# THOR Deliverable D09

| Deliverable description: | | Report on test data set experiments from coupled model | | | |
|---|---|---|---|---|---|
| WP No. | 5.2 | Lead Beneficiary: | UHAM | | |
| WP Title | Development of coupled ocean-atmosphere assimilation capabilities | | | | |
| Work duration[1)] | 1-13 | Delivery deadline[2)]: | 2009-11-30 | Delivery date: | 2009-12-21 |

[1)] *Work duration = project month*
[2)] *Delivery deadline: as contracted in Description of Work (Annex 1 to Grant Contract)*

| **Leader:** | **Detlef Stammer** | **University of Hamburg** |
|---|---|---|
| **Contributing partners:** | **Thomas Kaminski** | Subcontractor: FastOpt |
| | --- | MPG-M |
| | --- | ECMWF |
| | --- | KNMI |
| | | |
| | | |

## Index

1. Executive Summary ..... 2
2. Main objectives, description of work and role of participants (Annex I: DoW) ..... 2
3. Report on Deliverable D09 ..... 3
4. List of Publications ..... 6
5. The project / deliverable is delayed: ☒ Yes ☐ No ..... 7
6. Changes made and difficulties encountered, if any ..... 7
7. Efforts for the deliverable D09 ..... 7
8. Sustainability ..... 7

# 1. Executive Summary

Deliverable D09 consists in an observational atmospheric test data set. The team has prepared two test data sets and extended the model by flexible interfaces to assimilate these data sets. This gives capability to evaluate the cost function specifying model-data mismatch, which is demonstrated by plots of the respective cost function contributions over time. The capability to evaluate the cost function forms the basis for the development and testing of the assimilation system to be developed and applied within this work package (WP).

# 2. Main objectives, description of work and role of participants (Annex I: DoW)

**Objectives**

- To improve initialisations of coupled models using ocean syntheses
- To evaluate the improved skill of those coupled models and the building of coupled assimilation capabilities that ultimately will allow
- To constrain coupled model directly through climate observations

**Description of work and role of participants**

The work is organised in parallel streams, concerned with the development of strategies to use ocean syntheses for the initialisation of coupled models, with the coupling of the MITgcm to the Planet Simulator and the associated development of an assimilation system with the Planet Simulator, which will form the basis for the generation of a pilot coupled data assimilation system. Groups involved are primarily the University of Hamburg concerned with the generation of ocean state estimates, and the construction of a coupled assimilation system. The MPG-M, the KNMI and the ECMWF are all collaborators who will use the ocean state estimates for the initialisation of their coupled models and who will benefit from the initialisation methods developed here.

In detail, the activity can be broken down in the following activities:

- Develop strategies to use ocean state estimates for the initialisation of coupled models using the GECCO ocean state estimate approach and using all in-situ and satellite data available. The work will build on the simple coupled models developed in this packet and

respective results will be used for the initialisation of coupled models in WP 4. [UHAM, MPG-M, KNMI, ECMWF]

- Coupling MITgcm to Planet Simulator and testing. The Planet Simulator's ocean component will be replaced by the MITgcm. The extra code required for coupling will be designed in a form compliant with the automatic differentiation tool TAF. Test integrations of the coupled model will be performed. [UHAM, Peter Herrmann, FastOpt]
- Running forecast experiments. The coupled model from Task 5.2.1 is initialised with a state estimated from the GECCO global oceanic data assimilation system and run in hindcast mode. Strategies for coupling and assimilation will be evaluated and the forecast skill be analysed. [UHAM, KNMI, MPG-M]
- Preparation of observational atmospheric test data set. [UHAM, FastOpt, ECMWF]
- Developing and testing variational data assimilation system around the Planet Simulator. Tangent linear and adjoint codes of the Planet Simulator will be generated and tested. A variational assimilation system for the test data set (provided by Task 5.2.3) will be set up around the adjoint Planet Simulator and tested. [UHAM, FastOpt]

# 3. Report on Deliverable D09

The Deliverable D09 is associated with the task “Preparation of observational atmospheric test data set.” (see Section 2). This deliverable is rather a technological than a scientific achievement, which builds the backbone for scientific achievements to follow.

The team prepared two atmospheric test data sets. The first data set is generated by the Planet Simulator (PLASIM, Fraedrich et al, 2005; Lunkeit et al., 2007) itself. This data set (often termed 'pseudo data') is required for the so-called identical twin experiments, which provide the initial test of an assimilation system. The data are generated by a model run in the default configuration and default values of all control variables. The identical twin experiment then consists in recovering the data. A new module has been implemented that arranges the output of the data set in a highly flexible way in SERVICE format, a standard format that also contains basic metadata. The user can select the model fields and levels to be written. They can also specify time averages over arbitrary averaging periods.

| ERA-40 code | PLASIM code | Description | Comment |
|---|---|---|---|
| 138 | 138 | Atm. Vorticity | |
| 155 | 155 | Atm. Divergence | |
| 130 | 130 | Atm. Temperature | |
| 152 | 152 | Atm. Log surface pressure | |
| 133 | 133 | Specific humidity | |

*Table 1: Contents of atmospheric test data based on ERA-40.*

The second data set is produced by using the output of the reanalysis project of ECMWF (ERA-40, Uppala et al., 2005). Data of the type shown in Table 1 were prepared for assimilation into PLASIM for averaging periods of 6 hours for January 1996 and for March 1996 and for averaging periods of 1 month from January 1996 to December 1997. This included interpolation to the model's horizontal and vertical grid and format conversions. As source data for the observations, analysis fields on pressure levels on a 2.5° grid were chosen. For the vertical interpolation, surface pressure from a 1° dataset on model levels had to be interpolated onto the 2.5° grid and converted to SERVICE format. A linear vertical interpolation to ten PLASIM sigma levels was carried out along the pressure coordinate. The resulting fields were then again interpolated horizontally to match the Gaussian grid of PLASIM in T21 and T42 resolution. For the horizontal interpolations and file type conversions, the Climate Data Operators (CDO, Schulzweida et al., 2009), a standard software package maintained by MPI-M, were used.

As a prerequisite for assimilating of the test data, the model has been extended by a module that defines a mapping of control parameters, **x**, to a cost function, **J(x)**. As for the generation of the pseudo data, the module has been implemented to be highly flexible in terms of the contributing model fields. Also, arbitrary time averages of model output variables can be selected. The cost function, **J**, quantifies the misfit between model simulation, **M(x)**, and observations, **d**:

$$J(x) = \tfrac{1}{2} (M(x)-d)^T C_d^{-1} (M(x)-d) \qquad (1)$$

The covariance matrix $\mathbf{C_d}$ hereby quantifies the combined uncertainties from observational and model error. Additional measures had to be taken to ensure that this mapping is reproducible in the case that it is evaluated several times during one program execution, as is required for finite difference testing for gradient verification and by iterative minimisation algorithms.

To demonstrate the use of the data the cost function is evaluated for both data sets. Clearly, the pseudo data set produces a cost function value of 0, when running the model with default values of control variables. Hence, we run the model over one month with the initial temperature field in the lowest model layer perturbed. The perturbation is non-uniform with a size below 1K. Figure 1 shows the total cost function and individual contributions for this model run. As expected, the two runs diverge as the initial errors amplify. Note that, at this stage, a diagonal covariance matrix is used. For convenience the corresponding standard deviations are set to spatially uniform values of $10^{-6}$ 1/s for vorticity and divergence, 1 K for temperature, $10^{2}$ Pa for pressure and $10^{-3}$ kg/kg for moisture. Figure 2 shows the same quantities, but for the ERA-40 data and the unperturbed model. Here the contribution of surface pressure dominates.

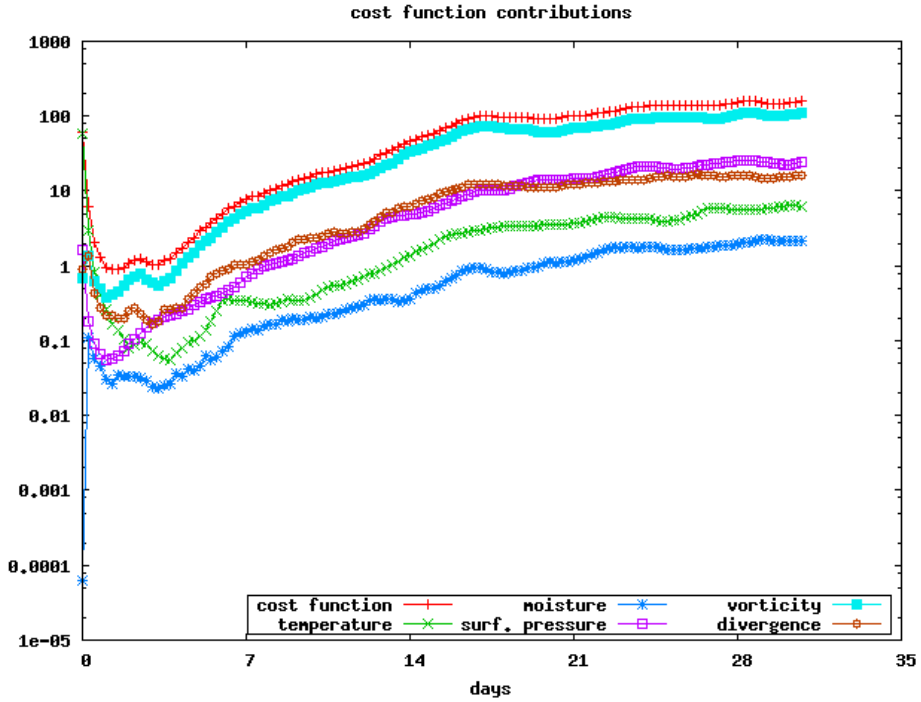


Figure 1: Total cost function and contributions of the five atmospheric fields at each 6 hour interval for pseudo observations and model run with perturbed initial temperatures.

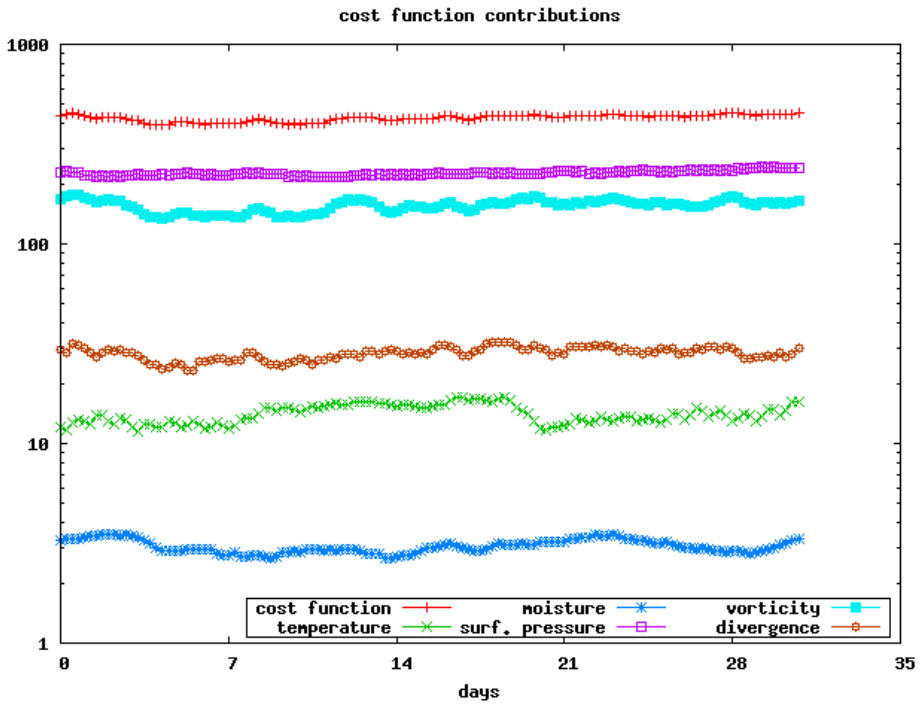


*Figure 2:* Total cost function and contributions of the five atmospheric fields at each 6 hour interval for ERA-40 observations and unperturbed model run.

**References:**

Fraedrich, K., H. Jansen, E. Kirk, U. Luksch, F. Lunkeit, 2005: The Planet Simulator: Towards a user friendly model. - Meteorol. Z. 14, 299-304.

Lunkeit, F., S. Blessing, K. Fraedrich, H. Jansen, E. Kirk, U. Luksch, F. Sielmann, 2007: Planet Simulator User's Guide - Version 15; available at http://www.mi.uni-hamburg.de/Downloads-an.245.0.html?&L=1

Schulzweida, U., Kornblüh, L., Quast, R., 2009: Climate Data Operators version 1.3.2; available at http://www.mpimet.mpg.de/cdo

Uppala, S.M., et al., 2005: The ERA-40 re-analysis. Quart. J. R. Meteorol. Soc., 131, 2961-3012.doi:10.1256/qj.04.176

# 4. List of Publications

There are no publications in preparation yet. This will follow later in the project.

## 5. The project / deliverable is delayed: ☒ Yes ☐ No

Due to the fact that the employment of post-doctoral researchers at UHAM as well as the subcontract with FastOpt was delayed, D09 was delivered 21 days behind the schedule.

## 6. Changes made and difficulties encountered, if any

The team expects to catch up with the delay, no changes have been or will be made.

## 7. Efforts for the deliverable D09

| Institute | Person-Months | Period |
|---|---|---|
| UHAM | 1 | 12.2009 |
| FastOpt | 1 | 12.2009 |

## 8. Sustainability

This deliverable consists of two observational atmospheric data sets. It forms the basis for development and testing of the assimilation system to be developed and applied within WP5.2. First of all, the pseudo data set will be applied in identical twin experiments and secondly, the ERA-40-based data set will be used. Finally, oceanic observations will be added to the set of data and will be assimilated.