Some challenges in assimilation of stratosphere/tropopause satellite data

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ASSET
Assimilation of Envisat Data

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Importance of stratosphere/tropopause

- radiative-dynamics-chemistry feedbacks associated with strat O_3 & relevant to studies of climate change & attribution (WMO 1999)

- quantitative evidence knowledge of the strat state may help predict the tropospheric state at time-scales of 10-45 days (Charlton et al. 2003)

- important role UTLS water vapour plays in atmos radiative budget (SPARC 2000)

- need realistic representation of the STE & transport between tropics & extra-tropics in strat -> key role in the distribution of strat O_3 (WMO 1999)

Importance of stratosphere/tropopause

Recognition of key role of stratospheric O_3 in determining temperature distribution & circulation of atmosphere ->

Incorporation of photochemical schemes of varying complexities into climate models:

- Coupled climate/chemistry models (e.g. Austin 2002)
- CTMs for study of ozone loss (e.g. Khattatov et al. 2003)
- Cariolle scheme in NWP systems (ECMWF; Struthers et al. 2002)

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Recent developments

- Satellite data (Research)
    - NASA: EOS-Terra, EOS-Aqua, EOS-Aura
    - ESA: ERS-2, Envisat, ESA's Living Planet Programme
    - NASDA: ADEOS-1,-2, GOSAT
    - ESA/CSA: ODIN
- Future satellite data (Operational): e.g. METOP, MSG
- Synergy between research & operational satellite data (make research satellite data operational?)

Recent developments

- Atmospheric models (increases in computing power)
  - ·Increases in horizontal resolution (T511 at ECMWF)
  - ·Increased vertical resolution in UTLS
  - ·Top of atmospheric models extended upwards

->Together with DA: Improve forecasting & long-term capability

- ·Extend range of validity of forecasts; novel geophysical parameters
- ·More consistent & realistic climate models
- ·Confront & evaluate forecast & climate models

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Recent developments

- Data assimilation
  - Increasing use outside NWP agencies (CTMs, NWP models)

- Use of DA by ESA
  - Envisat cal-val
  - OSSEs (e.g. SWIFT)

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Recent developments

- Computers
  - More power-> more sophisticated models
- GRID technology
  - Efficient use of data & models
  - Increased collaboration
  - Web-based training
- Many obstacles to be removed (e.g. access to large EO archives & metadata, common formats)

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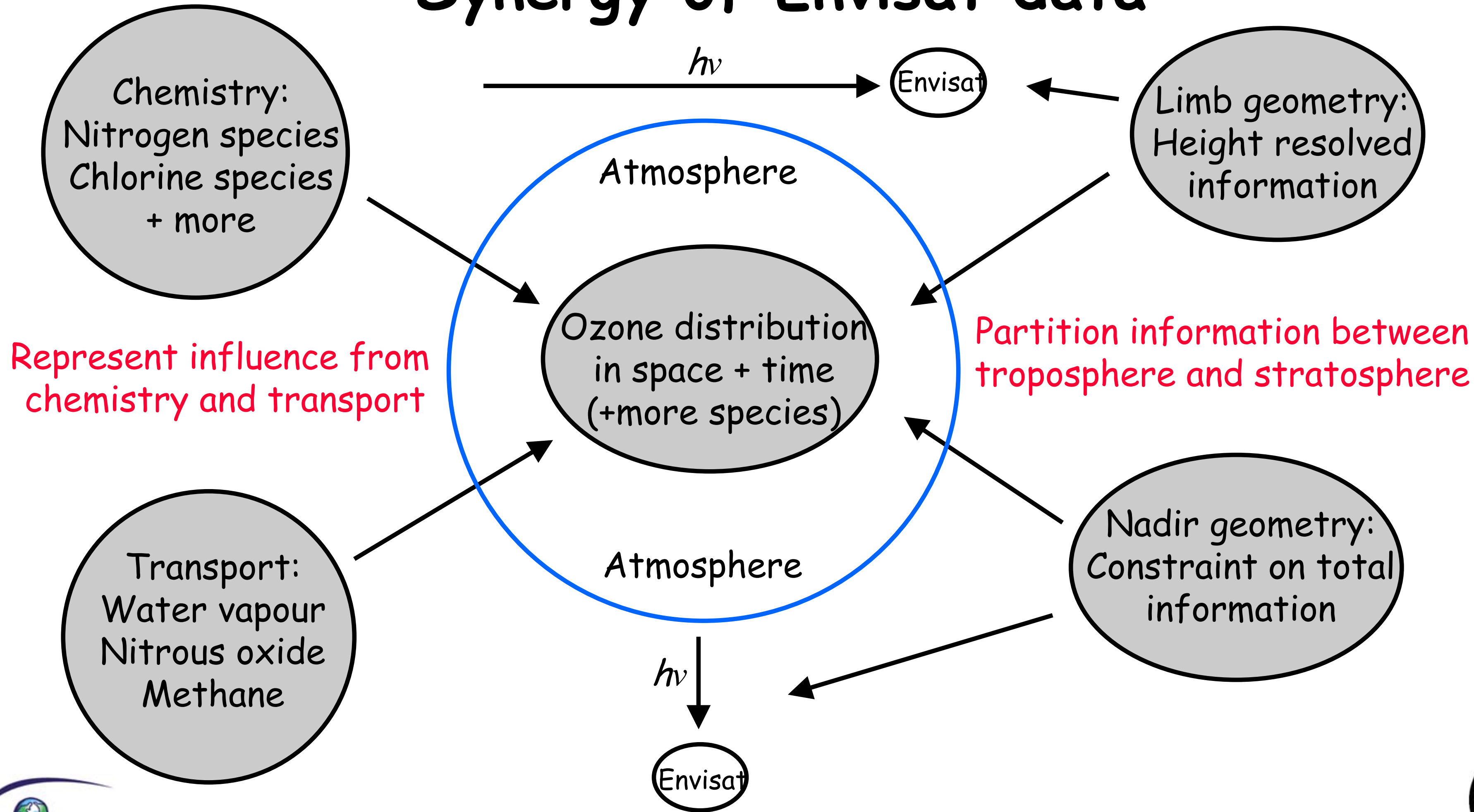
Wealth of Envisat data: ESA©

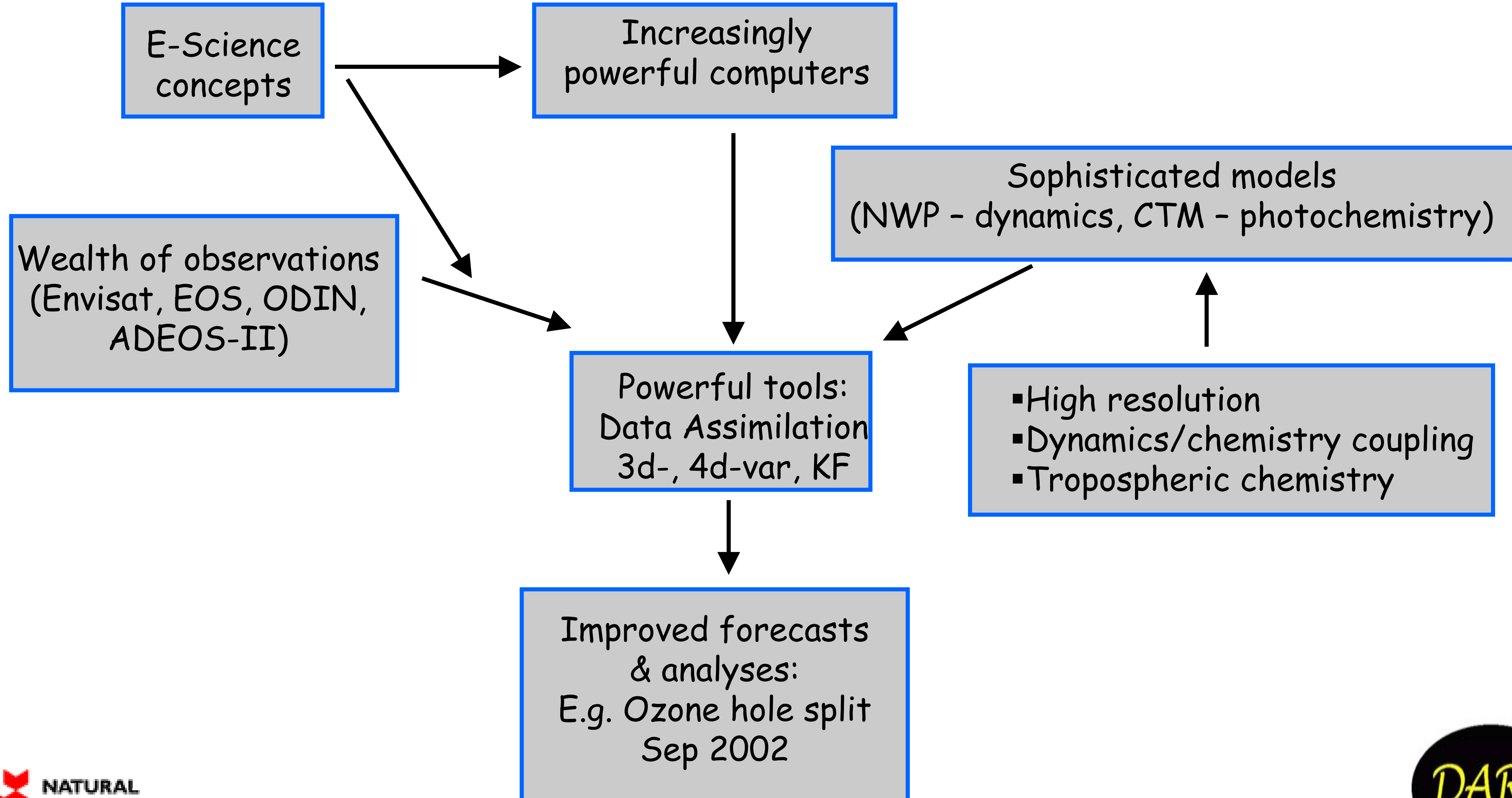
GOMOS: limb
Ozone
Water vapour
Temperature
+ more

SCIAMACHY:
Limb + nadir
Total column ozone
Total column nitrogen dioxide
Height resolved ozone
+ more

MIPAS: limb
Ozone, water vapour, methane
Nitrous oxide, nitrogen dioxide,
Nitric acid, temperature + more

Synergy of Envisat data





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Challenges in data assimilation (1)

- Assimilation of water vapour in stratosphere/tropopause region (challenge in assimilation: estimation of error statistics)

- Assimilation of novel geophysical parameters (e.g. ozone, stratospheric winds) into NWP systems

- Synergy from measurement geometries

- Coupled dynamics/chemistry in data assimilation

- Limb radiance assimilation

Challenges in data assimilation (2)

- Assimilation of novel photochemical species (e.g. CFC-11, CFC-12, $ClONO_2$)
- Aerosol assimilation (stratosphere & troposphere)
- Tropospheric chemistry
- Novel retrieval methods (e.g. tomography)
- Data management

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The ASSET (ASSimilation of Envisat daTa) consortium

Challenges listed addressed by ASSET partners (examples):

- UREADMY/MO: stratospheric water vapour assimilation (*)
- MF/CERFACS: Coupled dynamics/chemistry assimilation (*)
- ECMWF: Limb radiances (*)
- KNMI: Synergy from measurement geometries
- UPMC: Assimilation of novel photochemical species
- BIRA-IASB: stratospheric aerosol
- U. Koeln/U. Karlsruhe: Tropospheric chemistry/novel retrievals
- CNR.IFAC: Tomographic retrievals
- NILU: Data management

ASSET is a FP5 project: http://darc.nerc.ac.uk/asset

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Assimilation of water vapour in stratosphere/tropopause

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Water vapour:

Radiation: Dominant GHG in atmosphere

Dynamics: Diagnostic of atmospheric circulation

Chemistry: Source of OH; PSCs

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- Troposphere: hydrological cycle (climate change; precipitation)
- UTLS: radiative forcing from H_2O (climate change; monitoring environment)
- Troposphere/Stratosphere: transport studies (climate change; ozone loss via PSCs; testing climate models)

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Recommendations from SPARC assessment on UT/S water vapour (1):

- Quantify & understand differences between sensors (importance of high resolution in situ data for trop/strat transport)

- Strong validation programmes (previous lack in UT)

- Continuity of measurements to determine long-term changes (especially stratospheric H_2O)

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Recommendations from SPARC assessment on UT/S water vapour (2):

- Monitor UTH to determine long-term variations. Complementary observations

- Process studies of UTH & convection. Joint measurements of H_2O, cloud microphysical properties & tracers with signature of "age of air"

- More observations in tropical tropopause region (15-20 km) (*in situ* & remote sensing) needed to improve understanding of STE

- Monitor stratospheric H_2O (CH_4 measurements desirable). Overlap of future satellites with current instruments

- Theoretical work to understand observations

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Assimilation of UT/S data from Envisat (H_2O, as well as CH_4) will help address many of the recommendations in the SPARC assessment

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Stratospheric Humidity Assimilation (MO & UREADMY)

H_2O data assimilated:

- Troposphere:
  - ATOVS:
    - HIRS: ch 10-12 (900, 700 & 500 hPa)
    - AMSU-A: ch 18-20 (500, 750 & 900 hPa)
  - Radiosondes (up to 20 km)

- Stratosphere:
  - MIPAS (available 100 – 1 hPa; assimilated 100 – 40 hPa)

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Old dynamics

- RH is control variable (-> New dynamics, ND) Problems with RH: low values in stratosphere; dependence on temperature. Other options, q?

- B calculated using NMC method (turned off for levels above ~40 hPa; turned on in ND)

- No flow dependence (use Riishojgaard ideas?)

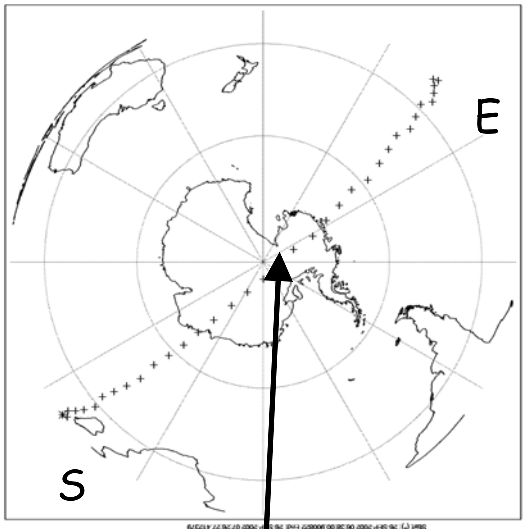
- No CH_4 oxidation (yes in ND)

Problems with existing stratospheric assimilation (found in old dynamics, reasons to believe are present in new dynamics)

- Ill-conditioned vertical transform of **B** matrix (currently weighted by mass and standard deviation - max in boundary layer).
- Excessive increments in lower stratosphere (e.g. 50 hPa), suspect due to spurious correlations with lower levels.

Also:

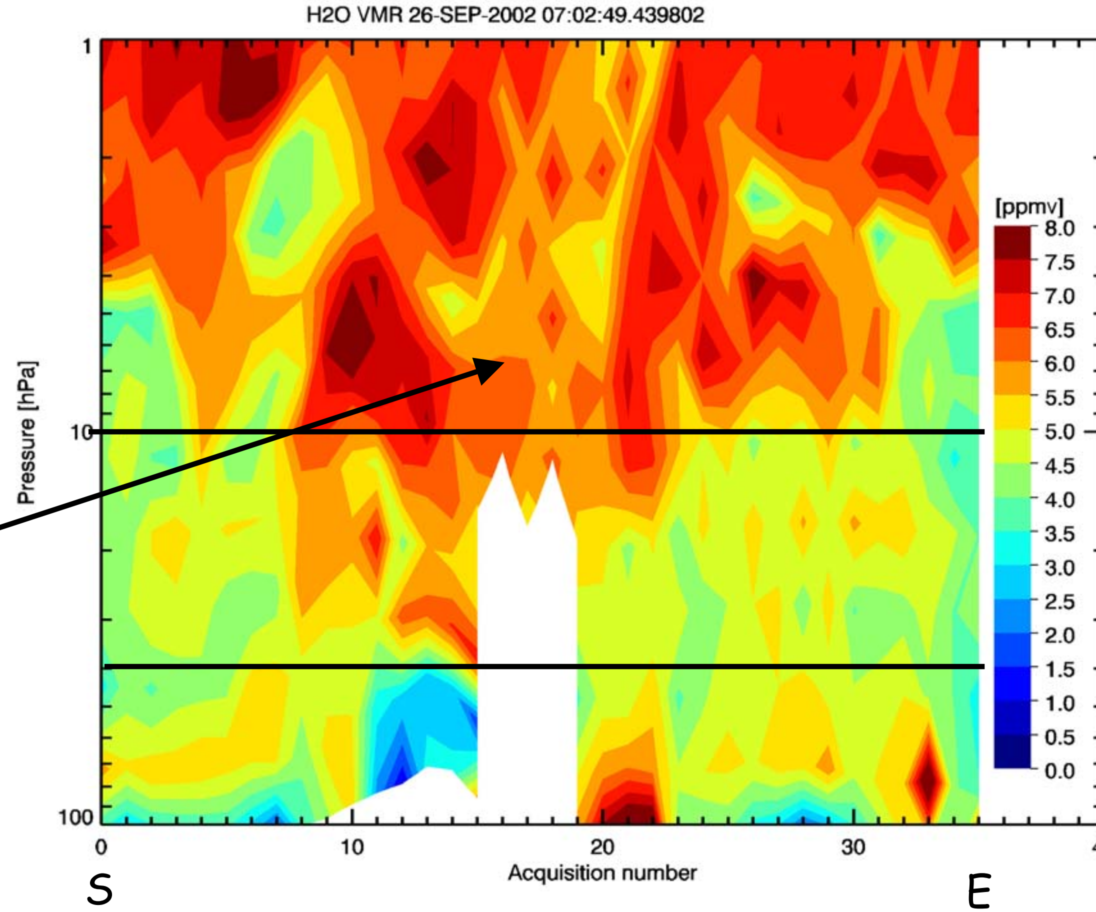
- To date, no assimilation of water vapour over the whole stratosphere (only MIPAS H_2O up to ~ 40 hPa – very preliminary results being evaluated).
- Desirable to assimilate CH_4 and N_2O (tracer advection scheme)



MIPAS H_2O data
ESA© 2002

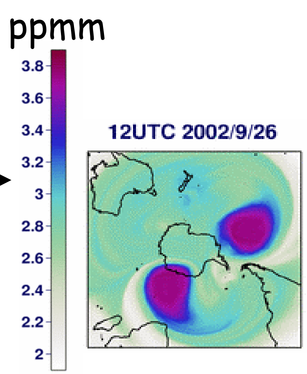
No
B
info

~10km



TROPOSPHERE
(ATOVS)

ECMWF H_2O
data
850 K



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Humidity assimilation - possible solutions (MO/UREADMY)

Need to revisit calculation of **B** matrix

- vertical weighting
- rotation of vertical modes
- treatment of tropopause?

Also for the future

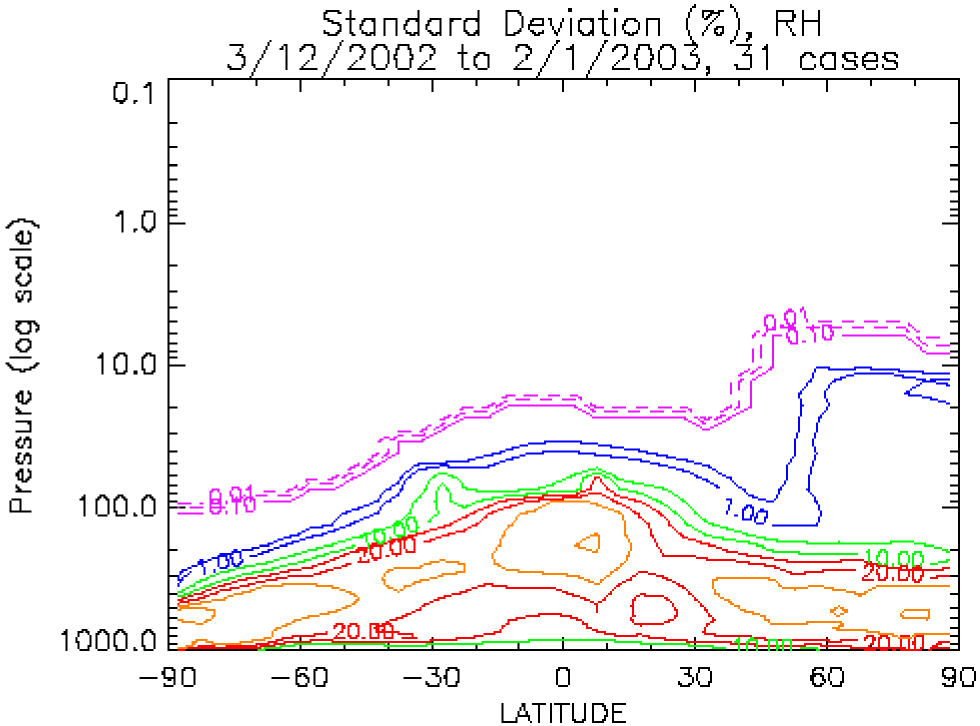
- flow dependence
- advection scheme

MO investigating performance of stratospheric H_2O in ND

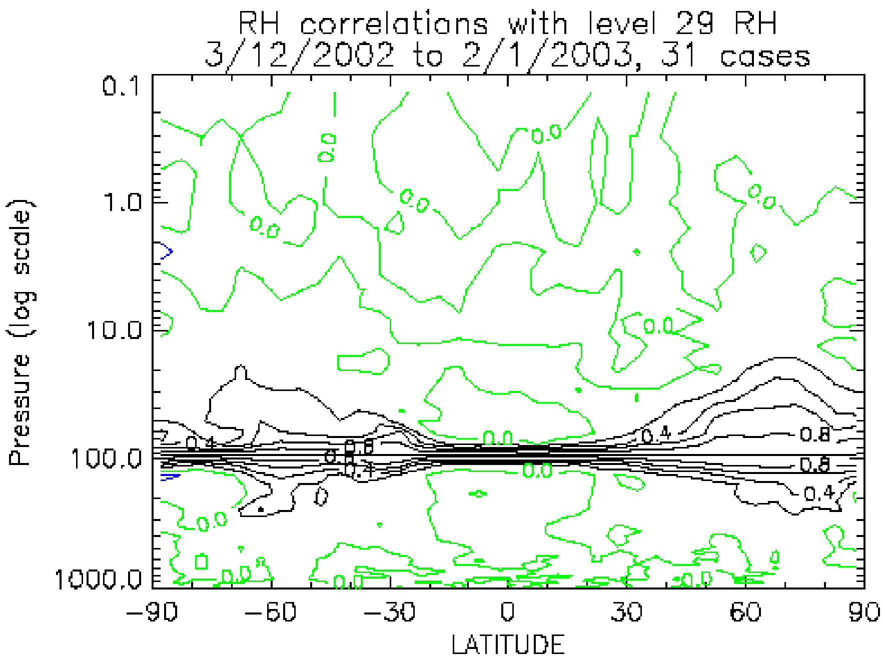
B: STD RH (%)
December

New Dynamics
50 levels
0-63 km

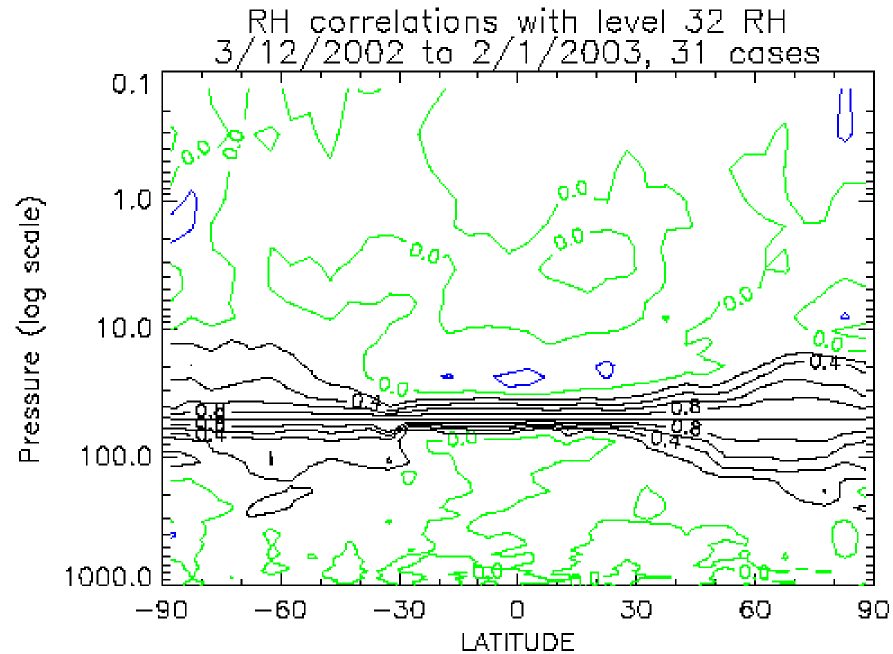
NMC Method



16 km



19.7 km



B: RH correlations, December.

New Dynamics: NMC Method

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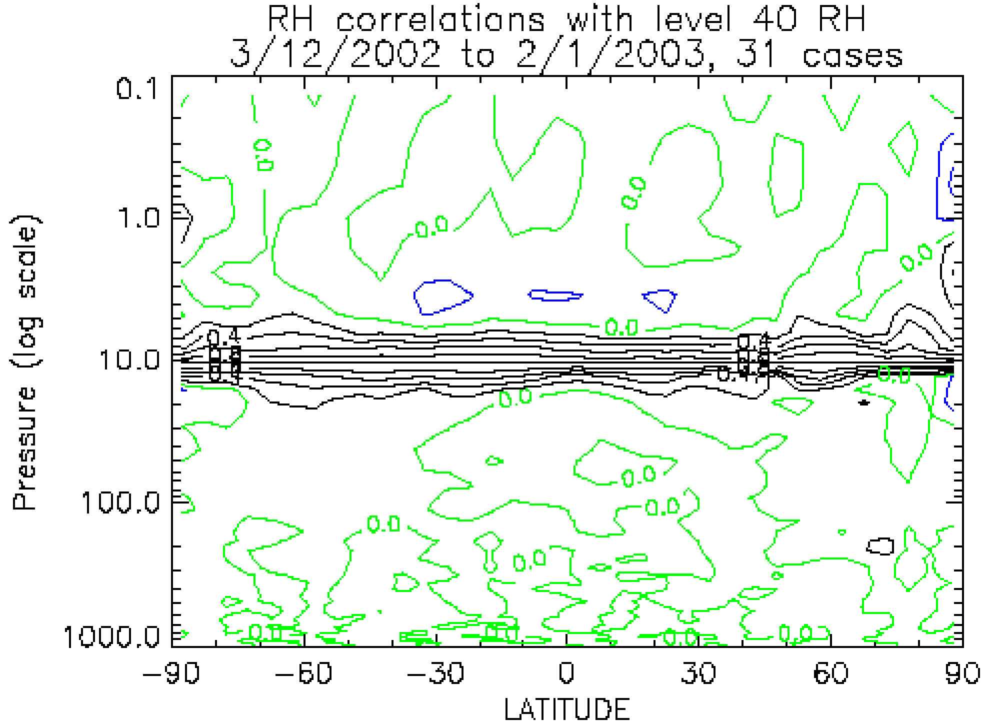
29.8 km



B: RH correlations, December.

New Dynamics: NMC Method

Coupled dynamics/chemistry in assimilation schemes

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Approaches to assimilation:

- GCM: dynamics with "simple" chemistry (Cariolle)
  - 3d-, 4d-var; Feedback between dynamics, chemistry & radiation; operational obs (UREADMY/MO, ECMWF)
- CTM: sophisticated photochemistry driven by off-line winds/temperature; KF, 4d-var
  - No feedbacks (KNMI, UPMC, BIRA-IASB, UKOELN)
- Coupled GCM/CTM (time-step?): Idea is to get the best from above approaches (MF/CERFACS)
- ASSET: assess strategies to assimilate data into NWP systems

Recent developments in assimilation:

- GCM:

    (1) incorporation of novel atmospheric species (ozone)

    (2) extensions of simple photochemical parametrizations (Cariolle)

    (3) incorporation of novel observation geometries (limb)

    (4) improvements in error characterization of model

    (5) radiance assimilation

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Recent developments in assimilation:

- CTM:

  (1) extension of models to include novel species (e.g. CFCs)

  (2) improvements in heterogeneous chemistry

  (3) incorporation of aerosols (troposphre & stratosphere)

  (4) improvements in error characterization of model

  (5) radiance assimilation

Recent developments in assimilation for GCMs & CTMs feed into coupled dynamics / chemistry assimilation

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Met. analyses
U,V,T,q,surface

ARPEGE

MOCAGE

Chem. analyses
3D ozone

Palm

Conventional data
Ozone ENVISAT data

ENVISAT data
GOME data…

Chemical data : L2, then L1

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Advantages:

- Improve assimilated winds & forecasts in NWP model
- Realistic O_3 (later aerosol) fields for NWP radiative transfer scheme
- CTM: improved distribution of photochemical species (observed & unobserved) & improved fluxes in the UV

Disadvantages: Complexity & cost

Limb radiance assimilation

Why assimilate radiances?

Better to assimilate information nearer in form to data received by instrument (i.e. radiances instead of retrievals)

Overcomes shortcomings associated with retrievals:

1) need to include *a priori* information to make problem well-posed & fill in data gaps – "contamination" of solution

2) common assumption that measurement errors uncorrelated (expediency) not strictly true for retrievals.

Why assimilate radiances?

- Radiance assimilation overcomes (to a large extent) these shortcomings

  (Note it has been argued that correlations between radiances can be important: T. von Clarmann & MIPAS)

- Estimation of observation errors & bias characteristics is generally easier for radiances than for retrievals

  (It is argued that shortcomings of standard retrievals can be overcome to a large extent by performing a SVD of retrievals; Rodgers and Connor (2003).)

Assimilation of MIPAS infrared limb radiances

Idea:

1. Use radiances as observations, rather than retrieved profiles of temperature, humidity, ozone, …
2. Observation operator includes (fast) radiative transfer calculations

Why?

1. Very successful at ECMWF for nadir sounders; flexibility
2. Estimation of observation error and bias characteristics easier for radiances than for retrievals
3. Avoids having to account for the use of *a priori* information in the retrievals

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Some challenges:

- **Limb geometry:**
  - Assimilation of IR limb radiances has not been done before.
- **Computationally feasible forward model for IR limb radiances:**
  - Current fast radiative transfer schemes have to be extended.
  - "Fast" means: Ideally similar to about 3.4s for the simulation of 8,461 IASI channels on IBM rs6000 workstation.
- **Data volumes:**
  - MIPAS provides measurements of ~60,000 spectral points/ "channels".
  - Need to select channels for simultaneous assimilation of p, T, H_2O, O_3 information, with selection optimised within resource limitations.
- **Error characteristics:**
  - Observations: Inter-channel correlations for high-spectral sounders?
  - Background: Improved characterisation in stratosphere and for ozone may be necessary.

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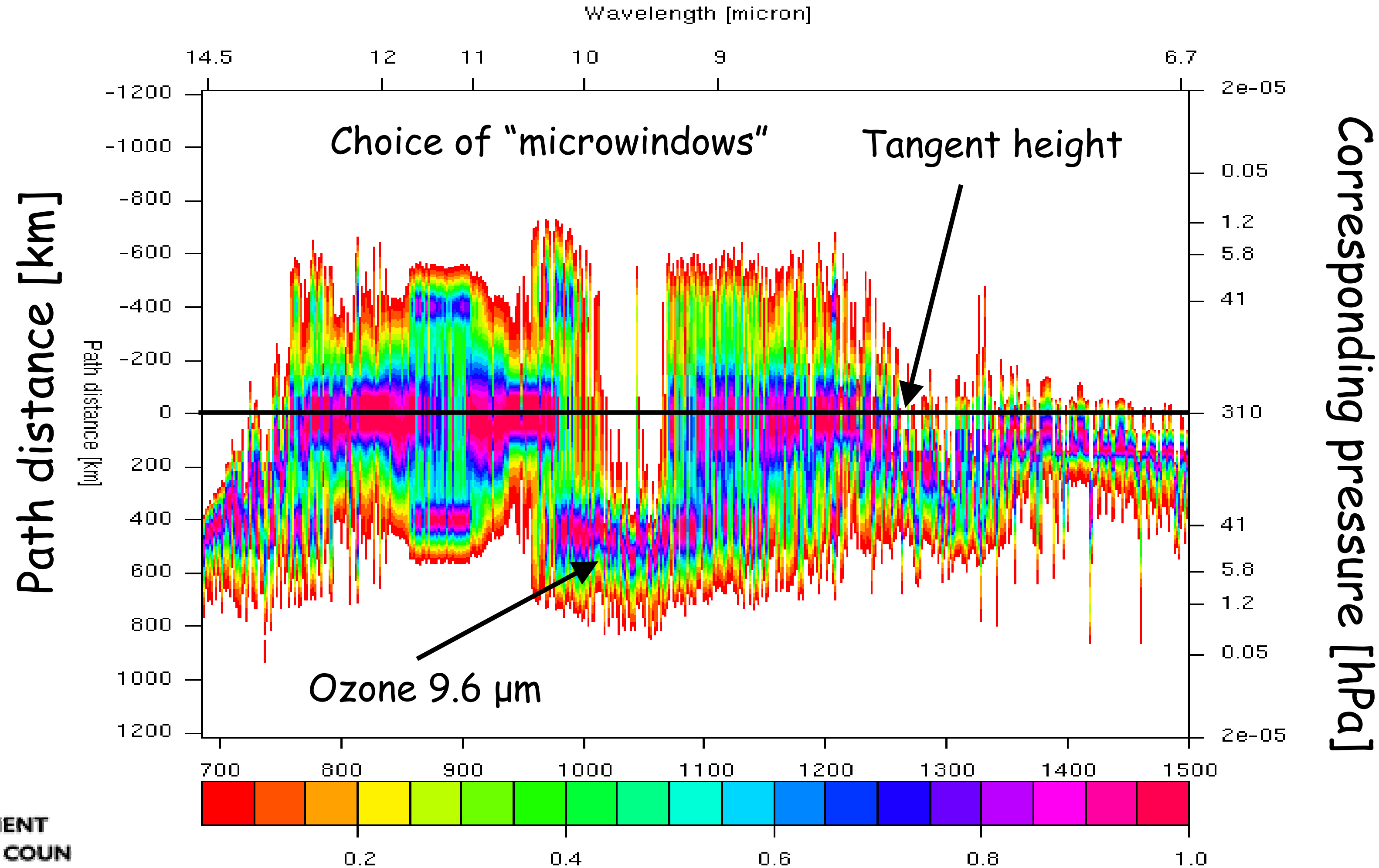
Normalised weighting functions for 9 km tangent height (along path)



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Future directions

- Operational use of research satellite data by NWP centres: ozone (already assimilated at ECMWF), stratospheric H_2O. Estimation of **B**: challenge throughout DA

- Assimilation of limb radiances by research/operational groups. Development of fast & accurate RT models & interface between models & assimilation. Progress more advanced for IR radiances than UV/Vis

- Chemical forecasting & tropospheric pollution forecasting

- Coupled dynamics/chemistry DA systems (e.g. GCM/CTM)

- Earth System approach to environmental & socio-economic issues