EUMETSAT

DARC

CCLRC
Rutherford Appleton Laboratory

ESA Atmospheric Science Conference 2006

New Developments in the Retrieval of Tropospheric Ozone from GOME, SCIAMACHY and SEVIRI

R. Siddans, B. Kerridge, B. G. Latter, C. Poulsen

Remote-Sensing Group
Space Science and Technology Department
Rutherford Appleton Laboratory

CCLRC Rutherford Appleton Laboratory

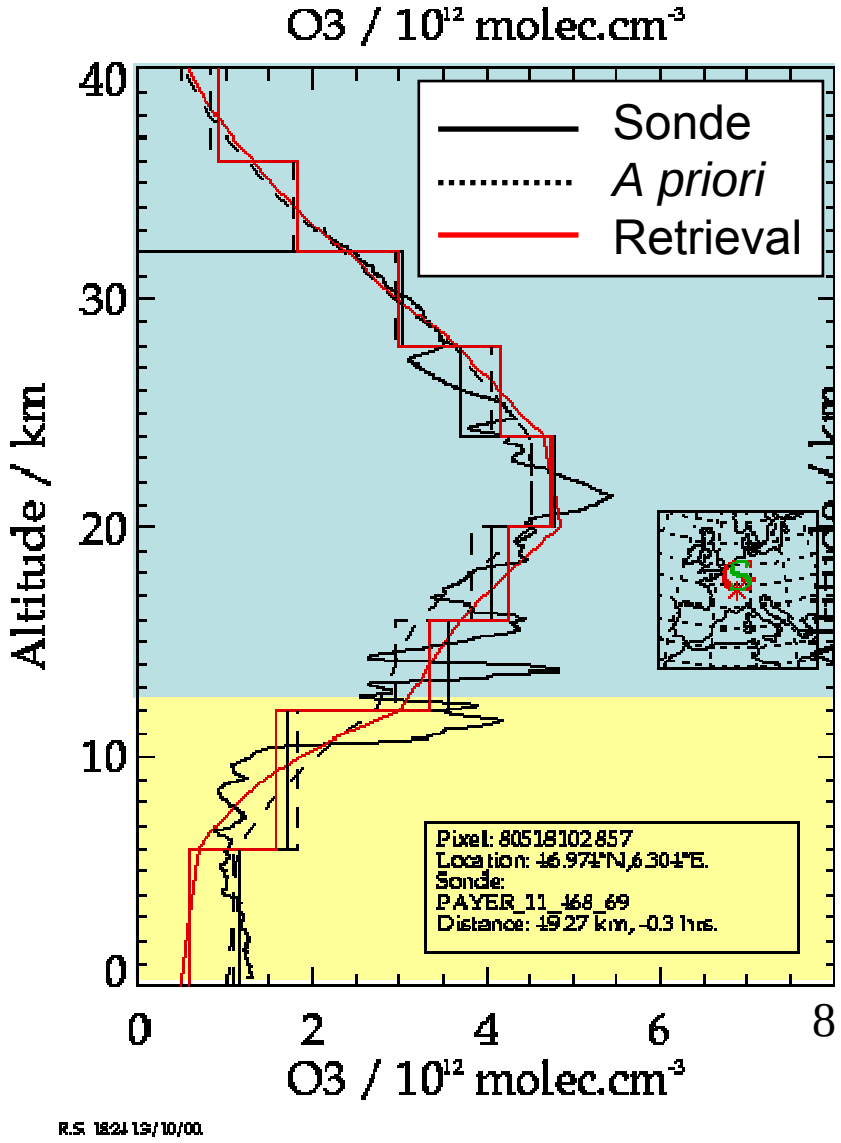
Overview

- Direct measurement of tropospheric ozone demonstrated by GOME
- However, quality of measurement is limited:
  - low vertical resolution (~tropospheric column)
  - biases caused by
    - presence of cloud & aerosol
    - insufficient radiometric calibration
      - NB spectral response function
- This talk
  - Overview of GOME tropospheric results
  - New approaches to mitigate limitations
    - In particular combination of uv-vis + ir 9.7 μm

DARC

EUMETSAT

Ozone profiles from GOME



1. Stratospheric Ozone Profile

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

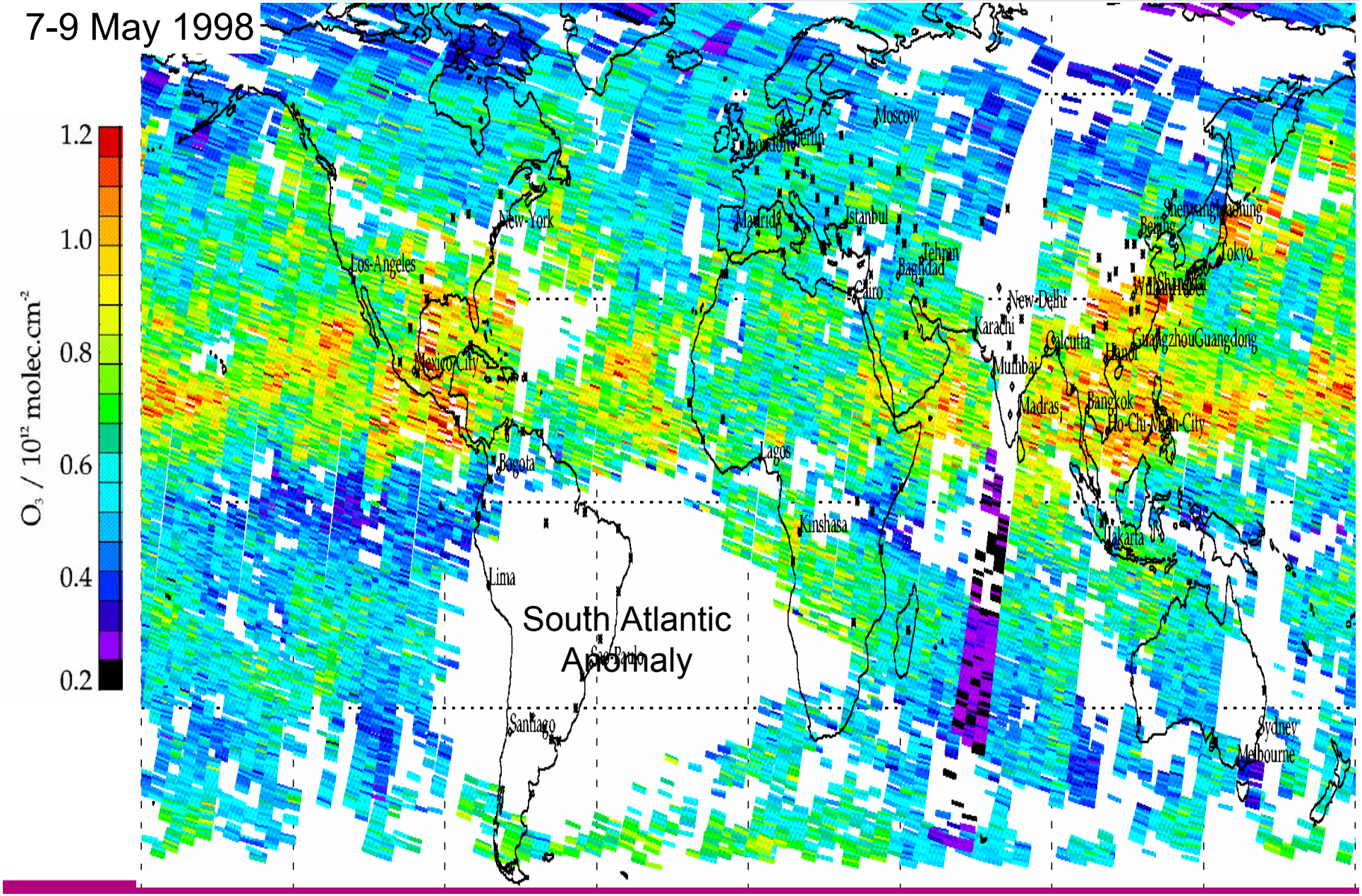
2. Lower Stratosphere + Troposphere

- Huggins bands (322-335nm)
- Temp. dependent cross-section
- Vertical temperature gradient
- Relies on differential structure not absolute calibration

RAL RSG first to use from space instrument

CCLRC
Rutherford Appleton Laboratory

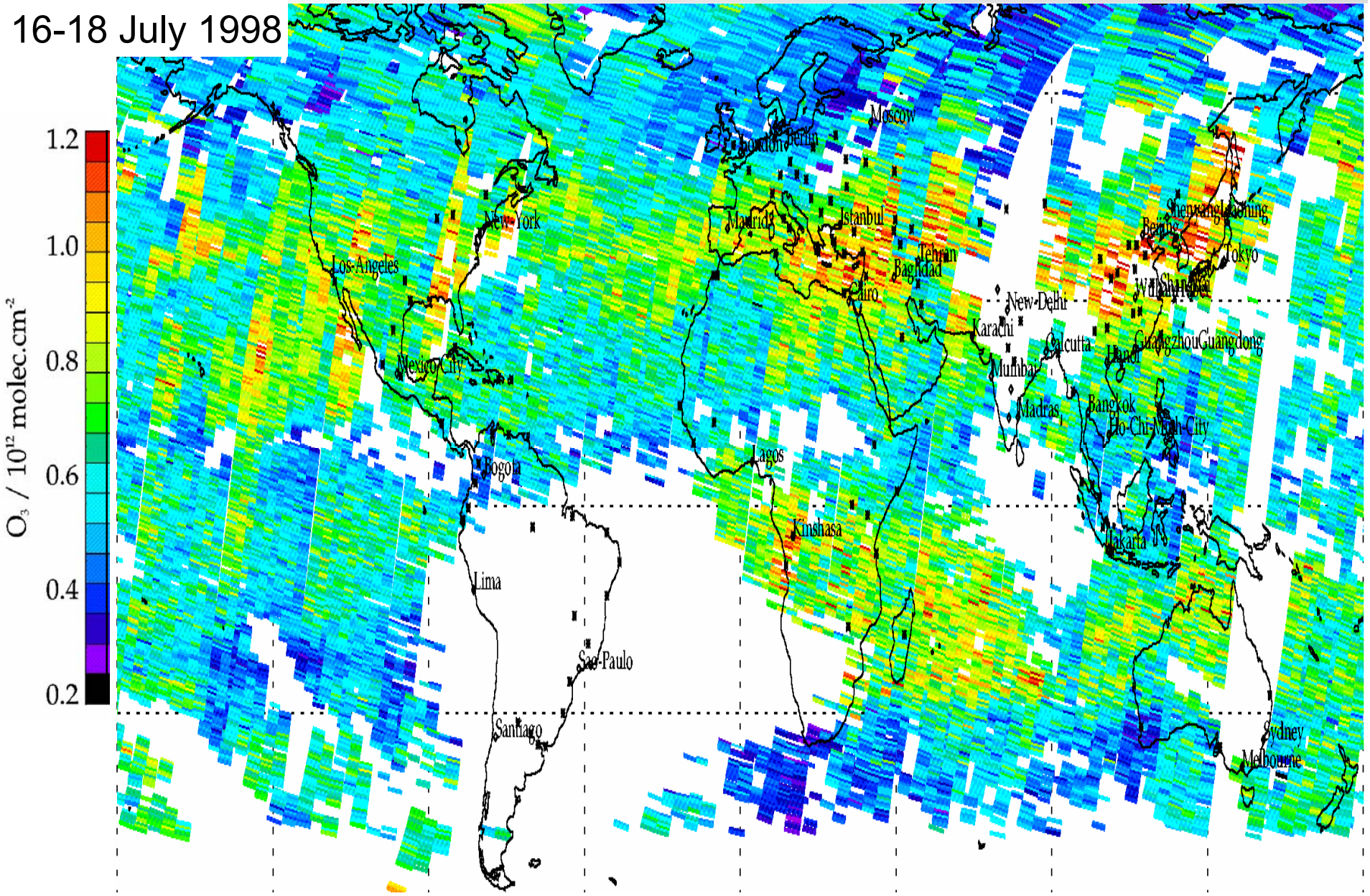
Tropospheric retrievals from GOME



CCLRC
Rutherford Appleton Laboratory

Tropospheric retrievals from GOME

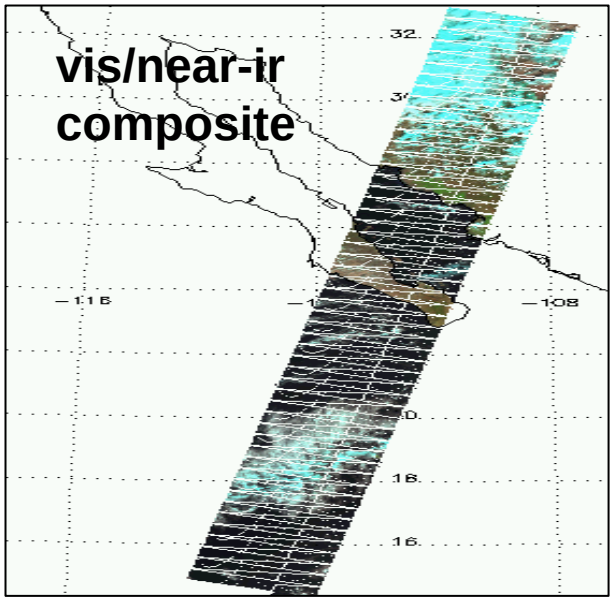
16-18 July 1998

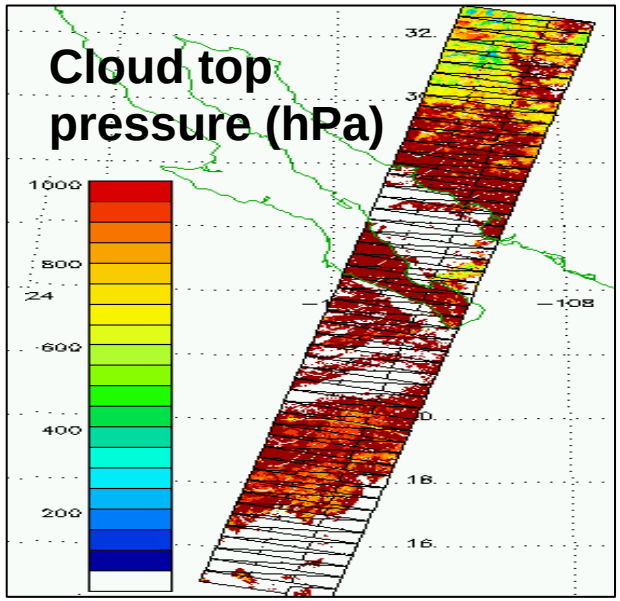


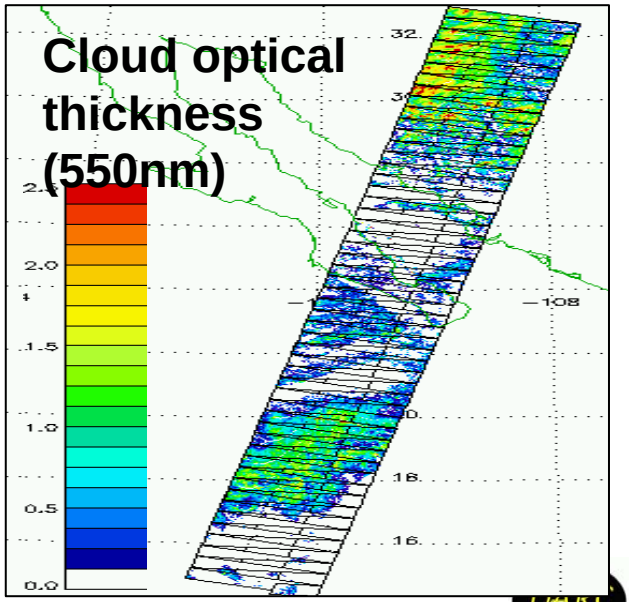
Current limitations & planned improvements

(i) Better treatment of cloud & aerosol

- Tropospheric O_3 retrievals are sensitive to cloud & aerosol
- Cloud and aerosol products have been produced from ERS-2 ATSR-2 in the NERC GRAPE project (Oxford / RAL)
- GOME-scene-specific product has been derived from GRAPE data
  - At present, can be used to flag ozone retrievals
  - "V2" scheme will use this info to properly model scattering profile





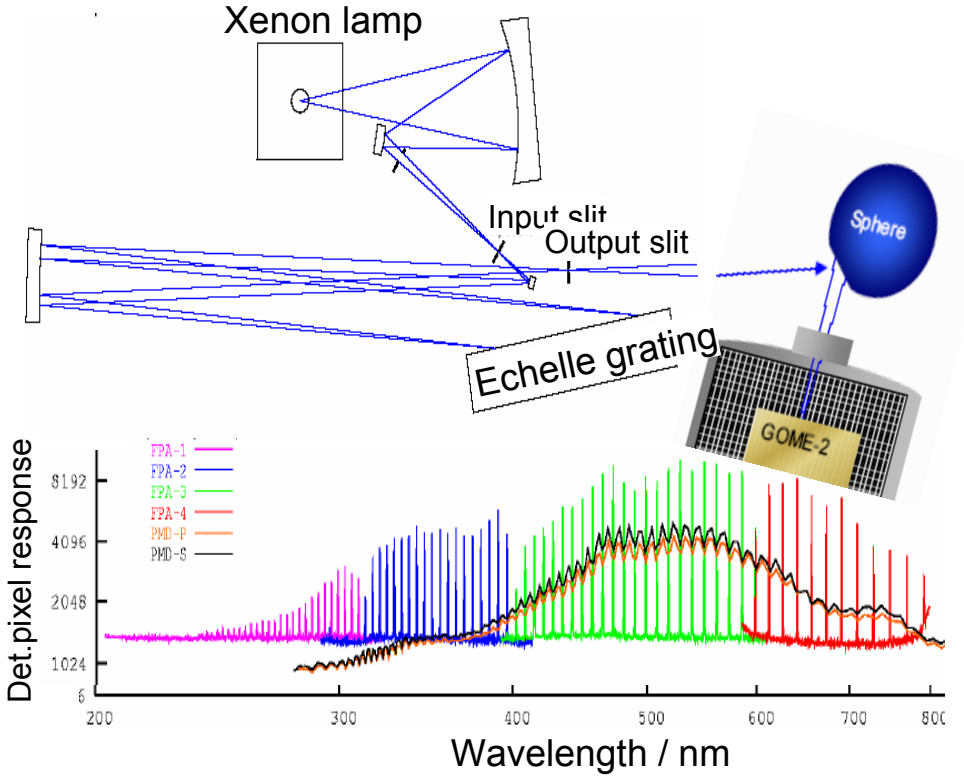


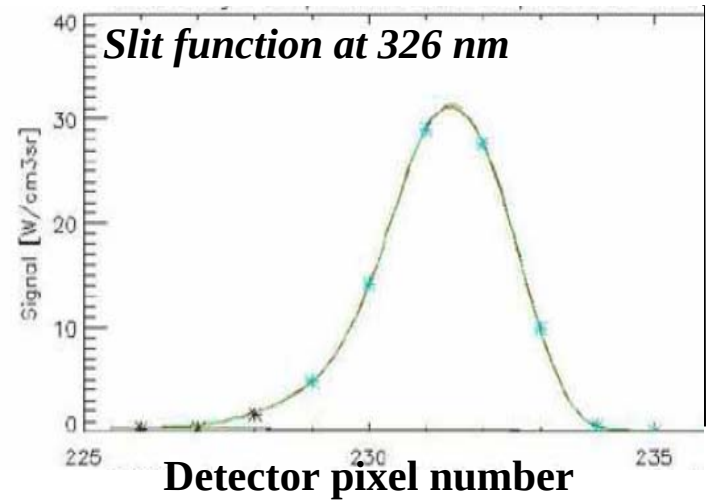
- Higher spatial resolution from new sensors (SCIA, GOME-2, OMI) will reduce impact of cloud

Current limitations & planned improvements

(ii) Better characterisation of slit-function

- Tropospheric bias up to ~100% due to spectral-response or slit-function errors.
- For GOME-2 measurements by TNO commissioned by Eumetsat
- Grating generates comb spectrum
- Deconvolution of measurements gives slit-function
- NB asymmetric in Huggins bands





→ *Expect much more accurate tropospheric O_3 from GOME-2*

→ *Some aspects of analysis approach & lessons learned can be applied to GOME-1 & SCIA*

CCLRC Rutherford Appleton Laboratory

Current limitations & planned improvements
(iii) Synergy with other sensors

- Limb-ir
  - Work underway to combine MIPAS limb + GOME/SCIA
    - requires careful treatment of UT cloud viewed in limb

- Nadir 9.7 μm nadir data
  - uv-vis sensitive to O_3 down to surface (solar scattering)
  - Thermal-ir has low sensitivity in lower troposphere (lack of temperature contrast with surface)
  - Distinct weighting functions → improved retrieval ?
  - Many instrument combinations possible
    - GOME-2+IASI; OMI+TES;
    - historically GOME/SCIA + HIRS

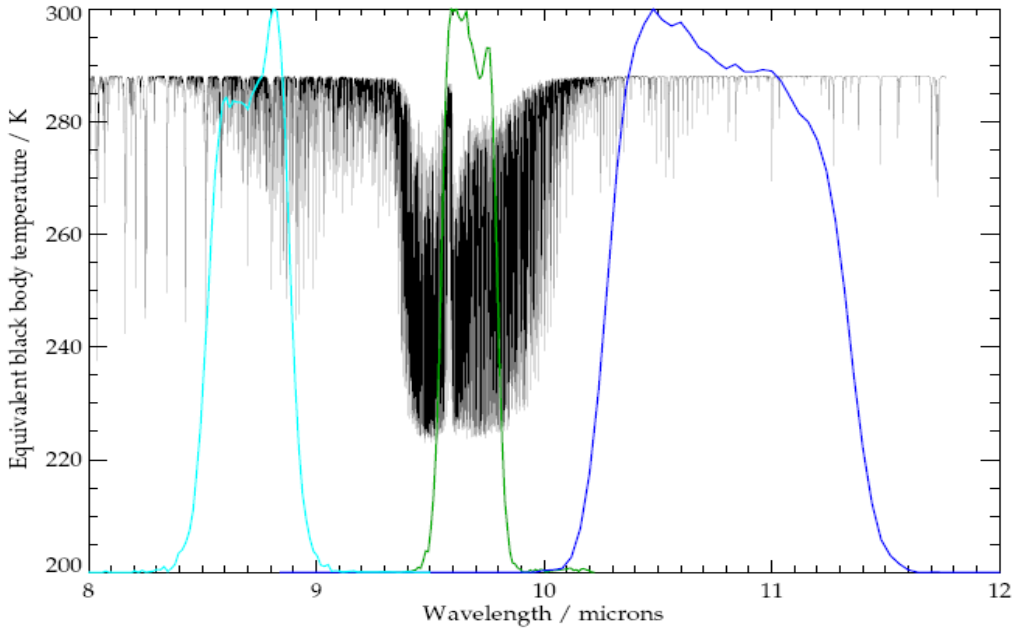
DARC

EUMETSAT

Eumetsat 9.7μm Study

Explore use of MSG SEVIRI 9.7 μm channel for atmospheric chemistry.

- first geostationary observations of trace gas
- opportunity to assess geo for ozone monitoring and air quality
  - One task is to determine cloud statistics
- Success of uv+ir combined retrieval would demonstrate utility of this combination on geo platform (MTG/GMES ?)



- SEVIRI (like TOVS) only has 1 broad-band channel in O_3 band.
- Study uses this channel + neighbouring 8.7 and 10.8μm window channels to allowl inear surface emissivity to be fitted in addition to O_3

DARC

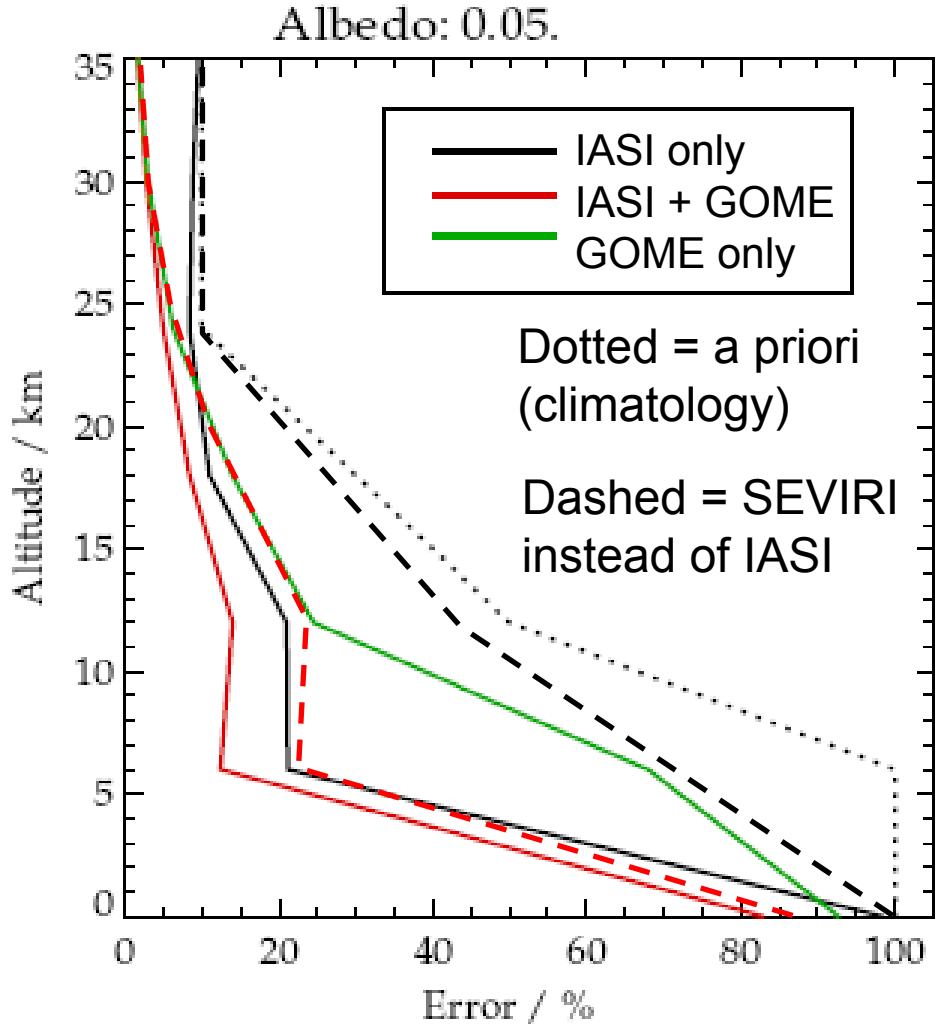
EUMETSAT

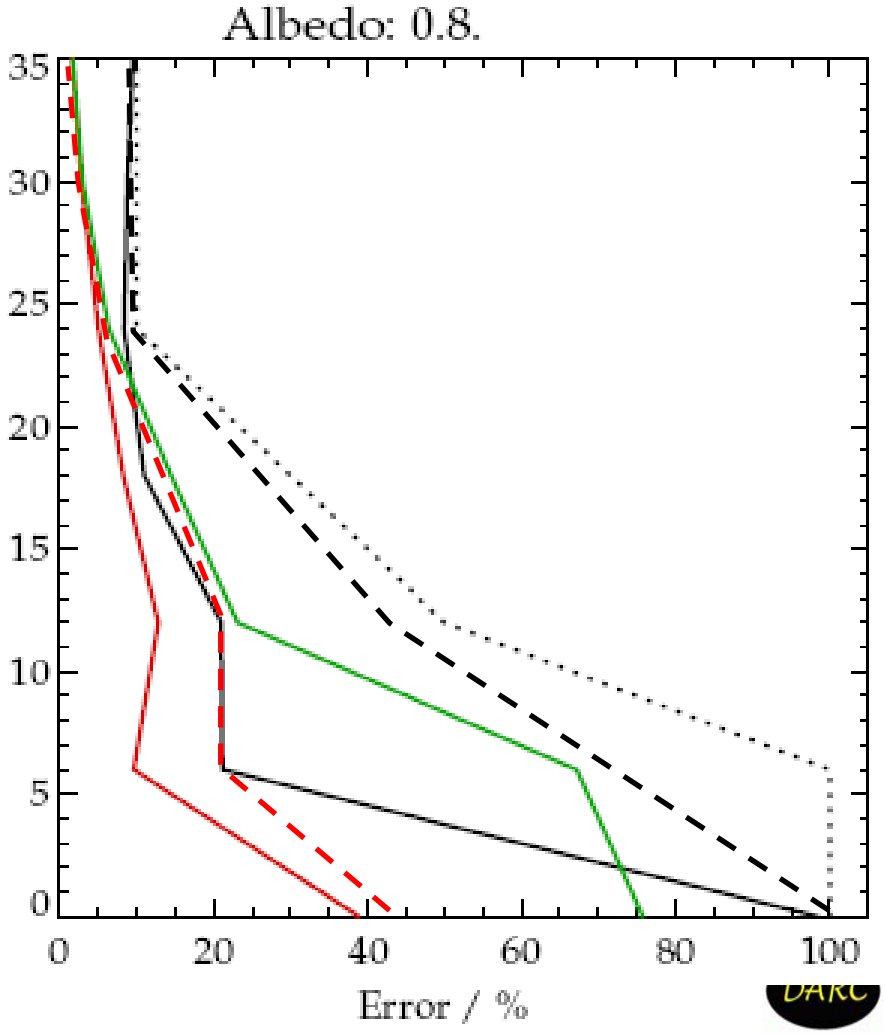
CCLRC Rutherford Appleton Laboratory

Theoretical Simulations:

Random errors on ozone profile

Simulated based on weighting functions from RT calculations

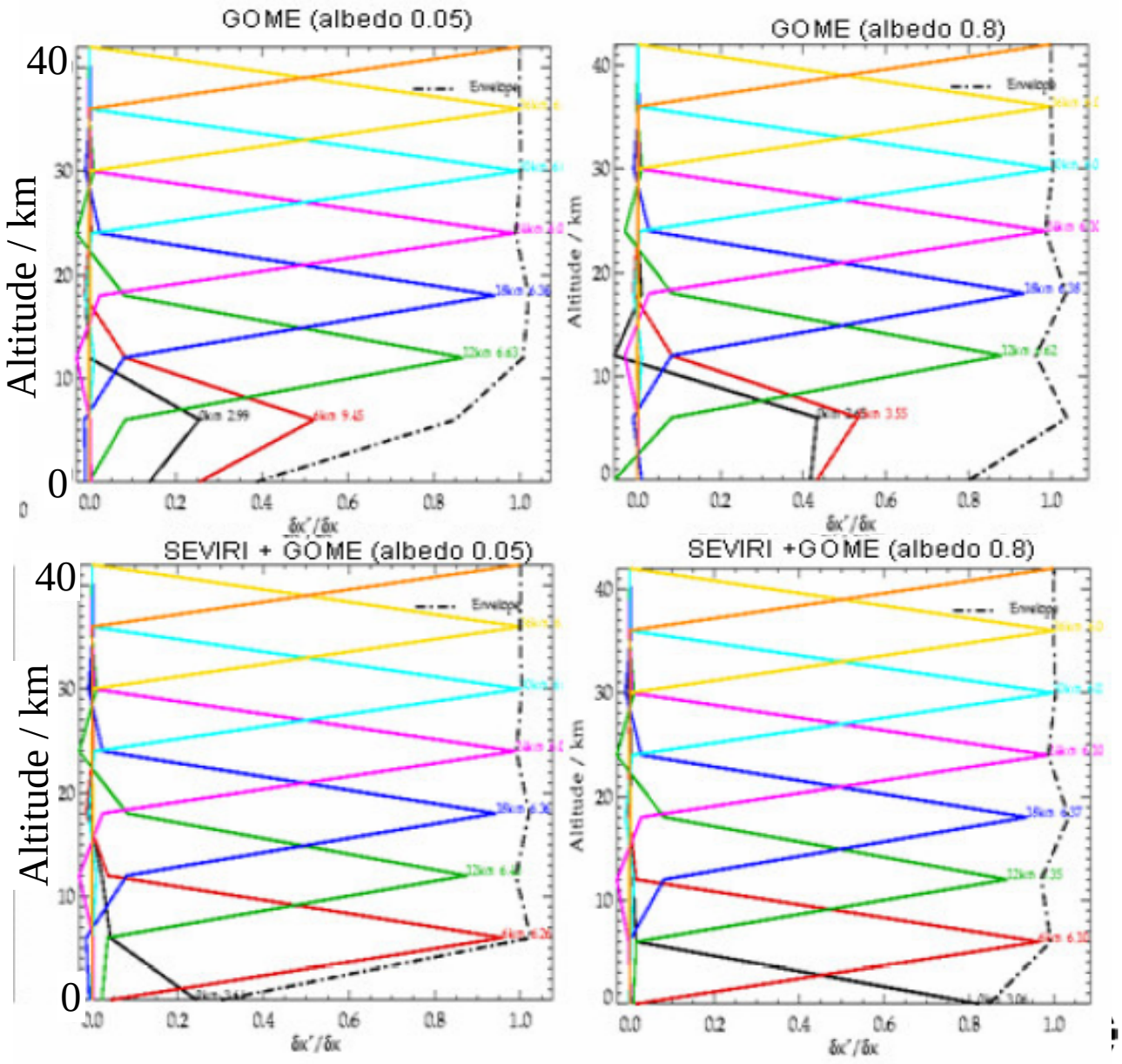




EUMETSAT

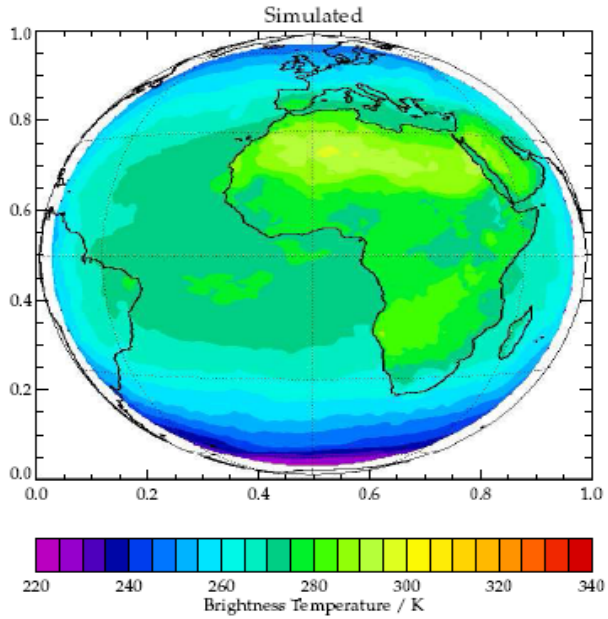
Theoretical Simulations: Averaging Kernels

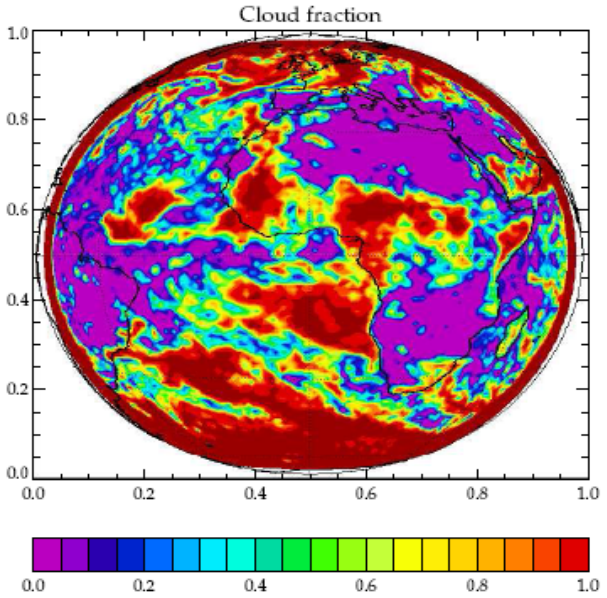
- UV-only
  - One piece of information in the troposphere
- UV + SEVIRI (or IASI)
  - 2 layers in troposphere now resolved
  - NB assumes 0.3K noise for SEVIRI

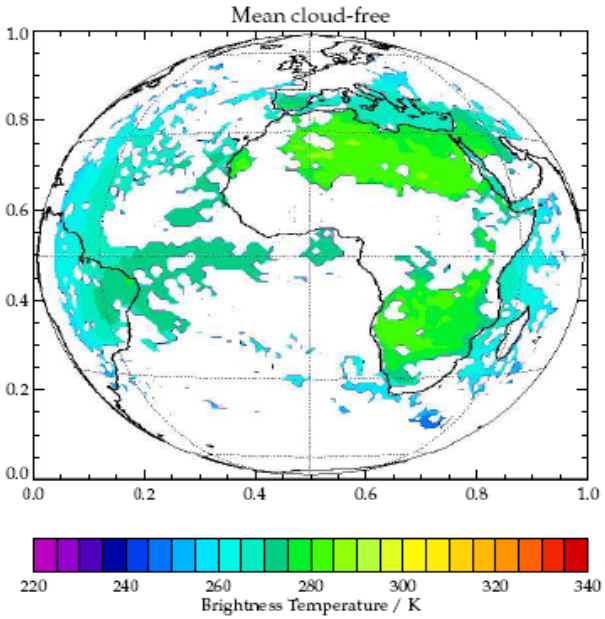


Comparison of SEVIRI & ECMWF+RTTOV radiances

- First step before attempting real retrievals is to assess radiometric accuracy of SEVIRI
- Performed by comparison of *cloud-free* obs. to RT calculations using
  - RTTOV
  - ECMWF T,H_2O,O_3
  - surface emissivity=1
- (Noted by comparison to ATSR flag 10% of scenes flagged as clear by Eumetsat flag are cloudy)



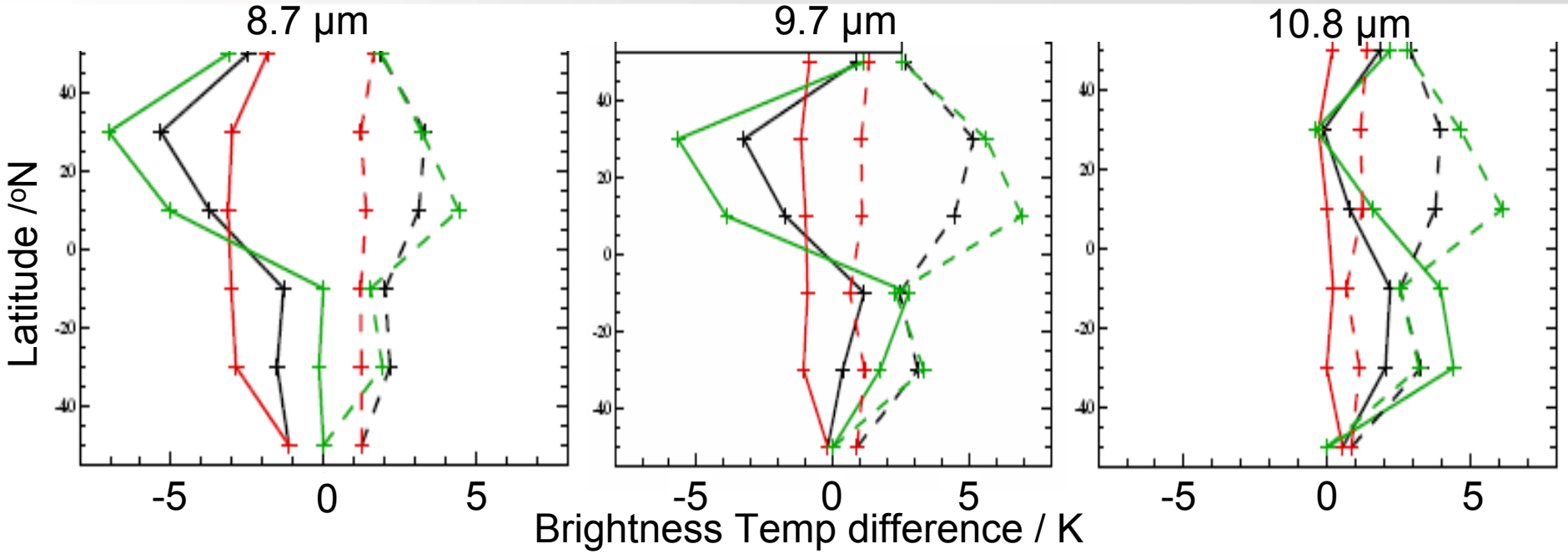




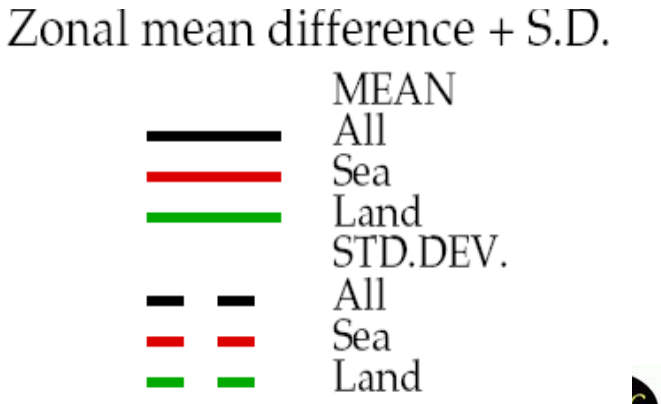
DARC

EUMETSAT

Comparison of SEVIRI & ECMWF+RTTOV radiances



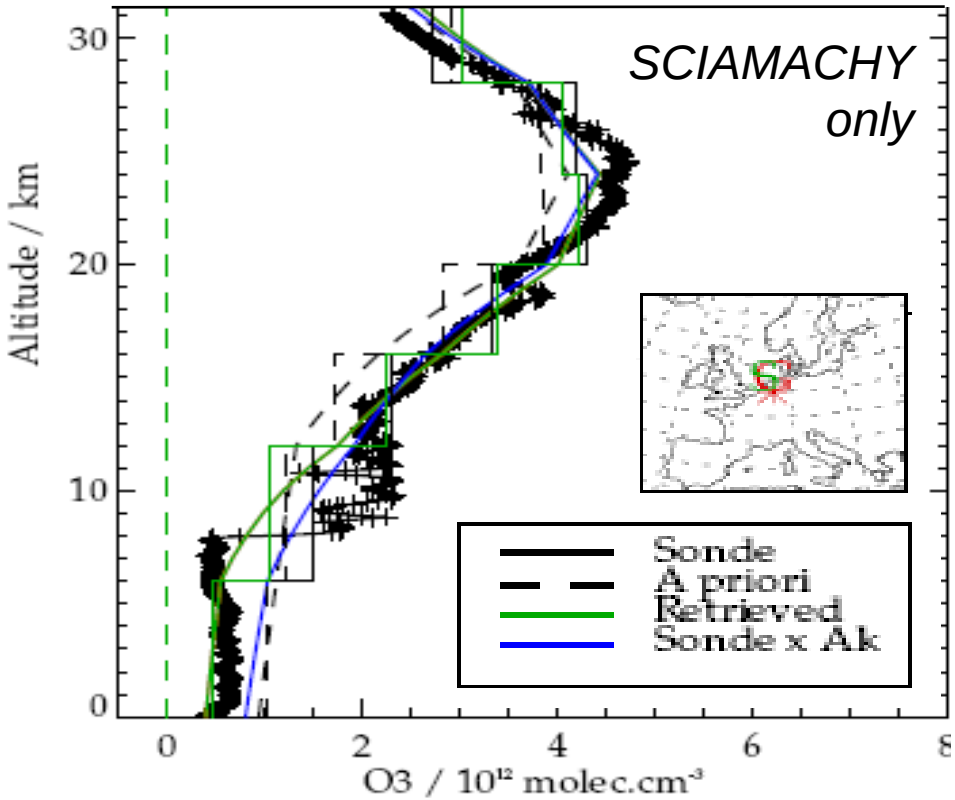
- Bias over ocean <1K 9.7 & 10.8 µm
- -3K bias at 8.7µm may be due to spectral dependence in surface emissivity
- Bias over desert due to surface T or emissivity
- Std.deviations (over sea) ~1K
- Initial indication that radiometric quality may be sufficient (will fit surface emissivity)

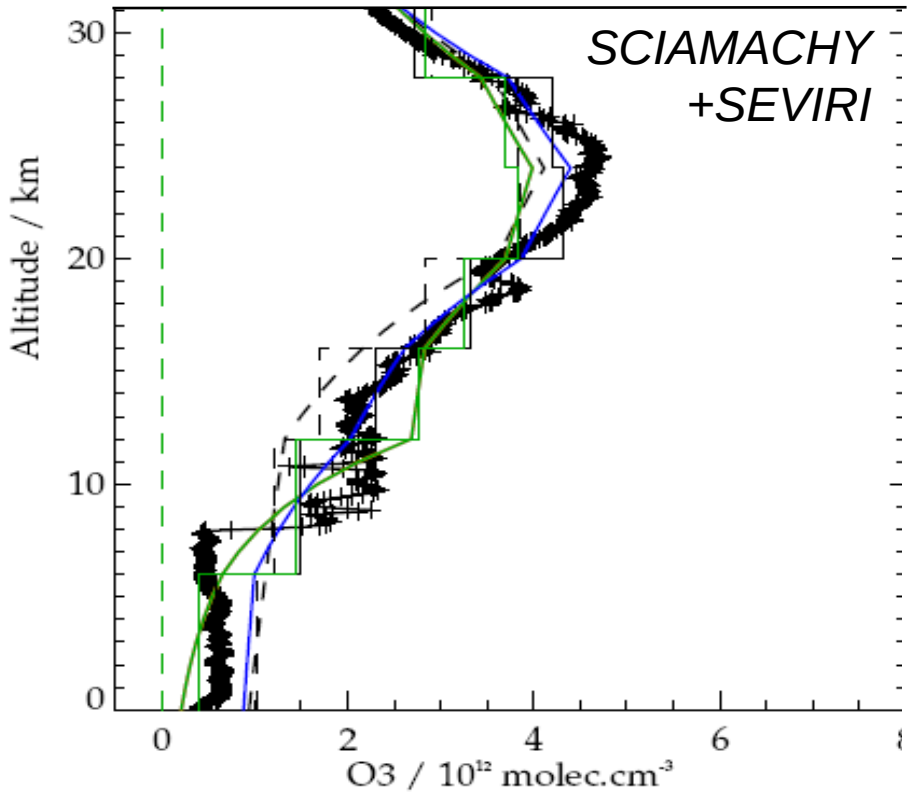


EUMETSAT

CCLRC Rutherford Appleton Laboratory

First real retrievals: SCIAMACHY + SEVIRI





- Based on 3 days of SCIA+ SEVIRI: 24-26 August 2004
  - SCIA used as GOME has (temporary) L1 calibration/software problems
- few sondes available for comparison & results so far inconclusive
  - need to process more data for statistical comparison
  - May be some radiometric/spectroscopic inconsistency

DARC

EUMETSAT

Conclusions & Outlook

- Though UK NERC/DARC funding tropospheric O3 dataset now avaliable from RAL scheme at http://badc.nerc.ac.uk/
- Scope to improve tropospheric O_3 retrievals through
  - Better characterisation of cloud & aerosol (GRAPE)
  - Better radiometric calibration (GOME-2 + feedback to GOME-1)
  - Synergy with other composition sounders
- Nadir uv+thermal ir offers potential to resolve two layers in troposphere
- Eumetsat study underway to demonstrate with SCIAMACHY+SEVIRI
  - GOME-2 + IASI, GOME-1 + TOVS, MTG uv+ir sounder potential candidates for similar analysis
  - Approach could also be applied to other species NB NO_2
  - First real retrievals performed. Results encouraging so far…
  - Next phase of study to analyse more data, validate properly & feed into assimilation trials (LISA+DARC) to assess usefulness of results for monitoring & air quality

Acknowledgements

Work was funded by the NERC (DARC) and Eumetsat.

ESA & DLR provided access to level 1 GOME & SCIA data & processing software.

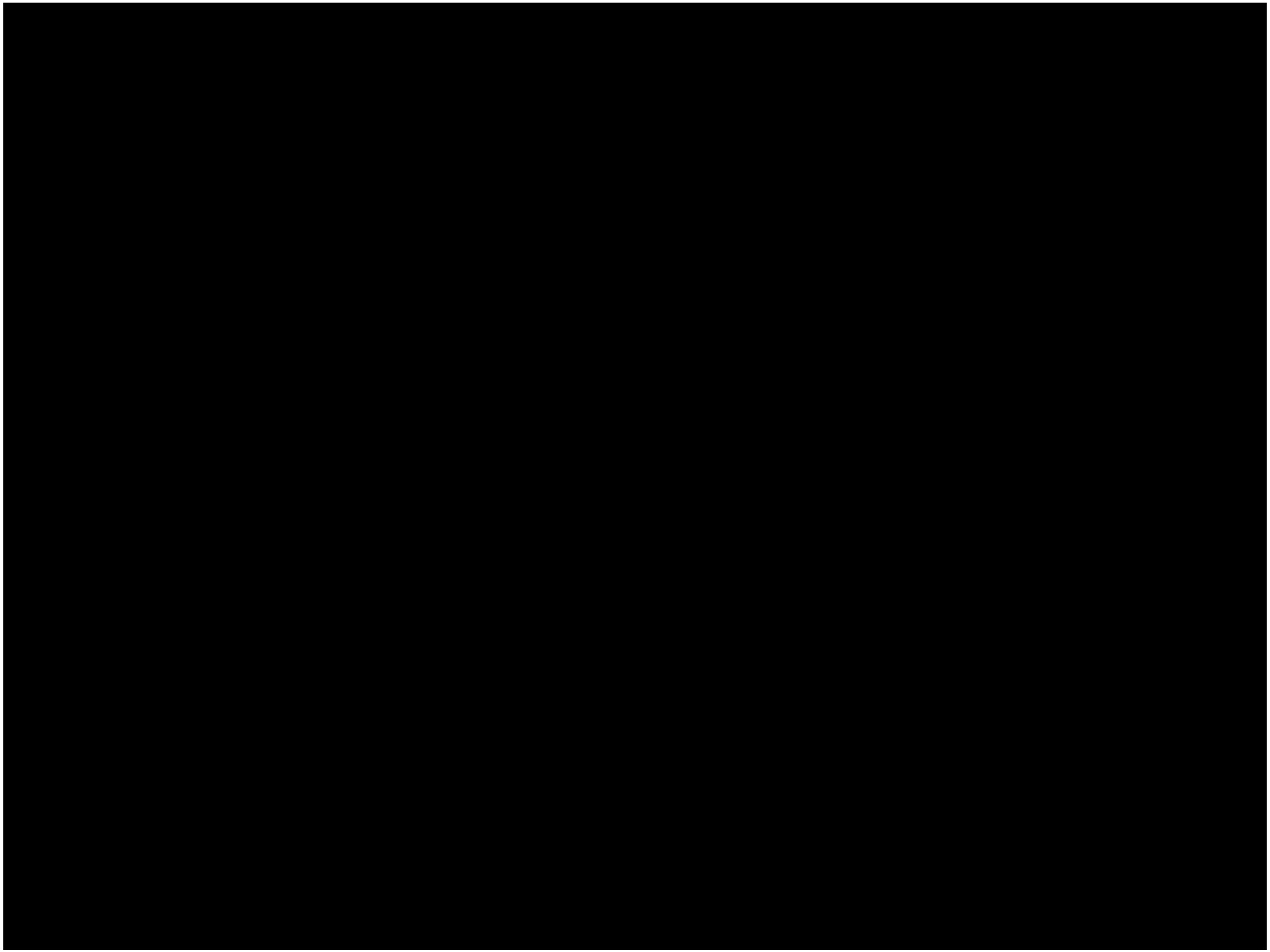
Eumetsat for provision of operational & offline MSG SEVIRI products

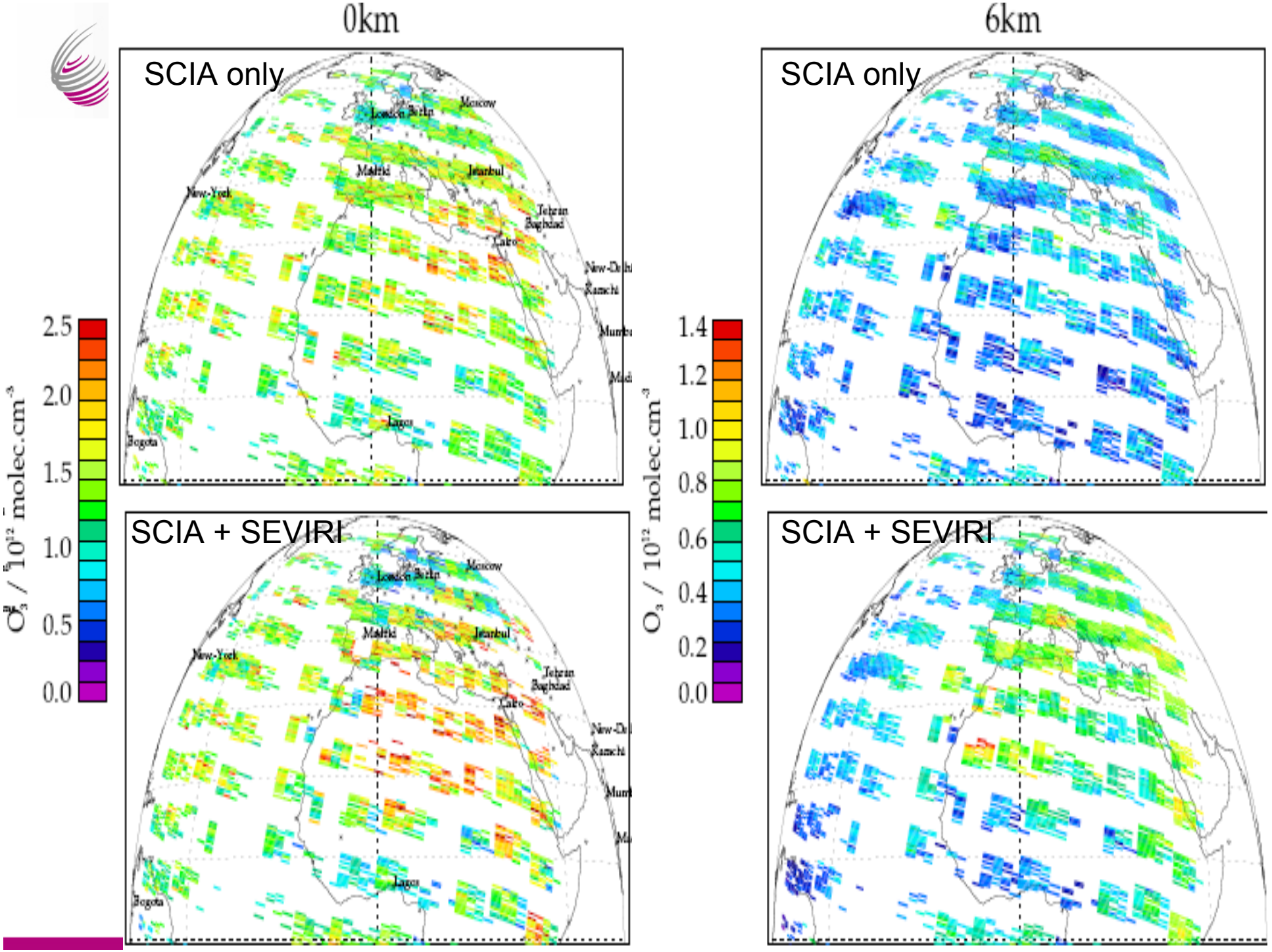
Met Office / NWP SAF for RTTOV radiative transfer model

Univ. Bremen for GOMETRAN uv-vis radiative transfer model

Harvard SAO for high resolution solar reference spectrum

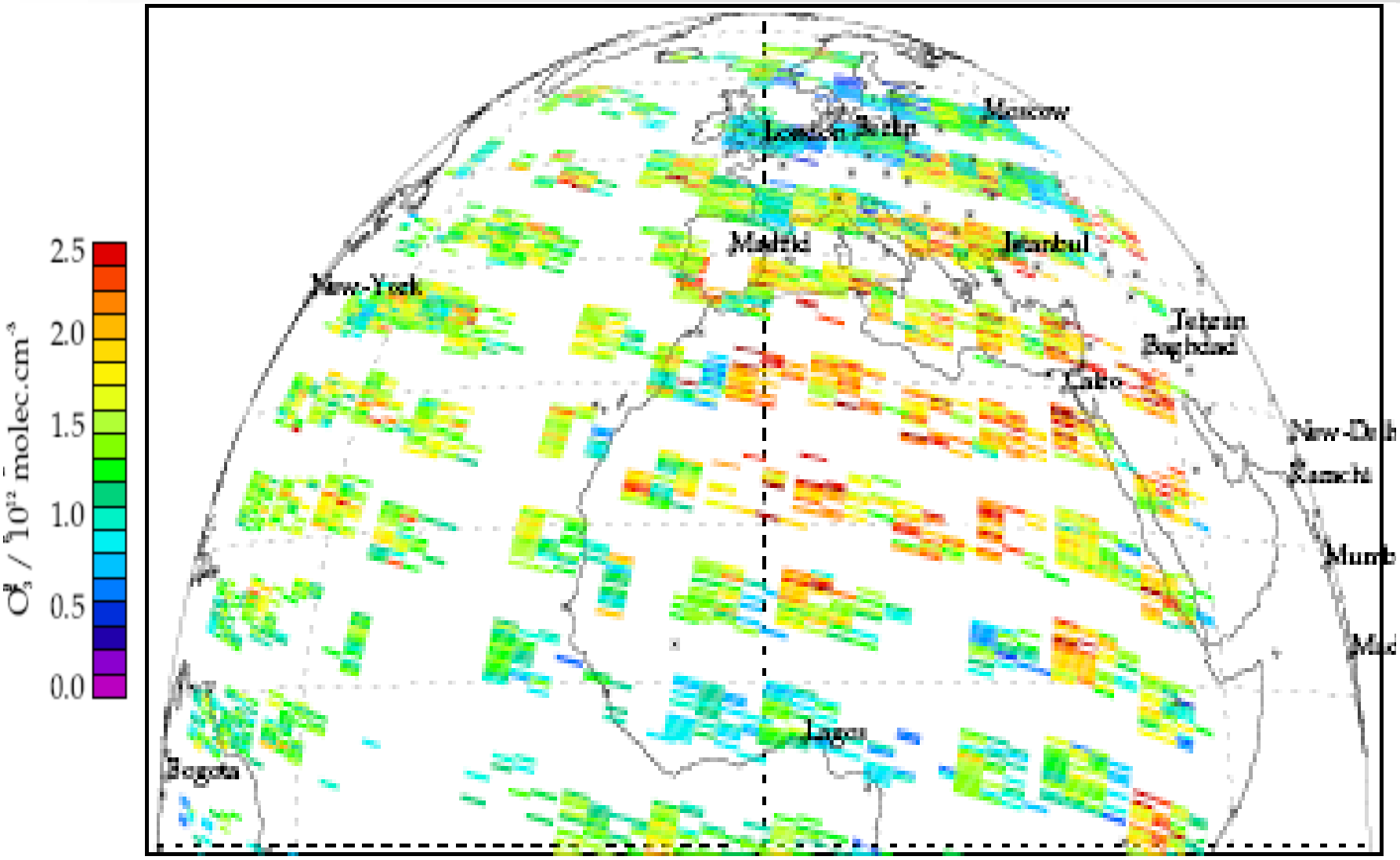
ECMWF for meteorological analyses and MSG SEVIRI radiance monitoring analysis




0km
6km
SCIA only
SCIA only
SCIA + SEVIRI
SCIA + SEVIRI
O_3 / 10^{12} molec.cm^{-3}
2.5
2.0
1.5
1.0
0.5
0.0
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Moscow
London
Berlin
Madrid
Istanbul
New-York
Tehran
Baghdad
Cairo
Lagos
Bogota

CCLRC
Rutherford Appleton Laboratory

SCIA only



DARC

EUMETSAT

CCLRC Rutherford Appleton Laboratory

SEVIRI 9.7μm Channel

- **Task 1**: Evaluation of existing cloud/radiance products. Calculation of cloud statistics.

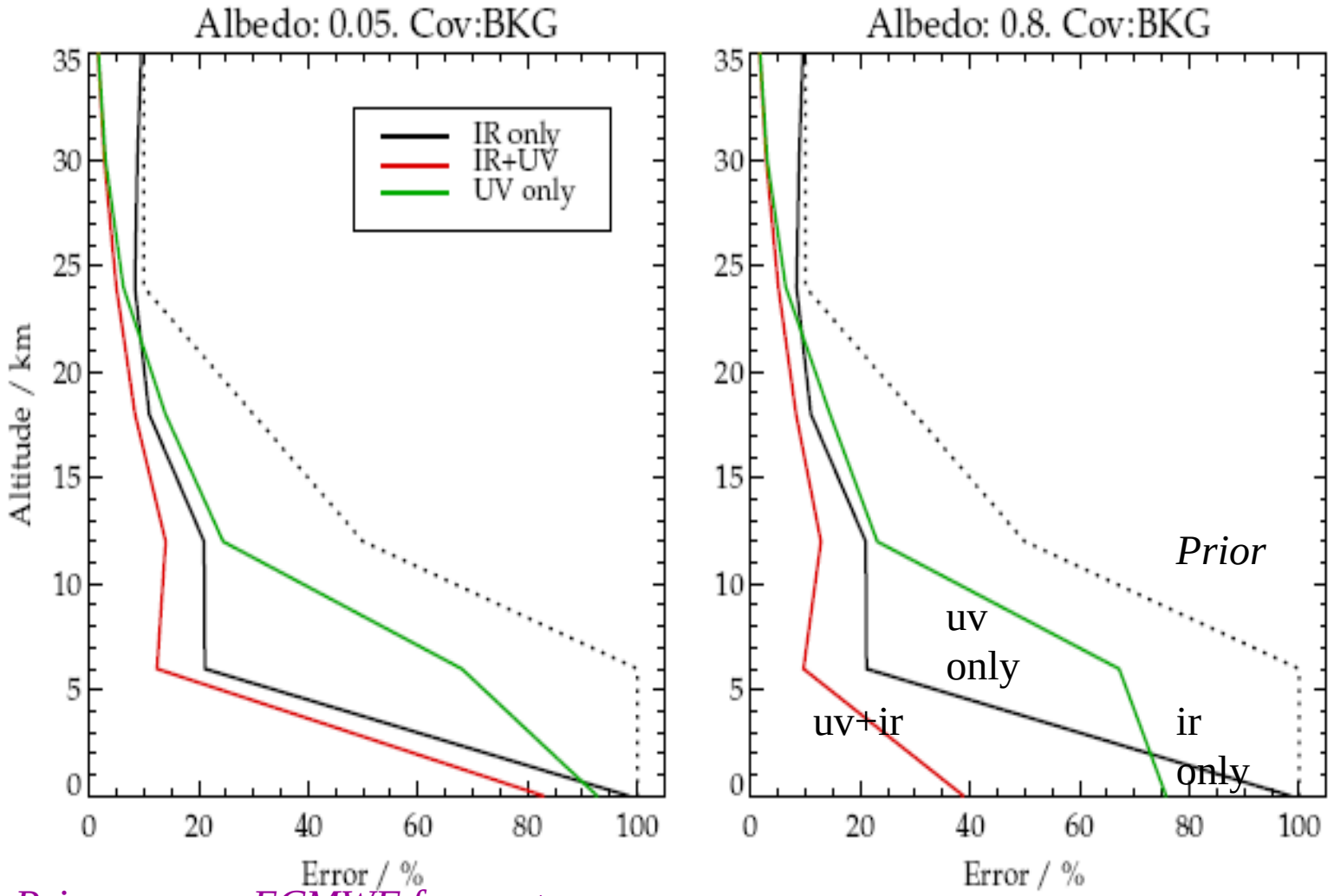
- **Task 2**: Develop combined GOME/SEVIRI retrieval scheme and estimate constituent retrieval errors.

- **Task 3**: Demonstrate improvements in assimilated regional air quality forecasts & global ozone monitoring (optional).

DARC

EUMETSAT

Ozone Profile Retrieval from Nadir-UV & -IR Combination



Prior error = ECMWF forecast error covariance

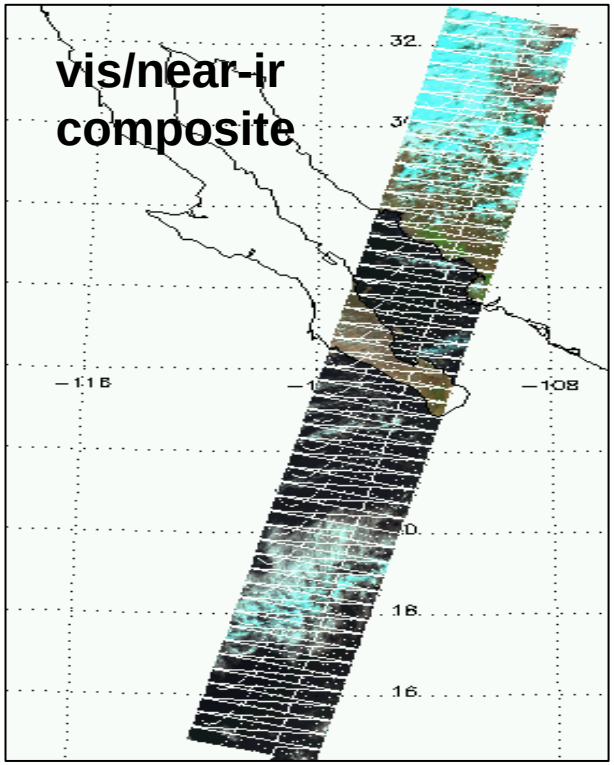
Processing the complete mission

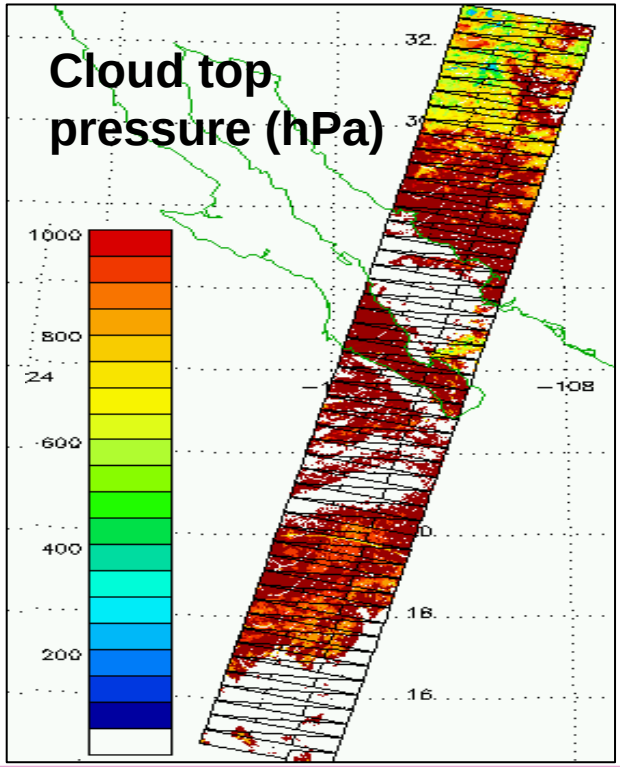
- With NERC / DARC , complete mission now being processed
  - 7.5 years from May 1995- Dec 2002 now at BADC
    http://badc.nerc.ac.uk/data/gome
  - Jan-June 2003 being processed this month
  - On 22 June 2003 ERS-2 tape recorder failed (but subsequent non-global data will still be analysed)
- "V2" scheme under development
  - re-processing planned for next year.

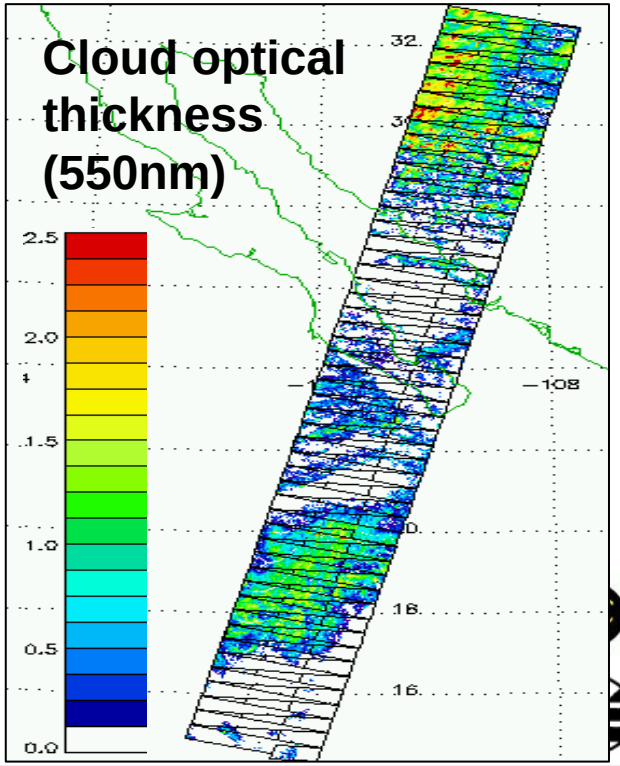
- Also preparing to apply scheme to METOP GOME-2 (to be launched next year)

Cloud & aerosol data from ATSR-2

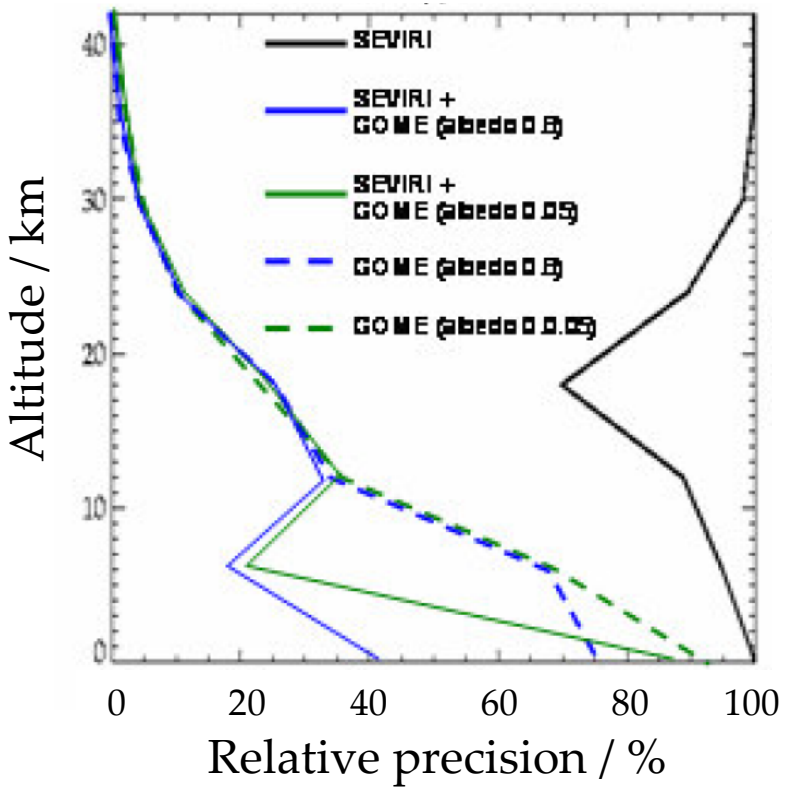
- Tropospheric O_3 retrievals are sensitive to cloud & aerosol
- Cloud and aerosol products have been produced from ERS-2 ATSR-2 in the NERC GRAPE project (Oxford / RAL)
- GOME-scene-specific product has been derived from GRAPE data
  - At present, can be used to flag ozone retrievals
  - “V2” scheme will use this info in RTM to improve retrievals

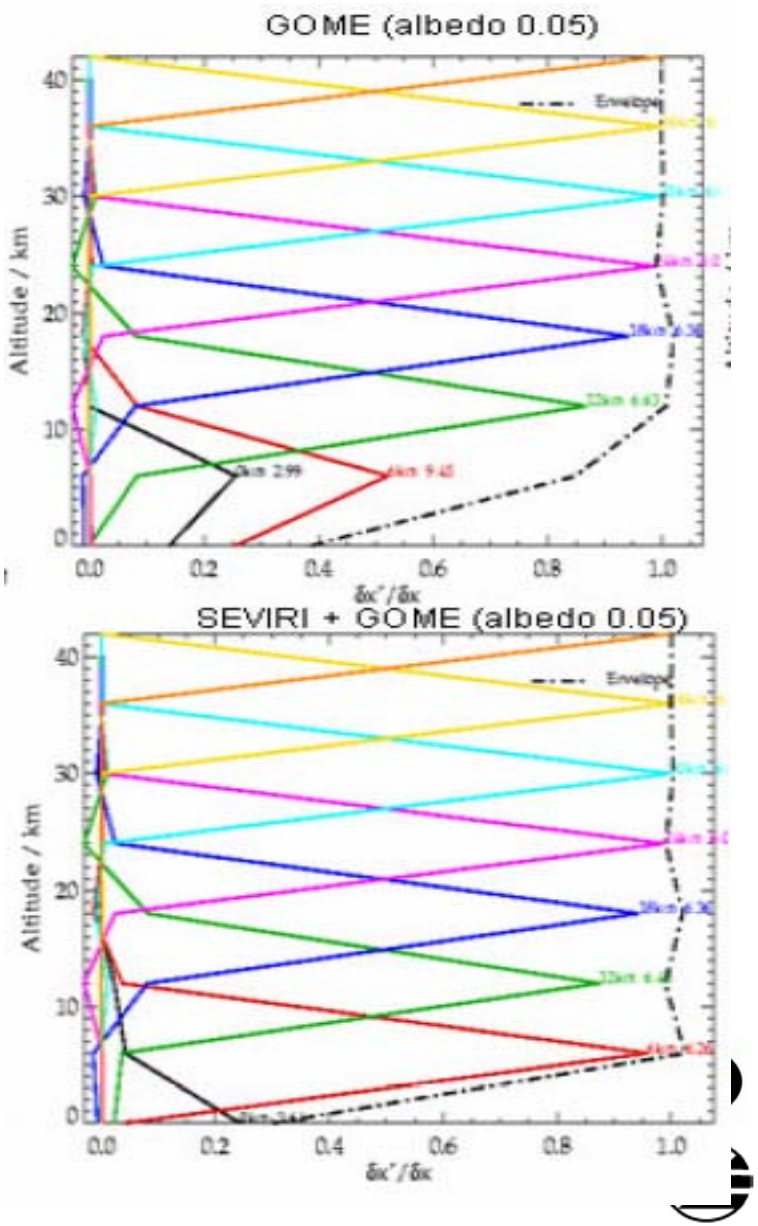






Potential of 9.7μm measurements





- Eumetsat study underway to demonstrate GOME+SEVIRI capability
- Study includes assimilation of results into GCM (Reading) and regional air-quality forecast model (LISA)

CCLRC Rutherford Appleton Laboratory

Conclusions & Outlook

- Though NERC funding state-of-the-art nadir-uv O_3 profile retrieval scheme developed for GOME
- Complete mission data available from

  http://badc.nerc.ac.uk/data/gome
- Next steps:
  - "Version 2" ozone profiles:
    - improve slit-function & wavelength calibration
    - include ATSR-2 cloud & aerosol in O_3 retrieval
  - Next generation scheme to combine information from multiple sounders & imagers
    - MIPAS + SCIAMACHY + SEVIRI + AATSR
    - GOME-2 + IASI + AVHRR/3
  - Combine CTM + RTM + O_3 profiles + cloud & aerosol to improve other tropospheric species from GOME...

DARC

EUMETSAT

Acknowledgements

Work was funded by the NERC, in recent years via RAL role in DARC.

Additional funding related to assessment of GOME-2 performance from Eumetsat.

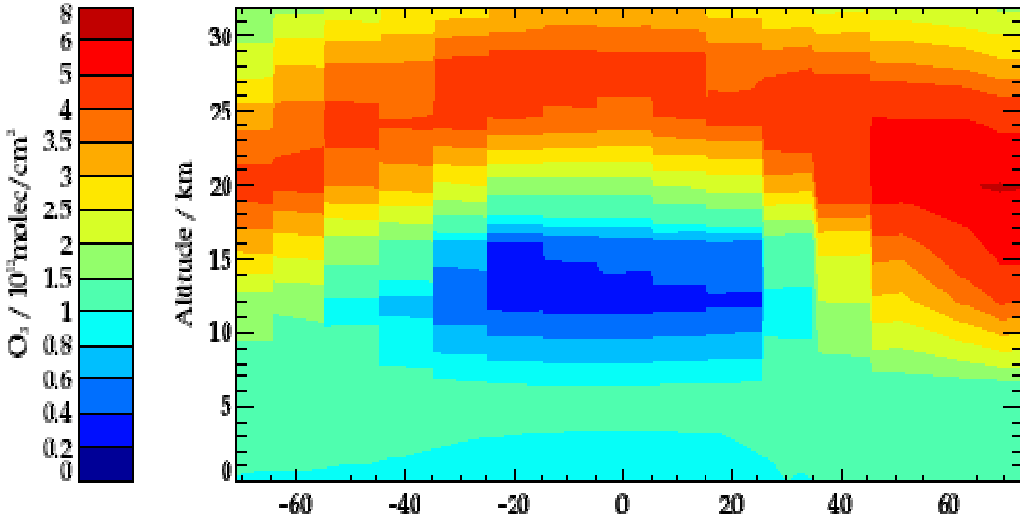
ESA & DLR provided access to level 1 data & processing software.

The GOMETRAN radiative transfer model, high resolution solar reference spectrum, and atmospheric temperature profiles used within the RAL retrieval scheme were provided by the University of Bremen, Harvard SAO and the Met.Office respectively.

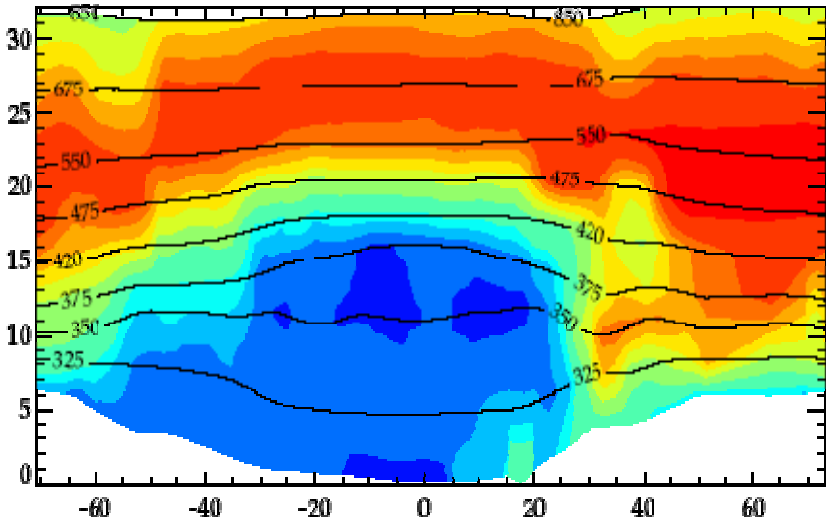
Example of lamination in lower stratosphere

Orbit cross-section from 14 March 1999

A priori O_3 number density

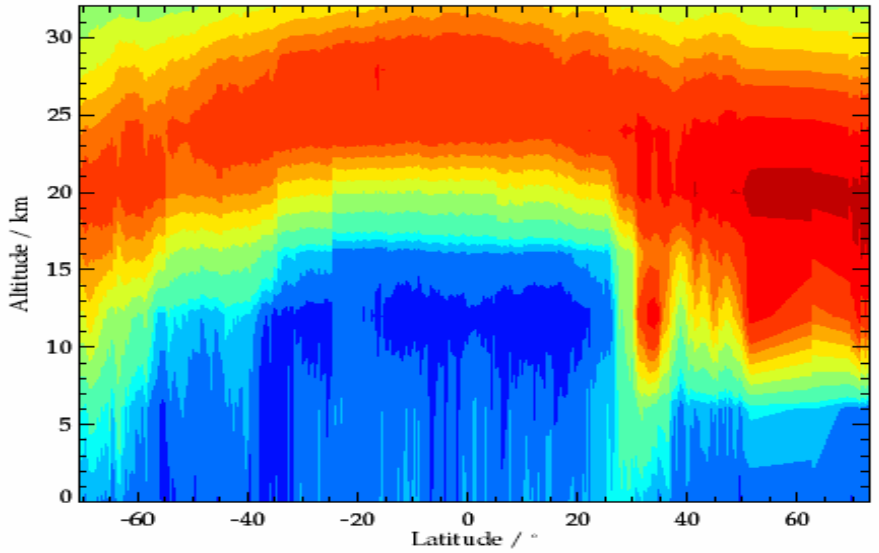


Model O_3 (assuming passive tracer)



➔GOME ozone profiles contain information on the dynamics of the lower stratosphere

Retrieved O_3 number density

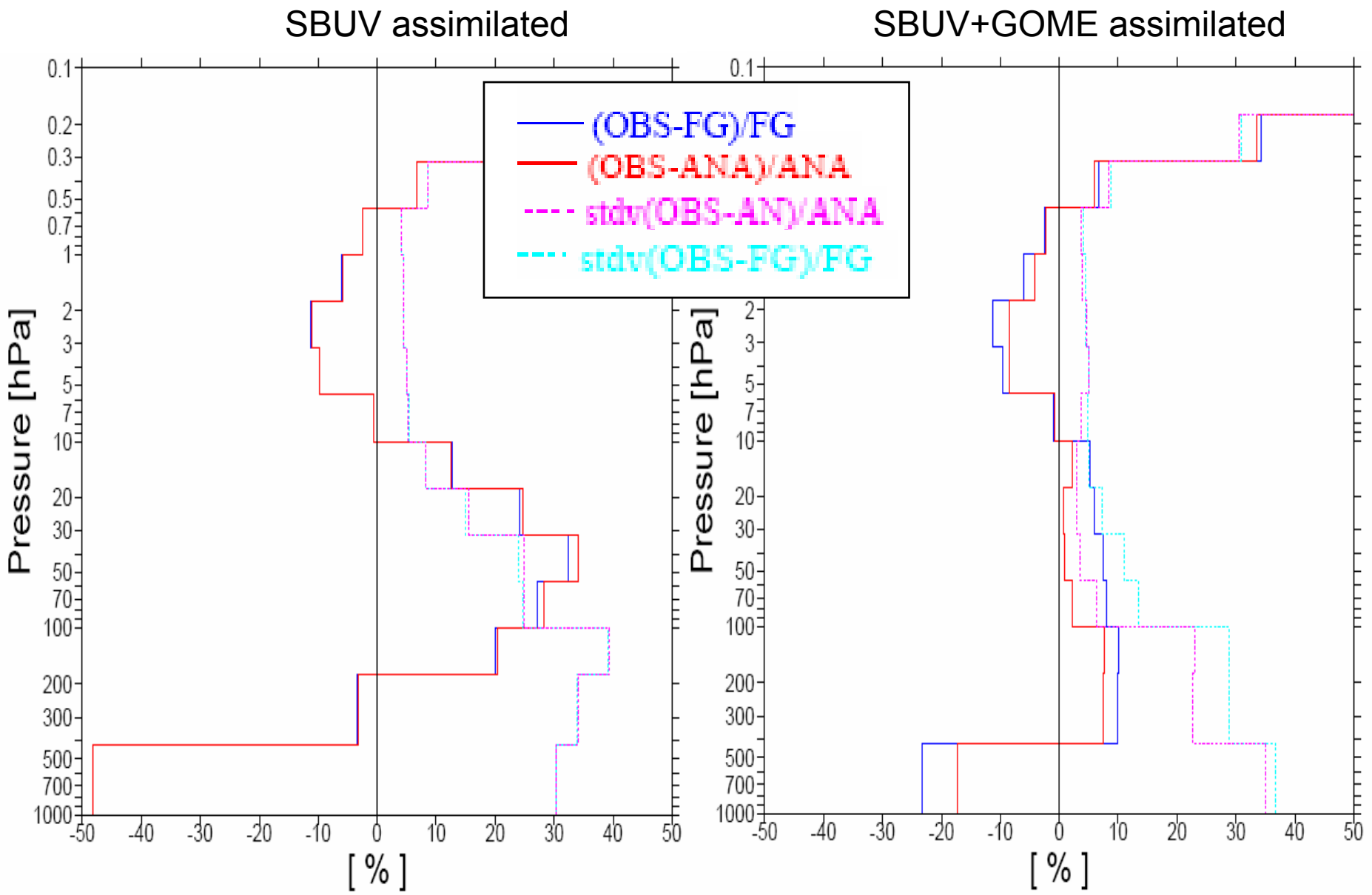


Application via Data assimilation

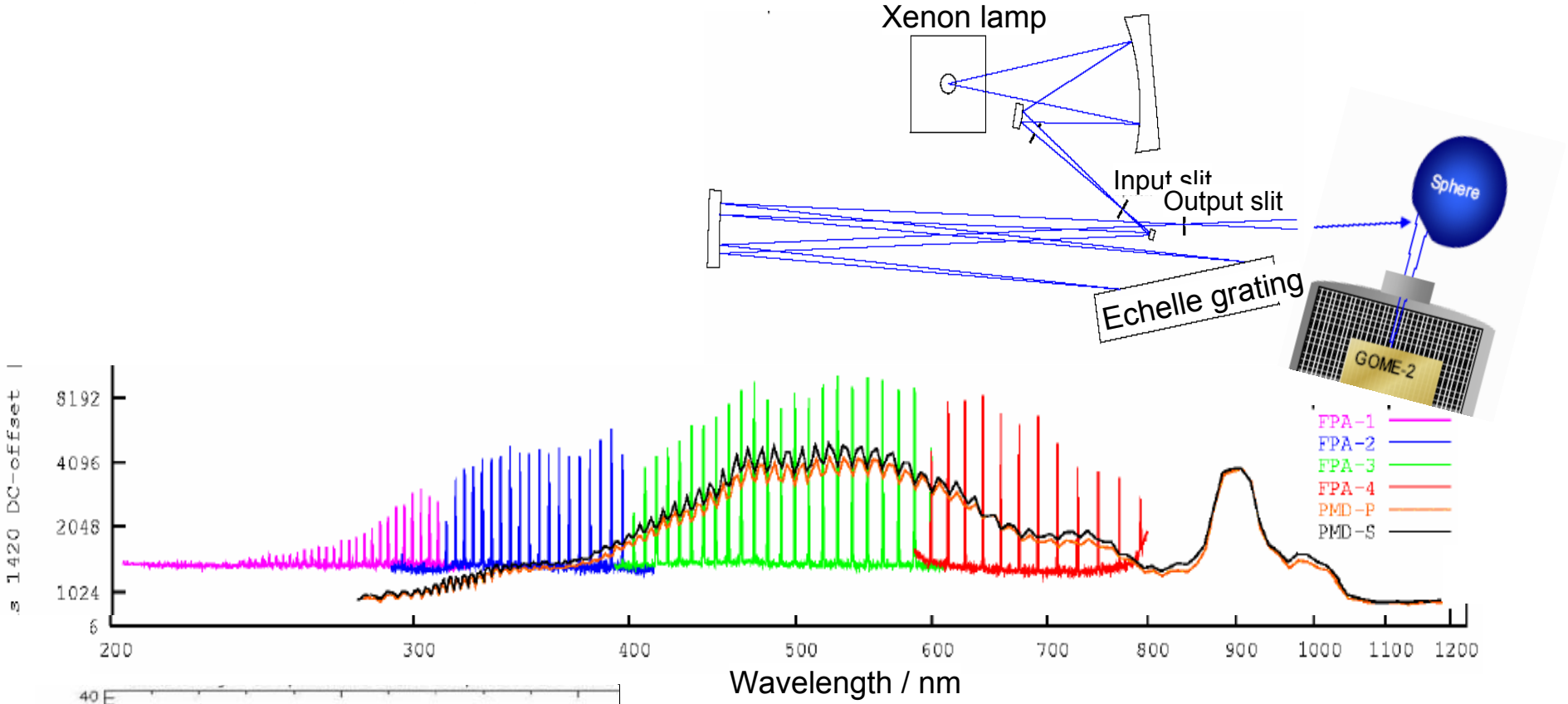
- 3 Groups currently using RAL GOME profile data for September 2002 in assimilation:
  - M. Juckes at RAL
    - Intercomparison with MIPAS / GOME / SAGE / HALOE
  - S. Migliorini & R. Dragani at DARC, Reading
    - Seeking to exploit optimal methods to assimilate GOME data into UKMO model, fully accounting for limited resolution
  - A. Dethof at ECMWF
    - Compared impact of GOME to that of SBUV
    - Currently preparing to assimilate data in 2002-3 in preparation for re-analysis with 8 year data-set

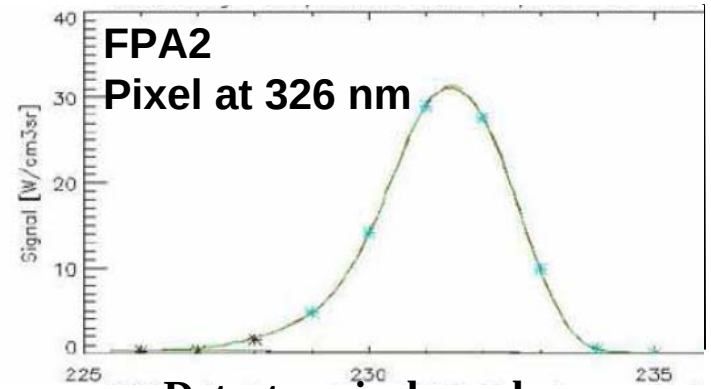
CCLRC Rutherford Appleton Laboratory

ECMWF assimilation trial results (Sept 2002 data)



SFS Measurements

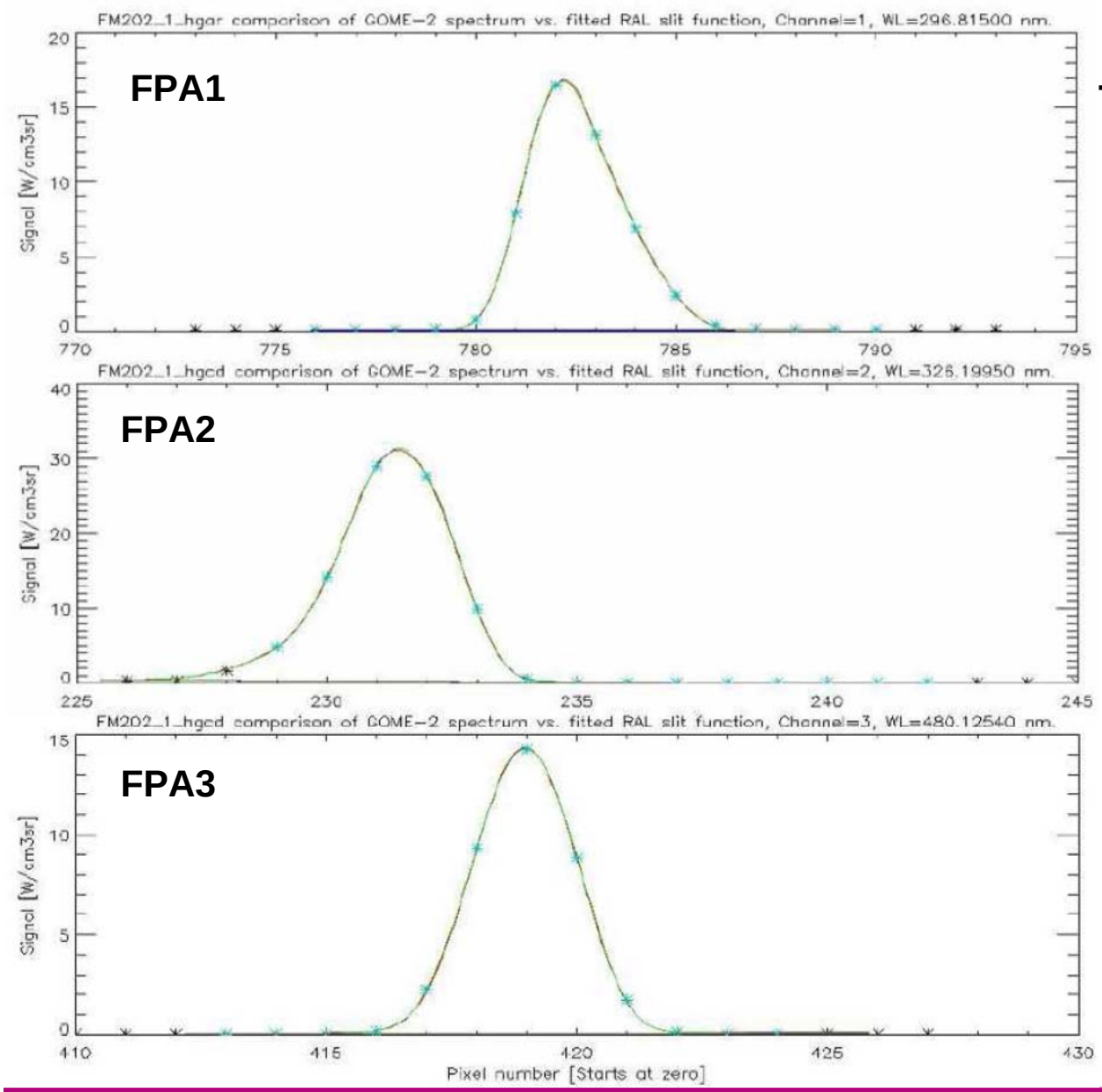




DARC

EUMETSAT

Example FM2 Slit functions



Retrieved slit-function

*** Measured response to lamp line (after linear correction for broad-band stray-light)**

- Strongly asymmetric line-shapes in
  - FPA-1 (Hartley)
  - FPA-2 (Huggins)

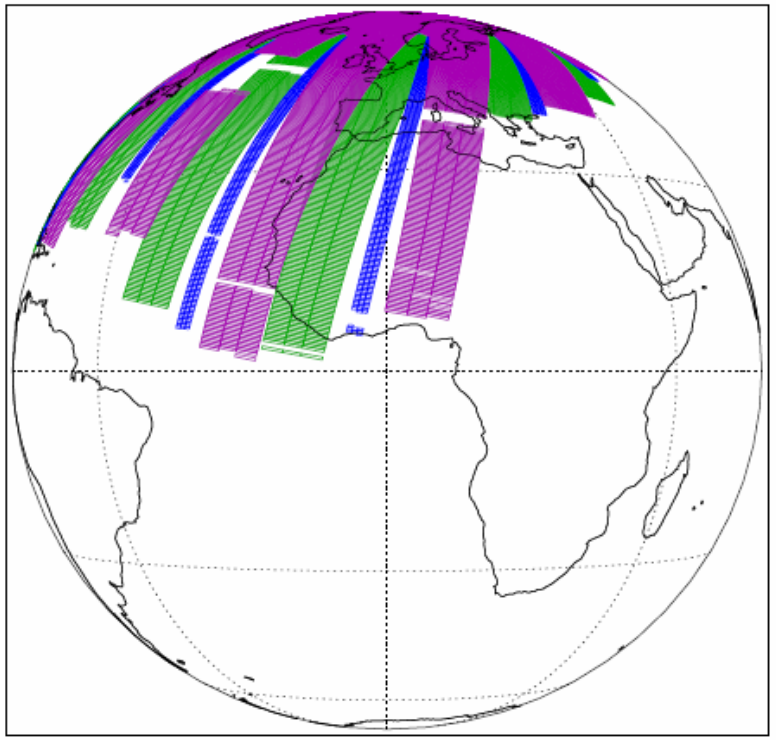
DARC

EUMETSAT

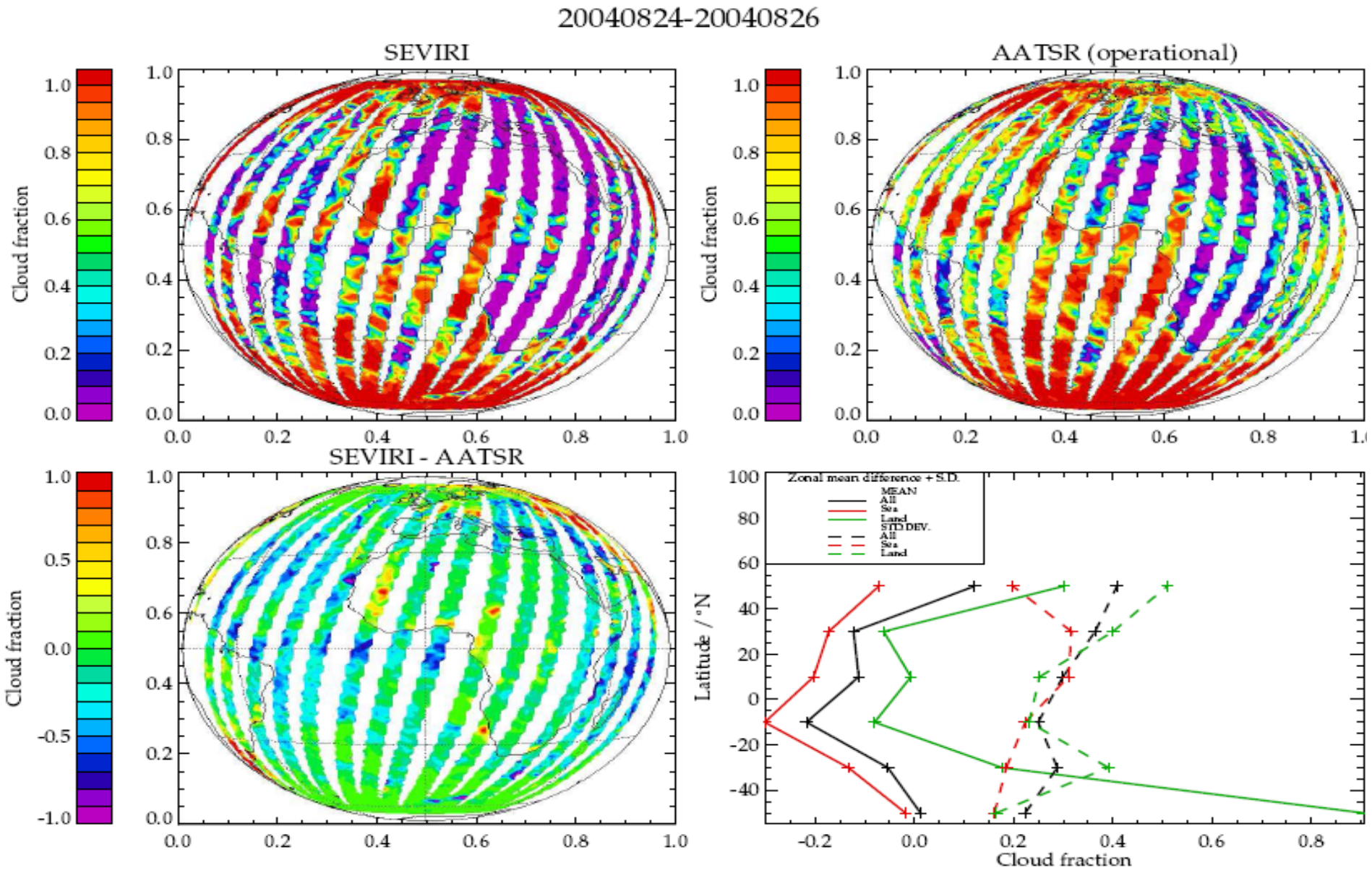
Datasets acquired

- SEVIRI L1.5 radiance data at full spatial, spectral and temporal sampling from 24 August - 30 September.
- Eumetsat operational cloud-flag for same period as above + 1 day in 10 for WP1400
- AATSR level 1 radiances at full spatial resolution
- AATSR operational cloud-flag.
- GOME level 1 data.
- SCIAMACHY level 1 data.
- ECMWF operational analyses
- MPEF TOZ products

GOME coverage 24-26 August 2004



Comparison with AATSR cloud flags



Gaseous absorption + SEVIRI filters

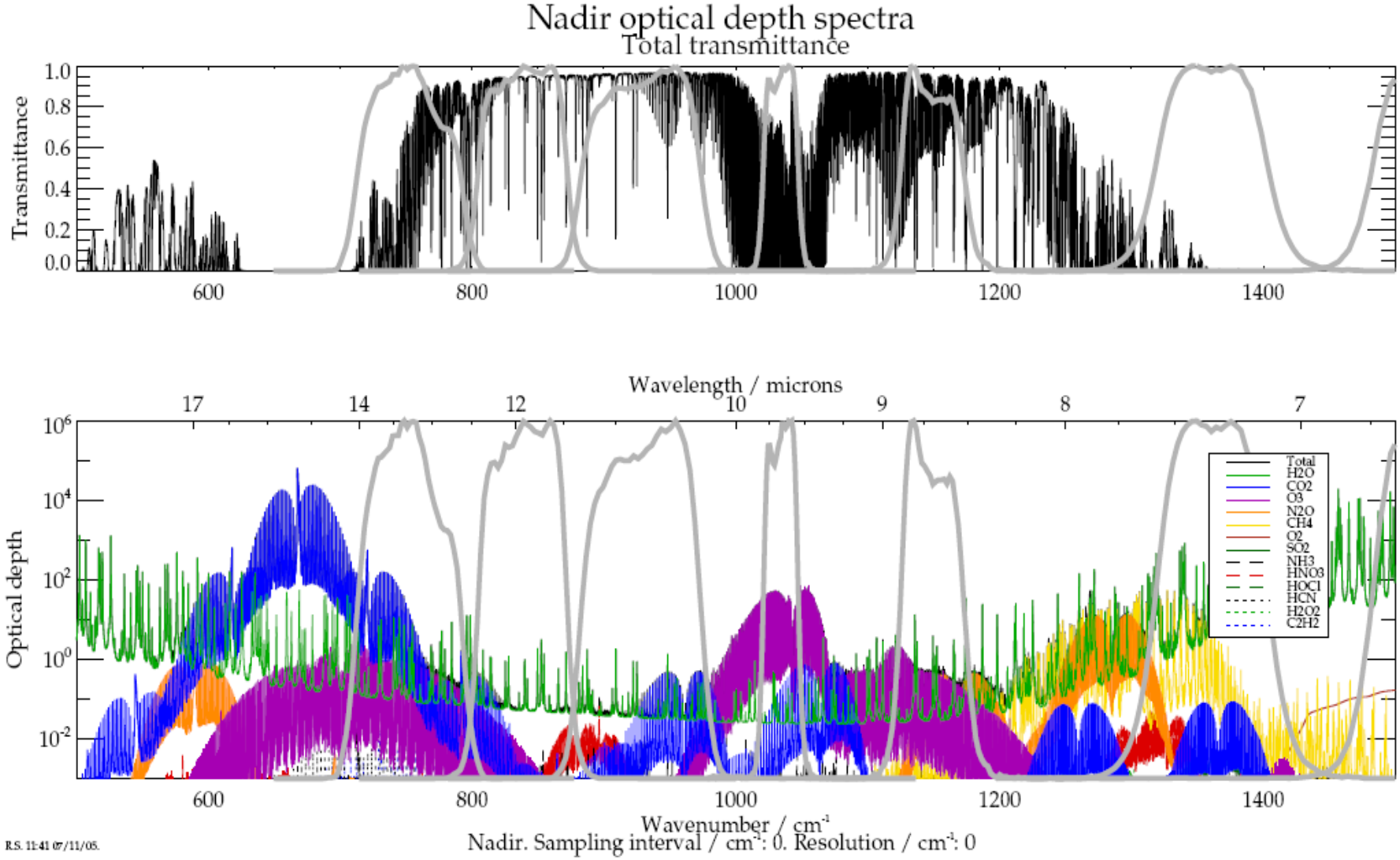
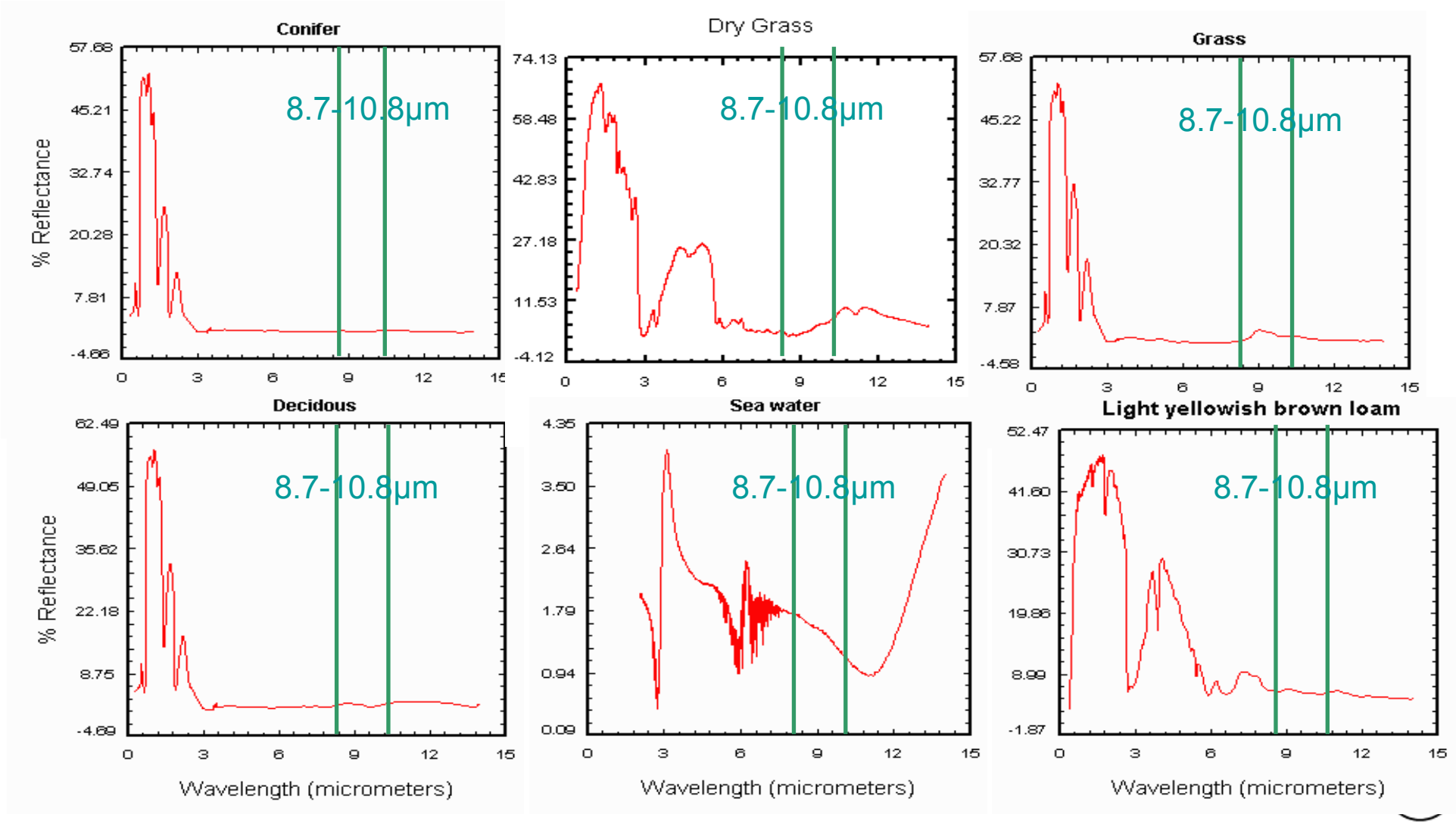


Figure 4.2: Typical vertical optical depths in the 500-1500 cm^{-1} region. SEVIRI spectra response functions are shown in grey.

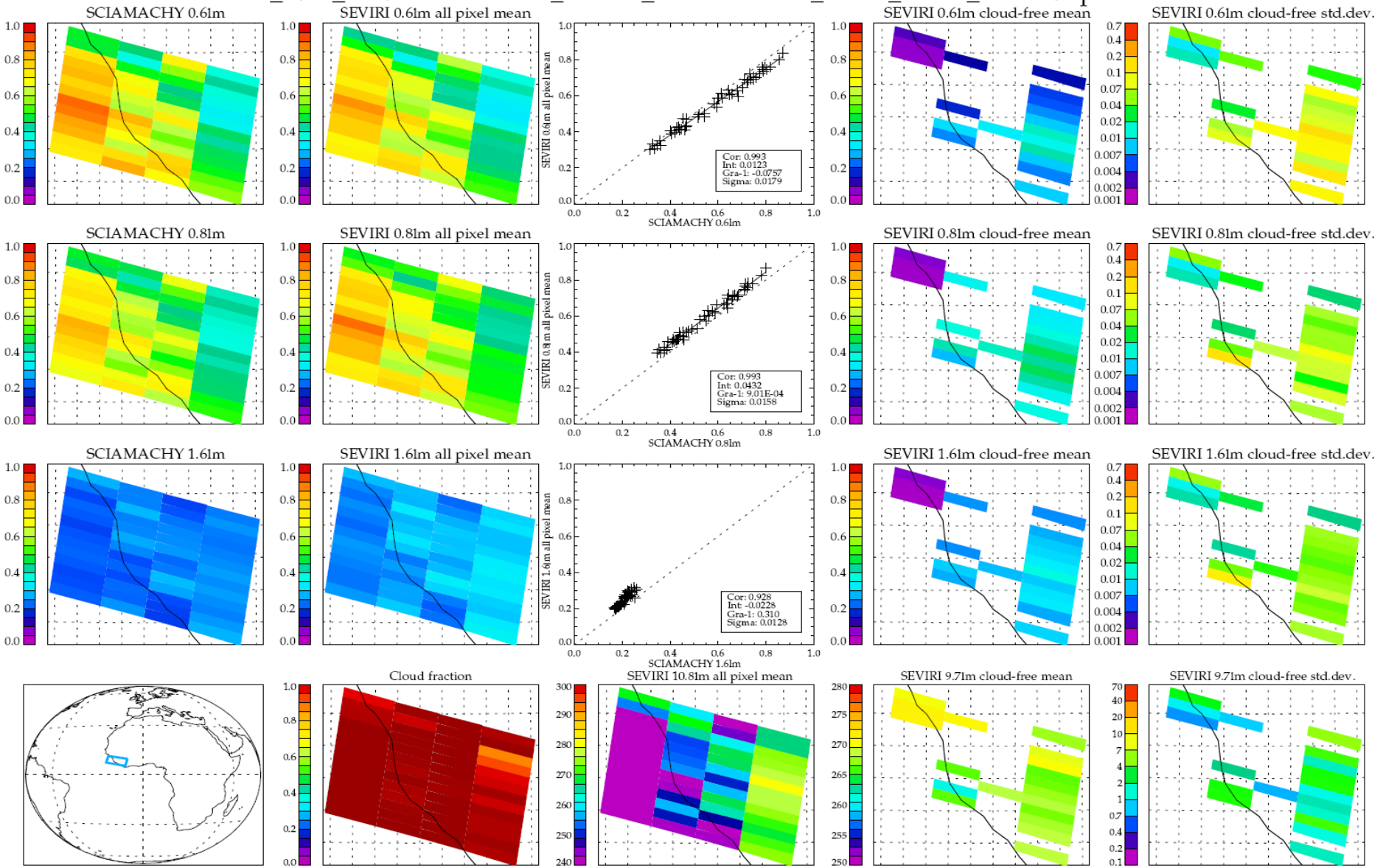
Surface emissivity

- **ASTER spectral library (http://speclib.jpl.nasa.gov)**



Co-location / comparison of SCIA & SEVIRI

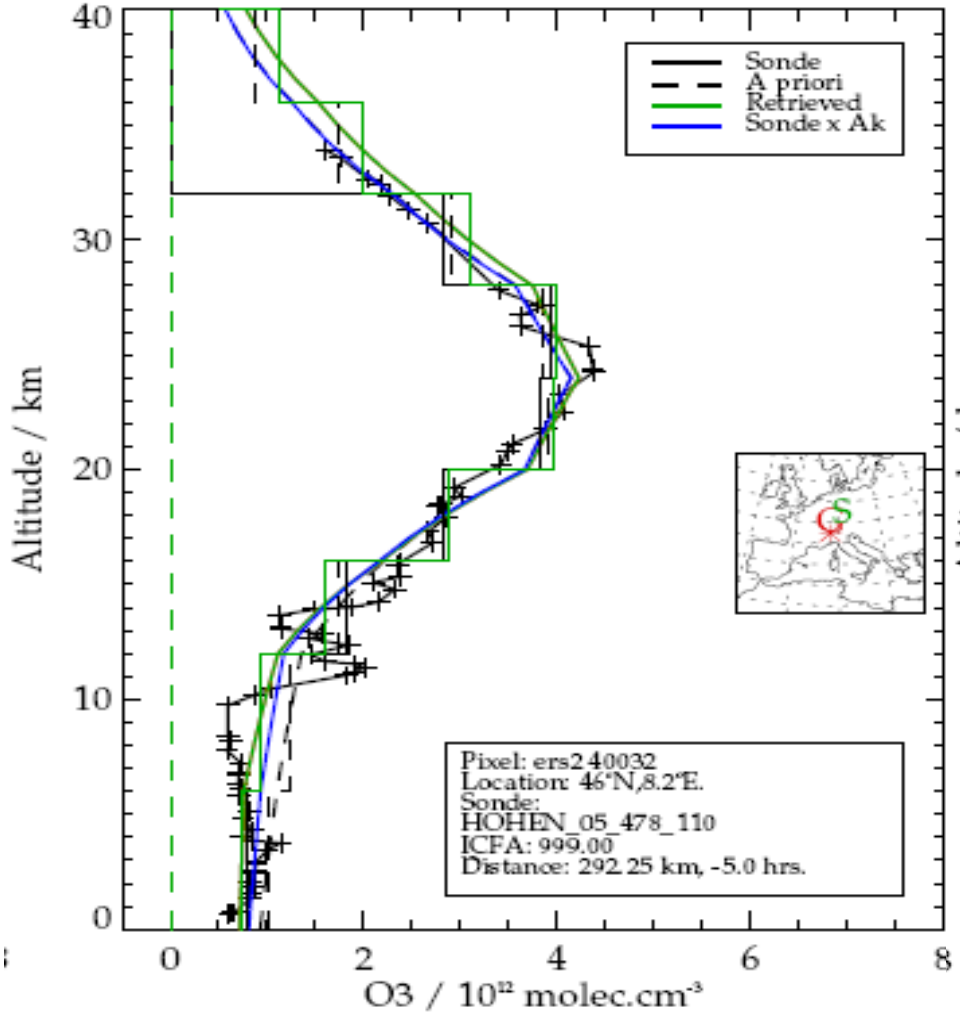
CCLRC Rutherford Appleton Laboratory

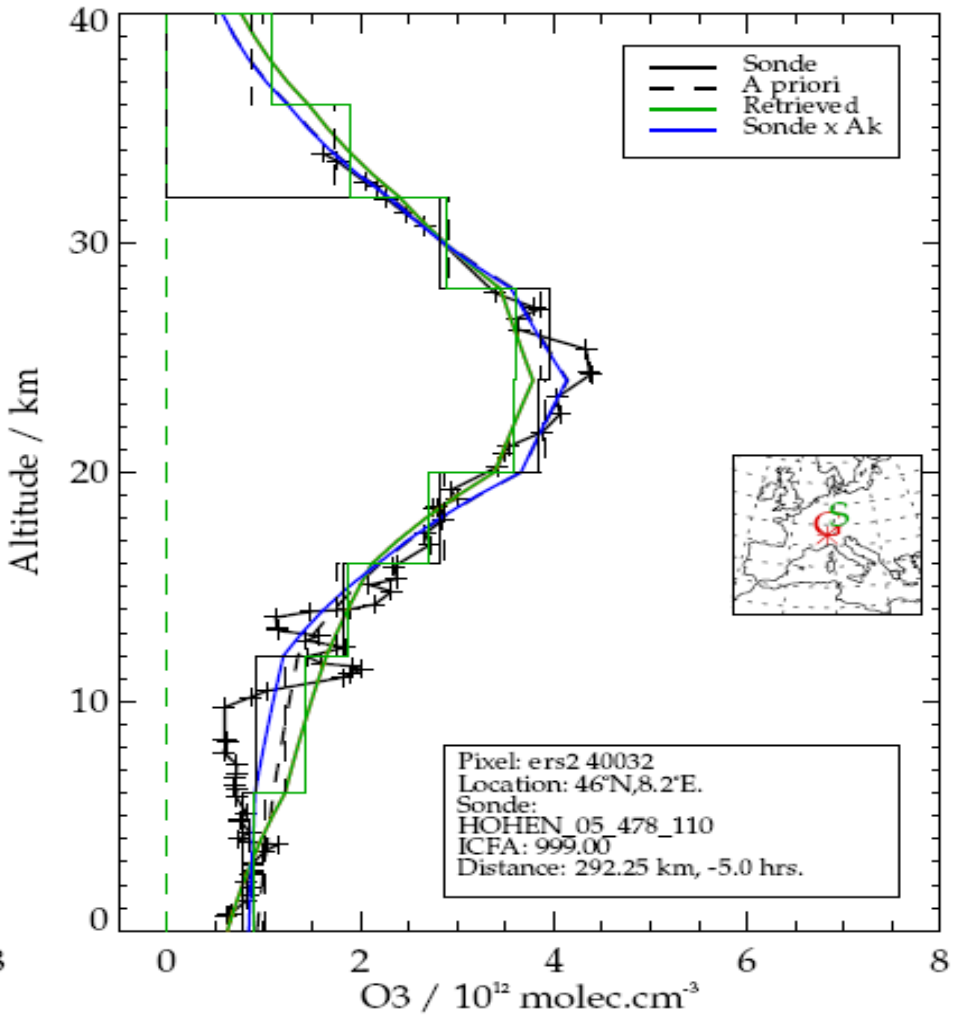


R.S. 15:01 04/02/06.

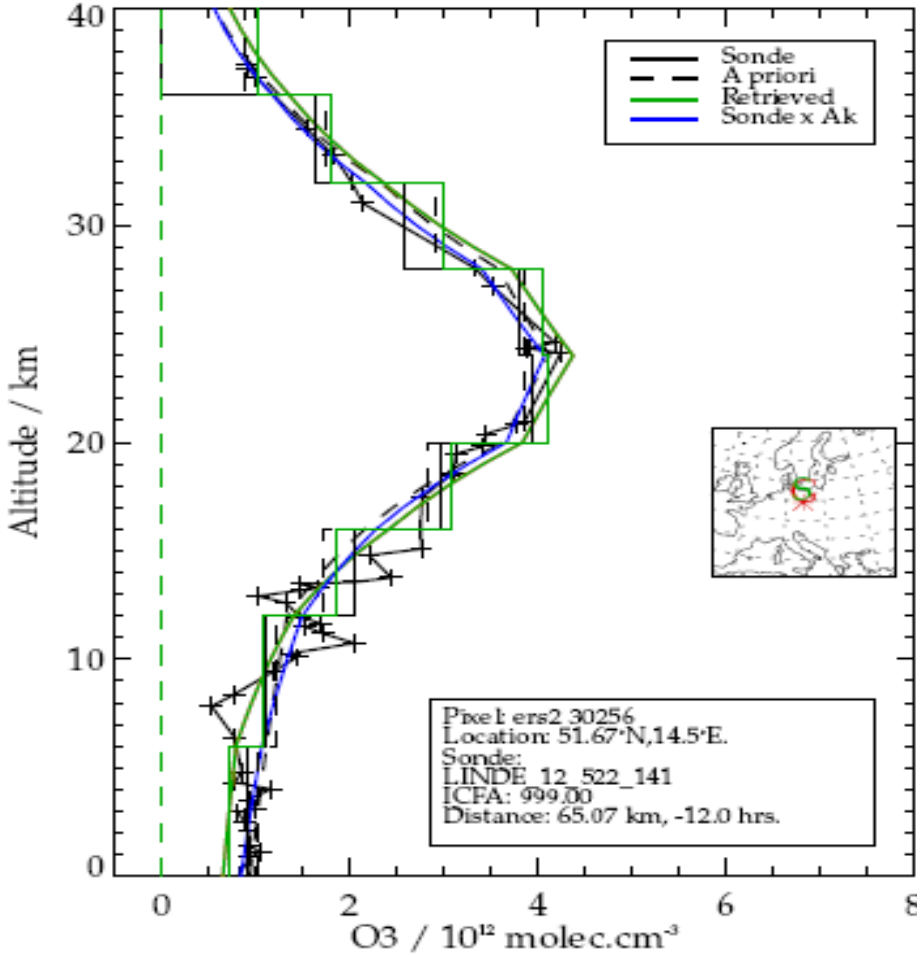
State: 9

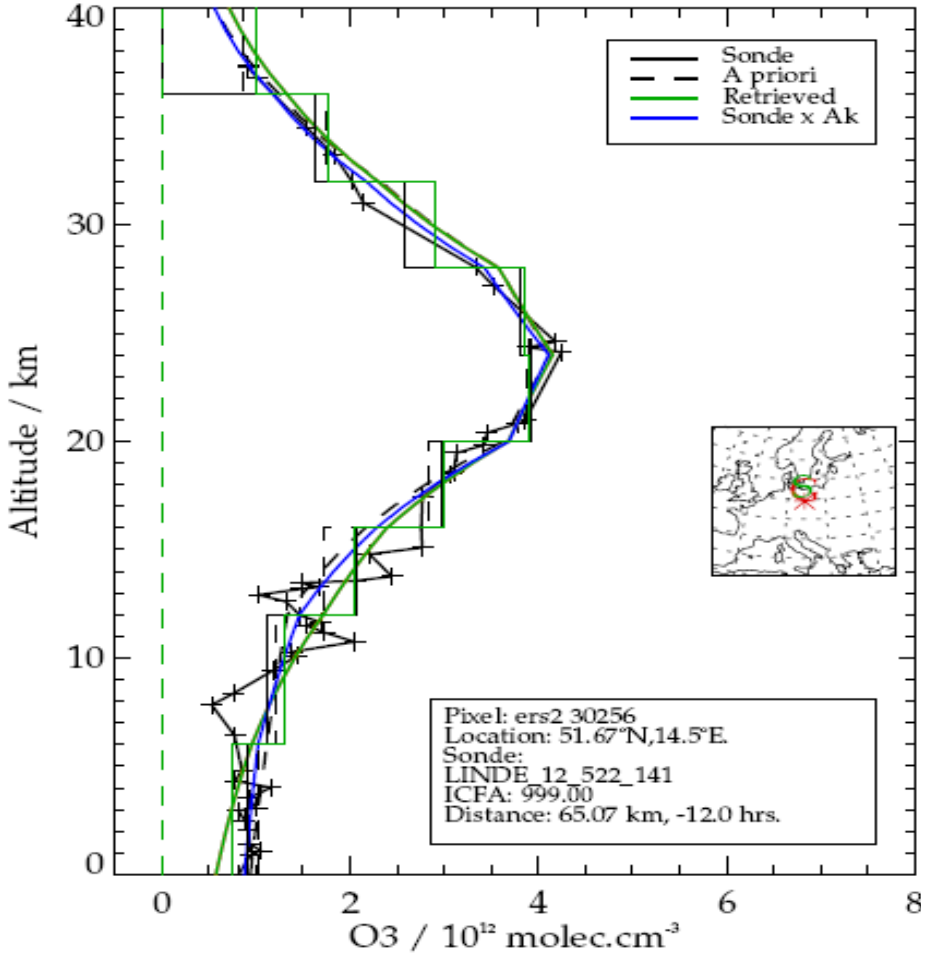
Real retrievals: “b1cov”



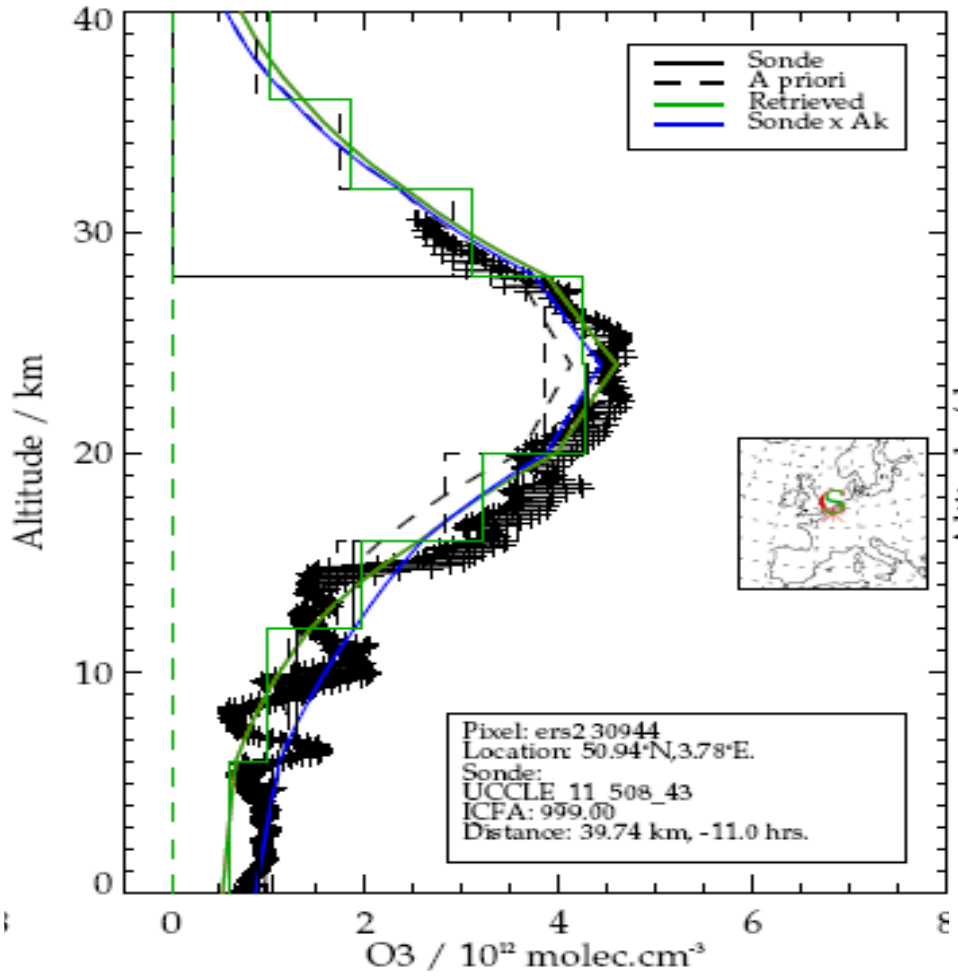


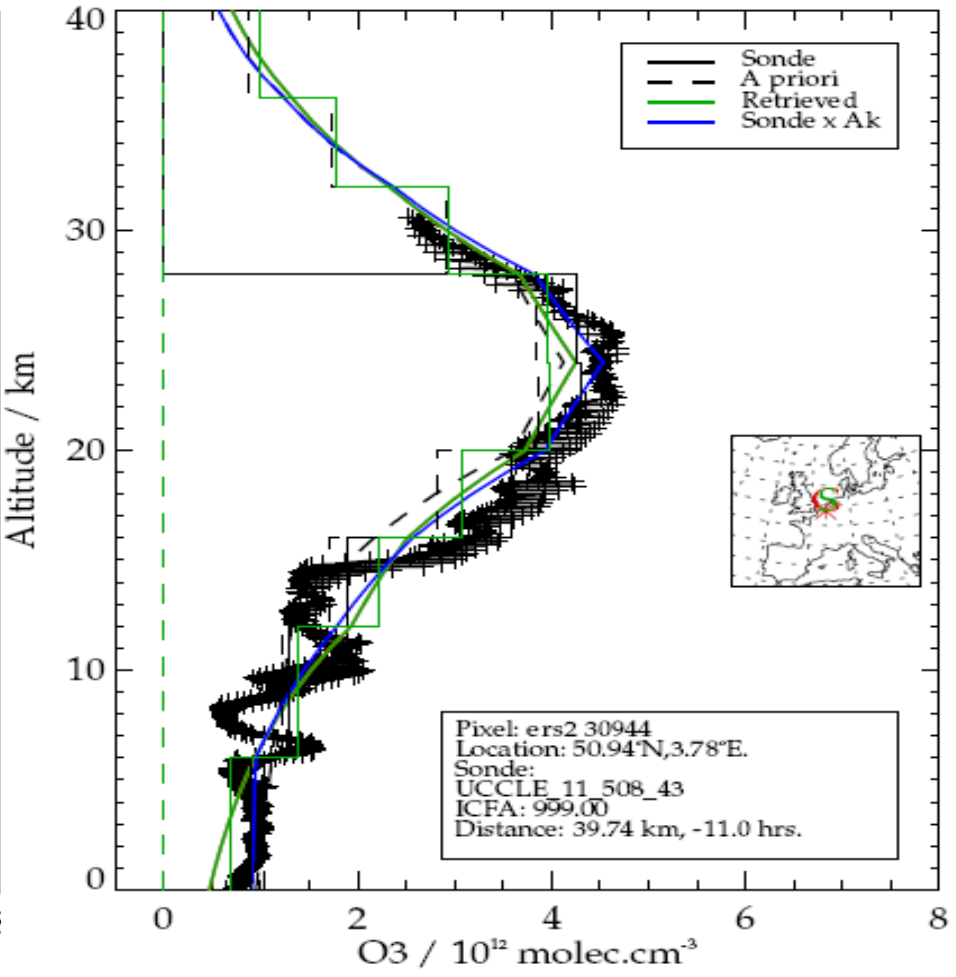
Real retrievals: “b1cov”



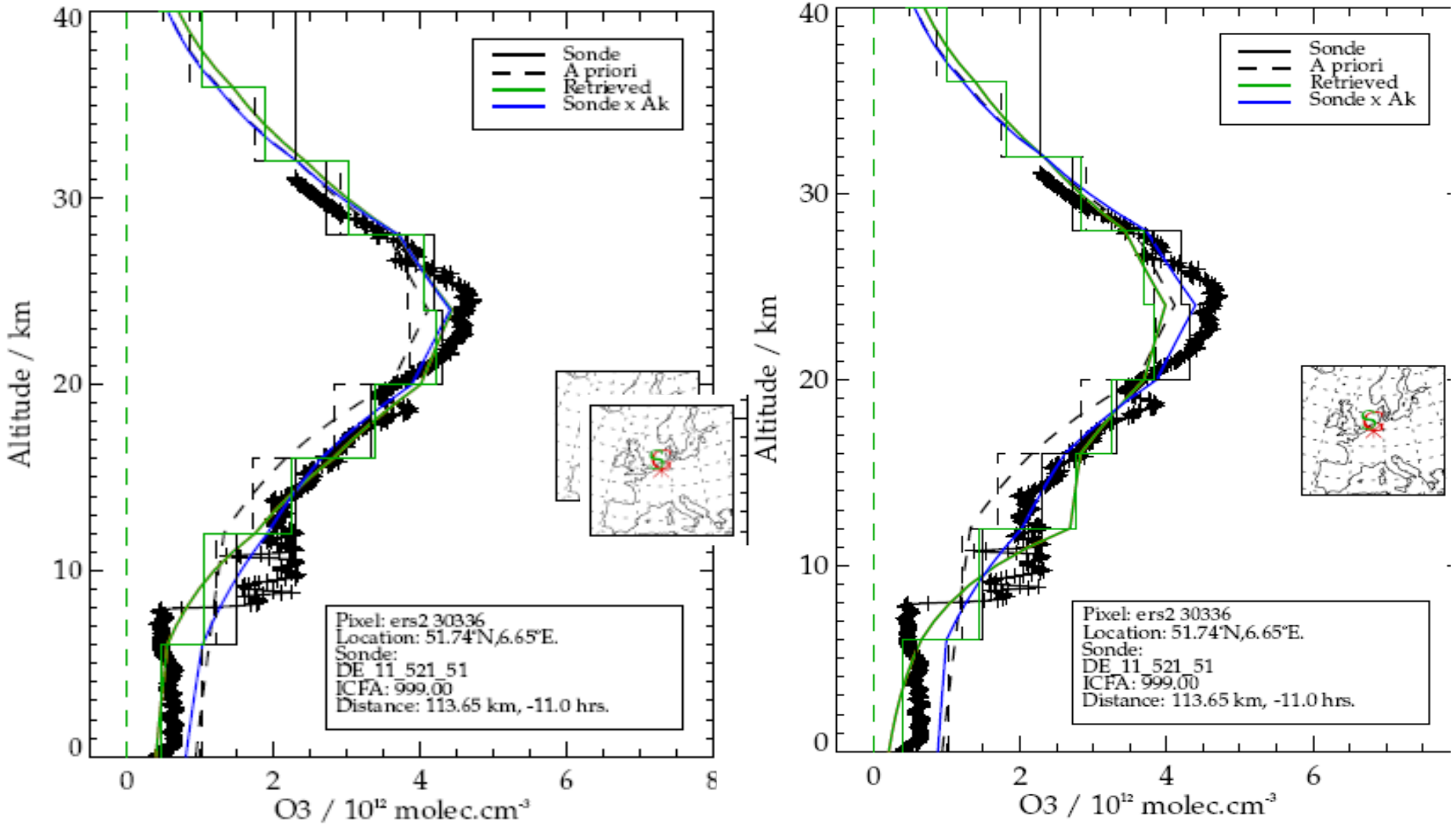


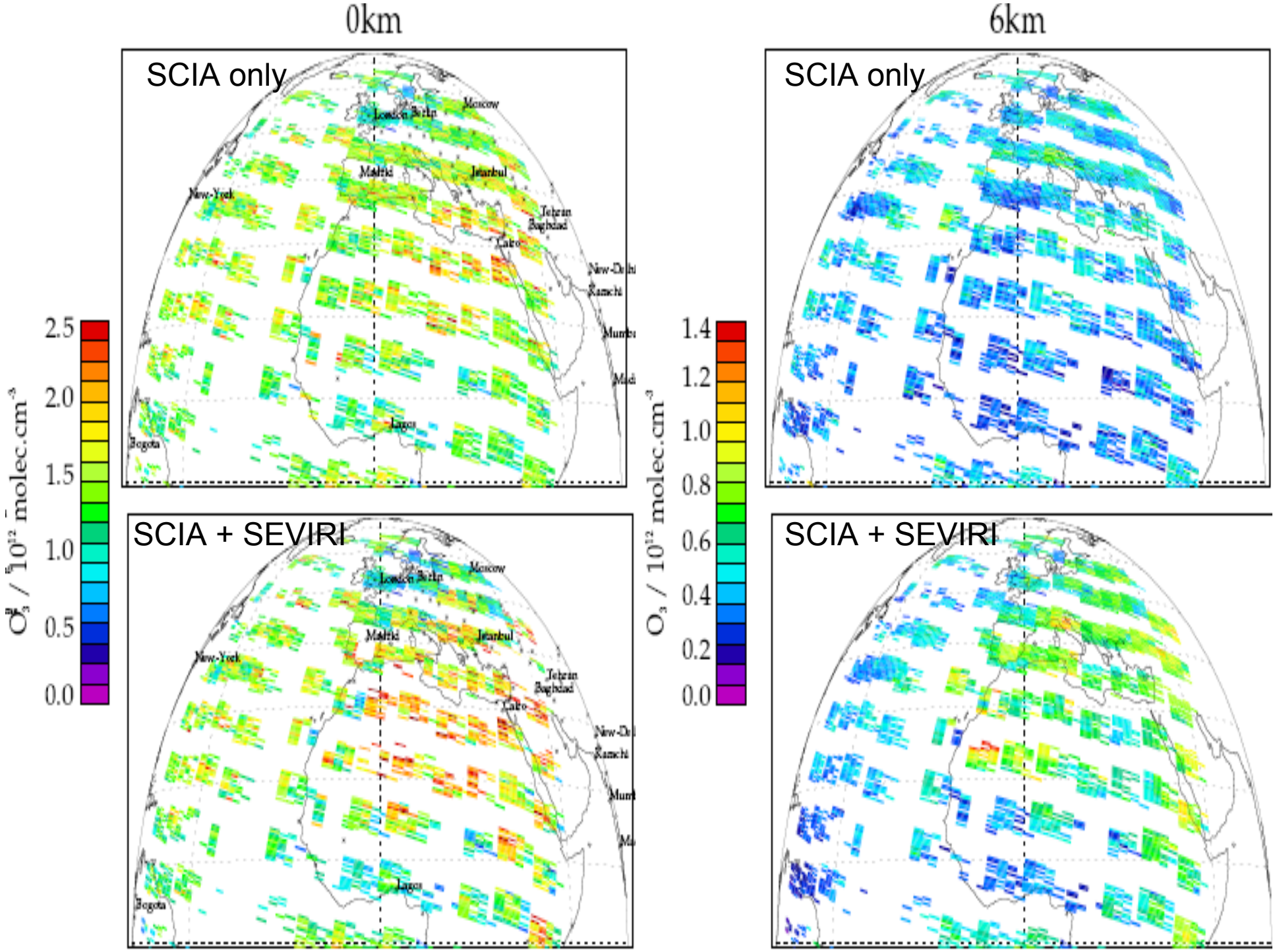
Real retrievals: “b1cov”



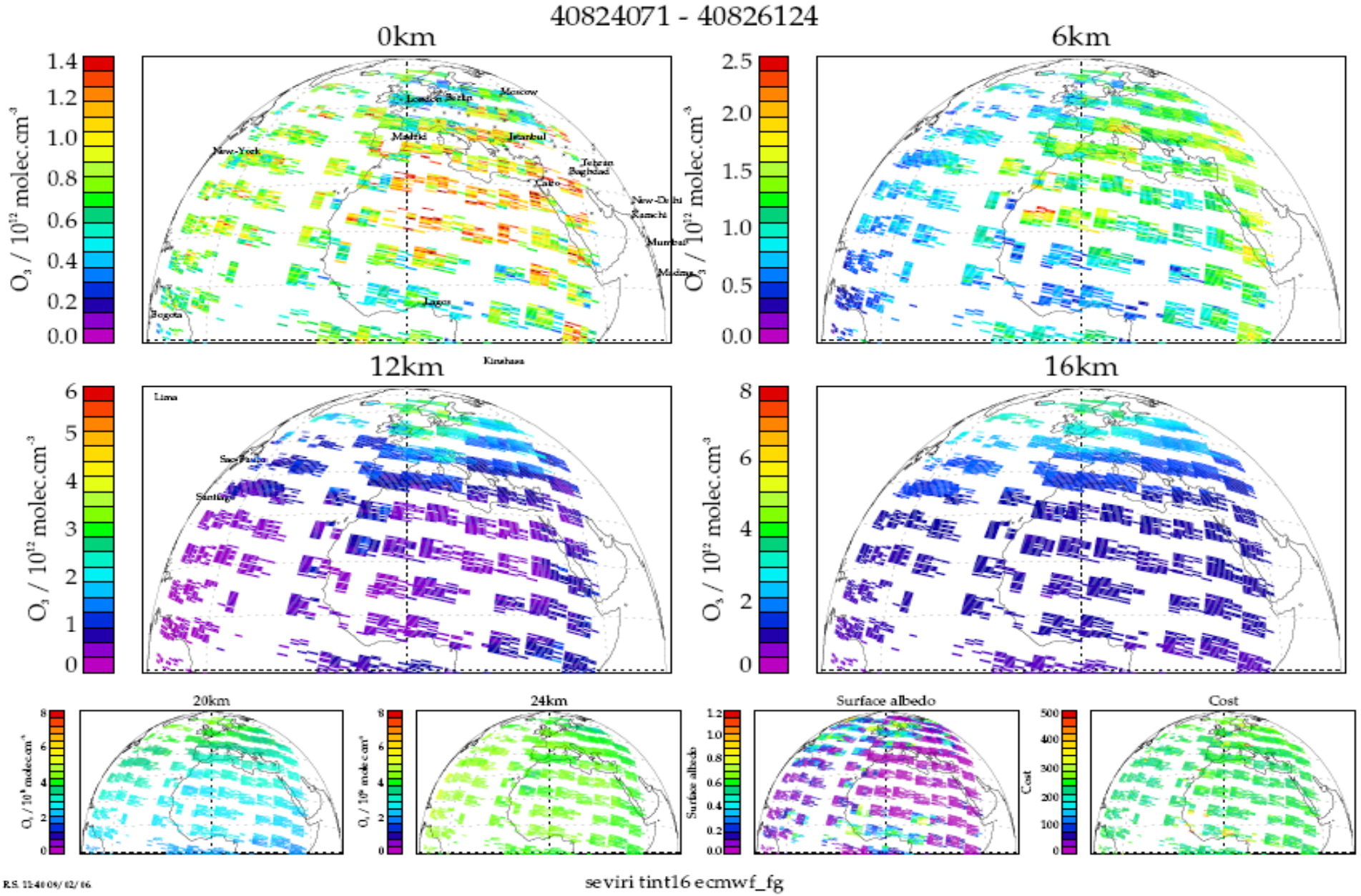


Real retrievals: “b1cov”




0km
6km
SCIA only
SCIA only
SCIA + SEVIRI
SCIA + SEVIRI
O_3 / 10^{12} molec.cm^{-3}
2.5
2.0
1.5
1.0
0.5
0.0
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Moscow
London
Berlin
Madrid
Istanbul
New-York
Tehran
Baghdad
Cairo
Lagos
Bogota

Maps: real retrieval (ir+uv)



Maps: real retrieval (ir+uv B1)