Variational Assimilation of ENVISAT Data and the new Icosahedral 4D–var Assimilation System

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Project objectives:
Given the expected wealth of geolocated trace gas retrievals from MIPAS, SCIAMACHY, and COMOS, as well as forthcoming satellite sensors, all offering an unprecedented surveillance capacity of a changing atmosphere, SACADA aims to devise an operational assimilation system to estimate synoptic fields of constituents. Respecting the general objective to upgrade data to information, in this 5 years project the following items are aimed (among others):
(i) optimal exploitation of satellite retrievals of various trace gases scattered in space and time and obtained from different sensors,
(ii) extension to the estimation of not observed species, which are chemically coupled to observed species,
(iii) portability of the system to future computational platforms, namely parallelisation.

Project methodology:
To comply with these and other requirements, an approach with the following features is selected:
1. four dimensional variational method as a feasible spatio-temporal data assimilation algorithm with the BLUE property (Best Linear Unbiased Estimator)
2. GCM: fully coupled Global Chemistry Circulation Model set-up
3. icosahedral grid structure and meteorological driver adapted from CME, after extension to 0.1 hPa.
4. The basic idea of 4D-var is to minimise a scalar cost function that measures the distance between a GCM model run and the observations on the one hand and an appropriate background field on the other hand. For a proper weighting of the information that is contained in the observations and in the background, covariances of all quantities have to be specified as accurate as possible. A simple method to model off diagonal elements of the background error covariance matrix is to add a curvature penalty term to the cost function (1):

\[ \text{cost function} = \sum (y - F(x)) \cdot \text{cov}^{-1} \cdot (y - F(x)) + \lambda \sum (\nabla^2 x) \cdot \text{cov}^{-1} \cdot (\nabla^2 x) \]

where y are the observations, F(x) are the model results, x is the analysis, \text{cov}^{-1} is the background error covariance matrix and \lambda is a weighting factor.

Advanced background error covariance modelling using a diffusion approach is currently under development (see poster of SCAI-FHG).

5. To comply with these and other requirements, an approach with the following features is selected:
(iii) portability of the system to future computational platforms, namely parallelisation.

Consortium composition:
RIU at the University of Cologne: development of the adjoint of the 3D/4D-var system
SAC, FHG, development of the forward GCCM and the square root ensemble Kalman filter.

RIU at the University of Bremen: 4D-var system; IFE, University of Bremen: SCIAMACHY occultation data;
TU-R - CRISTA data expert and Elasssen-Palm flux diagnostics.

Figure 1: Icosahedral grid in the resolution that is currently used by the SACADA GCCM (ni=32, i.e. ~250 km mesh size or ~T80)

First tests of the new icosahedral–based assimilation system:

Kernel of the new system is a novel stratospheric global chemistry circulation model GCM and its adjoint version, with the grid design adapted from the global weather forecast model (GME) of German Weather Service (see figure 1). The GCM provides as an online meteorological driver for the GCM while the icosahedral grid structure (see figure 1), the horizontal transport and the parallelisation strategy are adopted from CME. The stratospheric chemistry module accounts for 148 gas species and 138 heterogeneous reactions in 43 stratospheric constituents. To verify the numerical correctness and robustness of the program code, a comprehensive suite of so called observability and identical twin tests were conducted. Moreover, these tests were used to explore the potential and limits of 4D-var data assimilation applied to the particular problem of assimilating artificial ENVISAT MIPAS and SCIAMACHY observations. The experimental setup is described in figure 2 and selected results are shown in Figures 3 a and b.

Figure 7: Evolution of trace gas concentration distributions (mixing ratios) at 142.5°E, 30°N for top left to bottom right the altitude N2O, CH4, N2O, NO, HNO3 and NO2 shows the chemically and radiatively coupled model trajectory without assimilation in black and in the analysis in blue as well as the available measurements of the atmospheric profile. The model trajectory is drawn as a thin grey line on top of the actual trace gas concentration distribution.

Figure 8: Error margins for several species. By an increase of the number of iterations in the minimisation routine, we expect to achieve better compliance of model and observations.

Figure 9: State of the project:
By continuously improving ENVISAT data quality of concentrations as well as respective errors, additional products will become available for assimilation and the data assimilation system will be further developed towards assimilation optimisation. This mainly includes preconditions adaption and data input optimisation.

SACADA post–AFO 2000 application:
SACADA will run operationally at DdF and will serve as a German contribution to GME activities: the icosahedral concept fits into the ICON initiative in preparation of the post-ECHAM5 era (COSMOS-2) feasibility of grid design and will later extension to the troposphere with local refinements (convergence with SATEC40A objectives).

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