Regional nested tide-resolving real-time JCOPET modeling system for coastal waters of southern Japan

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Vocabulary

JAMSTEC  Japan Agency for Marine-Earth Science and Technology, Yokohama

JCOPE  Japan Coastal Ocean Predictability Experiment, the program run by JAMSTEC as a contribution on the way to the Operational Oceanography: moving from ocean climate simulation and studies to ocean weather understanding and prediction

JCOPET  the tide-resolving regional nested subsystem of JCOPE

JMA  Japan Meteorological Agency

NAO  Japan National Astronomic Observatory
JAMSTEC JCOPE Ocean Forecast System

Ocean models covers both the North Pacific and Indian Oceans; semi-global model version is in the pre-operational test phase (1/10 degree).

The real-time weather forecast data provided by JMA and NCEP

Wind stress and heat flux

Data assimilation

Data Assimilation (3DVAR, IAU)

Satellite SST

Satellite SSH

Temperature and salinity in situ observations

SST data

SSH data

ARGO/ship data
North-Western Pacific JCOPE system status

• **JCOPE2** basin-scale real-time modeling system:
  - Updated weekly
  - Produces daily-mean NW Pacific Ocean status estimates immediately available online
  - results include an assimilated analyses and up to 2.5 months ocean forecast
  - ~10 km resolution (1/12 degree), eddy resolving

• **Downscaling activities:**
  - The regional nested tide-resolving ocean modeling system is operated
  - Daily operational cycle
  - Hourly ocean conditions are estimated and predicted up to 1 week; results are immediately available online
  - ~3 km resolution (with the planned further downscaling to ~1km, ~300m resolution)
  - Hierarchy of non-tidal regional models is also operated (weekly)
Relative vertical vorticity

JCOPE2 – 1/12 degree, weekly (daily output)
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JCOPE2 – 1/12 degree, weekly (daily output)

JCOPET – 1/36 degree tide resolving, daily (hourly output)

** UV are interpolated from shifted grids **

Downscaling

Zoom-in
Japan Coastal Ocean Predictability Experiment, relative vorticity
JCOPE2 – 1/12 degree, weekly (daily output)
JCOPET – 1/36 degree tide resolving, daily (hourly output)
Domain of JCOPET real-time regional tide resolving 1/36 degree model (from the May 2010)
Simulation example: sea surface circulation in coastal waters around Kyushu, May 15-17, 2010 (time step 1 hour)
Potential expectations in coastal ocean modeling:

- Barotropic tides
- Storm surges, sudden intensification of sea currents [“Kyucho”] etc.
- River plumes
- Coastal topographic waves
- Upwelling, downwelling and alongshore currents
- Mesoscale instability eddies
- Contour currents and standing meanders
- Internal tides – often aperiodic (although with the external tidal “carrier frequency”) due to the mesoscale variations
- Surface fronts and sub-mesoscale vortices
- Wakes
- Littoral currents

Ref: J. C. McWilliams, Targeted coastal circulation phenomena in diagnostic analyses and forecasts, Dynamics of Atmospheres and Oceans, 48 (2009)
Regional nested JCOPE (POM) model version with the external tidal forcing as body force and as boundary tidal 2D volume fluxes and boundary SSHA adjustment (locally conservative); one way nested to NW Pacific JCOPE2 model

- Vertical resolution: 47 generalized sigma levels; min total depth 5 m; upper layers thickness: 2,3,5,7,…m
- Horizontal resolution: 1/36 degree, ~ 3 km
- Horizontal viscosity: harmonic, Smagorinsky type
- Horizontal diffusivity: harmonic, constant
- Important: permanent tests of the CFL criteria for the vertical cross-interfacial velocity
- $dt_{\text{ext}} = 2 \text{ sec}$, isplit=30 ($dt_{\text{int}} = 60 \text{ sec}$), leap-frog time integration scheme with the Asselin filtering
Example: harmonic Smagorinsky viscosity [0.3], large harmonic diffusivity [~5 m²/s], JCOPET vs observations, January 18, 2010

Model daily mean SST
JCOPET coastal downscaling subsystem parameters - 2

- Assimilation scheme:
  - assimilation is done in the JCOPE2 system (SSHA, SST, TS profiles);
  - tidal signals are treated as noise and formally removed by time averaging (7 days time window);
  - in the JCOPET goes nudging of model time-filtered (~2 days mean) TS fields to the JCOPE2 interpolated values
  - no nudging at the depth H < 20 m

- Tides are introduced both as a gravitational or “body” force and by means of open boundary conditions

- Used are up to 16 short-term harmonics (Q1,O1,M1,P1,K1,J1,O01,2N2,Mu2,N2,Nu2,M2,L2,T2,S2,K2) and 6 long-term harmonics (Mm, Mf, Ssa, Sa, Mtm, Msqm), for the SSHA,U,V (NAO2000)
**JOCPET coastal downscaling subsystem parameters - 3**

- **Meteorological data**: Wind, SLP, Ta, Hum, precipitated water, clouds
  - **JMA MSM** hourly data, updated 8 times per day. Analyses and 32h forecasts, 1/16 x 1/20 degree grid
  - **JMA GSM**, hourly data. SRF up to 3d15h updated 4 times per day (hourly data up to 3d15h) and MRF [reserve] up to 8d - once per day 1/4 x 1/5 degree grid
  - **NCEP GFS**, 3 hourly data, updated 4 times per day. SRF up to 7d12h on gaussian ~0.3125 [1/3] degree grid, MRF up to 16d – on gaussian ~0.625 degree grid

- **Fluxes**: TOGA-COARE bulk algorithm

- **Rivers discharge**: do not included yet in this version

MSM-GSM-GFS hourly wind (March 14-[18]-23, 2010)
Simulation schedule: daily forecasts, weekly assimilation

Job types:

1. **Cold Start** – very first run or recovery from the system crash
2. **Auto** – system selects one of:
   1. "Assimilation" Run
      • Each Friday, restart 2.5 weeks backward with nudging to the latest JCOPE2 analyses
      • Continue in forecast mode up to 15 days forward
   2. **Forecast Run**
      • All other days, restart from the latest Regular Restart Point
      • Run in forecast mode up to 15 days forward from the bulletin date
   3. **Recovery Run**
      • Continue Assimilation Run or Forecast Run simulation stopped due to the time limit of NQS
Some model validation: Barotropic tides
Example: Miyakejima st.
## Model validation: tides

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<th>Station</th>
<th>R</th>
<th>rms Err, m</th>
<th>rms Obs, m</th>
<th>rms Mod, m</th>
<th>Lon</th>
<th>Lat</th>
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<td>1.12</td>
<td>131.80</td>
<td>34.04</td>
<td>3.31</td>
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</table>
Barotropic tide with extended model domain

Chiba, Tokyo Bay: improved

Central Japan Sea, Awashima

Model do not well represents the low frequency sea level changes
Domain of JCPET real-time regional tide resolving 1/36 degree model from May, 2010
Example of surface sea currents variability and comparison with HF radar data

Maps of surface sea current estimates by

(1) JCG Long-Range HF Radar for Current Measurement (3h)
http://www1.kaiho.mlit.go.jp/KANKYO/KAIYO/hfradar/kairyu_inform.cgi

(2) RIAM Tsushima Strait HF Radar System (1h)
http://le-web.riam.kyushu-u.ac.jp/radar/index.html
January 18, 2010 18 JST
January 19, 2010 03 JST

Inconsistency SW of Mikurajima
January 19, 2010 03 JST

“Zoomed” Ooshima-Miyakejima area with surface wind field added
Tsushima Strait area

• This area is relatively shallow and has prominent tidal variability
January 18, 2010 09 JST
January 18, 2010 10 JST
January 18, 2010 11 JST

Inconsistency in Eastern Channel, HF radar shows “return” of outflow tidal current
January 18, 2010 12 JST

Inconsistency in Eastern Channel
January 18, 2010 13 JST
January 18, 2010 14 JST
Internal tides: what means "often aperiodic although with the external tidal 'carrier frequency' due to the mesoscale variations"
JCOPET: Wz(z=50m), May 15-20, 2010
Standard variability of Wz, 50m, 5 days mean
Red zoned exceed 1 mm/s, max > 10 mm/s
Z=400m, Pacific ocean shelf slope east of Kyushu and south of Shikoku, May 4-6, 2010: shades: vertical velocity, vectors: horizontal velocity
Other variability examples: longitude-time section of $W(z=200\text{m})$ along 32N off Kyushu
ADCP vs Model: 12-days statistics, point C0001_NT2-03
ADCP vs Model: 12-days statistics

RMS variability
Correlation of abs velocity component
Correlation for deviations from tide-filtered
Resume

- High resolution tide-resolving JCOPET downscaling system is developed and is operated daily in automatic mode
- Some processes like coastal circulation and circulation over the ocean shelf has relatively good (deterministic) predictability [direct forcing is primary]
- Processes controlled by inertial forces and instabilities like formation of mesoscale jets and eddies etc. require further improvement of model initialization and assimilation schemes and data
  Potentially, the variability in such zones could be predicted only statistically from ensemble of simulations due to the lack of deterministic predictability
- Modeling system improvement and validation is going
Web portal for JCOPE2-FRA re-analysis (free access) and JCOPE real-time products (please register or use temporary user name “visitor”, password “no”):

http://www.jamstec.go.jp/frcgc/jcope/vwp/
The diagrams illustrate the tidal harmonic analysis for different depth levels. Each graph represents the comparison between observed and modeled tidal harmonic data for different tidal components (M2, S2, and K2) across various depths. The x-axis indicates the velocity in m/s, while the y-axis represents depth in meters. The graphs show the variation of tidal velocities at different depths, highlighting the discrepancies and agreements between observed and modeled data. The color codes differentiate between the observed data and the modeled data, allowing for a clear comparison and analysis of the tidal harmonic behavior at the specified locations.
Introducing tides to the regional model - 1

• Astronomic (gravitational or “body”) force – relatively simple but has a small impact on small coastal models. Has analytical presentation and for the real – time simulations need only nodal factors.

• Applied: 16 short-term harmonics (Q1, O1, M1, P1, K1, J1, Oo1, 2N2, Mu2, N2, Nu2, M2, L2, T2, S2, K2) and 6 long-term harmonics (Mm, Mf, Ssa, Sa, Mtm, Msqm)

• Introduced by means of “equivalent tide” \( \eta_{et}(x, y, t) \)

\[
\frac{\partial \eta}{\partial x_i} \rightarrow \frac{\partial (\eta - \eta_{et})}{\partial x_i}
\]
Hourly equivalent tide snapshot maps for nest74 domain
Introducing tides to the regional model - 2

- Tidal waves passing through the open boundaries of regional model domain are often more important for the observed tidal variability compared with astronomic forcing.

- Natural open boundary conditions for the hydrostatic models are these for the boundary velocity. Sea level is estimated diagnostically.

- For the “single” tidal wave it is possible to estimate the barotropic tidal velocity from the sea level anomaly assuming that propagation direction is known:
  \[ V = \pm \sqrt{\frac{g}{h}} \eta \]

- For superposition of different tidal waves and, especially for the case of waves both entering and leaving model domain it is difficult to establish such simple relation.
Introducing tides to the regional model - 3

- Sea level variations at the JCOPE boundary \( i=1,IM \) and \( j=1,JM \) do not have any impact on the model, so sea level in the internal model points \( i=2,IM-1 \) and \( j=2,JM-1 \) has to be modified.

\[
\eta' = \eta' + \alpha_\eta \cdot (\eta_{\text{tide}} - \eta'),
\]

\[
\alpha_\eta \approx 2 / \text{split} \quad \text{- adjust in } \approx 0.5 \text{ of internal mode step}
\]

- Modification of simulated sea level artificially modifies barotropic cell volume, broke conservation features of model and generate artificial biases or even destabilize model.

- To overcome it there are at least 2 possibilities:
  do changes in conservative way (JCOPE)
  or
  apply special measures to suppress impact of non-conservative adjustment (like “flow relaxation” near the open boundaries etc.)
Introducing tides to the regional model - 4

- To support volume conservation, normal to open boundary barotropic velocity is corrected immediately following the sea level adjustment:

\[ V_{a'}_\perp = V_{a_\perp} + V_{adj}, \quad \text{where} \]

\[ V_{adj} = \pm \alpha_\eta \cdot (\eta_{\text{tide}} - \eta') \cdot A / [(H + \eta) \cdot D_\perp \cdot DTE2] \]

- After each external time step specify new boundary barotropic velocity used for the next step sea level estimation:

\[ V_\perp = V_{\perp JCOPE} + V_{\perp NAO} \]
Introducing tides to the regional model - 5

<table>
<thead>
<tr>
<th>Parameter</th>
<th>JCOPET default</th>
<th>Flather</th>
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<tbody>
<tr>
<td></td>
<td>1. Volume conservation</td>
<td>1. Volume conservation</td>
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<tr>
<td></td>
<td>2. Sea level adjustment</td>
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<tr>
<td></td>
<td>( E_l^{fin}<em>{b+1} = E_l</em>{b+1} + E_l_{adj} )</td>
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<tr>
<td></td>
<td>( E_l_{adj} = \alpha (E_l_{tide} - [E_l_{b+1} - E_l^{mean}_{b+1}] ) )</td>
<td>Equal if ( \alpha = \sqrt{g(H+E_l)} \frac{\Delta t}{\Delta n} )</td>
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<tr>
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<td>3. BVF adjustment</td>
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<td></td>
<td>( U_{adj} = \frac{E_l_{adj} \cdot A}{(H+E_l) \cdot \Delta l \cdot \Delta t} )</td>
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<tr>
<td>UA</td>
<td>( U_b = U_{mean} + U_{tide} )</td>
<td>( U_b = U_{mean} + U_{tide} + U_{adj} )</td>
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<tr>
<td></td>
<td>( U_{adj} = \sqrt{\frac{g}{H}} (E_l_{tide} - [E_l_{b+1} - E_l^{mean}_{b+1}] ) )</td>
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</tbody>
</table>