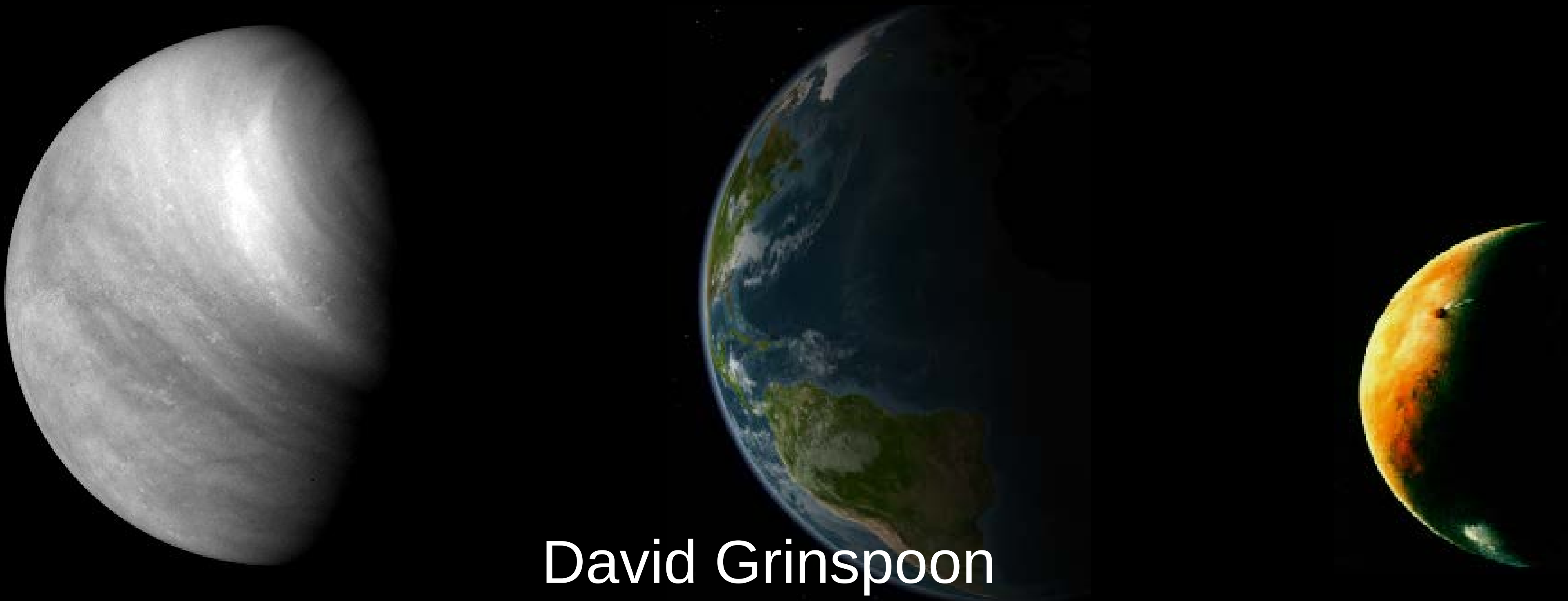
Comparative Climatology



David Grinspoon
Baruch S. Blumberg/NASA Chair of Astrobiology
Library of Congress

Comparative Climatology Symposium: New Approaches to Climate Research
NASA HQ
5/7/2012

Climate: A Problem of Planetary Physics

Arrhenius in 1896: Calculated that doubling Earth's CO_2 would raise Earth's T by 5°C.

Climate:
A Problem of Planetary Physics

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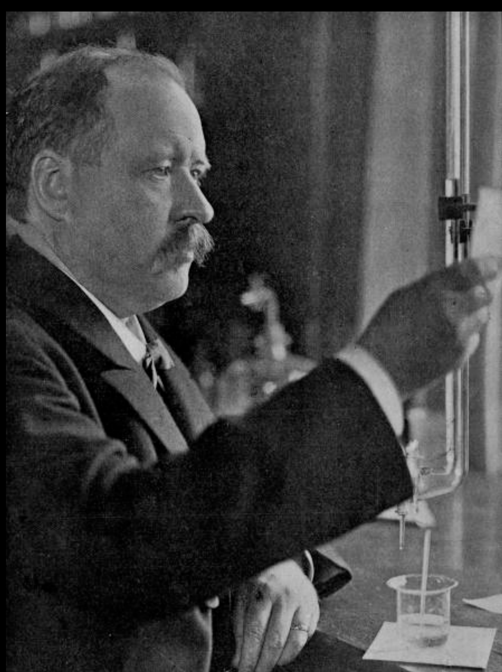


LIFE POSSIBLE ON VENUS.

Other Planets, Prof. Arrhenius Says, Are Quite Inhospitable.

From what we know of the surface conditions and climates of the various members of the solar system, Professor Svante Arrhenius concludes that Venus is the only planet besides the earth where life is possible. Venus has a dense, warm atmosphere of high humidity.

With everything dripping wet, life near the equator should be luxuriant, though of low order on account of the uniform climate and lack of need for specialization; but nearer the poles the climatic diversity is greater, suggesting a more varied development. Absence of any atmosphere, he thinks, makes life on Mercury and the moon impossible.

Mars, too, must be uninhabitable with a temperature averaging about 37 degrees Centigrade below zero, and scarcely rising to freezing point, even at noon on the equator, and its water supply is small.—Newark News.

The New York Times

Published: March 8, 1919

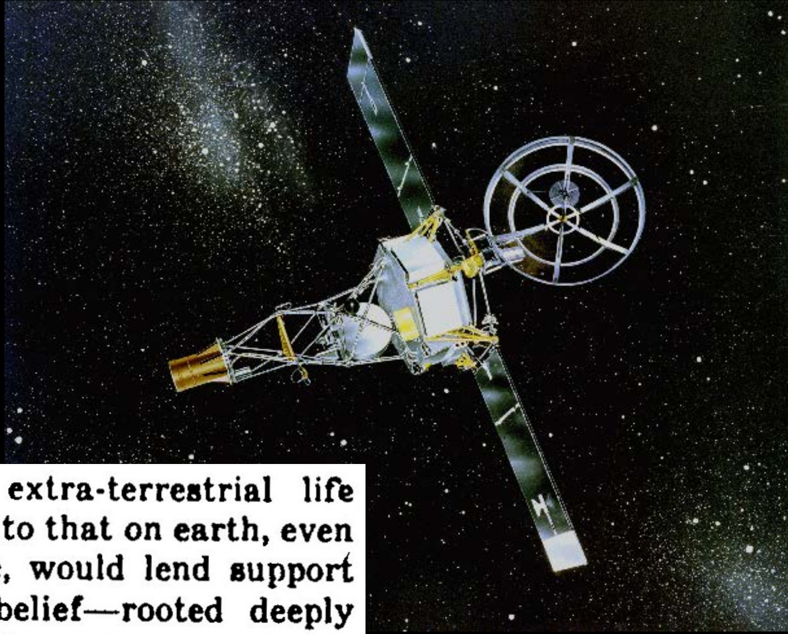
New York Times 2/26/1963

Venus Says 'No'

The first message from the Venus probe, Mariner 2, deciphered shortly after its historic fly-by of the planet on Dec. 14, at a distance of 21,564 miles, added important knowledge about Venus's magnetic field, its rate of rotation and other information shedding light on some of its mysteries. But one all-important question remained unanswered—whether or not life in some form existed on Venus and hence elsewhere in our solar system and possibly also beyond it.

Now comes a second message from Venus, via Mariner 2, with the first definite eagerly-awaited answer to this vital question, and the answer is a disheartening, disillusioning "No! Not on Venus!"

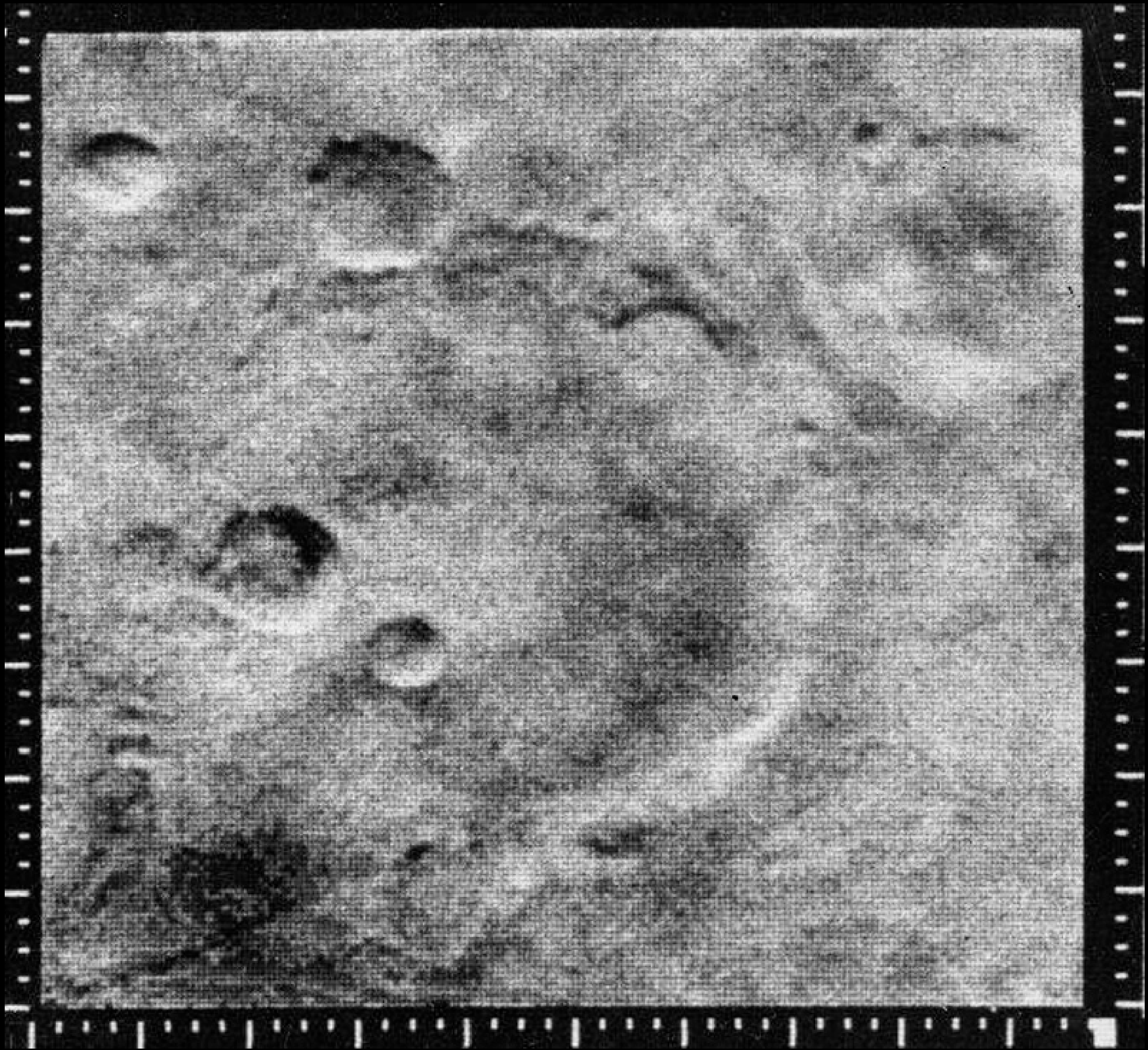
The newest message from Venus, sent down by the "cosmic thermometer" on Mariner 2, which made the first direct measurements of the surface temperature of the planet, informs earthlings that the temperature at or near the surface of our cloud-covered, planetary neighbor is between 300 and 400 degrees Fahrenheit. This high temperature, established for the first time, definitely rules out the possibility of the existence of life in any form even remotely resembling life as we know it on earth.



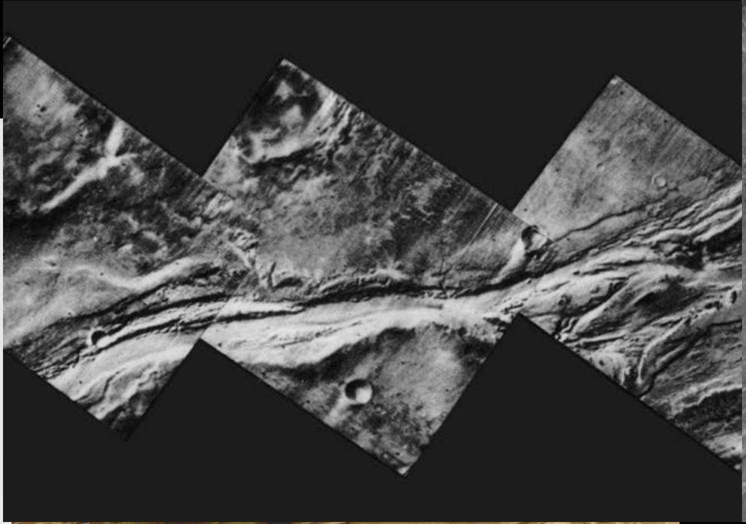
The finding of extra-terrestrial life in some form similar to that on earth, even at the lowliest stage, would lend support to the widespread belief—rooted deeply in the aspirations of mankind—that life as we know it is not unique to this insignificant corner of the universe, but exists in many other systems similar to ours throughout the universe. Indeed, there has been speculation among scientists, philosophers and poets that some of these systems have reached a stage of evolution much superior to ours. The message from Venus now reduces the hope of finding evidence in support of this speculation to one half, so far as our solar system is concerned.

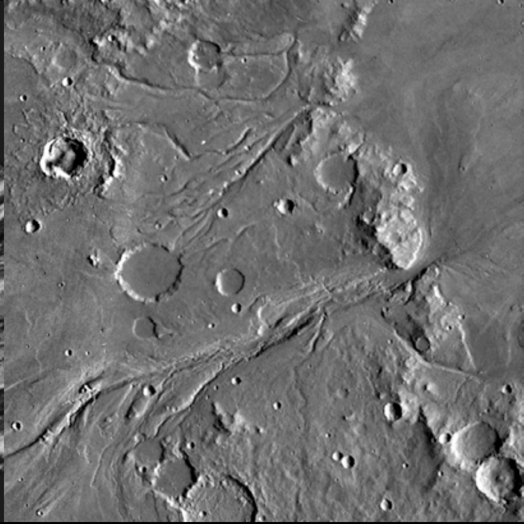
Mars now remains our only hope of turning this universal dream into reality, and the evidence so far is not very encouraging. The message from Venus may mark the beginning of the end of mankind's grand romantic dreams.

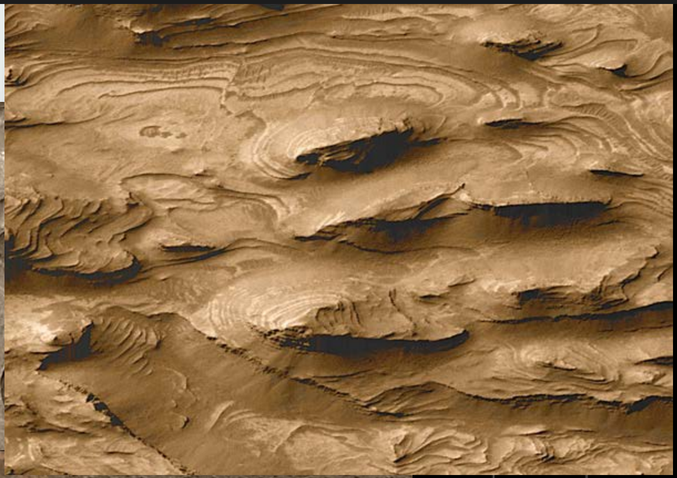
Mariner 4: First successful flyby of Mars on July 14, 1965.

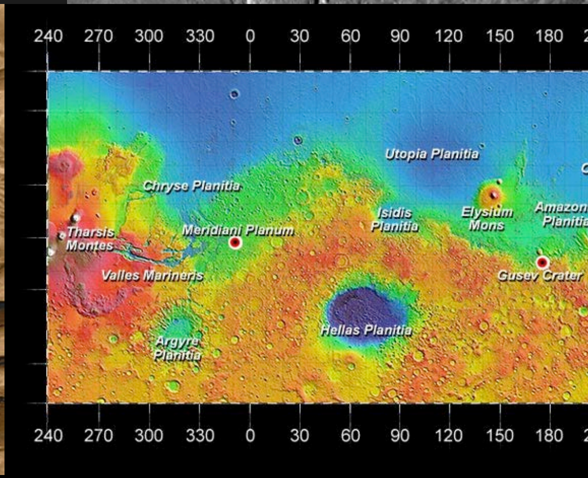


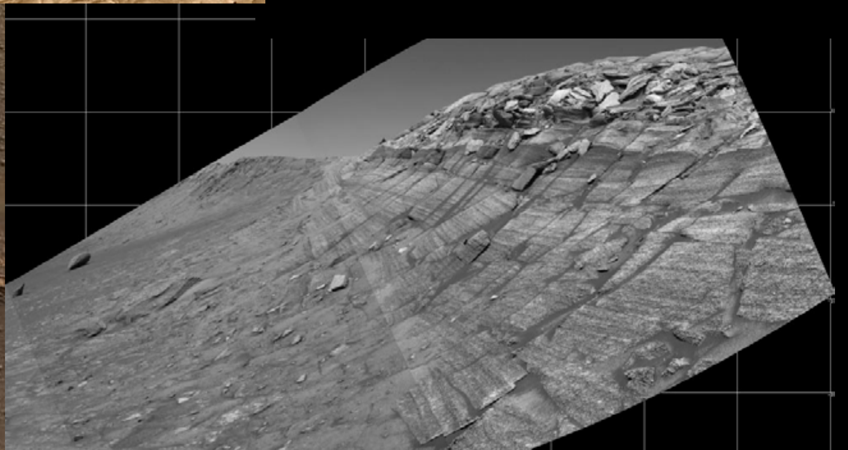
Water on Mars

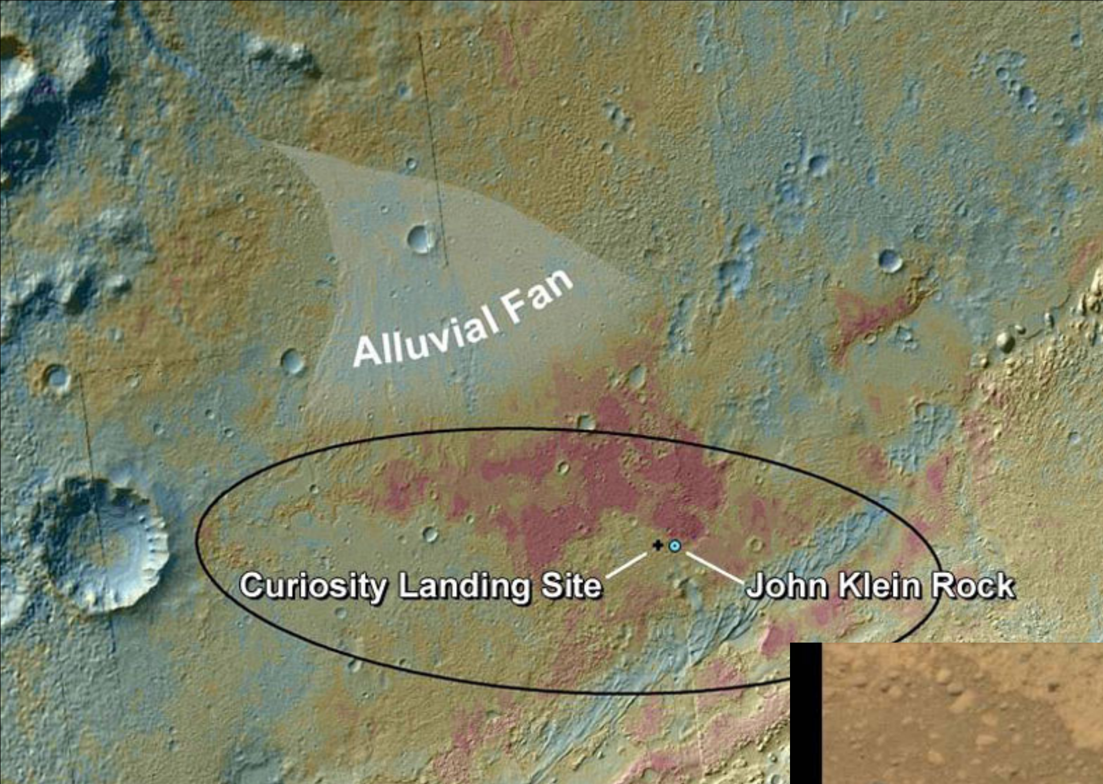











Alluvial Fan
Curiosity Landing Site
John Klein Rock


1 cm

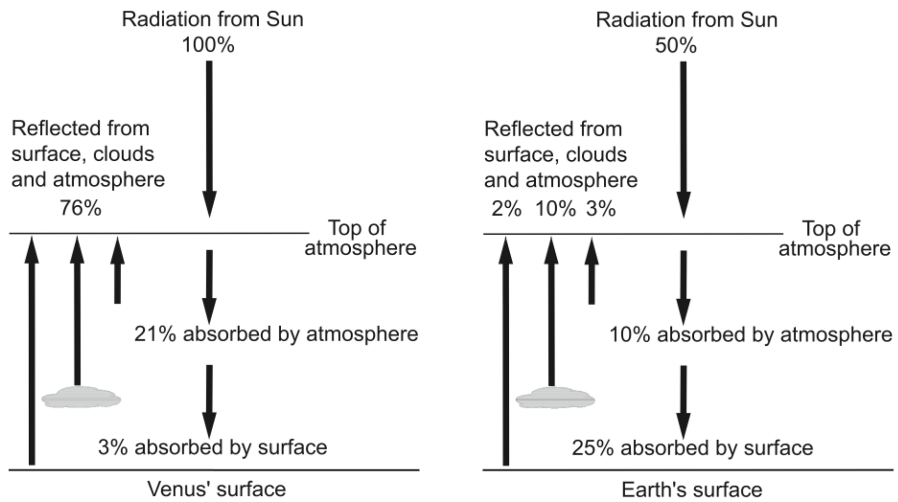
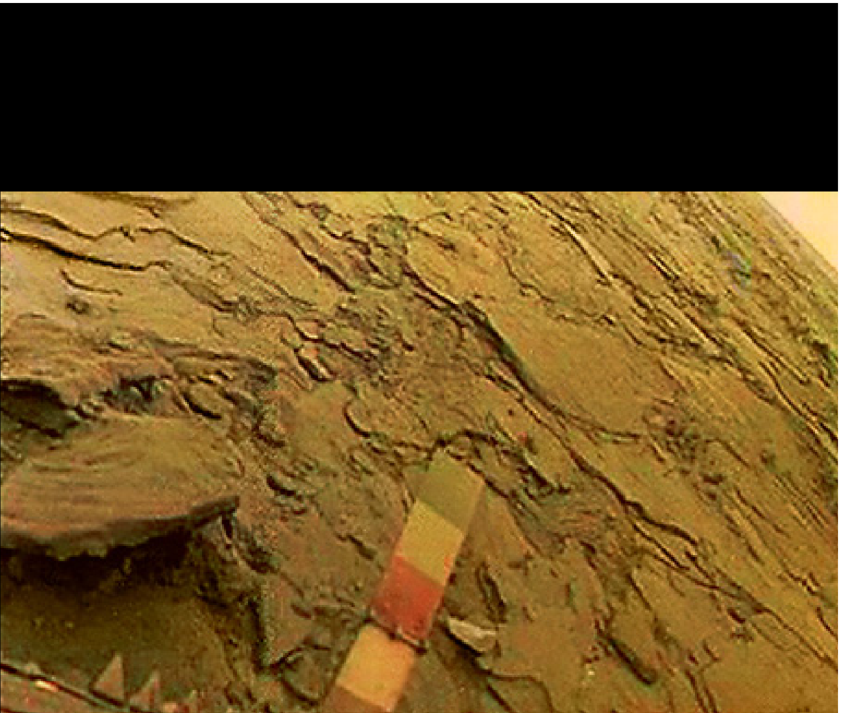
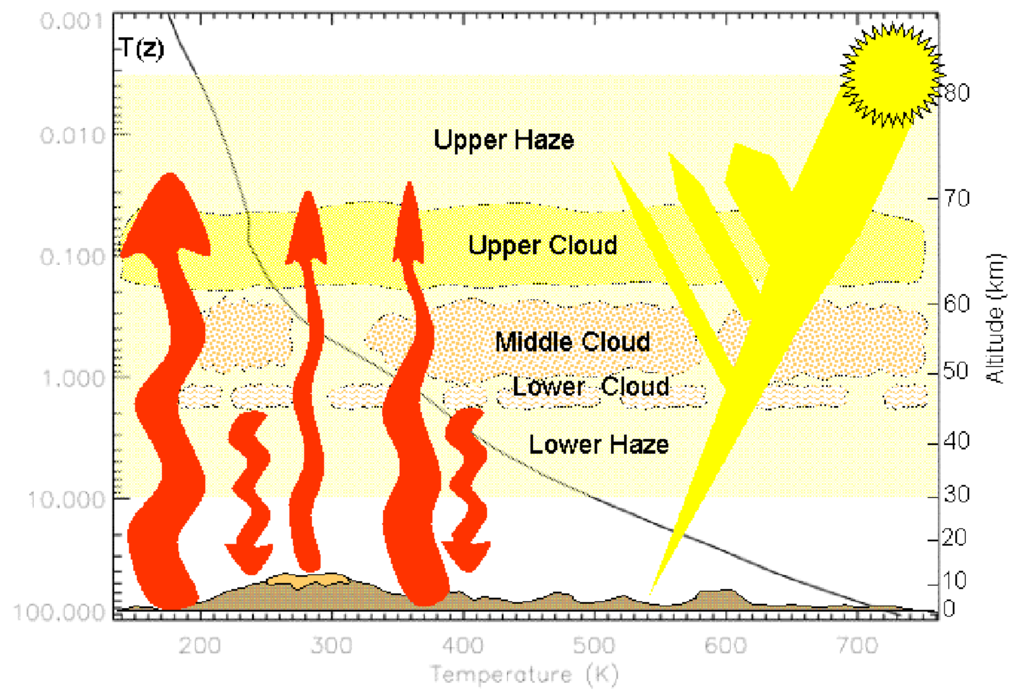
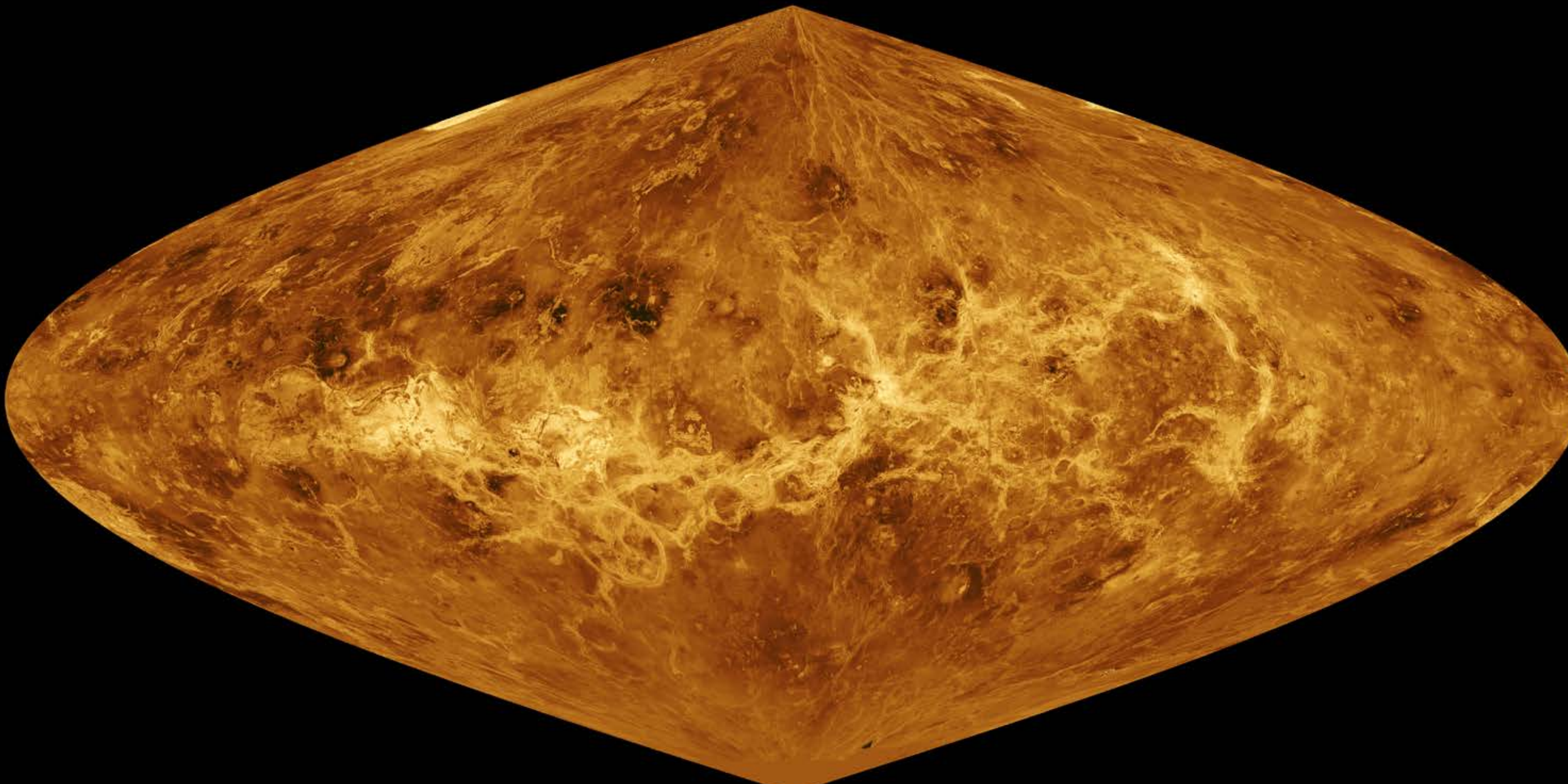


Figure 4. The different components of the radiative energy budgets of Venus and Earth are shown as planet-wide averages, taking the solar irradiance at Venus as 100% and Earth as half that. (Actually, the insolation at Earth relative to that at Venus varies between 50% and 55% when the orbital eccentricities of 0.0167 and 0.007, respectively, are taken into account.)





Magellan: The Surface of Venus

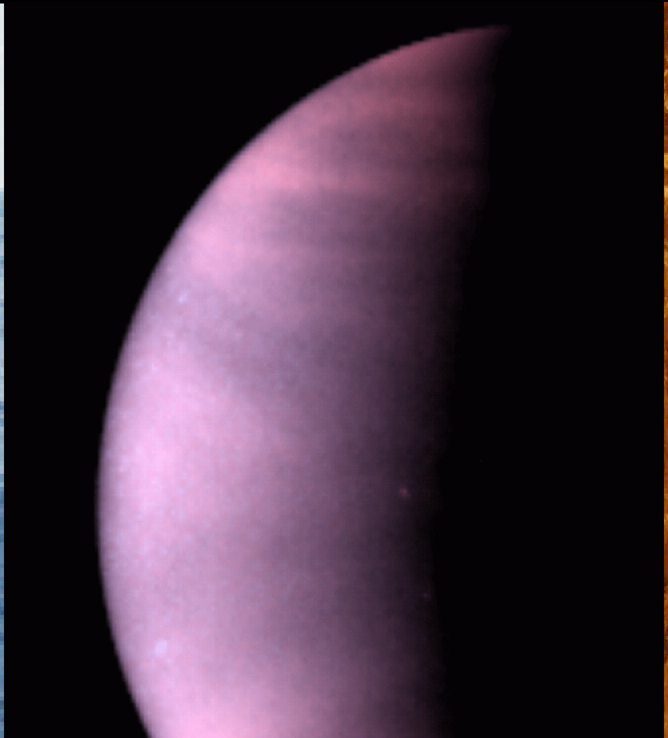


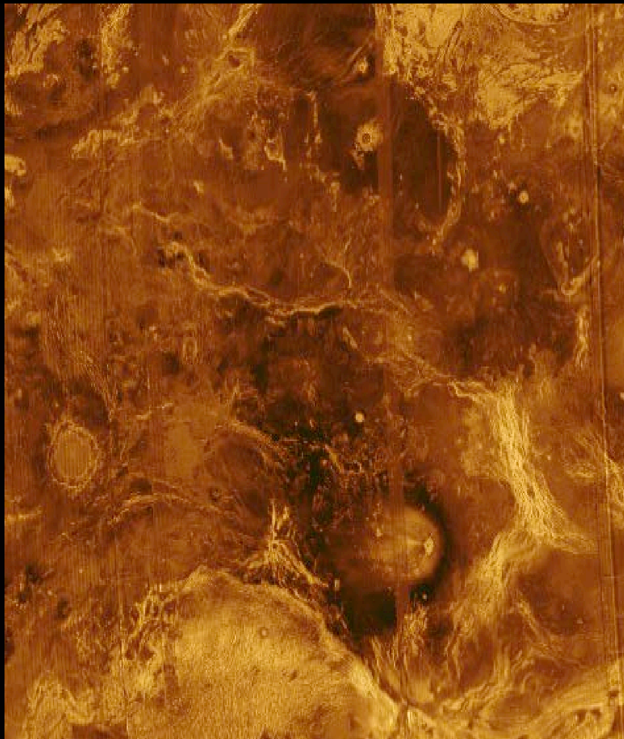
Venus

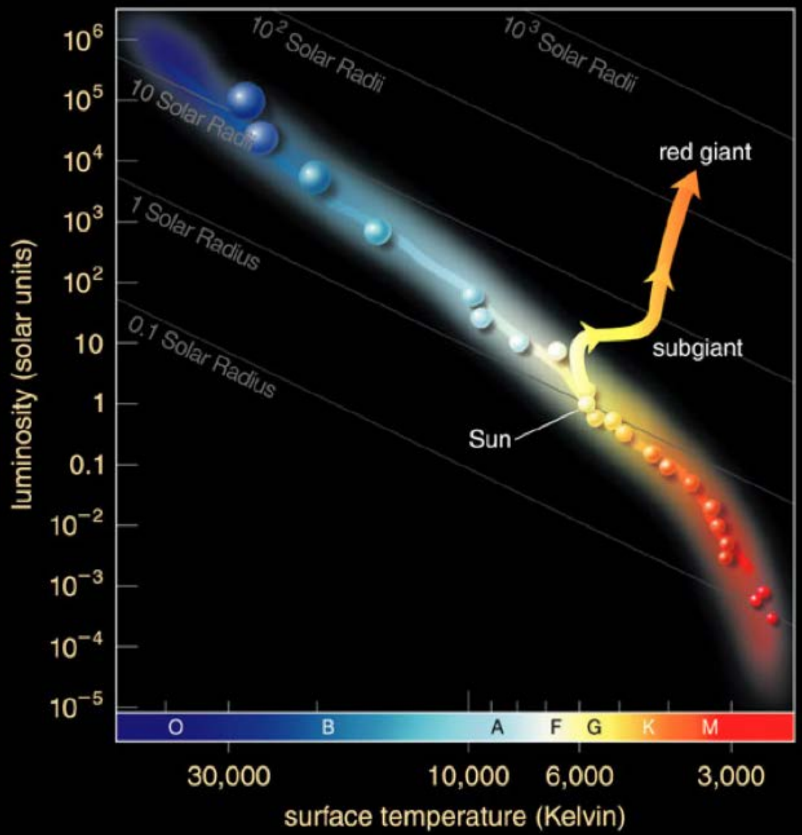
Uncertainties in longevity of an early Venus ocean are very large.

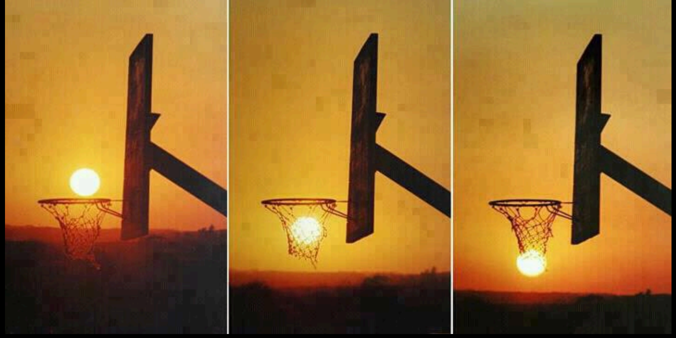
- **Clouds excluded from published models**.
- No cloud feedback which, qualitatively, is expected to stabilize surface temperatures against rising solar flux, and therefore extend the lifetime of the moist greenhouse.

- Cloud feedback may have extended the longevity of Venus oceans to 2 GY (Grinspoon & Bullock, 2007)

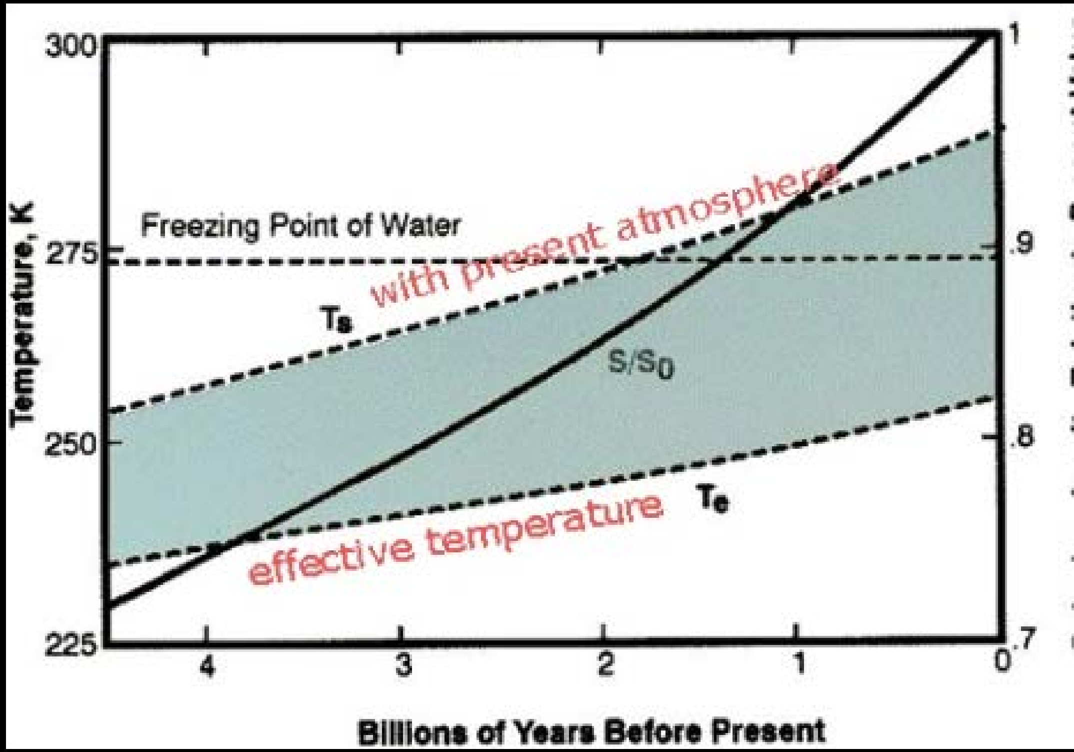








The Faint Young Sun

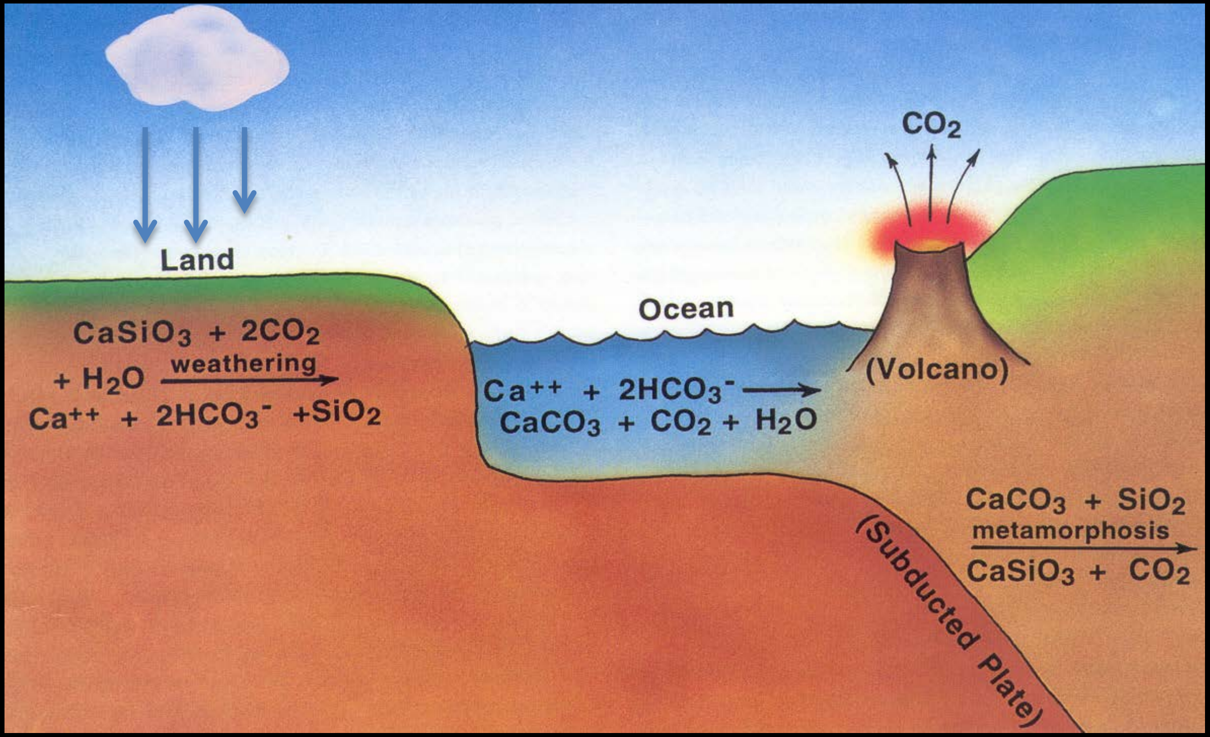


Greenhouse effect was stronger.
Atmosphere must have evolved.
CO_2? Biogenic CH_4?

Similar origins and early environments

Persistence of a habitable planetary environment over cosmological timescales may be much more rare than conditions for the origin of life.

Carbonate-silicate cycle is a climate thermostat.

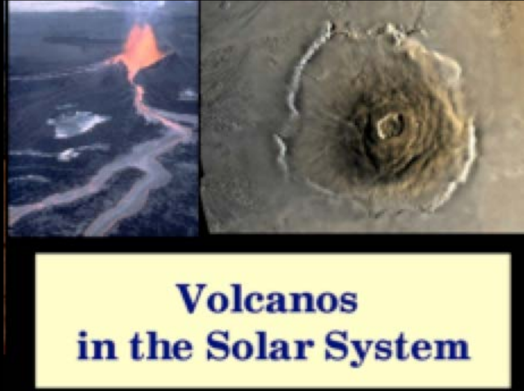


The same processes occurred early on Venus and Mars, but

Venus: no liquid water, no silicate weathering, volcanic CO_2 ends up in atmosphere.

Mars: most volcanism died out early, no CO_2 source, CO_2 lost to space.

Water loss from Venus, Atmospheric Loss from Mars began the divergent journeys.



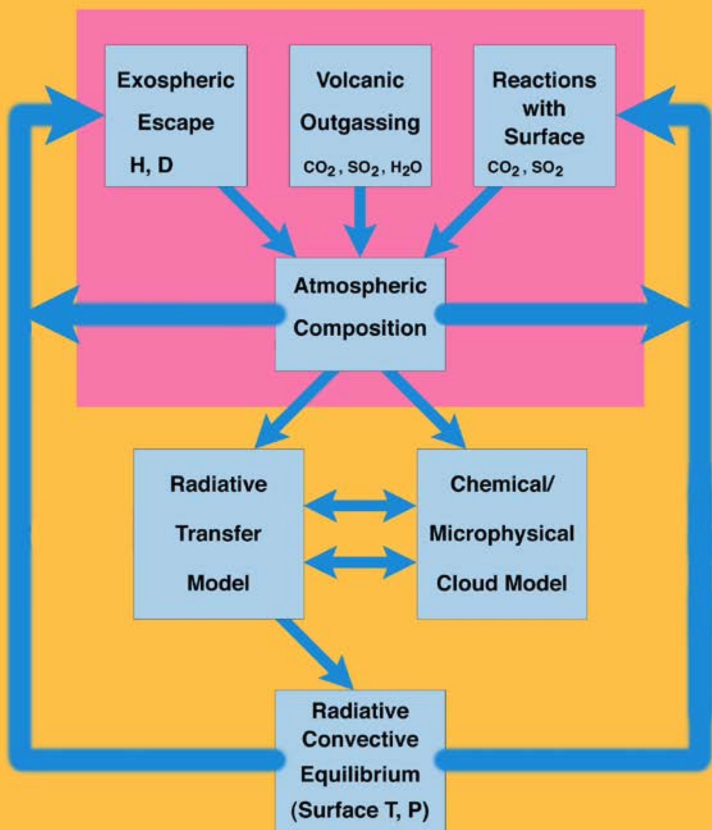
Each planet developed its own modes of volcano-climate interactions which further developed their idiosyncratic characters…

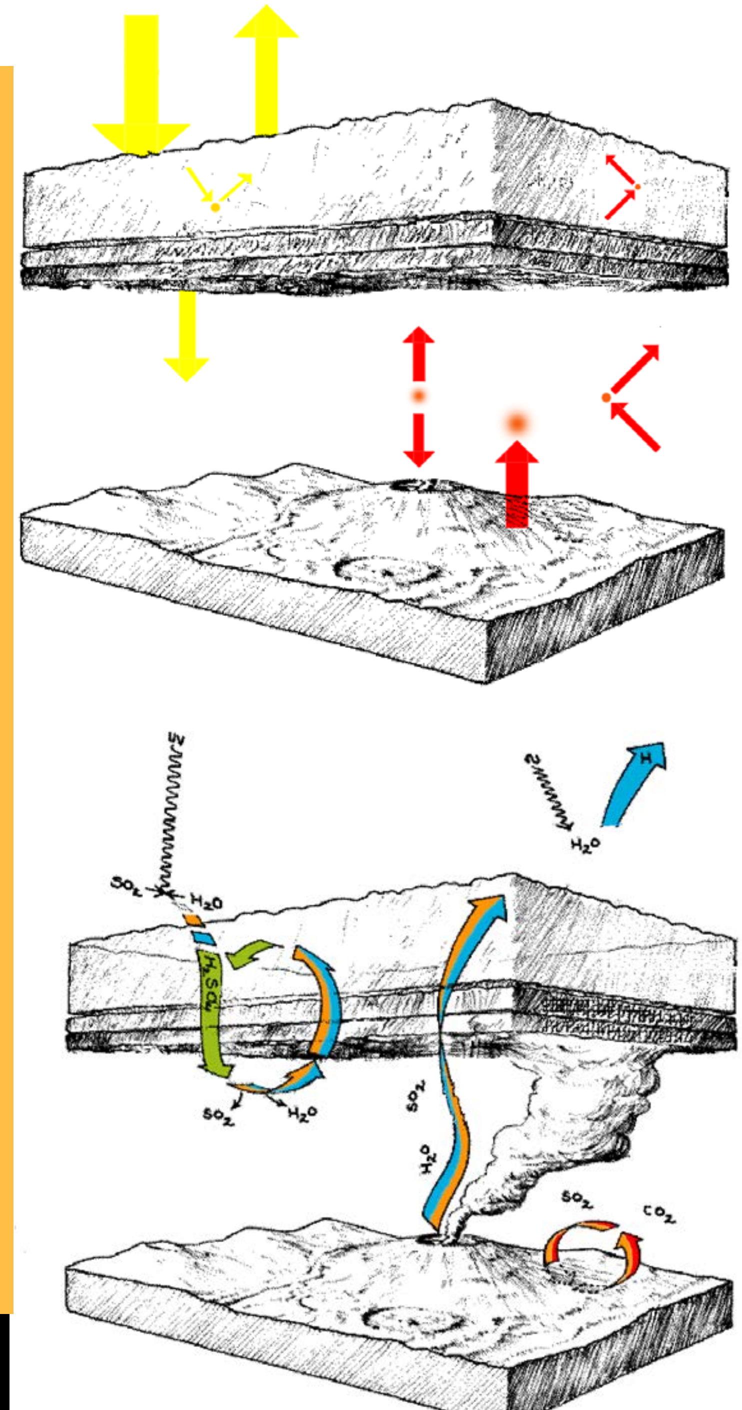
- Earth
  - Small eruptions cool the Earth
  - Large eruptions warm the Earth, required for recovering from snowball or ice-age
  - Hadean may have featured sulfuric acid venus-like clouds (mass-independent S fractionation)

- Mars
  - Large eruptions kept a dense CO_2 atmosphere from collapsing (carbonates not stable in acid waters.)
  - Sulfuric acid clouds may have engulfed Mars during the Noachian
  - Ancient sulfates are prima facie evidence

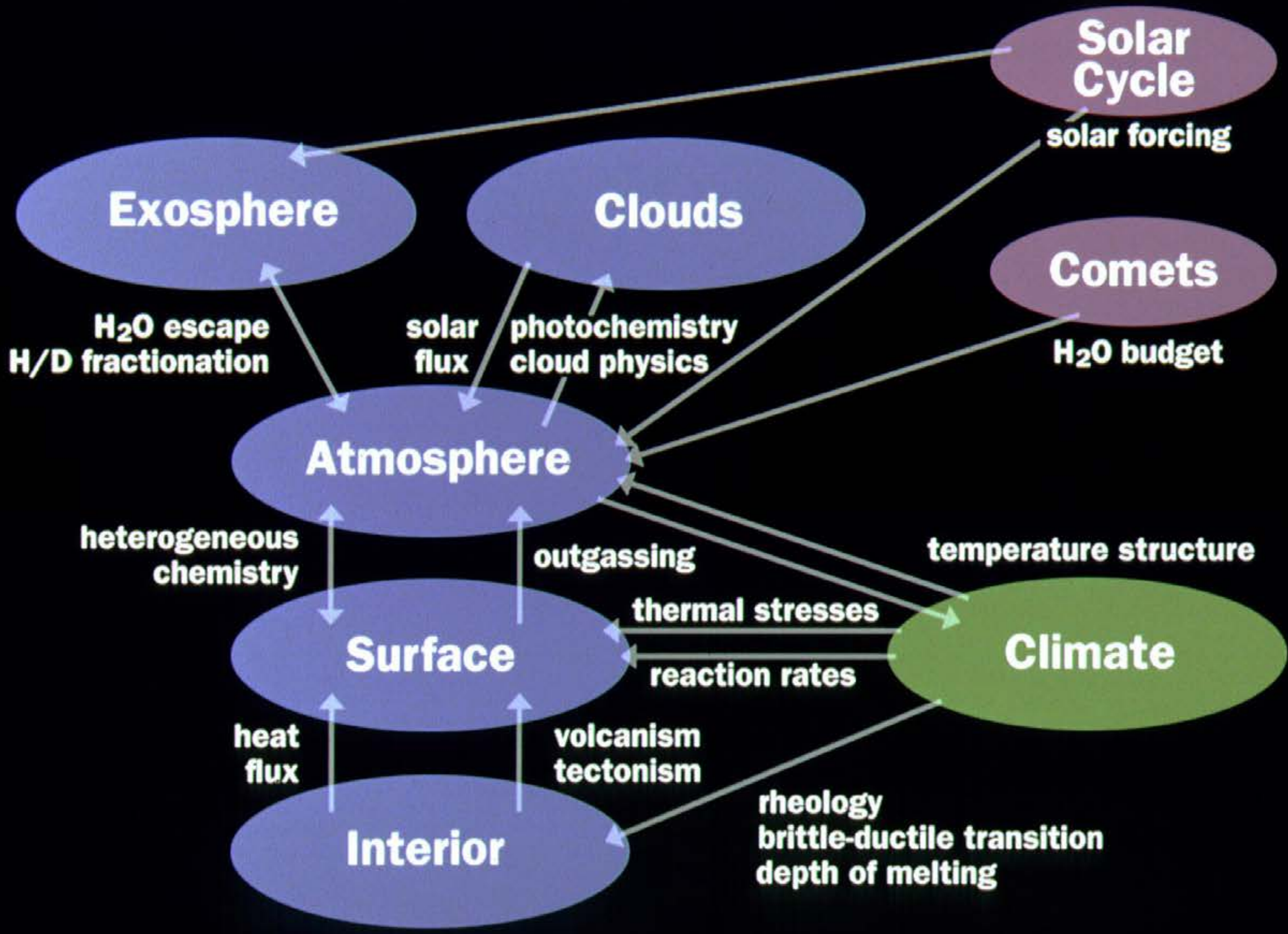
- Venus
  - Present-day volcanism necessary to sustain clouds
  - Large thermal and chemical pulse due to resurfacing propagated into lithosphere and created ridged plains
  - Outgassing warming and feedback with interior melting may influence episodic volcanism or tectonics.
  - Volcanism as ‘one-way’ carbon cycle needed to replenish massive CO_2 atmosphere after plate tectonics ceased

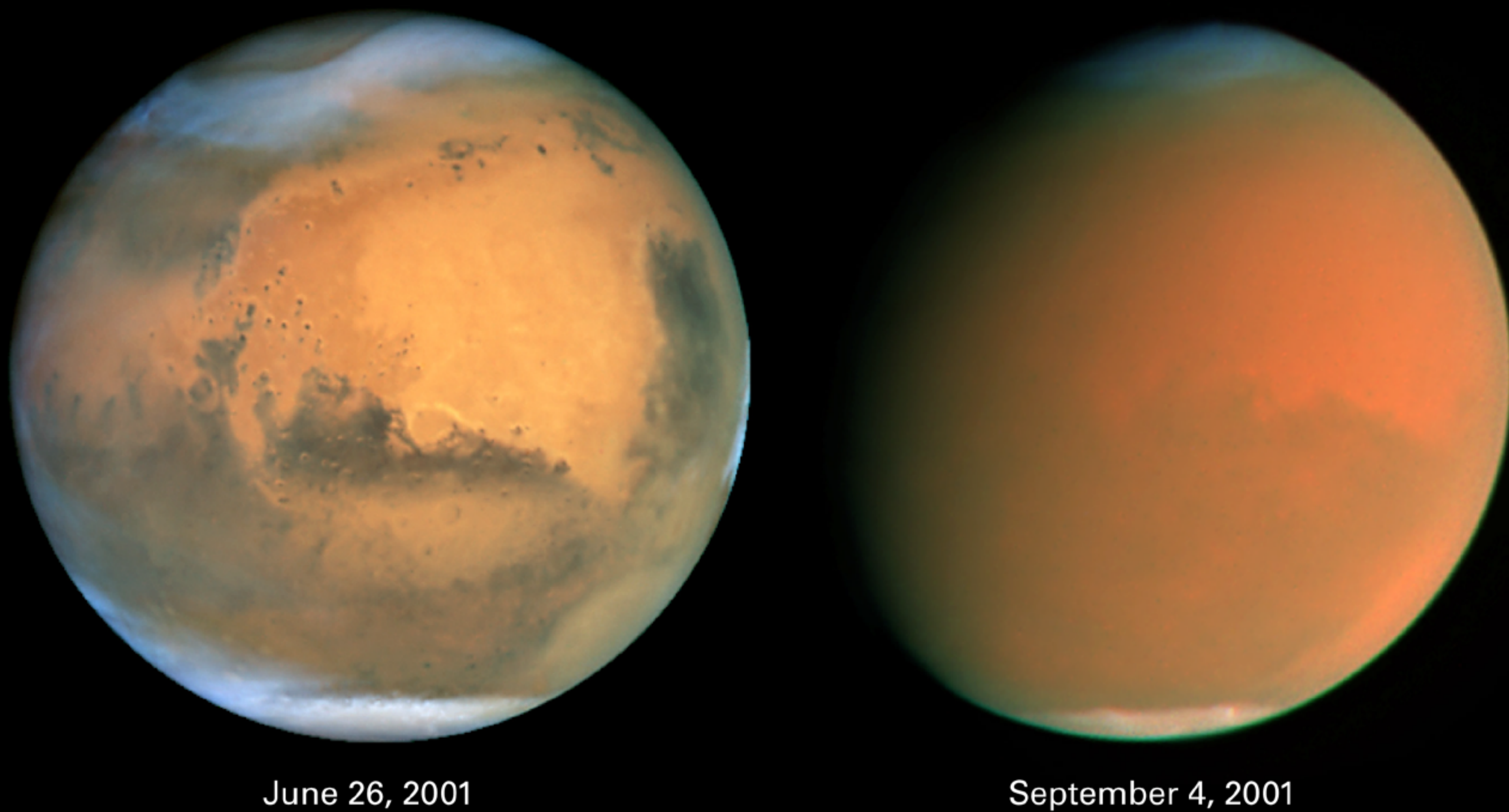
Venus Climate Model





Venus System Science





Mars • Global Dust Storm
Hubble Space Telescope • WFPC2

NASA, J. Bell (Cornell University), M. Wolff (SSI), and the Hubble Heritage Team (STScI/AURA) • STScI-PRC01-31

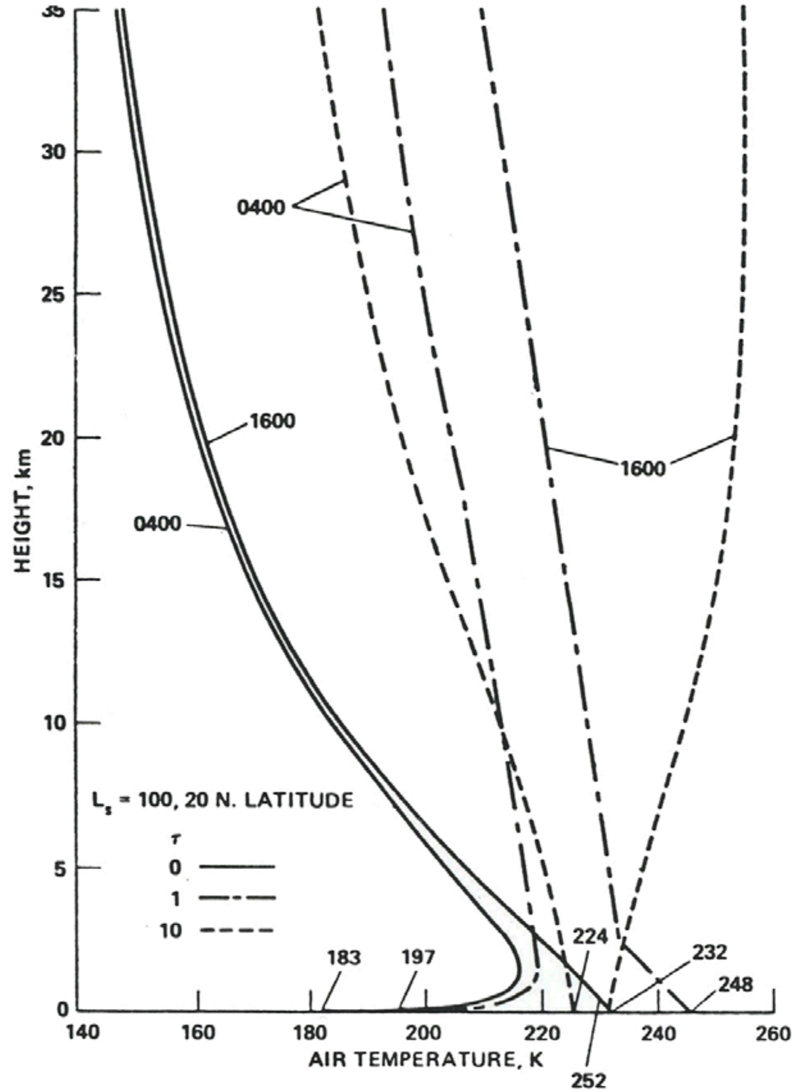
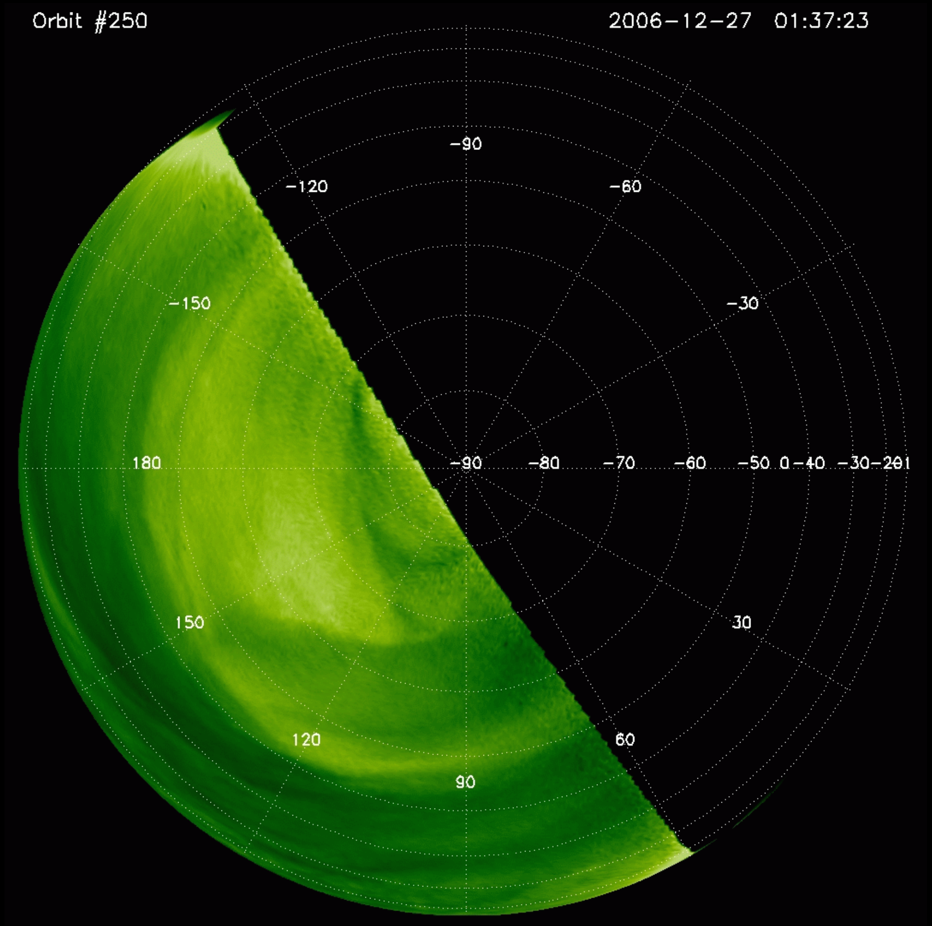


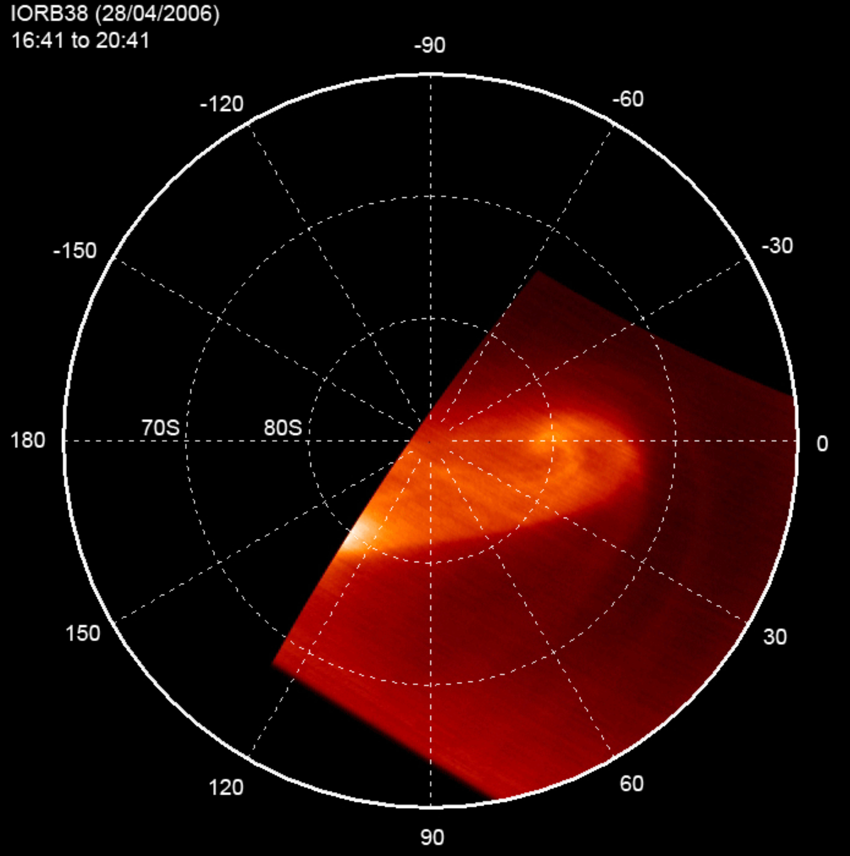
Figure 3.2. Temperature as a function of altitude for different values of the optical depth τ. For each optical depth separate curves are shown for two times of day. With a clear atmosphere ($\tau = 0$) temperature fluctuations are restricted to near the surface. As the atmosphere becomes loaded with dust, the vertical profile becomes more isothermal, daily fluctuations high in the atmosphere are amplified, and the oscillations near the surface are reduced. (From Pollack et al. 1979, copyrighted by the American Geophysical Union.)

Polar vortex rotation

P ~ 2.8 days

P ~ 2.5 days





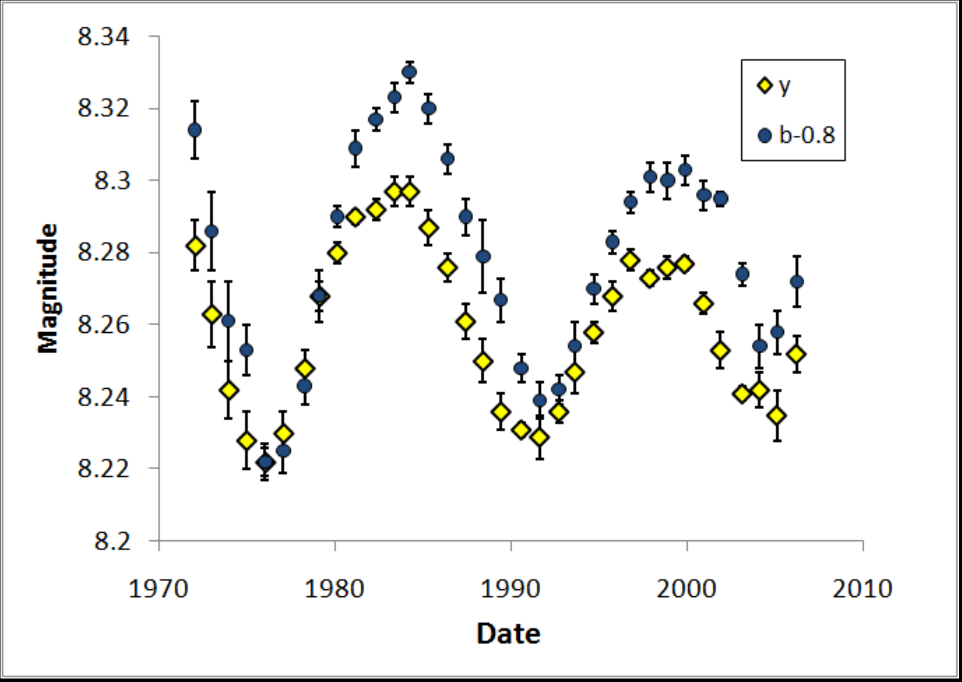
UV / Titov & VMC Team/

Thermal IR / Wilson & VIRTIS Team/

Polar Vortex Rotation Movie

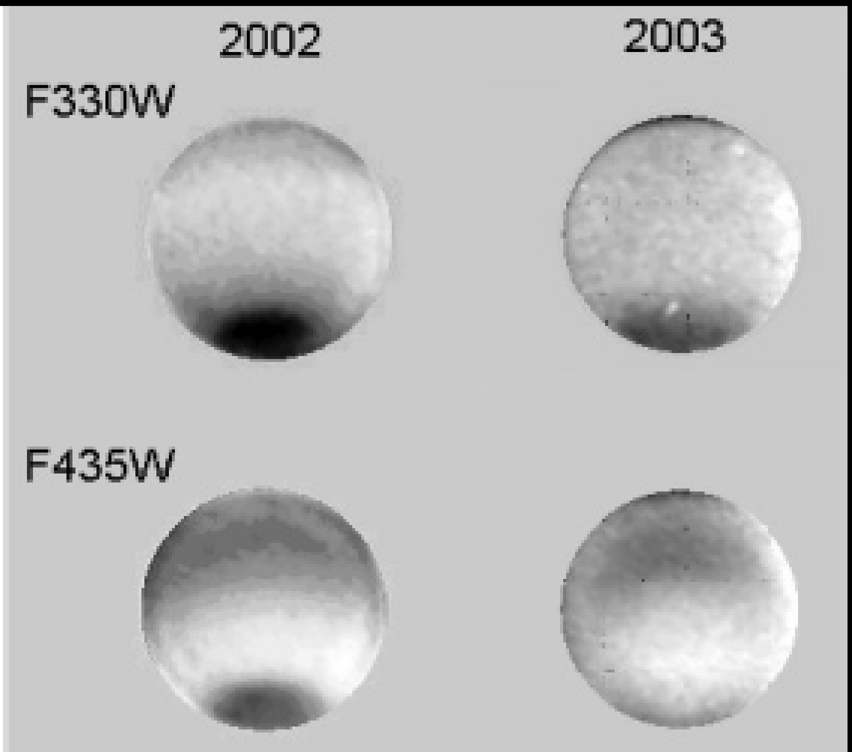
Titan's Surface-Atmosphere Interactions give many similarities with the terrestrial planets : Titan is an outstanding laboratory for comparative planetology and climatology.

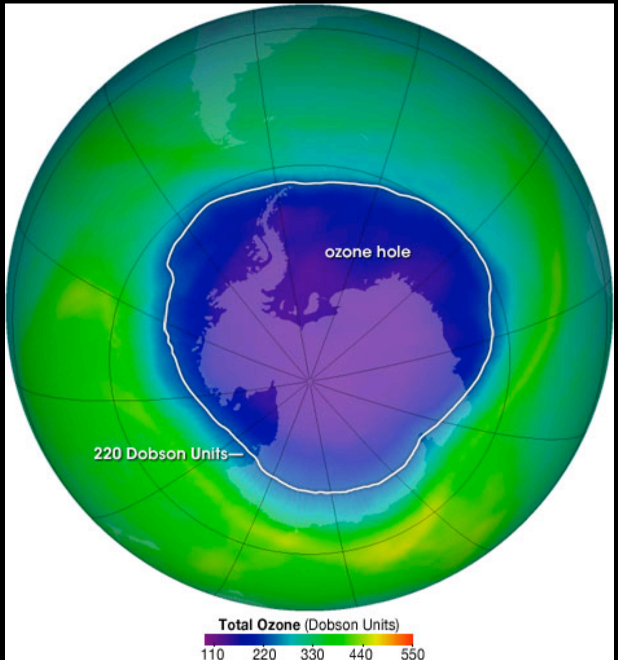
An active hydrology like Earth's, atmospheric dynamics like Venus and Mars, seasons like Earth and Mars, etc.

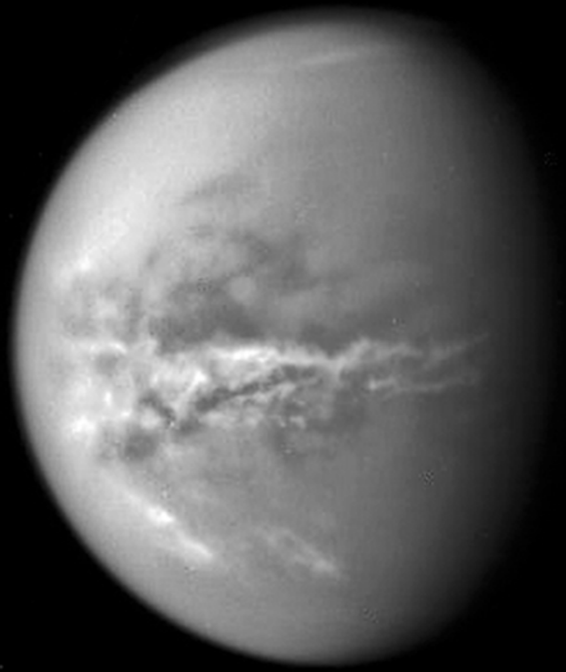


Changes on Titan now observed for over a Titan year (Lockwood and Thompson, 2009). Seasons do not repeat - interannual variability!

North-South haze asymmetry, plus polar hood structure (cf Earth's ozone hole)



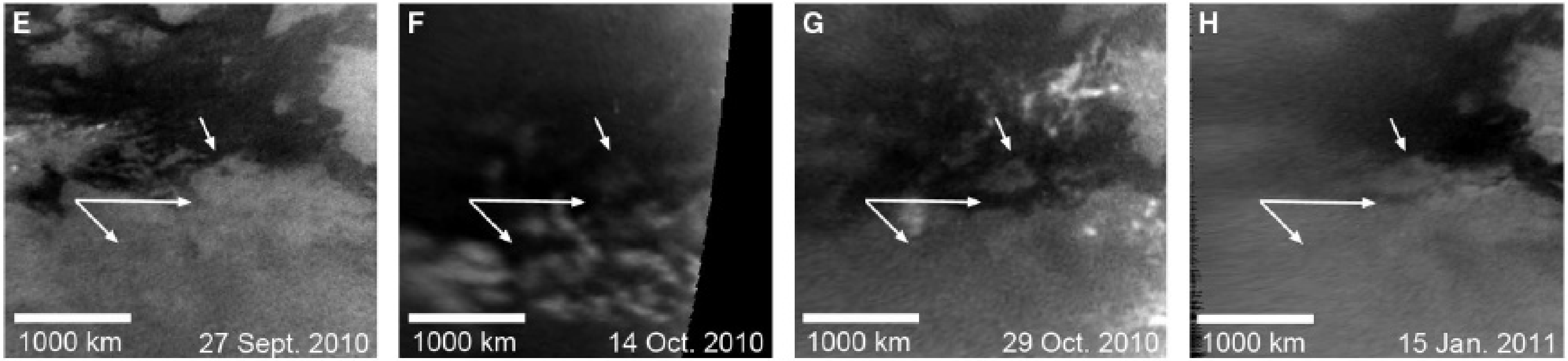




Turtle et al., 2011

Cassini has observed two events of temporary surface darkening associated with cloud activity; these are best interpreted as rain events. In 2004 Arrakis Planitia (34,000km^2, 80^{o}S) and in 2010 Concordia Regio (510,000km^2, 20^{o}S) – below.

Together, these represent ~0.7% of Titan's surface, in 6 years. Crudely, 100% of the surface would then be rained on in 6*100/0.7~860 years.



Atmosphere as a relaxation oscillator

Rainfall event instantly dehumidifies local atmosphere. Re-humidification takes place at constant rate. Once humidity reaches some threshold, rainfall occurs again, etc.

On Earth, ~2cm precipitable water vapor. 100cm/year average rainfall/evaporation. So get rain of some cm every ~2/100 yr, or ~1/week.

On Titan, methane column is ~3% * 1.5bar/1.35 = 3600 kg/m2, or ~10m of liquid. But only ~1cm per Earth year evaporation, thus ~1000 years between (big) events.

You can wave your hands about meteorological details, regional variation etc., but this is most of what you need to know.

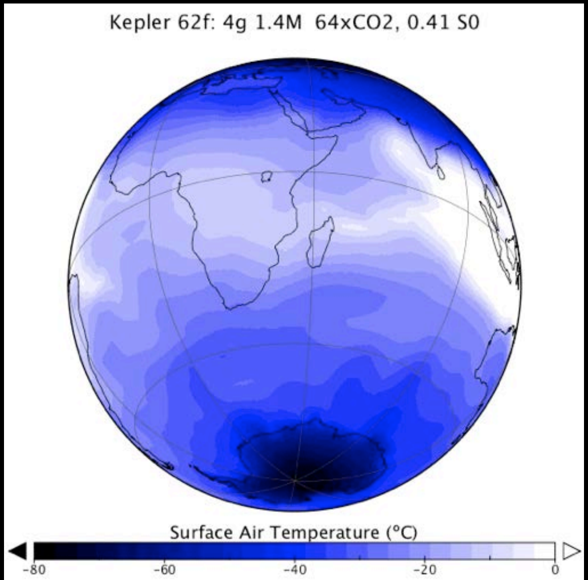
Lorenz et al., Convective Plumes and the Scarcity of Titan's Clouds, GRL, 2005

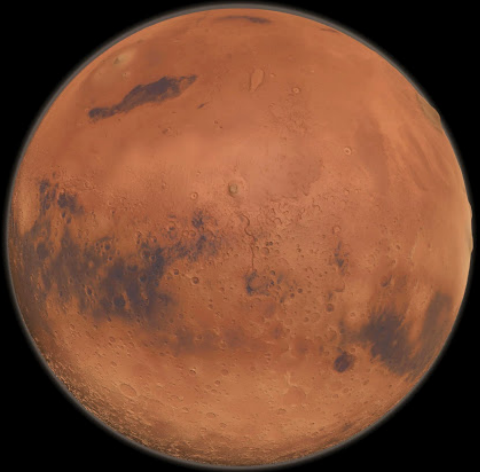
Titan's hydrology today may be caricatured as an extreme-greenhouse version of Earth's - slow forcing, large atmospheric storage. Methane inventory likely variable over geologic time. Astronomical (Croll-Milankovich) origin of lake distribution.

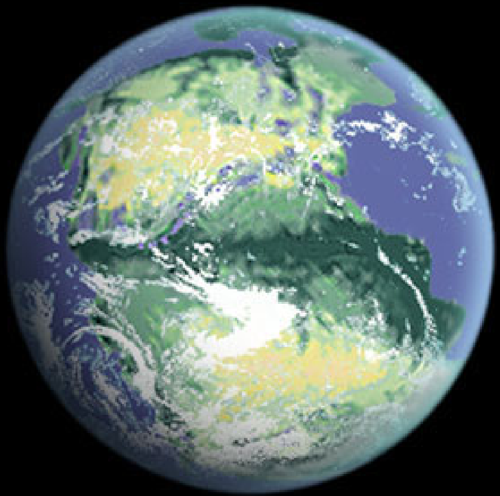
The hydrology is observable in action – convecting clouds, wetted/darkened surfaces followed by drying. Polar seas. Widespread valleys evidence of fluvial erosion. Evidence of solution erosion and evaporites ; possible indications of wetter epochs.

Ongoing seasonal change expected to be dramatic as we enter northern summer.
Titan begs further in-situ and orbital study !

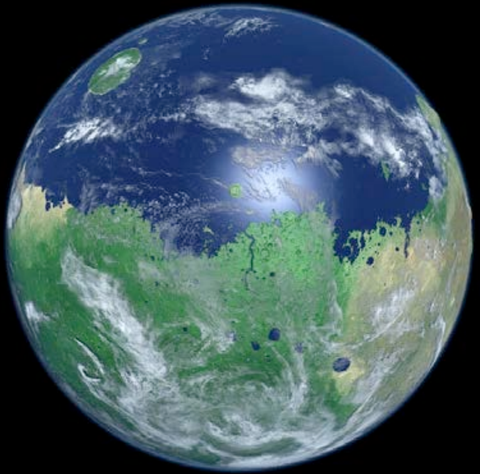
Earth, Mars and beyond!







GISS Generalized Rocky ExoPlanet (GREP) GCM



GREP: Formulation and Scope

Use GISS ModelE framework for climate modeling

- Extensively used for Earth modern + paleo-climate
- Expansion of functionality to benefit current Earth modeling
- Relax assumptions tied to present day conditions

Vary gravity, planet radius & mass, atmos. pressure, orbit, and solar/stellar constant

Tests: Mars-sized Earth, “Kepler-62f” simulations

In development:

- Improved RTM for high GHG, wider range of absorbers
- Generalized surface properties (type, altitude, roughness, albedo)
- Extended range of condensable constituents

Initial funding focused on early Martian climate

Anticipated expansion for Venus, Titan, exoplanets

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A

For 4 billion years Earth has been evolving under the influence of of forces that have apparently not been greatly at work on our neighboring planets.

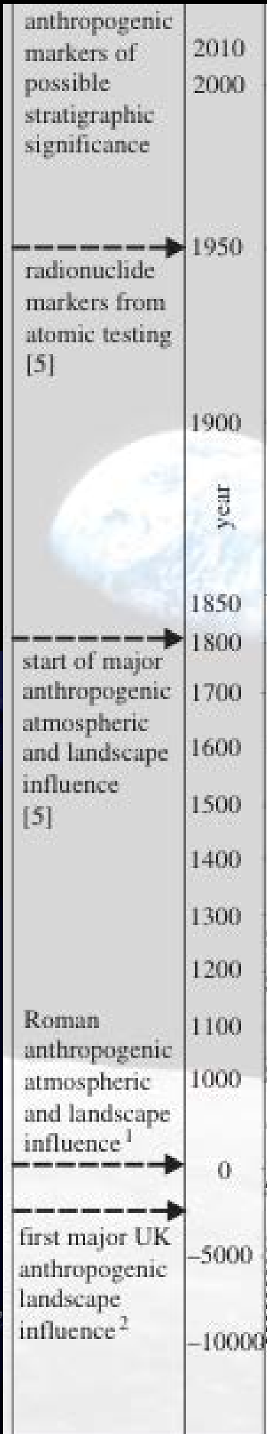
Colin Goldblatt at Exoclimes2:

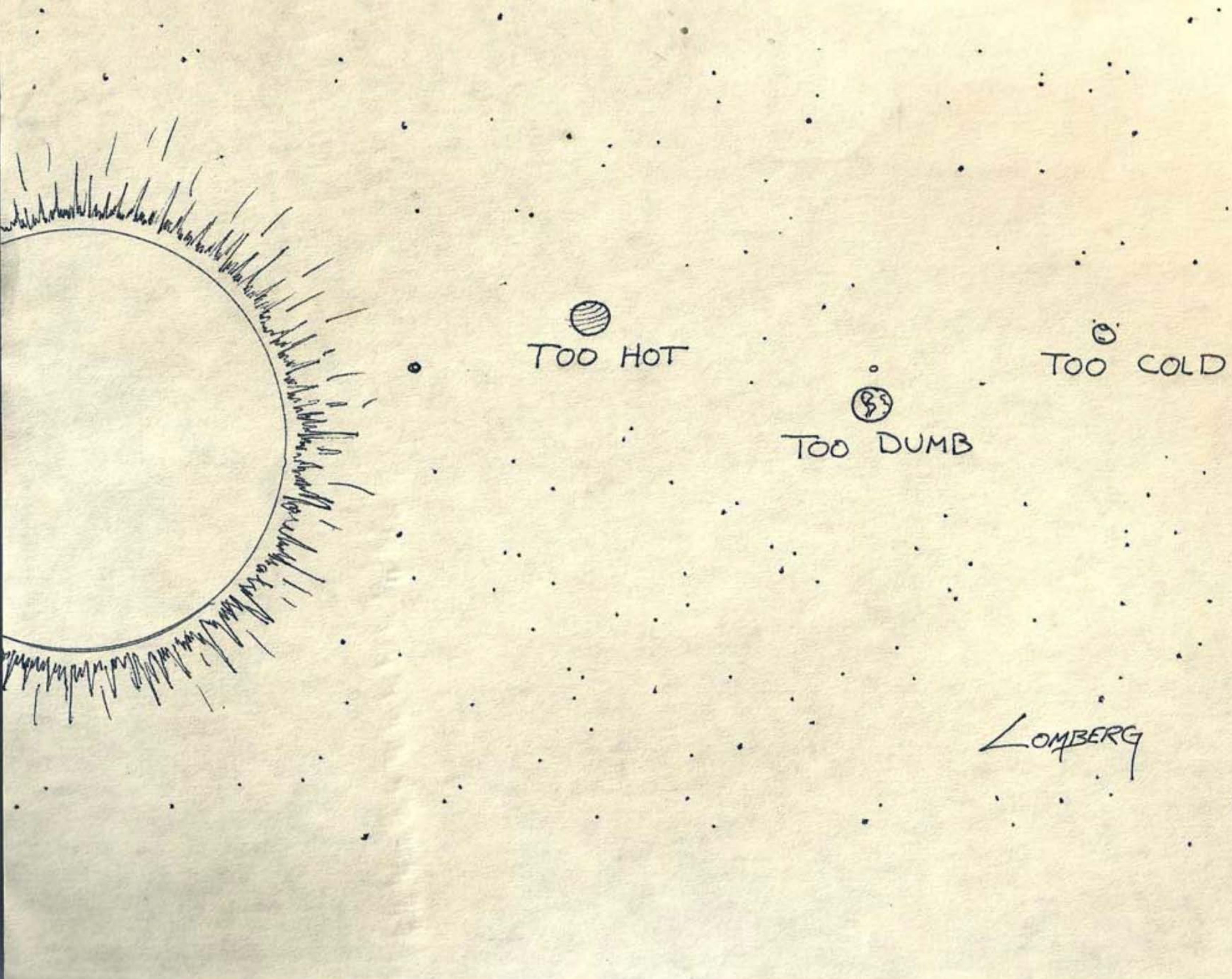
> "The defining characteristic of Earth is planetary scale life.
> Earth teaches us that habitability and inhabitance are inseparable."

More recently Earth has been under the influence of a new type of geological force – the global activities of humanity, defining **the anthropocene.**

Time scale = 10s to 10^4 y.

but, has altered the planet most extensively in just the time period that we have been able to gather global data sets about the Earth and begin to do comparative planetology as well.





"Intelligent Life in the Universe" by Jon Lomberg

COMPARATIVE PLANETARY CLIMATOLOGY

Science Connections

•aerosol microphysics and radiative properties.
•cloud morphologies and climate forcings.
•clouds & radiative balance
•photochemistry of Cl, O, and S .
•mesoscale and vortex dynamics.
•radiative transfer with variable trace gases.
•atmospheric responses to short and long term solar forcing.
•obliquity cycles and climate histories.
•responses to solar cycle.
•responses to long-term solar evolution, constraints on solar climate forcing.
•volcano-climate interactions.
•space weather environments and the upper atmospheres.