EFFECTS OF VARIATIONS IN SOLAR ACTIVITY ON TROPOSPHERIC CIRCULATION

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- based on
  - published papers
  - (so far) unpublished results
- in cooperation with
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  - D.Barriopedro, R.Trigo, University of Lisbon, Lisbon, Portugal
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- results presented for (unless otherwise stated)
  - winter (DJFM)
  - monthly mean data
  - period approx. 1950-2003
  - 500 hPa heights
  - Northern Hemisphere extratropics (north of 20°N)
- organized by main effects of solar variability

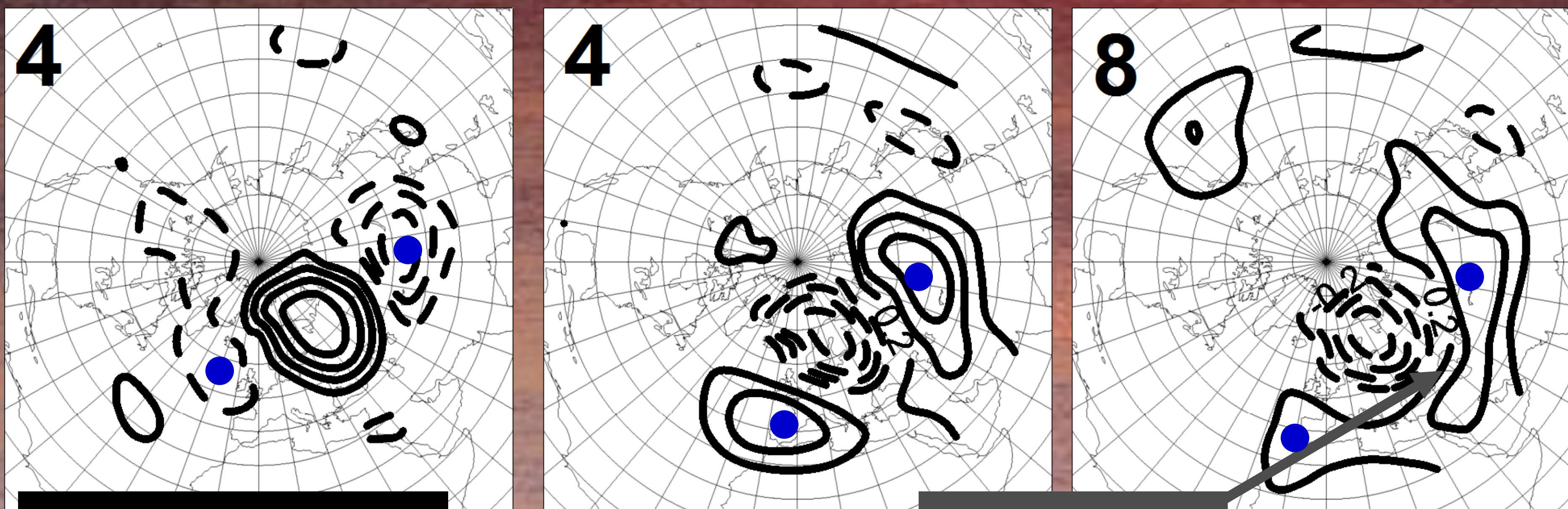
1. IN SOLAR MAXIMA, CIRCULATION IS MORE ZONAL

- modes of low-frequency variability
- detected by rotated Principal Component Analysis
- separately for low, moderate, and high solar activity

- **in high solar activity:**
- zonally oriented modes are more important (explain more variance)
  - North Atlantic Oscillation: ordered 2nd in low / 1st in high solar activity
  - East Atlantic pattern: 6 / 4
  - East Pacific pattern: absent / 7
- meridionally oriented modes are less important (explain less variance)
  - Eurasian, type 1: 4 / 8
  - Pacific / North American: 1 / 3
  - Tropical / Northern Hemisphere: 9 / absent

- **in high solar activity:**
- meridionally oriented modes attain more zonal shapes; example: EU1

min neutral max



solar maxima:

more zonal

both lateral centres: more zonally elongated, merging, forming a horseshoe-like structure

Synoptic types over central Europe (Hess & Brezowsky)

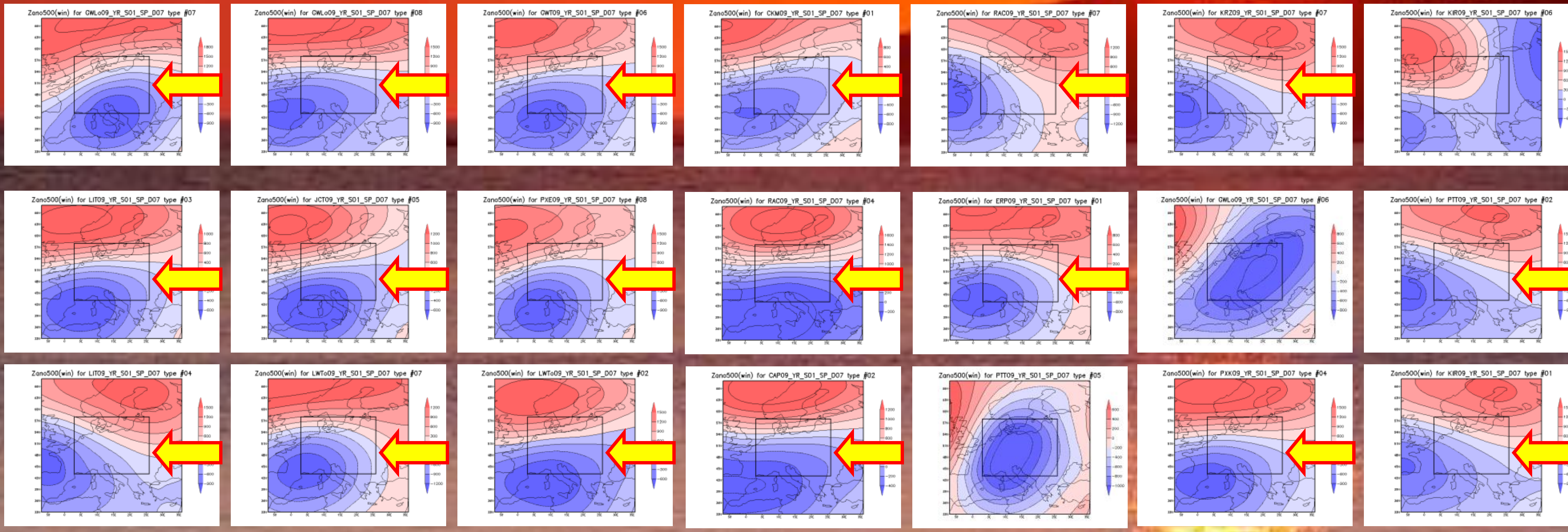
- **low solar activity:** W types **less than twice** as frequent as E types (39.5% vs. 20.4%)
- **moderate and high solar activity:** W types **almost four times** more frequent than E types (49.5% vs. 12.8%)

Another result for synoptic types

- 18 different objective classifications over central Europe
- circulation types with significantly enhanced frequency under solar minima (maxima) are identified

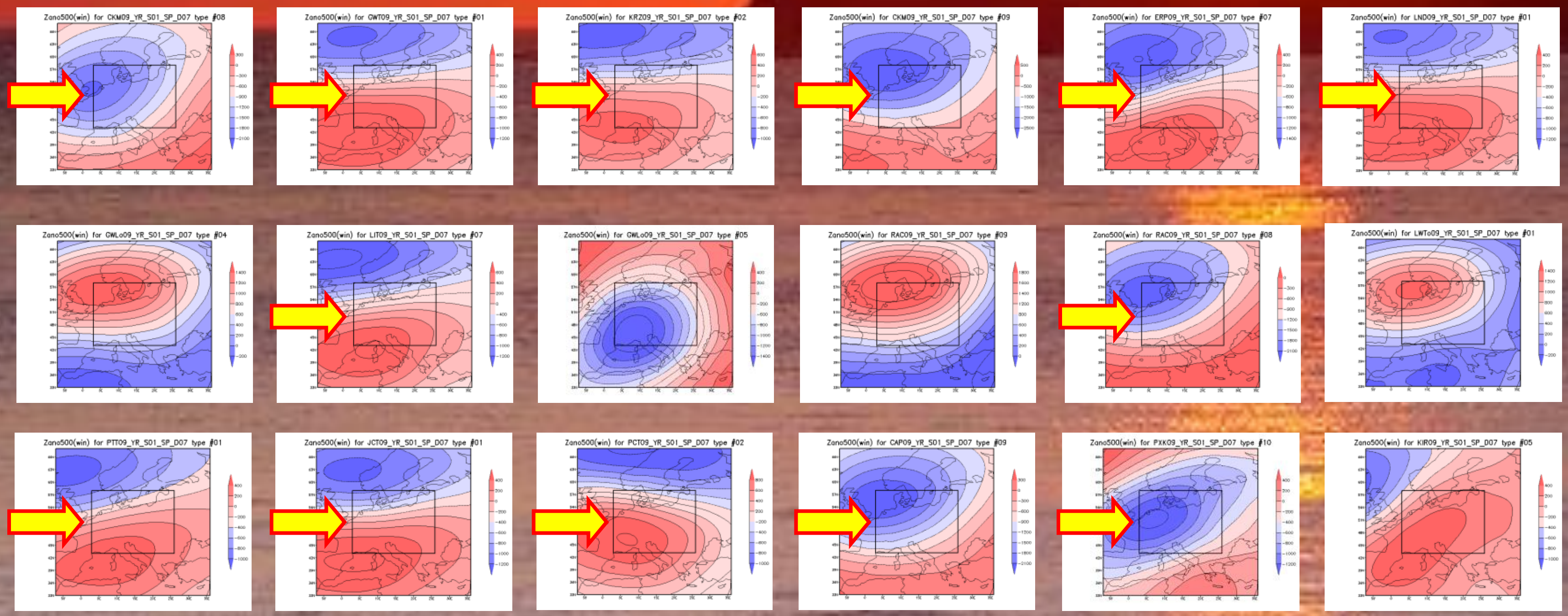
Types more frequent in solar minima

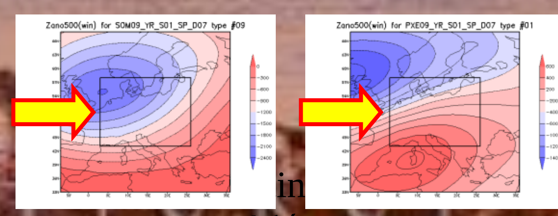
types with easterly anomaly flow prevail



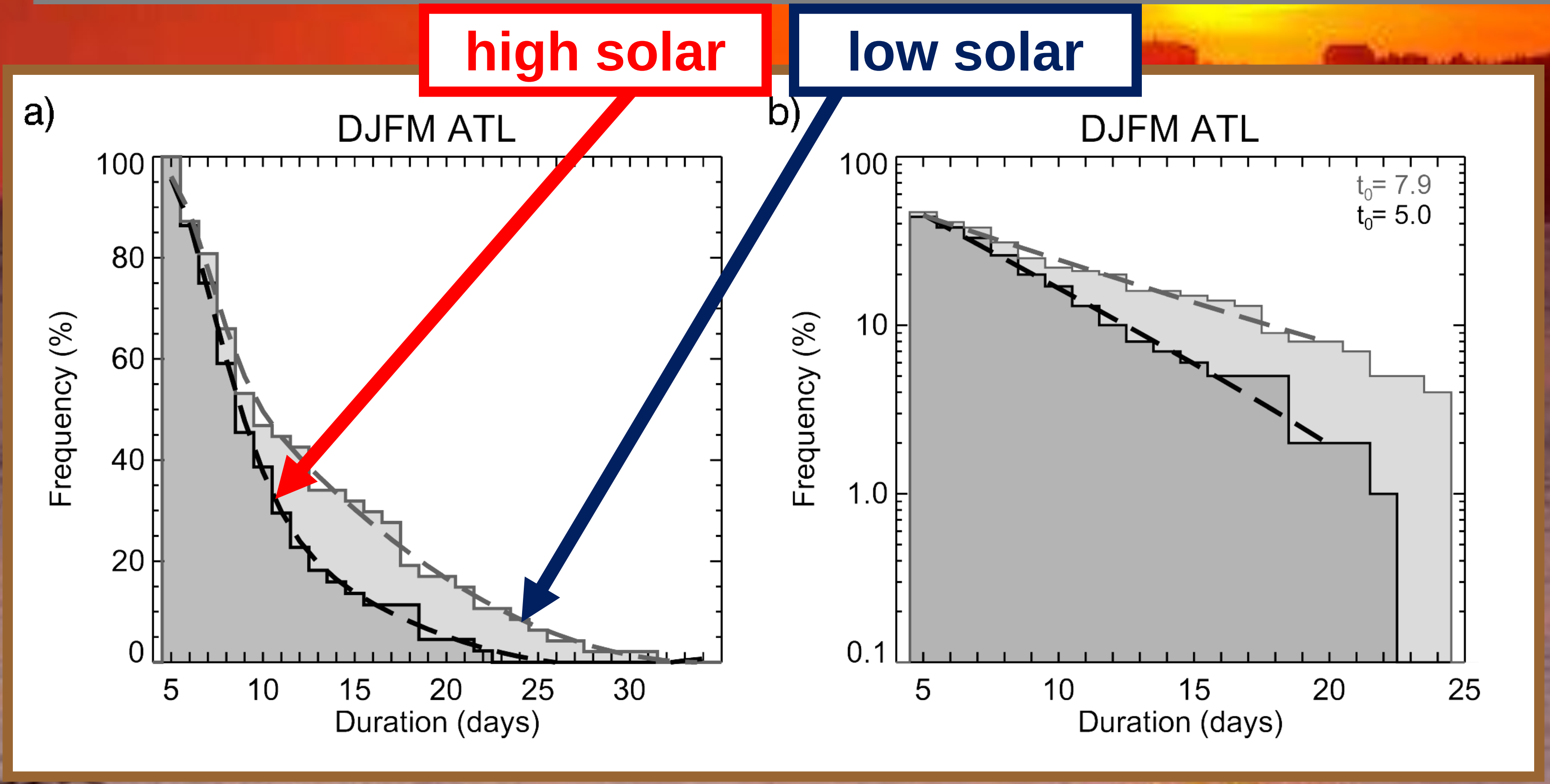
Types more frequent in solar maxima

types with westerly to south-westerly anomaly flow prevail

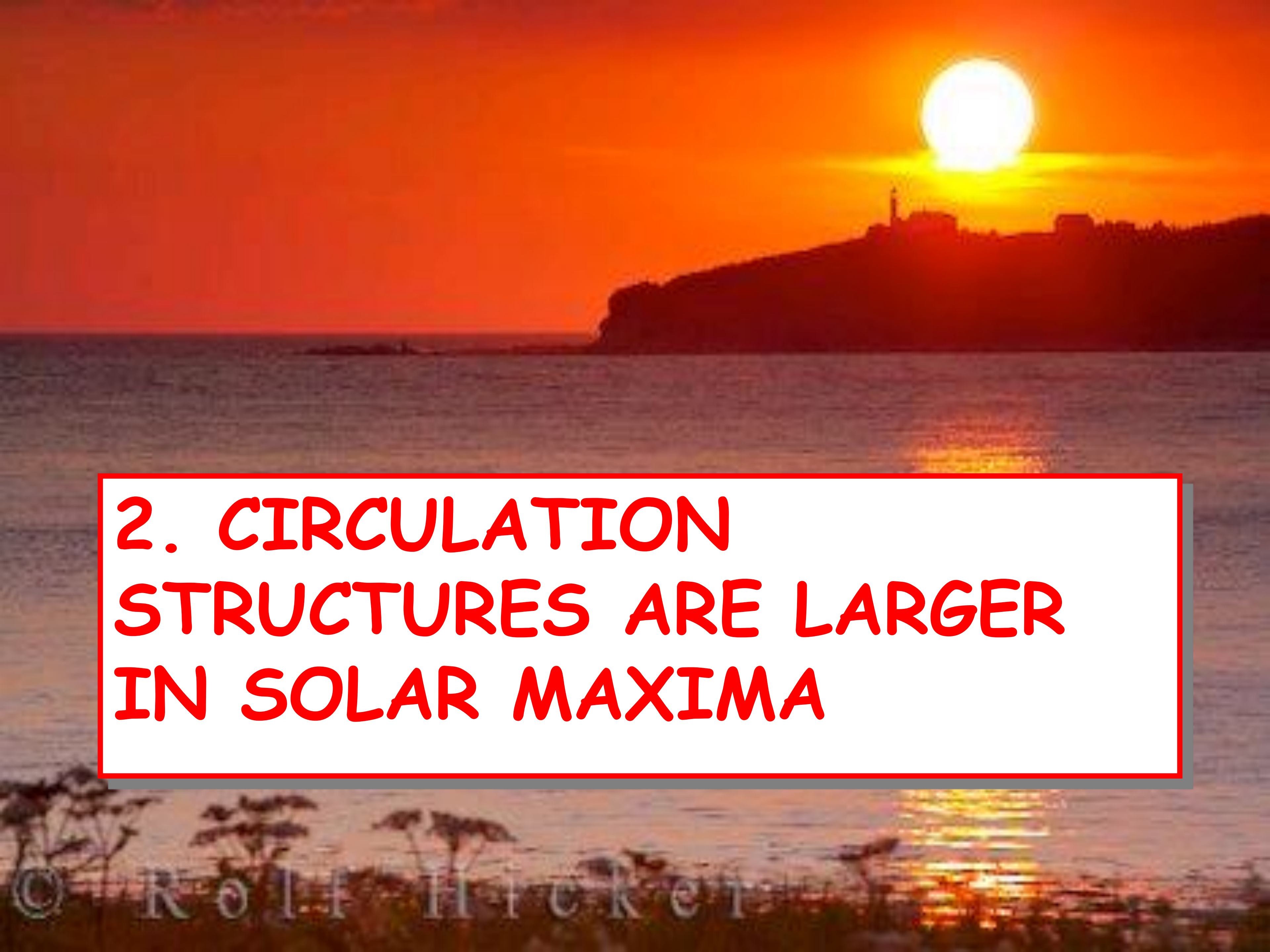




Blocking persistence, Atlantic sector



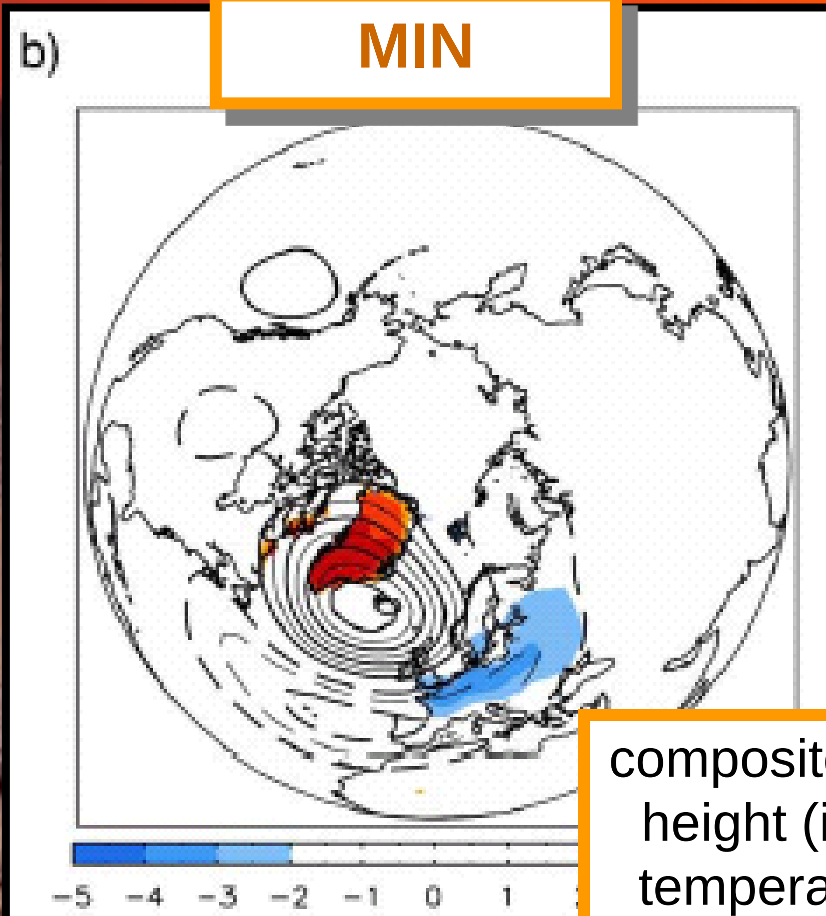
- blocks are shorter in solar maxima



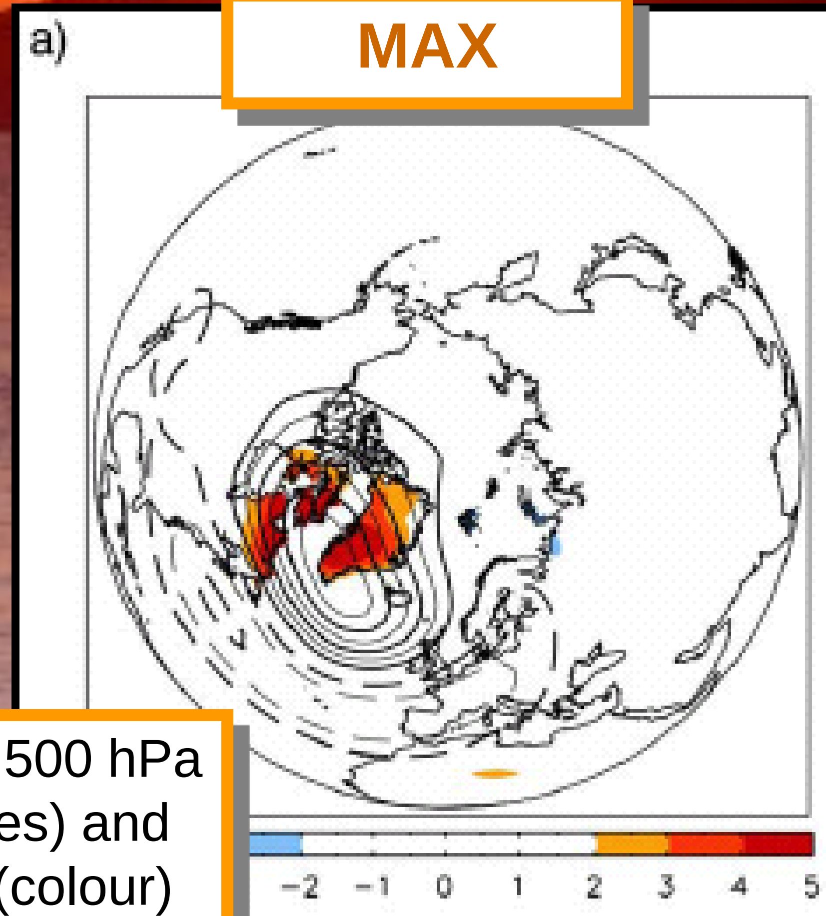
2. CIRCULATION STRUCTURES ARE LARGER IN SOLAR MAXIMA

Blockings, Atlantic domain: larger areal extent in solar max

MIN



MAX

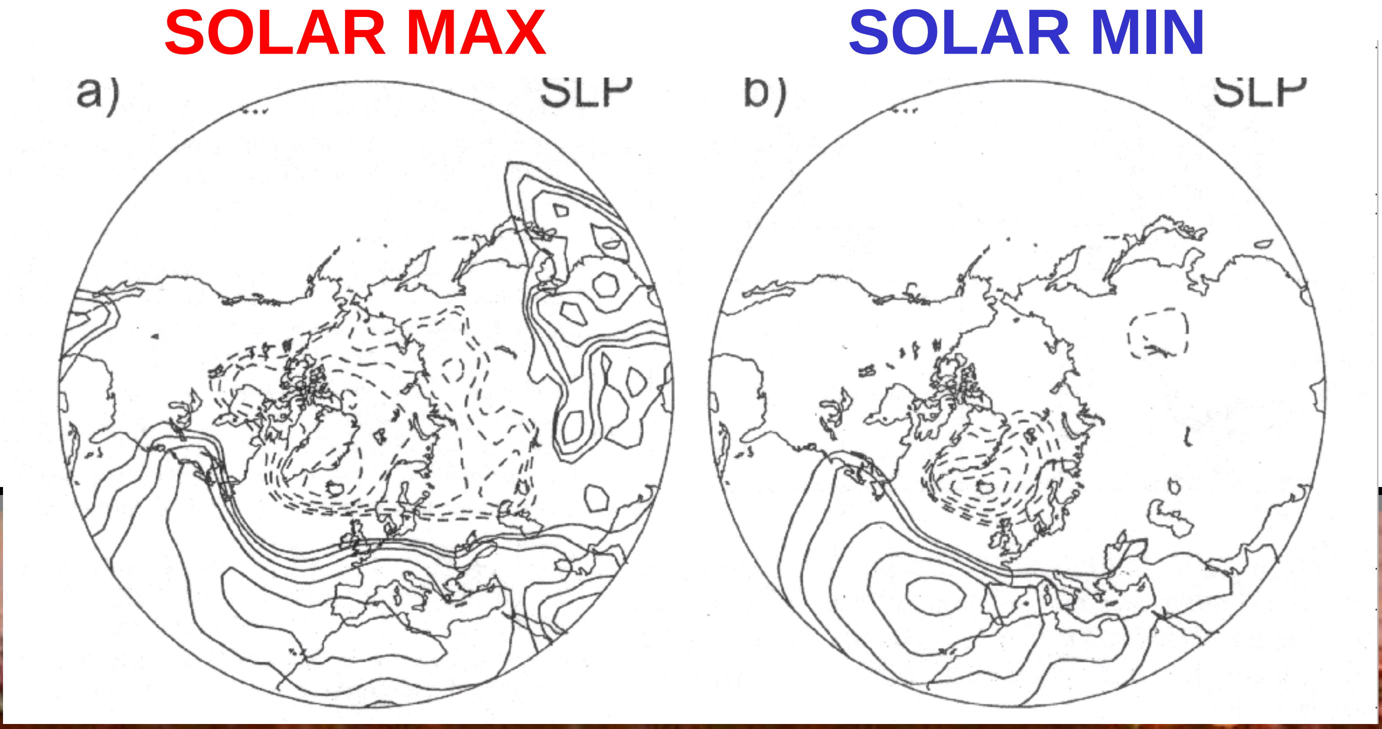


composites of 500 hPa height (isolines) and temperature (colour) anomalies

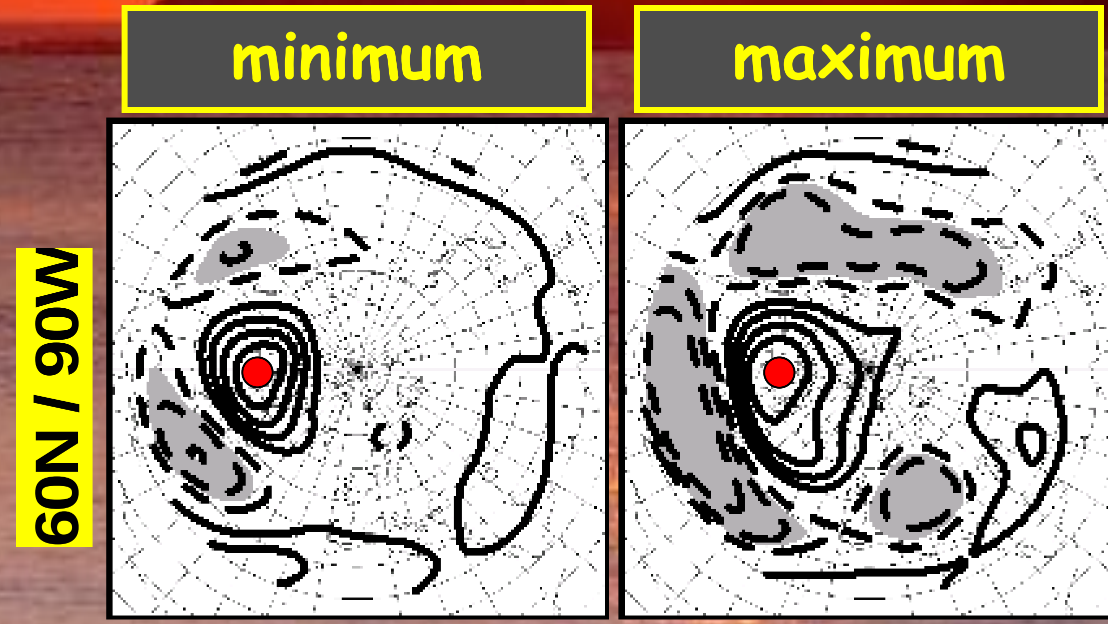
For NAO, already observed by Kodera (2002, 2003)

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

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



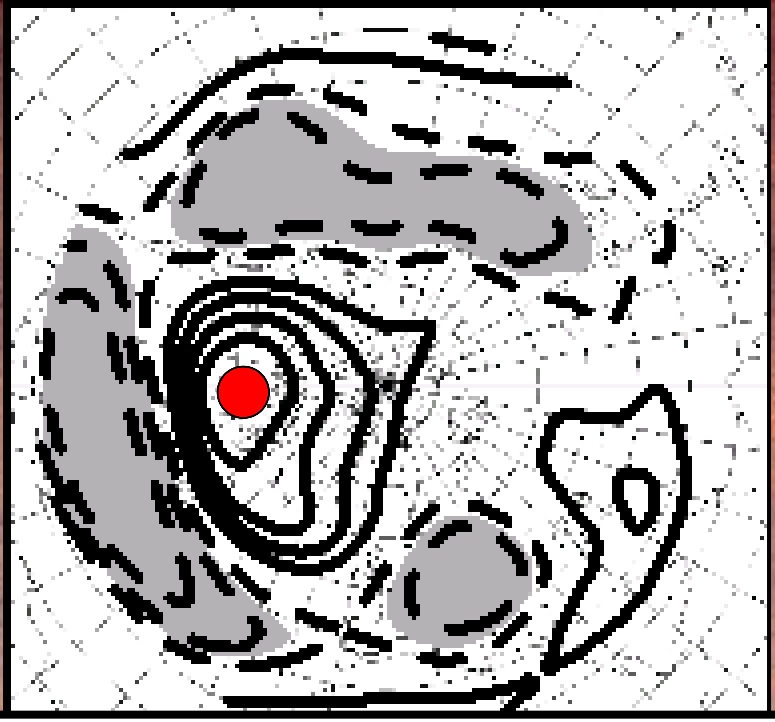
Spatial autocorrelations
(one-point correlation maps)



- highly (anti-)correlated areas are more spatially extensive in solar maxima, especially in the European / North Atlantic domain

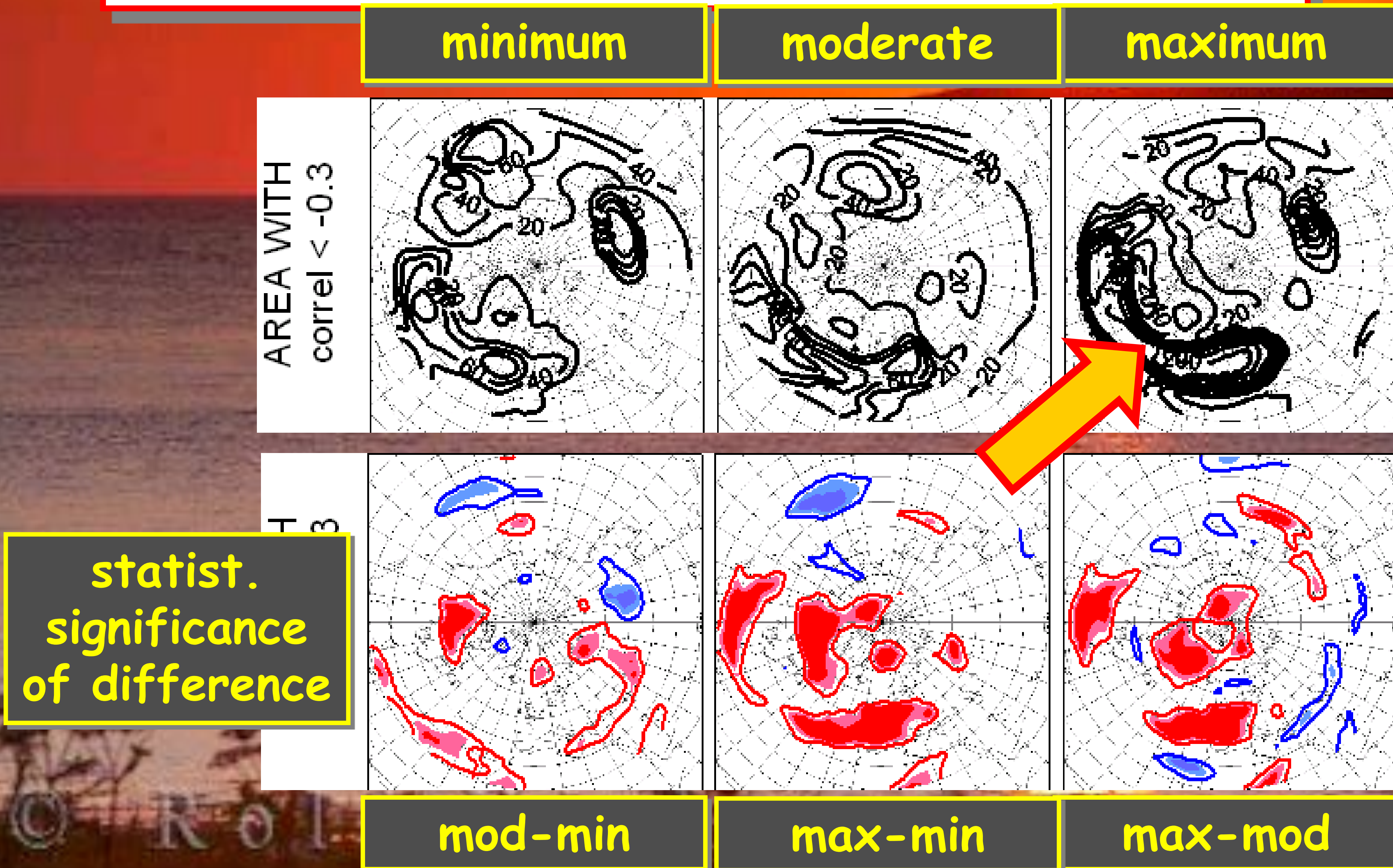
Teleconnected area

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



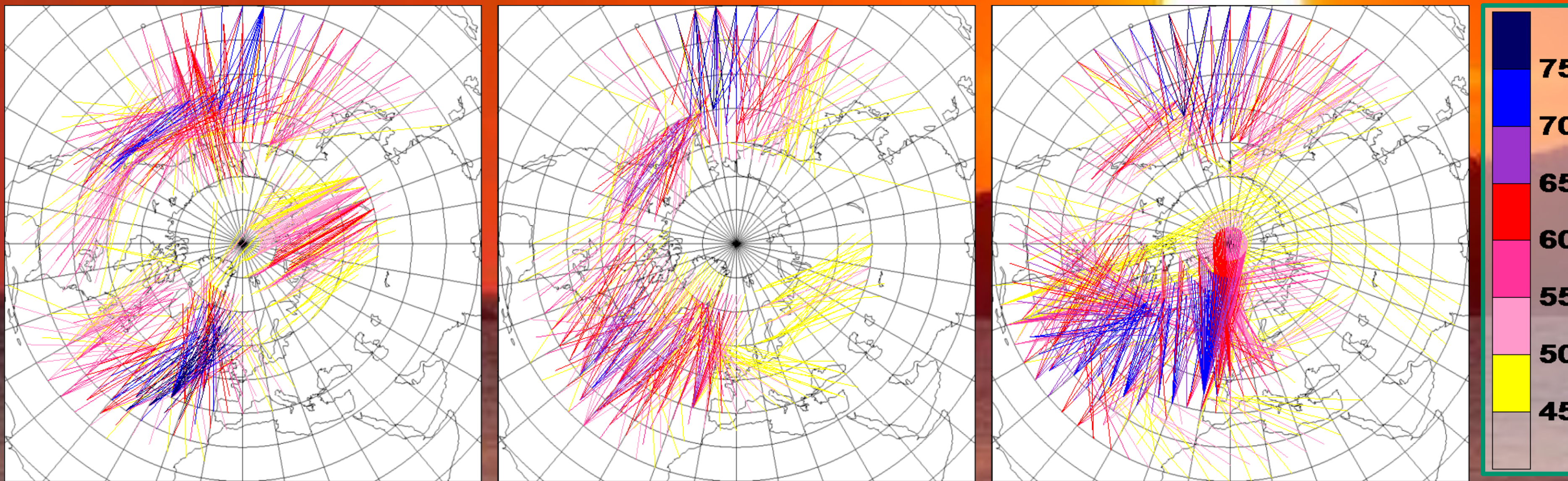
- result is then mapped

Teleconnected area



3. CORRELATION STRUCTURES CHANGE BETWEEN SOLAR MIN AND MAX

minimum | moderate | maximum



"HEDGEHOG" DIAGRAMS

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

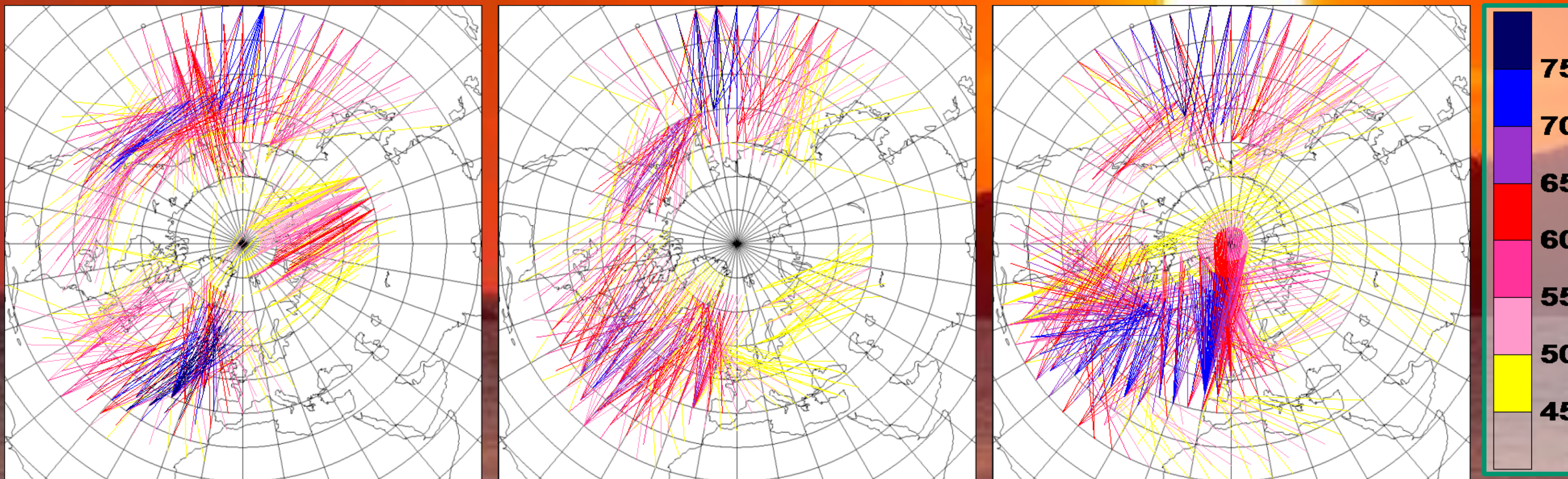
the magnitude of the correlation (in absolute terms, x100) is expressed by colours

only correlations over 0.45 are shown

minimum

moderate

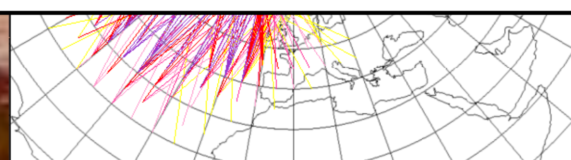
maximum



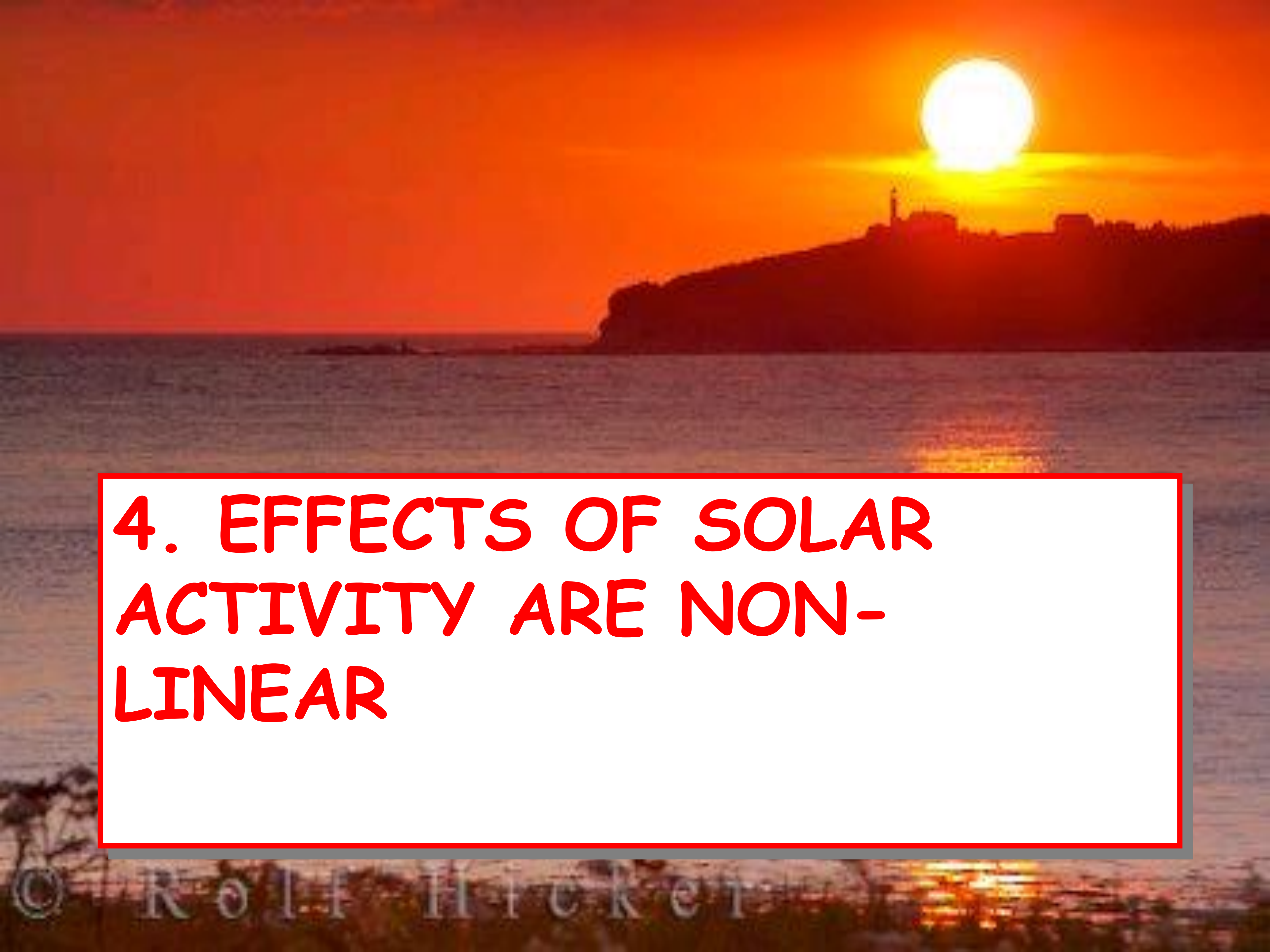
“HEDGEHOG” DIAGRAMS

largest difference: western N Atlantic / eastern N America

upstream links (to N Pacific) in solar min; downstream links (to N Atlantic + Europe) in solar max

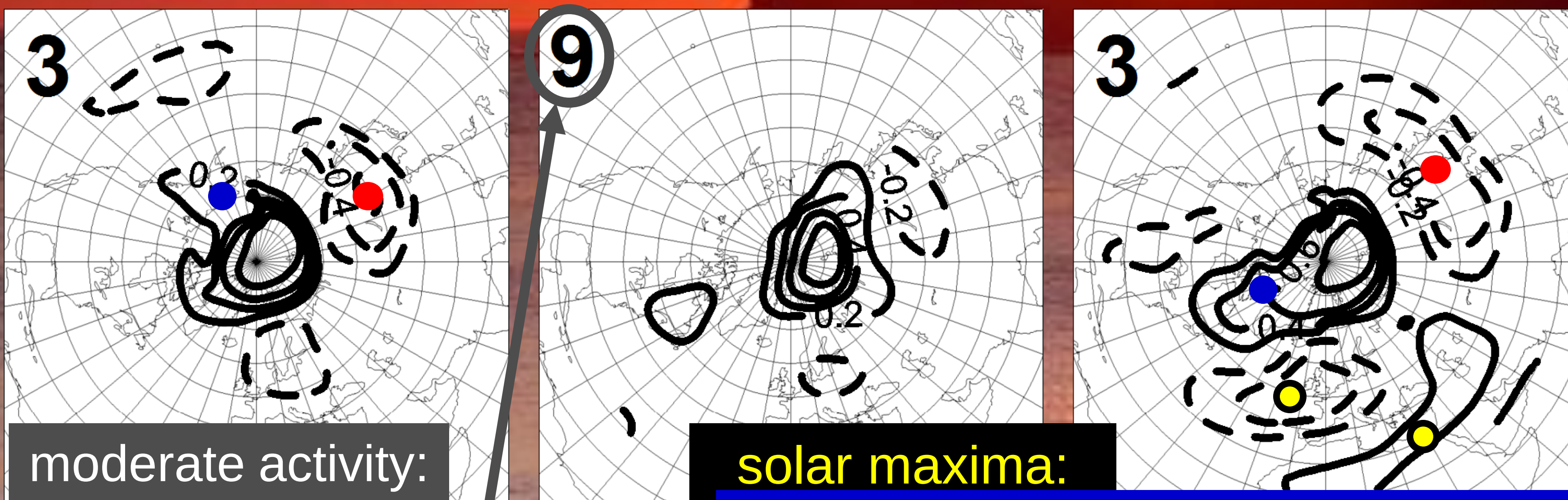


4. EFFECTS OF SOLAR ACTIVITY ARE NON-LINEAR



NAs (North Asian) mode

min | neutral | max



moderate activity:

much less importance (activity), much smaller extension of action centres

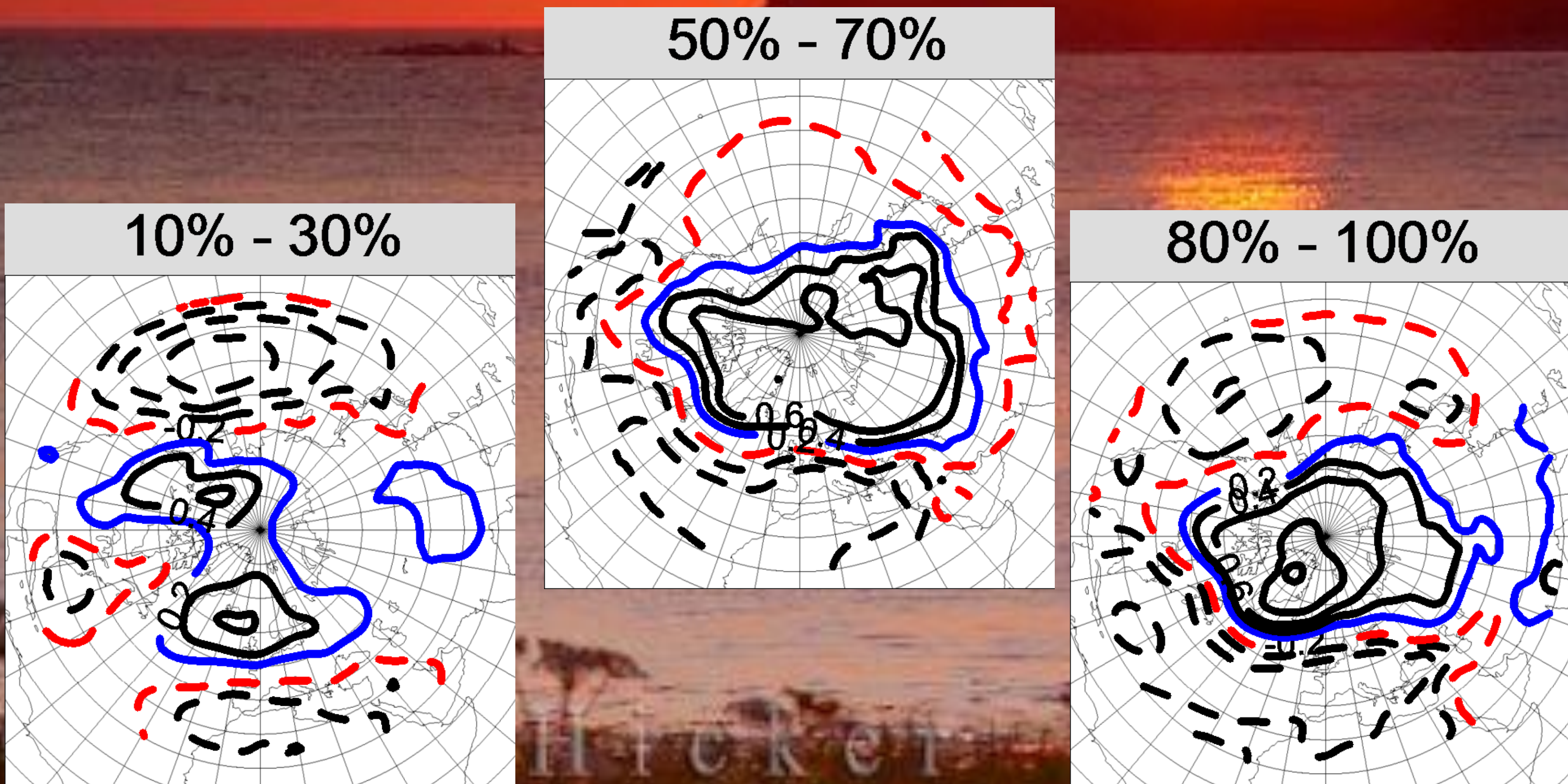
solar maxima:

Arctic centre: missing extension to Alaska, strong extension over E Canada instead

Siberian centre: weaker, more zonally elongated, esp. towards Pacific

attached 2 more centres over Europe (part of EU2?)

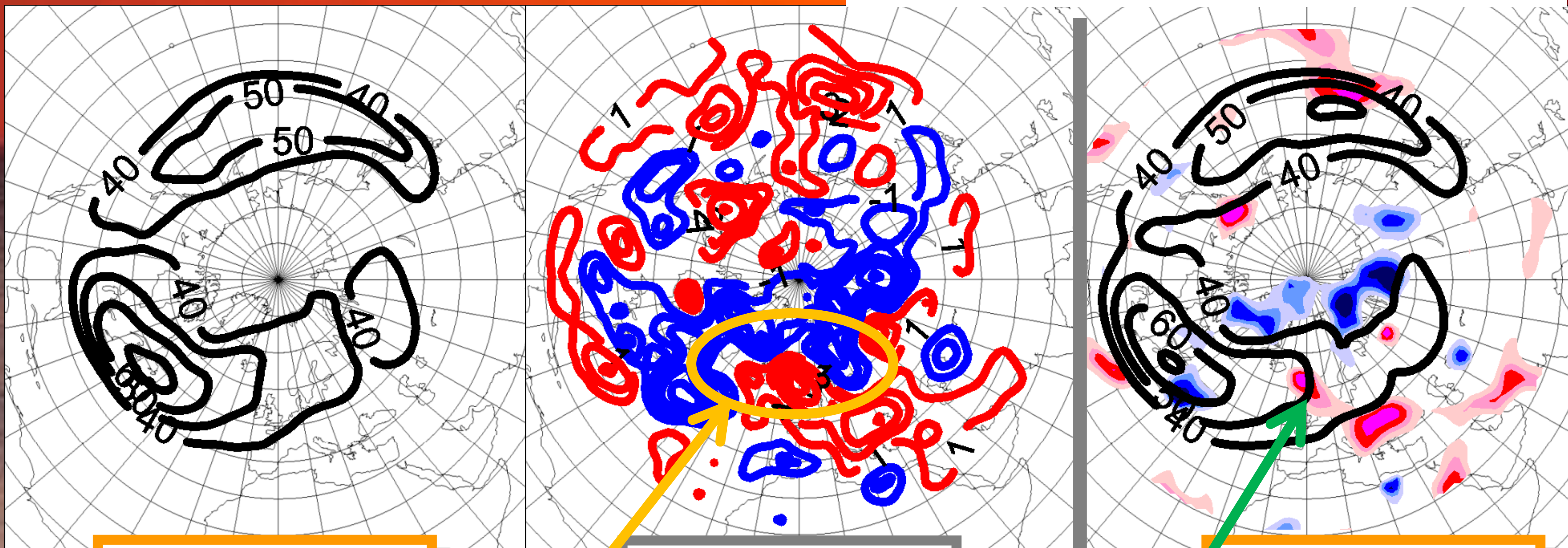
Arctic Oscillation for different quantile intervals of solar activity



5. LITTLE EFFECT IN SHORT (SYNOPTIC) TIME SCALES

Stormtracks

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

but little statistical significance

- very little observable effect on cyclones in Euro-Atlantic domain, and their properties (not shown here)
  - frequency
  - intensity (central pressure)
  - size

6. LARGEST EFFECTS APPEAR IN THE EUROPEAN / NORTH ATLANTIC DOMAIN

already shown…

6. LARGEST EFFECTS APPEAR IN THE EUROPEAN / NORTH ATLANTIC DOMAIN

And finally: A few 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

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

- response of troposphere is likely to differ for
  - 11-year solar cycle
  - longer-term changes

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 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
  - removal of the ‘other’ effects from data, e.g., by regression
  - 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 should not be incorporated into the testing procedure
- careful formulation of the null hypothesis
- we should not replace scientific rigour with wishful thinking

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 (example: difference in teleconnected area)

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 ➔ '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
- there are other possible approaches to assessing 'collective' significance *(Wilks, J.Appl.Meteorol. 2006)*