Chapter 20

INTERNAL METRICS DEFINITION FOR OPERATIONAL FORECAST SYSTEMS INTER-COMPARISON: EXAMPLE IN THE NORTH ATLANTIC AND MEDITERRANEAN SEA

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Abstract : The European MERSEA and international GODAE projects have built a common methodology for real-time inter-comparison of forecast systems. Internal metrics, i.e. a mathematical definition of chosen diagnostics, are defined and aim at testing the consistency, quality and performance of each system. They are sorted into four classes (Class 1 to 4) and described here for the North Atlantic basin and the Mediterranean Sea. Possible use of such metrics and comparison to existing litterature is also briefly described.

Keywords: MERSEA, GODAE, internal metrics, inter-comparison, North Atlantic, Mediterranean Sea.

1. Introduction: MERSEA framework

The European project MERSEA conducts a real time inter-comparison of 5 operational forecast systems for the North Atlantic and Mediterranean basins, gathering in alphabetical order: FOAM from UK, HYCOM-US from USA, MERCATOR from France, MFS from Italy and TOPAZ from Norway. MERSEA project has developped a web site: http://www.mersea.eu.org. Its final aim is to build a European GMES (Global Monitoring for Environment and Security) operational system in 2008. MERSEA teams have built a common methodology, defining a common grid on to interpolate their outputs and internal metrics which aim at testing the consistency, quality and performance of each system.

- ‘Consistency’ means that operational systems outputs have to be consistent with the current knowledge of the ocean circulation and climatologies.
- ‘Quality’ means that operational systems outputs have to be in agreement with independent observations (i.e. not assimilated).
- ‘Performance’ means that internal metrics should quantify the capacity of each system to provide accurate short term forecast.

Following those criteria, internal metrics are sorted into different classes. Class 1, 2, and 3 metrics allow testing the consistency and quality of the systems. Class 4 are diagnostics to check the performance of the system. Definitions for the North Atlantic and Mediterranean basins are given in this paper. Some complementary metrics (Class 1 to 4) are currently being defined in the context of GODAE for the Pacific Ocean (Masa Kamachi, personal communication), the Arctic and Antarctic Oceans with metrics for the ice (Gilles Garric, personal communication) and the Indian and Southern Oceans (Neville Smith, personal communication).

Standardized output fields and diagnostics are distributed via OPeNDAP servers and can be visualized through a Live Access Server (LAS) or with DODS clients.

2. OPeNDAP and LAS servers

2.1. OPeNDAP server

OPeNDAP allows to access remote data of interest over the internet, using familiar data analysis and visualization packages like: Matlab, Ferret and others, without worrying about data storage formats. More information about OPeNDAP/DODS can be found on the web:

- http://opendap.org/faq/what_is_OPeNDAP_software.html
- http://ferret.pmel.noaa.gov/Ferret/DODS/ferret_dods.html

A non exhaustive list of all datasets available via OPeNDAP servers is indicated on the OPeNDAP homepage: http://www.opendap.org/data/

2.2. LAS server

The Live Access Server (LAS) is a highly configurable Web server designed to provide flexible access to geo-referenced scientific data. LAS enables the Web user to visualize data with on-the-fly graphics, request subsets of variables in a choice of file formats. A user can quickly obtain products such as plots, images, and formatted files with any t, z, y, x combination. LAS has a comparison mode which allows the user to select any data sets distributed on Internet via OPeNDAP, and then compute differences (with automated re-gridding), overlay them graphically and view them as side-by-side plots.

More information about LAS can be found on the web:

- http://ferret.pmel.noaa.gov/Ferret/LAS/ferret_LAS.html
- http://ferret.pmel.noaa.gov/Ferret/LAS/LAS_forInSituData.pdf

2.3. MERSEA servers

Mersea **OPeNDAP server** URL addresses are (Password and user name are available upon request):

http://user:password@www.nerc-essc.ac.uk:9090/dodsC/ for FOAM
http://hycom.rsmas.miami.edu/dodsC/ for HYCOM-US
http://user:password@opendap.mercator-ocean.fr/dodsC/ for MERCATOR
http://thredds.sincem.unibo.it:8080/thredds/dodsC/ for MFS
http://mersea.nersc.no/dodsC/ for TOPAZ

MERSEA LAS URL is the following:

http://las.mersea.eu.org (restricted access)

2.4. MERSEA forecast systems main characteristics

Ocean Model? Vertical Coordinate? Ice Model? Spin Up Length? Mixing Parameterization? Which Basin?	**Horizontal and Vertical Resolution? Relaxation to Mediterranean Water?**	**Which Heat and Momentum Forcing? Relaxation?**	**Which Data Assimilation Method? Which Data Assimilated? Which MSSH used (Mean Sea Level used as a reference for data assimilation)?**
MERCATOR FR OPA 8.1 Z coord., Rigid Lid. Simple diagnostic sea ice. SPIN UP : 15days TKE . ATL + MED.	Hori.1/15°(5/7km) . Verti. 43 levels. Relaxation to Medatlas (T,S) in Gulf of Cadiz below 500m.	Daily ECMWF forcing. Relaxation to Reynolds SST and Reynaud SSS.	OI SOFA. SLA SSALTO-DUACS along track once a week. MSSH from Rio et al.(2004) in the Atlantic and blend of previous runs in Mediterranean basin.
TOPAZ NO HYCOM 1.0 Hybrid coord., Free surface. Dyn/thermodynanic sea ice. SPIN UP: 20years . KPP mixing. ATL.	Hori. 20 to 30km. Verti. 22 hybrid layers. Closed boundary without relaxation.	6 hourly ECMWF forcing (Bulk formulae momentum and heat). Precipitation Clim + Relaxation to Levitus SSS.	EnKF. SLA SSALTO-DUACS maps once a week. SST from CLS AVHRR. Maps of ice concentration. MSSH from previous OCCAM run.
FOAM UK Brian-Cox Hadley Center.	Hori. 1/9° (12km). Verti. 20 levels.	6 Hourly UK-Met-Office forcing.	OI Cooper&Haines. SLA SSALTO-DUACS along track once a week.

Z coord., Rigid Lid. Dyn/thermodynanic sea ice. SPIN UP: 5months. Kraus-Turner. ATL + MED.	No Med. Water relaxation.	Relaxation to Levitus SST and SSS.	SST 2.5° gridded (ARGO). (T+S) vertical profiles. Maps of ice concentration. MSSH from previous run.
MFS IT MOM 1.0 Z coord. , Rigid Lid. No ice model. SPIN UP: 7 years . Constant vertical mixing + vertical adjustment. MED.	Hori. 1/8°. Verti. 31 levels. Transport through Gibraltar parameterized.	6 Hourly ECMWF forcing (Bulk formulae momentum and heat). Relaxation to satellite night time SST and SSS climatologies.	OI SOFA. SLA SSALTO-DUACS along track once a week. SST and T vertical profiles along track once a week. MSSH from previous run with 1993-99 forcing.
HYCOM US HYCOM *2.1* Hybrid coord., Free surface. No ice model. SPIN UP: 15years. KPP mixing. ATL.	Hori1/12°(6.5km). Verti. 26 hybrid layers. Entrainment parameterization of Med Water Outflow.	3 hourly NOGAPS forcing (Bulk formulae for heat). SSS=50%(E-P) +50% relaxation to Levitus SSS. Relaxation to MODAS SST analysis.	OI Cooper&Haines. SLA MODAS Maps once a week. MSSH from previous 1/12° MICOM run with perpetual ECMWF forcing.

3. Definition of internal metrics

3.1. Common grid

All the systems interpolate their outputs on the so called MERSEA grid with:

- A horizontal resolution of 1/8°.
- A vertical resolution with 8 vertical levels (at 5, 30, 50, 100, 200, 500, 1000, and 2000 meters) in the Mediterranean basin.
- And 12 vertical levels (at 5, 30, 50, 100, 200, 400, 700, 1000, 1500, 2000, 2500, and 3000 meters) in the North Atlantic.

The common geographical domain extends from 10°N to 68°N for the North Atlantic and covers the whole Mediterranean Sea excluding the Black Sea from 6°W eastward.

Class 1 to 3 diagnostics are provided on a real time basis by all teams through their OPeNDAP server for the daily mean (or snapshots for HYCOM-US) best estimates fields (the best estimate corresponds to the best analysis field that each system can produce), as well as for the sixth day forecast.

3.2. Class 1 metrics

Class 1 diagnostics gathers 2-D and 3-D fields interpolated on the MERSEA grid. Two dimensions fields are:

- **The zonal and meridional wind stress (Pa)**,
- **The total net heat flux including relaxation term (W/m^2),**
- **The freshwater flux including relaxation term (kg/m^2/s),**
- **The Barotropic Streamfunction (henceforth BSF) (Sverdrup=10^{6}m^3/s).** The BSF characterizes the wind-driven circulation established in response to wind forcing. One year mean Sverdrup BSF can also be computed using the provided Class 1 wind stress fields. At 25°N, it is commonly assumed that the vertically integrated transport is governed by a flat-bottom Sverdrup balance (Towsend et al. 2000; Boning et al. 1991) at least in the eastern basin. The DYNAMO (Willebrand et al, 2001, their figure 15) five years mean numerical simulations without data assimilation at this latitude showed a good agreement in the eastern basin between models and Sverdrup for all models except the Sigma coordinates models.

- **The Mixed Layer Depth (henceforth MLD) (m).** Two kinds of MLD diagnostics are provided in the Atlantic basin: MLD(θ) with a 1 °C criteria and MLD(ρ) with a 0.05kg/m^3 surface potential density criteria. In the Mediterranean Sea, one MLD(ρ) with a 0.011kg/m^3 surface potential density criteria is provided. Hovmuller plots of the MLD behaviour in chosen regions can show convection time periods. In the mediterranean basin for example, in convection areas as the Levantine Basin, the MLD maximum depth could be plotted. Volume of newly formed Levantine Intermediate Water could be estimated (Castellari et al. 2000).

- **The Sea Surface Height (SSH) (m).** For instance, a zonal section at 48°N of the one year mean SSH can show whether systems have a realistic North Atlantic Current (Willebrand et al. 2001, their figure 13). The path of major currents can also be derived from SSH averaged over several months using the Le Provost and Bremond (2003) algorithm which allows to display path location associated with geostrophic currents. True current position which are well known from compilation of in situ data and remote sensing observations (Auer, 1987) can also be displayed. SSH time series at some moorings locations can also be compared to available observed tide gauge measurements (Smedstad et al. 2002; Tokmakian and McClean, 2003).

- **The Mean Sea Surface Height (henceforth MSSH) (m)** used as a reference sea level during the assimilation procedure. Each system is using a different MSSH field (cf section 2.4). Differences in the MSSH fields between the systems can be large is some areas and are shown to have major influence on the system behaviour (Birol et al. 2004).

The three dimensional fields are:

- **The potential temperature (°C) and salinity (psu).** Those Class 1 metrics allow to test the consistency and quality of the systems. For example, the comparison of the monthly mean Class 1 fields to available climatologies (Levitus 1998; Reynaud et al. 1998; Medatlas 2002) can put in light drifts in the systems away from initial climatological conditions at depths because of long spin-up. Such tests have been used in recent inter-comparison experiments such as DYNAMO (Meincke et al. 2001) and DAMÉE (Chassignet and Malanotte-Rizzoli, 2000).
- **The zonal and meridional velocity fields (m/s).** A derived Class 1 diagnostic is the surface Eddy Kinetic Energy (EKE) which can be computed using surface Class 1 velocities and compared to EKE observations derived from satellite altimetry (Ducet and Le Traon, 2001).

3.3. Class 2 metrics

Class 2 diagnostics are interpolated on high 10km resolution vertical sections (Figures 1 and 2). Class 2 fields are:

- **The potential temperature (°C) and salinity (psu).** The vertical Class 2 sections can be compared, when possible, to historical WOCE synoptic sections. This brings relevant insights on the systems water masses characteristics, for example the 18°C Mode Water (Worthington, 1959), Madeira Mode Water (Siedler et al. 1987), or the Mediterranean Water outflow (Bryden and Kinder, 1991). Class 2 model sections can also be compared to observed XBT MEDS sections gathered within the SOOP program.
- **The zonal and meridional velocity fields (m/s).** Those Class 2 bring information on the vertical structure of currents, as for example, the Deep Western Boundary Current below the Gulf Stream transporting North Atlantic Deep Water (Willebrand et al. 2001; Lee et al. 1996), the Azores current (Paillet and Mercier, 1997; Sy, 1988) and the North Brazil Current (Johns et al. 1998; Schott et al. 1998; Stramma and Schott, 1996). Class 2 model velocities can also be compared to observed ADCP data.

Another Class 2 diagnostic using the velocity fields is the EKE which can be computed for instance along the 48°N zonal section in the various systems and compared to EKE observations from Colin de Verdiere et al. (1989). EKE distribution through the Gulf Stream at 55°W has also been documented from current meter, drifter and float data by Richardson (1983; 1985). Abyssal eddy kinetic energy can also be referred to estimates given by Schmitz (1984; 1996).

3.4. Class 3 metrics

Class 3 diagnostics are integrated quantities (integration done on the original grid) such as:

- **Volume transports (Sverdrup=$10^6 m^3/s$)** across chosen sections (Figures 1 and 2). Depending on the section considered, one has to provide the total volume transport or the volume transport per defined potential temperature classes or density classes. For example, the water flowing through the Florida Strait comes from different Caribbean passages. The knowledge of the flow distribution through these passages appears to be a significant test for the North Atlantic model simulations (Böning et al. 1991; Maltrud et al. 1998). Class 3 model volume transport across the Florida Straits can be compared to real time Cable Voltage measurements (Larsen, 1992). These measurements indicate an annual mean mass transport of approximately 30 Sv, modulated by a seasonal cycle in transport of roughly 6 to 10 Sv.

  In the Mediterranean basin, the volume transport seasonal variablility across several straits in the models can be compared to observations gathered in Astraldi et al. (1999).

- **The Overturning Streamfunction (OSF) (Sverdrup=$10^6 m^3/s$)** as a function of latitude and depth (m) or potential temperature (°C) or potential density (kg/m^3). The OSF characterizes the thermohaline circulation established in response to external forcings (wind, heat and freshwater fluxes) and to the water masses conservation taking place in the buffer zones. The large scale overturning is not directly observable, but an annual mean maximum OSF from 16 to 20 Sv between 20°N and 40°N in the depth range 1000m to 1500m is consistent with the estimates of the corresponding heat transport. At 24°N, repeated transoceanic sections contributed to get a remarkably stable estimate of 17-18 Sv (Hall and Bryden, 1982; Roemmich and Wunsch, 1985).

- **The Meridional Heat Transport (MHT) (PW=10^{15}Watt).** The MHT is a variable of high climatological interest. The MHT is strongly linked to the OSF and mostly reflects the North Atlantic Deep Water (NADW) overturning cell behaviour: the stronger the NADW cell, the stronger the northward MHT. The canonical value is 1.2 +/- 0.3 PW at 24°N (Hall and Bryden, 1982). The OSF and MHT Class 3 diagnostics provide a significant index of the thermodynamic behaviour of the model.

3.5. Class 4 metrics

Class 4 metrics are root mean square statistics (equation 1) in the model and observation space to assess data assimilation performance and forecast skill.

$$rms\,(o - Hs) = \sqrt{\frac{1}{N}\sum (o - Hs)^2} \qquad (1)$$

"o" is the observation vector available in the [T0-7; T0] daily temporal window.

"s" is a hindcast, a forecast, an analysis or a persistence at day T0.

"H" is an operator that converts the "s" vector into the space in which the observation "o" is expressed, i.e. horizontal or vertical interpolation.

The state variables used are sea level anomaly, potential temperature and salinity. The results are given in the form of spatial averages over agreed regions and depth classes. Each team is using the exact same set of independent observations in order the diagnostics to be coherent and meaningful.

4. Conclusion

The methodology based on metrics definition and distribution of outputs through OPeNDAP servers has been applied during the MERSEA-strand1 project and allows a successful demonstration of real time inter-comparison of basin-scale systems in the North Atlantic and Mediterranean basins (Crosnier and Le Provost, 2004). The inter-comparison exercise is being pursued during the European MERSEA Integrated Project (2004-2008). The methodology developped provides a forum to share experience and discuss the areas where progress is needed. It allows identify required characteristics to build a performing operational system. Recommendations for improvement can regularly be addressed to system's team. The methodology allows a continuous and comprehensive assessment of the performances of each system including all components as the observing system, the modeling, assimilation and product distribution components. The framework built during the MERSEA-strand1 project helps setting up the GMES Ocean Component. It has also been adopted by the GODAE partners, who are defining more metrics adapted to the global Ocean.

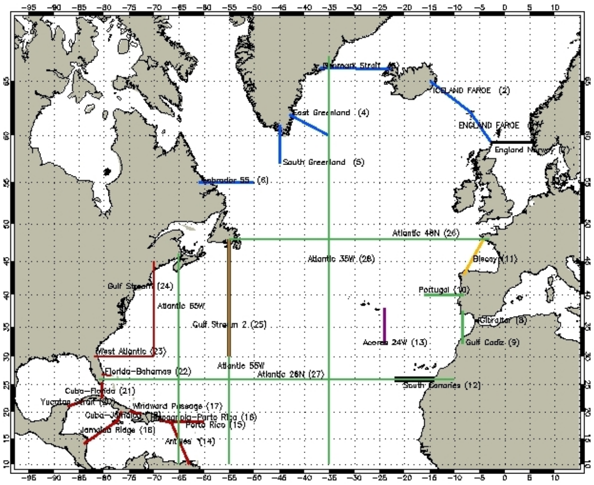

Figure 1. Class 2 sections in the Atlantic.

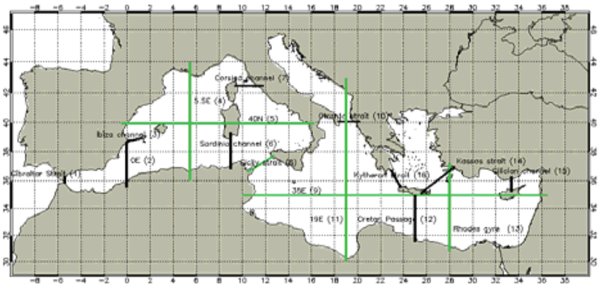

Figure 2. Class 2 sections in the Mediterranean Sea.

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