Earth rotation in sight of Climate modulations

Leonid Zotov[1,2], Sidorenkov N.S.[3], Bizouard Christian[4]

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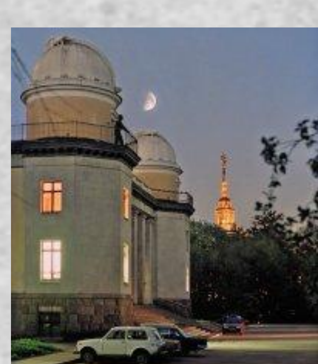
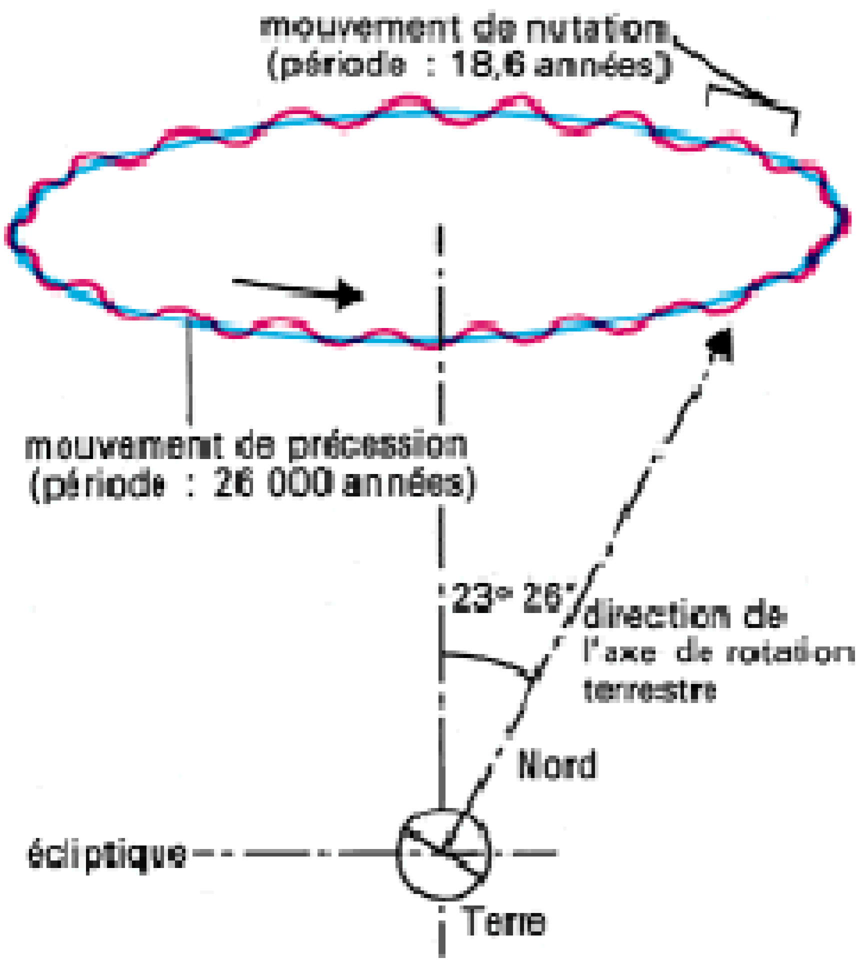
[2] Lomonosov Moscow State University, Sternberg Astronomical Institute, Moscow, Russia
[3] Hydrometeocenter of Russia, Moscow
[4] Paris observatory, SYRTE

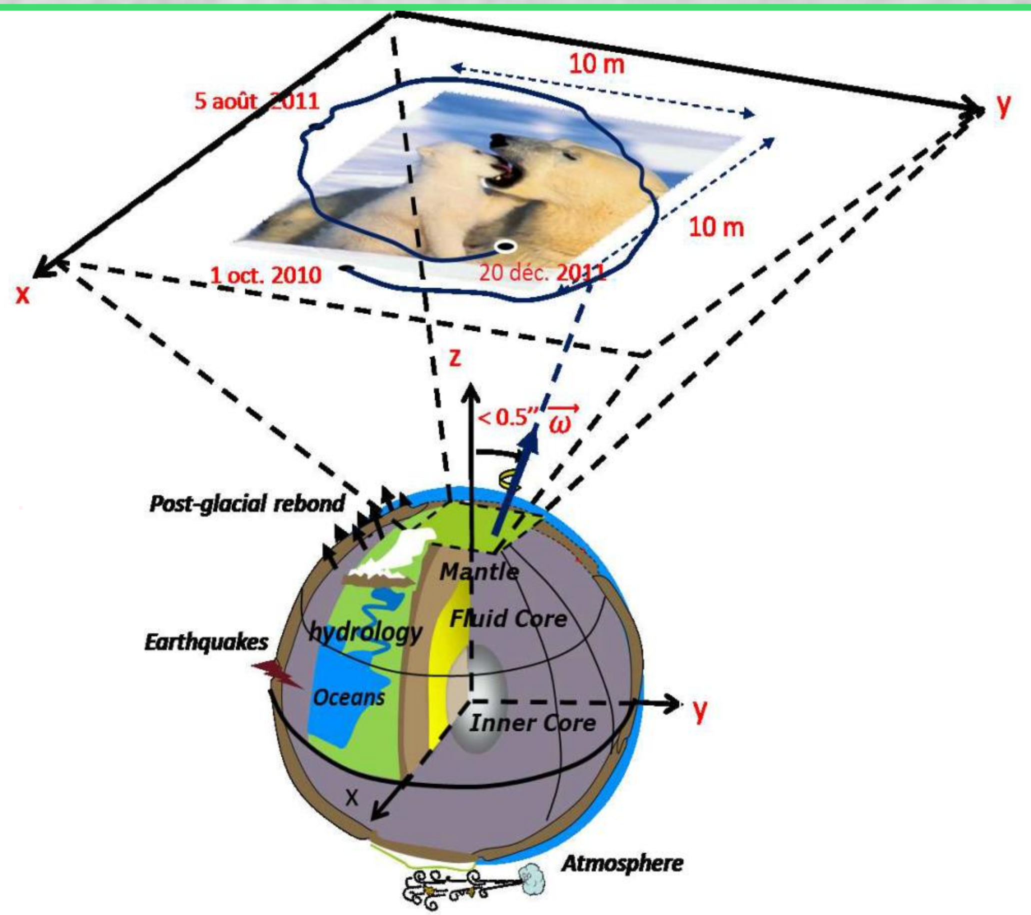


OBSPM 2017
Paris

Earth rotation variations

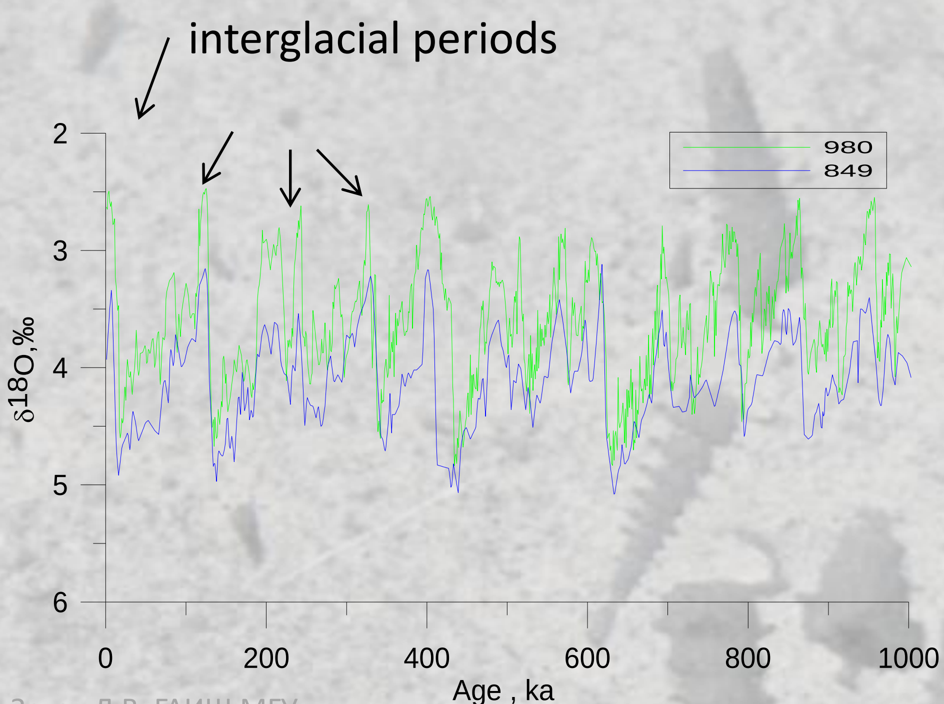
Precession and Nutation of the Earth axis
26 000, 18.6 years, 1, 0.5 year caused
by Sun and Moon tides

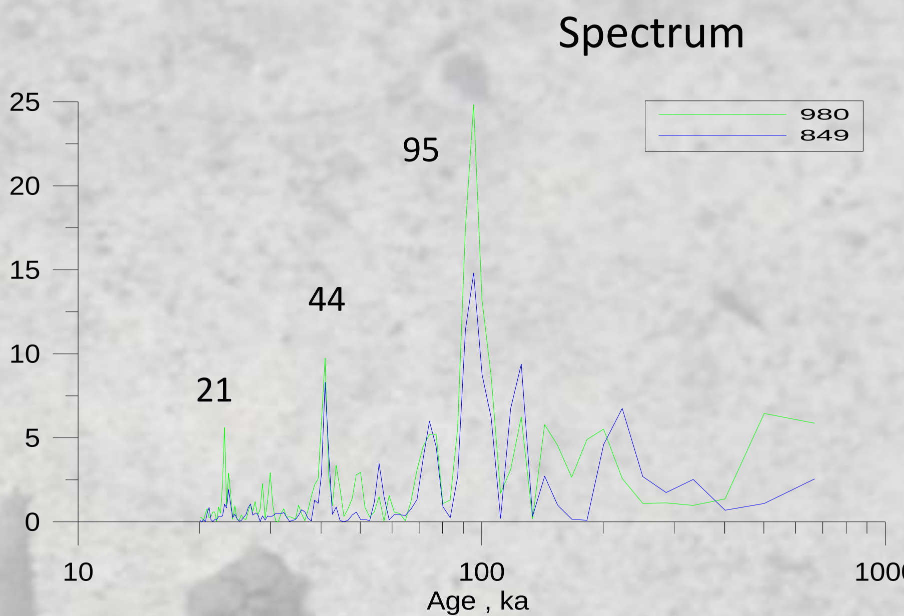




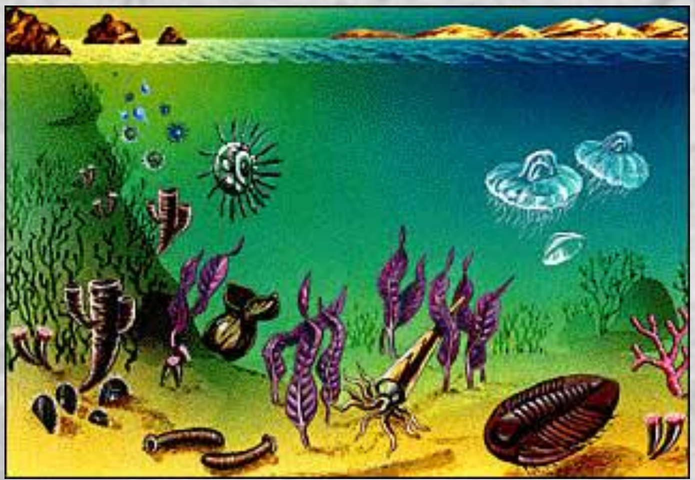
Earth's pole motion up to 10 meters
caused by geophysical effects –
momentum exchange between the Ocean,
Atmosphere, and Solid Earth

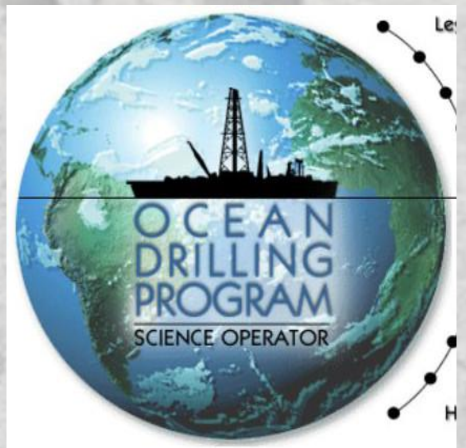
Paleoclimate





Зотов Л.В. ГАИШ МГУ





Milankovitch theory

Berger: Milankovitch Theory and Climate

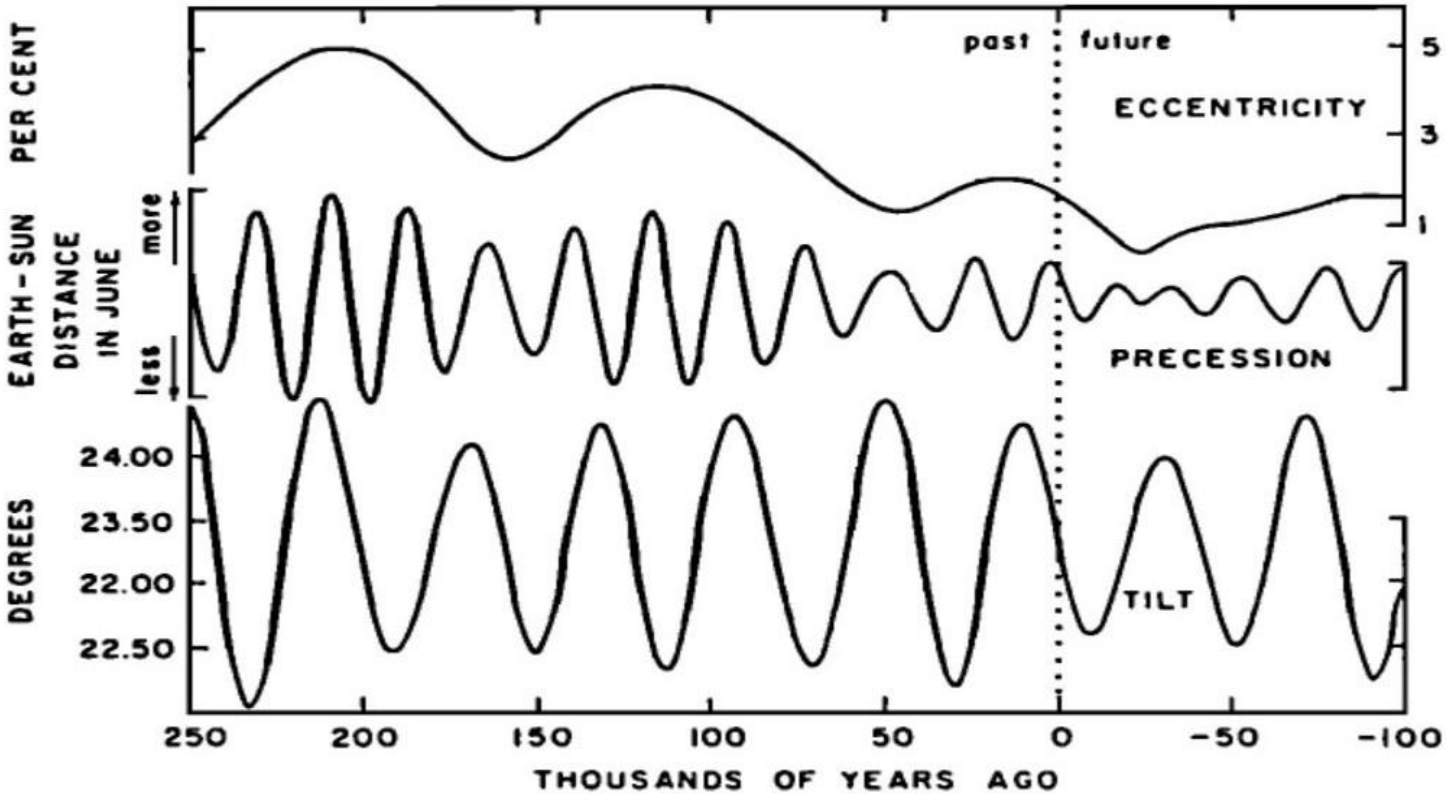
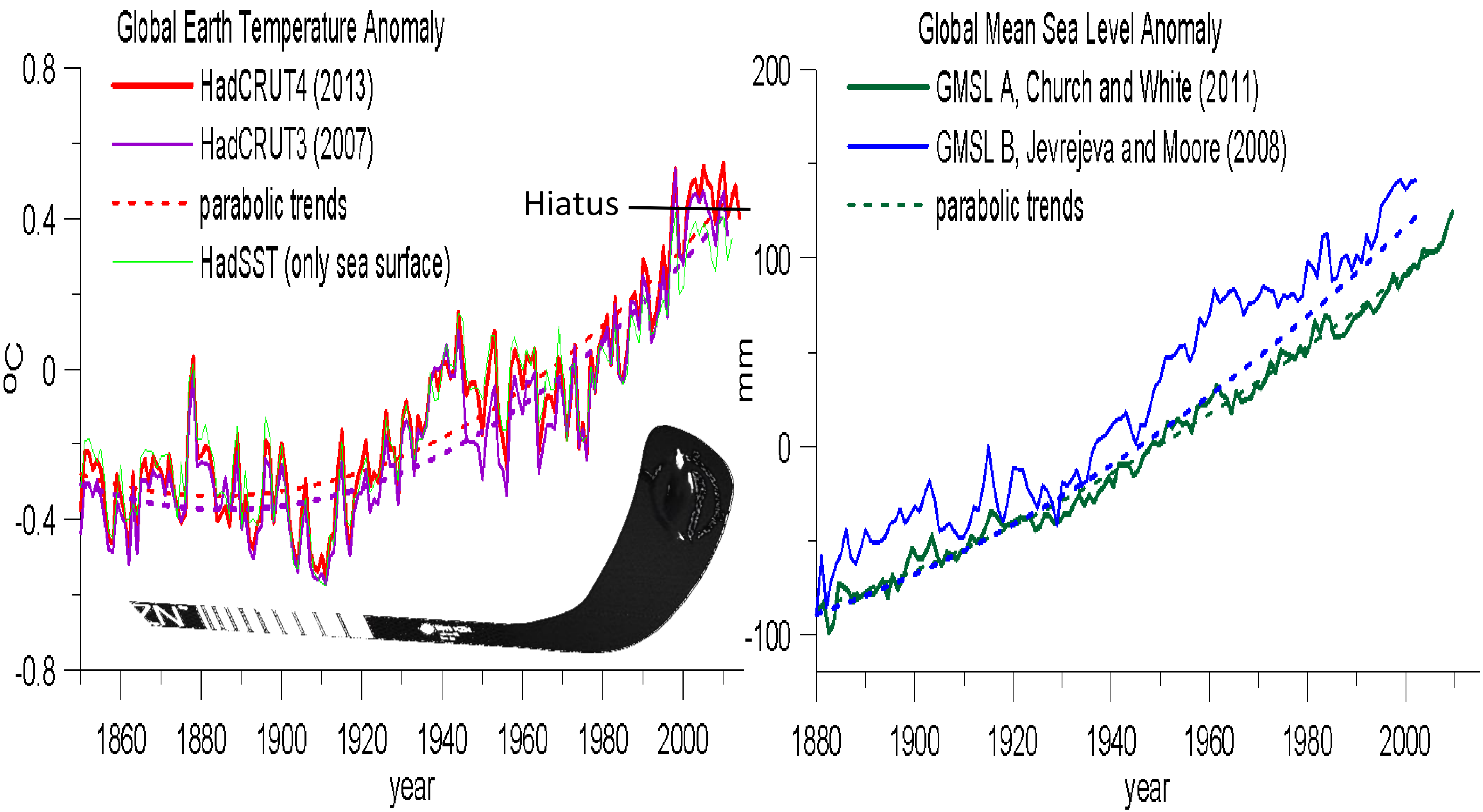


Fig. 11. Long-term variations of eccentricity, precession, and tilt from 250,000 years B.P. to 100,000 years A.P. [Berger, 1978c].

States that long-term Climate Change depends on Earth rotation and orbital motion

What about short-term?

Global Climate Change



Prediction of the Global Earth Temperature based on cyclic and polynomial trend made by Alexey Lyubushin in his book and in his article with L. Klyashtorin

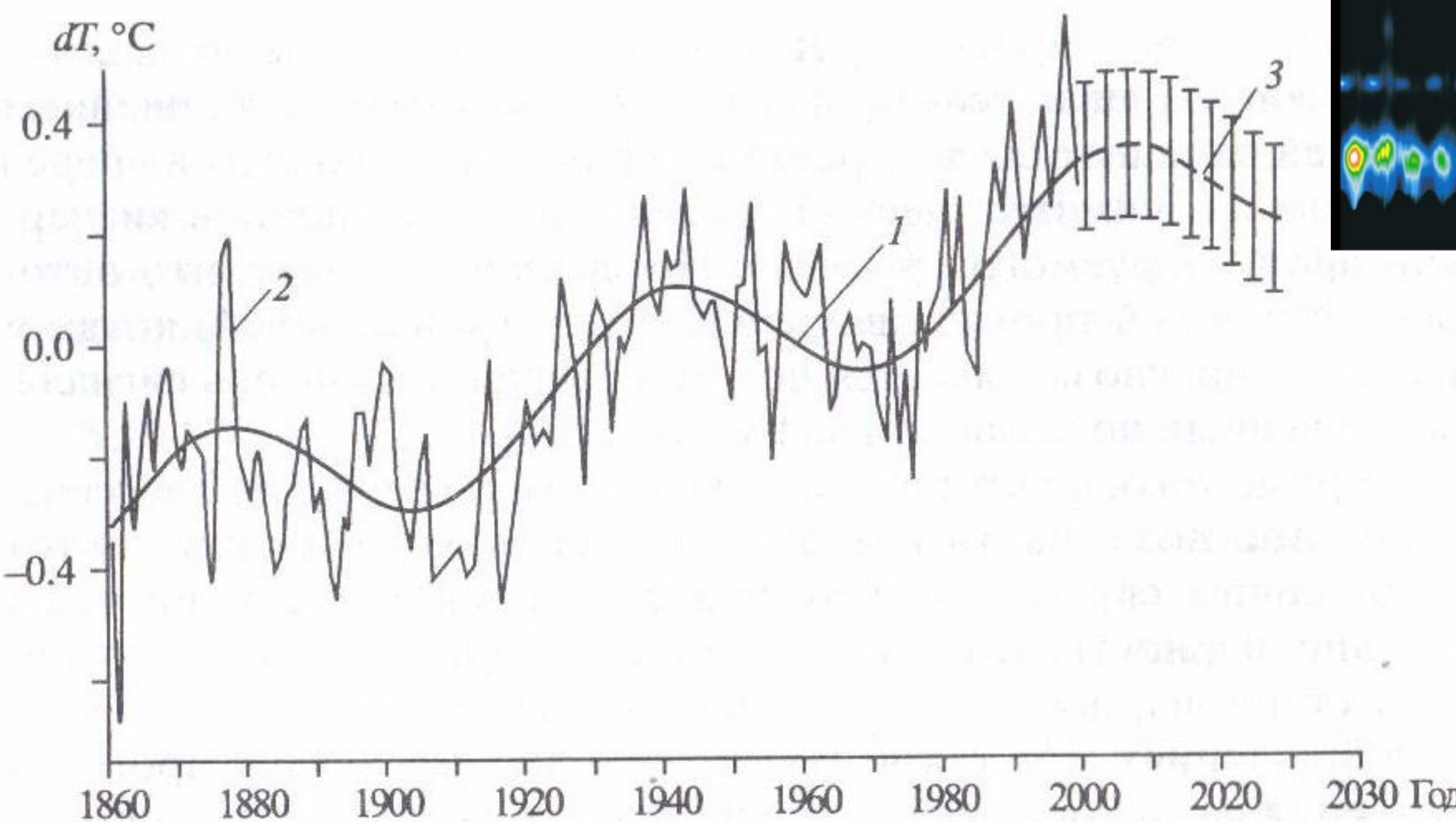
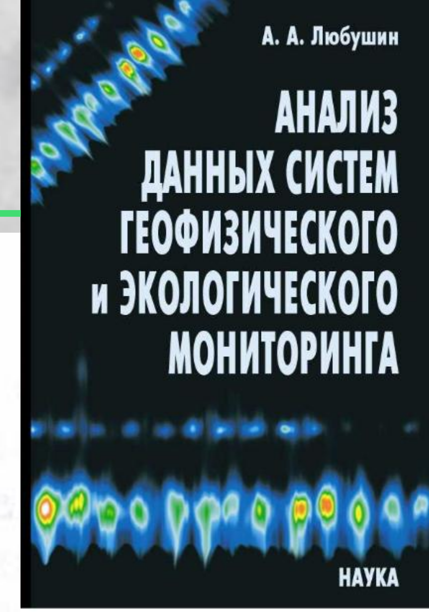


Рис. 1.1. Циклический тренд глобальной температурной аномалии (*1*), межгодовые вариации *dT* (2) и поведение тренда на 2000–2030 гг. (*3*)



http://alexeylyubushin.narod.ru/Geophysical_Monitoring_Systems_Data_Analysis_Book_Rus.pdf

Multichannel Singular Spectrum Analysys MSSA

1) Lag parameter *L* selection

SSA- generalization of PCA

Multichannel signal

$$x = (x_1, x_2, \dots, x_N)$$

Embedded into block matrix X

2) SVD — singular value decomposition of the matrix is performed

1D-SSA – “Caterpillar”

$$X = USV^T$$

3) For each singular number s_i the matrices are reconstructed

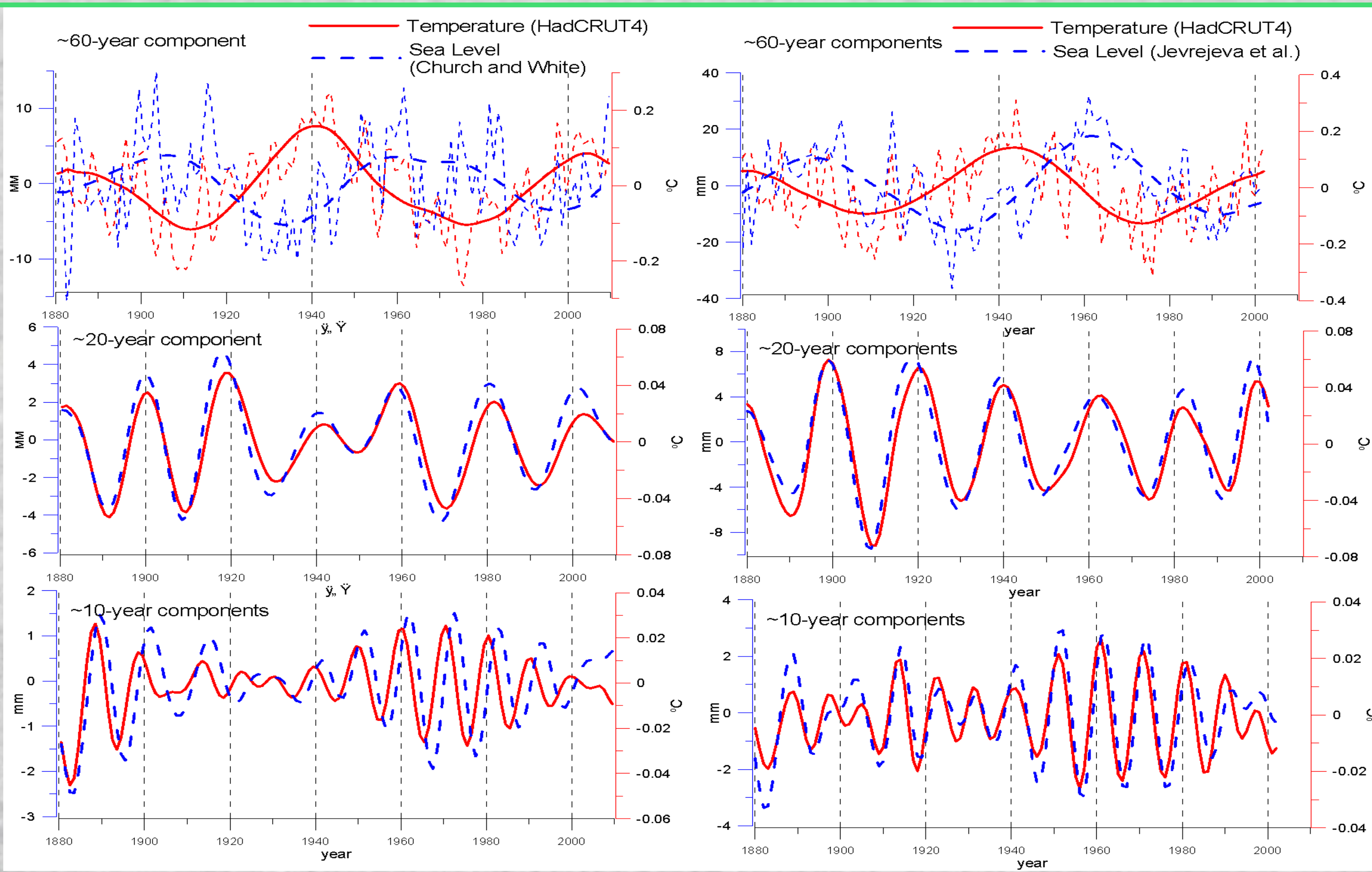
$$X^i = s_i u_i v_i^T,$$

and signal for every component is obtained by Hankelization

4) Similar signals are grouped into Principal Components (PCs)

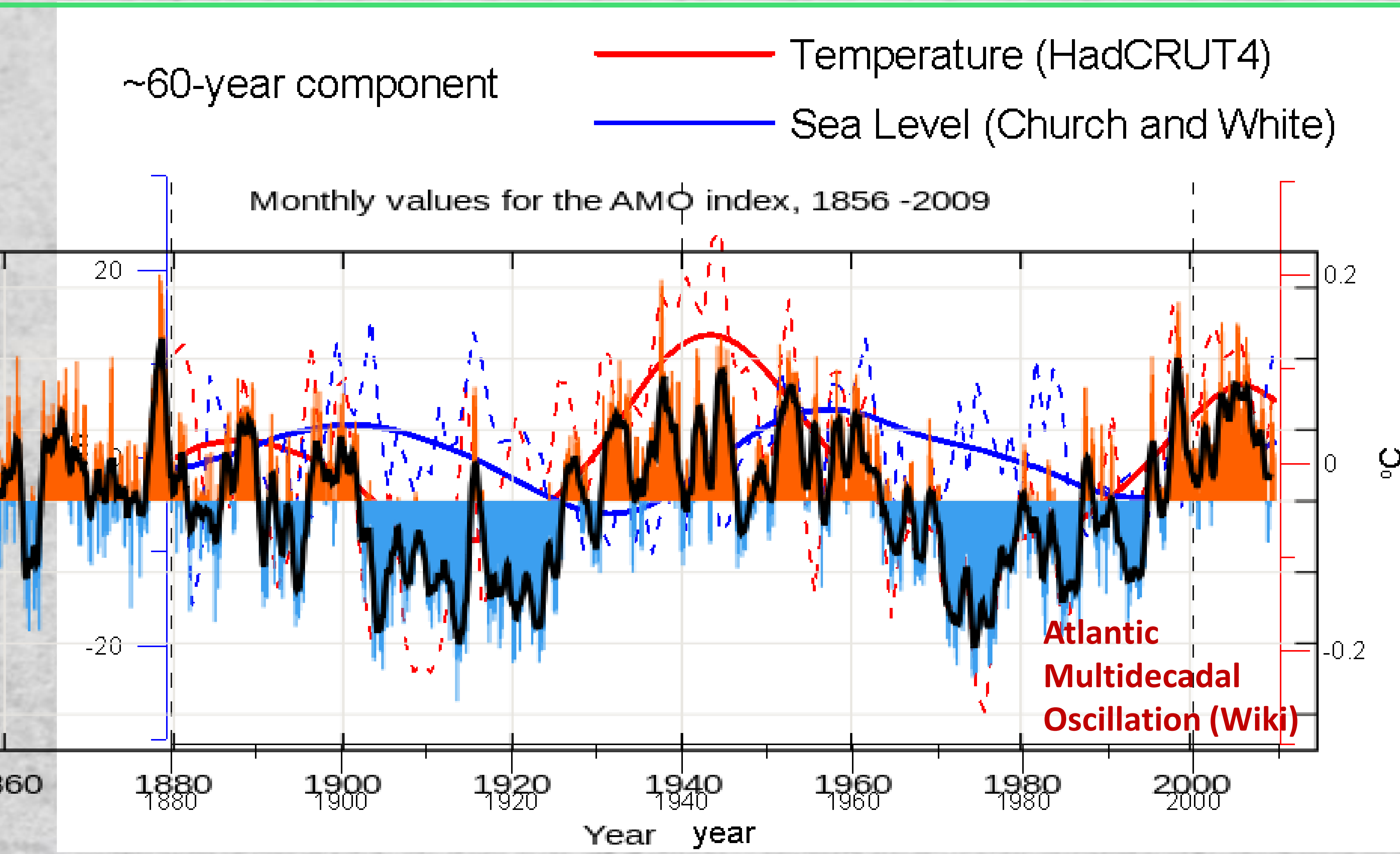
PC1, PC2, PC3…

Results of MSSA for Temperature and Sea Level



L=22, parabolic trends preliminarily removed

Results of MSSA for temperature and Sea Level



L=22, parabolic trends preliminarily removed

Why Climate oscillations are so important?

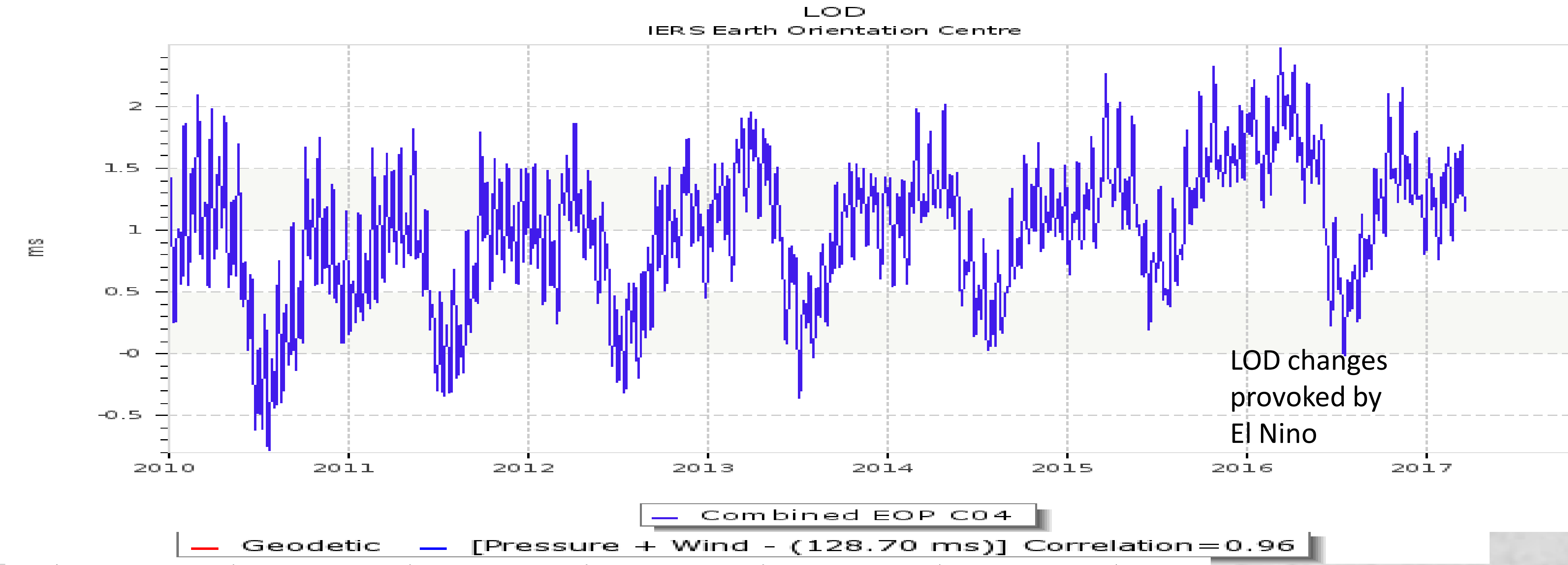

November-December 1812, at the west from Moscow.



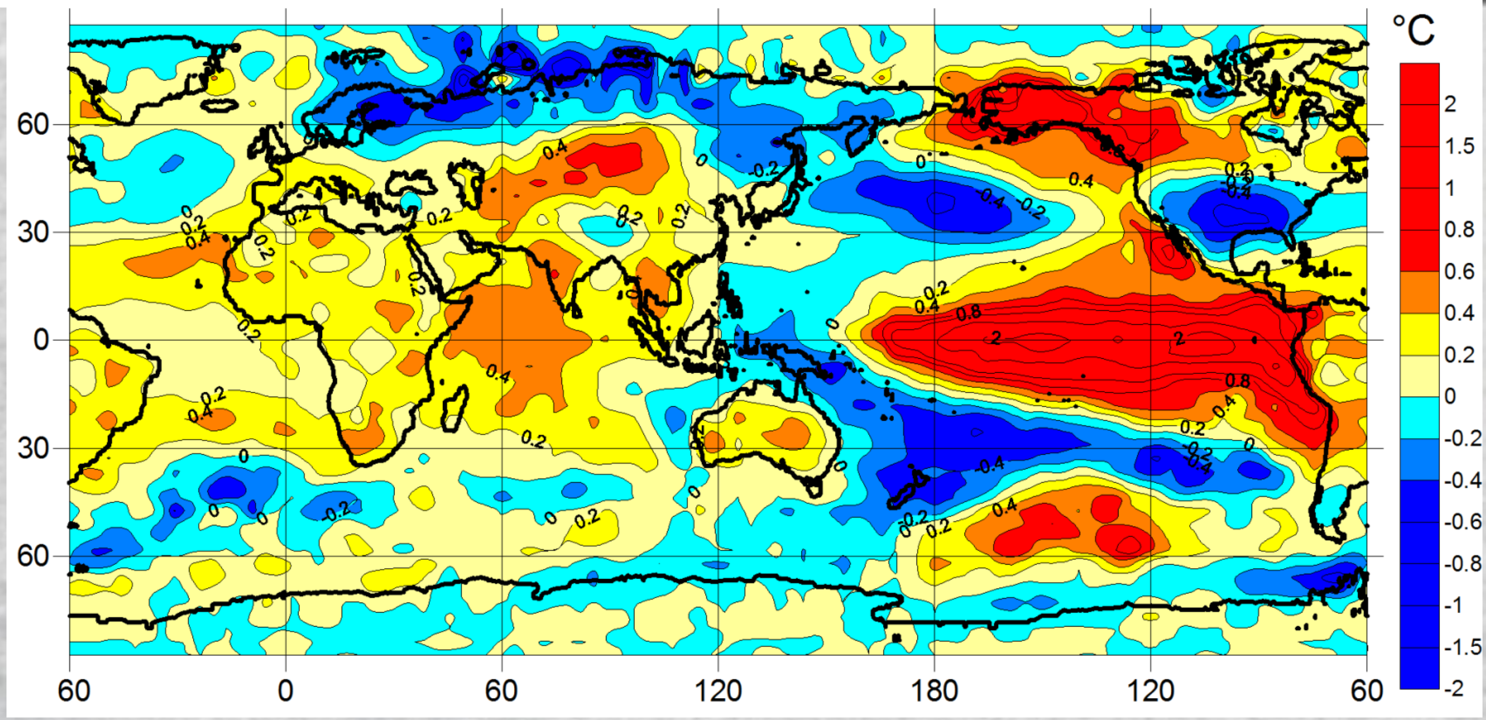
November-December 1941, at the west from Moscow.

Slide from Ilya Serykh

César Caviedes, "El Niño in History: Storming Through the Ages", 2001

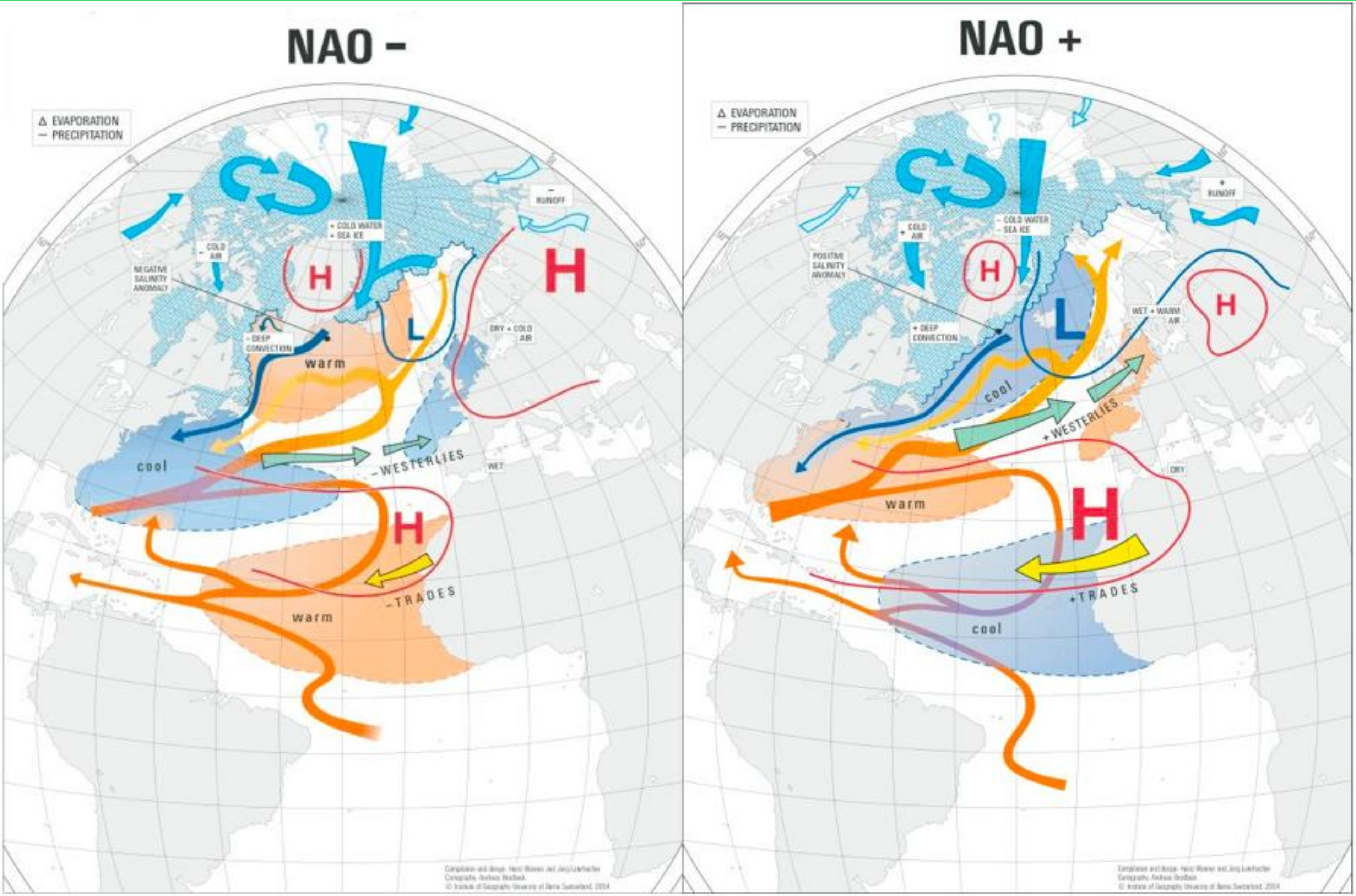


LOD changes provoked by El Nino

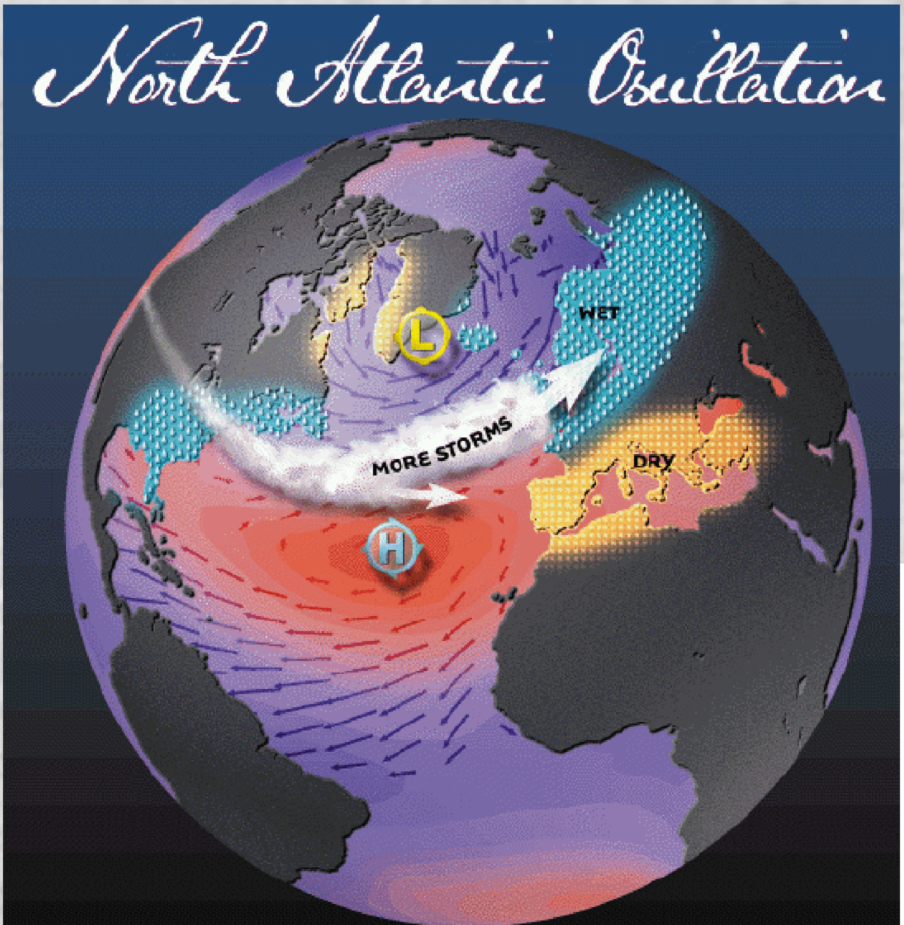


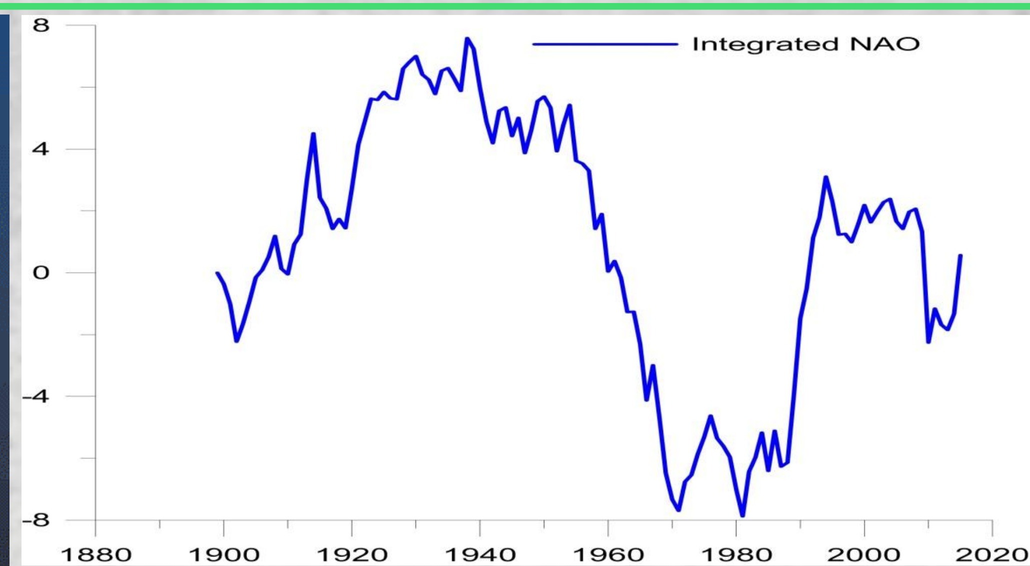
Average temperature difference between El Nino and La Nina
(I. Serikh)

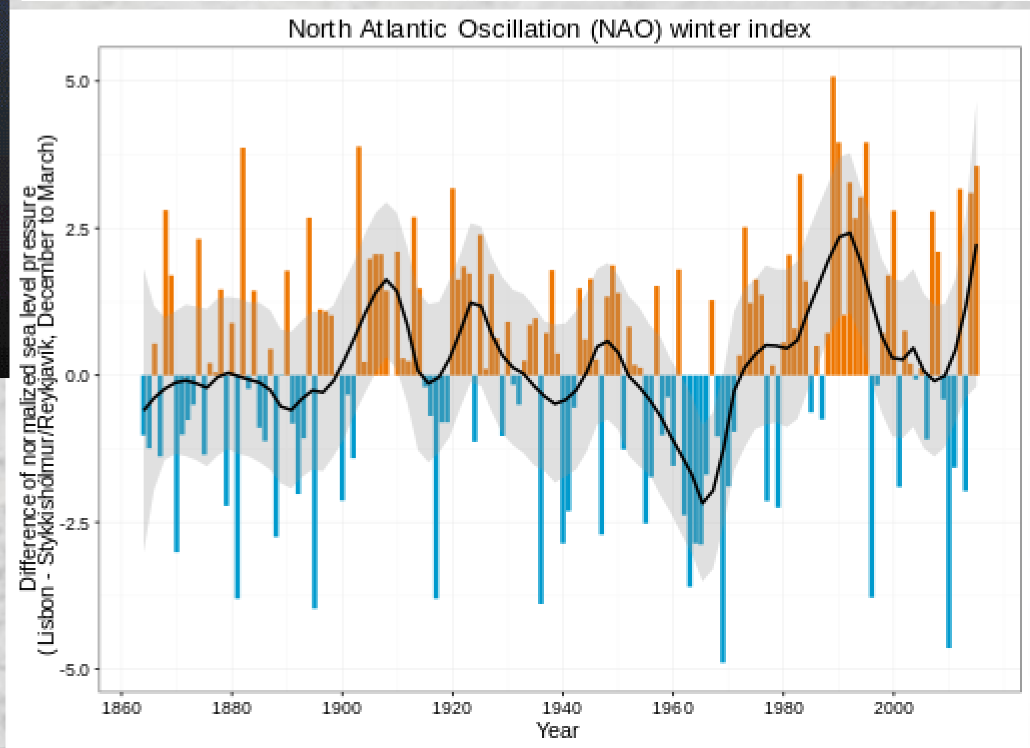
North Atlantic Oscillation (NAO)



AMO as integral of NAO







See:
Gulev Sergey K, Latif Mojib. Ocean science: the origins of a climate oscillation. Nature 2015;521:428430. http://dx.doi.org/10.1038/521428a

Earth System Research Laboratory
Physical Sciences Division

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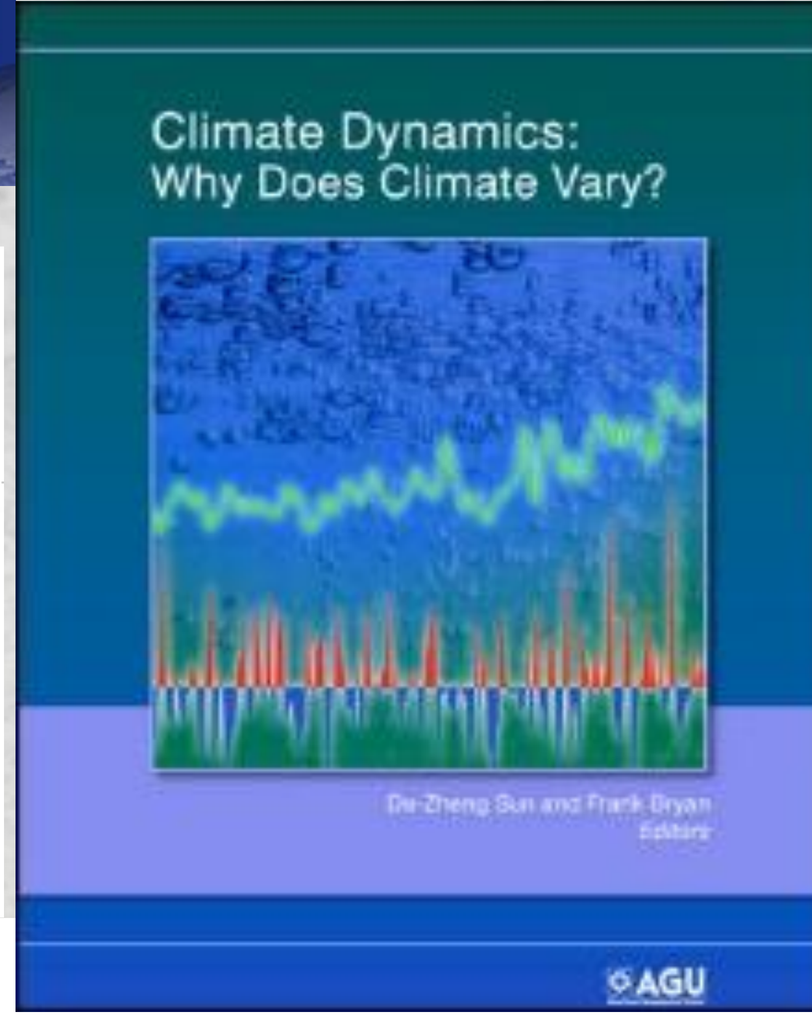
Curriculum Vitae • Publications



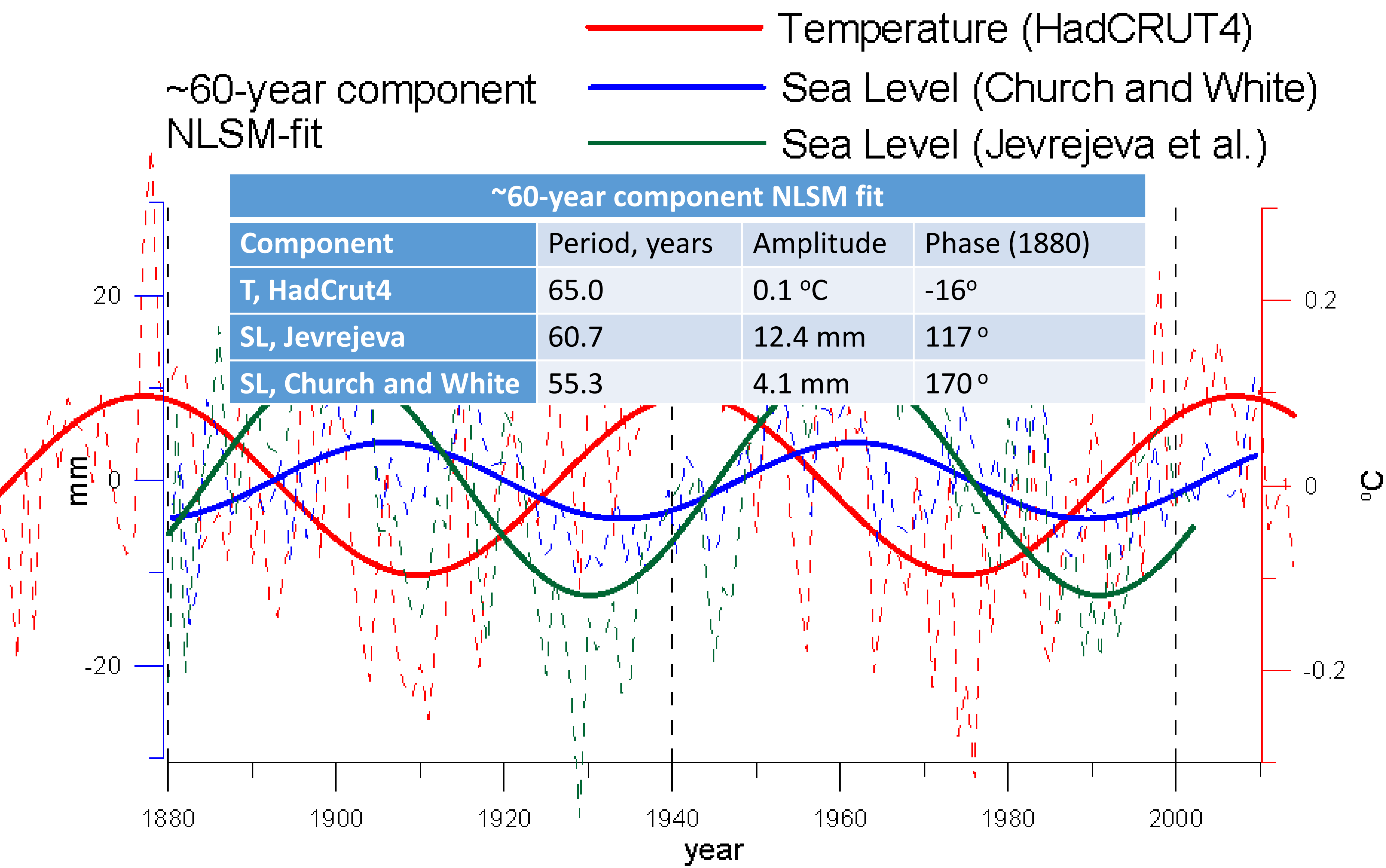
$$\mathbf{x}(t+\tau)=\exp(\mathbf{L}\tau)\mathbf{x}(t)+\int_0^{\tau}\exp\left(\mathbf{L}[\tau-s]\right)\mathbf{N}(t+s)\,ds\ .$$

Stochastic forcing of north tropical Atlantic sea surface temperatures by the North Atlantic Oscillation

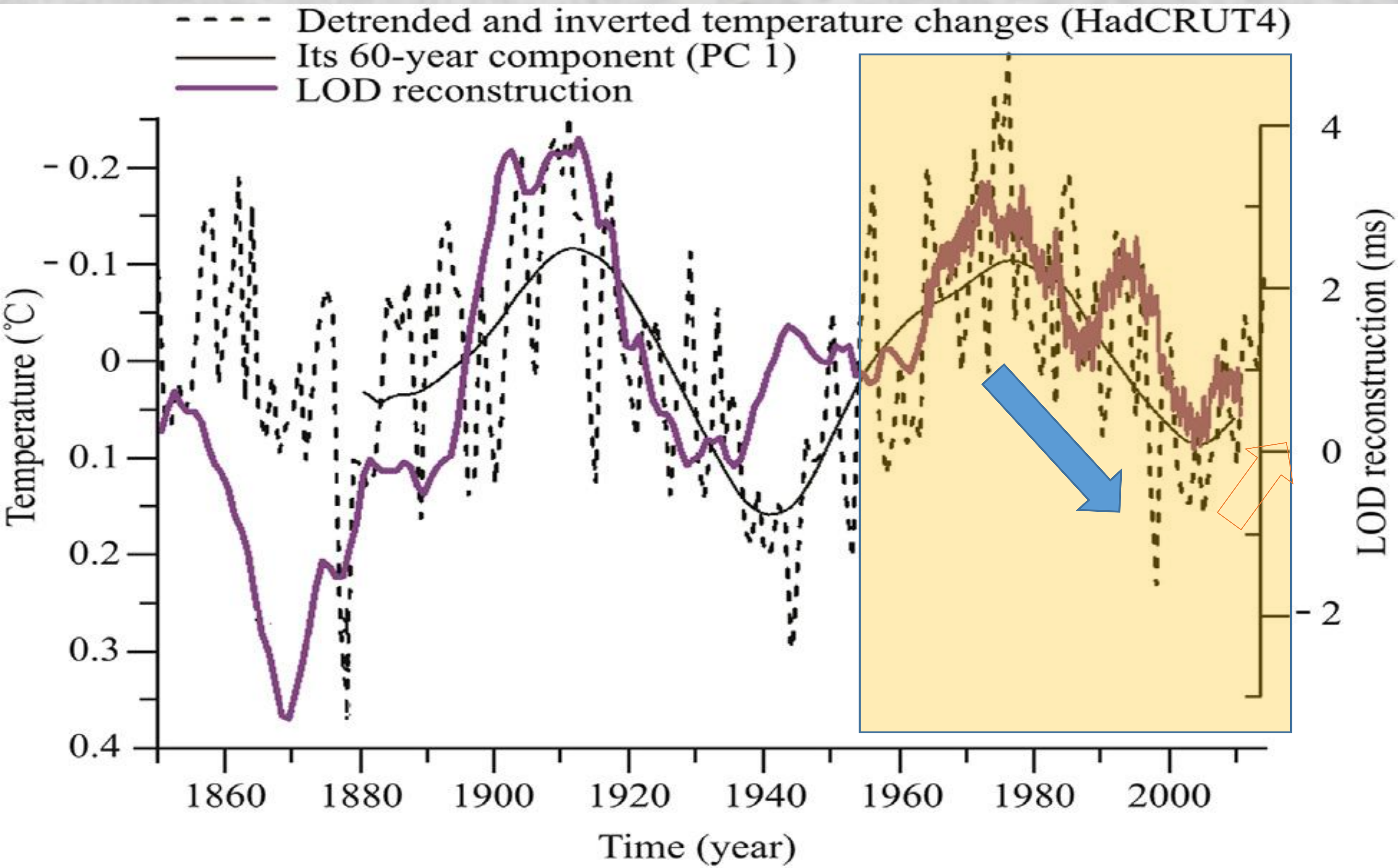
Results of non-linear LS-adjustment

~60-year component NLSM-fit

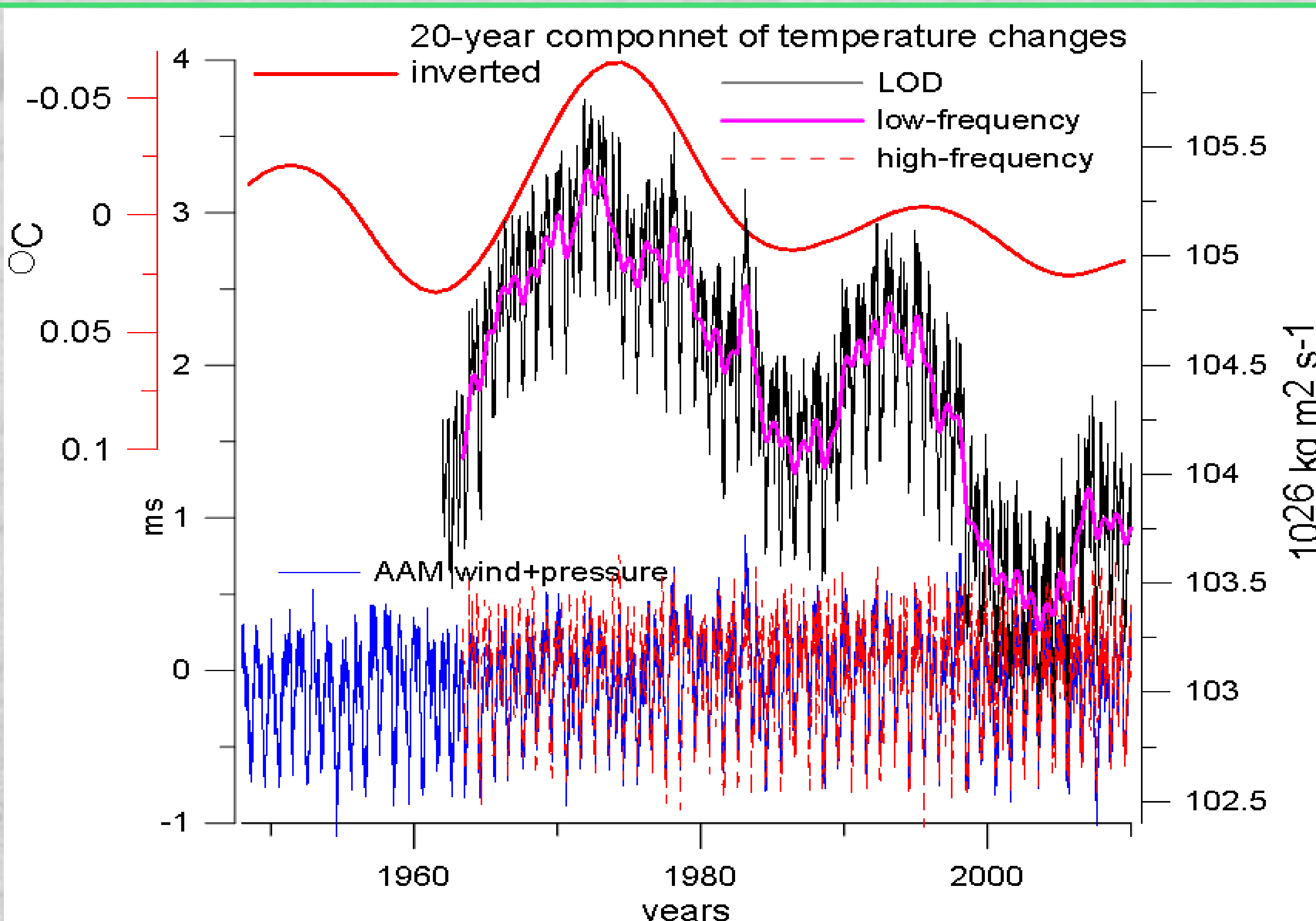
~60-year component NLSM fit			
Component	Period, years	Amplitude	Phase (1880)
T, HadCrut4	65.0	0.1 ^{o}C	-16^{o}
SL, Jevrejeva	60.7	12.4 mm	117^{o}
SL, Church and White	55.3	4.1 mm	170^{o}



Long-term (60-year) changes in Temperature and LOD



Non-tidal LOD and 20-year temperature changes



L.V.Zotov

The grave of Nikolay Mikhailovich Stoyko (1894-1976) at Snt. Genevieve de Bois
The director of the Bureau International de l'Heure, founder of annual LOD variations

L.V.Zotov,

Russian Meteorology and Hydrology
No. 8, pp. 1–8, 2005

Meteorologiya i Gidrologiya
UDC 551.324.24+525.35/.37

VARIATION OF THE MASS OF THE ICE SHEET OF ANTARCTICA AND INSTABILITY OF THE EARTH'S ROTATION

N. S. Sidorenkov*, O. V. Lutsenko*, N. N. Bryazgin**,
E. I. Aleksandrov**, and V. G. Zakharov***

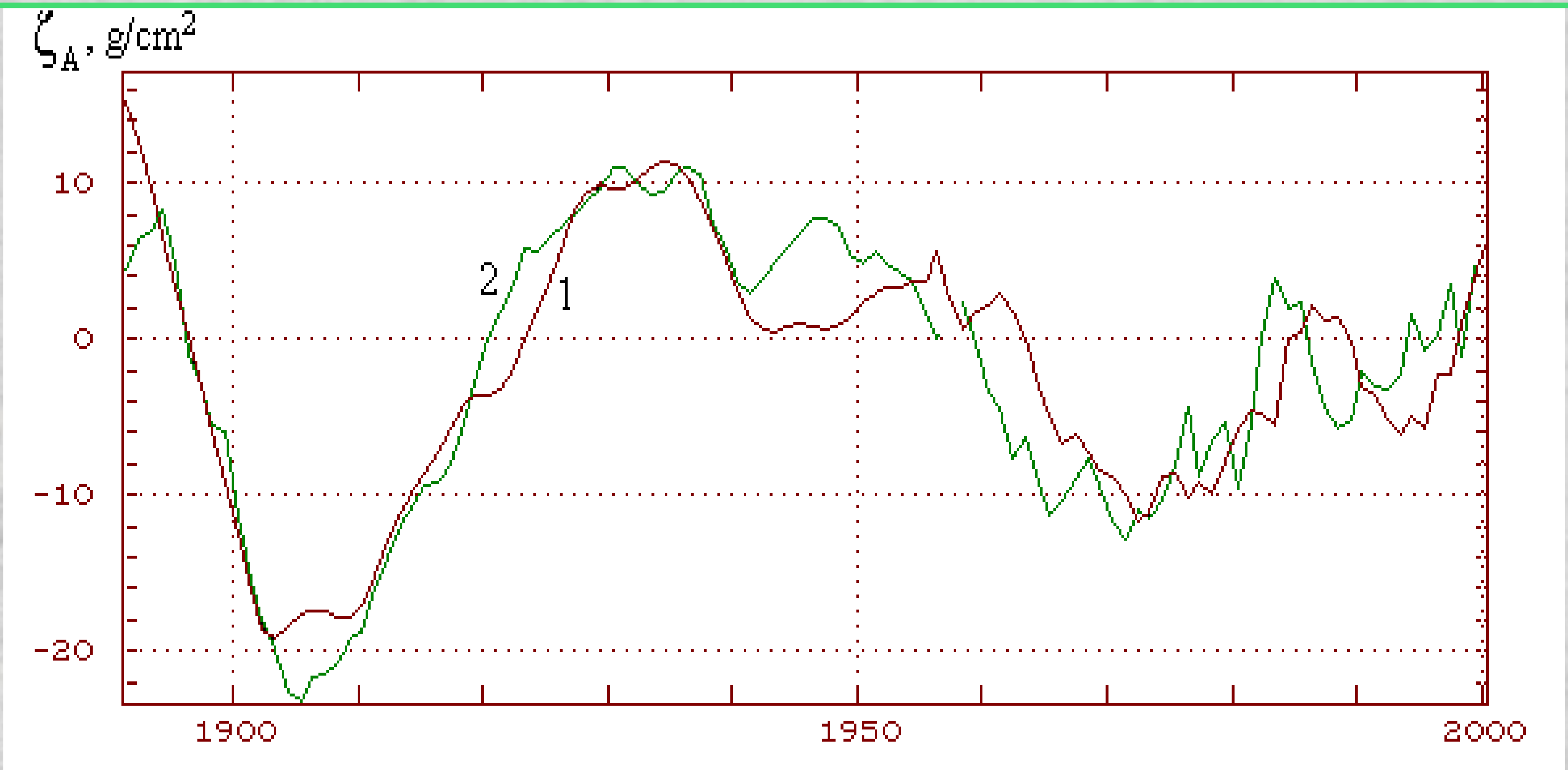
A theoretical series of the Antarctic ice mass variation from 1891 to 2000 is calculated using astronomical data on the movement of the North Pole and variation in the velocity of the Earth's daily rotation. The series is compared with the data of V. N. Petrov [3] on the annual layers of snow accumulation in Antarctica and precipitation series at Antarctic stations. It is shown that the theoretical series agrees well with results of actual snow measurements. It is concluded that the theoretical series can be used to test the results of empirical studies of the temporal variability of the ice sheet of Antarctica and of atmospheric precipitation in Antarctica.

$$-\frac{1}{\sigma}\frac{dv_2}{dt}+v_1=\frac{n_{13}}{C-A}=-\frac{r^2}{2(C-A)}\iint_s \zeta(\theta,\lambda,t)\sin 2\theta\cos\lambda\, ds;$$

$$\frac{1}{\sigma}\frac{dv_1}{dt}+v_2=\frac{n_{23}}{C-A}=-\frac{r^2}{2(C-A)}\iint_s \zeta(\theta,\lambda,t)\sin 2\theta\sin\lambda\, ds;$$

$$\delta v_3=-(1+k')\frac{\delta n_{33}}{C}=-(1+k')\frac{r^2}{C}\iint_s \zeta(\theta,\lambda,t)\sin^2\theta\, ds.$$

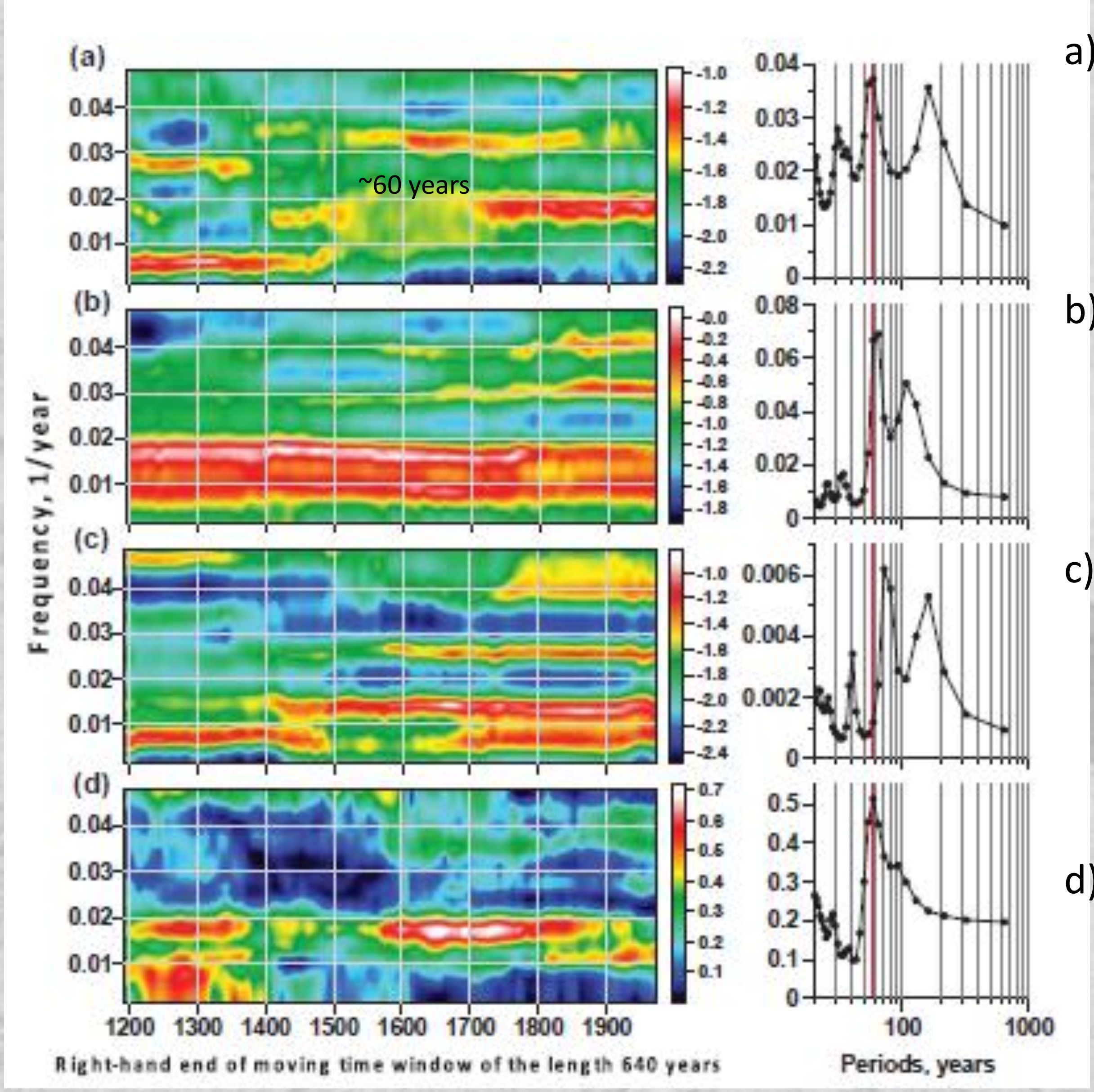
Ice mass of Antarctica and its reconstruction from LOD and PM



Temporal variations of the specific mass of ice in Antarctica, g·cm^{-2}.
1 – the theoretical value, obtained from EOP;
2 – the empirical value (Petrov, 1975; Bryazgin, 1990).

Russian Meteorology and Hydrology
No. 8, pp. 1–8, 2005
Meteorologiya i Gidrologiya
UDC 551.324.24+525.35/.37

Long-term (60-year) historical changes in Temperature



a) Mean winter temperatures in Greenland for time interval (553-1973) from ice cores (Dansgaard et. Al 1975)

b) Temperature anomaly on Sweden from tree rings of arctic pine 500-1980 (Briffa et al. 1990)

c) Humidity in Southern California from tree rings of moutaine pine 6000 B.C.-1979 (Graybill et all 1994)

d) Global temperature anomalies (Lawrimour et al. 2001)

A.Lyubushin, L. Klyashtorin Short term global dT prediction… Energy and Environment Vol 23 N 1 2012

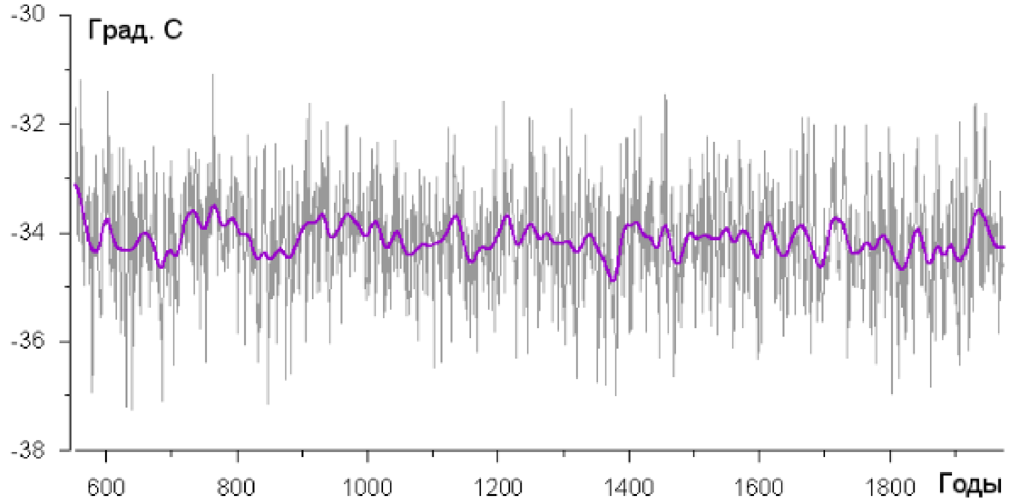
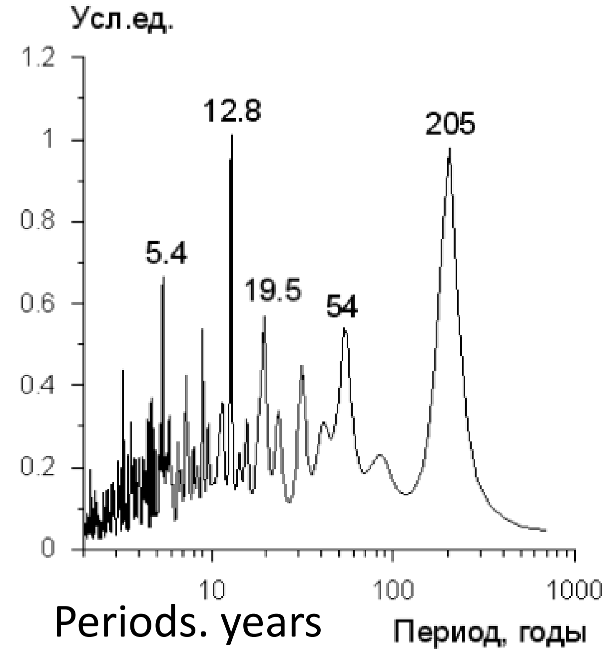
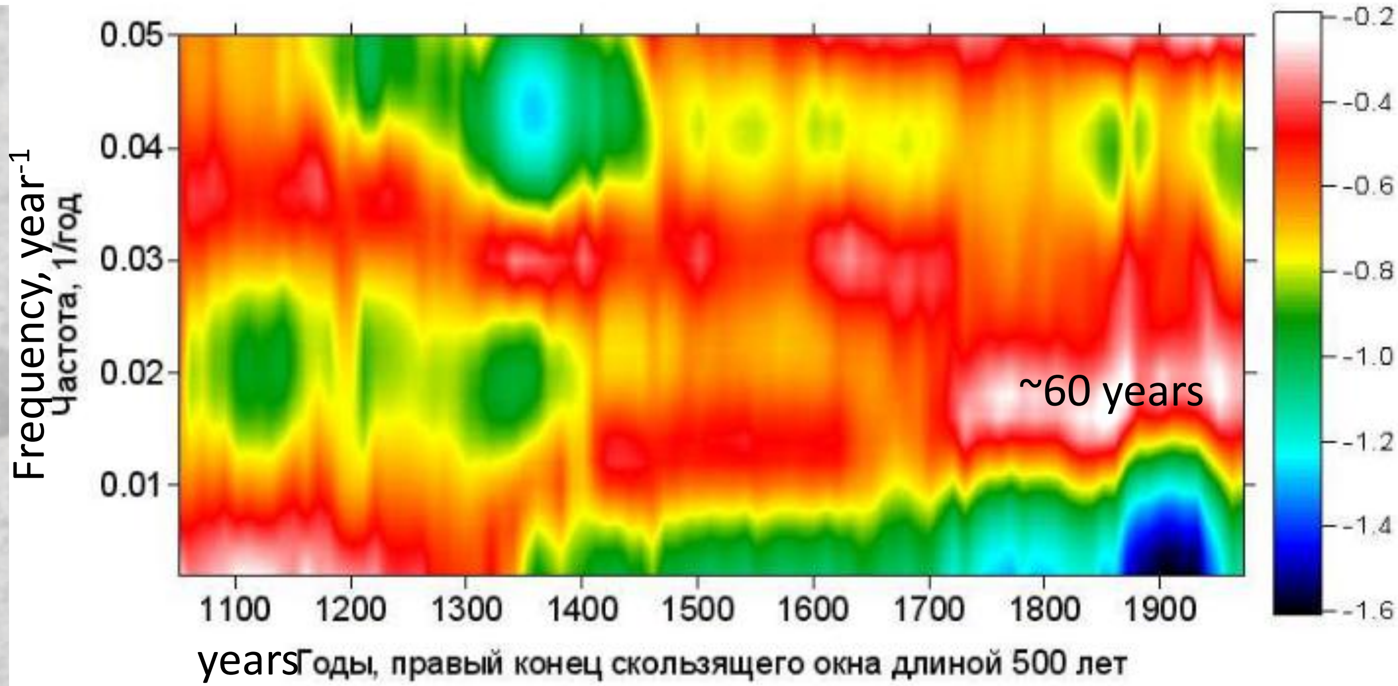


Рис.1.2. Гауссовский тренд с параметром усреднения 10 лет (толстая линия) данных ежегодных реконструкций зимних температур в Гренландии (553-1973 гг.) по содержанию изотопа ^{18}O в ледовых кернах (тонкая линия).



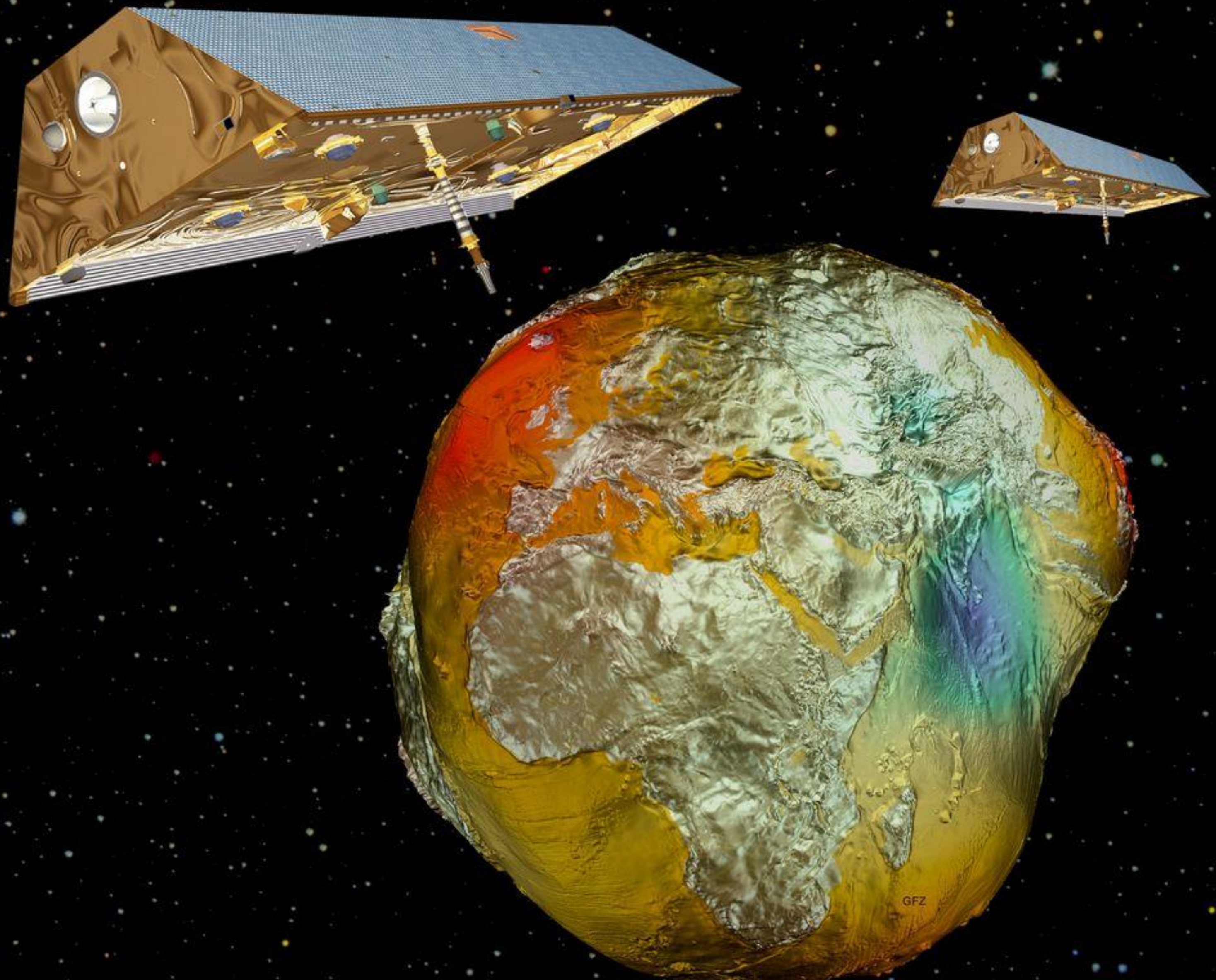
Greenland winter temperature reconstructions (553-1973) based on ^{18}O isotope (Dansgaard, 1975)

Its autoregressive spectrum and time-frequency analysis estimated by Alexey Lyubushin in his book

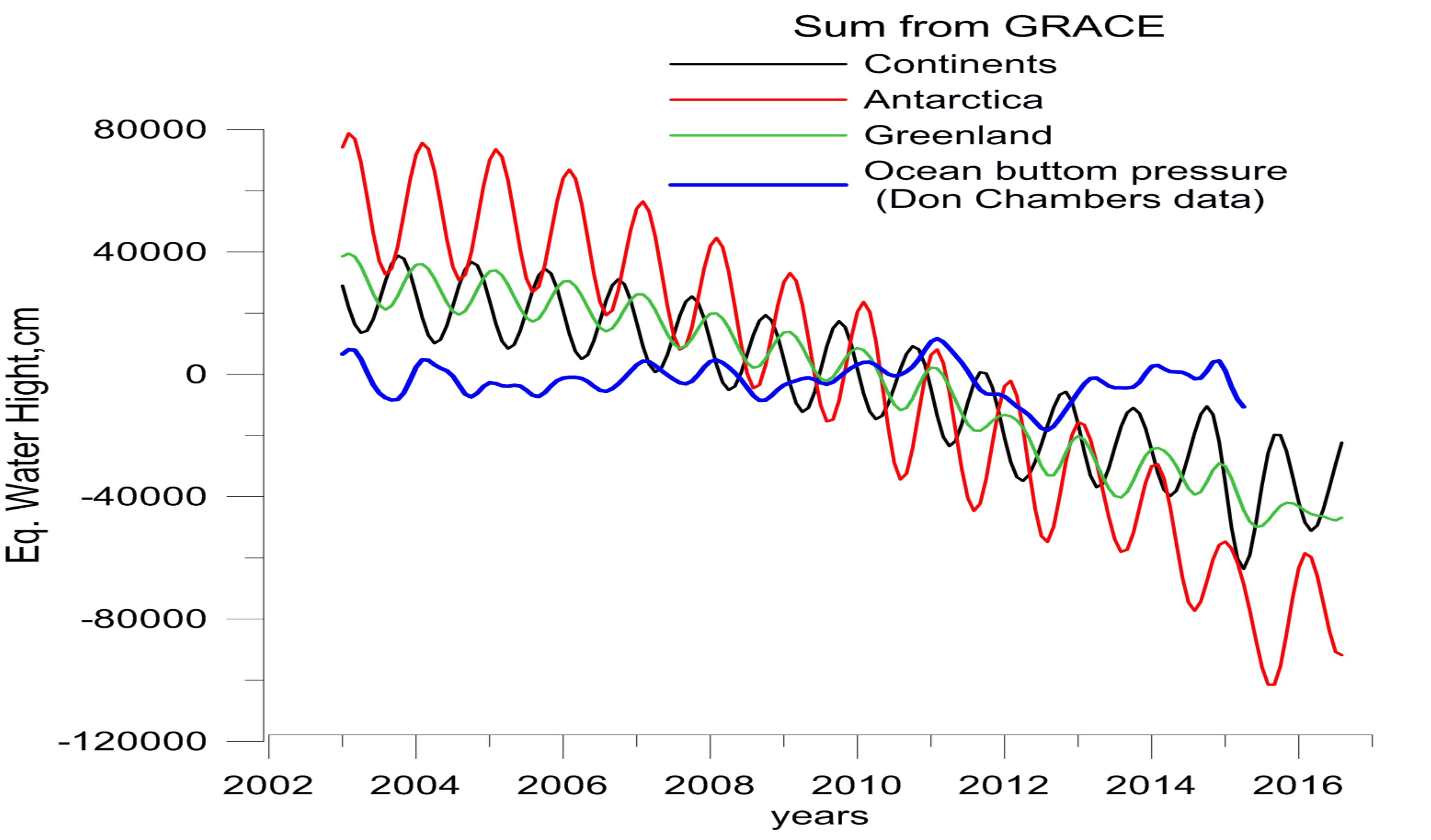


http://alexeylyubushin.narod.ru/Geophysical_Monitoring_Systems_Data_Analysis_Book_Rus.pdf

Gravity Recovery and Climate Experiment GRACE

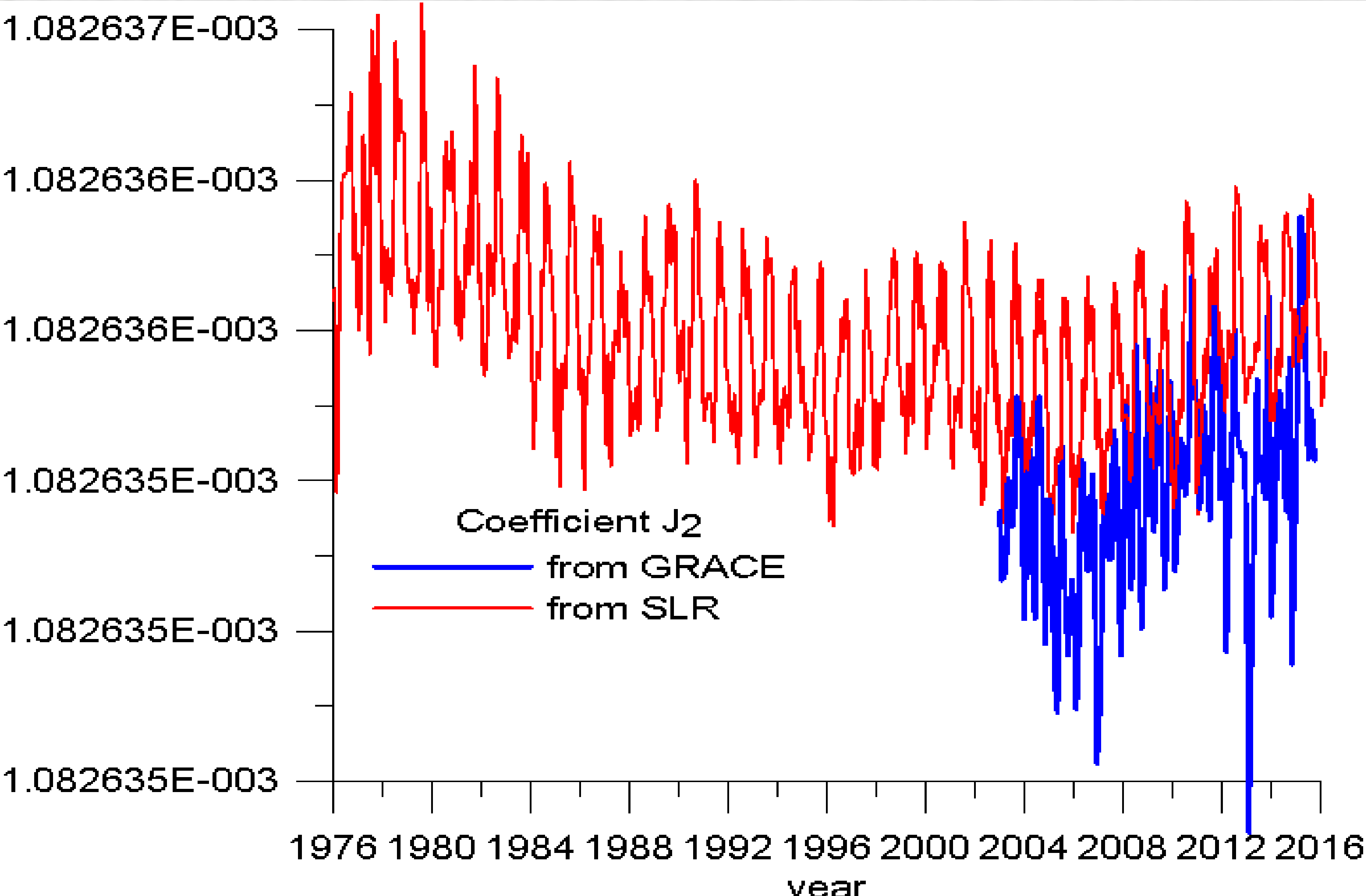


Global mass changes in GRACE epoch

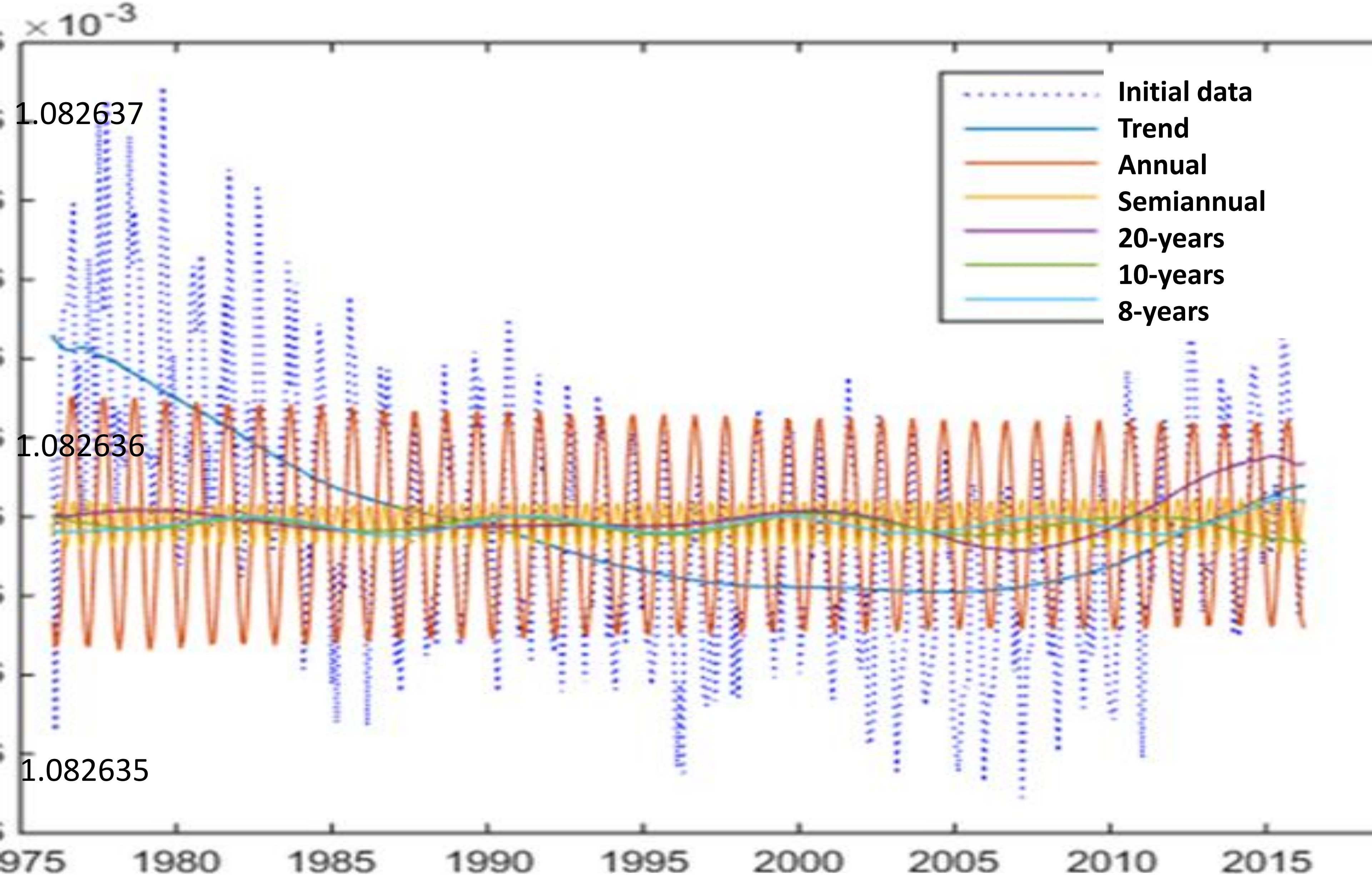


Estimated through MSSA of JPL Level 2 Data

Variations of J_2 coefficient from SLR and GRACE



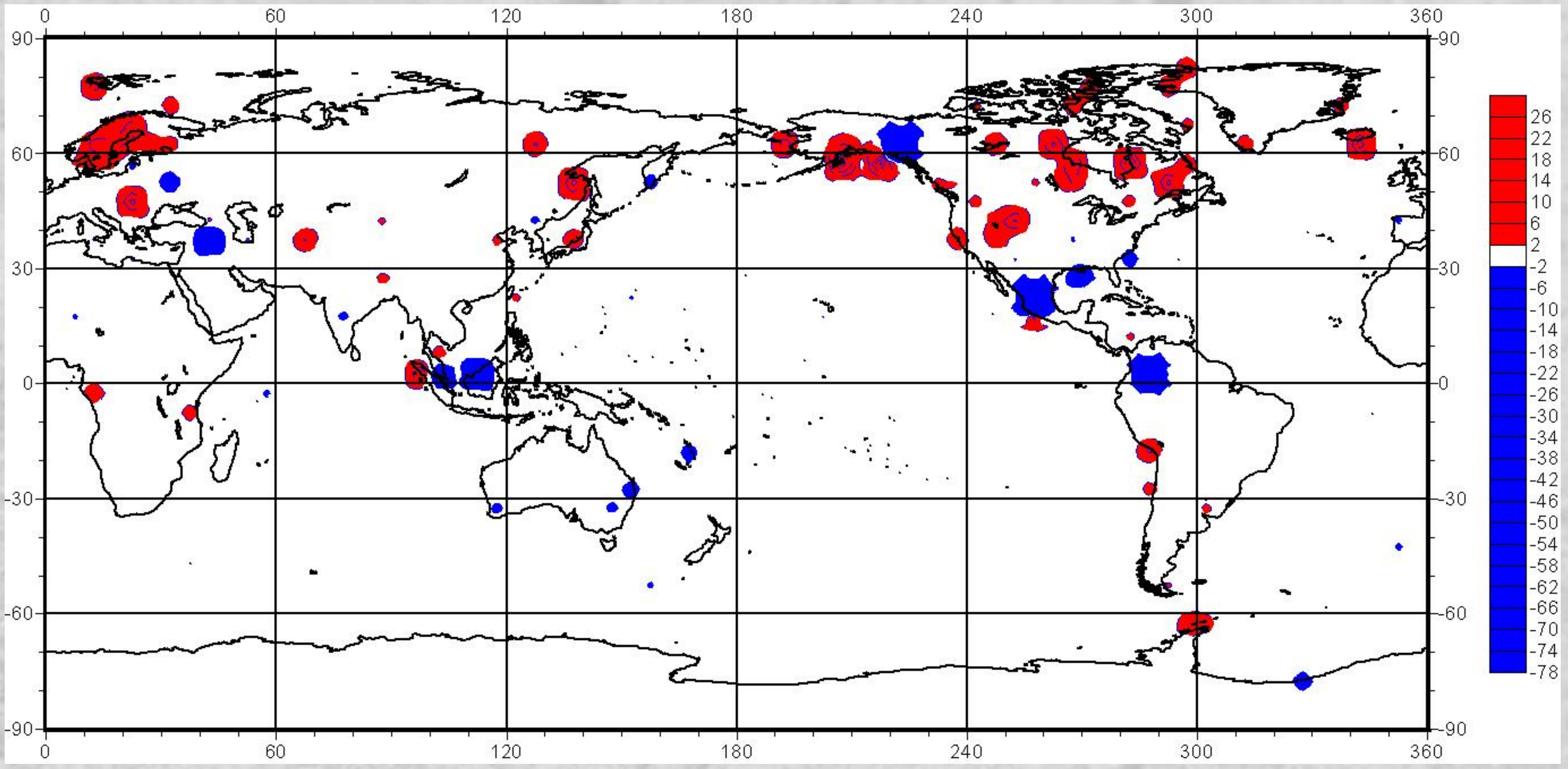
MSSA components of variations in J_2



Zotov, Balakireva, 2016

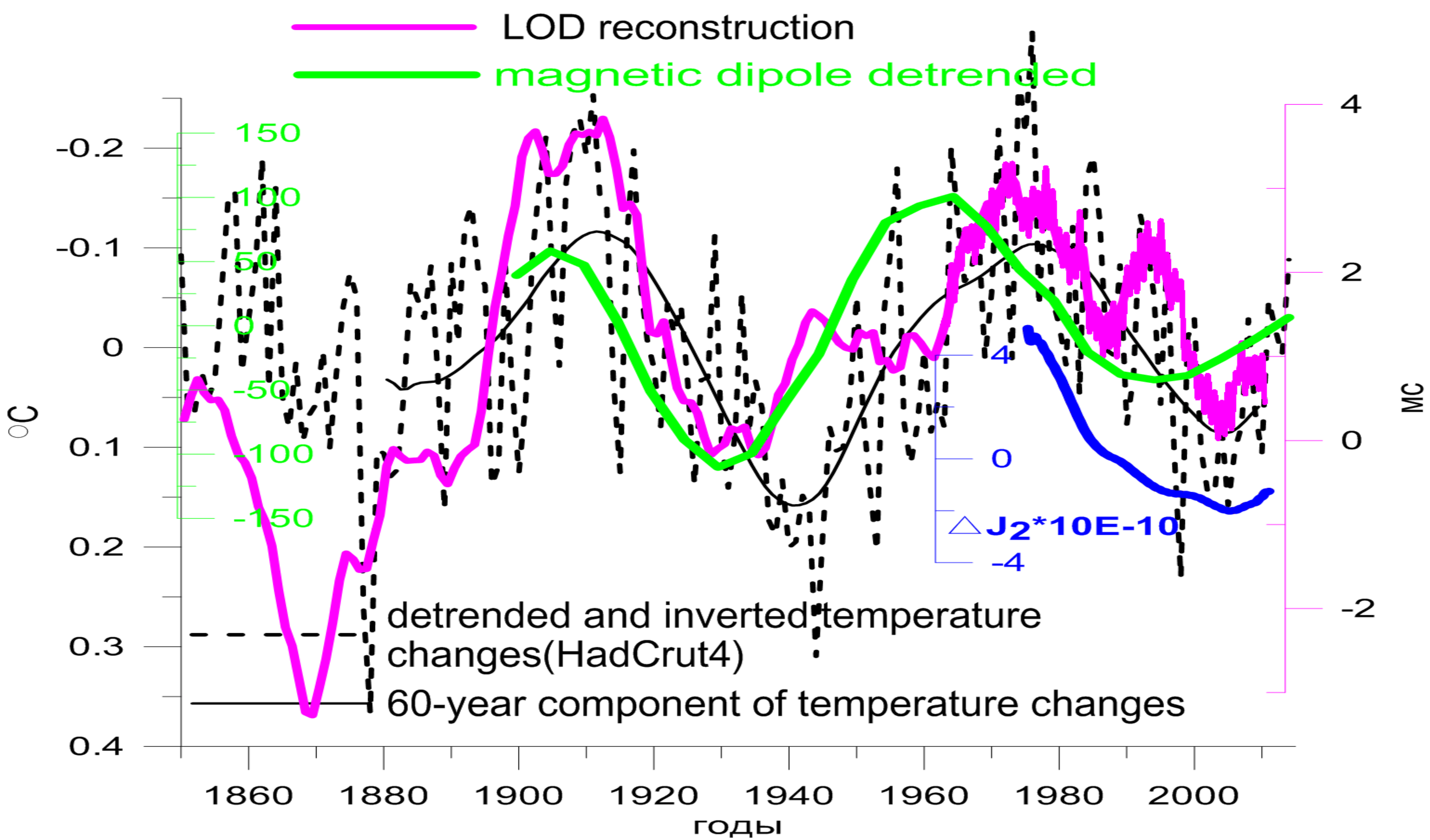
The Earth's flattening is decreasing, according to ITRF vertical motion spherical decomposition analysis by Chujkova et al.

ITRF 2008 vertical motions, red colour - positive values, blue colour - negative values



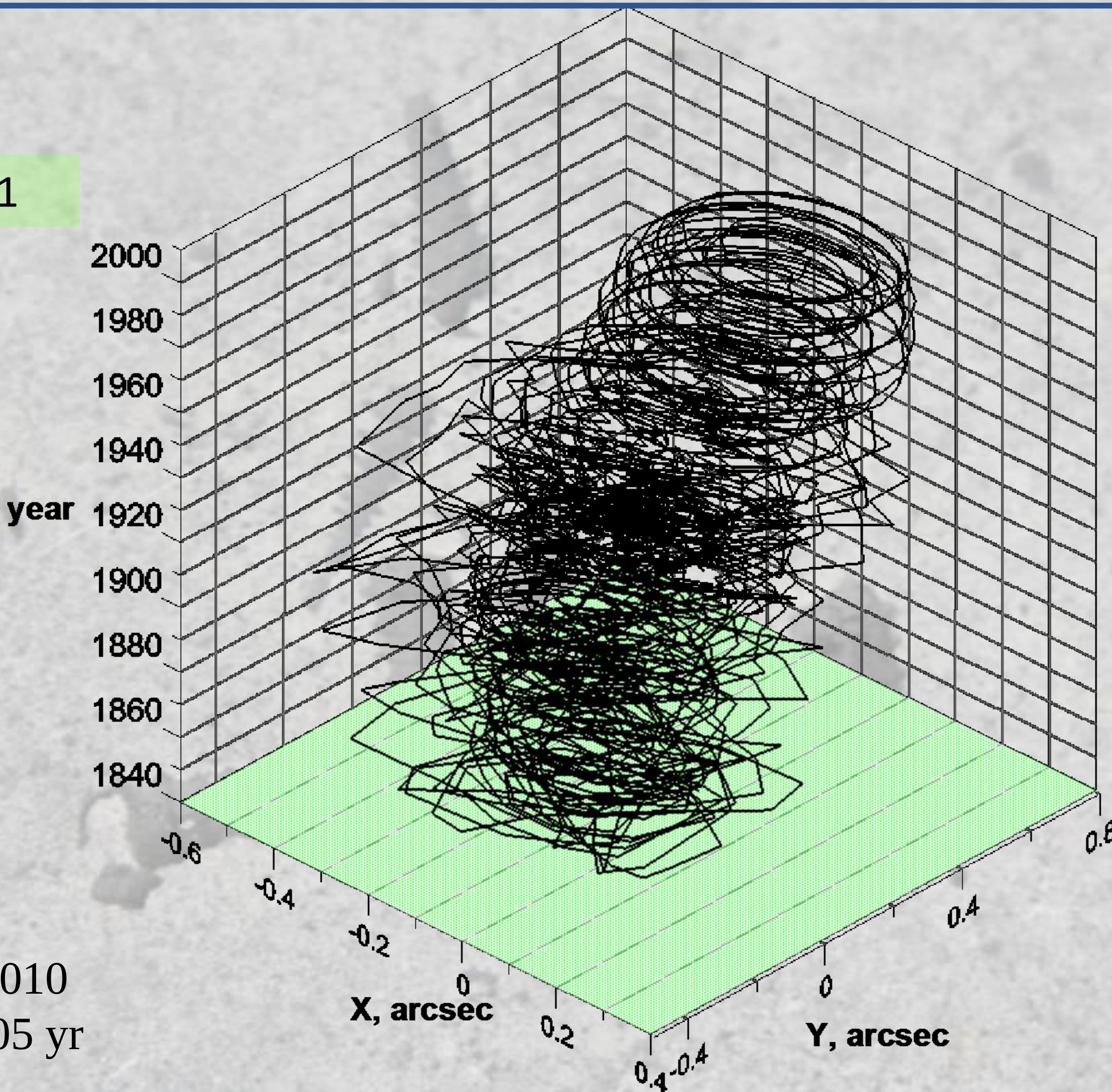
Chujkova N.A., Maximova T.G., Tchesnokova T.S., Grushinsky A.N., Vertical motions of the Earth crust from ITRF2000, ITRF2005, ITRF2008, ITRF2014 and their comparison. Physical geodesy, Russia, 2016

Long-term changes in J_2,T, LOD, and magnetic dipole (detrended)



Motion of the Earth’s pole

EOP CO1

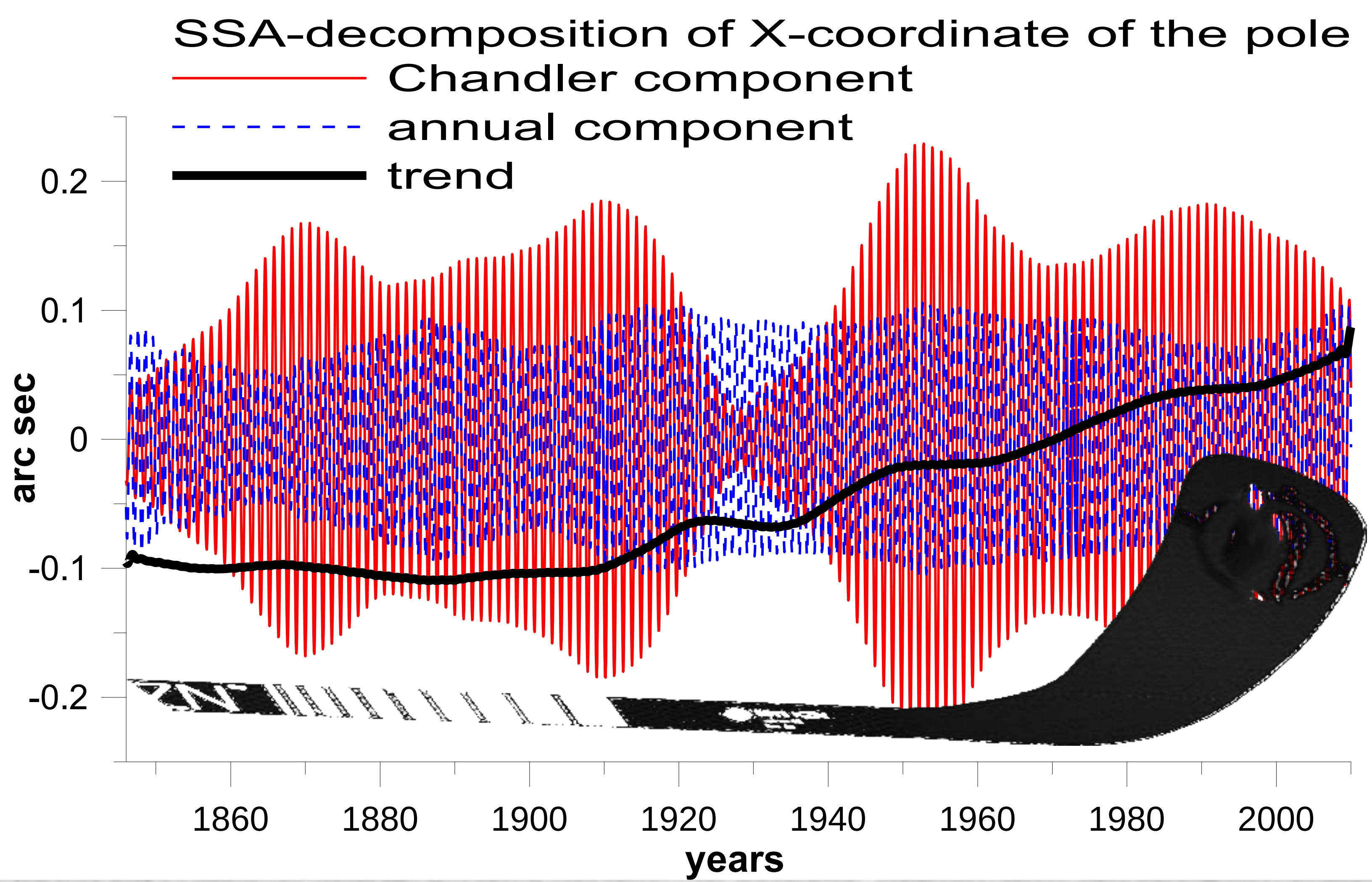


2D trajectory

$$m(t) = x - iy$$

1846-2010
step 0.05 yr

Singular Spectrum Analysis of Polar Motion



Dynamical model of the rotating Earth

$$\frac{i}{\sigma_c}\frac{dm(t)}{dt}+m(t)=\Psi(t)$$

$$m=m_1+im_2$$

$$\Psi=\Psi_{mass}+\Psi_{motion}$$

$$\sigma_c=2\pi f_c(1+i/2Q)$$

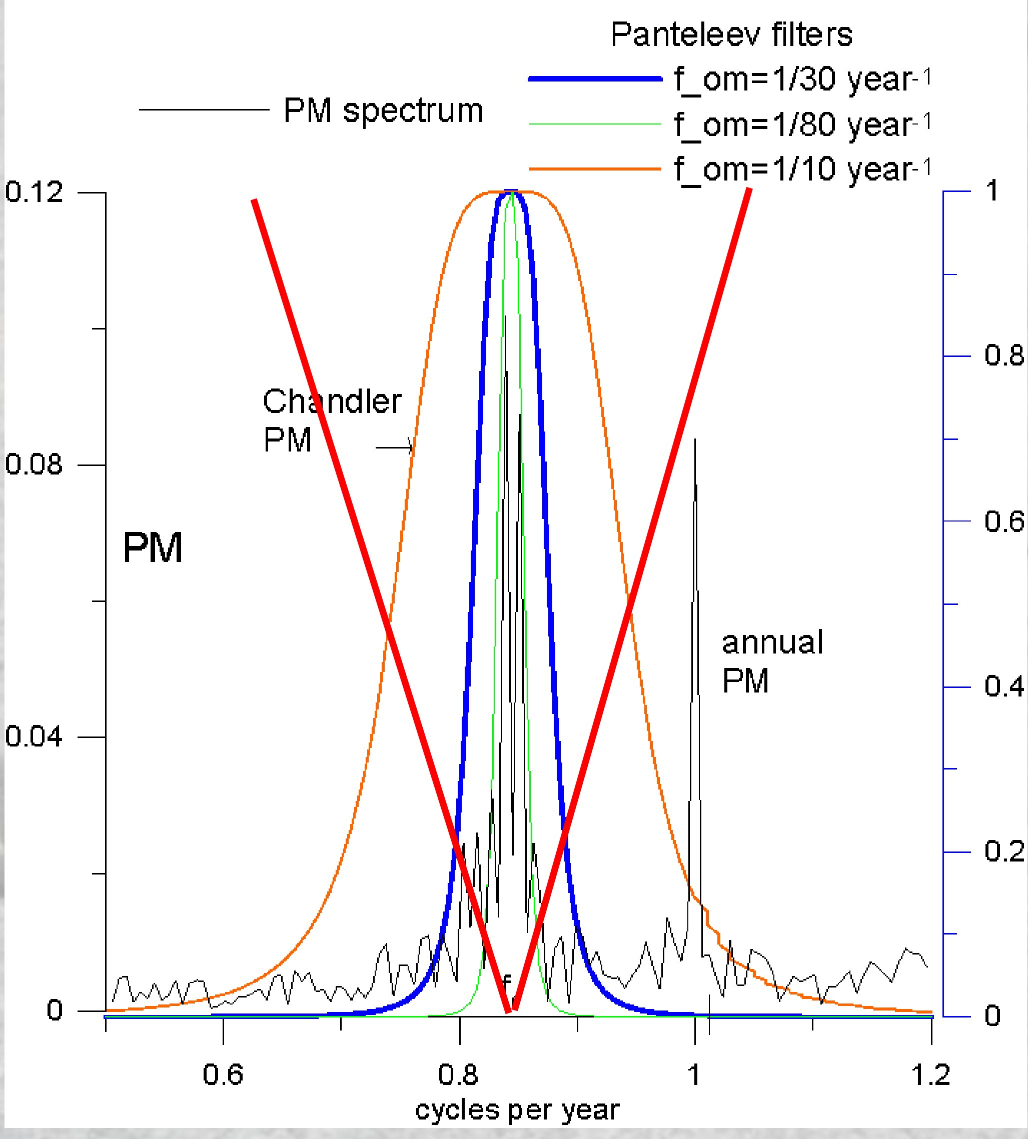
$$f_c=\frac{1}{433}$$ days^{-1} $$Q=100$$

Munk W.H., MacDonald G.J.F., The rotation of the Earth, 1960

Panteleev filtering in the Chandler band

V.L. Panteleev

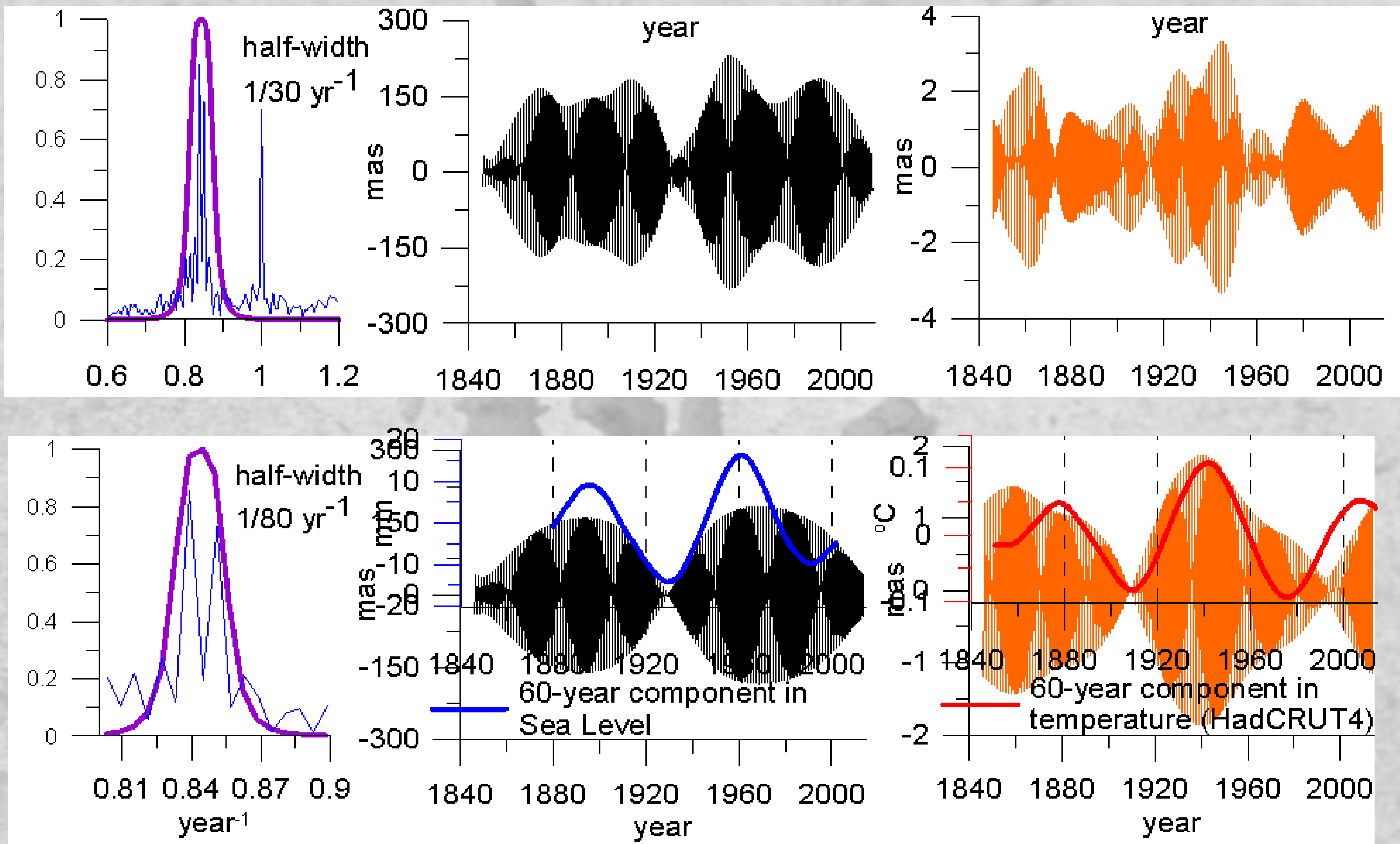
Several harmonics incorporate information about changes of Chandler wobble instantaneous amplitude and phase



Filtering in time domain – convolution

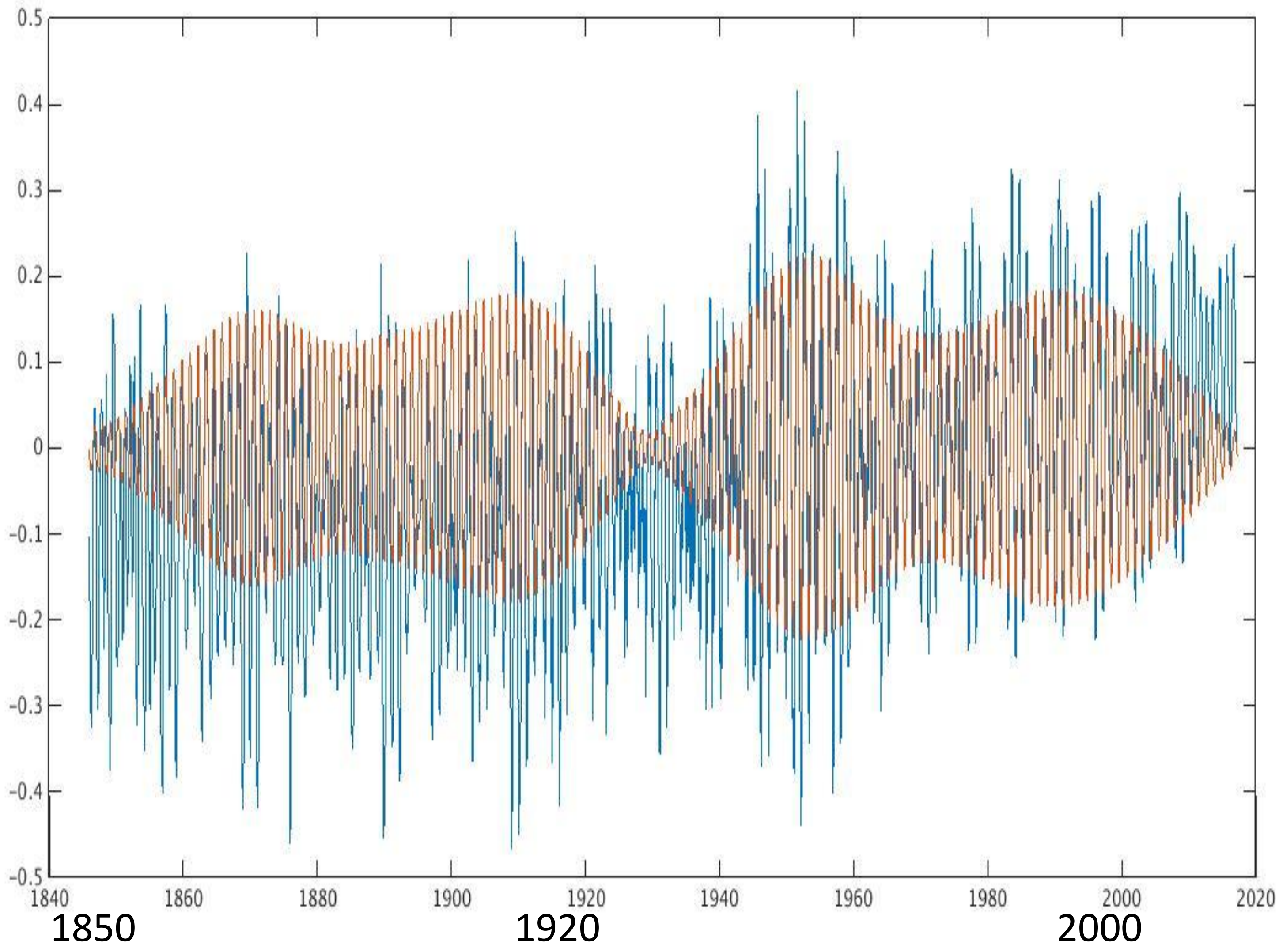
Filtering in frequency domain – spectra multiplication

Chandler wobble and its excitation depending on the filter width



L.V.Zotov

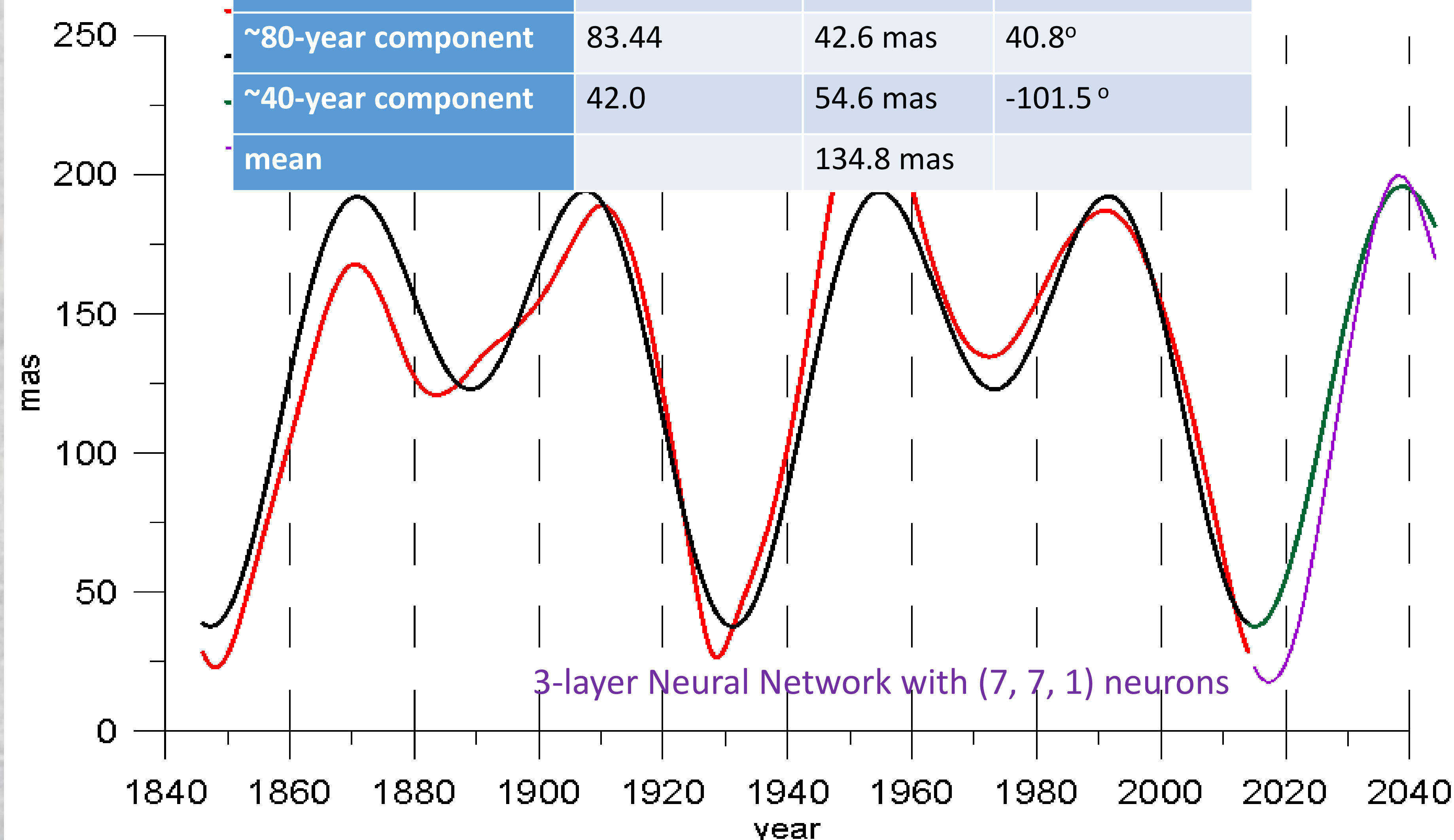
Chandler Wobble extracted from Polar Motion by means of Mean Squares Collocation



L.V.Zotov, See V.S. Gubanov book on Generalized Least Squares method, Snt. Petersburg, 1997

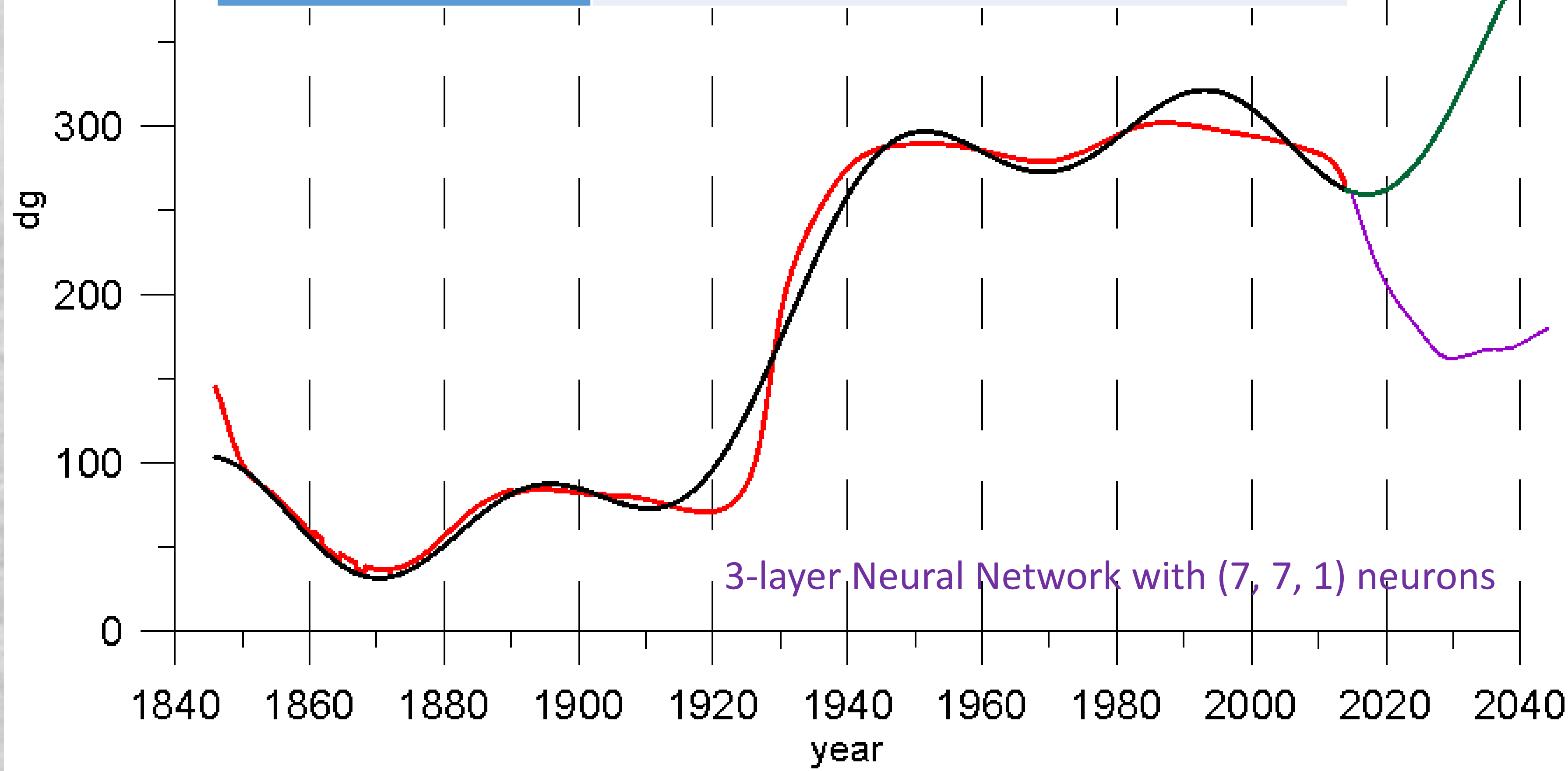
ChW Amplitude model and forecast

~Chandler wobble amplitude NLSM fit			
	Period, years	Amplitude	Phase (1880)
~80-year component	83.44	42.6 mas	40.8°
~40-year component	42.0	54.6 mas	-101.5 °
mean		134.8 mas	



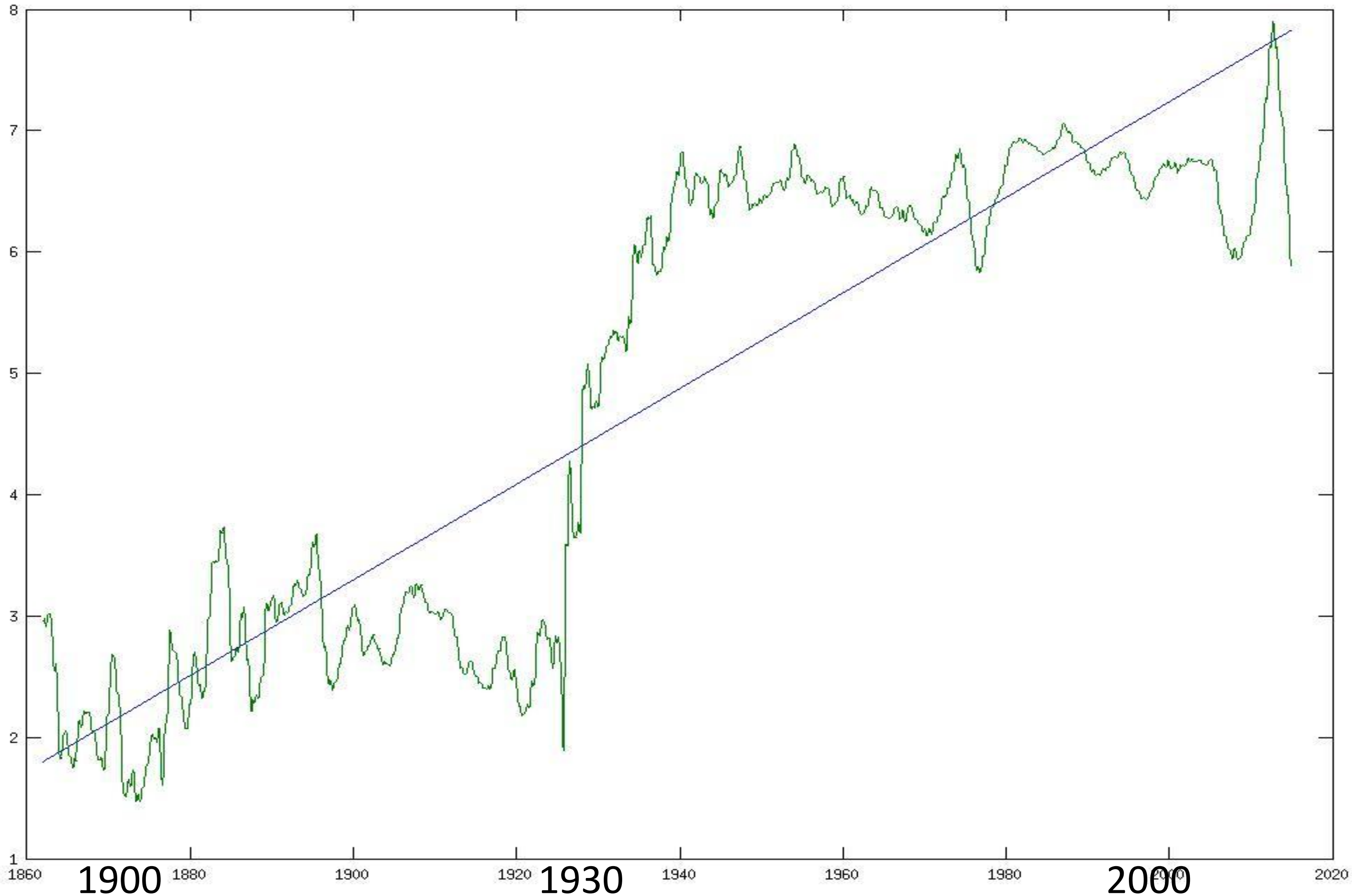
Phase model and forecast

~Chandler wobble phase NLSM fit			
	Period, years	Amplitude	Phase (1880)
~100-year component	117.8	59 dg	-118°
~50-year component	50.9	34 dg	95 °
1-order trend	2dg/year		



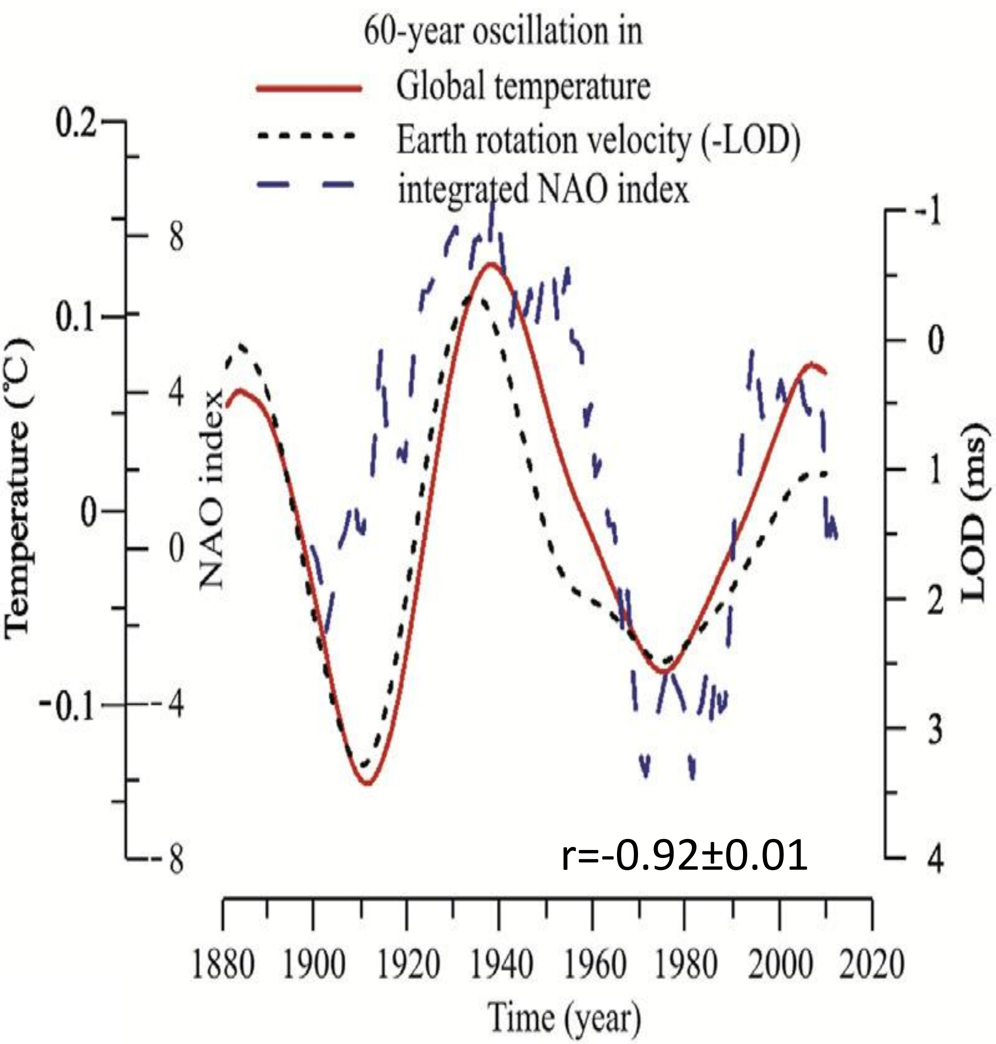
L.V.Zotov, C. M. Bizouard

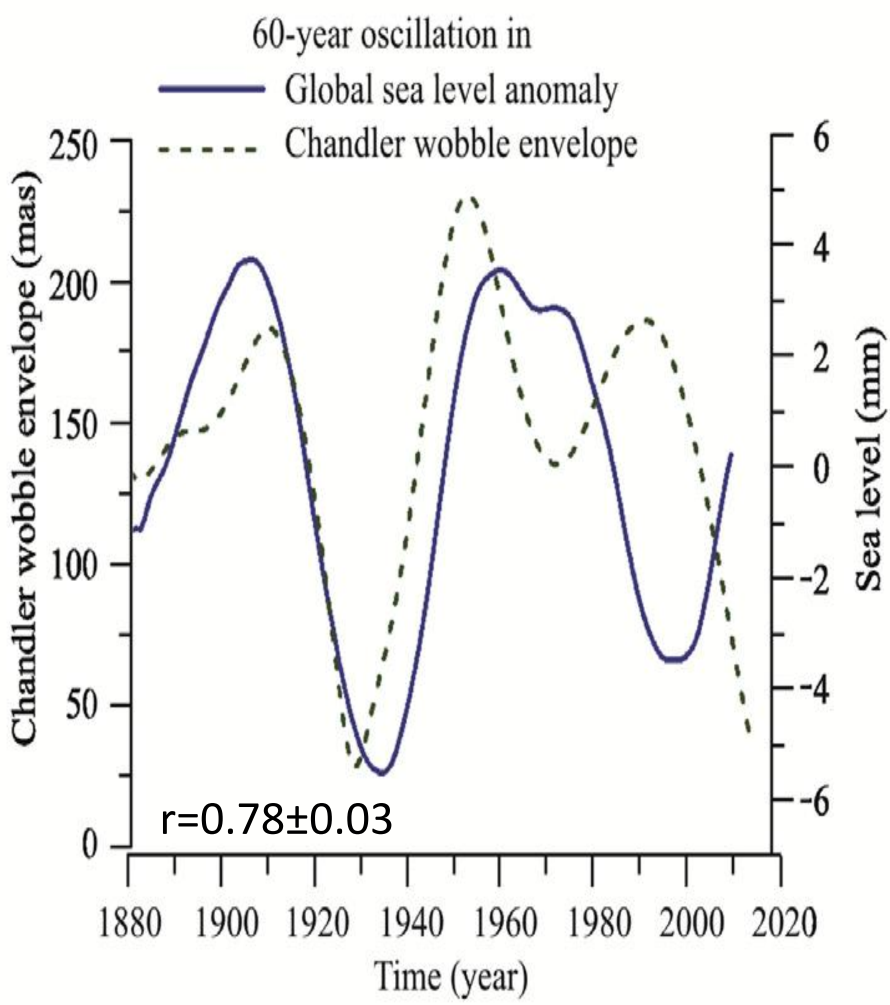
ChW phase, assuming Chandler period = 433 days



Instantaneous phase obtained by Mean Least Squares Filter, proposed by V.S. Gubanov
In his article on Dynamics of the Earth core from VLBI observations, Astronomy letters, 2009

Long-term (60-year) changes in Temperature, SL Chandler wobble envelope and LOD





4D MSSA with L=22 years, parabolic trends preliminarily removed

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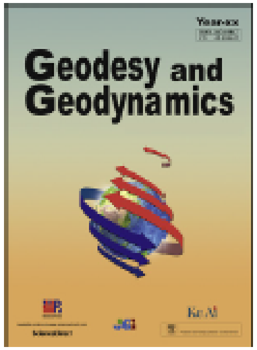
http://www.jgg09.com/jweb_ddcl_en/EN/volumn/home.shtml



A possible interrelation between Earth rotation and climatic variability at decadal time-scale

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[a] *National Research University Higher School of Economics, Moscow Institute of Electronics and Mathematics, Moscow, Russia*
[b] *Lomonosov Moscow State University, Sternberg Astronomical Institute, Moscow, Russia*
[c] *SYRTE, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universités, UPMC Univ. Paris 06, 61 avenue de l'Observatoire, 75014 Paris, France*
[d] *Division of Geodetic Science, School of Earth Sciences, The Ohio State University, USA*
[e] *State Key Laboratory of Geodesy and Earth's Dynamics, Institute of Geodesy & Geophysics, Chinese Academy of Sciences, Wuhan, China*

Geodesy and Geodynamics, China,
Volume 7, Issue 3, May 2016, Pages 216–222

Climate change and polar motion

Session Details (IG06)

AOGS

13th Annual Meeting

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016, Beijing

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between polar
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in a special issue

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Journal of Geophysical Research: Solid Earth

RESEARCH ARTICLE

10.1002/2015JB012708

Key Points:

- EOP and GRACE ΔC_{21} and ΔS_{21} variations agree remarkably well at a broad band of frequencies
- Four independent estimates (EOP, SLR, GRACE, and models) show significantly improved consistency
- Broadband noise variance and noise power spectrum are provided for each estimate

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Broadband assessment of degree-2 gravitational changes from GRACE and other estimates, 2002–2015

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Abstract Space geodetic measurements, including the Gravity Recovery and Climate Experiment (GRACE), satellite laser ranging (SLR), and Earth rotation provide independent and increasingly accurate estimates of variations in Earth's gravity field Stokes coefficients ΔC_{21}, ΔS_{21}, and ΔC_{20}. Mass redistribution predicted by climate models provides another independent estimate of air and water contributions to these degree-2 changes. SLR has been a successful technique in measuring these low-degree gravitational changes. Broadband comparisons of independent estimates of ΔC_{21}, ΔS_{21}, and ΔC_{20} from GRACE, SLR, Earth rotation, and climate models during the GRACE era from April 2002 to April 2015 show that the current GRACE release 5 solutions of ΔC_{21} and ΔS_{21} provided by the Center for Space Research (CSR) are greatly improved over earlier solutions and agree remarkably well with other estimates, especially on ΔS_{21} estimates. GRACE and Earth rotation ΔS_{21} agreement is exceptionally good across a very broad frequency band from intraseasonal, seasonal, to interannual and decadal periods. SLR ΔC_{20} estimates remain superior to GRACE and Earth rotation estimates, due to the large uncertainty in GRACE ΔC_{20} solutions and particularly high sensitivity of Earth rotation ΔC_{20} estimates to errors in the wind fields. With several estimates of ΔC_{21}, ΔS_{21}, and ΔC_{20} variations, it is possible to estimate broadband noise variance and noise power spectra in each, given reasonable assumptions about noise independence. The GRACE CSR release 5 solutions clearly outperform other estimates of ΔC ΔS_{21} variations with the lowest noise levels over a broad band of frequencies.

Can the Climate Change influence Earth rotation?

Can Earth rotation influence Climate ?

Can any external factor influence both Climate and Earth rotation?

There can be changes in Earth rotation related to

Changes of the Earth's moment of Inertia
I

External force
L

Changes of the relative angular momentum
h

Possible generalizations of Euler-Liouville equations

Classical form:

$$\frac{i}{\sigma_c}\frac{dm}{dt} + m(t) = \Psi(t)$$

Stochastic differential equation:

$$\frac{i}{\sigma_c} dm = \left(\Psi_{\mathbf{determenistic}}(t) - m(t)\right)dt + \Psi_{\mathbf{stochastic}}(t)dW$$

Here *dW* is the Wiener process increment

Synchronization?
see Blekhman I.I.

$$\frac{i}{\sigma_c}\frac{dm}{dt} + m(t) = \Psi_1(t) + \mu\Psi_{\mathbf{synchr}}(v,t)$$

$$\frac{\mathrm{d}v}{\mathrm{dt}} = \mathrm{F}(m, v, \Delta T, t)$$

Here μ is the small parameter, and
v is the variable, whose dynamics depends on ΔT – temperature anomaly, etc.

Ch. Bizouard Generalization for triaxial Earth:

$$(1+eU)\frac{i}{\sigma_c}\frac{dm}{dt} + (1-U)m(t) + eV\frac{i}{\sigma_c}\frac{dm^*}{dt} - Vm^* = \Psi_{\mathbf{Pure}}(t)$$

Here *U,V ,e* are known parameters

Conclusions

- We extract natural variations in global Earth temperature (HadCRUT4) and Sea Level (Jevrejeva, or Church and White) since 1850. Global worming trends (~0.7^{o} and ~20 cm) were removed.
- MSSA analysis of showed that besides the warming trend there are quasi - 60, 20 and 10-year oscillations in temperature and sea level
- 60/20-year components of temperature are anticorrelated with LOD
- Chandler wobble envelope has been analyzed and modeled. Model contains long-term component, correlated with 60 – year sea level changes, and 40-year component, produced by 20-year in excitation
- J2 from SLR shows long-term trend with maxima in 1970th and minima in 2005
- There are enough arguments collected to conclude that Earth rotation and Climate Changes are interrelated
- LOD could be connected with climate stronger then Polar Motion

But only the continuation of this study can help to identify the mechanism.

P. Brueghel the Yonger *Landscape with a Bird Trap* (1565), Tokyo museum of Western art

How all this can be explained?

Long-term processes in the atmosphere…

Long-term processes in the ocean…

Long-term processes in the core…

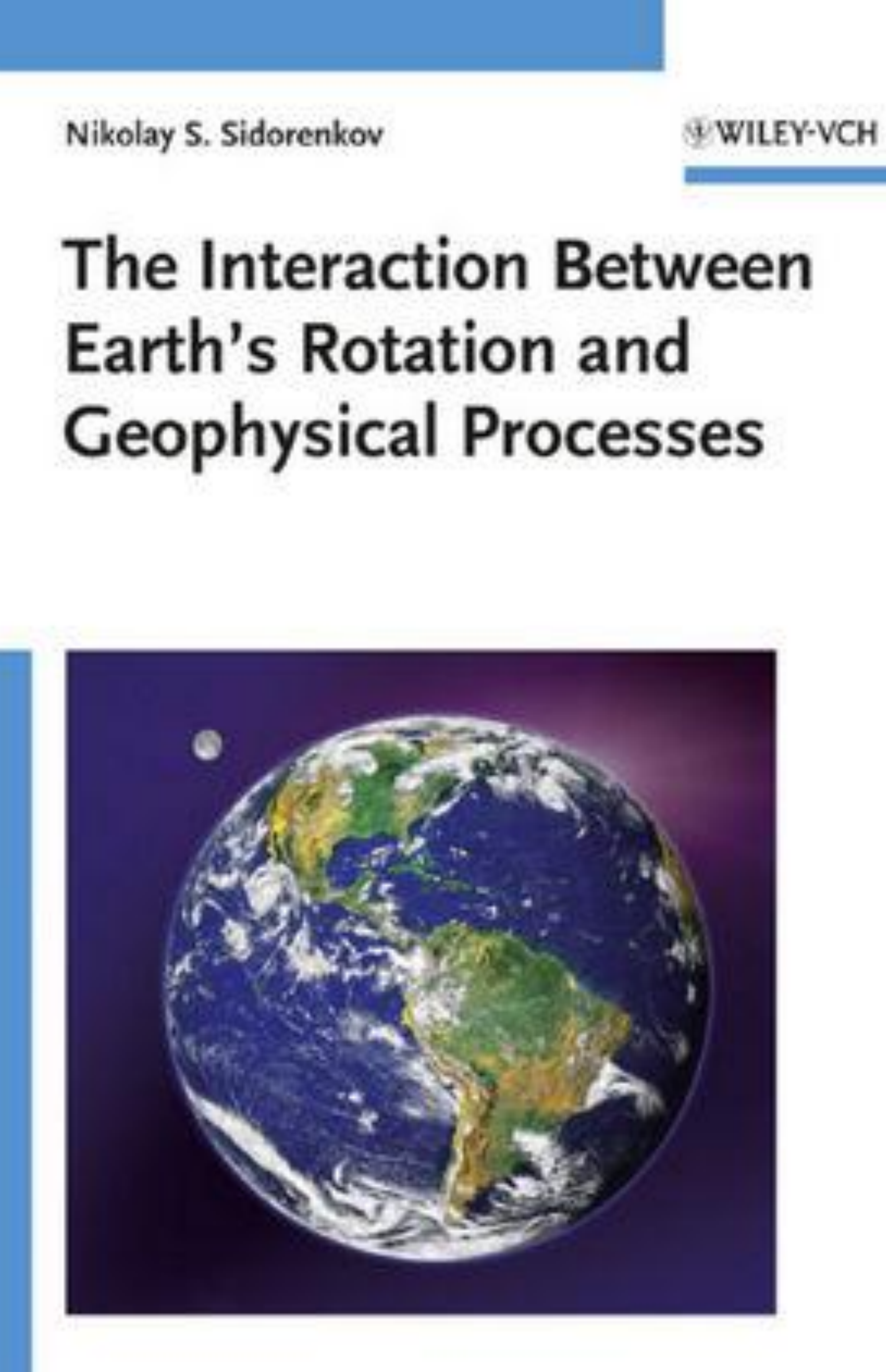
External factor which influence both climate and Earth rotation

Synchronization with some factor by nonlinear effect through small parameter

Tidal dissipation/input of energy

Influence of the Moon / Jupiter / Saturn ???

It just happened by chance, that 60-year oscillations are observed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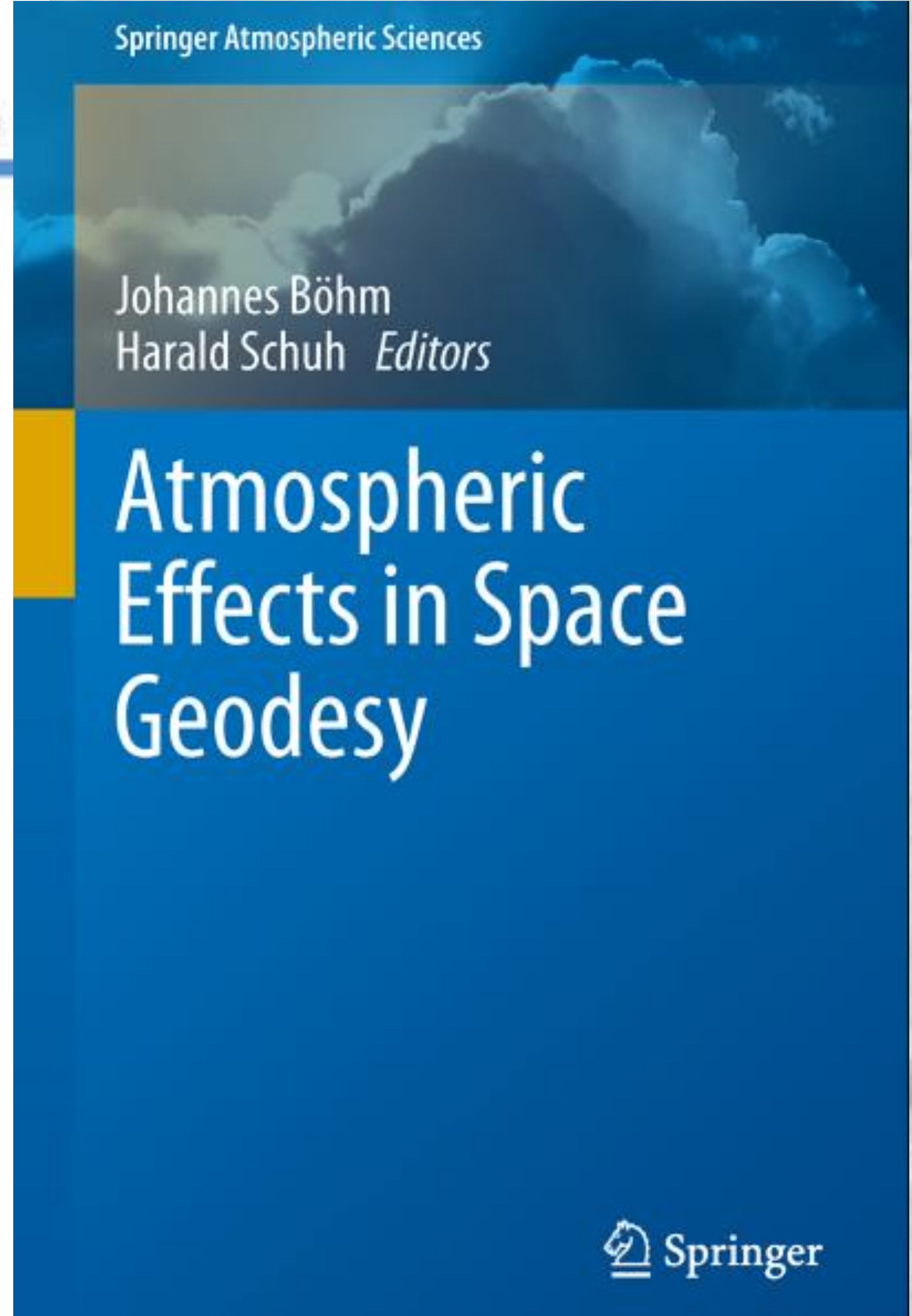
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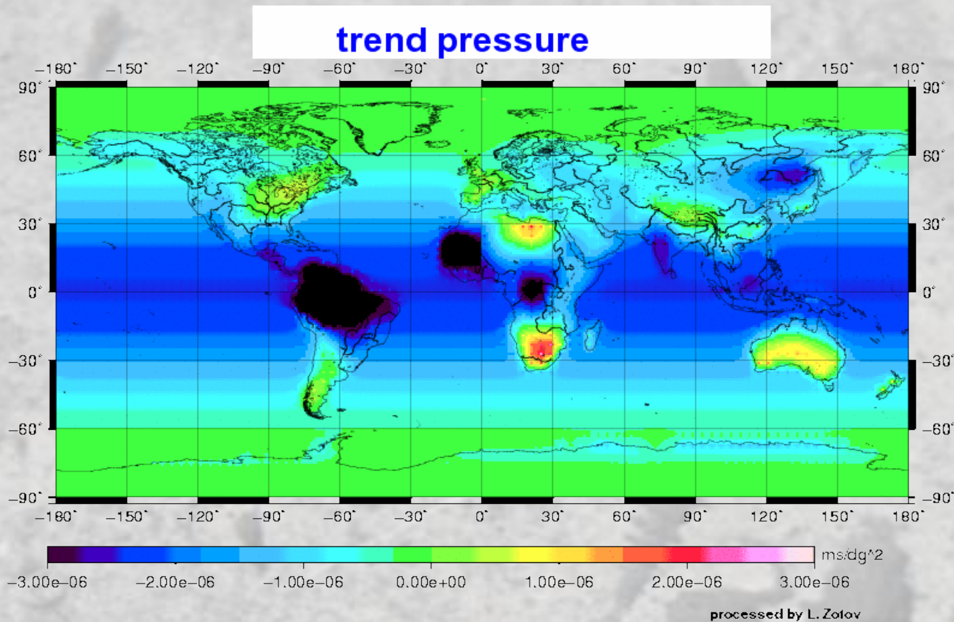
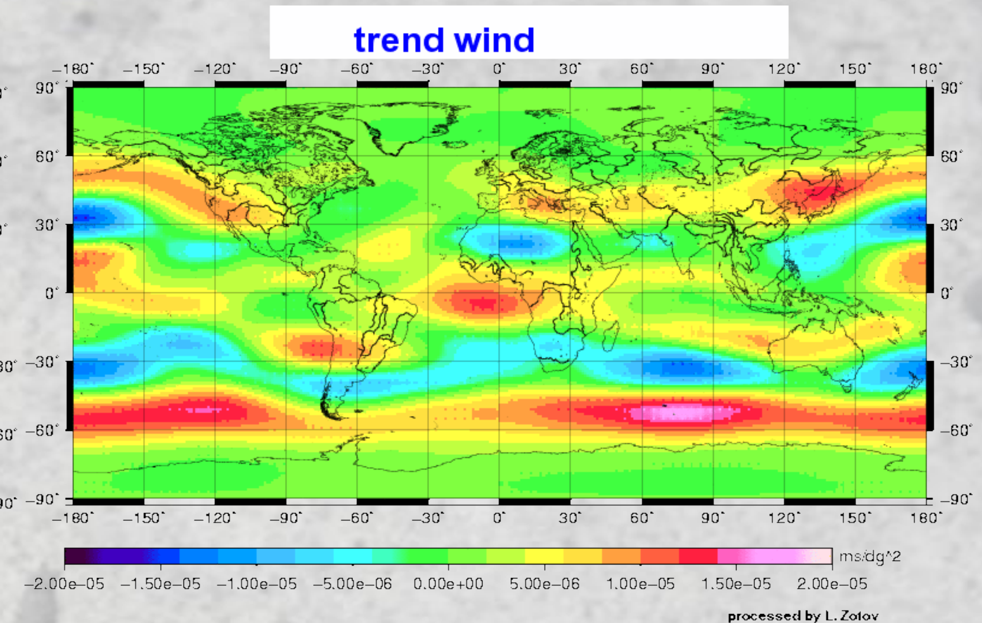
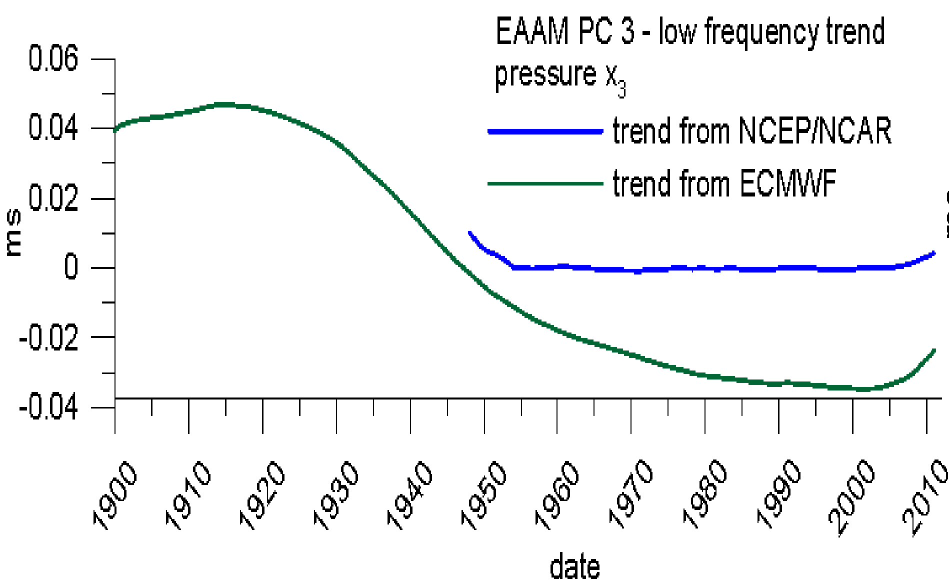
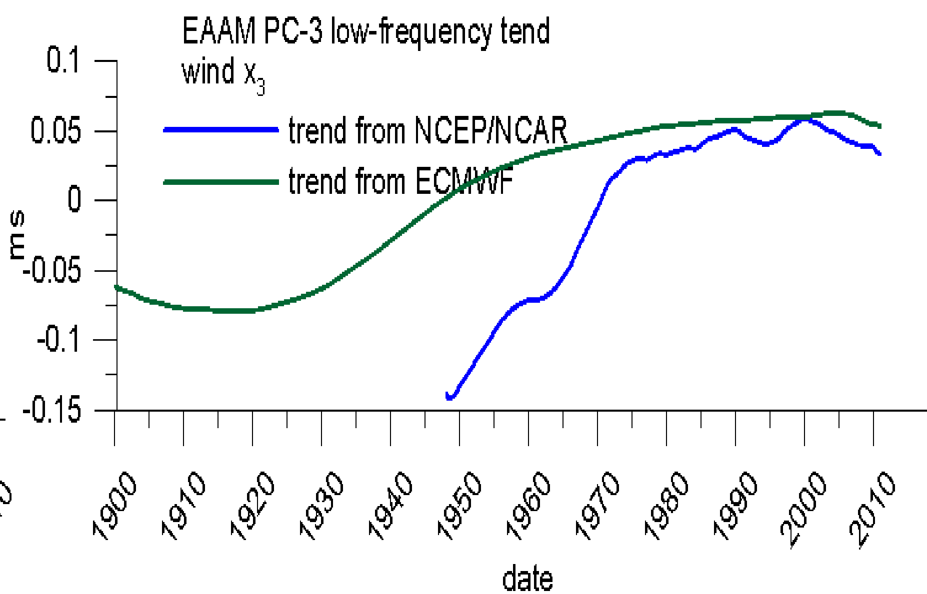
Zonal AAM ECMWF – trends PC 3









MSSA of Zonal-AAM has revealed slow trends in wind and pressure terms

50 - 2 DE VIRON ET AL.: EFFECT OF GLOBAL WARMING ON LOD

Table 1. Trend in the LOD (in μs/year)

Model	Pressure	Wind	Current	Total
BMRC	−1.0	1.4	0.0	0.4
CCCma	−1.0	2.6	0.1	1.6
CCSR	−0.1	4.4	0.1	4.4
CERFACS	−0.2	2.0	0.3	2.2
CSIRO	−0.8	0.7	0.1	0.0
ECHAM3	−0.9	0.7	0.1	−0.1
GFDL	−1.0	0.7	−0.1	−0.4
TAP	−0.6	−1.7	0.1	−2.2
EMD	−0.8	3.7	0.1	2.9
MRI	−0.6	1.3	0.0	0.7
NCAR CSM	−0.1	0.9	0.1	0.9
NRL	−0.1	1.2	0.0	1.1
HadCM2	−1.6	5.3	0.0	3.7
HadCM3	−1.5	2.0	0.0	0.5
Mean	−0.75	1.81	0.06	1.13
σ	0.49	1.77	0.09	1.74

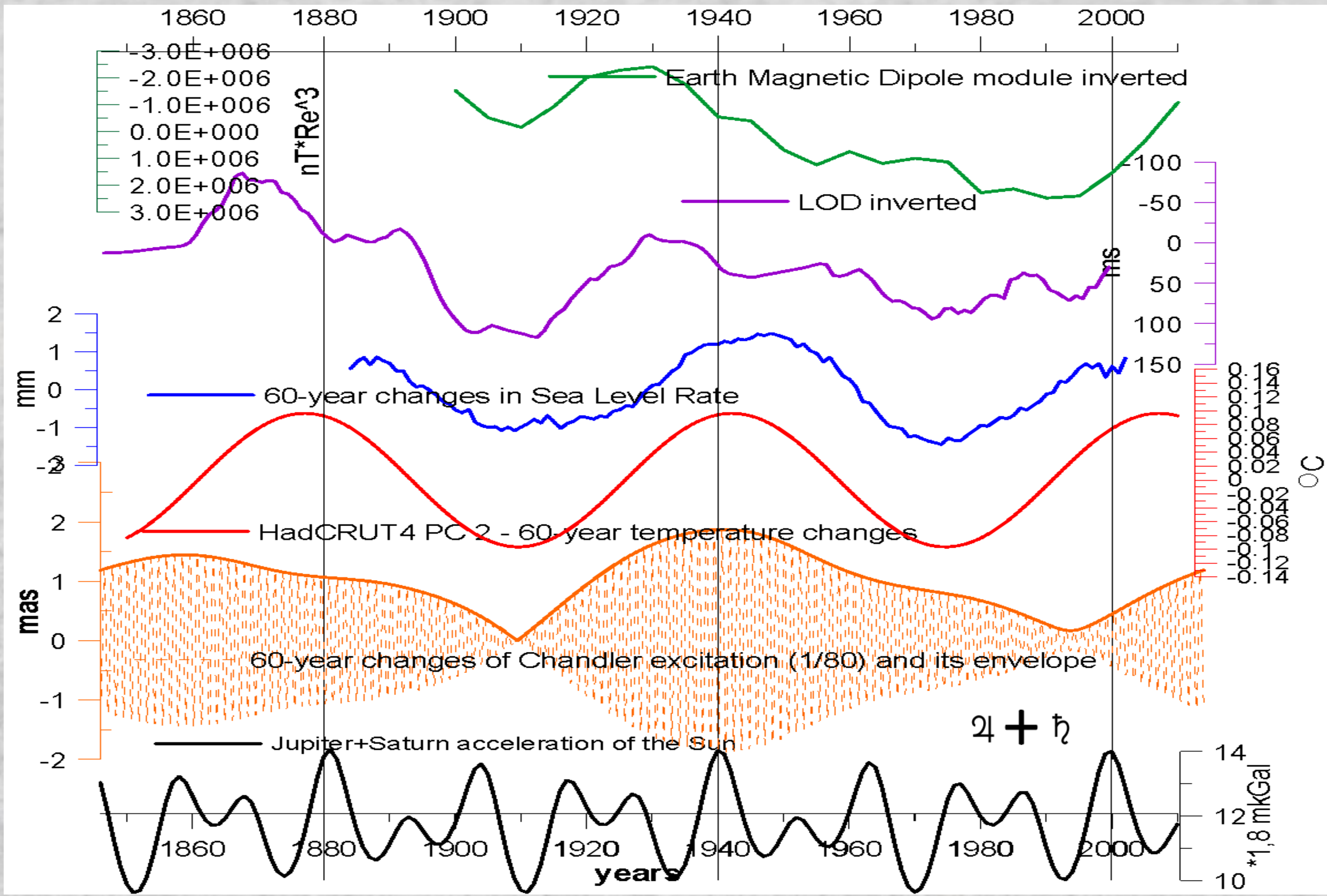
Table 2. Source of the Variation in the LOD at Low Frequency

Source	Data	Δ*LOD*
Core motion	observ.	1–2 *ms*[a]
Tidal friction	observ.	20μs/year
Contin. water res.	observ.	−6μs/year
Post glacial rebound	observ.	−5 μs/year
Wind AAM	CMIP	1.81μs/year
Mass term	CMIP	−0.75 μs/year
Sea level	observ.	0.5 μs/year
Glacier	observ.	0.4 μs/year
Earthquake	observ.	−0.1 μs/year
Ocean current	CMIP	0.1 μs/year

[a] Not a trend but a decadal variation.

term is given by the mass term of the atmosphere integrated over the continent plus the mass term associated with the mean atmospheric pressure over the whole ocean acting on each grid

60-year changes in SL, LOD, Temperature and Chandler excitation



APOD