ASSIMILATION OF METOP/GOME-2 AND IASI OBSERVATIONS FOR GLOBAL OZONE ANALYSIS AND FORECASTING

Thilo Erbertseder, Frank Baier, Julian Meyer-Arnek, Diego Loyola, Hendrick Elbern, Jörg Schwinger

(1) Applied Remote Sensing Cluster, DLR, 82230 Wessling, Germany
thilo.erbertseder@dlr.de; frank.baier@dlr.de; julian.meyer-arnek@dlr.de; diego.loyola@dlr.de
(2) Institute for Environmental Research at the University of Cologne, Aachenerstr 201-209, 5093 Köln, Germany
he@eurad.uni-koeln.de; js@eurad.uni-koeln.de

ABSTRACT

The EPS/MetOp RAO project AGORA\(^1\) aims at exploiting chemical observations from GOME-2 and IASI by means of Data Assimilation, Chemical Transport Modelling and General Chemistry Circulation Modelling. Focus will be on global monitoring and forecasting of ozone and ozone related species. Therefore, two data assimilation systems will be applied.

For continuation of GOME-1 and reanalysis purposes a well established sequential assimilation scheme will be used. It is based on an optimal interpolation approach using advanced assimilation parameters like error propagation and Chi2 monitoring and a CTM.

For ozone analysis and forecasting the 4D-Var data assimilation system SACADA will be applied. It allows a consistent chemical analysis for both, conservative and reactive species. The underlying GCCM of SACADA enables to perform global chemical forecasts of the stratosphere. The system is currently prepared for routine operation at DLR with direct interface to the O3 SAF Level 2 products. The global analyses and forecasts of ozone and related species will be operationally disseminated via the World Data Center for Remote Sensing of the Atmosphere (http://wdc.dlr.de).

1 INTRODUCTION

In order to derive consistent global chemical analyses from asynoptic and inhomogeneously distributed remote sensing observations data assimilation has been shown to be a valuable technique [1].

Polar orbiting satellites like MetOp with its instruments GOME-2 and IASI are well suited for providing substantial information on the variability of chemical species within the atmosphere on a global scale. To further analyse the variability and the underlying atmospheric processes (e.g. ozone depletion) optimal combination of these observations with models is essential. Here, data assimilation provides best knowledge of the state of the atmosphere based on model information and available measurements. Within this project will apply data assimilation techniques:

- to gain synoptic analyses from inhomogeneously gathered data.
- to provide forecasts based on satellite observations
- to derive improved and consistent chemical analyses
- to gain information on non-observed species and quantities like ClOx, indicating chlorine activation, chemical ozone loss and polar stratospheric clouds.
- to perform independent consistency checks of the trace gas retrievals
- to provide information on accuracy (error bars)

The sequential assimilation of chemical observations from satellite based instruments into chemistry-transport models has been successfully demonstrated by several studies [2, 3, 4, 5]. They all use schemes of the Kalman Filter type. So does the ozone forecasting system for GOME-1 by [6] which uses a transport model, an ozone chemistry parametrisation and ECMWF forecasts.

Four-Dimensional Variational Assimilation (4DVar) for tropospheric chemistry was introduced by [7, 8]. The first full stratospheric chemical 4D-var assimilation system based on a CTM was developed and applied to CRISTA data by [9]. A novel 4D-var data assimilation system intended for operational application at DLR to stratospheric trace gas observations has been developed within the German AFO 2000 project SACADA [10]. The Kernel of this system is a new stratospheric global chemistry circulation model (GCCM) and its adjoint version. The SACADA system will be used to derive daily analyses and 3-day forecasts of ozone and related species from GOME-2 and IASI.

2 SEQUENTIAL ASSIMILATION

At the German Remote Sensing Data Center at DLR, a sequential assimilation scheme has been used for the
assimilation of remote sensing data on a daily basis. The scheme comprises an optimum interpolation approach with error propagation and the chemistry-transport model ROSE/DLR. Analysed background errors constitute the main diagnostic. The quality of the ozone analysis is controlled using model first-guess minus observation error (FMO), analysis minus observation (AMO) and \( \chi^2 \) statistics. For details on the assimilation scheme the reader is referred to [5].

The scheme has been operationally applied to GOME-1 observations since 1998 and is still in use for SCIAMACHY [11, 12]. The results have been used to track streamers/ozone miniholes over Europe and to monitor the evolution the Antarctic ozone hole (Figure 1). Due to the excellent data coverage and accuracy of GOME and SCIAMACHY the bias of the analysis mainly coincides with the bias of the observations. Furthermore, the sequential system is currently used in the ESA project CHEOPS-GOME to perform a complete 8 year reanalysis of GOME ozone profile observations [13]. The ozone profiles were retrieved from GOME spectra by the Neural Network Ozone Retrieval System (NNORSY) [14]. Since data assimilation has become an important tool to support validation of trace gas retrievals the system is applied within CHEOPS to:

- trace inconsistencies in the GOME ozone profile retrievals
- control the quality of the ozone profiles by first guess of model
- identify outliers and systematic errors
- check the profiles in areas with known problems (South Atlantic Anomaly)

A comparison of the GOME/NNORSY ozone reanalysis to ozone soundings proves the good consistency and accuracy. As an example a comparison to all sondes from Lauder, NZ from 1996 to 1999 is shown in figure 2.

![Figure 2: GOME/NNORSY ozone reanalysis versus correlative ozone sonde data](image)

In the framework of the ESA GSE project PROMOTE a complete reanalysis of MIPAS chemical observations was derived [5]. The 3D ozone record allows studying the evolution of the Antarctic ozone hole and contributes to the evaluation of coupled-chemistry-climate models (CCMs). Reference [5] compared analyses based on two different MIPAS data sets: the MIPAS retrievals of the ESA processor (hereafter: MESA) and the scientific product of IMK (hereafter: MIMK) were exploited. The following table shows a comparison of the respective analysis to HALOE data.

<table>
<thead>
<tr>
<th>species</th>
<th>number</th>
<th>MESA 2003</th>
<th>MIMK 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>O3</td>
<td>12921</td>
<td>-1.08</td>
<td>-2.98</td>
</tr>
<tr>
<td>H2O</td>
<td>12916</td>
<td>2.58</td>
<td>4.92</td>
</tr>
<tr>
<td>NOx</td>
<td>7359</td>
<td>-3.50</td>
<td>4.31</td>
</tr>
<tr>
<td>CH4</td>
<td>22356</td>
<td>8.32</td>
<td>31.54</td>
</tr>
<tr>
<td>HCl</td>
<td>9936</td>
<td>-1.13</td>
<td>-0.48</td>
</tr>
</tbody>
</table>

Table 1: Results of analysis minus HALOE comparisons showing the mean relative error values for the assimilation experiments using MESA and MIMK data from October 21 to November 20, 2003. The last column shows reference results without assimilation of MIPAS data [5].
Within the German AFO2000 project SACADA (Synoptic Analysis of Chemical Constituents by Advanced Data Assimilation) a four-dimensional variational assimilation scheme (4Dvar) has been developed by the Rhenish Institute for Environmental Research (RIU) and the Fraunhofer Institute for Algorithms and Scientific Computing (SCAI) to assimilate reactive species as measured by space borne atmospheric instruments [10]. This system is currently prepared at DLR for routine application with near-real-time GOME-2 and IASI data. While the sequential scheme updates a model first-guess whenever an observation becomes available, in 4Dvar the initial conditions for a 24 hour model forecast are adjusted to better comply with observations for the whole time period.

The core of this new system is a novel stratospheric global chemistry circulation model (GCCM) and its adjoint version. The German Weather Service’s global forecast model (GME) with its icosahedral discretisation scheme serves as an online meteorological driver for the GCCM. Thus forecasts can be provided by the system as well. The main advantage of the intrinsic meteorological driver is to minimize interpolation errors of the meteorological fields.

As a first application the system ENVISAT MIPAS data has been assimilated for a selected period [10]. It could be demonstrated that the assimilation procedure gains a considerable improvement over legacy model runs, as the discrepancies between observations and the model are significantly reduced, while chemical consistency is maintained by the computationally costly, but efficient 4D-var technique

First multi-month assimilation results with the new 4Dvar assimilation system SACADA at DLR were compared to sequential assimilation (ROSE OI) using MIPAS ESA standard species H2O, O3, HNO3, CH4 and NO2 [15]. Both OI and 4Dvar appear well suited for prolonged assimilation periods. Most 4Dvar results were found superior to sequential OI’s (Table 2, Figure 3).

Due to good scaling characteristics on parallel processors, the method shows even great promise for climatic studies. Thus, SACADA can also be foreseen for the assimilation of historic remote sensing observations.

### Table 2: Independent evaluation of overall assimilation results compared to HALOE sunset and sunrise soundings. SACADA 4Dvar shows significantly better results for all species considered except for HCl. For HCl a underestimation above 10 hPa is evident [15].

<table>
<thead>
<tr>
<th>Species</th>
<th>Obs</th>
<th>Mean</th>
<th>Bias %</th>
<th>RMS %</th>
</tr>
</thead>
<tbody>
<tr>
<td>O3</td>
<td>46335</td>
<td>11.0</td>
<td>-0.37</td>
<td>0.43</td>
</tr>
<tr>
<td>H2O</td>
<td>46337</td>
<td>7.93</td>
<td>0.06</td>
<td>1.18</td>
</tr>
<tr>
<td>NOx</td>
<td>46127</td>
<td>5.12</td>
<td>3.29</td>
<td>28.24</td>
</tr>
<tr>
<td>CH4</td>
<td>46135</td>
<td>1.07</td>
<td>7.76</td>
<td>14.89</td>
</tr>
<tr>
<td>HCl</td>
<td>46133</td>
<td>1.57</td>
<td>-12.75</td>
<td>24.69</td>
</tr>
</tbody>
</table>

### Figure 3: SACADA 4DVar analysis at 61hPa for O3/vmr for 2004-01-17.

### 4 DISSEMINATION AND APPLICATIONS

The GOME-2/IASI ozone analyses and forecasts will be disseminated via the World Data Center for Remote Sensing of the Atmosphere (WDC/RSAT, [http://wdc.dlr.de](http://wdc.dlr.de)).

The focus will be on total column ozone, ozone volume mixing ratios for the stratosphere followed by chemical ozone loss, polar stratospheric clouds and ClOx. Forecasts up to three days will be provided. The data will be delivered in HDF format accompanied by image quicklooks. The data products will also consist
of first-guess minus observation statistics and the analysed error. Rigorous and continuous validation of analyses and forecasts will be carried out using ground-based and other satellite/air borne data. The quality of the forecasts will continuously controlled by anomaly correlation.

The analyses and forecasts themselves constitute important input parameters for several services and projects. One operational application is the provision of daily ozone total column forecasts for the UV-Check service (www.uv-check.com). UV-Check is part of the GSE PROMOTE. It delivers individual information on sun burn times for any location in Europe at any time via mobile phone or via the internet.

A further application of the total ozone analyses from GOME-2 and IASI will be within the ENVISOLAR project. ENVISOLAR aims at the increased use of satellite based solar radiation information in solar energy industries. ENVISOLAR is part of ESA's Earth Observation Services Market Development (EOMD) Activities.

The analyses and forecasts will further be used to support campaign planning.

In order to evaluate results from coupled chemistry climate models we aim further at providing long-term reanalyses and time series of species. This application has been started within the GSE PROMOTE-1 for the SPARC CCM Validation Initiative.

References