Potential of improved observation missions: METimage

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EUMETSAT
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Overview

To discuss the benefits of multichannel visible and infrared radiometry in a range of applications relevant to EUMETSAT Polar System Second Generation (EPS-SG) missions

- Experience with MODIS
- Compare with VIIRS

Metop-SG: Visible Infrared Imager

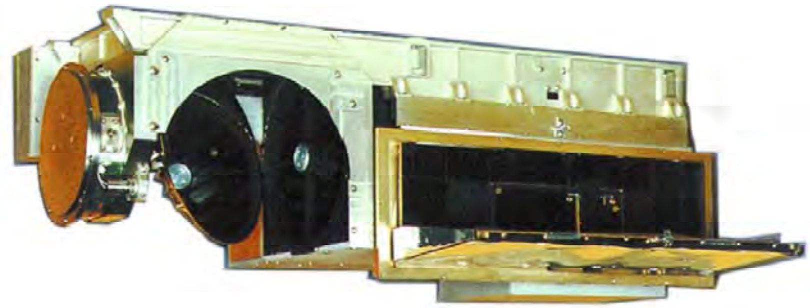
METimage mission requirements:

- Good coverage (i.e. wide swath to give daily global sampling)
- Good spatial resolution (< 1 km^2 at nadir)
- Good radiometric accuracy

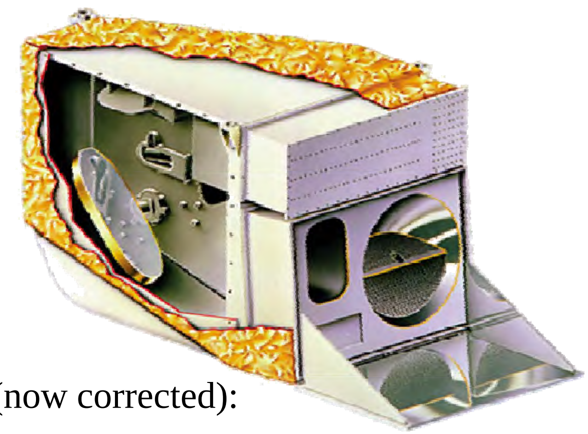
- Meteorological Mission:
  - Combination of visible and infrared channels for e.g. clouds, surface temperature, ice & snow cover, surface vegetation, temperature and humidity profiles, winds….
- Ocean Mission:
  - Infrared channels for sea-surface temperature, and visible for cloud-screening
  - (Ocean colour from OLCI on Sentinel-3)
- Climate Mission:
  - All of the above, plus high accuracy radiometry; reprocessing capacity.

All Missions require accurate assessment of the retrieval uncertainties by comparison with independent data sets; uncertainties are needed for assimilation into NWP models, ocean forecasting models, and for climate monitoring and research.

METimage heritage sensors



- AVHRR (operational):
  - multi-decadal time series
  - 5 or 6 spectral bands
  - no VIS calibration
  - adequate IR calibration
  - 10-bit digitization
  - simple instrument to understand – relatively few instrumental artifacts
- MODIS (non-operational):
  - decadal time series
  - 36 spectral bands
  - onboard VIS calibration
  - very good IR calibration
  - 12-bit digitization
  - Complex instrument to understand – significant instrumental artifacts (now corrected):
    - multiple sensors per band
    - two-sided "paddle-wheel" scan mirror
    - variable angle on the mirror across the scan
    - optical cross-talk (Terra MODIS)



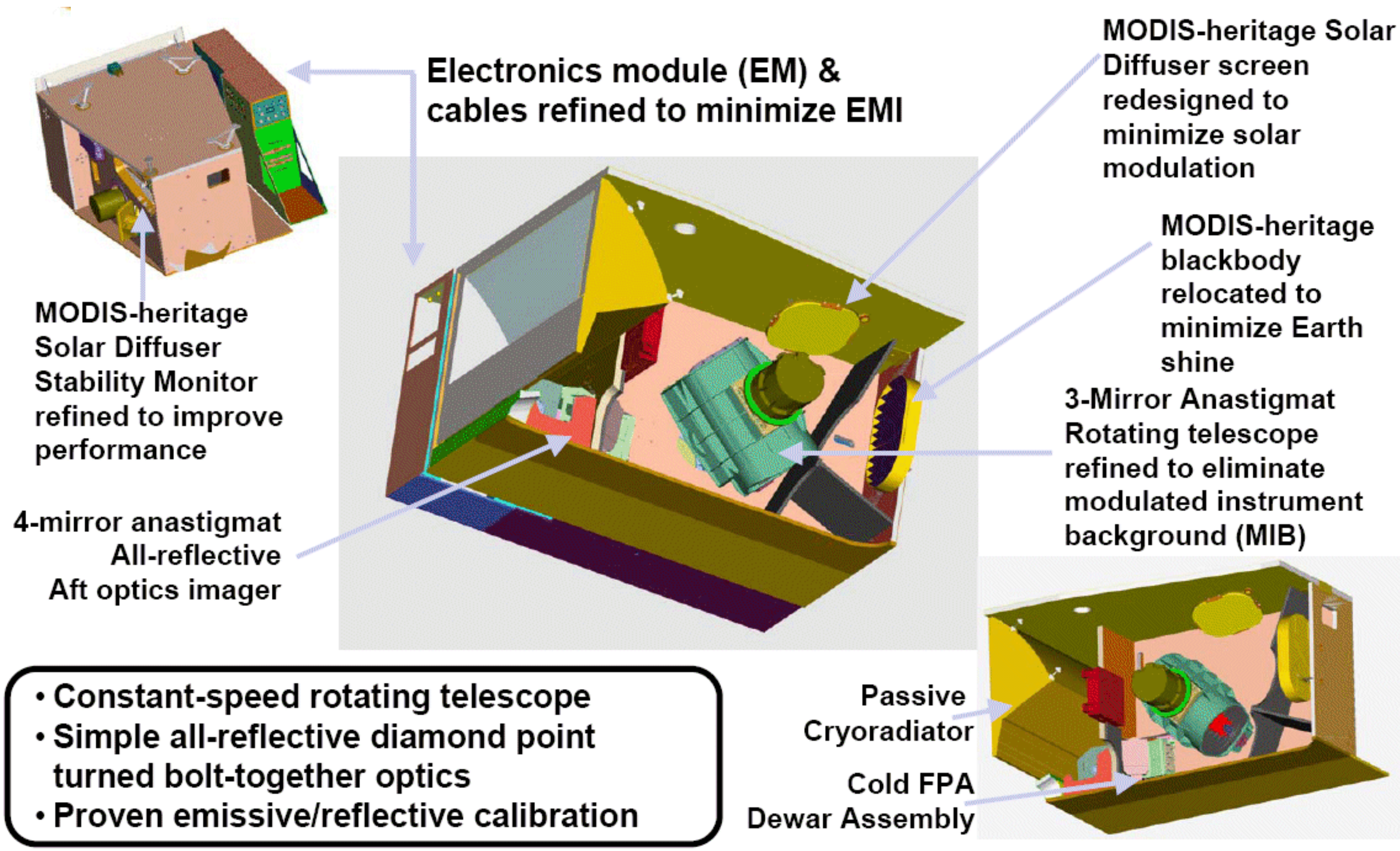
Companion sensor - VIIRS

Photo courtesy Ball Aerospace.

- VIIRS on NPP/JPSS (operational)
- VIIRS:
  - Multi-spectral scanning radiometer (22 bands between 0.4µm and 12 µm)
  - Nadir resolution ~0.75km; pixel aggregation to try to compensate for pixel growth away from nadir.
  - 12 bit digitization
  - Swath width: 3000 km
- Two "Key Performance Parameters" based on the Integrated Operational Requirements Document (IORD) II
  - **SST and Imagery**

NPP launch scheduled for October 25…..

VIIRS Components



- Constant-speed rotating telescope
- Simple all-reflective diamond point turned bolt-together optics
- Proven emissive/reflective calibration

VIIRS spectral bands

		Band No.	Wave-length (μm)	Horiz Sample Interval (km Downtrack x Crosstrack)		Driving EDRs	Radi-ance Range	Ltyp or Ttyp
				Nadir	End of Scan			
VIS/NIR FPA	Silicon PIN Diodes	M1	0.412	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	44.9 155
		M2	0.445	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	40 146
		M3	0.488	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	32 123
		M4	0.555	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	21 90
		I1	0.640	0.371 x 0.387	0.80 x 0.789	Imagery	Single	22
		M5	0.672	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	10 68
		M6	0.746	0.742 x 0.776	1.60 x 1.58	Atmospheric Corr'n	Single	9.6
		I2	0.865	0.371 x 0.387	0.80 x 0.789	NDVI	Single	25
		M7	0.865	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	6.4 33.4
CCD		DNB	0.7	0.742 x 0.742	0.742 x 0.742	Imagery	Var.	6.70E-05
S/MWIR	PV HgCdTe (HCT)	M8	1.24	0.742 x 0.776	1.60 x 1.58	Cloud Particle Size	Single	5.4
		M9	1.378	0.742 x 0.776	1.60 x 1.58	Cirrus/Cloud Cover	Single	6
		I3	1.61	0.371 x 0.387	0.80 x 0.789	Binary Snow Map	Single	7.3
		M10	1.61	0.742 x 0.776	1.60 x 1.58	Snow Fraction	Single	7.3
		M11	2.25	0.742 x 0.776	1.60 x 1.58	Clouds	Single	0.12
		I4	3.74	0.371 x 0.387	0.80 x 0.789	Imagery Clouds	Single	270 K
		M12	3.70	0.742 x 0.776	1.60 x 1.58	SST	Single	270 K
		M13	4.05	0.742 x 0.259	1.60 x 1.58	SST Fires	Low High	300 K 380 K
LWIR	PV HCT	M14	8.55	0.742 x 0.776	1.60 x 1.58	Cloud Top Properties	Single	270 K
		M15	10.763	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K
		I5	11.450	0.371 x 0.387	0.80 x 0.789	Cloud Imagery	Single	210 K
		M16	12.013	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K

VIIRS spectral bands

		Band No.	Wave-length (µm)	Horiz Sample Interval (km Downtrack x Crosstrack)		Driving EDRs	Radi-ance Range	Ltyp or Ttyp
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		M3	0.488	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	32
S	PV Hg	I4	3.74	0.371 x 0.387	0.80 x 0.789	Imagery Clouds	Single	270 K
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Spectral Bands:

- Visible/Near IR: 9 plus Day/Night Band
- Mid-Wave IR: 8
- Long-Wave IR: 4

Some bands have dual gain

VIIRS 22 EDRs

* Key Performance Parameters:

Imagery and
Sea-surface temperature

Name of Product	Group
Imagery *	Imagery
Precipitable Water	Atmosphere
Suspended Matter	Atmosphere
Aerosol Optical Thickness	Aerosol
Aerosol Particle Size	Aerosol
Cloud Base Height	Cloud
Cloud Cover/Layers	Cloud
Cloud Effective Particle Size	Cloud
Cloud Optical Thickness/Transmittance	Cloud
Cloud Top Height	Cloud
Cloud Top Pressure	Cloud
Cloud Top Temperature	Cloud
Active Fires	Land
Albedo (Surface)	Land
Land Surface Temperature	Land
Surface Type	Land
Vegetation Index	Land
Sea Surface Temperature *	Ocean
Ocean Color and Chlorophyll	Ocean
Sea Ice Characterization	Snow and Ice
Ice Surface Temperature	Snow and Ice
Snow Cover and Depth	Snow and Ice

VIIRS bands - EDRs

	Visible										Near Infrared					Infrared						
Band name	DNB	M1	M2	M3	M4	I1	M5	M6	M7	I2	M8	M9	M10	I3	M11	M12	I4	M13	M14	M15	I5	M16
Band position	700	412	445	488	555	645	672	751	865	865	1.2	1.4	1.6	1.6	2.3	3.7	3.7	4.1	8.6	10.8	11.5	12.0
Band width	400	20	18	20	20	50	20	15	39	39	0.02	0.015	0.06	0.06	0.05	0.18	0.38	0.16	0.30	1.00	1.90	0.95
Imagery																						
Sea Surface Temp.																						
Soil Moisture																						
Cloud Cover/Layers																						
Cloud Partical Size																						
Cloud Thickness																						
Cloud Top Height																						
Cloud Top Pressure																						
Cloud Top Temp.																						
Land Surface Temp.																						
Fire																						
Vegetation Index																						
Snow Cover (Binary)																						
Snow Cover (Fraction)																						
Vegetation/Type																						
Albedo																						
Fresh Water Ice																						
Ice Surface Temp.																						
Littoral Transport																						
Net Heat Flux																						
Ocean Color/Chloro.																						
Sea Ice age/motion																						
Mass (turbidity)																						
Aer Opt Thick (Ocean																						
Aer Opt Thick (Land)																						
Aer Part Size (Ocean)																						
Aer Part Size (Land)																						
Suspended Matter																						
Total Prec. Water																						
Cloud Mask																						

VIIRS and METimage channels

- Arguments **for** same channels:
  - Continuity with prior sensors
    - reduce disruption to assimilation and analysis schemes
    - continuity in CDRs
  - Reduce effects of cloud cover
    - clouds move between overpasses of the JPSS satellites allowing consistent compilation of multi-satellite fields
- Arguments **against** the same channels
  - Inhibits taking advantage of technological developments
  - Stifle innovation and development
  - Perpetuate sub-optimal selections

MODIS spectral bands

Primary Use	Band	Bandwidth	Spectral Radiance	Required SNR
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
Near Infrared	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
Visible	12	546 - 556	21.0	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10.0	167
	18	931 - 941	3.6	57
	19	915 - 965	15.0	250

Primary Use	Band	Bandwidth	Spectral Radiance	Required NE[delta]T(K)
Surface/Cloud Temperature	20	3.660 - 3.840	0.45(300K)	0.05
	21	3.929 - 3.989	2.38(335K)	2.00
Infrared	22	3.929 - 3.989	0.67(300K)	0.07
	23	4.020 - 4.080	0.79(300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17(250K)	0.25
	25	4.482 - 4.549	0.59(275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6.00	150(SNR)
	27	6.535 - 6.895	1.16(240K)	0.25
	28	7.175 - 7.475	2.18(250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Ozone	30	9.580 - 9.880	3.69(250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55(300K)	0.05
	32	11.770 - 12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52(260K)	0.25
	34	13.485 - 13.785	3.76(250K)	0.25
	35	13.785 - 14.085	3.11(240K)	0.25
	36	14.085 - 14.385	2.08(220K)	0.35

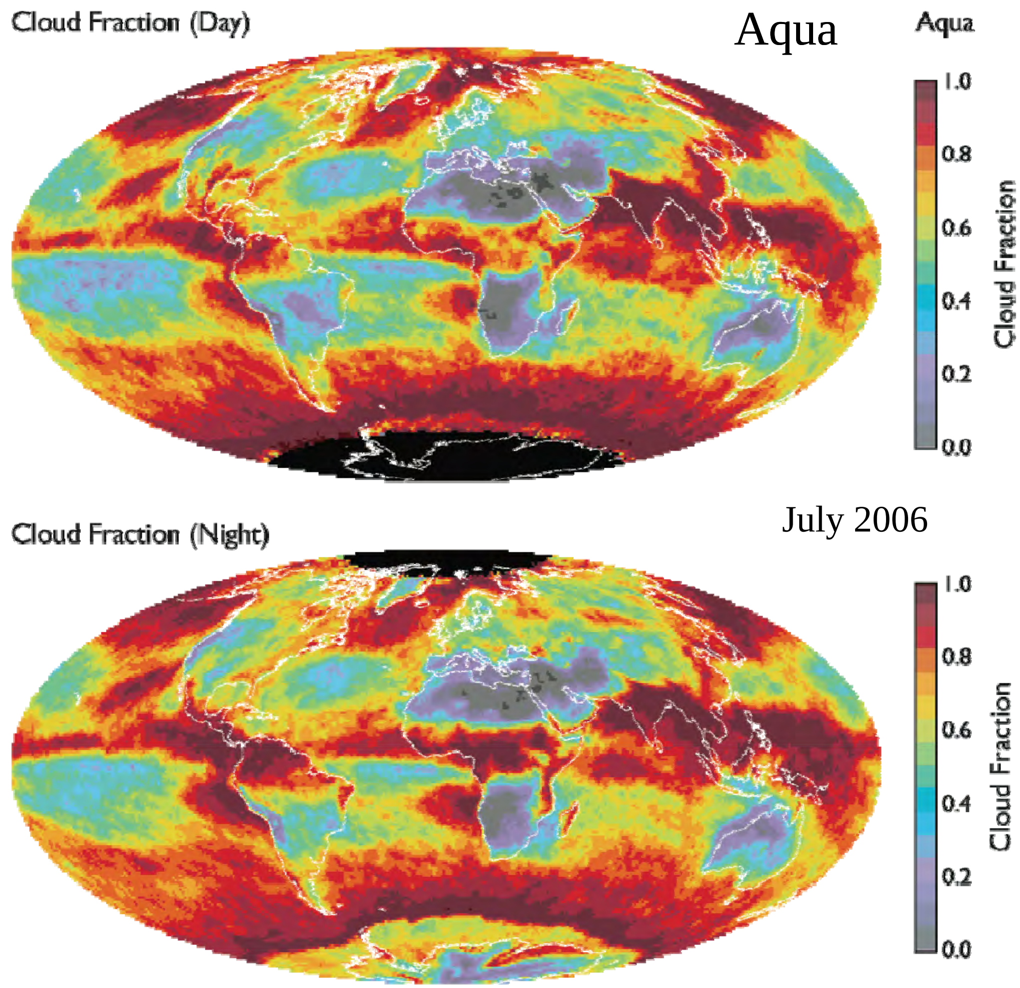
MODIS Atmosphere Data Products

- Pixel-level (Level-2) products
  - Cloud mask for distinguishing clear sky from clouds
  - Cloud radiative and microphysical properties
    - Cloud top pressure, temperature, and effective emissivity
    - Cloud optical thickness, thermodynamic phase, and effective radius
    - Thin cirrus reflectance in the visible
  - Aerosol optical properties
    - Optical thickness over the land and ocean
    - Size distribution (parameters) over the ocean
  - Atmospheric moisture and temperature gradients
  - Column water vapor amount
- Gridded time-averaged (Level-3) products
  - Cloud mask for distinguishing clear sky from clouds
  - Daily, 8-day, and monthly products
  - 1° × 1° equal angle grid
  - Mean, standard deviation, marginal probability density function, joint probability density functions

Monthly Mean Cloud Fraction

(S. A. Ackerman, R. A. Frey et al. – University of Wisconsin – Madison)

- Cloud fraction similar during day and night
  - High cloud amount
    - Roaring 40s
    - ITCZ
    - North Atlantic
    - Indonesia and western tropical Pacific
  - Low cloud amount
    - Subtropical gyres over the ocean
    - Deserts
    - Antarctica
    - Greenland



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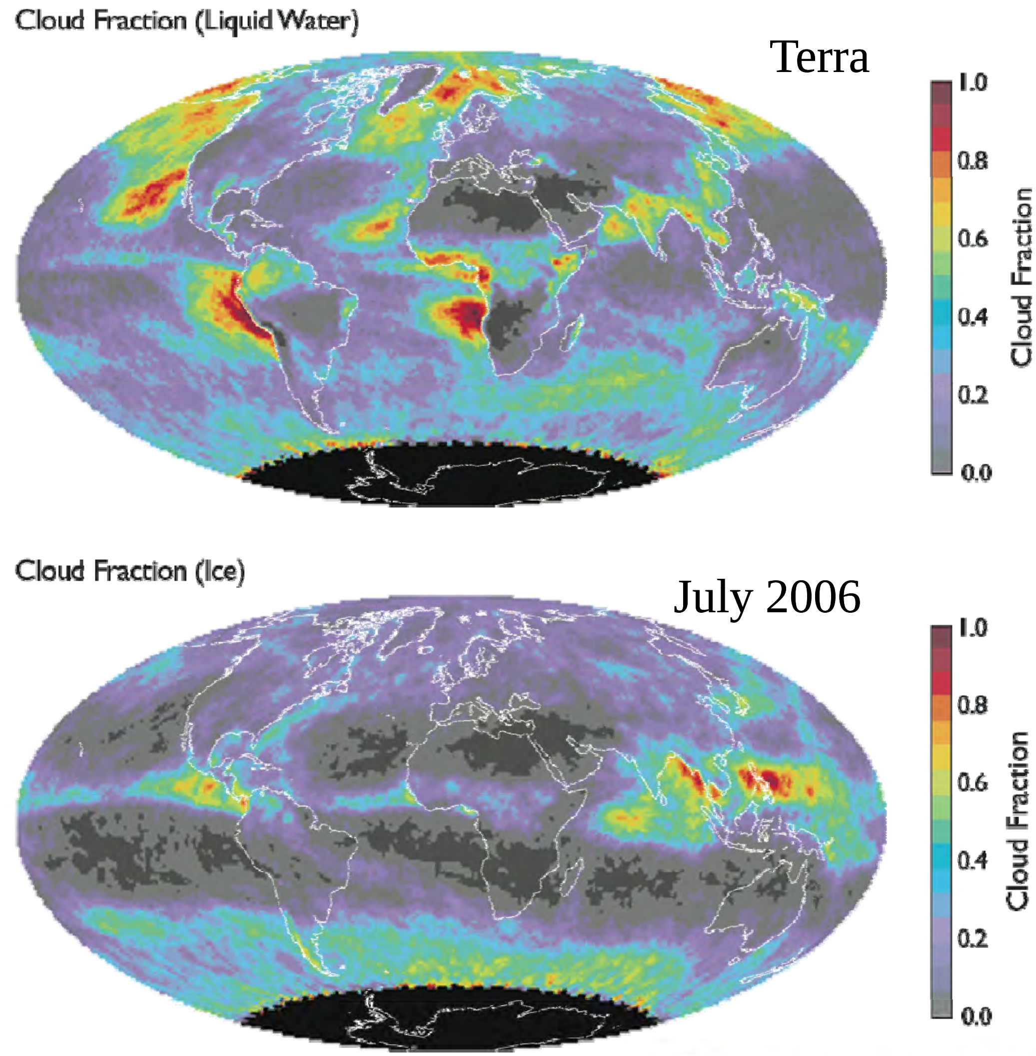
Monthly Mean Cloud Fraction by Phase

(M. D. King, S. Platnick et al. – NASA GSFC)

- Liquid water clouds
  - Marine stratocumulus regions
    - Angola/Namibia
    - Peru/Ecuador
    - California/Mexico
- Ice clouds
  - Tropics
    - Indonesia & western tropical Pacific
    - ITCZ
  - Roaring 40s



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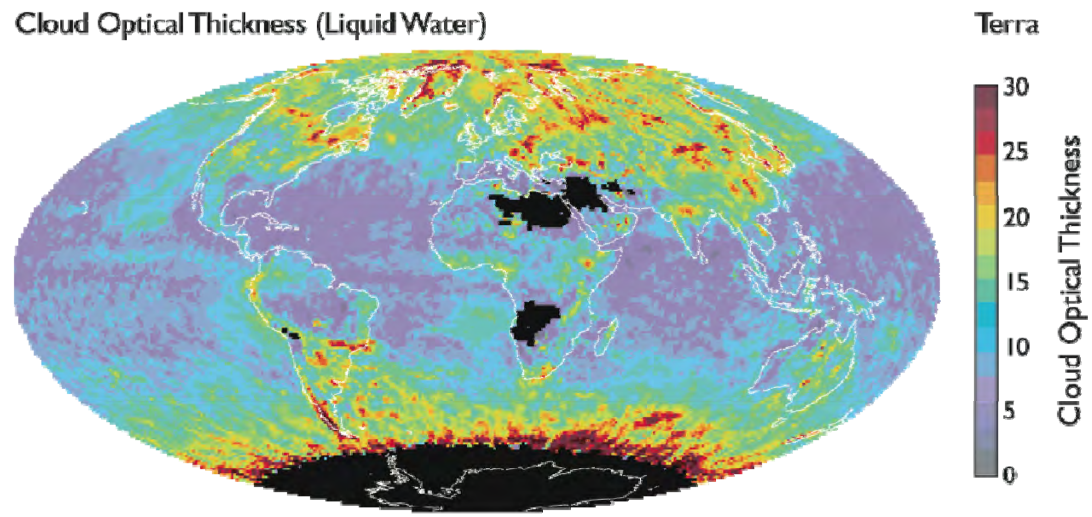
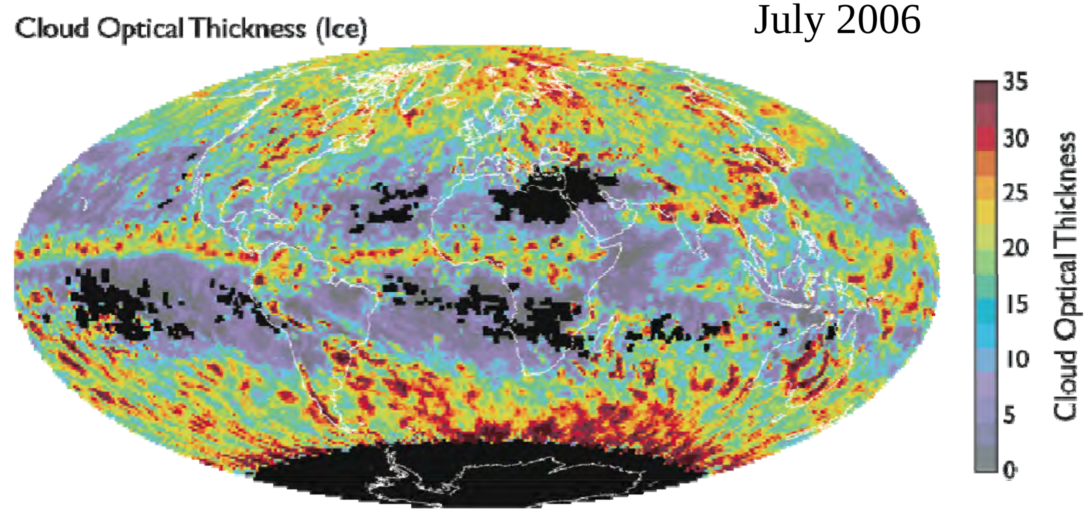
Monthly Mean Cloud Optical Thickness

(M. D. King, S. Platnick et al. – NASA GSFC)

- Liquid water clouds
  - Marine stratocumulus $\tau_c \sim 15$
  - Higher optical thickness over land than ocean
    - Cloud optical thickness near 5 in Indian Ocean
  - High optical thickness around roaring 40s
- Ice clouds
  - Larger in tropics (ITCZ)
  - High where deep convection occurs
    - Congo basin
    - Amazon basin
  - High optical thickness around roaring 40s
  - Higher over land than ocean



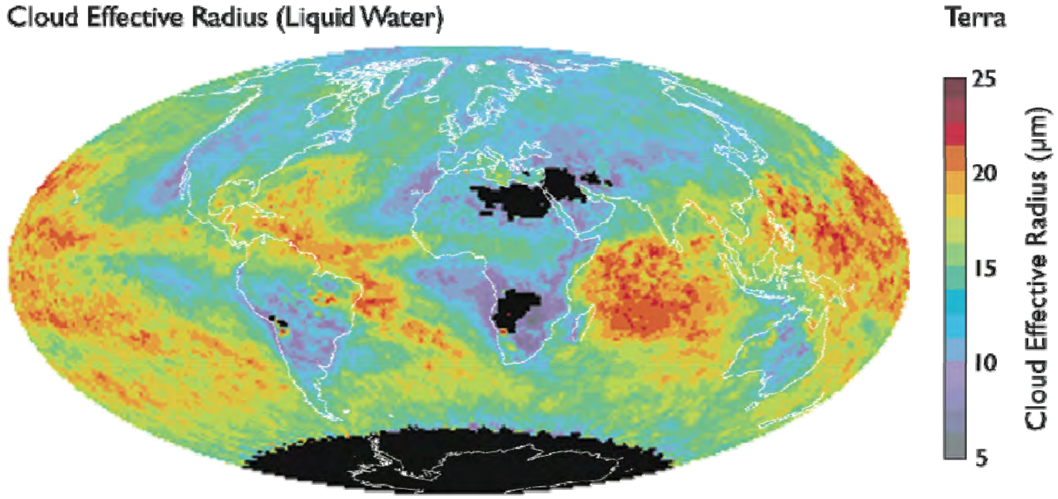
July 2006



Monthly Mean Cloud Effective Radius

(M. D. King, S. Platnick et al. – NASA GSFC)

- Liquid water clouds
  - Larger drops in SH than NH
  - Larger drops over ocean than land
    - Due to cloud condensation nuclei (aerosols)
- Ice clouds
  - Larger in tropics than high latitudes
    - Anvils
  - Small ice crystals at top of deep convection



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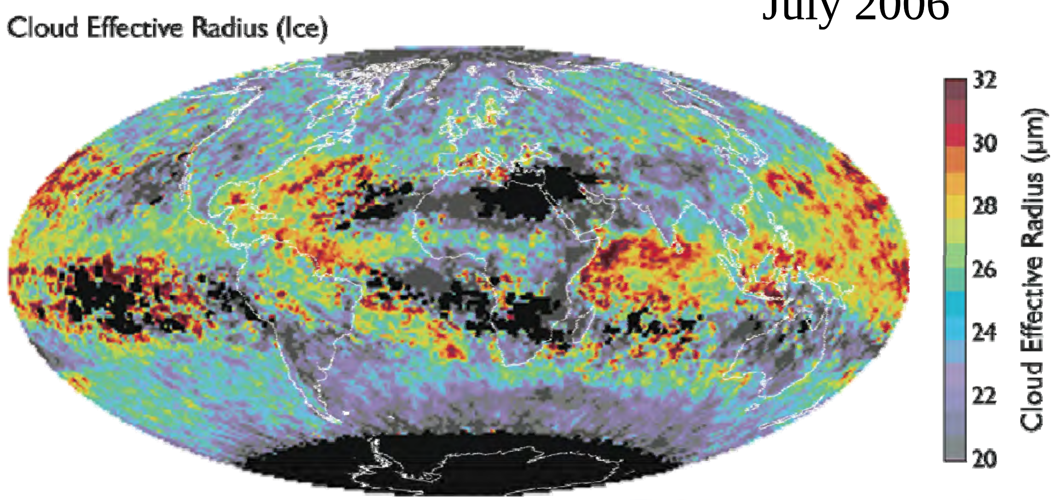
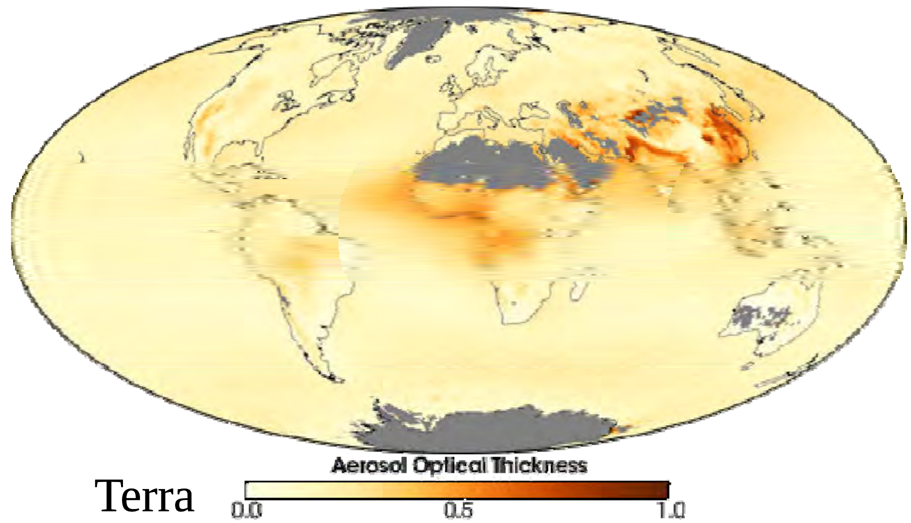
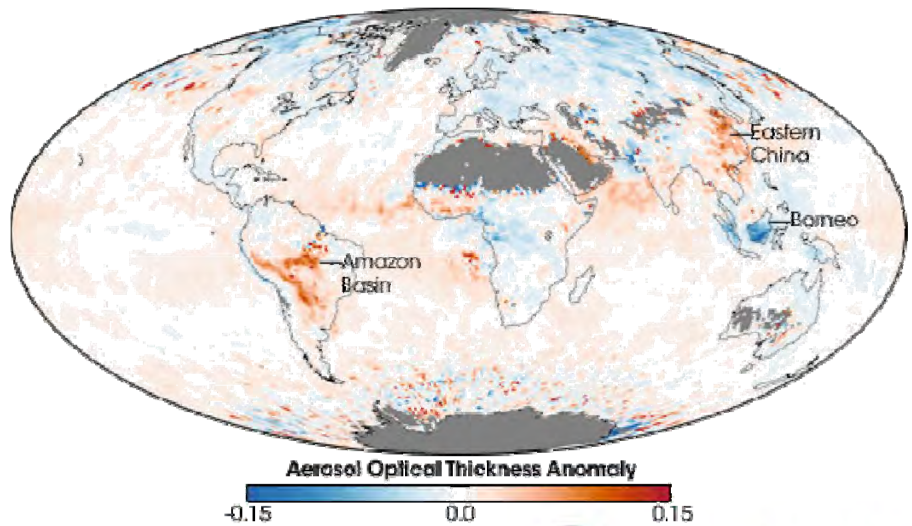


MODIS Aerosol Optical Thickness

(L. A. Remer, Y. J. Kaufman, D. Tanré – GSFC, Univ. Lille)

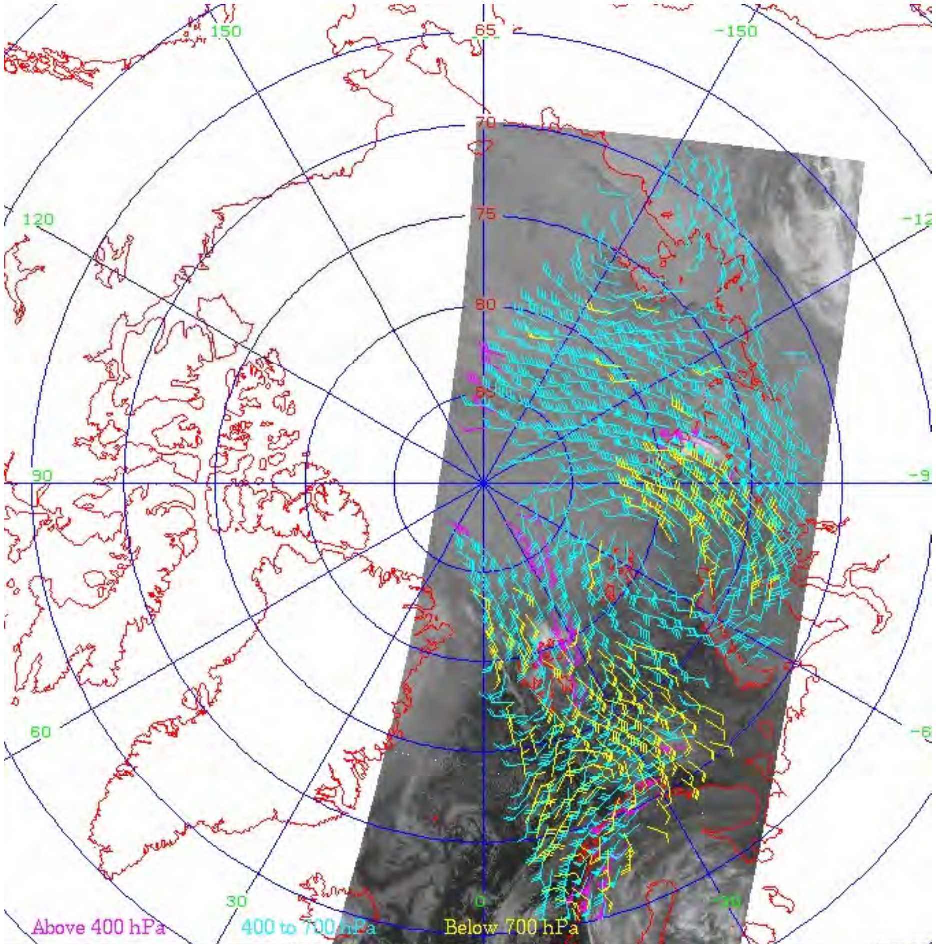
- Climatology (2000-2007)
  - Industrial pollution
    - China, India
  - Smoke from biomass burning
    - Brazil and Bolivia
    - Africa (DRC, Sub-Sahel)
  - Dust
    - Sahara, Iraq, Arabian Sea
- Anomaly (2007)
  - Enhancement
    - Amazon basin
    - Eastern China
  - Reduction
    - Borneo
    - Eurasia, Alaska





MODIS Polar Winds

(J. Key, NOAA/NESDIS)



MODIS – water vapour channel & clouds

- Aqua and Terra
- 1km
- Cloud-track and water vapour winds
- NCEP's GFS is used as the background
- Complete polar coverage

Compared to AVHRR Cloud-track winds:

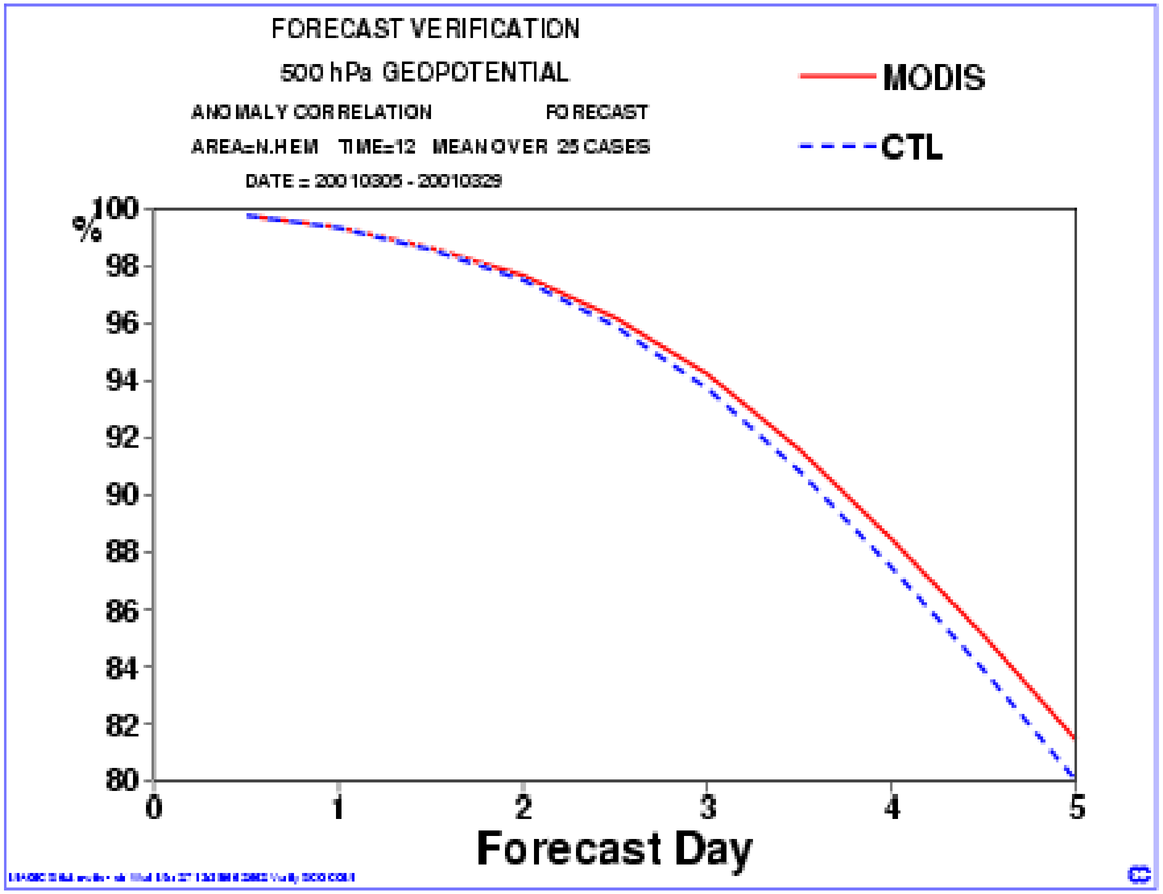
- Six satellites: NOAA-15, -16, -17, -18, -19, and Metop
- 4 km for GAC; 2 km for Metop
- Complete polar coverage; excellent temporal sampling with all satellites. Good preparation for VIIRS.
- Cons:
  - No water vapour clear winds (no clear sky).
  - Lower spatial resolution (GAC) yields fewer vectors.
  - Height assignment uncertainty for thin clouds.

NWP impact studies

Polar winds have a positive impact on weather forecasts not just in the polar regions, but globally.

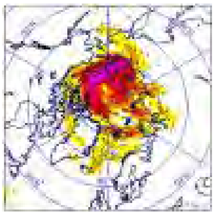
Figure: Anomaly correlations as a function of forecast range for the 500 hPa geopotential over the Northern Hemisphere extratropics (>20 ºN). Including the MODIS winds in the model (red line) extends the 5-day forecast at a given accuracy by 3-6 hrs.

(Figure courtesy of ECMWF)



Forecast scores (anomaly correlations) are the correlation between the forecast geopotential height anomalies, with and without the MODIS winds, and their own analyses.

MODIS Polar Winds in NWP



Current Operational Users:

- European Centre for Medium-Range Weather Forecasts (ECMWF) - since Jan 2003.
- NASA Global Modeling and Assimilation Office (GMAO) - since early 2003.
- Deutscher Wetterdienst (DWD) – since Nov 2003.
- Japan Meteorological Agency (JMA), Arctic only - since May 2004.
- Canadian Meteorological Centre (CMC) – since Sept 2004.
- US Navy, Fleet Numerical Meteorology and Oceanography Center (FNMOC) since Oct 2004. (AVHRR GAC and MetOp since Nov 2007.)
- UK Met Office – since Feb 2005.
- National Centers for Environmental Prediction (NCEP) and the Joint Center for Satellite Data Assimilation - since Nov 2005.
- MeteoFrance - since Jun 2006.
- National Center for Atmospheric Research (NCAR), Antarctic Mesoscale Model (AMPS) – since Oct 2006.
- Australian Bureau of Meteorology – since 2007
- Hydrological and Meteorological Centre of Russia (Hydrometcenter) – since mid-2010.

MODIS Land Products

(S. Running, University of Montana)

Energy Balance Product Suite

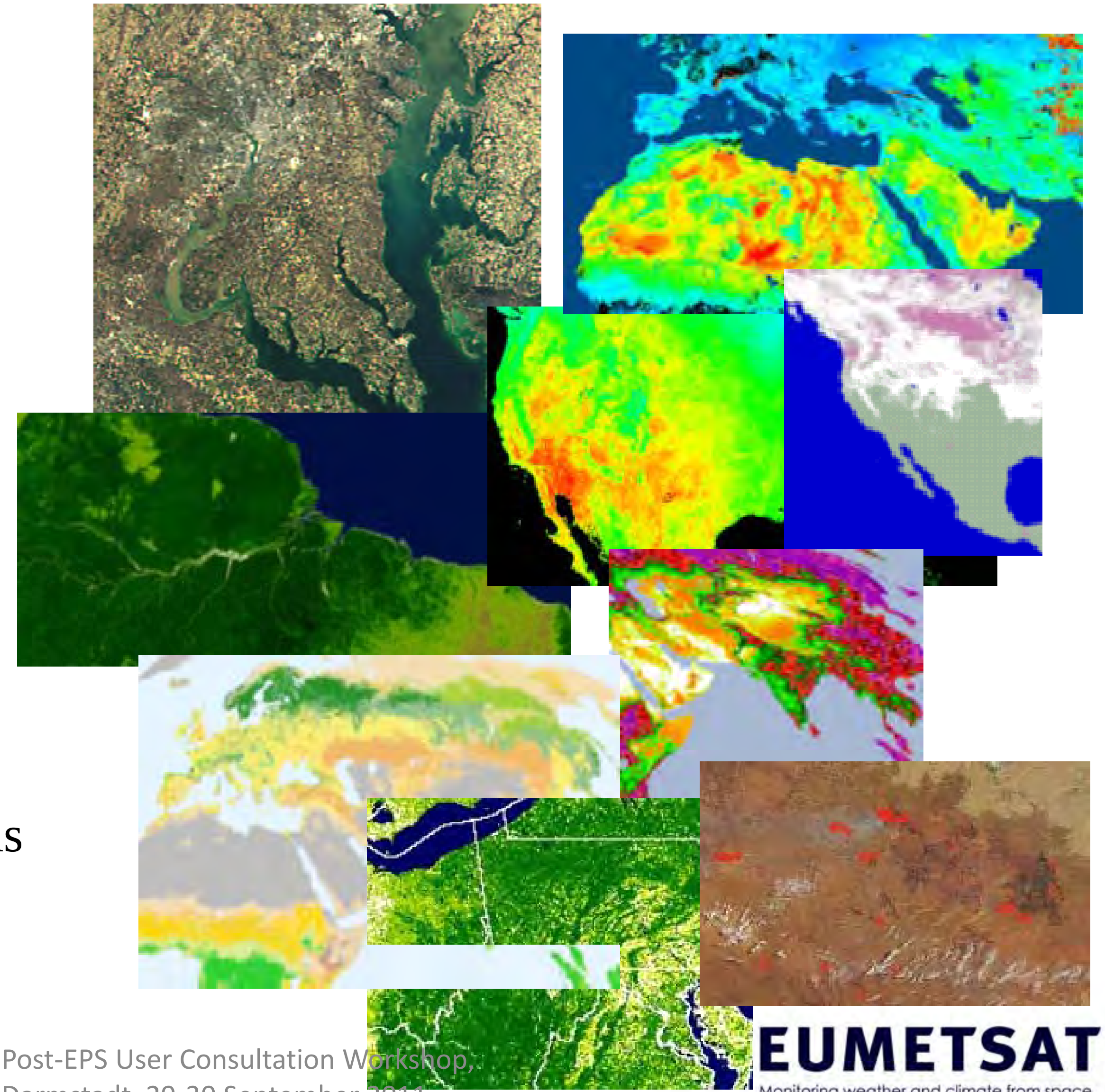
- Surface Reflectance
- Land Surface Temperature, Emissivity
- BRDF & Albedo
- Snow & ice Cover

Vegetation Parameters Suite

- Vegetation Indices
- LAI & FPAR
- GPP & NPP

Land Cover/Land Use Suite

- Land Cover &Vegetation Dynamics
- Vegetation Continuous Fields
- Vegetation Cover Change
- Fire and Burned Area



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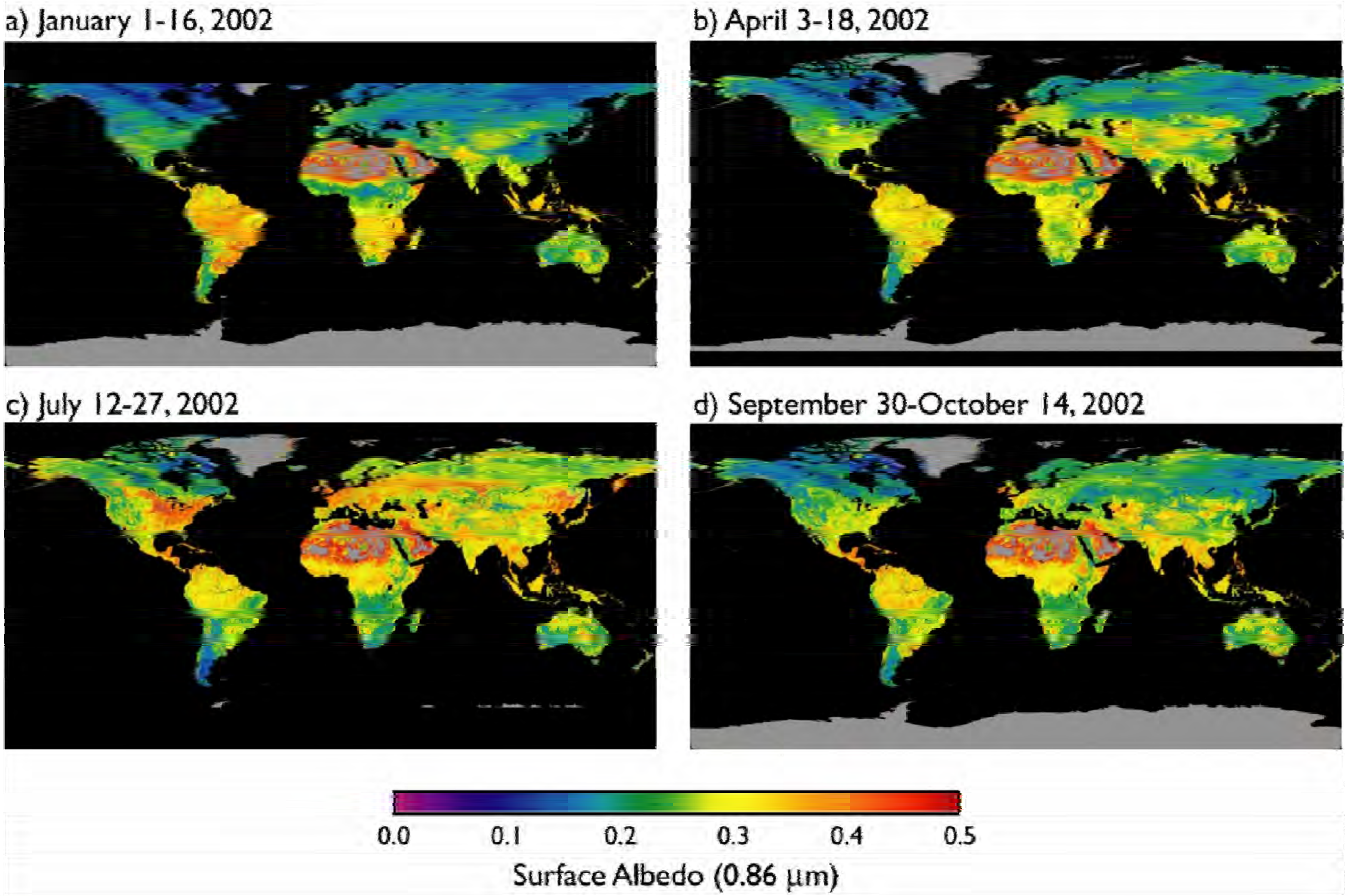
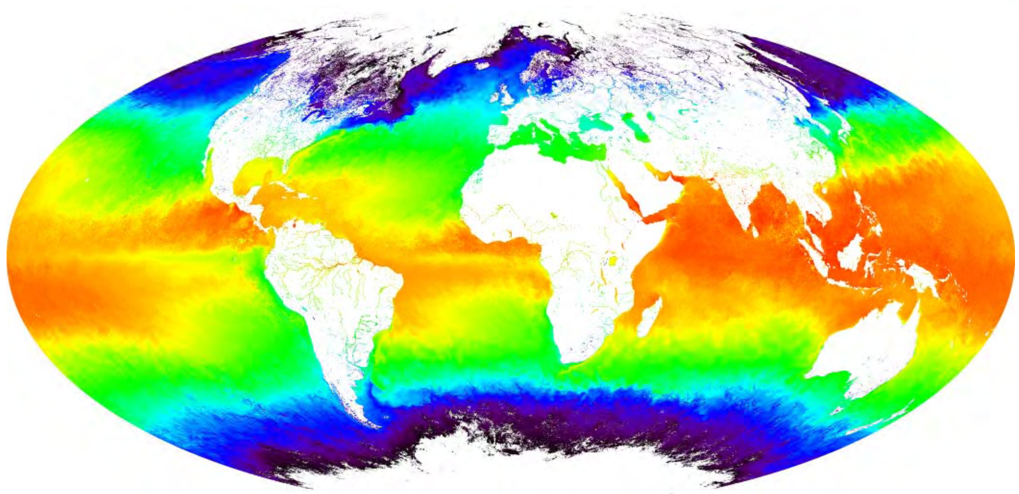
Land surface albedo

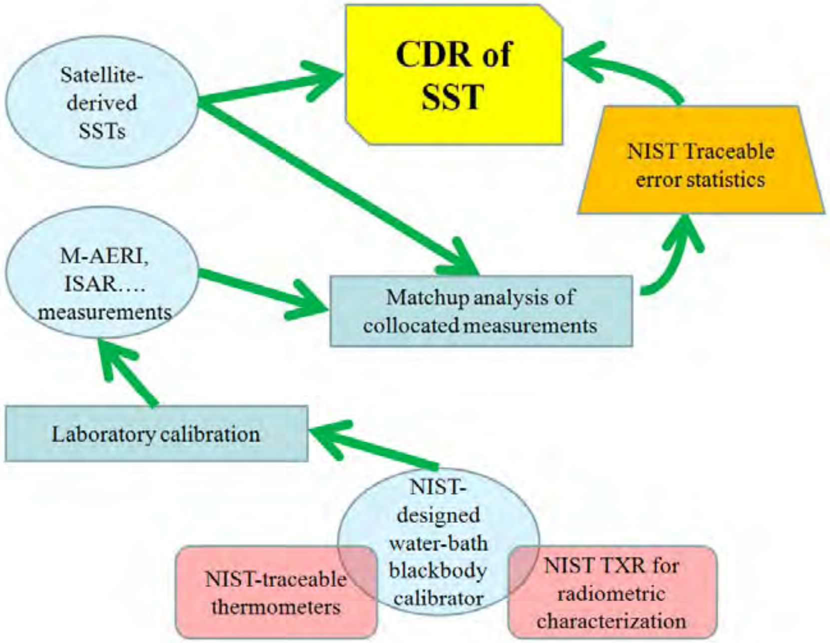
(E. G. Moody, M. D. King, S. Platnick, C. B. Schaaf, F. Gao – GSFC, BU)



MODIS Oceans - SST

- SST is the lower boundary of the atmosphere over most of the globe, and helps control the fluxes of momentum, heat, moisture and important gases between ocean and atmosphere
- SST is an Essential Climate Variable and by validation using SI-traceable radiometers, can form a CDR.





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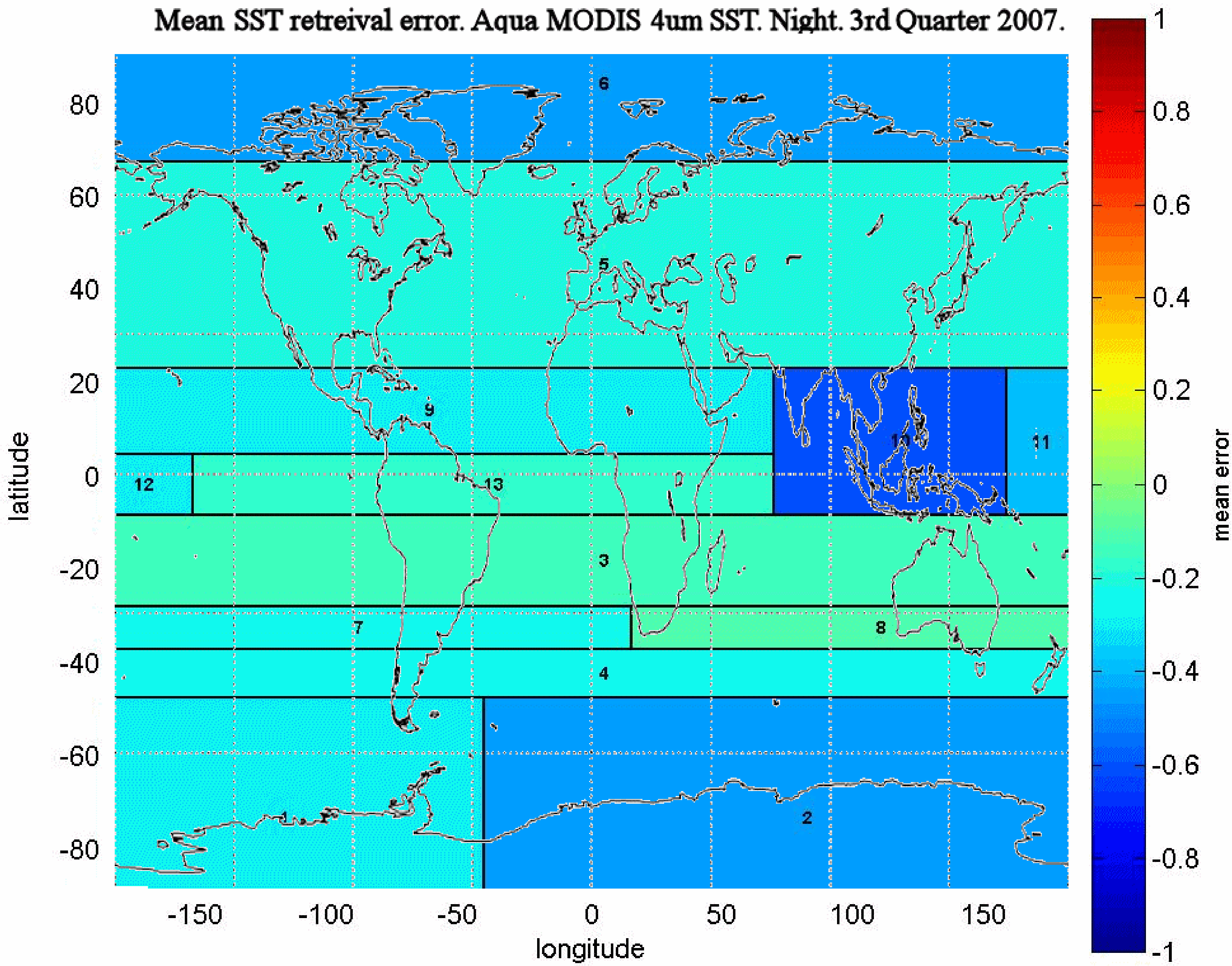
MODIS & VIIRS SSTs algorithms

- Day- and night-time atmospheric correction algorithm uses “split-window” approach: 11 & 12 µm data
- MODIS night-time also uses 3.95 & 4.05 µm data (cannot be used in the day because of solar contamination)
- VIIRS night-time will use 3.70 & 4.05 µm data (ditto)

New approaches to SST atmospheric correction algorithms – Machine Learning

- Machine Learning – based on information content of very large MODIS Match-Up Data Bases:
  - Genetic Algorithms
  - Regression Trees
  - Support Vector Machines
- Produce algorithms similar in form to the NLSST (with an additional term to correct for residual scan mirror effects in MODIS)
- Able to identify regions where particular algorithms and coefficient sets are applicable:
  - Geographic regions tend to be zonal
  - Seasonal progression of regions
  - Night-time 4µm SSTs have fewer regions, and more accurate than 11µm SSTs



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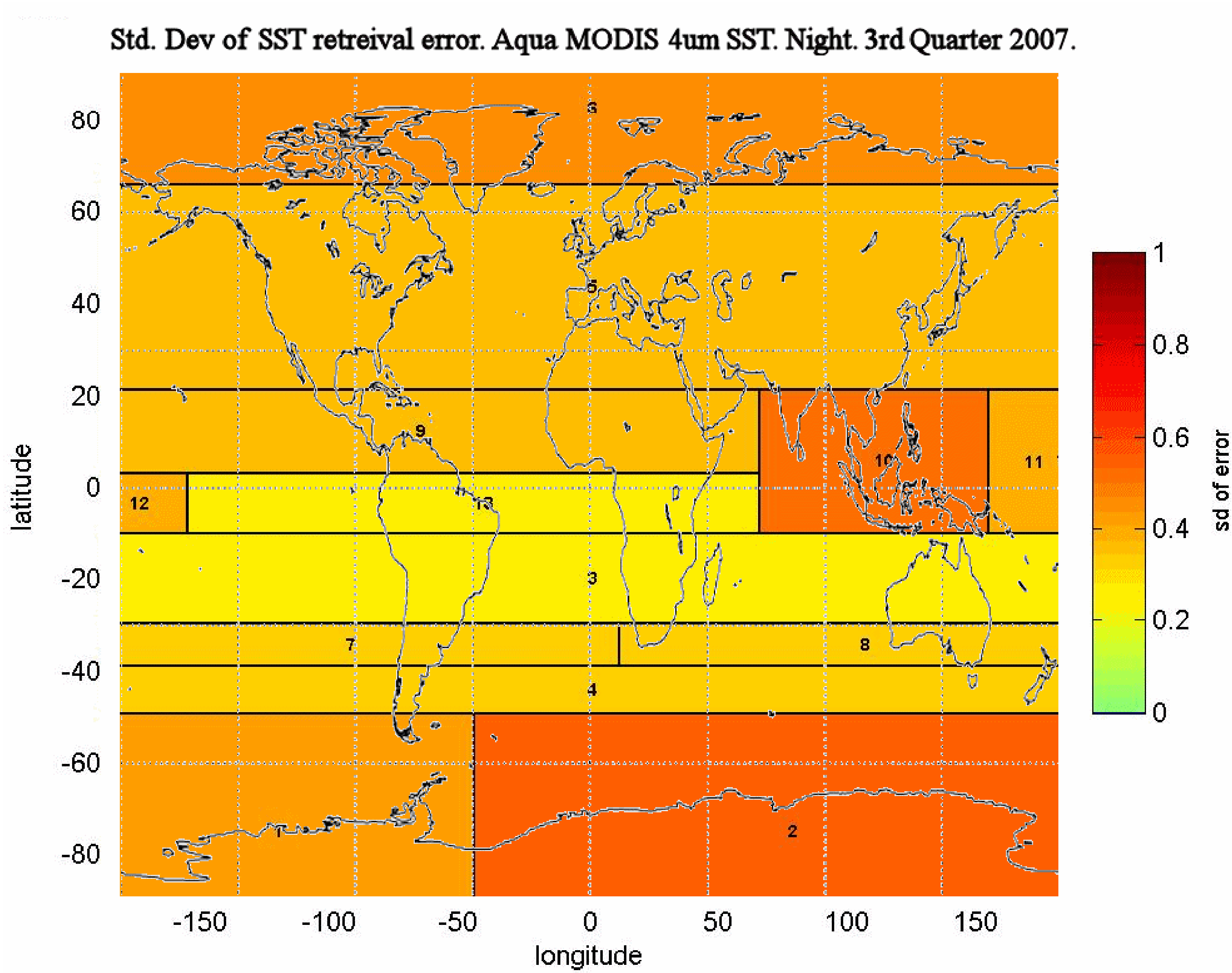

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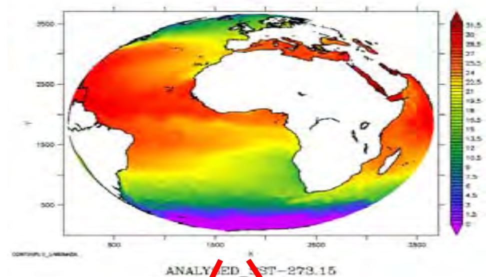
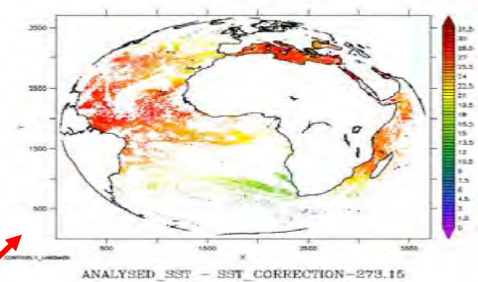
New approaches to atmospheric correction algorithms - The Forward Solution

(P. LeBorgne, OSI-SAF CMS, C. Merchant, U. Edinburgh)

Analysed SST (OSTIA)



Retrieved SST

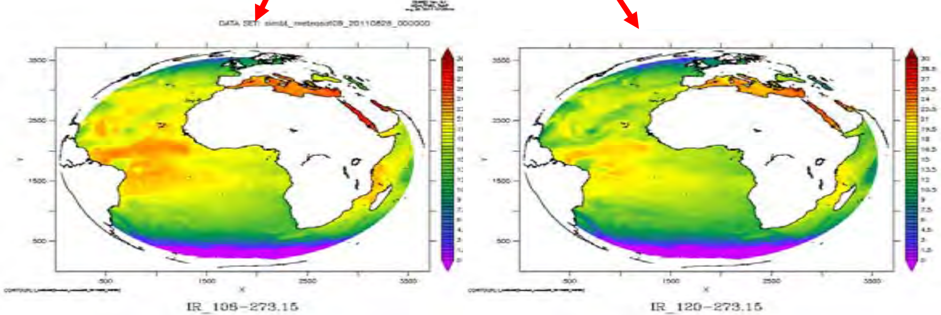


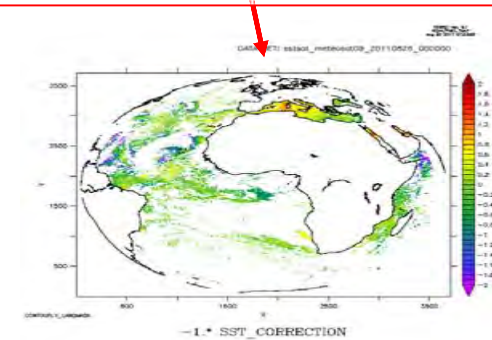
ECMWF profiles + RTTOV

Operational algorithm Applied to simulations

Retrieved – analyzed SST = Predicted algorithm error (used as a correction term)

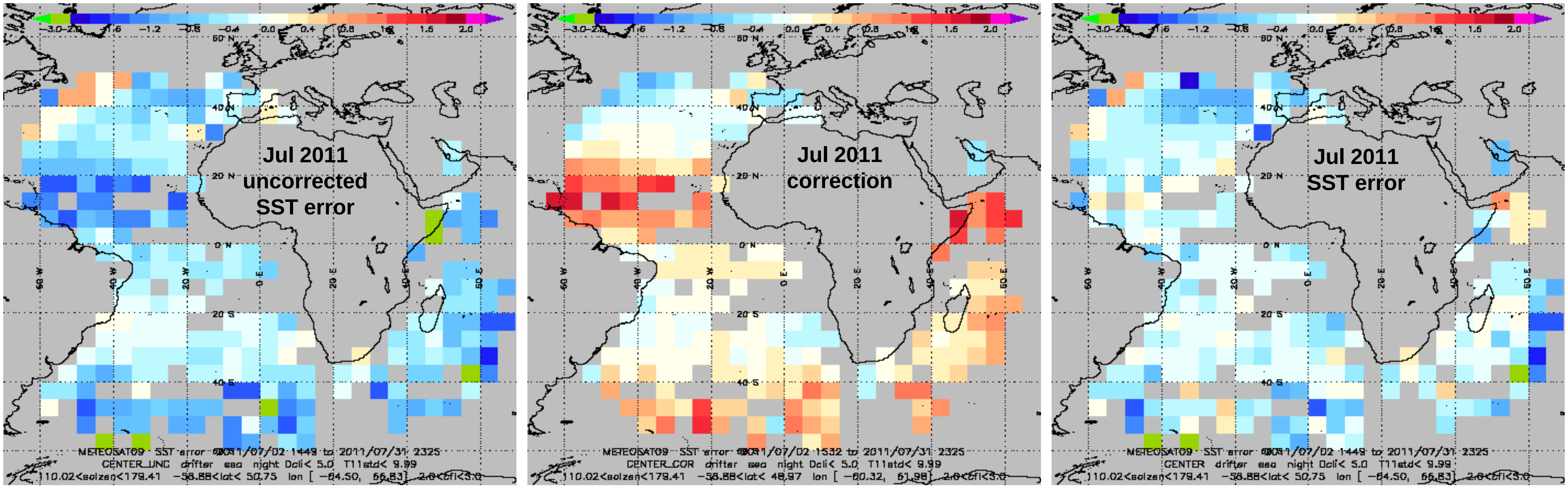
Simulated BTs





LeBorgne et al, 2010, EUMETSAT Conference, Cordoba

METEOSAT-9 night-time SST errors (July 2011)



The new OSI-SAF geostationary SST processing using the NWP derived bias correction method has been declared operational in August 2011

See also Le Borgne et al, RSE 2011

Marsouin et al, 2011, EUMETSAT Conference, Oslo

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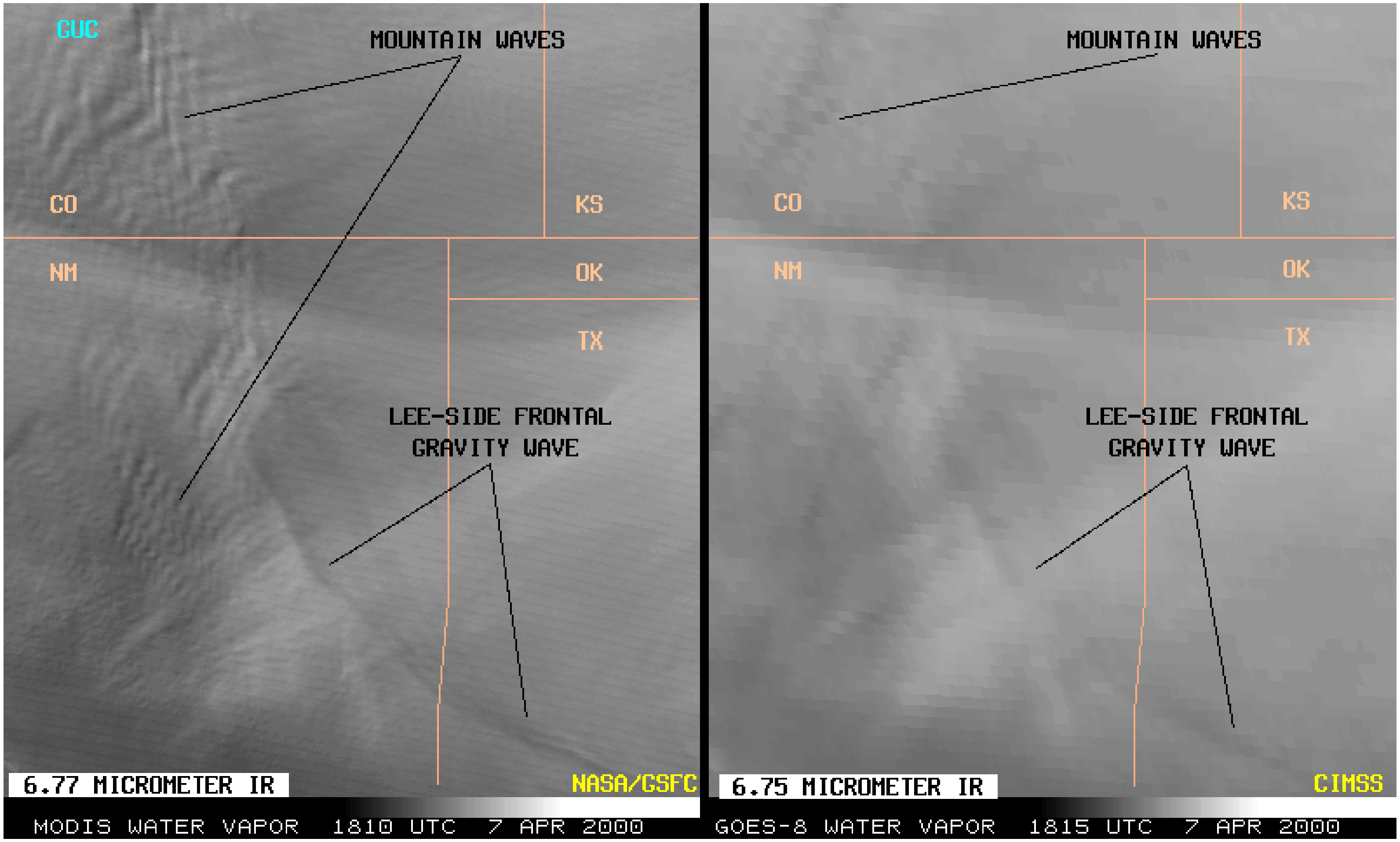
Improved radiometry and spatial resolution

- Better measurements of smaller-scale features in the atmosphere and on the ocean and land
- More meaningful spatial and temporal means and estimates of variability

→ better NWP forecasts

→ better Climate Data Records

MODIS vs GOES



MODIS has 1km water vapor band compared to 8km of GOES

Sea Surface Temperature gradients

Better representation of temperature gradients result from better radiometric resolution, and better defined pixels

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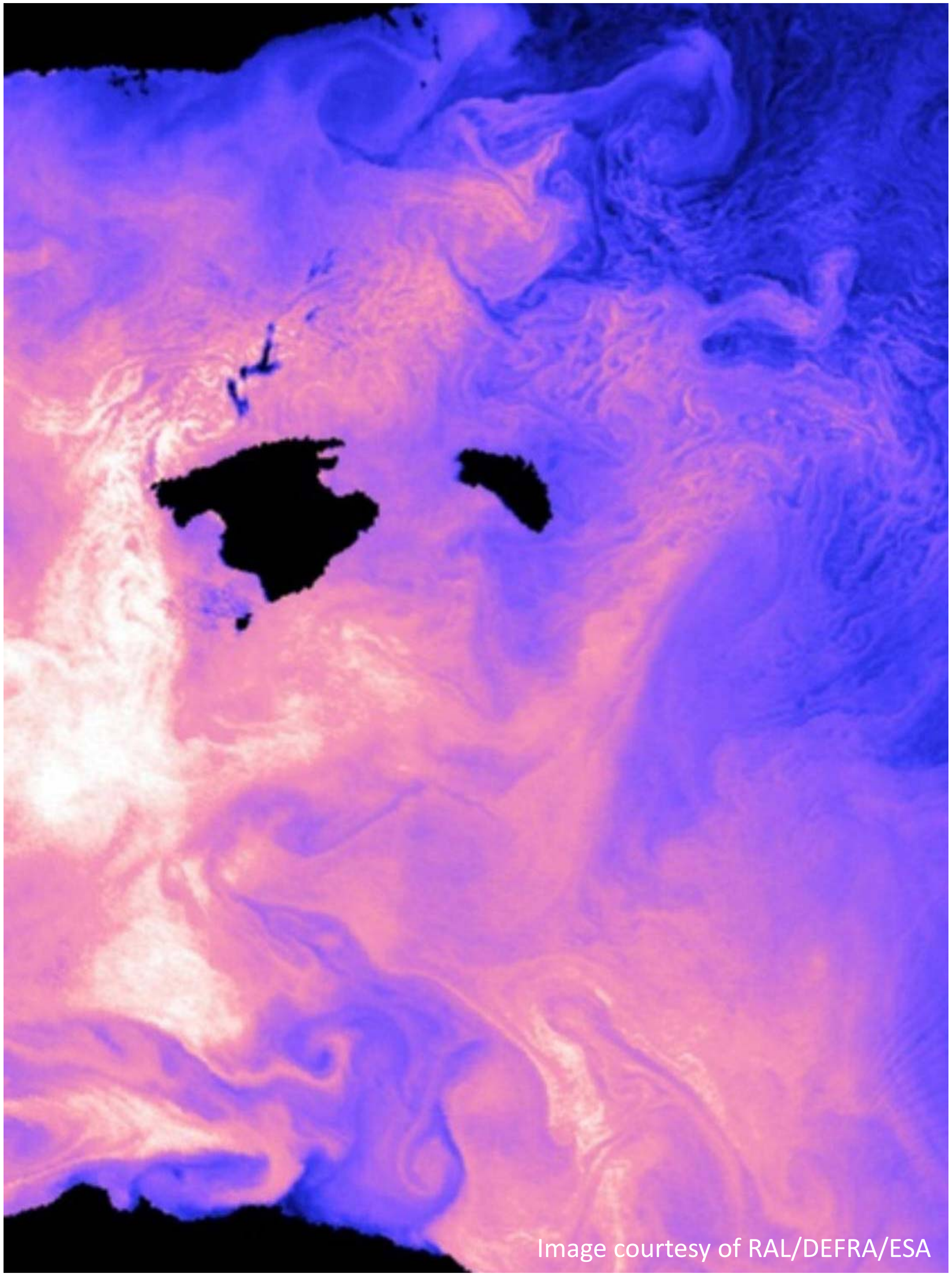

METimage synergies – cross platform

- OLCI
- SLSTR
- VIIRS
- AMSR-2
- NASA Decadal Survey Missions
- Other missions from China, India, Korea….
- Other sensors, e.g. active radars & lidars….

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