PTYS544

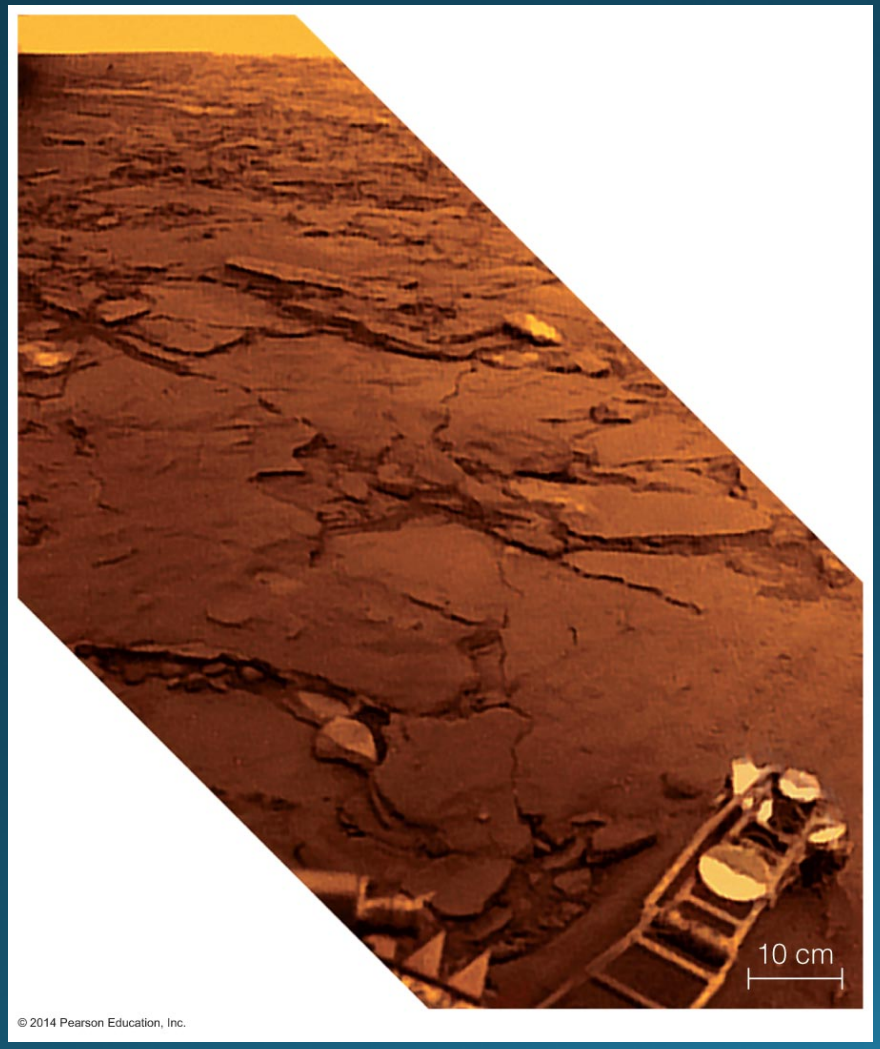
Physics of the High Atmosphere

Basic details

- Location / Time
  - Tuesday & Thursday, 12:30 – 13:45
  - Kuiper Space Science (KSS) 301 (except January 17 in 312)
- Instructor
  - Tommi Koskinen, KSS 421
  - tommi@lpl.arizona.edu

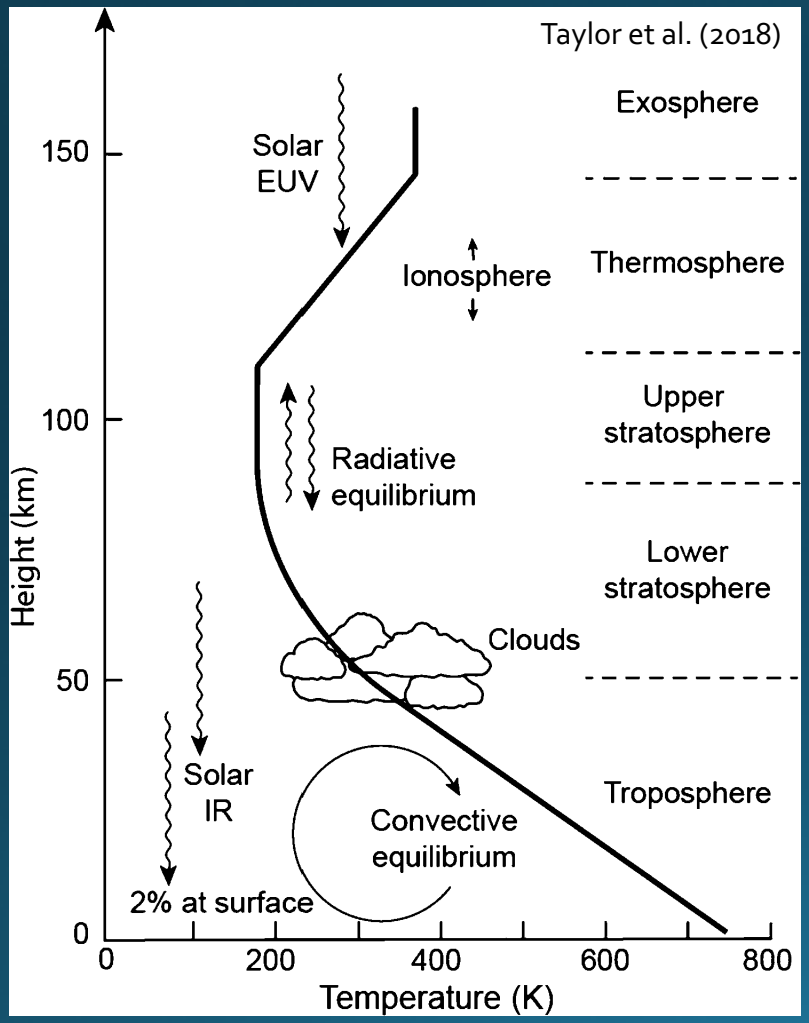
Right: Kakslauttanen Arctic Resort near Ivalo, Finland, built for viewing the aurora.

The Venusian atmosphere



Surface temperature:
740 K (day/night)
Surface pressure:
90 bar
Composition:
96% CO_2
3.5% N_2
Conditions:
Slow winds, acid rain, clouds of sulfuric acid

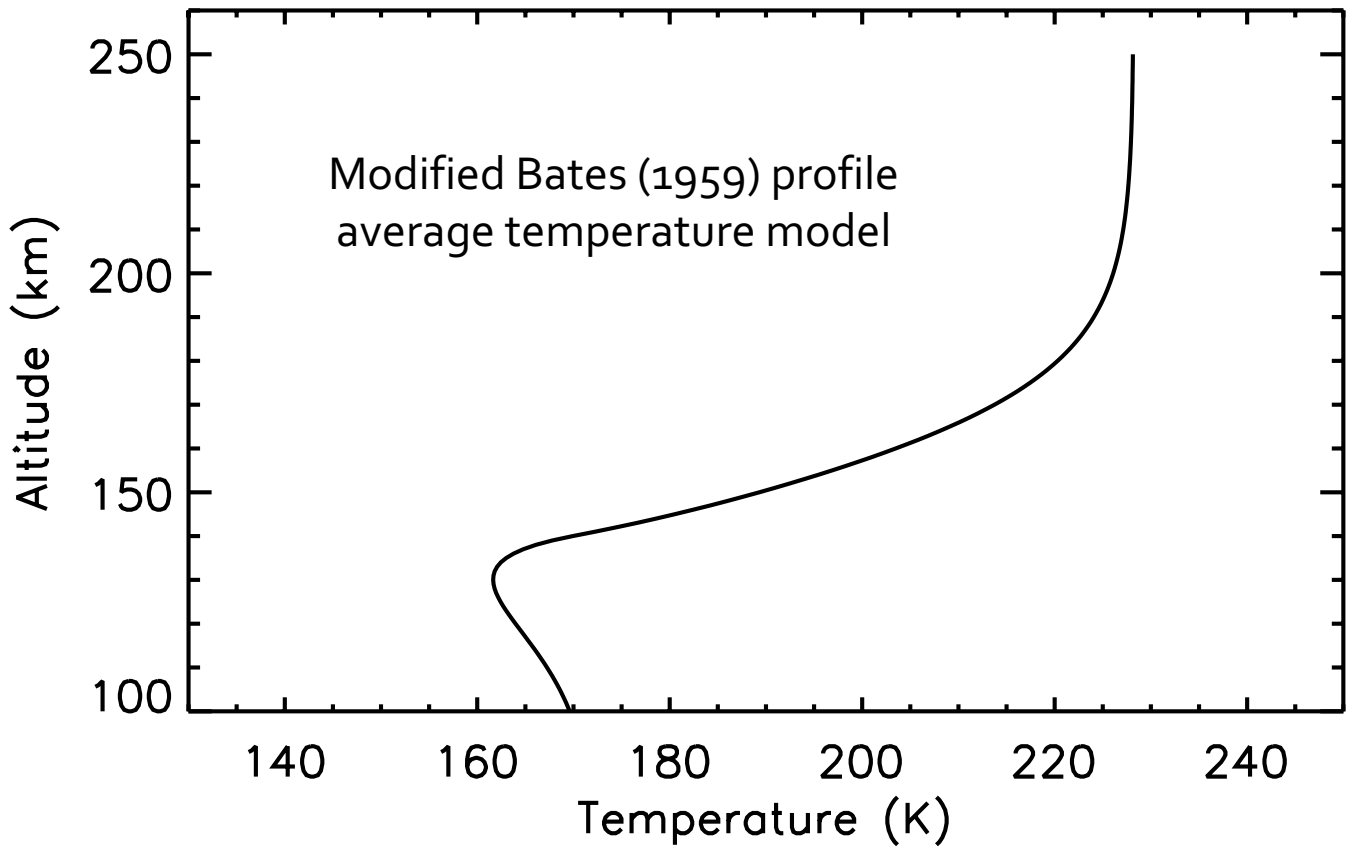
Venus



Thermosphere:
EUV and CO_2 near-IR heating.

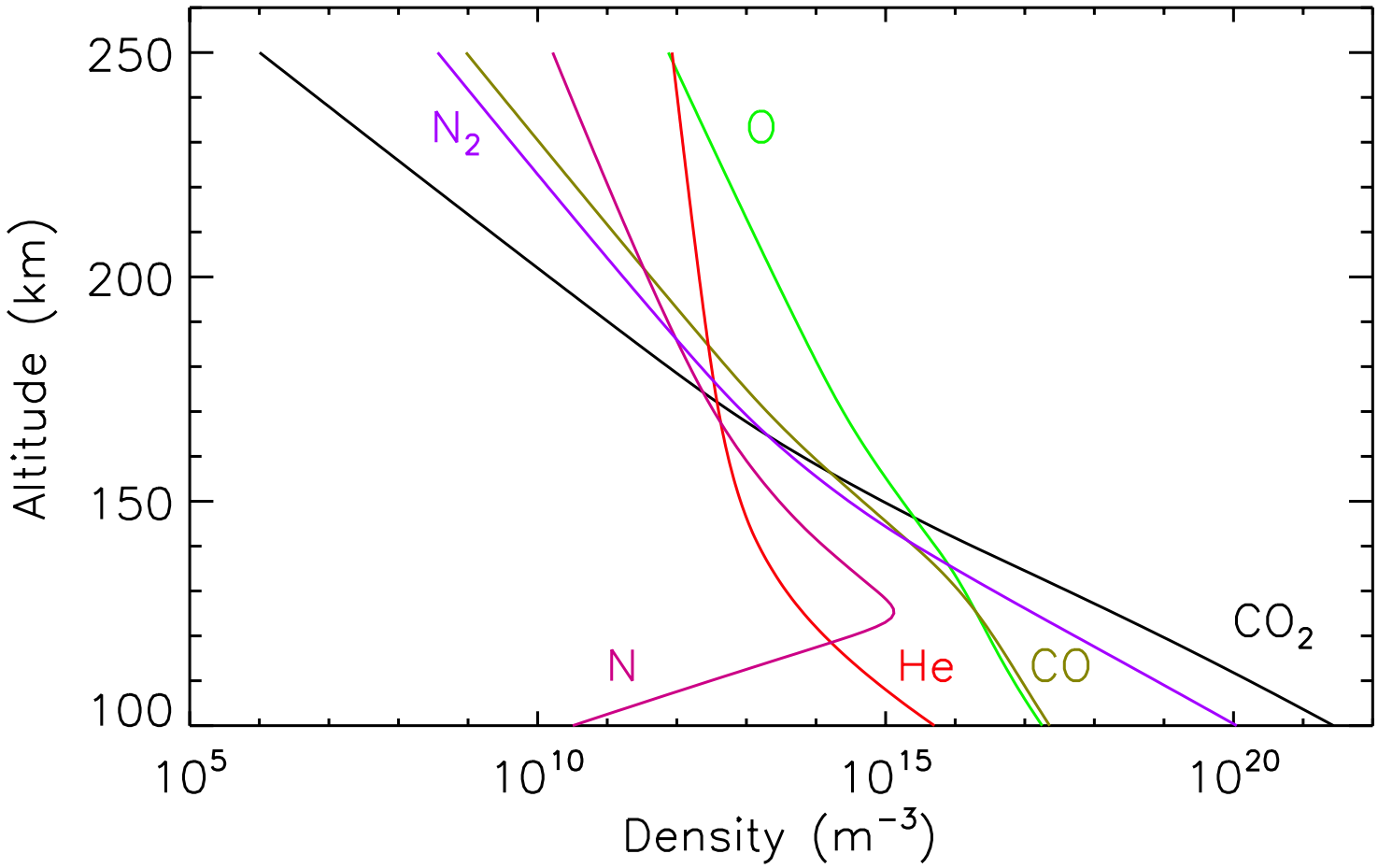
No stratospheric temperature inversion.

Troposphere:
Greenhouse effect due to a thick CO_2 atmosphere, convective equilibrium.



Global empirical model of the Venus thermosphere
(Hedin et al. 1983)

Mean neutral density profiles (Hedin+1983)



Venus heating rates

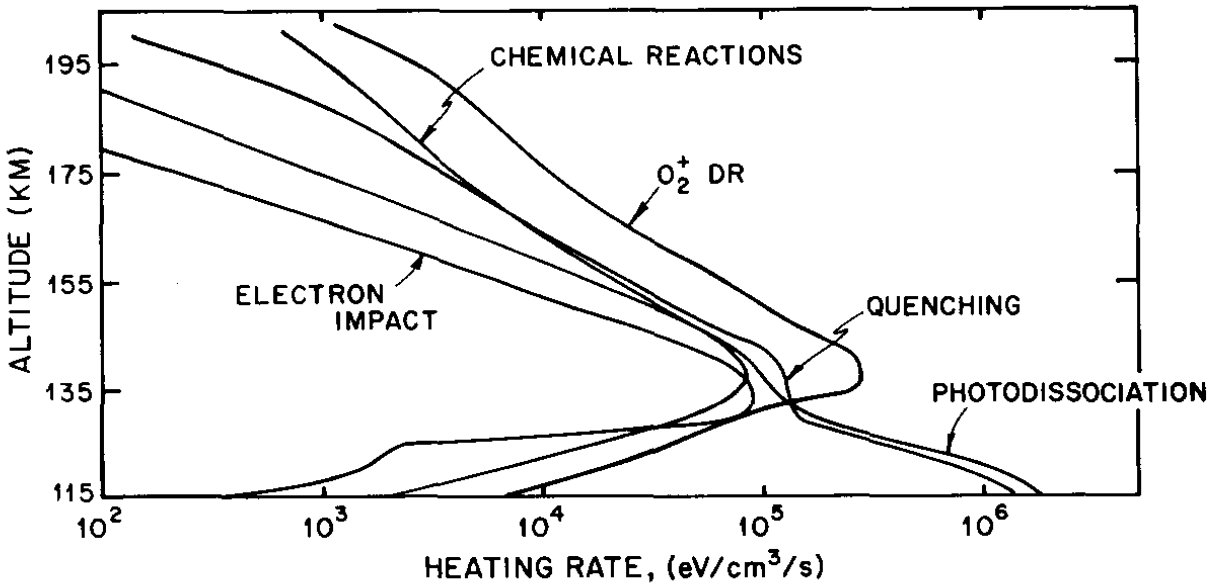


FIG. 1. ALTITUDE PROFILES OF HEATING RATES DUE TO THE MAJOR SOURCES OF NEUTRAL HEATING IN THE VENUSIAN THERMOSPHERE FROM 115 TO 200 km FROM THE STANDARD MODEL.

From Fox (1988)

Carbon dioxide: Ionization/dissociation

TABLE 7. Excited electronic states of CO_2

State[a]	Excitation energy (eV) from the ground state			
	Nakatsuji[44b]	Rabalais *et al.*[42c]	Chan *et al.*[43d]	Lee *et al.*[52e]
$^1\Pi_u$	11.39		11.28	
$^3\Pi_u$	11.31			
$^1\Sigma_u^+$	11.00	11.08	10.3	
$^1\Delta_u$	9.32	8.41	8.38	9.95
$^1\Sigma_u^-$	9.27	6.53		9.73
$^3\Sigma_u^-$	9.19			9.73
$^1\Pi_g$	8.93	9.31	9.30	
$^3\Delta_u$	8.80			9.13
$^3\Pi_g$	8.73			
$^3\Sigma_u^+$	8.15	4.89		8.53

$e + CO_2 \rightarrow$ CO_2^+ 13.8 eV,
CO^+ 19.5 eV,
O^+ 19.1 eV,
C^+ 27.8 eV,
CO_2^{++} 37.4 eV ,
C^{++} 51.2 eV,
O^{++} 54.2 eV.

Ground electronic state: $X\,^1\Sigma_g^+$

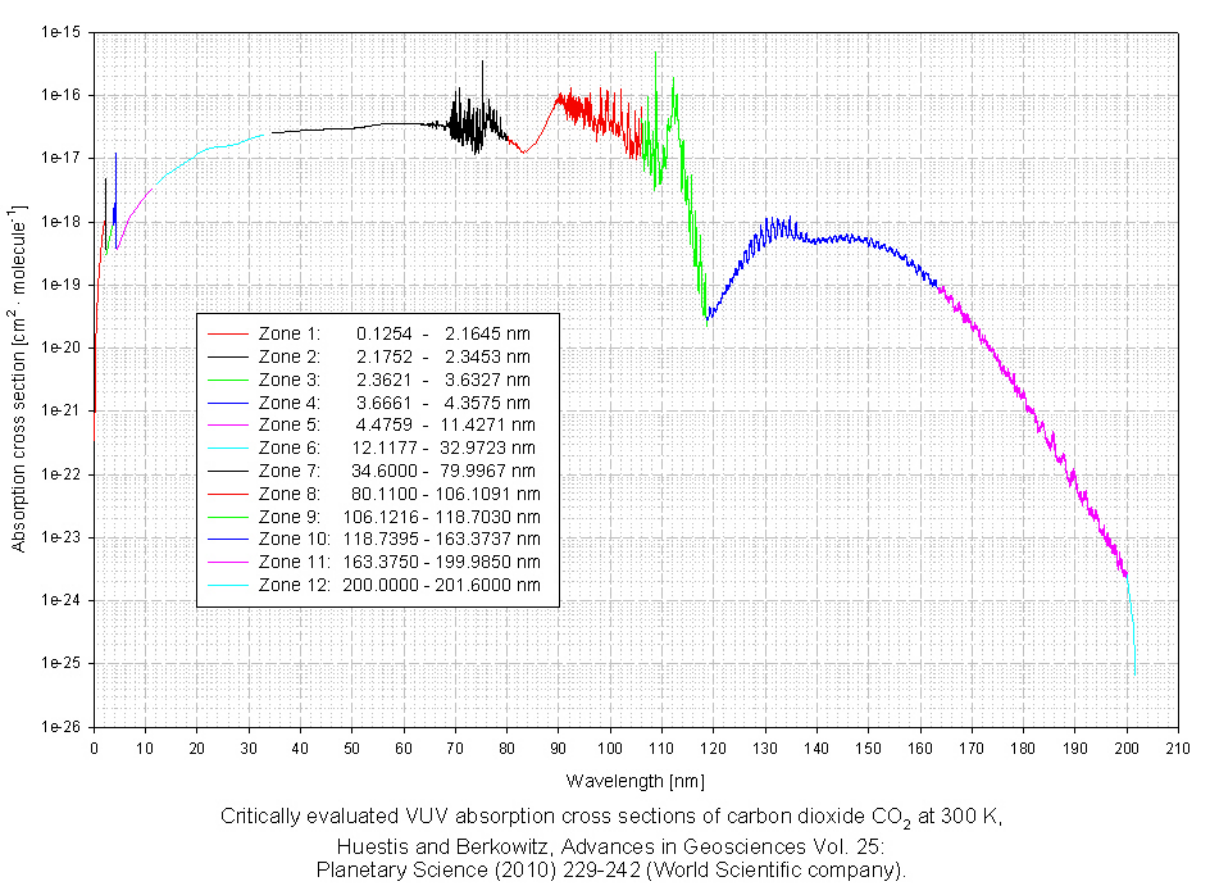
Itikawa (2002)

Dissociation threshold:

$$CO_2 + h\nu \rightarrow CO + O$$

requires 5.5 eV of energy i.e., wavelengths shorter than about 225 nm. In reality, dissociation effective at wavelengths shorter than about 169 nm.

Carbon dioxide: UV cross section

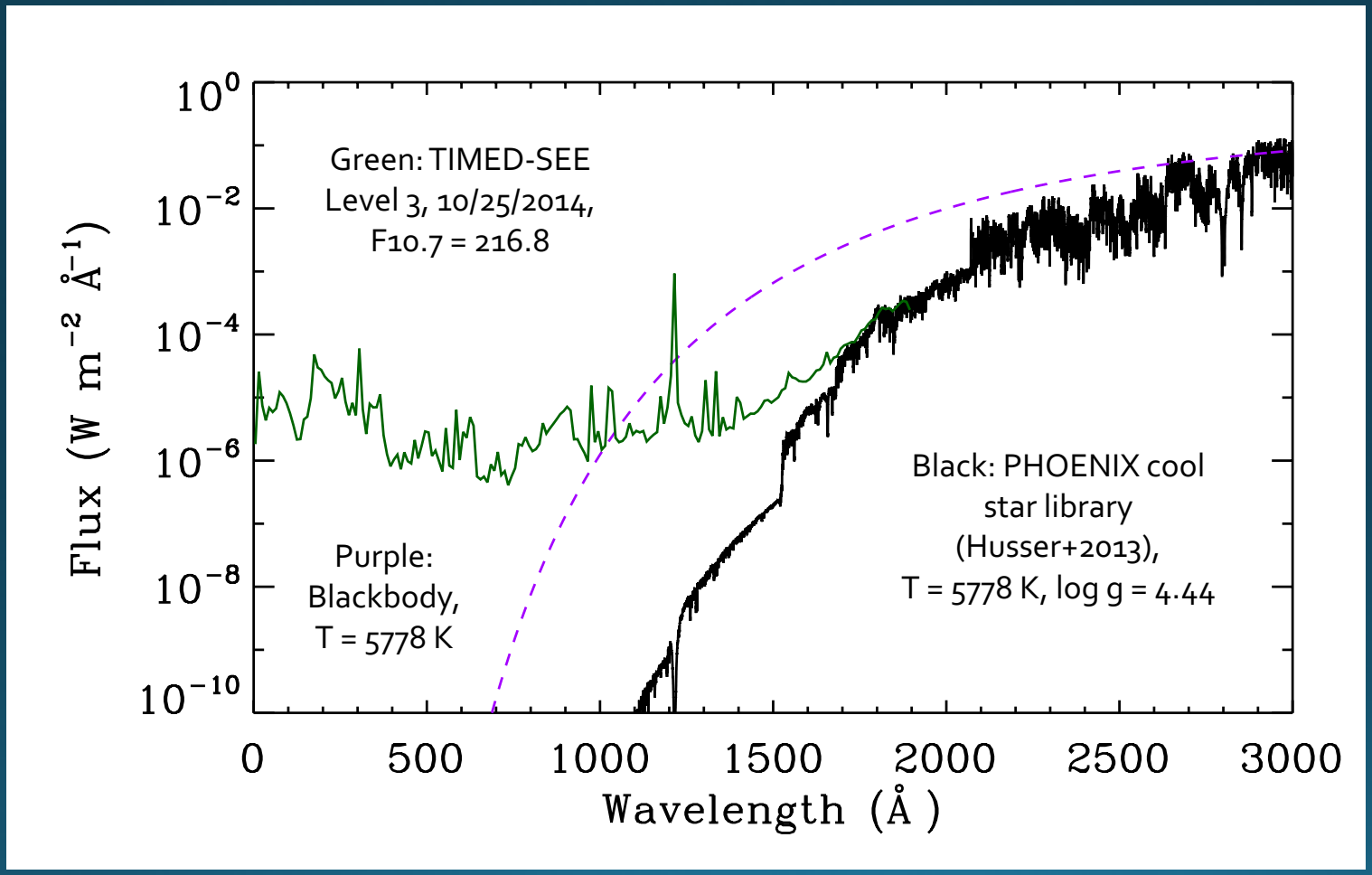


Critically evaluated VUV absorption cross sections of carbon dioxide CO_2 at 300 K,
Huestis and Berkowitz, Advances in Geosciences Vol. 25:
Planetary Science (2010) 229-242 (World Scientific company).

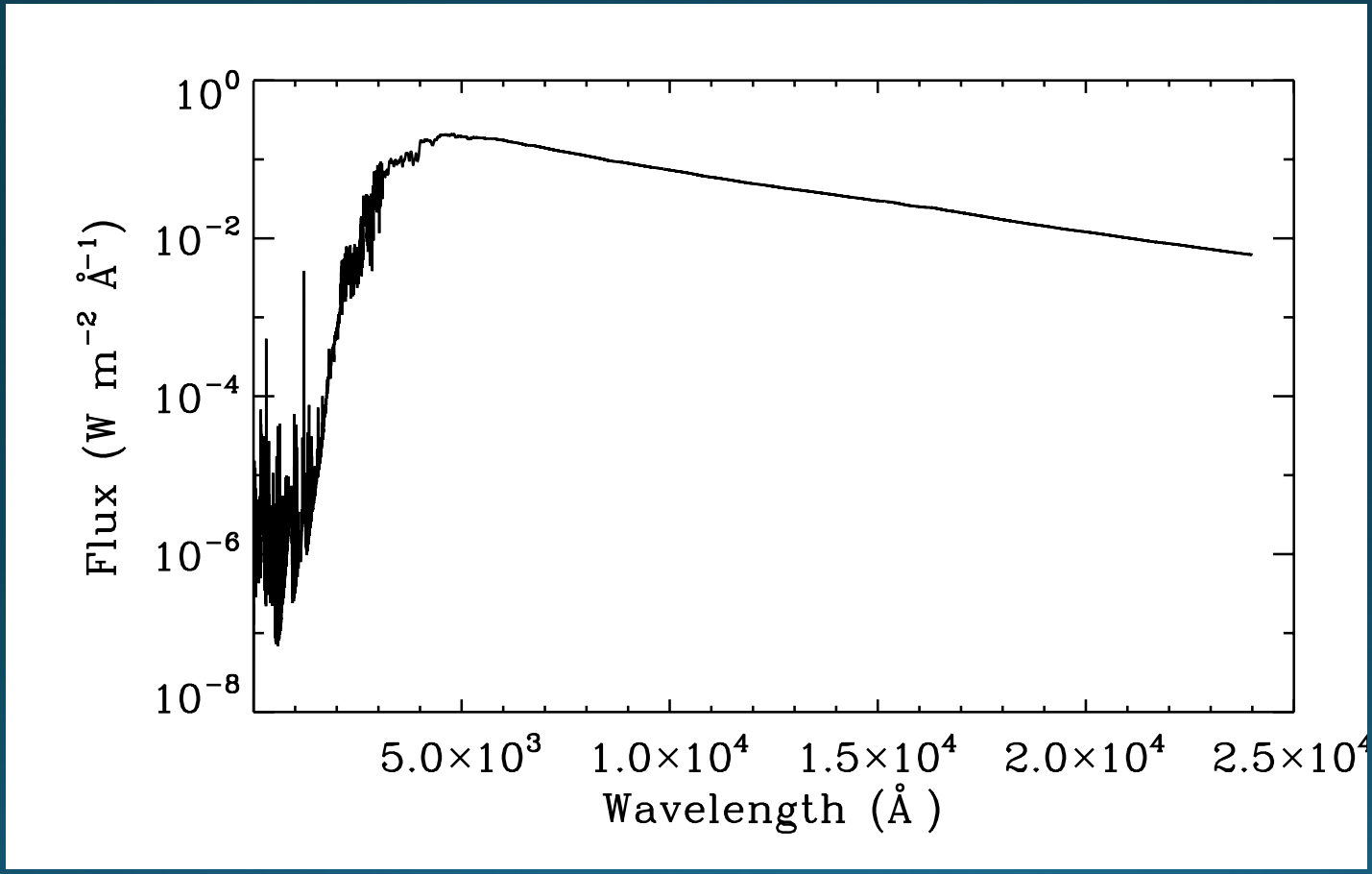
Cross section from: http://satellite.mpic.de/spectral_atlas,
see also Heays et al. (2017)

Solar spectrum products for high energy radiation: http://lasp.colorado.edu/lisird/

Solar spectrum at 1 AU (0.5-190.5 nm)

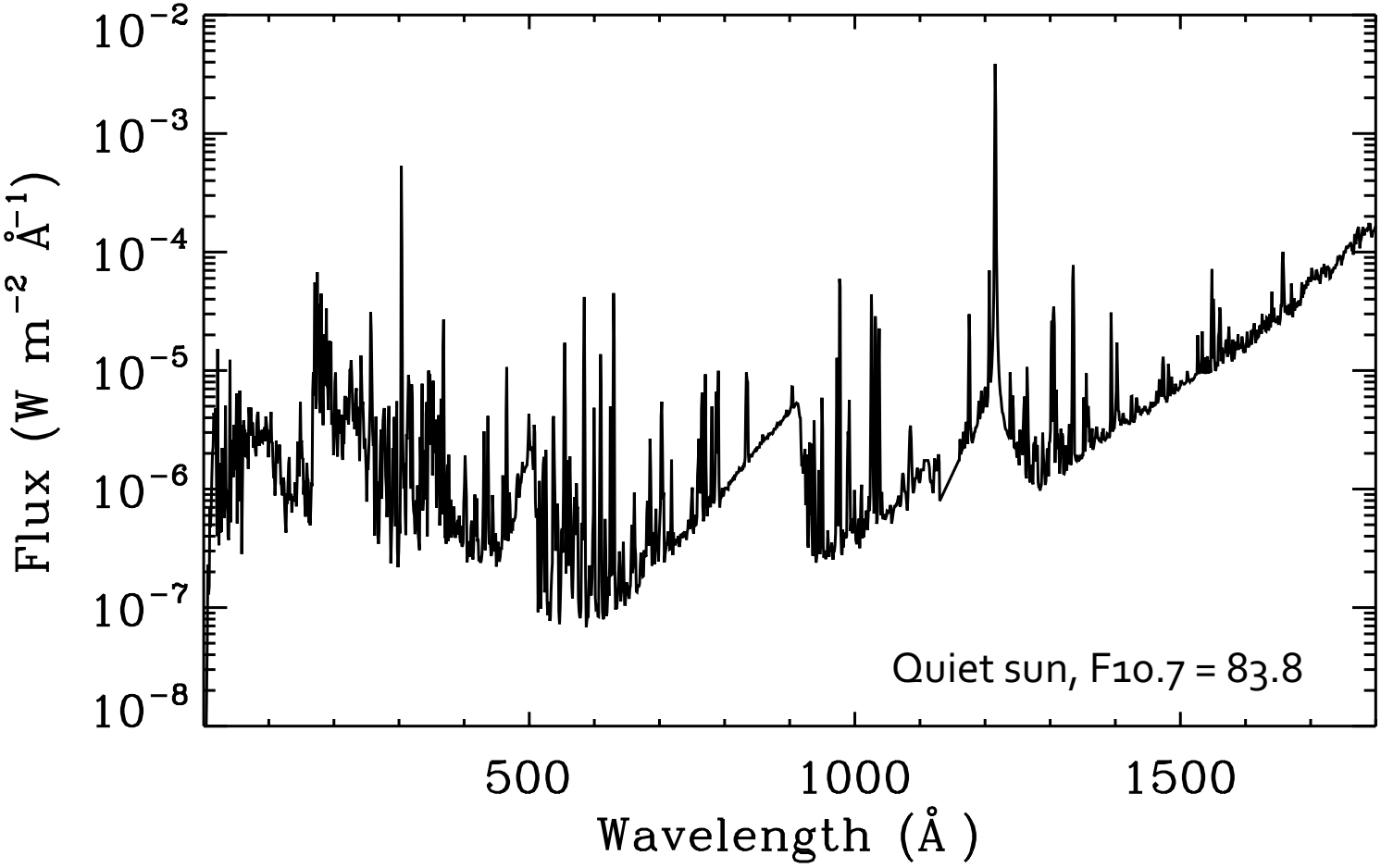


Solar spectral irradiance reference spectrum

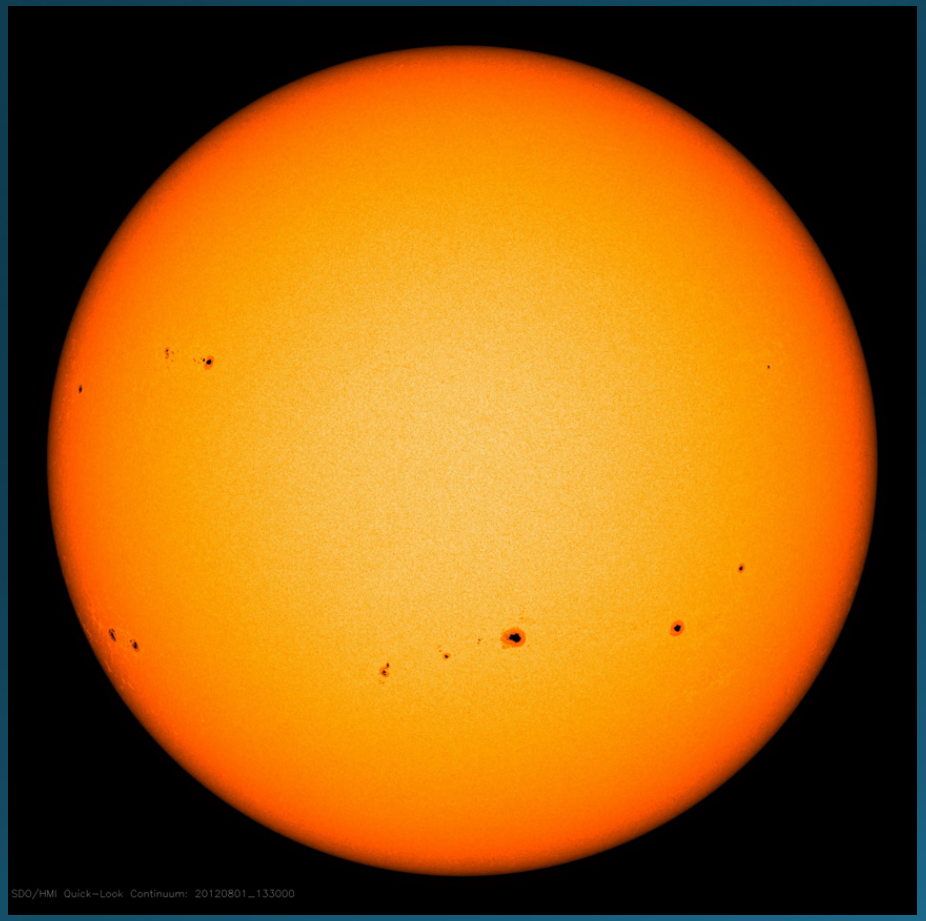


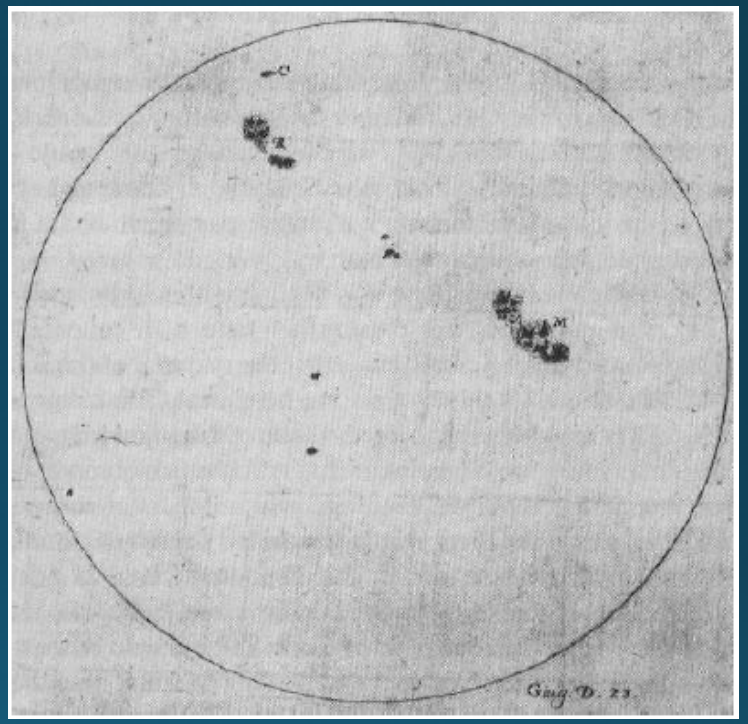
Whole Heliosphere Interval (WHI) 2008 version, March 25– March 29

WHI 2008 XUV spectrum



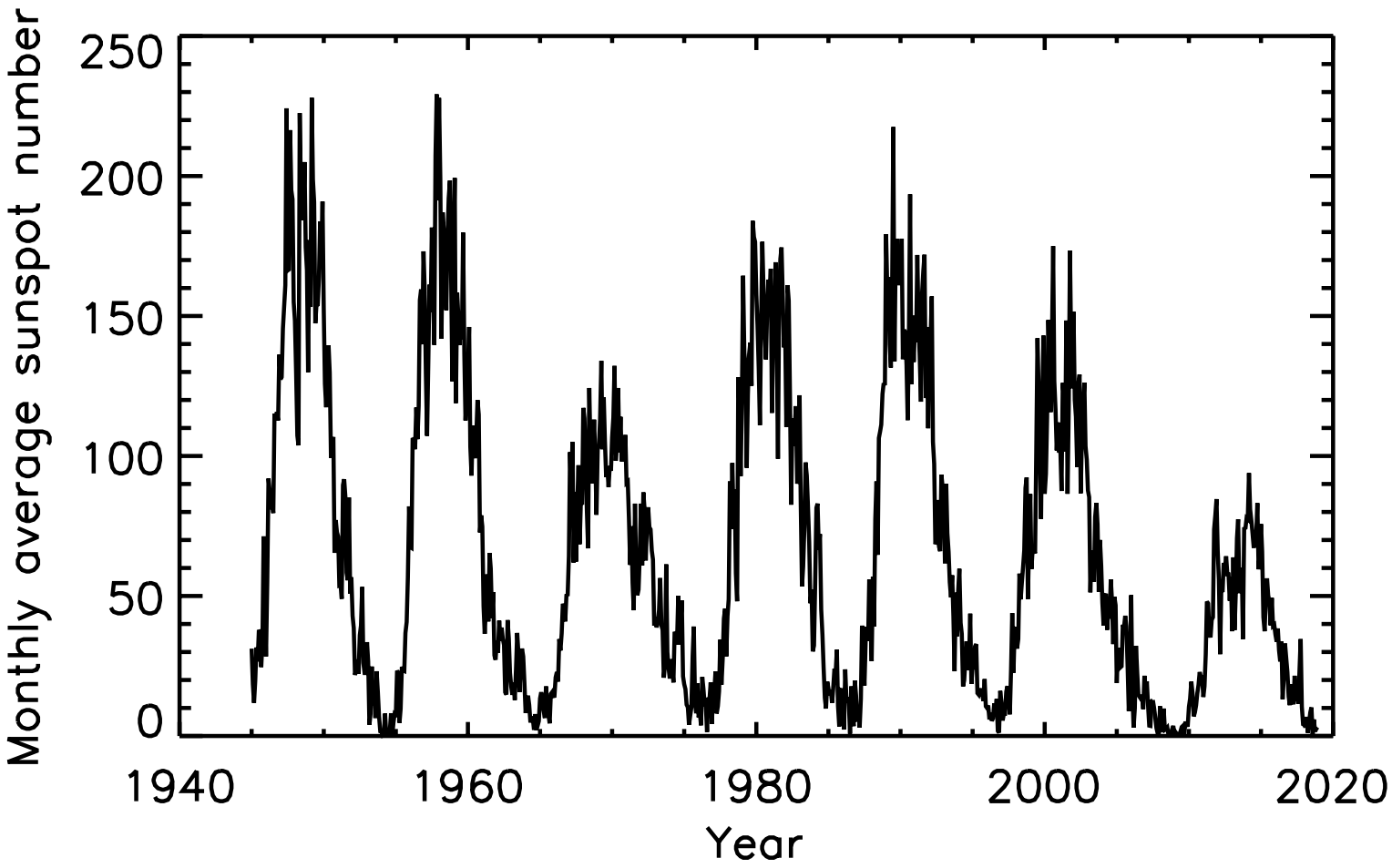
Solar activity



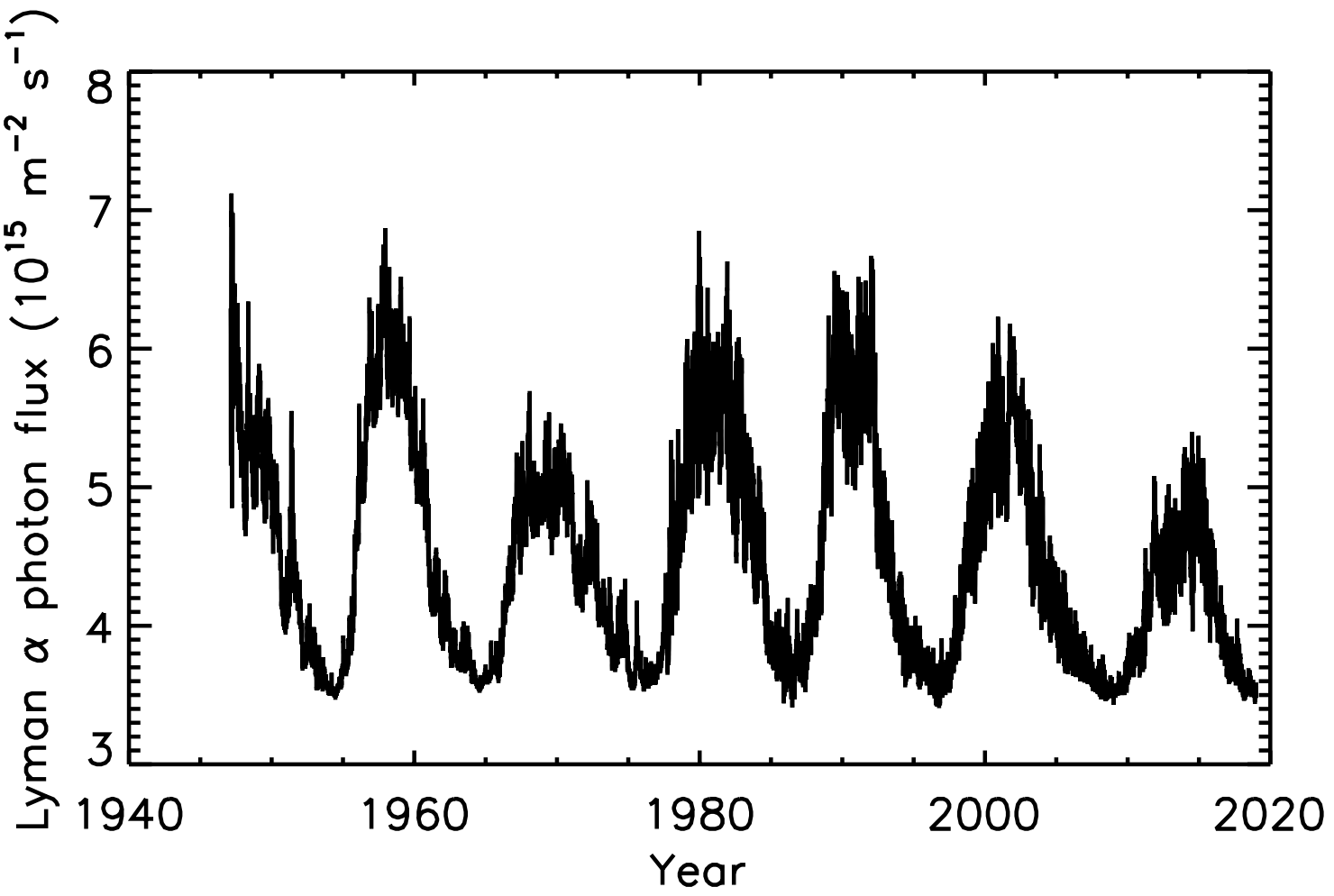


Above: A sketch of sunspots by Galileo. Left: Image of the sun (July 2012) from NASA/Solar Dynamics Observatory.

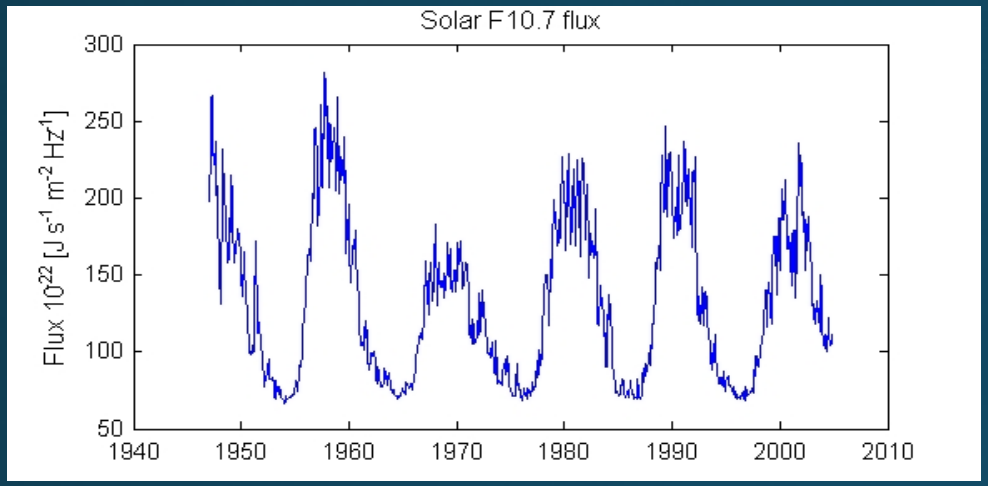
Monthly sunspot number



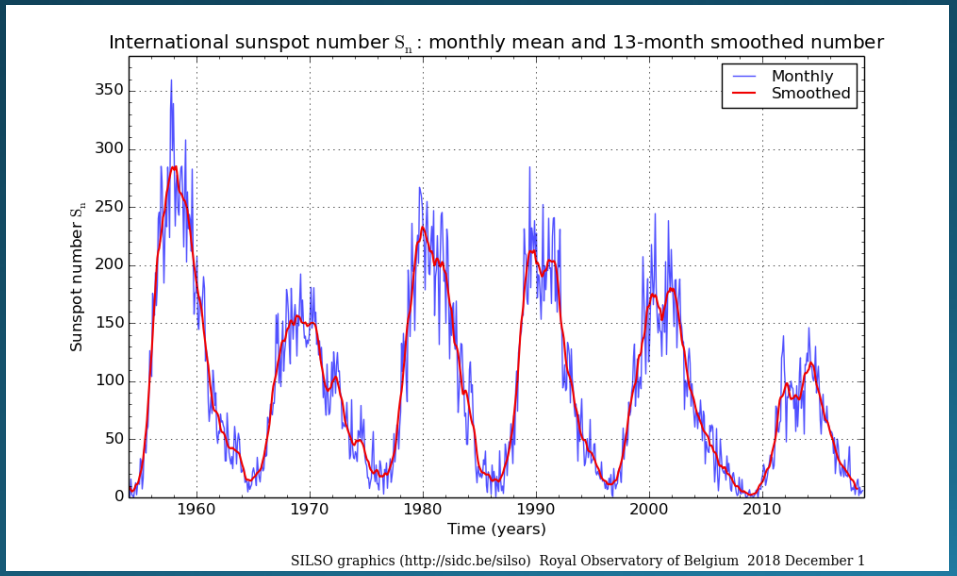
Composite Lyman α photon flux



F10.7 flux

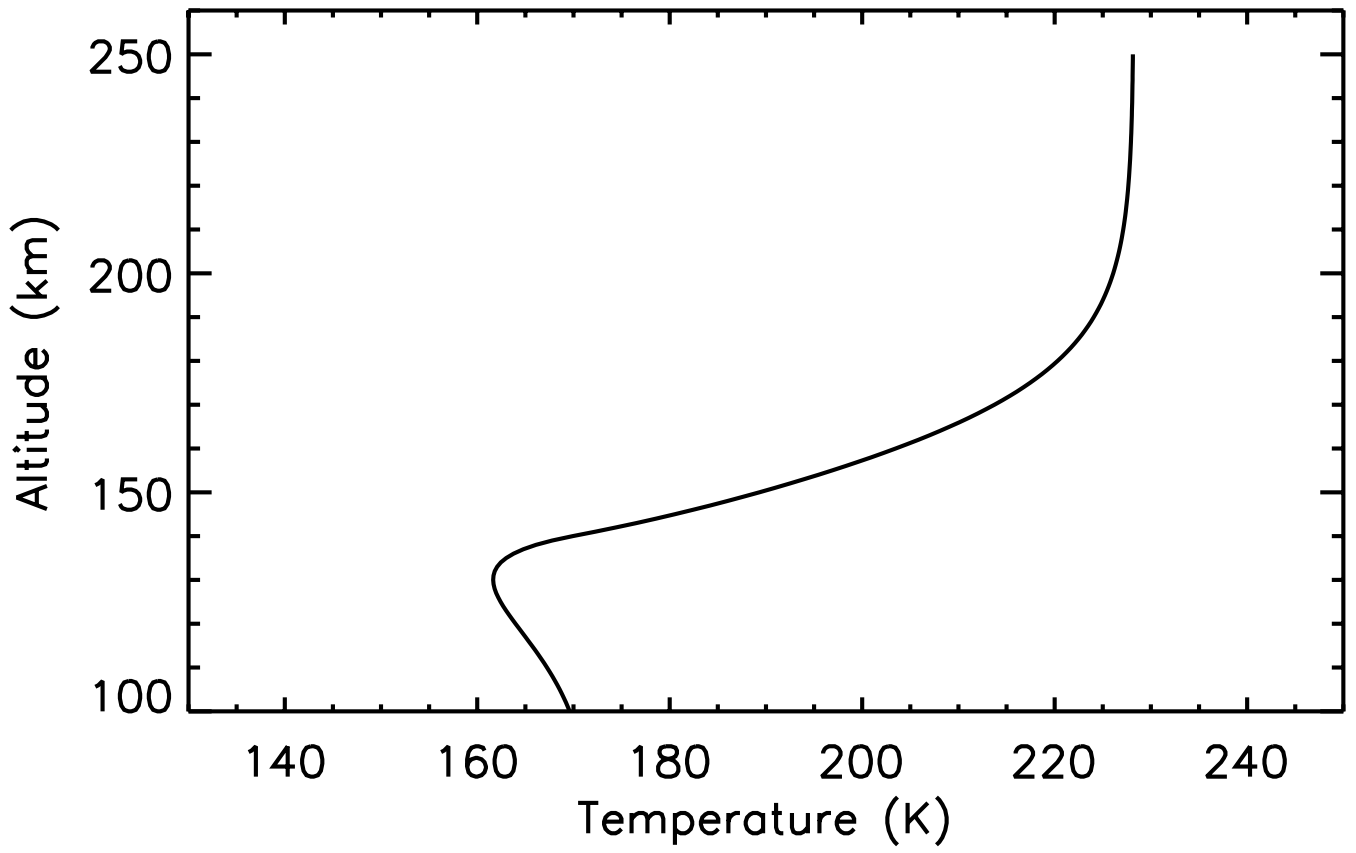


Solar 10.7 cm radio flux is emitted by the chromosphere and lower corona and thus follows the solar cycle. Shown here is disk-averaged monthly average received at Earth.

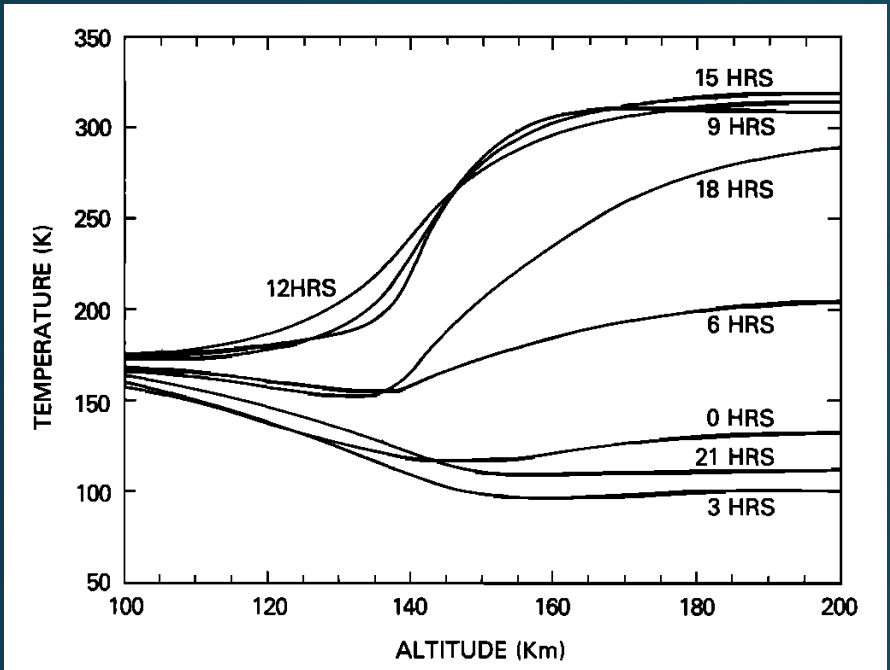


The sunspot number correlates with the 10.7 cm flux.

Okay, back to Venus…

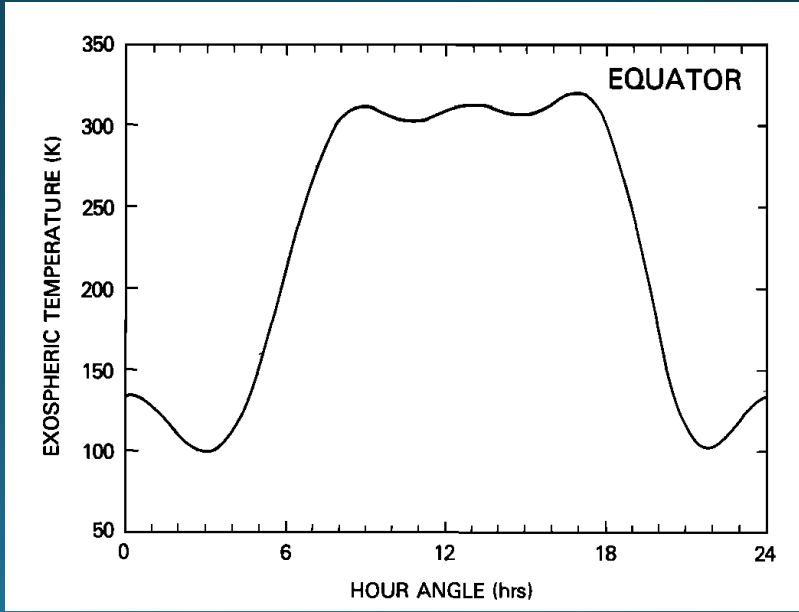


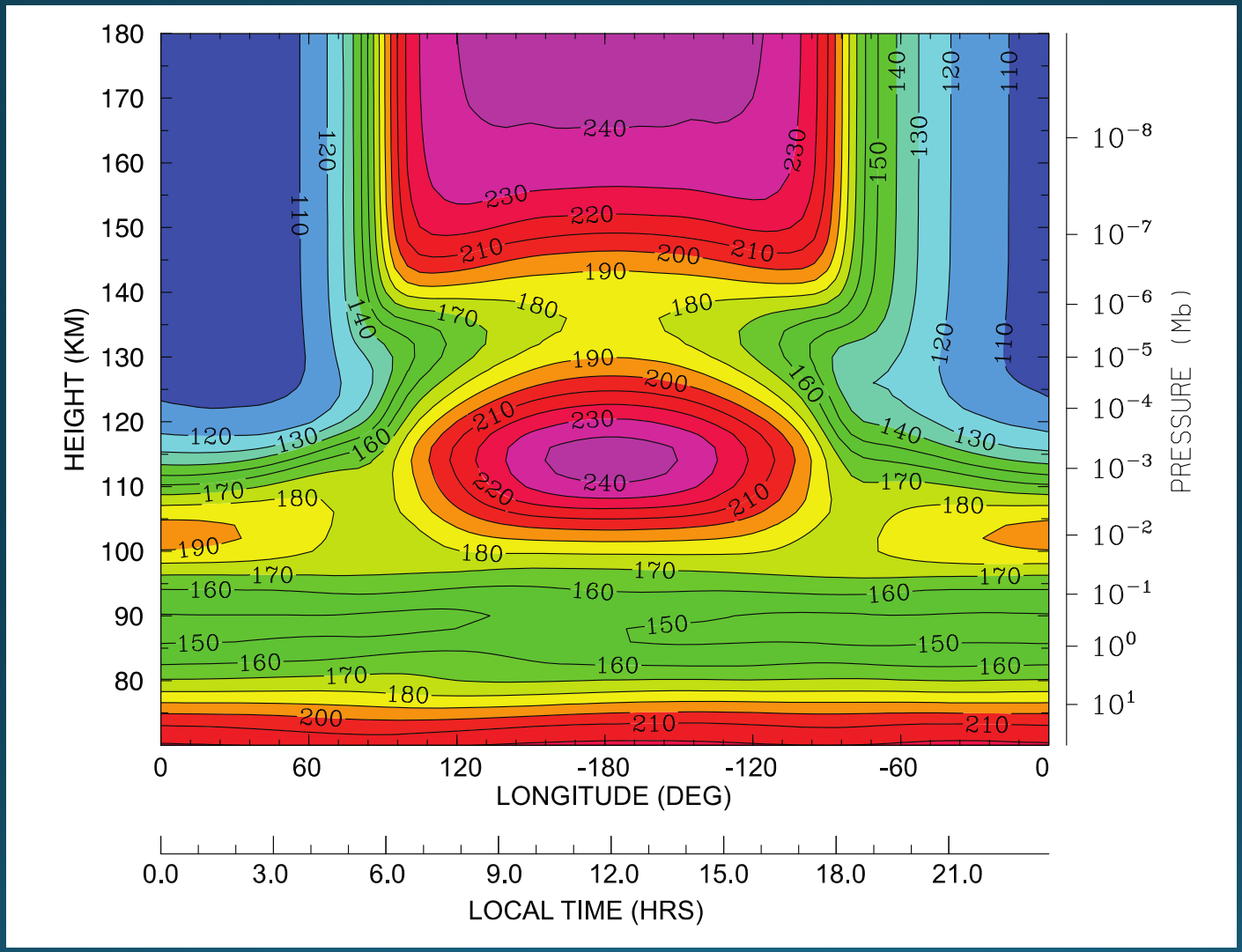
Global empirical model of the Venus thermosphere mean temperature profile (Hedin et al. 1983)



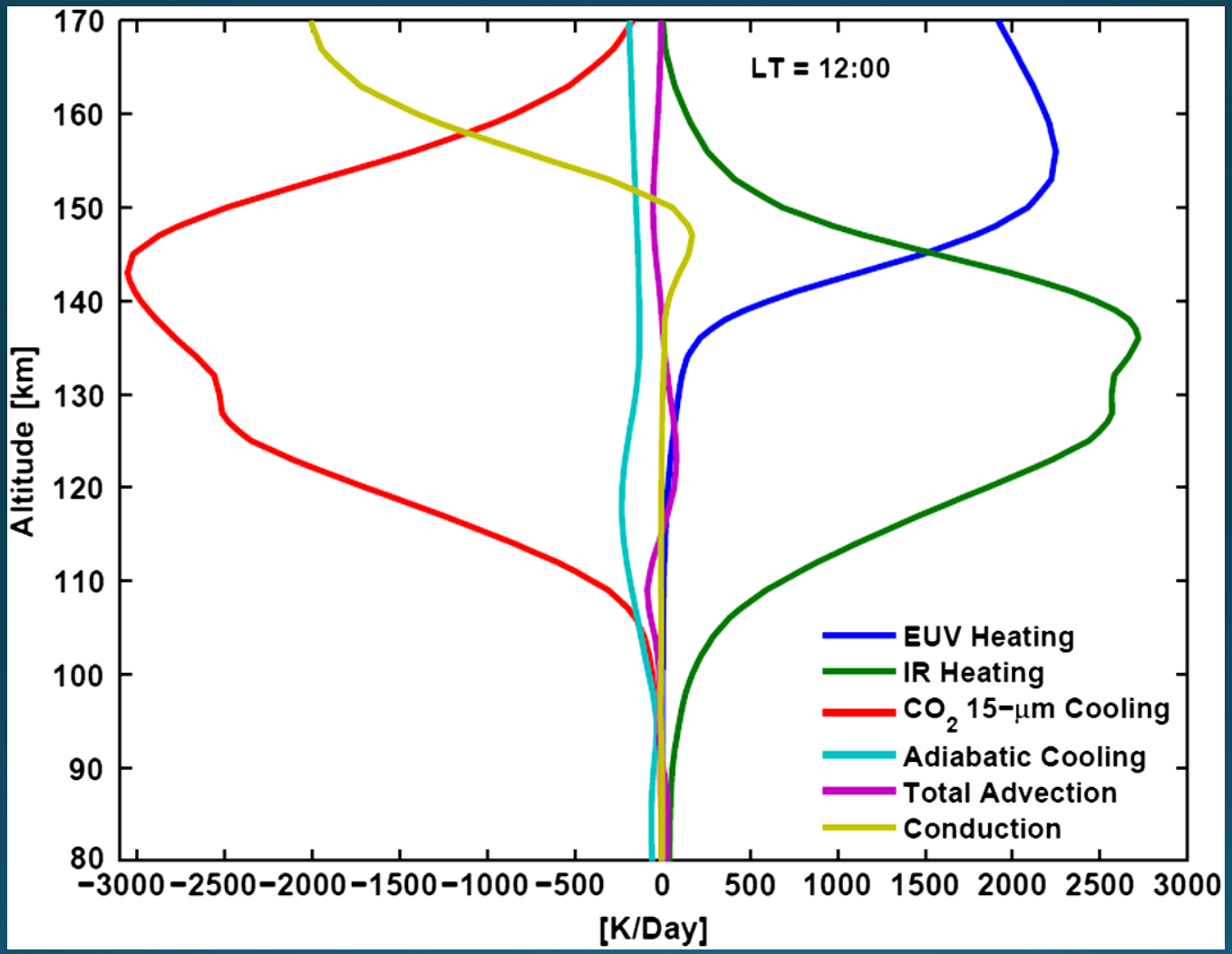
Strong variations with local time (Hedin et al. 1983).

Solar cycle variation in the topside temperature is about 60-70 K.



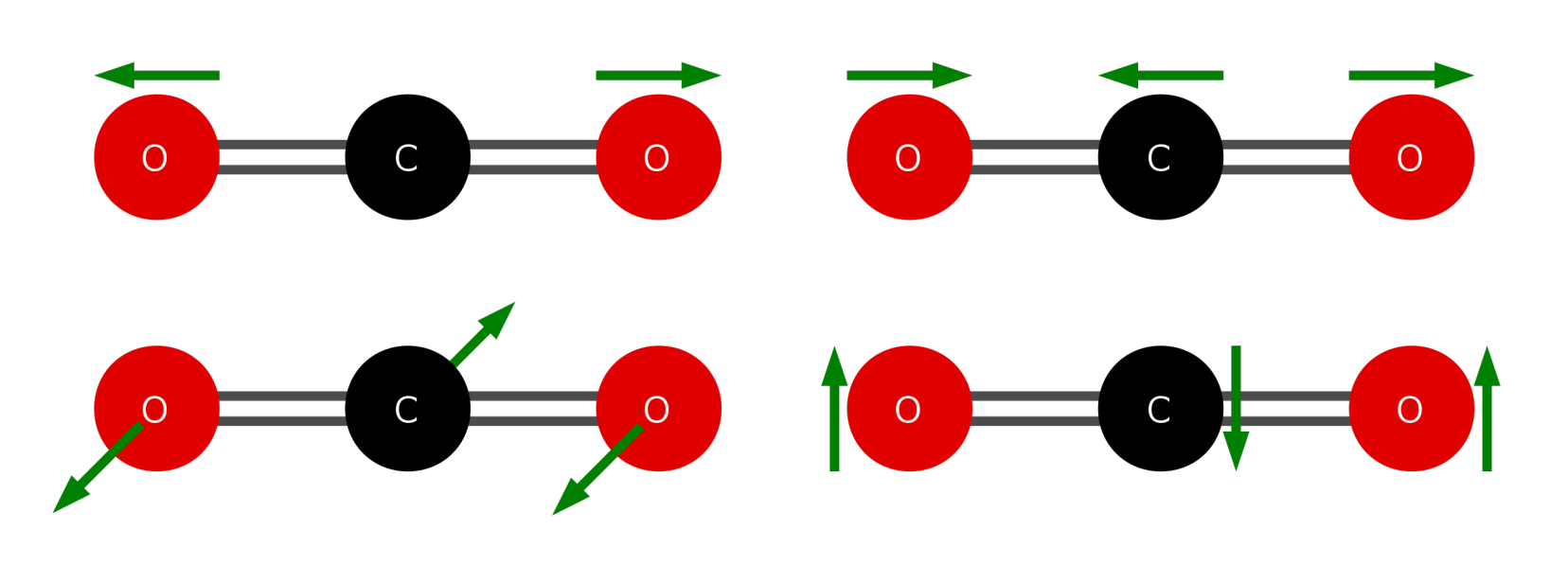


Equatorial temperature slice from the VTGCM model (Bougher et al. 2013): solar minimum conditions.



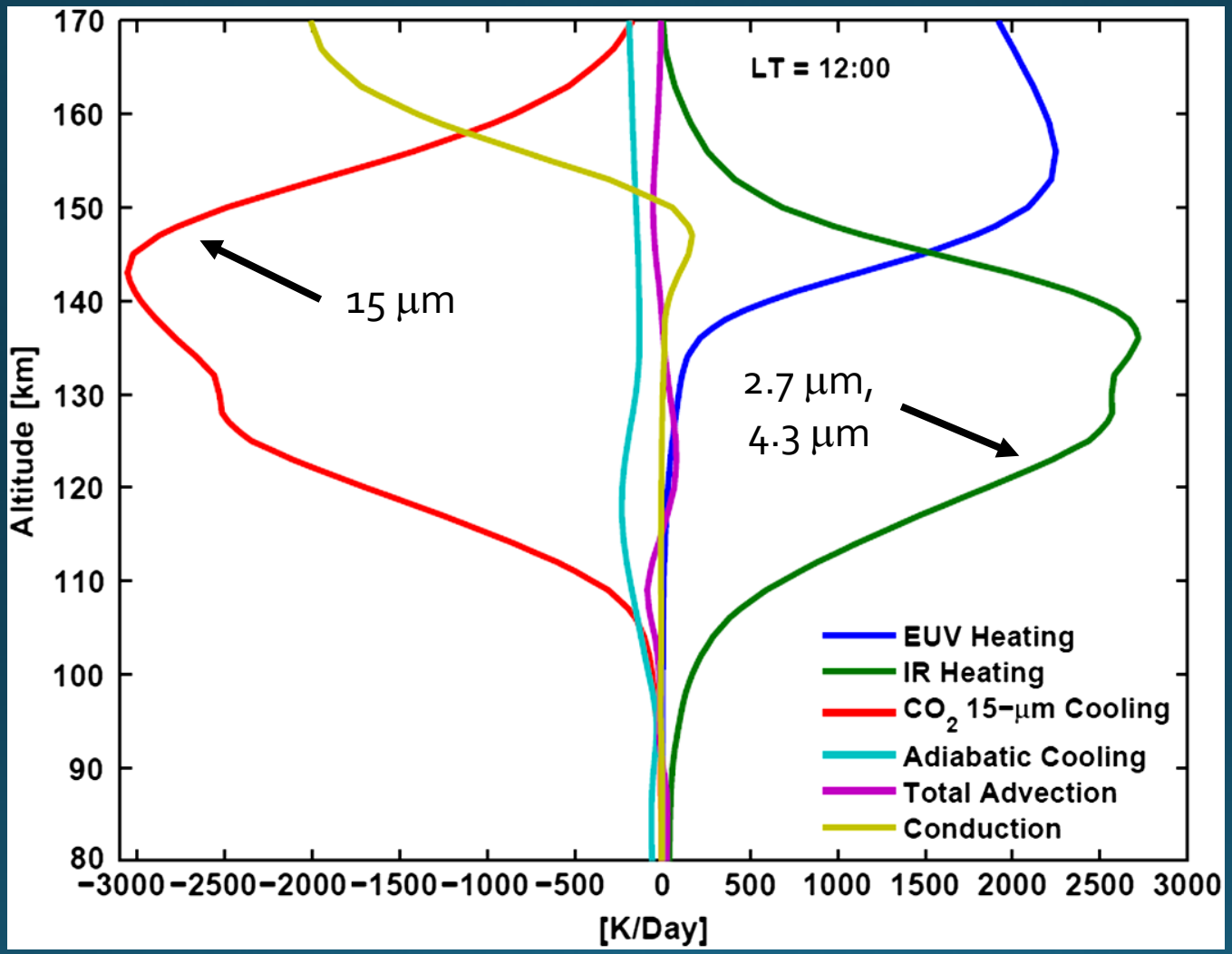
Energy equation terms for the overhead sun (SZA = 0°) (Brecht and Bougher 2012).

Carbon dioxide: Normal modes of vibration



Symmetric stretch mode (ν_1):
1388 cm^{-1} (7.2 μm)
and a degenerate bending mode (ν_2):
667 cm^{-1} (15 μm)

Antisymmetric stretch mode (ν_3):
2349 cm^{-1} (4.26 μm)
and a degenerate bending mode (ν_2):
667 cm^{-1} (15 μm)



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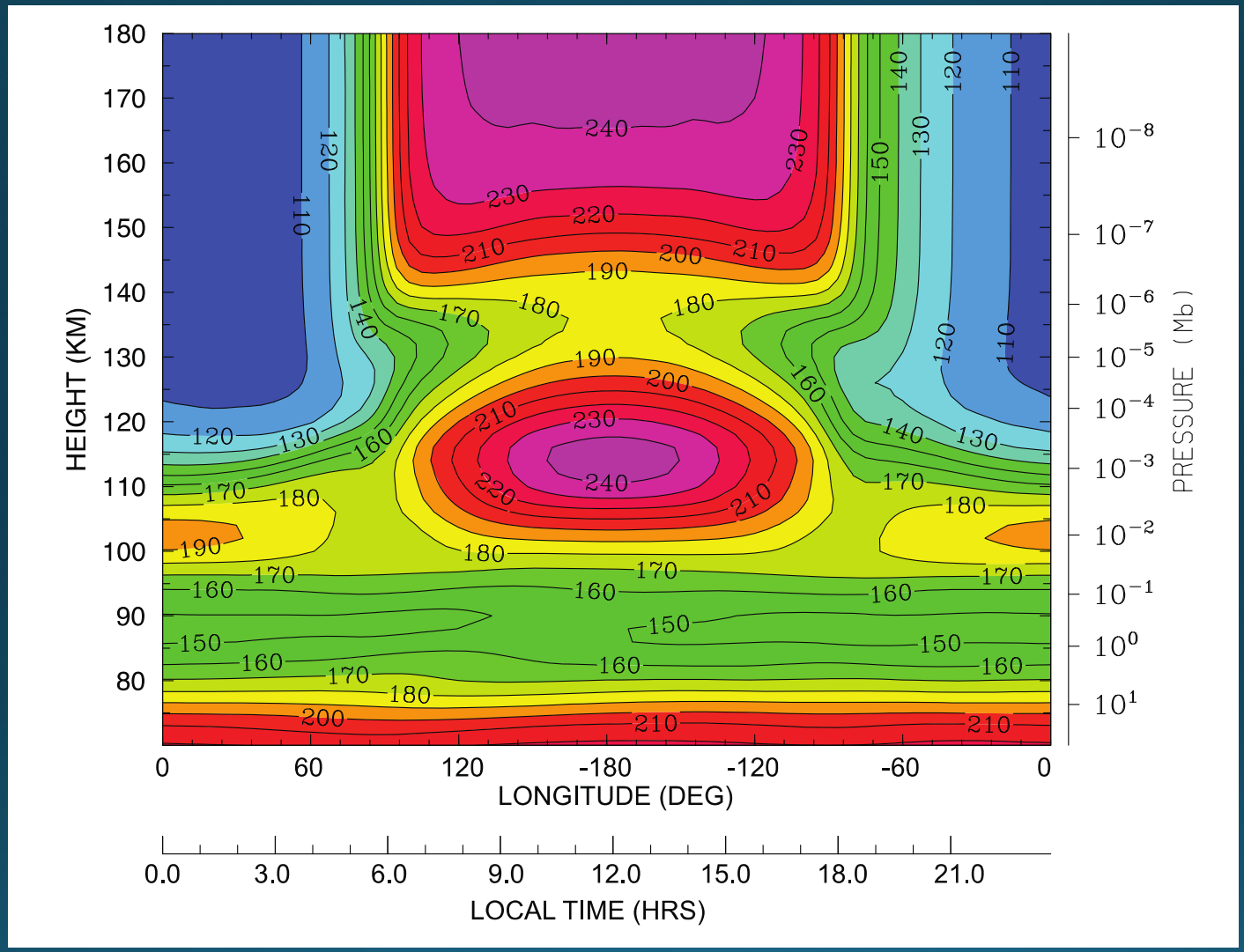
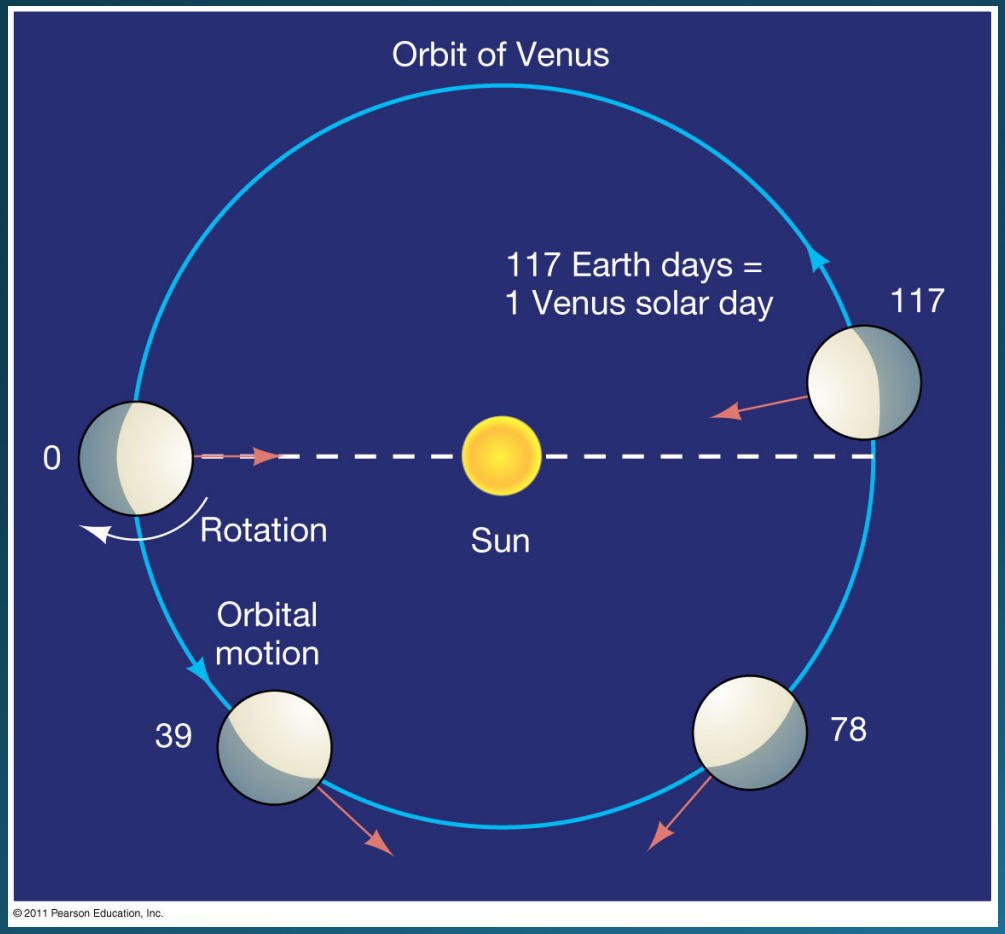


Equatorial temperature slice from the VTGCM model (Bougher et al. 2013):note the cryosphere.

The orbit of Venus

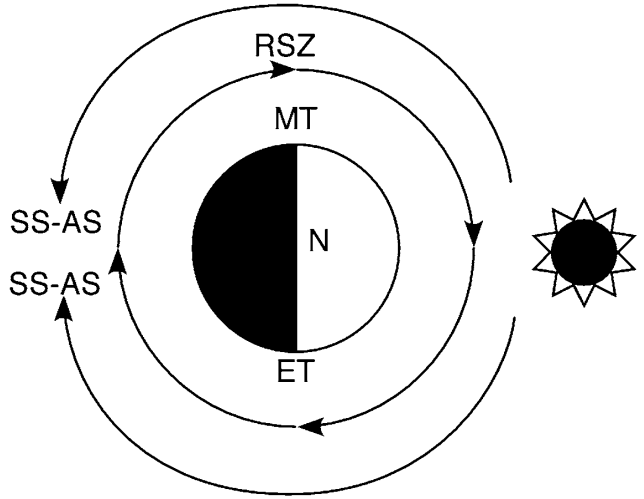


Venus rotates around its axis once every 244 days in the opposite sense to the Earth.

The orbit is nearly circular.

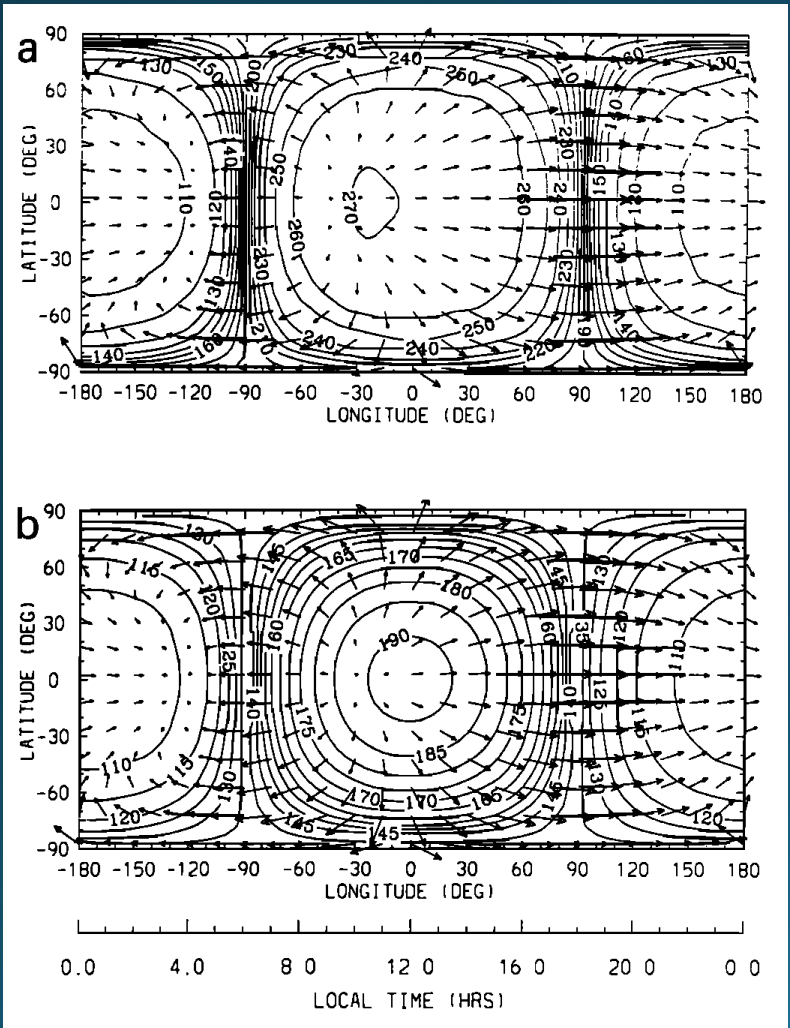
Circulation in Venus MUA

Fig. 18 Illustration of the major components of the global circulation of the Venus upper atmosphere. SS-AS (subsolar-to-antisolar), RSZ (retrograde superrotating zonal), ET (evening terminator), MT (morning terminator) (from Brecht et al. 2011)



From Gerard et al. (2017)

Circulation in Venus MUA



Solar medium conditions simulated by VTGCM (Bougher et al. 1999): Note that VTGCM uses Rayleigh drag to simulate momentum deposition by waves to match the large diurnal temperature difference.