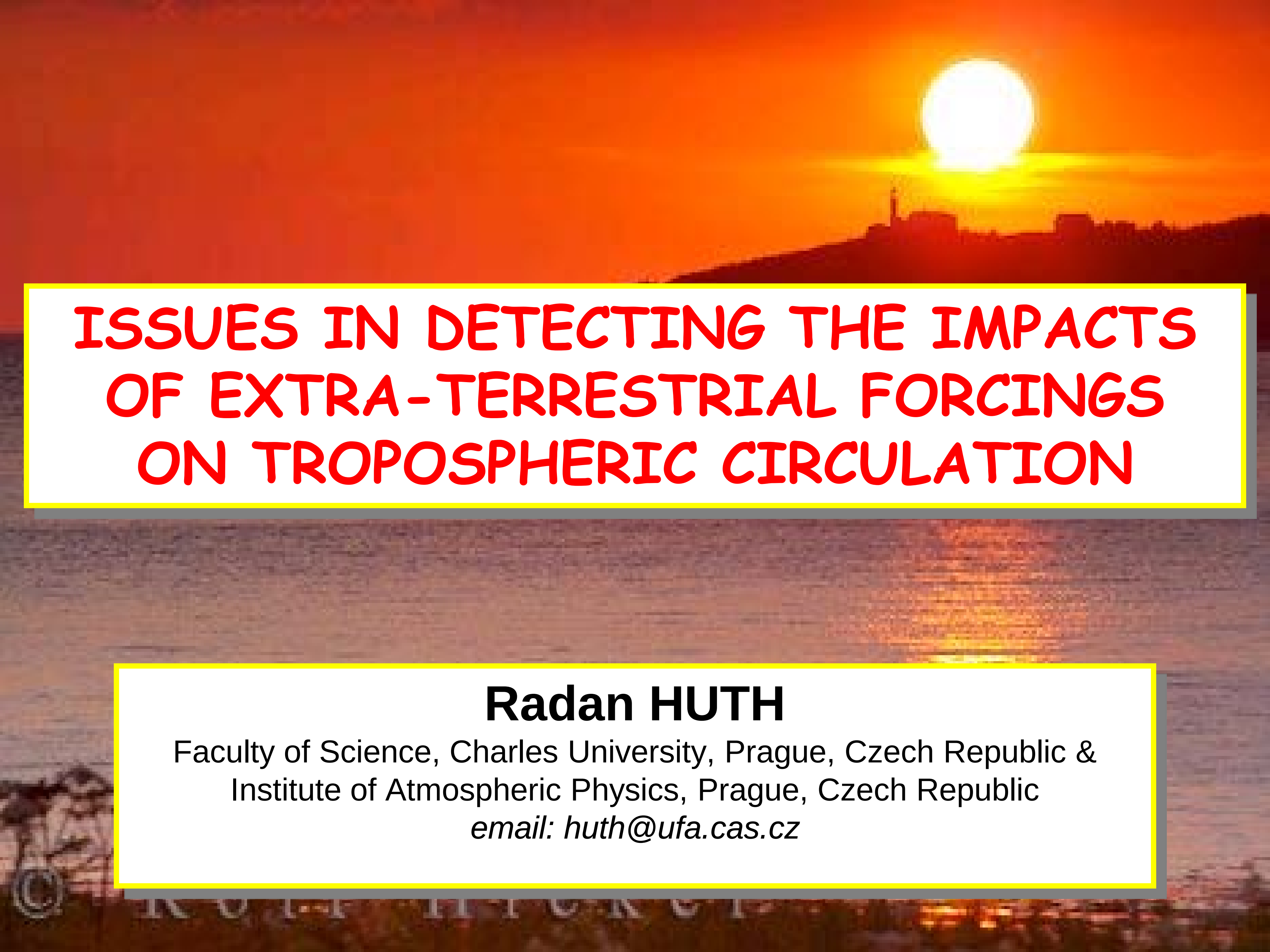

ISSUES IN DETECTING THE IMPACTS OF EXTRA-TERRESTRIAL FORCINGS ON TROPOSPHERIC CIRCULATION

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- I haven’t done much work on effects of ‘interplanetary disturbances’
- most of my work relates to 11-year solar cycle
- and detection of its effects on various aspects of tropospheric circulation
- by statistical procedures
- nevertheless, detection methods / procedures are general
- and may be applied to other external forcings as well
- therefore, my work is (hopefully) of some relevance to this group

- what has been done so far
- issues to think about, to resolve etc.

A. What has been done

Basic idea of our analyses

- sorting of data by the parameter of extra-terrestrial forcing (11-yr solar cycle, geomagnetic activity, …) into several (usually three) groups
  - low activity
  - moderate activity
  - high activity
- separate analysis conducted for each group

- here, analyses of solar activity are presented
- but we conducted similar analyses for geomagnetic activity
- analysis based on two indices is also possible (e.g. solar activity & QBO) and has been done

DATABASE & METHODOLOGY

- mostly: monthly values
- extended winter (Dec – Mar)
- 1949 – 2003 (or somewhat shorter depending on availability of circulation data)
- Northern Hemisphere (north of 20°N)
- mostly: NCEP / NCAR reanalysis
- either 500 hPa heights or sea level pressure (SLP)

1. Modes of low-frequency variability

(Huth et al., *J. Geophys. Res.*, 2006, **111**, D22107)

- defined by rotated principal component analysis (PCA)
- separate for each solar activity class
- 9 modes detected in each class
- we don't work on correlations between the intensity of the modes and solar activity; there is some limited correlation *(Barnston & Livezey, J.Climate 1989)*

1. Modes of low-frequency variability

(Huth et al., *J. Geophys. Res.*, 2006, **111**, D22107)

- locally significant difference high x low solar activity
- for all 9 modes in the NH winter
- for all 7 modes in the SH winter

NAO (North Atlantic Oscillation)

min … al

relatively weaker under minima

new subtropical centre in E Pacific

under solar max:

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

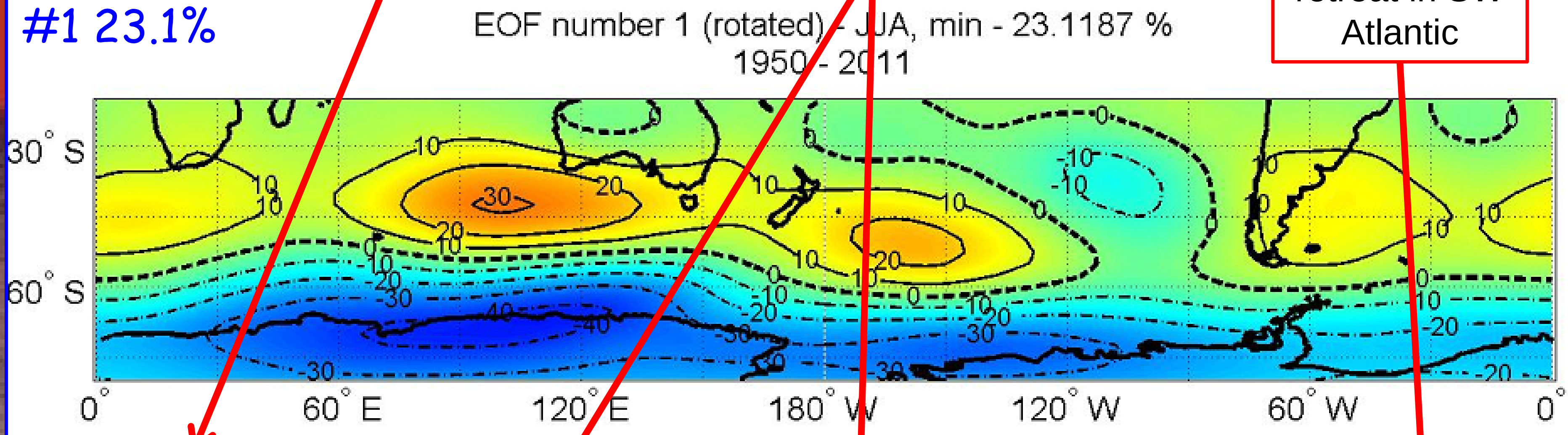
Southern Annular Mode (SAM)

weaker (less variance explained)

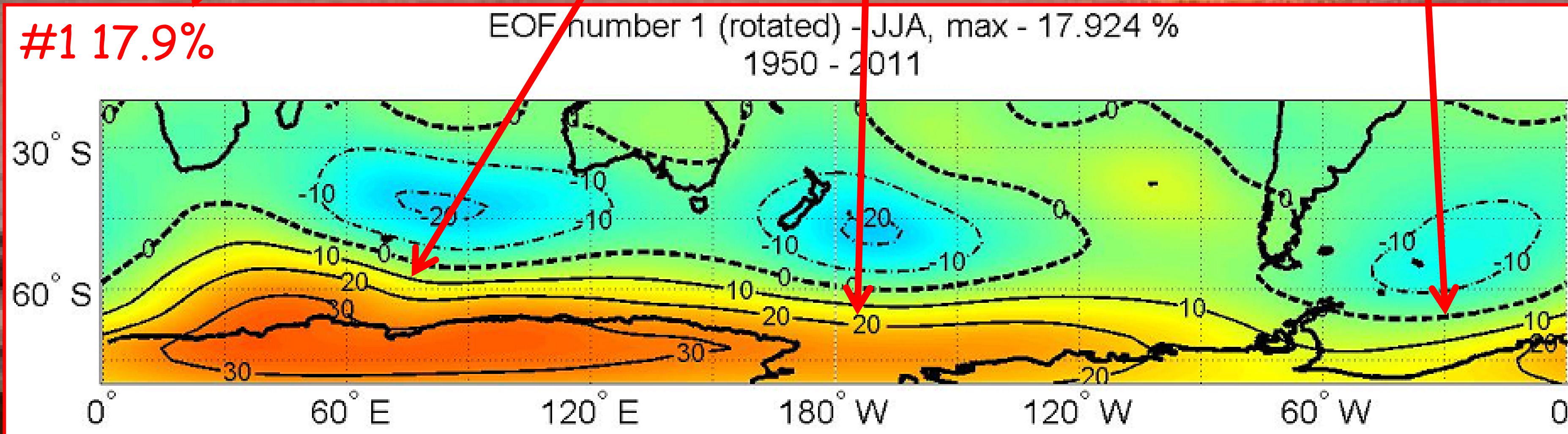
weaker gradient along 50°S

poleward retreat in SW Atlantic

#1 23.1%



#1 17.9%

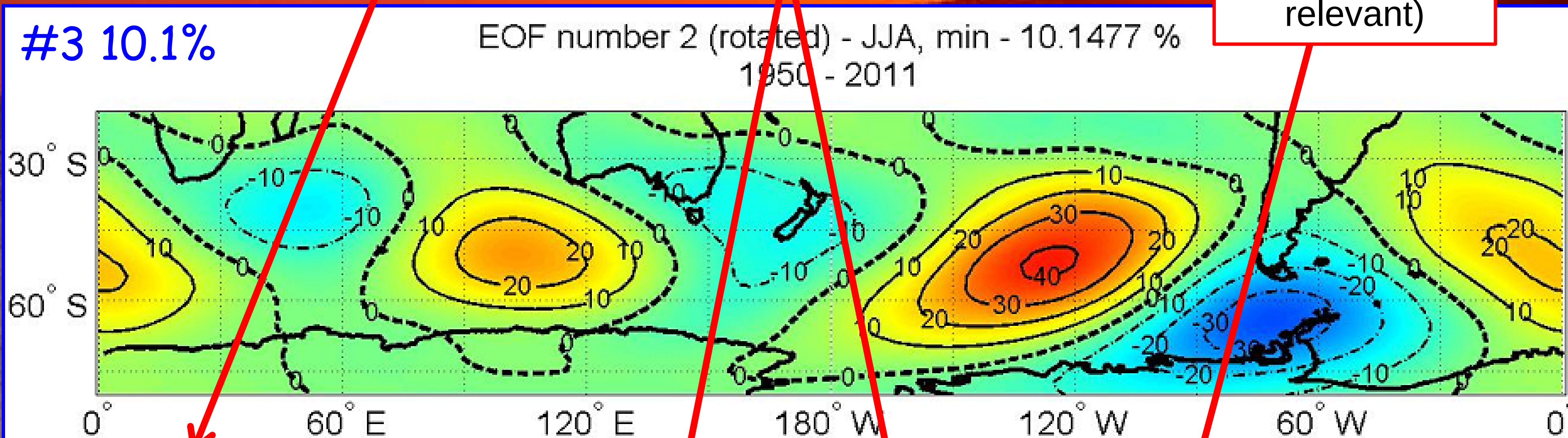


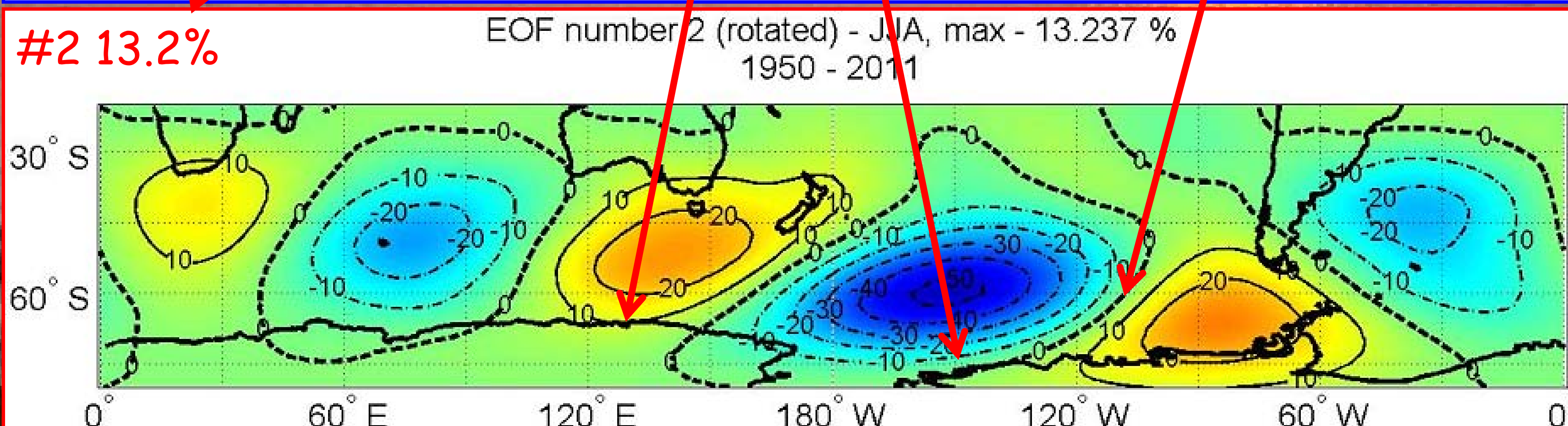
Pacific-South American (PSA) 2

stronger (more variance explained)

poleward shift in S Pacific

slightly different phase (probably not relevant)



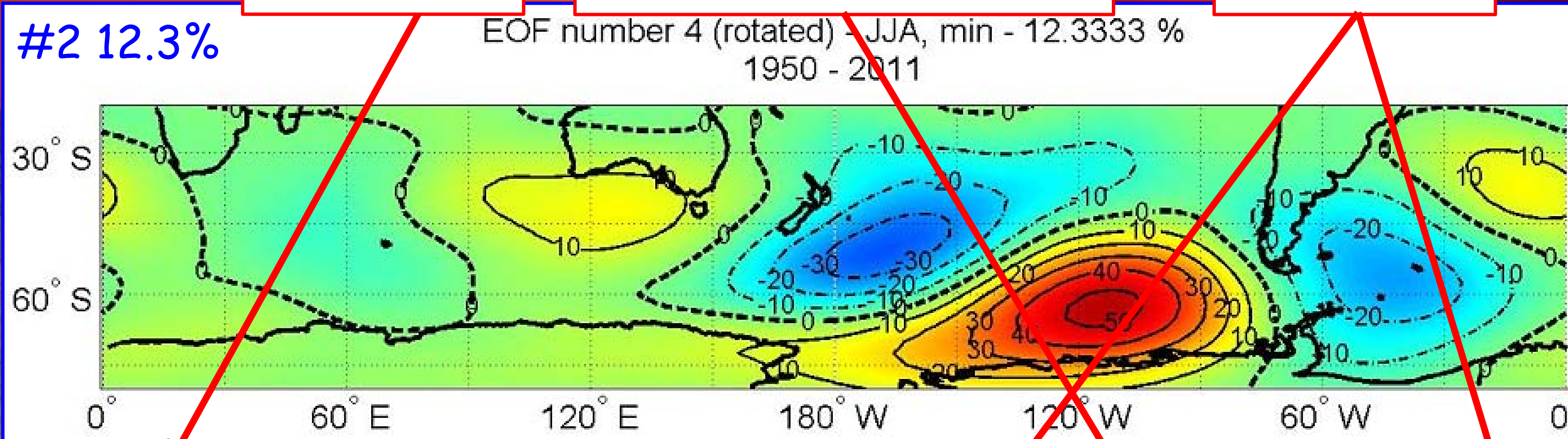


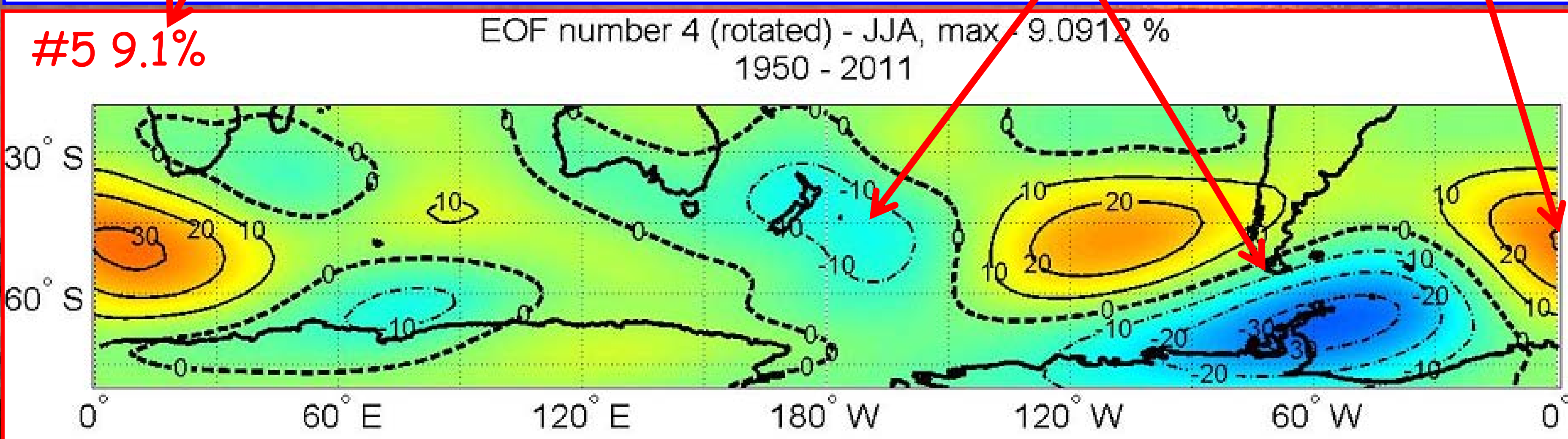
Pacific-South American (PSA) 1

weaker

different configuration over S America ➔ potentially different impact on climate in southern S America

shift of activity downstream of S America



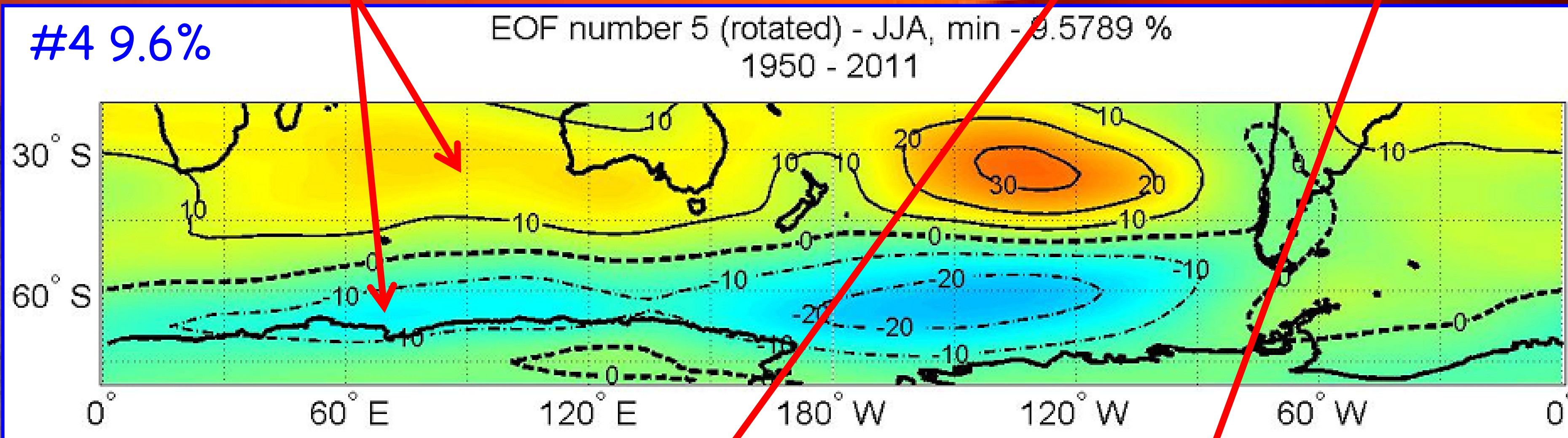


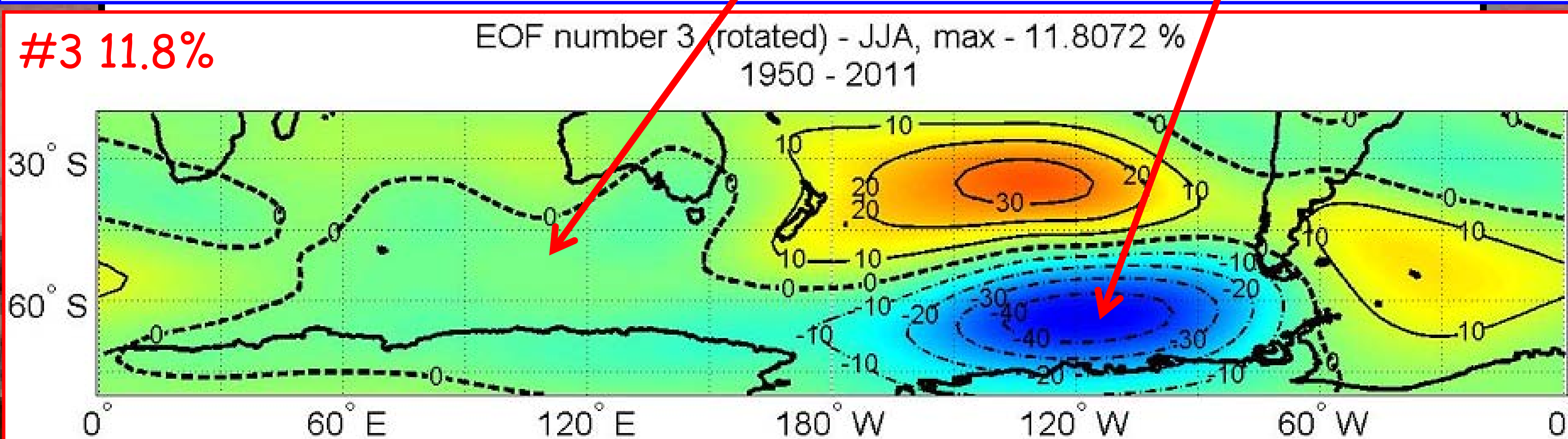
South Pacific dipole

seems to be blended with another mode

more geographically confined

stronger southern centre



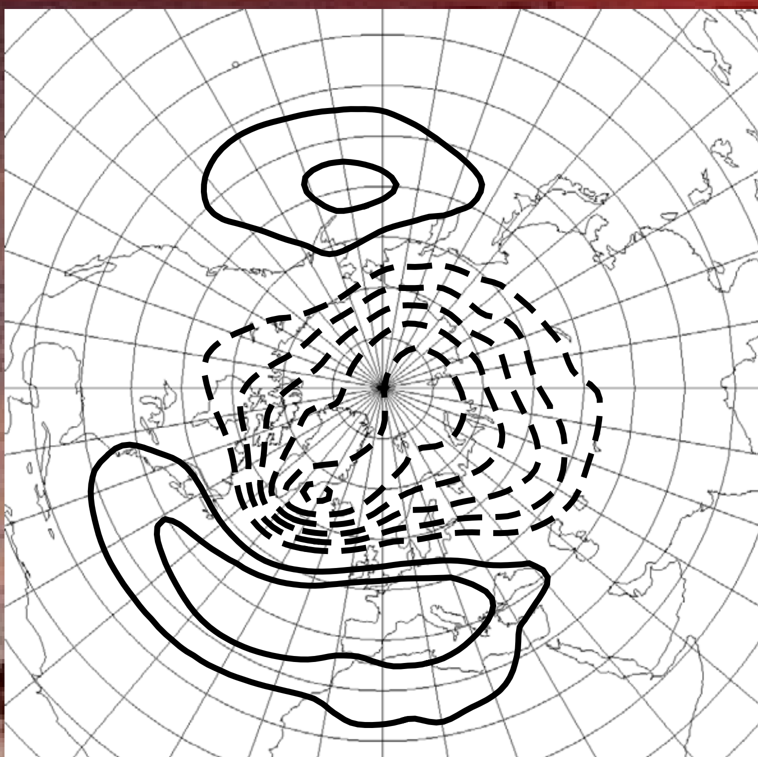


SUMMARY – modes

- all modes change their features and/or activity between solar cycle phases
- differences max-min between loading patterns are significant over large areas (not shown here)
- some modes vanish in some solar cycle phases (TNH, EP)
- under high solar activity – tendency towards
  - zonalization (NH only)
  - larger areal extent (NH only)
  - connections with remote centres
  - shift of activity „downstream“ from main centres
- important: changing position of action centres ➔ use of geographically fixed indices (e.g. NAO index) may not be suitable

2. Arctic Oscillation

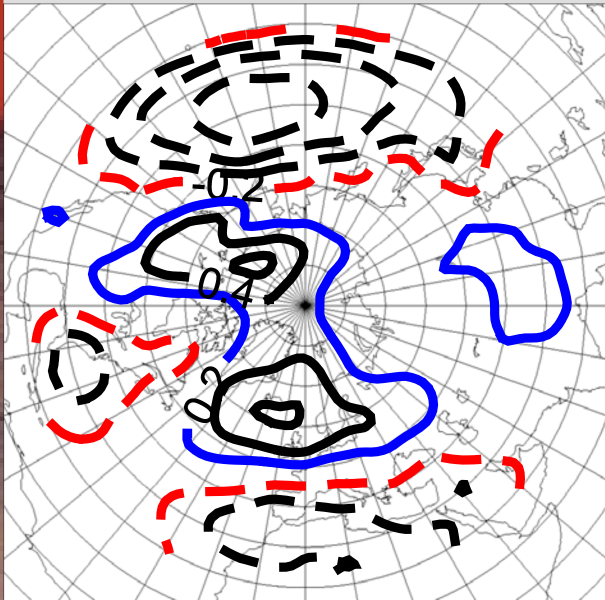
(Huth et al., *J. Atmos. Sol. Terr. Phys.*, 2007, **69**, 1095-1109)



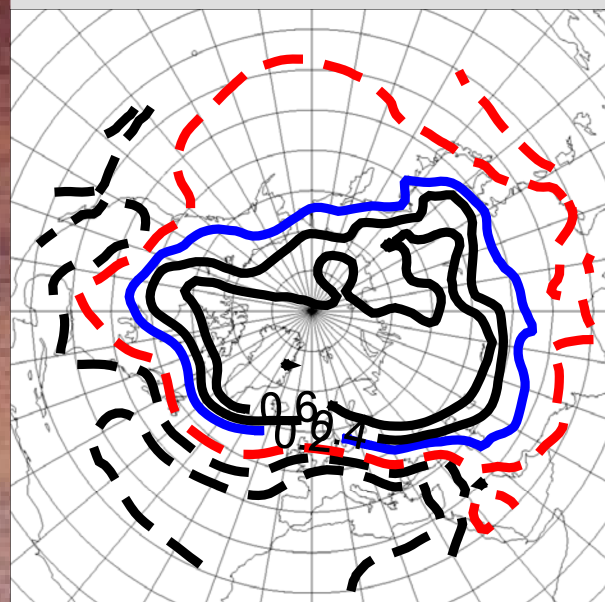
- AO = synonymum for surface representation of NAM
- Thompson & Wallace *(GRL, 1998)*: 1st principal component of monthly mean SLP anomalies
- NH, north of 20°N, winter
- 3 action centres
  - Arctic
  - North Atlantic (Azores)
  - North Pacific (Aleutian)
- physical realism questioned *(Deser, GRL 2000; Ambaum et al., J.Climate 2001; Huth, Tellus 2006)*
- weakest link: Pacific centre – almost uncorrelated with other two centres

AO for different quantile intervals of solar activity

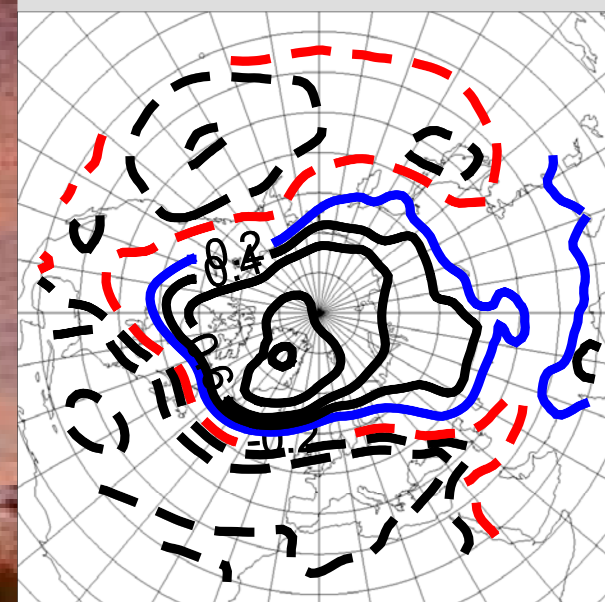
10% - 30%



50% - 70%



80% - 100%



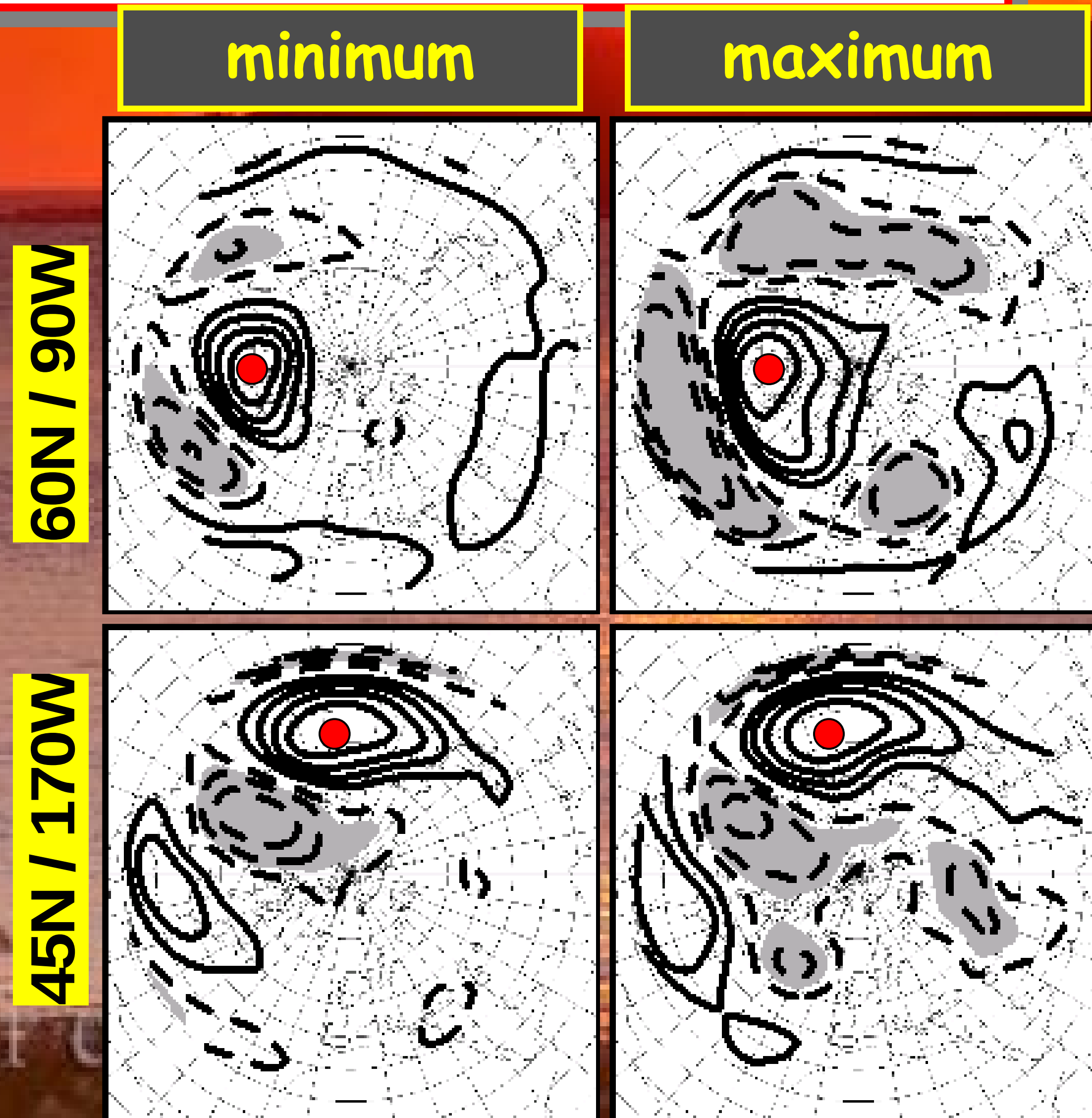
Arctic Oscillation - summary

- strong non-linear response of AO's shape (not amplitude!)
- AO stronger (more zonal) and more active under high solar activity
- moderate solar activity: weakening (almost disappearance) of Pacific centre

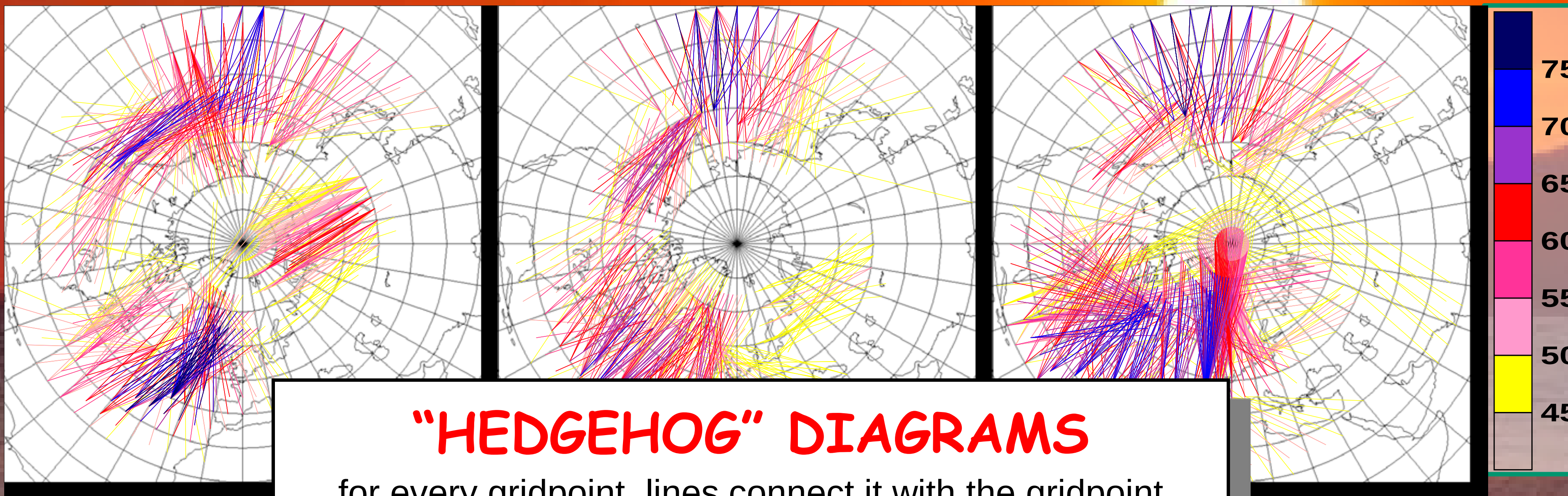
3. Spatial (auto)correlations & teleconnectivity

(not published yet)

Spatial autocorrelations
(one-point correlation maps)



minimum	moderate	maximum

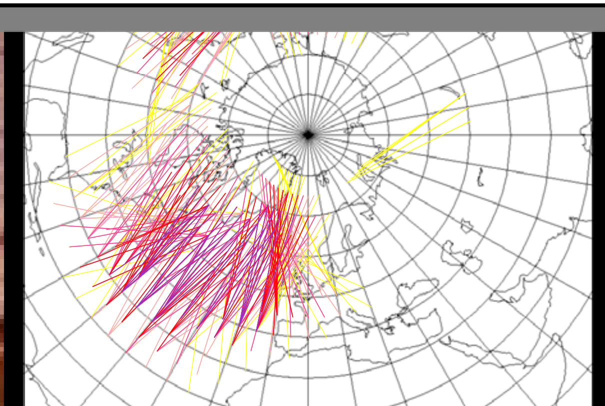


"HEDGEHOG" DIAGRAMS

for every gridpoint, lines connect it with the gridpoint with which it is most negatively correlated

the magnitude of the correlation (in absolute terms, x100) is expressed by colours

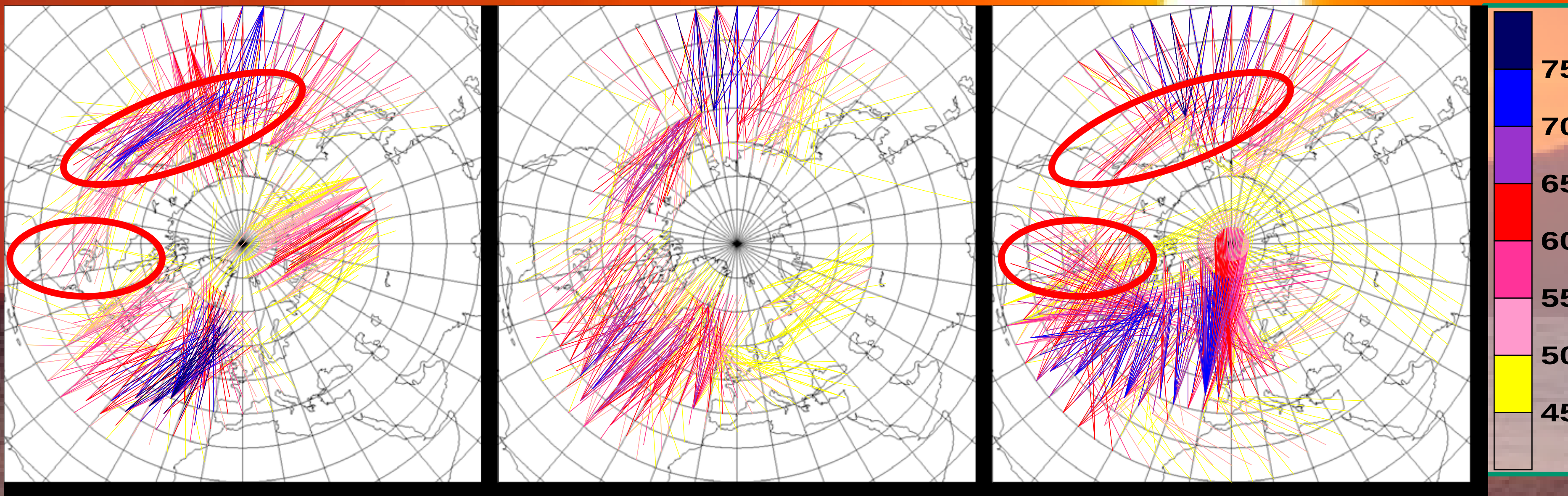
only correlations over 0.45 are shown



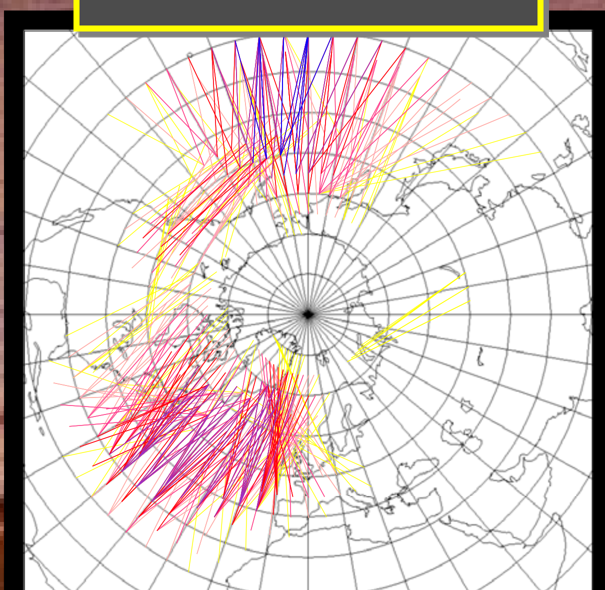
minimum

moderate

maximum

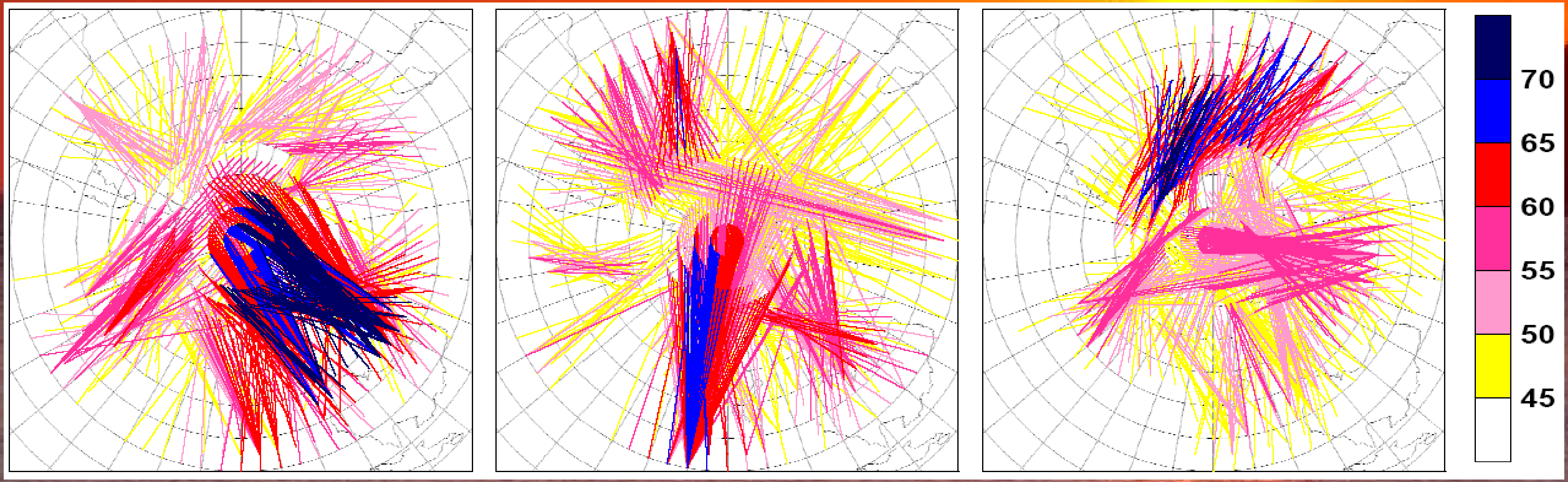


all



Northern Hemisphere

minimum | moderate | maximum

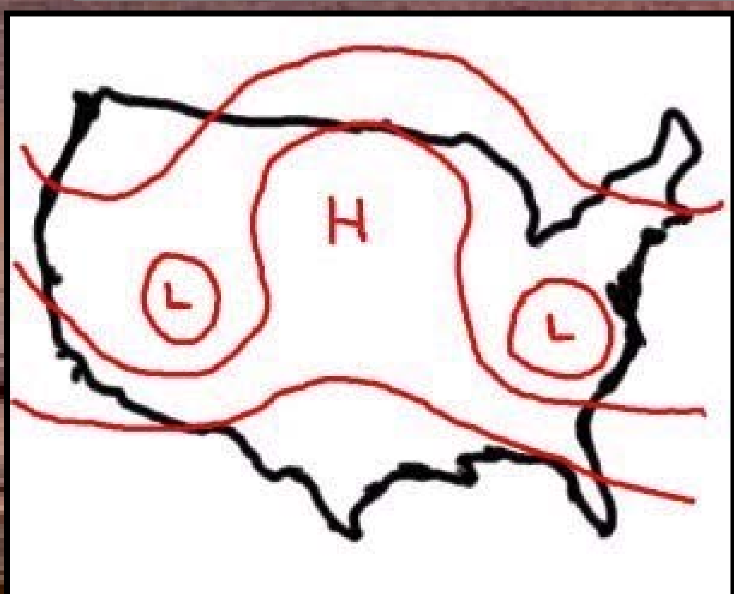


Southern Hemisphere

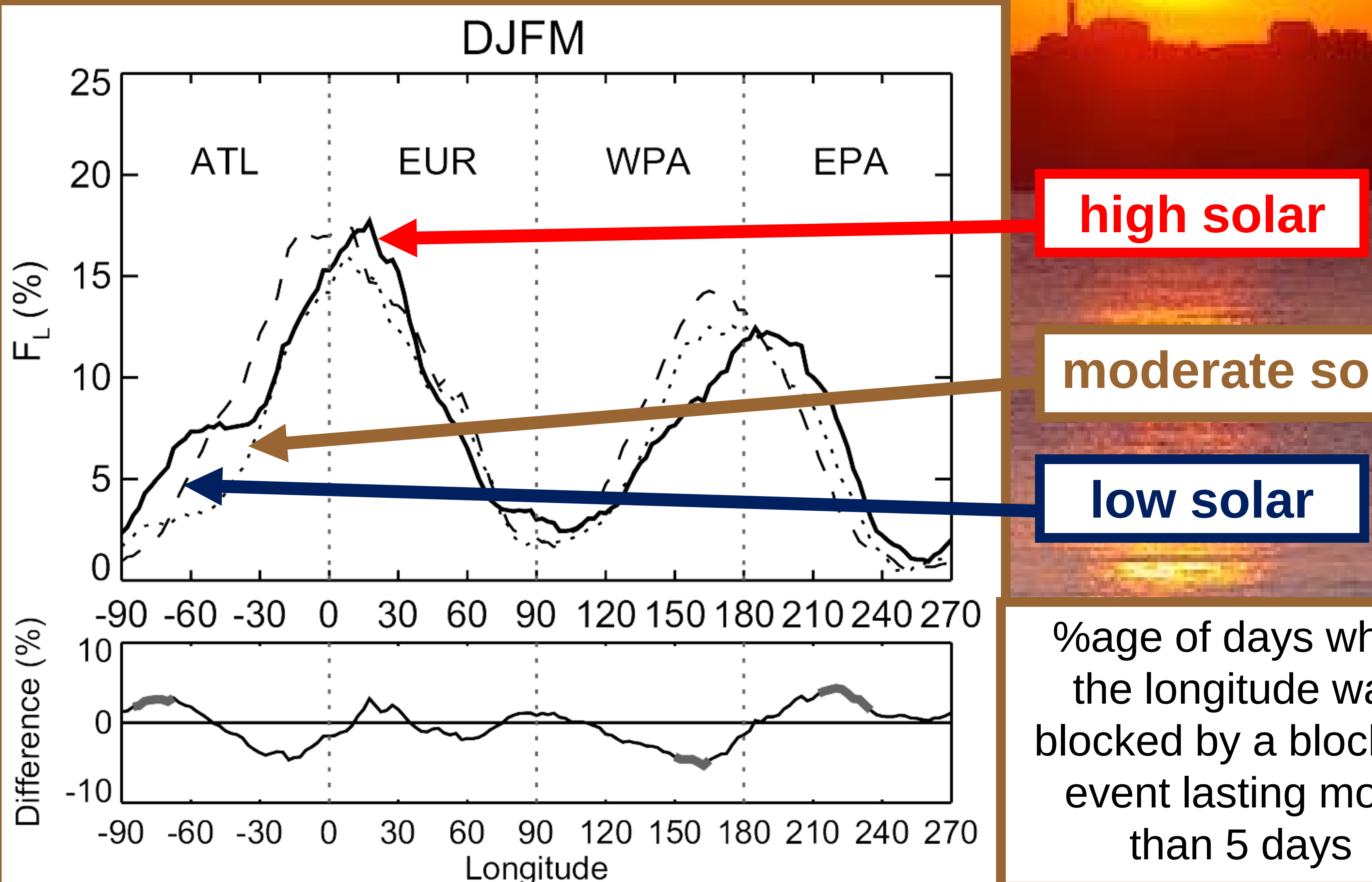
4. Blocking

(Barriopedro et al., *J. Geophys. Res.*, 2008, **113**, D14118)

- blockings:
  - quasi-stationary & persistent anticyclonic features
  - in mid-latitudes
  - interrupting zonal flow

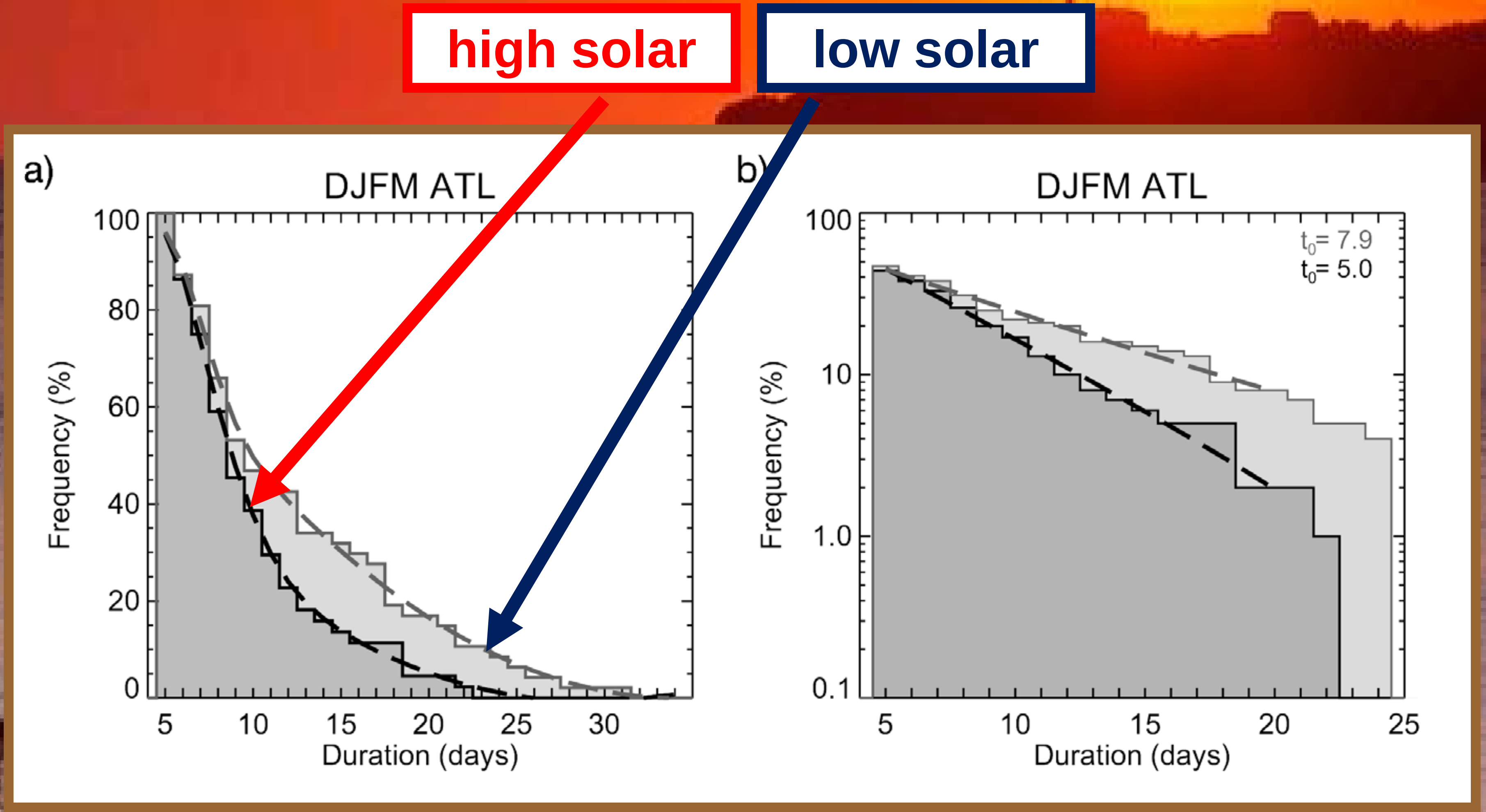


Blocking frequency



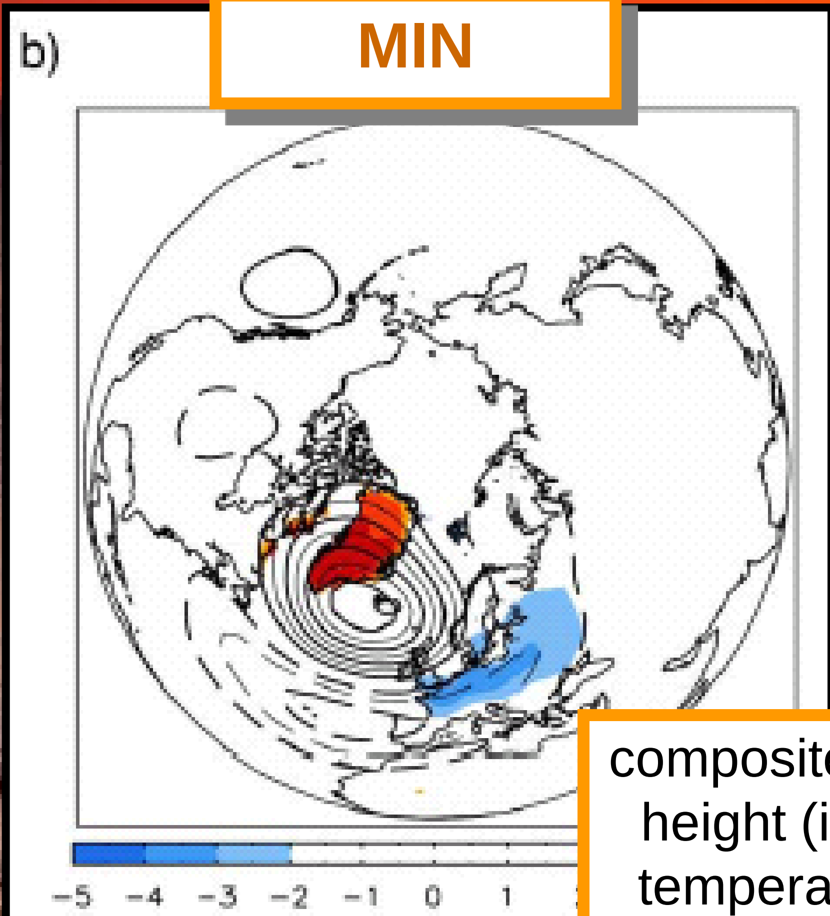
%age of days when the longitude was blocked by a blocking event lasting more than 5 days

Blocking persistence, ATL

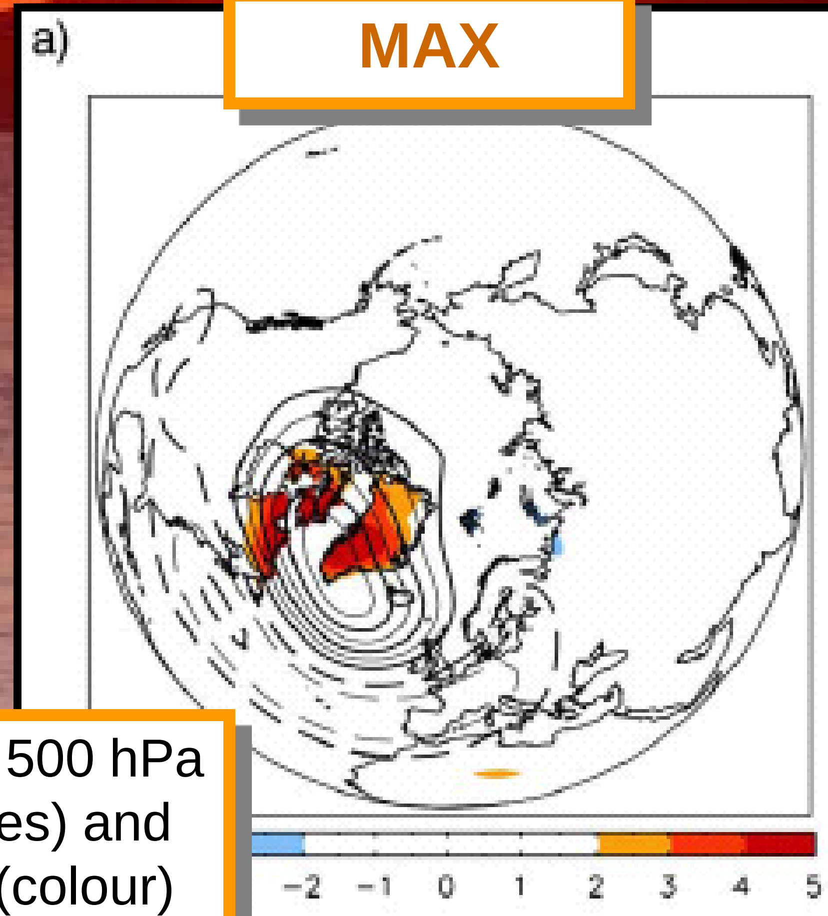


AREAL EXTENT & EFFECT ON TEMPERATURE – Atlantic domain

MIN



MAX

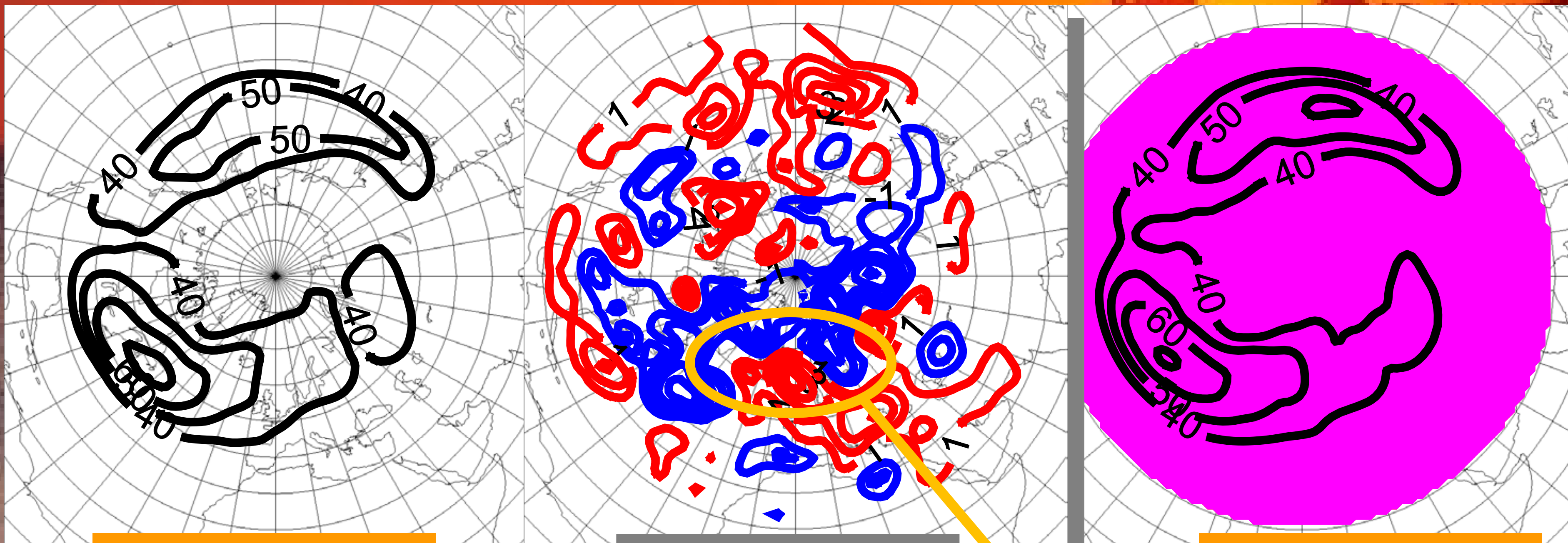


composites of 500 hPa height (isolines) and temperature (colour) anomalies

Blockings – summary

- under high solar activity:
  - ❑ E-ward shift of maximum occurrence in both ATL and PAC sectors
  - ❑ shorter duration – consistent with enhanced zonality
  - ❑ larger spatial extent
  - ❑ ATL blockings: weaker temperature response in Europe

5. Cyclones & stormtracks



MIN

max-min

MAX

stormtracks: Eulerian approach: stdev of 500 hPa height anomalies in synoptic (2.5 to 6 days) frequencies

signature of southward shift, smaller NE-ward tilt over NE Atlantic & W Europe

Summary – stormtracks & cyclones

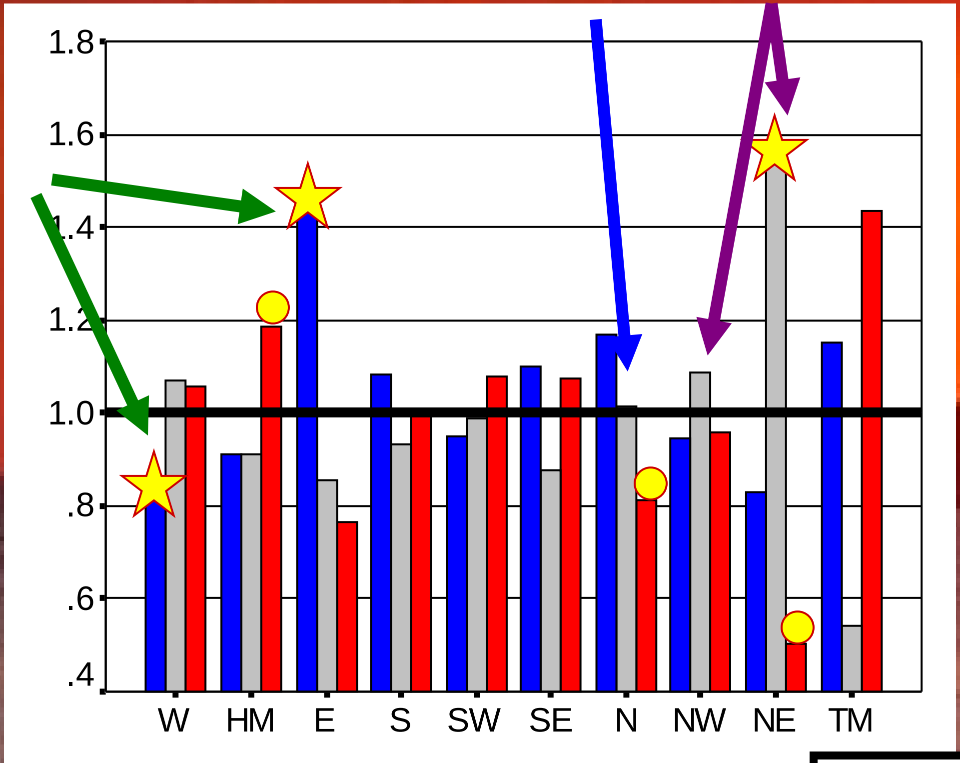
- solar effects on stormtracks / cyclones weaker than on blocks
- Why? Probably different time scale; solar effects on synoptic processes seem to be small

6. Synoptic (circulation) types

(Huth et al., *Ann. Geophys*., 2008, **26**, 1999-2004)

Hess & Brezowsky catalogue of synoptic types

- ❑ available since 1881, updated up to present
- ❑ each day classified with one type
- ❑ developed for central Europe (Germany)
- ❑ 29 types (+ 1 type undetermined)
- ❑ grouping into 10 "**major types**" according to their major circulation features
- ❑ for each class of solar activity:
  - ❑ mean frequency of major types
  - ❑ display: frequency in the solar activity class / climatological frequency



major types

N types – less frequent in solar maxima

NW + NE types – most frequent in moderate solar activity

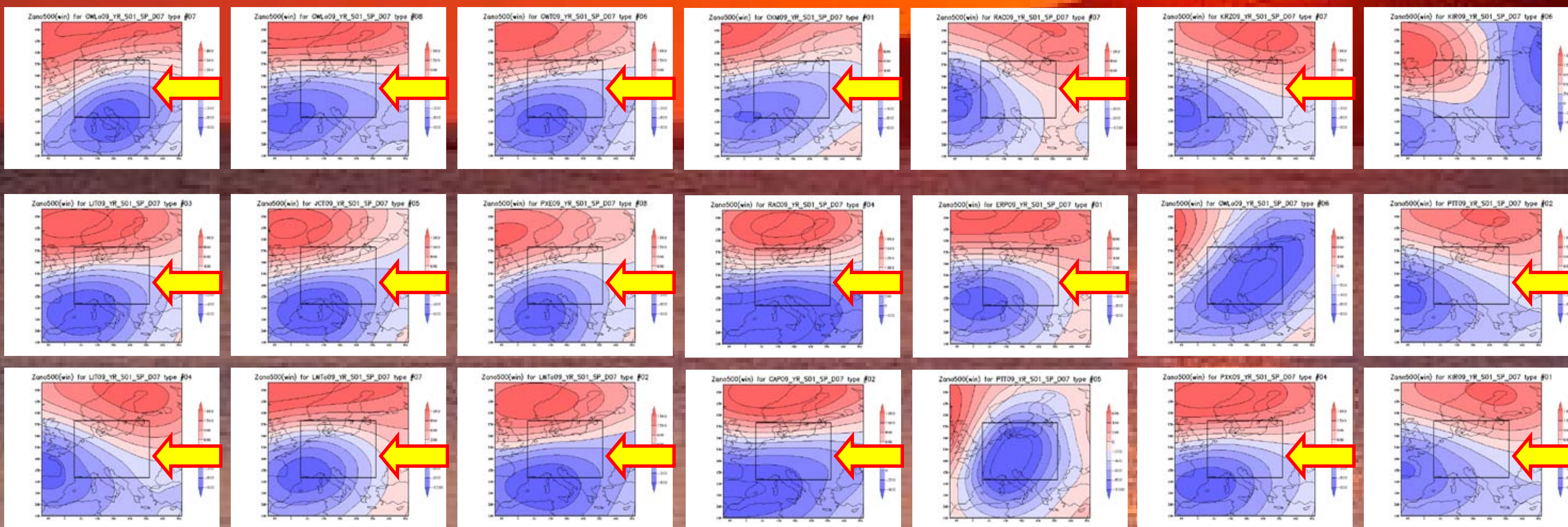
W / E types – less / more frequent in solar minima

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%)

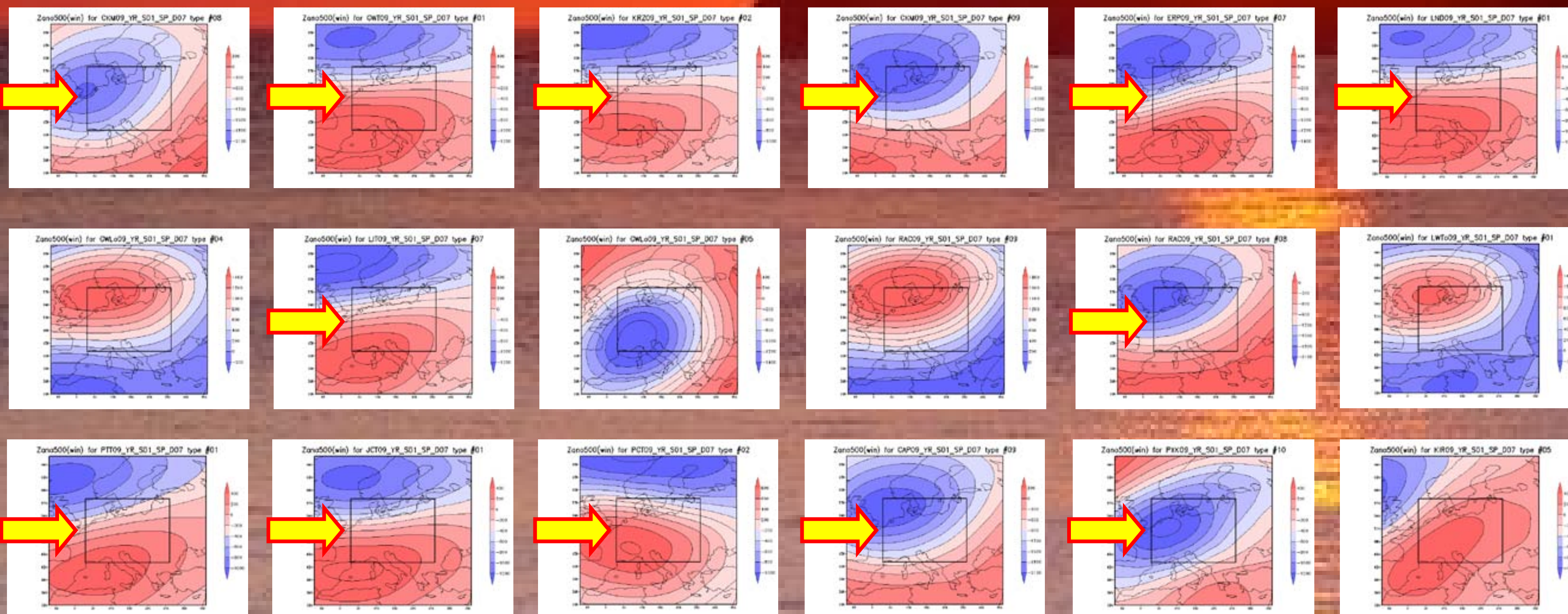
Types more frequent in solar minima

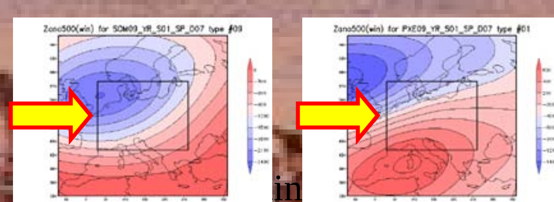
types with easterly anomaly flow prevail



Types more frequent in solar maxima

types with westerly to south-westerly anomaly flow prevail





Summary of solar effects on tropospheric circulation

- solar effects on NH tropospheric circulation in winter are significant, and some are surprisingly strong
- under solar maxima:
  - zonalization of flow, esp. over N.Atlantic / Europe
  - larger spatial extent / covariability / teleconnectivity
- solar effects are nonlinear; some are specific to moderate, non-extreme solar activity

B. Issues to discuss / resolve …

a. How is the NAO defined?

- (and not only the NAO, but also other variability modes as well)
- different definitions ➔ different response patterns
- action centres move in time *(Jung et al., J.Climate 2003)*, during annual cycle, in response to solar activity, … ➔ definition should be 'dynamic'
  - in particular, station-based definition of NAO does not make sense in summer – its action centres are far away from Iceland and Azores (south of Iberian Peninsula) *(Folland et al., J.Climate 2009)*
- that is, station-based ('static') definitions may not be appropriate
- but: it is these station-based definitions that are available for long periods (since mid 19th century at least)

b. Temporal stability

- most analyses have been done for the last few solar cycles ← atmospheric & external forcing data availability
- temporal stability of relationships?
  - specificity of the last period (high solar maxima)
  - long-term trends in solar input
- what we found on the recent period, may not hold in more distant past and may not be generally valid
- obstacles
  - data less reliable towards past (both atmospheric and solar)
  - some (most) solar etc. data not available or only available as derived proxies

c. Nonlinearity of effects

- many effects
  - are non-linear
    - effects may be monotonic, but not linear
    - effects are even not monotonic: specific effects appear e.g. for moderate solar activity (e.g., weakening of NAs pattern; disappearance of Pacific centre from AO)
  - cannot be detected by common linear methods for other (methodological) reasons (e.g., shift of action centres of the modes)
- simple linear tools cannot discover such effects
  - correlations (especially parametric [Pearson])
  - composite analysis
- in other words, linear methods can tell us only a part of the truth

d. Time-scale of forcing

- different detection techniques to be employed for different time-scales
  - individual events (geomagnetic storms, Forbush decreases, …) versus
  - more or less slowly varying (time averaged) forcings (solar activity, geomagnetic activity, …)

e. Time-scale of mechanisms of effects

- so far not clear which processes, and to what extent, are responsible for transferring and amplifying signals of external forcings
- different processes have different response times
  - days (cyclogenesis following geomagnetic storms)
  - month(s) (downward propagation of stratospheric disturbances to polar vortex; poleward propagation of signal from the Tropics)
  - year(s) (lagged effects propagating through memory e.g. in NH snow cover)
- ➔ different lags must be used in the analyses
- on the other hand, high temporal autocorrelation of (many) external forcings makes this issue less serious

f. Confounding effects

- external forcings do not operate in isolation
- other phenomena interact with them
  - ENSO, volcanic eruptions, QBO, SSWs, …
- their effects should be separated from external forcings
- difficult task also because of possible mutual interactions external forcing ↔ other phenomena ↔ tropospheric circulation
- possible ways out
  - subdivision of data (solar activity *AND* QBO-phase etc.) – unpleasant effect of decreasing sample sizes
  - compare effects with vs. without ‘the other’ phenomenon (e.g., exclude a few years after major volcanic eruptions or with strongest El Niños) – similar negative effect on sample size
  - incorporate this directly into significance testing procedure – only possible with resampling (Monte Carlo) methods – see later

g. Significance testing

- correct and **fair** significance testing is necessary
- **fair:** e.g., our *a posteriori* knowledge (or even wishful thinking) should not penetrate into the testing procedure
- careful formulation of the null hypothesis
- e.g., ‘superposed epoch analysis’ – used for detection of response to individual events – recent critical evaluation of testing procedures by Laken & Čalogović

h. Effect of autocorrelation on significance tesing

- difficulty: high temporal autocorrelation in data (external forcings in particular)
- temporal autocorrelation must be properly accounted for in significance testing
- sometimes difficult task within ‘classical’ (parametric) testing
- useful to resort to non-parametric tests, esp. those based on resampling (Monte Carlo)
- Monte Carlo approaches allow a much wider range of null hypotheses to be formulated

i. Multiple testing and spatial autocorrelation

- typically: multiple 'local' tests are conducted (e.g. at gridpoints)
- important question: couldn't the number of rejected 'local' tests appear by random? (issue of global / field significance)
- naïve approach: 'local' test at 5% significance level ➔ >5% of rejected 'local' tests indicates significance – **this is wrong!**
- number of rejected tests follows a binomial distribution ➔ much larger number of 'local' tests must be rejected to achieve 'global' ('collective') significance (unless the number of 'local' tests is **very** large) *(Livezey & Chen, Mon.Wea.Rev. 1983)*
- this holds for independent 'local' tests
- geophysical data are spatially autocorrelated (typically quite strongly!) ➔ 'local' tests are hardly independent
- the number of rejected 'local' tests needed for 'collective' significance is (much) higher than for independent 'local' tests
- for 500 hPa heights – certainly more than 20% of tests conducted on a 2.5° lat-lon grid must be rejected to achieve a 5% 'collective' significance
- this may resolve the discrepancy between e.g. a NAO (NAM or whatever else)-like response of a variable and no response in the magnitude in NAO (NAM or whatever else)
- there are other possible approaches to assessing 'collective' significance *(Wilks, J.Appl.Meteorol.Climatol. 2006)*