El Niño / La Niña Identification based on Takens Reconstruction Theory

Kohei Arai
Graduate School of Science and Engineering
Saga University
Saga City, Japan

Kaname Seto
Former Student, Graduate School of Science and Engineering, Saga University
Saga City, Japan

***Abstract*—An identification method for earth observation data according to a chaotic behavior based on Takens reconstruction theory is proposed. The proposed method is examined by using the observed time series data of SST (Sea Surface Temperature) and the SOI (Southern Oscillation Index) data. The experimental results show that the time for the identification of the proposed method is not later than that of the existing method. Author confirmed that by using the definitions of the Japan Meteorological Agency and the use of Equations, I can identify El Niño / La Niña at an earlier time. In other words, we do not necessarily need a numerical value for 10 months by identifying the proposed method. I confirmed that the time required for the identification judgment of the proposed method is about one month. The proposed method is not based on extrapolation method with numerical model or governing equation, but based on interpolation method using only actual observation time series.**

***Keywords*—Time series analysis; takens; sea surface temperature: SST; southern oscilation index: SOI; El Niño-southern oscillation: ENSO**

I. Introduction

El Niño phenomenon / La Niña phenomenon[1] has been noticed not only around the equator but also as one of the things affecting the weather in the world numerical prediction and estimation of the phenomenon using numerical models and governing equations. Also, in Japan, the Meteorological Agency has made a judgment of the El · Niño phenomenon / La Niña phenomenon. By the way, the definition of the El Niño phenomenon / La Niña phenomenon by the Meteorological Agency is defined as the El Nino surveillance area in the western coast of the eastern Pacific equatorial region from 4° North to 4° South and 150° West to 90° West.

It is assumed that the 5 month moving average value of the difference from the average sea surface temperature standard value (30 years average from 1961 to 1990) has reached 0.5° C or more (-0.5° C. or less) continuously for 6 months or more. In other words, data for minimum (2 + 6 + 2) months is necessary for judgment by the Meteorological Agency of the El · Niño phenomenon / La Niña phenomenon. If the 5-month moving average value of the difference with the monthly average sea surface temperature standard value of the survey area becomes 0.5° C or more (-0.5° C or less) consecutively for less than 6 months, non-La Niña. It is judged as "Niña").

[1] https://oceanservice.noaa.gov/facts/ninonina.html

El Niño - pacific trade wind and extraordinary high water temperature in eastern equatorial region is discussed [1]. Also, a new wave of climate research El Niño and Southern Oscillation [2] is reported. On the other hand, global aspects of ENSO (El Niño / Southern Oscillation) [3] is discussed together with global structure of the El Nino / Southern Oscillation-Part I [4] and II [5]. Meanwhile, abrupt enhancement of convective, activity and low-level westerly burst during the onset phase of the 1986-87 El Nino [6] is discussed.

Anomalously short duration of the easterly wind phase of the QBO: Quasi-Biennial Oscillation[2] at 50 hPa in 1987 and its relationship [7] is discussed. Meanwhile, development of a twin cyclone and westerly, bursts during the initial phase of the 1986-87 El Nino [8] is well reported. Meantime, efforts to solve the El Niño phenomenon [9] is discussed. El Niño and prediction of extreme weather [10] is reported.

Statistical features of temperature and precipitation in the world during the El Niño La Niña phenomenon period [11] is reported. A research toward the prediction of the El Niño phenomenon [12] is also well reported. The current state of research on prediction of El Niño and related abnormal weather [13] is summarized in Central Research Institute of Electric Power Industry Research Report T, 98056, pp. 1 - 23, 1999. "Monitoring and prediction of global warming and El Niño phenomenon," is published by Meteorological Agency Climate Oceanic Weather Department Climate Information Division [14].

Use of The Tropical Ocean Global Atmosphere program (TOGA) TAO / TRITON buoy[3] data[4] for monitoring and prediction of El Niño phenomenon [15] is reported. Meanwhile, a study on the interaction between the atmosphere and the ocean using satellite observations and numerical models [16] is conducted. Simulation of typhoon and El Niño Southern Oscillation by high resolution atmosphere and ocean binding model [17] is well reported. Also, large scale meteorological phenomena in tropical zone and The Tropical Rainfall Measuring Mission TRMM[5] observation - 1997-98 El Niño's termination and Madden-Julian vibration [18] is introduced.

[2] https://www.jstage.jst.go.jp/article/mripapers/48/1/48_1_1/_article
[3] https://www.pmel.noaa.gov/gtmba/
[4] https://climatedataguide.ucar.edu/climate-data/tropical-moored-buoy-system-tao-triton-pirata-rama-toga
[5] https://trmm.gsfc.nasa.gov/

About the work of the El Niño monitoring center [19] is reported. On the other hand, El Niño surveillance center [20] is also reported. Meteorological Agency El Niño Observation Forecast Center: reported “El Nino events occurred," [21]. Meanwhile, about the updated "El Niño surveillance bulletin" [22] is reported.

El Niño Chaos is introduced in the Mathematical Science society [23]. Furthermore, numerical modeling for prediction El Nino's dynamic [24] is proposed. Meanwhile, detecting strange attractors in turbulence in Dynamical Systems and Turbulence [25] is discussed. The Takens embedding theorem[6] is introduced [26].

El Nino phenomena analysis with Earth Observation Satellite data [27] is discussed. Also, El Nino and La Nina discrimination based on Takens reconstruction theory [7] is proposed [28]. Prediction method of ENSO: El Nino Southern Oscillation [8] event by means of wavelet based data compression with appropriate support length of base function [29] is also proposed.

The purpose of this research is to shorten the time required for judgment by the definition of the Japan Meteorological Agency. More generally, information on how long the state in which the absolute value of the 5-month moving average value of the difference from the reference value of the monthly average sea surface temperature in the surveillance area is α degree C. or more continues is obtained early Establishing a method.

In this paper, Takens reconstruction theorem possessing the feature that it is possible to extract its data characteristics only from target observation data having nonlinearity, and the feature that extrapolation problem can be transformed into interpolation problem A method for judging the La. Niño phenomenon / La Niña phenomenon is proposed. Also, the effectiveness of the proposed method is validated in this paper.

The next section describes the proposed method together with typical conventional Newton-Raphson method [9] for retrieving vertical profiles followed by experiments. Then conclusion with some discussions is followed by together with future research works.

II. Proposed Method

Consider extracting its dynamic characteristics from actual observation time series only. To realize dynamic characteristic extraction of the object time series [23], [24], we will estimate the behaviors of the hidden deterministic state variables Xi (i = 1, 2) of the actual observation time series. To estimate the deterministic rule, the reconstruction theorem by F. Takens [25], [26] is used.

[6] https://www.worldscientific.com/doi/abs/10.1142/S0218127491000634
[7] https://en.wikipedia.org/wiki/Takens%27s_theorem
[8] https://en.wikipedia.org/wiki/El_Niño–Southern_Oscillation
[9] http://www.sosmath.com/calculus/diff/der07/der07.html

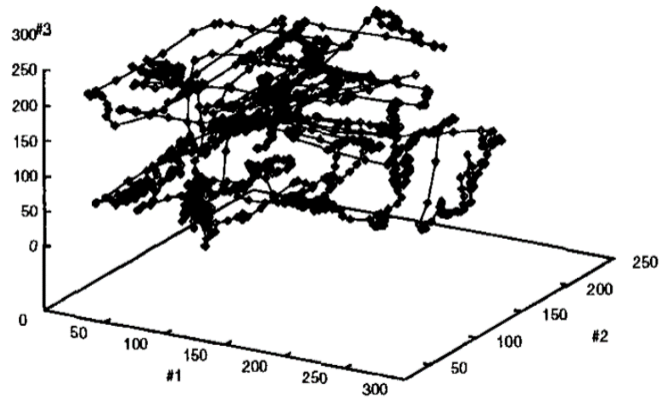


Fig. 1. Overview of the Trajectory of X_t.

A. Reconstruction Theorem of Takens

From two different scalar real observation time series ξ, η_i, $m_1 + m_2$ dimensional state variable,

$$X_1 = (\xi_1, \dots, \xi_1 - (m_1 - 1)\tau_1; \eta_1 - \beta, \dots, \eta_1 - (m_2 - 1)\tau_2 - \beta)$$

$$X_2 = (\xi_2, \dots, \xi_2 - (m_1 - 1)\tau_1; \eta_2 - \beta, \dots, \eta_2 - (m_2 - 1)\tau_2 - \beta)$$

$$X_l = (\xi_l, \dots, \xi_l - (m_1 - 1)\tau_1; \eta_l - \beta, \dots, \eta_l - (m_2 - 1)\tau_2 - \beta)$$

Are composed (T_1, τ_2, β: time delay). When analyzing based on actual observation data, how to choose the time delays τ_1, τ_2, β is a problem. Here, the parameters $m_1 + m_2$ are called embedded dimensions. X_1, X_2, ..., X, ... are temporal orders, and the displacement from $X_t X_{t+1}$ at an arbitrary time t depends on the actual observation time series ξ_i, η_i.

By analyzing the trajectory of $m_1 + m_2$ dimensional state change X_t, We estimate the characteristics of the real observation time series ξ_i, η_i. As an example, the trajectory of the three-dimensional state variable X_t is shown in Fig. 1.

B. Judgment Method

In the space of the state variable X_t, El Nino Year / La La Niña, the history of the year of Nina and non El Nino / non-La Niña. We think that it is different from the trajectory of the year.

III. Experiment

A. Data Used

The data used are SST (sea surface temperature) from the Japan Meteorological Agency and Make the monthly data of SOI (southern oscillation index). However, SST is the standard value of the monthly average sea surface temperature (30 years average value from 1961 to 1990).

SOI is the data of the difference between Tahiti and Oh on the South Pacific. It was indexed based on the atmospheric pressure deviation of Darwin on the Straia. It is a thing and is a measure of the strength of the trade wind, time limit. It is January 1972 to December 2001. Table I shows monthly mean sea level. Table I shows the mean values of SST per month derived from SST data from 1961 to 1990.

TABLE I. THE MEAN VALUES OF SST PER MONTH DERIVED FROM SST DATA FROM 1961 TO 1990

Month	Mean SST(deg.C)
January	25.4
February	26.2
March	26.9
April	27.1
May	26.6
June	26.1
July	25.2
August	24.6
September	24.6
October	24.6
November	24.6
December	24.9

It shows the reference value of water temperature. In addition, it was decided by the Meteorological Agency that the El Niño phenomenon occurred years is

- 1972-1973
- 1976-1977
- 1982-1983
- 1986-1988
- 1991-1993
- 1997-1998

It is judged that the La Niña phenomenon occurred years is

- 1972-1976
- 1984-1985
- 1988-1989
- 1998-2000

It is the 4th time of the year. These include El Niño phenomenon and there is a year when La Niña phenomenon occurred. In addition, one year is the period from January to December; also, in 1991-1993 El Niño phenomenon and La Nina in 1972-1976. There are two time periods for the El Niño and the La Niña phenomenon in 1998-2000.

B. *Experimental Method*

The proposed method analyzes the trajectory of mass points on multidimensional space, and from the viewpoint of visual understanding of the reader, this paper reports cases where $\beta = 0$, $m_1 = m_2 = 1$. That is, by setting $\beta = 0$, $m_1 = m_2 = 0$, and $\beta = 0$, $m_1 = m_2 = 1$, analysis on a two-dimensional plane can be performed. The reason for using the southern vibration index is that the sea surface temperature and the southern vibration index are interlocking with each other in order to take account of the influence.

A method for identification of El Niño / non El Niño is the followings:

1) The Meteorological Agency judged that El Niño phenomenon occurred. Appropriate reconstruction theorem for sea surface temperature and southern vibration index of year. Use it to display its trajectory.

2) The Japan Meteorological Agency did not judge that El Niño phenomenon occurred. Reconstruction for sea surface temperature and southern vibration index in a year. Apply the idea and display its trajectory.

3) The Meteorological Agency judged that the El Niño phenomenon occurred. The locus of the reconstruction space of the year and the Meteorological Agency issue the El Niño phenomenon. The difference from the trajectory of the reconstruction space of the year not determined to have been generated. Examination, El Niño passing the path of the year and non-El Niño. Find the area of the reconstruction space where the trajectory of the year does not pass.

4) In the locus of a certain year, the found reconstruction space. When that locus passes through the area of it is judged as El Niño year.

Identification of La Niña / Non La Niña can be done with the same method. The problems are the following:

1) Is there a region of reconstruction space through which the locus of the El Niño year passed and the trajectory of the non-El-Niño year does not pass?

2) Is there a region of reconstruction space through which the locus of La Niña passed and the trajectory of the non-La Niña year does not pass?

3) If the trajectory passes through the area of the found reconstruction space, does it agree with the judgment result by the definition of the Japan Meteorological Agency?

4) Does the decision timing by the proposed method become slower than the judgment timing based on the definition of the Japan Meteorological Agency?

C. *Application of Takens Reconstruction*

Below, the horizontal axis of Fig. 2 to 5 shows the difference from the standard value of monthly mean sea surface temperature and the vertical axis is the southern vibration index.

Fig. 2 shows the trajectory of (SST, SOl) from 1972 to 2001. The red line (72-73, 76-77, 82-83, 86-88, 91-93, 97-98) is the locus of the year determined by the Meteorological Agency that the El Niño phenomenon occurred and the green line (74-75, 78-81, 84-85, 89-90, 99-01). The blue line (94-96) is the locus of the year not judged by the Meteorological Agency that the El Niño phenomenon occurred (Fig. 3(a)).

Fig. 3(b) shows the locus of the year that was not judged by the Japan Meteorological Agency that the El Niño phenomenon occurred, and shows the locus of the year judged by the Japan Meteorological Agency that El Niño phenomenon occurred; it is expressed for each period.

Fig. 4 shows the trajectory of (SST, SOI) from 1972 to 2001. In the figure, the red line (72-76, 84-85, 88-89, 98-00) is the locus of the year determined by the Meteorological Agency that the La Niña phenomenon occurred and the green line (86-87, 01), Blue line (77-83), Light blue line (90-97) is the locus of the year that was not judged by the Meteorological Agency that the La Niña phenomenon occurred. Fig. 5(a) shows the locus of the year determined by the Meteorological Agency that the La Niña phenomenon occurred for each period, and Fig. 5(b) shows that the La Niña phenomenon occurred and the Meteorological Agency In each period, the trajectory of the year that was not determined by the period.

As shown in Fig. 5(b), SOI = 0, so the state of SST> 05 becomes a short period and it is not judged as El Niño from the definition of the Japan Meteorological Agency, and from Fig. 5(b) SOI < 0, the state of SST = - 0.5 became a short term and it is understood that there was a case that it was not judged as La Niña from the definition of the Japan Meteorological Agency. That is, the authors judge that the southern vibration index and sea surface temperature are necessary for early identification of El Niño / La Niña.

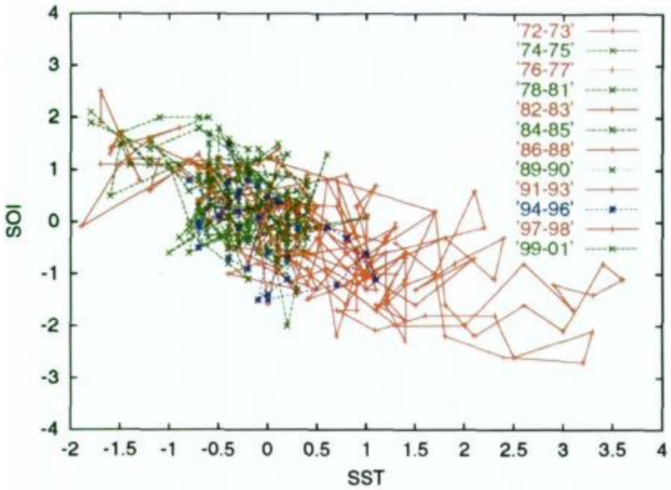
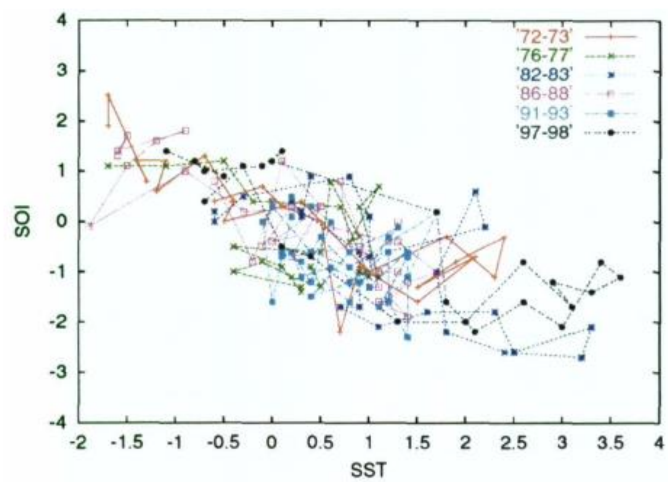
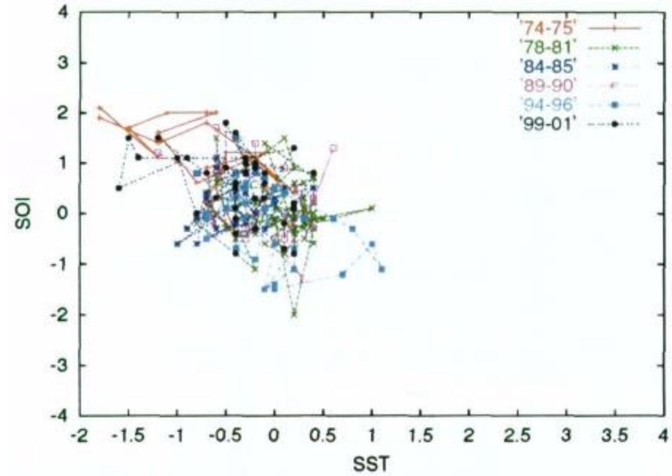


Fig. 2. The trajectory of SST-SOI Data during El Nifto years and non El Nino years from 1972 to 2001.



(a) The trajectories of SST-SOI data during El Nino years.



(b)The Trajectories of SST-SOI Data during non El Nino Years.

Fig. 3. The trajectories of SST-SOI Data during El Nino years and non El Nino years.

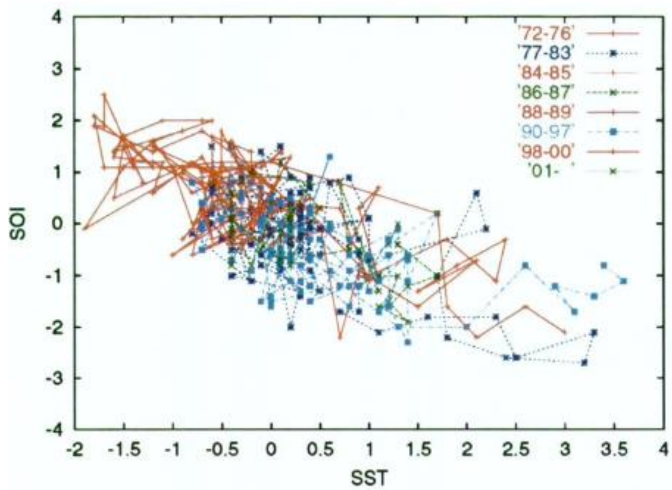
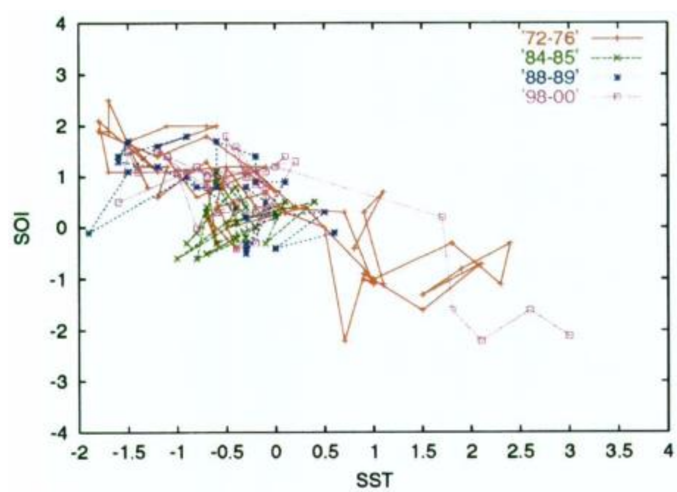
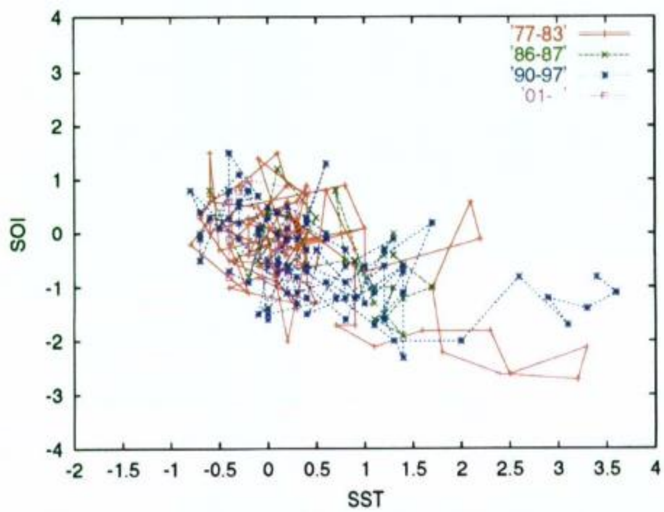


Fig. 4. The trajectory of SST-SOI Data during La Nina years and non La Nina years from 1972 to 2001.



(a) The trajectories of SST-SOI data during La Nina years.



(b) The trajectories of SST-SOI data during non La Nina years.

Fig. 5. The trajectories of SST-SOI data during La Nina years and non La Nina years.

Fig. 2 ~ Fig. 3 and Fig. 4 ~ Fig. 5, the trajectory of (SST, SOI) of the year judged by the Meteorological Agency that the El · Niño phenomenon / La · Niña phenomenon occurred and El · Niño phenomenon / It can be seen that there is a region different from the locus of (SST, SOI) of the year that was not judged by the Meteorological Agency when the La Niña phenomenon occurred. In other words, the locus of (SST, SOI) in the year that the Japan Meteorological Agency did not judge that the El · Niño phenomenon occurred does not pass through at least to the area of

SST> 1.1, SOI <0 (1)

It is understood that the locus of (SST, SOI) in the year that the Niña phenomenon occurred does not pass through at least to the region of

SST < - 1.0, SOI> 0 (2)

In addition, the locus of (SST, SOI) in the year when the Meteorological Agency judged that the El · Niño phenomenon / La Niña phenomenon occurred was passed, it was judged by the Meteorological Agency that the El Niño phenomenon / La Niña phenomenon occurred Once it enters an area where the trajectory of (SST, SOI) did not pass, it will be found that it will stay within that area for a while.

Tables II and III show the period of time required for judgment when identifying El Niño / La Niña using (1) and (2). From Tables II and III, it can be seen that the period required for judging the proposed method is shorter than the 10 months, which is the period required for judgment by El Niño / La Niña as defined by the Meteorological Agency. In other words, by using the definition of the Japan Meteorological Agency and the use of (1) and (2), it is possible to identify El Niño / La Niña at an earlier time. The advantage of using the definition of the Japan Meteorological Agency in combination is that in this paper 0.5 ≤ SST ≤ 1.1. Table II shows the time period for identification of El Nino. Meanwhile, Table III, the time period for identification of La Nina.

TABLE II. THE TIME PERIOD FOR IDENTIFICATION OF EL NINO

Year	Proposed
1972-1973	4
1976-1977	Definition of the JMA
1982-1983	5
1986-1988	7
1991-1992	2
1992-1993	3
1997-1998	1

TABLE III. THE TIME PERIOD FOR IDENTIFICATION OF LA NINA

Year	Proposed
1972-1974	2
1974-1976	9
1984-1985	4
1988-1989	1
1998-1999	4
1999-2000	3

And analysis of the following region:

-1.0 <SST = - 0.5 (3)

can be considered. In other words, there is a possibility that the definition of the Meteorological Agency may be satisfied by continuing to stay in the area of

0.5 <SST <1.1 or -1.0 <SST = - 50. (4)

Indeed, in Table II, 1976 - 1977, it remained in the region of 05 SST = 1.1, which is an example satisfying the definition of the Japan Meteorological Agency.

IV. CONCLUSION

An identification method for earth observation data according to a chaotic behavior based on Takens reconstruction theory is proposed. The proposed method is examined by using the observed time series data of SST (Sea Surface Temperature) and the SOI (Southern Oscillation Index) data. The experimental results show that the time for the identification of the proposed method is not later than that of the existing method.

We confirmed that by using the definitions of the Japan Meteorological Agency and the use of (1) and (2). I can identify El Niño / La Niña at an earlier time. In other words, we do not necessarily need a numerical value for ten months by identifying the proposed method. We also confirmed that the time required for the identification judgment of the proposed method is about one month. The proposed method is not based on extrapolation method with numerical model or governing equation, but based on interpolation method using only actual observation time series.

This paper does not change the definition of the Meteorological Agency's El Niño phenomenon / La Niña phenomenon. By analyzing the boundary of the area where the locus of El Nino Year (La Nina Year) passes and the trajectory of non-El-Niña year (non La Niña year) does not pass. El Niño / we confirmed that there is a discrimination method consistent with the identification result of La Niña.

Further investigation is required for validation of the proposed method with a variety of cases.

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AUTHOR'S PROFILE

Kohei Arai, He received BS, MS and PhD degrees in 1972, 1974 and 1982, respectively. He was with The Institute for Industrial Science and Technology of the University of Tokyo from April 1974 to December 1978 also was with National Space Development Agency of Japan from January, 1979 to March, 1990. During from 1985 to 1987, he was with Canada Centre for Remote Sensing as a Post Doctoral Fellow of National Science and Engineering Research Council of Canada. He moved to Saga University as a Professor in Department of Information Science on April 1990. He was a councilor for the Aeronautics and Space related to the Technology Committee of the Ministry of Science and Technology during from 1998 to 2000. He was a councilor of Saga University for 2002 and 2003. He also was an executive councilor for the Remote Sensing Society of Japan for 2003 to 2005. He is an Adjunct Professor of University of Arizona, USA since 1998. He also is Vice Chairman of the Science Commission "A" of ICSU/COSPAR since 2008 then he is now award committee member of ICSU/COSPAR. He wrote 37 books and published 570 journal papers. He received 30 of awards including ICSU/COSPAR Vikram Sarabhai Medal in 2016, and Science award of Ministry of Mister of Education of Japan in 2015. He is now Editor-in-Chief of IJACSA and IJISA. http://teagis.ip.is.saga-u.ac.jp/index.html