Interconnections between climate change and Earth rotation

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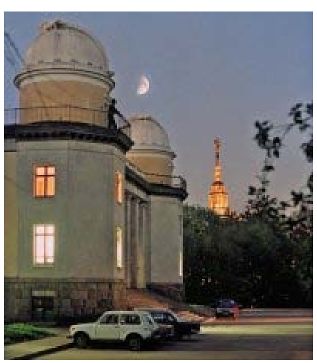

25-29 May 2015
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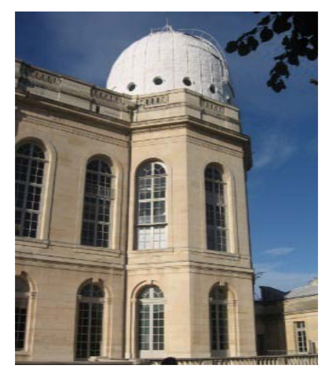
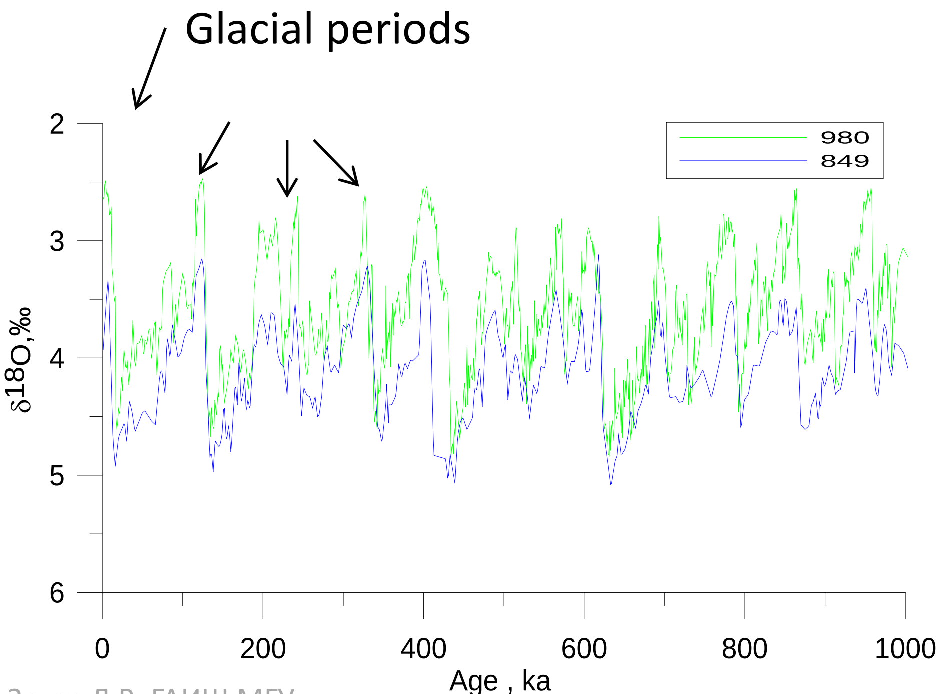
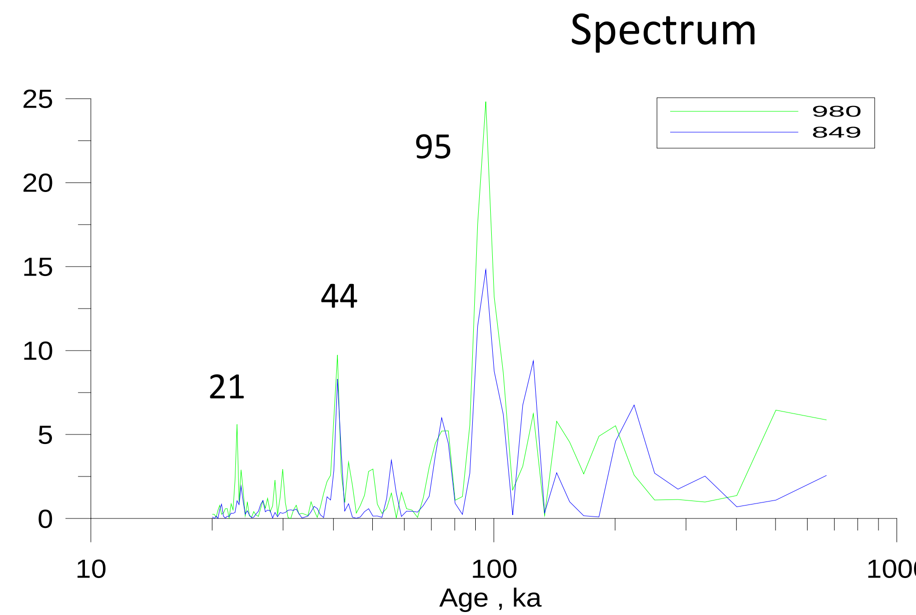
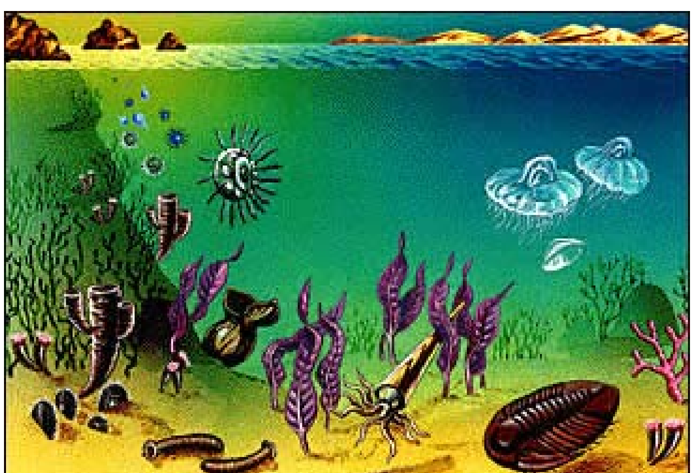


Paleoclimate





Зотов Л.В. ГАИШ МГУ



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Milankovitch theory

Berger: Milankovitch Theory and Climate

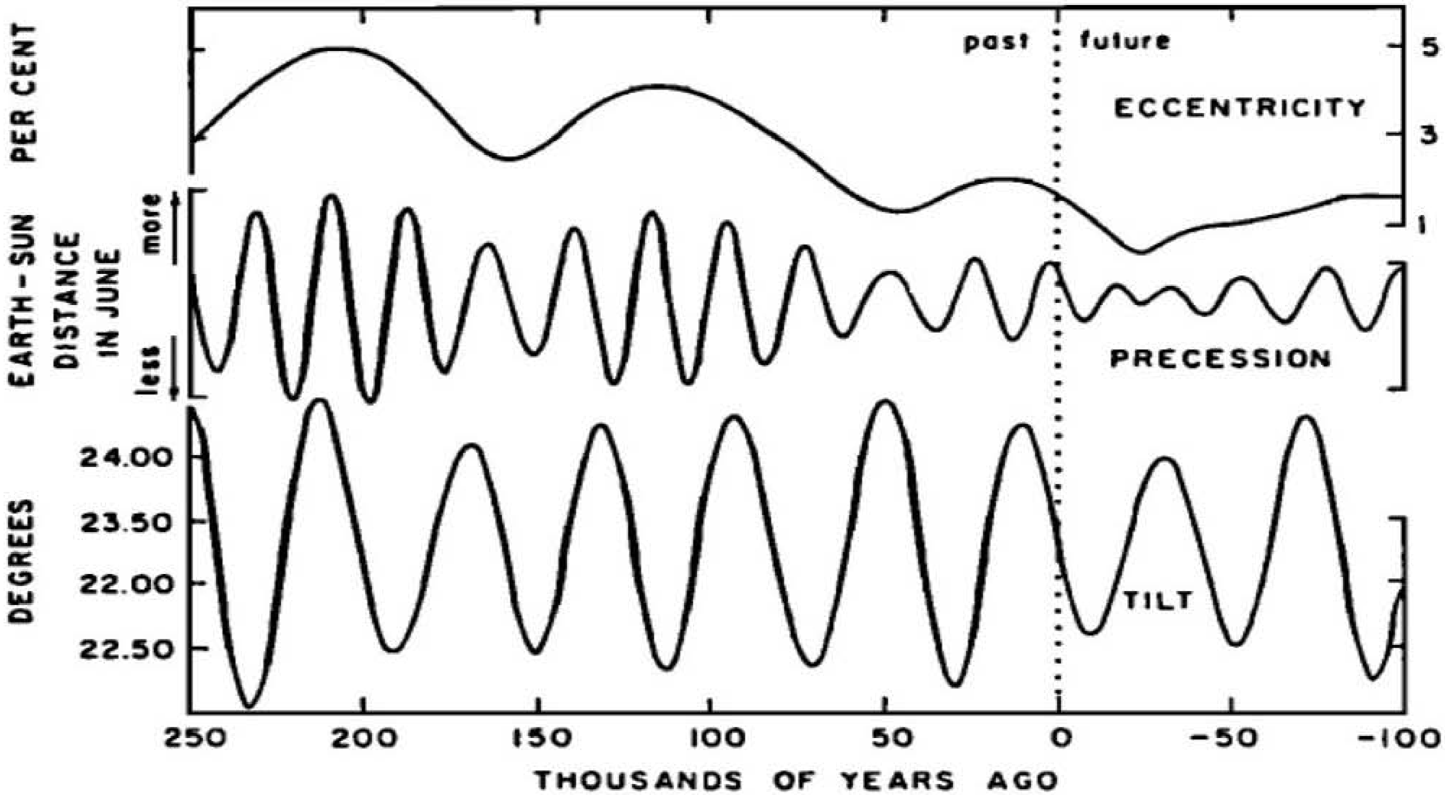
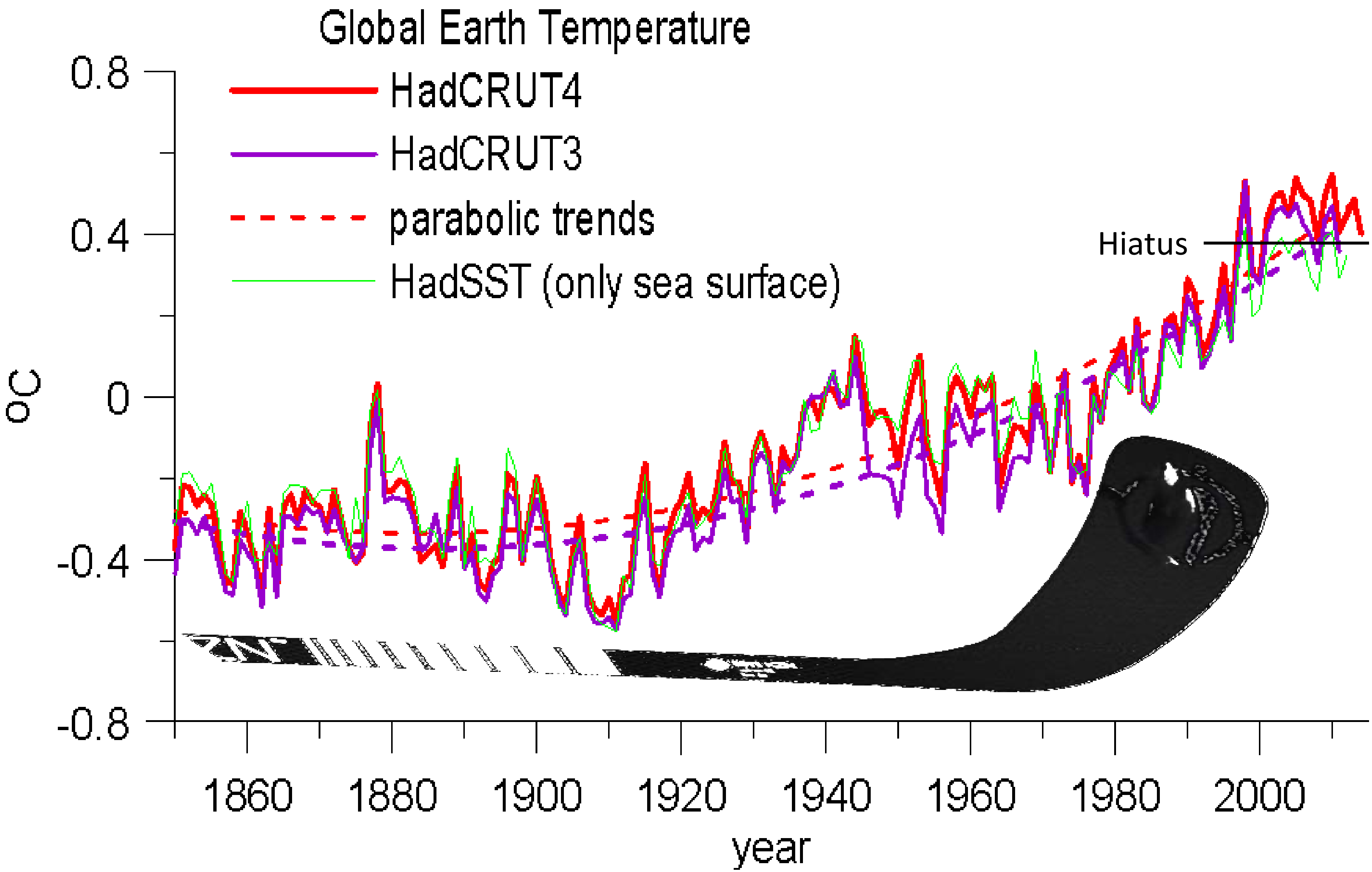


Fig. 11. Long-term variations of eccentricity, precession, and tilt from 250,000 years B.P. to 100,000 years A.P. [Berger, 1978c].

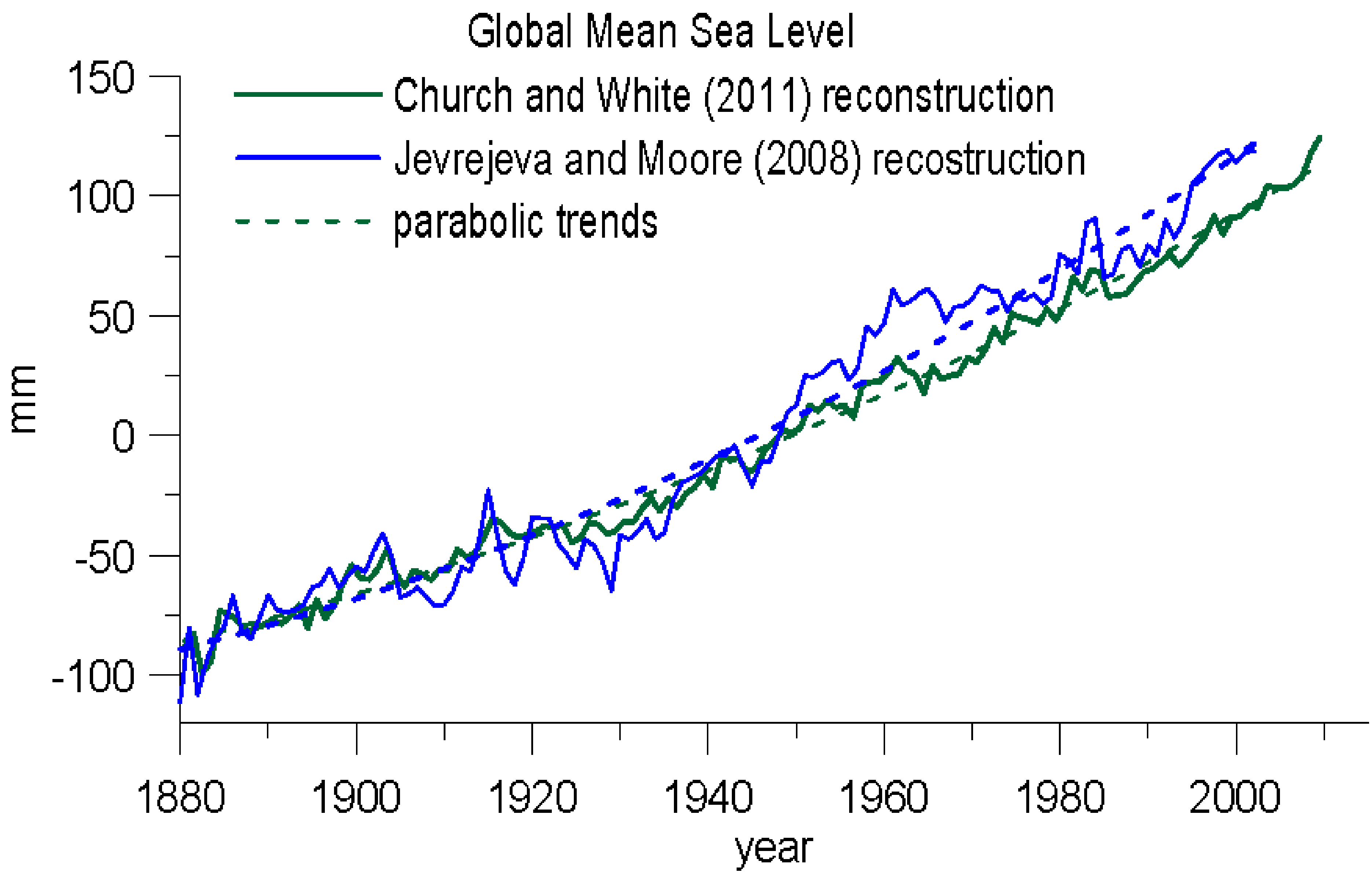
States that long-term Climate Change depends on Earth rotation and orbital motion

What about short-term?

Global Earth temperature

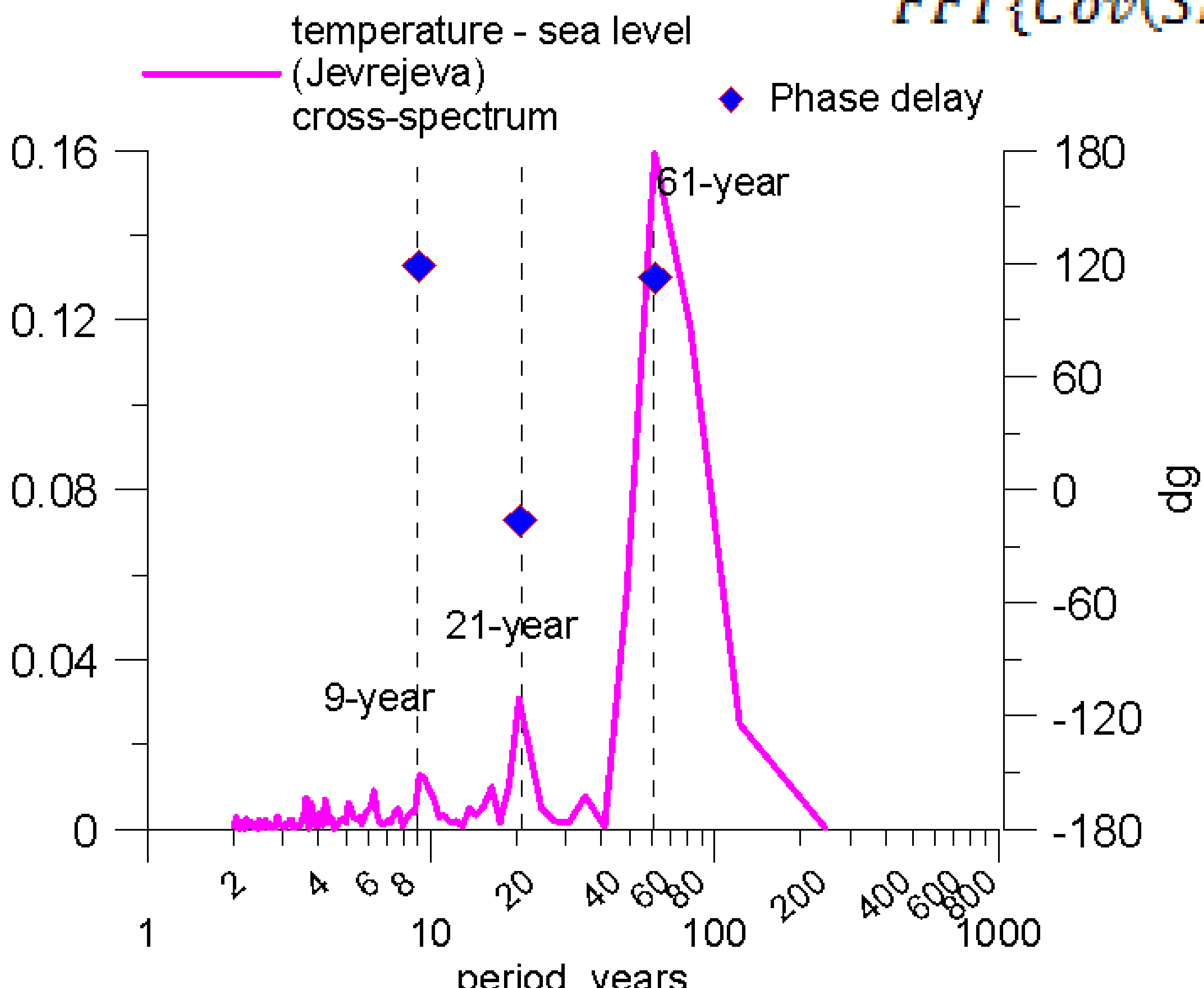


Global Mean Sea Level

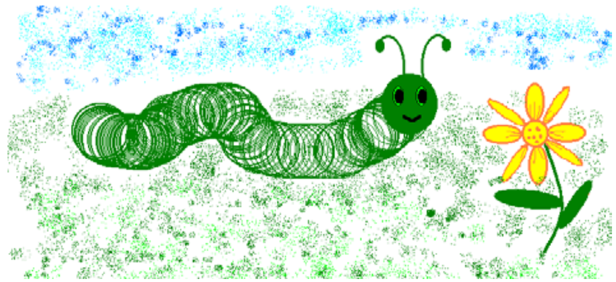


Temperature-Sea Level Cross-spectrum

$FFT\{Cov(SL,T)\}$



Singular Spectrum Analysis SSA – “Caterpillar”



1 Trajectory matrix

$$X = \begin{bmatrix} X_1 & \dots & X_K \end{bmatrix}$$

$$[L \times K]$$

2 SVD – decomposition

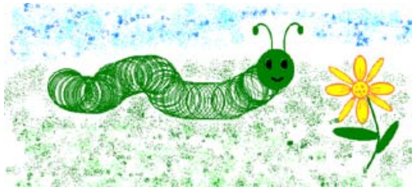
$$X = USV^T = \sqrt{\lambda_1} U_1 V_1^T + \dots + \sqrt{\lambda_d} U_d V_d^T$$

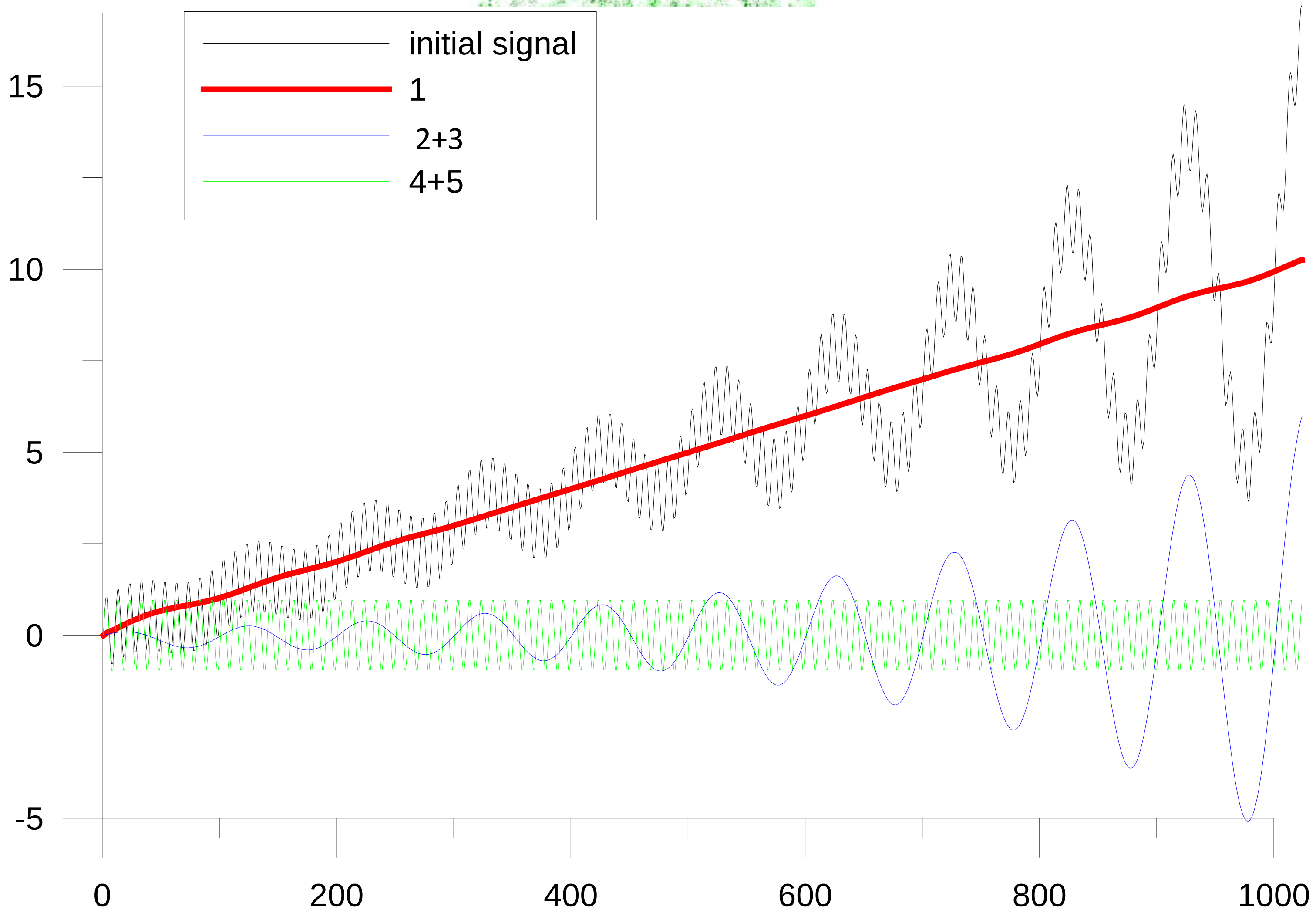
3 Principal Components (PCs) grouping

4 Hankelization

$$g_k = \begin{cases} \frac{1}{k+1} \sum_{m=1}^{k+1} y_{m,k-m+2}, & 0 \le k < L^* - 1 \\ \frac{1}{L^*} \sum_{m=1}^{L^*} y_{m,k-m+2}, & L^* - 1 \le k < K^* \\ \frac{1}{N-K} \sum_{m=k-K^*+2}^{N-K^*+1} y_{m,k-m+2}, & K^* \le k < N \end{cases}$$

1D SSA example





Multichannel Singular Spectrum Analysis CSSA

1) The delay parameter *L* is chosen.

SSA is a generalization of EOF (PCA)

Multivariate signal

$$x = (T, SL, LOD, Chw)$$

Incorporated into block trajectory matrix *Z*

2) SVD — singular value decomposition is performed

$$X = USV^T$$

3) Matrices for every singular number s_i are reconstructed

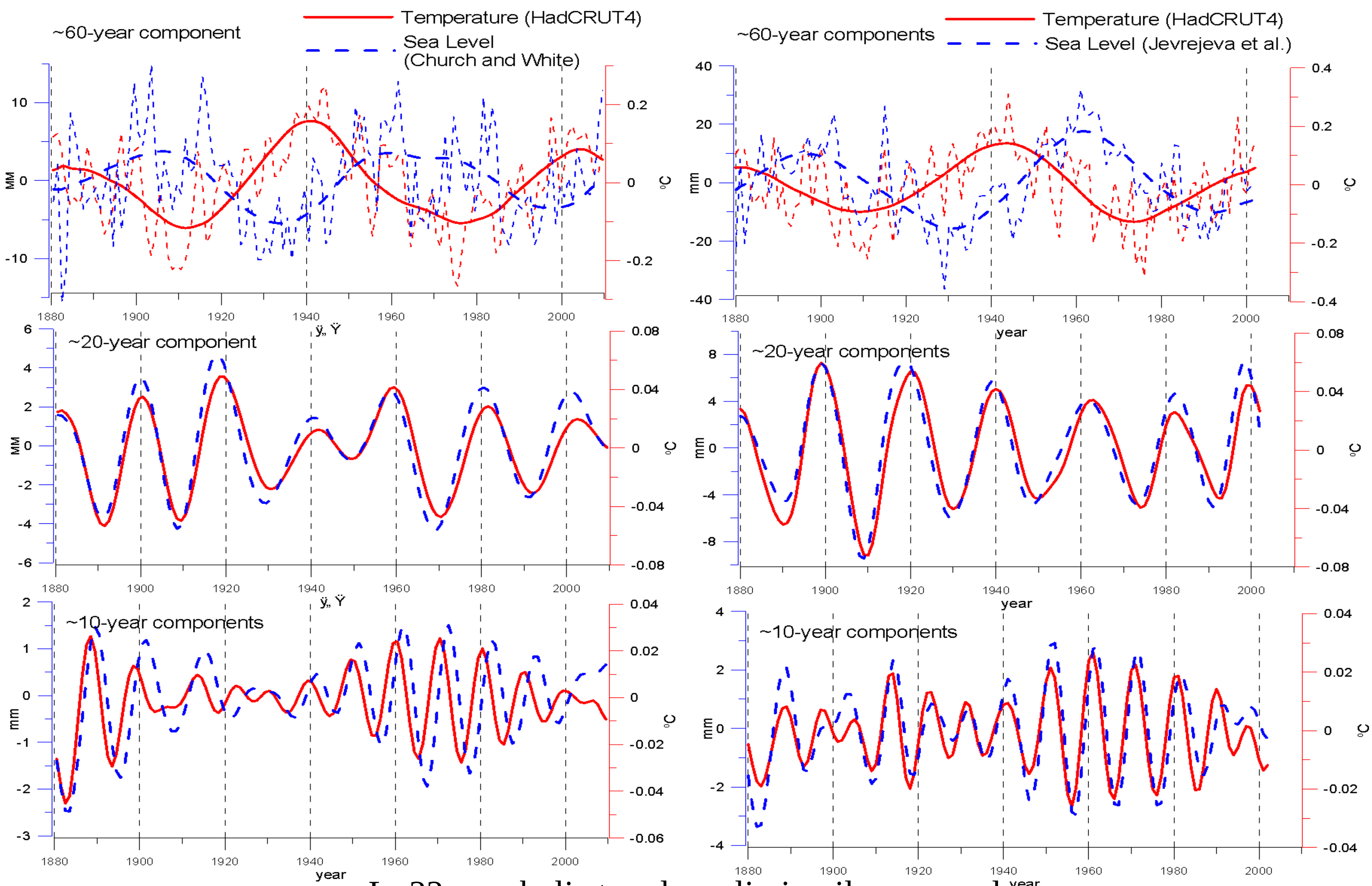
$$X^i = s_i u_i v_i^T,$$

signal for each component is obtained by Hankelization.

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

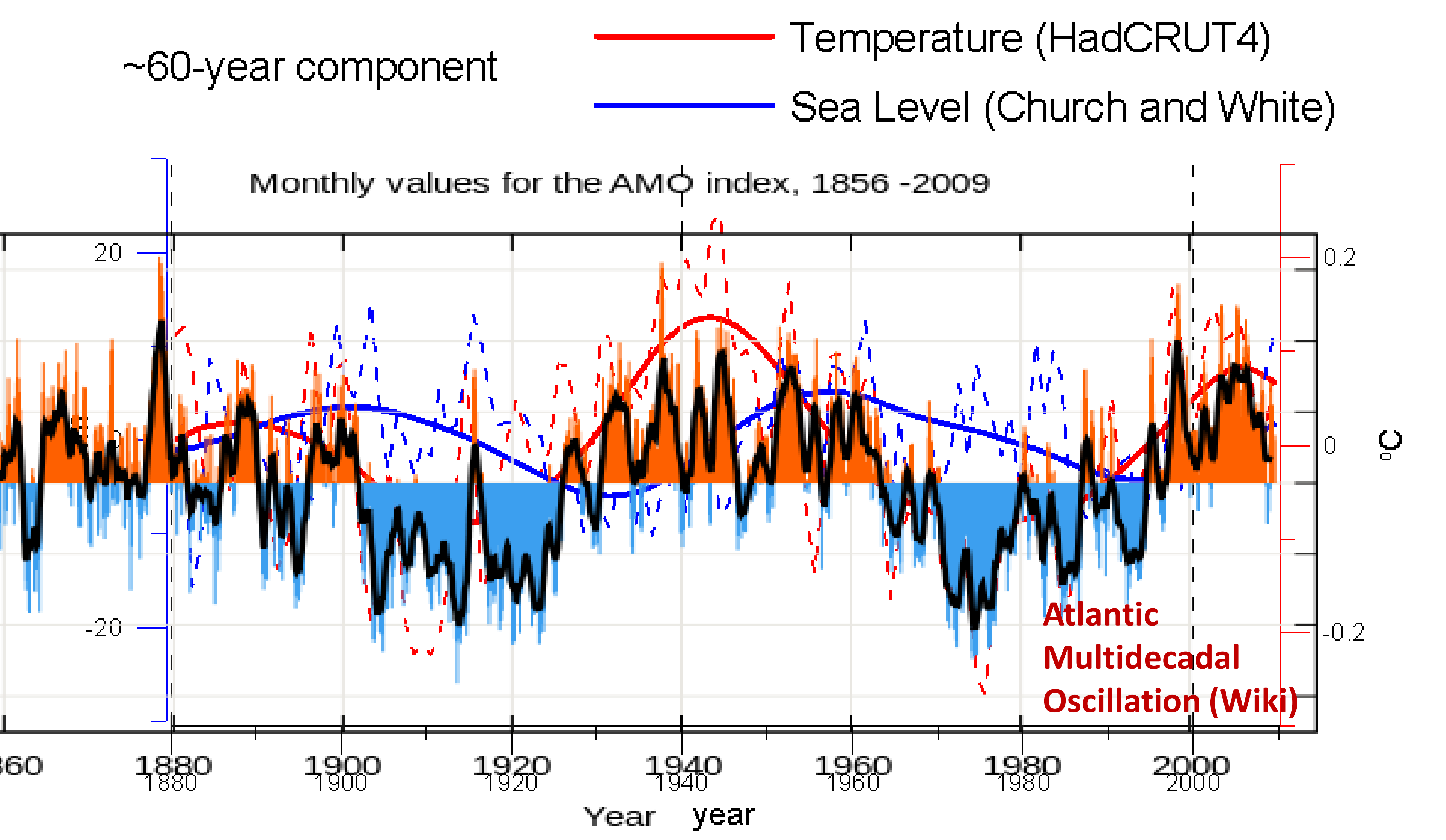
PC1, PC2, PC3…

Results of MSSA for Temperature and Sea Level



L=22, parabolic trends preliminarily removed

Results of CSSA for temperature and Sea Level



L=22, parabolic trends preliminarily removed

Temperature and Sea Level rate $\frac{dSL}{dt}$

19 JANUARY 2007 VOL 315 **SCIENCE** www.sciencemag.org

A Semi-Empirical Approach to Projecting Future Sea-Level Rise

Stefan Rahmstorf

A semi-empirical relation is presented that connects global sea-level rise to global mean surface temperature. It is proposed that, for time scales relevant to anthropogenic warming, the rate of sea-level rise is roughly proportional to the magnitude of warming above the temperatures of the pre–Industrial Age. This holds to good approximation for temperature and sea-level changes during the 20th century, with a proportionality constant of 3.4 millimeters/year per °C. When applied to future warming scenarios of the Intergovernmental Panel on Climate Change, this relationship results in a projected sea-level rise in 2100 of 0.5 to 1.4 meters above the 1990 level.

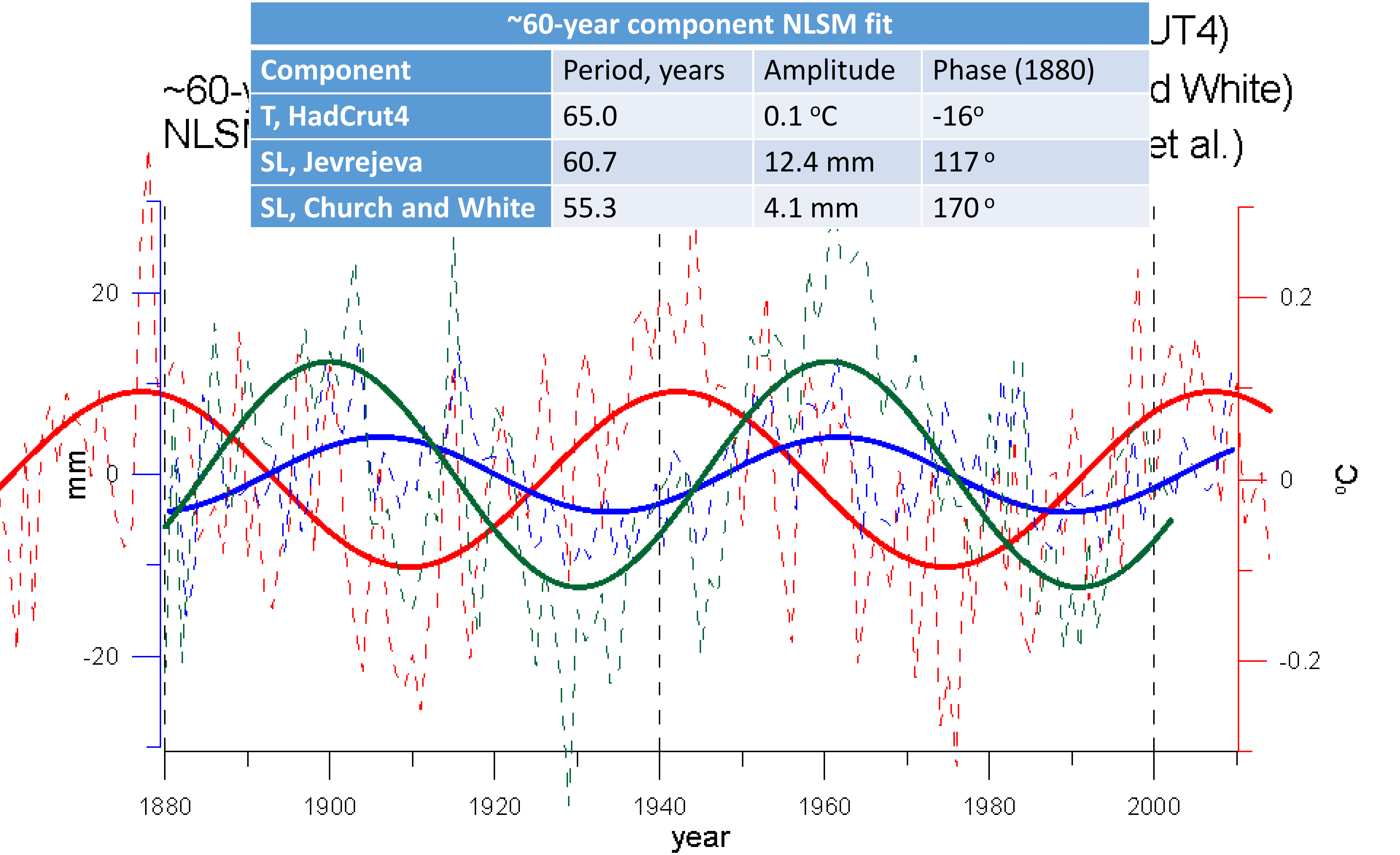
The initial rate of rise is expected to be proportional to the temperature increase

$$dH/dt = a\,(T - T_0) \qquad (1)$$

where H is the global mean sea level, t is time, a is the proportionality constant, T is the global mean temperature, and T_0 is the previous equilibrium temperature value. The equilibration

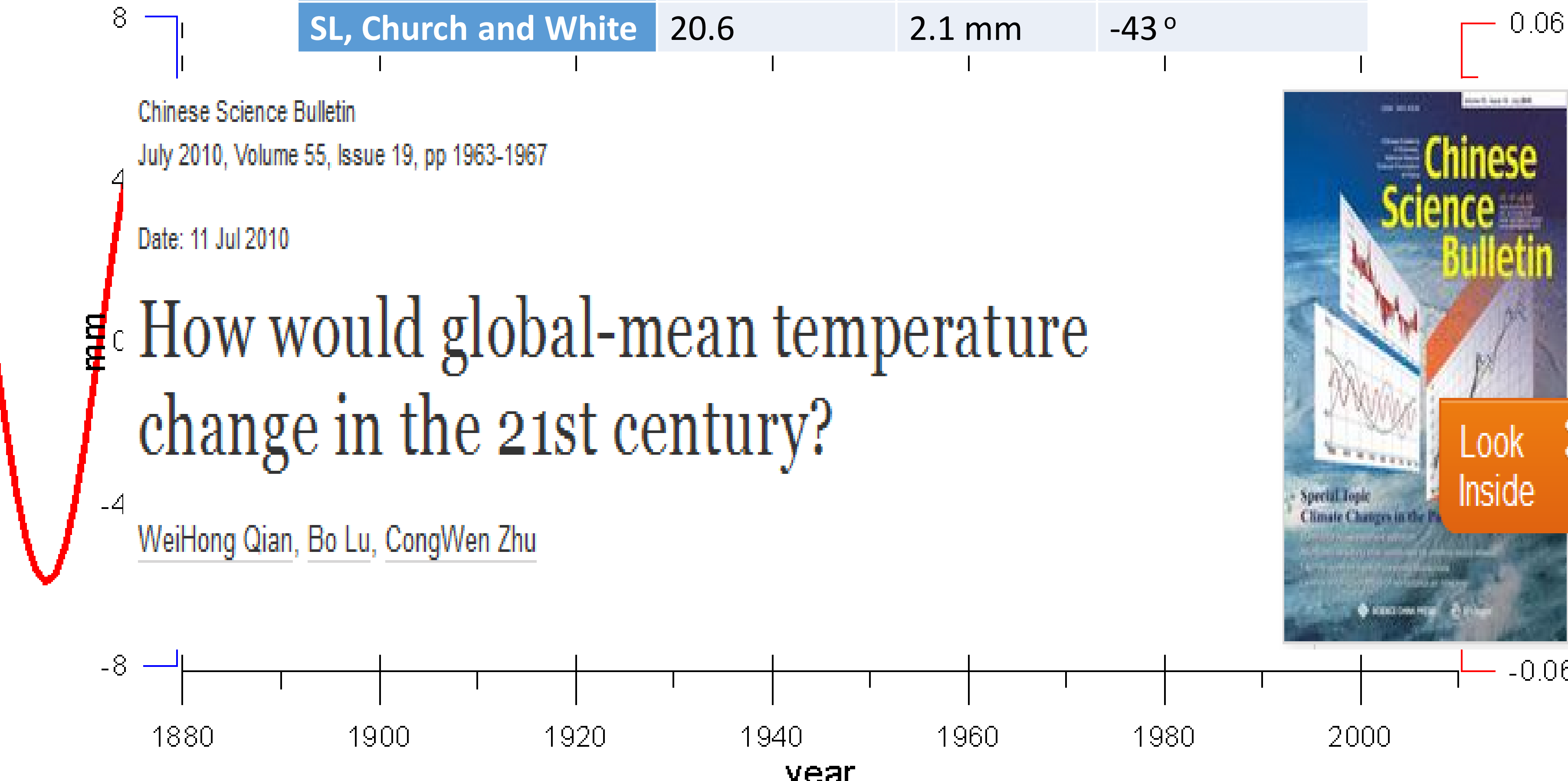
Results of non-linear LS-adjustment

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



Results of non-linear LS-adjustment

~20-year component NLSM fit			
Component	Period, years	Amplitude	Phase (1880)
T, HadCrut4	21.3	0.043 °C	-55°
SL, Jevrejeva	21.1	5.3 mm	-67°
SL, Church and White	20.6	2.1 mm	-43°



Chinese Science Bulletin

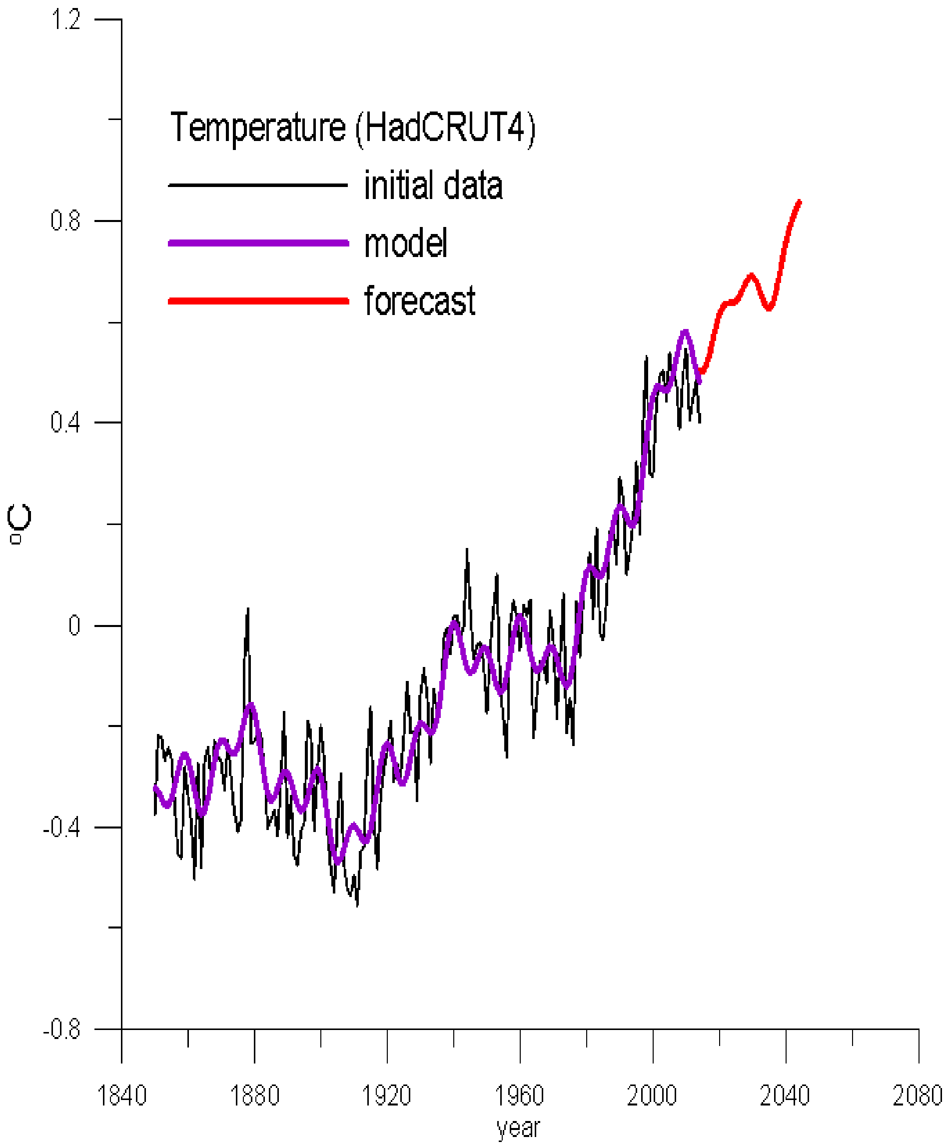
July 2010, Volume 55, Issue 19, pp 1963-1967

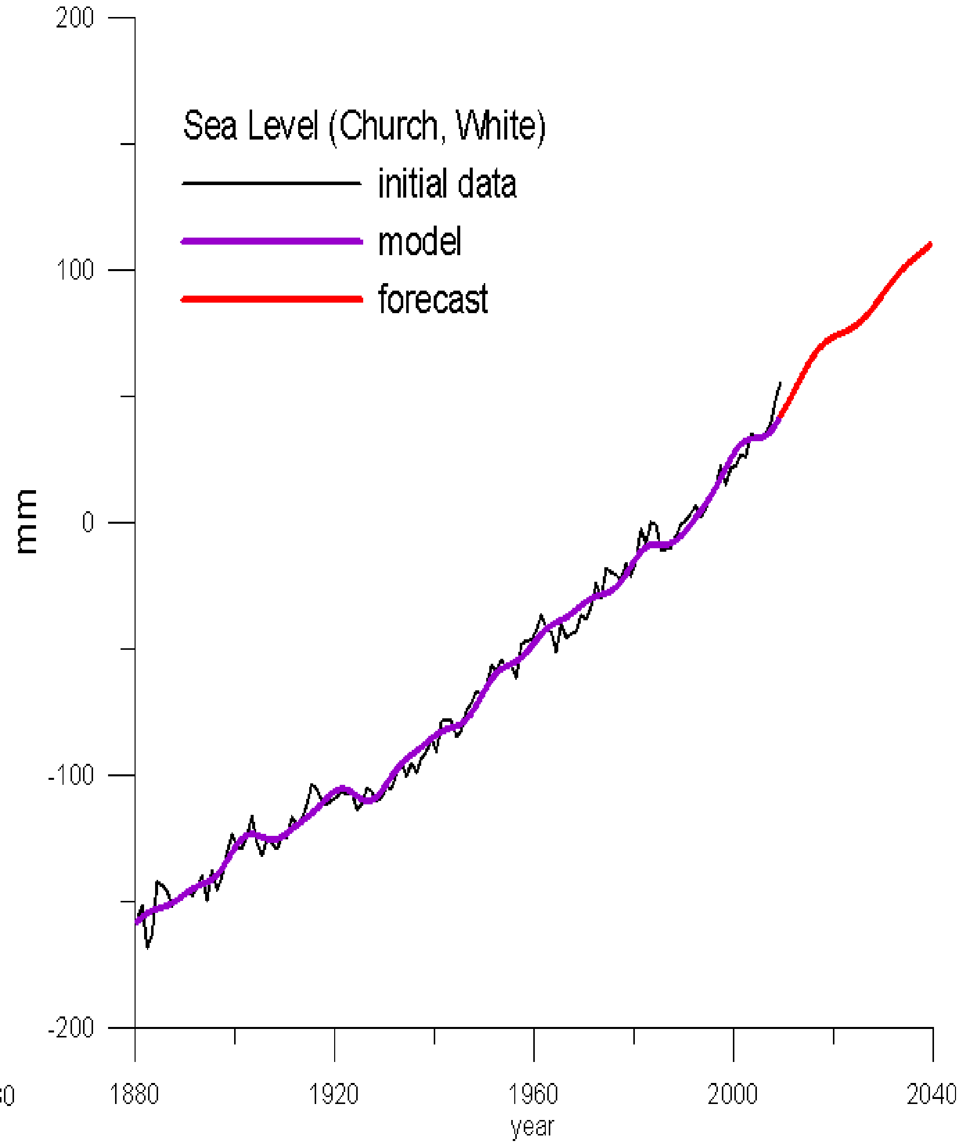
Date: 11 Jul 2010

How would global-mean temperature change in the 21st century?

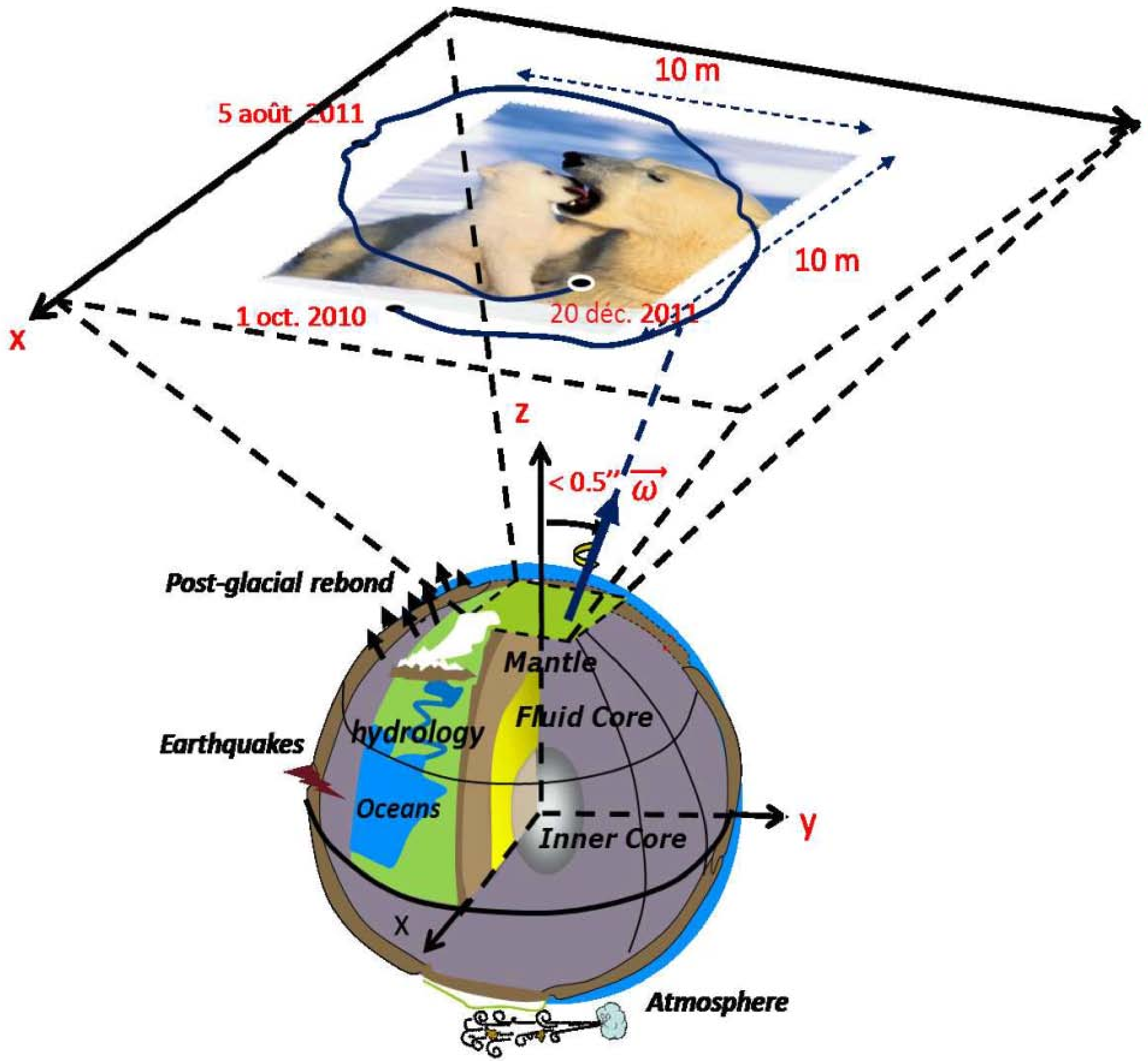
WeiHong Qian, Bo Lu, CongWen Zhu

CSSA-based Predictions for Temperature and SL



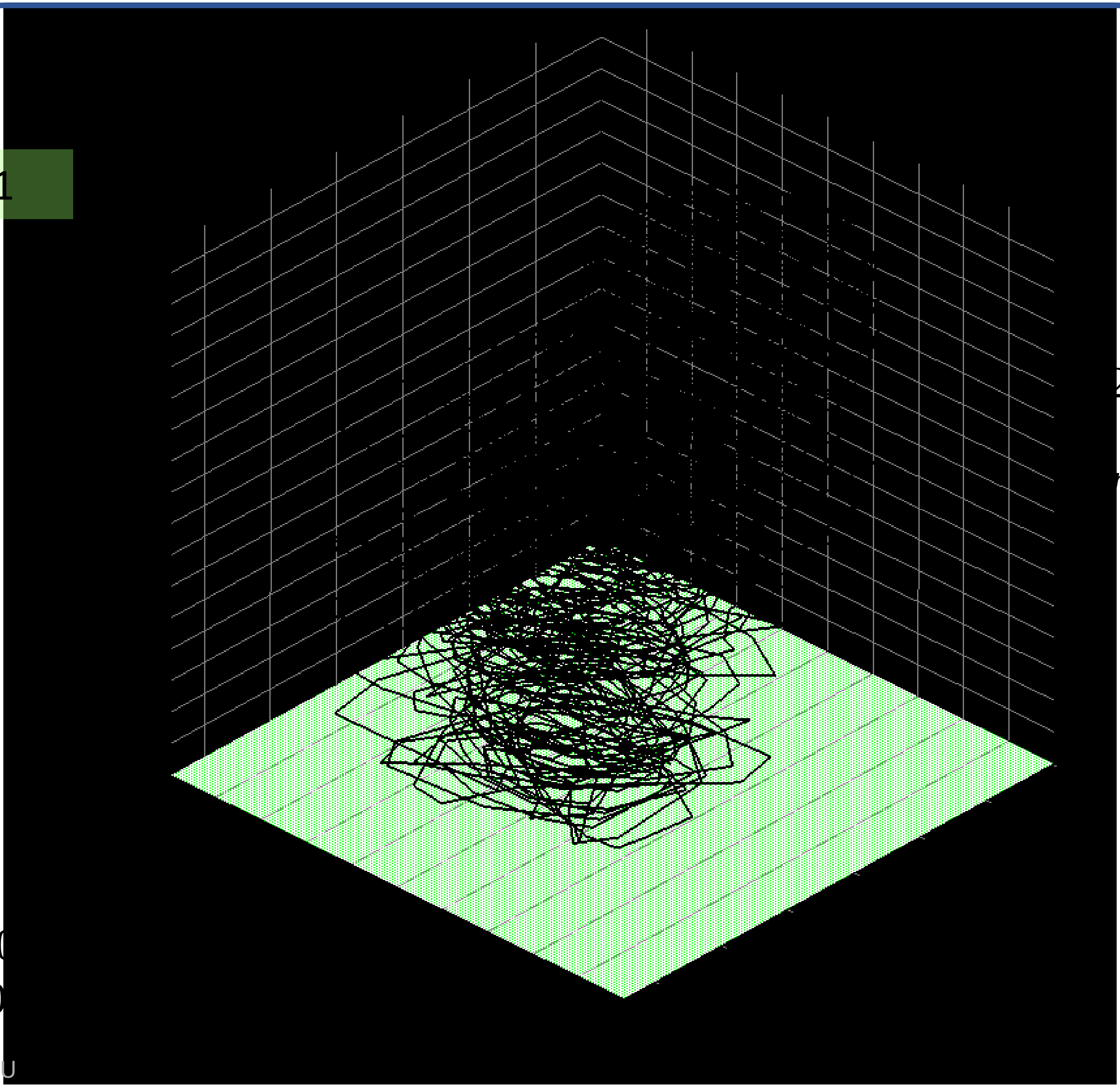


L.V.Zotov, C. M. Bizouard


10 m
5 août 2011
y
10 m
1 oct. 2010
20 déc. 2011
x
z
< 0.5″ $\overrightarrow{\omega}$
Post-glacial rebond
Mantle
Fluid Core
hydrology
Earthquakes
Oceans
Inner Core
y
x
Atmosphere

Motion of the Earth's pole

EOP CO1



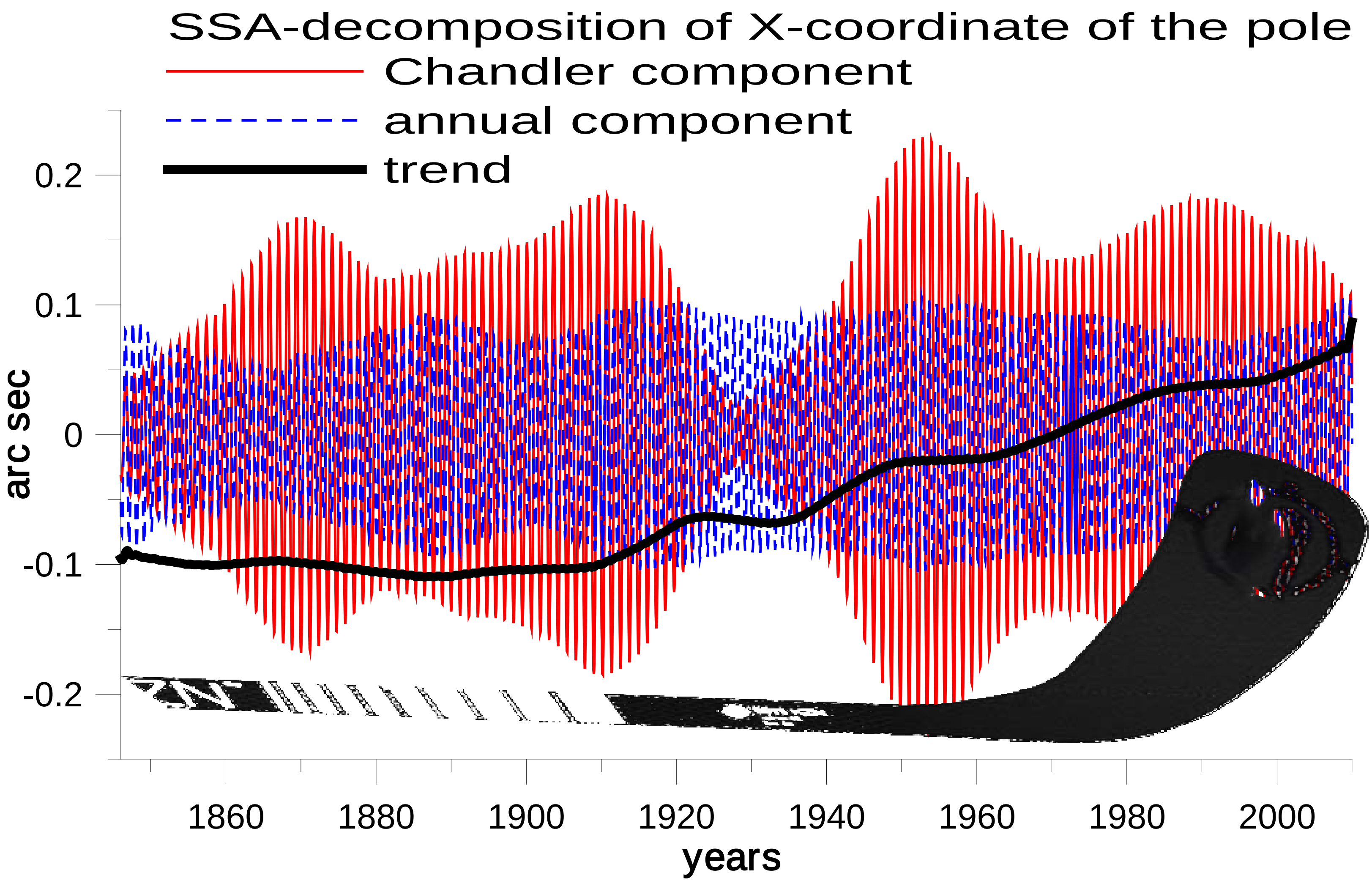
2D trajectory

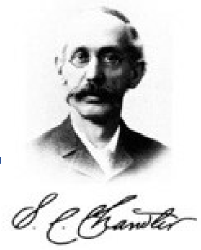
$m(t) = x - iy$

1846-20

step 0.0

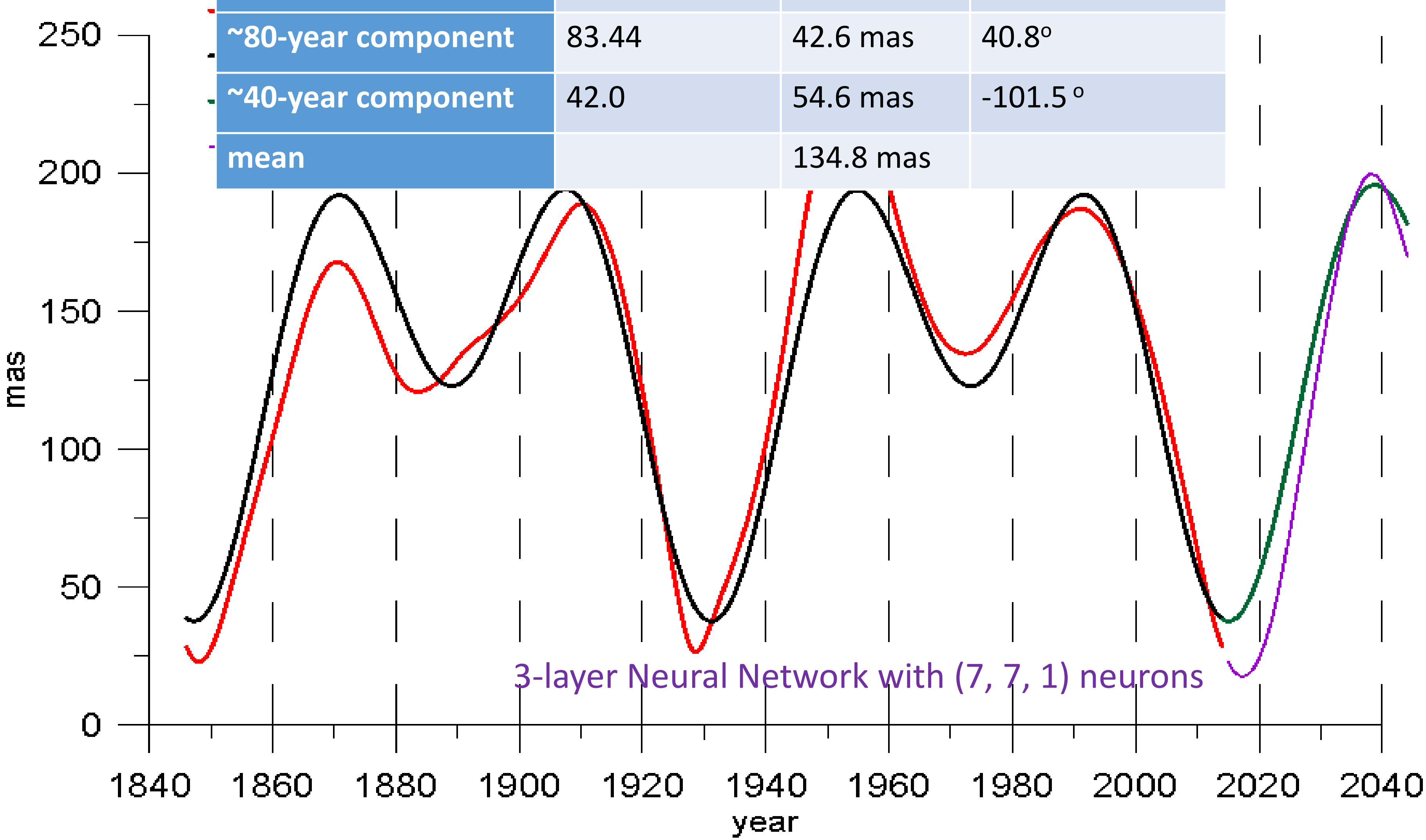
Singular Spectrum Analysis of Polar Motion





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	



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Dynamical model of the rotating Earth

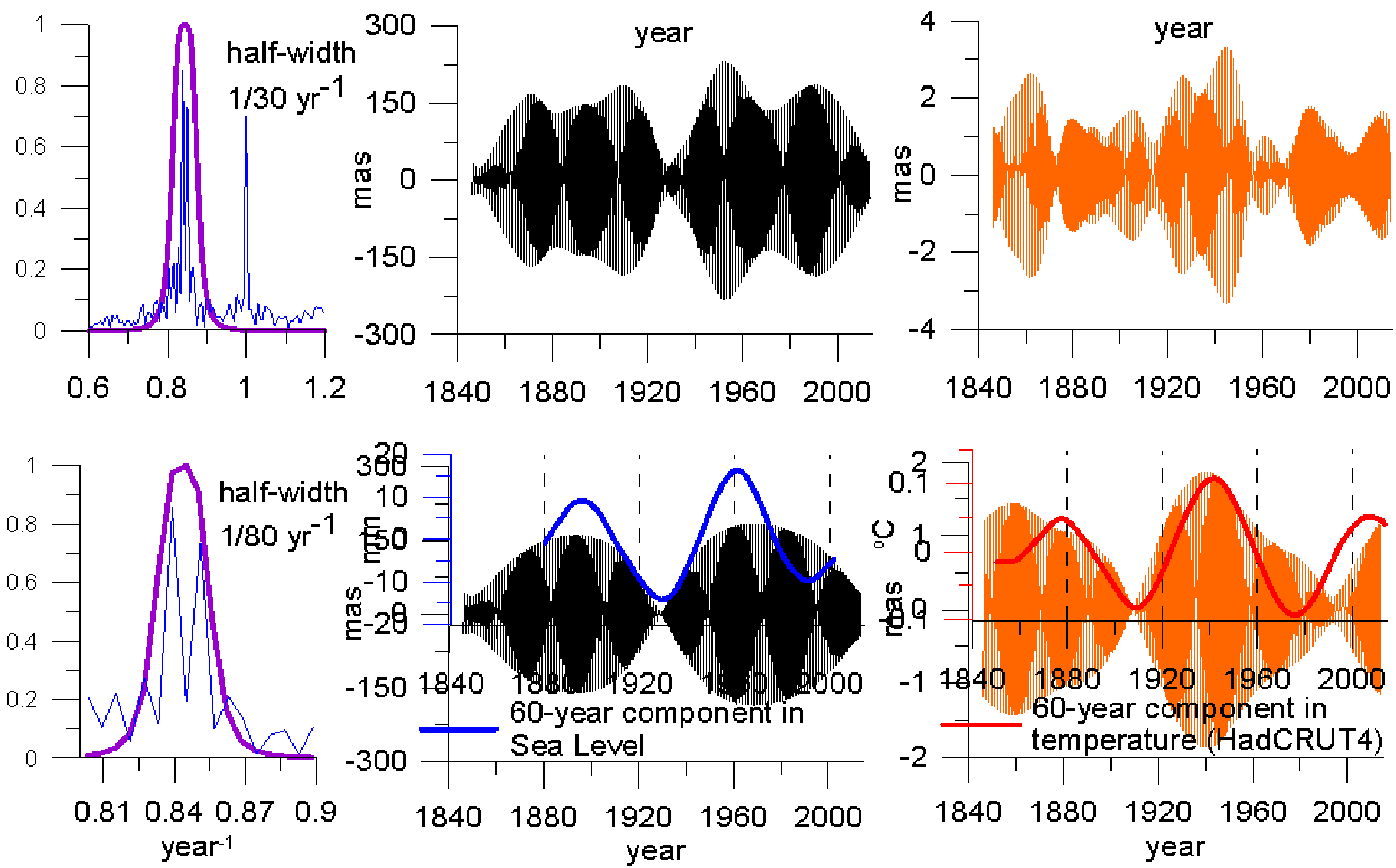
$$\frac{i}{\sigma_c}\frac{dm(t)}{dt} + m(t) = \chi(t)$$

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

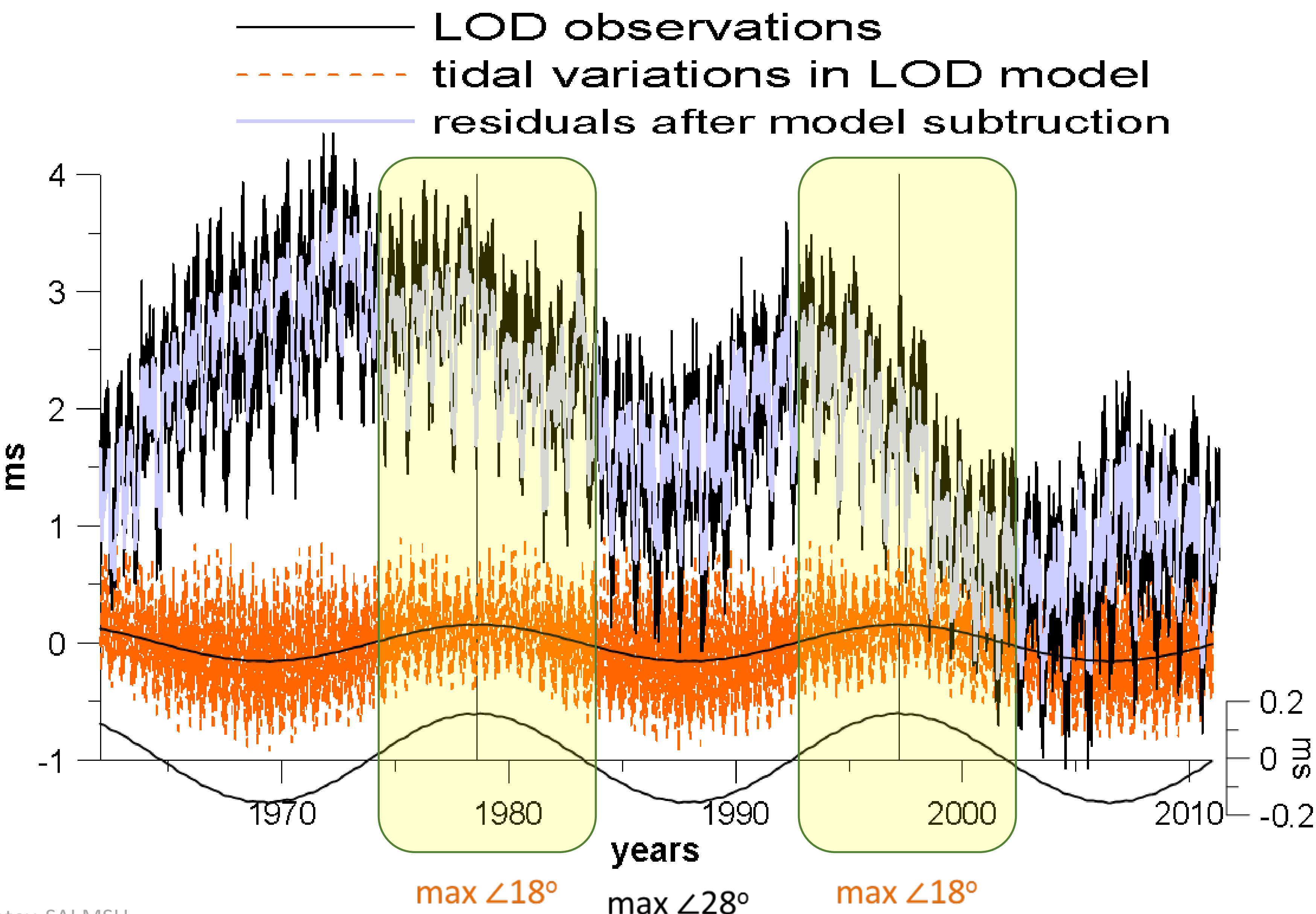
$$f_c = \frac{1}{433}\ \text{days}^{-1} \qquad Q = 175$$

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

Chandler wobble and its excitation depending on the filter width



Length of day (LOD) variability



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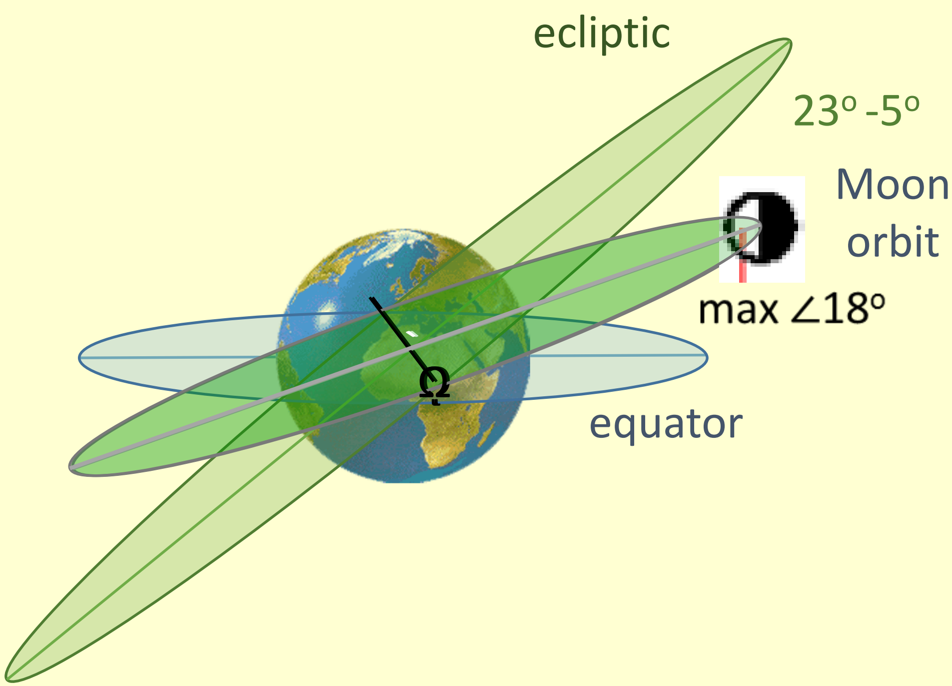
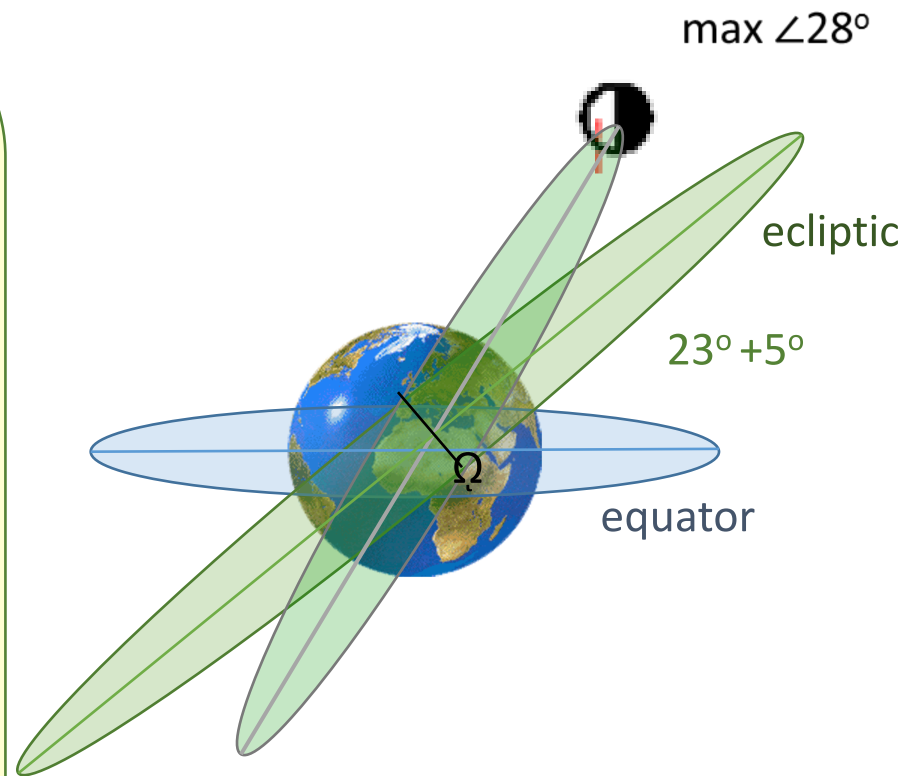
18.6 year period of orbital nodes regression



Moon orbit is between ecliptic and equator,
It does not have large inclinations

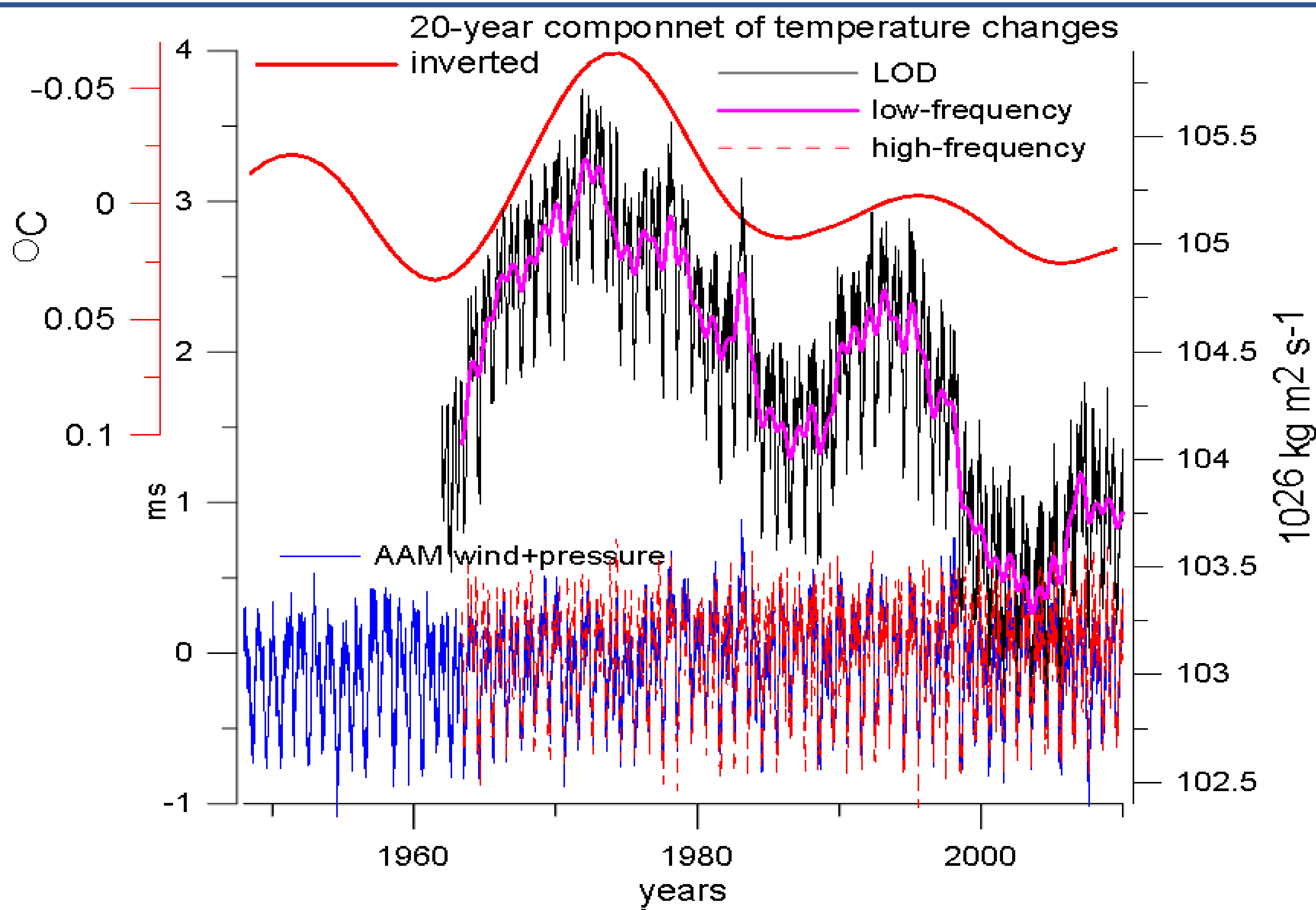
1997,
2015



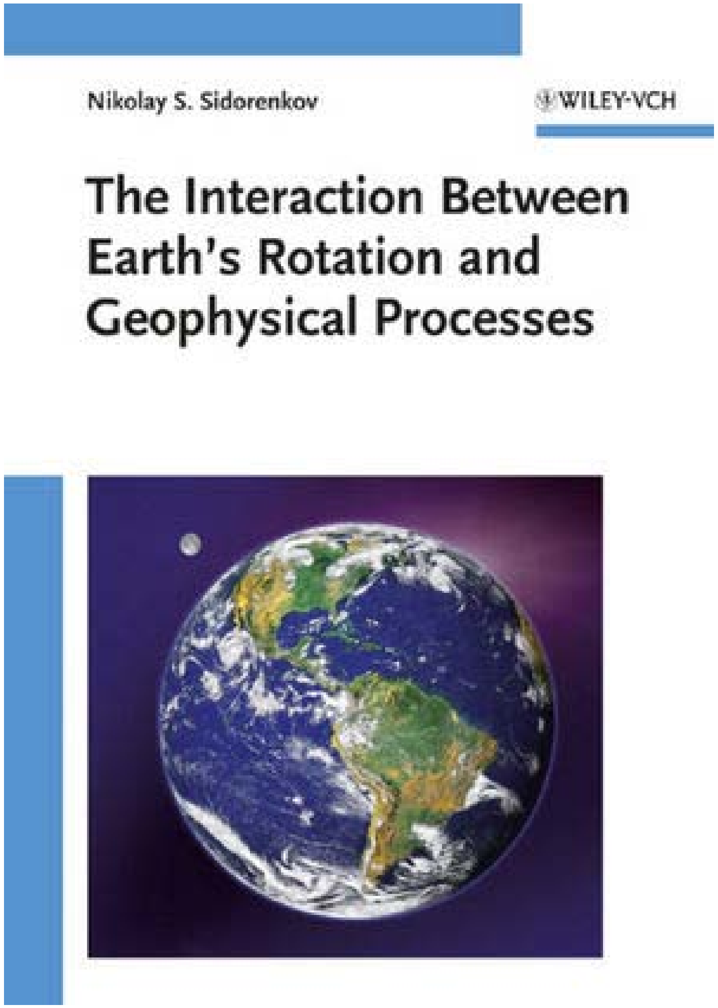
Moon orbit is above the ecliptic,
Its inclinations can be high

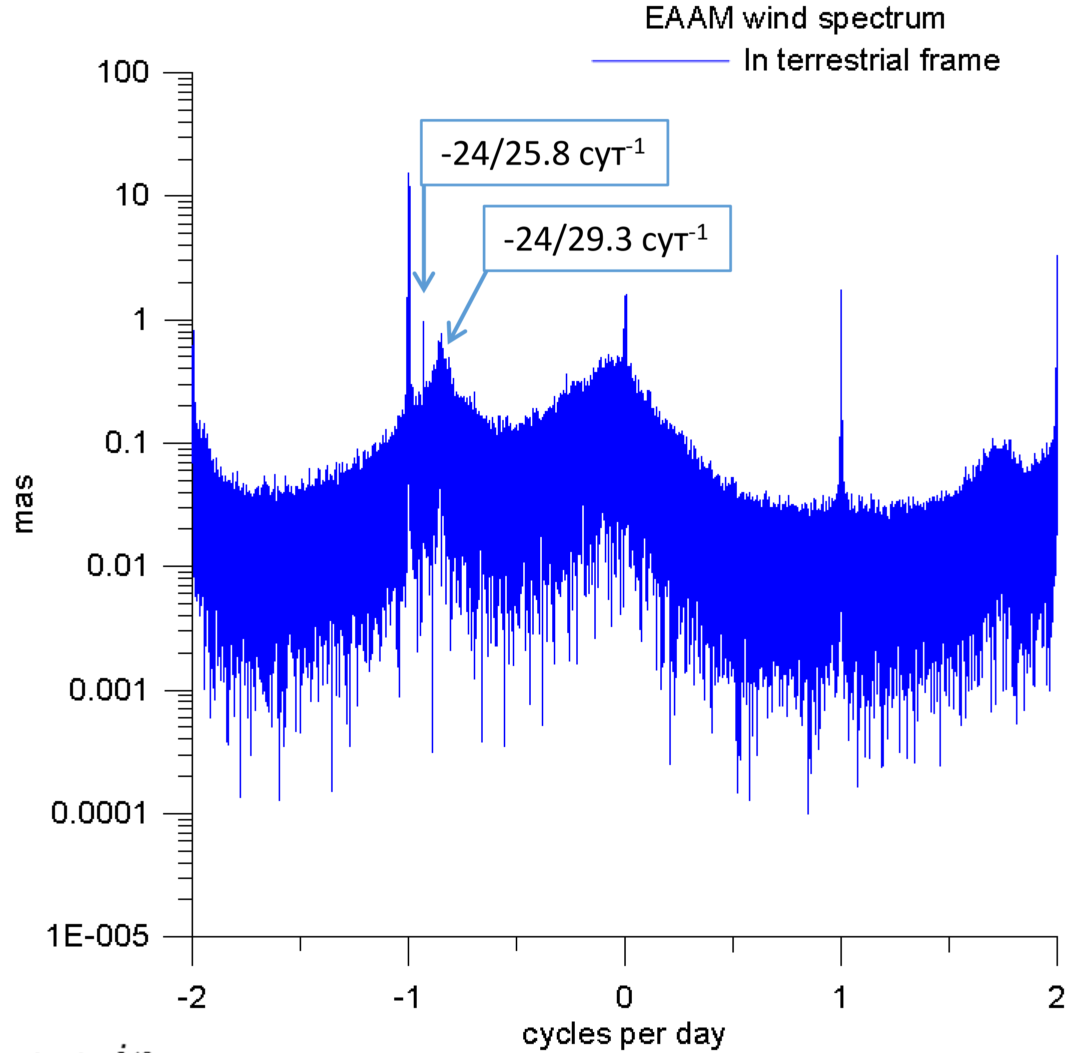
1988,
2007

Non-tidal LOD and 20-year temperature changes



Atmospheric Angular Momentum wind term spectra

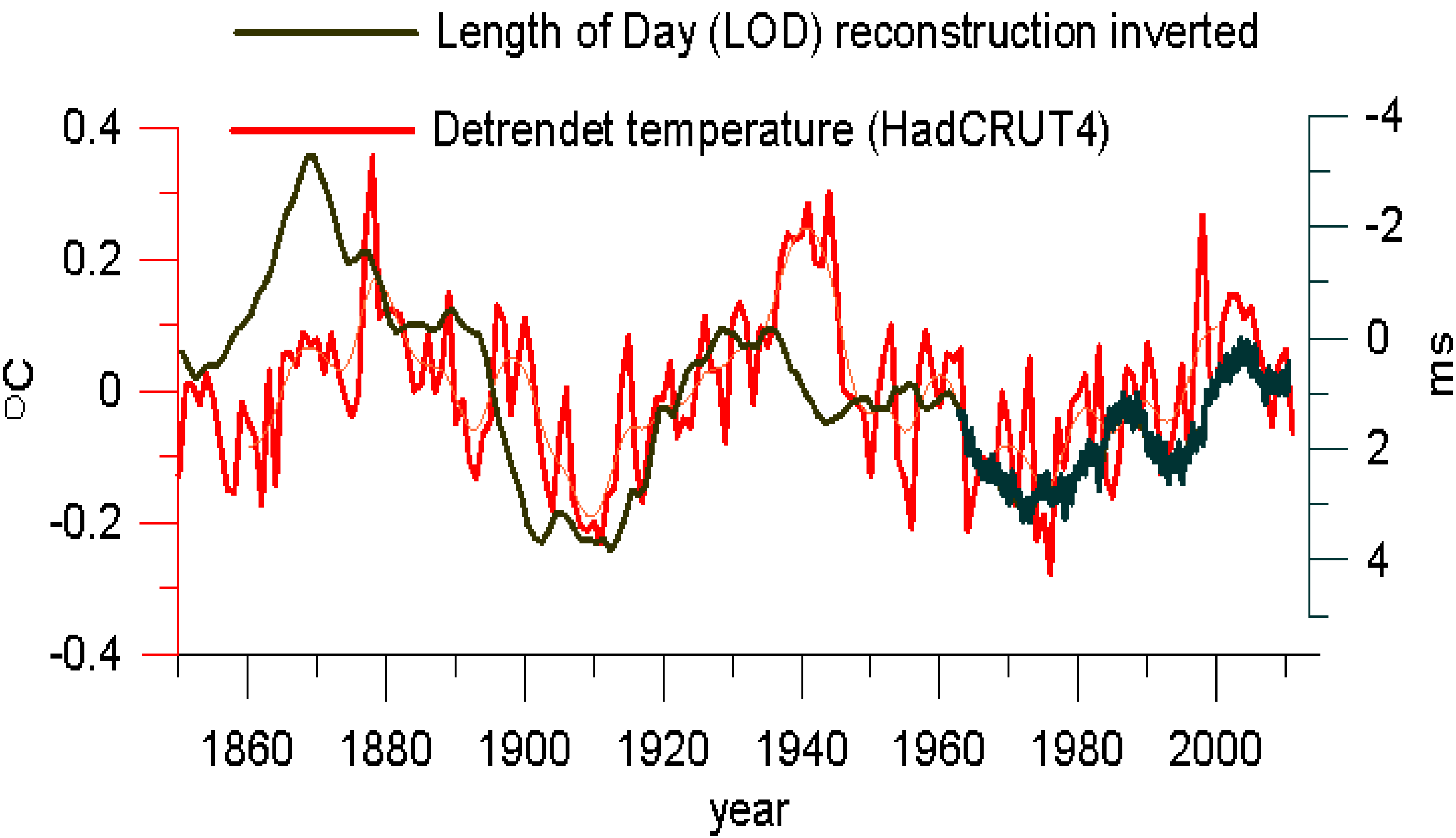




$\chi_1 + i\chi_2 = |\chi|e^{i\varphi}$ - EAAM axial component

C. Bizouard, L. Zotov, N. Sidorenkov Lunar influence on atmospheric angular momentum, Journal of Geophysical Research: Atmospheres, 2014, Wiley, DOI: 10.1002/2014JD022240

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



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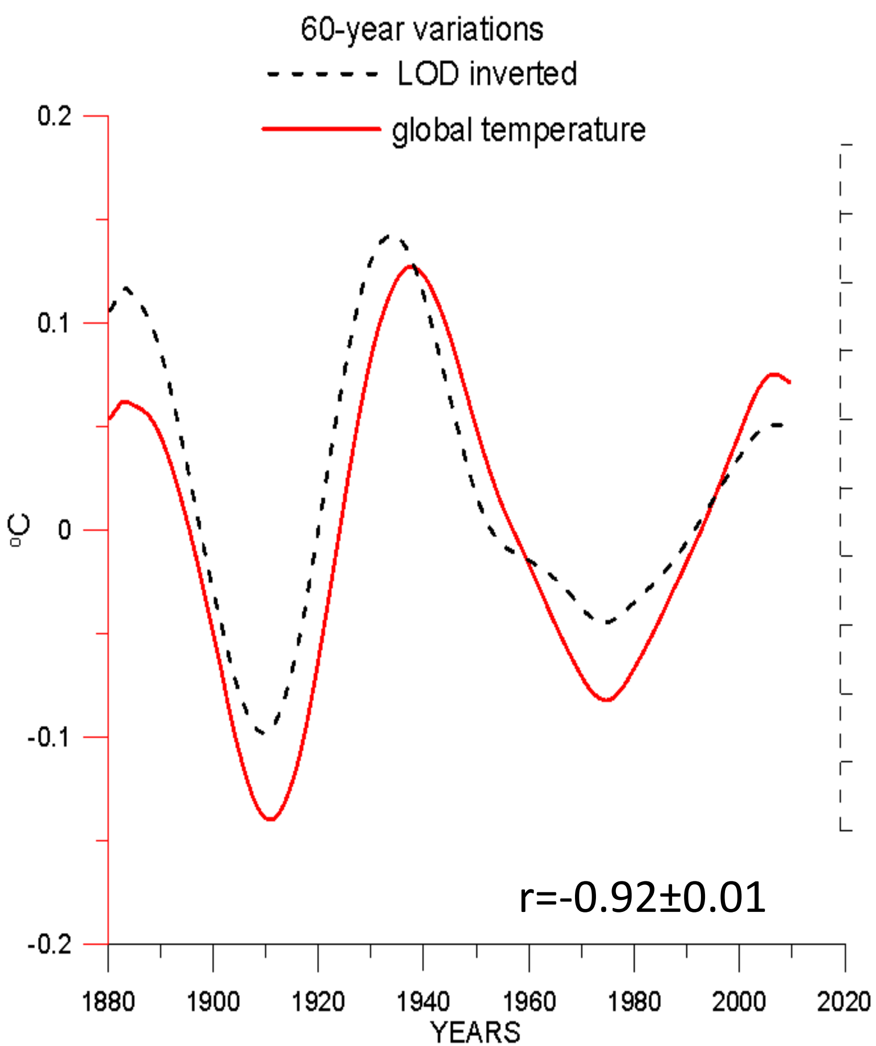
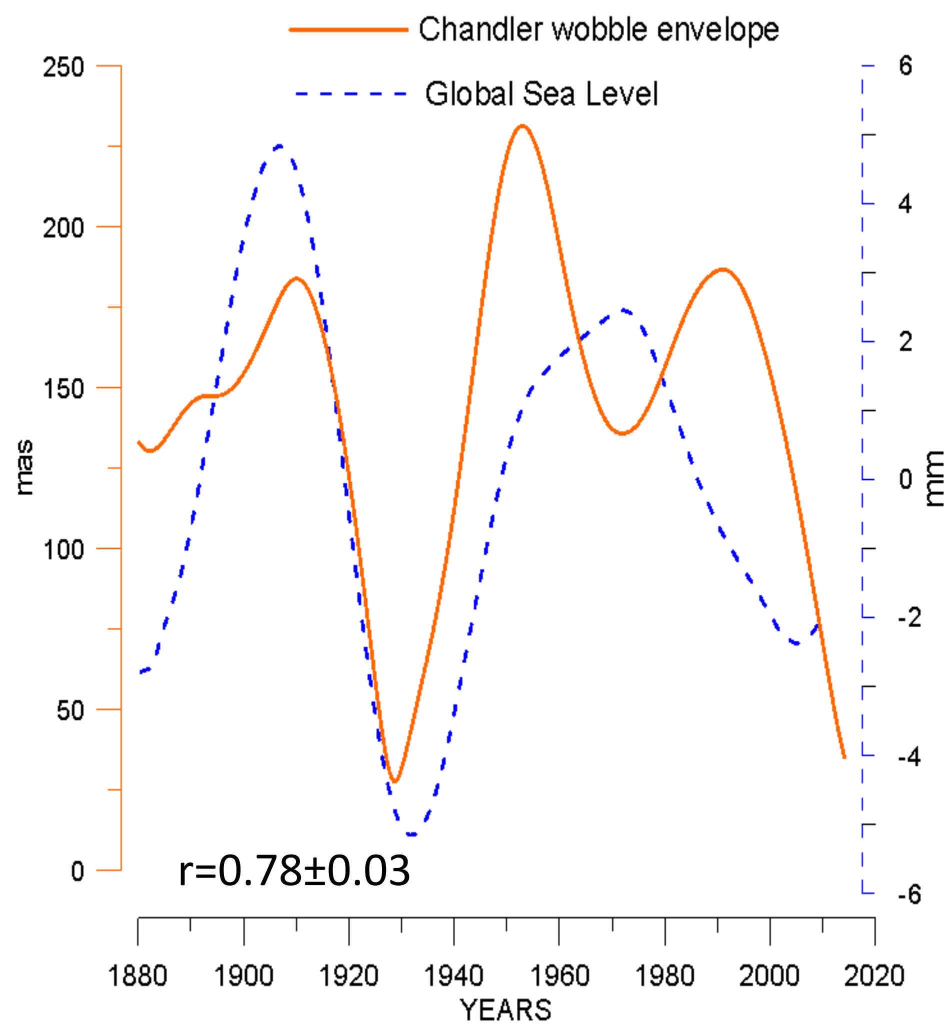
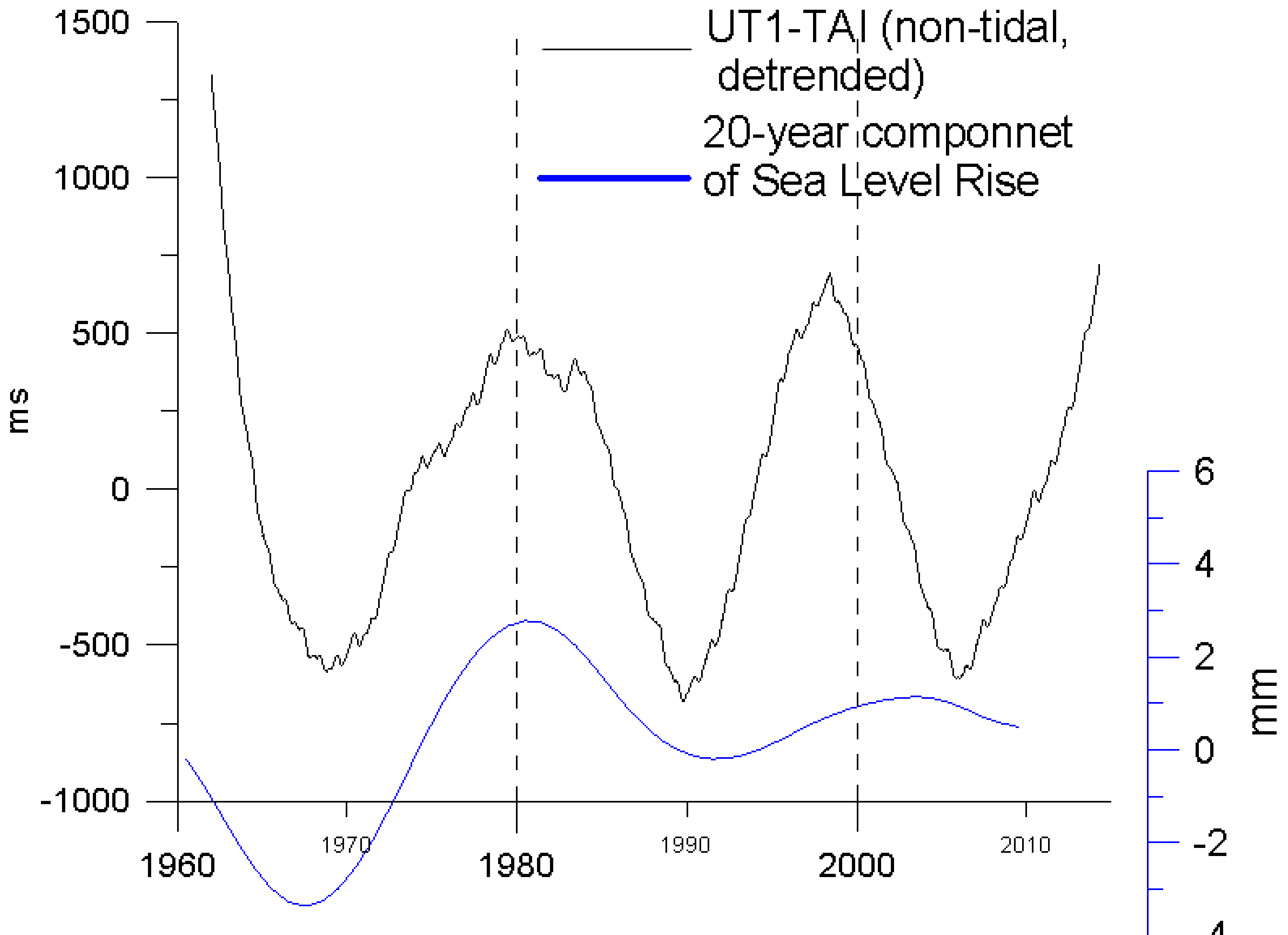
Long-term (60-year) changes in Temperature, SL Chandler wobble envelope and LOD



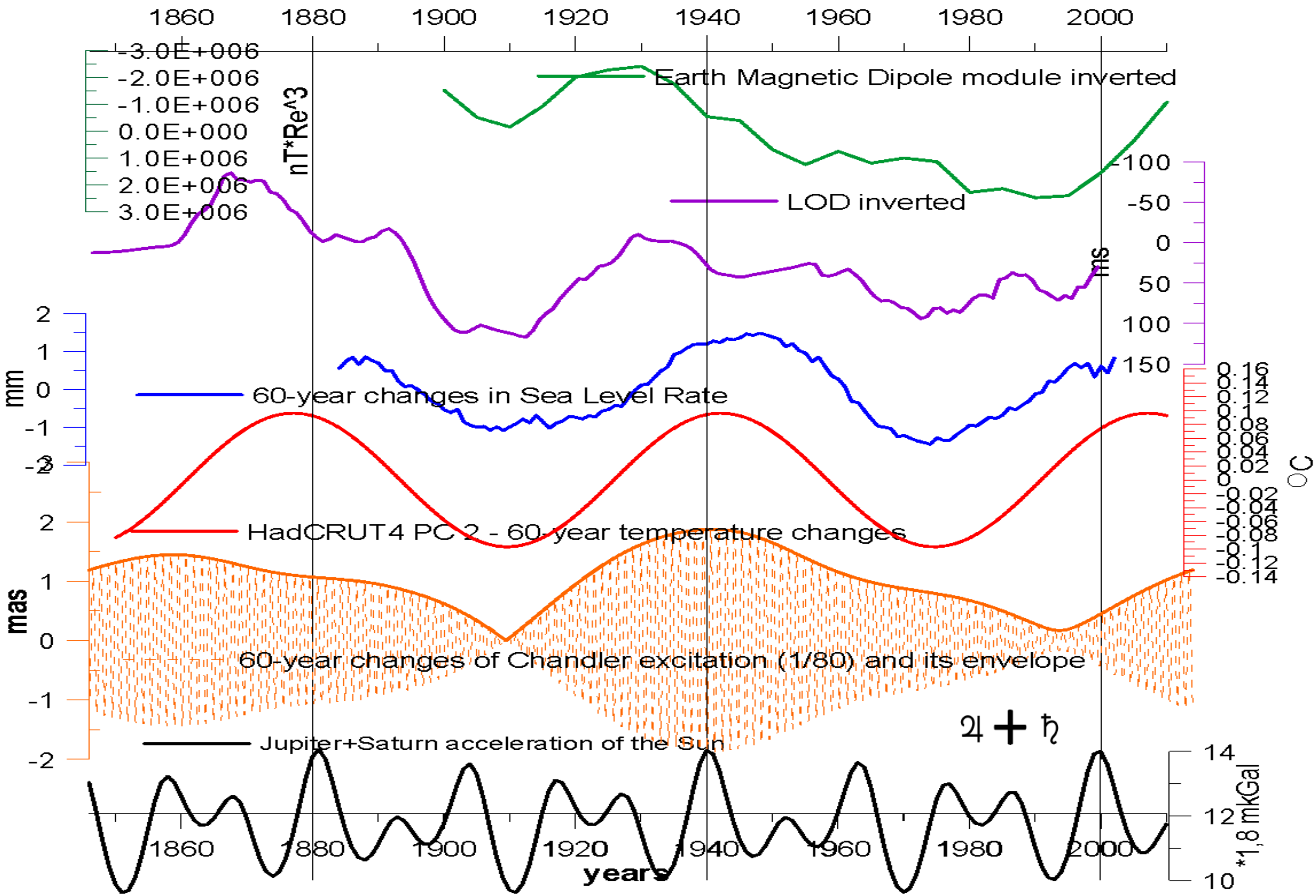


4D MSSA with L=22 years, parabolic trends preliminarily removed

20-year changes in Sea Level and UT1-UTC



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



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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

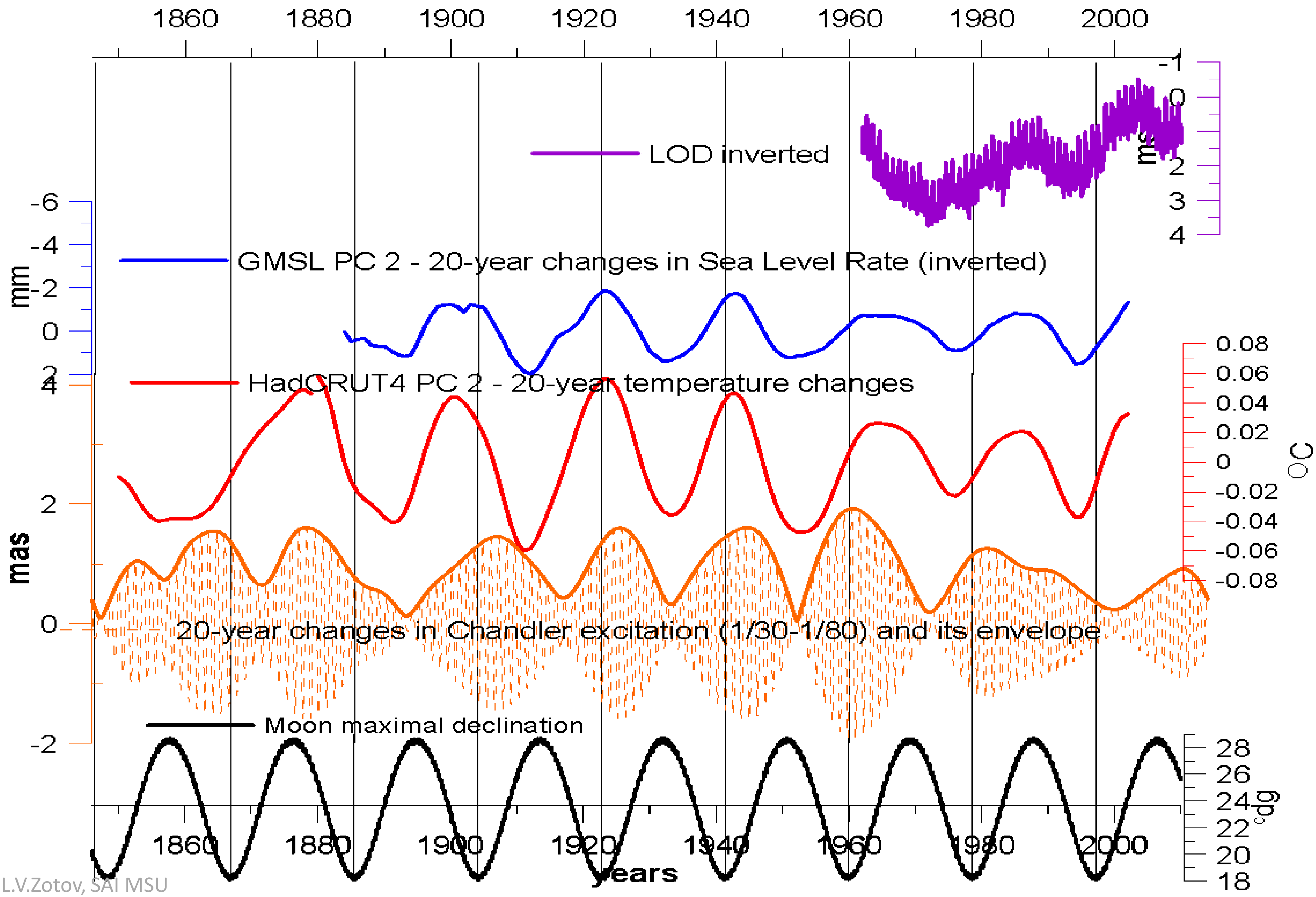
Conclusions

- We extract natural variations in global Earth temperature (HadCRUT4) and Sea Level (Jevrejeva, or Church and White) since 1850. Global warming 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
- Joint MSSA analysis of temperature, sea level, Chandler wobble envelope and LOD extracts similar 60 and 20-year oscillations in all mentioned time series
- 60 and 20-year components of temperature are anticorrelated with LOD
- Chandler wobble envelope is correlated with ~60 –year sea level changes
- 60-year component of Sea Level Rate (derivative) is correlated with temperature component. Similarities are well seen on the plots with LOD as a derivative of UT1-UTC and Chandler wobble as a derivative of excitation.
- 20-year components in Earth rotation and Climate characteristics could be related to the 18.6-year cycle of Moon orbital precession
- There are enough arguments collected, to come to the conclusion, that Earth rotation and Climate Changes are interrelated

Thank you

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

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



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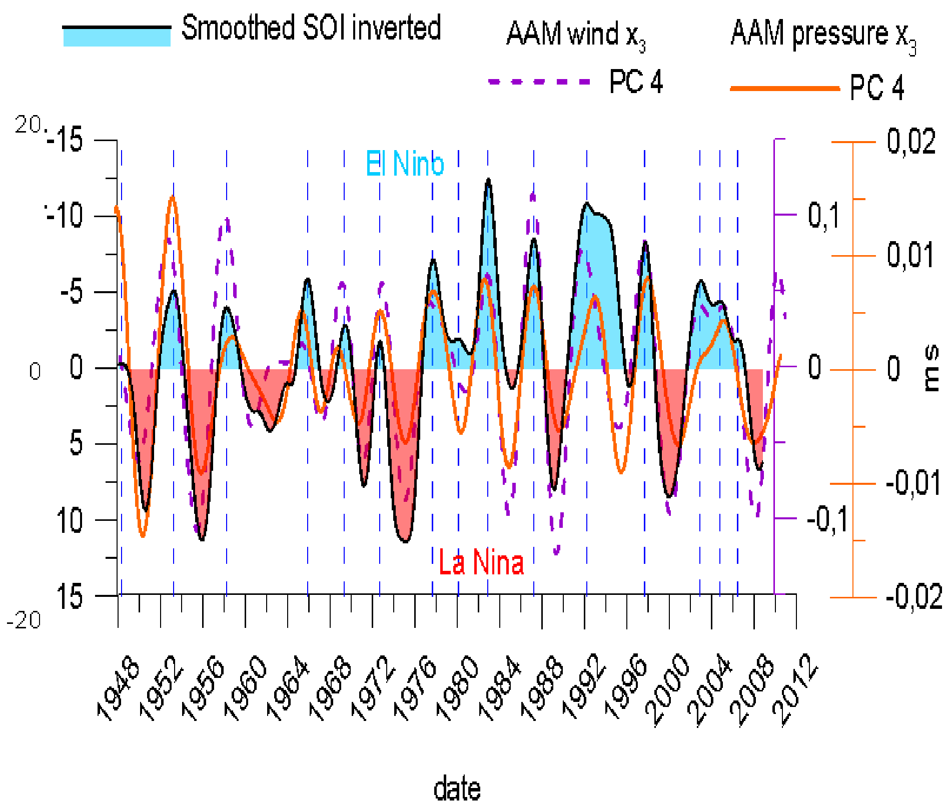
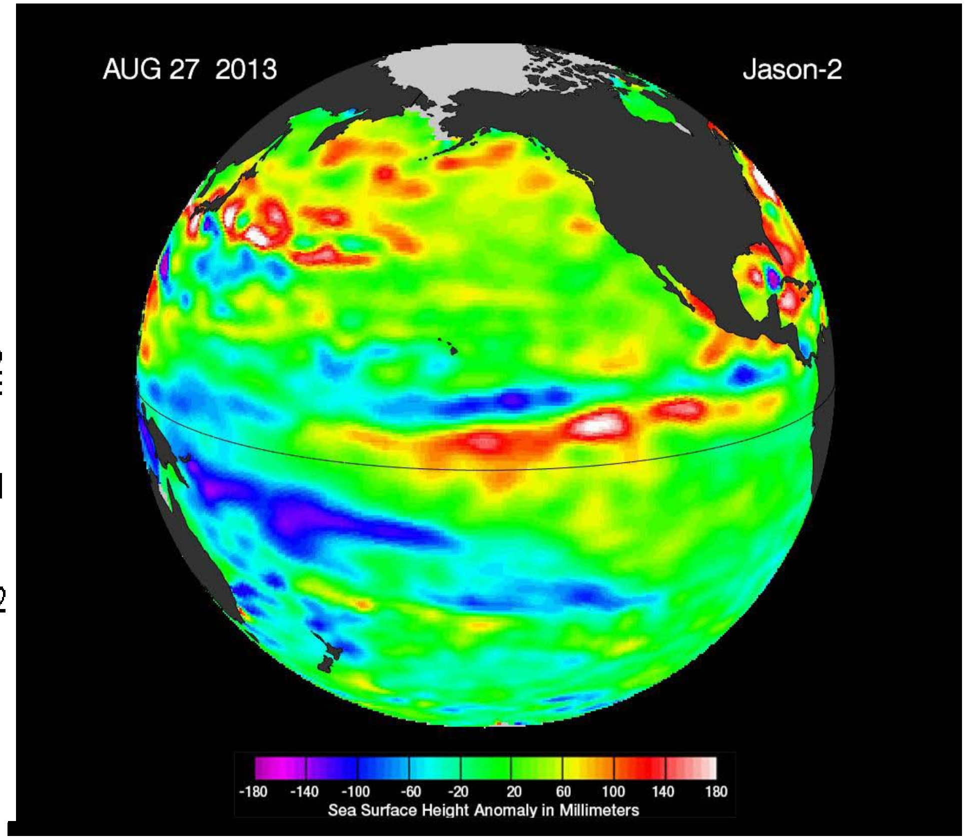
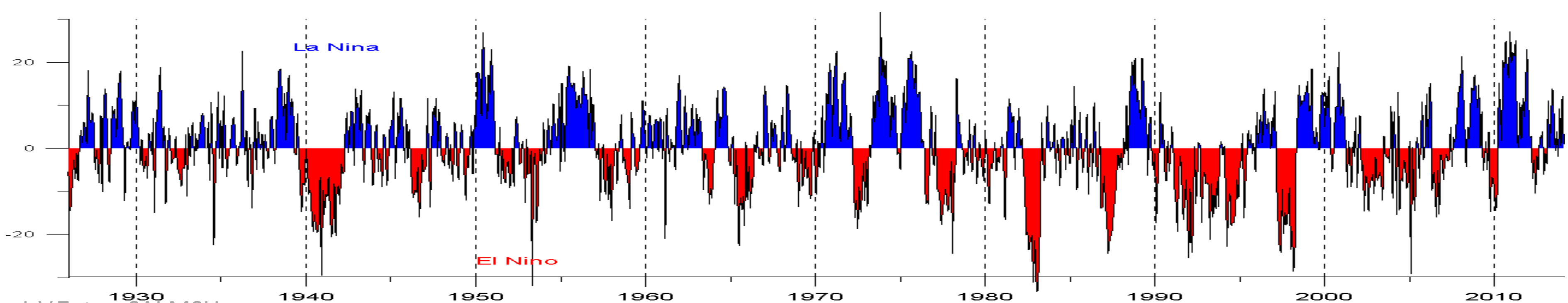
El-Nino, AAM and LOD





La Nada 2013



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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	ΔLOD
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

L. Zotov, N. Sidorenkov, C.K. Shum, Multichannel Singular Spectrum Analysis of Axial Atmospheric Angular Momentum, Journal of Geodynamics 2014, In press

Multichannel Singular Spectrum Analysis is a generalization of the principal components analysis (PCA)

1) The delay parameter *L* is chosen. For each component of a multidimensional time series the trajectory matrix is constructed. In our case - the channel (component) are Stokes coefficients *Aij* (*Cij* or *Sij*). Trajectory matrixes for all the components are embedded into the large block matrix *X*

$$X_{A_{ij}} = \begin{pmatrix} A_{ij}(t_0) & A_{ij}(t_1) & \ldots\ldots & A_{ij}(t_{K-1}) \\ A_{ij}(t_1) & A_{ij}(t_2) & \ldots\ldots & A_{ij}(t_K) \\ \ldots & \ldots & \ldots & \ldots \\ A_{ij}(t_{L-1}) & A_{ij}(t_L) & \ldots\ldots & A_{ij}(t_{N-1}) \end{pmatrix} \qquad K = N - L + 1$$

$$X = [X_{A_{1,1}}, X_{A_{2,1}}, X_{A_{1,2}} \ldots, X_{A_{ij}}, \ldots, X_{A_{P-1,Q}}, X_{A_{P,Q}}]^T$$

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

$$X = USV^T$$

3) Principal components (PC) correspond to every singular number s_i. The components with similar properties are grouped and their matrixes are obtained by multiplying of s_i by the first and the second singular basis vectors u_i, v_i

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

4) Signal in each channel is reconstructed from the X^i matrixes for each PC by averaging along the side diagonals (operation of Hankelization).

Журнал Природа, Май, 2014 г.

Момент импульса атмосферы

Н.С.Сидоренков, К.Бизуар, Л.В.Зотов, Д.Салстейн

Атмосфера, удерживаемая силой притяжения Земли, вращается относительно земной поверхности. Физической характеристикой этого движения служит момент импульса атмосферы; его анализ дает возможность составить представление о кинематике циркуляции воздуха и протекающих в нем процессах.

Модель

Воздушные массы движутся вдоль земной поверхности, которая имеет сферическую форму с кривизной, равной радиусу Земли R. На малых масштабах ($l << R$) кривизной земной поверхности можно пренебречь, движение масс рассматривать как плоскопараллельное; для его описания достаточно использовать закон сохранения импульса. На мас-

мое есть переносной момент импульса атмосферы, возникающий из-за твердотельного вращения атмосферы вместе с Землей со скоростью $\mathbf{\Omega}$. Второе слагаемое характеризует движения воздуха относительно неподвижной земной поверхности, т.е. ветер, поэтому $\mathbf{h}$ называют моментом импульса ветров. Изменения абсолютного момента импульса атмосферы возникают, во-первых, из-за вариаций компонентов тензора инерции атмосферы (в результате перераспределения воздушных и водных масс) и, во-вторых, из-за колебаний компонентов момента импульса ветров. В книгах [1, 2] показано, что вклад последнего фактора в изменения момента импульса Земли в несколько раз превышает вклад первого. Соответственно, в дальнейшем мы сосредоточимся на вариациях момента импульса ветров.

Будем пользоваться земной системой коорди-

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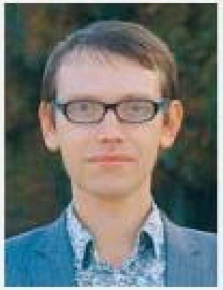

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