TUTORIAL

Venus: The Atmosphere, Chemistry, and Clouds

F.W. Taylor
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<table>
<thead>
<tr>
<th>Species</th>
<th>Abundance (mole fraction)</th>
<th>Species</th>
<th>Abundance (mole fraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>0.965</td>
<td>He</td>
<td>12 ppm</td>
</tr>
<tr>
<td>N₂</td>
<td>0.035</td>
<td>Ne</td>
<td>7 ppm</td>
</tr>
<tr>
<td>SO₂</td>
<td>150 ppm</td>
<td>H₂S</td>
<td>3 ppm</td>
</tr>
<tr>
<td>Ar</td>
<td>70 ppm</td>
<td>HCl</td>
<td>400 ppb</td>
</tr>
<tr>
<td>CO</td>
<td>30 ppm</td>
<td>Kr</td>
<td>30 ppb</td>
</tr>
<tr>
<td>H₂O</td>
<td>20 ppm</td>
<td>HF</td>
<td>5 ppb</td>
</tr>
</tbody>
</table>
• CO₂ and N₂ amounts ~‘same’ as the Earth
• Water very low (⇒ loss rate is high)
• D/H = 100 x Earth ⇒ possible ancient ocean
• Abundant SO₂, H₂S, H₂SO₄ ⇒ active volcanism?
• Some species are variable
SO$_2$ vs. Time (Na & Esposito, 1996)
Model Venus temperature profile
Pioneer Venus OIR Measured Temperatures (3-month mean) vs. Height & Longitude at 0° latitude
(Schofield & Taylor, 1982)
Pioneer Venus OIR Temperatures vs. Height & Longitude

Solar Tide
- wavenumber 2 in stratosphere
- wavenumber 1 at cloudtops
Pioneer Venus OIR Temperatures vs. Height and Latitude
Pioneer Venus OIR Temperatures vs. Height and Latitude

Temperature increases from equator to pole!

Polar collar

Polar Dipole
Four views of the North Polar region of Venus

(M10 TV, PV OIR)
The variation with latitude of carbon monoxide abundance near 30 km altitude (Collard et al., 1994).

Galileo NIMS data

CO mixing ratio, ppmv

Latitude
Conceptual model for CO sources on Venus: transport from the upper atmosphere via the polar vortices.
Profile of the clouds from the PV large probe
(RG Knollenberg and DM Hunten, 1980)
Atmospheric Chemistry dominated by Sulfur?

From ‘Physics and Chemistry of the Solar System’ by John S. Lewis
The ‘Ashen Light’ of Venus
first observed by Giovanni Riccioli on January 9, 1643

[P. Moore]
... at 2.3 microns

D. Crisp, NASA/JPL
Venus Near-IR Spectrum


240 K blackbody
Galileo NIMS view of mysterious ‘weather’ in the deep atmosphere of Venus (Carlson et al.)
Energy Balance of the Earth

Applying the Stefan-Boltzmann law we obtain for the total radiant power of the Sun, with temperature $T_S$ & radius $R_S$:

$$ E_{_{\text{Sun}}} = 4\pi R_S^2 \, \sigma (T_S)^4 = 4\pi S \, R_{ES}^2 $$

where $S$ is the solar constant and $R_{ES}$ the distance Earth–Sun. Now:

$$ E_E = 4\pi \sigma \, R_E^2 \, (T_E)^4 = (1-A) \, S \, \pi \, R_E^2 $$

$\rightarrow$ radiometric temperature of the Earth $T_E = 255$ K.

The mean surface temperature of the Earth is about 288 K. The difference is due to the fact that only a small part of the thermal emission to space takes place from the surface; most is from the colder regions near the tropopause.
Energy Balance of Venus

Applying the Stefan-Boltzmann law we obtain for the total radiant power of the Sun, with temperature $T_S$ & radius $R_S$:

$$E_{\text{Sun}} = 4\pi R_S^2 \sigma (T_S)^4 = 4\pi S R_{VS}^2$$

where $S$ is the solar constant and $R_{ES}$ the distance Earth–Sun. Now:

$$E_V = 4\pi \sigma R_V^2 (T_V)^4 = (1-A) S \pi R_V^2$$

→ radiometric temperature of Venus $T_V = 240$ K.

The mean surface temperature of Venus is about 760 K. The difference is due to the fact that only a small part of the thermal emission to space takes place from the surface; most is from the colder regions near the tropopause.
Magellan radio occultation temperature profile

Temperature of Venusian Atmosphere

Magellan Orbit 3213
Date: 5 October 1991
Latitude: 67N
LTST: 22:05
3-Sigma Uncertainty in Red
Radiative-convective equilibrium model

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Jon M. Jenkins 1 May 1995

Jenkins, 1995
Why is Venus so hot?

- CO$_2$ is in equilibrium with carbonates on surface (Urey, 1952)
- the dominant reaction is expected (Bullock & Grinspoon 1996) to be

$$\text{CaCO}_3 + \text{SiO}_2 \leftrightarrow \text{CaSiO}_3 + \text{CO}_2$$

- use thermodynamic data (e.g. Adamik and Draper, 1963) for the temperature dependence of the pressure of CO$_2$ in the form

$$\log P = \frac{\Delta H}{RT} + \frac{\Delta S}{R} + A + BT + CT^2$$

- use the radiative-convective equilibrium model for the surface pressure as a function of surface temperature
Venus Climate

- Rad-Conv Equilibrium
- Mineral Equilibrium

Surface Pressure vs. Surface Temperature
Summary Part 1:
More data! More data! From pole to equator! Measure everything, everywhere, all of the time!