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New techniques to sound the composition of the lower stratosphere and troposphere from space

Presentation by B.Kerridge
on behalf of RAL Remote-Sensing Group

ECMWF Workshop 23-26th June 2003

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1. Background

RAL *Remote-Sensing Group*:

Brian Kerridge
Jolyon Reburn and Richard Siddans
Victoria Jay and Barry Latter

Collaborations:

- RAL colleagues (eg Martin Juckes)
- NERC DARC
  - Reading, Oxford, Edinburgh, Cambridge
  - Co-supervision of doctoral students
- Other groups in UK and Europe
  - ESA, EU & Eumetsat projects

Background (contd)

Expertise:

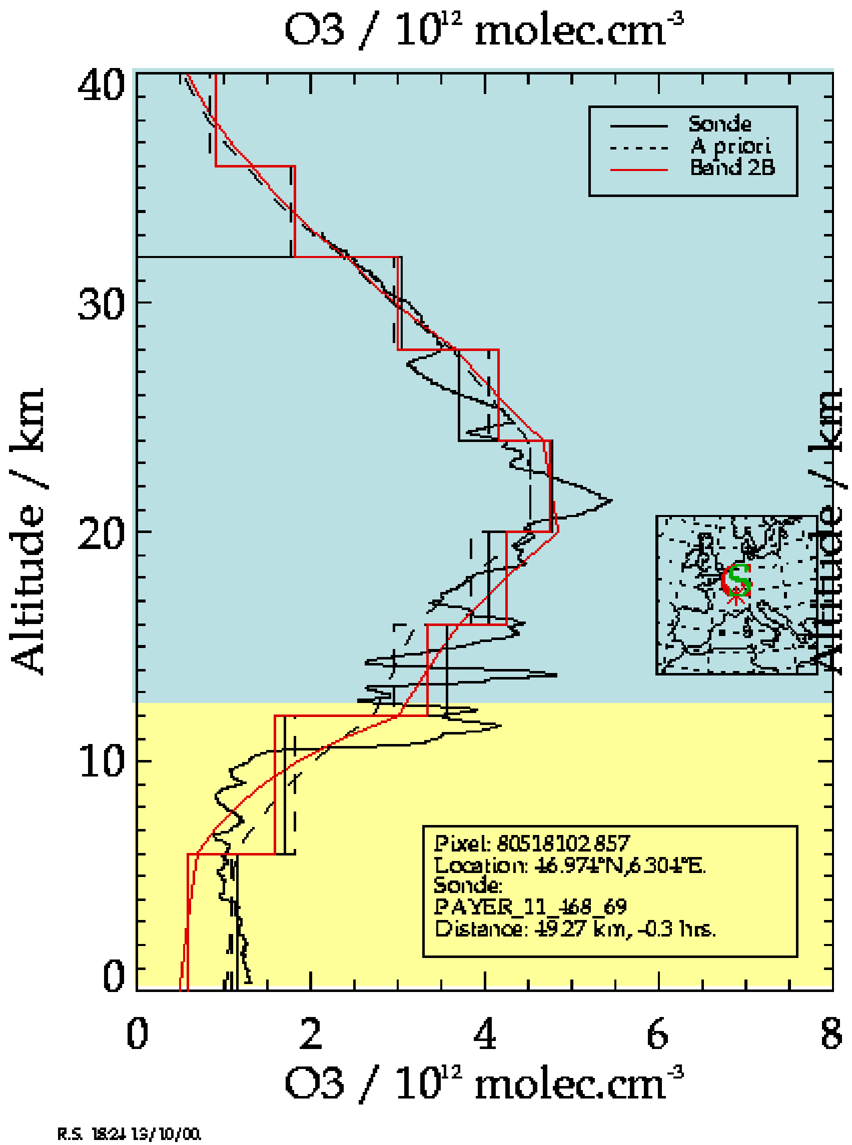
- Development and application of *radiative transfer models* and *retrieval schemes* for *satellite* and *airborne* remote-sensors:
  - Wavelengths from UV through IR to mm-wave
  - Nadir-, limb- and slant-viewing
- Processing, validation and scientific interpretation of data
- Retrieval simulations to define and optimise new sensors

Scientific Focus:

- Composition of troposphere & lower stratosphere
- Interactions with climate via radiative forcing & feedback (eg O_3 & H_2O), transport (eg O_3 & H_2O) and chemistry (eg O_3 & CO).

➢ *Aim: To produce novel data-sets on tropospheric and lower stratospheric constituents of importance to global change*.

2. Ozone profiles from GOME



1. Stratospheric Ozone Profile

- Hartley band (260-306 nm)
- Opacity strong & wavelength dependent

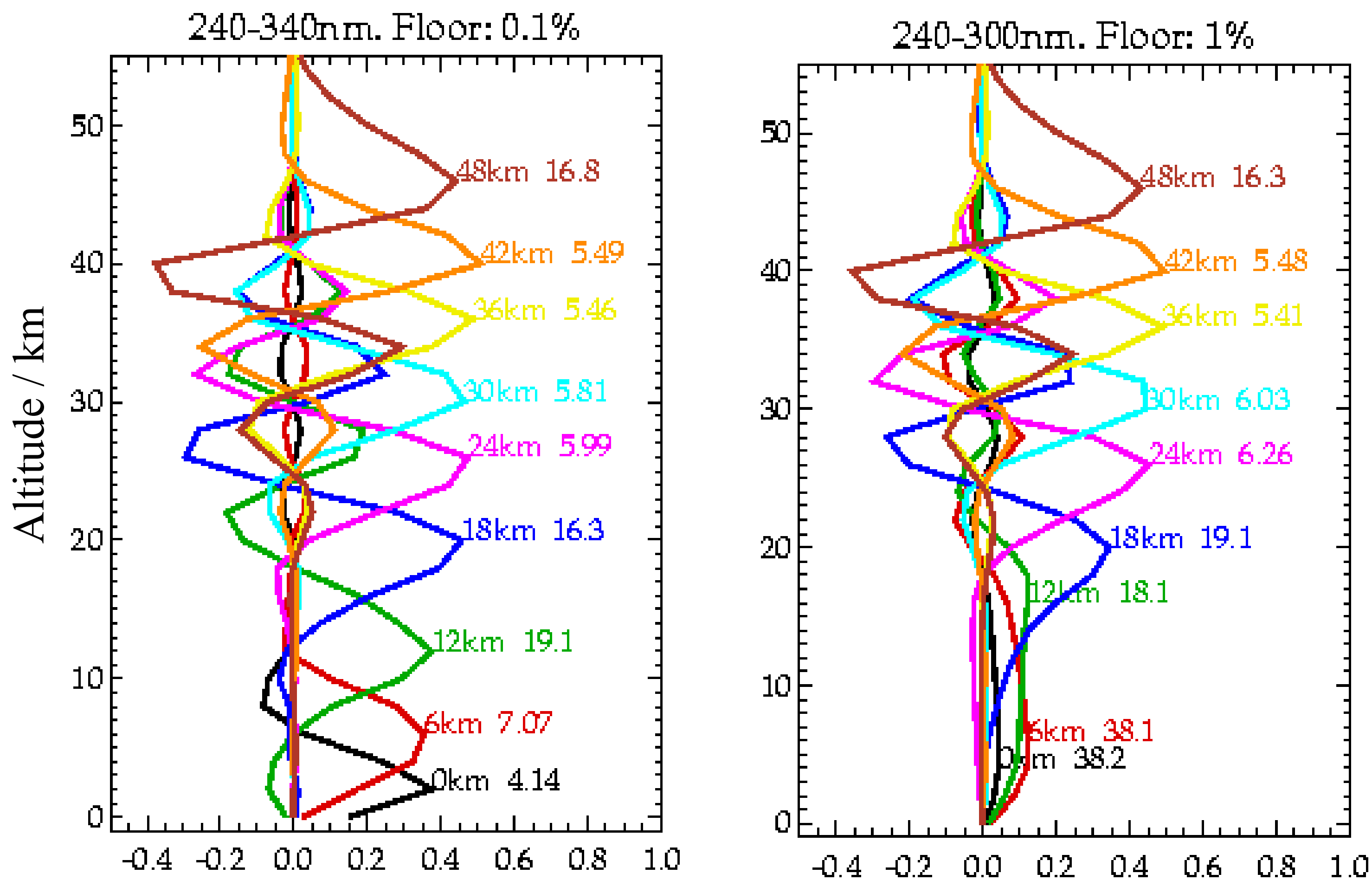
2. Lower Stratosphere + Troposphere

- Huggins bands (324-335nm)
- Temp. dependent cross-section
- Vertical temperature gradient
- Relies on differential structure not absolute calibration

RAL RSG first to use from space instrument

Composite O_3 Averaging Kernels

Band 2 + Band 1 | Band 1 only



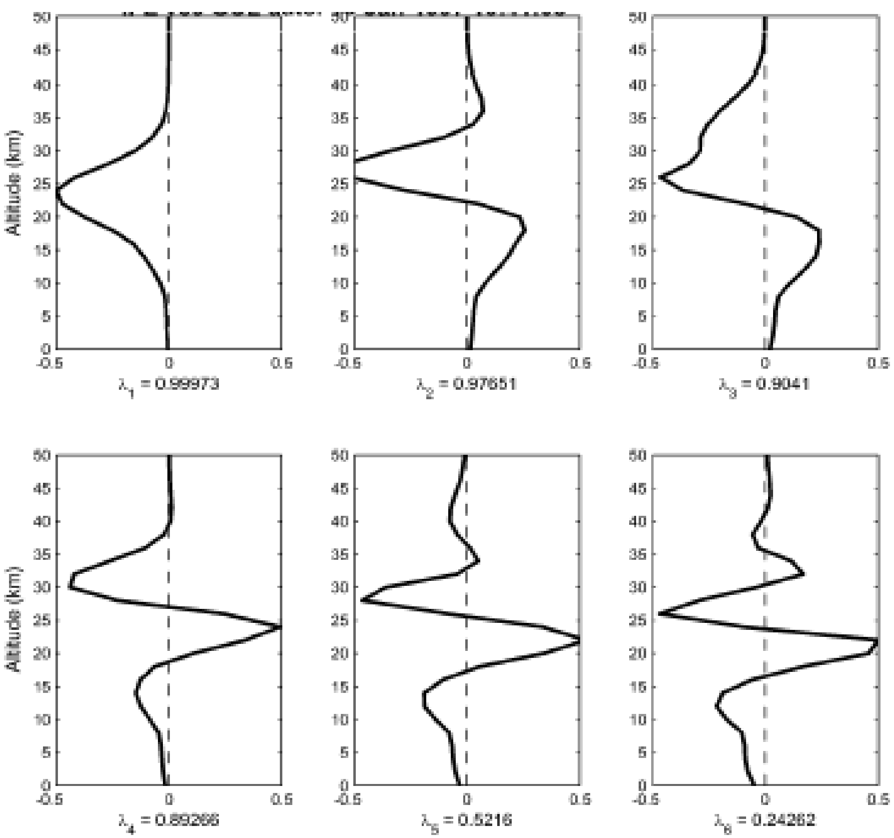
A priori uncertainty 100% at all levels

AK Eigenvectors and values : IFE & KNMI

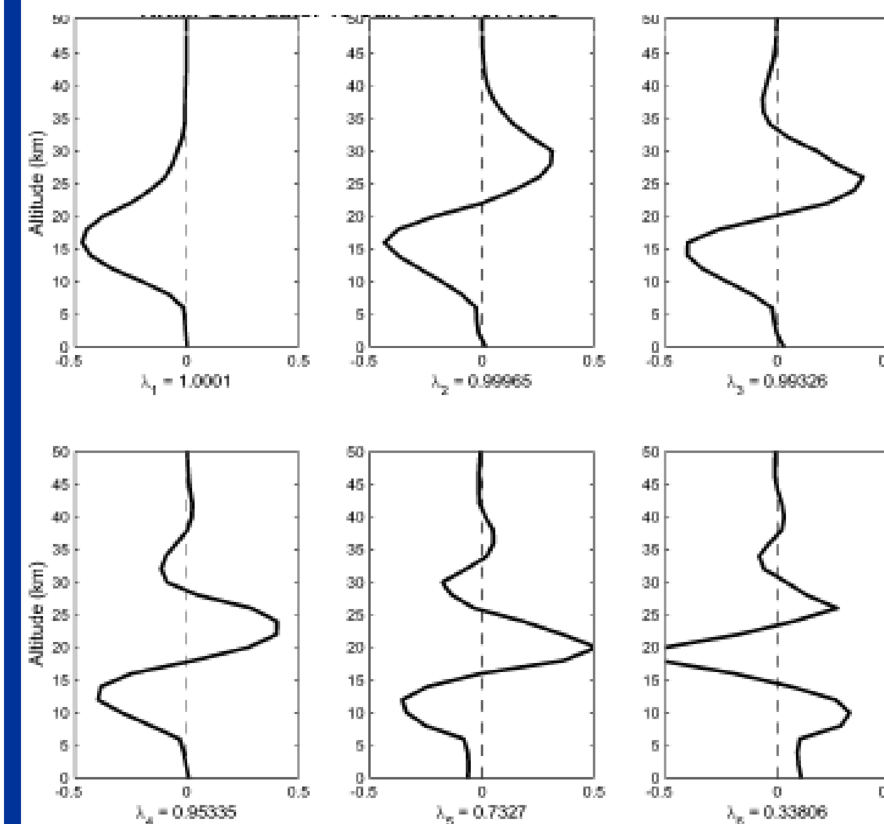
BIRA-IASB

6 highest eigenvalues

IFE v50 GCL



KNMI GCN



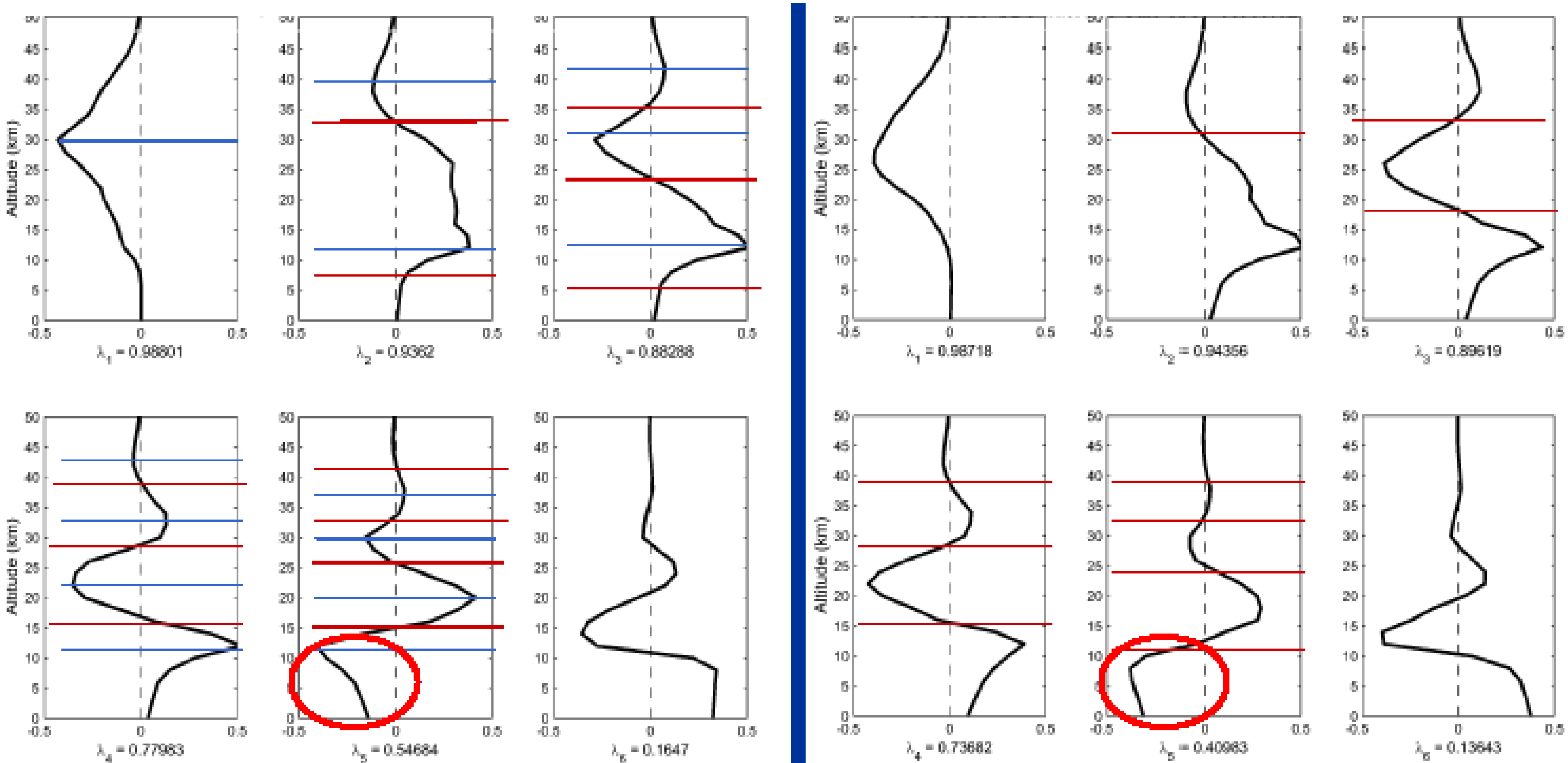
13-Jan-1997 10:41:12 (50.85°; 3.57°)

Vincent.Soebijanta@iasb.be

AK Eigenvectors and values : RAL

BIRA-IASB

RAL v21 GD0 6 highest eigenvalues **RAL v20 GD0**



13-Jan-1997 10:41:12 (50.85°; 3.57°)

Next phase: to intercompare with ozonesondes exhibiting tropospheric O_3 excursions

Processed Data

- O_3 profiles available at www.badc.rl.ac.uk
- Sub-sets of GOME data 1995-9 processed for a variety of applications (>30 users)
- Validated against ensemble of sondes
- Seasonal climatology produced from 1995-8 data (R.Siddans PhD thesis, 2003)

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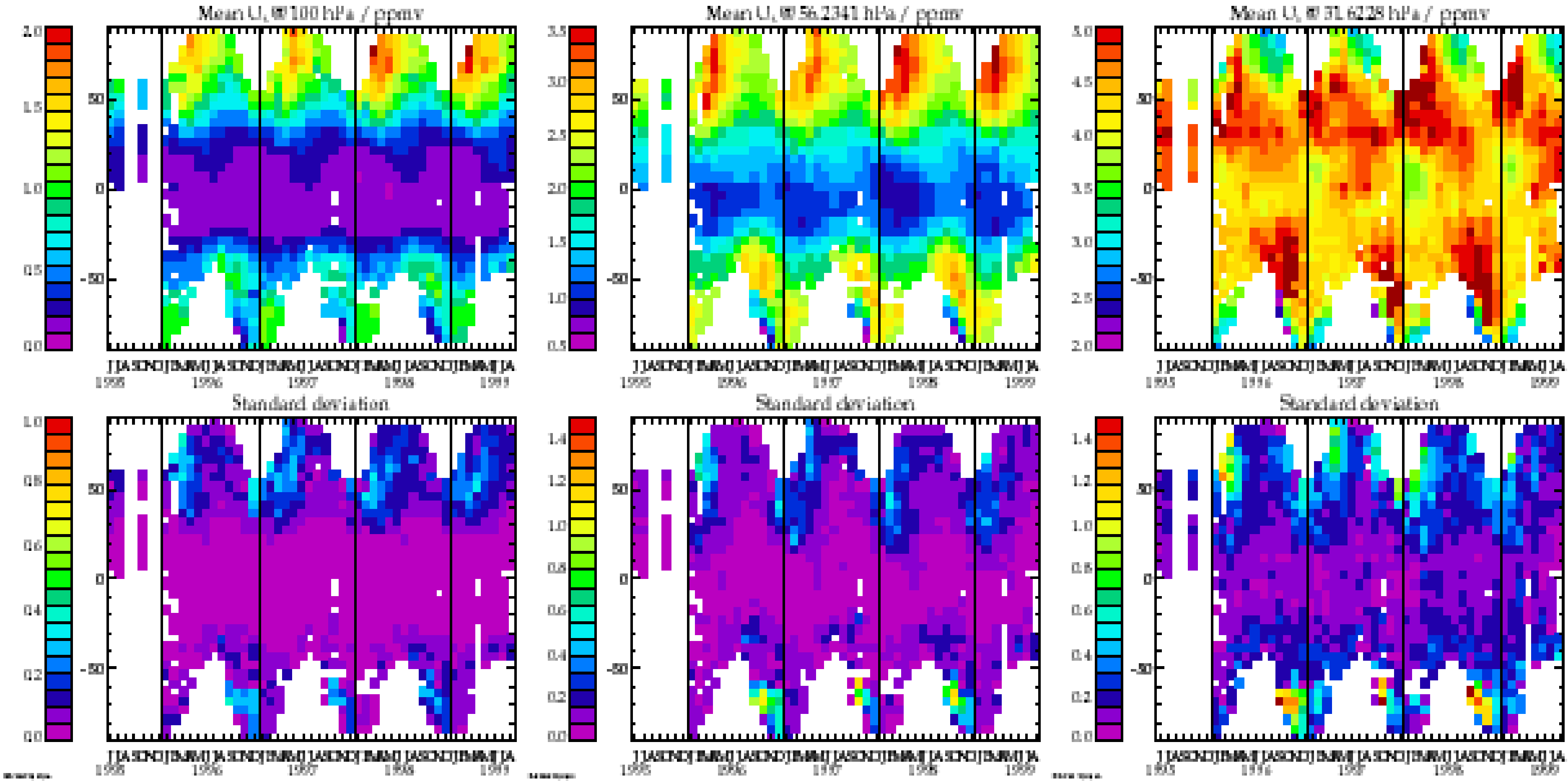
Zonal-mean time series 1995-9



1 or more days per month sampled from Jan’96
3 days per month *narrow-swath* from Apr’98 – Mar’99

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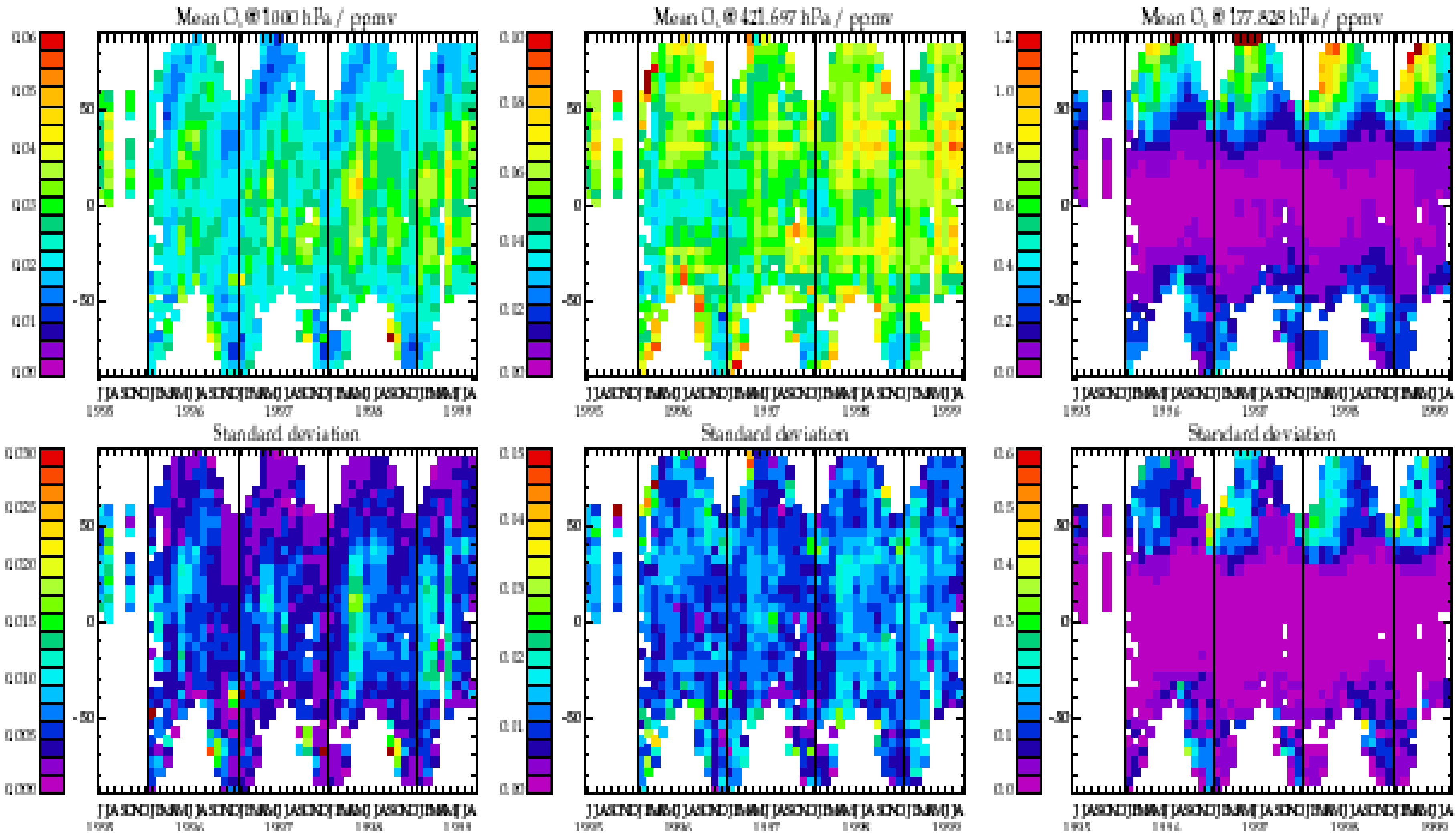
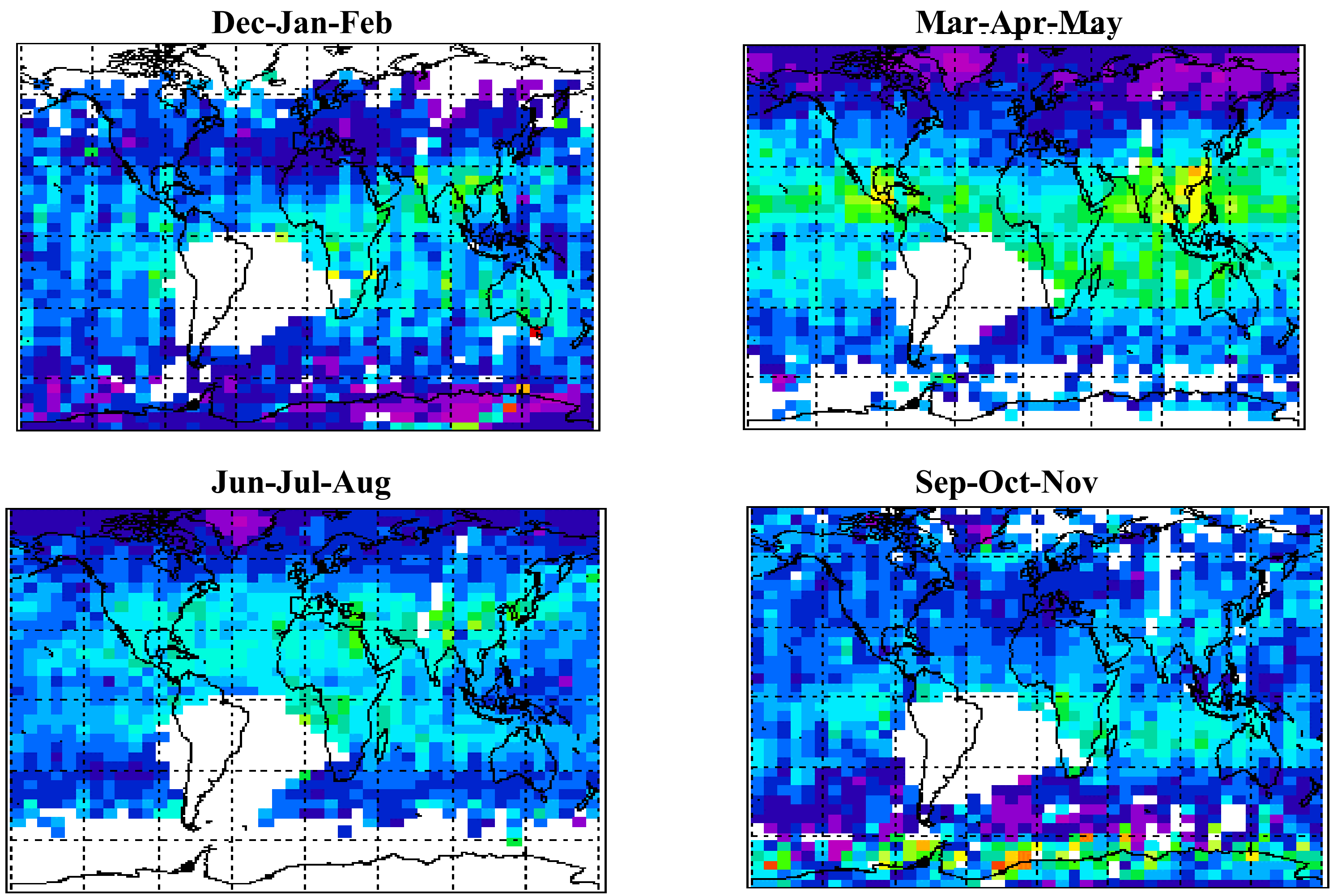
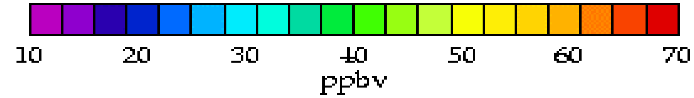
Zonal-mean time series 1995-9



Only cloud-free ground pixels selected

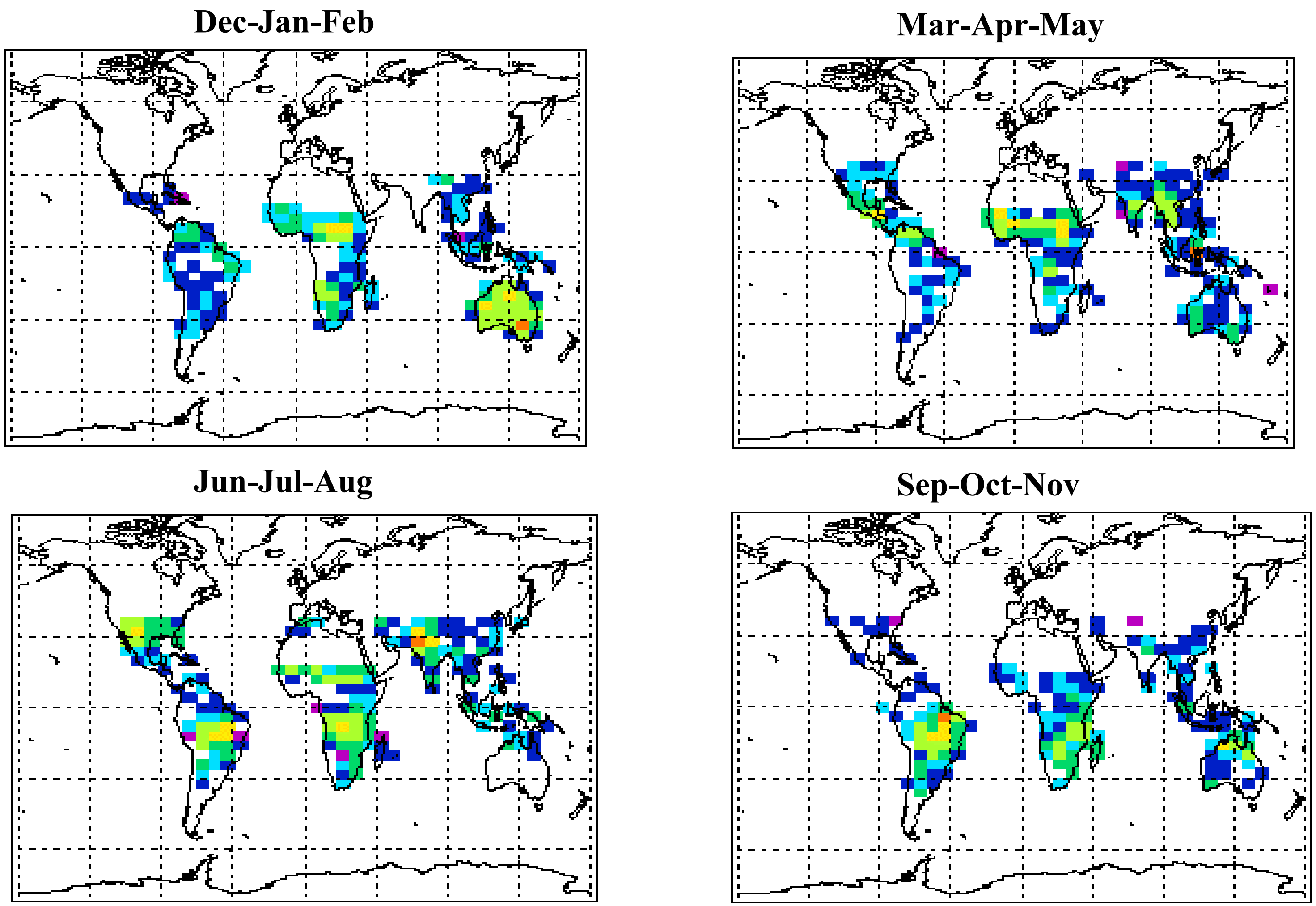
Seasonal Climatology 1995-98



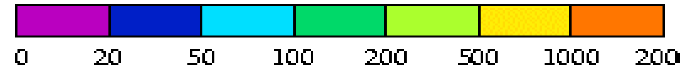


Lower Tropospheric O_3

Seasonal Climatology 1995-98

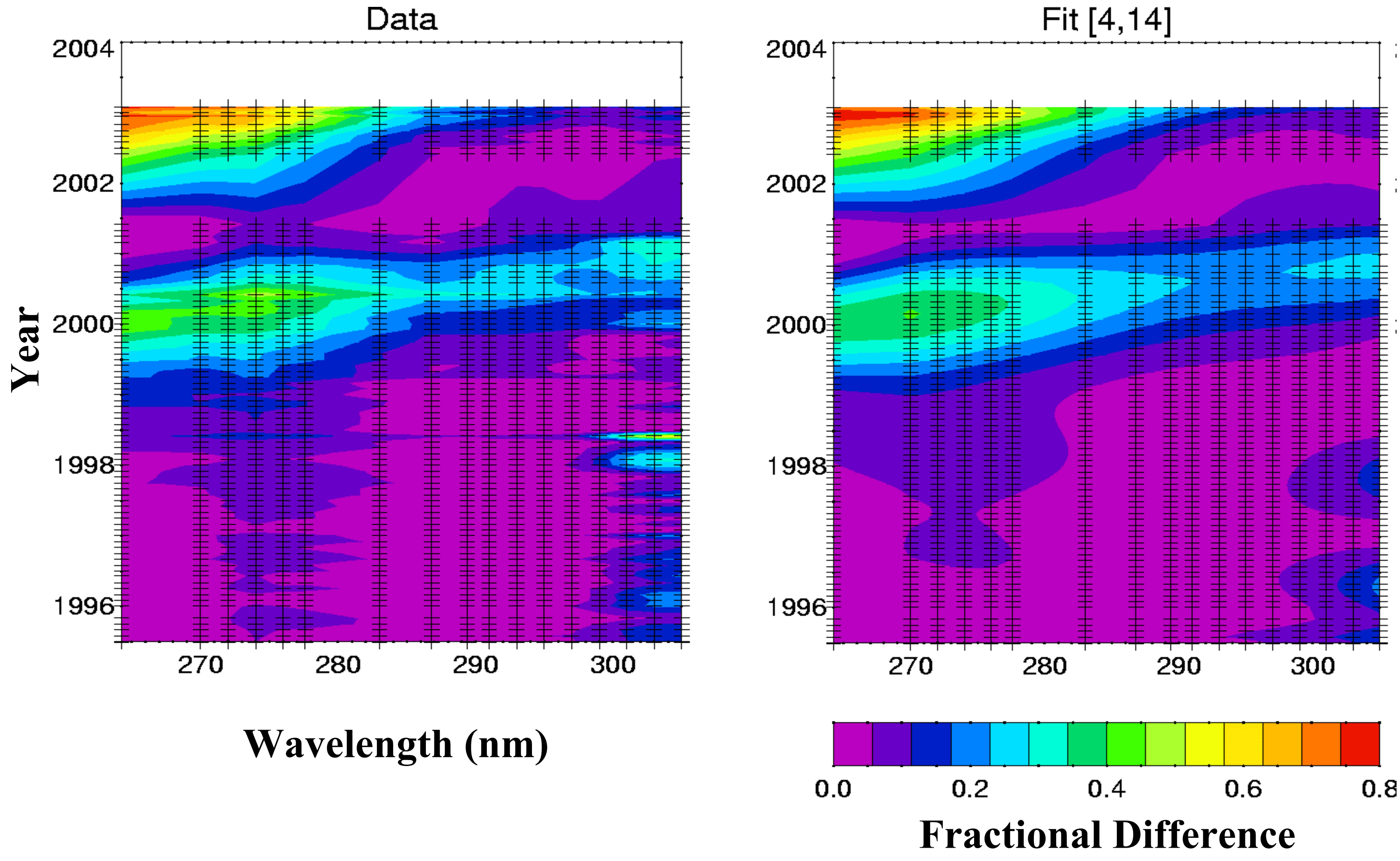


TRMM fire count 1997

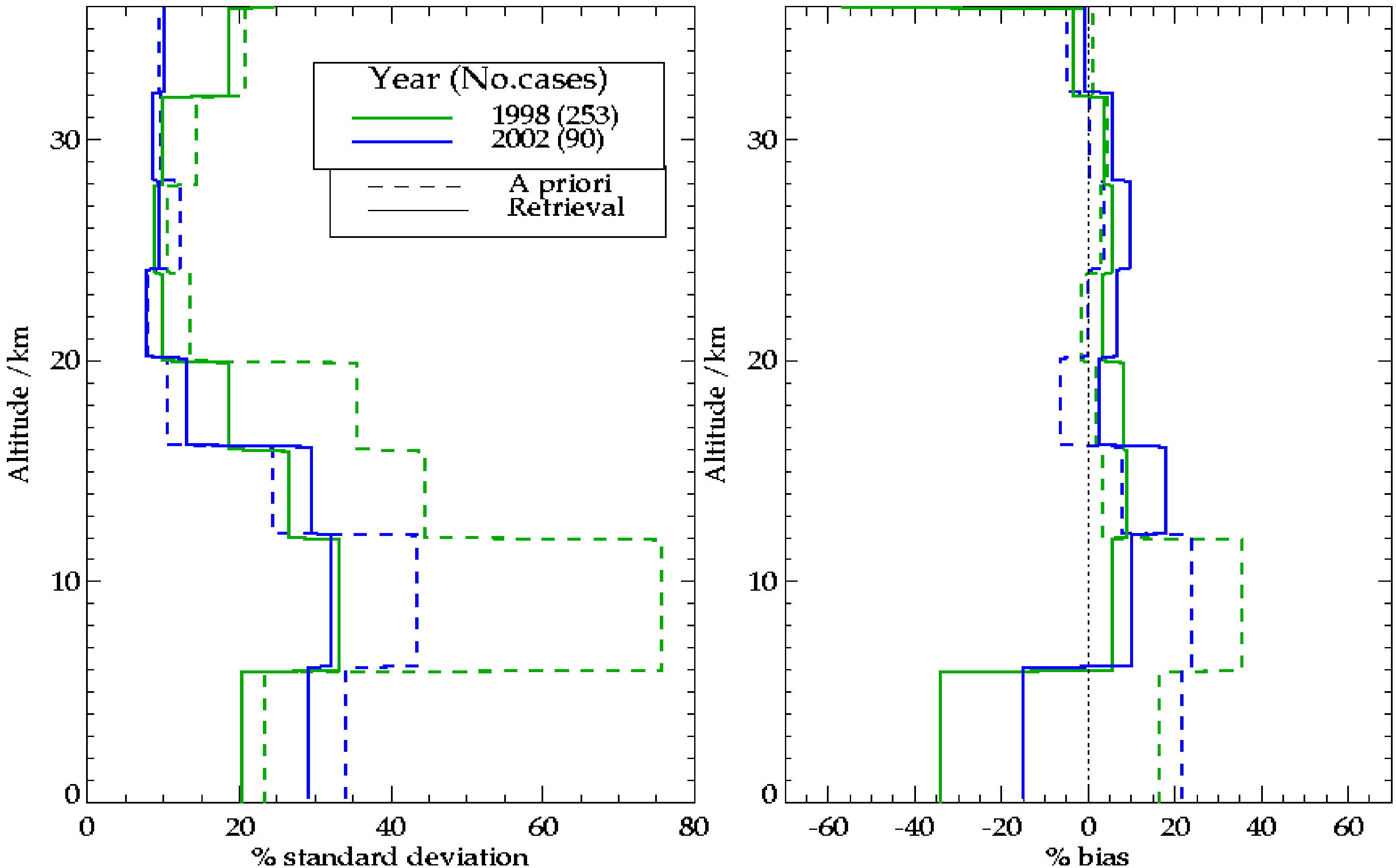


Change in Scan-Mirror UV Reflectivity

- Correction needed in Band 1 after 1998 to retrieve O_3
- *Empirical* scheme devised assuming climatology in RT



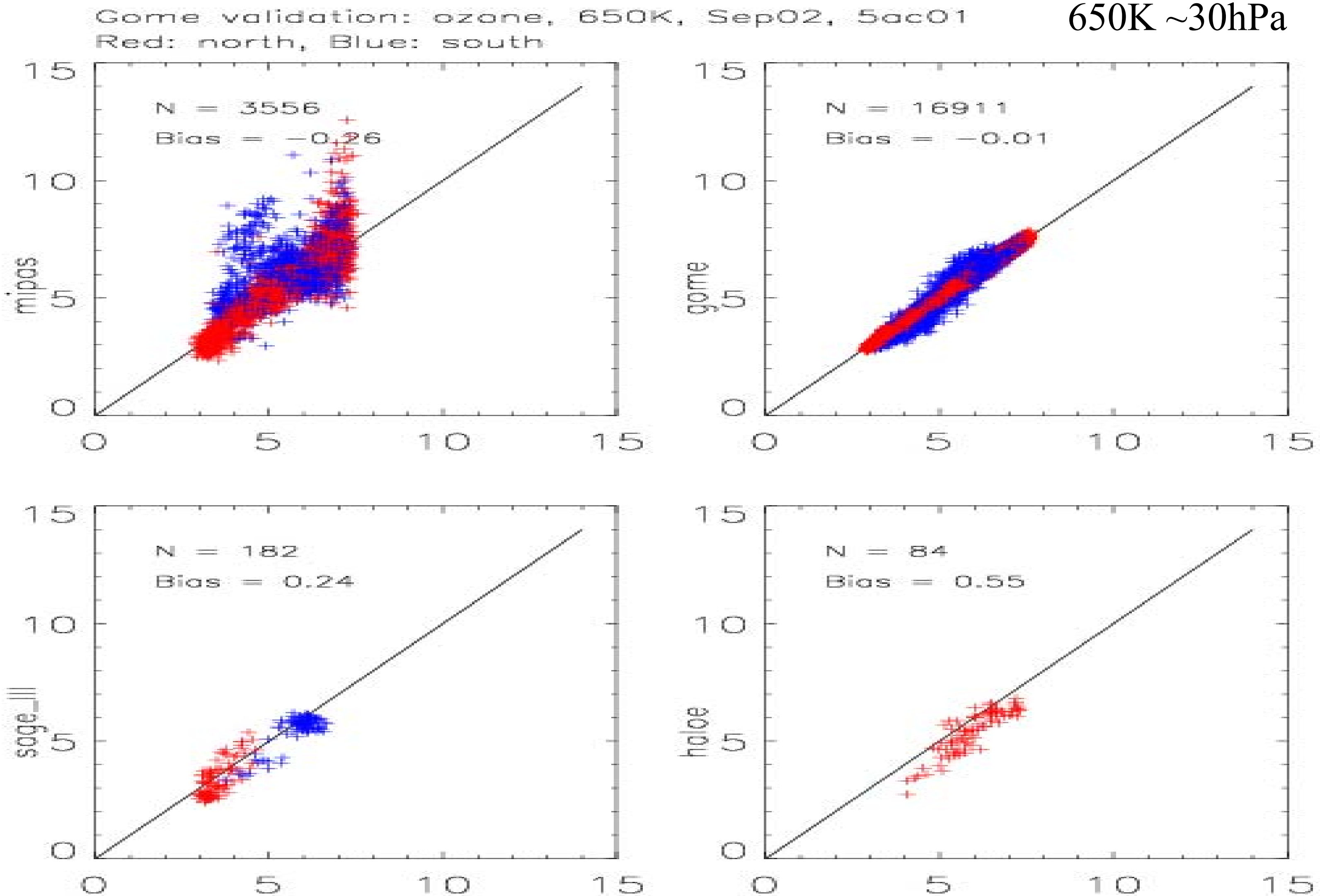
Ozonesonde comparisons before and since scan-mirror uv degradation



- Only *cloud-free* GOME scenes selected
- N.Hem winter/spring not sampled in 2002, so *a priori* variance much lower

Comparison of assimilated GOME to SAGE-III, HALOE and MIPAS profiles

650K ~30hPa



- Assimilation on 650K surface using ECMWF winds (splitting vortex) by M.Juckes

Processing the 8-year Mission

- Degradation correction satisfactory
- Increase (x3) in efficiency recently achieved.
- Aim: to process the 8-year mission within a 12 month period.

  →Interannual variability in troposphere & LS
- Cloud/surface properties to be produced for GOME from ATSR-2 in parallel project.

3. Limb-nadir Synergy

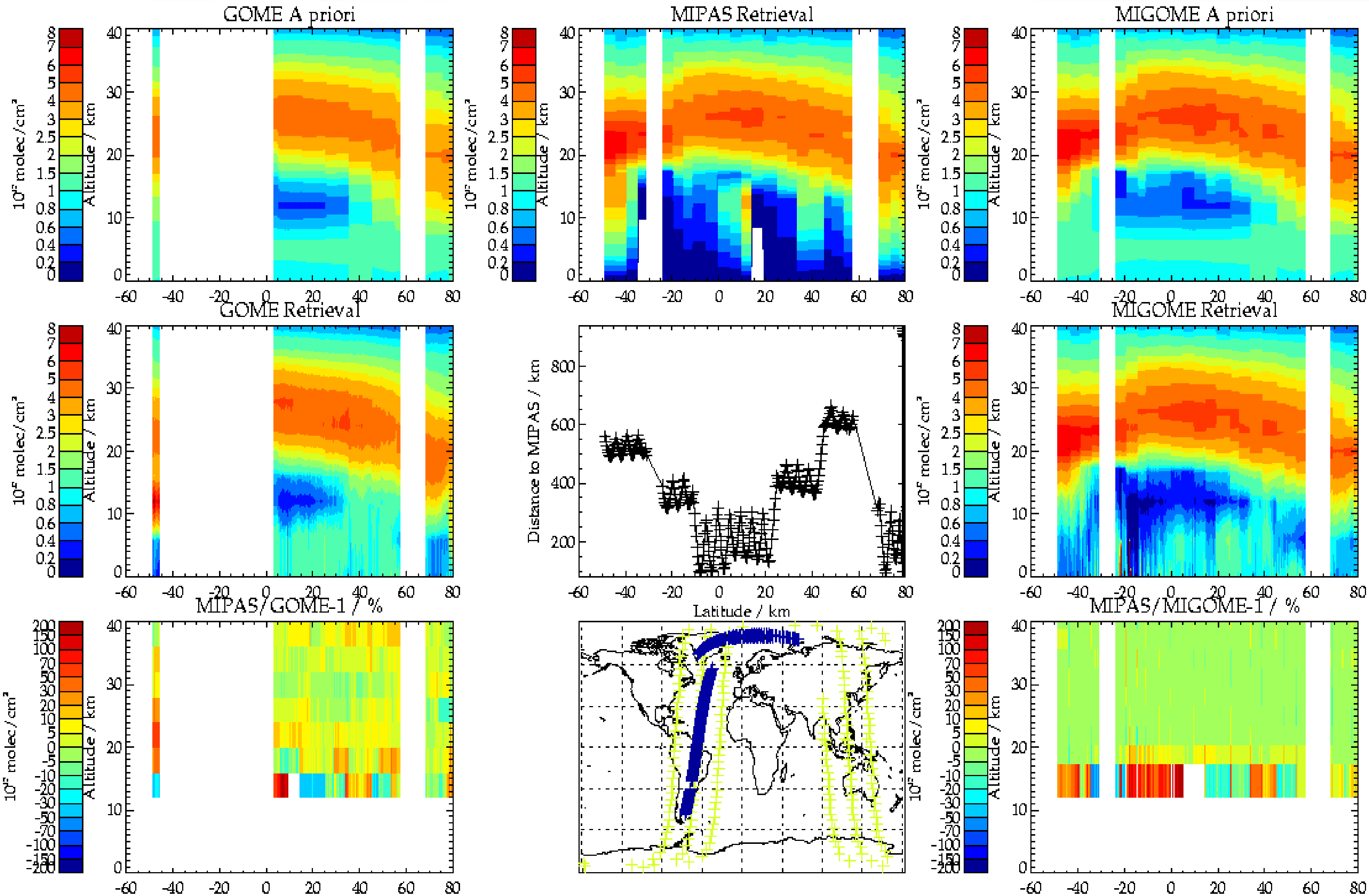
Purpose: Constrain GOME O_3 retrieval with stratospheric information from MIPAS

- In stratosphere, MIPAS L2 agrees with standard GOME retrieval to +/-10% (MIPAS vertical res lower than anticipated)
- In upper troposphere, MIPAS contaminated by cloud
- Two GOME Band-2 retrievals:
    1. GOME Band-1 as *a priori* (standard)
    2. MIPAS L2 product as *a priori* <100hPa

- Combined MIPAS-GOME retrieval:
    – follows MIPAS *a priori* in stratosphere
    – is not affected by cloud contamination in UT cf MIPAS
    – follows standard GOME retrieval in troposphere
    – covers south Atlantic anomaly (unlike GOME Band 1 retrieval)

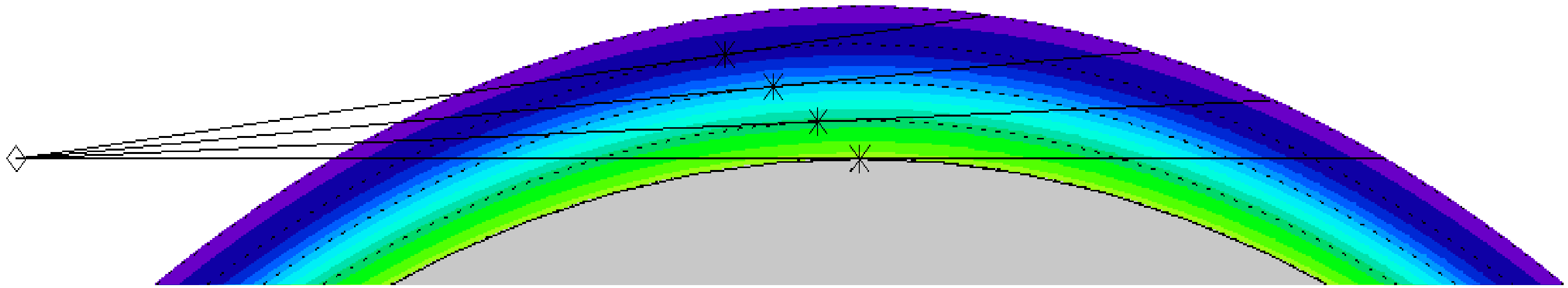
→ Satisfactory first demonstration of *limb-nadir synergy* in retrieval domain

MIPAS – GOME Synergy



4. Tomographic Limb Sounding

- Conventional limb-sounding assumes *spherical symmetry*:



  - at best, retrieved profiles average the true field;
  - at worst, retrievals compromised by inconsistencies between observed and modelled radiances

- *Tomographic* limb-sounding intended to address these problems

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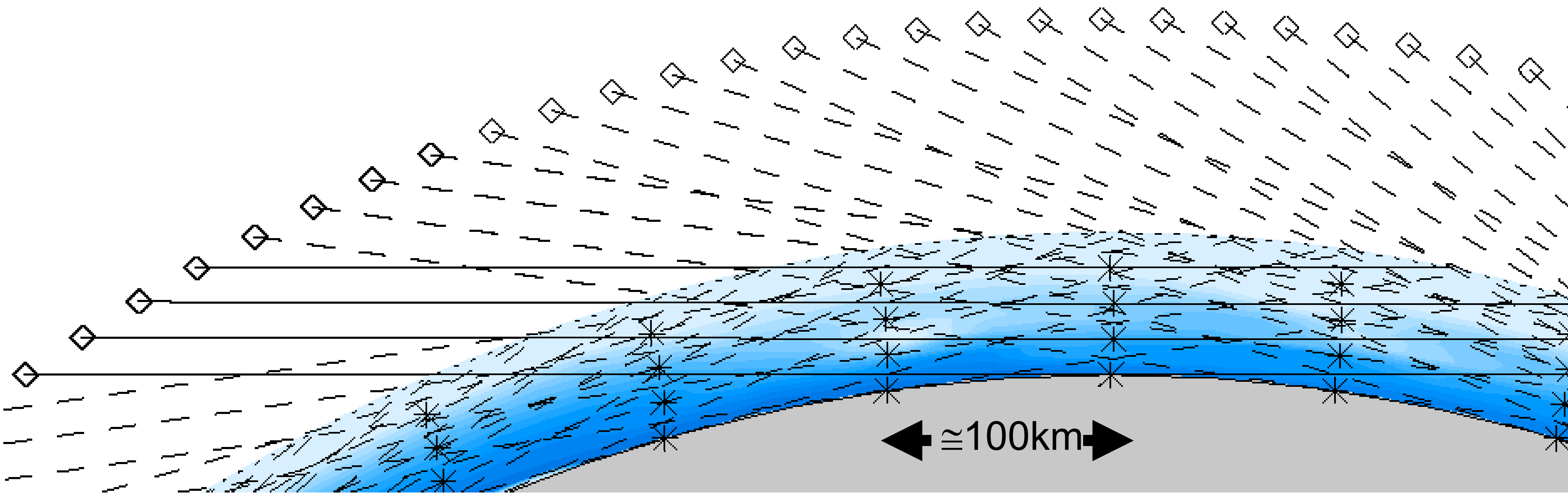
4. Tomographic Limb-Sounding Principles

- Assumption of spherical symmetry dropped in favour of fully 2-D RTM
- State-vector comprises fields on 2-D grid instead of 1-D profile
- Measurement vector comprises set of limb-scans which are inverted simultaneously
- Limb-scan spacing along-track (<100km) fine enough to *oversample* retrieval grid
- Given air volume viewed from many different directions -> *tomography*

Tomographic Limb Sounding



Practical Considerations

Iterative solution to *Optimal Estimation* equation:

$$x_{i+1} = x_i + (\mathbf{S}_a^{-1} + \mathbf{K}_i^T\mathbf{S}_y^{-1}\mathbf{K}_i)^{-1}\,\mathbf{K}_i^T\mathbf{S}_y^{-1}[y-F(x_i)]$$

- $\mathbf{S}_a$ is *a priori* covariance matrix of $\mathbf{x}$
- $\mathbf{K}_i$ is weighting function matrix w.r.t. $\mathbf{x}$
- $\mathbf{S}_y$ is measurement error covariance matrix

- Memory limitations preclude storage of matrices which have dimension N_y
- Provided $\mathbf{S}_y$ is diagonal, matrices such as $\mathbf{K}^T\mathbf{S}_y^{-1}\mathbf{K}$ can be *accumulated sequentially* on limb-view by limb-view basis
- Since N_x is also large, further matrix manipulation required to make the problem computationally viable.

H_2O 2-D Retrieval for Limb-mm
Linear Diagnostics

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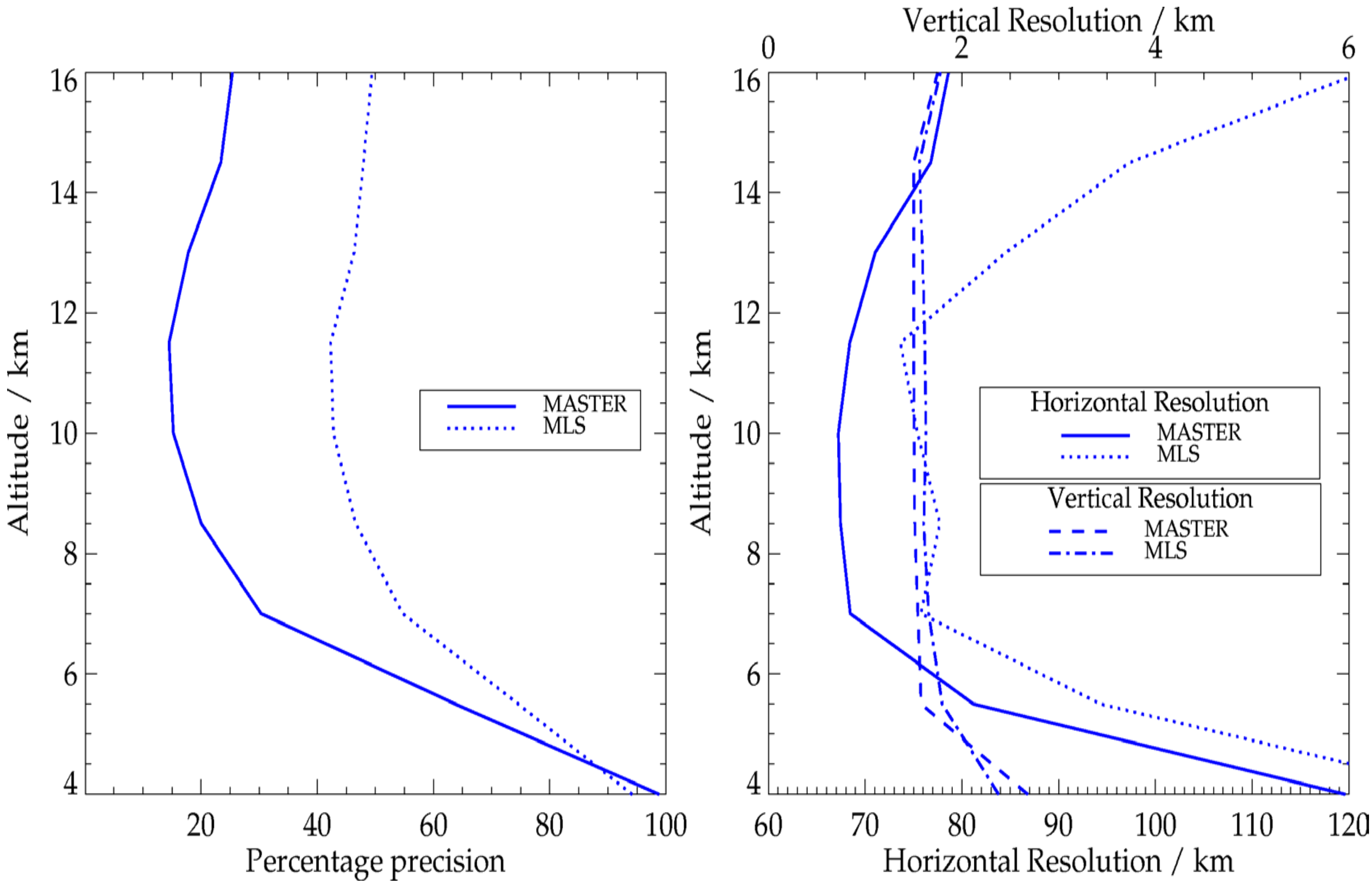
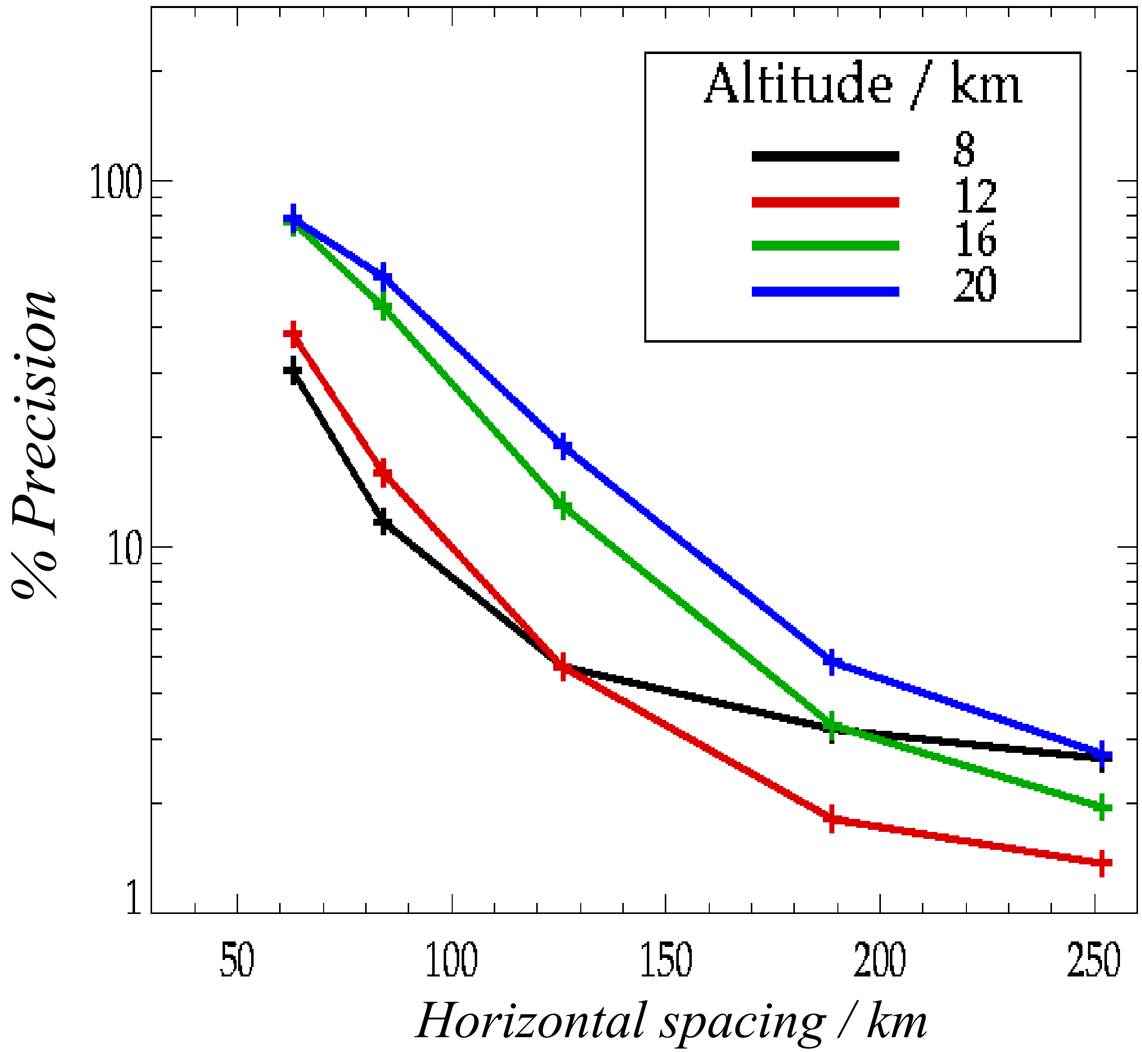


H_2O 2-D Retrieval for Limb-mm
Linear Diagnostics



Iterative 2-D H_2O simulation for mm-wave limb-sounder (MASTER)

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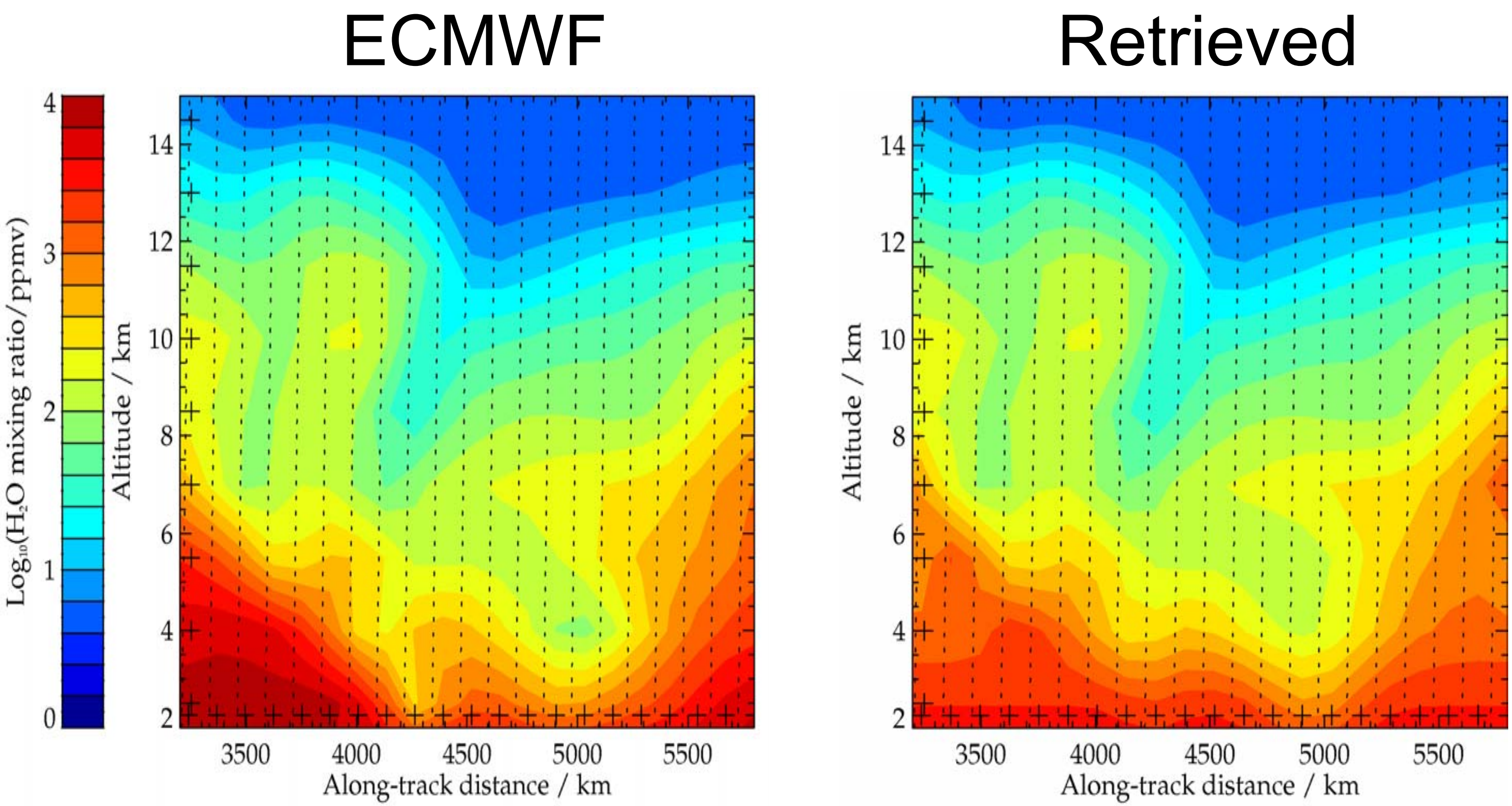
MASTER 325 GHz band



1st guess = *A priori* with no horizontal structure

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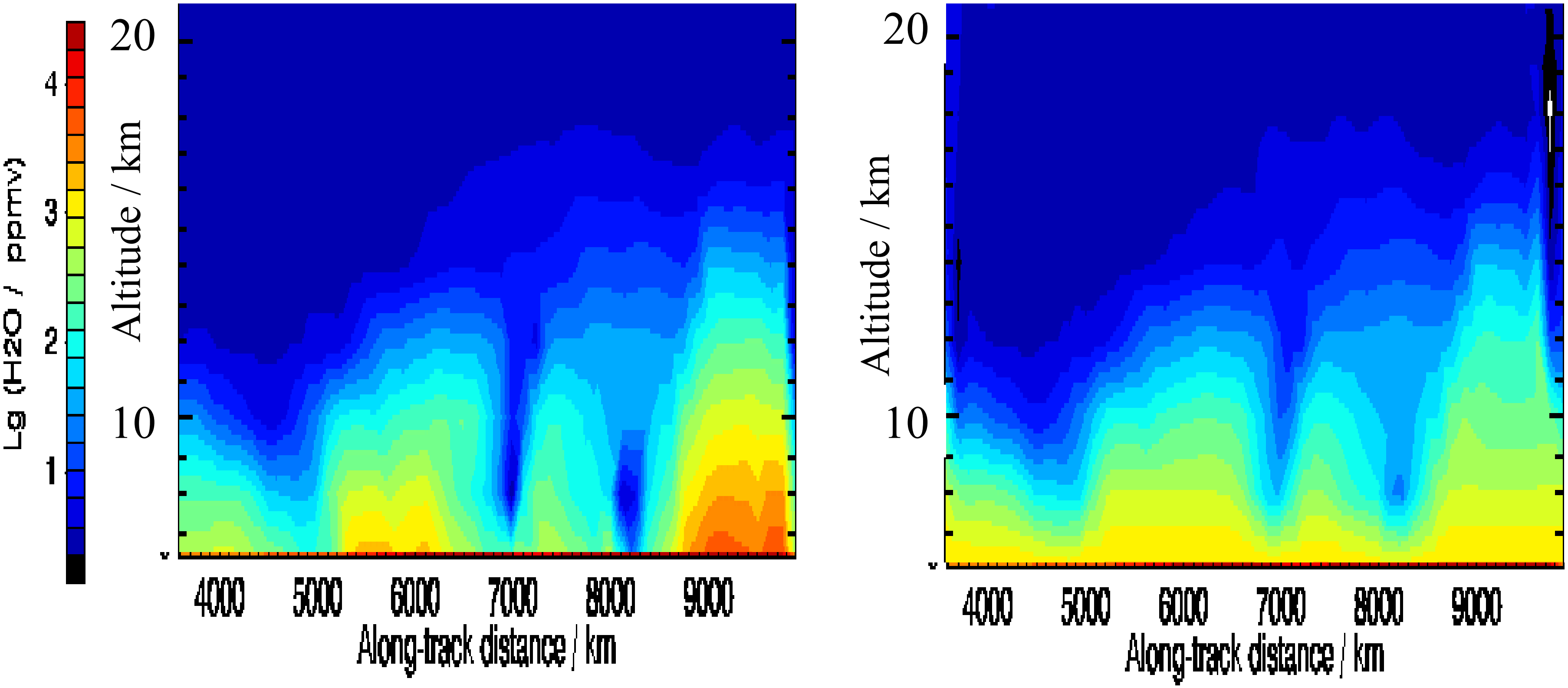
Iterative 2-D H_2O simulation for mm-wave limb-sounder (MASTER)

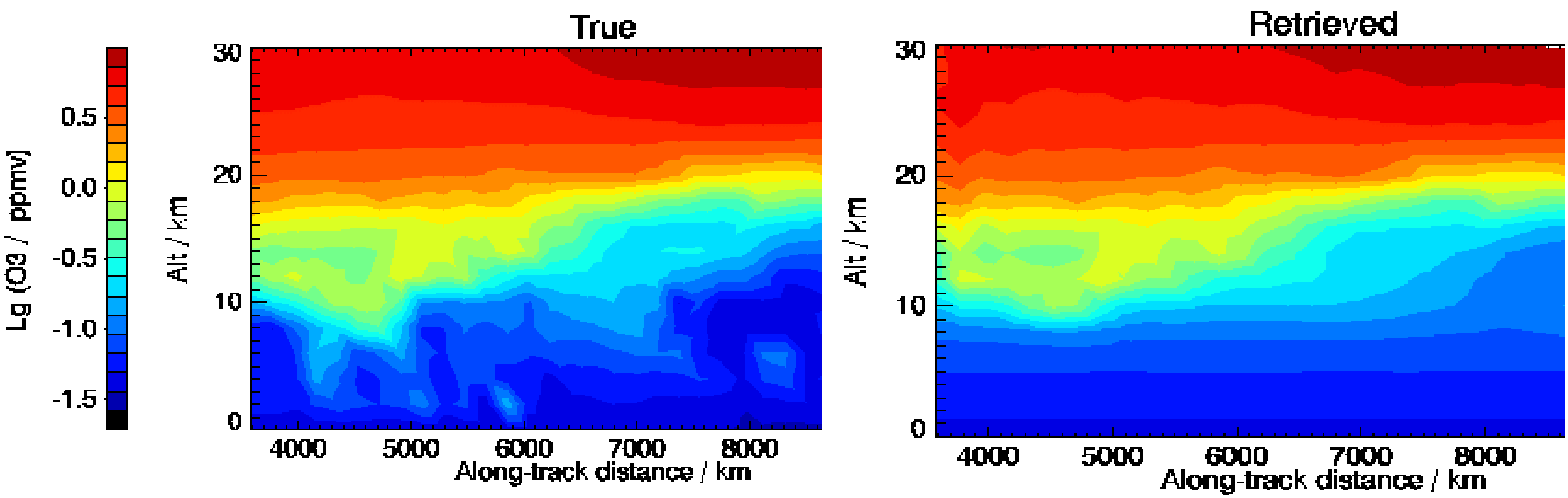


- MASTER 325 GHz band
- Tropospheric penetration limited by limb-opacity, controlled by H_2O

→ Structure recovered with good fidelity up to ~300ppmv

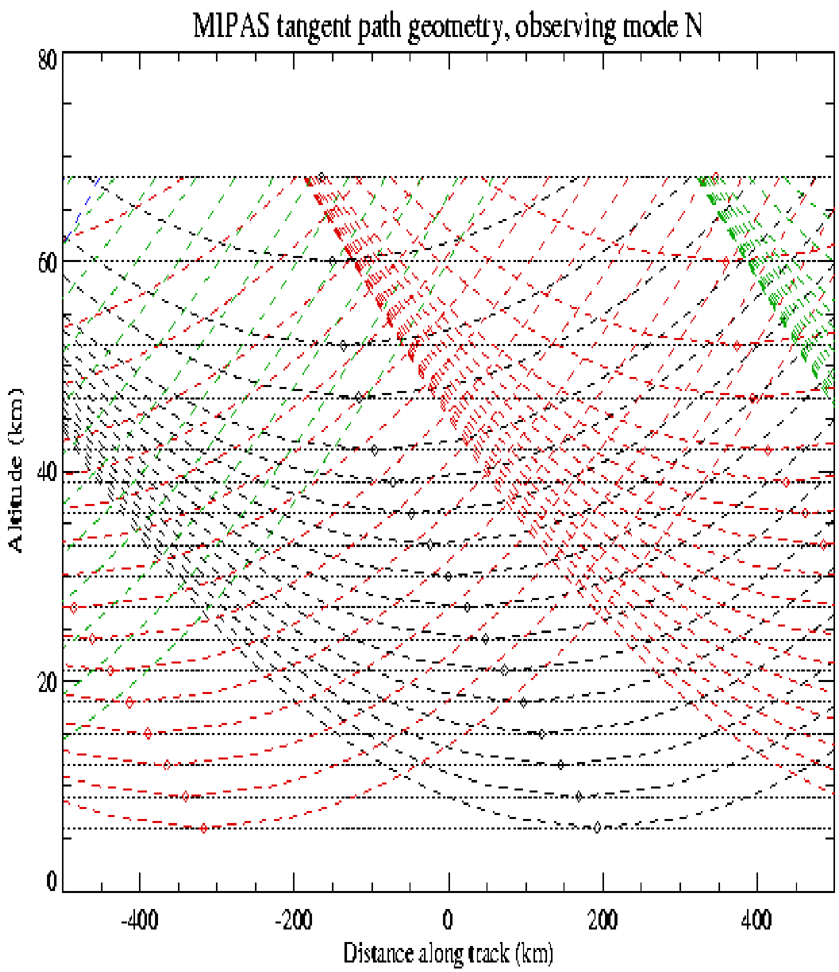
Iterative 2-D O_3 simulation for mm-wave limb-sounder (MASTER)

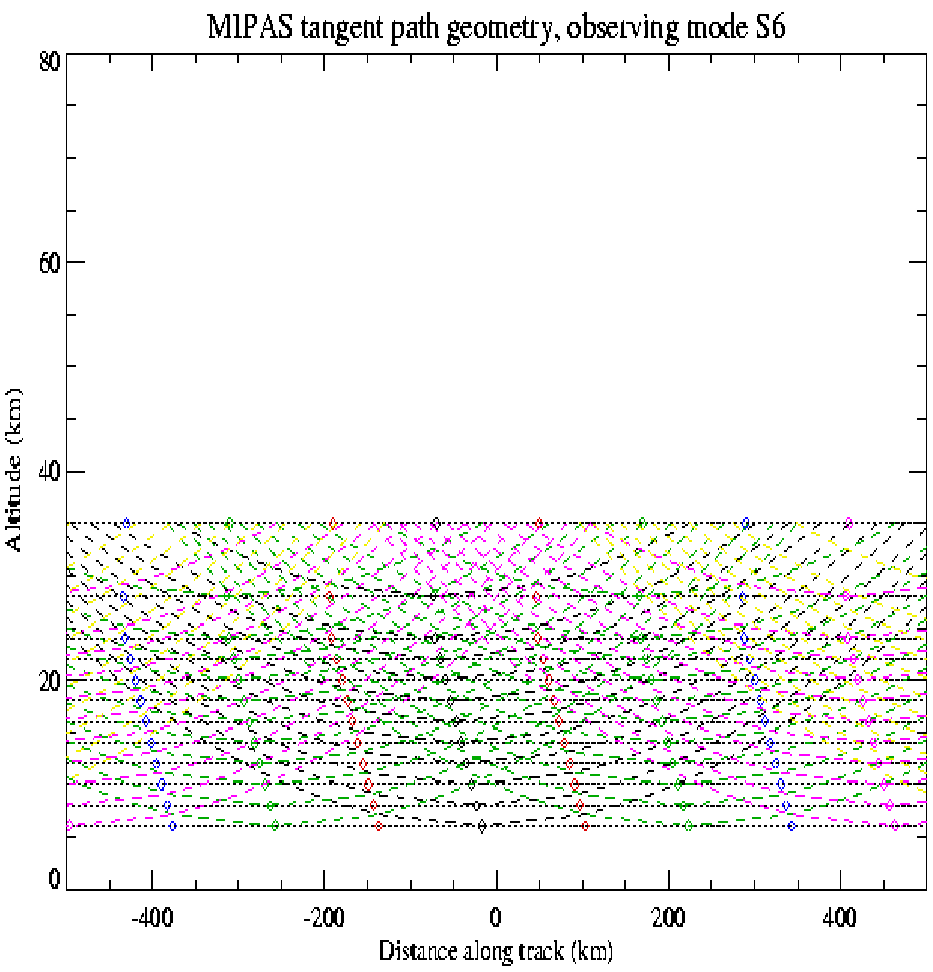
- MASTER 300 GHz band
- Temperature and pointing errors added to synthetic measurements in addition to noise.



- Next step: cloud to be added to simulations

MIPAS Limb-Geometry for Standard Mode and UTLS Special Mode (S6)





Spectral resolution reduced to 0.1cm^{-1} (cf 0.025cm^{-1} for standard mode)

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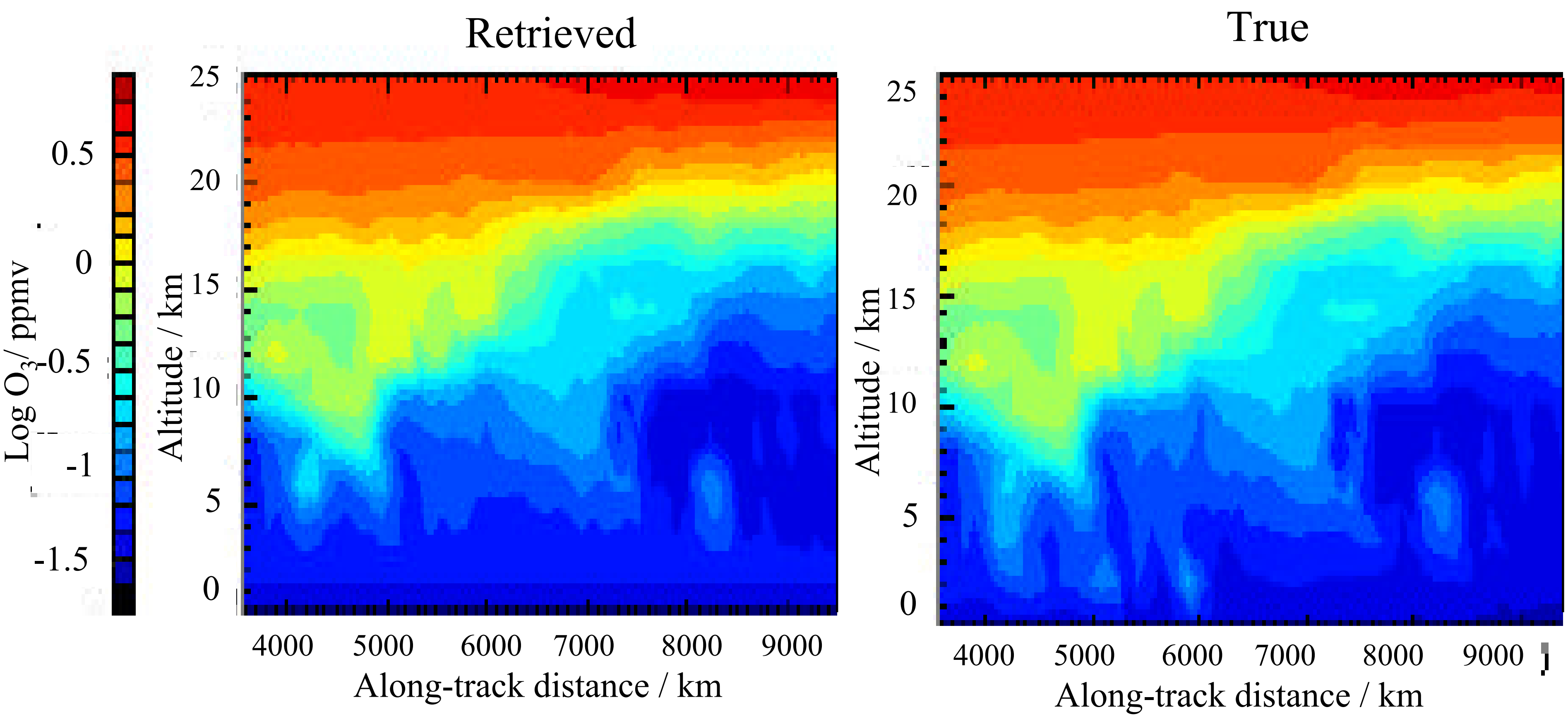
MIPAS O_3 2-D simulation for UTLS Special Mode



- Simulation for S6 mode by M.Parrington (Oxford) using RAL scheme
- No errors except instrument noise.

Summary and Future Work

- Challenge for satellite remote-sensing:
  - to measure global distributions of important trace gases on spatial scales required.
- Different techniques have complementary attributes, eg:
  - measurable species
  - vertical and horizontal resolution/sampling
  - penetration into troposphere
  - susceptibility to obscuration by cloud
- Nadir-viewing required to sound lower troposphere
- Contemporary nadir-uv sounders can retrieve O_3 profiles spanning troposphere and stratosphere.
- Plan to process >8-year GOME mission
- Explore assimilation of profiles & derived quantities

Summary and Future Work (contd)

- Envisat offers the first opportunity to pioneer two new techniques:
  1. Limb/nadir synergy (eg O_3 and H_2O)
  2. Tomographic limb-sounding

  and compare implementations via retrieval and assimilation (eg DARC)
- Next steps at RAL:
  - MIPAS H_2O & O_3 scheme optimised for low altitudes (UTLS)
  - Tropospheric H_2O/aerosol profiling from SCIA-nadir (near-IR)
  - Additional trace gases
- Longer term:
  - GOME-2 & IASI on MetOp offer advances on SCIA-nadir for tropospheric O_3 & H_2O, again in combination with MIPAS
  - Future mission to sound atmospheric composition should exploit these new techniques and advanced sensors (eg mm-wave).