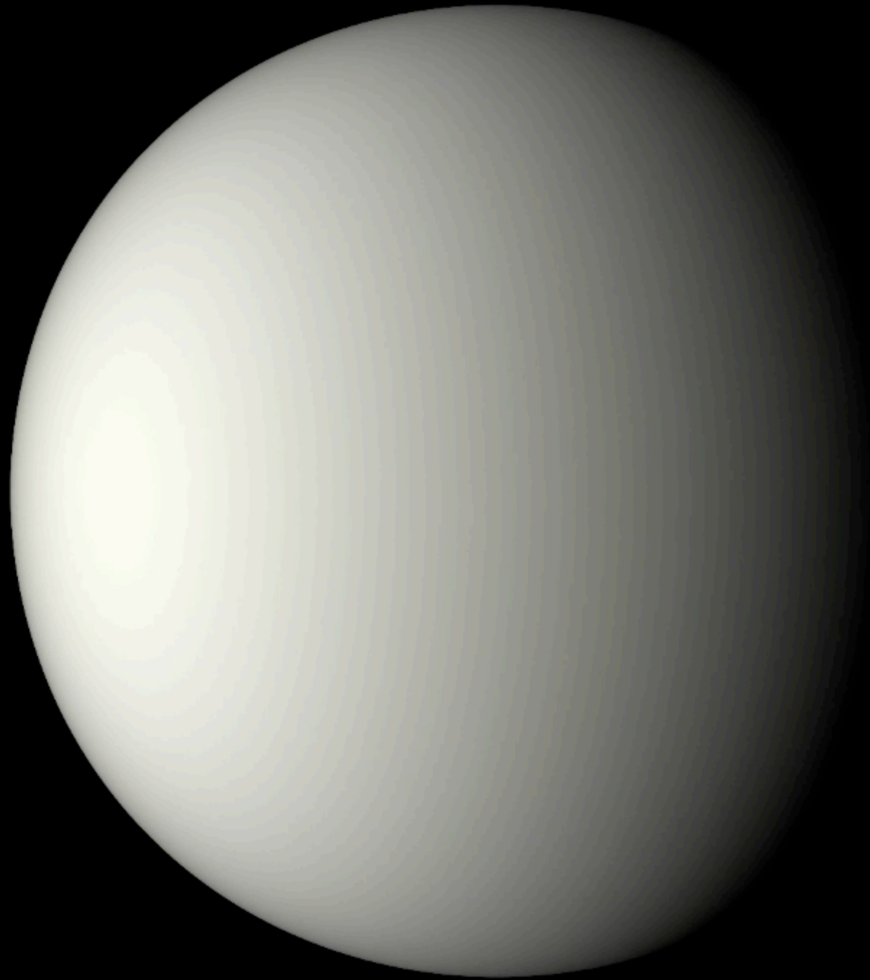
Modelling the in situ solar and thermal radiation environment for future entry probe missions to Venus



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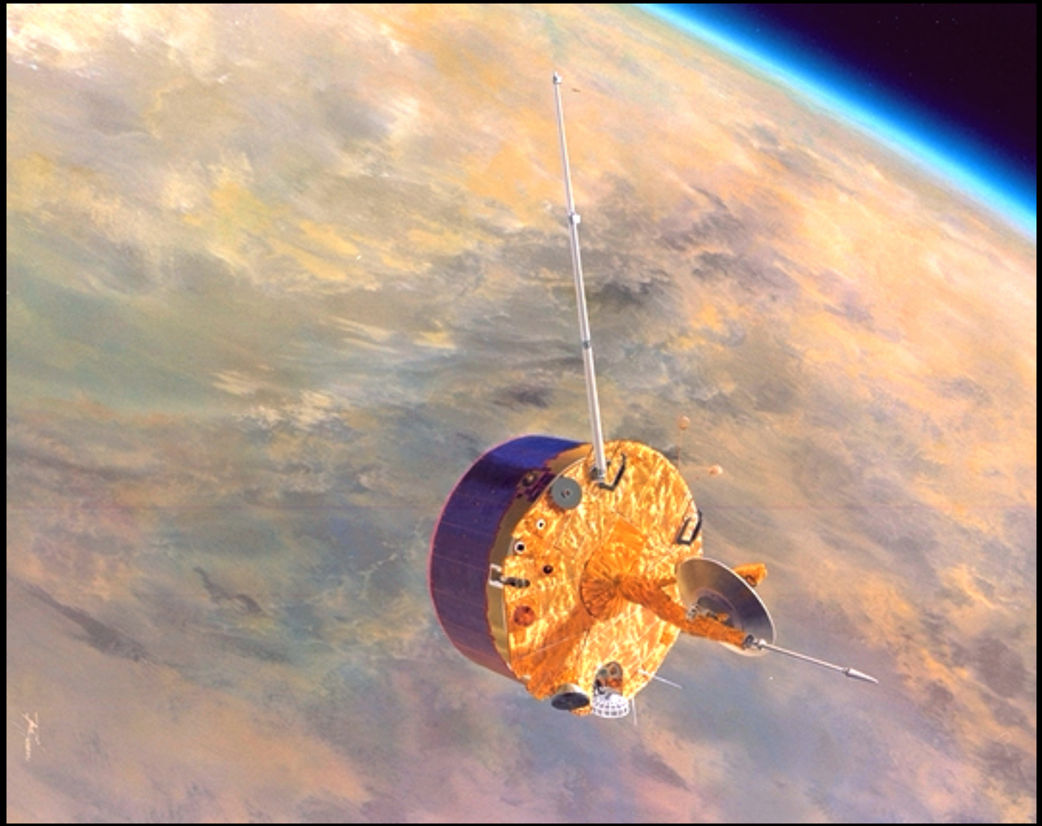
Motivation

- Work arose from study of a Net Flux Radiometer for possible inclusion on a probe mission to Uranus or Neptune (EPSC2020-306).
- We wanted to check the veracity of our calculations and realized that with Venus we have in situ observations from Pioneer Venus and Venera landers to compare with.
- Since the radiative transfer model we use (NEMESIS) can be applied to any planet it was straightforward to reconfigure for Venus.
- In doing so, we actually captured and fixed a significant bug!

In situ observations of Venus' atmosphere

- Pioneer Venus (Large probe).
  - December 9th 1978 at 4.4°N, 304°E
  - solar zenith angle 65.7°
- Venera 11.
  - December 25th 1978
  - 14°S, 299°E, solar zenith angle 20°
- Venera 13.
  - March 1st 1982
  - 7.5°S, 303.5°E, solar zenith angle 36°
- Venera 14.
  - March 5th 1982
  - 13°S, 310°E, solar zenith angle 35.5°



Pioneer Venus Clouds

- Knollenberg and Hunten (JGR 85, 8039, 1980) analyse Pioneer Venus LCPS data and find three main H_2SO_4 cloud layers and 3 main particle types.
- Cloud model later updated by Crisp (Icarus 67, 484, 1986) with mode 2 split. Further updated by Pollack et al. (Icarus 103, 1, 1993). H_2SO_4 particles with sizes:

Mode	Mean Radius (μm)	σ
Mode 1	0.30	0.44
Mode 2	1.00	0.25
Mode 2′	1.40	0.21
Mode 3	3.65	0.25

$$n(r) \propto r^{-1} \exp[-(\ln r - \ln \bar{r})^2/(2\sigma^2)]$$

- Tomasko et al. (JGR **85**, 8167, 1980) give estimates of opacities of different cloud layers and estimate solar flux absorbed at ground to be 17 W/m^2.

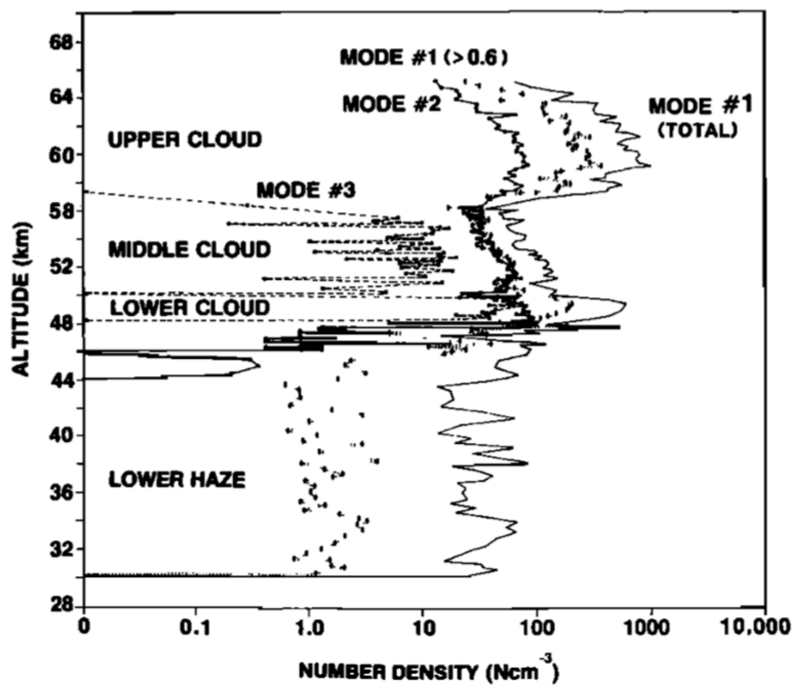


Fig. 16. Modal partitioning of number density. Mode 1 is shown for both the sizes measured by the LCPS and the total expected from modeling efforts. The greatest difference is in the lower haze where we also are least confident.

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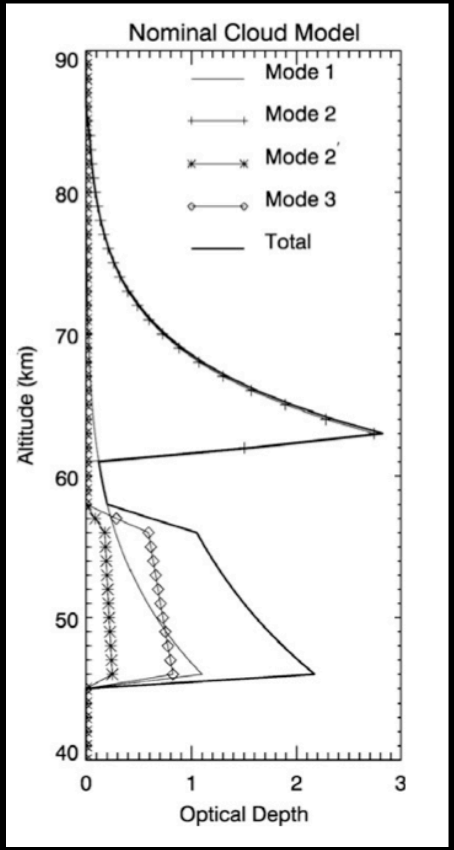
- Tomasko et al. (JGR **85**, 8167, 1980) give estimates of opacities of different cloud layers and estimate solar flux absorbed at ground to be 17 W/m^2.
- Barstow et al. (Icarus 217, 542, 2012) update cloud opacities to model Venus Express/VIRTIS data.
- Initial studies found too little absorption at short wavelengths. Properties of mode 1 particles modified to simulate UV/blue absorber coefficients of Crisp (1986). Otherwise use 85% concentration and coefficients of Palmer and Williams (1986).
- Found bug in code with Rayleigh-scattering single-scattering albedo!

Mode	Barstow	Tomasko
Mode 1	9	5.9
Mode 2	13.7	3.4
Mode 2’	2.7	5.7
Mode 3	8.9	17.6

Column opacity (630 nm)



NEMESIS ANALYSIS

- **N**on-linear Optimal **E**stimator for **M**ultivariat**E** Spectral Analy**SIS**
- Originally developed for solar system studies, but extended for exoplanets/brown dwarfs.
- Core retrieval code based on **Optimal Estimation**, but also extended for Bayesian **Nested-Sampling** retrievals.
- For multiple-scattering NEMESIS uses plane-parallel Matrix operator scattering code.
- Line-by-line and correlated-k used for gaseous absorption.
- k-tables generated from HITRAN and other sources

Venera 11,13,14

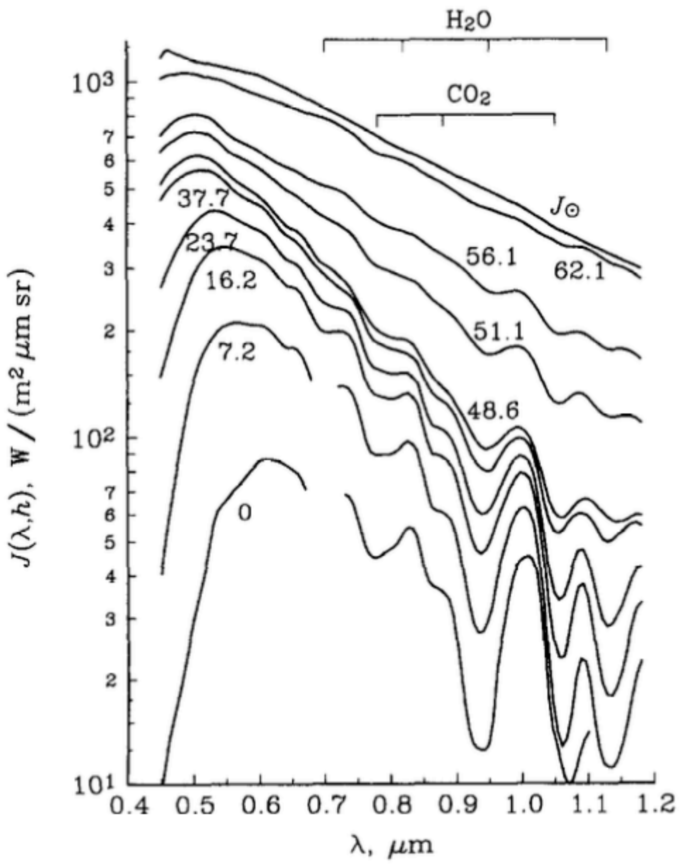
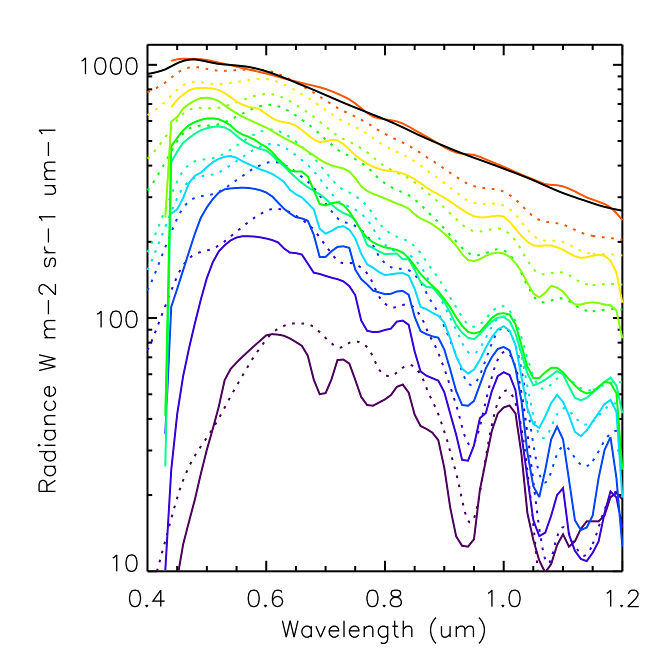
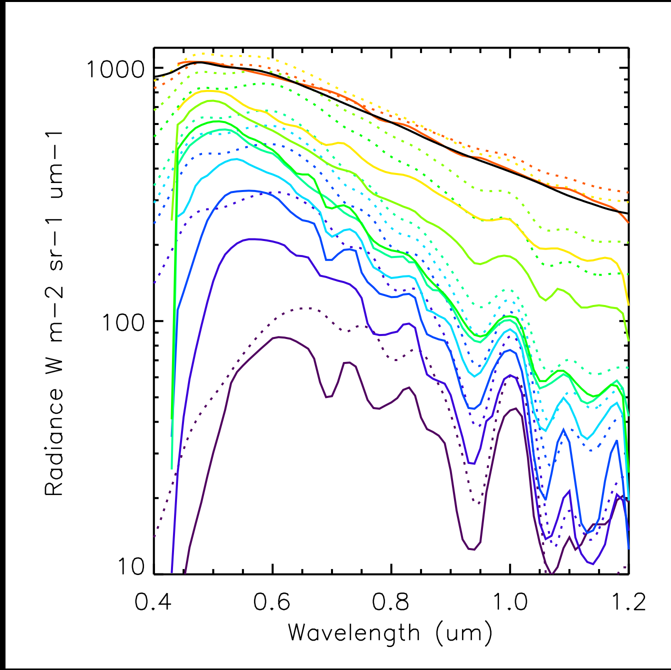


Fig. 1. Examples of the Venera 11 spectra of solar radiation scattered in the Venus atmosphere at some altitudes *h* (numbers near curves) above the ground

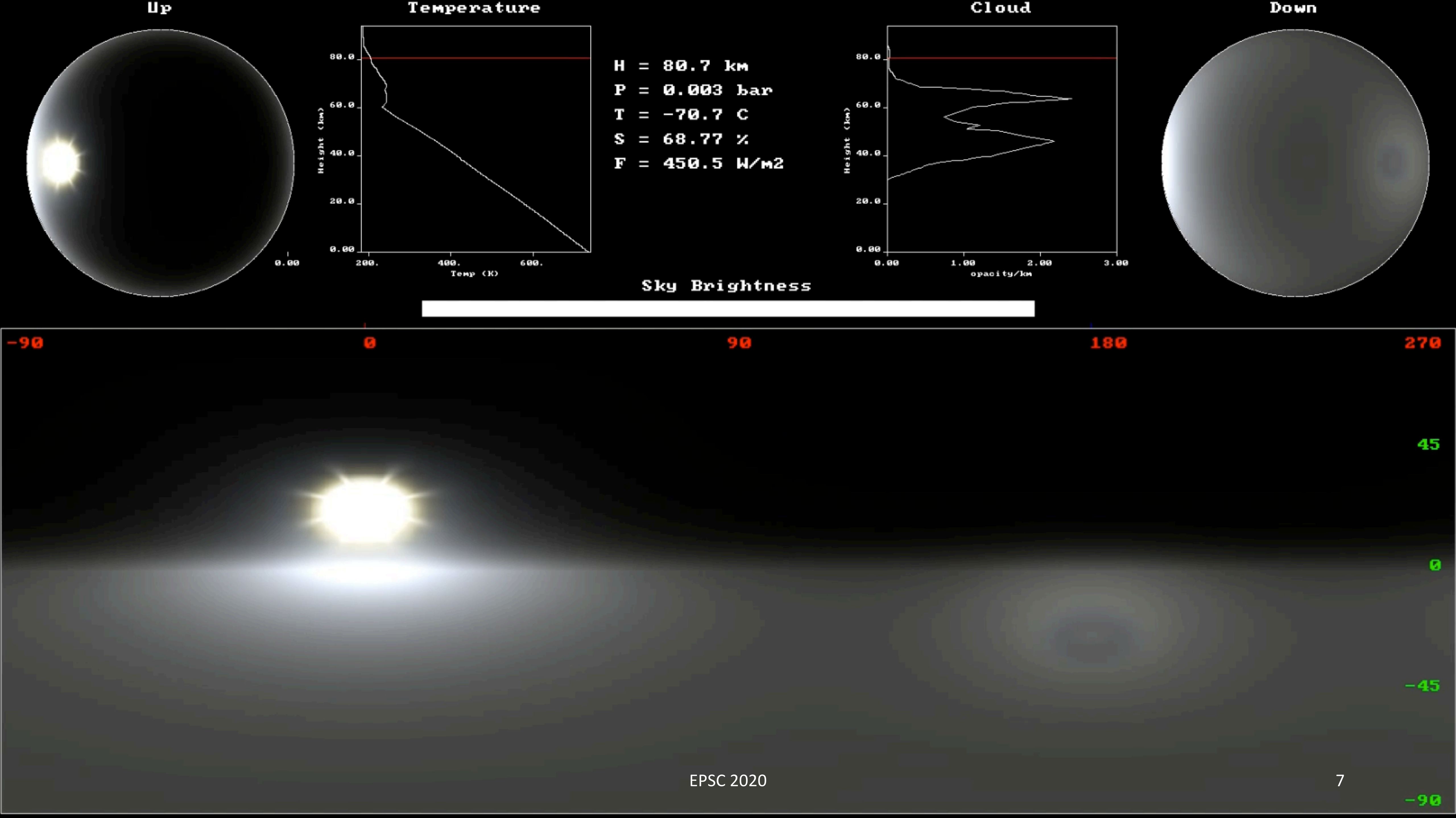
- Ignatiev et al. (PSS 45, 427, 1997) show spectra measured by spacecraft in upwards direction at different altitude.
- Used to compare simulations.

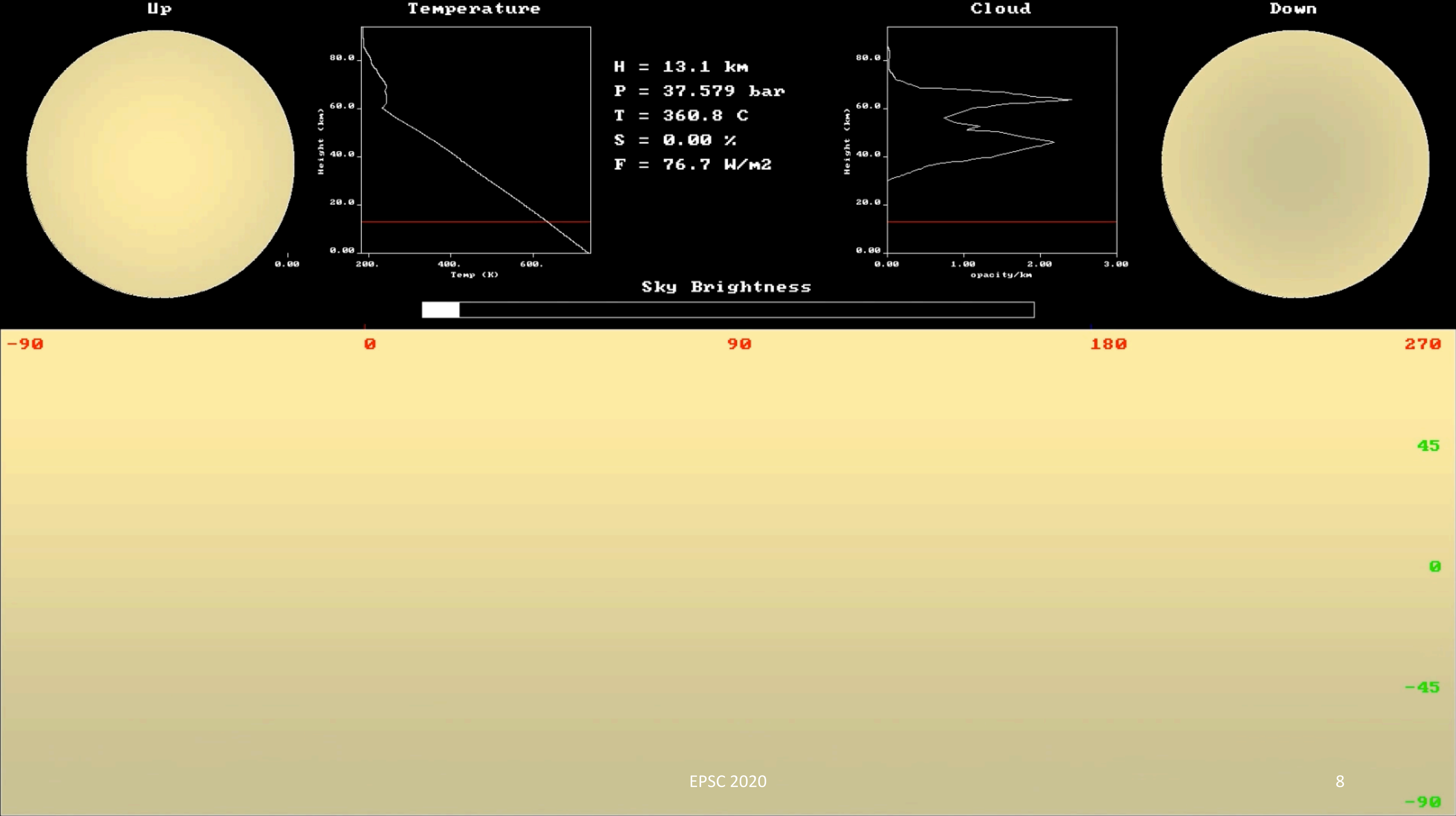


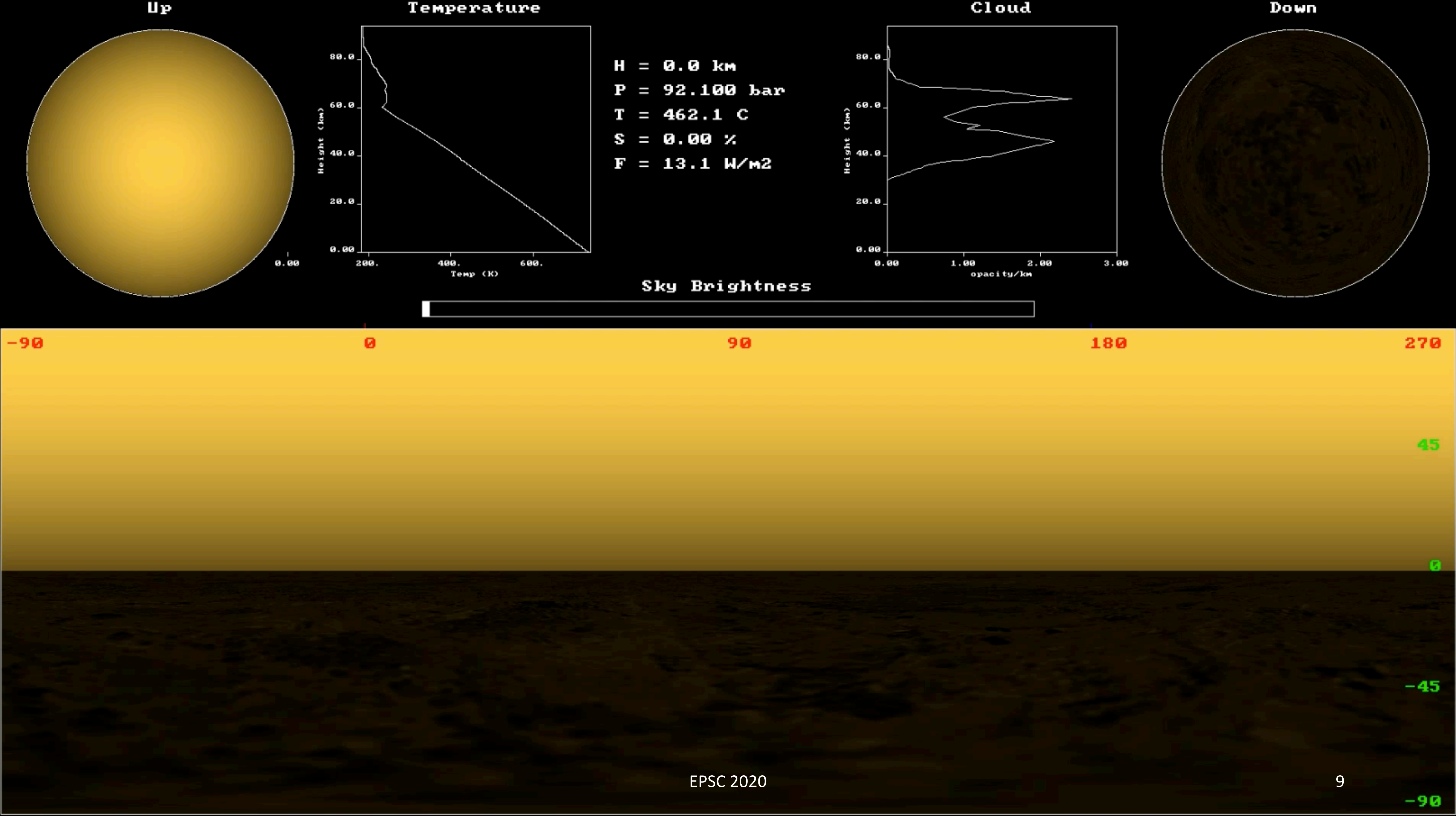
Barstow clouds



Barstow clouds – Tomasko opacity


Up
Temperature
Cloud
Down
H = 80.7 km
P = 0.003 bar
T = -70.7 C
S = 68.77 %
F = 450.5 W/m2
Height (km)
Temp (K)
opacity/km
Sky Brightness
-90
0
90
180
270
45
0
-45
-90


Up
Temperature
H = 13.1 km
P = 37.579 bar
T = 360.8 C
S = 0.00 %
F = 76.7 W/m2
Cloud
Down
Height (km)
Temp (K)
opacity/km
Sky Brightness
-90
0
90
180
270
45
0
-45
-90


Up
Temperature
Cloud
Down
80.0
60.0
40.0
20.0
0.00
Height (km)
200.
400.
600.
Temp (K)
H = 0.0 km
P = 92.100 bar
T = 462.1 C
S = 0.00 %
F = 13.1 W/m2
0.00
1.00
2.00
3.00
opacity/km
Sky Brightness
-90
0
90
180
270
45
0
-45
-90

3D-Modelling with Plane-Parallel Code

- Matrix-Operator multiple-scattering code assumes plane-parallel atmosphere.
- However can be used to simulate 3-D planets by assuming conditions locally plane-parallel, but setting solar zenith, viewing zenith and azimuth angles to those computed at points on planet using 3-D geometry.

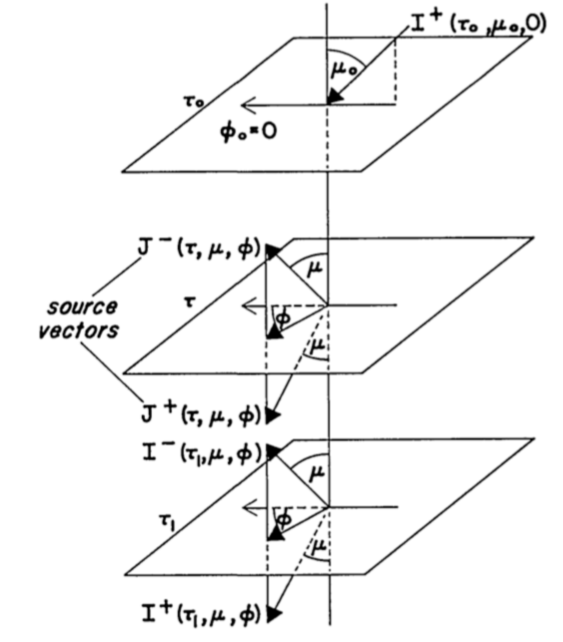
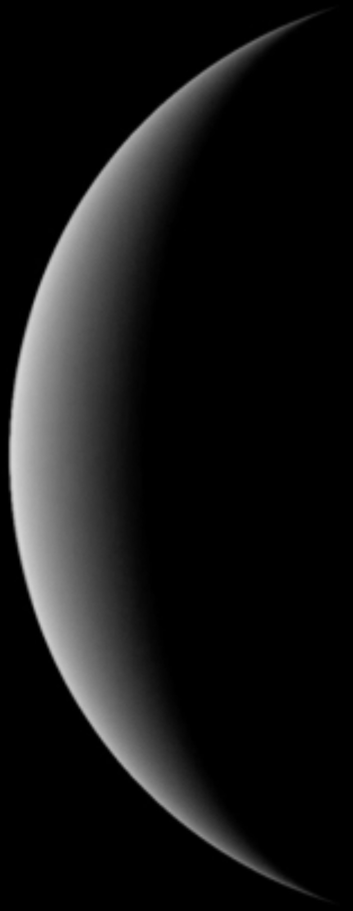


Fig. 1. Graphic representation of matrix operator vectors.

Plass et al. (1973)



Conclusion

- NEMESIS provides accurate modelling of probe NFR data.
- But work in progress!
  - Need to work on cloud model to match better the observations of Pioneer Venus and VENERA 12, 13 and 14.
  - Need to implement a fitting procedure to fit the cloud opacity at each level. Once done, can also revisit the retrieval of the H_2O abundance profile.
- Can also use model to simulate overall illumination conditions for a Venus entry probe.
- https://www.youtube.com/watch?v=YkeWhgwp7Xo&t=7s
- https://www2.physics.ox.ac.uk/news/2020/07/24/flights-of-fancy-exploring-uranus-and-landing-on-venus