“Overview about MERIS NRT WV product utilizing WV absorption in the 0.9µm band.”

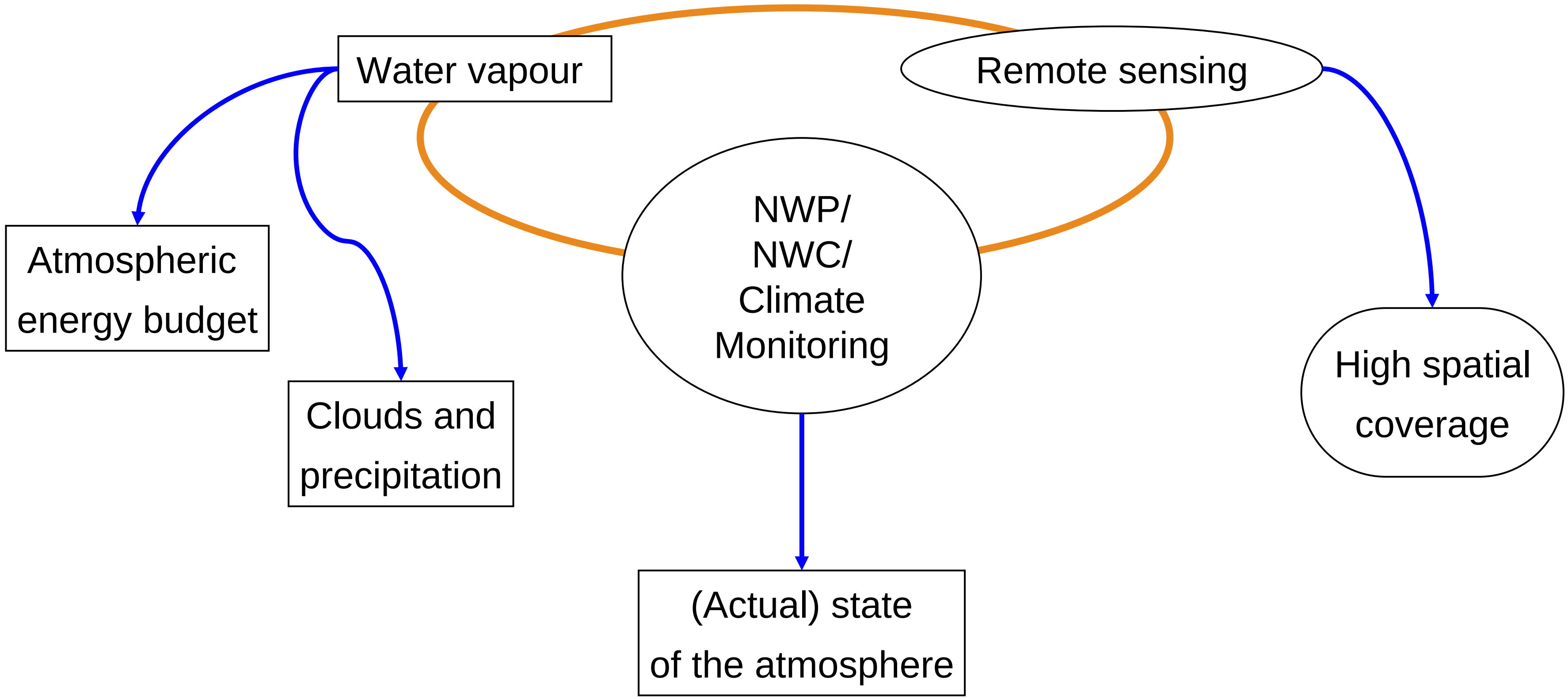
Peter Albert, Ralf Bennartz, Jürgen Fischer,
Kai Hermann, Ronny Leinweber, Rene Preusker

Outline

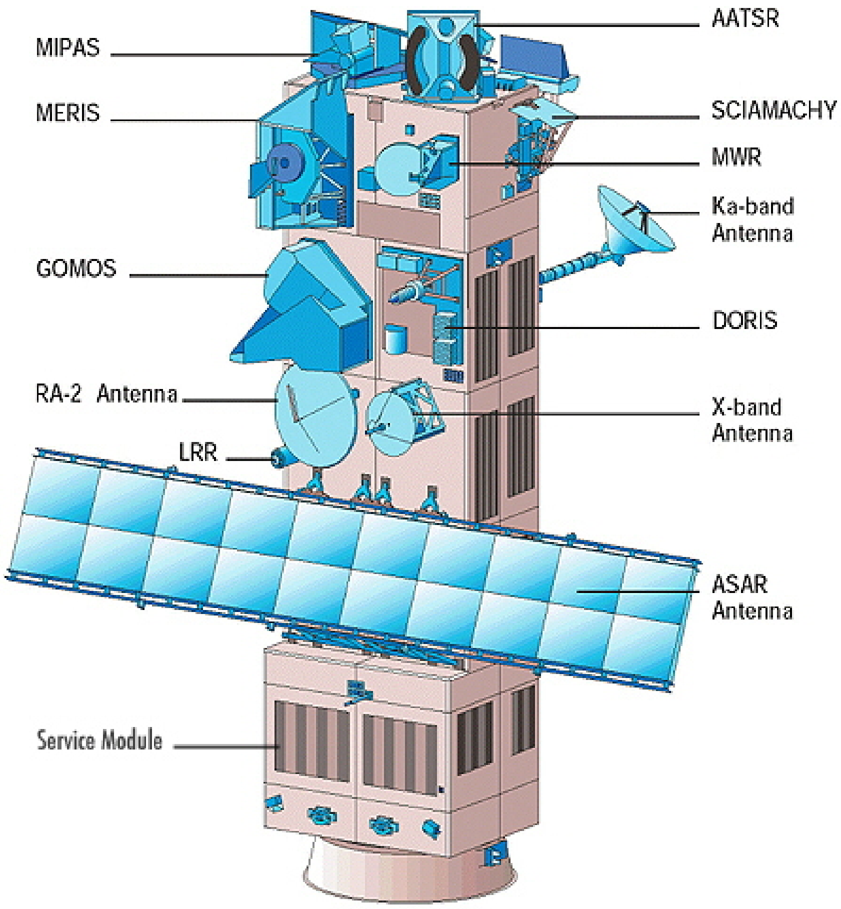
- Motivation
- Physical background

- Summary of validation efforts and conclusions
- „Climatological“ application

Motivation and overview



MERIS



ENVISAT (carrier)

launched: 1. März 2002 on Ariane 5 launcher (Kourou)

- weight : 8 tons
- costs : 2,3 billion Euro
- height : 800km
- orbit : sun-synchronous 10:30 AC

MERIS (instrument)

Medium Resolution Imaging Sectrometer on board ENVISAT

15 bands (390nm – 1040nm)

resolutions: FR 250m / RR 1km

swath: 1150km

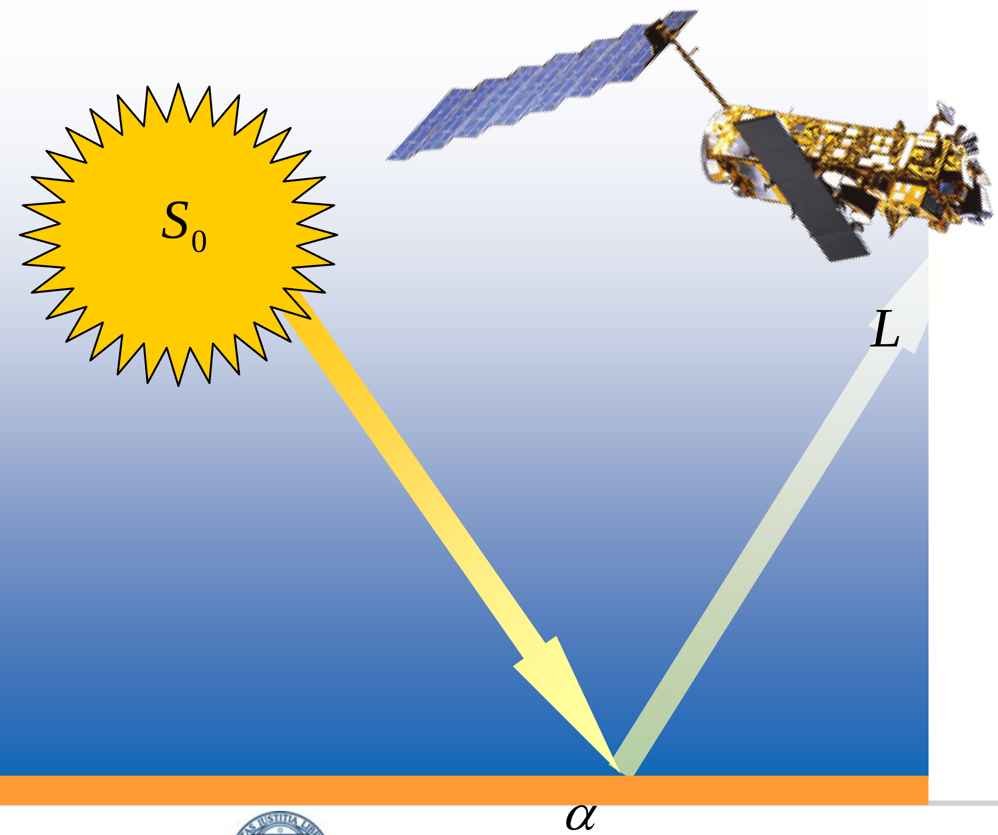
equator crossing time: 10:30h local time

over Germany: approx. 9:45h to 10:40h UTC (35 days repeat orbit)

global coverage every 3 days

Theory : **Differential Absorption**

Measured transmission is an exponential function of the amount of transmitted absorber mass ***s***



$$T = L / S_0$$

$$T = e^{-\tau}$$

$$\tau = \beta_{ext} \cdot s$$

$$\Rightarrow$$

$$\ln T \propto s \quad (water\ vapour)$$

Theory : **Differential Absorption**

$$\ln(Transmission) \propto absorbing\,mass$$

+ Independent from surface temperature and emissivity and almost independent from temperature profile

- No sounding
- Upper equation is still physical but not valid:
  - Band transmission does not follow *Lambert Beer*
  - Biased by multiple scattering
  - Biased by spectral surface reflectance effects

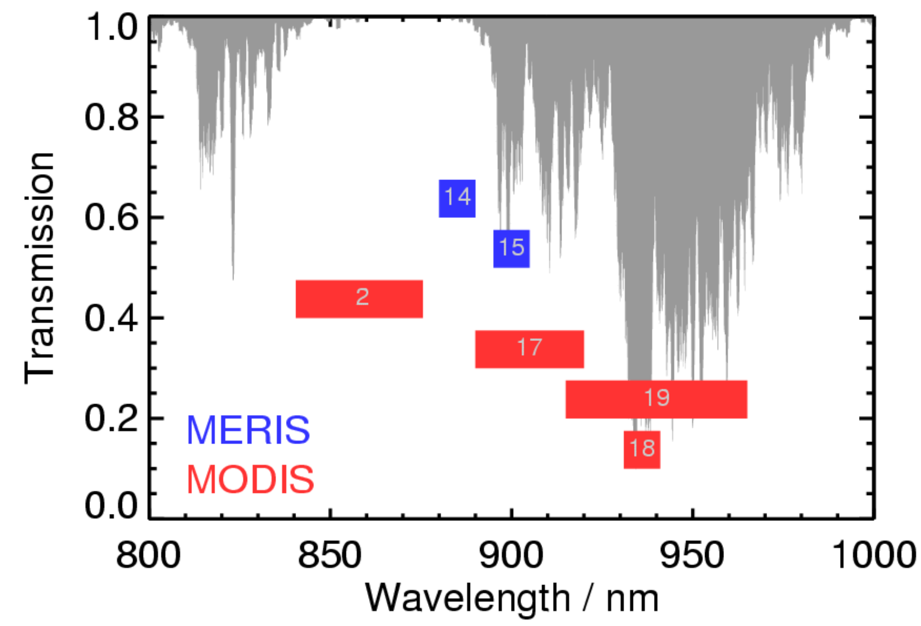
Theory

- Atmospheric transmission ≈ exp(IWV)
- Satellites do not measure atmospheric transmission → T is approximated using the radiance ratio of one window and one absorption channel

$$L_{win} = S_0 \cdot A$$

$$L_{abs} = S_0 \cdot A \cdot T^2$$

L: TOA-radiances
S_0: Solar constant
A: Surface albedo (win == abs?)
T: Atmospheric Transmission



Application

- Simulation of L_{win} and L_{abs} for a large number of atmospheric profiles of temperature and aerosol optical properties:

  IWV → L_{abs} / L_{win}

- Inversion using look-up tables or multidimensional non-linear regressions:

  L_{abs} / L_{win} → IWV

Application: Why LUT / Regression?

+ Fast : 30 sec for 1 Orbit (1000x14000 Pixel)

+ Simple to implement in operational environments (ESAs MERIS Ground Segment!!!) and easy to manage/update. (Note, that RTMs in the NIR/VIS are several orders of magnitude slower than RTMs in the TIR)

- Results slightly depend on the implicitly assumed *pdfs* of aerosol and surface properties

- No strict and pixel based error calculation as in e.g. OE

Application: Why LUT / Regression?

\+ Fast : 30 sec for 1 Orbit (1000x14000 Pixel)

\+ Simple to implement in operational environments (ESAs MERIS Ground Segment!!!) and easy to manage/update. (Note, that RTMs in the VIS are several orders of magnitude slower than RTMs in the TIR)

\- Results slightly depend on the implicitly assumed *pdfs* of aerosol and surface properties

→ "Minimize the statistic": Correction of *photon path length biases* using O_2 band transmission and direct correction of $\alpha(\lambda)$ using pre-calculated maps. (see later)

\- No strict and pixel based error calculation as in e.g. OE

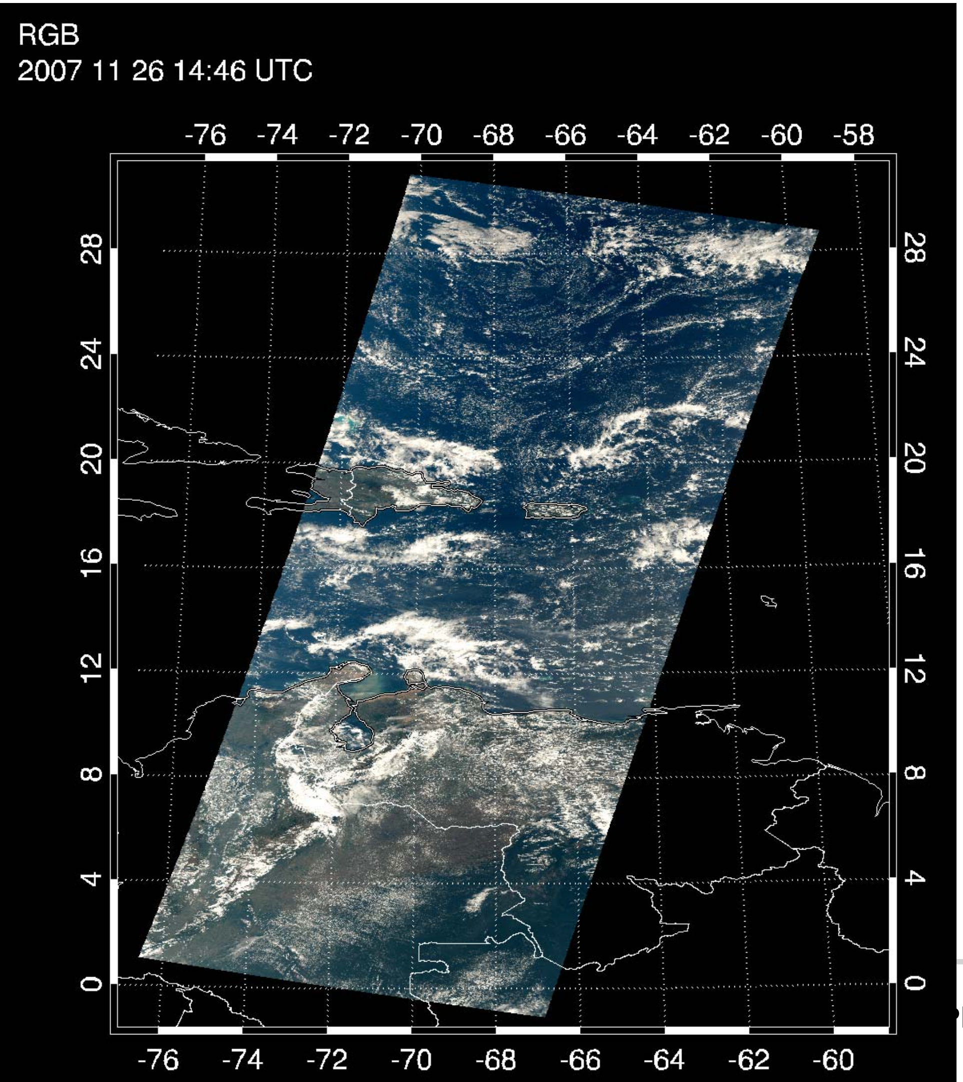
→ Intensive error analysis for a reasonable error estimation

Application

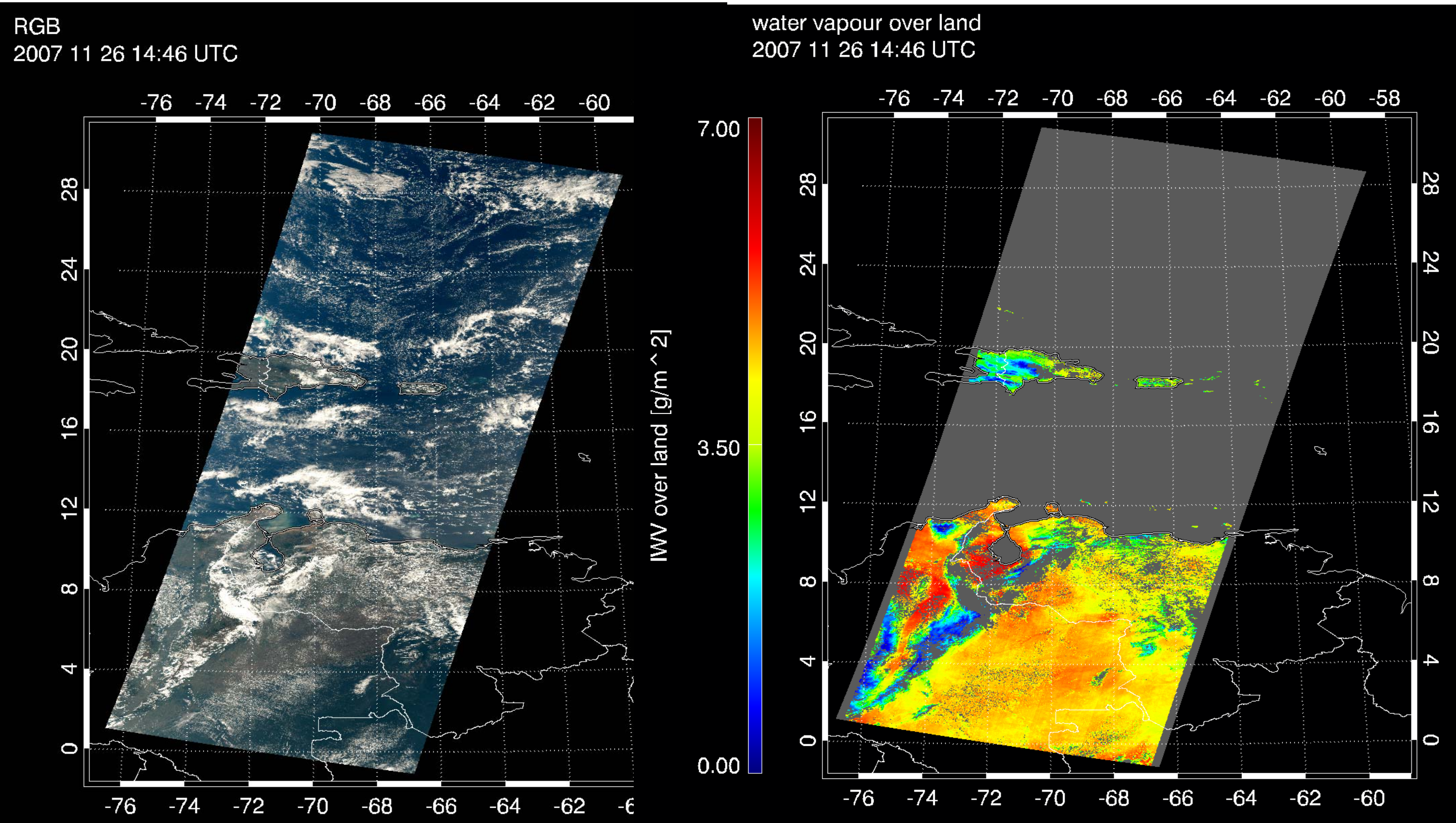
Individual algorithms have been developed for two satellite instruments: the Medium Resolution Imaging Spectrometer MERIS / ENVISAT and the Moderate Resolution Imaging Spectroradiometer MODIS / TERRA, AQUA for the retrieval of integrated water vapour above cloud free land surfaces, above cloud free ocean and above clouds. MERIS algorithms are part of MEGS.

Application: Examples

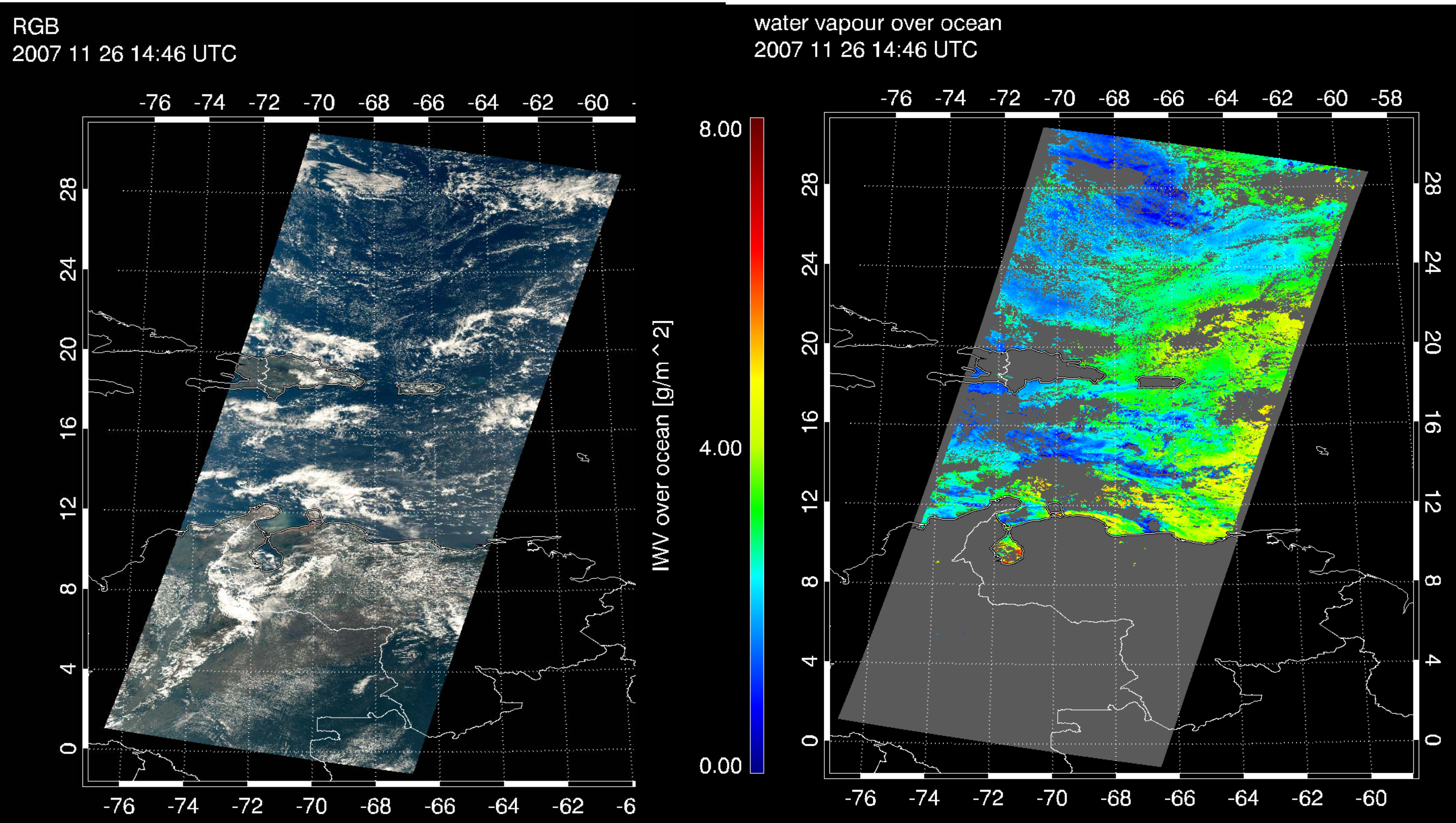
Application: Examples



Application: Examples



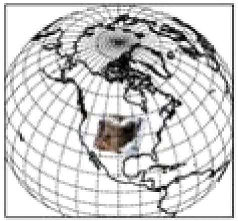
Application: Examples



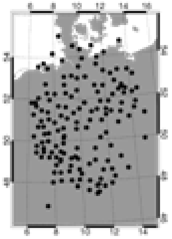
Application: Examples

cloud free conservative cloud detection is indispensable!!!!
(BTW: Is already developed, will be implemented in 2008, reprocessing ……)

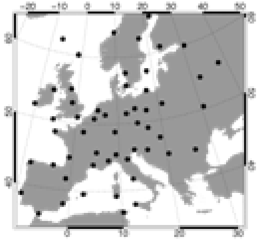
Validation



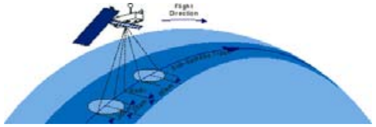
- ARM-SGP:
  - MERIS: 08/2002 – 09/2003, #: 36
  - MODIS: 01/2002 – 10/2002, #: 84



- GPS:
  - MERIS: 10/2002 – 09/2003, #: 2769
  - MODIS: 01/2003 – 10/2003, #: 10722

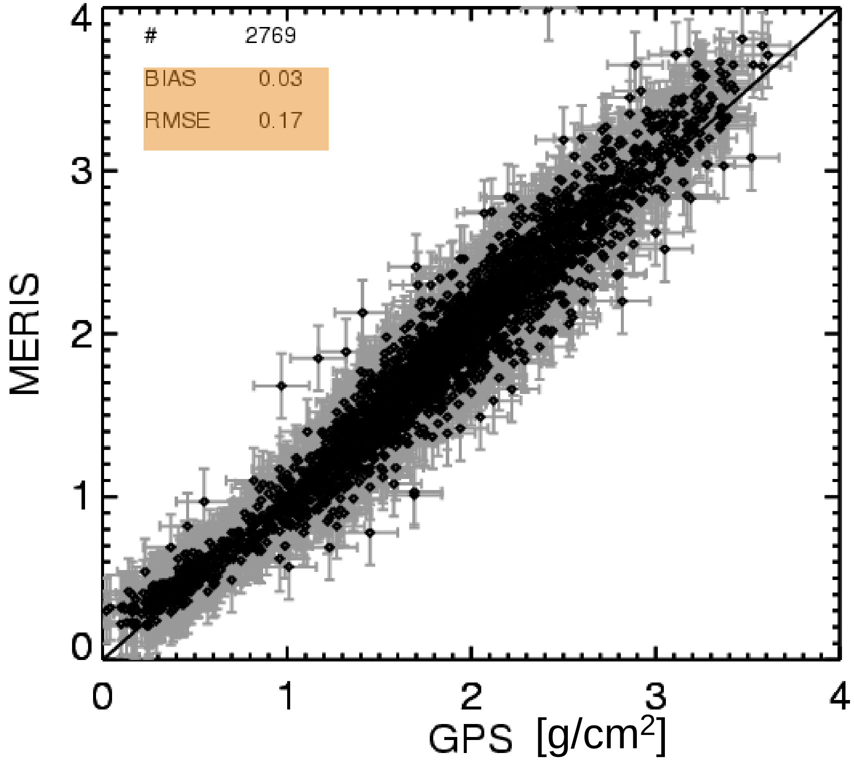


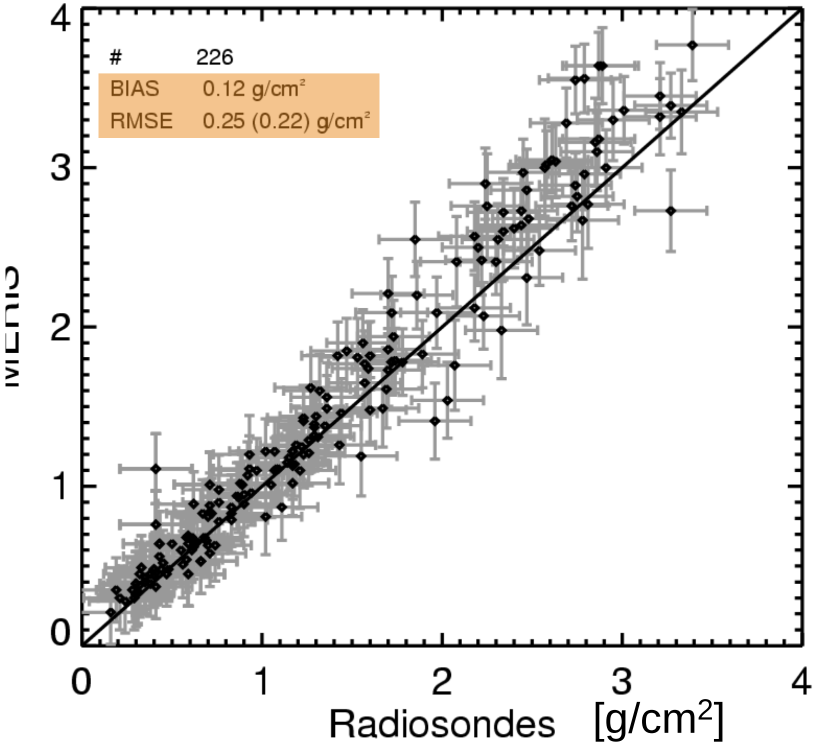
- RS:
  - MERIS: 10/2002 – 09/2003, #: 181
  - MODIS: 01/2003 – 10/2003, #: 2012



- MWR-ENVISAT:
  - MERIS: 04/2005 #: 2382

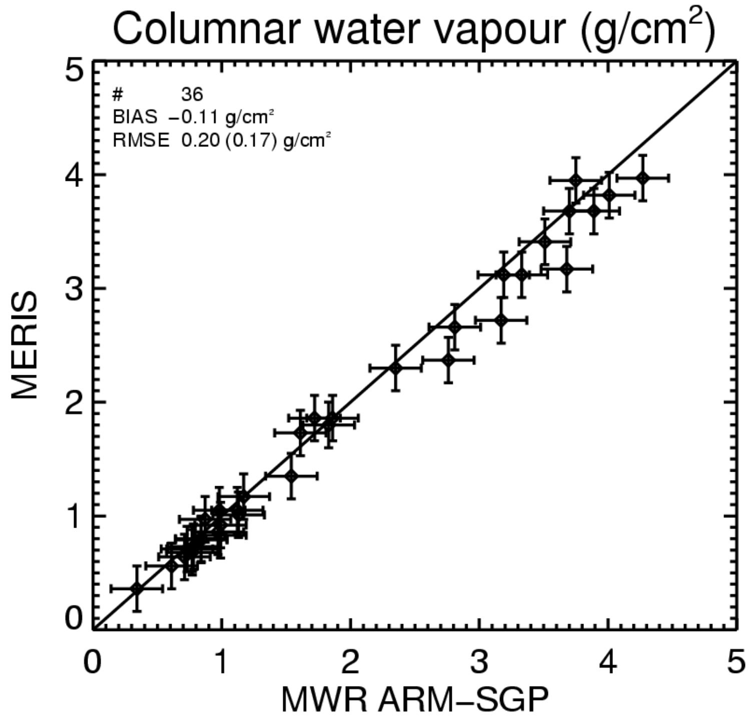
Validation: water vapour above land (RaObs in Europe, GPS in Germany)





Scatter plot of columnar water vapour measurements by radio soundings vs. MERIS measurements. Measurements are taken over Central Europe between October 2002 and August 2003

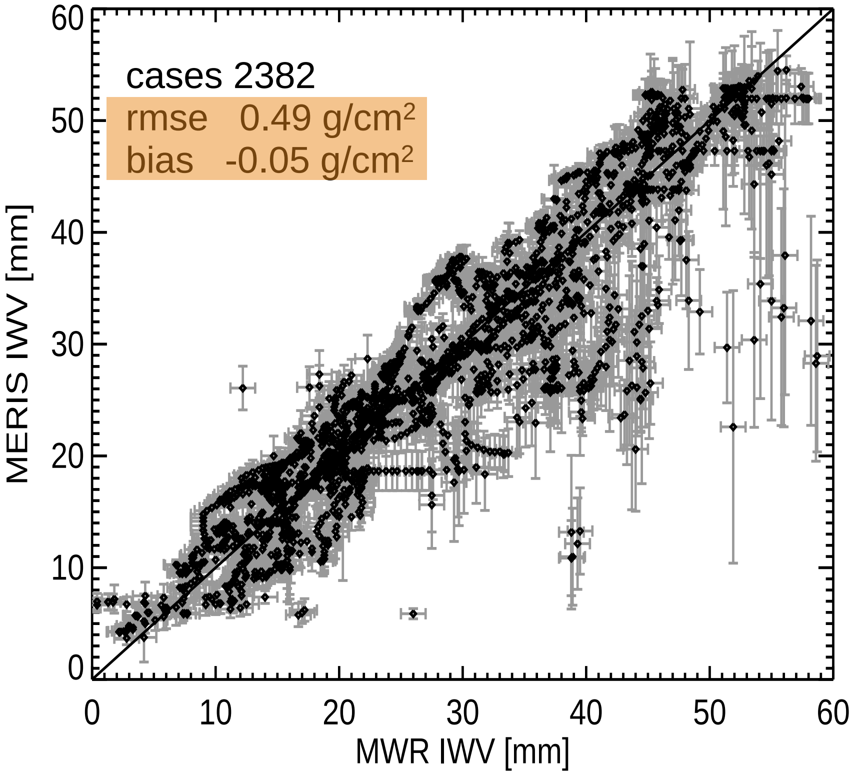
Validation: water vapour above land (MWR at SGP)



Scatter plot of columnar water vapour measurements by the Microwave Water Radiometer at the ARM-SGP site vs. MERIS measurements.

MWR data were obtained from the Atmospheric Radiation Measurement (ARM) Program sponsored by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research, Environmental Sciences Division.

Validation: water vapour above ocean (MWR on Envisat)



Scatter plot of columnar water vapour measured by ENVISAT's MWR above ocean (left) and GPS stations above land (right) vs. MERIS measurements.

Summary: Validation

All values in kg/m²	MERIS		MODIS	
	rms	bias	rms	bias
	Water vapour above land			
MWR (SGP)	2.0 | 1.7**	-1.1	1.7	0.6
GPS (Germany)	1.7	0.3	2.8 | 2.0*	-0.5 | –0.1*
RS (Europa)	2.4	1.1	2.0	-0.8
	Water vapour above clouds			
RS	2.4	1.1		
	Water vapour above ocean			
MWR-Envisat	6.8	-0.9		

* Falsely identified cloudy pixels manually removed

** Bias free

Summary: Validation

All values in kg/m²	MERIS		MODIS	
	rms	bias	rms	bias
	Water vapour above land			
MWR (SGP)	2.0 | 1.7**	-1.1	1.7	0.6
GPS (Germany)	1.7	0.3	2.8 | 2.0*	-0.5 | –0.1*
RS (Europa)	2.4	1.1	2.0	-0.8
	Water vapour above clouds			
RS	2.4	1.1		
	Water vapour above ocean			
MWR-Envisat	6.8	-0.9		

* Falsely identified cloudy pixels manually removed

** Bias free

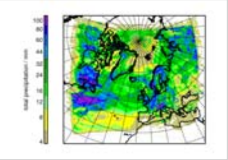
Summary: Validation

All values in kg/m^2	MERIS		MODIS	
	rms	bias	rms	bias
	Water vapour above land			
MWR (SGP)	2.0 | 1.7**	-1.1	1.7	0.6
GPS (Germany)	1.7	0.3	2.8 | 2.0*	-0.5 | –0.1*
RS (Europa)	2.4	1.1	2.0	-0.8
	Water vapour above clouds			
RS	2.4	1.1		
	Water vapour above ocean			
MWR-Envisat	6.8	-0.9		

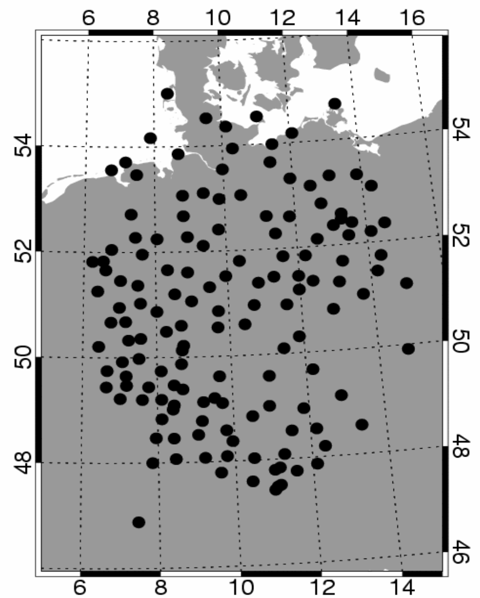
* Falsely identified cloudy pixels manually removed

** Bias free

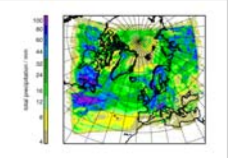
Observation error statistics



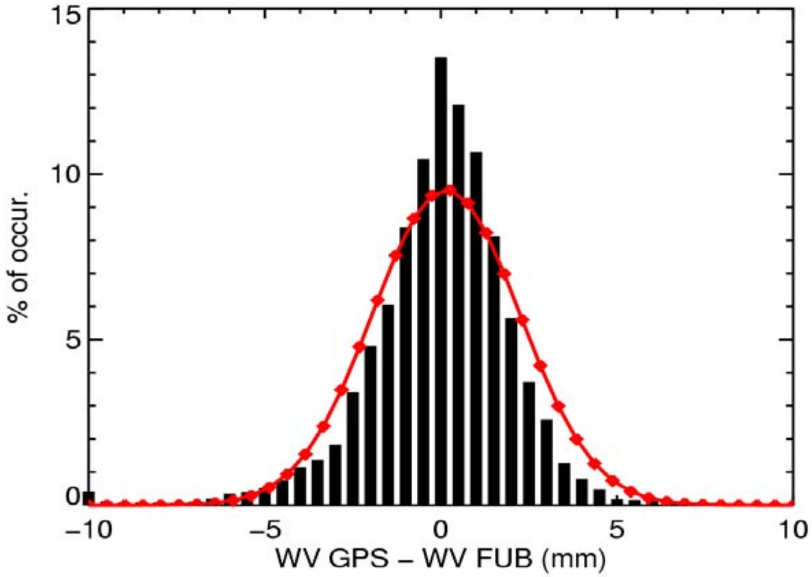
- Are the observation errors bias-free?
- Are the observation errors gaussian?
- Are the observation errors spatially correlated?

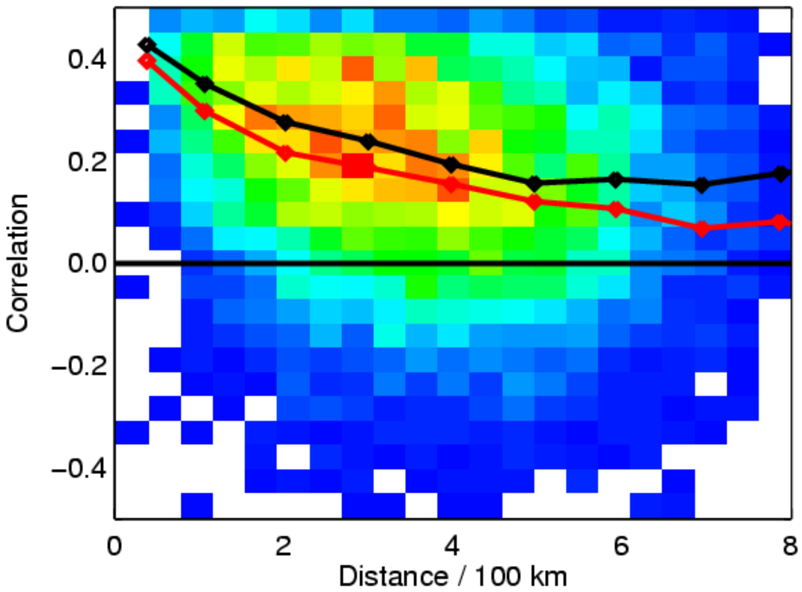


Observation error statistics



- Are the observation errors bias-free? almost
- Are the observation errors gaussian? almost
- Are the observation errors spatially correlated? yes



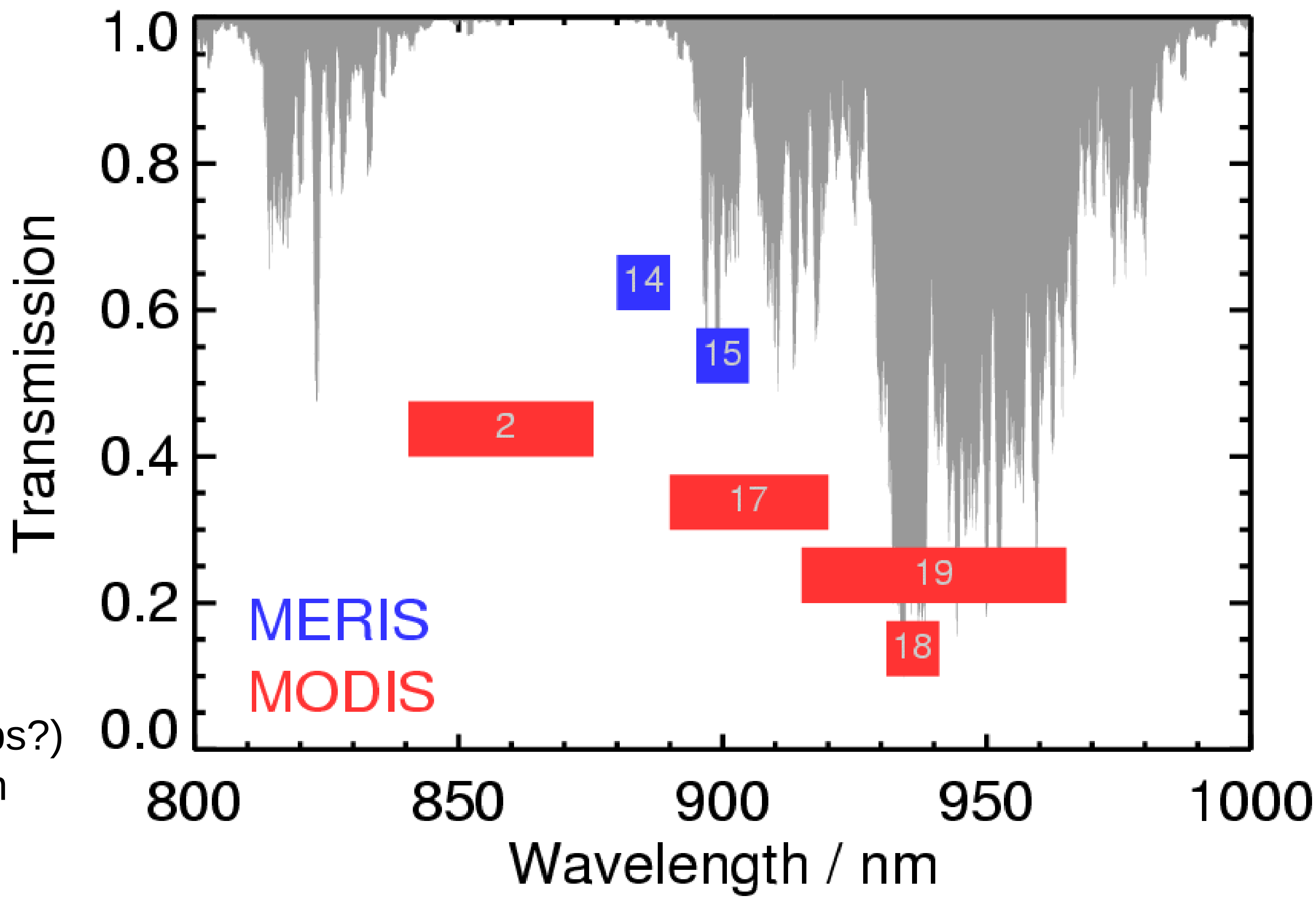


Theory

$$L_{win} = S_0 \cdot A$$

$$L_{abs} = S_0 \cdot A \cdot T^2$$

L: TOA-radiances
S_0: Solar constant
A: Surface albedo (win == abs?)
T: Atmospheric Transmission



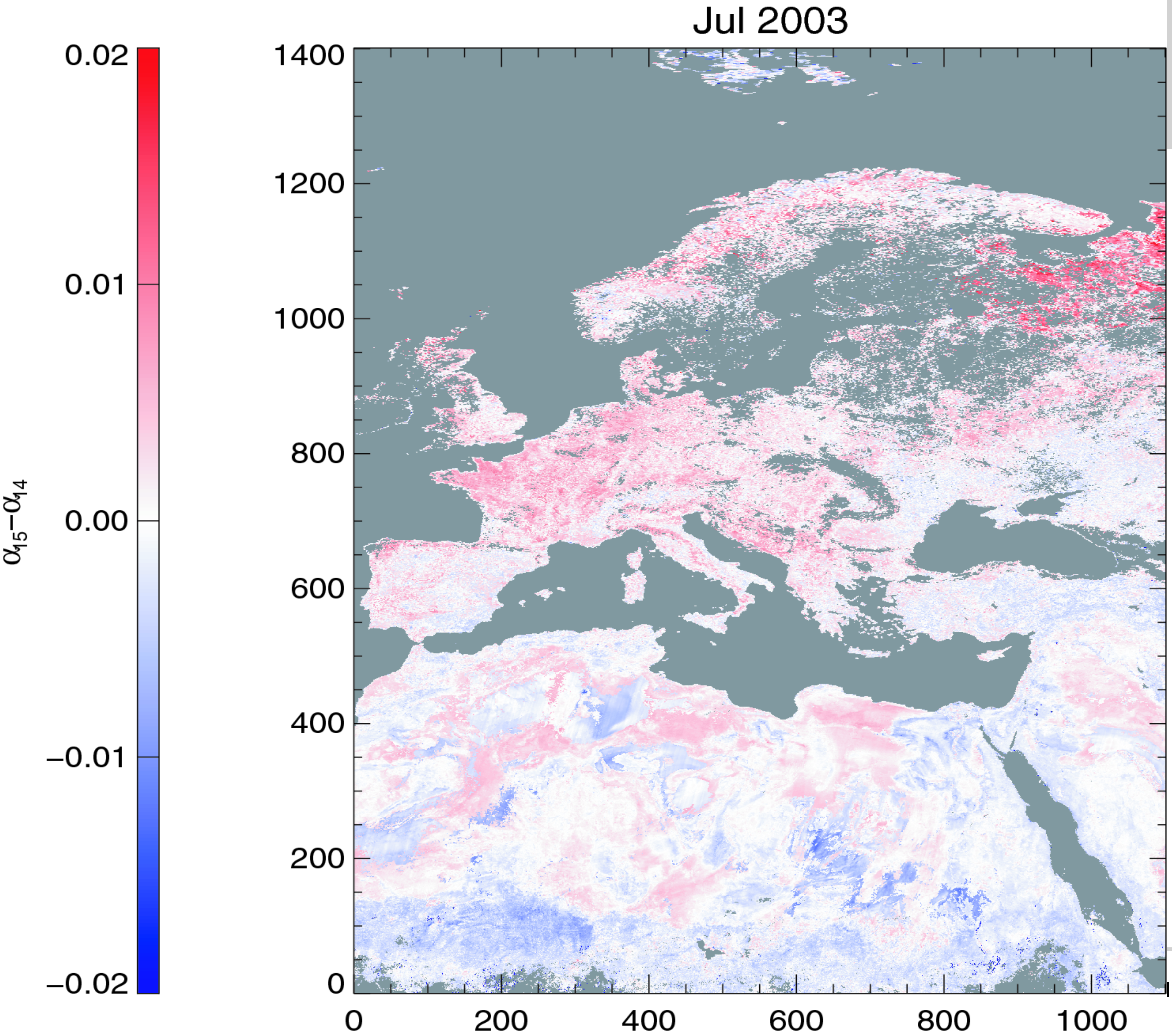
Intermediate: Transmission measurements at 0.9µm of MERIS or MODIS (or Polder or …)

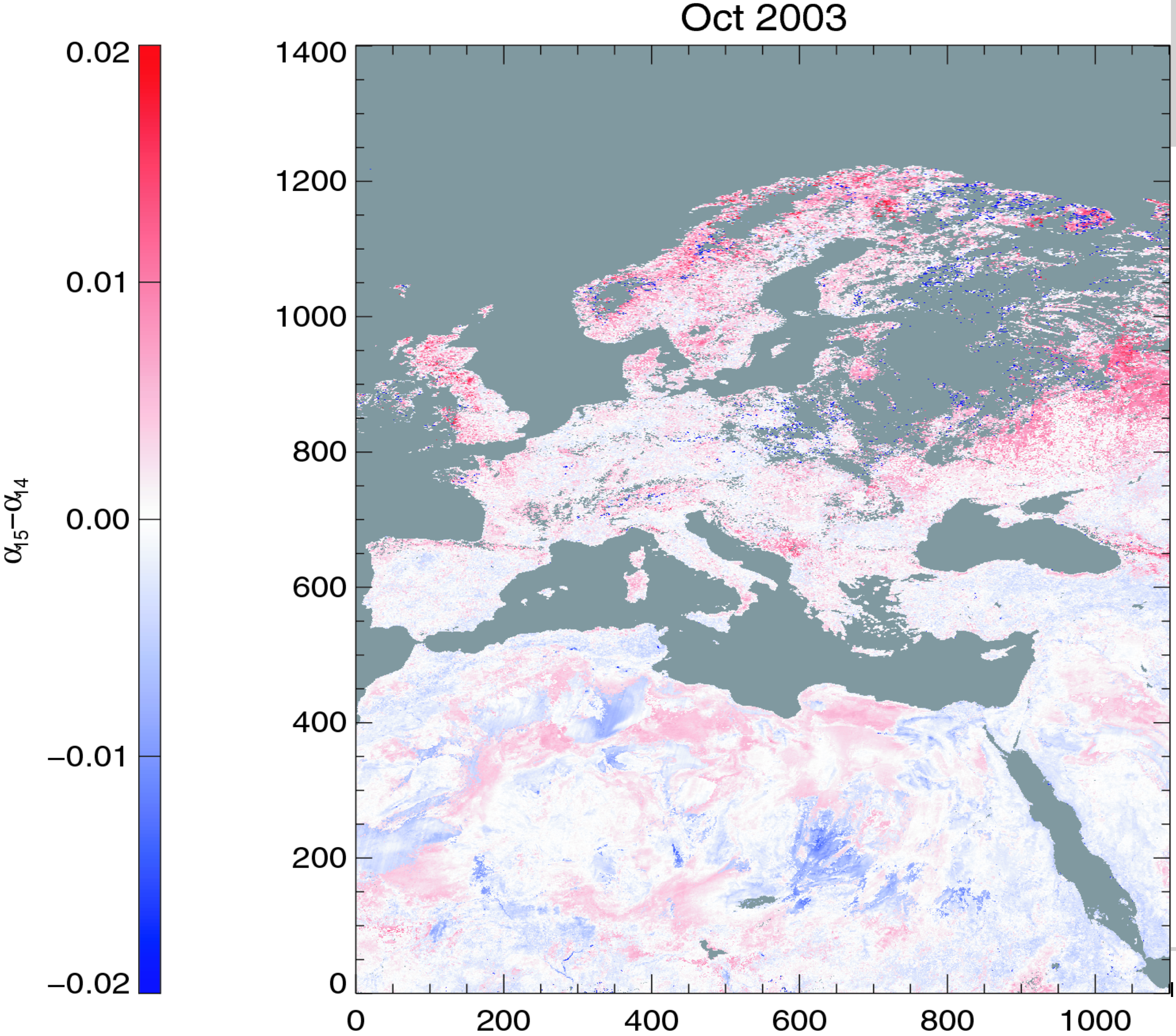
- can be used to retrieve the water vapour column (but no sounding!):
  - above land
  - above water
  - (above clouds)

- Accuracy
  - 2 kg/m^2 *rmse* and *bias* between -1 and +1 kg/m^2
  - 7 kg/m^2 *rmse* above water
  - is spatially correlated!
  - Needs *cloud free conservative* cloud screening

- *Bias* depends on
  - Area (SGP <-> Europe)
  - Instrument (MODIS and MERIS <-> RaObs)

although the used RTMs are the same!!!! This is a consequence of the implicitly assumed *pdfs* of aerosol and surface properties, the different surface and aerosol properties of the different areas and the different sensitivities of the instruments to the spectral surface properties!

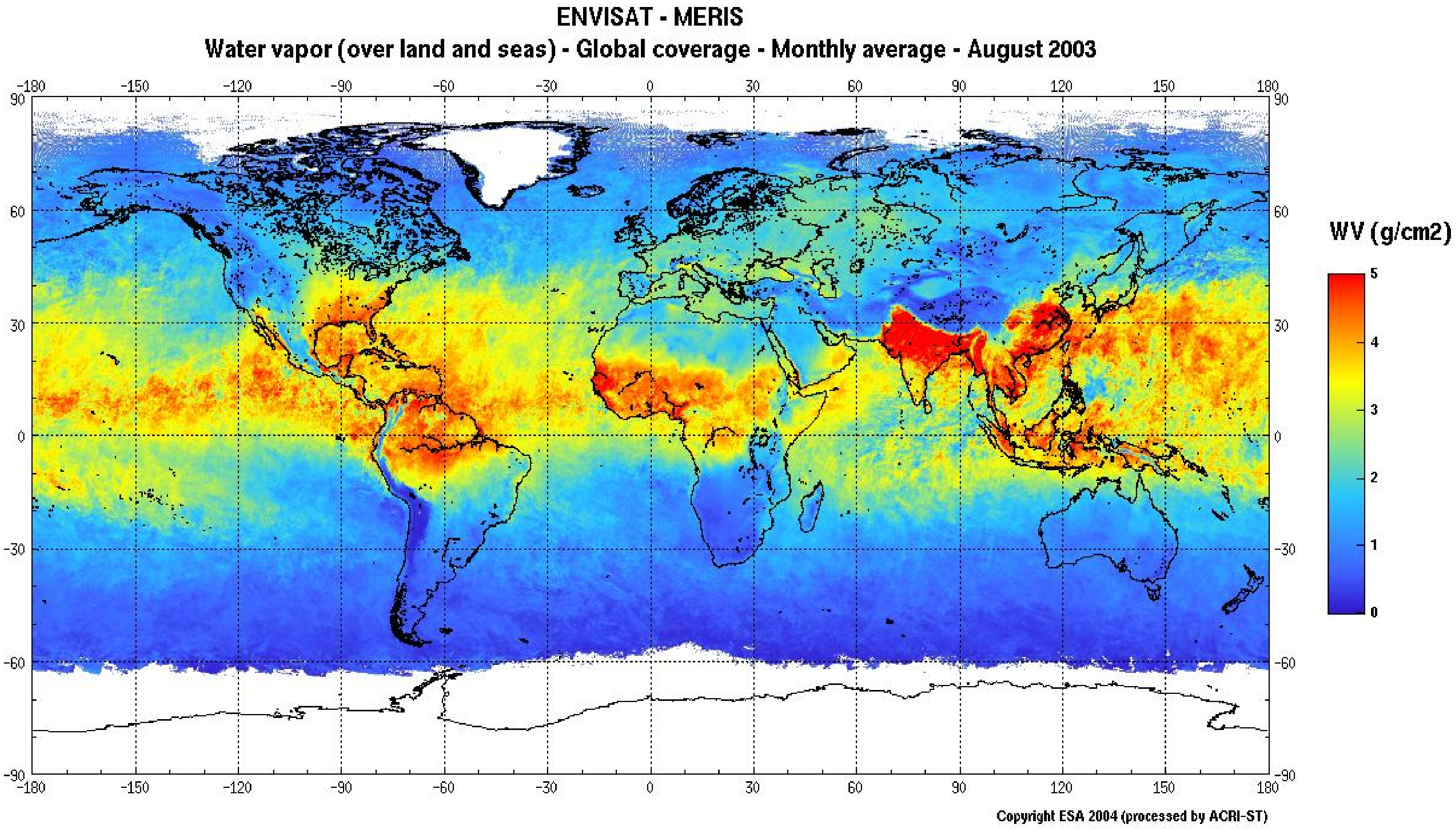

Jul 2003
0.02
0.01
0.00
−0.01
−0.02
$\alpha_{15}-\alpha_{14}$
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000

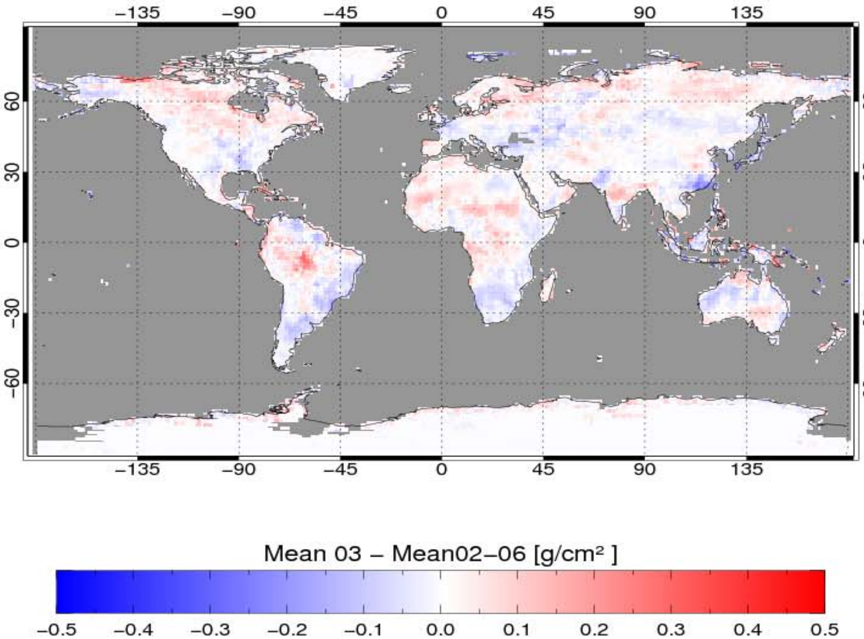


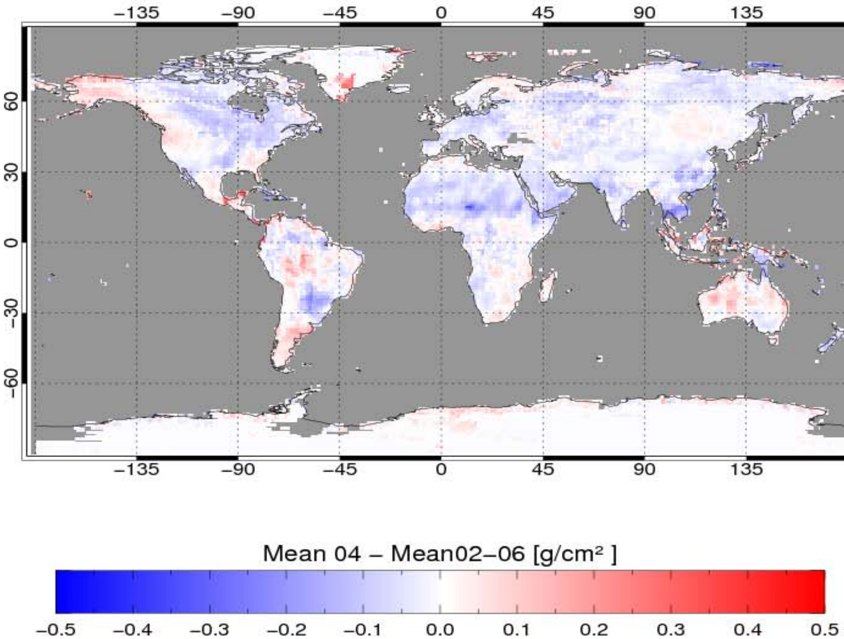
Oct 2003
0.02
0.01
0.00
−0.01
−0.02
$\alpha_{15}-\alpha_{14}$
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000

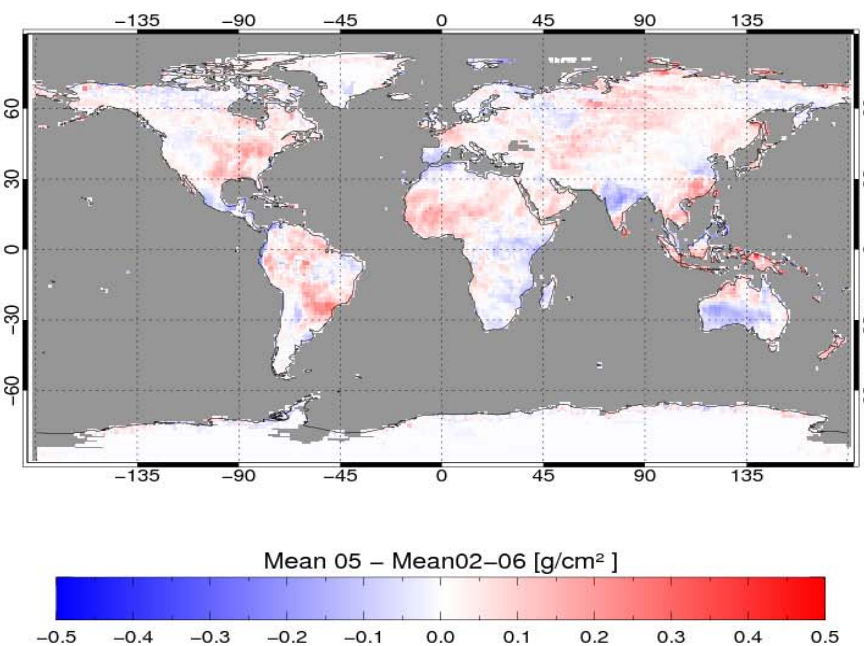
Application: Examples (II)

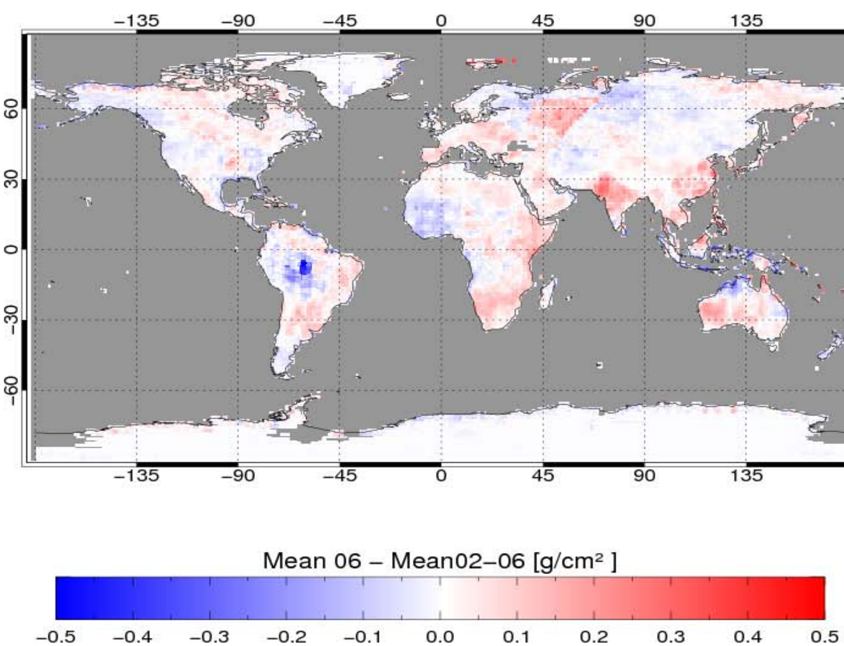
Application: MERIS – global water vapour – August 2003



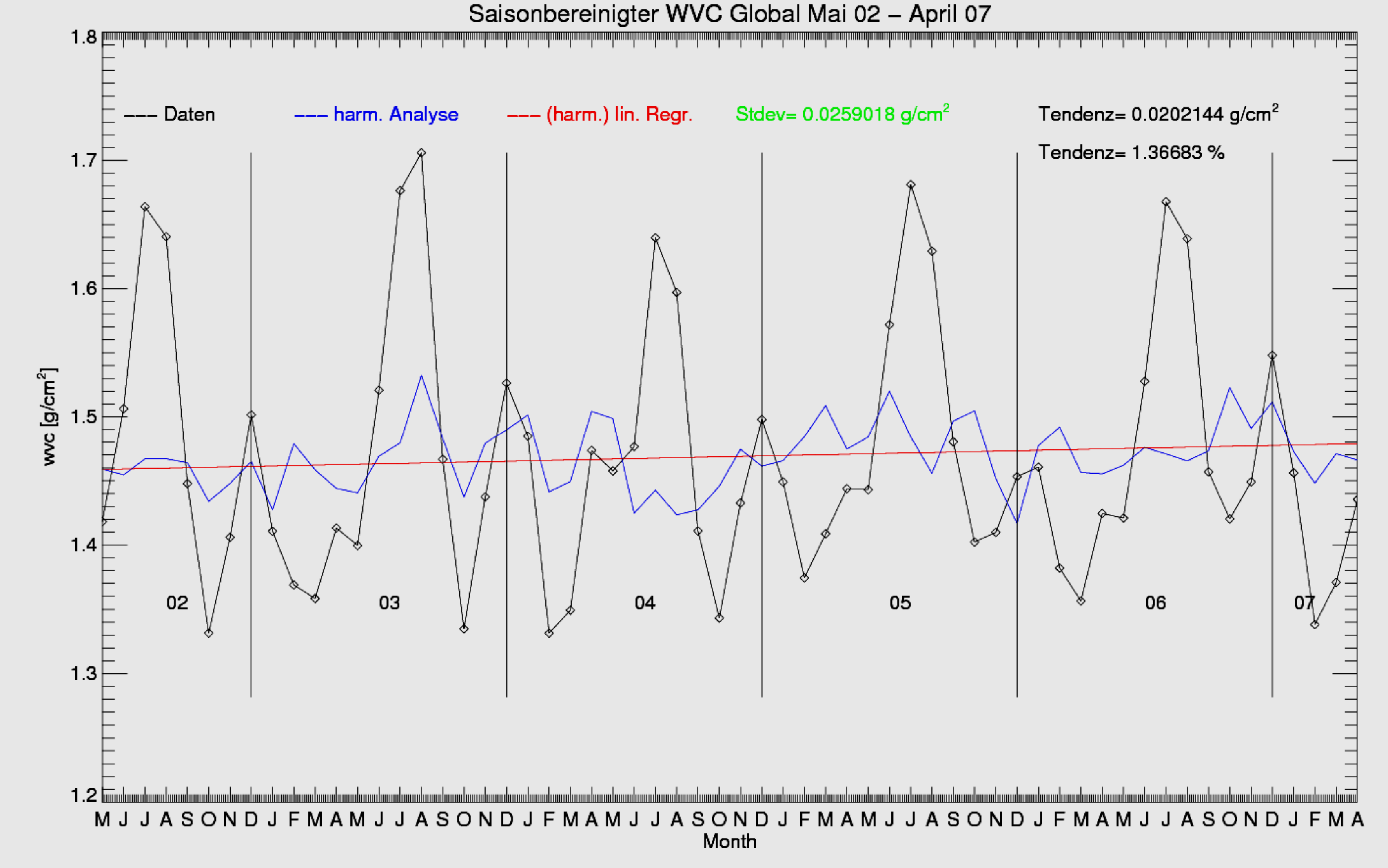

-135 -90 -45 0 45 90 135
60 30 0 -30 -60
Mean 03 – Mean02–06 [g/cm²]
-0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4 0.5


-135 -90 -45 0 45 90 135
60 30 0 -30 -60
Mean 04 – Mean02–06 [g/cm²]
-0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4 0.5

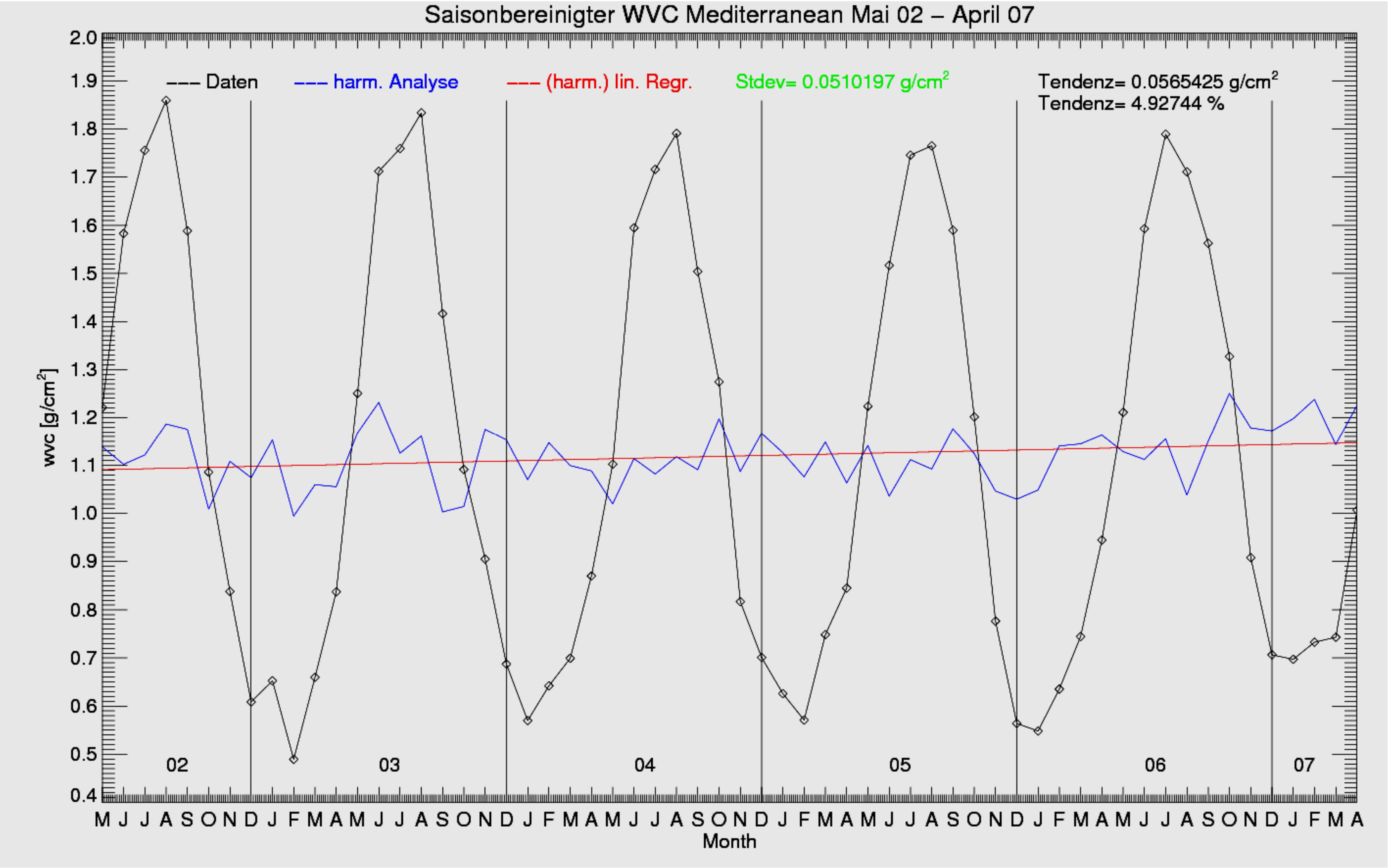

-135 -90 -45 0 45 90 135
60 30 0 -30 -60
Mean 05 – Mean02–06 [g/cm²]
-0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4 0.5


-135 -90 -45 0 45 90 135
60 30 0 -30 -60
Mean 06 – Mean02–06 [g/cm²]
-0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4 0.5

Harmonic analysis of water vapour 2002-2007



Harmonic analysis of water vapour 2002-2007



Outlook

1. Improve current MERIS / MODIS retrievals by using
   - Maps of spectral surface albedos
   - Oxygen transmission (MERIS only)
   - Better cloud detection

2. Using MERIS and MODIS water vapour as boundary condition / background information for improved MSG water vapor
   - Temporal interpolation <-> error characteristics