INDONESIAN THROUGHFLOW AND ITS PROXY FROM SATELLITE ALTIMETERS AND GRAVIMETERS

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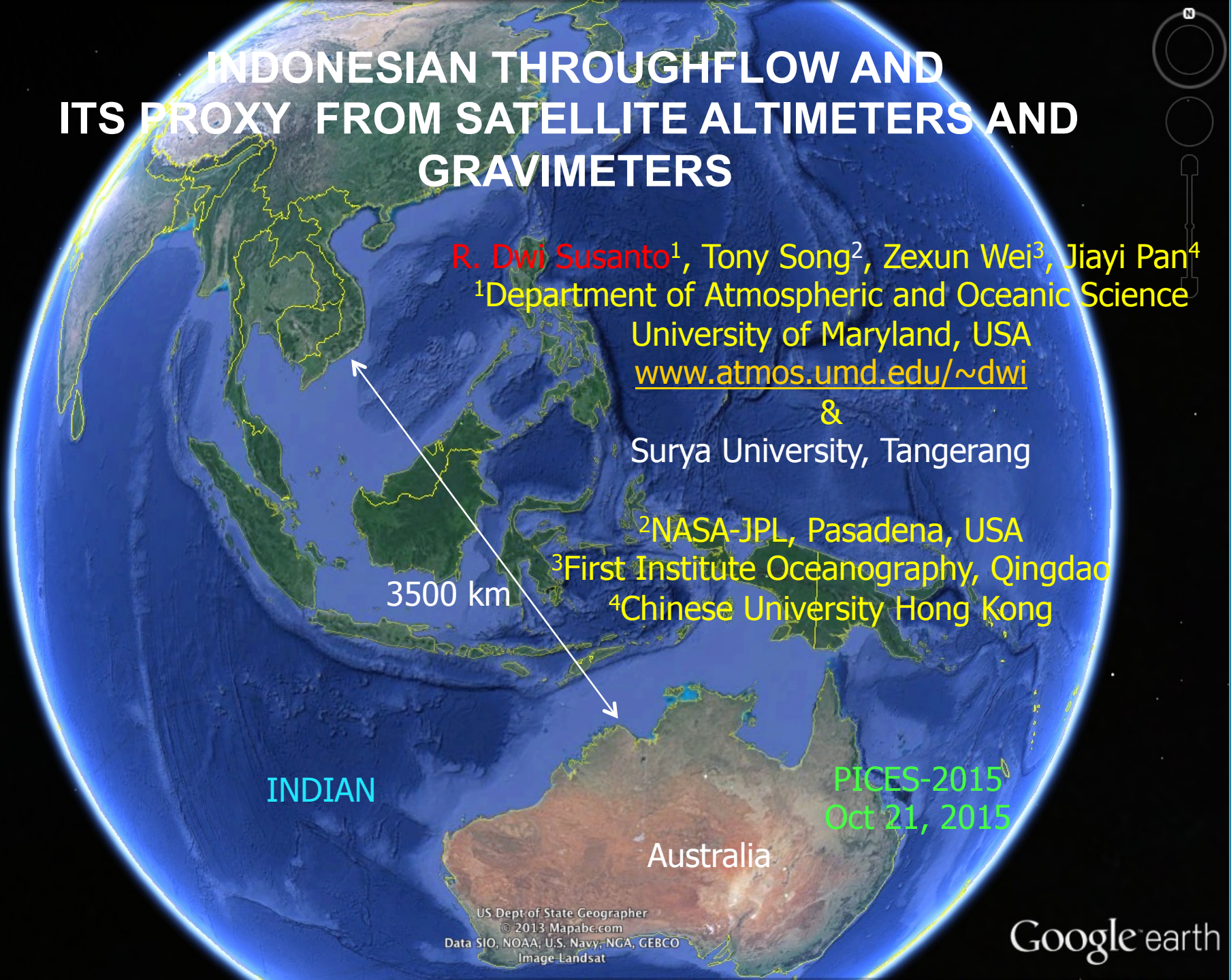
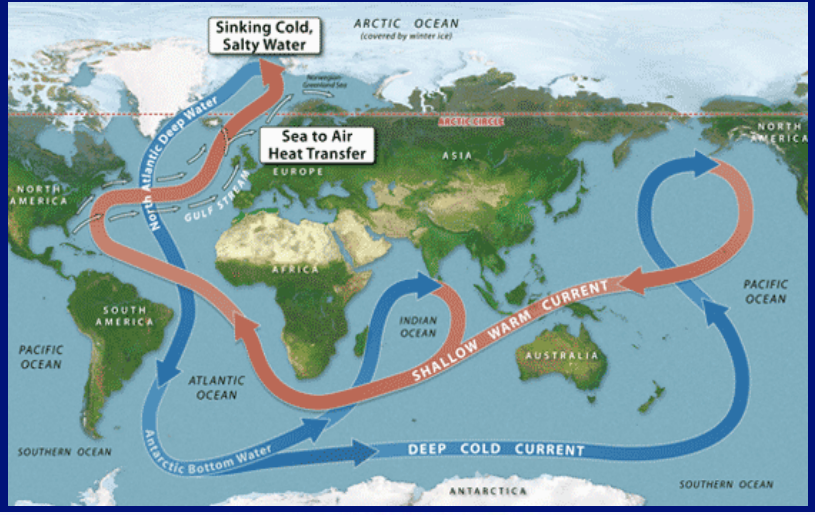
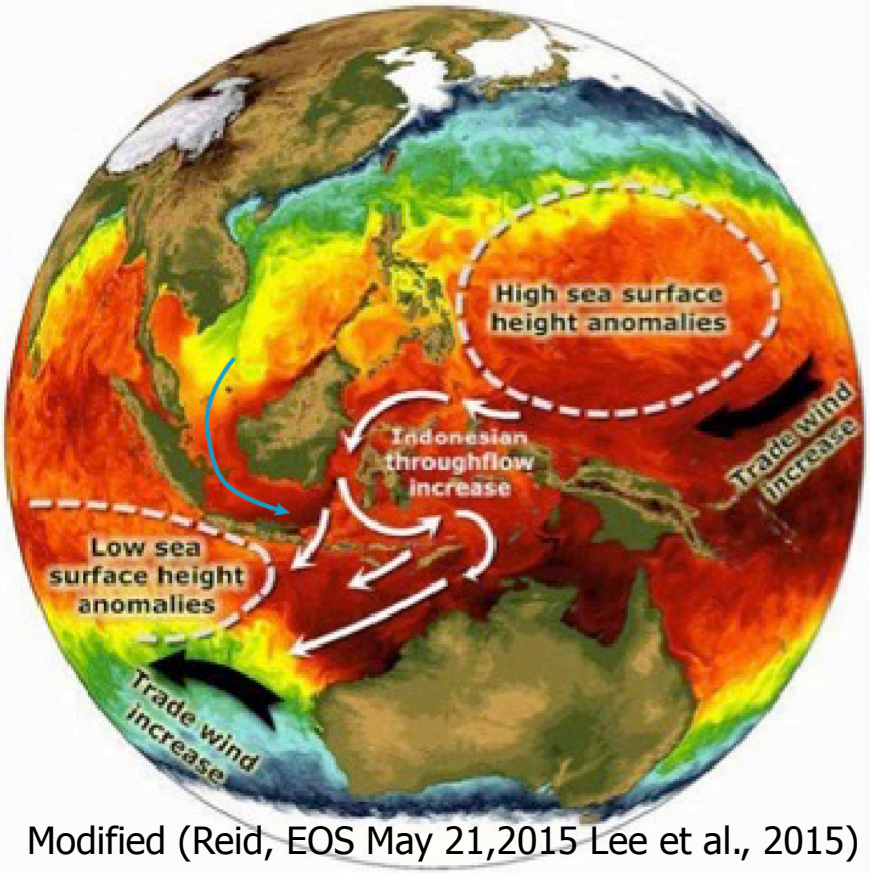






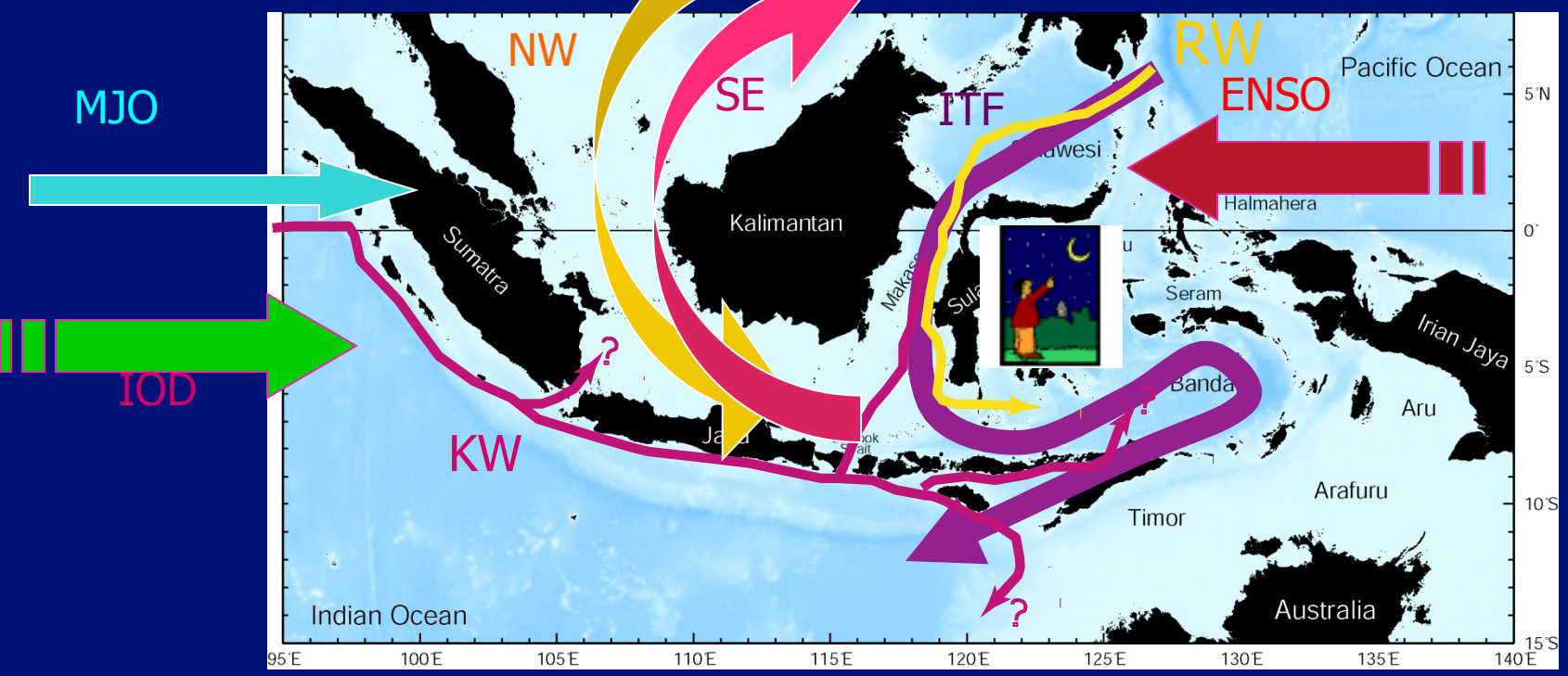
Modified (Reid, EOS May 21,2015 Lee et al., 2015)

- ✓ITF strongly influences the heat and freshwater budgets of Indian and Pacific Oceans, and may couple with ENSO and monsoon phenomena, altering global ocean circulation and climate.
- ✓ Change in ITF magnitude is expected to alter the SST, and therefore altering the ocean-atmosphere fluxes.
- ✓~15 Sv of ITF water flushes the Indian Ocean thermocline waters, boosting transport of the Agulhas Current [by ~15%], increasing southward ocean heat flux across 20-30°S over the no-ITF condition, thus altering the meridional overturning of the Indian Ocean
- ✓ To get the ITF amplitude and variability right are challenge for numerical models.

Goals

- ✓ Determine throughflow pathways
- ✓ Determine magnitude and its variability of volume transport mass-heat and fresh water fluxes from intraseasonal to interannual time scales
- ✓ Investigate the storage and modification of ITF water properties from Pacific into Indian Ocean (mixing, land-ocean-atmosphere interaction, upwelling)
- ✓ Determine impacts of local, regional, and remote forcing (MJO, monsoon, ENSO, IOD, PDO)
- ✓ Investigate the ITF impacts to Indian Ocean SST/stratification and climate?
- ✓ Derive long-term ITF transport proxy.

Major oceanic & atmospheric forcings:



- ✓ ENSO+IOD+Monsoon → affects Ocean and atmospheric conditions

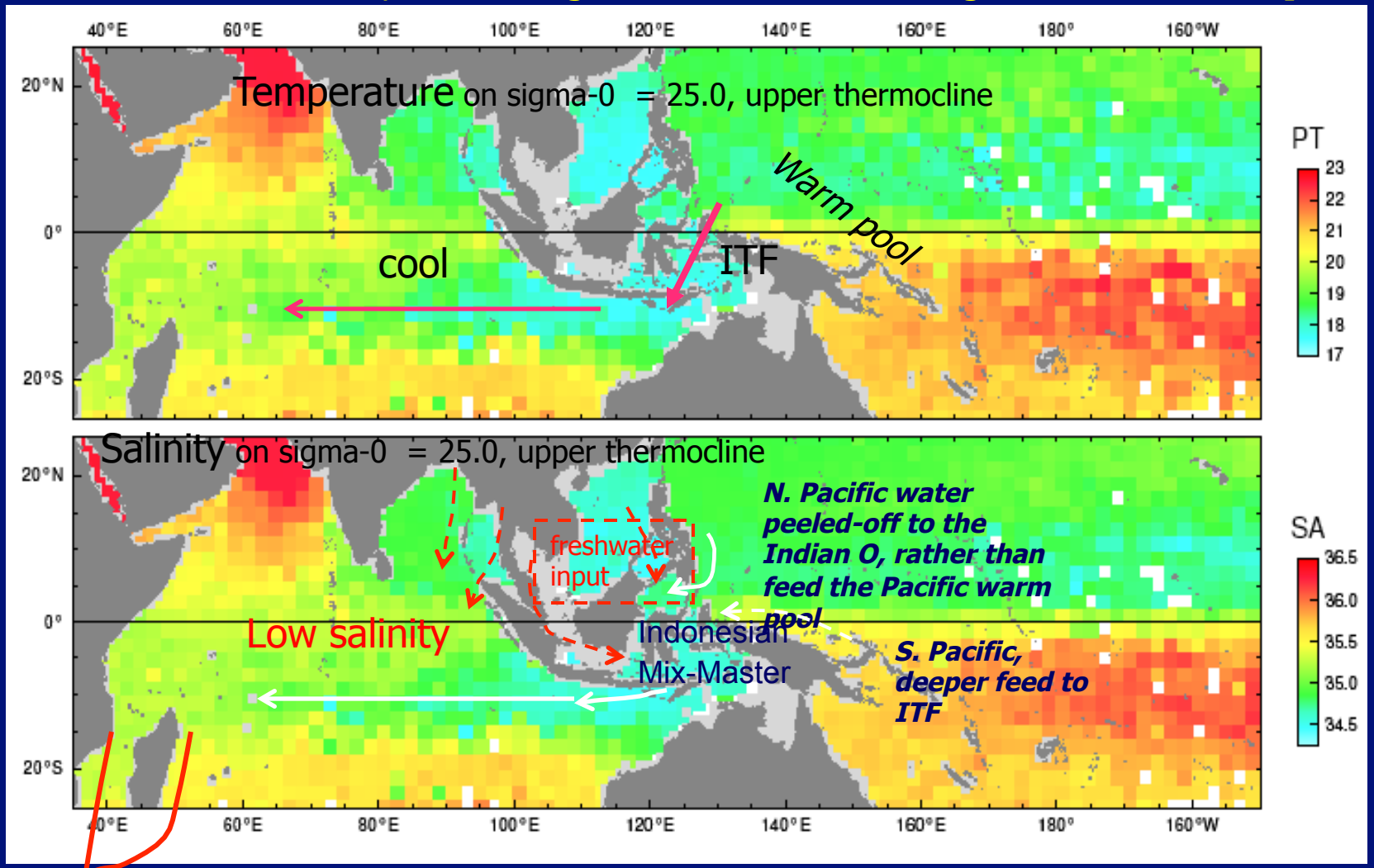
  Ocean: ITF, thermal structure, mixing, circulation, upwelling, fisheries

  (Susanto et al.,1999; 2000; 2001, Susanto and Gordon, 2005)

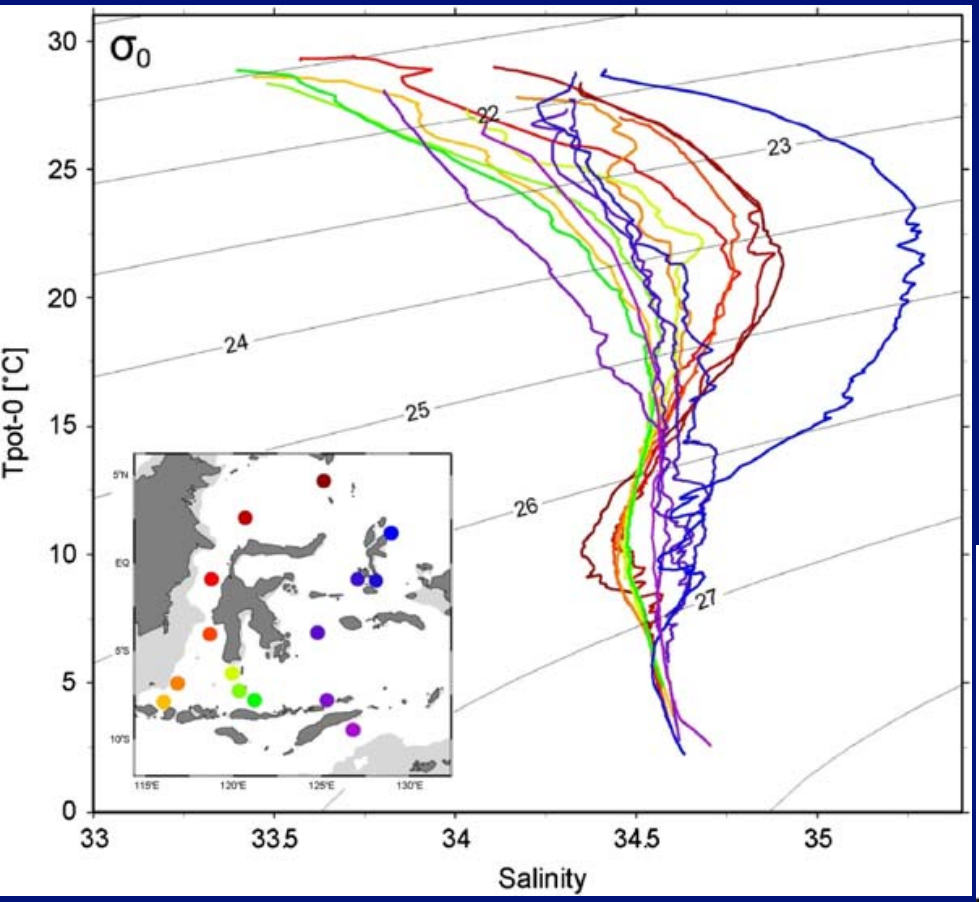
  Atmosphere: rainfall pattern (Aldrian and Susanto, 2003)
- ✓ Strong tide and rough topography → vigorous tidal mixing → internal waves

  (Susanto et al., 2005)

- **ITF cools and freshens the Indian Ocean thermocline [on isopycnals] relative to the ambient thermocline.**
- **~15 Sv of ITF water flushes the Indian Ocean thermocline waters to the south by boosting transport of the Agulhas Current [by ~15%], increasing southward ocean heat flux across 20-30°S over the no-ITF condition, thus altering the meridional overturning of the Indian Ocean [Pacific too]**

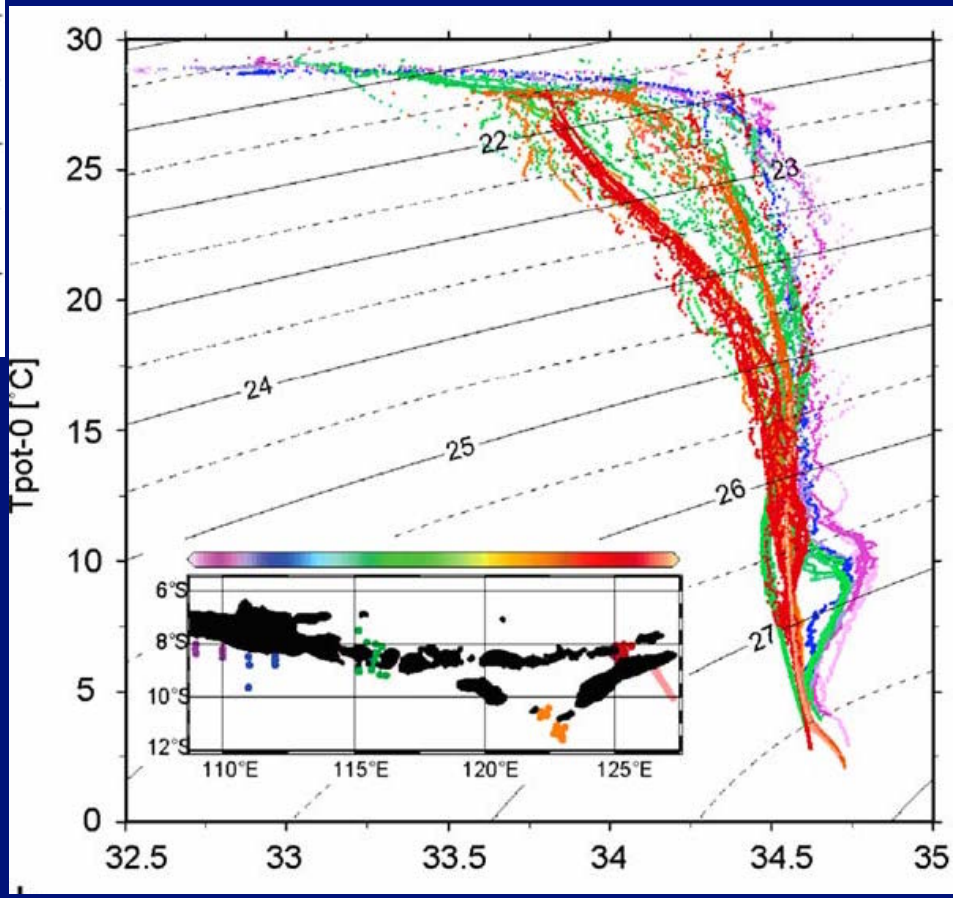


Indonesian Throughflow must exit the Indian Ocean within the Agulhas Current, the ITF follows a torturous route to the Agulhas Current [Song et al., 2004]



Strong Mixing within the Indonesian Seas, transform Pacific water into Indonesian water before exiting into the Indian Ocean

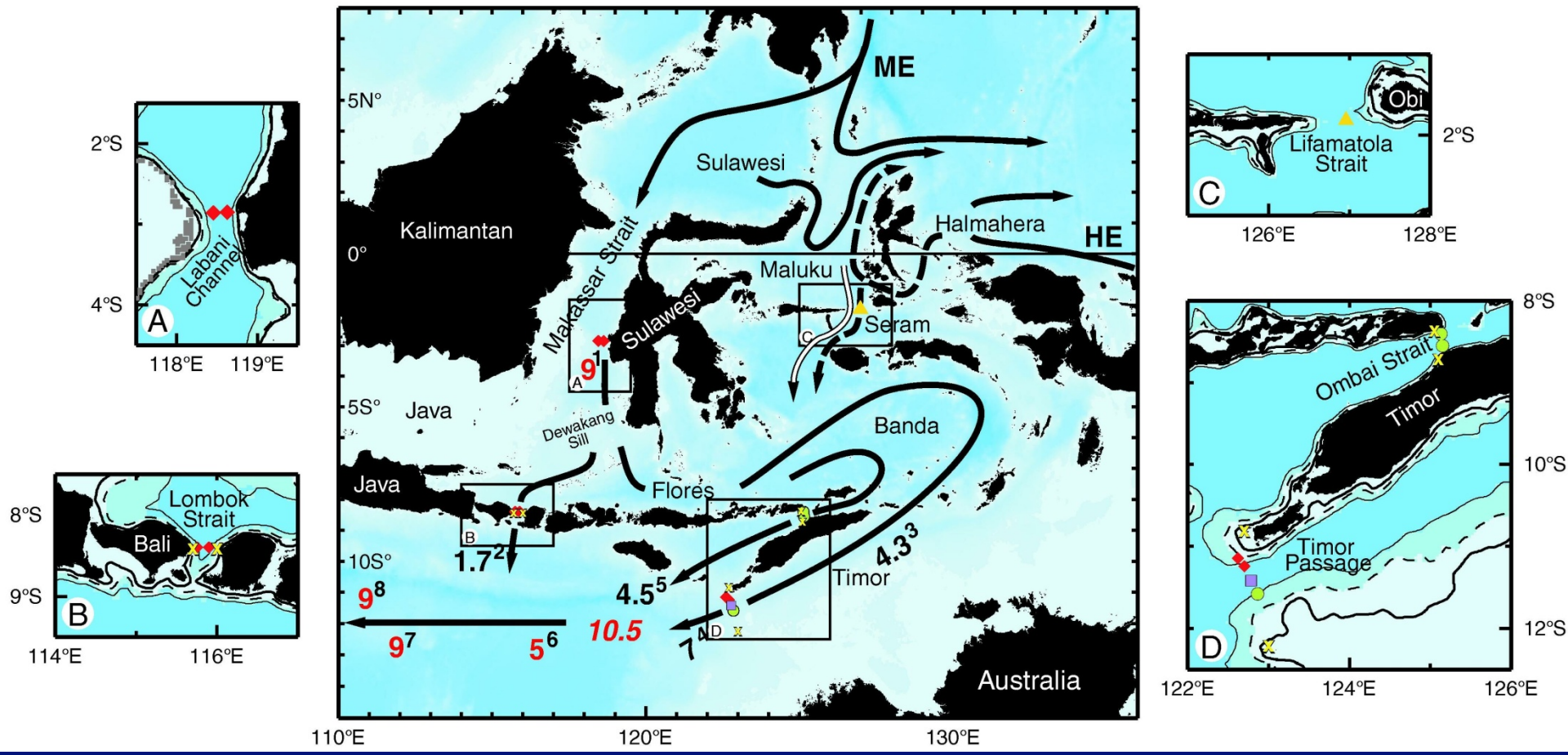
Along ITF pathways



Exit passages

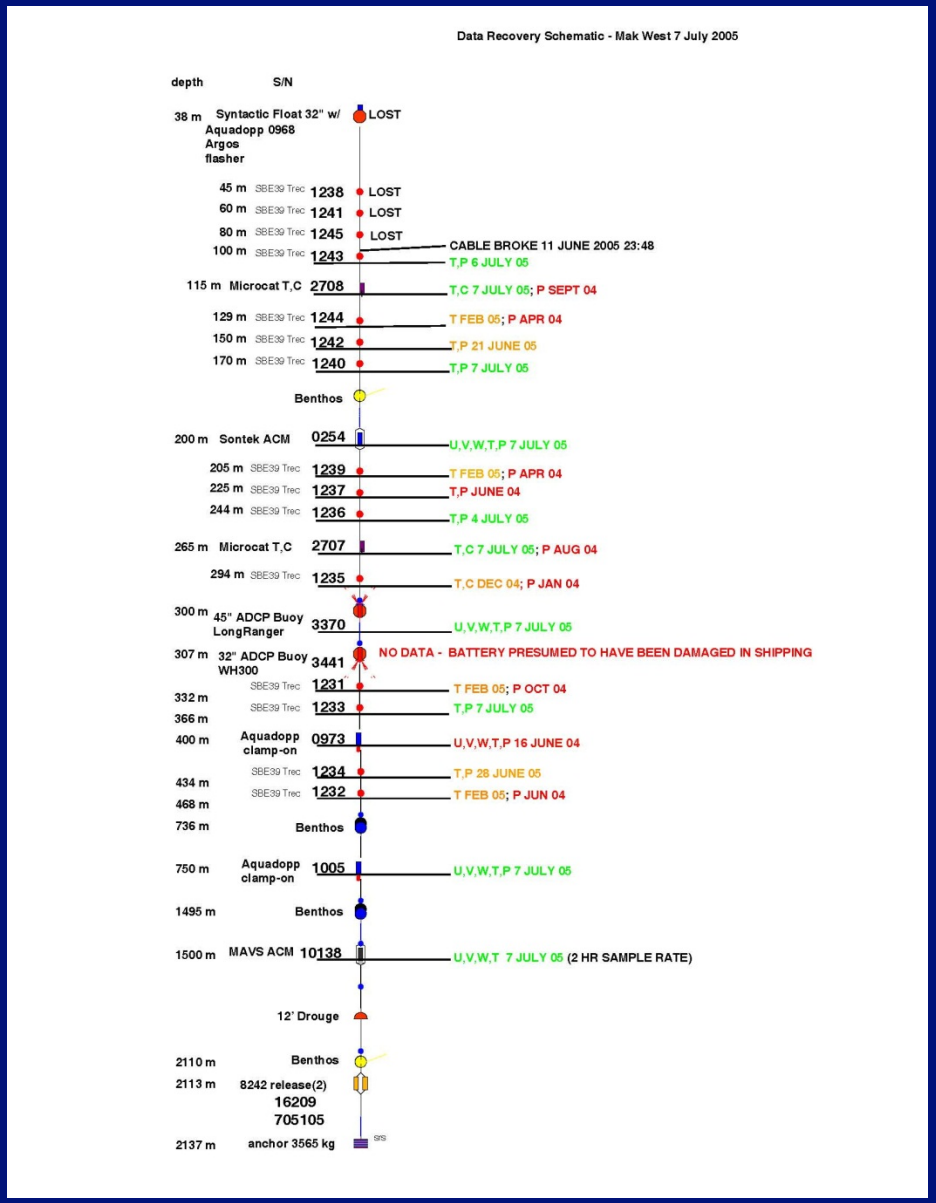
Atmadipoera et al., 2009

INSTANT: International Nusantara Stratification & Transport Program
Indonesia-USA-Australia-France-Netherlands (2003-2007)



A. Gordon & R.D. Susanto (LDEO), A. Ffield (ESR)
J. Sprintall (Scripps)
S. Wijffels (CSIRO)
H. Van Aken (Royal Netherlands Institute for Sea Research)
R. Molcard (LODYC)

Mooring

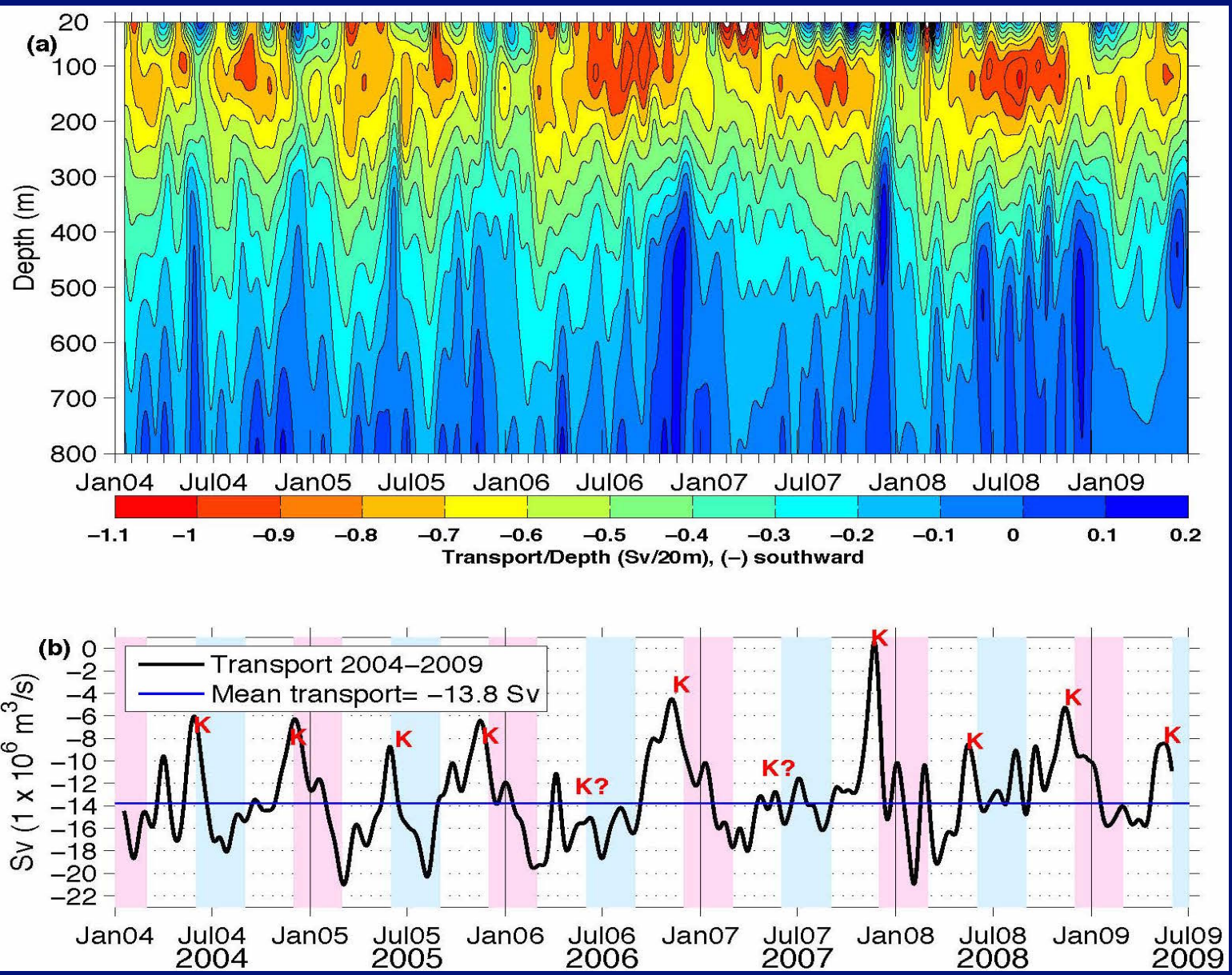

Data Recovery Schematic - Mak West 7 July 2005
depth
S/N
38 m Syntactic Float 32" w/ Aquadopp 0968 Argos flasher
LOST
45 m SBE39 Trec 1238 LOST
60 m SBE39 Trec 1241 LOST
80 m SBE39 Trec 1245 LOST
100 m SBE39 Trec 1243 CABLE BROKE 11 JUNE 2005 23:48
T,P 6 JULY 05
115 m Microcat T,C 2708 T,C 7 JULY 05; P SEPT 04
129 m SBE39 Trec 1244 T FEB 05; P APR 04
150 m SBE39 Trec 1242 T,P 21 JUNE 05
170 m SBE39 Trec 1240 T,P 7 JULY 05
Benthos
200 m Sontek ACM 0254 U,V,W,T,P 7 JULY 05
205 m SBE39 Trec 1239 T FEB 05; P APR 04
225 m SBE39 Trec 1237 T,P JUNE 04
244 m SBE39 Trec 1236 T,P 4 JULY 05
265 m Microcat T,C 2707 T,C 7 JULY 05; P AUG 04
294 m SBE39 Trec 1235 T,C DEC 04; P JAN 04
300 m 45" ADCP Buoy LongRanger 3370 U,V,W,T,P 7 JULY 05
307 m 32" ADCP Buoy WH300 3441 NO DATA - BATTERY PRESUMED TO HAVE BEEN DAMAGED IN SHIPPING
SBE39 Trec 1231 T FEB 05; P OCT 04
332 m
SBE39 Trec 1233 T,P 7 JULY 05
366 m
400 m Aquadopp clamp-on 0973 U,V,W,T,P 16 JUNE 04
SBE39 Trec 1234 T,P 28 JUNE 05
434 m
SBE39 Trec 1232 T FEB 05; P JUN 04
468 m
736 m Benthos
750 m Aquadopp clamp-on 1005 U,V,W,T,P 7 JULY 05
1495 m Benthos
1500 m MAVS ACM 10138 U,V,W,T 7 JULY 05 (2 HR SAMPLE RATE)
12' Drouge
2110 m Benthos
2113 m 8242 release(2)
16209
705105
2137 m anchor 3565 kg


26 11 2006


26 11 2006

ITF Transport in the Makassar Strait

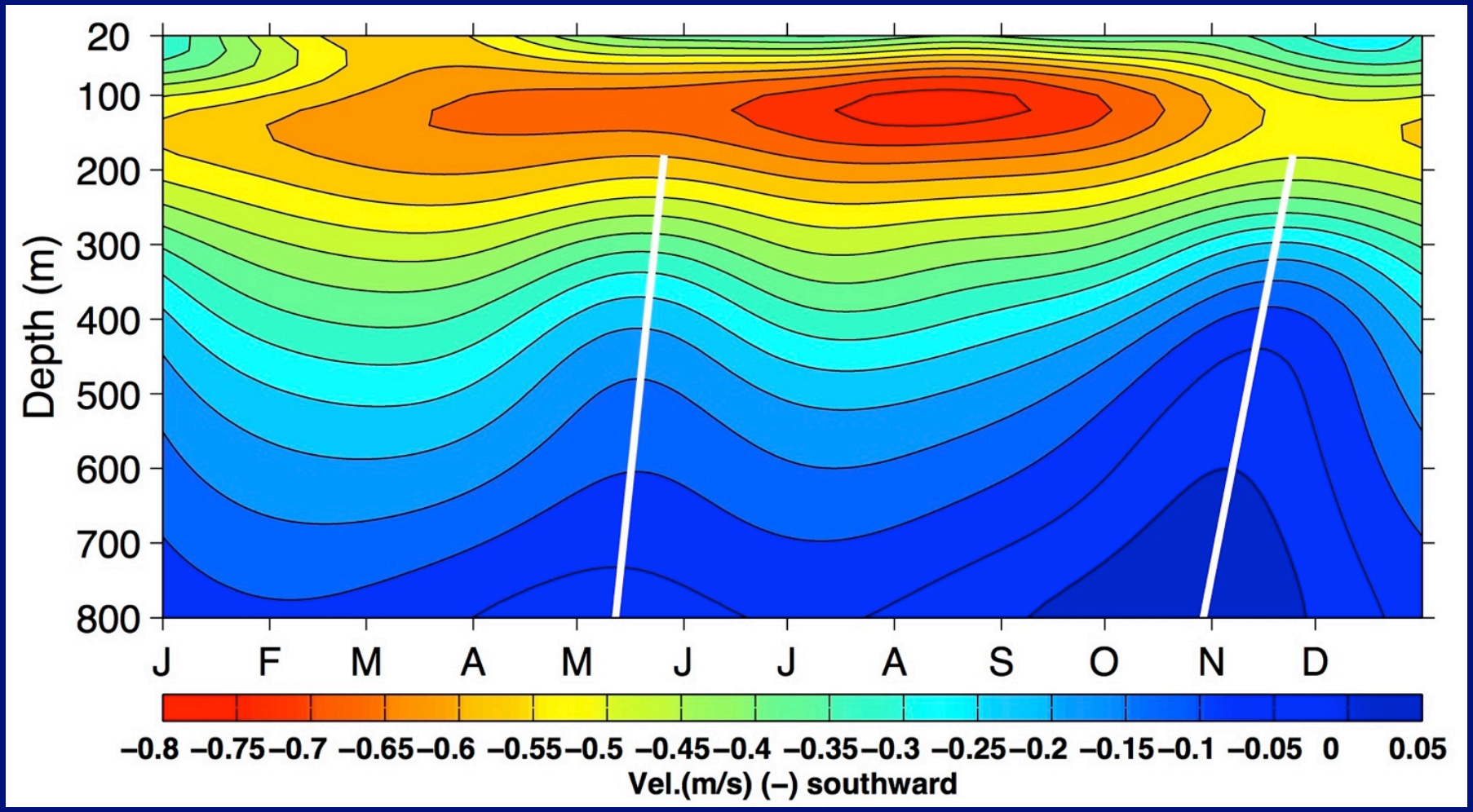
- Average volume transport: 13.3 Sv
- Thermocline intensified
- Instraseasonal-seasonal-interannual



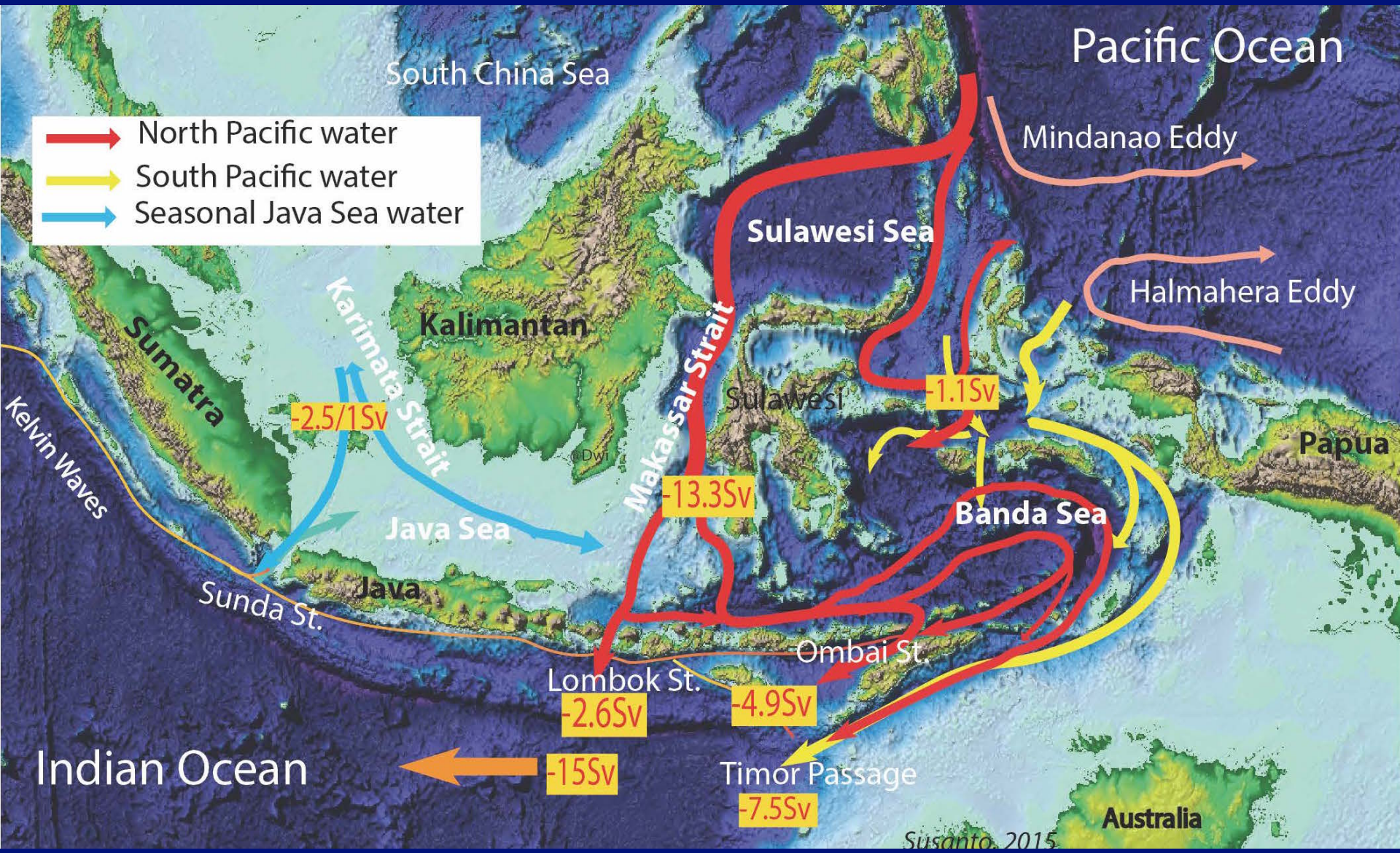
Max: 120-150m

Susanto et al, 2012

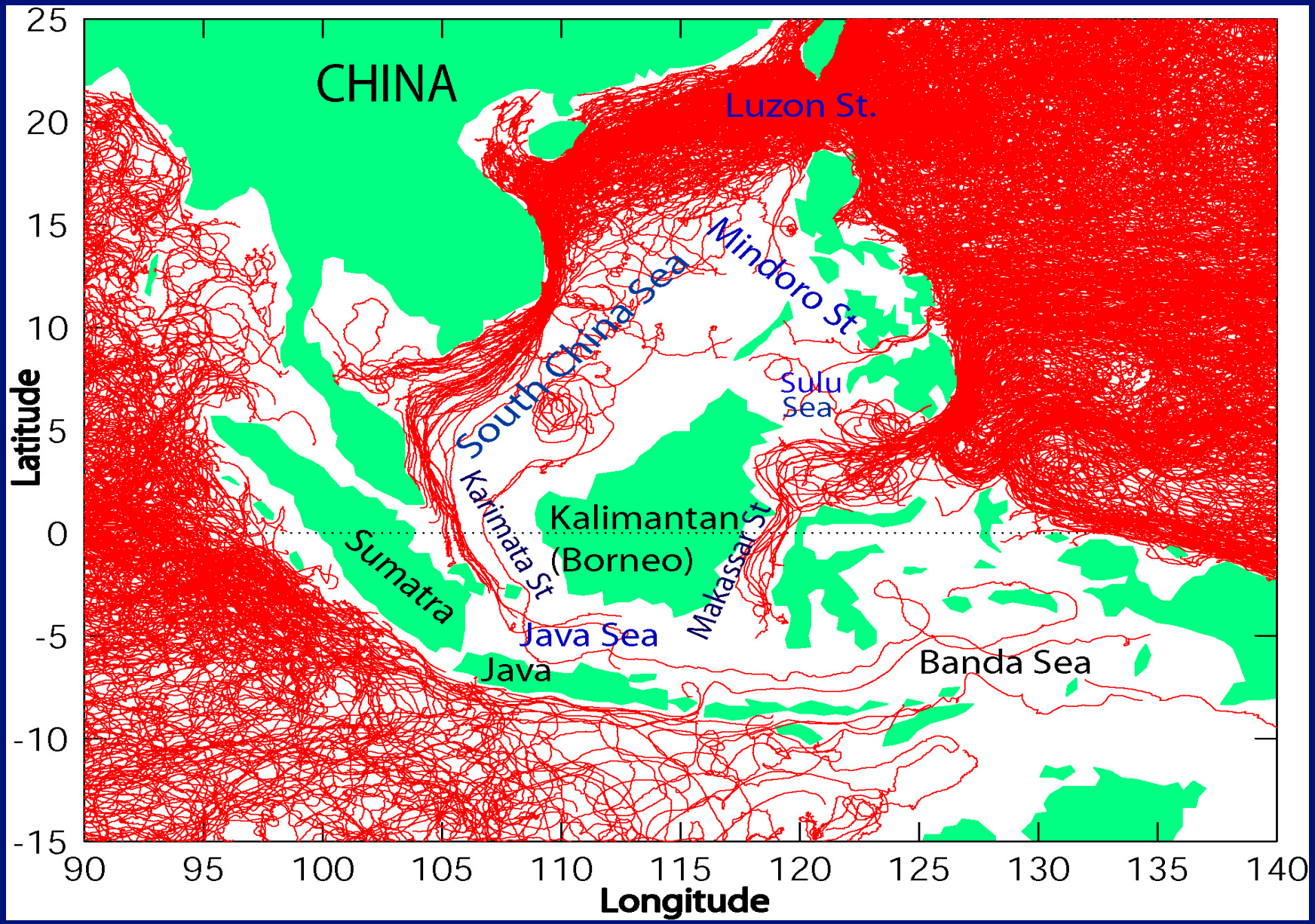
Seasonal variability and intrusion of Kelvin waves from Indian Ocean



ITF PATHWAYS



JADE (93-95), ARLINDO (96-98), INSTANT (03-06), MITF(07-11), & SITE (07-)projects



Trajectories satellite-track drift buoys from the Global Drifter Program (8/1988-6/2007) courtesy of Drifter Data Assembly Center at NOAA/AOML.

Susanto et al., 2010

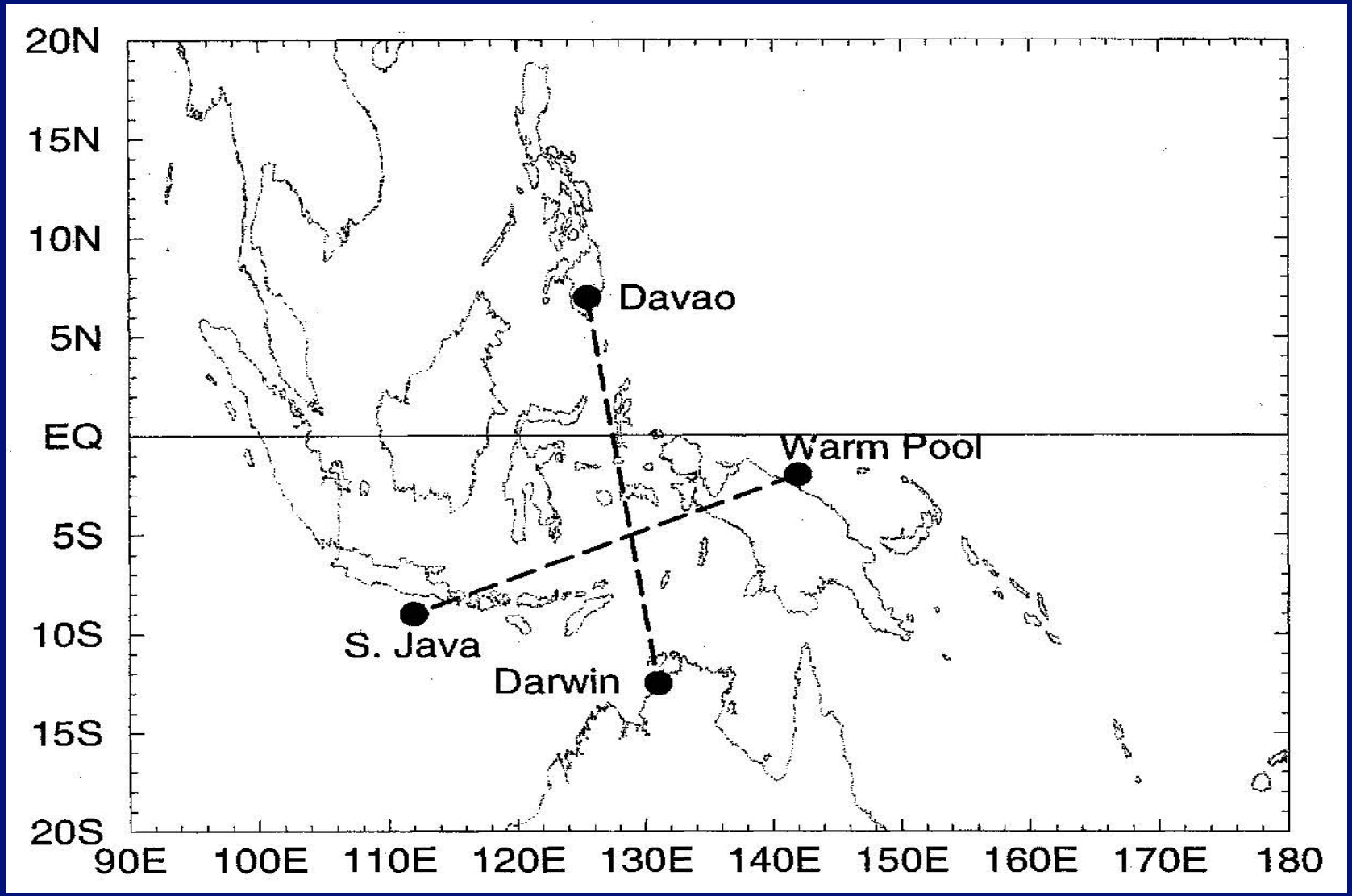
ITF plays important roles in global ocean circulation and climate. Thus, it is desirable to not only quantify the ITF and its variability, but also monitor it for a longer period of time.

Yet, a sustainable in situ observation is expensive and challenging

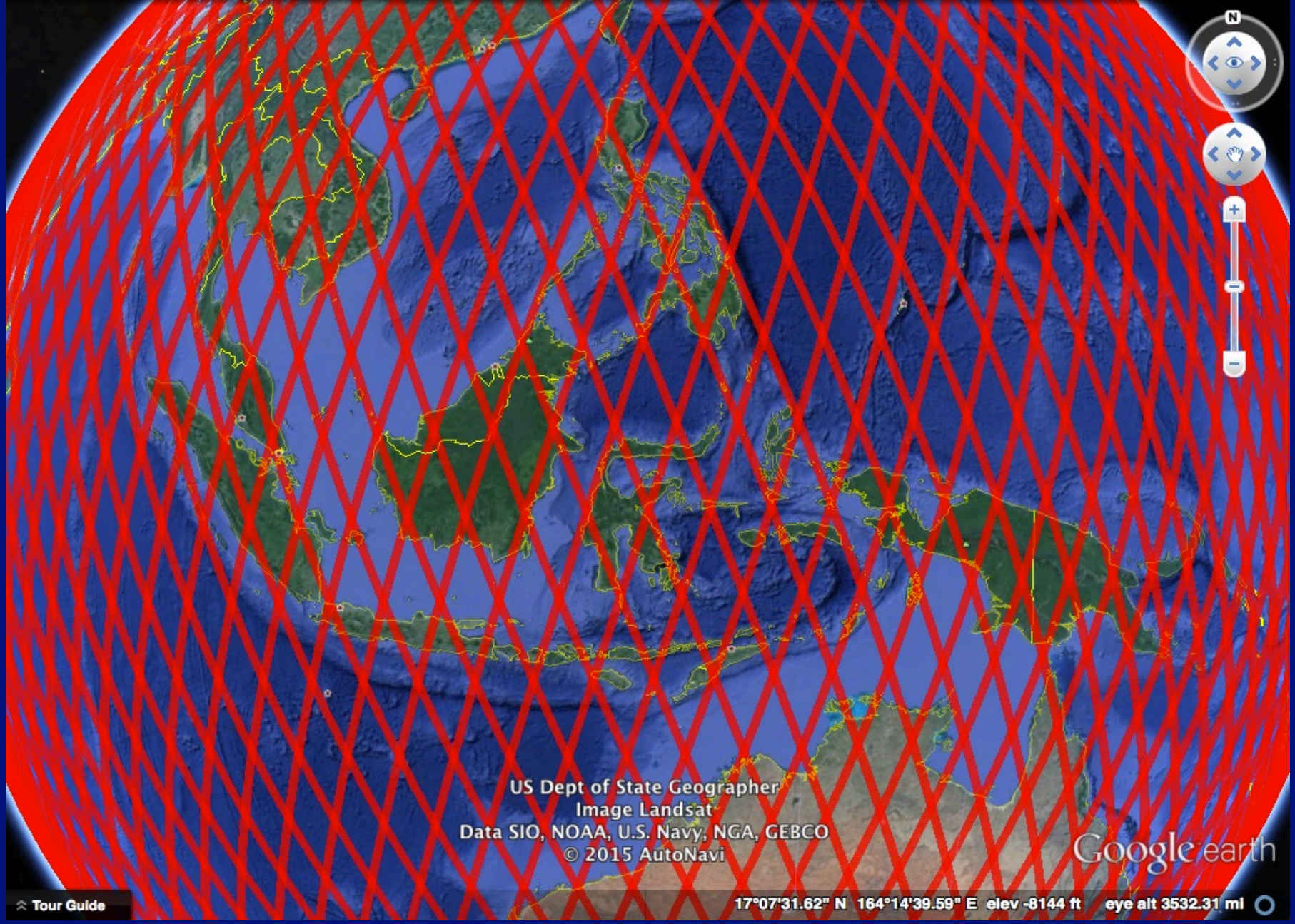
Example: comprehensive ITF INSTANT program last only for three years

Therefore, an alternative approach to gauge ITF transport or to develop a proxy is desirable.

Pressure gradient between Pacific and Indian Ocean

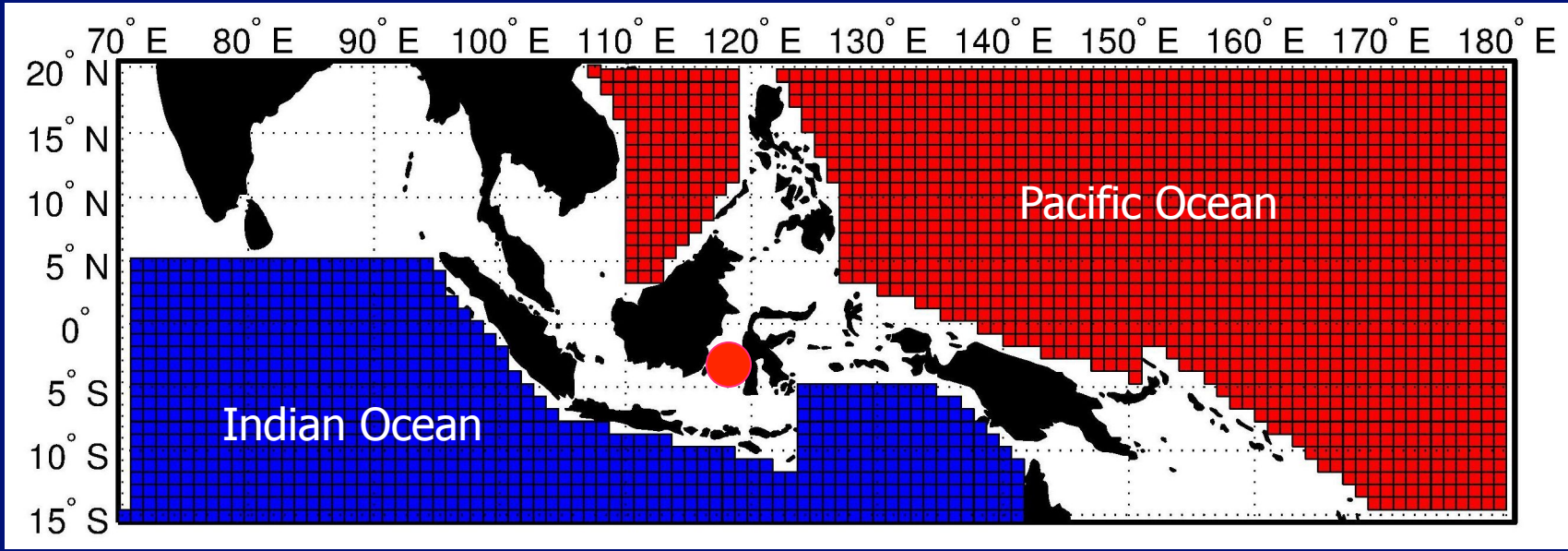


Wyrtki, 1987; Potemra et al., 1997; 2005 (using 4 & 5 regions in the Pac. & IO)



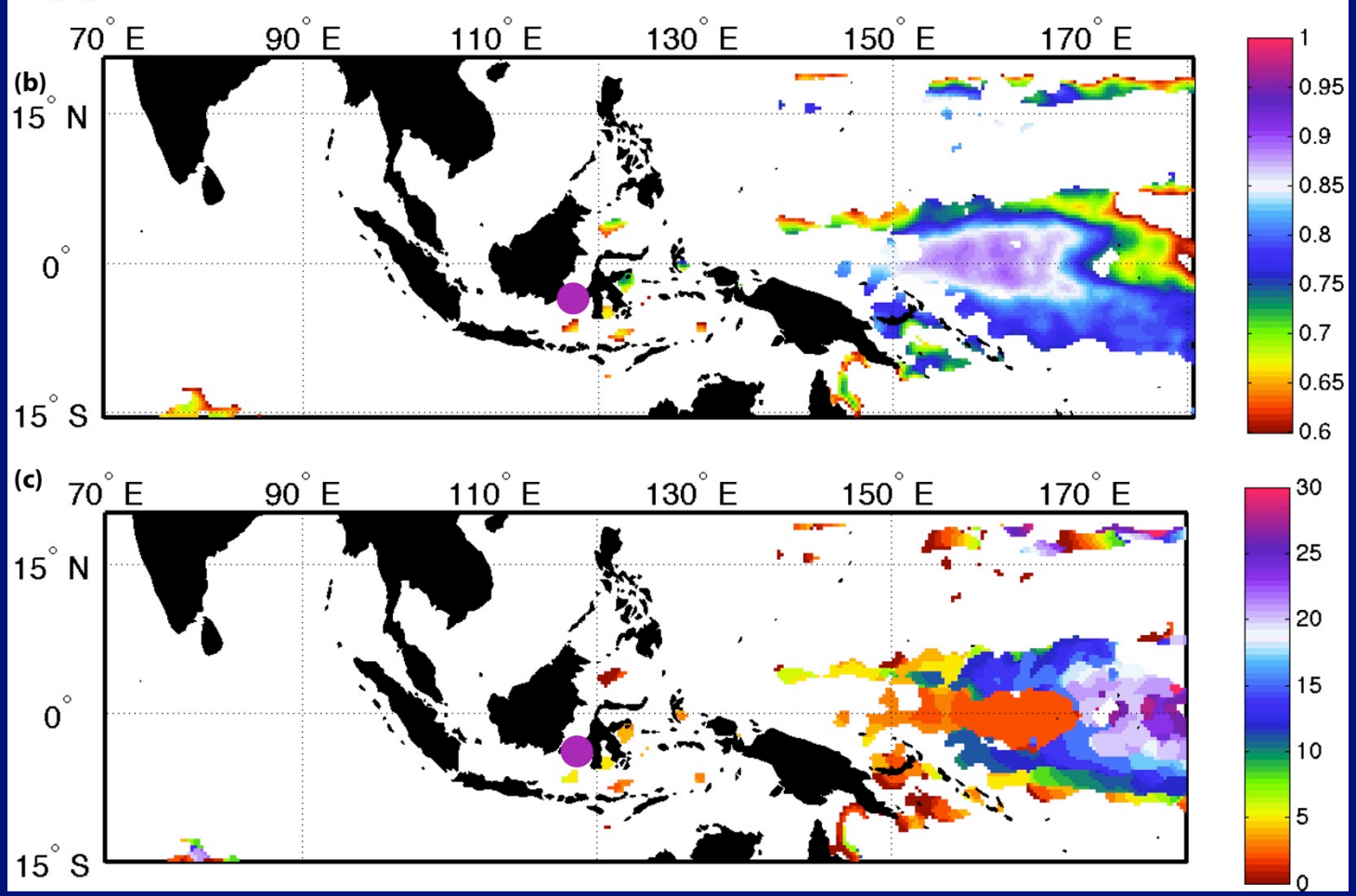
Using T/P-Jason ½ altimeters and gravimeters

Define grids (1°x 1°): Pacific Ocean (1134 grids) and Indian Ocean (968 grids)



- In situ observation in the Makassar Strait 2004-2011: (2004-2009 as testing period and 2009-2011 as validation period)
- 20-years of sea surface height from satellite altimeters (1992-2012)
- 10-years of ocean bottom pressure from Gravity Recovery and Climate Exp. (GRACE)
- Theoretical transport formula for two layer model (Qu & Song, 2009)

$$Q = \left\{ \frac{r_1 g}{\lambda + r_1 f} H_1 \Delta\eta + \kappa \frac{r_2 g}{\lambda + r_2 f} H_2 (\Delta p_b - \Delta\eta) \right.$$

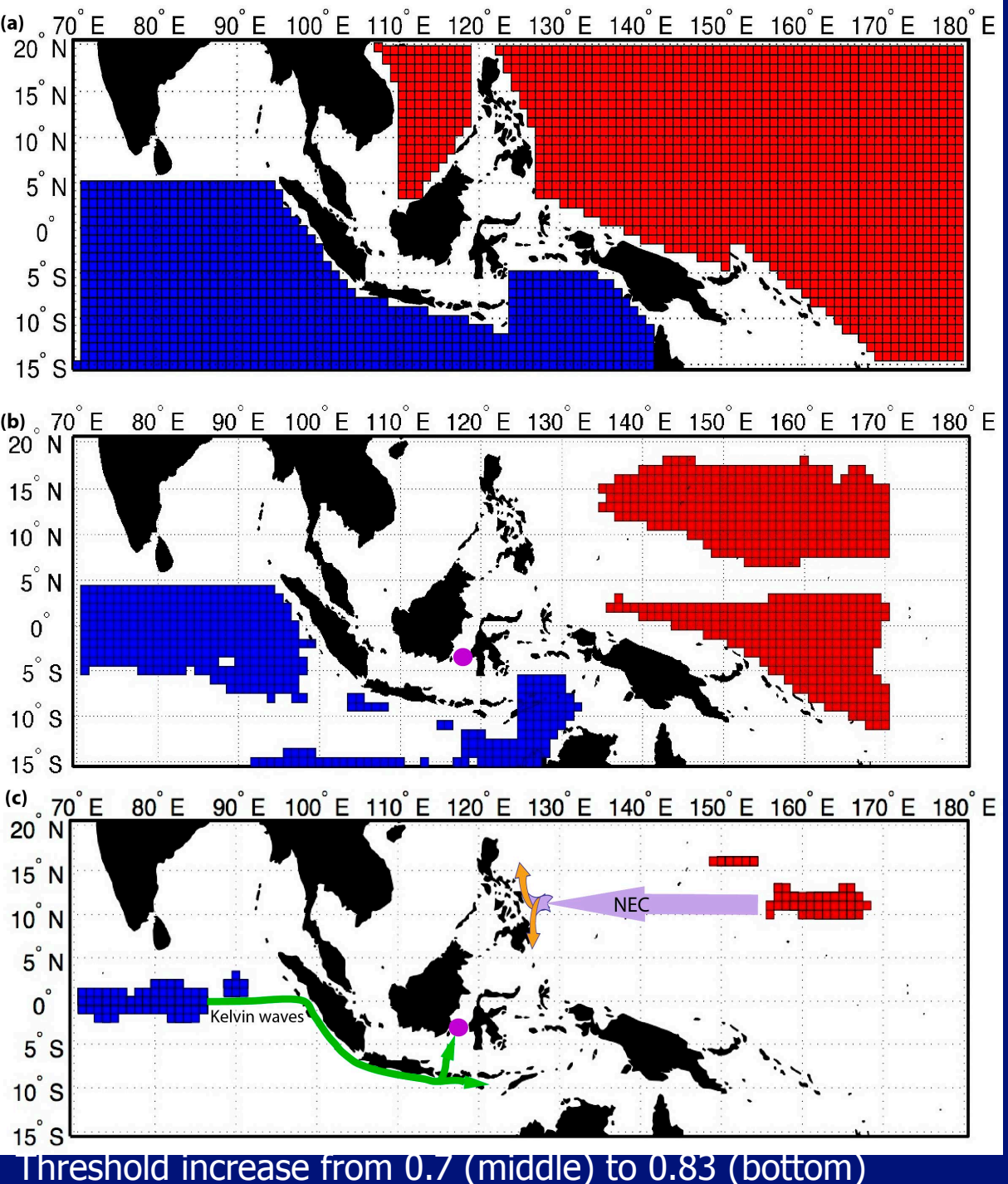


Correlation between ITF volume transport in the Makassar Strait in the Pacific and Indian Ocean, with time lag is positive (sea level ahead of the transport)

Correlation ($r^2 \geq 0.6$) & the Time-lag map in weeks

Sea level variations in the Pacific ocean have high relation with Makassar Strait transport
Weak correlation or negative time lag within the Indonesian seas and Indian

These one-side correlations indicate that sea level variability on one side does not necessarily control the throughflow variability because the throughflow variability and strength have to be affected by both oceans. Therefore, the maximum correlation region determined by this approach is not necessarily optimal for deriving the ITF transport.



Threshold increase from 0.7 (middle) to 0.83 (bottom)

ITF Inflow:

Makassar (Susanto et, 2013, Gordon et al., 2010)

Lifamatola (van Aken, 2009)

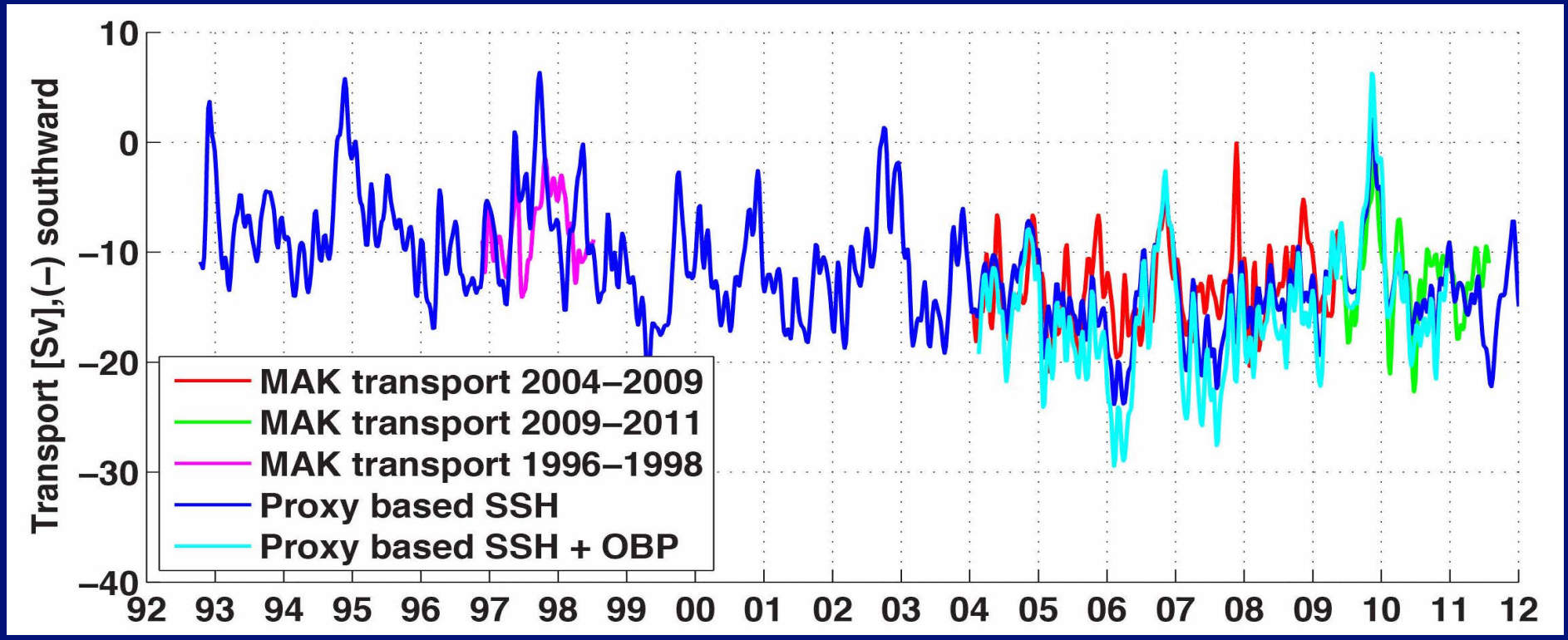
Karimata (Susanto et al, 2010; 2013, Fang et al., 2010)

ITF Outflow

Lombok, Ombai, Timor (Sprintall et al., 2009)

ITF proxy from satellite altimeters and gravimeter (Susanto & Song, JGR, 2015)

- ITF is controlled by both Pacific & Indian Ocean (SSH Pacific only is not sufficient)
- Optimal location for proxy: Pacific: 10N and 160-170E & Equatorial Indian Ocean.
- Associated with NEC and Westward Rossby waves in Pas. Kelvin waves generation in IO



Susanto & Song, 2015

ITF 2004-2009: testing period; 2009-2011 validation period
The proxy time series fits well with the observation from intraseasonal to interannual
The proxy during validation period 2009-2011 follows the observation quite well.

	Observation	Proxy
2004-2011	13.0 Sv	13.9 Sv (SSH) 15.8 Sv: SSH + OBP (2004-2010)
1993-2012		11.6 Sv

Summary and Potential application for climate prediction:

- ✓ ITF plays important role in transferring mass/heat/freshwater fluxes into the Indian Ocean
- ✓ SSH and ocean bottom pressure from satellite altimeters and gravimeters can be used as ITF Proxy couple months (1.5years) ahead of time.
- ✓ The ITF proxy can be calculated every 10days/month as soon as satellite derived altimeter and ocean bottom pressure data available, and should be assimilated into the NCEP climate model
- ✓ The ITF proxy can be used to estimate the heat and fresh water as well as biogeochemical fluxes to the Indian Ocean.

- ✓ South China Sea throughflow proxy

- ✓ Indonesia and China just deployed mooring in the North Makassar and Lombok (TIMIT Project), can be used to validate the proxy

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谢谢

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