# Future opportunities from MTG and Post-EPS

**Johannes Schmetz, Rolf Stuhlmann, Peter Schlüssel**
**and many colleagues**

**EUMETSAT**

Darmstadt, Germany

# Content:

- EUMETSAT programmes: current and future
- Current utilisation => best first guess for future
- Meteosat Second Generation
- Evolution to MTG
- EUMETSAT Polar Programme/Metop
- Evolution to Post-EPS
- A look at (or gleaning from) our partner NOAA/NESDIS
- Examples for future opportunities
- Importance of calibration

## FROM THE EUMETSAT CONVENTION

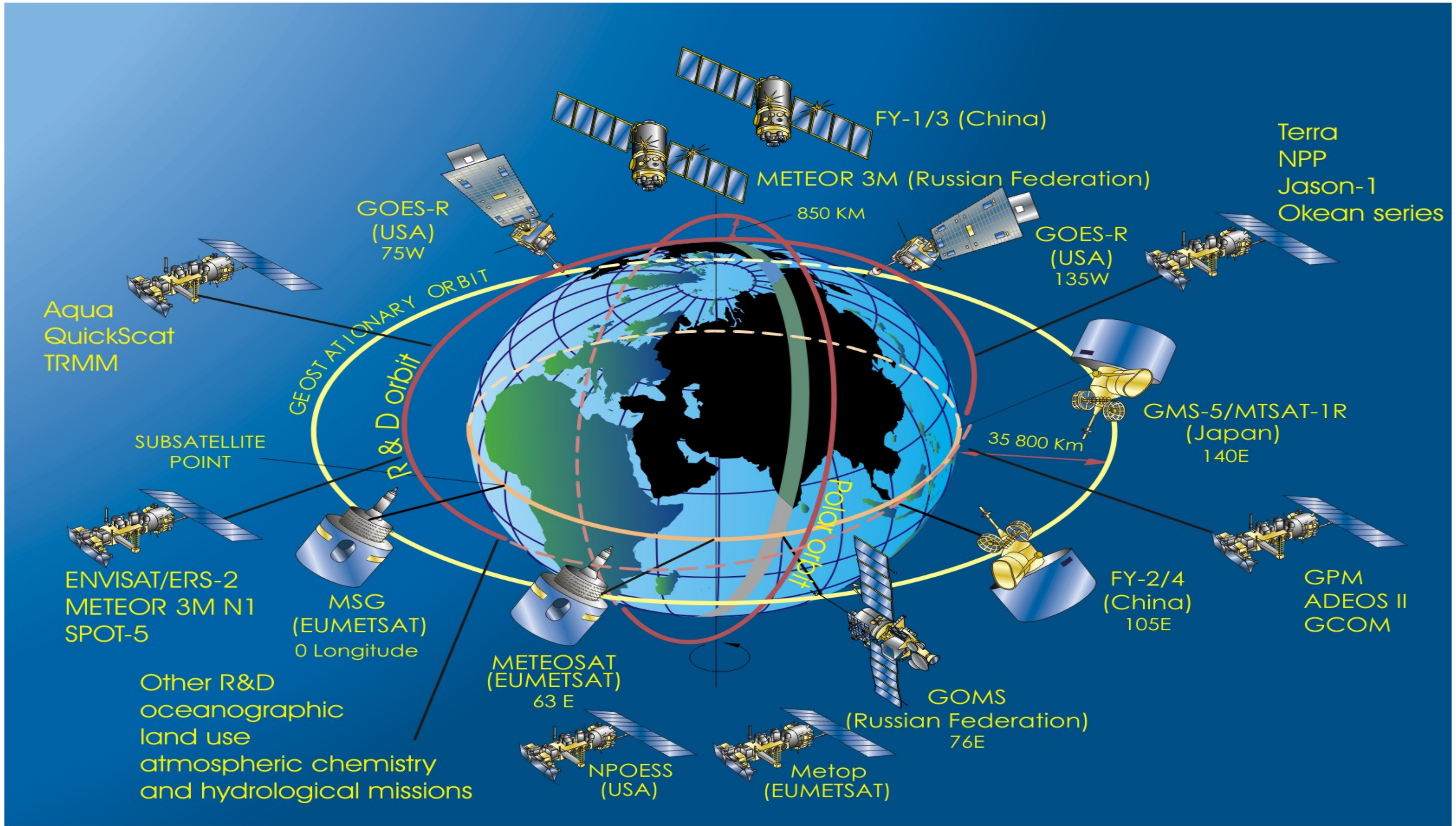
- **“ The <u>primary</u> objective ... is to establish, maintain and exploit European systems of operational meteorological satellites..... “**

- **“ A further objective ... is to contribute to the operational monitoring of the climate and the detection of global climatic changes.“**

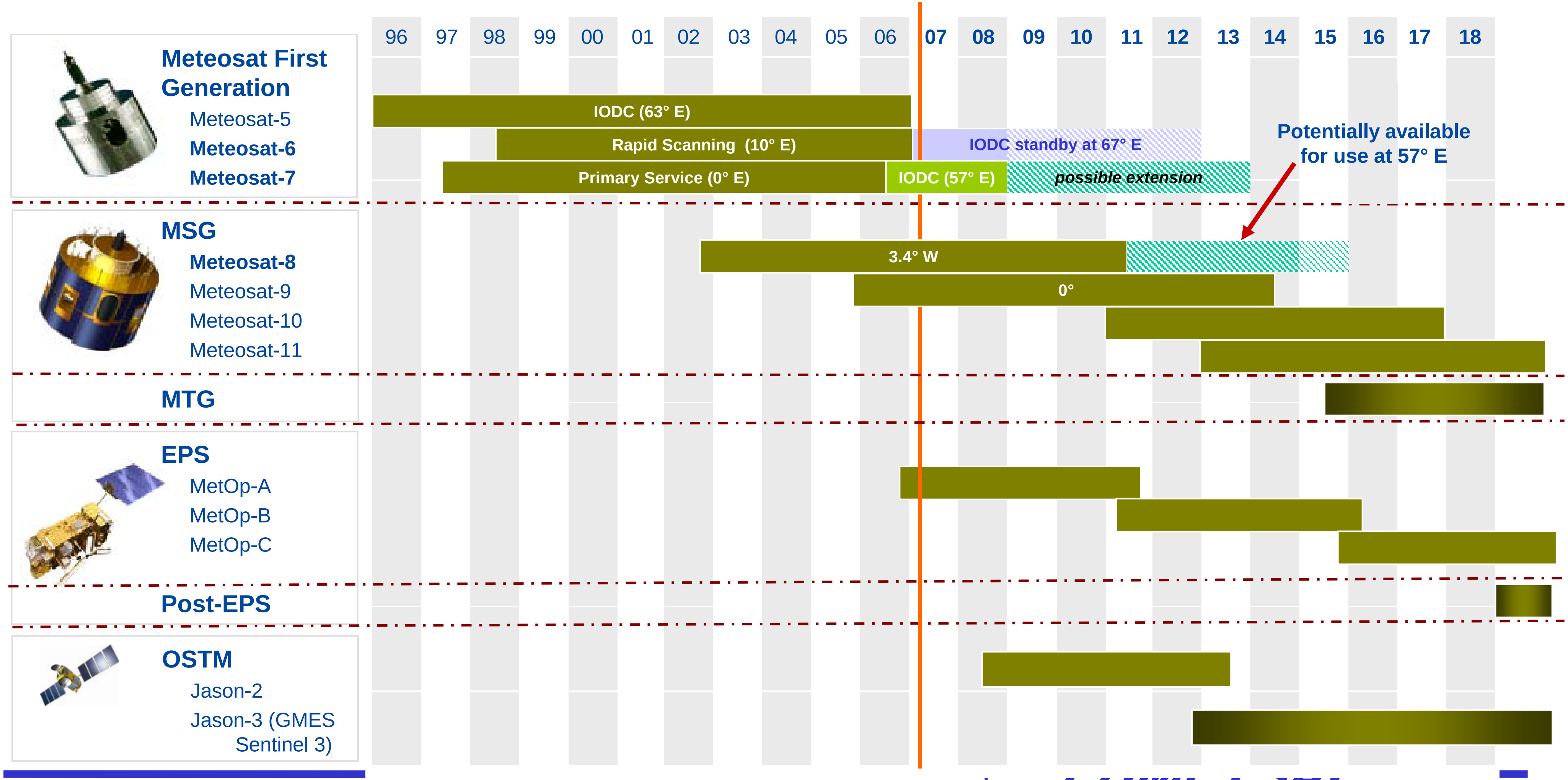
EUMETSAT's mission is:

- **To deliver cost efficient operational satellite data and products …. satisfy …. requirements of its Member States,**
- **taking into account the recommendations of the World Meteorological Organization.**

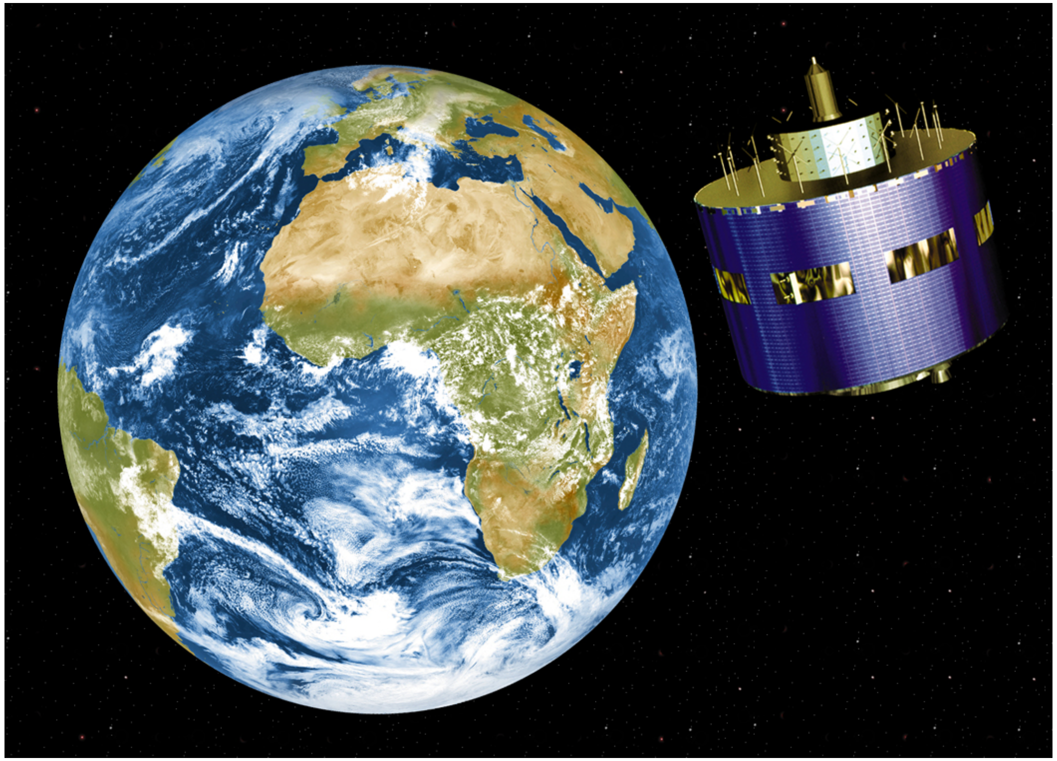
# Current Space Based Components of the Global Observing System



# EUMETSAT Programme Planning

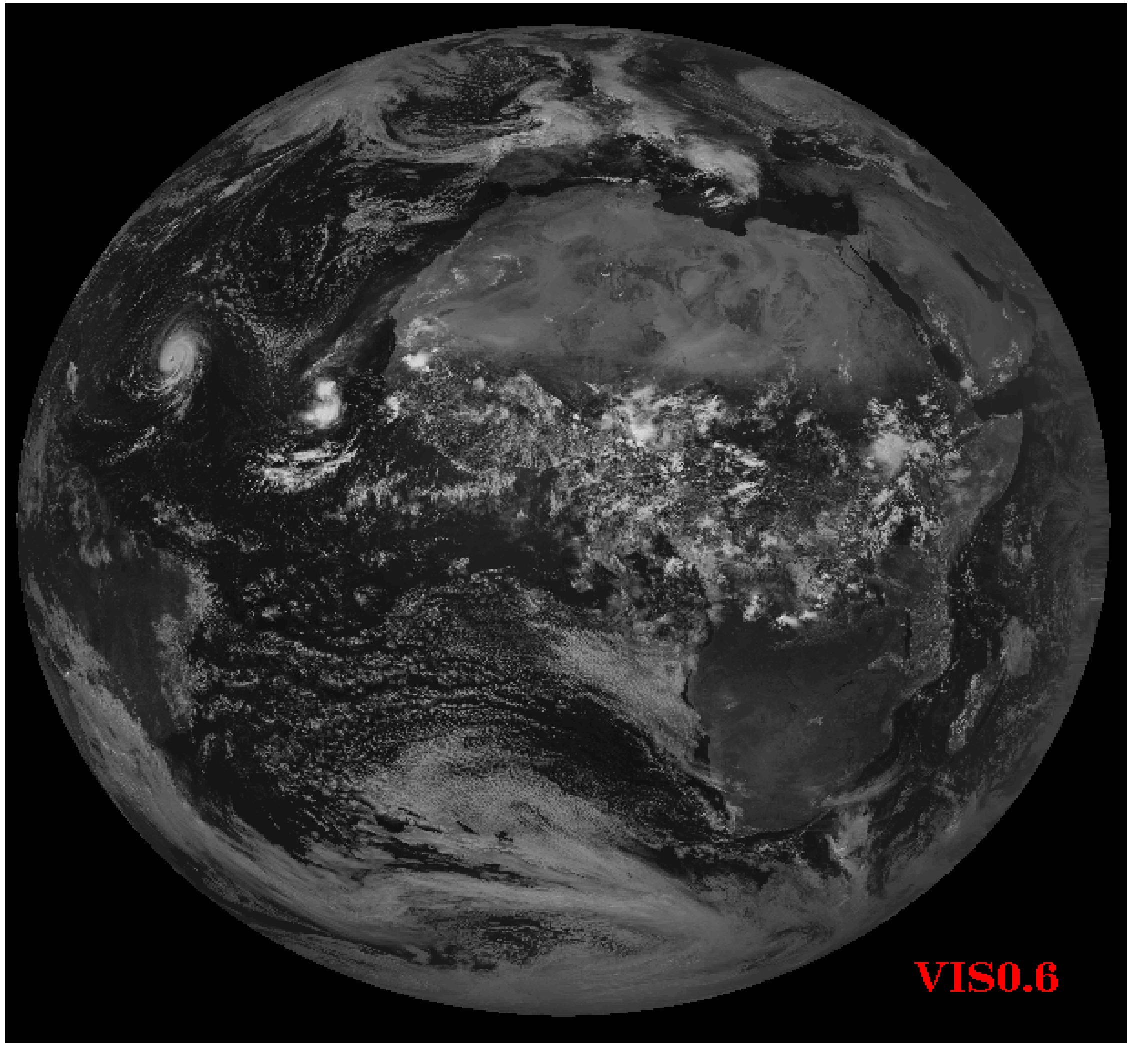


# Meteosat Second Generation:
## A breakthrough for meteorology



- Imager with 12 spectral channels
- Full-disk repeat cycle of 15 minutes
- Spatial sampling 3 km (1km for high resolution visible channel)
- On-board calibration for infrared channels
- GERB instrument => radiation budget
- Meteosat-8 (2002)
- Meteosat-9 (2005)
- Two more to follow

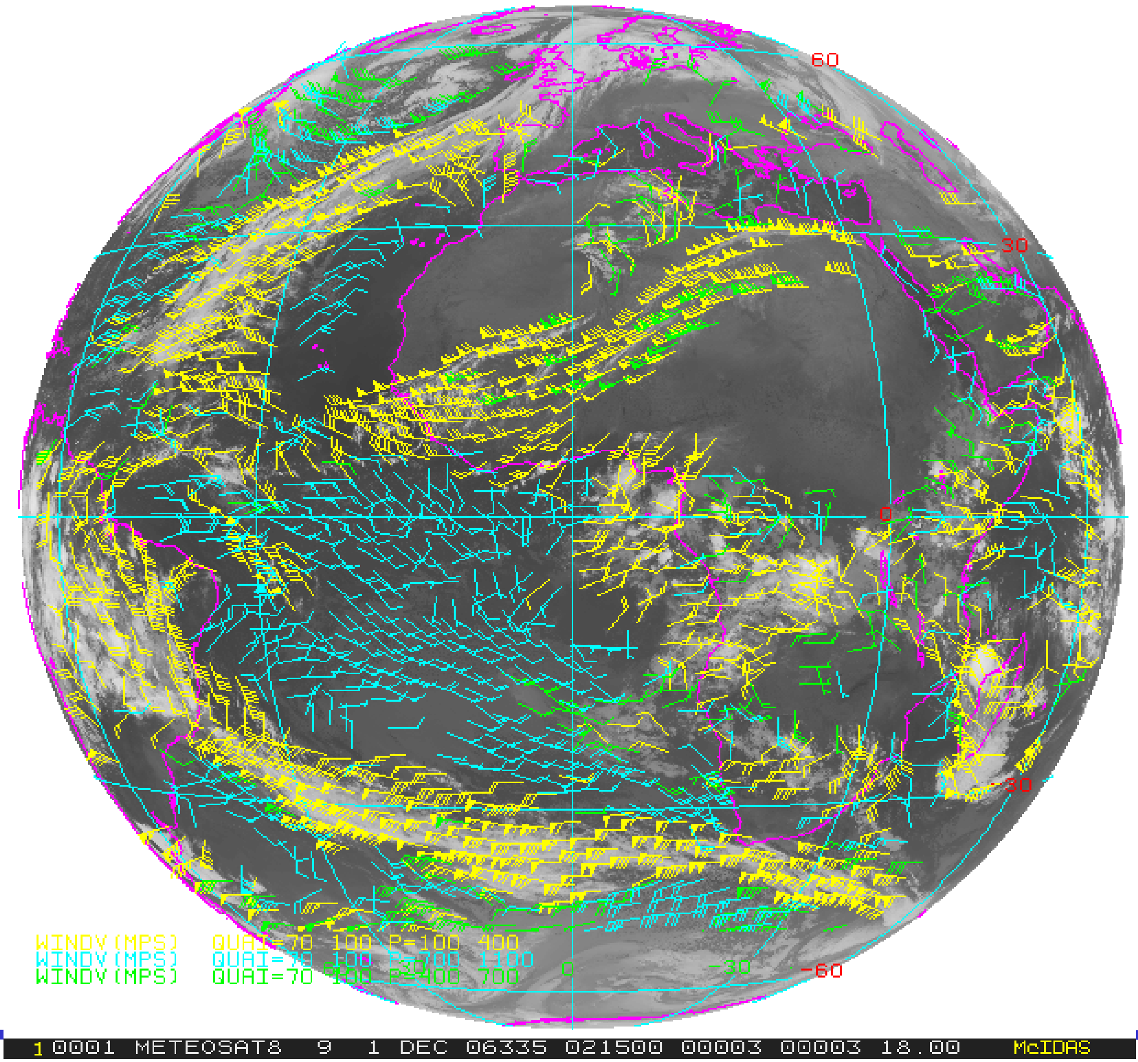
# Twelve spectral channels of Meteosat Second Generation




• so far in space Meteosat-8 and -9

# Winds for Numerical Weather Predictions

## (see also presentation by M. Forsythe on 3 September)

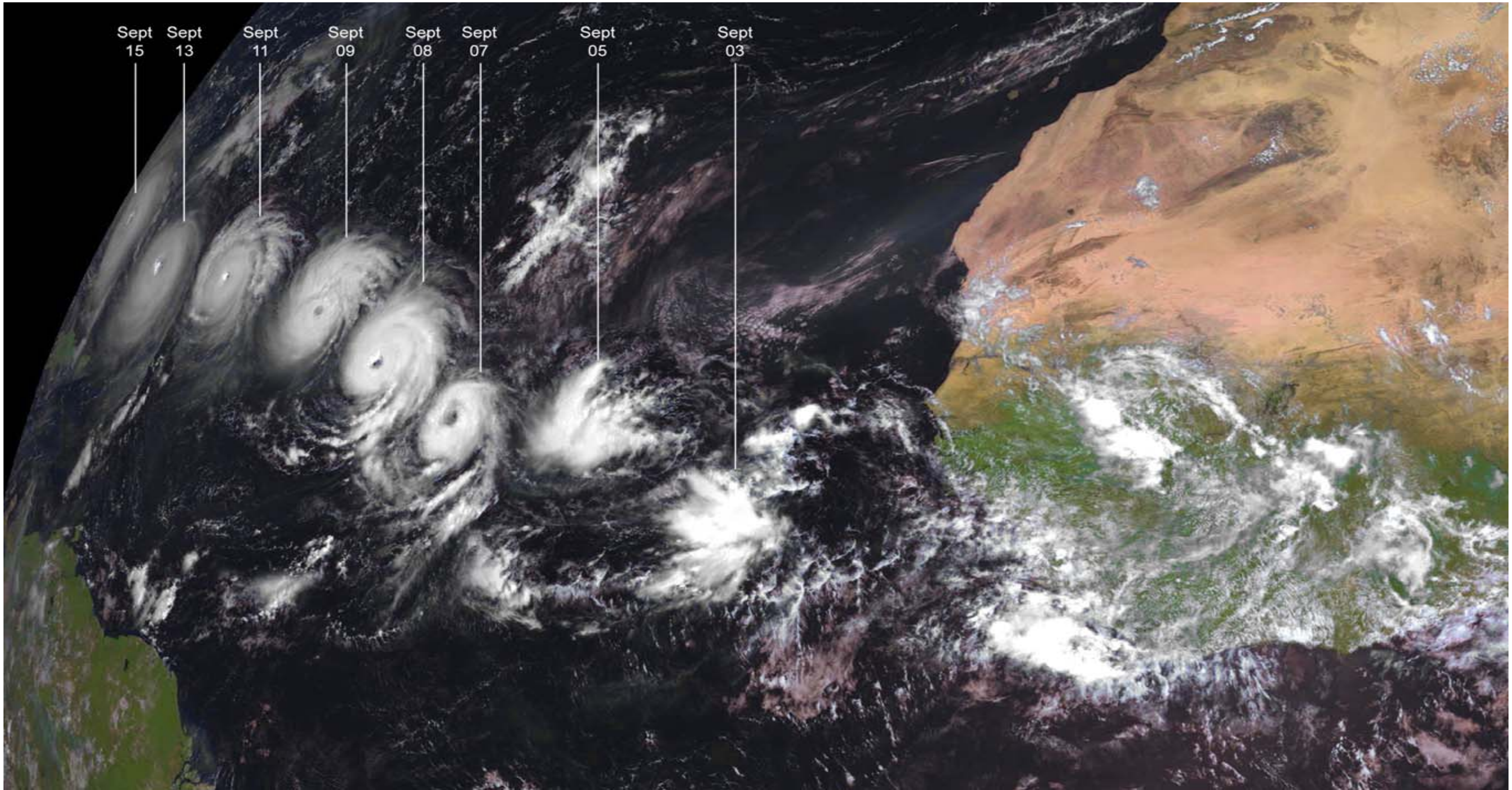



**Winds from tracking atmospheric motions**

**here:**
**10.8 µm channel**

**R. Borde, 2006**

# Observing the cradle of hurricanes: Combination of VIS images from Meteosat- 8 tracks Hurricane Isabel (September 2003)



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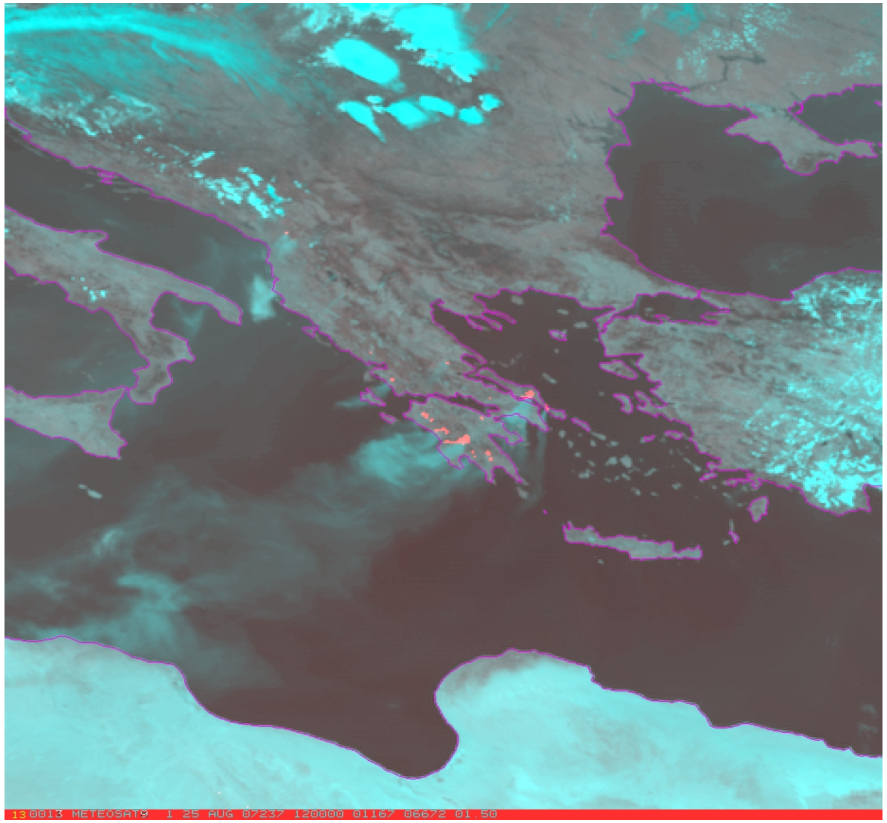
# Fire detection from MSG (=> perspective with MTG)

**Forest fires in Greece**

**Meteosat-9, 25 August 2007, 1200 UTC**



**Modis on Aura**

**H.J. Lutz, 2007**

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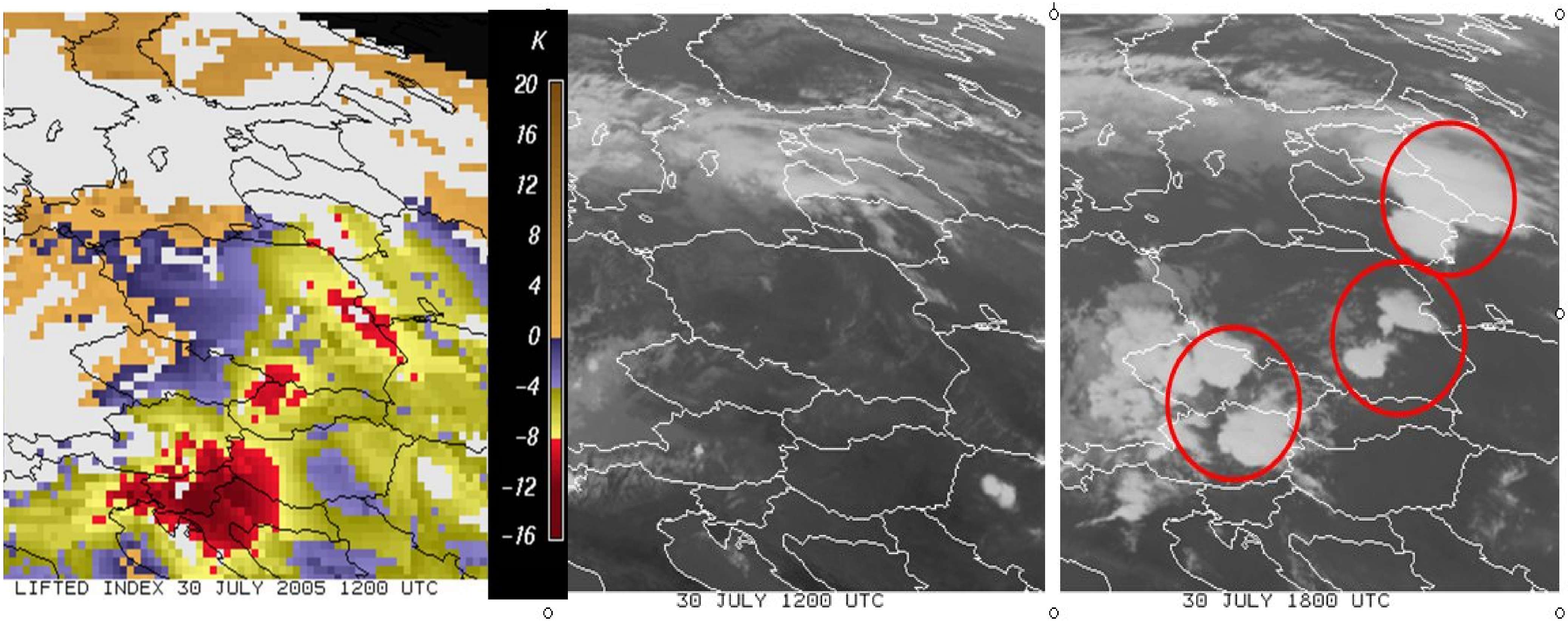
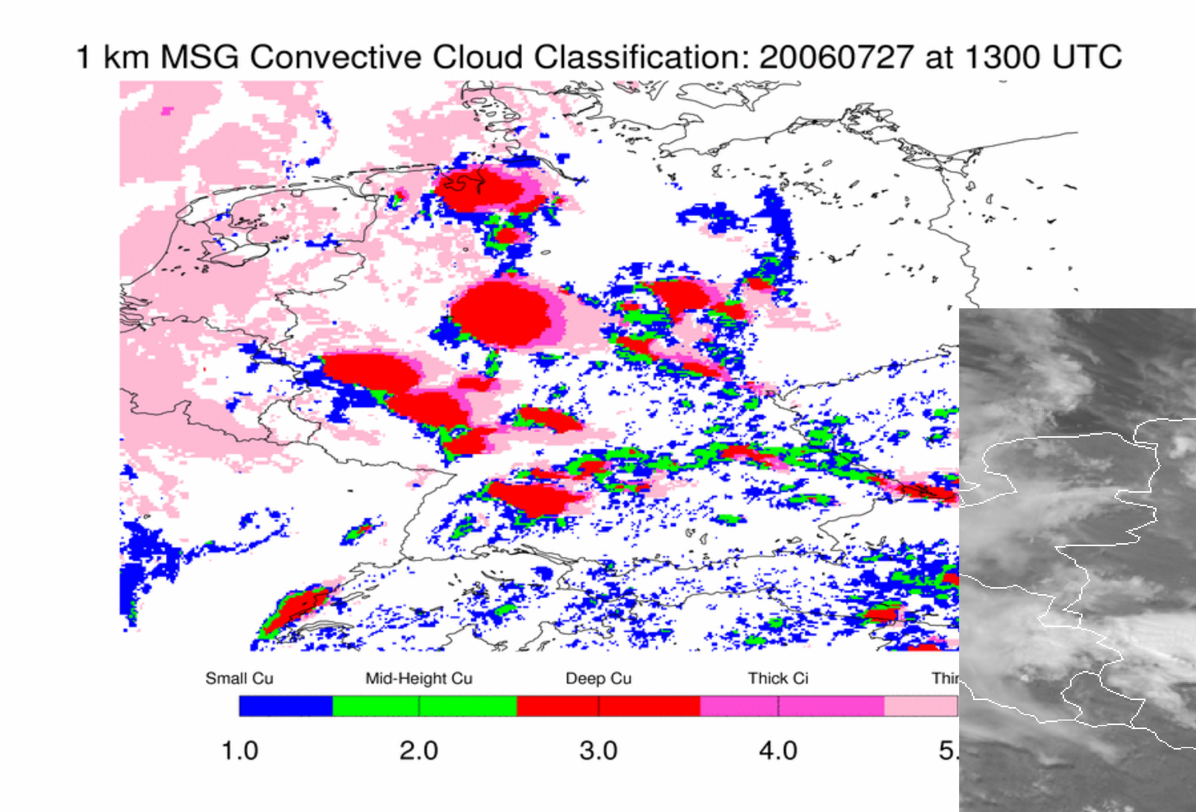
# Meteosat monitors onset of convection

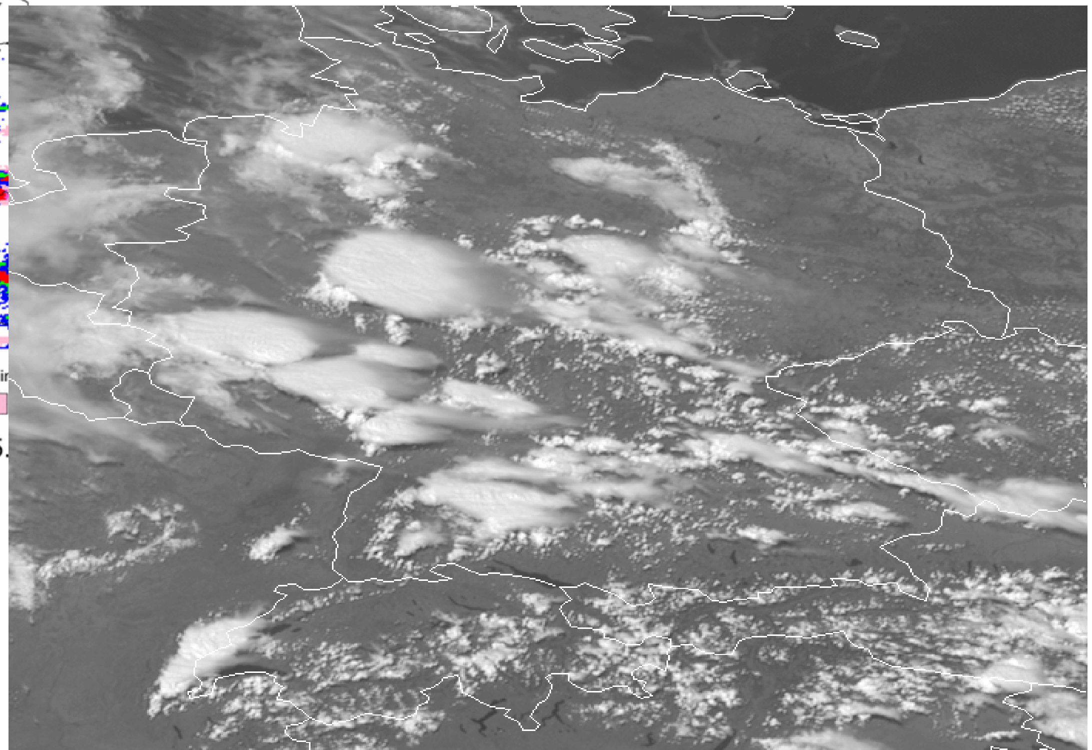
M. König, 2006

Lifted index at 1200 UTC | 10.8µm image at 1200 UTC | 10.8µm image at 1800 UTC



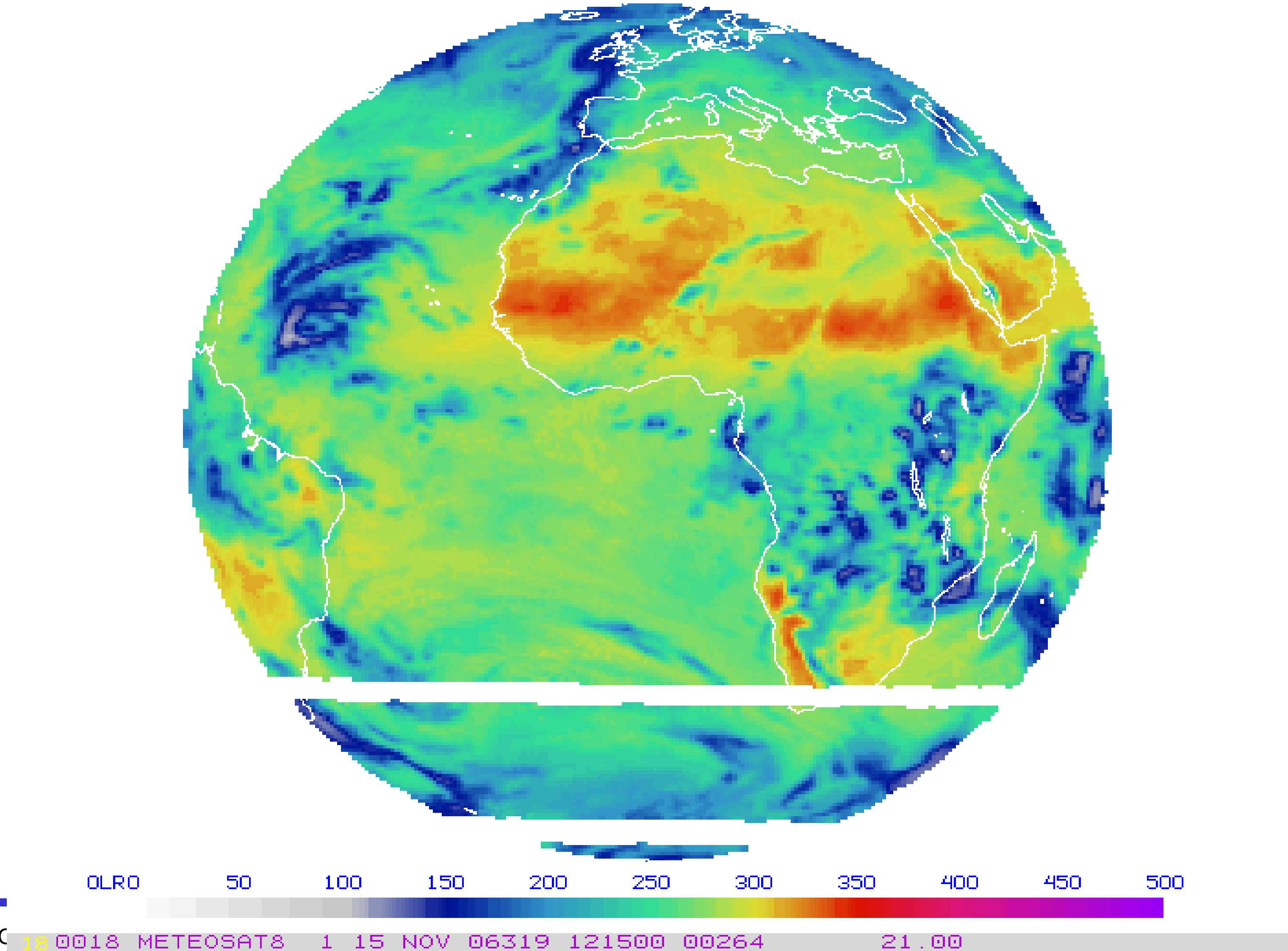
# Example of Convective Cloud Mask Product from MSG



**W. Feltz et al., pers. communication**

# Example of a climate product: Outgoing Longwave Radiation (OLR) *(courtesy M. König)*




**Bias**

**GERB – SEVIRI:**

**-1.3 to -1.9 $Wm^{-2}$**

## Future geostationary programme

## Meteosat Third Generation (MTG)

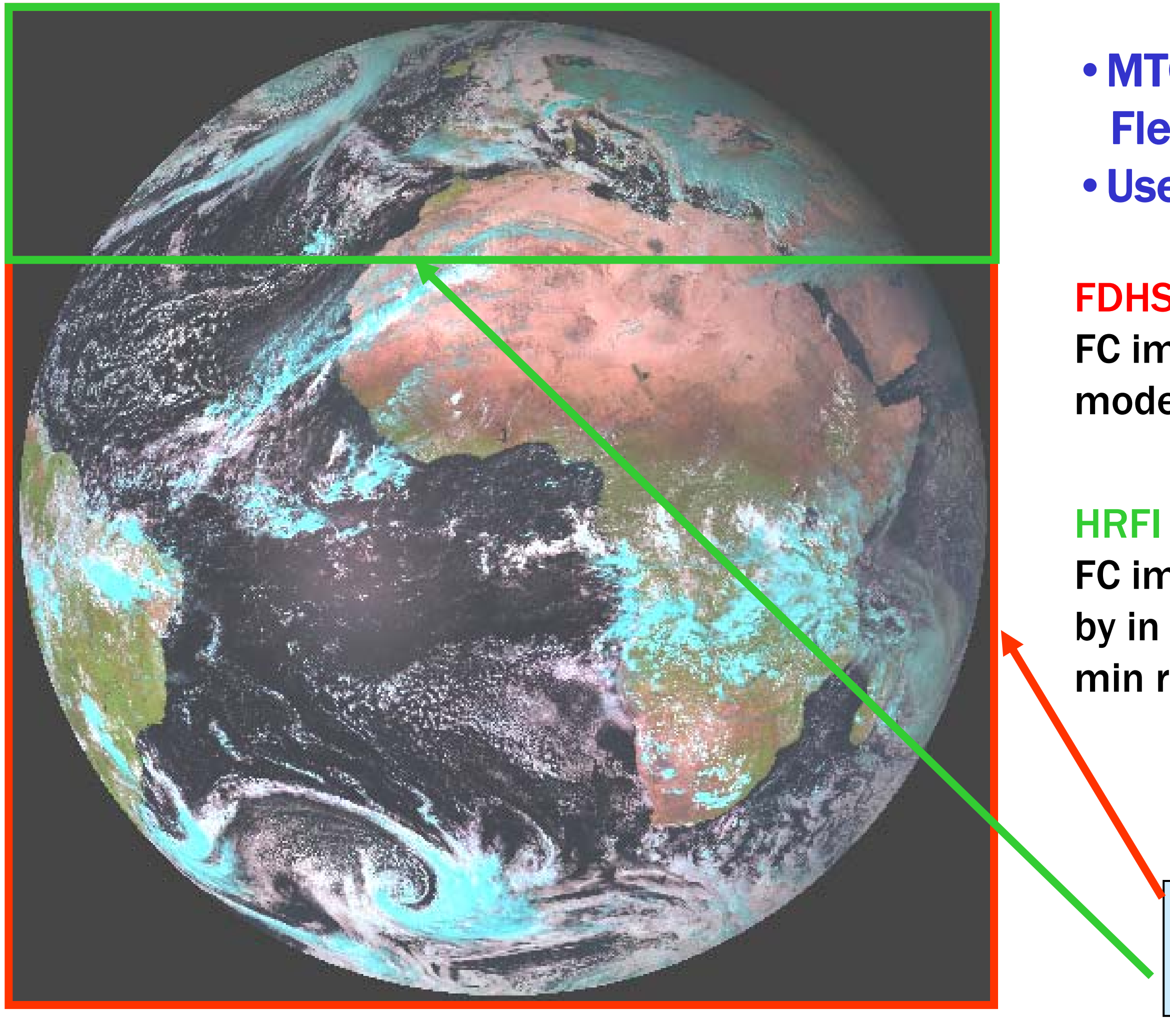
Focus is on Numerical Weather Prediction and Nowcasting.

Candidate missions:

- High Resolution Fast Imagery (HRFI) mission.
- Full Disk High Spectral Imagery (FDHSI) mission.
- Infrared Sounding (IRS) mission.
- Lightning Imagery (LI) mission.
- UV-VIS Sounding (UVS) mission.

The need date is 2015.
Technical analysis with ESA.

# MTG Imagery Missions



- MTG imagery missions served by a Flexible Combined (FC) imager
- Use of in-orbit spare satellite for rapid scan

**FDHSI mission (continuation of MSG-SEVIRI):**
FC imager on the operational satellite in Full Disk mode with 10 min repeat cycle

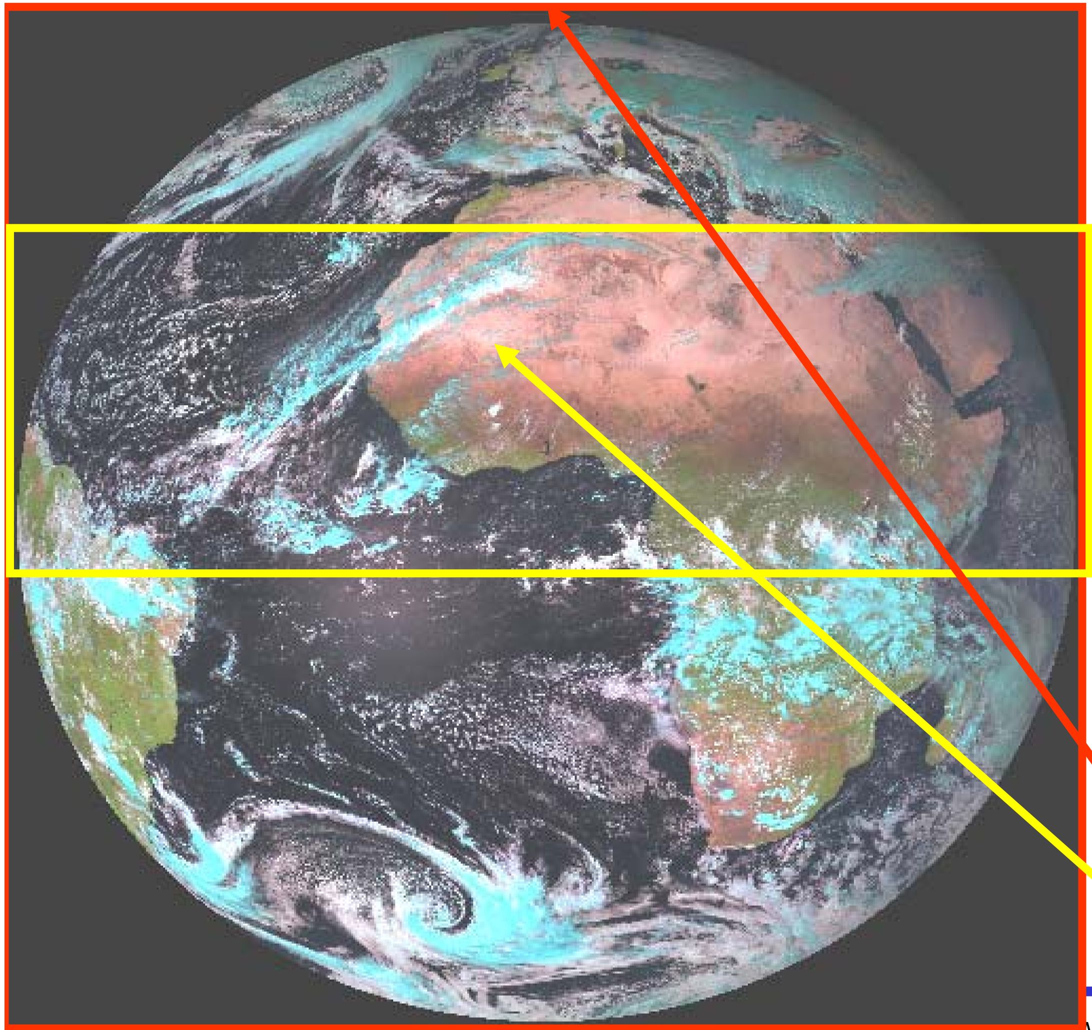
**HRFI mission (continuation of Rapid Scan):**
FC imager on fully commissioned in-orbit hot stand-by in Rapid Scan mode over ¼ of Full Disk with 2.5 min repeat cycle

| | Coverage | Repeat cycle |
|---|---|---|
| FDHSI mission | Full Disk | 10 min |
| HRFI mission | 1/4 FD | 2.5 min |

# MTG Imager Requirements

| | Meteosat 1st Generation | | | Meteosat 2nd Generartion | | | Meteosat 3rd Generation | | |
|---|---|---|---|---|---|---|---|---|---|
| 'Core' channels | Central wavelength (μm) | Width (FWHM) (μm) | Spatial Sampling (km) | Central wavelength (μm) | Width (FWHM) (μm) | Spatial Sampling (km) | Central wavelength (μm) | Width (FWHM) (μm) | Spatial Sampling* (km) |
| FC -VIS 0.4 | | | | | | | 0.444 | 0.06 | 1.0 |
| FC -VIS 0.5 | | | | | | | 0.510 | 0.05 | 1.0 |
| FC -VIS 0.6 | 0.7 | 0.35 | 2.5 | 0.635 | 0.08 | 3.0 | 0.645 | 0.08 | 0.5 |
| FC -VIS 0.8 | | | | 0.81 | 0.07 | 3.0 | 0.86 | 0.07 | 1.0 |
| FC -NIR 0.9 | | | | | | | 0.96 | 0.06 | 1.0 |
| FC -NIR 1.3 | | | | | | | 1.375 | 0.03 | 1.0 |
| FC -NIR 1.6 | | | | 1.64 | 0.14 | 3.0 | 1.61 | 0.06 | 1.0 |
| FC -NIR 2.1 | | | | | | | 2.26 | 0.05 | 0.5 |
| FC -IR 3.8 * | | | | 3.9 | 0.44 | 3.0 | 3.8 | 0.40 | 1.0 |
| FC -IR 6.7 | 6.1 | 1.3 | 5.0 | 6.3 | 1.0 | 3.0 | 6.3 | 1.00 | 2.0 |
| FC -IR 7.3 | | | | 7.35 | 0.5 | 3.0 | 7.35 | 0.50 | 2.0 |
| FC -IR 8.5 * | | | | 8.7 | 0.4 | 3.0 | 8.7 | 0.40 | 2.0 |
| FC -IR 9.7 | | | | 9.66 | 0.3 | 3.0 | 9.66 | 0.30 | 2.0 |
| FC -IR 10.8 | 11.5 | 1.9 | 5.0 | 10.8 | 1.0 | 3.0 | 10.5 | 0.7 | 1.0 |
| FC -IR 12.0 | | | | 12.0 | 1.0 | 3.0 | 12.3 | 0.5 | 2.0 |
| FC -IR 13.3 | | | | 13.4 | 1.0 | 3.0 | 13.3 | 0.60 | 2.0 |
| | | | | | | | | | |
| Repeat Cycle : | 30 min | | | 15 min | | | 10 min | | |

# MTG Infrared Sounder (IRS)



| Mission Band | Frequency range $cm^{-1}$ | | Main Contribution |
|---|---|---|---|
| IRS-1 | 700 | 770 | $CO_2$ |
| IRS-2 | 770 | 980 | Surface, Clouds |
| IRS-3 | 980 | 1070 | $O_3$ |
| IRS-4 | 1070 | 1210 | Surface, Clouds |
| IRS-6 | 1600 | 2000 | $H_2O$, |
| IRS-7 | 2000 | 2175 | CO, |

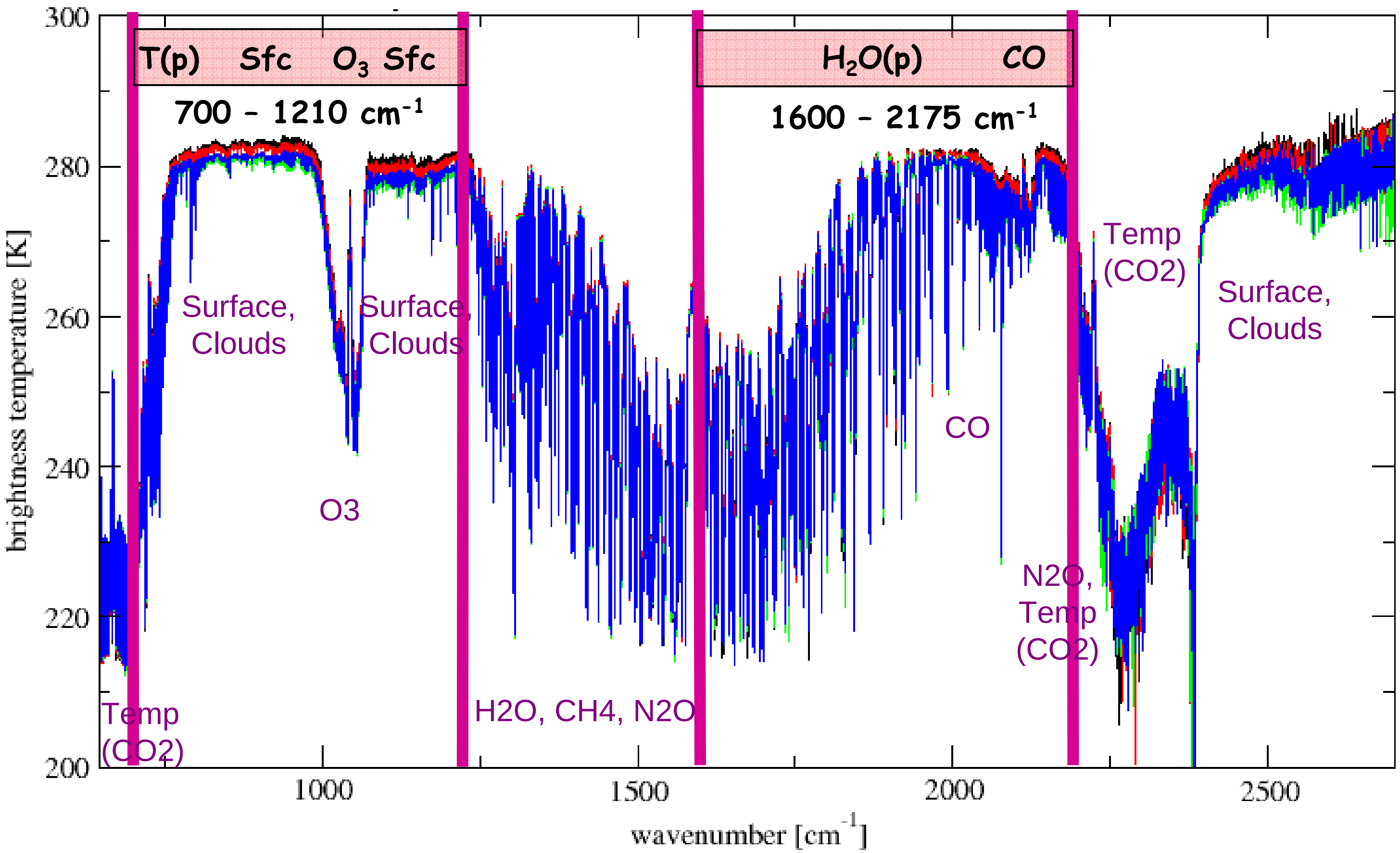
1800 channels
Spec.res. 0,62 1/cm

| | Coverage | Repeat cycle |
|---|---|---|
| Full Disk Coverage | 18°x18° | 30 min |
| Local Area Cov. | 18°x6° | 10 min |

# MTG InfraRed Sounder (IRS)

## First IASI Level 1C Spectra

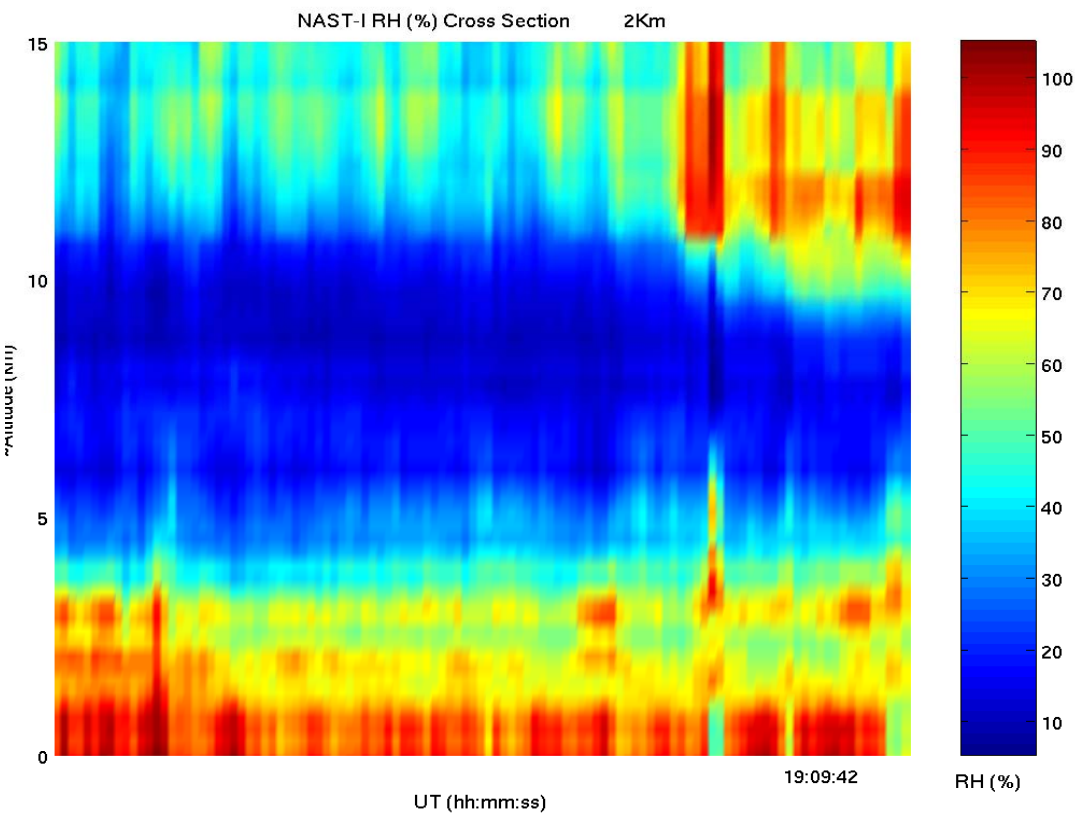
**29/11/2006, 13:42:11 UTC**




**MTG spectral coverage**

# MTG Infrared Sounder (IRS)

Hyperspectral IR sounding with focus on time evolution of vertically resolved water vapour structures

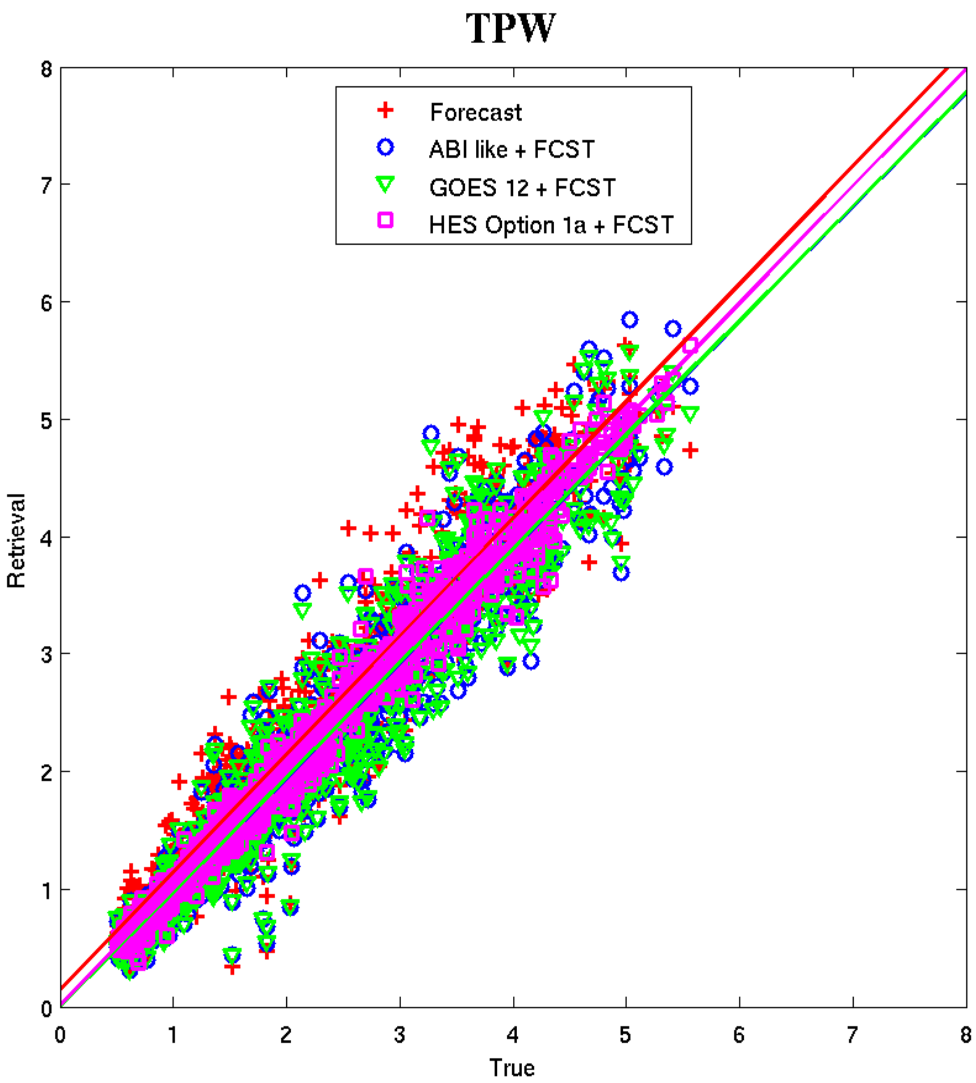



Priorities IRS Mission

- Atmospheric dynamic variables with high vertical resolution (e.g. water vapour flux, wind profile, transport of pollutant gases)
- More frequent information on Temperature and Humidity profiles for NWP (regional and global)
- Monitoring of instability / early warning of convective intensity
- Cloud microphysical structure
- support chemical weather and air quality applications

| | Coverage | Repeat cycle |
|---|---|---|
| Full Disk Coverage | 18°x18° | 30 min |
| Local Area Cov. | 18°x6° | 10 min |

# Benefits of high-spectral over broad-band measurements!

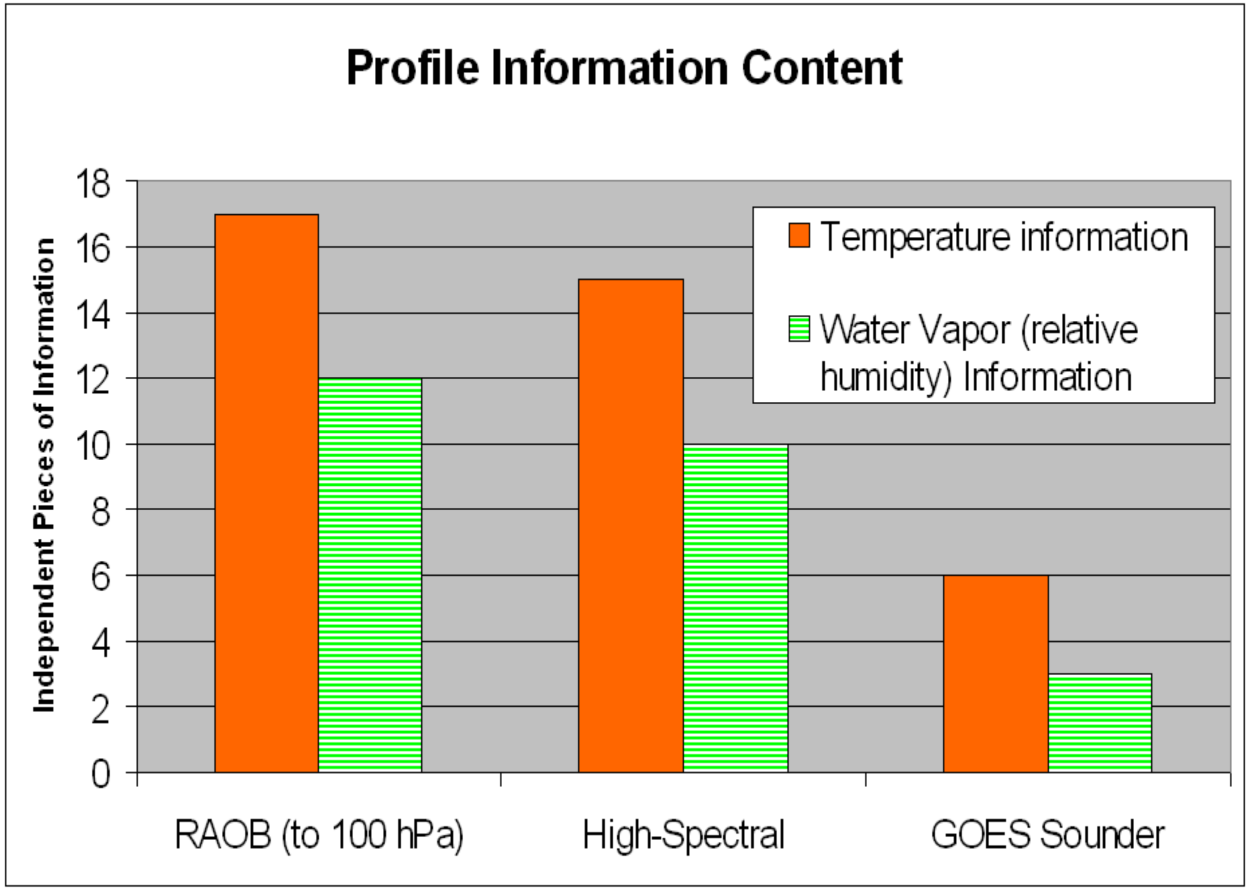



**Total Precipitable Water (TPW) from high-spectral (HES) data much improved over current broadband (GOES-12 + forecast).**

***Menzel et al. (2007)***

| **Root Mean Square Error** | |
|---|---|
| **Forecast:** | **0.40** |
| **ABI like + fcst:** | **0.35** |
| **GOES 12 + fcst:** | **0.34** |
| **HES + fcst:** | **0.16** |

# Information content

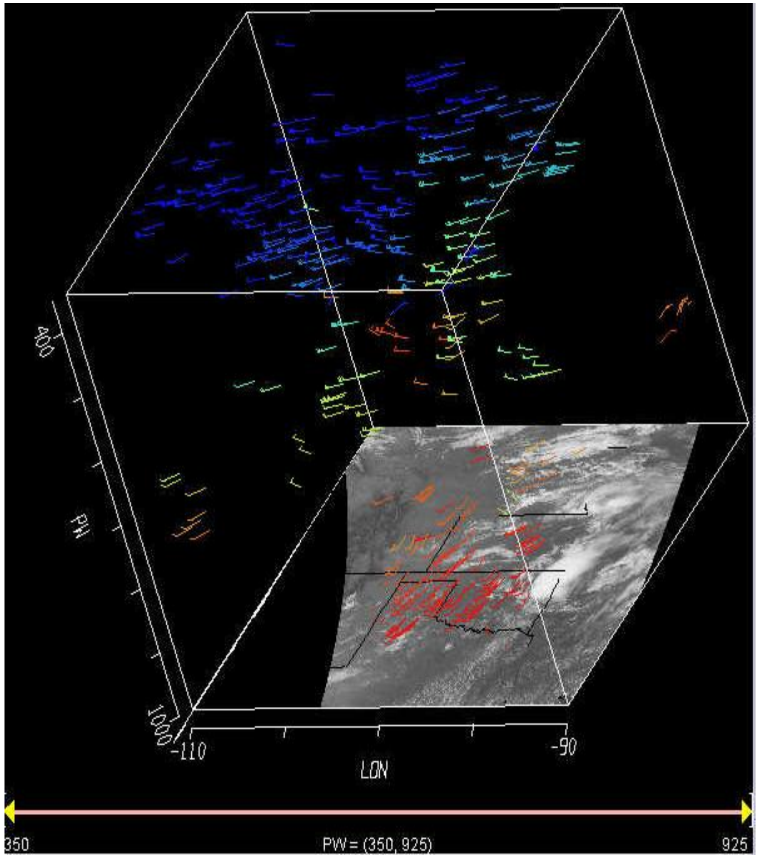



The relative vertical information is shown for radiosondes, a high-spectral infrared sounder and the current broad-band GOES Sounder. The high-spectral sounder is much improved over the current sounder.

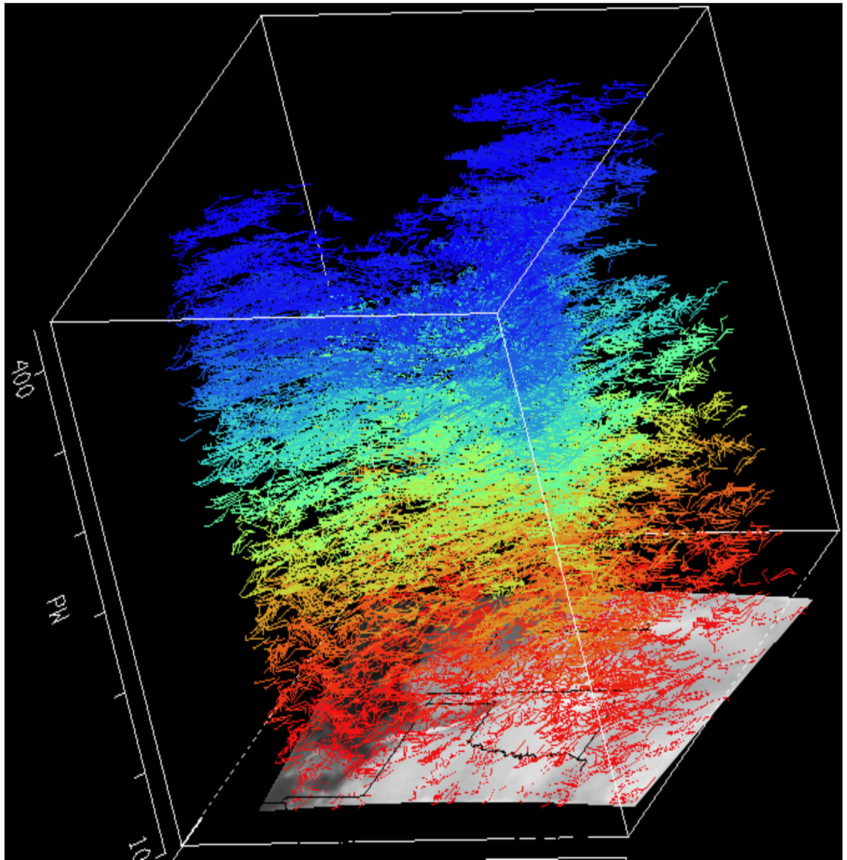
***Figure courtesy of A. Huang***

# Greatly Improved Atmospheric Motion Vectors with hyperspectral sounder
***(Figure courtesy of C. Velden)***

**Current GOES**

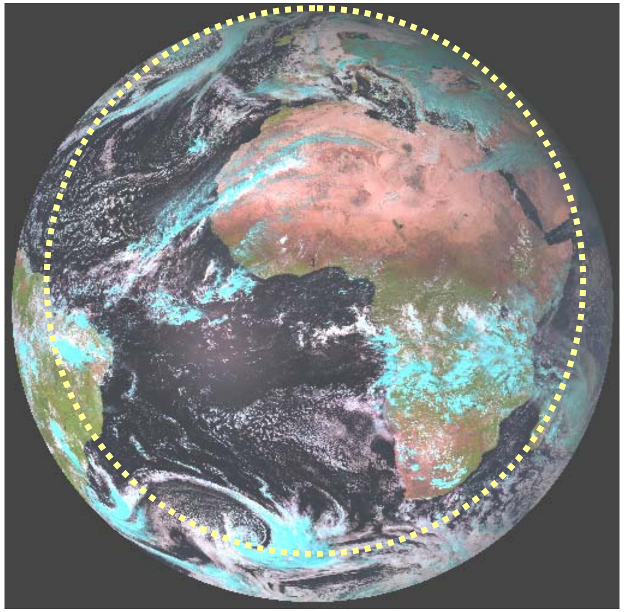



**High-spectral**



# MTG Lightning Imaging Mission

**User Request: detect 90% of lightest events**
**In Cloud (IC), Cloud to Cloud (CC), and Cloud to Ground (CG)**



| | |
|---|---|
| **FOV** | 16° Earth Disk ~ 80% of the Full Disk |
| **IFOV – Spatial Resolution** | **10 km** (45 degree North) |
| **Wavelength** | Neutral oxygen line OI(1) at 777.4 nm |
| **Integration time** | 2ms - 1ms optimised to meet DE and FAR |
| **Discharge optical pulse** | 0.5ms |
| **Energy range** | 4 - 400 $\mu Jm^{-2}sr^{-1}$ |
| **Detection Efficiency (DE)** | > **90% - 40%** for any individual event |
| **False Alarm Rate (FAR)** | < 1 flash/sec *(averaged over the full Earth, assuming 50% cloud cover)* |
| **Repeat cycle** | continuous (as integration time) |
| **Accuracy** | intensity better 50% (20% goal) |

Co-registration HRFI/FDHSI: better than 1 IFOV

event: single CCD-pixel above energy threshold integrated over time (1 – 2 ms)
group: optical pulse associated with a single discharge of a CG return stroke or a recoil streamer of IC/CC
flash : lightning flash, consisting of several discharges – strokes/recoil streamer - separated by 50-300 ms close in space
(65 % of all flashes consists of more than 5 groups)
(90% of all flashes have a discharge event with radiances above 10 $\mu Jm^{-2}sr^{-1}$)

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# Continuation and enhancement of Geostationary Services

- Absorbed Shortwave Radiation
- Active Fire Detection / Monitoring
- Aerosol/Dust Detection
- Aerosol Optical Thickness
- Aerosol Particle Size
- All Sky Radiances
- Aircraft Icing Threat
- Air Mass Analysis
- Atmospheric Moisture Profile
- Atmospheric Temperature Profile
- Capping Inversion Information
- Clear Sky Masks
- Clear Sky Radiances
- Clear Sky Reflectance Map
- Climate Data Set
- Cloud Coverage
- Cloud Ice Water Path
- Cloud Imagery
- Cloud Layers / Heights and Thickness
- Cloud Liquid Water
- Cloud Mask
- Cloud Optical Depth
- Cloud Particle Size Distribution
- Cloud Top Height

- Cloud Top Phase
- Cloud Top Pressure
- Cloud Top Temperature
- Cloud Type
- CO Concentration
- Convection Initiation
- Atmospheric Motion Vectors
- Downward Longwave Irradiance
- Downward Shortwave Irradiance
- Emitted Longwave Radiative Flux TOA
- Enhanced Overshooting Top Detection
- Fire Radiative Power
- Fire Radiative Energy
- Flood/Standing Water
- Global Instability Indices
- High Resolution Precipitation Index
- Humidity Products (upper/midlevel rel. Hu)
- Ice Covered Land
- Land Surface (Skin) Temperature
- Lightning Detection
- Low Cloud and Fog
- Moisture Flux
- Ozone Layers
- Ozone Total

- All Sky Radiances
- Rainfall Potential and Probability
- Rainfall Rate/ Multisensor QPE
- Reflected Solar Radiative Flux TOA
- Scene Analysis
- Sea & Lake Ice/Age
- Sea & Lake Ice/Concentration
- Sea & Lake Ice/ Displacement and Direction
- Sea & Lake Ice/Extent and Characterization
- Sea Surface Temperature
- Snow Cover
- $SO_2$ Concentration
- Surface Albedo
- Surface Emissivity
- Total Precipitable Water
- Total Water Content
- Turbulence
- Upward Longwave Radiation at Surface
- Vegetation Fraction LAI
- Vegetation Index
- Visibility
- Volcanic Ash
- Wind Divergence

Service supported by:

| | | |
|---|---|---|
| MTG Flexible Combined Imager | MTG Infrared Sounder | MTG Lightning Imager |

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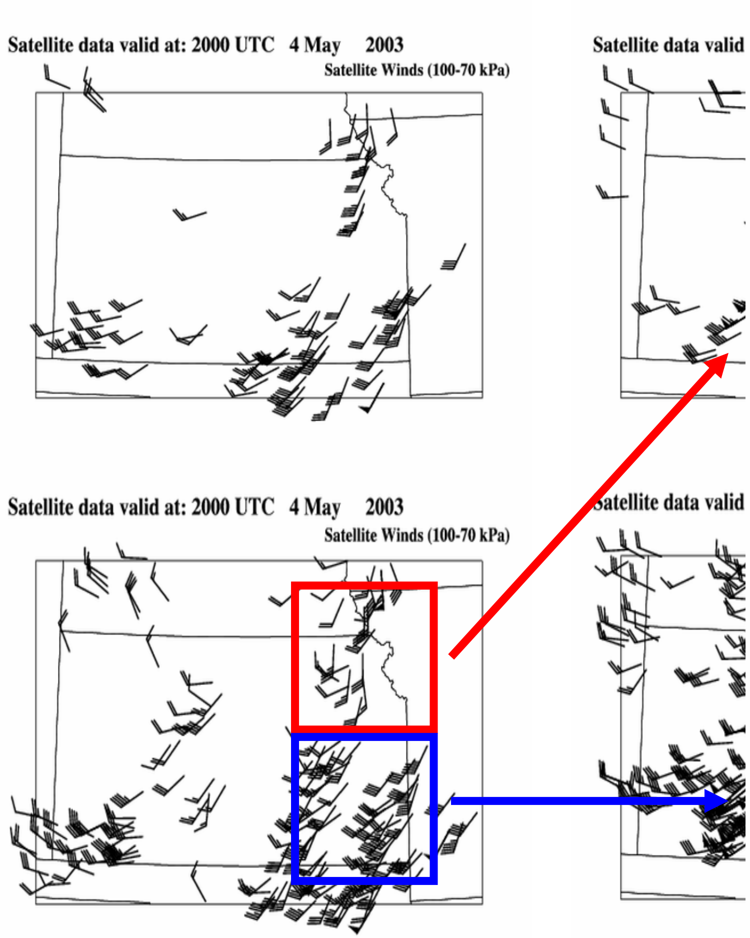
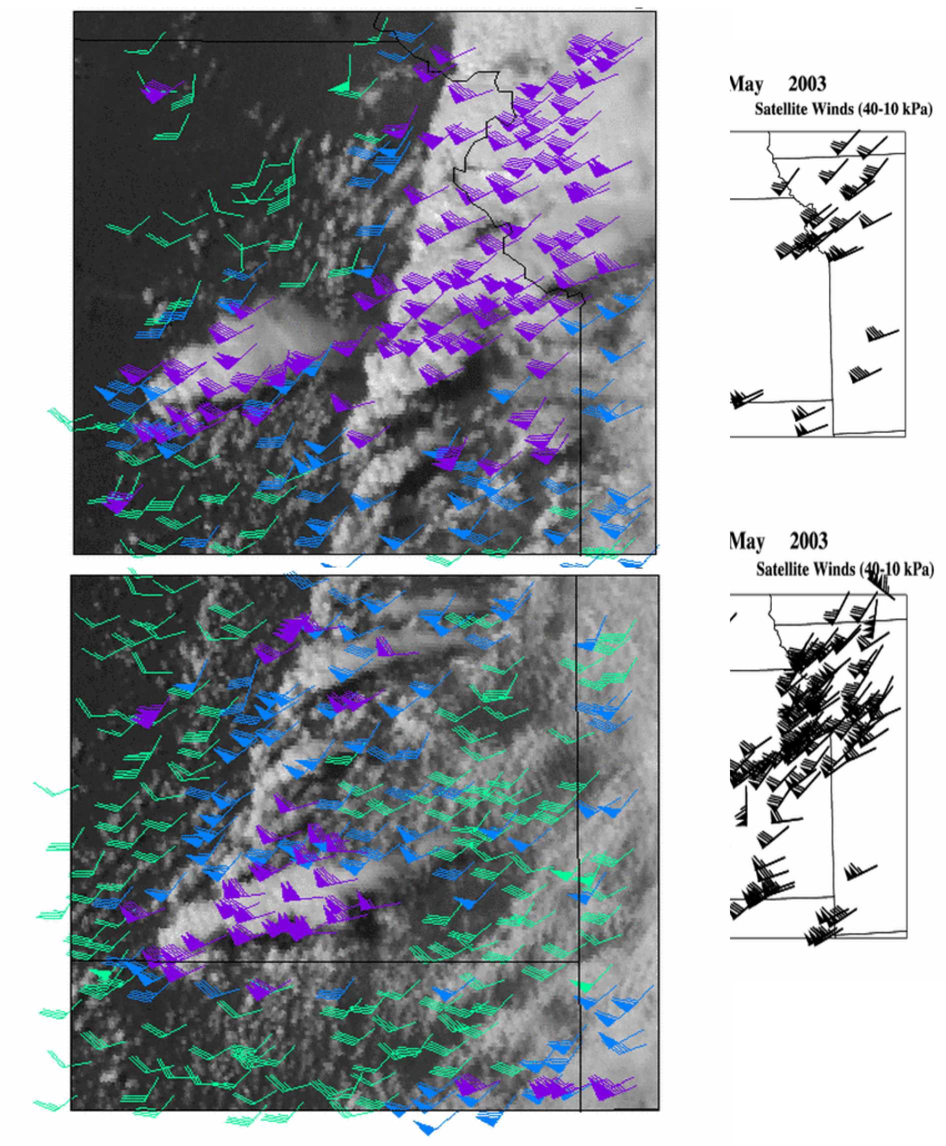
# “Mesoscale” Atmospheric Motion Vector Algorithm (courtesy J. Mecikalski)

“Operational Settings”

New Mesoscale AMVs

(only 20% shown)

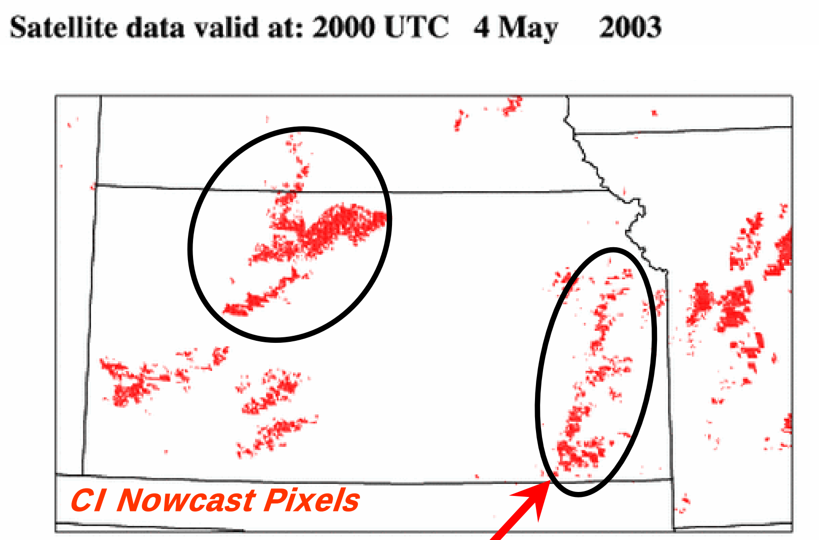


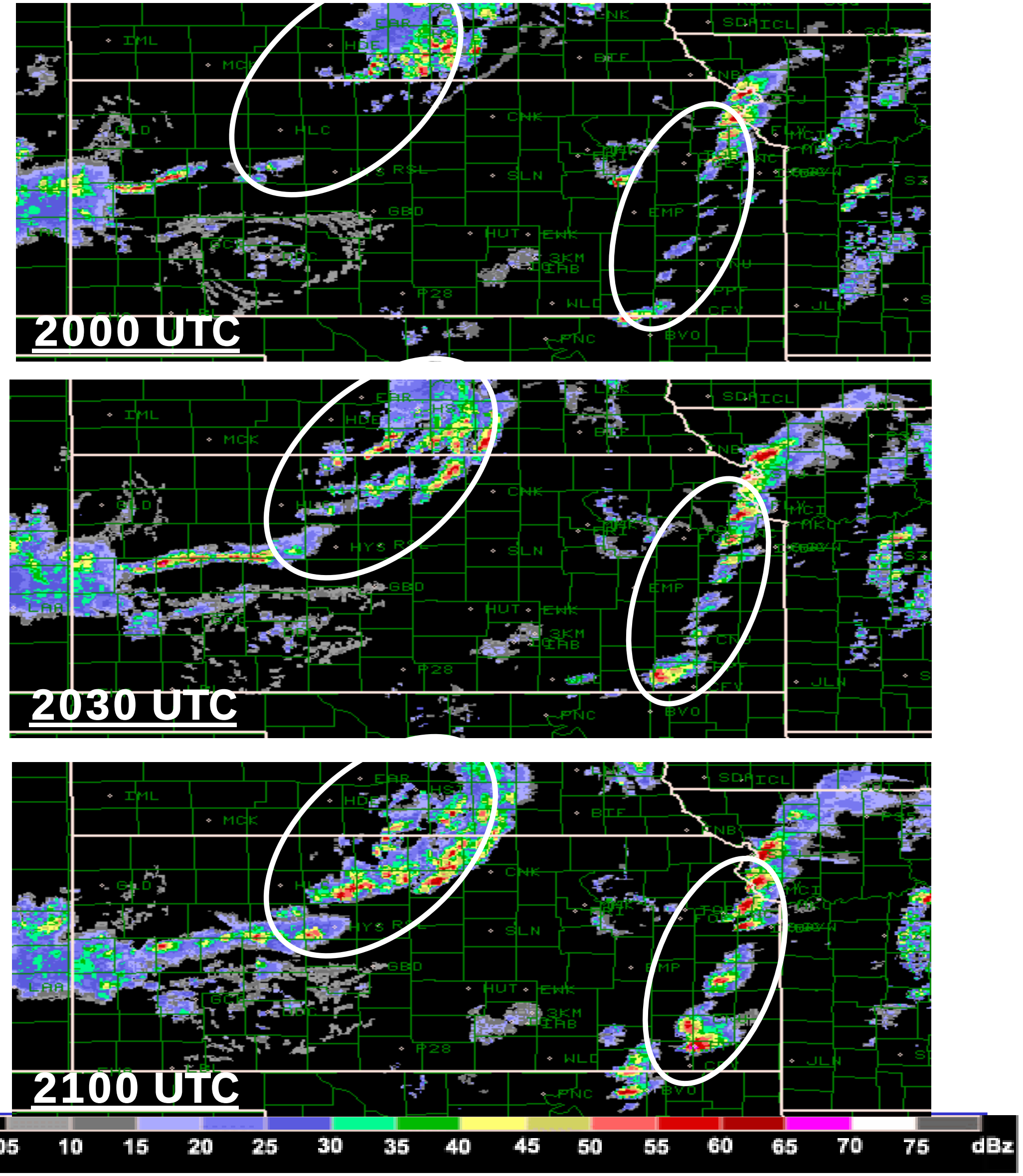

(50% shown)

• **Combination of mesoscale AMV’s with sequences of 10.7 μm $T_B$ imagery to identify growing convective clouds, which represent a hazard to the aviation community**

# Convective initiation (courtesy J. Mecikalski)




These are 1 hour forecasted CI locations!




- Satellite-based CI indicators provided *30-45 min advanced notice* of CI in E. and N. Central Kansas.

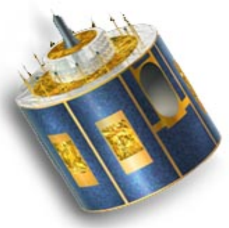
- ***Methods provide ~65% POD scores for 1-hour convective initiation.***

# MTG will provide continuity of EUMETSAT Services

**1977** — ***MOP/MTP***

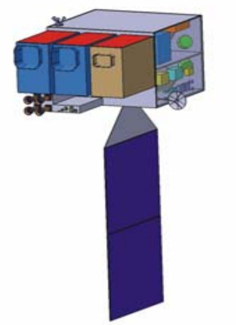
**1** observation mission:
-MVIRI: 3 channels
-**Spinning** satellite
800 kg

**2002** — ***MSG***



**2** observation missions:
- SEVIRI: 12 channels
- GERB
- **Spinning** satellite
Class 2-ton

**2015** — ***MTG***



**4** observation missions:
- Combined Imager: 16 channels
- Infra-Red Sounder
- Lightning Imager
-**3-axis stabilised** satellites
- Twin Sat configuration
2,5 and 2,2 t

Atmospheric Chemistry Mission (UVS) coordinated with ESA for implementation via GMES Sentinel 4/5

**Implementation of the EUMETSAT Mandate for the Geostationary Programme**

**... 30 years of continuous operations achieved ...**

# Polar-orbiting Satellites (Metop)

## EUMETSAT Polar System (EPS)

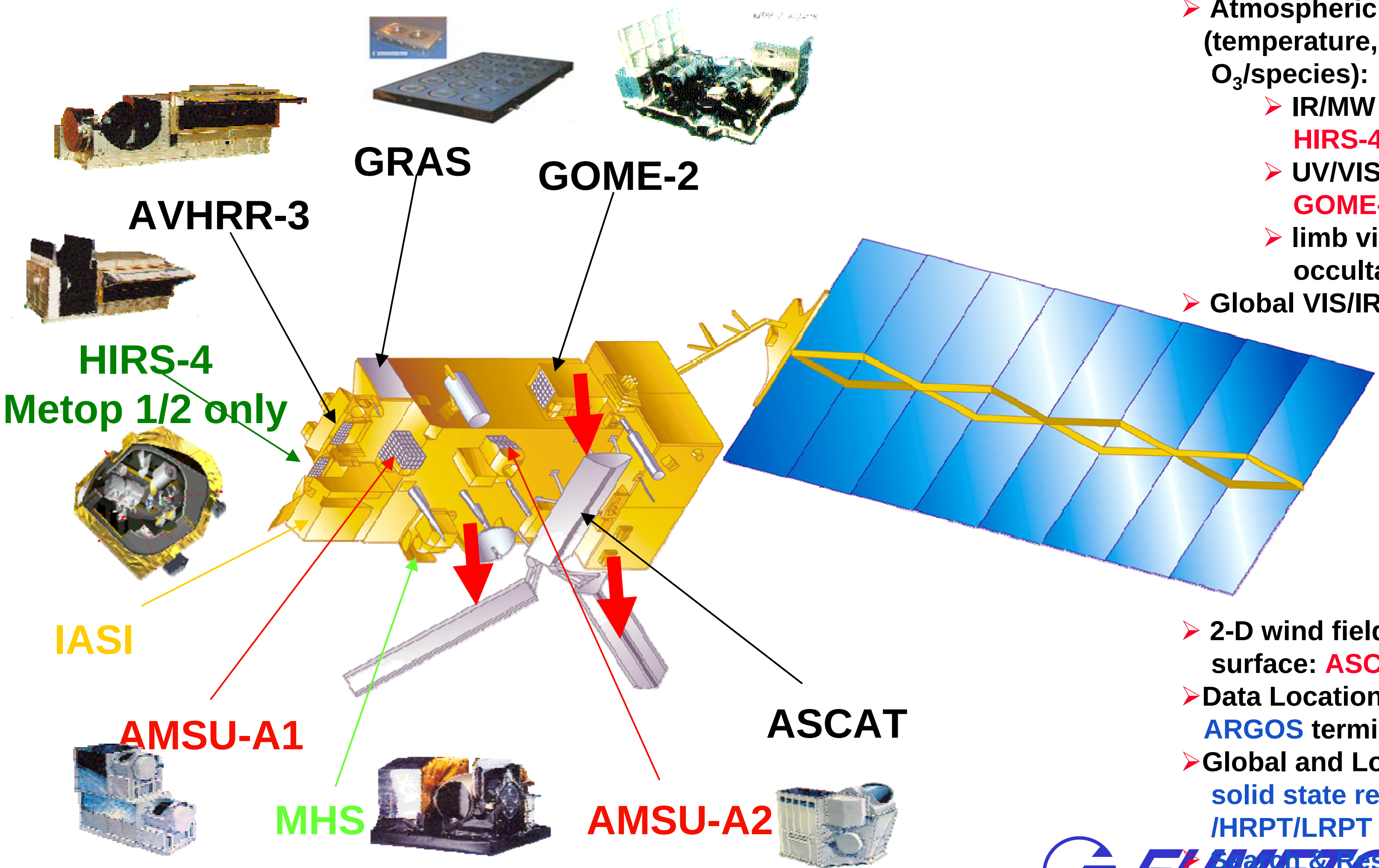
**EUMETSAT Polar System (EPS):**

- a series of three Metop satellites
- operate over  at least 14 years.

- Metop A launched in October 2006

- Metop also contributes to oceanography, environmental observations and fosters research

# EUMETSAT Polar System: Space Segment
# Metop Satellite, Instruments and Missions




- **Atmospheric Sounding (temperature, moisture, $O_3$/species):**
  - **IR/MW imaging sounders: HIRS-4/IASI, AMSU-A/MHS**
  - **UV/VIS imaging sounder : GOME-2**
  - **limb viewing radio-occultation sounder: GRAS**
- **Global VIS/IR Imagery: AVHRR/3**

- **2-D wind field at the ocean surface: ASCAT**
- **Data Location and Collection: ARGOS terminal**
- **Global and Local Data Access: solid state recorder /HRPT/LRPT**
- **Search & Rescue Terminal**

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## Metop instruments: Continuity + heritage + novel technology

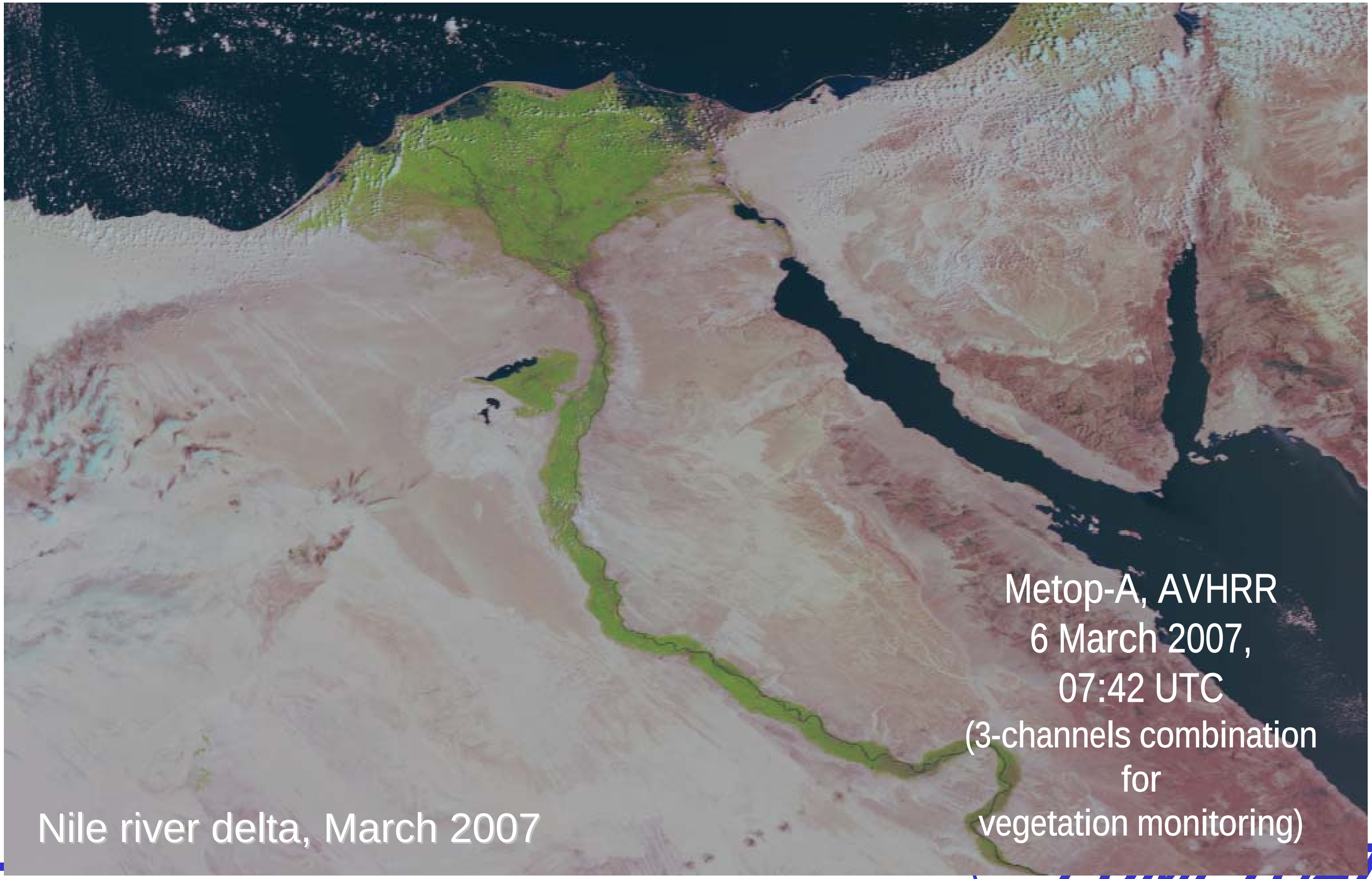
- Continuity:
- - Imaging => AVHRR (NOAA)
- - Sounding => HIRS (NOAA), MHS, AMSU-A (NOAA)
-
- Science heritage:
- - GOME-2 => ozone, aerosol, trace gases (ESA)
- - ASCAT => ocean surface winds (ESA)

- Novel:

- Hyperspectral sounding => IASI (CNES)
- Radio-occultation => GRAS

- => Initial Joint Polar System with NOAA

# Global imaging

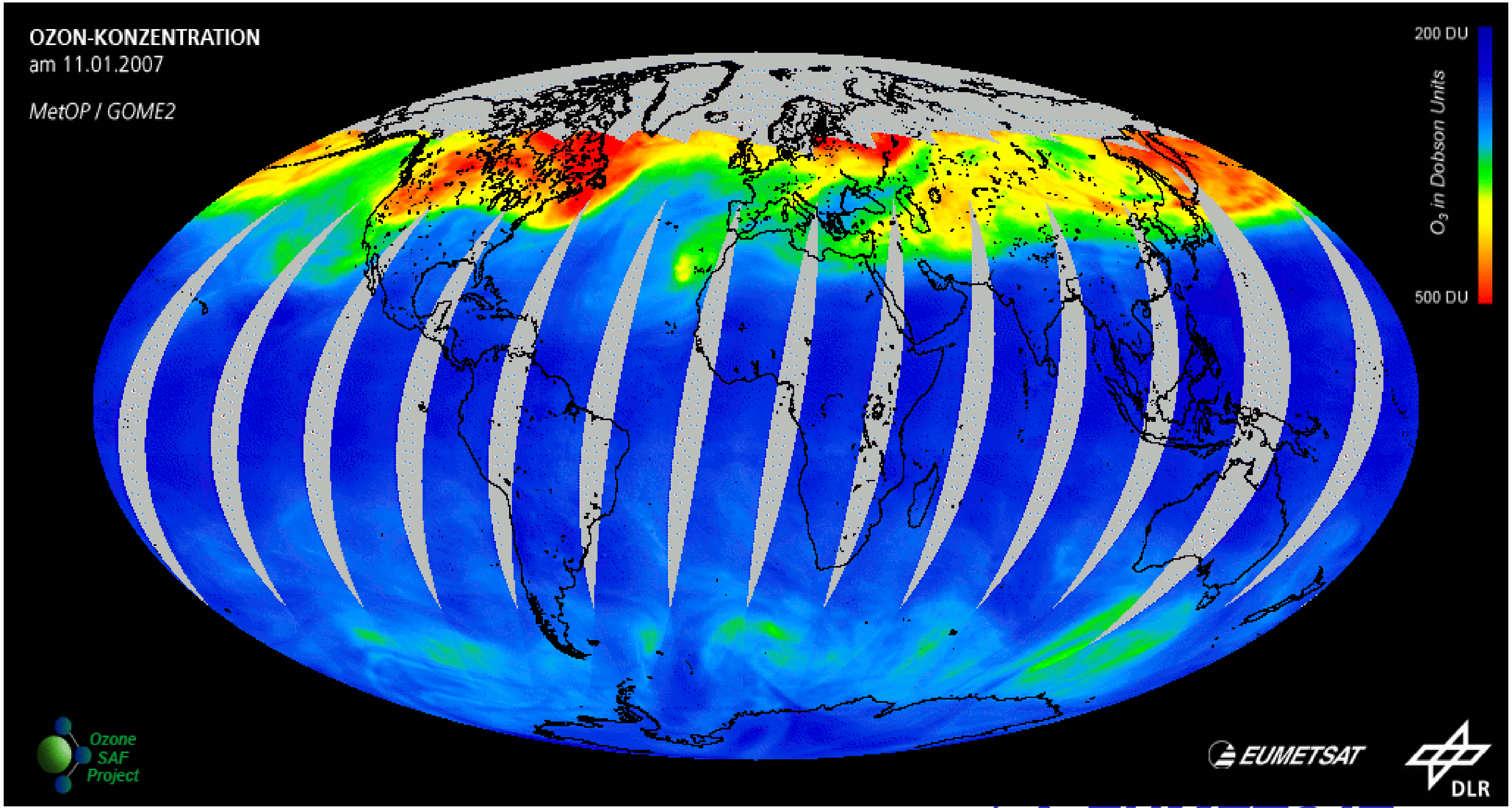


# IASI

- **Covered by dedicated talk by P. Schlüssel**

# GOME-2 Ozone measurements

## Provided courtesy of DLR (O3MSAF) http://wdc.dlr.de/sensors/gome2/index.html



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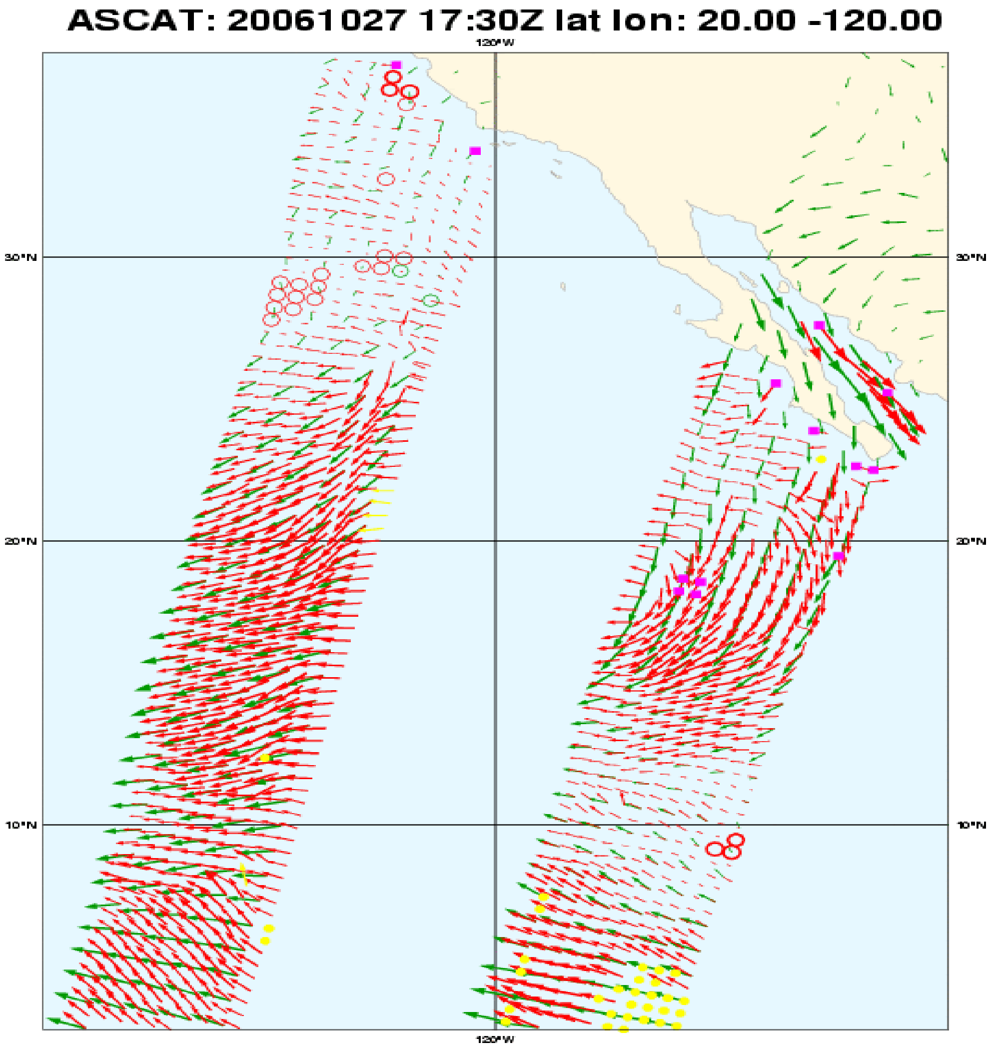
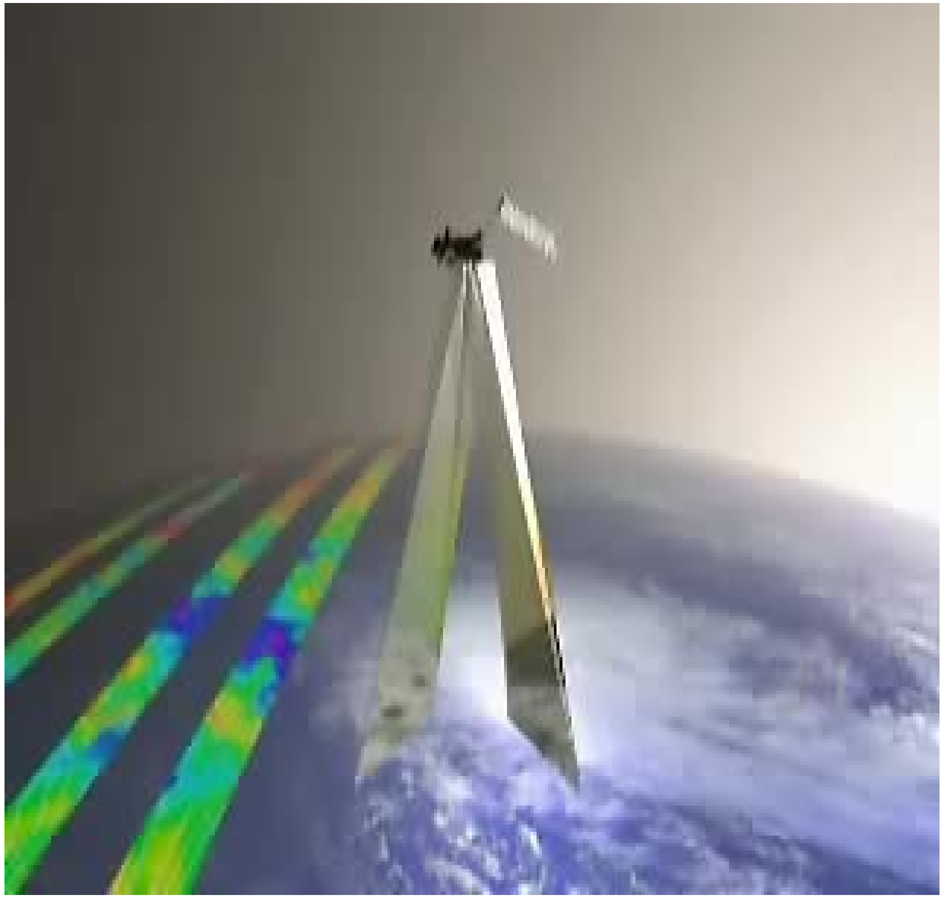
# Winds from ASCAT compared with ECMWF



**Courtesy, ESA, 2006**

Level-2 processing at OSI-SAF, KNMI

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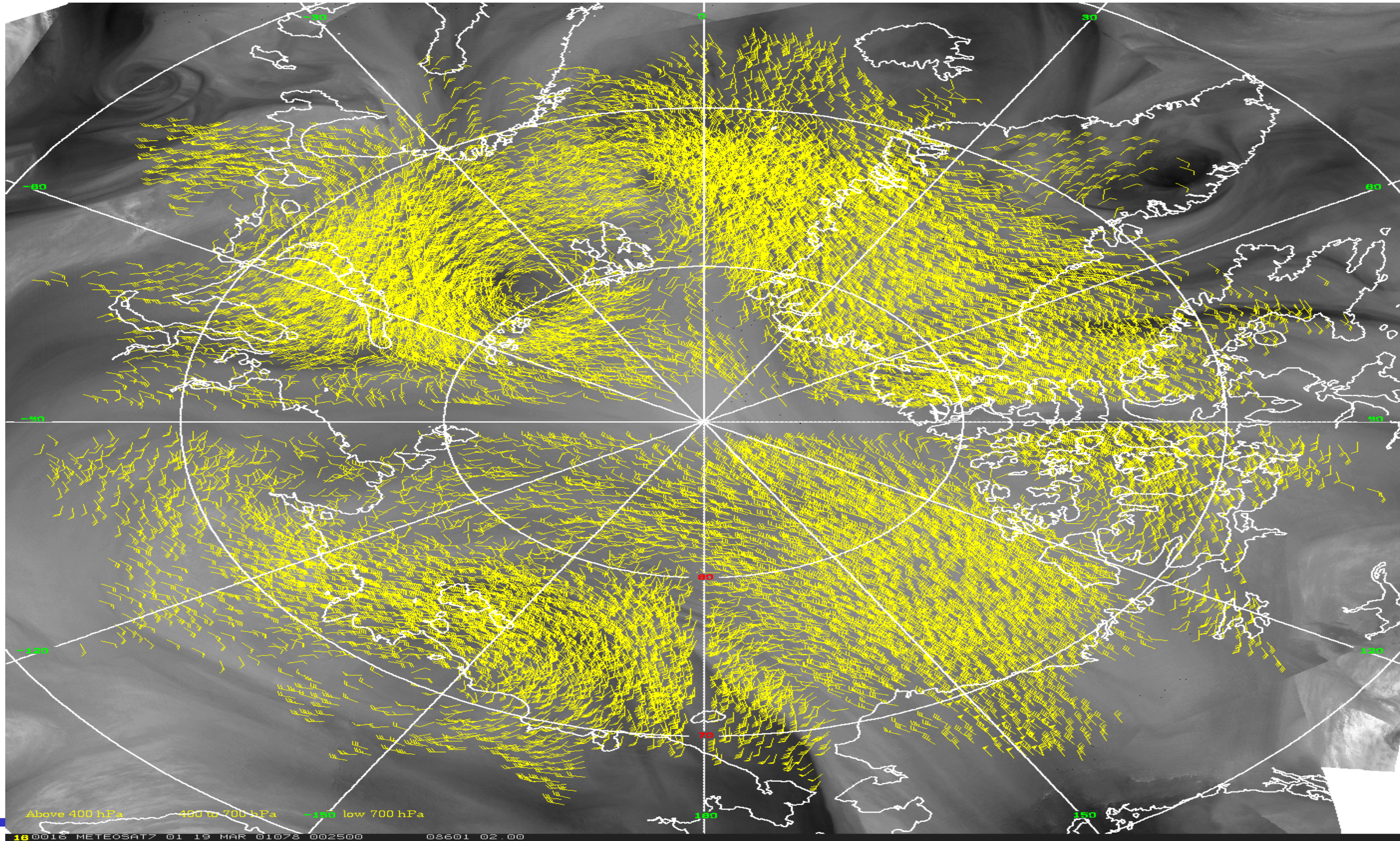
**Winds over polar regions (composite from MODIS), Key et al. 2003**

**⇒Large positive impact on forecasts**

**⇒**

**need to derive winds from AVHRR**



# EUMETSAT Strategic Guidelines for Post-EPS

**EUMETSAT will remain committed, as a minimum and top priority, to the mid - morning sounding mission**

**There is a joint commitment between EUM Member States and NOAA for a future Polar System (JPS)**

**Possible EUMETSAT contribution to a JPS fully open:**

**- instruments across the various orbits;**
**- satellites on different orbits; etc.**

**EUMETSAT will keep responsibility for at least one end-to-end system**

**Need date for the core mission with instruments for Atmospheric Temperature and Humidity Sounding 2018 (1st piority) , followed by the remaining missions in 2020**

# Future polar programme
# Post-EPS

For Post - EPS the user needs in the following areas are considered as result of User Consultation through Expert Groups:

Atmospheric Chemistry;
Atmospheric Sounding and Wind Profiling;
Climate Monitoring;
Cloud, Precipitation and Large Scale Land Surface Imaging;
Ocean Surface Topography and Imaging;
Nowcasting and NWP.

The need date is 2019 and the mission will be balanced with GMES and GEO needs.
Joint technical analysis with ESA.

# Post-EPS Candidate Missions

| Name | Rank |
|---|---|
| High-Resolution Infrared Sounding (IRS) | 3 |
| Microwave Sounding (MWS) | 3 |
| Scatterometry (SCA) | 3 |
| VIS/IR Imaging (VII) | 3 |
| Microwave Imaging (MWI) - Precipitation | 2 |
| Microwave Imaging (MWI) - Ocean and Land | 2 |
| Radio Occultation Sounding (RO) | 2 |
| Nadir viewing UV/VIS/NIR - SWIR Sounding (UVNS) | 1 |
| Doppler Wind Lidar (DWL) | 1 |
| Multi-viewing, Multi-channel, Multi-polarisation Imaging (3MI) | 1 |
| Dual View Radiometry (DVR) | 1 |
| Radar Altimetry (ALT) | 1 |

Note: Rank value 3: highest priority

# ‘Near’ simultaneous observations from space for operational Earth observation – Example: The A-Train (courtesy NASA)

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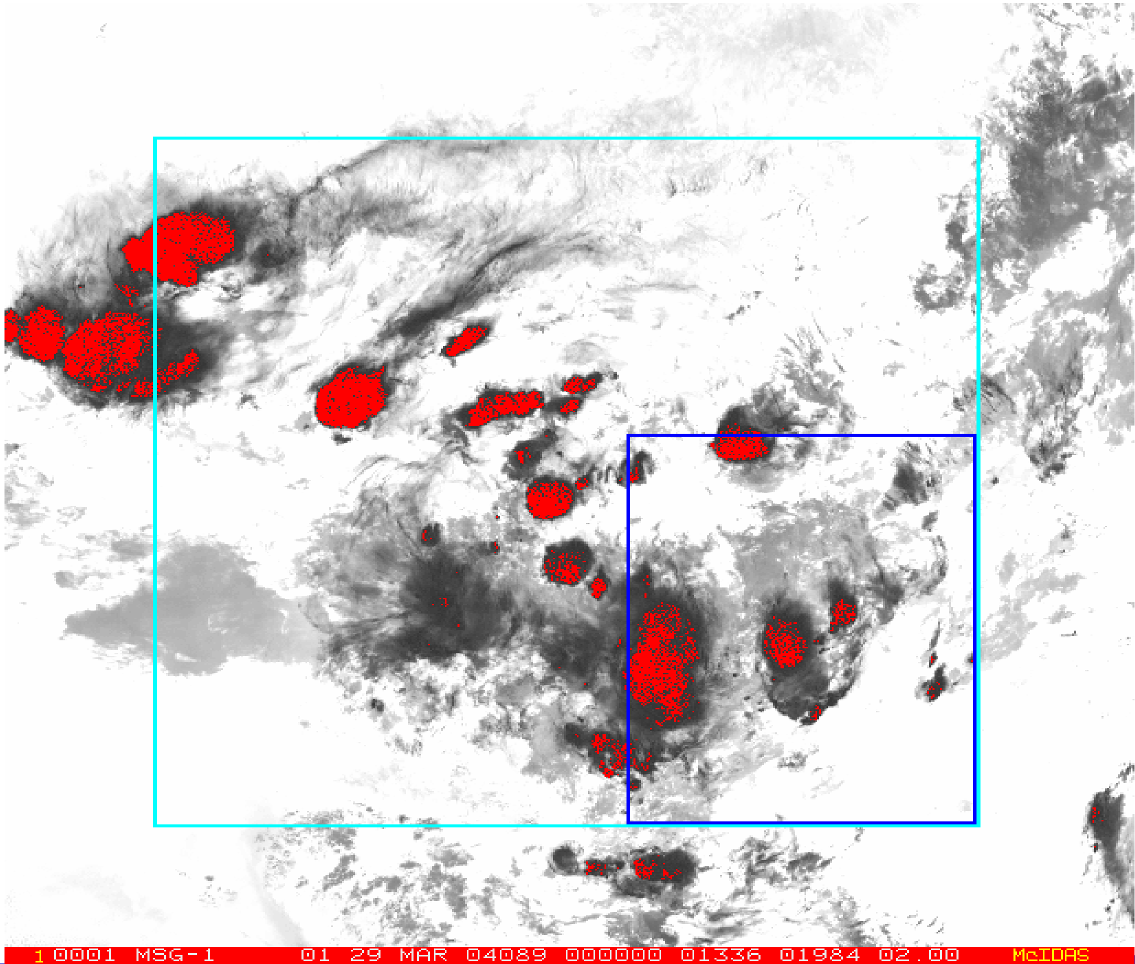
## Thought on a deployment secenario: ‘Near’ simultaneous observations from polar orbit for operational Earth observation:

- **4-D Var assimilation makes need for distribution of observations over time less critical**
- **For process studies and research near simultaneous observations are essential => this will advance understand and utilisation of data**

➢ **Trains of satellites might be an option for operational observations … serves operational (NWP) requirements and fosters research/utilisation**

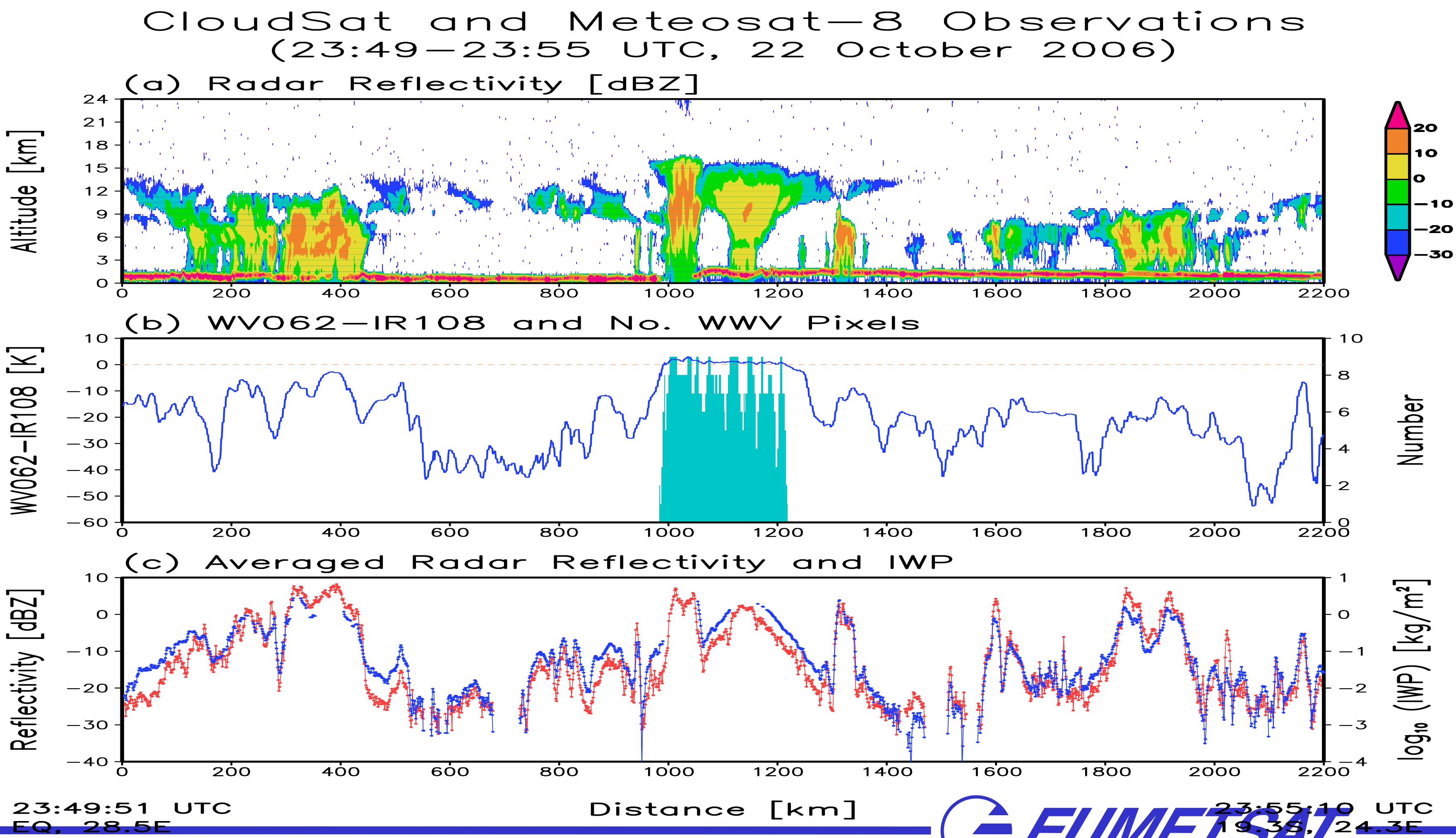
# Meteosat-8 monitors deep convective clouds



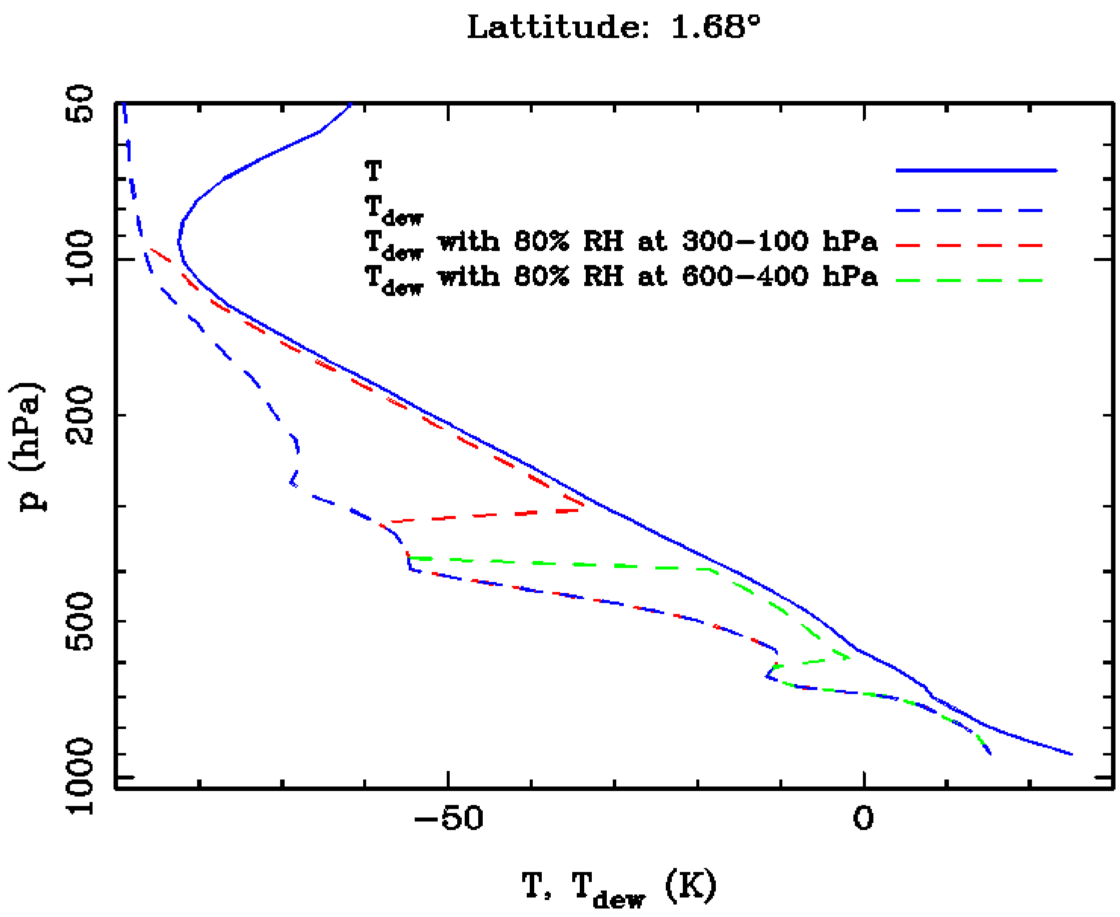

**Red pixels:**
**T6.2 > T10.8**

**How can this be explained?**

# Cloudsat explains physics in areas with T6.2 > T10.8
## (from Cloudsat website and adapted by Chung et al., 2007)

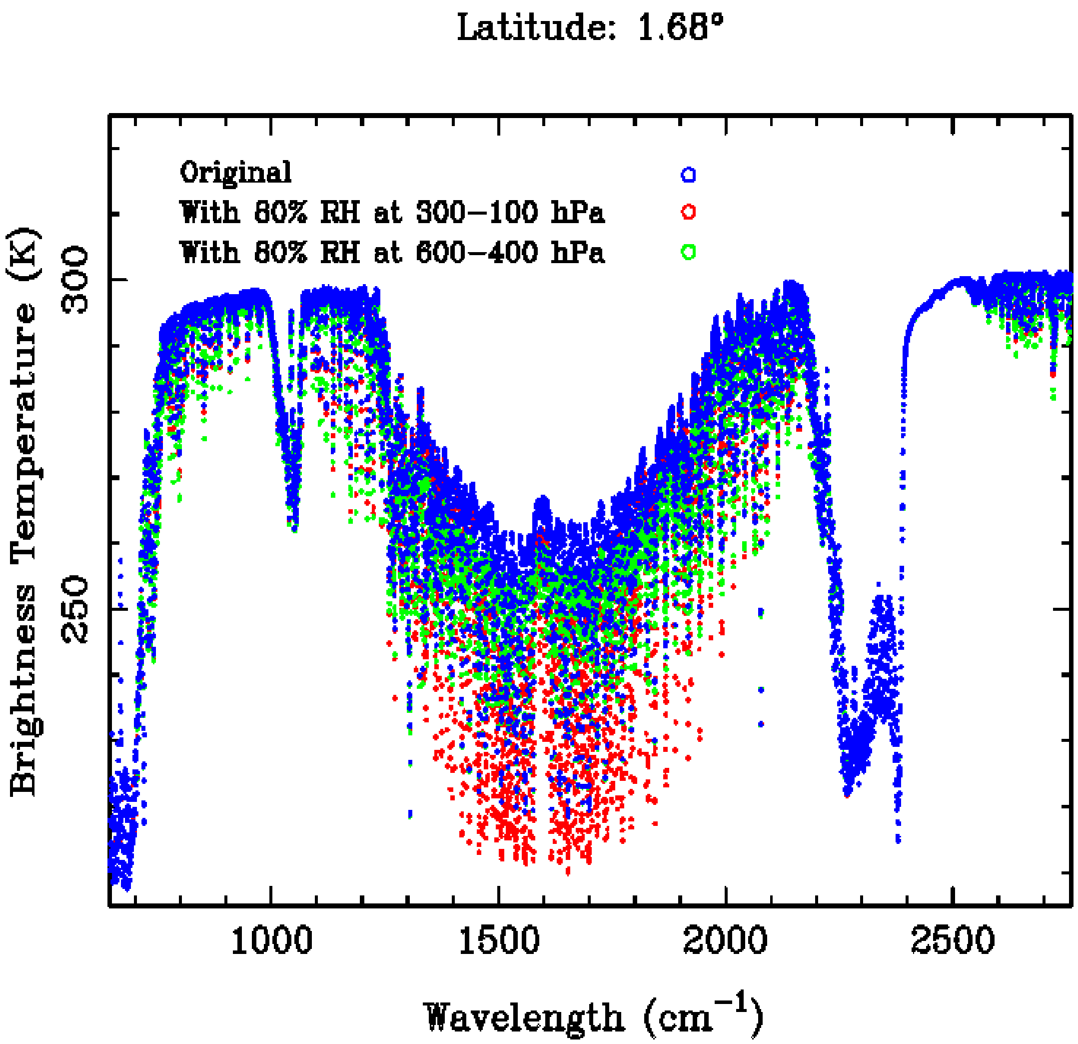


## Input data for IASI simulated spectra for a tropical atmosphere




IASI simulation by X. Calbet, personal ommunication

# IASI simulated spectra for a tropical atmosphere




**A hyperspectral sounder in a geostationary orbit could vertically slice and track the moisture outflow in tropical convective regions**

**⇒ an important process in the global water cycle**
**⇒ e.g. moistening of the UTLS**

IASI simulation by X. Calbet, personal communication



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## Reasons behind improvements in NWP due to satellite data

*(from Uccellini, 2007)*

- **Improvement due to a balance among**
  - **Observations**
  - **Data Assimilation & Model technology**
  - **Computing resources**
- **Estimated 30 - 40% of improvement from observations (principally global LEO satellite data) and 60 - 70% from data assimilation and modeling techniques and computing resources**

**Need to foster utilisation and continuous development has been recognised:**
**=> De-centralised applications ground segment:**
**Satellite Application Facilities (SAF)**

- Support to Nowcasting and Very Short Range Forecasting
- Ocean and Sea Ice
- Climate Monitoring
- Numerical Weather Prediction
- Land Surface Analysis
- Ozone & Atmospheric Chemistry Monitoring
- GRAS Meteorology
- Support to Operational Hydrology and Water Management

**=> BENEFITS:**

- Makes use of European expertise,
- Fosters cooperation and utilisation,
- Maximises return on investment

# The importance of good satellite calibration
# => GSICS (Global Space-based Inter-Calibration System)

- To improve the use of space-based global observations for weather, climate and environmental applications through operational inter-calibration of satellite sensors.

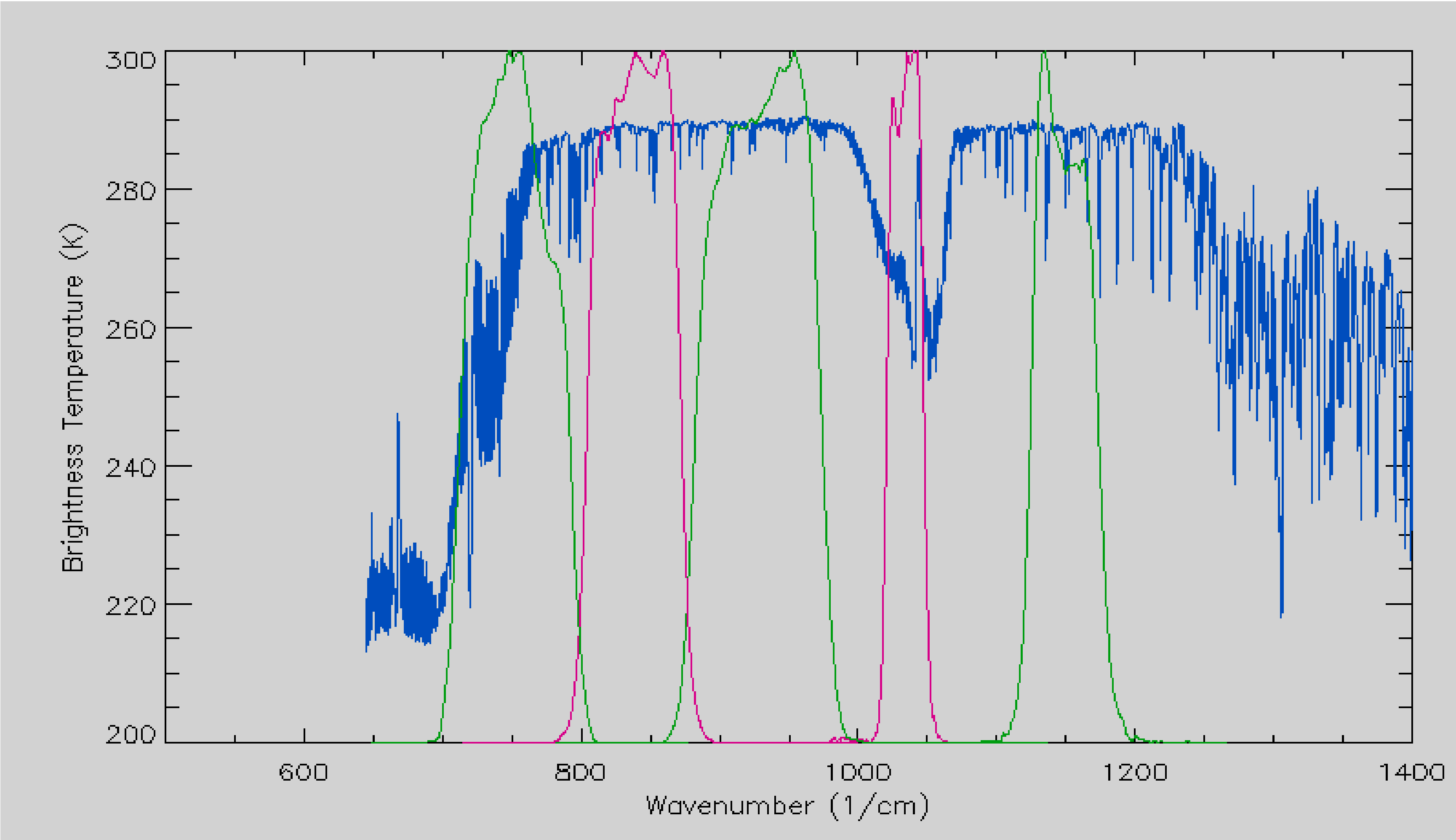
- Improve global satellite data sets by ensuring observations are well calibrated through operational analysis of instrument performance, satellite intercalibration, and validation over reference sites

- Provide ability to re-calibrate archived satellite data with consensus GSICS approach, leading to stable fundamental climate data records (FCDR)

- Ensure pre-launch testing is traceable to SI standards

- => Under WMO Space Programme
  - GSICS Implementation Plan and Program formally endorsed
  - at CGMS 34 (11/06)

# GSICS: Intercalibrating MSG with IASI




IR13.4 IR12.0 IR10.8 IR9.7 IR8.7

# IASI – like instruments will be excellent reference for calibration => climate monitoring

| Channel | ΔT IASI – Meteosat-8* | ΔT IASI – Meteosat-9 * |
|---|---|---|
| IR3.9 | -0.17 | -0.20 |
| WV6.2 | -0.24 | -0.40 |
| WV7.3 | -0.51 | -0.14 |
| IR8.7 | 0.15 | 0.15 |
| IR9.7 | 0.17 | 0.20 |
| IR10.8 | 0.16 | 0.07 |
| IR12.0 | 0.19 | 0.08 |
| IR13.4 | 0.44 | 1.7 |

***Uncertainty 0.1 – 0.2 K**

# Conclusion (1)

• Operational satellites do provide important contribution to meteorological services

• Need for continuous development of utilisation techniques ( e.g. algorithms, timeliness, interpretation, …)

• Future satellite missions hold promise for improved weather forecasting, better climate monitoring and better understanding of physical processes

• Realisation of future satellite systems is result of competing and complementary interests from: i) Existing operational requirements, ii) Science and anticipated future applications, iii) Technical constraints (feasibility), iv) Political considerations and v) Affordability

# Conclusions (2)

- **EUMETSAT satellite systems (Meteosat and Metop) are key elements of the operational space-based observing system**
- **Continuity and serving the evolving needs of our Member States has highest priority**
- **EUMETSAT's International partnership (e.g. the Joint Polar System with NOAA) ensures a European contribution to a Global Earth Observation System of Systems (GEOSS) that are mutually consistent and also cost-effective**
- **EUMETSAT mandate evolves, therefore a further priority is to develop new activities in operational oceanography and atmosphere monitoring jointly with partners (ESA, NOAA, ….)**
- **More information (including SAF links): www.eumetsat.int**