Climate Control on Venus:

Connections among Clouds, UV absorber, Surface Chemical Reaction, and Atmospheric Circulation

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CO as a probe for atmospheric circulation

- Meridional circulation is constrained by CO distribution.

CO as a driver for climate change

- Key chemical reactions depend on CO concentration.

Observation of CO

Iwagami et al. (2010) Icarus 207, 558-563.

- CO in the Venus' dayside atmosphere above the clouds was measured by ground-based 2.3 μm spectroscopy.
- The disc-averaged mixing ratio of 58 $\pm$ 17 ppm found at a representative height of 62–67 km is consistent with previous measurements.
- The hemispherical distributions found show no significant latitudinal or longitudinal structure.

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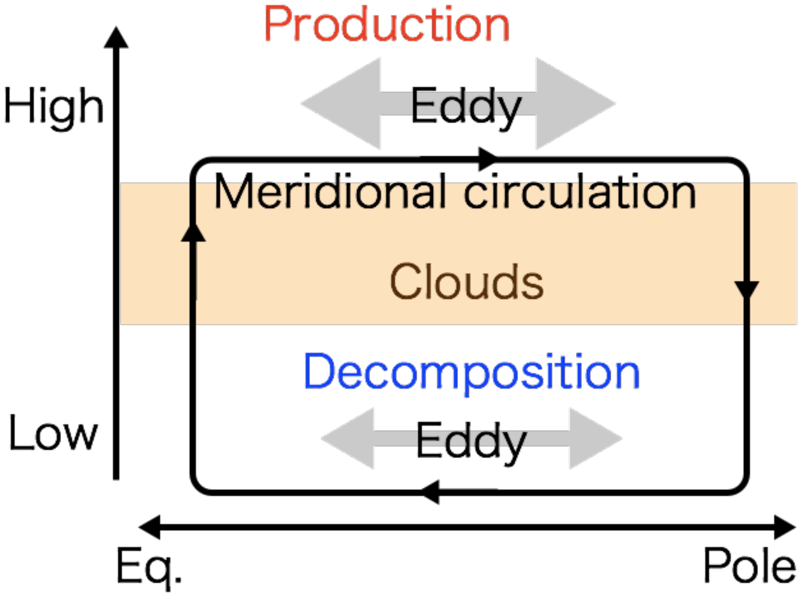
Do you think it's boring?

- There are many similar observations.
- But discussion based on CO distribution is interesting.

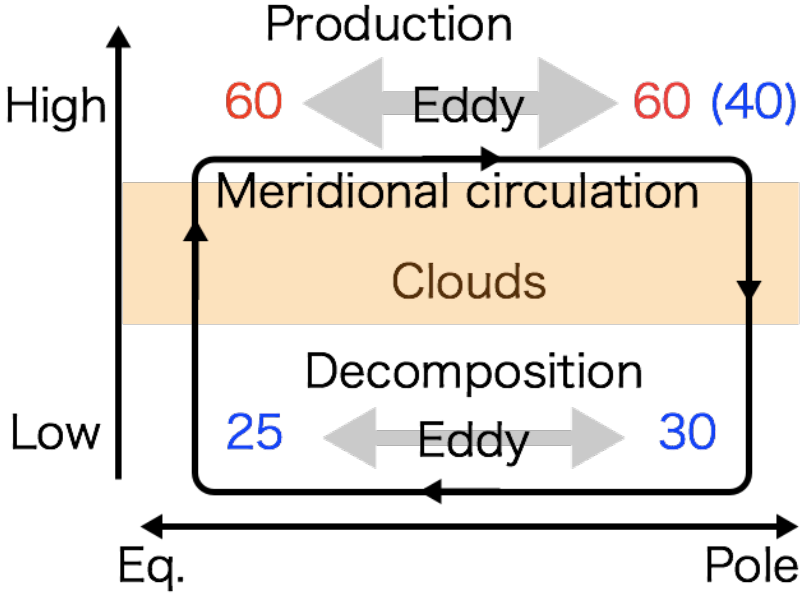
Probe for Atmospheric Circulation



Distribution of CO

	Dayside	Nightside
Above Clouds	Iwagami et al. (2010) 58 ± 17 ppm homogeneous Krasnopolsky (2008) 70 ± 10 ppm homogeneous	Irwin et al. (2008) 40 ± 10 ppm
Below Clouds		Collard et al. (1993) Marcq et al. (2005, 2008) Tsang et al. (2008, 2009) low lat. ~ 25 ppm high lat. ~ 30 ppm

Distribution of CO



Poleward Wind Speed Above Clouds

Observation

Ascend in the eq. region: 25 ppm

Descend in the polar region: 60 ppm

Photochemical model (e.g., Krasnopolsky and Pollack 1994)

CO production rate above 65 km: 0.1 ppm/day

Residence time in the upper atmosphere:

- $\tau_m = \frac{60 - 25}{0.1} \sim 350$ days

Net poleward wind speed of meridional circulation:

- $v = \frac{(2\pi R)/4}{\tau_m} \sim 0.3$ m/s

Horizontal Diffusivity Above Clouds

Observation

No significant latitudinal variation

Meridional circulation

CO-poor air ascends in the equatorial region

Horizontal Eddy Diffusion:

- Equator to pole gradient of CO should be diluted by horizontal eddy diffusion.
- $\tau_d \ll \tau_m \sim 350$ days

  Timescale for horizontal eddy diffusion: τ_d

  Timescale for poleward transport: τ_m

Cloud Tracking and AGCM

Cloud tracking

- Poleward wind speed above the clouds would be compared.

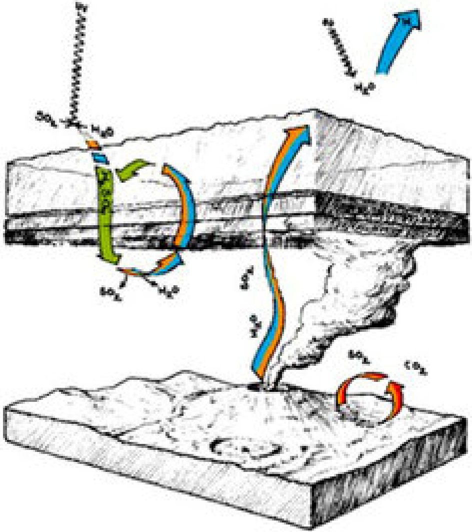
  - CO distribution represents a mean of circulation (averaged over the timescale of overturning).

AGCM

- Timescale for meridional overturning circulation and horizontal diffusion above the clouds would be a benchmark for model intercomparison.

  - Chemical model is not required.

Climate in Geological Timescale



In a geological timescale, atmospheric composition would be controlled by reaction on solid surface.

High T and high P condition prompt chemical reaction between the atmosphere and plnaetary surface (e.g., Fegley and Treiman, 1992).

Image: `https://www.esa.int/spaceinimages/Images/2007/11/Climate_evolution_on_Venus`

Feedback Loops Mediated by SO_2

SO_2 will play an important role in Venus' climate system.

Composition $\rightarrow$ Temperature

- Greenhouse effect
- Clouds ($H_2O + SO_2 + O \rightarrow H_2SO_4$)

  cf. H_2SO_4 clouds control planetary albedo (~ 0.76).

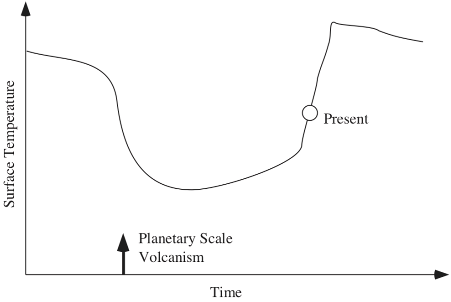
Temperature $\rightarrow$ Composition

- Carbonate model (e.g., Fegley and Treiman 1992)
  $CaCO_3 + SO_2 \leftrightarrow CaSO_4 + CO$
- Pyrite model (e.g., Zolotov 1991, 1995)
  $3\ FeS_2 + 16\ CO_2 \leftrightarrow Fe_3O_4 + 6\ SO_2 + 16\ CO$

Prediction of Climate Models

Carbonate model

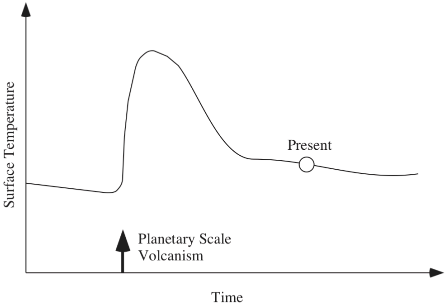
(Bullock and Grinspoon 2001)



- Current state is unstable, and catastrophic climate change occurs.

Pyrite model

(Hashimoto and Abe 2000)



- Current state is stabilized by adjusting SO_2.

Hashimoto and Abe (2005)

Redox State: Problem that still remains

Key reactions depend on the redox state

$$CaCO_3 + SO_2 \leftrightarrow CaSO_4 + CO$$

$$3\ FeS_2 + 16\ CO_2 \leftrightarrow Fe_3O_4 + 6\ SO_2 + 16\ CO$$

Redox state (CO concentration) is controlled by the transport from the upper atmosphere and the rate of thermochemical reaction in the lower atmosphere (e.g., Krasnopolsky 2007).

Climate change may be caused by a change in the strength of meridional circulation.

Feedback Should be Reconsidered

We need to explore feedback loops.

- SO_2 definitely plays an important role in Venus' climate, but not the only one.
- CO is a promising candidate that connects the subsystems and create a feedback loop.
- Strength of meridional circulation may be a key that control the surface chemical reaction.

- Chemical species which can affect the radiative balance would be candidates.

  e.g., OCS, S_x, UV absorber

Summary

CO as a probe for atmospheric circulation

- Poleward wind speed above clouds ~ 0.3 m/s
- Horizontal eddy diffusion above clouds $\ll 350$ days
- Useful to evaluate the performance of cloud tracking and AGCM

CO as a driver for climate change

- Key chemical reactions depend on the redox state (CO concentration) of the near surface atmosphere.
- CO transport by meridional circulation may control the current state of Venus' climate.