The Indo-Pacific Heritage of Prof. Klaus Wyrtki
-A Personal View-

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In retrospect, a letter from Prof. Klaus Wyrtki in summer of 1981 opened a door to dome oceanography, IO and Pacific variations (Wyrtki Jets, IT, NEC, KE), climate variations (ENSO/IOD/Modoki), and prediction of climate modes for application to society.
Simple statistical model for predicting the Kuroshio Extension and the NEC
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July 21, 1981

Prof. Toshio Yamagata
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812 Japan

Dear Prof. Yamagata:

Thanks for sending me your very interesting paper on the long term variability of the subtropical gyre. Fortunately, Professor Chaen of Kogoshima University is here as a visitor and he was kind enough to translate important points of your paper for me. I'm very glad to note that you find a relationship between fluctuations in the Kuroshio and the North Equatorial Current. Your Figure 6 is definitely an improvement over the earlier analysis by White and makes much more sense. Logic demands that Kuroshio transports follow the transports in the North Equatorial Current. I'm not so sure about the successive feedback via the wind systems, but your analysis makes it very plausible. I'm very surprised about the high degree to which your simple theory predicts the fluctuations in the various ocean-atmosphere components, and I hope to see the paper published soon. It would be very helpful if someone could produce an English version of this interesting article.

Best regards,

Very Truly Yours,

Klaus Wyrtki
Professor of Oceanography

KW:lv
Klaus’s NAGA Report and his Pioneering Work on the Indonesian Throughflow
Pacific low-latitude western boundary currents and the Indonesian Throughflow
The JGR Special Section born from the meetings at Bali and Fukuoka in 1994 to update the NAGA report.
Figure 1. Map of the western tropical Pacific Ocean and Indonesian Seas showing the major geographic names and surface to intermediate depth currents, including the Kuroshio, Mindanao Current (MC), North Equatorial Current (NEC), North Equatorial Countercurrent (NECC), New Guinea Coast Current (NGCC), South Equatorial Current (SEC), South Equatorial Countercurrent (SECC), East Australia Current (EAC), South Java Current (SJC), and the Leeuwin Current (LC). The subsurface currents are the New Guinea Coastal Undercurrent (NGUC), Equatorial Undercurrent (EUC), Northern and Southern Subsurface Countercurrents (NSCC and SSCC), Mindanao Undercurrent (MUC), and Great Barrier Reef Undercurrent (GBRUC). The Mindanao Eddy (ME) and Halmahera Eddy (HE) are also indicated. Solid lines indicate surface flow, thick dashed lines indicate thermocline flow, and thin dashed lines indicate the flow of Antarctic Intermediate Water (AAIW). The inset shows the region of Vitiaz Strait east of New Guinea at 5°S, 148°E [after Fine et al., 1994].
Systematic Ocean Upwelling: Thermal Domes
UPWELLING IN THE COSTA RICA DOME

by Klaus Wyrtki

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ABSTRACT

The Costa Rica Dome is an area off the coast of Costa Rica where the strong tropical thermocline reaches to within 10 meters of the sea surface. The dome measures about 150 by 300 kilometers. It is situated near lat. 9° N., long. 89° W., at the eastern end of a ridge in the topography of the thermocline along the northern boundary of the Equatorial Countercurrent. This current, the Costa Rica Coastal Current, and parts of the North Equatorial Current form a cyclonic circulation around the dome.

At the surface the dome appears as an area of slightly reduced temperature, higher salinity and phosphate contents, and reduced oxygen saturation, which are indications of upwelling. The balance between the energy available for heating of the surface layer and the ascending of cooler water gives an average ascending velocity of $10^{-4}$ cm/sec. These movements add only $7 \times 10^{13}$ cm$^3$/sec. to the surface layer, compared with transports of about $20 \times 10^{12}$ cm$^3$/sec. of the horizontal circulation. The upwelling in the dome is caused by the cyclonic flow around the dome. When the Countercurrent strongly changes direction, the necessary adjustment of its velocity requires a cross-current velocity of about 0.9 cm/sec., which is sufficient to maintain the upwelling. During the Costa Rica Dome survey a deep-reaching eddy transporting $20 \times 10^{12}$ cm$^3$/sec. appeared to be separated and to drift north with the Costa Rica Coastal Current.

Comparison of the topography of an isothermal layer during six surveys in the area showed that the dome was always present and maintained its position within 200 km. These observations indicate that the Costa Rica Dome, although a permanent feature, is subject to considerable fluctuations in its structure and circulation and may contribute essentially to large-scale mixing.

i. Where is the upwelling area located, and what is its size?

ii. What is the amount of upwelling?

iii. Where does the ascending water come from?

iv. How is the upwelling conditioned dynamically?

v. Is the Costa Rica Dome a permanent or temporary feature?
OGCM experiment tried to simulate a real regional ocean phenomenon.

Response of the Eastern Tropical Pacific to Meridional Migration of the ITCZ: The Generation of the Costa Rica Dome

S. UMATANI AND T. YAMAGATA

ABSTRACT

A regional ocean circulation model with fine horizontal resolution has captured a coherent seasonal picture of the eastern tropical Pacific off Central America. The Costa Rica Dome with a cyclonic circulation grows rapidly in late summer and early fall in accord with the northward migration of the cold tongue. Converging in the southernmost ITCZ from three passages in Central America, eddies are formed in the upper layer. These anticyclones are identified as the Matsuura and Yamagata models.

The Costa Rica Dome is eroded in winter and early spring by the west breeze, but at the same time, a new embryo forms. The dome becomes evident in the early summer, and the Costa Rica Dome is formed with the influence of the El Niño. The Costa Rica Dome is the response of the local wind stress curl.

Fig. 1. Revised Heilmeier-Reynaud's monthly mean wind stress used in the present study. Three winds from the north are well resolved.

Fig. 7. Annual march of subsurface temperature at a depth of 50 m. Data interval is 1°C. The temperature less than 20°C is shaded.
Inspired by the Costa Rica paper, 5 received Ph. D in my group
The Wyrtki Jet

Prof. Kozo Yoshida discussed the equatorial trapped jet theoretically in 1959. Prof. Klaus Wyrtki discovered the phenomenon in the IO in 1973, Prof. O’Brien and Dr. Hurlburt demonstrated the above relation clearly by numerical simulation in 1974.
An Equatorial Jet in the Indian Ocean

Abstract. At the surface of the Indian Ocean along the equator a narrow, jet-like current flows eastward at high speed during both transition periods between the two monsoons. The formation of the jet is accompanied by thermocline uplifting at the western origin of the jet and by sinking at its eastern terminus. This demonstrates that a time-variable current can have profound effects in changing the mass structure in the ocean.

Fig. 1. The equatorial jet in the Indian Ocean in May and October shown by surface current vectors for all 1-degree squares where the speed exceeds 20 miles per day (43 cm/sec), according to data in (7).
Equatorial Jet in the Indian Ocean: Theory

Abstract. A nonlinear numerical model and a simple analytical theory explain the basic features of the equatorial surface jet in the Indian Ocean recently reported by Wyrtki. The observed width of this transient current, 500 kilometers, is given theoretically by twice the baroclinic equatorial radius of deformation. The numerical model reproduces all Wyrtki’s observations of this natural phenomenon.
Unusual Wyrtki Jet during the fall in 1994 led us to the Indian Ocean Dipole Mode


Response of the Equatorial Indian Ocean to an unusual wind event during 1994

P. N. Vinayachandran¹, N. H. Saji¹ and Toshio Yamagata¹,²

In a normal year two surges of westerlies occur along the equatorial Indian Ocean; first during April-May and second during October-November. An unusually strong and persistent westward anomaly of the winds occurred during 1994 in the equatorial Indian Ocean east of 60°E (Figure 1). Strong southeasterlies occurred along the coast of Indonesia, which extended north of the equator. These winds pushed the line of zero zonal wind stress north of the equator resulting in an easterly component along the equator, which is quite unusual during spring and fall.

Figure 1. Wind stress (dynes cm⁻²) anomalies (vectors) and SST [Reynolds and Smith, 1994] anomalies (color filled contours at 0.5°C interval) during May 1994 and October 1994 over the Indian Ocean. The wind stress is calculated from Legler et al. [1989] using a constant drag coefficient of 0.0013. The anomalies are from the mean during the period 1970-96.
Figure 4. a) Time-longitude section of sea surface height anomaly from TOPEX/POSEIDON averaged from 2°S-2°N. A 5-point Hanning smoothing in time is applied to the 10-day data before plotting. b) Horizontal distribution of the SSH during October, 1993 in the equatorial Indian Ocean. c) Same as in b) but for October, 1994. In all panels contour interval is 5cm and positive anomalies are shown in red and negative anomalies are shown in blue. Land areas are shown in green.
The wind and ocean act on each other.

from Prof. Klaus Wyrtki
IOD Evolution Locked to Seasons

Saji et al. 1999, Nature
IOD: Ocean-Atmosphere Coupled Evolution

The year before a DM event

During a DM event

After a DM event

East-west SST contrast

Easterly

Normalized anomaly


$U_{eq}$

$U_{eq} = 0.96$ m/s

$q_{DMI} = 0.9^\circ$C
インド洋のダイポールモード現象の模式図
Schematic Picture of Indian Ocean Dipole

負のダイポール
Negative IOD

正のダイポール
Positive IOD
Seasonal Prediction by a Coupled General Circulation Model (e.g., SINTEX-F1)

Ocean: OPA8.2 ORCAR2 Grid

2\(^0\)X1.5\(^0\) Eq-0.5 Level 31

Atmosphere: ECHAM4 T106 L19

Non-flux adjustment

Every 2 hrs Coupler-OASIS 2.2

North Pole is replaced by two land points

Earth Simulator
It may be that the system cannot be solved for long term forecasting but it is hoped that predictions of a shorter time scale, monthly or yearly, are possible.

http://www.jamstec.go.jp/frcgc/research/d1/iod/e_seasonal/outlook.html
Strange Pacific Condition in 1994
No El Niño (JMA), El Niño (BMRC)
El Niño Modoki  
(Pseudo El Niño)  

This term was coined in 2004 to explain extremely hot summer conditions in Japan despite the so-called El -Niño year,  
(Ashok et al.2007, JGR)  

In recent decades, the central Pacific warming is more frequent with cool SST anomaly in the eastern Pacific in contrast to the conventional El Niño.
The El Niño Modoki events, distinguished by a tripolar SSTA pattern in tropical Pacific. These are occurring with increased frequency since late 1970s, and are distinctly different from canonical ENSO in terms of evolution and impacts (Ashok et al., 2007). The El Niño Modoki, such as seen in 2004, is associated with anomalous twin Walker cells with common ascending limb in the anomalously warm central tropical Pacific resulting in impacts (Ashok et al., 2007, 2009; Weng et al, 2007, 2008; Taschetto et al., 2009) distinct from those of the canonical El Niño, such as that in 1997.
On the Coastal (Ningaloo) Niño

Kataoka, Tozuka, Behera and Yamagata, 2013, submitted to Climate Dynamics

- 36-14°S, 100-120°E
- 52.0%

(Correlation coefficient with the time series of EOF1: 0.87)
Define a Ningaloo Niño year as the year when the DJF-averaged NNI exceeds one standard deviation. Peaking in Dec.-Feb.
Composites of SST anomalies

95% confidence level
Composites of surface wind anomalies

95% confidence level

Sep.(0)  Oct.(0)  Nov.(0)  Dec.(0)  Jan.(1)  Feb.(1)  Mar.(1)  Apr.(1)

5m/s
DJF-mean coastal wind index (CWI)

Ningaloo Niño

- locally amplified
- non-locally amplified
Locally amplified mode

SST and surface wind anomaly composite (Jan.1)

95% confidence level

low pressure anomalies

warm SST anomalies

northerly wind anomalies

NNI and CWI composites (locally amplified Niño)

-1 x normalized CWI

-2.5

-2.0

-1.5

-1.0

-0.5

0

0.5

1.0

1.5

2.0

2.5

normalized NNI

-99%

-95%

-90%

Jul(0) A S O N D Jan(1) F M A M J

90S

20S

40S

0E

90E

120E

5 m/s

(°C)
Non-locally amplified case

There are almost no significant wind anomalies that may cause coastal downwelling anomalies.
Difference between locally and non-locally amplified mode

Significant at SLP: 85%, wind: 95% confidence level

**Locally amplified case**

Because of positive continental SLP anomalies, the anomalous low forms a meridionally elongated cell-like pattern. → Coastal wind anomalies can contribute to the growth of NN.

**Non-locally amplified case**

Because of negative continental SLP anomalies, the anomalous low forms a zonally elongated pattern. → Coastal wind anomalies cannot contribute to the growth of NN.

Locally amplified … Because of positive continental SLP anomalies, the anomalous low forms a meridionally elongated cell-like pattern. → Coastal wind anomalies can contribute to the growth of NN.
Non-locally amplified … Because of negative continental SLP anomalies, the anomalous low forms a zonally elongated pattern. → Coastal wind anomalies cannot contribute to the growth of NN.
There is a new regional climate mode named “Ningaloo Niño”.

There are two types of Ningaloo Niño: Locally and non-locally amplified mode. The former develops through an intrinsic unstable air-sea interaction off western Australia. The latter is associated with coastal waves originating in the tropics.

Positive SST anomalies in both modes are associated with an anomalous low off Western Australia. The difference is related to conditions of the continental SLP modulated by the Australian summer monsoon and/or the Southern Annular Mode.
Legacy of Prof. Klaus Wyrtki to Our Ocean-Atmosphere Community

If you measure more often and more frequently in time and space, you are bound to discover something new –basic law of science.

From “Becoming and oceanographer 40 years ago” (Oceanography seminar by Klaus Wyrtki, 29 September, 1988)