Evolution of SST and SSS in the Northern Bay of Bengal

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Abstract

High resolution observations of atmospheric and oceanic variables are carried out at northern Bay of Bengal from 22nd July to 6th August 2009 on-board ORV Sagarkanya under the Continental Tropical Convergence Zone research/observational programme. Freshening of surface layer by more than 4 psu within 24 hours is observed, which is followed by warming in the surface layer temperature. The heat and salt budget analysis primarily indicates dominant role of advection processes on the evolution of temperature and salinity. The amount of rainfall received at observation site could not explain the observed freshening, thus an extensive analysis using wavelet coherence is done to find out the source of advected fresh water to the observed location. It is found that surface salinity in the northern Bay of Bengal (at 15°N) varies coherently with the rainfall over Ganga-Brahmaputra catchment area on intraseasonal time scale and with lag of about 60 days. Based on above observations, this study hypothesize that the intraseasonal rainfall variation modulates the amount of river discharge, which in turn modulates the salinity over northern Bay of Bengal on intraseasonal time scale. Since surface warming always follows the surface freshening, the time delay between the rainfall over catchment area and freshening at northern Bay of Bengal may explain the post monsoon warming. Importance of atmosphere-ocean coupling in driving the dynamics of the northern bay of Bengal has been clearly brought out in this study.

1 Introduction

The northern Bay of Bengal (BoB) during summer monsoon (June-September) is generally characterized by high sea surface temperature (SST), shallow surface layer of low salinity and weak wind compared to the Arabian Sea (Shenoi et al., 2002; Sprintall and Tomczak, 1992; McCreary et al., 1993; Schott and McCreary, 2001). The weak winds cannot overturn the stratified low-salinity surface layer and hence results into a shallow surface mixed layer. Once the strong stratification in the surface layer takes place, the SST is mainly driven by surface net heat flux. As a consequence, though the Arabian Sea and BoB gets almost same amount of net radiative heating, the SST over BoB is much warmer than that over Arabian Sea (Shenoi et al., 2002). In general, the SST of northern BoB remains higher than 28°C throughout the year, a condition favorable for generation of active convection (Gadgil et al., 1984; Graham and Barnett, 1987). SST values higher than 28°C supports large-scale deep convection in the atmosphere during the Indian summer monsoon season. Release of latent heat due to condensation maintains the atmospheric heating and sustains the monsoon circulation and
associated rainfall over Indian subcontinent (e.g. Webster et al., 1998).
Most of the studies on monsoon breaks have identified mechanisms involving various
atmospheric processes as the possible reason for break monsoon conditions (Krishnan et al., 2000). But, oceanic parameters (like SST and salinity) also play crucial
role in the evolution of break conditions (e.g. Vecchi and Harrison, 2002). The in-
traseasonal SST changes can be associated with changes in the surface winds and
atmospheric convection over BoB. On the other hand, these atmospheric changes
may be responsible for the observed SST variability over the Bay. Therefore, the
intraseasonal SST variability and monsoon rainfall are dynamically linked with each
other (Parampil et al., 2010; Vecchi and Harrison, 2002).

Fresh water from the local rainfall and river discharges maintains the low salinity
surface layer over the BoB (Parampil et al., 2010; Shetye et al., 1996). In the
Bay of Bengal Monsoon Experiment (BOBMEX) during July-August, 1999, several
active and weak spells of convection occurred (Bhat et al., 2001) and it was found
that the SST decreases during rain events and increases in cloud free conditions.
During phase-I (27th July to 6th August, 1999) of BOBMEX, the northern bay
was convectively very active and three monsoon systems developed, SST remained
around 28.5°C and arrival of a low-saline water plume was reported (Bhat, 2002;
Vinayachandran et al., 2002). This plume caused the surface salinity to decrease
from 33 practical salinity unit (psu) to less than 29 psu in a span of just 4 days.
However, the dynamics behind the abrupt decrease in salinity is not understood
completely. Phase-II of BOBMEX (13−24th August, 1999) experienced a weak phase
of convection with low winds and clear sky conditions. An increase of 1.5°C SST was
observed (from 28°C to 29.5°C) within an interval of 5 days. Bhat (2002) made an
one-dimensional heat budget analysis (so called calorimetric experiment) and used
observed surface fluxes to predict SST. This model had limited success and could
not predict SST for all conditions prevailing over northern BoB. They argued that,
the horizontal advection is important for determining SST, but it was not possible to
quantify the relative role of advection on the SST evolution. Vinayachandran et al.
(2002) suggested the source of fresh water plume mainly to river discharge, which
get advected from east coast due to Ekman flow and consequently accelerated due
to presence of two low pressure systems over BoB. This study gave a broad overview
of the source of fresh water plume, but could not localize it and cannot identify how
intraseasonal oscillation of rainfall modulates this source.

Using in-situ observation, we have for the first time quantified the relative role of
advection and surface net heat flux on the evolution of SST and salinity in northern
BoB. Longer period of salinity and SST data from Research Moored Array for
African-Asian-Australian Monsoon Analysis and Prediction (RAMA) buoy have
been utilized to show that the changes in salinity are linked with the rainfall over
Ganga and Brahmaputra river catchment area. Section 2 describes the data used
for this study and applied methodology. Results are discussed in section 3. The
outcomes of this study are summarized in section 4.
2 Data and Methodology

The Indian Climate Research Programme (ICRP) has formulated the Continental Tropical Convergence Zone (CTCZ) programme to understand the mechanisms leading to space-time variation of the CTCZ and the embedded monsoon disturbances during the summer monsoon. The complete overview and detailed objectives of CTCZ programme is available at http://www.imd.gov.in/SciencePlanofFDPs/CTCZ. Under this national program (CTCZ), oceanic and atmospheric observations are taken on-board ocean research vessel (ORV) SagarKanya (SK-261). The cruise track is shown in Figure 1. The research vessel started on 15th July 2009 from the port of Chennai and reached the time series location (TSL) at 89°E,19°N on 22nd July and stationed there for 15 days (up to 6th August). Two hourly profiling up to the depth of 760 m was done for the measurement of salinity and temperature.

Total 218 profiles were measured using Conductivity-Temperature-Depth (CTD) instrument, manufactured by Idronaut. To estimate the horizontal advection of salinity and temperature, CTD measurement at 4 other locations situated at North, South, East and West of the TSL and at a distance of 3 nautical miles from the TSL were carried out. In order to avoid the influence of solar insolation, the CTD measurement at North, South, East and West locations are done once at night and up to the depth of 150 m. The temperature and conductivity sensor of Idronaut CTD has an accuracy of 0.001 °C and 0.0001 S m⁻¹ respectively and scan frequency is of 40 Hz. The speed of probe during downcast and up-cast was between 0.5 – 1 m s⁻¹. The downcast and up-cast data were averaged into 1 m depth bins. The tendency of temperature and salinity can be calculated by using the following equations (Nisha et al., 2009).

\[
\frac{\partial T}{\partial t} = -(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z}) + \frac{Q_s}{\rho C_P h} + D
\]  

where, \( T \) is the ocean water temperature, \( u, v, w \) are zonal, meridional and vertical component of the currents, \( Q_s \) is the net surface heat flux, \( \rho \) is the density of water, \( h \) is the mixed layer depth, \( C_P = 3993.0 \text{ J kg}^{-1} \text{ K}^{-1} \) is the heat capacity of water, \( S \) is the salinity of water, \( E, P \) are evaporation and precipitation rate respectively. \( w_h \) is the vertical advection below mixed layer (m month⁻¹), \( H \) is the Heaviside step function \([=0 \text{ if } (w_h + \frac{dh}{dt}) > 0, =1 \text{ if } (w_h + \frac{dh}{dt}) < 0]\) and \( S_h \) is the salinity just below the mixed layer base.

The net surface heat flux is used from NCEP reanalysis (Kalnay et al., 1996). The oceanic \( u, v \) currents are from NCEP Global Ocean Data Assimilation System (GO-DAS, data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/). High resolution oceanic currents (Ekman and geostrophy) are derived using quick scatterometer (QuikSCAT) (Ebuchi...
et al., 2002) wind and AVISO (Analysis, Validation and Investigation of Satellite Oceanography) sea surface height data (Ducet et al., 2000) respectively. The Ekman current is calculated using the following equation

\[ u_{ek} = \frac{\tau_y}{f \rho_o h} \quad \text{and} \quad v_{ek} = -\frac{\tau_x}{f \rho_o h}, \]  

where Coriolis force \( f = 2\Omega \sin\theta \), \( \rho_o \) = mixed layer ocean water density, wind stress \( \tau_x = \rho_a C_D u^2 \) and \( \tau_y = \rho_a C_D v^2 \), with \( C_D = 1.5 \times 10^{-3} \), \( \rho_a = 1.252 \text{ kg m}^{-3} \). Using sea surface height \( (H) \) data, the geostrophic current is calculated using the following equation

\[ u_g = -\frac{g}{f} \frac{\partial H}{\partial y} \quad \text{and} \quad v_g = \frac{g}{f} \frac{\partial H}{\partial x}, \]  

In addition to the cruise data, we have used daily surface layer salinity, temperature and rainfall measured at 15°N, 90°E from RAMA Buoy for the period October 2008 to December 2010 (McPhaden et al., 2009). Daily rainfall data from GPCP are used in order to identify the large scale monsoon events (http://precip.gsfc.nasa.gov/index.html). In addition to that, high resolution daily rainfall data from 3B42 (Huffman et al., 1995, 2007) for the period 1st June to 31st December 2009 are used.

3 Results

3.1 Observed Features

Time series location witnessed three rainfall events; first one on 24 – 25\textsuperscript{th} July, second on 27 – 28\textsuperscript{th} July and third on 2 – 5\textsuperscript{th} August (Figure 2a). The cruise left the TSL location on 6\textsuperscript{th} August at noon, therefore rainfall data of that day is not complete. However, rainfall from 3B42 shows the last event continued till 9\textsuperscript{th} August (Figure not shown). Since there are no clear gap between 1\textsuperscript{st} and 2\textsuperscript{nd} event, together they can be considered as an active phase of monsoon intraseasonal oscillation (ISO) with peak around 27 – 28\textsuperscript{th} July and the second active phase with peak around 5 – 6\textsuperscript{th} August. Temperature and salinity profile up to 100 m depth and their evolution during 15 days at TSL location are shown in Figures 2b, 2c respectively. Prior to the beginning of rainfall activity, the SST increased to 28.5°C for a brief period of about 2 days (23 – 24\textsuperscript{th} July, Figure 2a). A rapid decrease in surface layer salinity is observed during 29 – 30\textsuperscript{th} July. After the initiation of freshening, the water temperature at the surface layer (10 – 15 m) remained always above 28.5°C. Furthermore, from 30\textsuperscript{th} July onward the salinity of top 10 – 15 m layer maintained
at minimum value and that level coincides with the warm water ($\geq 28.5^\circ C$) layer at the top. The average mixed layer salinity (depth) between 22 – 28th July is 32.4 psu (30.72 m) and the average between 31st July to 6th August is 28.07 psu (6.297 m). The salinity dropped by more than 4 psu within the 24 hours (Figure 2f). Changes in temperature of mixed layer also took place almost at the same time. The average mixed layer temperature during 22 – 28th July (31st July - 6th August) is 28.45 $^\circ C$ (28.81 $^\circ C$). The mixed layer depth (MLD) started shoaling immediately after the first active phase and continued to shoal until end of the cruise (Figure 2d). Similarly the barrier layer thickness started to deepen immediately after the first active phase of rainfall. Similar decrease in sea surface salinity (SSS) was also observed by Bhat (2002) in BOBMEX experiment (Bhat et al., 2001) in its phase 1, where SSS decreased from 33 psu to 29 psu during 27th July to 3rd August 1999 and remained low for the rest observation period. During BOBMEX salinity dropped gradually (4 psu in 7 days), while during CTCZ cruise similar amount of salinity dropped within 24 hours. Therefore, it is very interesting to understand the mechanism behind rapid decrease of salinity during CTCZ cruise.

3.2 Heat and Salt Budget

The estimated temperature tendency at TSL using GODAS currents are able to capture the observed tendency reasonably well (Figure 3a). The mixed layer temperature is controlled equally by both, advection and net surface heat flux. As from 30th July onward the mixed layer salinity started to fall, the advection of fresh and cold water decreases the temperature. On the other hand, the net surface heat flux (mainly the radiative flux) causes extreme warming, probably due to presence of shallow barrier layer (Figure 2d). Since the mixed layer depth became shallow, the net surface heat flux became very effective in increasing temperature. The salinity budget analysis reveals that advection is the major source of fresh water at TSL and the sudden fall in salinity on 29 – 30th July is mainly due to advected fresh water (figure 3b). The change in salinity due local fresh water flux (i.e. E-P) is very small. Similar analysis using estimated Ekman and geostrophic current closes the heat and salinity budgets quite well till 29th July and afterward the advection of salinity and temperature is too strong (not shown). The reasons for overestimation of advection due to Ekman and geostrophic currents are not clear. The estimated geostrophic currents derived from sea surface height (from satellites and in-situ data) over estimate the advection component of budget. Using data collected during BOBMEX expedition, Vinayachandran et al. (2002) concluded that wind driven circulation i.e. Ekman current determines the path of fresh water in the BoB. They further concluded that fresh water advected eastward from the coast of India to the study location at 17.5°N, 89°E. However, during our observational period the average mixed layer current in GODAS reanalysis was always southward and south-westward (Figure 3c). On the other hand, the estimated total current were south-westward when the budgets are almost closed (i.e. till 29th
July) and became south-eastern afterward when the budget is not closed (figure not shown). The river discharge from the north coast is much higher (Ganga and Brahmaputra) compared to the east coast (Mahanadi, Godavari, Krishna and Cauvery) (Rao and Sivakumar, 2003). It is plausible that if advection of fresh water takes place from north, the freshening will be larger compared to cases when advection is from the east coast of India. Therefore, it is evident from the above analysis that, southward current tends to close the heat and salinity budget reasonably well and hence, freshwater may have advected mainly from the north (i.e. discharged from Ganga and Brahmaputra rivers). This can explain the rapid (slow) decrease in salinity during CTCZ (BOBMEX) cruise.

3.3 Intraseasonal Variability

Using in-situ data at the TSL, it is not possible to know whether the freshening continued throughout the monsoon season with the same level. If the freshening is dominated by river discharge, the monsoon ISO signal may be present in the surface layer salinity with certain time lag and this can modulate the surface layer temperature. Since long term data are not available to address the above, we have selected a close by buoy data for this purpose. RAMA buoy data at 90°E,15°N (south-east of TSL; Figure 1) have longer observation period and indeed it shows oscillation in the surface layer salinity during monsoon period and beyond (Figure 4b). It may be noted that a sudden freshening started at the beginning of October 2009 and continued for the next few month with some variability. However, the local rainfall is quite negligible and hence change in salinity cannot be explained through local fresh water flux (i.e E-P). Such variability in salinity/SST are not unique, but also observed in other years (i.e. 2008 and 2010) as evident from available continuous observation for the period October 2008 to December 2010 (Figure 4b, 4c). Simultaneous response in surface layer warming is also evident (Figure 4c). Power spectrum analysis of June-December 2009 salinity (temperature) averaged over top 35 m shows significant variance at around 13 (15) days. Other significant peaks in salinity and temperature are found between 30-60 days period (Figure 5). SST also shows significant peak quite similar to that of 35 m average water temperature (figure not shown). These two preferred band are similar to the summer monsoon rainfall variability on the intraseasonal time scale (i.e. 10-20 and 30-60 days mode). Similarly two epochs of rainfall during CTCZ cruise are also separated by 10 days. Power spectrum analysis using GPCP rainfall, averaged around TSL (87°-92°E, 17°-21°N) for 2009 summer monsoon season (JJAS) shows significant power at 12.5 days period (figure not shown). Therefore, the observed rainfall activity belongs to quasi bi-weekly (10-20 days) mode of intraseasonal oscillation, which in general propagates westward (Chatterjee and Goswami, 2004).

In order to find out the maximum rainfall variability region and to relate it with the
observed salinity, variance of 10-100 days filtered rainfall anomaly (June-
December 2009) are calculated. The heavy rainfall regions due to monsoon
ISOs are depicted by large variance (Figure 6). Therefore, there is possibility that
fresh water of those region may modify the salinity either locally or through ad-
vection processes. Thus, four regions (D1, D2, D3, D4) are identified based on the
larger rainfall variance which may modify the salinity at the location of RAMA
buoy on monsoon rainfall ISO time scale (Figure 6). Domain D1 (86°- 93°E, 22°-
27°N) and D2 (79°- 87°E, 18°- 23°N) represent the river catchment area of Ganga,
Brahmaputra and Mahanadi. D3 (88°- 95°E, 12°- 19°N) represent the area over
BoB with maximum rainfall ISO variance and the RAMA buoy is located within
this box. D4 (88°- 92°E, 13°- 17°N) represent the smaller domain surrounding the
RAMA buoy and it also covers part of maximum rainfall ISO variance region.

Power spectrum analysis of rainfall averaged over individual domain shows signifi-
cant variances at 3-7 days time scale except in D1, where the significant variances
are at around 10 days (Figure 7). In addition to that, rainfall at D1 shows
significant variability at about 50 days period. Similar analysis of surface
layer salinity and temperature (top 35m average) at RAMA buoy
also reveals the prominence of power at the ISO bands (Figure 5). Thus
both rainfall over domain D1 and salinity at RAMA buoy has the dom-
inance on the ISO time scale, which imply that rainfall over D1 may
affect salinity at RAMA buoy in a delayed mode and at the same time,
the local rainfall as well as river discharged water from Indian east coast
can’t explain the observed salinity variability. Cross spectrum analysis of
rainfall at D1 and salinity for the period June to December 2009 further
reveals large coherence at 10 and 50 days time scale and rainfall leads
the salinity by about 60 days (Figure 8). Similar analysis using rainfall
of other domain shows maximum coherence at synoptic time scale (3-7
days) and hence can’t explain the variation of salinity on ISO time scale.
To advect fresh water from the TSL to RAMA buoy, the average speed of
southerly current should be about \(8.75 \text{ cm s}^{-1}\), which is within the range
of observed southerly current. Therefore, it is very likely that the first
pulse of observed freshening at TSL may have advected towards south
and reached RAMA buoy location on the beginning of October 2009.

To further confirm this possibility in detail we have used Wavelet analysis (Grinsted
et al., 2004). It is a powerful tool giving both the information of the dominant mode
of variability in spectral domain and their exact occurrences in time domain. Cross
wavelet transform (CWT) has been performed between salinity at RAMA buoy and
rainfall averaged over D1 for the time period 1st June 2009 to 28th February
2010. Significant common power on 10-20 days mode are observed twice viz. 15th
July to 15th August and 10th September to 20th October (Figure 9a). Phase angle
during July-August period suggests that the salinity change was almost simultaneous
with the rainfall over D1. This further indicates that rainfall over both the location
is from the active phase of ISO, which occurred almost simultaneously over northern
BoB as well as over D1. However during September-October, the rainfall and salinity
are in opposite phase. Hence, sudden freshening at the beginning of month October
is directly related with the rainfall over D1 which took place earlier. The squared
wavelet coherence (WC) also shows significant coherence on 10-20 days time scale
during September-October (Figure 9b). This indeed shows that sudden freshening at
RAMA buoy on the beginning of October is due to rainfall at D1 and the same fresh
water is observed first at TSL and subsequently at the buoy location. Significant
cohere is also evident on 30-60 days band during month of August to
September. Therefore, salinity at RAMA buoy is affected by rainfall at
D1 from both mode of ISOs.

In order to bring out a clear picture of lead/lag relation between salin-
ity and rainfall, filtered salinity anomaly at RAMA buoy are linearly
regressed with filtered rainfall and current anomalies (estimated) of all
other points. Here, 10-100 days and 30-60 days Lanczos band pass fil-
ter are used. Regressed anomalies averaged over 88°-92°E (Figure 10)
show a clear southward propagation of fresh water and it takes about
50-60 days to reach RAMA buoy from D1. Rainfall regressed with SST
at RAMA also shows similar lead/lag relation (Figure not shown). Fur-
thermore, regressed current anomaly shows strong southerly component
(Figure 11), which implies southward advection of river discharged fresh
water through oceanic currents. As evident from spectrum analysis, the
30-60 days mode has large variance and as a consequence all the regressed
anomalies are stronger on the same ISO band.

4 Summary and Conclusions

Under the CTCZ program, oceanic and atmospheric observations are taken on-
board ORV SagarKanya. She started on 15th July 2009 from the port of Chennai
and reached the TSL on 22nd July and stayed there up to 6th August. In every
2 hours of interval, salinity and temperature profile up to the depth of 760 m was
measured. Total 218 profiles were measured using Idronaut CTD. To estimate
the horizontal advection of salinity and temperature, CTD measurement at 4 other
locations situated at North, South, East and West of the TSL and at a distance of
3 nautical miles from the TSL are carried out.

A sudden freshening is observed during 29–30th July, where the mixed layer averaged
salinity dropped by more than 4 psu within 24 hours time. A simultaneous increase
in mixed layer averaged temperature by 0.36 °C is also observed. The budget analysis
of salinity and heat primarily indicates dominant role of advection processes on
temperature and salinity at the northern BoB. As the local rainfall contribution to
the salinity change was meager, the freshening can only be explained through the
southerly Ekman flow which advected river discharged water from the north. Even
though previous studies expected that due to strong stratification, heat budget into northern BoB can be considered as one dimensional problem, we have presented an evidence that advection also plays a major role.

Daily salinity and temperature data (averaged over top 35m) at southeast of TSL from RAMA (90°E, 15°N) reveals significant variance at time scale which falls within the 10-20 days bands of monsoon ISO. Again, the local rainfall is not large enough to explain the salinity change. Among the different catchment area, only rainfall at Ganga-Brahmaputra catchment areas shows maximum coherence at 10 and 50 days time scale with lag of about 60 days. Wavelet co-spectrum and coherence analysis of above two time series further reveals significant power and maximum resonance respectively at 10-20, and 30-60 days time scale during September-October. Anti phase relation between time series of salinity at RAMA location and rainfall over Ganga-Brahmaputra river catchment area further suggests that intraseasonal variation of salinity is mainly due to river runoff and the same varies with the monsoon rainfall ISO over river catchment areas. Regressed rainfall, oceanic current with salinity and temperature at RAMA buoy illustrate the southward advection of fresh water from the Ganga-Brahmaputra river catchment area on ISO time scale.

This study aids in further our understanding of ocean advection, playing a crucial role in forming barrier layer and thus modifying SST significantly. Thus providing a different perspective in terms of lagged response of salinity which dictates the convective activity over BoB during the withdrawal and post monsoon phases. Most of the climate models prescribe fixed amount of river discharge. As a result models may not be able to capture the post-monsoon SST/SSS variability merely due to the lagged response of rainfall over Ganga-Brahmaputra catchment area and hence may affect the genesis of post-monsoon cyclone over BoB.

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Figure 4: Rainfall, temperature and salinity profile measured at RAMA buoy location (15°N, 90°E) a) Rainfall in $mm\ day^{-1}$. b) Salinity of top 100 m layer in psu. c) Temperature of top 100 m layer. Isoline of 28.5 °C is marked by black contour.
Figure 5: Spectra of surface layer (top 35 m average) a) temperature and b) salinity using RAMA buoy data at 15°N, 90°E for the time period 1st June to 31st December 2009. Red and blue curve represent 5% and 95% “red noise” confidence bounds. Smoothing of 7 days and 0.3 percent taper are used.
Figure 6: Variance of 10-100 days filtered rainfall anomaly from 3B42 data (in $mm^2 day^{-2}$) of the period 1st June to 31st December 2009.
Figure 7: Spectra of rainfall time series (1st June to 31st December 2009) using daily 3B42RT data and averaged over a) D1 (86°- 93°E, 22°- 27°N), b) D2 (79°- 87°E, 18°- 23°N), c) D3 (88°- 95°E, 12°- 19°N), d) D4 (88°- 92°E, 13°- 17°N). Red and blue curve represent 5% and 95% “red noise” confidence bounds.
Figure 8: a) Coherence and b) phase angle between rainfall averaged over domain D1 (86°- 93°E, 22°- 27°N) and salinity at RAMA buoy (15°N, 90°E) for the time period 1st June to 31st December 2009.
Figure 9: a) Wavelet co-spectrum and b) squared wavelet coherence between rainfall (averaged over D1) and salinity at RAMA buoy (top 35m averaged) for the period June-December 2009. Thick contour shows the area significant at 95% level and arrow indicates the phase angle between these two time series.
Figure 10: Lag-latitude section (88°-92°E average) of regressed rainfall anomalies over D1 with top 35 m average salinity at RAMA buoy (1st June-31st December 2009). a) 10-100 days filtered anomalies, b) 30-60 days filtered anomalies.
Figure 11: Regressed estimated current anomaly with top 35 m average salinity at RAMA buoy (1st June-31st October 2009). a) 10-100 days filtered Ekman current, b) 30-60 days filtered Ekman current, c) 10-100 days filtered total (Ekman + Geostrophy) current, d) 30-60 days filtered total current.