Assimilation of water vapour into the Unified Model

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Topics

- Motivation
  - Why is water vapour (WV) important in the atmosphere?
- Shortcomings (especially in UTLS)
  - Observations of WV
  - Modelling WV
- Water vapour assimilation
  - Added value
  - Issues: large variation in WV, error covariance matrix, control variable
- Recent work & possible ways forward

Motivation

Importance of water vapour is well established:

- Radiation, Dynamics, Chemistry
- Troposphere, stratosphere, UTLS region

Recommendations from SPARC, WCRP & U.S. Climate Change Science Program-> Observing priorities in troposphere/lower stratosphere

Radiation & WV (1):

- WV dominant greenhouse gas in atmosphere

- Sensitivity of greenhouse effect to changes of water vapour in UT larger than for LT (Spencer & Braswell 1997; Rind 1998)

- Forster & Shine (1999):

    - if increase of LS WV reported over Boulder (O & H 1995) occurs globally, contribution to surface warming 40% of that from CO_2 increase over same time period

    - increase in WV causes cooling of LS comparable to contribution from O_3 changes.

Radiation & WV (2):

Current radiative problems needing accurate knowledge of the WV include (see SPARC 2000):

- Cooling to space in the upper troposphere (UT) in presence of variations in WV

- Sign of WV feedback in the UT

- Whether spectrum of outgoing LW radiation (reflecting impact of WV variability) contains signatures of climate change

- Radiative impact of changes in stratospheric WV

Dynamics & WV:

•WV useful diagnostic of the atmospheric circulation, especially in the stratosphere where WV acts as a tracer over ~ a season

•Uncertainties in WV pathways between troposphere & stratosphere (UTLS, TTL): Why is the stratosphere so dry?

See this workshop

Chemistry & WV:

- WV a source of OH
  - -> OH plays a key role in many chemical cycles, in both the stratosphere and troposphere
  - -> HOx ($OH+HO_2$) plays an important role in catalytic cycles that destroy O_3
  - -> OH controls oxidizing capacity of atmosphere for short-lived gases & regulates lifetimes of longer-lived species, e.g., CO & CH_4.
- WV a constituent of PSCs along with, e.g., HNO_3
  - -> distribution & variability can influence stratospheric O_3 loss via heterogeneous chemical processes

Importance of water vapour in UTLS region:

- Surface energy budget significantly affected by misrepresentation of WV concentrations in region (Forster & Shine 1999)

- Amounts of WV entering stratosphere, which affect stratospheric chemistry & have a non-negligible climatic impact, set in UTLS (Gettelman et al. 2004) -> WV pathways

See this workshop

Shortcomings

- Observations of water vapour
- Modelling water vapour

Observation issues:

- Need to overcome paucity of H_2O observations in UTLS
- Recognition of increased need for higher vertical resolution H_2O observations (e.g. AIRS, IASI)
- Developments in EO System: global coverage (satellites), more data, higher spatial & temporal resolution

Modelling issues:

- Statosphere-troposphere exchange
- Phase changes in water vapour
- Clouds
- Parametrizations (convection, clouds)

See this workshop

Expected benefits of WV observations:

- NWP: better analyses of humidity
- Humidity datasets: extend/improve H_2O data record (especially in UTLS region)
- Climate models: better initial conditions, better analyses to evaluate models
- Transport: dehydration mechanisms in TTL
- Monitoring: long-term trends
- Other datasets: evaluation

- CONFRONT MODELS WITH DATA
- FILL GAPS OF H_2O DATA RECORD

Added value: expected benefits of DA

- Fill in information "gaps" using our understanding (models) ->observations discrete in space & time
- Synergistic use of observations (e.g. nadir/limb geometries)
- Evaluate observations
- Confront climate models with observations
- Quality-controlled analyses->monitoring/science

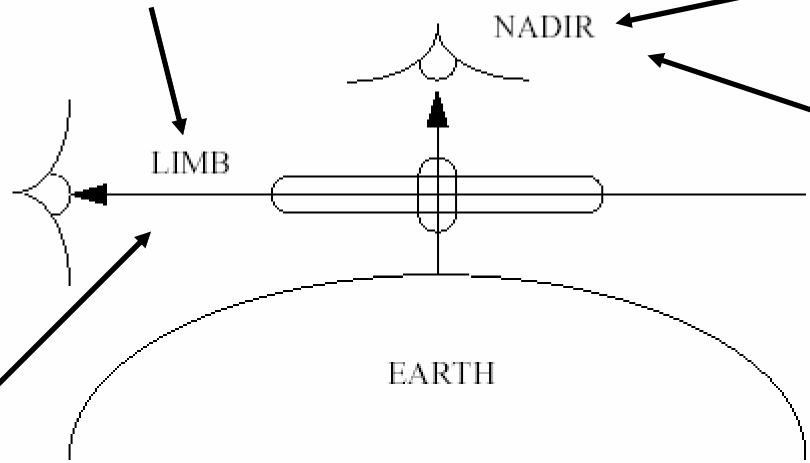
MIPAS

Relatively poor horizontal resolution

Relatively good vertical resolution

Operational satellites

Relatively good horizontal resolution
Relatively poor vertical resolution



Used by met agencies

Used by research groups

Combine features from
components of observing system
-> synergy

Courtesy NATO ASI 2003

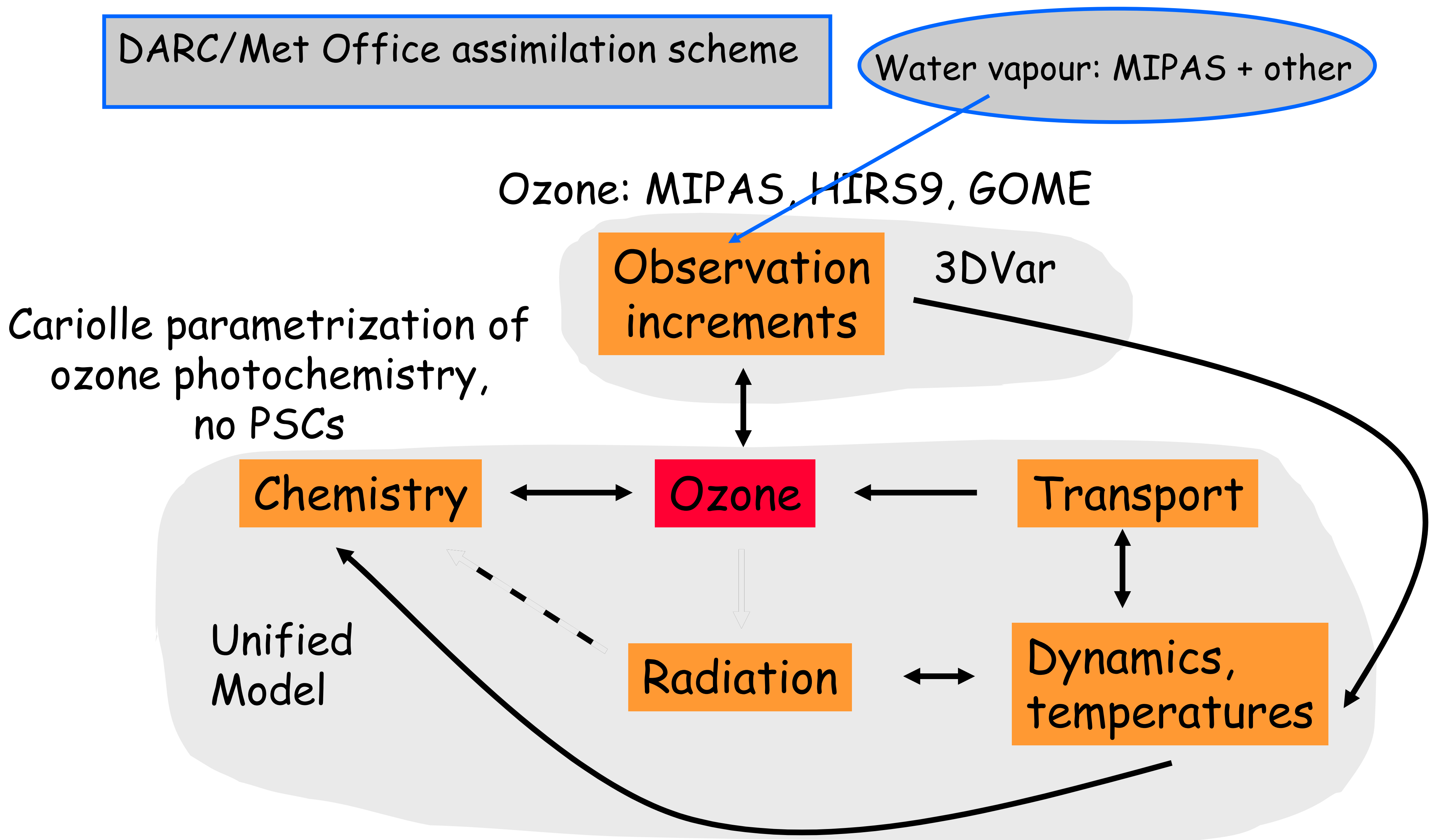
Recent work

- Assimilation of WV in troposphere/stratosphere assimilation systems:

  -> MO/DARC

  -> ECMWF

DARC/Met Office assimilation scheme



Problems with WV assimilation in troposphere-stratosphere

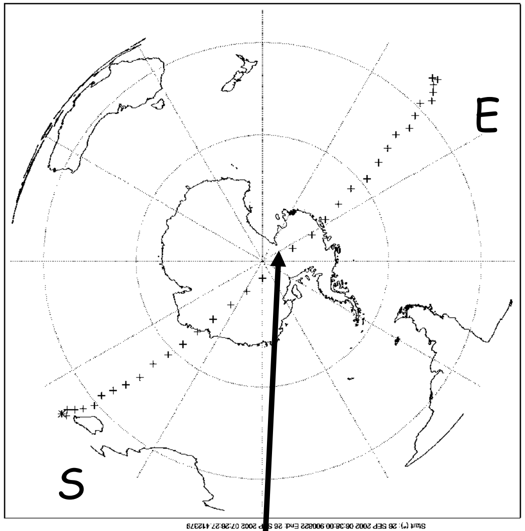
- What control variable? : RH or specific humidity
  - RH better for troposphere
  - specific humidity better for stratosphere

- Large variability in H_2O amount: 4 orders of magnitude
  - Background error (vertical correlations)
  - Define a new control variable:
    - Pseudo RH: divide mixing ratio by saturation mixing ratio of background (Dee & da Silva 2003)
    - Normalized RH: divide RH by background error (Hólm et al. 2002)

Assimilation of MIPAS H_2O discussed at ACVE-2

http://envisat.esa.int/workshops/acve2/presentations

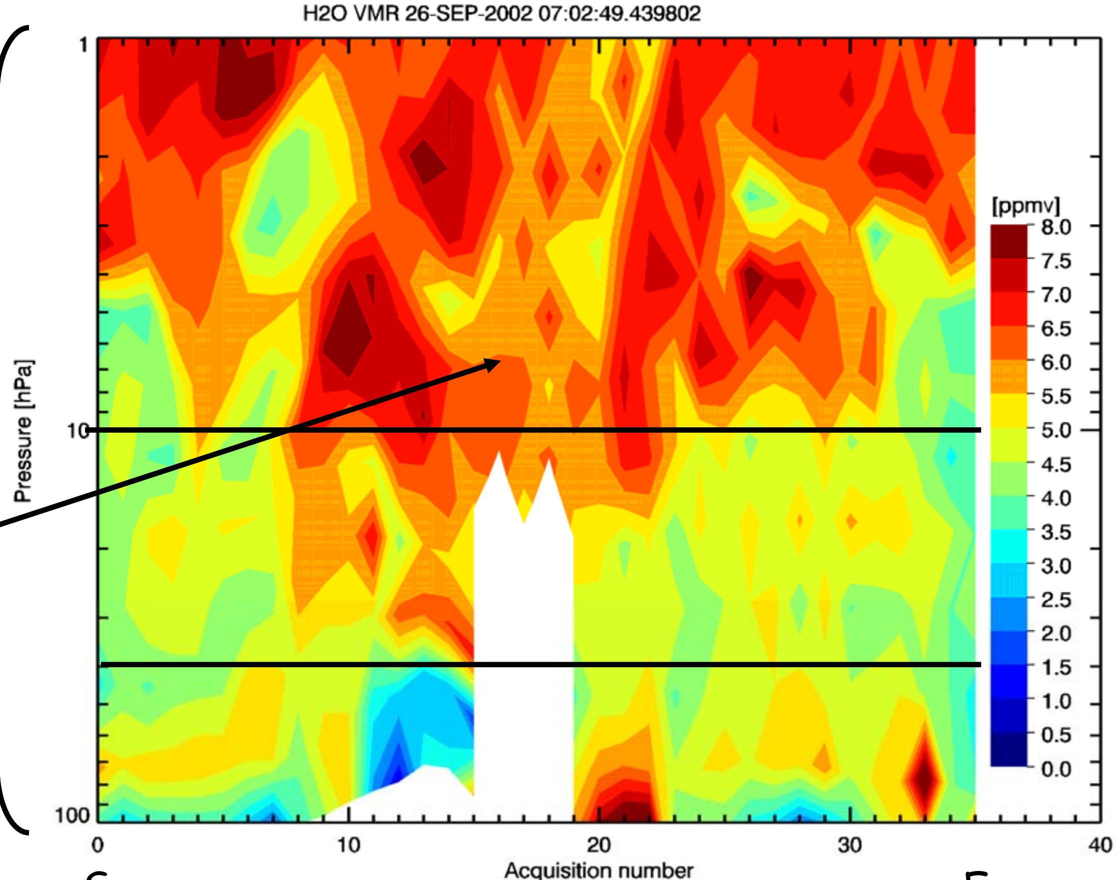
Water vapour variability



MIPAS H_2O data

MIPAS impact

ATOVS impact

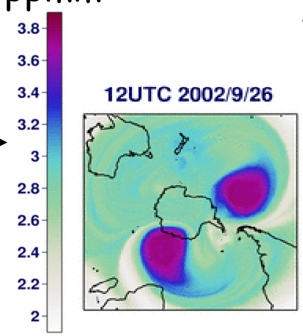


S E

TROPOSPHERE (ATOVS)

ECMWF H_2O data 850 K

ppmm



Stratospheric Water vapour Assimilation Met Office/DARC

- Previously untried
- Ill-conditioned vertical transform of background error covariance matrix B
- Unrealistic stratospheric increments
- Met Office: Run 3D-VAR experiments for 1 cycle

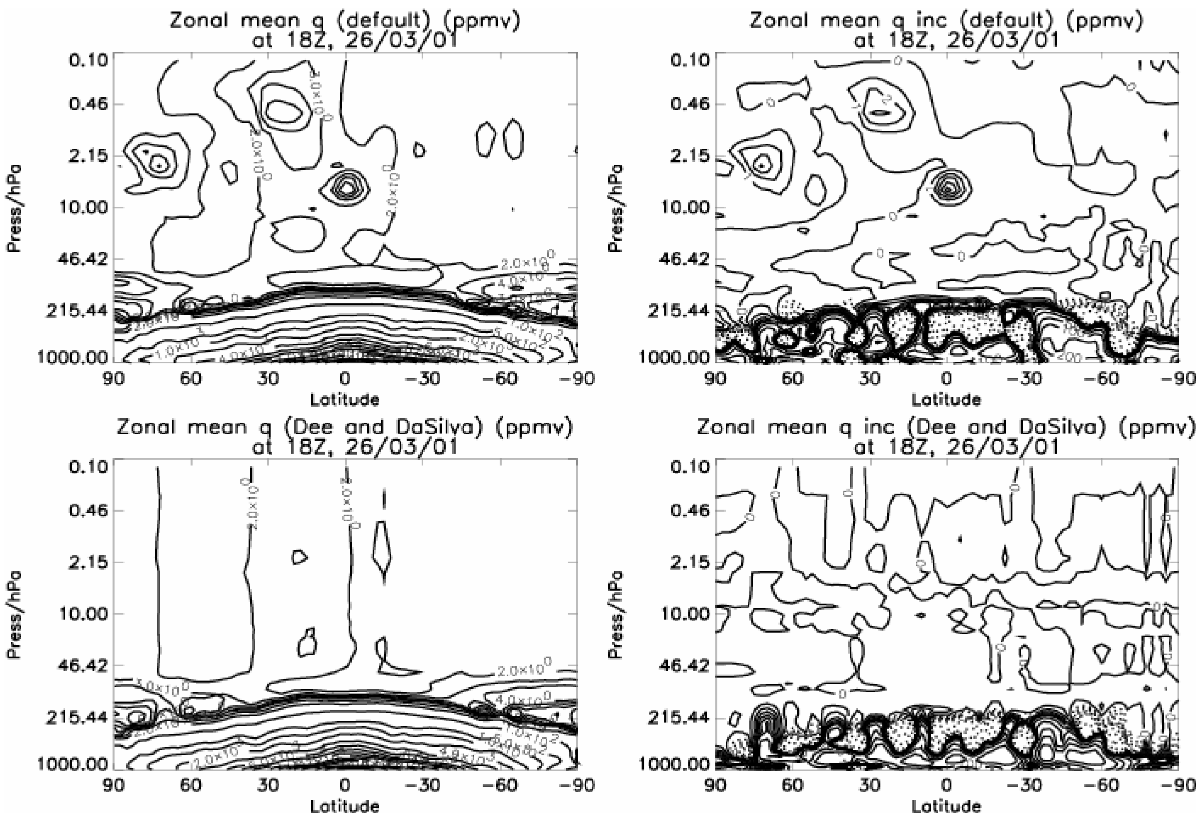
Impact of Dee and da Silva

Courtesy Met Office

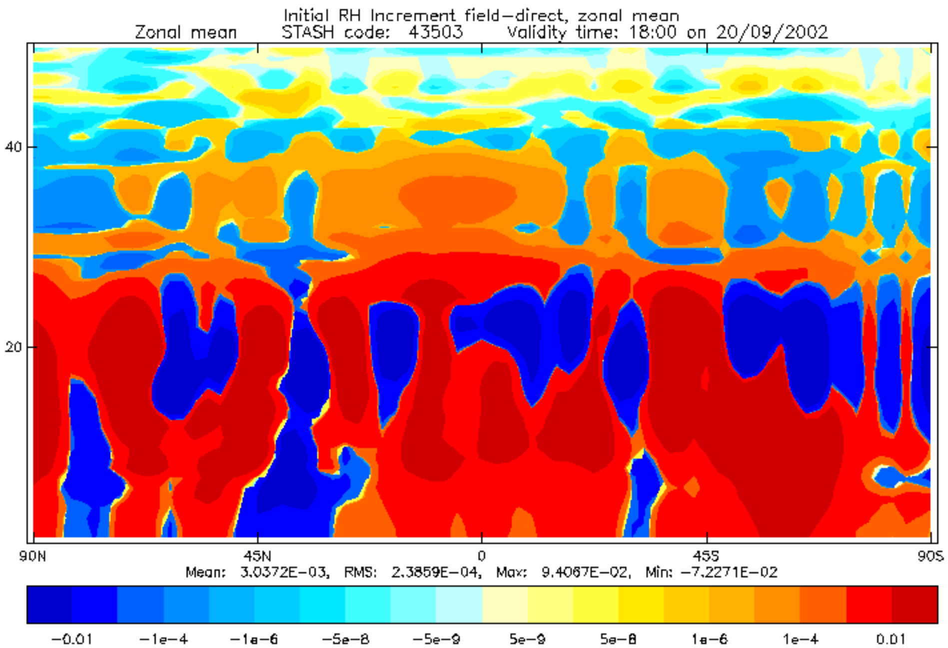
q analysis — q increment

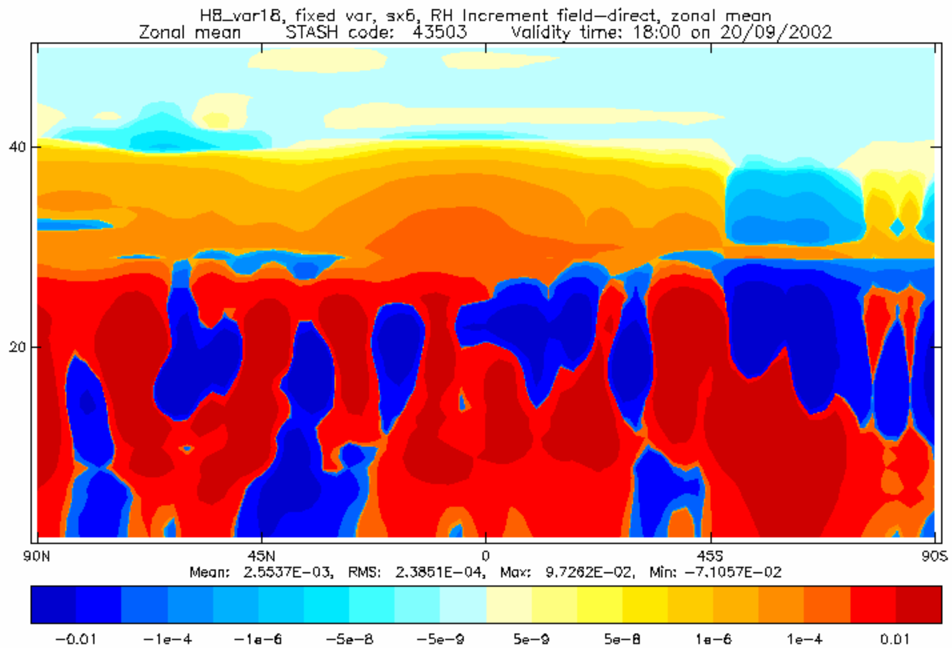
Default

Dee and da Silva (2003)



RH increments



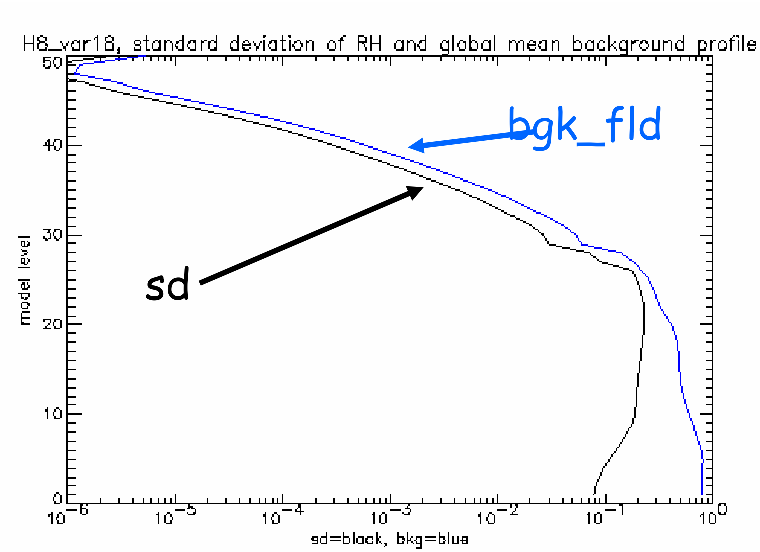


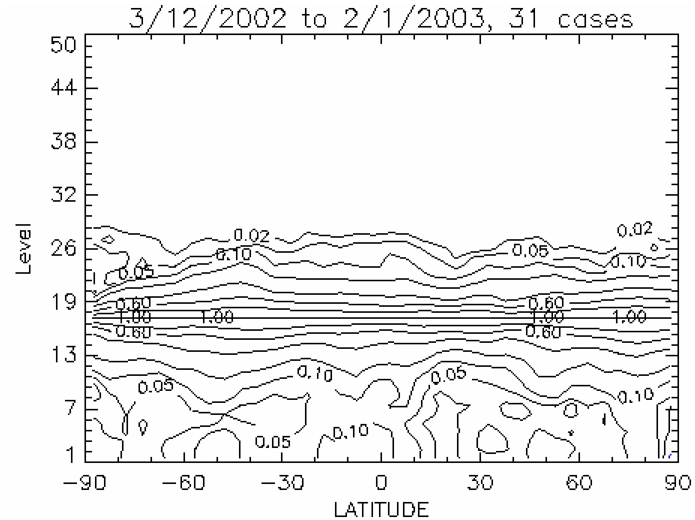
After a single 6-hr var cycle

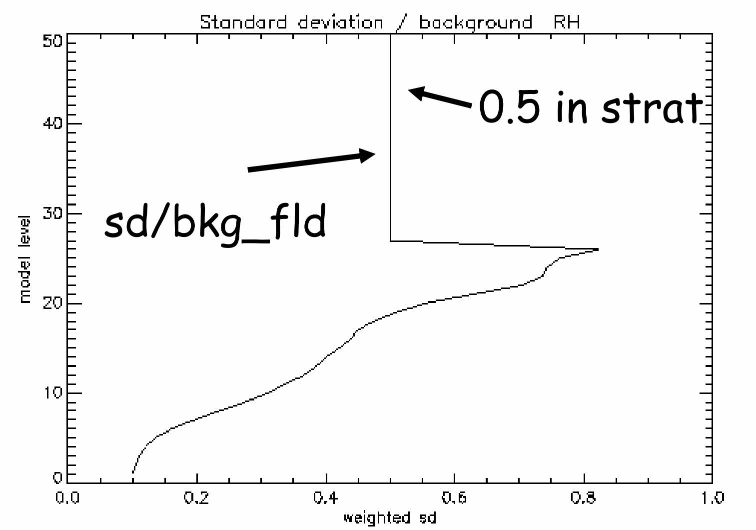
After 18-hr, with “best case” scaling:
Correlation & variance scaling to **B**
Dee & da Silva humidity variable
Scaling-> more weight to strat

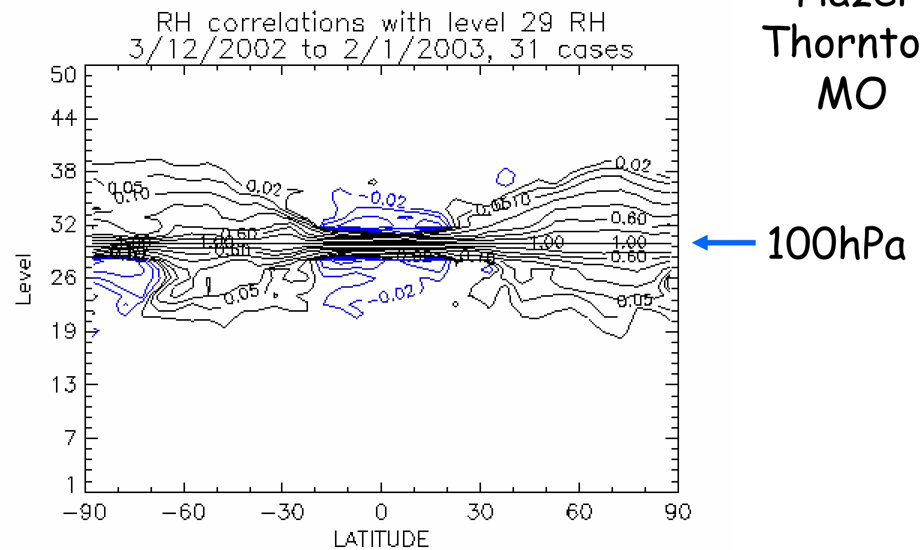
Courtesy Hazel Thornton (MO)

Scaled RH variances (LH) & vertical correlations (RH)









Courtesy
Hazel
Thornton
MO

Observing System Experiments (OSEs):

- Apply to MIPAS ozone & water vapour (also temperature)

  -> analyses of key species

  -> Envisat cal-val

  -> strategy for assimilating Envisat data, or from other satellites (ASSET: http://darc.nerc.ac.uk/asset) :
  compare different methods, e.g., photochemistry, radiation or profiles

  -> study ozone & water vapour distribution (ASSET):
  different models & robustness

Conclusions & way forward

- Assimilation of WV in troposphere/stratosphere desirable (radiation/dynamics/chemistry; monitoring) but difficult (WV variability, B matrix, control variable)
- Approaches being tested at DARC/MO & ECMWF (and perhaps elsewhere)
- Retrieval vs radiance assimilation (nadir/limb)
- DA benefits: QC-analyses; cal-val; monitoring; better models