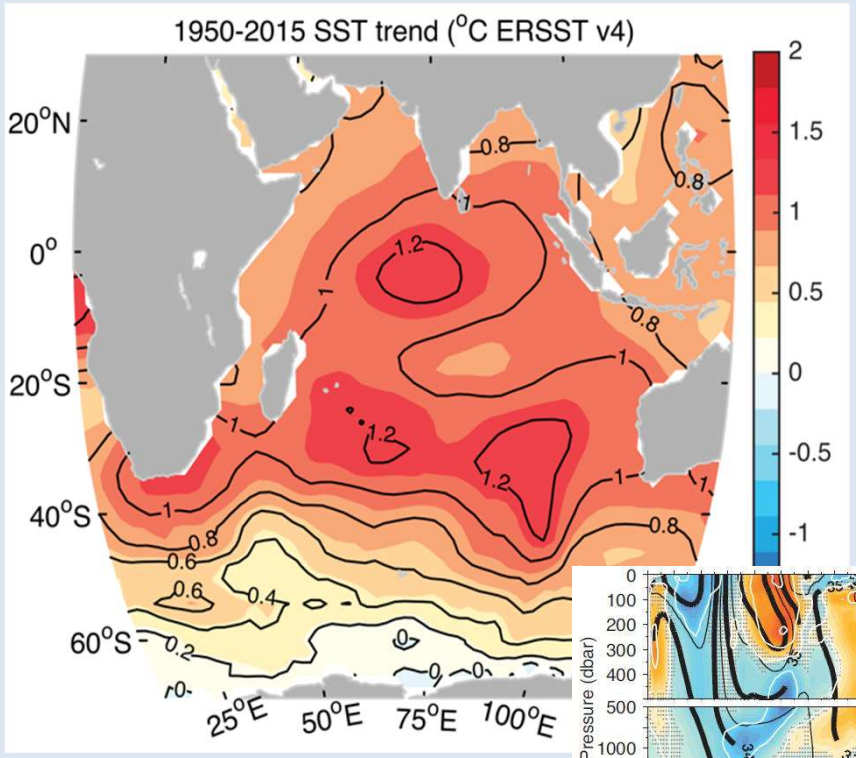
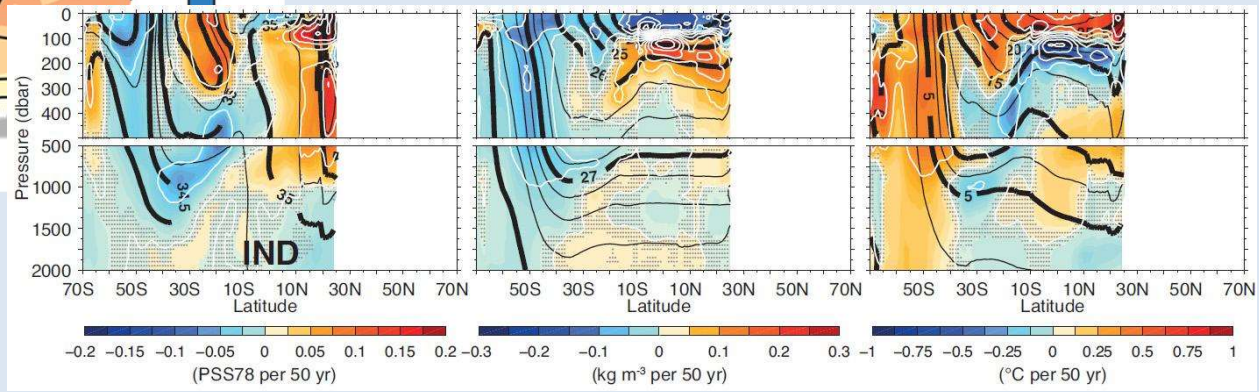
Anthropogenic climate change in the Indian Ocean





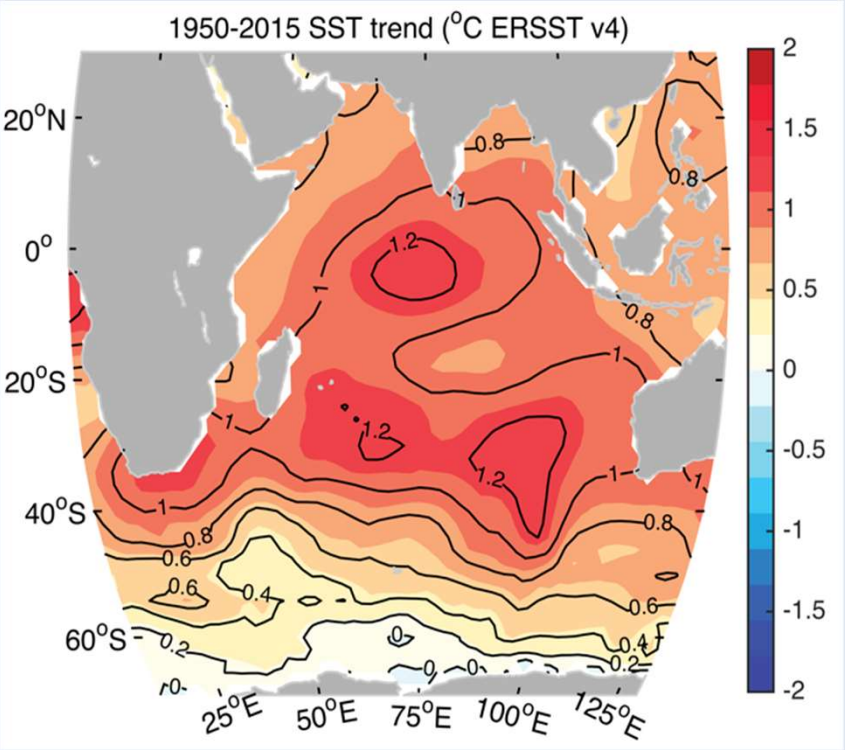
Zhou [2], P.J. Durack [3], W. Han [4] and J.

IndOOS Review, Jakarta, 22-23 March 2018

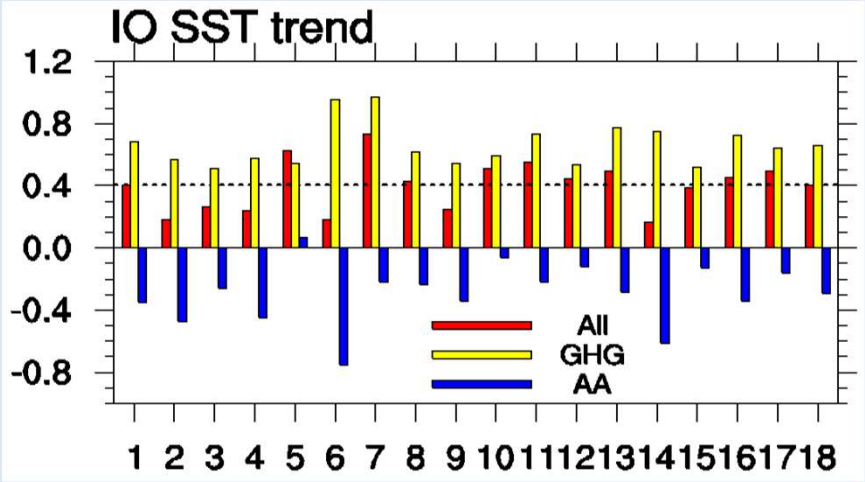
[1]IITM, India, [2]IAP, China, [3]LLNL, USA, [4]Univ. Colorado, USA, [5]IRD, France

Changes – Basin-wide SST warming

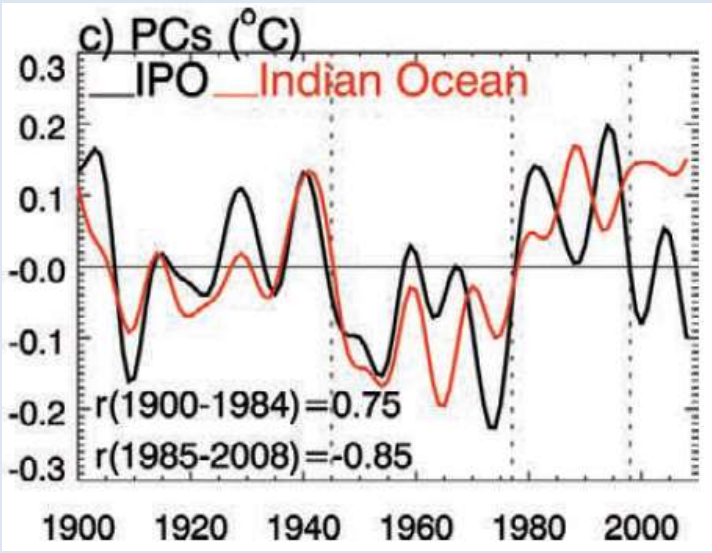
Basin-wide warming



Anthropogenic signature?

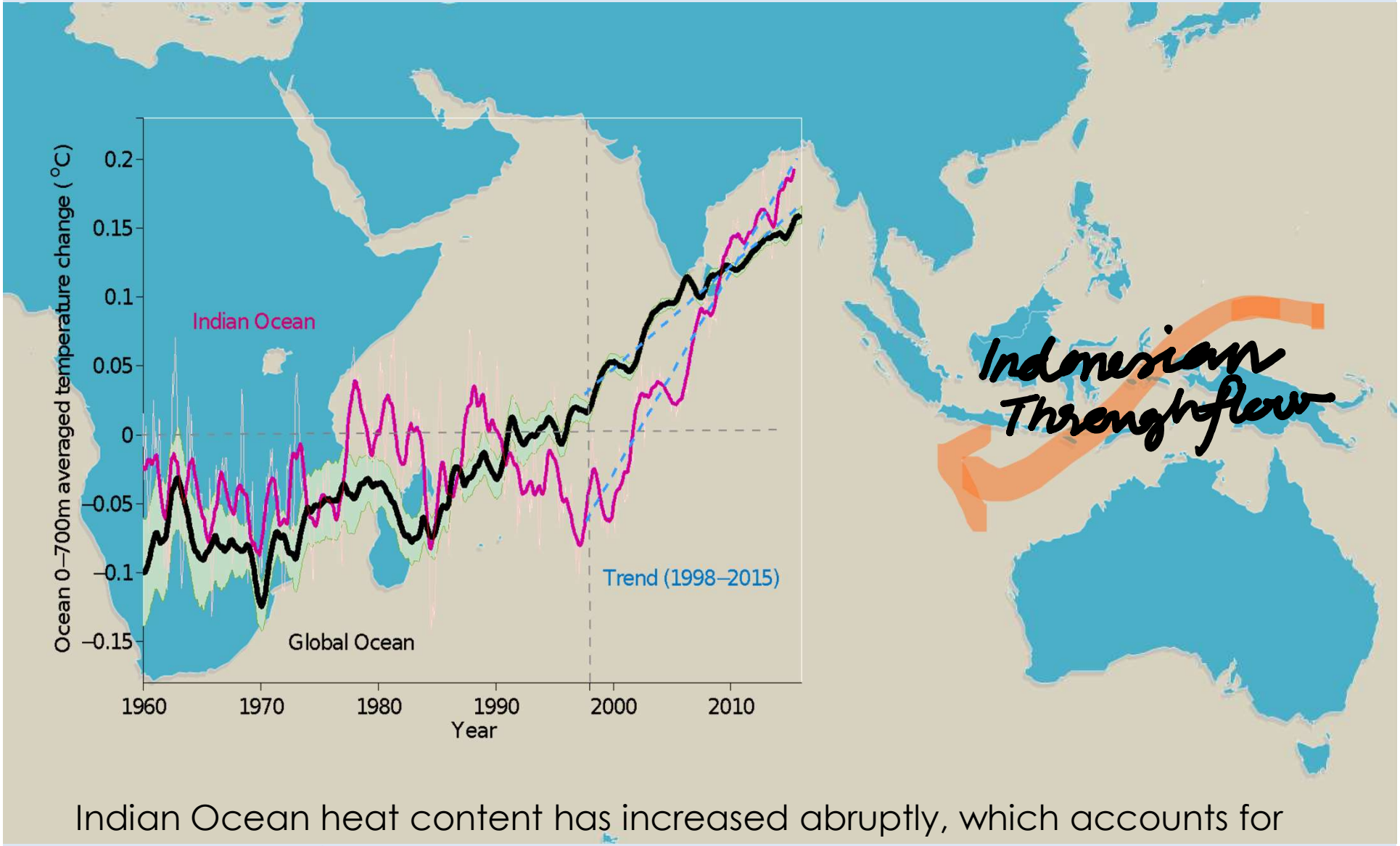


…what about decadal variability?



Cheng et al., 2017; Dong et al., 2014; Han et al., 2014

Changes – Subsurface warming

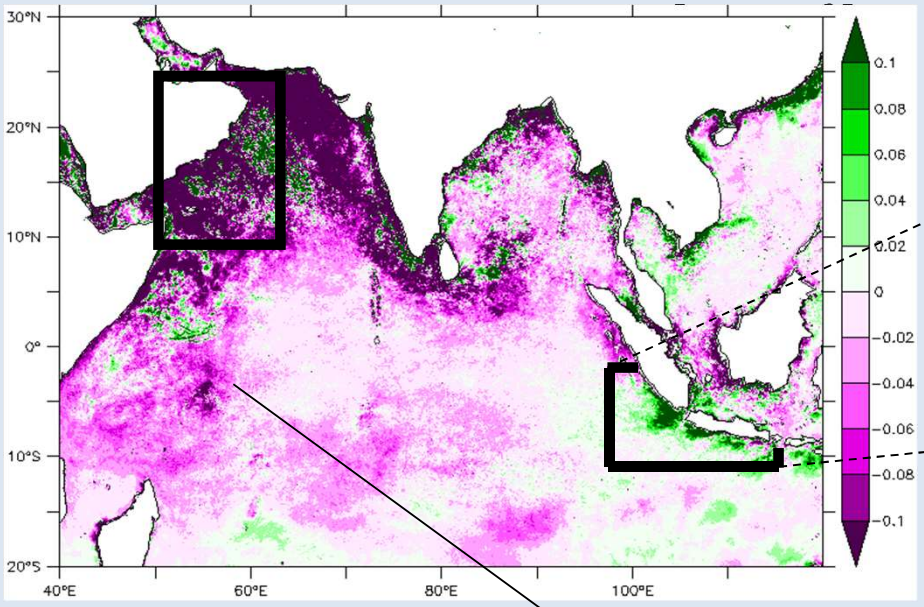


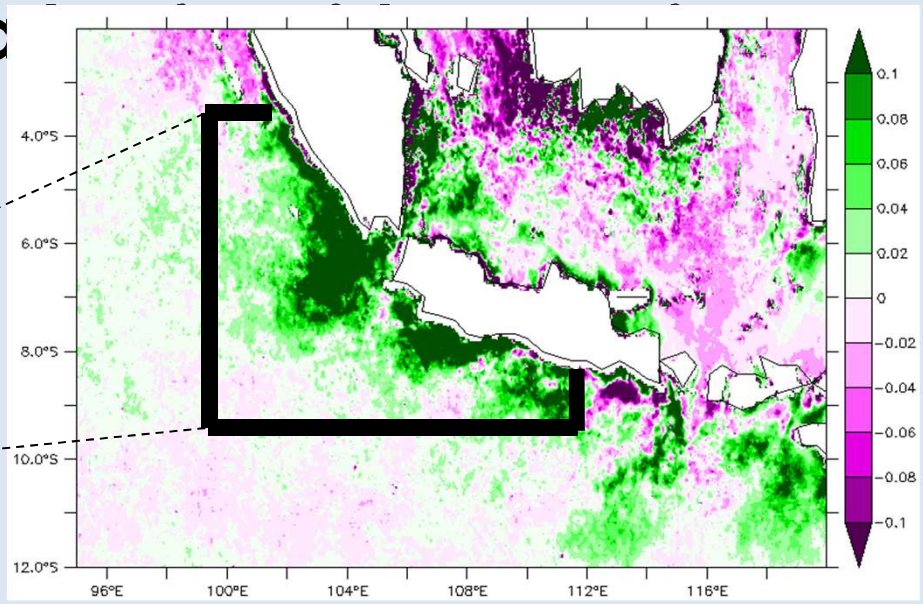
Indian Ocean heat content has increased abruptly, which accounts for more than 70% of the global ocean heat gain in the upper 700m during the past decade

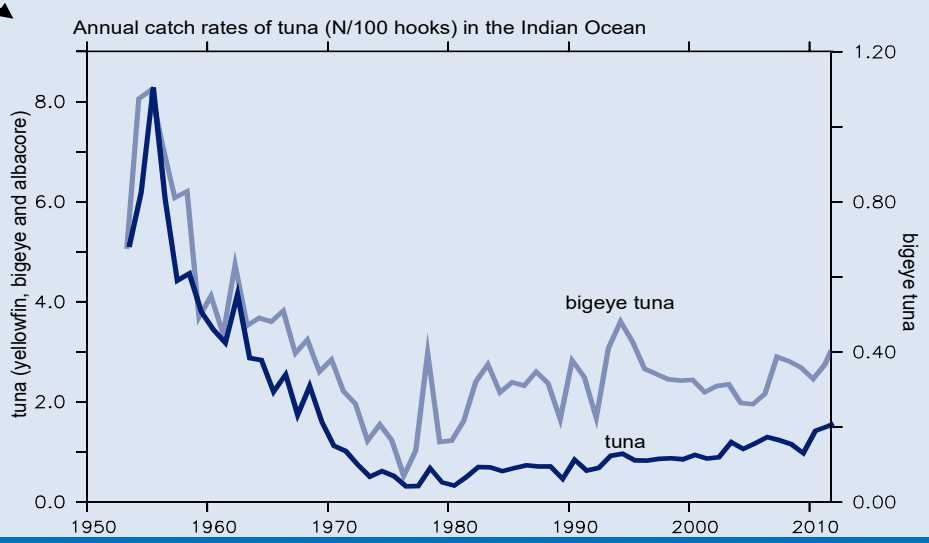
Cheng et al., 2017; Lee et al. 2015

Impacts – Monsoon, Marine Ecosystem, Tropics

Impacts – Contrasting trends in Chl in the Indian Ocean

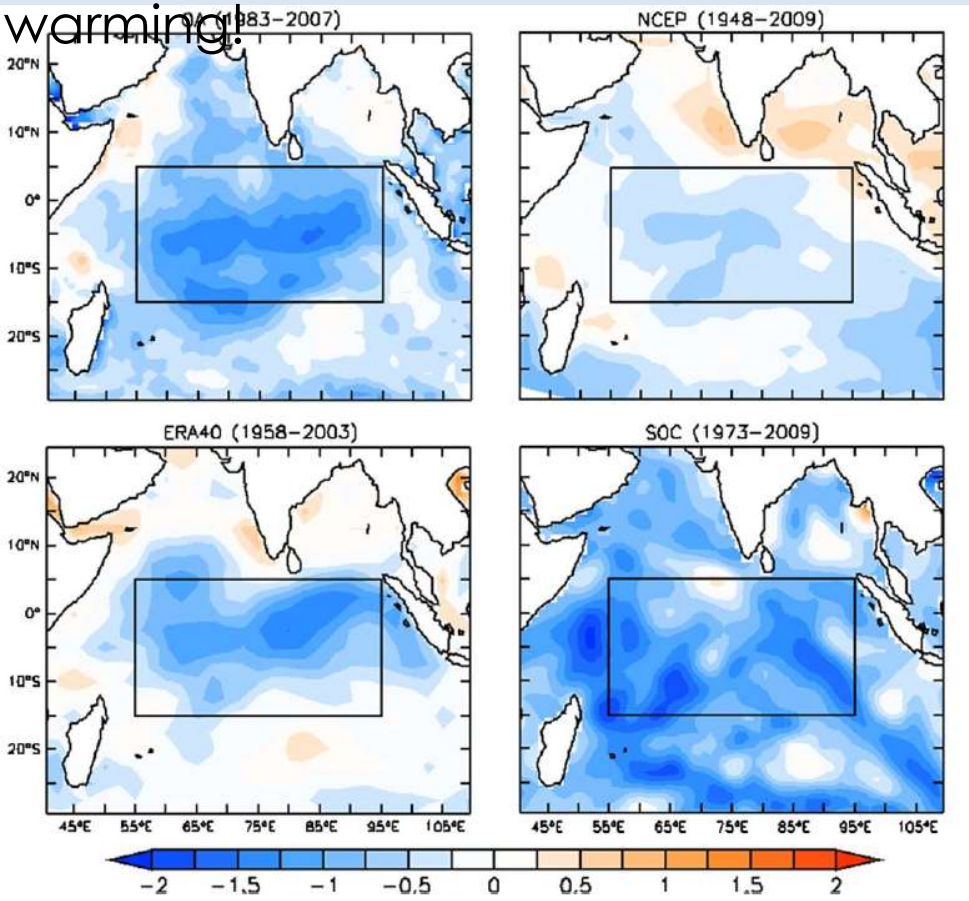




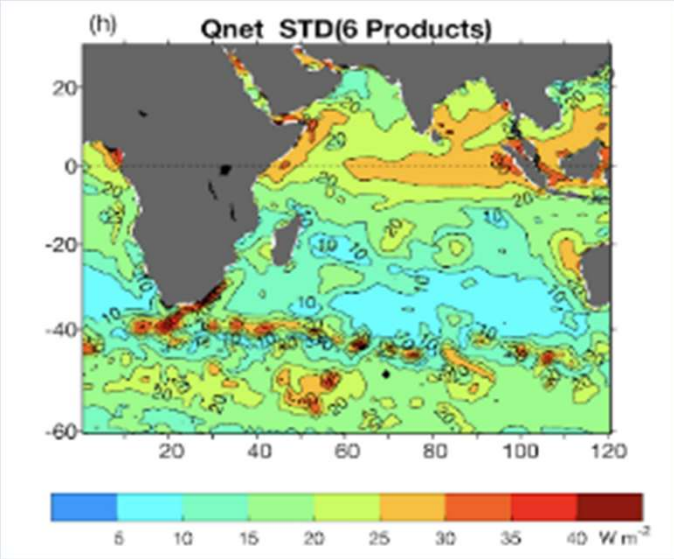


Issues? Fluxes don't match with the SST trends

Neat heat fluxes show decreasing trends, do not explain warming!



Flux products disagree with each other
- Std. Dev. spread among different flux products

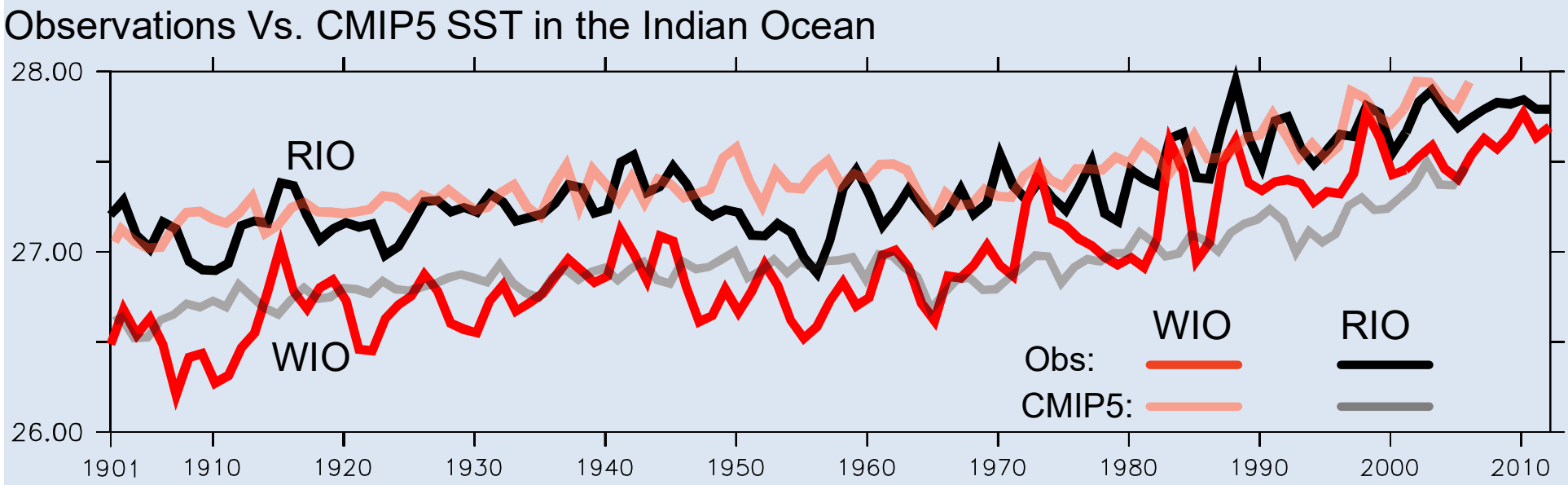


>> Points to the role of ocean dynamics/processes

Rao et al., 2012; Rahul and Gnanaseelan, 2013; Lisan Yu

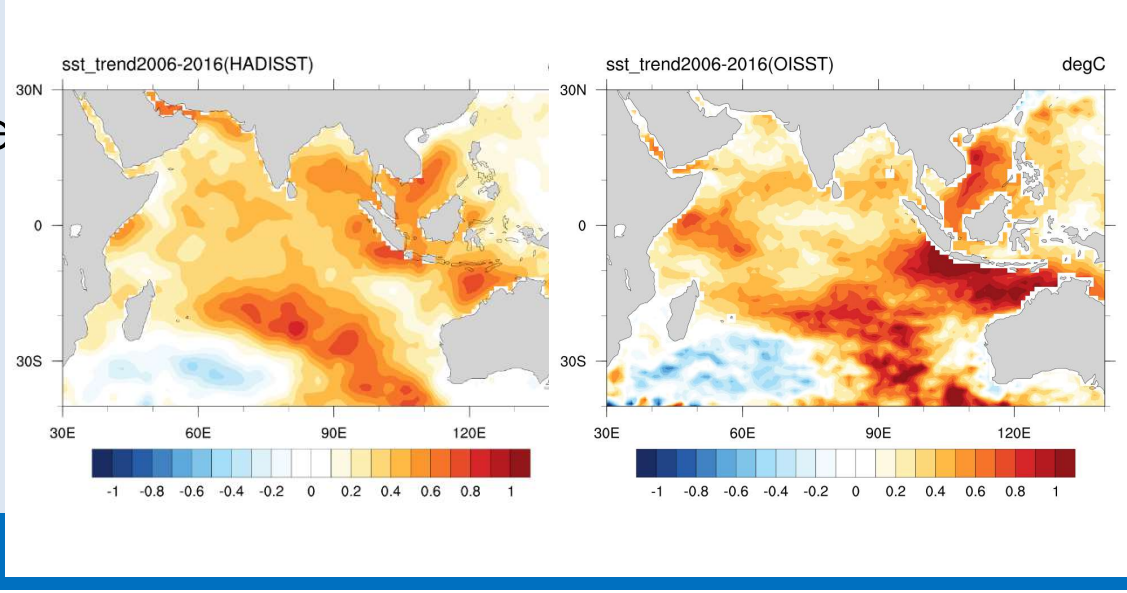
Other Issues? Observations Vs Historical Simulations

Simulations fail to reproduce the Indian Ocean SSTs –bias in thermocline/equatorial dynamics?



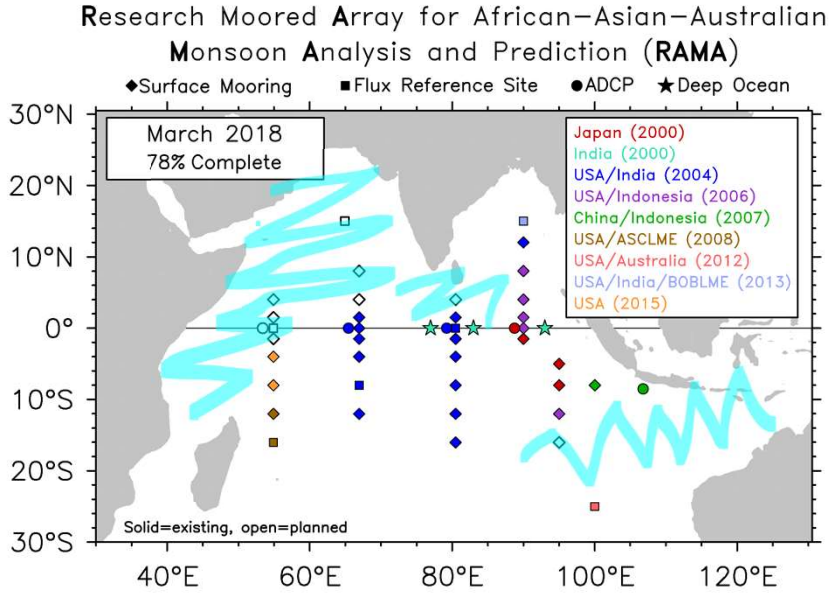
Even observed datasets diffe

This matters for the monsoon forecasts!



Roxy et al., 2014

Recommendations – RAMA



Actionable recommendations

1. Maintain and complete the RAMA array, to provide sustained high-frequency observations of surface and subsurface temperatures, winds, air-sea fluxes.

   Expand the array into the Arabian Sea and western Indian Ocean – where the air-sea flux uncertainties are large.

Essential Ocean Variables

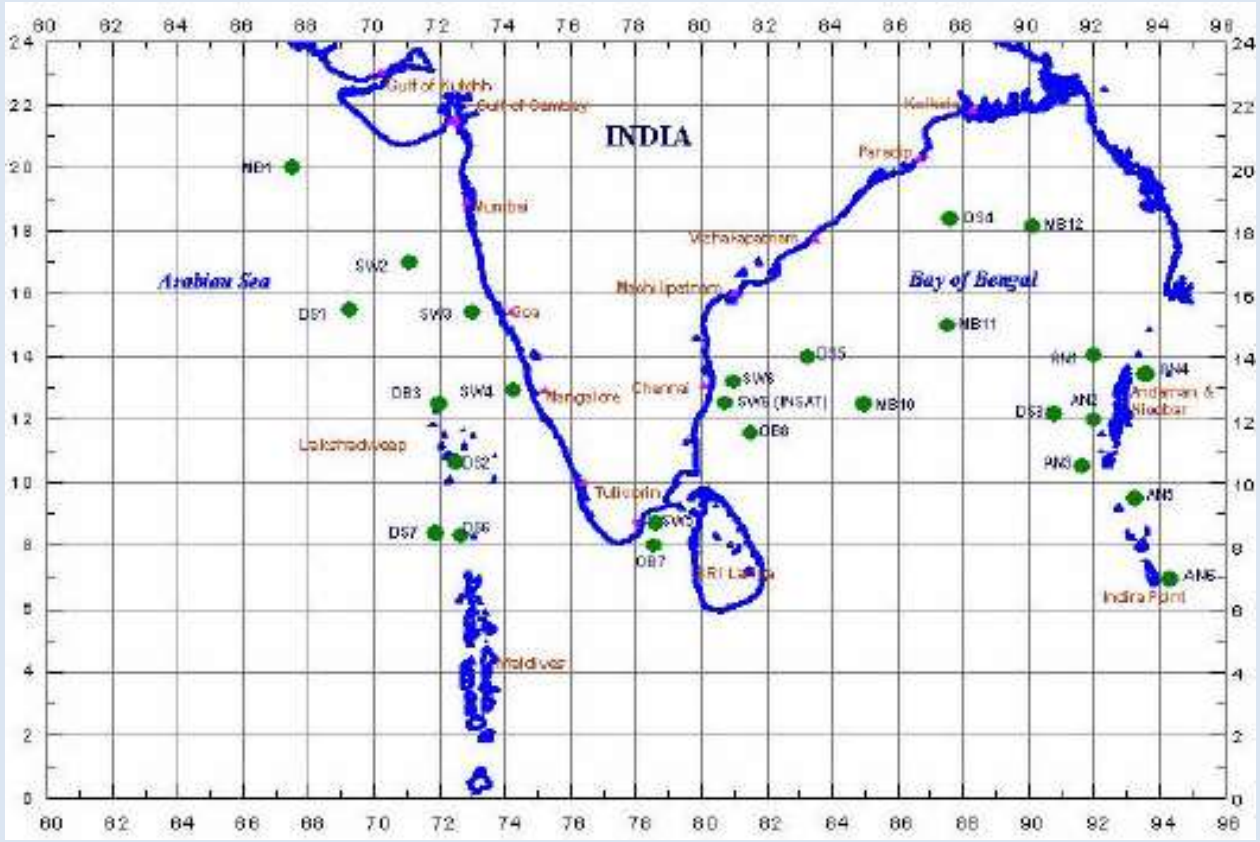
a. In situ data to monitor the **SST trend at the basin-scale**.

b. Improved monitoring of **mass, heat and salt transport at the key Indian Ocean entrances** (ITF) and exits (section along 32S, including the Leeuwin and Agulhas boundary currents), as a tool for basin-scale budget studies.

c. Improved long term time series of **air-sea heat fluxes and constituent turbulent and radiative components across the basin**, which are currently not consistent with SST trends, as a tool for basin-scale budget studies.

d. Basin scale measurements **of subsurface temperature and salinity**, in order to provide reliable estimates of the long-term heat and salt content trends.

Recommendations – RAMA



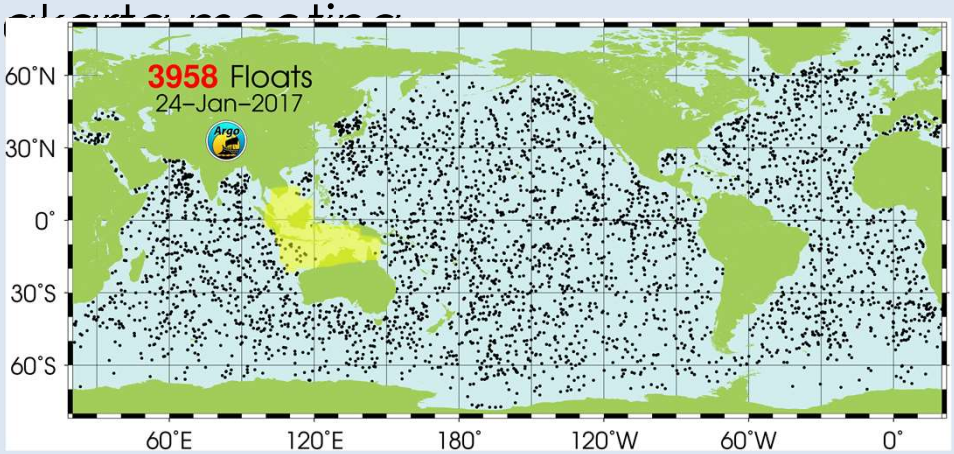
Actionable recommendations

2. The NIOT and the RAMA mooring programs may think about partnership?

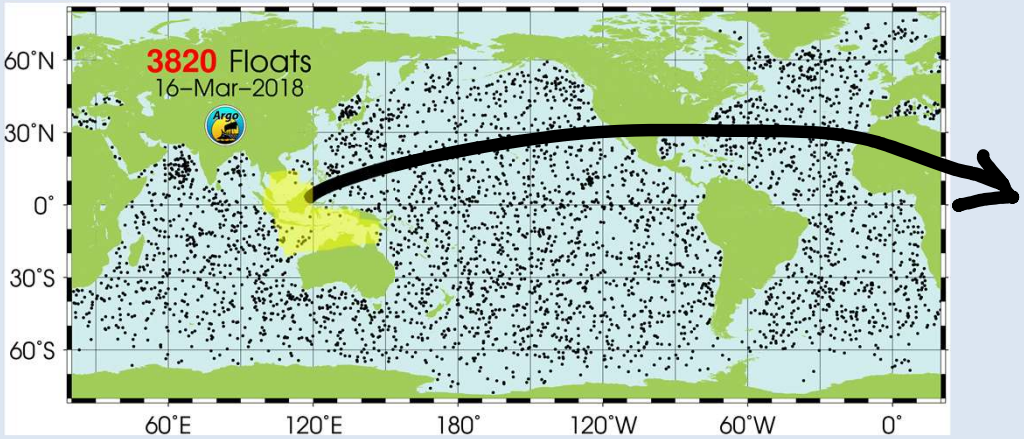
   These are mooring systems which can support sensors through the entire depth.

Recommendations – ARGO

Total number of Argo Floats have reduced between Perth and Jakarta meeting:



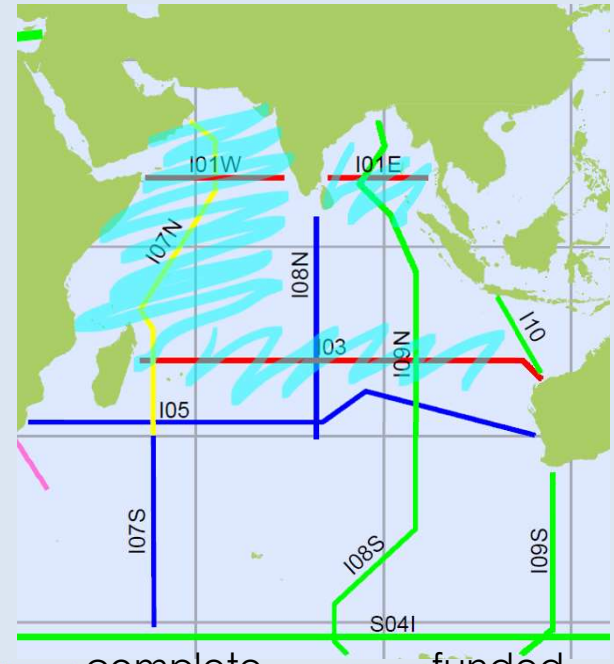
↓ 138 less?



3. The current **Argo program has data gap in the Indonesian/South China seas.** Enhance ARGO observations.

4. If ARGO is not feasible, Explore the technical feasibility of using **GLIDERs**.

Recommendations – GO-SHIP



GO-SHIP section	Nominal location	Year	Country
I08S	95°E south of 32°S	2015-2016	U.S.A.
I09N	95°E north of 32°S	2015-2016	U.S.A.
I01E	10°N Bay of Bengal	2016	U.S.A.
I09S	115°E	2017	Australia
I05	32°S	2018	U.S.A.
I06S	30°E	2019	U.S.A.
I08N	90°E north of 32°S	2015 or 2018	Japan/India
I07N	60°E	No commitment (due to security reasons)	See ^
I10/IR06	Java to NW Australia (110°E)	2015 or 2018	Japan
I03	20°S Australia to Madagascar	No commitment	See #
S04I	62°S	No commitment	
I01W	10°N Arabian Sea	No commitment	

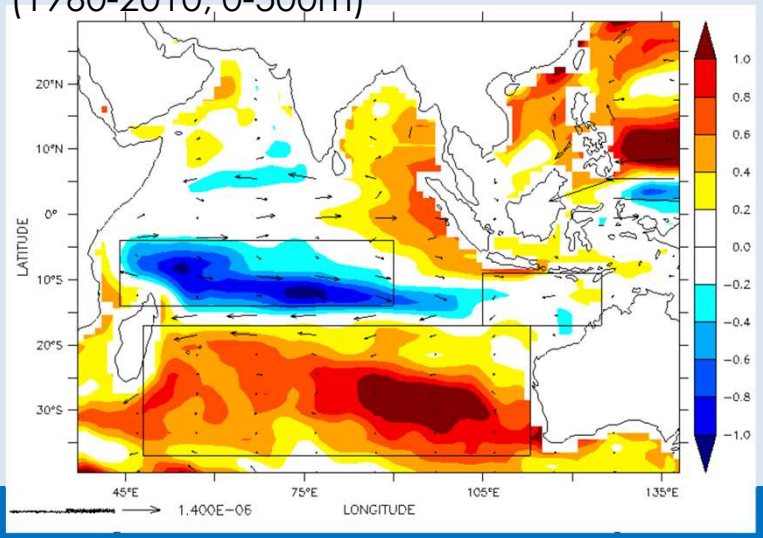
^ Although not in the USA planning, they will do the section if international security warnings are removed.

Under discussion between Indian partners and UK IIOE2.

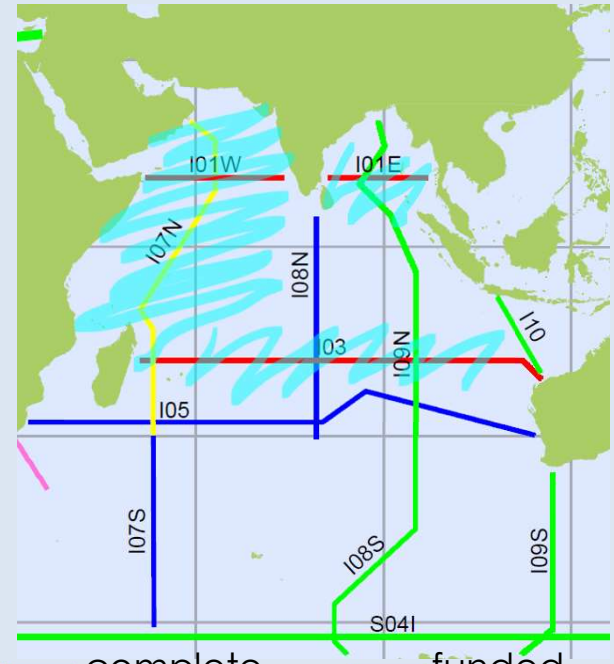
Actionable recommendations

5. Maintain the GO-SHIP array of repeat hydrographic sections in the Indian Ocean to ensure long-term, full-depth measurements to quantify ongoing change and provide regional calibration targets for deep Argo in the region.

Trend in heat content and heat transport (1960-2010, 0-500m)



Recommendations – GO-SHIP



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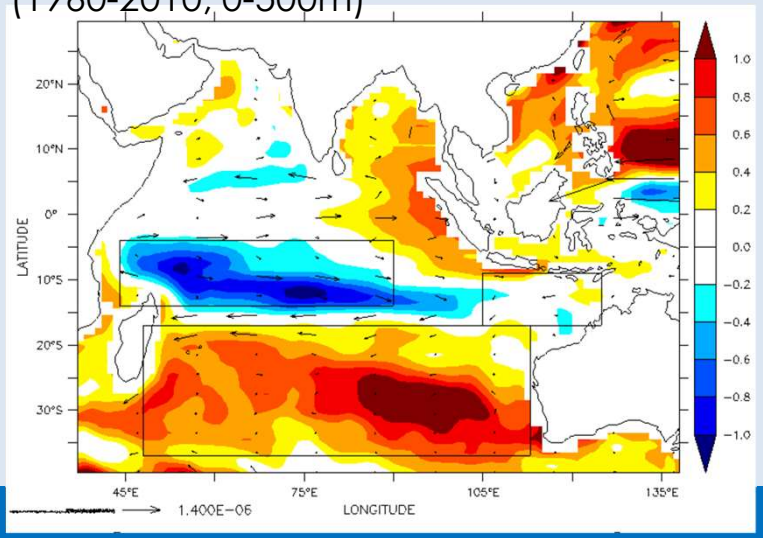
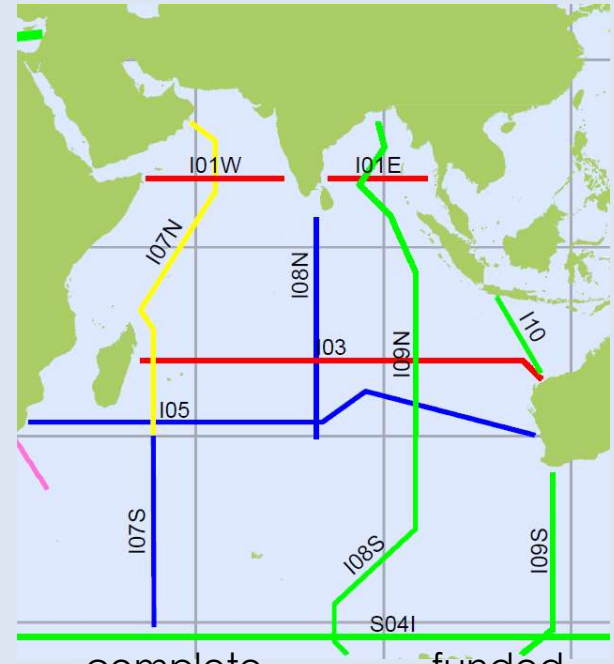
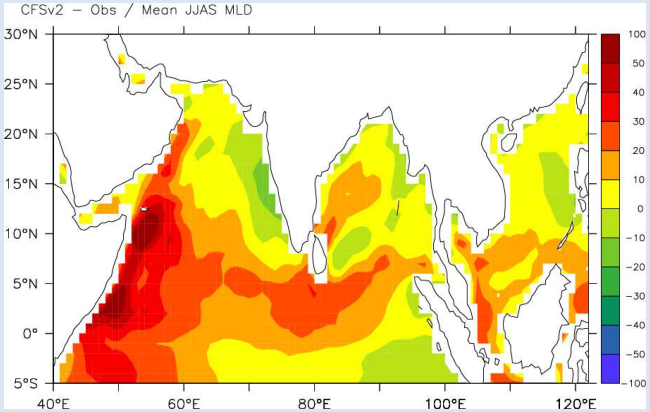


Recommendations – GO-SHIP





Shallow MLD -> ISO amplified
Deep MLD -> ISO weakened

Actionable recommendations

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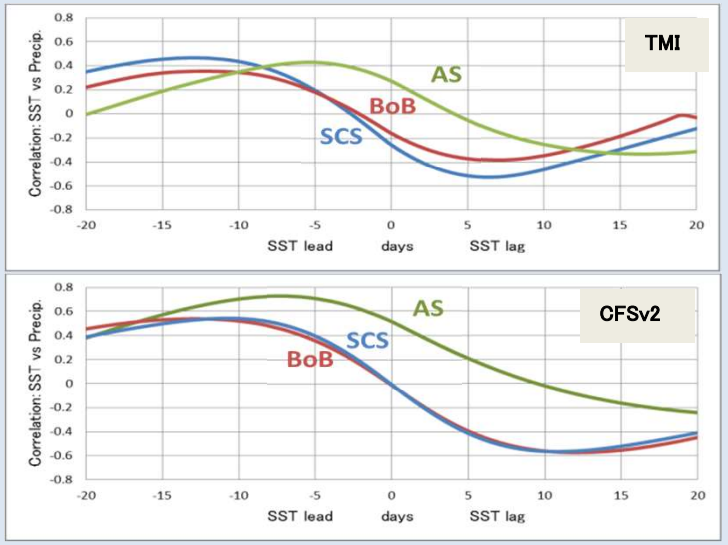


SST – precipitation relationship in observations and model

Actionable recommendations – Full List

1. Maintain and complete the RAMA array, to provide sustained high-frequency observations of surface-subsurface temperatures, winds, air-sea fluxes. Expand the array into the WIO–where the air-sea flux uncertainties are large.

2. Maintain the current Argo coverage in the Indian Ocean, but
   a) Enhance the coverage near the ITF exit.
   b) Explore the technical feasibility of enhancing Argo in the ITF region.
   c) Consider deep Argo in southern subtropical IO.

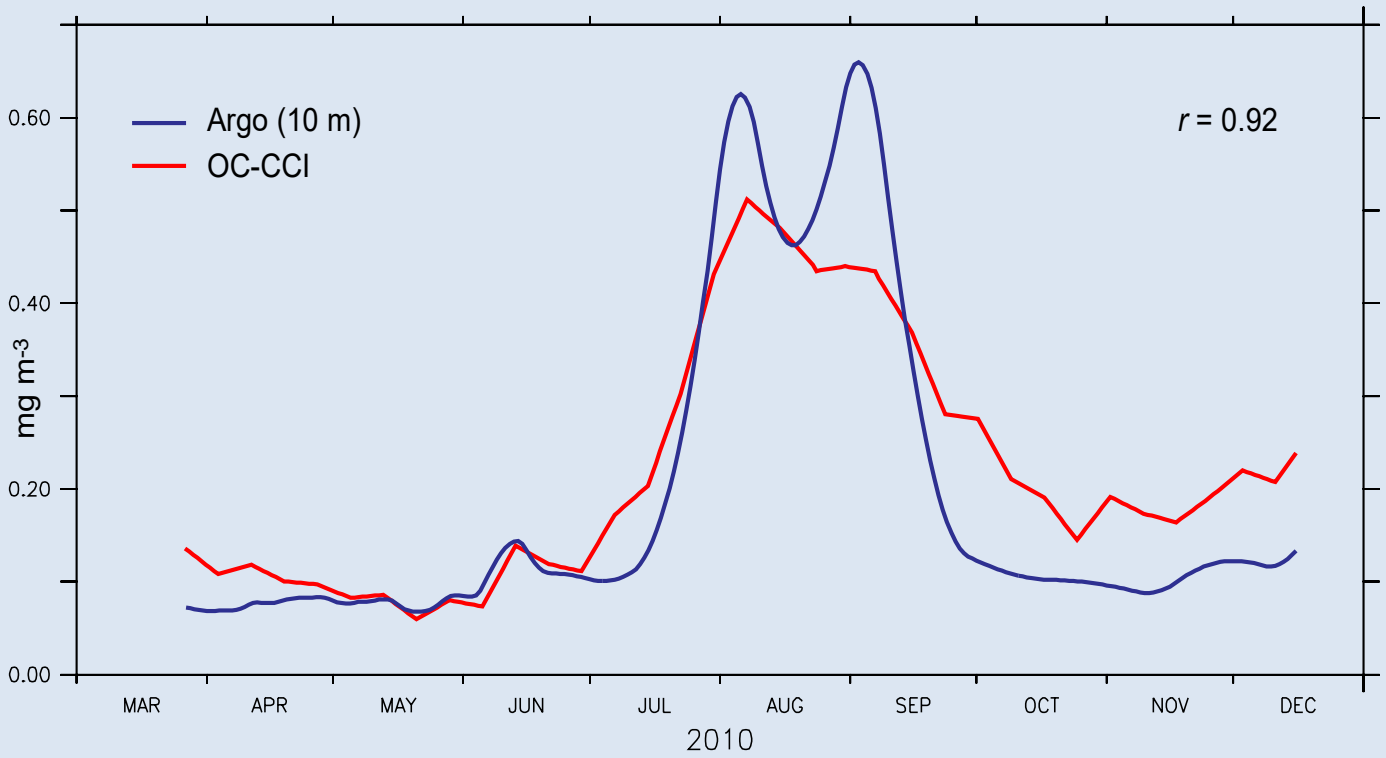
3. Explore the technical feasibility of gliders along ITF and 32S.

4. Maintain GO-SHIP repeat hydrographic sections for long-term, full-depth measurements in order to quantify ongoing change and provide regional calibration targets for deep Argo.

5. Maintain the XBT line to monitor the geostrophic volume/heat transport at ITF exit.

6. Maintain basin-scale satellite observations that are inter-calibrated between various missions in order to reach climate-grade quality. Ensure that these important measurements are acknowledged, and this information is conveyed to the agencies for maintaining and renewing these satellite missions.

What Satellites don't see over the Indian Ocean



Temporal evolution of chlorophyll-a during the year 2010, derived from an Argo float at 10 m depth (blue) and OC-CCCI data (red) for a region where the data points coincide in the Arabian Sea (60-70° E, 5-15° N).