Remote Sensing of the Earth System: Challenges & Way Ahead

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IEEE-GRSS Kolkata Chapter and Centre for Soft Computing Research
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Approach

- Introduction to Big Data
- Big Data in the Earth System
- Remote Sensing Applications
- Current Challenges in Remote Sensing
- The way forward
**Big Data** is a high-volume and high-velocity and/or high-variety information assets that demand cost-effective, innovative forms of information processing to enable enhanced insight, decision-making, and process automation.

**Data Analytics** is the science of examining raw data with the purpose of finding patterns and drawing conclusions about that information by applying an algorithmic or mechanical process to derive insights.

**Refs:**
- https://www.gartner.com/technology/home.jsp
The Earth’s climate system is quite complex.

System is highly non-linear due to multiple interactions.
## The Earth System: Essential Climate Variables (ECVs)

<table>
<thead>
<tr>
<th>Domain</th>
<th>Essential Climate Variables (50)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Terrestrial</strong></td>
<td>River discharge, Water use, Groundwater, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Above-ground biomass, Soil carbon, Fire disturbance, Soil moisture.</td>
</tr>
</tbody>
</table>

[1] Including measurements at standardized, but globally varying heights in close proximity to the surface.  
[3] Including nitrous oxide ($N_2O$), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride ($SF_6$), and perfluorocarbons (PFCs).  
[4] In particular nitrogen dioxide ($NO_2$), sulphur dioxide ($SO_2$), formaldehyde (HCHO) and carbon monoxide (CO).  
[5] Including measurements within the surface mixed layer, usually within the upper 15m.  

*Source: UNFCC & IPCC*
Complexities in the North Indian Ocean

Seasonal SST Climatology

Seasonal SSS Climatology

Seasonal Sea Surface Height Anomaly

Wind Speed Climatology

Source: Swain, 2009
A few degrees doesn't seem much!!!

Temperature Change ~ +/- 6 degrees

The difference between an ice age and ice-free age is only this!

Calls for continuous high spatio-temporal resolution multi-parameter observations (Big Data !!)
(i) Monitoring Surface Changes: Vegetation

Data: MODIS
(ii) Monitoring Surface Changes: Snow Cover

The 28 year trend in snow extent derived from visible and passive microwave satellite data indicates an annual decrease of approx. 1 to 3 % per decade with greater decreases of approx. 3 to 5 % during spring and summer.
(iii) Monitoring Surface Changes: Glacial Retreat

ASTER image of the Himalaya mountains documents glacier stagnation & lake formation (2001)

(Advanced Space borne Thermal Emission & and reflection Radiometer - instrument flown on NASA's Terra satellite)
The disappearance of the Aral Sea, as seen by Landsat satellite during the period 1973 to 2000.

Over this period, more than 60% of the lake vanished, replaced with a dry, dusty plain.
Satellite studies indicate Arctic sea ice cover is declining annually.
Sea Ice Cover: NH and SH

Over 30 years period for sea ice cover:
- Continuous downward trend both during the summer (-13.3 % per decade) and winter (-3.0 % per decade) periods over the Arctic region.
- Increasing trend of 4.5 % per decade for summer and 1.3 % per decade during winter periods over the Antarctic region.
(vi) Monitoring Oceanic Changes: Sea Surface Temperature
Altimeters on satellites provided the first detailed picture of global sea level and now track its change (Source: NOAA/NASA)
(viii) Monitoring Ocean Circulations: Ocean Eddies
Monitoring Atmospheric Changes: Ozone Hole

2009 Southern Hemisphere Ozone Hole Area

*NOAA SBUV/2*

*Current Year Compared Against Past 10 Years*

- Million Sq Km
- Updated through Nov 29, 2009

(Ozone Hole Area vs. Month)

- 2009
- 2008
- 2007
- 99-08 Mean
- 99-08 Max
- 99-08 Min

(Source: NOAA/NASA)
Warmer temperatures enable an increase in atmospheric water vapor (H\textsubscript{2}O - the most abundant greenhouse gas)
(xi) Monitoring Land-Atmosphere Exchanges: Volcanoes

Source: www.geo.mtu.edu
(xii) Monitoring Air-Sea Interactions: Cyclones

Cyclone Phailin
Data Requirements

• High Resolution Global in situ Observations (spatial and temporal)

• Long term Satellite based imagery (multiple resolutions and wavelengths)

• Multi-dimensional bulk data analysis & modeling

• Data Intensive and High Computational Prowess
  - Data Mining Techniques
  - Genetic Algorithms
  - Artificial Neural Networks
  - EOFs / Fractals, etc......
Known Event / Large Data

I know what phenomena I want to detect but I do not know the characteristics of the phenomena.

I want to find anomalies in the data sets!

Data Managing System

Refine your algorithm using iteration

Earth Science Data Sets

- Relationship analysis
- Coincidence searches
- Input for other algorithms

I know what phenomena to detect but I don’t have the algorithm to do so!
• Ocean Surface Winds
• Waves (wind/internal/swell waves)
• Ocean Currents/Circulation
• Oceanic Rings/Eddies/Gyres
• Tides
• Fronts
• Upwelling
• Mixed Layer Dynamics
• Air-Sea Interaction
• El-Nino
• Morpho-dynamic changes
• Photosynthesis
Oceanography Applications

Altimeters

**SARAL AltiKa**: 35.75 GHz (Ka-band)

Scatterometers

**Scatsat-1**: 13.515 GHz (Ku-band)
<table>
<thead>
<tr>
<th>Bands</th>
<th>Frequency (Wavelength)</th>
</tr>
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<tbody>
<tr>
<td>P</td>
<td>0.3 – 1 GHz (30 – 100 cm)</td>
</tr>
<tr>
<td>L</td>
<td>1 – 2 GHz (15 – 30 cm)</td>
</tr>
<tr>
<td>S</td>
<td>2 – 4 GHz (7.5 – 15 cm)</td>
</tr>
<tr>
<td>C</td>
<td>4 – 8 GHz (3.8 – 7.5 cm)</td>
</tr>
<tr>
<td>X</td>
<td>8 – 12.5 GHz (2.4 – 3.8 cm)</td>
</tr>
<tr>
<td>Ku</td>
<td>12.5 – 18 GHz (1.7 – 2.4 cm)</td>
</tr>
<tr>
<td>K</td>
<td>18 – 26.5 GHz (1.1 – 1.7 cm)</td>
</tr>
<tr>
<td>Ka</td>
<td>26.5 – 40 GHz (0.75 – 1.1 cm)</td>
</tr>
</tbody>
</table>
Satellite Altimetry for Geoid and Gravity Anomaly

FREE-AIR GRAVITY ANOMALY AT BOMBAY HIGH

Courtesy: ISRO
Satellite altimeters are radars, which transmit short pulses toward the earth beneath them.

The return time of the pulse after reflection at the earth's surface is measured, and this yields the height of the satellite.

**Altimeters:**
ERS-1, ERS-2, TOPEX/Poseidon, Jason-1,2, SARAL/AltiKa satellites.
Sea surface is rough rather than flat. So the first reflection of energy commences when the leading edge of the pulse reaches the topmost crests of the waves, earlier than for the flat surface.

But the reflected energy does not achieve its maximum until the trailing edge reaches the lowest wave trough.

In this way, the altimeter is able to average out the effect of the ocean waves. This parameter is called a Significant Wave Height (SWH).
As a result of random distribution of the ocean wave facets at any instant, each individual return signal is very noisy, but averaging many successive pulses can reduce this.
### Group Members

Number of members: 220

<table>
<thead>
<tr>
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<th>Type</th>
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</thead>
<tbody>
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<td>qual_inst_corr_1hz_sig0_c</td>
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</tr>
</tbody>
</table>
Scatterometer Winds Applications

- Generation of surface waves
- Shipping safety and efficiency
- Oil platform operations
- Storm surges
- Upwelling
- Coupled Ocean-Atmosphere General Circulation Models
- Cyclone studies
Microwave scatterometer is based on the principle of the resonant Bragg scattering.

For a smooth surface, oblique viewing of the surface with active Radar yields virtually no return. If the surface is rough, significant backscatter occurs.
The interference of scattering from many different parts of the surface results in a reinforcement of scattering from periodic structures in the surface roughness which have suitable wavelengths, and destructive interference of all other reflections.

\[(2d \sin \theta = n \lambda)\]
Computation of Wind based Upwelling Index (UI)

Ekman transport is considered as the wind based UI (a function of alongshore wind stress and Coriolis parameter) computed as:

\[
\text{Alongshore wind stress } (\tau_l) = \rho_a C_d V_l (U^2 + V^2)^{1/2}
\]

where:

- \( \rho_a = \text{Air density} \ (1.225 \text{ kg m}^{-3}) \)
- \( C_d = \text{Drag coefficient} \ (1.43 \times 10^{-3}) \)
- \( V_l = \text{Upwelling favourable wind} \)
- \( U = \text{Zonal Wind} \)
- \( V = \text{Meridional Wind} \)
Computation of Upwelling Index Contd...

\[ V_l = - \left( \frac{\text{lat}}{\text{abs(lat)}} \right) (U \cos(\theta - \pi/2)) + (V \sin(\theta - \pi/2)) \]

where, \( \theta \) is the angle defined by an unitary vector normal to the shoreline and pointing seaward (following Cropper et al. 2014; Varela et al. 2015)

- **Ekman transport**: \( M_e = \tau_l / f \) (Bakun, 1973)

- **Ekman pumping velocity**: \( W_e = \text{curl} \tau_l / (\rho_o f) \) (Wiafe and Nyadjro, 2015)

\[ \rho_o \text{ is the water density (1024 kg m}^{-3}) \]
\[ f \text{ is the Coriolis parameter (2}\Omega\sin\phi) \]
\[ \Omega \text{ is the angular velocity of the Earth} \]
\[ \phi \text{ is the latitude} \]
SCATSAT – 1, L4 25 km Analysed Winds & Wind Stress Curl

(a) & (c) Jun-Aug 2017; (b) & (d) Nov-16-Feb 2017

Latitude

Longitude

R3
R2
R1

Weather

Season

WS (m/s)

WST Curl

(N/m$^3$) x 10$^7$

15
13
11
9
7
5
3
1

12.0

5
4
3
2
1
0
-1
-2
SCATSAT–1 Winds (Summer Monsoon)

Prominent Upwelling Regions in the Arabian Sea

Latitude

Longitude

OMAN COAST R2

SOMALIA COAST R3

KERALA COAST R1

WS (m/s)
Along-Shore Wind Speed (m/s) in R1: SEAS
Ekman Transport (kg/m²/s) in R1: SEAS
Ekman Transport (kg/m²/s) in R1: SEAS

Ekman Transport (kg m^-2 s^-1)
June - August, 2017
Surface Geostrophic Currents (from Altimeter)
(computed as the gradient of SSH from absolute SSH)

\[ u_s = -\frac{g}{f} \frac{\partial \zeta}{\partial y}; \quad v_s = \frac{g}{f} \frac{\partial \zeta}{\partial x} \]

where, \( g \) is the acceleration due to gravity, \( f \) is the Coriolis parameter \( (f = 2 \Omega \sin \varphi) \), \( \zeta \) is the height of the sea surface above a level surface (elevation), \( \varphi \) is the latitude and \( \Omega \) is the angular velocity of the earth's rotation \( (= 0.729 \times 10^{-4}) \).

Wind Driven Ekman Currents (from Scatterometer)

\[ [u, v] = V_0 \exp(-z/D) \left[ \cos(\pi/4 - z/D), \sin(\pi/4 - z/D) \right] \]

where, wind stress is assumed northward is the surface amplitude; \( D \) is the e-folding scale depth; \( z \) is depth taken positive downward; and \( \rho \) is the density of seawater that can be assumed constant.
Artificial Neural Network Technique

Model Profile: RBF 3:3-200-1:1

Input Layer with 3 neurons

Hidden Layer with 200 neurons

Output Layer with a single neuron

\[
Y_q = A_{q0} + \sum_{j=1}^{k} A_{qj} \Phi(B_{j0} + \sum_{i=1}^{n} B_{ji}X_i), \quad q = 1, 2, \ldots, m
\]

where, \(X_i\) & \(Y_q\) are the components of the input and output vectors, respectively

\(A\) & \(B\): fitting parameters

\(\Phi\): the activation function

\(n\) & \(m\): the number of inputs and outputs, respectively

\(k\): the number of neurons in the layer
**Artificial Neural Network Approach**

**Derivation of Ocean Sound Speed Profiles from Remote Sensing Data**

**In situ Data**
- Levitus Monthly climatological T/S profiles at 1° X 1°
- T/S profiles from Argo floats during 2002 – 2006
- T/S profiles and surface parameters from WHOI mooring data
- T/S profiles and surface parameters from ARMEX during 21 Apr – 3 May 2005 at 8°N & 73°E

**Remote Sensing Data**
- 3 day average wind speed from TMI during 2002 – 2006

**Input parameters:** DH, SST, WS, NHF, Radiation

**Output parameters:** Sound speed at different depths till 100 m (3 hourly profiles at 1 m interval)

**Model used:** ANN MLP with 3 input neurons, 14 hidden neurons and 18 output neurons
Scatter between observed and predicted SSP

Histogram of the residuals in ANN predicted SSP

Sensitivity Analysis

Rank 1: DH
Rank 2: SST
Rank 3: WS
Rank 4: NHF
Rank 5: Radiation

\[ y = 0.99 \times + 20.12 \]
\[ R^2 = 0.98 \]
\[ RMSE = 1.16 \text{ m/s} \]
\[ Per. \text{ Err.} = 0.05 \]
Comparison of in situ estimated and ANN predicted SSP at 27 depths

<table>
<thead>
<tr>
<th>Date</th>
<th>Depth (m)</th>
<th>Estimated SSP</th>
<th>ANN predicted SSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 Oct 94</td>
<td>y = 0.99x + 16.86</td>
<td>R² = 0.97</td>
<td></td>
</tr>
<tr>
<td>16 Dec 94</td>
<td>y = 1.01x - 22.80</td>
<td>R² = 0.99</td>
<td></td>
</tr>
<tr>
<td>16 Mar 95</td>
<td>y = 1.02x - 32.92</td>
<td>R² = 0.99</td>
<td></td>
</tr>
<tr>
<td>16 May 95</td>
<td>y = x - 9.79</td>
<td>R² = 0.98</td>
<td></td>
</tr>
<tr>
<td>16 Jul 95</td>
<td>y = 0.96x + 54.03</td>
<td>R² = 0.93</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Depth (m)</th>
<th>Estimated SSP</th>
<th>ANN predicted SSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 Nov 94</td>
<td>y = 0.94x + 88.72</td>
<td>R² = 0.99</td>
<td></td>
</tr>
<tr>
<td>16 Jan 95</td>
<td>y = 0.96x - 63.74</td>
<td>R² = 0.99</td>
<td></td>
</tr>
<tr>
<td>16 Apr 95</td>
<td>y = 0.99x + 14.03</td>
<td>R² = 0.98</td>
<td></td>
</tr>
<tr>
<td>16 Jun 95</td>
<td>y = x + 4.57</td>
<td>R² = 0.99</td>
<td></td>
</tr>
</tbody>
</table>

Courtesy: Jain et al., NRSC / ISRO
Estimation of Ocean Temperature Profiles & Mixed Layer Depth from Surface Parameters

**16 Nov-94**

\[ y = 0.9417x + 1.4682 \]
\[ R^2 = 0.9903 \]

**16 Dec-94**

\[ y = 0.9856x + 0.0387 \]
\[ R^2 = 0.9724 \]

**16 Feb-95**

\[ y = 0.9695x + 0.776 \]
\[ R^2 = 0.9975 \]

**16 Mar-95**

\[ y = 0.9833x + 0.2097 \]
\[ R^2 = 0.9982 \]

**Source:** Ali et al. (2004), GRL; Swain et al. (2006), JMR

**Blue colour:** in situ observations

**Purple colour:** ANN Estimations

\[ y = 2.773 + 0.951x \]
\[ R^2 = 0.937 \]

\[ y = 27.718 + 0.524x \]
\[ R^2 = 0.529 \]
Estimation of Bathymetry using GEOSAT/ERS-1 Data

Under Sea Features:
• Seamount, knoll, abyssal plain, hill, trench

Bathymetry Estimation & Feature Classification

Applications:
• Navigational safety, exploration and drilling of offshore oil/gas wells, pipeline/cable route planning
• Studies relating to understanding the physical, bio-geo-chemical processes of the ocean

Estimation of bathymetry from gravity:
Indirect & a very complex approach (abrupt variations in topography/gravity ratios spatially, owing to factors like changes in sediment thickness and others)

Approach: Artificial Neural Networks

• Input: Geosat/ERS-1 Gravity Anomaly
• Output: Multi-Beam Echo Sounder (MBES) Bathymetry
Validation

• MBES Bathymetry
• Model bathymetry products (1’ Spatial Resolution):
  (a) SS V13.1 (Smith and Sandwell, 1997)
  (b) Earth Topography One Arc-Minute Global Relief Model (ETOPO1, 2009)
  (c) General Bathymetric Charts of the Oceans (GEBCO V2.0, 2008)
BATHYMETRY IMAGES:
(a) MBES survey
(b) ANN Technique
(c) SS V13.1
(d) ETOPO1
(e) GEBCO V2.0

(circles represent ship tracks of SBES survey)

ANN estimated bathymetry is improved than the global model bathymetry products

Source: Jena et al. (2012), IJAEOG
Retrieval of Atmospheric Temperature profiles from INSAT-3D with improved Vertical Resolution

**Data:** High vertical resolution atmospheric temperature profiles; INSAT-3D IR Sounder observations (coarse vertical resolution, but high temporal and spatial coverage)

**Available techniques:**
- Radio Occultation observations: Limited spatial and temporal coverage but high vertical resolution (~200 m)
- Microwave Sounders: Estimate the temperature of thick layer (~10 Km).
Simulated INSAT-3D temperature (19 pressure levels) → High resolution GPSRO temperature (171 pressure levels) → ANN model → High vertical resolution INSAT-3D temperature profile

Technique Used: Empirical Approach (Artificial Neural Network)
Single model for entire domain, all seasons

Test data: COSMIC Radio occultation data (2007-2009)
Total profiles: 10,485
Training data set: 4112
Testing data set: 3331
Validation data set: 3042

19 pressure levels of INSAT-3D → 171 pressure levels (vertical resolution of 5hPa)
Statistics for validation data set

RMSD: 0.51
SI: 0.002

Absolute difference temperature (K)

Correlation coefficient

Scatter Index (SI)

ANN estimated
Radio occultation

Temperature (K)
Pressure (hPa)

Courtesy: Sharma et al., NRSC & SAC/ISRO
MSMR Wind Speed Retrieval using ANN

**Inputs:** MSMR brightness-temperature ($T_B$) in four channels (with dual polarizations)

**Output:** DS Buoy SSWS

**Data Sets:** collocated & concurrent observations

Training : 50%
Verification: 25%
Validation : 25%
(Random Selection)

**ANN:** Radial Basis Function Model

<table>
<thead>
<tr>
<th>PARA</th>
<th>RMSE</th>
<th>BIAS</th>
<th>+2 m/s</th>
<th>+4 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANN vs Buoy</strong></td>
<td>1.8 m/s</td>
<td>-0.4 m/s</td>
<td>74%</td>
<td>~100%</td>
</tr>
<tr>
<td><strong>OGRA vs Buoy</strong></td>
<td>3.4 m/s</td>
<td>2.5 m/s</td>
<td>38%</td>
<td>73%</td>
</tr>
</tbody>
</table>
Wind Speed Estimation

Source: Jena et al. (2010), IEEE-GRSL
Long term linear growth rate of (a) SLA and (b) STA in the Tropical Indian Ocean

First three temporal functions of CEOF modes of SLA and STA

Percentage contributions of the first five Complex-EOF modes of SLA and STA

<table>
<thead>
<tr>
<th>CEOF</th>
<th>SLA (%)</th>
<th>STA (%)</th>
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<tbody>
<tr>
<td>1</td>
<td>49.11</td>
<td>46.69</td>
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<tr>
<td>2</td>
<td>25.48</td>
<td>24.26</td>
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<tr>
<td>3</td>
<td>14.28</td>
<td>13.32</td>
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<tr>
<td>4</td>
<td>6.36</td>
<td>8.75</td>
</tr>
<tr>
<td>5</td>
<td>4.78</td>
<td>6.98</td>
</tr>
</tbody>
</table>

Source: Nayak et al. (2012), JISRS
Bay of Bengal Coastal Observatory

A Joint Centre of
IIT Bhubaneswar and Ministry of Earth Sciences

NATIONAL

• Indian National Centre for Ocean Information Services (INCOIS), Hyderabad

• National Institute of Ocean Technology (NIOT), Chennai

INTERNATIONAL

• Massachusetts Institute of Technology, Massachusetts (USA)

• University of Massachusetts, Dartmouth (USA)

• The University of Rhode Island (USA)

• Woods Hole Oceanographic Institution, Woods Hole (USA)

• University of Southampton, Southampton (UK)
### Short-term and Long-term Thrust Areas

<table>
<thead>
<tr>
<th>Short-term Areas</th>
<th>Long-term Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean Modeling and Predictions</td>
<td>Storm Surge</td>
</tr>
<tr>
<td>Air-Sea Interactions</td>
<td>Ocean Biogeochemistry</td>
</tr>
<tr>
<td>Cyclone Research</td>
<td></td>
</tr>
<tr>
<td>Modeling of Seasonal, Sub-seasonal to Inter-annual climate variability</td>
<td></td>
</tr>
<tr>
<td>Climate Change modeling</td>
<td></td>
</tr>
<tr>
<td>Exploration Seismology and Ocean Floor Monitoring</td>
<td></td>
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<tr>
<td>Fresh water balance</td>
<td>Deep Circulation Studies</td>
</tr>
<tr>
<td>Ocean Acidification and Ocean heat content in a changing climate</td>
<td>Deep Ocean Carbon Observations</td>
</tr>
<tr>
<td>Multi hazard Coastal and Social Vulnerability</td>
<td>Geothermal Energy Resources</td>
</tr>
<tr>
<td>Hydrothermal Sulfide and Cobalt Crust Programme</td>
<td>Sea Level Rise</td>
</tr>
<tr>
<td>Ocean Engineering and Technology</td>
<td>Studies on Benthos</td>
</tr>
</tbody>
</table>
**Objective:** To obtain the seasonality of the ocean current structure using existing observations.

**Figure A1:** Reversal of Boundary Current from daily field: Northward from daily field is 1.8 m/s during March associated the Western Boundary Current and reverses during November with maximum value 1.2 m/s.

**Figure A2:** The power spectrum of the current at SW07P (20.192°N, 86.702°E) near Paradip showed the maximum peak of amplitude close to 2.5 m/s at 48 days with other dominant peaks at 7, 12 and 18 days during November, 1997 to 31st March, 1998.

**Time series data of surface and subsurface current are to be collected near Puri, Odisha. Along with current data, the temperature and salinity will be collected as well to study the heat and salt transport along the Odisha coast associated with boundary currents.**

*Source: Sil et al.*
Investigations of the Biogeochemical Processes in the Bay of Bengal

Objective
Understand the role of thermohaline variations on upper ocean dynamics in the Bay of Bengal (BoB)

Analyses in progress:
(a) Investigations on short-term variability of barrier layer thickness (BLT) in the Bay

Data: Temperature, salinity & depth profiles, met-ocean parameters during October 2013 – September 2014 (OMNI buoys)

Observations:
• BLT maximum during January-2014 and minimum during April-2014.
• Seasonal build-up of warm water in the upper ocean during the summer period (April-May, 2014).
• Barrier Layer formed in summer monsoon continued to exist throughout the post monsoon season as well.

(b) Initiation of marine observations
• Observations of temperature and salinity profiles in Lake Chilika.
• Regular observations planned for measurement of water quality as well as other physical parameters

Source: Swain et al.
Impact of air-sea interactions over Bay of Bengal on propagation of equatorial waves and intraseasonal oscillations

Data
- Satellite data: Outgoing longwave radiation
- Reanalysis: NCEP Reanalysis and ERA40
- IMD data: 1degree resolution precipitation and Cyclone intensity and track

Tools
- Two dimensional FFT analysis to identify equatorial waves and intraseasonal oscillations
- Two dimensional wavenumber frequency filtering to quantify different waves over time and longitude

Preliminary Results
- Convectively coupled equatorial waves and intraseasonal oscillations quantified over Bay
- Periods of intense MJO activity over the Bay identified and compared with phase of global MJO phenomena
- Work in progress

Relationship between MJO and cyclone activity over Bay of Bengal being studied

Source: Kiran et al.
Coastal Ocean Sensing and Forecasting for Fisheries Management: Practical Systems for India

Potential Impacts

- Greater catch per unit effort for fishermen
- Better sustainable fisheries management, monitoring, financial hedging, and re-insurance.
- Reduce poverty and improve the social conditions of disadvantaged workers in the large unorganized fisheries sector in India.

Proposed System

Numerical model with uncertainty quantification (DO-PE)
- Dynamically Orthogonal-Primitive equation

Data
- Remote sensing, buoys etc.
- Gaussian Mixture Models (GMM-DO)
- Dynamically Orthogonal

Improved Potential Fishing Zone (PFZ) advisory

The 12 fishing zones in India [Source: INCOIS]

Sample Chlorophyll map from Oceansat-2 [Source: NRSC/ISRO]

Source: Avijit, UMassD
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