CO_2 Concentration Change Detection in Time and Space Domains by Means of Wavelet Analysis of MRA: Multi-Resolution Analysis

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***Abstract*—A method for change detection in time and space domains based on wavelet MRA: Multi-Resolution Analysis is proposed. Measuring stations for carbon dioxide concentration are sparsely situated. Also the measuring stations monitor the carbon dioxide concentration in an irregular basis so that some interpolation techniques are required for creation of carbon dioxide concentration with a regular interval in both time and space domains. After all, time and space of MRA is applied to the interpolated carbon dioxide concentration then reconstruction is done without low frequency of LLL component. Thus relatively large change locations and time periods are detected. Through an experiment with 11 years of carbon dioxide concentration data starting from 1990 provided by WDCGG: World Data Center for Greenhouse Gasses, it is found that there exists seasonal change and relatively large changes are occurred in El Nino years. It is also found that the carbon dioxide is concentrated in European continent.**

Keywords- wavelet analysis; carbon di-oxide distribution; change detection.

I. INTRODUCTION

As the results from the investigations in the pacific, Atlantic and Indian oceans for one decade starting from 1989 and ended in 1998, it was fund that 48% of carbon dioxide of generated from the human activity of fossil derived fuels consumptions and is put into the atmosphere absorbed by the oceans [1], [2]. Not only global carbon dioxide distributions but also regional distributions have being measured and estimated [3].

The carbon dioxide distributions in the atmosphere are measured and estimated at the fixed observation stations irregularly. It is getting much important to identify areas and time periods of which carbon dioxide amount changes in time and space domains through the investigations and analyzing the incomplete measured data for estimation of contiguous series of carbon dioxide distributions with interpolations in time and space domains. In order to detect the carbon dioxide distribution changes, wavelet based Multi Resolution Analysis (MRA) with appropriate parameters, base function and the level of MRA which is corresponding to the frequency component of the changes is proposed. Through experiments with the proposed MRA based method, relatively great changes are found and are highly related to the El Nino. Daubechies and Haar base function for wavelet based MRA are tried with the different levels for determination of most appropriate base function and levels which corresponds to frequency component it may concern.

The following chapter describes the proposed method followed by some experiments with the 10 years of carbon dioxide distribution data. Then, finally, conclusions and some discussions are followed.

II. PROPOSED METHOD

A. Interpolation Method

The carbon dioxide measurement stations are sparsely situated and collect carbon dioxide distribution (73 of measuring stations are situated in the world) in the atmosphere irregularly. Therefore interpolation methods are highly required in particular for space domain. The interpolation method used here can be represented with the following equations,

$$Z = \frac{\sum_{i=1}^{n} a_i z_i}{\sum_{i=1}^{n} a_i} \quad (1)$$

$$a_i = \frac{1}{d_i^p} \quad (2)$$

where z, z_i ,a_i, d_i denote carbon dioxide concentration at the desired location, carbon dioxide concentration at the relatively closed measurement stations to the desired location, weighting coefficients, and the distance between the desired location and the closed measurement stations, respectively. Fig. 1 shows the definition of the desired location (black circle) and three of the closed measurement stations (red circles). Weighting coefficients are inversely proportional to the distance.

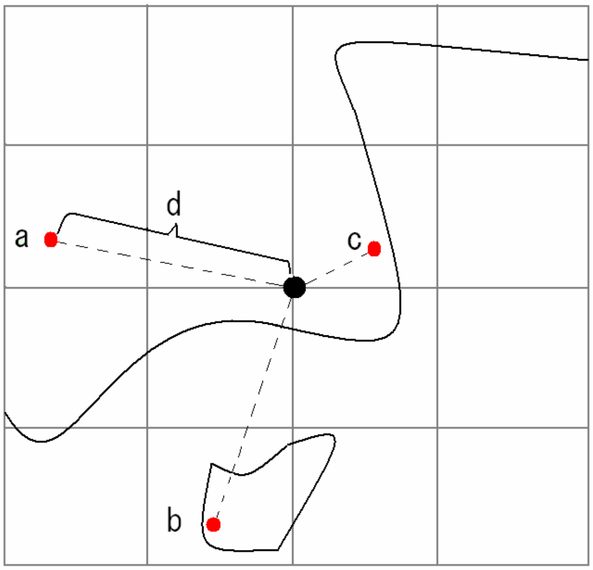

Figure 1 Definition of the desired location (black circle) and three of the closed measurement stations (red circles).

B. *Wavelet Based Multi Resolution Analysis(MRA)*

The locations and time periods representing relatively large changes of carbon dioxide distribution in time and space domains can be found through wavelet based MRA method. Namely, MRA is applied to the space and time series of carbon dioxide distribution of measured data and then reconstruct original data without low frequency component. Thus relatively large changes are corresponding to the comparatively high frequency components so that relatively large changes are detected.

III. EXPERIMETS

A. *The Data Used*

WDCGG (World Data Center for Greenhouse Gasses) of Japanese Meteorological Agency provides the measured carbon dioxide distribution data [5]. WDCGG was established to collect and distribute the data related to greenhouse gasses and the other related gasses in the atmosphere and the oceans as well as relating to global warming. They collect the data from the observation and measuring stations networks of the world atmospheric monitoring program and NOAA: National Oceanic and Atmospheric Administration. A small portion of data is shown in Table 1 and Fig. 2.

Fig. 2 shows the monthly trend of carbon oxide concentrations measured at 53:20N, 9:54W during from 1990 to 2005. It shows gradually increasing of the carbon dioxide concentrations as well as seasonal changes. The trend of the carbon dioxide concentration is almost same in the world. At least, the trend measured at the 73 of observation measurement stations show a similar trend of the trend of Fig. 2.

These data are a small portion of data. Other than these, there are a plenty of data which are provided by the stations and agencies.

Table 1 shows the monthly data of carbon dioxide in unit of ppm with the header information which includes location of the station, station name, data provider name etc. This format is common to all the measurement and observation stations.

Interpolated and re-configured data as one degree of meshed data is generated based on the proposed method. One of the examples of the re-configured data is shown in Fig. 3.

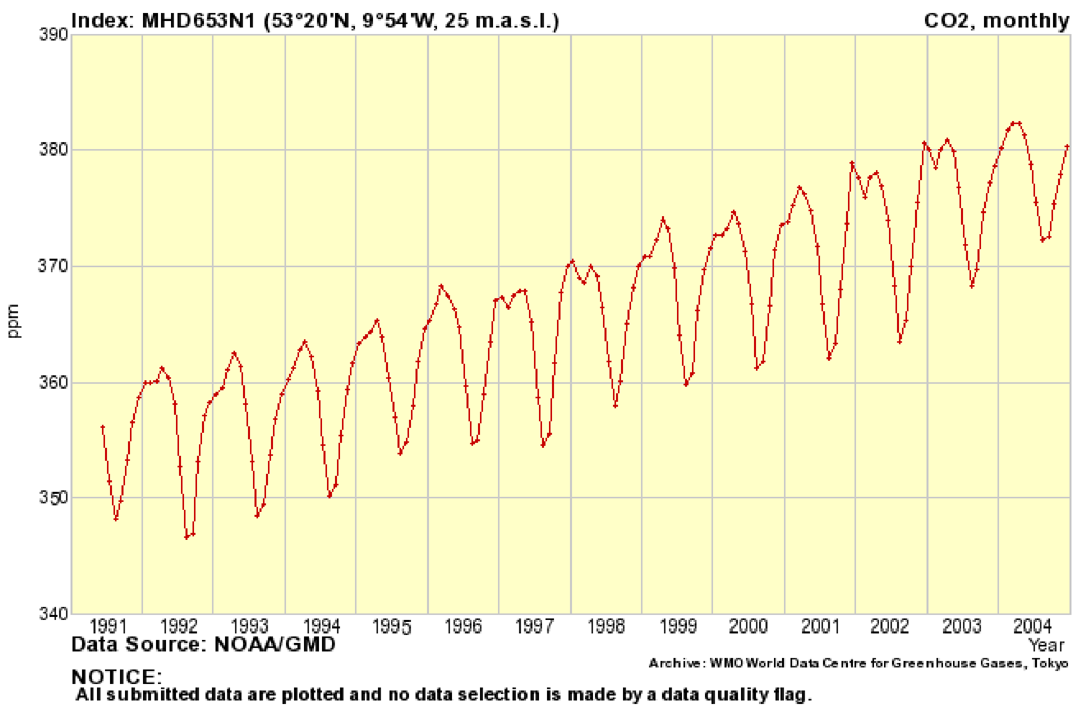

Figure 2 A small portion of measured data of the time series of carbon dioxide at 53:20N, 9:54W during from 1990 to 2005.

Warm colors mean densely concentration of carbon dioxide while cool colored areas show thinner carbon dioxide concentrations. Carbon dioxide concentration in the northern hemisphere is greater than that in the southern hemisphere. In this case of the carbon dioxide in January 1995, carbon dioxide concentration in European countries areas is densely situated, in particular, in comparison to the other areas. There are some artificial shapes of the densely distributed carbon dioxide concentration in the European countries areas. 1995 is not El Nino year so that not so warm sea surface temperature is not observed in the El Nino offshore area of Peru.

It is just an example. Another example of 1 degree mesh data of carbon dioxide distribution trend for 11 years starting from January 1990 is shown in Fig. 4. The car5bon dioxide distribution is shrinking in the horizontal direction, in particular, in order to show the trend much clearly. The black arrows in the bottom indicate El Nino years, 1990, 1993, and 1997-1998. As shown in Fig. 4, warm sea surface temperature is observed in the El Nino offshore areas coincidentally to the well known El Nino years.

B. *Extraction of Spatial Features*

In order to demonstrate a usefulness of the proposed method for extraction of spatial features, 2D wavelet transformation is applied to the spatial distribution data of carbon dioxide which is measured in April 1994. Fig. 5 (a) shows the original distribution while Fig. 5 (b), (c), and (d) shows the resultant images after the wavelet transformations.

TABLE I. SMALL PORTION OF MEASURED DATA OF THE TIME SERIES OF THE CARBON DIOXIDE AT MINAMI-TORISHIMA ISLAND, JAPAN.

REM01 EXPLANATORY 25-LINE FOR THE MONTHLY DATA
REM02
REM03 STATION: Minamitorishima
REM04 CATEGORY: Global
REM05 COUNTRY/TERRITORY: Japan
REM06 SUBMITTED BY: JMA
REM07 LATITUDE: 24 18' N
REM08 LONGITUDE: 153 58' E
REM09 ALTITUDE: 8 m
REM10

REM24 M	CO2	V	ND	SD	F
REM25	ppm				
1993 01	-9999999	2F9	0	-99999	2
1993 02	360.98	018	85	0.684	3
1993 03	360.57	012	570	0.942	3
1993 04	361.66	012	574	1.247	3
1993 05	360.78	012	526	0.998	3
1993 06	359.58	013	471	0.656	3
1993 07	357.69	011	630	1.114	3
1993 08	355.53	013	507	1.240	3
1993 09	353.71	011	635	1.111	3
1993 10	354.76	010	690	1.059	3
1993 11	355.91	014	404	0.802	3
1993 12	357.84	012	580	1.043	3
1994 01	359.67	011	648	0.816	3
1994 02	361.09	012	531	0.854	3

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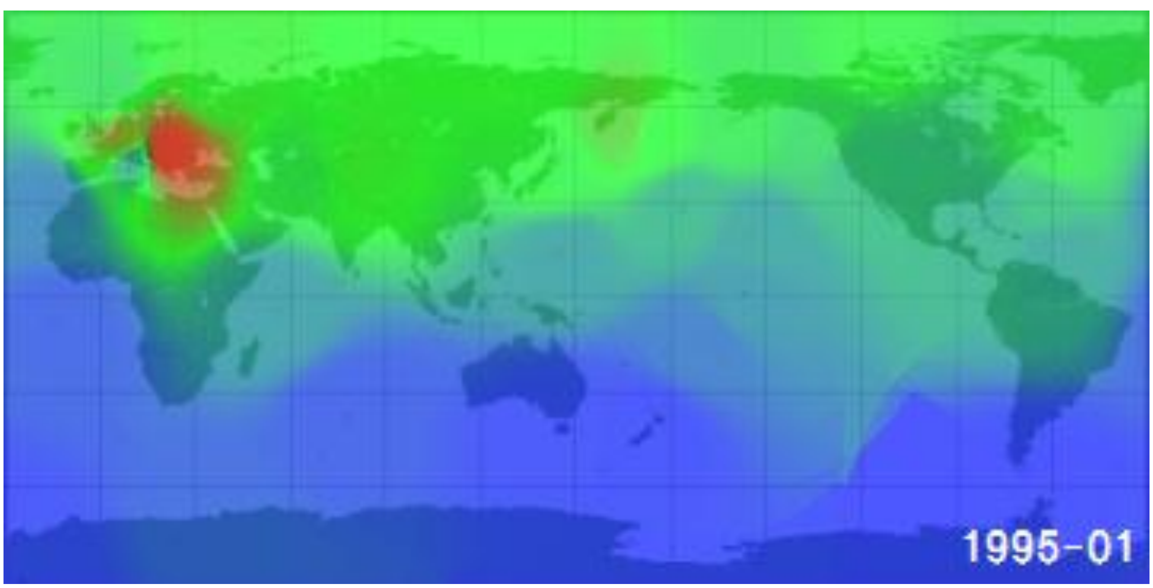


Figure 3 One degree meshed data of carbon dioxide distribution for January 1995.

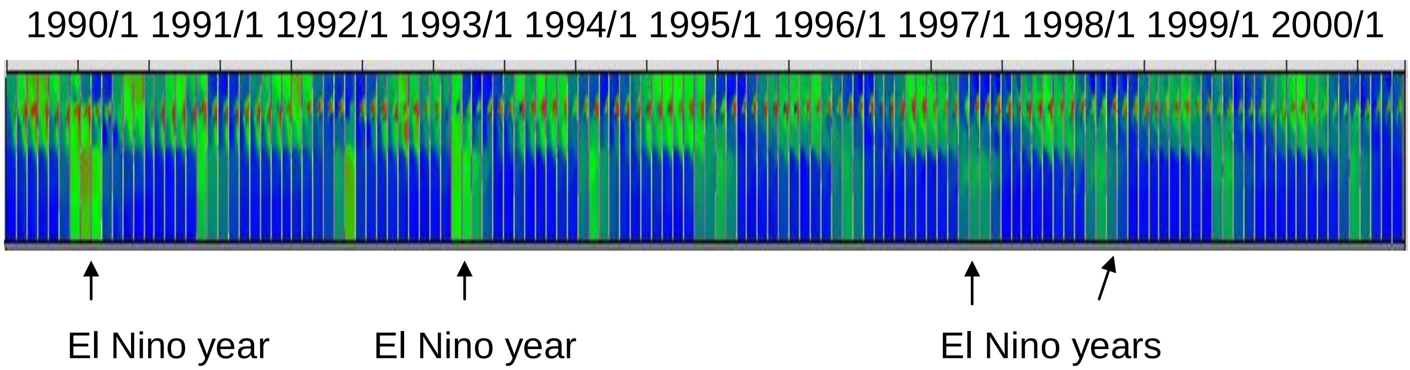
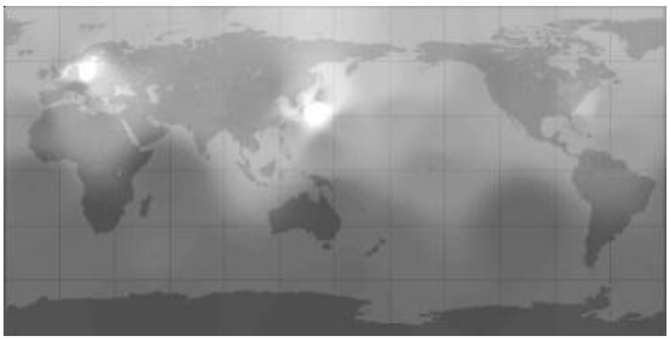


Figure 4 One degree mesh data of time series of carbon dioxide distribution trend for 11 years starting from January 1990.



(a)Original

(b)Level 1

(c)Level 2

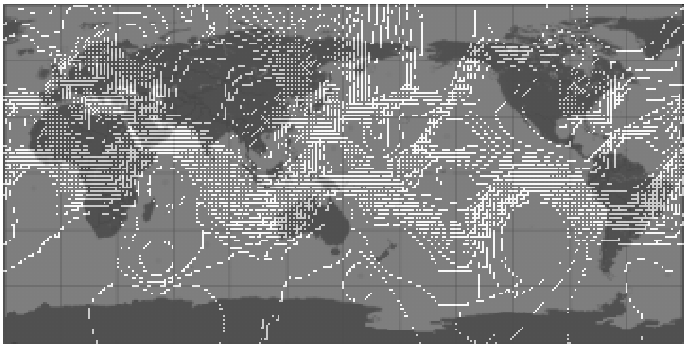
(d)Level 4

Figure 5 Spatial variability detection of carbon dioxide distributions in April 1994.

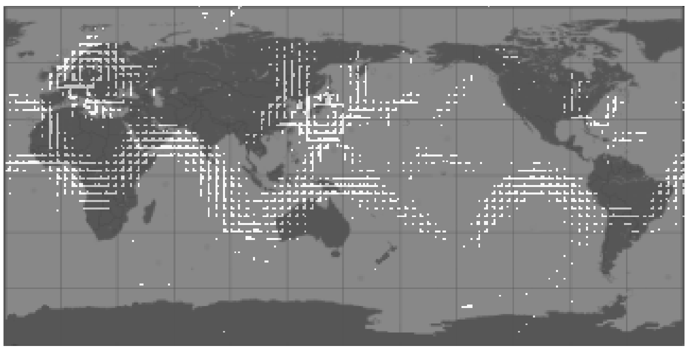
In April 1994, there are two densely distributed carbon dioxide concentration. One is situated in European countries and the other one is situated in south east area. In these cases, LL component is situated at top left corner while HH is situated at the bottom right corner. Mean while LH and HL are situated at the top right corner and the bottom left corner, respectively. It is comprehensive that spatial variability of carbon dioxide distribution is estimated with the different level of the MRA of resultant images.

Using the resultant images, reconstruction process is applied to the 3D (horizontal, vertical, and time dimensions) carbon dioxide distributions without low frequency components which should represent relatively large changes. Namely, spatial frequency components of the spatial variability can be recognized with the reconstructed images. The reconstructed images of each level are shown in Fig. 6 (a), (b), (c), and (d). In the reconstructed images, spatially calm and steeply changed areas can be detected depending upon the degree of changes.

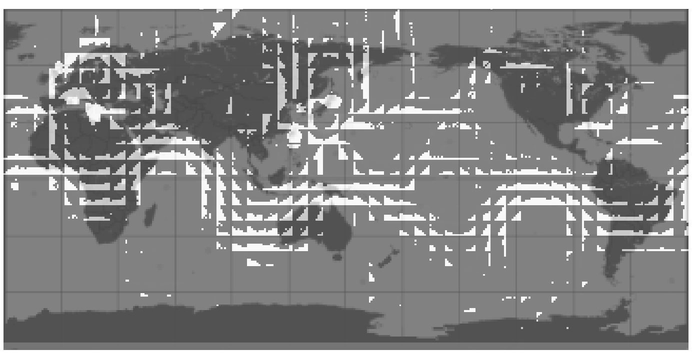
Meanwhile, carbon dioxide changes in time is tried to extract from the 3D concentration of the monthly average of carbon dioxide distribution images for 11 years which is shown in Fig. 7 with the different types of base function of MRA. Daubechies base function is superior to Haar base function for these experiments in terms of detailed information on large changes of carbon dioxide concentration distribution in time.



(a)Level1



(b)Level2



(C)Level3

Figure 6 Time changes detection with the different levels of MRA.

For 11 years, there are some significantly changed areas. These are not only European countries, but also middle and southern portion of African continents and Middle Eastern countries areas. There is the stream shape of large changed areas which is situated from El Nino offshore area and it goes to middle southern portion of South American continent as well as it goes through Atlantic ocean to the middle southern portion of African continent and it goes up to the middle eastern countries, after that it goes down to the western portion of Australian continent through Indian ocean and it goes up to Japanese island and the Pacific ocean area as well as it is divided into the other way to the east-ward and then goes down to the middle northern portion of the Pacific ocean are found.

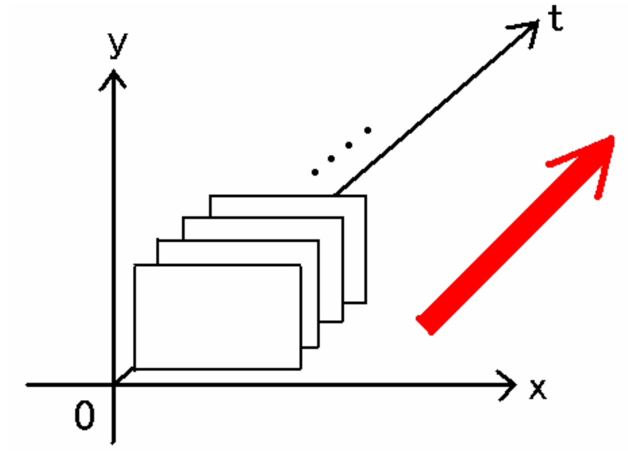


Figure 7 Time series of spatial distribution of carbon dioxide concentration distributions.

Moreover, large changed area is found at east coastal area of Asian continent. Furthermore, the detected these large changed areas are recognizable depending on the change frequency component which corresponds to the levels of MRA.

The reconstructed image without LLL component cannot be shown in figures, so that one dimensional reconstructed trend of carbon dioxide changes is illustrated in Fig. 8. The reconstructed data at the location of 13 degree south, 46 degree west (Tanzania eastern offshore) shows relatively large changes in time at the around 70 and 100 months after January 1990 which are corresponding to 1993 and 1997 of the El Nino years. In this case, level 1 of MRA with Daubechies base function is applied to the original carbon dioxide concentration distribution of image. Also Haar of base function is attempted to the original image. The results from the Daubechies base function are superior to that of Haar base function. The details of the large changed areas detected with Daubechies base function is much clear rather than that of Haar base function.

IV. Conclusions

Contiguous dataset of carbon dioxide concentration distribution can be derived from the sparsely situated data in space domain by using distant dependent linear interpolation.

Through an experiment with 11 years of carbon dioxide concentration data starting from 1990 provided by WDCGG: World Data Center for Greenhouse Gasses, it is found that there exists seasonal change and relatively large changes are occurred in El Nino years. It is also found that the carbon dioxide is concentrated in European continent.

It is found that the proposed 3D wavelet based MRA is useful to detect large changes of carbon dioxide concentration distribution in space and time domains. Also Daubechies base function is superior to Haar base function for details of the detected large changes. Level of MRA depends on the frequency components of large changes which would like to be detected.

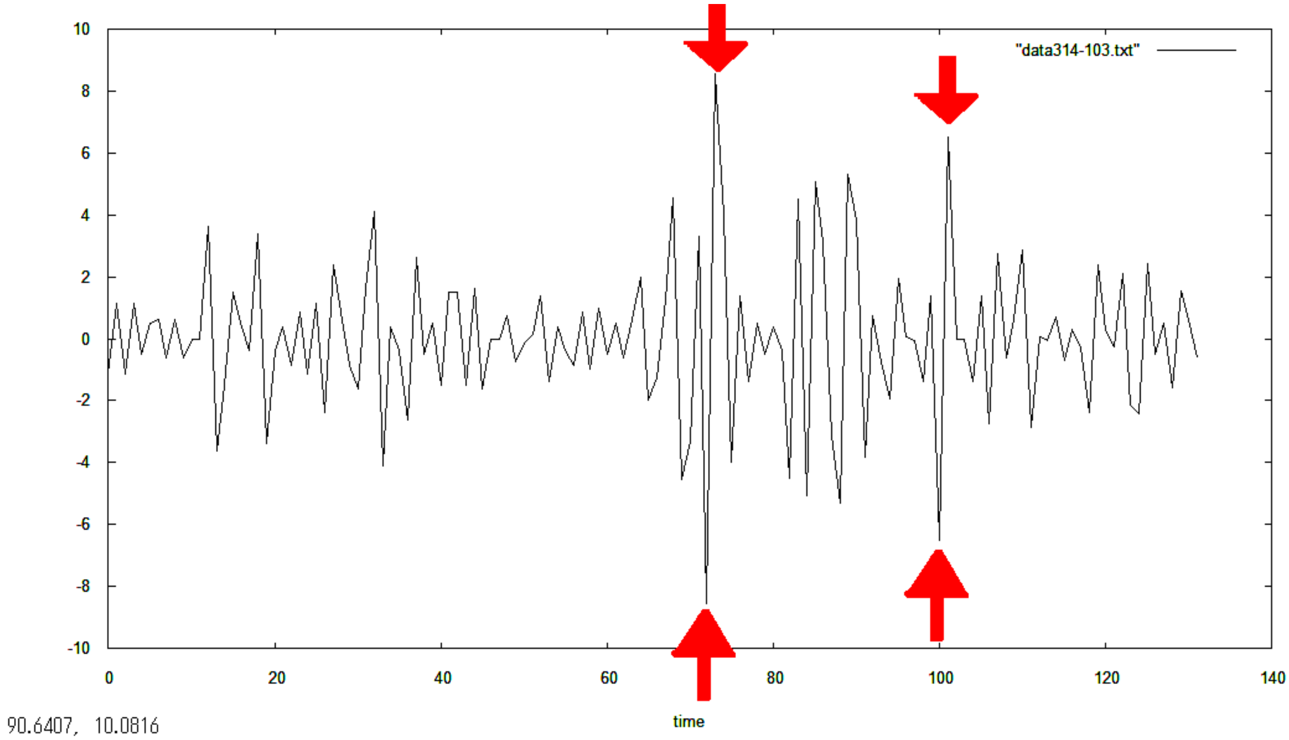


Figure 8 Time changes detected with wavelet based MRA with Daubechies base function and with level 3 which is applied to the original one dimensional time series of carbon dioxide concentration distribution data at the eastern portion of Tanzania. El Nino phenomena are observed at not only El Nino offshore of Peru but also the other stream lines of areas including the eastern portion of Tanzania.

Acknowledgment

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[6] The World Data Centre for Greenhouse Gases (WDCGG) is established under the Global Atmosphere Watch (GAW) programme to collect, archive and provide data for greenhouse (CO_2, CH_4, CFCs, N_2O, etc.) and related (CO, NO_X, SO_2, VOC, etc.) gases and surface ozone in the atmosphere and ocean, measured under GAW and other programmes

Authors Profile

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Kohei Arai received a PhD from Nihon University in 1982. He was subsequently appointed to the University of Tokyo, CCRS, and the Japan Aerospace Exploration Agency. He was appointed professor at Saga University in 1990. He is also an adjunct professor at the University of Arizona and is Vice Chairman of ICSU/COSPAR Commission A.