Data assimilation: A tool for climate-chemistry studies

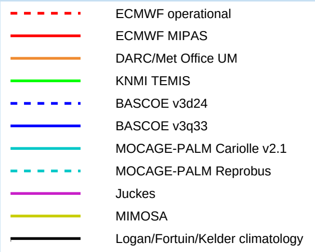
W.A. Lahoz
NILU, Norway
wal@nilu.no, http://www.nilu.no

Current state of stratospheric constituent data assimilation:

- 1990s, constituent data assimilation (DA) developed, strong focus on stratospheric ozone
- Evolved from testing methodology to ozone forecasts at ECMWF (since April 2002)

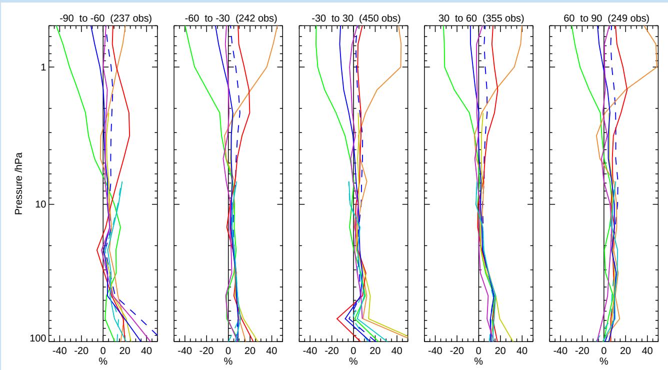
Aims for stratospheric ozone DA:

- Ozone and UV forecasting; ozone monitoring (Montreal protocol)
- Technical reasons (observational constraints; radiance DA; dynamics)
- NWP (Numerical Weather Prediction): use constituent information to improve forecast



Several ozone analyses are compared against HALOE ozone and ozonesonde observations – see panels 1 & 2

Colour key used in figures in panels 1 & 2. See Geer *et al.* (2006), Lahoz *et al.* (2007a).

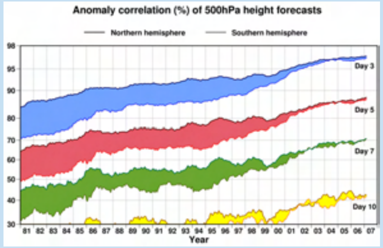


Mean of Analysis minus HALOE ozone differences, normalized by climatology for the period 18 August-30 November 2003. The numbers in brackets indicate the HALOE/analyses coincidences within each latitude bin. Units: percent. These data are used to evaluate the performance of the ozone analyses.

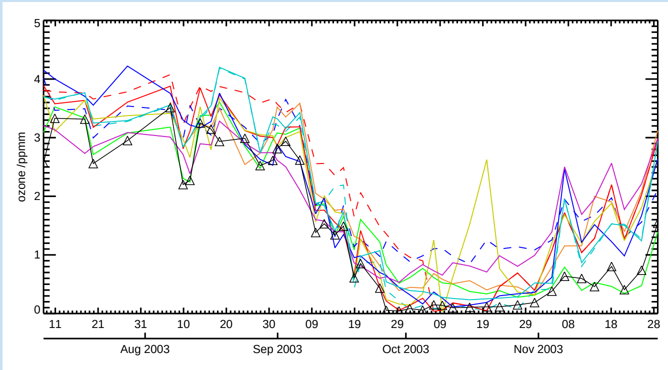
For levels between 50 hPa and 2 hPa, the Analysis minus HALOE differences are usually within ±10% of the HALOE instrument. Similar results are obtained against ozonesonde data for levels between 100 hPa and 10 hPa (not shown).

Data assimilation, confronting models with observations:

Very successful in NWP (right): Anomaly correlation (%), 3-, 5-, 7- & 10-day ECMWF 500 hPa height forecasts for extra-tropical NH & SH, annual running means of archived monthly-mean scores, Jan 1980-Nov 2006. Values plotted for a particular month are averages over that month & 11 preceding months. Coloured shadings show differences in scores between the two hemispheres at the forecast ranges indicated (based on Simmons & Hollingsworth 2002).



Recently, ideas applied more generally:
(i) improve parametrizations in climate GCMs, General Circulation Models (Phillips *et al.* 2004); (ii) evaluate ozone chemistry (Geer *et al.* 2006, 2007; Lahoz *et al.* 2007a, b).



Comparison of analyses & ozonesondes at the South Pole, 68 hPa, Aug-Nov 2003: Note

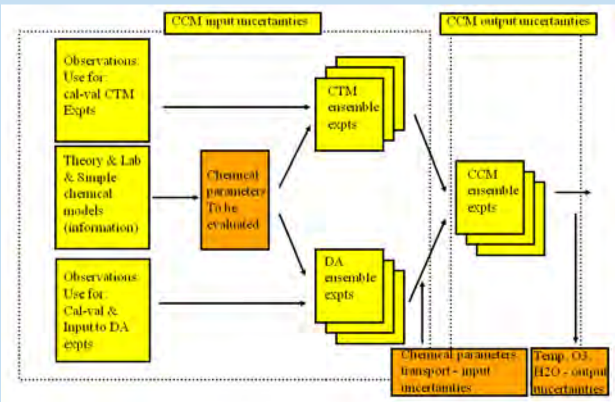
- Qualitatively good agreement between the analyses & ozonesondes:
- Despite qualitatively good agreement, biases between the analyses and & ozonesondes;
- Improvement in BASCOE model from v3d24 (blue dashed line) to v3q33 (blue solid line);
- Improvement in ECMWF operational system (red solid line) when MIPAS ozone data is assimilated (red dashed line). This is ascribed to the higher vertical resolution of the ozone MIPAS profiles compared to SBUV/2 ozone layer measurements & GOME total column ozone measurements.

Potential strategies for implementing data assimilation in climate-chemistry models (CCMs):

It has been suggested DA could be used to quantify uncertainties in CCMs due to uncertainties in stratospheric ozone chemistry (Lahoz 2008; see below). At WCRP Climate Summit at ECMWF, the use of observations, including DA ideas, to evaluate climate models was discussed (Trenberth 2008).

Example of a strategy: *Quantify output uncertainties as a function of input uncertainties.*

- Use theory and simple model experiments to determine chemical parameters to be evaluated. Examples: ClOOCl photolysis (e.g. Pope *et al.* 2007), denitrification via PSC sedimentation, total Bry, formation rate of HOCl, onset of Cl activation;
- Use multi-model DA CTM (chemistry transport model) experiments (e.g. different DA schemes) to evaluate chemical parameters (mean and spread) – CTM must represent chemical parameters & biases must be taken into account;
- Supplement with multi-model CTM experiments (no DA): e.g. PSC parameters, transport;
- CCM multi-model experiments with input uncertainties (cf. ensemble mean, low, high values) to provide output uncertainties (e.g. of temperature, ozone, water vapour);
- Compare against baseline experiments (old values of parameters).



Schematic of methodology discussed above. Yellow boxes indicate elements of the strategy; orange boxes indicate inputs/outputs

Ways forward:

Data assimilation can play an important role in climate-chemistry studies

Focus: *confront models with observations & build on NWP heritage*

- Desirable to have an NWP system developed parallel to CCM (but not necessary);
- Ensemble approach helps minimize model dependence of results.

Potential data assimilation approaches:

- Estimate input uncertainty using ensemble of CTM-based DA systems: use this to estimate output uncertainty given input uncertainty, CTM can be different from CCM chemistry module – ***perturbed chemistry approach & multi-model approach*** (panel 3);
- Estimate parameters and their uncertainties using DA on a subsystem of the CCM (e.g. chemistry module);
- Complement different approaches: e.g. SPARC CCMVal (comparing/evaluating performance of various dynamical/chemical aspects of CCMs) – currently, to our knowledge, this effort does not use data assimilation ideas.

References:

Geer, A.J., *et al.* (2006): The ASSET intercomparison of ozone analyses: method and first results. *Atmos. Chem. Phys*, **6**, 5445-5474.
Geer, A.J., *et al.* (2007): Evaluation of linear ozone photochemistry parametrizations in a stratosphere-troposphere data assimilation system. *Atmos. Chem. Phys.*, **7**, 939-959.
Lahoz, W.A. (2008): Data assimilation: a tool for climate-chemistry studies. EGU, Austria, April 2008.
Lahoz, W.A., *et al.* (2007a): Data assimilation of stratospheric constituents: a review. *Atmos. Chem. Phys.*, **7**, 5745-5773.
Lahoz, W.A., *et al.* (2007b): The Assimilation of Envisat data (ASSET) project. *Atmos. Chem. Phys.*, **7**, 1773-1796.
Phillips, T.J., *et al.* (2004): Evaluating parameterizations in general circulation models: Climate simulation meets weather prediction. *Bull. Amer. Meteorol. Soc.*, **85**, 1-13.
Pope, F.D., *et al.* (2007): Ultraviolet absorption spectrum of chlorine peroxide, ClOOCl, *J. Phys. Chem. A*, **111**, 4322-4332.
Simmons, A.J. & Hollingsworth, A. (2002): Some aspects of the improvement in skill in numerical weather prediction. *Quart. J. Roy. Meteorol. Soc.*, **128**, 547-677.
Trenberth, K.E. (2008): Exploiting and evaluating models with observations. WCRP Modelling Summit, ECMWF, UK, May 2008

NILU PP 8/2008