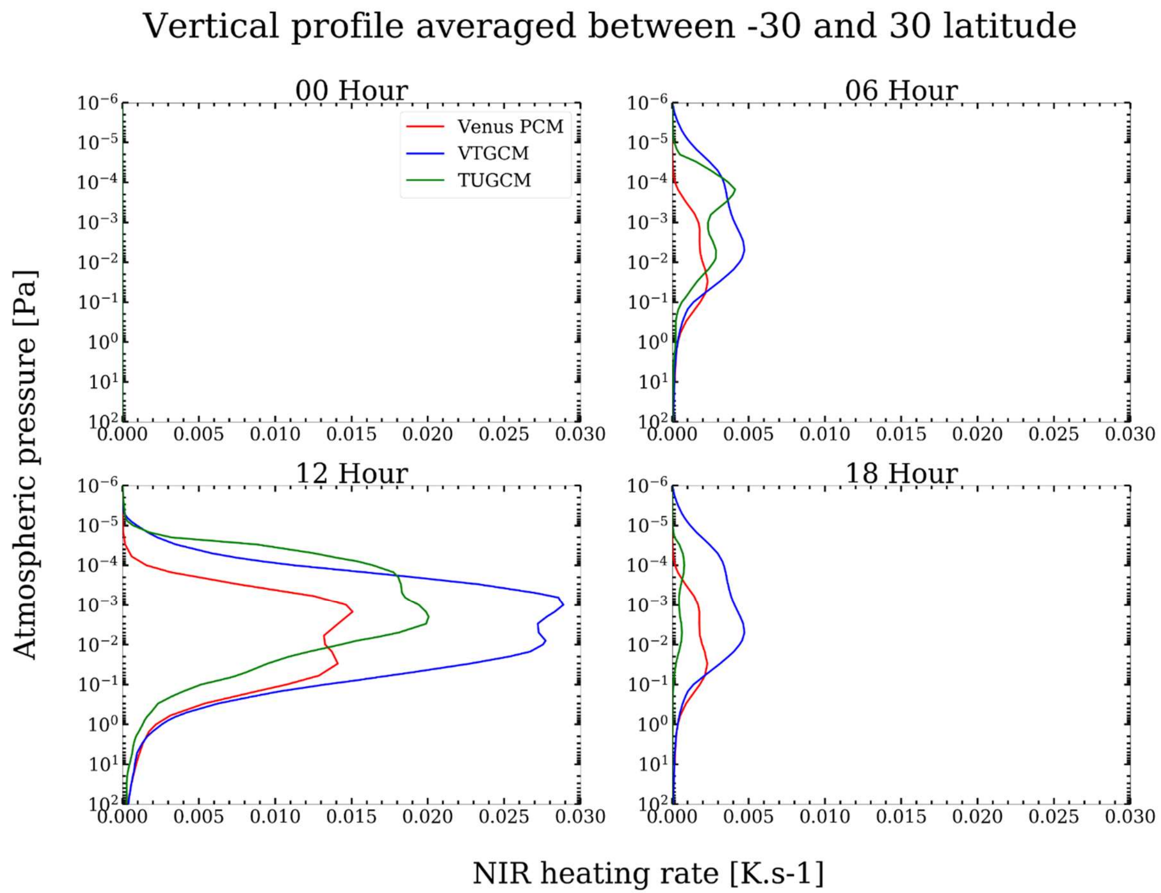
- Vertical profile of the NIR heating rate–
- High solar activity -

VTGCM: NLTE: look-up table from non-LTE radiative transfert line-by-line model results in Roldàn et al., 2000

TUGCM: multiplying the NIR heating rate calculated with the assumption of LTE by a factor that results in the global mean LTE NIR heating rate matching the reference NIR heating rate.

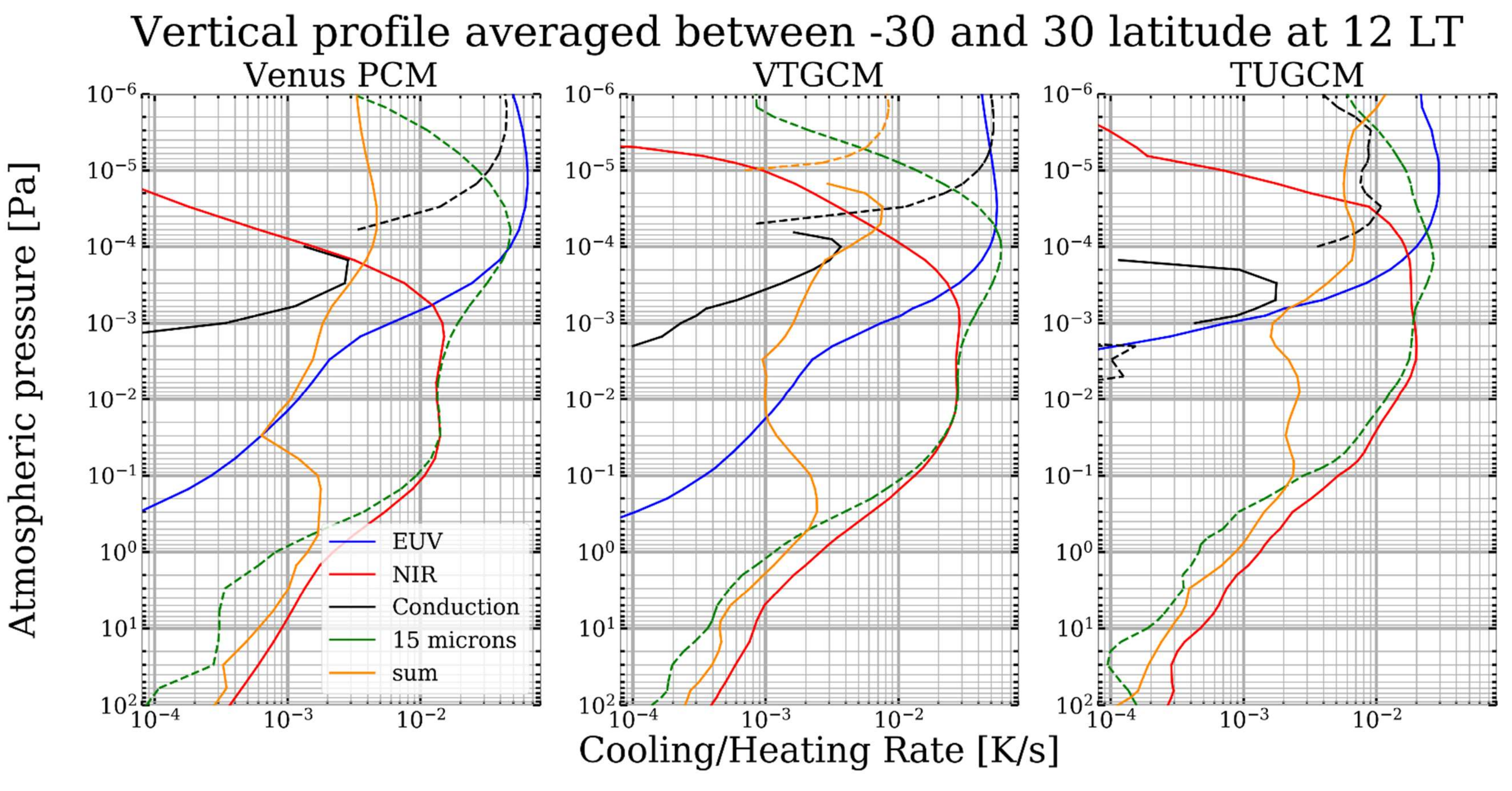
VPCM: Fit the NIR vertical profile of Roldan et al 2000, slightly reduce the peak amplitude and the modify the pressure peak. (Tuning)

Difference explained by the difference between pressure and altitude reference and some tuning in comparison to Roldan et al. 2000



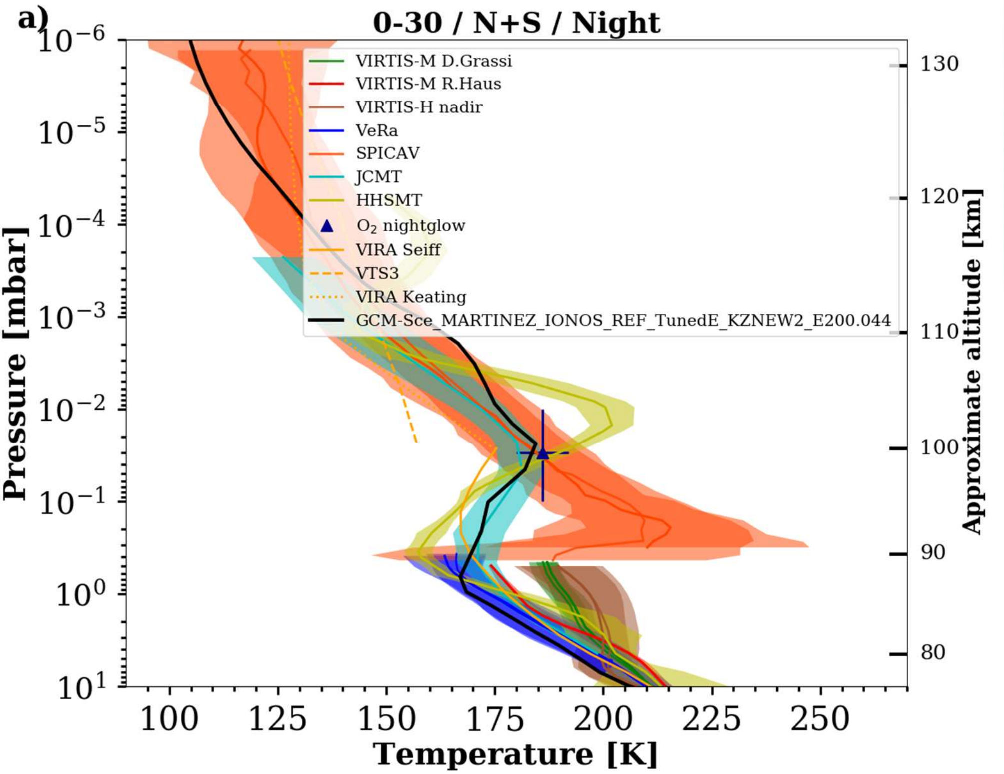
- Vertical profile of the NIR heating rate–
- High solar activity -

Temperature of TUGCM and VTGCM lower than VPCM below 1E-1 Pa due to a lower NIR than in VPCM.



Vertical profile of temperature - nightside

AFTER



For p< 10-3 Pa:

T(REF,VPCM) = 120 - 125 K

T(KNEW2,VPCM) = 97 - 105 K

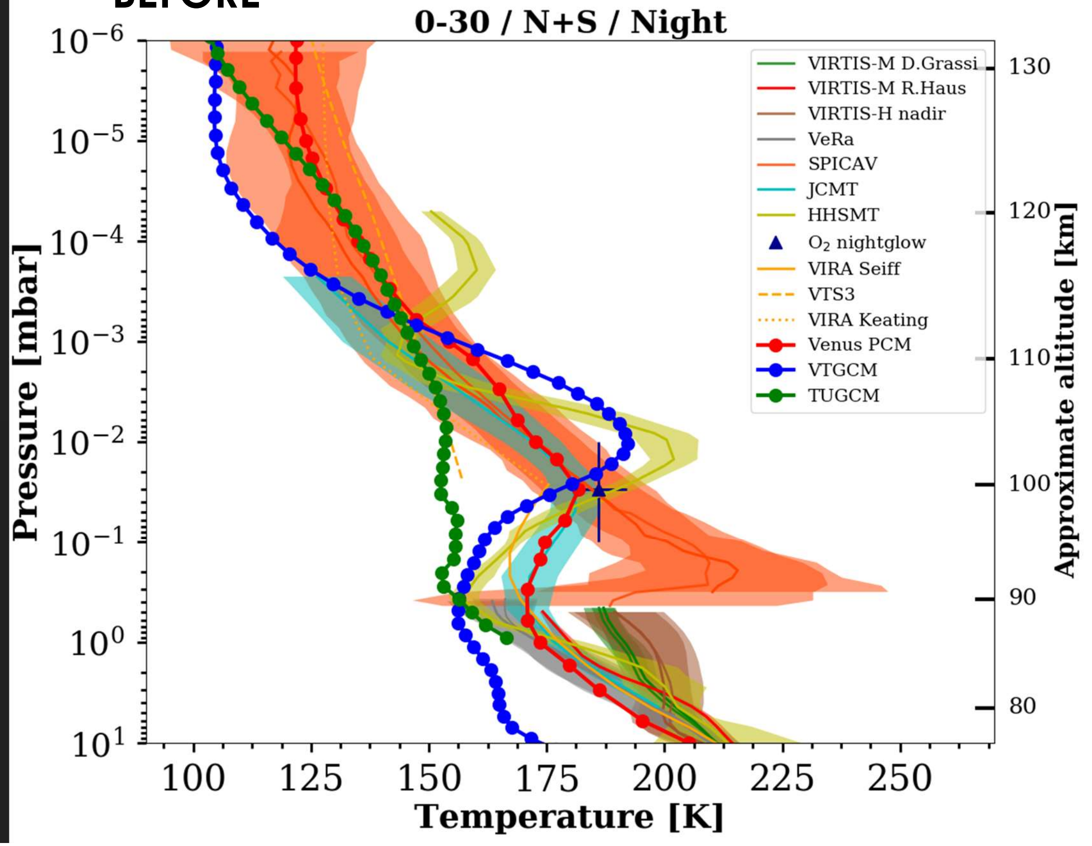
NIGHTSIDE

KNEW2 = min[500,A/sqrt(Number density)] m².s-1 | Kmax at P = 1.5E-3 Pa

K(VTGCM)= min[100,min[1000,A/SQRT(N)]]] m².s-1 | Kmax at 125 km

K(TUGCM)= 500 * min[1,(p/(1.2*10^(-4)))**0.5] m².s-1 | Kmax at P = 1.2E-4 Pa

BEFORE



Conclusion

== Thank you for your attention ==

- Atomic oxygen is underestimated in the thermosphere, inducing over-estimation of the Dayside exospheric temperature and underestimation of mass density.

  =>**Where's the missing oxygen? Good questions (maybe transport ?)**

- A major source of variability in the vertical altitude profile of mass density for GCMs is related to temperature differences (notably above 120 km) as presented for the nightside.
- Eddy conduction is responsible for the difference between VPCM and other models, providing an additional source of cooling on the night side.
- GW parameterization has an indirect effect on the temperature because of its influence on the circurlation in the thermosphere (Dynamical effects).

Keep in mind: the analysis is going on.

More Slides

== It is not over (sorry) ==

Torr et al.: Ionization Frequencies

TABLE 3. Solar UV Flux Data

UV Spectrum from 50–1050A

Intensity Incident on Earth (10^9 Photons cm^{-2} s^{-1})

SOLAR FLUX PERIOD			74113	76200	78348	79022	79050
Interval	Wavelength A	ION					
1	50– 100		.3984	.4382	1.0337	1.2904	1.3710
2	100– 150		.1497	.1687	.3623	.4419	.4675
3	150– 200		2.3683	1.8692	4.1772	5.3708	5.7024
4	200– 250		1.5632	1.3951	4.7953	6.6473	7.1448
5	256.3	HeII, SiX	.4600	.5064	.8805	1.0331	1.0832
6	284.15	FeXV	.2100	.0773	3.2613	5.2352	5.7229
7	250– 300		1.6794	1.3556	7.5081	11.2278	12.1600
8	303.31	SiXI	.8000	.6000	2.9100	4.3380	4.6908
9	303.78	HeII	6.9000	7.7625	12.3424	13.8172	14.3956
10	300– 350		.9650	.8671	4.3119	6.3164	6.8315
11	368.07	MgIX	.6500	.7394	1.2891	1.4661	1.5355
12	350– 400		.3140	.2121	1.5298	2.3413	2.5423
13	400– 450		.3832	.4073	1.0922	1.4330	1.5310
14	465.22	NeVII	.2900	.3299	.6102	.7004	.7358
15	450– 500		.2851	.3081	1.2120	1.6912	1.8228
16	500– 550		.4520	.5085	1.2303	1.5496	1.6486
17	554.37	OIV	.7200	.7992	1.2943	1.4537	1.5163
18	584.33	HeI	1.2700	1.5875	3.4608	4.0646	4.3005
19	550– 600		.3568	.4843	.8732	.9985	1.0477
20	609.76	MgX	.5300	.6333	1.6782	2.3242	2.4838
21	629.73	OV	1.5900	1.8484	3.2443	3.6938	3.8701
22	600– 650		.3421	.4002	.9606	1.2842	1.3672
23	650– 700		.2302	.2623	.4521	.5149	.5388
24	703.31	OIII	.3600	.3915	.6363	.7152	.7461
25	700– 750		.1409	.1667	.3439	.4046	.4287
26	765.15	NIV	.1700	.1997	.3647	.4178	.4386
27	770.41	NeVIII	.2600	.2425	.7760	1.1058	1.1873
28	789.36	OIV	.7024	.7831	1.2870	1.4501	1.5140
29	750– 800		.7581	.8728	1.8909	2.3132	2.4541
30	800– 850		1.6250	1.9311	3.9278	4.5911	4.8538
31	850– 900		3.5370	4.4325	9.7798	11.5292	12.2187
32	900– 950		3.0003	3.6994	7.9445	9.3134	9.8513
33	977.02	CIII	4.4000	4.8400	8.5523	9.7478	10.2165
34	950–1000		1.4746	1.7155	3.3468	3.8723	4.0779
35	1025.72	HI	3.5000	4.3750	9.5375	11.2000	11.8519
36	1031.91	OVI	2.1000	1.9425	4.2929	5.7459	6.1049
37	1000–1050		2.4665	2.4775	4.7145	5.7798	6.0928
F10.7	(10^{-22} $Wm^{-2}H_z^{-1}$)		71.0	68.0	206.0	234.0	243.0

EUV range: <120 nm

UV range:

| 100 – 400 | nm

VPCM:

0.1-800 nm

TUGCM:

5-105 nm

VTGCM:

1-220 nm

Torr et al. 1979

E04S02 FOX: VENUS NEAR-TER

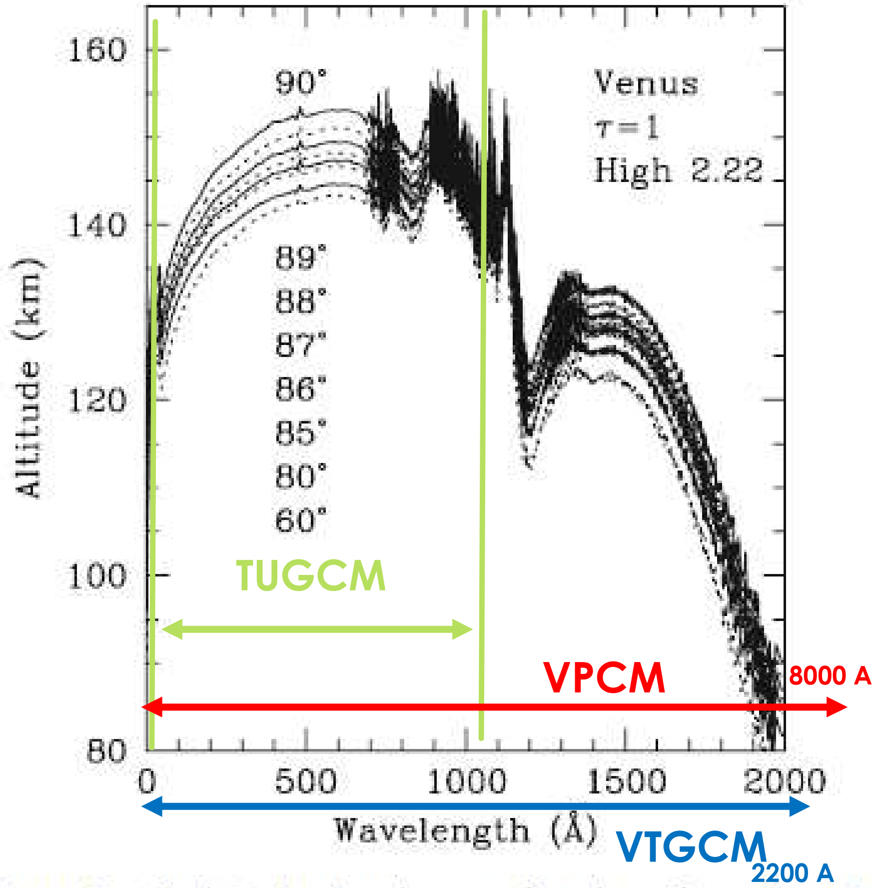
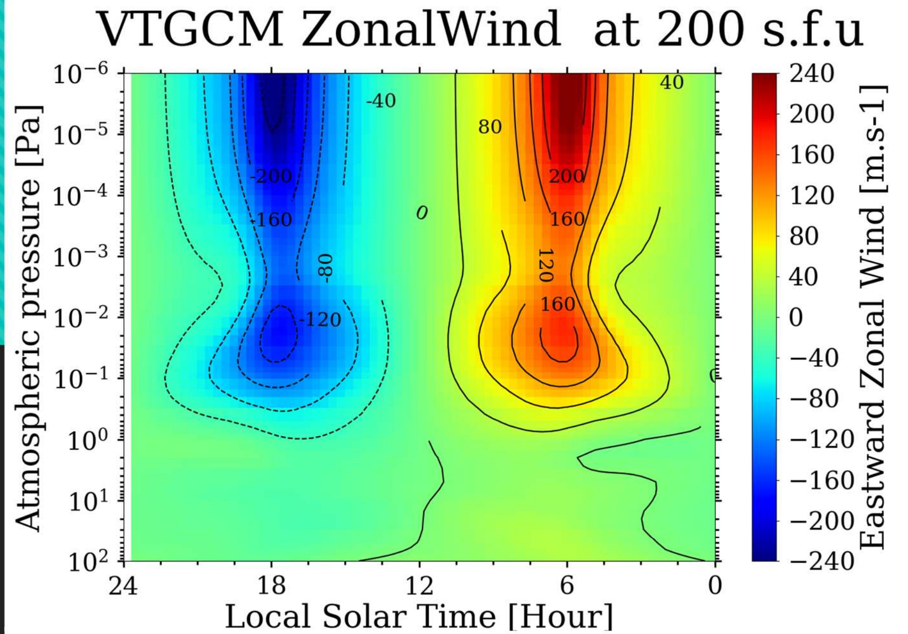
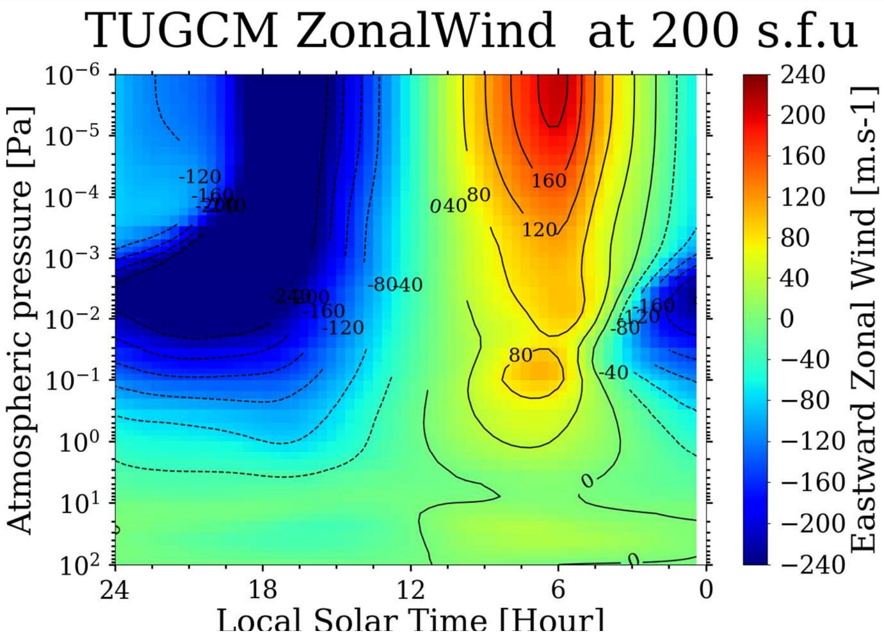


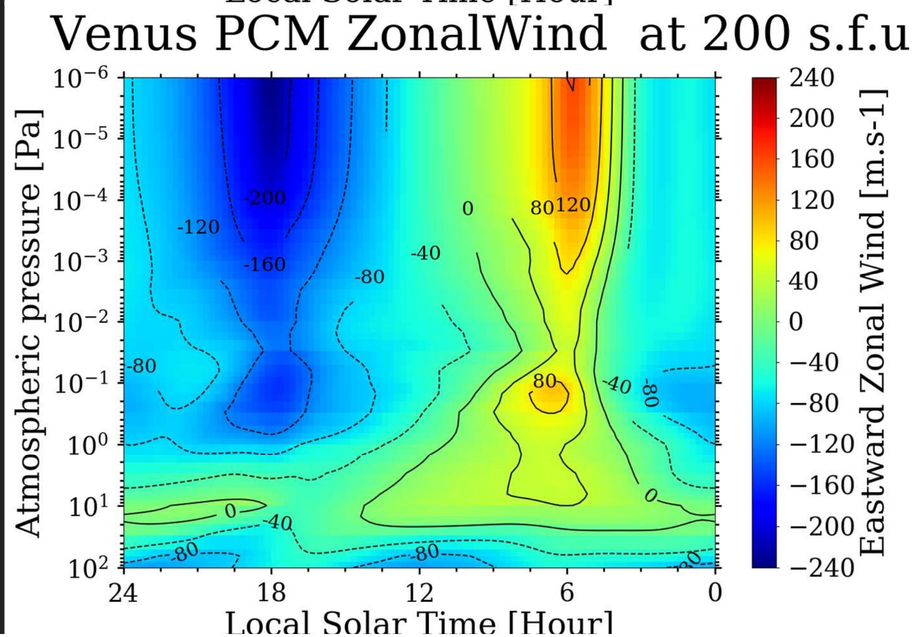
Figure 1. Optical depth unity as a function of wavelength for the range 0 to 2000 Å for the 60, 80, 85, 86, 87, 88, 89, and 90° SZA models, in order of increasing altitude. The results for the different solar zenith angle models alternate between solid and dotted curves for readability. Note that the curves for the 65, 70, and 75° models are not shown.

- Equatorial Zonal Wind –
- High solar activity -

- Influence of GW (TUGCM, VPCM)
- Shift to morning (TUGCM, VPCM)
- Absence of GW (VTGCM) and







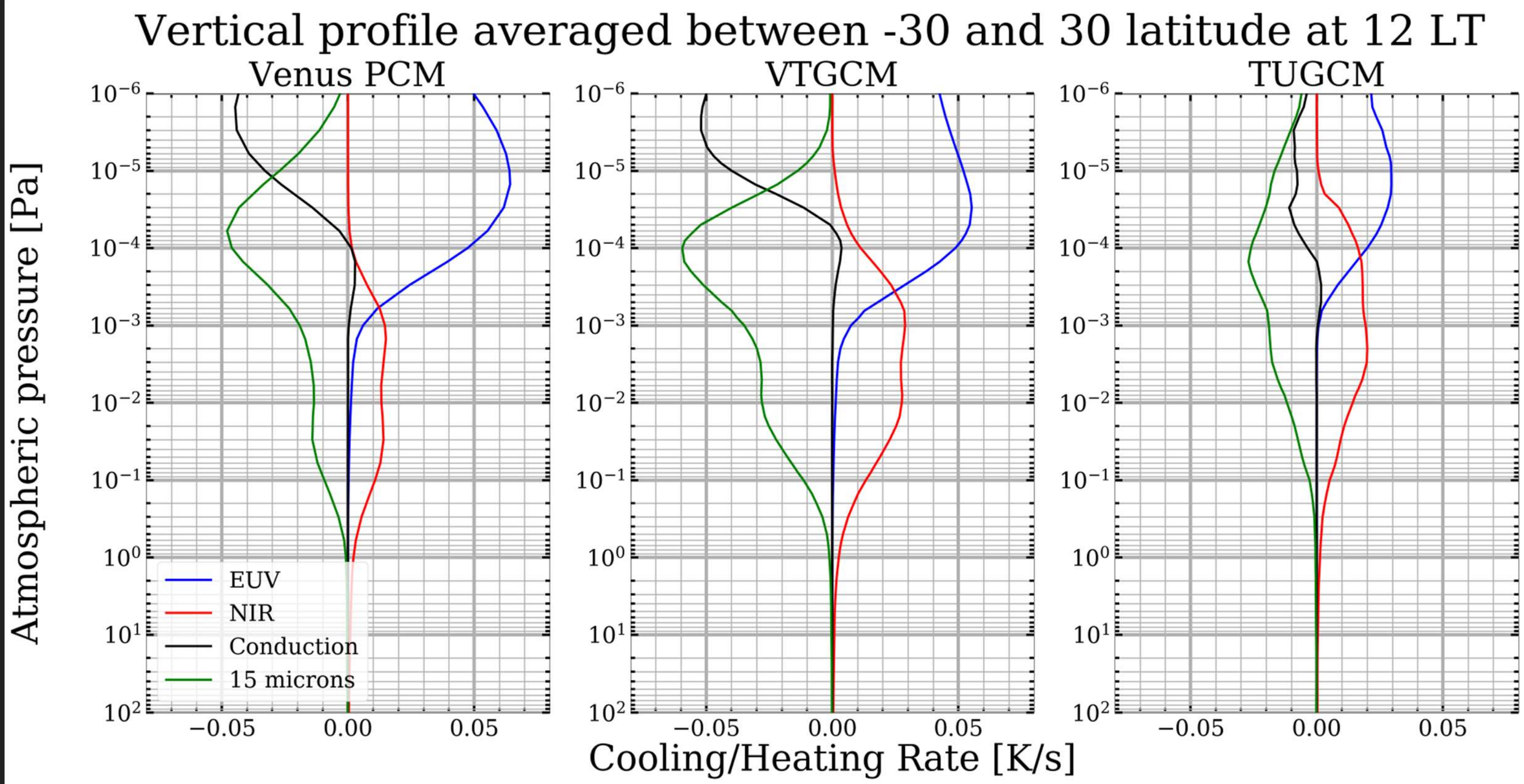
TUGCM conduction

- **Conduction appears to be greatly underestimated by TUGCM in comparison to VTGCM and VPCM.**
- It is likely that the need for TUGCM to have an EUV efficiency of 10% is linked to this.
- The rate of conduction depends on several parameters:
  - the heat capacity of the atmosphere
  - the thermal conductivity of the atmosphere (which is a function of each component)
  - the flux at the top if the top of the model is at too low altitude

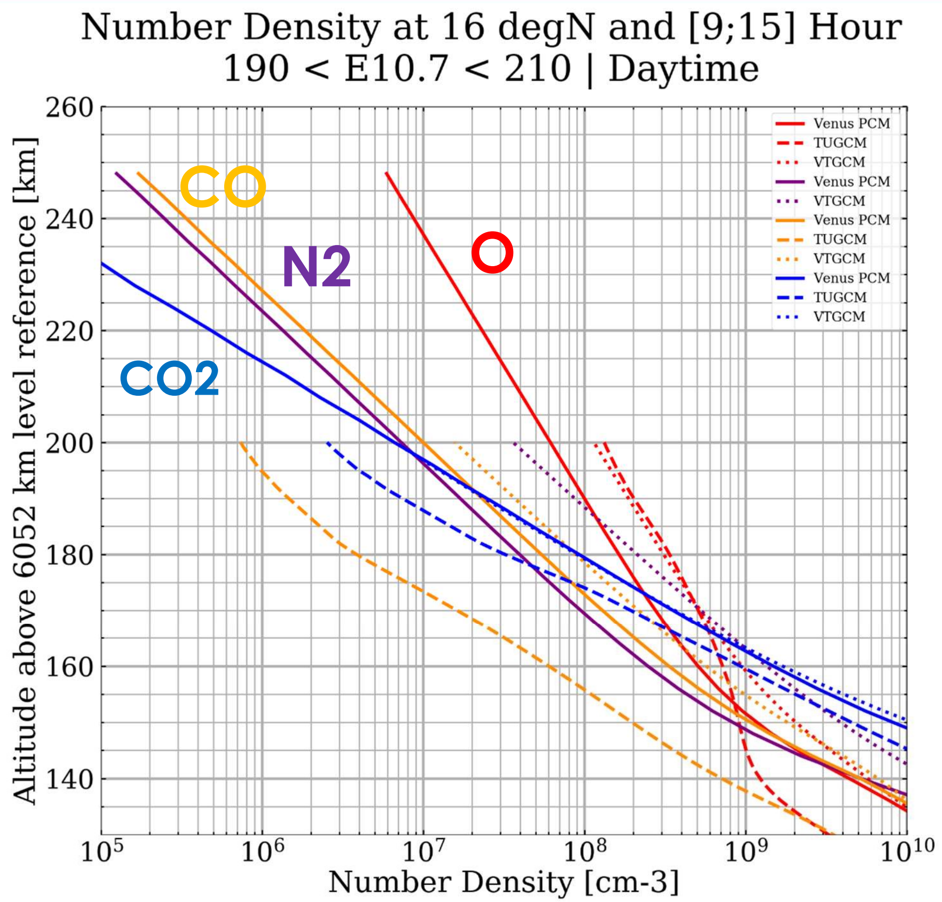
The TUGCM conduction code needs to be studied in greater depth to explain this underestimation.

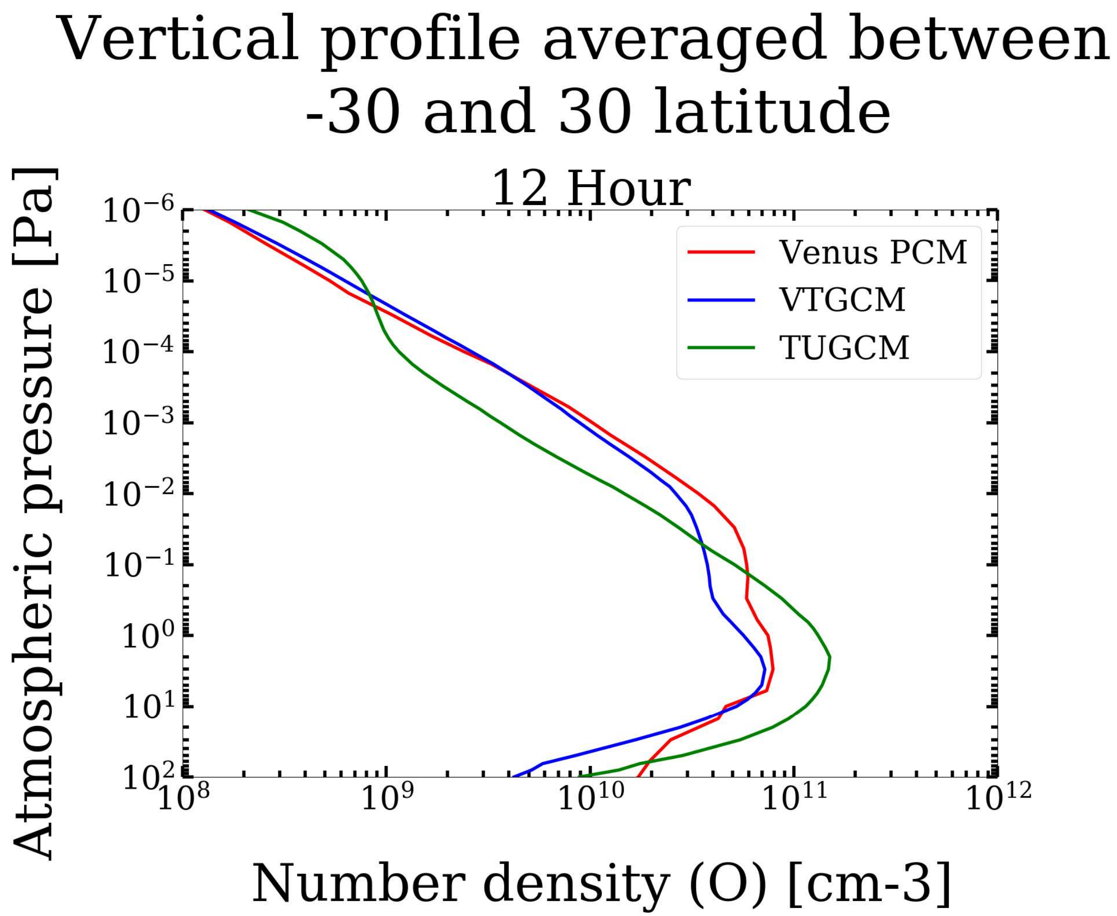
EUV Efficiency: Recommanded values: (16-25)%

19.5%	20% (EUV) - 22% (UV)	10%



Atomic Oxygen underestimation

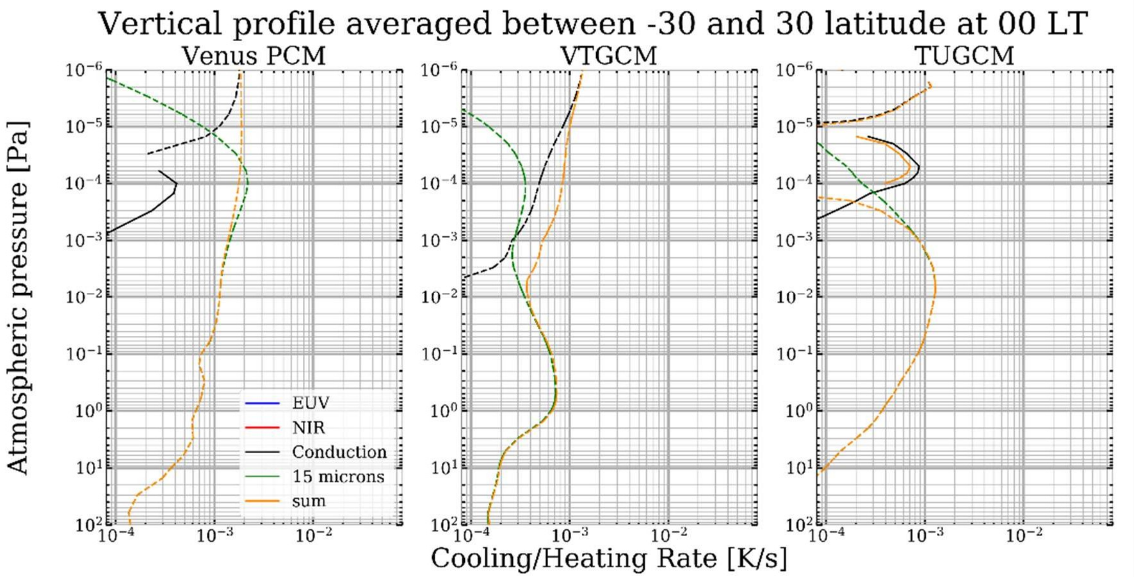




Despite a similar pressure for 2E+8 cm-3 of O between VTGCM and VPCM, there is a difference in altitude of 15 km.

Strange vertical variation of O for TUGCM, molecular diffusion is suspected [without evidence].

HOSHINO ET AL. 2012



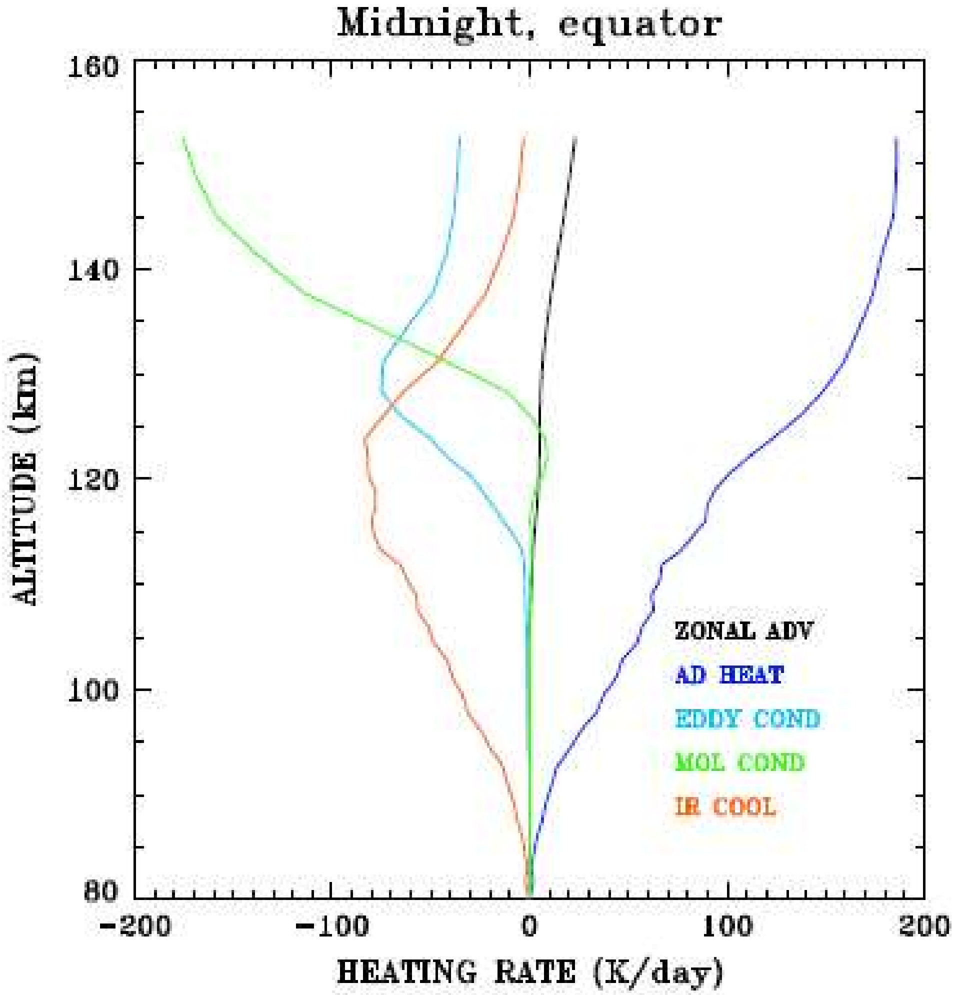
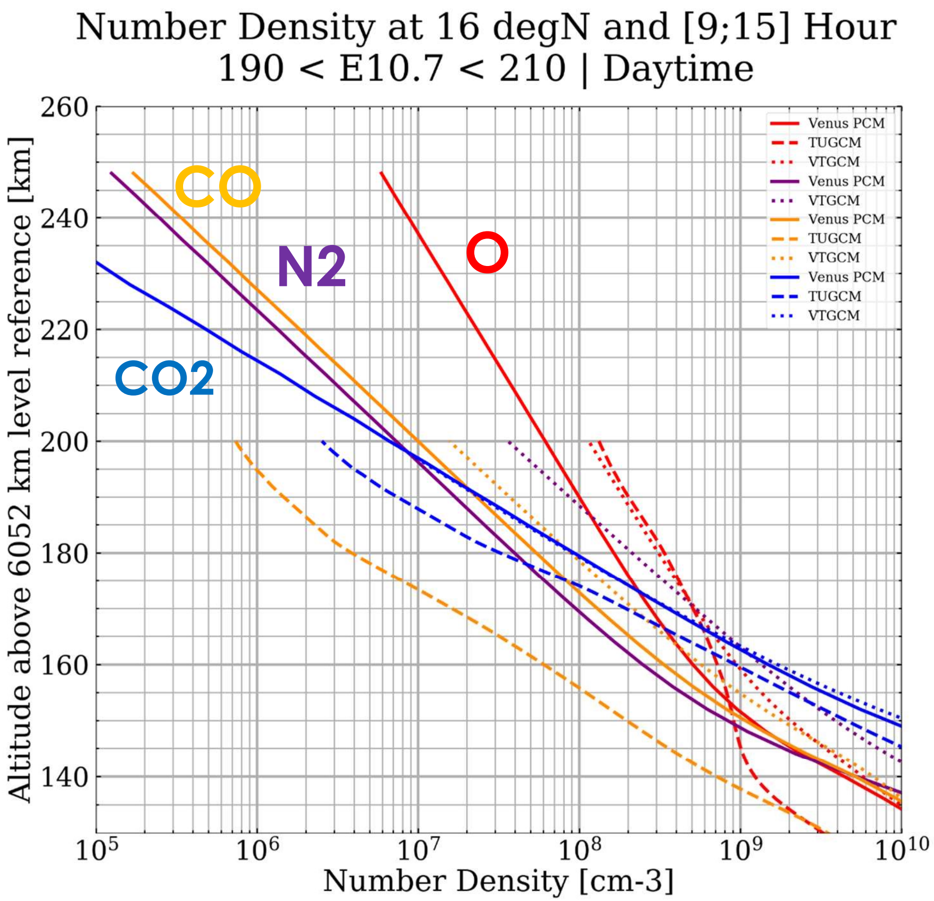
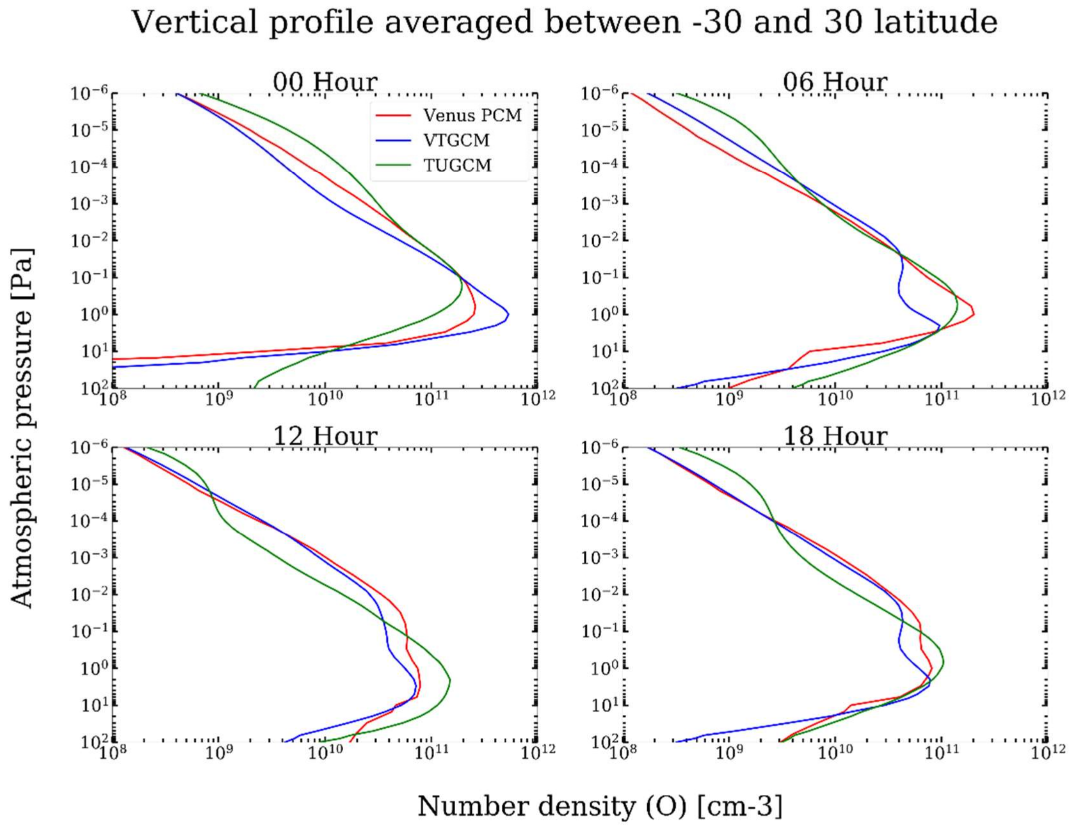


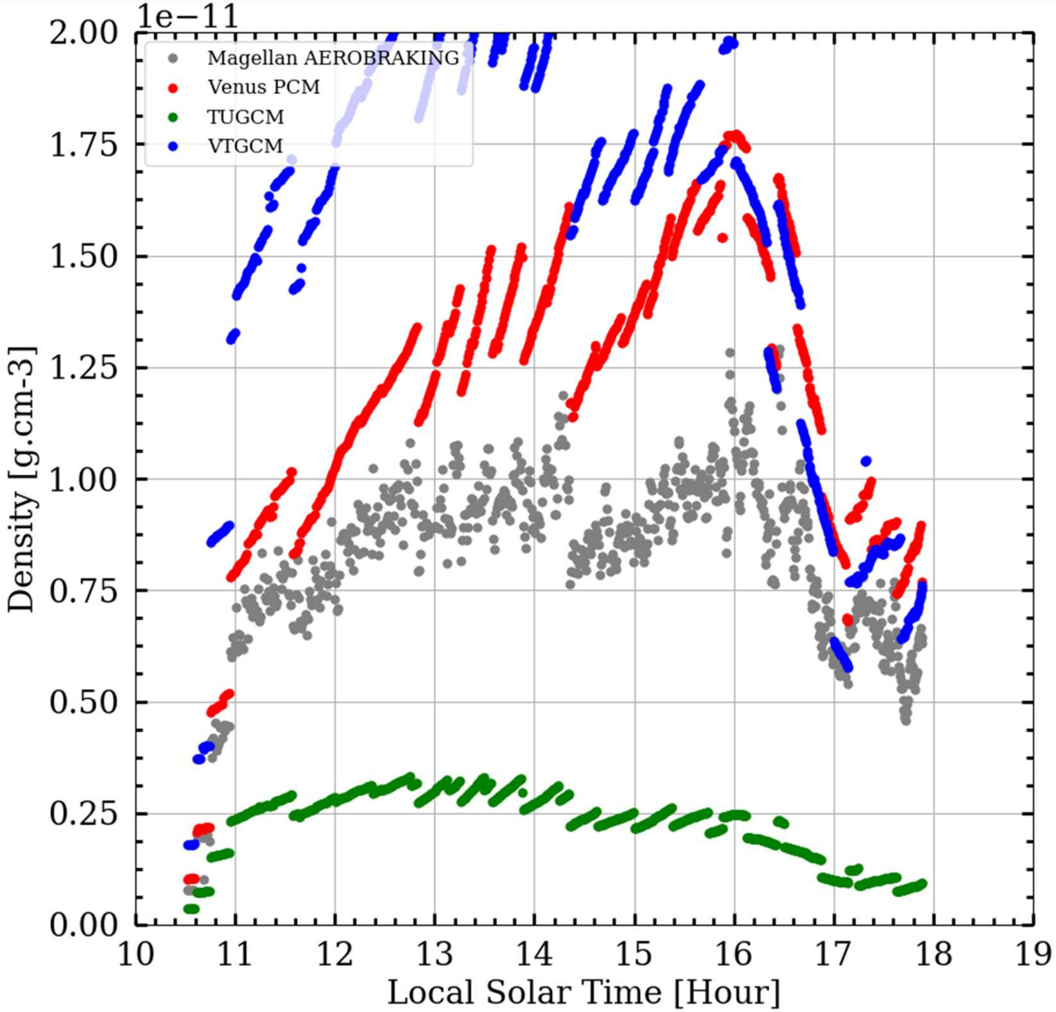
Fig. 8. The altitude profiles of the heating and cooling rates at the anti-solar point, in units of K/day. Black, blue, light blue, green, and orange lines denote the heating and cooling rates of zonal advection, adiabatic heating, eddy heat conduction, molecular heat conduction, and IR cooling, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

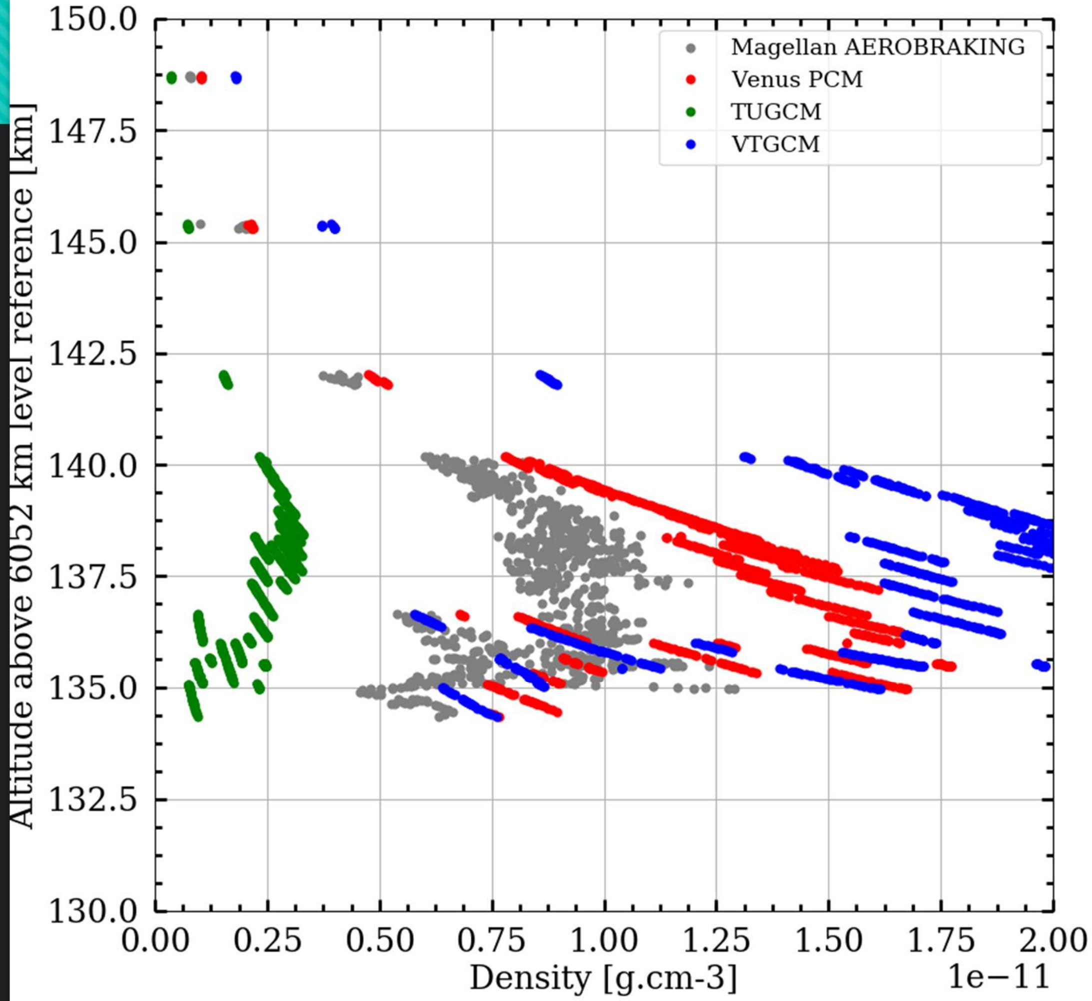
Atomic Oxygen underestimation

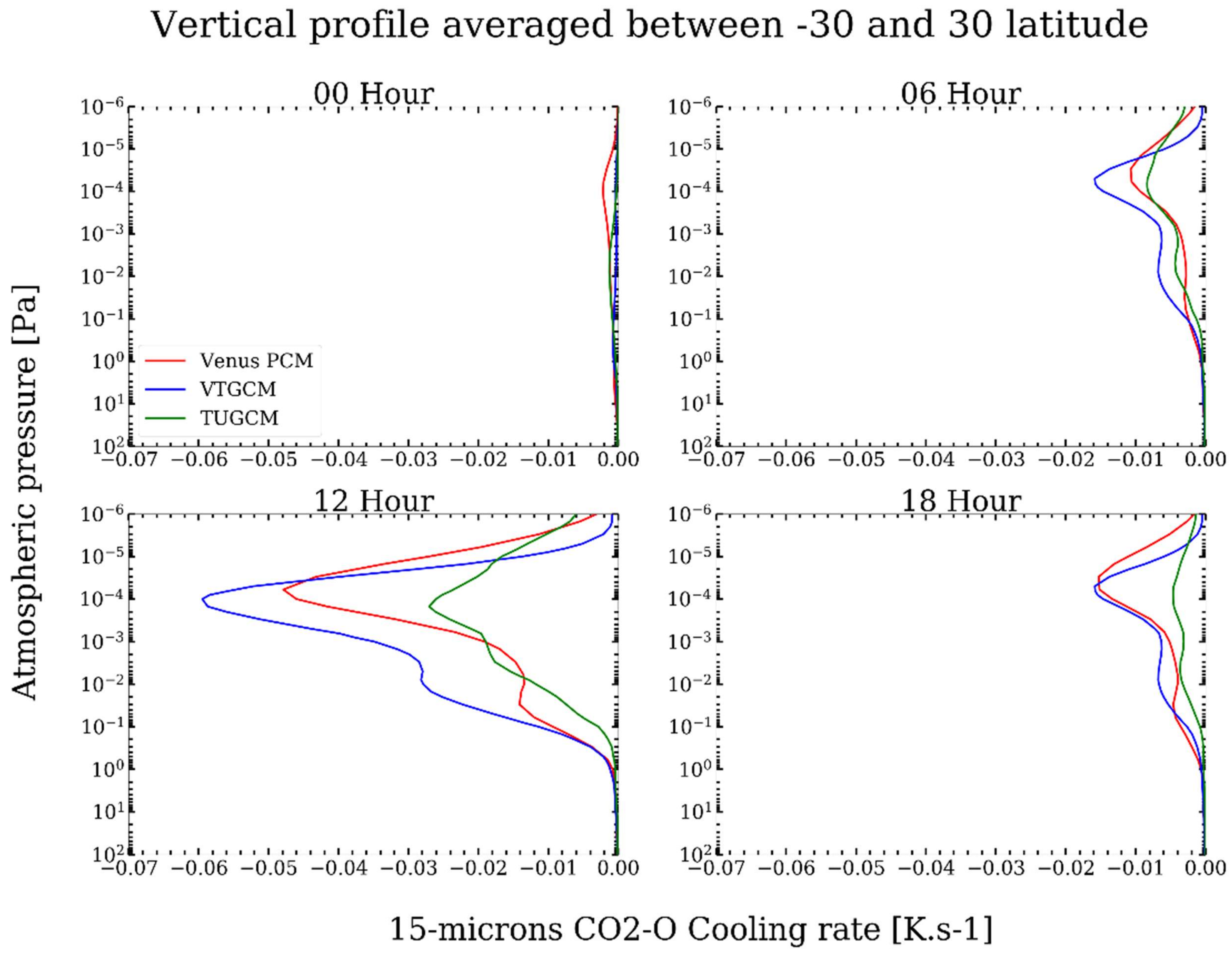




MAGELLAN DATA

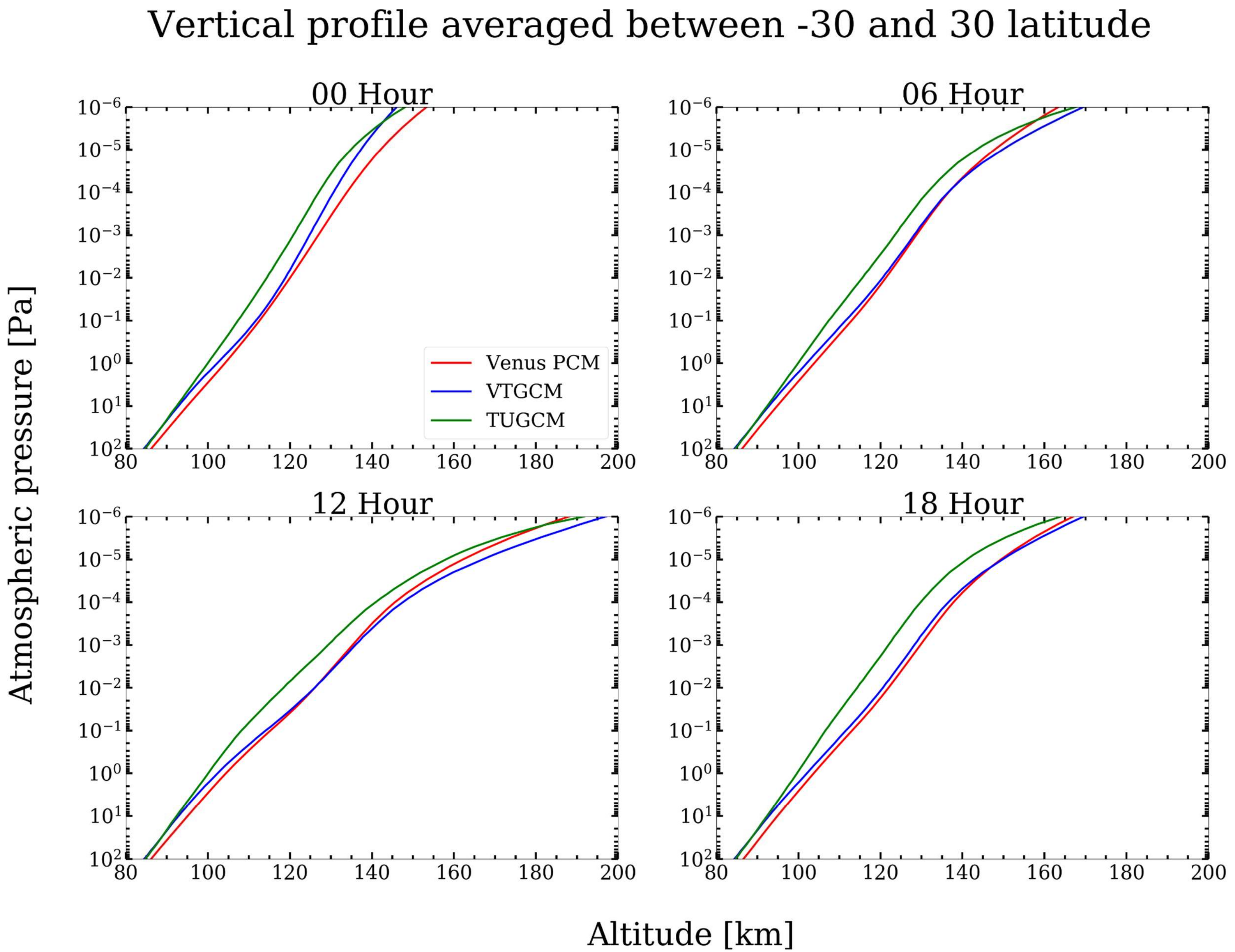




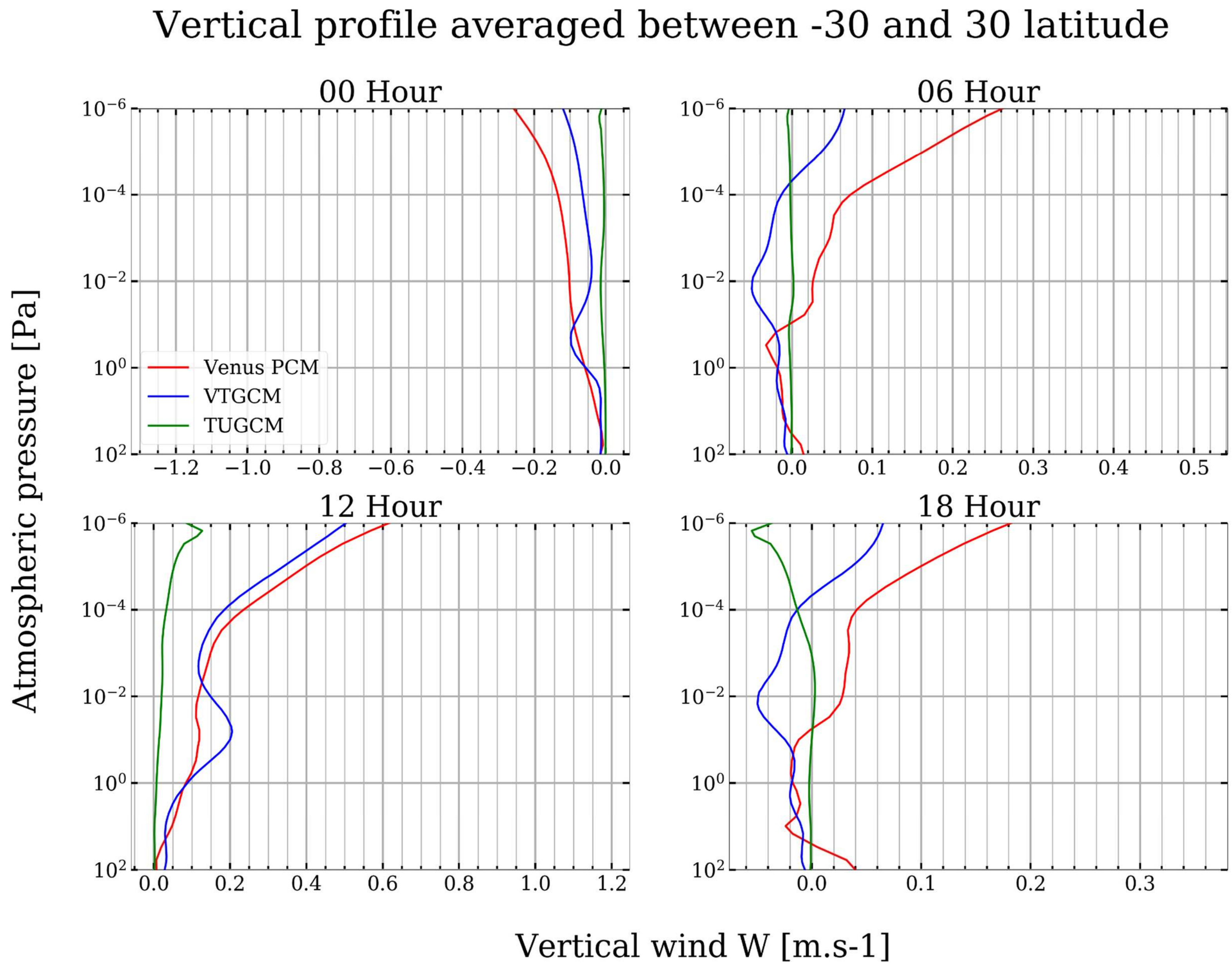


Vertical profile averaged between -30 and 30 latitude
00 Hour
06 Hour
12 Hour
18 Hour
Venus PCM
VTGCM
TUGCM
Atmospheric pressure [Pa]
15-microns CO2-O Cooling rate [K.s-1]

200 SFU


Vertical profile averaged between -30 and 30 latitude
00 Hour
06 Hour
12 Hour
18 Hour
Venus PCM
VTGCM
TUGCM
Atmospheric pressure [Pa]
Altitude [km]

200 SFU



Vertical profile averaged between -30 and 30 latitude
00 Hour
06 Hour
12 Hour
18 Hour
Atmospheric pressure [Pa]
Vertical wind W [m.s-1]
Venus PCM
VTGCM
TUGCM

200
SFU