Modern Grand Solar Minimum versus global warming

https://solargsm.com/solar-activity/

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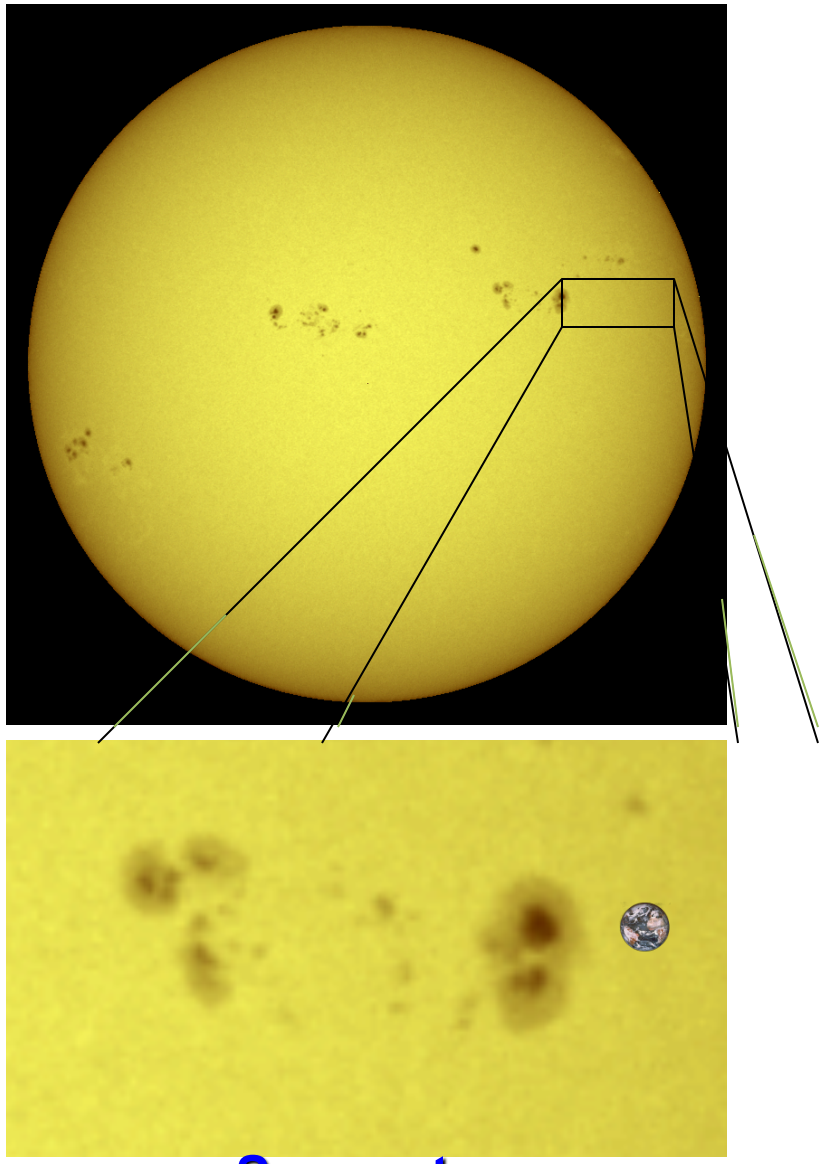
With thanks to Drs. S. Shepherd (UK, S. Zharkov (UK)

https://solargsm.com/publications/

Solar activity

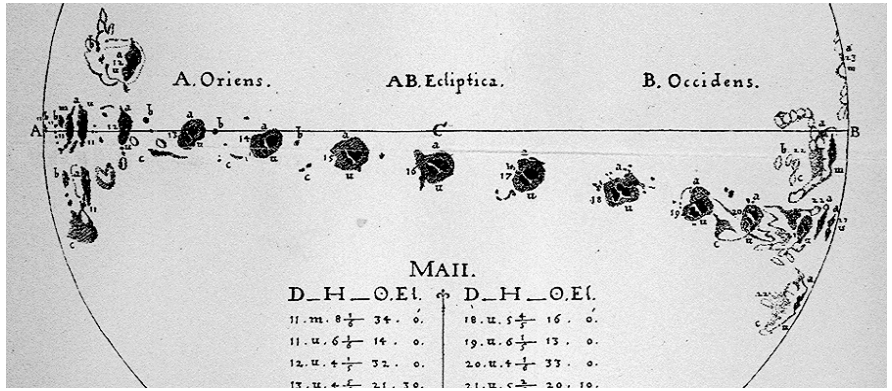


Sunspots

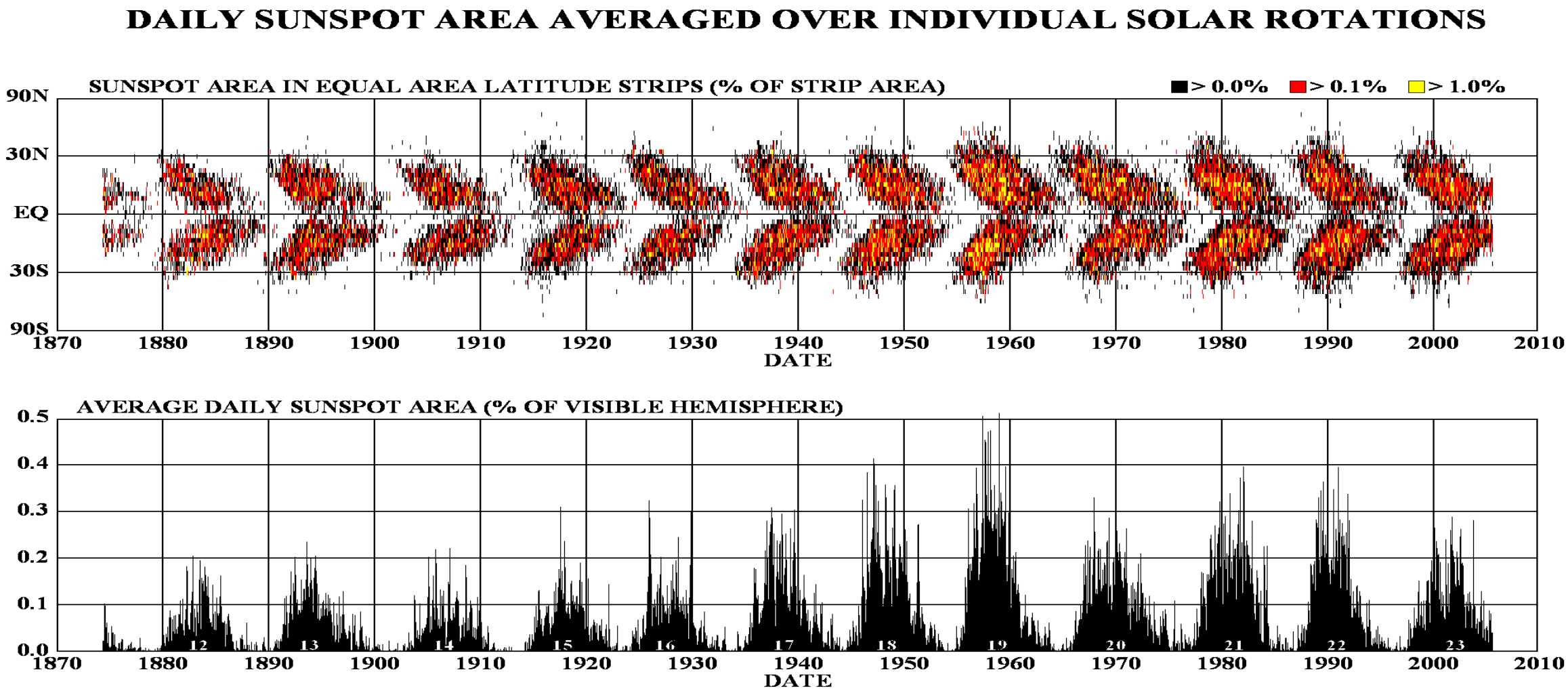
Sunspots are dark (and cooler) regions on the surface of the Sun. They have a darker inner region (the Umbra) surrounded by a lighter ring (the Penumbra).
Sunspots usually appear in groups that form over hours or days and last for days or weeks.

These early sunspot observations indicated that the Sun rotates once in about 27 days.

Solar activity index – average sunspot numbers



Current solar activity index



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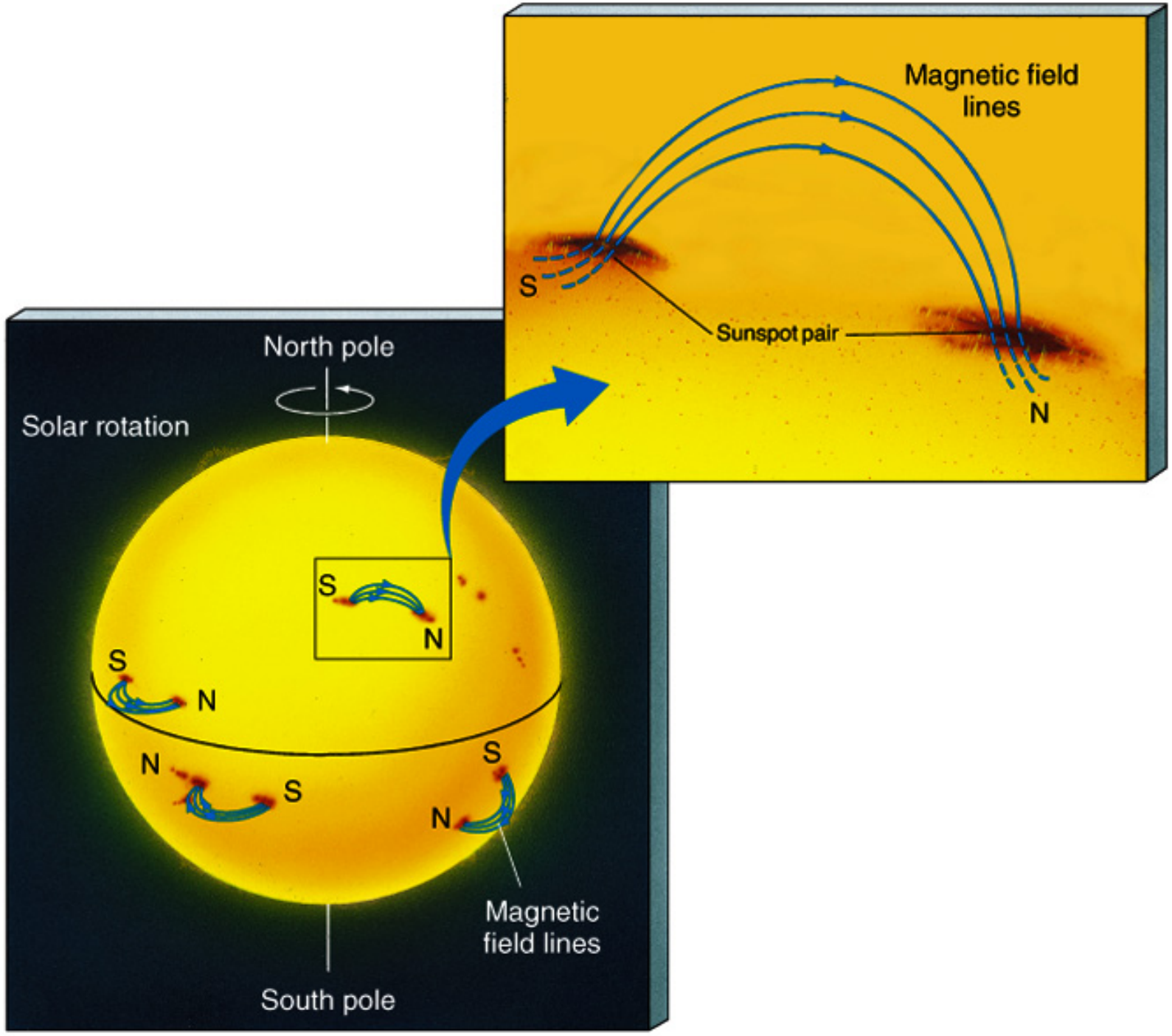
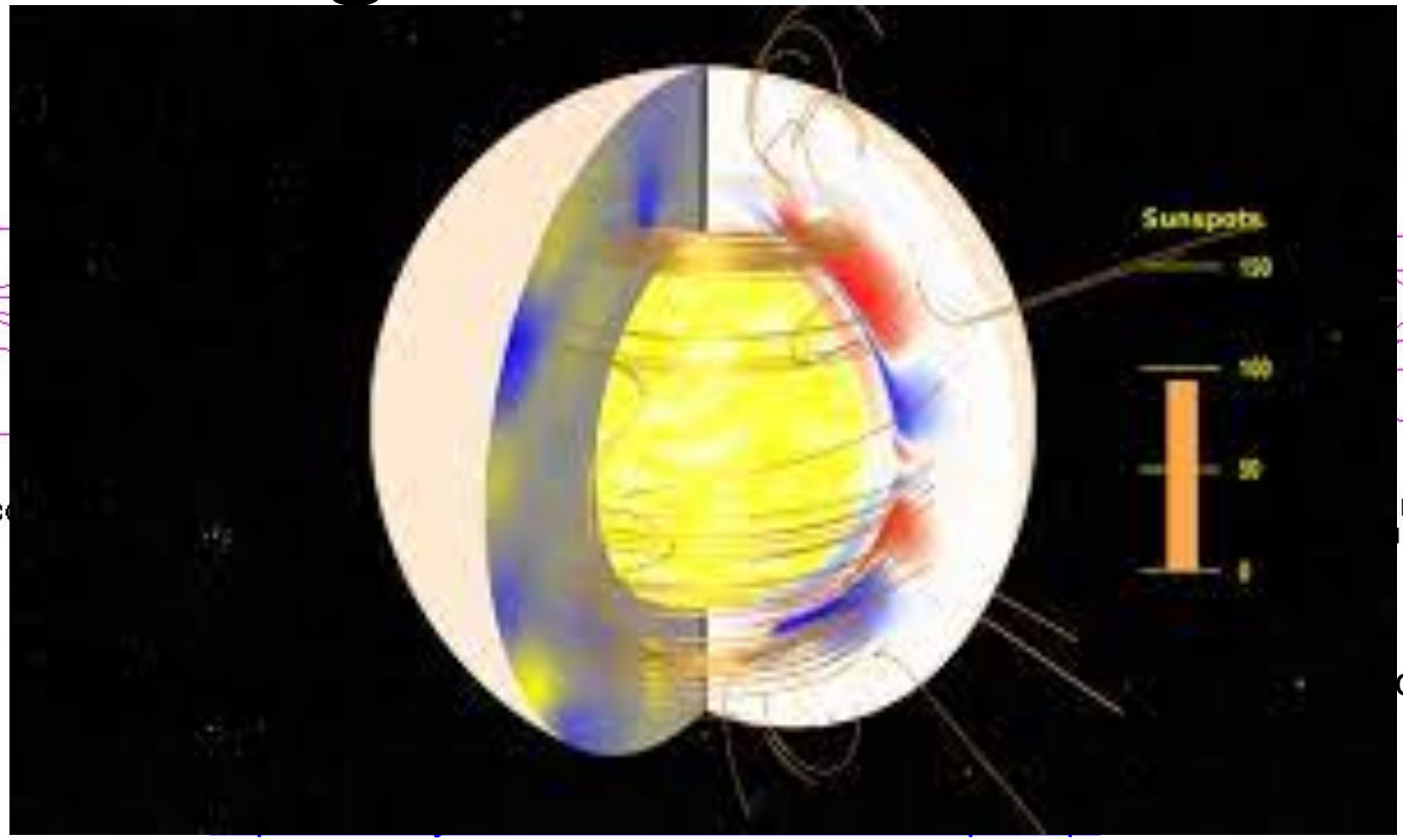

Magnetic field lines
S
Sunspot pair
N
North pole
Solar rotation
S
N
S
N
N
S
S
N
Magnetic field lines
South pole

Solar magnetic field reversal

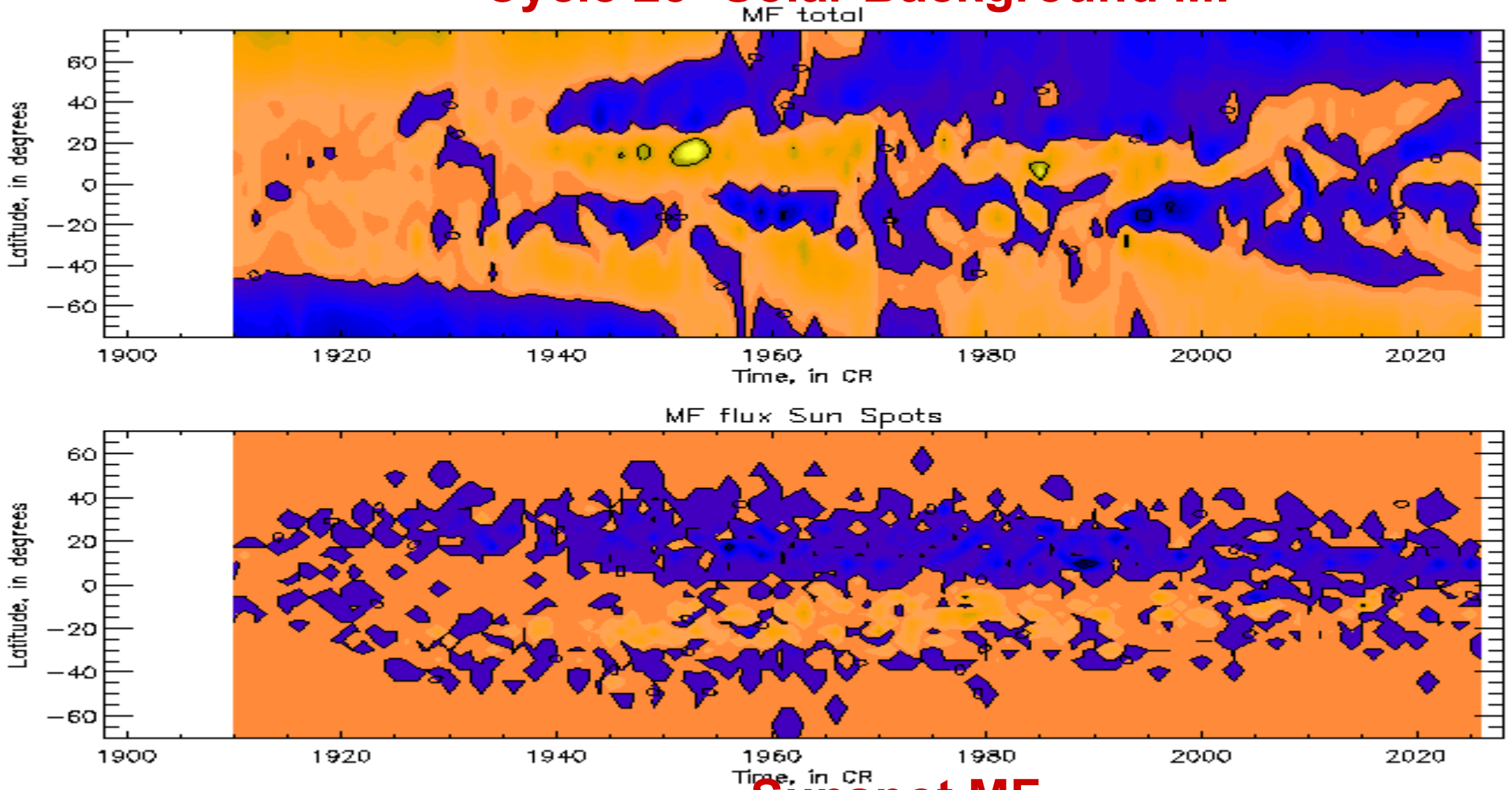


New proxy for solar activity index

SBMF (top) and sunspot MF (bottom)

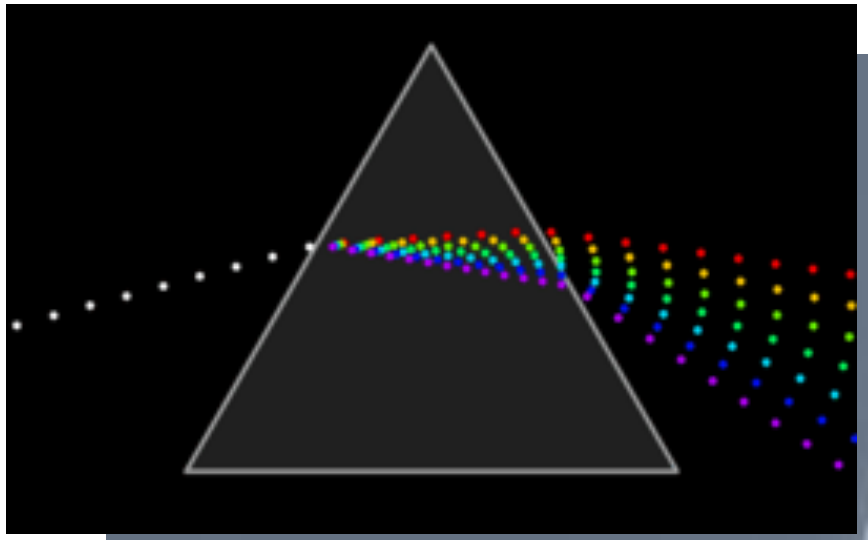
(Zharkov et al, 2008, Stix 1976)

Cycle 23 -Solar Background MF



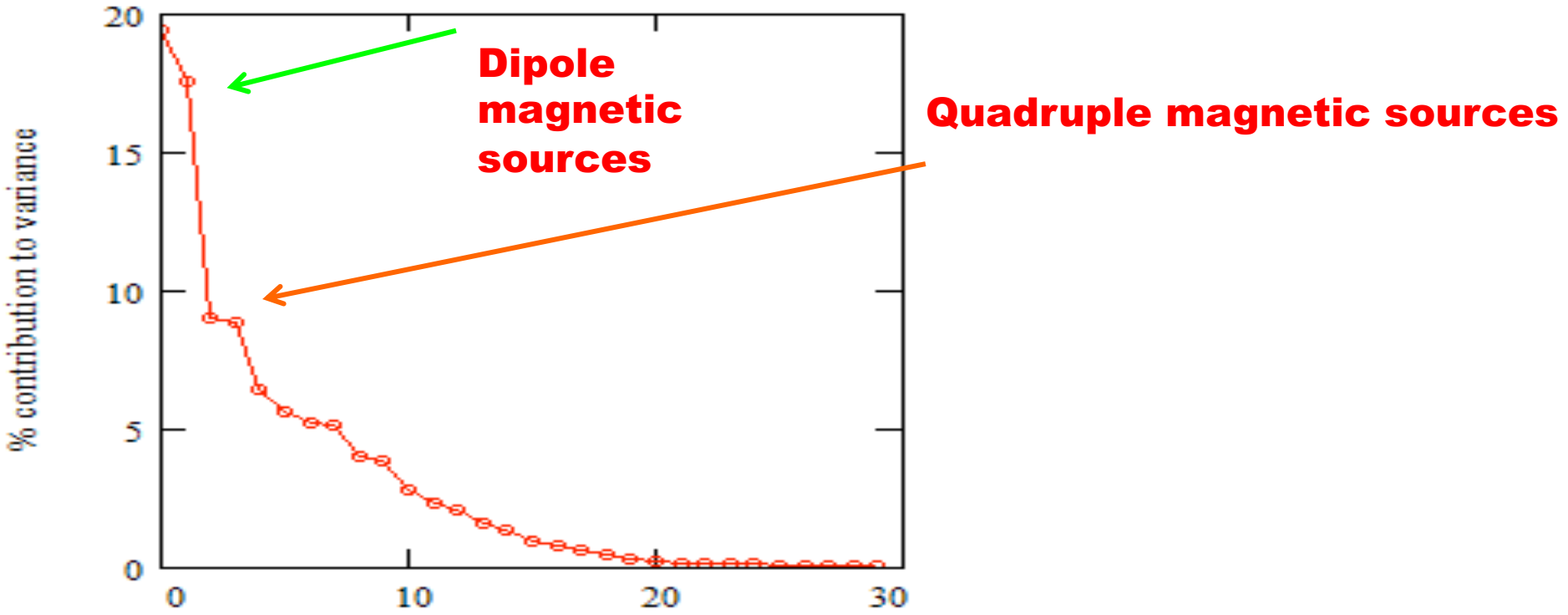
Sunspot MF

White light refraction into waves of different colors, or wavelengths

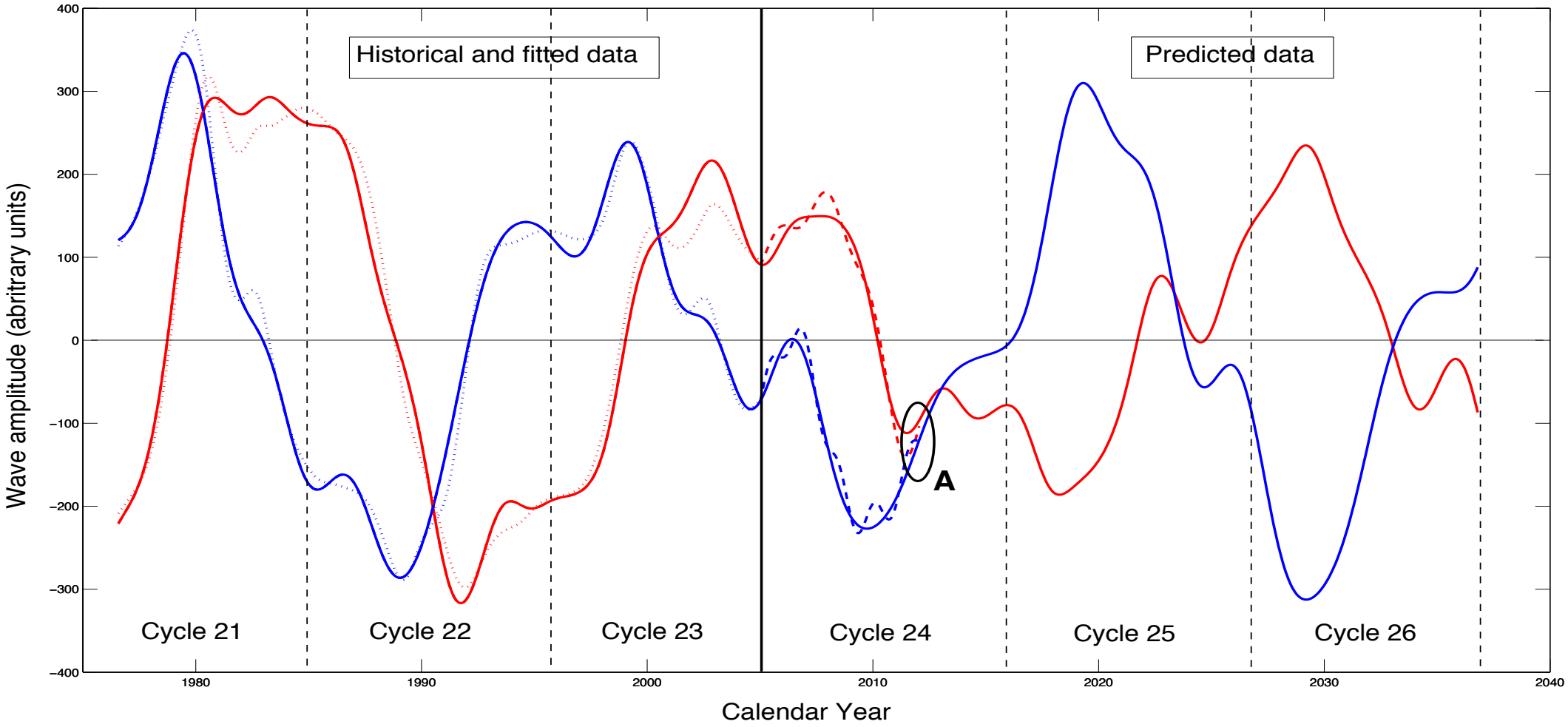


SBMF results: Scree plot (->prizm) Eigenvalues vs variances (Zharkova et al, 2012)

- 2 main eigenvalues covering 40% of variance – (67% of SDV) -
- 3 pairs (6 eigenvalues) to cover



Eigen vectors come in pairs, here are PCs



Zharkova et al, 2015 https://www.nature.com/articles/srep15689
Zharkova 2020
https://www.tandfonline.com/doi/full/10.1080/23328940.2020.1796243

Mathematical laws from PCs: Symbolic regression -Hamiltonian approach (Schmidt and Lipton, 2009, Science)

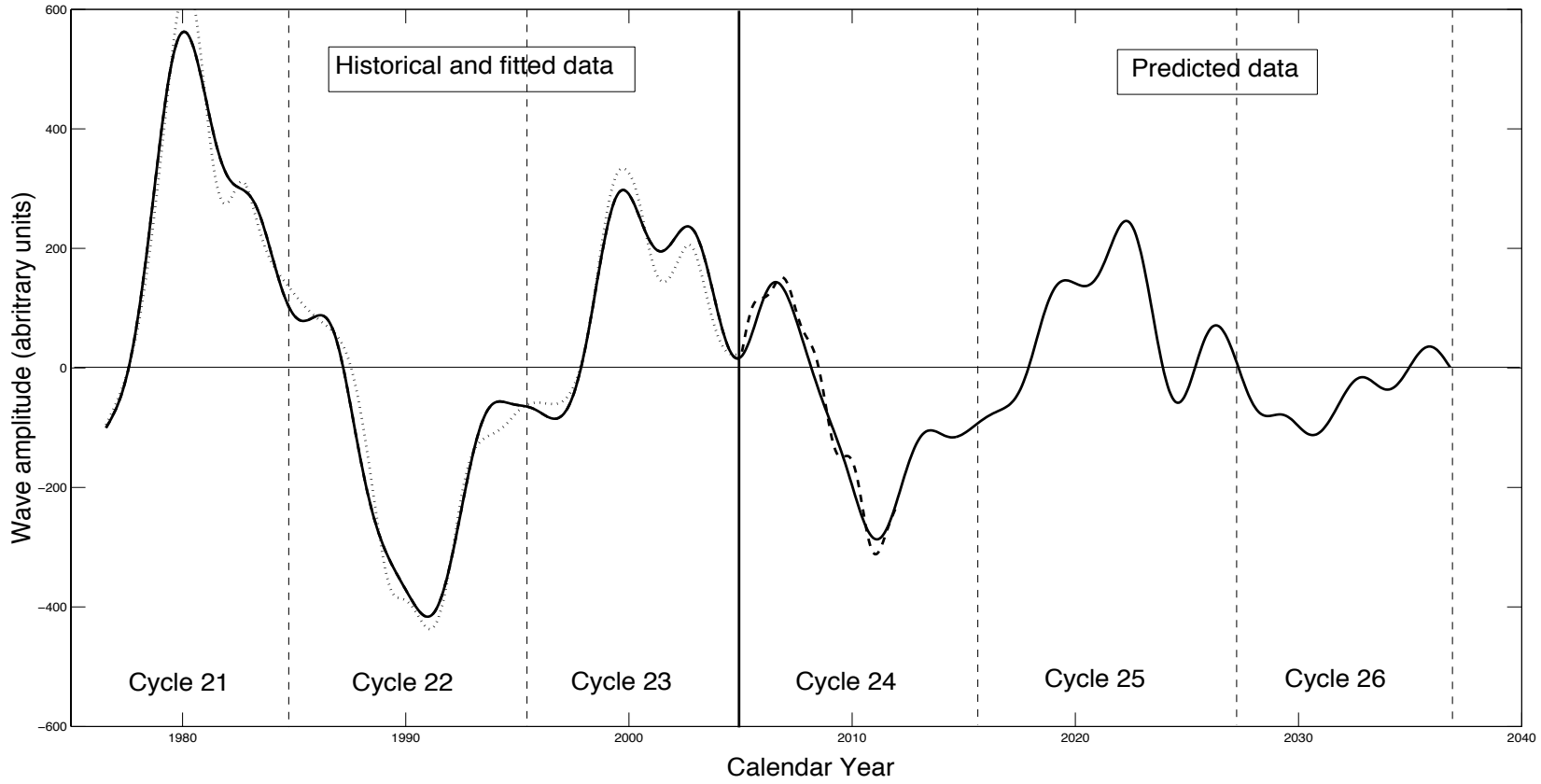
- Mathematical law for the first principal component:

$$F_1(t) = \Sigma_{k=1,..,5} A_k \cos(\omega_{k,1} t + \phi_{k,1}) \cos(B_{k,1} \cos(\omega_{k,1} t + \phi_{k,1})$$

- Mathematical law for the second principal component:

$$F_2(t) = \Sigma_{k=1,..,5} A_k \cos(\omega_{k,2} t + \phi_{k,2}) \cos(B_{k,2} \cos(\omega_{k,2} t + \phi_{k,2})$$

Summary curve of 2 PCs



Zharkova et al, 2015 https://www.nature.com/articles/srep15689
Zharkova 2020
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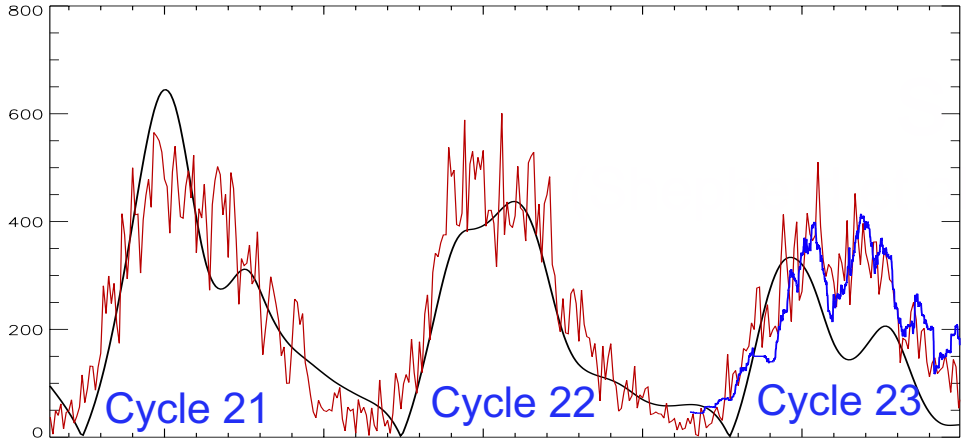
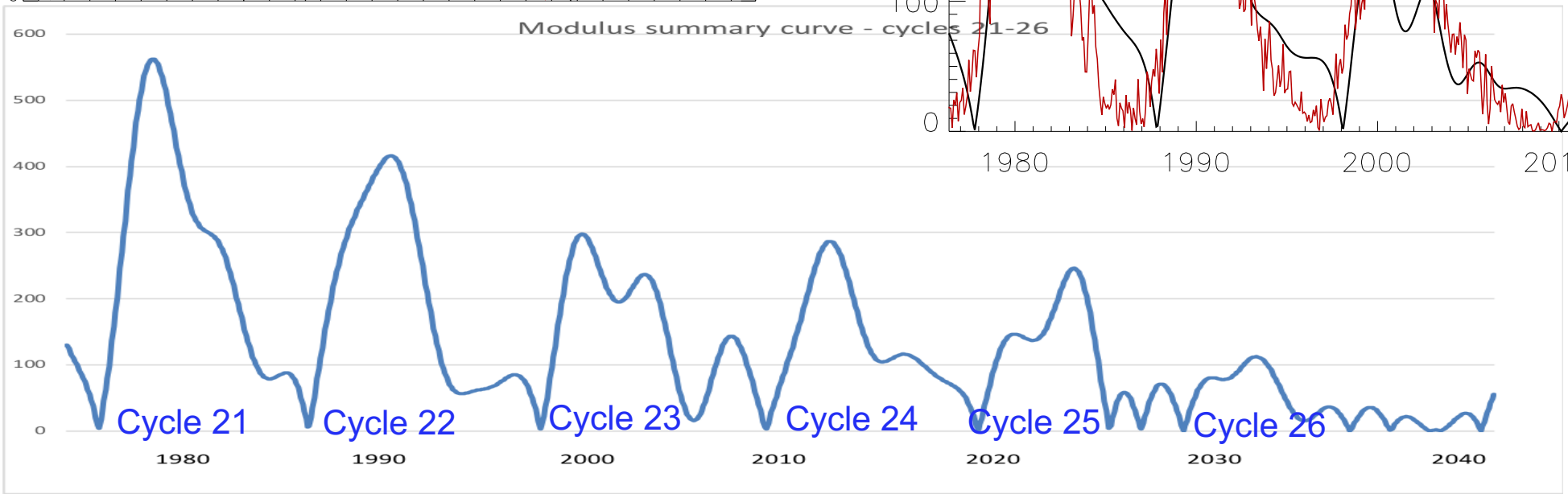
Modulus summary curve

(Zharkova et al, 2015, SciRep; 2020, Temp.,



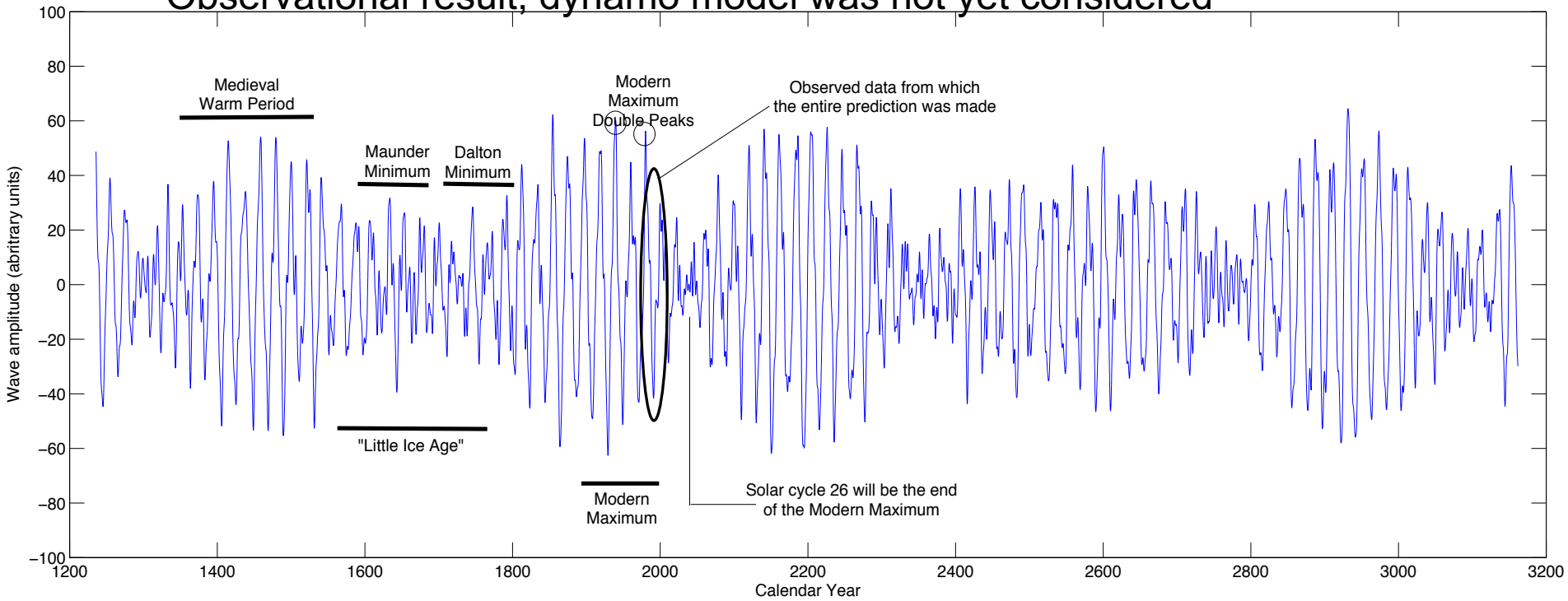


Predicted solar activity (Zharkova et al, 2015, SR)

https://www.nature.com/articles/srep15689

https://nam2015.org/index.php/press-releases/64-irregular-heartbeat-of-the-sun-driven-by-double-dynamo

Observational result, dynamo model was not yet considered



Discovery of grand solar cycles :350-400 years

In addition to 11 year cycles

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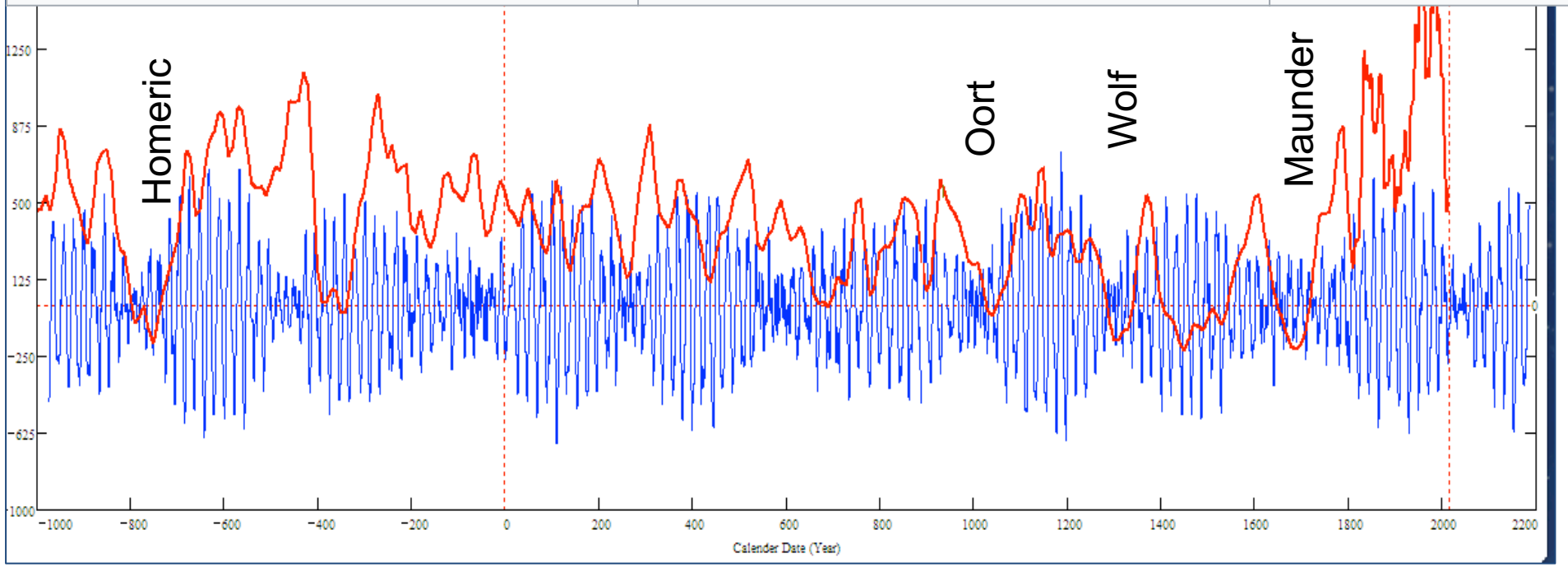
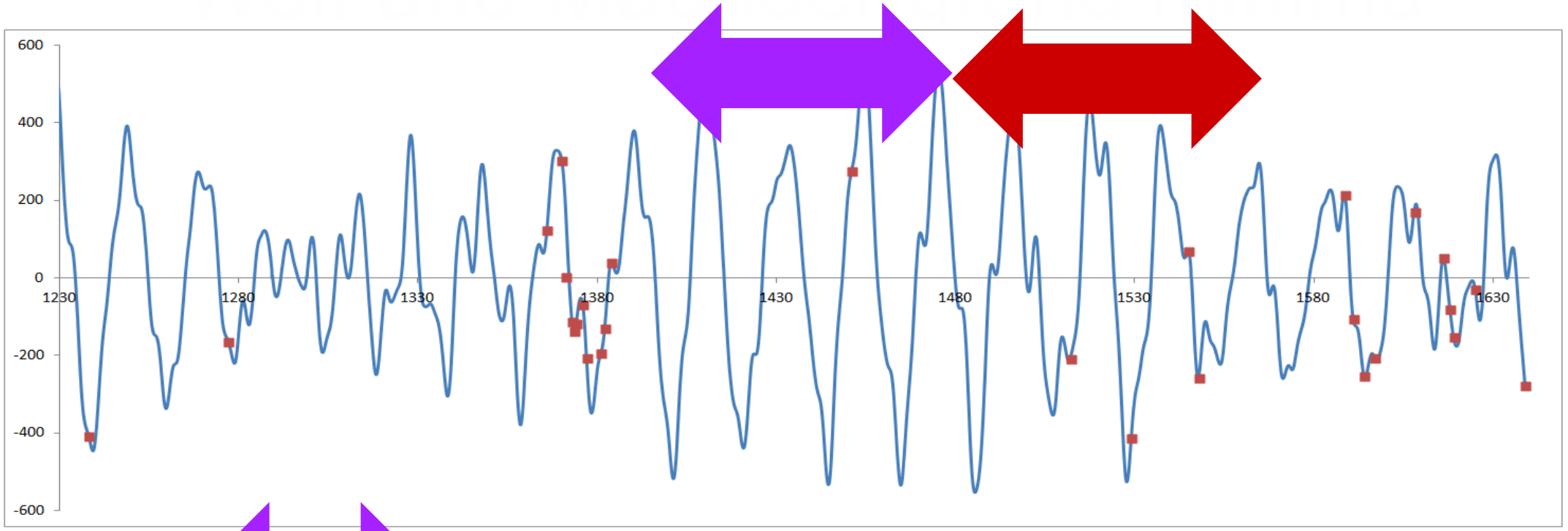
ver

Homeric minimum[13]	750 BCE	550 BCE
Oort minimum	1040 CE	1080 CE
Medieval maximum	1100	1250
Wolf minimum	1280	1350
Spörer Minimum	1450	1550
Maunder Minimum	1645	1715
Dalton Minimum	1790	1820



Periods – grand cycle: 350-400 years and super-grand cycle :2000-2100 years

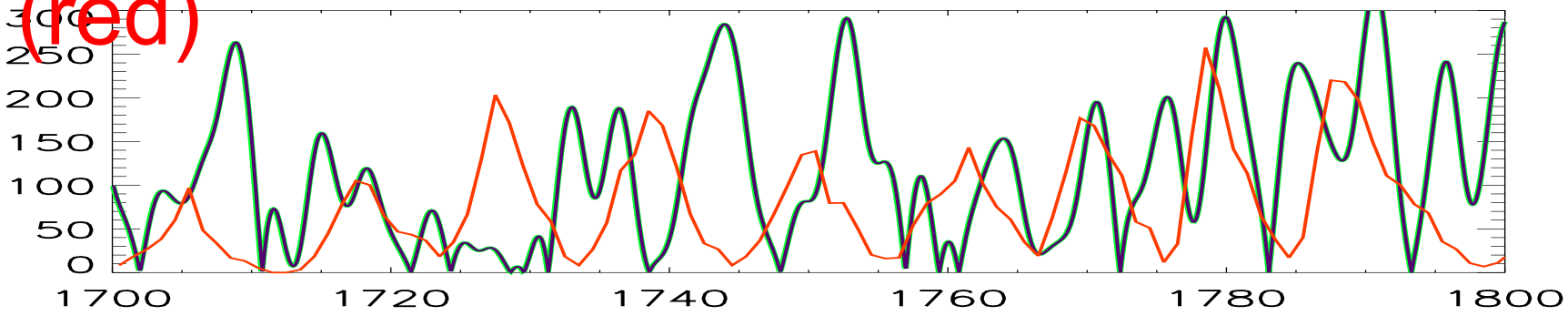
Verification of summary curve with large s/s for grand cycle prior MM (Zharkova etal, 2017, 2018)

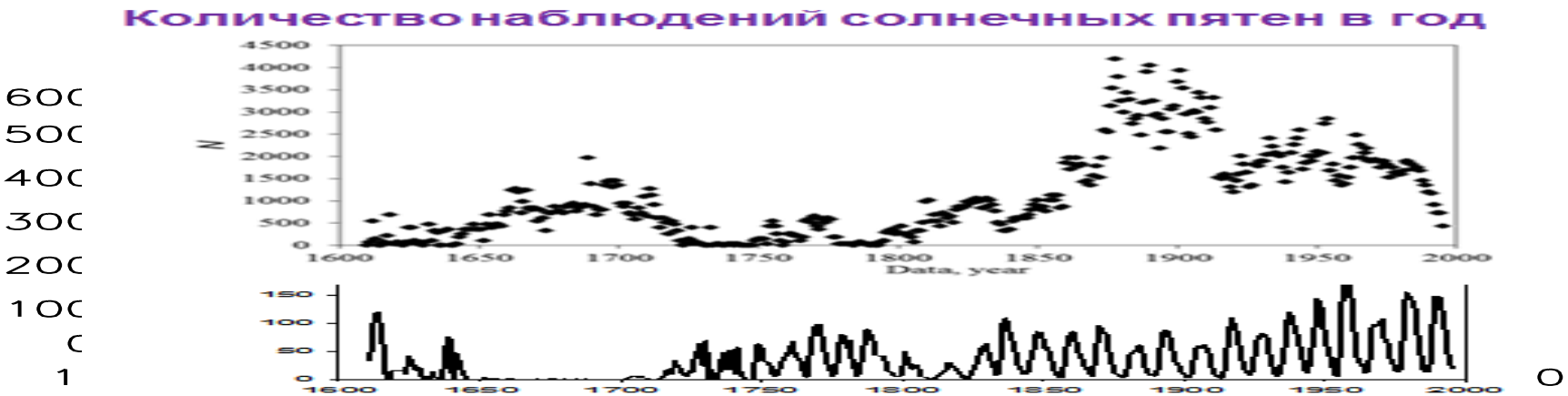


Severe diseases in China, no observers

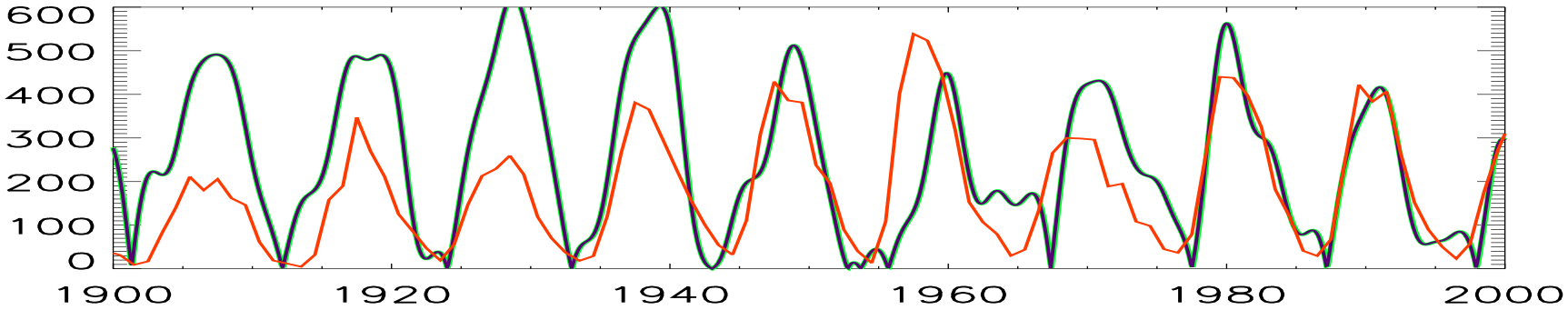
New dynasty in China, Great Wall project

Verification of summary curve (green) with sunspot index (red)





Numbers of sunspot observations showing poor data in 18 century



Disagreement in 1720-1760 can be caused by a lack of observations

While a disagreement for 3 cycles in 19 century can be Related to the change of calendar to Gregorian by different countries in different years

Under investigation!

northumbria UNIVERSITY NEWCASTLE

Summary: new proxy of solar activity

- New proxy of SA -Principal components of SBMF
- PCs are paired – double dynamo waves
- The strongest 2 PCs cover more than 40% of variance or 67% of SD
- Prediction of the solar activity on a millennium scale shows grand solar cycle with a period of 350-400 years
- Next grand solar minimum is underway in 2020-2053
- Prediction for 3000-10000 years backwards fits the main grand minima and warming periods

https://solargsm.com/solar-activity/

2 layer dynamo model explaining some PCA features

Zharkova et al, 2015, Popova et al, 2013

We included the meridional flows in each layer:

$$\frac{\partial B}{\partial t} + \frac{\partial (V B)}{\partial \theta} = \beta \Delta B, \qquad \frac{\partial A}{\partial t} + V \frac{\partial A}{\partial \theta} = \alpha B + \beta \Delta A, \tag{2.3}$$

$$\frac{\partial b}{\partial t} + \frac{\partial (v b)}{\partial \theta} = D \cos\theta \frac{\partial a}{\partial \theta} + \Delta b, \qquad \frac{\partial a}{\partial t} + v \frac{\partial a}{\partial \theta} = \Delta a\,, \tag{2.4}$$

here $V(\theta), v(\theta)$ are the meridional flows in the respective layers.

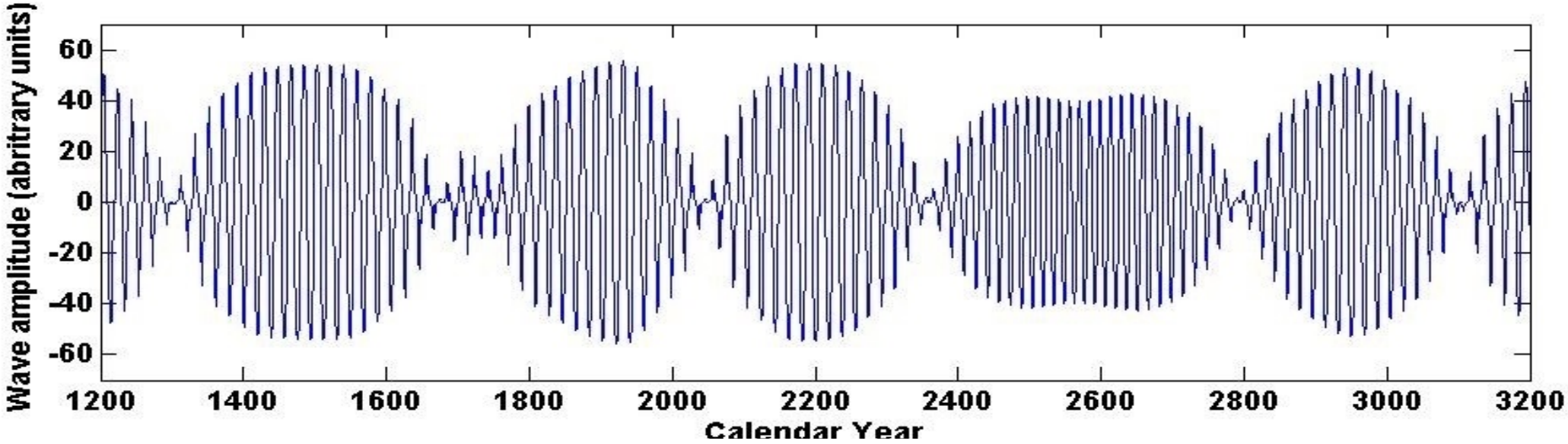
Following Parker we prescribe $r = 0$ for the radial boundary between two layers and use boundary conditions:

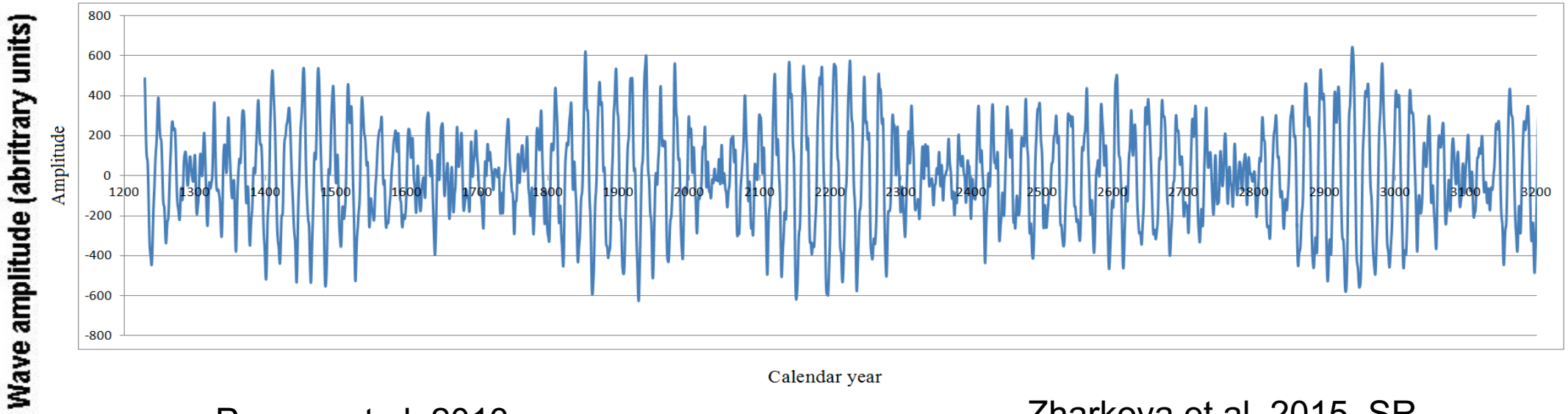
$$b = B, \qquad a = A, \qquad \frac{\partial b}{\partial r} = \beta \frac{\partial B}{\partial r}, \qquad \frac{\partial a}{\partial r} = \frac{\partial A}{\partial r}. \tag{2.5}$$

In view of the symmetry conditions $\alpha(-\theta) = -\alpha(\theta)$, $V(-\theta) = -V(\theta)$ the above system of equations can be considered in only one (e.g., the northern) hemisphere using anti-symmetry (dipolar symmetry) or symmetry (quadrupolar symmetry) conditions at the equator.

We obtained Hamilton-Jacobi equation for eqs. (2.3) and (2.4) by a method similar to the method described in Popova et al. (2010).

Dynamo model (top) and summary curve (bottom

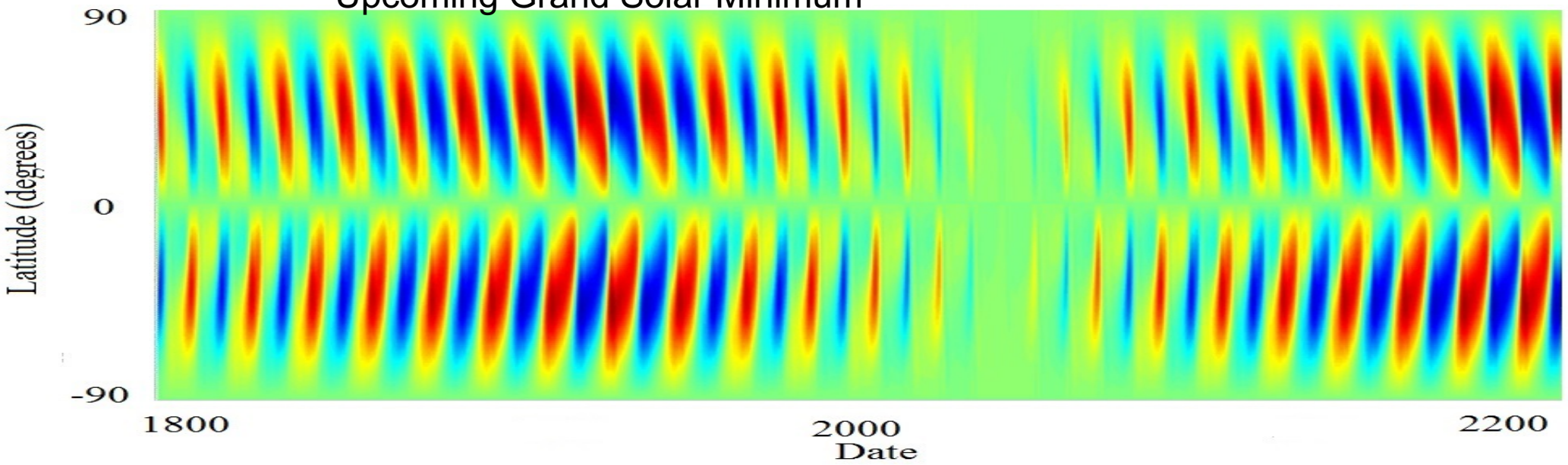




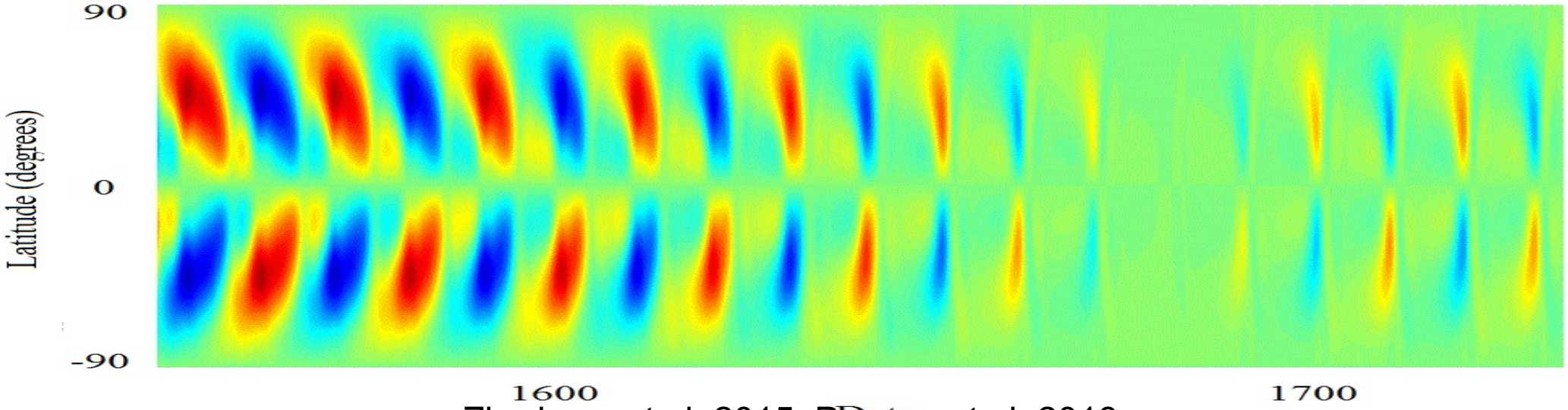
Popova et al, 2013

Zharkova et al, 2015, SR
https://www.nature.com/articles/srep15689

Upcoming Grand Solar Minimum



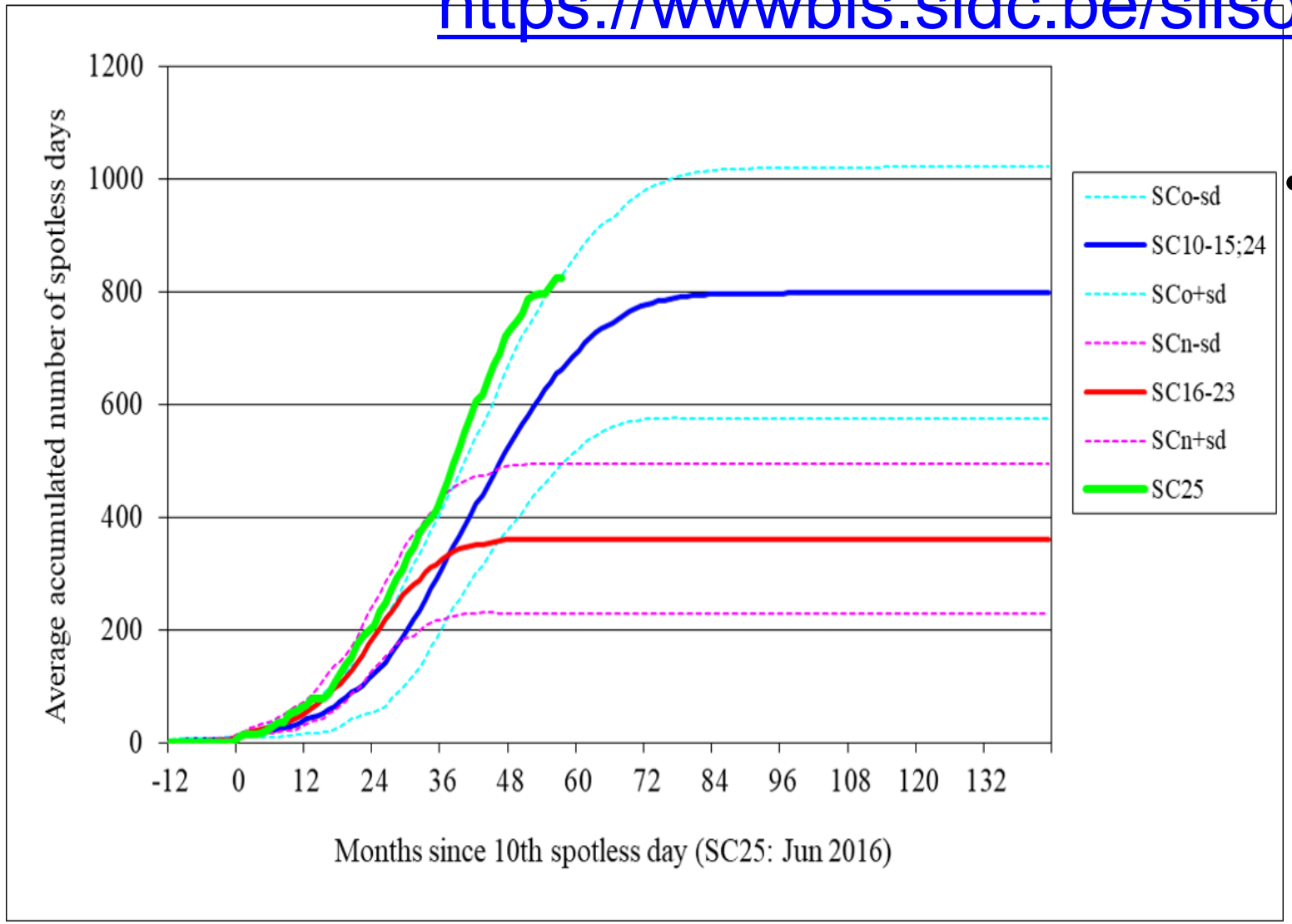
Maunder Grand Solar Minimum



Zharkova et al, 2015, Popova et al, 2018,
Zharkova et al, 2021

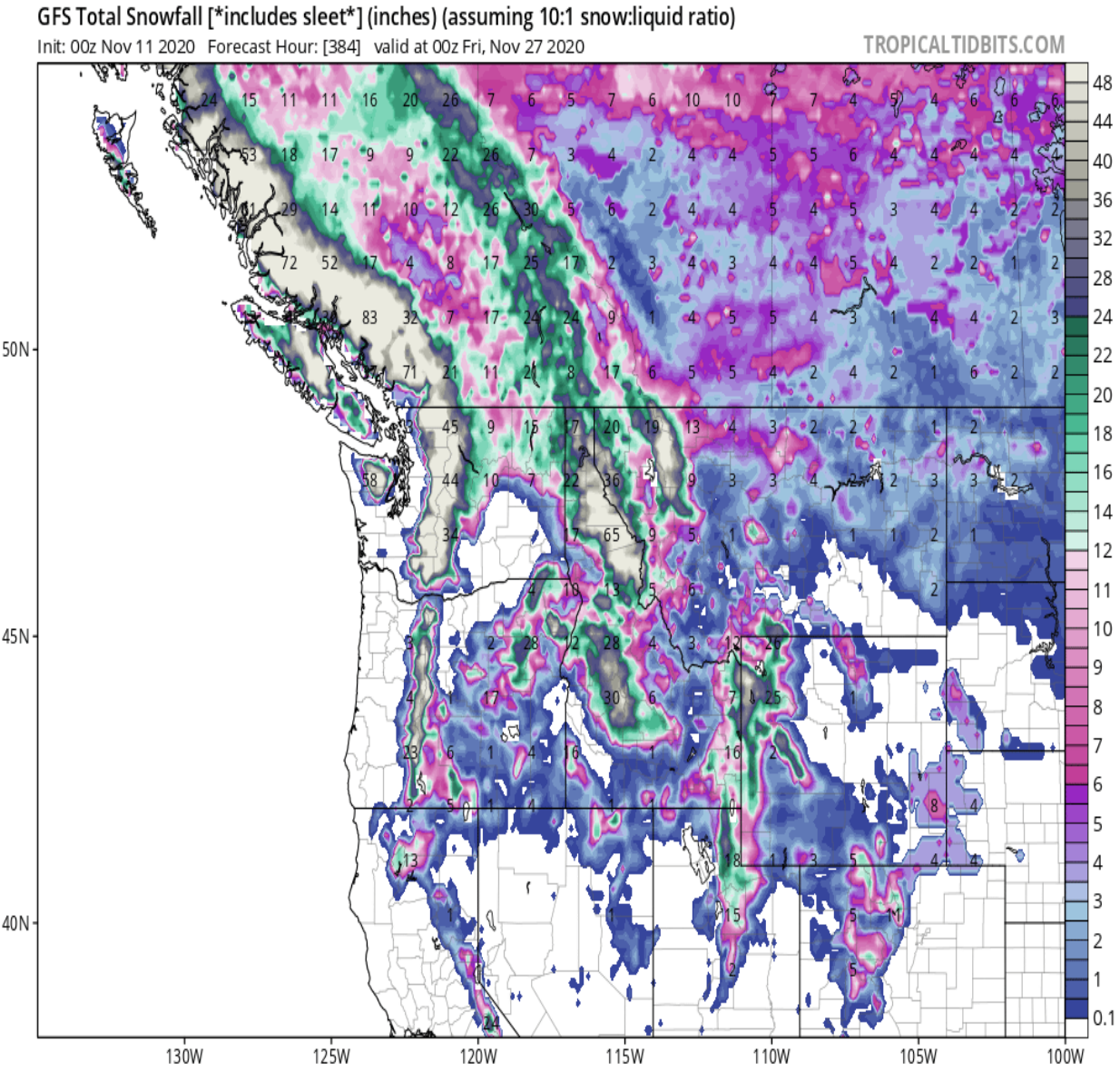
Grand solar minimum arrived

https://wwwbis.sidc.be/silso/spotless



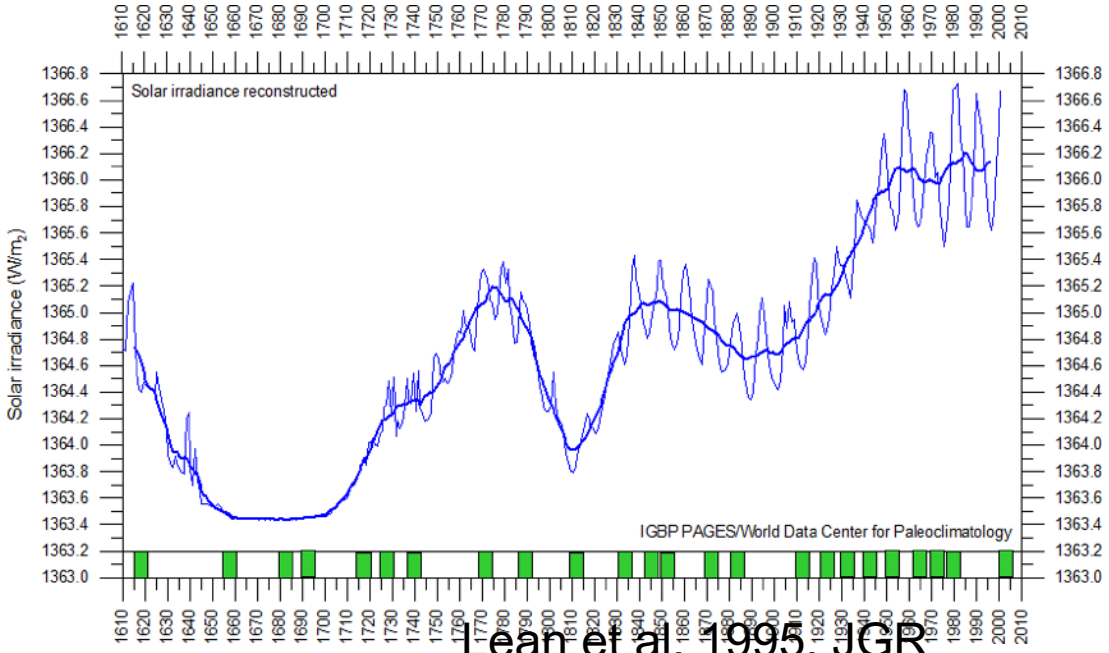
- Cycle 25 (green line) shows a steeper growth of the number of spotless days than any other cycles including the ones during Dalton min (cycles 15 and 24) (blue line)

Modern GSM is progressing –November 2020

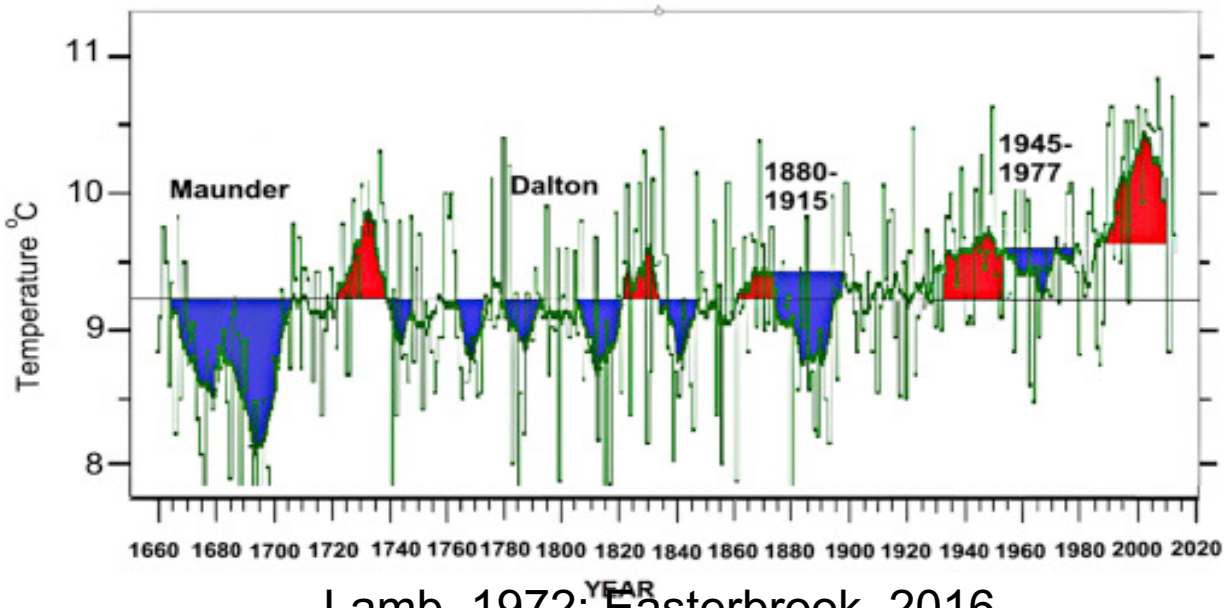


- UNPRECEDENTED WINTER STORM HITS BRITISH COLUMBIA
- Both NOAA and NASA appear to agree, *if you read between the lines*, with NOAA saying we're entering a 'full-blown' Grand Solar Minimum in the late-2020s
- NASA seeing this upcoming solar cycle *(25)* as "the weakest of the past 200 years", with the agency correlating previous solar shutdowns to prolonged periods of global cooling here.

Solar irradiance and terrestrial temperature during MM



Lean et al, 1995, JGR



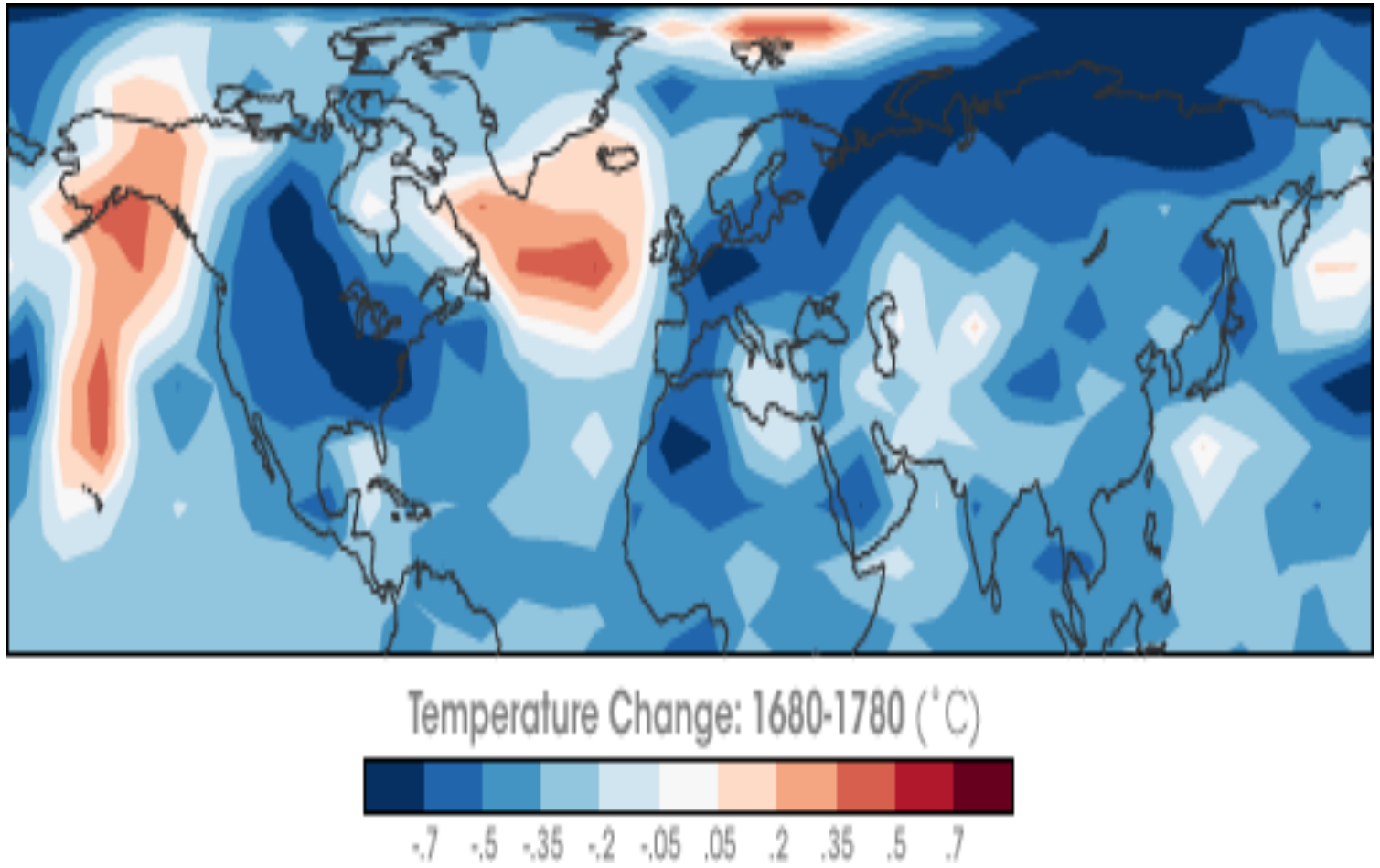
Lamb, 1972; Easterbrook, 2016

Authors	S, Maunder minimum, W/m²	S 1990-2000, W/m²	ΔS from MM, %
Lean et. Al., 1995	1363	1366	0.22
Steinhilber et al, 2012	1364	1366	0.22
Shirley et al., 1990	---	1370	0.51
Wolff and Hickey, 1987	---	1371	0.51
Lee et al., 1995	---	1372	0.51

After the TSI data were re-normalized the old data are hardly usable

Temperature restoration during/after MM

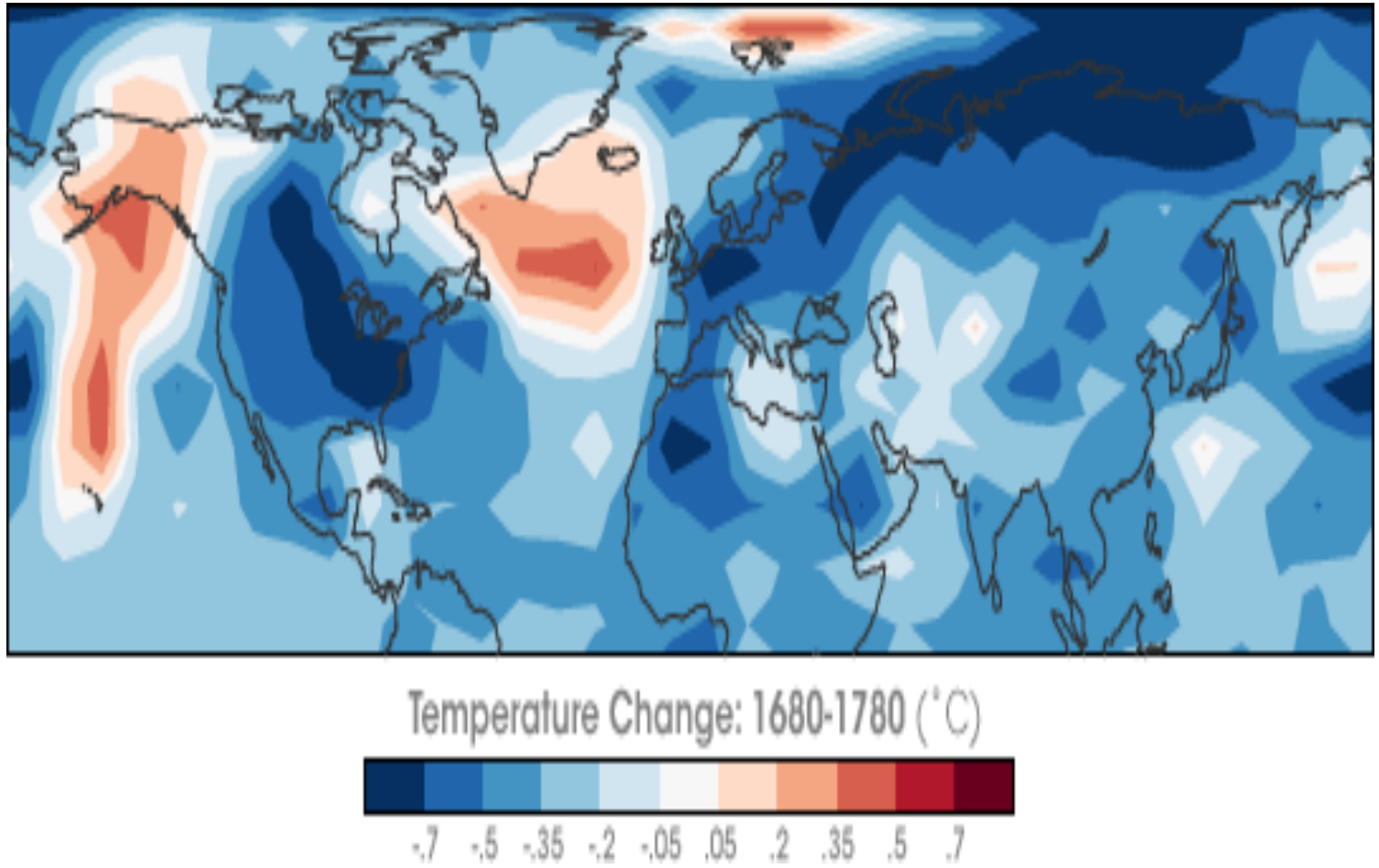
(Shindell et al., 2001, Science)



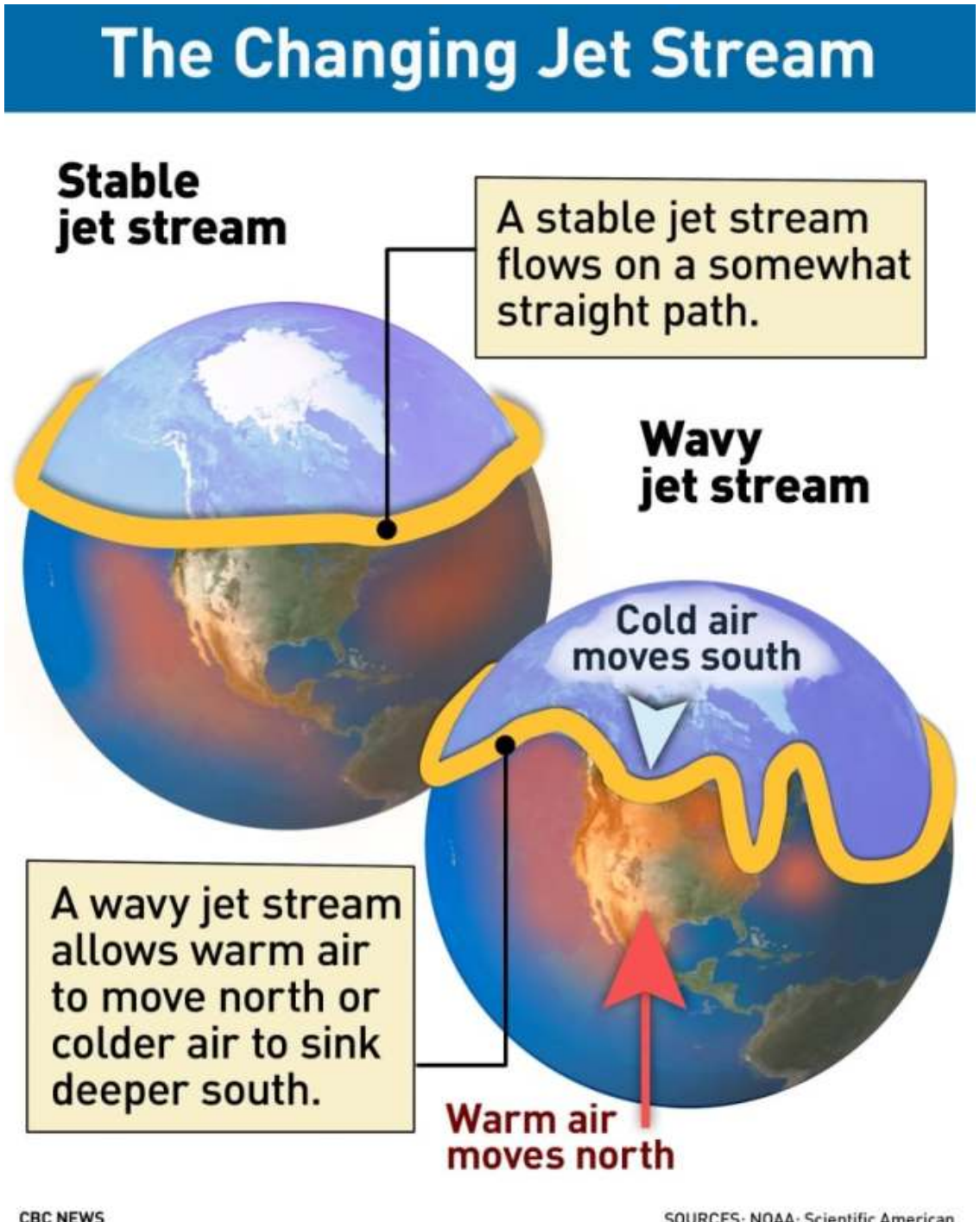
- The surface temperature of the Earth was reduced all over the Globe
- Europe and North America went into a deep freeze
- Alpine glaciers extended over valley farmland
- Sea ice crept south from the Arctic
- Dunab and Thames rivers & canals in the Netherlands froze regularly

Temperature restoration during MM

(Shindell et al., 2001, Science)



- the drop in the temperature was related to dropped abundances of ozone created by solar ultra-violate light in the stratosphere, the layer of the atmosphere located between 10 and 50 kilometers from the Earth's surface



- Less ozone affected planetary atmosphere waves
- They, in turn, caused the giant wiggles in the jet stream as shown in picture on the left
- It kicked the North Atlantic Oscillation (NAO)—the balance between a permanent low-pressure system near Greenland and a permanent high-pressure system to its south—into a negative phase
- that led to Europe to remain unusually cold during the MM

Shindell et al., 2001

Modern Grand Solar Minimum 2020-2053

Snow in Carpathian mountains

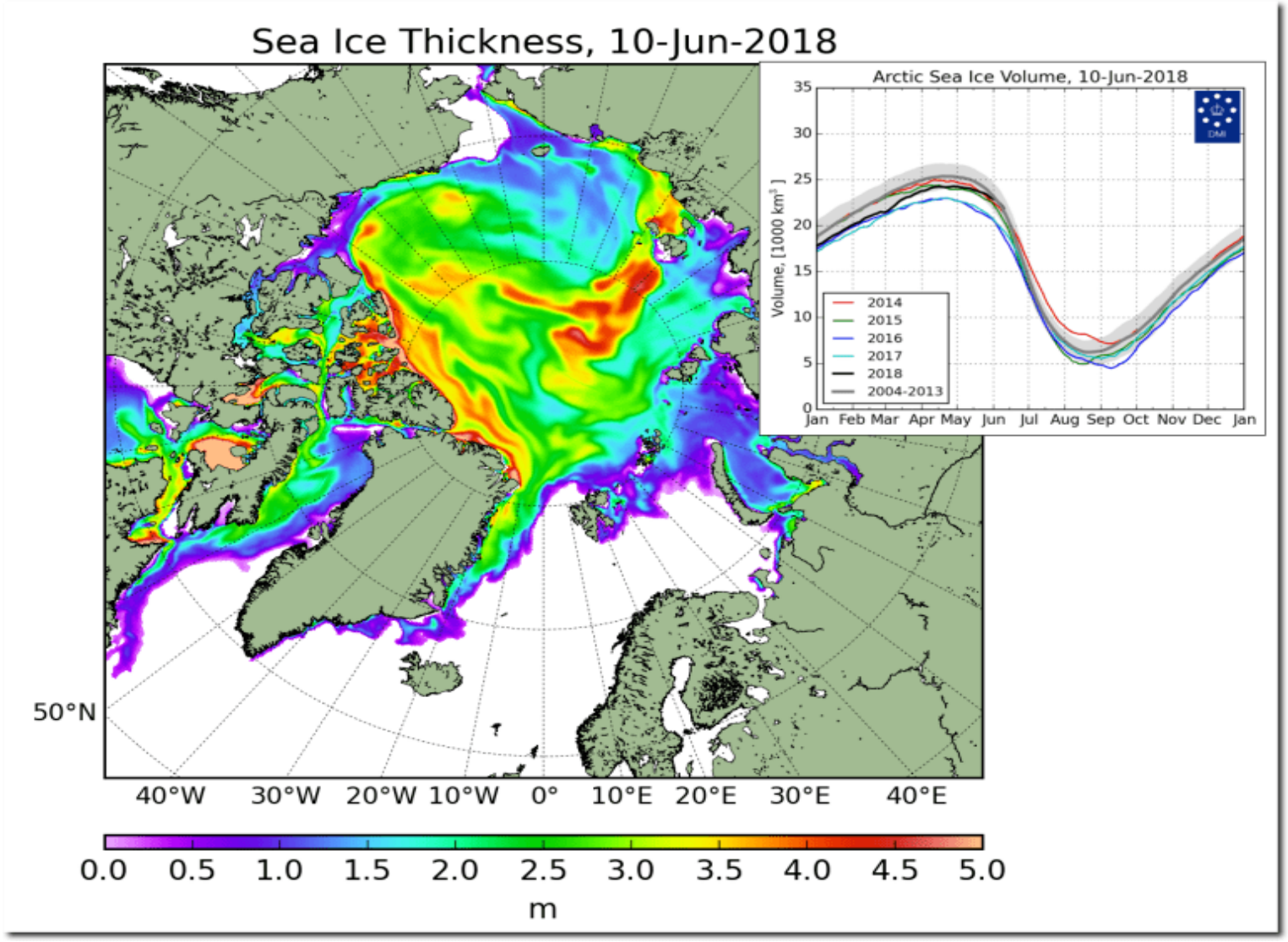
7, 14 July'19 July –Ukraine, 12 July 2019, Romania

- January 2020 snow and frost - 2C was recorded in Amman, Arabia, first in 150 years
- Early snow in Canada in September' 20
- Summer snow in south of Australia

Snow in Africa's desert 8 December 2020

https://twitter.com/GerryAMcG/status/1336420778582138886

Modern GSM: Sea ice thickness increase in 2018-2020



- Contrary to prediction of JAMES HANSEN, 1989: “NEW YORK CITY’S WEST SIDE HIGHWAY WILL BE UNDERWATER BY 2009”
- Arctic sea ice thickness grown significantly in 2018 and continues to grow
- Coldest winter 2021 in Antarctic

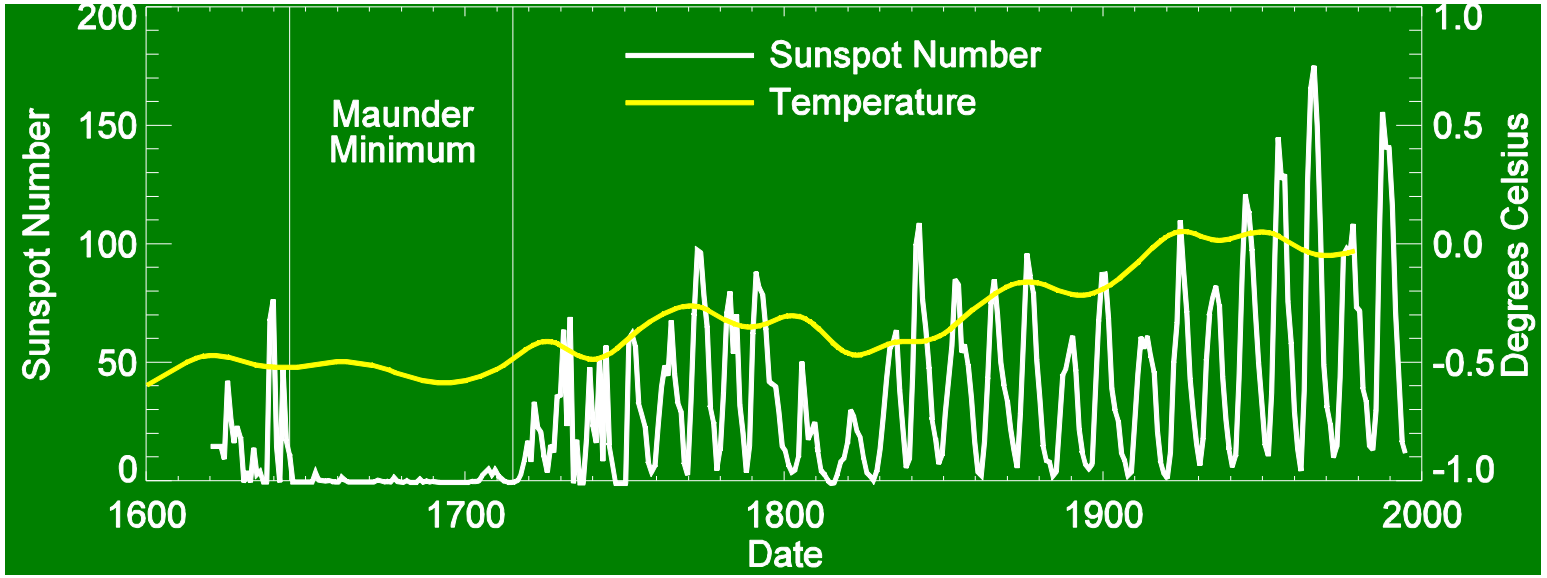
Modern Grand Solar Minimum

https://solargsm.com/solar-activity/

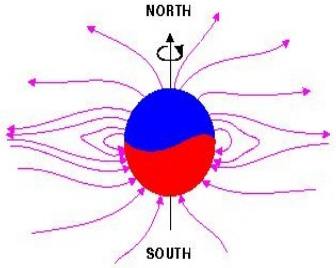
- To occur in 2020 – 2053
- This is a unique event in solar-terrestrial connection → will reveal the pros and cons of solar dynamo models
- Big impact on the terrestrial temperature via TSI and reduction of magnetic field (cold winters and summers, ozone reduction, high cloud formation, jet changes)
- Increase of volcanic and earthquake activities
- Shortage of vegetation periods can lead to possible food shortages in 2028-2042
- Need inter-government efforts to avoid disasters

Total Solar Irradiance and Climate

The 0.1% change in the Total Solar Irradiance seen over the last three solar cycles only produces a 0.1° C temperature change in climate models. However, the Sun seems to have a bigger impact.

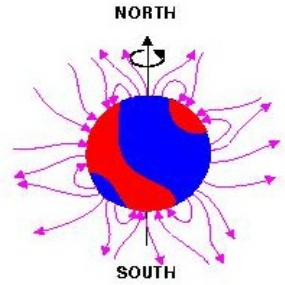


Two other mechanisms (besides direct forcing by the Total Solar Irradiance variations) are under study: 1) solar ultraviolet and extreme ultraviolet variability and 2) Cosmic Ray modulation on cloud cover.

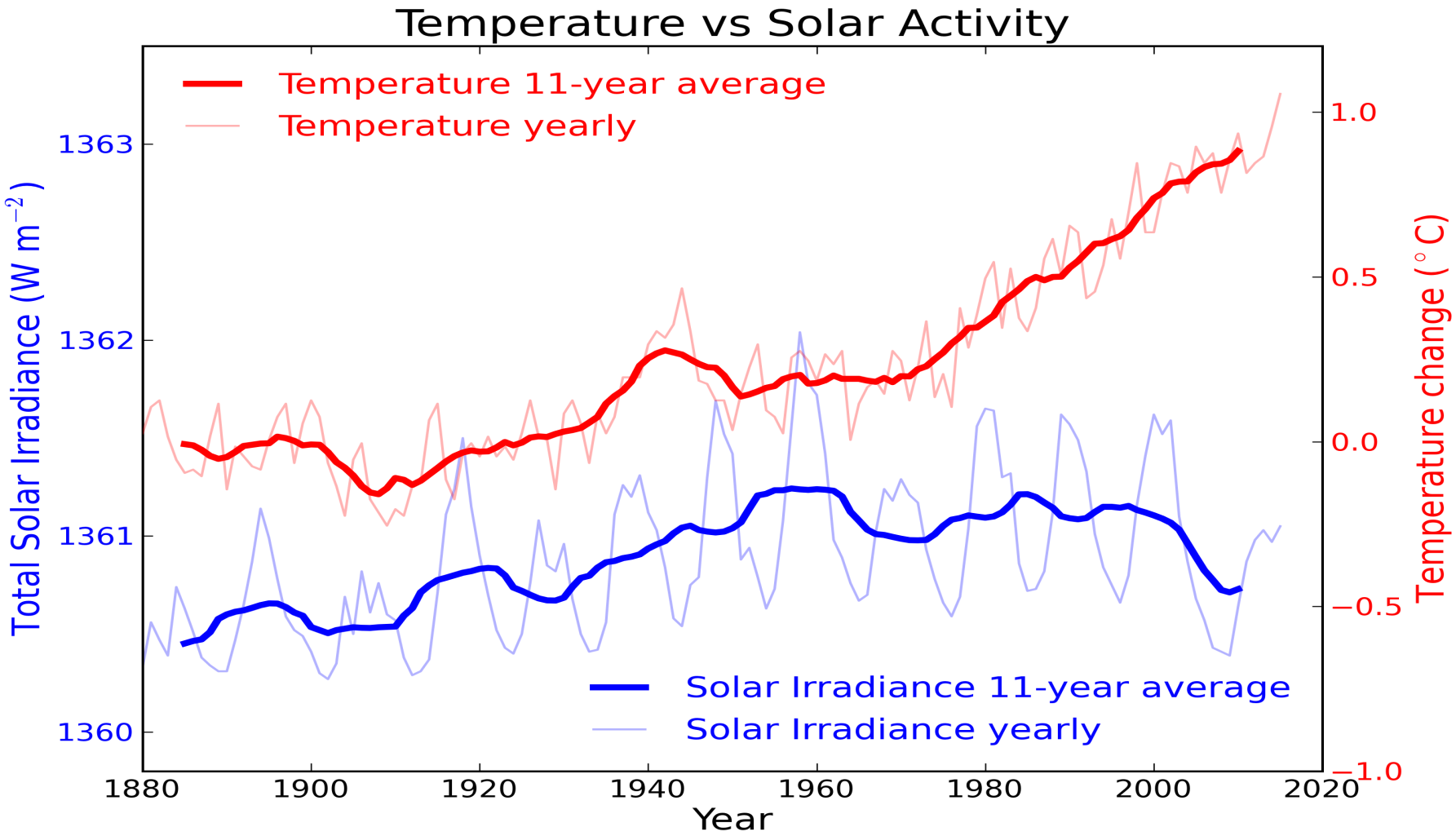


CORONAL MAGNETIC FIELD LINES AT SOLAR MINIMUM ACTIVITY

Terrestrial temperature increase after mini ice age during MM

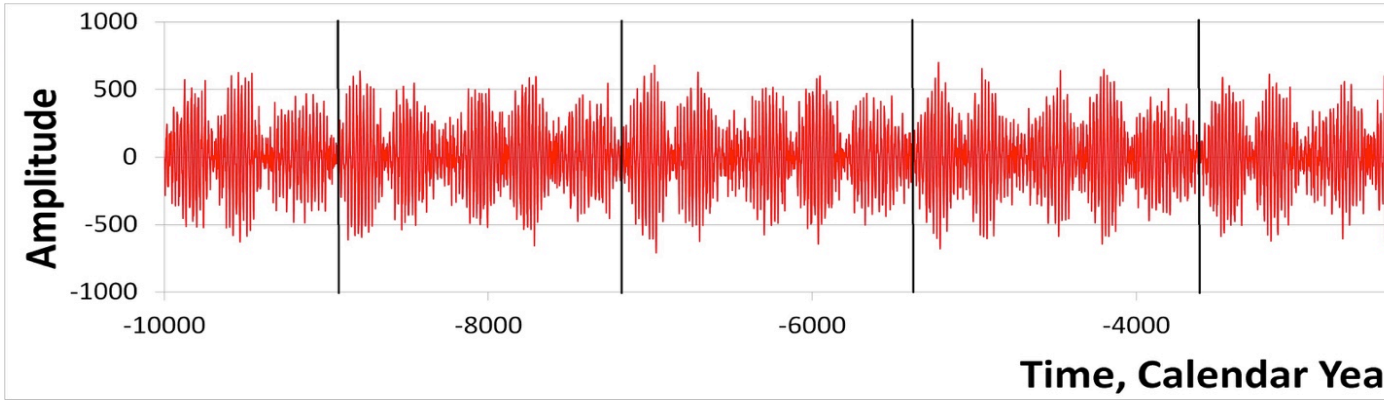


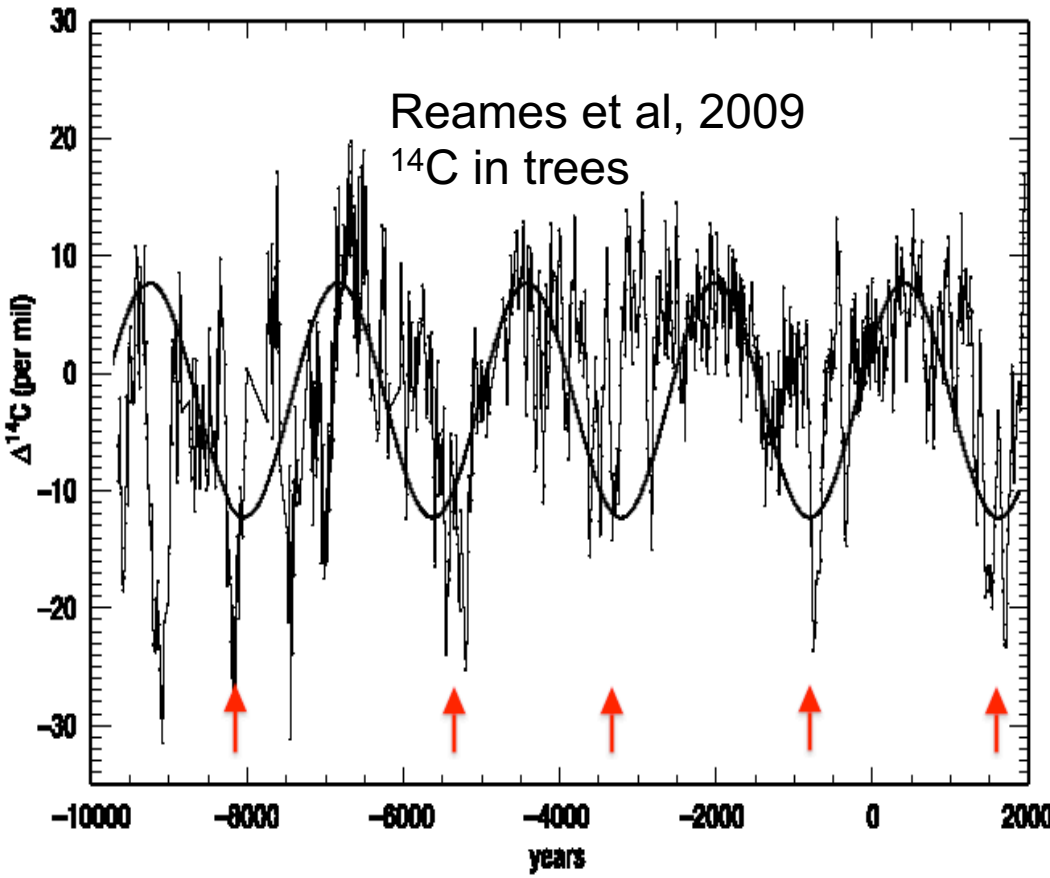
CORONAL MAGNETIC FIELD LINES AT SOLAR MAXIMUM ACTIVITY

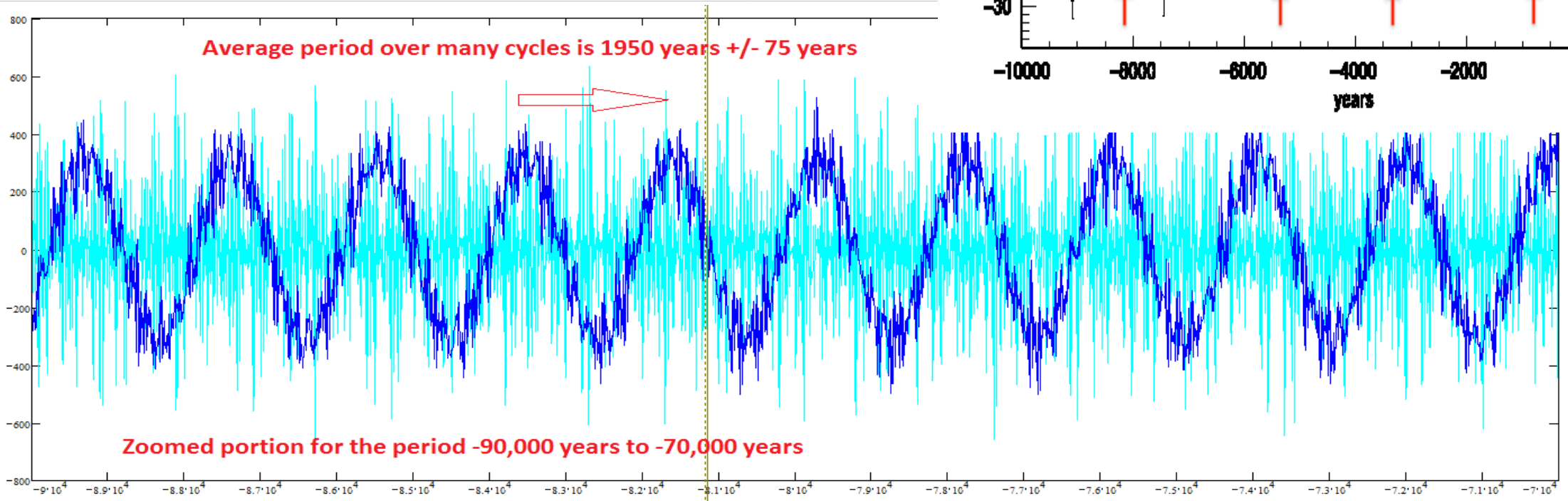


Solar magnetic field (top) baseline oscillations (bottom

Zharkova et., 2019, 2020

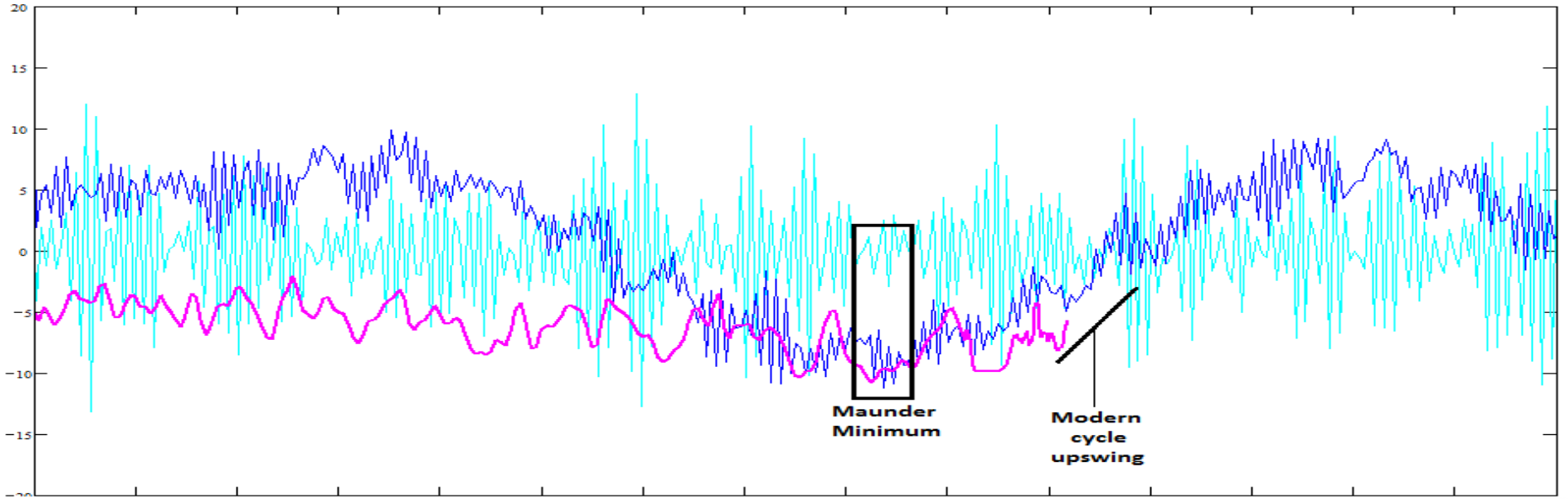


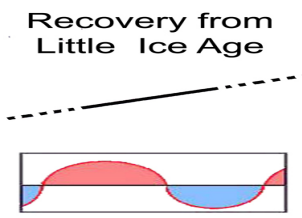


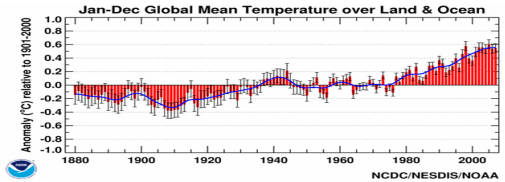


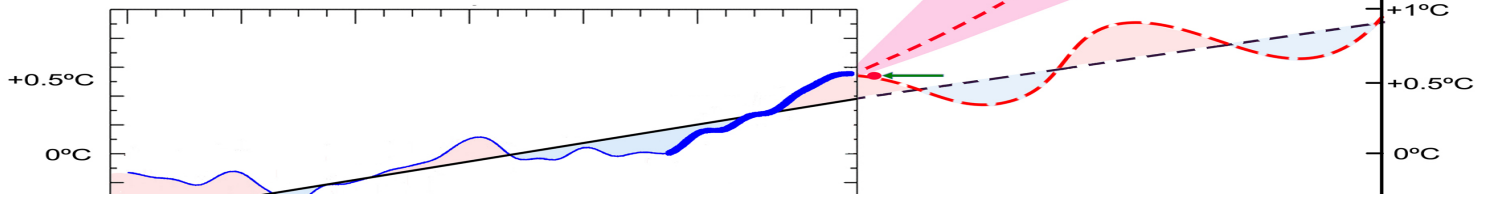
2000-2100 year oscillations (Zharkova et al, 2019, 2020)

of the MF baseline coincides with that of the solar irradiance (Vierra et al, 2011)







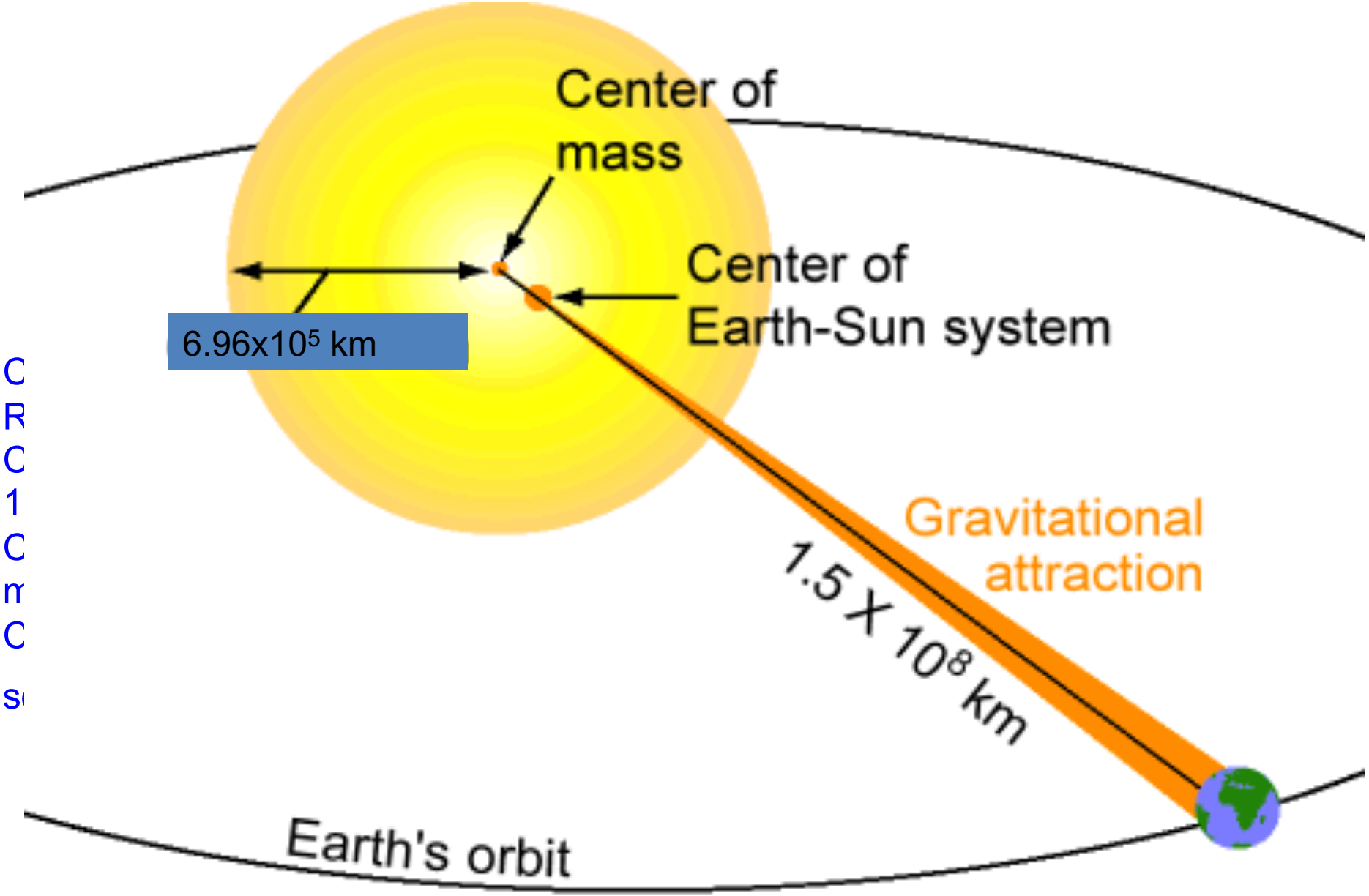


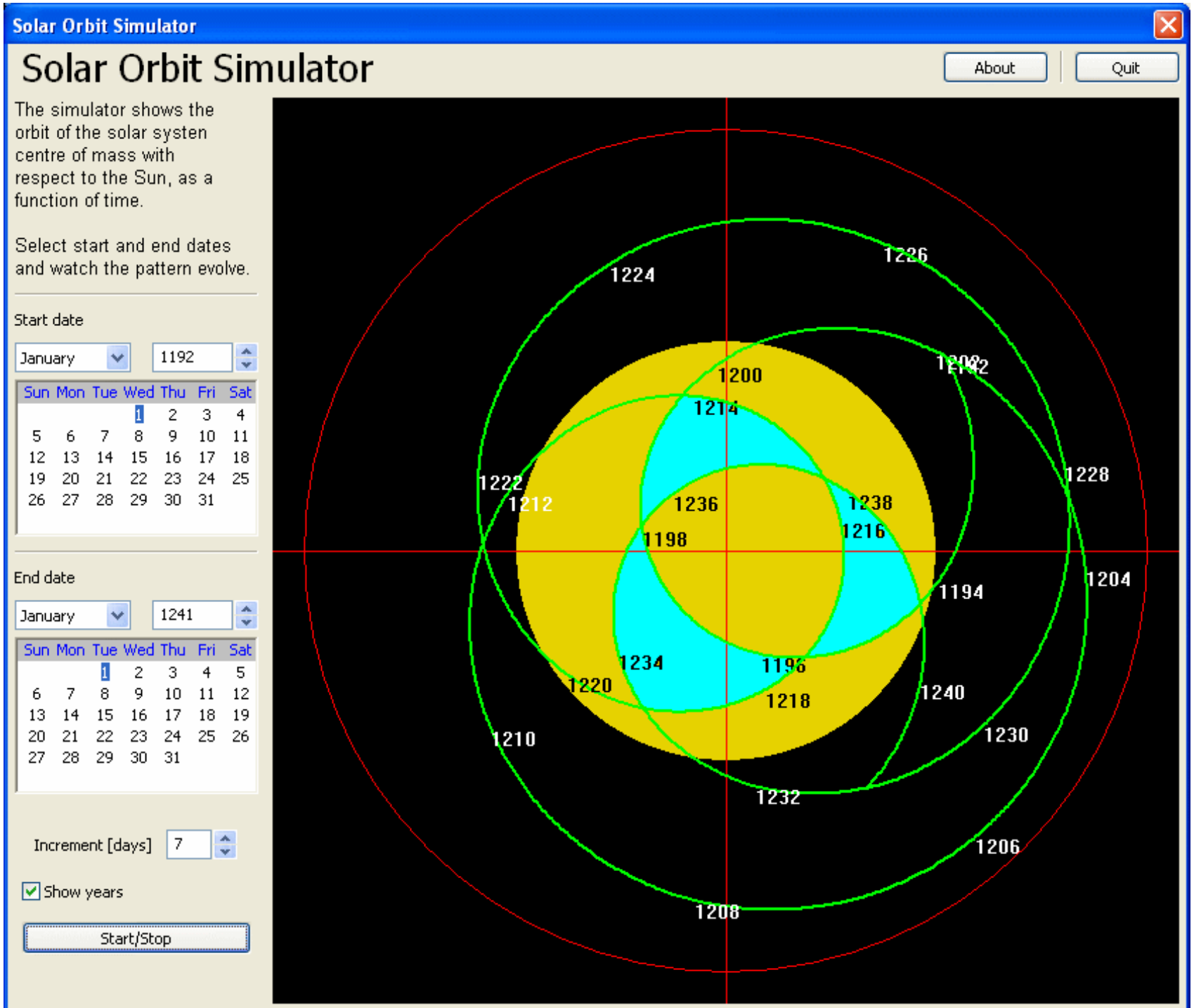
Little Ice Age

(Akasofu, 2010)

Zharkova et al, 2019, 2020

Solar Inertial Motion



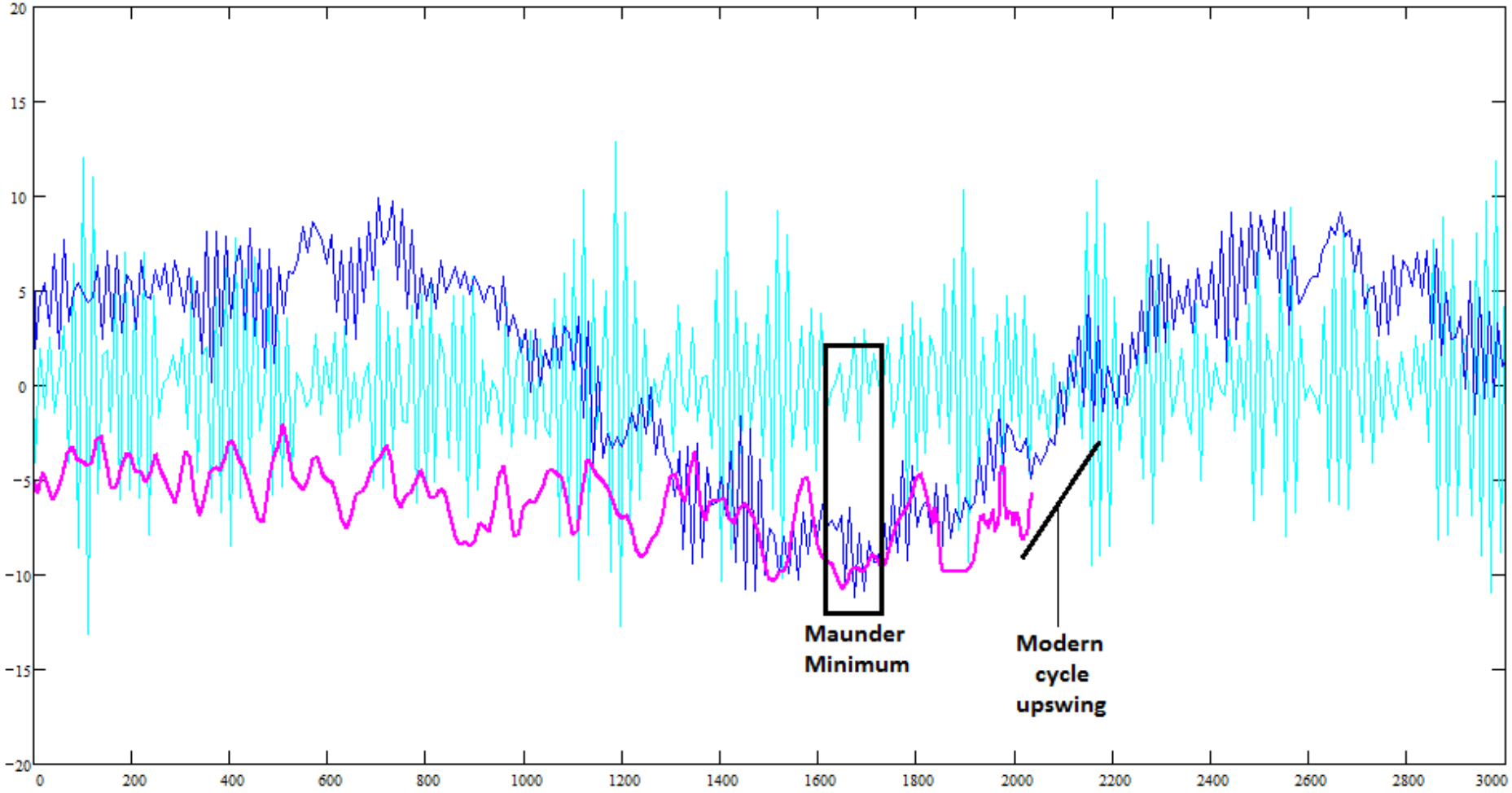


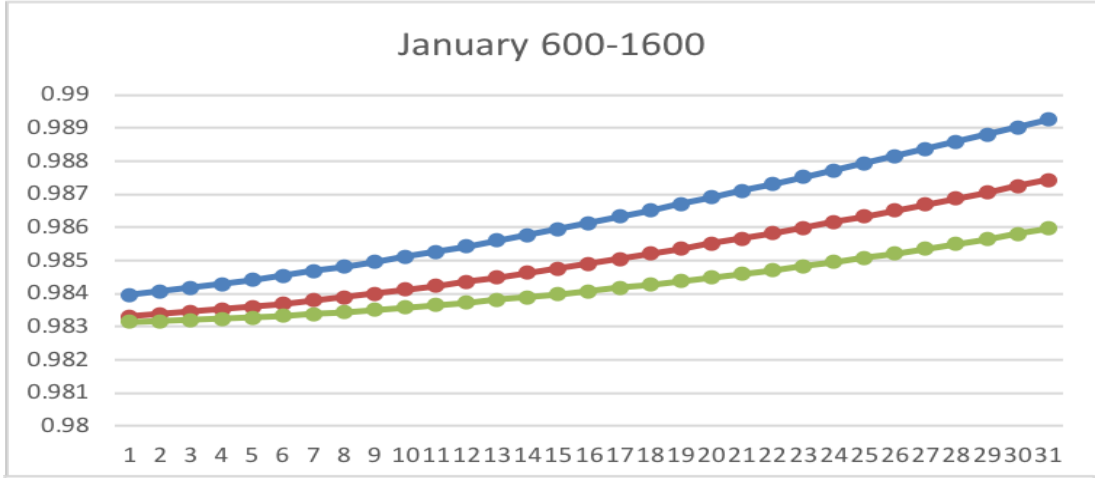
Sun's axial rotation (or spin) changes due to changes in the Sun's orbital revolution (speed along its orbit about the solar system barycenter) because of the varying distance from the barycenter

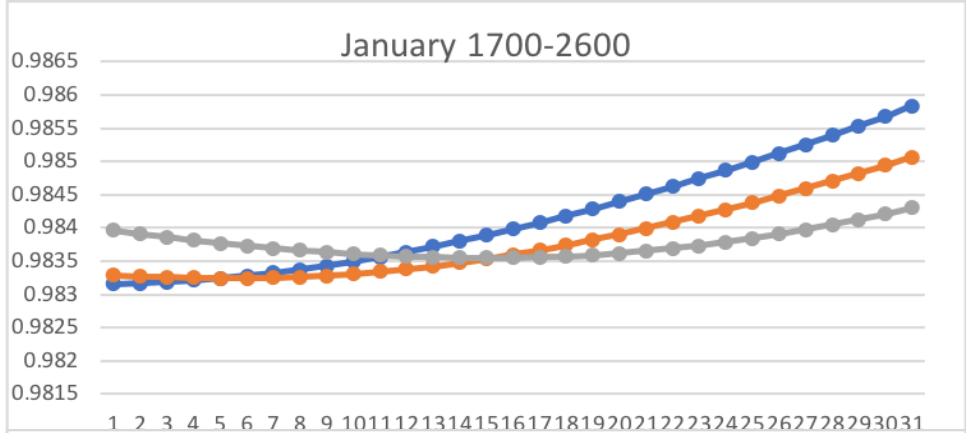
Period of one trifall - ~370 years

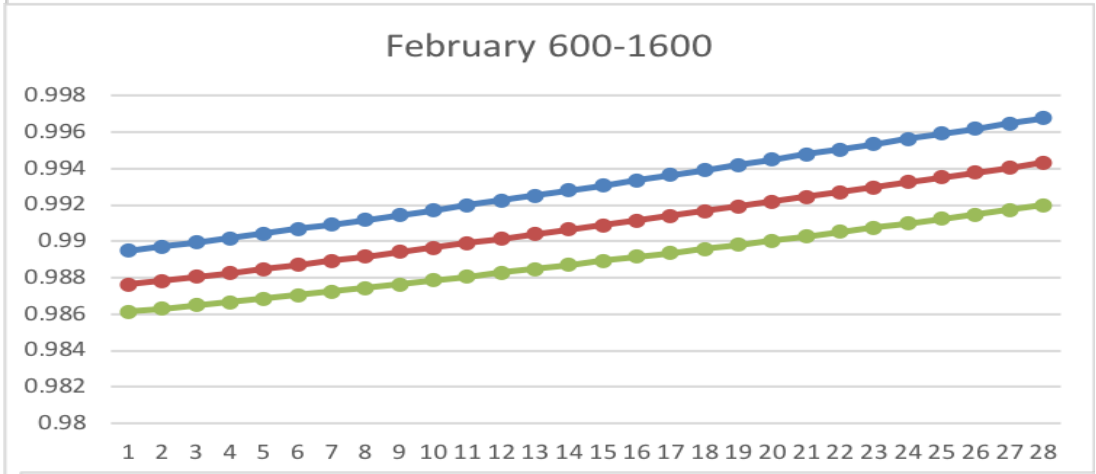
Full repeat - ~2200 years

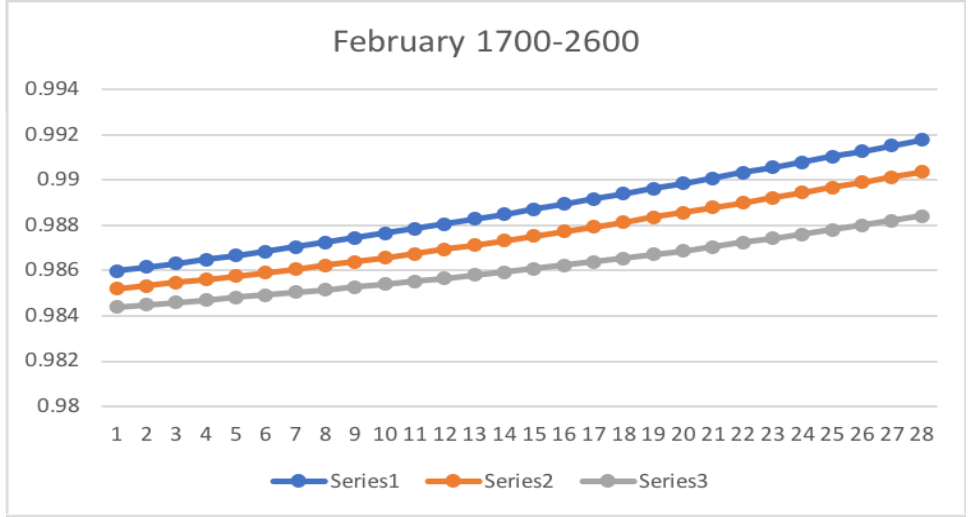
2100 year oscillations of the summary curve (Zharkova et al, 2019 ®, Zharkova 2021) and solar irradiance (Vieira et al, 2011)

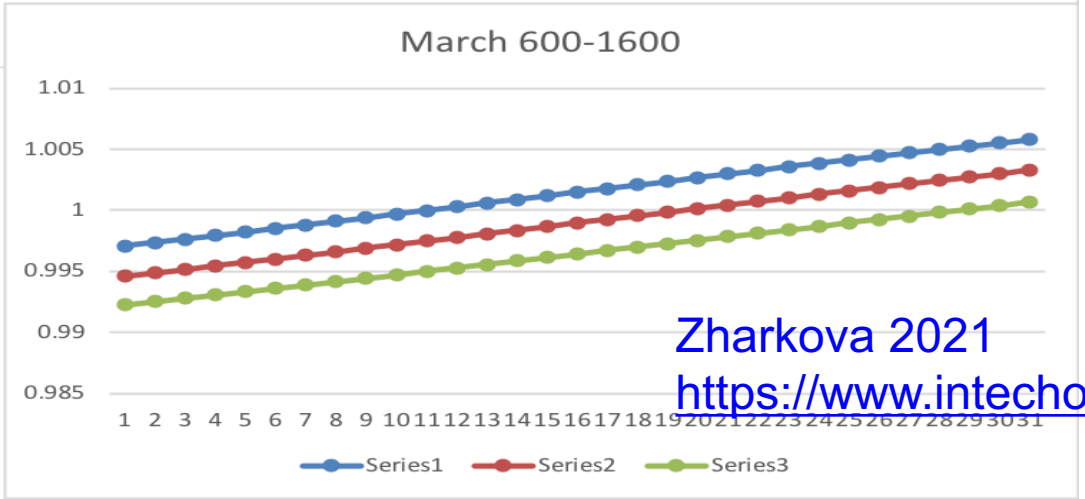


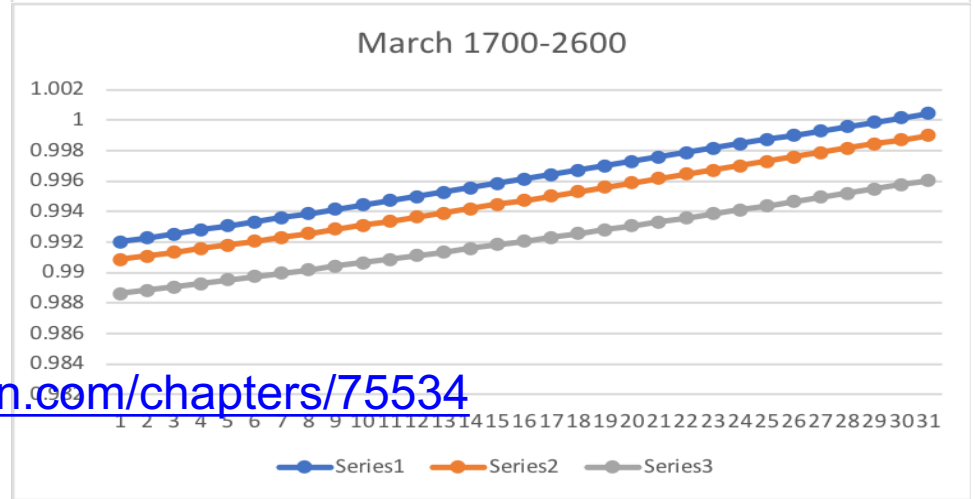




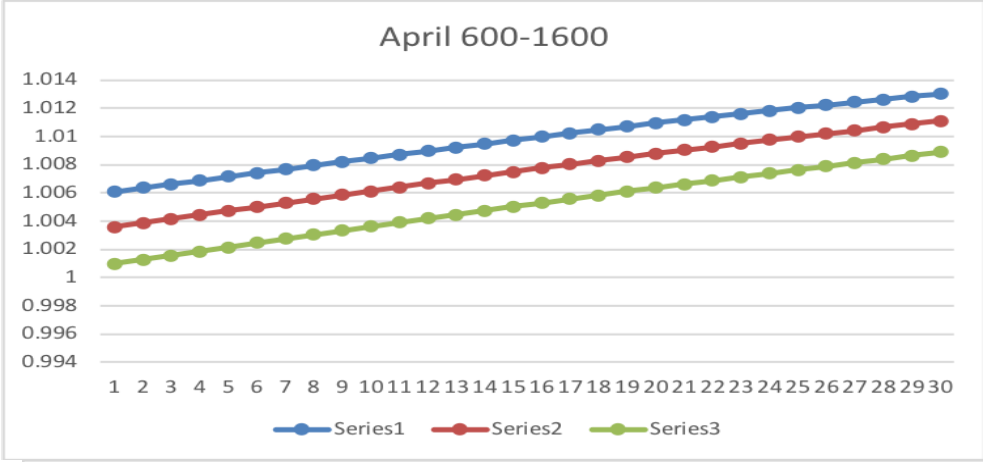


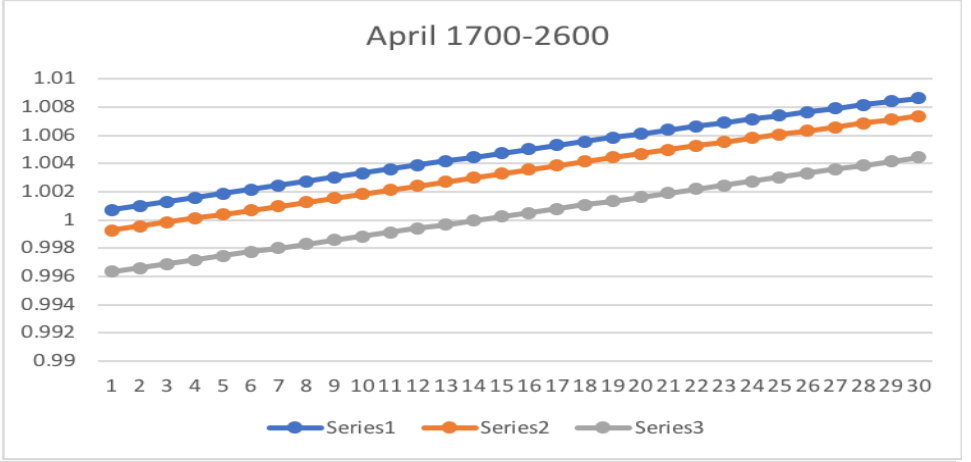


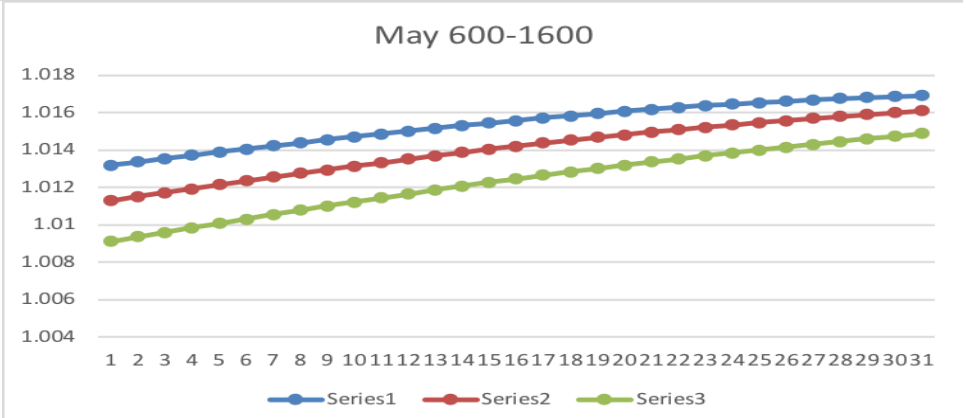


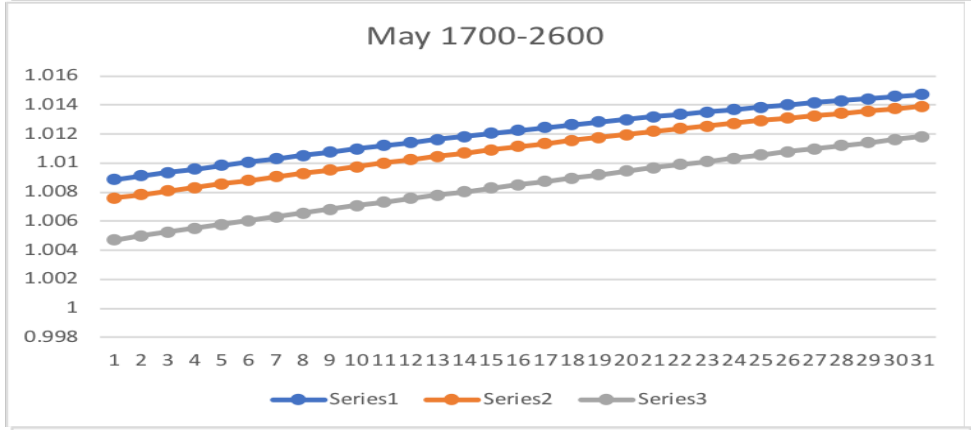


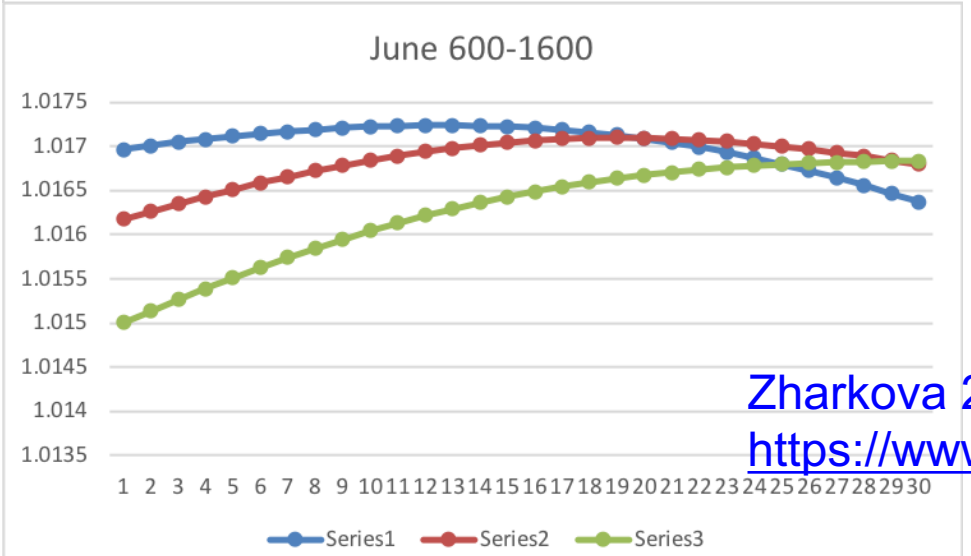
Zharkova 2021
https://www.intechopen.com/chapters/75534

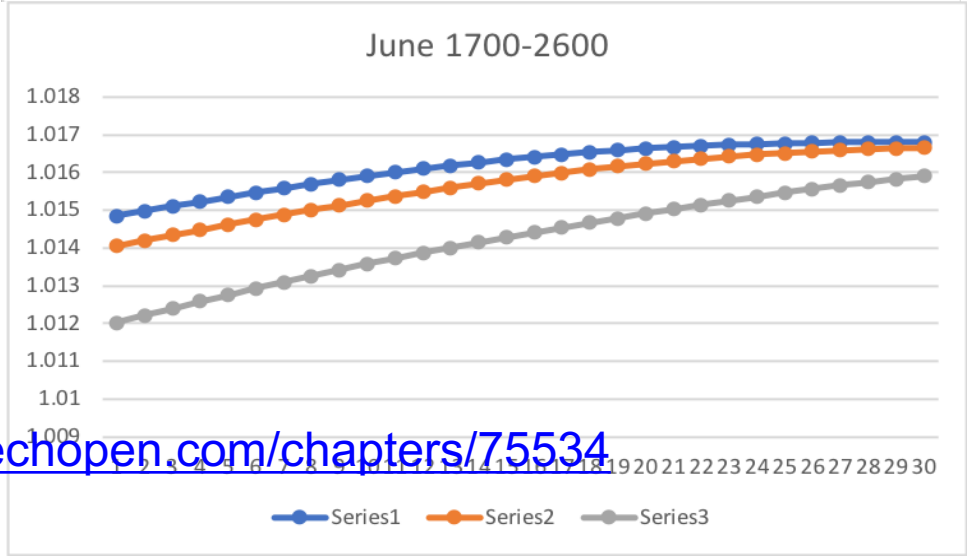




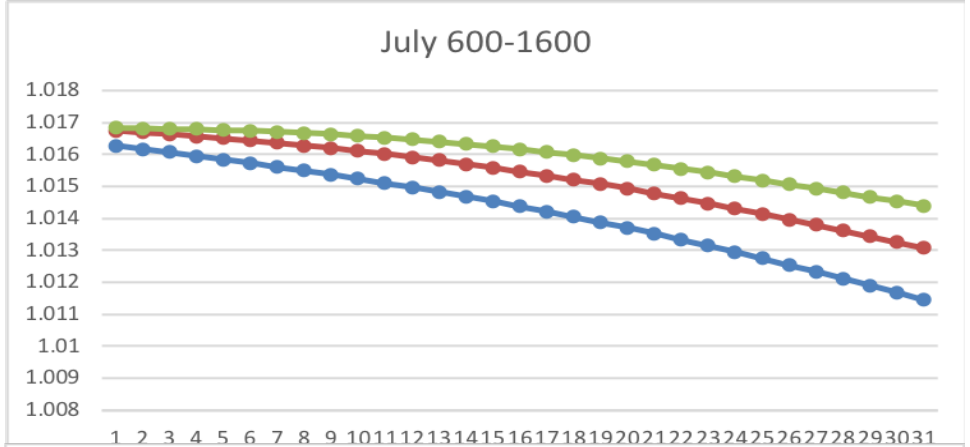


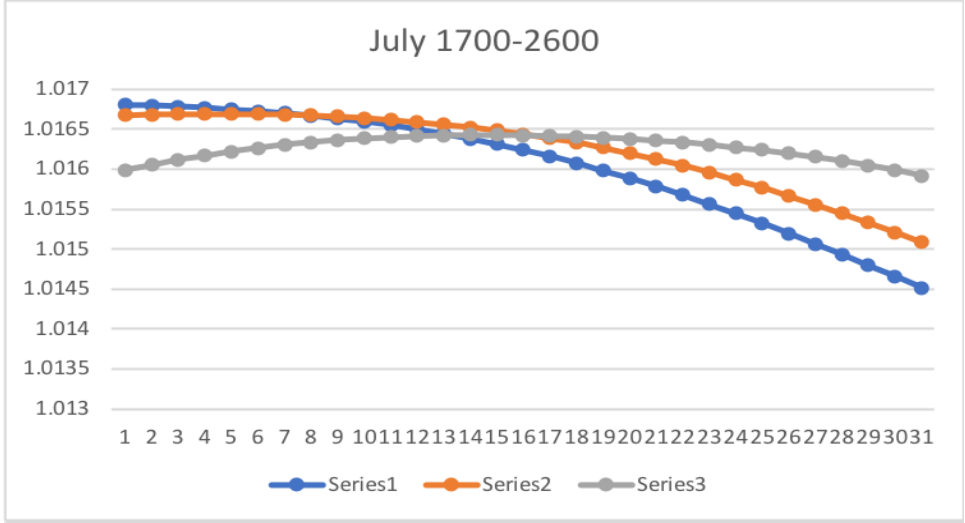


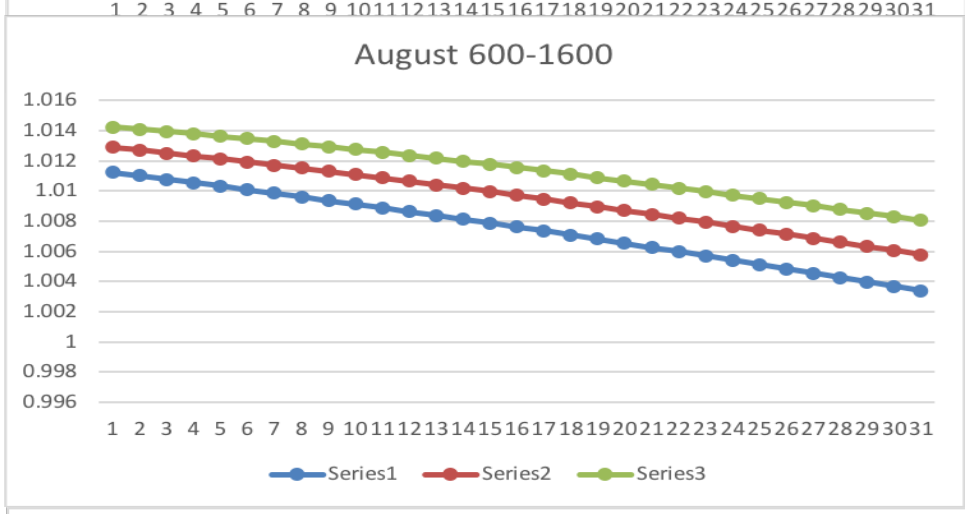


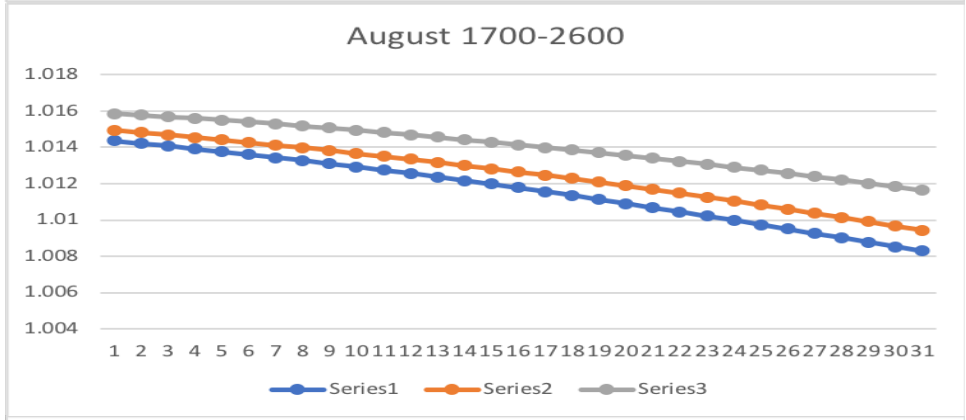


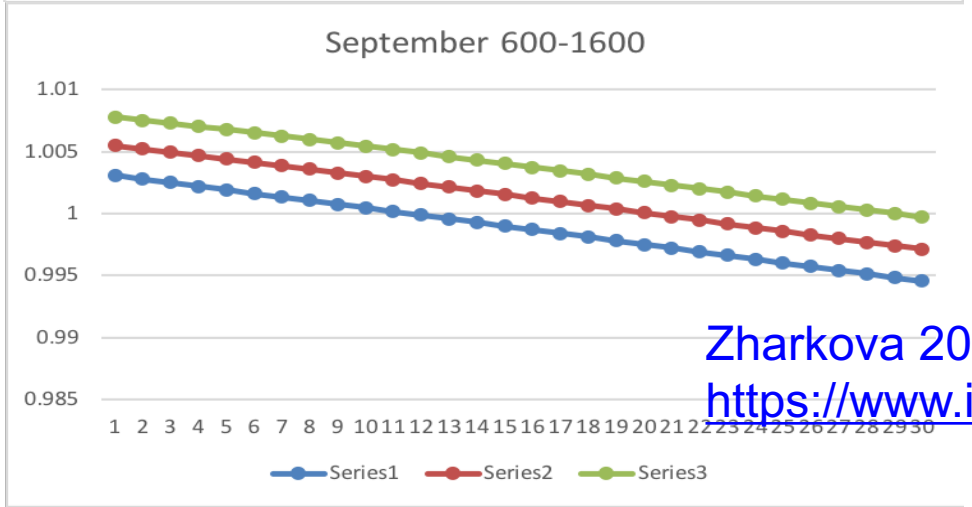
Zharkova 2021
https://www.intechopen.com/chapters/75534

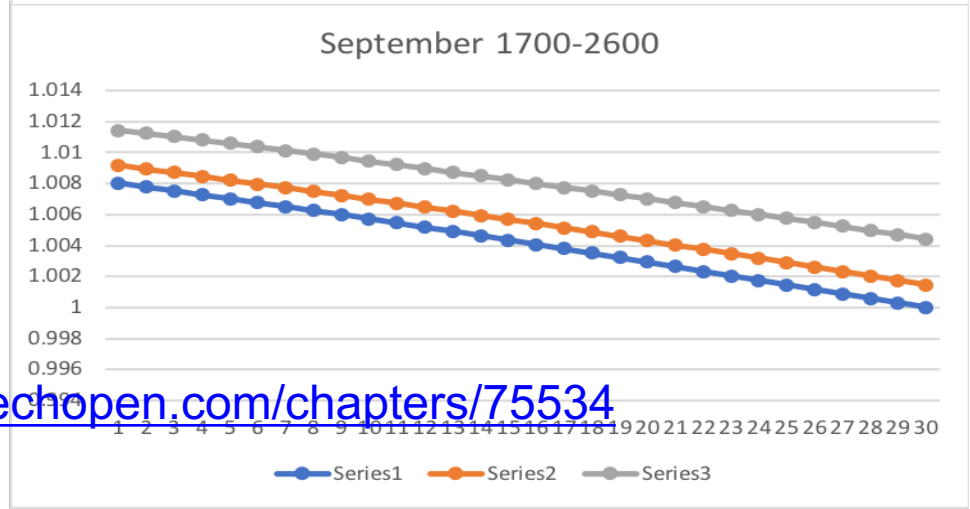












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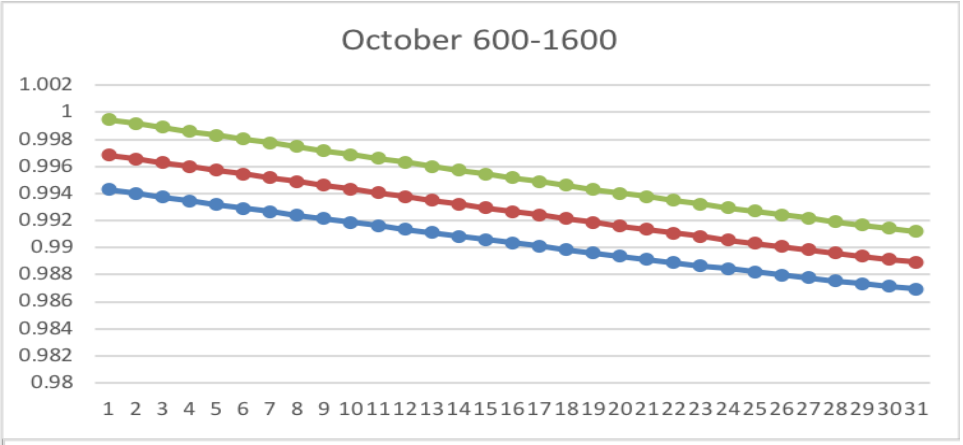

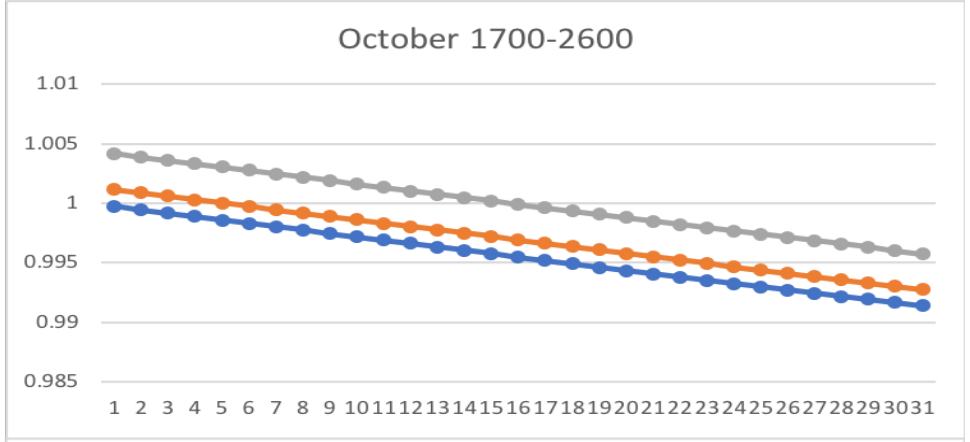

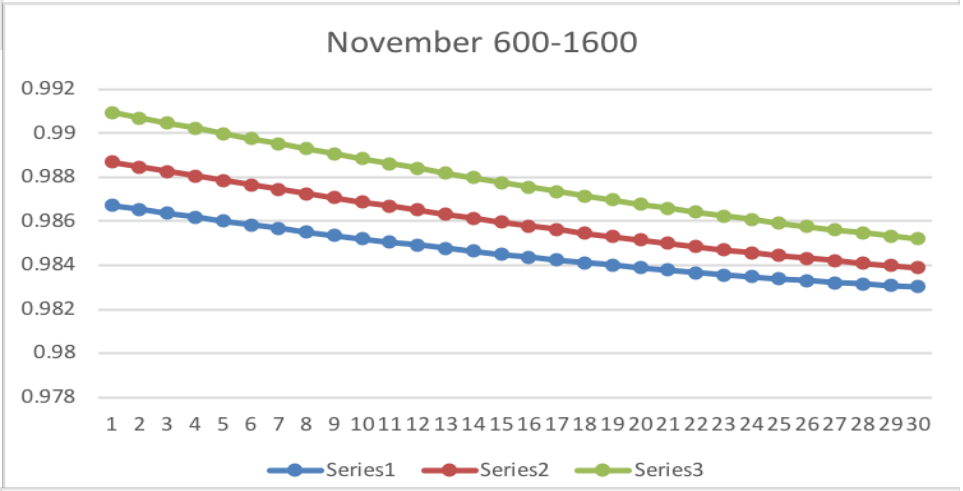

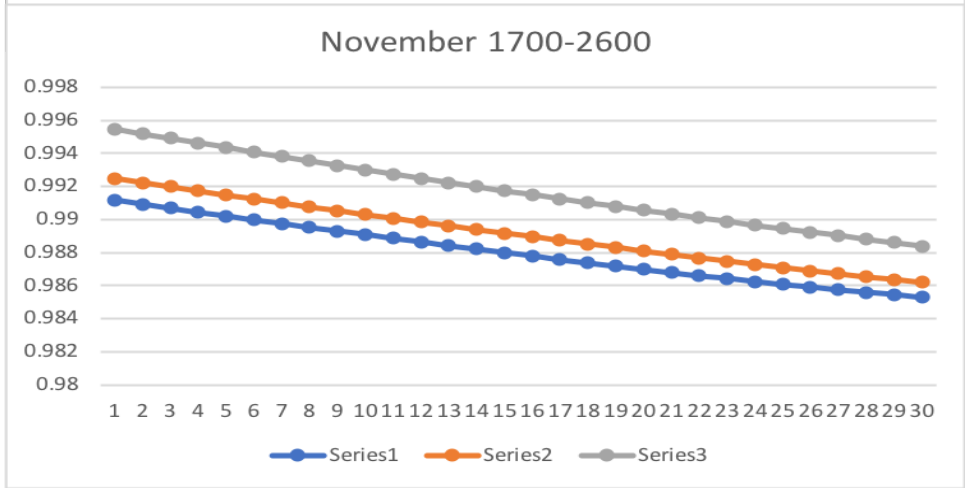

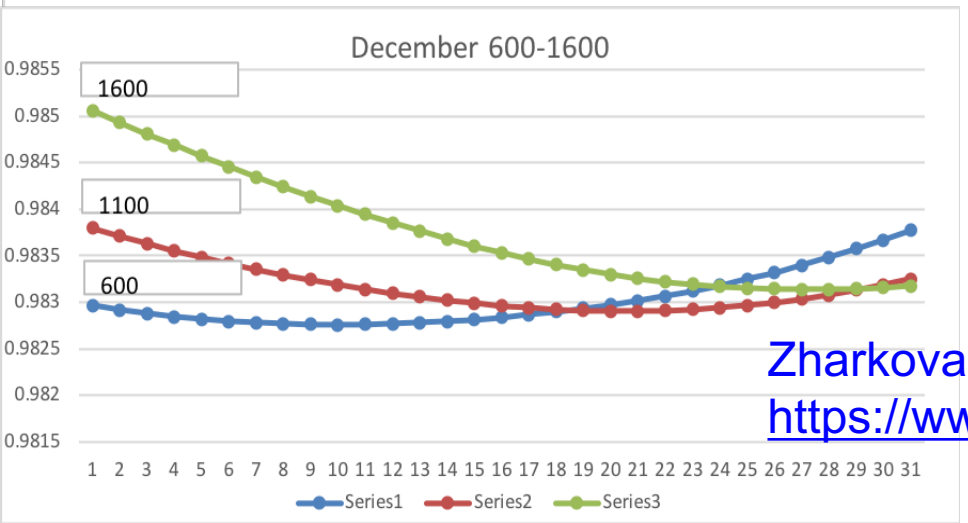

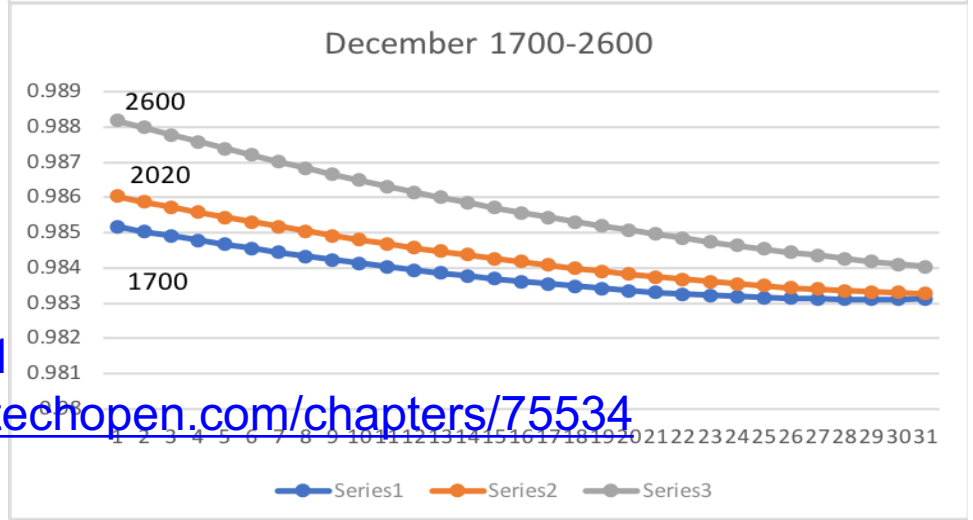

Zharkova 2021
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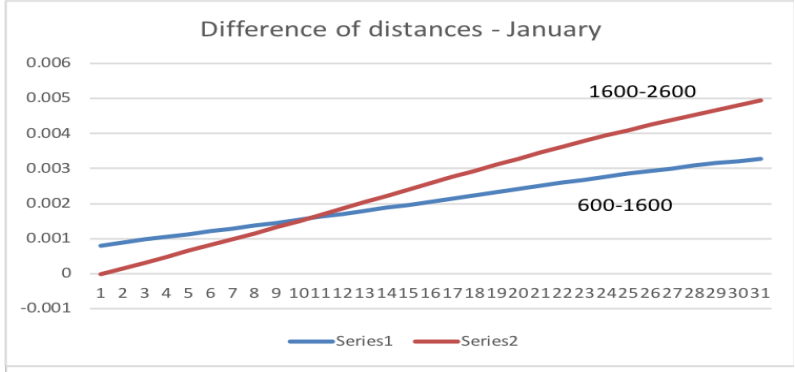
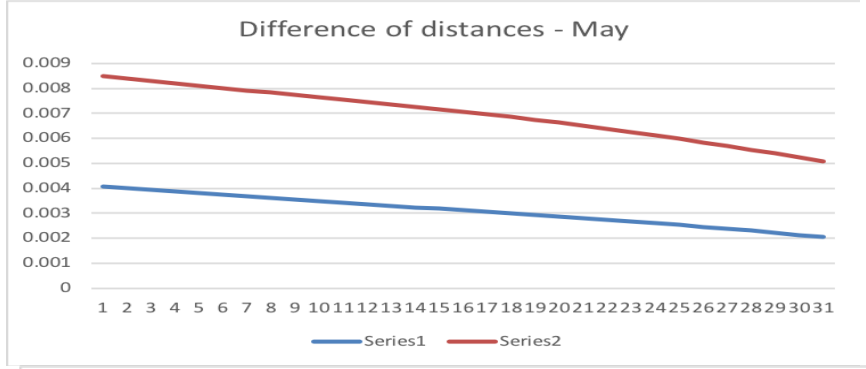
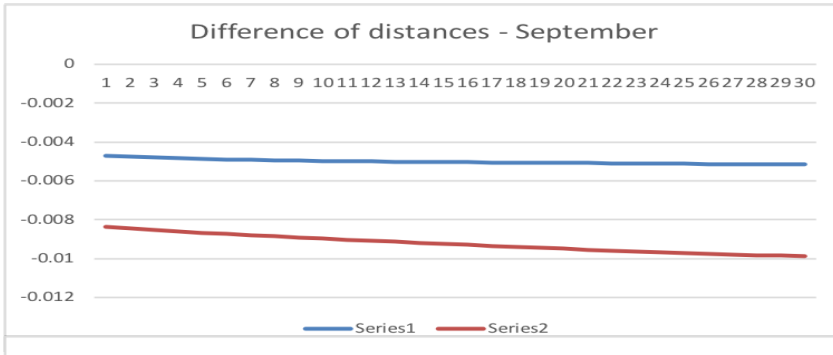
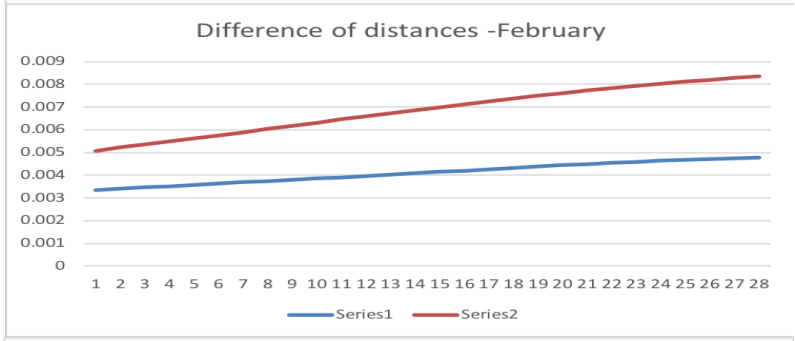
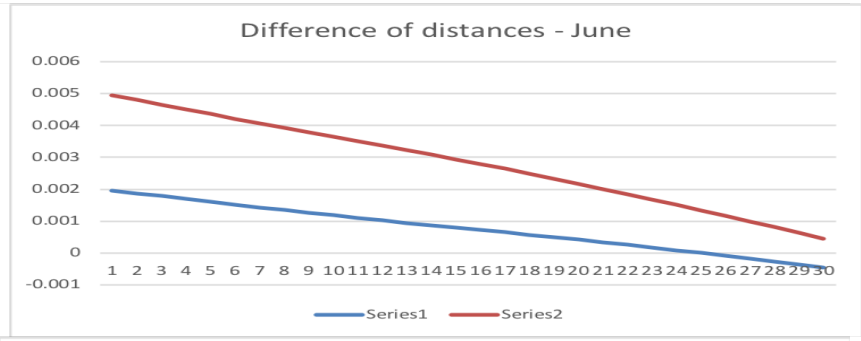
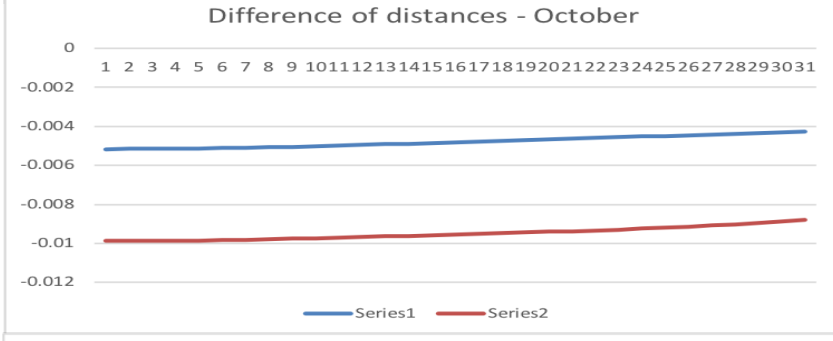


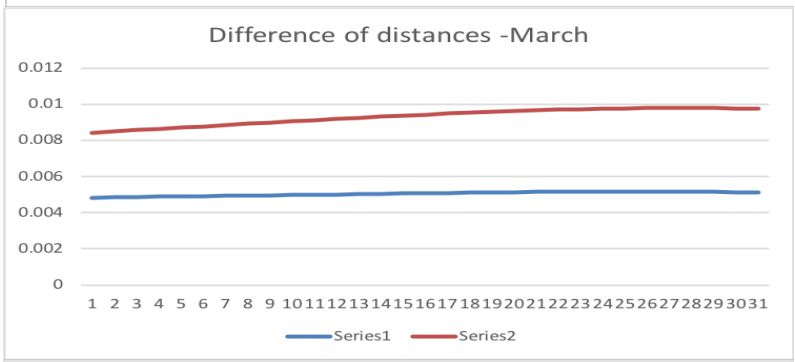


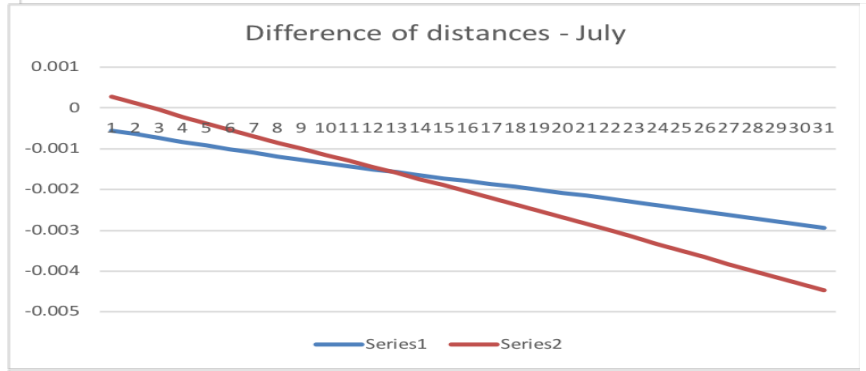


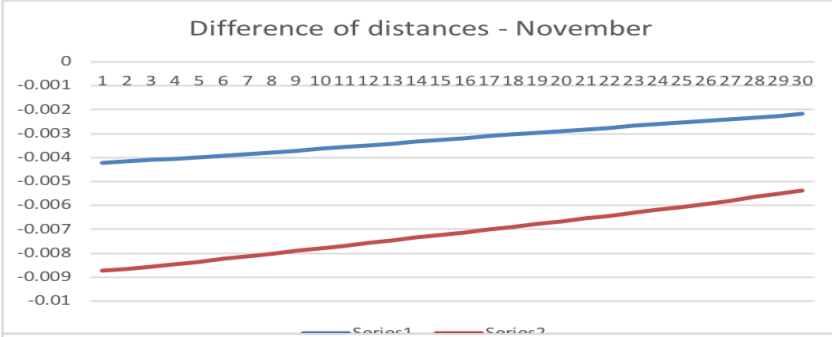


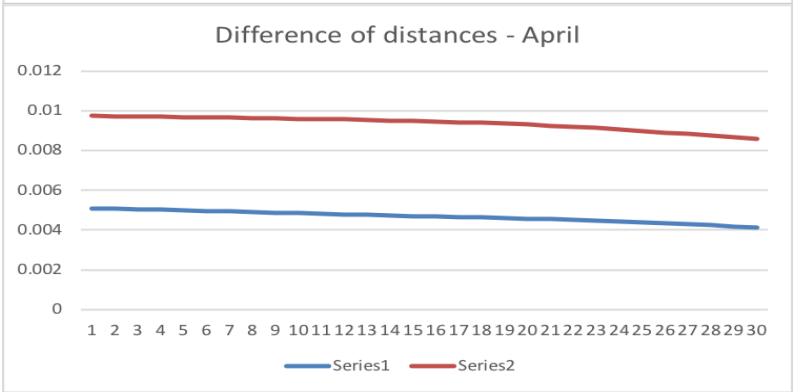


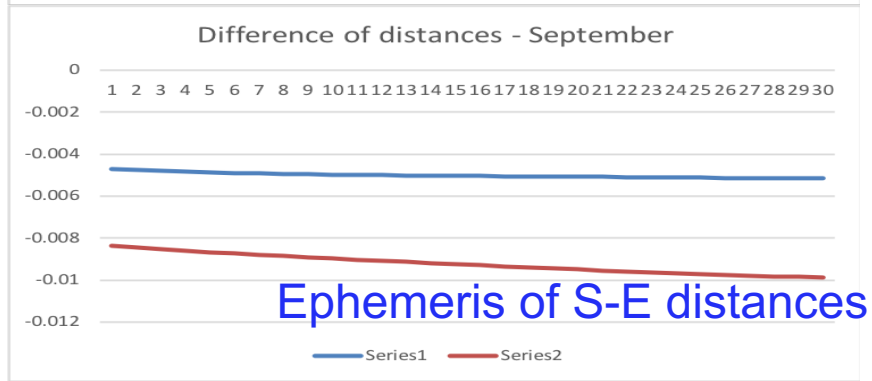


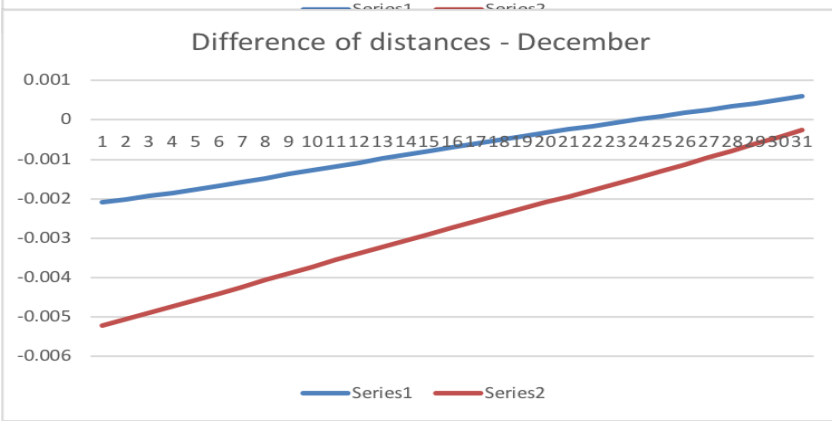








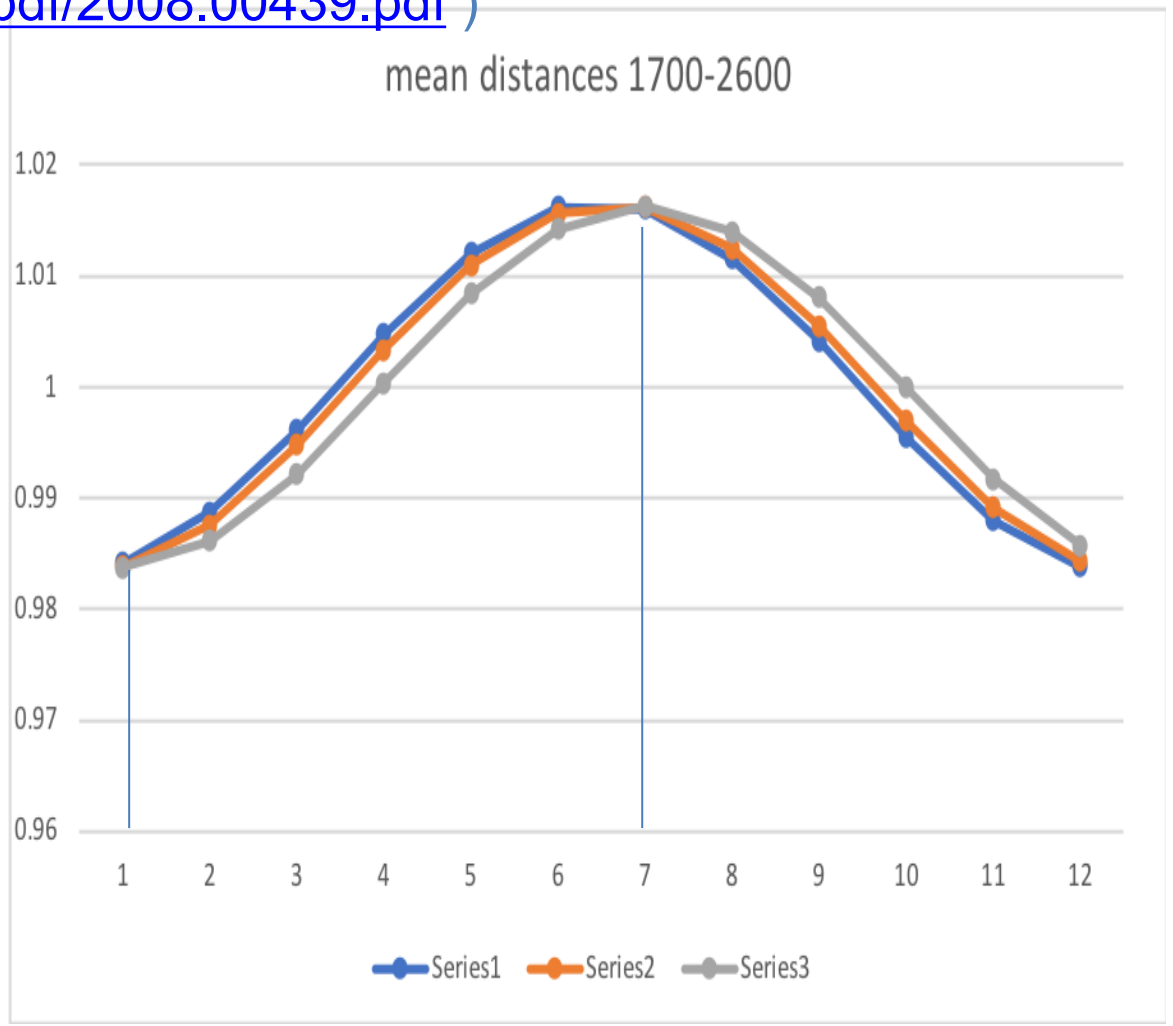




Ephemeris of S-E distances

Annual variations of mean S-E distances (ephemeris) in M1 (600-1600) and M2 (1700-2600)

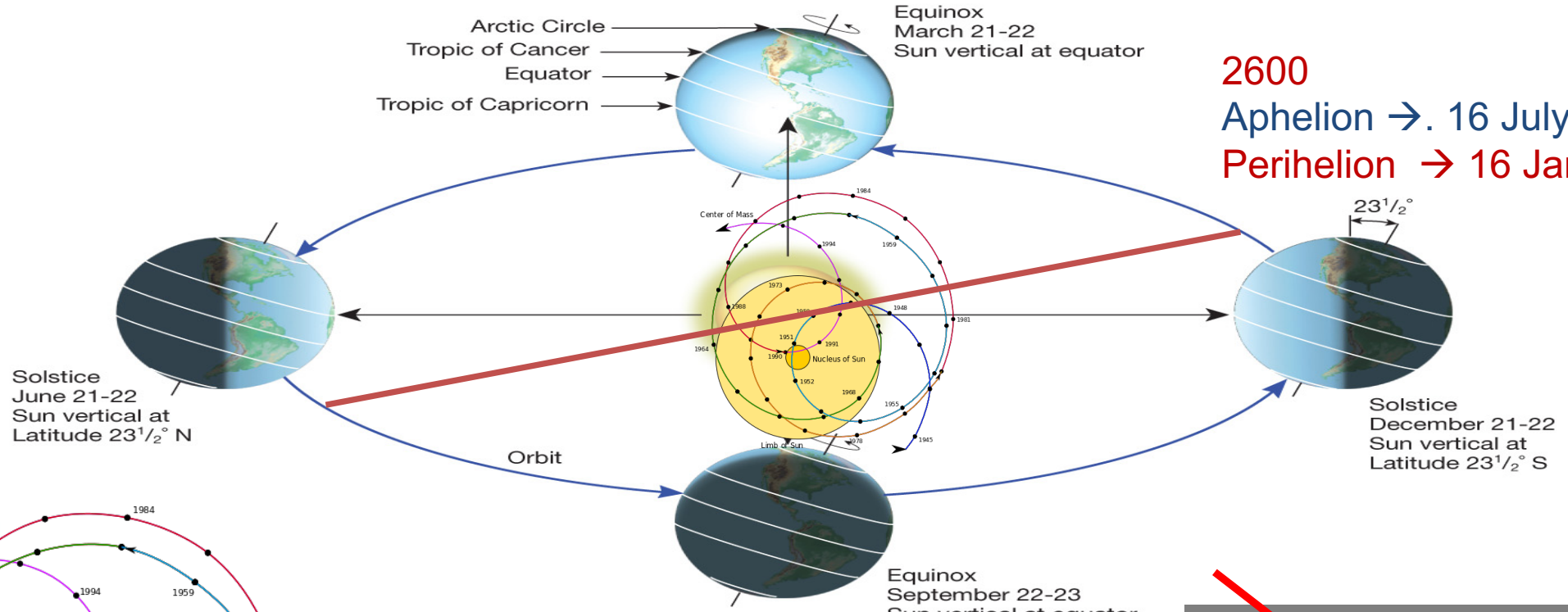
(Zharkova, 2020 https://arxiv.org/pdf/2008.00439.pdf)



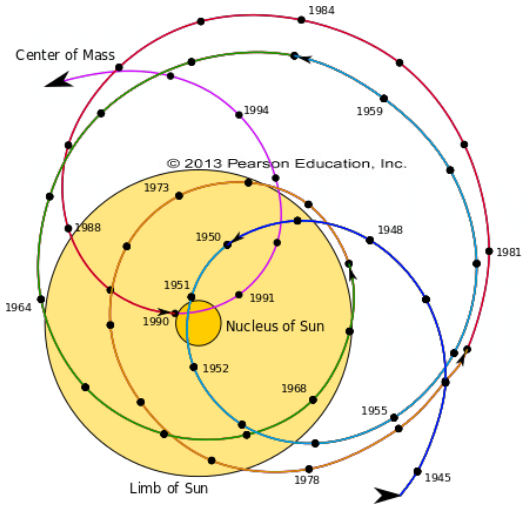
M1 – aphelion is in June, shifting to mid-July in M2

a - Sun - in the ellipse focus

b - Sun shifted by SIM to spring equinox



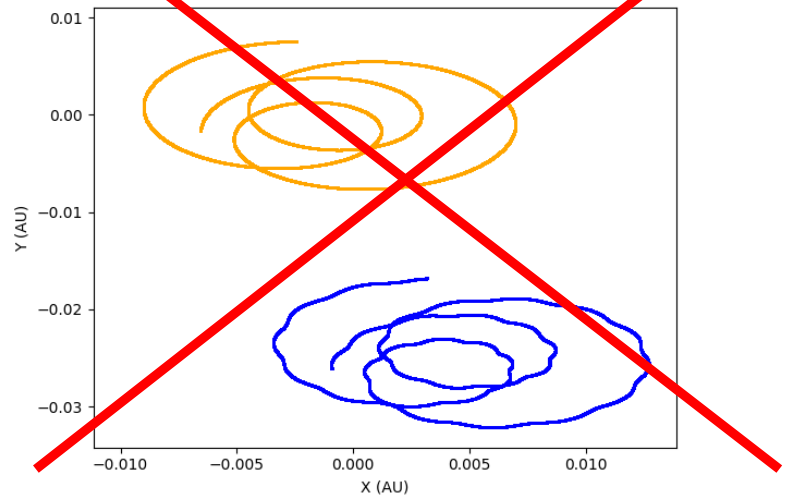
2600
Aphelion →. 16 July
Perihelion → 16 January



S. Perminov, E.D. Kuznetsov, 2018
SIM imposed by planets Jupiter, Saturn, Neptune and Uranus

Charvatova, 1988,
Palus et al, 2007

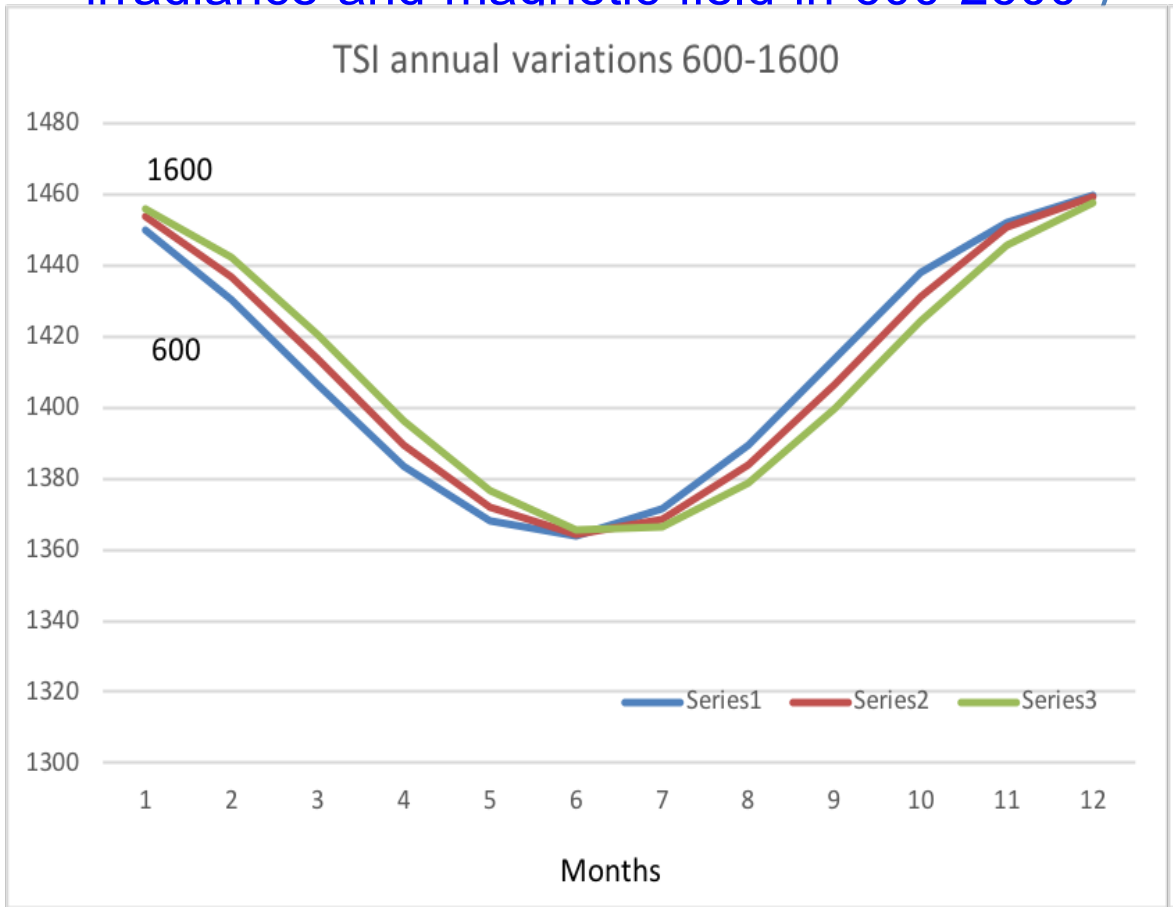
https://youtu.be/vDgUmTq4a2Q

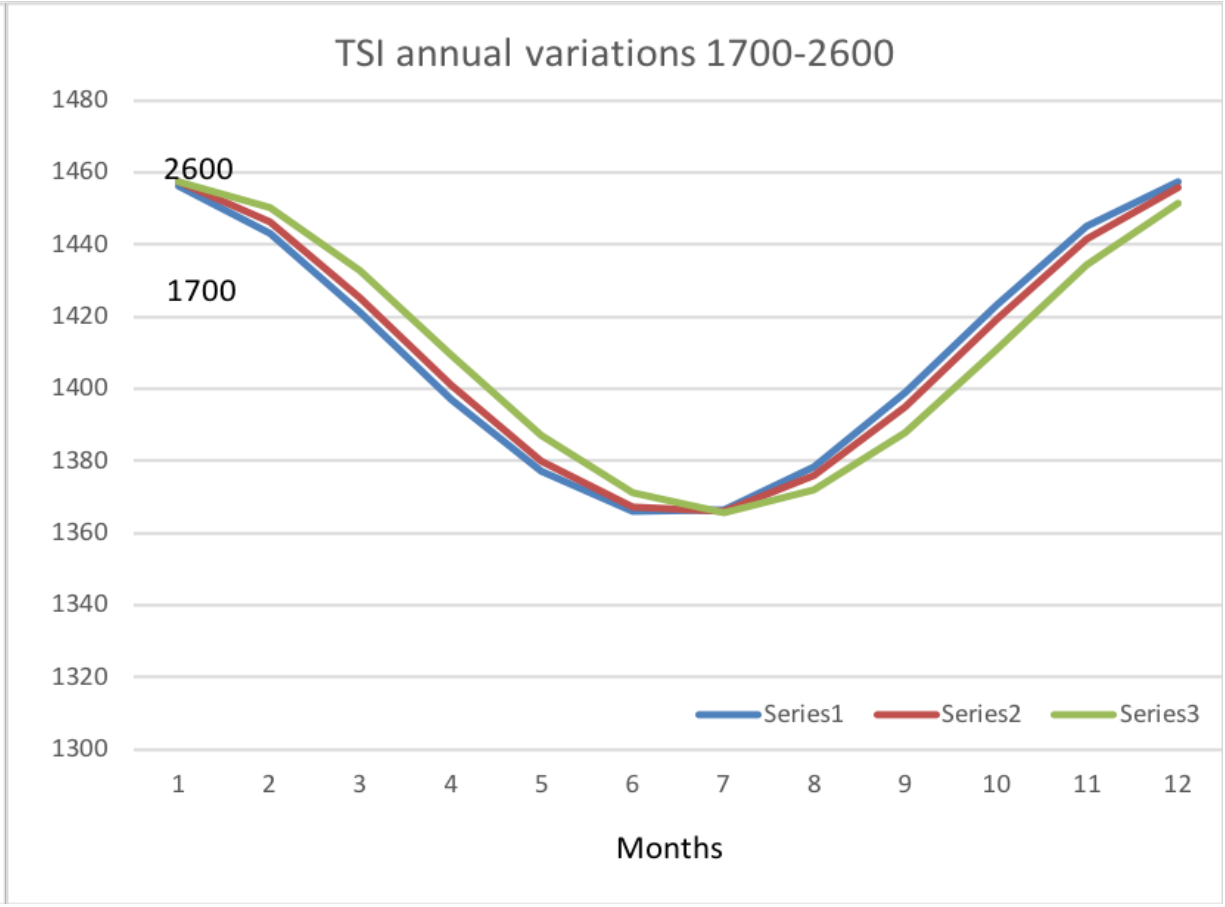


Rice et al, PP comments #72, 96

Annual TSI variations in M1 (600-1600) and M2 (1700-2600)

Zharkova, 2021 https://www.intechopen.com/online-first/millennial-oscillations-of-solar-irradiance-and-magnetic-field-in-600-2600)

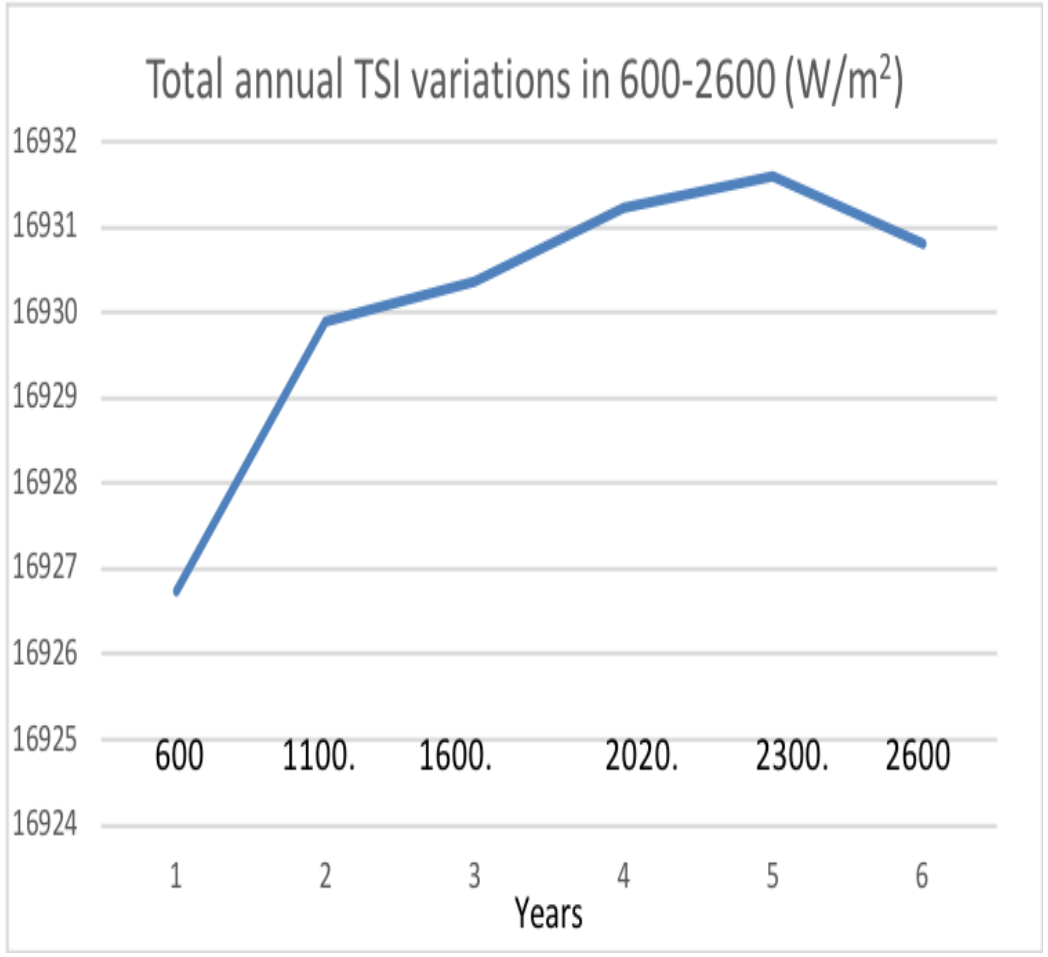


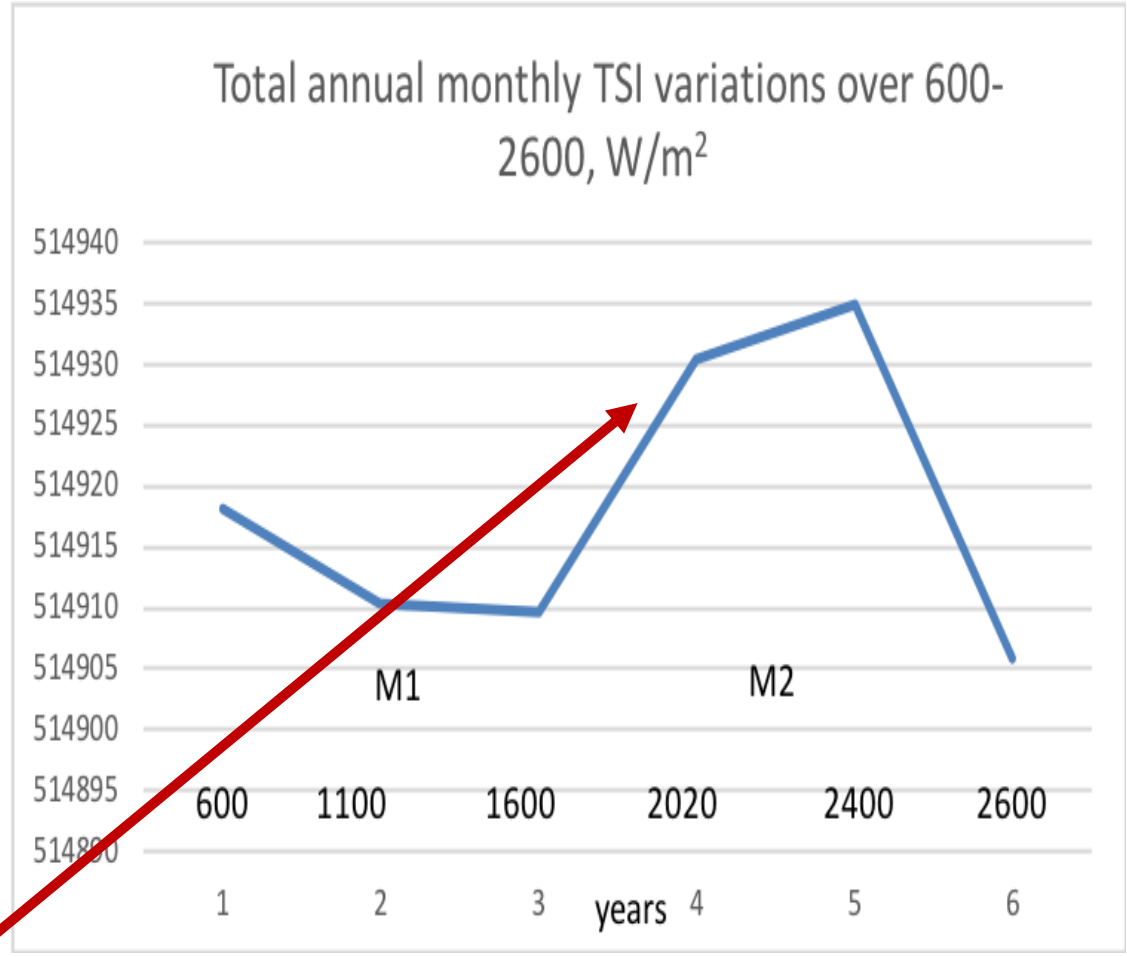


M1: TSI significantly increases in February – June, and decreases in June-December. M2: the aphelion shifts to mid-July →TSI decrease in July – January is not fully compensated!

Variations of the total annual TSI
in M1 (600-1600) and M2 (1600-2600) averaged for each month (left) and daily (right)

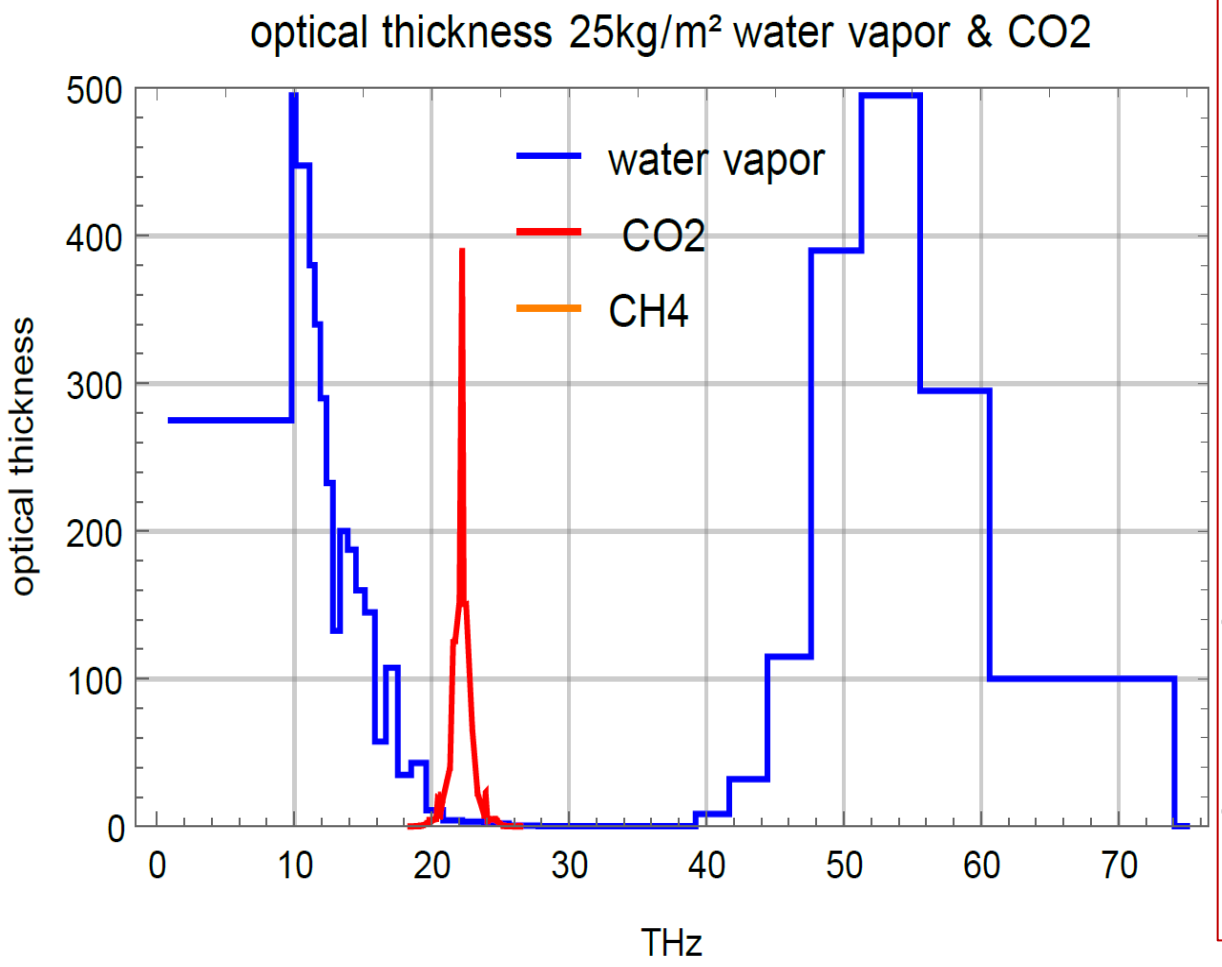
https://arxiv.org/pdf/2008.00439.pdf
Zharkova et al, 2019, Zharkova, 2020





Solar forcing is much stronger in 1600-2600 than accepted by IPCC

The optical thickness τ of the atmosphere is the parameter to use to compute the diffuse radiation in an absorbing and radiating medium like the atmosphere (Chandrasekhar 1948, K. Ya. Kondratiev 1969)



- $f_{down}(\nu, z) =$

$$\pi \int_0^{\tau(\nu,z)} B(\nu, T(t')) \, 2 \, E_2(\tau(\nu, z) - t') \, dt'$$

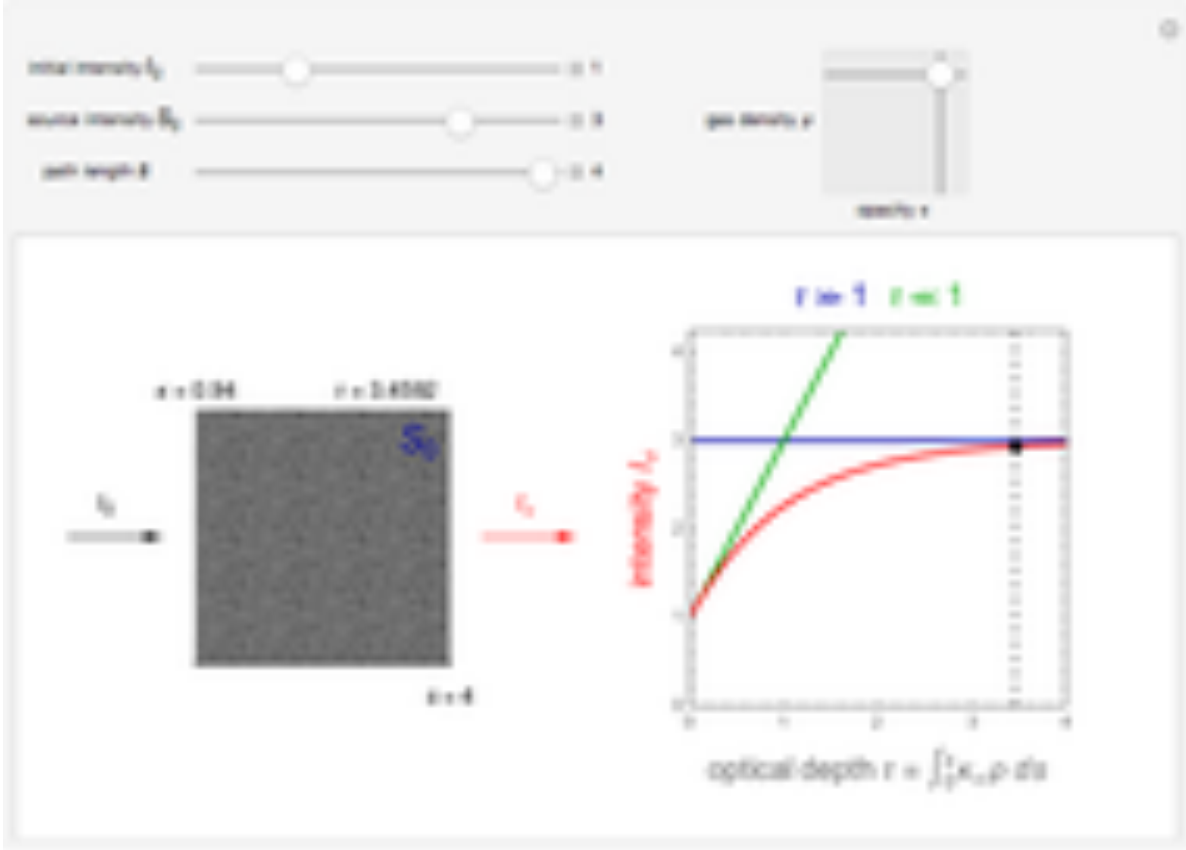
$$f_{up}(\nu, z) =$$

$$= \pi \int_{\tau(\nu,z)}^{\tau max} B(\nu, T(t')) \, 2 \, E_2(t' - \tau(\nu, z)) \, dt'$$

- $f_{surface}(\nu, z) = \pi B(\nu, T_{surface}) \, 2 \, E_3(t_{max} - \tau(\nu, z))$
- B Planck's function, E_2 and E_3 exponential integral functions

80% of the thermal radiation from a body is produced in its skin or "pellicle" of optical thickness τ = 1,07

Radiative transfer in action



https://demonstrations.wolfram.com/ComputationOfRadiativeTransfer/

- intensity of emission from the gray area on the left.
- for tau<1 emission (green curve) the emitted intensity is proportional to the density of excited molecules (CO2)
- for tau>1 it becomes saturated (red curve).
- IPCC assumes that all CO2 emitting as green curve while its tau>>1, so it is emitting as the red curve (saturated).

Conclusions

- **Principal components of SBMF are paired – double dynamo waves**
- **Prediction of the solar activity on a millennium scale shows grand cycle variations with period of 350-400 years**
- **Prediction for 3000-10000 years backwards fits the main warming and cooling periods**
- **Analysis of summary curve for 100,000 years detects weak variations of the magnetic field baseline with a period of ~2100-2200 years – Hallstatt's cycle**
- **These MF variations are closely linked to the solar inertial motion about a barycentre of the solar system**
- The SIM would impose an increase of SI in 2100 by 0.22%, or by further 3 W/m^2
- Owing to SIM SI would increase from 1600 to 2500 by further 20-25 W/m^2 per year (10-12 W/m^2 per hemisphere)
- Increase of SI with a decrease of S-E distance would lead to the increase of T by 1.2C by 2010, and by further 2.5-3.0 C in 2500.
- However, the GSM to occur in 2020 – 2053 → Different narratives for governments!