Forcing of the Earth's Atmosphere by Solar Radiation

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Overview

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1) Annual change of the Sun-Earth distance and associated change of total solar irradiance ("1-year solar cycle")

2) Annual asymmetry of the ionosphere in global mean TEC

3) Annual temperature anomaly in the tropics (h=0-540 km, NRLMSISE-00 climatology)

4) Annual asymmetry of zonal wind around the tropical stratopause (CIRA-86)

5) Conclusions

Annual Change of the Sun-Earth Distance: The Facts

- Sun-Earth distance changes by about $\pm$**1.7%** over the year

- Total solar irradiance at the position of the Earth changes by about $\pm$**3.3%** over the year

- Annual change of total solar irradiance is about $\pm$**45.7 W/m^2**

- Nearest distance is around **January,3** (maximal solar irradiance)

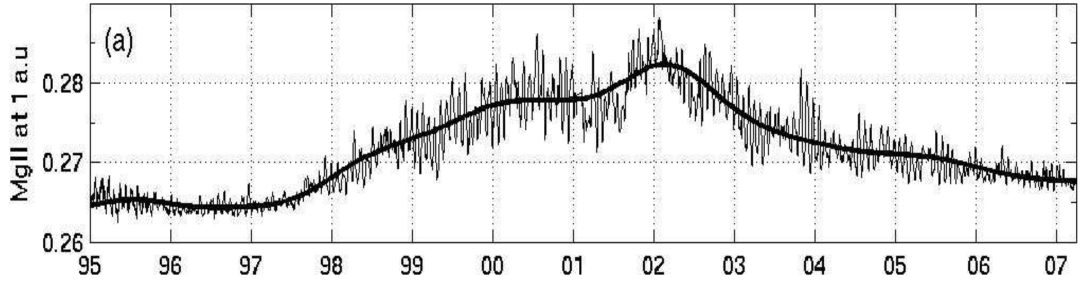
- Furthest distance is around **July,4** (minimal solar irradiance)

How reacts the Earth's atmosphere to this strong solar forcing?

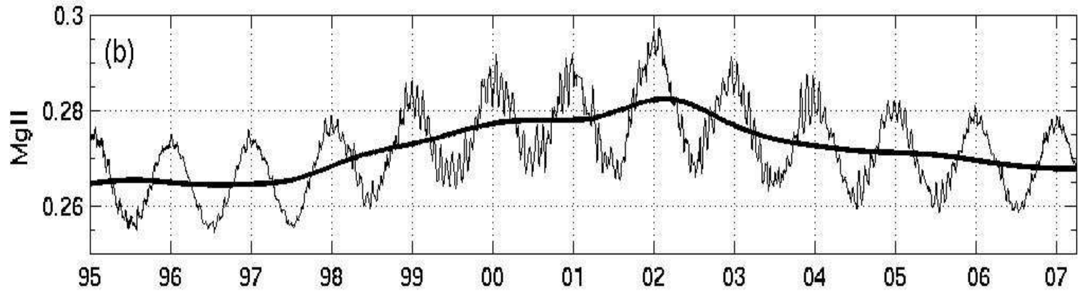
Solar EUV (Mg II index) and the Total Electron Column of the Ionosphere (Global Mean TEC) during Solar Cycle 23:

GNSS ground stations receive GPS and GLONASS signals.
Global TEC maps are retrieved by **Stefan Schaer** (**Astronomical Institute of University Bern):** -> time series of Global Mean TEC

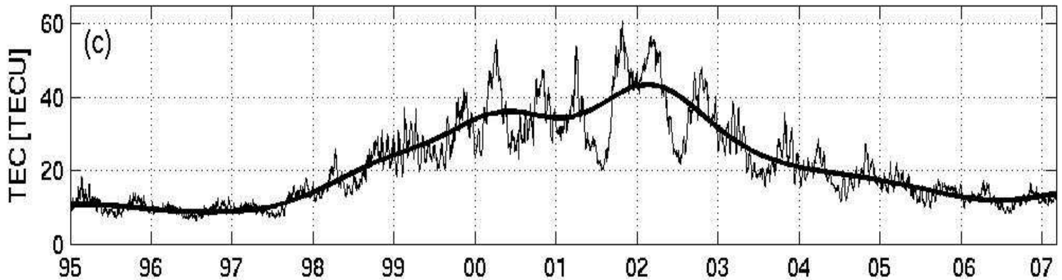
EUV irradiance (linear proportional to the Mg II index) at 1 a.u. ->



True EUV irradiance at the position of the Earth ("1-year solar cycle" is as large as the 11-year solar cycle ->



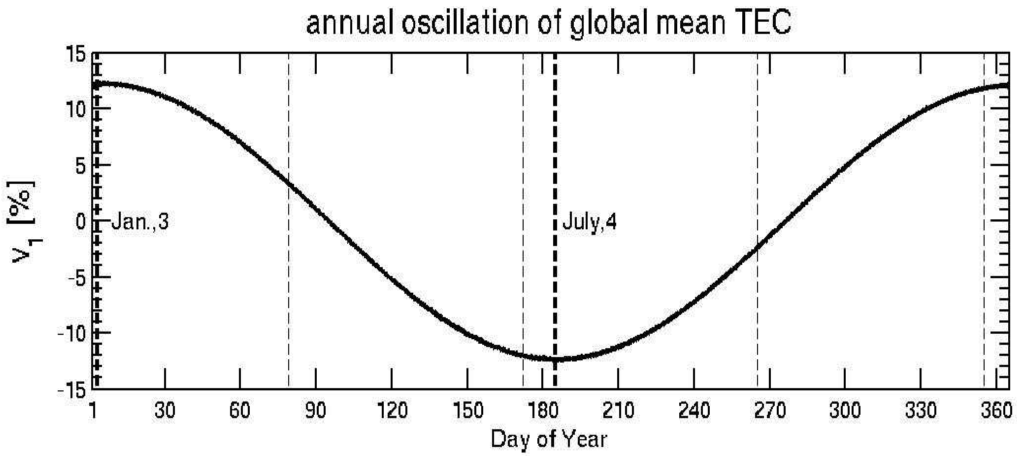
Global Mean TEC with 11-year, 1-year, 0.5-year and 27-day oscillations ->

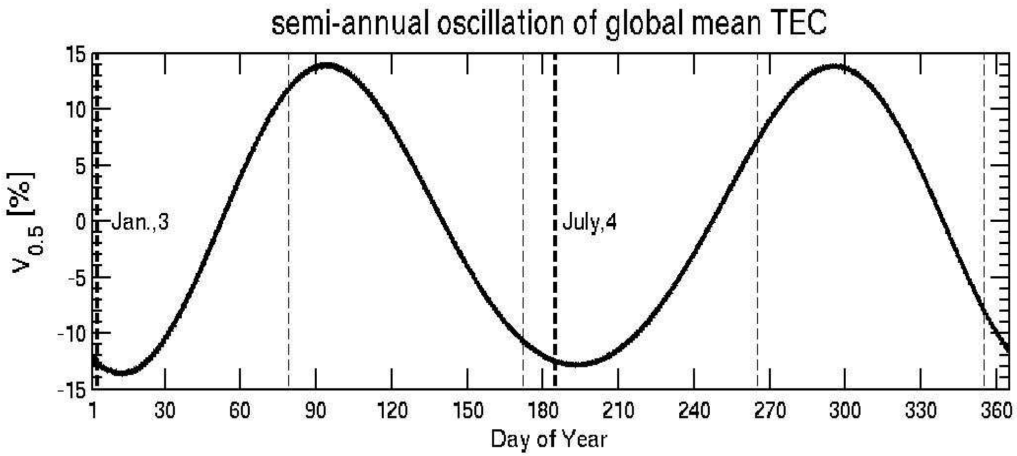


Annual asymmetry of the Earth's Ionosphere
or „Why is there more Ionosphere in January than in July?“ [1)]

Analysis: -> global mean TEC series of solar cycle 23
-> average, yearly curve of global mean TEC
-> decomposition into annual and semi-annual oscillation of global mean TEC

Amplitude of annual TEC oscillation is 12% and in phase with annual oscillation of solar irradiance (due to changing Sun-Earth distance)





-> Result is okay,
but 12% is 4 times greater than Chapman theory predicts (photoionization without plasma transport and composition changes)

-> Result is in agreement with previous studies by **Rishbeth**[1)], **Afraimovich, Mendillo and others** using other data sets

How is the Response of the Temperature to the Changing Sun-Earth Distance?

Assumption of radiative equilibrium:

atmospheric layer at altitude z absorbs a certain fraction of the total solar irradiance F: $Q(z) = F(z+\Delta z) - F(z)$

Stefan-Boltzmann equation: $$\frac{\pi\,(r_E+z)^2\,Q(z)}{4\,\pi\,(r_E+z)^2} = \sigma\,T_{eff}(z)^4$$

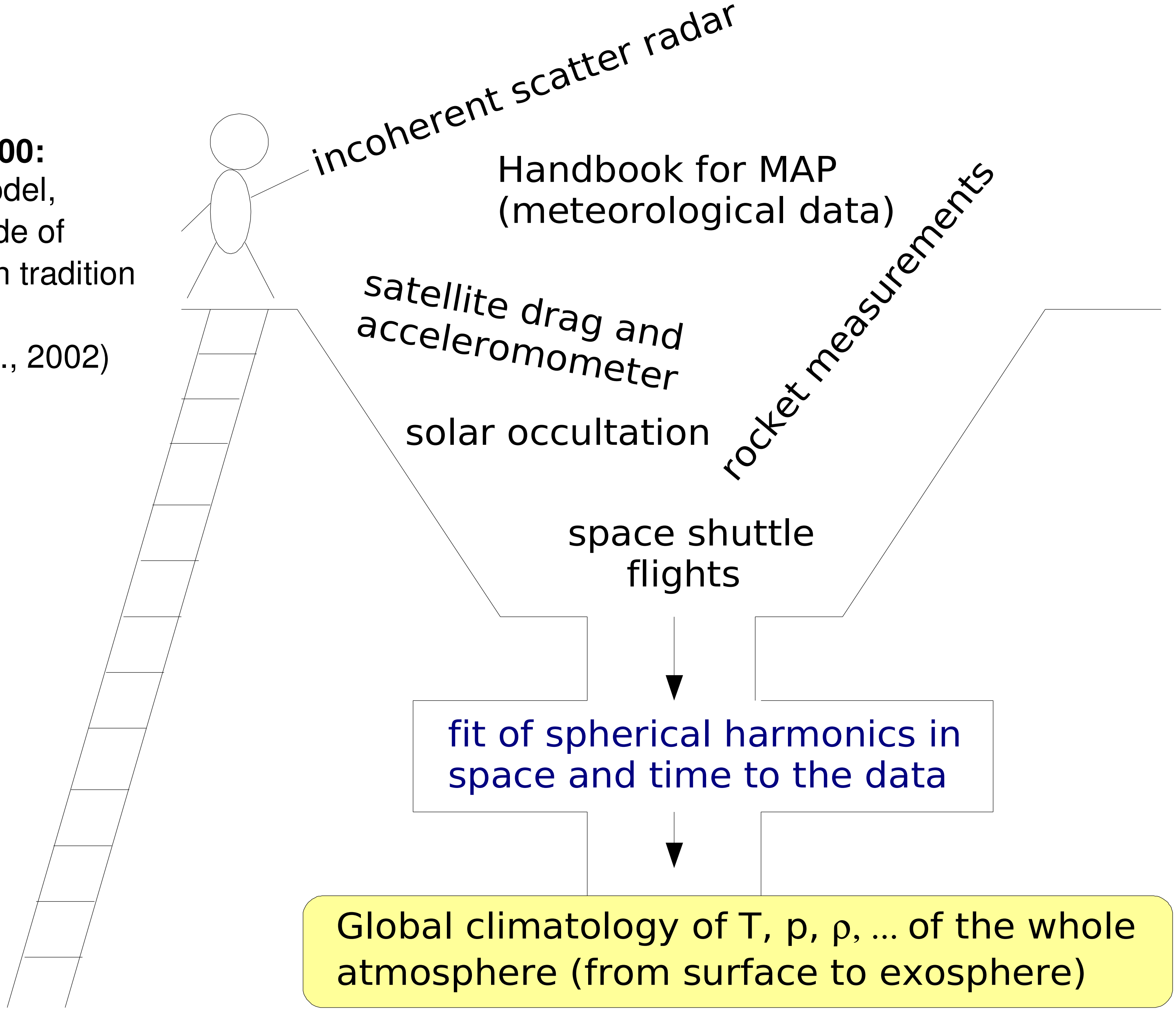
differentiation

due to annual change of Sun-Earth distance

$$\boxed{\frac{\Delta\,T_{eff}(z)}{T_{eff}(z)} = \frac{\Delta\,Q(z)}{4\,Q(z)} \approx \frac{3.3\%}{4} \approx 0.8\%}$$

Annual perturbation of T_{eff} is about 2 Kelvin for T_{eff}=280K

NRLMSISE-00:
empirical model,
major upgrade of
MSISE-90, in tradition
of CIRA
(Picone et al., 2002)



Annual Variation of Temperature in the Tropics:

-> we take the zonal mean T of NRLMSISE-90 in the tropics (averaged from 20S to 20N) as function of pressure level and Day of Year

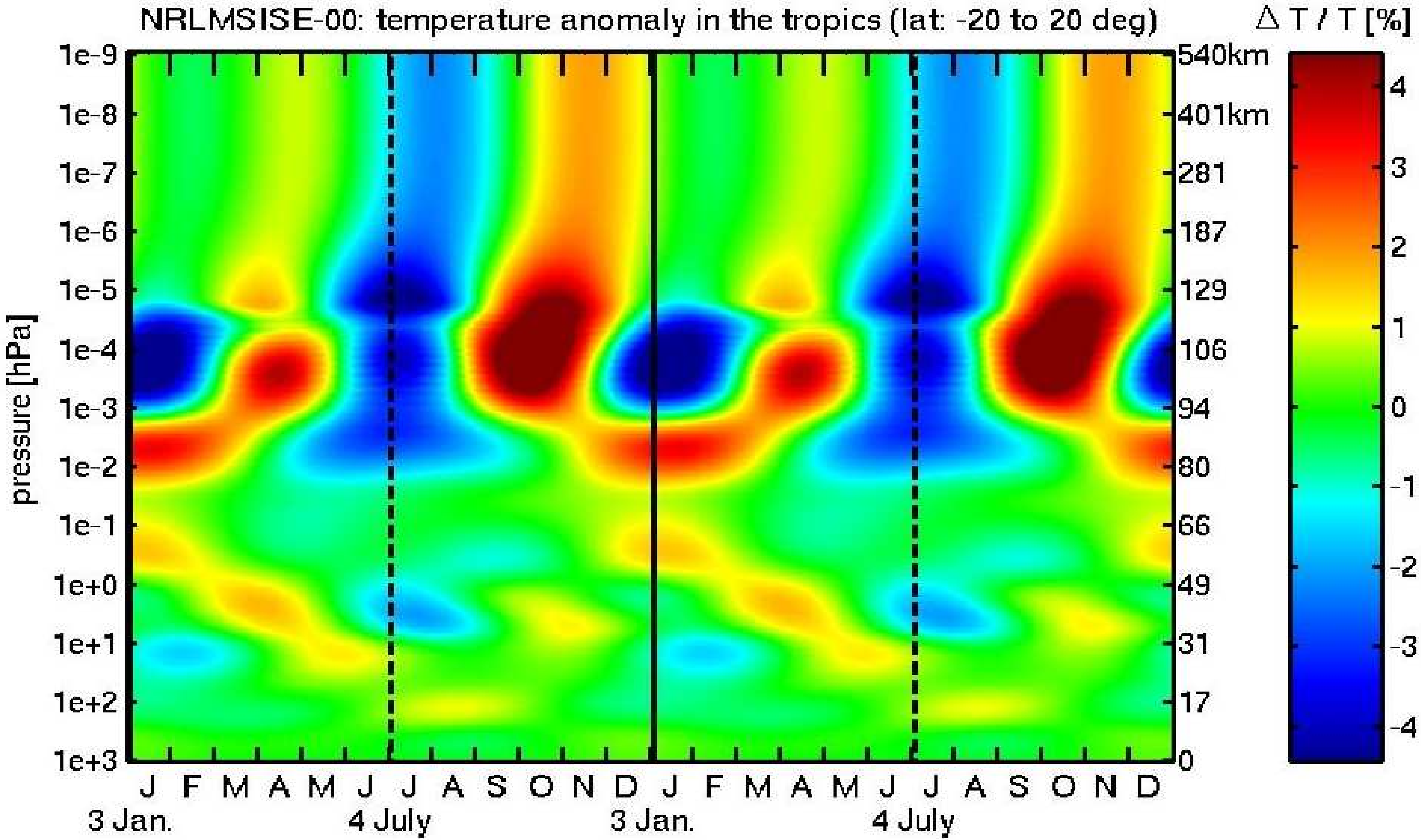
-> calculation of the **annual temperature anomaly** defined by

$$\frac{\Delta T}{T} = \frac{T(p,t) - \langle T(p,t) \rangle_{year}}{\langle T(p,t) \rangle_{year}}$$

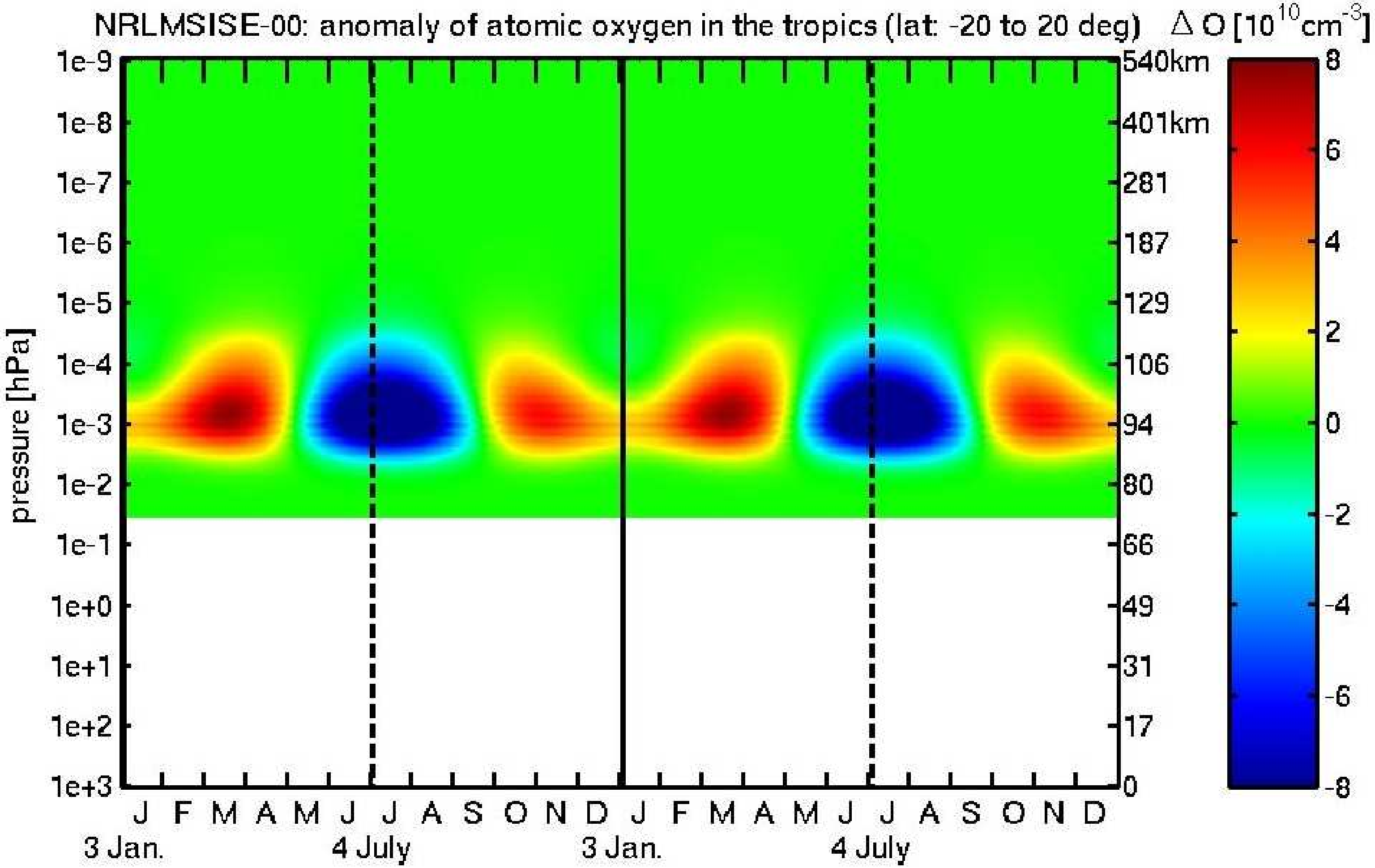
Time-height cross section of the tropical temperature anomaly will show:

1) strong SAO in the dynamo region (105 km)
2) clear AO in the upper mesosphere (80-85 km) with temperature maximum in January
3) warm tropopause region (17 km) around August (switch of the tropical tape recorder of water vapor)
4) signature of downward control from mesopause to tropopause
5) many other things ...

Time-Height Cross Section of the Temperature Anomaly in the Tropics (20S-20N, 2-year interval) :

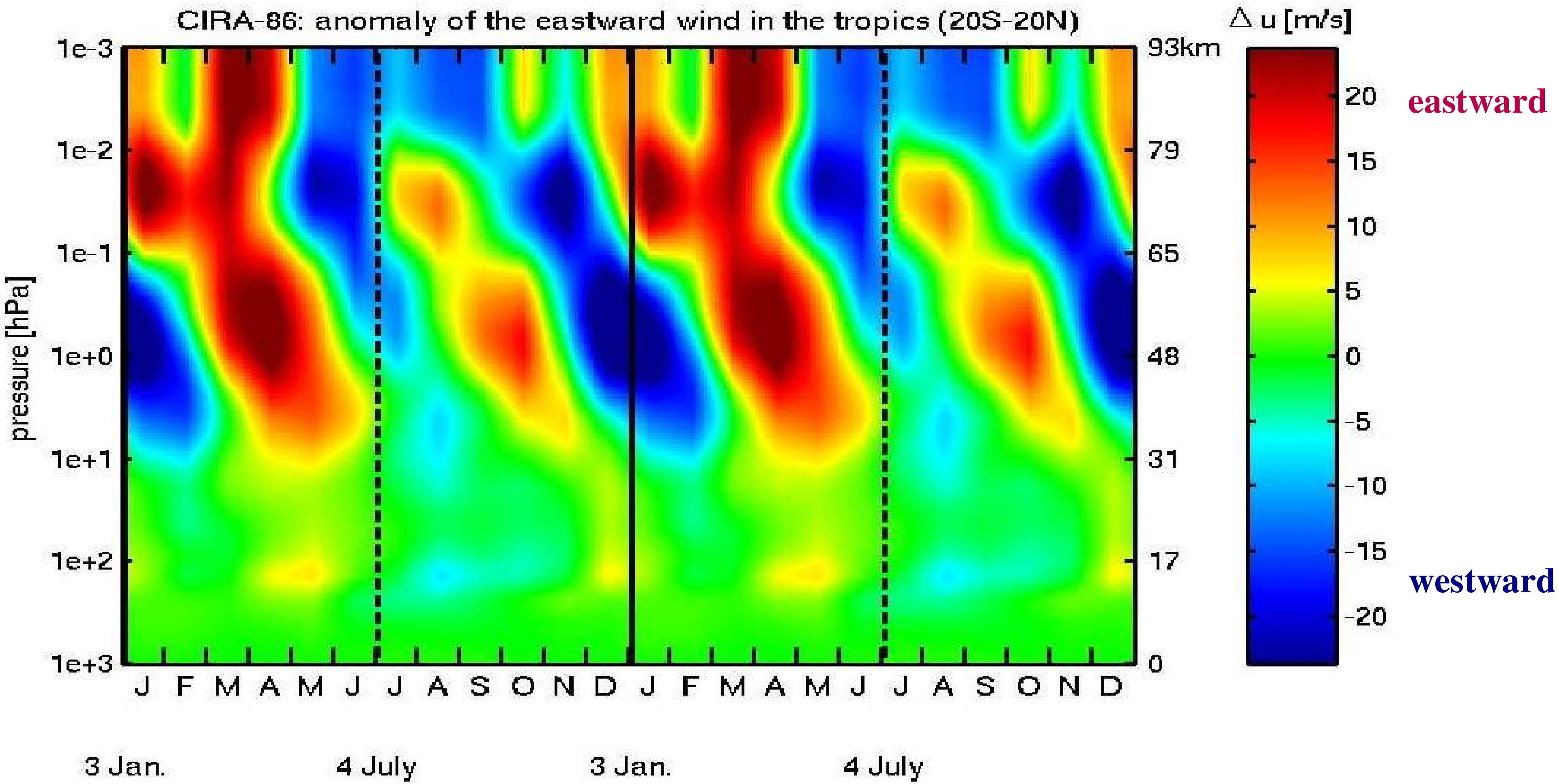


Time-Height Cross Section of the Anomaly of Atomic Oxygen in the Tropics (20S-20N, NRLMSISE-00):

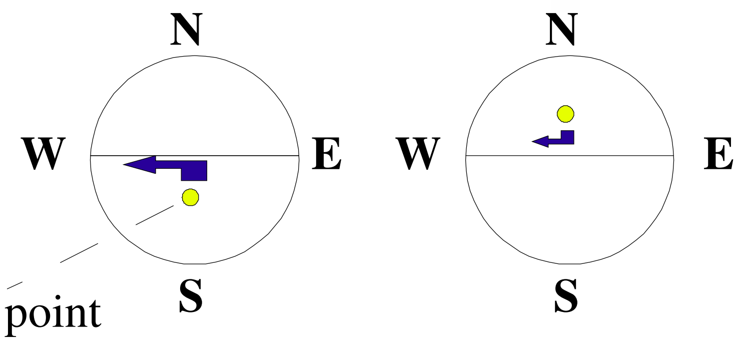


Atomic oxygen density is decreased by about 15% around the mesopause in July. Due to reduced photodissociation rate of O_2 in July?

Time-Height Cross Section of Eastward Wind Anomaly in the Tropics (20S-20N) :



Jan.: minimal
Sun-Earth distance
-> maximal heating



July: maximal
Sun-Earth distance
-> minimal heating

Conclusions:

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- Annual variation of Sun-Earth distance possibly induces the annual asymmetry of global mean TEC, but amplification is needed (e.g., upward plasma drift, composition change). 3.3% change of EUV gives 12% change of TEC

- Annual variation of temperature (ca. 3%) in the upper tropical mesosphere is in phase with the annual oscillation of solar irradiance

- Signature of a dynamical, downward control from the mesosphere to the tropopause is present in the NRLMSISE-00 climatology
  -> effect on annual asymmetry of tropical tropopause?

- Annual anomaly of westward wind around the stratopause (CIRA-86) in phase with annual oscillation of solar irradiance

- Other causes: hemispheric differences, gravity waves, ...