The GHER hydrodynamical model is implemented in the Black Sea, and run operationally since 21/12/2011. The model runs daily in free mode and as a data-assimilative ensemble run. The ensemble is built by applying multiple, random but physically consistent perturbations to the members. The ensemble forecast allows to estimate the a priori forecast uncertainty. When observations become available, - model performance is assessed (validation of the ensemble mean) - the forecast uncertainty is evaluated a posteriori (validation of the ensemble spread) - observations are assimilated using an EnKF (OAK). Operational forecasts of the ocean state and its expected uncertainty (as estimated with the ensemble) are publicly available on http://www.seamod.ro

Submitted to Ocean Modelling (revision 24/04/2015)

**Introduction**

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**GHER hydrodynamic model**

- model already implemented in different studies of the Black Sea
- long-term, extensive validation (see 2)
- horizontal resolution ~4km
- 31 vertical double-sigma levels
- Baroclinic timestep: 10 minutes
- 6 rivers, Bosphorus channel
- Bulk formulae using atmospheric fields downloaded from NOAA NCEP GFS

**Data assimilation**

**DATA ASSIMILATION**

- daily assimilation of SST and ARGO profiles
- observations uncorrelated, rms : 0.25°C, 0.05psu
- data assimilation localisation radius ~ 100km
- correction limited to 1°C (temperature), 0.3psu (salinity), 5cm/s (velocity), 3cm (elevation)

**COMPARISON W/ INDEPENDENT OBSERVATIONS**

Temperature rms error (average over 2014):

<table>
<thead>
<tr>
<th>Lead days</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>rms error</td>
<td>0.71</td>
<td>0.76</td>
<td>0.85</td>
<td>0.92</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Comparison with Chlorophyl satellite images:

**Validation of the ensemble**

The a priori error (estimated by the ensemble spread) corresponds well to the a posteriori error (ensemble mean minus observations), suggesting that the ensemble initialization and perturbations during the simulation are sized relatively well. Differences between a priori and a posteriori errors indicate that the ensemble slightly underestimates the error (e.g. ~0.1°C for temperature).

If the error distribution were Gaussian, 60,85 and 90% of points would fall within 1,2, and 3 std.dev. around the mean. The ensemble simulation has slightly lower amounts of points, again indicating that the ensemble spread is slightly too low.

**Model validation**

- operational model simulates well the large scales:
  - Rim current position
  - semi-permanent eddies
  - elevation difference from coastal areas and open see ~ 20 cm
  - surface and deep salinity values
  - hydrodynamic regime on the shelf

- Also simulates well shelf-open sea exchanges
- Also simulates well the mixed layed depth spatial distribution

**Ensemble generation**

Model parameters, inputs... that are not perfectly known are different in each ensemble member

- rivers flow and diffusion coefficients
- when (exceptionally) creating a new member, initial conditions are perturbed using the WCE⁴ method
- atmospheric forcing fields are perturbed using their EOFs

Example of ensemble spread for SSH (a priori error):

**References**

1 Vandenbulcke et al, Onboard implementation of the GHER model for the Black Sea with SST and CTD data assimilation. J. of Operational Oceanography, 2010
3 Barth et al, Dynamically constrained ensemble perturbation – application to tides on the West Florida Shelf. Ocean Science, 2009
4 Ocean Assimilation Kit, Barth et al, see publication list and software source on http://www.data-assimilation.net/mediawiki/index.php/Ocean_Assimilation_Kit