Study of barotropic and internal tides : Application of ADCP data

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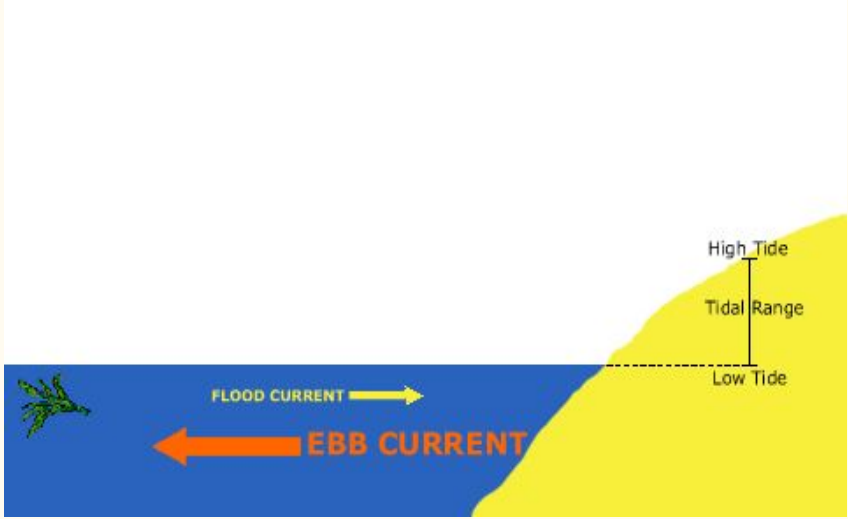
Tidal currents

- Horizontal flow accompanied by rise and fall of tide



Why tidal currents are important ?

- They are in the order few cm/s in the open ocean, but they becomes strong in the coastal areas ($>$10 cm/s).
  - Example: Magnitude of tidal currents reaches up to $\sim$ 32 cm/s on the shelf off Mumbai ($\sim$19N).
  - It can reaches up to 1 m/s in the nearshore regions
  - Semidiurnal tides amplify over wide continental shelves
- They have impacts on
  - Sediment transport
  - Acoustic propagation
  - Vertical mixing
  - Enhancing the biological productivity on the continental shelf and slope.
- Even though they are periodic, magnitude of tidal currents varies both spatial and temporal scales in the due to the varying background conditions.(eg : bathymetry)

- Tidal currents in the ocean

  → **Barotropic tidal currents**

  → **Internal tides (baroclinic tidal currents)**

- **Barotropic tidal currents**

  → Depth independent
  → Generated by the direct astronomical forcing.

- **Internal tide (Baroclinic tides)**
  → Depth dependent currents.
  → They are internal waves at tidal frequencies.
  → **Generated by the interaction of barotropic tidal currents with the topographic features such as continental shelves, slopes and ridges in the stratified ocean**

Analysis of tidal currents

First step is the calculation of barotropic and baroclinic currents. We deal with barotropic and internal tides separately.

- **Barotropic currents.**

  → Depth average of raw currents

- **Baroclinic currents**

  → Subtract depth averaged current from the raw current

Data requirement

- Both barotropic and baroclinic tidal currents are present in the ocean.
- The point measurements (at particular depth) are not sufficient to separate barotropic and baroclinic tidal currents.
- Current data at various vertical levels are required to calculate barotropic currents and baroclinic currents.
- ADCP data with maximum vertical coverage is required, especially in the coastal regions (shelf and slope)

Extraction of tidal currents : Harmonic analysis

- The basis of harmonic analysis is the assumption that the tidal variations can be represented by a **finite number of harmonic terms .**

$$u(t) = \sum_{n=1}^{k} a_n \cos(\omega_n t + \alpha_n)$$

a_n: *amplitude*
α_n: *phase*
k: considered harmonic components and
ω_n: *corresponding angular frequencies.*

- Observed tide is separated into basic harmonic constituents using least square fit and determine the amplitude and phase of each tidal constituents.
- Harmonic analysis tools : TASK 2000, T_tide, u_tide, etc ….

"One man's noise is another man's signal"

Major tidal constituents

- Major semi-diurnal components :

  M2 : 12.42 hours (Principal lunar semidiurnal constituent)
  S2 : 12.00 hours (Principal solar semidiurnal constituent)

- Major diurnal components :

  K1 : 23.9344 hours (Lunar diurnal constituent)
  O1 : 25.819 hours (Lunar diurnal constituent)

- Form ratio = (K1 + O1) / (M2 + S2)

- $F < 0.25$ semidiurnal
  $0.25 \leq F < 1.5$ mixed primarily semidiurnal
  $1.5 \leq F < 3$ mixed primarily diurnal
  $F > 3$ Diurnal

Tides, Surges and Mean Sea-Level. David T Pugh

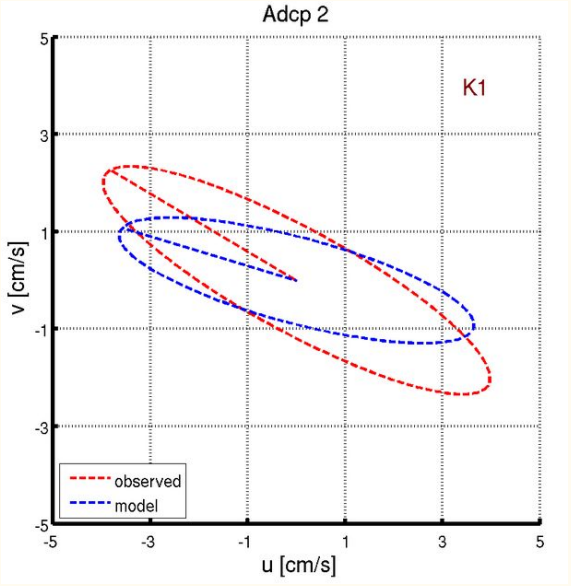
Tidal ellipses and ellipse parameters

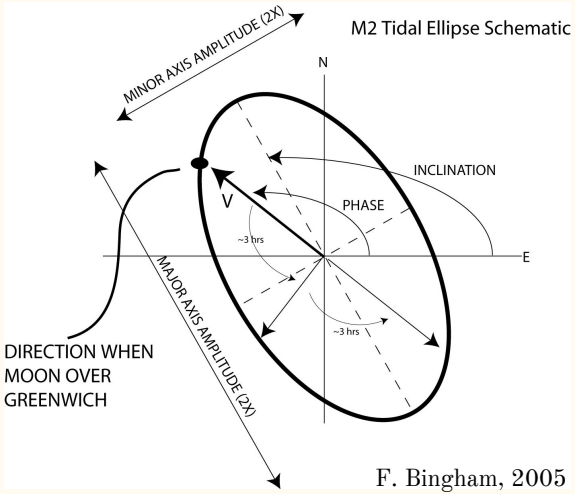
Semi-major axis : Maximum tidal current velocity

Eccentricity : Ratio of semi-major to semi-minor axis -ve value indicate ellipse is traversed in clockwise direction.

Inclination : Angle between east and semi-major axis

Phase : Time of maximum velocity with respect to a chosen origin of time





- Detailed document is available at ***Ellipse parameters conversion and vertical velocity profiles for tidal currents*** *by Zhigang Xu, Bedford Institute of Oceanography*

Harmonic analysis of current using TASK 2000

- Harmonic analysis is done by using *TASK2000* toolkit (fortran programs).
- Other tools are available (U_tide, T_tide etc)
- For the demonstration, we use TASK 2000 (*http://noc.ac.uk/using-science/products/tidal-harmonic-analysis; http://www.psmsl.org/train_and_info/software/task2k.php*).
- Harmonic analysis of currents is done separately for each velocity components (u and v). The results are shown in the form of tidal ellipses.

- Input data should be in standard TASK format and details should be provided in the control (*tira.ctl*) file.
- *tira.f* programme is used to extract the tidal signal from the input data.

A TASK-2000 file is a formatted ASCII file in two parts. The first part consists of 20 lines of text which the user can use to record details of the data.
The second part consists of the data records themselves in format
I6,1X,I1,1X,I4,1X,I3,F7.3,5F8.2

```
     1 0 2010 152   0.000    25.47     0.00     0.00     0.00     0.00
     2 0 2010 152   1.000    31.46     0.00     0.00     0.00     0.00
     3 0 2010 152   2.000    31.22     0.00     0.00     0.00     0.00
     4 0 2010 152   3.000    30.59     0.00     0.00     0.00     0.00
     5 0 2010 152   4.000    27.73     0.00     0.00     0.00     0.00
     6 0 2010 152   5.000    27.87     0.00     0.00     0.00     0.00
     7 0 2010 152   6.000    33.29     0.00     0.00     0.00     0.00
     8 0 2010 152   7.000    31.12     0.00     0.00     0.00     0.00
     9 0 2010 152   8.000    30.65     0.00     0.00     0.00     0.00
    10 0 2010 152   9.000    28.58     0.00     0.00     0.00     0.00
    11 0 2010 152  10.000    23.81     0.00     0.00     0.00     0.00
    12 0 2010 152  11.000    26.95     0.00     0.00     0.00     0.00
    13 0 2010 152  12.000    26.93     0.00     0.00     0.00     0.00
    14 0 2010 152  13.000    26.47     0.00     0.00     0.00     0.00
    15 0 2010 152  14.000    30.04     0.00     0.00     0.00     0.00
```

```
***** INPUT FILE NAME *****
inuput_filename
**** OUTPUT FILE NAME *****
output_filename
  NREL  NSIG  LREC  NREC CHOBS CHPRE CHRES
     8    27     1  2906     8     9    10
   PI1    K1  14.9178647  15.0410686    0.019      0.0
    P1    K1  14.9589314  15.0410686    0.331      0.0
  PSI1    K1  15.0821353  15.0410686    0.008      0.0
  PHI1    K1  15.1232059  15.0410686    0.014      0.0
   2N2    N2  27.8953548  28.4397295    0.133      0.0
   NU2    N2  28.5125831  28.4397295    0.194      0.0
    T2    S2  29.9589333  30.0          0.059      0.0
    K2    S2  30.0821373  30.0          0.272      0.0
    Z0
    MM      5443747
   MSF     10158958
    Q1    133986609
    O1    139430356
    M1    144920521
    K1    150410686
    J1    155854433
   OO1    161391017
   MU2    279682084
    N2    284397295
    M2    289841042
```

- Harmonic analysis is carried out for barotropic and baroclinic currents computed separately.
- Output is stored in a file “output_filename”. The output will be in the same format of input file but with t**idal and residual velocity components at 9th and 10th column** respectively.
- Amplitude and phase of tidal constituents will be saved in “**tira.pri**” file.
- These amplitude and phase of each tidal constituents are used to construct tidal ellipses.

Tools for harmonic analysis

- **T_tide tool** for matlab, freely available

  Pawlowicz, R., B. Beardsley, and S. Lentz (2002), *Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE, Comput.* Geosci., 28, 929–937 (available at *https://www.eoas.ubc.ca/~rich/)*

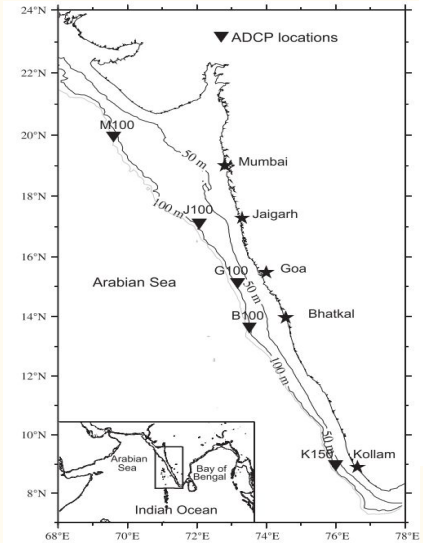
Python version of T_tide is available at *https://ocefpaf.github.io/python4oceanographers/blog/2015/01/19/ttide_py/*

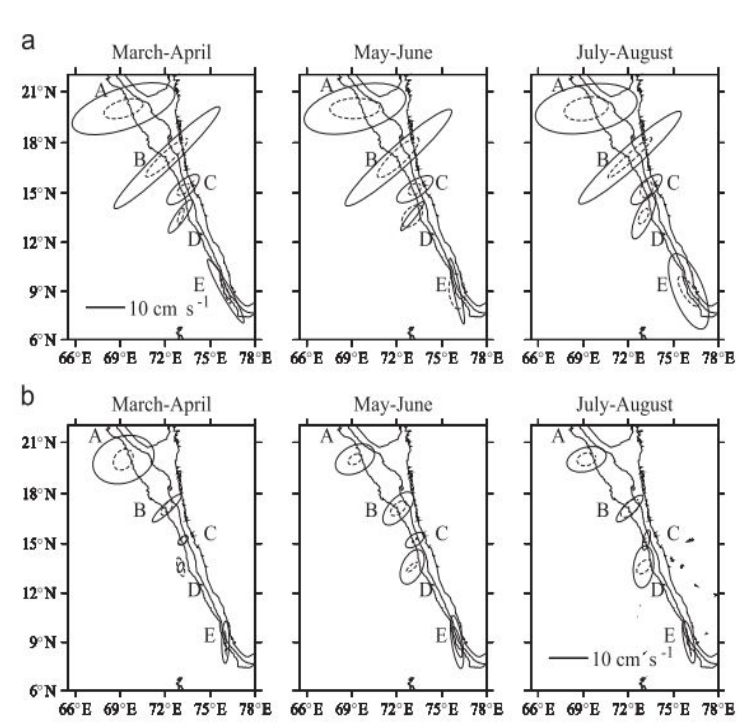
Observed tidal currents off the Indian Coasts

Tidal currents off the the the Indian coasts : *West coast of India*

Barotropic tidal currents

- Observations were made by ADCPs deployed on the shelf
- Semidiurnal variability occurs mainly in M2 and S2 and diurnal variability occurs mainly in K1 and O1
- Maximum cross-isobath tidal current is found at northern shelf locations (for instance, about 32 cm s/s off Mumbai) than those in south (about 10 cm /s) off Bhatkal, at 131N).
- Semidiurnal tidal currents found to be amplified due to the wide continental shelf in the north

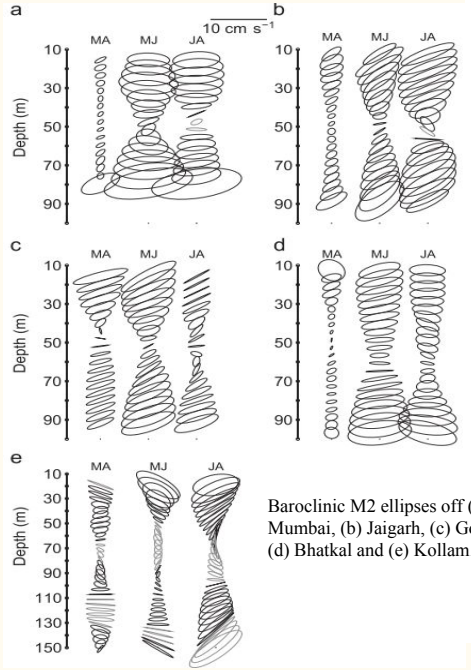




Subeesh et al., 2013, CSR

Internal tides on the shelf off west coast of India

- An increase in the amplitude of semidiurnal and diurnal internal tide is apparent when the stratification on the shelf increases from pre-monsoon to SW monsoon period.
- Magnitude of Baroclinic ellipses is varies with depth



Baroclinic M2 ellipses off (a) Mumbai, (b) Jaigarh, (c) Goa, (d) Bhatkal and (e) Kollam.

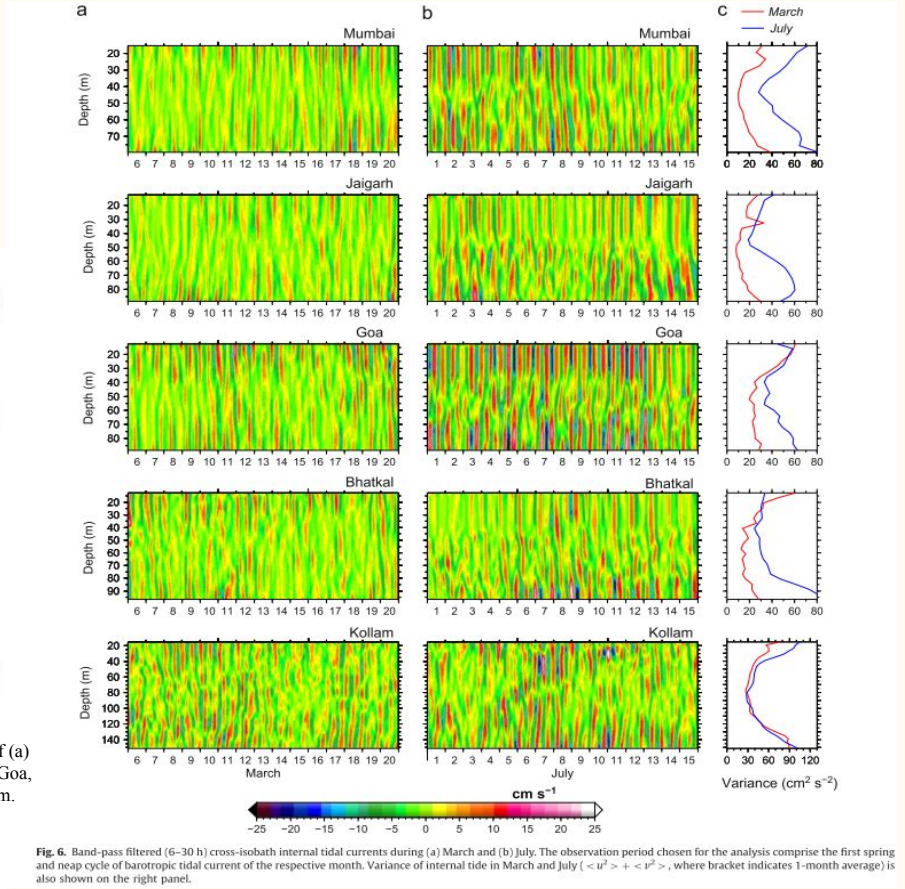
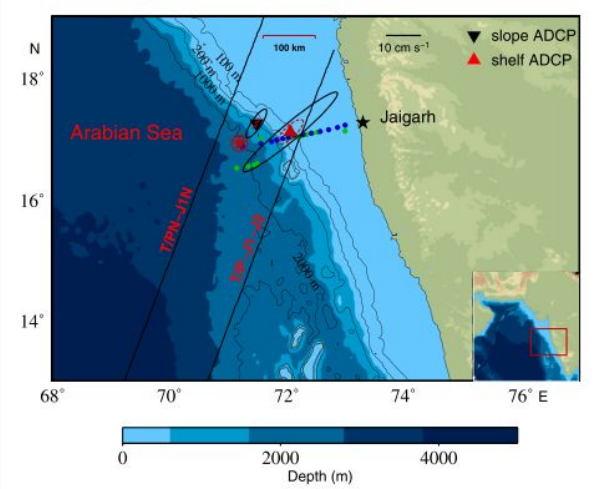


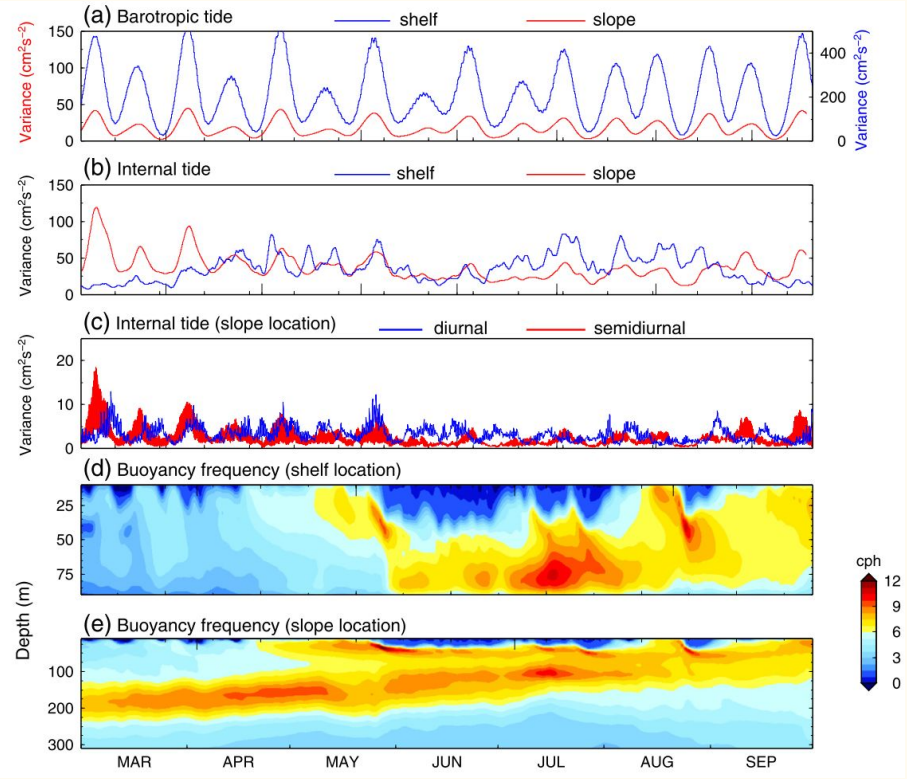
Fig. 6. Band-pass filtered (6–30 h) cross-isobath internal tidal currents during (a) March and (b) July. The observation period chosen for the analysis comprise the first spring and neap cycle of barotropic tidal current of the respective month. Variance of internal tide in March and July ($< u^2 > + < v^2 >$, where bracket indicates 1-month average) is also shown on the right panel.

Subeesh et al., 2013, CSR

Internal tides off jaigarh, west coast of India

- IT on the slope is found to be energetic, with a strong IT during March to mid-April (pre-monsoon period).
- IT is weak during the pre-monsoon and found to be strong in the southwest monsoon.
- Stratification is found to be weak on the shelf and strong on the slope during pre-monsoon.



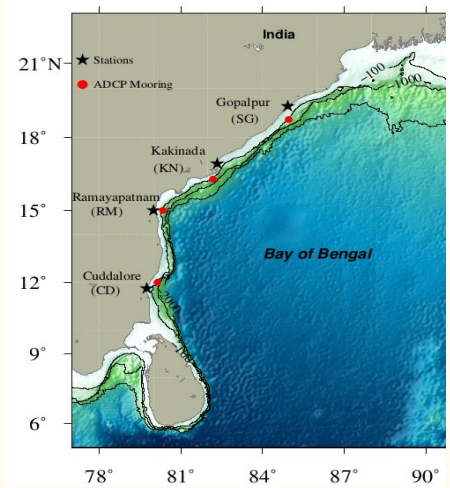


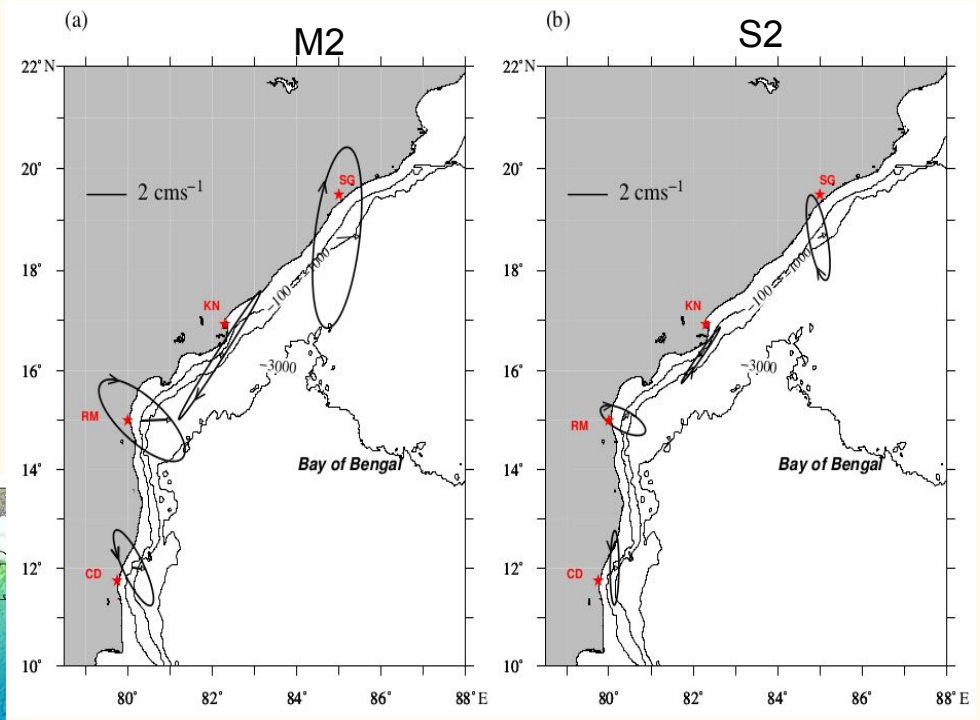
(a) Time series of variance of barotropic tidal currents ($u^2 + v^2$) for shelf and slope locations. (b) Time series of total IT variance, c) Time series of semidiurnal and diurnal IT variances on the slope location. d-e) Buoyancy frequency

Subeesh et al., 2016, JMS

Tidal currents off the east coast of India

- Tidal currents are mainly semi-diurnal in nature and M2 is the largest component.
- Barotropic tidal currents gradually increases from southern to northern part of the shelf.
- Tidal ellipses are oriented in a cross-isobath direction, except off Kakinada

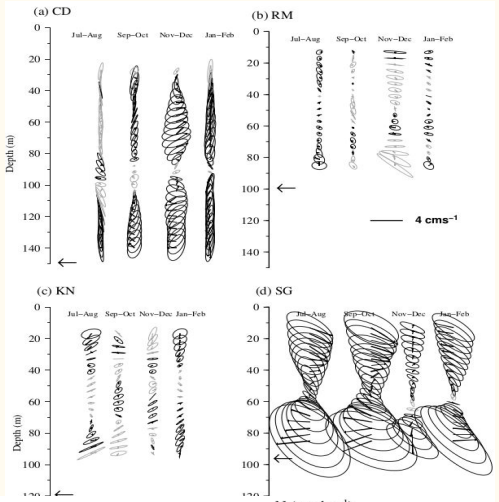




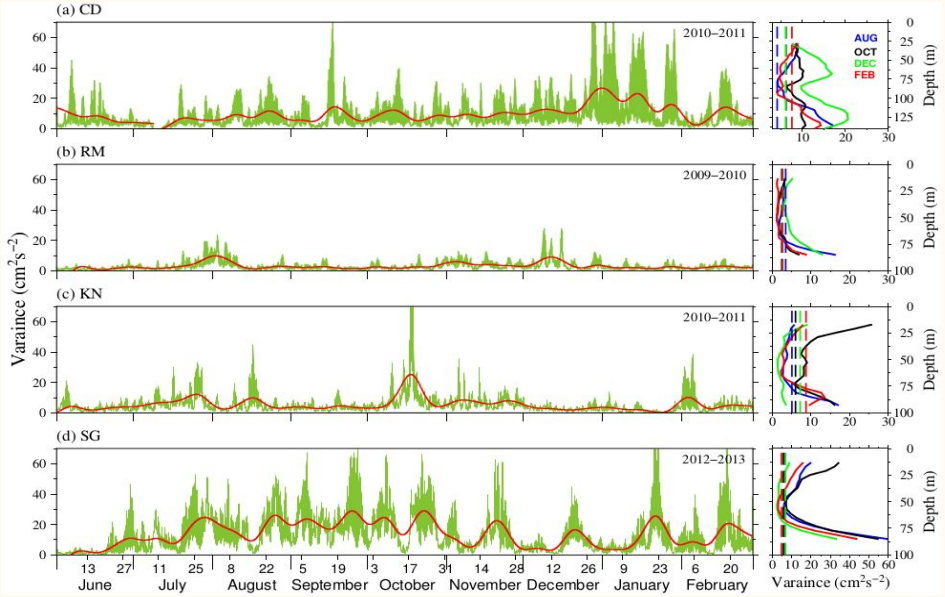
Jithin et al., under review, CSR

Internal tides on the shelf

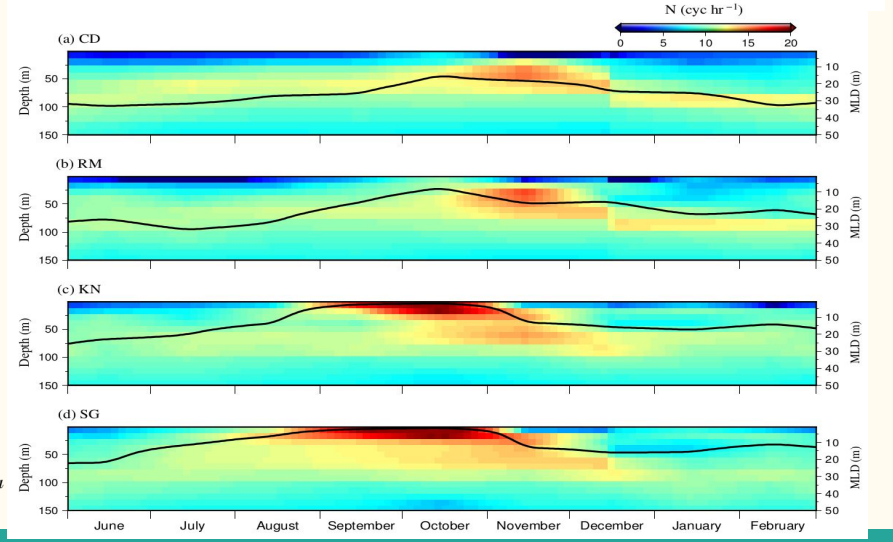
- Semidiurnal internal tides are stronger than barotropic tidal currents.
- Semi-diurnal internal tides are in the order of 8-15cm/s on the shelf.
- Amplitude of semidiurnal internal tides show seasonal variation and it is attributed to the change in stratification on the shelf.



Baroclinic M2 ellipses off a) Cuddalore, b) Ramayapatnam, c) Kakinada and d) south of Gopalpur



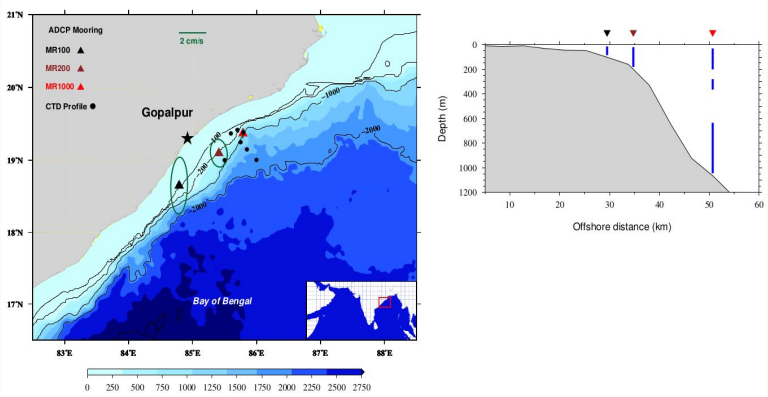
Time series of variance of semidiurnal baroclinic tidal currents ($u^2 + v^2$) off a)Cuddalore, b) Ramayapatnam, c) Kakinada and d) south of Gopalpur

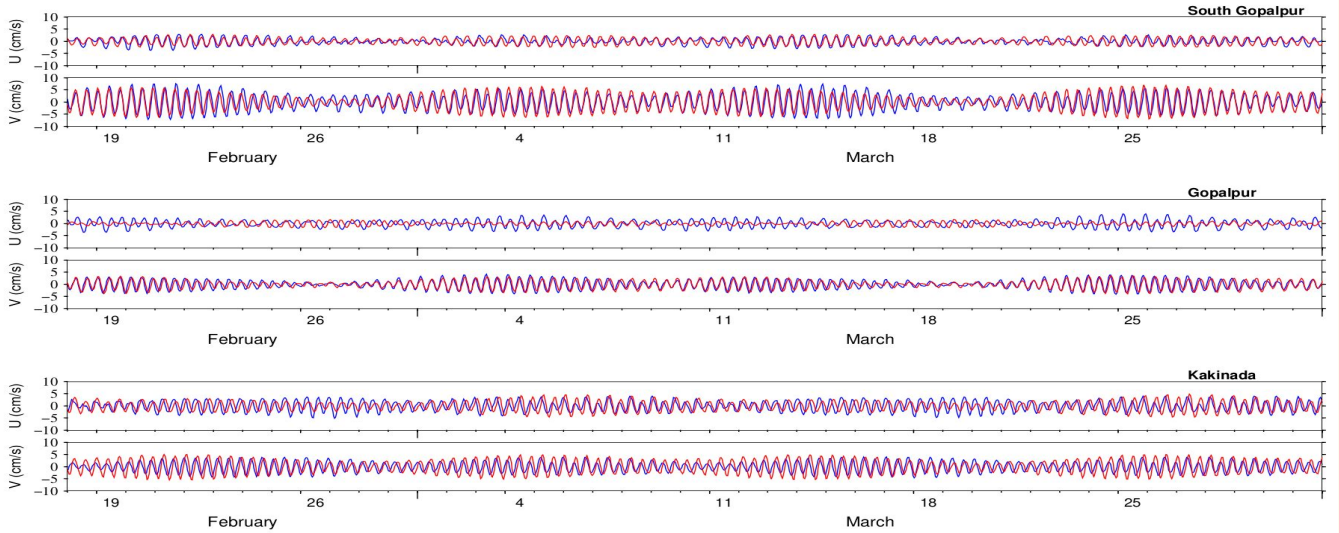


Jithin et al., under review, CSR

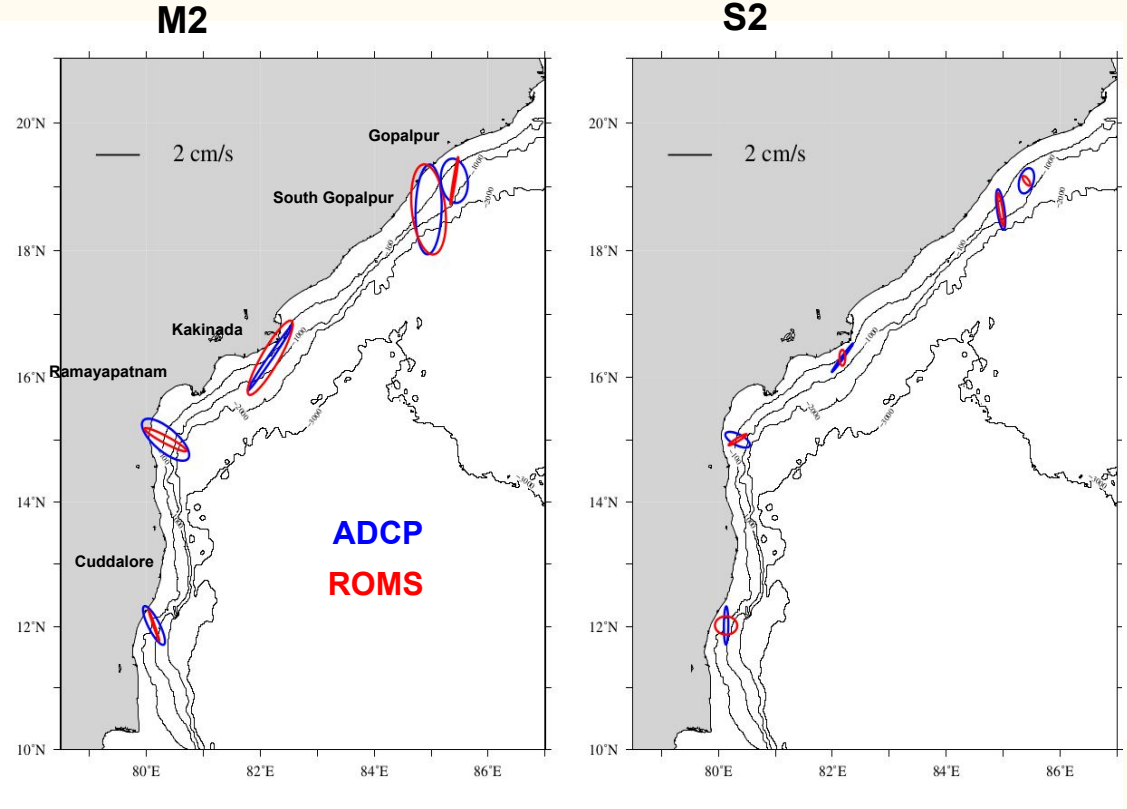
Model validation of tidal currents using ADCP data

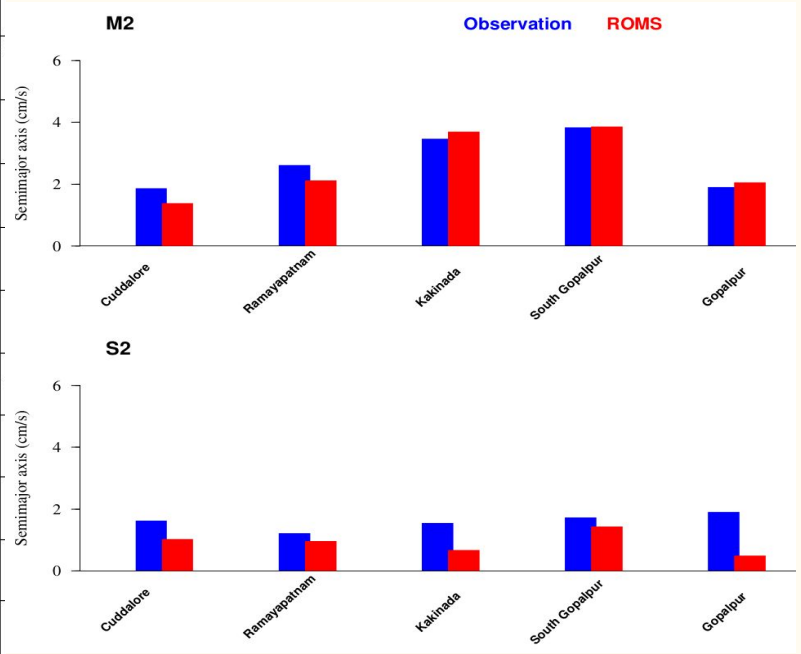
- Vertical profile of currents are required to calculate the barotropic tides.
- ADCP data are useful for the model validations of barotropic and internal tides





Comparison of barotropic tidal ellipses





Summary

- Analysis of ADCP data revealed the presence of strong barotropic and internal tides off the indian coasts.
- Tidal currents are mixed, dominated by semidiurnal along the west coast.
- Tidal currents are semidiurnal in nature along the east coast.
- Tidal currents amplified over wide continental shelf off west coast of India.
- Spatial and temporal variation of internal tide is observed.
- Temporal variability of internal tides are related to the changes in the vertical stratification.

Practical : Analysis of tidal currents

Data

Velocity data (u & v components) are given in a text file.

Method

Harmonic analysis using TASK 2000.

Objectives

1) Extract tidal current from the given time series data.
2) Plot tidal currents and residual current.
3) Find out the nature of tidal currents using form ratio $(K1 + O1)/(M2+S2)$ and find out which component is dominant.
4) Construct tidal ellipse for major tidal components.

Thank You

Effect of declination will give rise to two constituents. Lunar declination takes place in 27.3216 solar days. i.e., 655.7 hours. This means an oscillation either side of the equator in 327.85 hours. This gives rise to 360.0/327.85 =1.098
For M2, this will give two constituents,
28.984+1.098 =30.082 K2 lunar declinational semi-diurnal constituent
28.984 -1.098 =27.886

Declination of the moon takes place in 655.7 hours (27.32 days) , which gives a speed number of 0.549.
For getting the diurnal lunar tide,
14.492 + 0.549 = 15.041 K1 (half of M2 plus 0.549)
14.492 - 0.549 = 13.943 O1

N2, L2 – Modulate M2, conversion from the circular orbit to the elliptical orbit in the plane of the equator

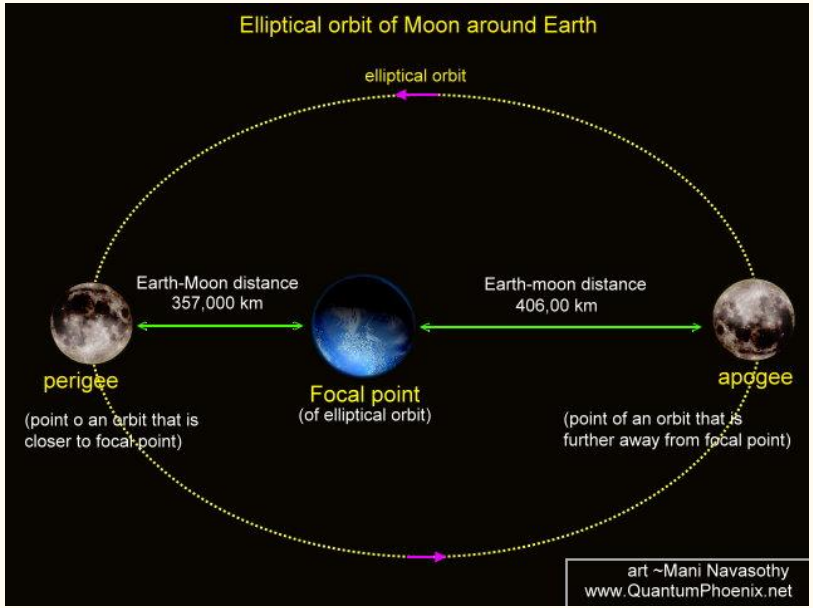
Tidal Component	Period (solar hours)	Description	Nature
M2	12.42	Principal lunar	semi-diurnal
S2	12.00	Principal solar	semi-diurnal
N2	12.66	Larger lunar elliptic	semi-diurnal
K2	11.97	Luni-solar	semi-diurnal
K1	23.93	Luni-solar diurnal	diurnal
O1	25.82	Principal lunar diurnal	diurnal
P1	24.07	Principal solar diurnal	diurnal
Q1	26.87	Larger lunar elliptic	diurnal
MF	327.90	Lunar fortnightly	Long term
MM	661.30	Lunar monthly	Long term
SSA	4383.00	solar semi annual	Long term
M4	6.21		Compound
MS4	6.10		Compound

Table: Primary Tidal Components

Raleigh criterion gives the minimum number of days of data required to separate any two constituents. It is given by 360/ (diff in angular speeds)

For instance, to separate M2 from S2, one

requires 360/ (30.0-28.984). The unit is in hours (354.330 hr, ~ 14.7 day)


Elliptical orbit of Moon around Earth
elliptical orbit
Earth-Moon distance
357,000 km
Earth-moon distance
406,00 km
perigee
(point o an orbit that is
closer to focal point)
Focal point
(of elliptical orbit)
apogee
(point of an orbit that is
further away from focal point)
art ~Mani Navasothy
www.QuantumPhoenix.net


Earth
Orbit
Moon
Orbit
Inclination
5.14°
1,738 km
4,641 km
Barycenter
6,378 km
Radius
Axial tilt
to orbit
23.44°
Axial tilt
to orbit
6.68°
384,405 km