Coupled Physical Processes in the Bay of Bengal and Monsoon Air-Sea Interaction

"Ocean Mixing and Monsoon (OMM)"

Programme under the National Monsoon Mission, 2013-2017

INCOIS NIOT NIO IISc. SAC TIFR Hyderabad IIT Madras IIT BBS

Monsoon Mission Review 18-20 February 2015

INDO – US collaborative Project ASIRI-OMM

Air-Sea Interactions in the Northern Indian Ocean – Regional Initiative (ASIRI)

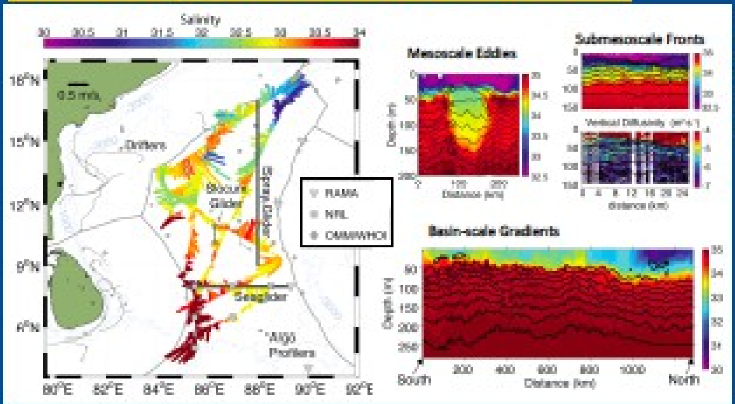
Ocean Mixing and Monsoons (OMM)


India R/V Sagar Nidhi


USA R/V Roger Revelle

Collaborating on establishing a legacy of ocean observations, models, human and technological capacity for improved cyclone and intraseasonal monsoon forecasts

A multi-faceted approach for multi-scale processes



Far left: Salinity and velocity data collected during the 2013 Pilot. Map shows ship track and observational assets, many highlighted below. Subpanels: Salinity sections at different scales highlighting some of the physical features of the Bay of Bengal.

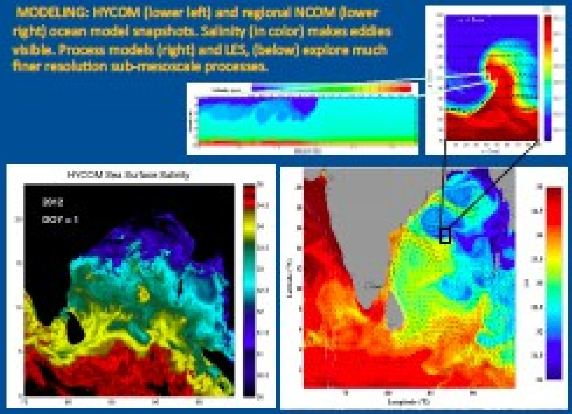
Training and capacity building

Shipboard training and research on joint cruises: Nov-Dec 2013, June 2014, August 2014 and November 2014

Bay of Bengal Upper Ocean Physics Workshop IISc Bengaluru July 9-21, 2014

Multi-scale Ocean Modeling

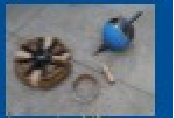
MODELING: HYCOM (lower left) and regional NCOM (lower right) ocean model snapshots. Salinity (in color) makes eddies visible. Process models (right) and LES, (below) explore much finer resolution sub-mesoscale processes.



Observational Tools

Long term endurance gliders Spray (left) and Seaglider (right) measure subsurface temperature and salinity structure.

Lagrangian float follows density or pressure levels while taking measurements and is remotely programmable.

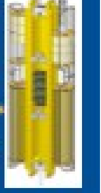


Lagrangian drifters measure near-surface ocean currents, atmospheric pressure, sea surface temperature and sea surface salinity

Air-sea flux mooring measures air-sea exchange of heat, momentum, and freshwater and temperature, salinity, and velocity in the ocean.

Turbulent motions are being measured from moorings, CTD rosettes, and autonomous profilers using chipods.

Slocum turbulence glider measures microstructure shear and mixing.



Surface wave-driven wirewalker measures temperature, salinity, currents and optical variables at cm scale resolution

Indian Institutions

Indian Institute of Science, Indian National Centre for Ocean Information Services, National Institute of Ocean Technology, National Institute of Oceanography, Indian Institute of Tropical Meteorology, Space Applications Centre, Tata Institute of Fundamental Research, Indian Institute of Technology Madras, Indian Institute of Technology Bhubaneswar

United States Institutions

Scripps Institution of Oceanography, Woods Hole Oceanographic Institution, University of Massachusetts Dartmouth, Oregon State University, University of Washington, University of Notre Dame, Colorado State University, Columbia University, University of Miami, University of Alaska, US Naval Research Laboratory

Main Science Issues/Questions:

- Pathways, persistence, balance of freshwater
- Physics of thin, fresh upper layer, lateral salinity gradients (fronts)
- Key processes of upper ocean stratification/mixing and balances
- *Consequences of shallow, fresh upper layer and deep, warm subsurface layer for air-sea coupling*

- Causes of unique near-surface air-sea gradients
- Surface flux algorithms/parameterisation
- Local atmospheric mixed layer/ABL stability, in relation to shallow-deep transition of organised convection* (*aircraft)
- *Air sea fluxes and coupling diurnal to intraseasonal scales*

Hypothesis and Approach:

Surface fresh layer influences ocean dynamics, thermodynamics, air-sea fluxes and coupling

Synthesis of multi-scale observations and models

Timeline

Six Cruises

Sl. No.	Cruises	Chief Scientist	Period	Participants
1.	Roger Revelle	Andrew Lucas Scripps	10-27 Nov, 2013	26
2.	Roger Revelle	Emily Shroyer Oregon State U.	27 Nov-13 Dec, 2013	29
3.	Sagar Nidhi	M. Ravichandran INCOIS	15 Nov-2 Dec, 2013	22
4.	Roger Revelle	Andrew Lucas Scripps	17-28 June, 2014	22
5.	Sagar Nidhi	M. Ravichandran INCOIS	19 Aug-8 Sep, 2014	22
6.	Sagar Nidhi	N. Suresh Kumar INCOIS	24 Nov-13Dec, 2014	17

61 Indian participants on *Sagar Nidhi*, 29 on *Roger Revelle* from: INCOIS NIOT NIO IISc SAC IIT BBS IIT Madras TIFR PRL NRSC NCAOR

Formal start of project: March 2014 (IISc); September 2014 (INCOIS)

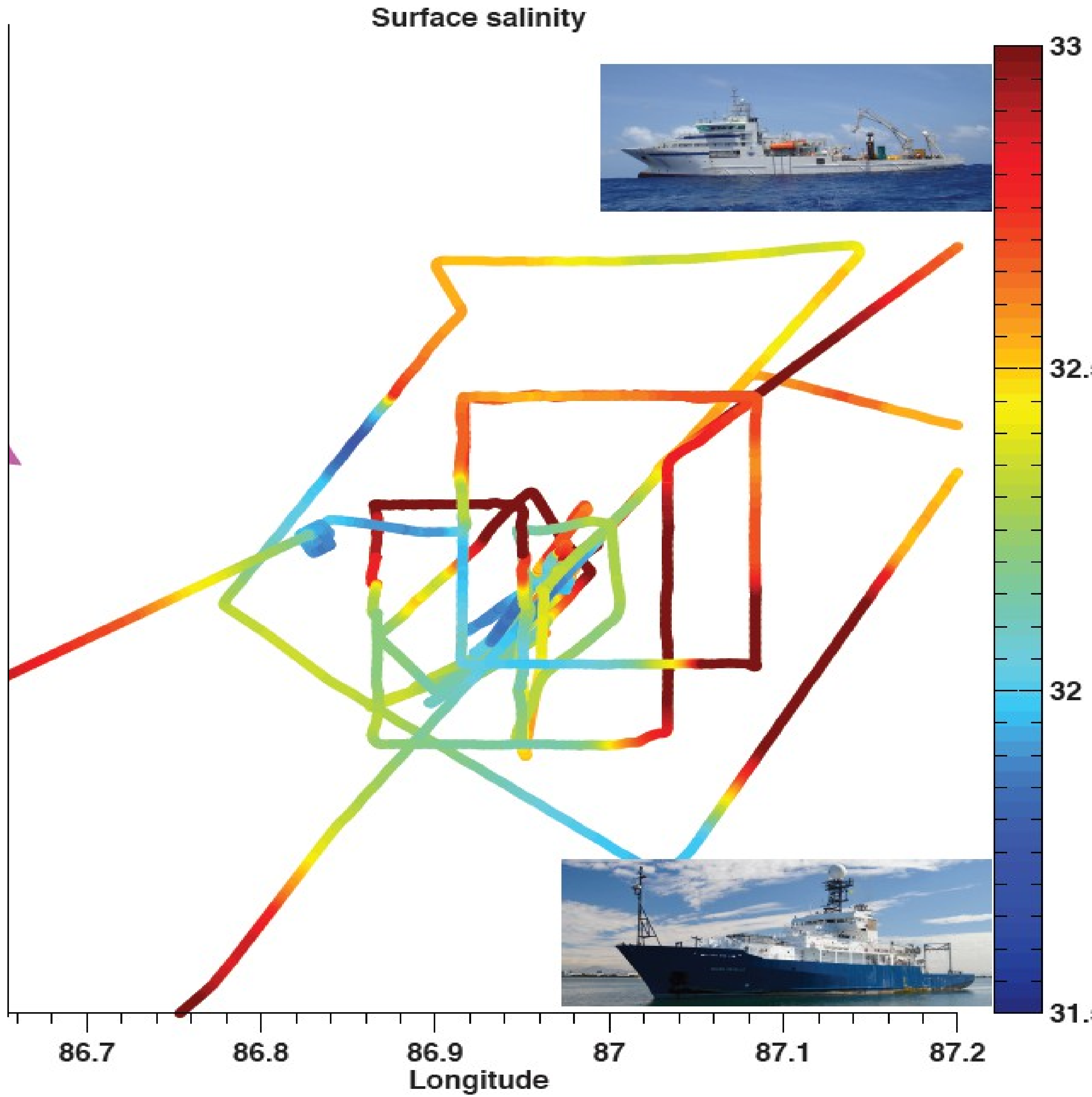
Ph.D. students

Dipanjan Chaudhuri
Sree Lekha J
V. Thanga Prakash
P. Vijay
Dheeraj Varma
S. Ganga Prasath

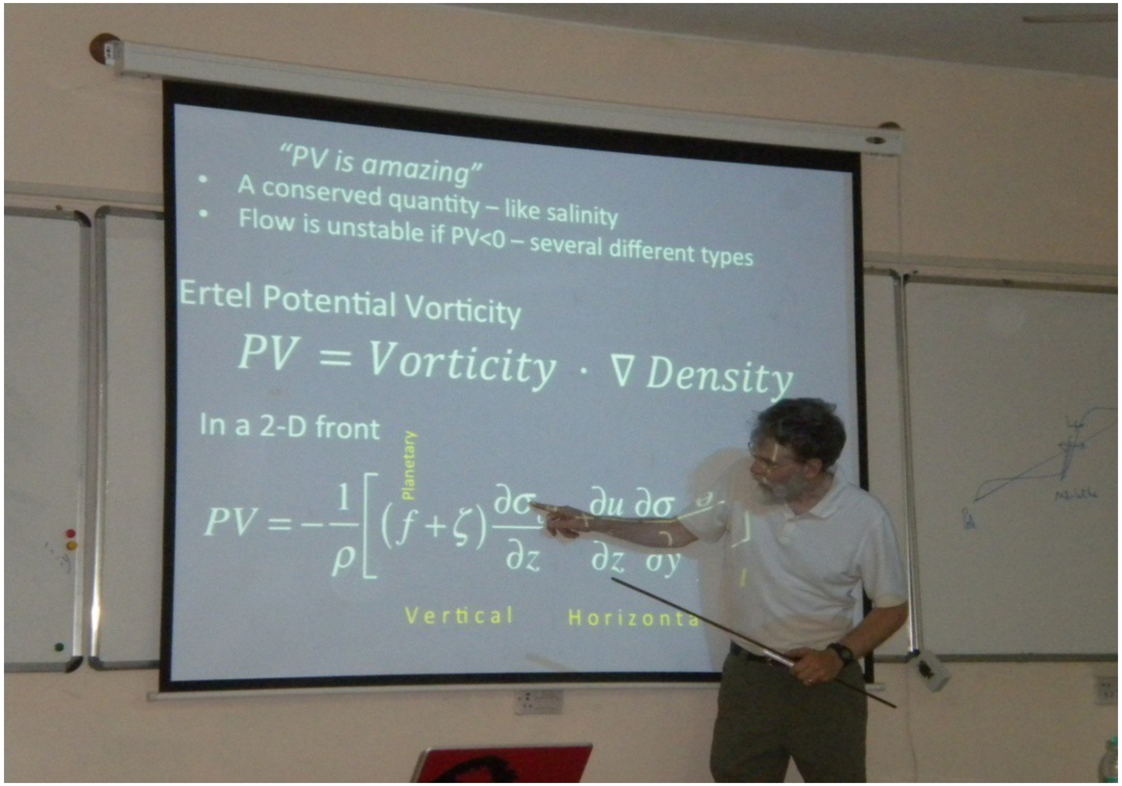
Two-ship work

Sagar Nidhi *Roger Revelle*

Nov – Dec 2013



Workshop "Bay of Bengal Upper Ocean Physics" *IISc.* 9-21 July 2014



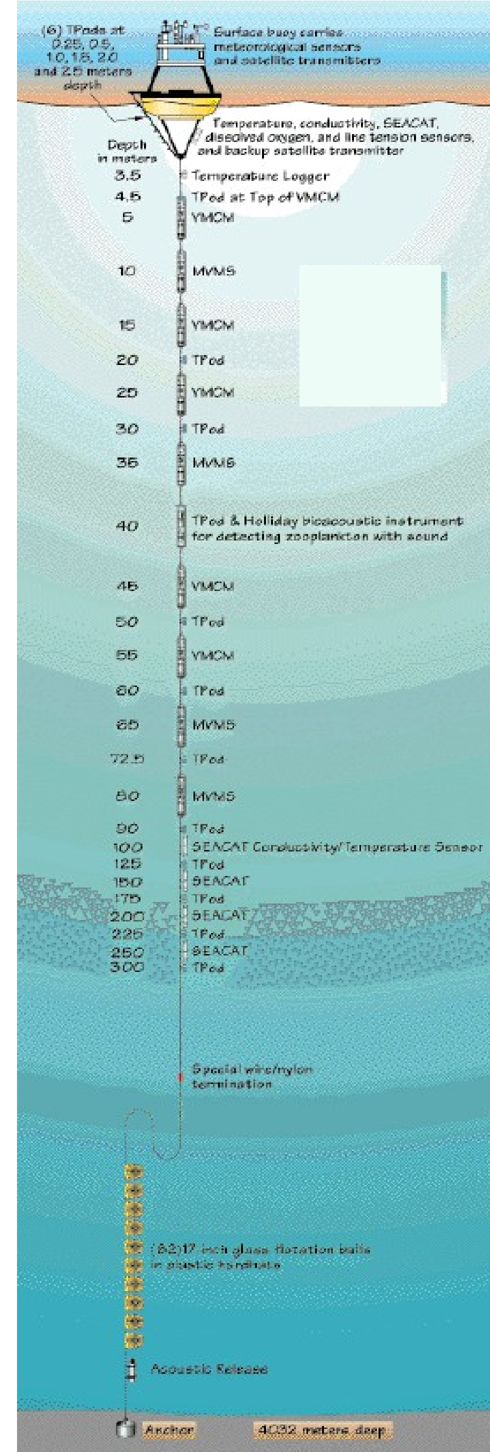
Eric D'Asaro U Washington
Amit Tandon U Mass
Louis St.Laurent WHOI
Karan Venayagamoorthy Colo St.U
G.S. Bhat IISc

18 Participants

Science/Planning Meeting Chennai. 15-18 December 2014 46 Participants

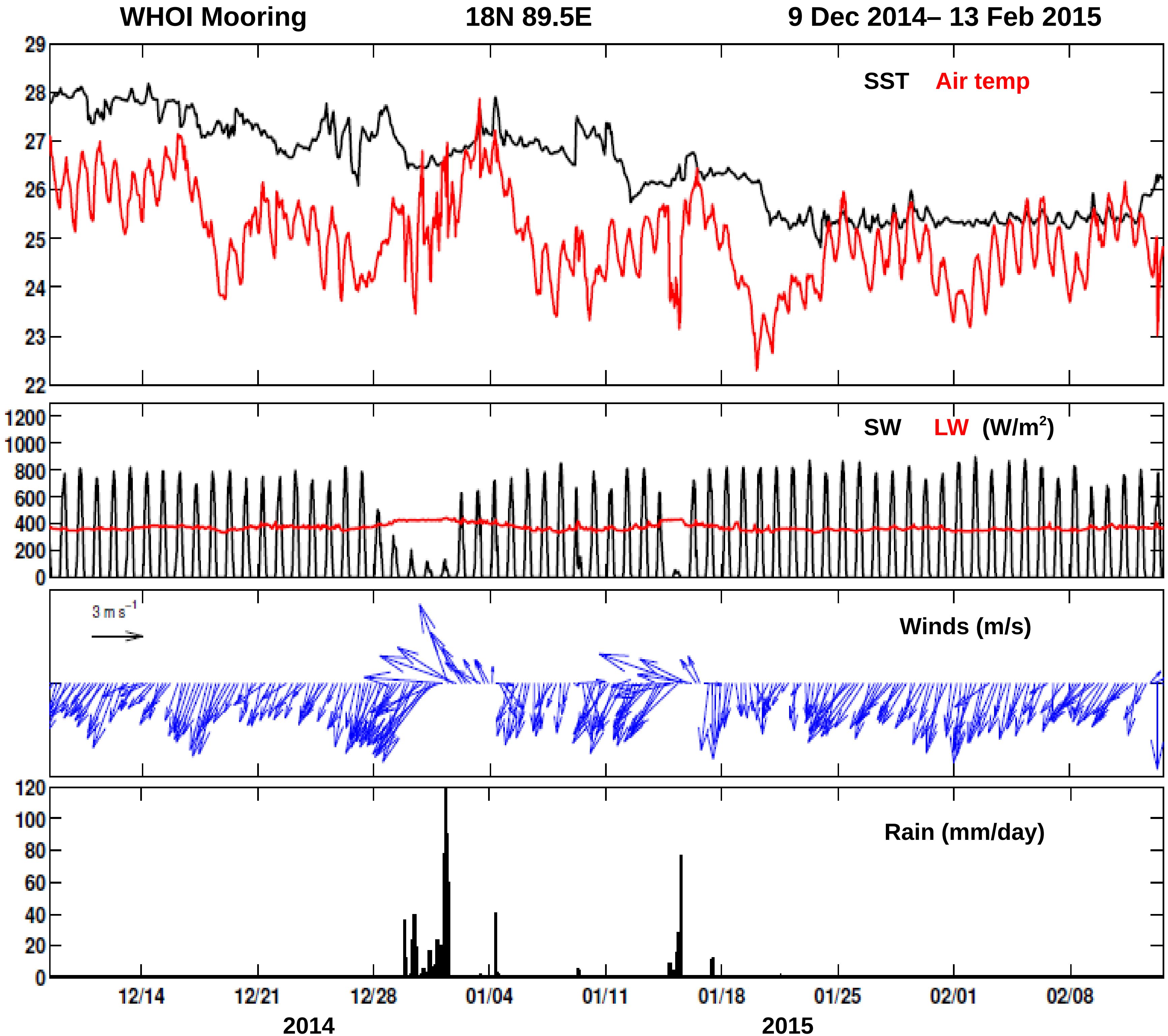
Deployed 18N 89.5E 9 Dec 2014 *Sagar Nidhi*

WHOI Flux Mooring



Surface fluxes, minimal flow distortion; subsurface observations with 2-3 m vertical resolution.

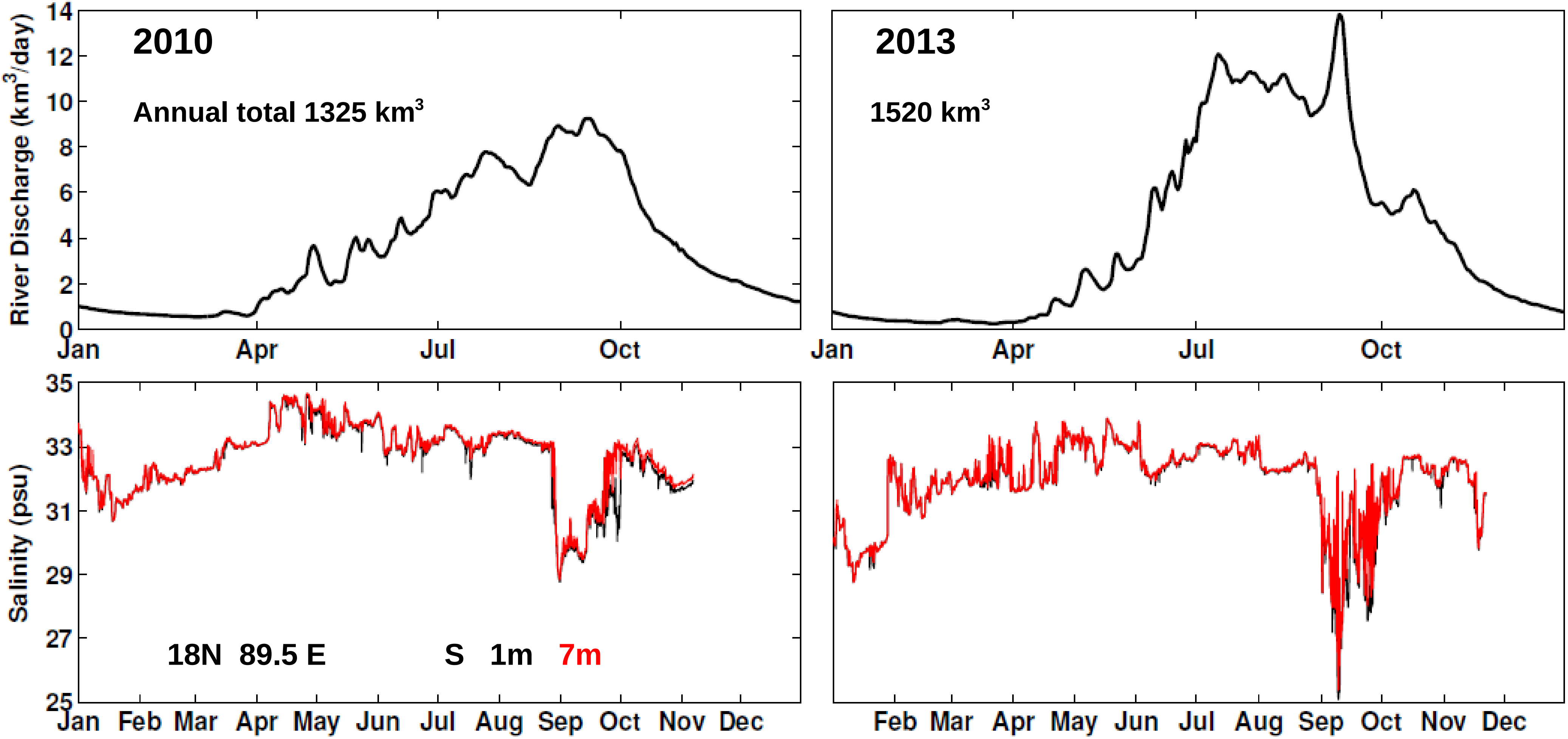
Plan: Covariance fluxes for 6 months summer 2016.



WHOI Mooring
18N 89.5E
9 Dec 2014– 13 Feb 2015
SST
Air temp
29
28
27
26
25
24
23
22
SW
LW
(W/m2)
1200
1000
800
600
400
200
0
3 m s-1
Winds (m/s)
Rain (mm/day)
120
100
80
60
40
20
0
12/14
12/21
12/28
01/04
01/11
01/18
01/25
02/01
02/08
2014
2015

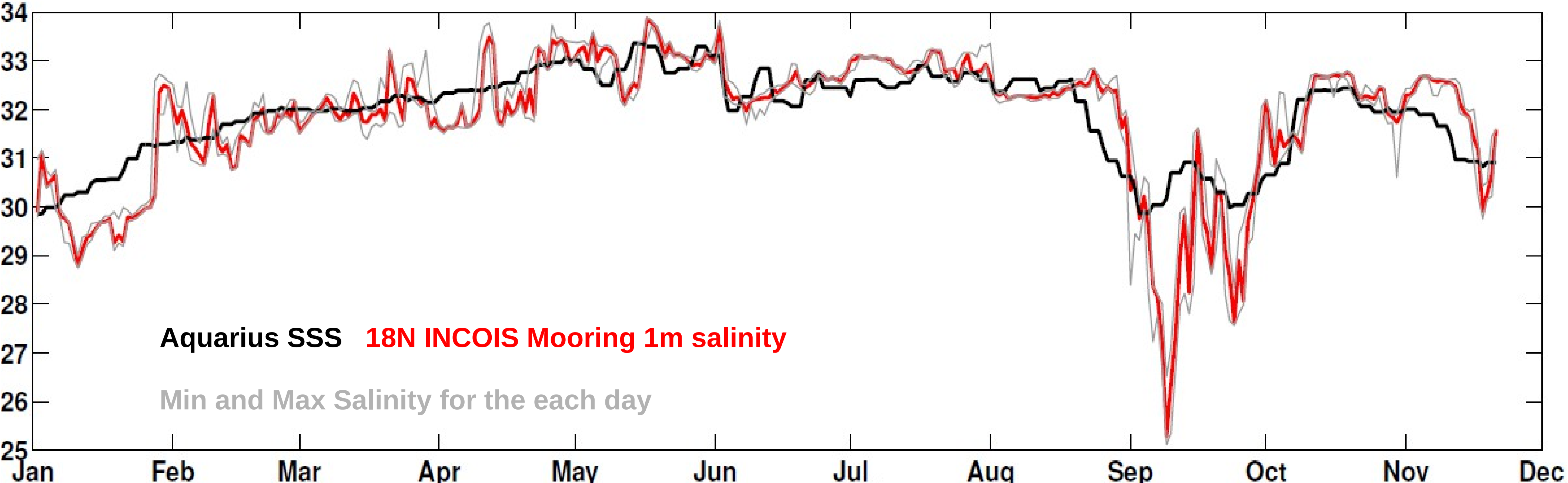
River water at INCOIS Mooring

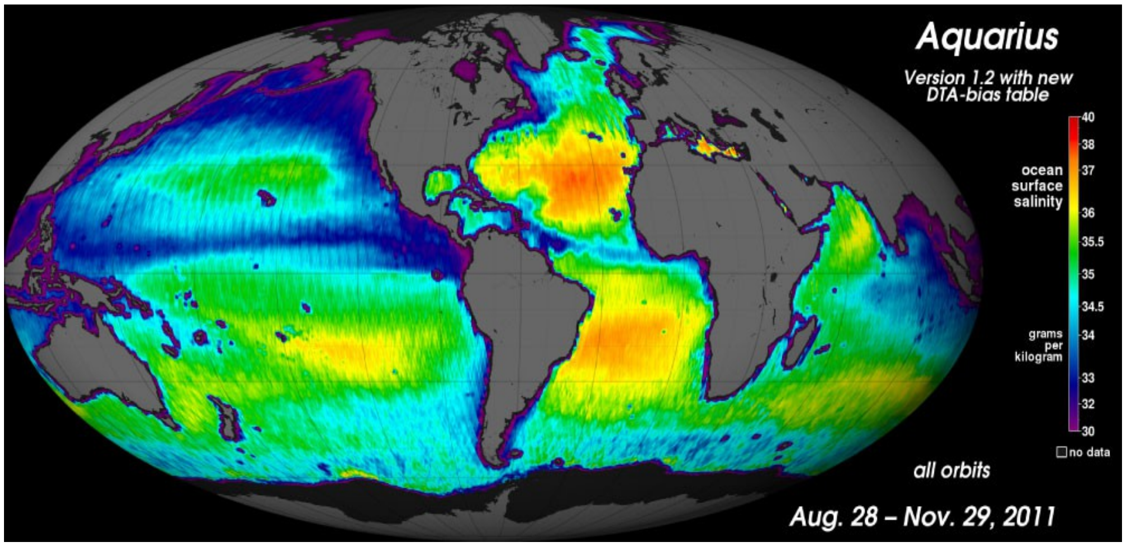
Ganga-Brahmaputra daily river discharge and salinity at 18N 89.5E

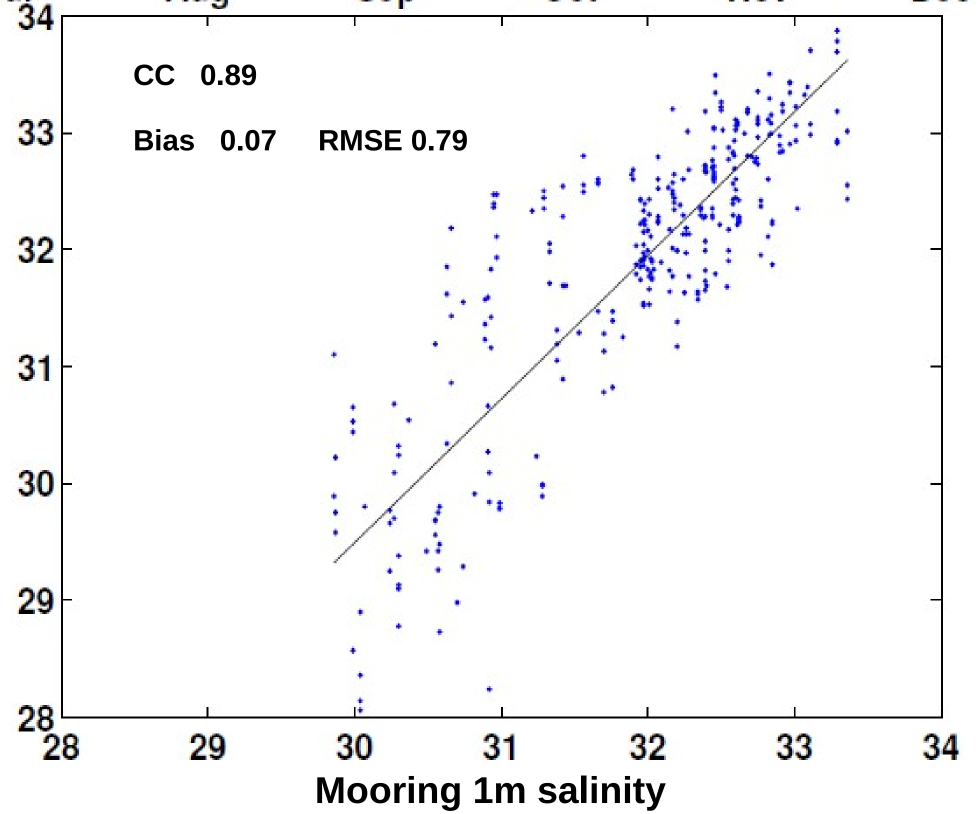


Discharge data courtesy: Bangladesh Univ. Engg. Tech., Fabrice Papa

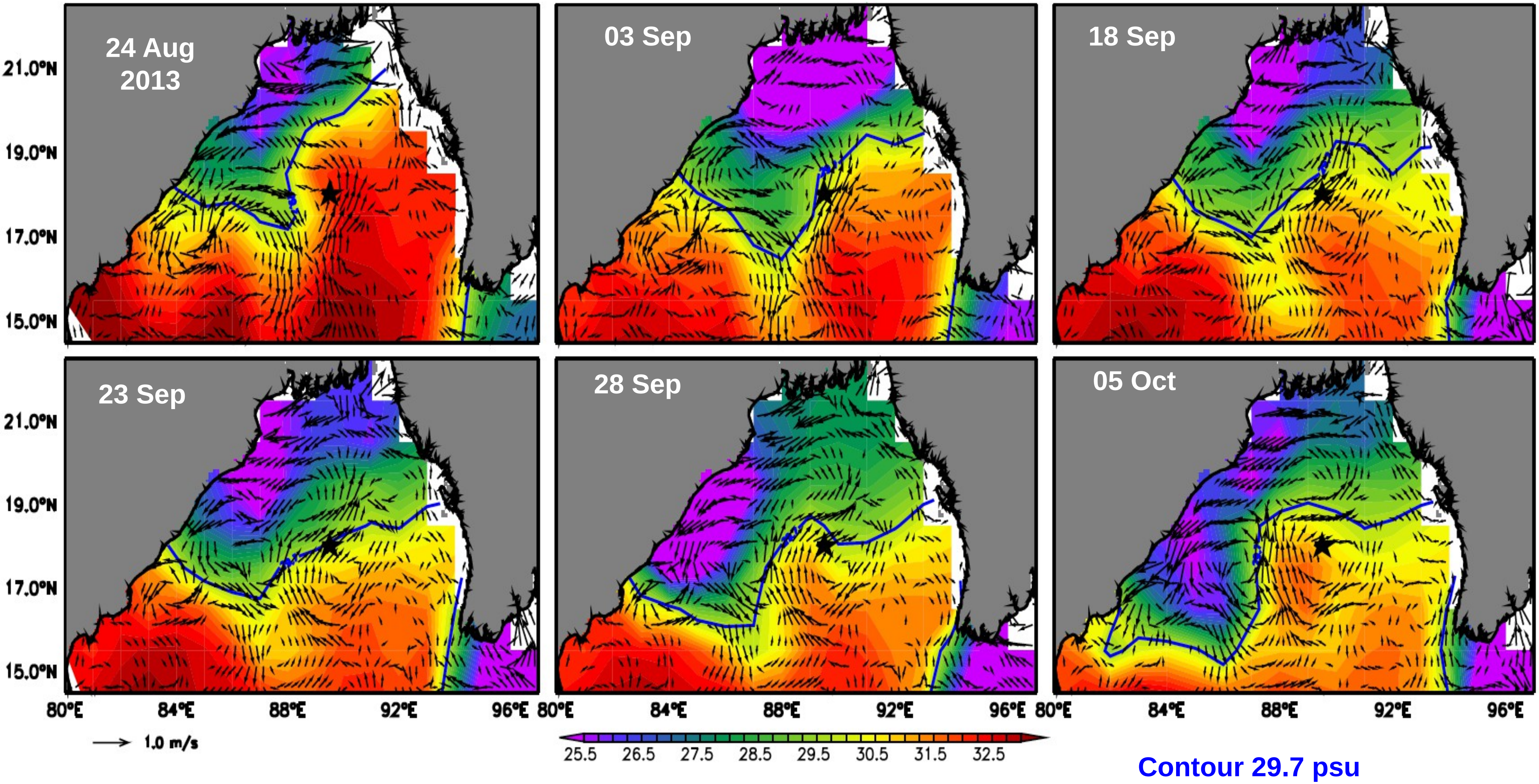
1 Jan – 22 Nov 2013



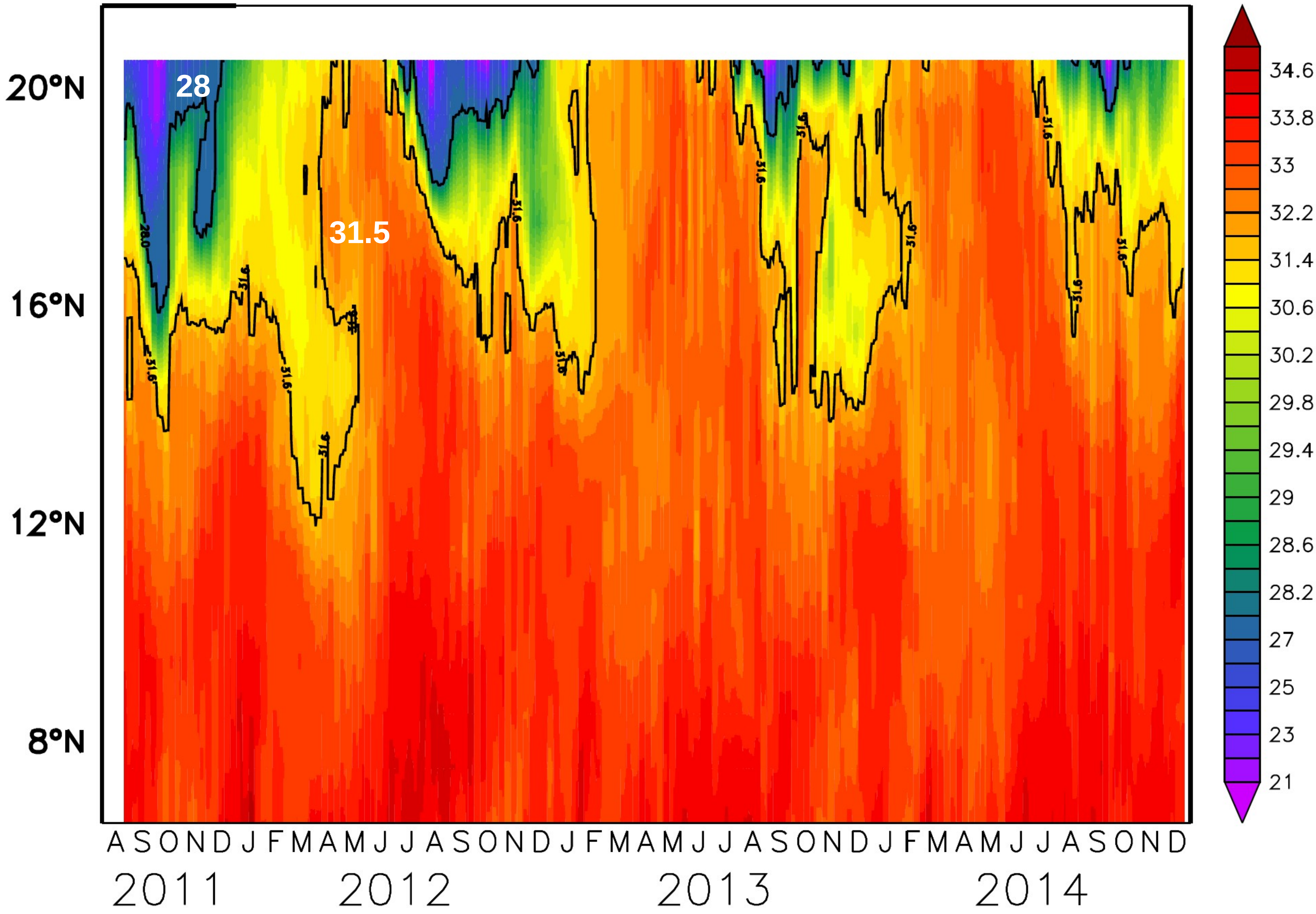


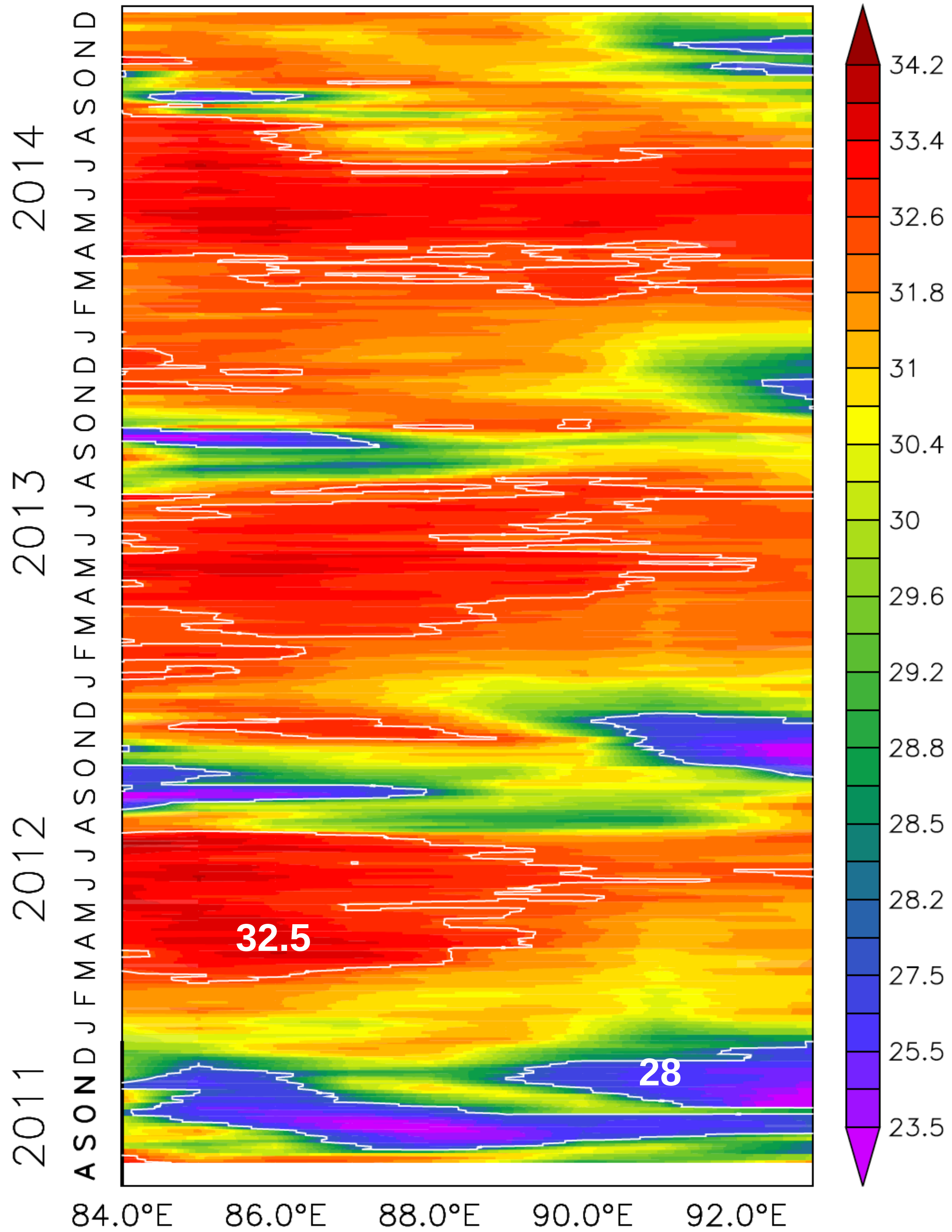


Pathway of river water: Aquarius SSS and AVISO Geostrophic currents
Aug-Oct 2013



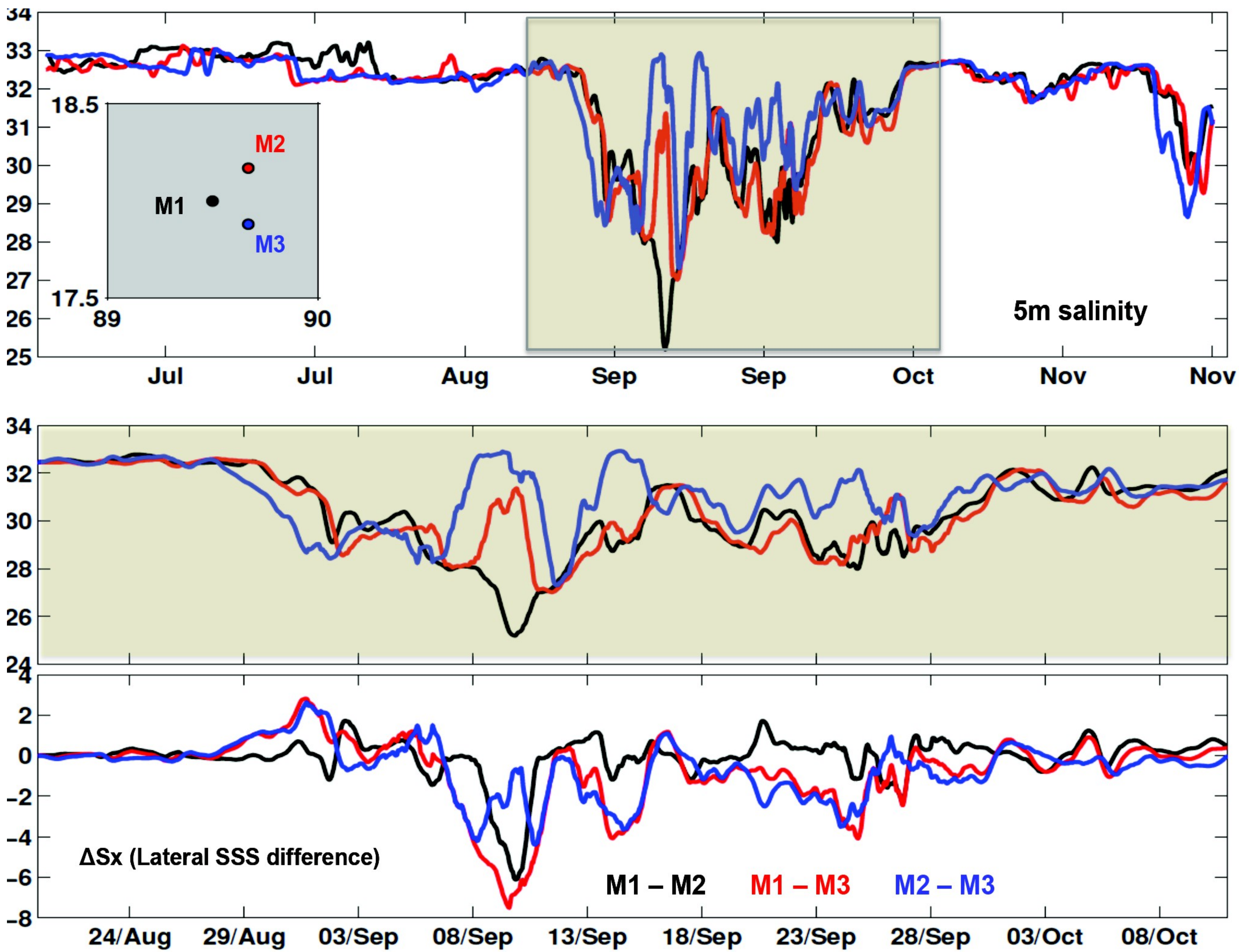
Aquarius sea surface salinity along 89.5 E



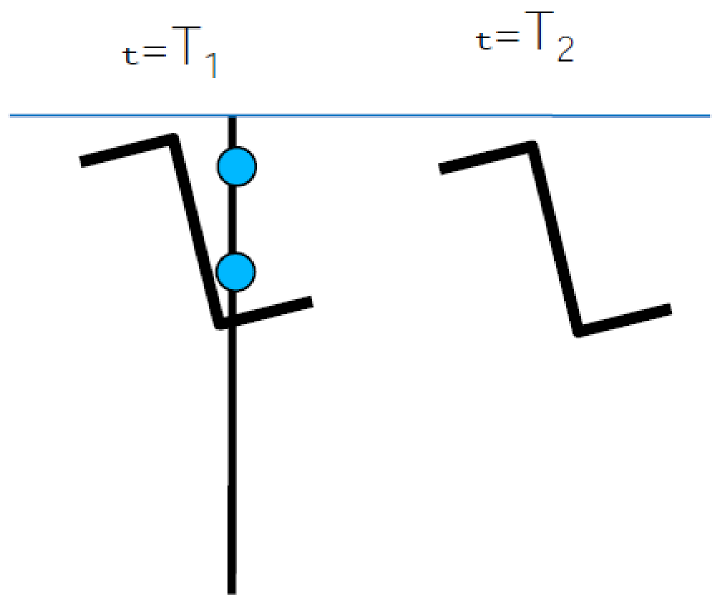


Aquarius SSS along 18N

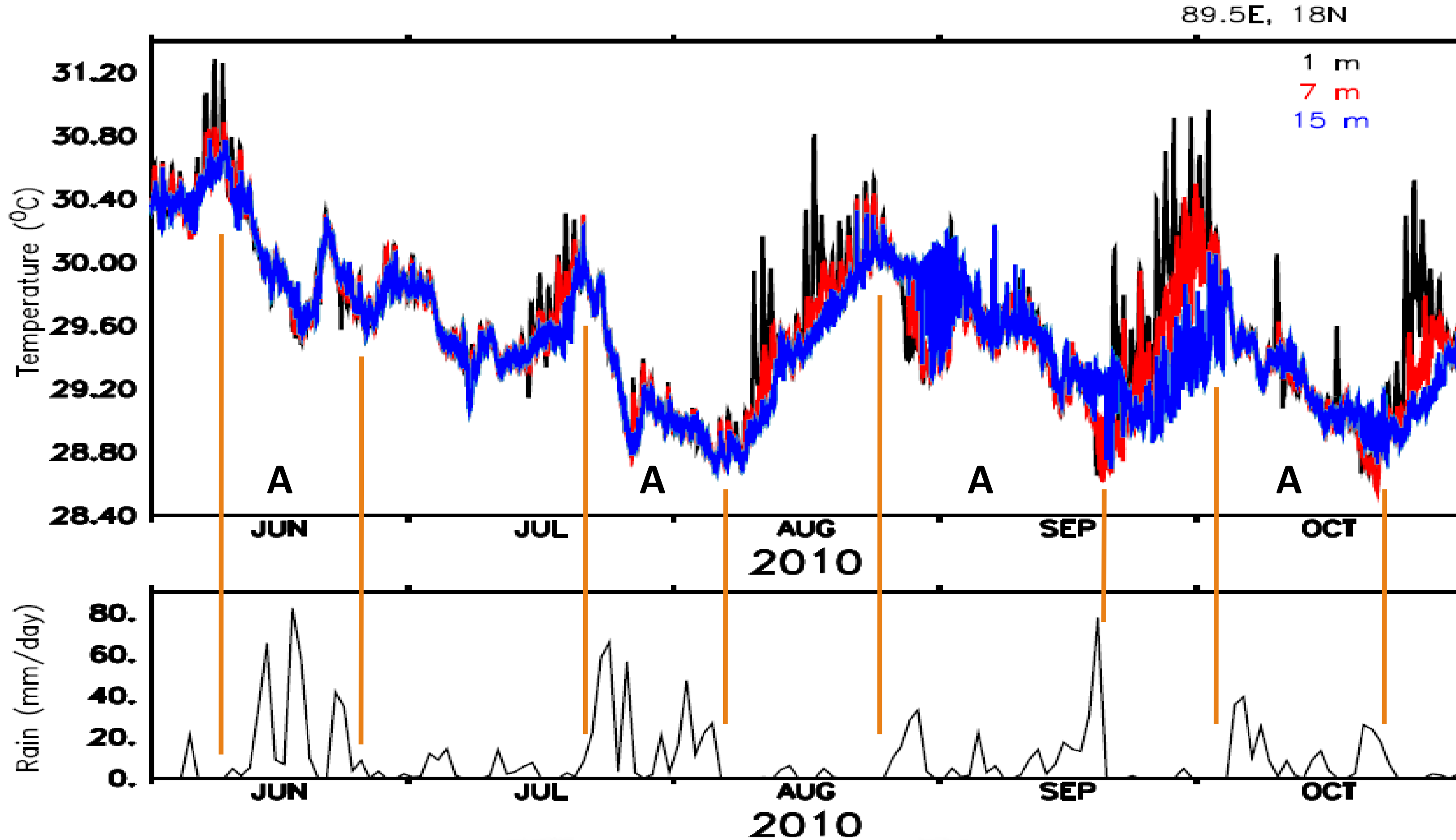
Small scale salinity gradients BoB Observatory 2013



G. I. Taylor's "frozen" field hypothesis:



dS/dt=0, i.e. $\partial S/\partial t = -u\partial S/\partial x$



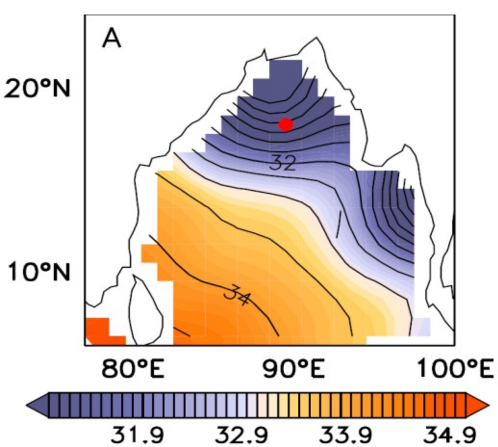
18°N 2010
Monsoon ISO

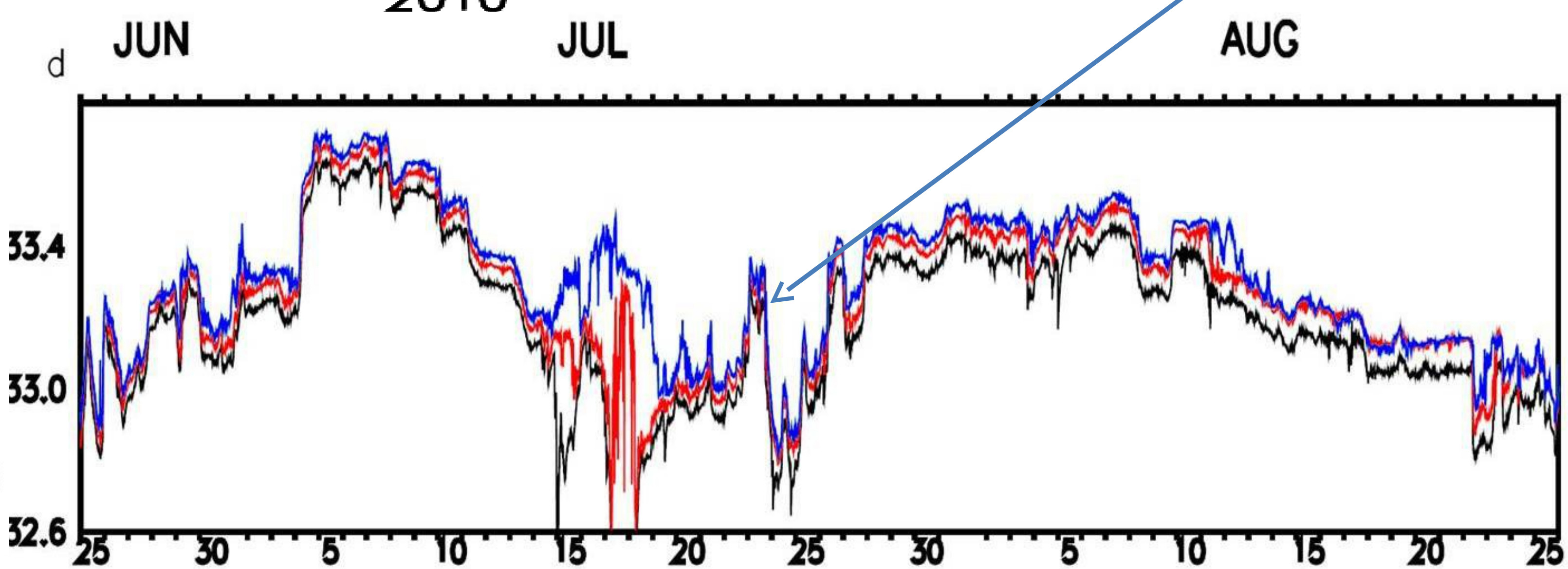
Salinity stays Stratified

Fronts

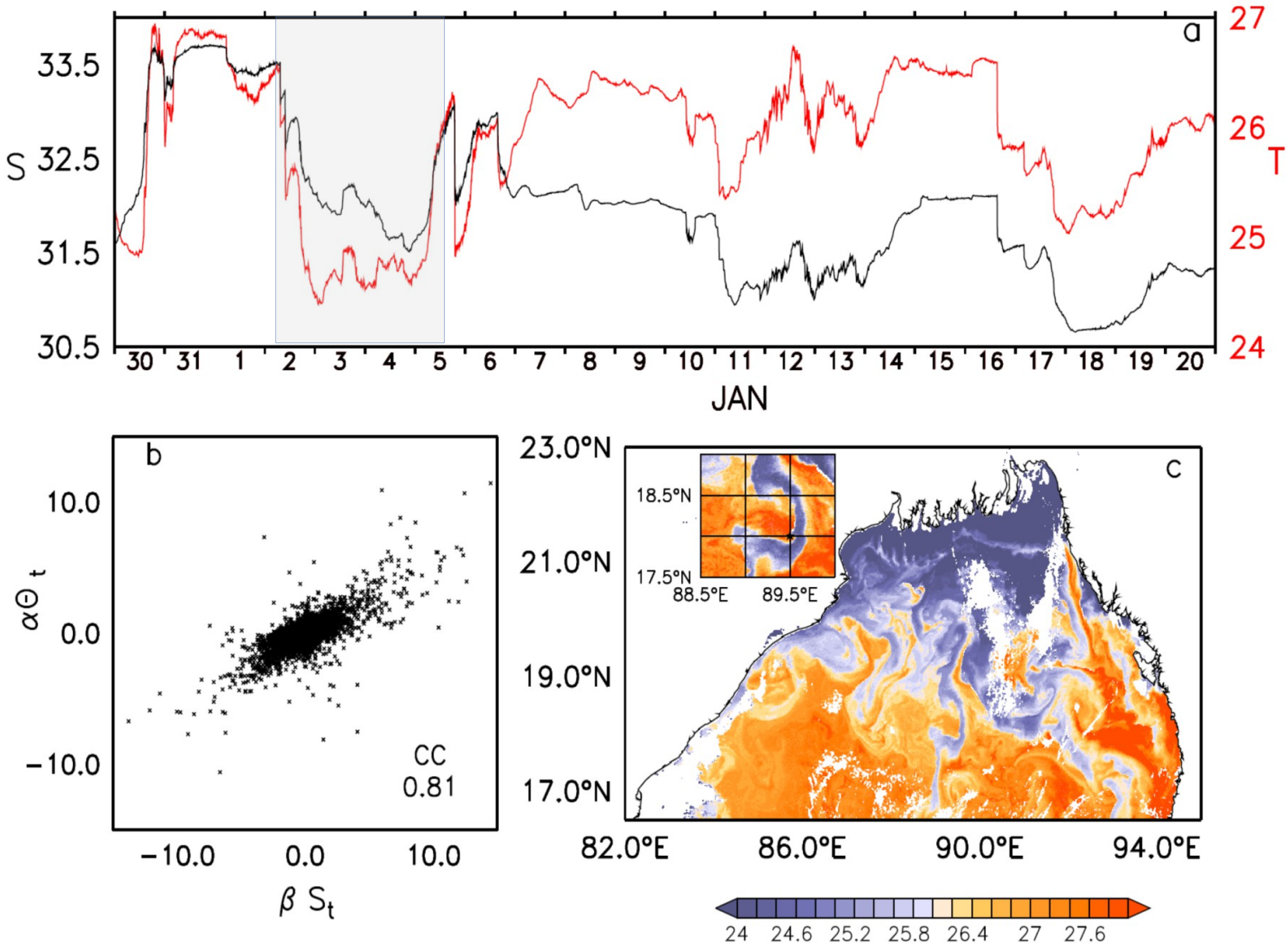
1-40 km fronts

Persistent front





Salinity dominated sub-mesoscale (1-20 km) fronts



Baroclinic Rossby radius north Bay ~ 50 km; 1 psu Δ S or -2.3°C $\Delta\theta$ implies 0.075 kg/m³ $\Delta\rho$

Submesoscale processes

- Distinct from quasi-geostrophic mesoscale processes and internal gravity waves.
- Particularly dominant in the upper ocean due to lateral buoyancy gradients, associated surface frontogenesis, weak stratification, smaller Rossby radii.
- O(1) Rossby and Burger numbers consistent with small PV where horizontal gradients contribute; largely hydrostatic.

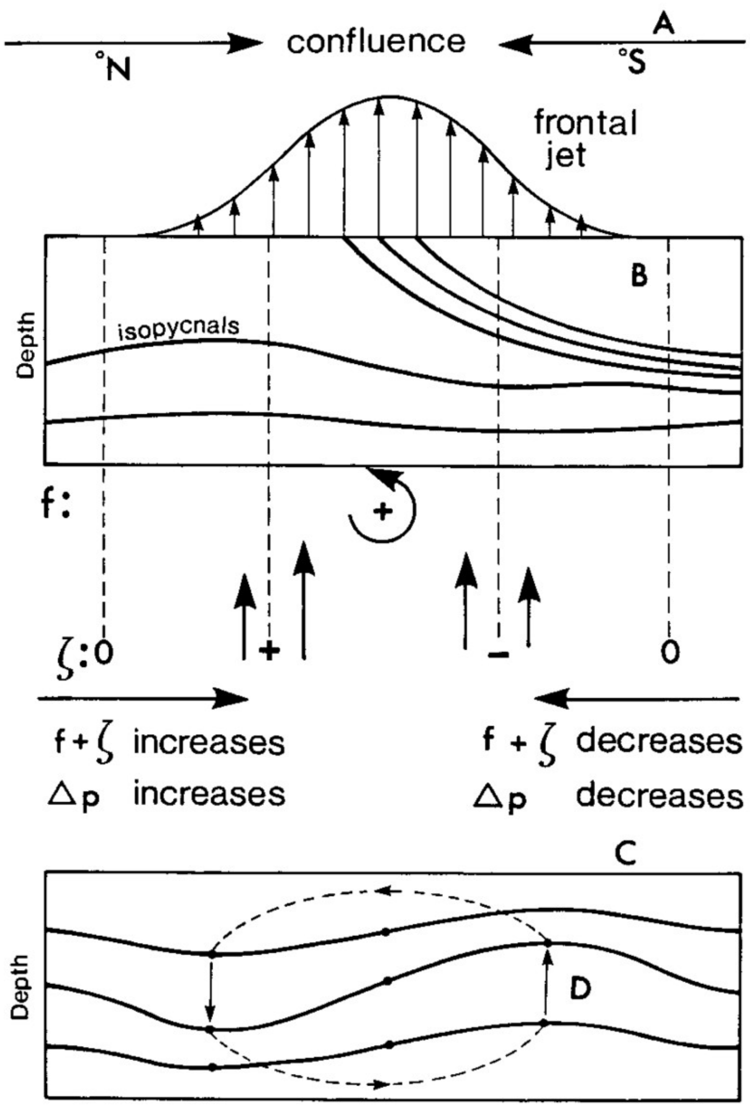
$$U / fL = 1 \text{ and } NH / fL = 1$$

$$\text{leads to bulk Ri} = U / NH = 1.$$

- What if the horizontal gradients are modified by confluence?

FRONTS

Slumping at sub-mesoscale fronts creates stratification

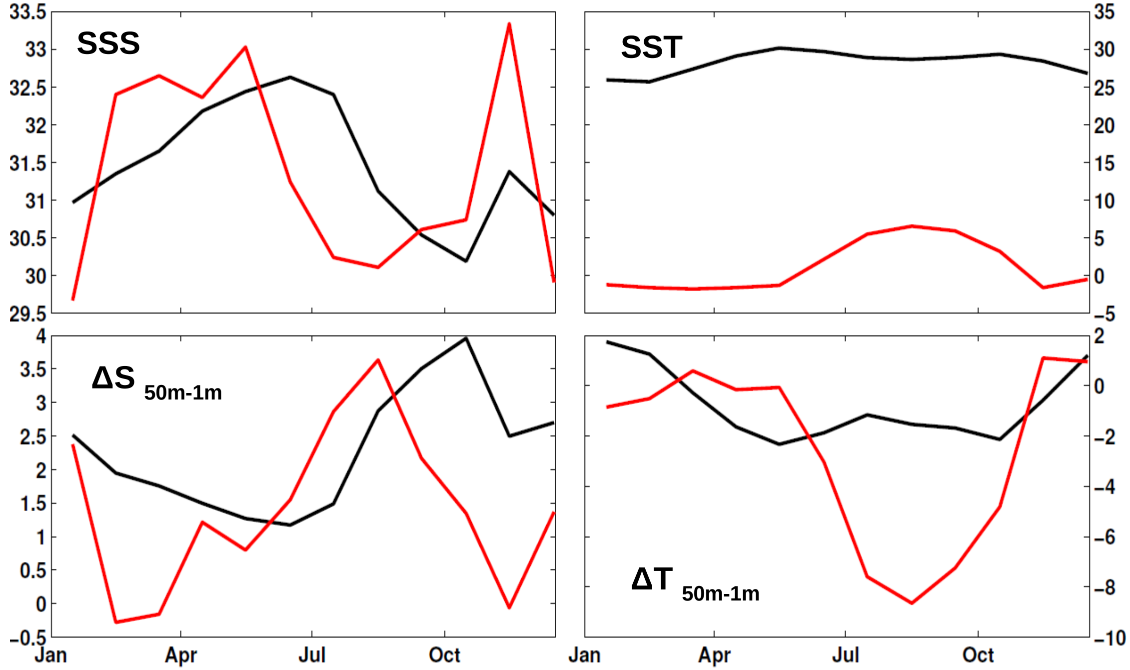


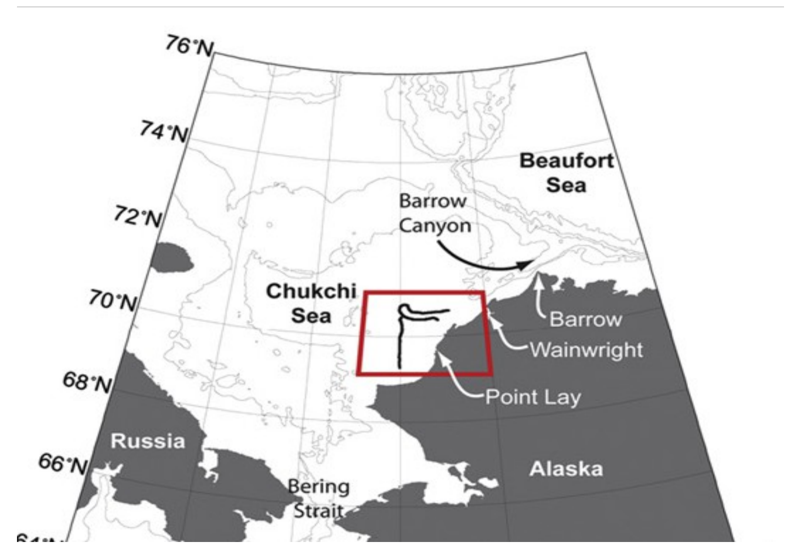
Downwelling on the dense side of the front and upwelling on the less dense side.

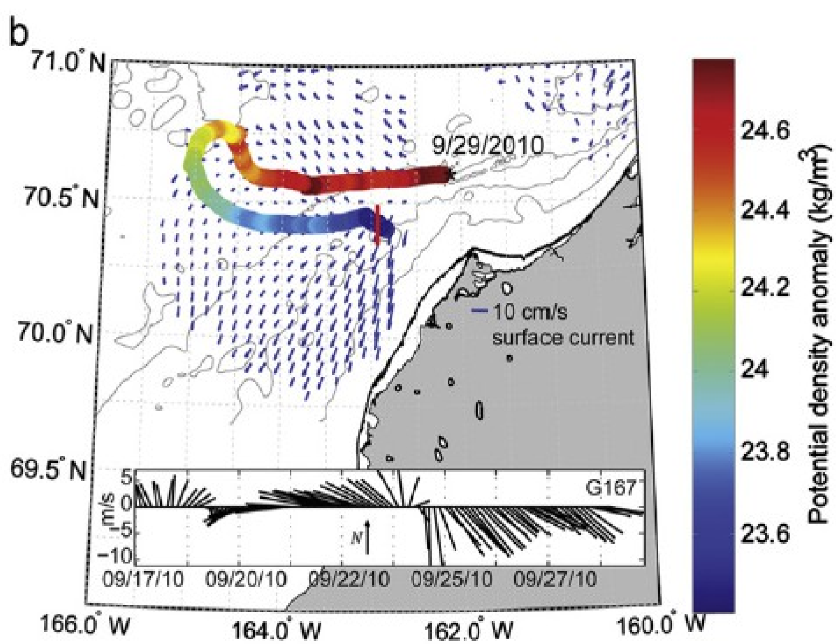
Pollard Regier 1991

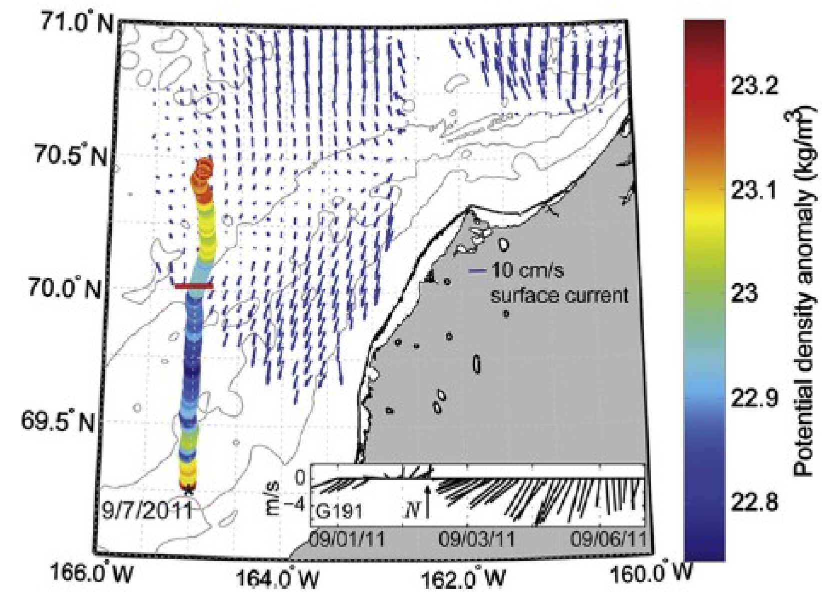
Arctic salinity stratification

WOA13 BoB 87-93E 17-19N Arctic 166-160W 69-71N



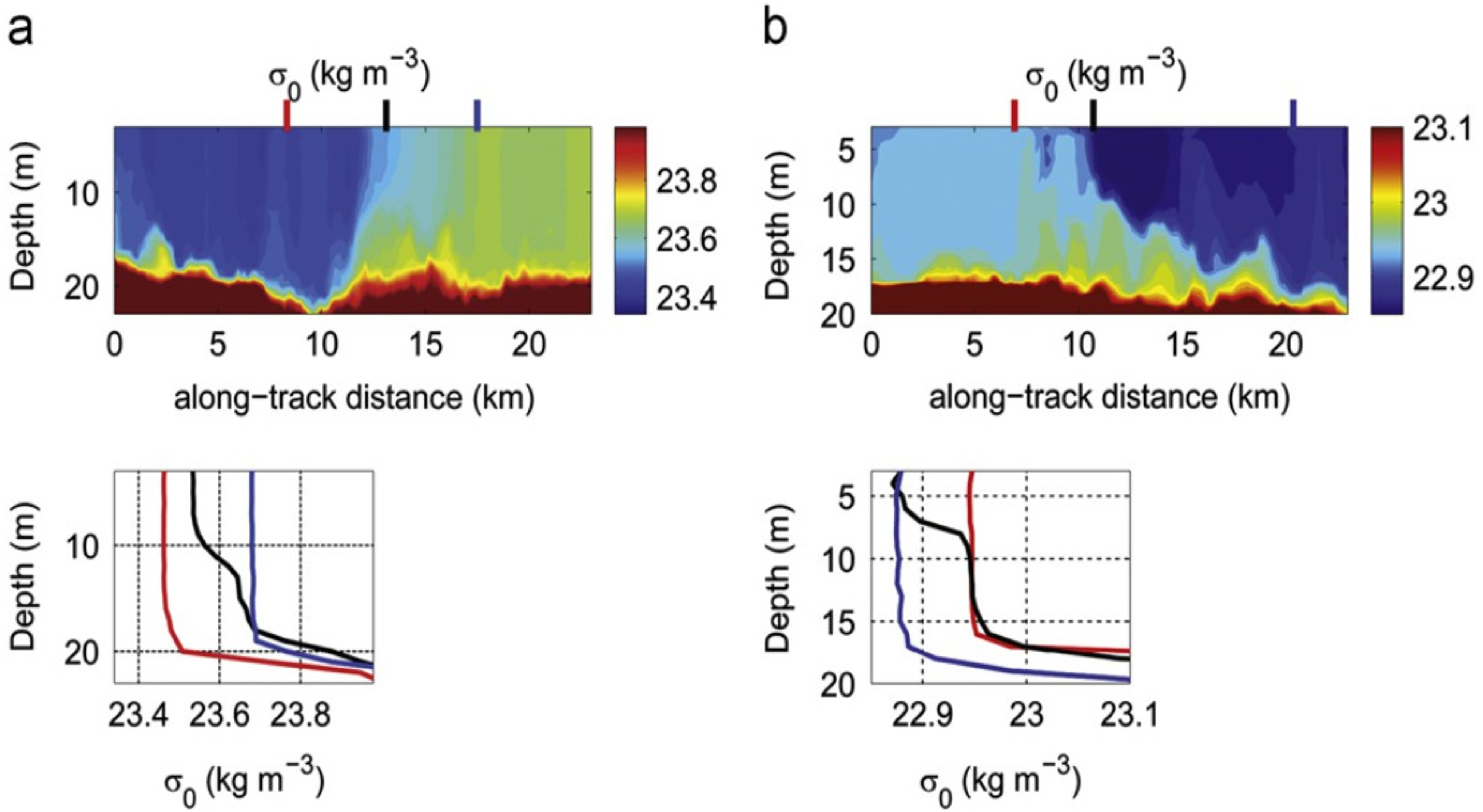






Glider 120 m horizontal resolution

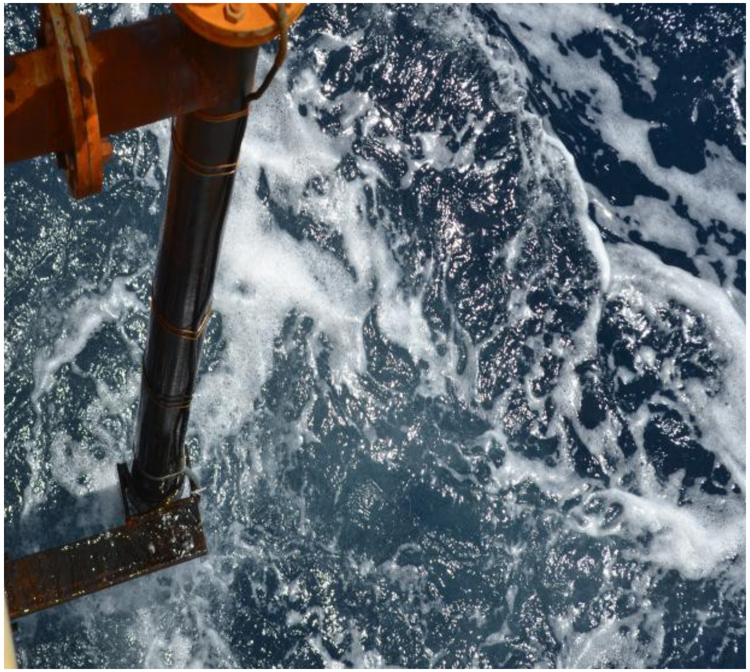
Timmermans Winsor 2013



Slumping at fronts creates shallow stratification

Timmermans Winsor 2013

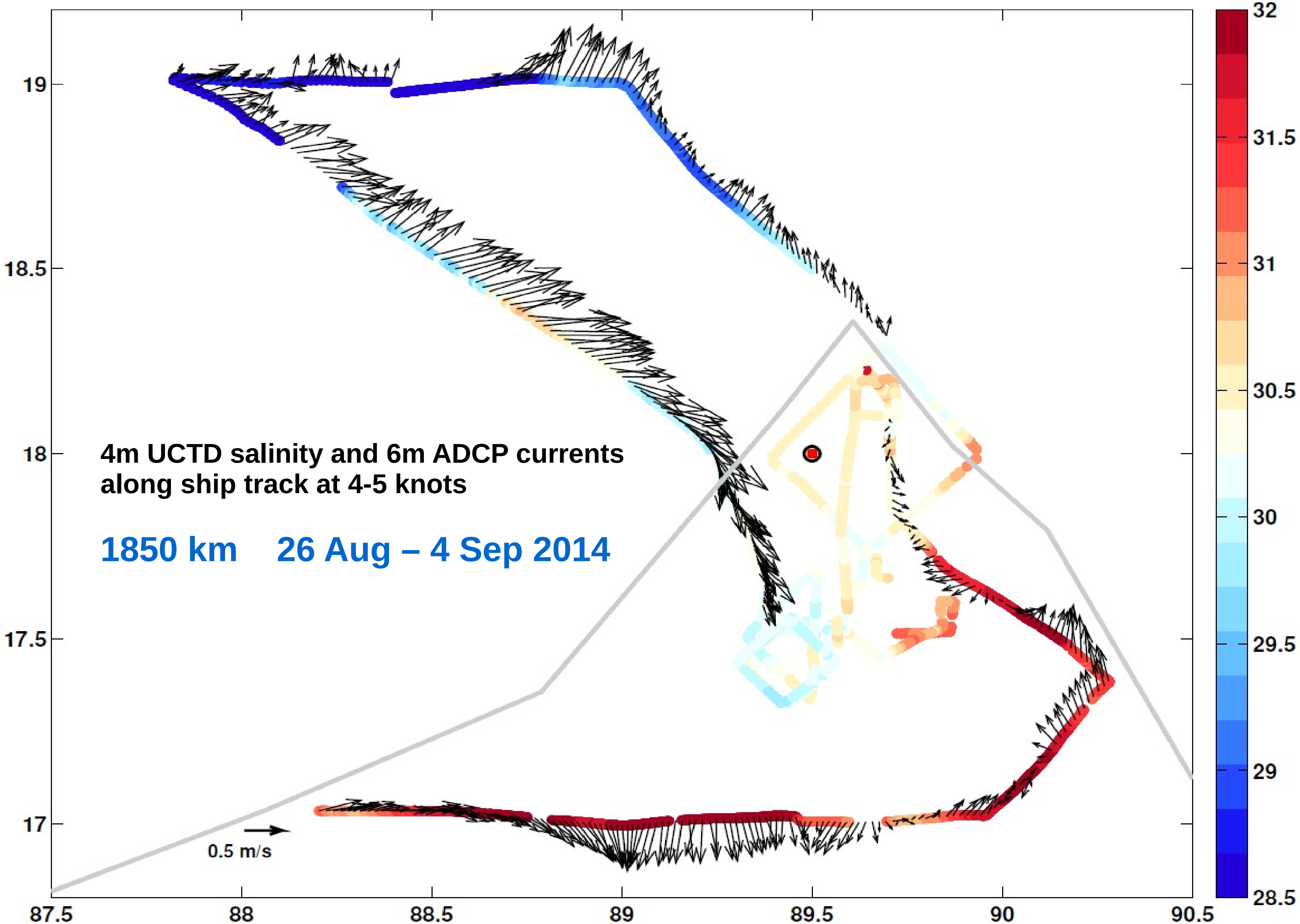
OMM Sagar Nidhi Aug-Sep 2014



300 kHz over the side Acoustic Doppler Current Profiler (ADCP)

resolution 270 m 2 m, 6-80 m

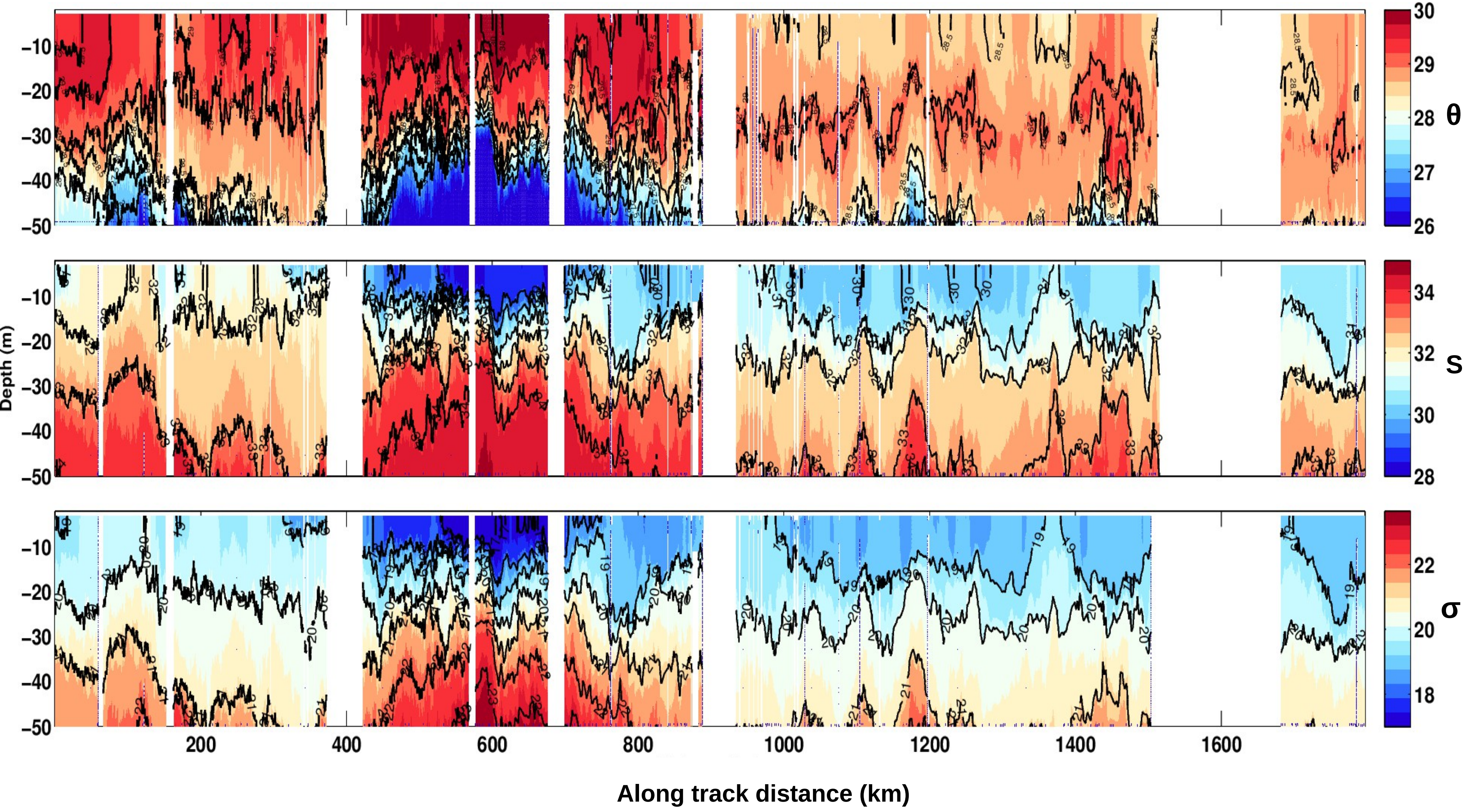
Underway CTD



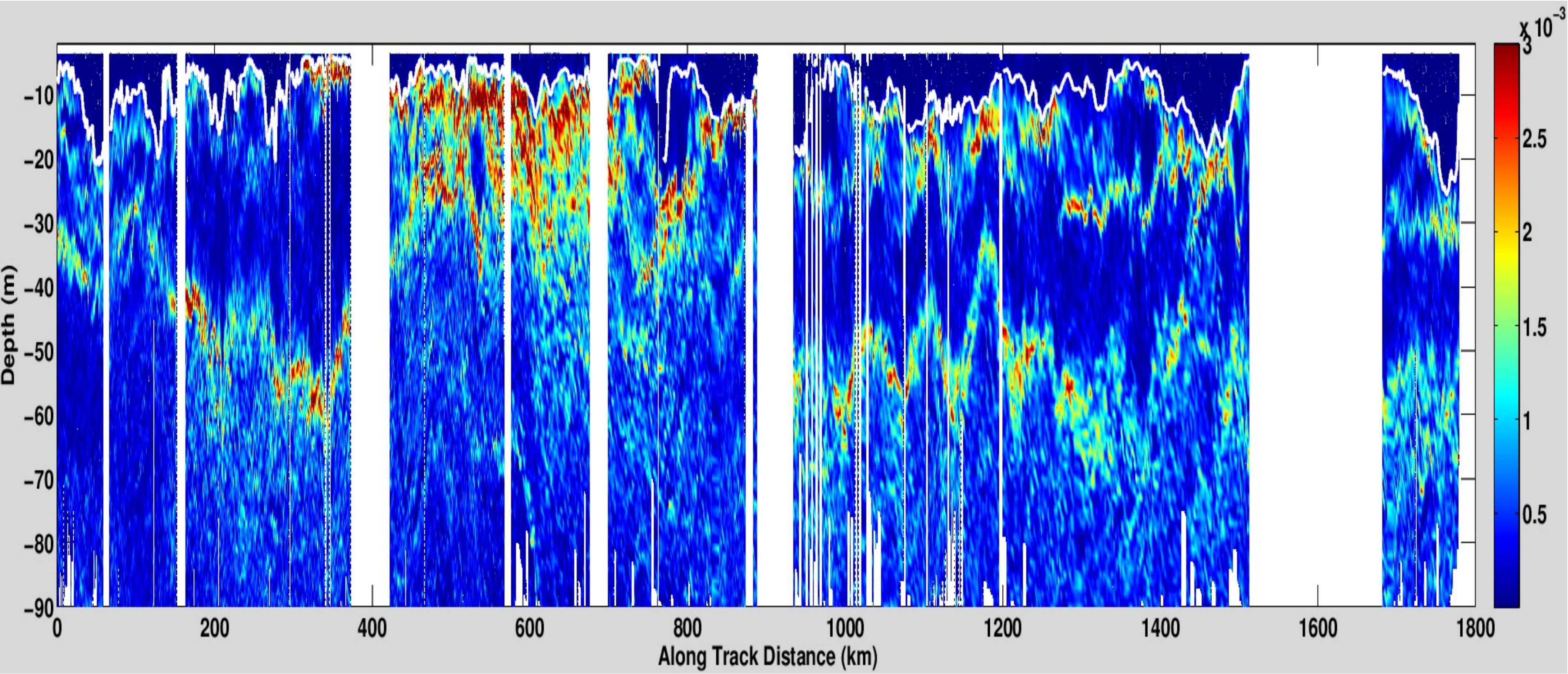
Summer SN88 cruise track decided in real time based on satellite (SSH, currents, SSS) and model inputs

1800 km of underway CTD at 4-5 knots; total 1880 profiles

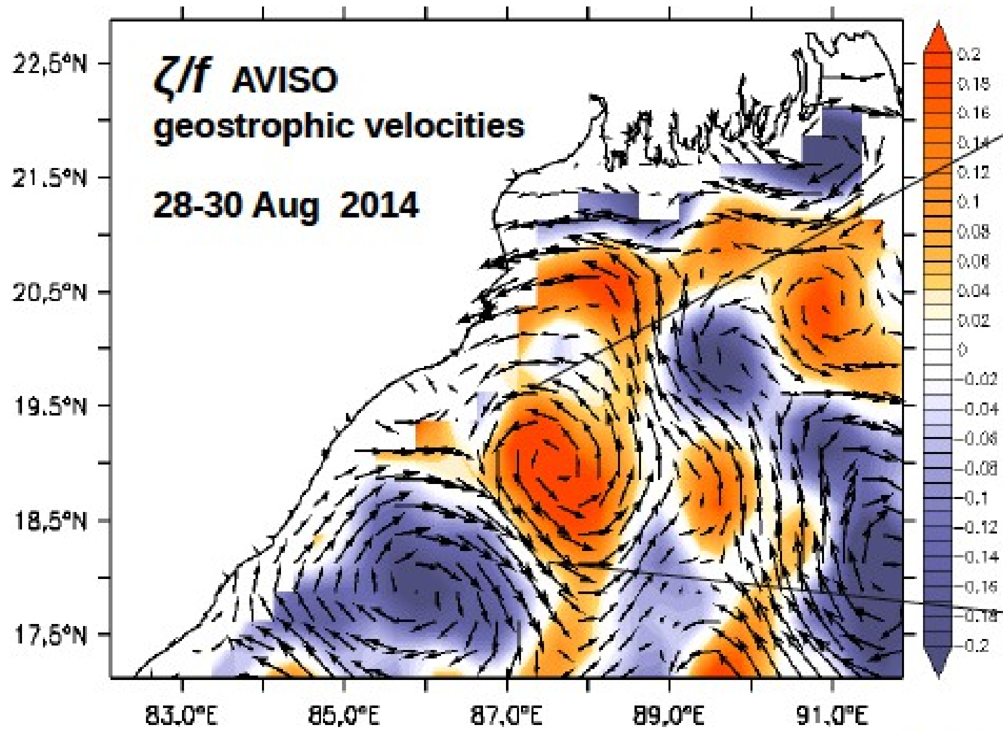
0-560 km : profile every 3 minutes, 470 m horizontal res; 1 m vertical res
560-1800 km : profile every 10 minutes, 1370 m horizontal res;

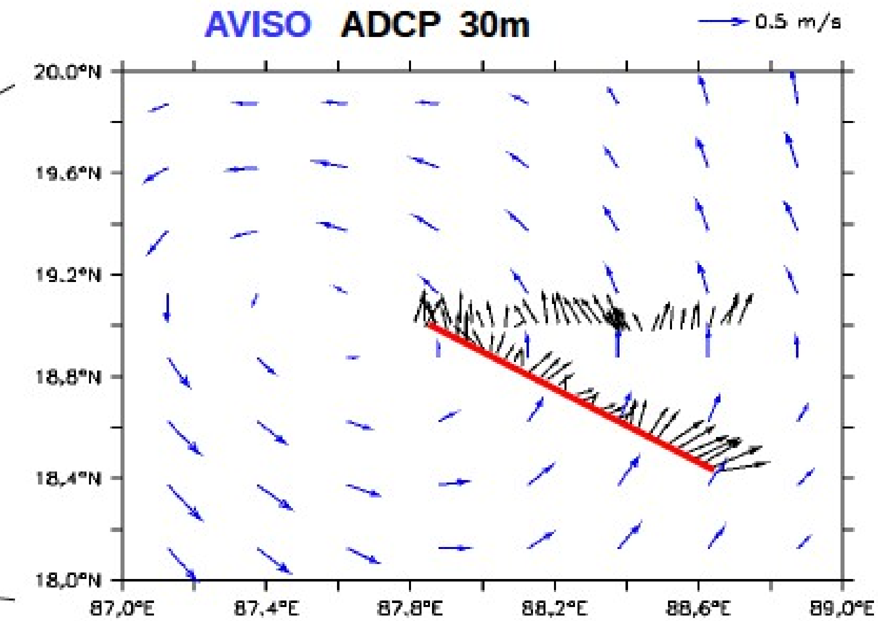


Brunt Vaisala Frequency $N^2 = -g/\rho \, (d\rho/dz)$ $(1/s^2)$



Mixed layer depth $\sigma_{mld} - \sigma_{4m} > 0.03$ kg/m^3

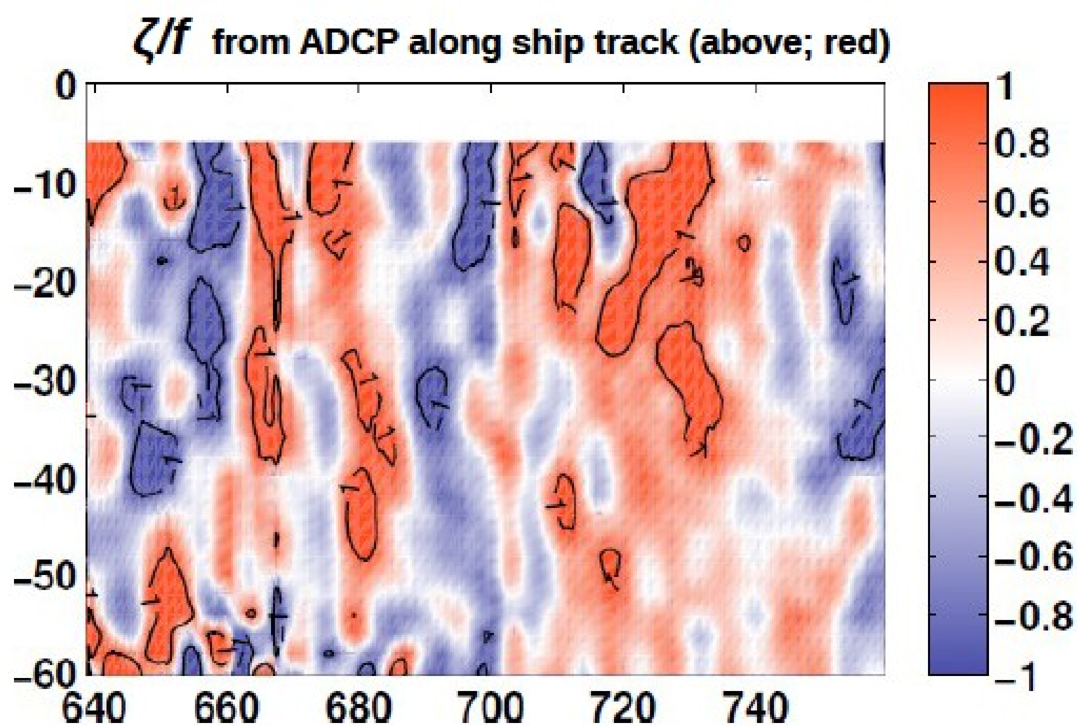


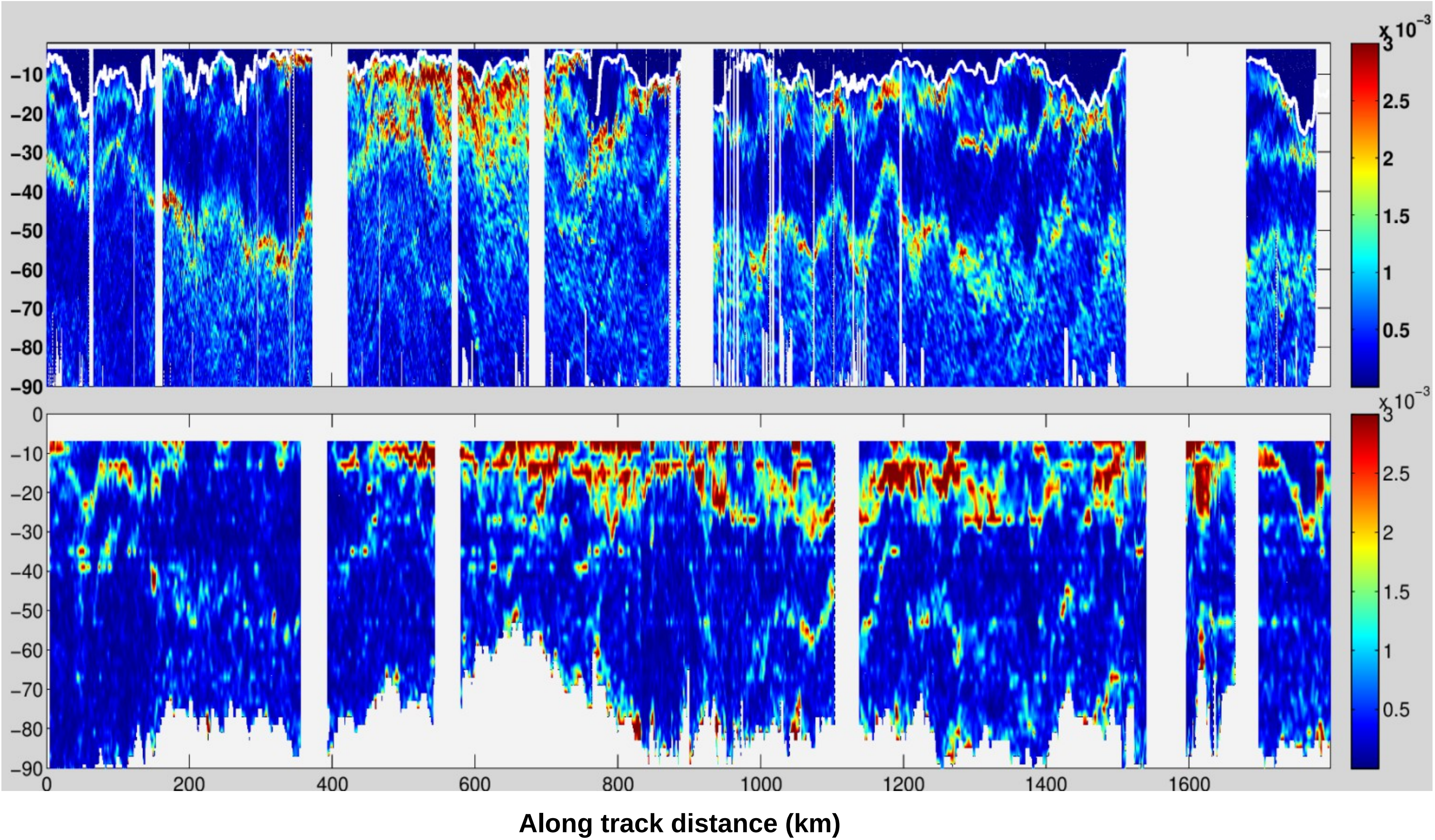


ζ/f

O(0.1-0.2) on 100 km scales

O(1) on 10-20 km scales



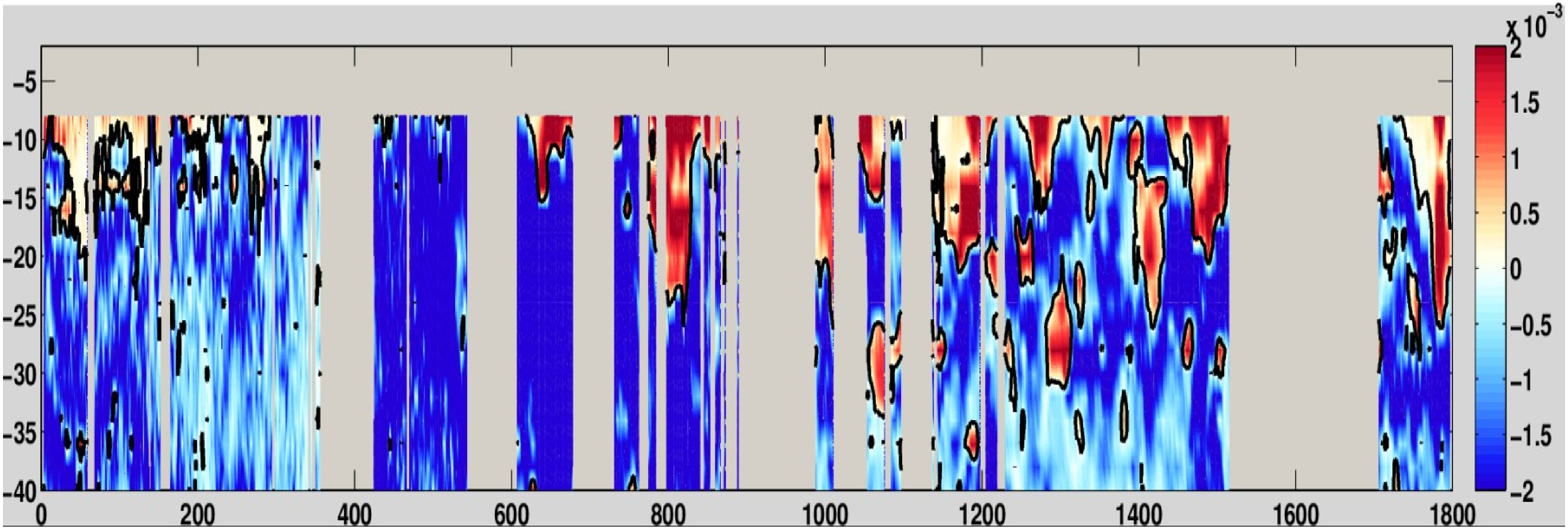


Brunt Vaisala Frequency $N^2 = -g/\rho\,(d\rho/dz)$ $1/s^2$

Shear squared $S^2 = ((\partial u/\partial z)^2+(\partial v/\partial z)^2)$ $1/s^2$

Mixed layer depth $\sigma_{mld} - \sigma_{4m} > 0.03\ kg/m^3$

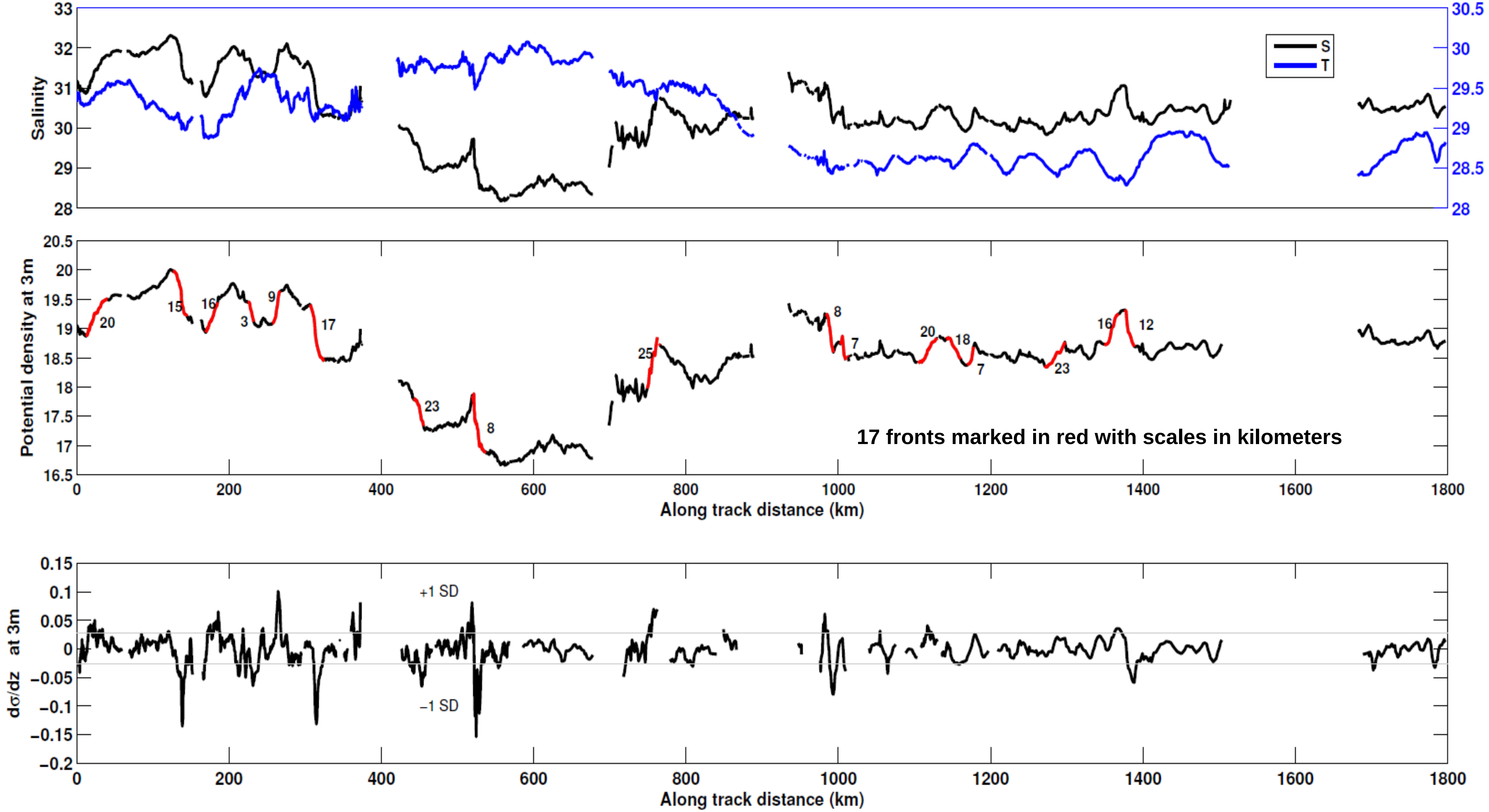
Reduced Shear $= S^2 - 4N^2$



Along track distance (km)

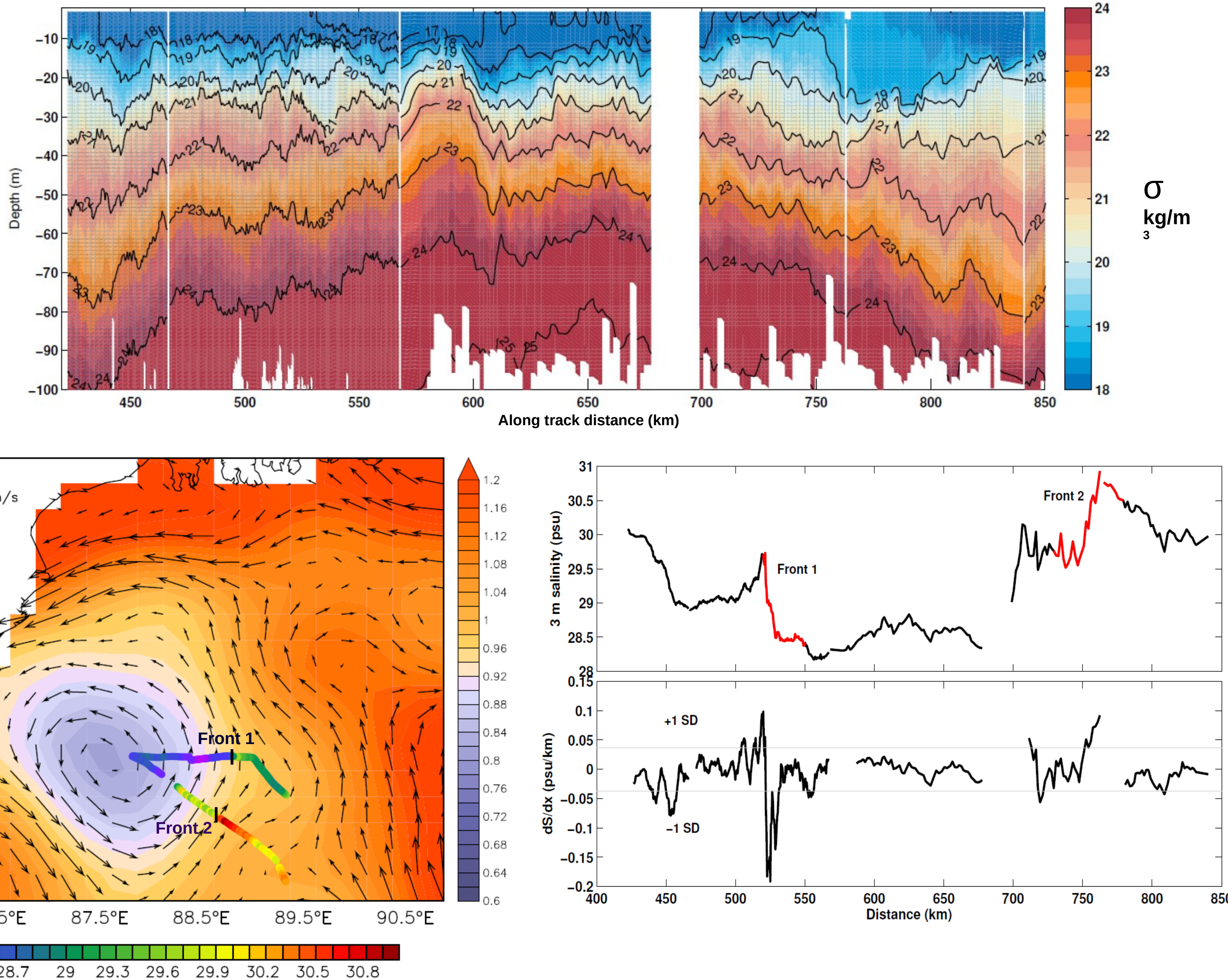
Reduced shear < 0 means Richardson number > 0.25 – stable

Reduced shear > 0 means Richardson number < 0.25 – unstable

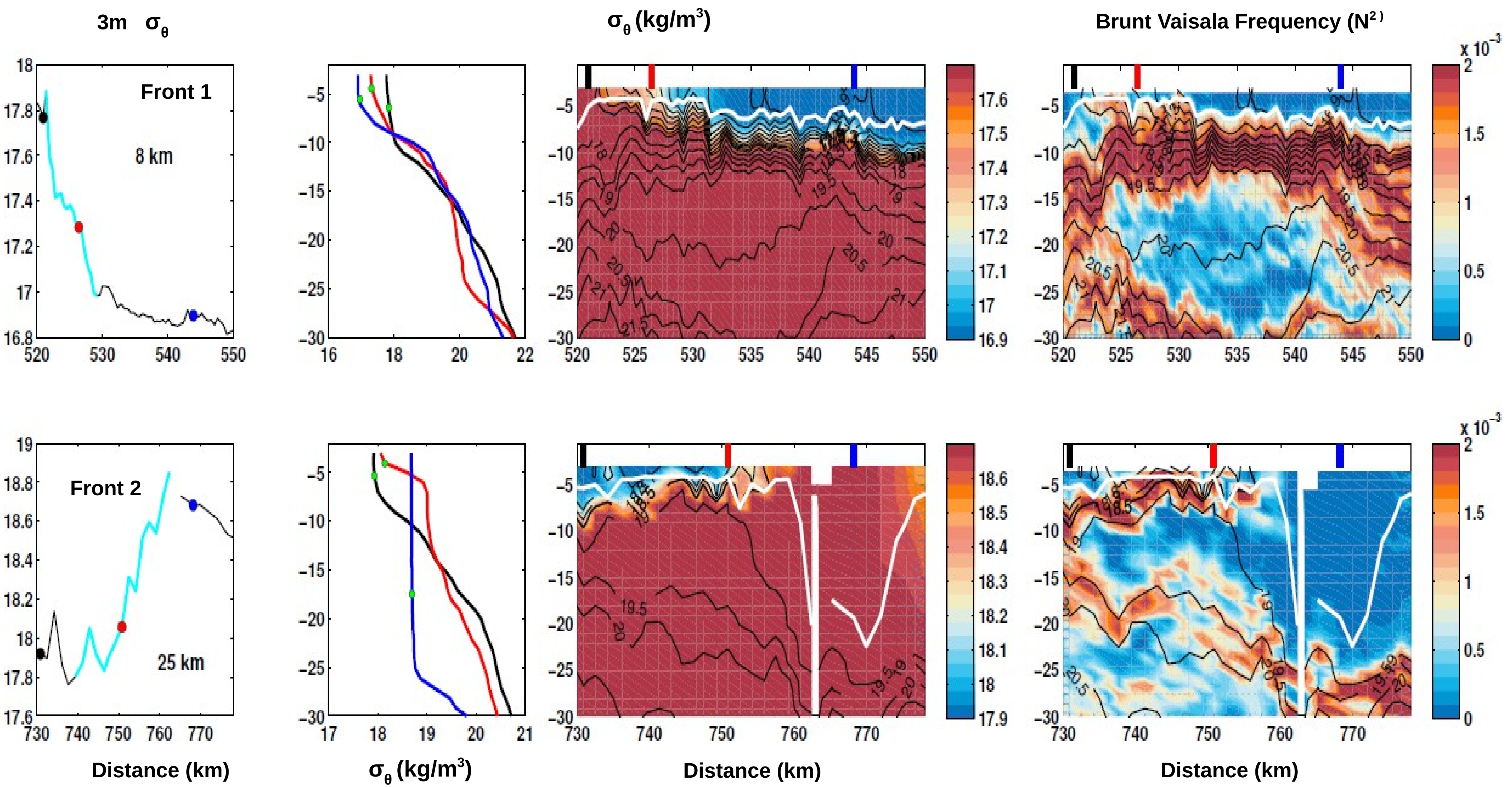


Size of front (kg/m^3)	Number	Scale (km)	Number
size < 0.3	1	<10	6
0.3 < size < 0.5	5	10-20	6
size > 0.5	11	20-25	5

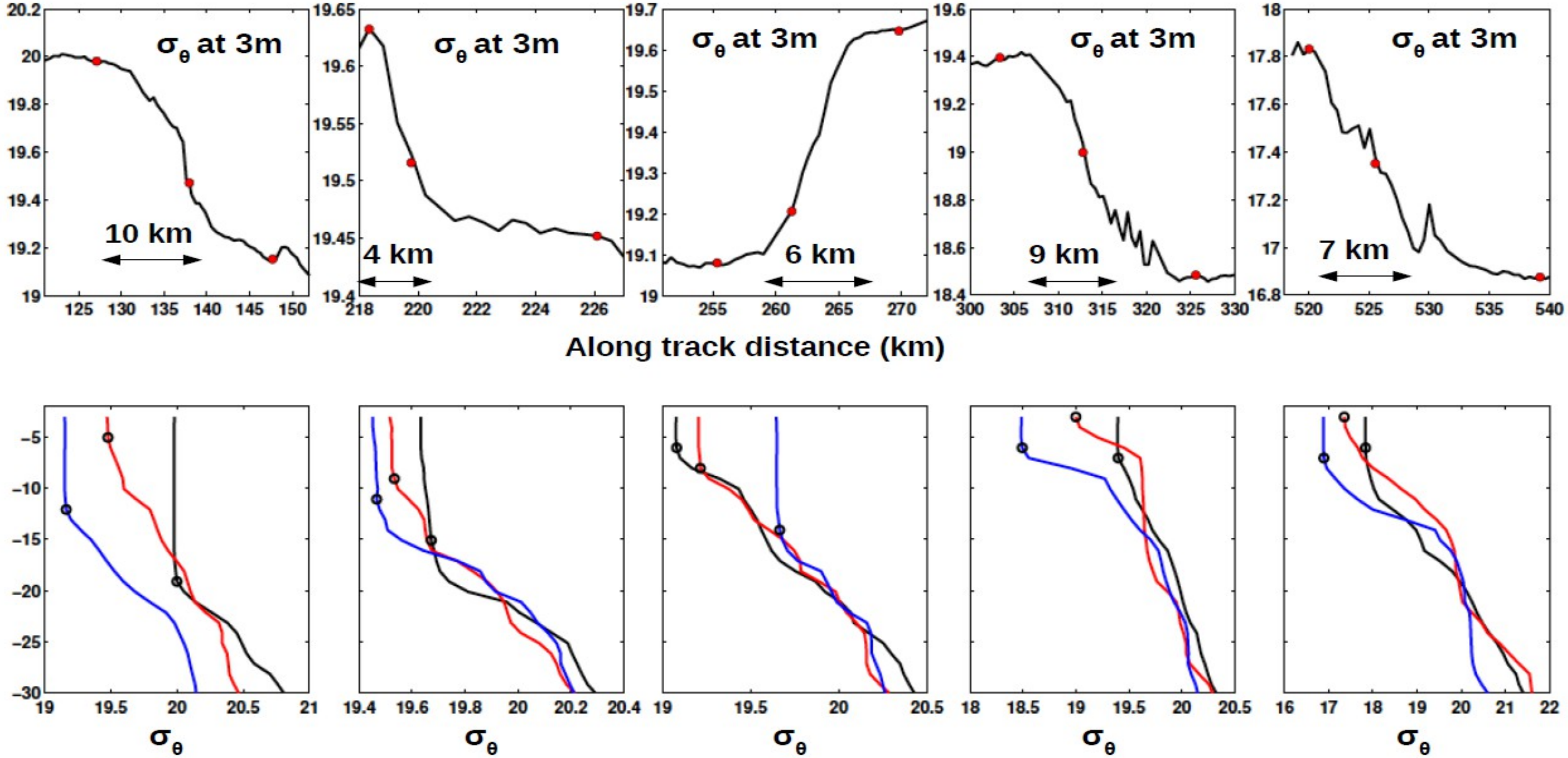
Signature of an upwelling eddy 28 - 30 August 2014



AVISO SSH, geostrophic currents show cyclonic eddy. 3 m uctd salinity plotted along shiptrack shows fresh water trapped inside the eddy.



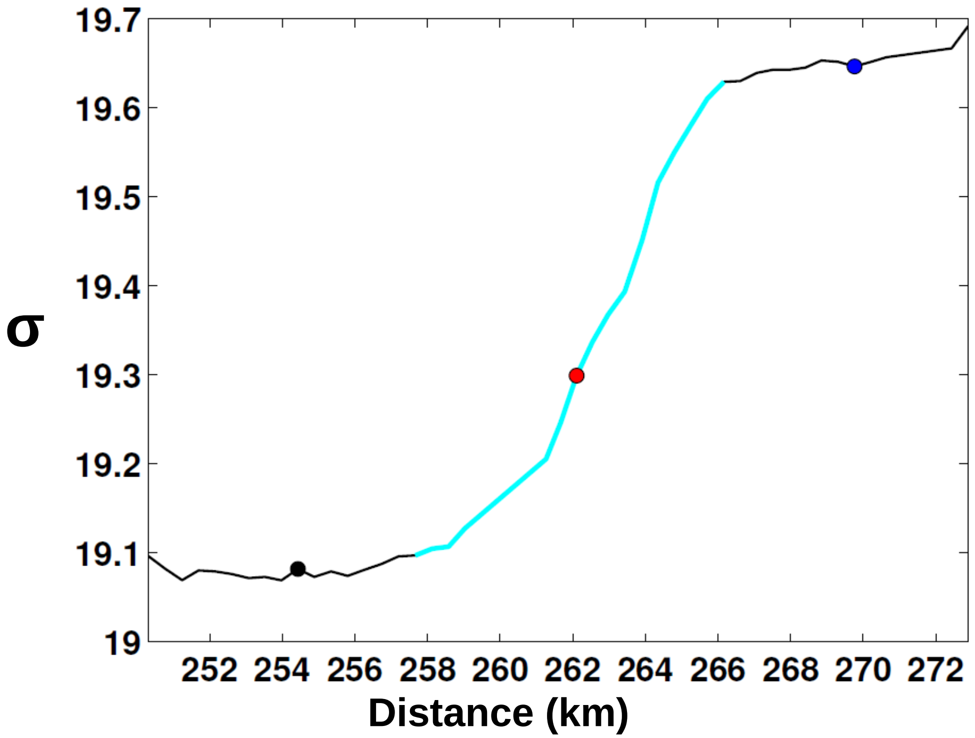
3m σθ
σθ (kg/m3)
Brunt Vaisala Frequency (N2)
Front 1
8 km
Front 2
25 km
Distance (km)
σθ (kg/m3)
Distance (km)
Distance (km)

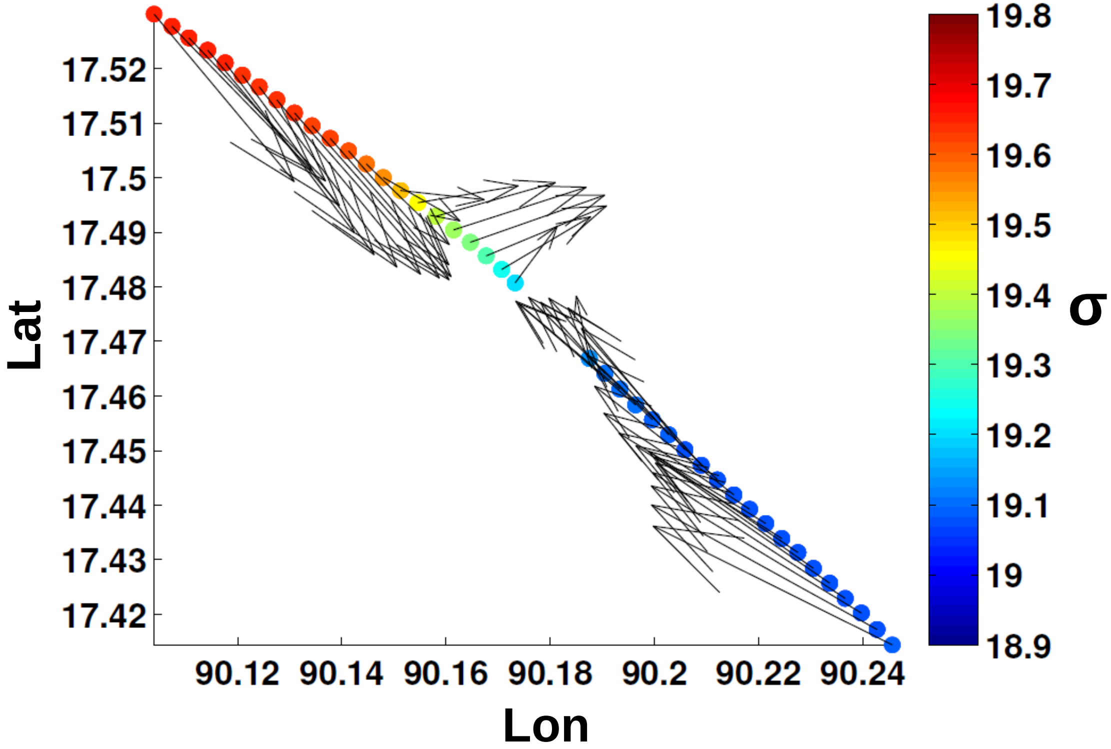


Size of front (kg/m^3)	Number	Scale (km)	Number
size < 0.3	1	<10	6
0.3 < size < 0.5	5	10-20	6
size > 0.5	11	20-25	5

Shallow mixed layer under 14 out of 17 large fronts

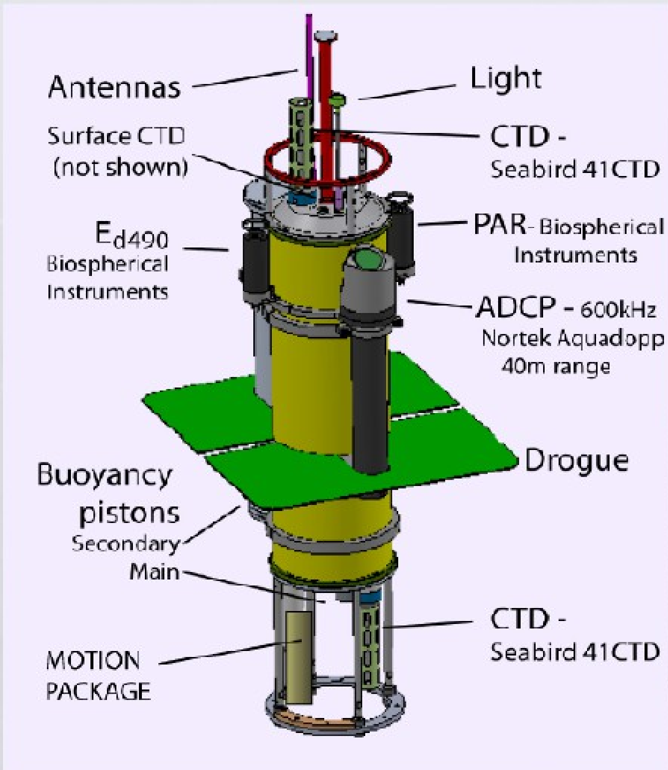
Dynamics at Fronts

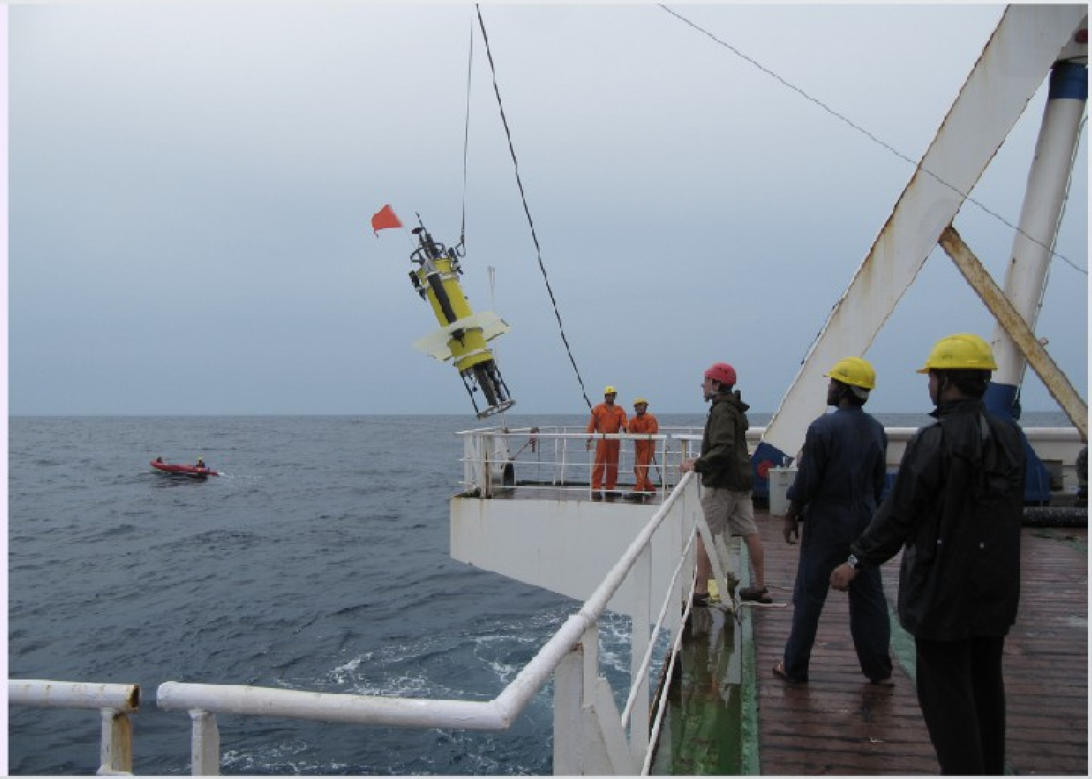




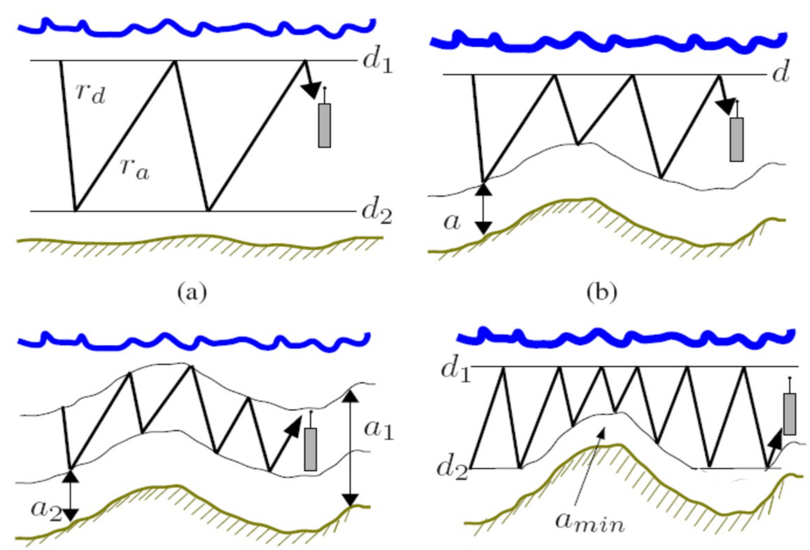
Potential density at 4m and current anomaly at 6m depth

Lagrangian Float SN88



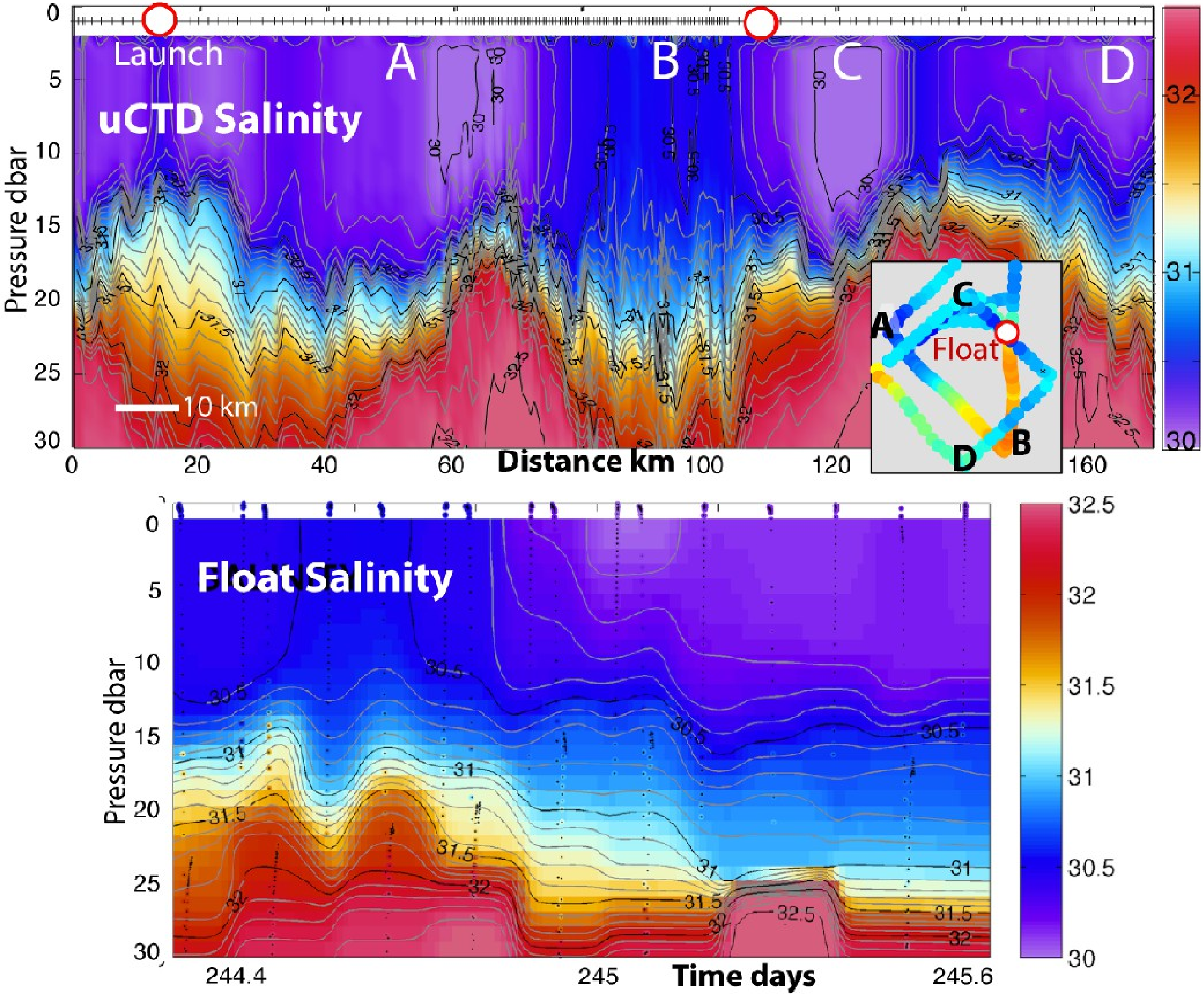


Acceleration package, GPS and Iridium antennas, 3 CTDS, 600 kHz ADCP, PAR, E_{d490}



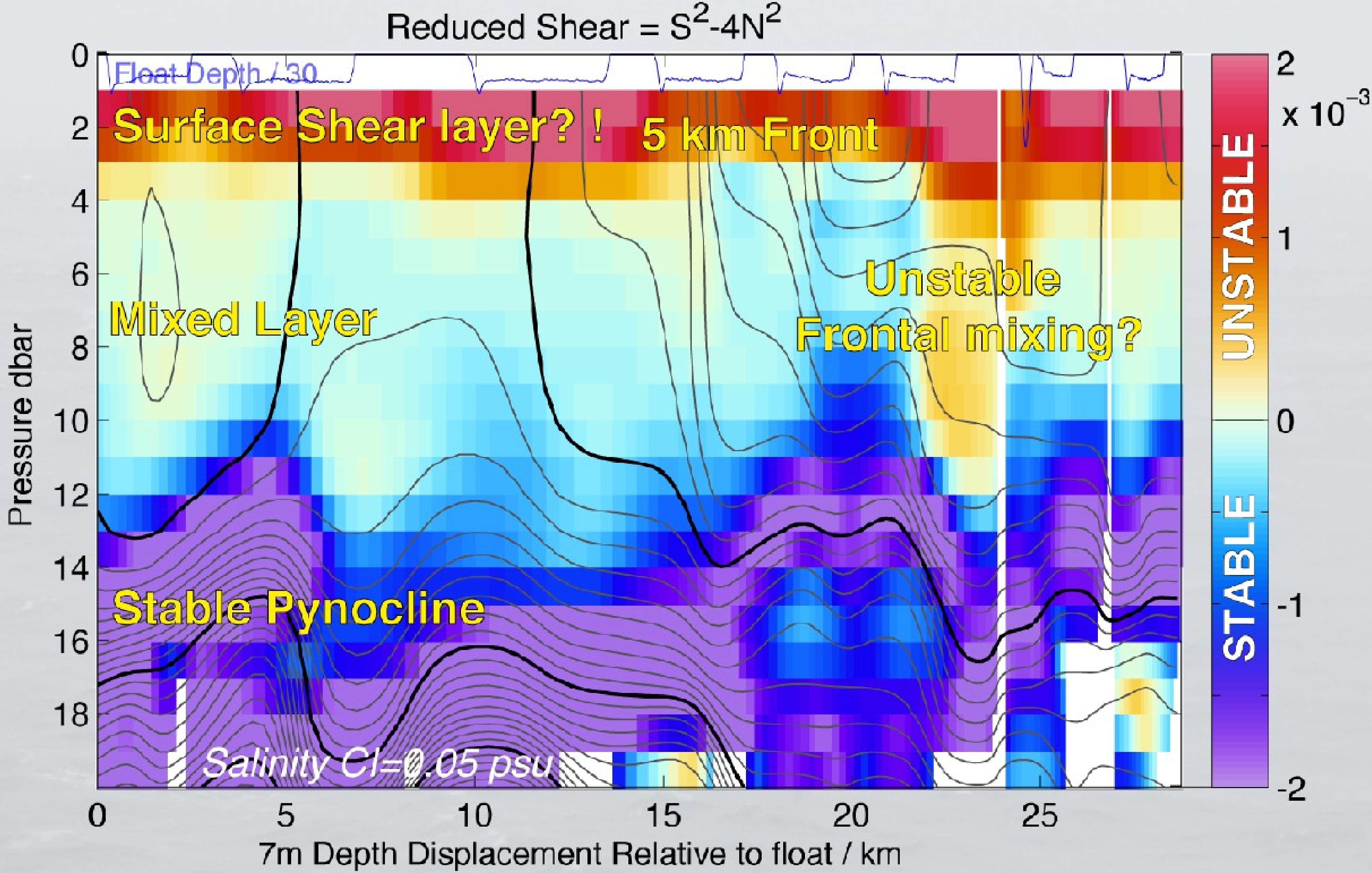
The Lagrangian Float (APL, U. Washington) has the same density and compressibility as sea water

Float launched near a front and slowly crosses it

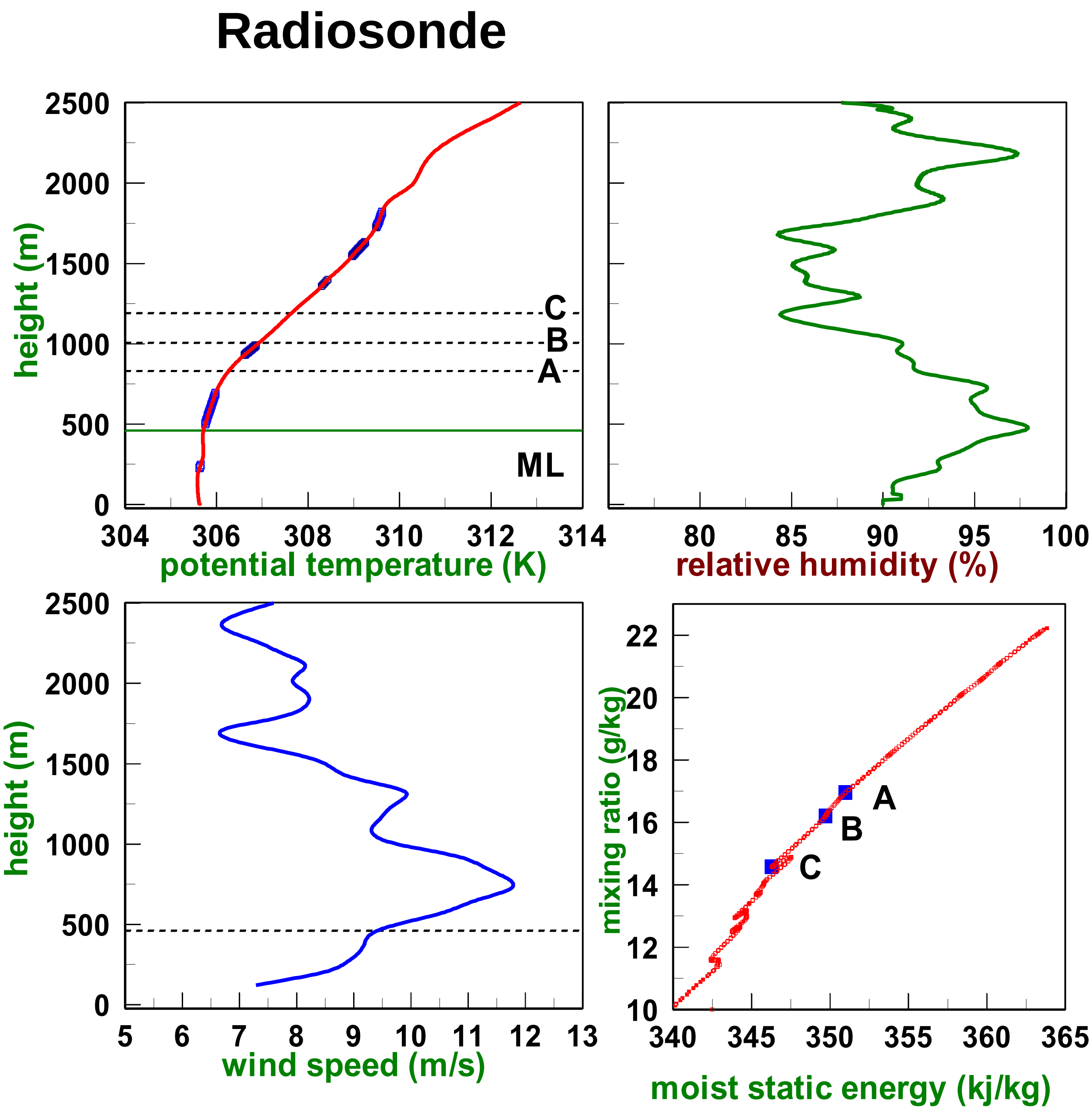


Frontal Section of Shear Instability

Distance from integrated velocity



OMM Cruise SN88
Sep 02, 1050 IST



Stratified shear layer (blue regions) may be unstable, leading to vertical mixing. The layers are less than 200 m in size.

Most numerical models may not resolve the unstable layers.

Surface buoyancy ~0, strong shear in the mixed layer

At ML top, $Ri_g<1$, turbulent mixing responsible for SST-Ta ~0 ?

In Progress

Science:

Internal waves and tides; inertial oscillations, Ekman flow and vertical momentum transport in the upper ocean

Variability of upper ocean stratification and shear from hours to years

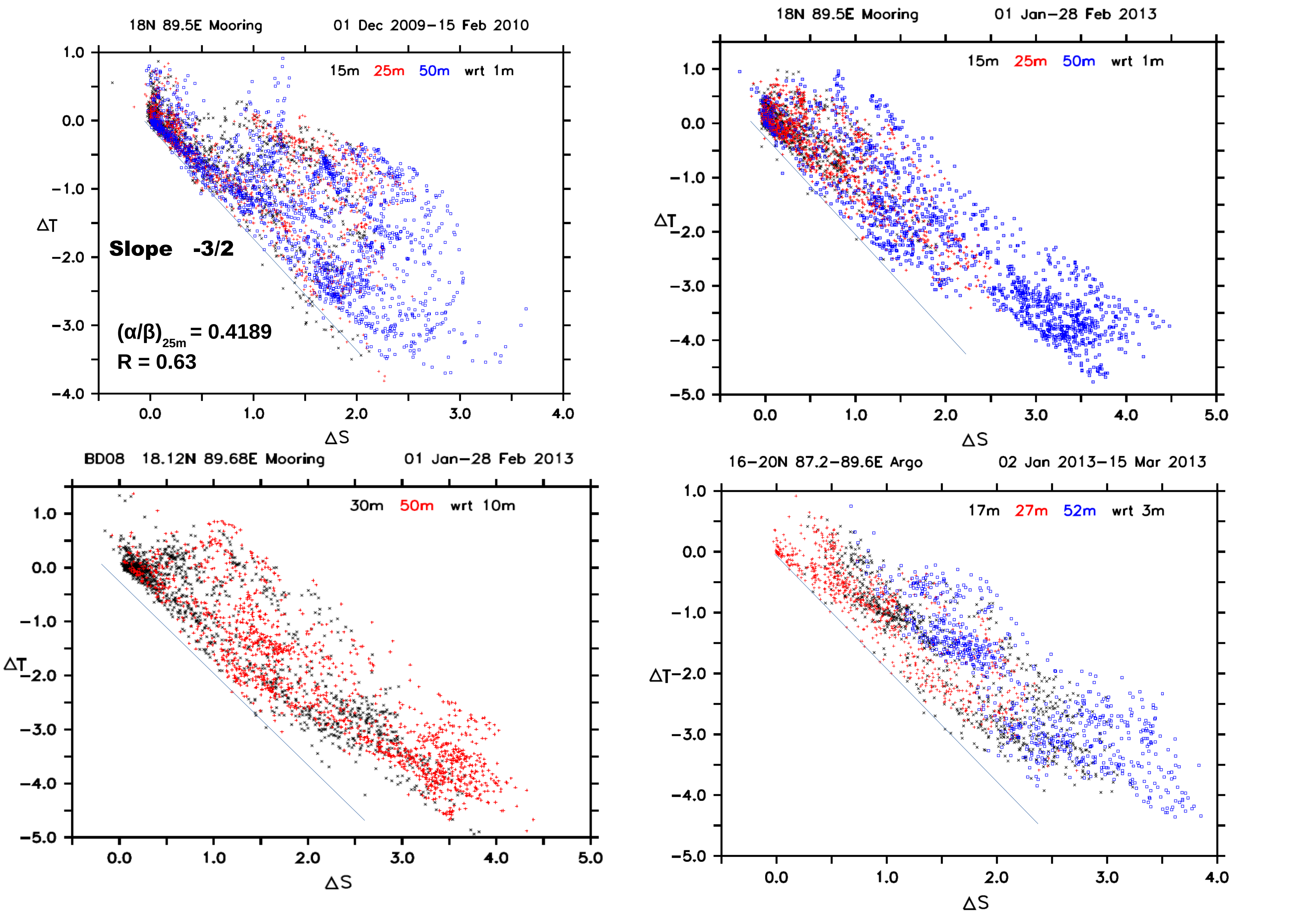
Turbidity, ocean optics and heat balance

Instruments:

Sea Glider and WHOI Met Sensors ordered

Lagrangian float, Wirewalker being ordered

Many open problems



Salinity stratification versus temperature inversion, winter 2010 and 2013
Temperature inversion of 3ºC requires a minimum salinity stratification of 2 psu

Work Plan upto May 2016

4 Cruises:

Sagar Nidhi Aug-Sep 2015, _Roger Revelle_ Aug-Sep 2015

River plume along the western boundary, near surface stratification, surface fluxes, atmospheric boundary layer and monsoon air-sea interaction

Sagar Kanya January 2016

Upper ocean variability and mixing in the northwest Bay

Sagar Nidhi April 2016

Spring western boundary current and deployment of WHOI mooring

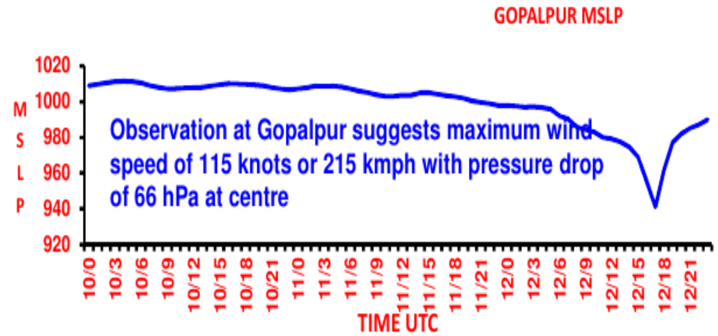
Training of Scientists/Engineers and PhD students on gliders, moorings, Lagrangian float and wirewalker in the US and in India

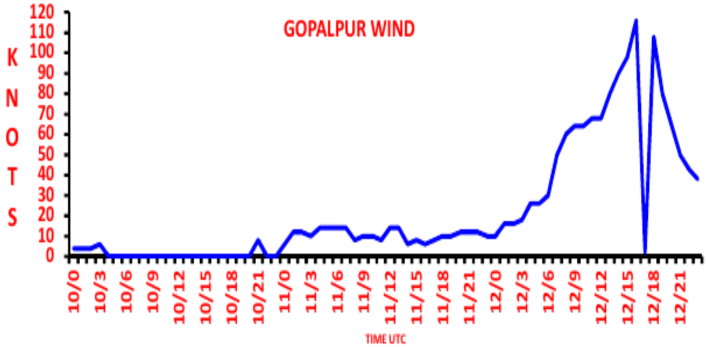
e.g. glider deployment, assembly, piloting, communication, software and data analysis; glider control lab at INCOIS Hyderabad.

Training and implementation process models and regional ocean models for intepretation and synthesis. Visits for collaborative science

Winter School at INCOIS

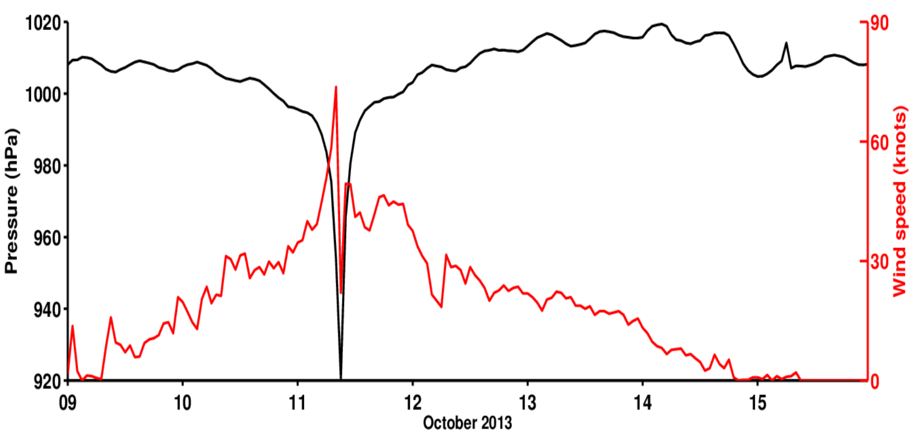
Cyclone Phailin



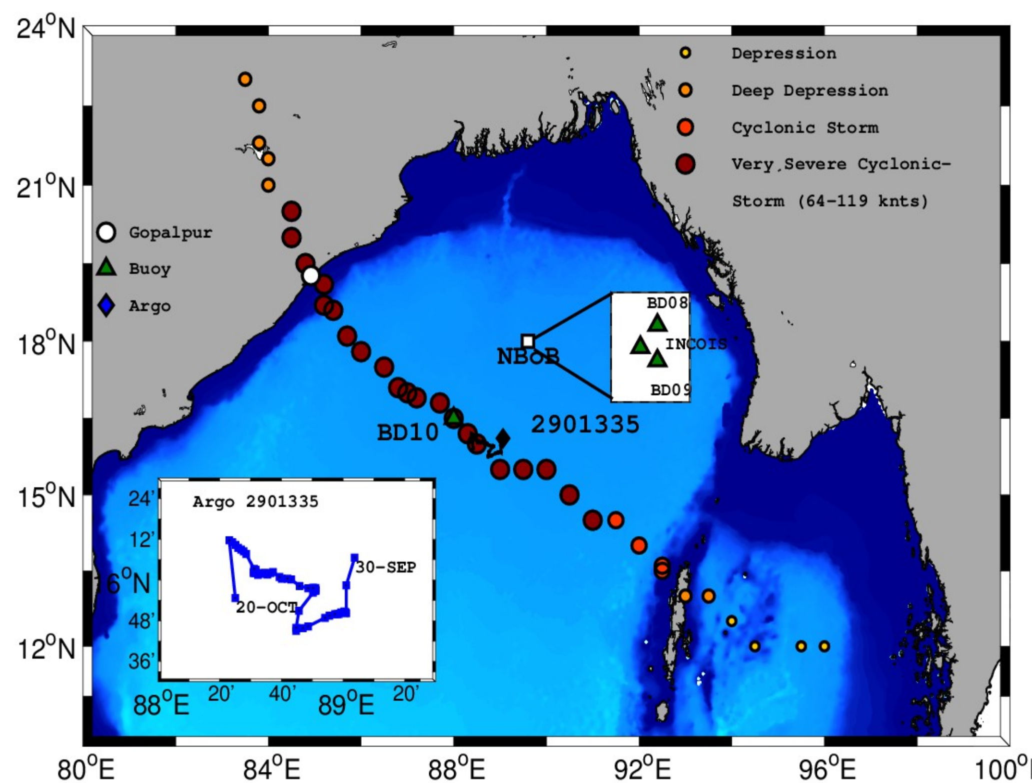


Mean sea level pressure and wind speed at Gopalpur

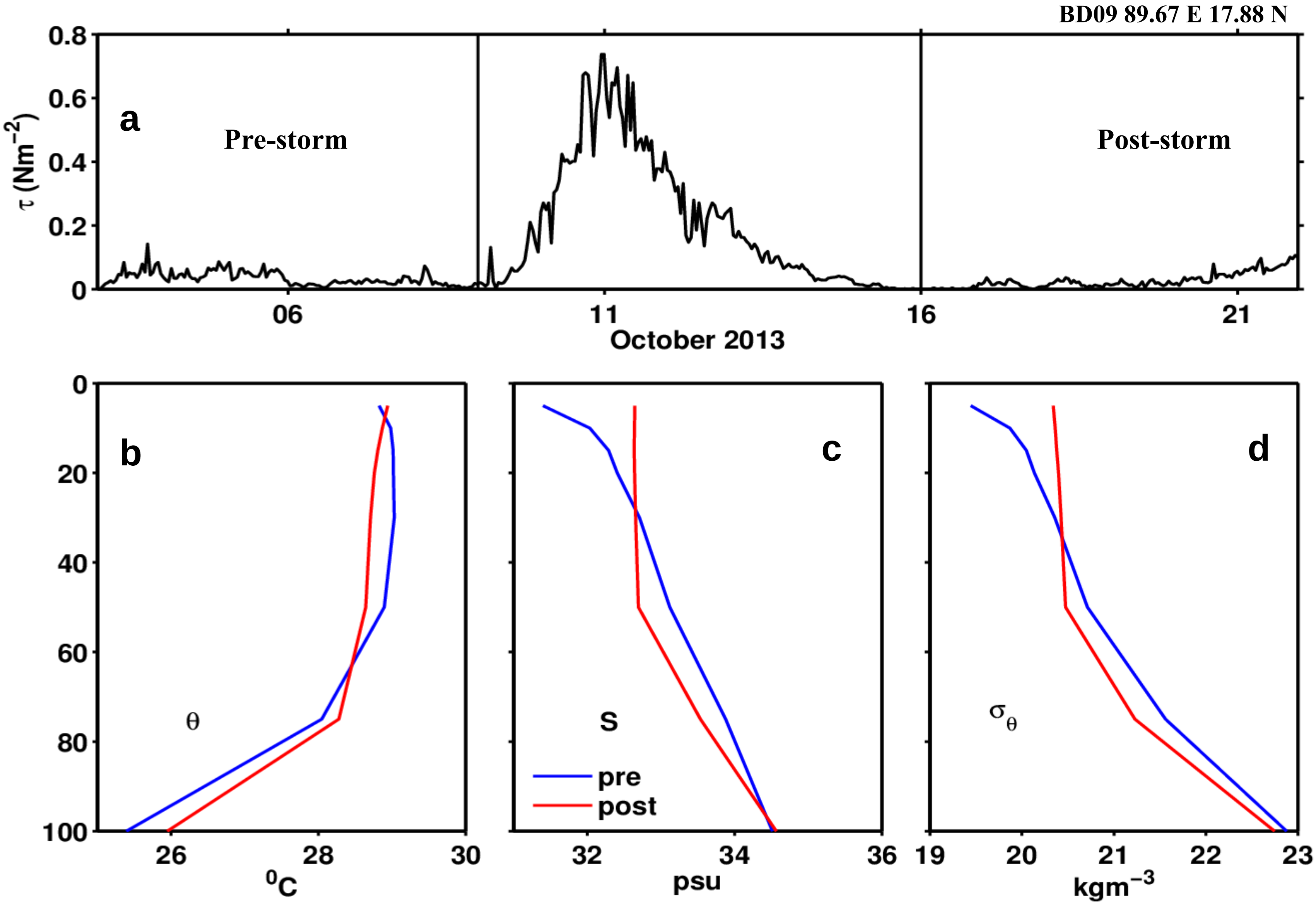
"Very Severe Cyclonic Storm Phailin: A Report"
Cyclone Warning Division IMD Oct 2013



Surface pressure (hPa) and wind speed (knots) NIOT Buoy BD10 (88E 16.5N)



Phailin Track 8-13 October 2013, NIOT mooring BD10. NBoB has three moorings at 18N (inset); Argo float 2901335 30 Sep-20 Oct 2013 (inset)

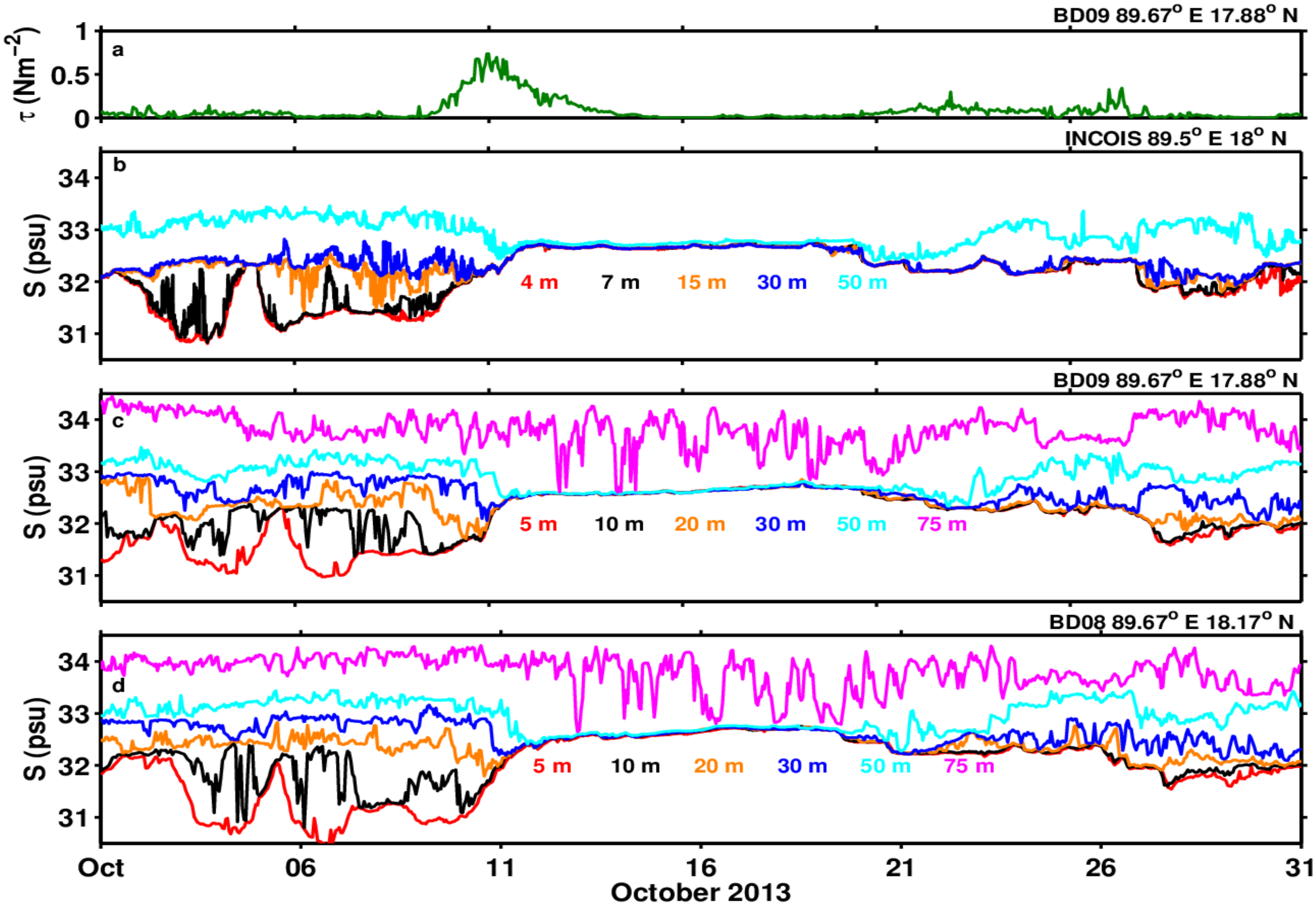


Hourly wind stress from BD09. Profiles of potential temperature, salinity and potential density before (3-8 Oct) and after (16-21 Oct) the storm. SSS increases by 1.6 psu.

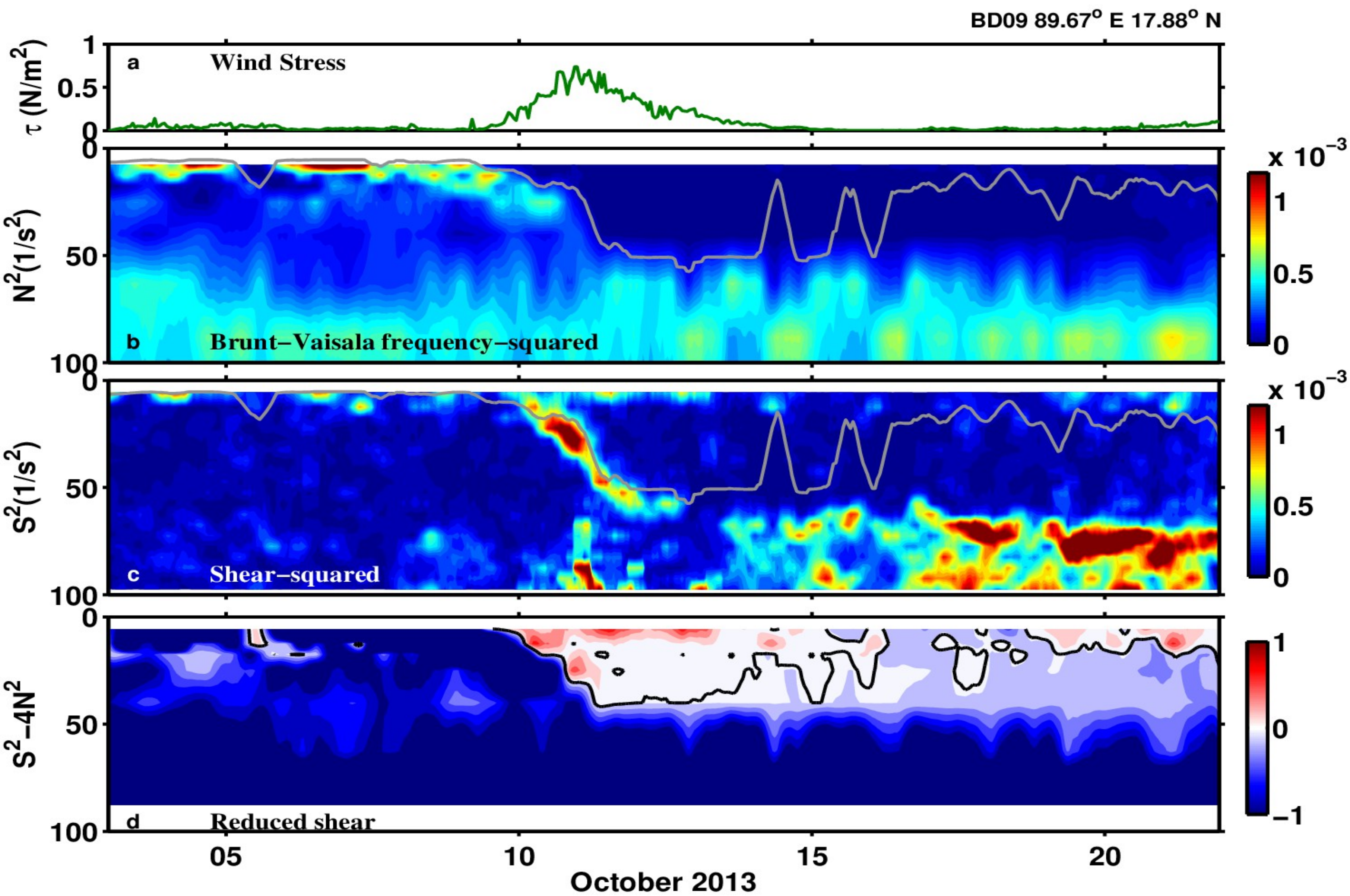
Post monsoon cyclones in the north Bay of Bengal do not cool SST

(Sengupta et al. 2008, Singh et al., 2012, Balaguru et al., 2013, Vincent et al., 2013)

Vertical mixing: Cyclone Phailin

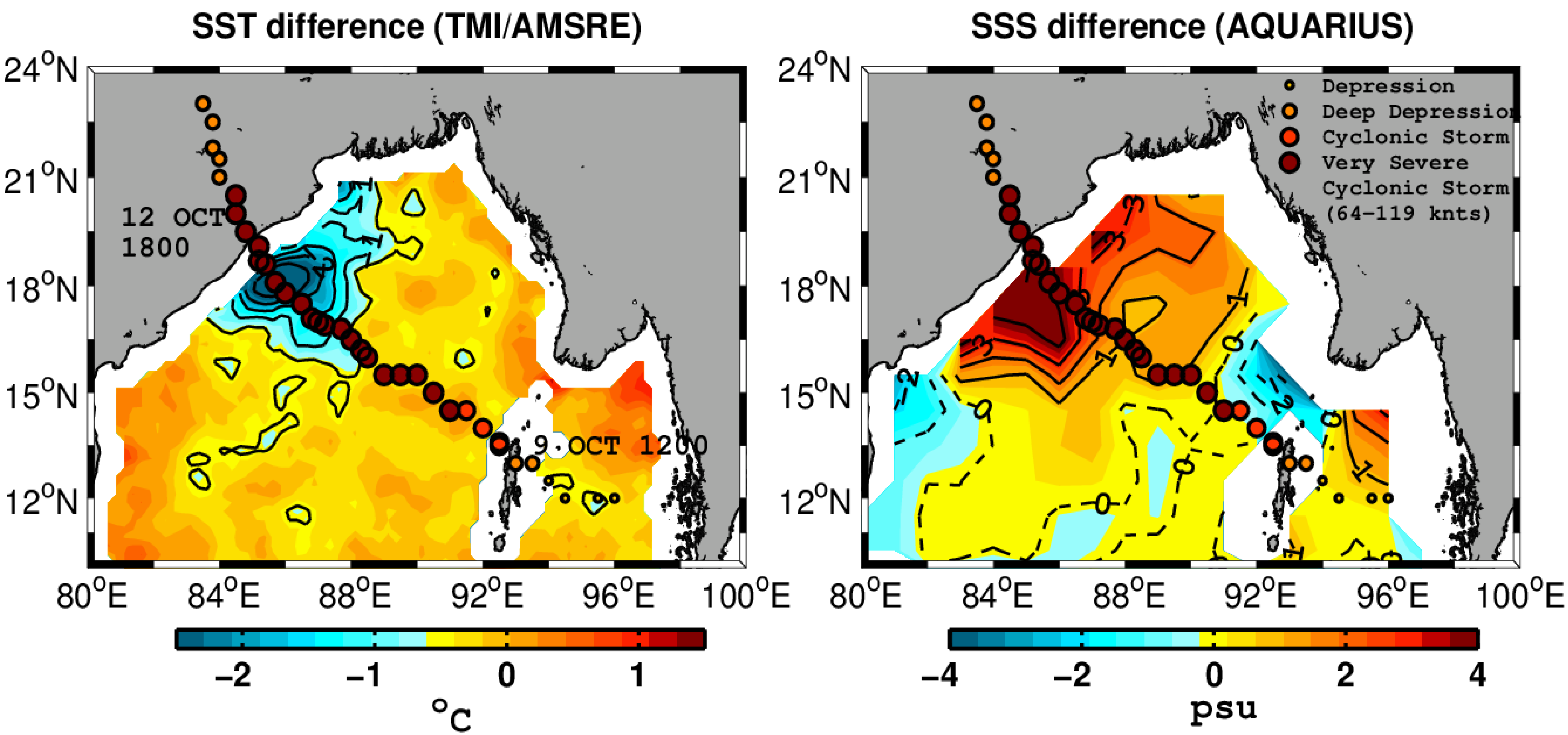


Hourly wind stress and salinity from moorings. SSS increases by 1.5 psu

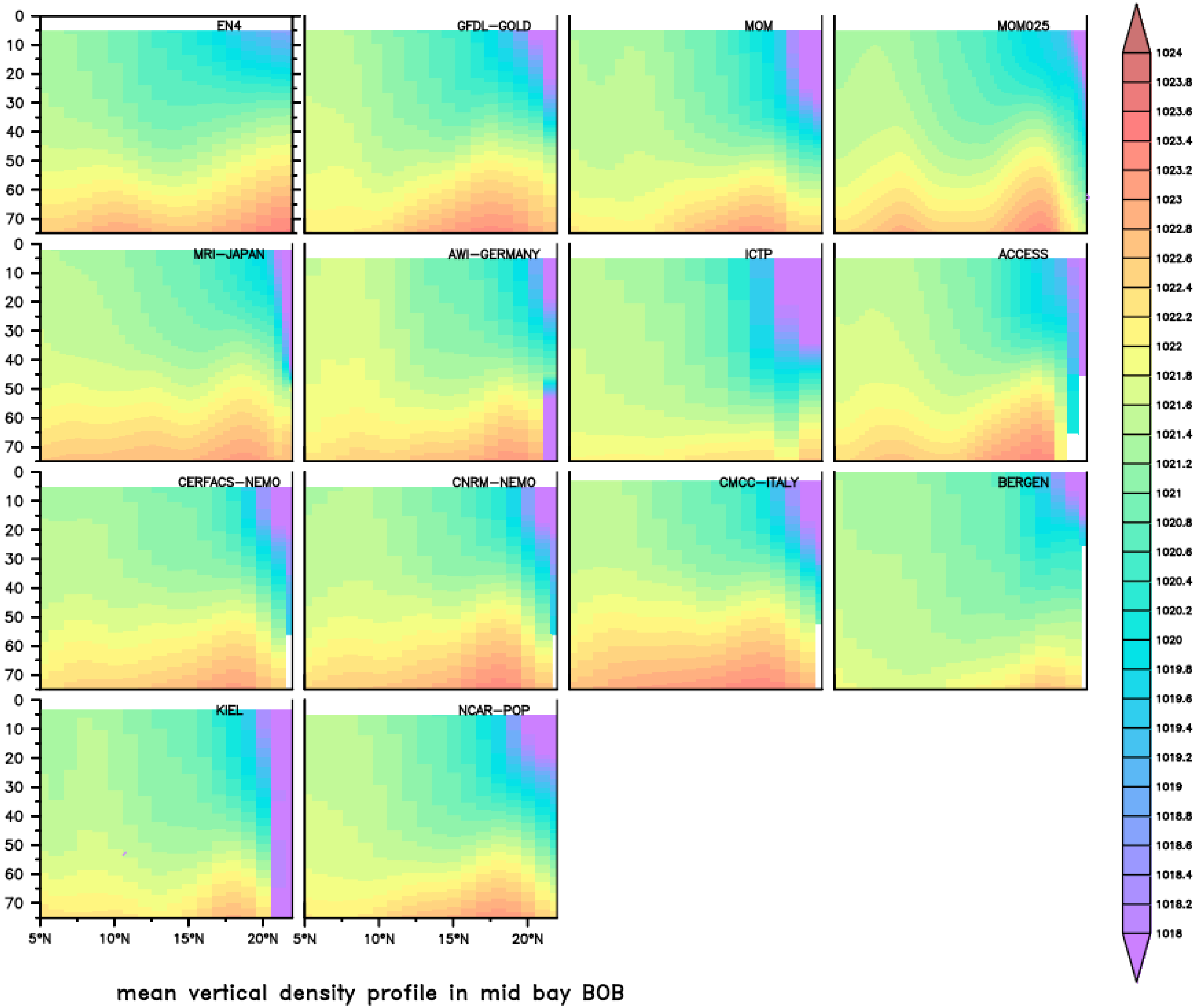


Hourly wind stress, stability ($N^2=-(g/\rho)(\partial\sigma_\theta/\partial z)$), shear-squared ($S^2=((\partial u/\partial z)^2+(\partial v/\partial z)^2)$), and reduced shear ($S^2-4N^2$) from NIOT mooring BD09. Zero reduced shear means Richardson number = 0.25

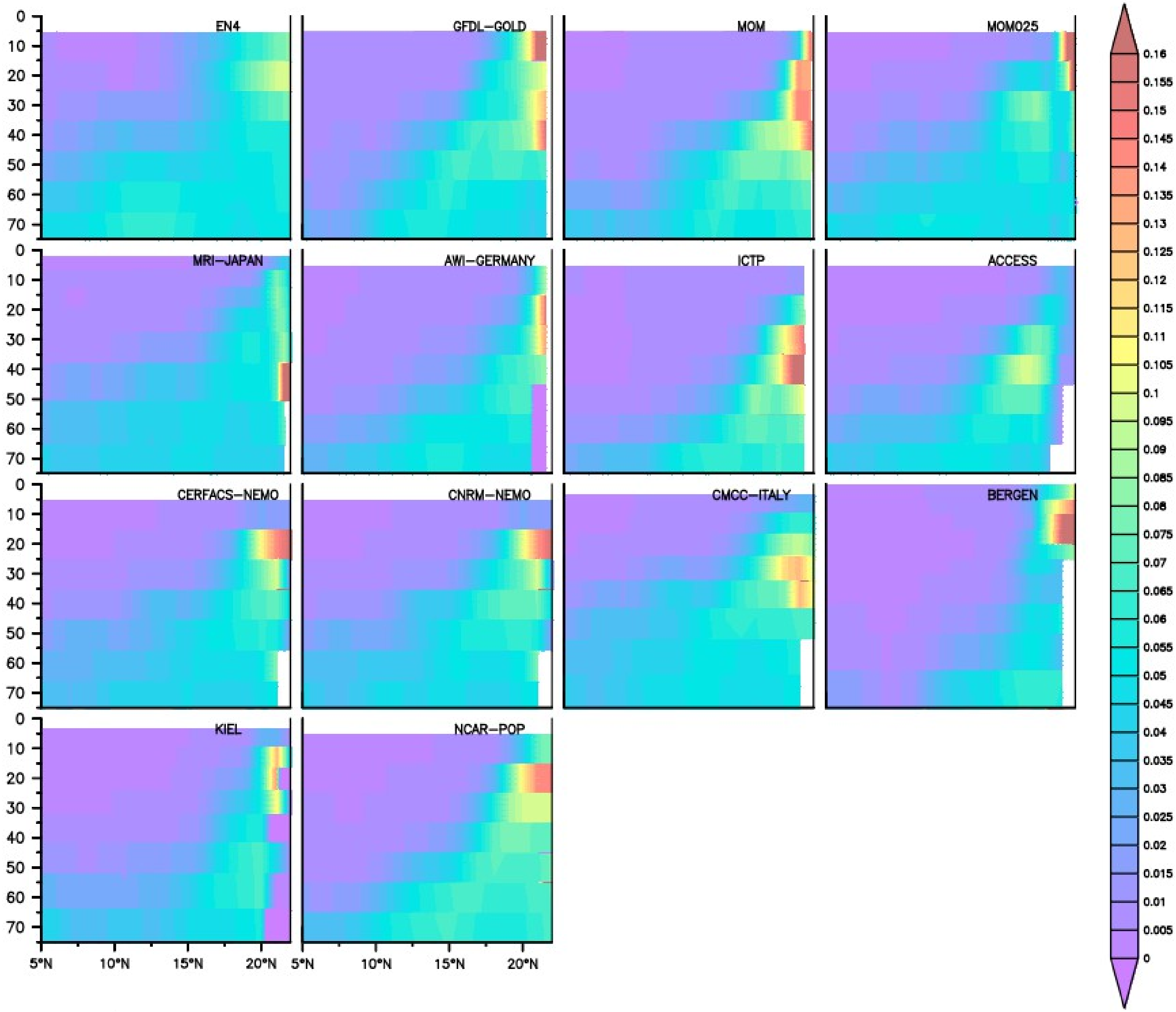
Shear induced turbulent mixing deepens mixed layer



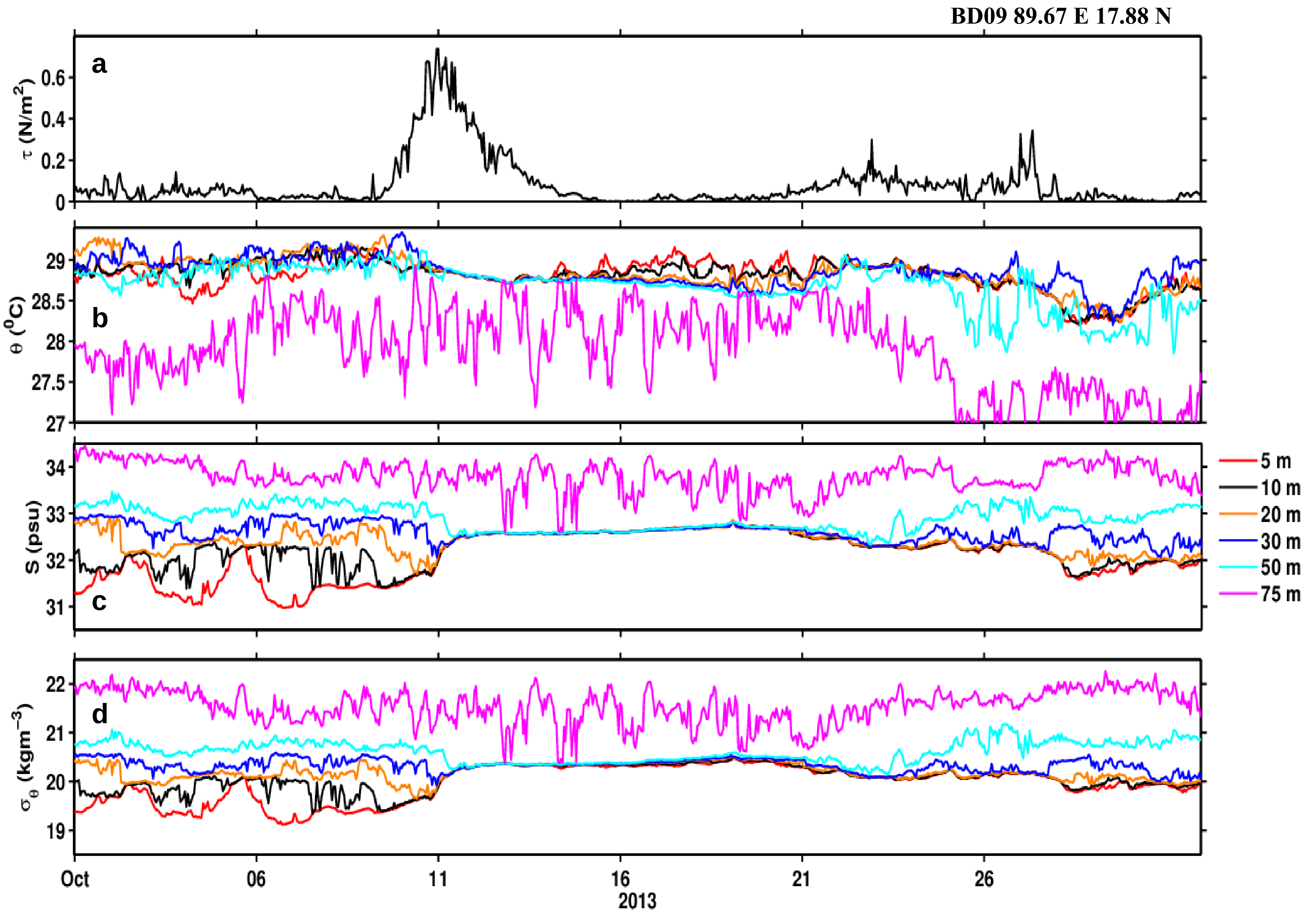
Post-storm (16-21 Oct) minus pre-storm (3-8 Oct) Microwave SST and Sea Surface Salinity



ρ (85-90 E) in Observations (top left) and ocean models forced by CORE II fluxes

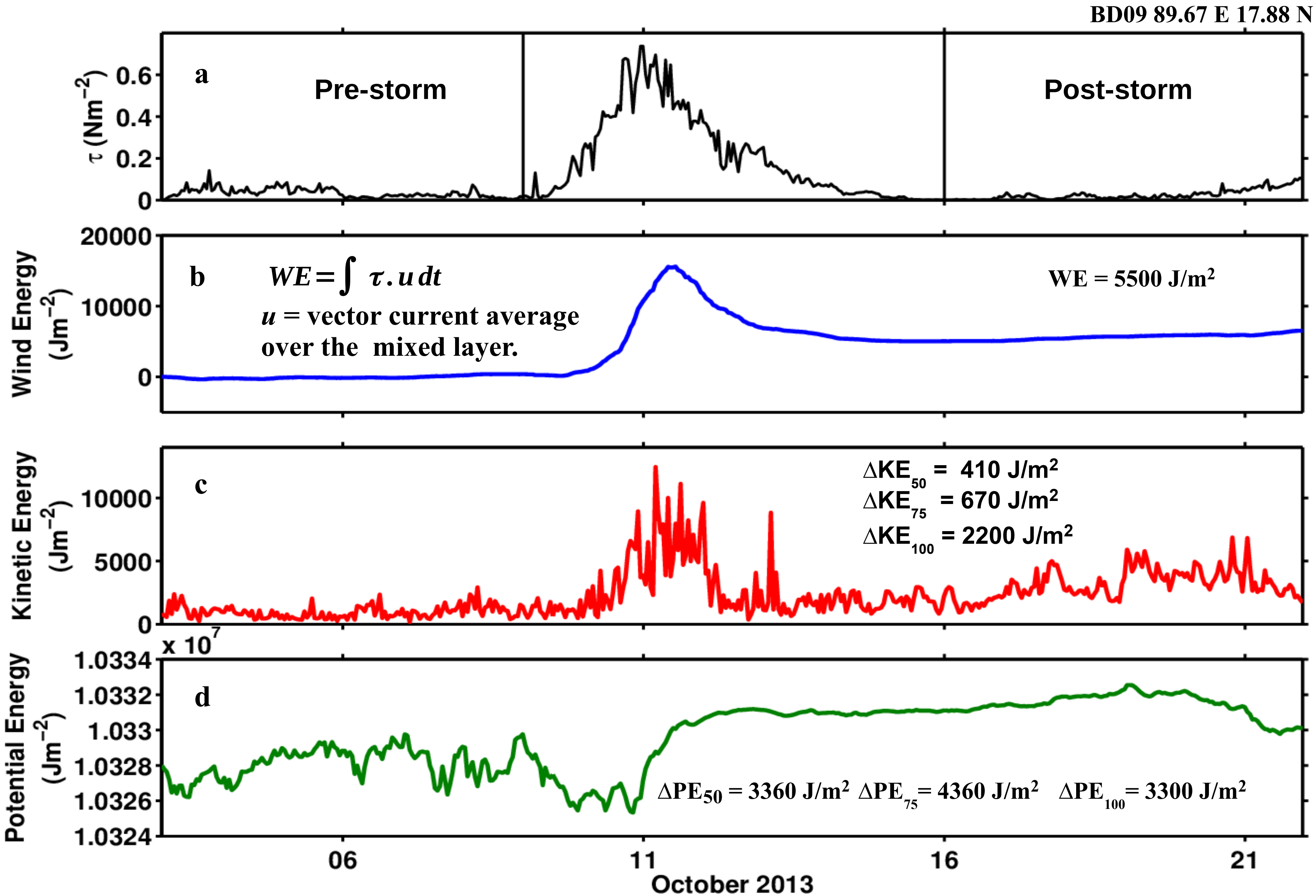


dρ/dz in Observations (top left) and ocean models forced by CORE II fluxes



Hourly wind stress, potential temperature, salinity and potential density from NIOT mooring BD09

Storm induced vertical mixing to at least 50 m



Hourly a) wind stress. b) Enery input (WE) from wind to ocean mixed layer. c) Kinetic energy (3-21 October mean current removed) of the upper 100 m. d) Potential energy of the upper 50 m. The change in Wind energy (input of the energy by the wind stress), change in kinetic energy and change in potential energy due to the storm are mentioned in the pannels.

Change in wind energy apparently balances change in potential and kinetic energy.

How does energy get to dissipative scales?

In QG theory cascade is inverse!

Non-dissipative 2-D

Mesoscales

Ro << 1, Ri >> 1
L ~ 50-200 km
D/L << 1, hydrostatic

→ How do energy and properties get fluxed downscale? →

Submesoscales?

Dissipative 3-D

Small scales

Ro >> 1, Ri << 1
L < 100 m
D/L ~ 1, nonhydrostatic

FRONTS!

From Amit Tandon

AVISO ADCP 30m

ζ/f AVISO
geostrophic velocities

28-30 Aug 2014

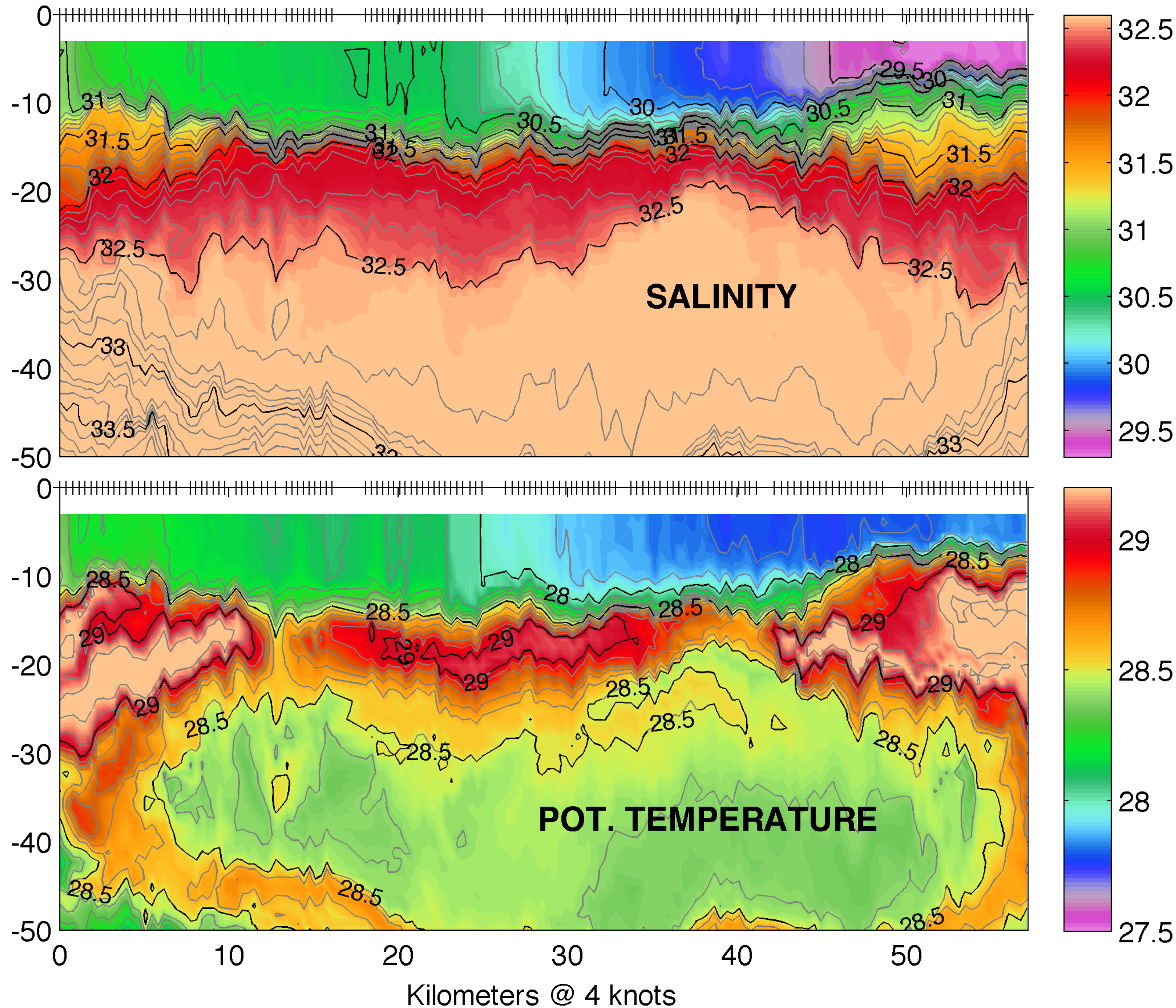
ζ/f from ADCP along ship track (above; red)

ζ/f

O(0.1-0.2) on 100 km scales

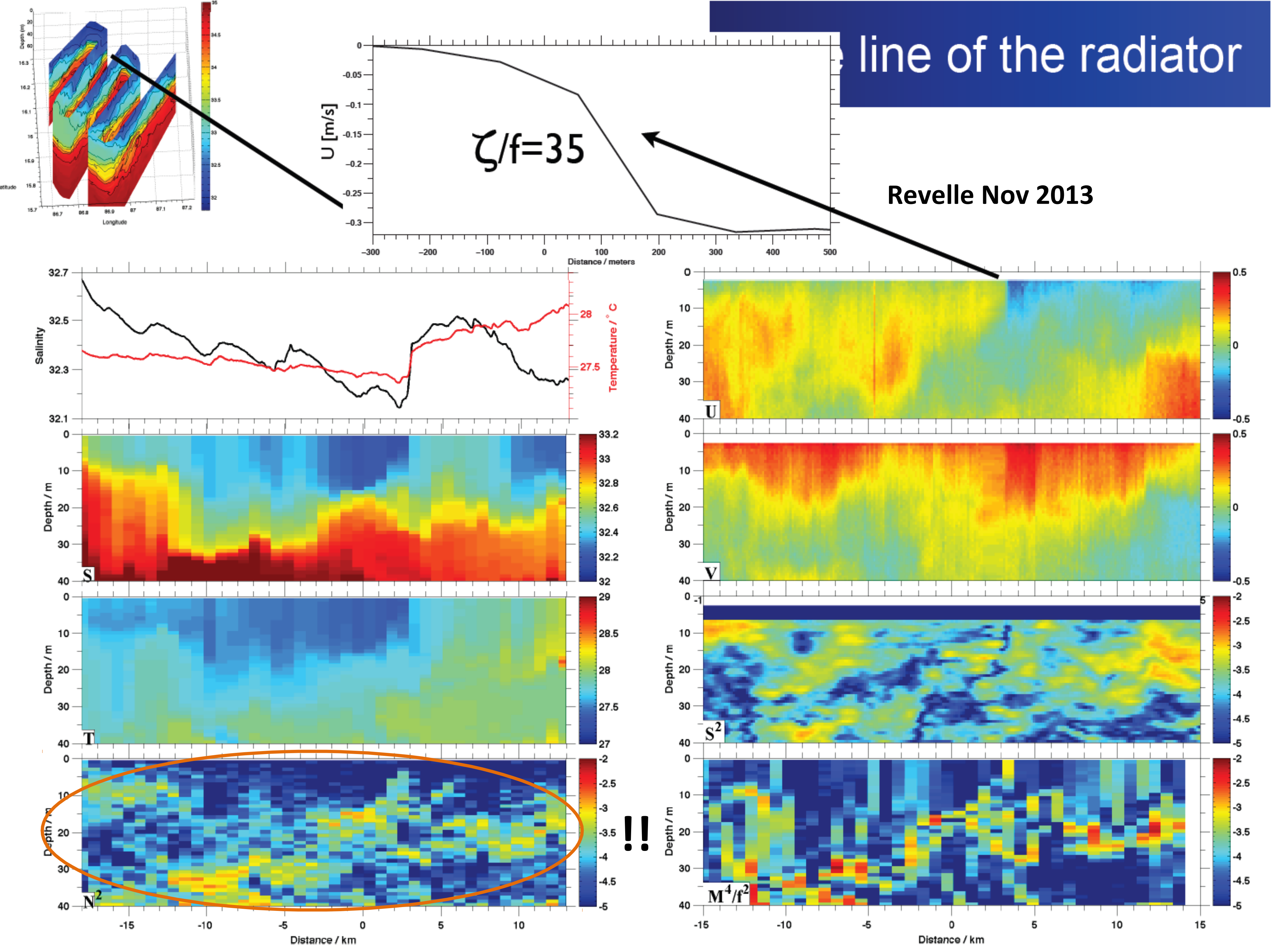
O(1) on 10-20 km scales

Bay of Bengal: Looking for 1-20 km fronts



Underway CTD *Sagar Nidhi* Nov 2013; resolution 300 m 1 m, 4-100 m

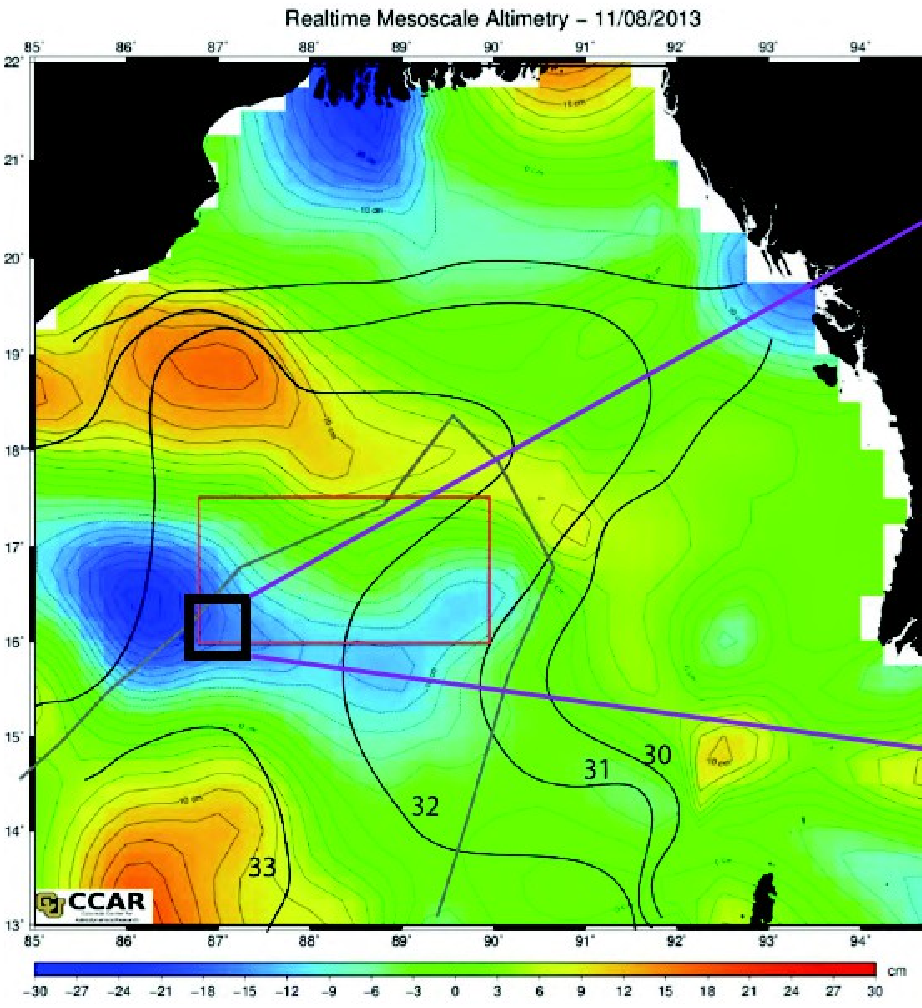
Discussions onboard Sagar Nidhi Cruise SN082 Nov-Dec 2013
Real-time guidance from remote sensing


line of the radiator
ζ/f=35
U [m/s]
Distance / meters
Revelle Nov 2013
Salinity
Temperature / °C
Depth / m
Longitude
Distance / km
U
V
S
T
S²
N²
M⁴/f²
!!

Lagrangian Float

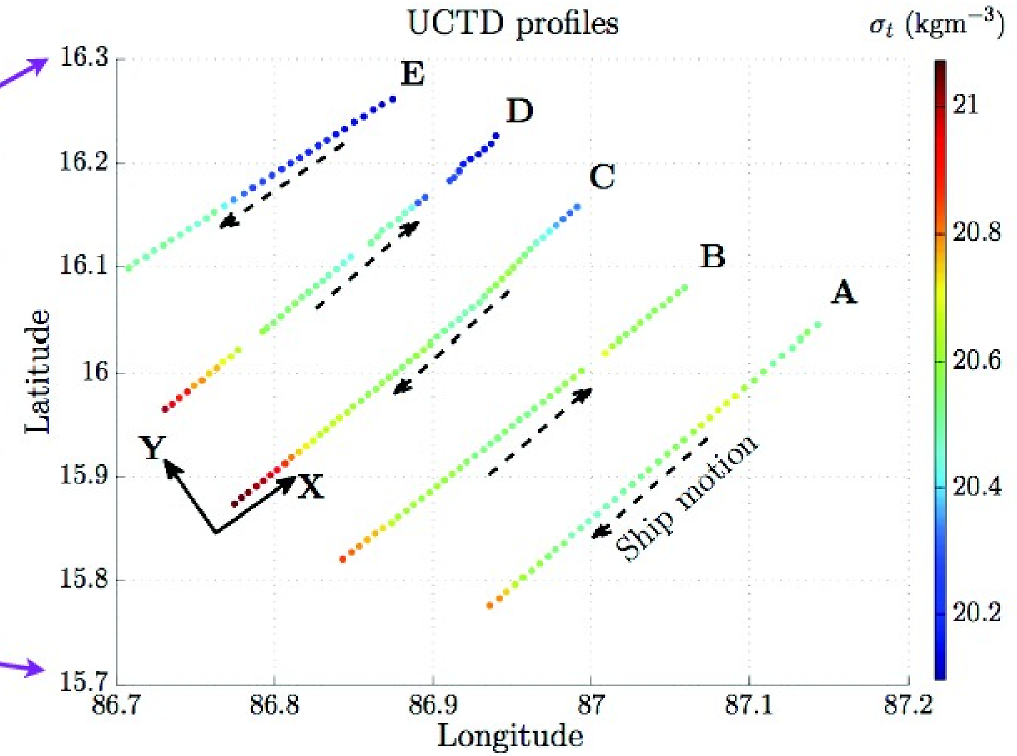
Profiles following density surfaces, endurance upto 100 days on each deployment, remotely programmable.

Leg 1: Process study at 16N



SSHA from CCAR (color)
+ Salinity (thick black lines)
+ EEZ (thick gray line)

Density averaged over 1-10m

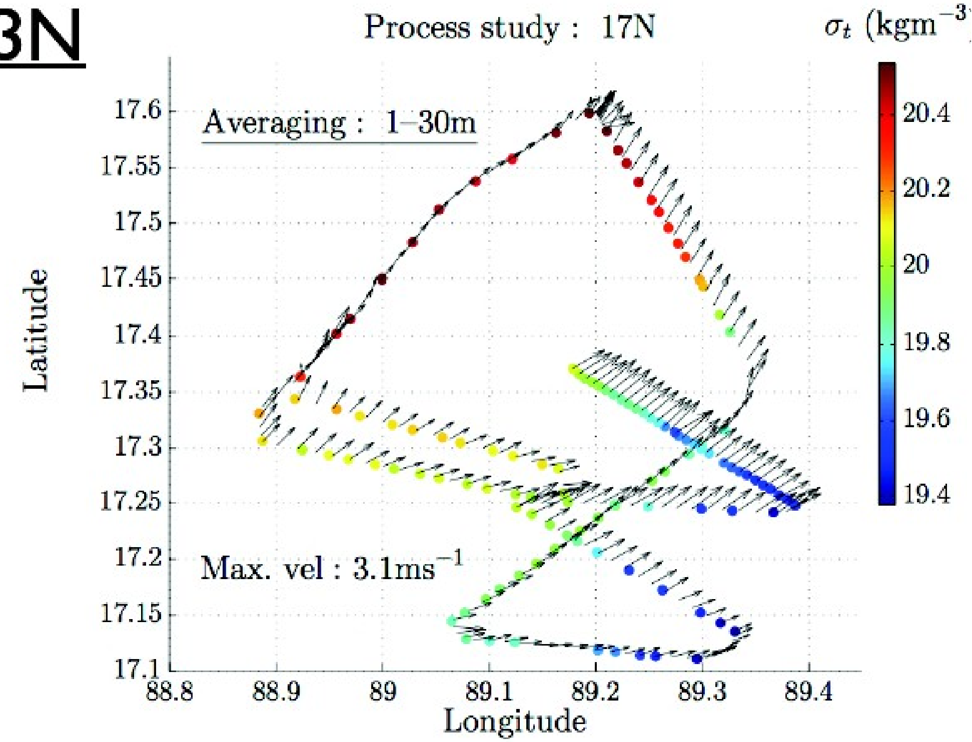


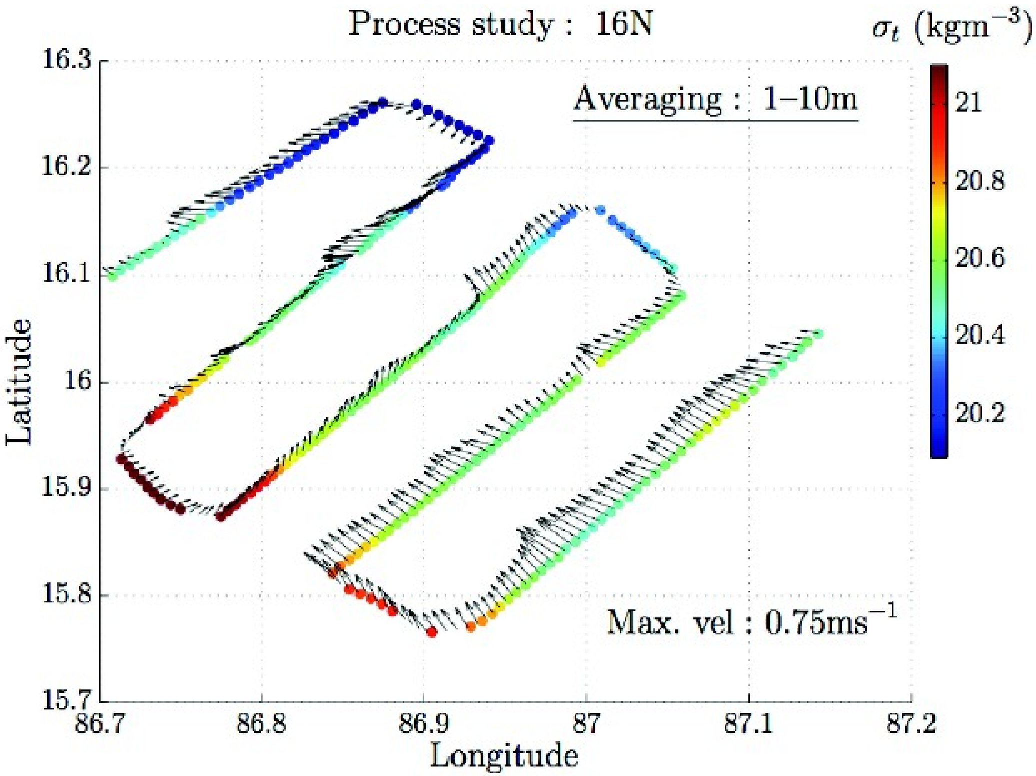
Distance between UCTD profiles: 0.7-1.0km

Duration of transects: 4-6hrs

One-minute currents

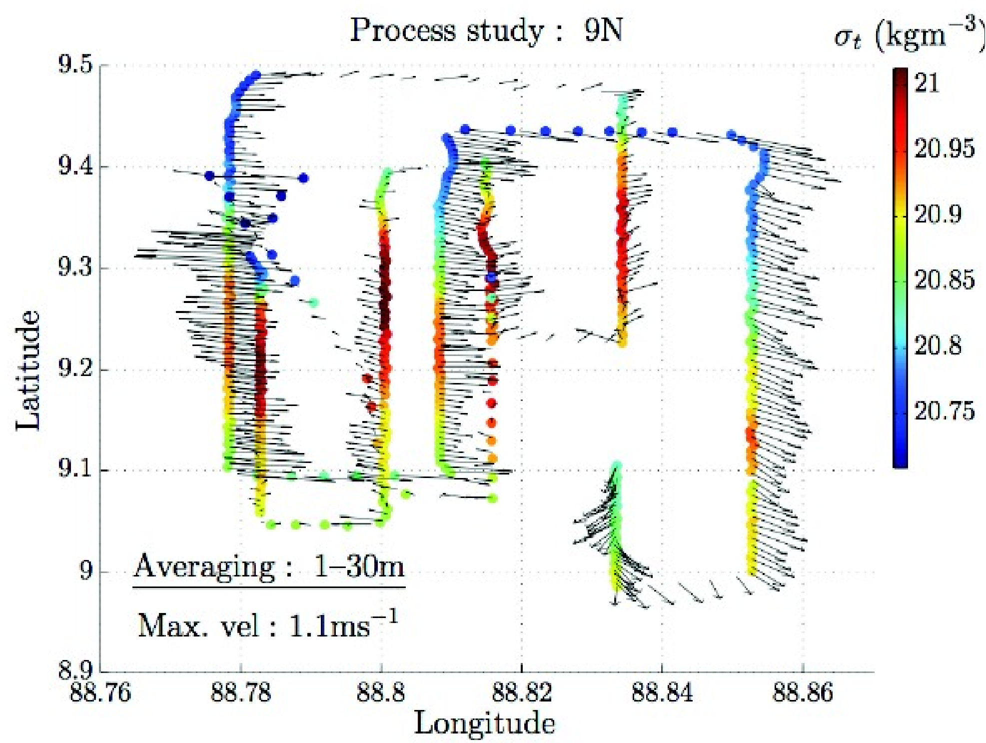
17.3N





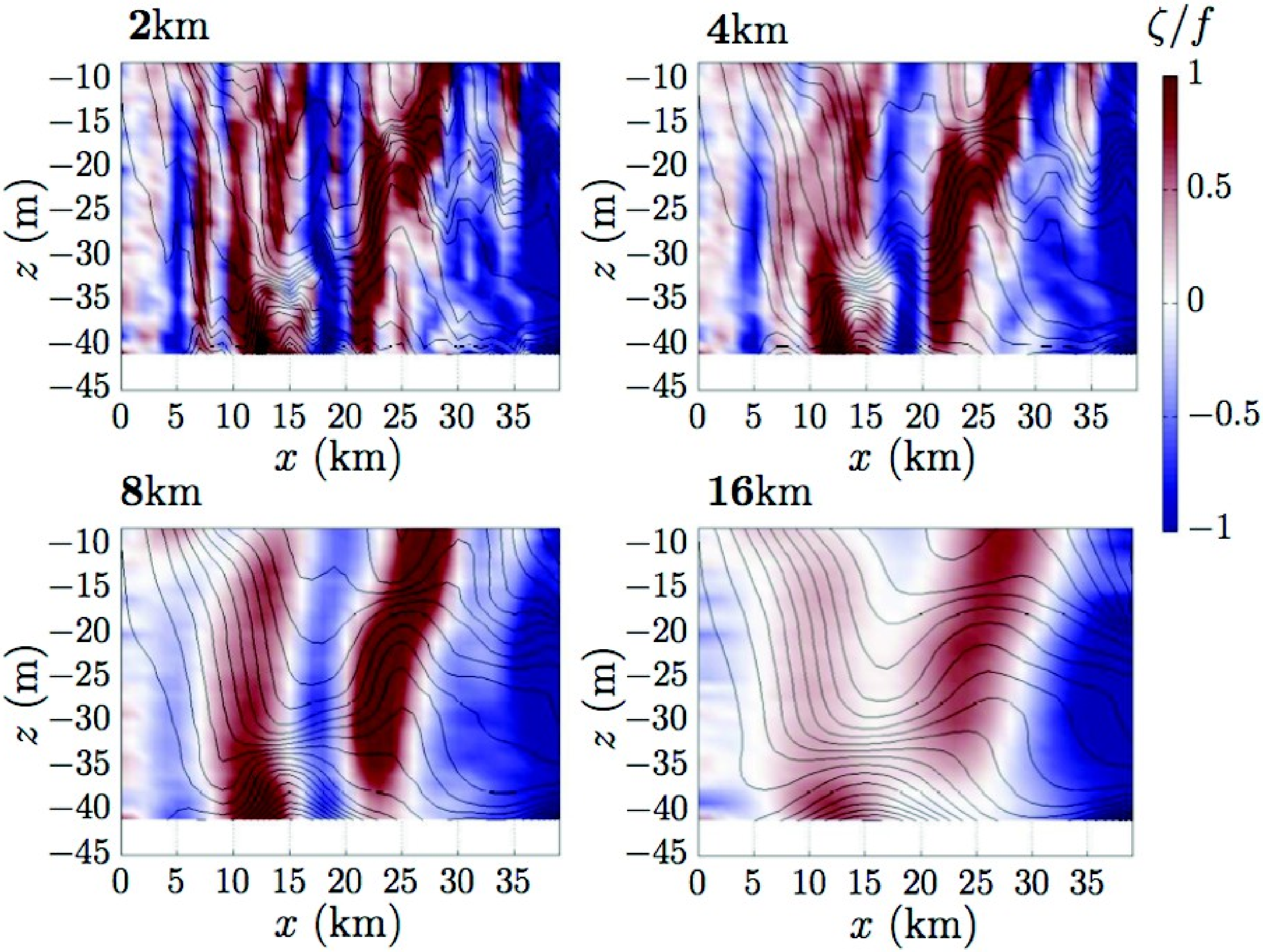
16.1N

9.2N



How does vorticity change with scale?

16.1N



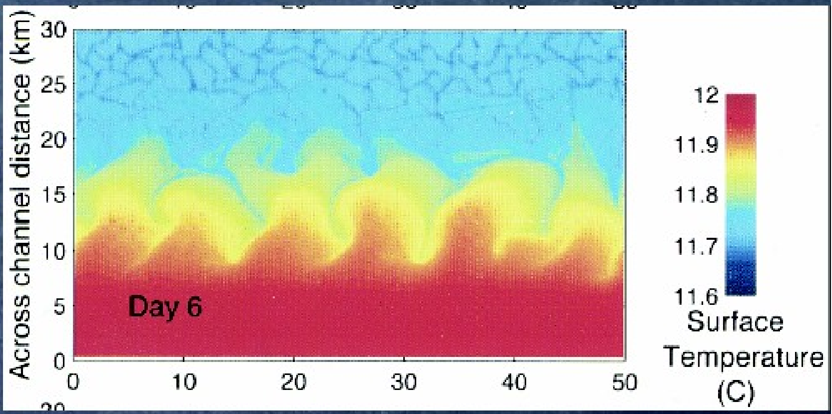
$\zeta/f \sim O(1)$

at scales O(1-10km) is a signature of submesoscale instabilities

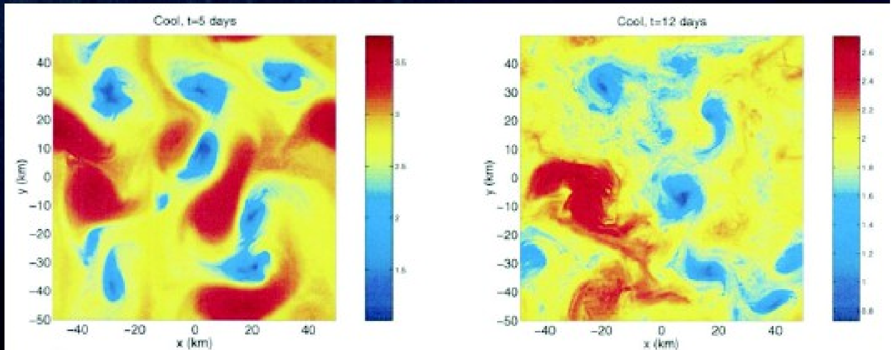
Generation Mechanisms (forced)

- **Forced instabilities:** Submesoscale generation by buoyancy fluxes:

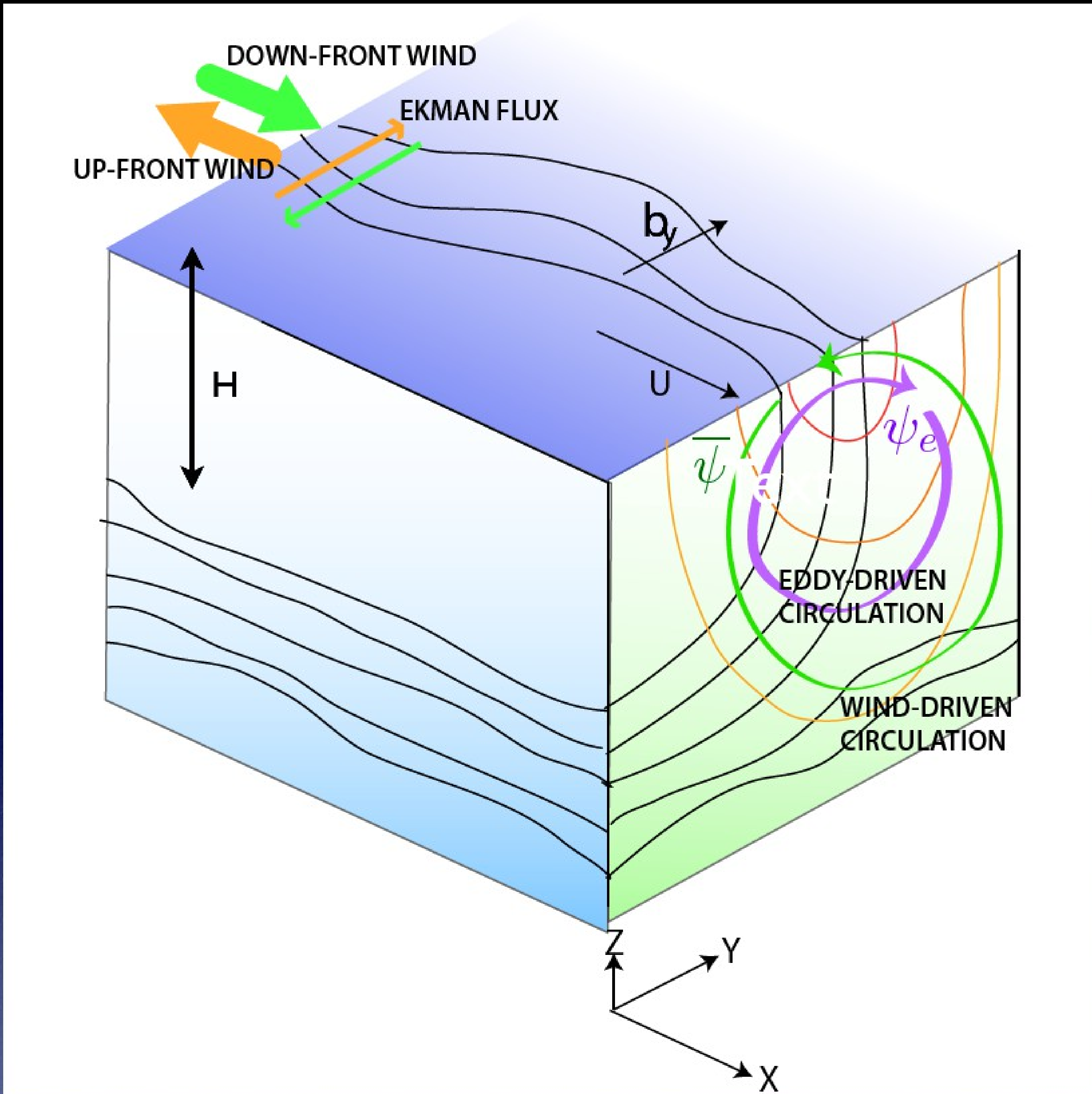
Differential cooling generating MLI in 3-d (Haine and Marshall 1998)



Surface cooling on mesoscale eddies generating submesoscale baroclinic instability (Legg et al. 1998, Legg and McWilliams 2001);



In the presence of wind forcing?



Scaling

Eddy-driven

$$\psi_e \sim 0.06 H^2 \overline{b_y}/f$$

Fox-Kemper et al., 2008

Wind-driven

$$\overline{\psi} \approx -\tau^x/\rho f$$

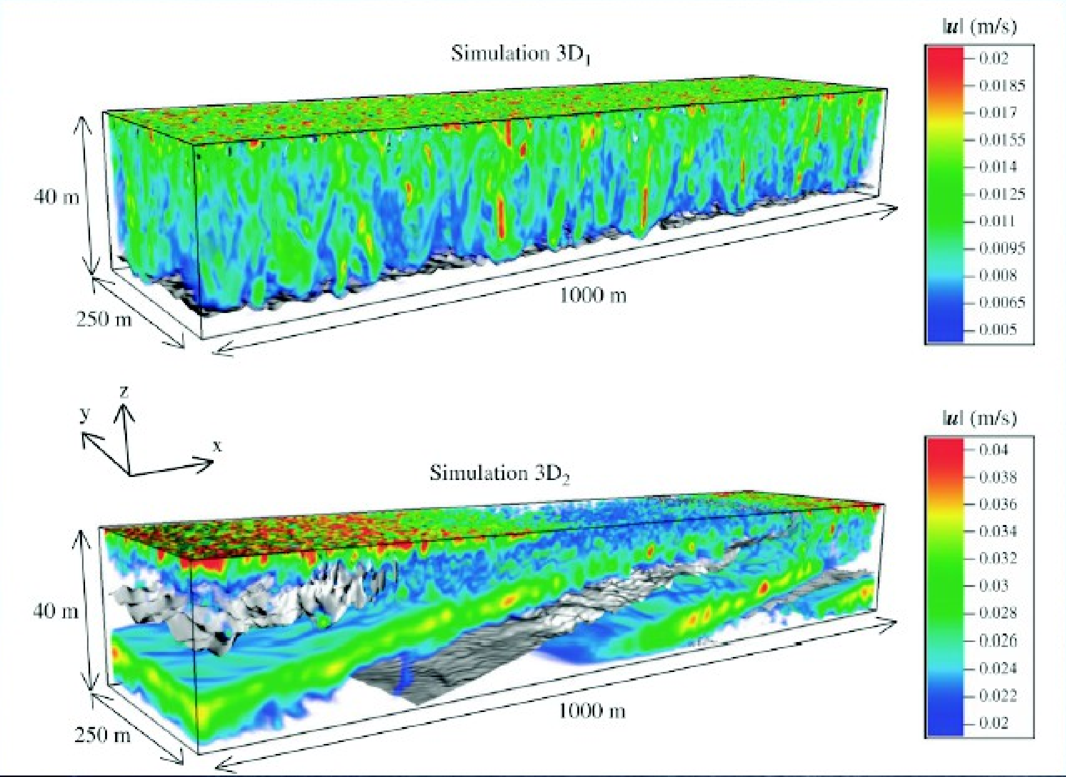
$$r \equiv |\overline{\psi}/\psi_e| = \tau_0/(0.06\rho H^2 \overline{b_y})$$

$r < 1$ MLE win restratification

$r \geq 1$ wind has pinned the front

Mahadevan, Tandon, Ferrari (2010)

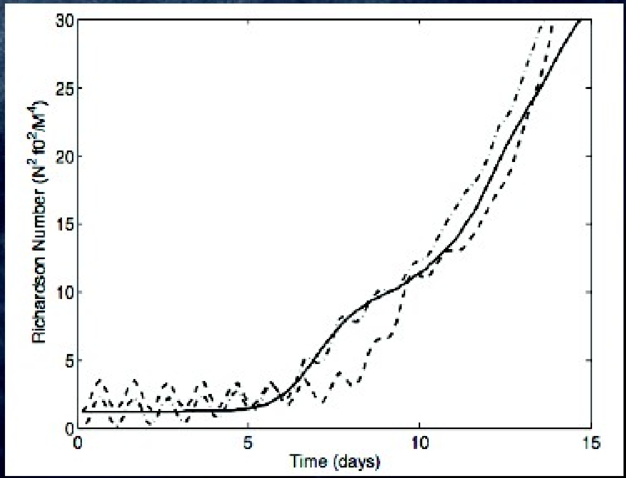
Forced Generation: Symmetric Instability



- Symmetric instability leads to slantwise convection resetting the PV to zero (Taylor and Ferrari 2010)

What about MLI?

- On longer time-scales, as the mixed layer re-stratifies and Ri>1, ageostrophic baroclinic instability matters and leads to ML eddies.



6 Cruises, 1 workshop, 1 Science/Planning Meeting

Participants in *Roger Revelle* and *Sagar Nidhi* cruises and IISc. Workshop

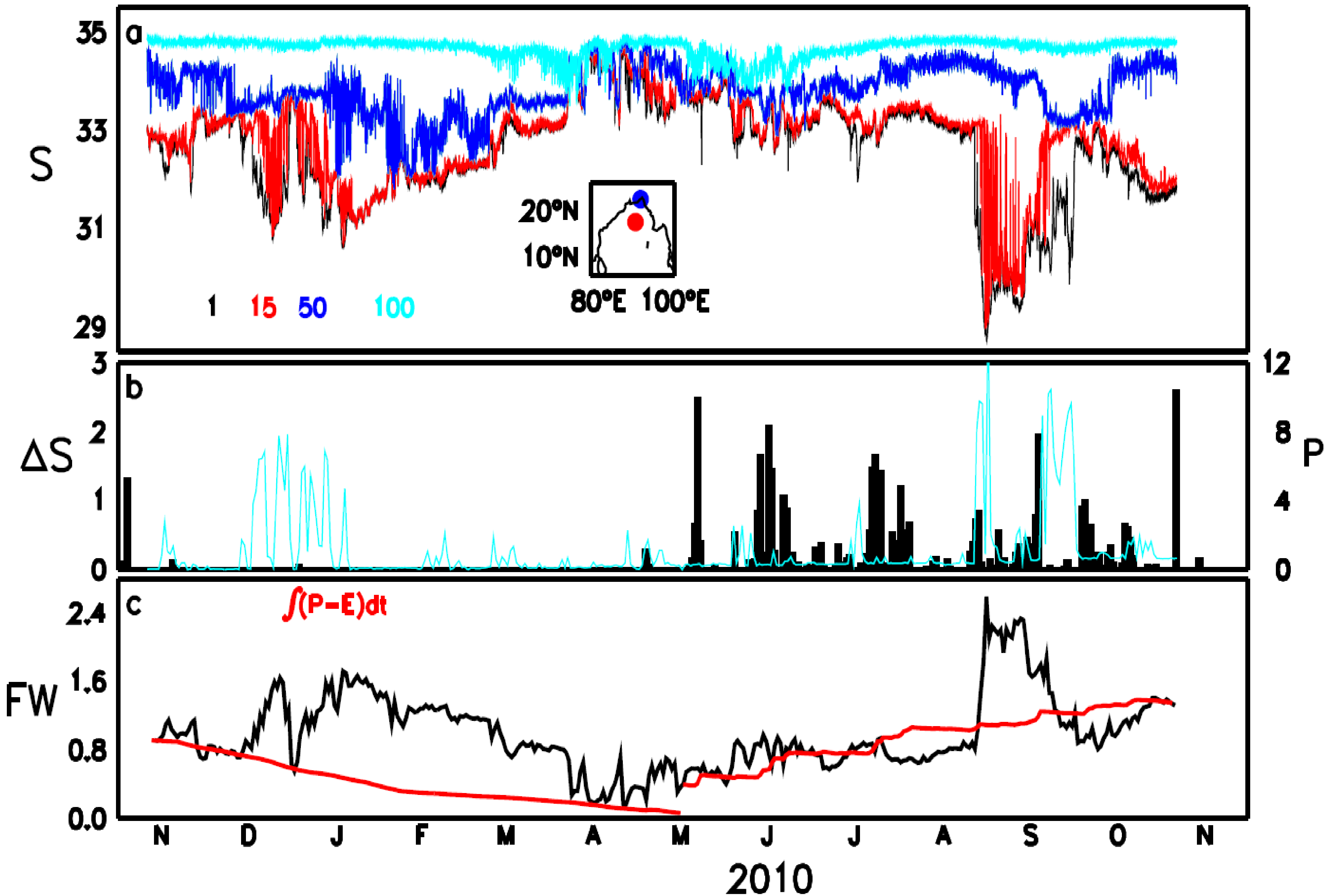
Dr. Girish Kumar, Mr. Nimit, Mr. Muthukumar, Mr. D. Gowthaman, Mr. S. K. Mozamil, Miss. Manita Chouksey, Mr. R. Shivaprasad, Dr. Aneesh Lotliker, Mr. Dinesh Kumar, Dr. Hari Kumar, Mr. Dipanjan Chaudhuri , Ms. J. Sreelekha ,Mr. Midhun Madhavan, Ms. Lekshmi Ravishankar , Mr. R. Kumaraswami, Mr. Kesava Kumar ,Mr. Vivek,Mr. Sheik Meeran, Dr. Satya Prakash, Mr. Praveen Kumar, Mr. Durga Rao, Ms. Smitha Ratheesh, Mr. Jagadeesh Kadiyam, Ms. Simi Kennady, Dr. Ajith Kumar, Dr. Rajani Mishra, Ms. Divya Panicker, Mr. S. Ravichandran, Mr. R. Viswanadham, Mr. N. L. Dheeraj Varma, Mr. David Nagarathinam , Mr. P. Vijay, Mr. Thangaprakash, Mr. C. K. Sherin, Mr. D. Bhaskara Rao, Mr. Atul Kumar Yadev, Mr. Aditya Choudhary, Mr. Srinivasa Gopalakrishnan, Mr. Murugesh Pothikasalam, Mr. Abhisek Chakraborty, Mr. Anjaneyulu. C, Mr. Ganga Prasath, Mr. Hani Talamala, Mr. Jagadeesh . K, Mr. Nihar Paul, Mr. Phanindra Reddy, Mr. Sunil Kumar . Ms. K, Vimala .J, Ms. Sridevi .B

INCOIS 16 NIOT 11 NIO 8 IISc 5 SAC 4 IIT BBS 4 IIT Madras 3 TIFR 3 PRL 2 **Total 56 Participants**

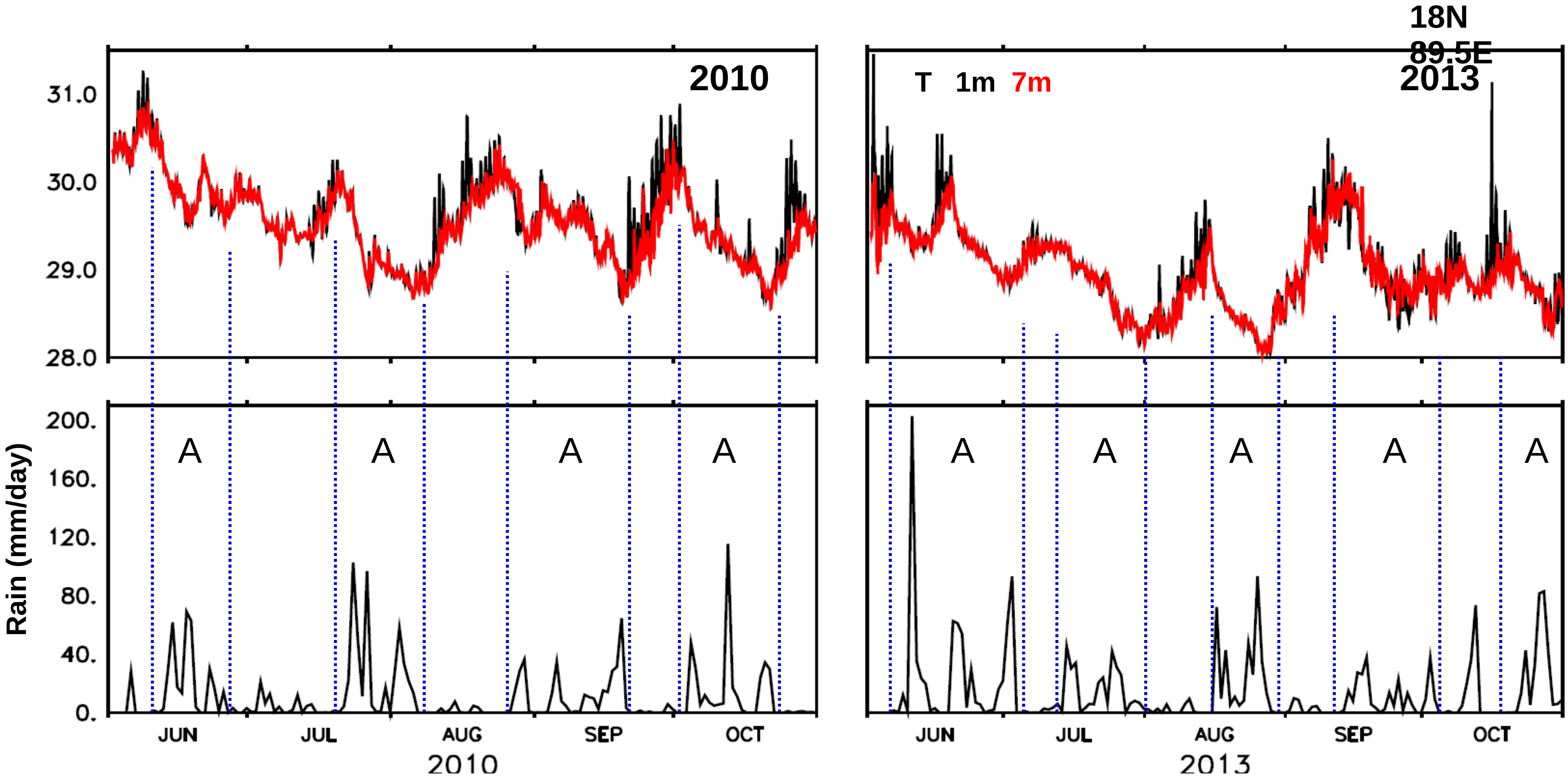
4 Ph.D. students

Dipanjan Chaudhuri *– IISc Bangalore*
Sree Lekha J *– IISc Bangalore*
V. Thanga Prakash *– INCOIS Hyderabad*
P. Vijay *– INCOIS Hyderabad*

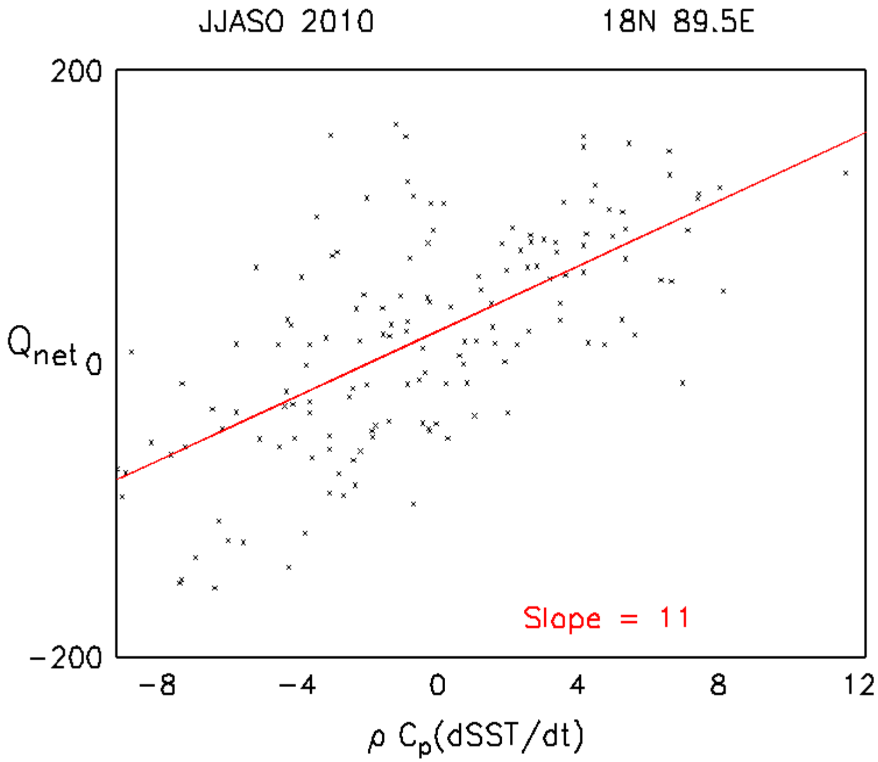
18N 89.5E

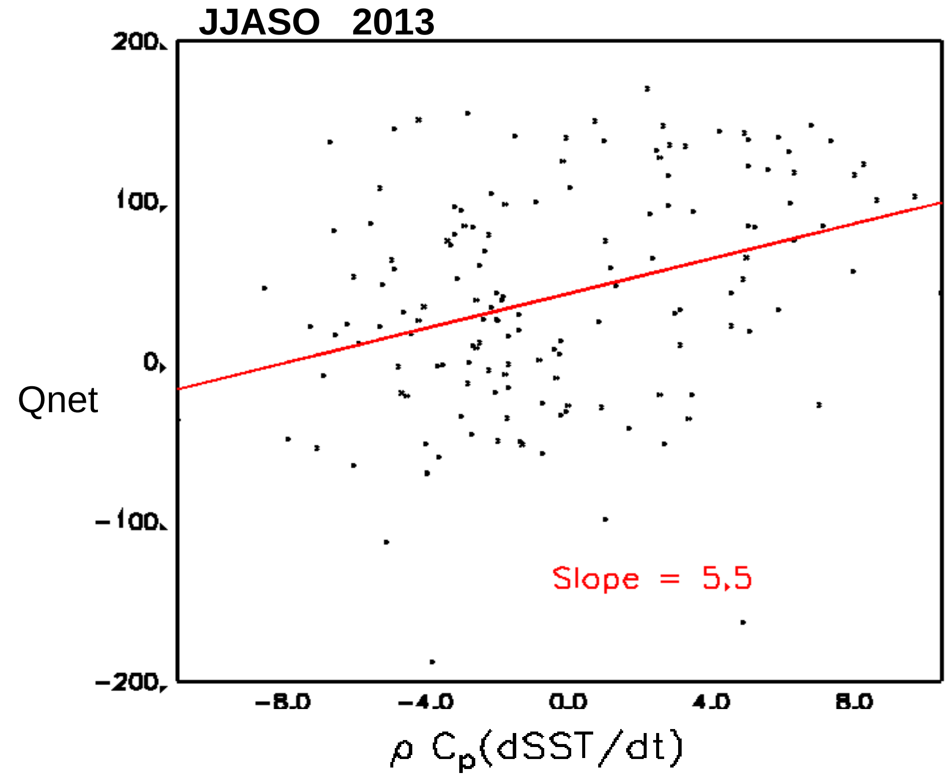


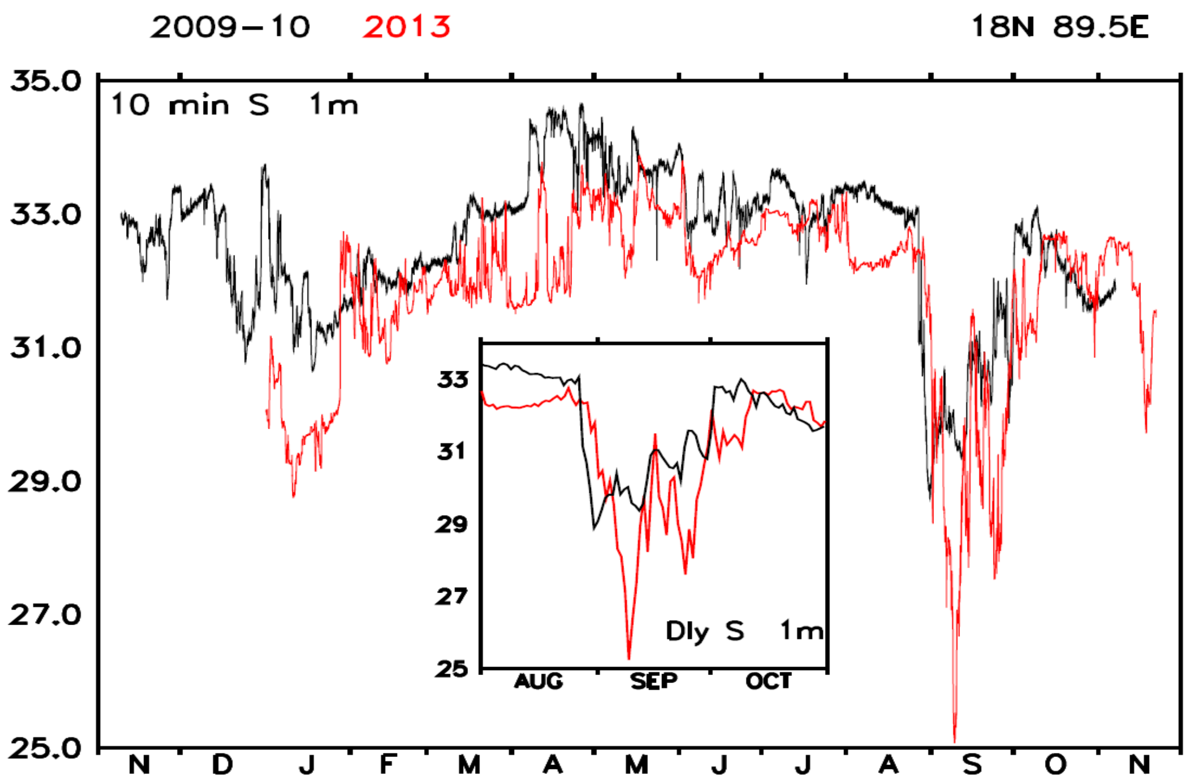
a
S
35
33
31
29
1 15 50 100
20°N
10°N
80°E 100°E
b
ΔS
3
2
1
0
12
8
4
0
P
c
∫(P–E)dt
FW
2.4
1.6
0.8
0.0
N D J F M A M J J A S O N
2010



18N
89.5E
2010
2013
T 1m 7m
31.0
30.0
29.0
28.0
Rain (mm/day)
200.
160.
120.
80.
40.
0.
A
JUN
JUL
AUG
SEP
OCT
2010
2013

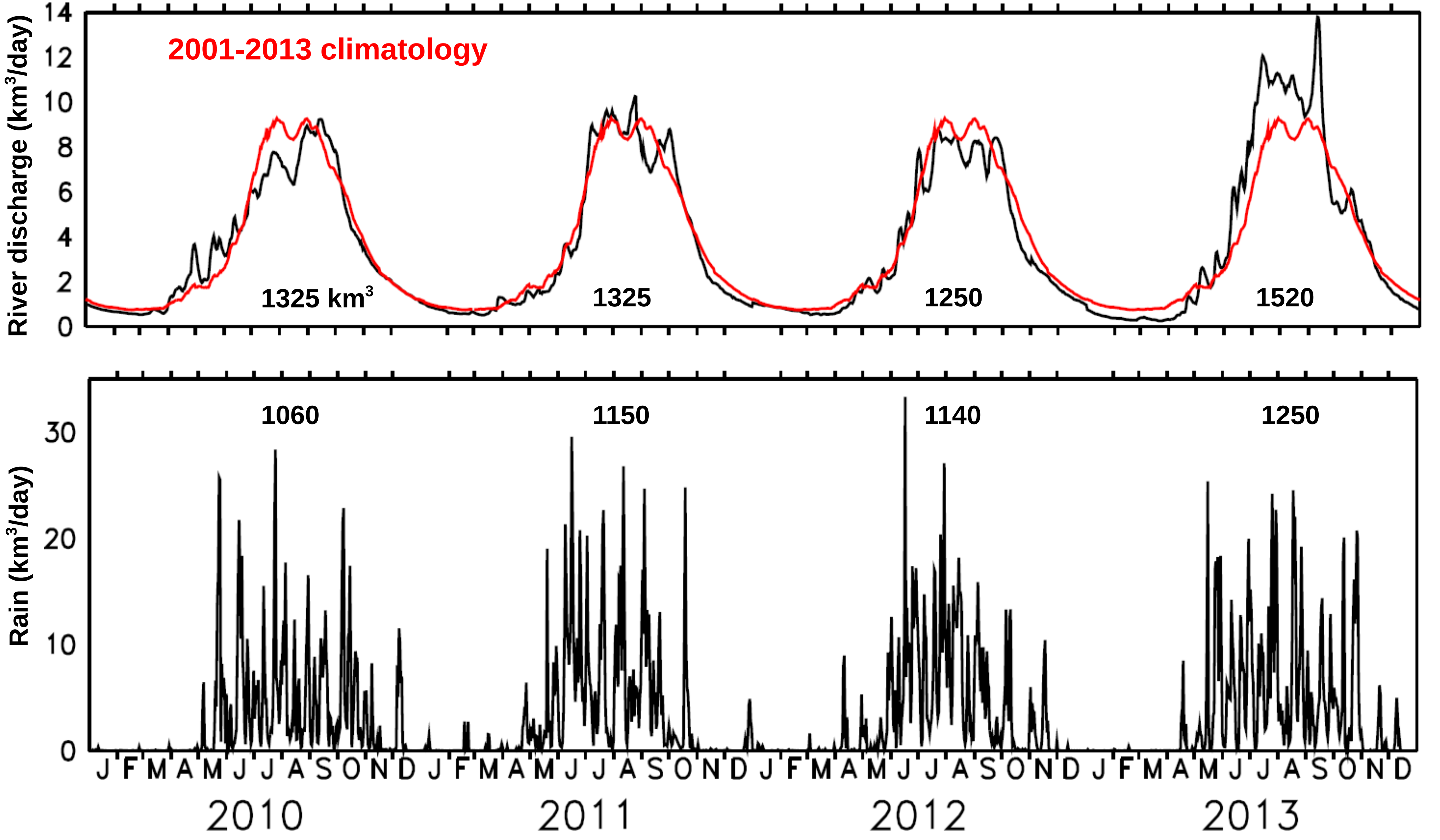






Mean $\Delta S_{15m\text{-}1m}$ 0.38 0.7

Ganga-Brahmaputra daily river discharge and TRMM daily rainfall average north of 17N



Discharge data courtesy: Bangladesh River Service, Fabrice Papa

Data:

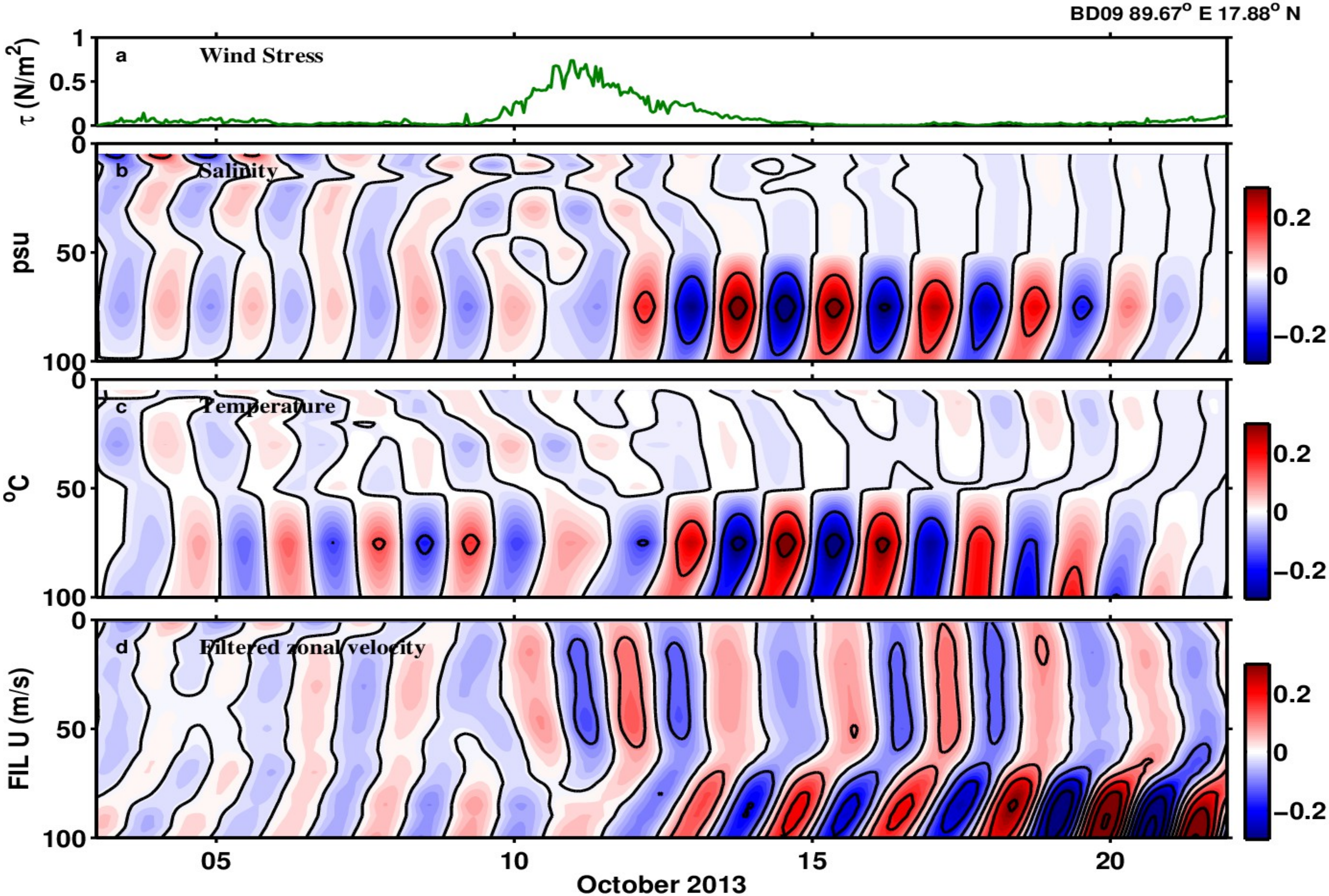
Three moorings 200 km to the right of the cyclone track:

NIOT BD09	89.67° E 17.88° N	hourly data
NIOT BD08	89.67° E 18.17° N	hourly data
INCOIS	89.5° E 18° N	10 minute data

One mooring under the cyclone track:

NIOT BD10	88° E 16.5° N	hourly data
Argo float *2901335*		***3-5 hour sampling***

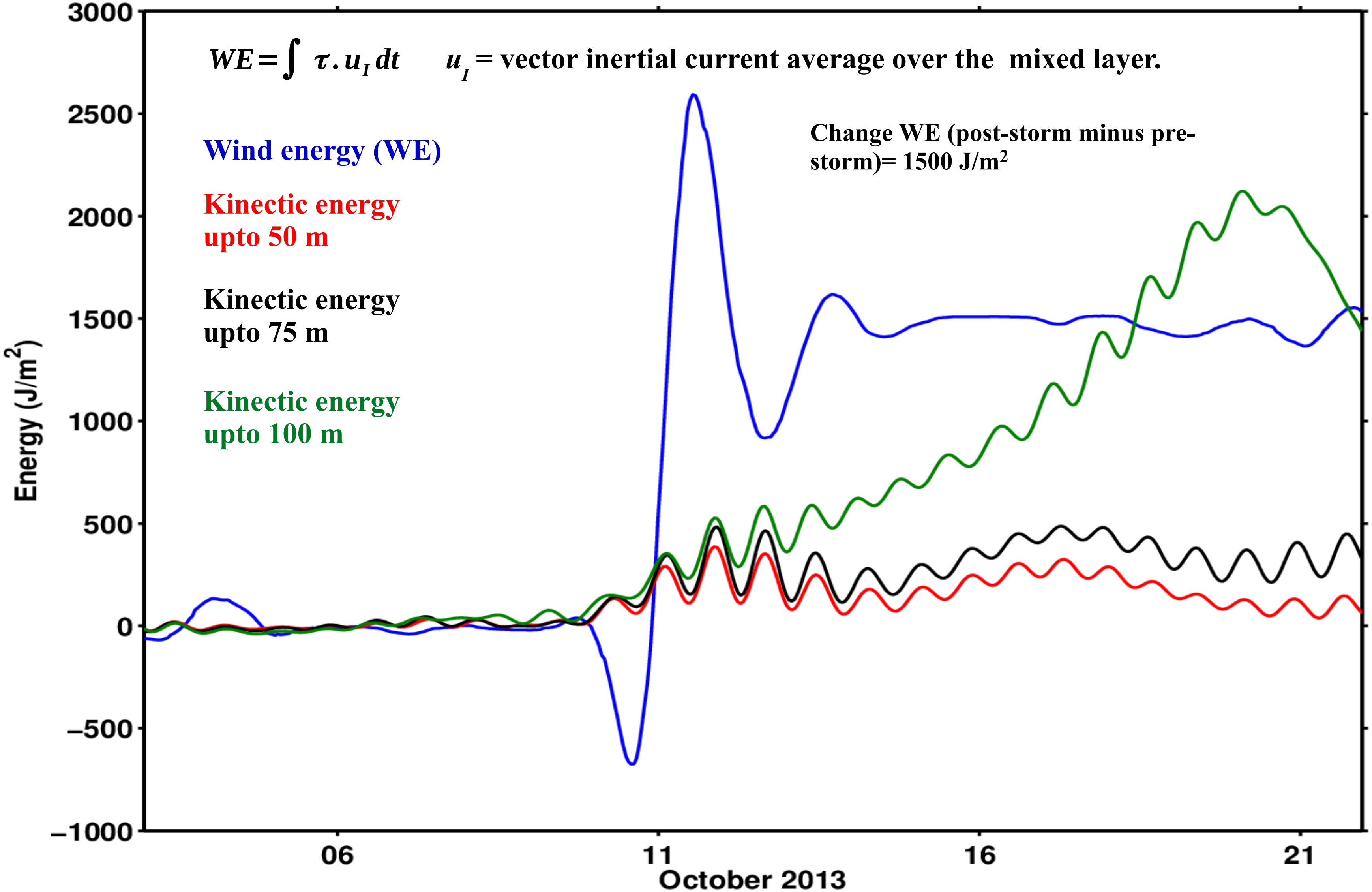
TMI/AMSRE Merged Microwave SST	**0.25^0 daily**
Aquarius Sea Surface Salinity	**1^0 daily**



Hourly a) wind stress. Band-passed (30-46 hours) near-inertial b) salinity c) temperature d) zonal velocity from mooring BD09.

Large near-inertial oscillations is present in both salinity and temperature below 50 m.
Strong near-inertial signal is present below 50 m but not in the upper 50 m.

BD09 88.67 E 17.88 N



Inertial energy input and change in inertial kinetic energy. Because the intention is to focus on the change in energetics of response to the storm, the initial (3-8 October) wind energy and kinetic energy has been subtracted from the observed record at BD09 from respective quantity.

Inertial kinetic energy upto 100 m exceeds the inertial wind energy input after 17 October.

Why might Submesoscales be Important?

They are really there - *the ocean has lots of small-fronts.*
Is ignorance bliss?

Theory and models suggest:

An energy sink -
May allow a proper closure of the ocean's energy budget

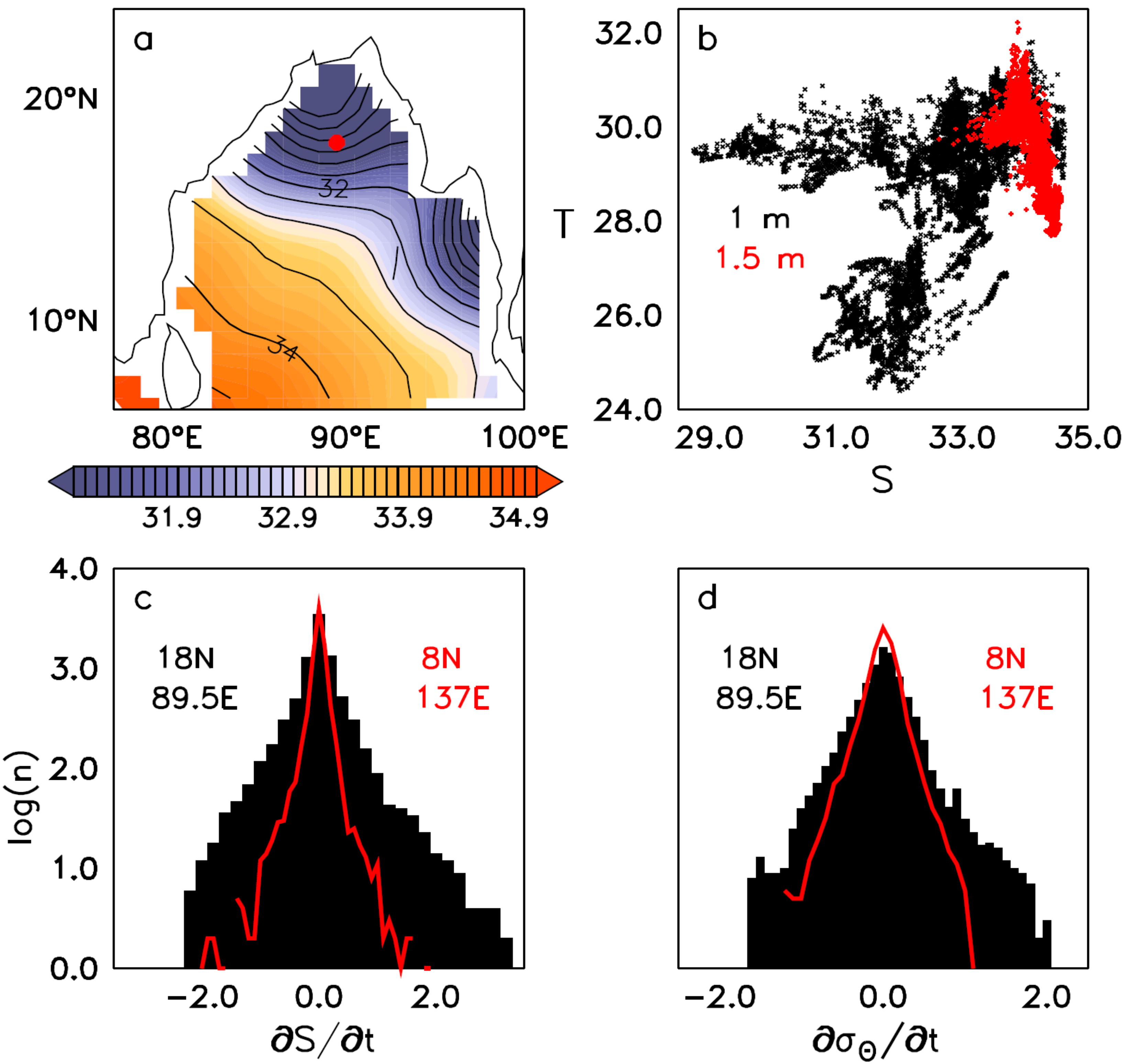
Increased vertical exchange in upper ocean
A big effect on biological productivity

Increased lateral dispersion
e.g. How fast does an oil spill spread?

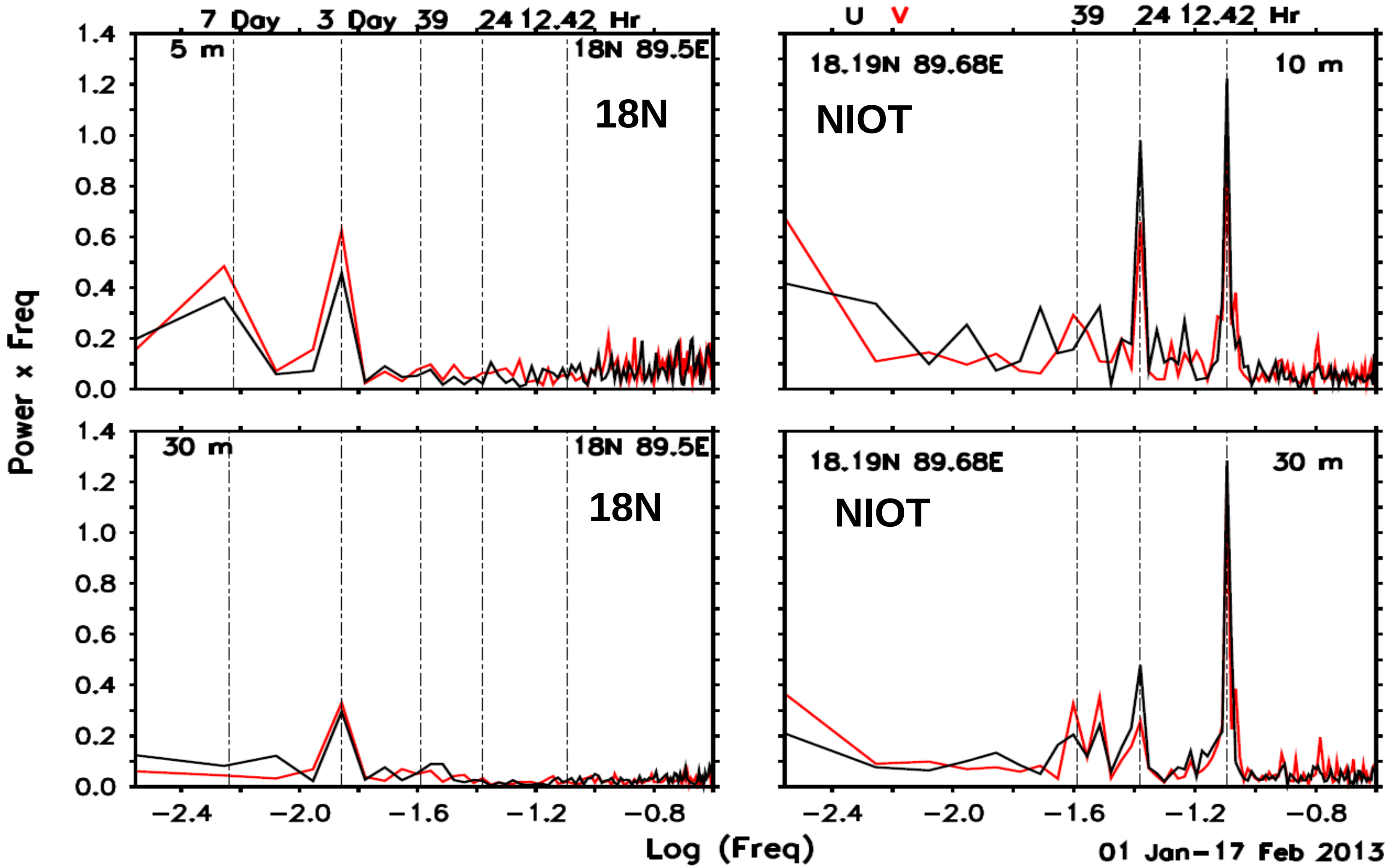
Lateral stratification of the upper ocean

Shallower mixed layers

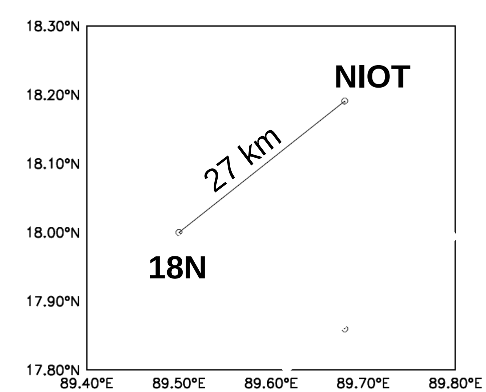
From Eric D'Asaro



a
20°N
10°N
32
34
80°E
90°E
100°E
31.9
32.9
33.9
34.9
b
T
32.0
30.0
28.0
26.0
24.0
1 m
1.5 m
29.0
31.0
33.0
35.0
S
c
4.0
3.0
2.0
1.0
0.0
log(n)
18N
89.5E
8N
137E
−2.0
0.0
2.0
∂S/∂t
d
18N
89.5E
8N
137E
−2.0
0.0
2.0
∂σΘ/∂t



Variance-preserving spectra of currents



No semidiurnal tidal peak in velocity (u,v) at the INCOIS mooring at 18N, but significant tidal energy at the NIOT mooring, 27 km away.