Use of Argo data in ocean forecasting systems at the UK Met Office

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Argo Science Workshop, Hangzhou, March 2009

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Overview of ocean forecasting systems using Argo data at the UK Met Office

Modelling/prediction systems
- Short-range forecasting: FOAM
- Seasonal forecasting: GloSea
- Decadal prediction: DePreSys
- Long-range climate prediction: HadGEM3

Objective analyses
- Monthly analyses produced routinely: EN3
- Monthly analyses for ocean heat content estimates: HadGOA

Underpinning systems
- Automatic observation processing and QC system.
- EN3 data-set

Initialization of ocean initial conditions using assimilation of data, including Argo data.

Validation and monitoring includes use of Argo data.
Contents

• Short-range operational ocean forecasting - FOAM:
  • New FOAM system.
  • Improvements to enable better use to be made of the data.
• Seasonal and decadal forecasting.
• Automatic quality control of sub-surface data and objective analyses for heat content.
• Summary and sufficiency of Argo.
Forecasting Ocean Assimilation Model (FOAM)

Short range operational ocean forecasting

Matt Martin, Rosa Barciela, Ed Blockley, Catherine Guiavar’ch, Adrian Hines, Rachel Furner, Dan Lea, Ray Mahdon, Dave Storkey
Overview of the FOAM system

- Forecasting Ocean Assimilation Model
- Daily analyses and forecasts out to 5 days.
- Hindcast capability (back to 1997)
Review of previous results
Assessing the impact of Argo data in FOAM

- RMS errors compared to all profile observations before they are assimilated, averaged over a 5 year hindcast (2001-2005).

- Assimilation of Argo data significantly improves the fit to temperature, even with other profile data present.

- Assimilating only non-Argo data can make salinity errors slightly worse due disruption of the density structure when assimilating T and not S.

- Assimilating Argo salinity data reduces the near-surface errors by half.

Solid line – All data
Dotted line – No Argo data
Dashed line – No profile data

Martin et al. 2007
The new FOAM system: Model configurations

- The system has recently been changed to use the NEMO-LIM2 ocean-sea-ice model, with various upgrades to the data assimilation. All models have 50 vertical levels.

- **Global ¼° (ORCA025)**, developed in conjunction with Mercator

- **North Atlantic 1/12°**

- **Med. 1/12°**

- **Indian Ocean 1/12°**
Overview of the FOAM system
Data types assimilated

• All FOAM configurations assimilate a range of data using a multivariate Optimal Interpolation type method.

Temperature and salinity profiles including Argo floats (also XBTs, CTDs, buoys,…) over the GTS.

- In situ and satellite SST (IR and MW from GHRSST)
- Altimeter SLA (Envisat, Jason1&2, from CLS)
- SSM/I sea-ice concentration (EUMETSAT OSI-SAF)
Improvements to the data assimilation

*Error covariances*

- New estimates of the forecast error covariances. Made by combining the output from two techniques:
  1. Observation based method which uses (o-b) statistics to give large scale estimates of error variances and correlations.
  2. Model based method which uses statistics of $(x_{T+48}-x_{T+24})$ to give estimates of forecast error covariances on the model grid.
- Estimates from the observation-based method are used to inflate the variances calculated from the model-based method.

![Temperature forecast error variances at 100m depth](image)
Improvements to the data assimilation

**PV dependent correlation scales:**

- Calculates horizontal gradients of Potential Vorticity and sets the correlation scales inversely proportional to these gradients.

- Attempts to prevent observational information being spread across fronts into areas where there is little correlation. Introduces some flow-dependence in the covariances.

**Cycling:**

- The model is first run without data assimilation, during which the model counterpart of each observation is calculated at the correct time and place (First-Guess-At-Appropriate-Time). This provides an accurate estimate of the “innovation” which can be used in the data assimilation.

- The analysis is performed (currently using an OI type scheme).

- The model is re-run, during which the changes which have been determined by the analysis are input (using Incremental Analysis Updates).
Animations of SST: January – April 2006

Tropical Pacific Sea Surface Temperature °C

Old FOAM-UM

New FOAM-NEMO ¼°
Assessing the new system
Global RMS and mean errors

Dotted – mean error
Solid – RMS errors

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Impact of horizontal model resolution in FOAM
Comparison using Argo data

- Domain: North Atlantic Basin
- Impact of $1/4^\circ$ vs. $1/12^\circ$ resolution on the sub-surface temperature and salinity
- The higher resolution model has improved fit to the Argo data in both temperature and salinity.
- Significant impact can also be seen on surface fields.
Development work with FOAM

NEMOVAR

- Implementation of the NEMOVAR data assimilation scheme is underway.
- It is an incremental variational scheme designed to work with the NEMO model, developed by CERFACS and ECMWF.
- Currently a 3DVar scheme, but will eventually be a 4DVar scheme (the adjoint of NEMO is currently being coded).
- The background error covariance matrix uses physical balance relationships to transfer information between variables
  - Temperature information is transferred to salinity using the model’s T/S relationships
  - The unbalanced part of salinity is only changed when salinity data is available.
  - Similarly, geostrophic corrections are made to the velocities.
- Easier to include new data types (e.g. Argo trajectory data) in a consistent manner.
• A more advanced data assimilation scheme should improve our use of data, including Argo.

• Initial investigations have included one month test runs with a one degree NEMO configuration.

• Two integrations:
  • one with the old OI-type data assimilation scheme
  • one with new NEMOVAR scheme
  • both experiments assimilate exactly the same data (SLA, SST, T/S profile)
Development work with FOAM
NEMOVAR

• Profile statistics compared to all in situ data are significantly improved compared to current assimilation scheme.
- Temperature and salinity (not shown) RMS errors are reduced everywhere with NEMOVAR, except for the Mediterranean Sea.
Future work with FOAM

- Using the new system to run Observing System Experiments to show the impact of Argo data on forecasts (part of Euro-Argo project)
- Continue implementing and developing NEMOVAR.
- Investigating impact of different changes of variable, e.g. density/spiciness assimilation, to make better use of the data.

Density level depth $z(\rho)$ before and after assimilation

Spiciness increment $\pi(\rho)$

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Seasonal forecasting

GloSea

- Coupled ocean-atmosphere model.
- Ocean model is NEMO at 1° resolution.
- Initialisation of ocean is done using the same data assimilation scheme as FOAM.
- They have done similar work to FOAM in re-calculating error covariances.
- Initialisation of atmosphere done using information from the Met Office’s NWP atmospheric system.
- New system still under development which will run once a week to produce monthly and seasonal forecasts.
- Argo was shown to be useful in previous system.

Drew Peterson and Alberto Arribas
DePreSys

Coupled ocean-atmosphere decadal forecasting

Nick Dunstone, Doug Smith
Using Argo to initialise decadal climate models

- The limited observational timebase makes assessing the impact of Argo data to initialise global climate models difficult.
- Instead we present a set of idealised experiments.
- These simulate the procedure used to produce real decadal forecasts by Smith et al 2007.
- Anomaly-based OI scheme with ensemble forecasts.
- Control run based on long run of the Hadley Centre coupled climate model.

Four initialisation experiments:

- **‘Perfect Model’** - uses conditions from original control run
- **‘Full Depth’** - assimilate full field, ocean full depth Temperature & Salinity (T & S)
- **‘2000m’** - assimilate full field, ocean T & S to a depth of 2000m (like Argo data)
- **‘SST Only’** - assimilate SST only following Keenlyside et al 2008.
Forecasting the Atlantic MOC
Comparing the global skill of the four experiments

Spatial correlations of Sea Surface Temperature (SST):

- Correlations are for five year means
- Skill is dependant upon the amount of information assimilated.
- Using 2000m T & S (like Argo data) potentially produces much more skilful forecasts than using SST data.
Quality control

Simon Good, Bruce Ingleby
Quality control system

- Developed under the ENACT and ENSEMBLES EU projects (Bruce Ingleby)
- Designed to process data from any instrument collecting subsurface ocean profiles
- A uniform set of quality control checks are applied to all data
- The QC system is run in near-real time for FOAM and GloSea, taking data from the GTS.
- It is run monthly in delayed mode, taking in data from various sources including Argo GDAC, GTSP, Met Office database from GTS.
  - The background used for a gross background check is an objective analysis which is produced along with the quality controlled dataset.
- Will be further developed to investigate ideas of performing checks on density rather than T and S separately.

Quality control system

- Profiles
  - Vertical thinning
  - XBT fall rate corrections
- Manual exclusions
- Track check
- Buddy check
- Background checks
- Multi level check
- Output

- Duplicate check/thinning
- Profile spike check
- Stability check
Quality control - examples


Spike check: an Argo profile from January 2006.

Background check: an Argo profile from June 2004.
Objective analysis and ocean heat content

HadGOA

Matt Palmer, Nick Rayner
Estimating global ocean heat uptake using isotherms: HadGOA

Dominated by ocean advection (part due to changes in depth of 14°C isotherm)

Dominated by air-sea heatflux (part due to changes in average temperature above 14°C isotherm)

Same ideas could be used even more effectively using Argo density measurements (isopycnals vs isotherms)

Palmer and Haines – J. Clim (in review)
See also Palmer et al. (2007)

In collaboration with NERC ESSC
Argo for estimating global ocean heat uptake

How can Argo help now?
1. Provide an improved climatology
2. Provide error covariances for objective analysis (in-filling) of historical data.

How can Argo help in future?
1. Provide routine, quasi-global observations to 2000m
2. Warming relative to isopycnals rather than isotherms => better understanding of dynamic and thermodynamic influences
Summary and conclusions
Summary

• Recently made significant improvements to the FOAM system including model and assimilation scheme.

• Will run some data withholding experiments to show the impact of Argo data on FOAM forecasts.

• Currently implementing a new variational data assimilation system which should improve our use of Argo data.

• GloSea uses the same data assimilation scheme as FOAM which makes good use of Argo for seasonal forecasts.

• Idealised experiments show large potential impact of Argo on decadal predictions.

• Ocean heat content from objective analysis performed using isotherms.

• Underpinning system of quality control for real-time and delayed mode.
Sufficiency of Argo

- Is the density of floats sufficient for your work?
  - For short-range forecasting, although Argo doesn’t resolve the scales to be initialised, it provides information to initialise the large-scale density so that satellite altimeter data can be used properly to initialise the mesoscale.
  - Sub-surface density information in areas such as Gulf of Mexico would be very useful.
  - For longer term forecasting, 3°x3° is probably sufficient, but difficult to test with real data as the time-scales over which data is available is short in this context.

- Should we have had a subset of floats diving deeper?
  - For decadal prediction, idealised experiments show that having at least some deeper floats would improve long term predictions.
Timeliness of Argo for operational system

Argo receipt time delay for 06/2001
Average delay 7.65 days   3.7% profiles < 1 day   96.3% profiles >= 1 day

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Feb 2009: Argo receipt time minus observation time in days

0 to 0.25 days: 9% (9% < 0.25 days)
0.25 to 0.5 days: 30% (39% < 0.5 days)
0.5 to 0.75 days: 31% (70% < 0.75 days)
0.75 to 1 days: 22% (92% < 1 day)
>1 day: 8%
Sufficiency of Argo

- Timeliness of the floats shown to have improved significantly since Argo first started. Further improvement to timeliness would still benefit the daily operational systems.

- Higher vertical resolution near the surface:
  - Useful for FOAM as it can be used to validate the near-surface layers of the model.
  - Also very useful for SST analysis systems like OSTIA and HadISST, both for validation/calibration of different satellite and in situ SST measurements, and also to boost the in situ SST observing system.

Impact on NWP systems.

- New sensors such as O2 would be very useful for validation of (assimilation in) coupled physical-biological models.
Thank you
GloSea4: System design/infrastructure

**Monday**
- Grab NWP data
- Run ODA (1-day cycle)
- Weekly IC (atmos. recon.)
- N forecasts (6-month)
- Archiving/post-processing

**Tue - Sun**
- Grab NWP data
- Run ODA
- N forecasts (6-month)
- Archiving/post-processing

**Every week**
- Pull together last 4-weeks fcsts/hcst
- Post-processing
- Products / web display

**Every day**
- Grab data. ‘Weekly’ ICs (1, 9, 17, 25)
- N forecasts (6-month) to accumulate minimum: Myears, X members
- Archiving/post-processing

**Off line**
- Continuous ODA (e.g. 1989 – 1998)
- ‘Weekly’ Atmos + land.surf. Reanalysis data
- Archiving/post-processing

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High vertical resolution
Overview of ocean forecasting systems using Argo data at the UK Met Office

Horizontal resolution:
- 1.25°
- 1.00°
- 0.25°-0.08°

Timescale:
- 5 days
- 1 month
- 6 months
- 1 year
- 10 years

Systems:
- FOAM
- GloSea
- DePreSys
Questions

- # Is the density of floats sufficient for your work?
- # Is Argo absolutely perfect for your work?
- # Should we have had a subset of floats diving deeper?
- # Does your research indicate a strong case for more frequent sampling?
Questions

• Answer to the questions is that it depends on which application.

• For decadal prediction, a sub-set of deeper floats would be useful.

• For short-range ocean forecasting and SST analysis systems, higher vertical resolution in the top 10m would be beneficial.

• # Is the density of floats sufficient for your work?

• # Is Argo absolutely perfect for your work?

• # Should we have had a subset of floats diving deeper?

• # Does your research indicate a strong case for more frequent sampling?
Forecast of global seasonal mean temperature.
Black line is the observational record from HadCRUT3
White line and red shading is the June 2005 forecast from Smith et al (2007)
Green line is a forecast from March 2007
Blue line is the latest forecast made in September 2008.
Contents

• Short-range operational ocean forecasting:
  • Previous results showing impact of Argo in FOAM
  • New FOAM system – improved sub-surface accuracy
  • Future improvements (NEMOVAR) will enable even better use to be made of the data

• Seasonal forecasting:
  • Shares the same assimilation code as FOAM with more concentration on bias correction ideas to avoid shocks to the model when correcting model drifts.

• Decadal forecasting:
  • Difficult to show impact of Argo because of limited duration of full array, but idealised experiments have shown large impact of Argo. Some evidence that deeper floats could be useful.

• System for automatic quality control of sub-surface data underpins all these systems.

• The data from the QC is also used in some objective analysis work to provide a means of validating the Hadley Centre climate models.

• Answering the questions sent by Howard.
Review of previous results
Impact of Argo data in FOAM-UM

Average salinity differences to Levitus climatology at 1000m depth
A set of hindcast experiments was run to assess the impact of Argo data on the FOAM analyses.

The period for the hindcasts is January 2001 to July 2005.

Initial conditions were obtained from the operational FOAM models.

The global 1°, North Atlantic and Arctic 1/3° and North Atlantic 1/9° configurations were run as a nested suite of models.

This suite was run three times:

- assimilating all available in situ temperature and salinity data
- with all in situ data except the Argo data
- with no data assimilation
Review of previous results
Impact of Argo data in FOAM-UM

No Argo data
With Argo data

Average salinity differences to Levitus climatology at 1000m depth
Review of previous results
Assessing the impact of Argo data in FOAM

- RMS errors compared to all profile observations before they are assimilated, averaged over a 5 year hindcast (2001-2005).

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Solid line – All data
Dotted line – No Argo data
Dashed line – No profile data
Review of previous results
Impact of Argo data in FOAM

No Argo data

With Argo data

Average potential temperature differences to Levitus climatology at 1000m depth
Review of previous results
Impact of Argo data in FOAM-UM

No Argo data

With Argo data

Average potential temperature increments at 1000m depth
Review of previous results
Impact of Argo data in FOAM-UM

No Argo data

With Argo data

Average salinity increments at 1000m depth
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- assimilating all available in situ temperature and salinity data
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Assessing the new system
Global RMS and mean errors

Dotted – mean error
Solid – RMS errors

Temperature errors (K)  Salinity errors (psu)

Sea ice conc. error

SSH error (m)

SST error (°C)