Satellite Observations

Mohamed Dahoui
Mohamed.Dahoui@ecmwf.int
Office 160 Phone +44-118-9499 043

Outline

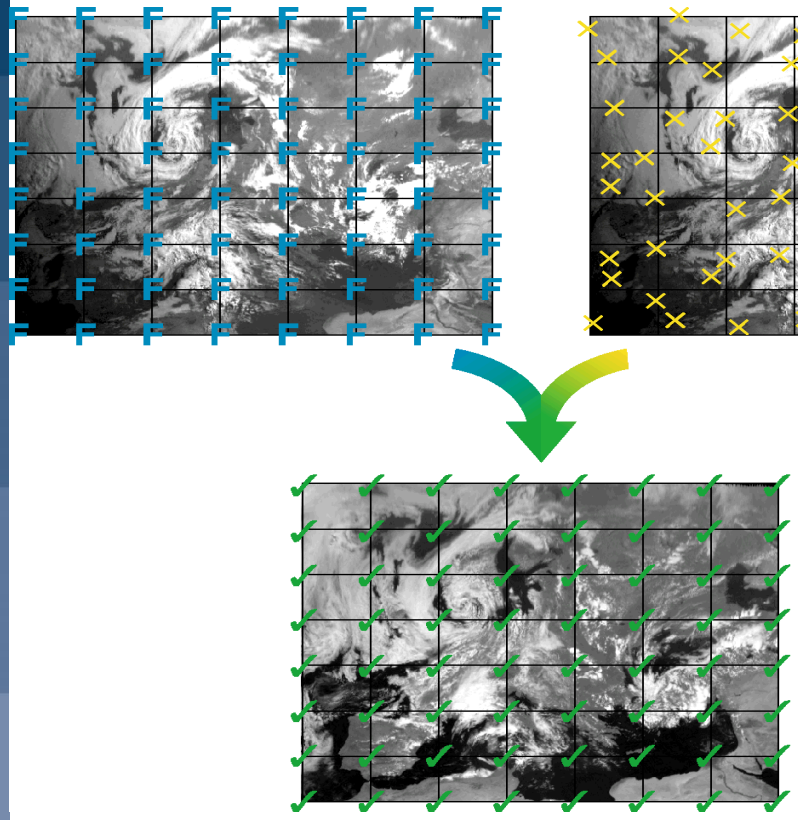
- **Data sources and role of satellite observations**
- **What do satellites measure ?**
- **Assimilation and monitoring of satellite data**

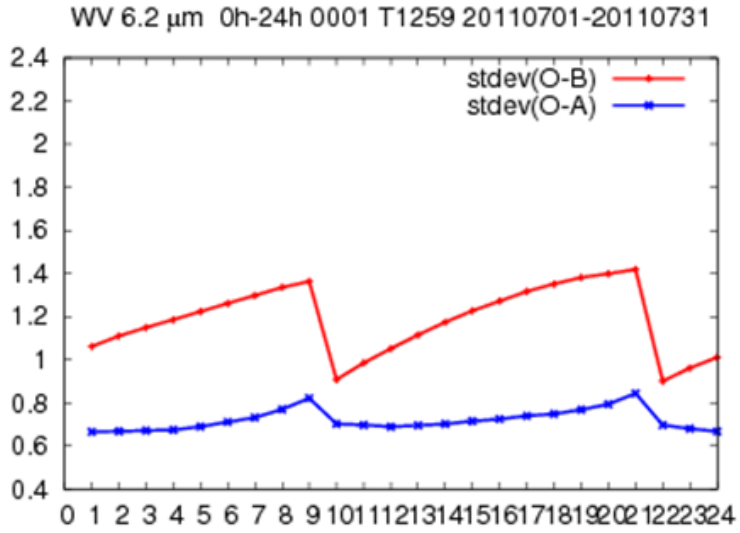
Outline

- **Data sources and role of satellite observations**
- **What do satellites measure ?**
- **Assimilation and monitoring of satellite data**

Role of observations

Every 12 hours we assimilate ~7,000,000 observations to correct the 100,000,000 variables that define the model's initial state..





Observations limit error growth and make forecasting possible....

conventional observations

SYNOP/SHIP/METAR:

→ **temperature, dew-point temperature, wind (land: 2m, ships: 25m)**

BUOYS:

→ **temperature, pressure, wind**

TEMP/TEMPSHIP/DROPSONDES:

→ **temperature, humidity, pressure, wind *profiles***

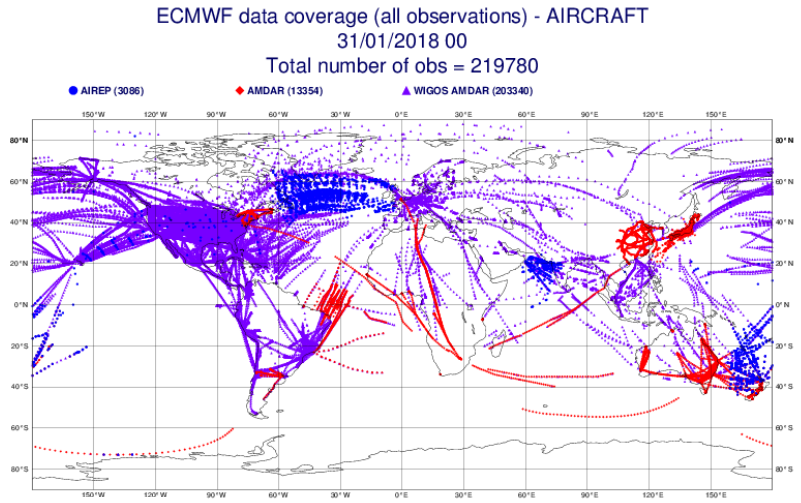
PROFILERS:

→ **wind *profiles***

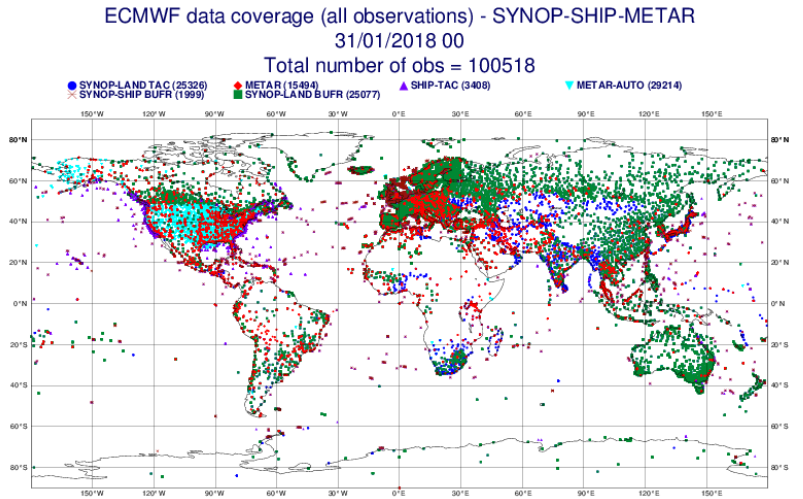
Aircraft:

→ **temperature, pressure, wind *profiles***

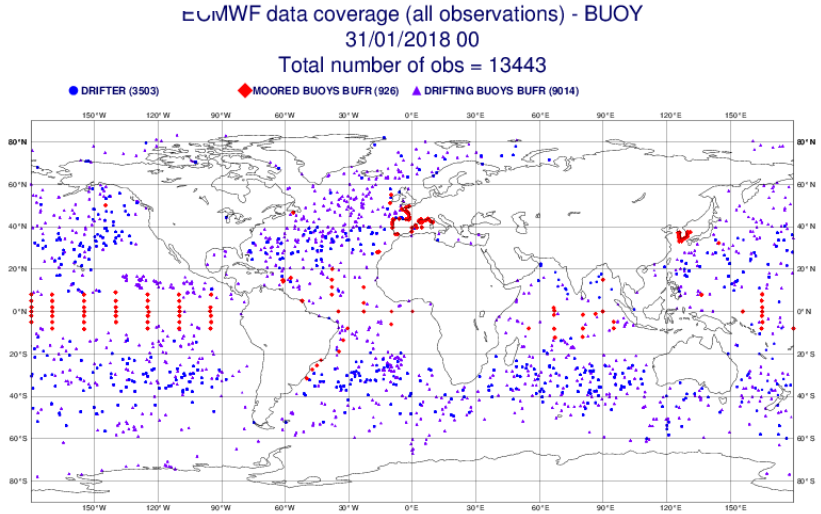
Example of conventional data coverage (6 hours)



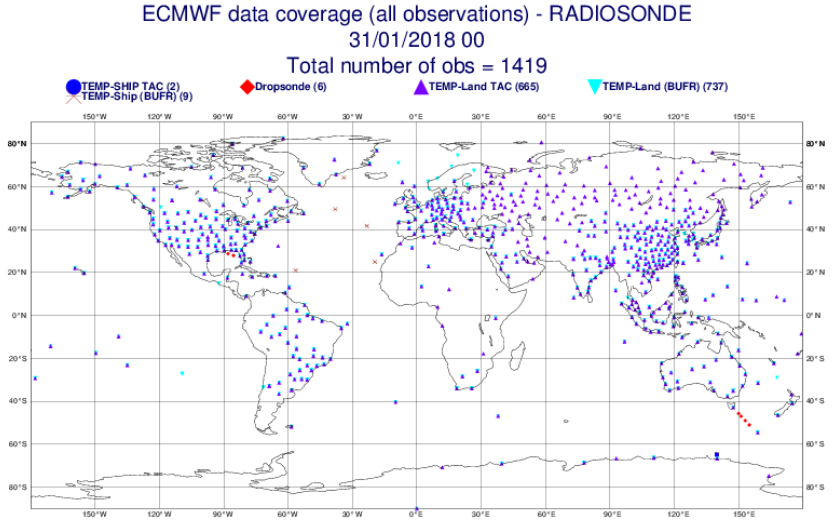
Aircraft



Synop-Metar-Ship



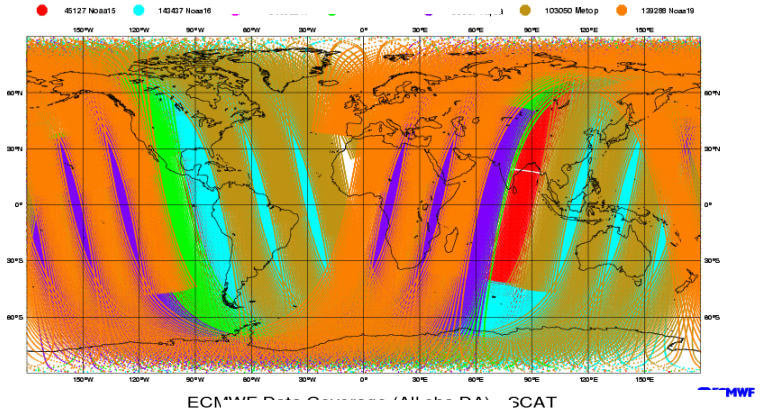
Buoy



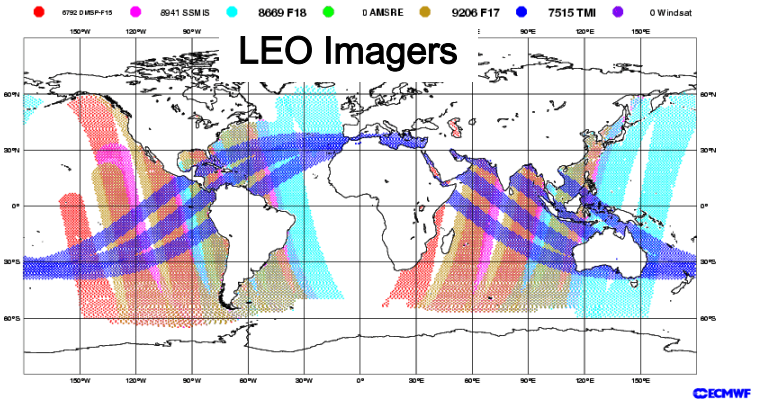
Radiosondes

Example of 6-hourly satellite data coverage

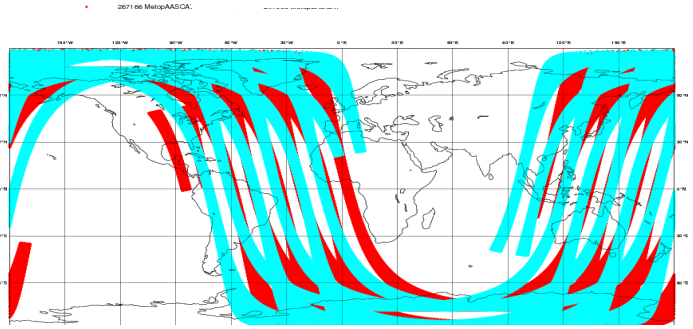
LEO Sounders



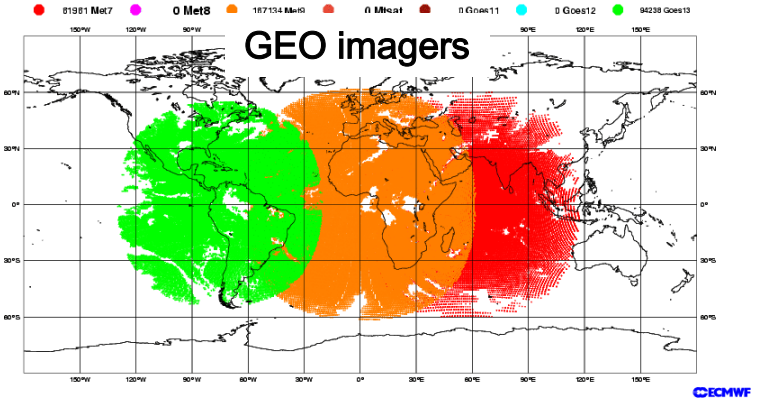
LEO Imagers



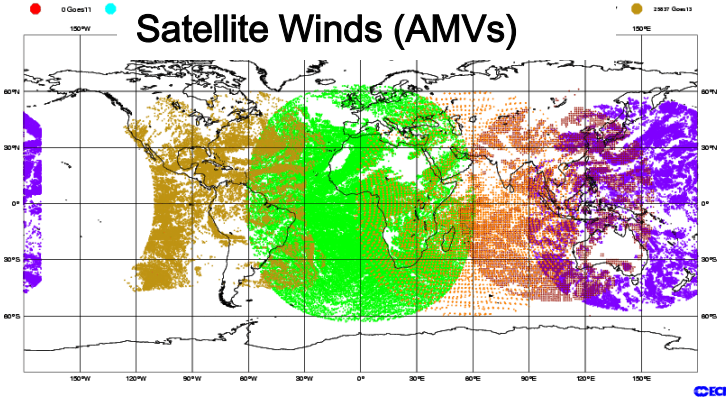
Scatterometers



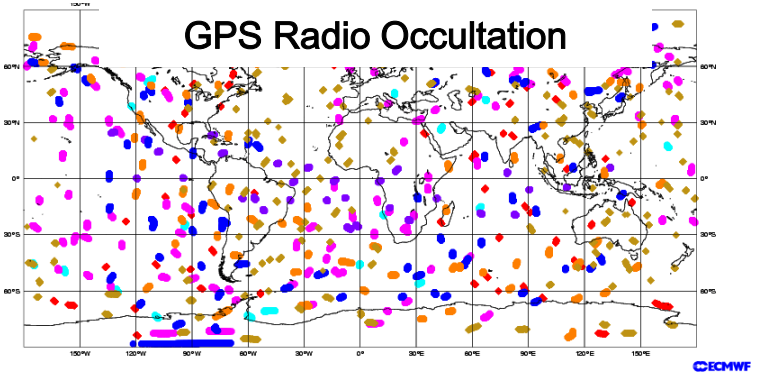
GEO imagers



Satellite Winds (AMVs)

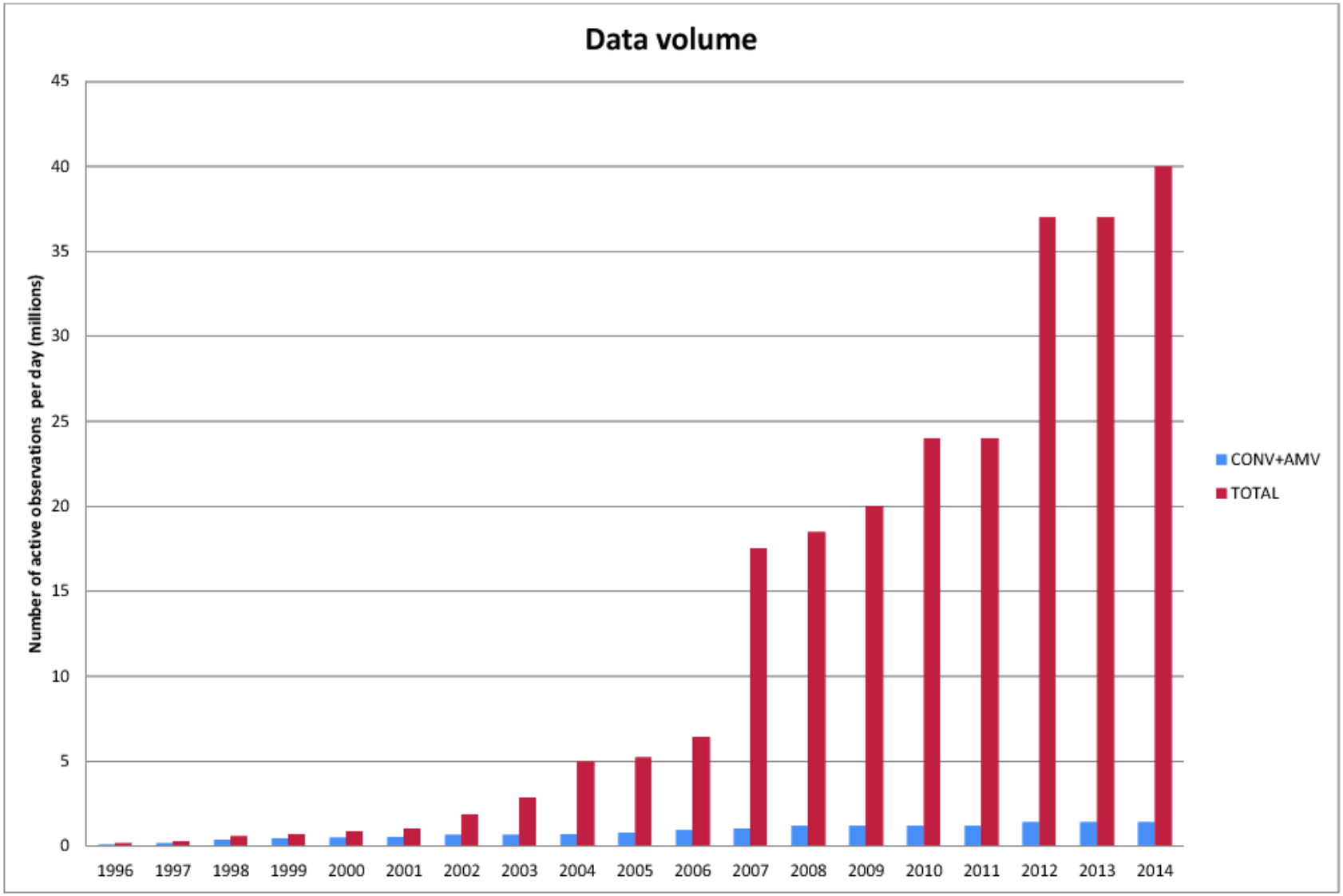


GPS Radio Occultation

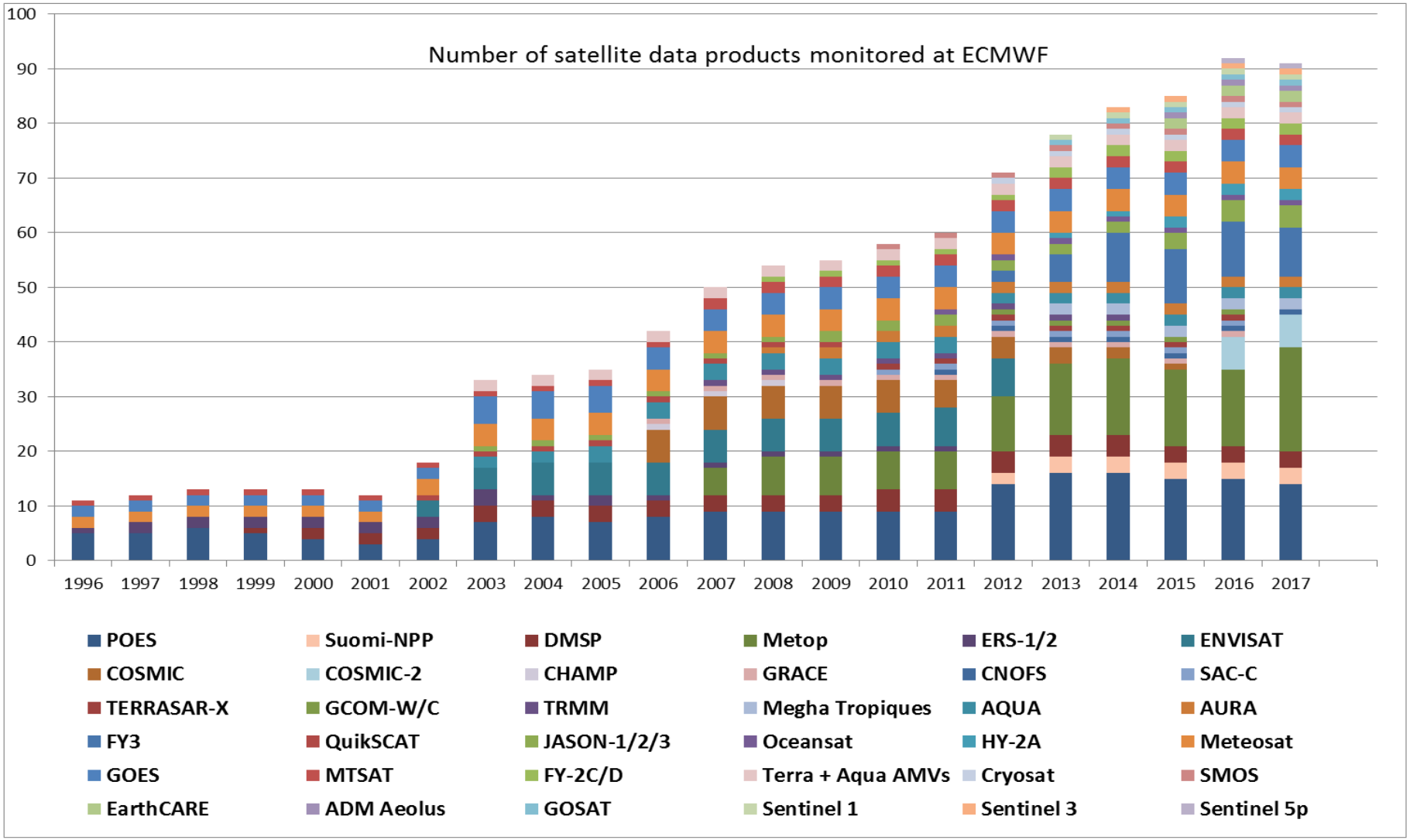


30 March 2012 00 UTC

Number of used satellite data is increasing



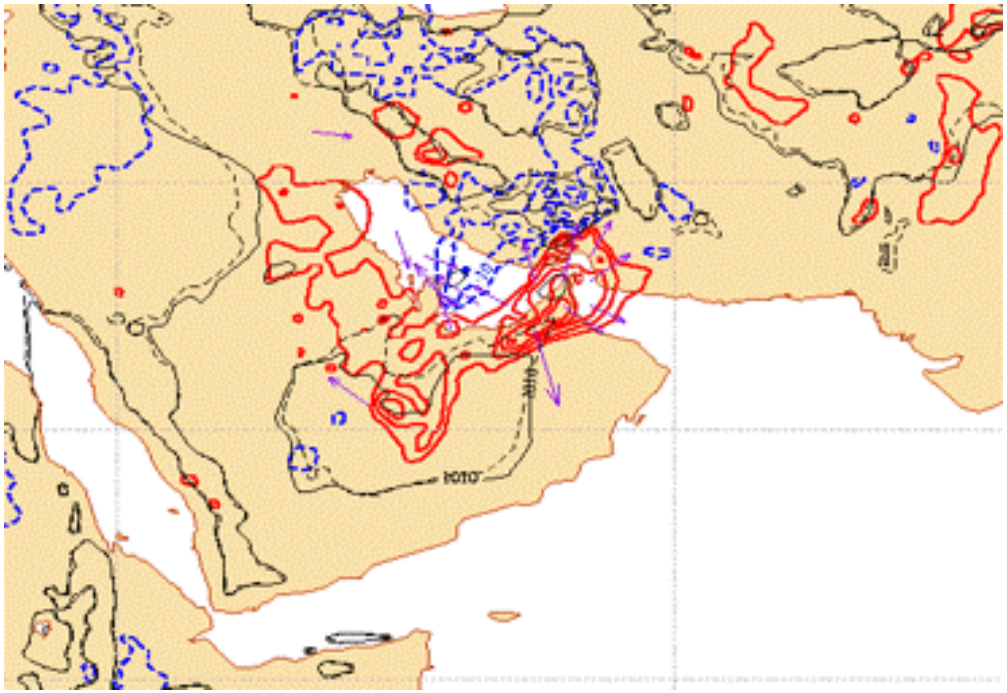
Number of used satellite data is increasing



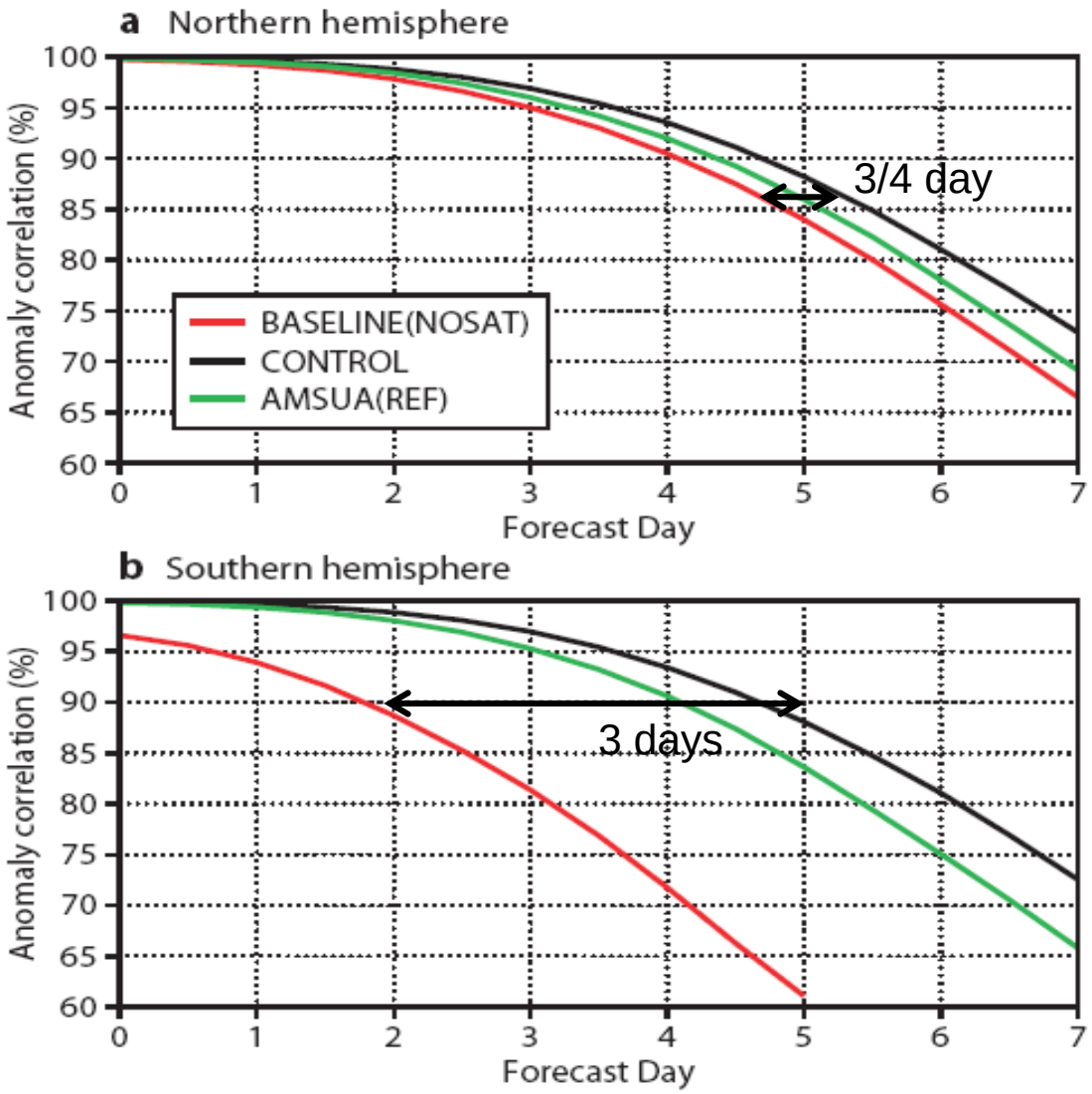
Slide from S. English

Why important ?

- **Vital** for less observed regions (oceans, deserts).
- **global coverage with a high spatial and temporal resolution.**
- Capacity to correct **small-amplitude** large scale errors



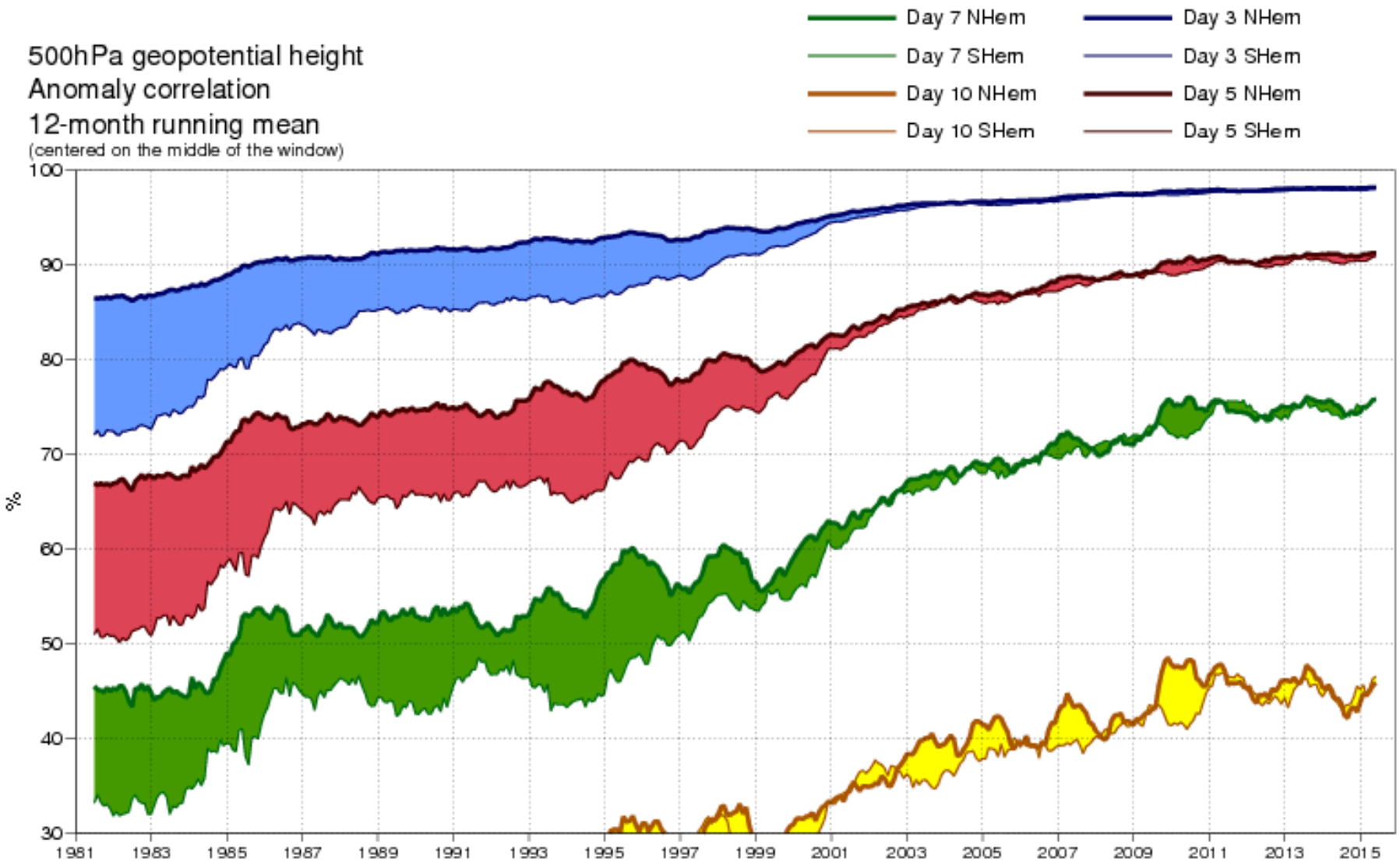
Why important ?



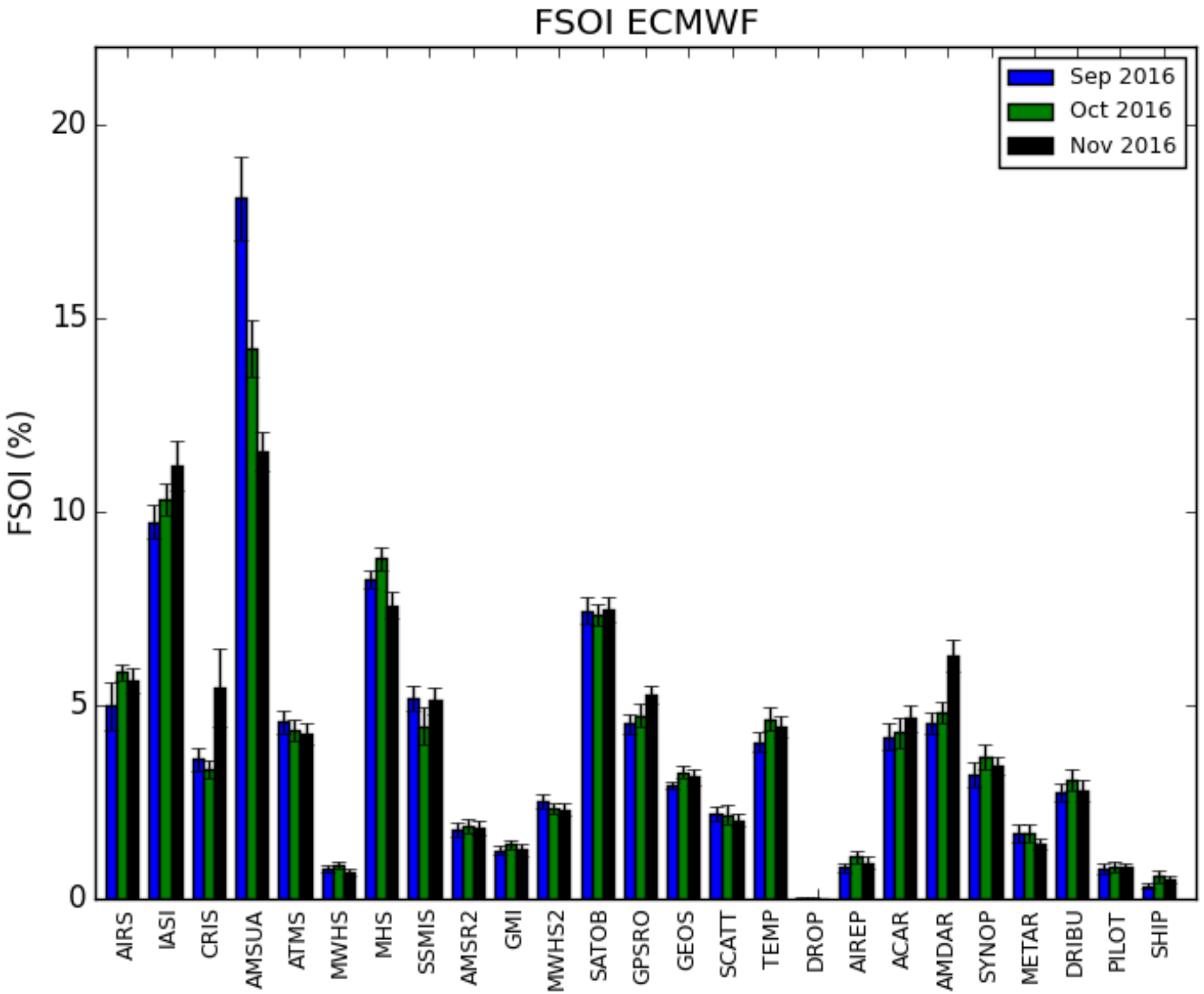
EUCOS Observing System Experiments (OSEs):

- 2007 ECMWF forecasting system,
- winter & summer season,
- different baseline systems:
  - no satellite data (NOSAT),
  - NOSAT + 1 AMSU-A,
  - Control (all data)

Why important ?



Forecast Sensitivity to Observations Impact

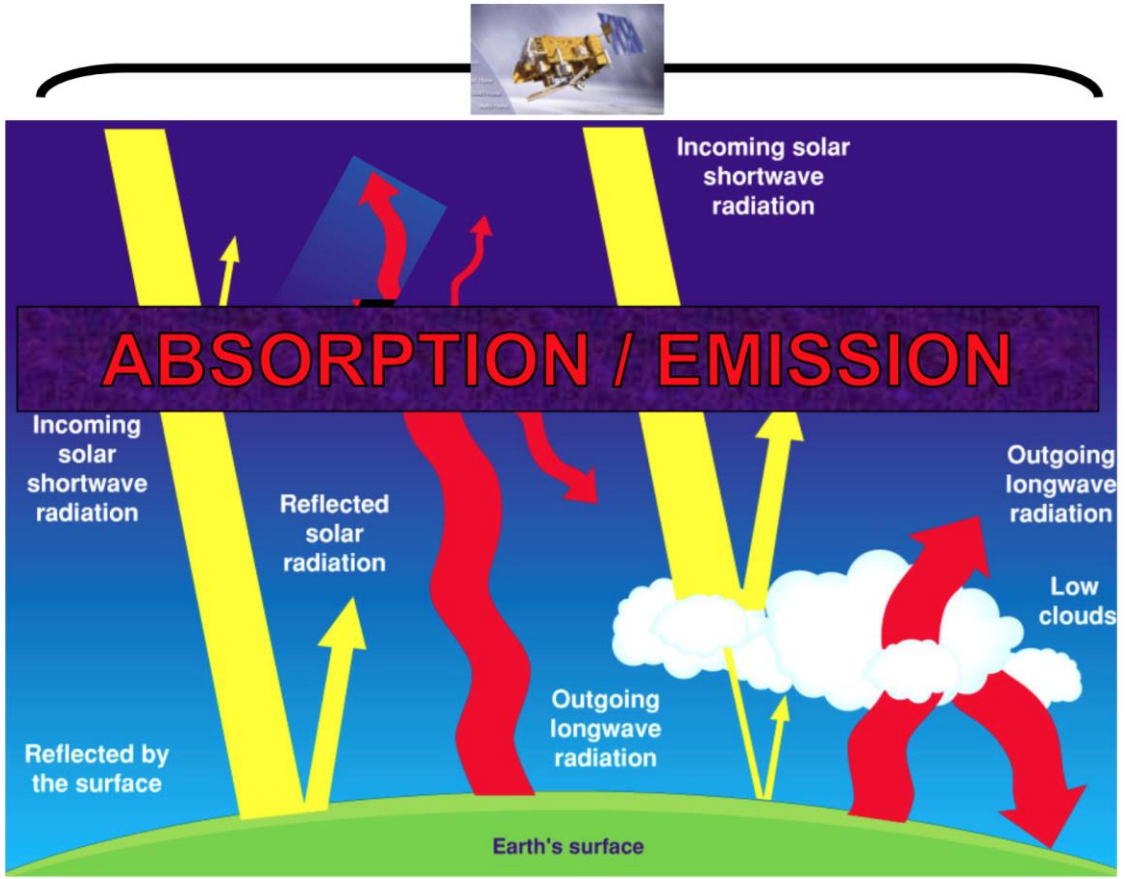


Outline

- Data sources and role of satellite observations
- **What do satellites measure ?**
- Assimilation and monitoring of satellite data

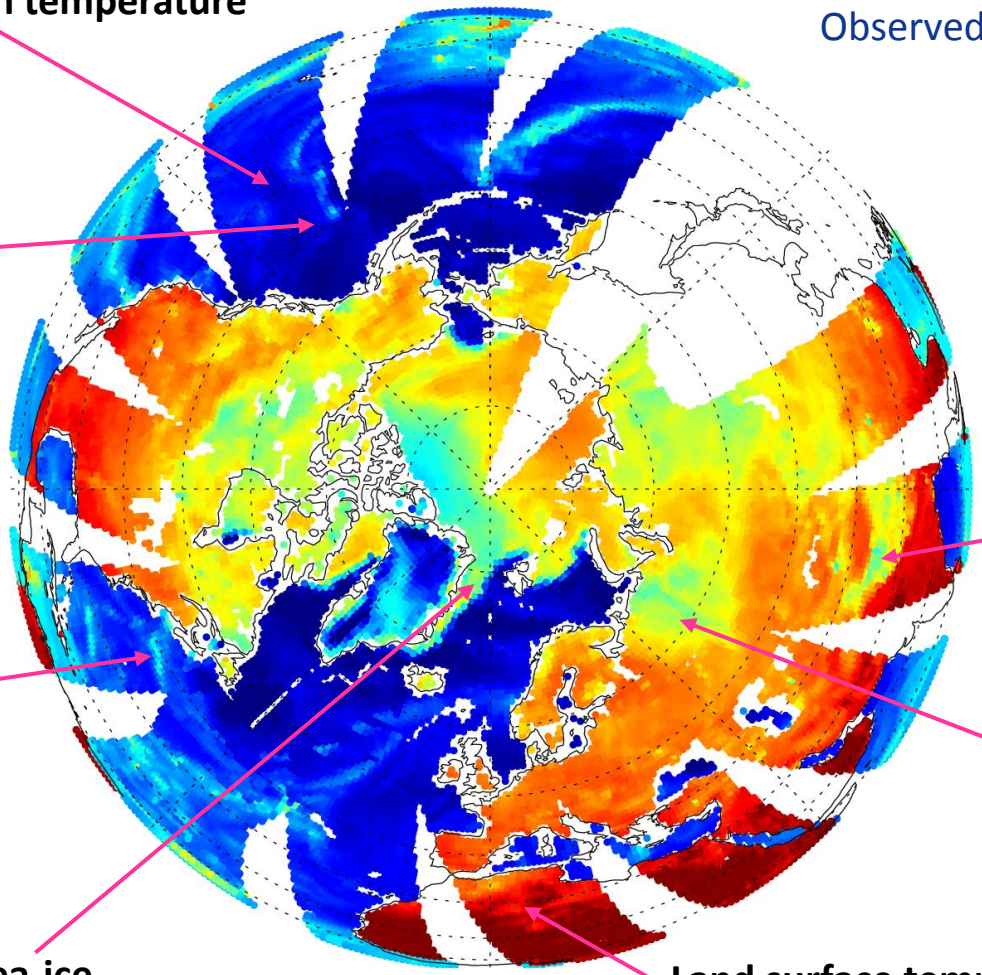
Satellites ONLY measure out-going electromagnetic radiation from the atmosphere at selected frequencies

Measured radiance is related to geophysical atmospheric parameters (Temperature, Wind, Humidity, etc) by the radiative transfer equation



Geophysical parameters

SSMIS F-17 channel 13 (19 GHz, v)
Observed TB, 3rd December 2014



Ocean waves, wind, skin temperature

Atmospheric water vapour

Cloud and precipitation

Sea-ice

High altitude

Snow cover

Land surface temperature, biomass, soil/rock, soil moisture

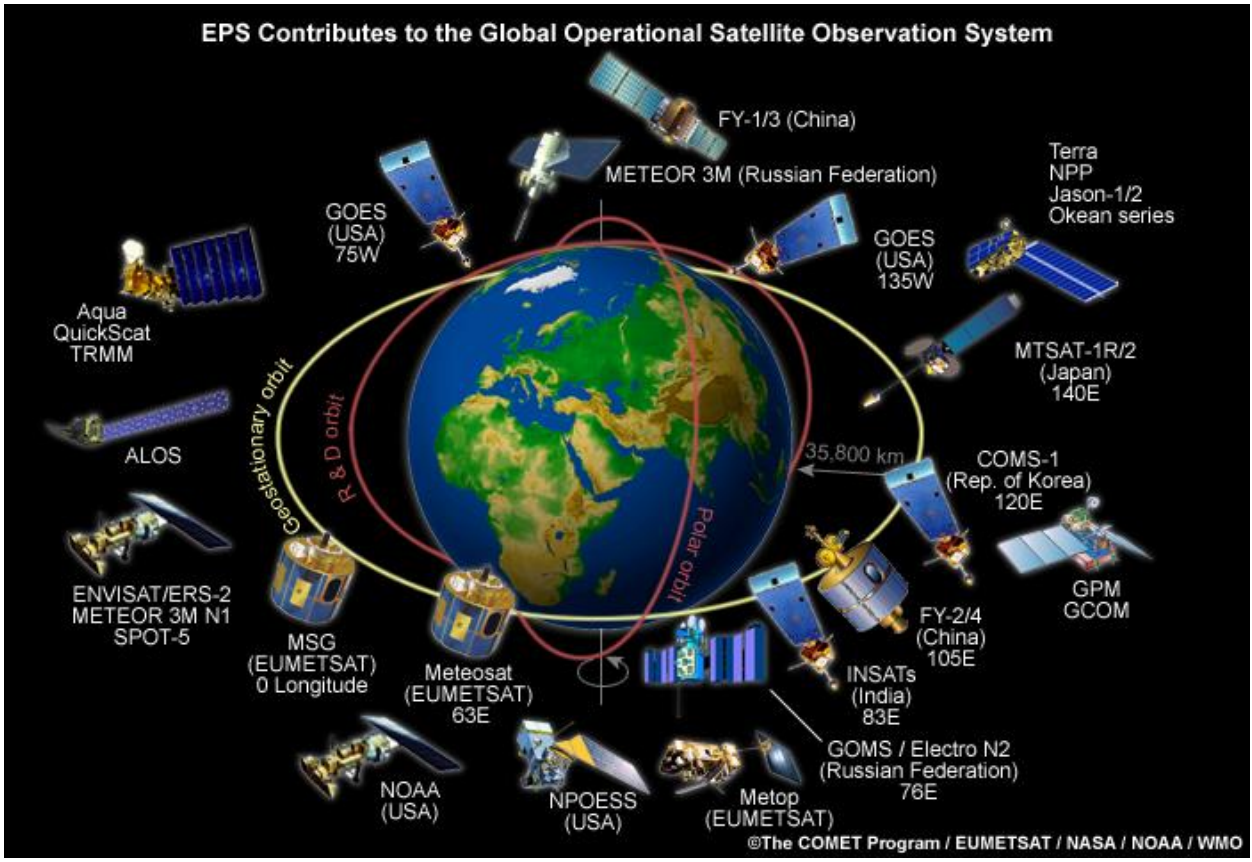
Types of satellites

- **Geostationary satellites (GEO)**

  Orbits in earth's equatorial plan at heights of 36.000 Km

- **Low Orbiting satellites (LEO)**

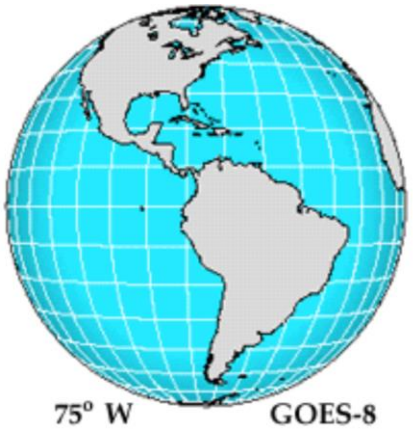
  Orbits at heights between 400 and 850 Km



GEO satellites

Advantages

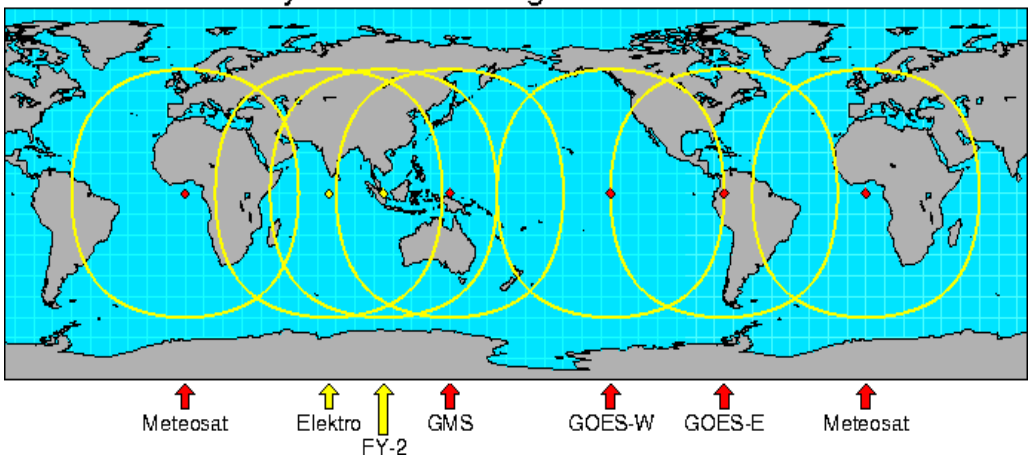
- Good regional coverage
- Excellent temporal resolution



Limitations

- No global coverage by a single satellite (collaboration needed)
- Unsuitable for polar regions
- Microwave spectrum is not observed

Global Geostationary Satellite Coverage



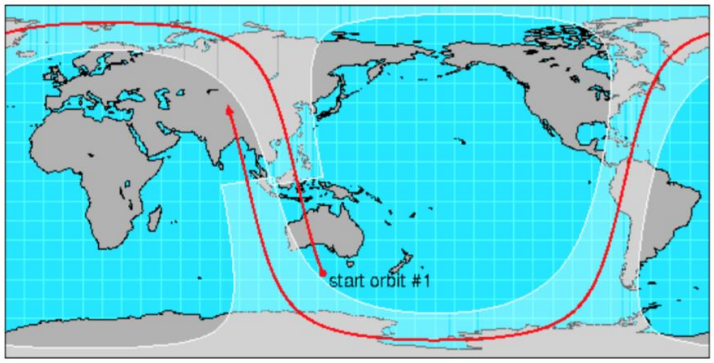
LEO satellites

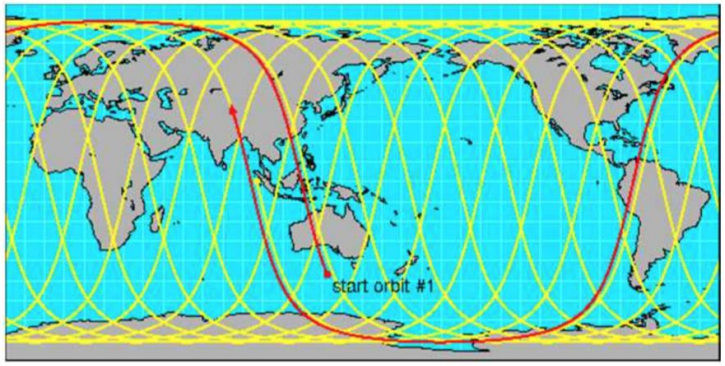
Advantages

- Global coverage with single satellite
- Good spatial and spectral resolution
- All the meteorologically useful electromagnetic spectrum can be covered (including microwave)

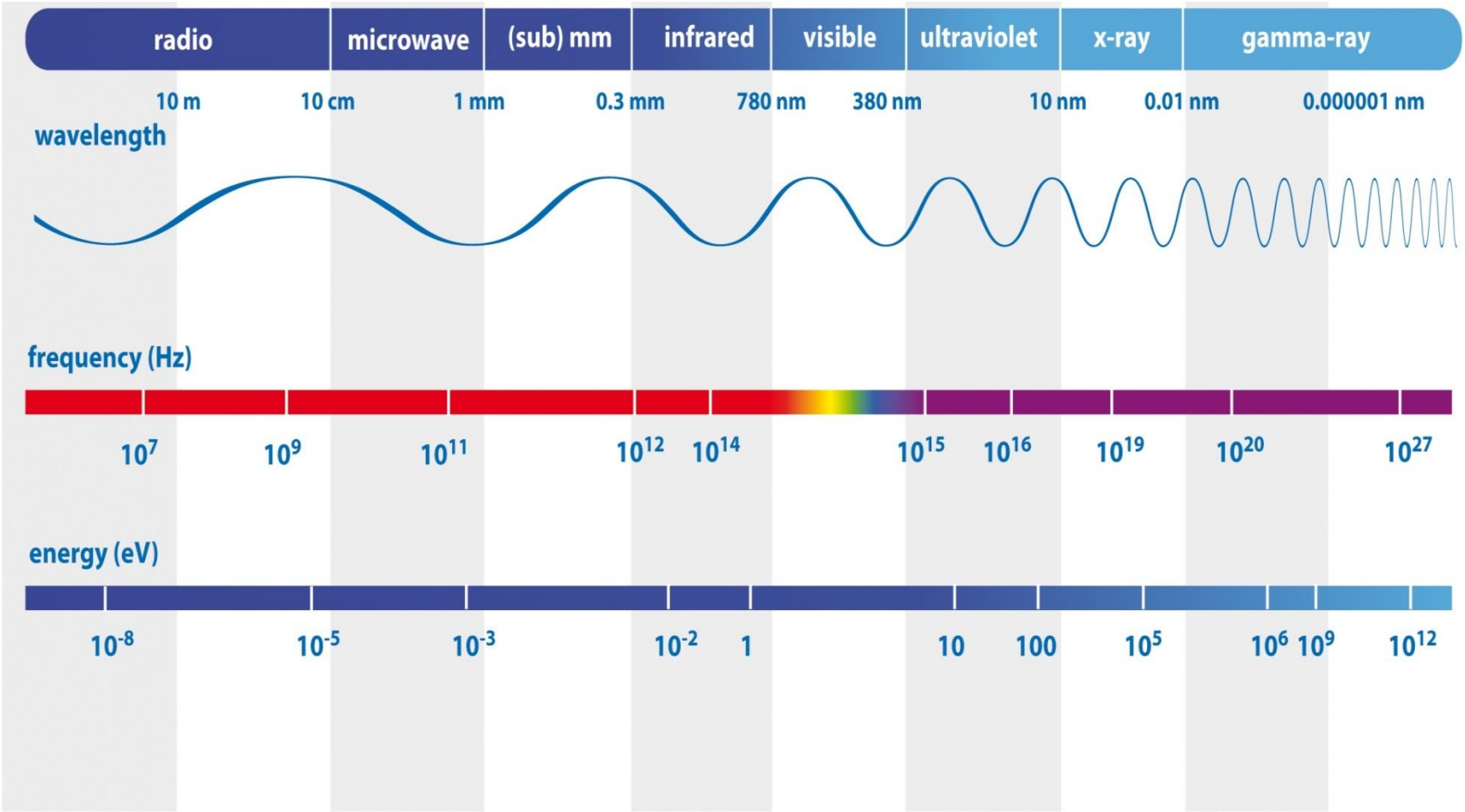
Limitations

- Poor temporal resolution (not useful for now casting)



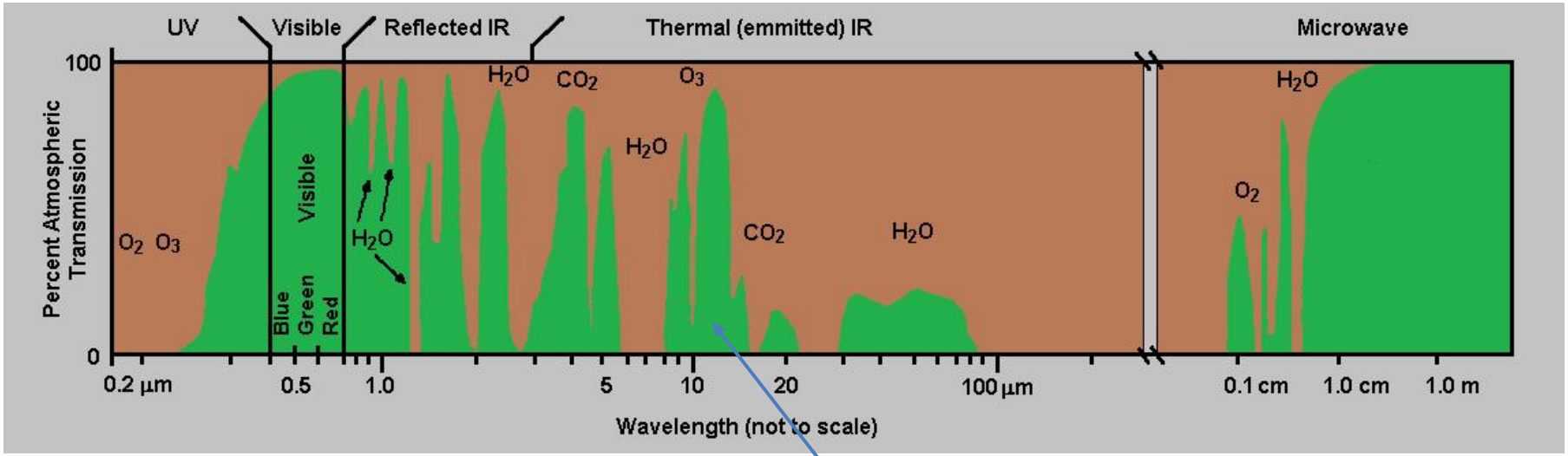


Electromagnetic radiation



Electromagnetic radiation

Depending on the frequency, atmospheric gases either absorb the electromagnetic radiation or let it transmit freely.



Atmospheric Windows

Radiative transfer

The radiance *L(ν)* that reaches the top of the atmosphere at a certain frequency *ν* is given by :

measured by the satellite

Our description of the atmosphere

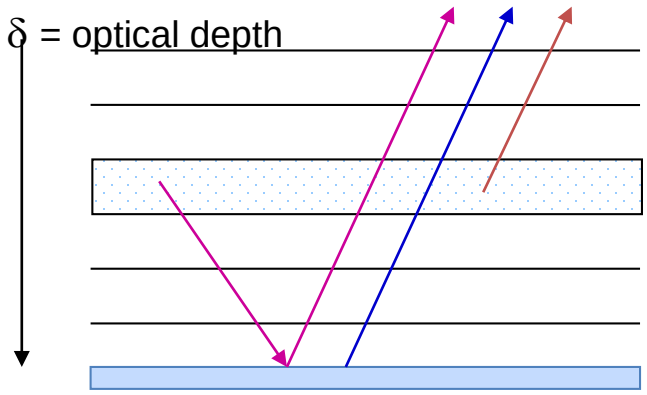
$$L(\nu) = \int_0^{\infty} B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz + \text{Surface emission} + \text{Surface reflection/scattering} + \text{Cloud/rain contribution} + \ldots$$

Planck source term* depending on temperature of the atmosphere

Absorption in the atmosphere

Other contributions to the measured radiances

where: B = Planck function
z = height
T = temperature
τ = transmittance
ν = frequency



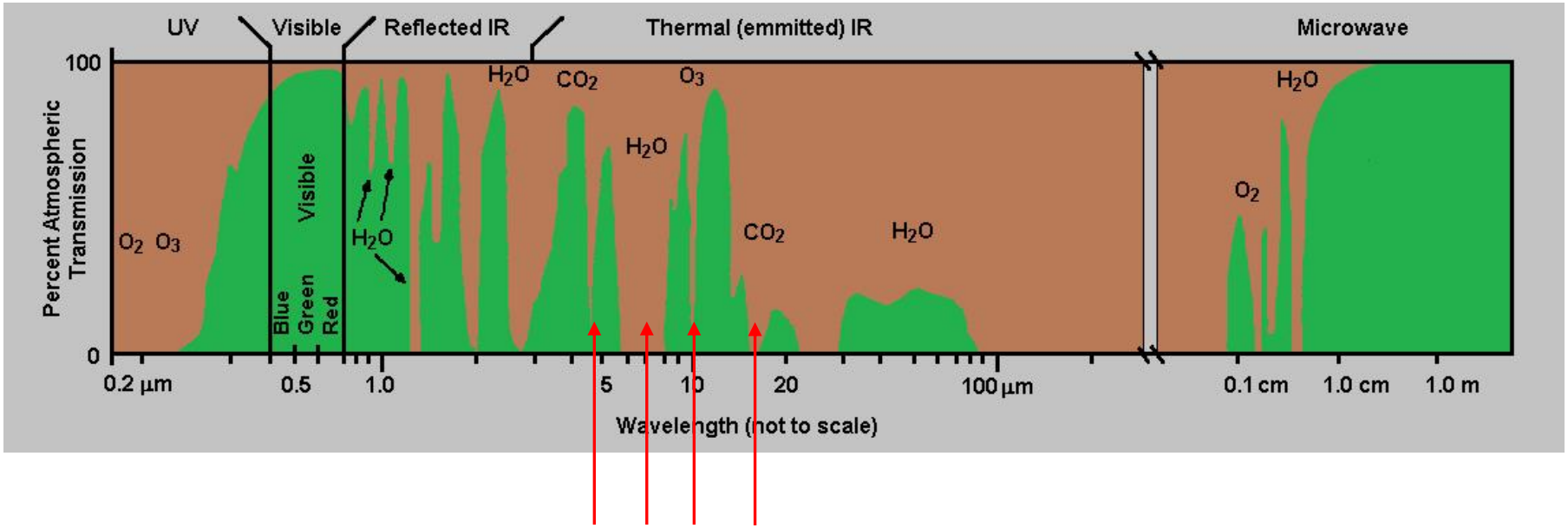
Remote sensing techniques

By the selection of frequencies (CHANNELS) satellite instruments can provide information on specific geophysical variables for different regions of the atmosphere.

- **Passive sensing of the atmosphere and the surface**
- **Active sensing (scatterometry, GPS RO)**

Atmospheric Passive Sounding

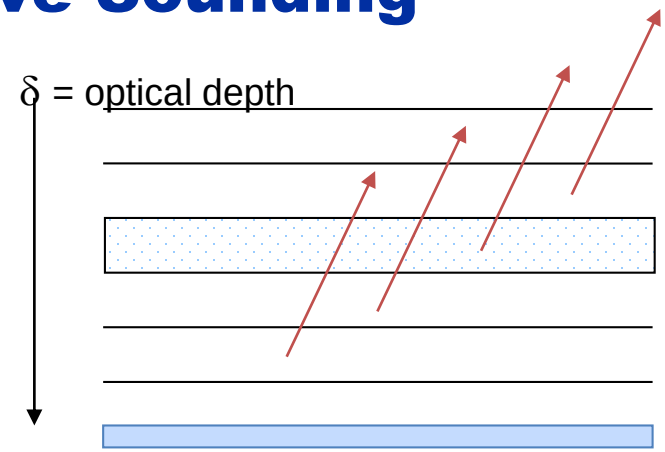
Mainly used to derive the vertical distribution of temperature, humidity and the concentration of other constituents affecting the transmittance (no contribution from the surface).



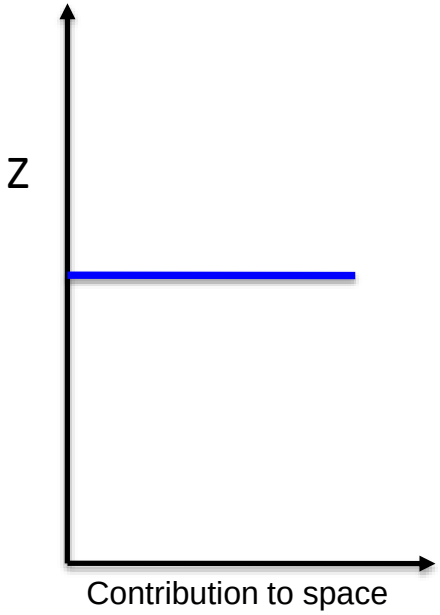
$$L_v = \int_0^{\infty} B(v, T(z)) \left[\frac{d\tau(v)}{dz} \right] dz + \text{Surface emission} + \text{Surface reflection}$$

Atmospheric Passive Sounding

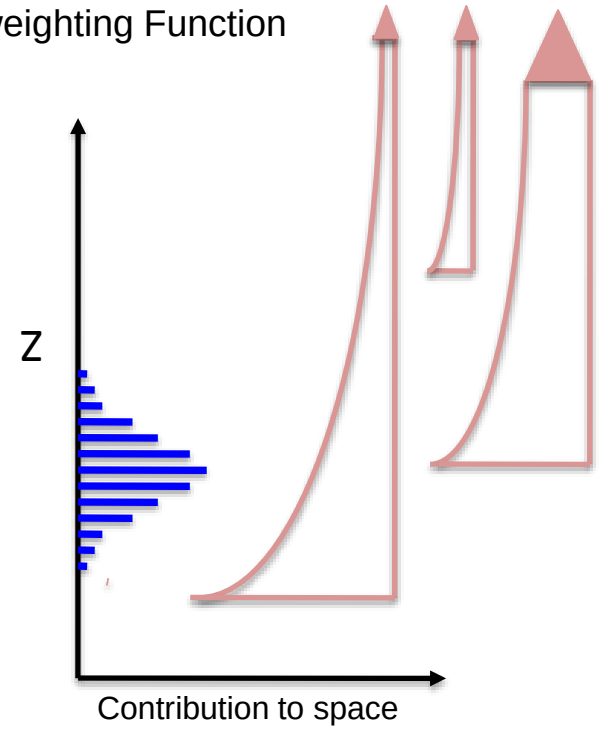
$$L_\nu = \int_0^\infty B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz$$



Ideal weighting function



Real weighting Function

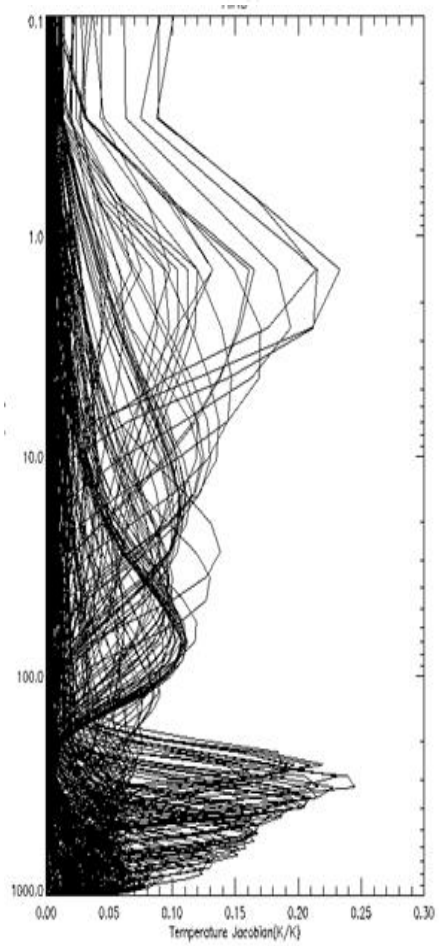


Atmospheric Passive Sounding

- **With a careful selection of a number of channels, one can derive atmospheric parameters at several layers**

- **The weighting functions are broad → limits the capacity to derive small scale properties in the vertical**

- **The weighting functions are highly overlapping → limits the sampling of the vertical**



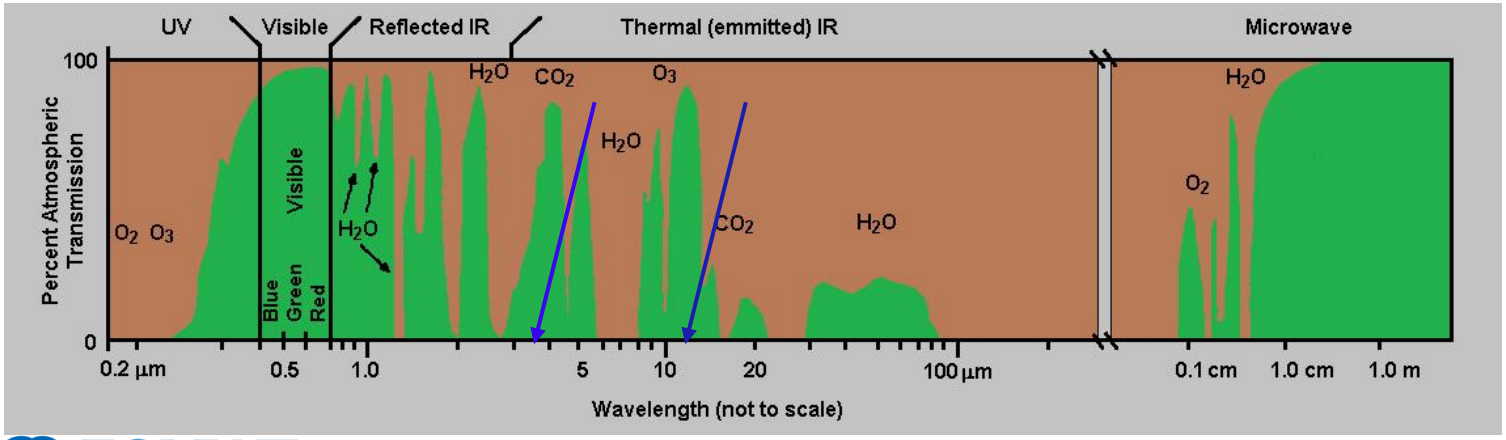
Surface sensing (passive)

These channels are located in window regions of the Infra-red/Microwave spectrum at frequencies where the main contribution to the measured radiance is coming from the surface (no contribution from the atmosphere) :

$$L_\nu = \int_0^\infty B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz + \text{Surface emission} + \text{Surface reflection}$$

$$L(\nu) \approx B[\nu, T_{surf}]\varepsilon(u,v)$$

T_{surf} = skin temperature ε = surface emissivity



Surface sensing (passive)

These are primarily used to obtain:

- **Information on the surface temperature**
- **Inform on quantities that influence the surface emissivity such as wind (ocean) and vegetation (land).**
- **Provide information on clouds/rain and cloud movements (to provide wind information)**

Surface sensing (Active)

- **Selecting channels where there is no contribution from the atmosphere or emission from the surface.**

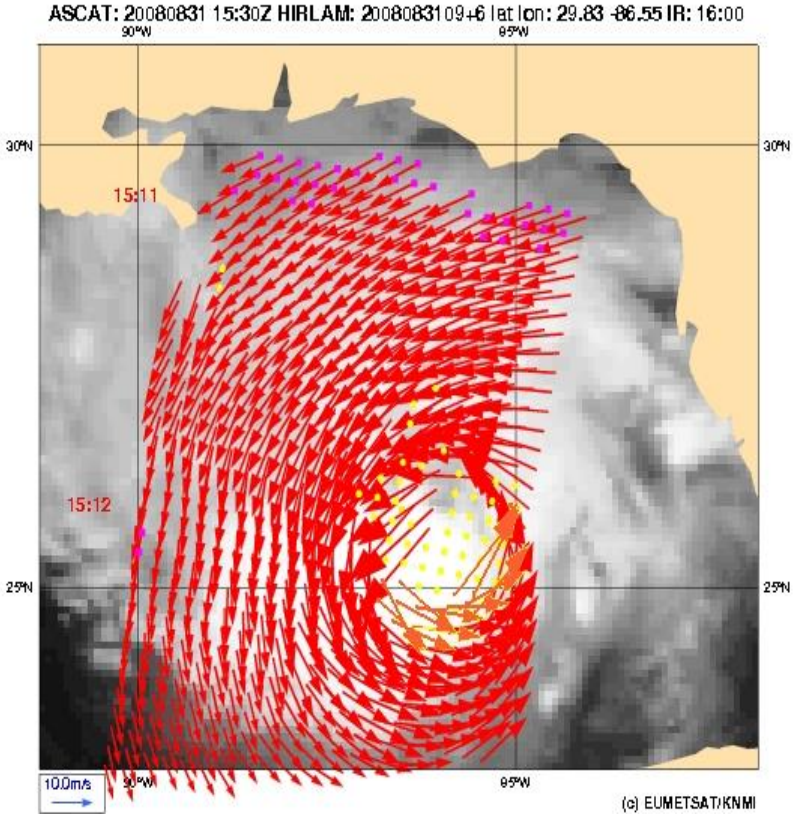
- **Active instruments (e.g. Scatterometers) illuminate the earth's surface by emitting energy in atmospheric window regions and measure the radiance that is scattered back.**

$$L_v = \int_0^{\infty} B(v, T(z)) \left[\frac{d\tau(v)}{dz} \right] dz + \textit{Surface emission} + \textit{Surface reflection}$$

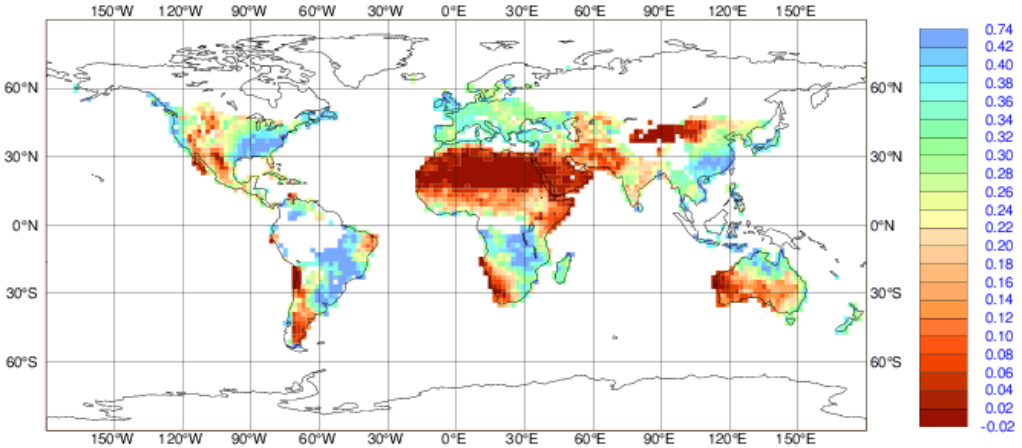
Provide information on surface winds, waves (over sea) and soil moisture (over land),

Active Surface sensing

Surface winds (ocean)



Soil moisture (land)

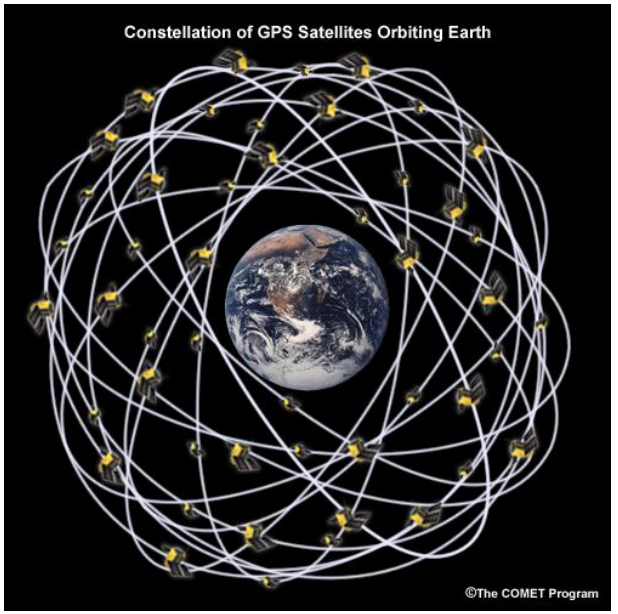


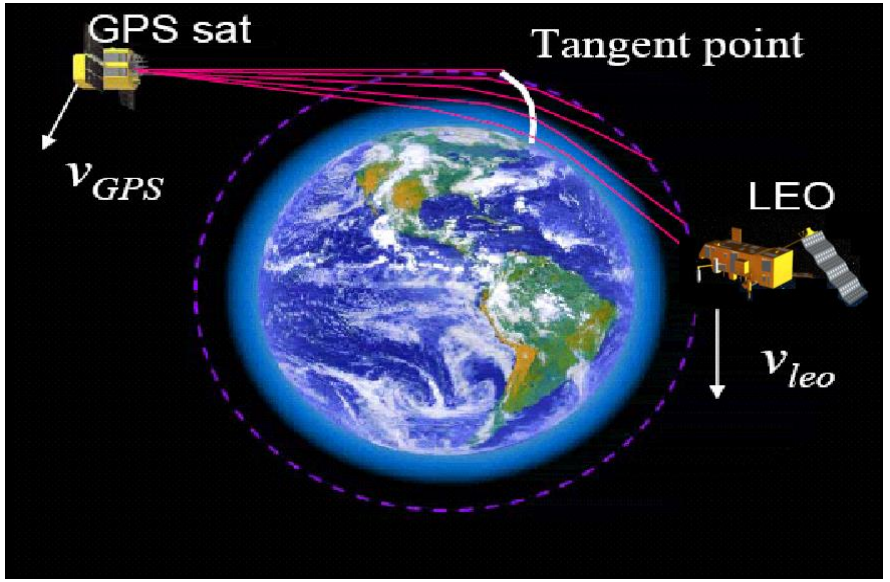
GPS Radio Occultation

- Measures the bending angle of the radio signal as it propagates through the atmosphere. Occultation occurs just after there is no line of sight between the GPS satellite and the GPS receiver.

- Receivers on LEOs record quasi-vertical profiles of the

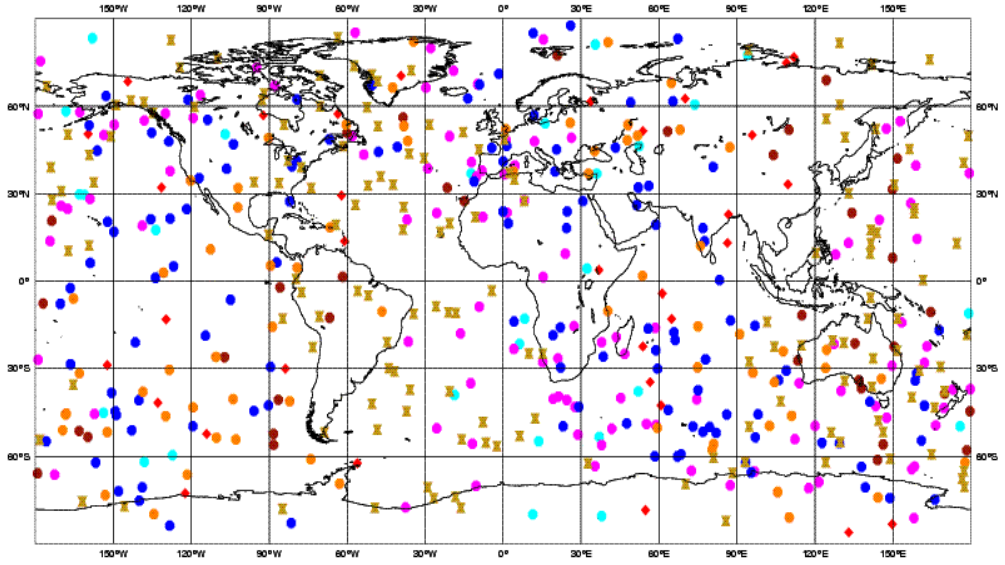
- Bending angles are related to refractivity which is dependent of temperature and humidity





GPS Radio occultation

- **High vertical resolution (~ 250 m),**
- **Good horizontal coverage,**
- **High stability in time**
- **All weather sensing capability (not affected by cloudy or rainy conditions),**

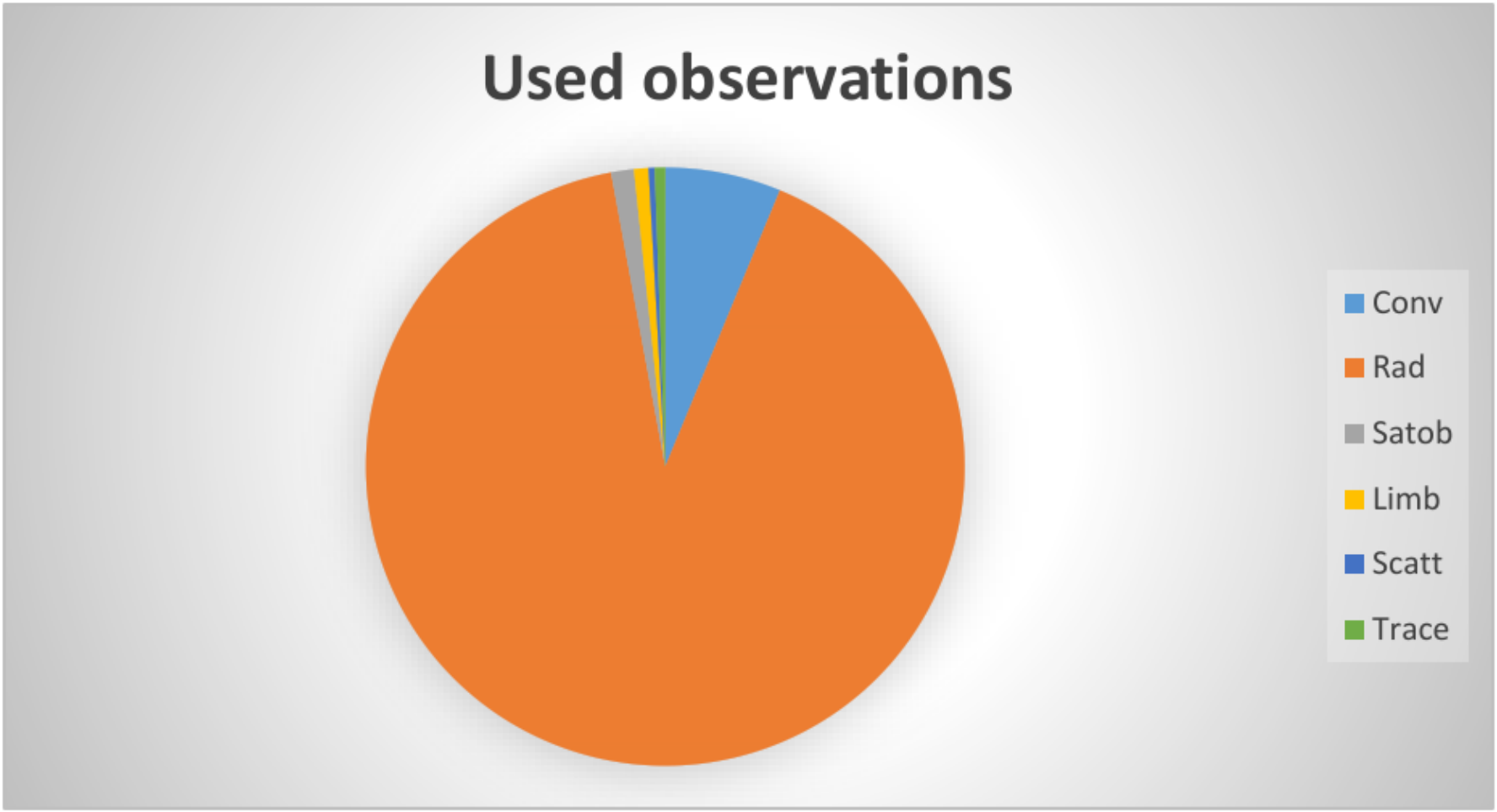


Satellite data used by ECMWF

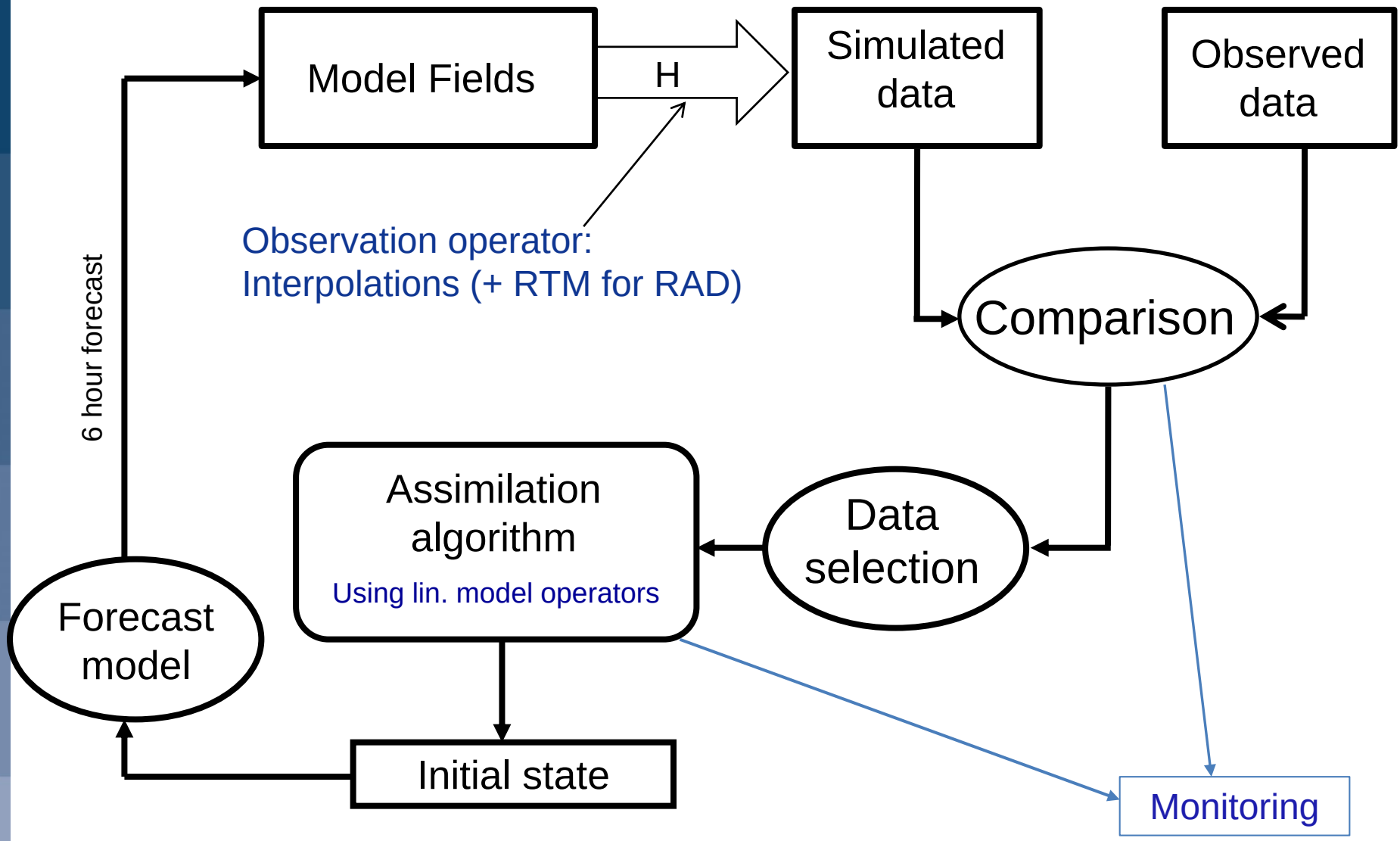
Instruments	Satellites
AMSU-A (microwave)	NOAA, METOP-A, METOP-B, AQUA
AMSU-B/MHS (microwave)	NOAA, METOP-A, METOP-B
ATMS (microwave)	NPP
MWHS-2 and MWHS	FY-3B and FY-3C
IASI (Hyper spectral Infrared)	METOP-A/METOP-B
AIRS (Hyper spectral Infrared)	AQUA
CrIS (Hyper spectral Infrared)	NPP
GPSRO	CHAMP, GRACE-A, COSMIC series, METOP-A, METOP-B, TERRA-SARX, TanDEM-X, FY-3C
SSMIS, AMSR2, SAPHIR and GMI (microwave)	DMSP series, TRMM, WINDSAT, GCOM-W1, GMI, MEGHA-TROPIQUES
Polar Winds	AQUA, TERRA, AVHRR (METOP and NOAA satellites), VIIRS
Scaterrometer (surface winds, soil moisture)	METOP-A/ASCAT, METOP-B/ASCAT
Altimeter (surface winds, waves)	Jason, SARAL/Altika and Cryosat
SBUV, OMI, GOME-2, OMPS	NOAA, AURA, METOP and NPP
Geostationary instruments (Radiances & derived AMVs)	METEOSAT, MSG, GEOS, Himawari-8

Outline

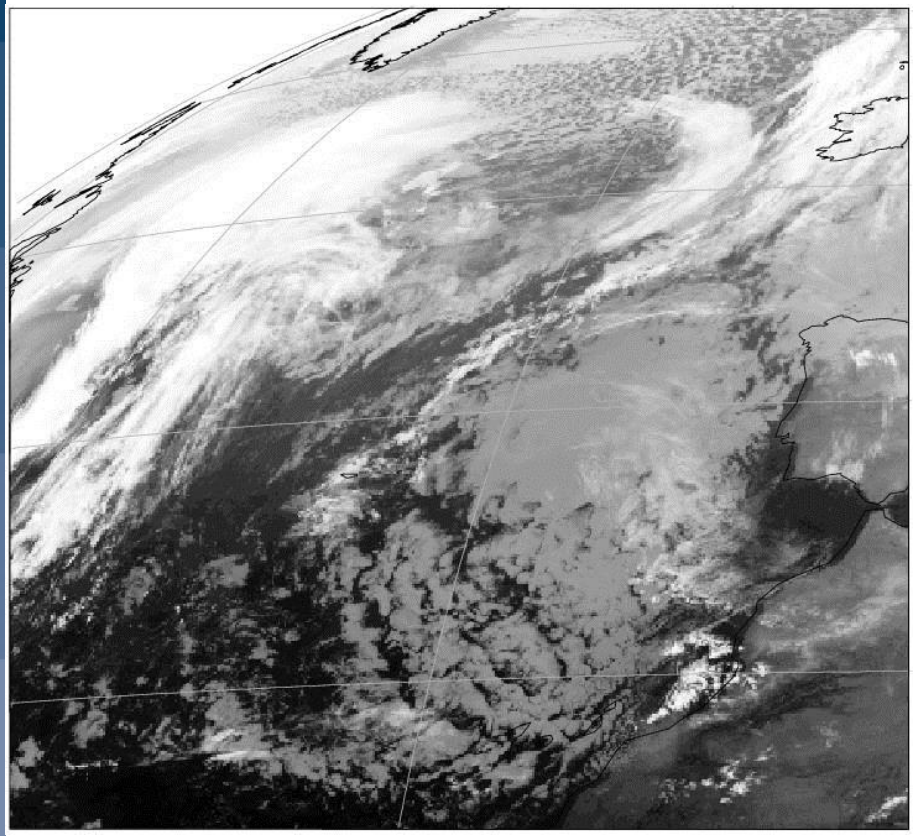
- Data sources and role of satellite observations
- What do satellites measure ?
- **Assimilation and monitoring of satellite data**


Used observations
Conv
Rad
Satob
Limb
Scatt
Trace

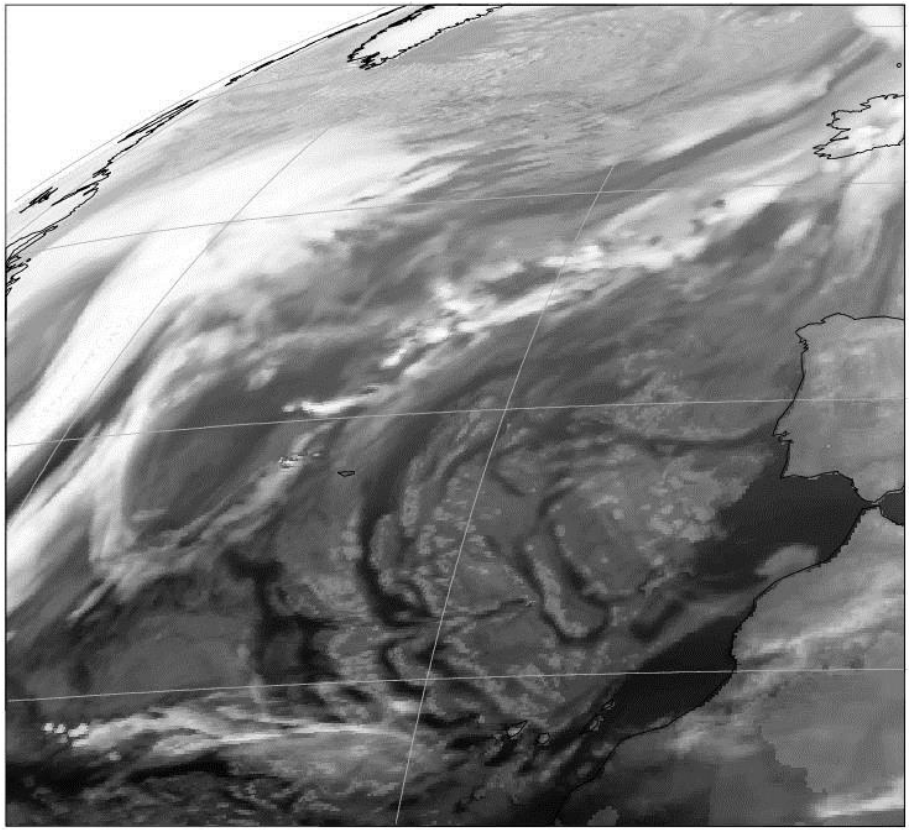
Assimilation of satellite data



Met-8 IR (Observations)



Met-8 IR (from the model)



Monitoring of satellite data

Data monitoring is an important component of the data assimilation diagnostic system:

- Important to define and evaluate the data usage
- It allows continuous control of the availability and quality of the observing system.
- Helps diagnosing model problems

Observation monitoring

Charts

Monitoring of the observing system

Datasets

Quality of our forecasts

Documentation and support

Accessing forecasts

Filters

Show All

Parameter

- [x] Radiances (41/90)

Data type

- [x] Microwave radiances (41/79)

Instrument

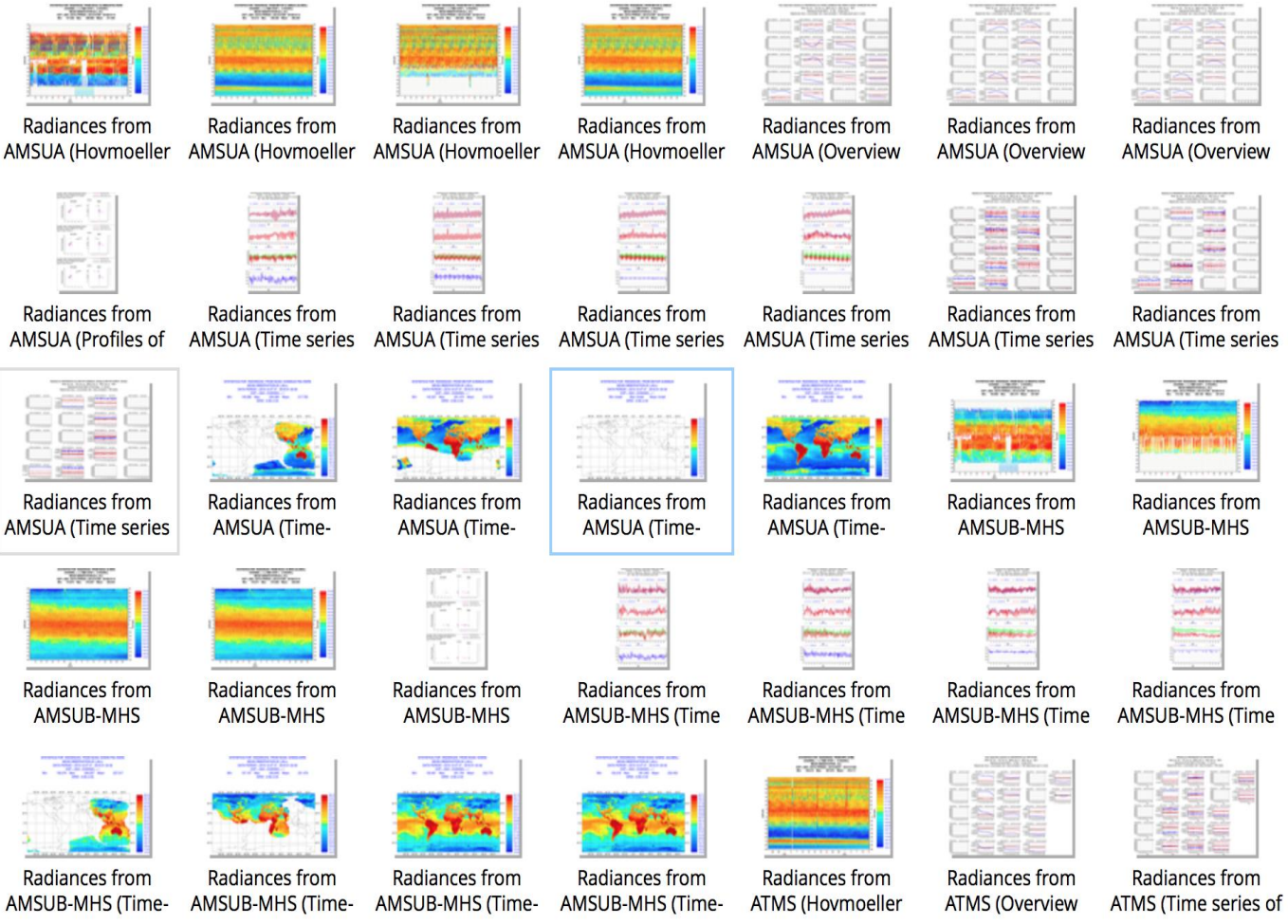
- [ ] AMSUA (19)
- [ ] AMSUB-MHS (13)
- [ ] ATMS (5)
- [ ] MWHS (4)

Data Stream

- [ ] All data streams combined (6)
- [ ] EARS (8)

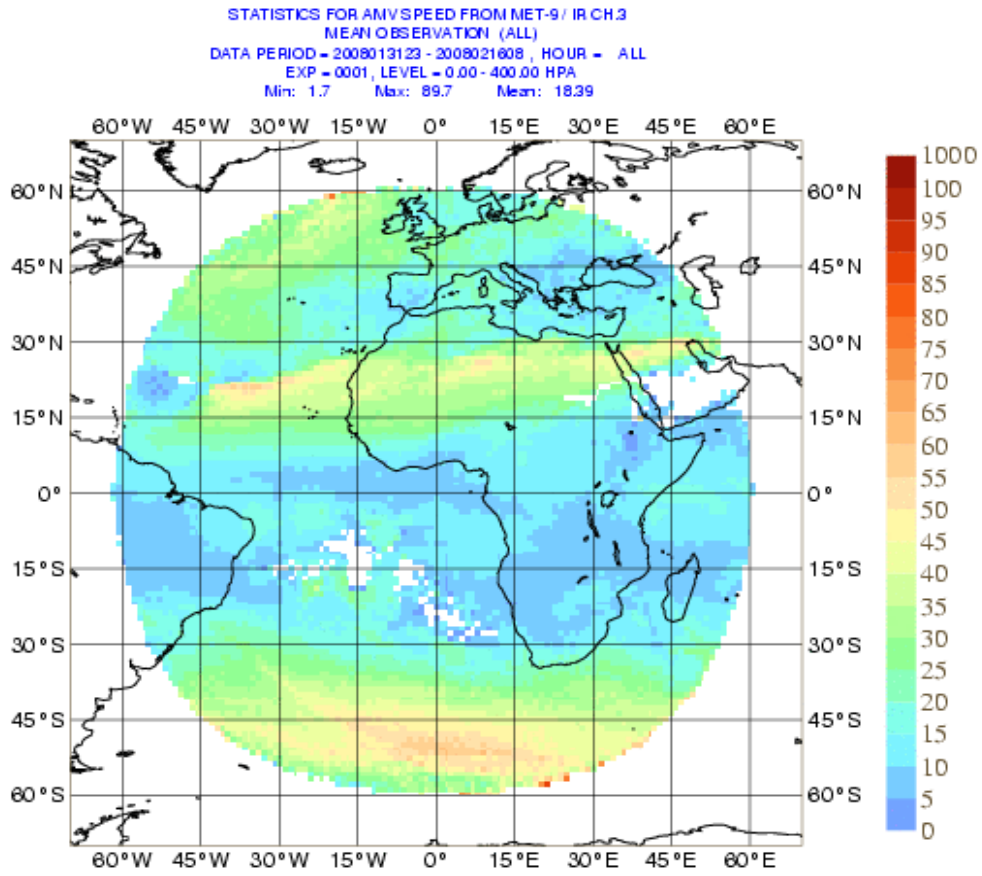
41 matching items

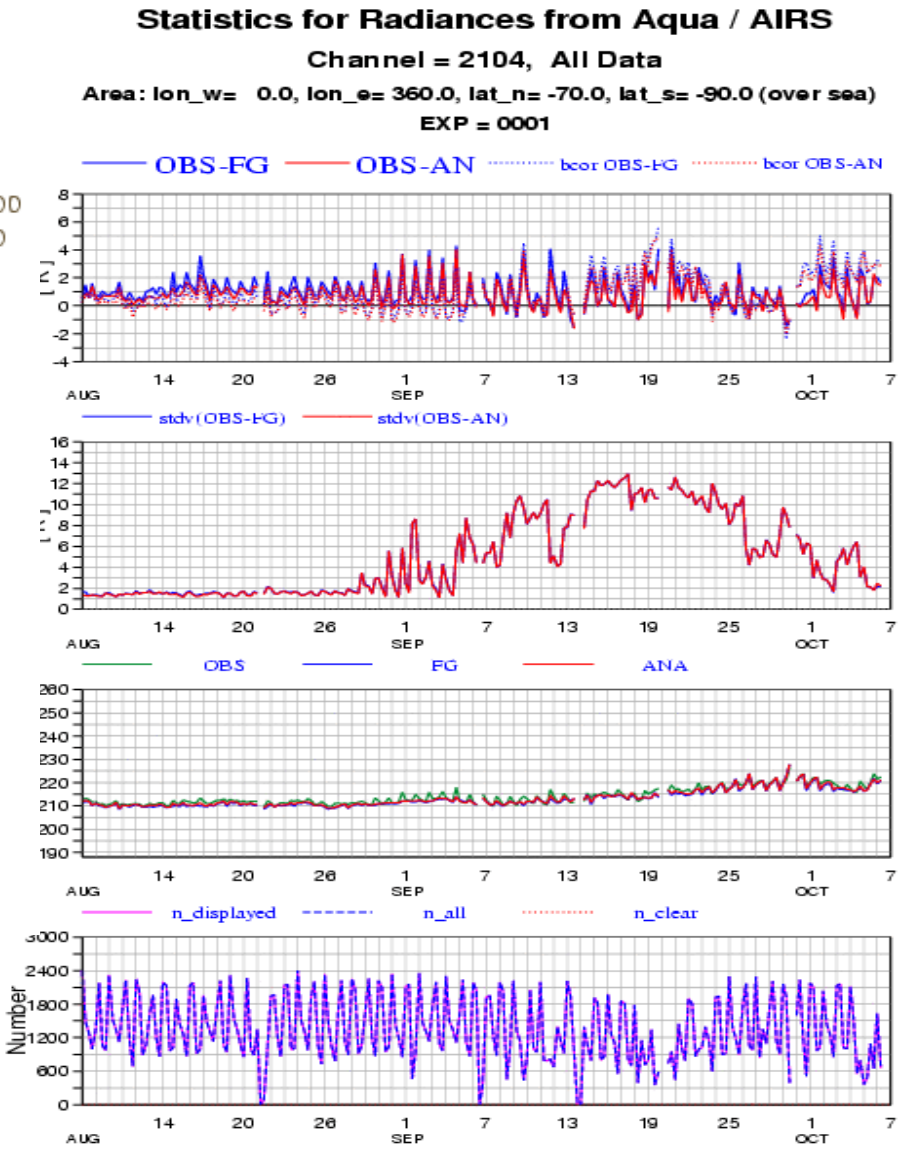
Parameter: Radiances / Data type: Microwave radiances



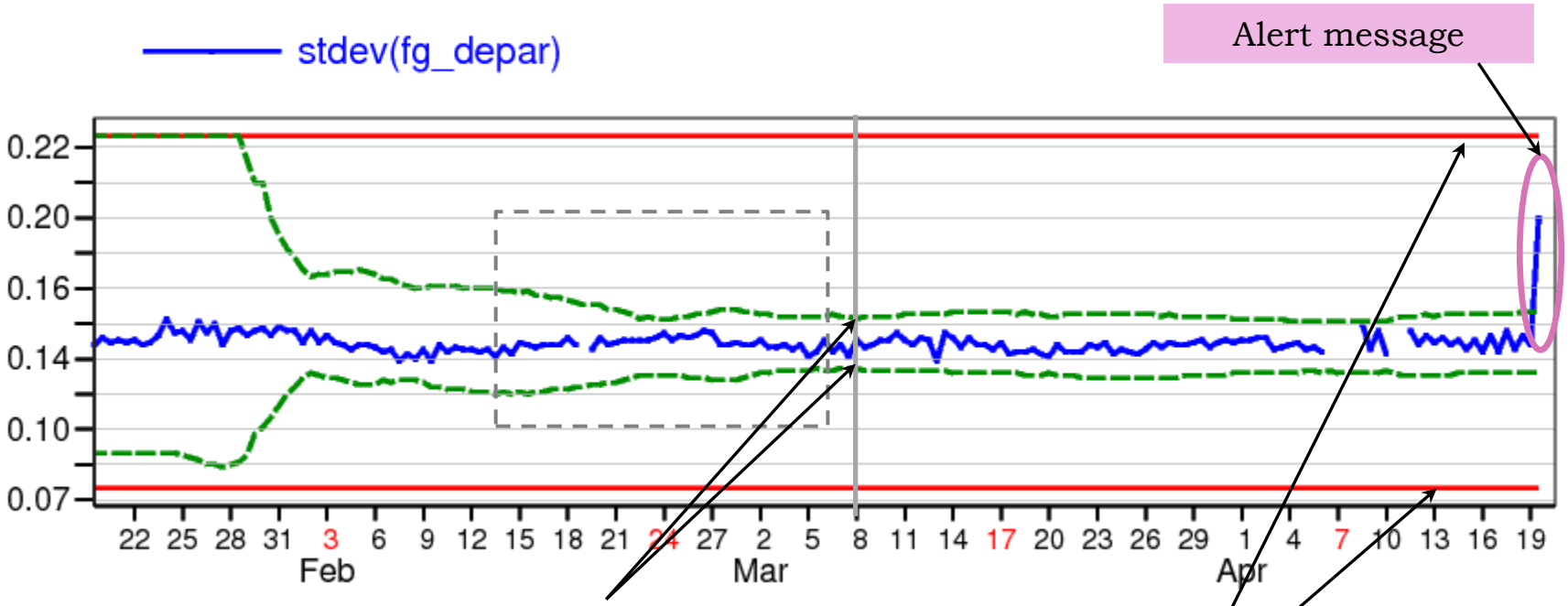
Time series

Time evolution of statistics over predefined areas/surfaces/flags





Automatic Alarm system

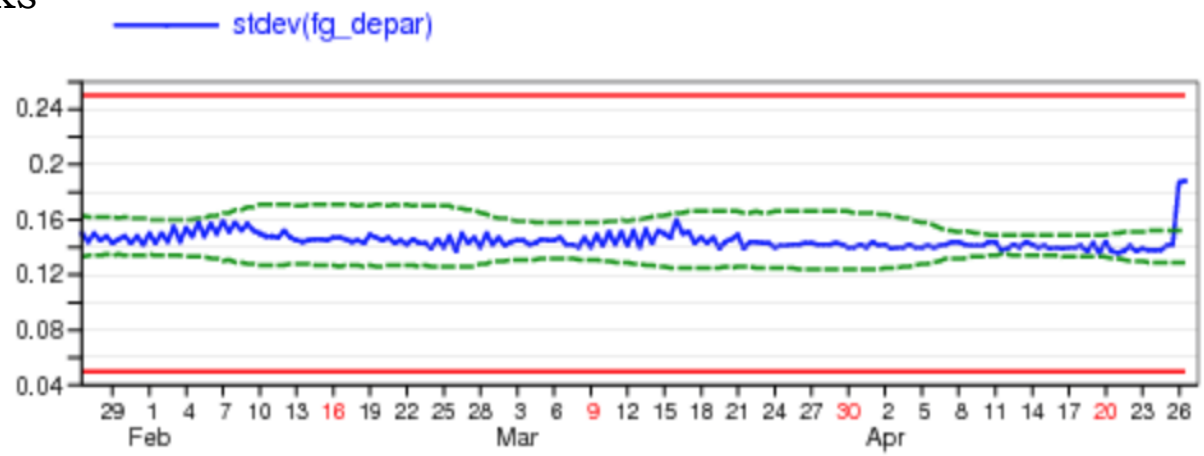


Slightly: Statistics outside ±5 stdev from the mean
Considerably: Statistics outside ±7.5 stdev from the mean
Severely: Statistics outside ±10 stdev from the mean

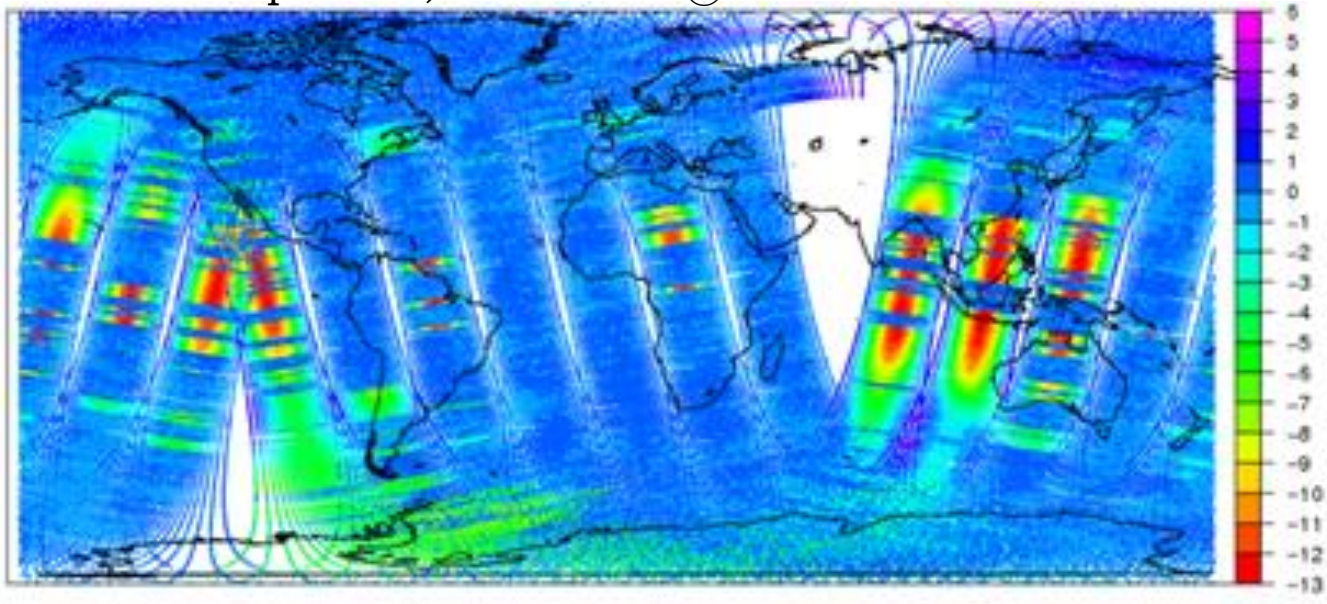
ATMS Ch9 @2014042612

ATMS blacklisted for 2 weeks

```
NPP ATMS radiances 9 : out of range:

    (1 times in last 10 days for at least one item)

    2014042612_atms_224_19_210_9.png

    Severely:       stdev(fg_depar)=0.188,          expected range: 0.129 0.152
```



FG departure, ATMS Ch9 @2014042612



ECMWF EUF

Diagnosing model problems

When statistics from independent data types show a consistent jump it's most likely due to model problems:

Stratosphere: Microwave and Infrared data from various satellites.

Troposphere: Microwave and Infrared radiances from various satellite

Surface: Microwave and scaterrometer data from various satellites.

Thank you for your attention