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Dynamic Harmonic Regression approach for global terrestrial temperature system identification

Abir Mayoufi, Stephane Victor, Rachid Malti, Mohamed Aoun

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DOCUMENT DE SOUMISSION

Journées Doctorales GDR MACS – 5 / 7 juin 2019

NOM ET PRENOM DES AUTEURS **MAYOUFI Abir/ VICTOR Stéphane/ MALTI Rachid/ AOUN Mohamed**

ETABLISSEMENT / LABORATOIRE **IMS-Bordeaux, France /MACS-Gabès, Tunisie**

TITRE DE LA PRESENTATION

Dynamic Harmonic Regression approach for global terrestrial temperature system identification

BLOC DISCIPLINAIRE
Indiquer la discipline à laquelle vos travaux appartiennent – 1 choix possible

- ☒ Automatique
- ☐ Systèmes de production

CLASSES DE SYSTEMES
Plusieurs choix possibles

- ☐ Systèmes dynamiques
- ☐ Systèmes EDP
- ☐ Systèmes non linéaires
- ☐ Systèmes hybrides
- ☐ Systèmes à événements discrets
- ☐ Systèmes de systèmes
- ☒ Systèmes stochastiques
- ☐ Systèmes Homme Machine

THEMATIQUES
Plusieurs choix possibles

- ☐ Connaissances - Compétences
- ☐ Modélisation - Simulation
- ☒ Identification
- ☐ Aide à la décision
- ☐ Systèmes d'information
- ☐ Conception – Cycle de vie
- ☐ Observations – Contrôle / Commande
- ☐ Optimisation – Robustesse - Performance
- ☐ Ordonnancement – Pilotage
- ☐ Apprentissage - IA
- ☐ Diagnostic – Pronostic – Maintenance – Sureté de fonctionnement - Supervision
- ☐ Autre (préciser ci-dessous)

Saisir la thématique

ENJEUX SOCIETAUX
Plusieurs choix possibles

- ☐ Numériques (lot, réseaux, …)
- ☐ Transports
- ☐ Energie
- ☐ Bio(techno)logie et santé
- ☐ Robotique
- ☐ Industrie 4.0
- ☐ Développement Durable
- ☐ Service
- ☐ Intelligence artificielle (au sens de sa diffusion dans la société)
- ☒ Autre (préciser ci-dessous)

Environnement

INFORMATIONS COMPLEMENTAIRES
Si nécessaire

RESUME ETENDU

Deux pages maximum, en français ou en anglais

The current and future evolution of the global climate raises many questions about how it works. In this context, a terrestrial climate model was proposed by De Larminat [1] which identifies the dynamic relationship between solar activity, volcanic activity, human activity and the averaged measures of temperature. On one hand the total solar irradiance (TSI, or solar activity) has an 11 year cycle, on the other hand, the aerosol emissions (volcanic activity) and the greenhouse gas emissions (anthropogenic activity) do not have this cyclic component.

Trying to enrich knowledge of this model, this study aims to find all the cyclic components of the TSI signal and the output temperature signal.

Terrestrial climate system

Consider a MISO terrestrial climate model [1] such as the one given in Figure 1.

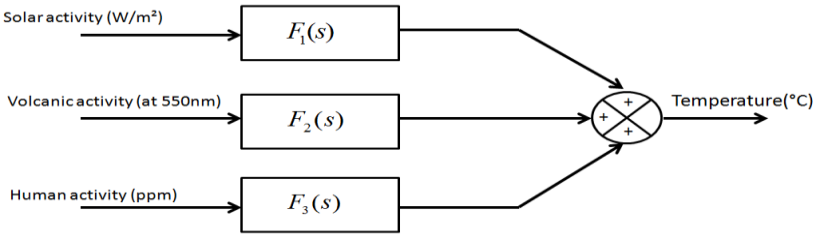

Fig. 1: Terrestrial climate model

The input signals are composed of the solar, volcanic and human activities. These inputs can be natural (the variations of radiation intensity (solar activity) and aerosol emissions (volcanic activity)) or anthropogenic through greenhouse gas emissions (carbon dioxide).

The climate system reacts to these forcing factors with temperature variations.

Figure 2 shows a set of input/output reconstructions considered as the connection of two recordings: satellite recording with calibrated proxies records from National Oceanic and Atmospheric Administration (NOAA).

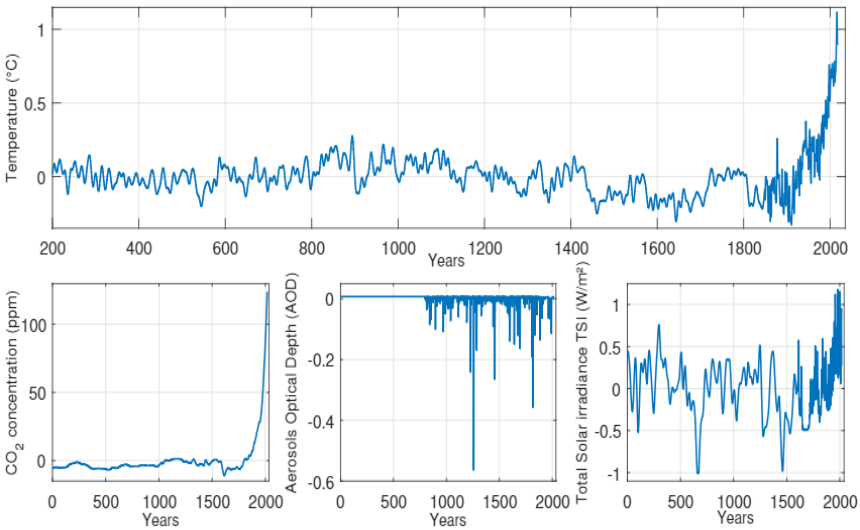

Fig. 2 Input/output reconstruction

A. Human activity (CO2 concentration)

Carbon dioxide is probably the most well-known greenhouse gas. The signal considered as human activity is considered as the connection of two records, measurement of the centre of Mauna Loa and proxy measurement, to obtain a single piece of data set.

B. Natural forcing

a. Solar activity (Total Solar Irradiance)

The intensity and movement of sunspots presents an 11 year cycle, from these sunspots a reconstruction of the Total Solar Irradiance (TSI) was introduced by the TIM instrument (Total Irradiance Monitor), another proxy reconstruction was determined based on isotopic proxies. These two reconstructions were combined to obtain a single piece of data set.

b. Volcanic activity (Aerosol Optical depth)

Aerosols change the climate in several ways. The first effect is observed through the diffusion and absorption of solar radiation, which modifies the irradiative balance of the planet. The Aerosols Optical Depth (AOD) more specifically describes how aerosols affect the passage of light through the atmosphere, for a given wavelength (in this manuscript the wavelength is 550 nm).The signal of volcanic activity is considered as the connection of two recordings: satellite recording with calibrated sulphate records in Antarctic ice cores.

C. Temperature

These forcing factors are considered as the input signals of the terrestrial climate system and temperature, considered as the connection of proxy records and HadCRUT records, as the output.

Dynamic Harmonic Regression model

A Dynamic Harmonic Regression (DHR) model helps to reveal the presence of dynamically, non-stationary, quasi-cyclical components. This Unobserved Component (UC) model takes the following form:

$$y(k) = T(k) + C(k) + e(k)$$

where $y(k)$ is the signal to be analyzed, $T(k)$ is the trend, $C(k)$ is a cyclical or quasi-cyclical component and $e(k)$ is an irregular

component, which is a normally distributed Gaussian sequence with zero mean value and variance σ^2. The quasi-cyclical component can be represented by the following form:

$$C(k) = \sum_{i=1}^{R} \left[a_{i,k} \cos(f_i k) + b_{i,k} \sin(f_i k)\right]$$

where R is the number of peaks determined from the Auto-regressive AR spectrum and $a_{i,k}$ and $b_{i,k}$ are stochastic time variable parameters (TVP). The trend component can be considered as a stochastic time variable parameter also that could be incorporated into the cyclical component as a zero-frequency term ($i = 0$ with f_0 set equal to zero). The DHR model is an extension of the classical harmonic regression model with constant parameter (Fourier series) where the gain and phase of the harmonic components vary according to changes in the parameters $a_{i,k}$ and $b_{i,k}$.

The complete DHR estimation algorithm consists of the following steps: first, the dominant harmonic frequencies are extracted from the AR spectrum of the observed signal. Then, the unknown parameters are estimated from a least squares optimization function. Once these parameters have been estimated, the trend and harmonic components varying over time can be obtained using the Kalman filter approach [2].

Applying this approach to the temperature output signal, a spectral analysis is carried out by using the auto-regressive spectrum (see Figure 3). The associated $AR(31)$ spectrum is characterized by $R = 9$ peaks, which respectively correspond to 21.96, 6.08, 4.78, 4.23, 3.60, 3.17, 2.86, 2.58, and 2.36 years/cycle. This study consists to isolate the fundamental frequency characterized by the peaks at 21.95 by applying the DHR method to extract the trend and cyclical component (see Figure 4).

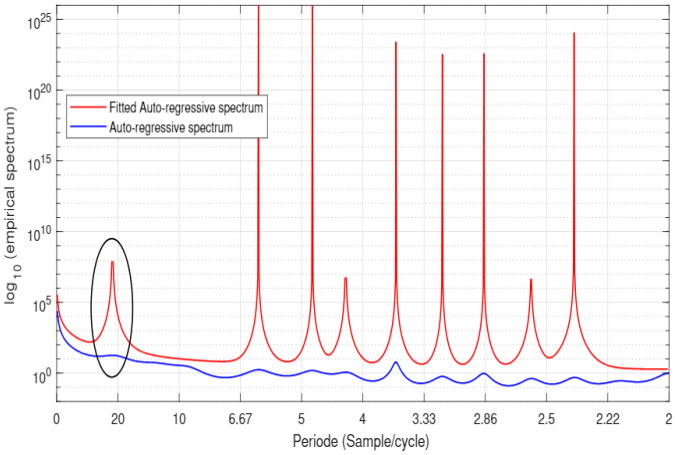

Fig.3 pseudo-spectrum 'fitted' (red) vs. empirical spectrum (blue) for the temperature output signal

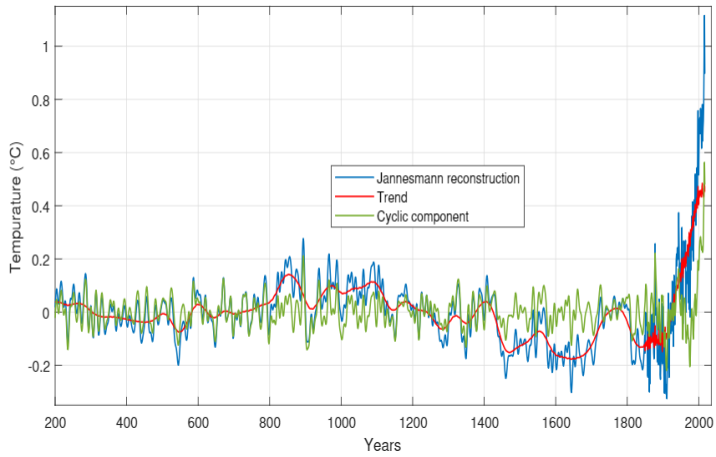

Fig.4 Data, trend and cyclical component

Applying this approach, searching for a cyclic component at this frequency (21.96 years/cycle) in the TSI signal, using the DHR model, to extract the trend and cyclical component (see Figure 5)

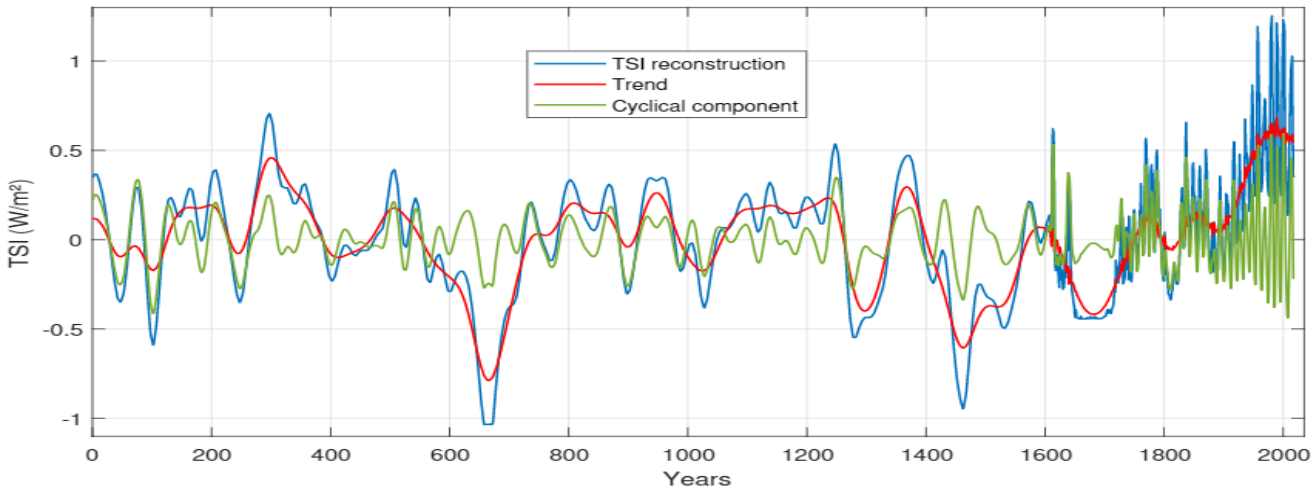

Fig.5 Data, trend and cyclical component

A clearly defined peak can be noticed at 21.96 years/cycle in the estimated spectrum of the DHR model for the output signal (see Figure 3), which apparently is present in the TSI input. Therefore, a cyclical component $C(k)$ at 21.96 years/cycle is extracted on both temperature signal and TSI signal (see Figures 4/5). For future works, the resulting reconstructed signals can be used along the other exogenous inputs for classical parameter system identification purposes.
The DHR method provides an approach that helps analyzing non-stationary time-series and allows identifying all unobserved components. More specifically, a cyclic component has been characterized and identified so that the temperature output becomes freed of this specific component.

[1] P. de Larminat, Climate Change: Identification and Projections. John Wiley & Sons, 2014.
[2] « Dynamic harmonic regression - Young - 1999 - Journal of Forecasting - Wiley Online Library »