Solar Impact on Earth Climate

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- Source of energy for the Earth System /planets

What are the sources of variation in solar radiation?
- Solar activity
- Orbital variations

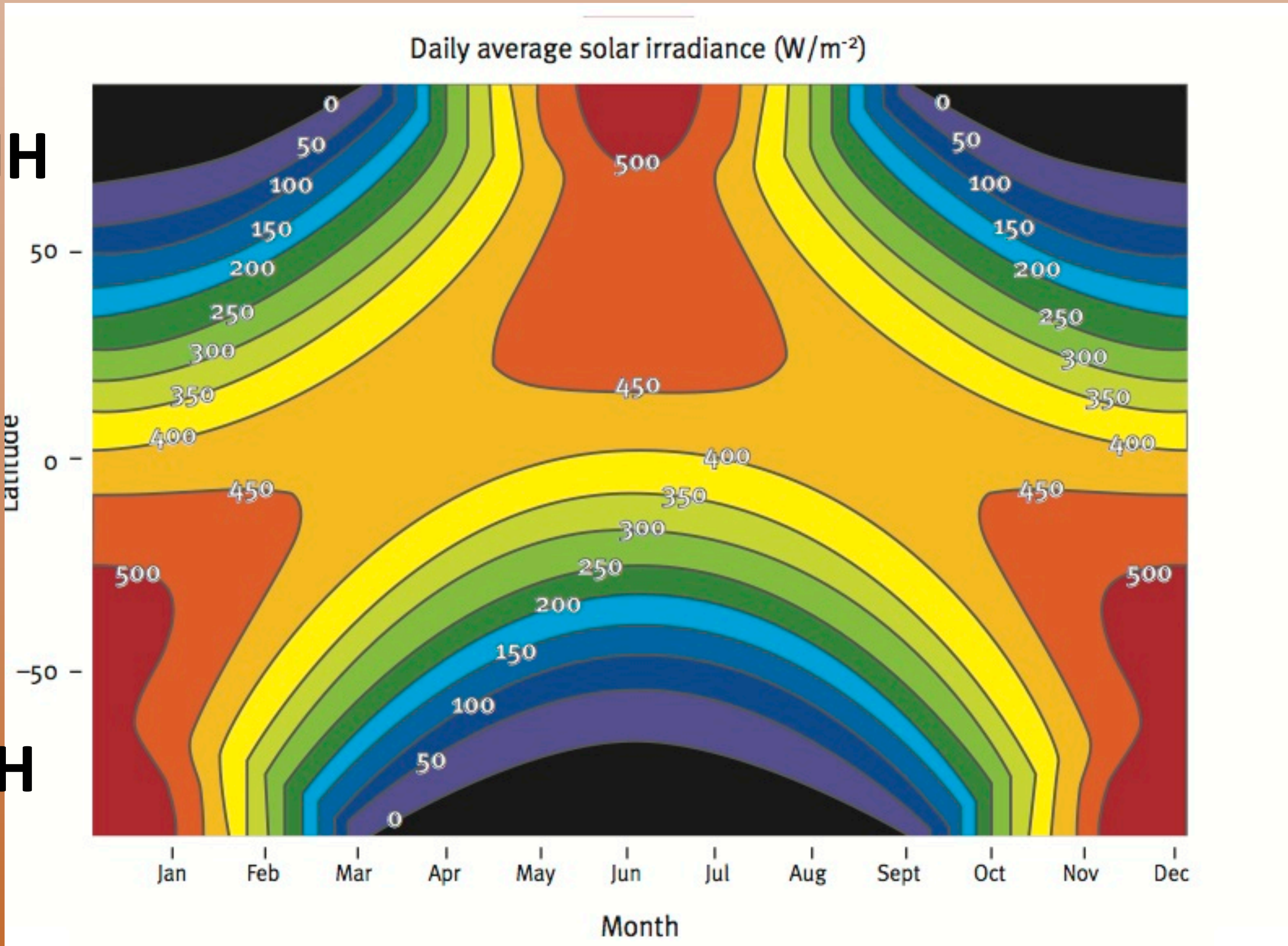
Do these changes affect the climate?

Do we understand the processes involved?

Gray et al, Rev Geophys, 2010 and Haigh et al.

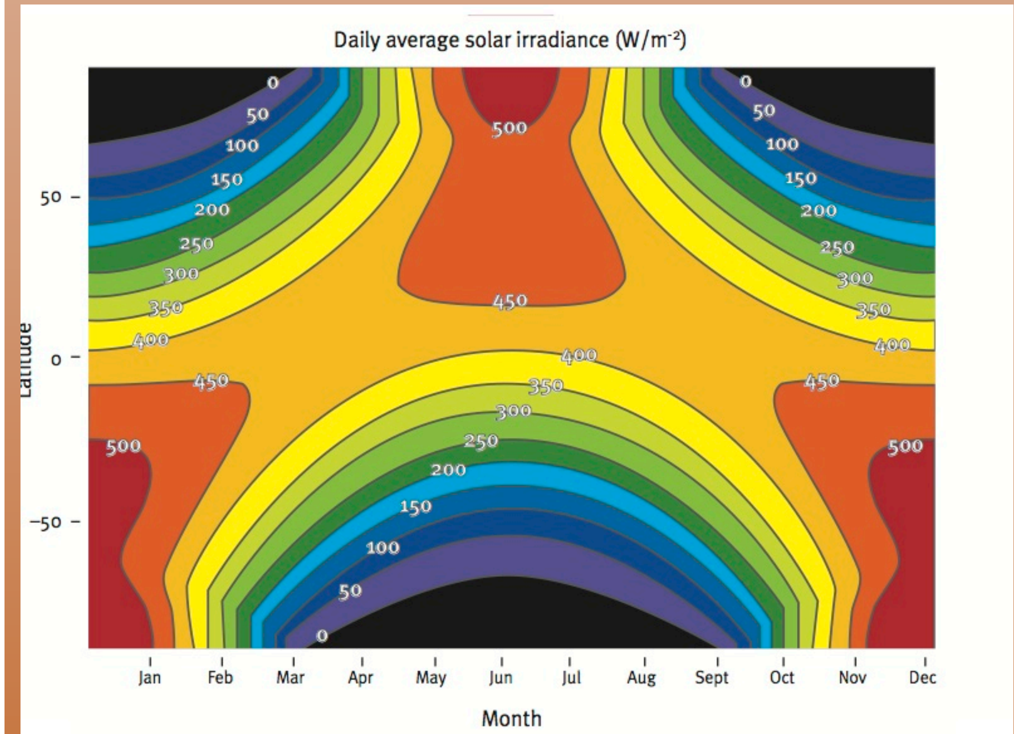
Distribution of Solar radiation at TOA

NH



SH

Distribution of Solar radiation at TOA



Mean E-S distance:
1.496 * 10^11 m (= AU)

Max E-S distance:
1.521 * 10^11 m (= 1.017 AU)

Min E-S distance:
1.471 * 10^11 m (= 0.983 AU)

Eccenricity = 0.0167

Tilt = 23°27’

Geometry

F = irradiance
Z= zenith angle
d=distance E-S
h=hour angle

$$F_{SW} = F_{SW}^{0} \cos(Z)$$

$$F_{SW}^{0} = S(d_m / d)^2$$

$$\cos Z = \sin\phi \sin\delta + \cos\phi \cos\delta \cos h$$

$$Q_0 = S(d_m / d)^2 \int_{sunrise}^{sunset} \cos(Z)\, dt$$

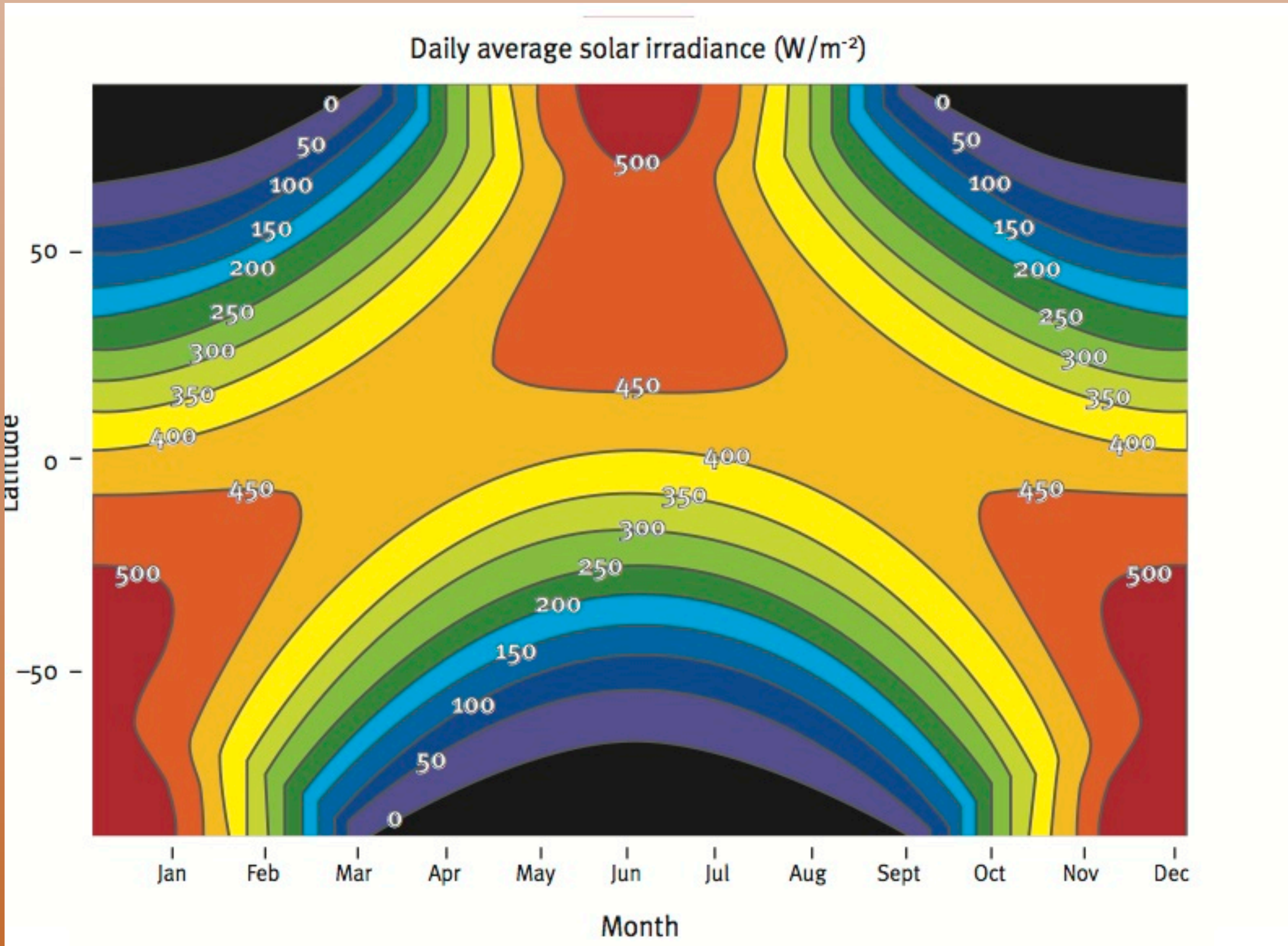
Total daily insolation

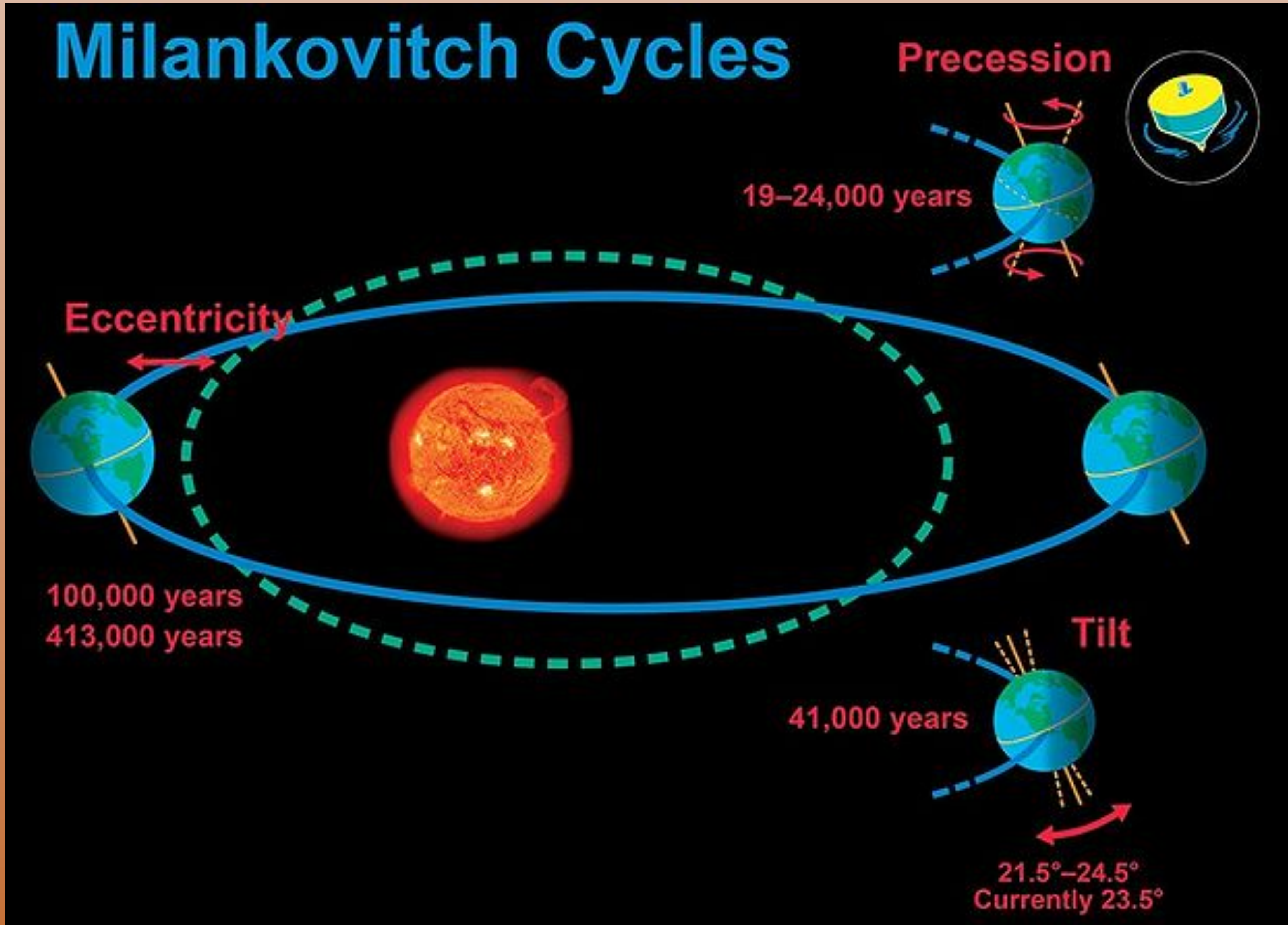
$$Q_0 = \frac{24}{\pi} S(d_m / d)^2 \left(\int_0^H \sin\phi \sin\delta\, dh + \int_0^H \cos\phi \cos\delta\, dh\right) =$$

$$\frac{24}{\pi} S(d_m / d)^2 (H \sin\phi \sin\delta + \cos\phi \cos\delta \sin h)$$

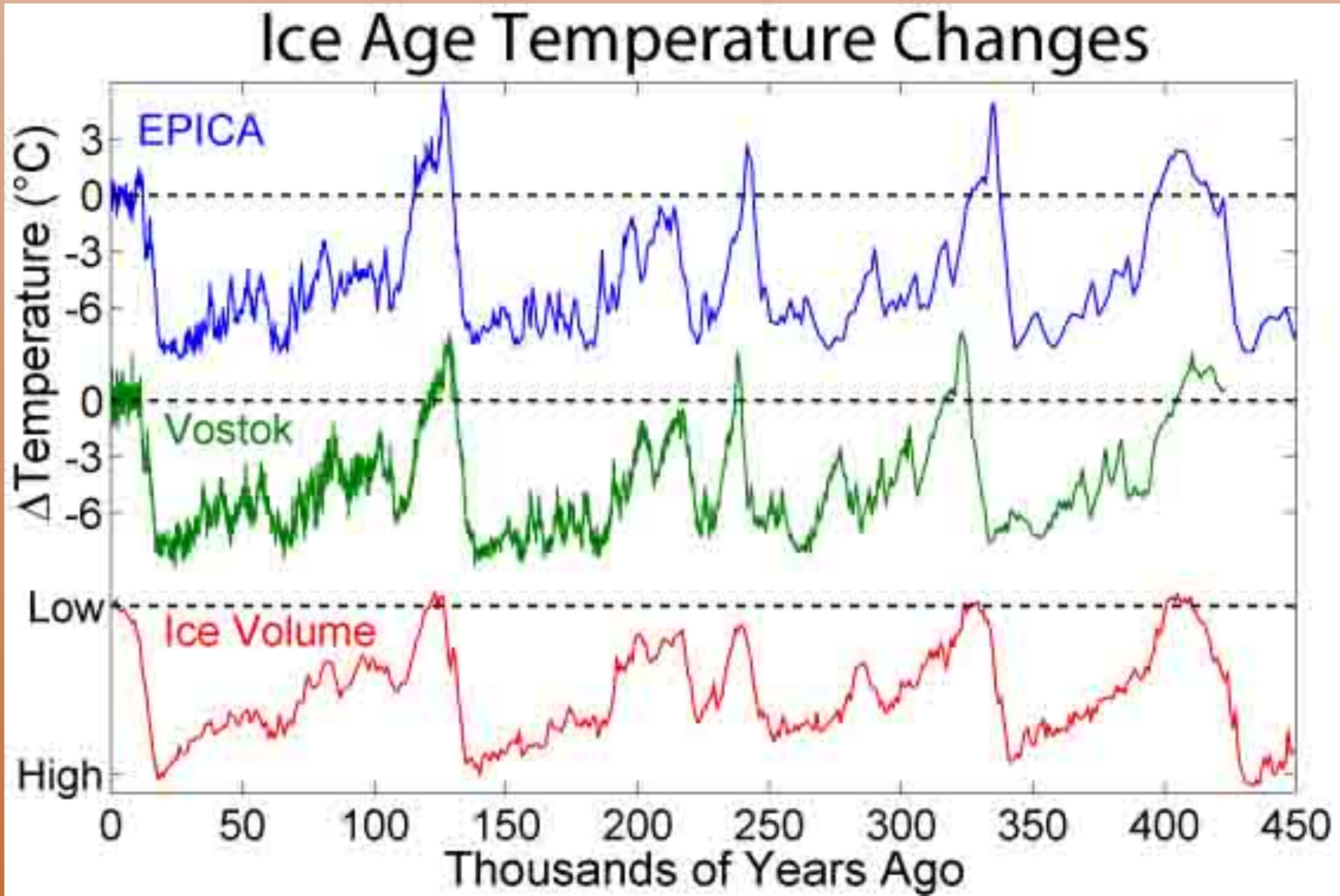
H=rotation_rate *(local_time-12)

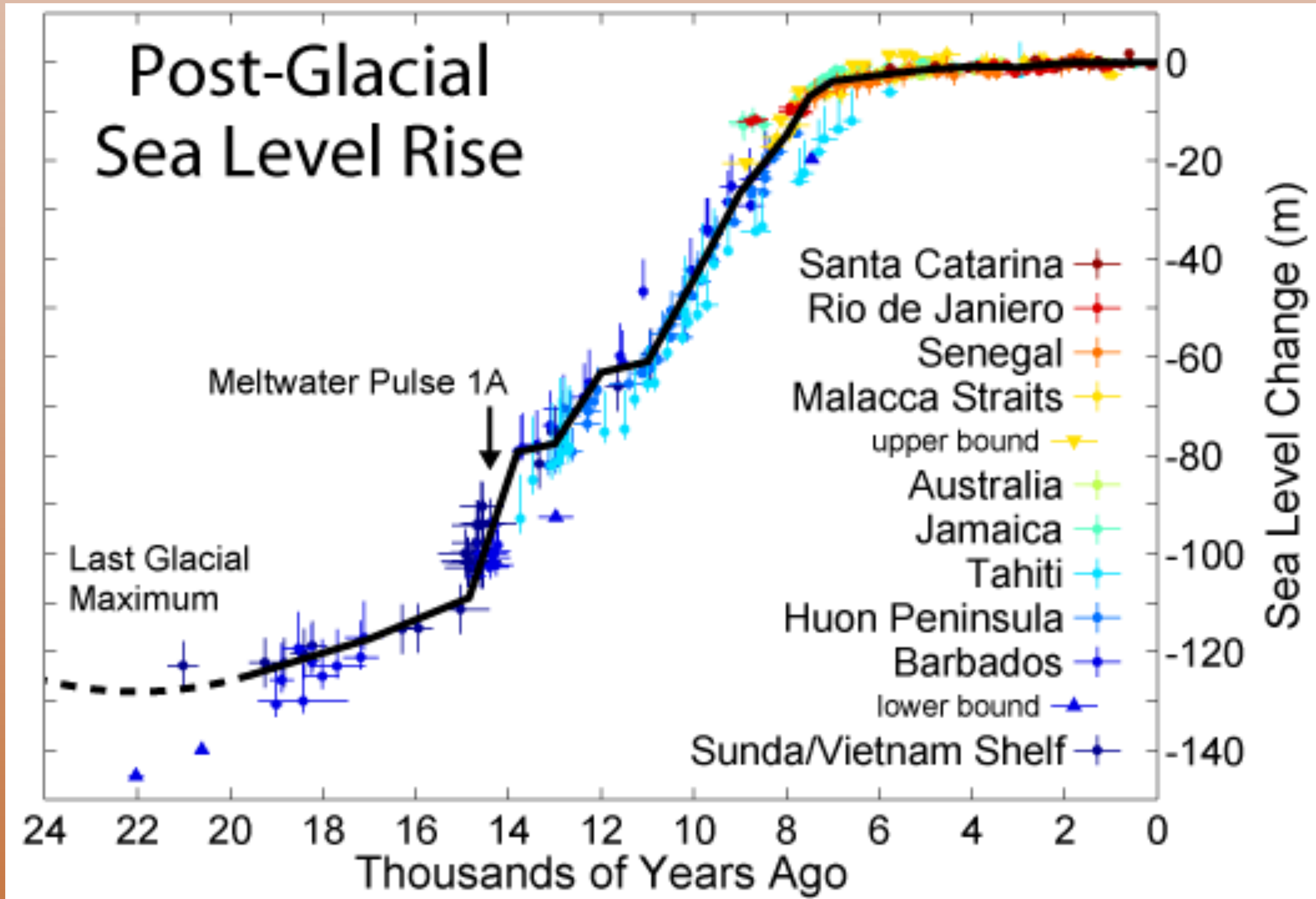
Distribution of Solar radiation at TOA




Milankovitch Cycles
Precession
19–24,000 years
Eccentricity
100,000 years
413,000 years
Tilt
41,000 years
21.5°–24.5°
Currently 23.5°

Paleoclimate proxies

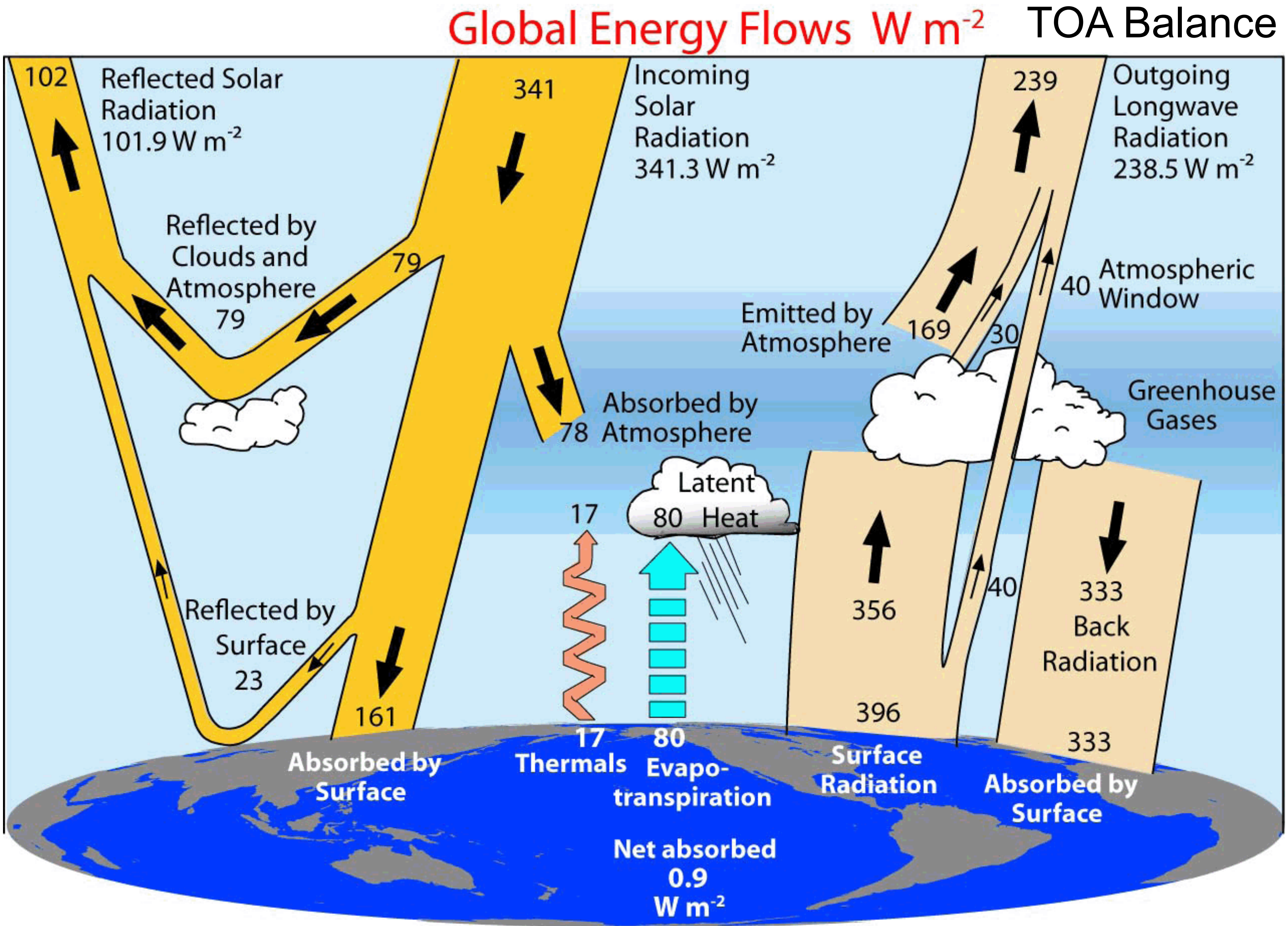




10 W/m**2 at the pole(deltaS)

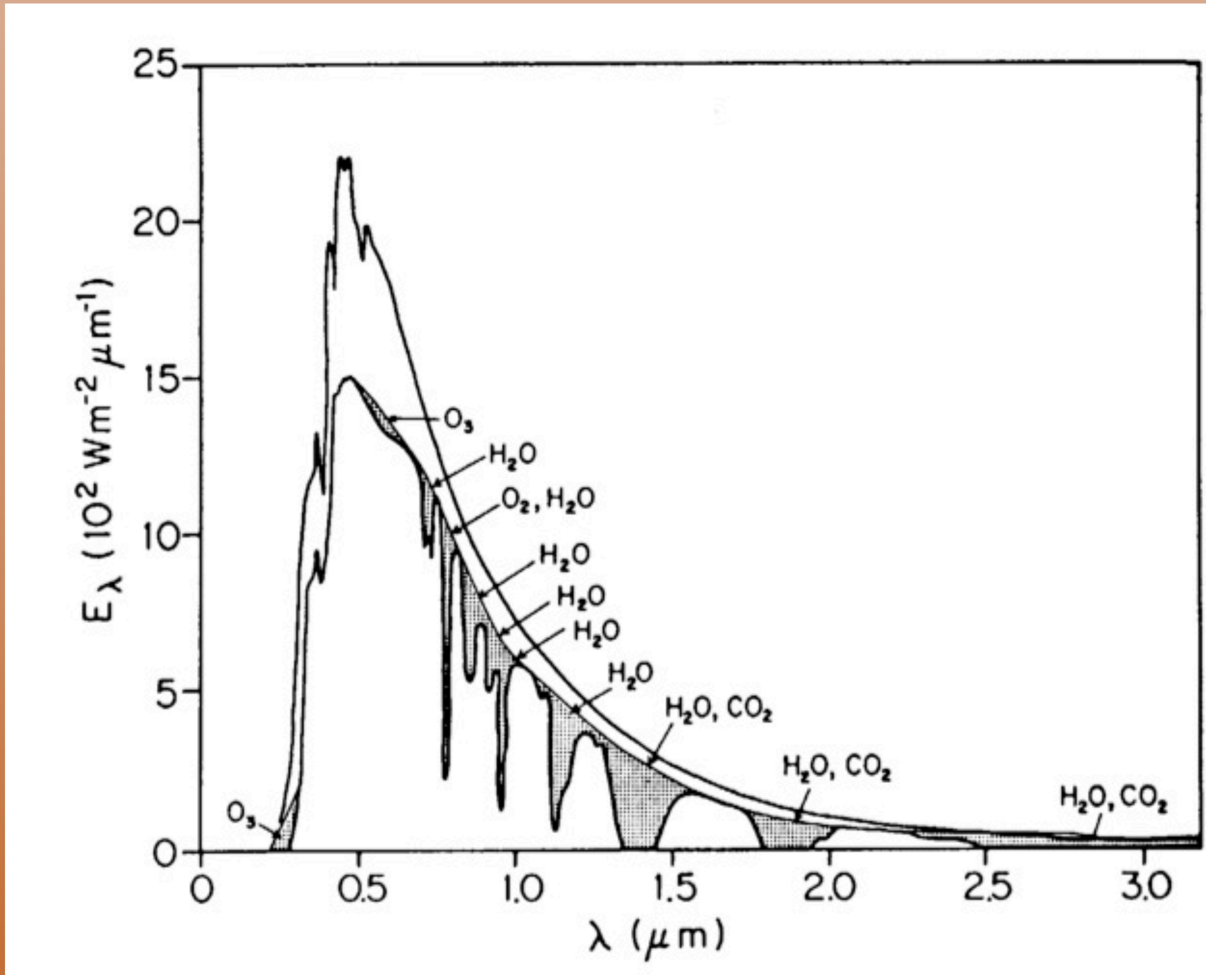
5 deg (global delta T)

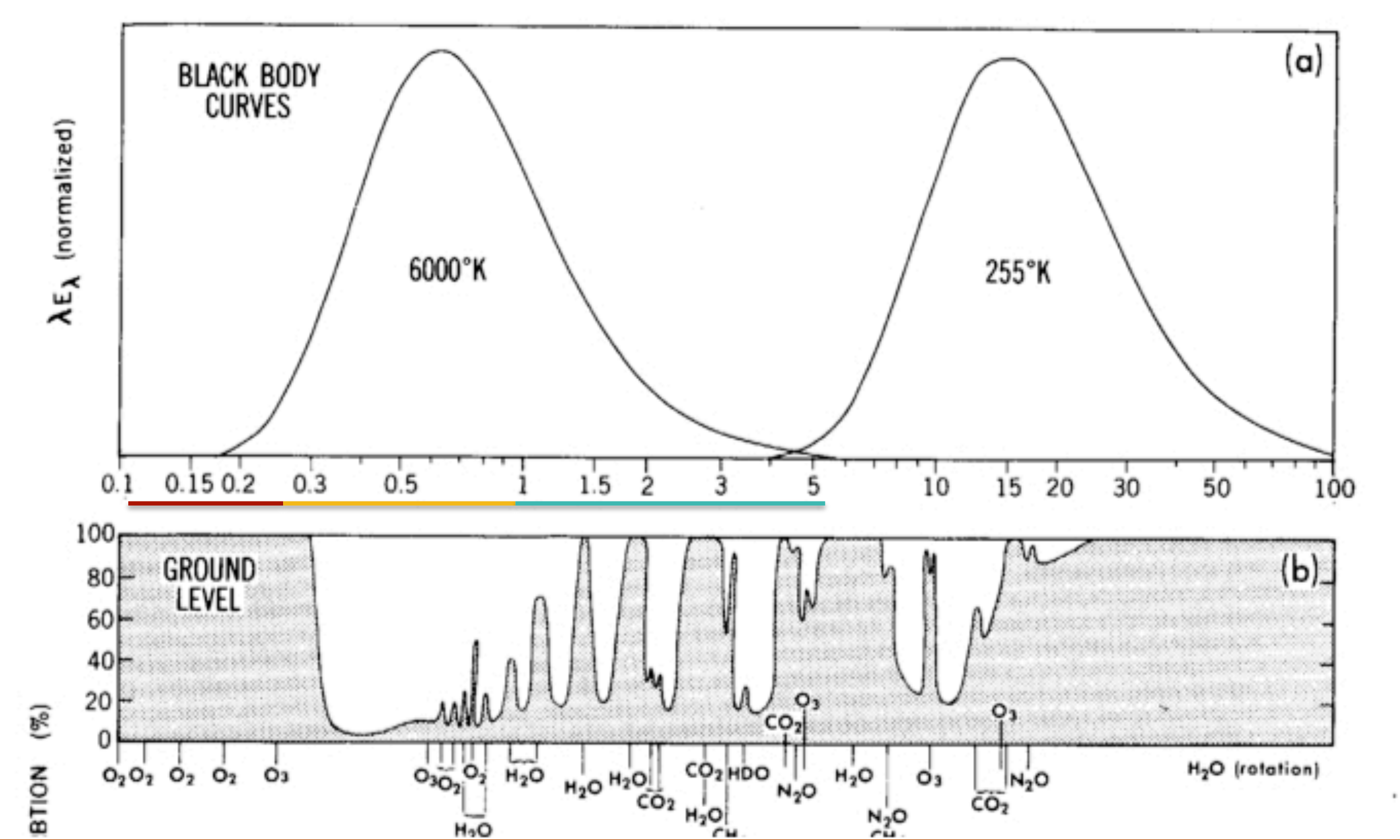
TOA Balance



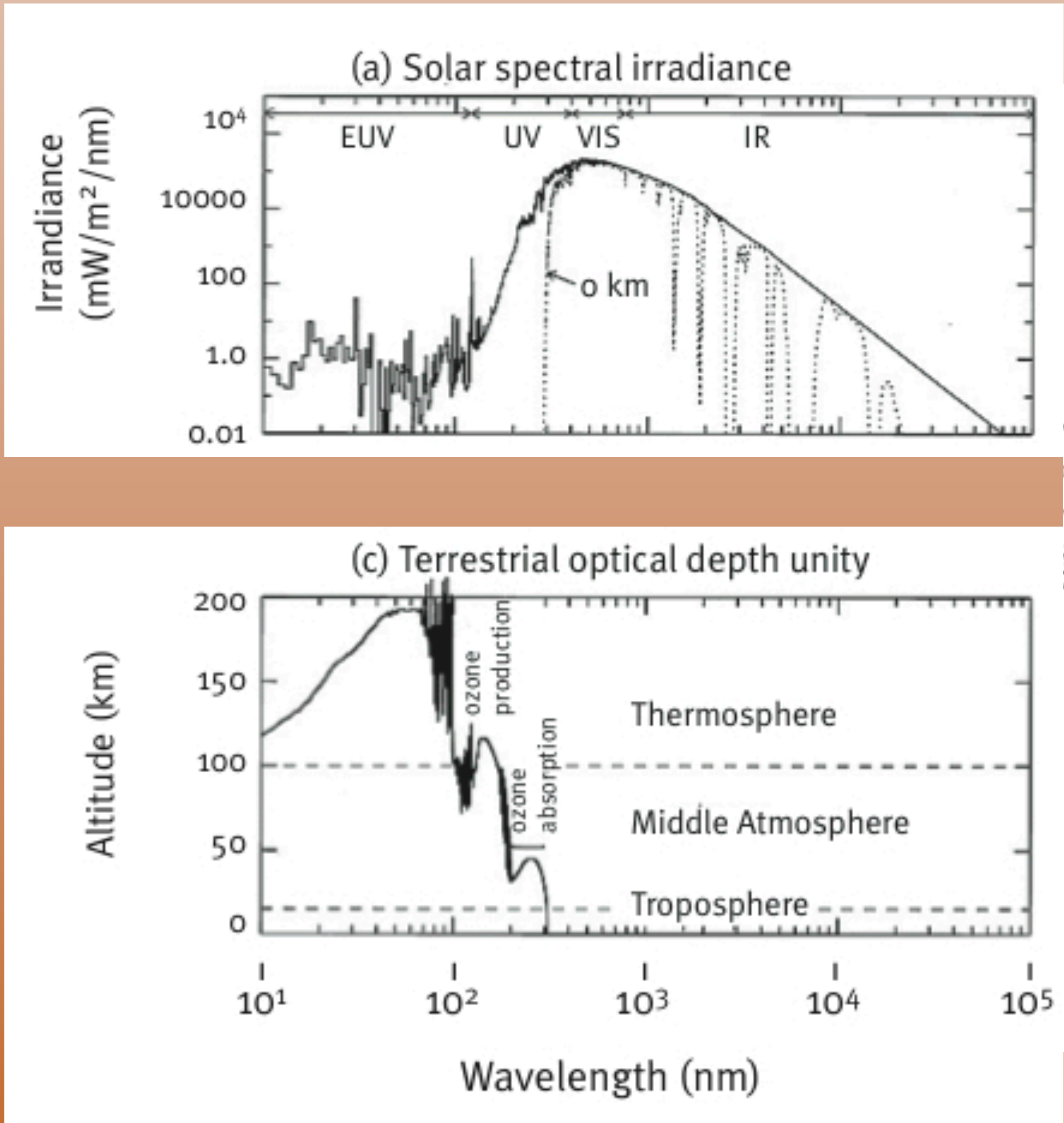
Global Energy Flows W m-2
102
Reflected Solar Radiation 101.9 W m-2
341
Incoming Solar Radiation 341.3 W m-2
239
Outgoing Longwave Radiation 238.5 W m-2
Reflected by Clouds and Atmosphere 79
79
40 Atmospheric Window
Emitted by Atmosphere
169
30
Greenhouse Gases
Absorbed by
78 Atmosphere
Latent
80 Heat
17
Reflected by Surface 23
356
40
333 Back Radiation
161
396
333
17 Thermals
80 Evapo-transpiration
Absorbed by Surface
Surface Radiation
Absorbed by Surface
Net absorbed 0.9 W m-2

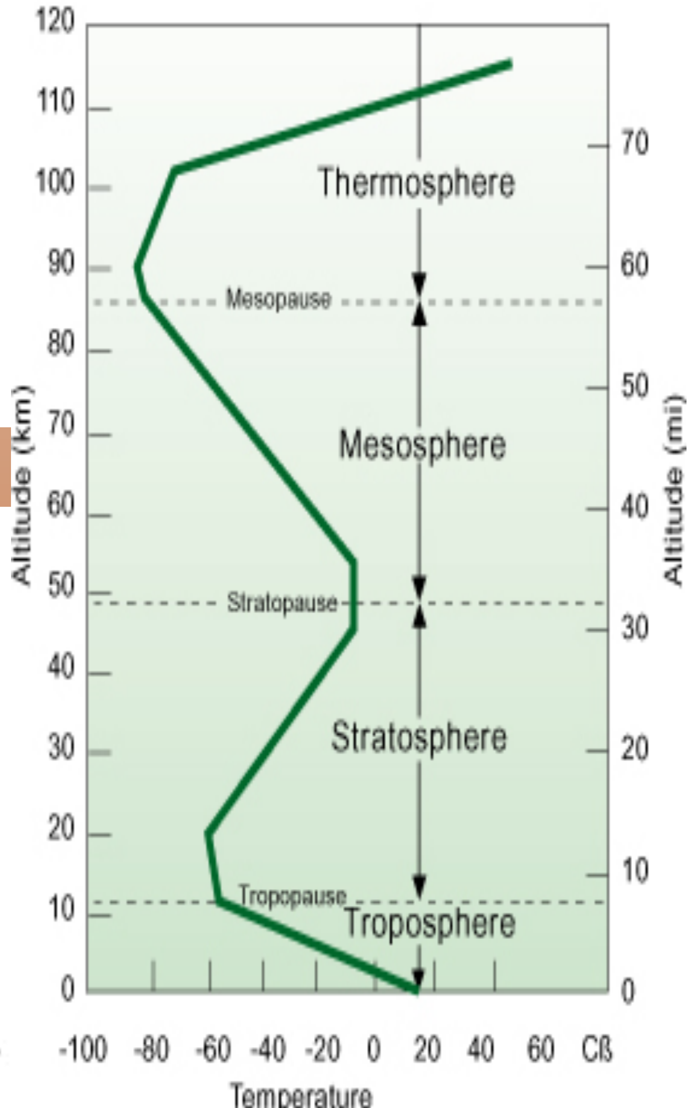
Spectral distribution of Solar Irradiance at TOA and sea level



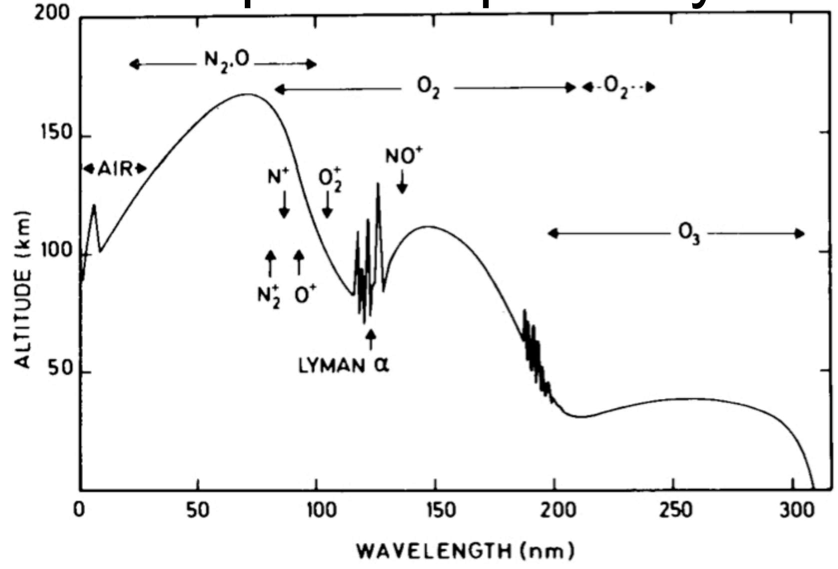

BLACK BODY CURVES
(a)
6000°K
255°K
λEλ (normalized)
0.1 0.15 0.2 0.3 0.5 1 1.5 2 3 5 10 15 20 30 50 100
GROUND LEVEL
(b)
100 80 60 40 20 0
H2O (rotation)

micron


(a) Solar spectral irradiance
Irrandiance (mW/m²/nm)
10⁴
10000
100
1.0
0.01
EUV
UV
VIS
IR
0 km
(c) Terrestrial optical depth unity
Altitude (km)
200
150
100
50
0
ozone production
ozone absorption
Thermosphere
Middle Atmosphere
Troposphere
10¹
10²
10³
10⁴
10⁵
Wavelength (nm)


Altitude (km)
Altitude (mi)
Thermosphere
Mesopause
Mesosphere
Stratopause
Stratosphere
Tropopause
Troposphere
Temperature
-100
-80
-60
-40
-20
0
20
40
60
CB

Optical depth unity



Chapman Cycle

$(J_2);\ O_2 + h\nu \rightarrow O + O$

$(J_2^*);\ O_2 + h\nu \rightarrow O(^1D) + O$

$(k_2);\ O + O_2 + M \rightarrow O_3 + M$

$(k_3);\ O + O_3 \rightarrow O_2 + O_2$

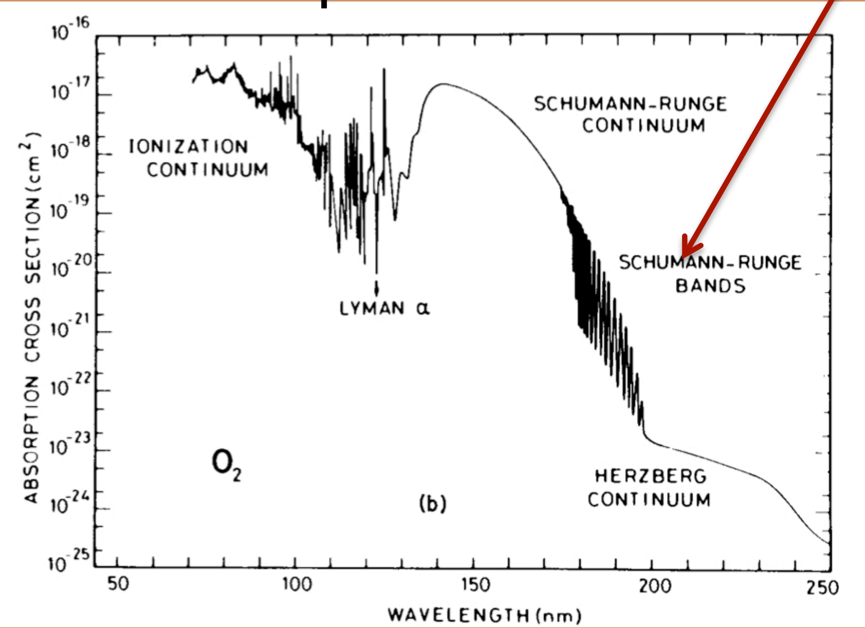
$(k_5);\ O(^1D) + O_3 \rightarrow O_2 + O_2$

$(J_3);\ O_3 + h\nu \rightarrow O_2 + O$

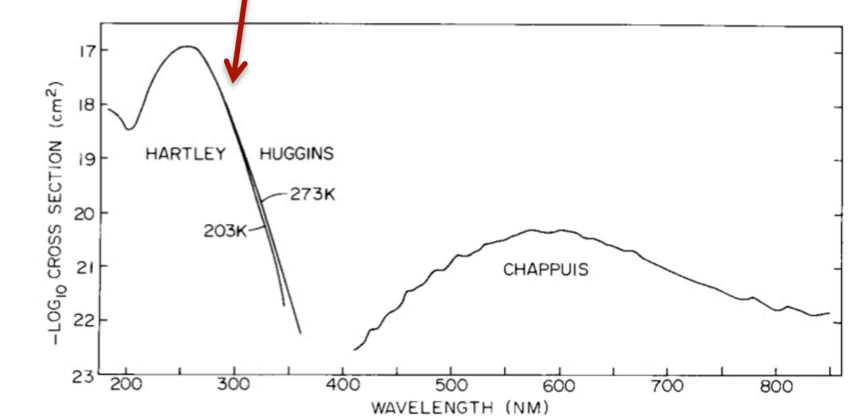
$(J_3^*);\ O_3 + h\nu \rightarrow O_2(^1\Delta_g) + O(^1D$

$(k_1);\ O + O + M \rightarrow O_2 + M.$

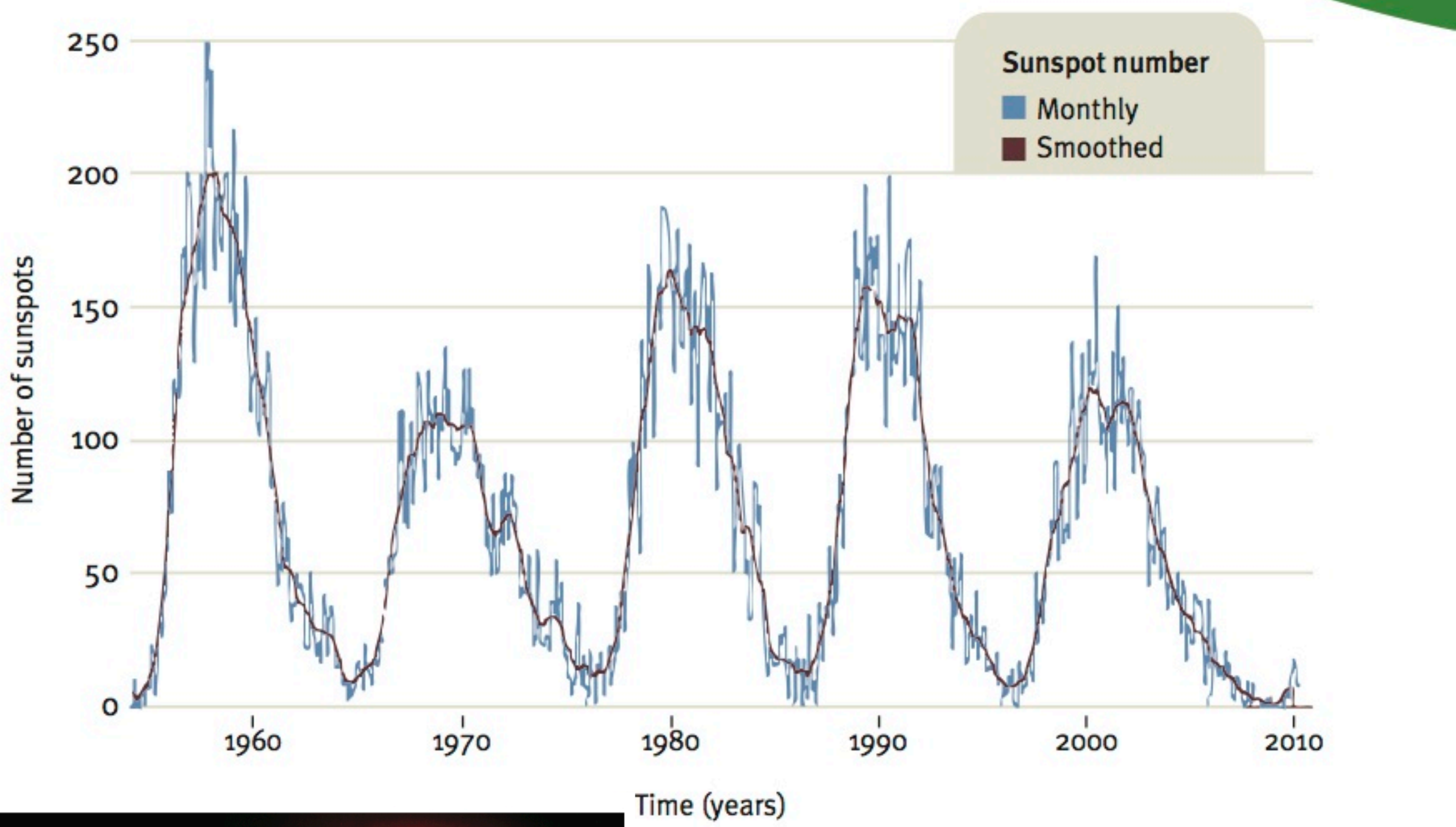
O2 Absorption cross section



O3 Absorption cross section



Indicators of solar activity : sunspot numbers



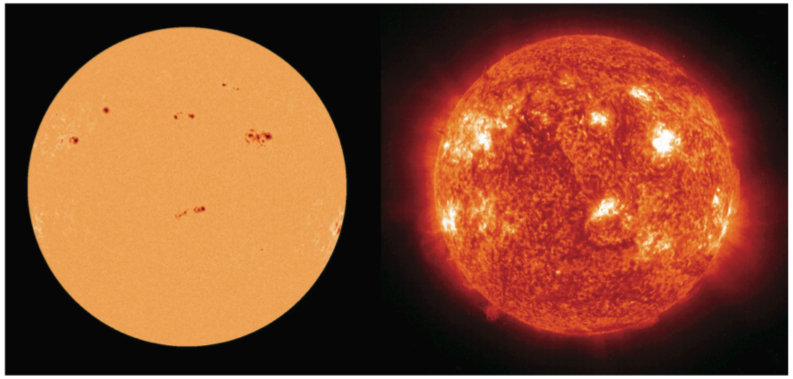


Figure 8. The Sun observed on 20 March 2000, near the maximum of the most recent solar activity cycle. Left: in visible light, showing sunspots; Right: in the ultraviolet, revealing areas of intense activity associated with the sunspots[10].

Indicators of solar activity

Sunspot

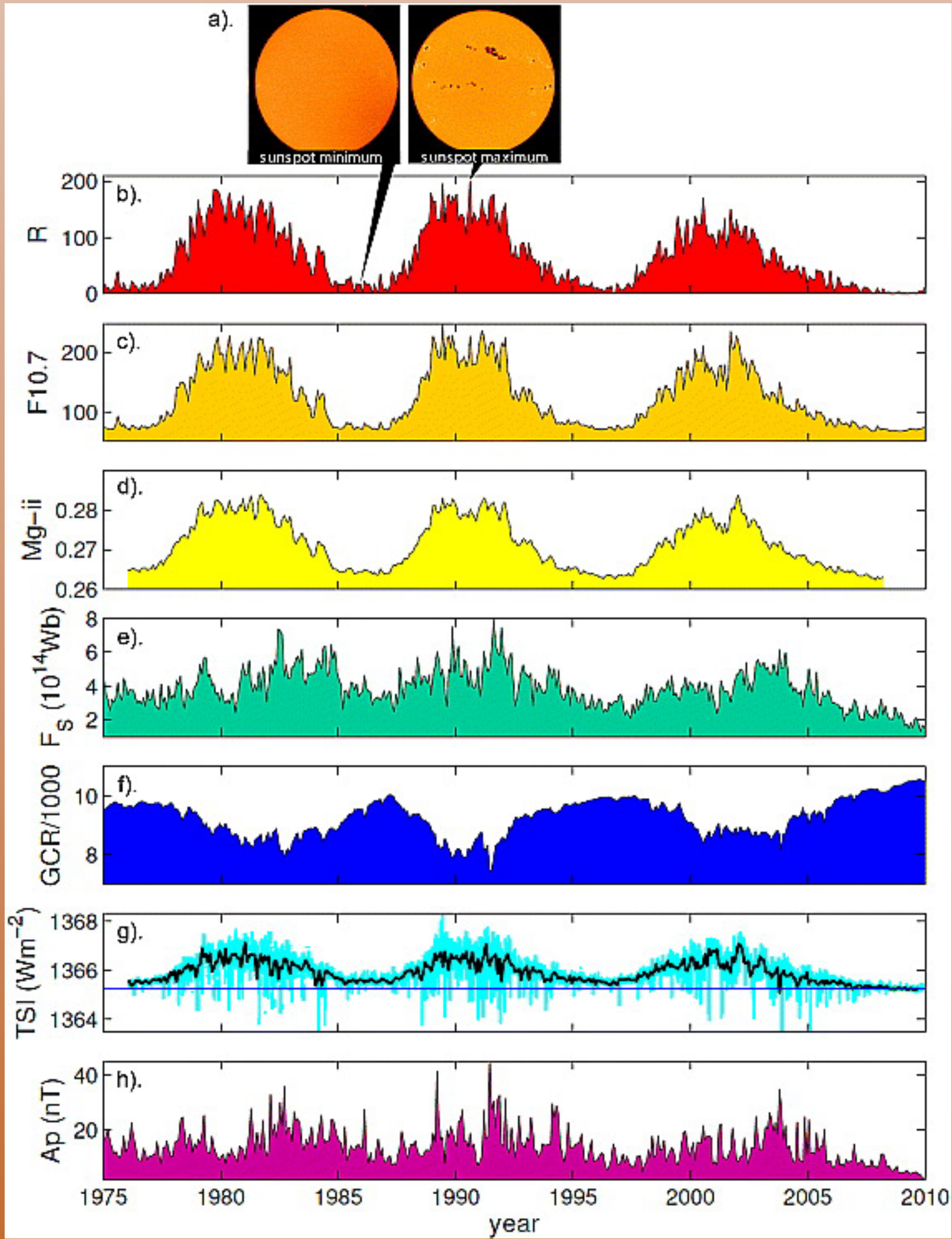
10.7 cm radio flux

Mg II

GPC

TSI

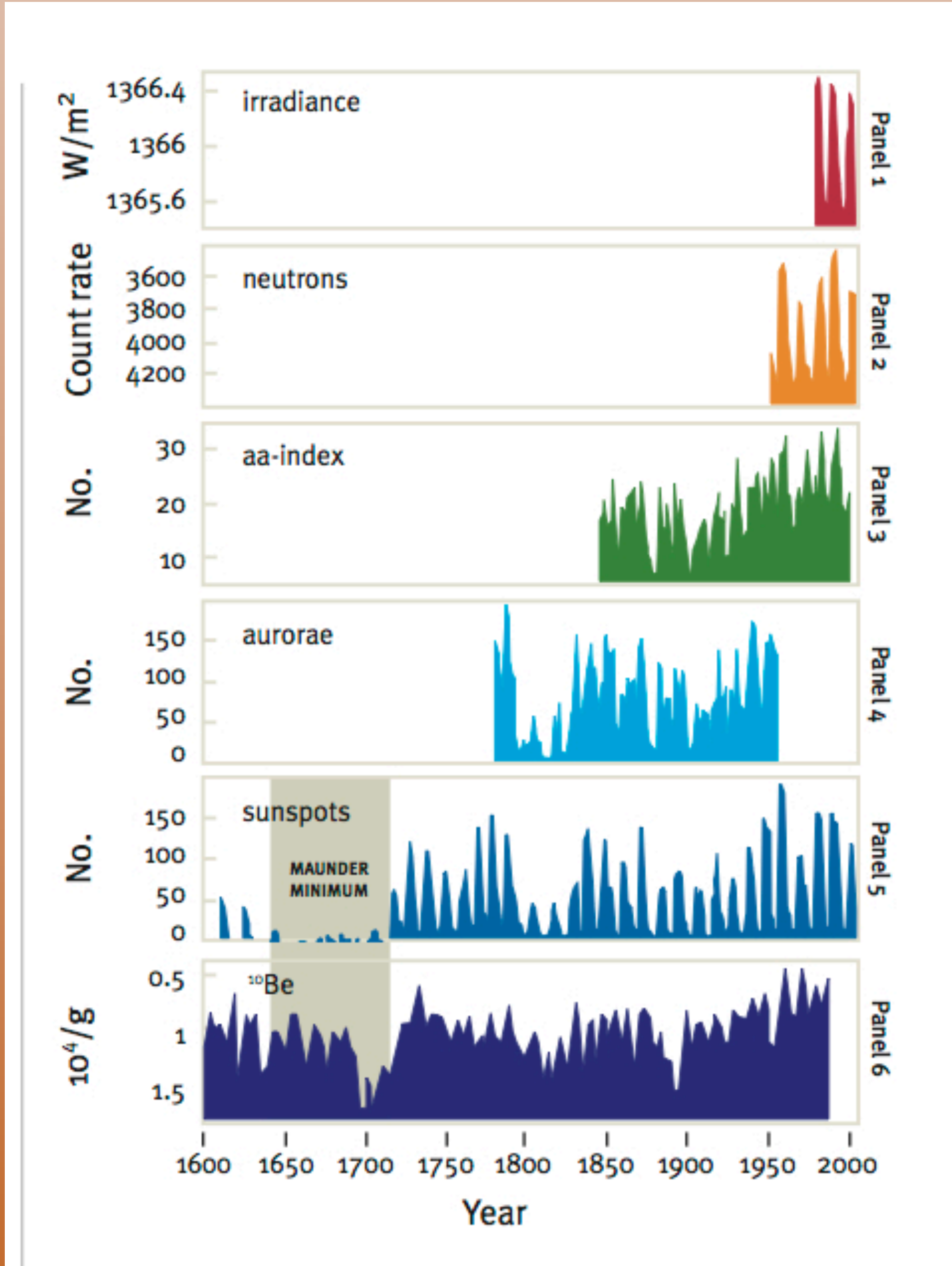
Index of gm disturbance



Indicators of solar activity

TSI

Sunspot numbers



- Proxies for solar irradiance are used for climate-sun relationship

- If we could get understanding of how sun’s magnetic activity is related to solar irradiance, we could reconstruct past solar irradiance

- Predict solar irradiance → effects on climate

The first candidate: TSI

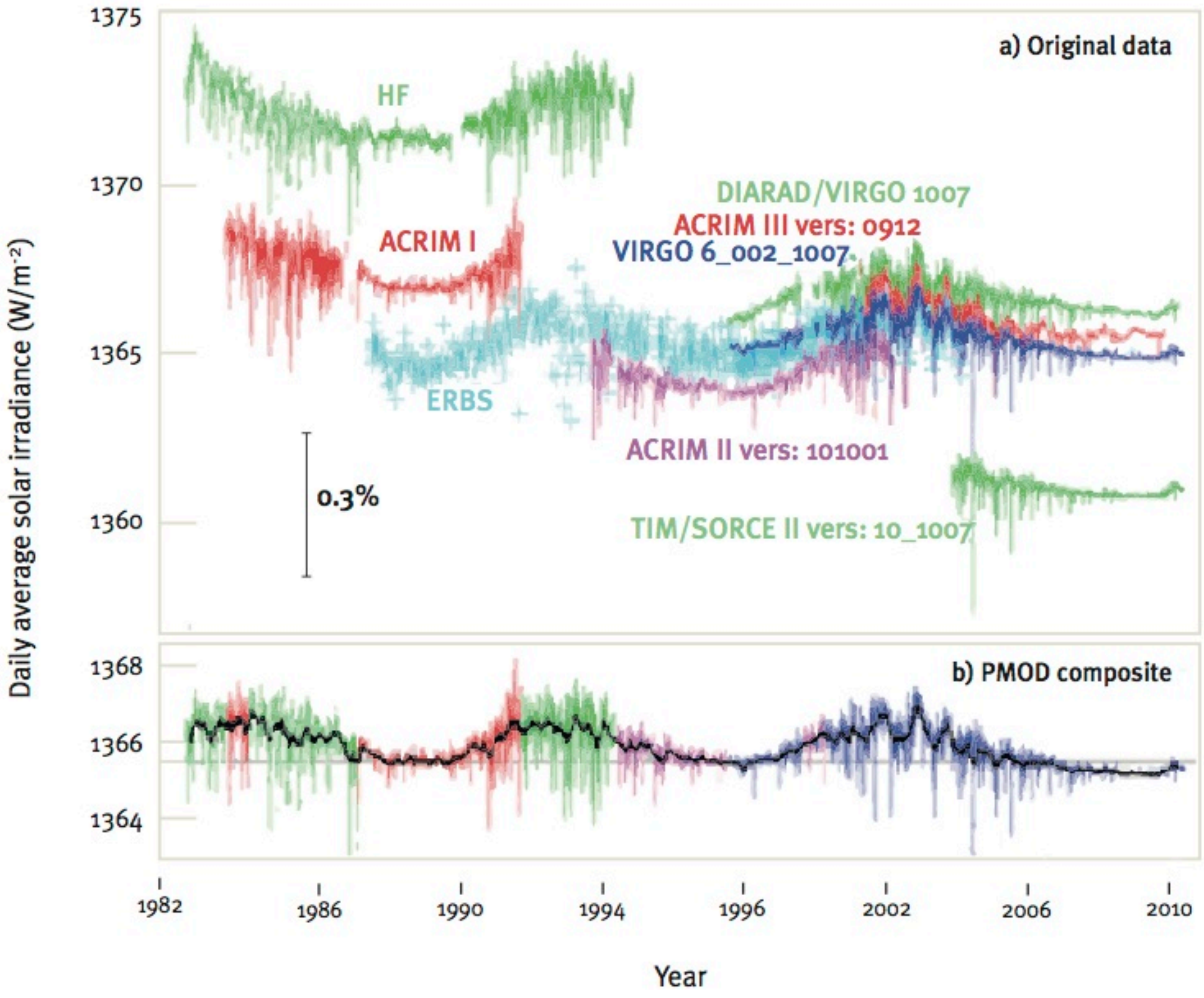


Figure 10. (a) Daily-averaged total solar irradiance (Wm⁻²) from 1978 to present: all measurements made from satellites. (b) Composite record obtained by inter-calibration of the data from the individual instruments[16].

Solar energy absorbed by the Earth = (1 – A)S/4,
where A is the Earth's albedo and S is the total solar irradiance

Smax-Smin = of about 1 W m−2

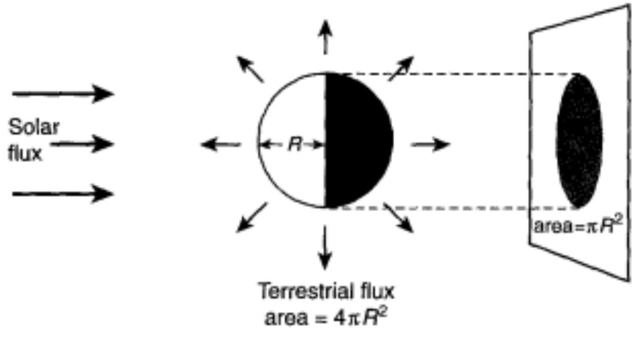
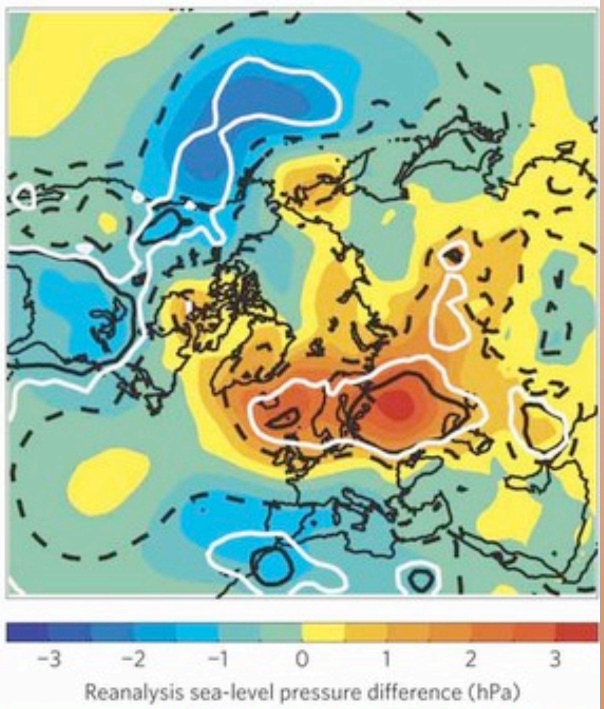


Fig. 7.3
The Earth intercepts the incoming solar flux with its cross-sectional area πR^2, but emits long-wave terrestrial radiation over its entire spherical surface of area $4\pi R^2$.

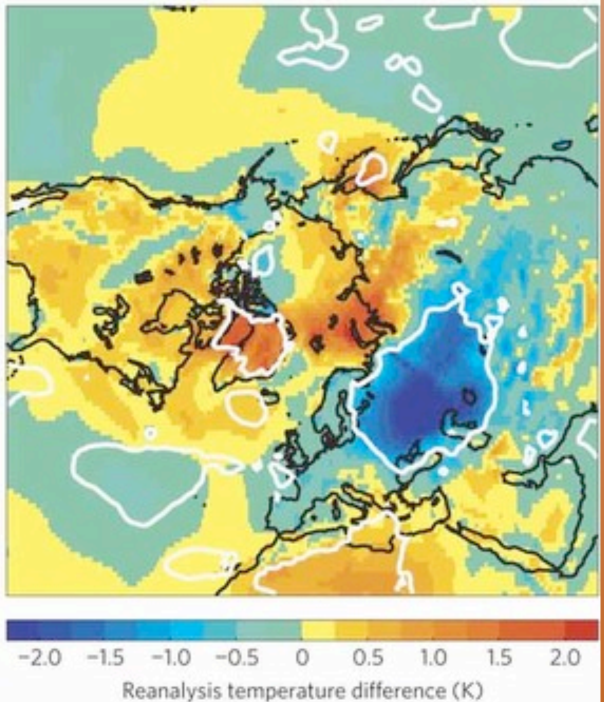
S = 1366 W m−2 and A = 0.3,
the solar power available to the Earth system = 239 W m−2
with an 11 year SC variation of ~0.17 W m−2, or ~0.07%

Impact at the surface : DTs=l*DF, l=climate sensitivity 0.5K(W/m**2)-1 → DTs=0.07 K
What do Observations show ?



Sea Level Pressure

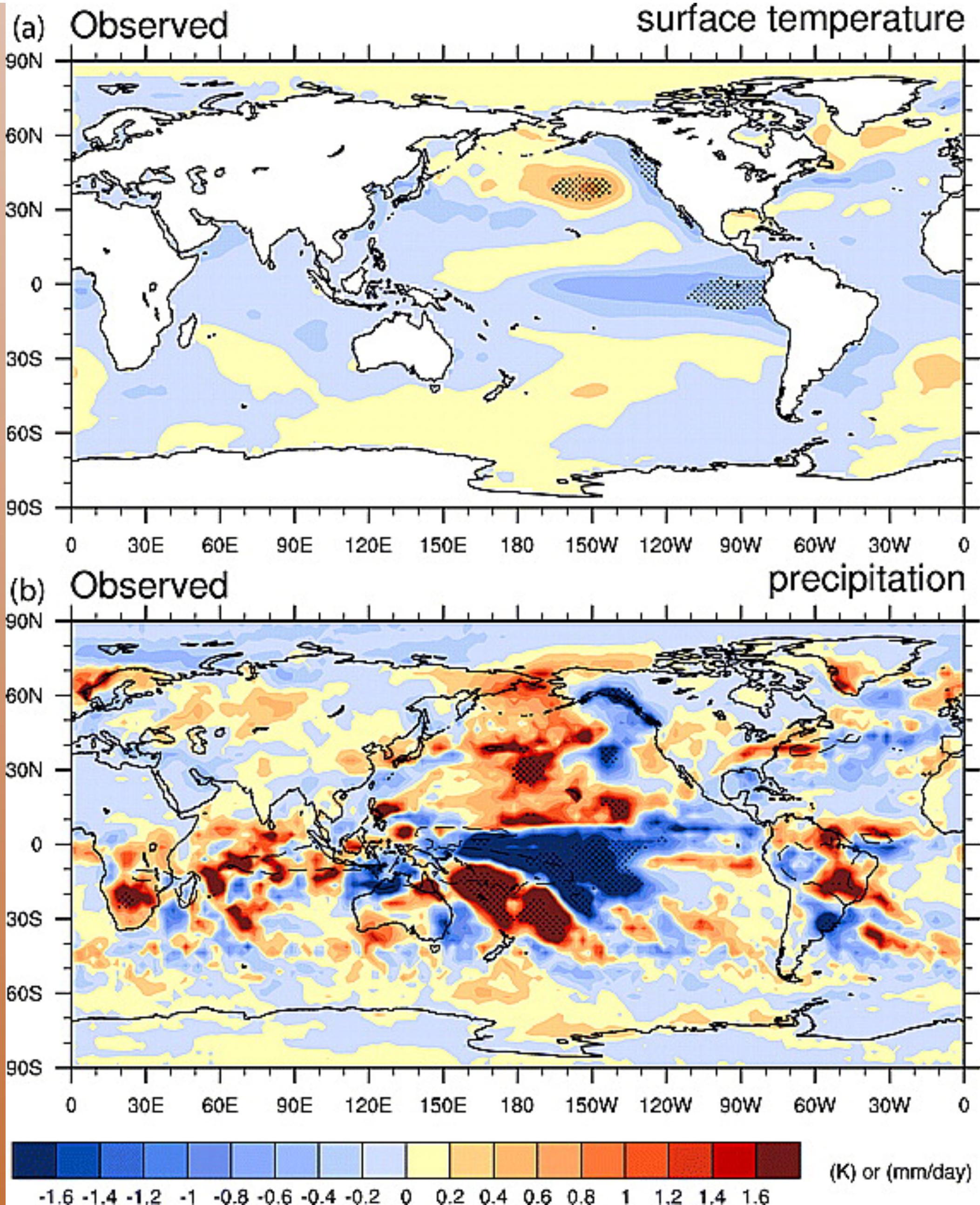
EXTRATROPICS
SLP and temperature
solar cycle signal at the
surface from reanalyses



Surface temperature

Ineson et al., Nature Geosciene 2011

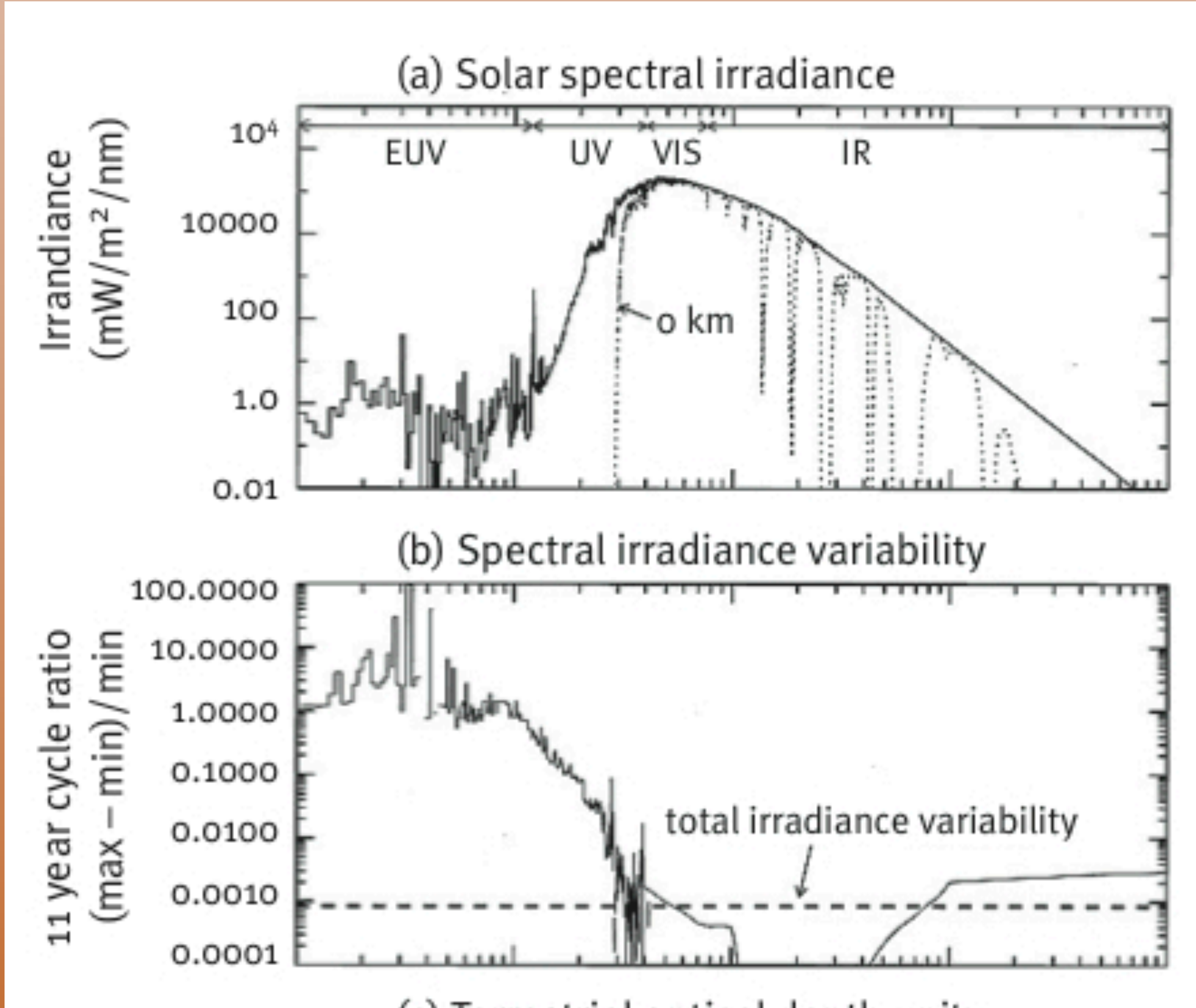
TROPICS



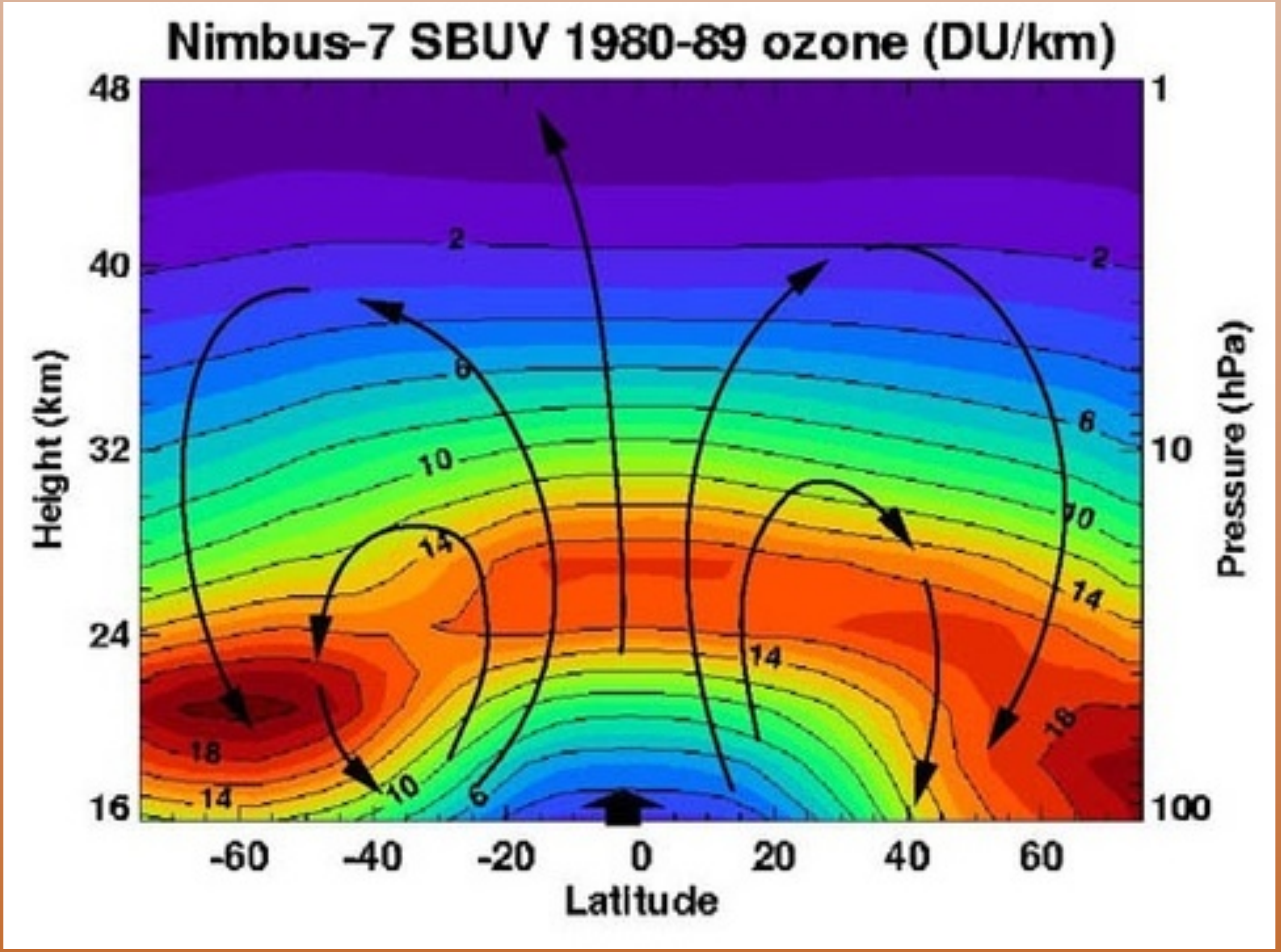
Meehl et al., Science

Regional responses larger than expected global mean :
Feedbacks ? Amplyfing mechanism ??

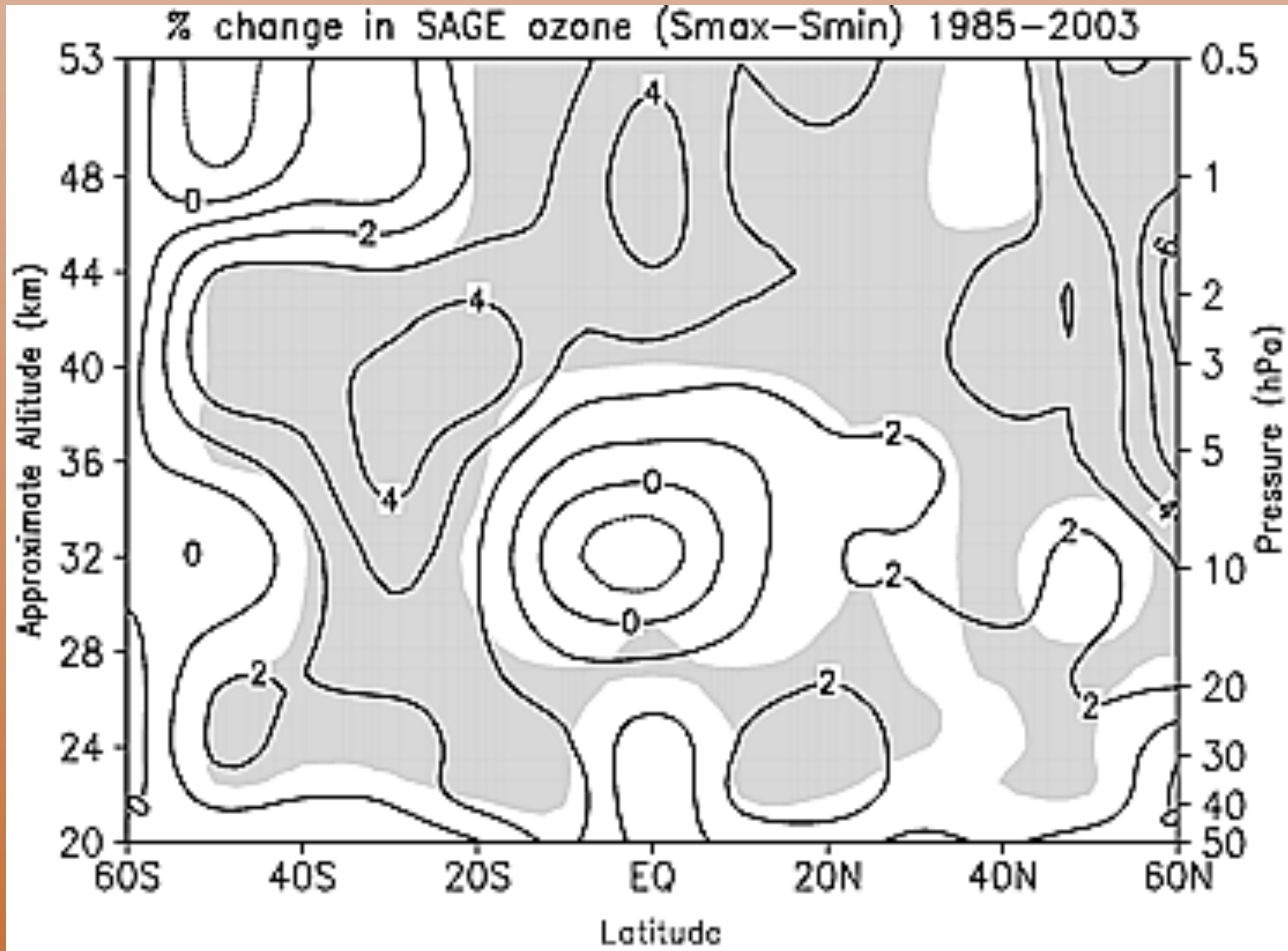
The second candidate: SSI



Stratospheric Ozone Climatology- year mean

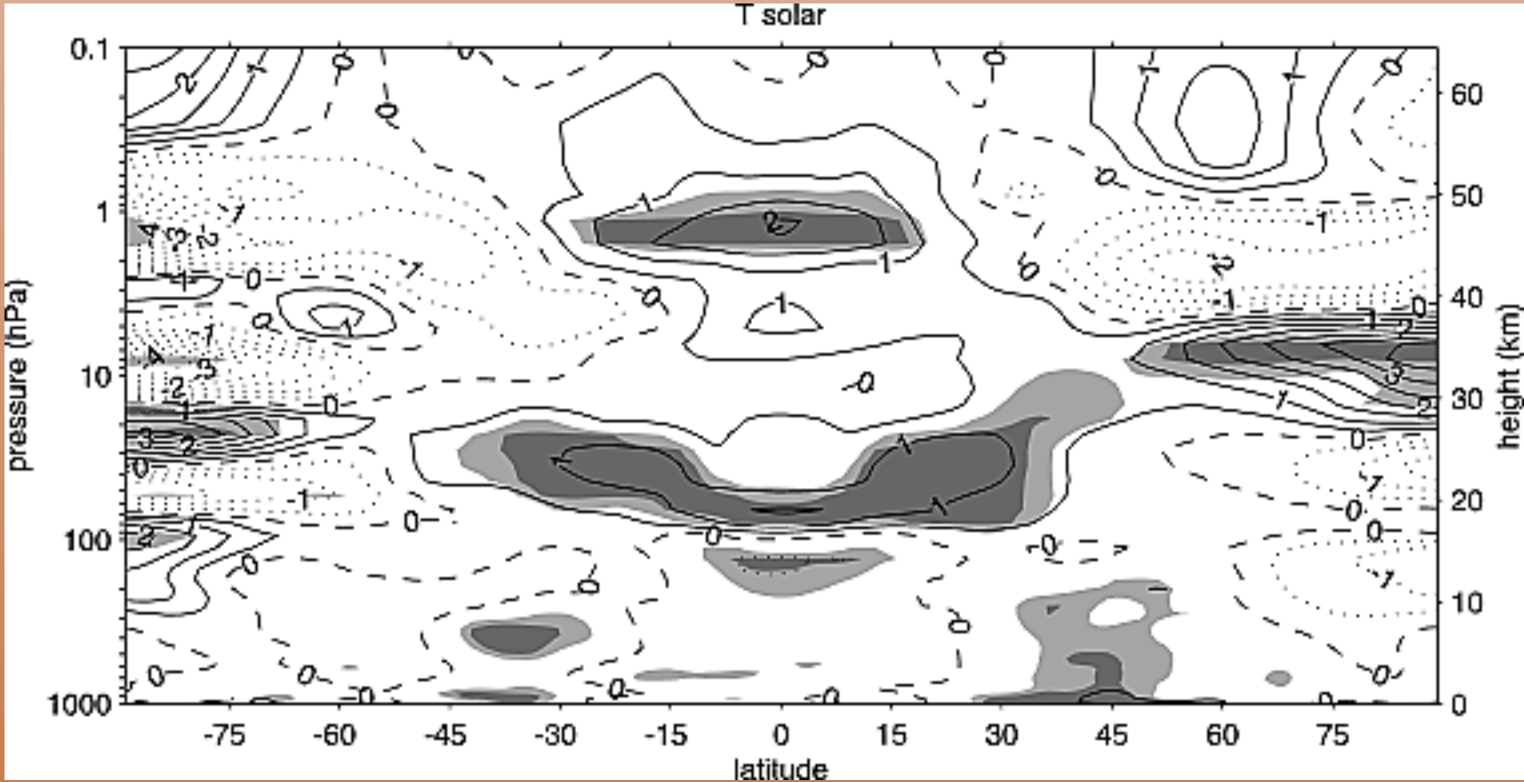


11-yr Solar signal on Ozone



Soukharev and Hood 2006

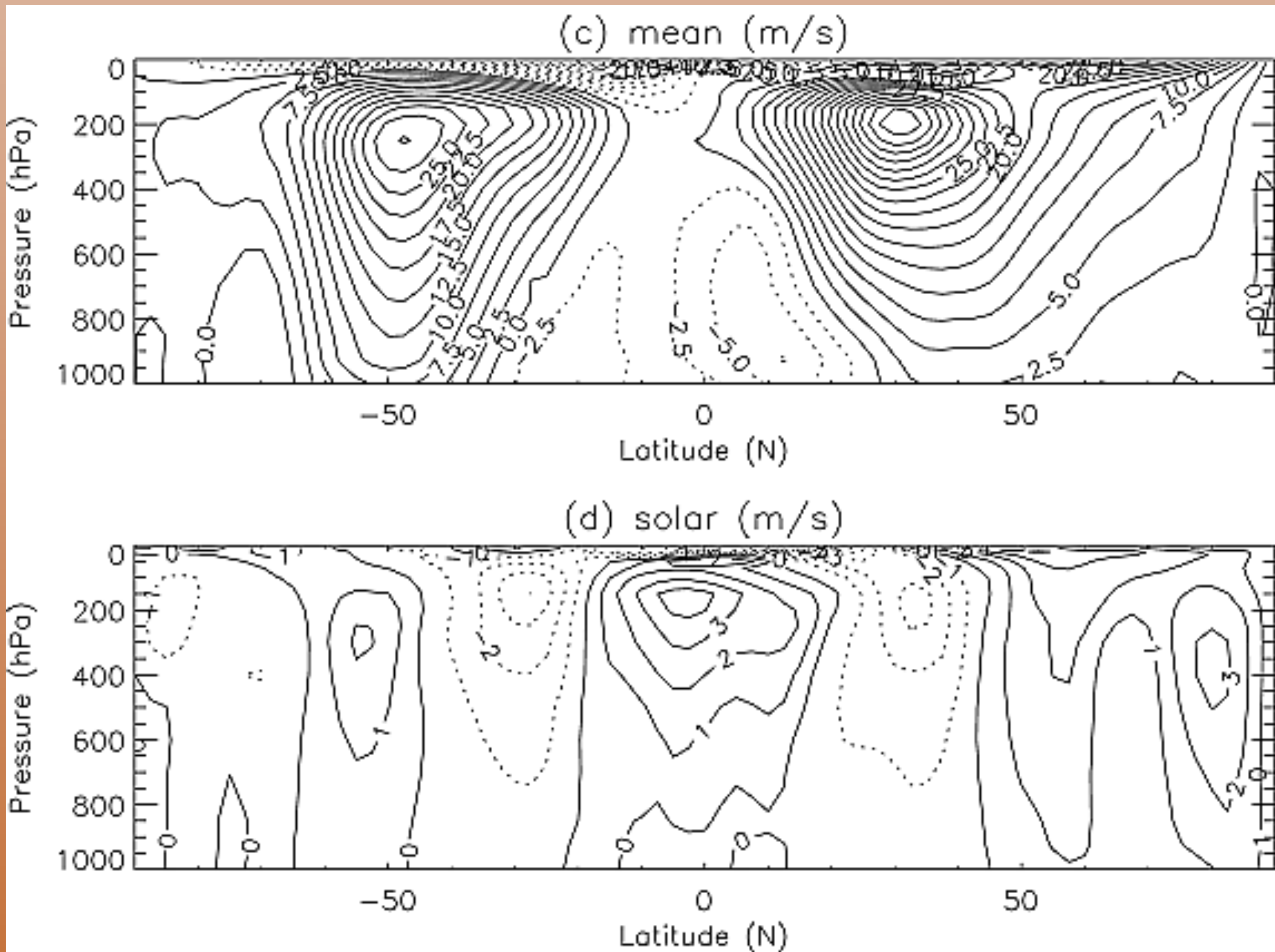
11-yr Solar signal on Temperature



Chnage the temperature → change in the circulation

Gray et al., 2010

11-yr Solar signal on winds



Chnage the temperature → change in the circulation

The possible Mechanisms

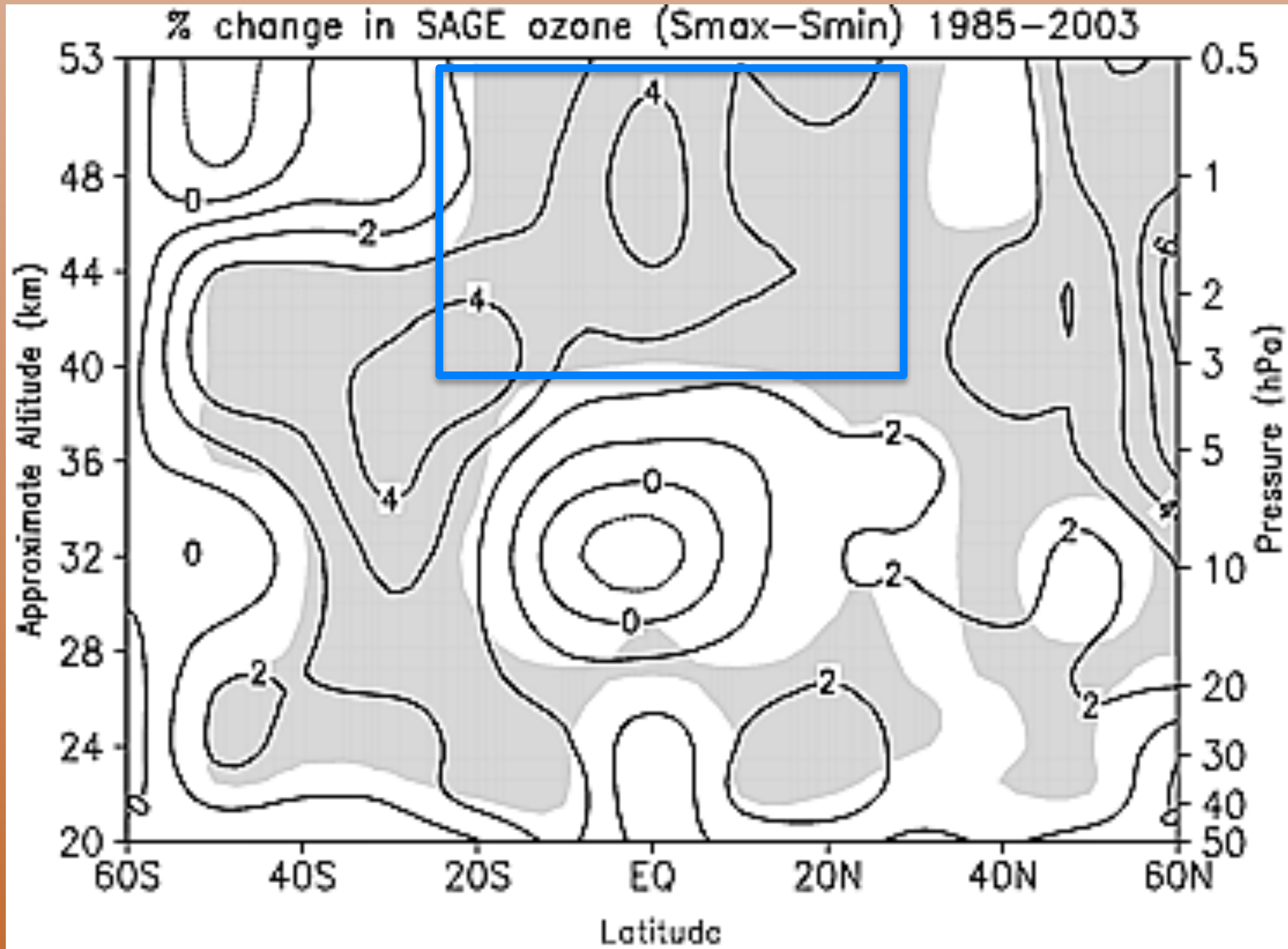
Top-down mechanism, 1.through the stratospheric ozone – polar route in winter, 2. at equator, all year (SSI)

Bottom-up mechanism, in the tropics (TSI)

Interaction between GCRs and clouds

Top-Down

+ phase Solar cycle in the UV → + Ozone Tropics, middle atm

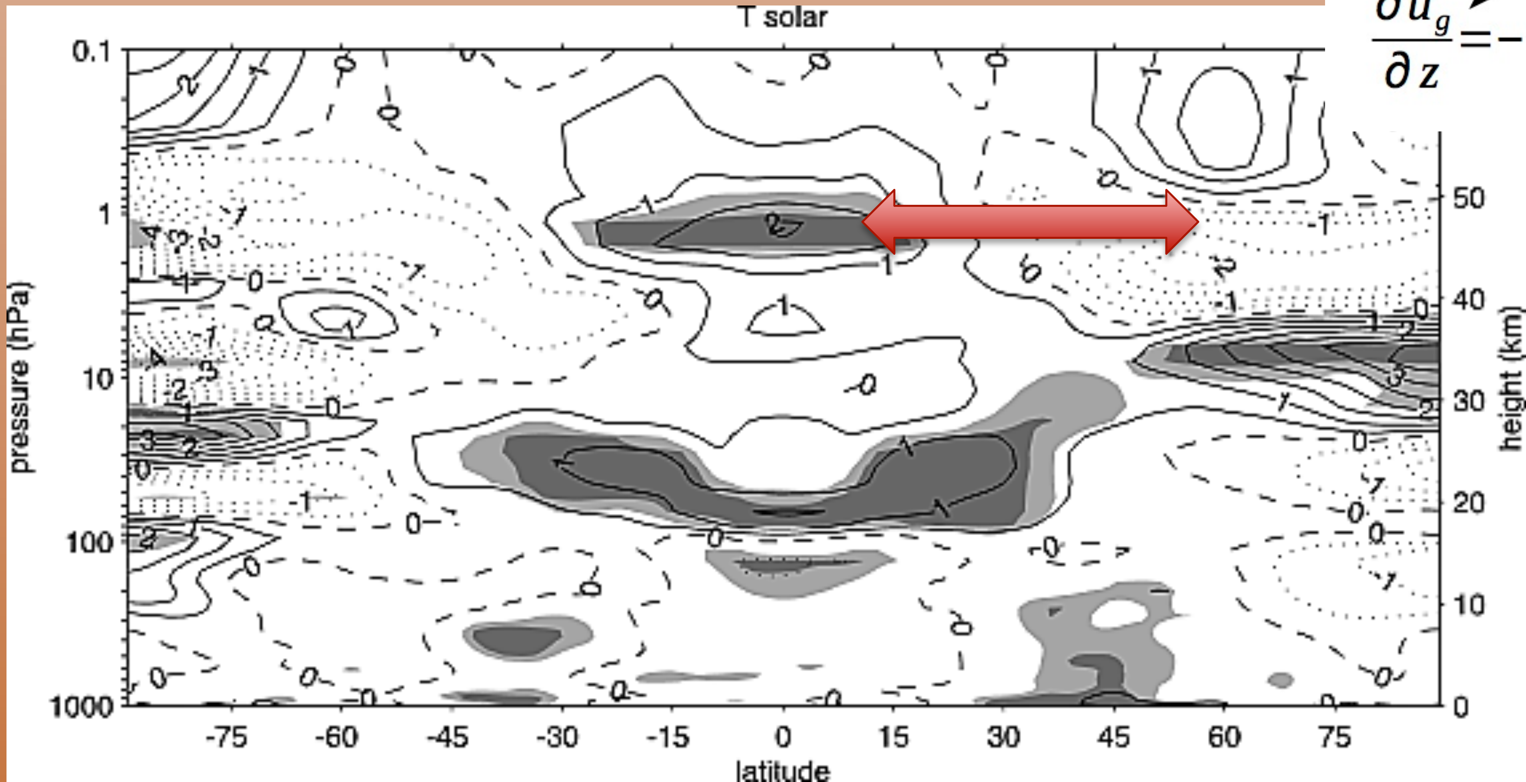


Top-Down, polar route

+ phase Solar cycle in the UV → + Ozone Tropics, middle atm

→ Warming of tropical lats → impact on the meridional T gradient

$$\frac{\partial u_g}{\partial z} = -\frac{R}{Hf_0}\frac{\partial T}{\partial y}$$



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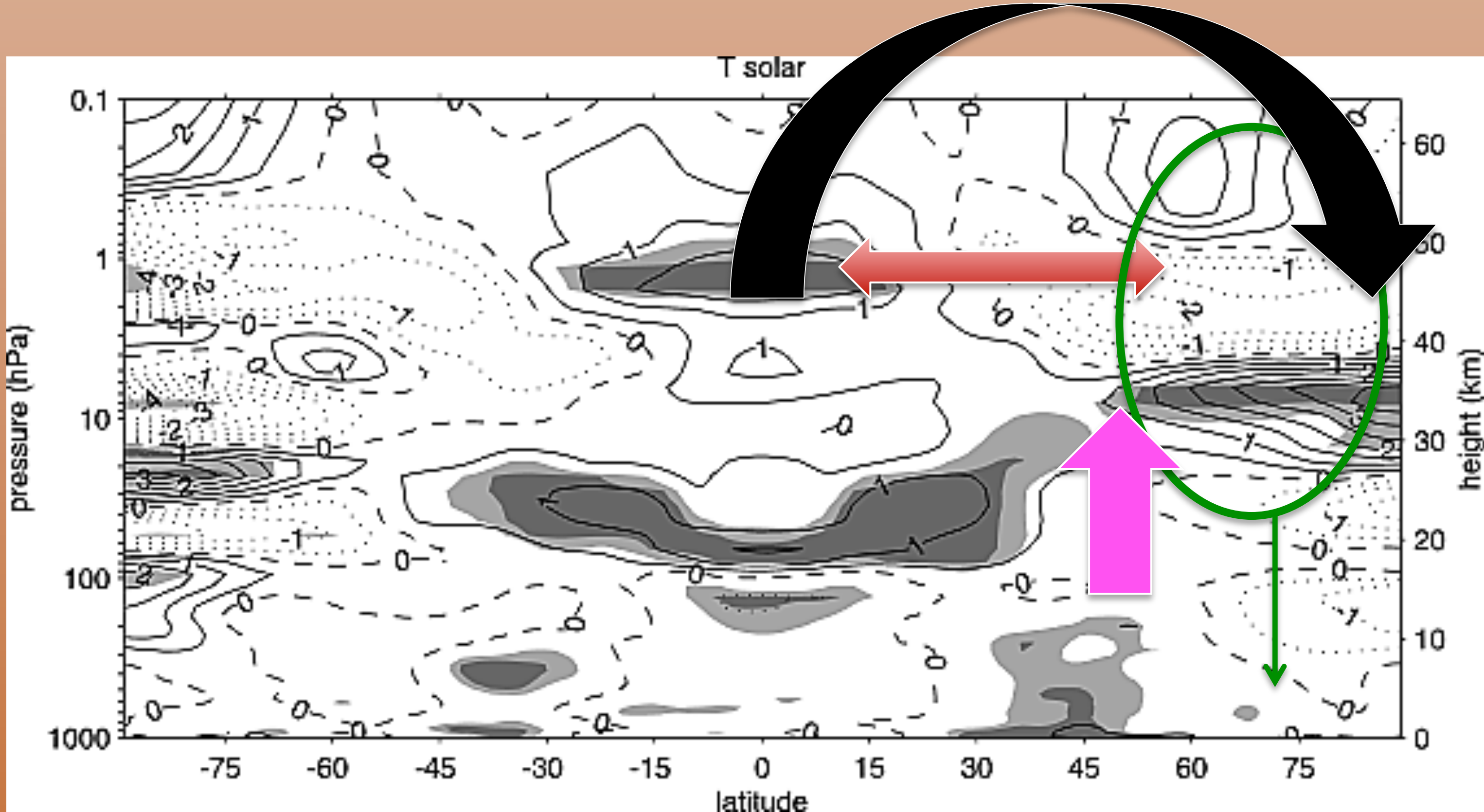
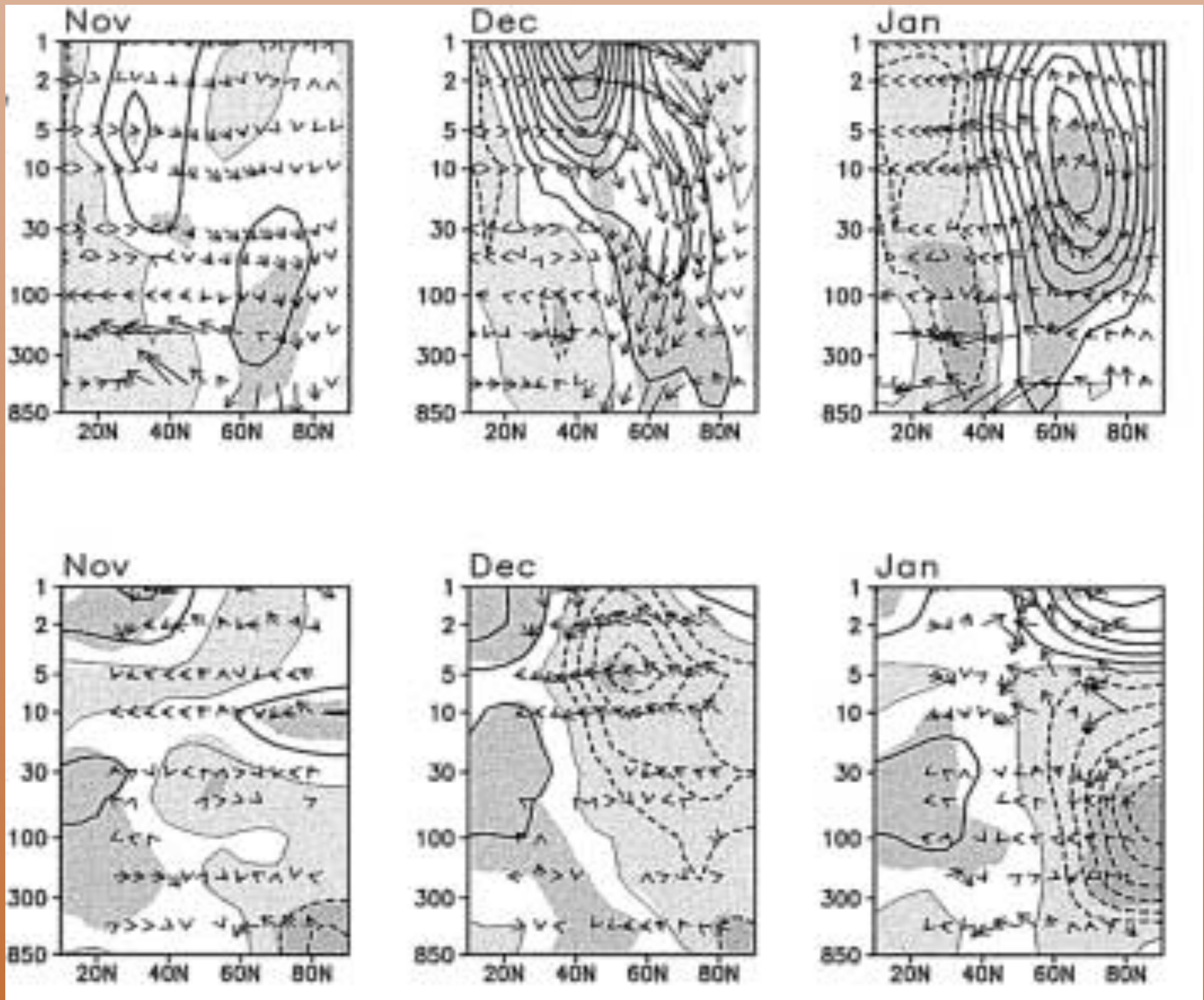


→ Impact on the winds (+) -> Planetary wave propagation →
→ Meridional circulation(-), wind anomalies propagate down

Evolution of wind and T, beginning of winter



Wind

Temperature

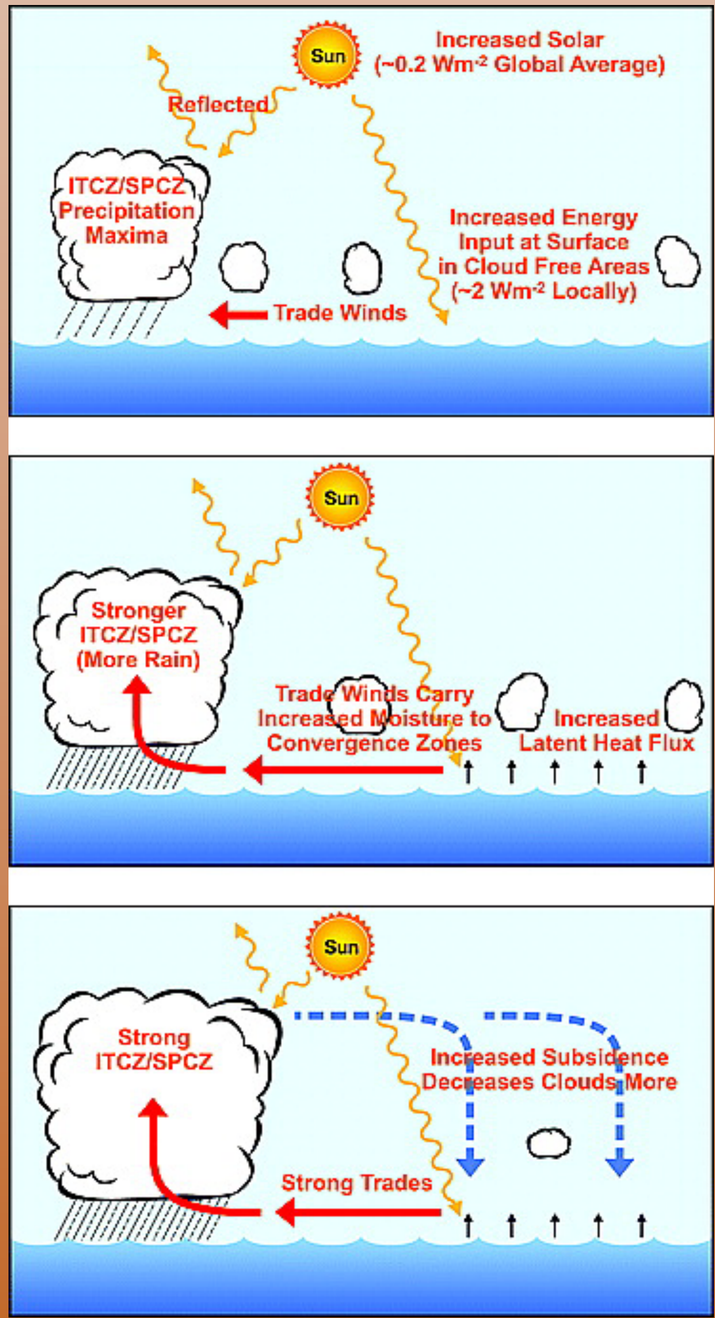
Kodera and Kuroda, 2002

Bottom-up:

Absorption of solar radiation over cloud free subtropical ocean, larger during Smax →

larger evaporation and more moisture transported into precipitation zones -> larger upward vertical motion

-> stronger trade winds → ocean upwelling → colder SSTs → feedback reducing clouds



Charged particles:

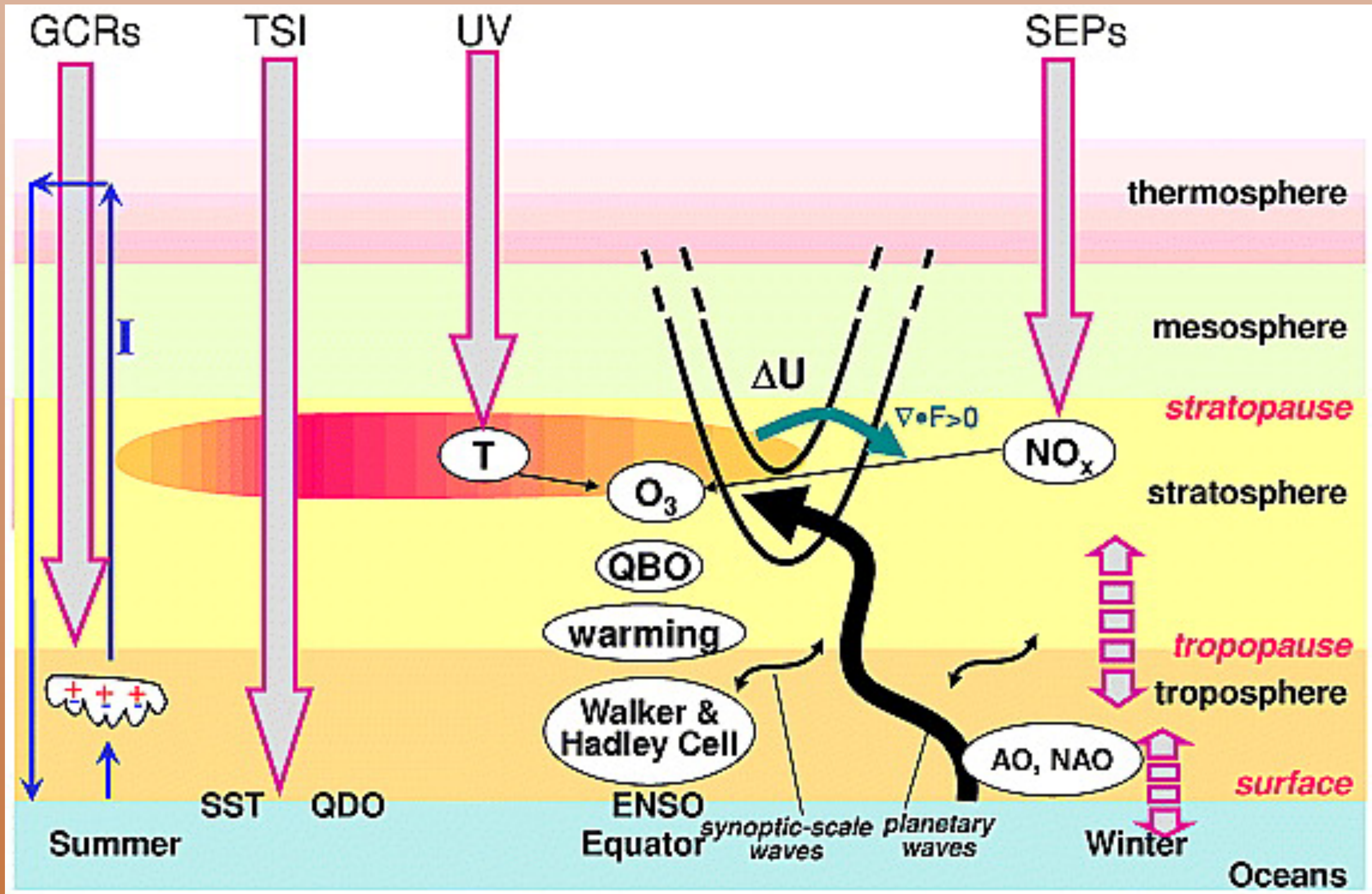
Cosmic rays generate ions. Two different routes might result in this ionisation influencing cloud cover:

- preferential growth of ionised particles to a size which is energetically favourable for cloud droplet formation, then other processes are needed to really have enhanced CCN

- ionisation might influence cloud cover through changes in the global electrical circuit where currents flowing between the surface and the ionosphere initiated by thunderstorm activity. Near the edges of clouds charge can accumulate and this can influence both evaporation of cloud droplets and interactions between them

Plausible mechanism, but no evidence

EPP influence chemical constituents (HOx, NOx..) that is transported in the polar vortex may impact polar O3


GCRs
TSI
UV
SEPs
thermosphere
mesosphere
stratopause
stratosphere
tropopause
troposphere
surface
Oceans
I
ΔU
∇•F>0
T
O3
NOx
QBO
warming
Walker &
Hadley Cell
AO, NAO
SST
QDO
ENSO
Equator
synoptic-scale
waves
planetary
waves
Summer
Winter

Uncertainty in the SSI, may be important?

NATURE GEOSCIENCE DOI: 10.1038/NGEO2640 LETTERS

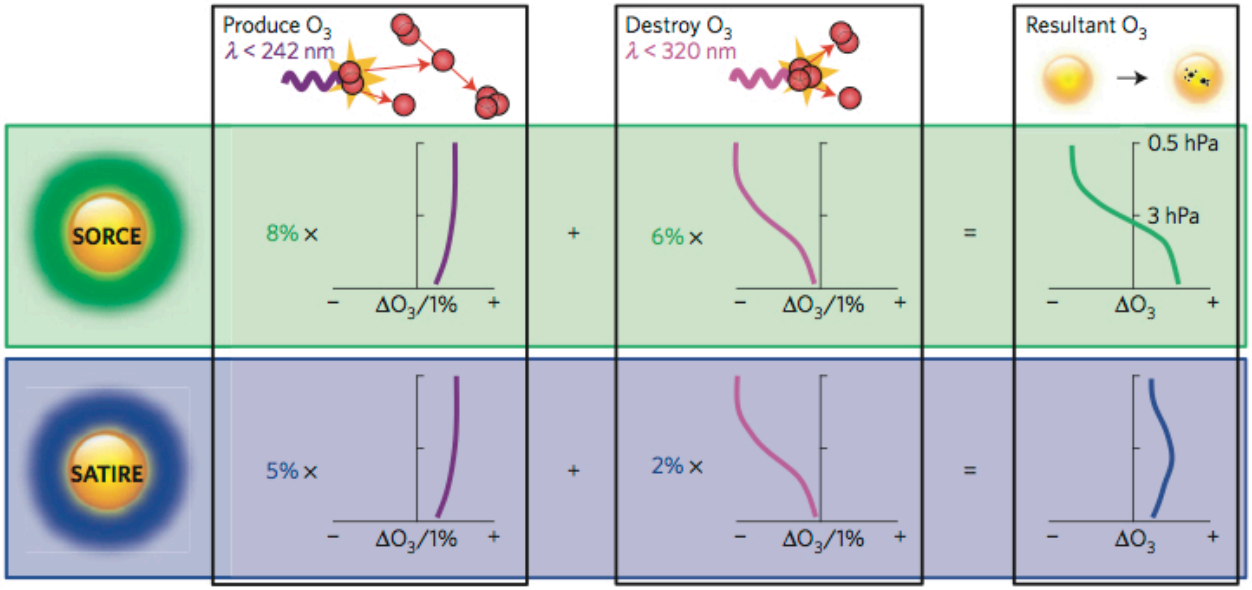


Figure 1 | Illustration of photolytic solar cycle ozone response. The solar max-min photolytic ozone response to integrated-UV below 242 nm (left column) produces ozone. Below 320 nm (middle), O_3 photolysis leads to catalytic loss of O_3 if the O does not recombine with O_2. The resultant response (right) is approximately the sum of these[9]. The far larger SORCE changes at ozone-destroying wavelengths more than compensates for the larger UV changes at shorter wavelengths, leading to a negative response higher up, whereas SATIRE-S is positive at all altitudes. Pressure levels are illustrative of Fig. 4. Percentages are the relative solar cycle changes.

SIM on SORCE shows, over the period 2003-2007 (i.e. during the declining phase of the most recent solar cycle), a much larger decline in the UV than would be anticipated from current understanding and an *increase* in visible

Thinkings..

Understanding the role of solar variability in solar activity is essential to the interpretation of past climate and prediction of the future.

Solar activity changes might also play a role in regional climate that we need to understand in the context of informing climate adaptation efforts.

Knowledge of the solar radiation incident on the Earth is an essential prerequisite of any quantitative studies of the Sun's impact on climate (discrepancies of 4-5 Wm-2 between current observations of TSI and estimates of its values back in time to the period of low activity).

Continuing efforts to obtain measurements of high accuracy and precision are needed, alongside further effort in understanding the relationship between activity indicators and irradiance.

..Thinkings..

SSI measurements are essential, if SORCE were correct we should revisit our expectations and interpretation of past / future of solar impact on climate

Mechanisms:

Top-down, uncontroversial. Not howvere the subsequent impact at the surface

Bottom-up : uncontroversial the first part, not the feedback via the circulation

responses in cloudiness to solar-induced changes in atmospheric ionisation by galactic cosmic rays, requires more evidence

Climate models, need to include all relevant processes.. However they need correct SSI input data!

..Thinkings

Solar activity and climate change:

Increases in solar activity probably contributed 7-30% of the global warming apparent over the century leading up to the 1960s, the warming in the latter part of the 20th century is almost entirely due to the increasing concentrations of greenhouse gases from human activity

Understanding the physical processes involved in solar-climate connections is crucial to the interpretation of meteorological records, and to the prediction of aspects of the future climate.

Prediction in solar activity are difficult. Moreover, it is not necessarily the case that an Earth with a global net radiation balance but different radiative components (viz. less absorbed solar radiation but more “greenhouse” trapping of infrared radiation) will have the same climate

Exoplanets excercise

Pos.

Neg.

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