Status and needs for reanalysis: User views

Chemical Transport Modelling

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With contributions from:
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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

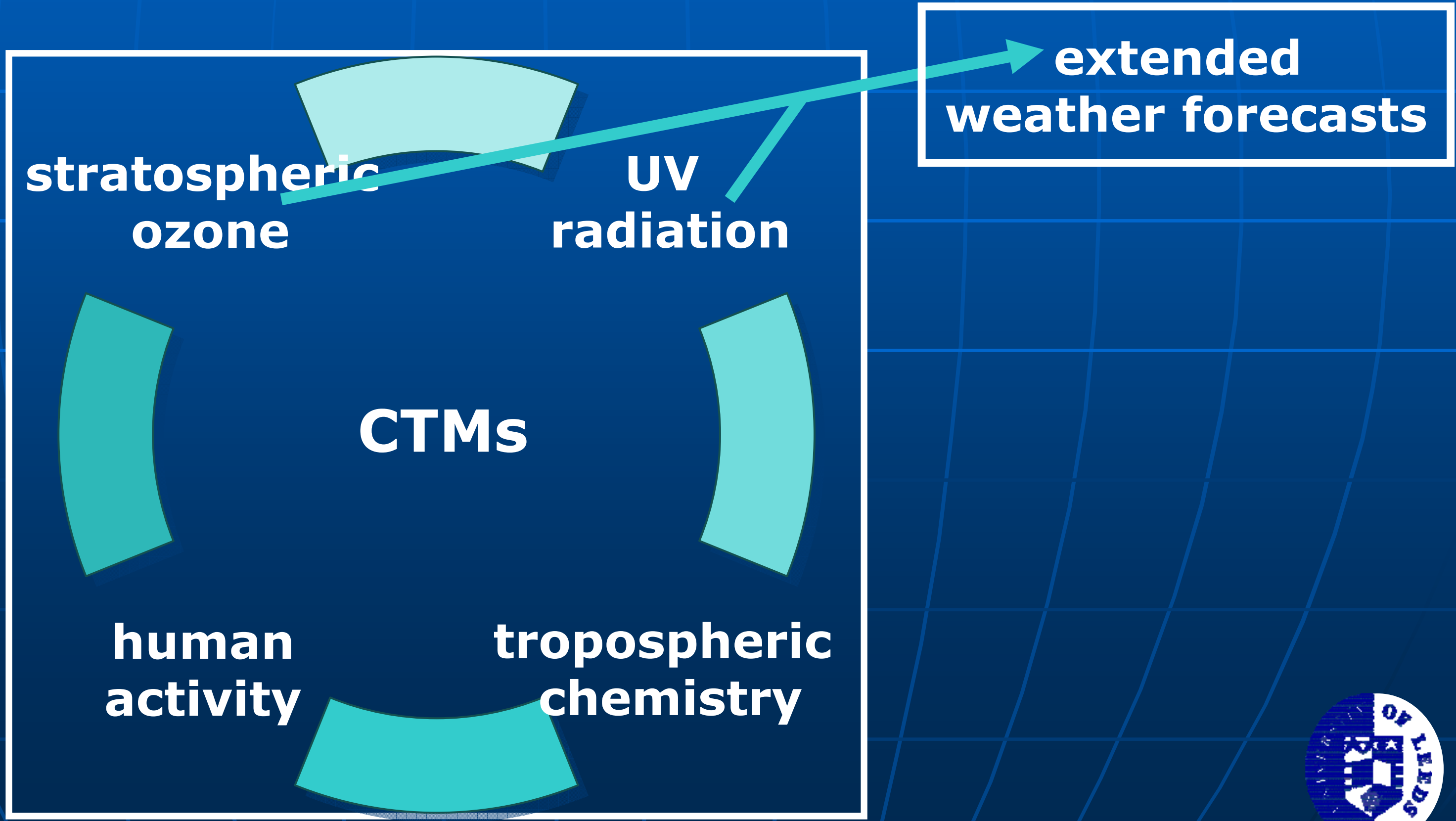
- 3D off-line. Eulerian and Lagrangian
- Winds from GCMs or analyses
- Analyses → direct comparison with observations
- Re-analyses → direct comparison with obs into the past
- Reliance on (re)analyses quality → **diagnostic tool for analyses**
- Longer experience in the stratosphere

What do CTMs investigate?

Stratosphere

Long-term O_3 loss last 25 years

Polar O_3 loss



What do CTMs investigate?

Stratosphere

Long-term O_3 loss last 25 years

Accurate transport

Polar O_3 loss

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 → 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) $G(x,t)$

- 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:

$$\Gamma(\boldsymbol{x}, \boldsymbol{x}_0) = \boldsymbol{t} - \frac{\gamma(\boldsymbol{x}, \boldsymbol{t})}{\alpha}$$

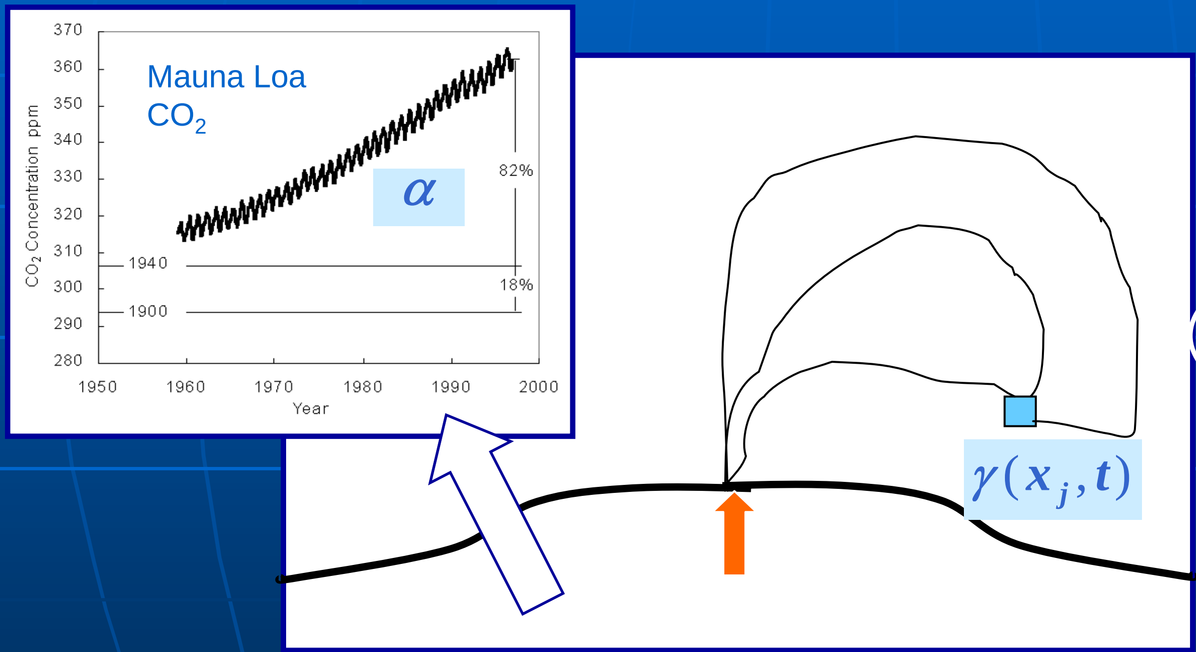
α : *mixing ratio trend*

CO_2, SF_6

Age of air: calculation

Age-of-air → chemistry independent transport diagnostic

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



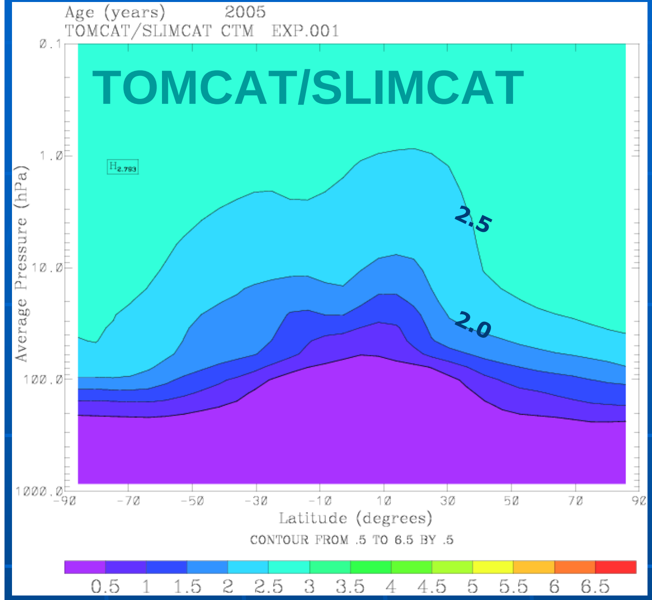
$$\Gamma(x, x_0) = t - \frac{\gamma(x,t)}{\alpha}$$

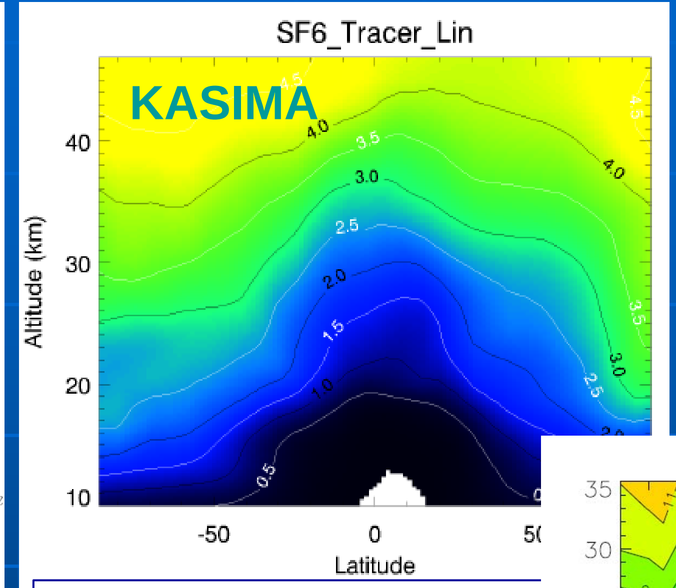
α : *mixing ratio trend*

CO_2, SF_6

- Sparse in-situ measurements (~20km)
- MIPAS SF_6 (G. Stiller, Karlsruhe Univ.)

Age of air: cross-sections

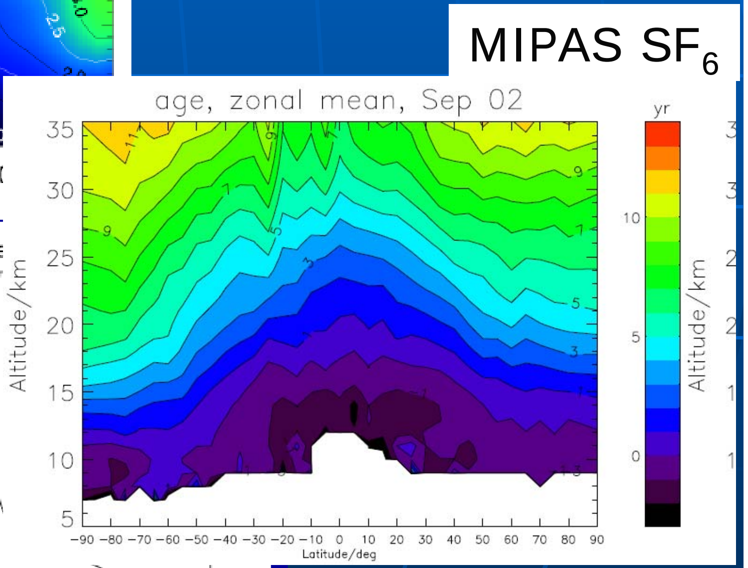


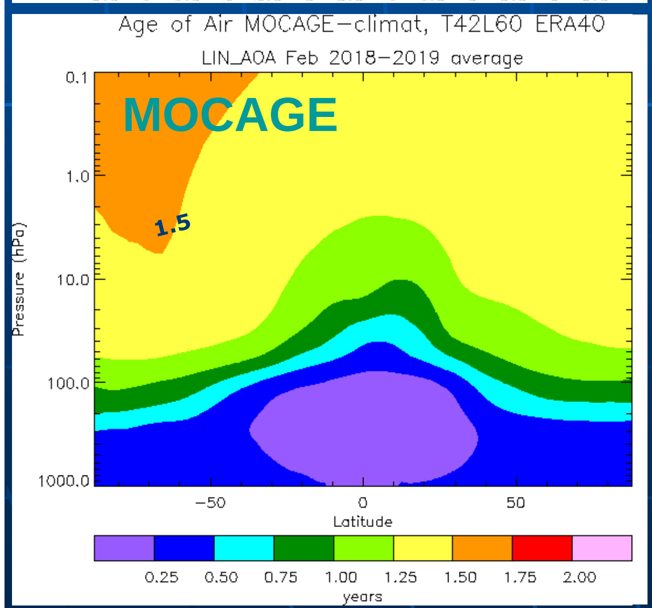


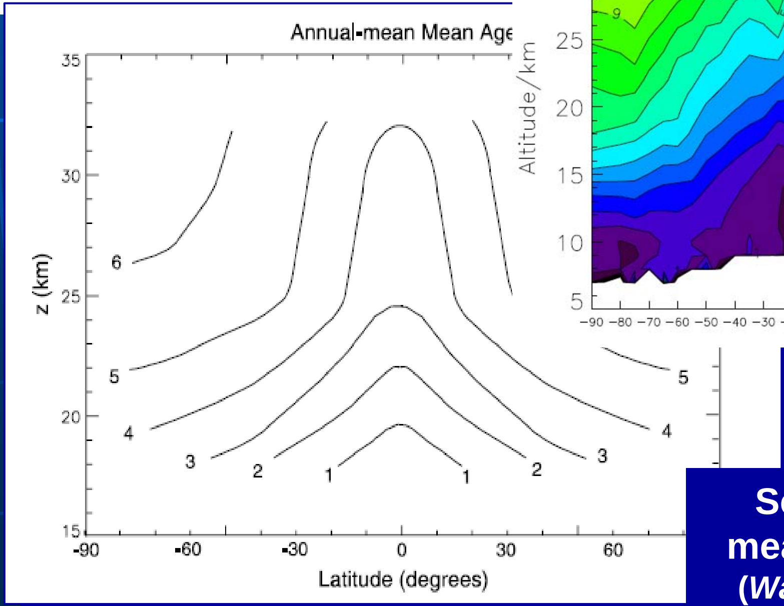
CTMs with ERA-40:

underestimation

unrealistic shape



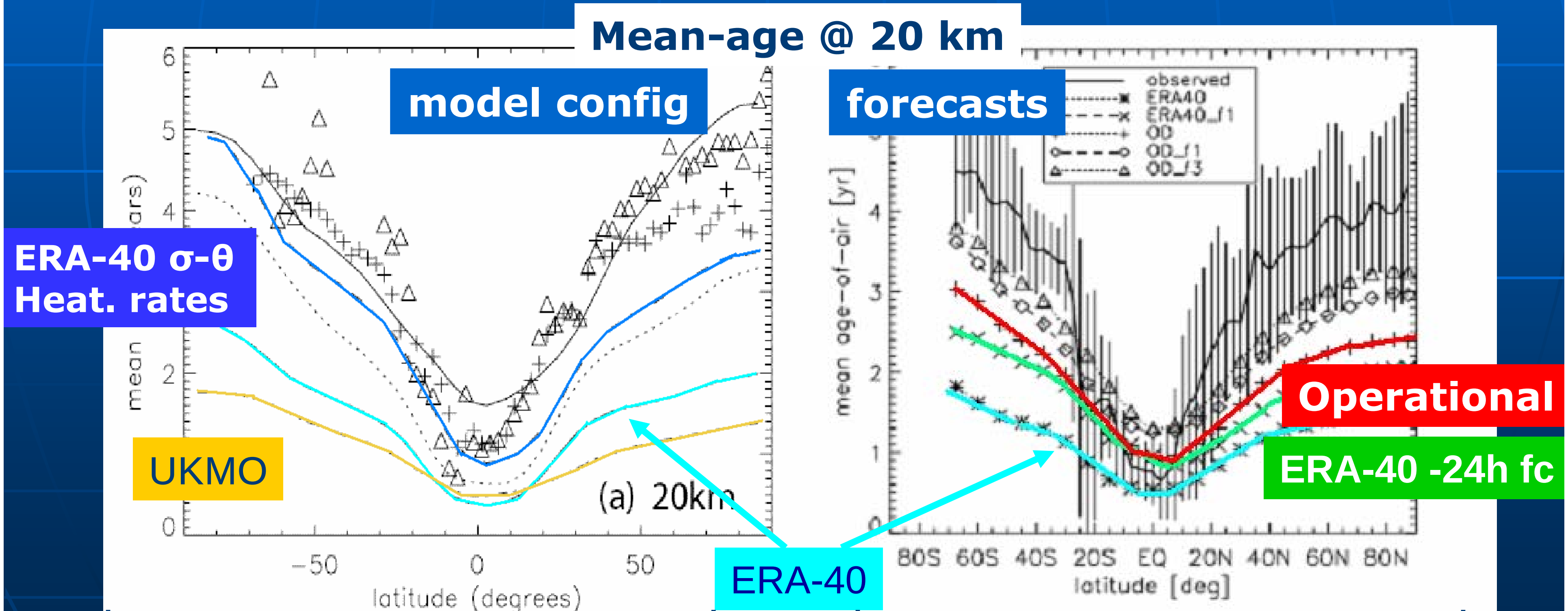




Schematic annual mean mean-age, from (*Waugh and Hall, 2002*)

Some strategies

- **Isentropic vertical coordinate: σ-θ**
- **Derived vertical velocities: Heating rates**
- **Use of forecasts**



from (*Chipperfield*, 2006)

from (*Meijer et al.*, 2004)

Some strategies

- Isentropic vertical coordinate: σ-θ
- Derived vertical velocities: Heating rates
- Use of forecasts

What if we have better reanalysis?

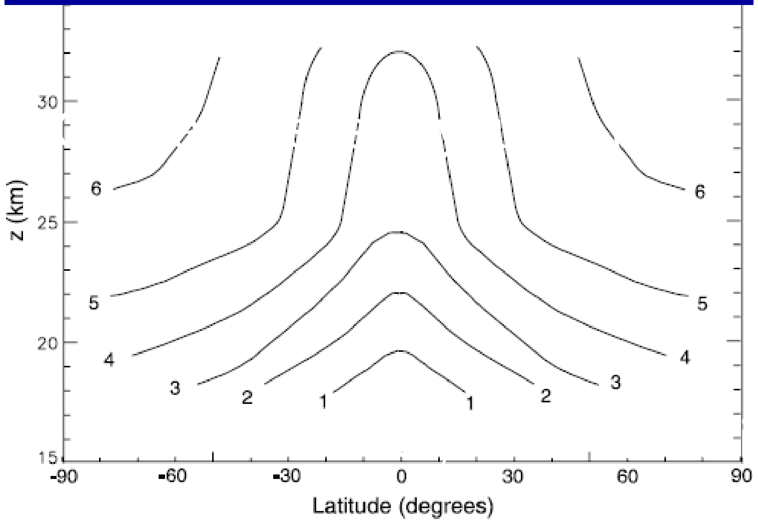
ERA-Interim

Age of air: TOMCAT

cross sections annual mean 2000

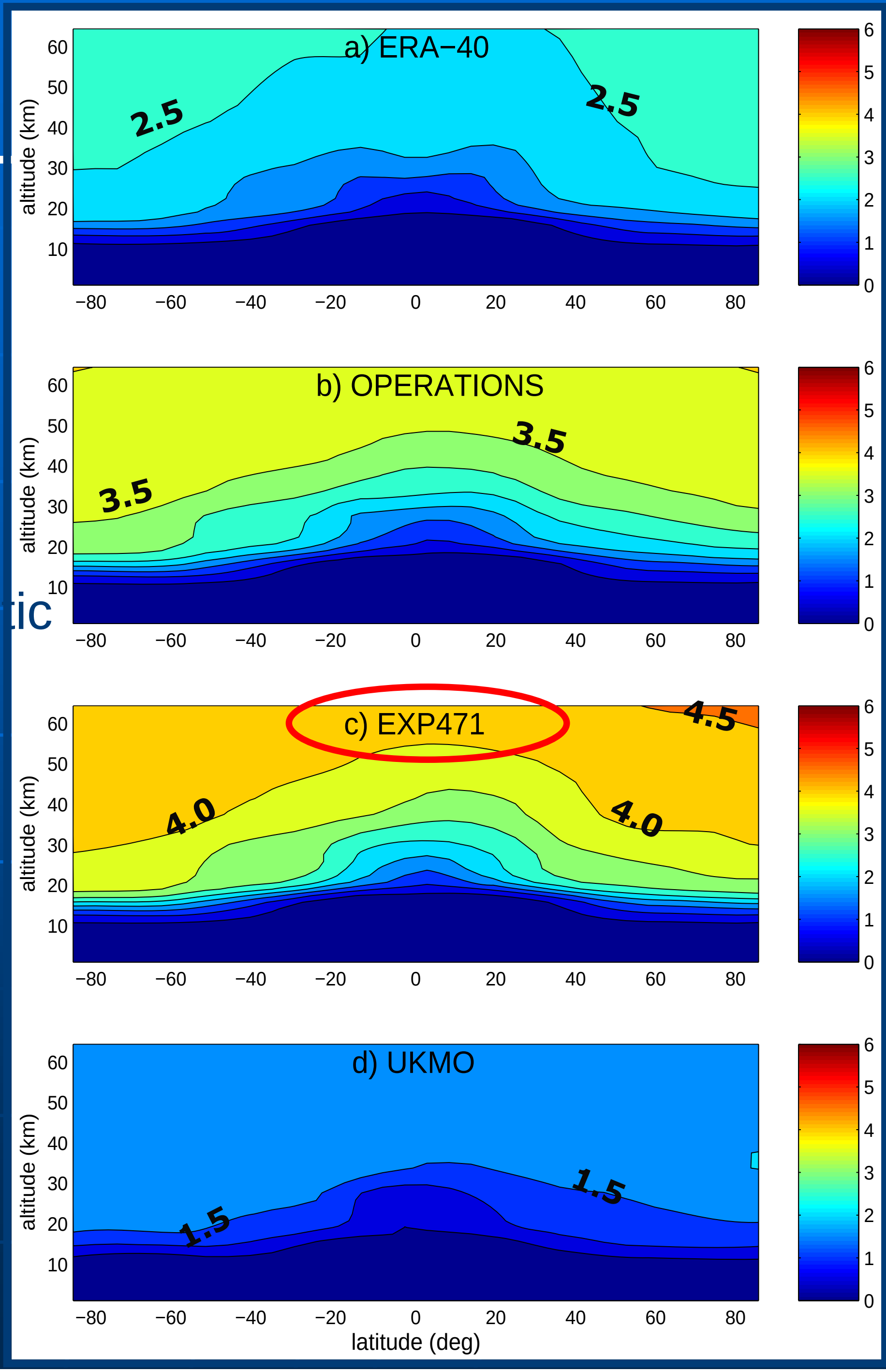
- ERA-40: too young, non-realistic

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

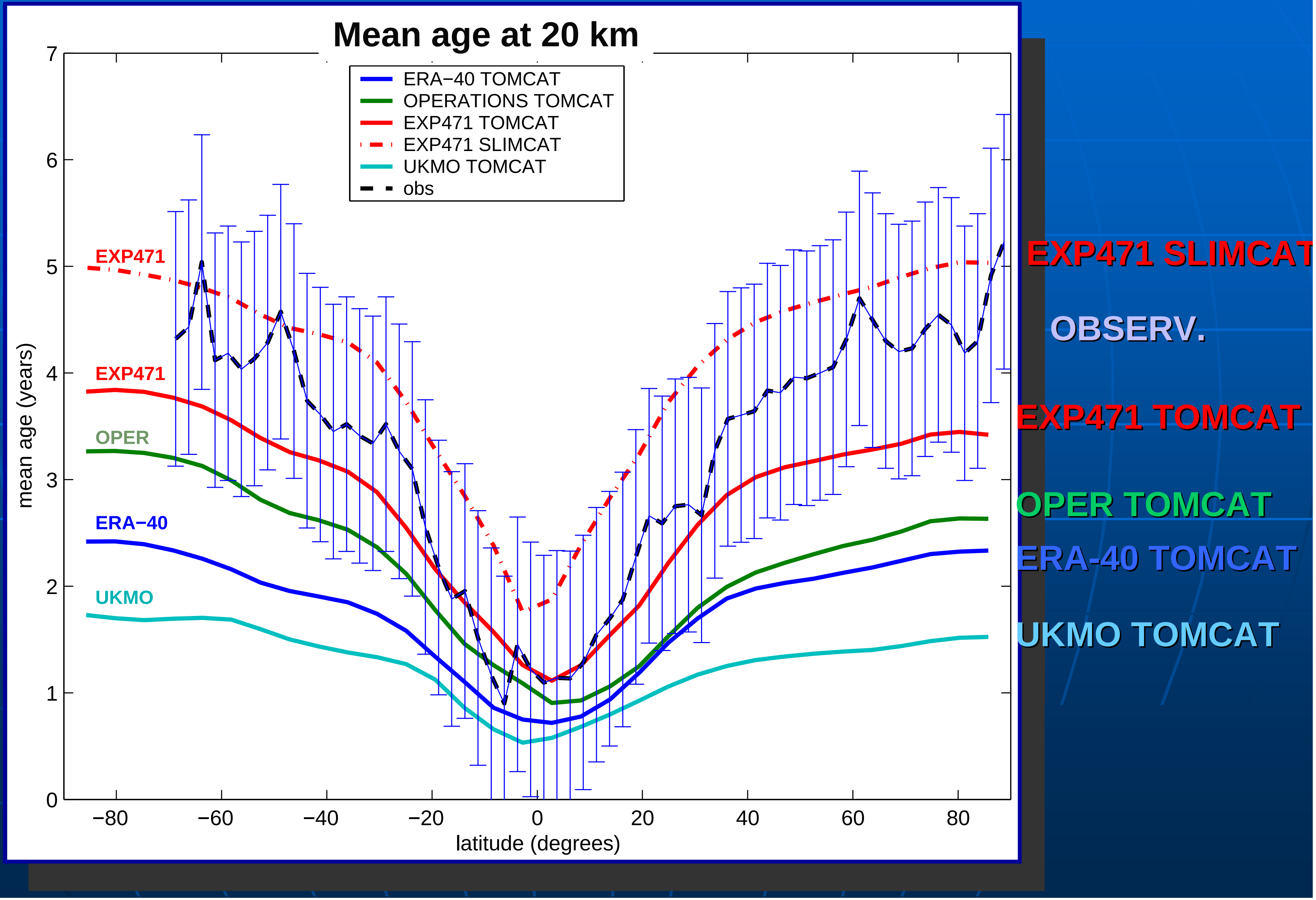


alistic

- UKMO: too young, non-realistic

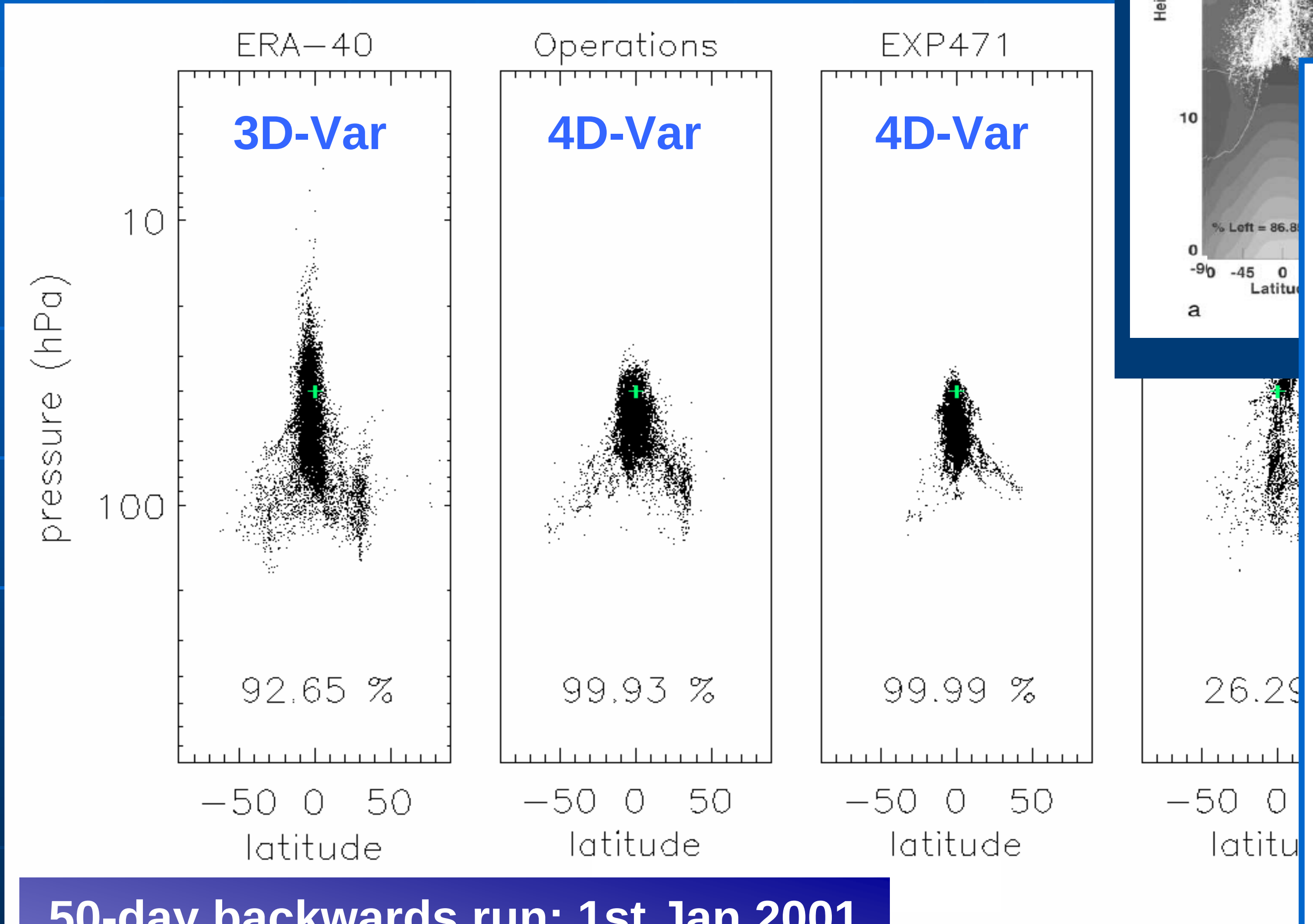


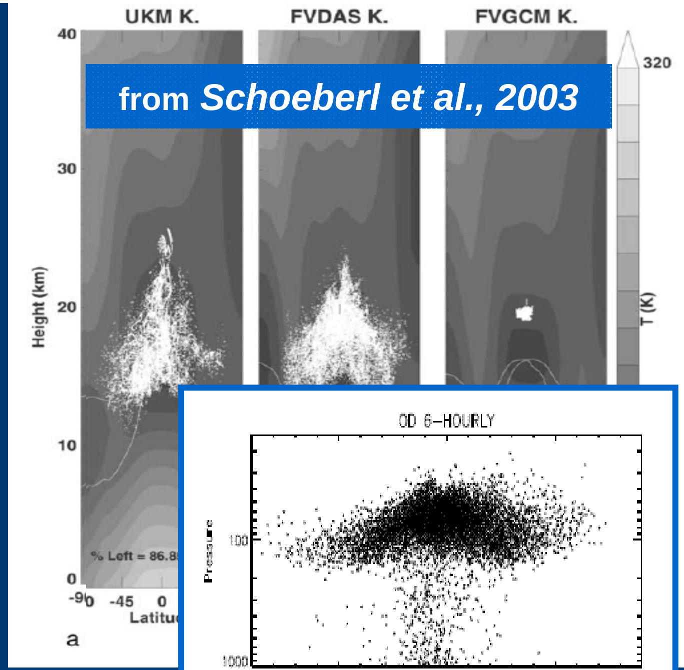
ERA-Interim: TOMCAT/SLIMCAT v. observations



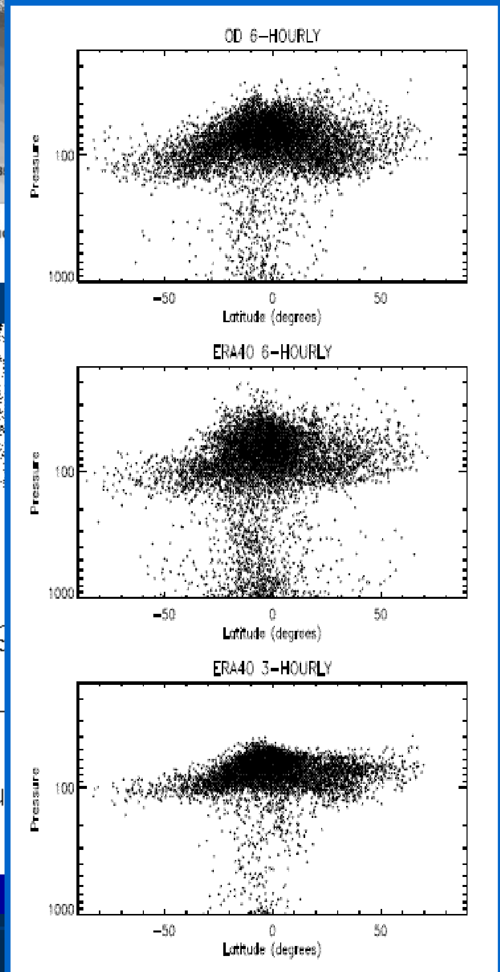
Tropical isolation

TOMCAT Trajectories





from *Schoeberl et al., 2003*



From *Bregman et al*, 2006

50-day backwards run: 1st Jan 2001

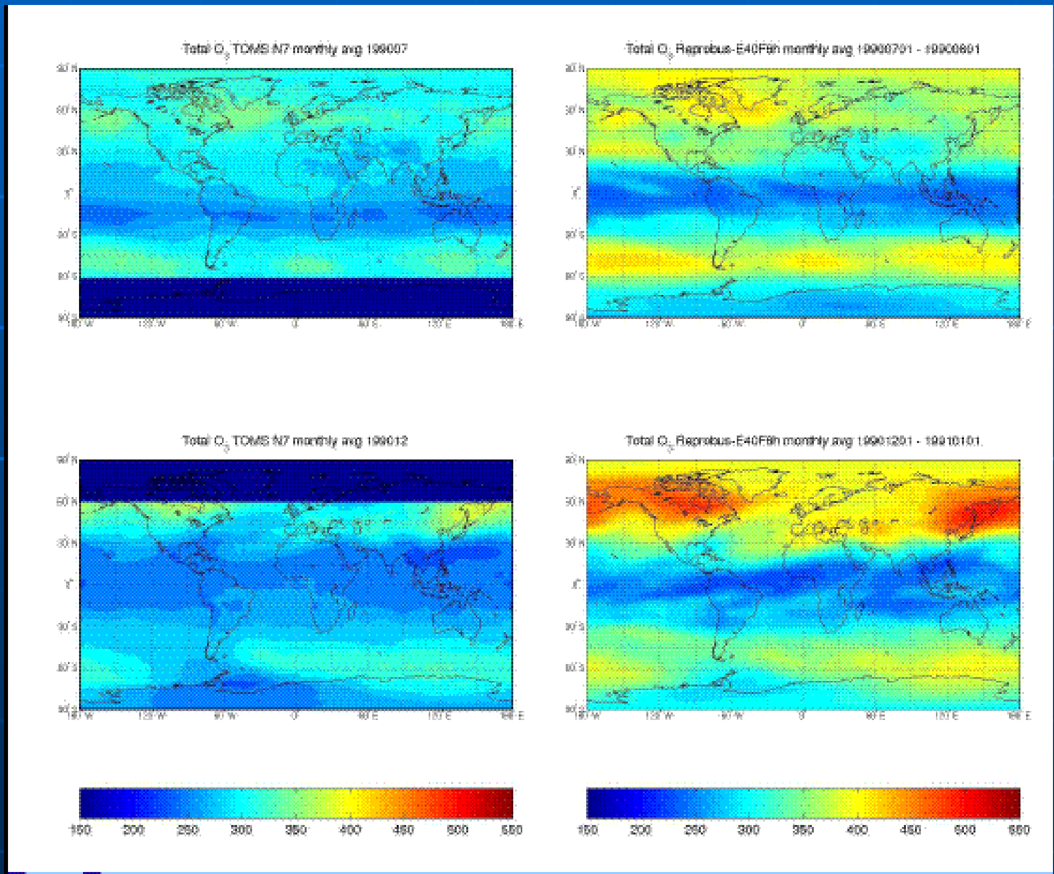
36.000 parcels: 0º ± 1º

460K ± 5K

Ozone distributions

Total ozone in July and Dec 1990

TOMS **REPROBUS ERA-40**



From F. Lefèvre

Transport problems translated into unrealistic tracers

- 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

Polar Temperatures

- ERA-40 oscillations

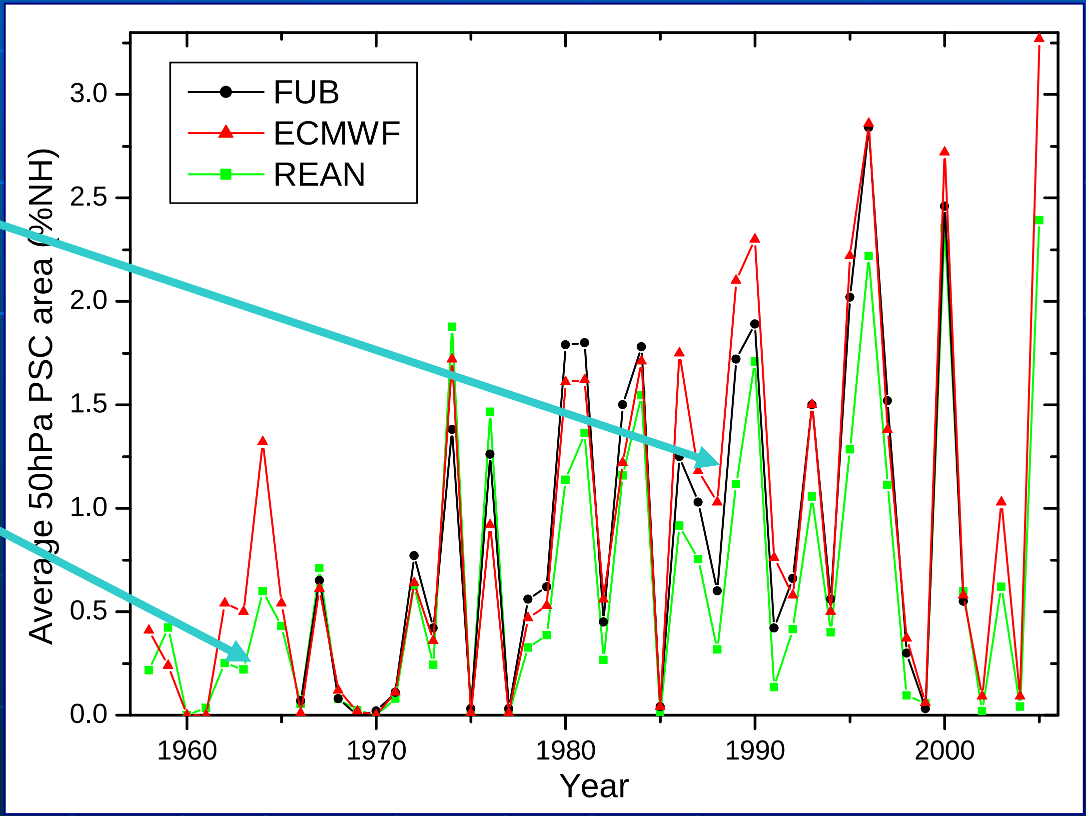
Randel et al., 2004
Manney et al., 2005

- Large differences between analyses

Unrealistic PSC areas → unrealistic polar O_3 loss

Winter 1988/1989

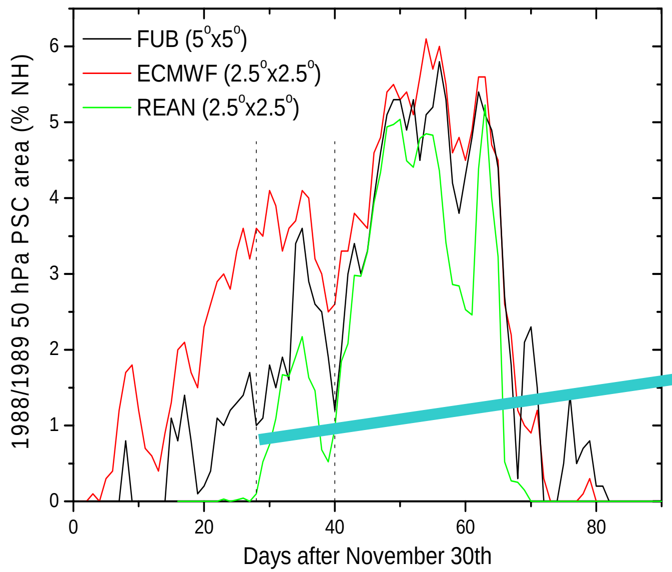
Winter 1963/1964
pre-satellite



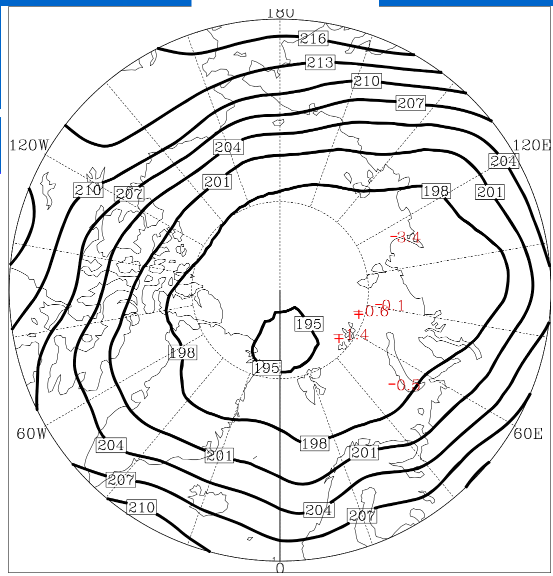
from Bjoern Knudsen (DMI)

Polar Temperatures

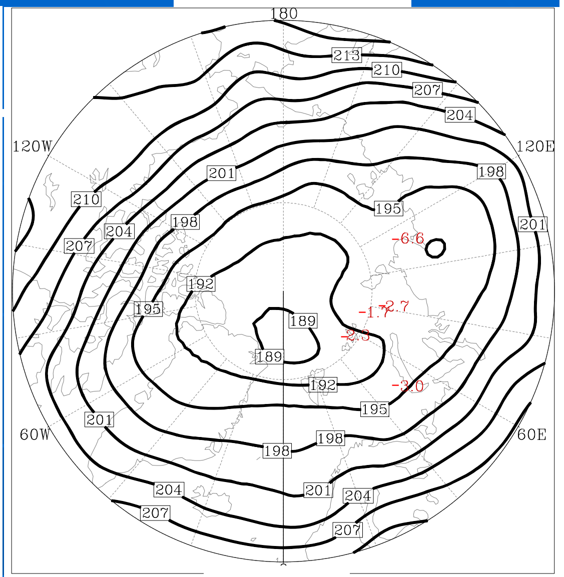
PSC area NH 1988/1989



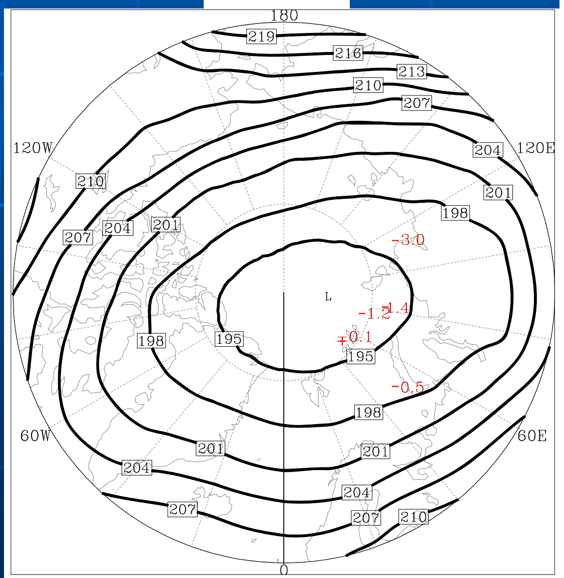
REAN



ERA-40



FUB



28 Dec 1988

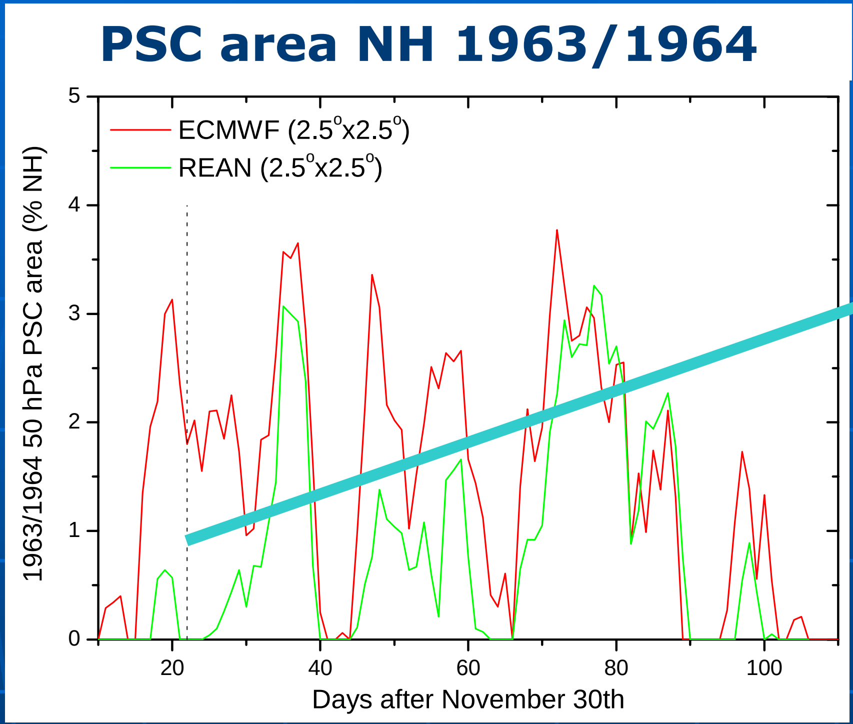
Comparison with radiosondes T

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

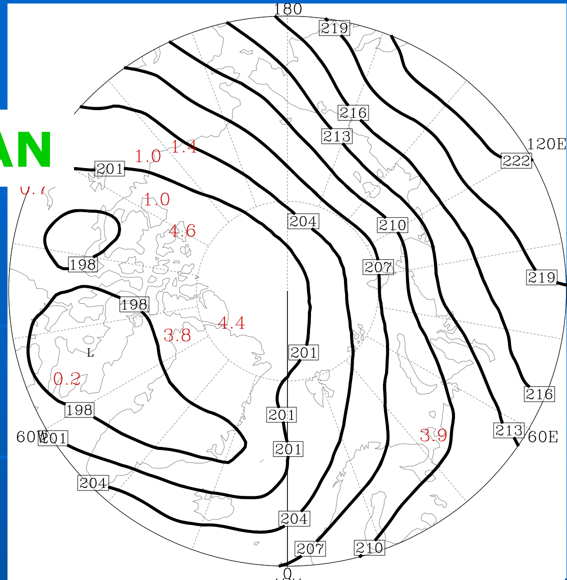
from Bjoern Knudsen (DMI)

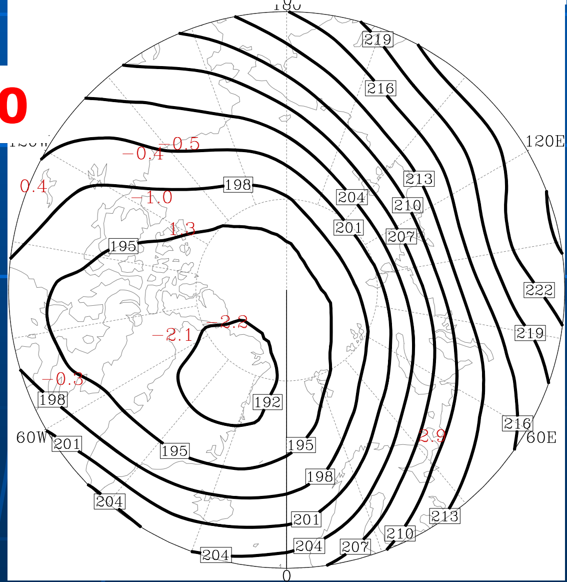
$T_{AN} - T_{RS}$

Polar Temperatures -- presatellite



22 Dec 1963





$T_{AN} - T_{RS}$

Comparison with radiosondes T

- **ERA-40 too cold**
- **REAN warm bias**
- **Neither of them good enough for PSCs**

from Bjoern Knudsen (DMI)

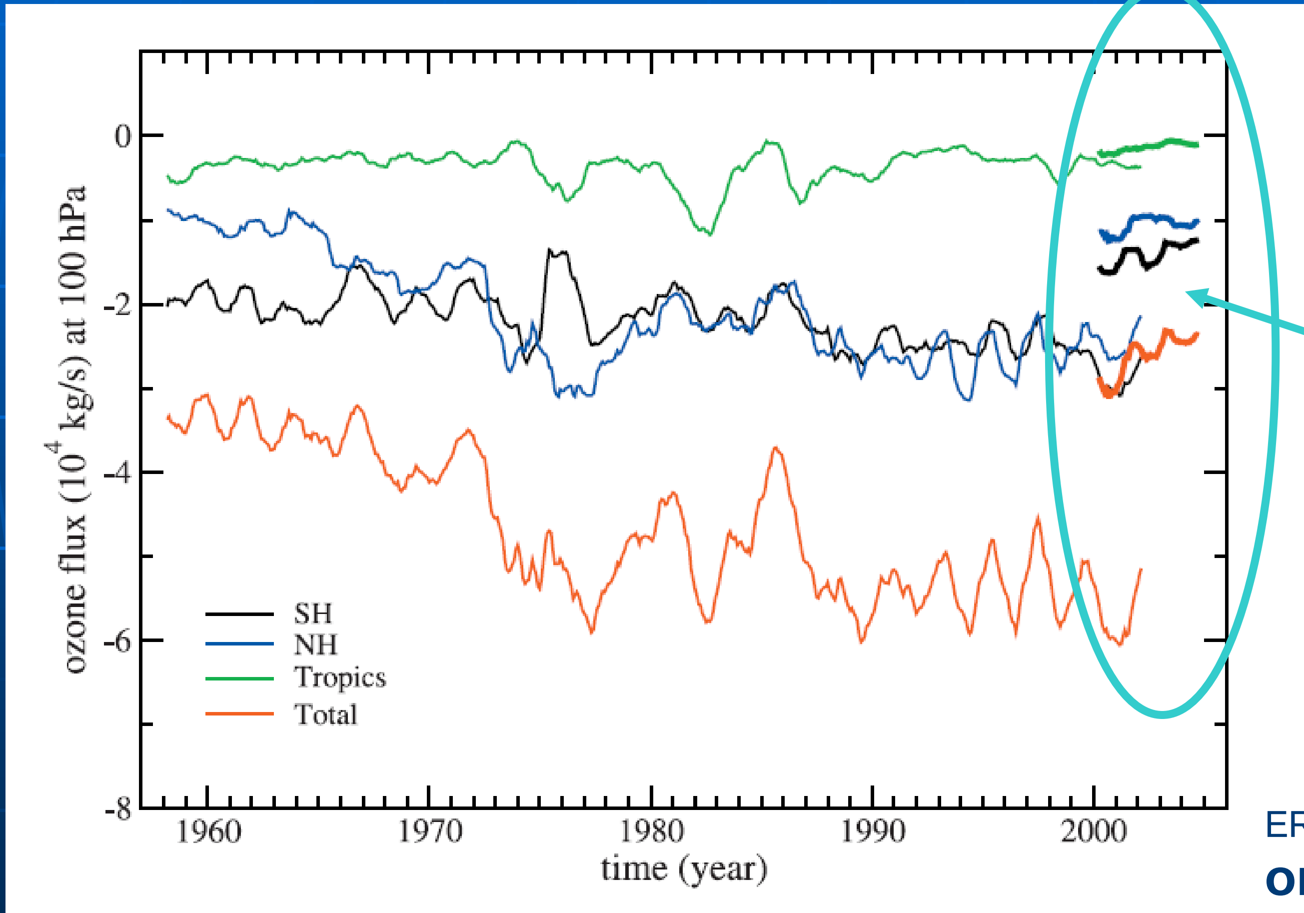
Troposphere

STE T. van Noije (KNMI)

TTL Kirstin Krüger (IFM-GEOMAR/**AWI**)

Stratosphere-Troposphere Exchange

O_3 monthly STE fluxes with ERA-40 and OD



ERA-40 temporal inhomogeneities

ERA-40 higher STE than OD

Fluxes reduced using forecasts

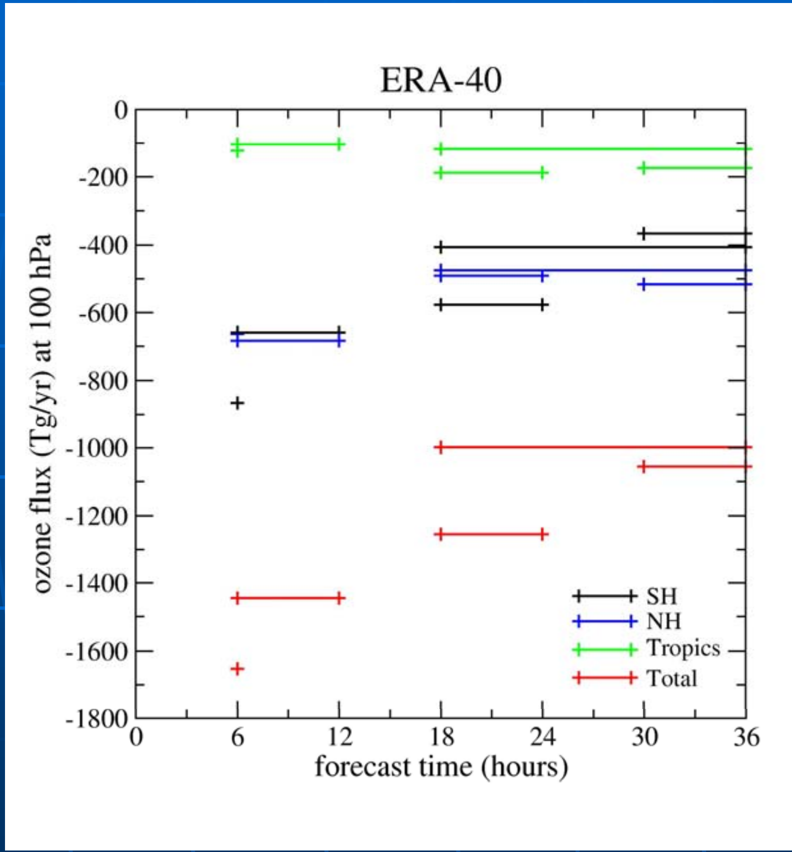
ERA-40 (thin)

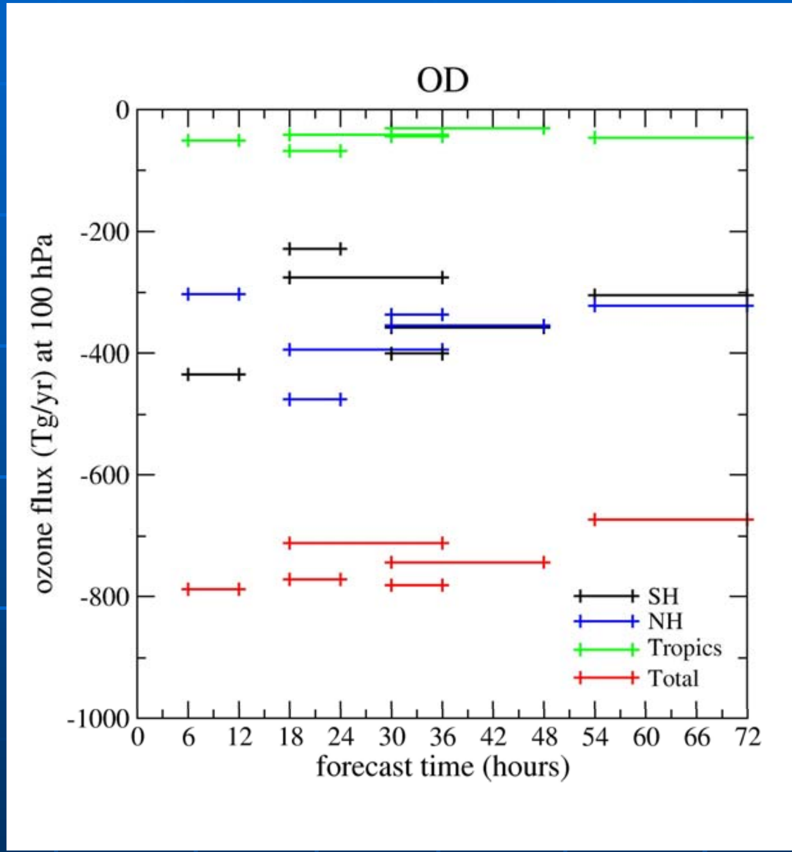
OD (thick)

from van Noije et al. (2006) (KNMI)

Stratosphere-Troposphere Exchange

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



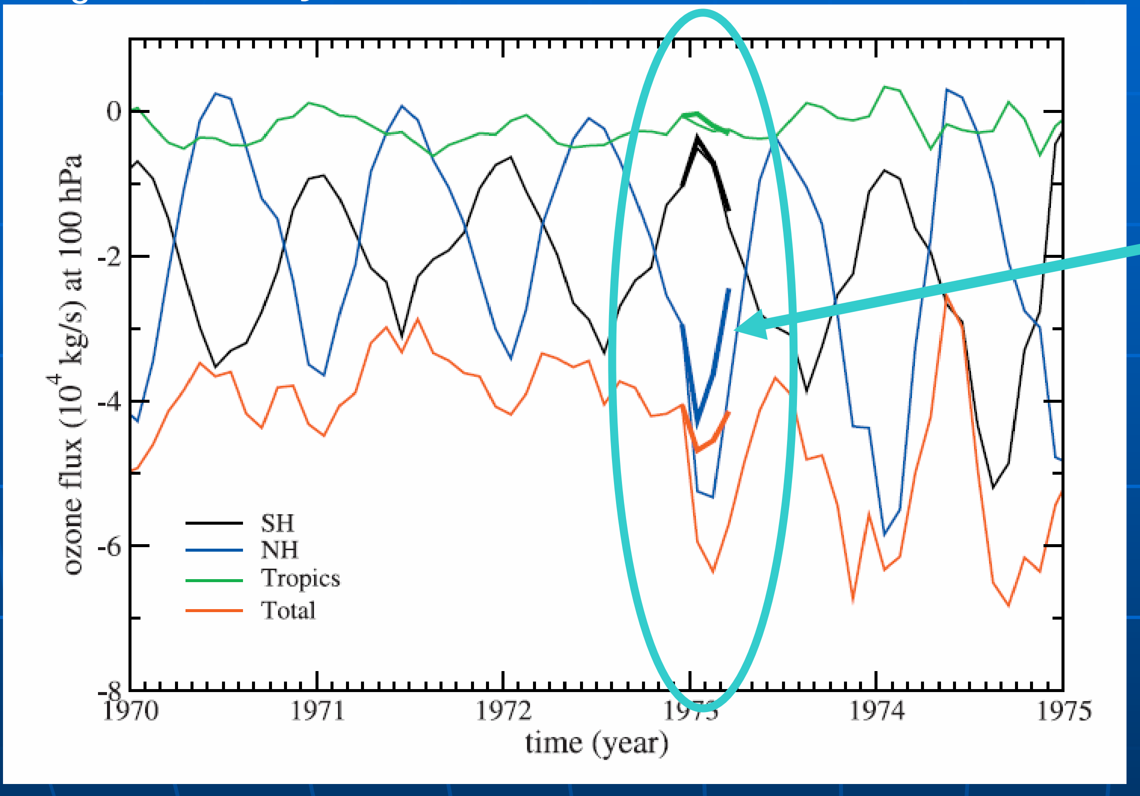


Dependence on forecast range; merged forecasts are indicated by a line connecting begin and end time of the forecast range. **Forecasts → reduction flux**

from van Noije et al. (2006) (KNMI)

Stratosphere-Troposphere Exchange

O_3 monthly STE fluxes with ERA-40: satellite observations



ERA-40
Sat. radiances
affect NH

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

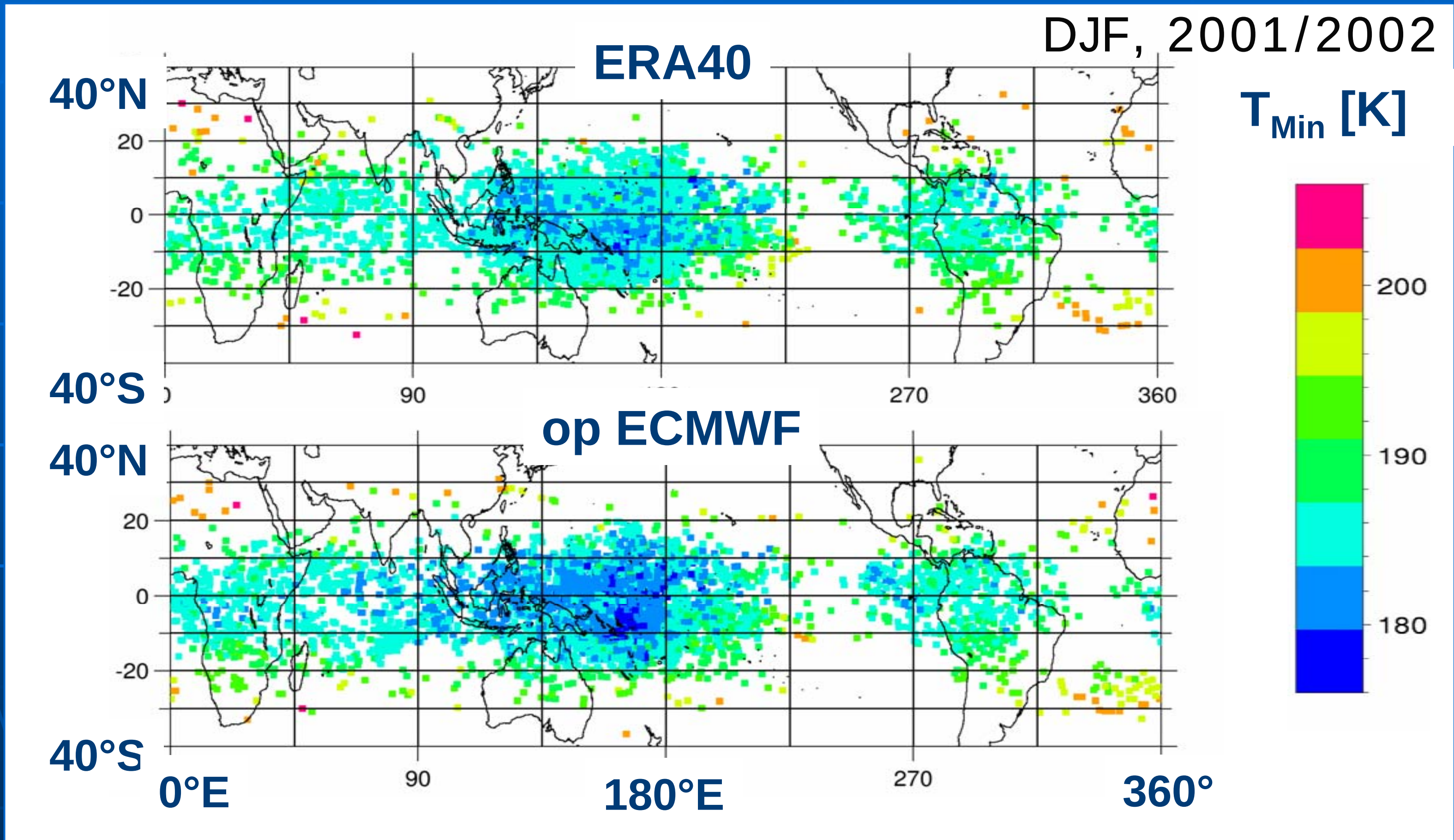
- Trajectories to study water vapour into the stratosphere
- Vertical motion from heating rates to avoid noisy w field
- Compare ERA-40 and ECMWF Operations

T_{Min} in trajectories ≈ dehydration points of strat. H_2O

from Kirstin Krüger (IFM-GEOMAR/AWI)

Tropical Tropopause Layer

T_{Min} in trajectories ≈ dehydration points of strat. H_2O



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

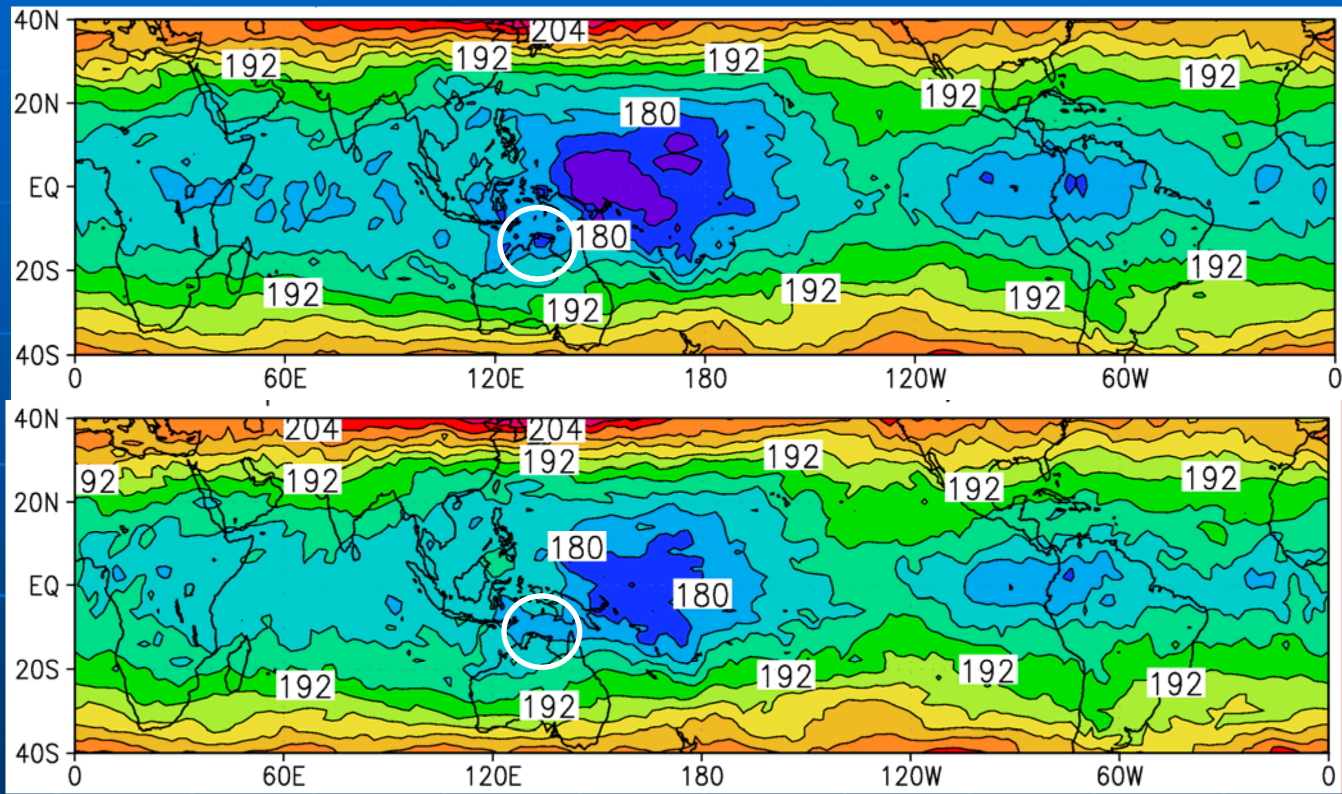
from Kirstin Krüger (IFM-GEOMAR/AWI)

TTL

T_{Min} at 80hPa, Nov 2005 - Jan 2006

op ECMWF
(T511/L60)

op ECMWF
(T799/L91)



→ **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 H_2O 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 !!!

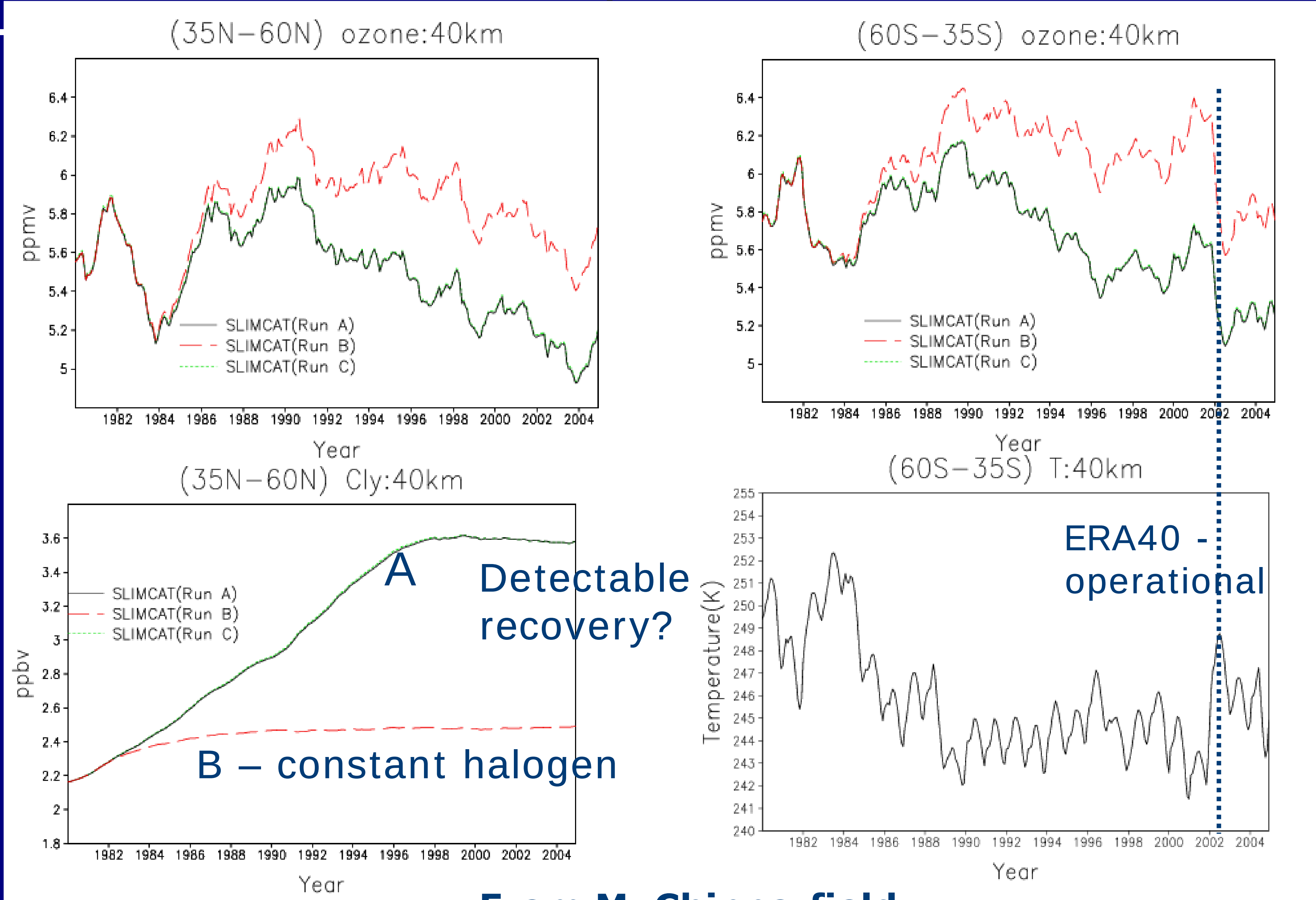
Requirements for future reanalysis

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

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!

Acknowledgements

Steve Arnold, Paul Berrisford, Wuhu Feng,
John Methven, Adrian Simmons, Sakari Uppala …

Acknowledgements

THANK YOU!