Near surface circulation and downward ocean heat pumping induced by Tropical Cyclones in the Bay of Bengal

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IOGOOS, Oct 18-20, 2012, Cape Town, South Africa

1. Background

Tropical Cyclones (TCs) of the BoB have strong societal & economic consequences;

Climatically, TCs - mixing agent – pump heat downward into the tropical Thermocline, and then transport poleward, playing an important role in regulating global meridional ocean heat transport & heat balance (*Emanuel 2001; Sriver and Huber 2007; Sriver et al. 2008*).

3 Steps are suggested to be involved in this scenario:

Emanuel (2001)

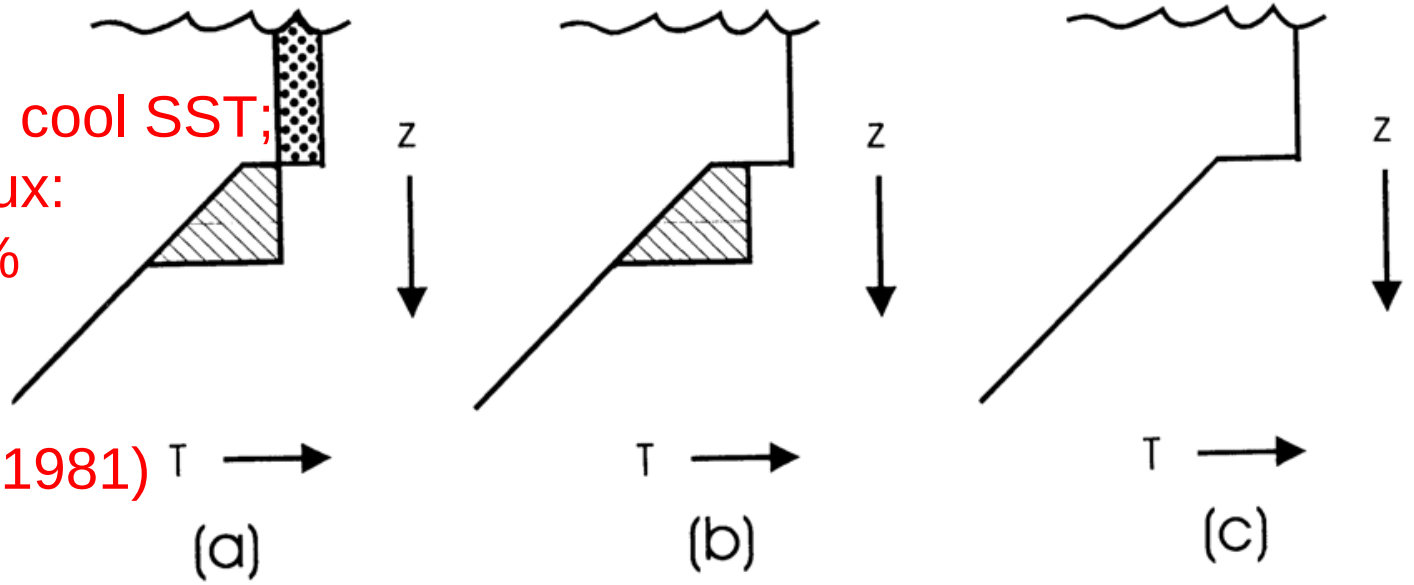
Strong wind: T homogenization

Tm restoration after TC by heating = DOHP

The pumped heat is transported away

Mixing: cool SST;
Heat flux:
10-15%

(e.g.
Price, 1981)



Based on this, Sriver & Huber (2007), Sriver et al. (2008) estimated global TCs DOHP

Question: Is this scenario hold for the Indian Ocean, especially the Bay of Bengal, where freshwater flux is important and barrier layer exist?

Goal:

- ***Understand the upper ocean response & processes to TC forcing in the Bay of Bengal (BoB);***

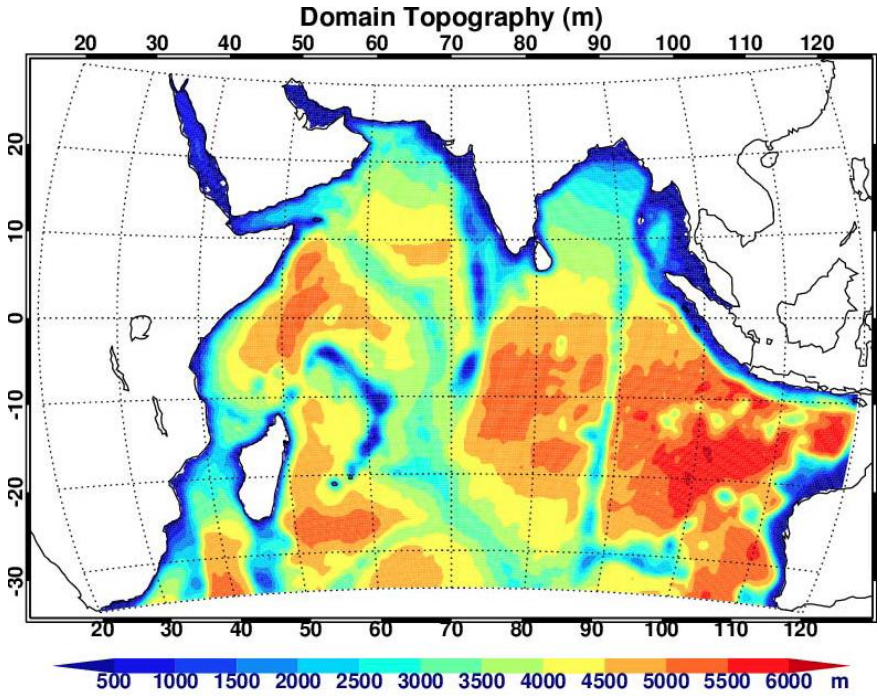
- ***Quantify the BoB TCs Downward Ocean Heat Pumping (DOHP), & compare with the estimates of Sriver & Huber (2007), Sriver et al. (2008) using SST & fixed or climatological hm.***

2. Approach

Ocean General Circulation Model (OGCM) experiments: (i)Lack of 3-D, spatially & temporally continuous observations; (ii) OGCM – isolate TC effects

a)OGCM: ***0.25°x0.25°*** eddy permitting HYCOM, ***32 vertical layers*** for the Indian Ocean basin

Forcing: 6-hourly multi-satellite Merged 0.25°x0.25° CCMP wind, TRMM rain, 0.7°x0.7° ERA-I Other fields.

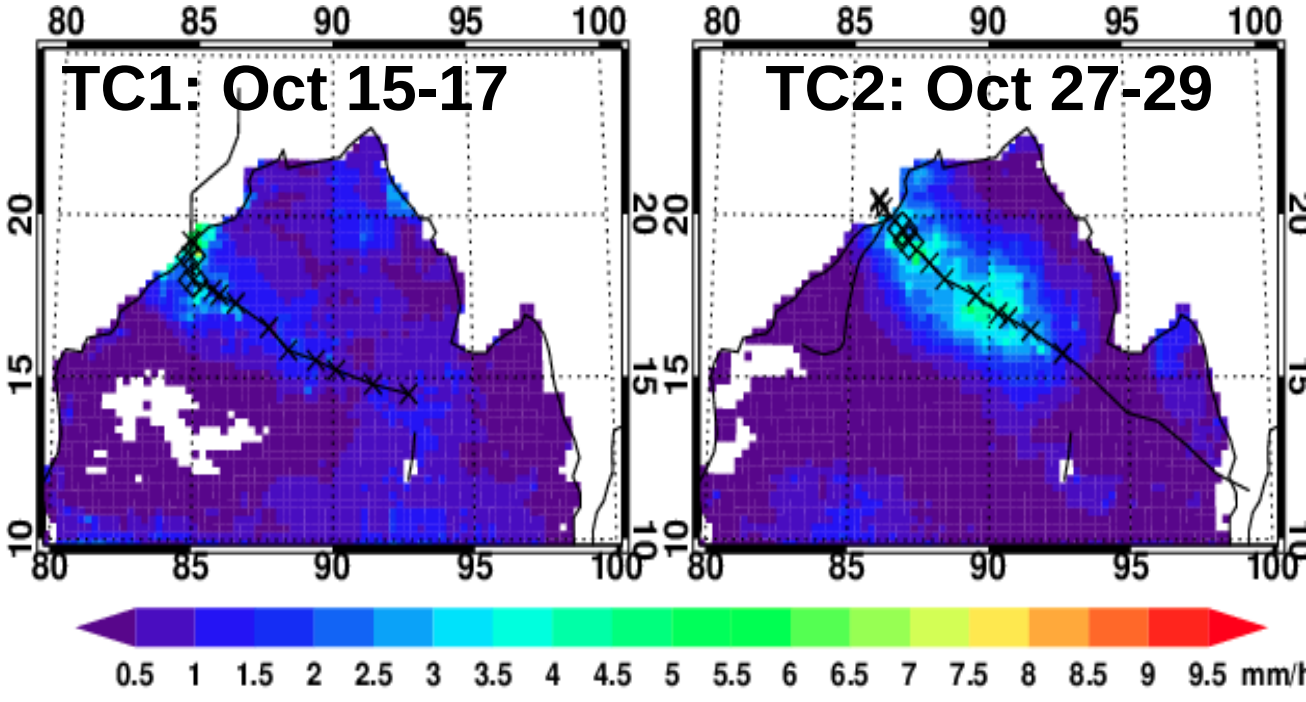


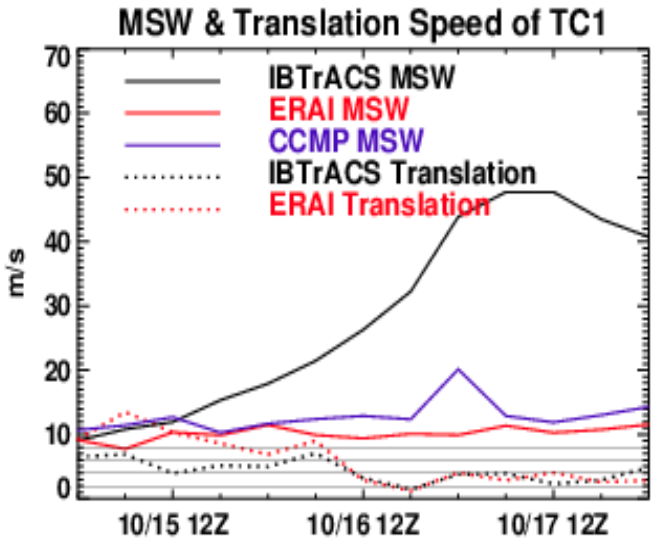
b) The two TCs during October **1999**, landed near Orissa, India in the BoB

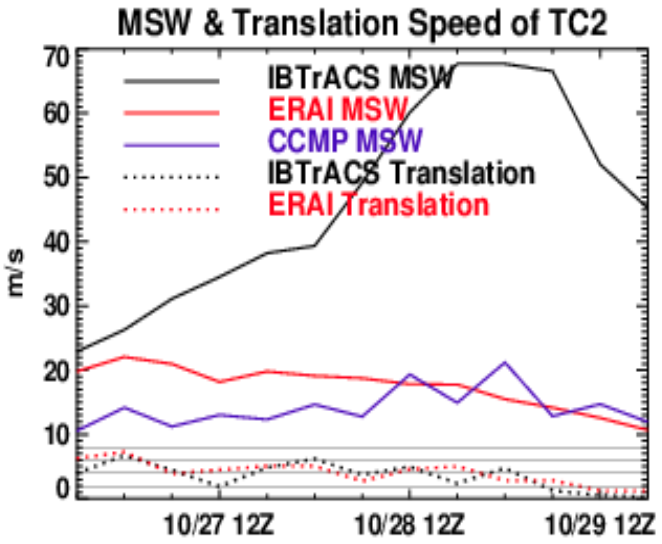
Importance of in situ measurement:

Satellite: can not Observe high wind associated with strong rain

TRMM Precipitation & TC Tracks





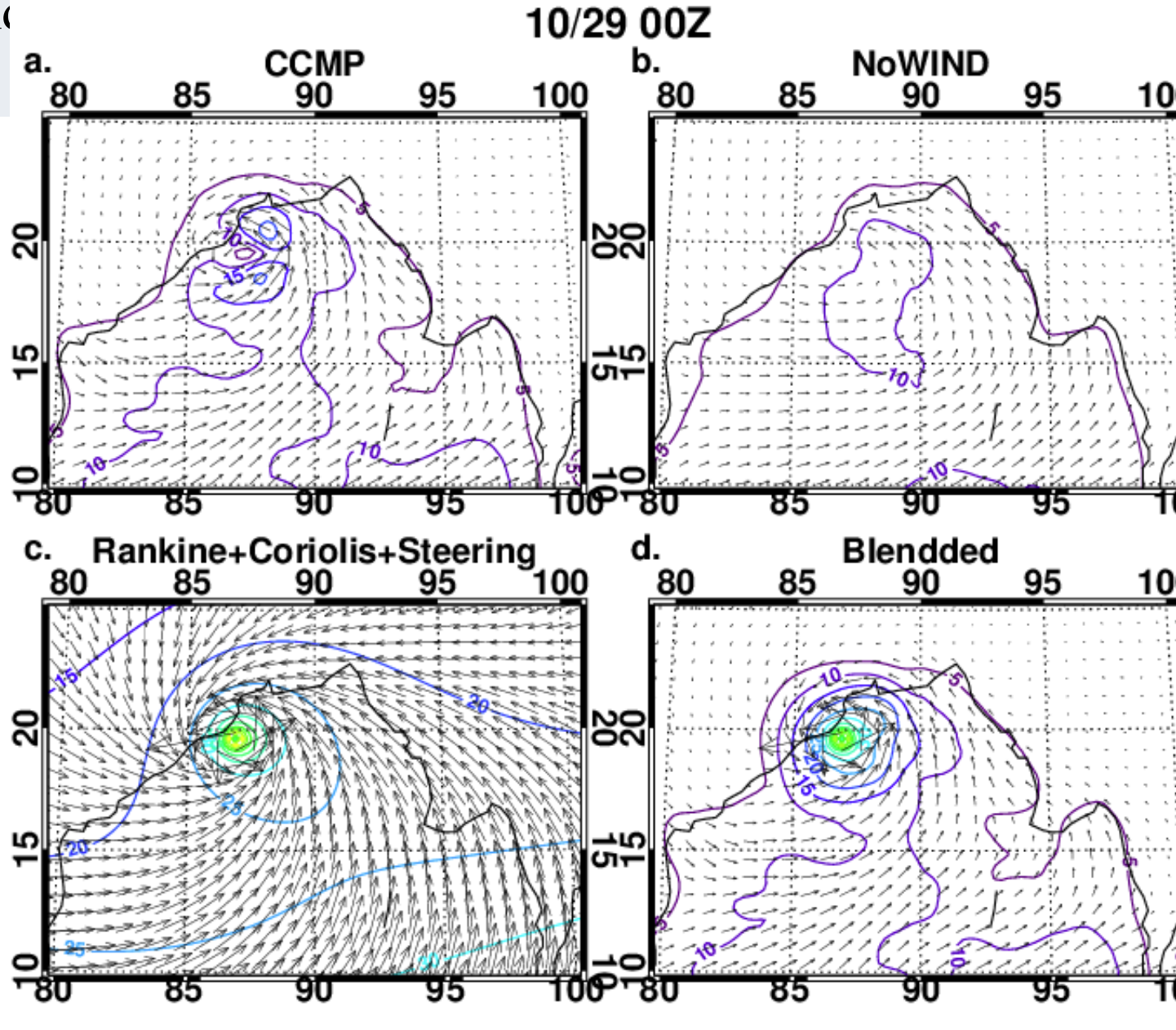


Modified Rankine vortex (Holland 1980) is used to reconstruct TC's high wind

Reconstruct:

>45m/s for TC1;

>65m/s for TC2

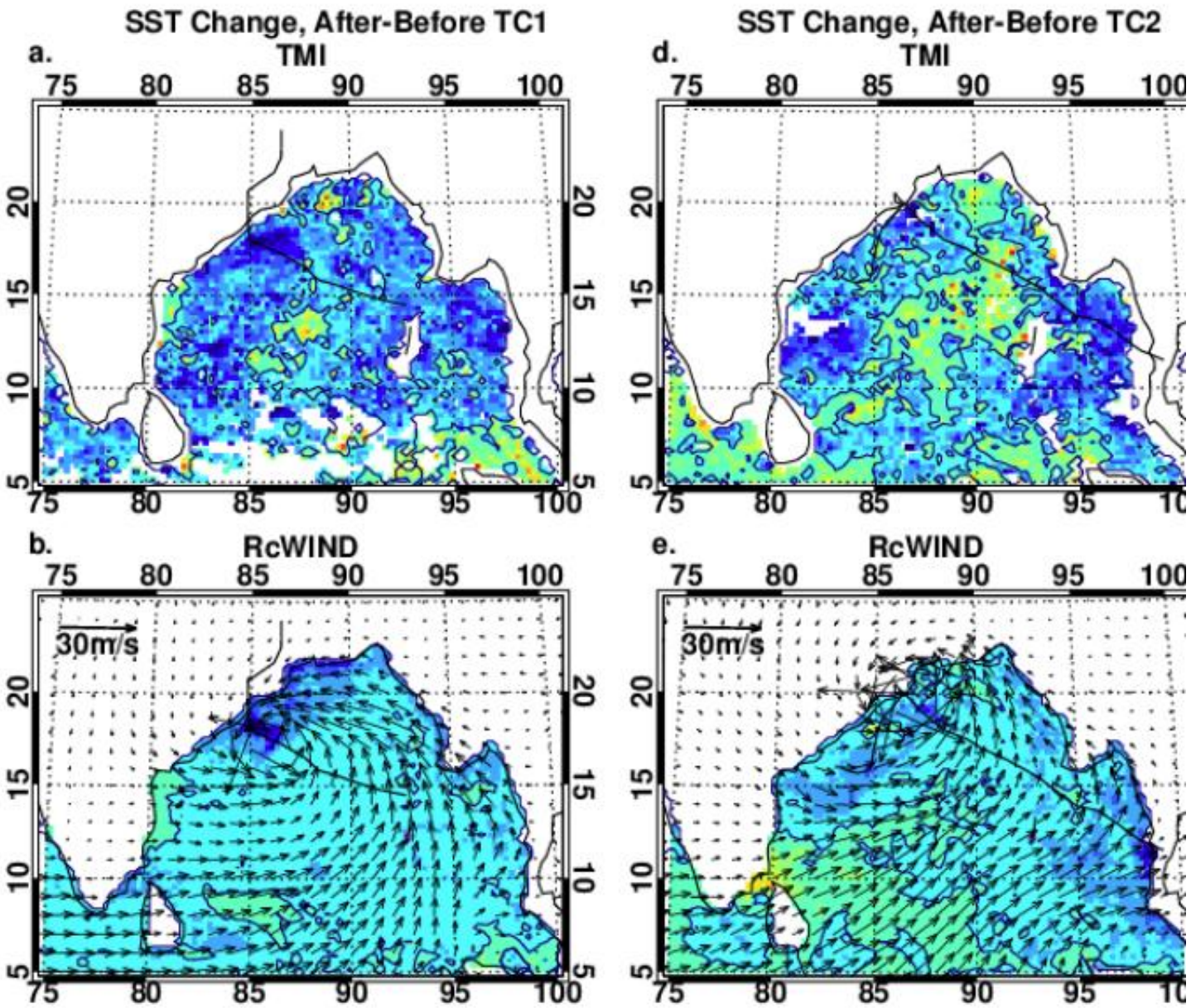


c) HYCOM Experiments

Group	Model Runs	Forcings	Space Ramping	Time Ramping	Study Purpose
A	MR	air temperature, radiative flux, and humidity from ERAI; wind from CCMP; rain rate from ERAI before 1998, from TRMM since 1998	None	None	Model/data comparison
A & B	RcWIND	wind speed and stress re-constructed for high wind period of TC1 and TC2	2 times of 35-kt radius	None	Model/data comparison and effect of wind
B	NoWIND	wind speed and stress filtered for TC1 and TC2	70°E-75°E, 105°E-110°E, 0°-5°N.	Before TC1 and after TC2	Wind processes (mixing, transport, fluxes, etc.)
B	NoRAIN	precipitation filtered for TC1 and TC2	70°E-75°E, 105°E-110°E, 0°-5°N	before and after TC2	Effect of rain
B	NoRAD	radiative fluxes filtered for TC1 and TC2	70°E-75°E, 105°E-110°E, 0°-5°N	before and after TC2	Effect of radiation
B	NoTC	all the forcings filtered for TC1 and TC2	70°E-75°E, 105°E-110°E, 0°-5°N	before and after TC2	Total TC effects
C	NoWSTR	wind stress filtered for TC1 and TC2	70°E-75°E, 105°E-110°E, 0°-5°N.	Before TC1 and after TC2	Wind processes (mixing, transport, etc.)
C	NoWSPD	wind speed filtered for TC1 and TC2	70°E-75°E, 105°E-110°E, 0°-5°N.	Before TC1 and after TC2	Wind effect on surface heat flux

3. Results *a) Model/data Comparison*

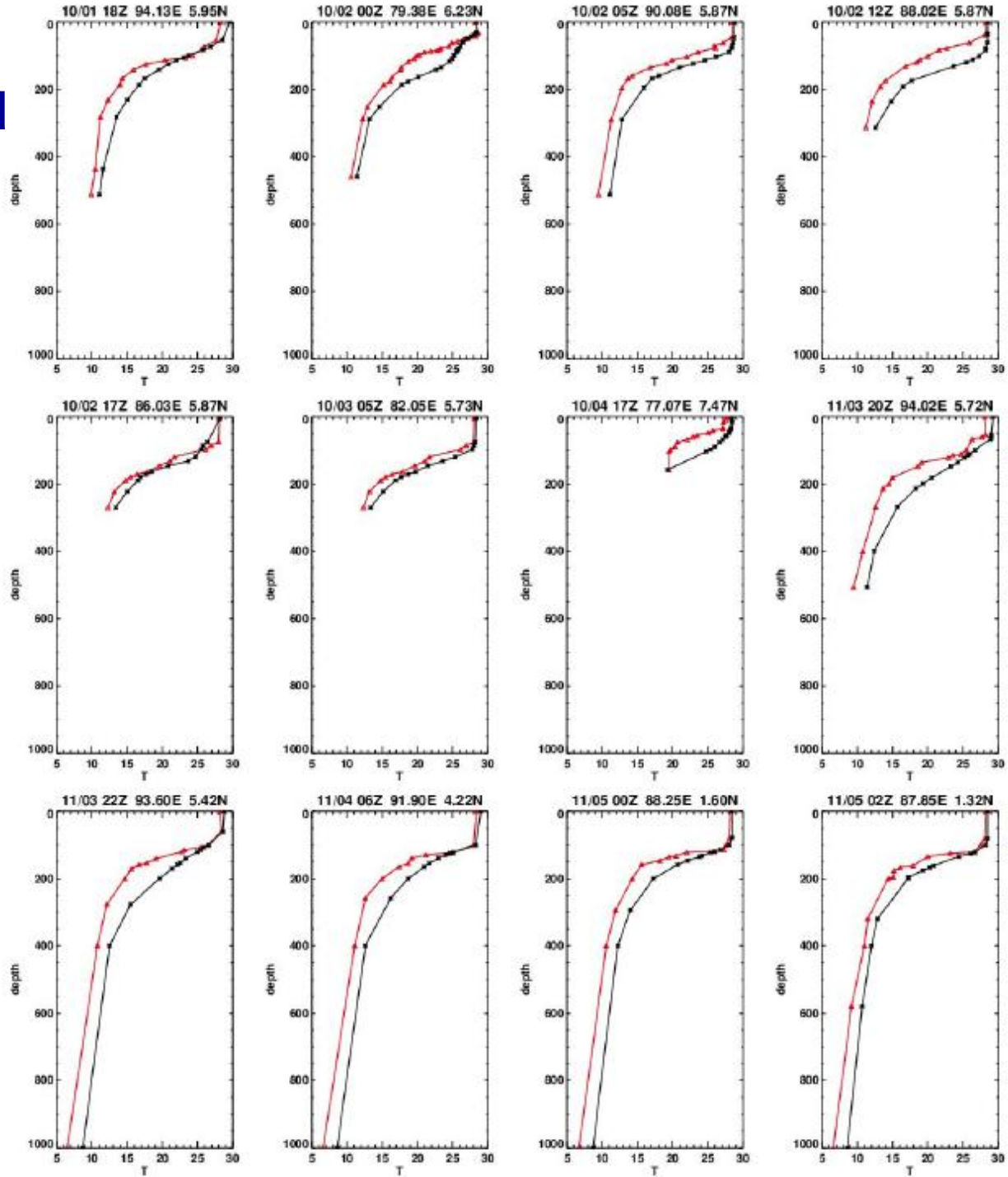
SST (after–before) TCs



Observed/simulated Temp profiles at various locations & times of the Southern Bay:

Red: observed

Black: RcWIND Exp

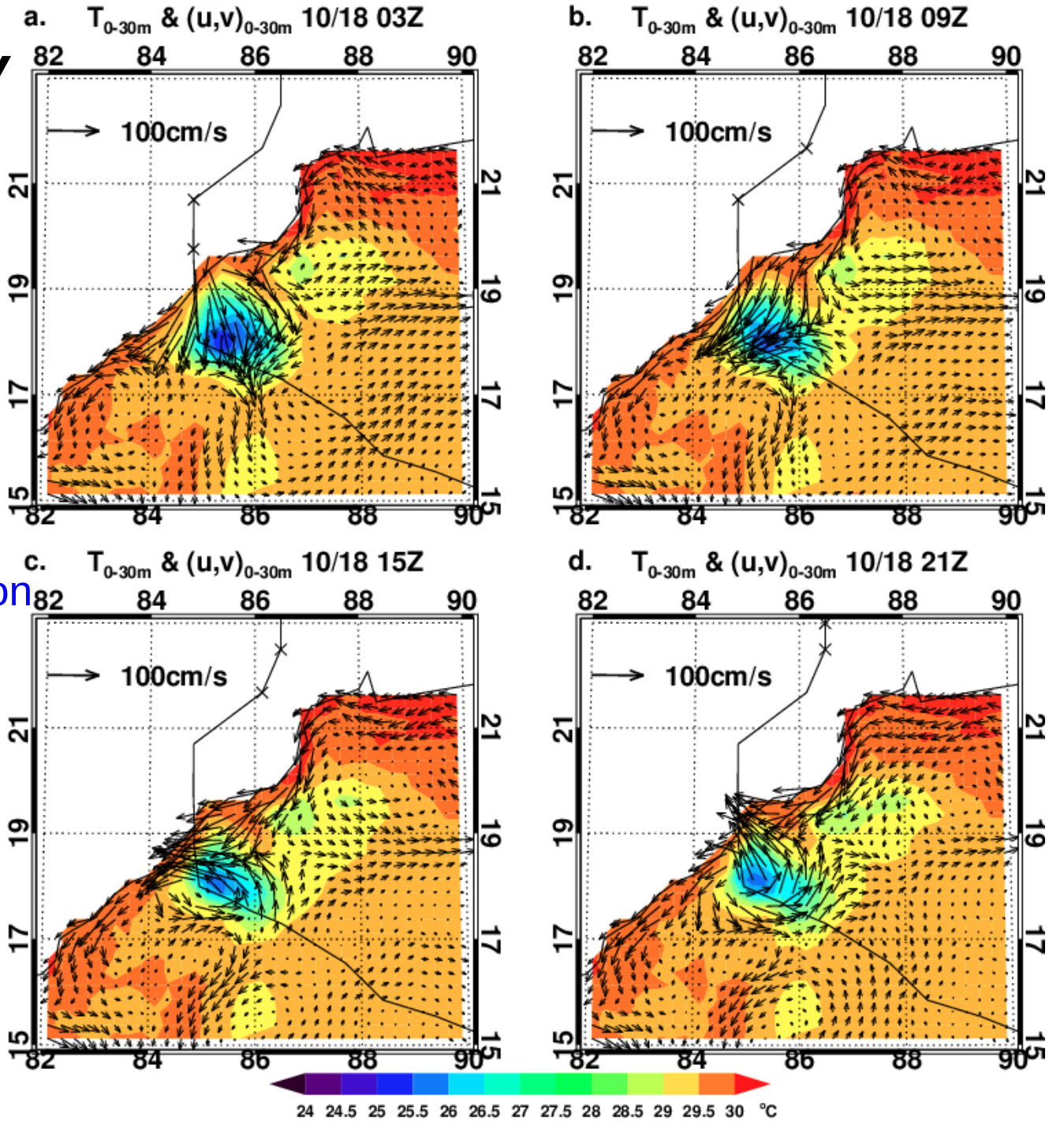


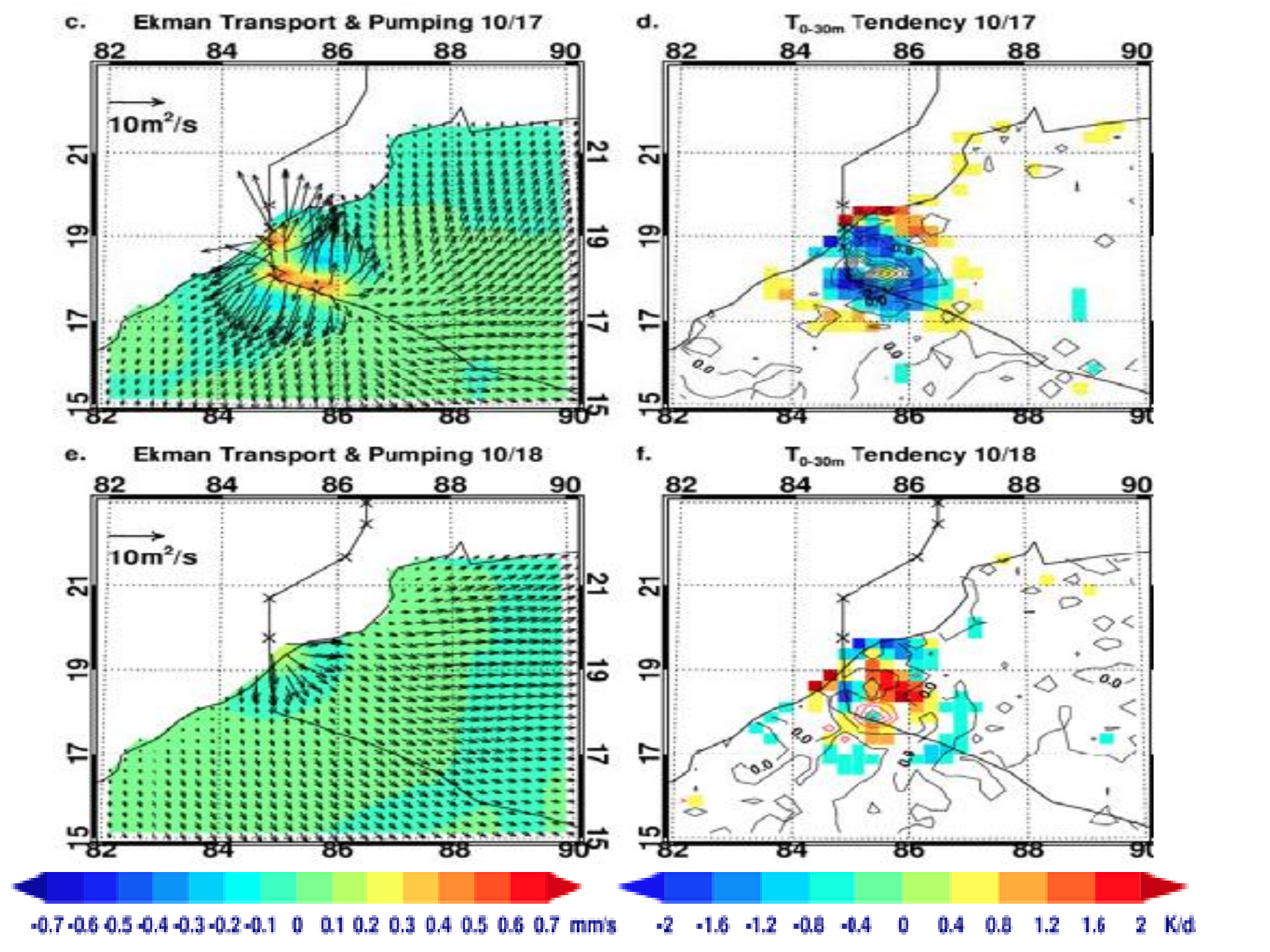
Thanks for Dr. Luc Bujold for providing buoy and cruise observation data

b) 0-30m T & V RcWIND exp:

Oct 18

Cooling: 3~4C;
Rightward bias;
Near Inertial Oscillation



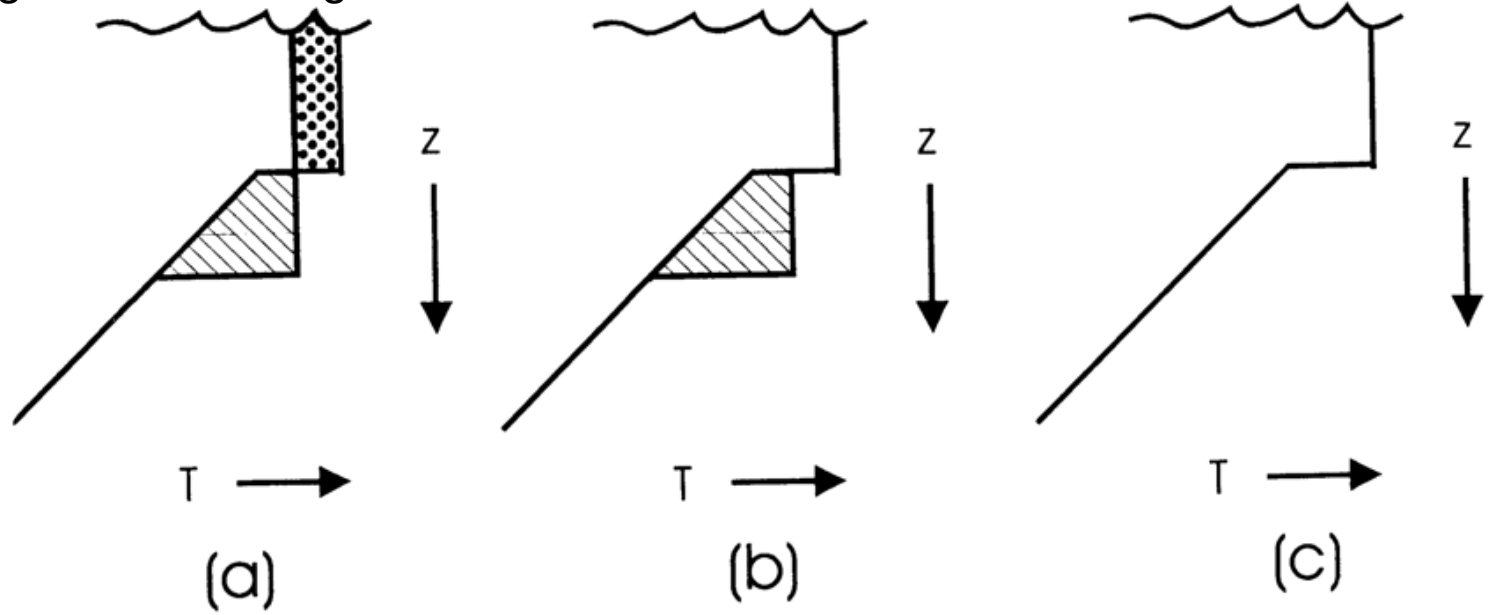

c. Ekman Transport & Pumping 10/17
d. $T_{0\text{-}30m}$ Tendency 10/17
e. Ekman Transport & Pumping 10/18
f. $T_{0\text{-}30m}$ Tendency 10/18
10m²/s
82 84 86 88 90
15 17 19 21
-0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 mm/s
-2 -1.6 -1.2 -0.8 -0.4 0 0.4 0.8 1.2 1.6 2 K/d

c) Impact of TCs on the BoB Ocean heat content (OHC)

Strong wind: T homogenization

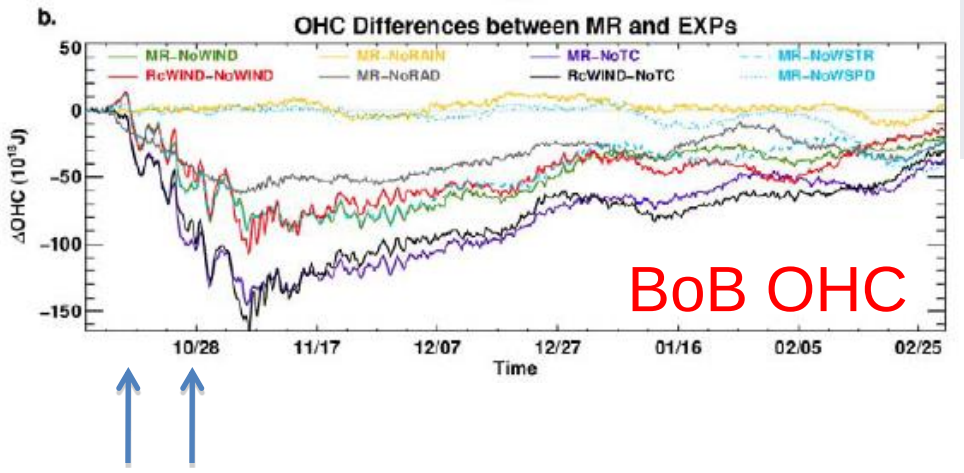
Tm restoration after TC by heating = DOHP

The pumped heat is transported away

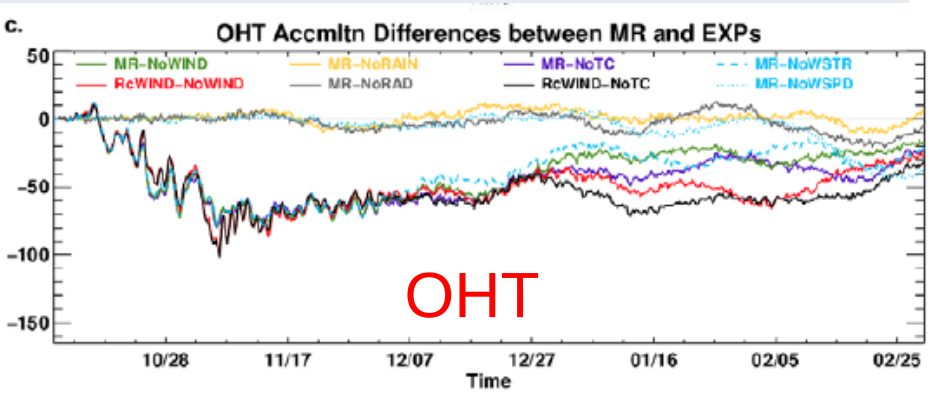


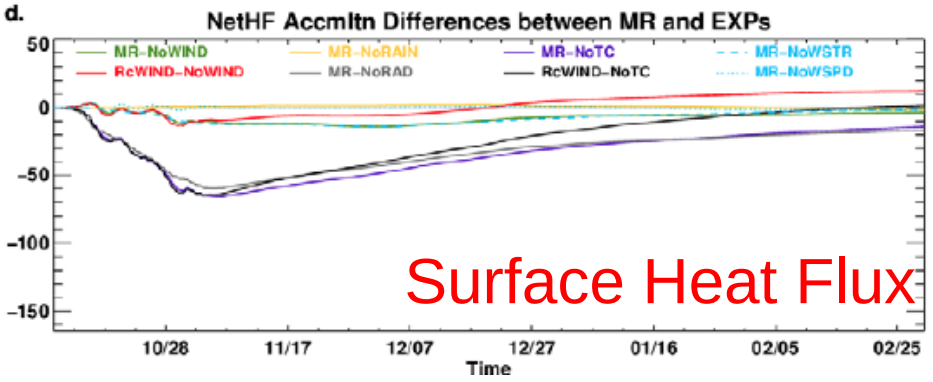
From Emanuel 2001

c) Impact of TCs on the BoB Ocean heat content (OHC)



TC1 TC2





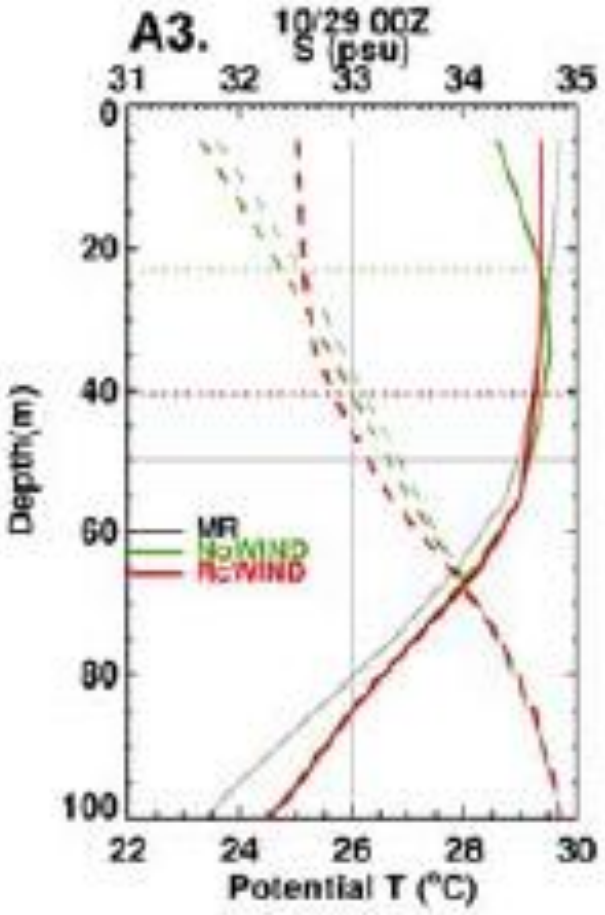
Advantage: no assumptions

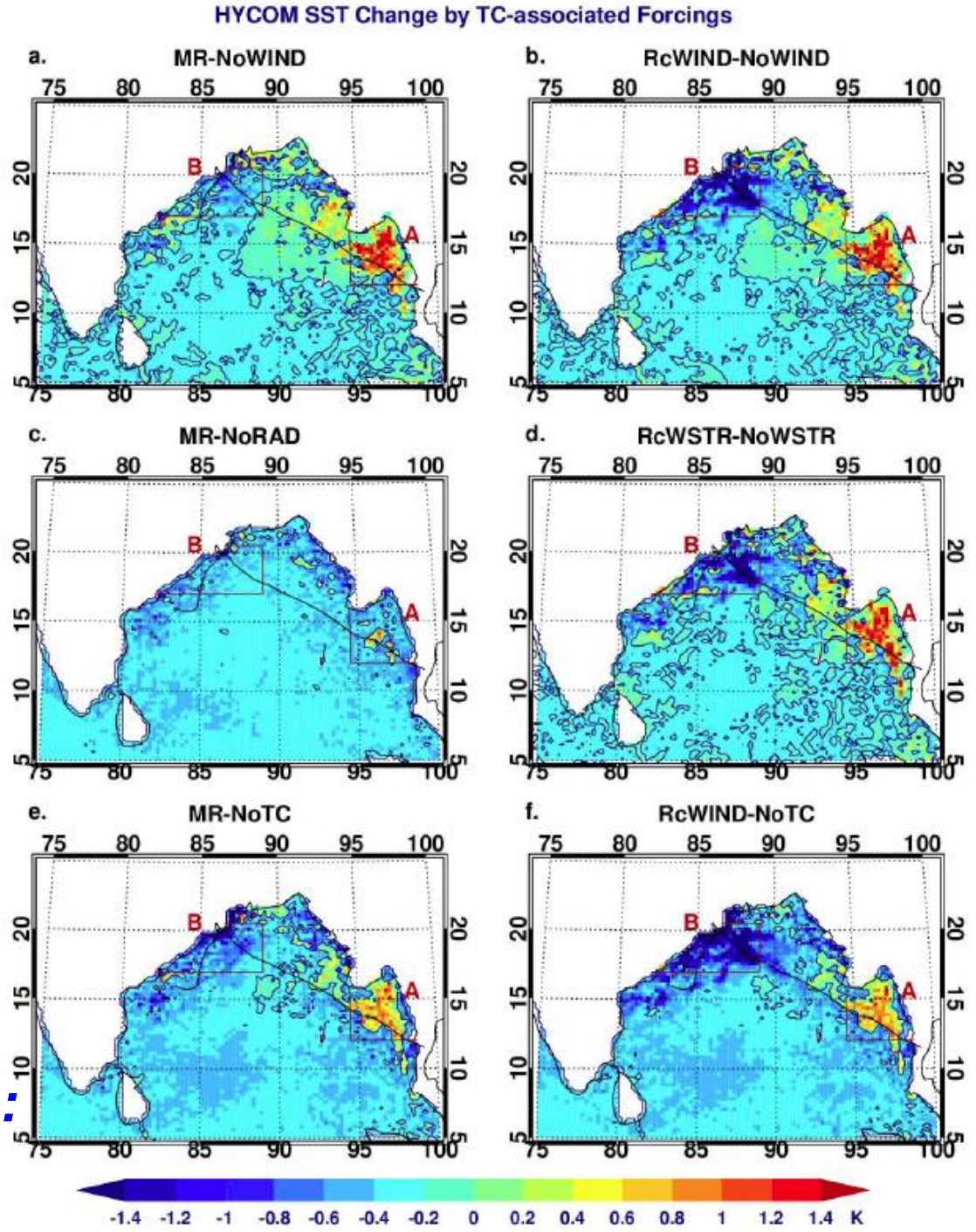
Needed:DOHP=integrated NetHF (during TC+after TC)

1.74×10^{18} J

TRMM SST/climatological mixing depth [Sriver et al. 2008]	0.85×10^{20}J TC1	1.18×10^{20}J TC2
RcWIND SST/RcWIND mixing depth	0.69×10^{20}J	1.16×10^{20}J

Nov. 3 mean of SST Change due to TCs





(2) Barrier layer existence: reduce DOHP!

4. Summary

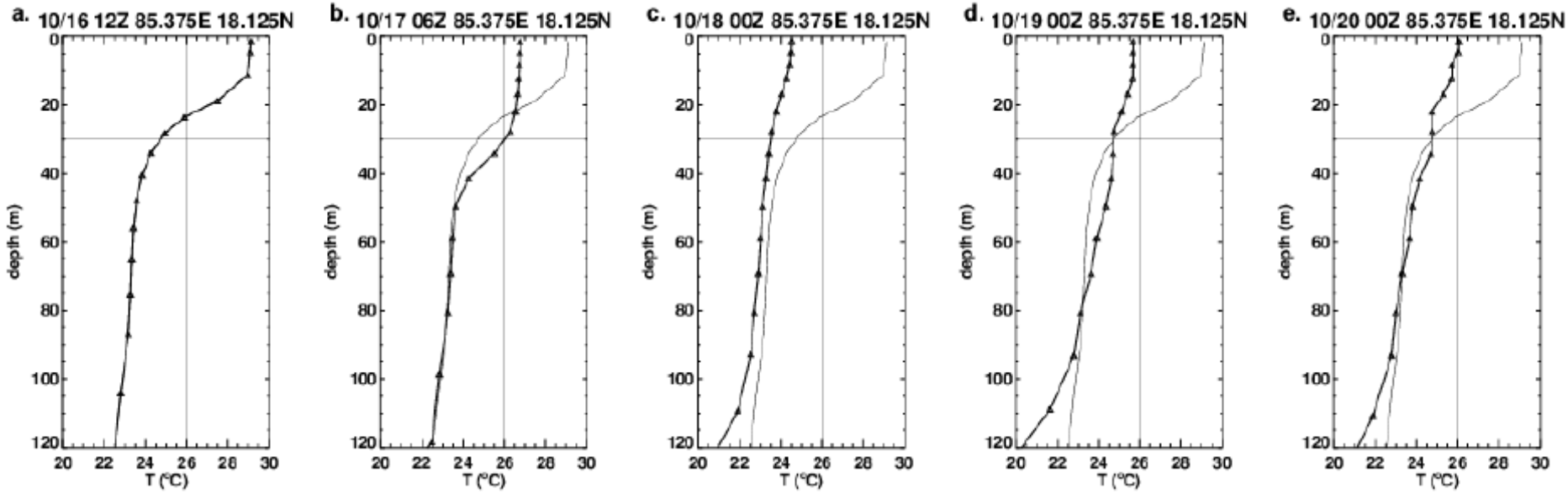
- The rightward bias of TC-induced surface cooling is caused by the asymmetry of both upwelling (+advection) and vertical mixing process;

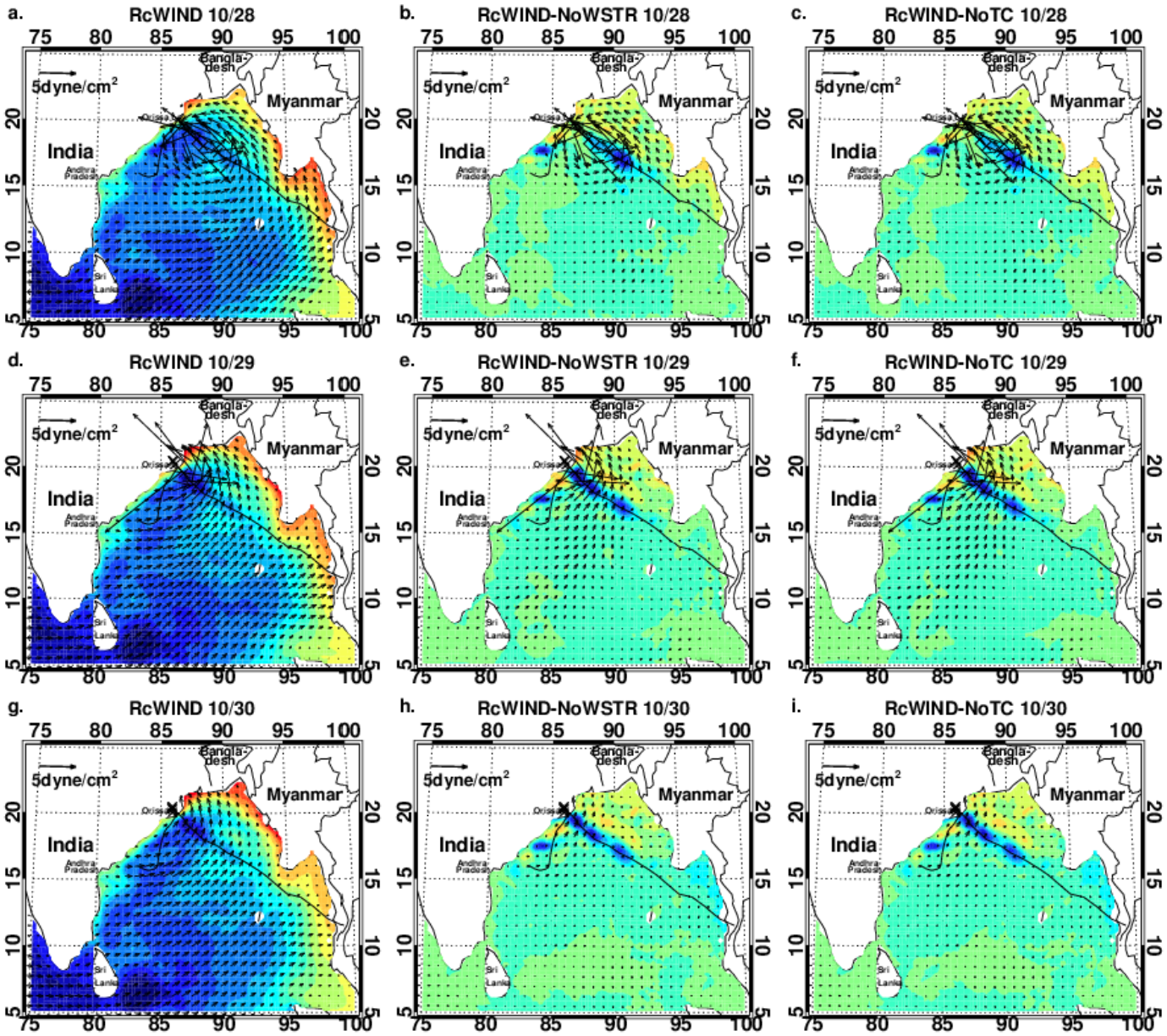
- The DOHP is an order of magnitude weaker than that estimated by the observed SST before/after TCs, due to barrier layer formation and the large effect of solar radiation associated with the TCs.

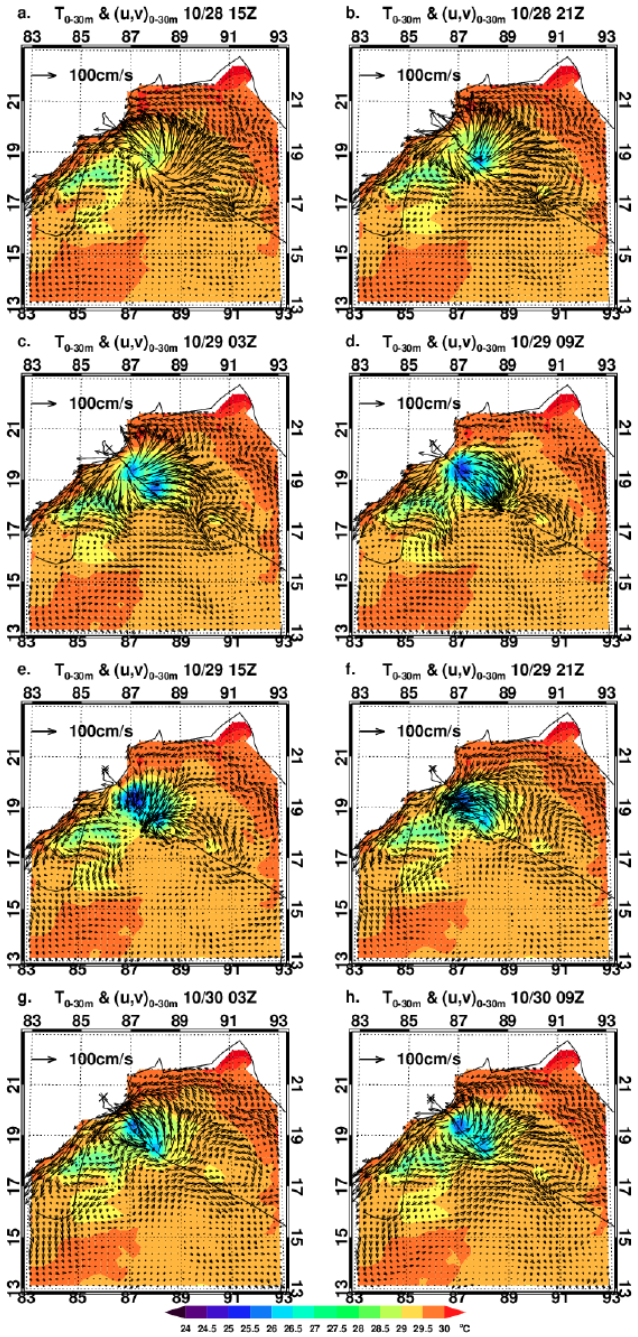
IOGOOS – in situ 3-D sustained observations, combined with Model experiments, is important for advancing our understanding and improved prediction of the Indian Ocean processes & its role in regional/global climate

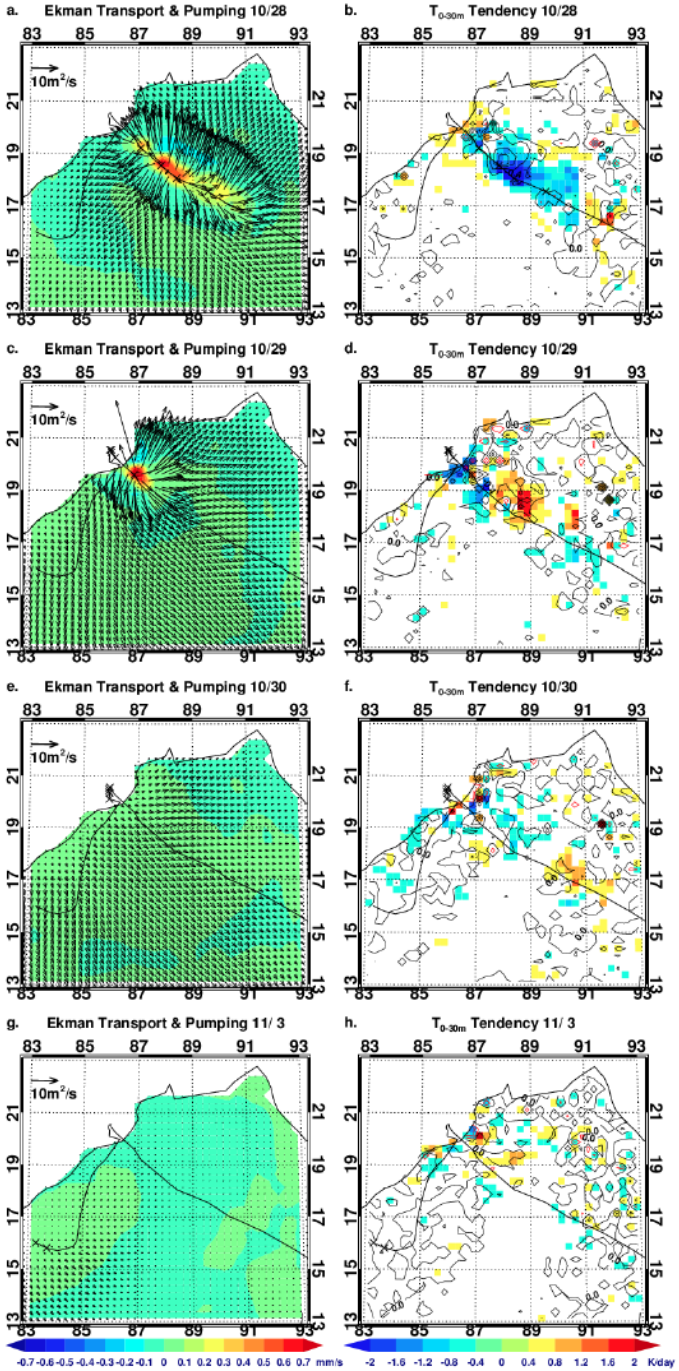
Thank you for your attention!

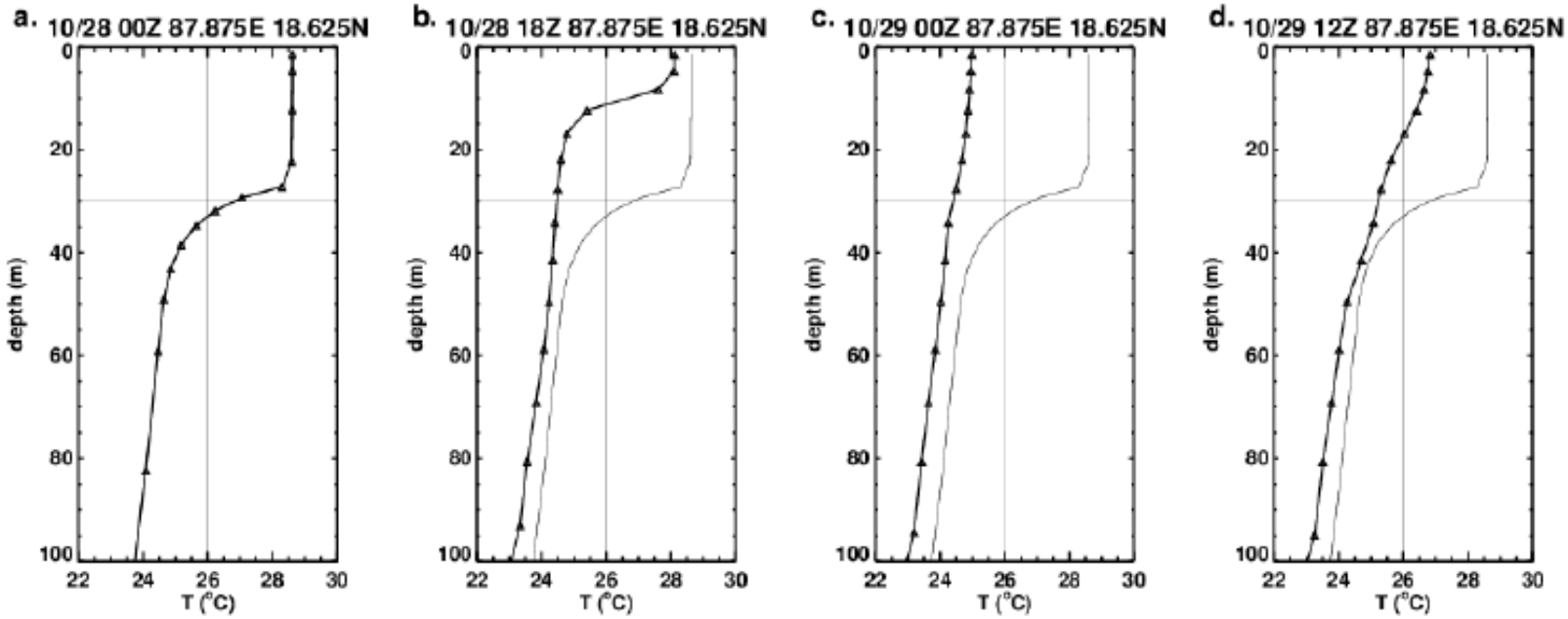
Evolutions of T – profile during TC1




a.
RcWIND 10/28
b.
RcWIND-NoWSTR 10/28
c.
RcWIND-NoTC 10/28
d.
RcWIND 10/29
e.
RcWIND-NoWSTR 10/29
f.
RcWIND-NoTC 10/29
g.
RcWIND 10/30
h.
RcWIND-NoWSTR 10/30
i.
RcWIND-NoTC 10/30
5dyne/cm2
India
Myanmar
Bangla-desh
Sri Lanka
Andhra Pradesh
Orissa
75
80
85
90
95
100
5
10
15
20

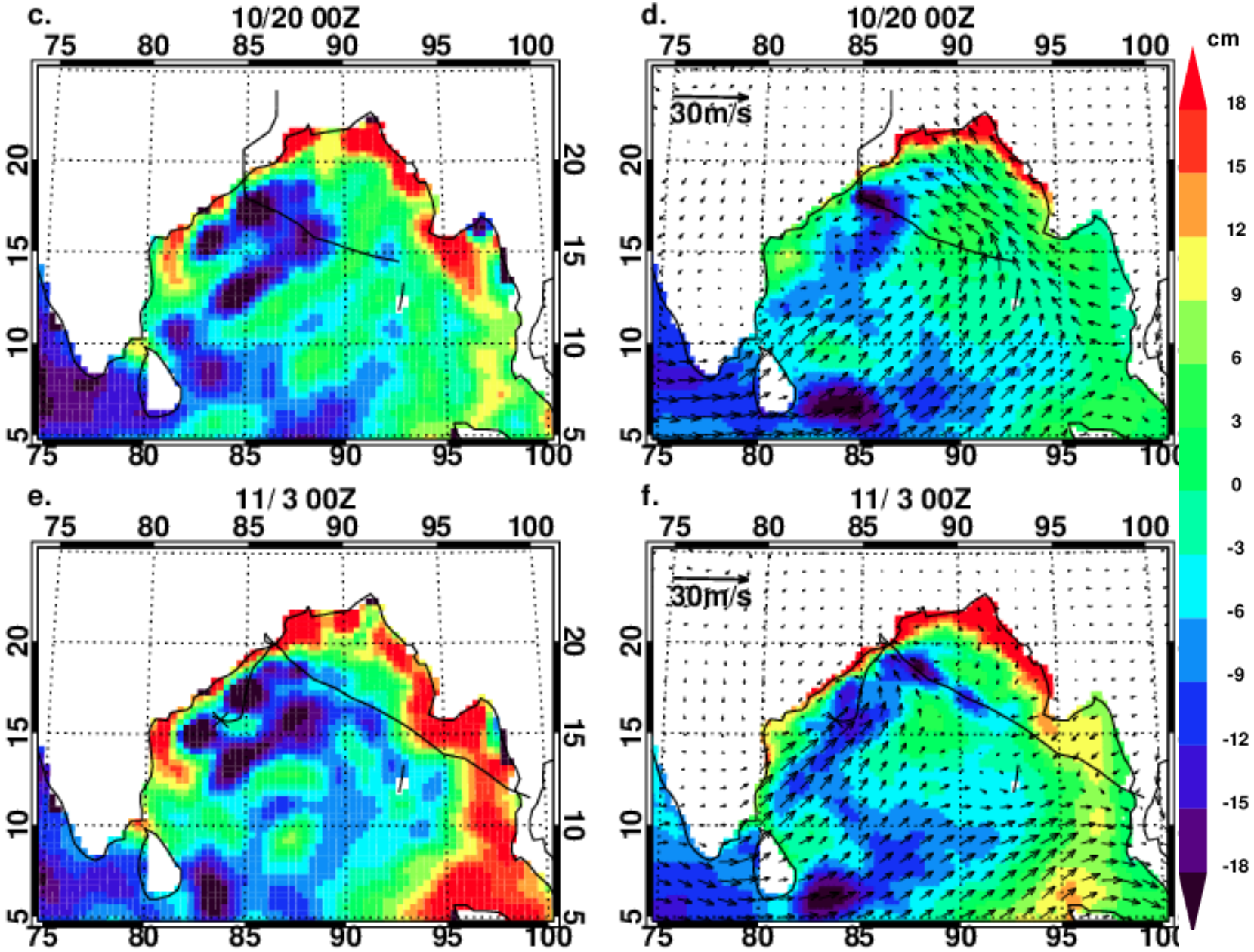

a. T0-30m & (u,v)0-30m 10/28 15Z
b. T0-30m & (u,v)0-30m 10/28 21Z
c. T0-30m & (u,v)0-30m 10/29 03Z
d. T0-30m & (u,v)0-30m 10/29 09Z
e. T0-30m & (u,v)0-30m 10/29 15Z
f. T0-30m & (u,v)0-30m 10/29 21Z
g. T0-30m & (u,v)0-30m 10/30 03Z
h. T0-30m & (u,v)0-30m 10/30 09Z
100cm/s
24 24.5 25 25.5 26 26.5 27 27.5 28 28.5 29 29.5 30 °C


a. Ekman Transport & Pumping 10/28
b. T0-30m Tendency 10/28
c. Ekman Transport & Pumping 10/29
d. T0-30m Tendency 10/29
e. Ekman Transport & Pumping 10/30
f. T0-30m Tendency 10/30
g. Ekman Transport & Pumping 11/ 3
h. T0-30m Tendency 11/ 3
10m²/s
-0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 mm/s
-2 -1.6 -1.2 -0.8 -0.4 0 0.4 0.8 1.2 1.6 2 K/day


a. 10/28 00Z 87.875E 18.625N
b. 10/28 18Z 87.875E 18.625N
c. 10/29 00Z 87.875E 18.625N
d. 10/29 12Z 87.875E 18.625N
depth (m)
0
20
40
60
80
100
22
24
26
28
30
T (°C)

OBS AVISO SSHA

Model SSHA & wind



b) SSHA & V (0-30m) induced by TC1