Indian Ocean and South-Asian monsoon: upper-ocean processes relevant to monsoon annual cycle

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"A big thanks to Jay"

"Thanks to reviewers on the first draft"

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Talk Outline

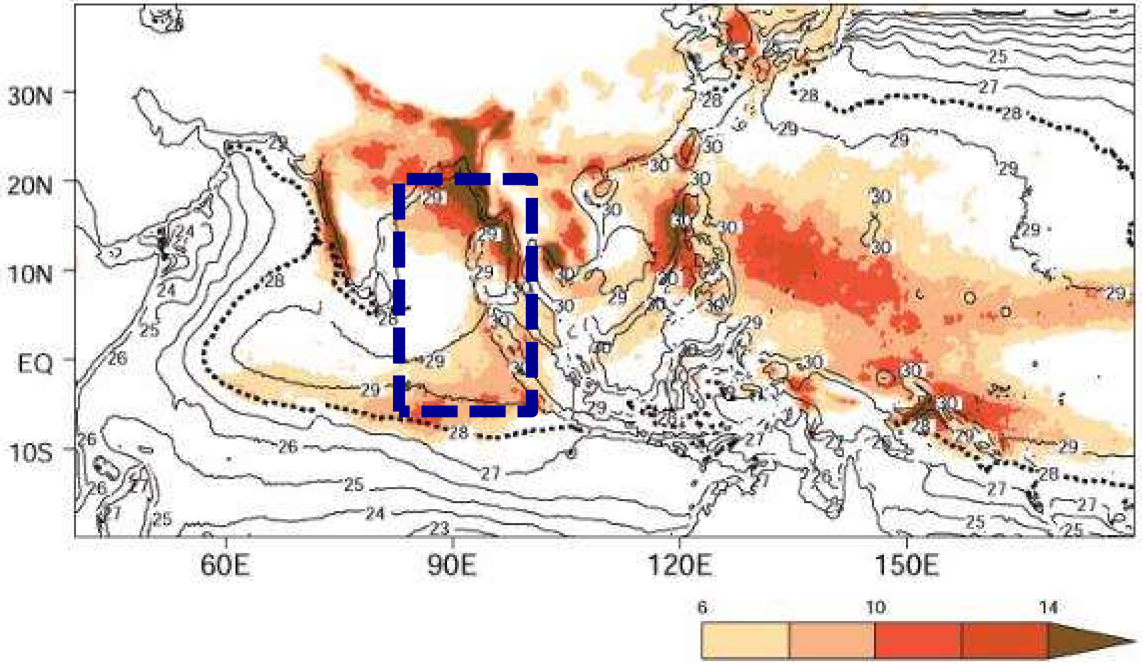
- Model systematic errors in ocean-atmosphere variables persist for the last few decades (despite data available from multiple observational platforms (in-situ, satellite, field experiments)
- Model errors - limitations in representing multiple processes and their interactions
- Current suite of observations not adequate enough to understand the monsoons and constrain model physics

Focus on upper-ocean processes (thermal and salinity stratification)

(Shenoi et al. 2002; Schott et al. 2009; Seo et al. 2009; Annamalai et al. 2015; Thadathil et al. 2016; Nagura et al. 2015; Mahadevan et al. 2016)

Precipitation and SST

Boreal Summer (JJA)

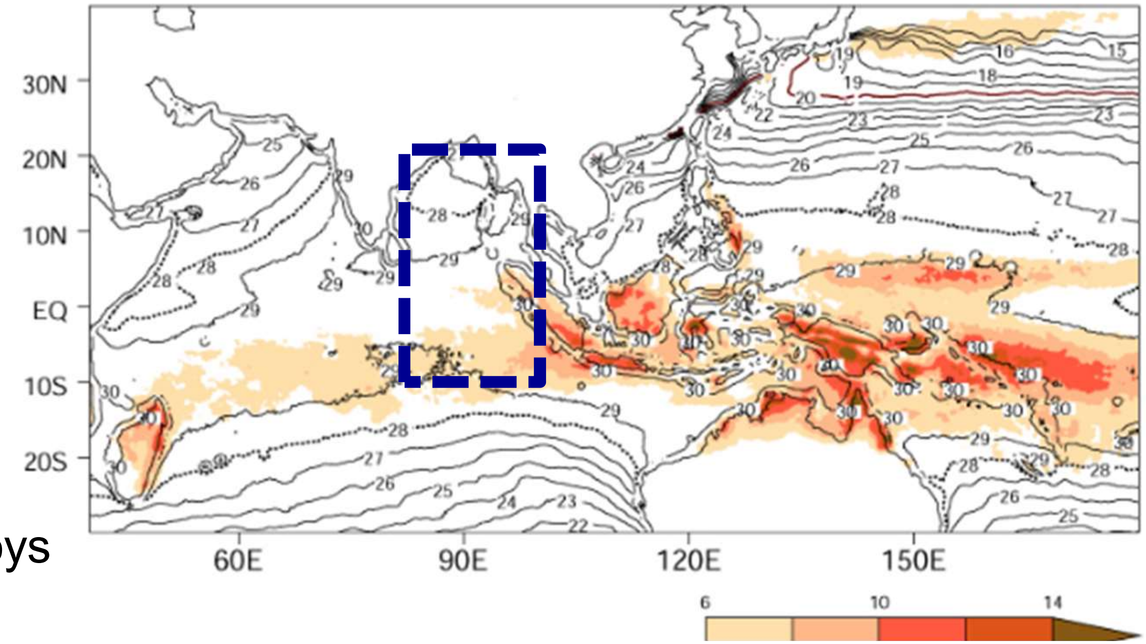


EIO SST remains > 28°C

Equatorial, eastward Wyrtki Jets

Precip occurs year-around
Upper-ocean stratification

Boreal Winter (DJF)

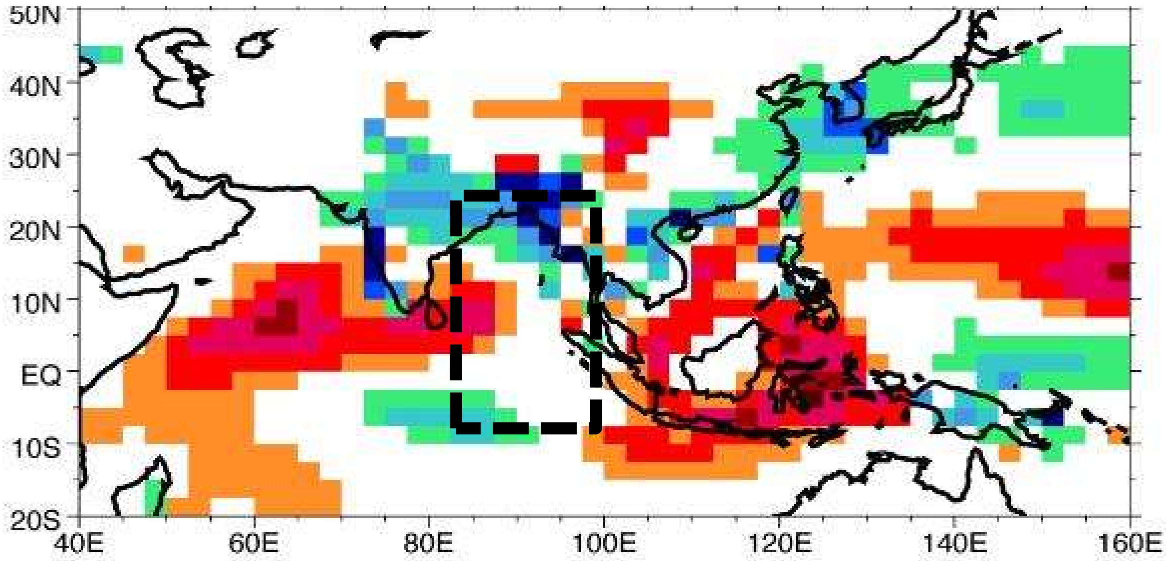


Bay of Bengal SST > 28°C

Upper-ocean stratification

Cold/dry winter monsoon near-surface air temperature drops <26°C but SST remains High – Temperature inversion peaks (Nov-Dec) – RAMA buoys (Thadathi l et al. 206)

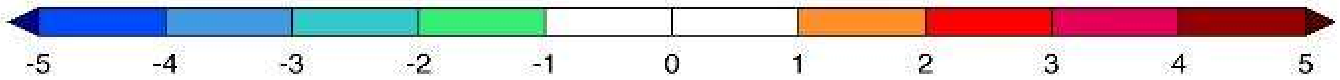
CMIP3 MMM – GPCP



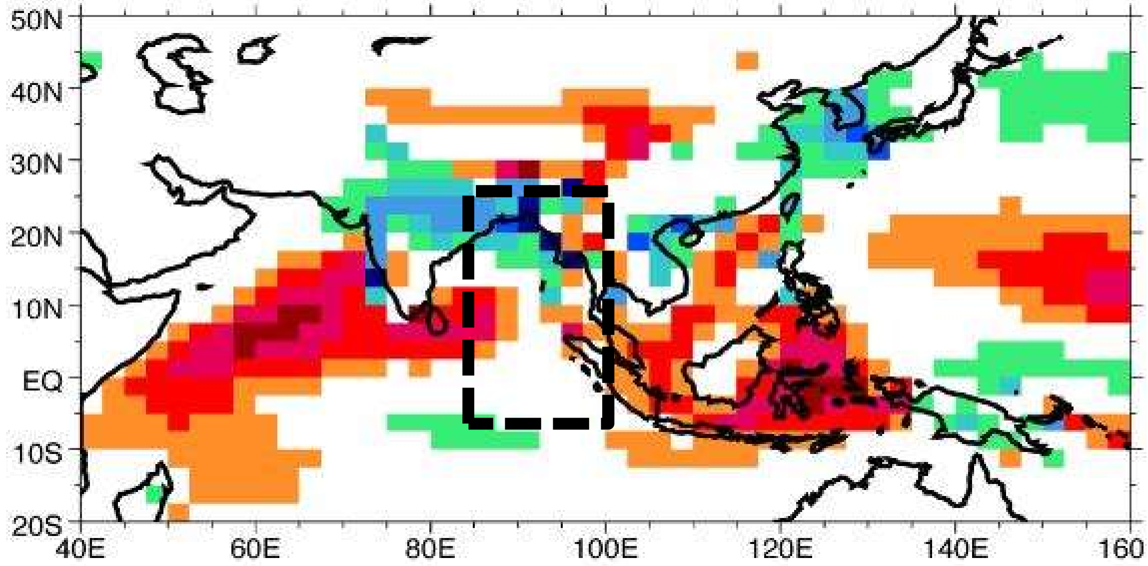
JJAS - Precipitation

(Sperber et al. 2013)

(mm/day)



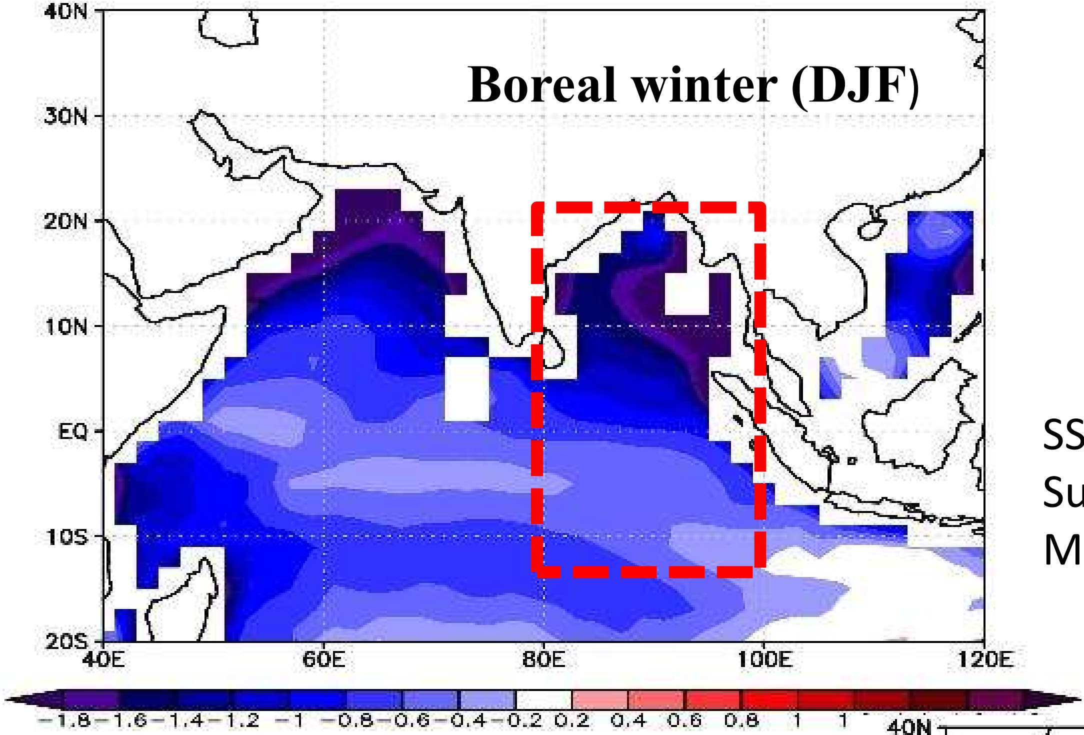
CMIP5 MMM – GPCP



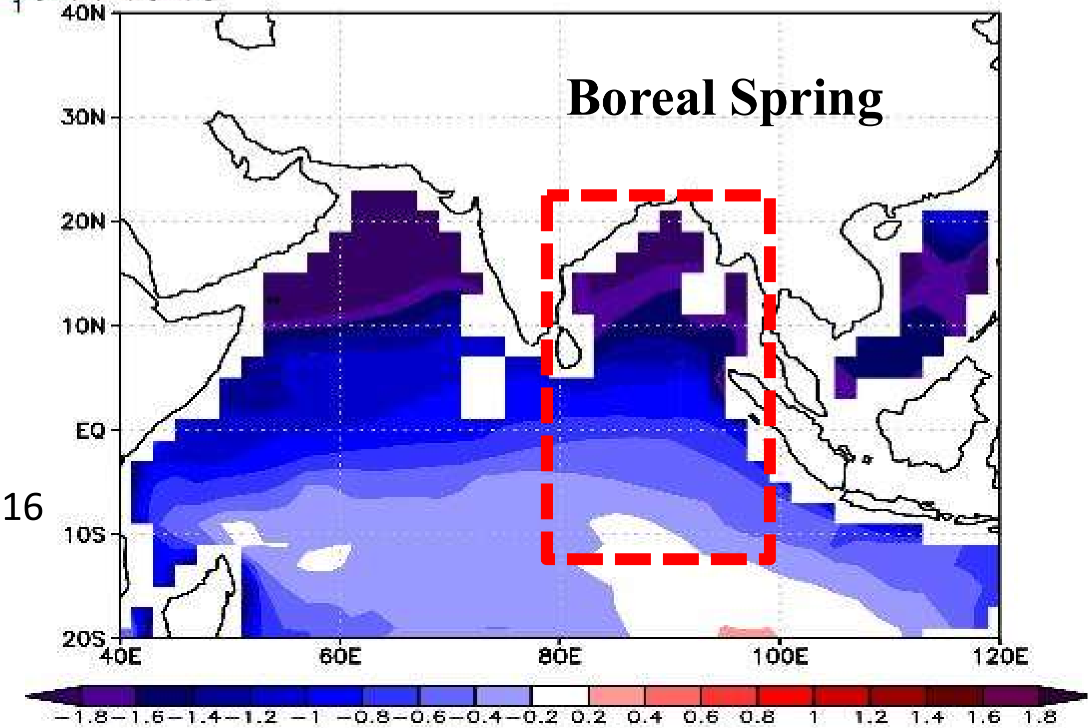
Bay of Bengal
Eastern EIO

Nagura, McCreary and Annamalai 2018
BoB precip and salinity errors-
EICC – stratification in Northern AS
Errors in Mixed-layer depth and D20

CMIP5 MMM SST biases



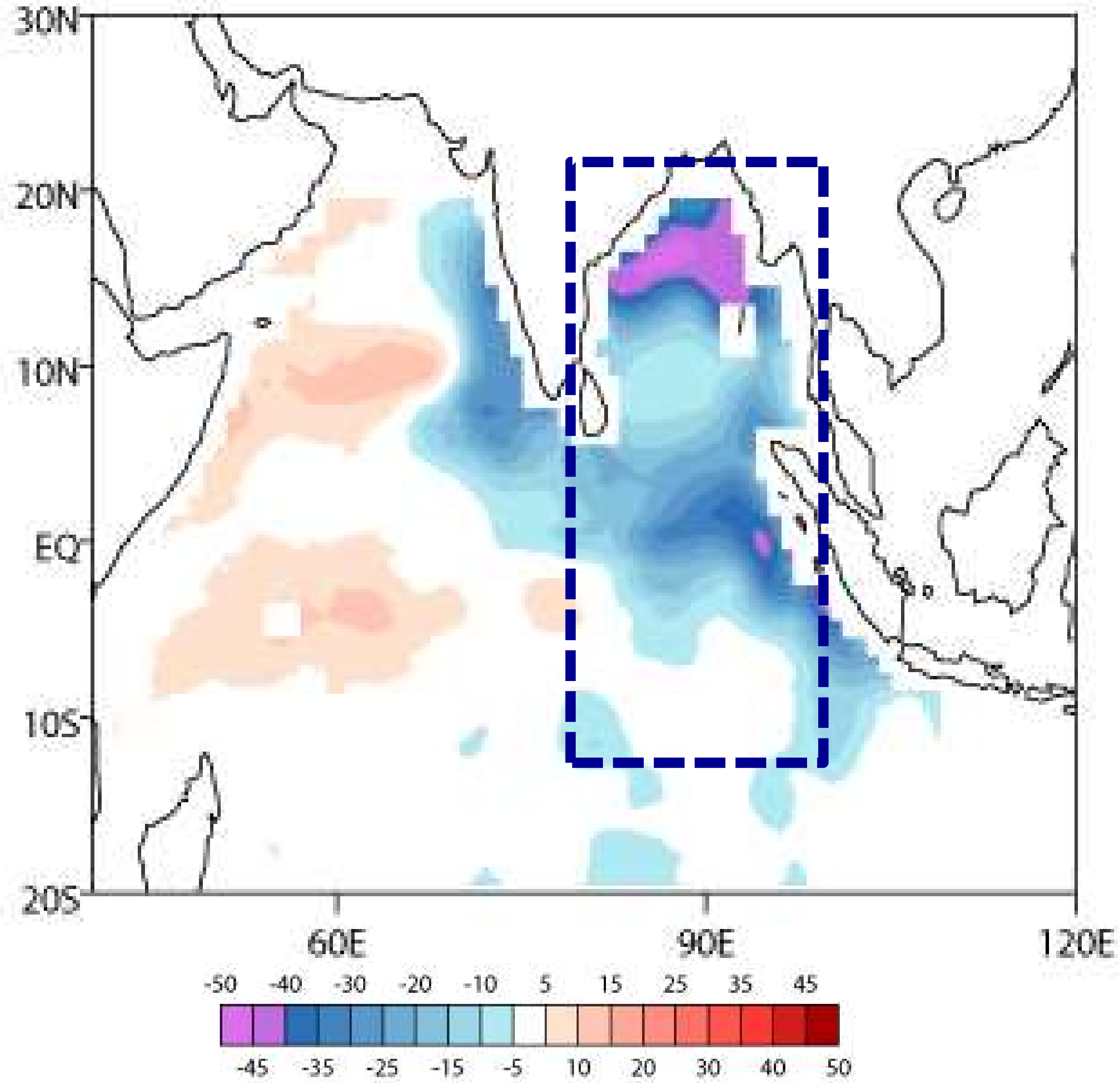
SST biases persist into the boreal spring and Summer seasons impacting the ensuing Monsoon during summer



“ SST – precip – SST “ In regions of high mean precip, two-way interaction needs to be understood and modeled

Levin et al. 2013; Sandeep and Ajayamohan 2016
Annamalai 2018

CMIP5 MMM errors in barrier-layer thickness (DJF)

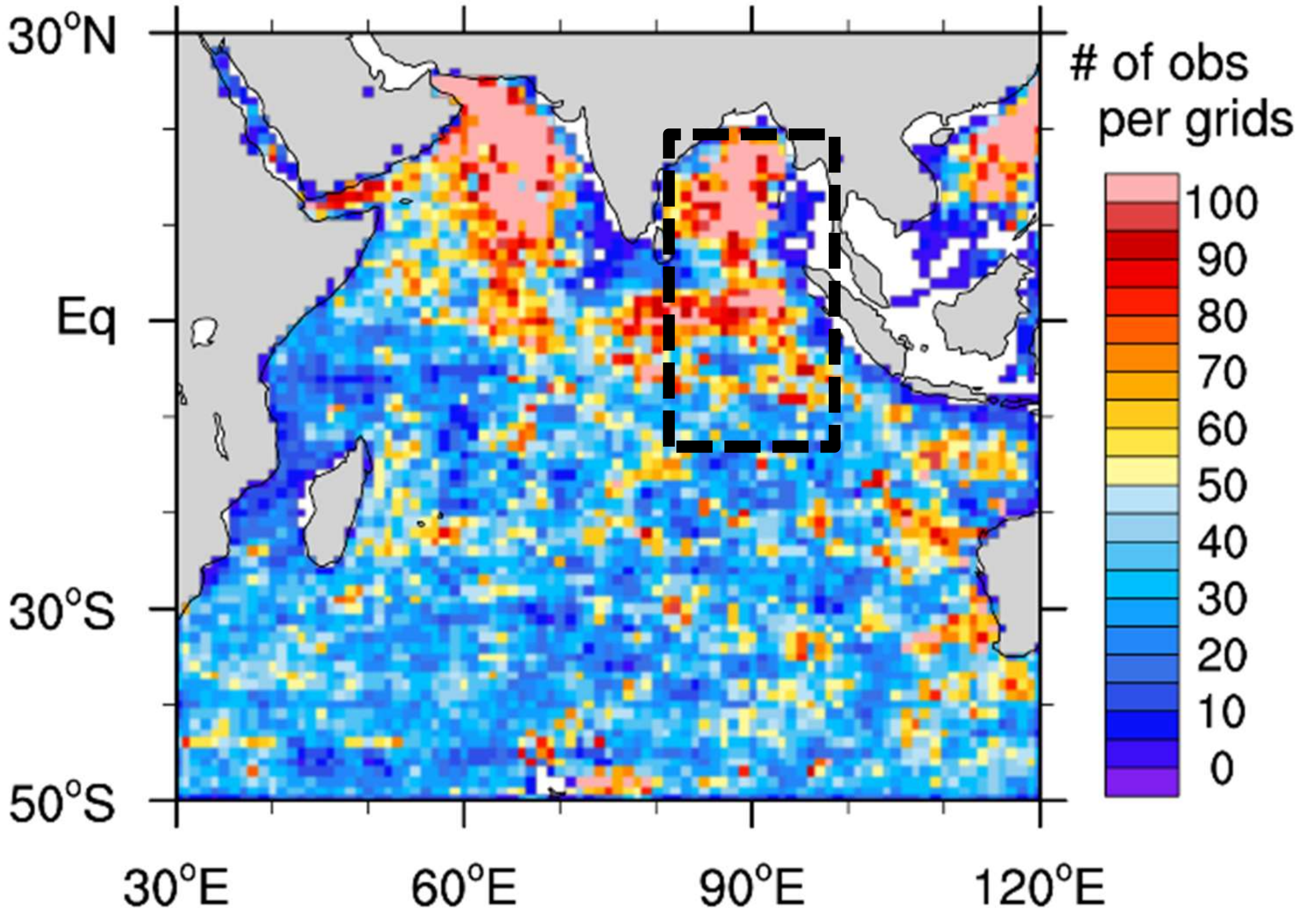


"SST-> Pr -> SST"

Salinity and temperature Stratifications in the Upper-ocean

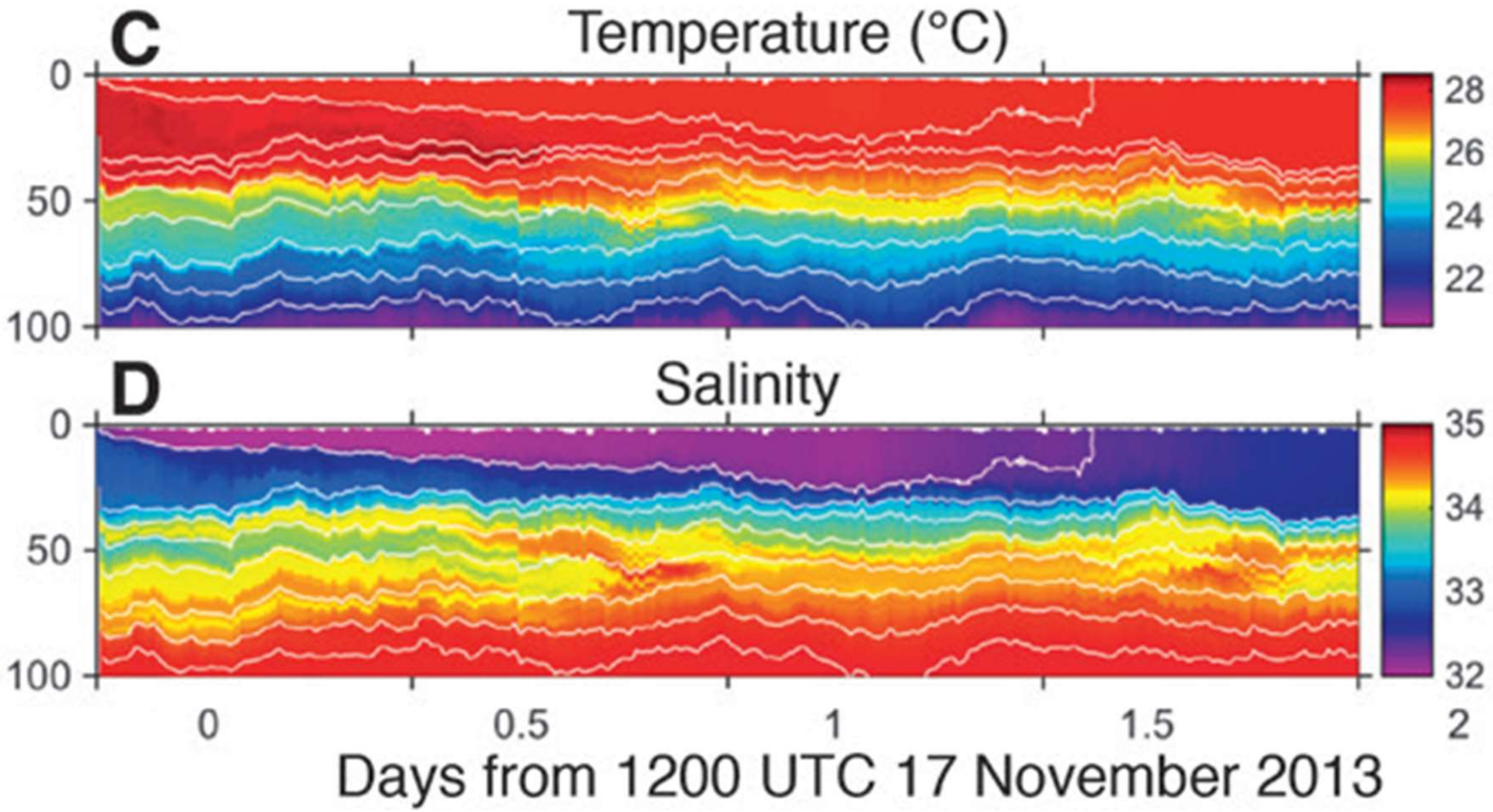
Mixed-layer < 10 m

Number of in-situ observations (CTD/Argo floats) – Since 1961
To measure temperature and salinity



1. Argo floats – limitations (top 25 m – where stratification is strong)
2. Eastern EIO / coastal regions (limited observations)
3. Limited observations over the SIO Thermocline ridge / Arabian Sea warm pool

An Ocean-Atmosphere Initiative for Bay of Bengal (ASIRI)



Contours density

A 2-day drift of two wire walkers near 16°N, 87°E

Wijesekera et al. (2016)

Anderson and Riser (2014)
Argo – auxiliary STS sensors
Vertical res. 10 cm (top 2-4 m)
Stratification / ver. gradient

Ocean-model vertical resolution needed? Kelvin Richards

Recent/on-going observations field camps relevant to Upper-ocean processes

- **An Ocean-Atmosphere Initiative for Bay of Bengal (ASIRI) –**

  High-resolution observations from multiple platforms
  Shallow salinity-controlled mixed-layers result from high rainfall and river-runoff
  Mixed-layers over the northern Bay are of the ~ 20m, and meso-scale oceanic features contribute to upper-ocean stratification (Nov-Dec 2013)

- **Auxiliary surface temperature and salinity (STS) sensors – Argo floats**

  ~10 cm vertical resolution in the top 15 m / strong vertical gradient (3 sites – BoB)

- **SPURS-2 Salinity Processes in the Upper-ocean Regional Study**

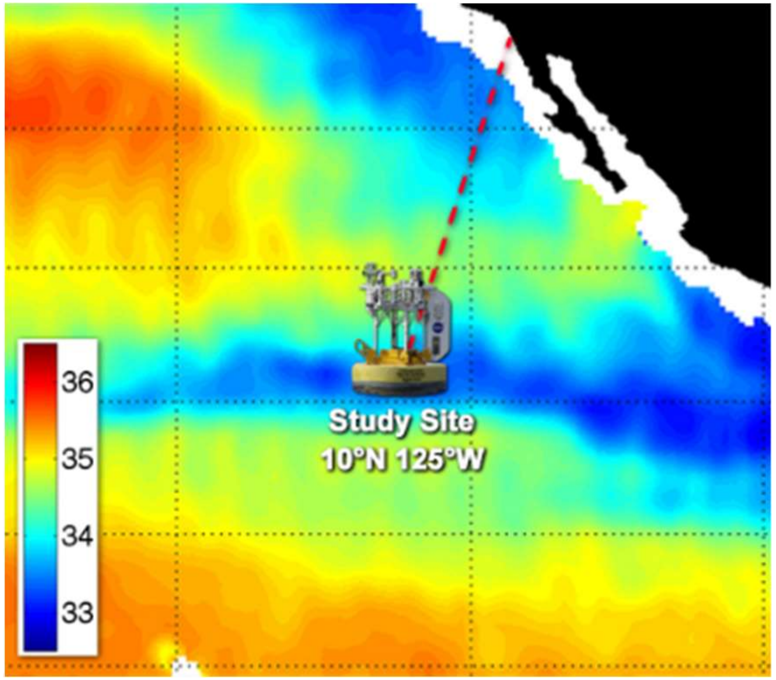
  Eastern Pacific ITCZ (high-mean precipitation region)

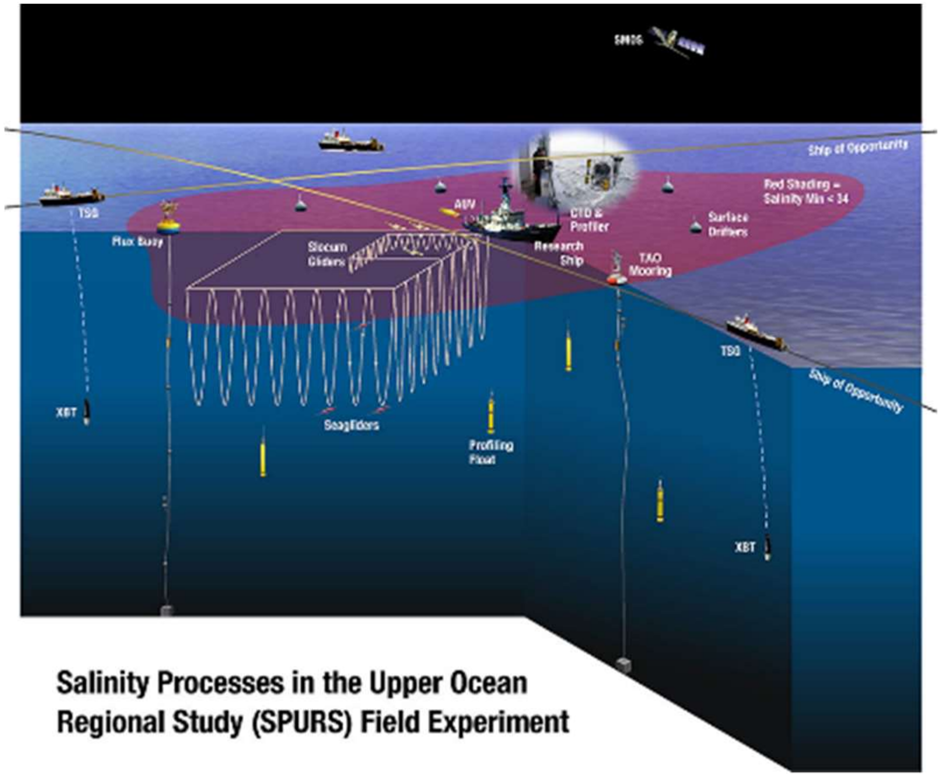
Wijesekera et al. (2016); Anderson and Riser (2014); Rainville et al. (2017); Lindstorm et al. (2017 –

Multiple platforms observations for sustained monitoring

Upper-ocean stratifications

In regions of high-mean precipitation such as BoB/EEIO





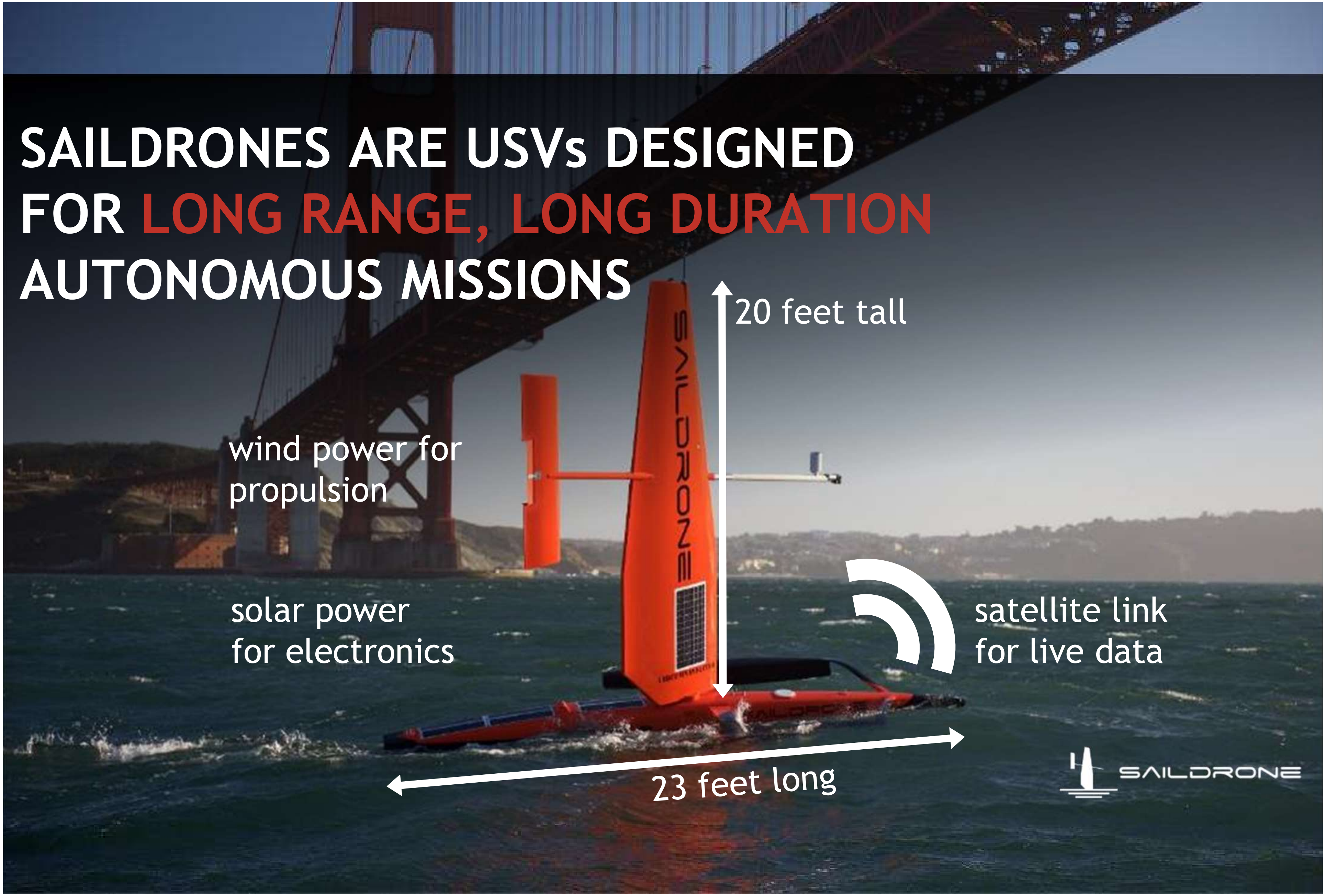
Actionable Recommendations of EOV

Upper-ocean processes – Bay of Bengal – 12°-22°N, 80°-100°E

Temperature and Salinity – upper ocean; near-surface atmospheric variables

1. Moored buoys (2°x2° degree or even finer)
2. Argo floats – equip with auxiliary STS sensors (~10 cm ver. res top 2-20m)
3. Repeated glider sections and a suite of autonomous vehicles as in SPURS – vehicles such as SVP and SVP-2 drifters, sea/wave gliders,
4. SAILDRONES (being tested now along the equatorial western Pacific)

Rectangular mesh: Estimation of advection of salinity in and out of Bay of Bengal
To augment reliability and in regions of shallow mixed-layers, repeated glider sections (Rainville et al. 2017) and a suite of autonomous vehicles (Lindstorm et al. 2017l


SAILDRONES ARE USVs DESIGNED
FOR LONG RANGE, LONG DURATION
AUTONOMOUS MISSIONS
20 feet tall
wind power for
propulsion
solar power
for electronics
satellite link
for live data
23 feet long
SAILDRONE
SAILDRONE

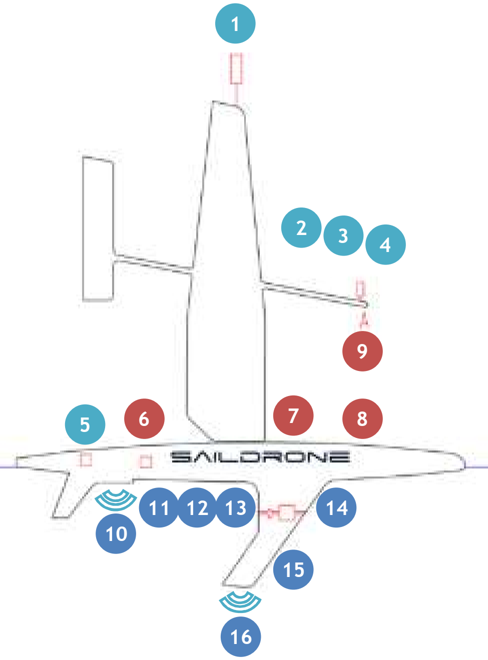
COLLECTING AND TRANSMITTING REAL-TIME DATA

Atmospheric Measurements

- Wind Speed, Wind Direction — **1** **Anemometer @ +4.5m** Gill Windmaster 3D ultrasonic 20H
- Sunlight — **2** **Sunshine Pyranometer @ +2.2m** Delta-T Devices SPN1; **3** **Pyranometer @ +2.2m** Eppley PSP & PIR
- Air Temperature, Humidity — **4** **Meteorological Probe @ +2.2m** Rotronic HC2 - S3 with rad shield
- Air Pressure — **5** **Digital Barometer @ +0.2m** Vaisala BAROCAP PTB210

Oceanic Surface Measurements

- Wave Height & Period — **6** **Dual GPS & IMU** Vectornav / KVH
- *pCO_2* — **7** **CO_2 System @ +0.3m** **PMEL ASVCO_2**
- Magnetic Field — **8** **Magnetometer @ 0m** Barrington MAG 648
- Skin Temperature — **9** **SST IR Pyrometer @ +2.2m** Heitronics KT15 II



Length:23 ft
Height: 15 ft
Depth: 7 ft
Weight:1200 lbs, loaded
Speed: Transit ~ 3 Kt, Max ~ 8 Kt
Payload Power: 30w Steady state
Payload Capacity: 250 lbs
Max deployed duration; 12 months
Longest voyage: 10,000 miles

Oceanic Sub-Surface Measurements

- Ocean Currents — **10** **ADCP @ -0.2m** Teledyne RDI Workhorse 300 kHz
- Chl*a*, CDOM Concentration, Red Backscatter — **11** **Fluorometer @ -0.2m** Sea-bird Scientific WET labs Eco Triplet
- Dissolved Oxygen — **12** Oxygen Optode @ **-0.5m** Aanderaa 4831
- *pCO_2* — **13** **CO_2 System @ -0.5m** **PMEL ASVCO_2** **Sea-Bird Scientific SBE Prawler** **Honeywell Durafet**
- Water Temperature, Salinity — **14** **Thermosalinograph @ -0.5m** **Teledyne RDI Citadel TS-NH**
- Marine Mammal Presence — **15** **Passive Acoustic Recorder** **Greenridge Sciences Inc.** **Acousonde**
- Fish Biomass, Bathymetry — **16** **WBAT @ -2.5m** SIMRAD EK 80 **Multi-beam Sonar @ -2.5m** **Norbit iWBMS**

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- 55’ tall wing
- 1 Ton payload
- 10-15 knots cruise

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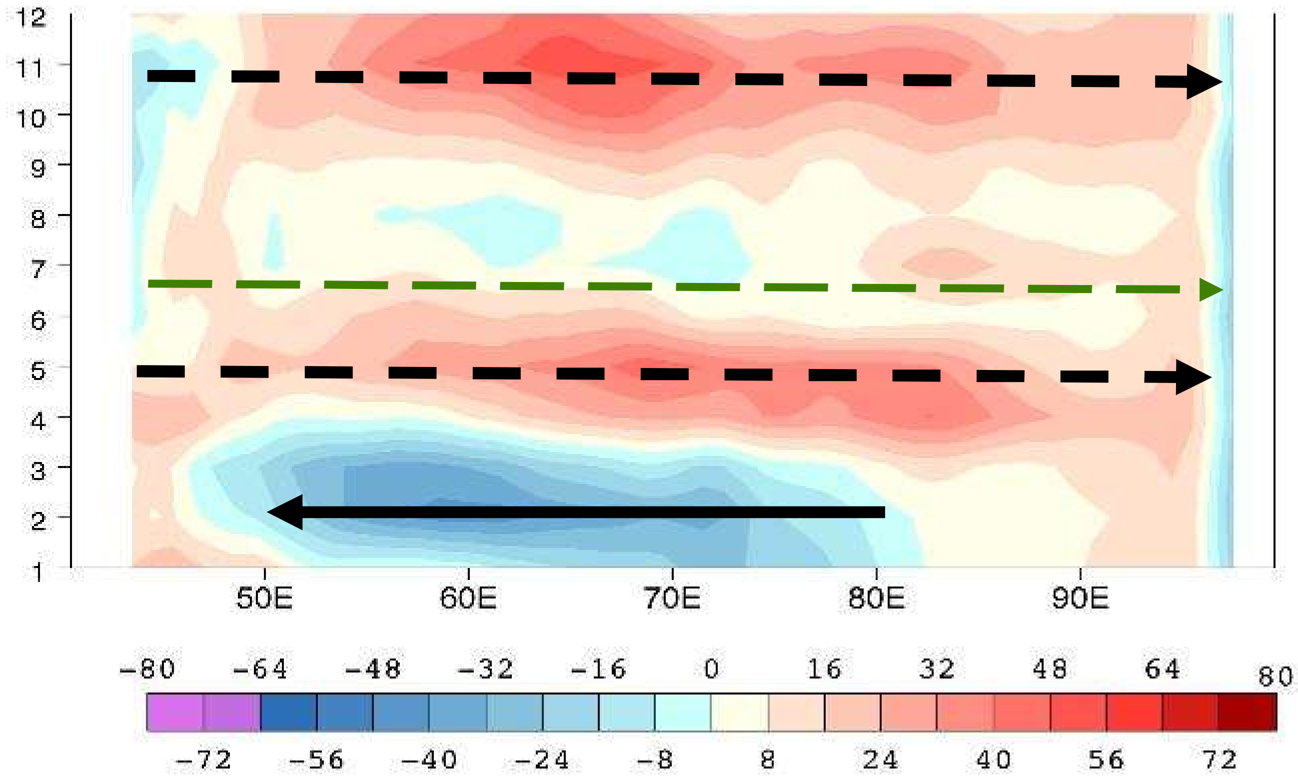
SAILDRONE



3^{o}S-3^{o}N – surface currents

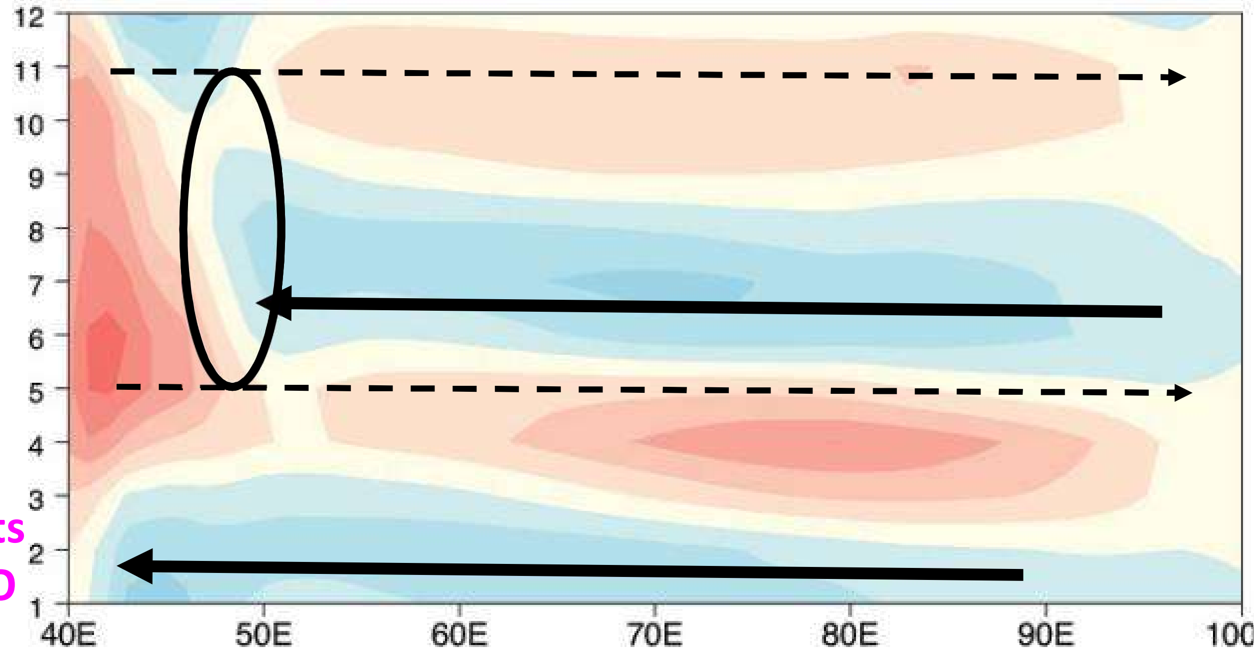
Observations (OSCAR)

Annamalai et al. 2017, JC

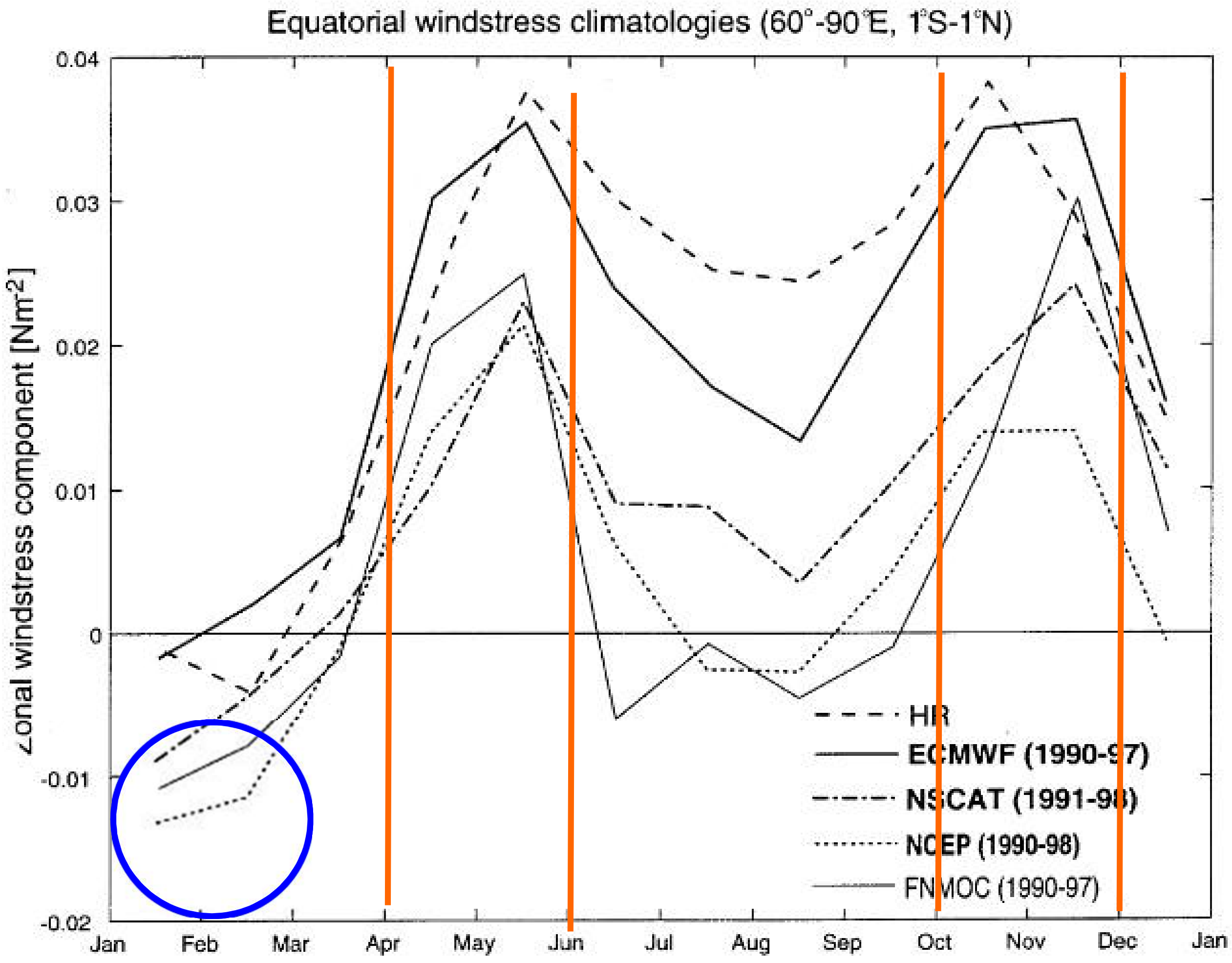
(cm/s)

3^{o}S-3^{o}N – surface currents

CMIP5 MMM

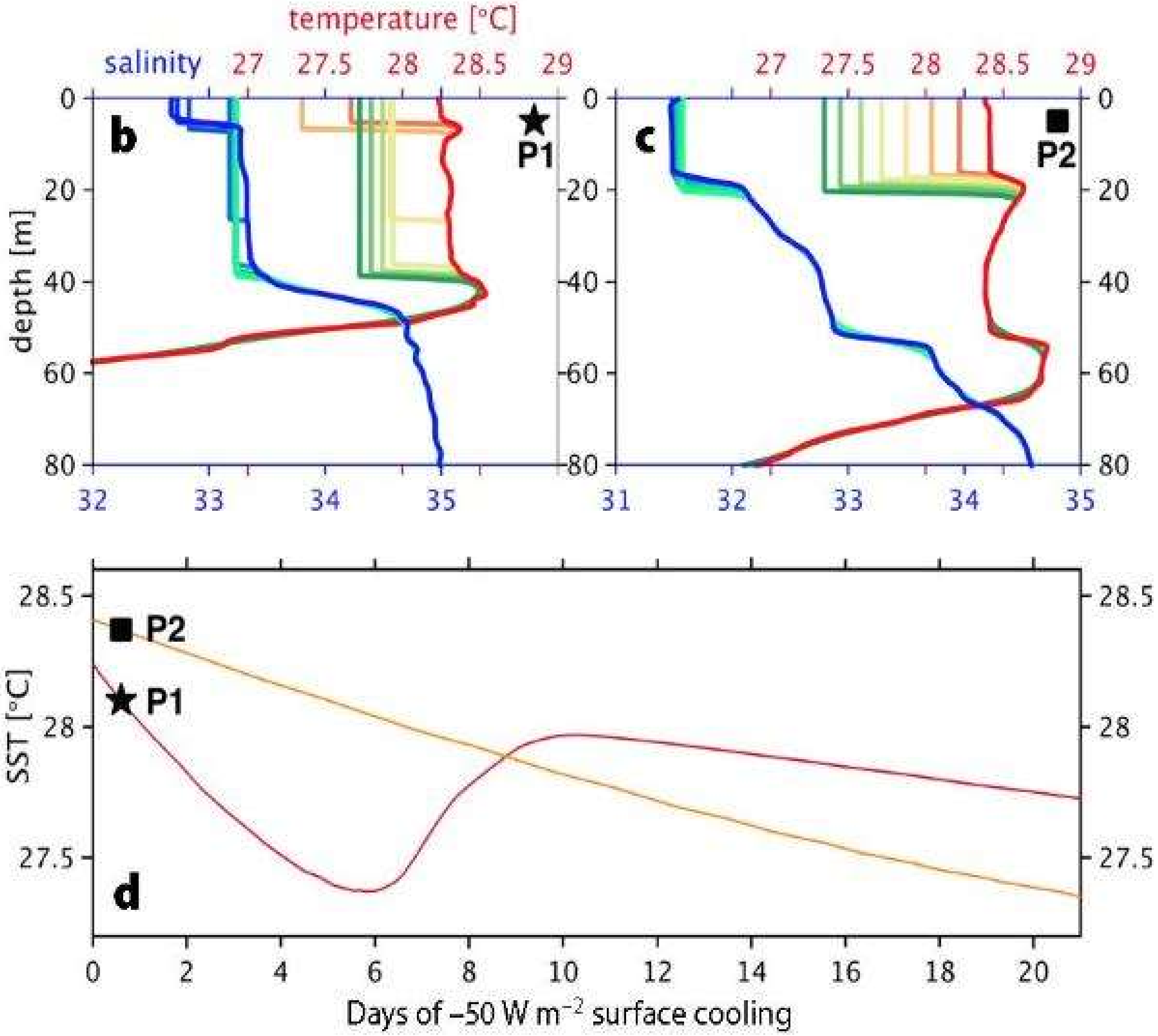


1. Weak eastward WJs
2. Unrealistic westward currents
3. Pile-up of warm waters WEIO



Schott and McCreary (2001)

Do we need in-situ near-surface wind observations to construct reliable wind-stress climatology?



temperature [°C]
salinity
27
27.5
28
28.5
29
0
20
40
60
80
depth [m]
b
P1
c
P2
32
33
34
35
31
SST [°C]
28.5
28
27.5
d
0
2
4
6
8
10
12
14
16
18
20
Days of −50 W m−2 surface cooling

As for salinity observations, I think it is good to have moored buoys in addition to Argo floats. The former gives a better time resolution and a robust mean field, and the latter gives a wide spatial coverage. Salinity observations by moored buoys are usually coarse in the vertical direction (typically 20 to 50 m intervals), because many salinity sensors are necessary to increase vertical resolution. Argo floats move vertically, and salinity profiles can be measured by one sensor. So, moored buoys and Argo floats compensate for each other in the sense of vertical resolution too. Moored buoys are costly, and Argo floats are cheap. The basic strategy must be many Argo floats plus several moored buoys at selected sites.

As for Arabian Sea mini warm pool, four moored buoys are necessary at 60, 65, 70, 75E along 5N, which is the region for the thick barrier layer. The spatial structure of the barrier layer is wide in the zonal direction, and thus intervals of 5 degrees should be good enough. South of the southern tip of India (Eq-10N, 70-80E) is the location of sparse Argo float observations, and this region should be filled by deploying more Argo floats. It is perfect if we have data at 10 m intervals from moored buoys and 1 m intervals from Argo floats in the upper 200 m. (I have no idea if observations at each 10 m depth is feasible for moored buoys. But 1-m resolution for Argo floats sounds more likely.)