Status and needs for reanalysis: User views

Chemical Transport Modelling

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Outline

- What are CTMs?
- What are CTMs for?
- Past/present experiences with (re)analyses
  - Long term stratospheric O$_3$ loss
  - Polar O$_3$ loss
  - Strat-Trop Exchange
  - Tropical Tropopause Layer (TTL)
- Requirements for future (re)analysis
What are Chemical Transport Models (CTMs)?

Numerical models
Use prescribed meteorology
Calculate concentrations of species in the atmosphere

- 3D off-line. Eulerian and Lagrangian
- Winds from GCMs or analyses
- Analyses → direct comparison with observations
- Re-analyses → direct comparison with obs into the past
- Reliance on (re)analyses quality → diagnostic tool for analyses
- Longer experience in the stratosphere
What do CTMs investigate?

- Long-term O$_3$ loss last 25 years
- Polar O$_3$ loss

Stratosphere

- Stratospheric ozone
- UV radiation
- CTMs
- Human activity
- Tropospheric chemistry

Extended weather forecasts
What do CTMs investigate?

- Long-term O₃ loss last 25 years
- Polar O₃ loss
- Accurate transport
- Polar Temperatures

CTMs need from reanalyses

Bad news: No existing reanalysis seems to be good enough

Good news: We are on our way → ERA-Interim
What do CTMs investigate?

Troposphere

Stratosphere-Troposphere Exchange

Tropical Tropopause Layer

Tropical convection

What CTMs need:

• Realistic transport
• Certain parameters to make parameterisations in the CTM consistent with those in the meteo. model.
Stratospheric transport

Current (re)analyses (e.g. ERA-40, GEOS-4, UKMO):
- Too strong Brewer-Dobson circulation
- Not enough tropical isolation

Unrealistic distribution of chemical tracers

- CTMs for transport diagnostics: Age of air Trajectories
Age of air: definition

- **Diagnostic** for stratospheric transport, chemistry independent \(\rightarrow\) Assessment of stratospheric analyses and intercomparison of CTMs

- **Age spectrum**: distribution of transit times of an air parcel from a source to a certain location (in the stratosphere)

- **Mean age-of-air**: first moment of age spectrum

\[
\Gamma(x, x_0) = \int_0^\infty t \ G(x, x_0, t) \ dt
\]

- For a **conserved linear tracer**: \(\text{CO}_2, \text{SF}_6\)

\[
\Gamma(x, x_0) = t - \frac{\gamma(x, t)}{\alpha}
\]

\(\alpha\) : mixing ratio trend
Age of air: calculation

Age-of-air → chemistry independent transport diagnostic

Conserved linear tracer → mean-age ("observational")

\[
\Gamma(x, x_0) = t - \frac{\gamma(x, t)}{\alpha}
\]

\(\alpha: mixing\ ratio\ trend\)

- Sparse in-situ measurements (~20km)
- \(\text{CO}_2, \text{SF}_6\)
- MIPAS \(\text{SF}_6\) (G. Stiller, Karlsruhe Univ.)
Age of air: cross-sections

CTMs with ERA-40:
- underestimation
- unrealistic shape

KASIMA

Schematic annual mean mean-age, from (Waugh and Hall, 2002)
Some strategies

- Isentropic vertical coordinate: $\sigma$-$\theta$
- Derived vertical velocities: Heating rates
- Use of forecasts

Mean-age @ 20 km

Operational
ERA-40 -24h fc

ERA-40 $\sigma$-$\theta$
Heat. rates

model config
forecasts

from (Chipperfield, 2006)
ERA-40

from (Meijer et al., 2004)
UKMO
Some strategies

- Isentropic vertical coordinate: $\sigma-\theta$
- Derived vertical velocities: Heating rates
- Use of forecasts

What if we have better reanalysis?

ERA-Interim
Age of air: TOMCAT

cross sections annual mean 2000

- ERA-40: too young, non-realistic

- UKMO: too young, non-realistic

Schematic annual mean mean-age, from (Waugh and Hall, 2002)

ERA-40: too young, non-realistic

Operations: still young, more realistic

EXP471: oldest, most realistic
Tropical isolation

TOMCAT Trajectories

50-day backwards run: 1st Jan 2001
36,000 parcels: 0° ± 1°
460K ± 5K

From Schoeberl et al., 2003

From Bregman et al., 2006
**Ozone distributions**

Total ozone in July and Dec 1990

**TOMS**

**REPROBUS**

**ERA-40**

- Too low O$_3$ over tropics
- Too high O$_3$ over poles

Too strong Brewer-Dobson circ.:
- Removes too much from tropics
- Accumulates too much over poles

From F. Lefèvre
**Polar Temperatures**

- ERA-40 oscillations
- Large differences between analyses

Unrealistic PSC areas → unrealistic polar O₃ loss

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**Winter 1988/1989**

**Winter 1963/1964 pre-satellite**

from Bjoern Knudsen (DMI)
Polar Temperatures

Polar Temperatures

• ERA-40 too cold
• FUB better than automatised (satellites outweigh radiosonde data)

Comparison with radiosondes $T$

- ERA-40 too cold
- FUB better than automatised (satellites outweigh radiosonde data)

from Bjoern Knudsen (DMI)
Polar Temperatures -- presatellite

PSC area NH 1963/1964

Comparison with radiosondes T
- ERA-40 too cold
- REAN warm bias
- Neither of them good enough for PSCs

from Bjoern Knudsen (DMI)
Troposphere

STE  T. van Noije (KNMI)

TTL  Kirstin Krüger (IFM-GEOMAR/AWI)
Stratosphere-Troposphere Exchange

O$_3$ monthly STE fluxes with ERA-40 and OD

from van Noije et al. (2006) (KNMI)
Stratosphere-Troposphere Exchange

Annual total $O_3$ STE flux with ERA-40 and OD: forecast length

Dependence on forecast range; merged forecasts are indicated by a line connecting begin and end time of the forecast range. Forecasts $\rightarrow$ reduction flux

from van Noije et al. (2006) (KNMI)
Stratosphere-Troposphere Exchange

O$_3$ monthly STE fluxes with ERA-40: satellite observations

Comparison of ERA-40 first-guess fields (thin) and first-guess from ERA-40 run with no satellite radiance observations assimilated during Jan-Mar 1973 (thick)

from van Noije et al. (2006) (KNMI)
Tropical Tropopause Layer

- Trajectories to study water vapour into the stratosphere
- Vertical motion from heating rates to avoid noisy w field
- Compare ERA-40 and ECMWF Operations

\[ T_{\text{Min}} \text{ in trajectories} \approx \text{dehydration points of strat. } H_2O \]

from Kirstin Krüger (IFM-GEOMAR/AWI)
Tropical Tropopause Layer

$T_{\text{Min}}$ in trajectories $\approx$ dehydration points of strat. $\text{H}_2\text{O}$

$T_{\text{Min}}$ in trajectories $\approx$ dehydration points of strat. $\text{H}_2\text{O}$

→ Lower $T_{\text{Min}}$ in op ECMWF (cold bias in tropical stratosp?)

from Kirstin Krüger (IFM-GEOMAR/AWI)
Cold bias in TTL reduced in new T799/L91

From Kirstin Krüger (IFM-GEOMAR/AWI)
Requirements for future reanalysis

**Improvements needed**

- Keep improving Brewer-Dobson → for long-term studies
- Improve T over the poles (more radiosondes) → PSCs
- STE large uncertainties → constrain analyses
- Less noise in vertical velocity?
- Improve vertical motion and T → positive impact on H₂O vapour
- 3h winds?
Requirements for future reanalysis

Data availability

- Access to data
  - NCEP: ok
  - ECMWF: would gain many “CTM clients” if easier access and NetCDF format for certain key fields

- Archived quantities:
  - Heating rates → consistency vertical/horizontal motion
  - Eta-dot → consistency vertical/horiz motion
  - Convective parameters → consistency of parametr.

Archived for ERA-40 but not operationally

BUT ERA-40 STOPPED IN 2002 !!!
Requirements for future reanalysis

**Updates for trend studies**

- Need also the most recent data
- Same model version is needed
- ERA-40 updates every 6 months?
- Example: Cl$_y$ decrease, T and ozone (SLIMCAT)
Trend studies: $O_3$, $T$, $Cl_y$ @ 40 km (SLIMCAT)

**From M. Chipperfield**

- Figure 1: (35N-60N) ozone @ 40 km

- Figure 2: (60S-35S) ozone @ 40 km

**Key Points**

- ERA-40 updates every 6 months?
- Same model version is needed?
- **A** Detectable recovery?
- **B** - constant halogen

**Notes:**

- **SLIMCAT(Run A)**
- **SLIMCAT(Run B)**
- **SLIMCAT(Run C)**

**Operational Status:**

- **ERA40**
Summary

- CTMs treat key atmospheric science issues
- CTMs and (re)analyses: two-way road
  - CTMs need accurate (re)analyses
  - CTMs are helping ECMWF to spot problems (esp. in stratosphere)

...so let’s keep on working!
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