Monitoring the Indonesian Throughflow in Makassar Strait

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1. Abstract

Directly after the recovery of the NSF funded INSTANT western Makassar mooring in November 2006, a NOAA funded mooring was deployed at the same site (2°51' S; 118°28' E) on 22 November 2006. The NOAA-MAK was recovered on 31 May 2009 and re-deployed for another 2 years to continue to build the time series. We now have a 5.5-year continuous time series of the Makassar Throughflow, which represents ~80% of the total Indonesian Throughflow (ITF). The NOAA-MAK time series from late November 2006 to the end of May 2009 spans a predominately La Niña period, reaching a peak in strength in early 2008; a weak El Niño was present in the latter half of 2006. The Indian Ocean Dipole index (DMI) switched into a positive mode during 2006, remaining so throughout the NOAA-ITF time series. Three consecutive years with a positive IOD phase has not been detected in the historical SST records. The +DMI is likely related to the change in the along channel speed profile observed in 2006 and continued in the full record of the NOAA-MAK mooring: the thermocline flow was intensified and shallower, with a maximum speed near 75 m, rather than at 140 m as recorded during the INSTANT period. The role of this change in the ITF profile to the coupled ocean-atmosphere climate system is now being considered.

2. Project Summary

The Indonesian Throughflow (ITF) transfers sea water, heat and freshwater from the western Pacific into the tropical Indian Ocean, at a rate of ~11 to 15 million m^3/sec [Figure 1]. The strong monsoonal winds and tides amidst the complex sea floor morphology of the archipelago stretching from SE Asia to Australia, alter the temperature and salinity profiles of the ITF, which in combination with the velocity profile, link via an ocean route the Pacific and Indian Ocean climate systems. As the ITF region is at the nexus of ENSO (El Niño/La Niña) and the Asian monsoon phenomena, it is highly likely, as indicated by model studies, that the ITF serves as a key component of the larger scale climate system. Recording the ITF, and its connection to

fluctuations in ENSO and the Asian monsoon, is an effective and cost effect way to monitor a component of the larger scale ocean and climate system, with the intent to enable a climate predictive capability.

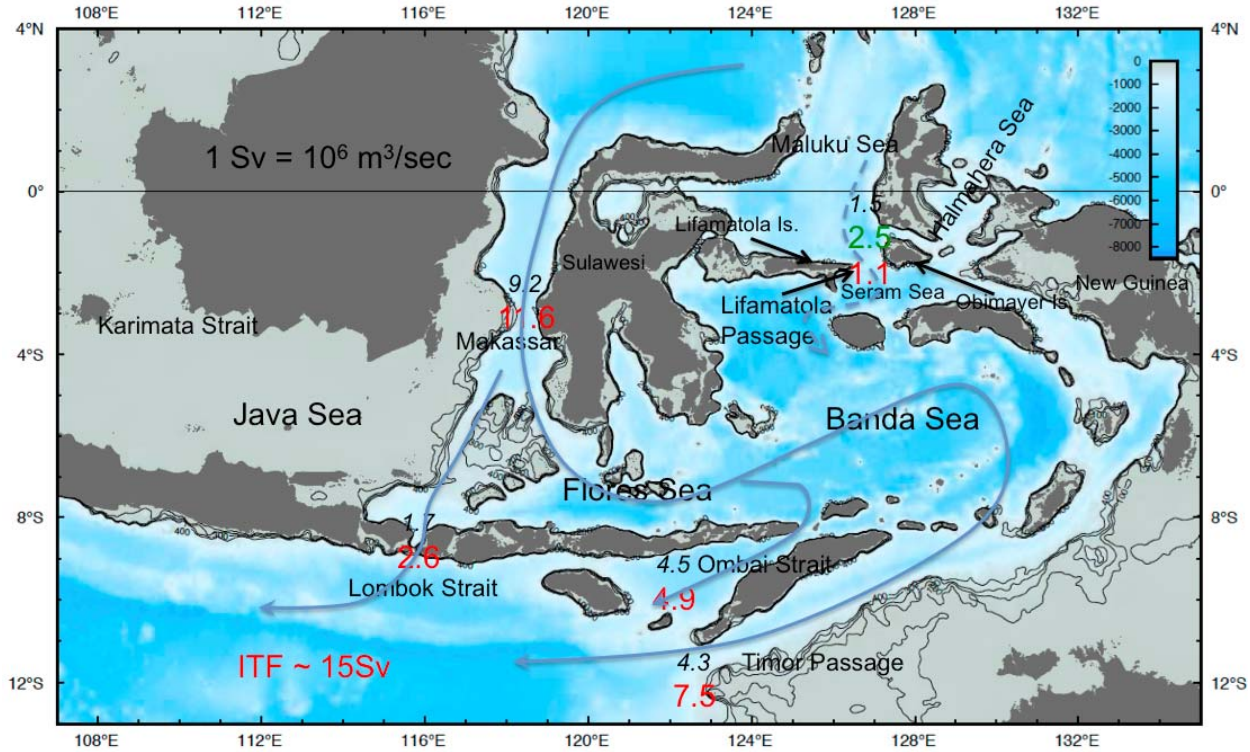


Figure 1 Transport values in 10^6 m^3/sec within the passages measured by the INSTANT program, 2004-2006. The italics numbers in black represent transport values based on pre-INSTANT data: Makassar Strait, 1997; Lombok Strait, 1985; Timor Passage (south of Timor) from March 1992 to April 1993; Ombai Strait (north of Timor) for 1996. The pre-INSTANT value of 1.5 Sv for the Lifamatola Passage represents overflow of dense water at depths greater than 1500 m based on 3.5 months of current meter measurement in early 1985. The red numbers are the 3-year mean transports measured by INSTANT. In Lifamatola Passage, the green number is the INSTANT overflow transport >1250 m, and the red number is the total transport measured by INSTANT below 200 m.

As the ITF weaves through many passages of the Indonesian seas, from the Pacific inflow channels to the export channels to the Indian Ocean, a sustained observational array of mooring for measuring all of the pathways is not yet financially practical. However, a significant step towards this goal can be met by monitoring the throughflow with Makassar Strait, which carries ~80% (and >90% of the thermocline layer component) of the ITF. This is presently underway with the NOAA/OCO funded current measuring mooring near 3°S in the Labani Channel constriction of Makassar Strait.

While assessing the role of the ITF to the larger scale climate system for the improvement of ENSO and Asian monsoon climate predictions has clear societal benefits, there are also local benefits. Here I give an example of two:

1. There is very active pursuit of the oil resources within Makassar Strait. Many companies are involved, including EXXON-Mobil, who plan to enter into an operational program in Labani Channel, just south of the NOAA-MAK mooring site. I have informed oil company personnel of the NOAA-ITF program, following prior interaction associated with the NSF funded INSTANT moorings in Labani channel. In June 2009 I sent NOAA-MAK hourly data at selected ocean depths to Marathon Oil, who are working with EXXON-Mobil.

2. I was asked by Gani Ilahude, a colleague of mine in Indonesia: "A tugboat while entering the Bali Strait from Java Sea toward Indian Ocean- sank in 23 Dec. 2007, due to strong (about 6 knots) opposing current. His company wanted me to be the company's witness in their claim during the claim litigation in Singapore. Any general information about the non tidal and tidal current in Bali Strait - not Lombok Strait - during SE and NW monsoons?" I provided NOAA-MAK data along with some satellite based wind data in the Bali Sea region to Ilahude, noting that in Dec and January 07/08 there were week long periods of strong surface layer northward flow in the Makassar Strait that would likely be related to surface currents in the Bali Sea, generated by strong west to east wind events in the Java Sea.

Other 'colleague' interactions:

1. The relationship of the ITF to the Indian Ocean Dipole that was revealed with the NOAA-MAK time series, is being investigated with Prof. Toshio Yamagata, The University of Tokyo. Toshio has been central to the studies of the IDO and its role in the Asian climate system.

2. The relationship of the November 2007 event to equatorial Indian Ocean variability is being investigated with Janet Sprintall, Scripps Institution of Oceanography/.

3. Scientific Accomplishments

Directly after the recovery of the NSF funded INSTANT western Makassar mooring in November 2006, a NOAA funded mooring was deployed at the same site (2°51' S; 118°28' E; 2147 m) on 22 November 2006. The NOAA-MAK was recovered on 31 May 2009, and re-deployed for another 2 years to continue to build the time series. We used R/V Geomarin III, the newest Indonesian R/V ship built by PT. PAL Surabaya, an Indonesian shipyard. Dr. Dwi Susanto, of Lamont-Doherty and co-PI on the NOAA-MAK program, was chief scientist. Bruce Huber, also from Lamont-Doherty, provided technical expertise.

We now have with the INSTANT 2004-2006 record 5.5-year continuous time series of Makassar Throughflow; with the 1997/98 Arlindo data we have a full 7 years of Makassar Throughflow recorded [Figure 2]. This extensive time series allows us to investigate the connection [with lead and lags attributes] of the ITF to larger scale climate events, such as ENSO and the Asian Monsoon. The NOAA ITF mooring was redeployed on 1 June 2009, with a planned recovery in mid-2011.

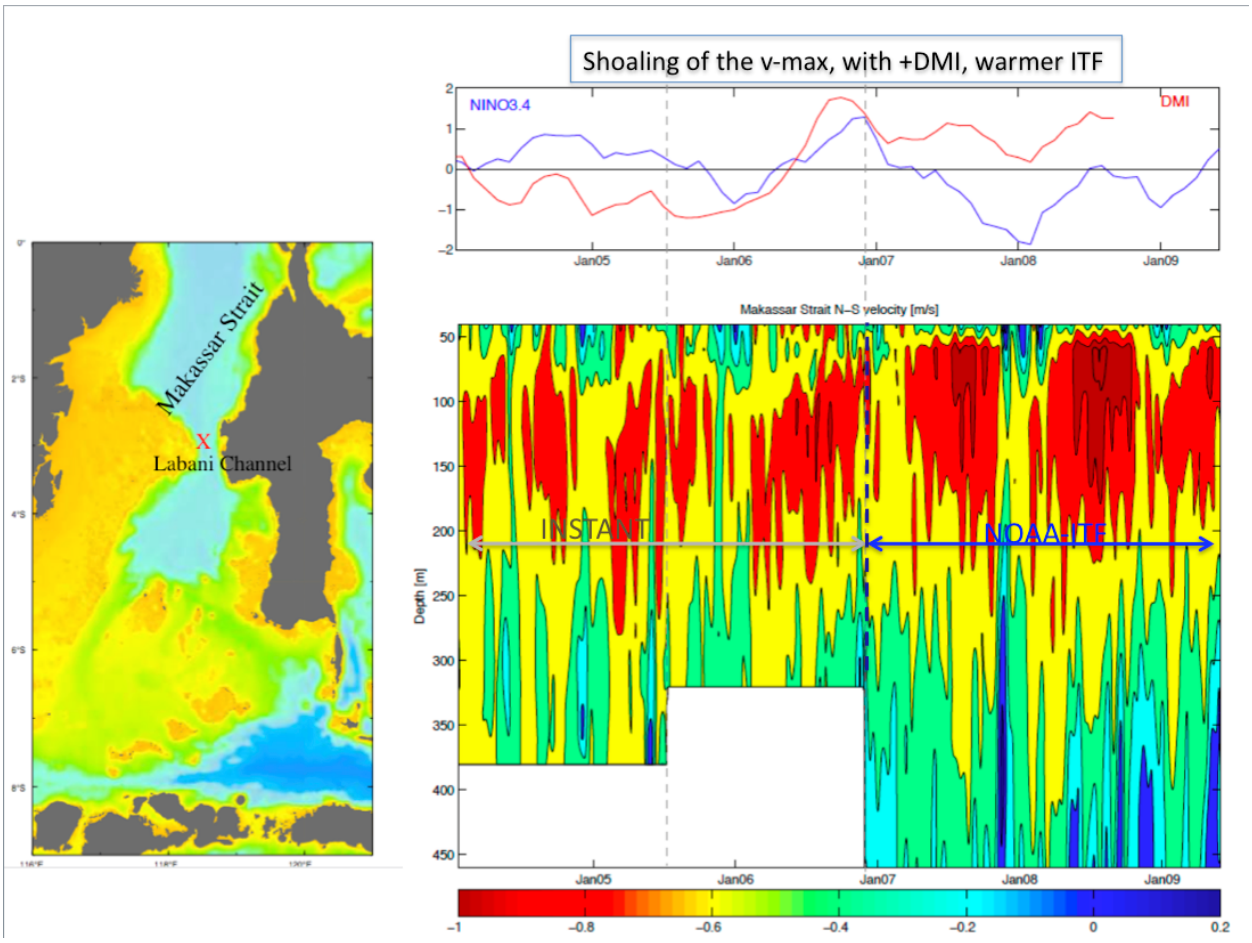


Figure 2 A 5.5 year time series of the along channel flow (30-day low) in Makassar Strait, combining the upward-looking ADCP data from the INSTANT 2004/06 and the NOAA-MAK time series Dec 06 through May 09. The nino3.4 and DMI (Indian Ocean Dipole Mode Index)indices are given in top panel.

During the INSTANT periods ENSO was in a weak El Niño state, with a brief La Niña phase occurring in early 2006. The NOAA mooring period from late November 2006 to the end of May 2009 spans a predominately La Niña period, reaching a peak in strength in early 2008; a weak El Niño was present in the latter half of 2006. The ITF is reduced during El Niño, elevated during La Niña phases, but this signal is rather weak in comparison to intraseasonal and seasonal events. The exception was during the Arlindo period when the ITF was substantially reduced during the strong El Niño event of 1997.

The December 2006 through May 2009 record displays many of the same attributes as earlier time series: 1. general southward surface layer flow interrupted by reversals in the December-March period corresponding to strong monsoonal eastward winds in the Java Sea; 2. the 2004-2009 record reveals a seasonal signal with maximum flow in August, with minimum flow in November. But there were also some unique events recorded: a particularly weak southward flow of November 2007 may be a consequence of a strong Kelvin Wave derived from the Indian

Ocean; the persistent core of maximum southward flow within the thermocline, which began to shoal from 140 m to 75 m during the last 6 months of the INSTANT time series, continued throughout the NOAA-MAK period.

The shoaling of the v-max feature to the upper thermocline is a significant and rather unexpected event. The Indian Ocean Dipole index (DMI) switched into a positive mode during 2006, remaining so throughout the NOAA-ITF time series. Three consecutive years with a positive IOD phase has not been detected in the historical SST records. The +DMI is likely related to the change in the along channel speed profile observed in 2006 and continued in the full record of the NOAA-MAK mooring, noted above. While the Makassar transport may have increased somewhat during 2007-2009, a more important factor may be the shallower depth of the thermocline maximum current, in that it marks a sustained increase in the heat transfer from the Pacific to the Indian Ocean via the ITF. The role of this change in the ITF profile to the coupled ocean-atmosphere climate system is now being considered.

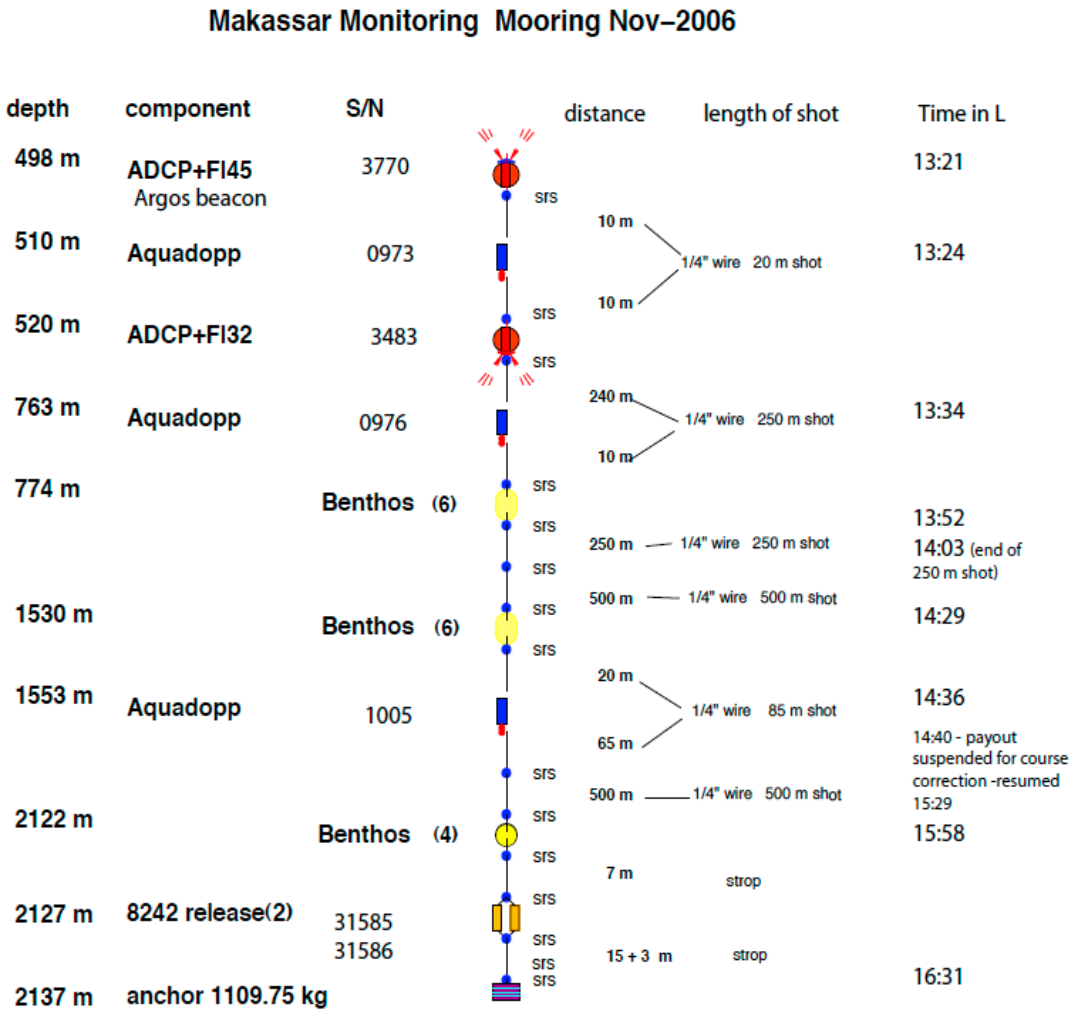
Resolving the link between the regional and larger scale climate variability with the mass/heat transfer of Pacific water into the Indian Ocean, the Indonesian Throughflow, via the pathways of the Indonesian seas, will provide an observational based quantitative appreciation of the ocean role in such climate elements as El Niño and the Asian monsoon.

What, if any, information was jeopardized due to a lack of funding, lack of instrumentation, or inability to carry out the work? The NOAA-MAK mooring is adequate for monitoring the major component of the ITF inflow, noting that the throughflow with Makassar Strait carries ~80% (and >90% of the thermocline layer component) of the ITF. However, monitoring of the export routes of the ITF into the Indian Ocean via the channels of the Sunda Islands would provide a much fuller view of the ITF and its connections to the climate system. A more complete ITF observing system would enable assessment of the modification of ITF waters within the Indonesian seas, which is governed by sea-air exchange, the critical link between the atmosphere and ocean. It is recommended that a mooring in Lombok Strait be added at the same time in 2011 that the Makassar mooring is recovered/re-deployed. Sharing of the ship time will reduce the ship costs / mooring.

Noting that the data return from the NOAA-MAK mooring was returned to Lamont in June 2009, towards the end of this Progress Report period, the data availability is presently being developed. The metadata are catalogued in the OceanSites directory, and the data will be made available via the web as part of the FY2010 activities (URL to be determined while the data portal is being constructed. In the interim, data is available upon request to bhuber@ldeo.columbia.edu).

The recovery of the NOAA-MAK mooring on 31 May 2009 had an excellent data return. We have a 2.5 year record of the flow within the upper kilometer. Everything worked but the downward looking WorkHorse ADCP placed directly below the upward looking long range ADCP near 500 m depth. But then there was a current meter at 510 m within its intended range of coverage. Most importantly was that the long rangers worked, as they cover the entire thermocline that provides continuous records for 30 months. All three aquadopp current meters are out of memory on February 6, 2009. We have a fantastic observational data set. We look

forward to processing and producing the data in collaboration with other scientists to produce better prediction of ocean circulation and climate. Figure 3 shows the configuration of the mooring recovered on 31 May 2009, and that deployed on 1 June 2009, with planned recovery in May/June 2011.



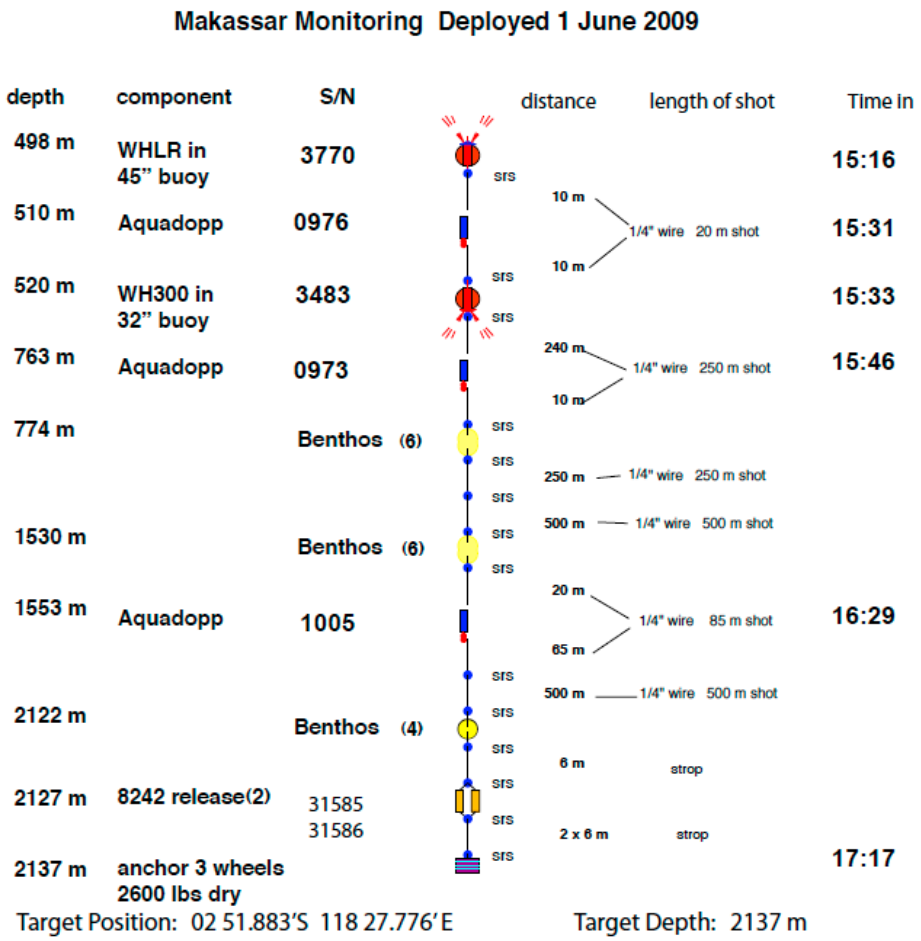


Figure 3- The NOAA-MAK mooring configuration of the 2006-2009 mooring recovered on 31 May 2009 [top panel]; the NOAA-MAK mooring configuration of the 2009-2011 mooring deployed on 1 June 2009.

4. Education and Outreach

I have assigned study of the Indian Ocean Dipole relationship to the NOAA-MAK time series to a graduate student taking my Introduction to Physical Oceanography class at Columbia University. It is possible that that class assignment will encourage further research as part of the student's PhD dissertation.

5. Publications and Reports

5.1. Publications by Principal Investigators

Gordon, A.L., Sprintall, J., Wijffels, S., Susanto, D., Molcard, R., Van Aken, H.M, Ffield, A.L., deRuijter, W, Lutjeharms, J. Speich, S and Beal, L. (2010) "Interocean Exchange of Thermocline Water: Indonesian Throughflow; "Tassie" Leakage; Agulhas Leakage" in

Proceedings of the "OceanObs'09: Sustained Ocean Observations and Information for Society" Conference (Vol. 1), Venice, Italy, 21-25 September 2009, Hall, J., Harrison D.E. and Stammer, D., Eds., ESA Publication WPP-306, 2010.

Gordon, A.L., Dwi Susanto, Bruce A. Huber, Budi Sulistyo and Agus Supangat (2010) "Seven Years of measuring the Makassar Strait throughflow, the primary component of the Indonesian Throughflow" in Proceedings of the "OceanObs'09: Sustained Ocean Observations and Information for Society" Conference (Vol. 1), Venice, Italy, 21-25 September 2009, Hall, J., Harrison D.E. and Stammer, D., Eds., ESA Publication WPP-306, 2010.