# Climate Change and prediction of the Chandler Wobble

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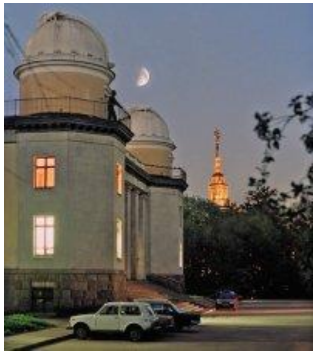
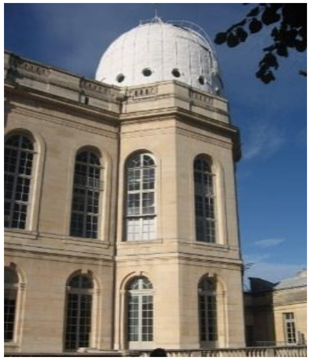
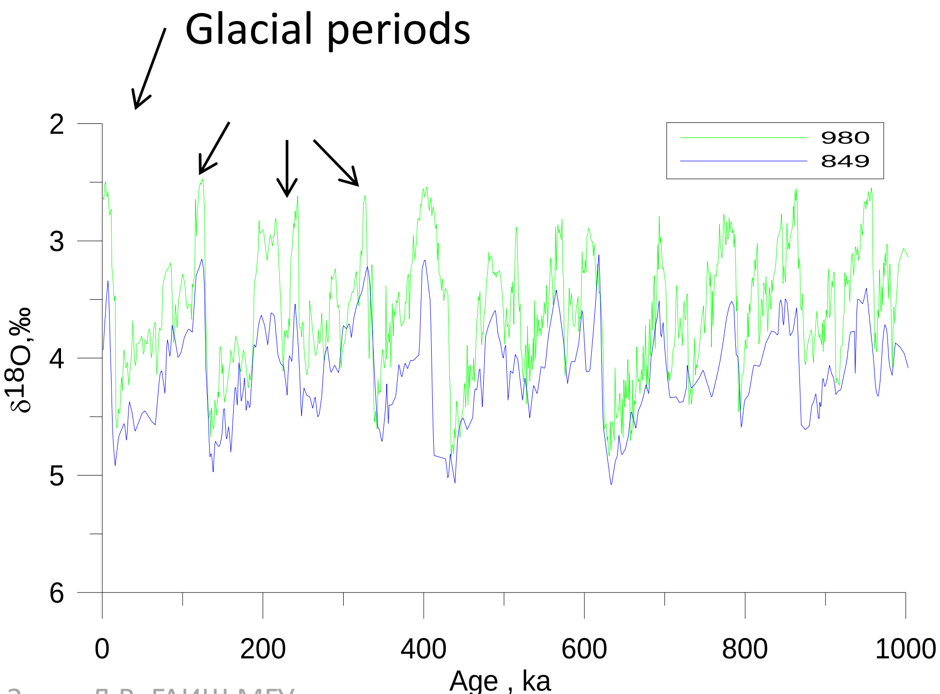
[1] Sternberg Astronomical Institute of Moscow State University
[2]Paris Observatory, SYRTE, France
[3] Moscow Institute of Electronics and Mathematics (MIEM) HSE

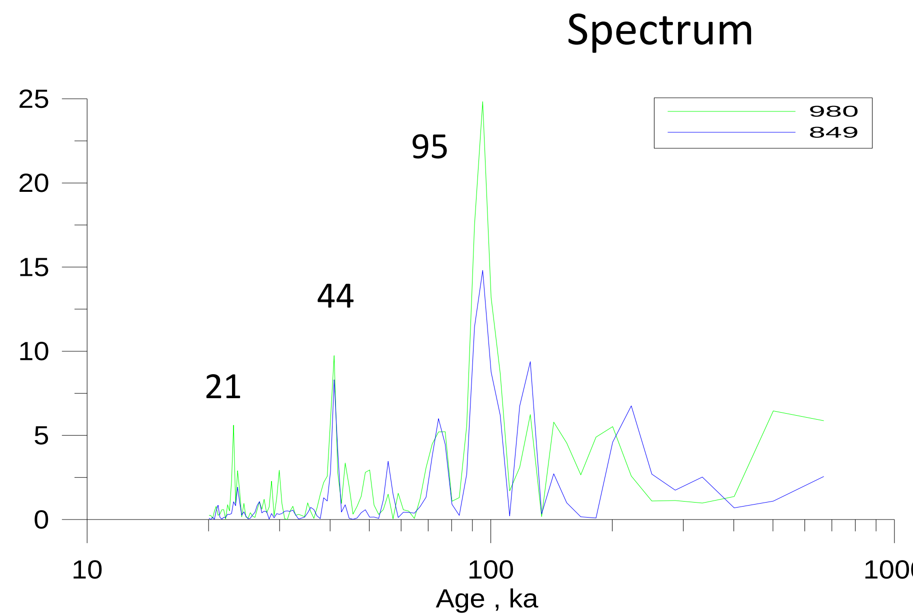


22 September 2015
Pulokovo-2015

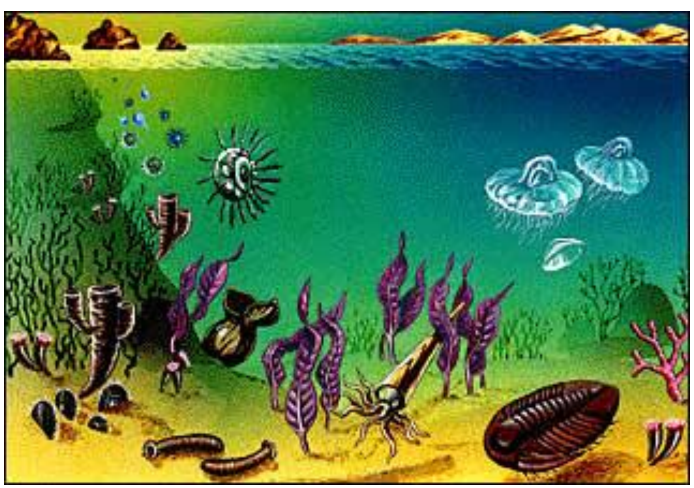


# Paleoclimate




Зотов Л.В. ГАИШ МГУ




# Milankovitch theory

Berger: Milankovitch Theory and Climate

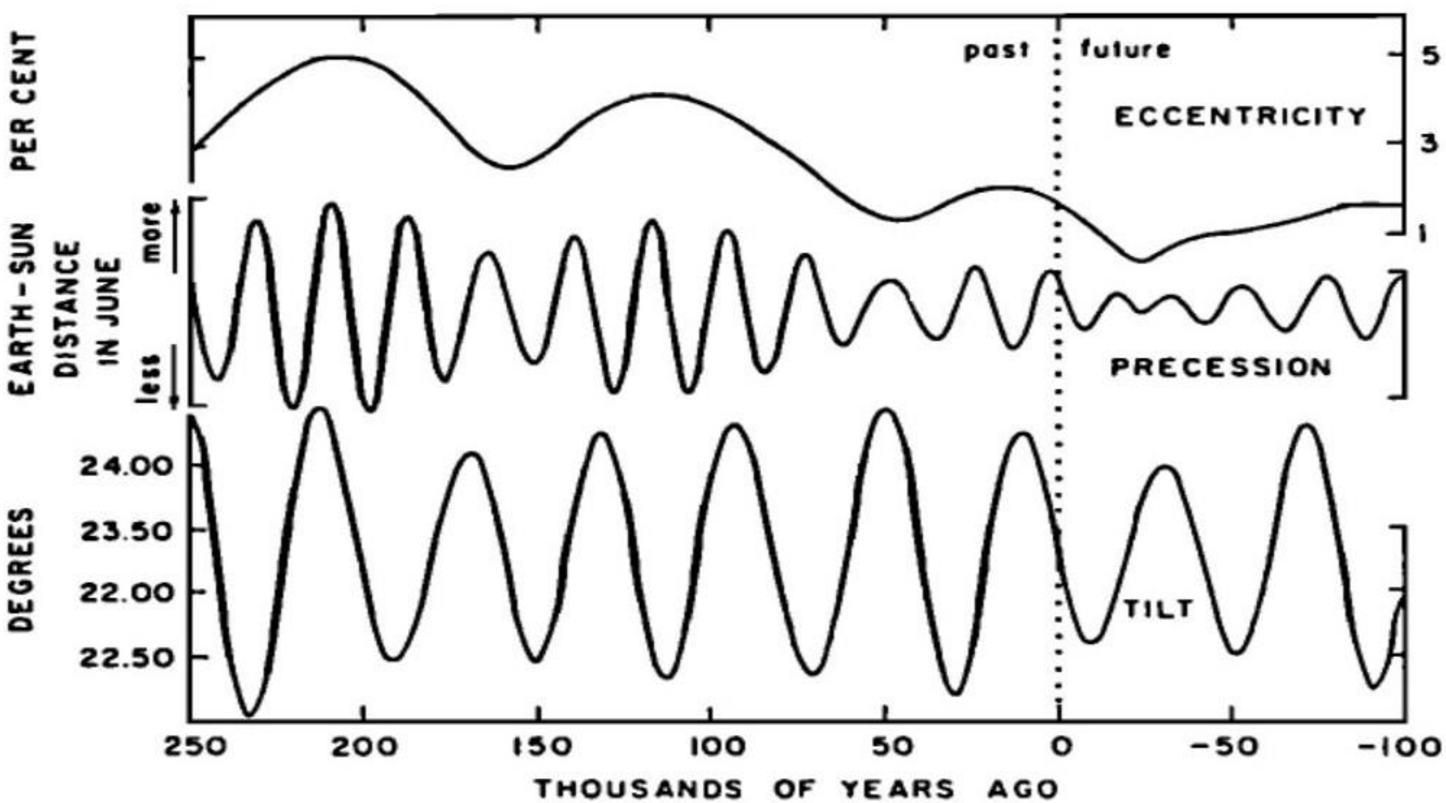
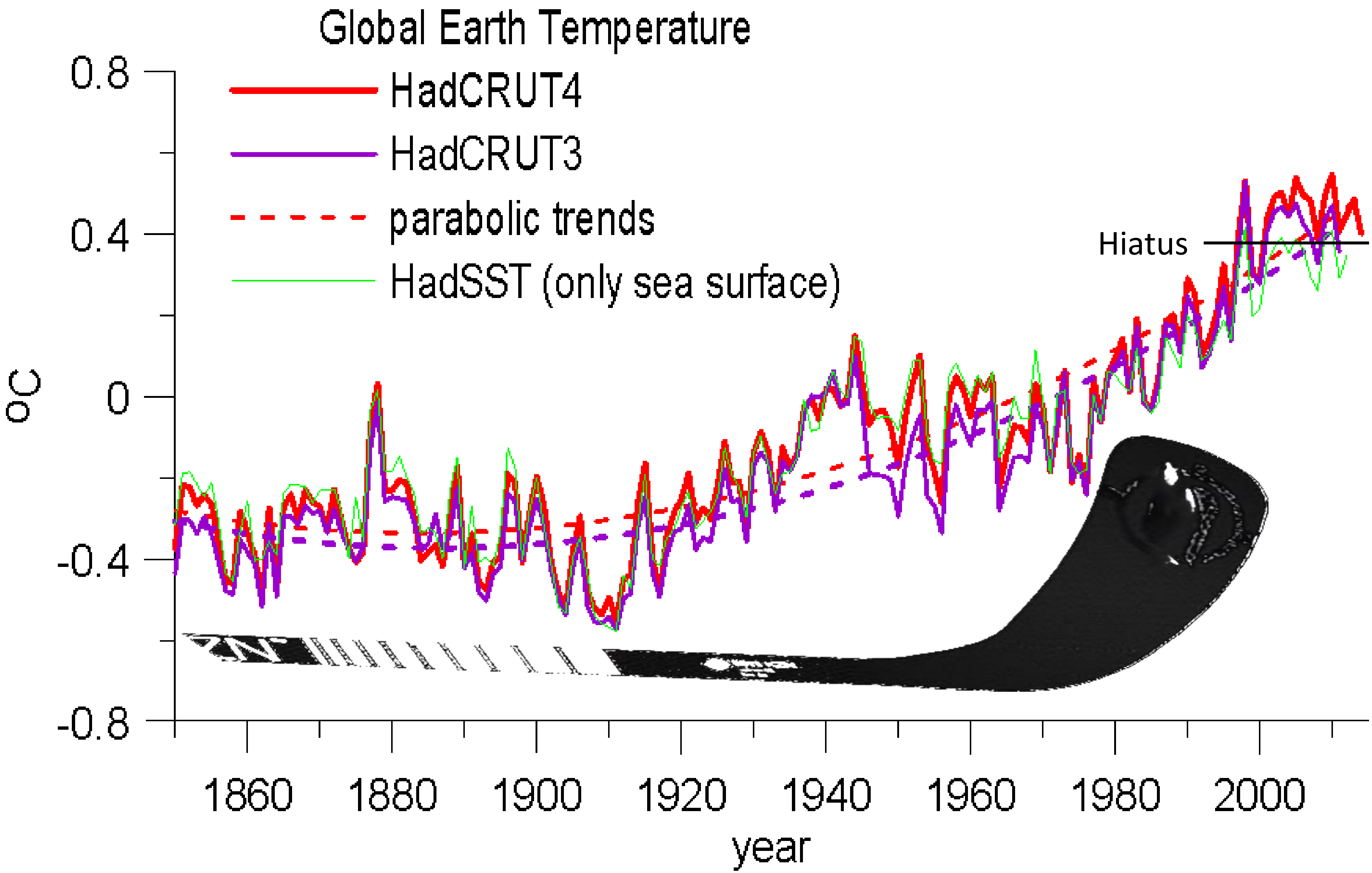



Fig. 11. Long-term variations of eccentricity, precession, and tilt from 250,000 years B.P. to 100,000 years A.P. [Berger, 1978c].

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

What about short-term?

# Global Earth temperature



# Global Mean Sea Level

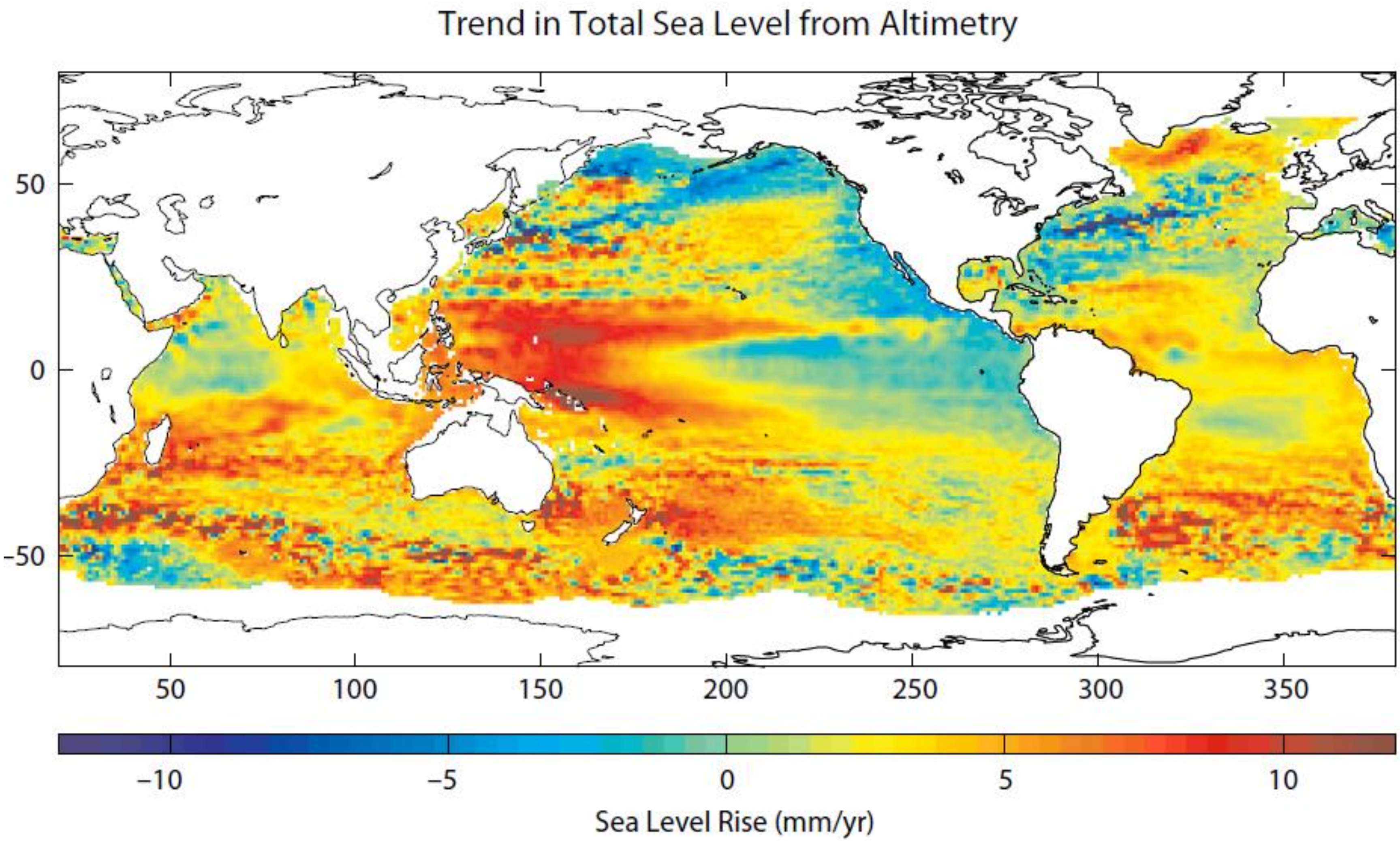
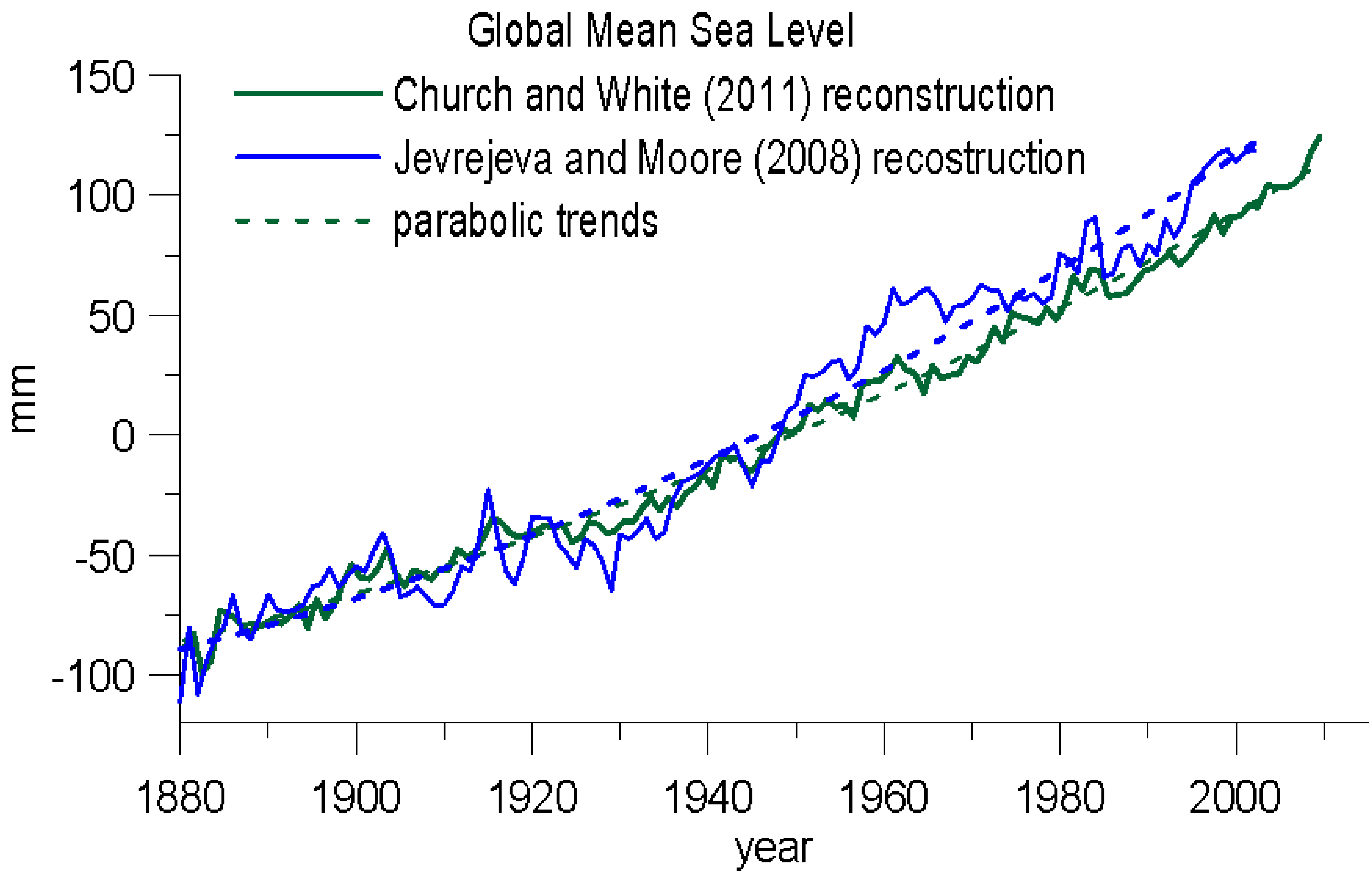


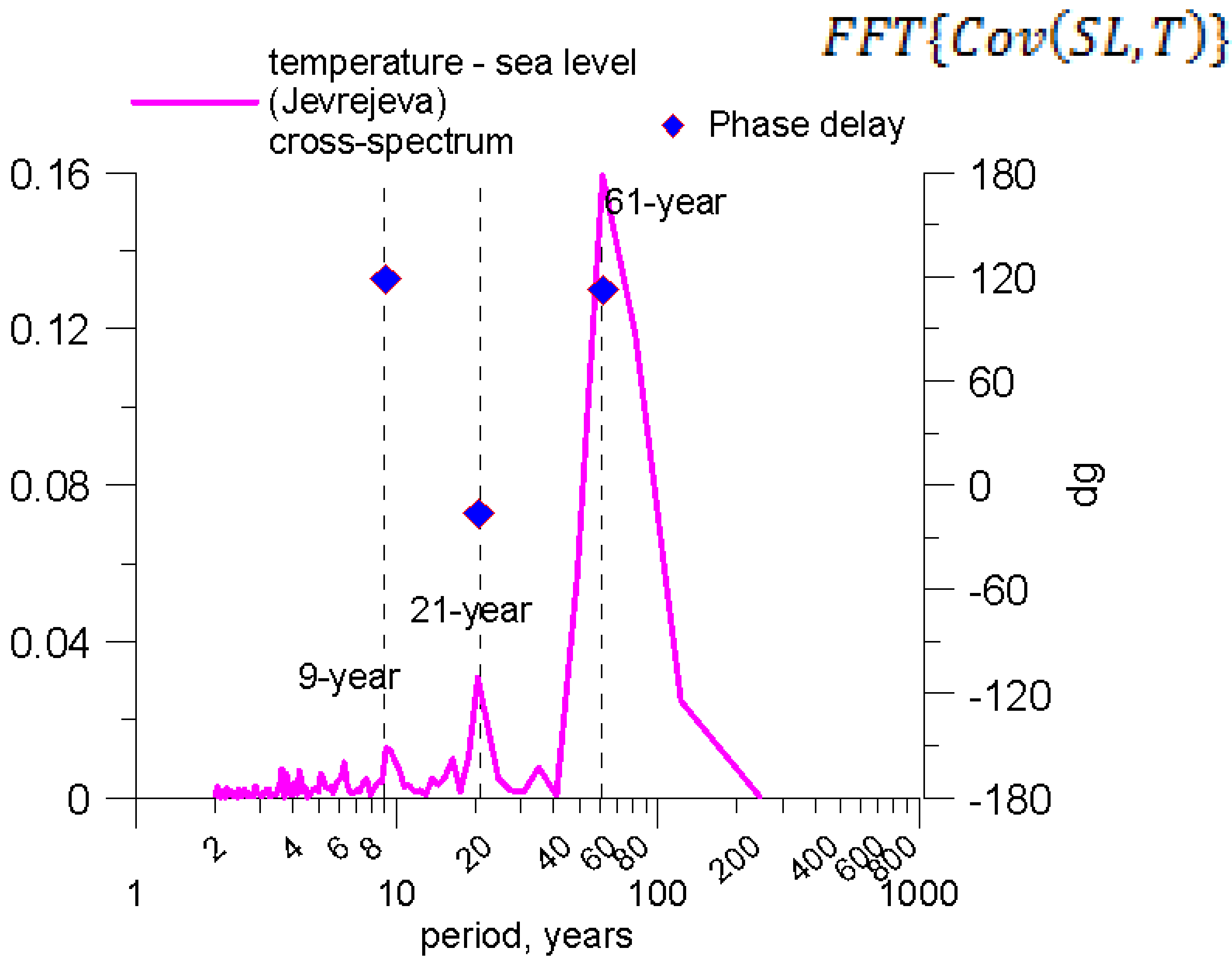

Figure 1. The regional change in sea level based on the 17-year trend from 1993 through 2009 from radar altimeter data from several satellites. Despite a fairly steady increase in globally averaged sea level rise (see Figure 2, inset), regional- scale changes over this duration are complicated and generally reflect changes in ocean circulation. Patterns reflecting other geophysical impacts, such as the net input of freshwater and changes in the gravity field due to loss of land ice, are expected to become clearer as the record length increases.

Josh K . W i ll i s et al. Oceanographer 2010

# Global Mean Sea Level



# Temperature-Sea Level Cross-spectrum



# Multichannel Singular Spectrum Analysis MSSA

**SSA is a generalization of EOF (PCA)**

1) The delay parameter $L$ is chosen.

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

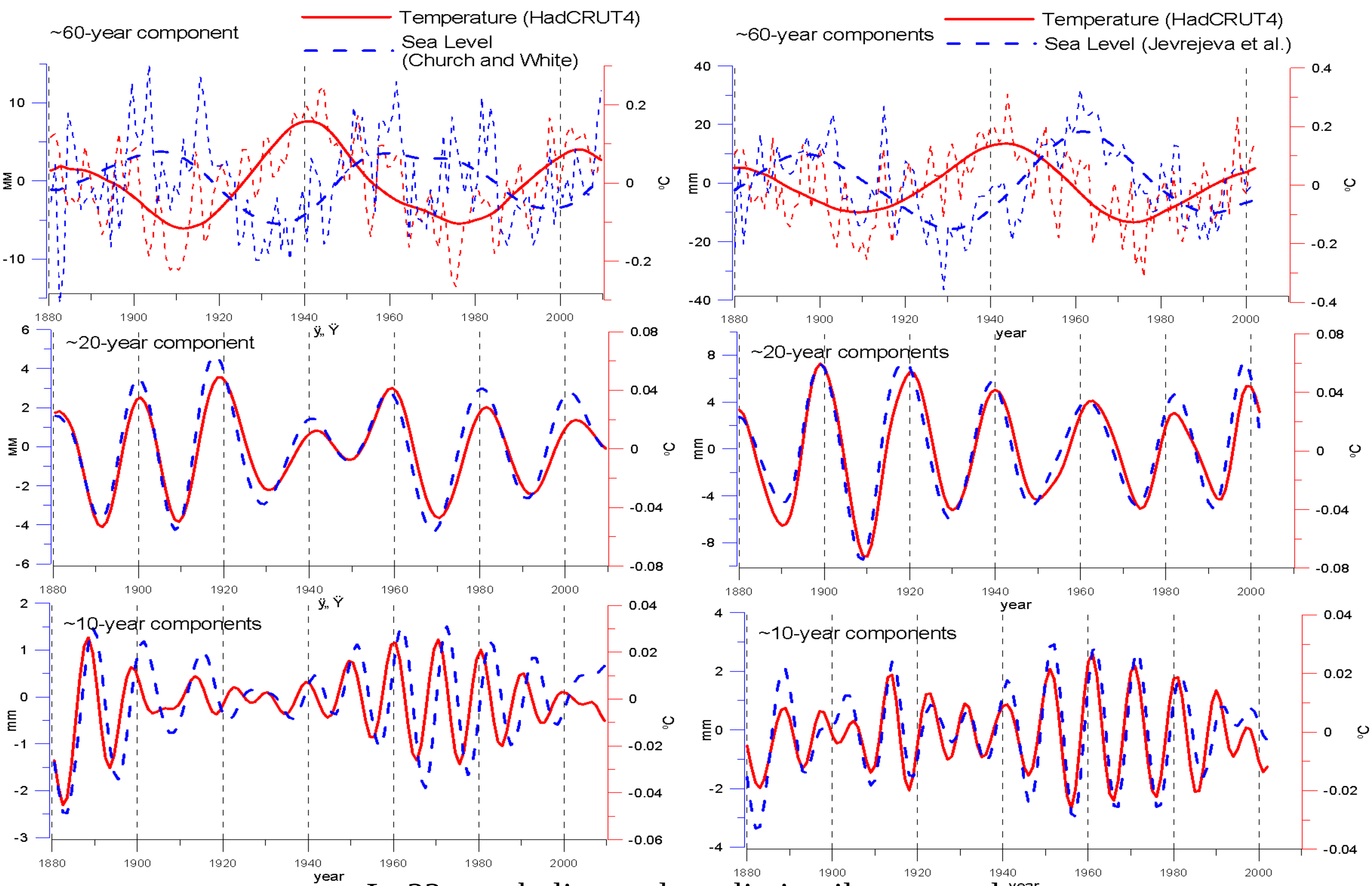
$$X^i = s_i u_i v_i^T,$$

signal for each component is obtained by Hankelization.

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

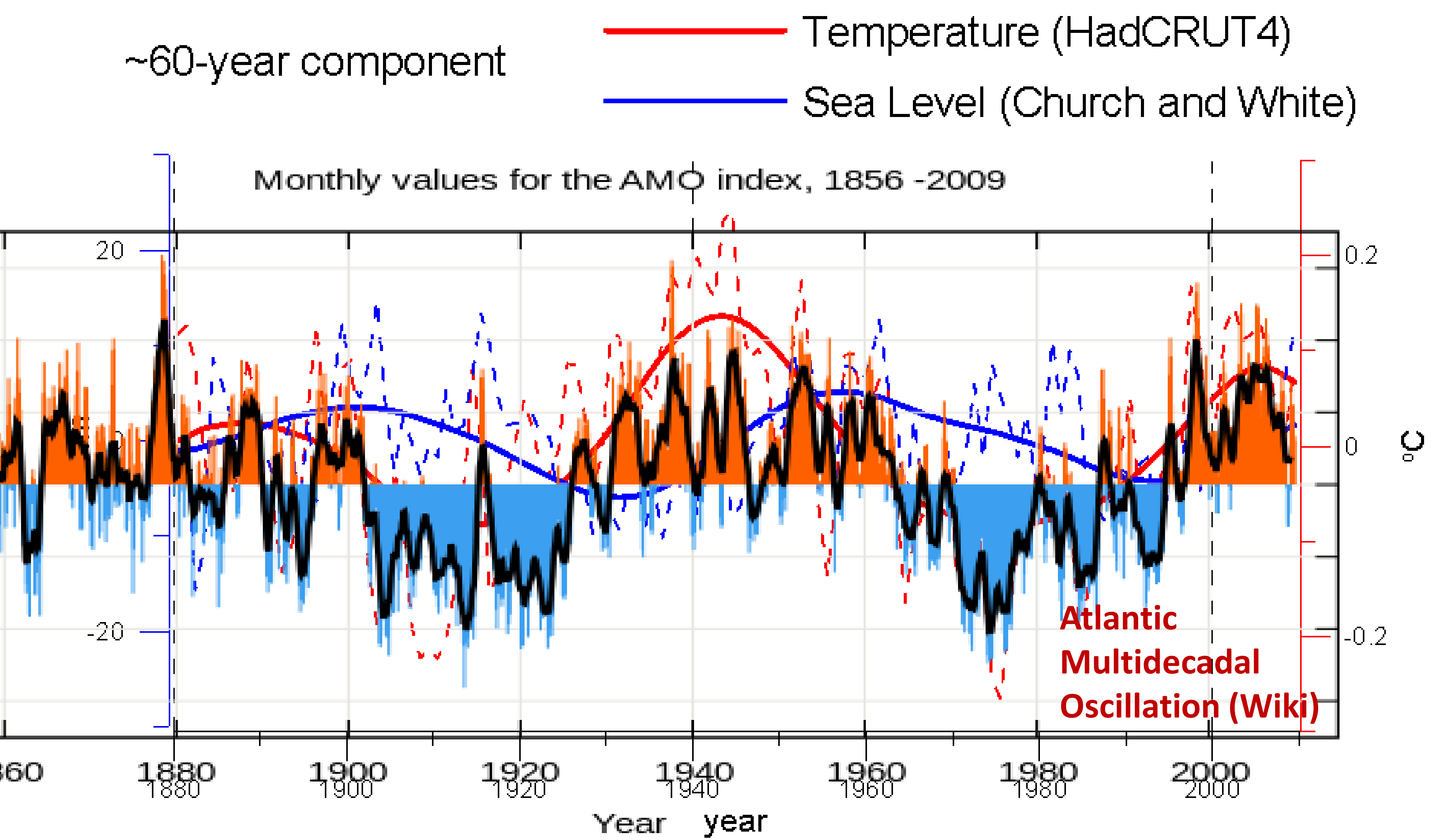
PC1, PC2, PC3…

# 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

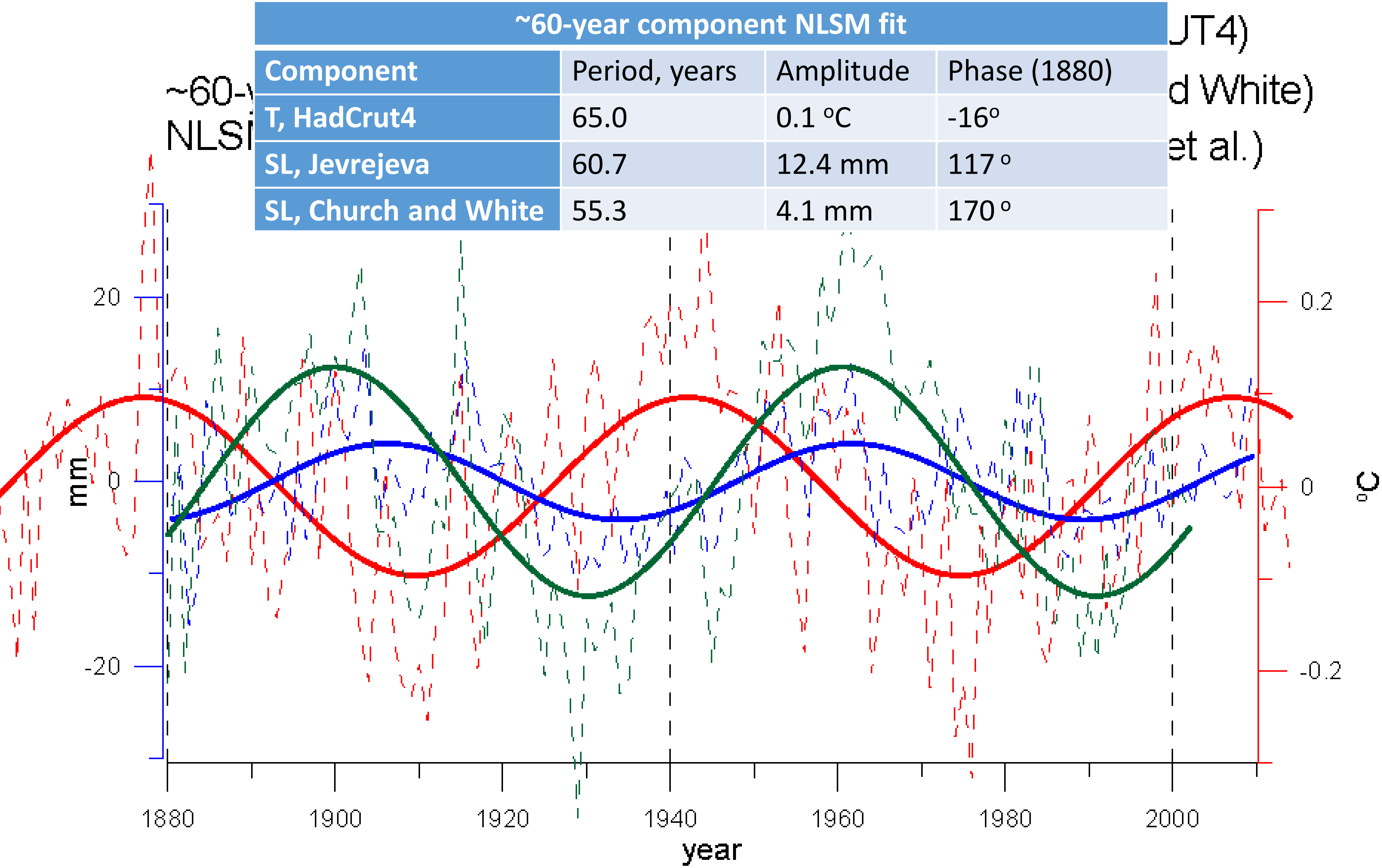
mm/year

°C

1880 1900 2000

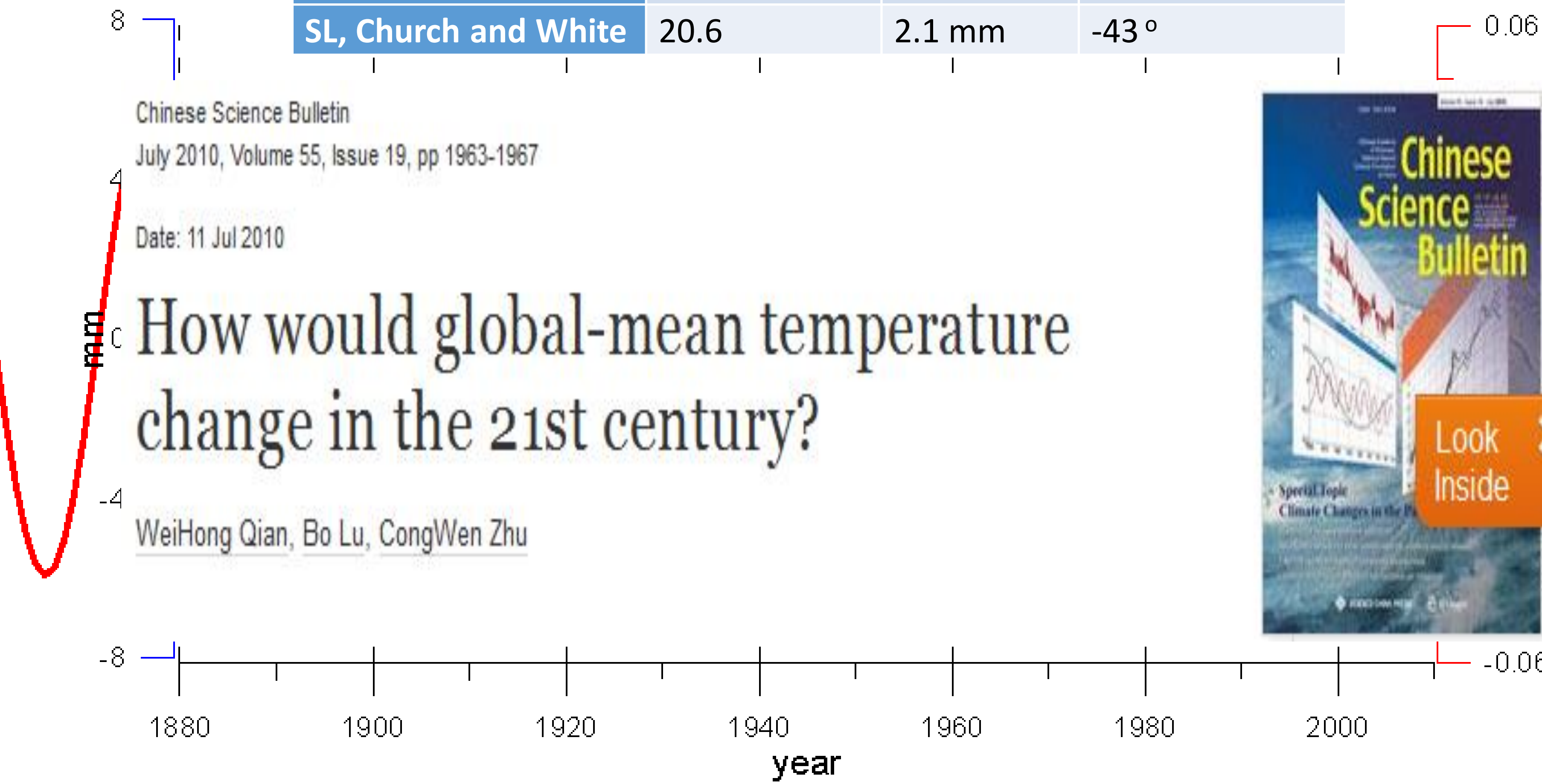
# Results of non-linear LS-adjustment

| ~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 ° |



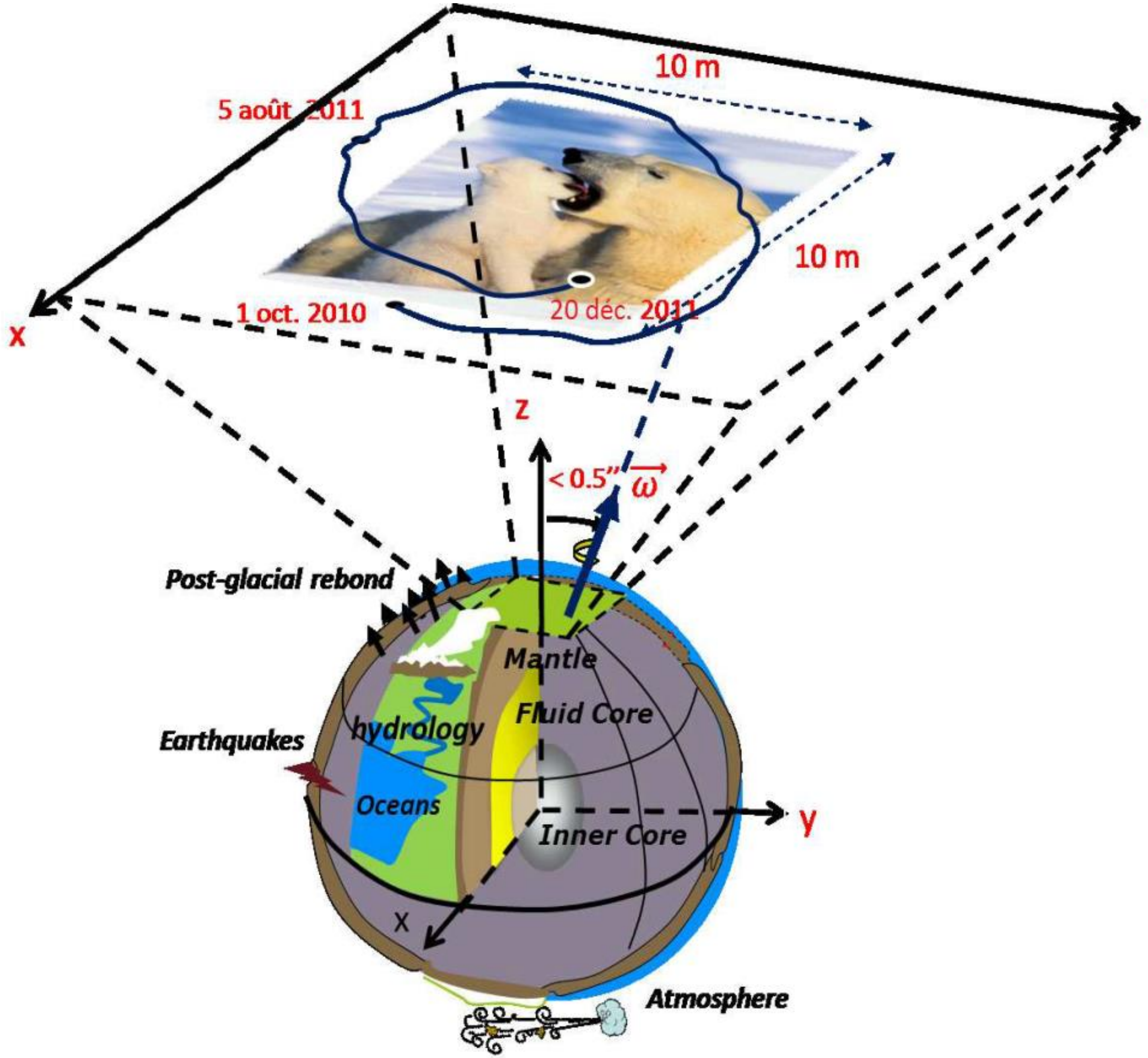

Chinese Science Bulletin

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

Date: 11 Jul 2010

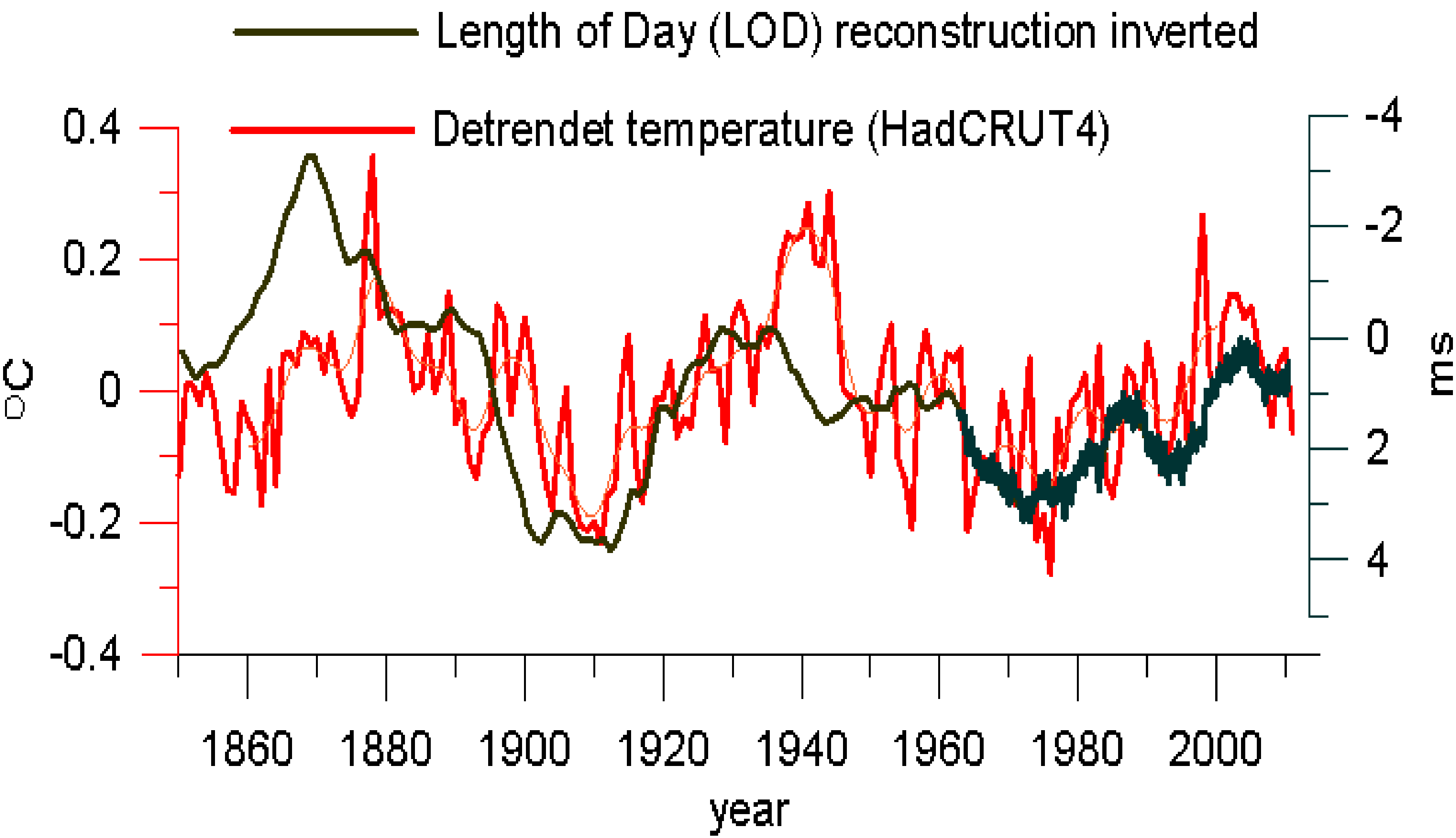
## How would global-mean temperature change in the 21st century?

WeiHong Qian, Bo Lu, CongWen Zhu



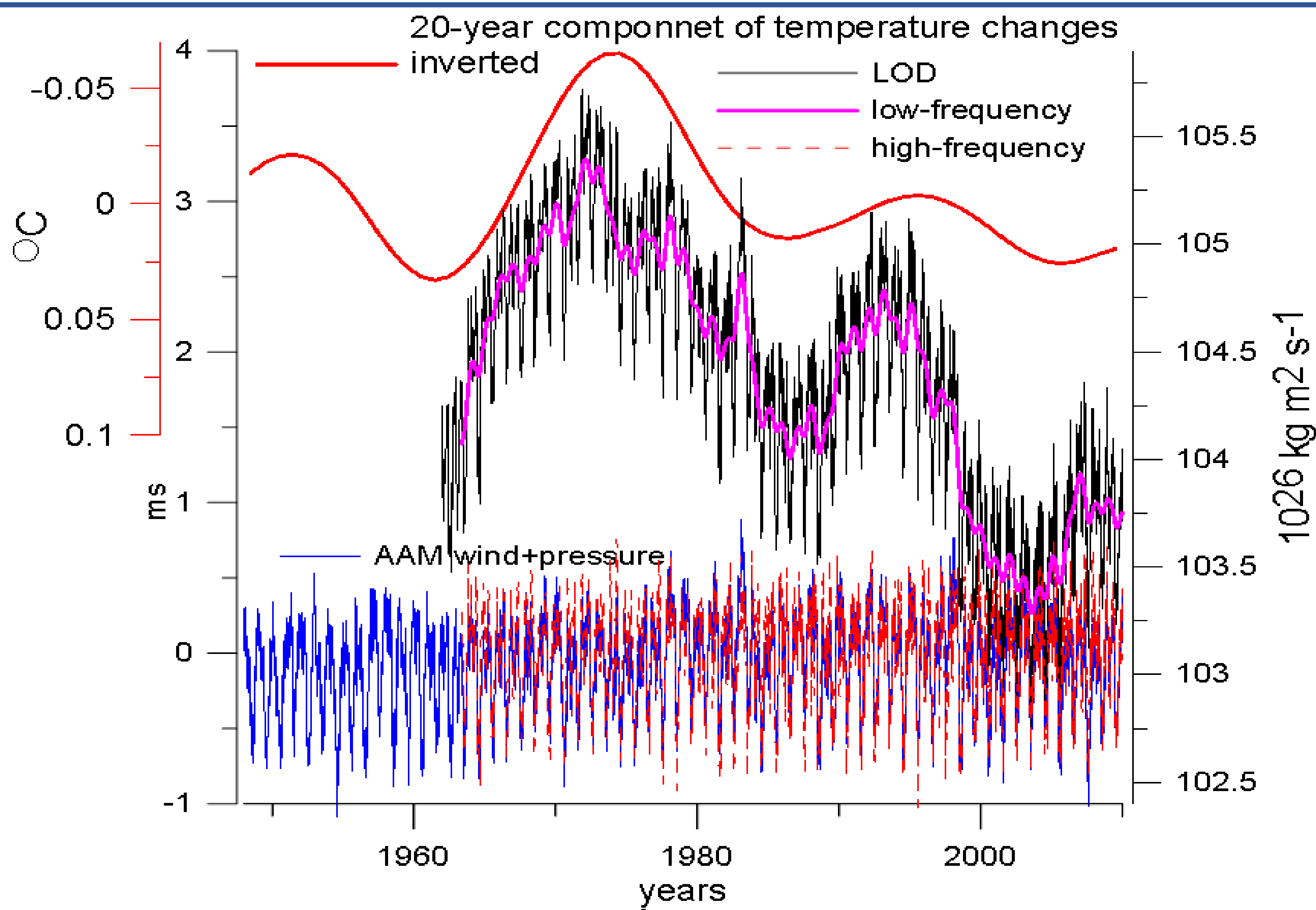
10 m
5 août 2011
y
10 m
1 oct. 2010
20 déc. 2011
x
z
< 0.5"
$\overrightarrow{\omega}$
Post-glacial rebond
Mantle
Fluid Core
hydrology
Earthquakes
Oceans
y
Inner Core
x
Atmosphere

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




L.V.Zotov, SAI MSU

# Non-tidal LOD and 20-year temperature changes

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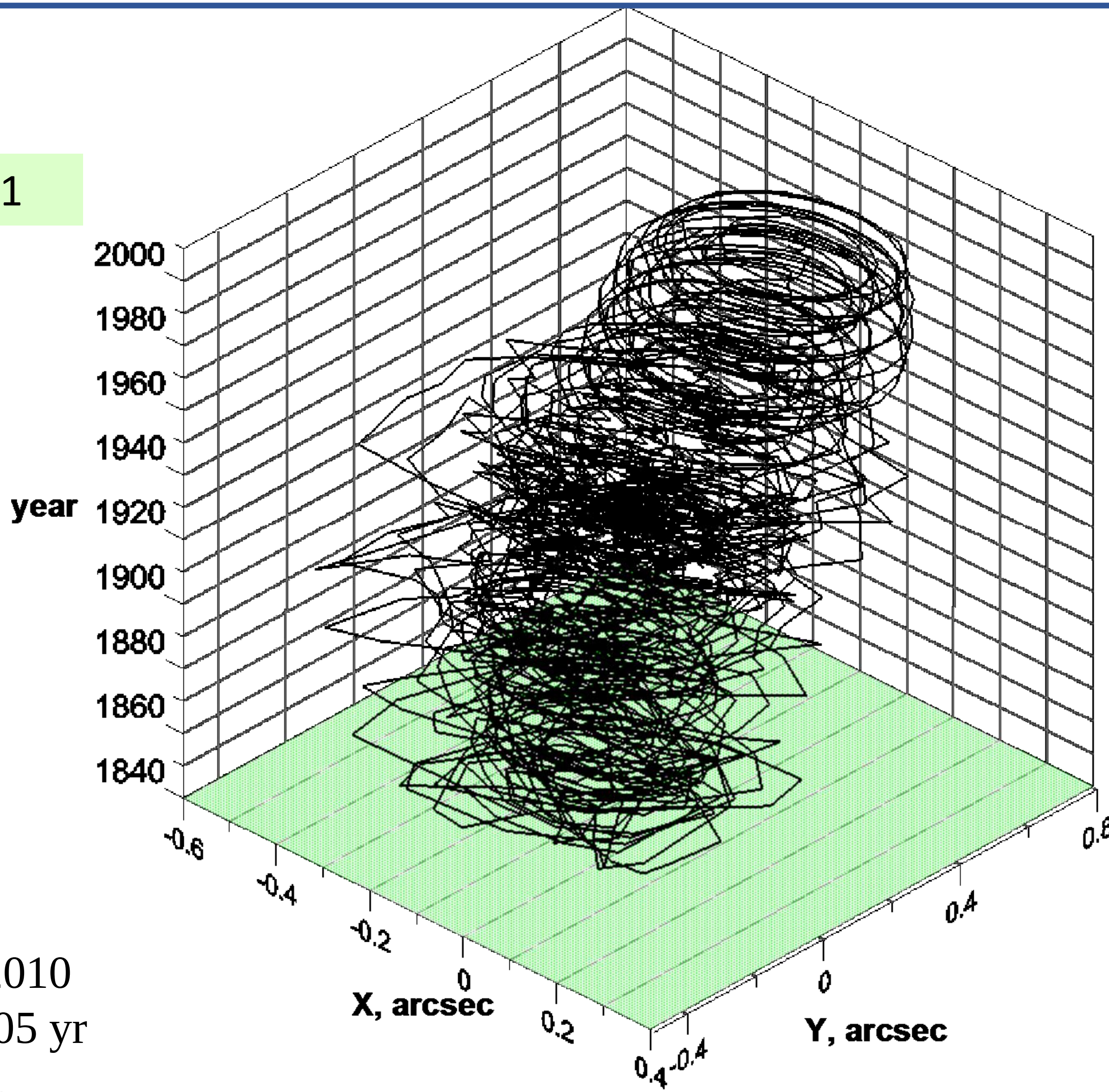
# Motion of the Earth's pole

EOP CO1

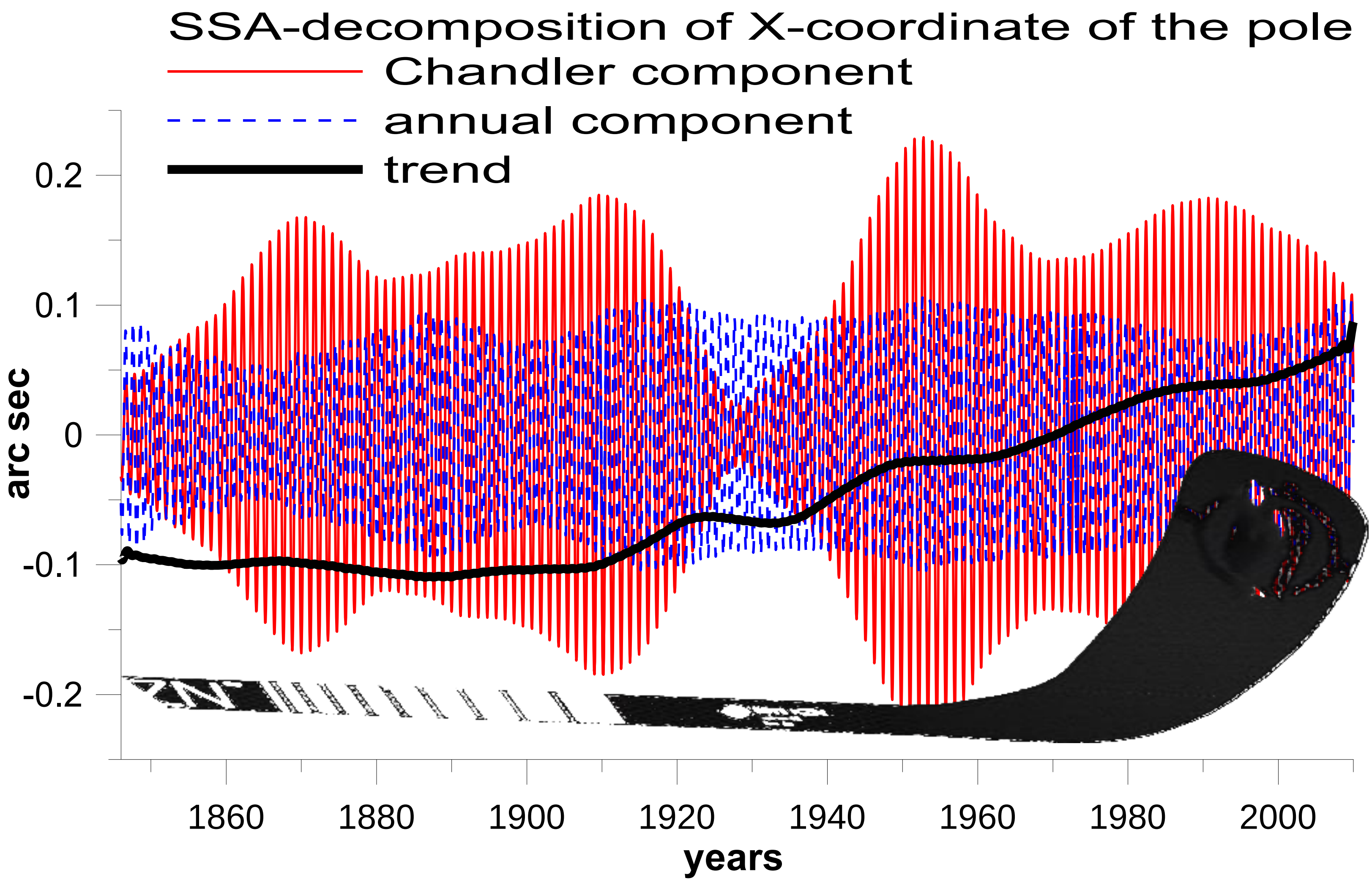



2D trajectory

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

1846-2010
step 0.05 yr

# Singular Spectrum Analysis of Polar Motion



# Dynamical model of the rotating Earth

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

$$m=m_1+im_2$$

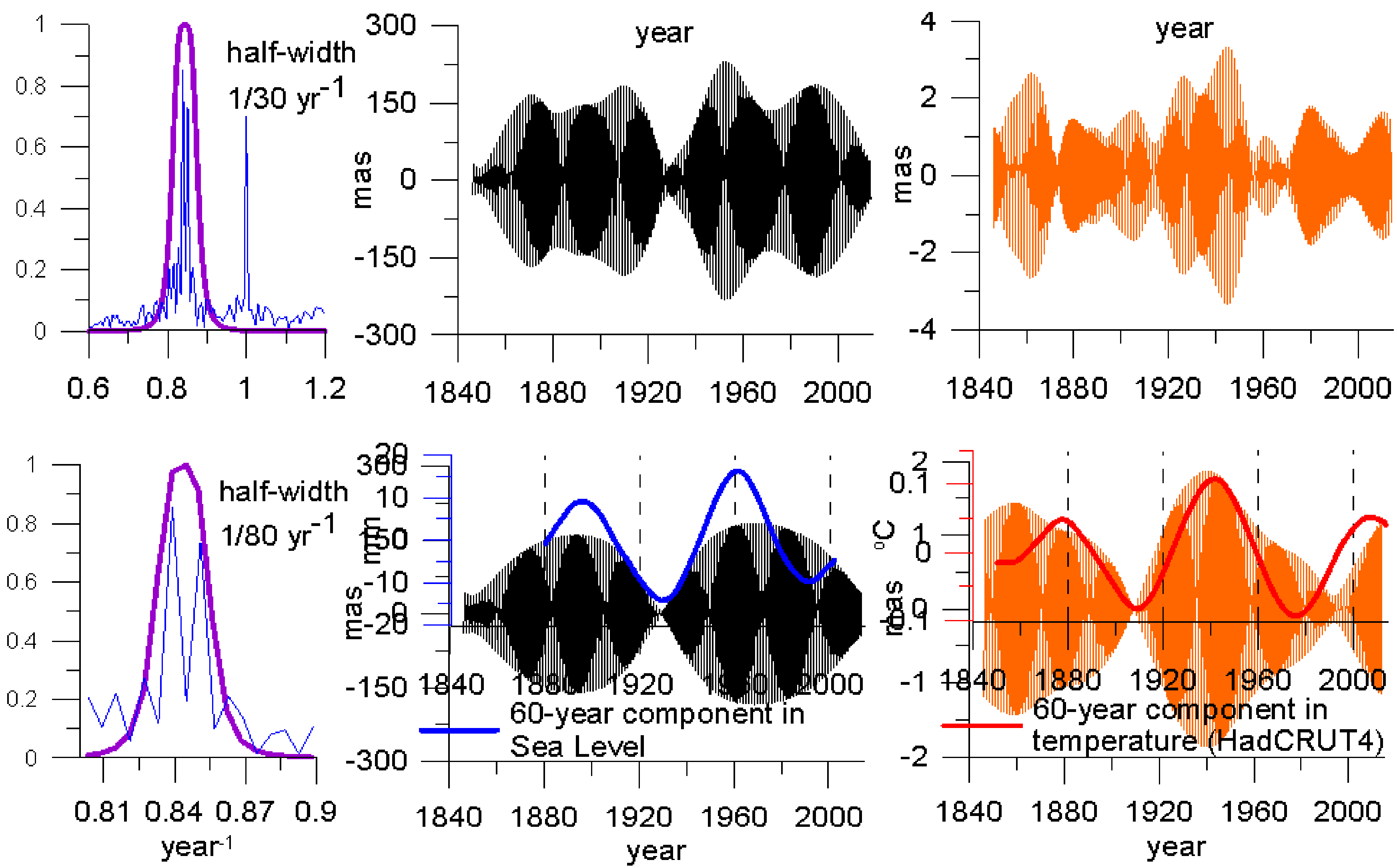
$$\Psi=\Psi_{mass}+\Psi_{motion}$$

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

$f_c=\dfrac{1}{433}$ 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

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# Envelope can be transferred through the dynamical model

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

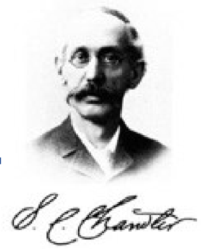
$$m(t)=\boxed{A(t)e^{i\varphi(t)}}e^{i\omega_c t} \qquad \Psi(t)=\boxed{E(t)e^{i\vartheta(t)}}e^{i\omega_c t}$$

$$E(t)e^{i\vartheta(t)}e^{-i\varphi(t)}=$$

$$=\frac{i}{\sigma_c}\left(\dot{A}(t)+i\dot{\varphi}(t)A(t)\right)+\left(1-\frac{\omega_c}{\sigma_c}\right)A(t)$$

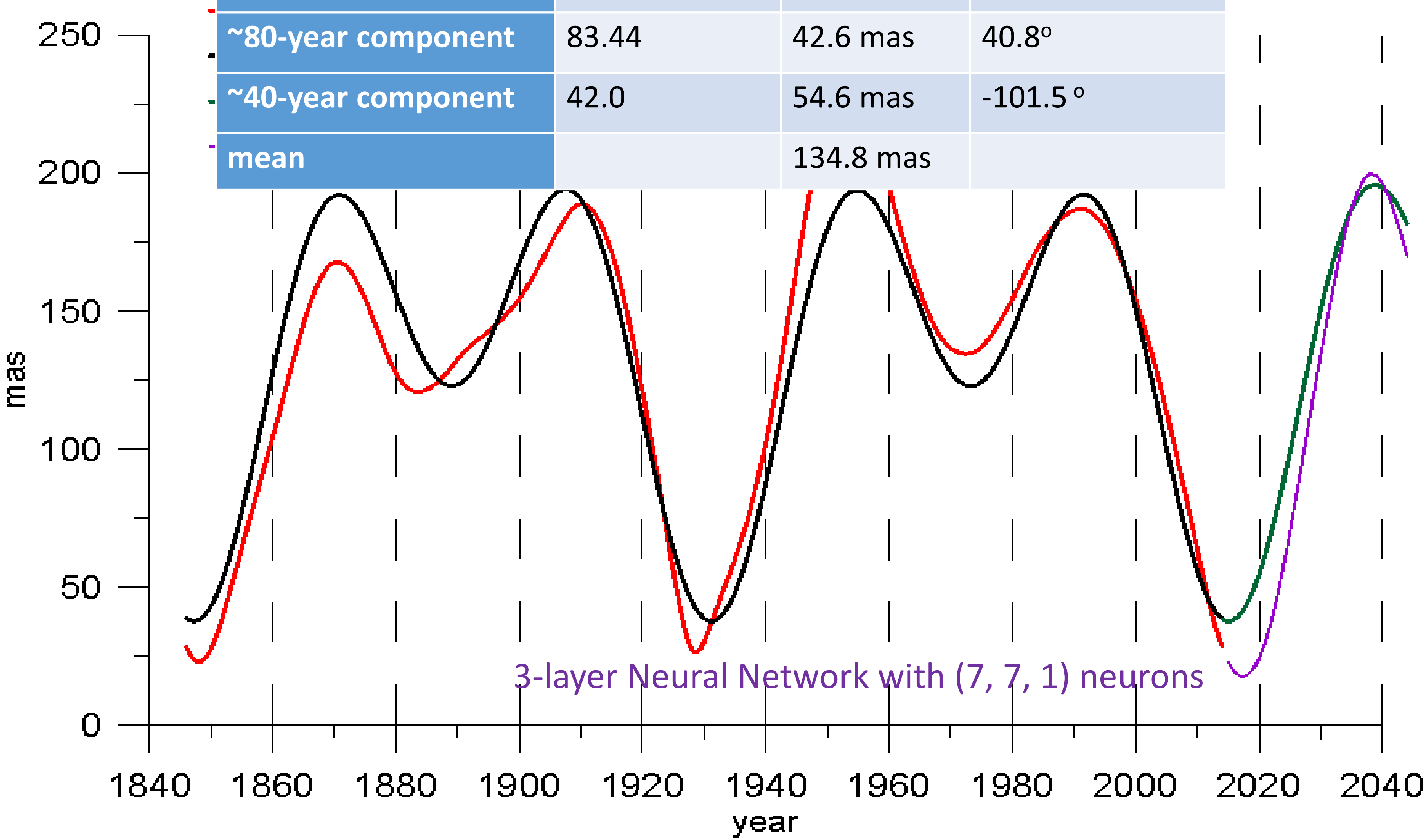
$\omega_c=2\pi f_c$ $\sigma_c=2\pi f_c(1+i/2Q)$ $f_c=\frac{1}{433}$ days$^{-1}$ $Q=175$

L.V.Zotov, C. M. Bizouard



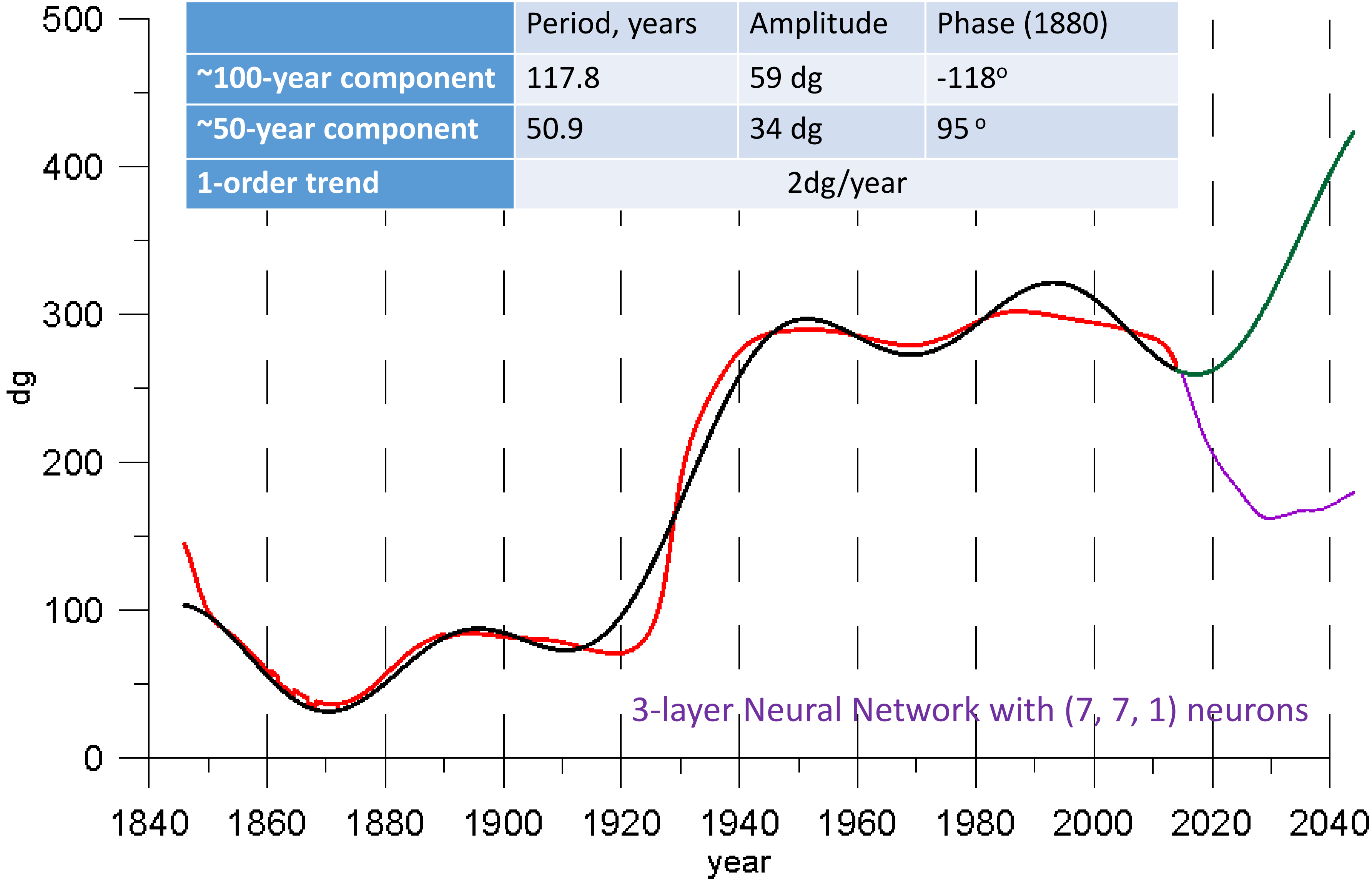
# Chw Amplitude model and forecast

| ~Chandler wobble amplitude NLSM fit | | | |
|---|---|---|---|
| | Period, years | Amplitude | Phase (1880) |
| **~80-year component** | 83.44 | 42.6 mas | 40.8$^o$ |
| **~40-year component** | 42.0 | 54.6 mas | -101.5 $^o$ |
| **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 | | |

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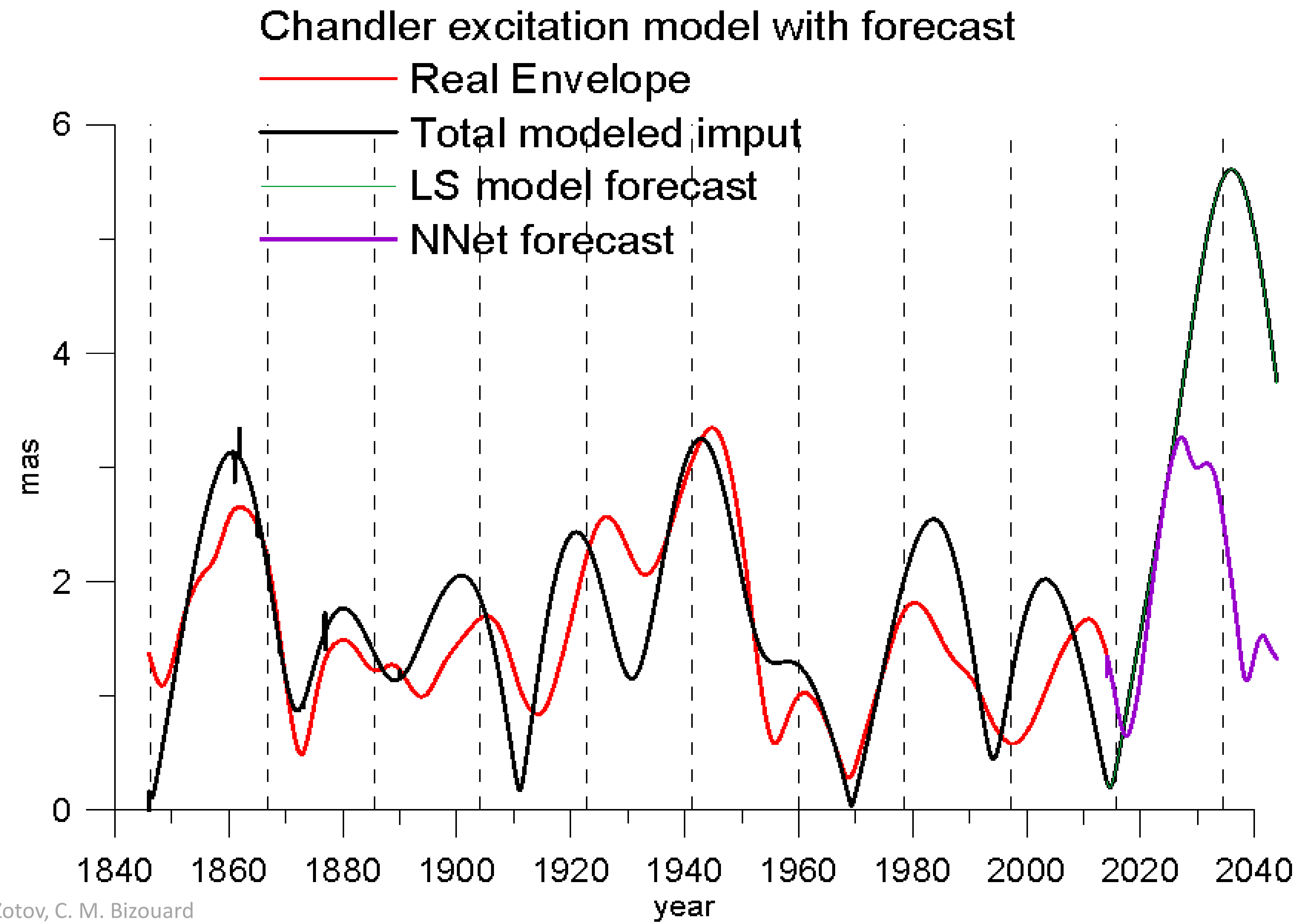
# Excitation forecast

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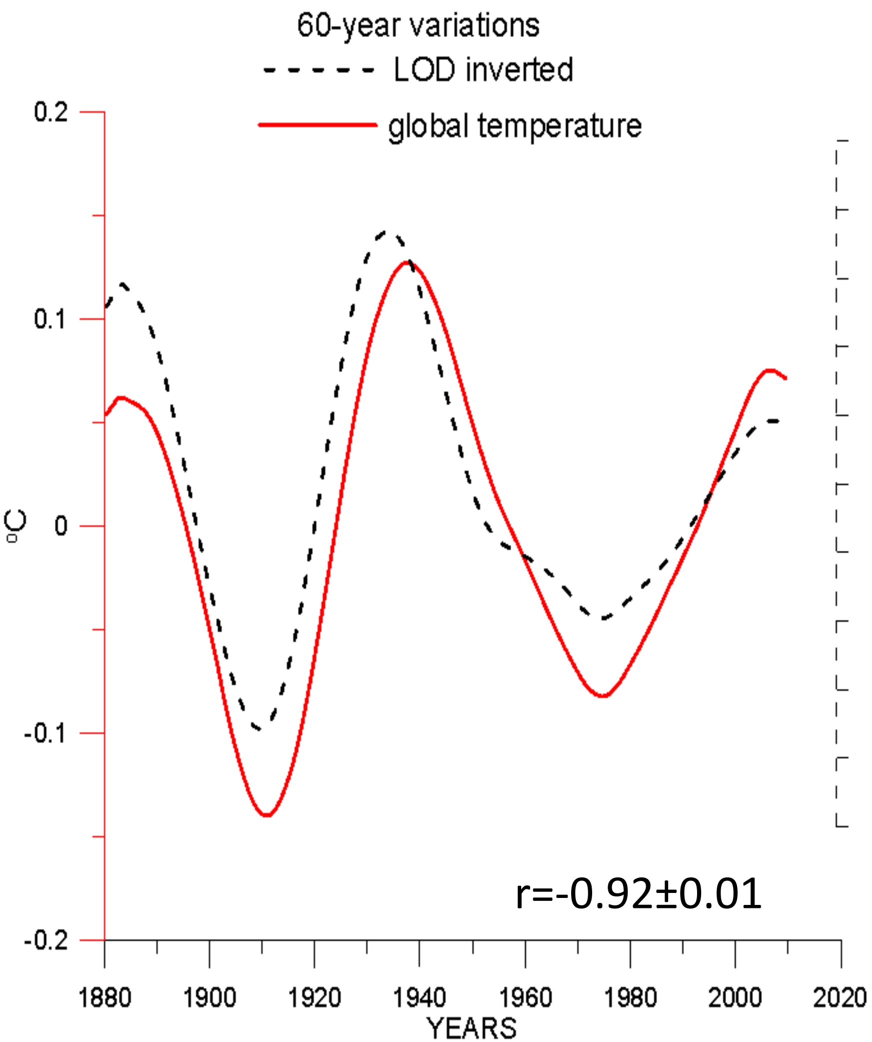
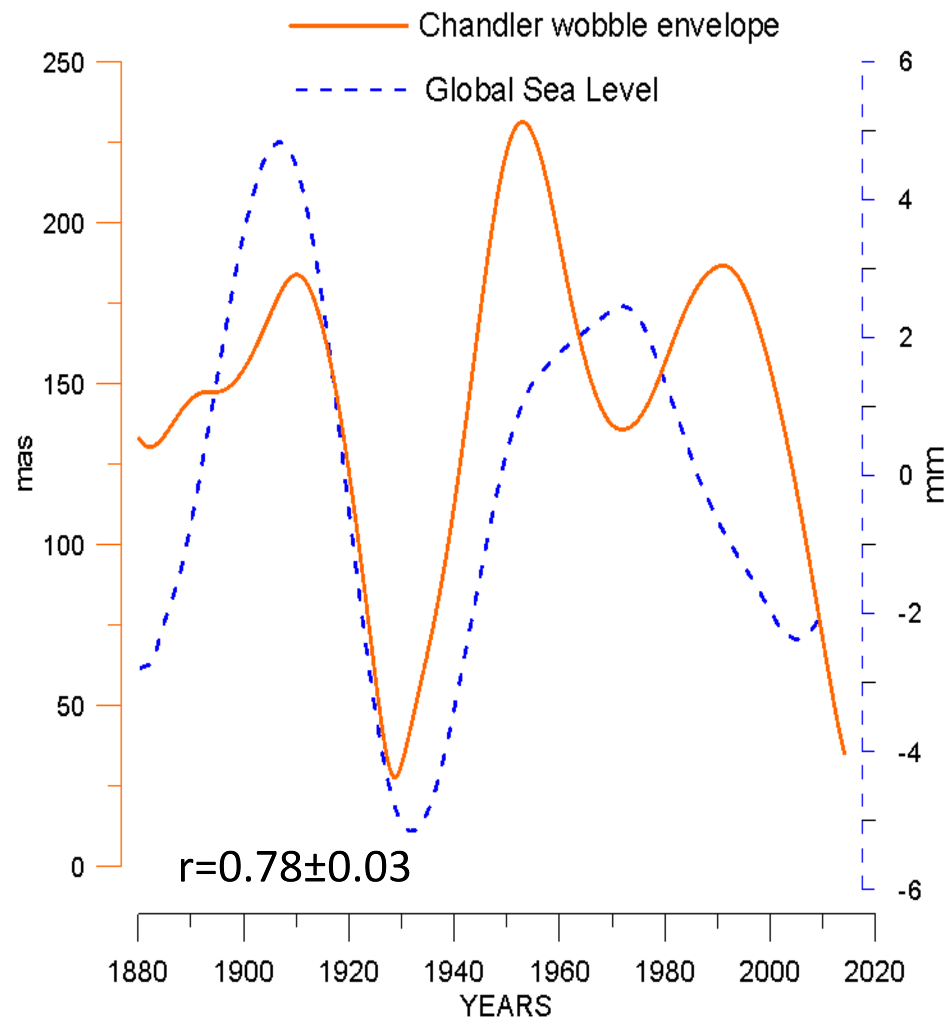
# Long-term (60-year) changes in Temperature, SL Chandler wobble envelope and LOD




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

# Variations in J2 can be related to Sea Level change

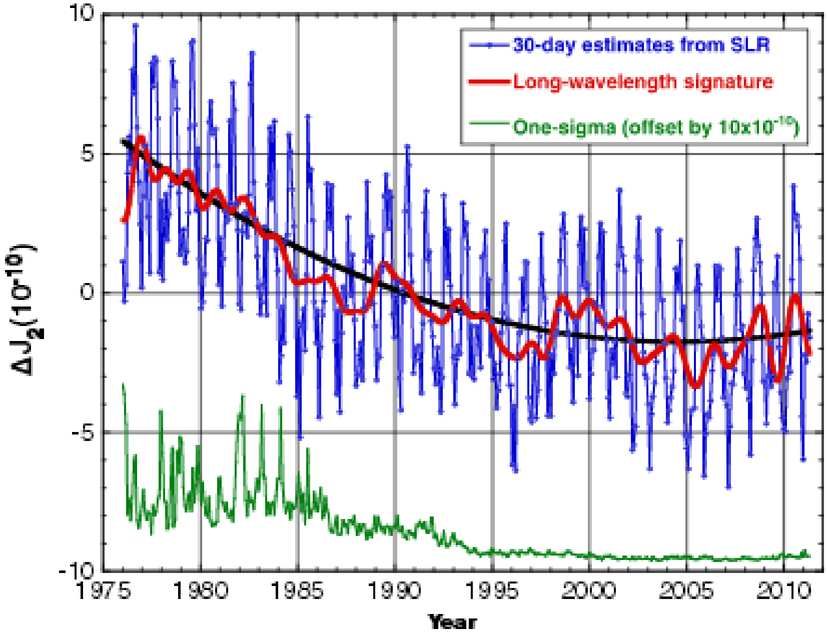
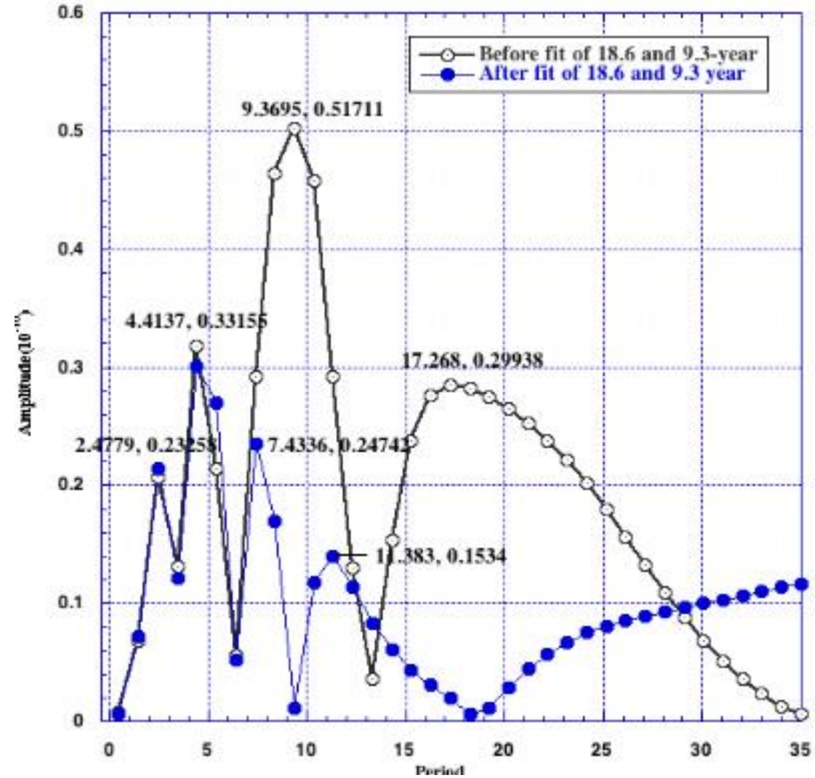



**Figure 1.** 30 day estimates of $J_2$ from SLR (blue line) and its long-wavelength signature represented by the decadal spectral band of the wavelet filtering (red line). The uncertainty estimates (green line) are offset by $10 \times 10^{-10}$ for clarity. Superposed is a quadratic fit (black line) to the 30 day estimates illustrating the quadratic nature of the long-term trend.




## Uniform sea-level rise and J2

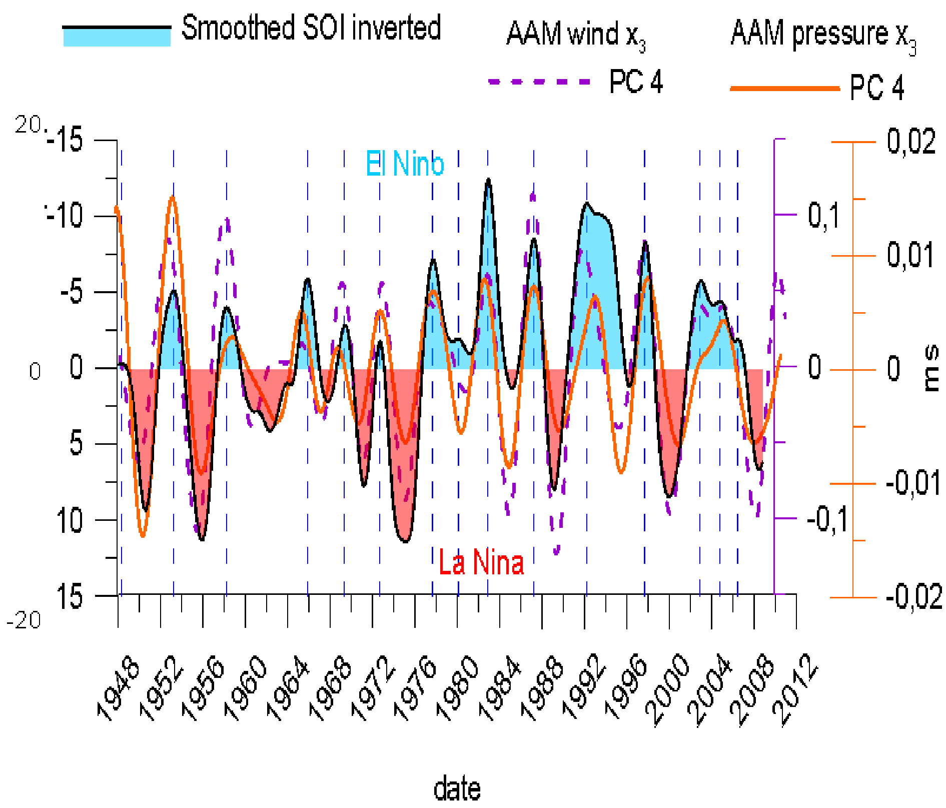
$$\Delta \dot{J}_2 = 0.157 \times 10^{-11} \Delta \dot{h} \; mm/yr$$
$$\Delta \dot{h} \; = 1.33 \; mm/yr$$
$$\Delta \dot{J}_2 == 0.2 \times 10^{-11}/yr$$

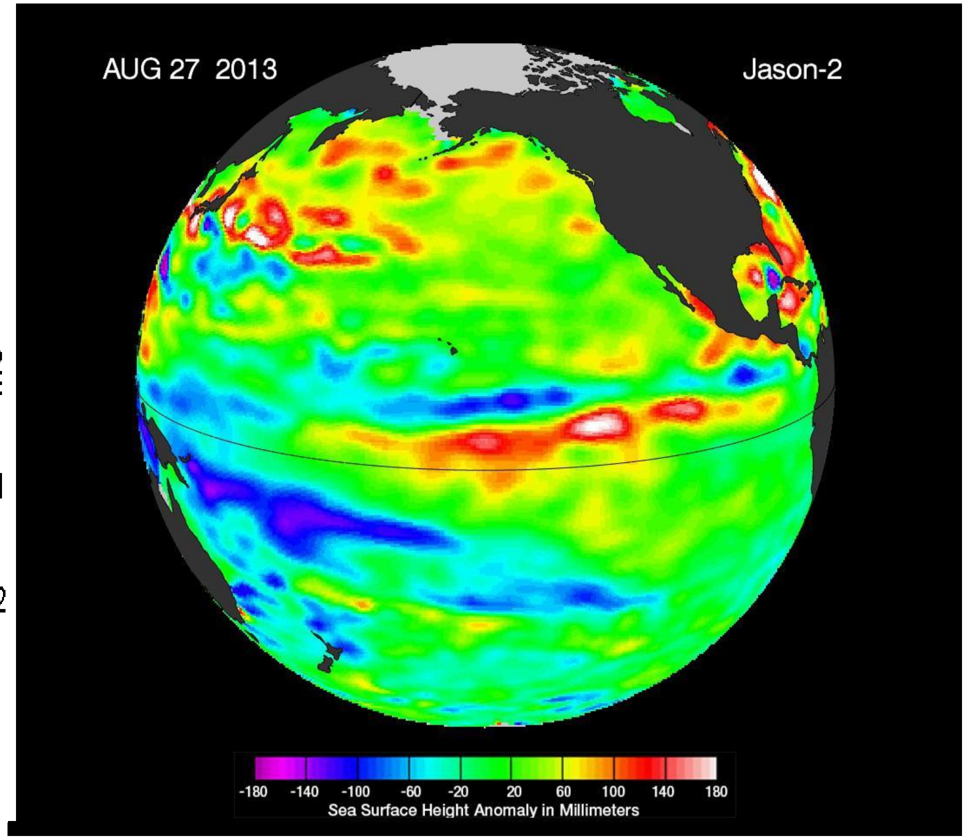
$$J_2 = -C_{20} = \frac{C - A}{MR^2} \qquad f_c = \frac{\Omega}{2\pi}\left(\frac{C - A - \Omega R^5 k/3G}{A + \Omega R^5 k/3G}\right)$$

**Deceleration in the Earth's oblateness**

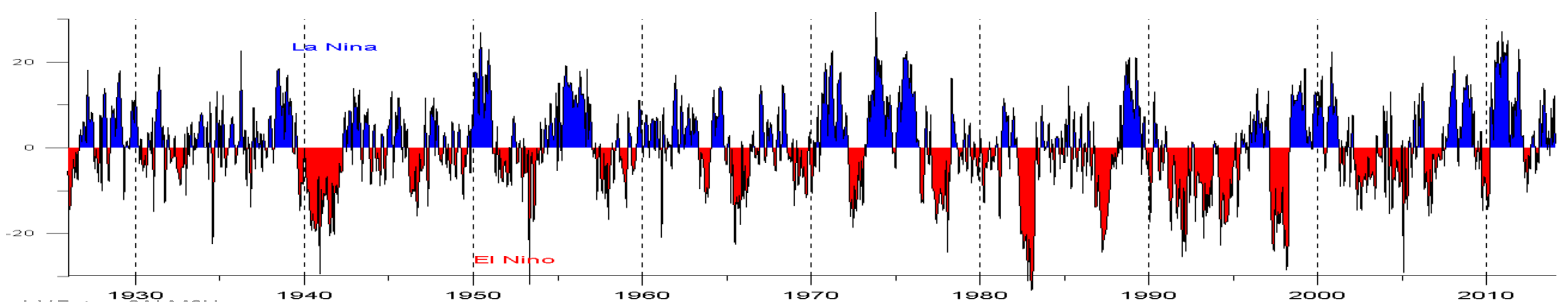
Minkang Cheng,[1] Byron D. Tapley,[1] and John C. Ries[1]

# El-Nino, AAM and LOD

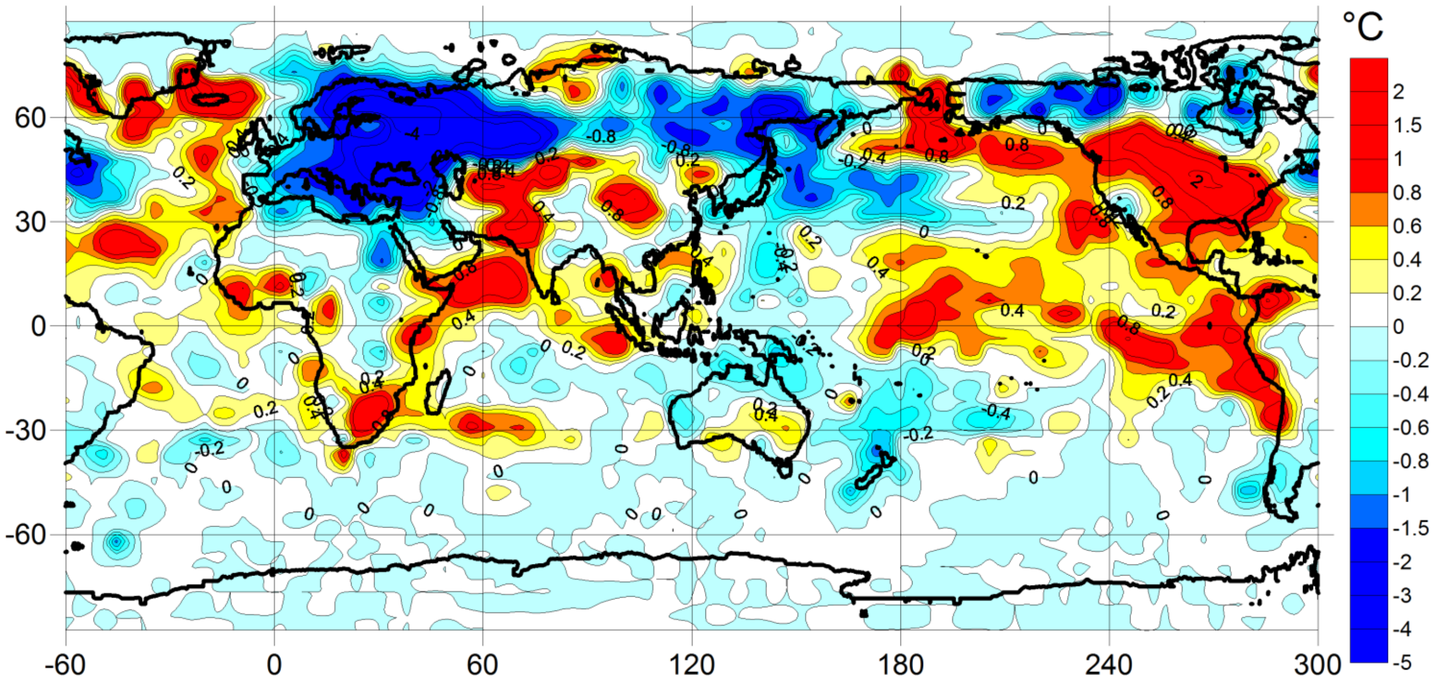


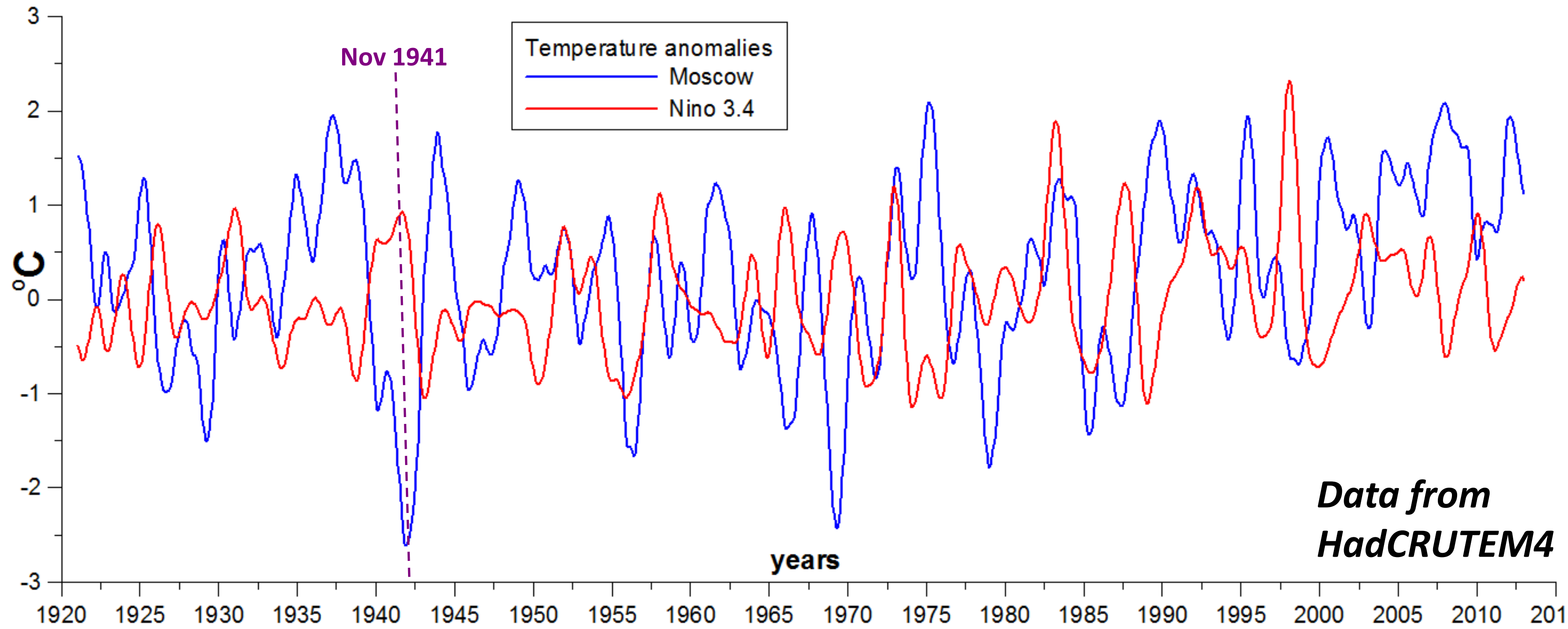

**La Nada 2013**



Serykh Ilya




Anomalies of the near-surface temperature averaged for the October-December 1941.



# Why El Niño is so important?


November-December 1812, at the west from Moscow.

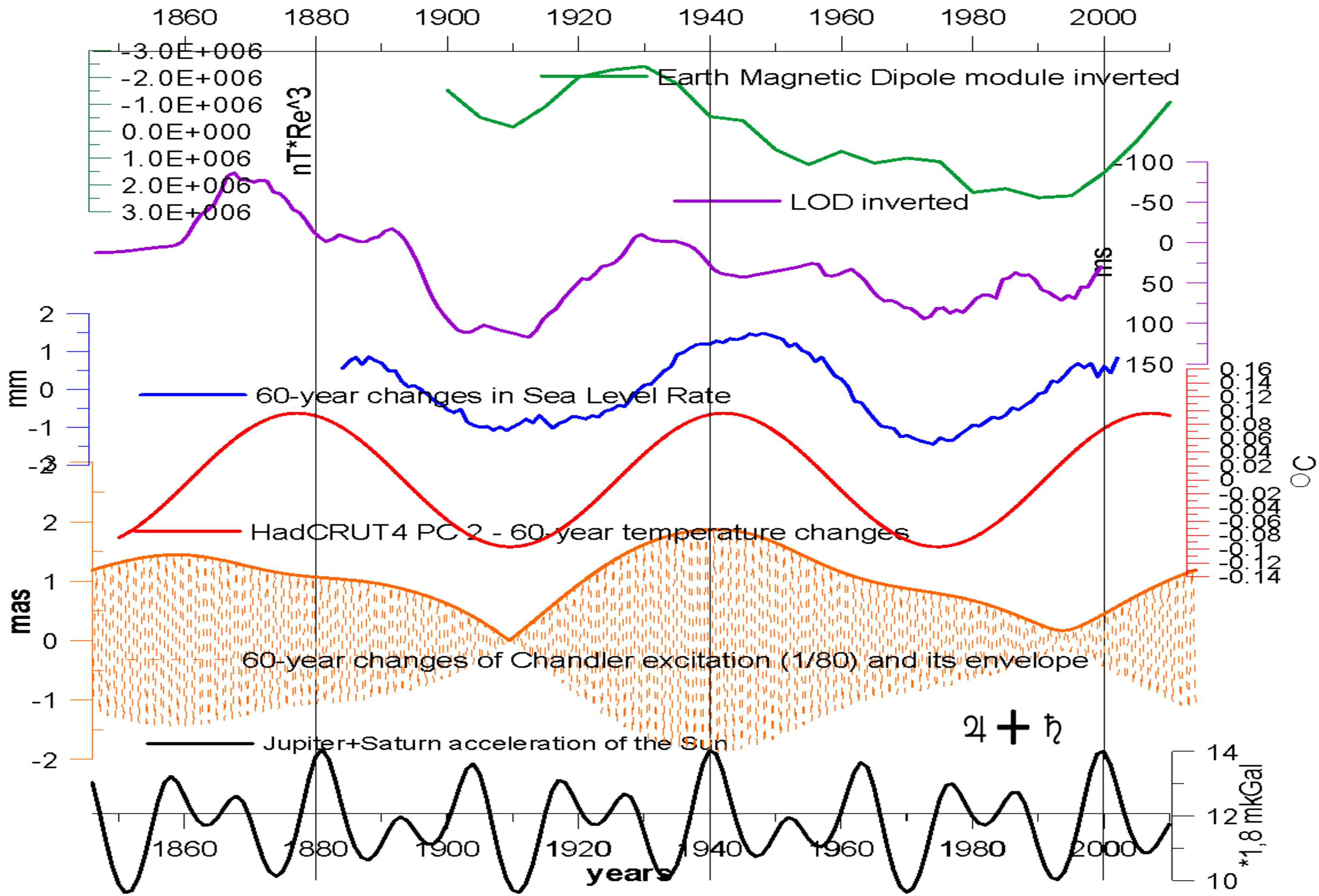


November-December 1941, at the west from Moscow.

Serykh Ilya

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

# 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?

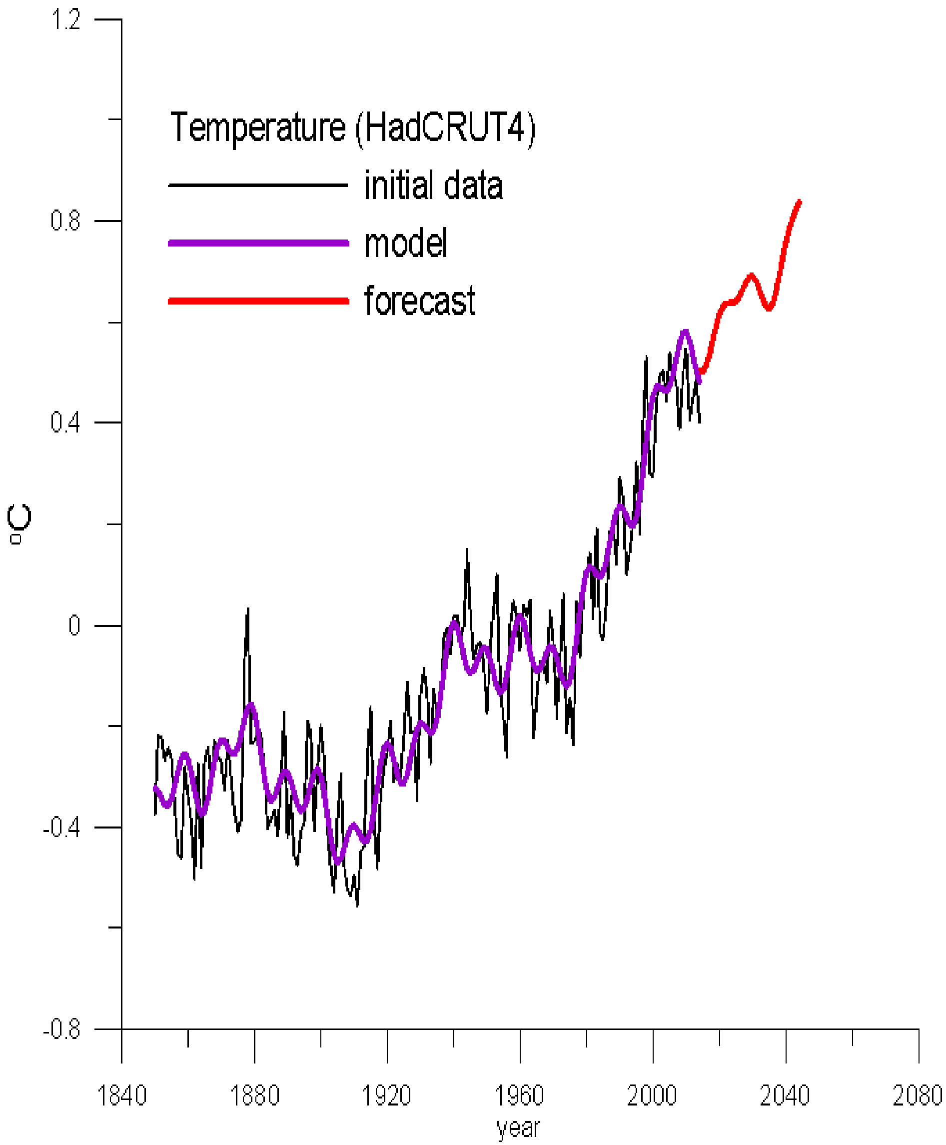
**There can be changes in Earth rotation related to**

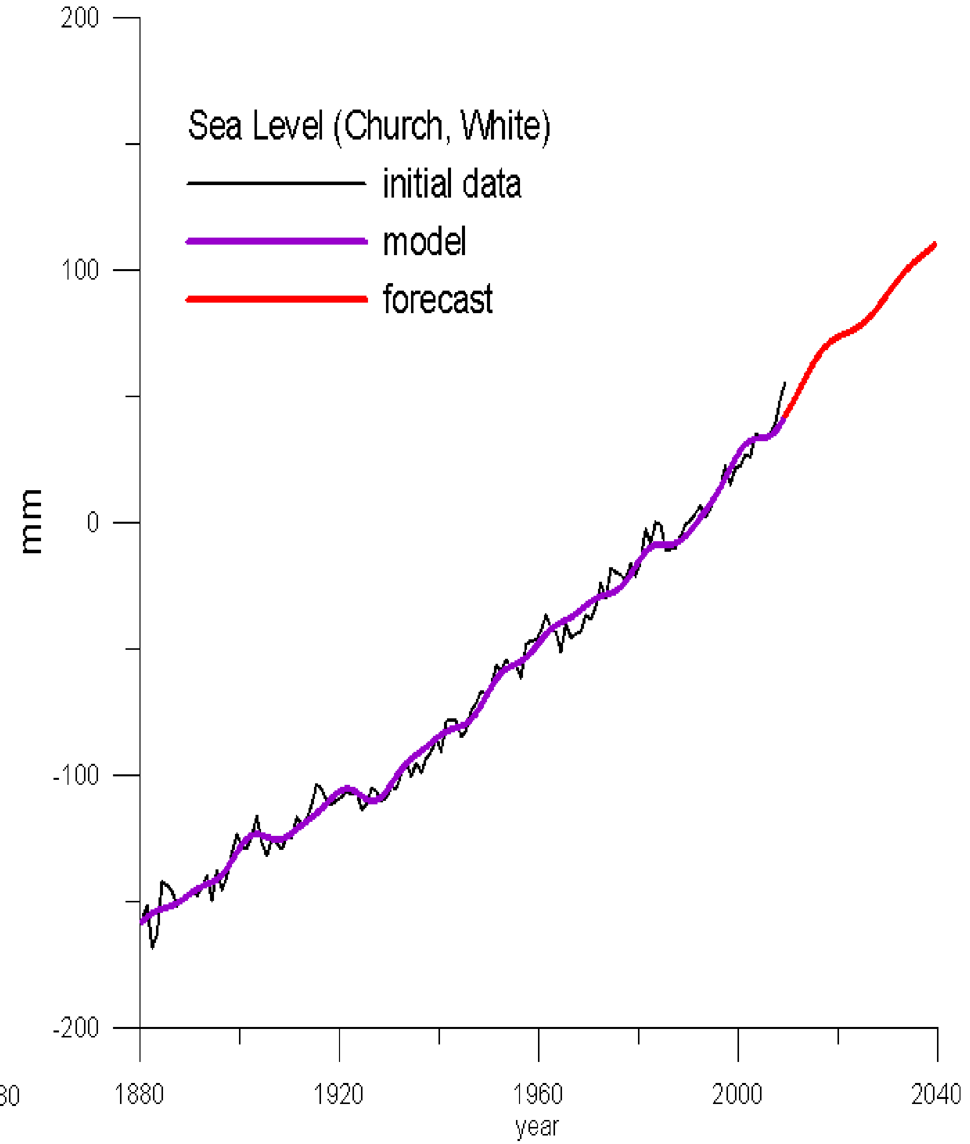
**Changes of the Earth's moment of Inertia**
***I***

**External force**
***L***

**Changes of the relative angular momentum**
***h***

# CSSA-based Predictions for Temperature and SL



# 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 and 20-year components of temperature are anticorrelated with LOD
- Chandler wobble envelope is correlated with ~60 –year sea level changes
- Chandler envelope can be modeled with 83 and 42-years waves and forecasted
- There are enough arguments collected to conclude that Earth rotation and Climate Changes are interrelated, this informational link can help to predict them



Grate Thanks to Dr. Wenbin Shen for support.

Thank you

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

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 ($l \ll R$) кривизной земной поверхности можно пренебречь, движение масс рассматривать как плоскопараллельное; для его описания достаточно использовать закон сохранения импульса. На массе 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-



*Николай Сергеевич Сидоренков*, доктор физико-математических наук, заведующий лабораторией планетарной циркуляции и гелиогеофизических исследований Гидрометцентра России. Основные работы посвящены исследованиям неравномерности вращения Земли, движения полюсов и глобальных геофизических процессов. Неоднократно публиковался в «Природе».

*Кристиан Бизуар (Christian Bizouard)*, доктор астрономии, сотрудник Службы вращения Земли Парижской обсерватории. Занимается изучением вращения Земли, движения полюсов, прецессии, нутации и геофизических возбуждений.

*Леонид Валентинович Зотов*, кандидат физико-математических наук, ведущий научный сотрудник Государственного астрономического института имени П.К.Штернберга Московского государственного университета имени М.В.Ломоносова. Область научных интересов — вращение Земли, гравитационное поле, климатические изменения, методы обработки данных.

*Давид Салстейн (David Salstein)*, доктор метеорологии, работает в системе «Исследование атмосферы и окружающей среды» (AER) США, директор Специального бюро атмосферного углового момента Международной службы вращения Земли и систем отсчета (IERS). Руководит оперативными вычислениями момента импульса атмосферы. Исследует атмосферную циркуляцию, динамику системы Земля и изменения климата.

# 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).