Climate Sensitivities of Venus and Earth

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Venus Atmosphere Energy Balance

Diagram showing the energy balance in the Venus atmosphere, with different layers labeled as Upper Haze, Upper Cloud, Middle Cloud, Lower Cloud, and Lower Haze. Numbers represent specific values or pressures: 17,900, 655, 524, 130, and 17.
Energy Distribution

- Blue – Solar
- Red – Thermal
- Outgoing thermal energy almost constant with latitude
IPCC – Terrestrial Radiative Forcing

- 250 years of industrial activity
- Greenhouse gas forcing increased 3 W/m²
- Aerosols 1.25 W/m²
Radiative Forcing and Response

**Instantaneous RF**
- RF = net flux imbalance at tropopause
- temperature fixed everywhere

**Equilibrium climate response**
- No flux imbalance
- temperatures adjust everywhere

ΔTs
Climate Forcing and Response

\[ F = F \left( [CO_2], T \right) \]

\[ \Delta F = \frac{\partial F}{\partial [CO_2]} \Delta [CO_2] + \frac{\partial F}{\partial T} \Delta T \]

Forcing Term
Response Term
Doubling CO$_2$ without Feedbacks

\[ \Delta T = - \left( \frac{\partial F}{\partial T} \right) \left( \frac{\partial F}{\partial [CO_2]} \right) \Delta [CO_2] \]

For Earth, doubling CO$_2$

\[ \frac{\partial F}{\partial [CO_2]} \Delta [CO_2] = -4 \frac{W}{m^2} \]
Water Vapor Feedback

\[ F = F([CO_2],[H_2O]T) \]

\[ \Delta F = \frac{\partial F}{\partial [CO_2]} \Delta [CO_2] + \frac{\partial F}{\partial T} \Delta T + \frac{\partial F}{\partial [H_2O]} \frac{\partial [H_2O]}{\partial T} \Delta T \]

Forcing  Response  Feedback
Include Albedo Feedback

\[ \frac{S_o}{4} \left( \frac{d\alpha}{dT} \right) \]

\[ \Delta T = \frac{-\frac{\partial F}{\partial [CO_2]} \Delta [CO_2]}{\frac{\partial F}{\partial [H_2O]} + \frac{\partial F}{\partial [H_2O]} \frac{\partial [H_2O]}{\partial T} + \frac{S_o}{4} \left( \frac{d\alpha}{dT} \right)} = \frac{\Delta Q}{\lambda} \]

Forcing

Feedback

4 W/m²

-4 W/m²

3.5 W/m²

-1.6 W/m²

-0.5 W/m²
Earth Atmosphere Sensitivity

\[ \Delta T = \frac{\Delta Q}{\lambda} = \frac{4}{1.4} = 2.9^o C \]
Venus Model – Surface Temperatures

![Graph showing surface temperatures versus atmospheric mixing ratios for H₂O and SO₂. The graph indicates a sharp increase in surface temperature at higher mixing ratios for H₂O.](image-url)
Venus Climate Sensitivity
Doubling H$_2$O

\[ \Delta T = -\frac{\partial F}{\partial \left[H_2O\right]} \Delta \left[H_2O\right] \]

\[ = \frac{\Delta Q}{\lambda} = -2.9K \]

2.8 W/m$^2$ K \quad -11.1 W/m$^2$ K

-24.1 W/m$^2$
Venus Climate Sensitivity
Doubling SO$_2$

\[
\Delta T = \frac{-\frac{\partial F}{\partial [SO_2]} \Delta [SO_2]}{\frac{\partial F}{\partial T} + \frac{S_o}{4} \left( \frac{\partial \alpha}{\partial T} \right)_{SO_2}} = \frac{\Delta Q}{\lambda} = -8.0 K
\]

-1.2 W/m$^2$

2.8 W/m$^2$ K

-2.95 W/m$^2$ K
## Summary
### Climate Sensitivity to Doubling

<table>
<thead>
<tr>
<th></th>
<th>Earth CO$_2$</th>
<th>Venus H$_2$O</th>
<th>Venus SO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forcing</strong> (W/m$^2$)</td>
<td>-4</td>
<td>-24.1</td>
<td>-1.2</td>
</tr>
<tr>
<td><strong>Response</strong> (W/m$^2$-K)</td>
<td>3.5</td>
<td>2.8</td>
<td>2.8</td>
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<tr>
<td><strong>Feedback</strong> (W/m$^2$-K)</td>
<td>-2.1</td>
<td>-11.1</td>
<td>-2.9</td>
</tr>
<tr>
<td><strong>ΔT (K)</strong></td>
<td>2.9</td>
<td>-2.9</td>
<td>-8.0</td>
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