Global Cloud Type Distribution from GOME/ERS-2 and GOME-2/MetOp

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DLR
Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Outline

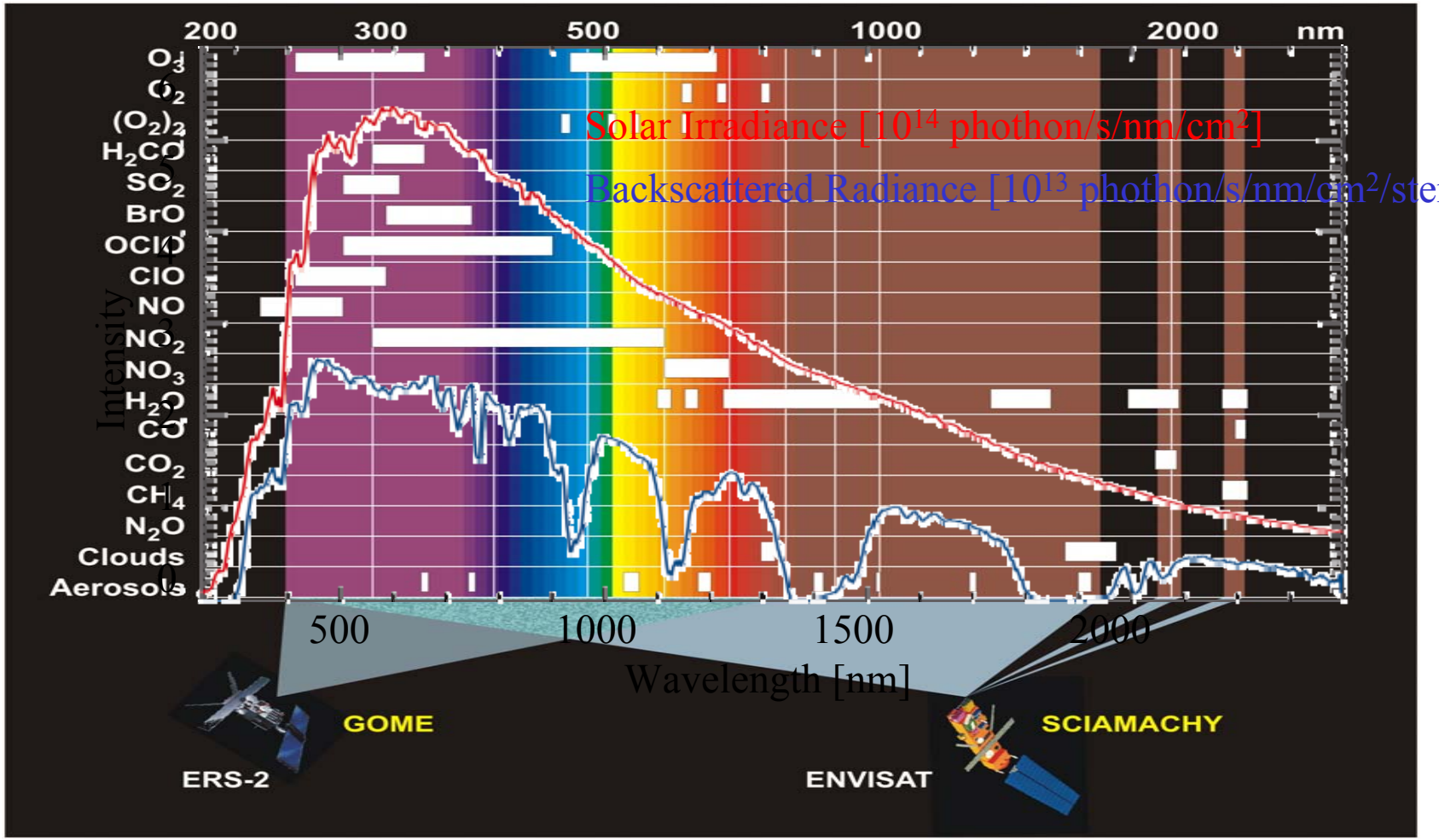
- Motivation
- OCRA and ROCINN Algorithms
- Global Cloud Type Distribution from GOME
- Outlook

GOME-2 Instrument (changes wrt GOME-1 highlighted)

Principle	Nadir-scanning UV/VIS grating spectrometer
Wavelength range	4 main channels: 240-790nm, 2 polarisation channels: 300-800nm
Detectors	1024-element Reticon linear diode arrays
Readout time	46.875 ms (complete array) /2
Spectral sampling	0.12-0.21 nm
Spectral resolution	FWHM 0.26-0.51 nm (main channels)
Swath width/type	Default 1920 km, constant ground pixel size
Min. effective IT	187.5 ms /8
Spatial resolution	Default 80x40 km² (main channels) /4
Internal calibration	LED, Spectral lamp (PtCrNeAr), White lamp
Sun diffuser	Quartz quasi-volume
Data rate	400 kbit/s (300 MB/orbit) *10

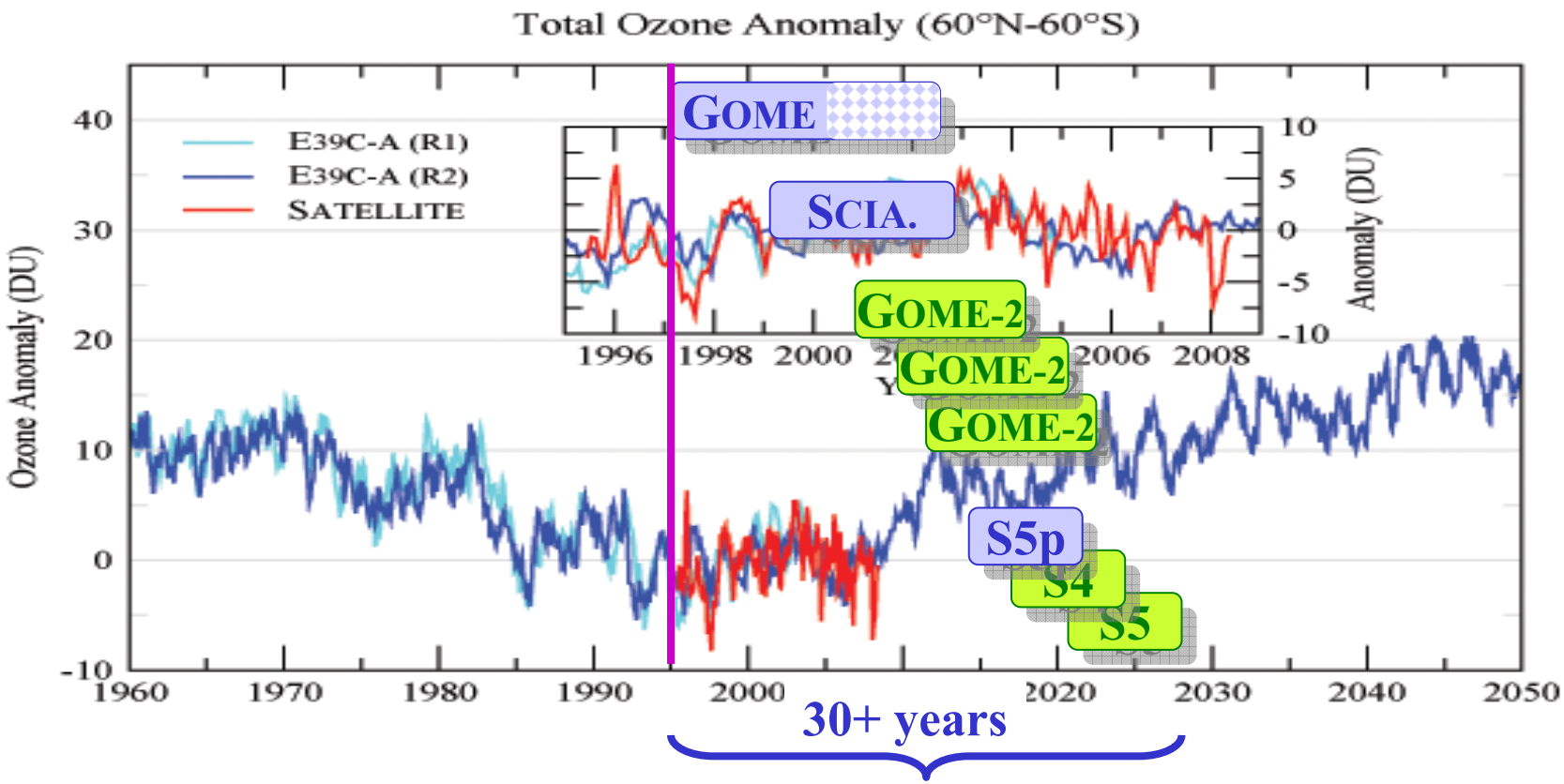
courtesy M. Eisinger/ESA

Atmospheric Composition with GOME & SCIAMACHY



courtesy Uni. Bremen

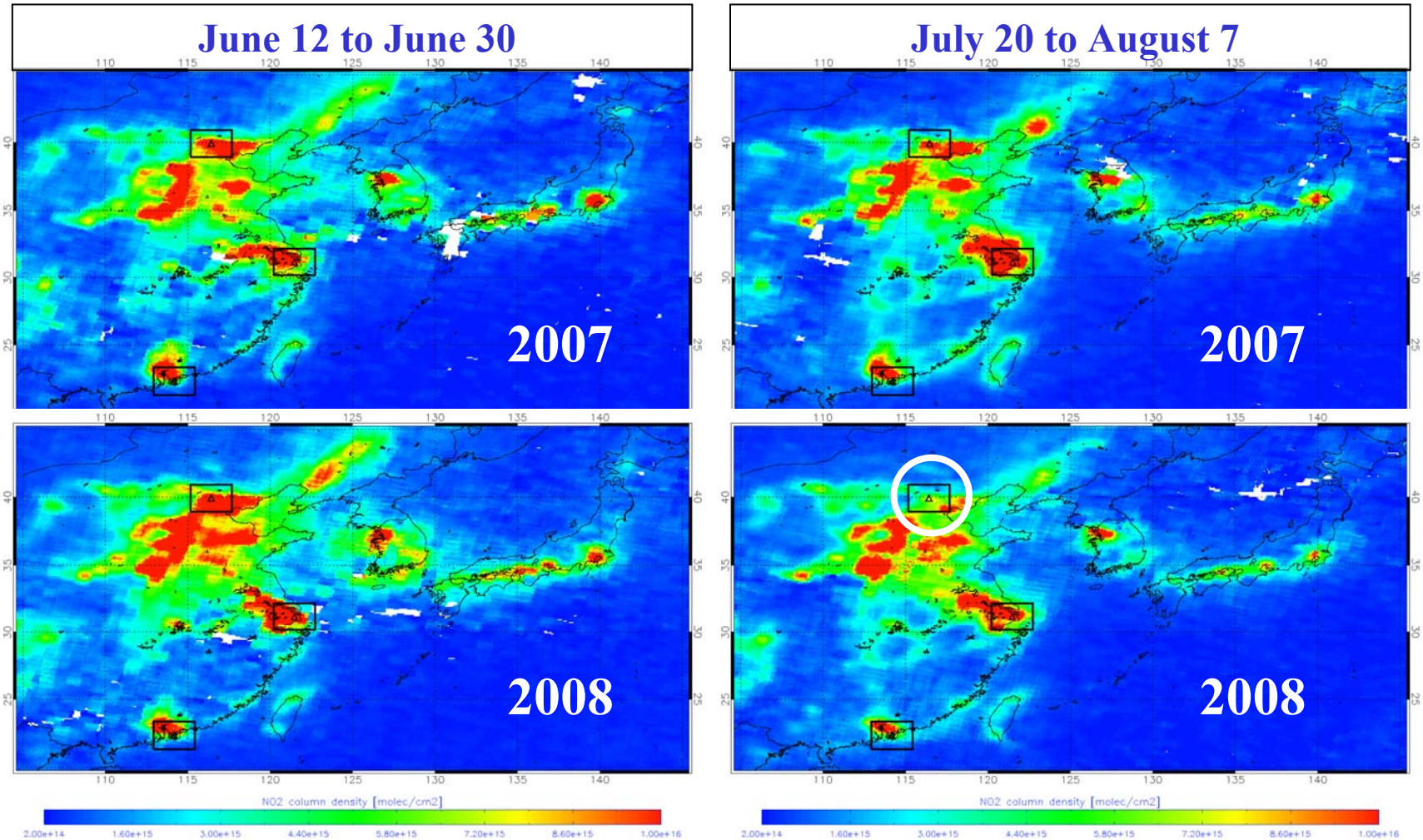
Ozone Long-Term Monitoring with GOME Type Sensor



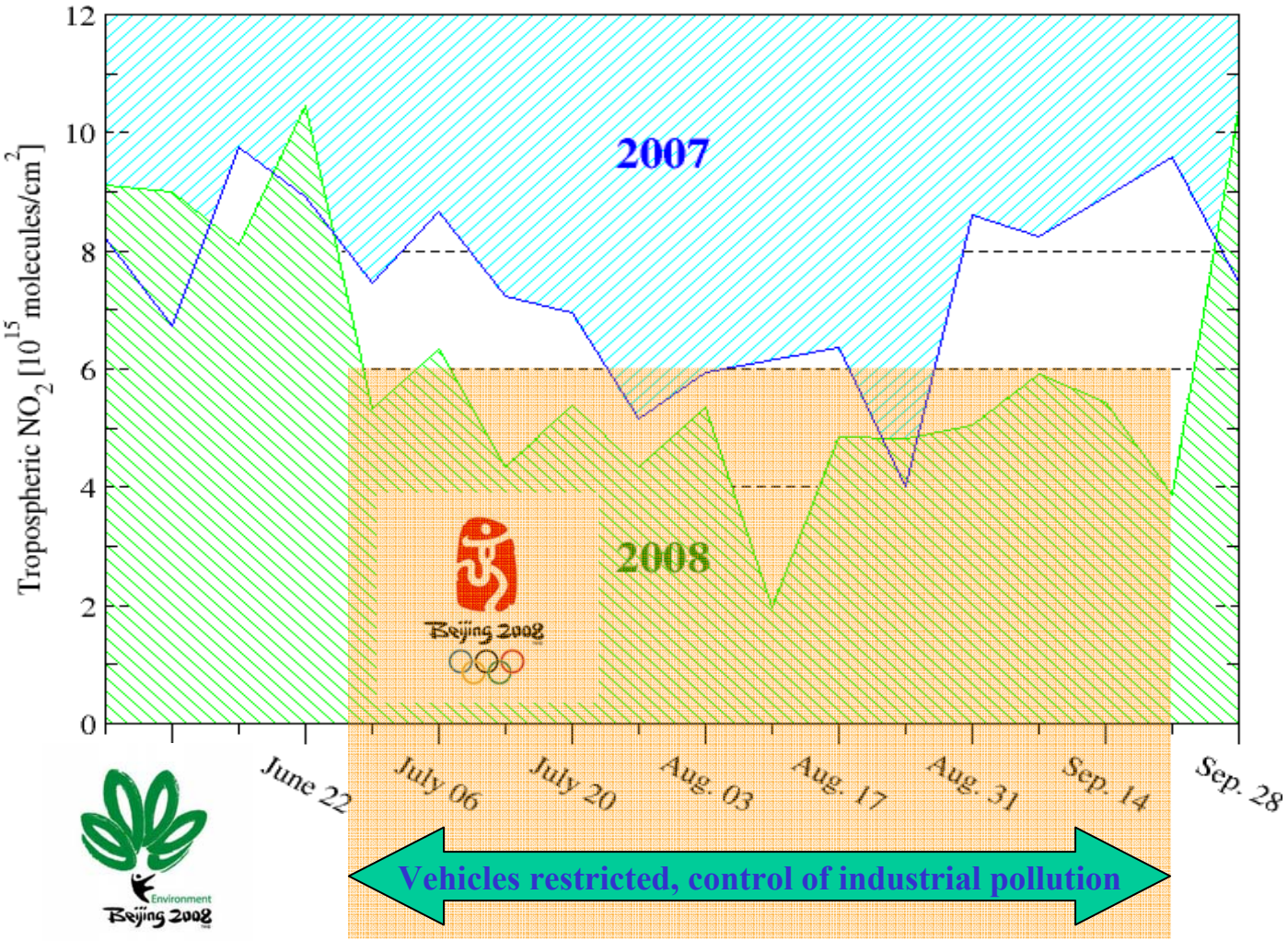
— E39C-A (R1/R2), Stenke et al., ACPD 2008

— GOME/SCIAMACHY/GOME-2, Loyola et al., IJRS Montreal Protocol special issue, 2009

Tropospheric NO_2 – GOME-2 over China



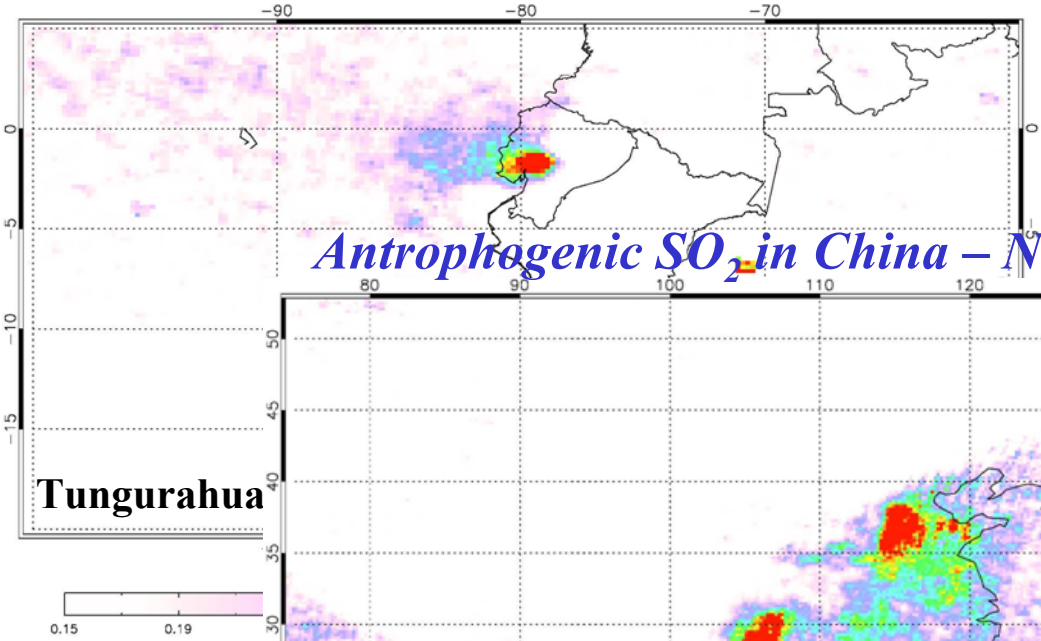
Tropospheric NO_2 – GOME-2 over Beijing



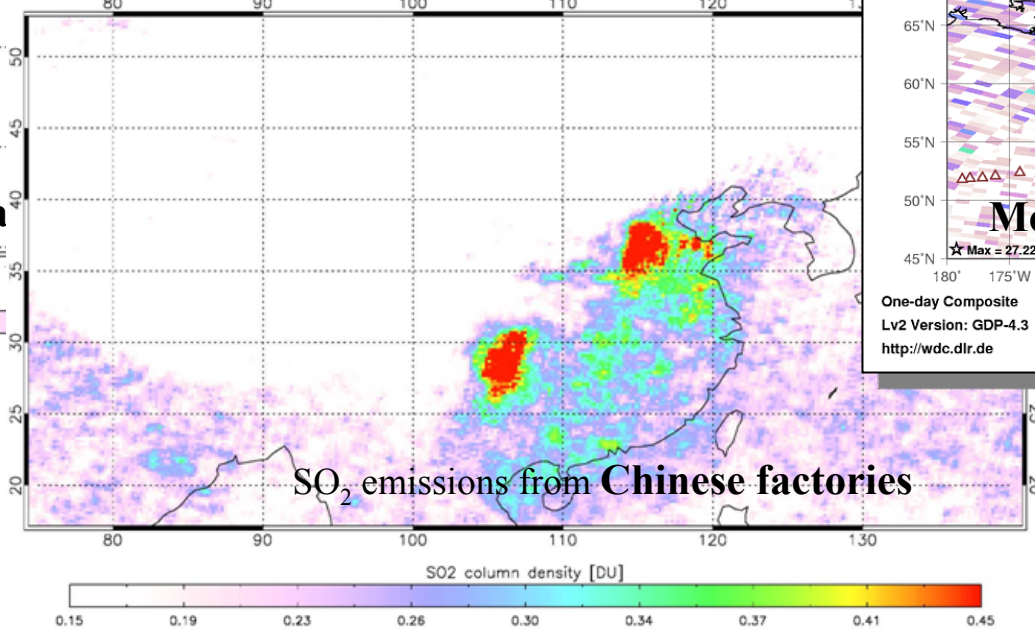
Environment Beijing 2008

Tropospheric SO_2 – GOME-2 in 2007 and 2009

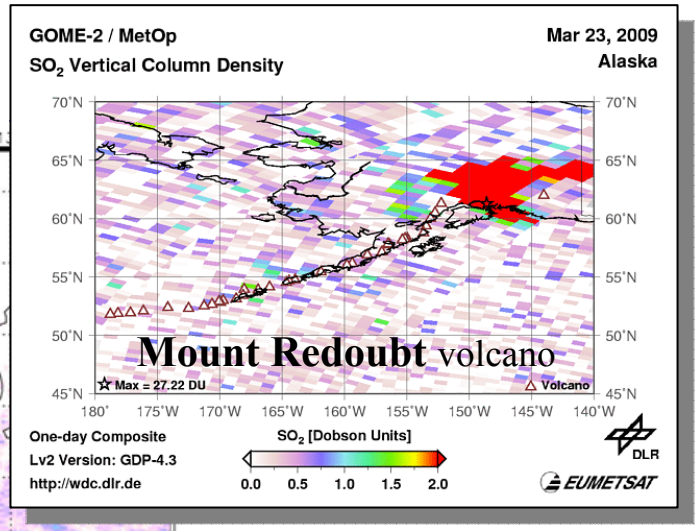
Volcanic Degassing in Ecuador – Nov. 2007



Antrophogenic SO_2 in China – Nov.



Volcan in Alaska – 2009



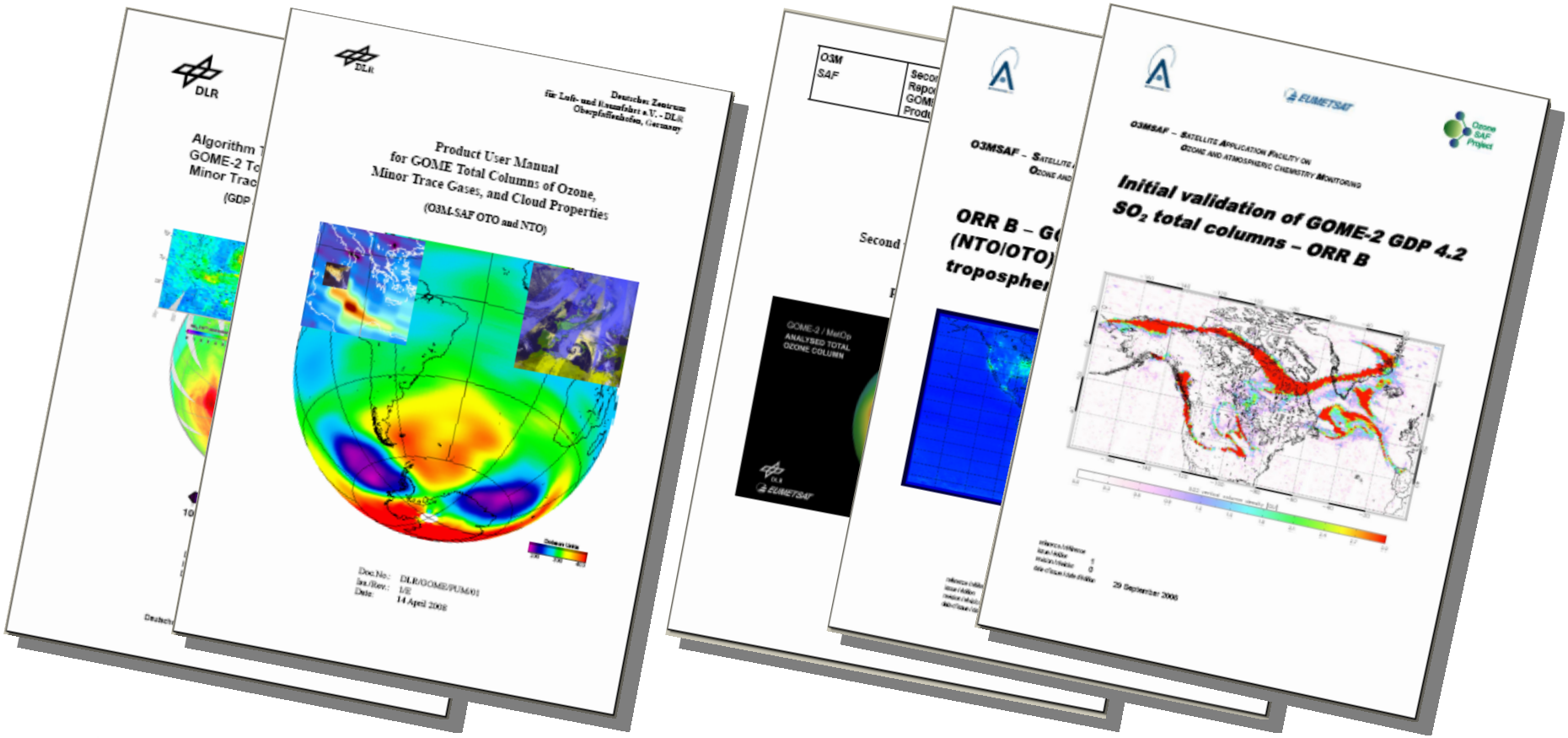
GDP 4.x Algorithm – Key Features

- GDP 4.x the operational algorithm for O_3, NO_2, BrO, SO_2, H_2O, HCHO, …
  - GOME/ERS-2 since 2004
  - SCIAMACHY/ENVISAT since 2006
  - GOME-2/MetOp since 2007

- Improved trace gas retrieval:
  - Molecular Ring Correction (M. van Roozendael et al., JGR 2006)
  - On-the-fly RTM simulations using LIDORT V2.2+ (R. Spurr, 2003)
  - Cloud algorithms: OCRA&ROCINN (D. Loyola et al., TGRS 2007)

- Independent geophysical validation (D. Balis et al., JGR 2007, M. Anton et al., AnnGeo 2008 and M. Anton et al., AnnGeo 2009)

GOME-2 Documentation: ATBD, PUM, Validation



GDP 4.x Algorithm – Dependency on Clouds

$$V^{(n+1)} = \frac{\overset{\{c_f,\, c_z,\, c_a\}}{E^{(n)}} + \phi \overset{\{c_z\}}{G^{(n)}} \overset{\{c_z,\, c_a\}}{A^{(n)}_{cloud}}}{\underset{\{c_f\}}{(1-\phi) A^{(n)}_{clear}} + \underset{\{c_z,\, c_a\}}{\phi A^{(n)}_{cloud}}}$$

- Cloud fraction c_f
- Cloud-top height c_z
- Cloud-top albedo c_a

where

- $V^{(n+1)}$ is the Vertical Column at the n+1th iteration
- $E^{(n)}$ is the Molecular Ring corrected Slant Column at the nth iteration
- ϕ is the intensity-weighted Cloud Fraction
- $G^{(n)}$ is the associated Ghost Column (below the cloud-top pressure level)
- $A^{(n)}$ is the Air Mass Factor at the nth iteration based on guess $V^{(n)}$.

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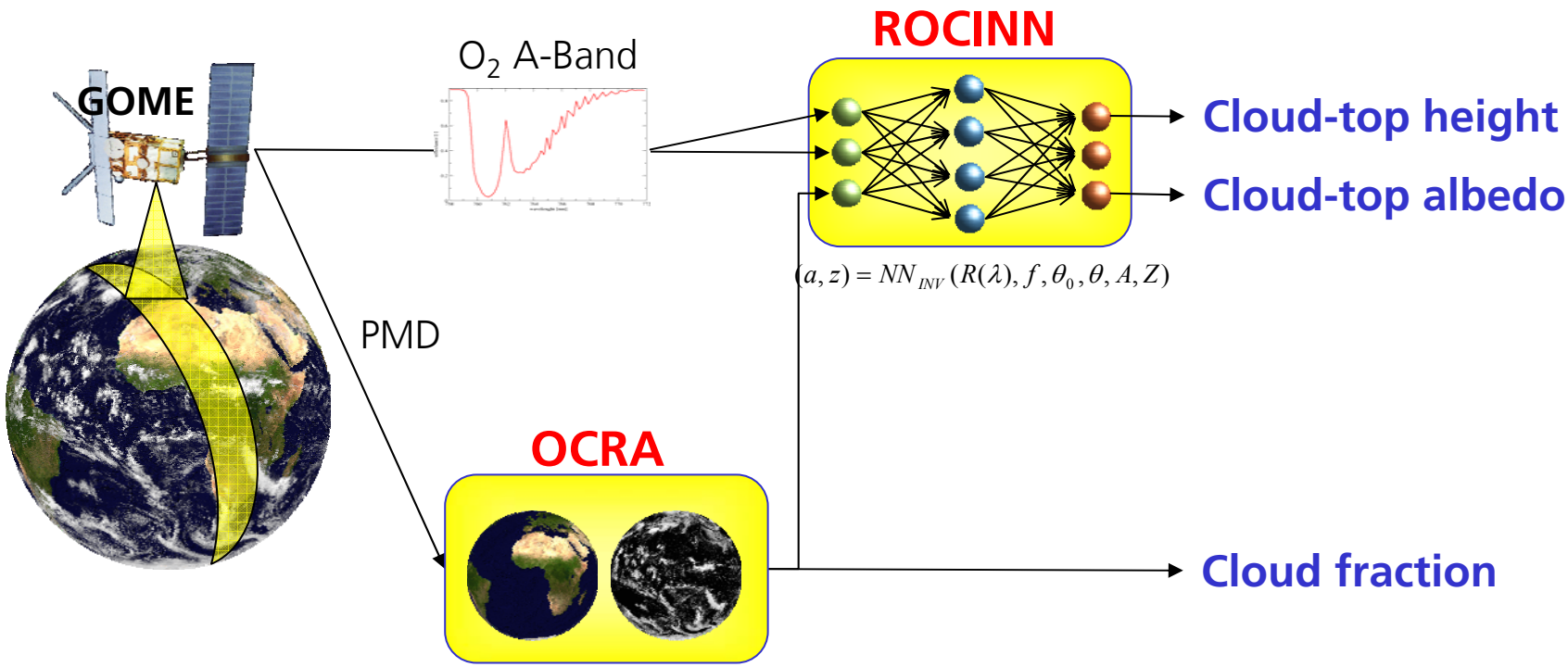
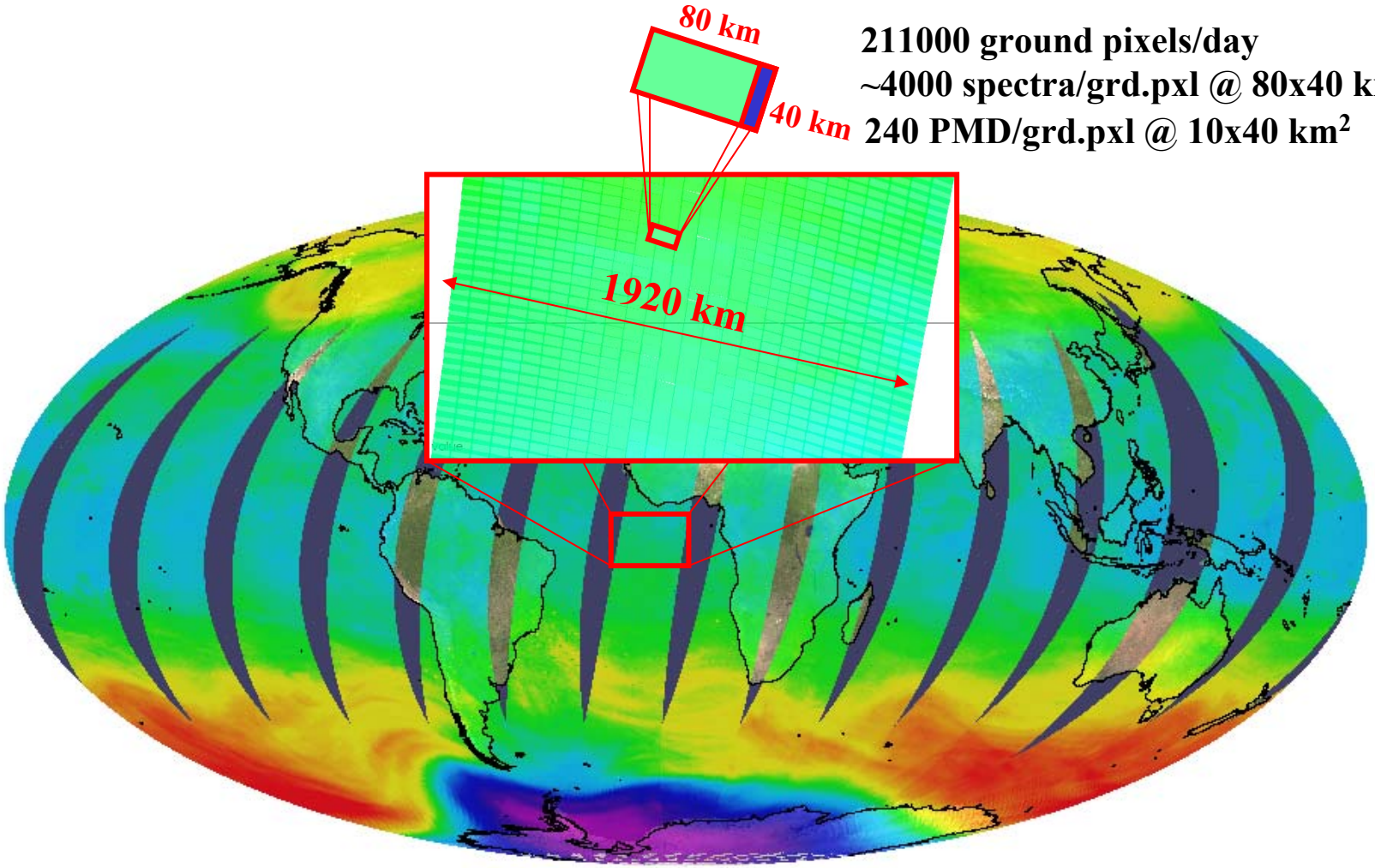
OCRA and ROCINN – Overview



$$f = \sqrt{\sum_{i=R,G,B_i} \alpha(\lambda_i) \max(0, [\rho(\lambda_i) - \rho_{CF}(\lambda_i)]^2 - \beta(\lambda_i))}$$

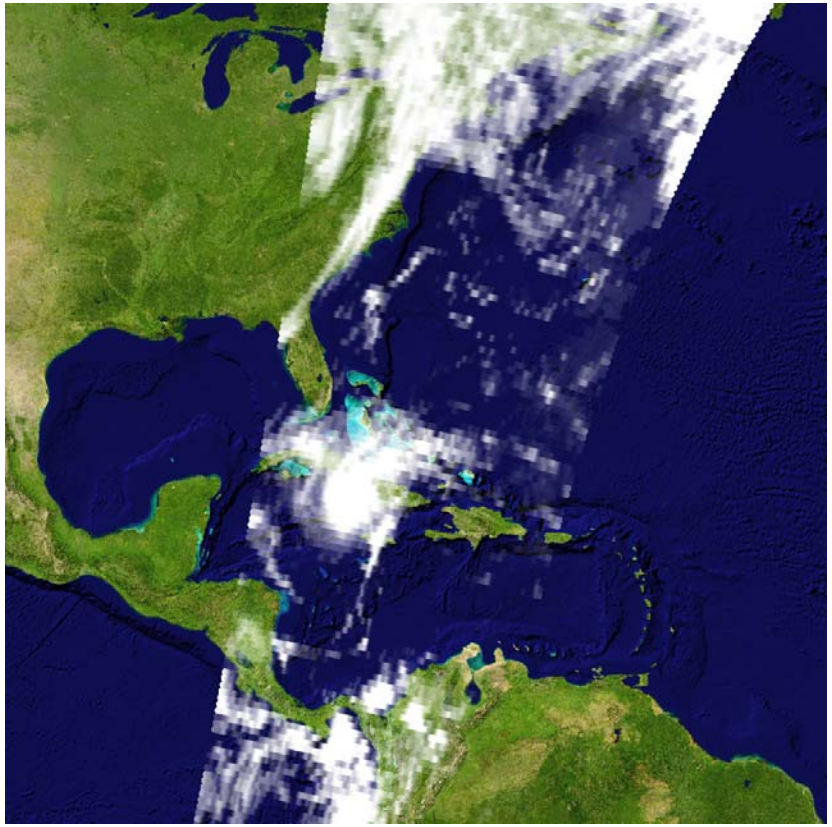
GOME-2 Daily Coverage and Pixel Size



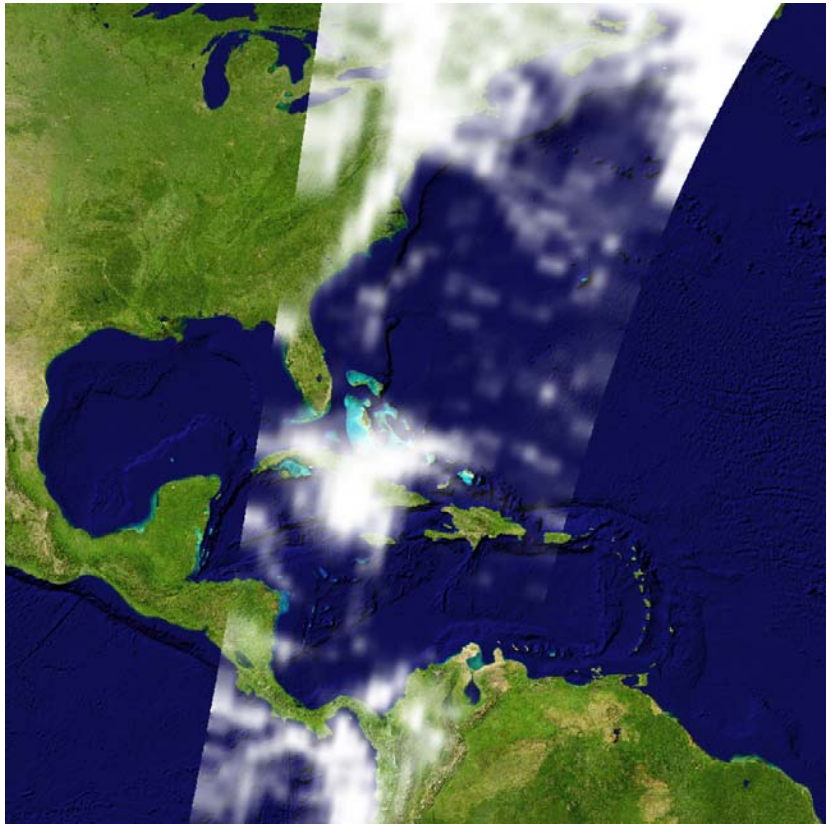
211000 ground pixels/day
~4000 spectra/grd.pxl @ 80x40 km^2
240 PMD/grd.pxl @ 10x40 km^2

GOME-2 Resolution – Hurricane Paloma, 7 Nov. 2008

CF with PMD Resolution

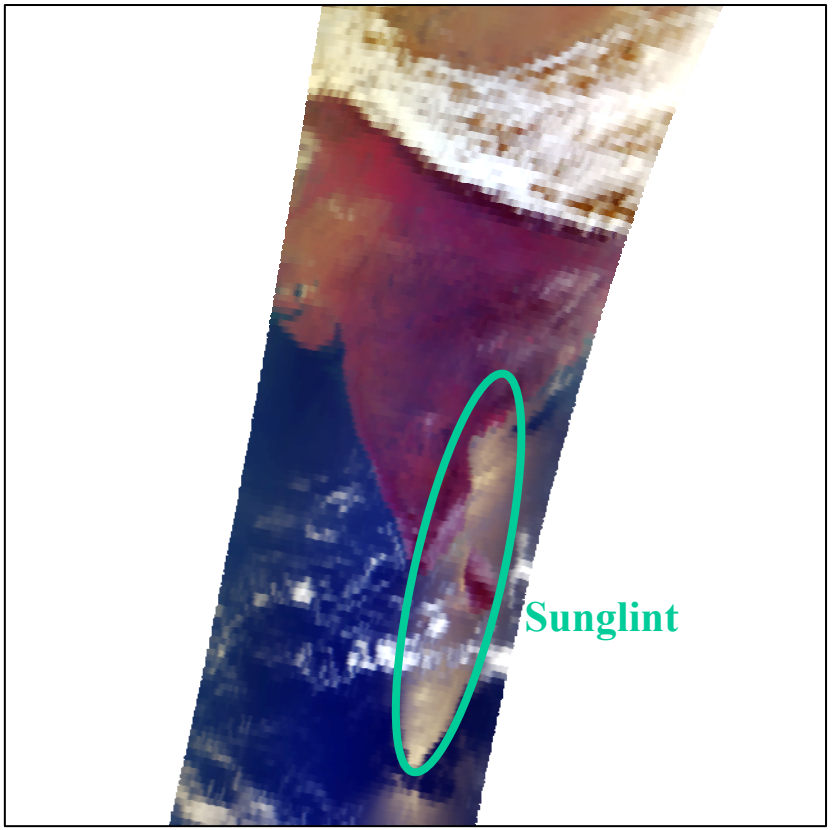


CF with Main Channels Resolution

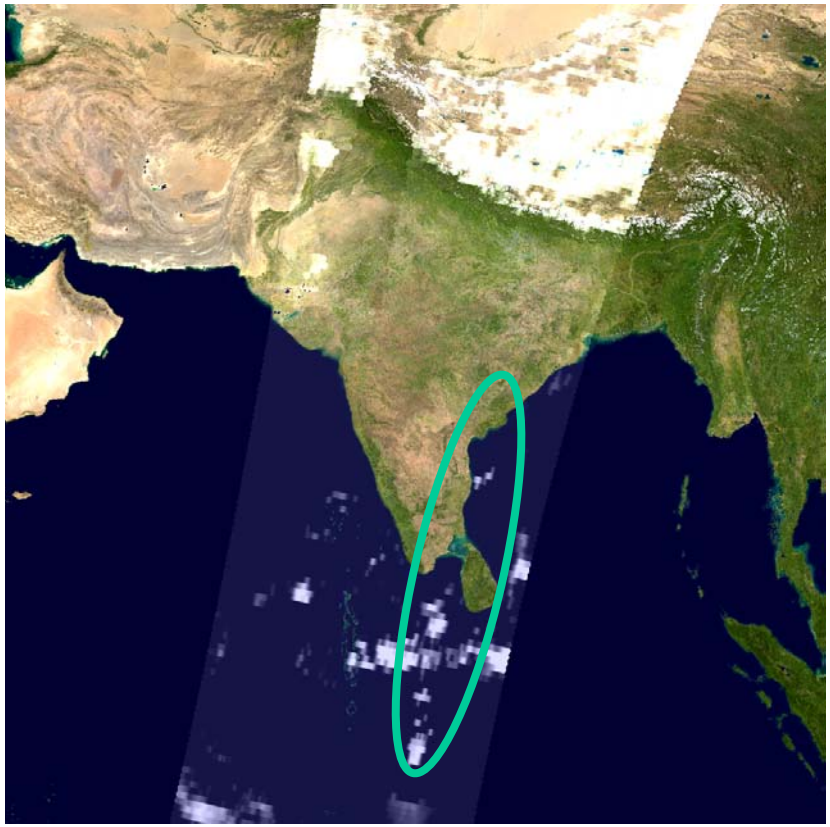


OCRA for GOME-2 – Sunglint Recognition

GOME-2 RGB 2007-03-15

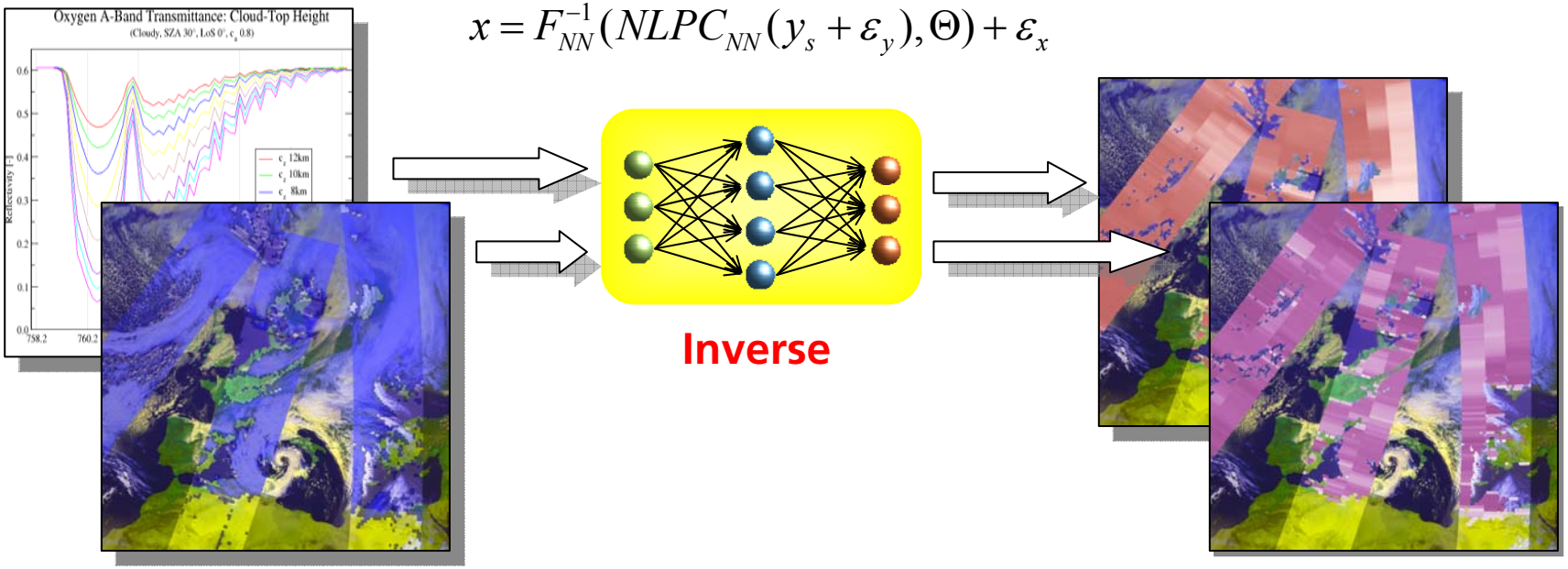


GOME-2 Cloud Fraction



ROCINN Principles

$$x = F_{NN}^{-1}(NLPC_{NN}(y_s + \varepsilon_y), \Theta) + \varepsilon_x$$



OCRA Cloud Fraction

Cloud-top Albedo & Height

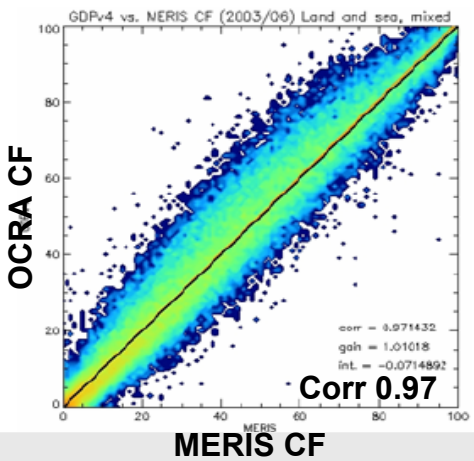
- Loyola D., "***Applications of Neural Network Methods to the Processing of Earth Observation Satellite Data***", *Neural Networks*, vol. 19, no. 2, pp. 168-177, 2006.
- Loyola D., Thomas W., Livschitz Y., Ruppert T., Albert P., Hollmann R., "***Cloud properties derived from GOME/ERS-2 backscatter data for trace gas retrieval***", *IEEE Transactions on Geoscience and Remote Sensing*, vol. 45, no. 9, pp. 2747-2758, 2007.

OCRA and ROCINN – Published Validation

- Tuinder, O. N. E., de Winter-Sorkina, R., and Builtjes, P. J. H., ***"Retrieval methods of effective cloud cover from the GOME instrument: an intercomparison"***, Atmos. Chem. Phys., 4, 255-273, 2004.

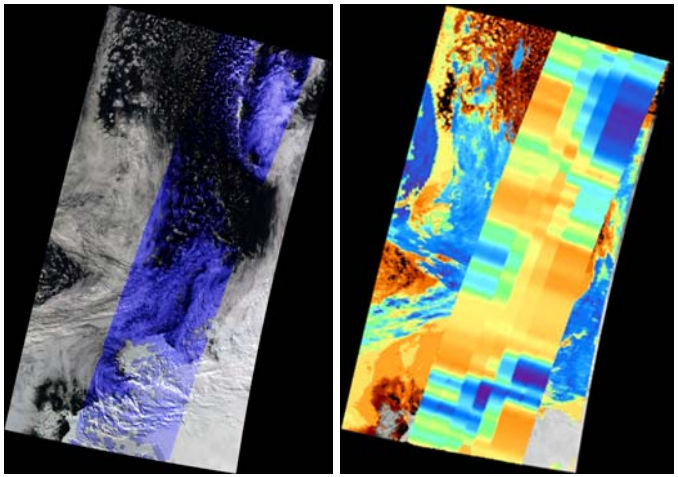
Comparison	md	RMS	sd	r^2	N
ICFA - SYNOP	−38.9	44.2	21.0	0.467	234
PC2K - SYNOP					
ind. co-locations	−25.3	33.7	22.1	0.469	662
avg. co-locations	−24.4	30.6	18.3	0.596	234
avg. GOME pixel	−22.9	29.3	18.1	0.603	234
$OCRA_{IMAU}$ - SYNOP					
ind. co-locations	−33.7	41.5	24.1	0.462	662
avg. co-locations	−32.7	38.3	19.9	0.576	234
avg. GOME pixel	−31.9	36.8	18.3	0.607	234
$OCRA_{DLR}$ - SYNOP					
ind. co-locations	−8.8	30.6	29.3	0.553	662
avg. co-locations	0.5	24.4	22.5	0.684	234
avg. GOME pixel	−10.0	23.3	21.1	0.645	234
FRESCO - SYNOP					
ind. co-locations	−20.2	29.1	21.0	0.496	662
avg. GOME pixel	−19.7	27.5	19.1	0.559	234

- Stefano Casadio and Claus Zehner, "***GOME-MERIS water vapour total column inter-comparison on global scale: January-June 2003***", MERIS workshop 2005.



OCRA and ROCINN – Published Validation (2)

- Loyola D., ***"Automatic Cloud Analysis from Polar-Orbiting Satellites Using Neural Network and Data Fusion Techniques"***, *IEEE International Geoscience and Remote Sensing Symposium*, 2004.

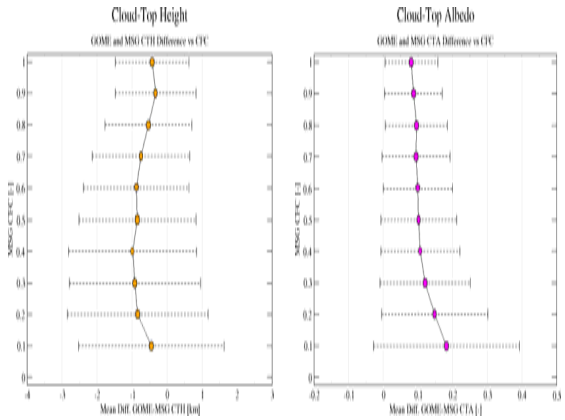


- Rozanov V.V., Kokhanovsky A.A., Loyola D., Siddans R., Latter B., Stevens A., Burrows J.P., "***Intercomparison of cloud top altitudes as derived using GOME and ATSR-2 instruments onboard ERS-2***", *Remote Sensing of Environment*, vol. 102, no. 1-2, pp. 186-193, 2006.

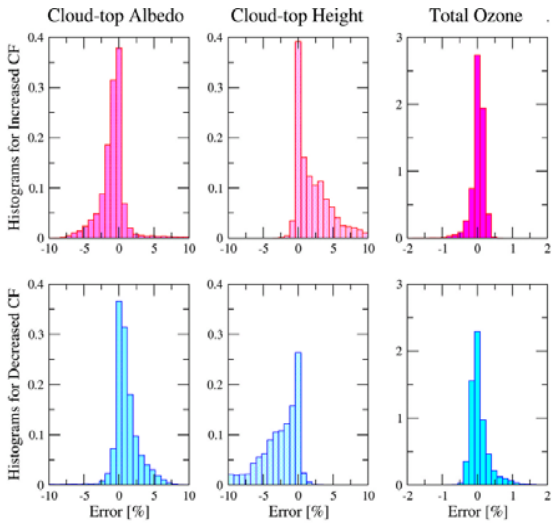
Orbit	15453 04.04.1998	16910 15.07.1998	18366 25.10.1998	19537 14.01.1999	All orbits
Number of GOME pixels	234	159	325	214	931
$\langle H_{IR} \rangle$	6.5	6.6	5.9	6.4	6.4±0.3
$\langle H_s \rangle$	6.5	6.8	7.0	7.2	6.9±0.3
$\langle H_R \rangle$	5.2	5.0	6.2	6.8	5.8±0.8
$\langle H_{stereo} \rangle$	5.4	6.4	5.1	6.1	5.8±0.6
$\langle B_s \rangle$	0.1	0.1	1.1	0.8	0.6±0.6
$\langle B_R \rangle$	−1.3	−1.6	0.2	0.3	−0.5±1.0
$\langle B_{stereo} \rangle$	−1.1	−0.2	−0.9	−0.3	−0.6±0.4
σ_s	1.6	1.5	2.1	2.2	1.8±0.4
σ_R	2.4	2.3	2.4	1.7	2.2±0.3
σ_{stereo}	3.4	1.9	3.8	3.0	3.0±0.8

OCRA and ROCINN – Published Validation (3)

- Loyola D., Thomas W., Livschitz Y., Ruppert T., Albert P., Hollmann. R., "***Cloud properties derived from GOME/ERS-2 backscatter data for trace gas retrieval***", *IEEE Transactions on Geoscience and Remote Sensing*, vol. 45, no. 9, pp. 2747-2758, 2007.



- Van Roozendael M., Loyola D., Spurr R., Balis D., Lambert J-C., Livschitz Y., Valks P., Ruppert T., Kenter P., Fayt C., Zehner C., "***Ten years of GOME/ERS-2 total ozone data: the new GOME Data Processor (GDP) Version 4: I. Algorithm Description***", *Journal of Geophysical Research*, vol. 111, D14311, 2006.



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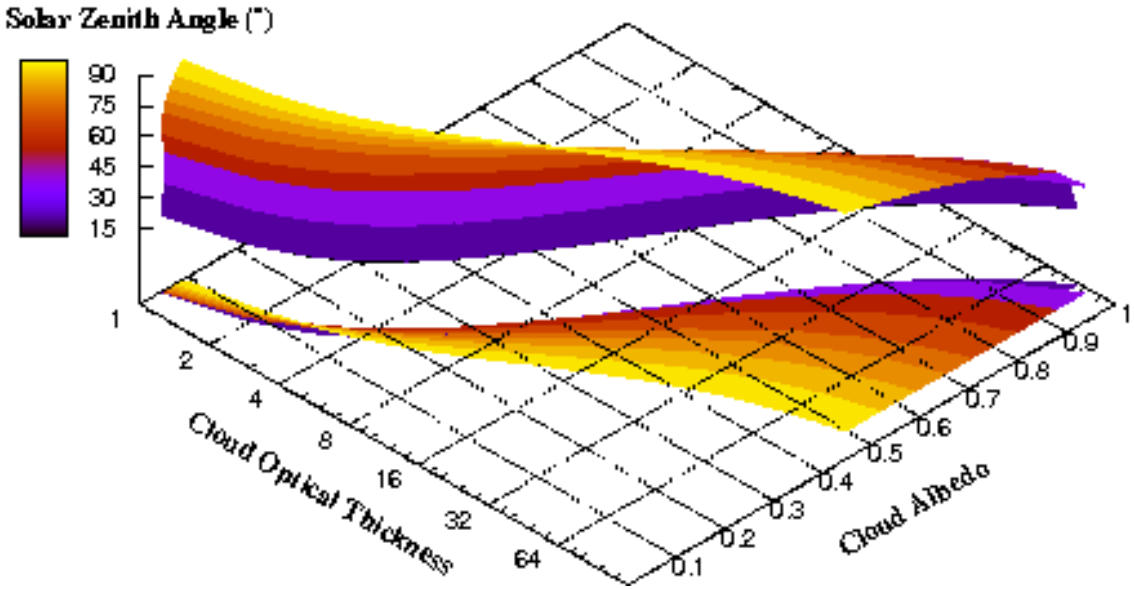
Cloud Optical Thickness Determination

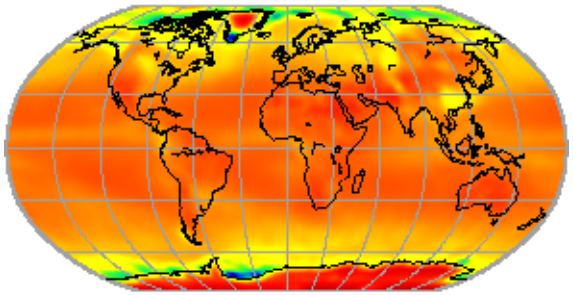
LibRadtran simulations at 760 nm

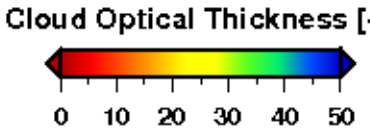


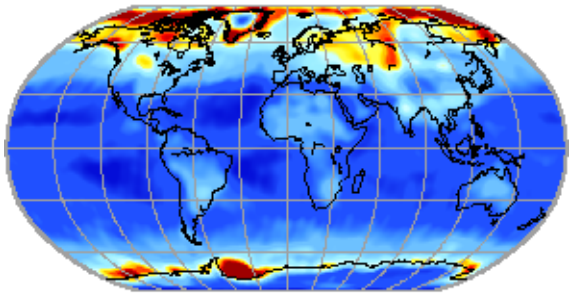
- Loyola D., Thomas W., Spurr R., Mayer B., "***Global patterns in daytime cloud properties derived from GOME backscatter UV-VIS measurements***", *International Journal of Remote Sensing*, in press, 2009.

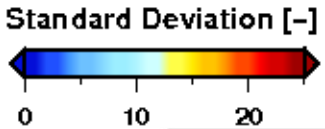
Cloud Optical Thickness – GOME and GOME-2

GOME 1996-2003

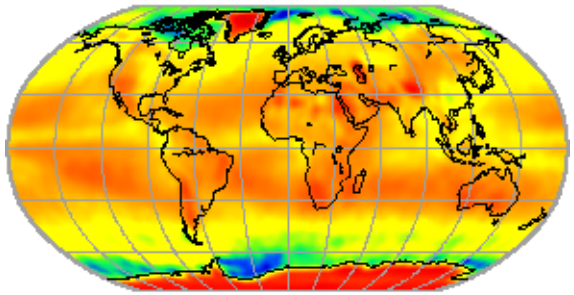


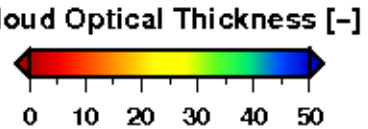


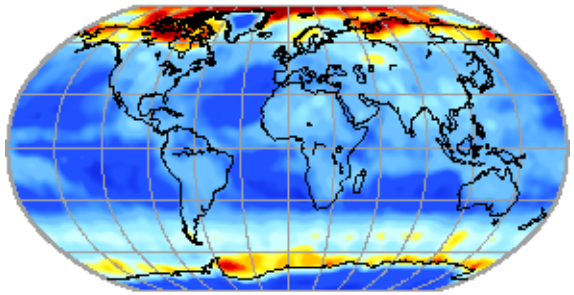


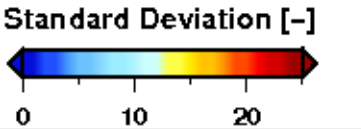


GOME-2 2007-2008



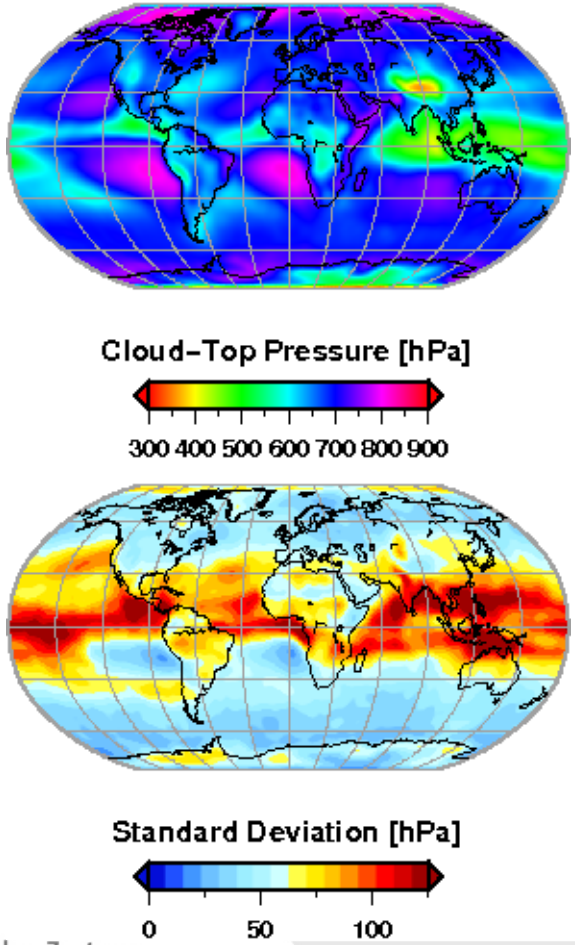




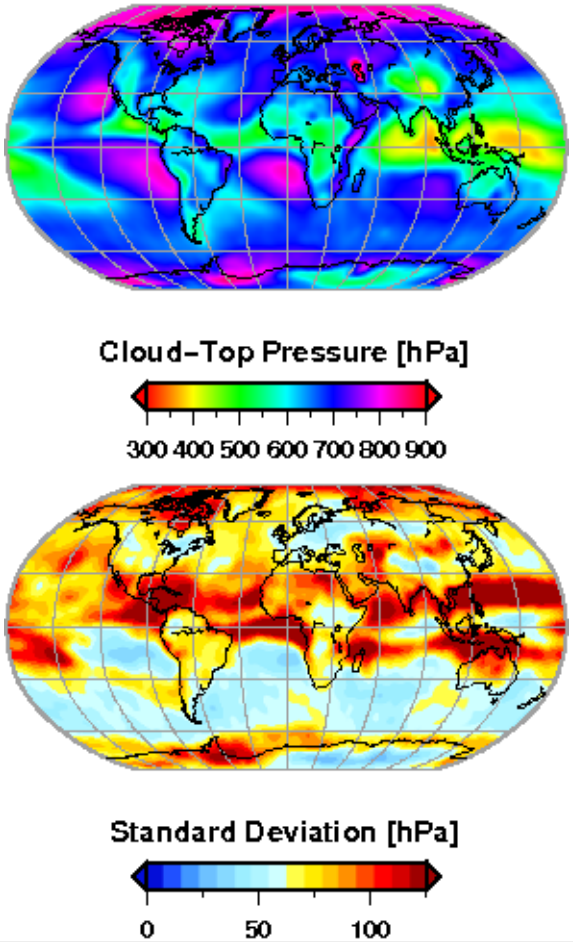


Cloud-Top Pressure – GOME and GOME-2

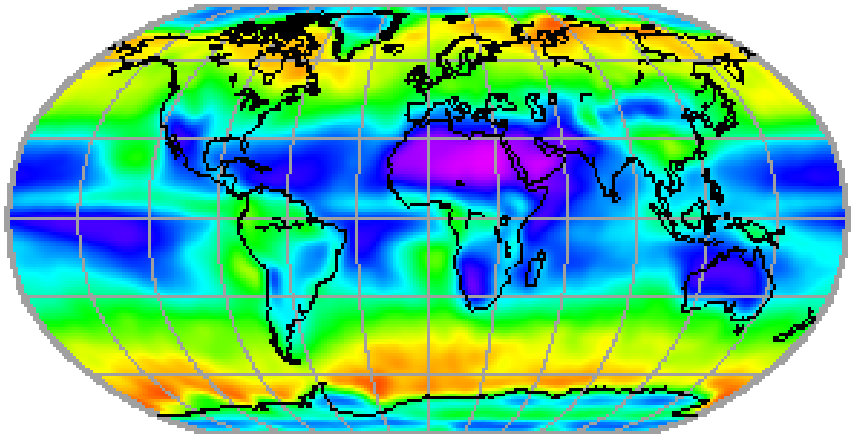
GOME 1996-2003

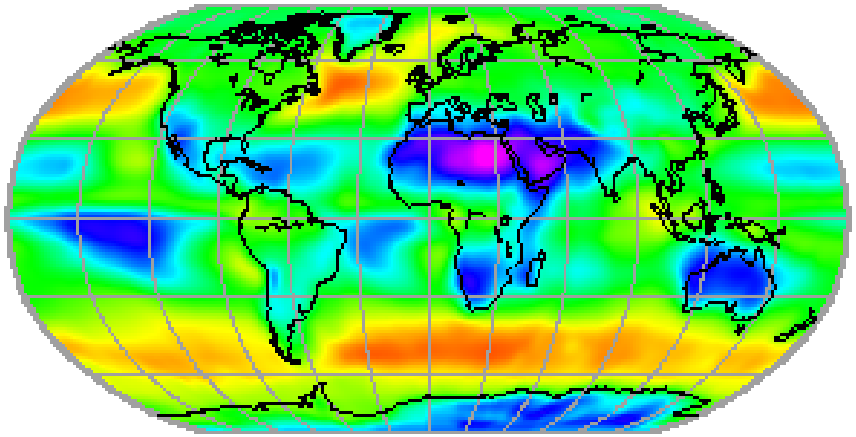


GOME-2 2007-2008

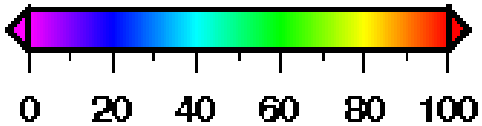


Cloud Amount – GOME and ISCCP

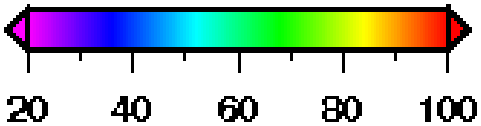




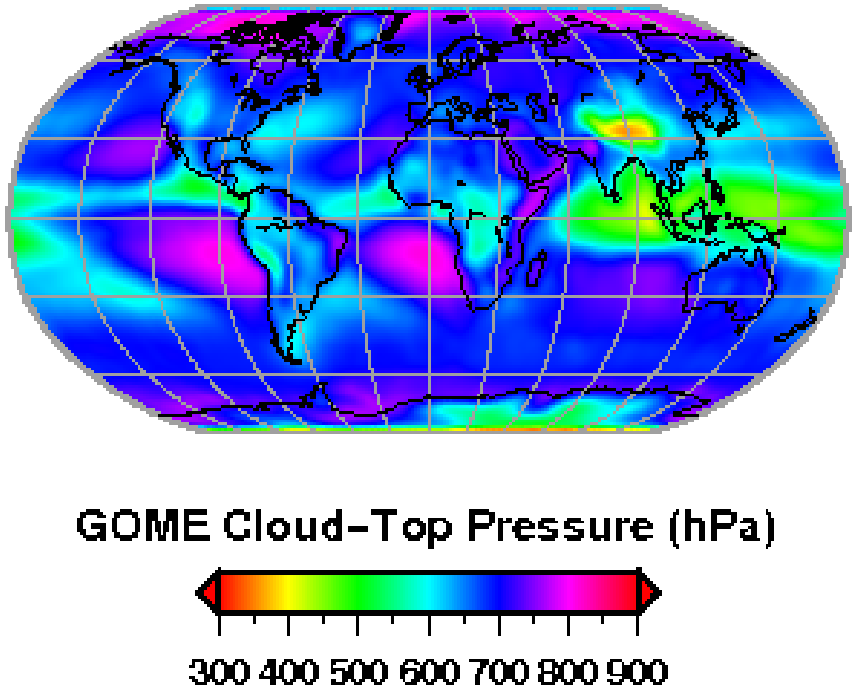
GOME Cloud Amount (%)

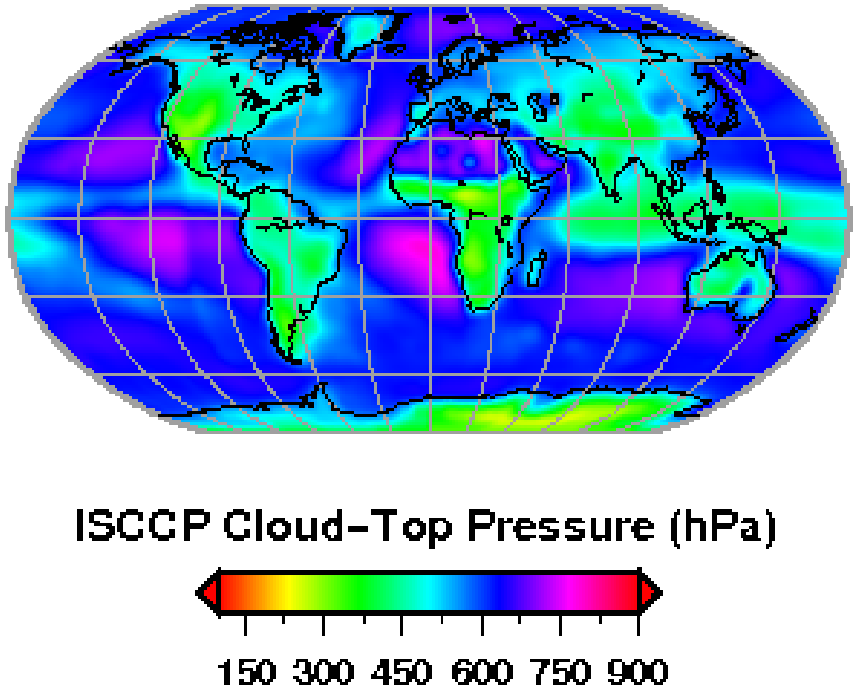


ISCCP Cloud Amount (%)

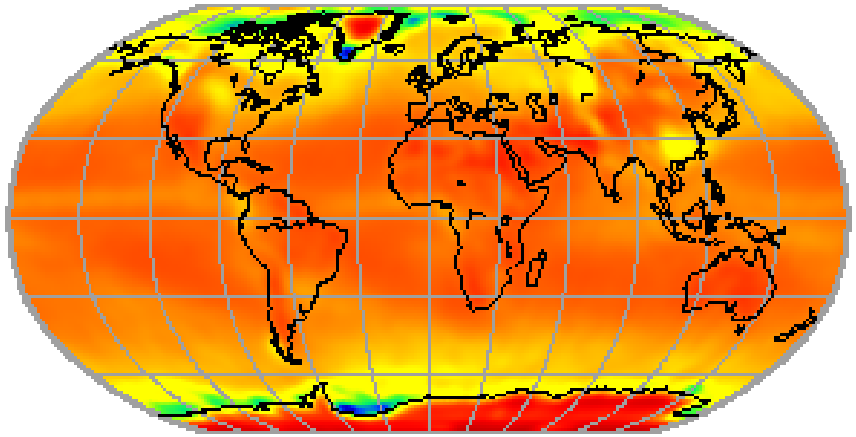


Cloud-top Pressure – GOME and ISCCP

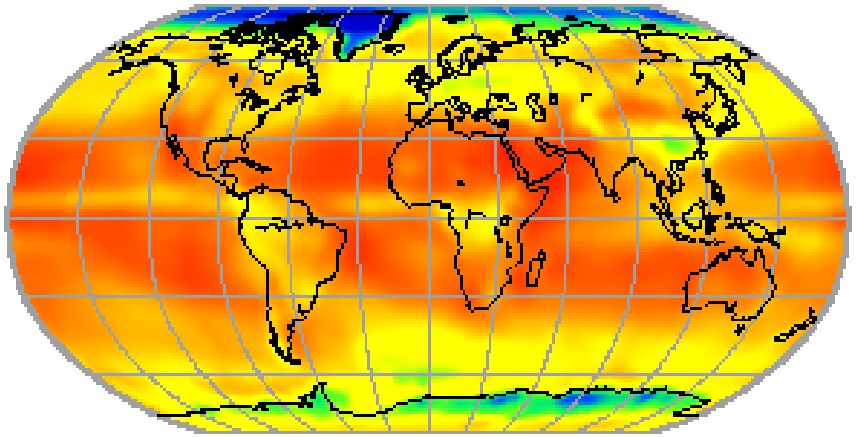




Cloud Optical Thickness – GOME and ISCCP

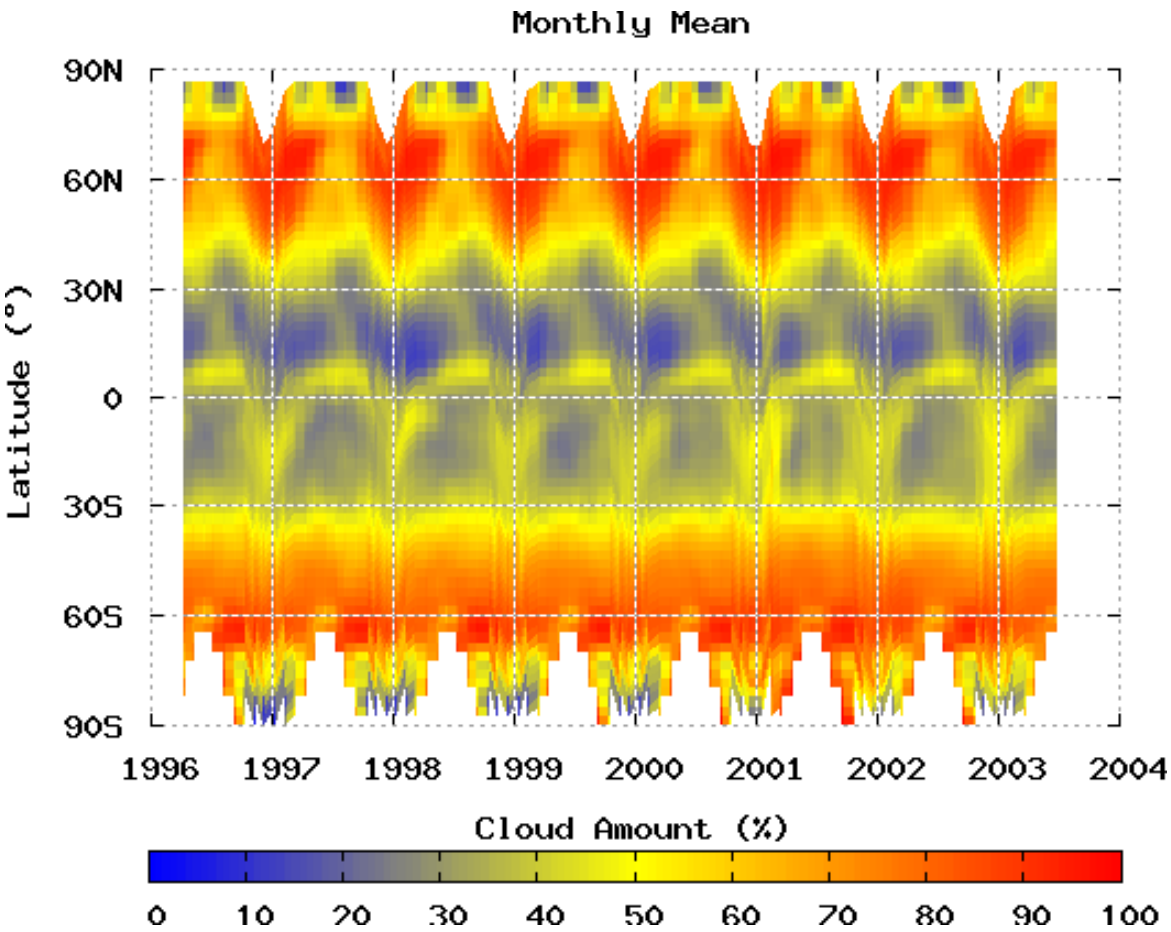


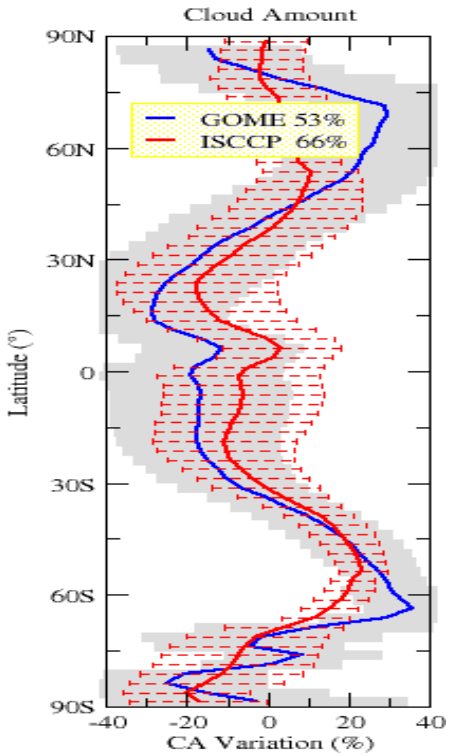
GOME Cloud Optical Thickness



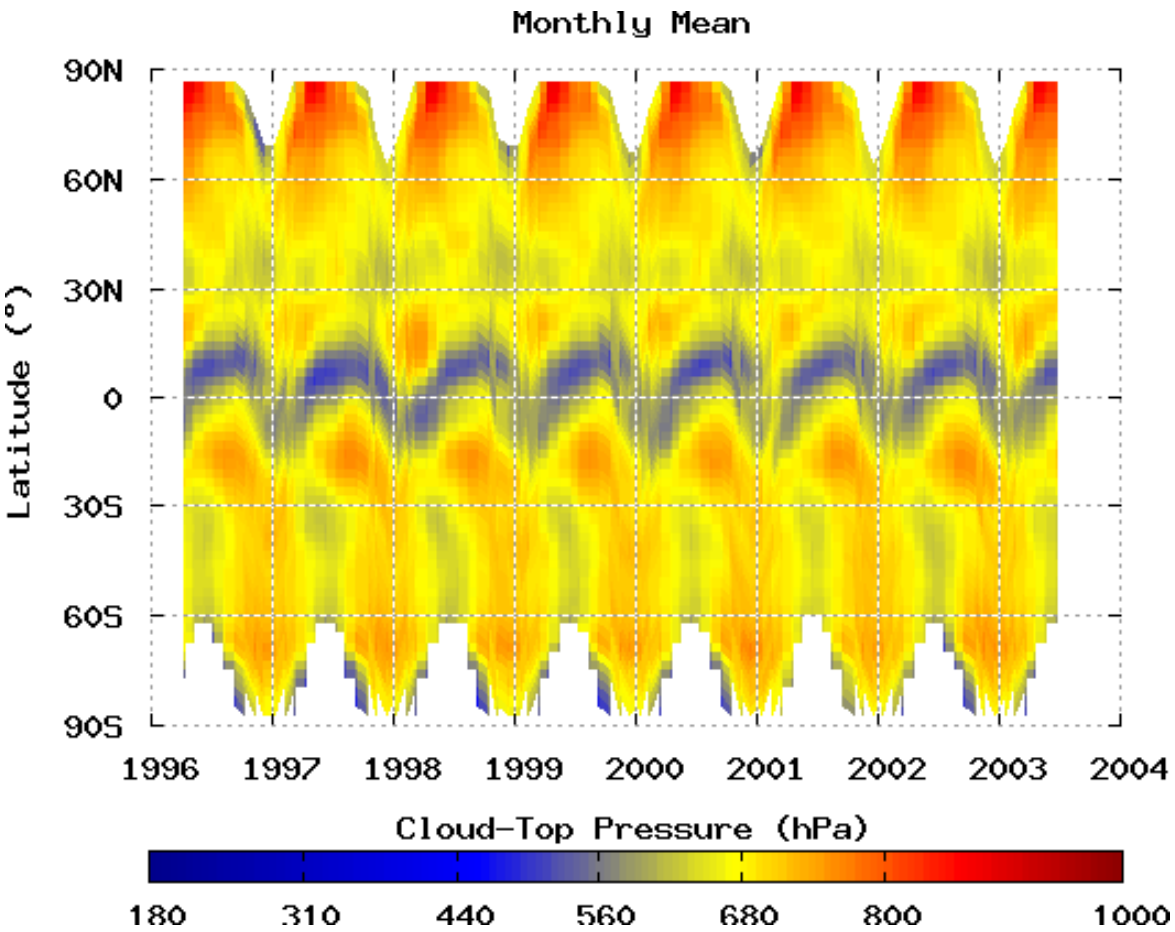
ISCCP Cloud Optical Thickness

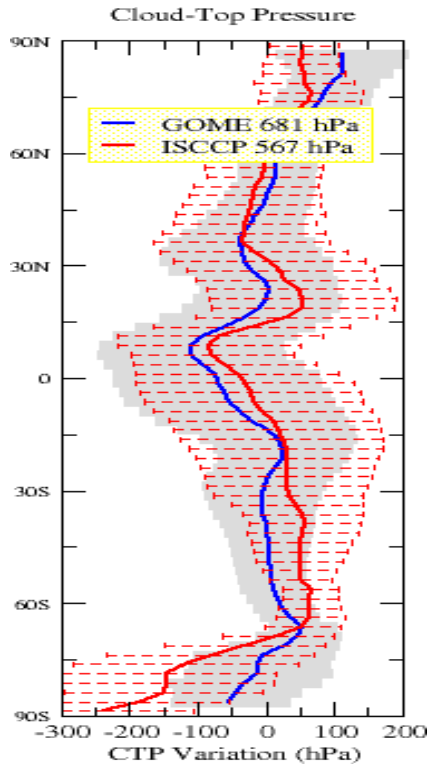
OCRA – GOME Cloud Amount



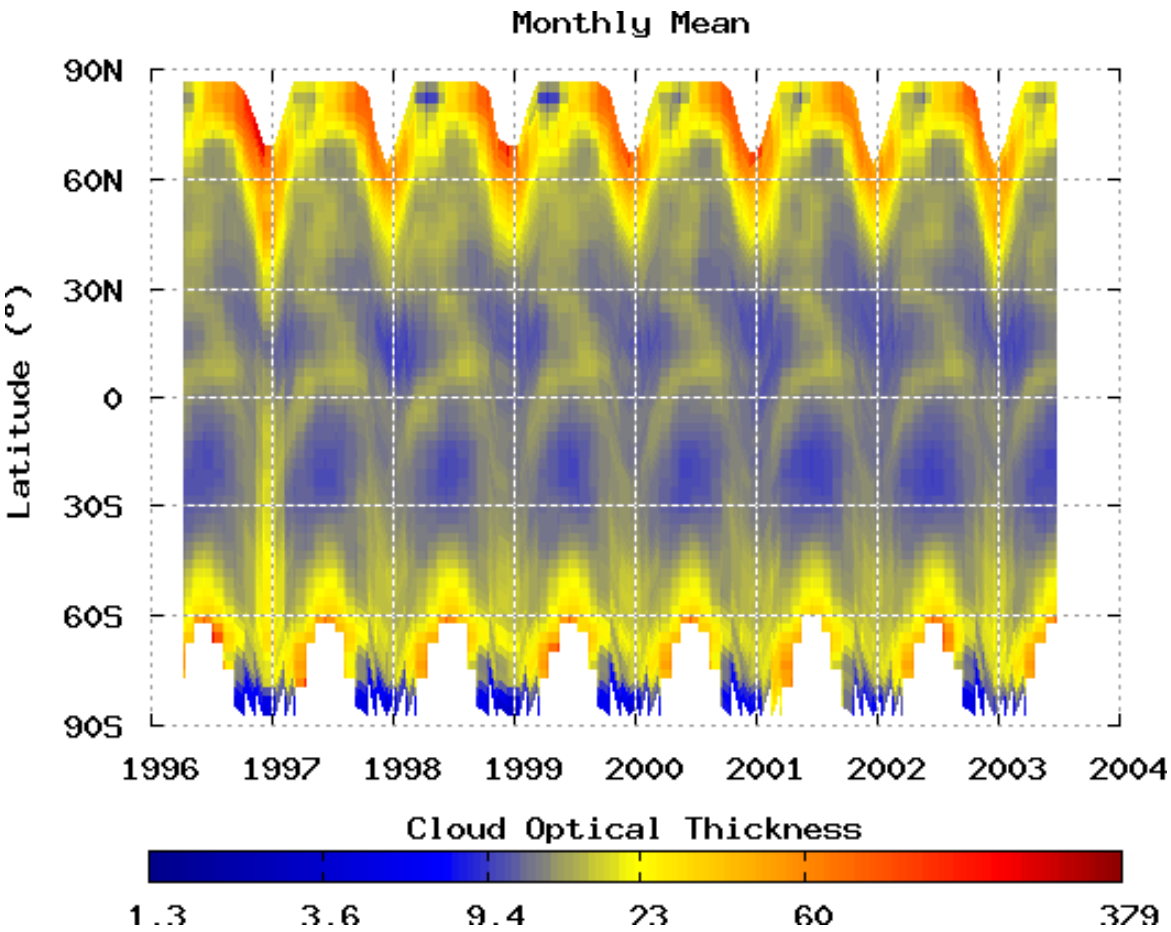


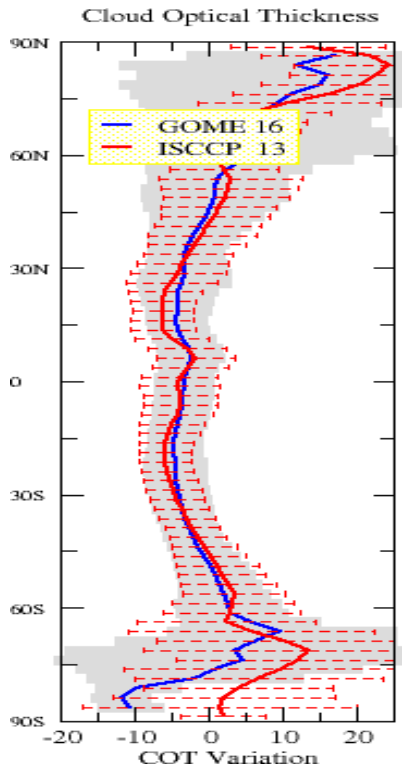
ROCINN – GOME Cloud-Top Pressure



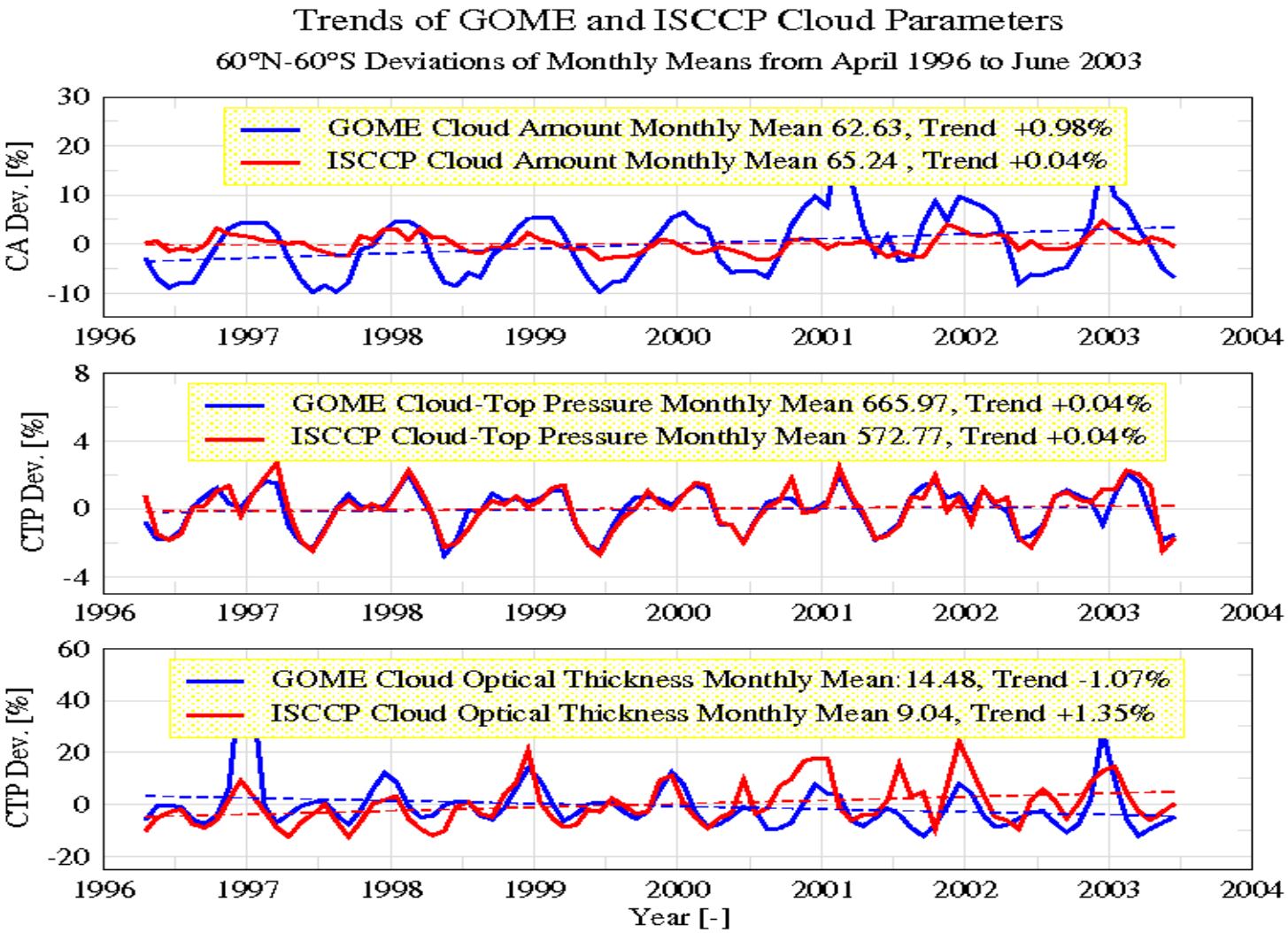


ROCINN – GOME Cloud Optical Thickness

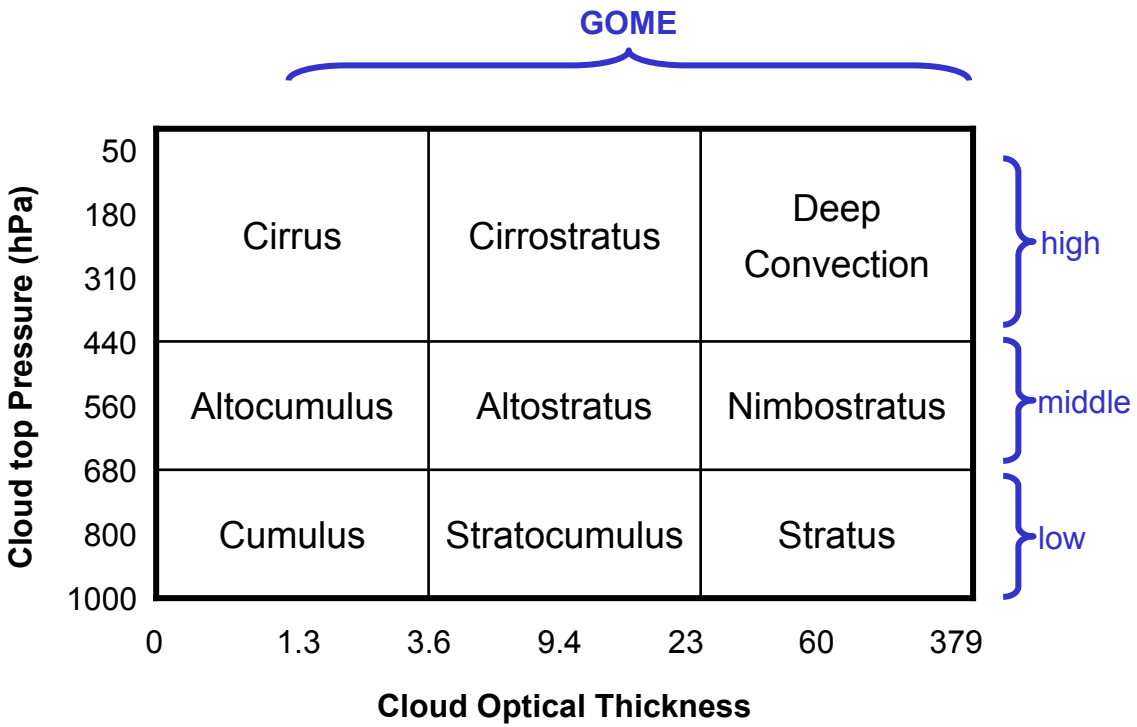




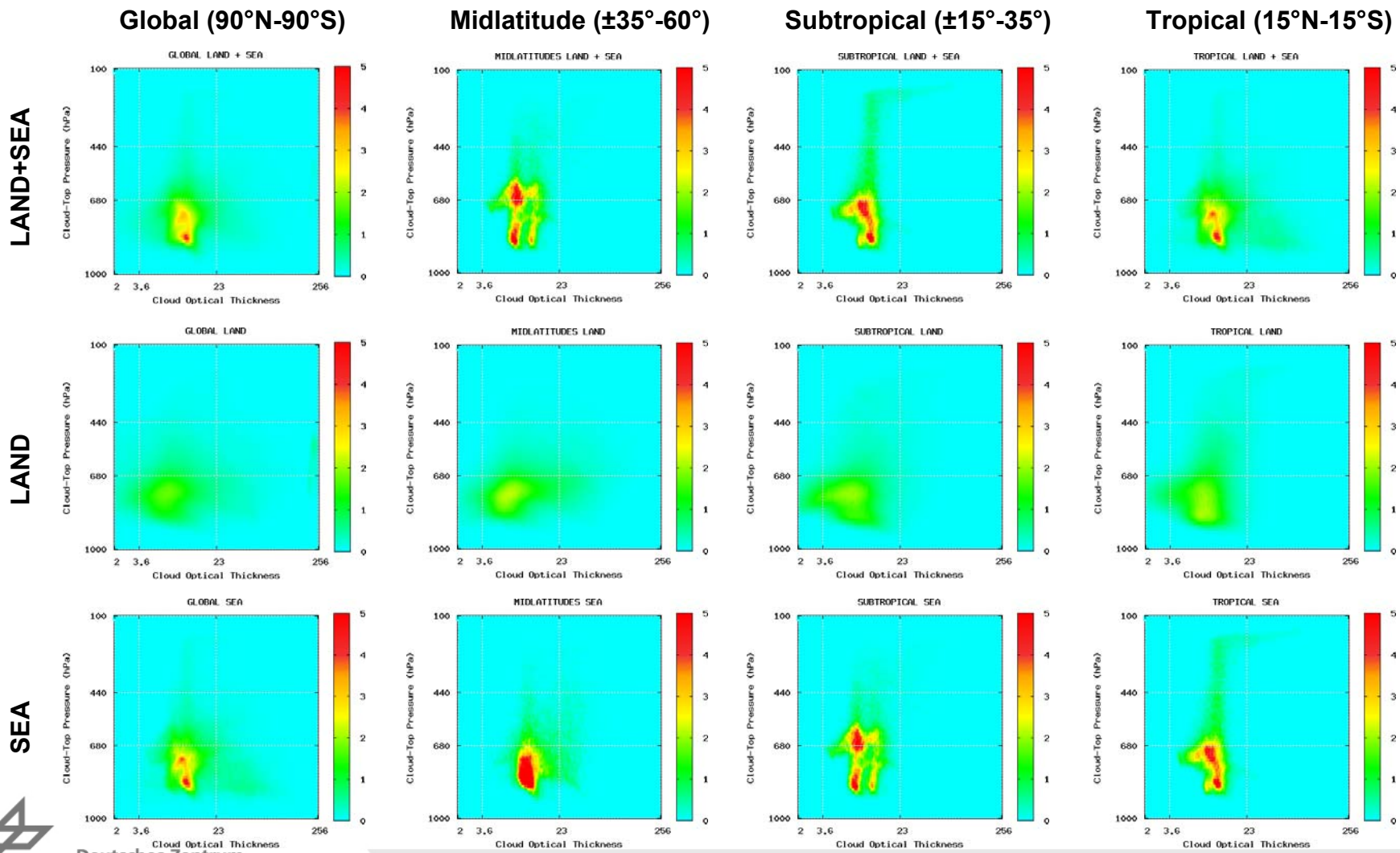
Cloud Trends with GOME and ISCCP



ISCCP D-series Cloud Type Classification



GOME – Cloud CTP vs. COT Histograms

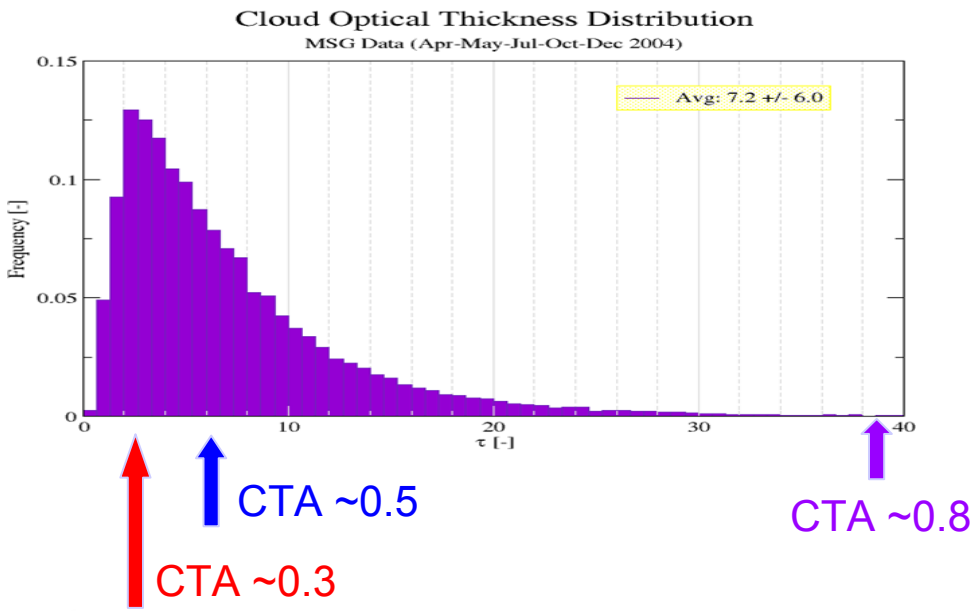


Outline

- Motivation
- OCRA and ROCINN Algorithms
- Global Cloud Type Distribution from GOME
- **Outlook**

GDP 4.x Algorithm – CRB Limitations

- GDP 4.x treats clouds as a reflecting and absorbing boundary (CRB)
  - Neglects scattering and absorption within clouds
  - Neglects the scattering contribution below the clouds
- CRB assumption valid for cloud-top albedo larger than 0.8



Summary

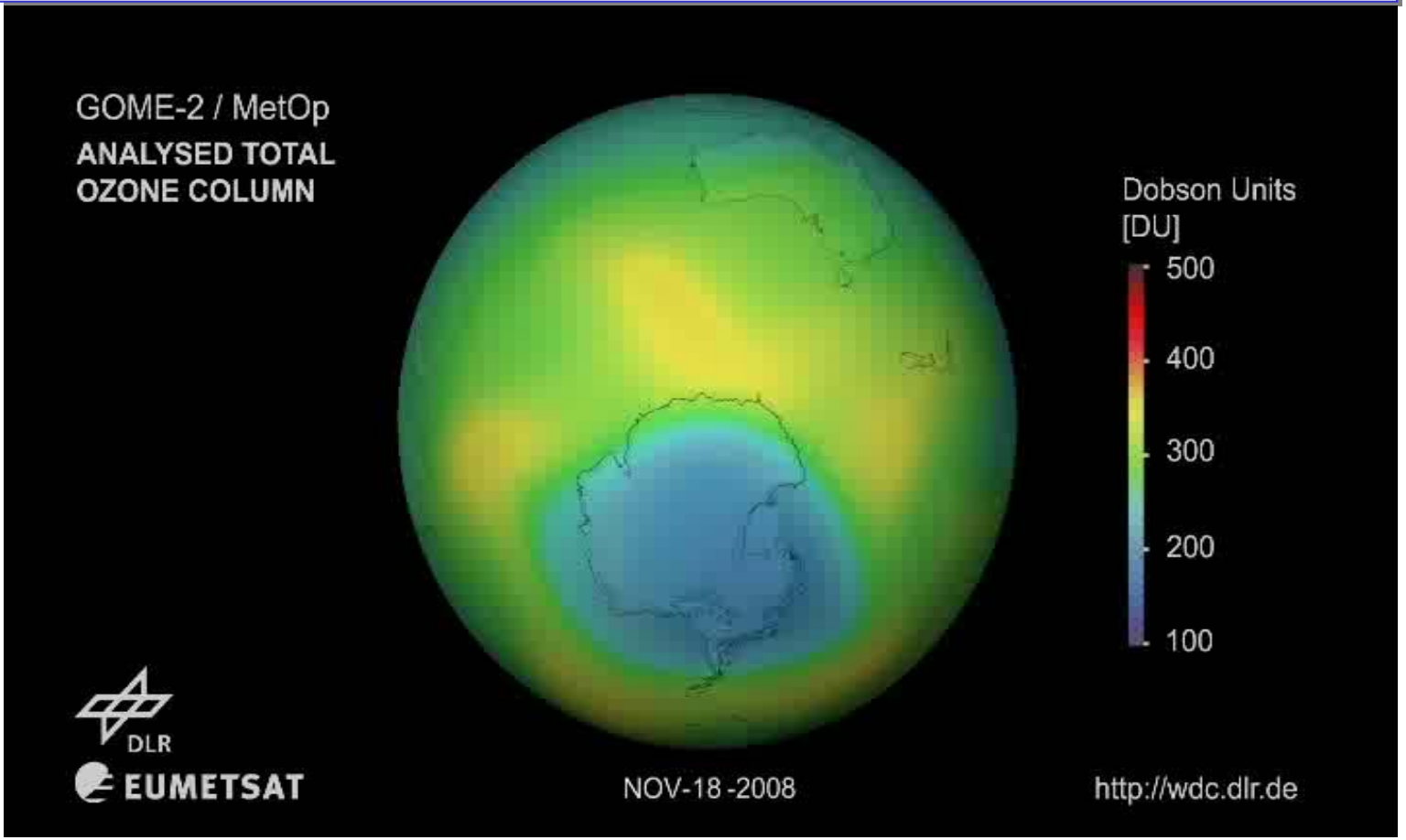
- OCRA & ROCINN are extremely **robust**, very **fast** (GOME orbit processed in less than 0.2 sec.) algorithms and work with **all GOME/GOME-2 scenes**.
- GOME cloud properties (CF, CTP, COT with error estimates) **validated** with synoptic and satellite data.
- Good agreement with ISCCP with the following differences for 60°N-60°S:
  - Cloud Amount: -2.61%
  - Cloud-Top Pressure: +93.2 hPa
  - Cloud Optical Thickness: +5,44
- Excelent agreement with ISCCP zonal mean variations
- GOME **cloud type distribution** following ISCCP presented for the first time:
  - Loyola D., Thomas W., Spurr R., Mayer B., "***Global patterns in daytime cloud properties derived from GOME backscatter UV-VIS measurements***", *IJRS*, in press, 2009.
- GOME type instruments provide **global independent** (UV-VIS) cloud properties covering a time period of **more than 30 years**.

GlobCloud Workshop Questions

1. Which cloud parameters are most useful for trace gas retrieval?
   - Cloud Fraction, Cloud-Top Pressure, Cloud Optical Thickness
   - More realistic cloud models (e.g. Cloud as Layers)

2. Which important cloud parameters are currently missing for trace gas retrieval?
   - Snow/ice and cloud discrimination using only UV/VIS measurements

3. What is the needed geographical and temporal coverage for satellite observation of clouds in climate research?
   - GOME type UV/VIS daytime observations with large ground pixels and constant local visit time (Sun-synchronous polar satellite) provide climatological statistical summaries comparable to ISCCP

GOME-2 Products including Clouds at WDC-RSAT

http://wdc.dlr.de/sensors/gome2