Science & Technology Facilities Council

Are cold winters in the UK associated with low solar activity?

Mike Lockwood

(University of Reading,
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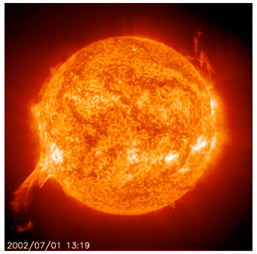
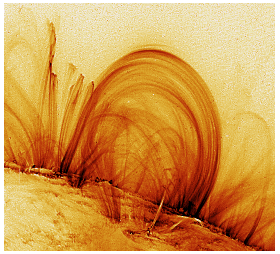
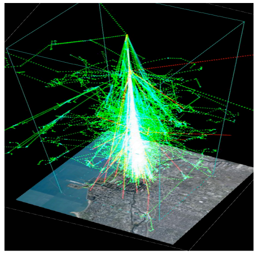
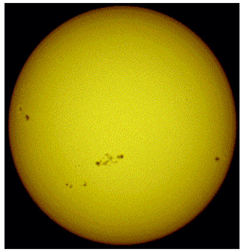
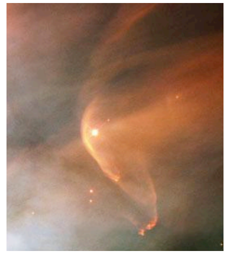
STFC/Rutherford Appleton Laboratory)

Seminar, MSSL, 16 February 2010



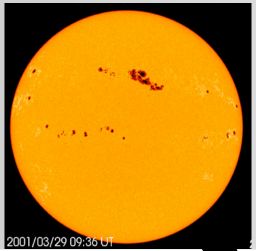


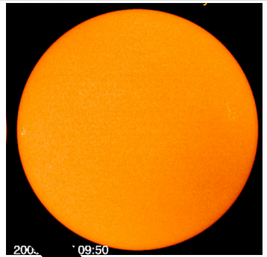



the recent solar minimum
UK winter temperatures
effect of open solar flux
estimating open solar flux
why open solar flux?
implications for the future

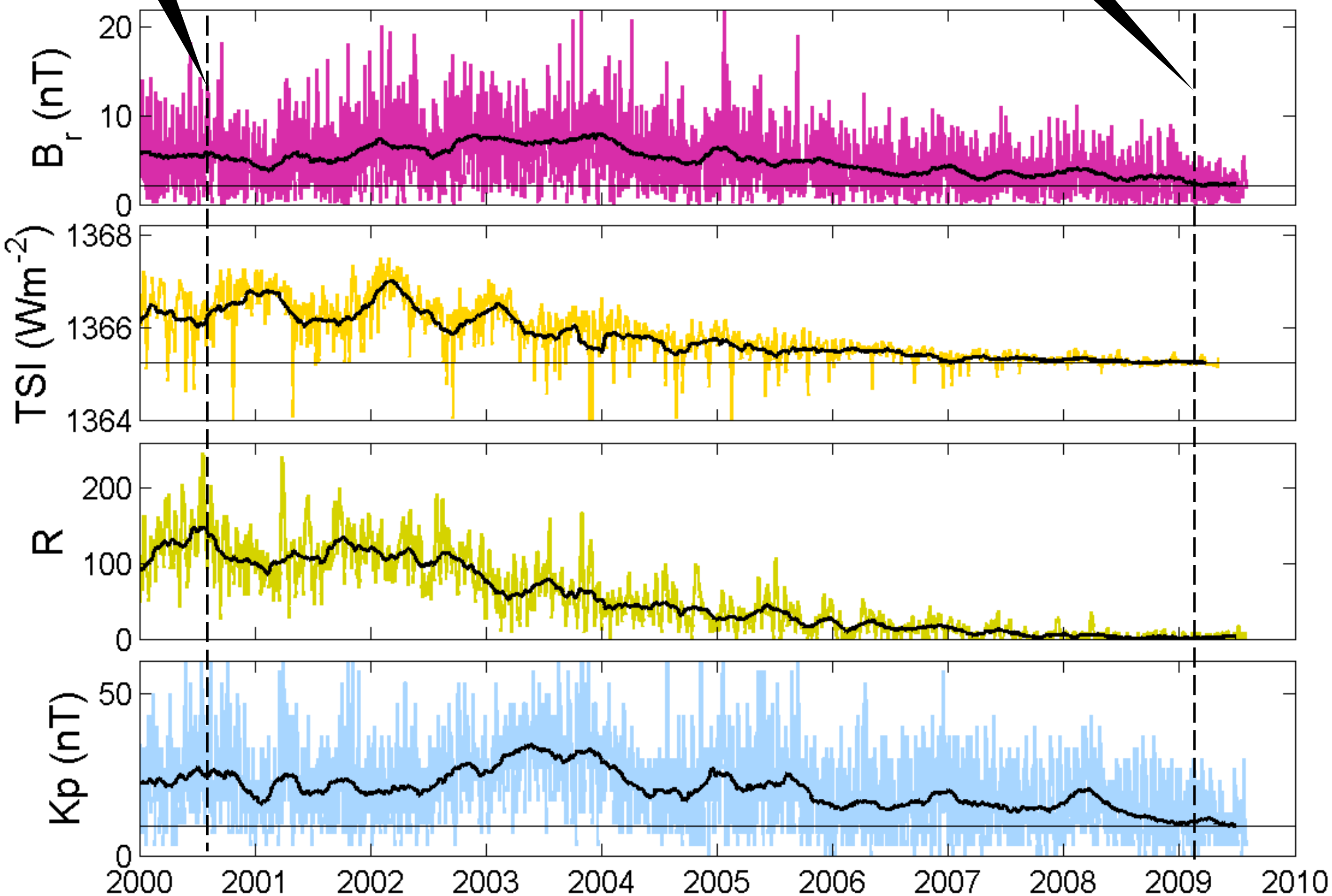
- the recent solar minimum

Recent Data

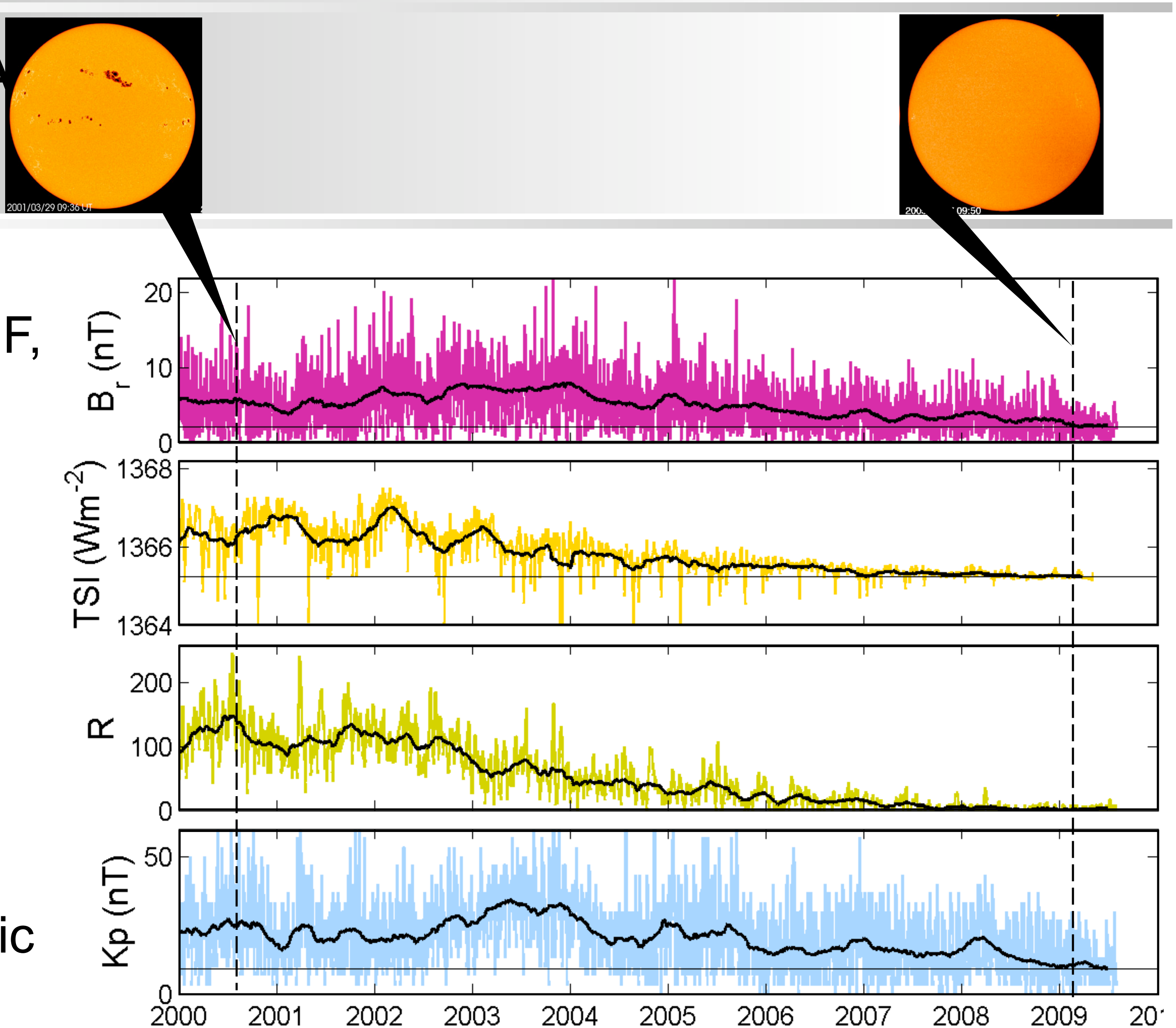




- ▶ radial IMF, $|B_r|$
- ▶ PMOD composite of TSI
- ▶ sunspot number, R
- ▶ Kp geomagnetic index



Space Data



- radial IMF, $|B_r|$
- PMOD composite of TSI
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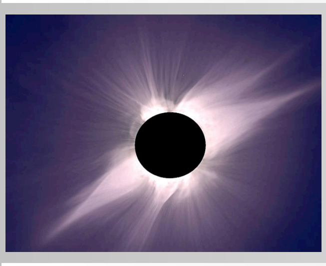


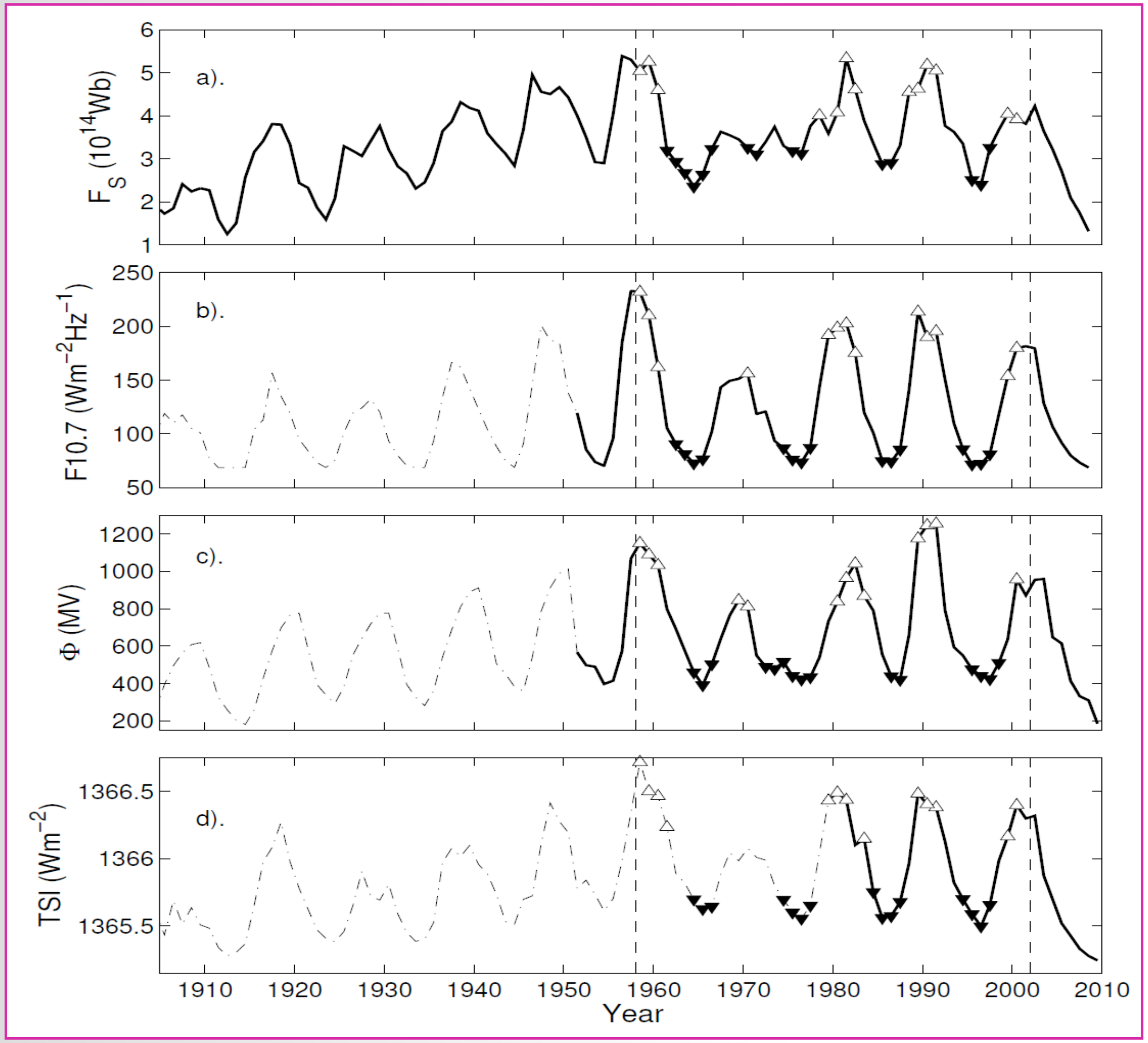
Decadal and Centennial Solar Variations

- ▶ open solar flux

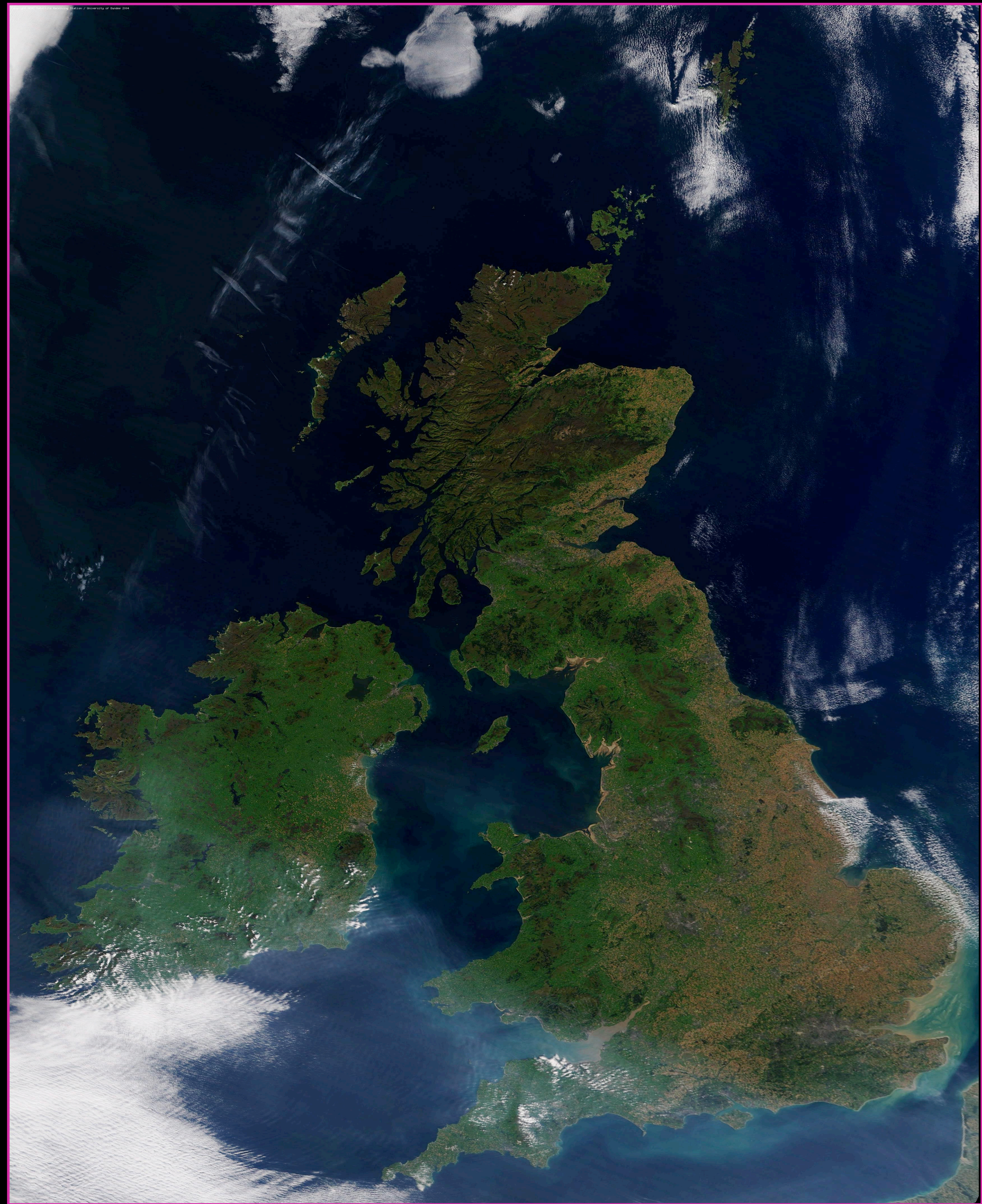
- ▶ F10.7 radio flux

- ▶ GCR modulation parameter

- ▶ Total Solar Irradiance (TSI) (PMOD Composite)



- UK winter temperatures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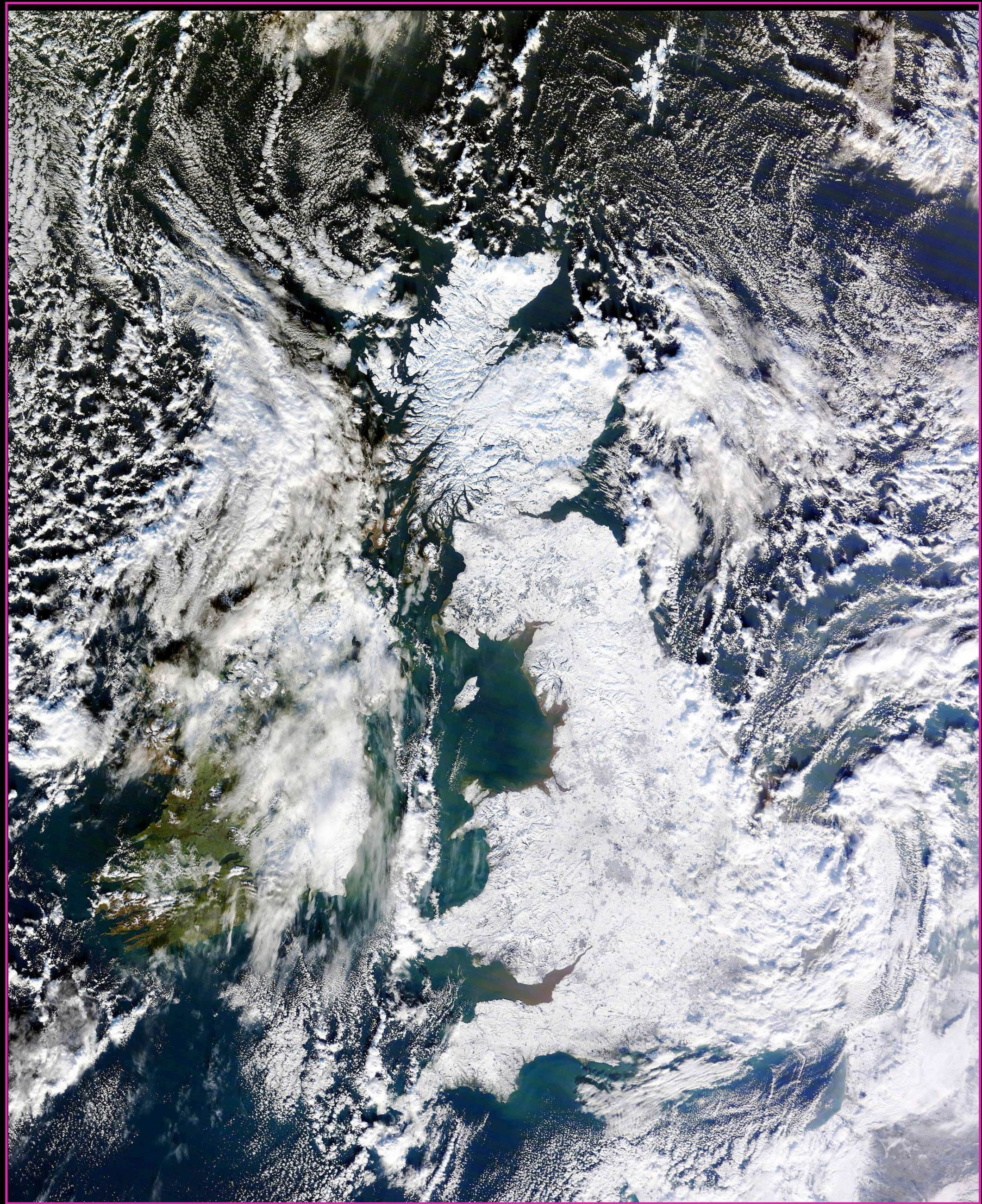
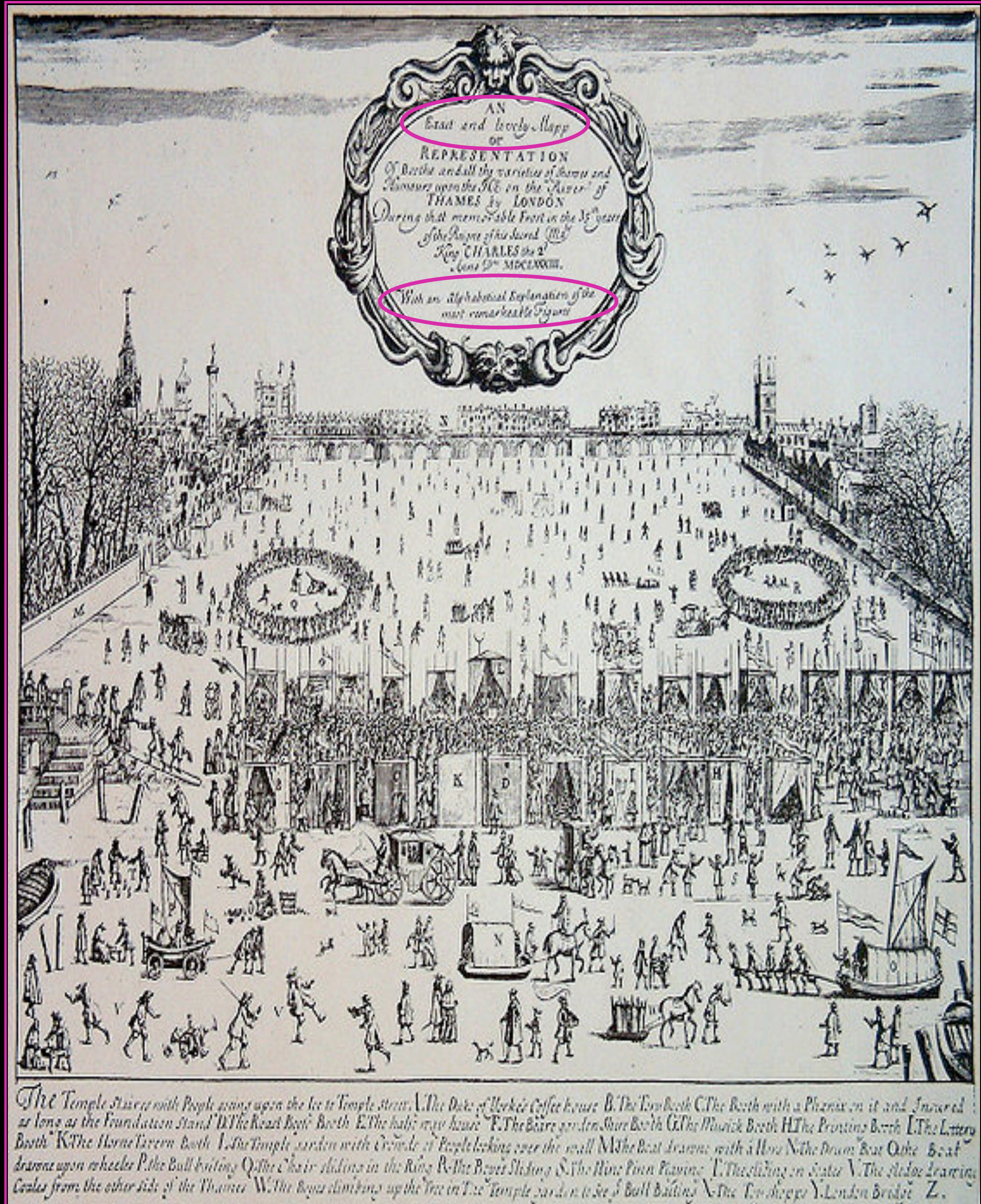
January 2010



January 1683

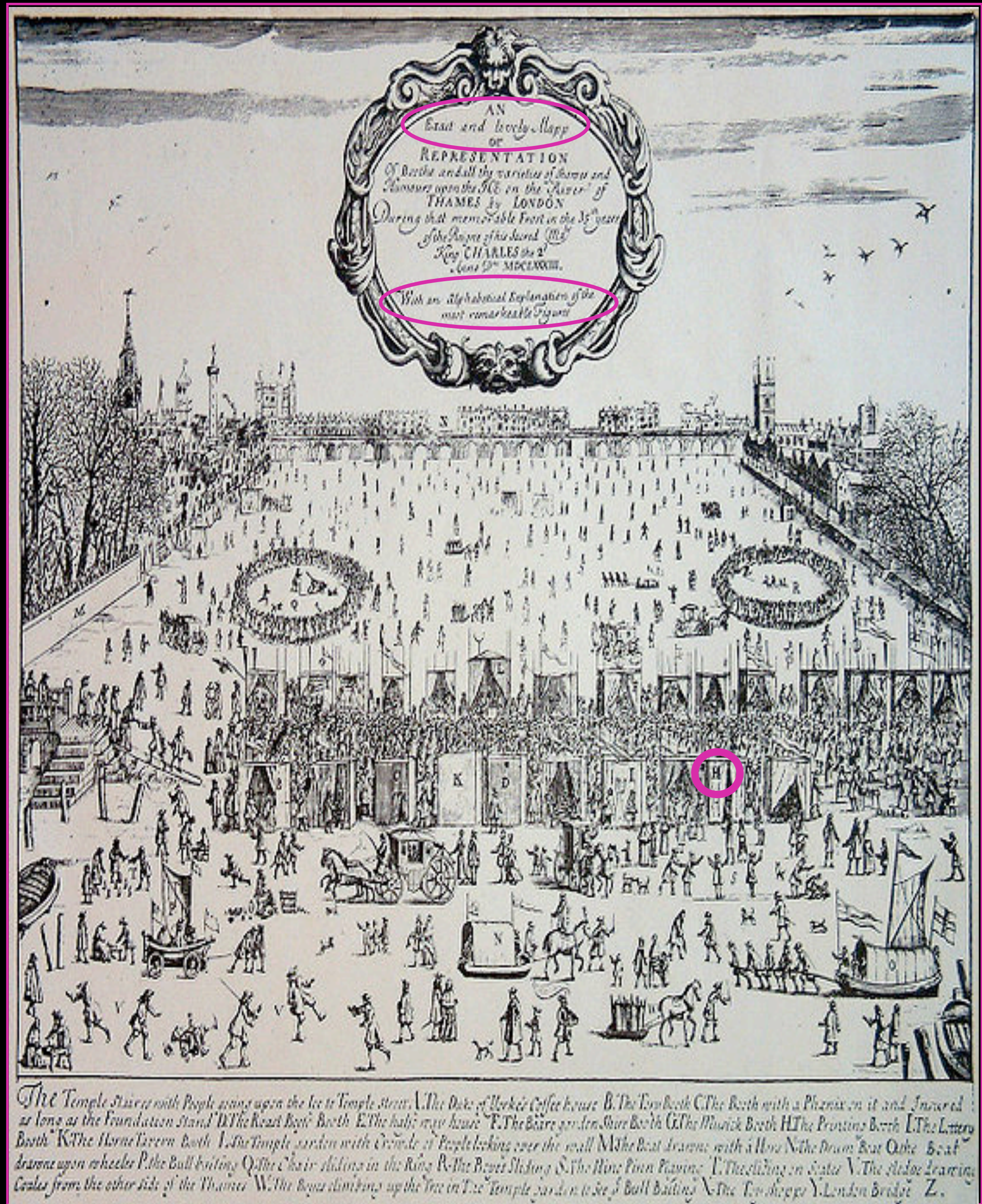
A Frost Fair on the Thames in London. The river froze in central London relatively frequently during the Maunder Minimum of sunspot activity

"An exact and lively mapp … with an alphabetical explanation of the most remarkable figures"



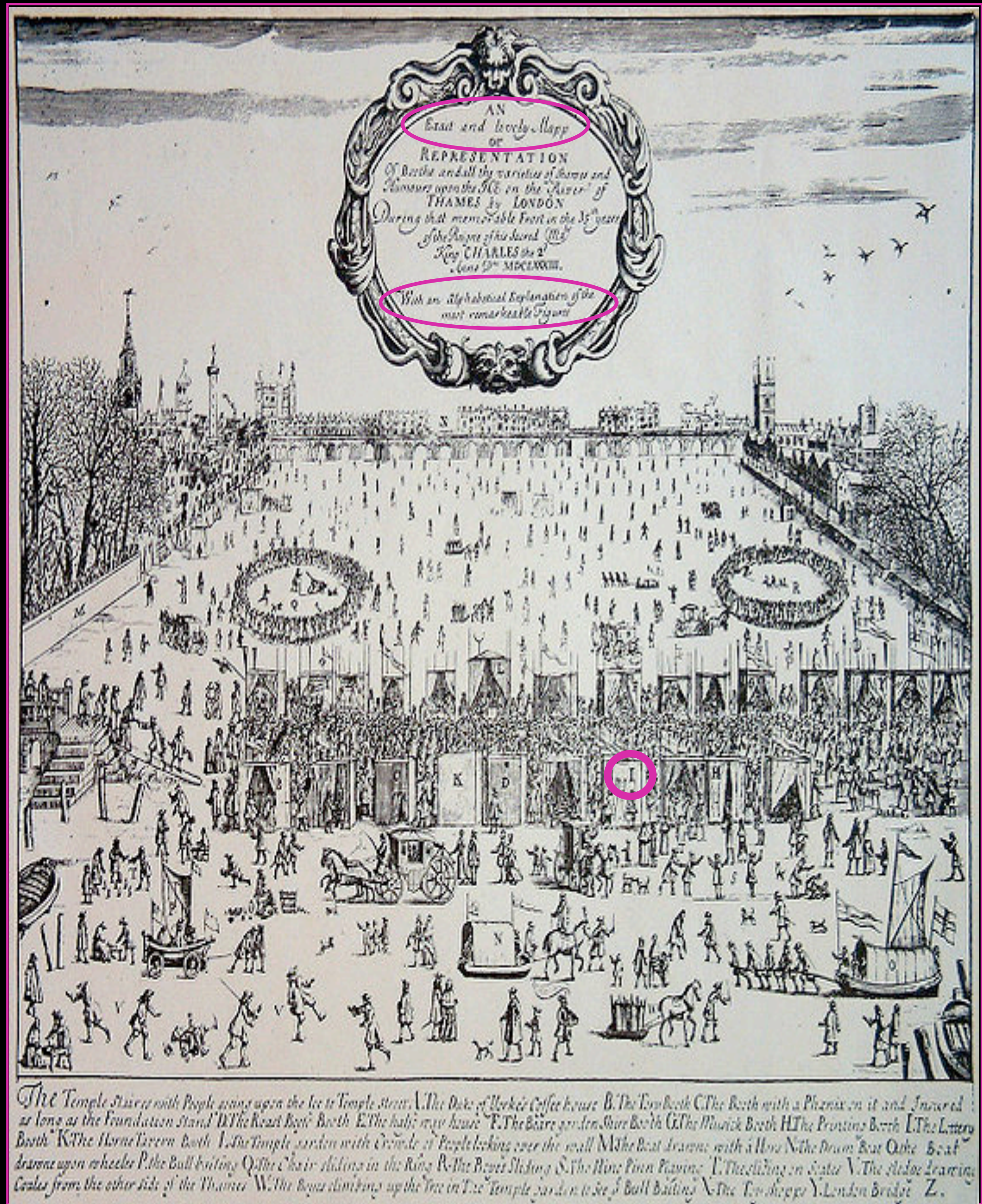
“An exact and lively mapp … with an alphabetical explanation of the most remarkable figures”

H. The Musick Booth



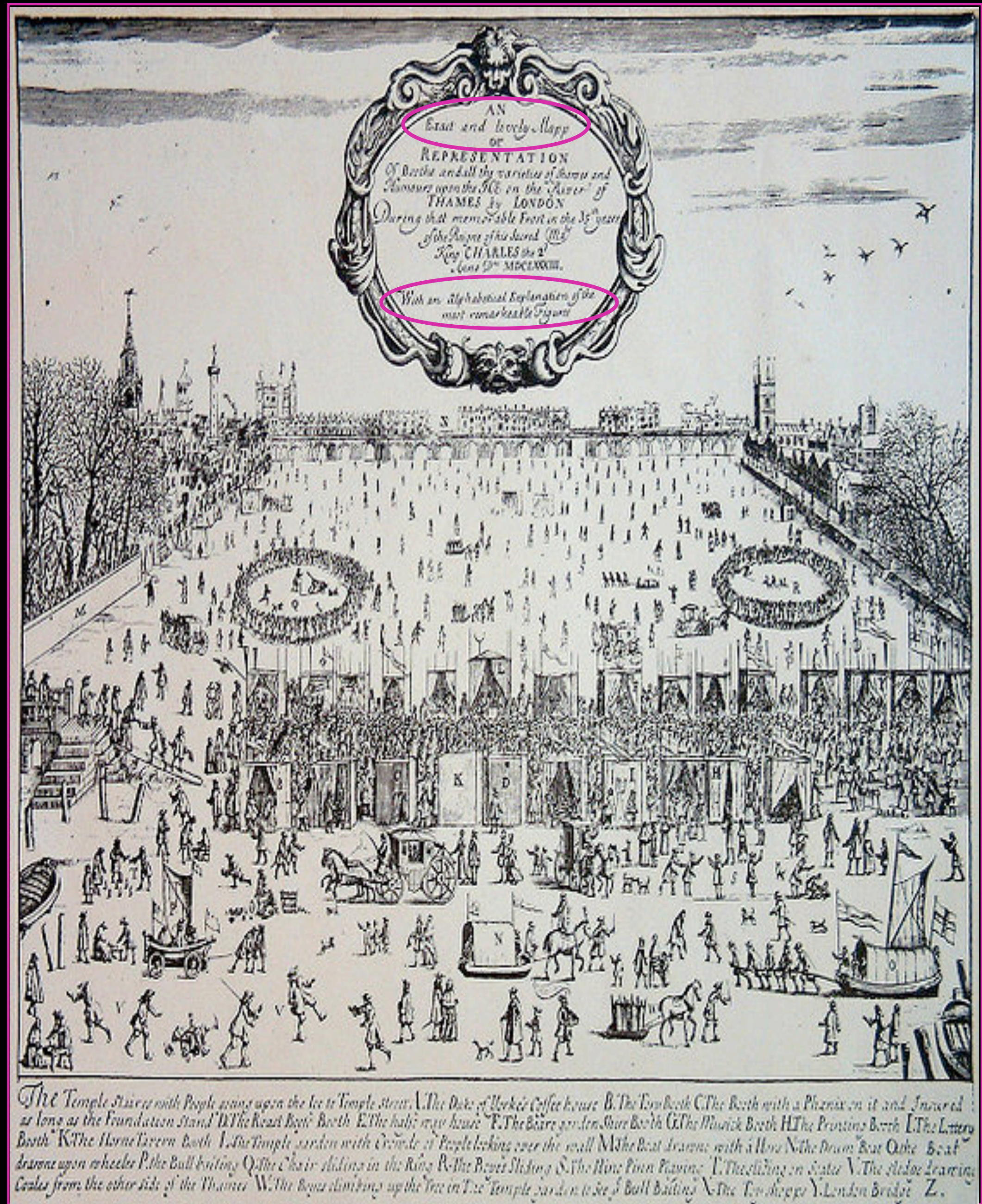
“An exact and lively mapp … with an alphabetical explanation of the most remarkable figures”

I. The Printing Booth



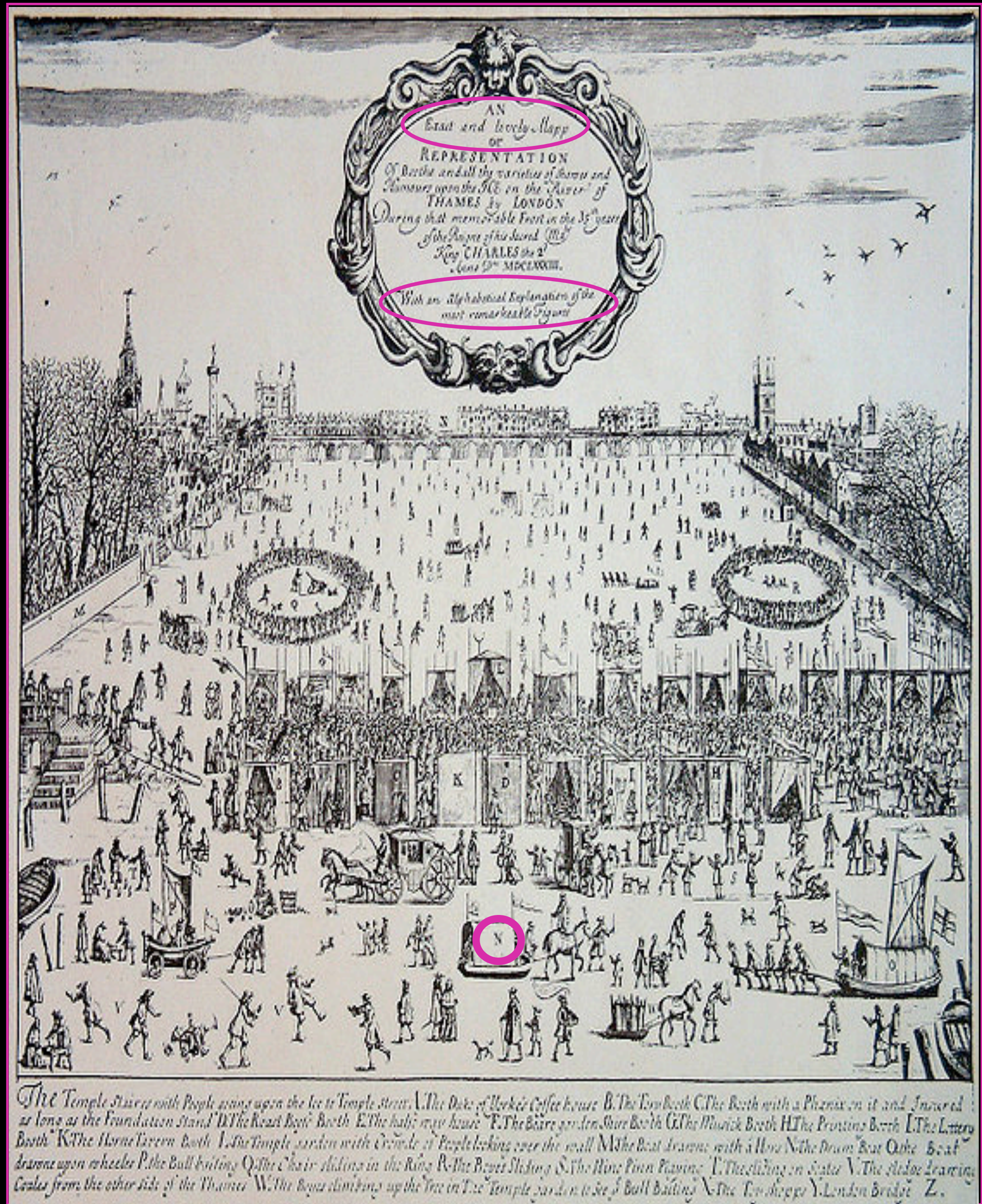
“An exact and lively mapp … with an alphabetical explanation of the most remarkable figures”

E. The Roast Beefe Booth



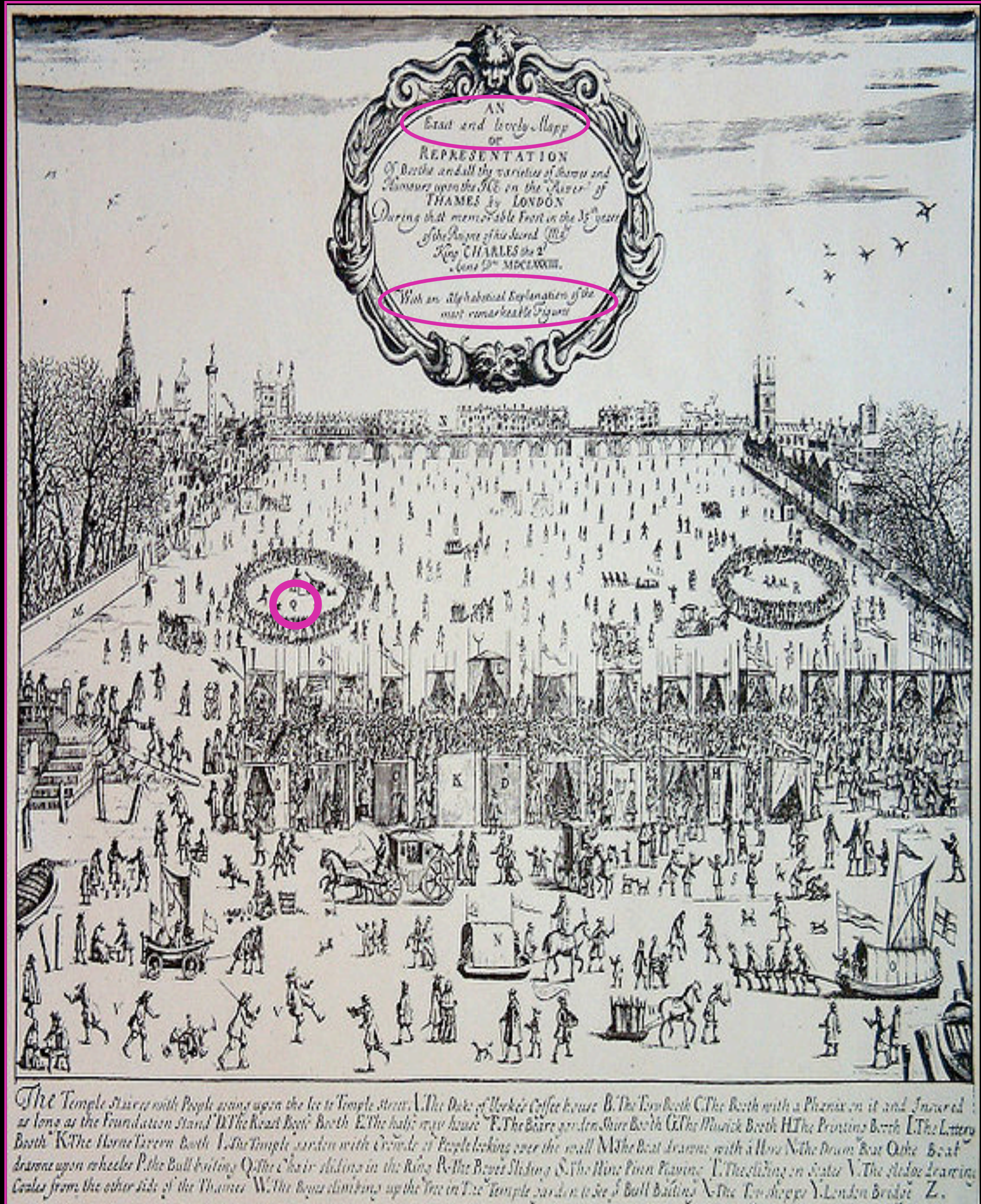
"An exact and lively mapp … with an alphabetical explanation of the most remarkable figures"

N. The Boat drawne with a Hors



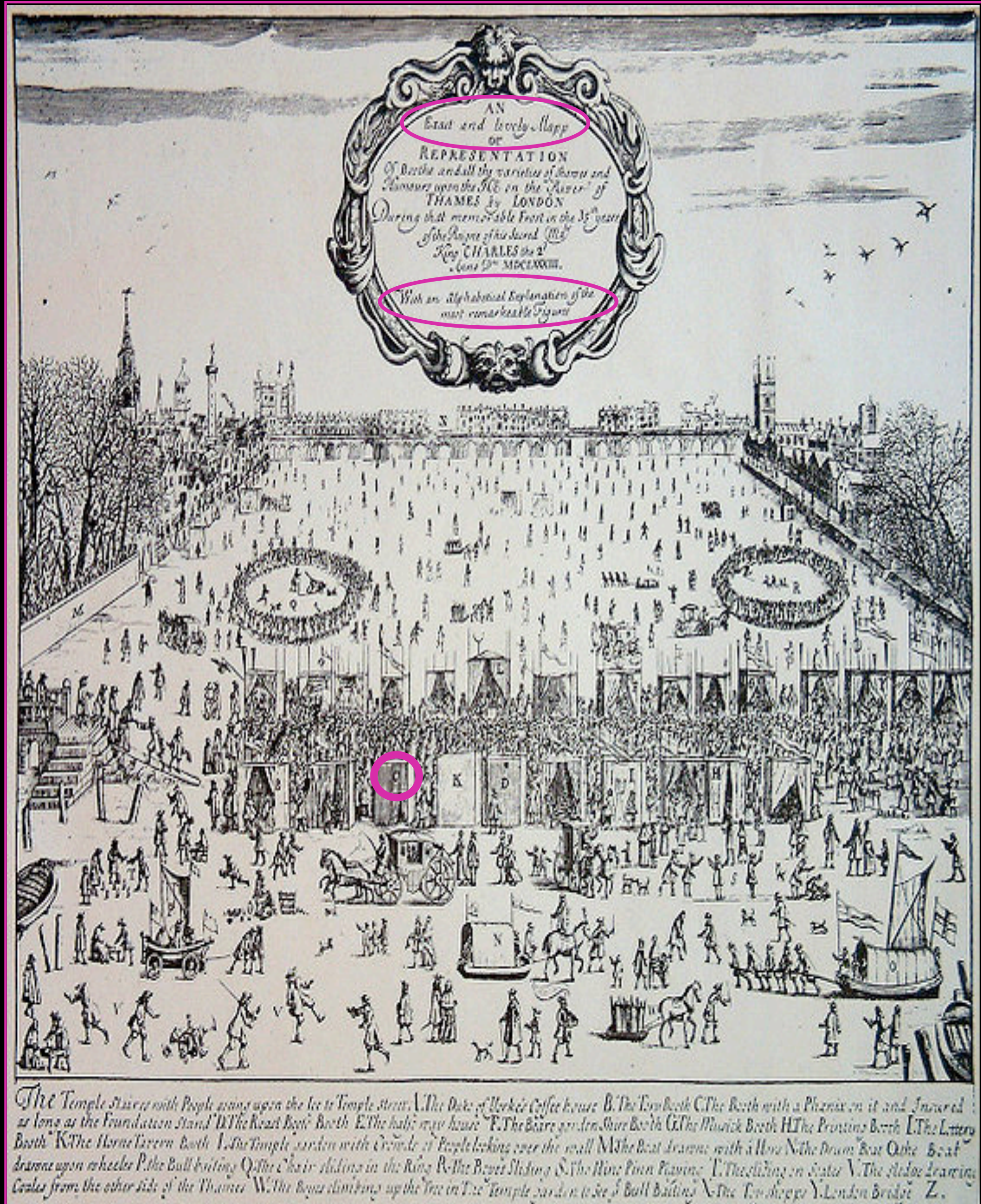
“An exact and lively mapp … with an alphabetical explanation of the most remarkable figures”

Q. The Bull Baiting



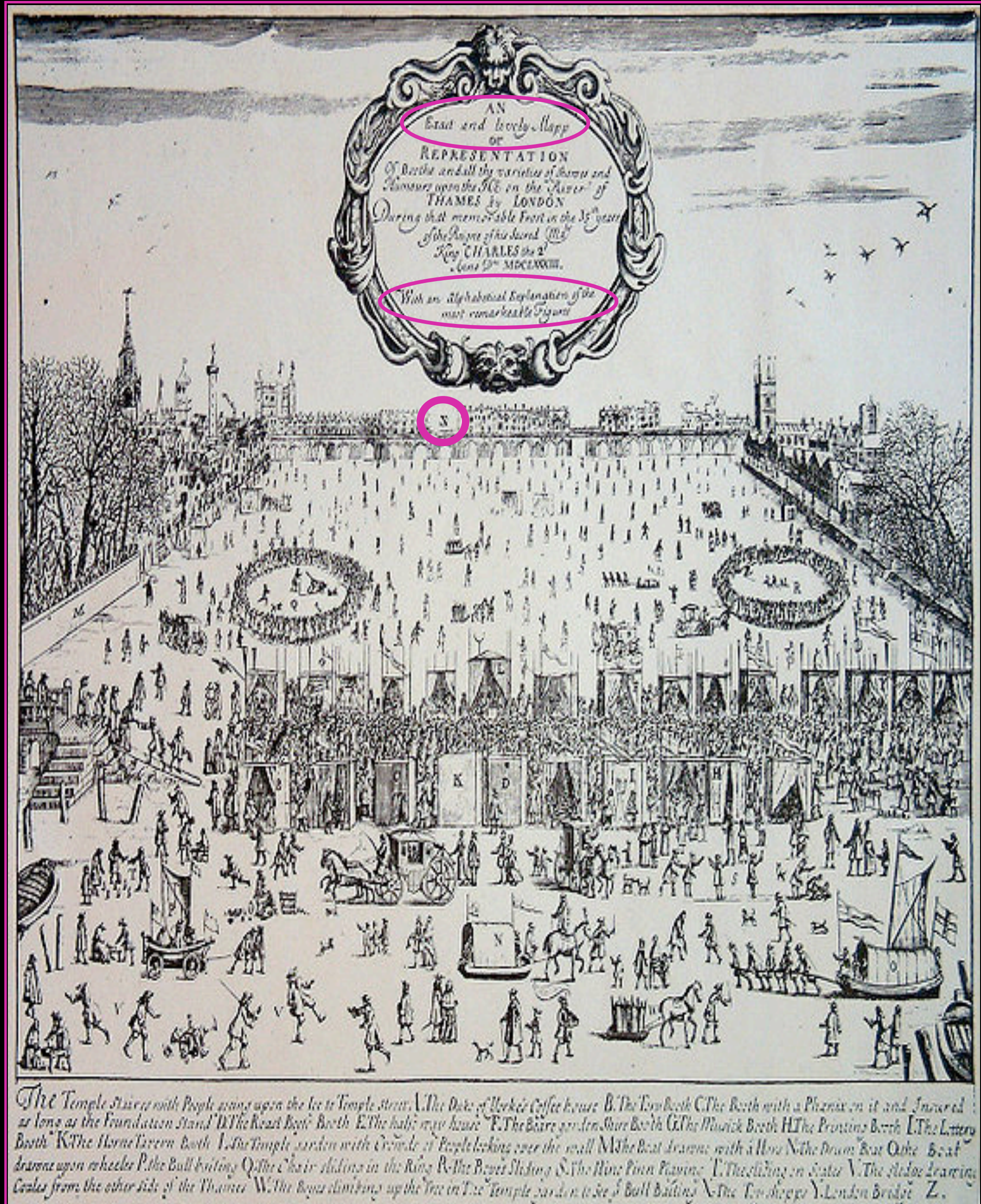
“An exact and lively mapp … with an alphabetical explanation of the most remarkable figures”

C. The Tory Booth



“An exact and lively mapp … with an alphabetical explanation of the most remarkable figures”

Z. London Bridge



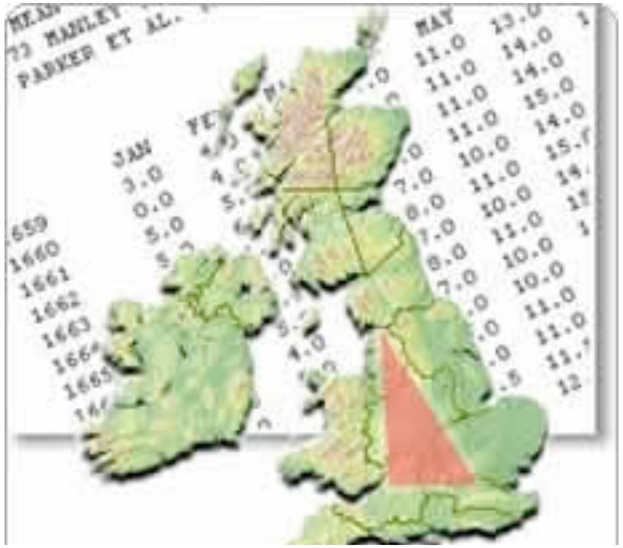
Central England Temperature (CET)

- Manley (1953,1974) Parker et al (1992)
- Monthly 1659 to present
- Maintained by UKMO
- Longest instrumental temperature record in the world
- Representative of a roughly triangular area between Bristol, Lancashire & London

Central England Temperature (CET)

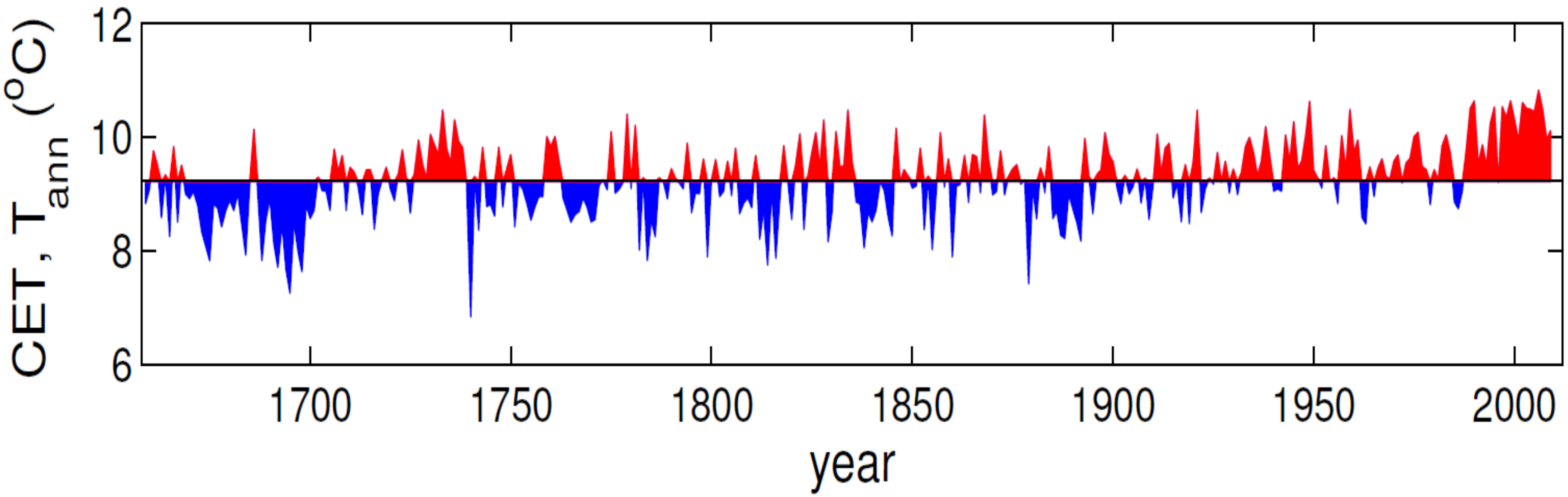
- since Jan.1878 UKMO have used sites at Rothamsted, Malvern, Squires Gate & Ringway.
- Ringway replaced Stonyhurst in Nov. 2004
- Since 1974 the data adjusted by 0.1-0.3°C to allow for urban warming

Central England Temperature (CET)



Annual Means

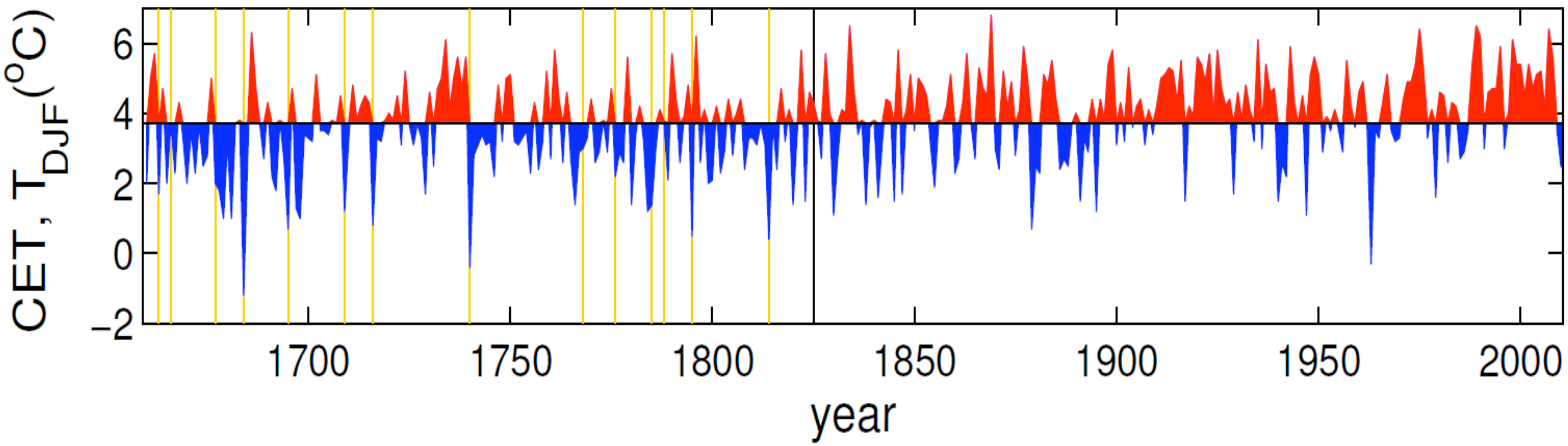
- show upward drift
- (linear) rate of rise
  $dT_{ann}/dt = 0.26\ ^{\circ}C\ c^{-1}$



Central England Temperature (CET)

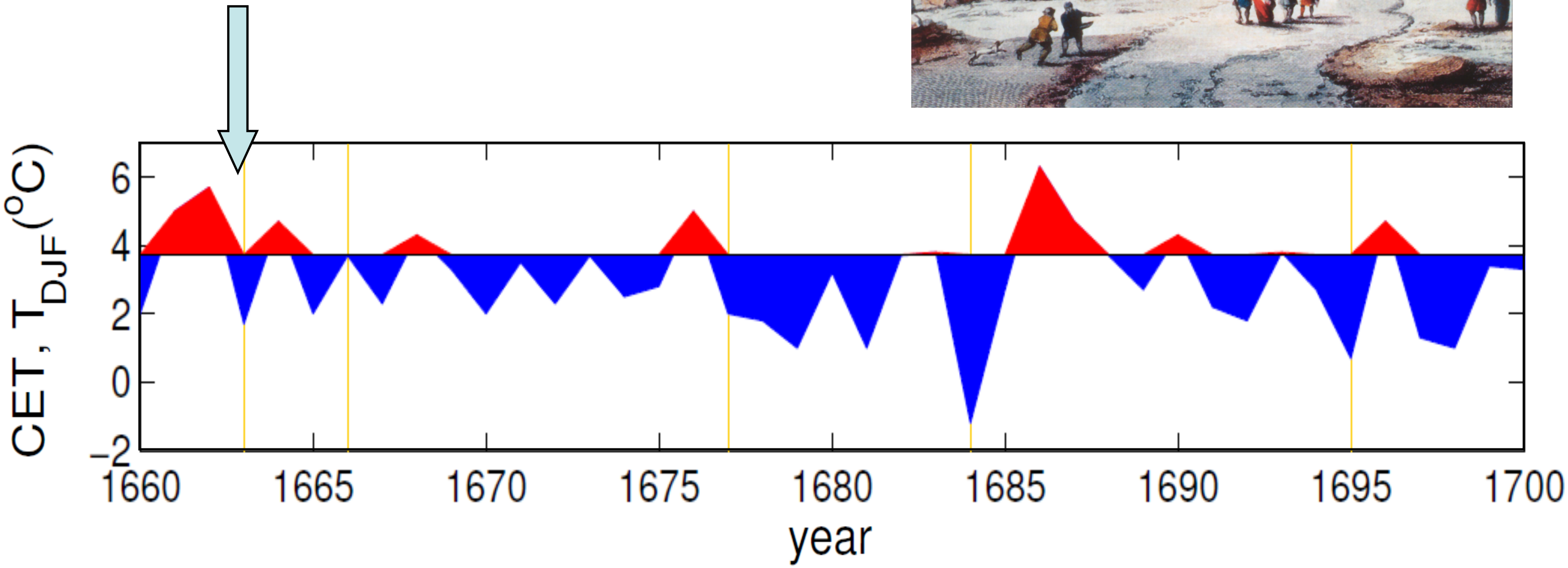
Winter Means (DJF)

- show upward drift
- (linear) rate of rise $dT_{ann}/dt = 0.37\ ^\circ C\ c^{-1}$



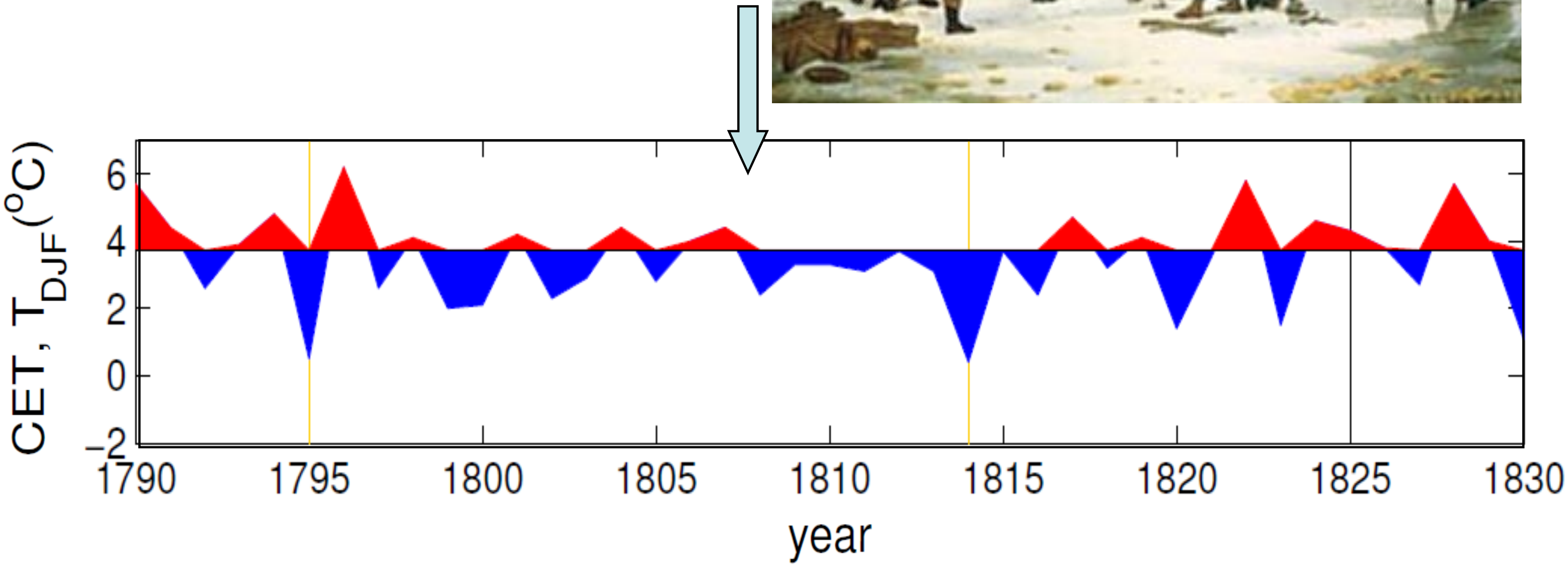
Frost Fairs on the Thames

- e.g. Winter 1683/4. Painted by Dutch artist Thomas Wijk (1616-1677)
- N.B. notice how warm the next year was!



Frost Fairs on the Thames

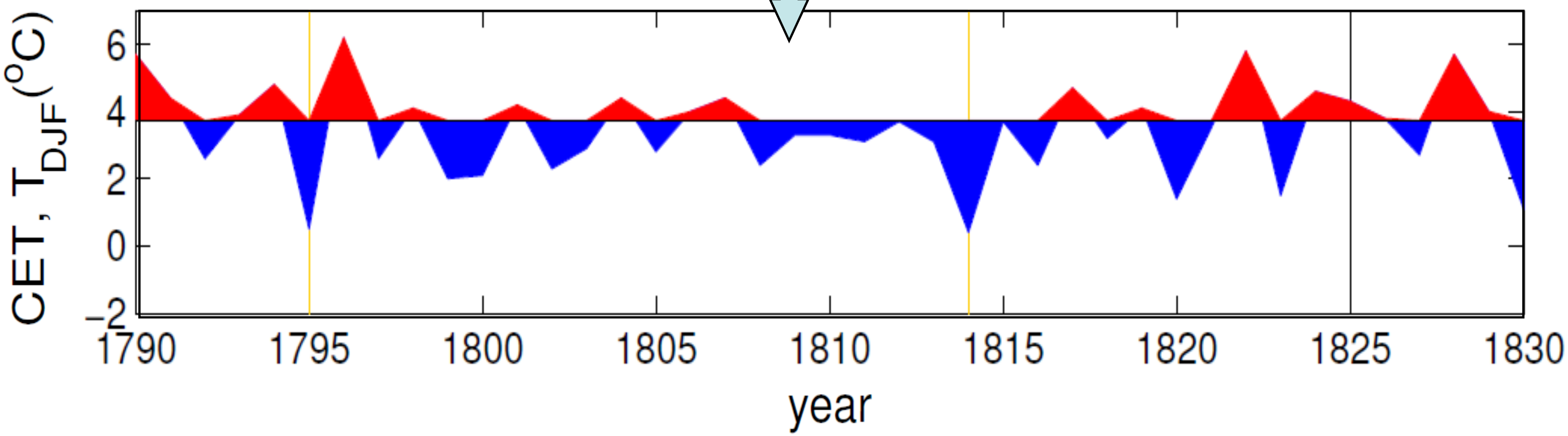
- The last one was 1813/14. Painted by Luke Clenell (1781 – 1840)



Thames Freezing Over

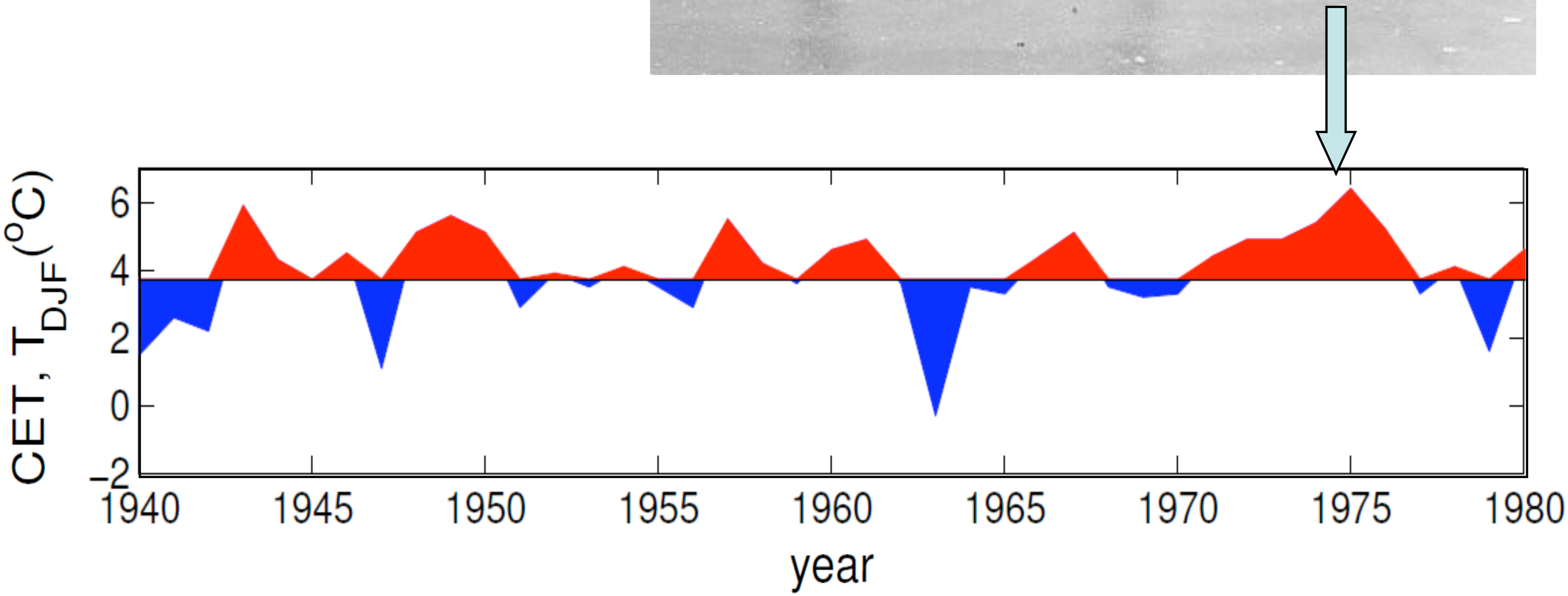
- N.B. in 1825 London Bridge demolished – acted as a salt water barrage

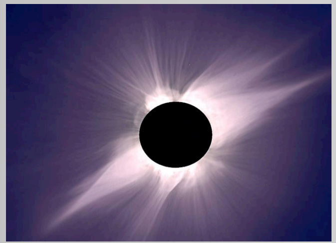
- plus embankment increased flow rate



Thames Freezing Over

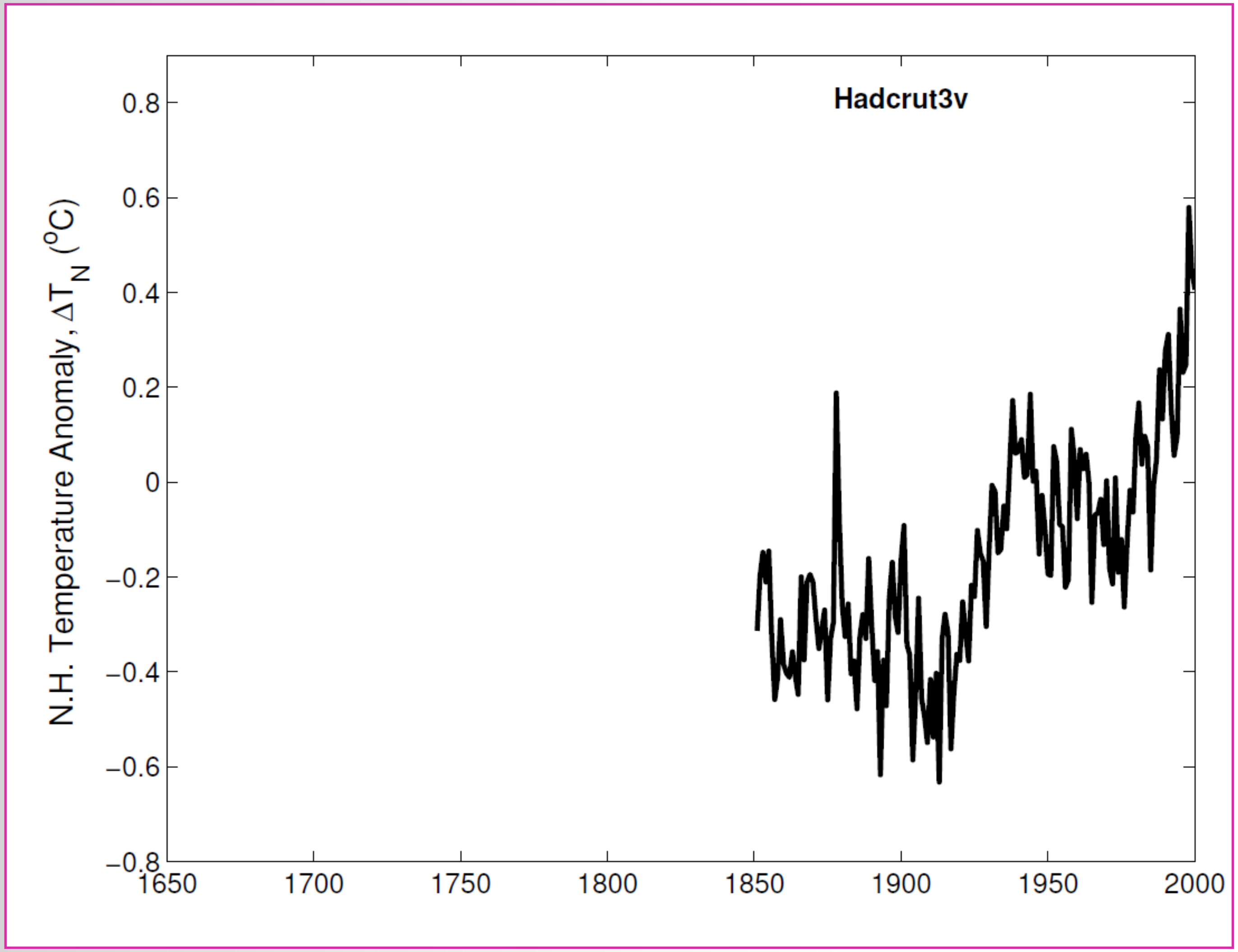
- 1963 Thames at Windsor

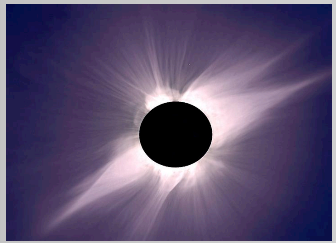




Northern Hemisphere Temperature Anomaly. (*Brohan et al, 2007*)

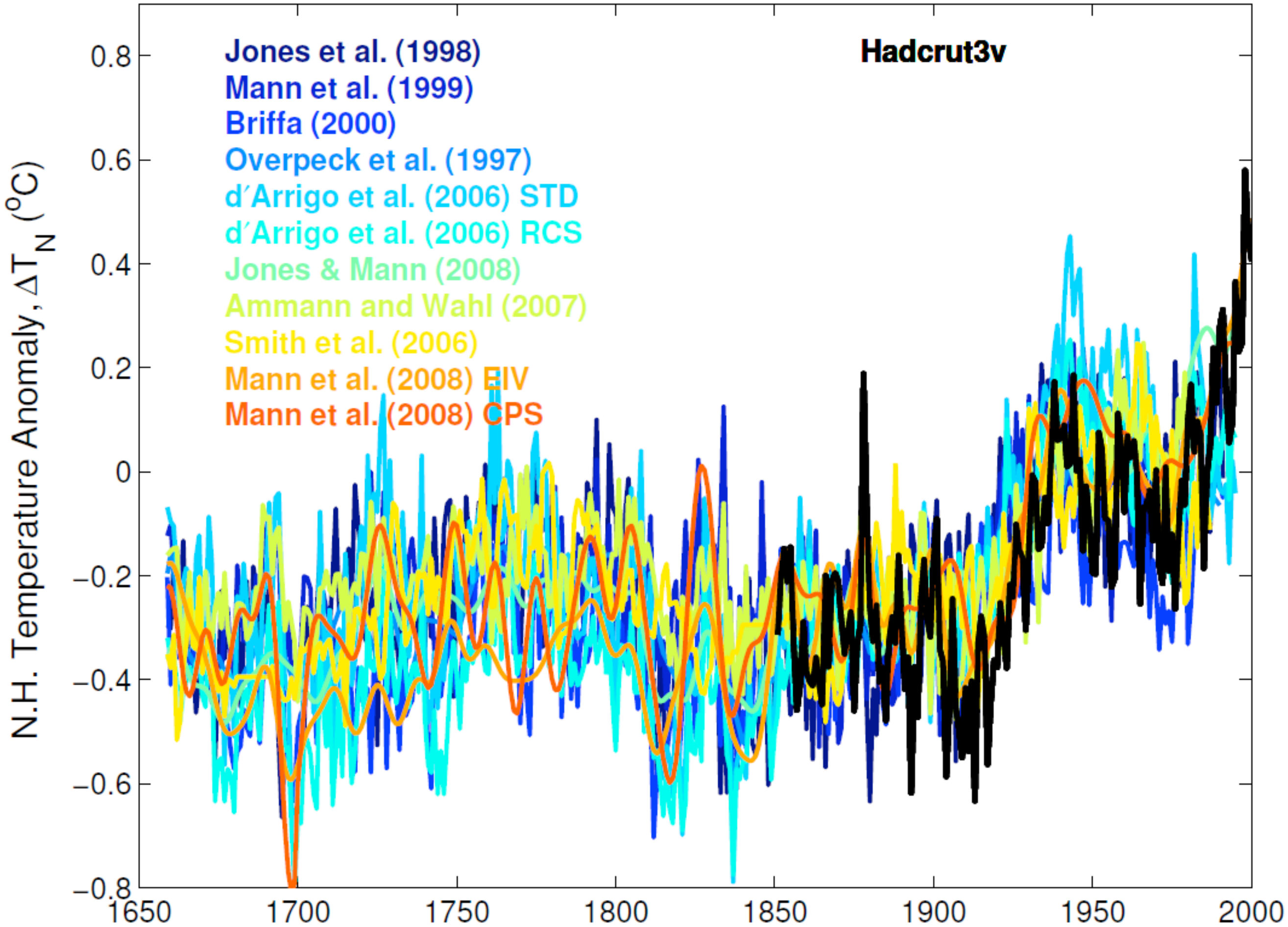
- ► HadCRUT3v reconstruction from data by UKMO/UEA-CRU
- ► extends back to 1850





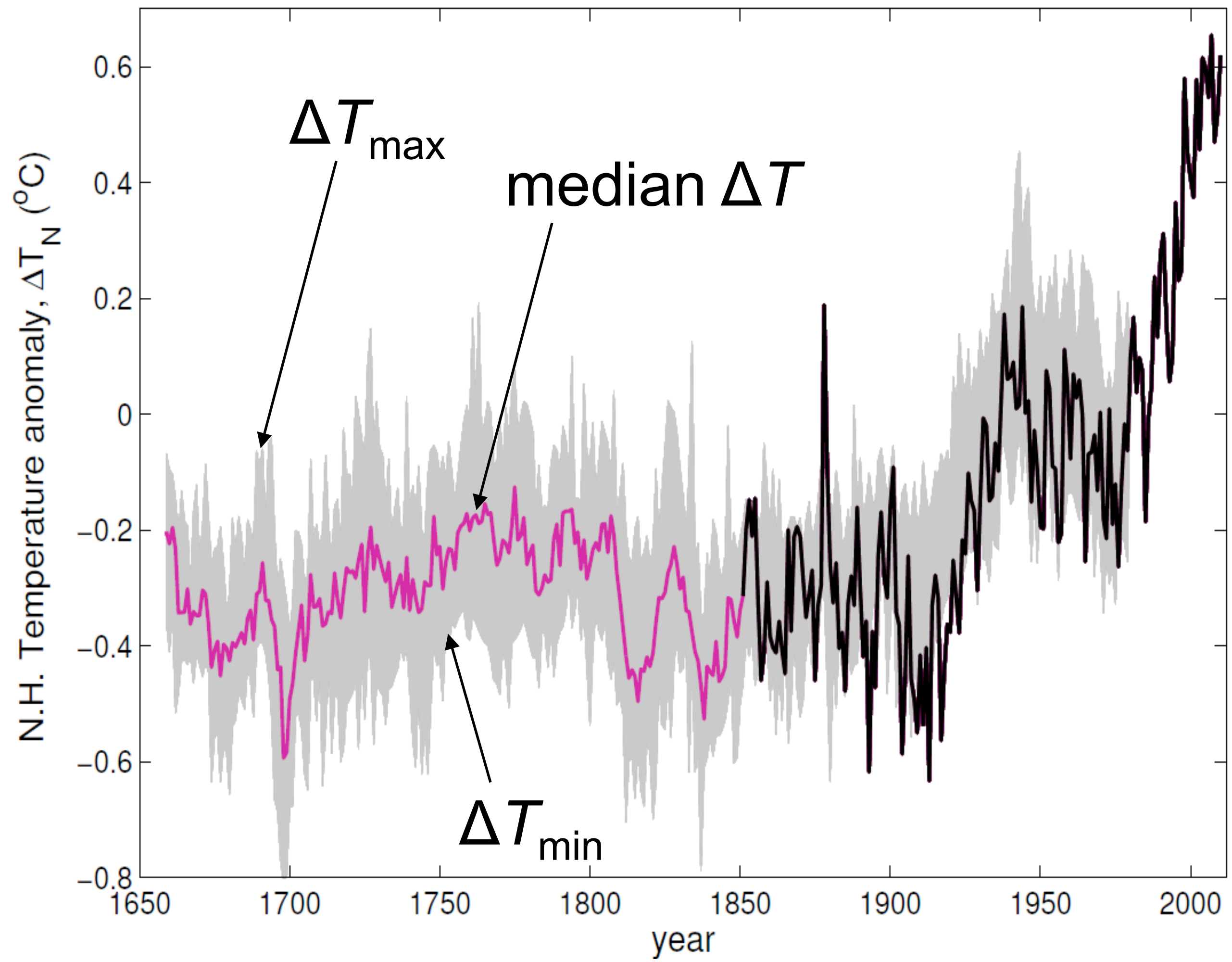
Ensemble of 11 reconstructions based on temperature proxy data

- Earlier reconstructions based on tree-ring data
- also now use marine sediment, speleothem, lacustrine, ice cores, coral, and historical documents



Ensemble of 11 reconstructions based on temperature proxy data

- Use the median of the 11 for 1659-1850
- use upper and lower deciles for 1659-1850, ΔT_{max} and ΔT_{min} to test for effect of reconstruction

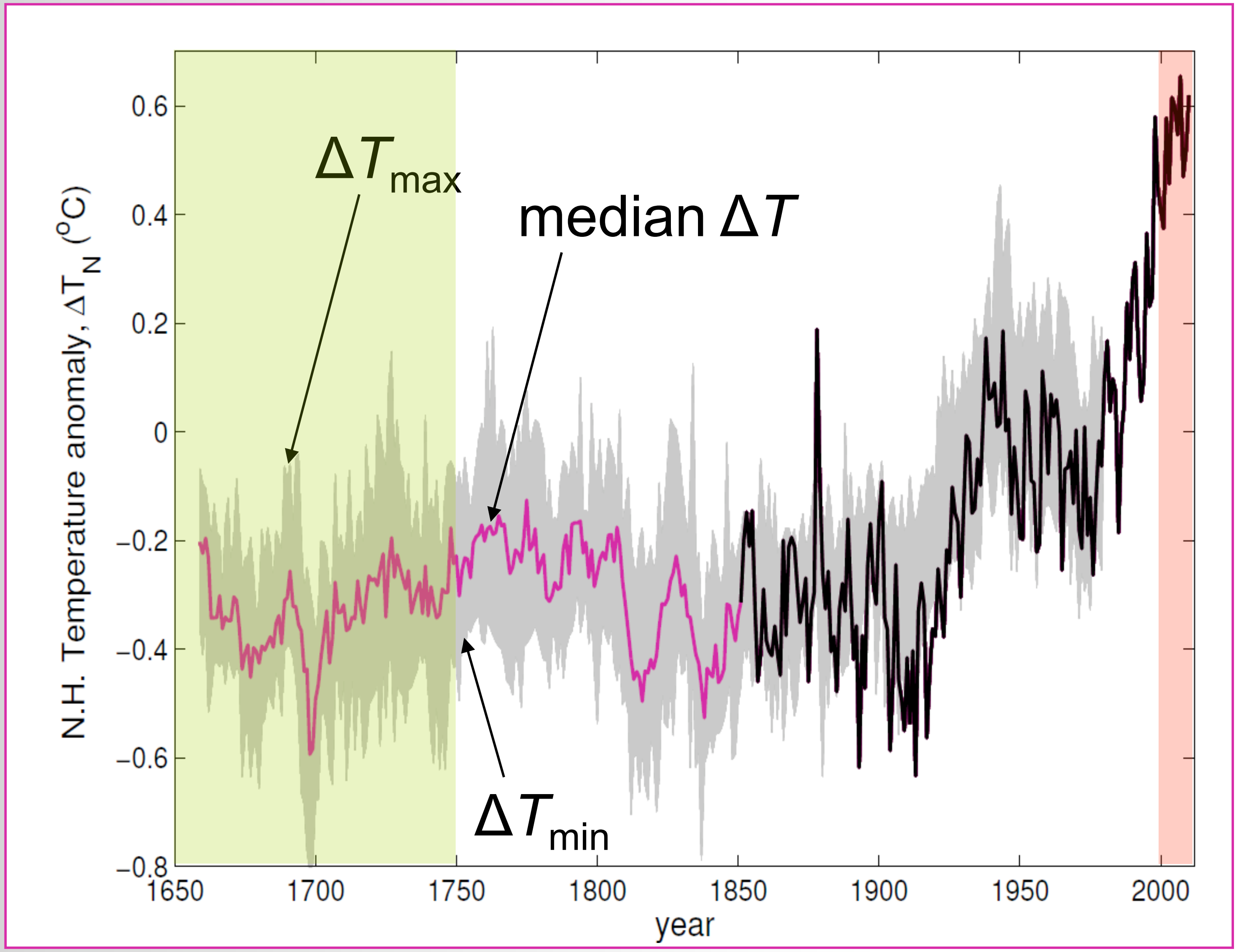


Ensemble of 11 reconstructions based on temperature proxy data

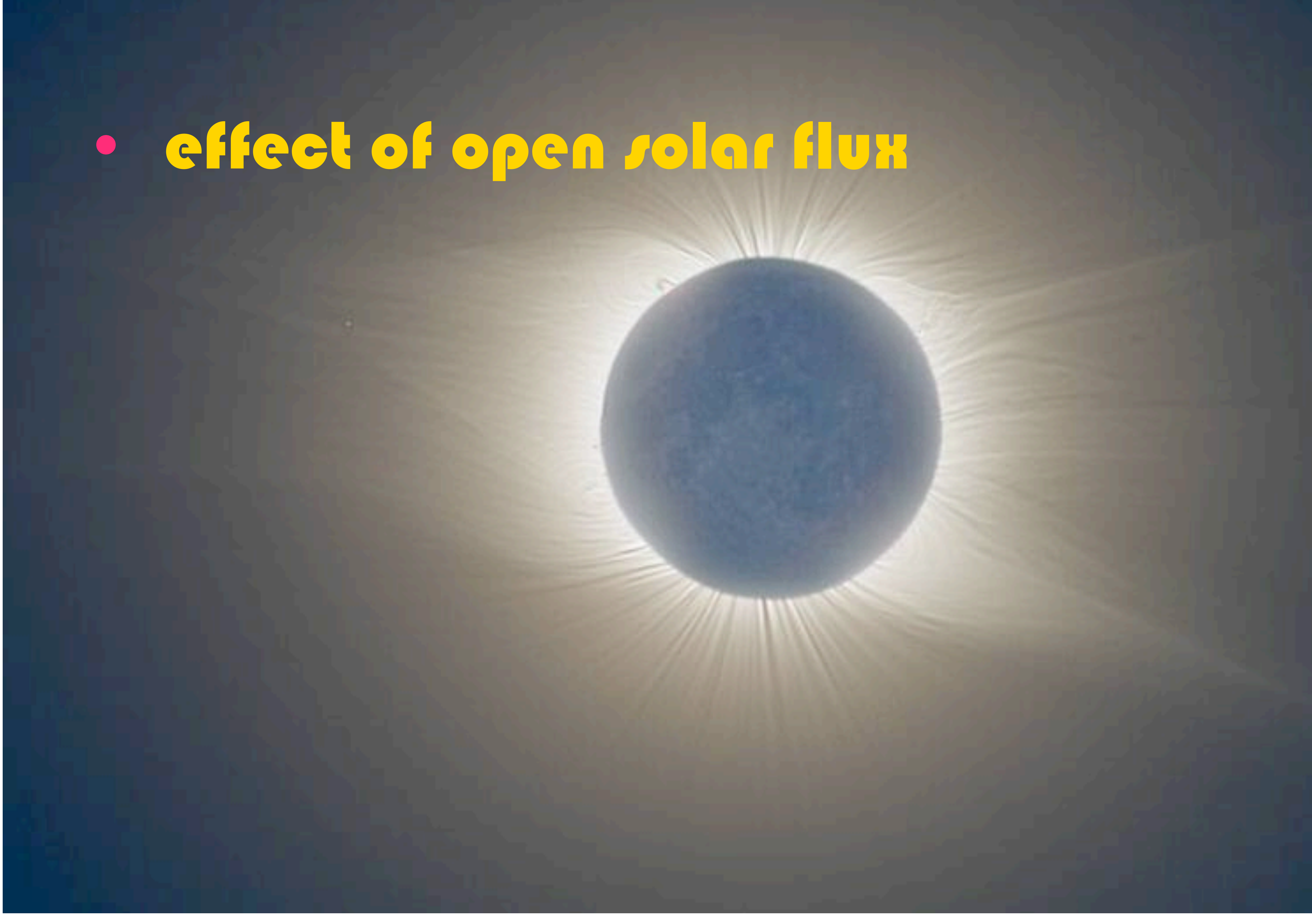
► compare mean for 1650-1750 with mean for 2000-2009

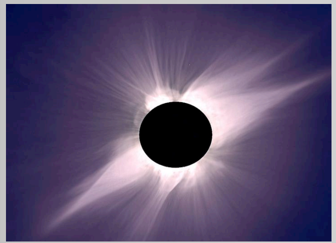
► gives drift since pre-industrial times of:

0.69°C (ΔT_{max})
0.86°C (median)
1.03°C (ΔT_{min})



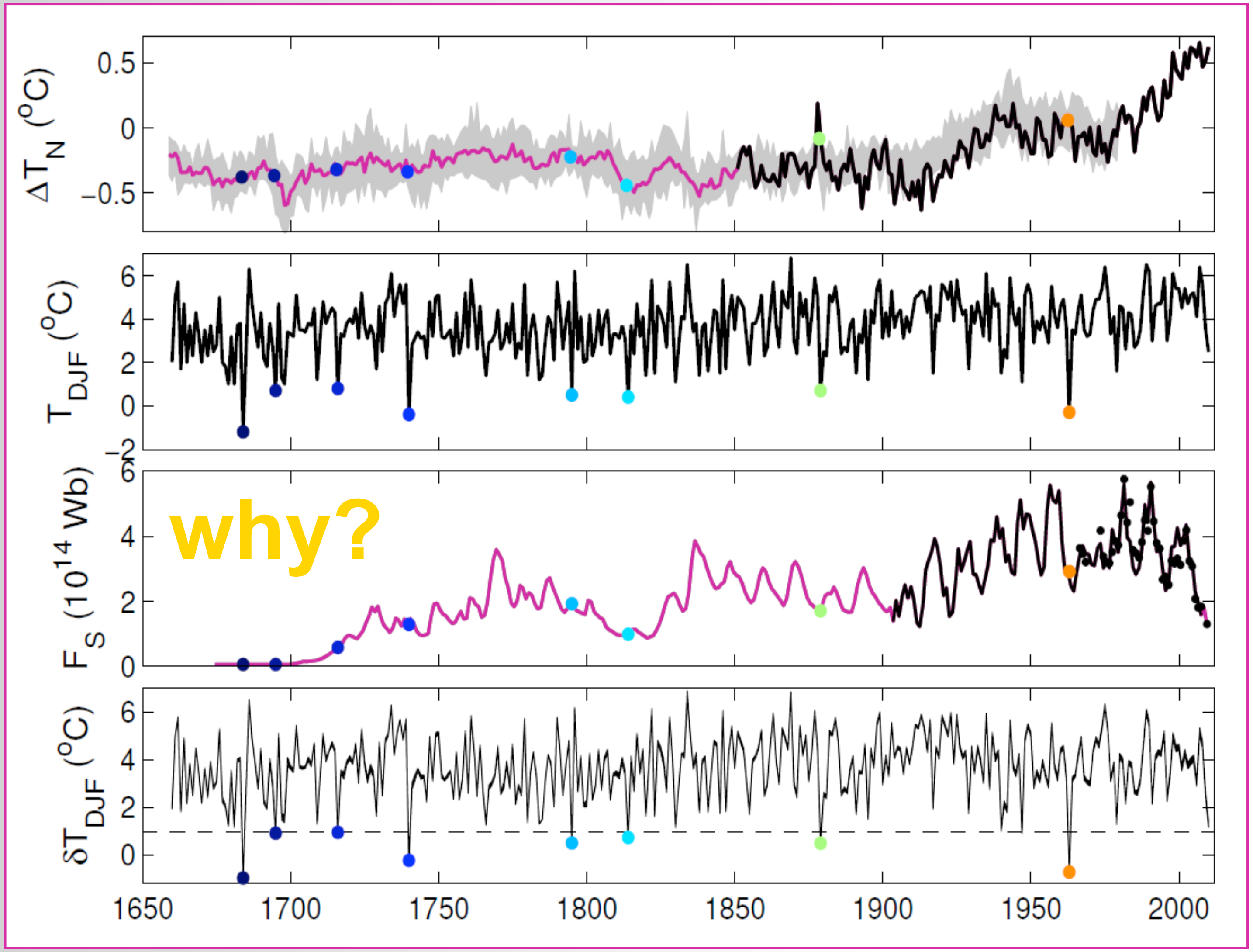
- effect of open solar flux

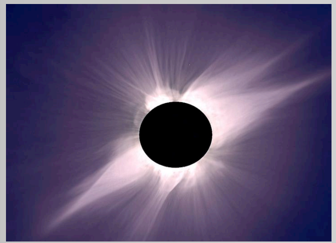




Time Series

- NH temp anomaly
- CET, DJF means
- open solar flux
- detrended CET, DJF means



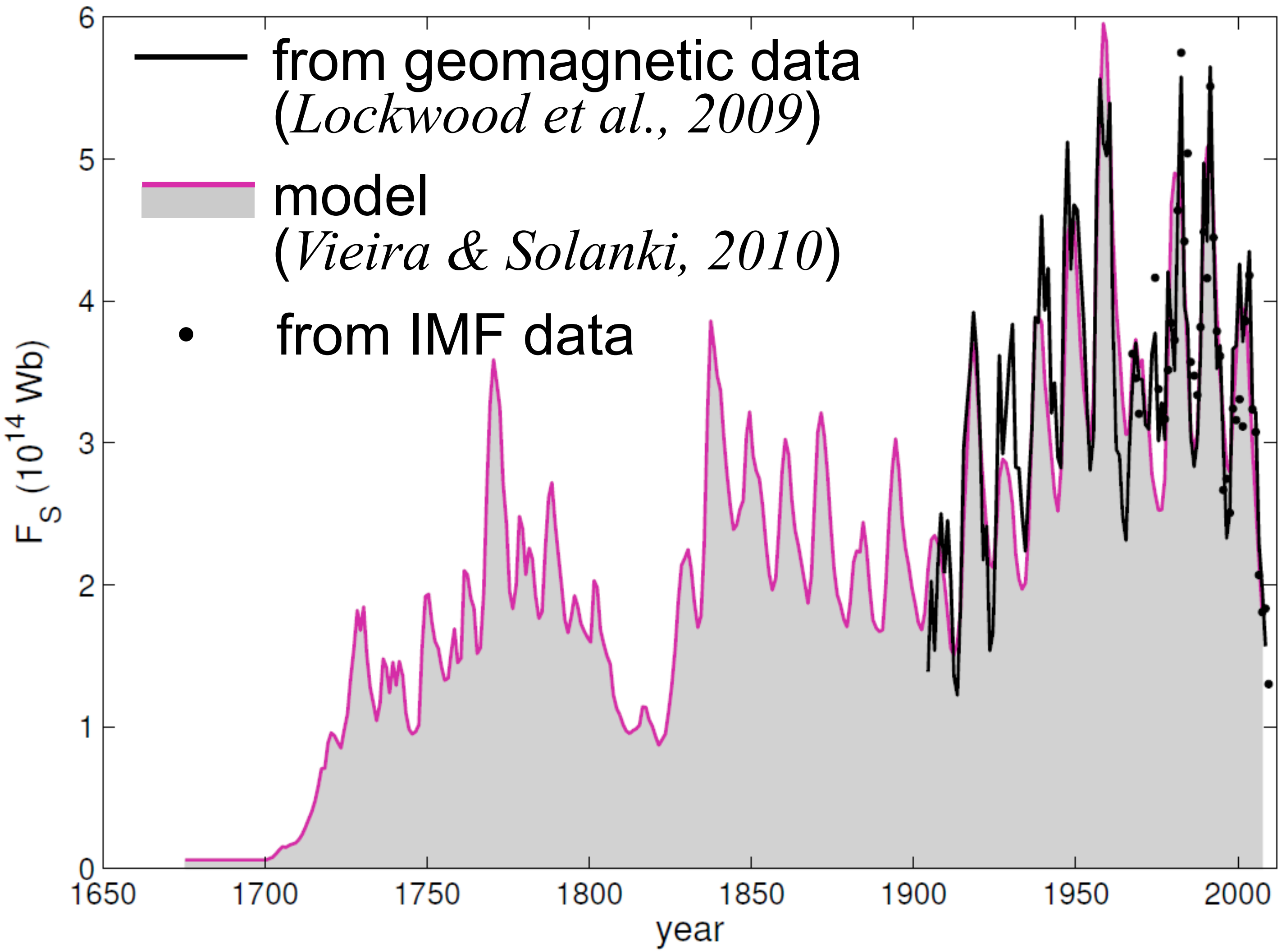


Open Solar Flux, F_S

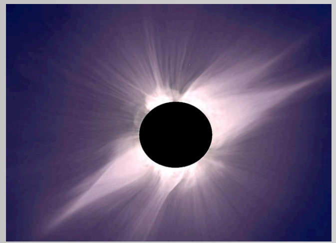
(allowing for longitudinal structure in solar wind)

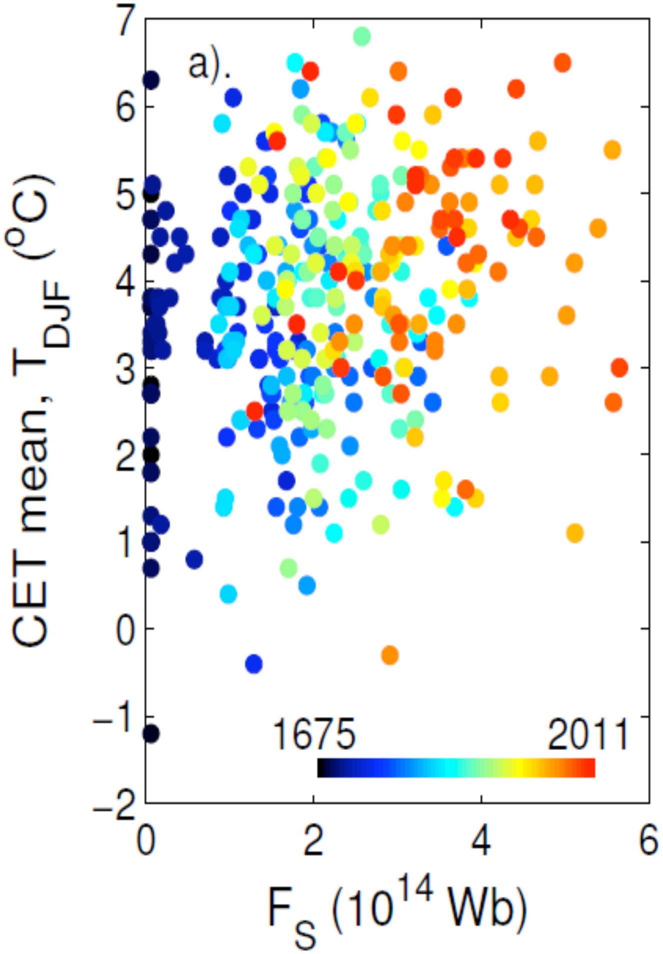
- use both range and hourly mean geomagnetic data

- model emergence from sunspot number with two time constants for decay of open flux

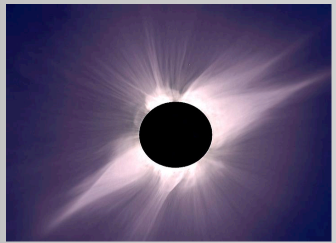


Scatter Plots





r = 0.25



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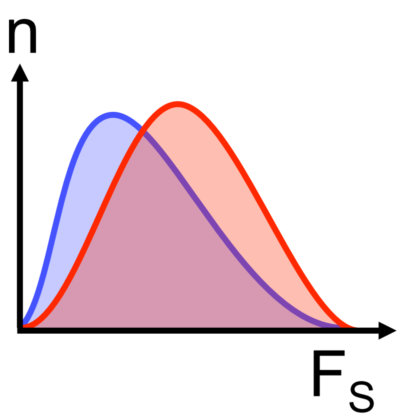
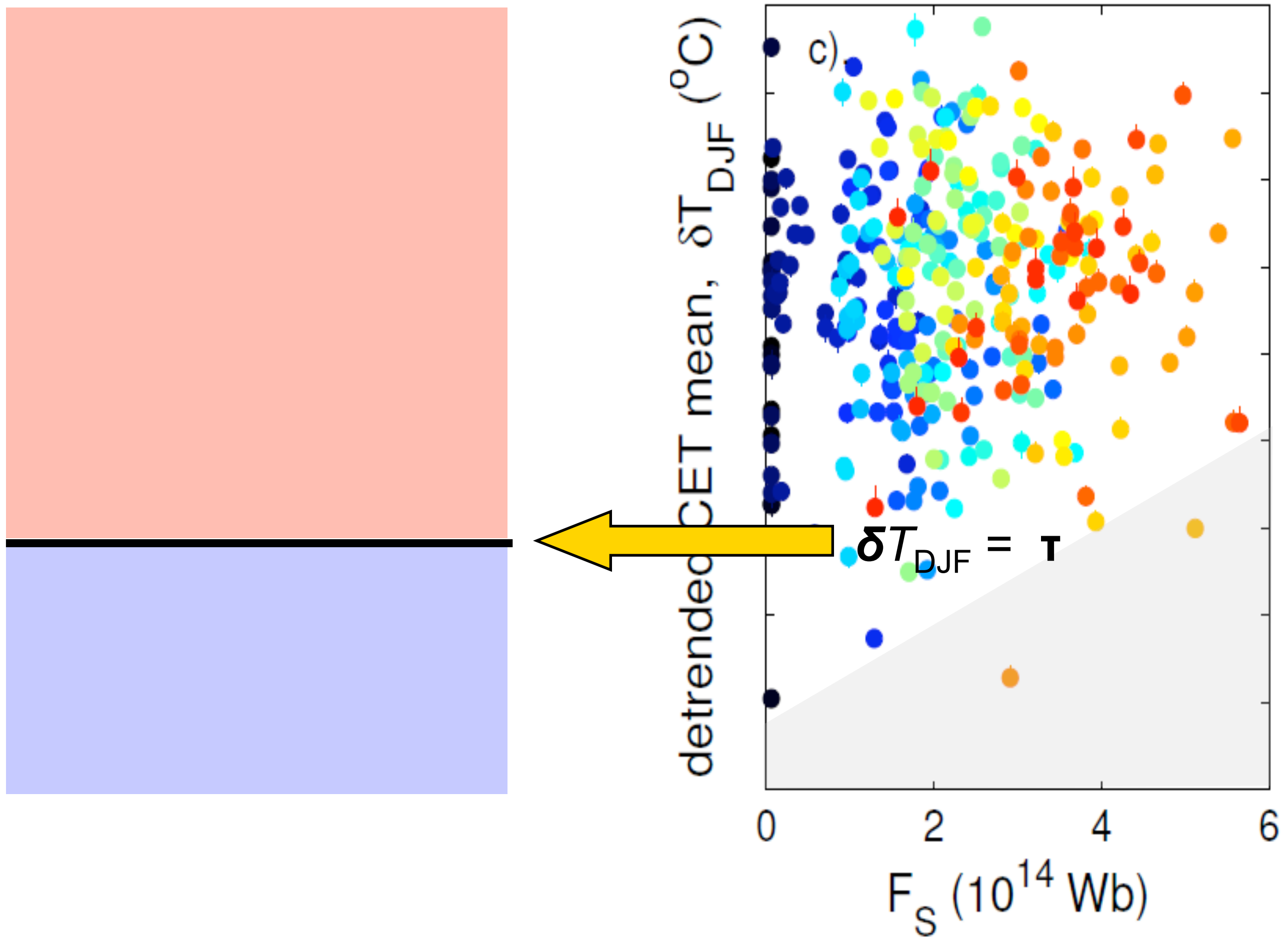
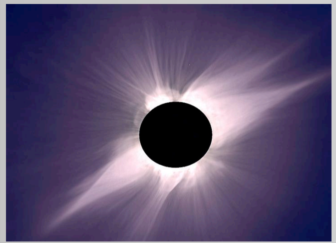
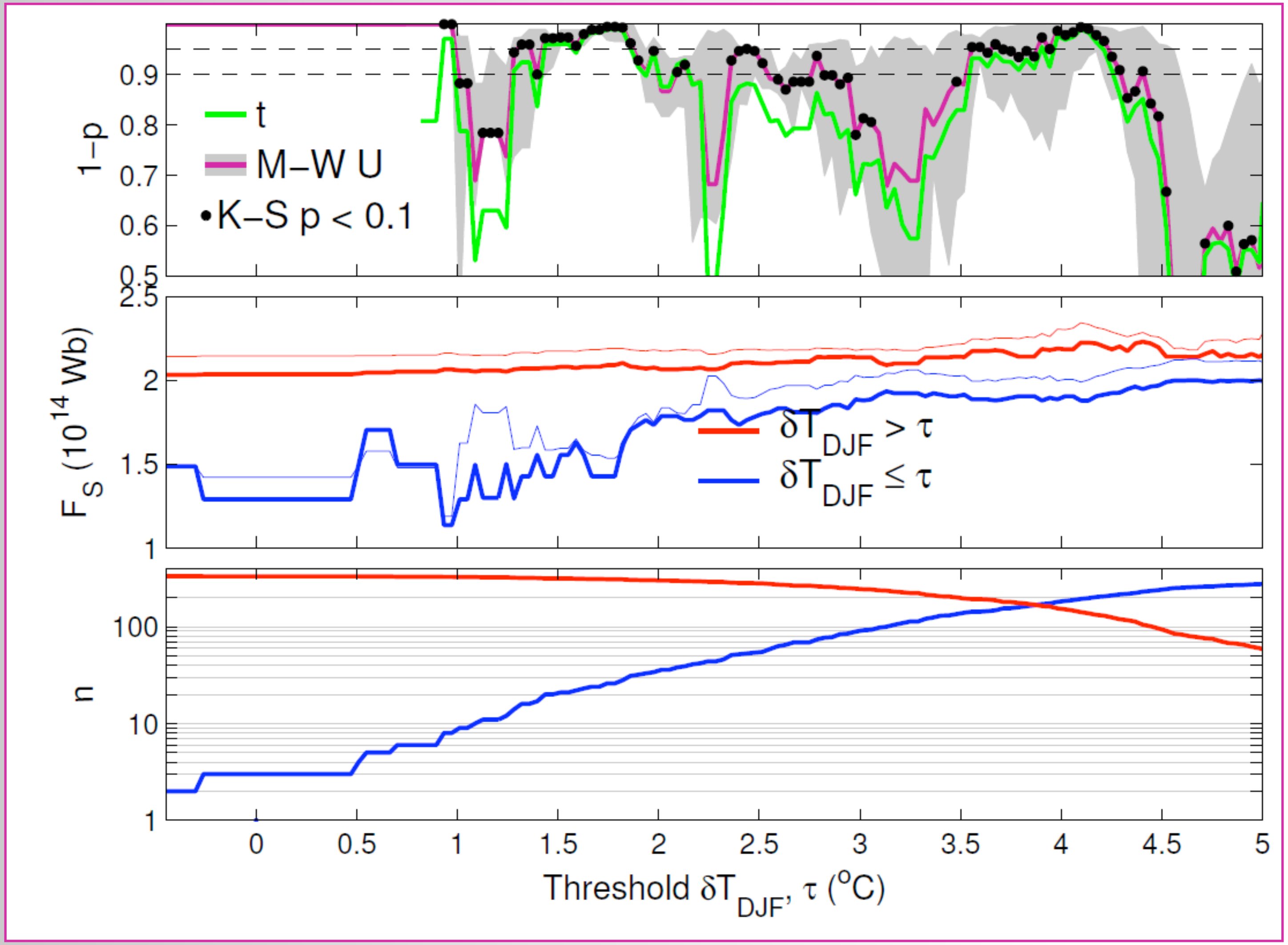


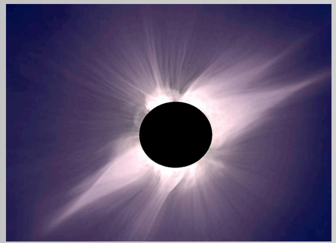


Distribution tests for various τ



Student's t test of means (parametric); Mann-Whitney U (Wilcoxon) test & Kolmogorov–Smirnov test of "medians")





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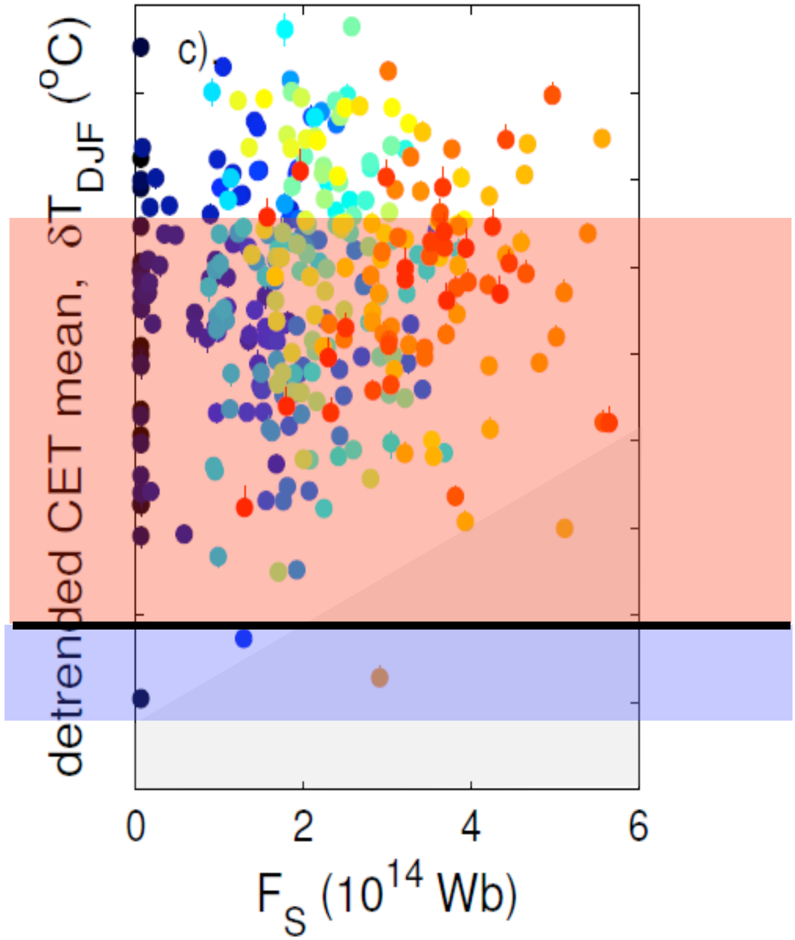

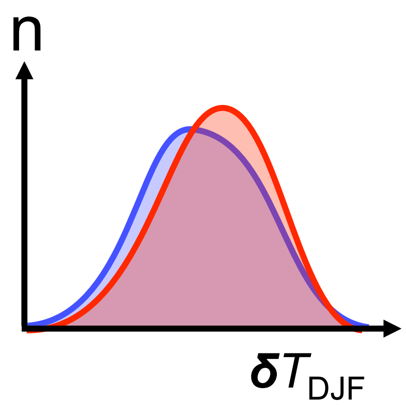

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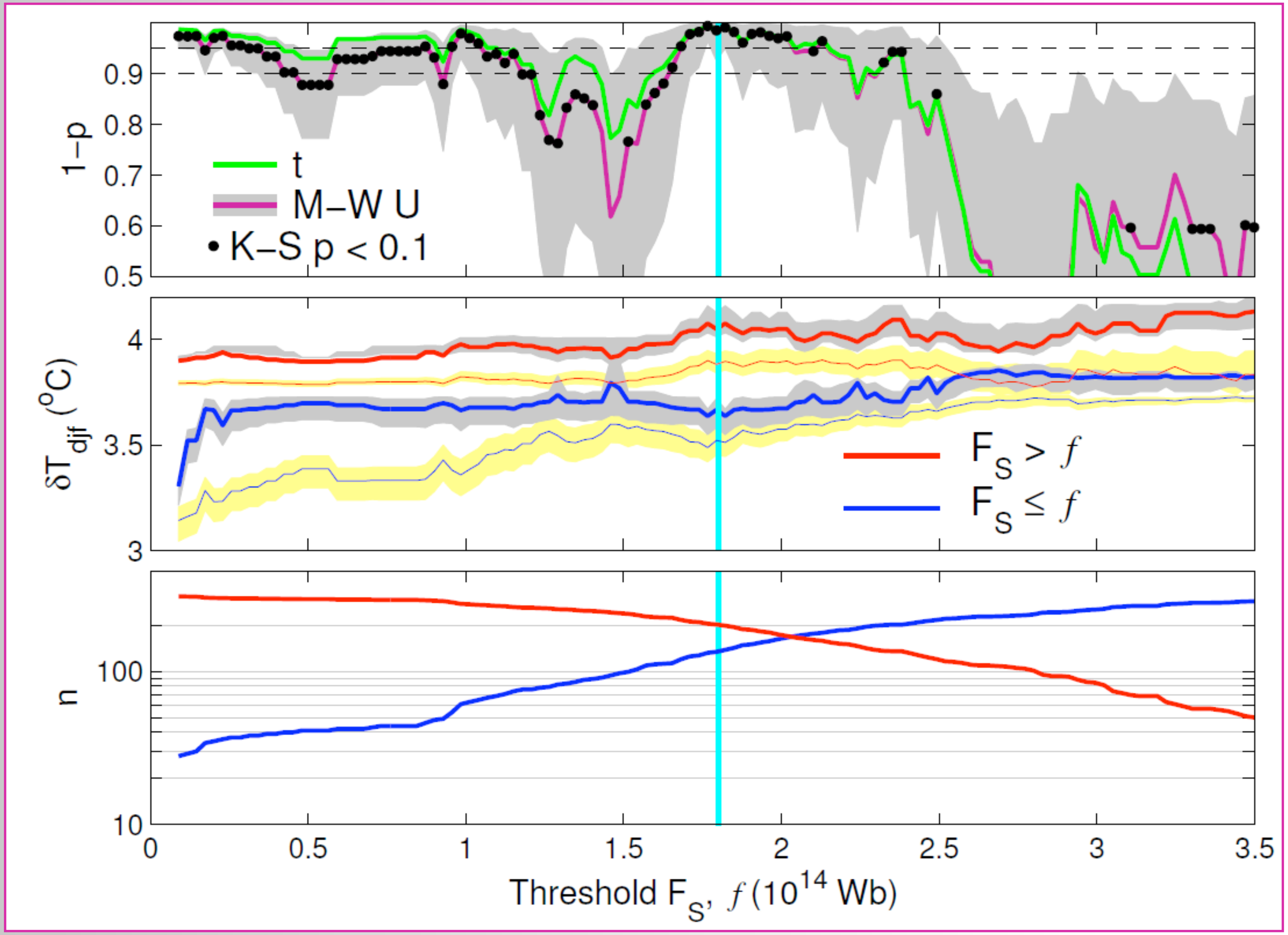

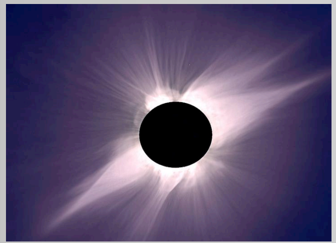

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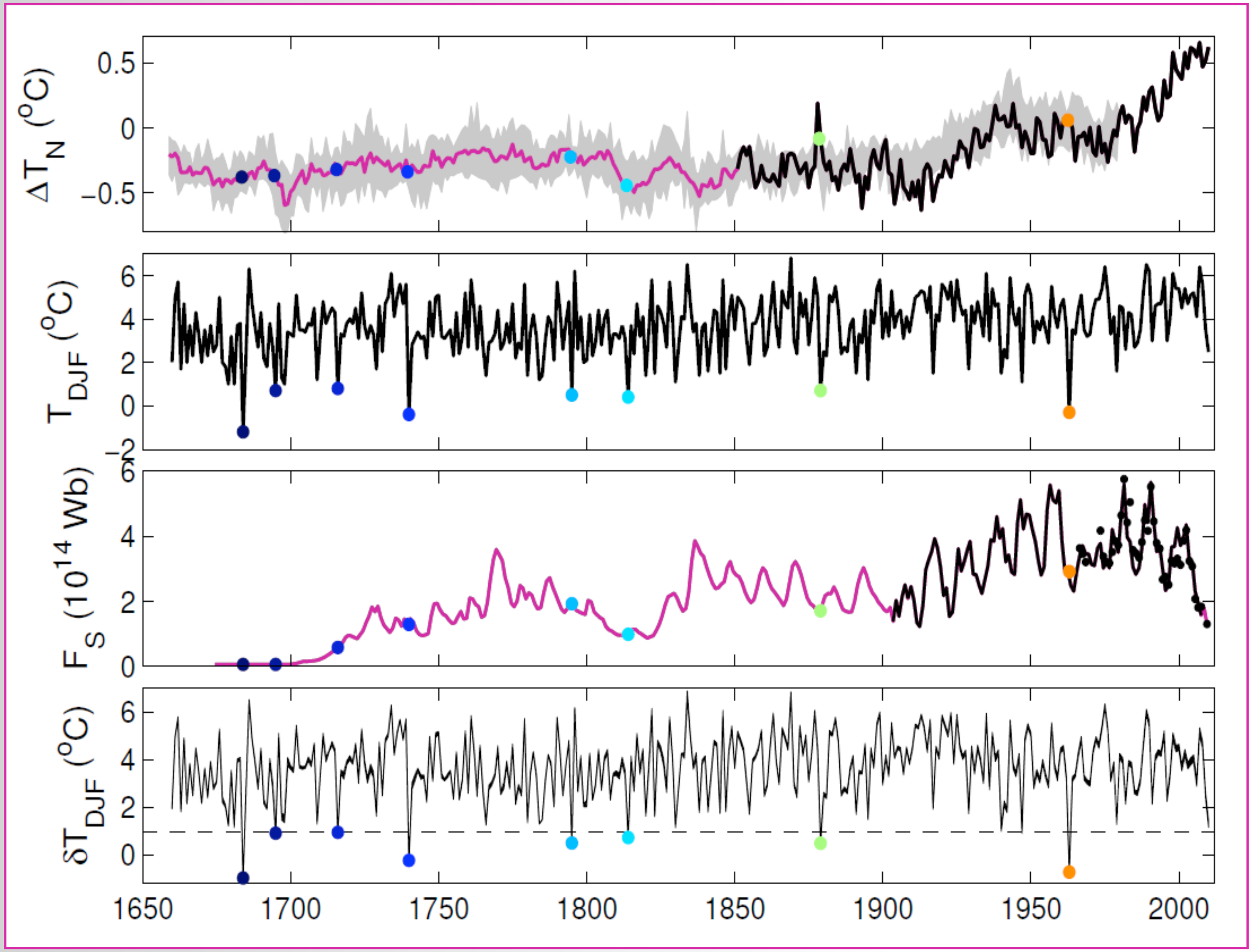
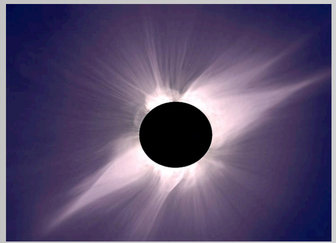
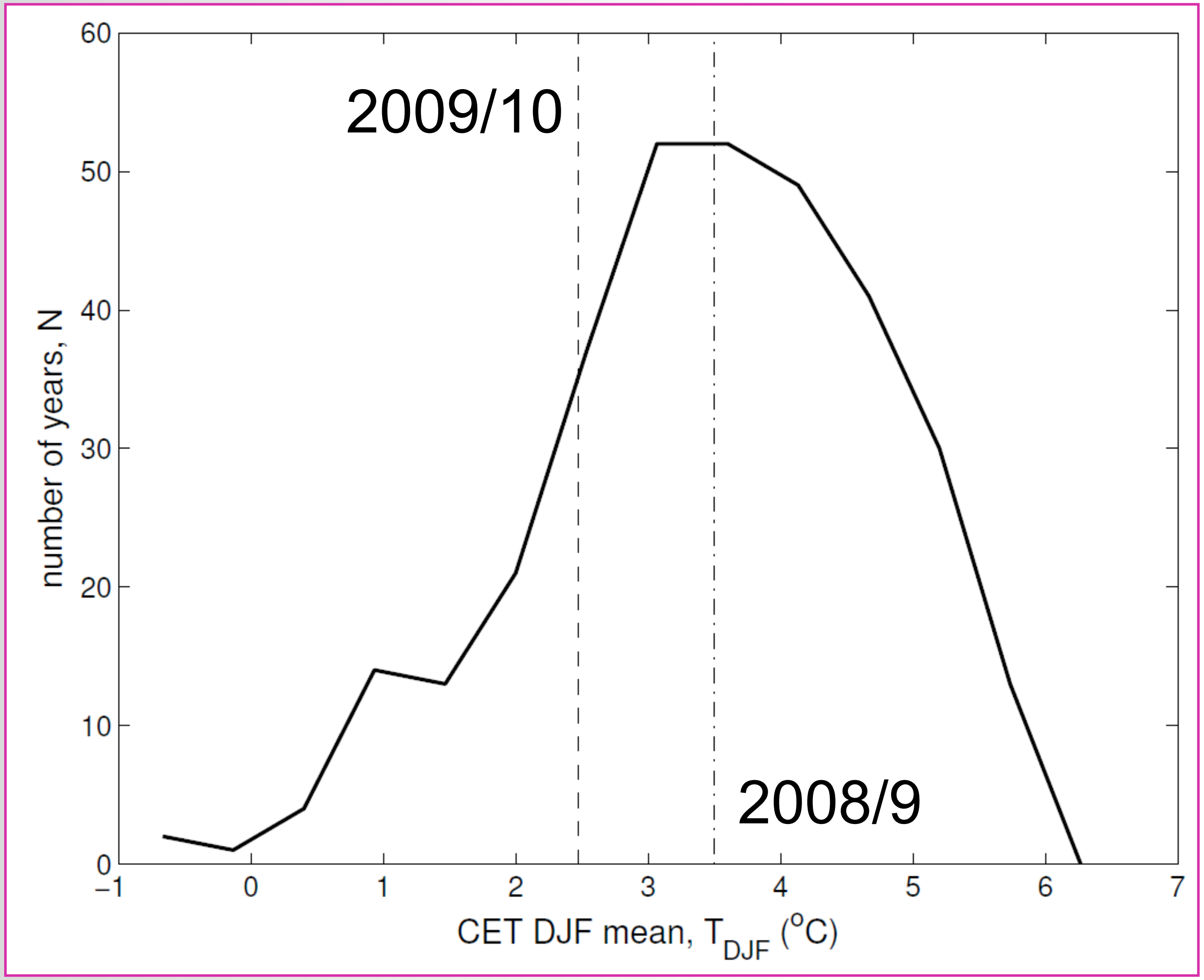
- detrended CET, DJF means

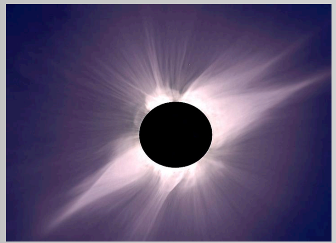




Recent winters in context

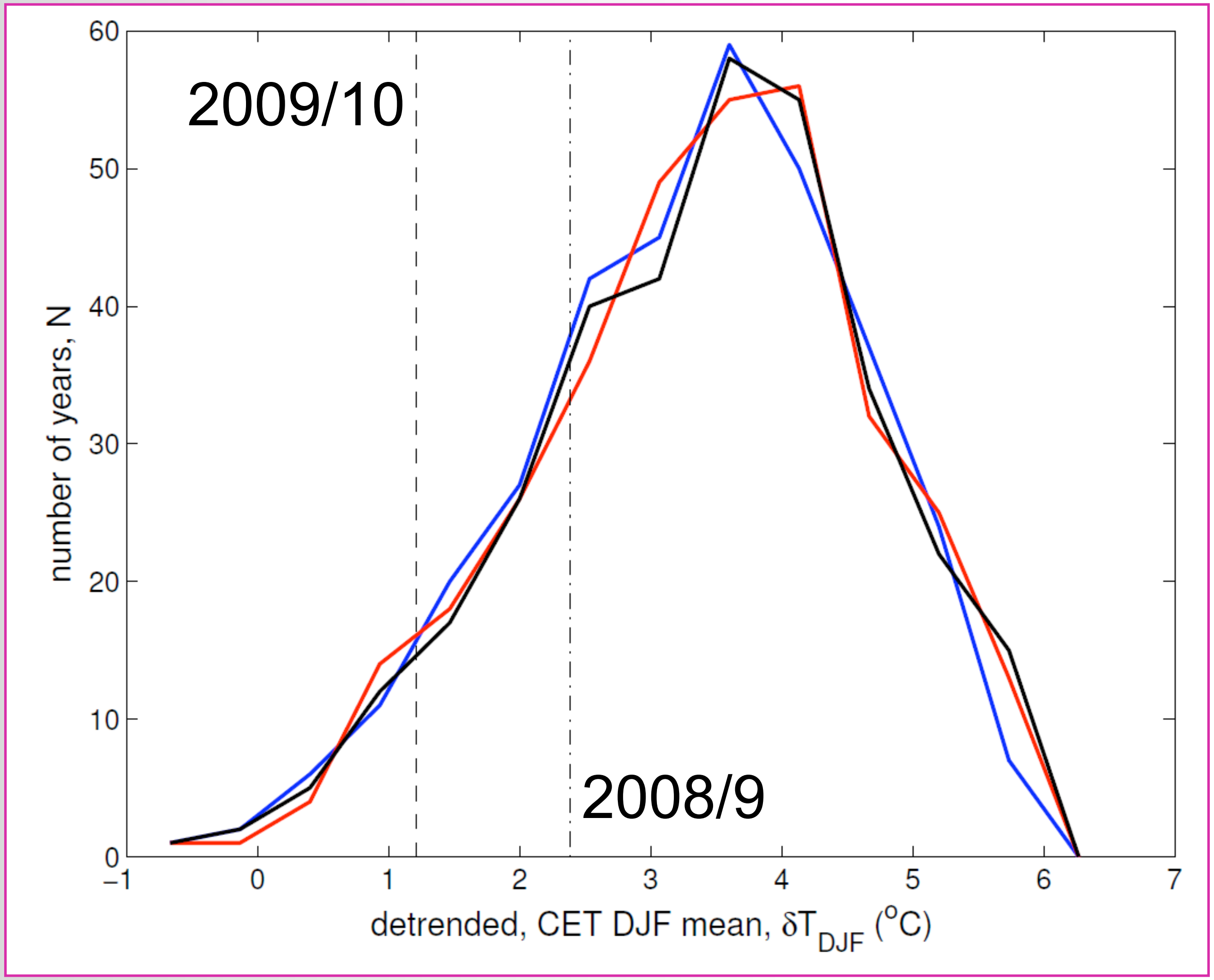
- distribution of 344 winter temperatures in CET record
- 2008/9 is the coldest 145 (43%)
- 2009/10 is the coldest 53 (16%)



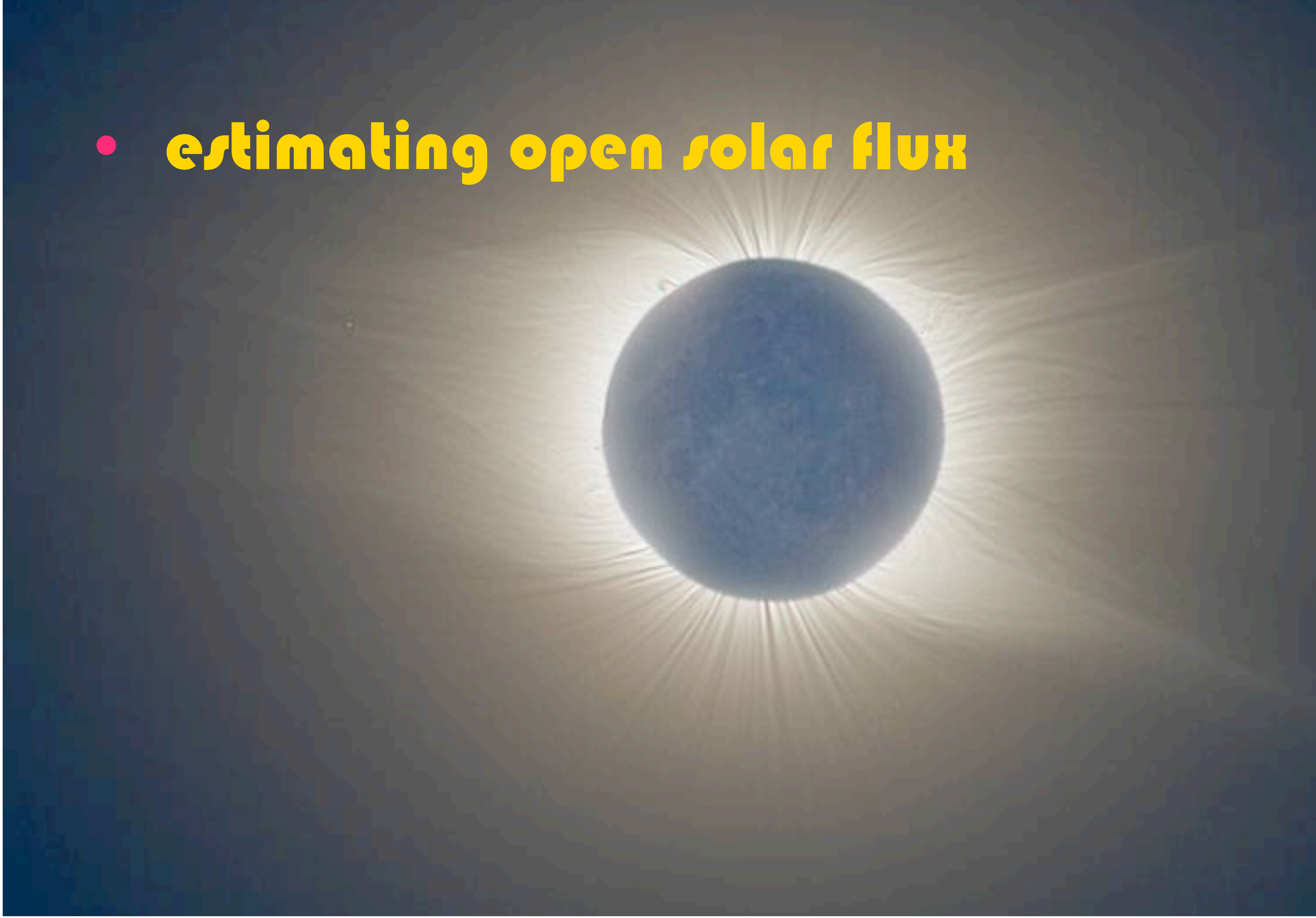


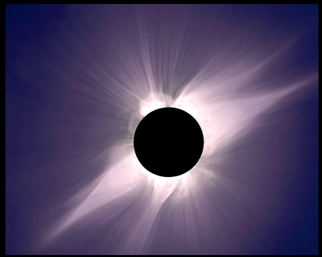
Recent winters in context

- distribution of detrended winter temperatures in CET record
- 2008/9 is the coldest 53 (16%)
- 2009/10 is the coldest 11 (3.3%)
- N.B. dists. for ΔT_{max} & ΔT_{min} are very similar



- estimating open solar flux

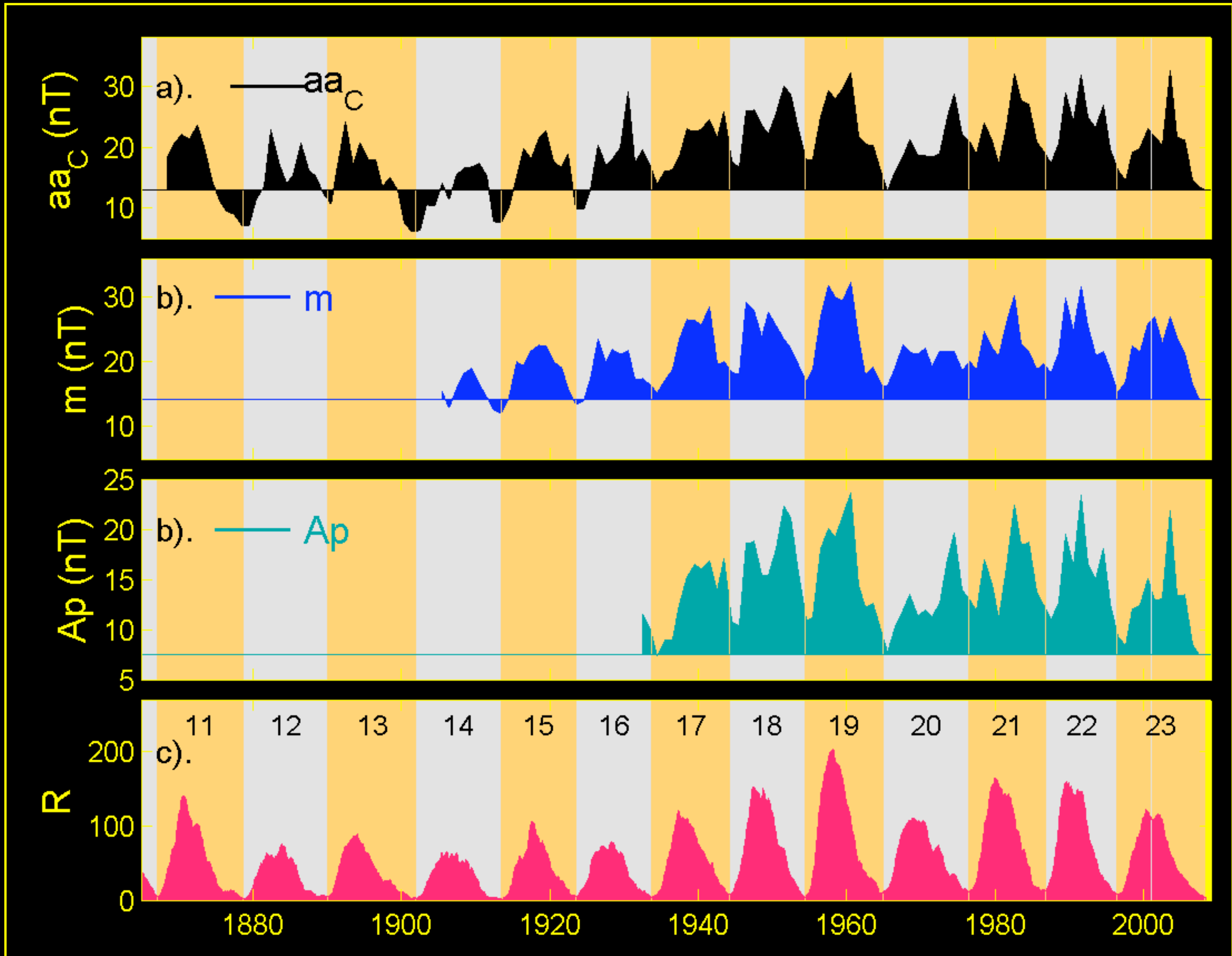


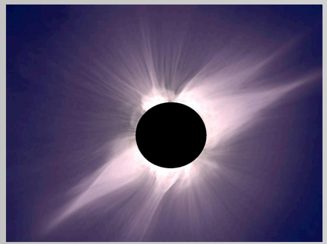


Centennial Variations
- Geomagnetic Activity Indices

- show the present minimum 23/24 is close to minima 19/20 and 16/17

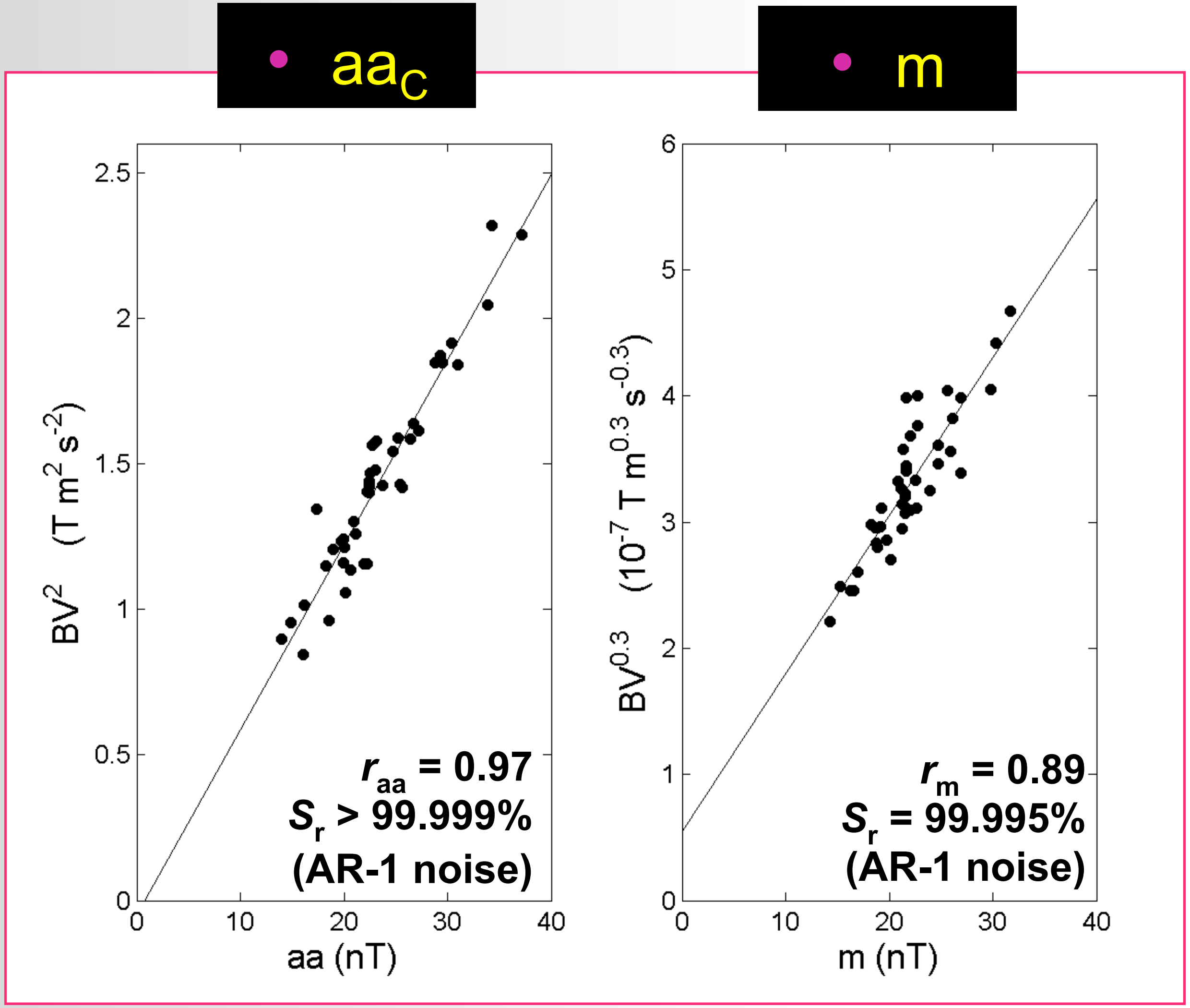
- earlier minima are lower

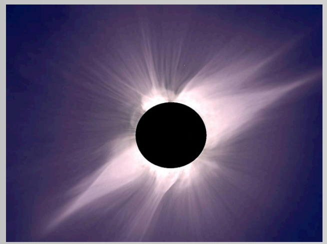




Geomagnetic activity annual means: correlations with solar wind & IMF

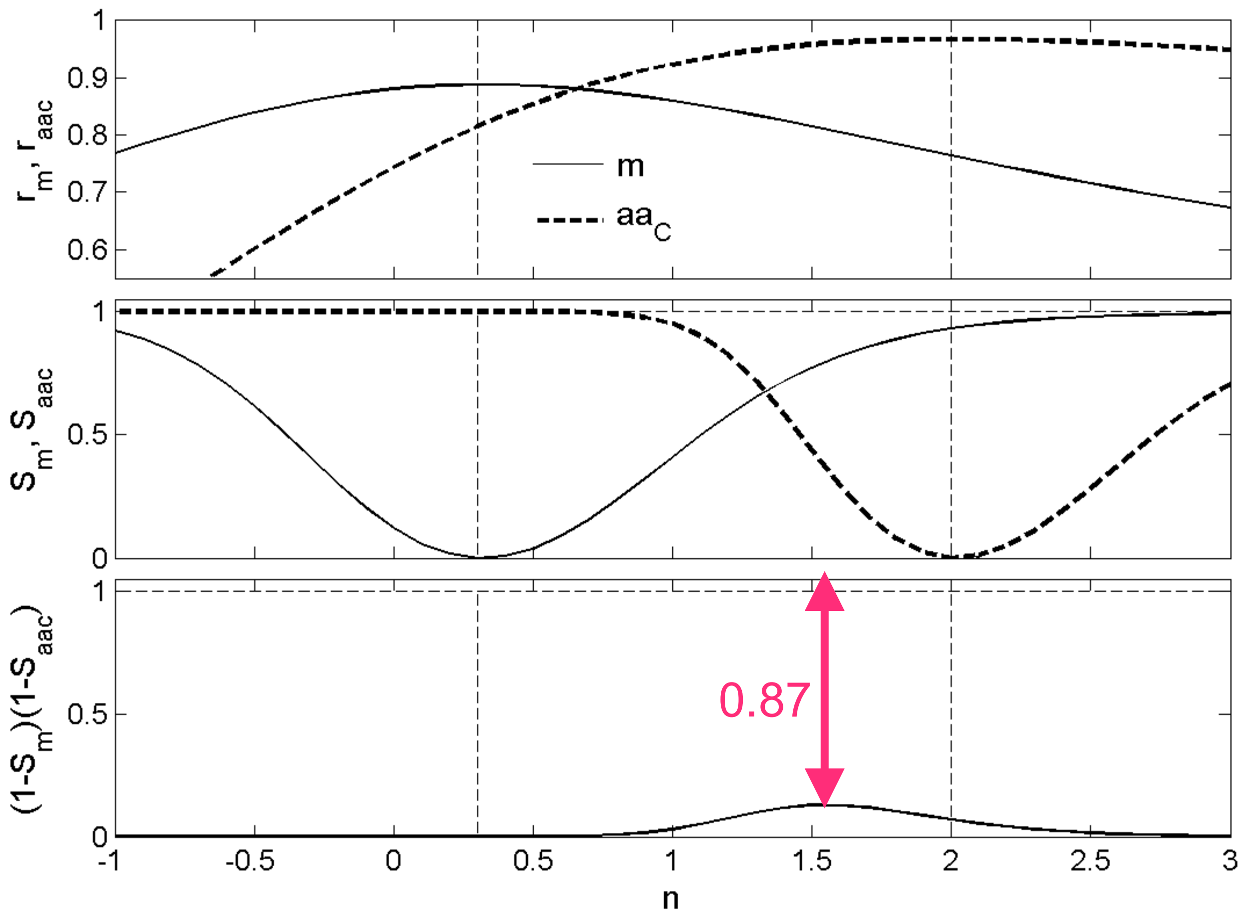
- the corrected aa index is a range index & correlates best with $B_{IMF}V_{SW}^2$
- the median index m is from hourly mean data & correlates best with $B_{IMF}V_{SW}^{0.3}$





Centennial Variations geomagnetic activity

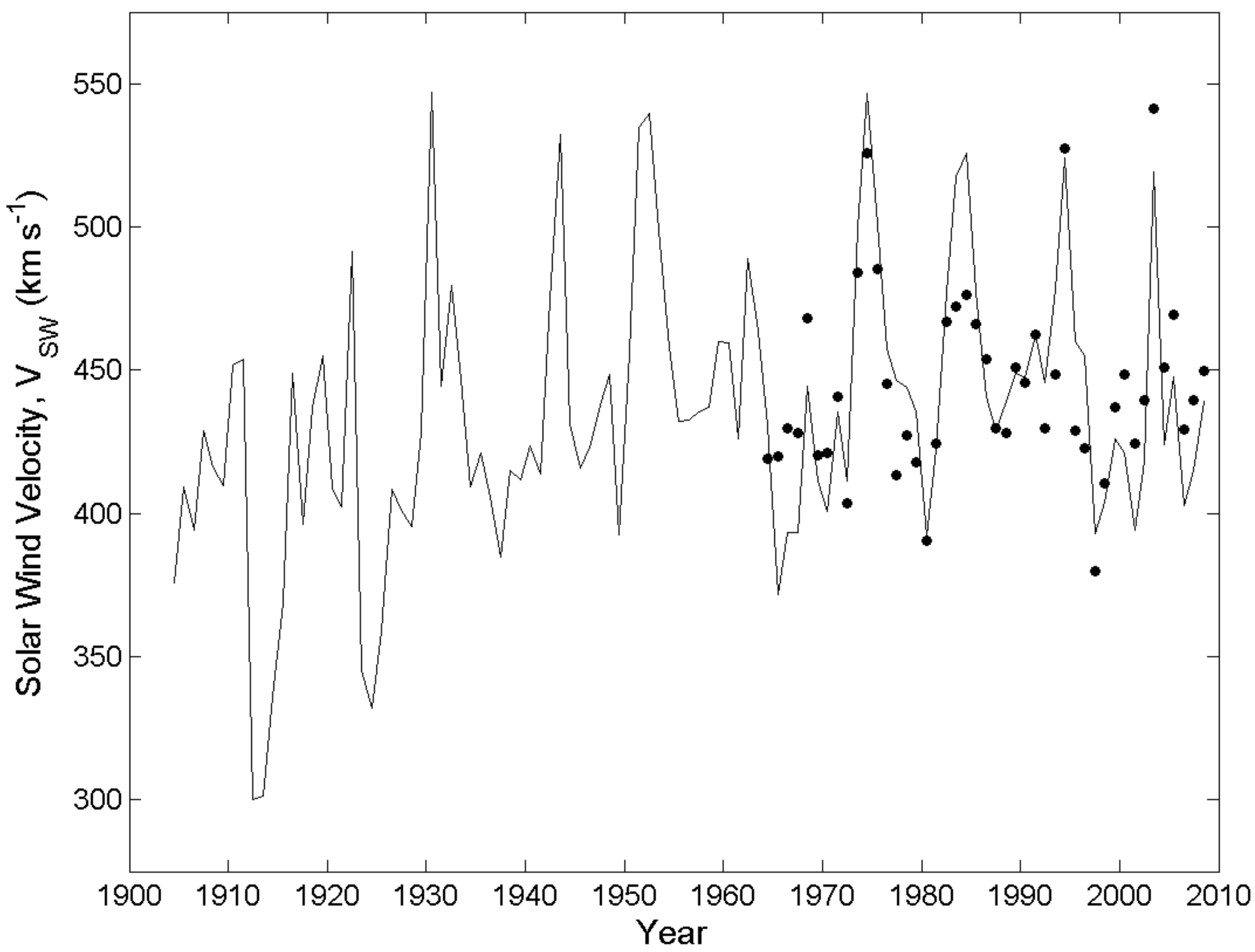
- the different dependences of aa_C and m on V_{SW} are significant at the 87% level.

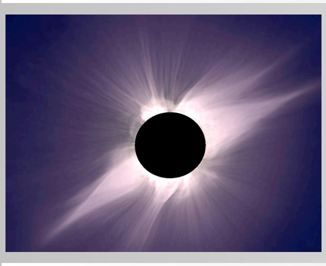


Variation of solar wind V

From m and aa_C

- uses improved m and aa_c compared to *Rouillard et al. (2007)* but result almost identical

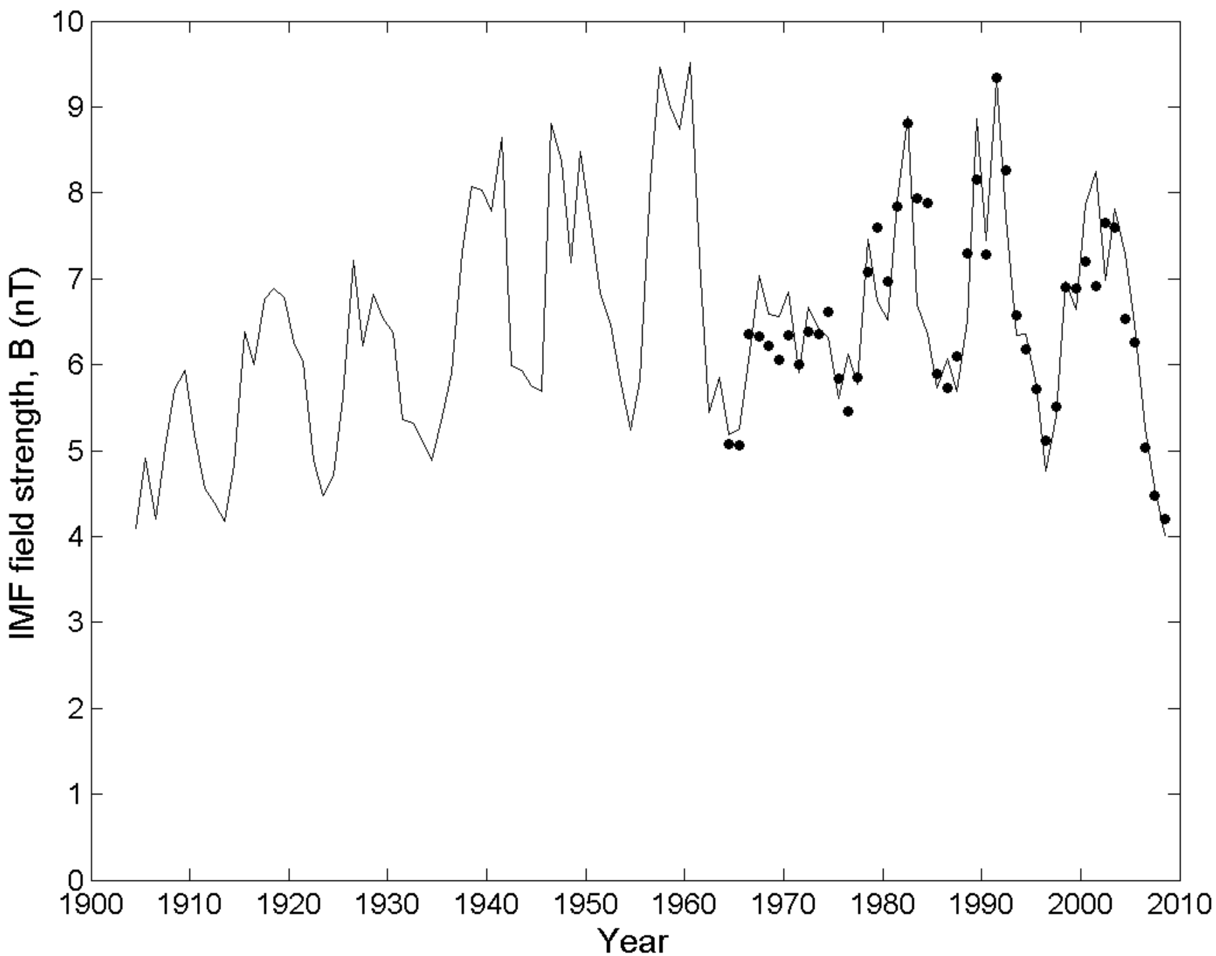


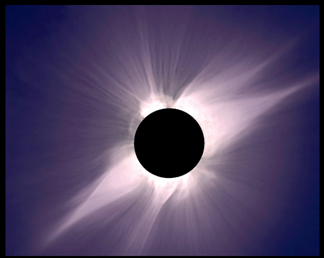


Variation of IMF B

From m and aa_C

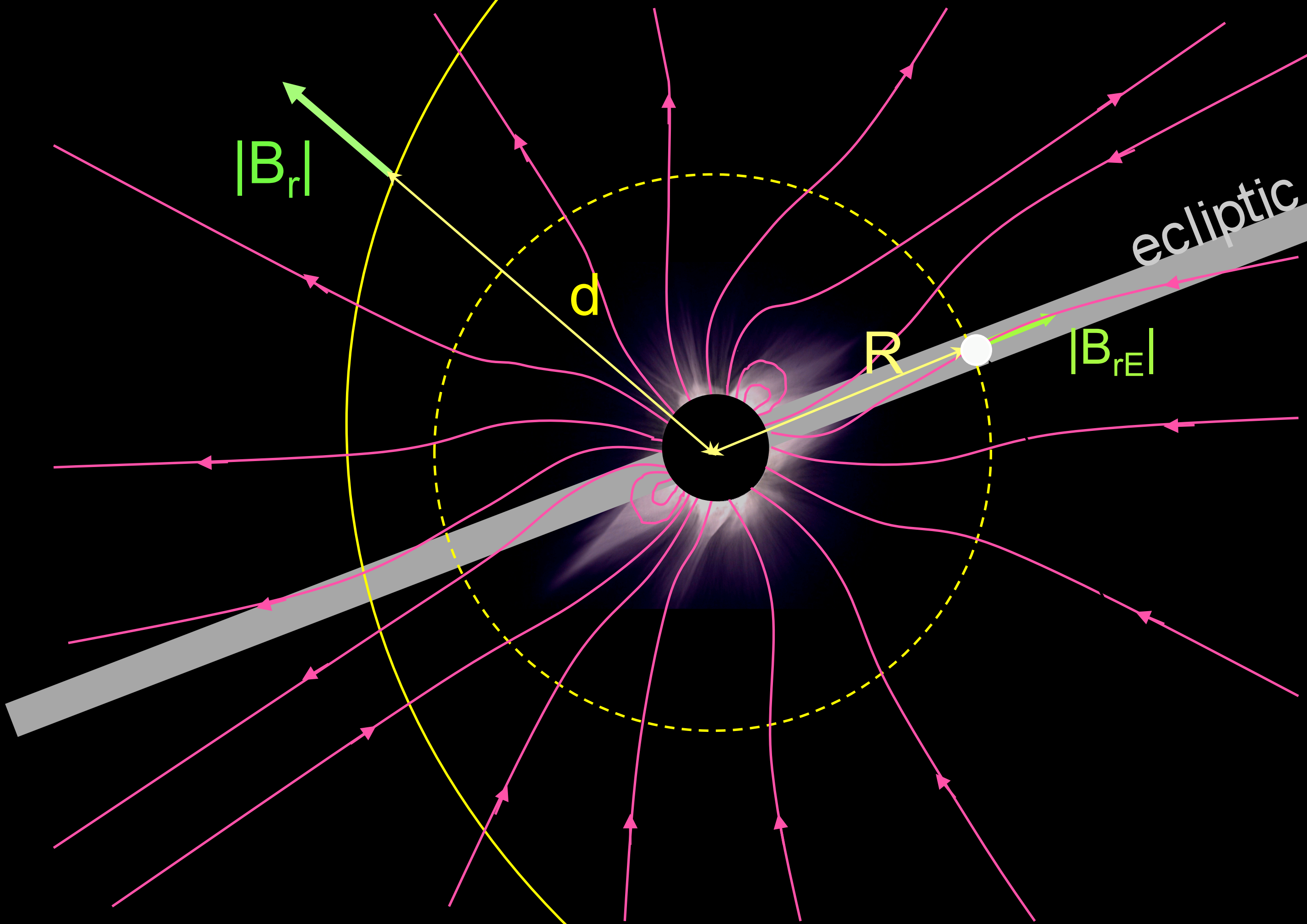
- uses improved m and aa_c compared to *Rouillard et al. (2007)* but result almost identical





Ulysses

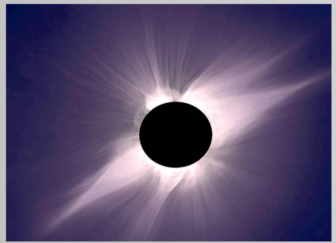
Balogh et al., 1995; Smith et al., 2001



Ulysses showed that everywhere $|B_r|(d/R)^2 = |B_{rE}|$

Thus total signed magnetic flux leaving the sun = $(1/2) \times 4\pi R^2 |B_{rE}|$

With "kinematic correction", *Lockwood and Owens* (2009) show this equation is accurate to within 2%



Kinematic Excess Flux Correction

(*Owens et al. 2008, Lockwood et al. 2009b)*

- ► excess flux,

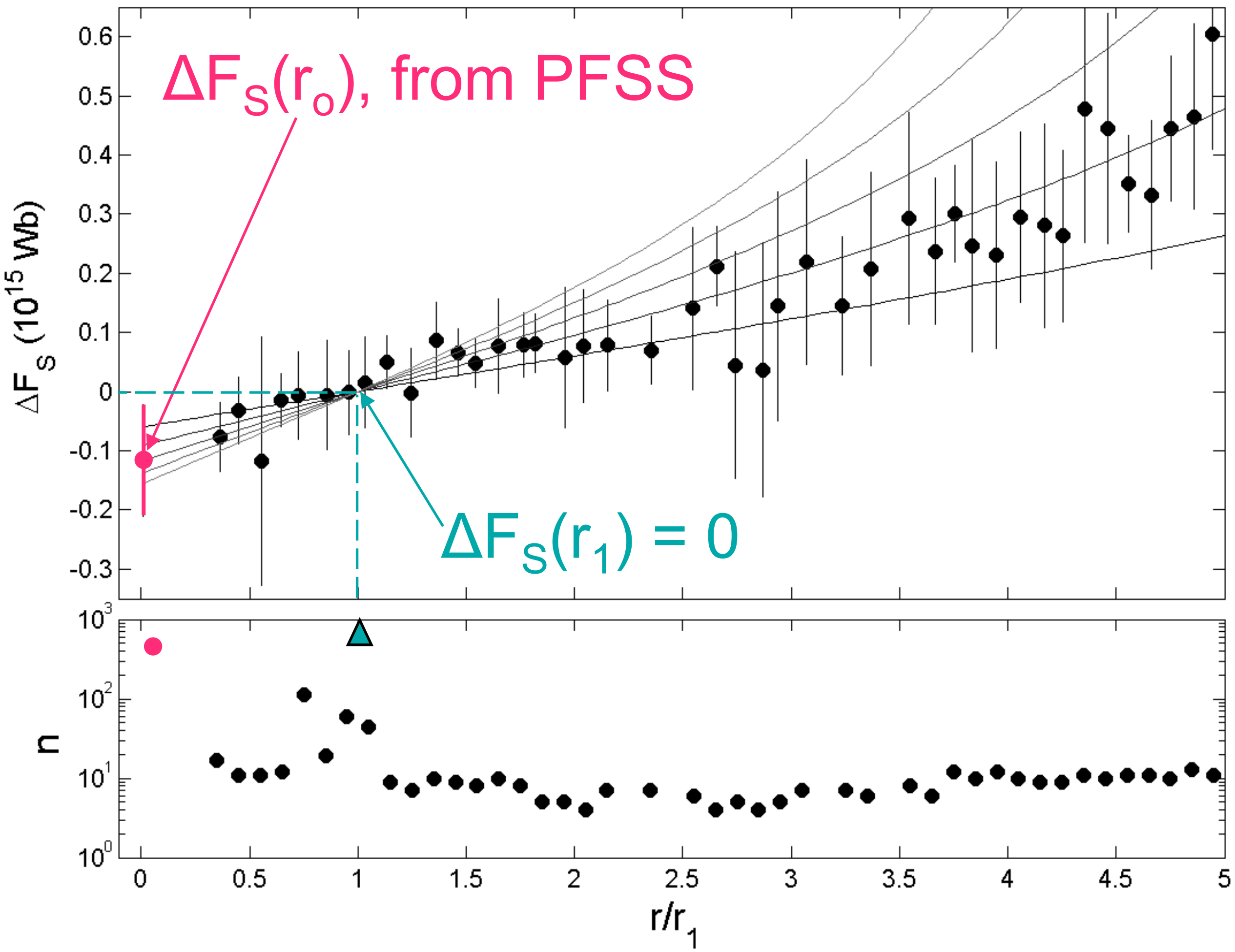
$\Delta F_S(r) =$

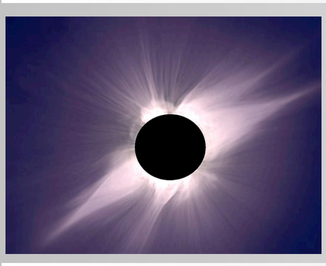
$2\pi r^2|B_r(r)| -$

$2\pi r_1{}^2|B_r(r_1)|$

- ► $r_o = 2.5R_\odot$

- ► PFSS values from photospheric magnetograms





Flux Excess

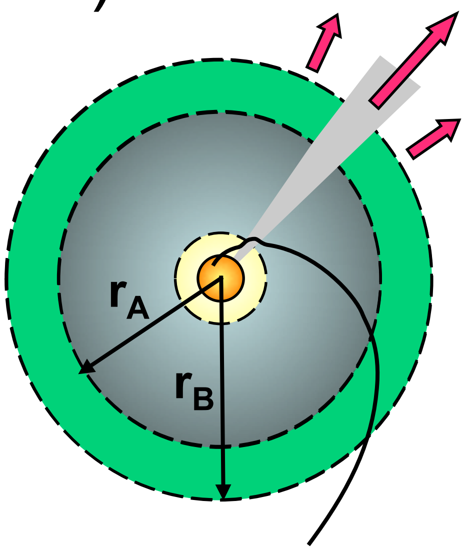
Longitudinal flow structure threaded by seed field

here $4\pi r_B^2<|B_r|>_B$
$=4\pi r_A^2<|B_r|>_A$

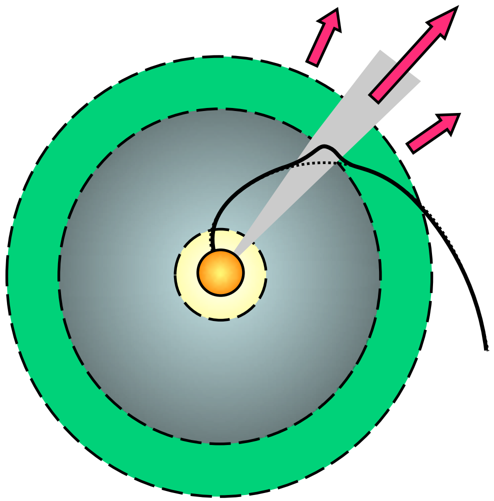
still $4\pi r_B^{\mathbf{2}}<|B_r|>_B$
$=4\pi r_A^2<|B_r|>_A$

Now $4\pi r_B^2<|B_r|>_B$
$> 4\pi r_A^2<|B_r|>_A$

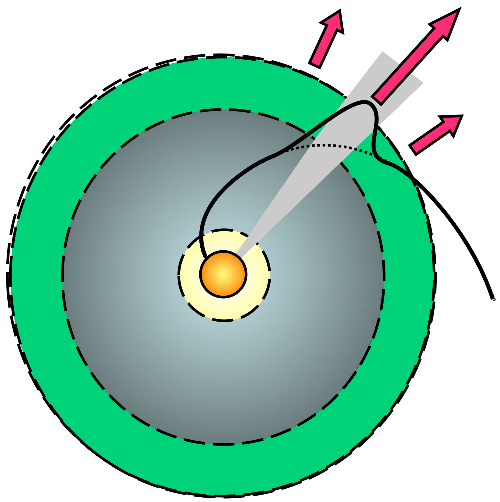
- a).



- b).



- c).

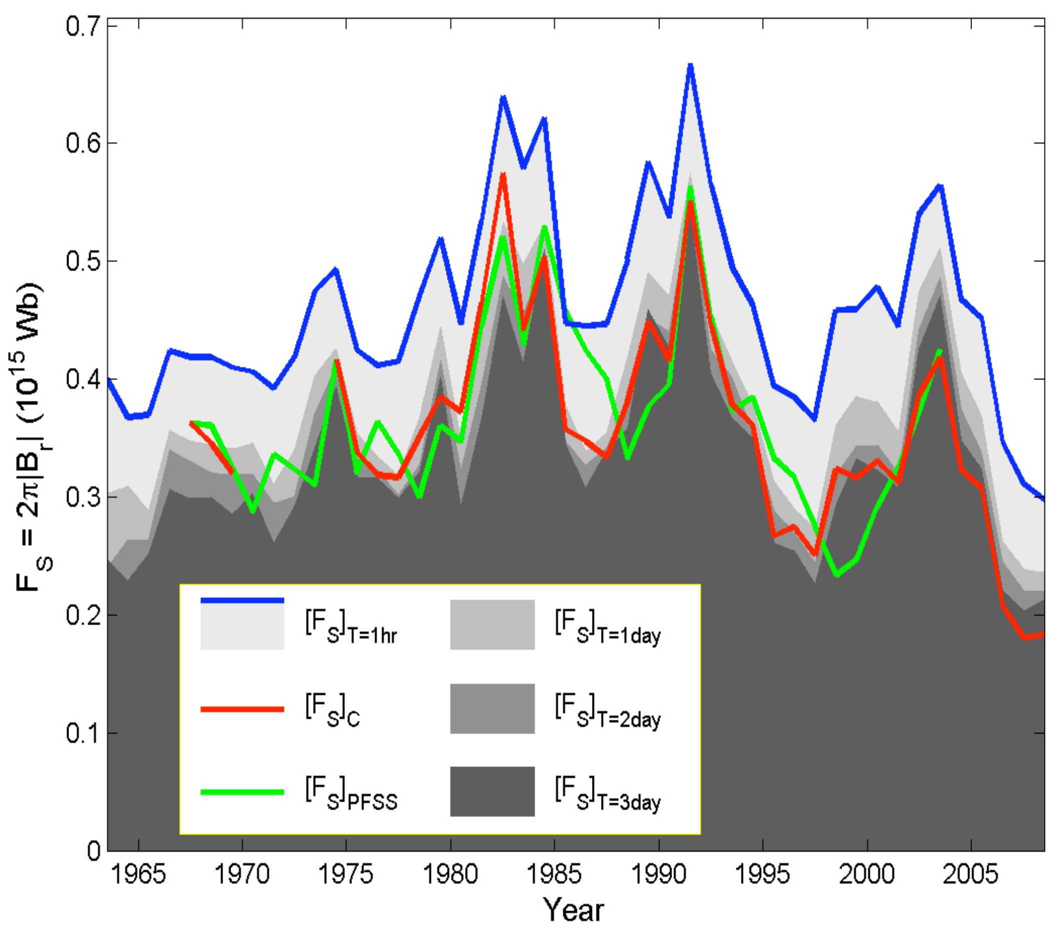


Open Flux Variation from IMF data

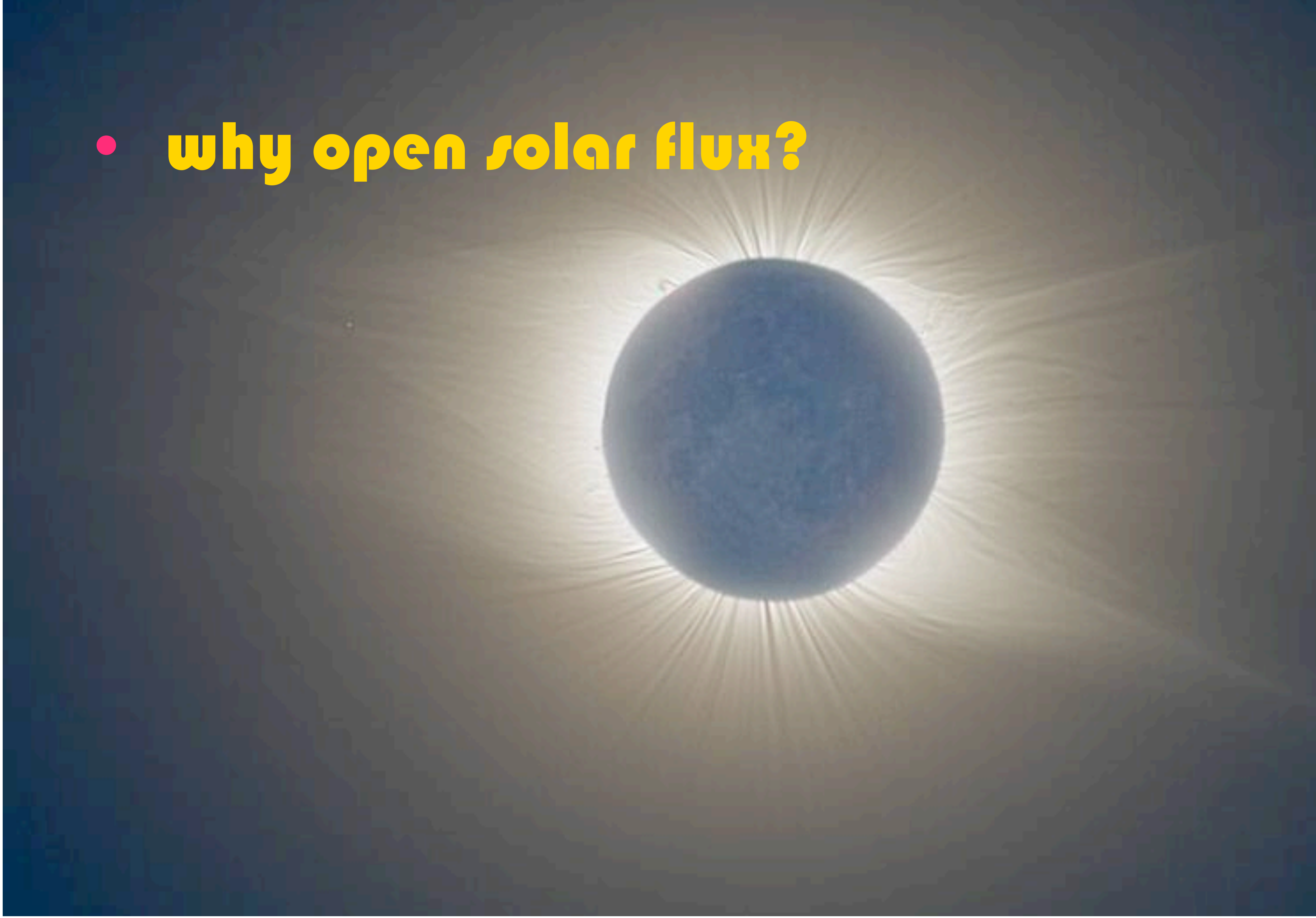
Lockwood et al. (2009b;c)

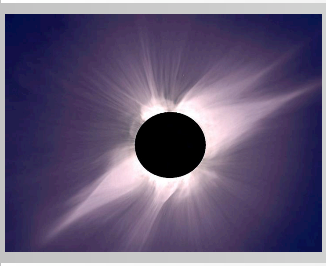
- kinematic, time-of-flight correction gives good agreement with PFSS values

- taking $|B_x|$ using averages over T=1day is a reasonable approximation



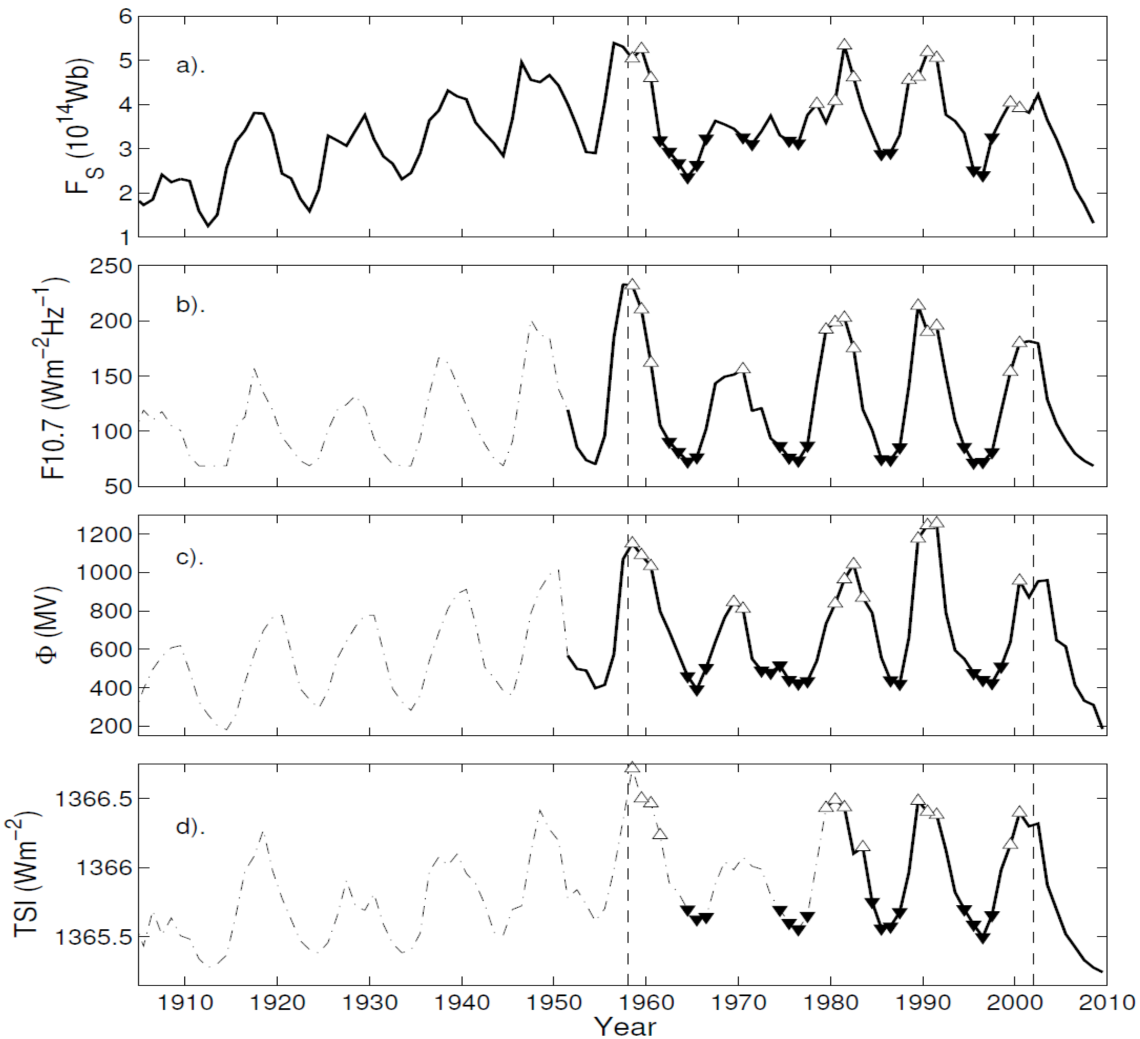
- **why open solar flux?**

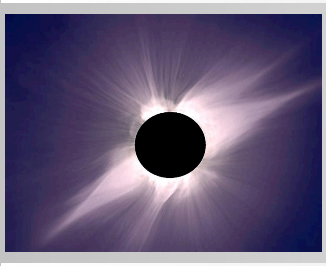




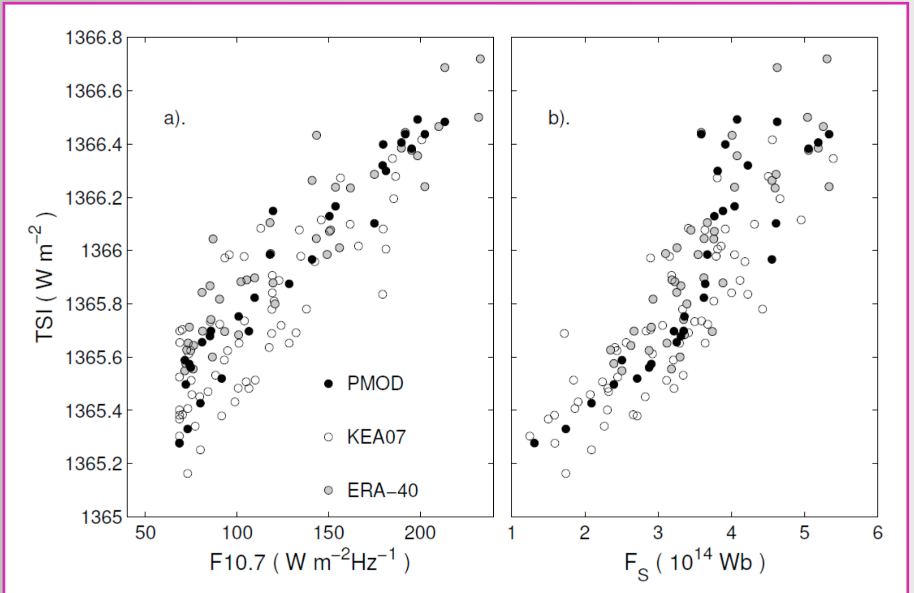
Decadal and Centennial Solar Variations

- ▶ open solar flux
- ▶ F10.7 radio flux
- ▶ GCR modulation parameter
- ▶ Total Solar Irradiance (TSI) (PMOD Composite)

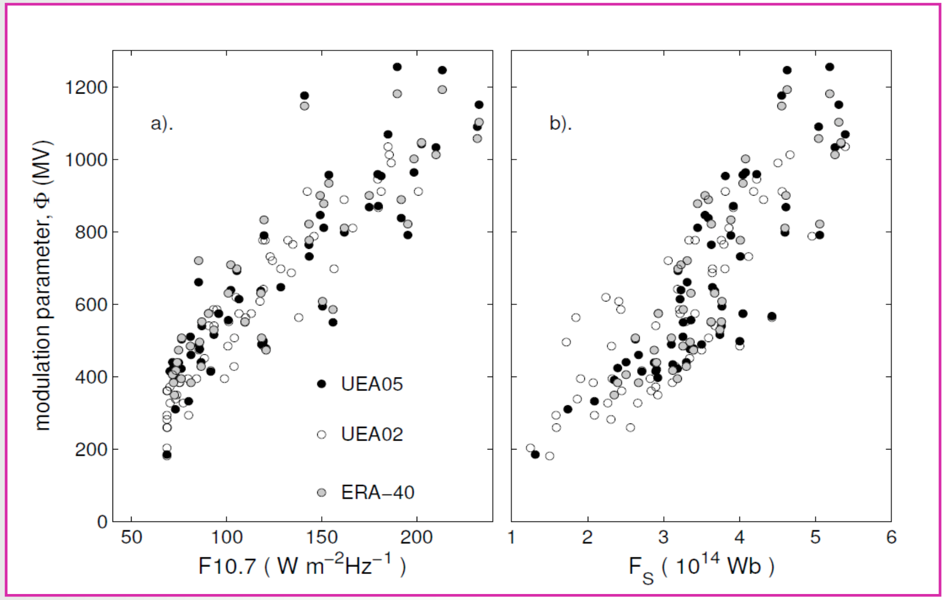




Correlations: all very high and all very significant - but there are differences



▶ F10.7 and open solar flux and radio flux against TSI (PMOD Composite)



▶ F10.7 and open solar flux against GCR modulation parameter

How might solar variations influence global or regional climate?

- ► **TSI variations**

  influence troposphere directly
  - but variations small (≈ 0.1%)

- ► **UV spectral variations**

  influence stratosphere -
  fractional variations large - but low power flux
  - may influence jet stream latitudes, blocking occurrence and polar troposphere

- ► **SEP event occurrence and fluence**

  generate NO_x and destroy stratospheric O_3

- ► **GCR flux variations**

  postulated modulation of low-altitude cloud

Relevance of Open Solar Flux, F_S?

- **TSI variations**

  recent data shows centennial drift and solar cycle variation of TSI both mirroring F_S changes *(Fröhlich, 2009)*.

- **UV spectral variations**

  decline in recent values larger than expected *(Harder et al., 2009)* …. ***And*** ….

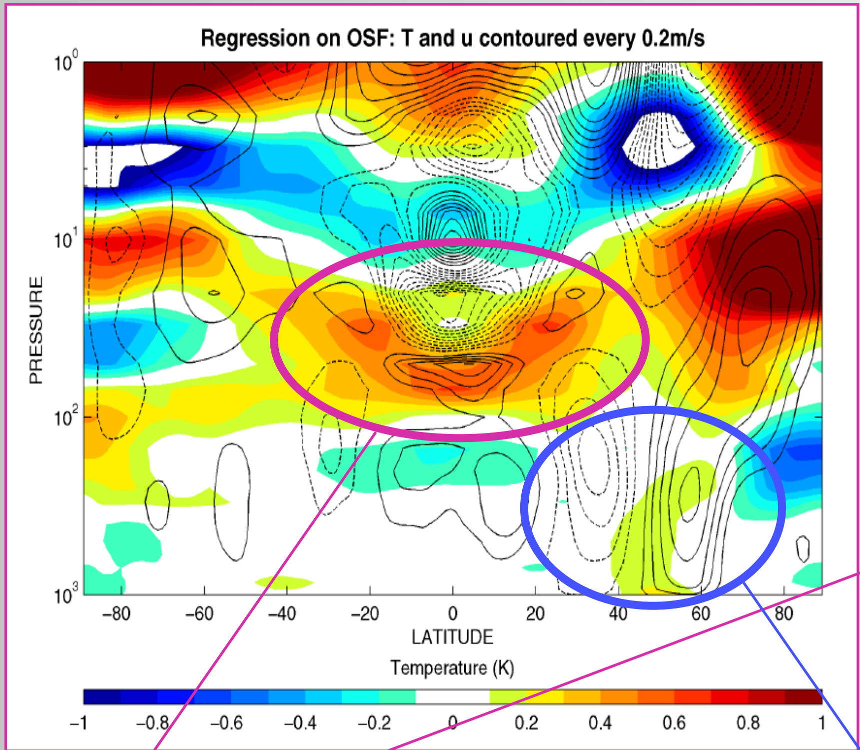
- **SEP event occurrence and fluence**

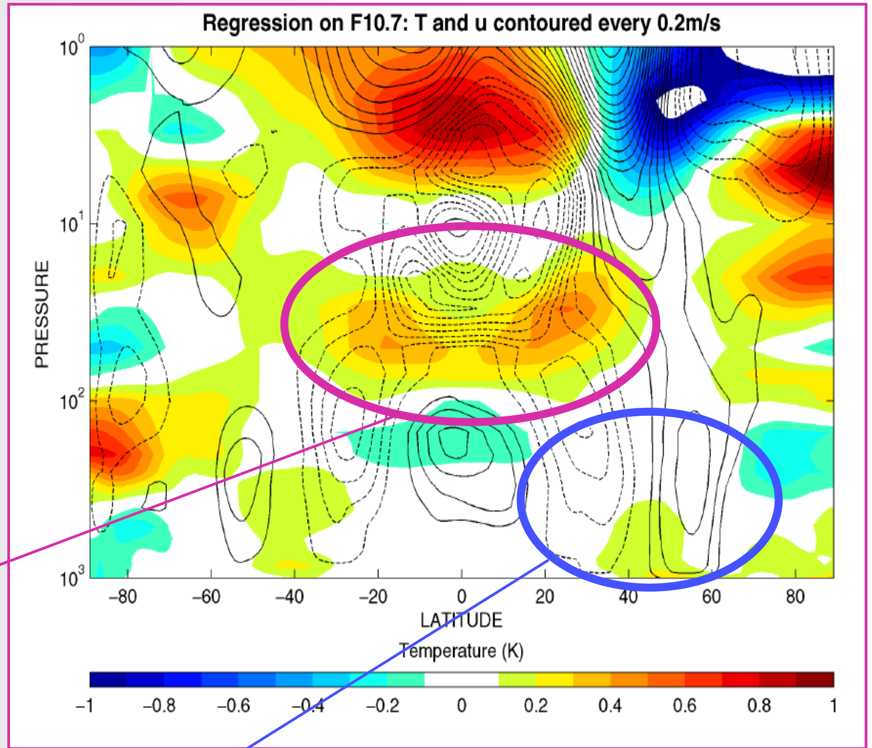
  SEPs depend on Alvén speed? *(McCracken, 2008)*

- **GCR flux variations**

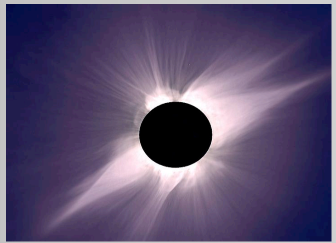
  GCR flux highly anticorrelated with F_S

UV effects in lower stratosphere: more effect of F_S than F10.7





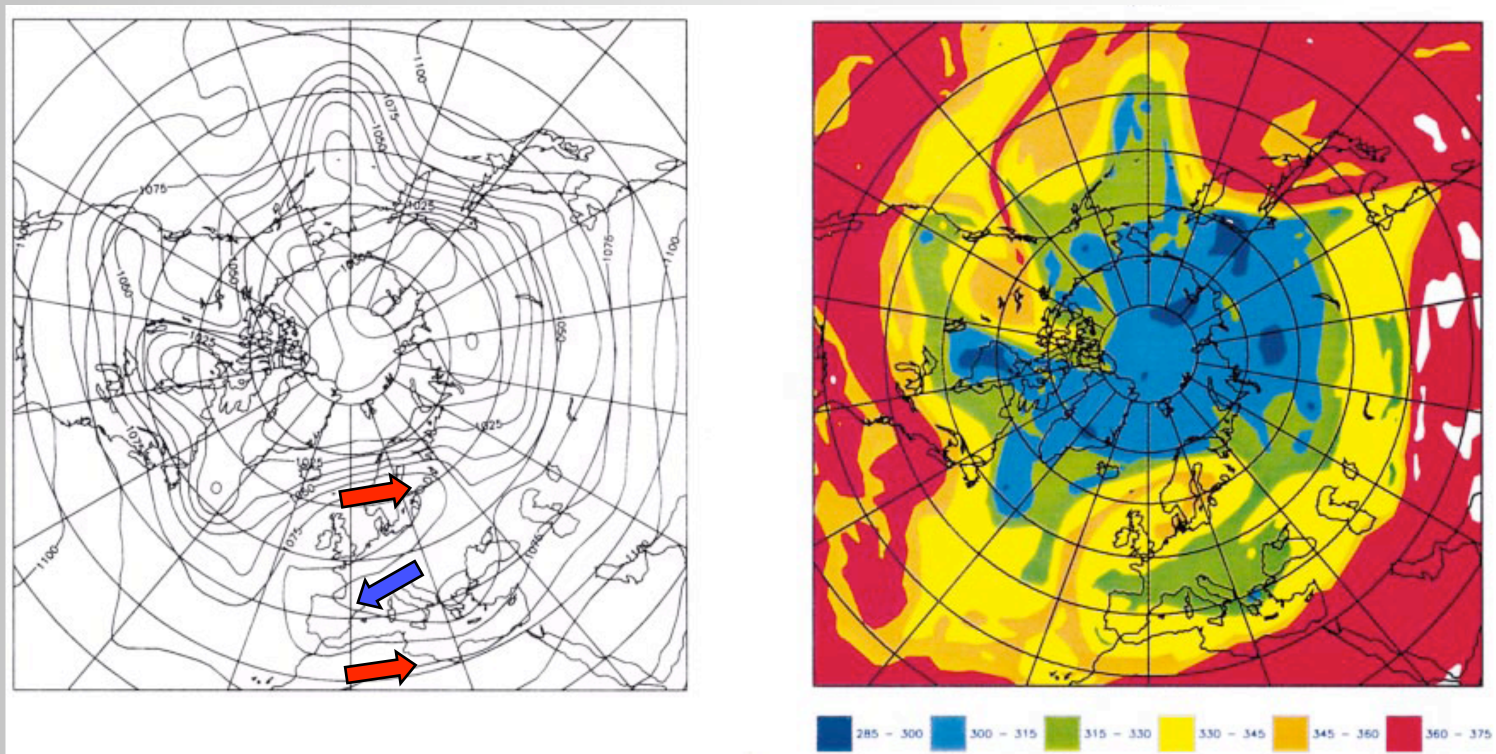
- Stronger effect on equatorial low-altitude stratospheric temperatures
- Stronger effect on low-altitude tropospheric winds in N.H.



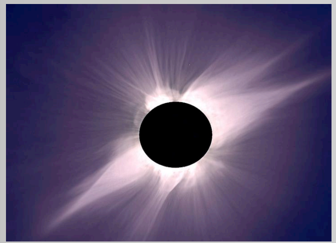
Atlantic blocking events

(Plelly and Hoskins, 2003)

► blocking events are large long-lived anticyclones which disrupt easterly flow of storms, bifurcating the jet stream and, in winter, causing cold winds from the east over Europe



Example at 12UT, 21 Sept, 1998: on the potential vorticity PV=2 surface
(a) 250-hPa geopotential height (b) potential temperature θ (K)



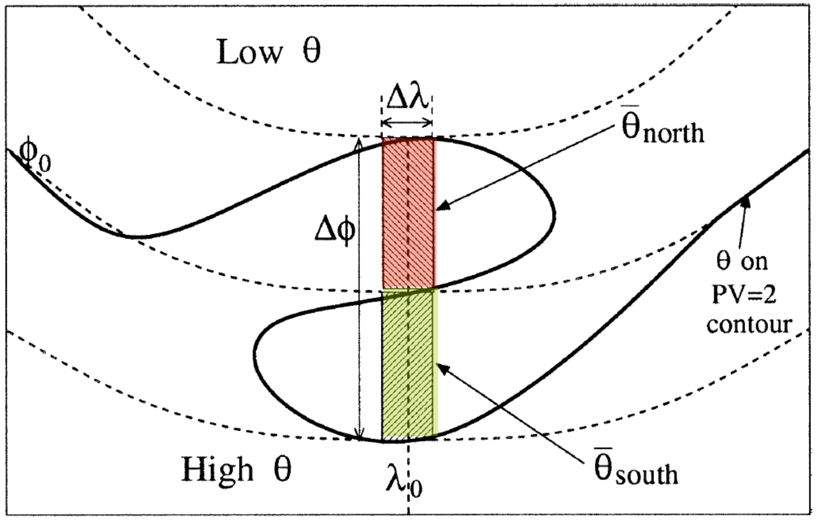
Blocking Intensity Indices

- *Lejenäs and Økland (1983)* required a region of easterly winds and used $Z(\lambda, \varphi_o+\Delta\varphi/2)-Z(\lambda, \varphi_o-\Delta\varphi/2)$ where Z is a constant height geopotential, λ is the longitude and φ the latitude

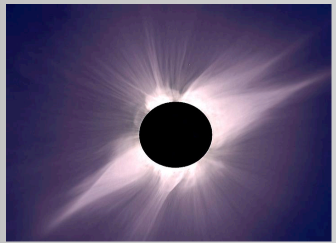
- *Barriopedro et al. (2006,2008)* used $BI = 100\cdot\{[Z(\lambda_o, \varphi_o)/RC]-1\}$ where $RC = \{Z(\lambda_o+\Delta\lambda, \varphi_o) - Z(\lambda_o-\Delta\lambda, \varphi_o)\} / 2$

- *Pelly and Hoskins (2006,2008)* used mean potential temperature θ in the red and green areas of the plot B =

$$(2/\Delta\varphi) \int_{\varphi_o}^{\varphi_o+\Delta\varphi/2} \theta \, d\varphi - (2/\Delta\varphi)\int_{\varphi_o-\Delta\varphi/2}^{\varphi_o} \theta \, d\varphi$$



Solar influence on European winter Temperatures via Blocking events

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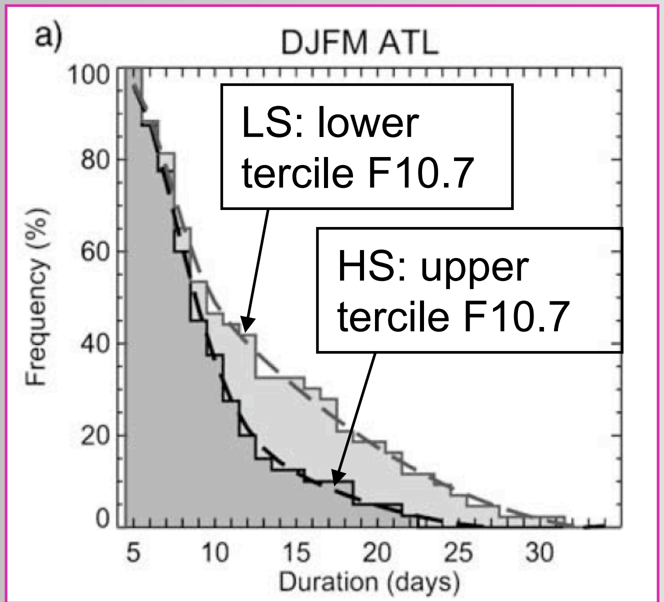
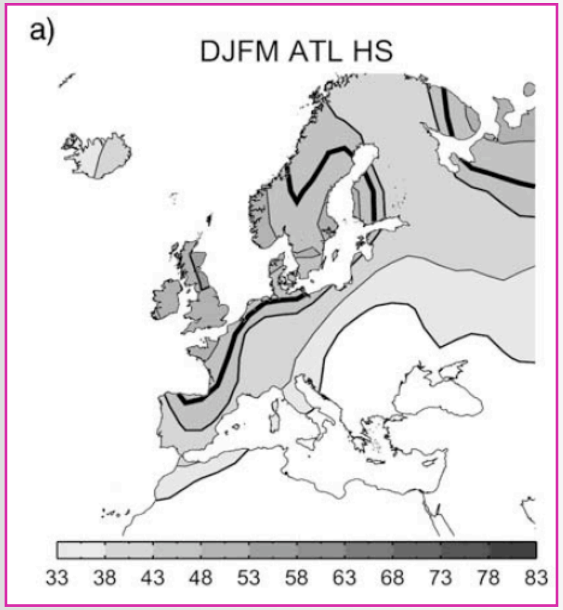
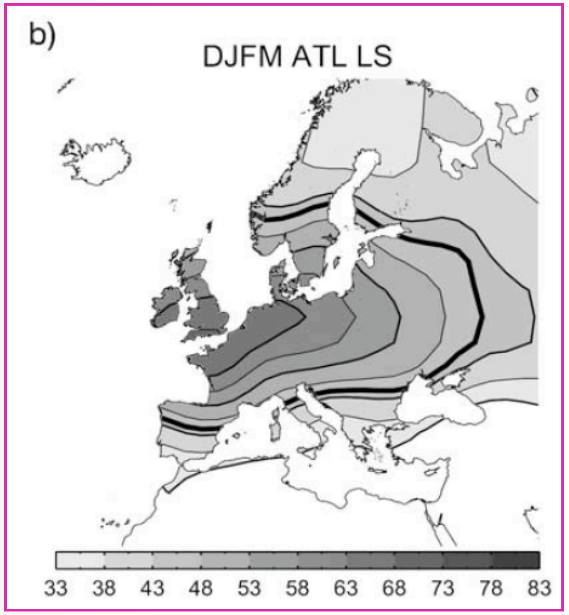
Solar modulation of Northern Hemisphere winter blocking

David Barriopedro,[1,2,3] Ricardo García-Herrera,[2] and Radan Huth[4]

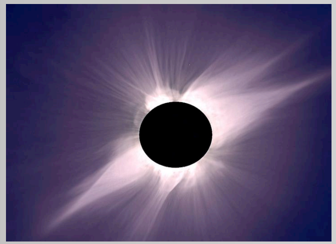






► atlantic blocking events longer lived for LS than HS

► % of blocked days that lead to temperature anomalies in lower tercile is higher for LS



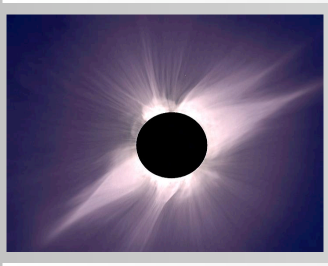
Blocking & the Stratosphere

► *Woollings et al. (2010)* compute B from data and models

► blocking events modulate stratospheric winds via upward propagating planetary wave disturbances

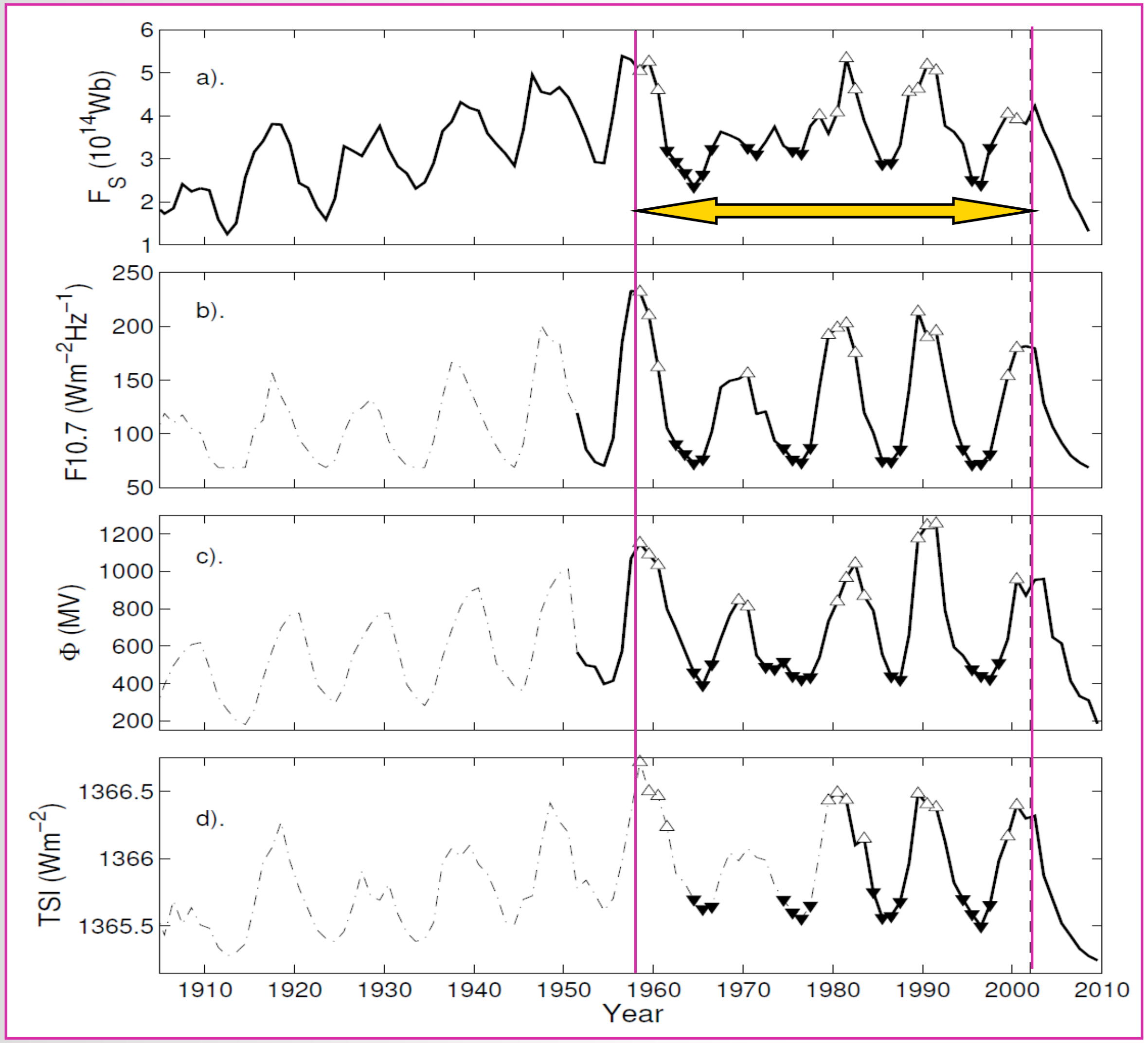
► the magnitude, extent and lag of the correlations over Europe strongly suggest that the perturbation to the stratospheric wind pattern can, in turn, influence the blocking

► Note all models seriously underestimate degree of blocking. Problem is not solved by coupling a stratosphere to the thermosphere model. Something is missing



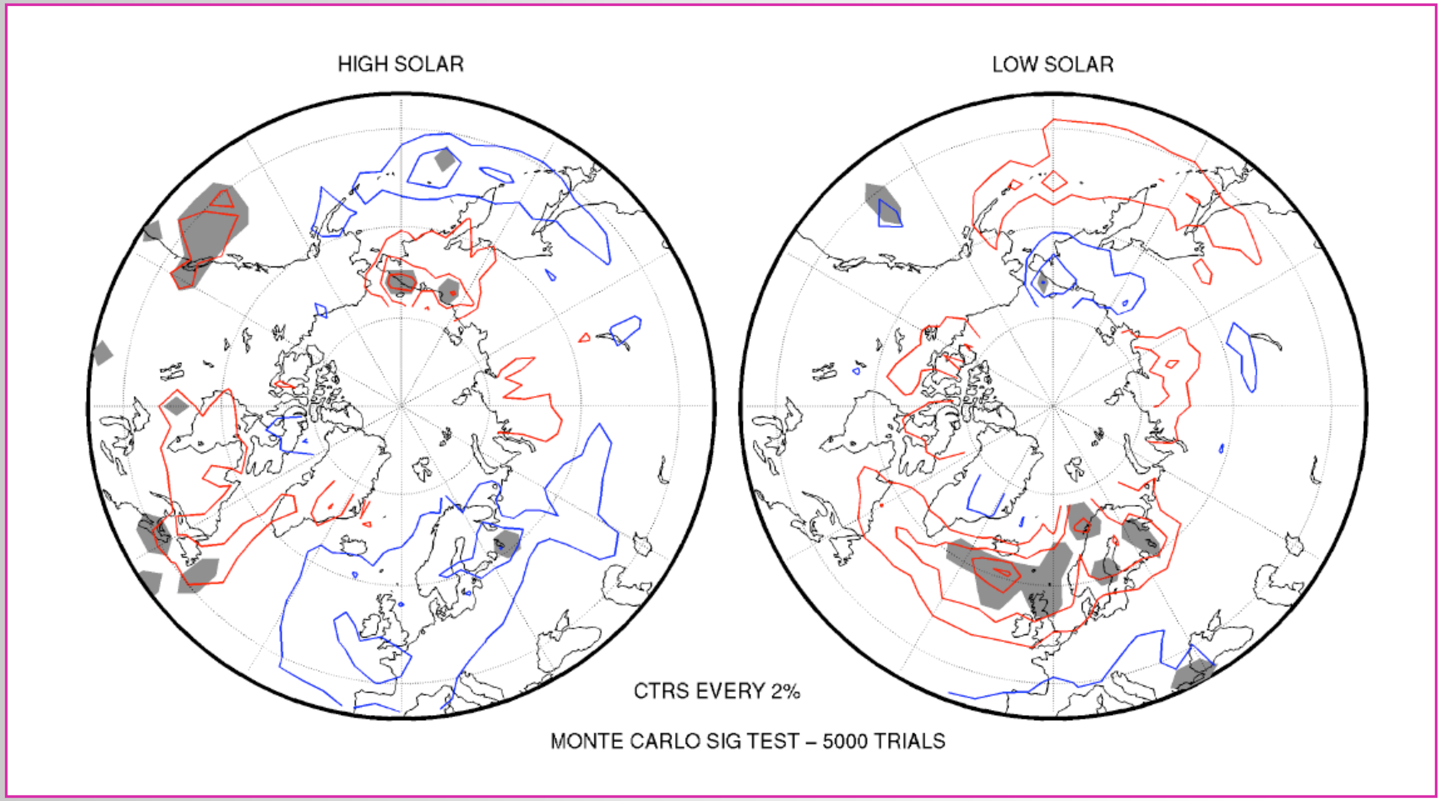
ERA-40 Re-analysis interval

- ▶ open solar flux
- ▶ F10.7 radio flux
- ▶ GCR modulation parameter
- ▶ Total Solar Irradiance (TSI) (PMOD Composite)



ERA-40 Analysis of Blocking Index

(change of terciles relative to whole set)



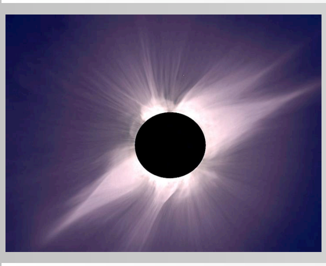
► sorted using F10.7

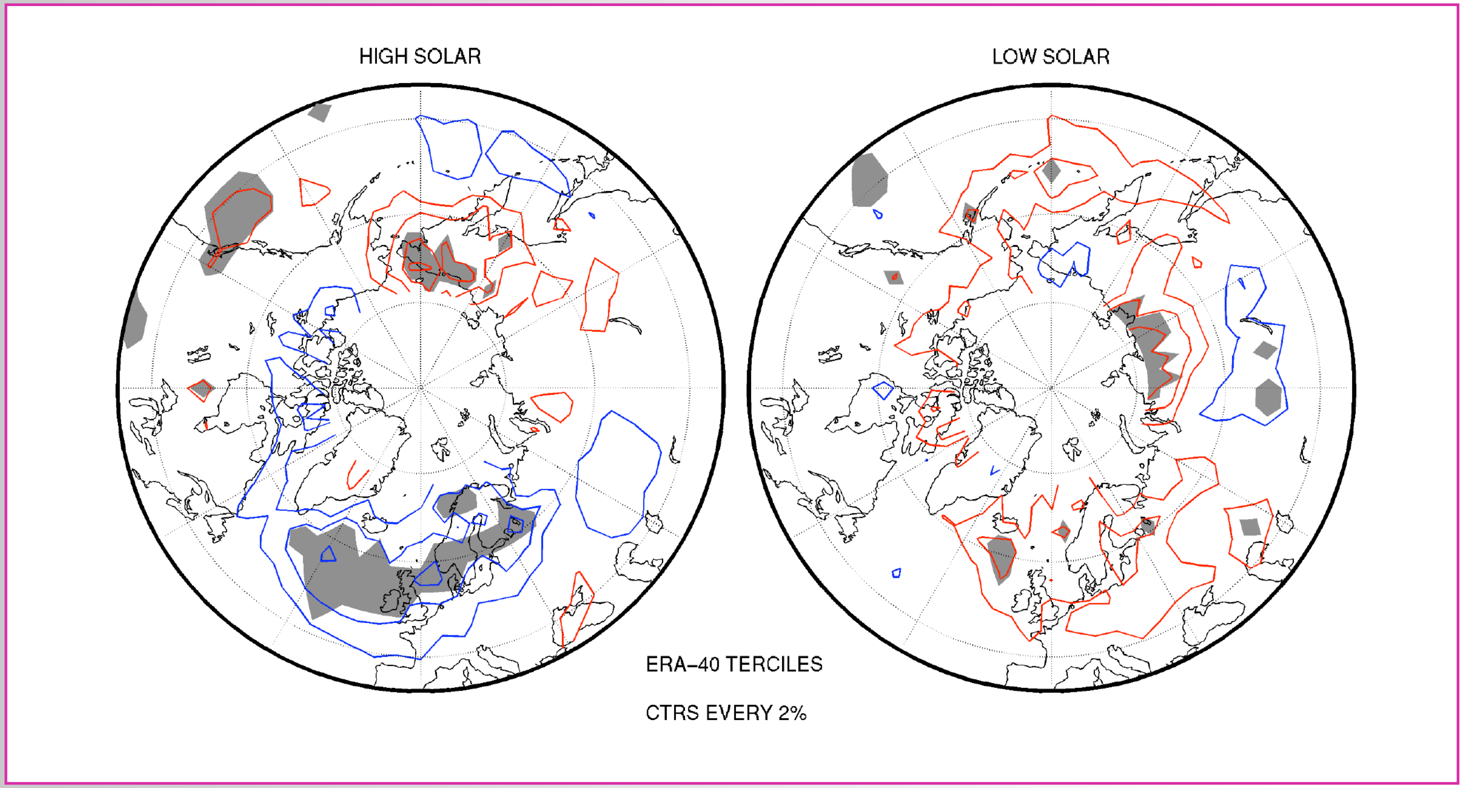
Low solar activity gives enhanced (up to 8%) blocking over east Atlantic and Europe.
Grey area shows significance from Monte-Carlo technique > 95%
Asymmetric as only weak effect for high solar activity

Consistent with results of Bariopiedro et al. (2008)

ERA-40 Analysis of Blocking Index

(change of terciles relative to whole set)

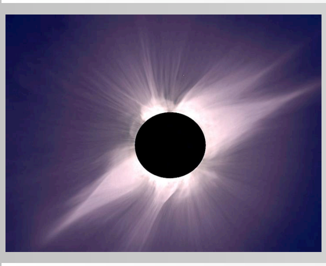




► sorted using modulation parameter Φ (GCRs)

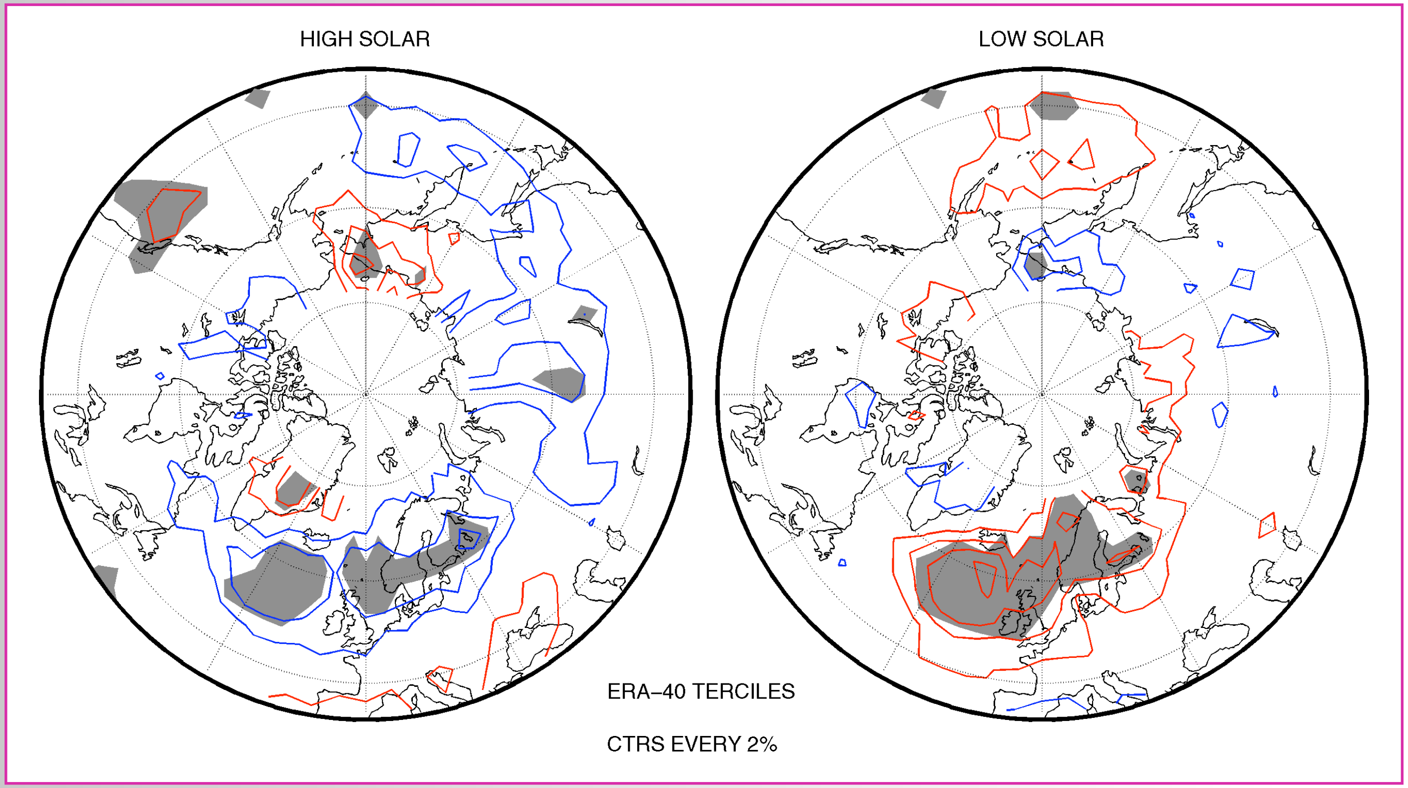
High solar activity gives reduced (up to 6%) blocking over east Atlantic and Europe.
Grey area shows significance from Monte-Carlo technique > 95%
Asymmetric as almost no effect for low solar activity

Could explain paleoclimate resulats like Bond et al. (2001)



ERA-40 Analysis of Blocking Index

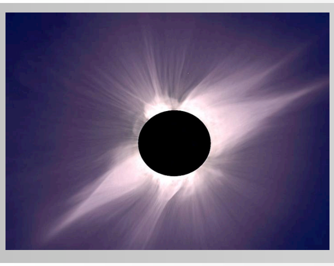
(change of terciles relative to whole set)



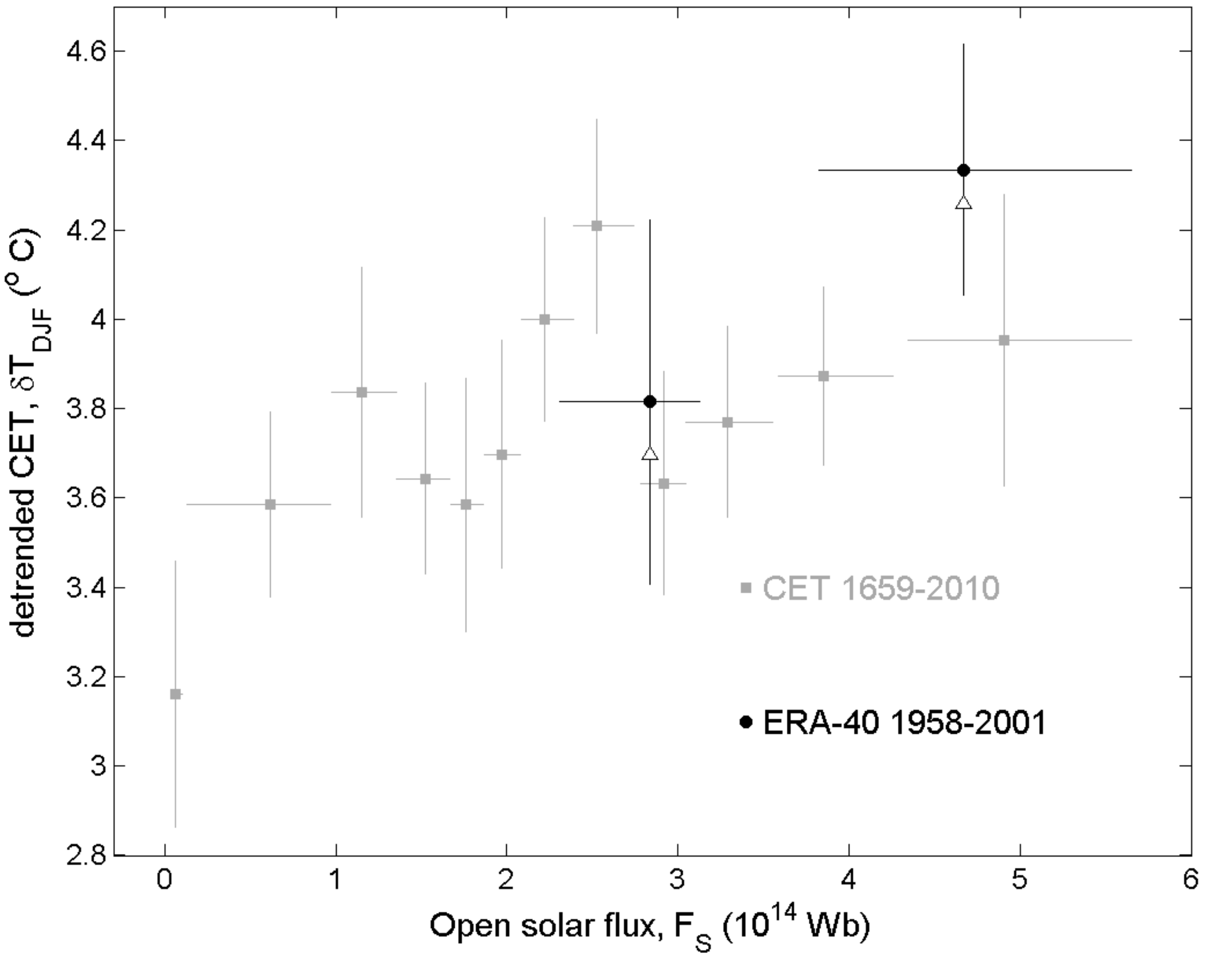
- sorted using open solar flux F_S

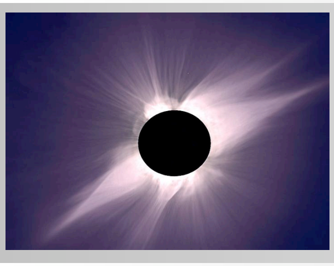
High/Low solar activity gives reduced/enhanced (up to 8%) blocking over east Atlantic and Europe (symmetric effect)
Consistent and localised effect
Grey area shows significance from Monte-Carlo technique > 95%

Does this fit with the CET results?

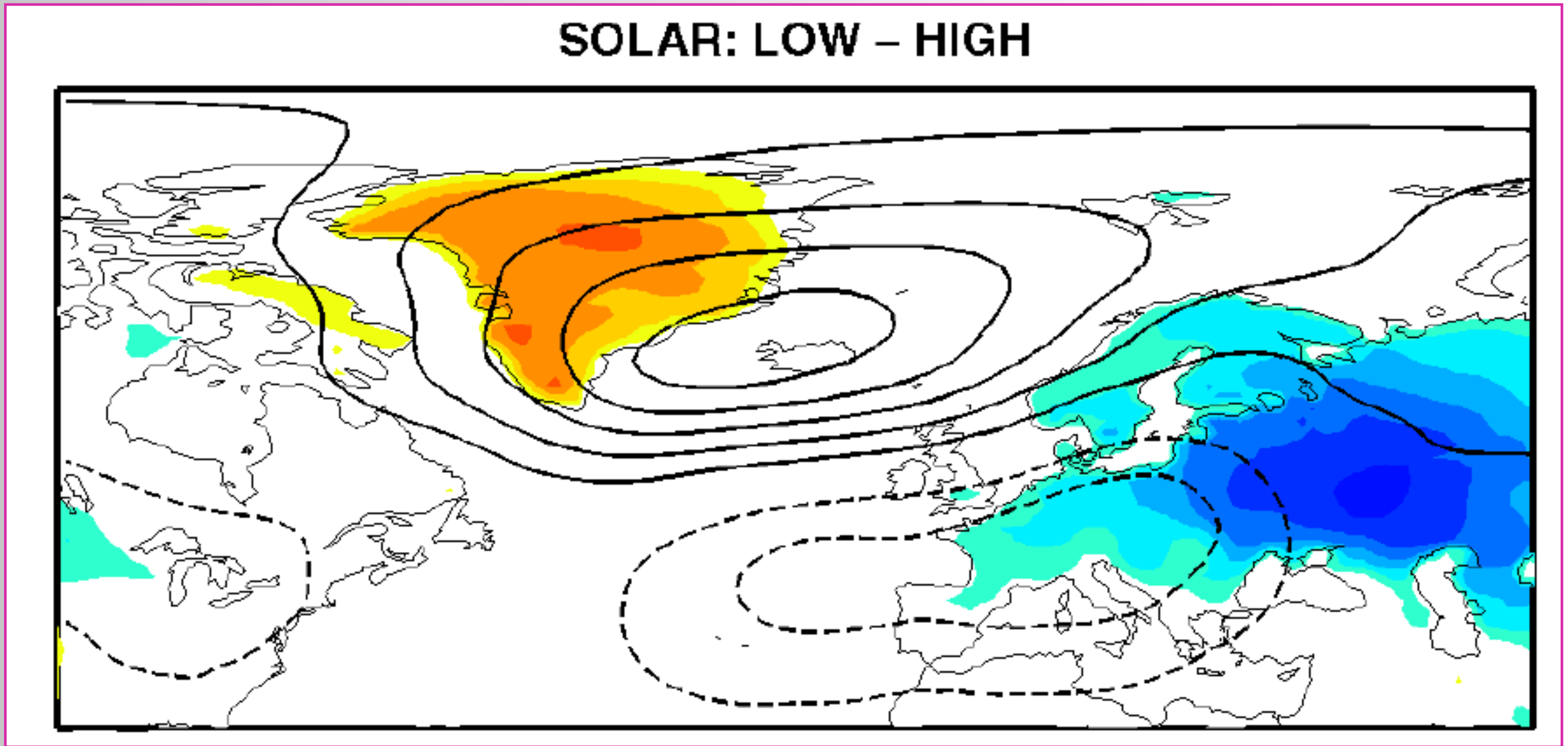


Comparison of ERA-40 and full CET analysis of DJF temperatures





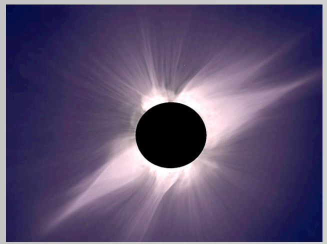
ERA-40 Analysis of DJF temperatures & circulation (difference of high and low tercile subsets)



► sorted using open solar flux F_S

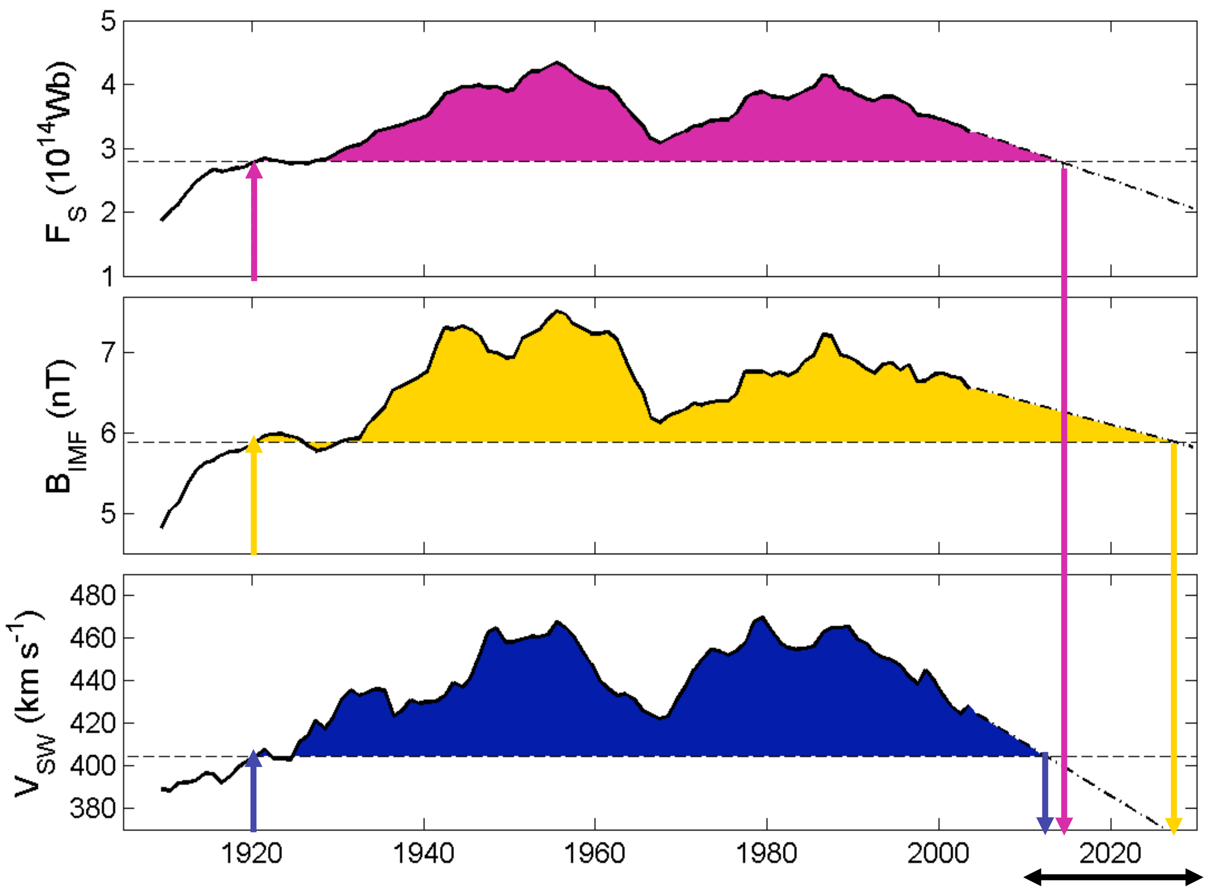
Low solar activity gives lower surface temperatures in central England
Effect much stronger in central Europe
Analysis shows a distict systemn to NAO

- **implications for the future**



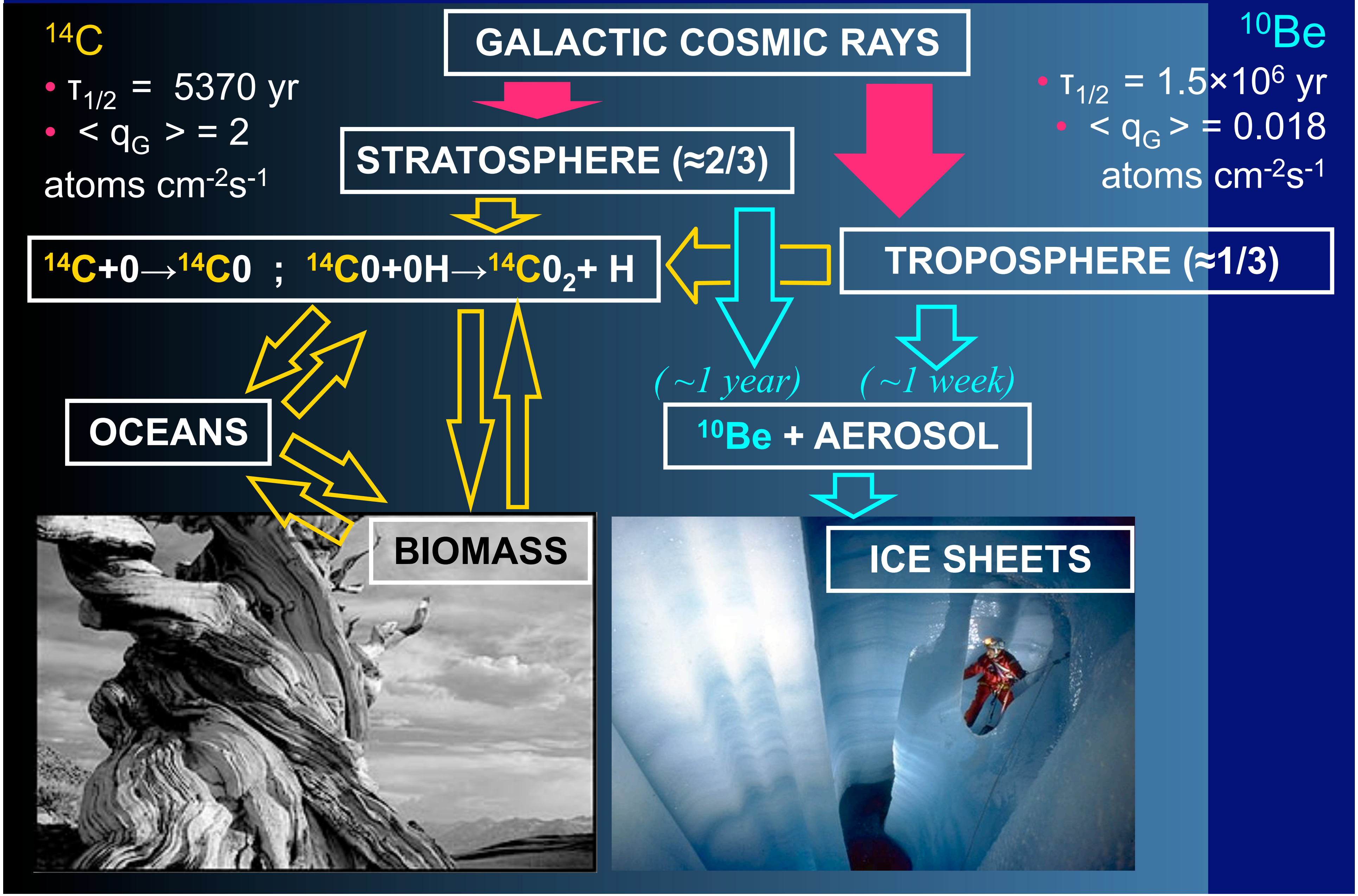
Centennial Variations: the rise and fall of the current grand maximum (GSM)

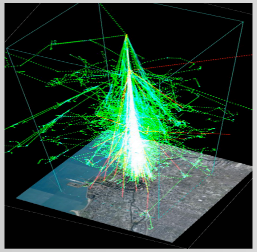
- solar cycle running means
- defining start of Grand Solar Maximum as 1920
- linear extrapolation gives end dates consistent with GSM durations



Abreu et al. (2008)

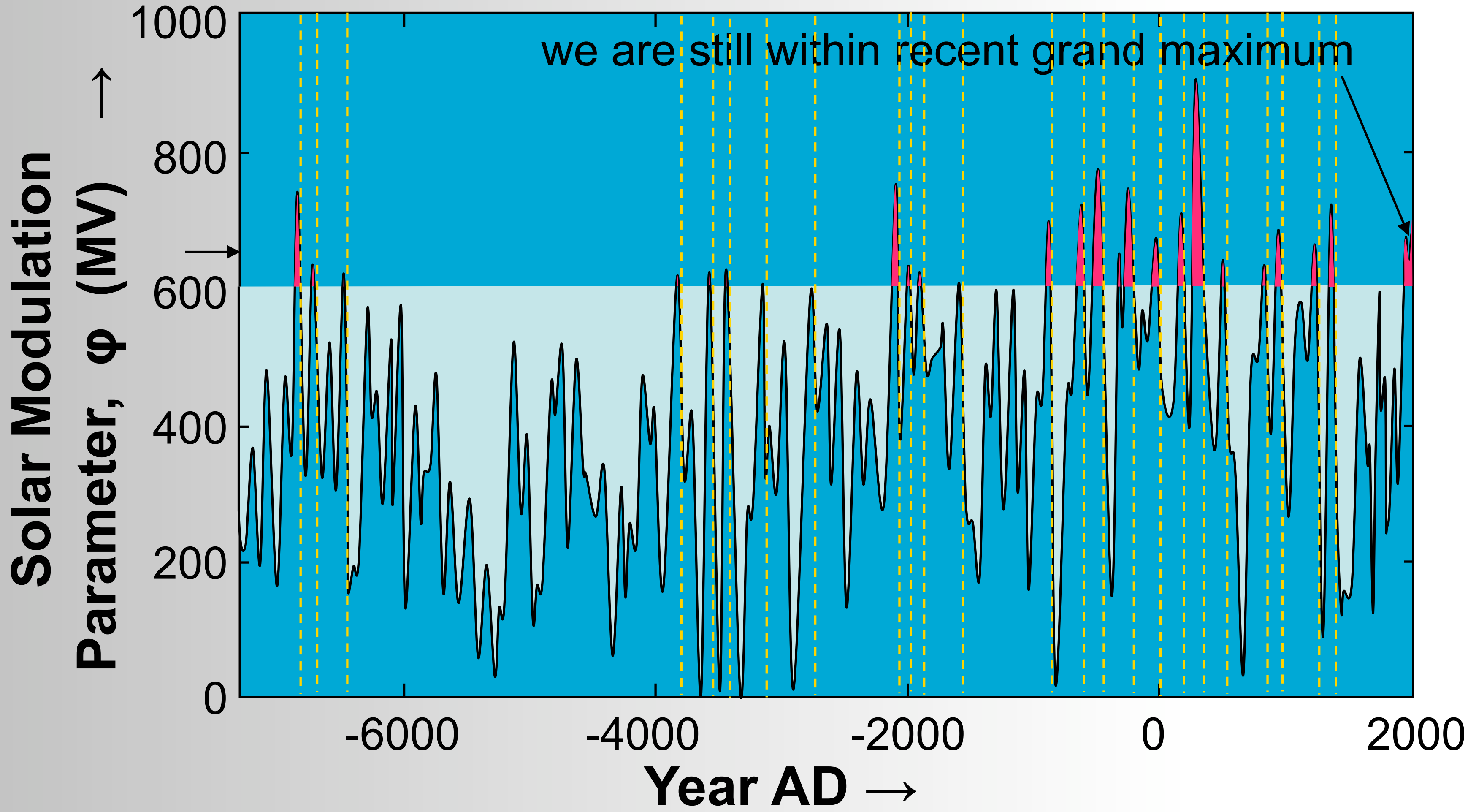
^{14}C & ^{10}Be: spallation products from O, N & Ar



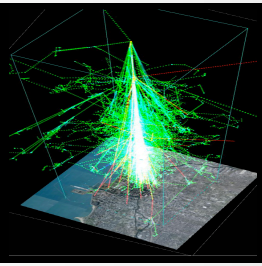


Millennial Variation

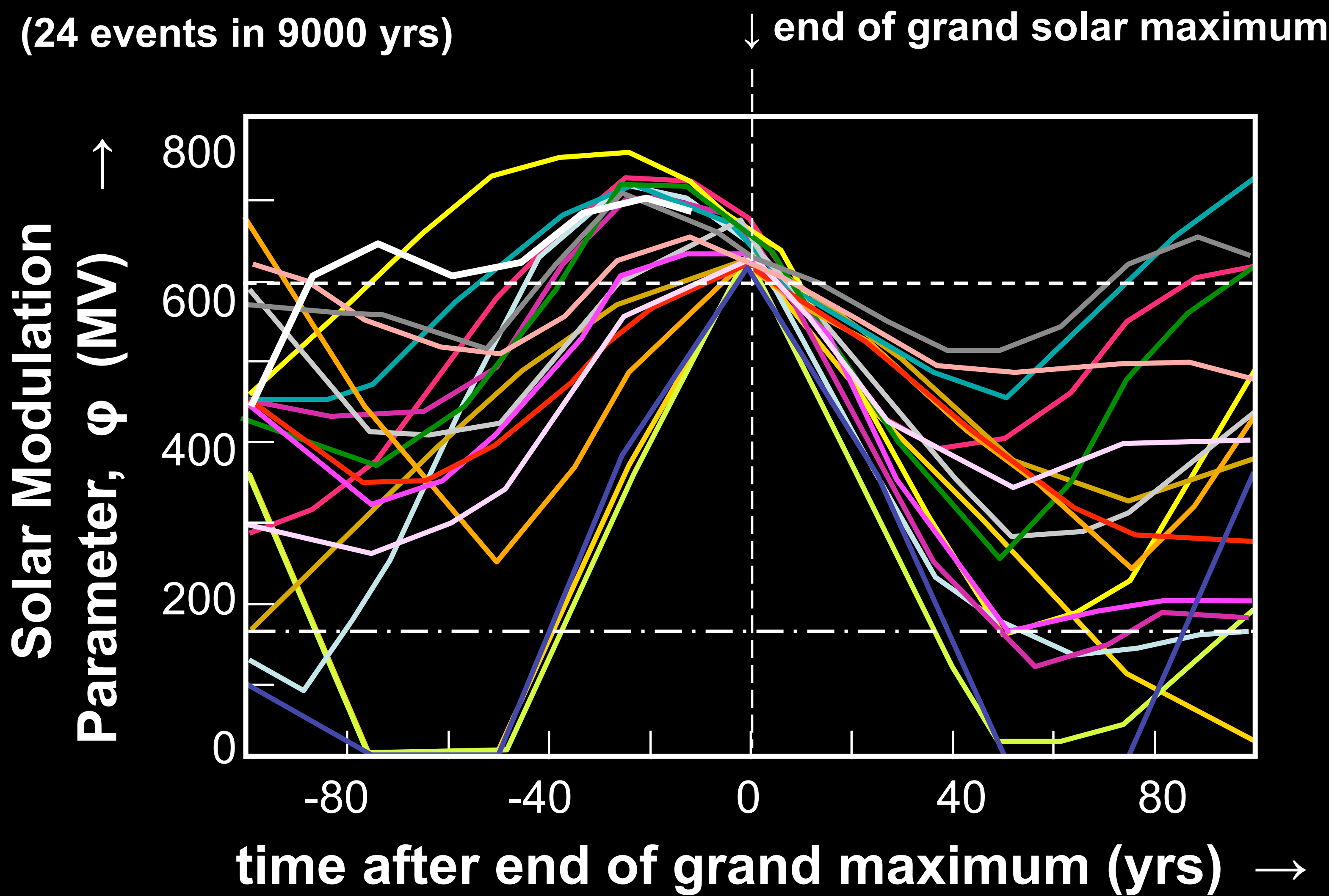
φ composite (25-year means) from cosmogenic isotopes ^{14}C & ^{10}Be by Steinhilber et al. (2008)

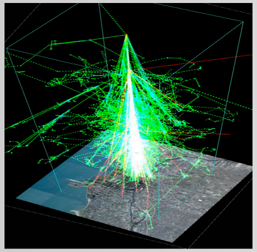


composite from Solanki et al., 2004; Vonmoos et al., 2006 & Muscheler et al., 2007

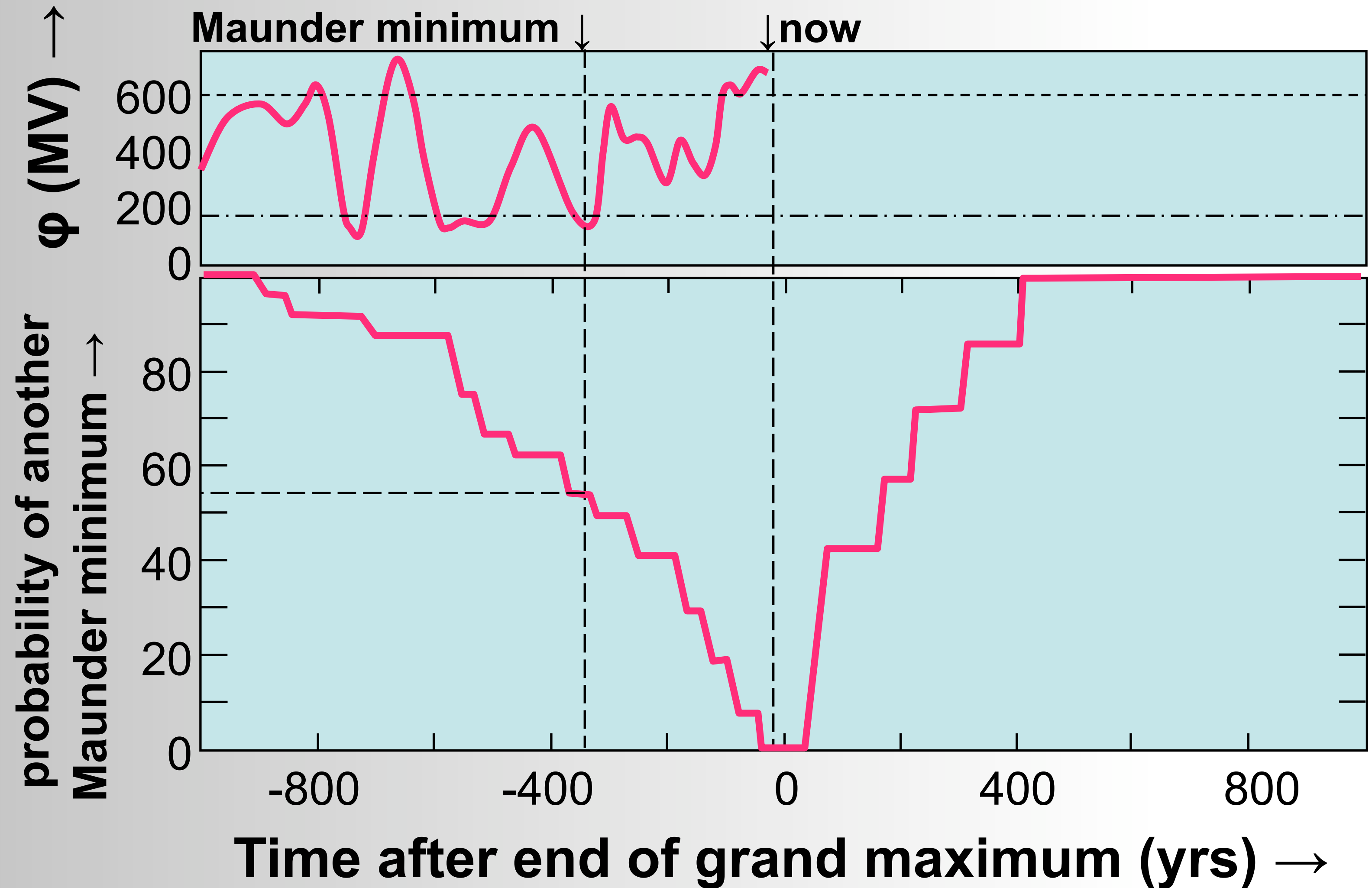


Superposed epoch study of the end of grand maxima





How Long Before the Next Maunder Minimum?




• just one conclusion .....
• the world will warm but the UK is likely to have colder winters!