Satellite Observations

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❶ Data sources

❷ Why satellite data important ?

❸ Principals of satellite measurements

❹ Satellite data usage

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Overview of data sources

conventional observations

SYNOP/SHIP/METAR:

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

BUOYS:

→ temperature, pressure, wind

TEMP/TEMPSHIP/DROPSONDES:

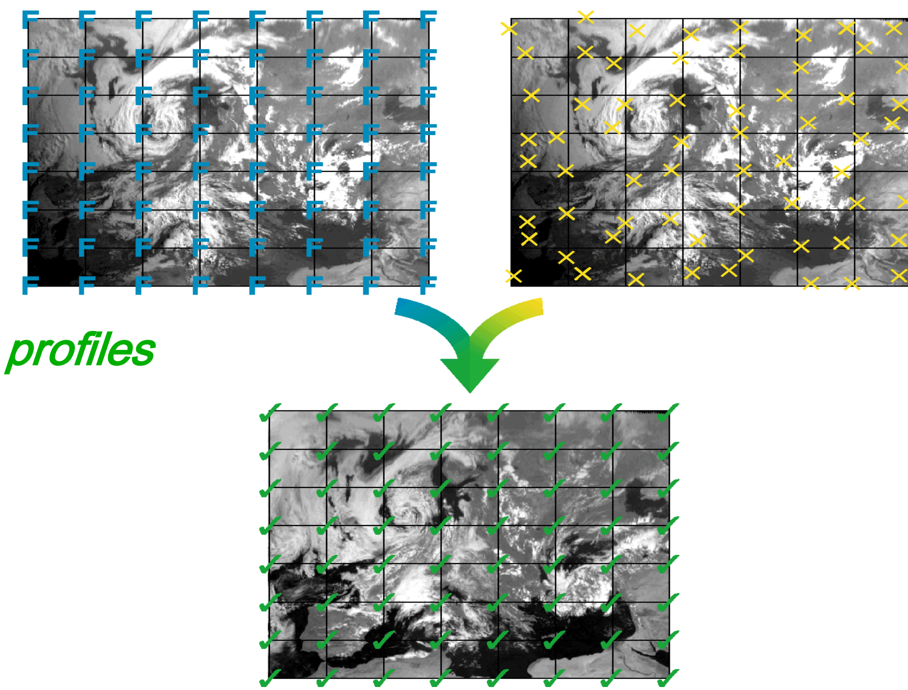
→ temperature, humidity, pressure, wind *profiles*

PROFILERS:

→ wind *profiles*

Aircraft:

→ temperature, pressure, wind *profiles*



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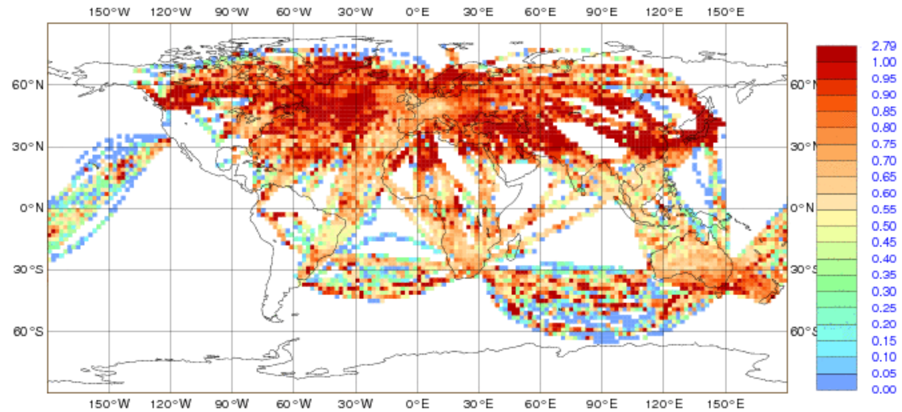
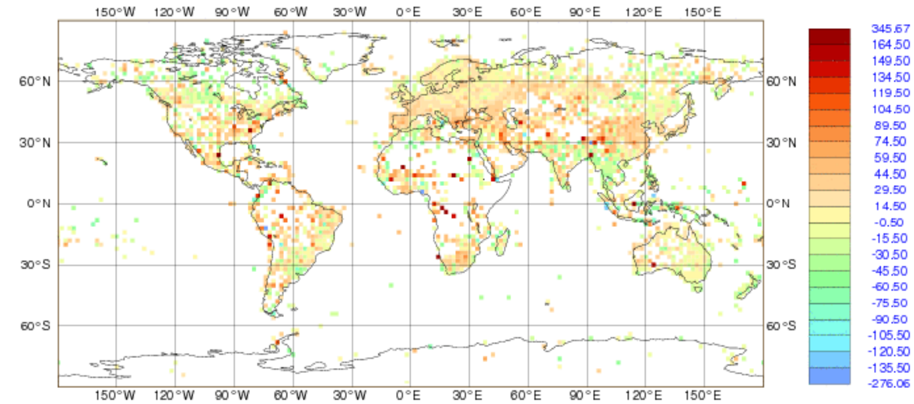
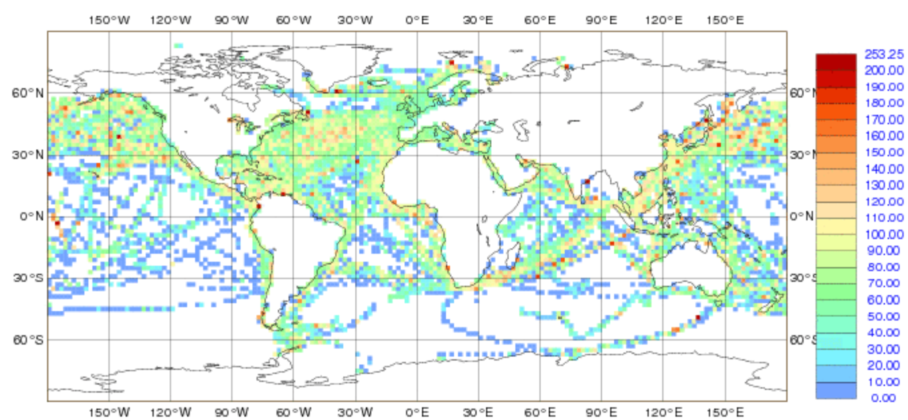
Example of conventional data coverage (one month)



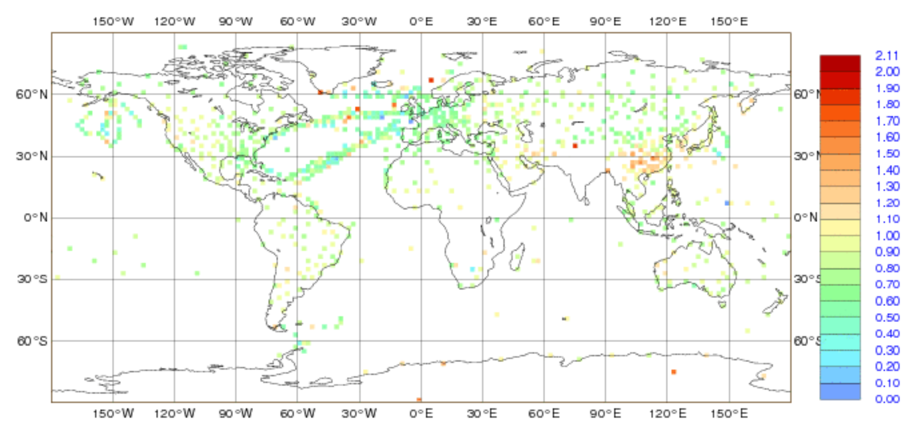
Aircraft – AMDAR



Synop

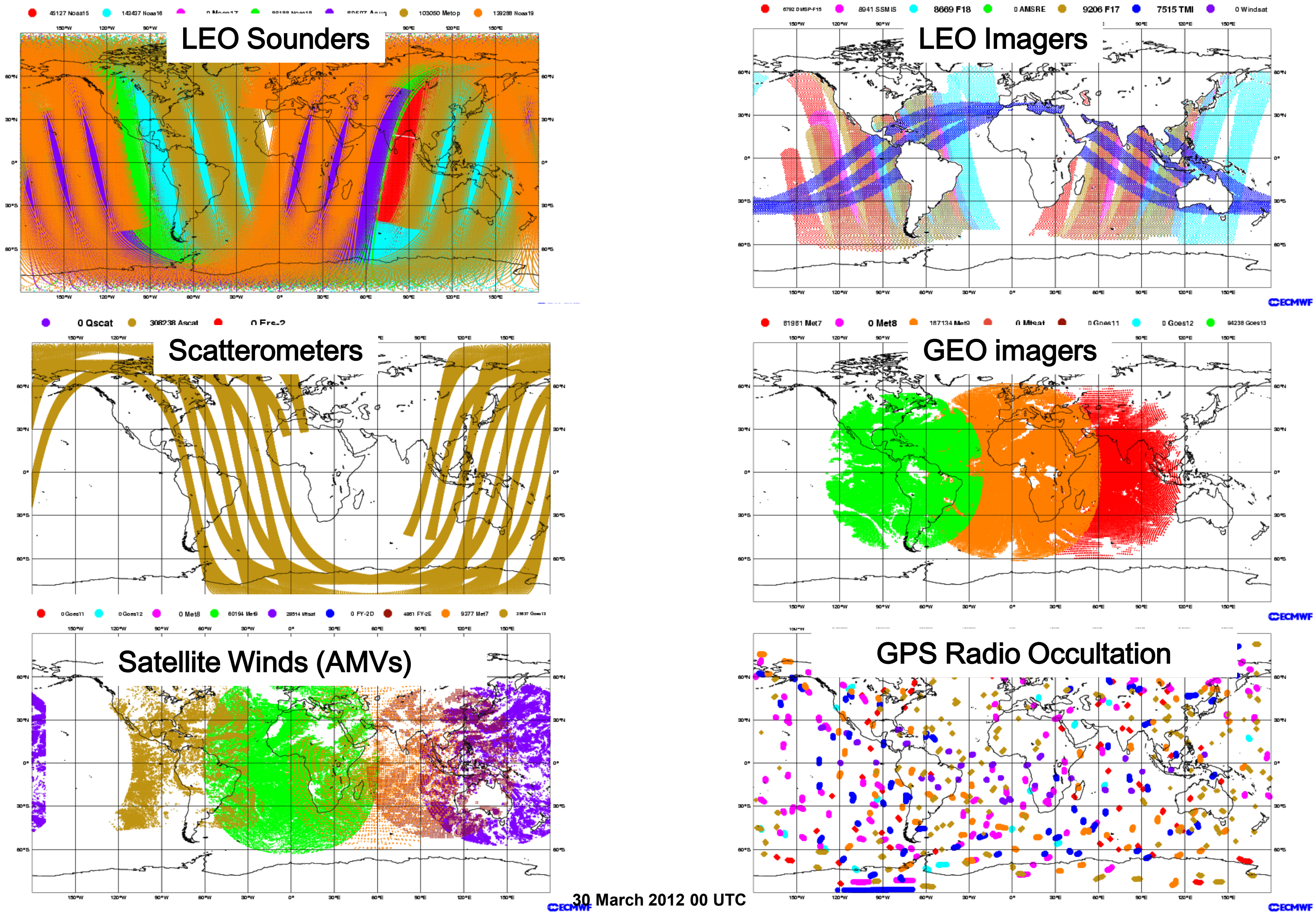


ship

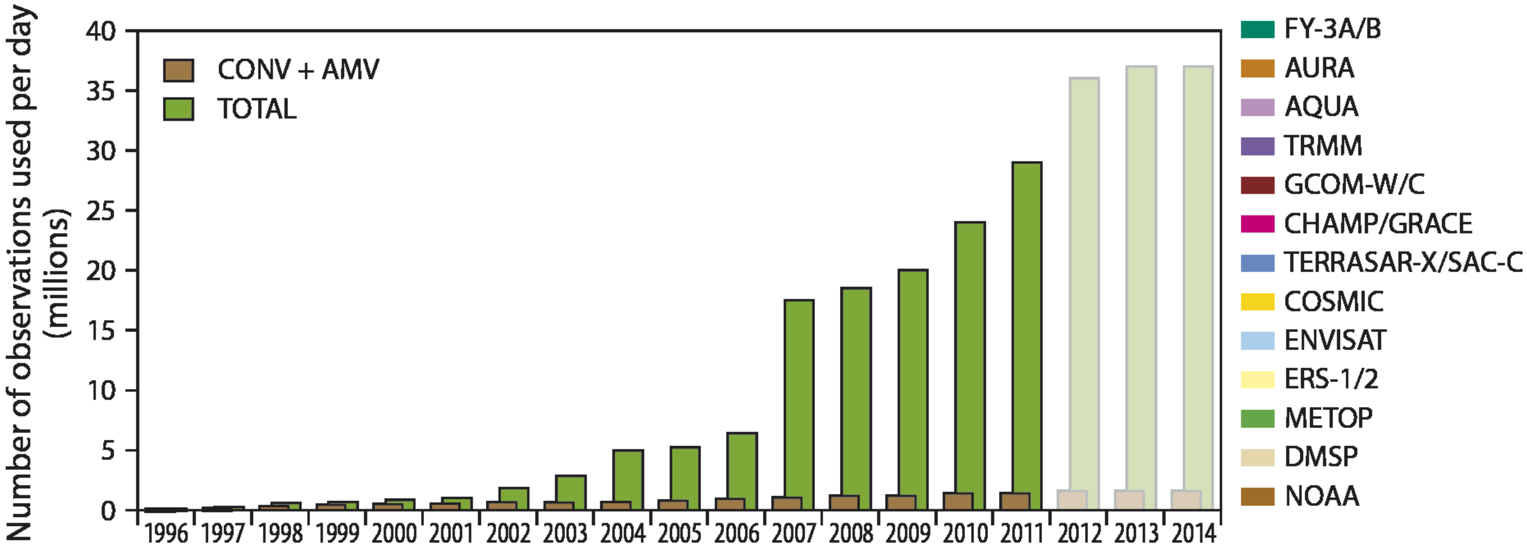


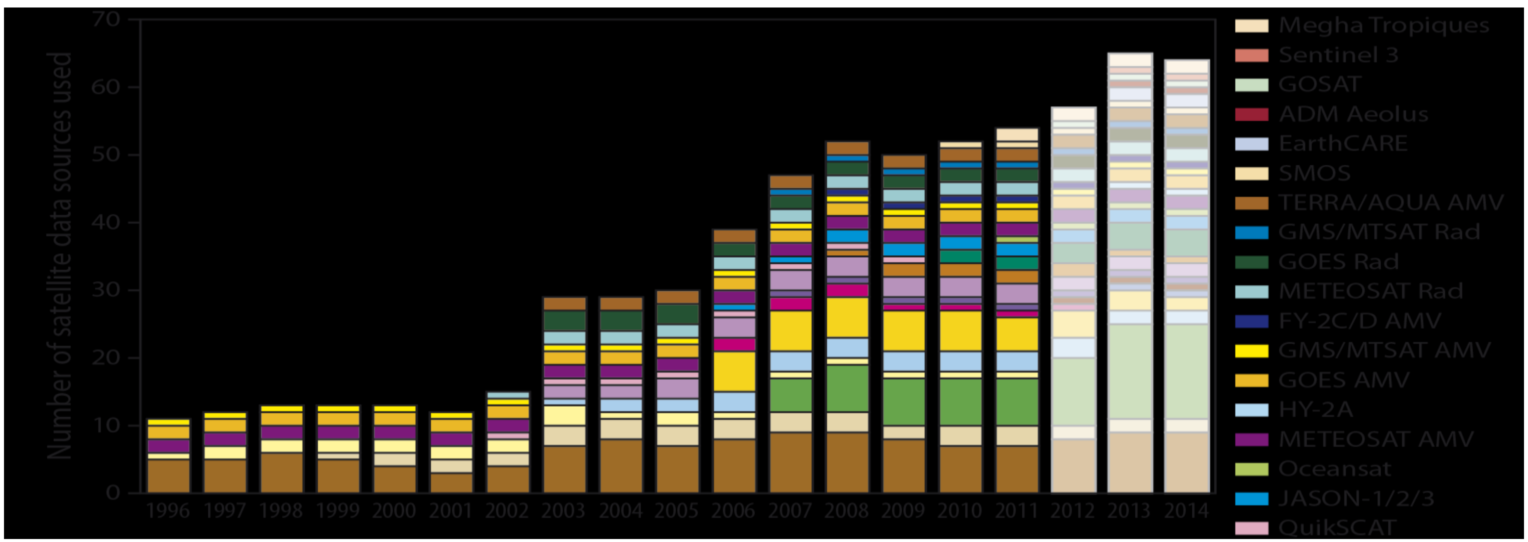
Temp

Example of 6-hourly satellite data coverage



Number of used satellite data is increasing





A scientific and technical challenge

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4. Satellite data usage at NWP
5. Monitoring of satellite data

Importance of satellite data

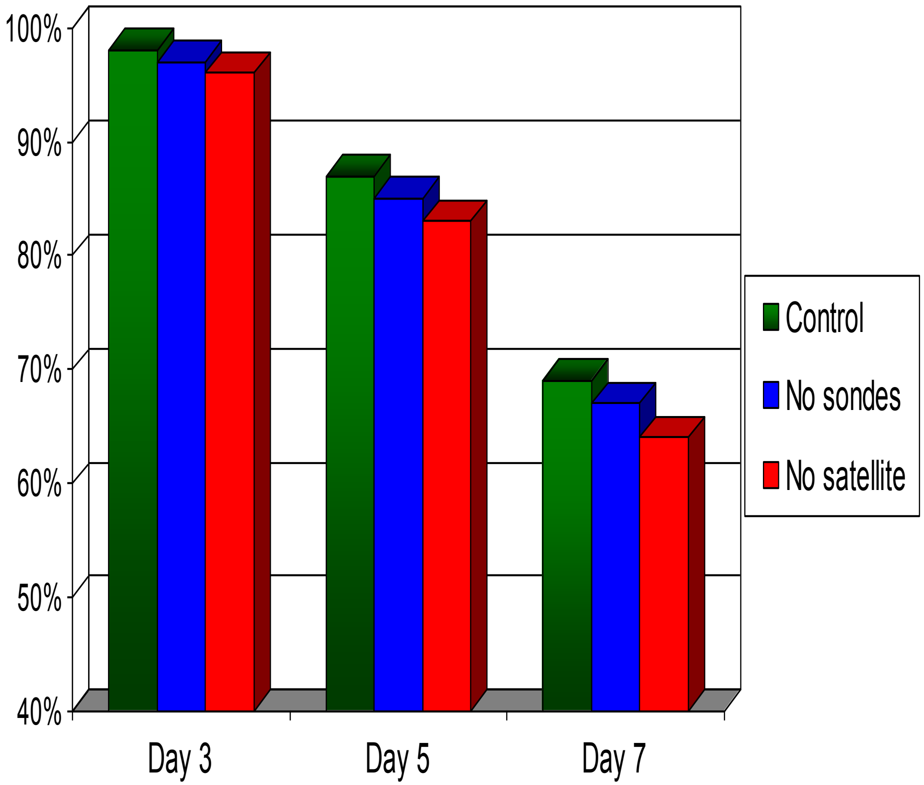
Why important ?

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

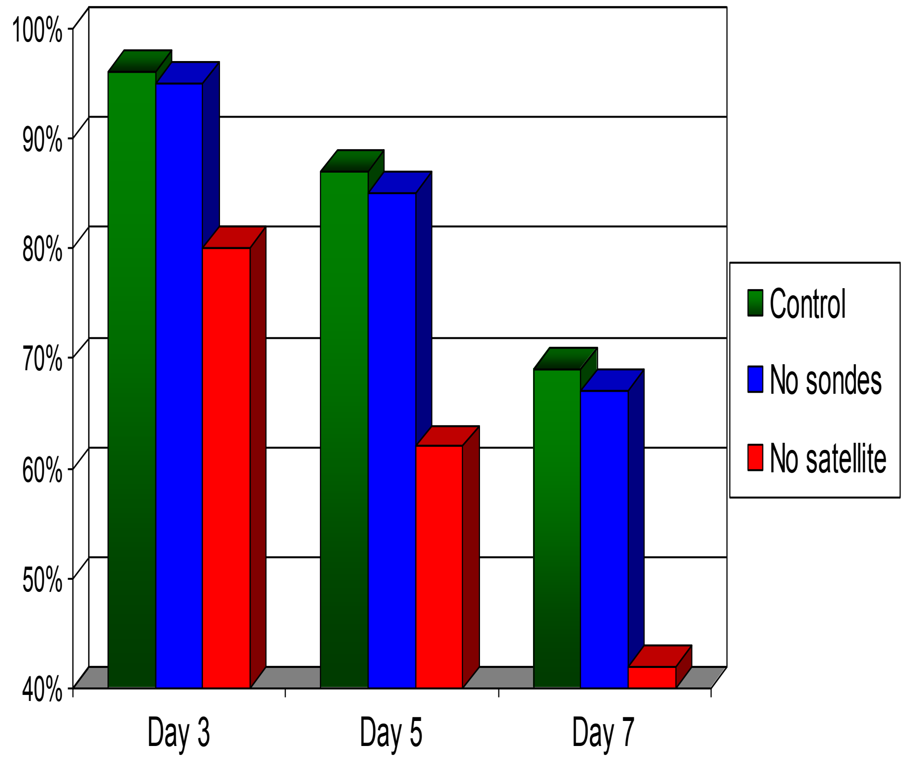
Importance of satellite data

Why important ?

Anomaly correlation of 500hPa height for northern hemisphere



Anomaly correlation of 500hPa height for southern hemisphere



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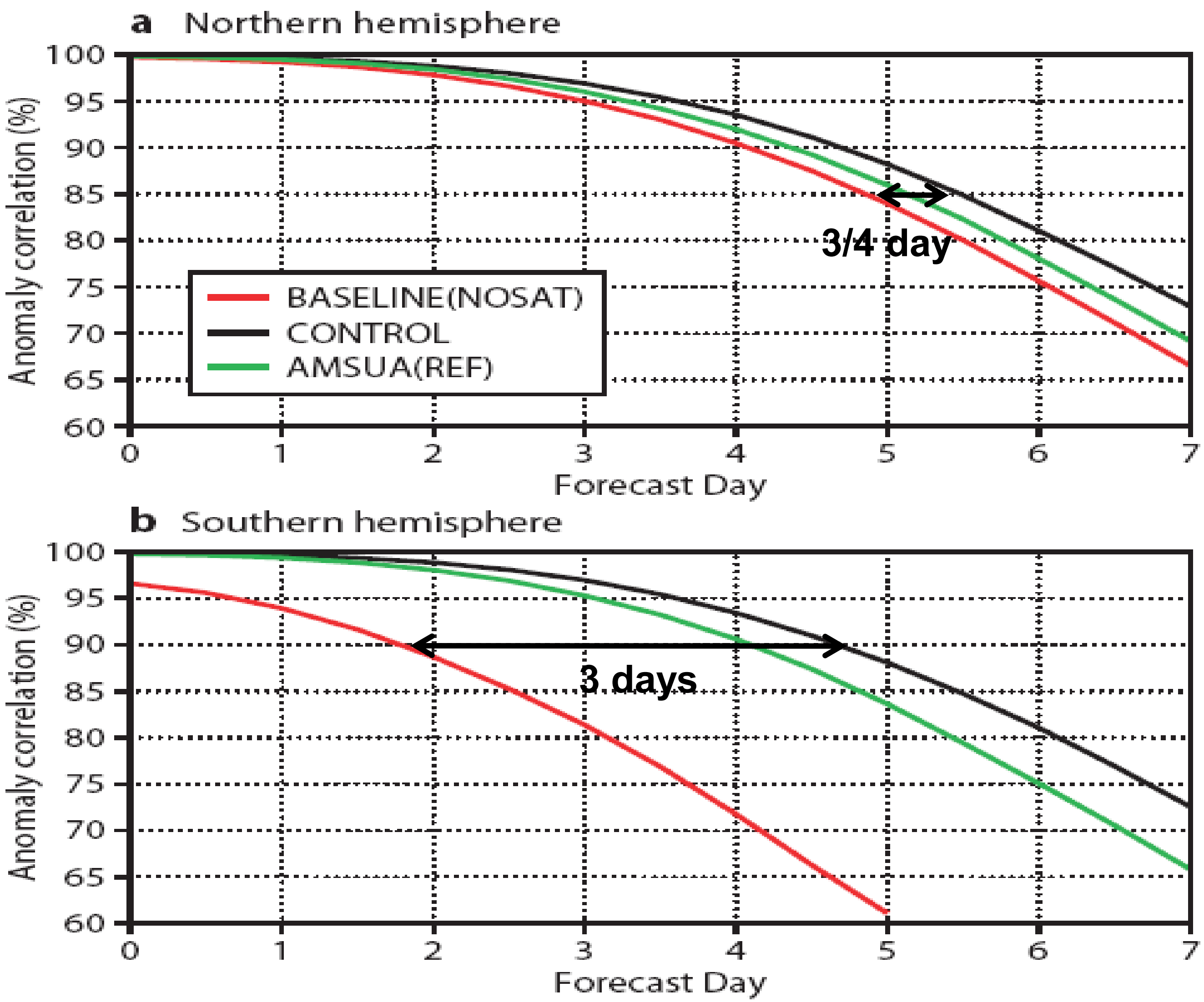
Importance of satellite data

Why important ?



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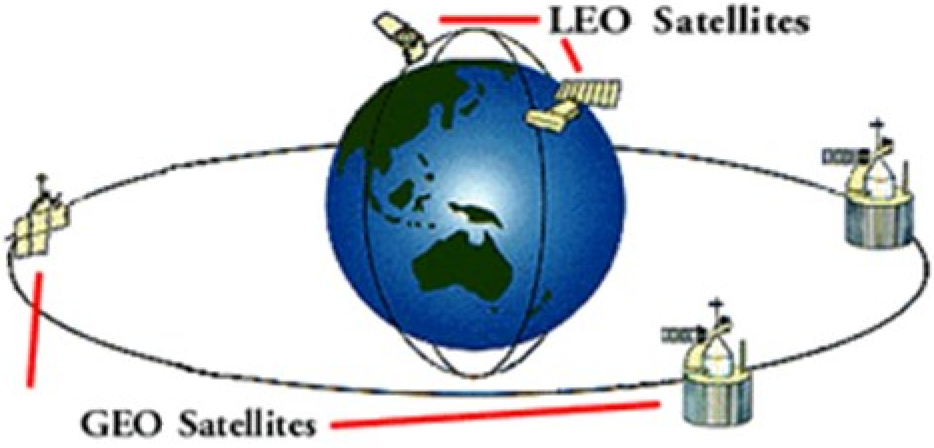
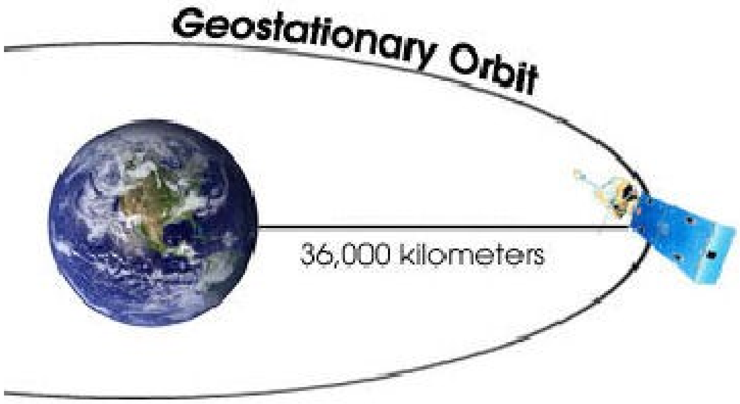
Types of satellites

- Geostationary satellites
- Low Orbiting satellites (LEO)



Geostationary Satellites

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



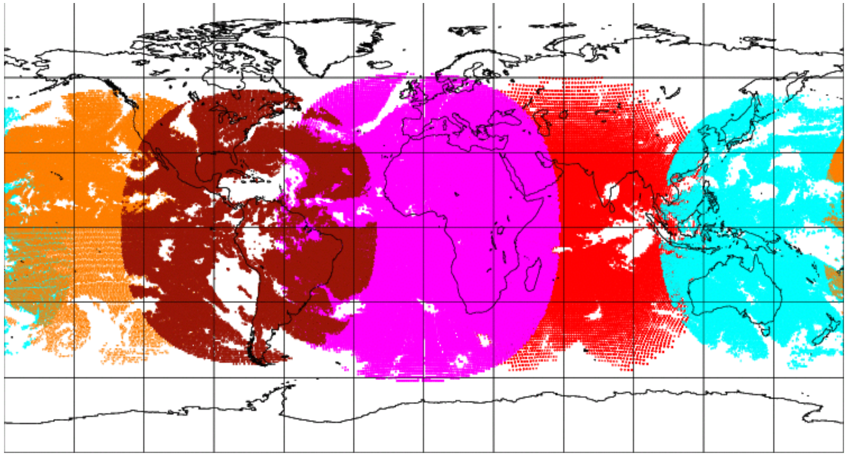
- Satellites are stationary with respect to a point on the earth's surface,

- Wide coverage and high spatial and temporal resolution (now-casting and short range forecasting, diurnal phenomena and feature tracking),

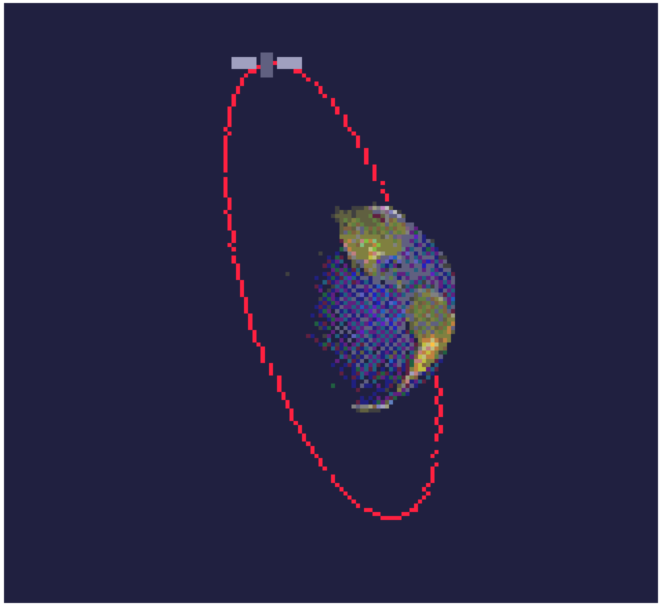
- Due to the high satellite altitude, some important parts of the EM spectrum cannot be observed (e.g microwave part) and channels are generally broad (the signal is week),

- Necessity of a constellation of satellites to cover the whole globe,

- Unsuitable to observe polar regions.



Low Orbiting Satellites



- Orbits at heights between 400 and 850 Km
- Orbits are circular and pass (nearly) over the poles.
- Each satellite completes around 14 orbits in one day (period between 98 and 102 min). Imagery from successive orbits overlay with each other to give global daily coverage.

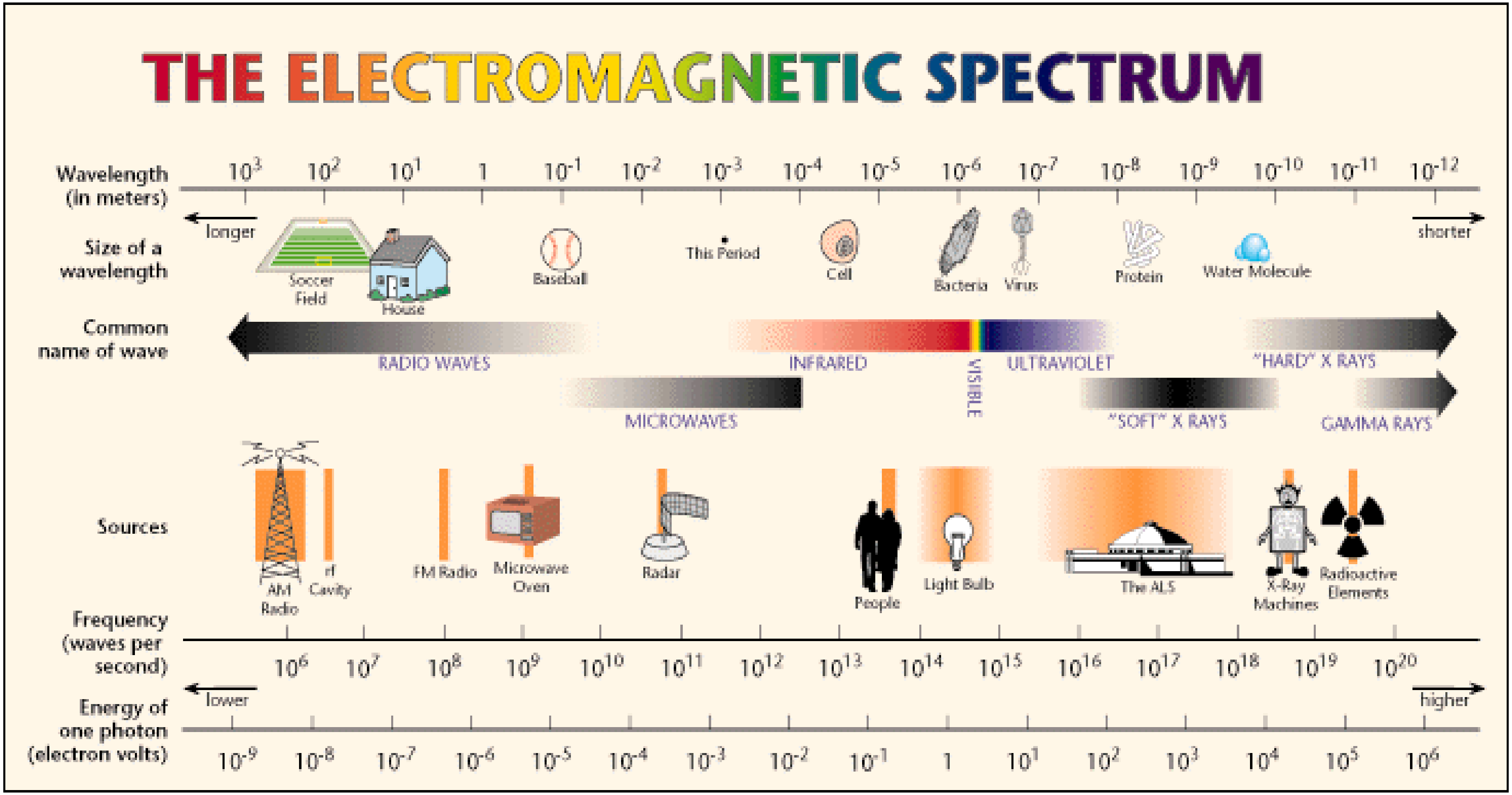
- Due to the low height of satellites :
  - All the meteorologically useful electromagnetic spectrum can be covered (including microwave spectrum),
  - High spectral resolution measurements can be achieved (the noise remains less important than the real signal),
  - High spatial resolution
  - Active measurements can be achieved (with radars and lidars).

- Moderate temporal sampling → not useful for now casting.

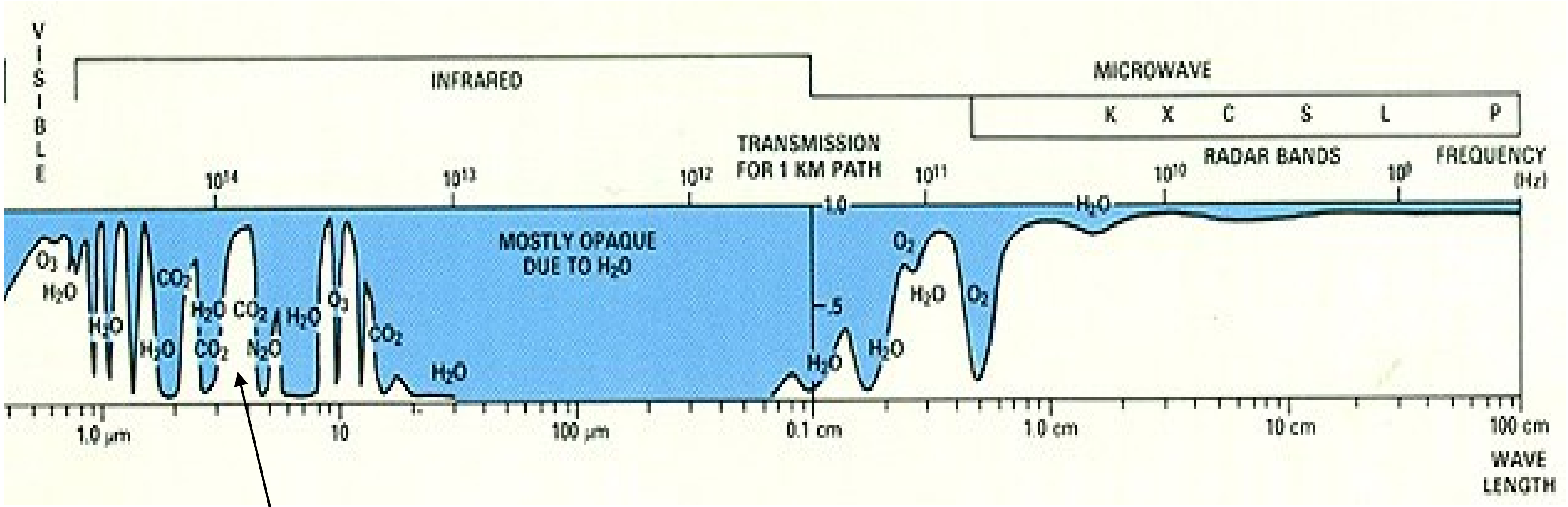
Satellite instruments do not measure directly geophysical atmospheric parameters (Temperature, Humidity, Ozone, Wind, ...)

Satellite instruments measure the electromagnetic radiation that reaches the top of the atmosphere at certain frequencies

Measured radiance is related to geophysical atmospheric parameters by the radiative transfer equation


THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20}
lower
higher
Energy of one photon (electron volts)
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10^1 10^2 10^3 10^4 10^5 10^6

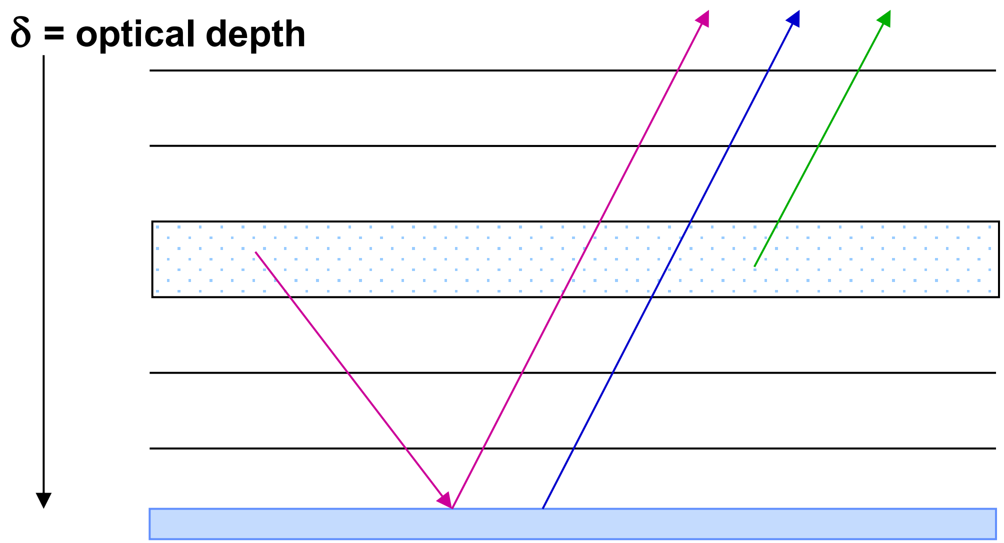
Depending on the frequency, atmospheric gases either absorb the electromagnetic radiation or let it transmit freely.



Atmospheric Windows

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

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



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The measurement of geophysical properties of the surface and the atmosphere can be achieved using :

- **Atmospheric sounding/imaging** from **passive** instruments
- **Surface** sensing from **passive** instruments

Most sounding instruments

- **Surface** sensing from **active** instruments
- **Atmospheric sounding** by GPS Radio Occultation.

L1 data: raw data (after some minor pre-processing)
L2 data: derived products

- Mainly used to derive the vertical distribution of temperature, humidity and the concentration of other constituents affecting the transmittance.

- Located in parts of the infrared and microwave spectrum for which the main contribution to the measured radiance comes from the atmosphere gases. They avoid channels for which surface radiation is important.

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

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

Satellite measurements

- To measure the temperature we need to select frequencies for which the absorption is due to gases with quasi-fixed and known concentration (like CO2 and O2) → *L(v)* depends only on temperature,

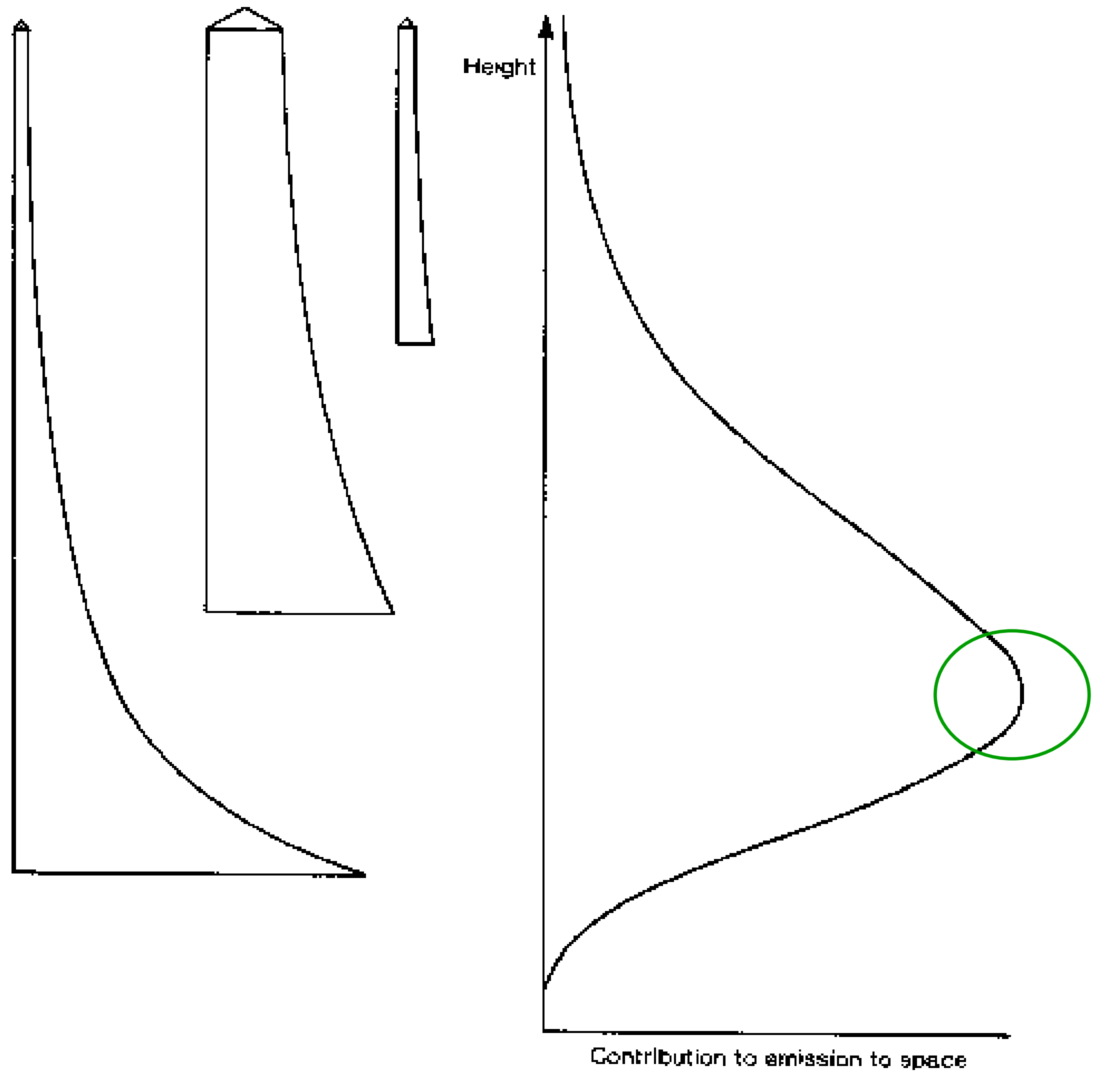
e.g. Microwave bands around 60 and 120 GHz
Infrared bands around 15 μm and 4.3 μm

- To measure the humidity or ozone we need to select frequencies for which Water vapor or ozone are a potential absorbers.

e.g. Infrared band near 6 μm for humidity
Infrared band near 9 μm for ozone

Satellite measurements

For a given frequency *v*, The weighting function *Kv(z)* has his highest value in the atmospheric layer which contribute to the maximum of the outgoing radiance

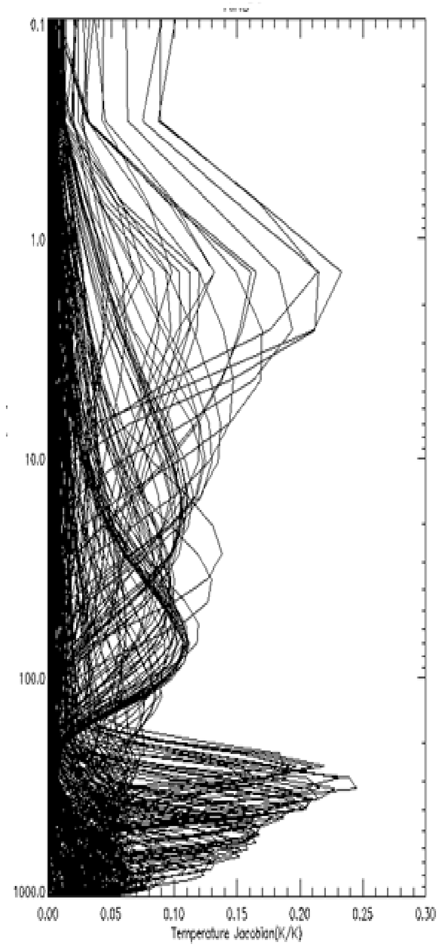


Satellite measurements

- With a careful selection of frequencies, 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



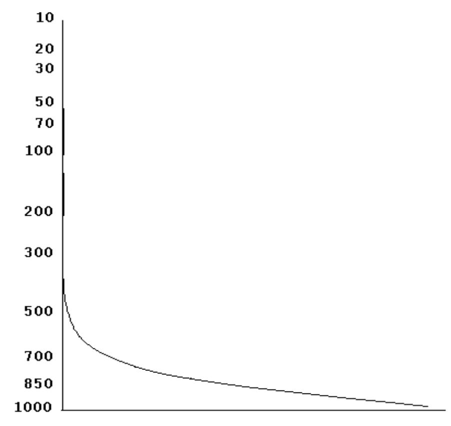
These channels are located in window regions of the spectrum at frequencies where the main contribution to the measured radiance is coming from the surface:

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

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

T_{surf} = surface temperature ***ε = surface emissivity***

Used to obtain information about the surface temperature, vegetation and surface wind (over sea).



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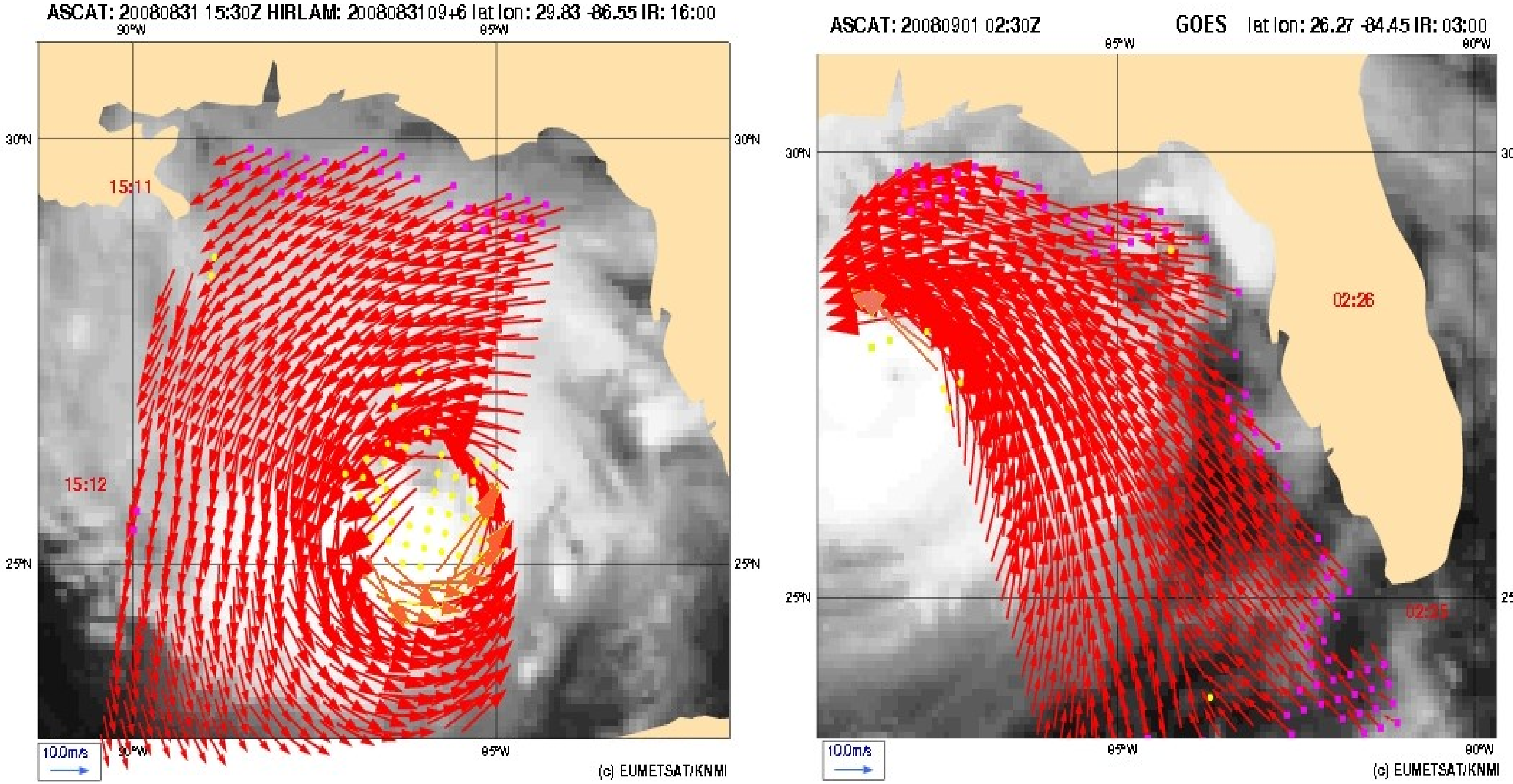
- These instruments (e.g. Scatterometers and altimeters) illuminate the earth's surface by emitting energy in **atmospheric window (VIS/NIR & MW)** regions and measure the radiance that is scattered back.

Main contribution to the measured radiance is:

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

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

Hurricane Gustave (31/08/2008) captured by ASCAT



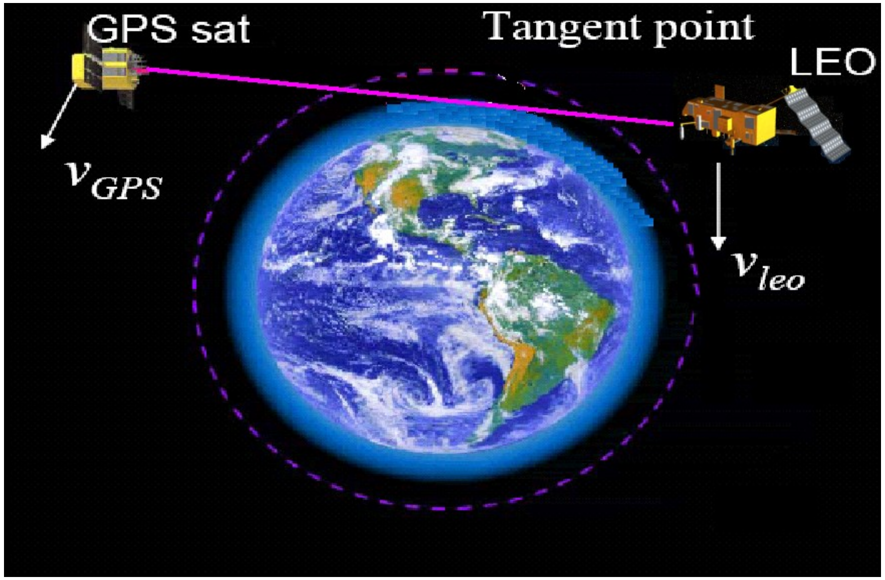
Satellite measurements

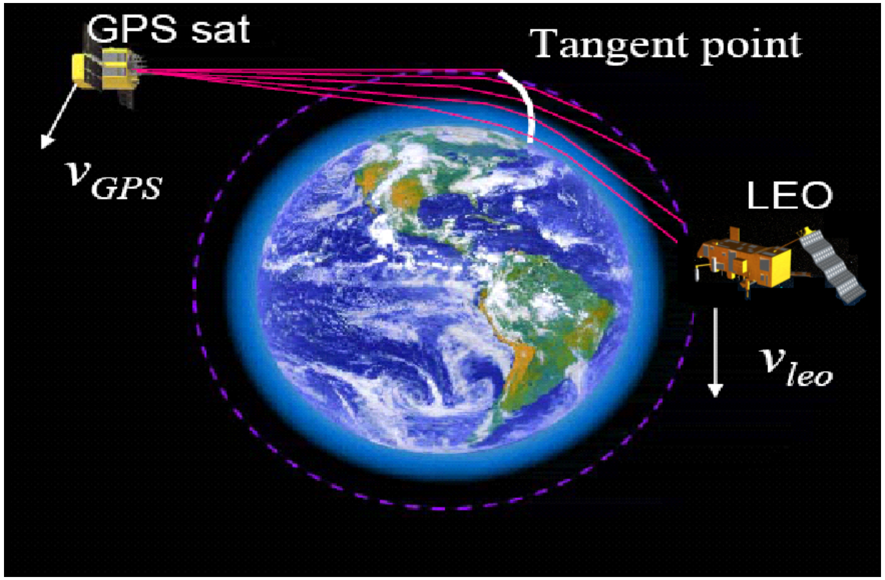
GPS Radio occultation

● The impact of the atmosphere on the radio signal propagation depends on the refractivity

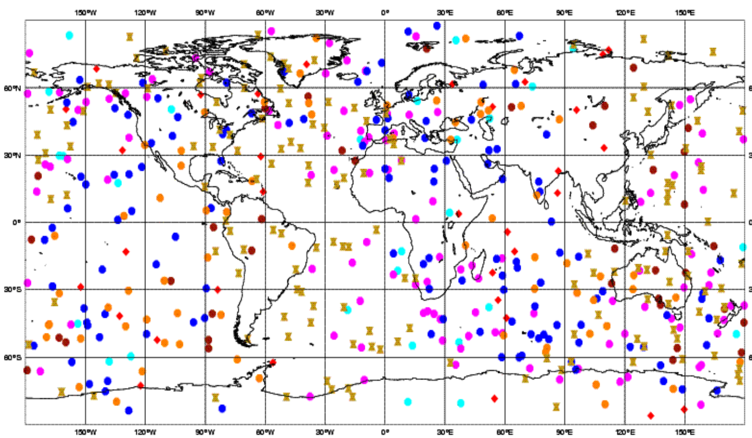
● Receivers on LEOs record quasi-vertical profiles of the atmosphere (ionosphere and neutral) including :

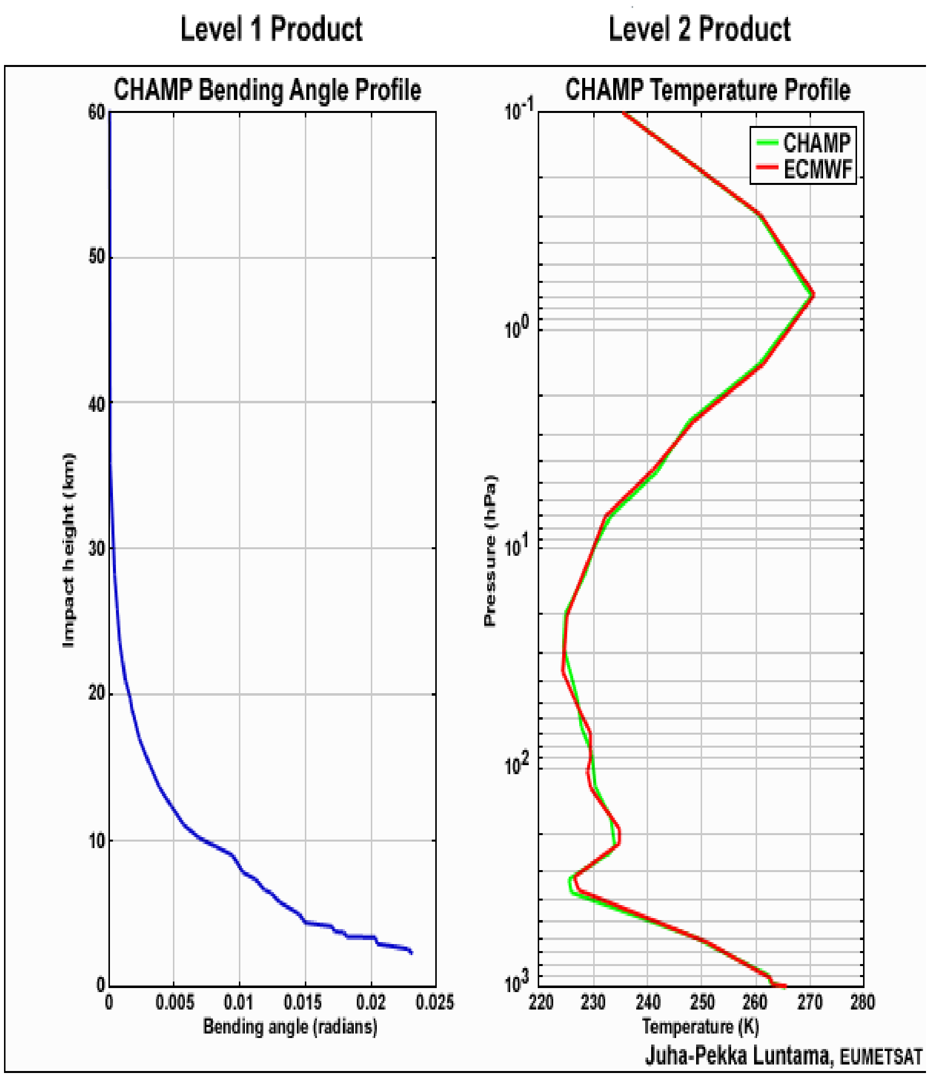
- **Bending angle >>**
- **Refractivity >>**
- **(Temperature, humidity)**





- High vertical resolution (~1 km),
- Good horizontal coverage,
- High stability in time
- All weather sensing capability (not affected by cloudy or rainy conditions),





Picture from Eumetsat website

Satellite measurements

Satellite instruments used/monitored at ECMWF

Instruments	Plateforme
HIRS (Infrared)	NOAA series, METOP
AMSU-A, AMSU-B/MHS (microwave)	NOAA, METOP-A, METOP-B, AQUA
IASI (Infrared)	METOP-A
AIRS (Infrared)	AQUA
GPSRO	CHAMP, GRACE-A, COSMIC series, METOP-A, METOP-B, TERRA-SARX
SSMI, SSMIS (microwave), TMI, WINDSAT	DMSP series, TRMM, WINDSAT
MODIS (AMVs)	AQUA, TERRA
Scaterrometer (surface winds, soil moisture)	METOP-A/ASCAT
Altimeter (surface winds, waves)	Jason, Envisat
Sciamachy, SBUV, OMI, GOME-2, SEVIRI and GOMOS (Ozone)	Envisat, NOAA, AURA, MSG, ERS, METOP
Imaging instruments (Radiances & derived AMVs)	METEOSAT, MSG, GEOS, MTSAT

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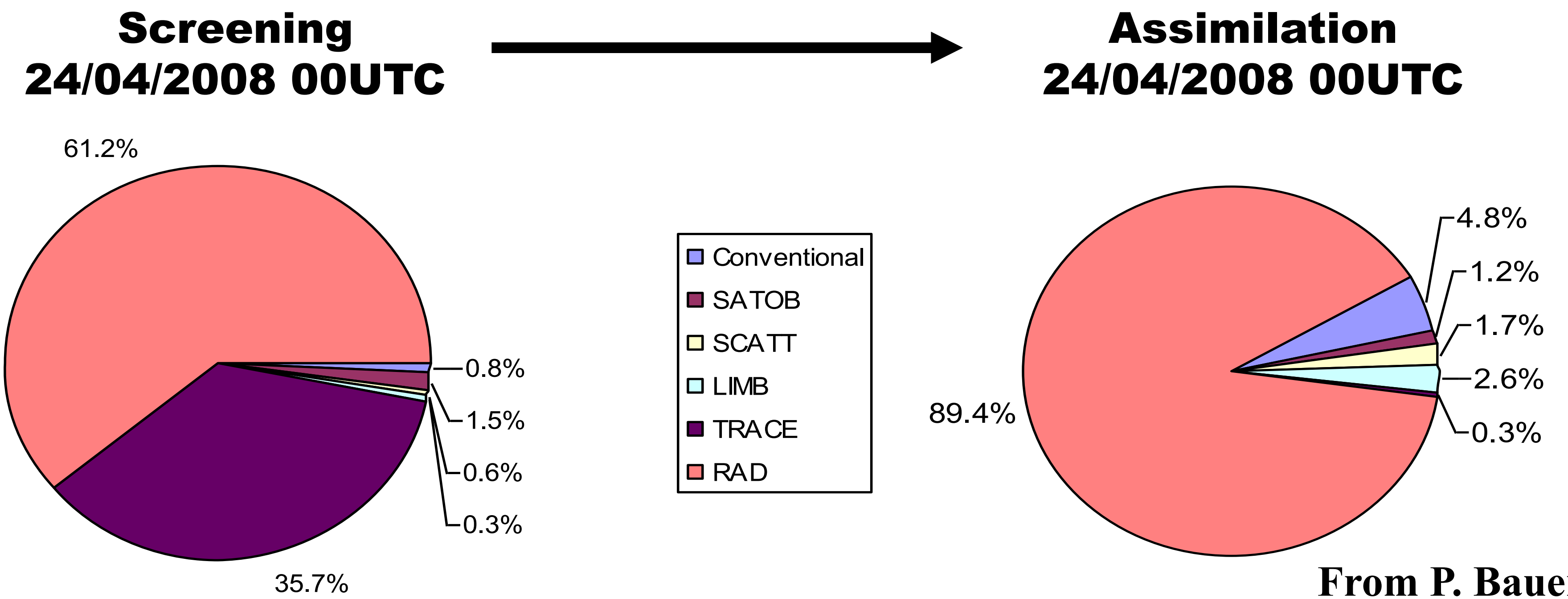
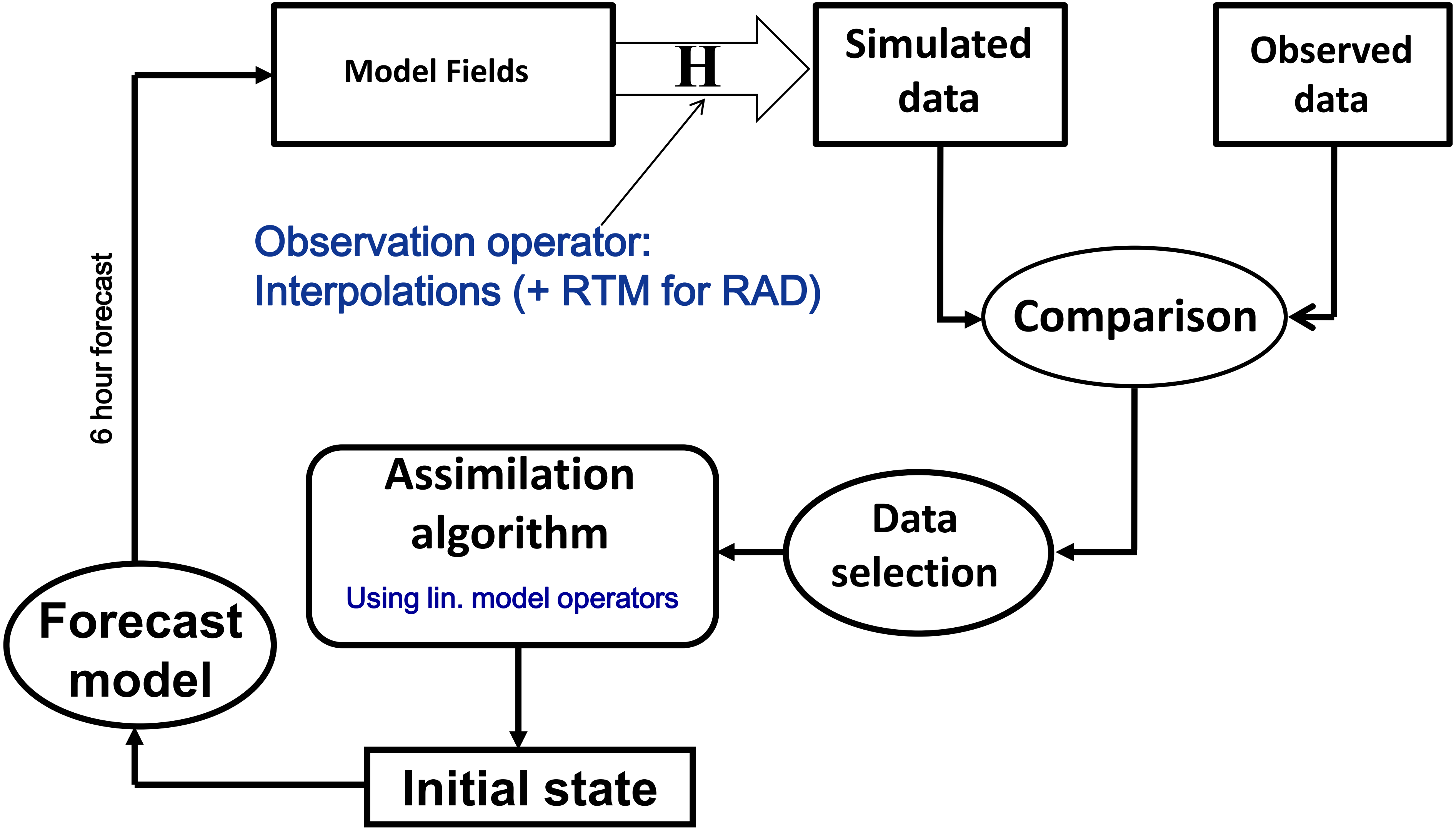
Satellite data usage at NWP

- At ECMWF, satellite data are principally used by the assimilation systems (4D-Var, Wave OI) to define the initial conditions for the forecast model,
- Satellite data amounts to 99% in screening and 95% in assimilation.
- Radiance data dominates assimilation with 90%.
- Relative GPSRO (limb) data amount strongly increases between screening and assimilation while ozone data is largely reduced.

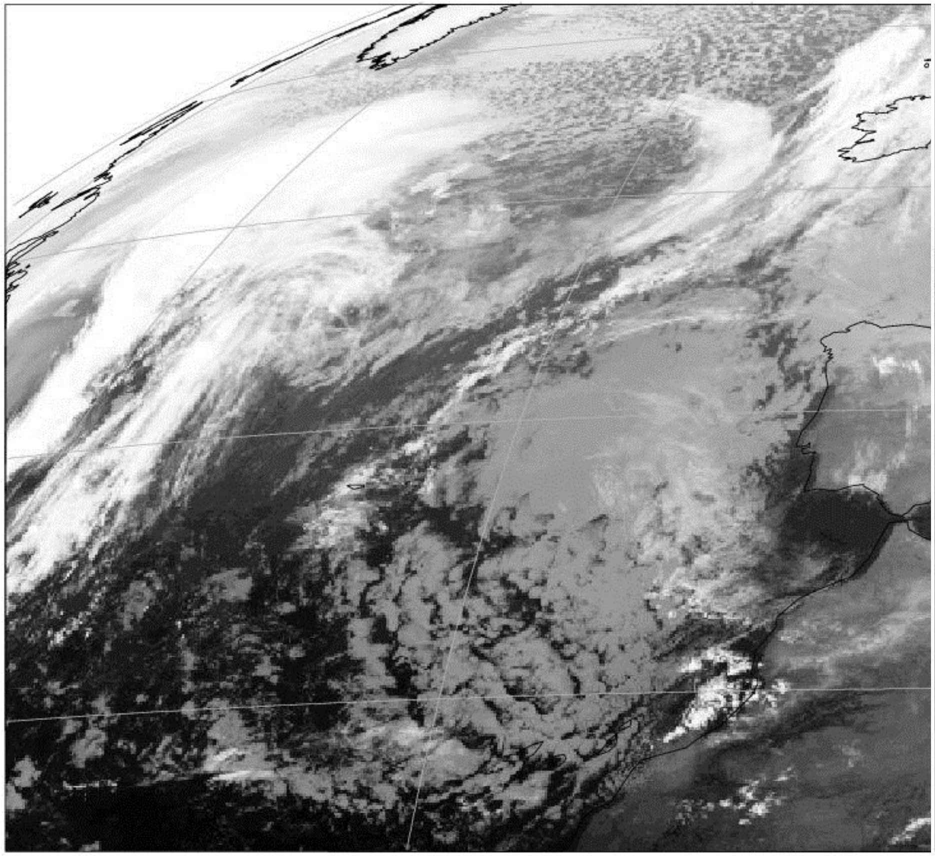


From P. Bauer

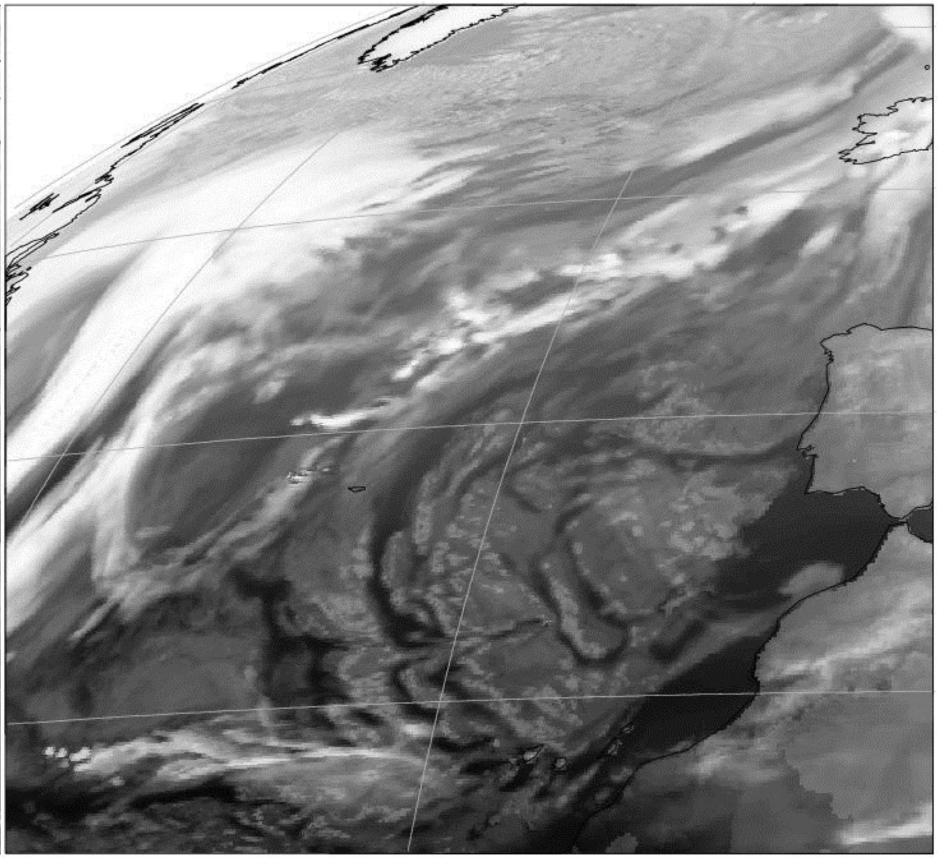
Direct assimilation of raw data



Met-8 IR (Observations)



Met-8 IR (from the model)



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Satellite data monitoring

- Data monitoring is a crucial component of the data assimilation diagnostic system. It allows the control of the availability, the quality and the impact of the observing system.
- Data monitoring can help diagnosing model problems.
- Monitoring outputs are important to define and evaluate the data usage
- Data monitoring consists of the production of statistics over large data samples. Statistics are generally computed for quantities related to the data assimilation
- Data monitoring tools allow investigating the data from various perspectives.

Satellite data monitoring

- In the daily model monitoring (analysis, increments, forecasts, …), it's generally not easy to spot the impact of satellite data,

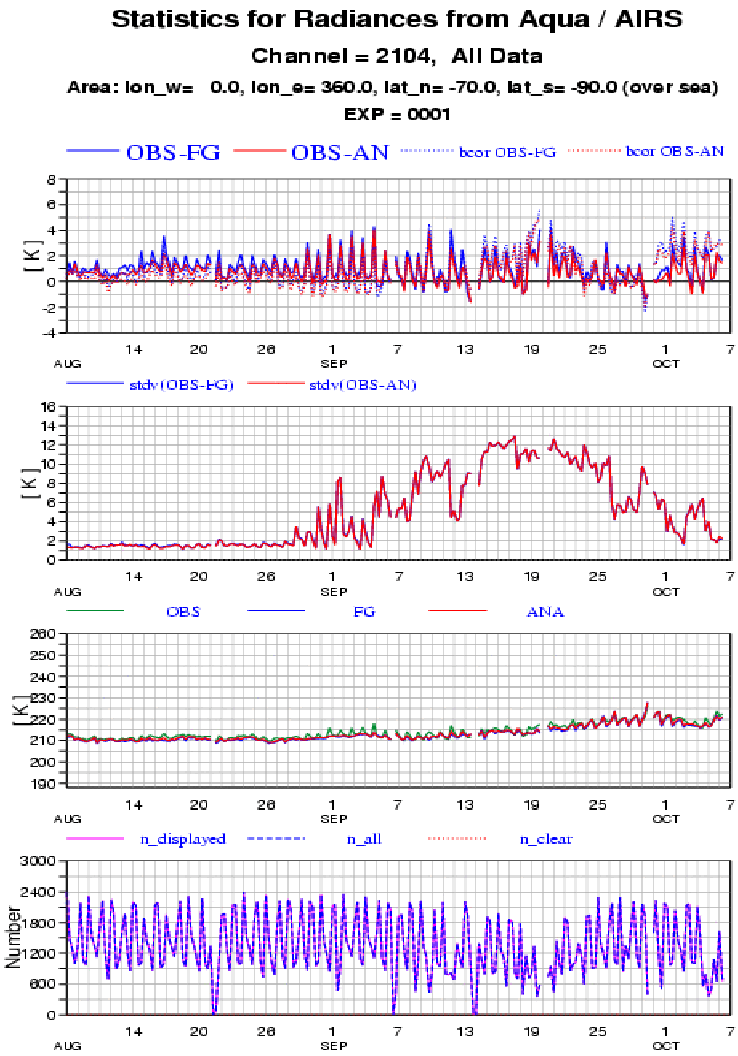
- However, any important degradation of the quality or the availability of satellite data may affect, few days later, the quality of the forecasts.

- It's crucial to report any change in data quality or availability. This is important to trigger corrective actions (blacklisting, ….),

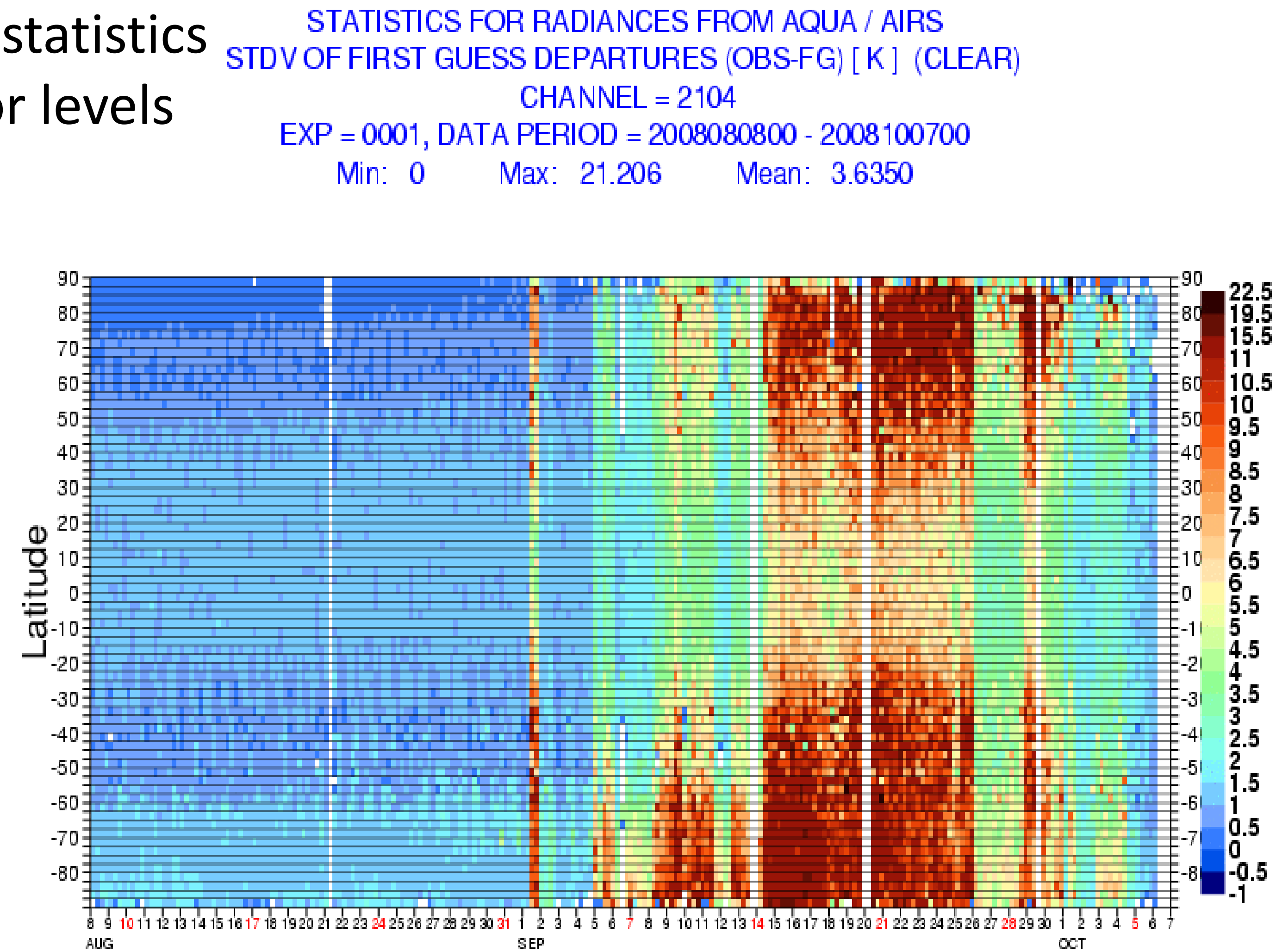
Satellite data monitoring

Time series

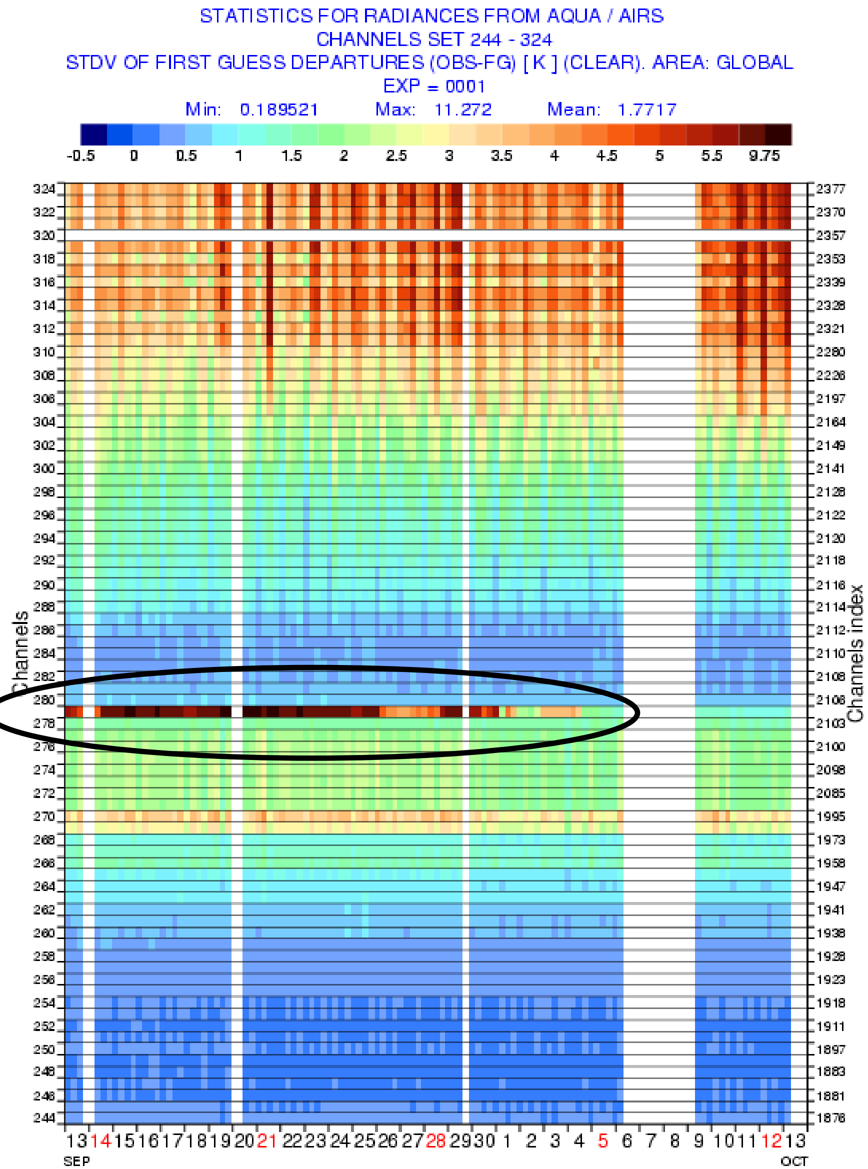
Time evolution of statistics over predefined areas/surfaces/flags



Time evolution of statistics of zonal means or levels means



Time series compact product for high spectral resolution sounders



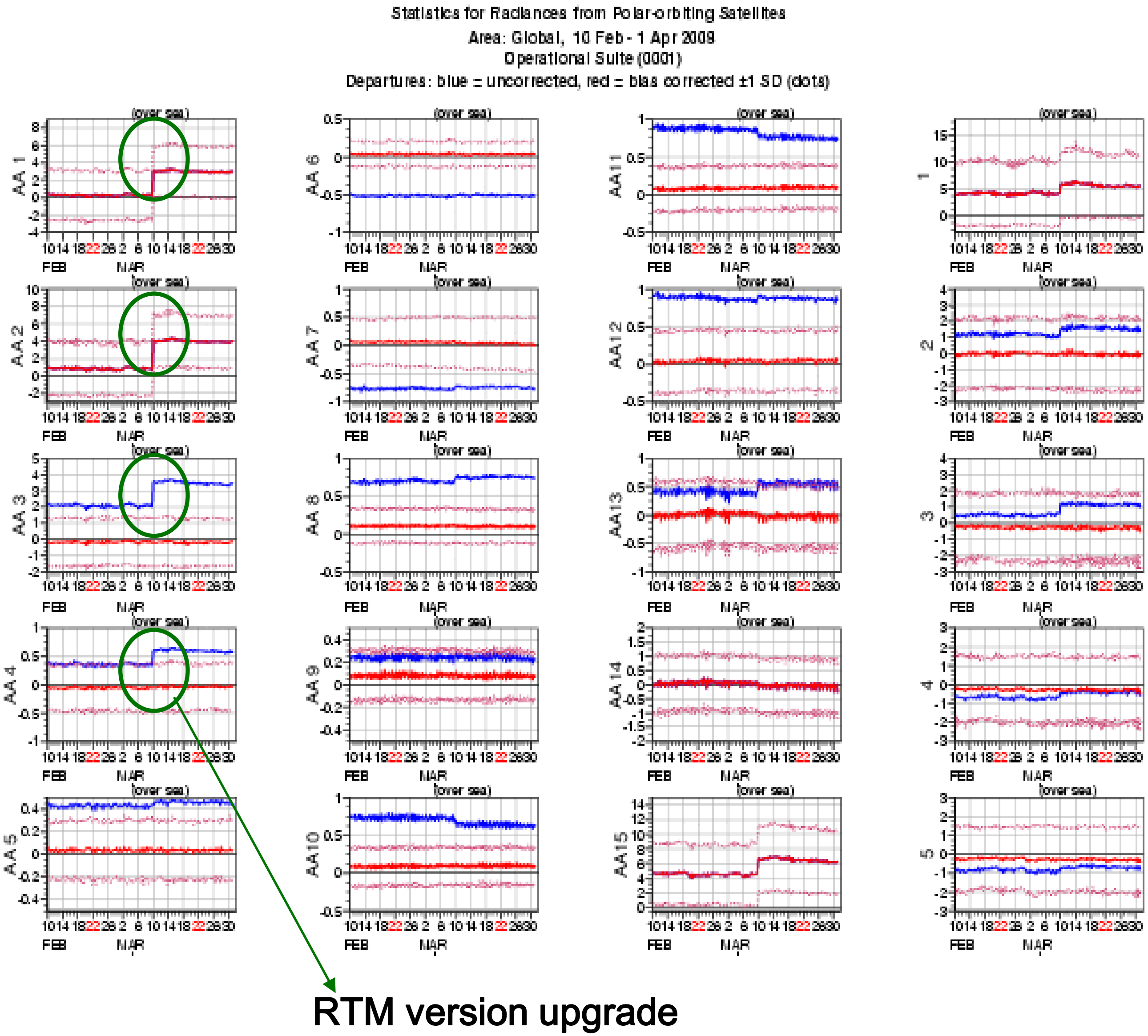
Increase of the noise of AIRS channel 2104

When a problem is spotted, individual time series and Hovmöller diagrams can be checked.

Time evolution of statistics for several channels

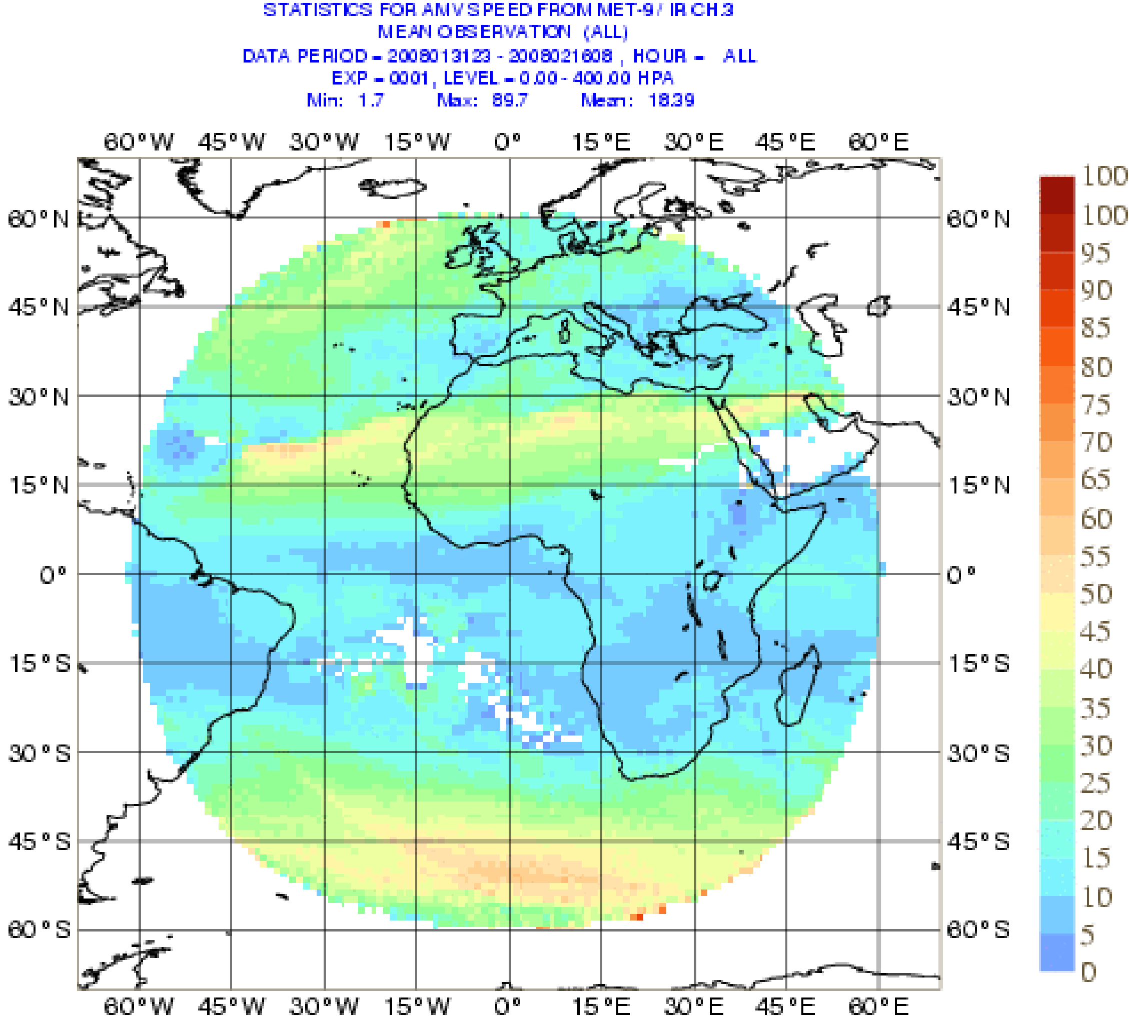
Useful for quick and routine verifications

Can not be used for high spectral resolution sounders

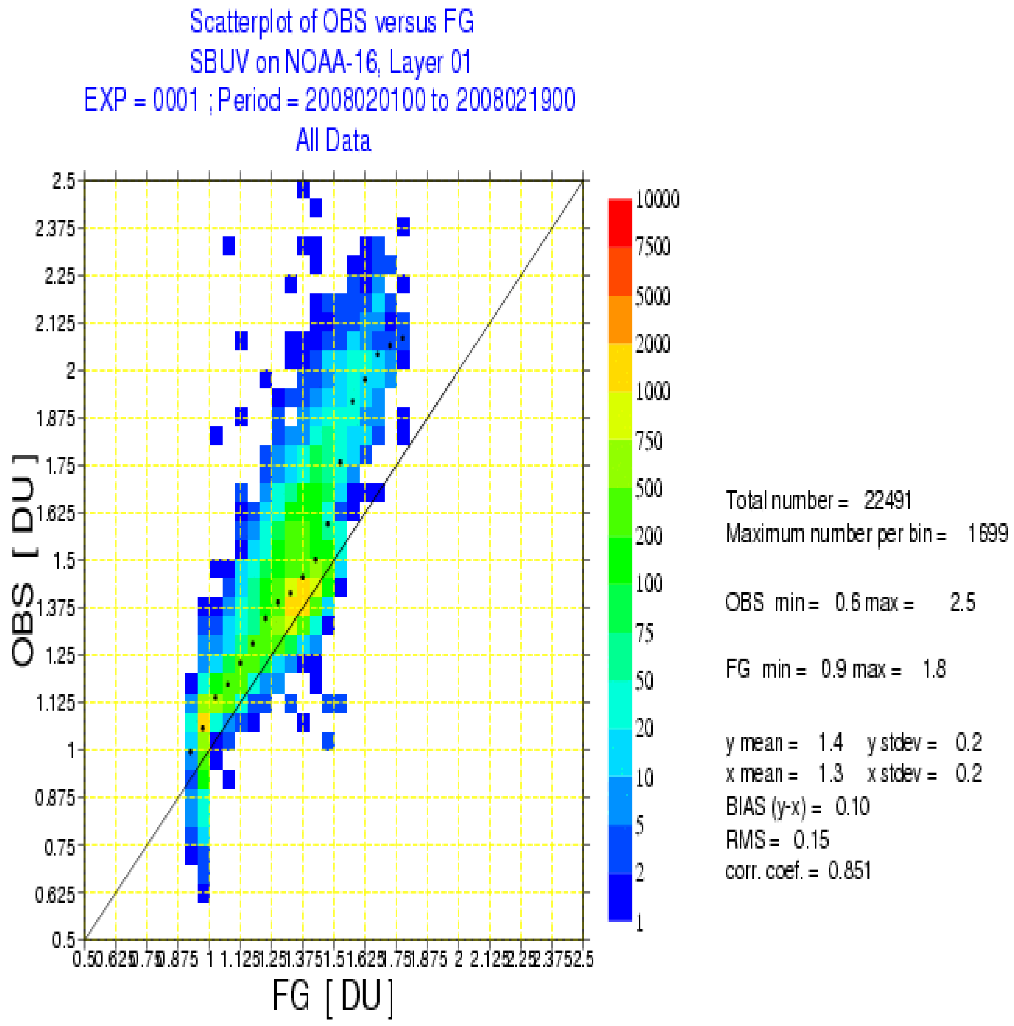


Assessment of the geographical variability of statistics:

- location effect
- air mass effect

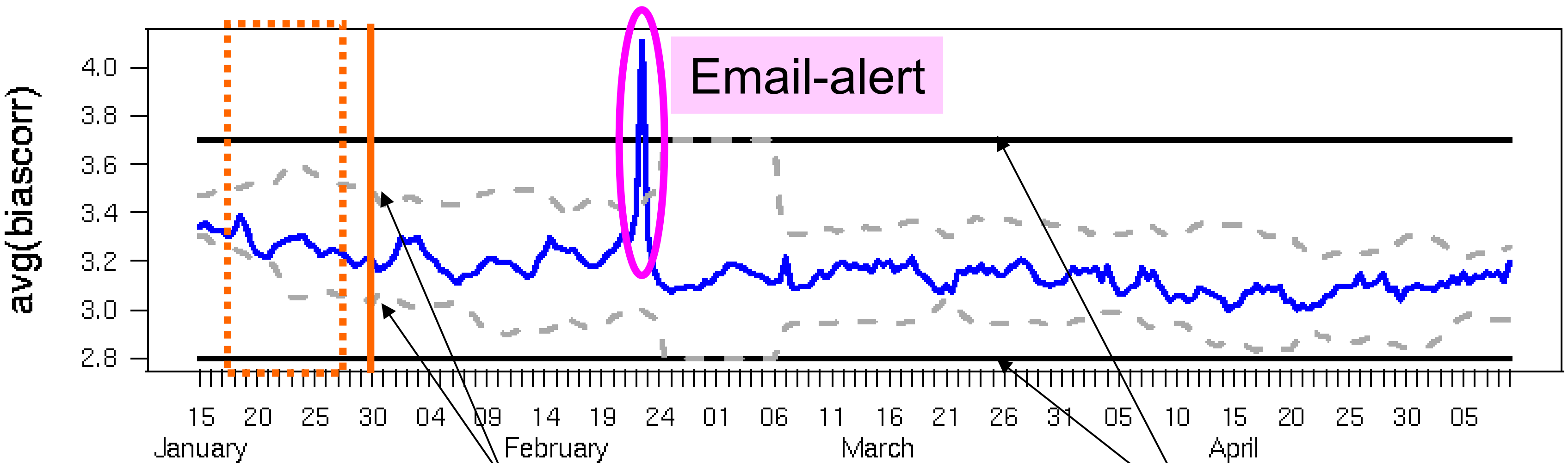


comprehensive way to compare observed values against model ones



Selected statistics are checked against an expected range.

E.g., global mean bias correction for GOES-12 (in blue):



Soft limits (mean ± 5 stdev of statistic to be checked, calculated from past statistics over a period of 20 days, ending 2 days earlier)

Hard limits (fixed)

Satellite data monitoring

Alarm system

Satellite Data Automatic Checking http://nwmstest.ecmwf.int/products/forecasts/satellite...

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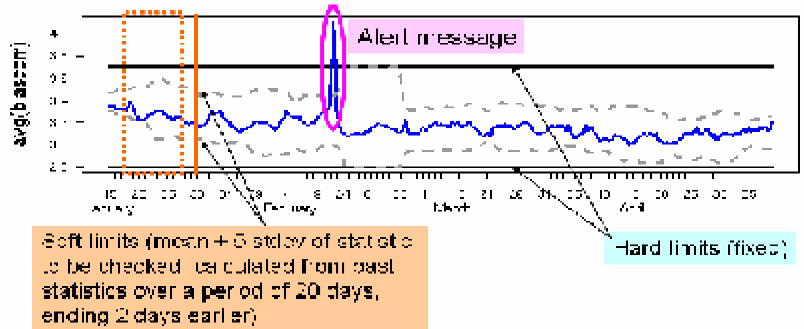
Satellite Data Automatic Checking

An experimental automatic satellite data checking system has been implemented recently at ECMWF. It triggers the production of alarm messages if an anomaly is detected in the quality or the availability of the satellite data assimilated by the model.

Selected statistical parameters (number of observations, bias correction, and mean bias-corrected background and analysis departures) are checked against an expected range. An appropriate alert message (including a time series plot) is generated if statistics are outside the specified ranges. A severity level (slight, considerable, severe) is assigned to each message depending on how far statistics are from the expected values. Two kinds of ranges are used by the automatic checking: Soft and Hard limits. Soft limits are updated automatically using statistics from the last twenty days (extremes are excluded during this process). Hard limits are adjusted manually when required.



Currently, the automatic checking is limited to data passing through the minimisation process (including VarBC passive data). It's being applied, twice a day, to the long cut-off 4D-VAR cycles (DCDA).

- Experimental Satellite Data Checking for 2008110412 DCDA
- Experimental Satellite Data Checking for 2008110400 DCDA

24.10.2008 © ECMWF

http://www.ecmwf.int/products/forecasts/satellite_check/

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

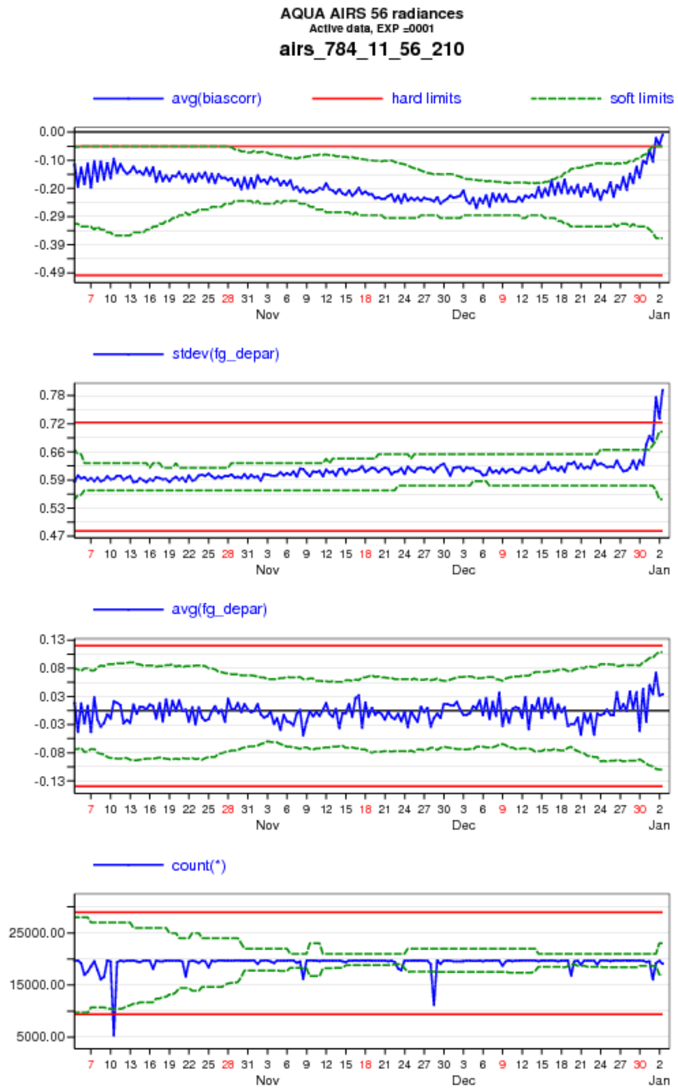
Surface: Microwave and scaterrometer data from various satellites.

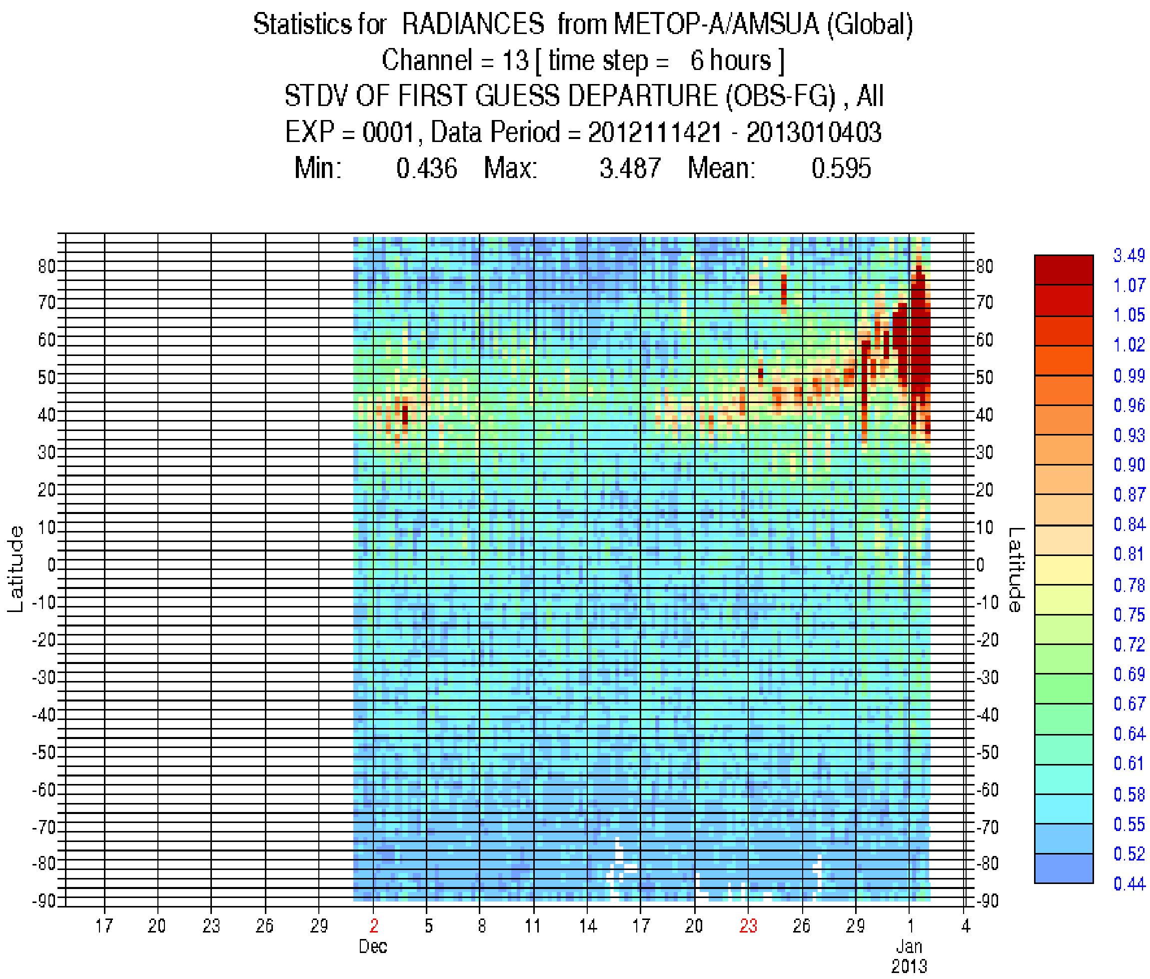
Early January 2013, the automatic alarm system generated severe alarms associated to an increase of the noise for infrared and microwave stratospheric peaking channels

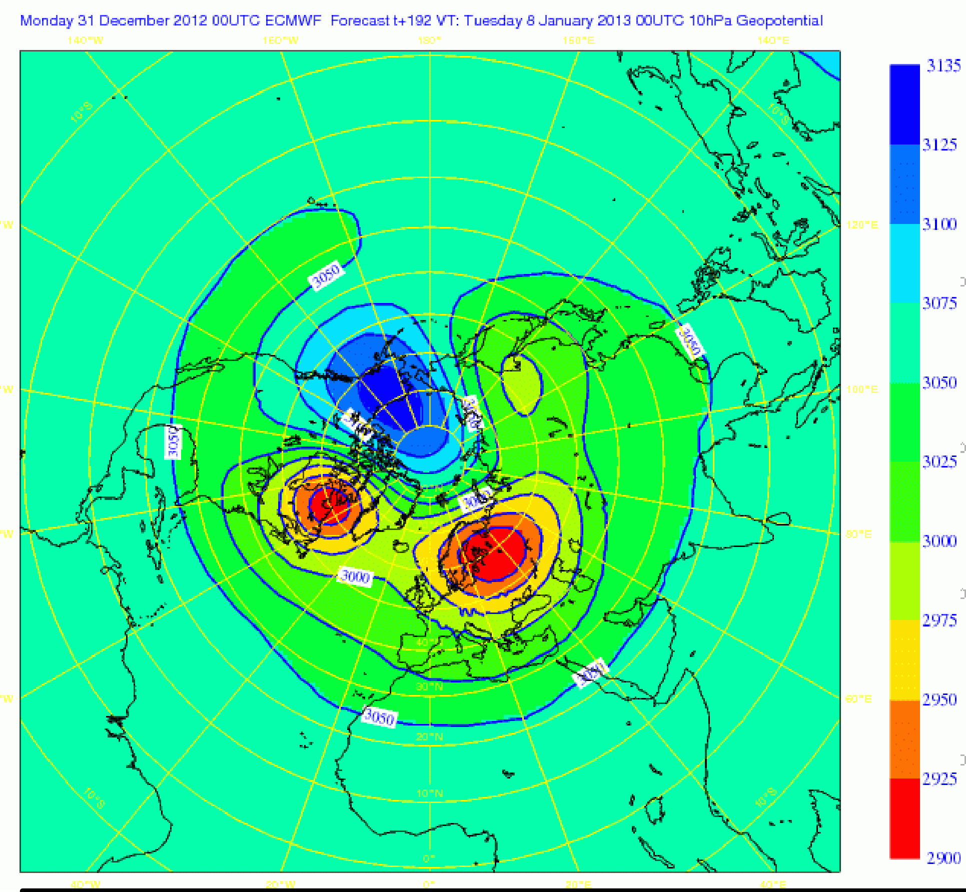
```
Checking 0001 DCDA 2013010212
=====================================
AQUA AIRS 56 radiances : out of range:
  (3 times in last 10 days for at least one item)
 http://www.ecmwf.int/products/forecasts/satellite_check//do/get/satcheck/3215/110485?showfile=true
  Severely:     stdev(fg_depar)=0.777,            expected range: 0.57 0.68
  Slightly:     avg(biascorr)=-0.02000005,        expected range: -0.37 -0.05(H)

METOP-A IASI 89 radiances : out of range:
  (6 times in last 10 days for at least one item)
 http://www.ecmwf.int/products/forecasts/satellite_check//do/get/satcheck/3217/111259?showfile=true
  Severely:     stdev(fg_depar)=0.459,            expected range: 0.33 0.41
```

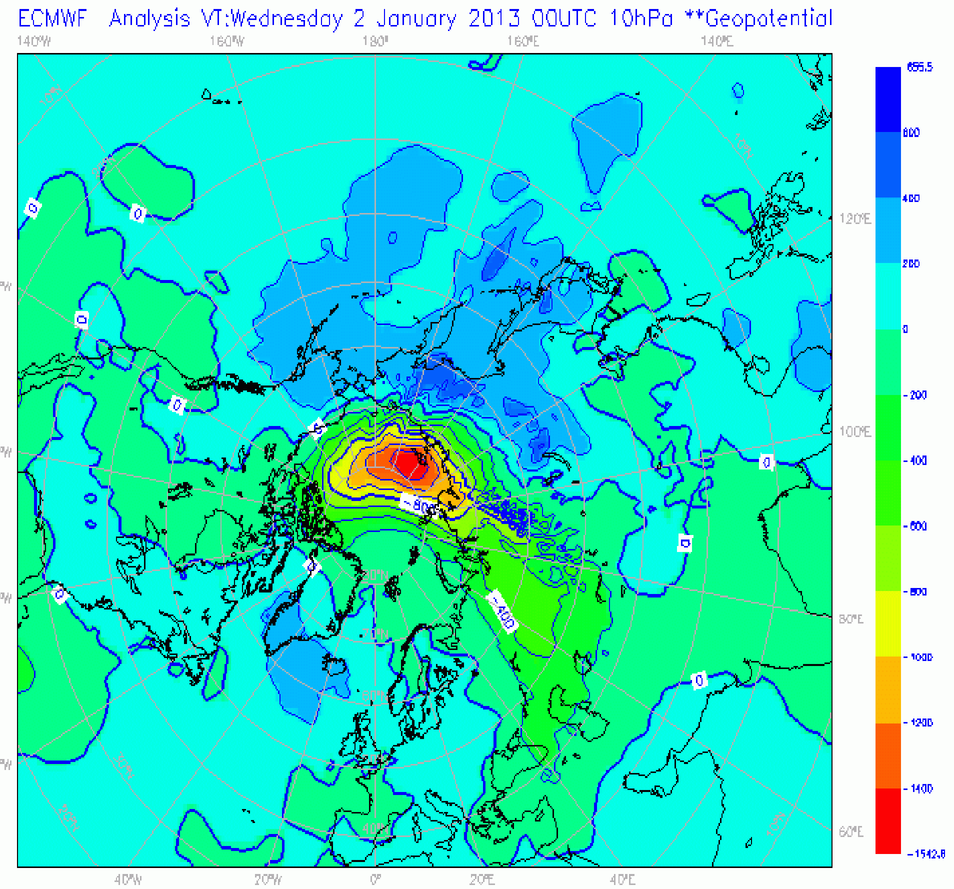
Satellite data monitoring

Diagnosing model problems (3/4)









The increase of the noise is due to the onset of the polar vortex breaking out process (SSW). The model predicted the onset of the process but not accurately in the beginning. A lot of data failed the QC check and delayed the model recovery.

The SSW was a clear indication that a cold spell will hit Europe one to two weeks later.

Satellite data

Useful links

- ECMWF newsletter articles

http://www.ecmwf.int/publications/newsletters/

  - Spring 2003: “Assimilation of high-resolution satellite data.”
  - Spring 1999: “The use of raw TOVS/ATOVS radiances in the ECMWF 4D-Var assimilation system”

- ECMWF Technical Memoranda

http://www.ecmwf.int/publications/library/do/references/list/14

  - TM 345: “An improved general fast radiative transfer model for the assimilation of radiance observations”,

- ECMWF monitoring web site

http://www.ecmwf.int/products/forecasts/d/charts/monitoring/satellite

Thank you for your attention