
And now for something totally different…

EFFECTS OF SOLAR ACTIVITY ON THE EARTH'S CLIMATE

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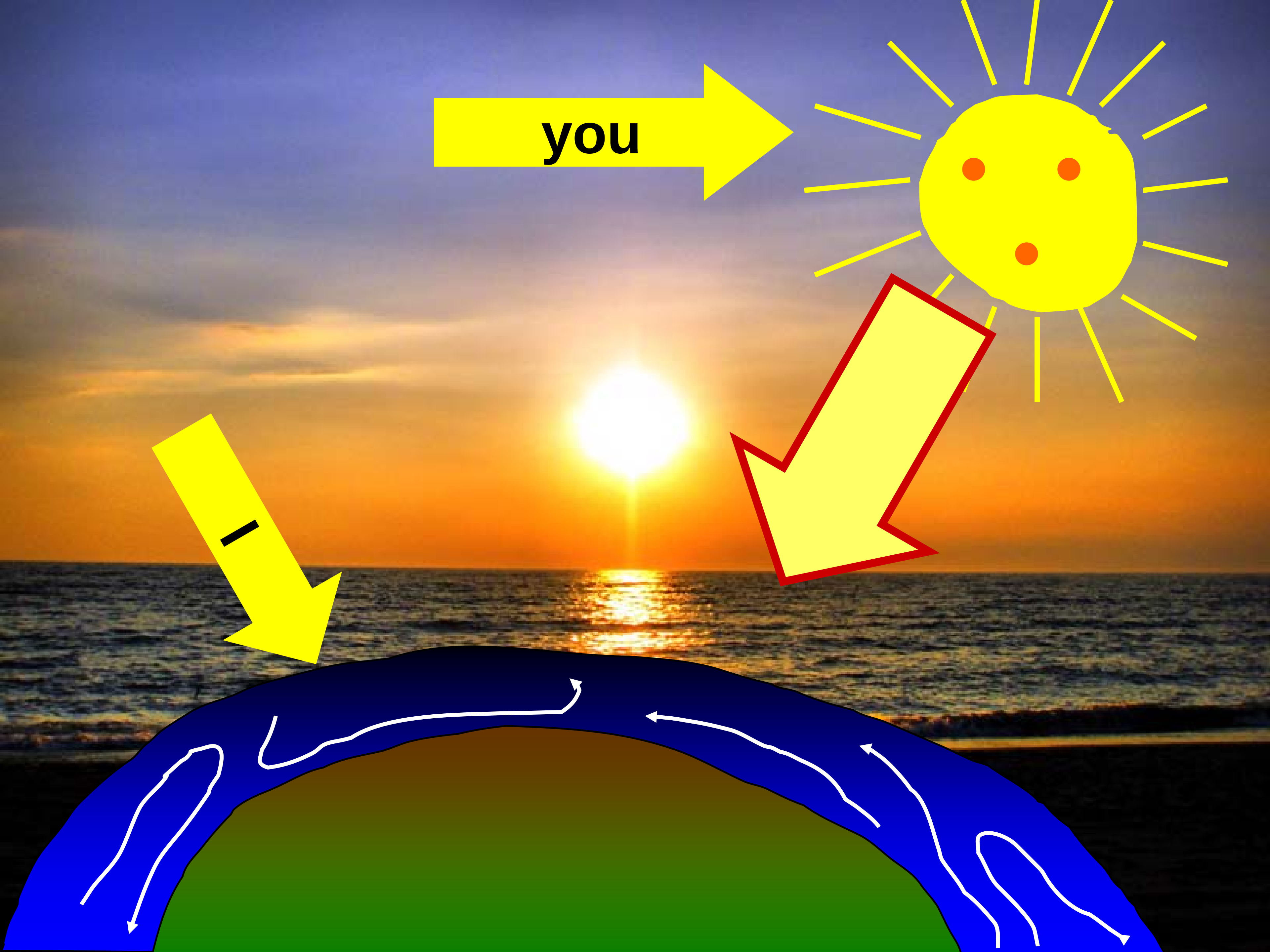
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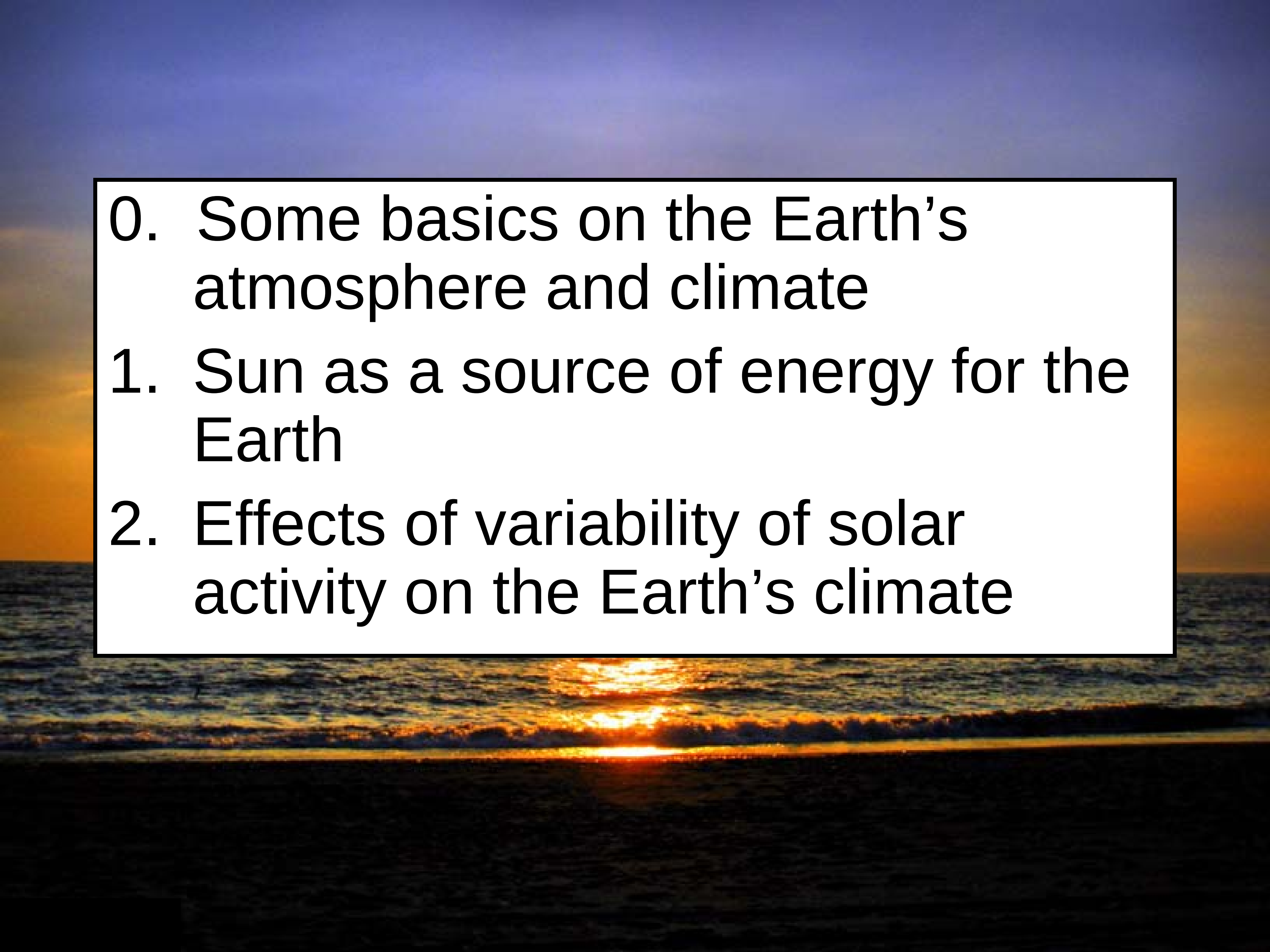
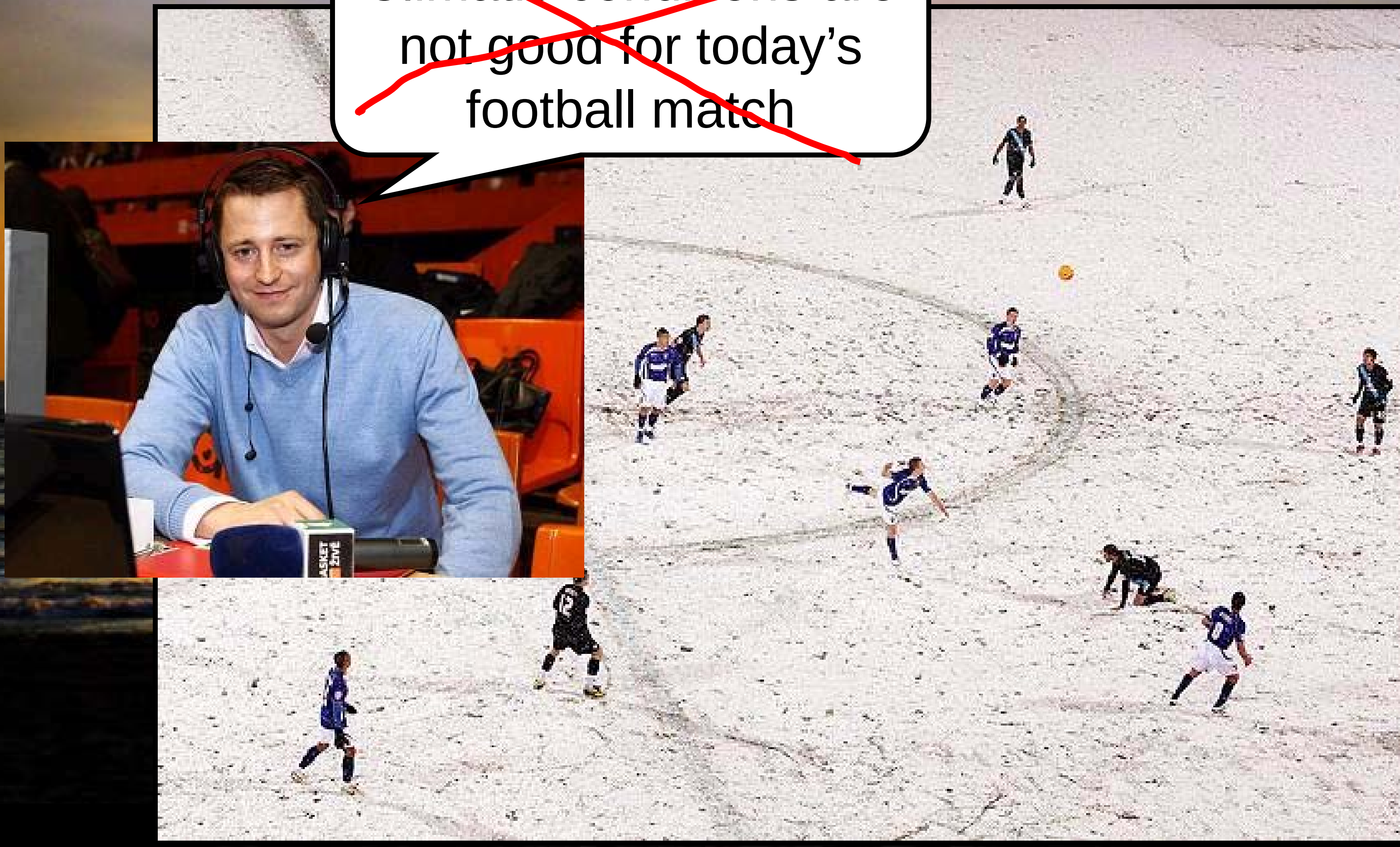
1. Sun as a source of energy for the Earth
2. Effects of variability of solar activity on the Earth's climate



0. Some basics on the Earth’s atmosphere and climate
1. Sun as a source of energy for the Earth
2. Effects of variability of solar activity on the Earth’s climate

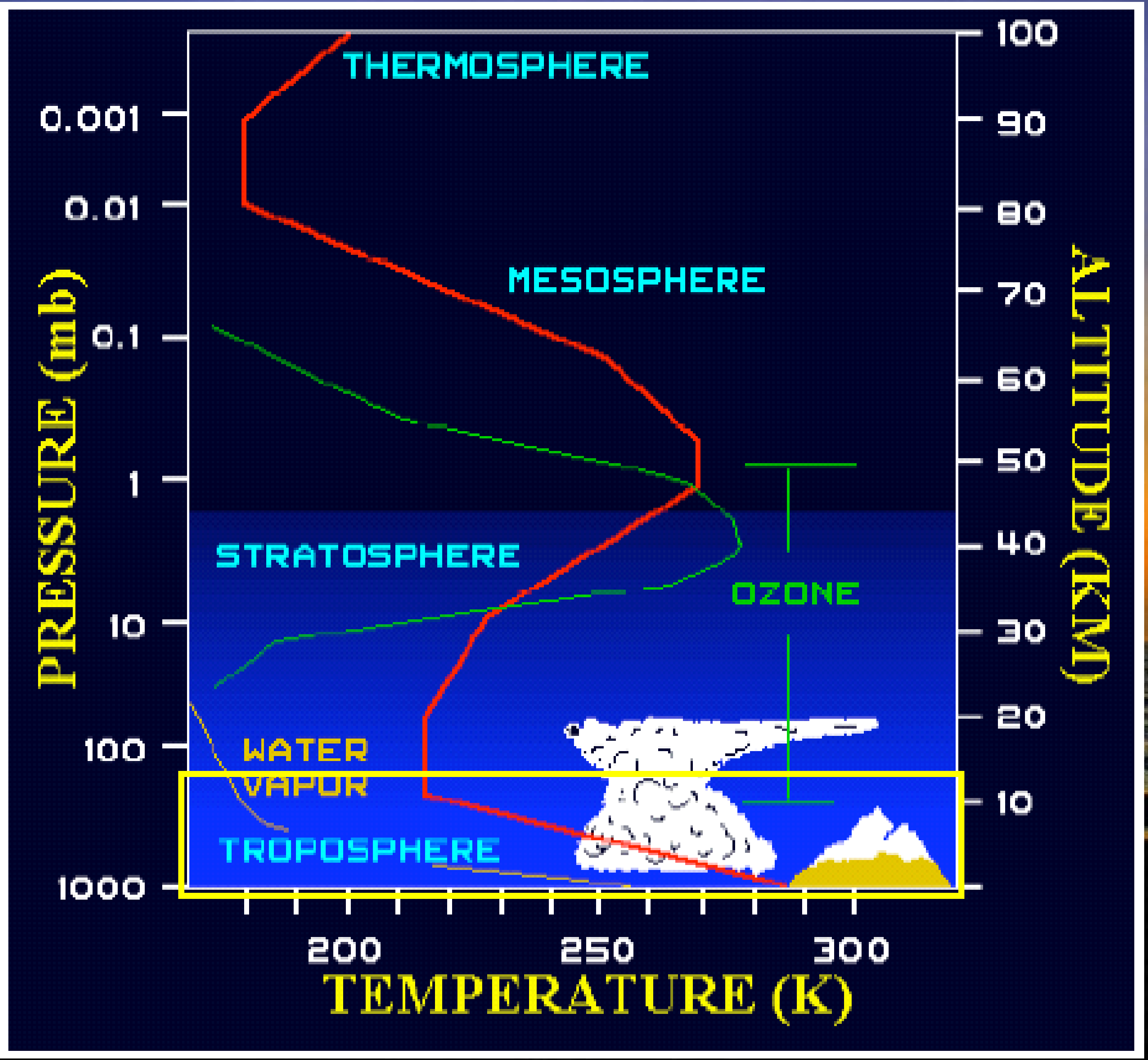
Climate vs. weather

~~Climatic conditions are not good for today's football match~~



Climate vs. weather

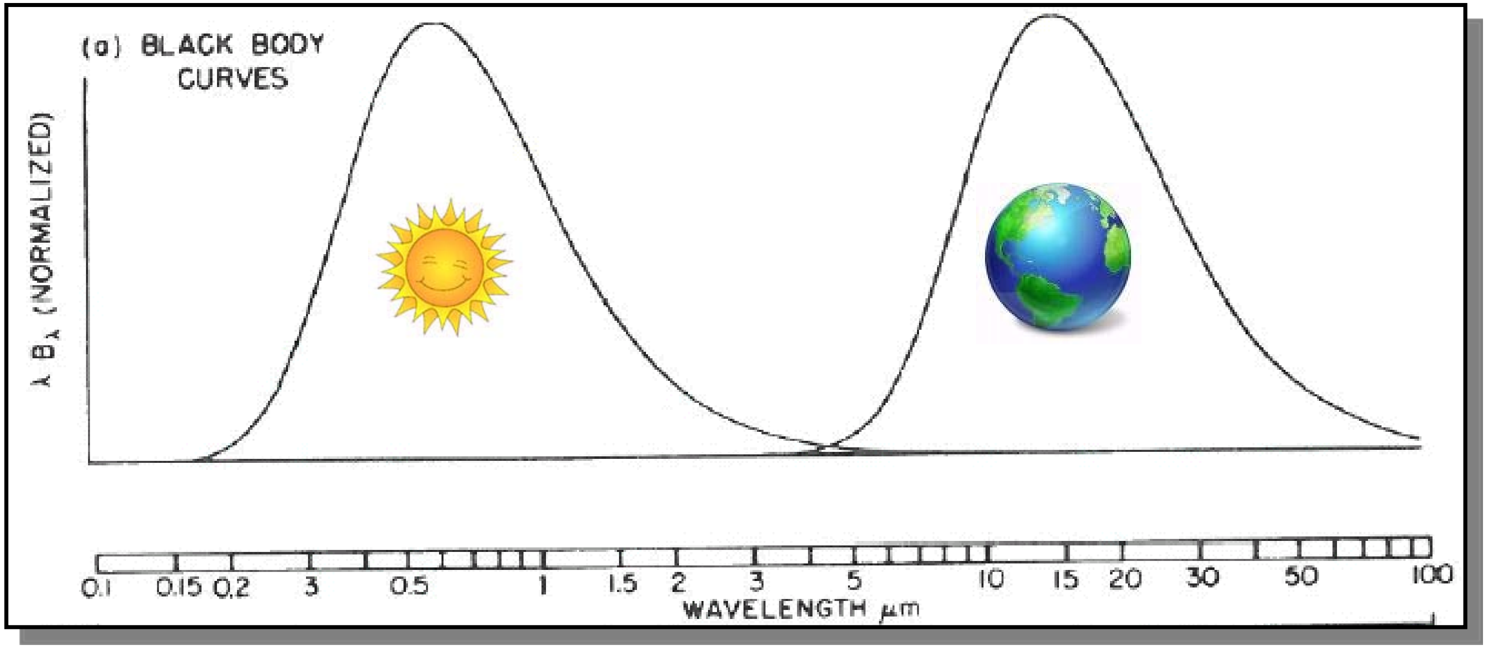
- Climate
  - synthesis of weather at a given site
  - long-term characteristic regime of weather
- ... weather ?
  - instantaneous state of the atmosphere
- climatology x meteorology



THERMOSPHERE
MESOSPHERE
STRATOSPHERE
OZONE
WATER VAPOR
TROPOSPHERE
PRESSURE (mb)
0.001
0.01
0.1
1
10
100
1000
ALTITUDE (KM)
100
90
80
70
60
50
40
30
20
10
200
250
300
TEMPERATURE (K)

Radiative spectra: Earth vs. Sun

- Earth: lower temperature ➔ longer wavelength



- in infrared
- what's the Earth's radiative temperature?

Earth's radiation

absorbed solar radiation = emitted planetary radiation

(from Stefan-Boltzmann's law; supposing Earth is a black body)

solar "constant" x
ratio of absorbed radiation x
area

σ x (radiative temperature)^4
x area

$$S_0(1-\alpha_p)\pi r^2 = \sigma T_Z^4 4\pi r^2$$

???

$$T_Z = \sqrt[4]{\frac{(S_0/4)(1-\alpha_p)}{\sigma}} \Rightarrow T_Z = 255K = -18^oC$$

BUT: real mean surface temperature of the Earth is **+15 °C**

Greenhouse effect

- keeps Earth's surface ~ 33 °C warmer than what corrersponds to the radiative balance (i.e. what it would have been in the absence of atmosphere)
- warms the Earth's surface ← atmosphere is
  - permeable for solar SW radiation
  - impermeable for Earth's LW radiation

  (atmosphere absorbs LW radiation from Earth's surface and re-emits it as a black body)
- what can be blamed?
  - greenhouse gases: water vapour, CO_2, CH_4, O_3, N_2O, chloroflourocarbons (CFC's), …

Energy budget of the atmosphere

- solar radiation absorbed by the Earth and its atmosphere is affected by
  - albedo
  - geographical latitude
- resultant radiative budget

  difference

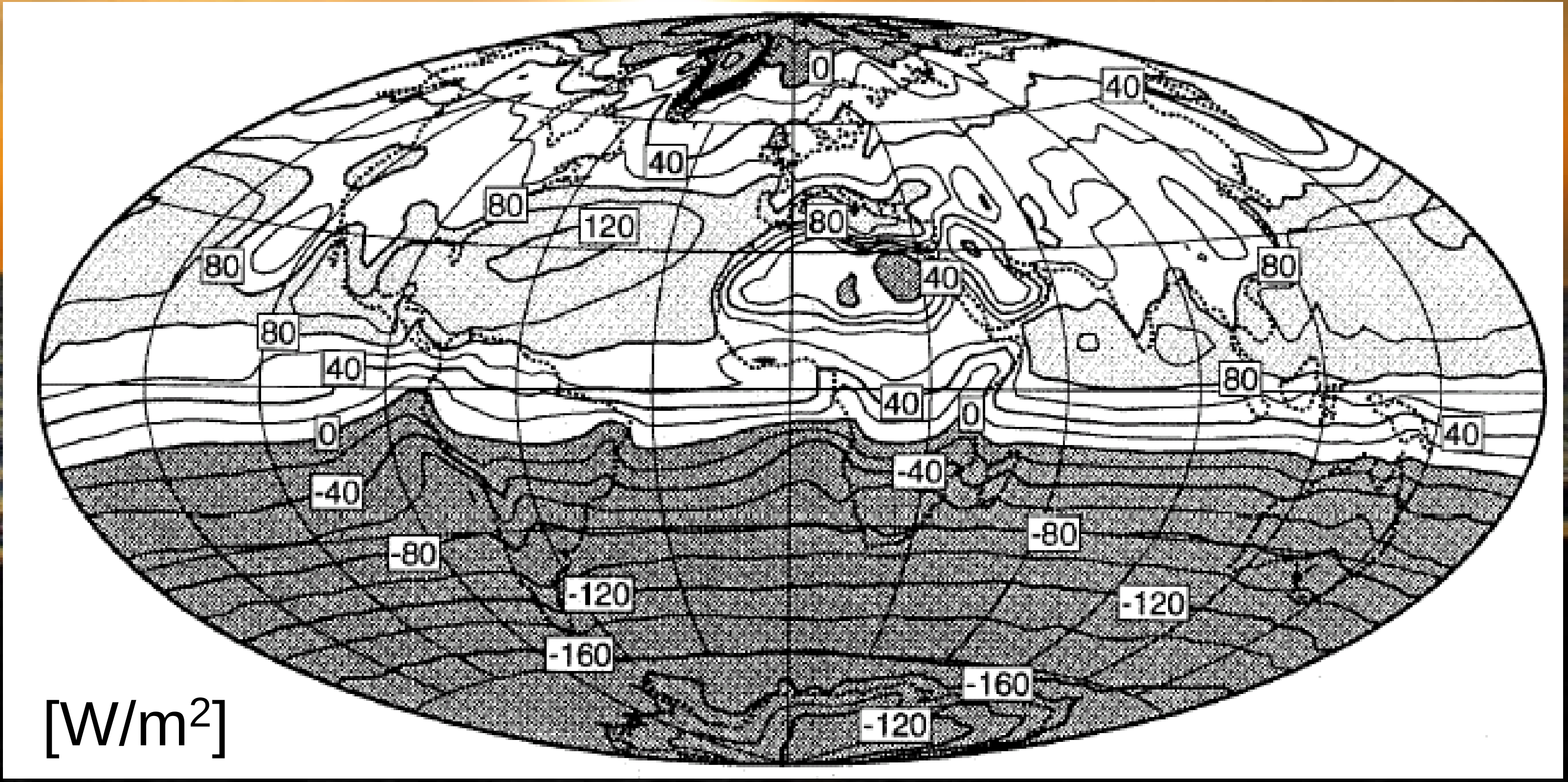
  incoming SW (solar) radiation

  minus

  outgoing emitted LW radiation

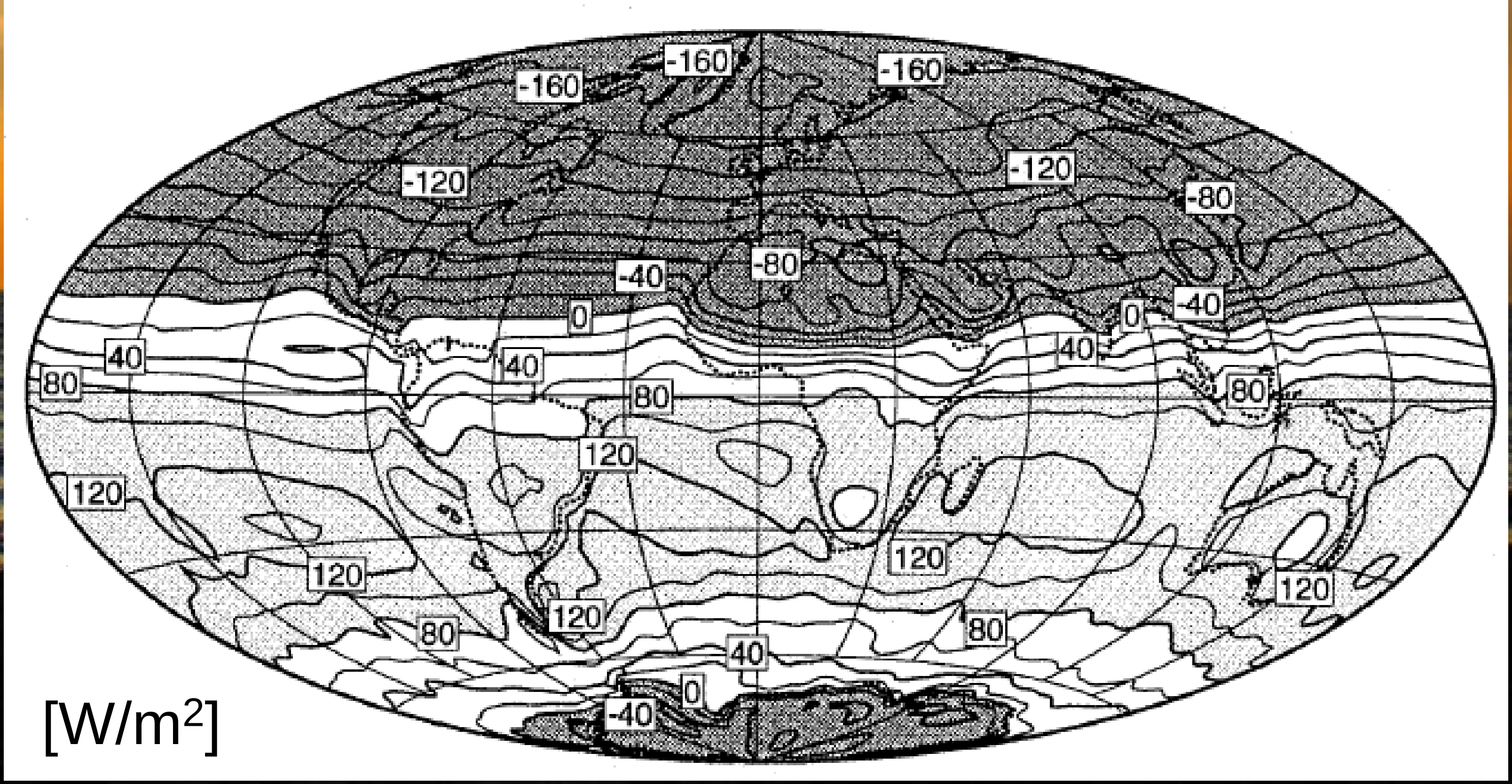
Energy budget of the atmosphere

- resultant radiative budget: Northern Hemisphere summer



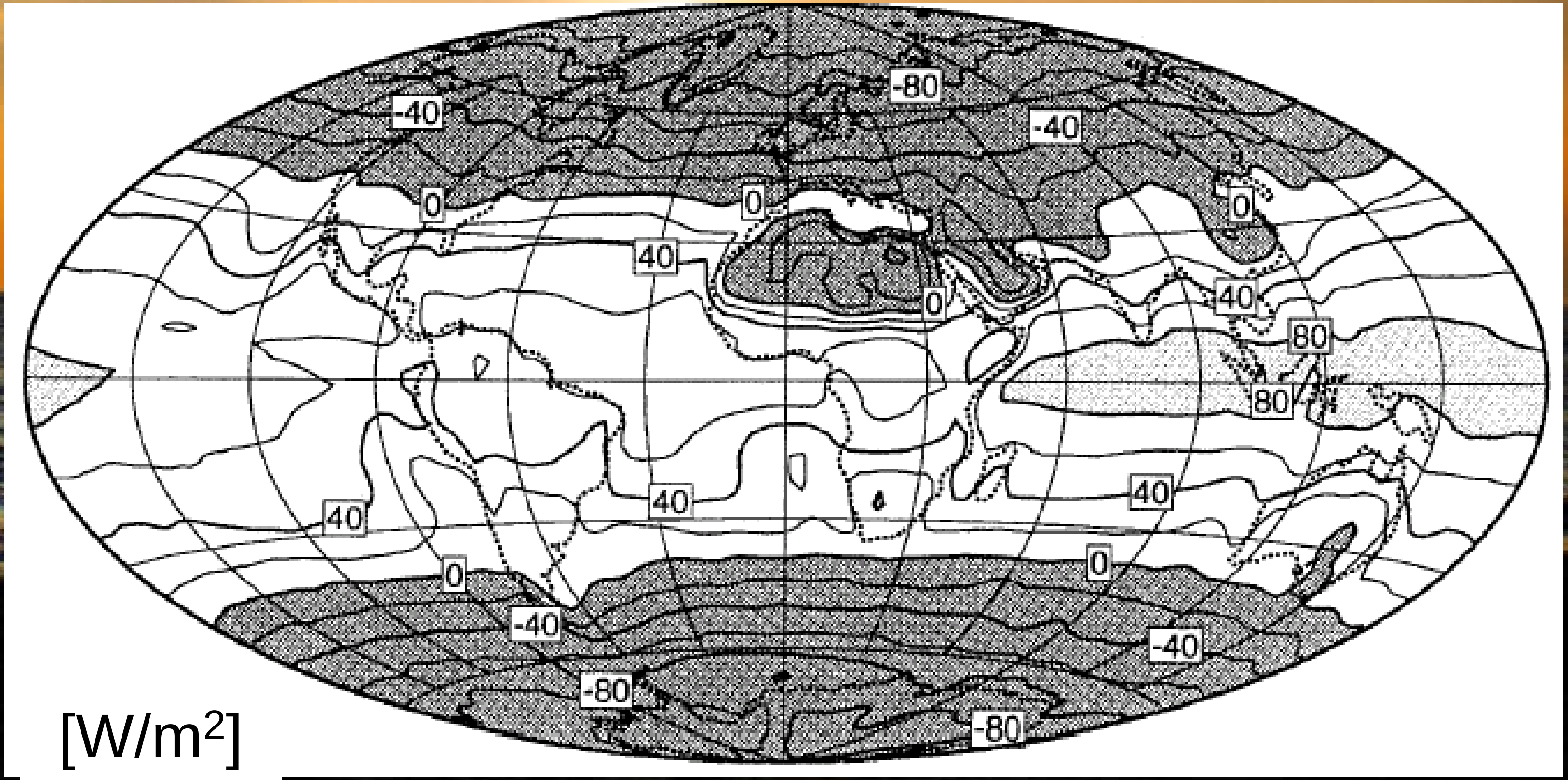
Energy budget of the atmosphere

- resultant radiative budget: Northern Hemisphere winter



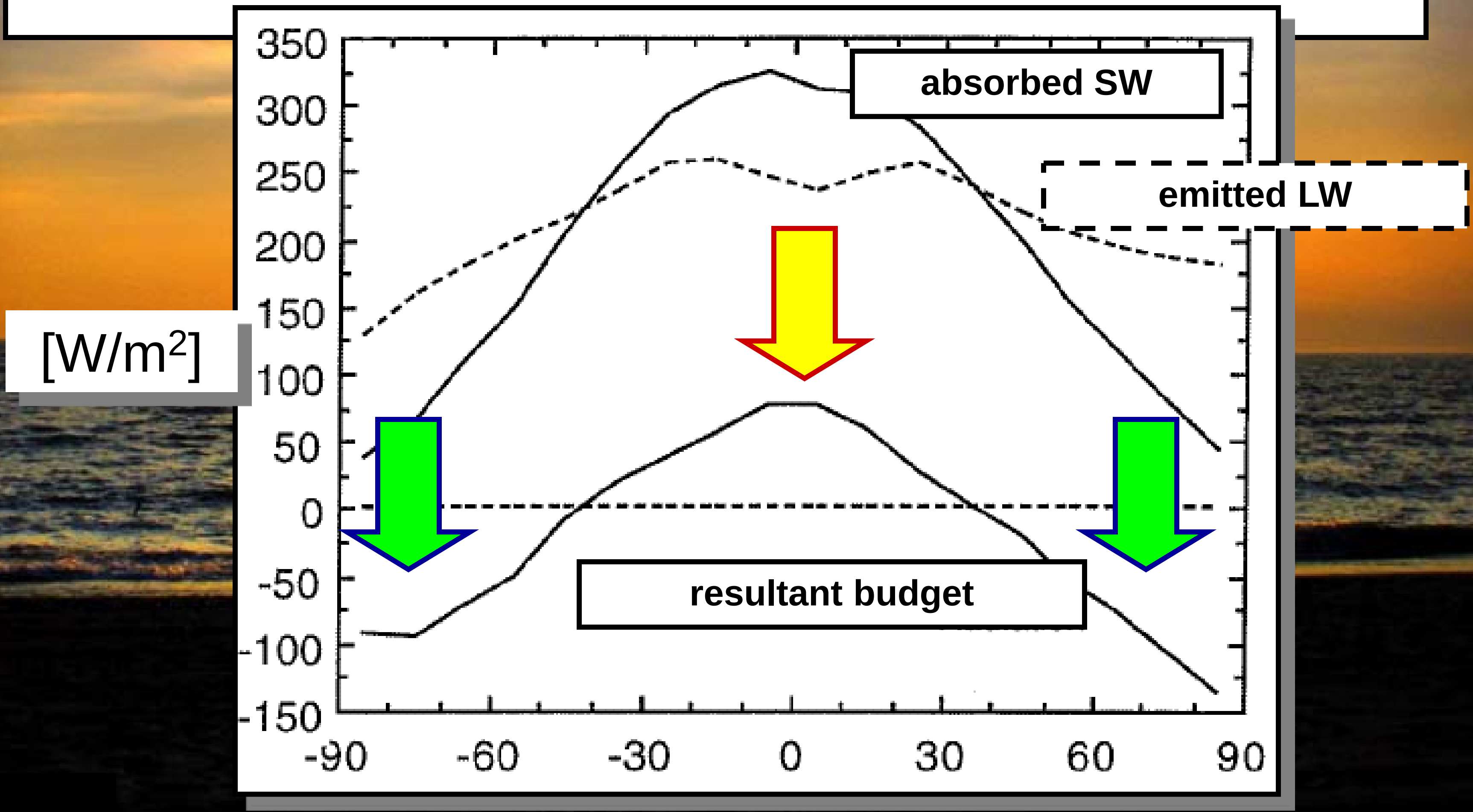
Energy budget of the atmosphere

- resultant radiative budget: annual



Energy budget of the atmosphere

- zonal average



Meridional heat transport

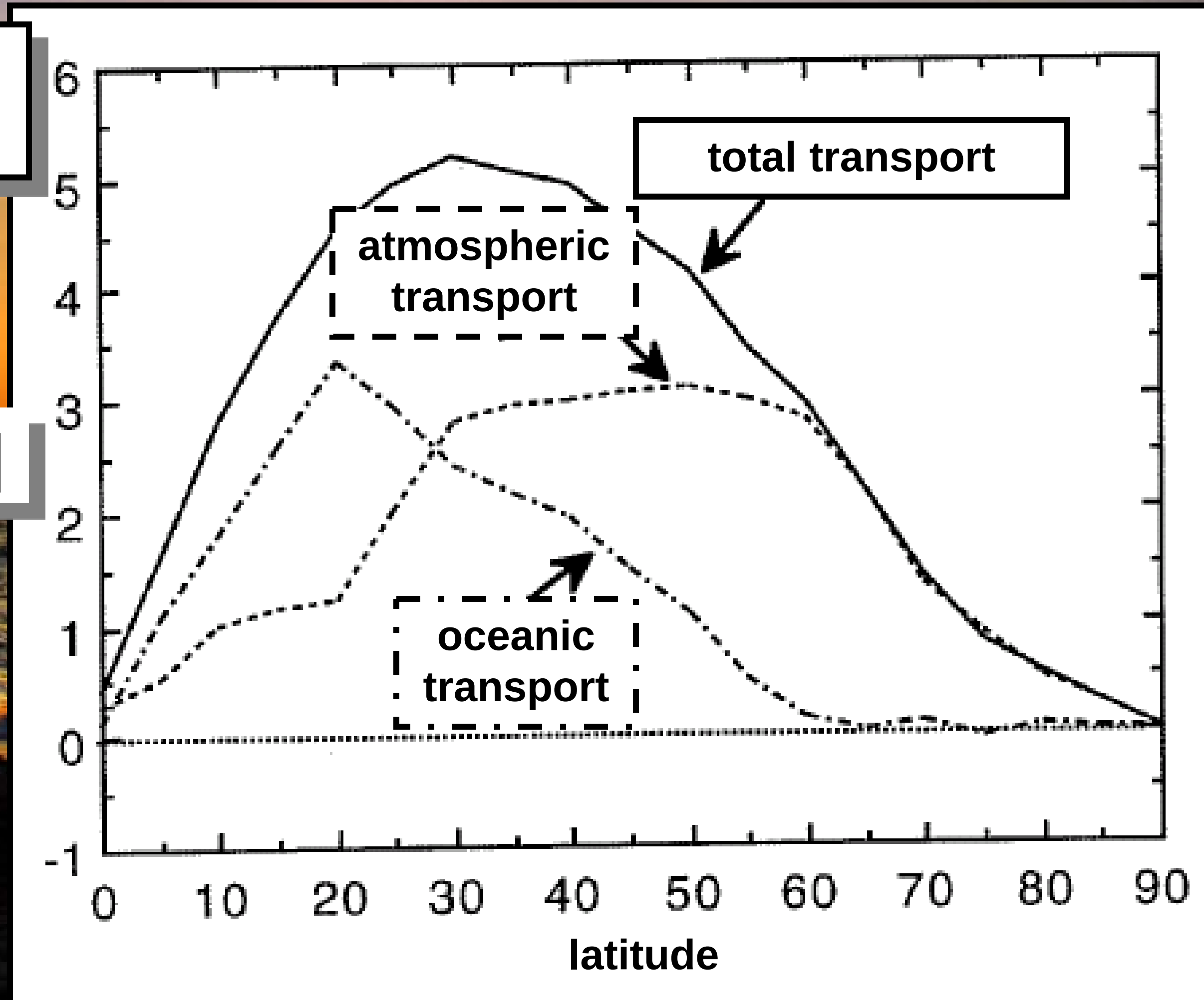
- ❑ heat can't accummulate →
- ❑ radiative imbalance must be adjusted
- ❑ mechanism: meridional heat transport (along meridians, i.e., N←→S)
  - – through atmosphere
  - – through ocean
- ❑ geographical imbalance of the radiation budget – one of the two major mechanisms to maintain global atmospheric and oceanic circulation

Meridional heat transport

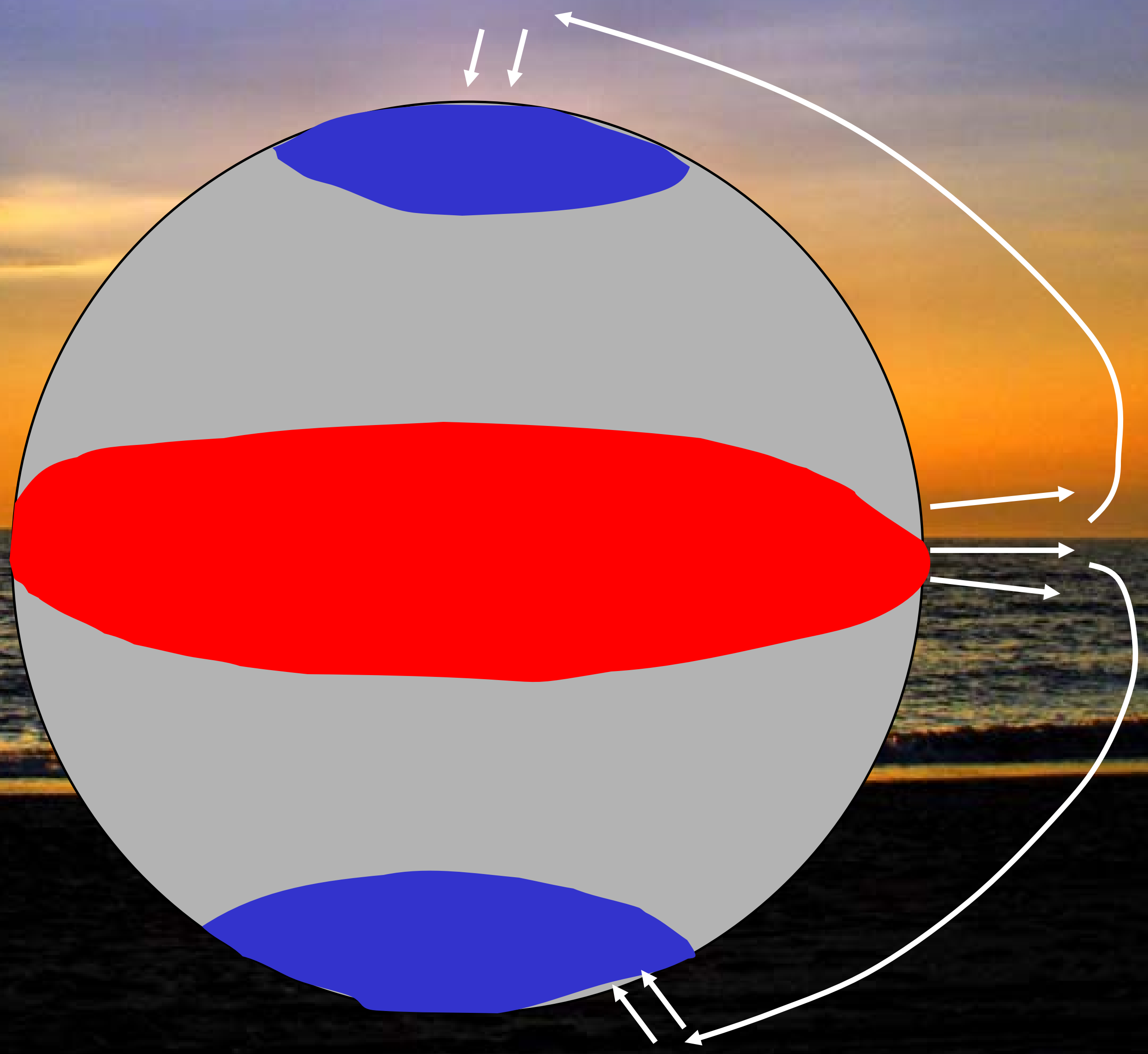
(Northern Hemisphere, annually)

[pW]

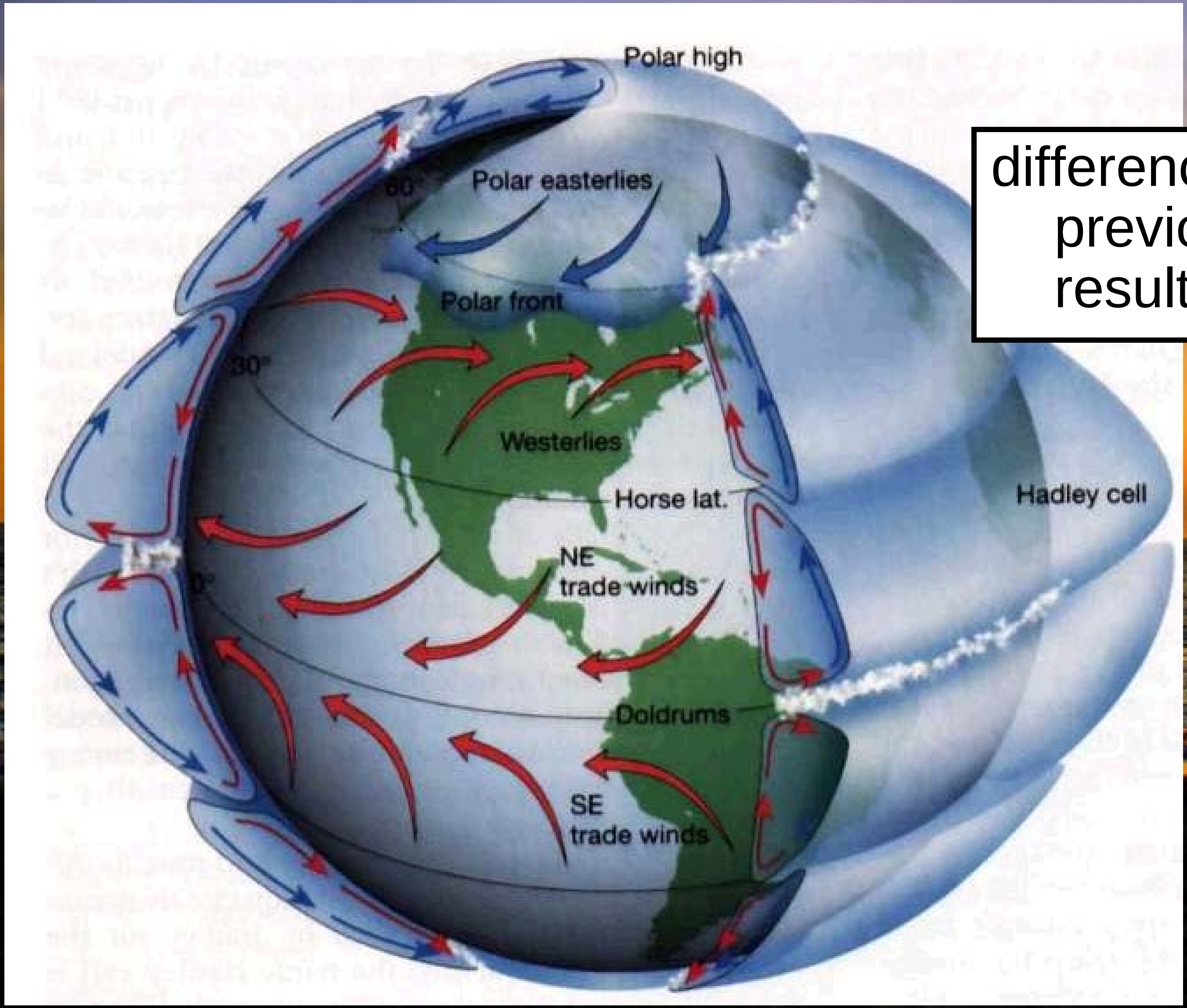
(p = peta ~ 10^{15})



Global atmospheric circulation – if there's no Earth's rotation



… and with rotation …



difference from the previous slide – a result of Coriolis force

Effects of solar variability

- on a wide rage of timescales
  - – from billions of years
  - – up to seasonal

Extremely long time scale

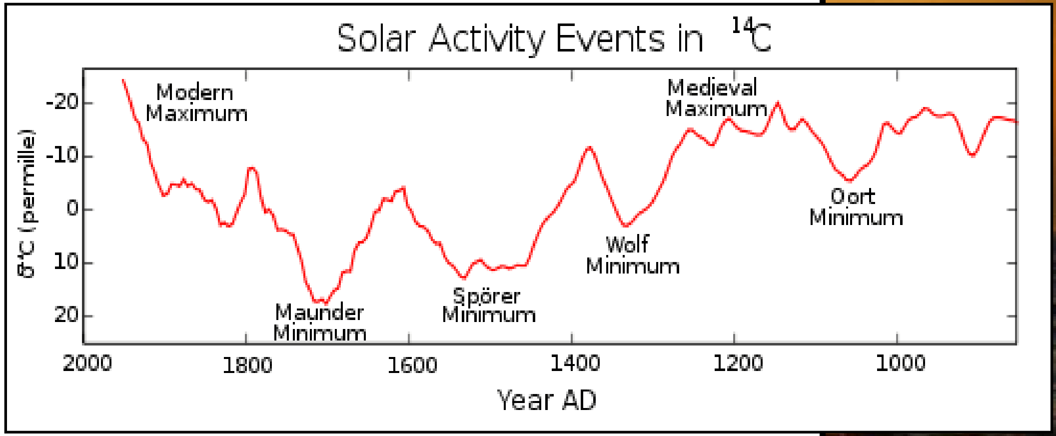
- luminosity of the Sun – is said to have grown by ~ 30% since its formation
- geological findings don’t correspond to a cooler climate in the distant past
  - presence of liquid water 3.8 bill. yr ago
  - absence of ice cover 2.7 bill. yr and more ago
- discrepancy: less shining Sun x warm Earth’s climate
- likely explanation: much stronger greenhouse effect than today

Multi-millenial time scale

- changes in the parameters of the Earth's orbit
  - excentricity:
    - the more excentric, the more solar radiation is received
  - tilt (obliquity) of Earth's axis:
    - governs latitudinal distribution of incoming radiation
  - precession:
    - re-distribution of incoming radiation during year
- proceed with periods of the order of 10 kyr
- Milankovich theory: this drives the alteration of glacials / interglacials during the past Myr
- in the last 700 kyr, climate was as warm as or warmer than today for only 8% of time

Centennial time-scales

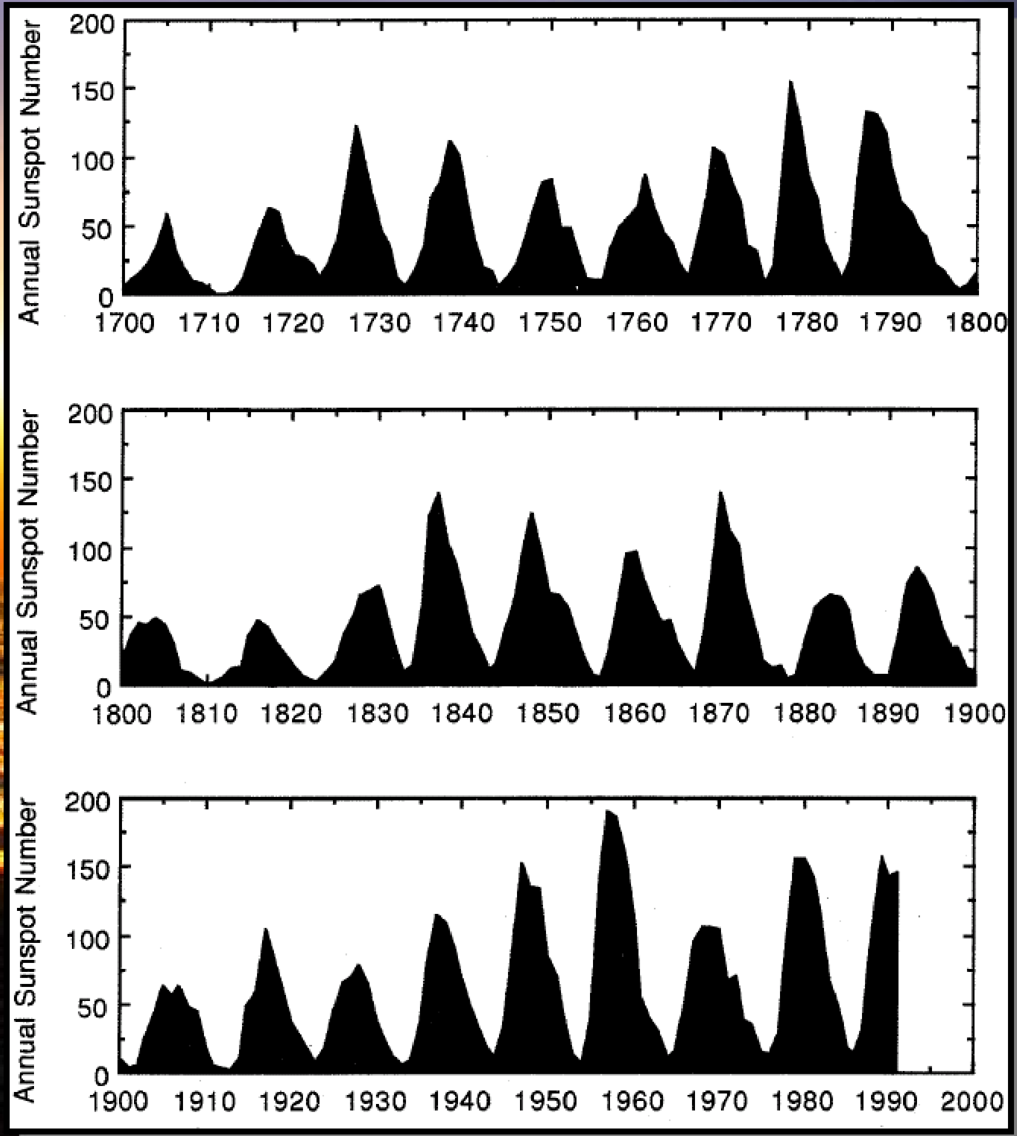
- periods of low solar activity (as measured by numbers of sunspots) coincide with lower temperatures on Earth
  - – Dalton minimum
  - – Maunder minimum
  - – Spörer minimum
  - – ...



- causality has not been (dis)proved, but is likely

Decadal to seasonal time-scales

- ❑ related mainly to the 11-year (Schwabe) cycle



Effects of 11-yr cycle

- changes in the 11-yr cycle → changes in incoming solar radiation by 1,5 W/m^2, i.e., by mere 0,1%
- change in energy income very small compared to the energy of the whole atmosphere
- can such a small variation affect the Earth's climate?
- rather controversial question

Effects of 11-yr cycle

- effects on upper atmosphere (down to stratosphere) already accepted in the scientific community
- effects on **troposphere** – controversial topic for a long time, “serious” topic only recently
  - mainly because of the imbalance between weak changes in solar energy input x strong energy of tropospheric circulation
- proofs that solar effects on troposphere (densest part of the atmosphere) are possible are becoming more and more numerous
- what about potential mechanisms?

Potential mechanisms

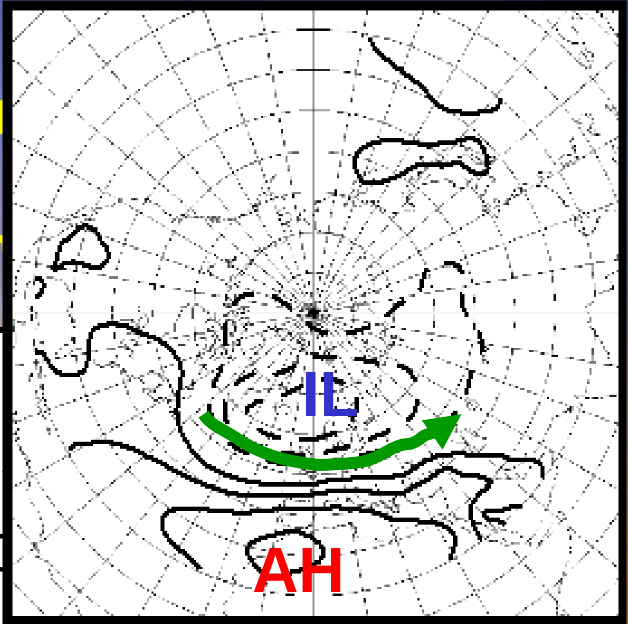
- ❑ several potential mechanisms, so far not clear which, and to what extent, do contribute
- ❑ mechanism #1 – via **stratosphere**:
  - changes in the UV part of spectrum are much larger (up to 7%)
  - possible physical mechanism: change in incoming solar UV radiation ➔ change in O_3 concentration ➔ change in stratospheric temperature ➔ change in stratospheric circulation ➔ downward propagation to troposphere
  - for it to work, downward propagation must be possible ➔ only winter season in the Northern Hemisphere

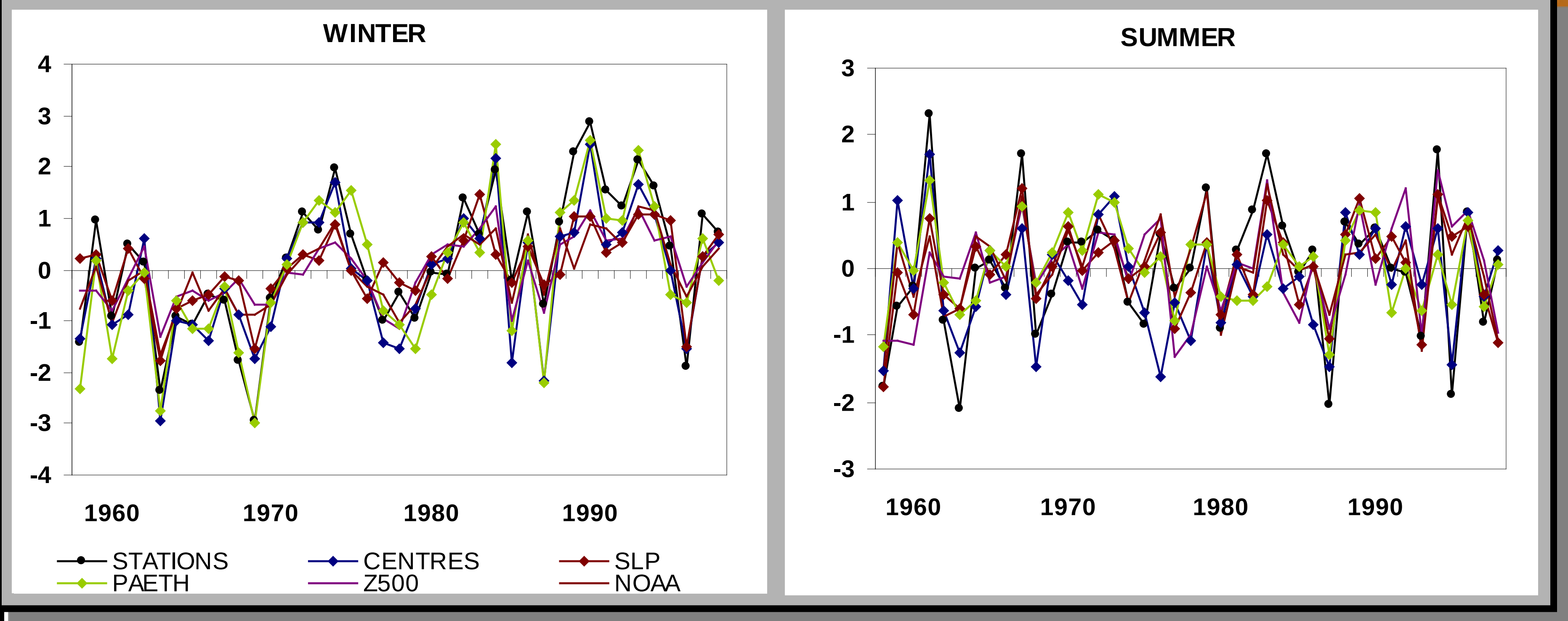
Potential mechanisms

- other hypotheses on potential mechanisms of solar effects on the Earth’s climate:
  - modulation of global **electric circuit** ➔ changing atmospheric conductivity in high latitudes ➔ changing cloud microphysics ➔ cyclogenesis
  - energetic particles act as condensation nuclei ➔ changes in **cloudiness**
  - direct effects of visible radiation in Tropics ➔ coupled **air-sea-cloud feedbacks** ➔ poleward transmission

Example 1: North Atlantic Oscillation (and some sir

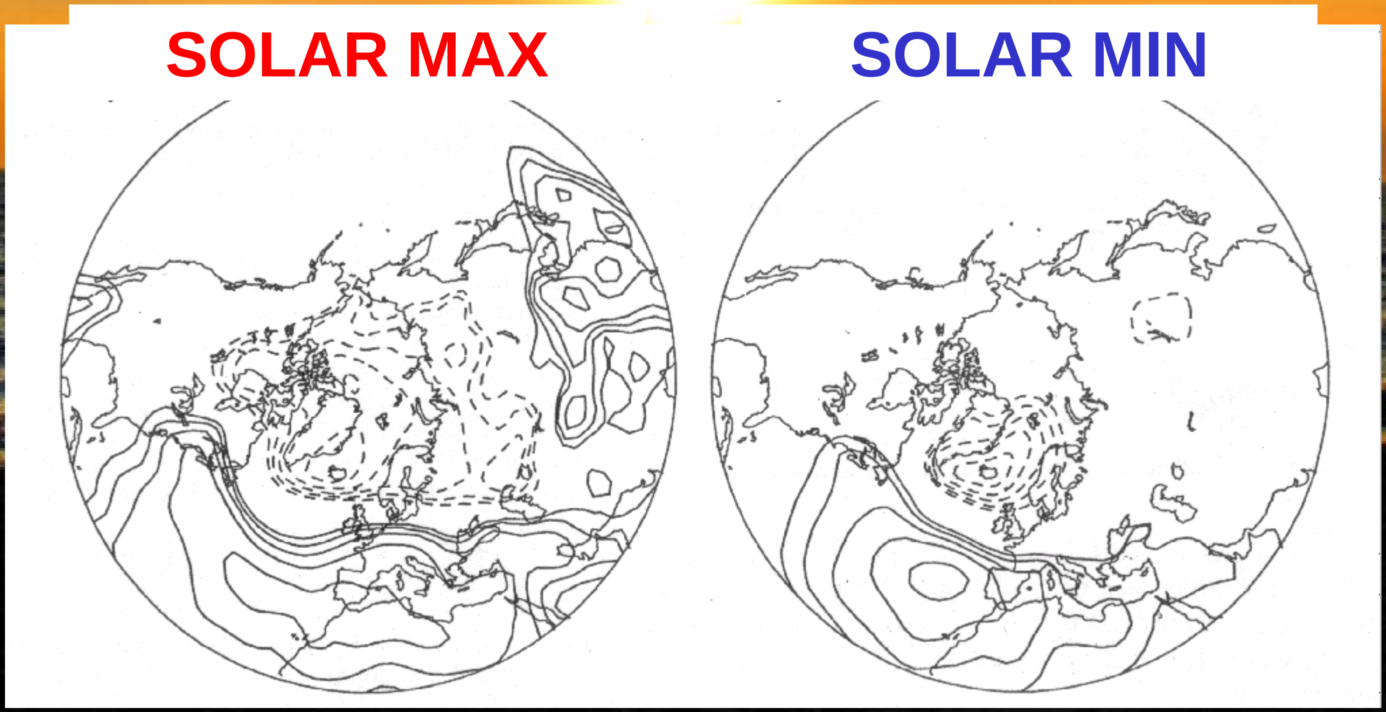
- North Atlantic Oscillation (NAO) – a s between Icelandic Low (IL) and Azore
- NAO = most important driver of Europ weather, especially in winter





Kodera (*Geophys. Res. Lett.* 2002, 2003):

NAO in sea level pressure (i.e., correlations of NAO index with it) – much larger geographical extension under maxima of 11-year solar cycle



NAO (North Atlantic Oscillation)

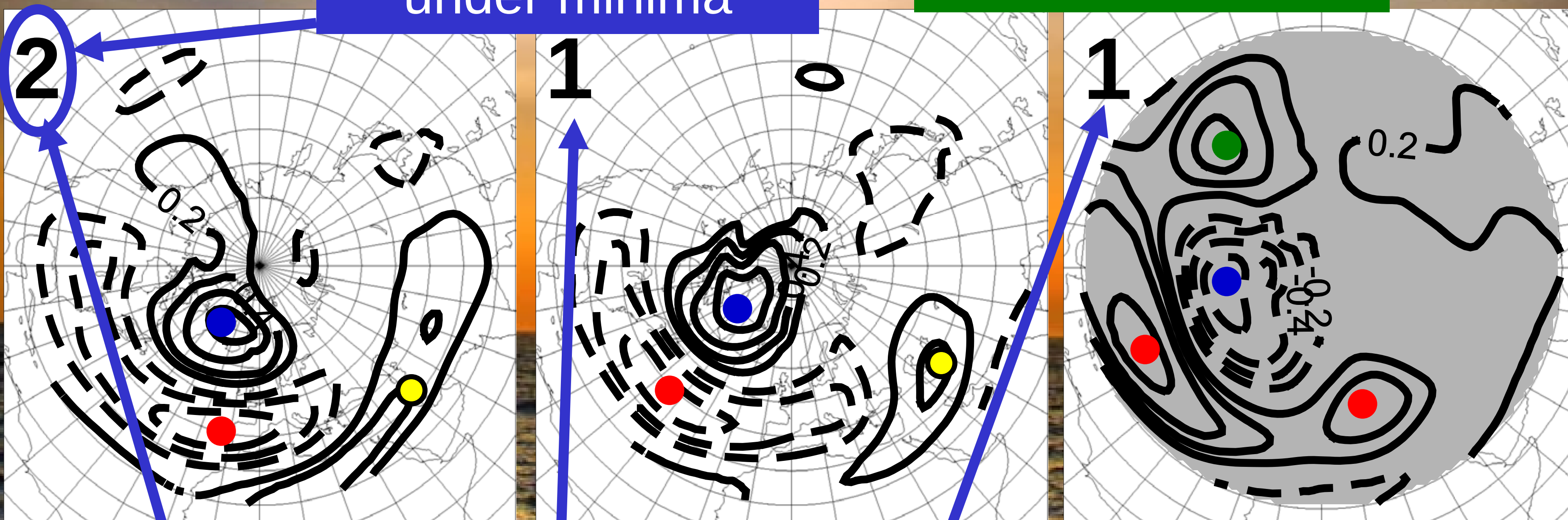
(Huth et al., J. Geophys. Res. 2006)

min

relatively weaker
under minima

ral

new subtropical
centre in E Pacific



under solar max:

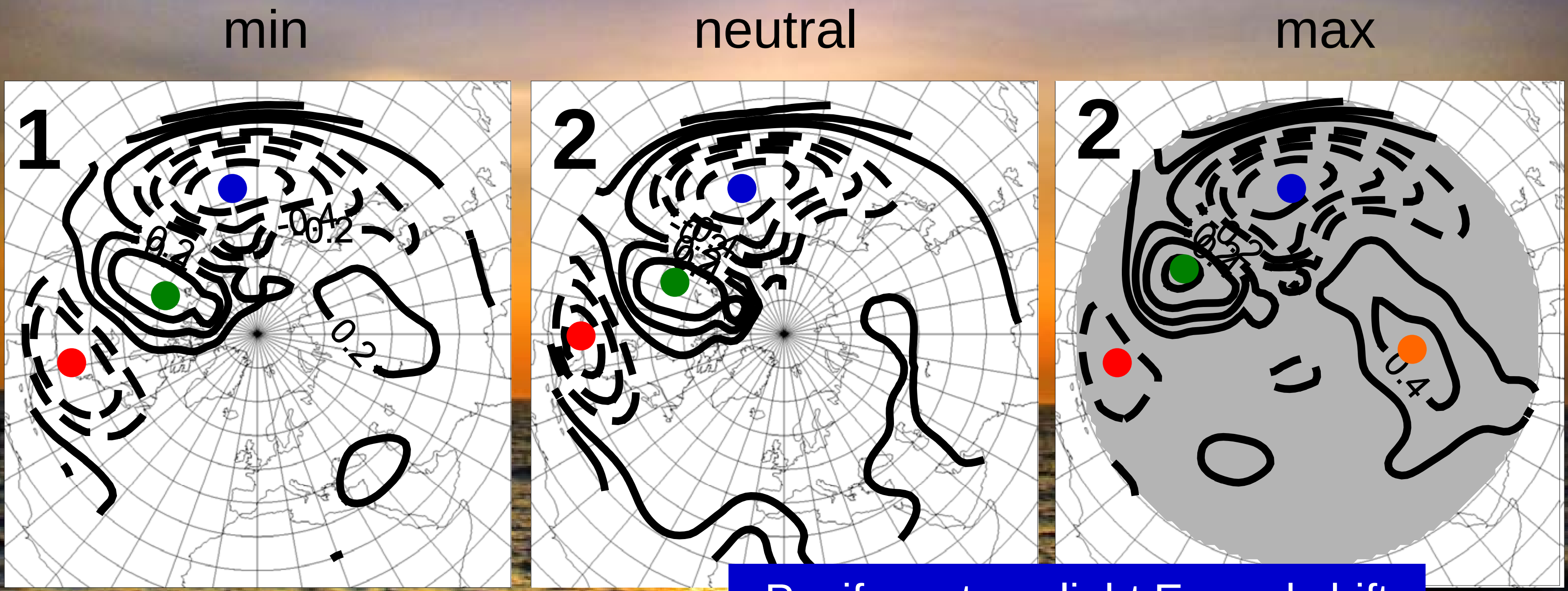
node in

Icelandic centre – SW/S
shift, more extensive

Azores centre – split
into 2 cores, W-ward
shift of the main centre,
weakening in E

belt into central Asia
vanishing

PNA (Pacific / North American)



solar maximum:

Pacif. centre: slight E-ward shift

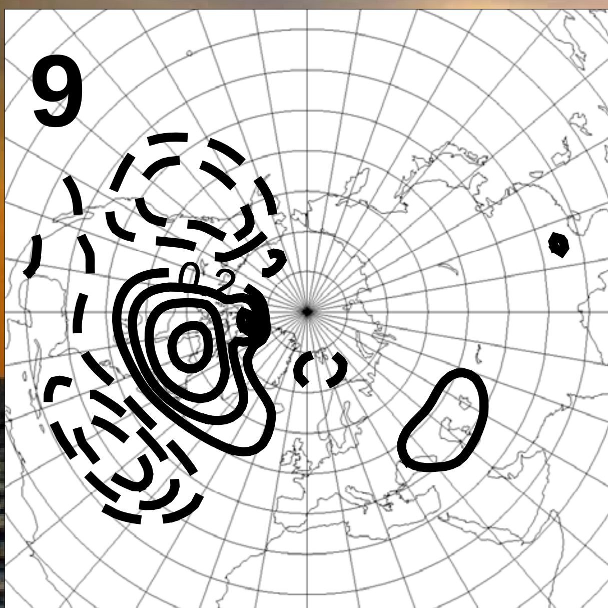
N-Amer. centre: S-ward shift

Florida centre: weakening

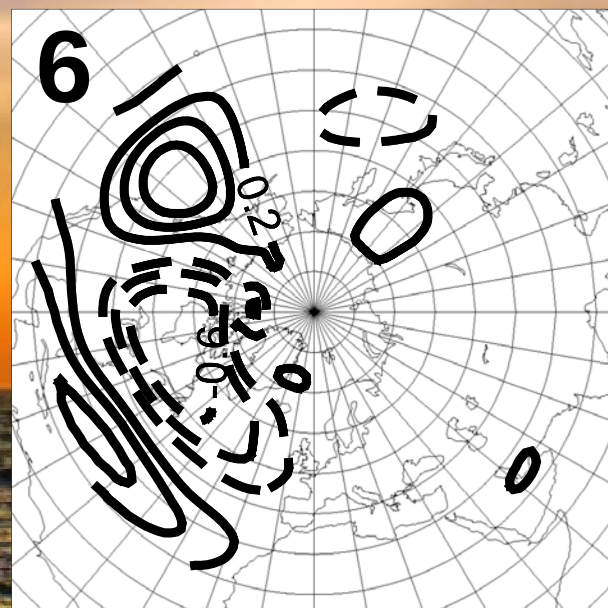
new remote centre over central Siberia

TNH (Tropical / Northern Hemispheric)

min



neutral



max

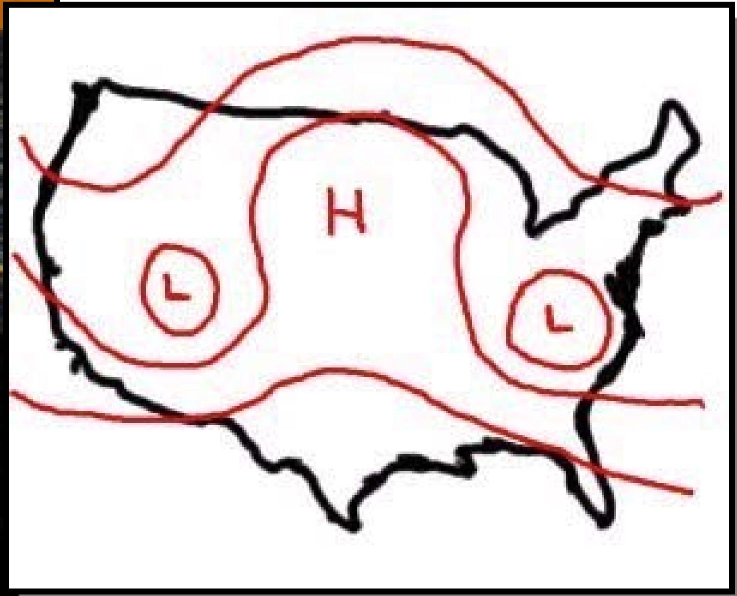
remnants of TNH appear in another mode

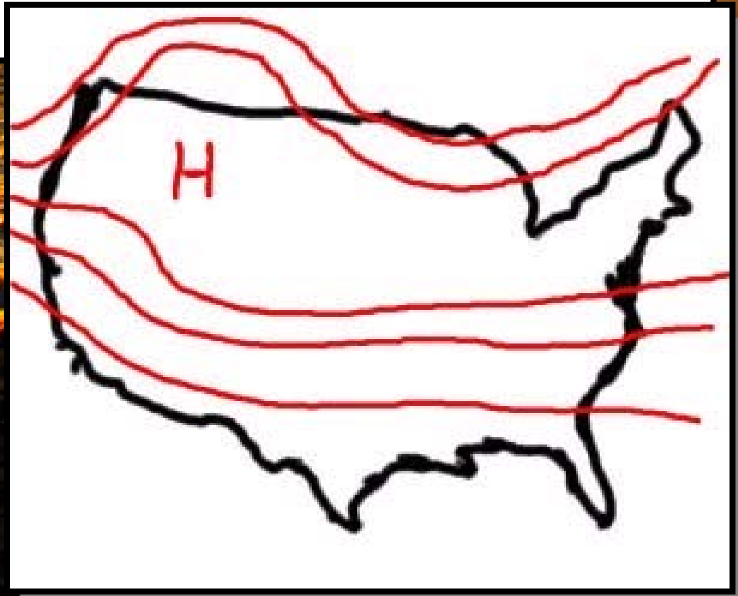
MISSING under high solar activity !!!

Example 2: Atmospheric blocks

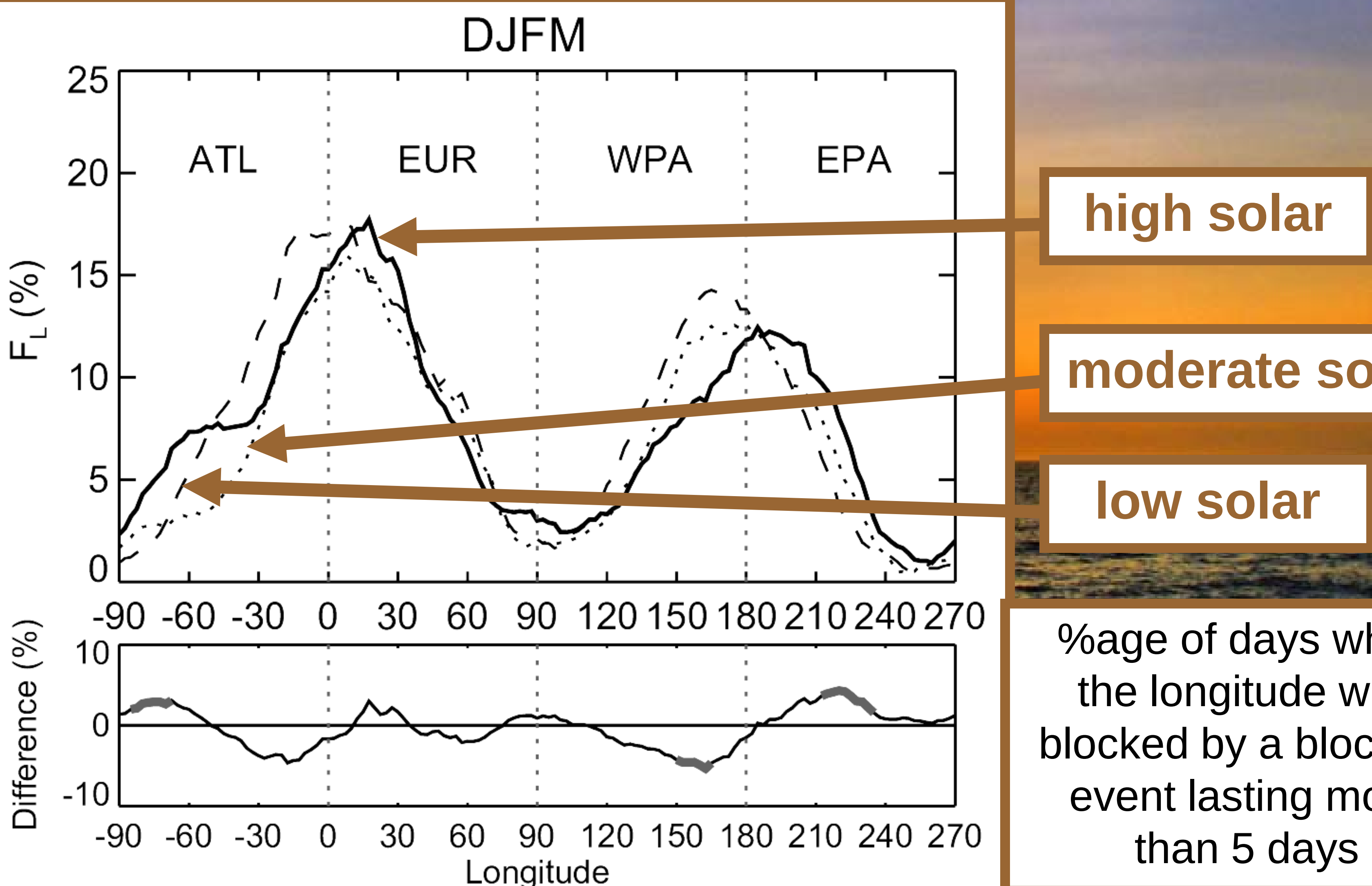
(Barriopedro et al., J. Geophys. Res. 2008)

- quasi-stationary and persistent formations
- anticyclones / ridges of high pressure
- in mid latitudes
- interrupt / deflect / split zonal flow
- ➔ considerably affect weather conditions
- typically occur e.g. under the negative phase of NAO





Blocking frequency

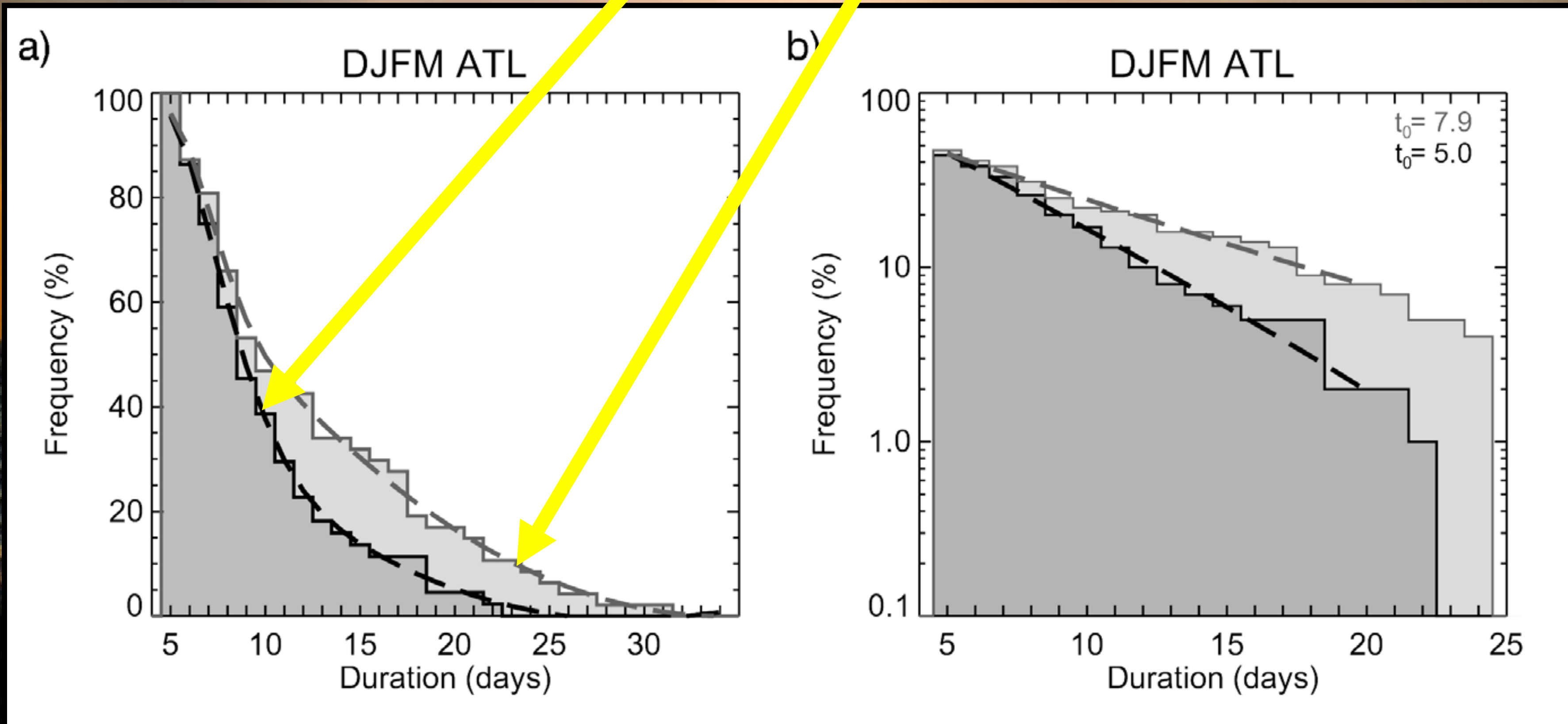


%age of days when the longitude was blocked by a blocking event lasting more than 5 days

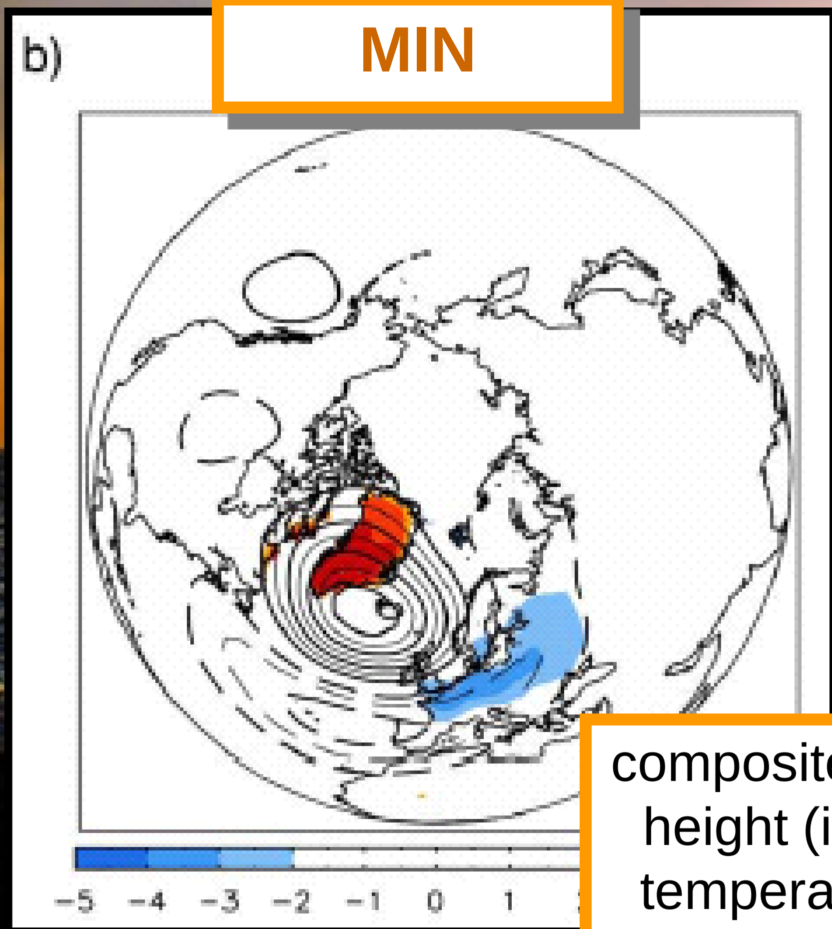
Blocking persistence, ATL

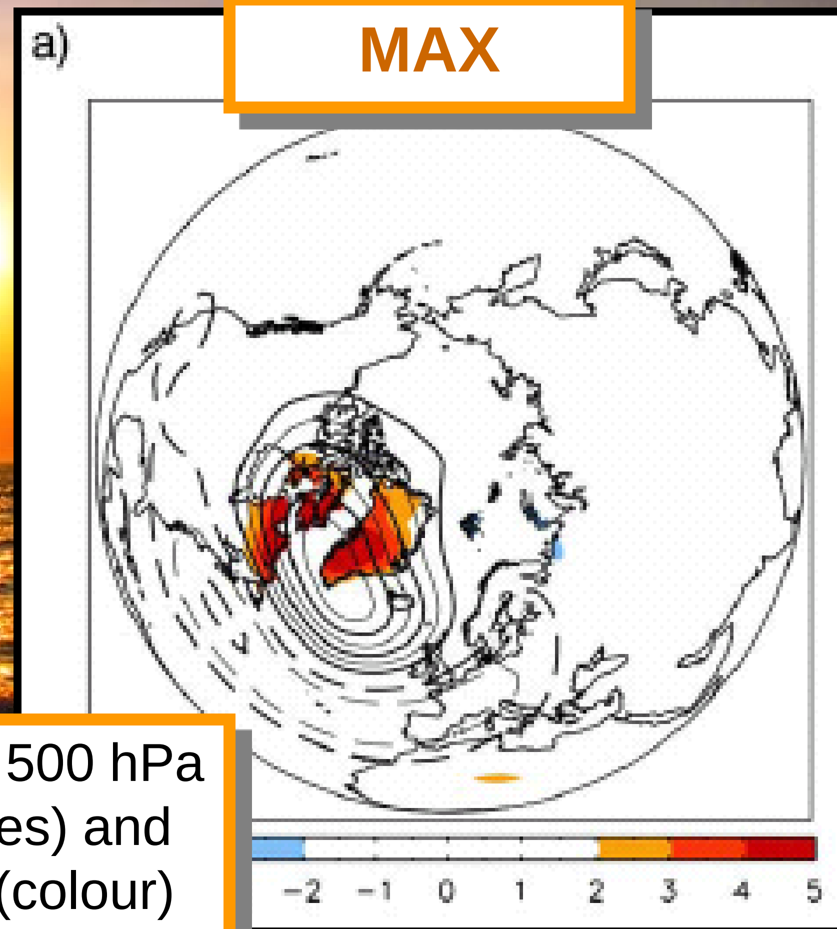
high solar

low solar



AREAL EXTENT & EFFECT ON TEMPERATURE – Atlantic domain



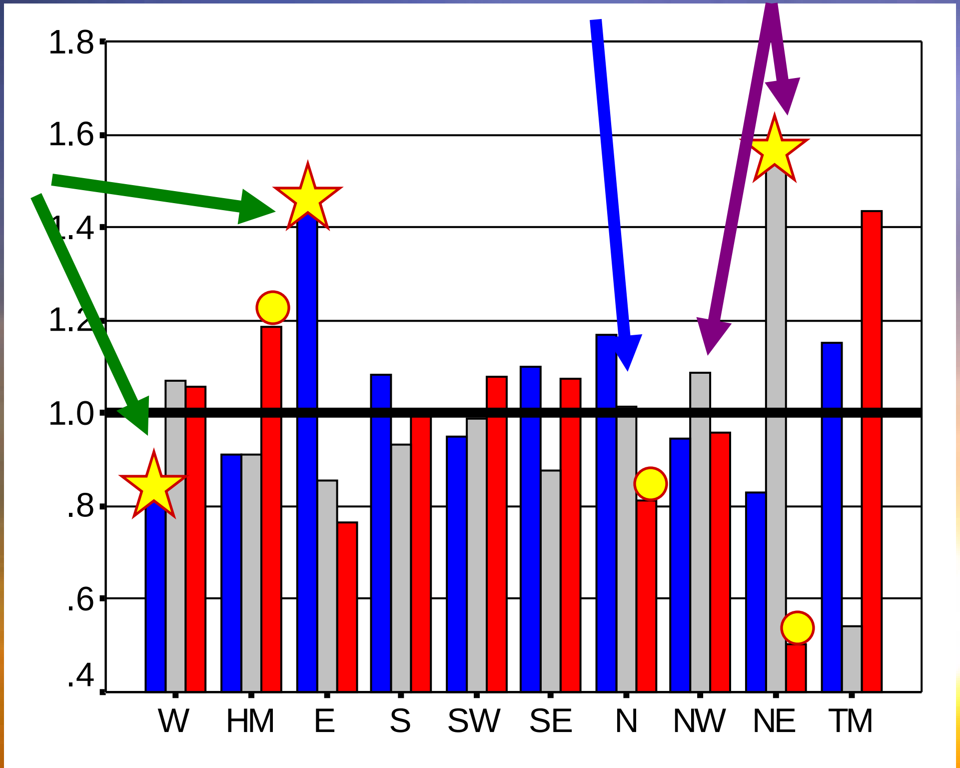


composites of 500 hPa height (isolines) and temperature (colour) anomalies

Example 3 – Frequency of circulation patterns

(Huth et al., Ann. Geophys. 2008)

- pattern of tropospheric circulation (usually sea level pressure) is taken for each day
- patterns are classified into a number of groups according to
  - direction fo airflow
  - intensity of airflow
  - (anti)cyclonicity of flow
- frequency of patterns is calculated separately for phases of solar cycle



major types

N types – less frequent in solar maxima

NW + NE types – most frequent in moderate solar activity

W / E types – less / more frequent in solar minima

moderate vs. high solar activity – little difference

- Most striking effect:
  - low solar activity: W types **less than twice** as frequent as E types (39.5% vs. 20.4%)
  - moderate solar activity: W types almost **four times more** frequent than E types (49.5% vs. 12.8%)

Example 4: teleconnectivity

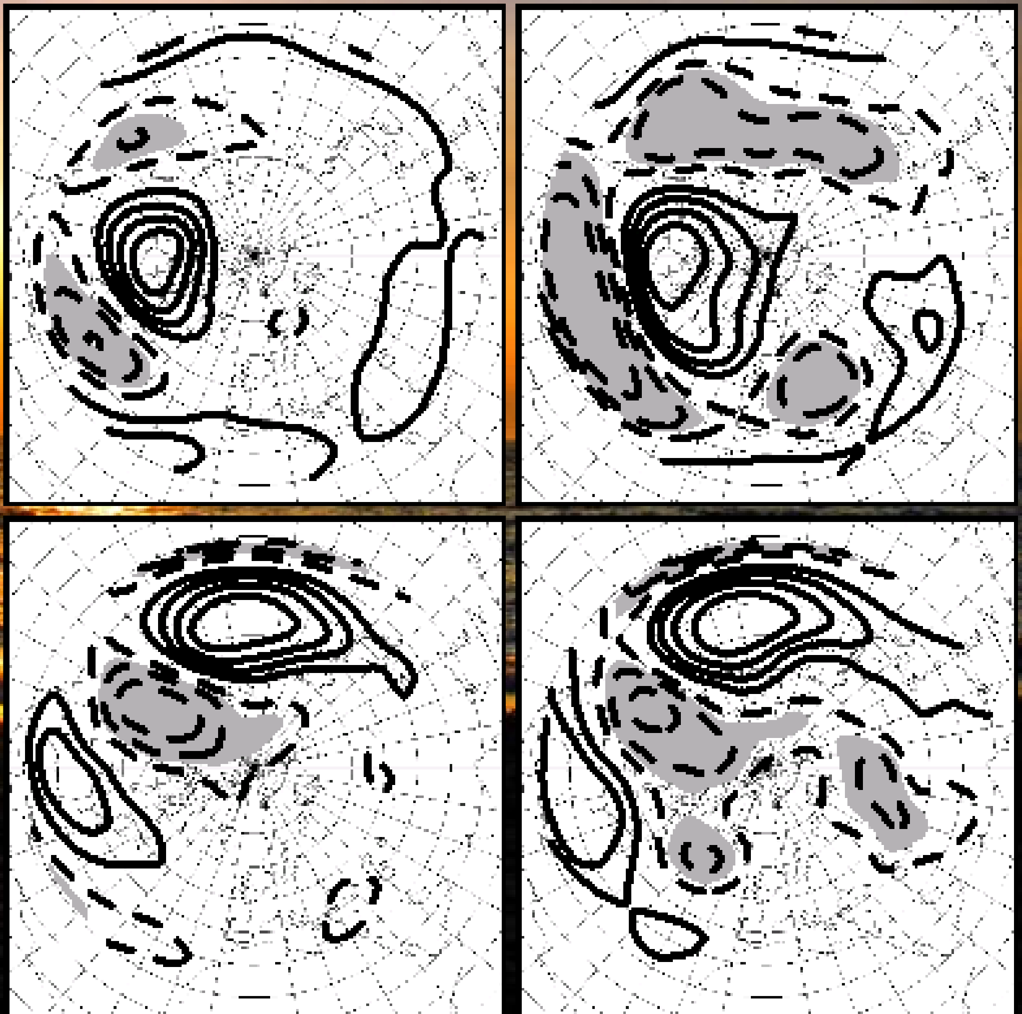
(property of being correlated over long distances) (unpublished so far)

spatial autocorrelations with the basis gridpoint

minimum | maximum

60N / 90W

45N / 170W



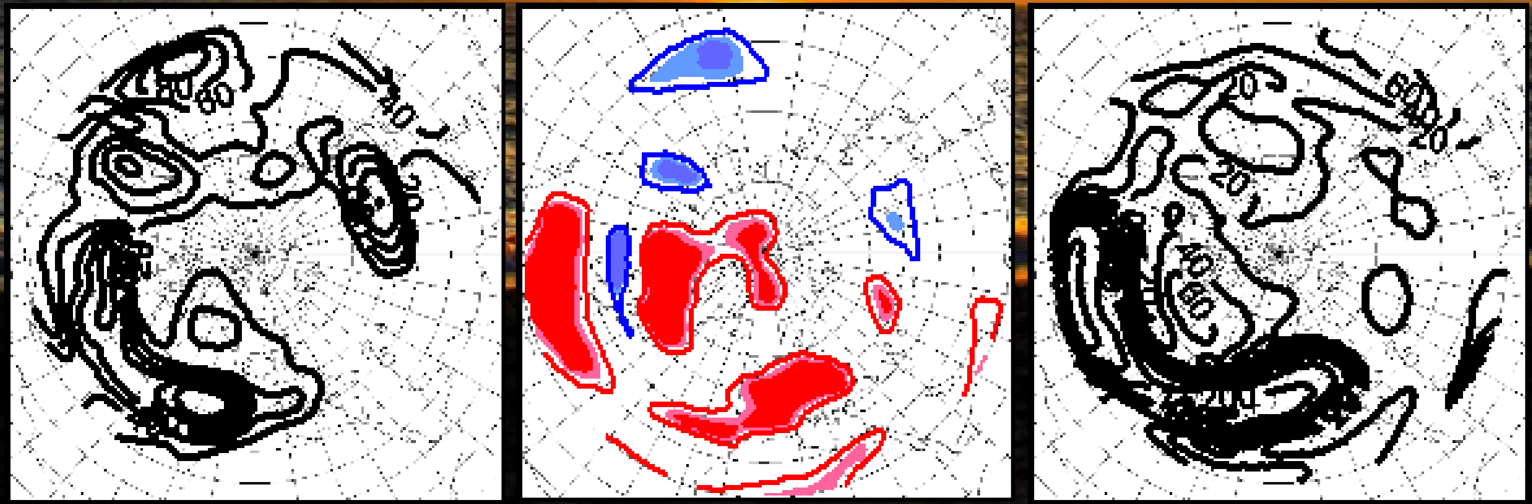
Teleconnected area

- ❑ for each grid point, area with correlations below –0.3 is mapped

minimum

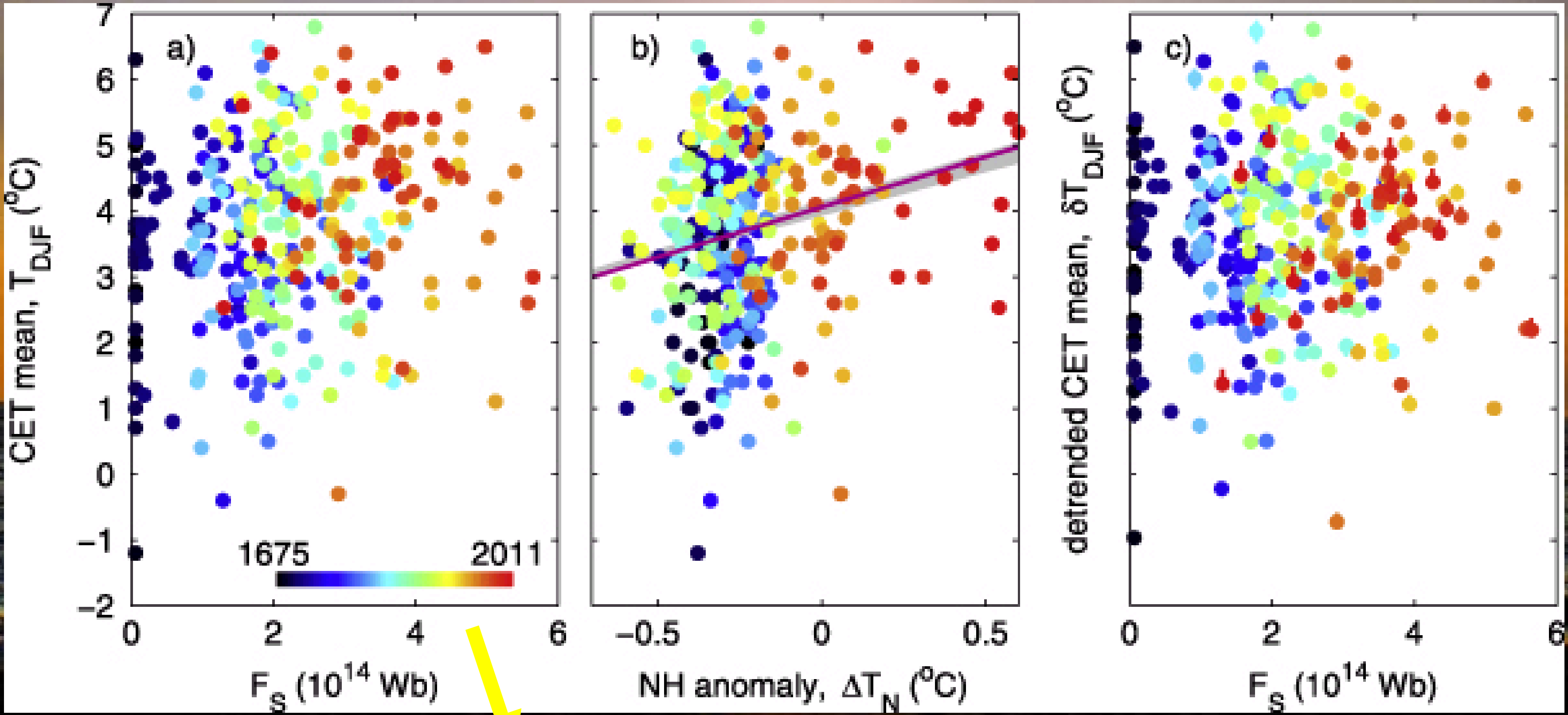
statist. significance of difference

maximum



Example 5: Central England temperature in winter

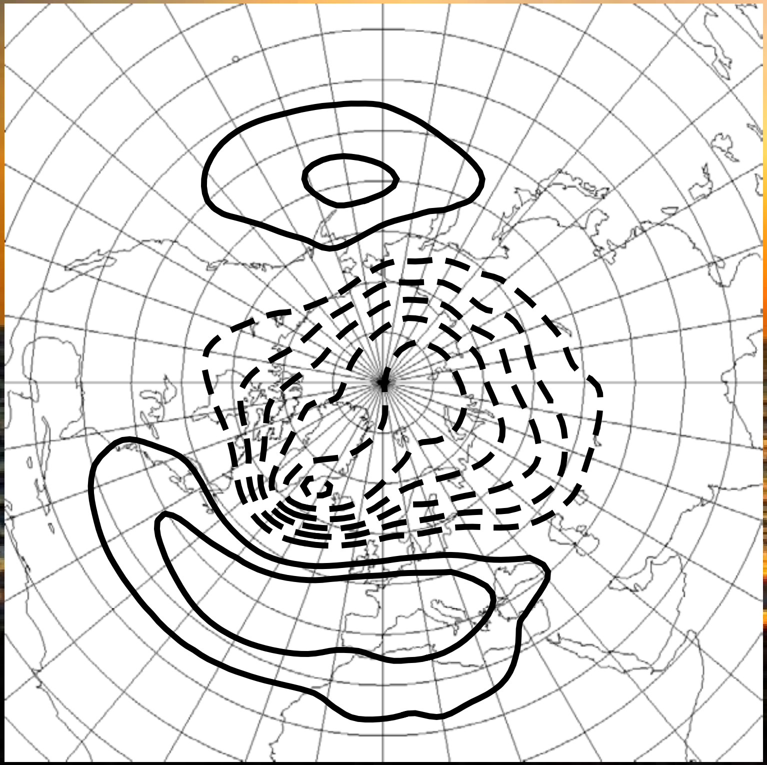
(Lockwood et al., Environ. Res. Lett. 2010)



- correlation between solar flux and mean winter temperature is 0.23 *(not very convincing…)*

Example 6: Arctic Oscillation

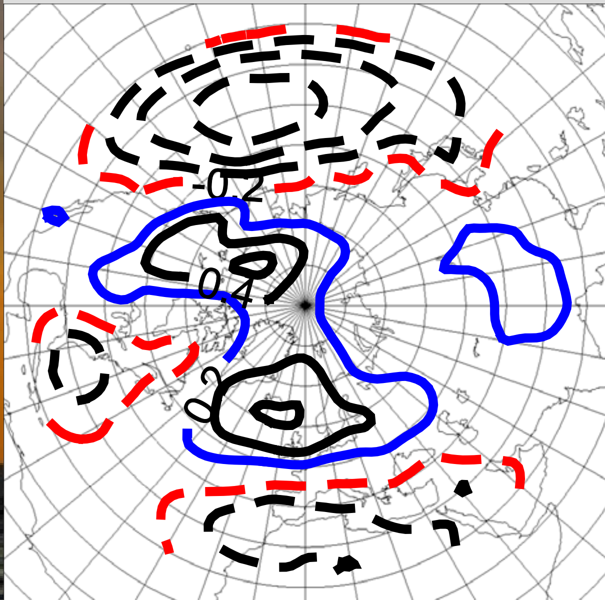
(Huth et al., J. Atmos. Sol. Terr. Phys. 2007)



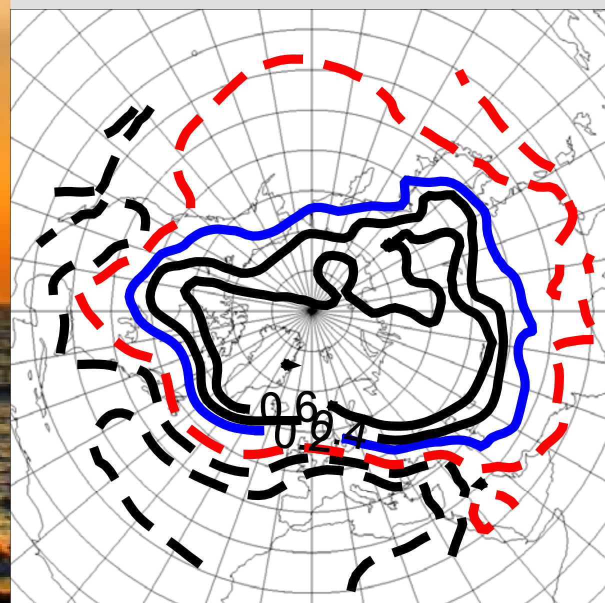
- Thompson & Wallace (1998): 1st principal component of monthly mean SLP anomalies
- NH, north of 20°N, winter
- 3 action centres
  - Arctic
  - North Atlantic (Azores)
  - North Pacific (Aleutian)
- physical realism questioned
- weakest link: Pacific centre – almost uncorrelated with other two centres

INTERVAL-BASED AO

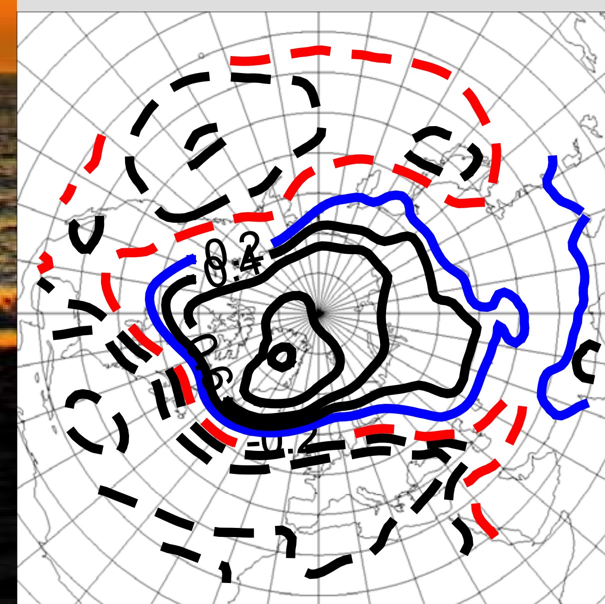
10% - 30%



50% - 70%



80% - 100%



Summary

- ❑ solar variations on 11-yr scale have detectable effect on troposphere
- ❑ in solar maxima
  - – circulation tends to be more zonal
    - • implying milder and wetter winters in European mid latitudes
  - – circulation tends to be more spatially extensive
- ❑ effects are not linear ➔ simple correlation analyses are not a good tool

Prospects

- certainly more research is needed
- impacts of solar variations on surface climate (temperature, precipitation, …) should be investigated in more detail
  - by analyzing observed datasets
- mechanisms of transmission and amplification of solar effect into lower atmosphere should be identified
  - by analyzing numerical simulations of atmosphere with imposed forcings
- new international COST *(european COoperation in Scientific and Technological development)* action: “Towards a more complete assessment of the impact of solar variability on the Earth’s climate” (ES1005)