Synoptic Ocean Forecasting and Data Assimilation -- A Feature Oriented Perspective: 1997—2006

Avijit Gangopadhyay

University of Massachusetts Dartmouth

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OUTLINE

• Overview of feature-oriented modeling

• Operational Forecasting in GOMGB and WNA

• FORMS for Other Oceans

• Basin-scale modeling of North Atlantic -- funded by NASA and GLOBEC
Gulf Stream Front and Ring Analysis

February 11, 2002 Frontal Analysis

2/11/02
Gangopadhyay et al. (1997, JAOT)
Robinson and Gangopadhyay (1997, JAOT)
Gangopadhyay and Robinson (1997, JAOT)
Features in Western North Atlantic

**Deep Sea region (GSMR)**
- Gulf Stream
- Warm Core Rings
- Cold Core Rings
- Southern Recirculation Gyre
- Northern Recirculation Gyre
- Deep Western Boundary Current
  - Gangopadhyay et al., 3-part series in 1997: Journal of Atmospheric and Oceanic Tech. (14) 1314:1365

**Coastal region (GOMGB)**
- Maine Coastal Current
- NEC Inflow
- GSC Outflow
- Jordan Basin Gyre
- Wilkinson Basin Gyre
- Georges Basin Gyre
- Georges Bank Gyre
- Tidal Mixing Front
  - Gangopadhyay et al. 2003 (Continental Shelf Res.(3-4))
\[ T(x,y,z) = T_a(x,z) + \alpha(x,z) \Gamma(y) \]

where,
\[ T_a(x,z) = \{[T_0(x) - T_b(x)] \Phi(x,z) + T_b(x) \} \]

\[ U(x,y,z) = \gamma(y) \{[U_T(x) - U_B(x)] \phi(x,z) + U_B(x) \} \]

Fig. 4. (a) Velocity-based Feature model parameters, which can be used for transport dominated frontal system such as GS, Kuroshio, Brazil Current and others. See Eq. (1). (b) Water mass T-S Feature model parameters for buoyancy currents, fronts and flows, such as described by Eq. (2).
\[ T_{ss}(x,y,Z) = T_{sh} + (T_{sl} - T_{sh}) \cdot m(\eta,Z) \]

Where, \( m \) is the melding function:

\[ m(\eta,Z) = \frac{1}{2} + \frac{1}{2} \tanh\left[\frac{\eta - \theta \cdot Z}{\gamma}\right] \]

Fig. 5. Schematic representation of (a) shelfbreak feature model front; and (b) analytical water mass (t-s) melding from shallow to deep regions.
In general, a coastal current (CC), a front (SSF) and an eddy/gyre (E/G) are represented by:

**CC:** \[ T^M(x, \eta, z) = T^M_a(x, z) + \alpha^M(x, z) \Gamma^M(\eta) \]

**SSF:** \[ T^{ss}(x, y, z) = T^{sh}(x, z) + (T^{sl}(x, z) - T^{sh}(x, z)) \mu(\eta, z) \]

**E/G:** \[ T(r, z) = T_c(z) - [T_c(z) - T_k(z)] \{1 - \exp(-r/R)\} \]

where,

- \(T^M_a(x, z), T^{sh}(x, z)\) and \(T_c(z)\) are axis, shelf and core
- \(\Gamma(\eta) = \pm \eta (0 \leq \eta \leq W)\)
- \(\mu(\eta, z) = \frac{1}{2} + \frac{1}{2} \tanh[(\eta - \theta.Z)/\gamma]\)

This is what is called “Feature Modeling”
Strategy for GOMGB

Feature Models at feature locations
+
Regional climatology
=
FORMS

MCC WBG JBG GBG GBAG TMF SSF Inflow/Outflow
FORMS Protocol

- Identify Circulation and Water mass features
- Regional Synthesis -- Processes from a modeling perspective
- Synoptic Data sets -- in-situ and satellite
- Regional Climatology (Background Circulation)
- OA (Climatology + Feature Models)
- Simulation -- Nowcasting/Forecasting
FORMS Applications in Different Oceans

- Western north Atlantic – Operational modeling in GOMGB – AFMIS-RFAC
- Strait of Sicily – Dynamical analysis
- Monterey Bay real-time forecasting with ROMS – AOSN-II in summer 2003 -- Upwelling
- Brazil Current Meander-eddy-Upwelling System
- Persian Gulf, Arabian Sea – Rapid response
- Chilean Waters – Northern Humboldt Current – Biophysical modeling
Feature oriented methodology is applicable to ALL different Numerical Models

- MOM (Modular Ocean Model)
- POP (Parallel Ocean Program)
- ROMS (Regional Ocean Model System)
- POM (Princeton Ocean Model)
- MIT GCM
- HOPS (Harvard Ocean Prediction System)
- Finite Element / Finite Volume models

It is an Initialization and Assimilation Methodology
Issues for t-s Initialization Using GOMGB--FORMS

- FORMS locations can be made available to interested research groups
- Summer t-s profiles are readily available
- Use of SST for creating synthetic t-s structures might be useful for hindcasting
- Might be useful for event-based analysis – comparing summer, 1995 against summer, 1999
SST

Day 1

14 Jan 2002
Assimilation

Day 3
Brown et al., 2006
(accepted in JOE)

Day 7
Effect of Assimilation of SST in shallow water

Nowcast

Assimilated 5-day Forecast

Brown et al., 2006 (accepted in JOE)
Model vs. GOMOOS Buoy E
Inter-comparison

Brown et al., 2006 (accepted in JOE)
Feature model based vertical extension methodology

SST + FORMS $\Rightarrow$ T-S Synthetics
Meander-eddy-Upwelling System

Brazil Current System

Calado et al., 2006, GRL
<table>
<thead>
<tr>
<th>Brazil Current</th>
<th>Mascarenhas et al., 1971; Signorini (1978); Miranda and Castro (1981); Evans et al. (1983); Evans and Signorini (1985); Garfield (1990); Zemba (1990); Campos et al. (1995,1996); Silveira et al., (2000); Lima (1997); Castro and Miranda (1998).</th>
</tr>
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<tbody>
<tr>
<td>Eddies off Cape Sao Tome, Cape Frio and Vitoria Eddy, Santos Bight eddy</td>
<td>Mascarenhas et al., 1971; Signorini (1978); Silveira and Lima (unpub.); Calado (2001); Fernandes (2001), Gaeta et al. (1999); Schmidt et al. (1994); Campos et al. (2000)</td>
</tr>
</tbody>
</table>
This schematic shows the complexity in the meander-eddy-upwelling system of the California Current off Oregon and California in the Spring / Summer. The coastal jet coming from the north moves offshore as the season progresses (denoted by the March, May, and July lines), and contributes downstream to the low-salinity core of the California Current.

This core delineates the higher variability region nearshore from the less active regions offshore. The offshore region consists of the mean southeastward flow of the wind-driven subtropical gyre. The inshore region is populated by upwelling centers concentrated near the capes. Eddies generated by the meandering jet are found in both regions, and may exhibit either cyclonic or anticyclonic rotation (hence the ? in the figure). Temporally transient eddies of various sizes have been observed.
FORMS for HOPS and ROMS

SST Frontal Analysis/Composite

Feature Models of fronts, eddies, upwelling jets, filaments

Background Seasonal Climatology

Multiscale Objective Analysis

Synoptic Initialization and Assimilation Fields

Internal Adjustment (0-24Hr)

Wind driven Adjustment (24-48Hr)

Nested HOPS and ROMS

Nowcast, Forecast and Assimilation

3D Comparison with available in-situ data
(a) Eddy, upwelling and front features were automatically detected for 8/8/03 in Monterey Bay, CA. (b) The mushroom in (a) was detected from a zoomed chlorophyll composite for 8/8/03.
Norwegian Coastal Current
Feature modeling

- Originates in Skagerrak, hugging the Norwegian Coast for 2000 km.

- Density driven, low salinity mixture of
  - Baltic Water overflow
  - North Sea water (modified Atlantic water)
  - run-off from European rivers.

- Maintains its integrity until entering the Barents Sea E of North Cape.

- Running parallel to water masses of Atlantic origin (the NE Atlantic current)

Jan Kristian Jensen
Norwegian Defense Res. Est.
Features at SW Norw. coast

Frequent meandering and eddy generation of the NCC. Interaction between meandering NCC and Atlantic water (which is re-circulated and runs parallel to the NCC). Topography is an important control mechanism (the Norwegian Trench, 250-350 m).

Thick brown contour: 200 m
Brown contours for every 100 m, 0-1000 m
Blue color: 500 m depth interval.

Jan Kristian Jensen
Norwegian Defense Res. Est.
Doppler HF Radar

• Vertical Projection Method (Shen and Evans, 2001) obtains subsurface current structure within the Ekman Layer from OSCR

• We extended this method to include baroclinic structure in the form of a simple “plume feature model” in the Chesapeake Bay

• Possible use of this technique in Buzzards Bay

Gangopadhyay et al., 2005
Gangopadhyay et al., 2005
Density Profile

Sea surface

Density increasing

Ambient Shelf Water

Density increasing

Outflow Plume

Gangopadhyay et al., 2005
ADCP vs. Projection velocity section comparison

Gangopadhyay et al., 2005
Basin-scale to Regional-scale

Climate-scale to Plankton-scale to Fisheries

Climate - Physics - Biology - Chemistry - Geology

NAO -- GS -- GOM -- Plankton -- Nutrients -- Topography
NASA and GLOBEC Efforts

- 1/6 degree North Atlantic Model -- Chao, Gangopadhyay, Holland and Bryan, GRL, 1996
- Multidecadal Variability -- 40s vs 90s -- Petrie and Drinkwater, 1993.
- Connect to FORMS in GOMGB
- Partners: UMASSD, Bigelow, UMaine, OSU, URI
ROMS + FORMS
Basin-Scale + Regional Synoptic fields

Western North Atlantic

GOMGB
Conclusion

• Synoptic Ocean Prediction is in its infancy
• Several components do exist – Data, Models, Knowledge-base
• Integration needs to happen to produce socially valuable, marketable products on an ongoing basis
• Call for establishing a Ocean Forecasting Portal
• Focus on the western north Atlantic