Overview of aerosol, land-surface and ocean information from high spectral, reduced spatial resolution Imagers

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Launched in 2002, Envisat is the largest Earth Observation spacecraft ever built. It carries ten sophisticated optical and radar instruments to provide continuous observation and monitoring of the Earth's land, atmosphere, oceans and ice caps.

Envisat data collectively provide a wealth of information on the workings of the Earth system, including insights into factors contributing to climate change. The data returned by its suite of instruments are also facilitating the development of a number of operational and commercial applications. Furthermore, crucial data for global climate study are offered by Envisat's level 3 products.

Two of Envisat’s instruments, namely the Medium Resolution Imaging Spectrometer (MERIS) and the Advanced Along Track Scanning Radiometer (AATSR) are operating in the optical range of the spectrum. They are reduced resolution imagers with the capability to provide information for scientific as well as (semi-) operational applications.

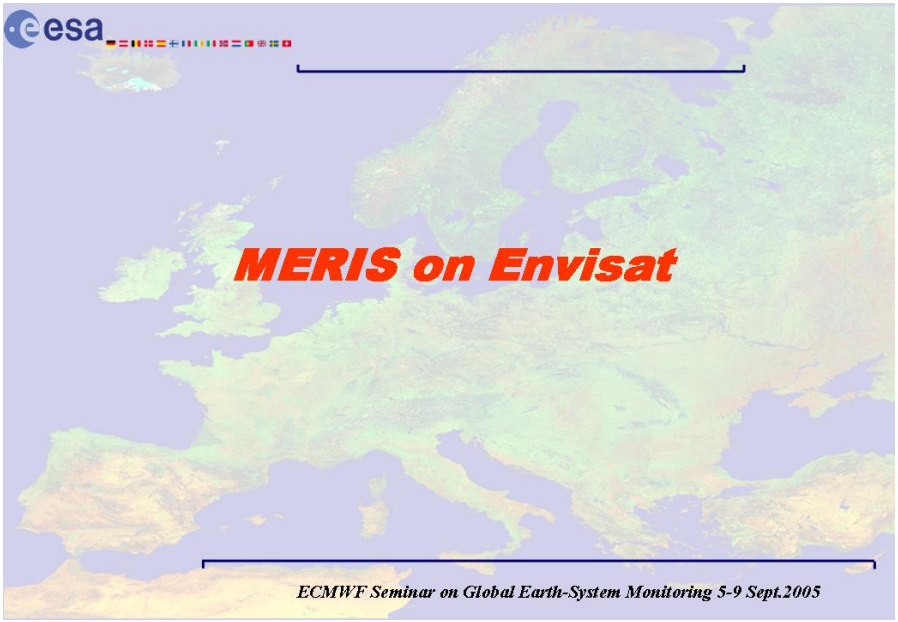
MERIS is a spectrometer that measures the solar radiation reflected by the Earth, at a ground spatial resolution of 300m, with 15 spectral bands in visible and near infra-red and programmable in width and position. MERIS allows global coverage of the Earth every 3 days. The primary mission of MERIS is the measurement of sea colour in oceans and coastal areas. Knowledge of sea colour can be converted into a measurement of chlorophyll pigment concentration, suspended sediment concentration and aerosol loads over marine areas. It is also used for land and atmospheric monitoring providing data products for vegetation monitoring and atmospheric water vapour and aerosol studies.

The prime objective of AATSR is to establish continuity of the ATSR-1 and ATSR-2 data sets of precise sea surface temperature (SST), thereby ensuring the production of a unique 10 year near-continuous data set at the levels of accuracy required (0.3 K or better) for climate research and for the community of operational as well as scientific users who have been developed through the ERS-1 and ERS-2 missions.

Envisat's AATSR, a visible to thermal infrared imaging radiometer and its predecessors ATSR-1 and ATSR-2 flown on the ERS satellites are about to complete 15 years of Sea Surface Temperature measurements with the accuracy required for climate research. In anticipation and as a demonstration, Global SST Level 3 products from AATSR from September 2002 to January 2005 have been generated at two spatial resolutions, 10 arcminutes and 30 arcminutes.

Likewise, a number of MERIS Level 3 demonstration products have been generated. The first sets available are Global Ocean Chlorophyll Concentration, and Water Vapour for the year 2003 - 2005. Aerosol optical thickness and Angstroem coefficient are also now available. The Envisat Image Showcase provides access to a large set of images of interesting areas and features as seen by Envisat from space. Data from the MERIS and AATSR instruments are now routinely processed and provided to the user community.

Data products and case study results from MERIS and AATSR are together with examples from the wide-swath, high spectral resolution imager MODIS, flown on the US platforms TERRA and AQUA and the NASA ocean colour mission SeaWIFS shown in this presentation.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MERIS on Envisat
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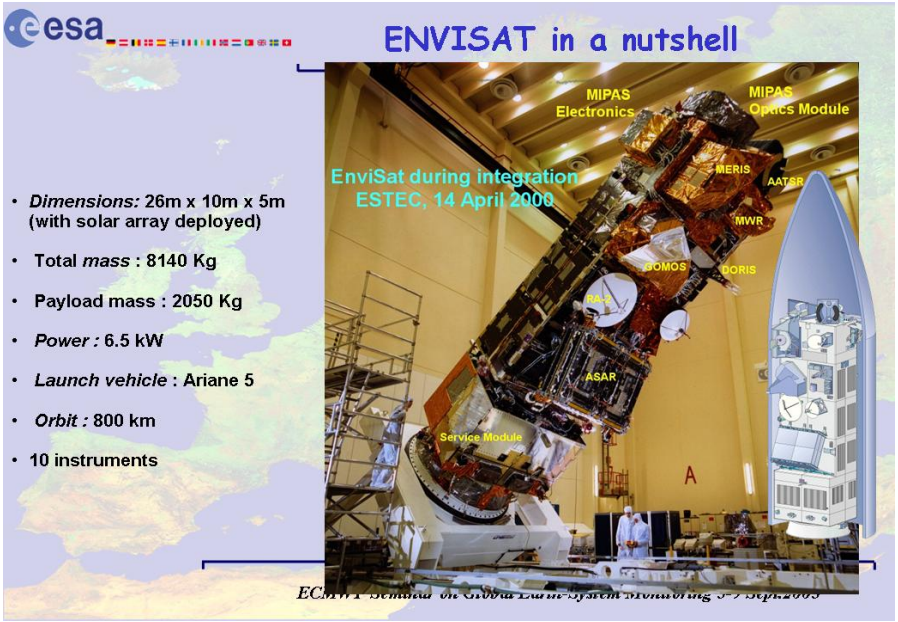
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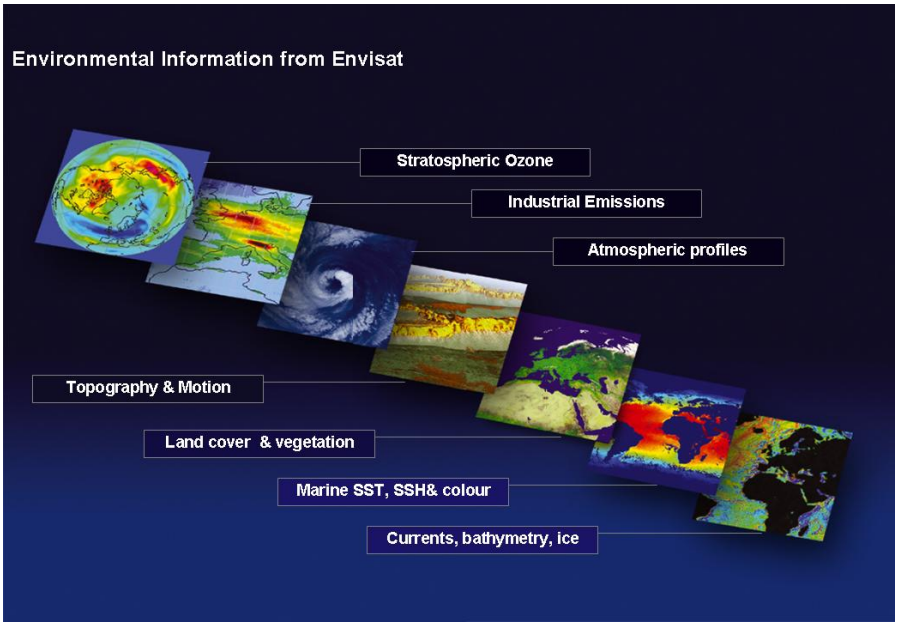
ENVISAT in a nutshell
• Dimensions: 26m x 10m x 5m (with solar array deployed)
• Total mass : 8140 Kg
• Payload mass : 2050 Kg
• Power : 6.5 kW
• Launch vehicle : Ariane 5
• Orbit : 800 km
• 10 instruments
EnviSat during integration
ESTEC, 14 April 2000
MIPAS Electronics
MIPAS Optics Module
MERIS
AATSR
MWR
GOMOS
DORIS
RA-2
ASAR
Service Module
A


Environmental Information from Envisat
Stratospheric Ozone
Industrial Emissions
Atmospheric profiles
Topography & Motion
Land cover & vegetation
Marine SST, SSH& colour
Currents, bathymetry, ice

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MEdium Resolution Imaging Spectrometer (MERIS)

- Onboard ESA's Envisat
- 15 programmable bands in region of 390-1040nm
- Pushbroom imaging spectrometer
- 1150km swath on ground
- Two spatial resolutions
  - Full resolution (FR)-300m
  - Reduced resolution (RR)-1200m
- Global coverage in 3 days

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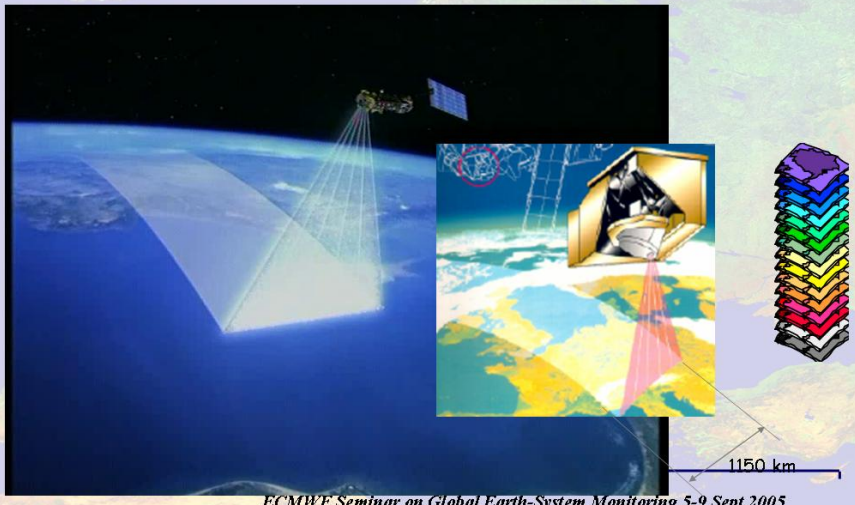
The Medium Resolution Imaging Spectrometer



Animation: ESA

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The MERIS spectral bands

#	Centre (nm)	Width (nm)	Potential Applications
1	412.5	10	Yellow substance and detrital pigments
2	442.5	10	Chlorophyll absorption maximum
3	490	10	Chlorophyll and other pigments
4	510	10	Suspended sediment, red tides
5	560	10	Chlorophyll absorption minimum
6	620	10	Suspended sediment
7	665	10	Chlorophyll absorption and fluo. reference
8	681.25	7.5	Chlorophyll fluorescence peak
9	708.75	10	Fluo. Reference, atmospheric corrections
10	753.75	7.5	Vegetation, cloud
11	760.625	3.75	Oxygen absorption R-branch
12	778.75	15	Atmosphere corrections
13	865	20	Vegetation, water vapour reference
14	885	10	Atmosphere corrections
15	900	10	Water vapour, land

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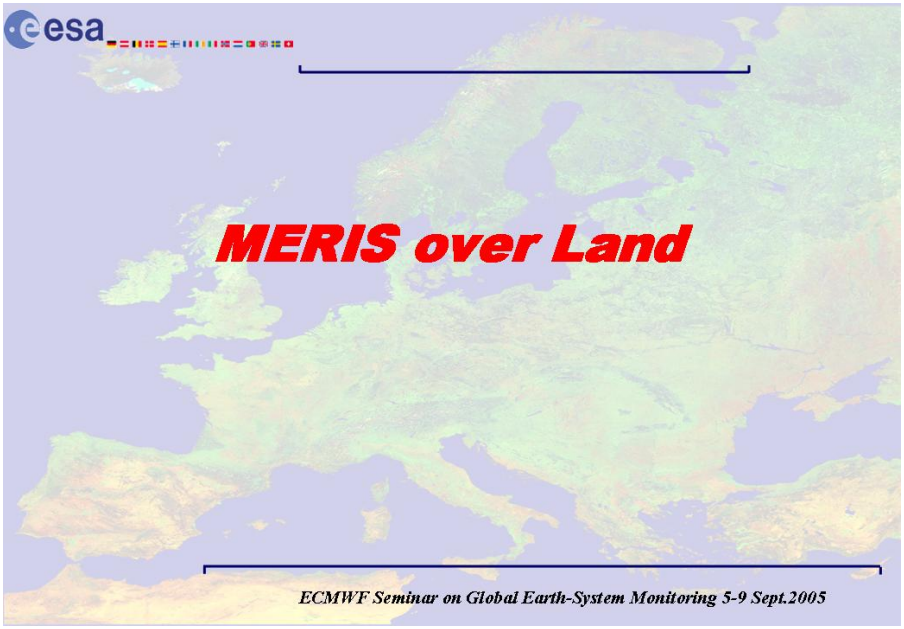
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MERIS over Land
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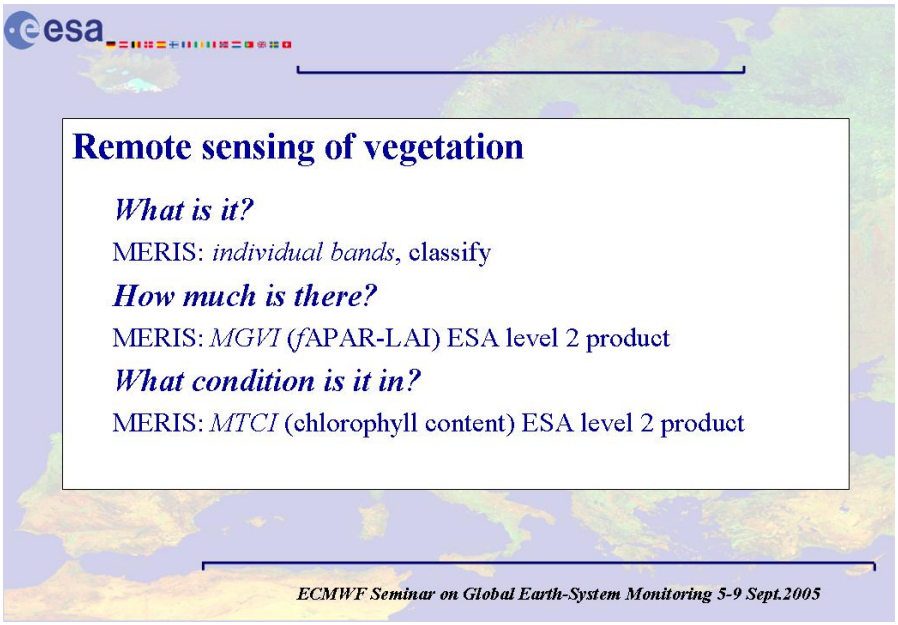
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Remote sensing of vegetation
What is it?
MERIS: individual bands, classify
How much is there?
MERIS: MGVI (fAPAR-LAI) ESA level 2 product
What condition is it in?
MERIS: MTCI (chlorophyll content) ESA level 2 product
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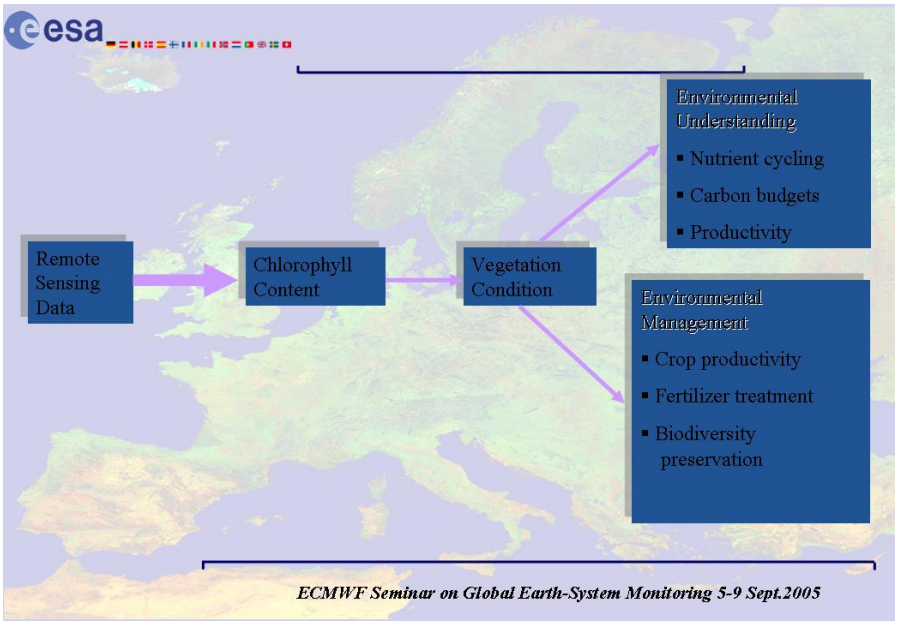
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Remote Sensing Data
Chlorophyll Content
Vegetation Condition
Environmental Understanding
Nutrient cycling
Carbon budgets
Productivity
Environmental Management
Crop productivity
Fertilizer treatment
Biodiversity preservation
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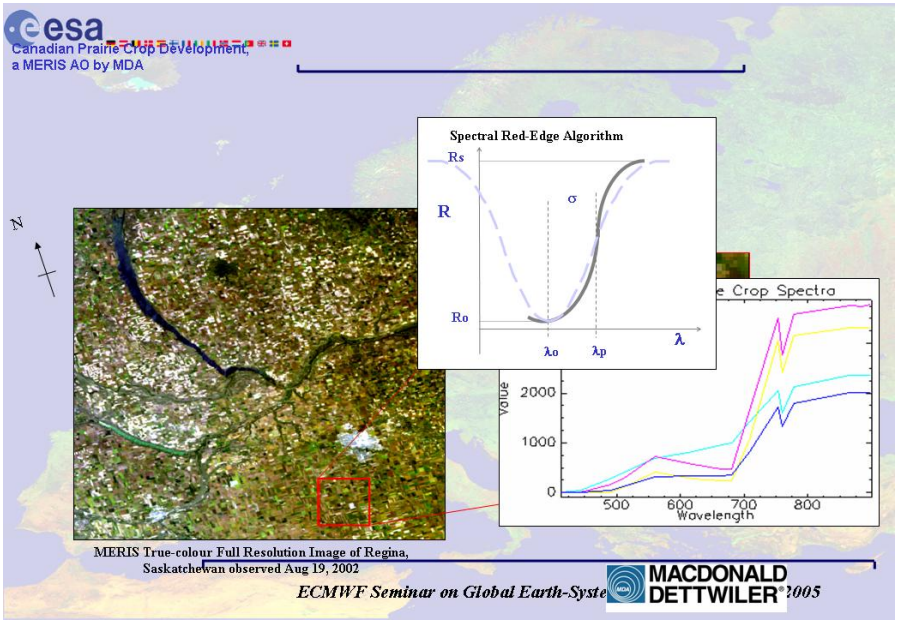
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Canadian Prairie Crop Development,
a MERIS AO by MDA
Spectral Red-Edge Algorithm
Rs
R
Ro
σ
λo
λp
λ
N
Crop Spectra
Value
2000
1000
0
500
600
700
800
Wavelength
MERIS True-colour Full Resolution Image of Regina,
Saskatchewan observed Aug 19, 2002
MACDONALD DETTWILER
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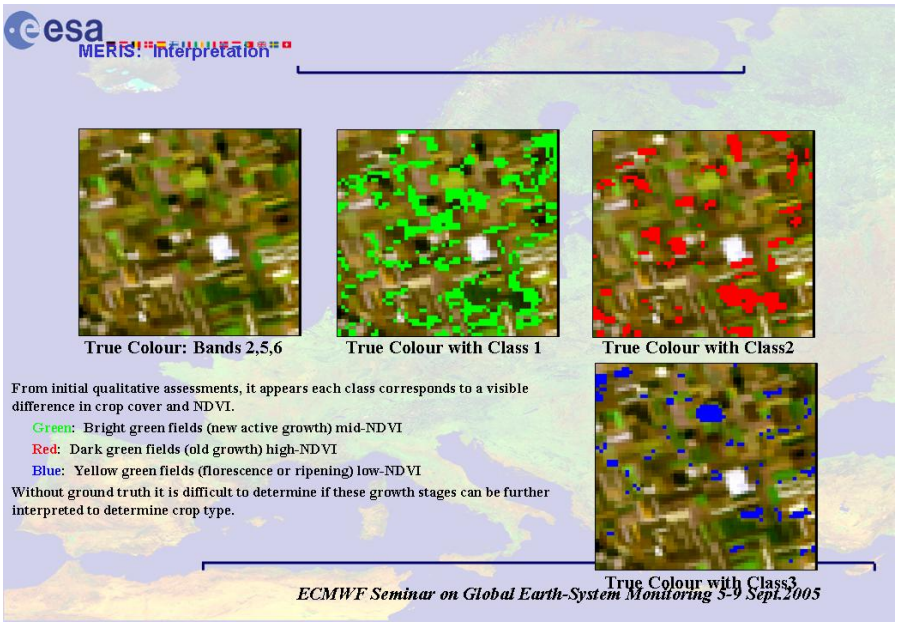
2005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MERIS: Interpretation
True Colour: Bands 2,5,6
True Colour with Class 1
True Colour with Class2
True Colour with Class3
From initial qualitative assessments, it appears each class corresponds to a visible difference in crop cover and NDVI.
Green: Bright green fields (new active growth) mid-NDVI
Red: Dark green fields (old growth) high-NDVI
Blue: Yellow green fields (florescence or ripening) low-NDVI
Without ground truth it is difficult to determine if these growth stages can be further interpreted to determine crop type.
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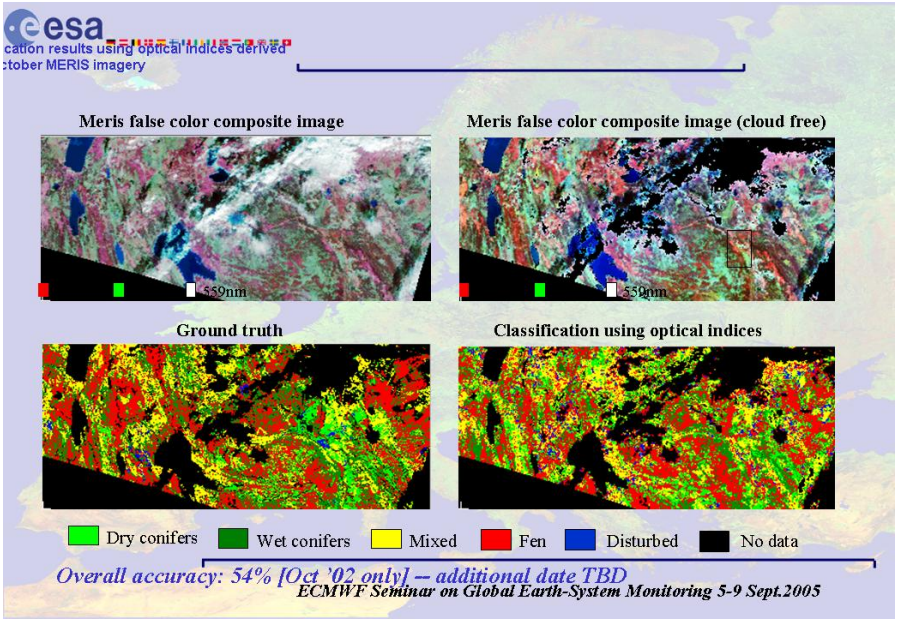
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cation results using optical indices derived
tober MERIS imagery
Meris false color composite image
Meris false color composite image (cloud free)
559nm
559nm
Ground truth
Classification using optical indices
Dry conifers
Wet conifers
Mixed
Fen
Disturbed
No data
Overall accuracy: 54% [Oct '02 only] -- additional date TBD
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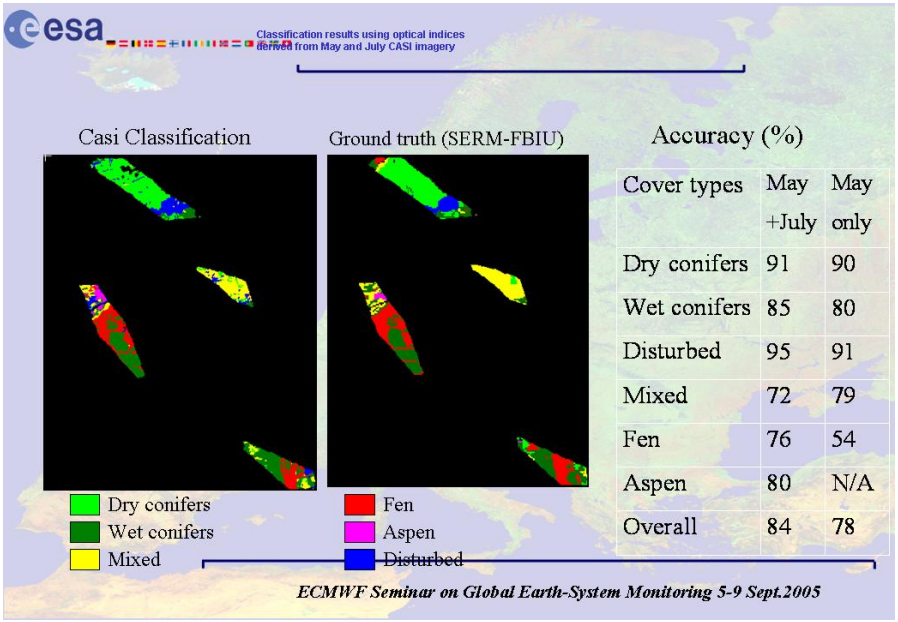
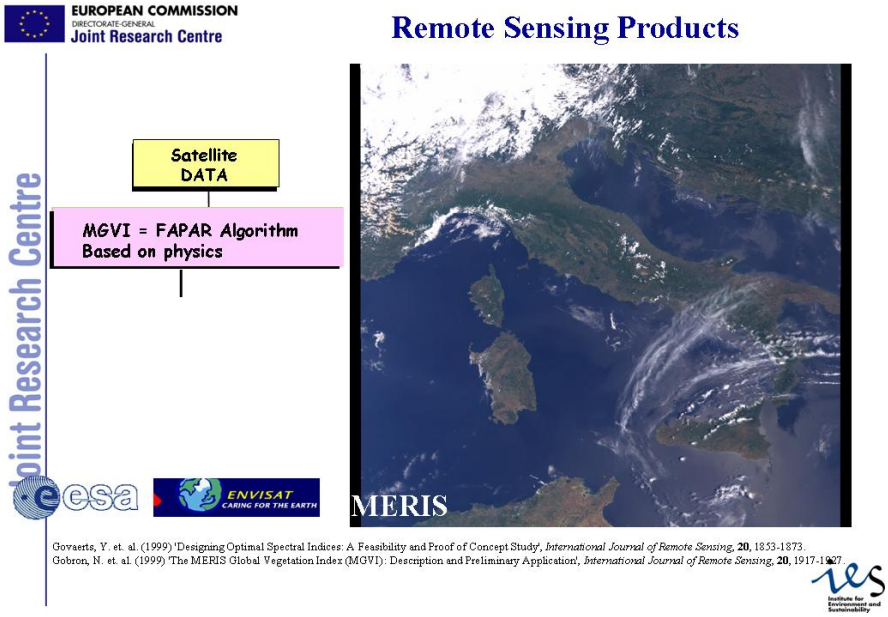
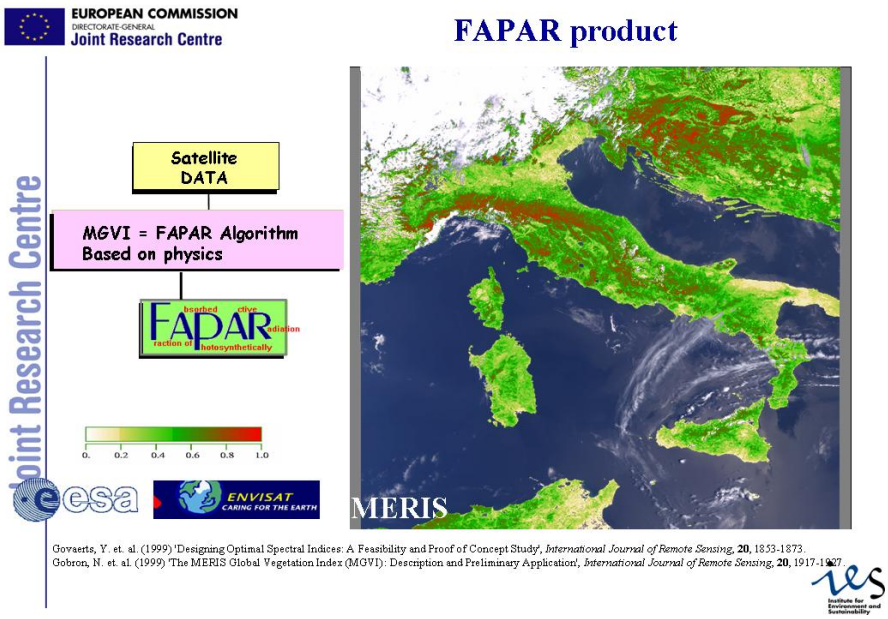
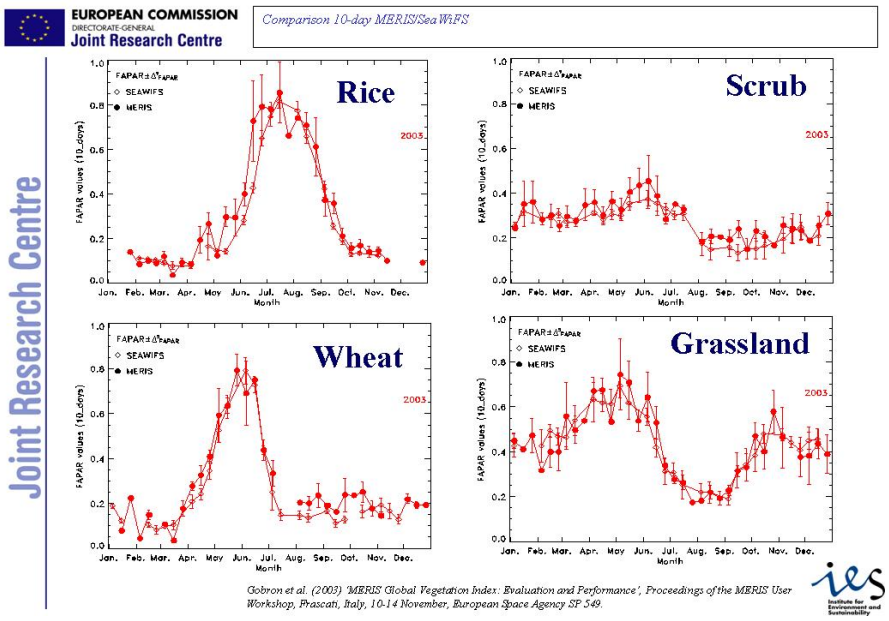
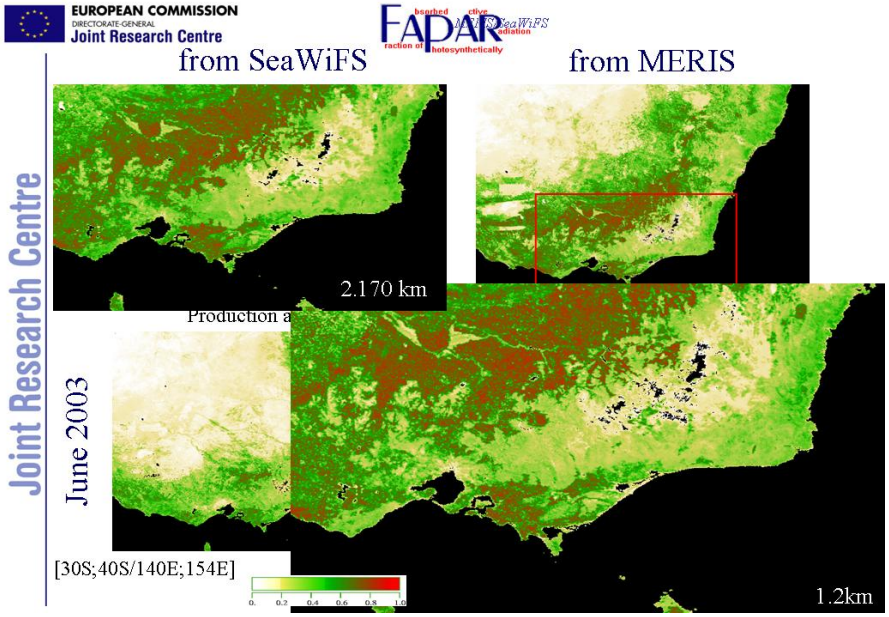


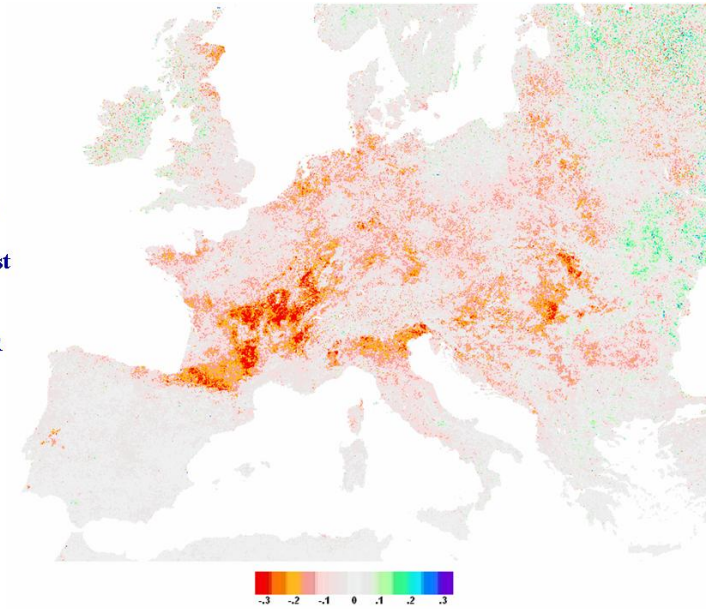
Accuracy (%)		
Cover types	May +July	May only
Dry conifers	91	90
Wet conifers	85	80
Disturbed	95	91
Mixed	72	79
Fen	76	54
Aspen	80	N/A
Overall	84	78






EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre
Comparison 10-day MERIS/SeaWiFS
Joint Research Centre
Rice
Scrub
Wheat
Grassland
FAPAR values (10_days)
SEAWIFS
MERIS
2003
Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.
Month
Gobron et al. (2003) 'MERIS Global Vegetation Index: Evaluation and Performance', Proceedings of the MERIS User Workshop, Frascati, Italy, 10-14 November, European Space Agency SP 549.


EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre
from SeaWiFS
from MERIS
Joint Research Centre
June 2003
2.170 km
[30S;40S/140E;154E]
1.2km


Drought stress over Europe in August 2003 observed with MERIS derived FAPAR anomalies
-.3 -.2 -.1 0 .1 .2 .3

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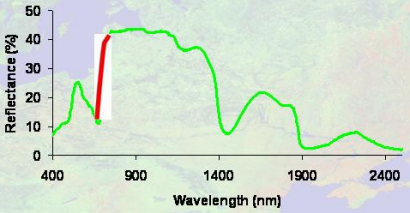
Red edge position (REP):

- links remotely sensed data and chlorophyll content
- is defined as the ***point of maximum slope*** of the curve in red / near infrared region



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MERIS to estimate REP at a landscape scale

We have

- *Large volumes* of discontinuous spectral data
- *High variation* in chlorophyll values

We require

- *Unique* value for an index
- *Automation*

Problems with REP estimation techniques in literature

- Designed for small volumes of continuous spectral data
- Insensitive to high chlorophyll values
- REP value depends on technique used
- Two-step process, requires user intervention

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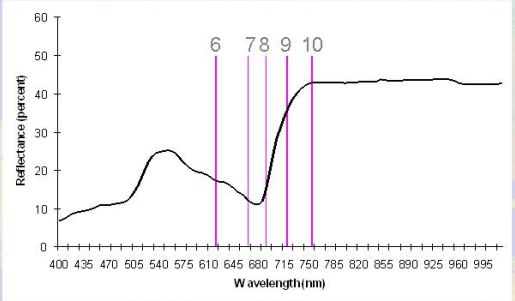
In some respects MERIS is well suited ▸ high SNR (around 600:1 in blue wavelengths to around 250:1 in near-IR wavelengths over vegetation) ▸ well-placed wavebands

Band no	Central wavelength (nm)
1	412.5
2	442.5
3	490
4	510
5	560
6	620
7	665
8	681.25
9	708.75
10	753.75
11	760.625
12	778.75
13	865
14	885
15	900



Position of MERIS standard band setting on a vegetation reflectance spectrum

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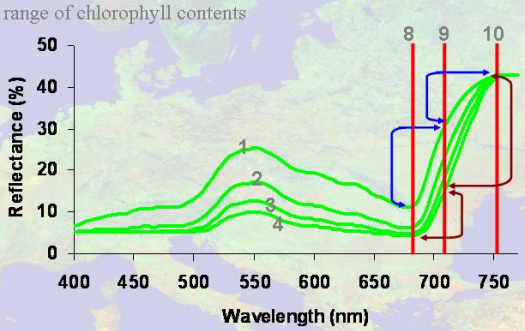
Designing the MERIS Terrestrial Chlorophyll Index (MTCI)

Requirements:

(i) Easy to calculate from MERIS data

(ii) Sensitive to wide range of chlorophyll contents



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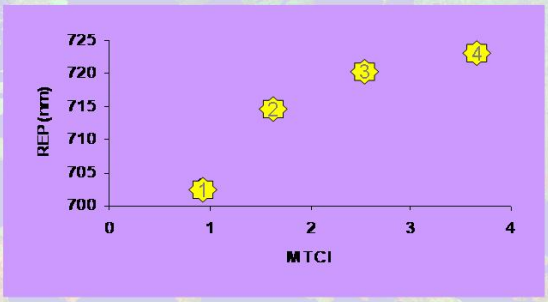
Equation

$$MTCI = \frac{R_{Band\,10} - R_{Band\,9}}{R_{Band\,9} - R_{Band\,8}} = \frac{R_{753.75} - R_{708.75}}{R_{708.75} - R_{681.25}}$$



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Preliminary evaluation

Model

- **LIBSAIL** (LIBERTY+SAIL)
- Reflectance from 400-2500 nm
- Averaged to get the MERIS standard band setting

Field

- Collected for Maple and Douglas-fir (NASA ACCP 1992-93)
- Canopy spectral reflectance (400-2500nm)
- Canopy chlorophyll content

MERIS

- Study area: New Forest, Hampshire, UK
- Acquisition date 19 October 2002
- Top-of-canopy reflectance

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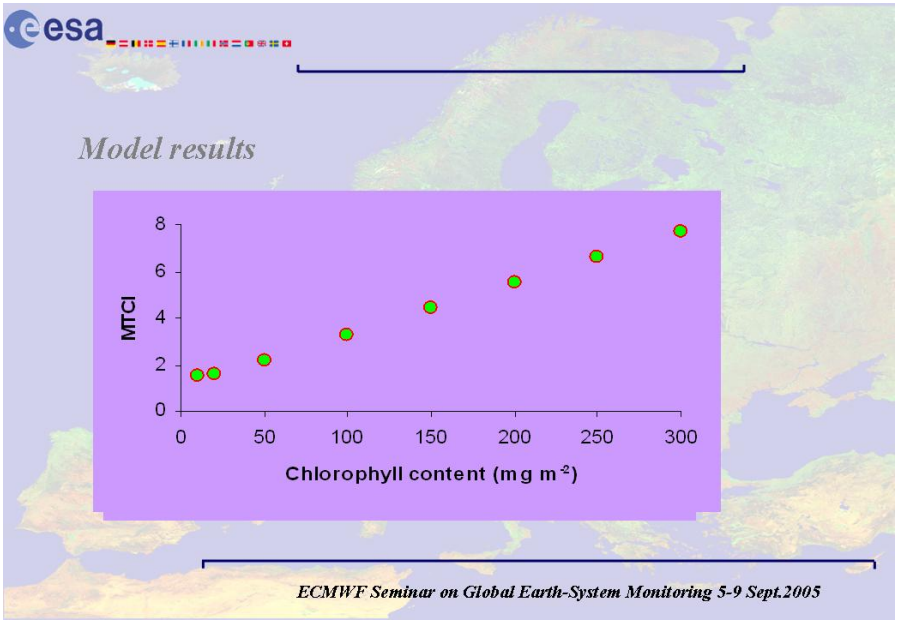
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Model results
MTCI
0
2
4
6
8
0
50
100
150
200
250
300
Chlorophyll content (mg m-2)
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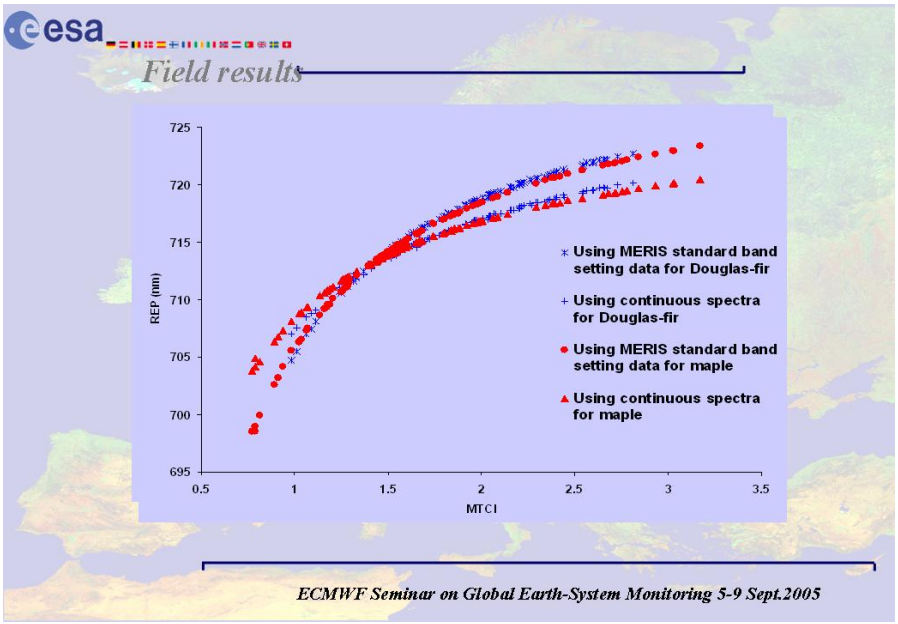
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Field results
REP (nm)
725
720
715
710
705
700
695
0.5
1
1.5
2
2.5
3
3.5
MTCI
Using MERIS standard band setting data for Douglas-fir
Using continuous spectra for Douglas-fir
Using MERIS standard band setting data for maple
Using continuous spectra for maple
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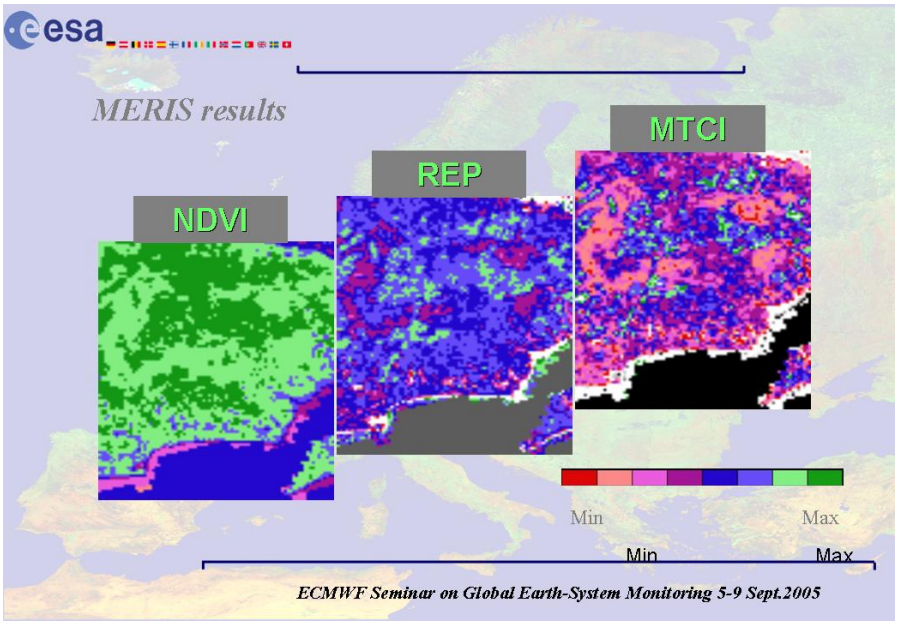
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MERIS results
NDVI
REP
MTCI
Min
Max
Min
Max
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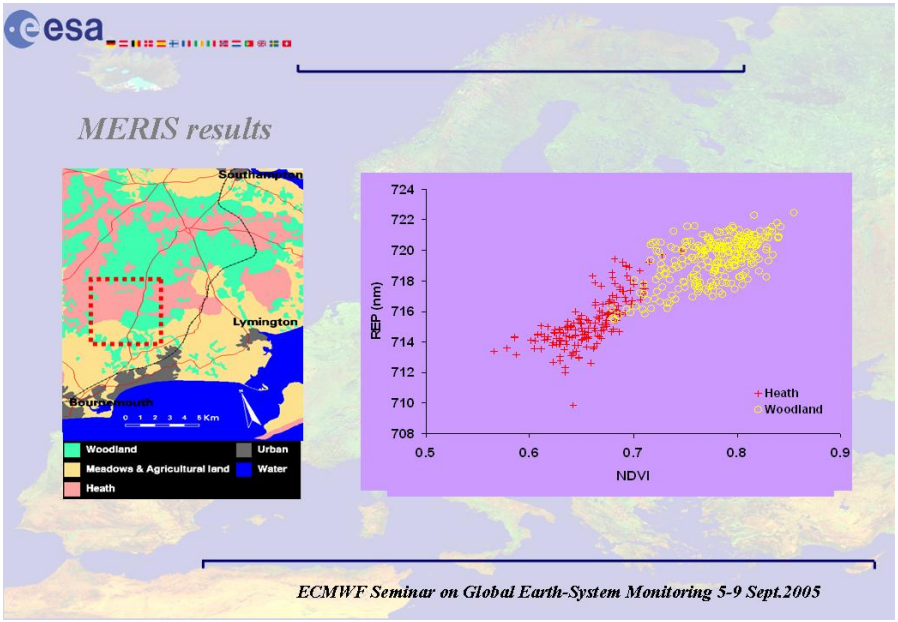
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MERIS results
Southampton
Lymington
Bournemouth
0 1 2 3 4 5Km
Woodland
Urban
Meadows & Agricultural land
Water
Heath
REP (nm)
724
722
720
718
716
714
712
710
708
0.5
0.6
0.7
0.8
0.9
NDVI
Heath
Woodland
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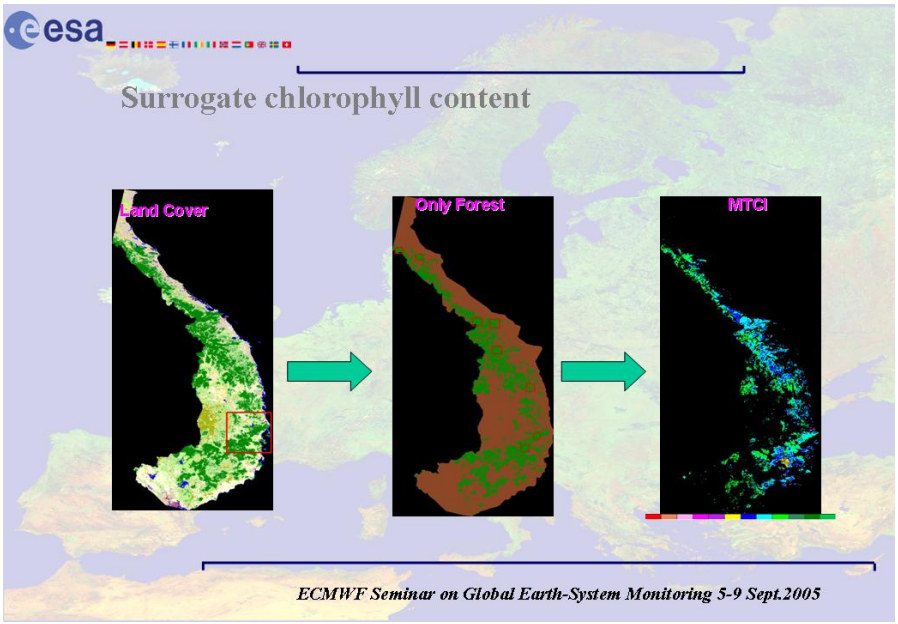
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Surrogate chlorophyll content
Land Cover
Only Forest
MTCI
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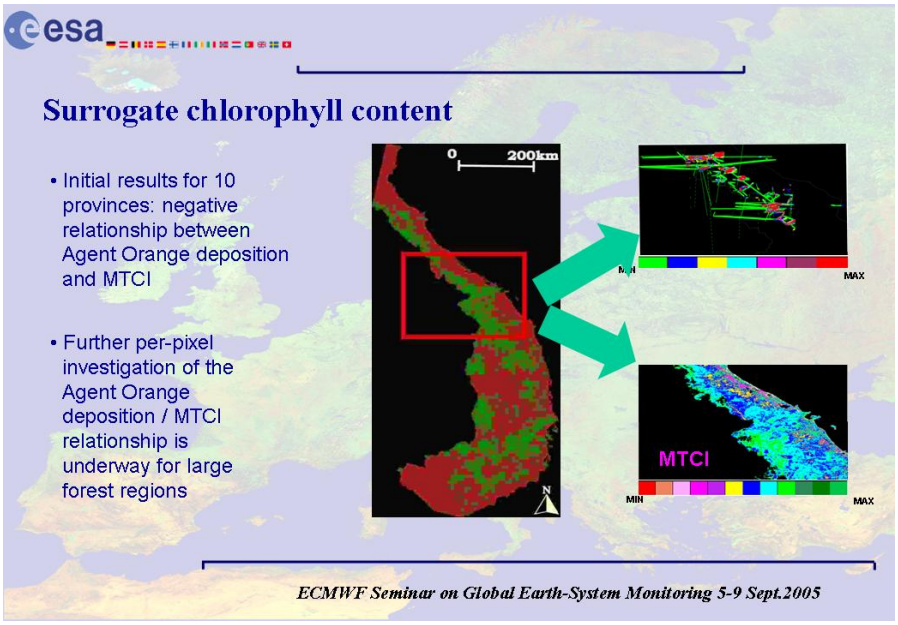
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Surrogate chlorophyll content
• Initial results for 10 provinces: negative relationship between Agent Orange deposition and MTCI
• Further per-pixel investigation of the Agent Orange deposition / MTCI relationship is underway for large forest regions
0
200km
N
MAX
MTCI
MIN
MAX
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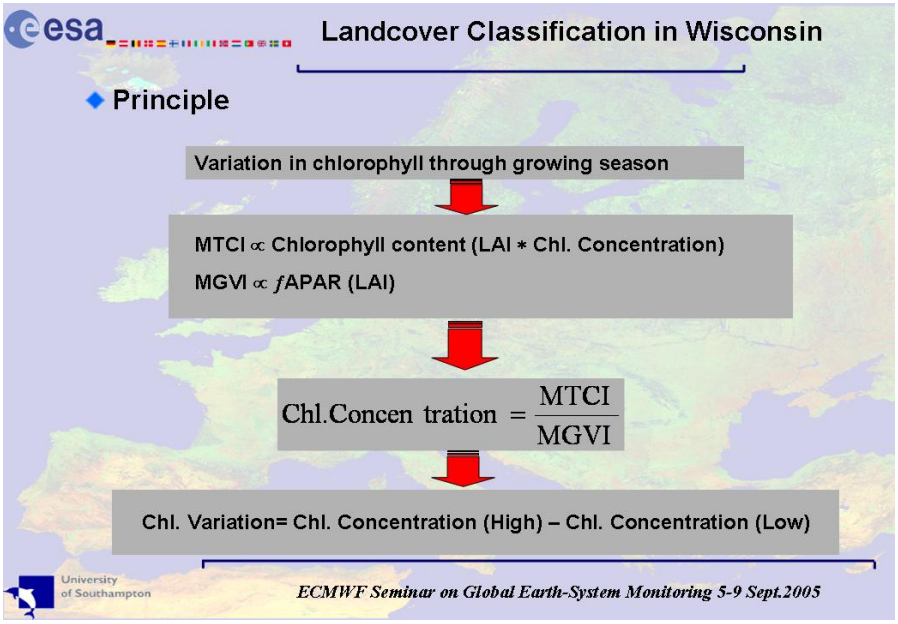
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Landcover Classification in Wisconsin
Principle
Variation in chlorophyll through growing season
MTCI ∝ Chlorophyll content (LAI * Chl. Concentration)
MGVI ∝ fAPAR (LAI)
Chl.Concen tration = MTCI / MGVI
Chl. Variation= Chl. Concentration (High) – Chl. Concentration (Low)
University of Southampton
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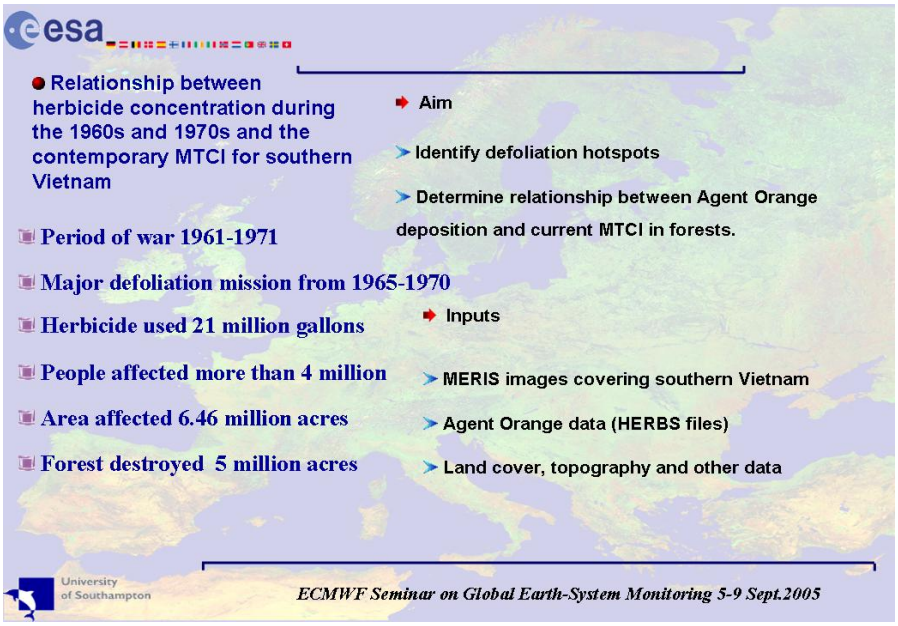
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Relationship between herbicide concentration during the 1960s and 1970s and the contemporary MTCI for southern Vietnam
Period of war 1961-1971
Major defoliation mission from 1965-1970
Herbicide used 21 million gallons
People affected more than 4 million
Area affected 6.46 million acres
Forest destroyed 5 million acres
Aim
Identify defoliation hotspots
Determine relationship between Agent Orange deposition and current MTCI in forests.
Inputs
MERIS images covering southern Vietnam
Agent Orange data (HERBS files)
Land cover, topography and other data
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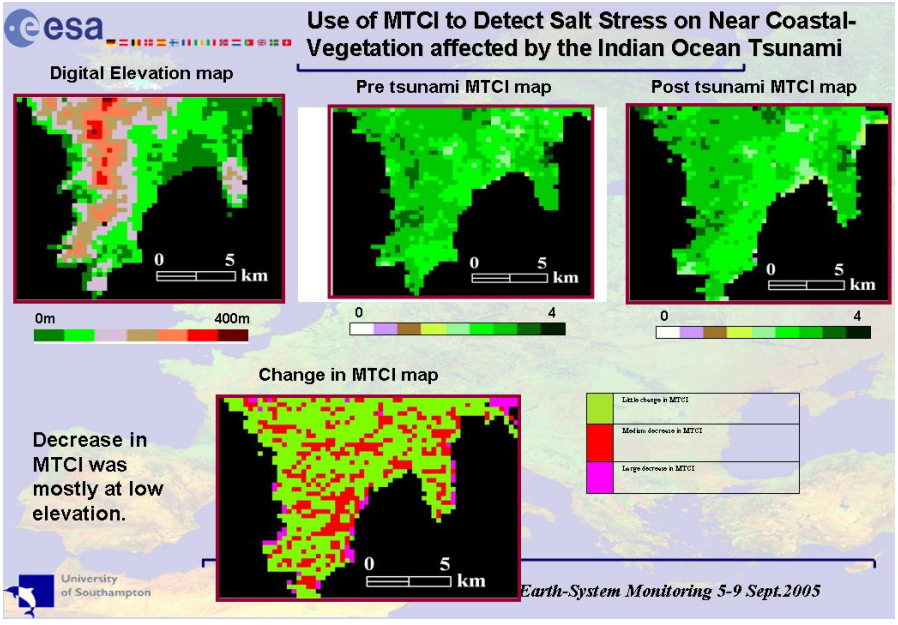
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Use of MTCI to Detect Salt Stress on Near Coastal-Vegetation affected by the Indian Ocean Tsunami
Digital Elevation map
Pre tsunami MTCI map
Post tsunami MTCI map
0 5 km
0m 400m
0 4
Change in MTCI map
Decrease in MTCI was mostly at low elevation.
University of Southampton
Earth-System Monitoring 5-9 Sept.2005

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CASI Maps

Seasonal change in LAI: early, mid and late growth stages

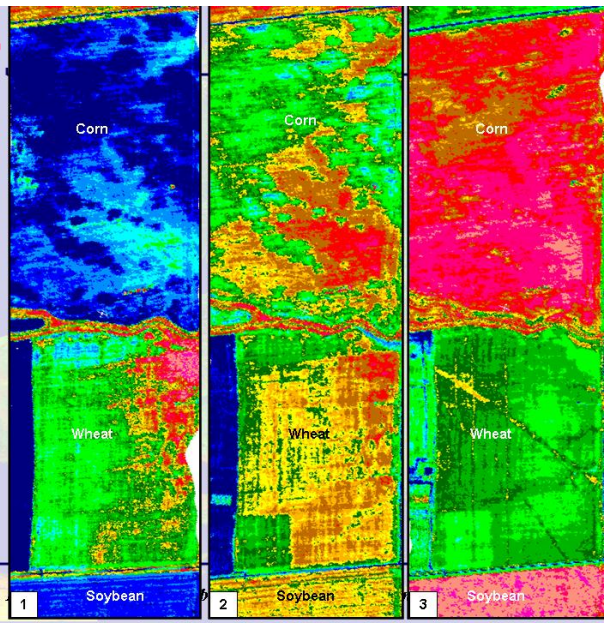
LAI colour key:

Blue: 0.15 – 0.50

Green: 0.51 – 2.0

Yellow: 2.01 – 4.0

Red: 4.01 – 8.0



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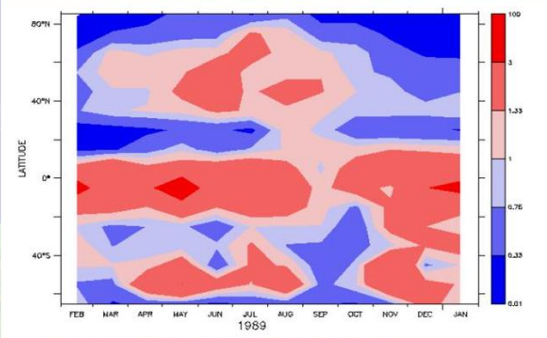
Global ensemble simulations with ECMWF NWP model including seasonal vegetation

Biome – specific seasonal LAI

ISLSCP 1°x 1° monthly LAI data set 1982 – 1990

Temporal averaging and integration by biome: Courtesy to Sietse Los and Forrest Hall

NWP assimilation: B. v.d. Hurk



LAI experiment = 5 runs with the same atmosphere but with random 25 % noise on LAI
Atm experiment = 5 runs with the same seasonal LAI distribution but with 5 different initial atmospheres
LAI / Atm > 1 (reddish): ***LAI random error results in larger evaporation variability than the atmospheric variability***

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MERIS over Ocean

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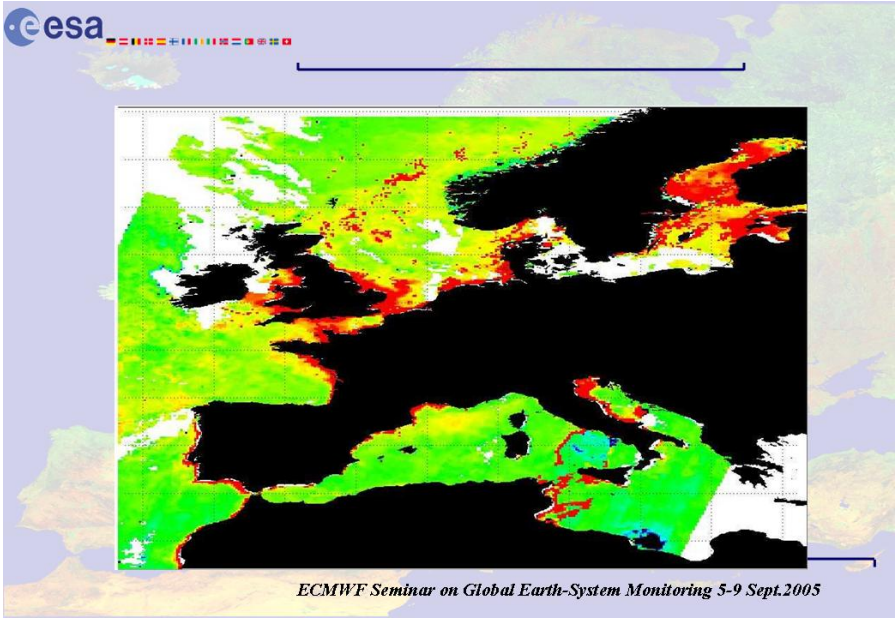
esa
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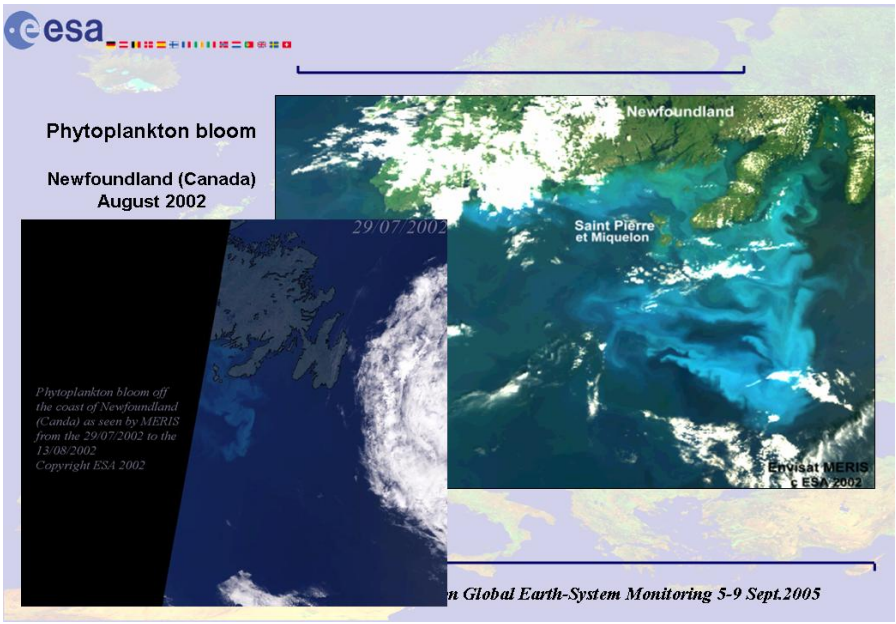
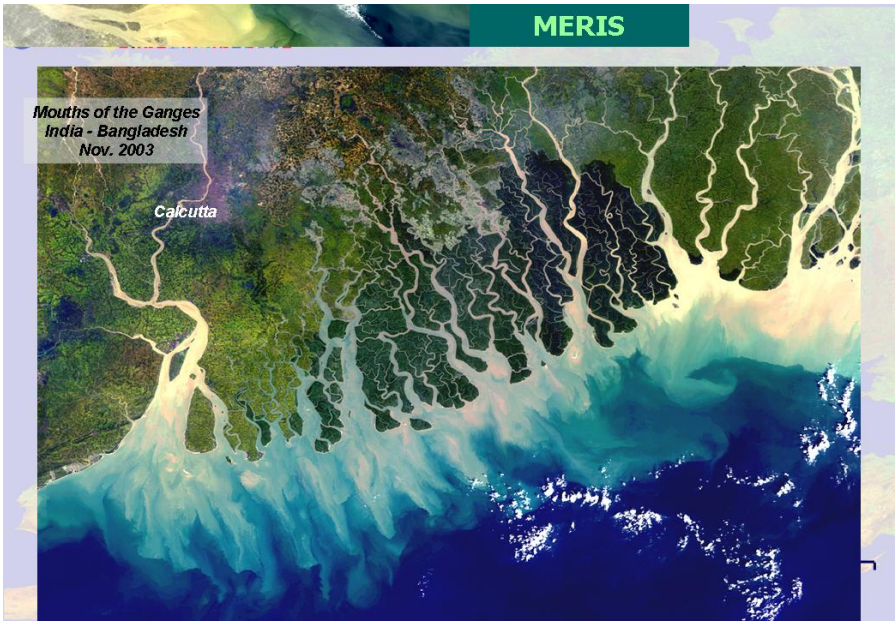
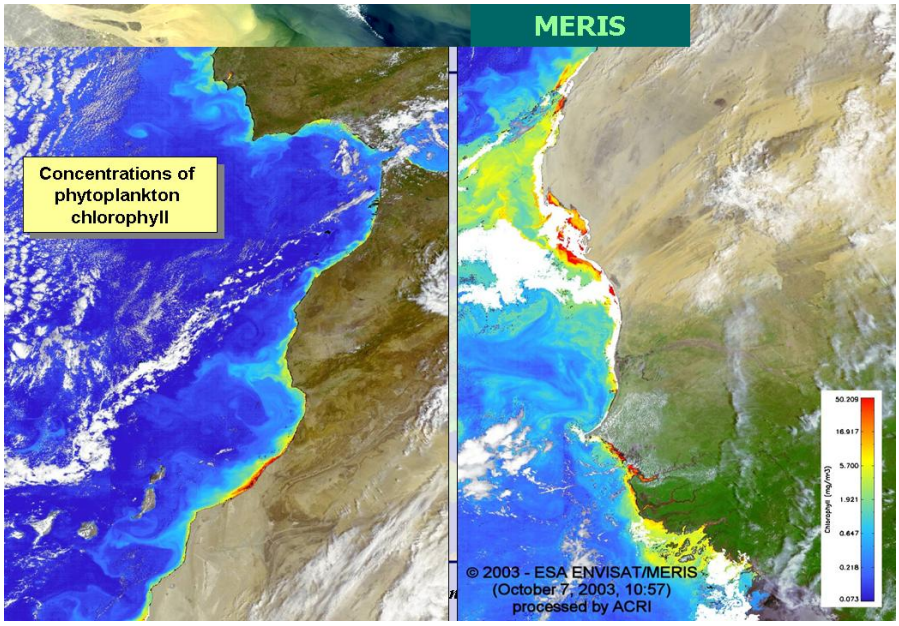
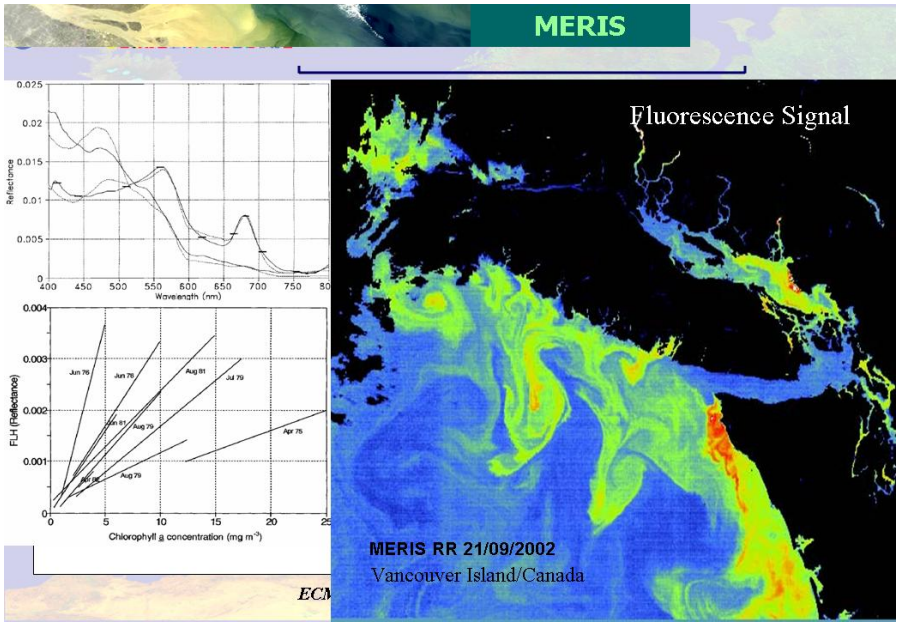
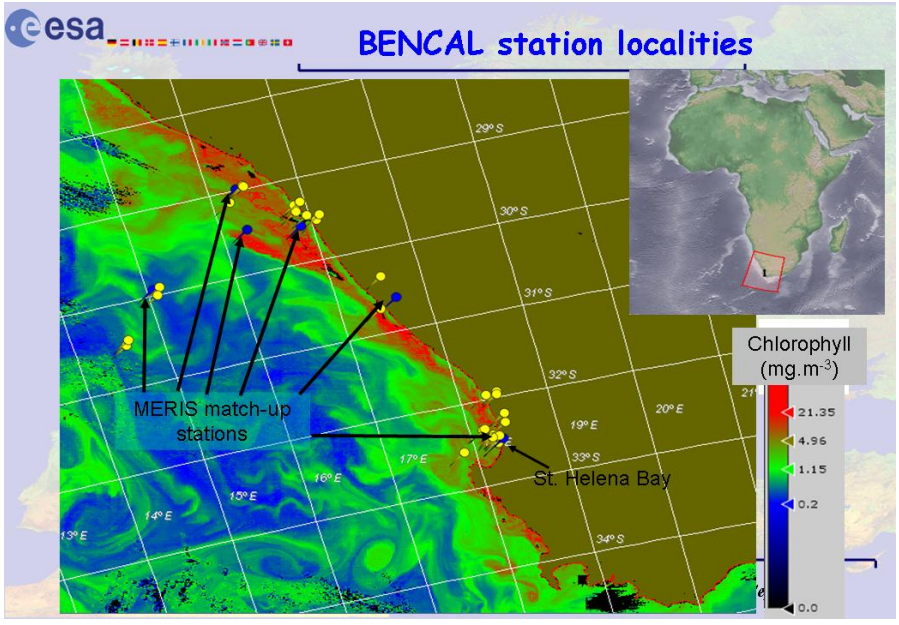
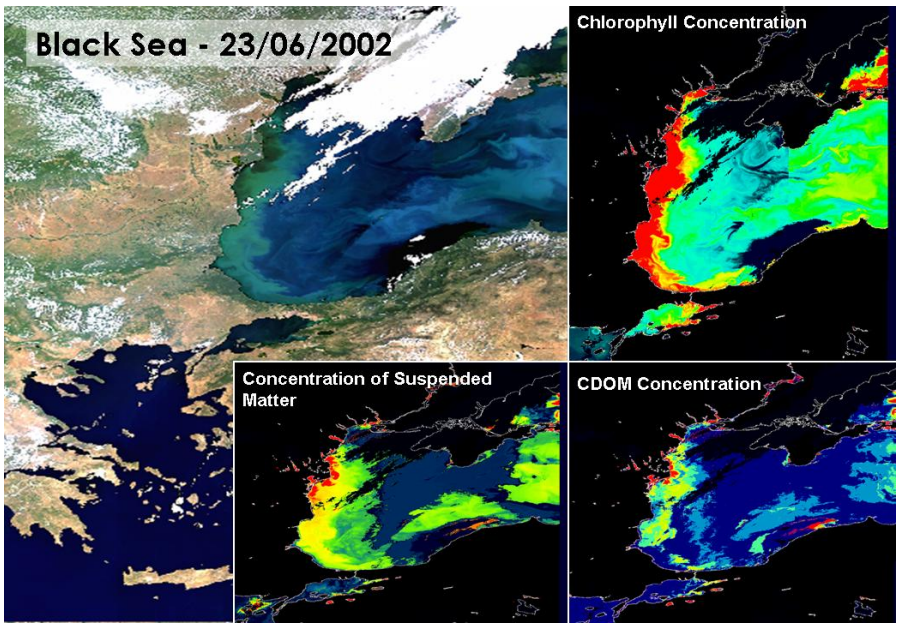

esa
Phytoplankton bloom
Newfoundland (Canada)
August 2002
Newfoundland
Saint Pierre
et Miquelon
29/07/2002
Phytoplankton bloom off the coast of Newfoundland (Canda) as seen by MERIS from the 29/07/2002 to the 13/08/2002
Copyright ESA 2002
Envisat MERIS
© ESA 2002
n Global Earth-System Monitoring 5-9 Sept.2005

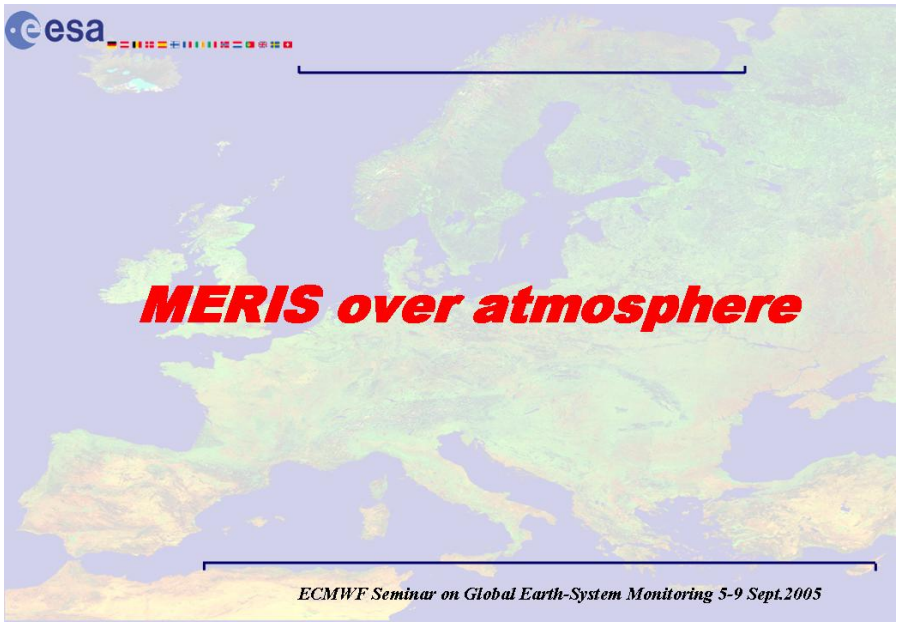

MERIS
Mouths of the Ganges
India - Bangladesh
Nov. 2003
Calcutta


MERIS
Concentrations of phytoplankton chlorophyll
© 2003 - ESA ENVISAT/MERIS
(October 7, 2003, 10:57)
processed by ACRI


MERIS
Fluorescence Signal
MERIS RR 21/09/2002
Vancouver Island/Canada
Chlorophyll a concentration (mg m⁻³)


esa
BENCAL station localities
MERIS match-up stations
St. Helena Bay
Chlorophyll (mg.m⁻³)
21.35
4.96
1.15
0.2
0.0


Black Sea - 23/06/2002
Chlorophyll Concentration
Concentration of Suspended Matter
CDOM Concentration


esa
MERIS over atmosphere
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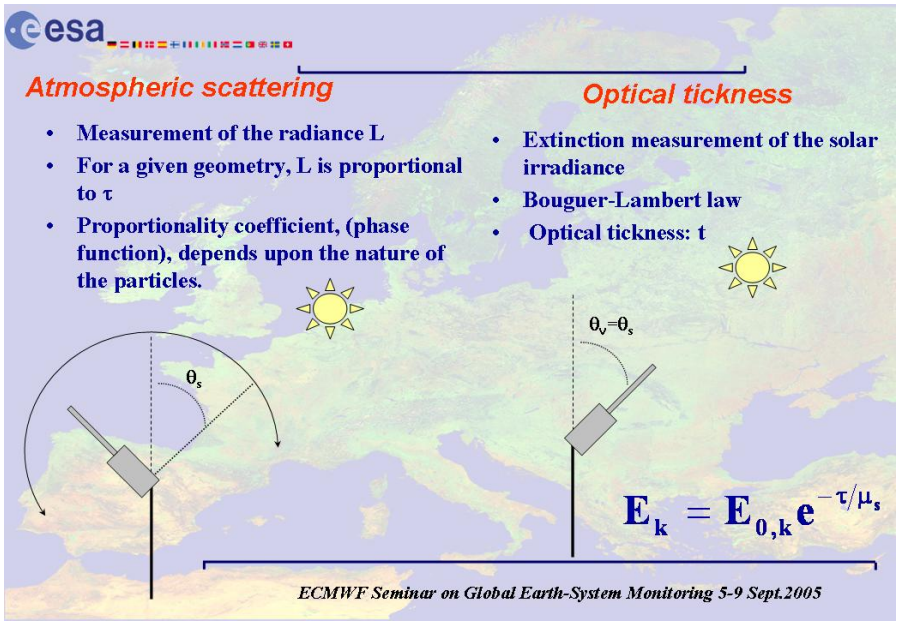
esa
Atmospheric scattering
Measurement of the radiance L
For a given geometry, L is proportional to τ
Proportionality coefficient, (phase function), depends upon the nature of the particles.
Optical tickness
Extinction measurement of the solar irradiance
Bouguer-Lambert law
Optical tickness: t
θs
θv=θs
E_k = E_0,k e^−τ/μs
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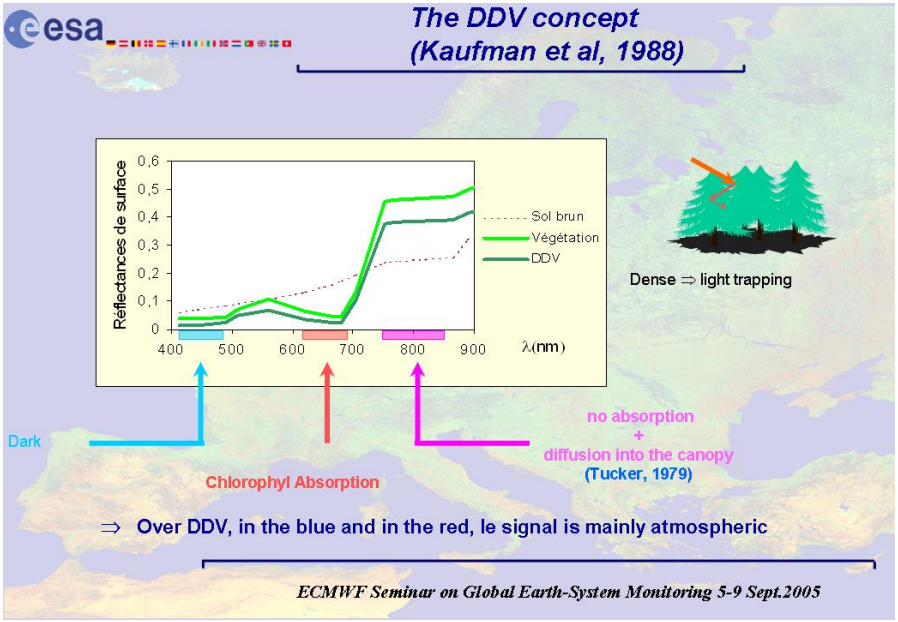
The DDV concept
(Kaufman et al, 1988)
Réflectances de surface
0,6
0,5
0,4
0,3
0,2
0,1
0
400
500
600
700
800
900
λ(nm)
Sol brun
Végétation
DDV
Dense ⇒ light trapping
Dark
Chlorophyl Absorption
no absorption
+
diffusion into the canopy
(Tucker, 1979)
⇒ Over DDV, in the blue and in the red, le signal is mainly atmospheric
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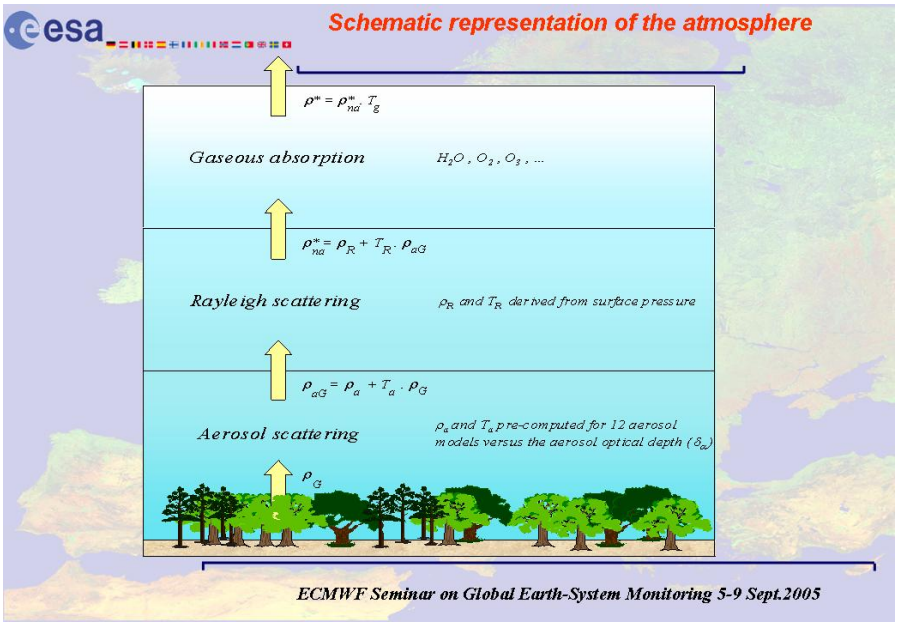
Schematic representation of the atmosphere
$\rho^* = \rho^*_{na} \cdot T_g$
Gaseous absorption
H_2O , O_2 , O_3 , ...
$\rho^*_{na} = \rho_R + T_R \cdot \rho_{aG}$
Rayleigh scattering
ρ_R and T_R derived from surface pressure
$\rho_{aG} = \rho_a + T_a \cdot \rho_G$
Aerosol scattering
ρ_a and T_a pre-computed for 12 aerosol models versus the aerosol optical depth (δ_a)
ρ_G
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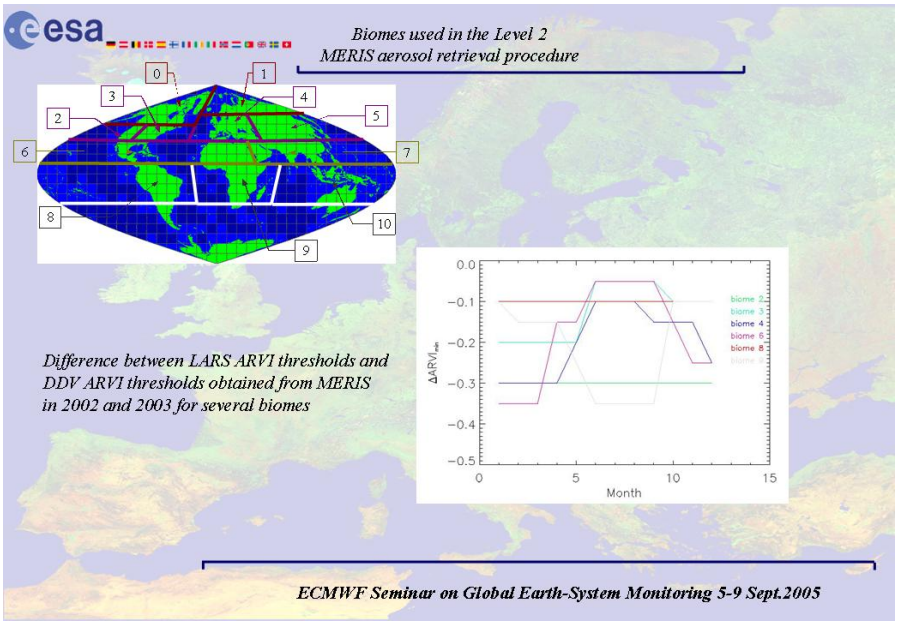
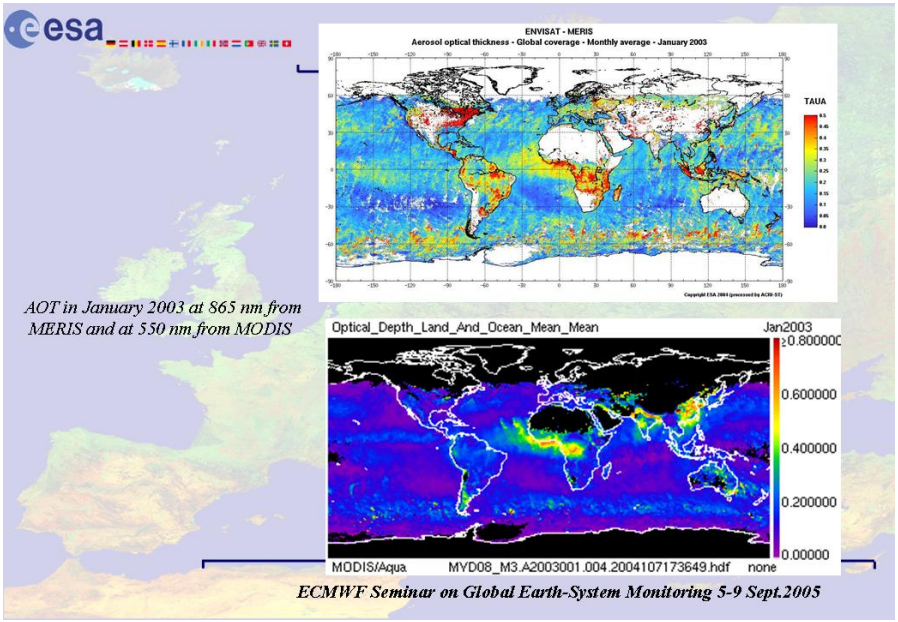
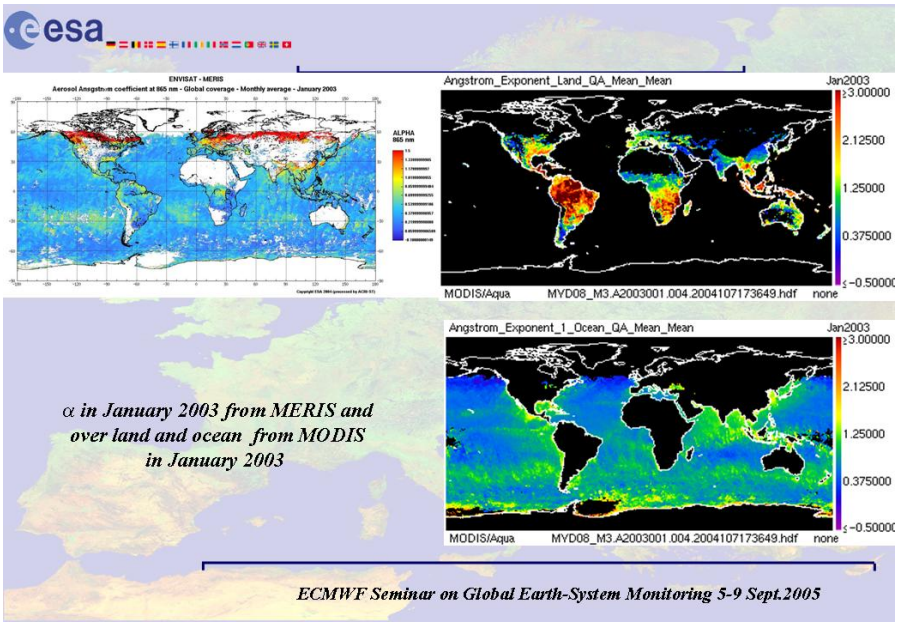
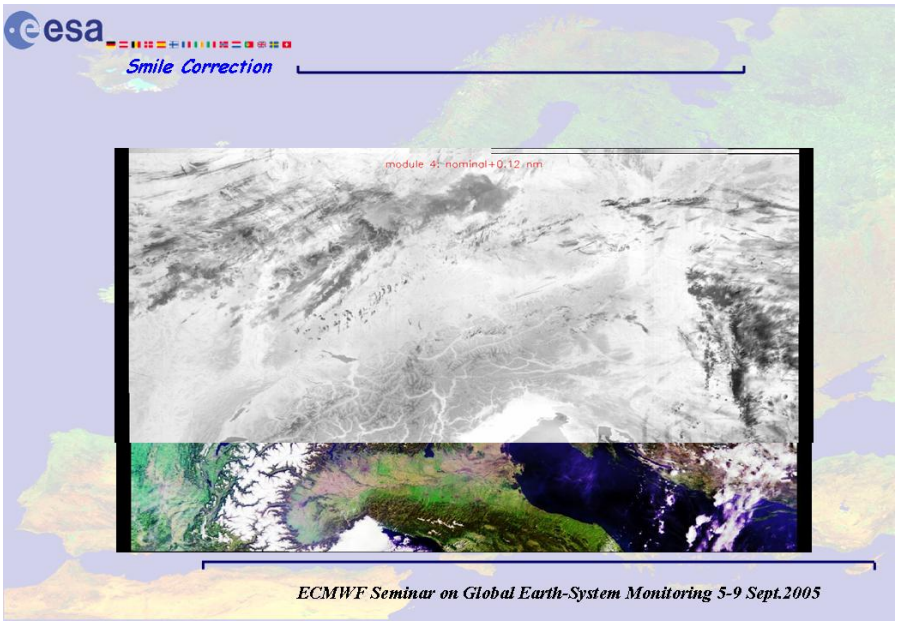

Biomes used in the Level 2
MERIS aerosol retrieval procedure
0
1
2
3
4
5
6
7
8
9
10
Difference between LARS ARVI thresholds and
DDV ARVI thresholds obtained from MERIS
in 2002 and 2003 for several biomes
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
0
5
10
15
Month
ECMWF Seminar on Global Earth-System Monitoring 5-9 Sept.2005


esa
ENVISAT - MERIS
Aerosol optical thickness - Global coverage - Monthly average - January 2003
TAUA
AOT in January 2003 at 865 nm from MERIS and at 550 nm from MODIS
Optical_Depth_Land_And_Ocean_Mean_Mean
Jan2003
0.800000
0.600000
0.400000
0.200000
0.00000
MODIS/Aqua
MYD08_M3.A2003001.004.2004107173649.hdf
none
ECMWF Seminar on Global Earth-System Monitoring 5-9 Sept.2005


esa
ENVISAT - MERIS
Aerosol Angstrom coefficient at 865 nm - Global coverage - Monthly average - January 2003
ALPHA
865 nm
Angstrom_Exponent_Land_QA_Mean_Mean
Jan2003
3.00000
2.12500
1.25000
0.375000
-0.50000
MODIS/Aqua
MYD08_M3.A2003001.004.2004107173649.hdf
none
α in January 2003 from MERIS and over land and ocean from MODIS in January 2003
Angstrom_Exponent_1_Ocean_QA_Mean_Mean
Jan2003
3.00000
2.12500
1.25000
0.375000
-0.50000
MODIS/Aqua
MYD08_M3.A2003001.004.2004107173649.hdf
none
ECMWF Seminar on Global Earth-System Monitoring 5-9 Sept.2005


esa
Smile Correction
module 4: nominal+0.12 nm
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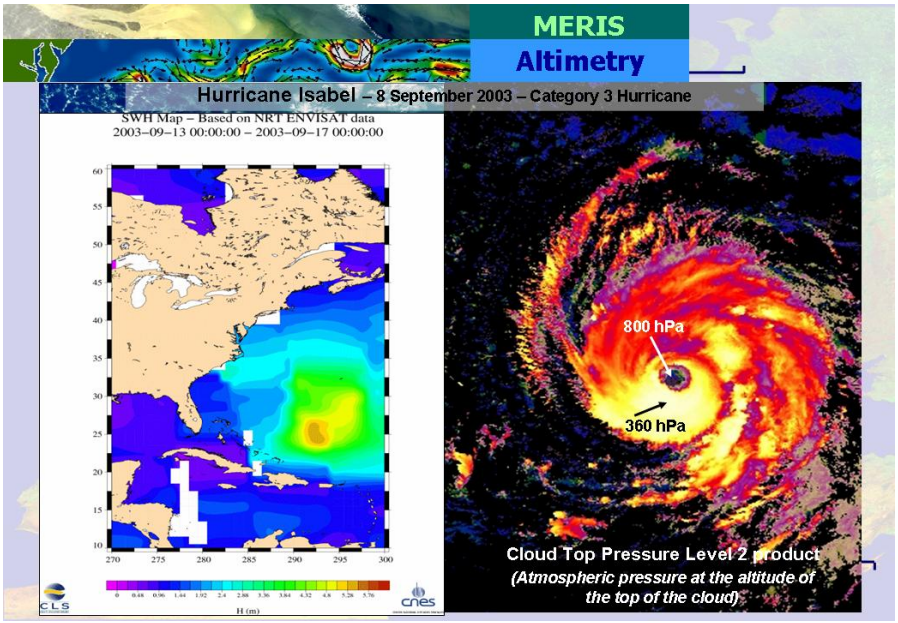
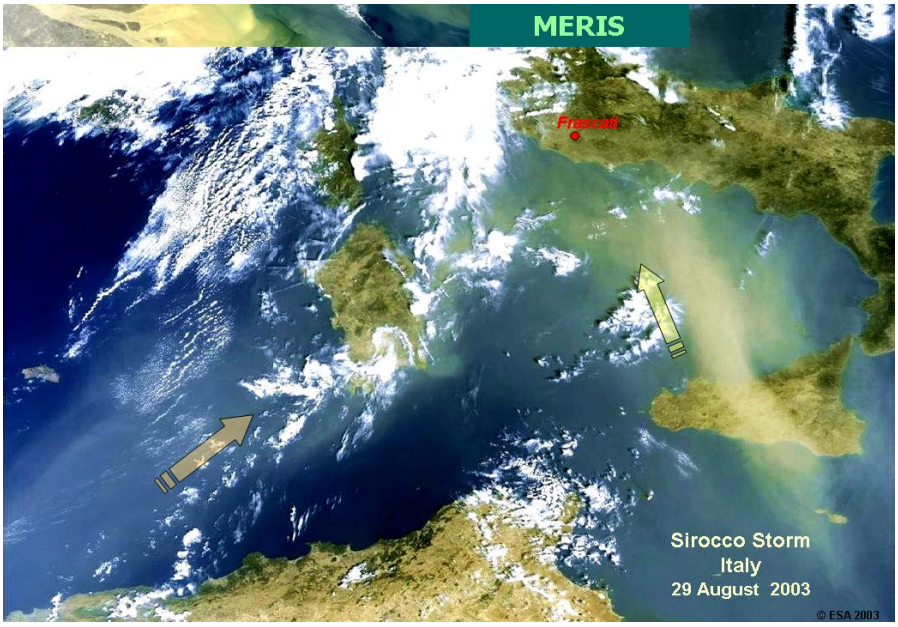
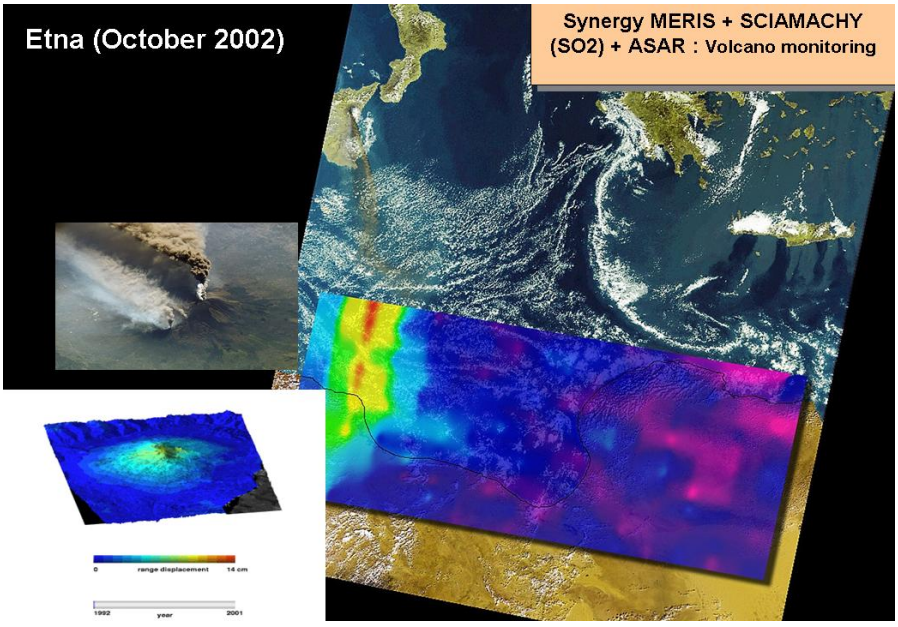
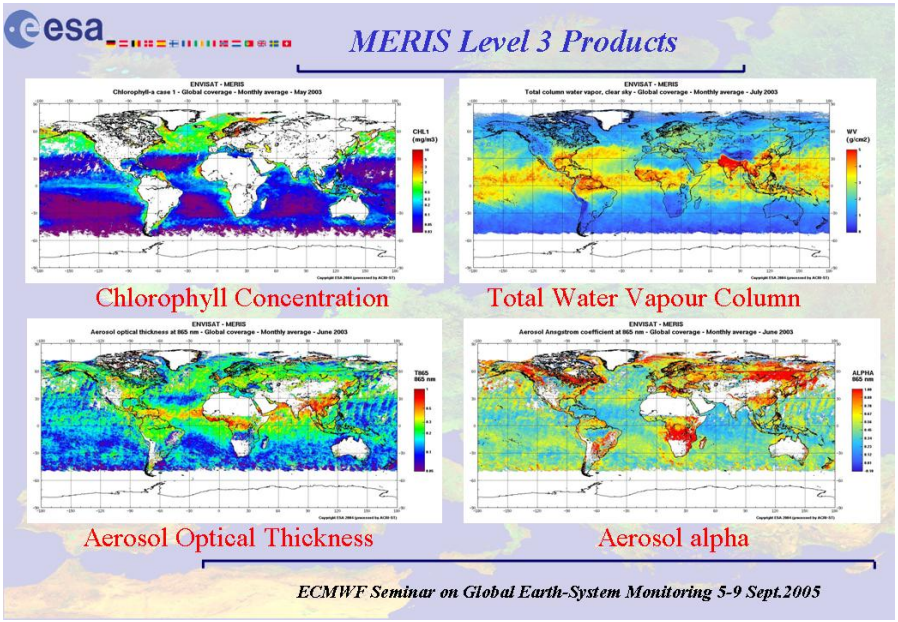

MERIS
Altimetry
Hurricane Isabel – 8 September 2003 – Category 3 Hurricane
SWH Map – Based on NRT ENVISAT data
2003-09-13 00:00:00 – 2003-09-17 00:00:00
800 hPa
360 hPa
Cloud Top Pressure Level 2 product
(Atmospheric pressure at the altitude of the top of the cloud)


MERIS
Frascati
Sirocco Storm
Italy
29 August 2003
© ESA 2003


Etna (October 2002)
Synergy MERIS + SCIAMACHY
(SO2) + ASAR : Volcano monitoring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MERIS Level 3 Products
Chlorophyll Concentration
Total Water Vapour Column
Aerosol Optical Thickness
Aerosol alpha
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Envisat User Tools
Envisat User Tools V2 Delivered in Source code for (A)SAR, MERIS, (A)ATSR, Atmospheric Instruments data
•Adapters for importing Envisat/ERS products into COTS
• Capabilities for viewing, analysing, converting products
•Scientific modules for generating new products
•Portable tools accessible from standard platforms
•Fully documented with clear interface specifications
Free download
Image View
Panner
Magnifier
Main tool bar
Product browser
Contrast stretch window
Meta data view
ENVISAT MERIS/(A)ATSR TOOLBOX
ENVISAT
beam
the basic Envisat
TOOLBOX
for (A)ATSR and MERIS
esa