Satellite Observations

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Outline

- Data sources
- Why satellite data important ?
- Principals of satellite measurements
- Satellite data usage
- Monitoring of satellite data

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- **Data sources**
- Why satellite data important ?
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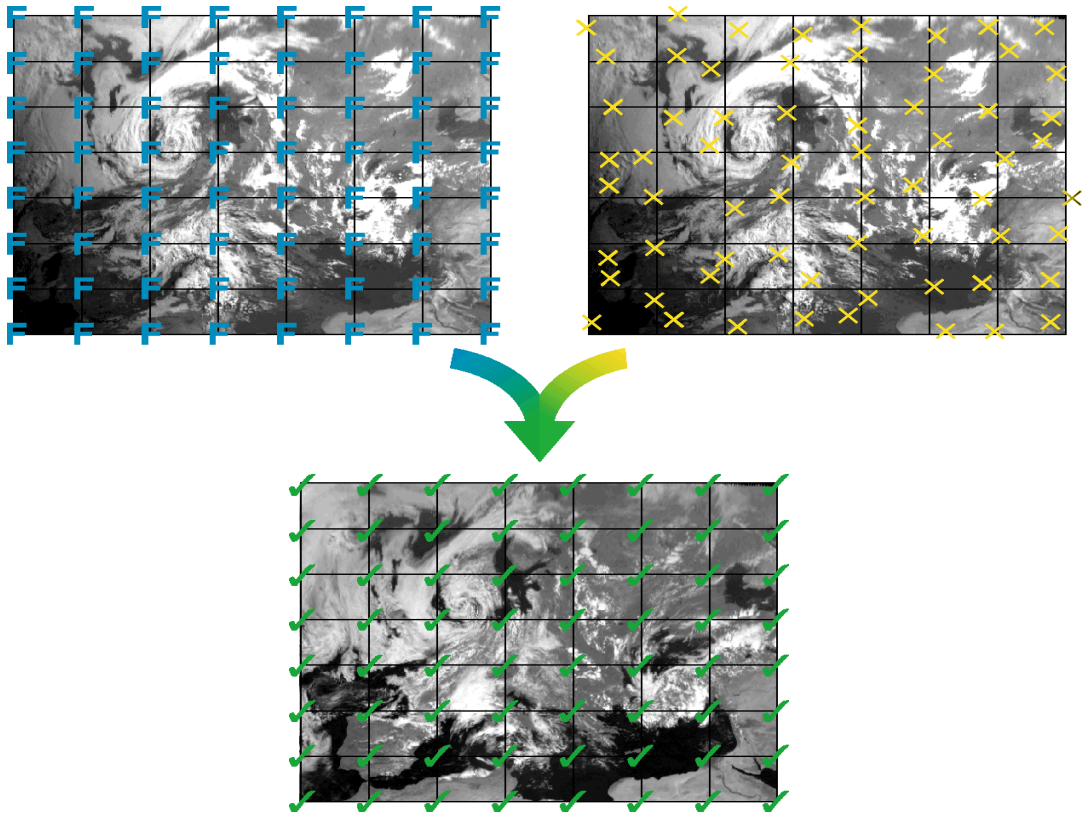
Role of observations

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*

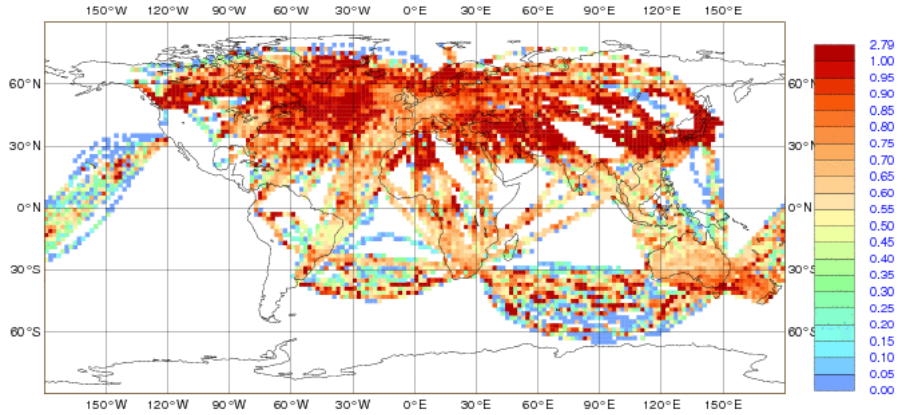
PROFILERS:

→ wind *profiles*

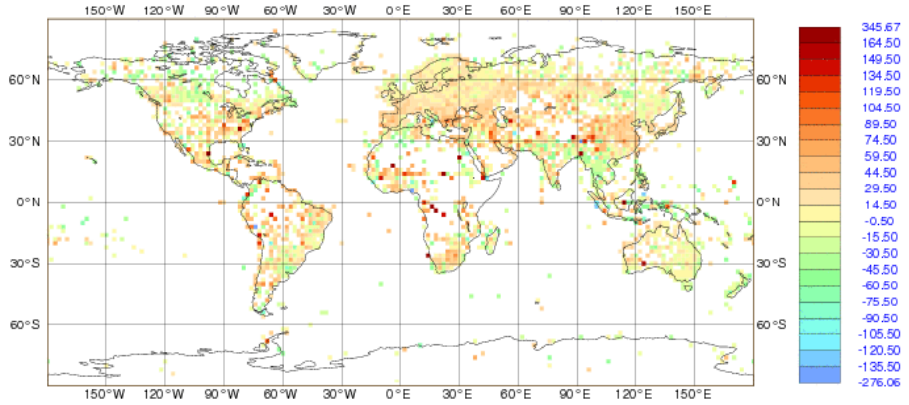
Aircraft:

→ temperature, pressure, wind *profiles*

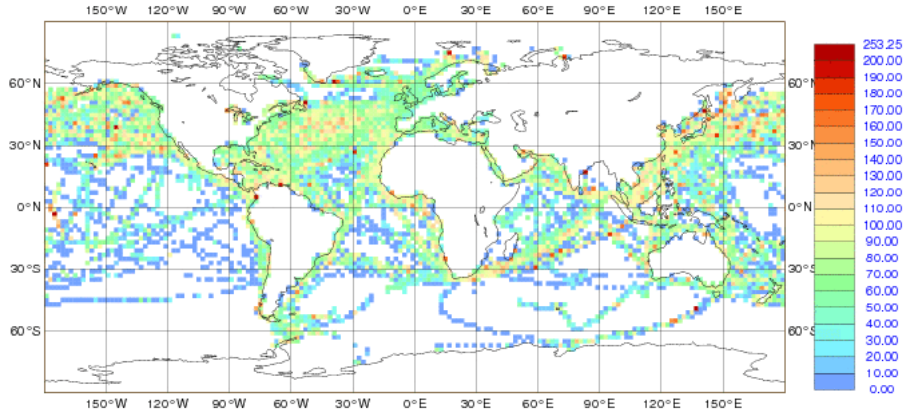
Example of conventional data coverage (one month)



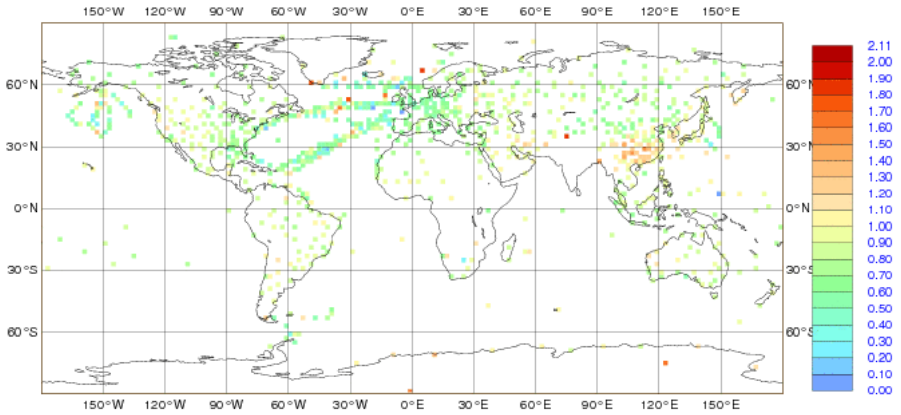
Aircraft – AMDAR



Synop

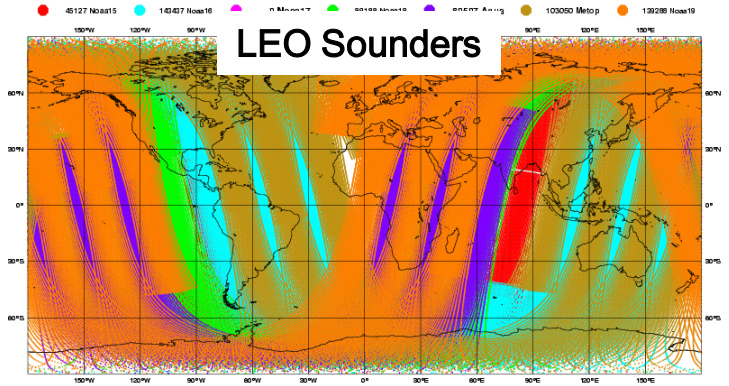


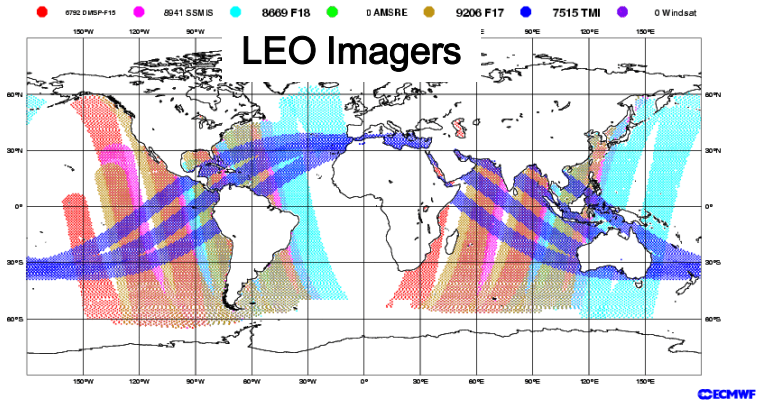
ship

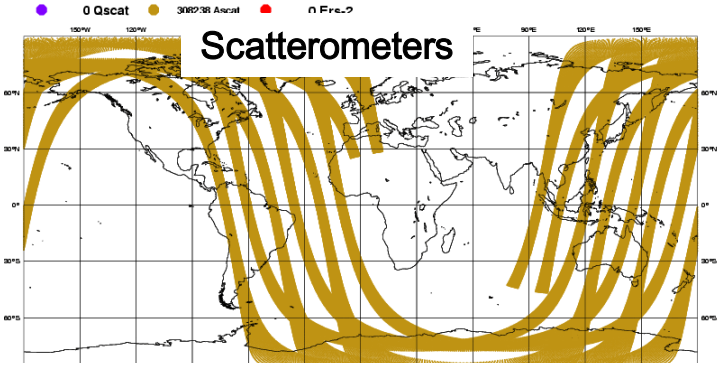


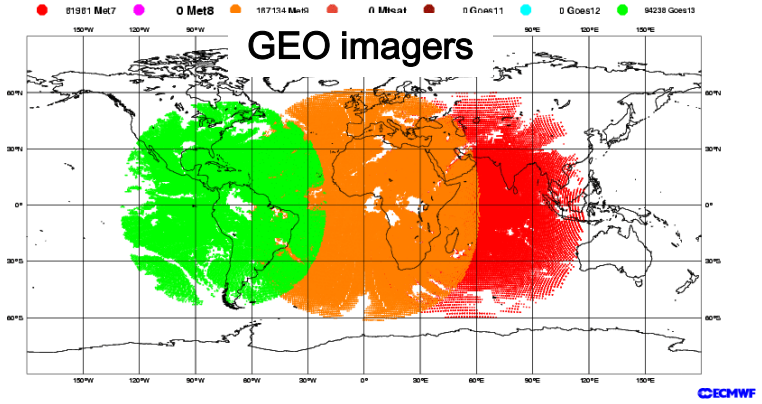
Temp

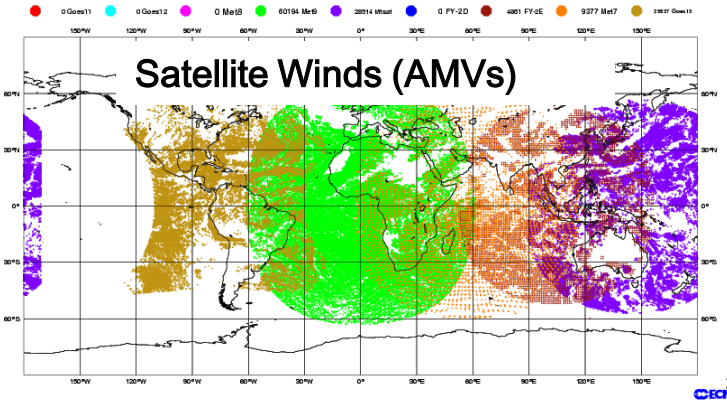
Example of 6-hourly satellite data coverage

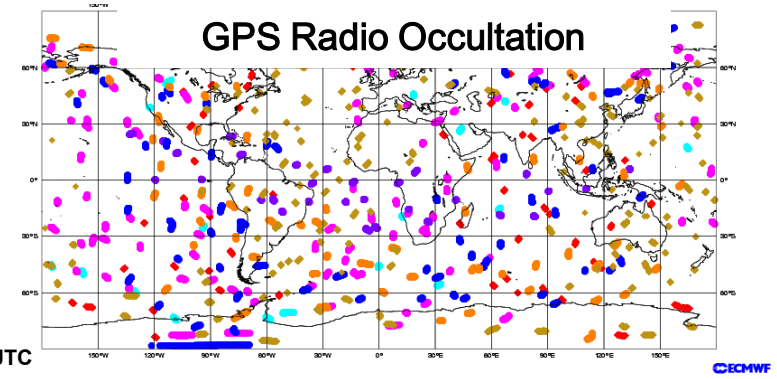






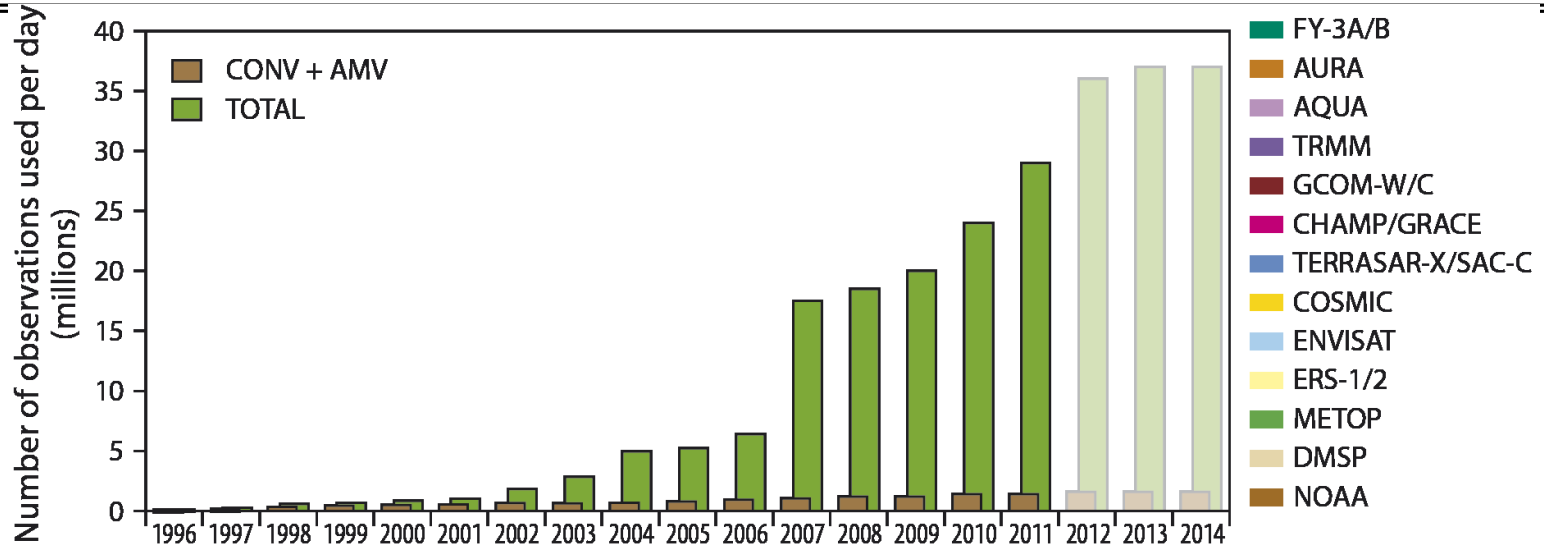


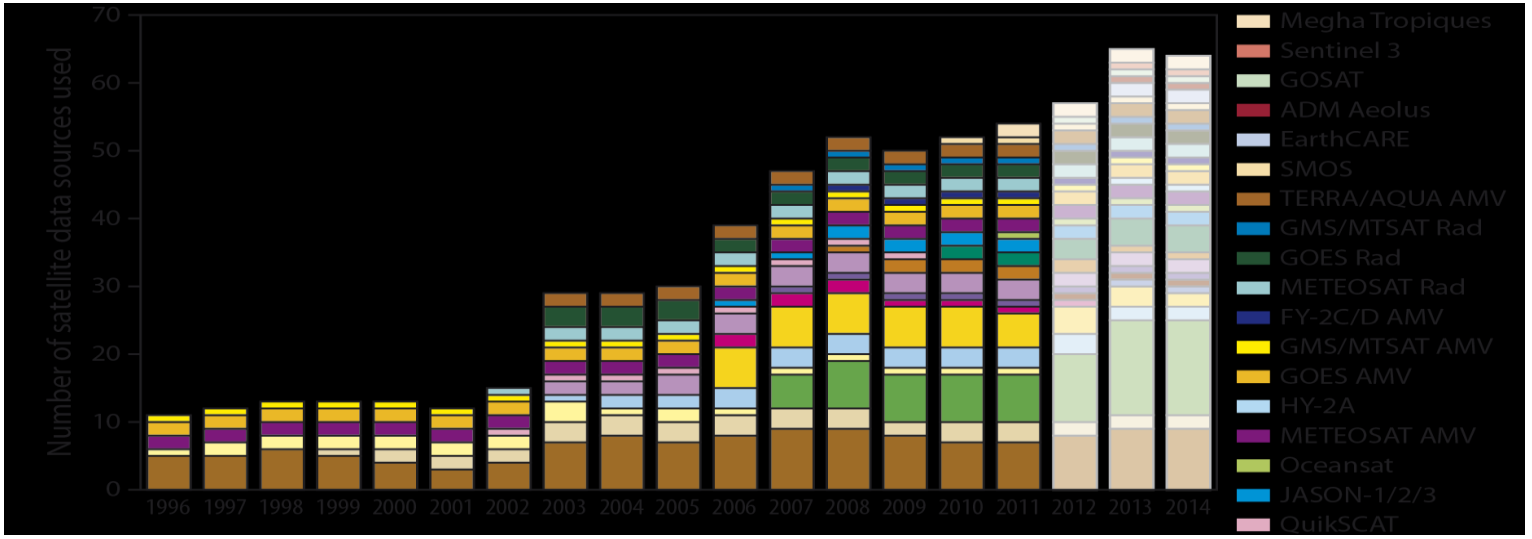




30 March 2012 00 UTC

Number of used satellite data is increasing





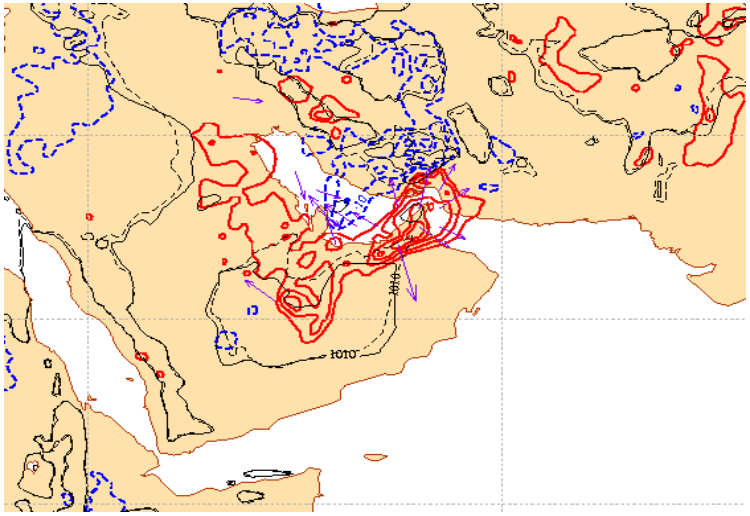
A scientific and technical challenge

Outline

- Data sources
- **Why satellite data important ?**
- Principals of satellite measurements
- Satellite data usage
- Monitoring of satellite data

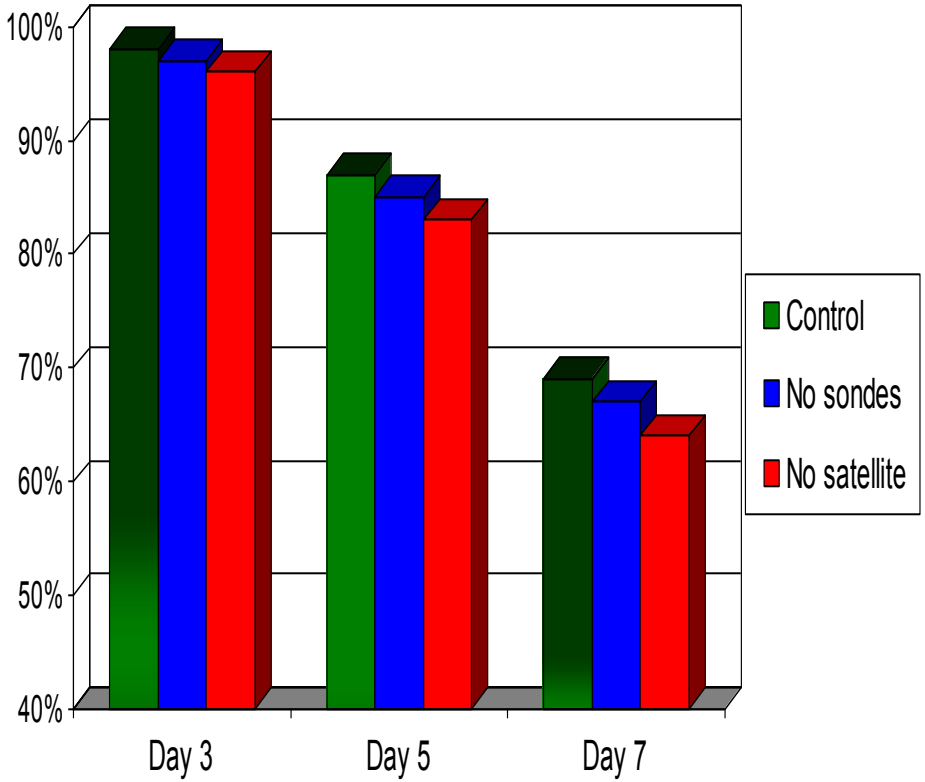
Why important ?

- **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**

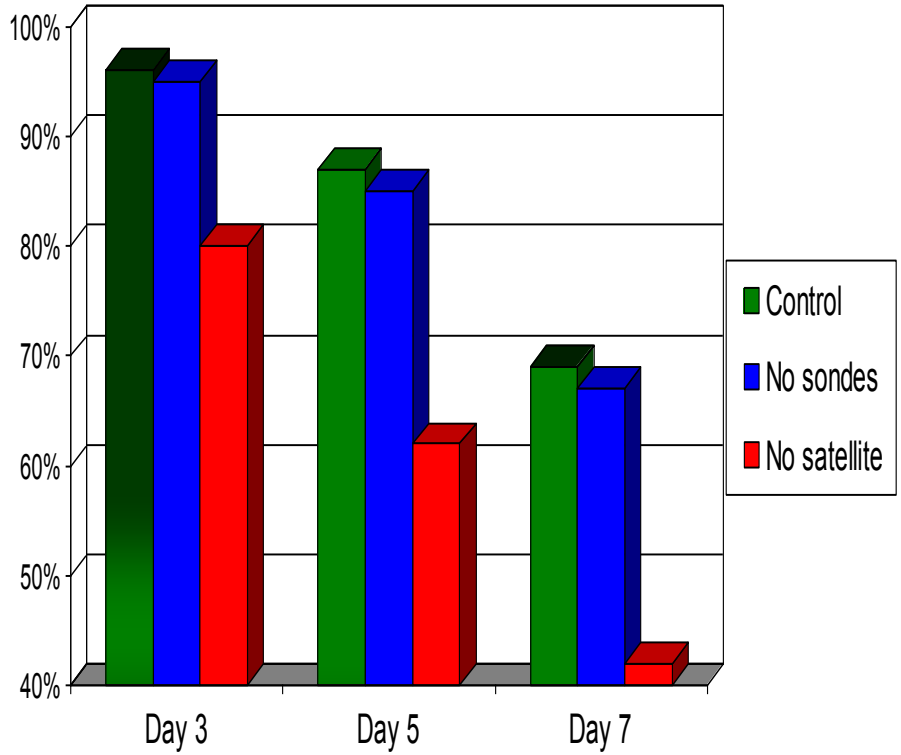


Why important ?

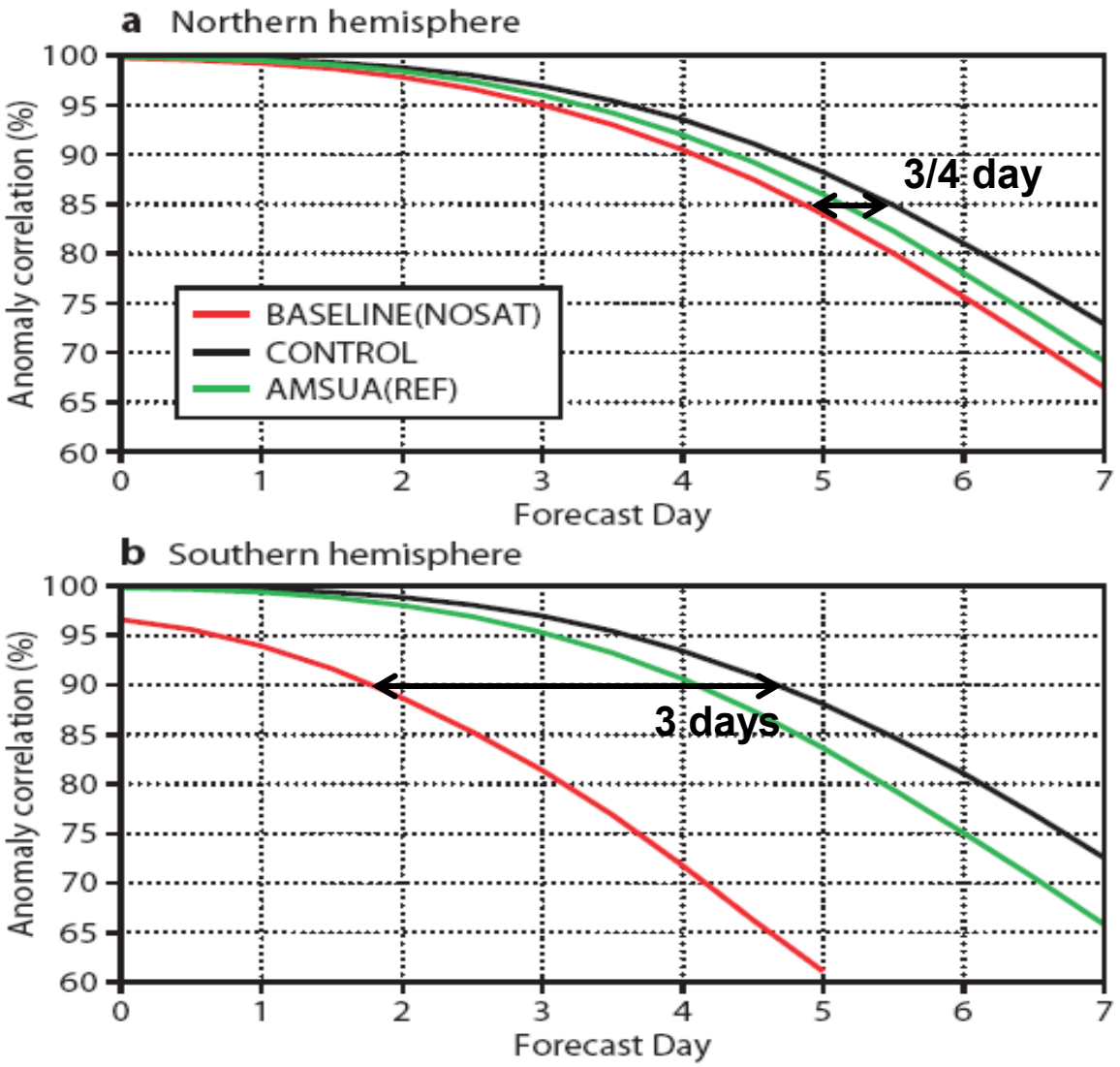
Anomaly correlation of 500hPa height for northern hemisphere



Anomaly correlation of 500hPa height for southern hemisphere



Why important ?



EUCOS Observing System Experiments (OSEs):

- 2007 ECMWF forecasting system,
- winter & summer season,
- different baseline systems:
  - no satellite data (NOSAT),
  - NOSAT + AMVs,
  - NOSAT + 1 AMSU-A,
- general impact of satellites,
- impact of individual systems,
- all conventional observations.

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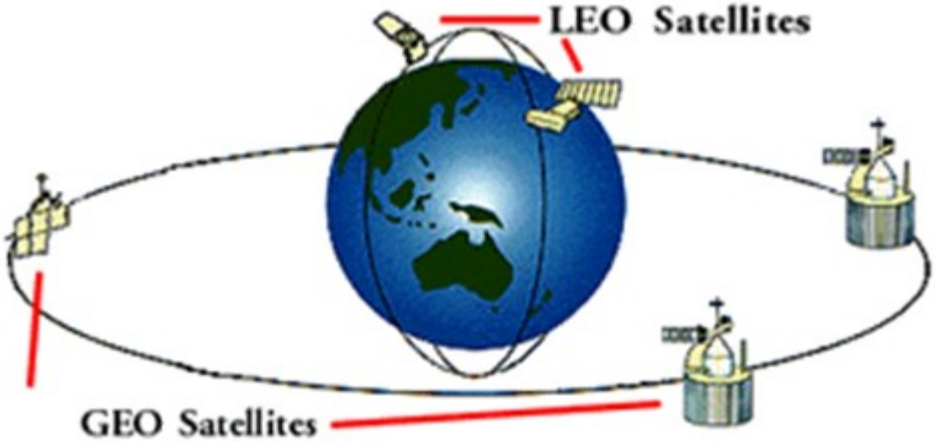
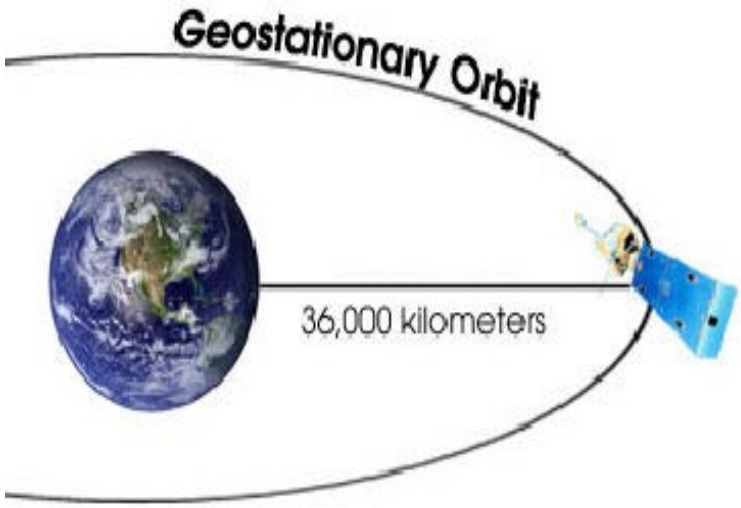
Types of satellites

- **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**

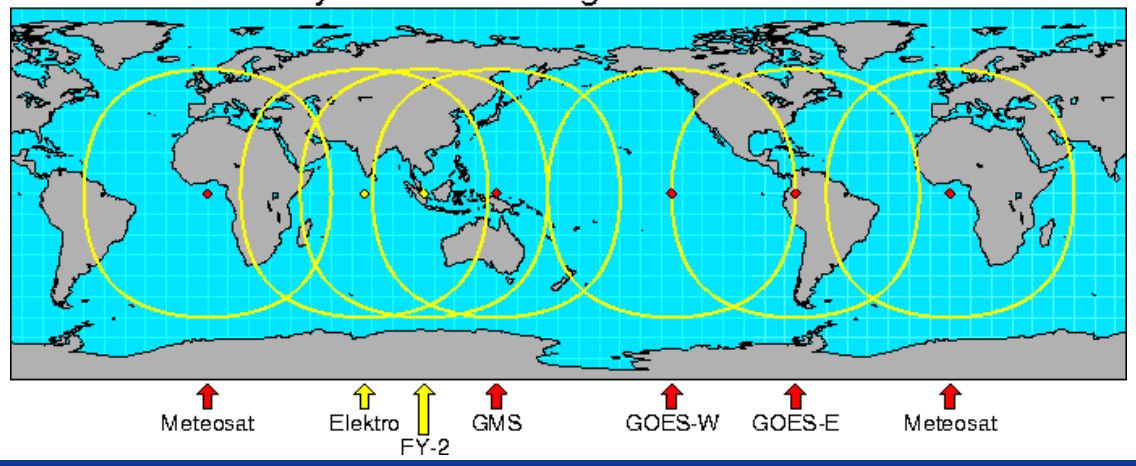
Geostationary Satellites

- **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,**

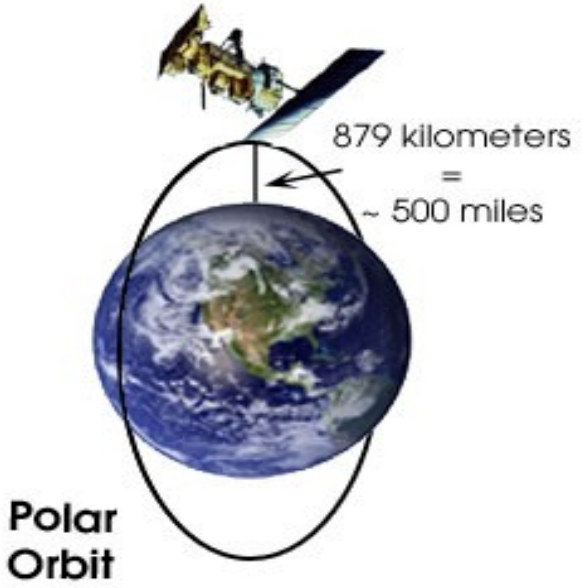
- **Unsuitable to observe polar regions.**

Global Geostationary Satellite Coverage



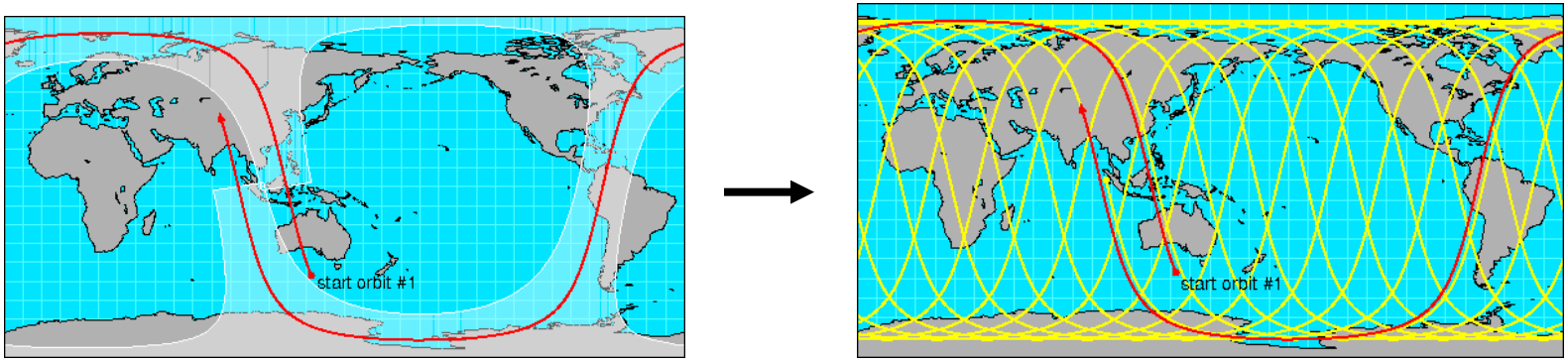
Low Orbiting Satellites

- **Orbits at heights between 400 and 850 Km**



- **Orbits are circular and pass (nearly) over the poles.**

- **Each satellite completes several orbits in one day (period between 98 and 102 min → Global coverage with one satellite**



Low Orbiting Satellites

- **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.**

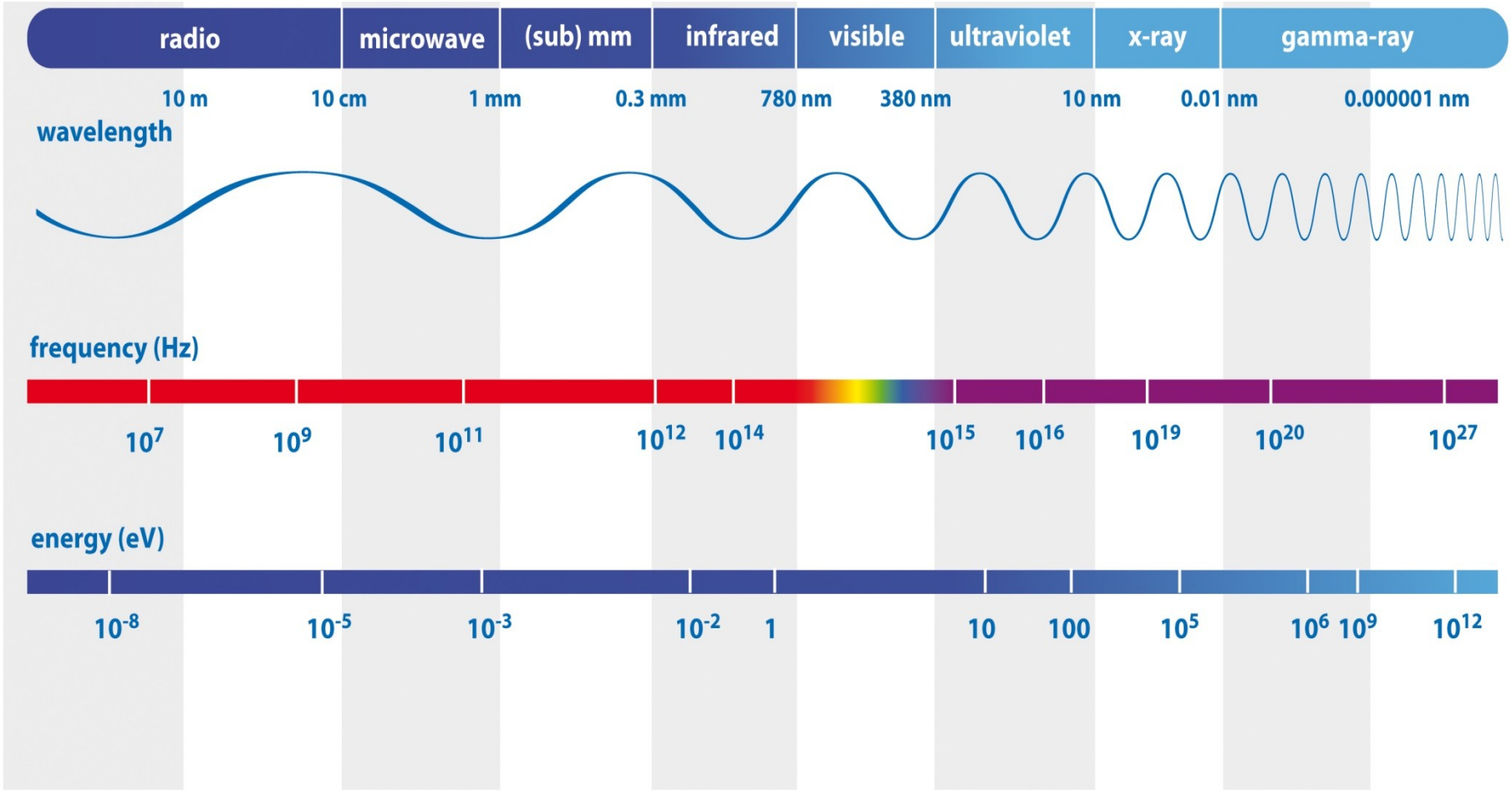
What's measured ?

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

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

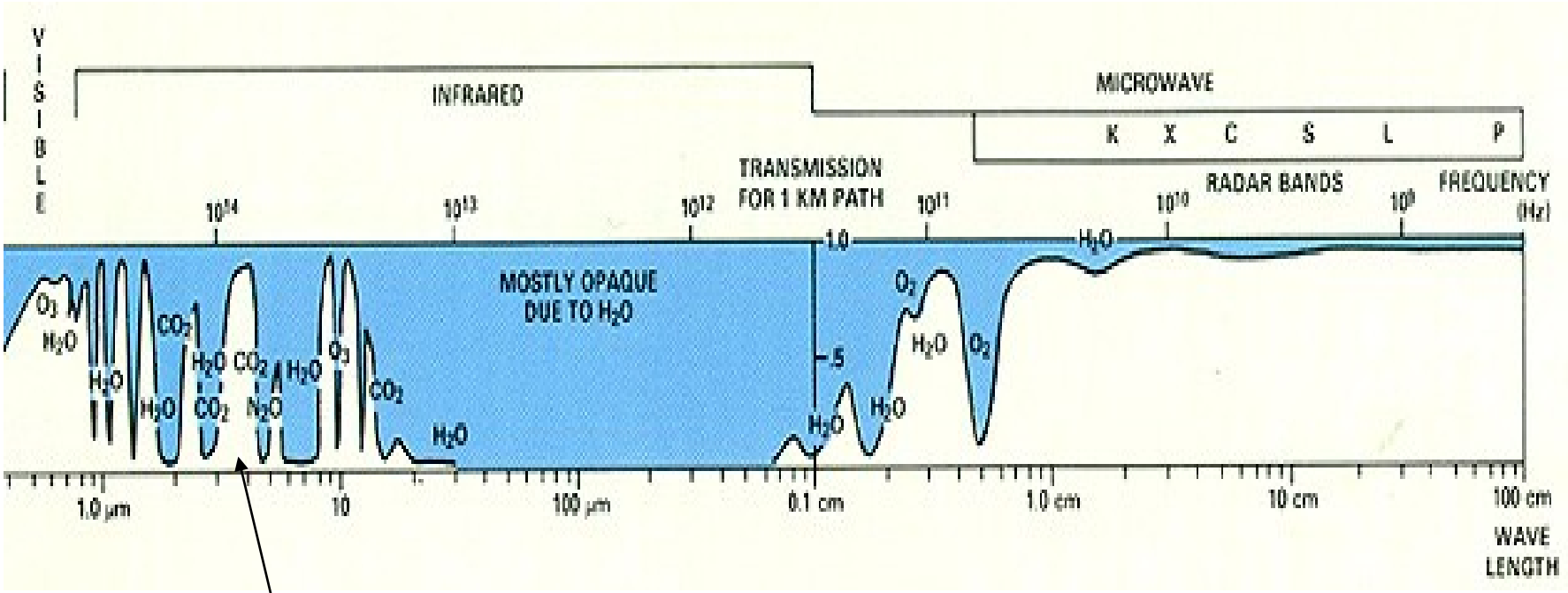
Measured radiance is related to geophysical atmospheric parameters by the radiative transfer equation

Electromagnetic radiation



Electromagnetic radiation

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



Atmospheric Windows

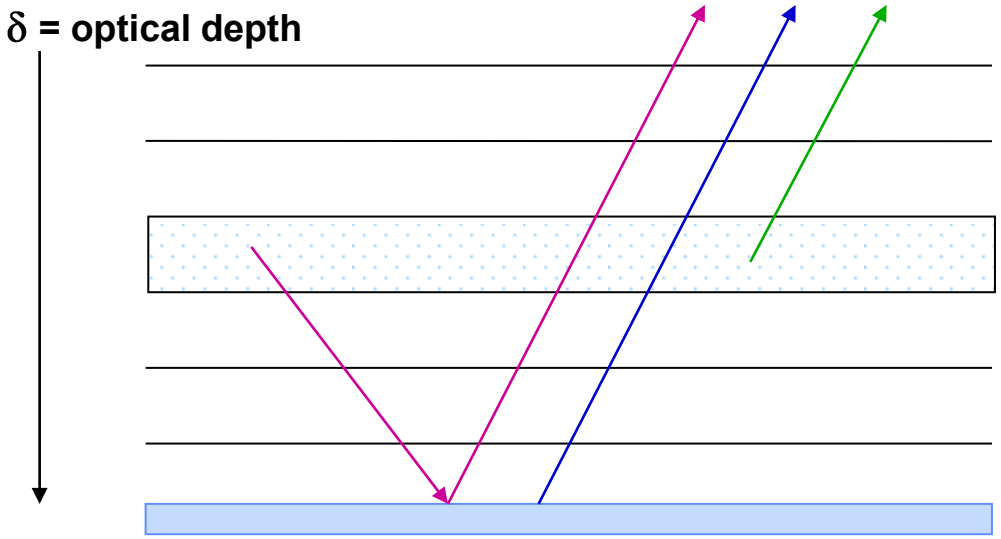
ECMWF

Radiative transfer

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

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

Given the radiance what's the state of the atmosphere



Remote sensing techniques

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

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

} Most instruments

- **Satellite 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.**

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

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

where: B = Planck function z = height T = temperature

τ = transmittance v = frequency

Atmospheric Passive Sounding

- **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,**

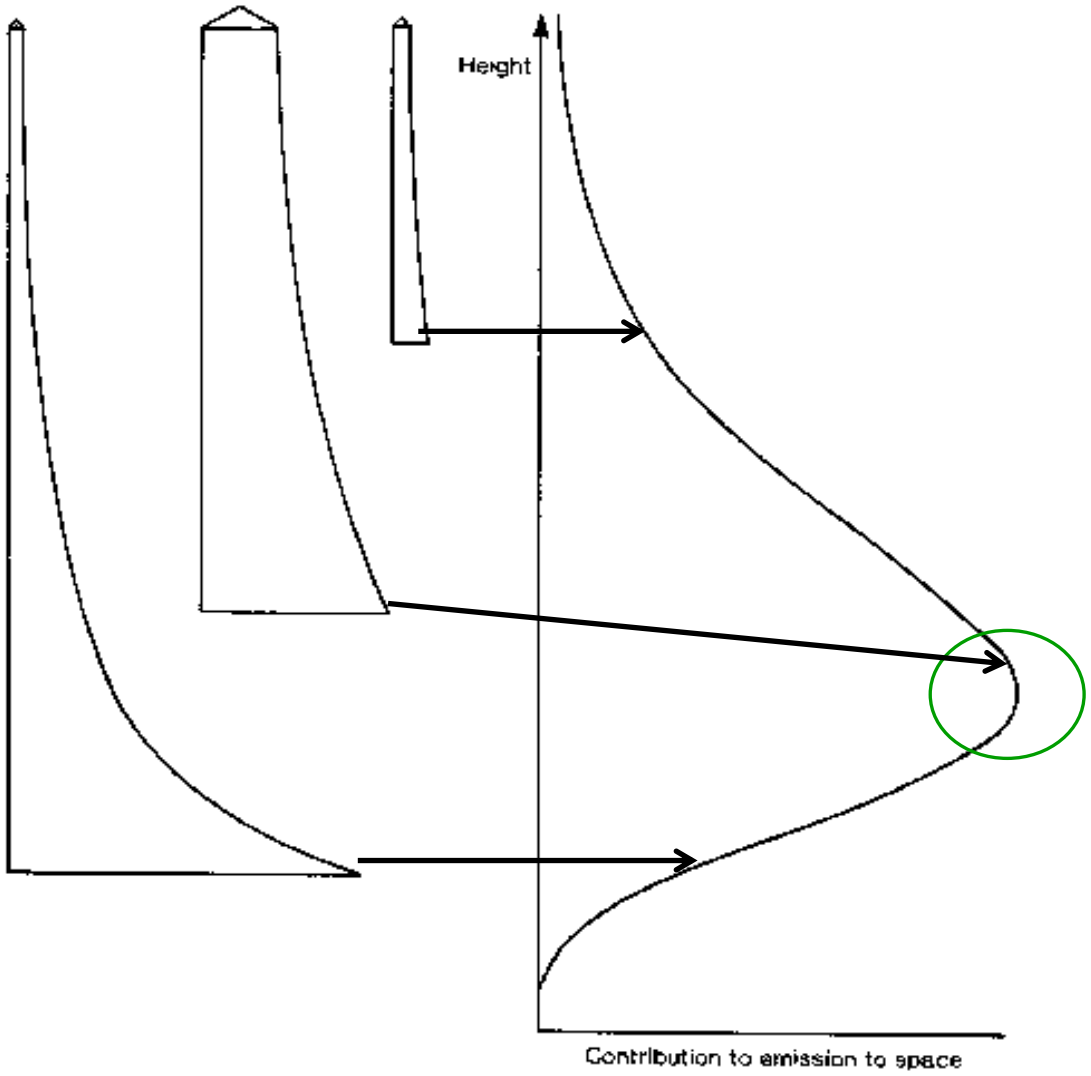
e.g. Microwave bands around 60 and 120 GHz
Infrared bands around 15 μm and 4.3 μm

- **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

Atmospheric Passive Sounding

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

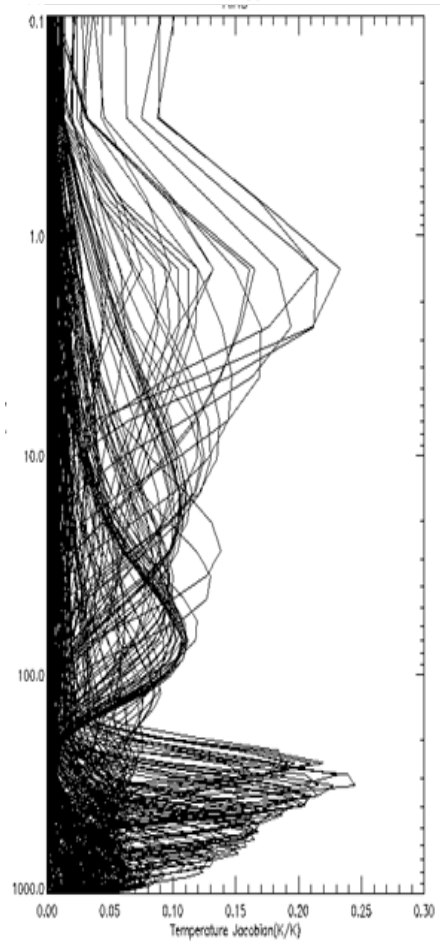


Atmospheric Passive Sounding

- **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**



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:

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

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

T_{surf} = surface temperature ε = surface emissivity

These are primarily used to obtain information on the surface temperature and quantities that influence the surface emissivity such as wind (ocean) and vegetation (land).

Satellite Active Sensing

- **Scatterometry/Altimetry**
- **GPS Radio Occultation**

Surface sensing (Active)

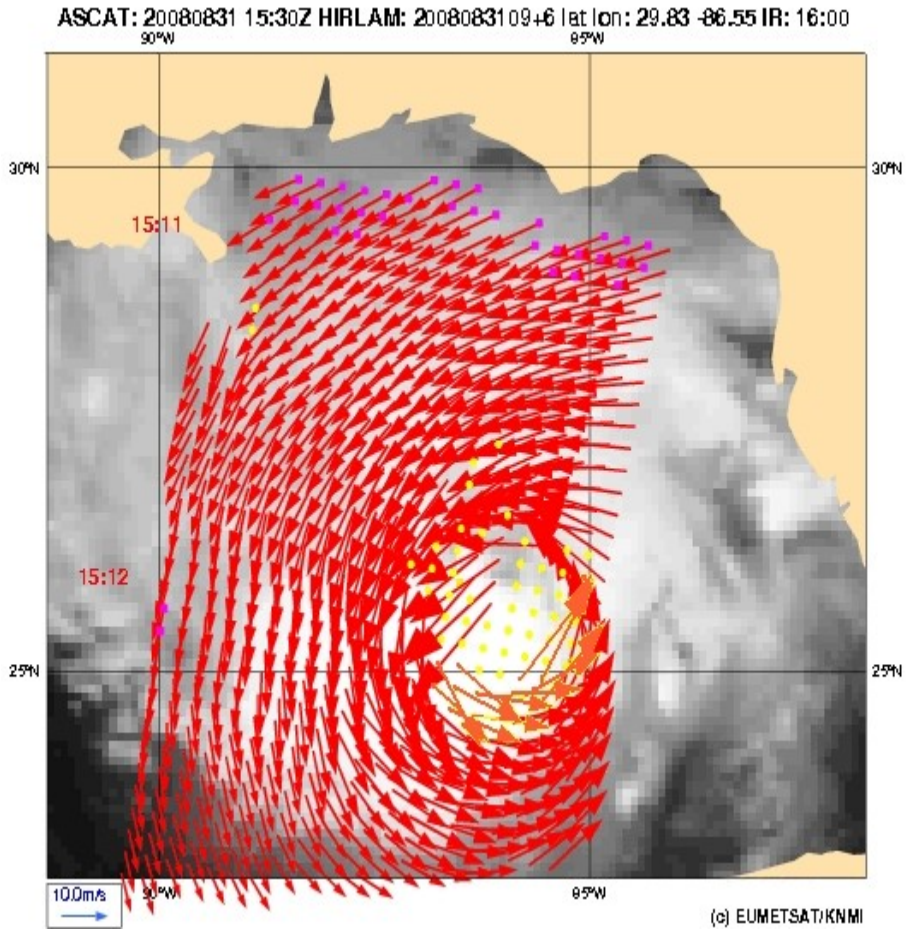
- **These instruments (e.g. Scatterometers and altimeters) illuminate the earth's surface by emitting energy in atmospheric window (VIS/NIR & MW) regions and measure the radiance that is scattered back.**

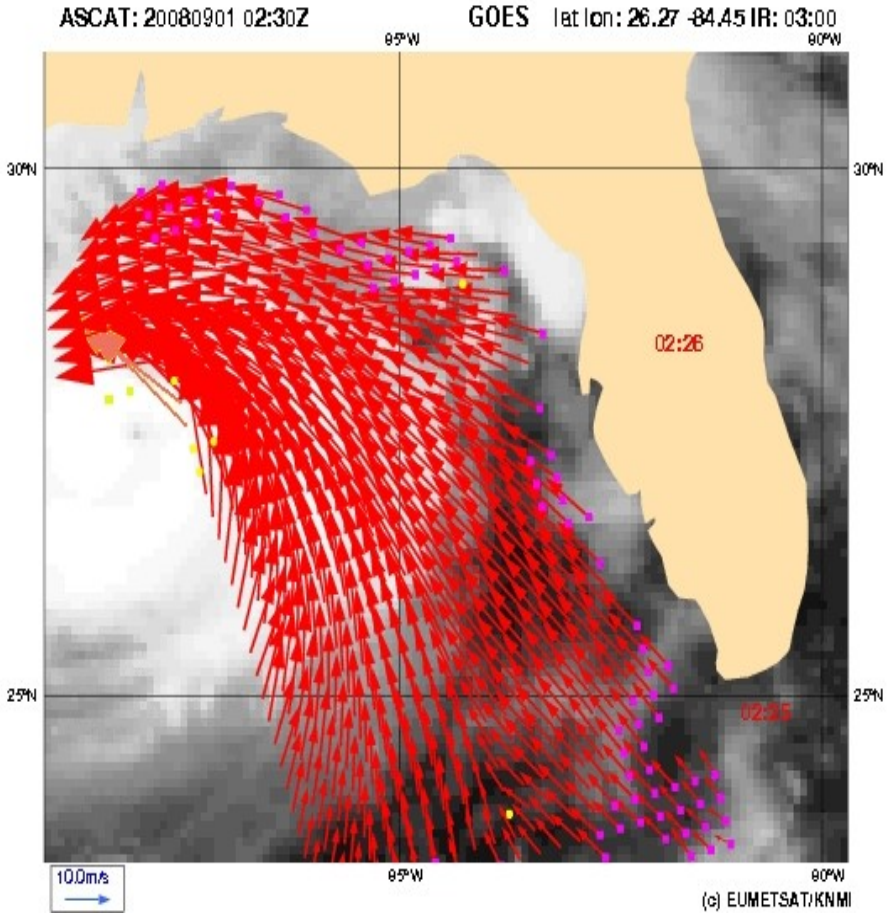
$$L_v = \int_0^{\infty} B(v, T(z)) \left[\frac{d\tau(v)}{dz} \right] dz + \text{Surface emission} + \text{Surface reflection} + \text{Cloud/Rain interaction}$$

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

Active Surface sensing

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



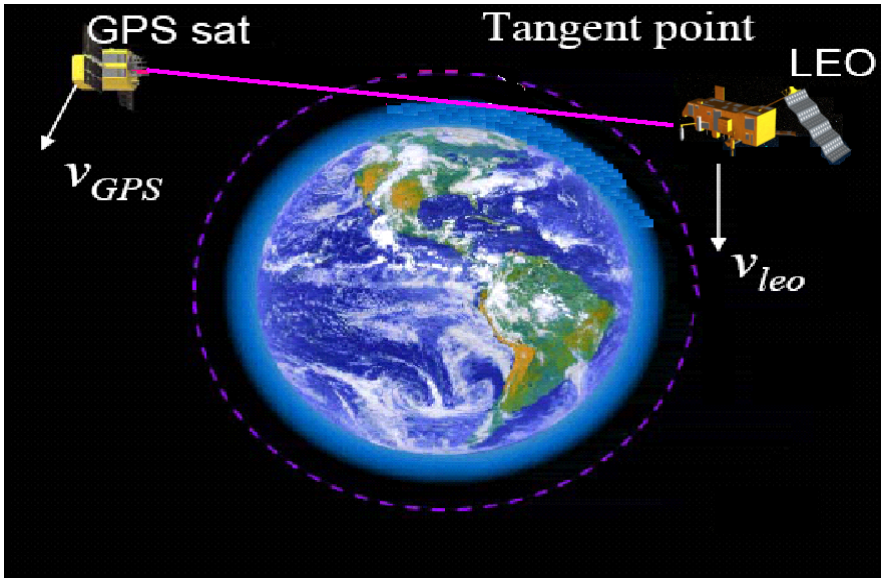


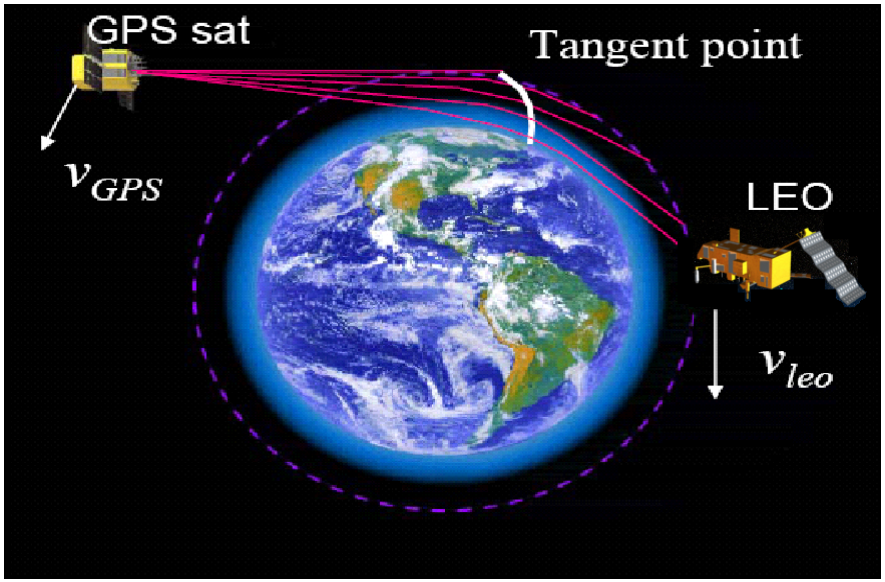
ECMWF

GPS Radio occultation

- **The impact of the atmosphere on the radio signal propagation depends on the refractivity**

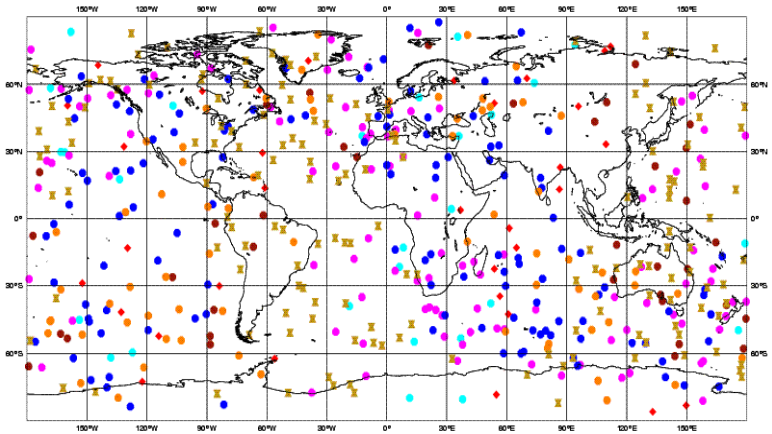
- **Receivers on LEOs record quasi-vertical profiles of the atmosphere (ionosphere and neutral) including :**
  - Bending angle >>
  - Refractivity >>
  - (Temperature, humidity)

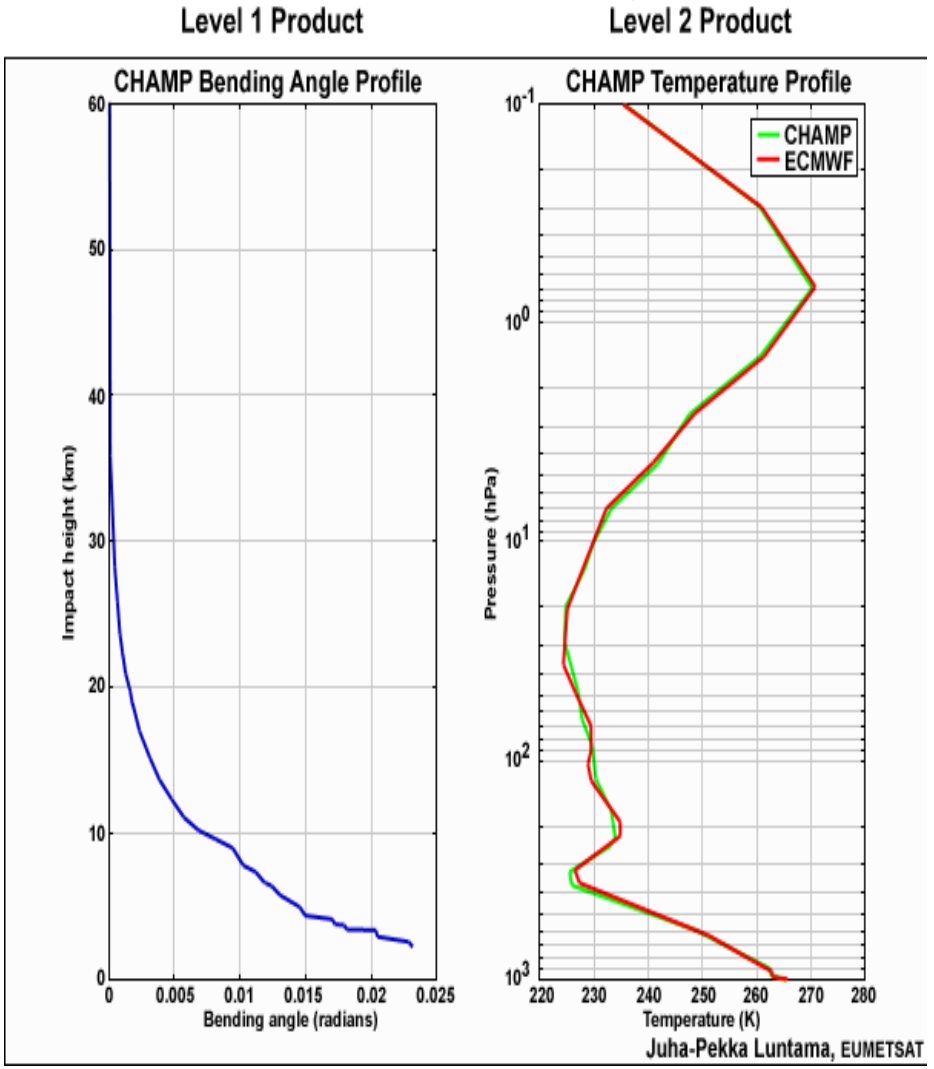




GPS Radio occultation

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





Picture from Eumetsat website

Instruments	Plateforme
HIRS (Infrared)	NOAA series, METOP
AMSU-A, AMSU-B/MHS (microwave)	NOAA, METOP-A, METOP-B, AQUA
ATMS	NPP
IASI (Infrared)	METOP-A/METOP-B
AIRS (Infrared)	AQUA
CrIS	NPP
GPSRO	CHAMP, GRACE-A, COSMIC series, METOP-A, METOP-B, TERRA-SARX
SSMI, SSMIS (microwave), TMI, WINDSAT, AMSR2	DMSP series, TRMM, WINDSAT, GCOM-W1
MODIS (AMVs)	AQUA, TERRA
Scaterrometer (surface winds, soil moisture)	METOP-A/ASCAT, METOP-B/ASCAT, OCEANSAT-2/OSCAT
Altimeter (surface winds, waves)	Jason
SBUV, OMI, GOME-2	NOAA, AURA, METOP
Imaging instruments (Radiances & derived AMVs)	METEOSAT, MSG, GEOS, MTSAT

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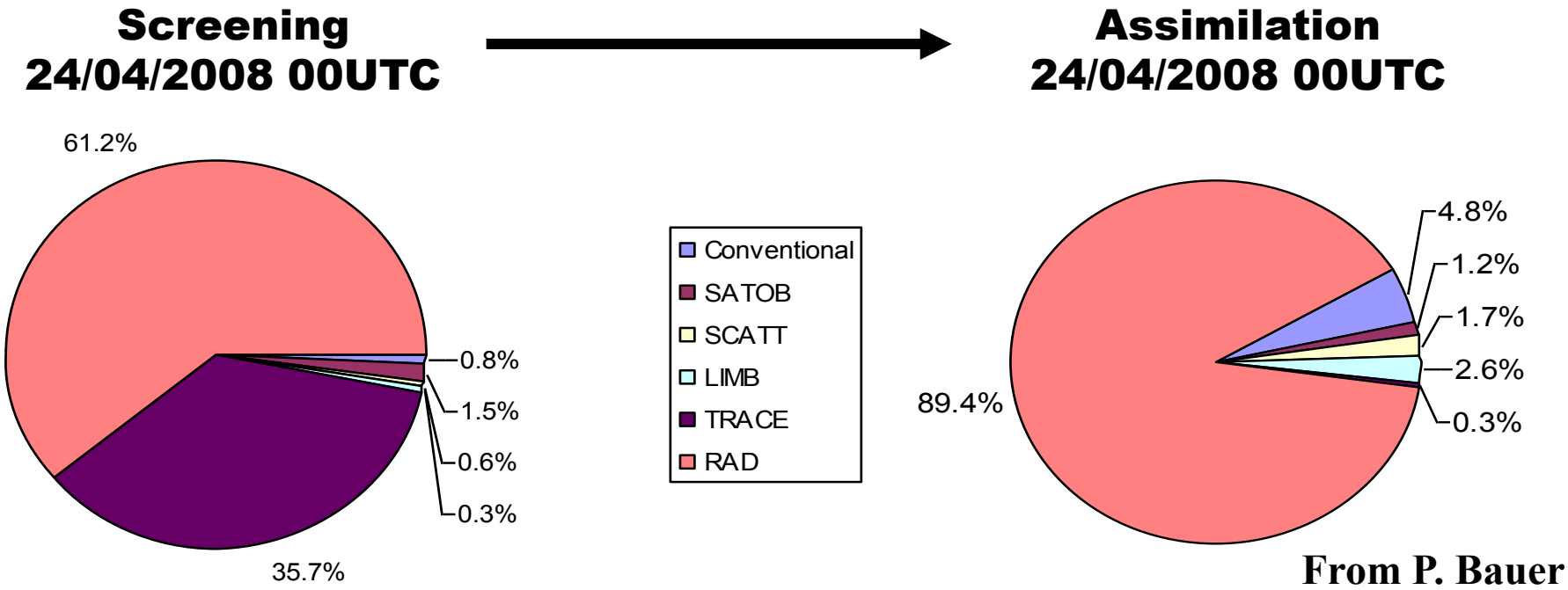
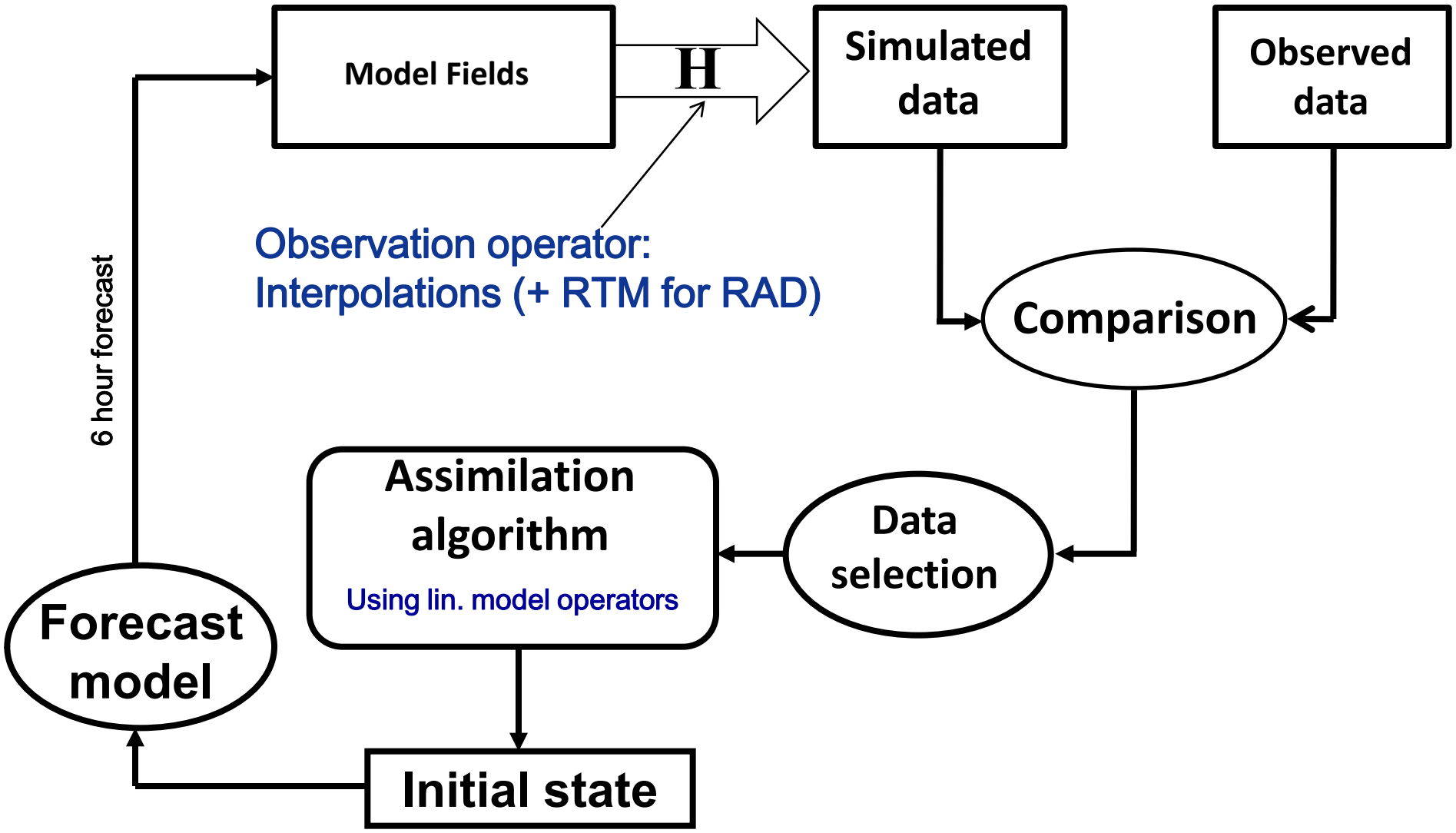
- Why satellite data important ?
- Principals of satellite measurements
- **Satellite data usage**
- Monitoring of satellite data

- 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.



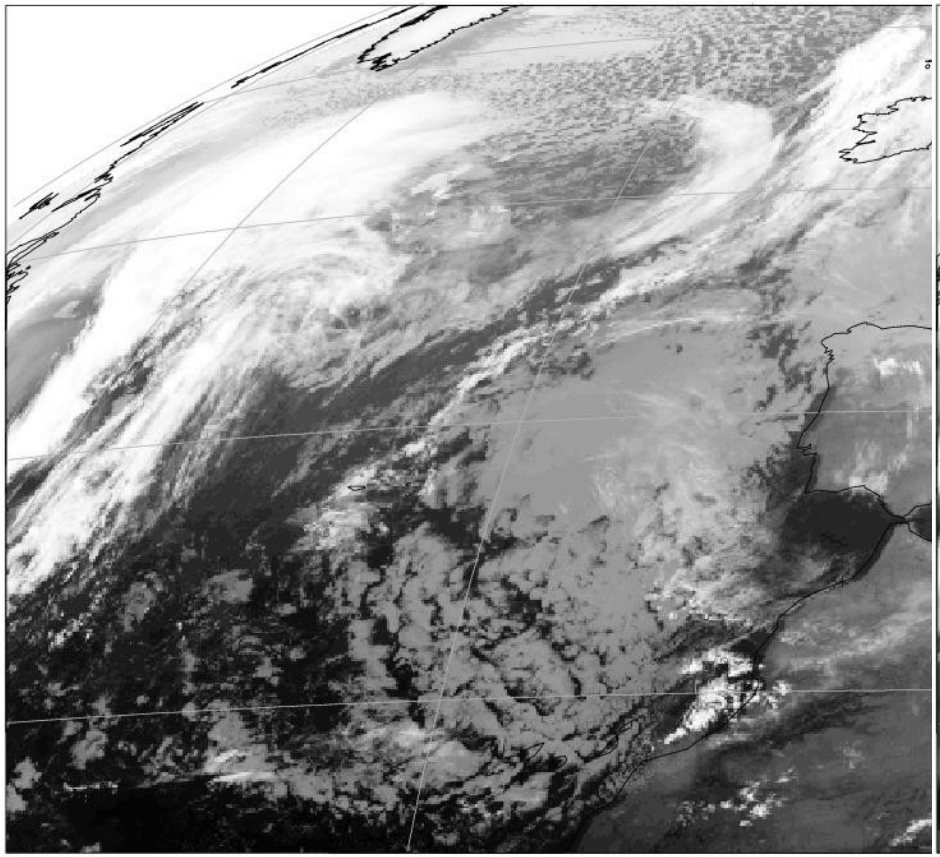
From P. Bauer

Direct assimilation of raw data

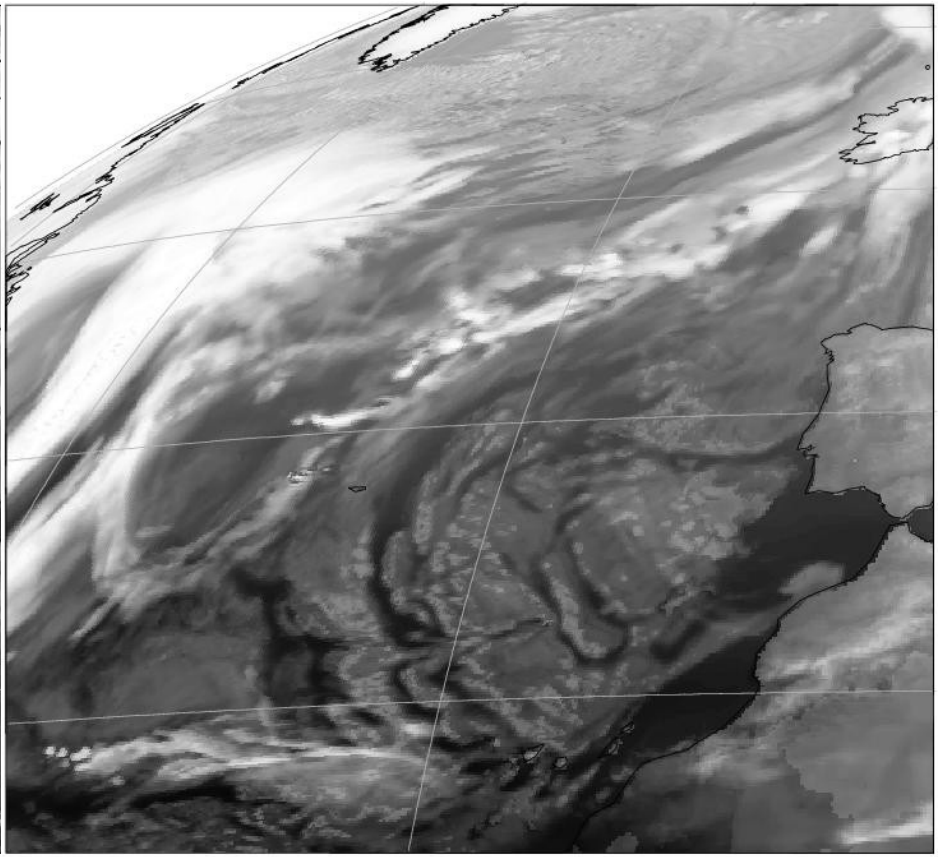


Observation operator

Met-8 IR (Observations)



Met-8 IR (from the model)



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- **Monitoring of satellite data**

Monitoring of satellite data

- **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.**

- **Monitoring outputs are important to define and evaluate the data usage**

- **Data monitoring can help diagnosing model problems.**

Monitoring of satellite data

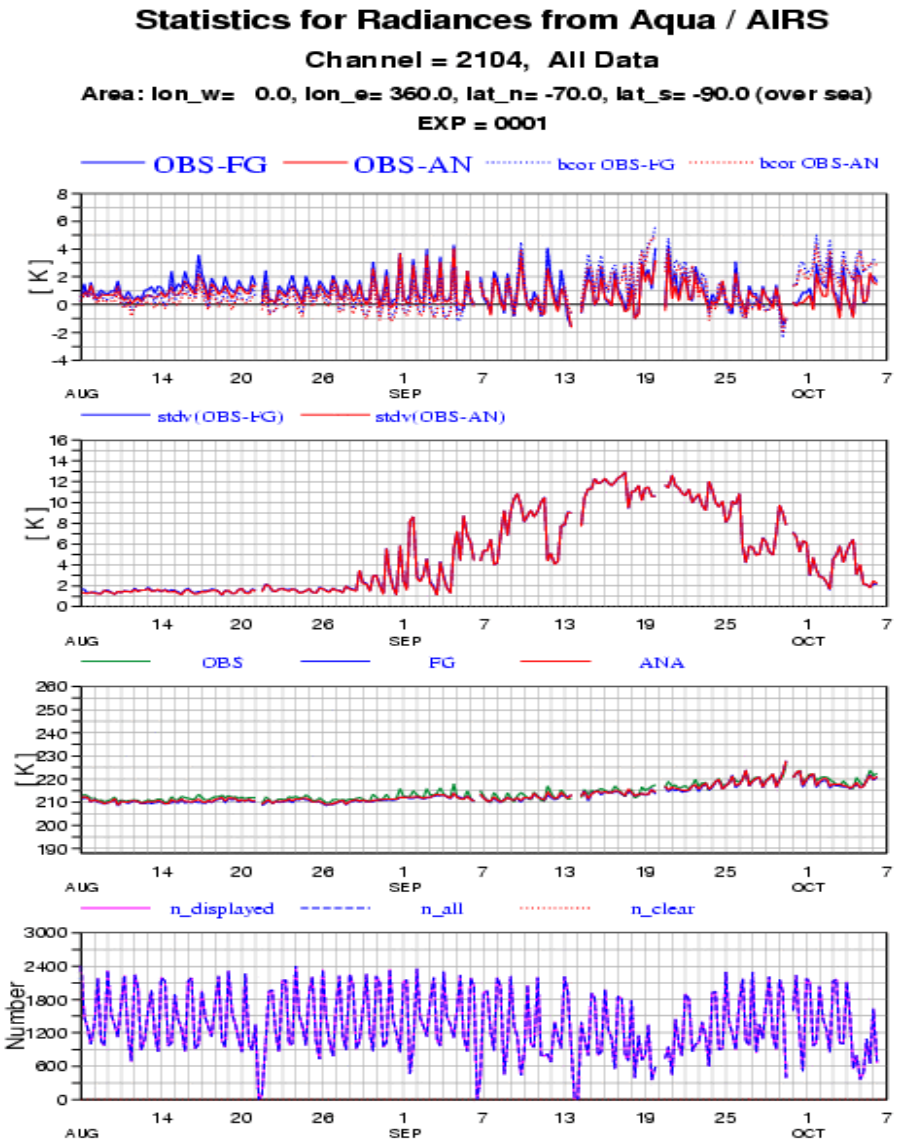
- In the daily model monitoring (analysis, increments, forecasts, …), it's generally not easy to spot the impact of satellite data,

- 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, ….),

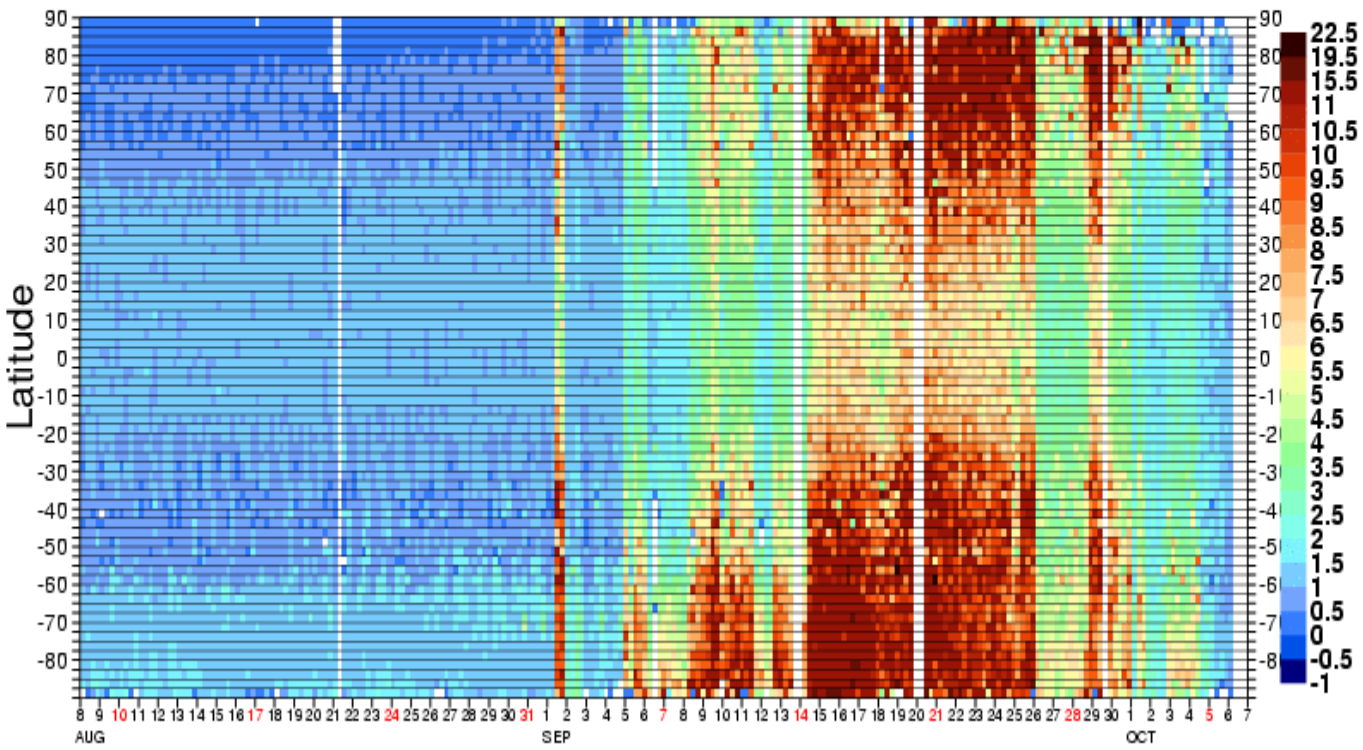
Time series

Time evolution of statistics over predefined areas/surfaces/flags



Hovmeoller diagrams

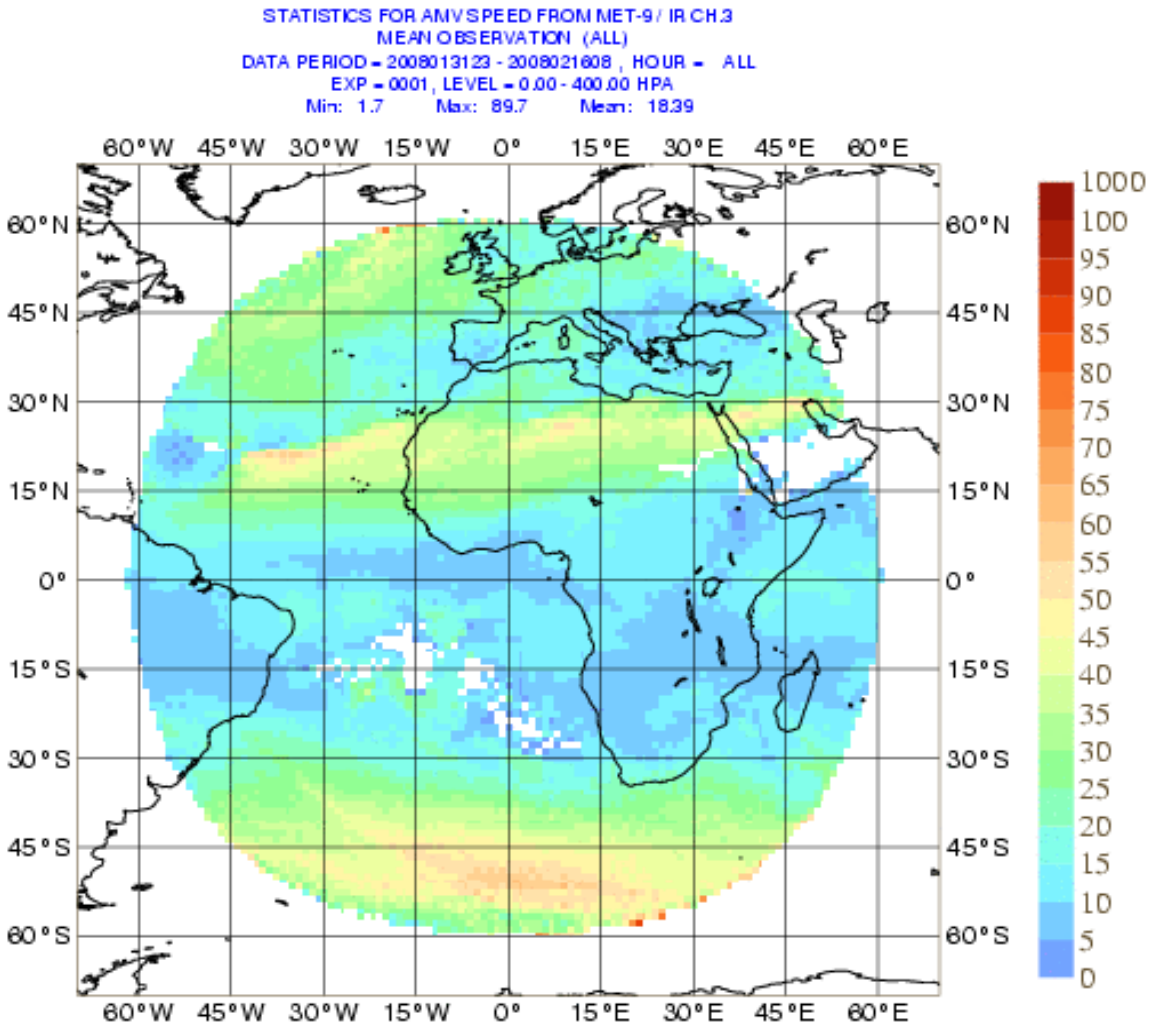
Time evolution of statistics of zonal means or levels means



Geographical means

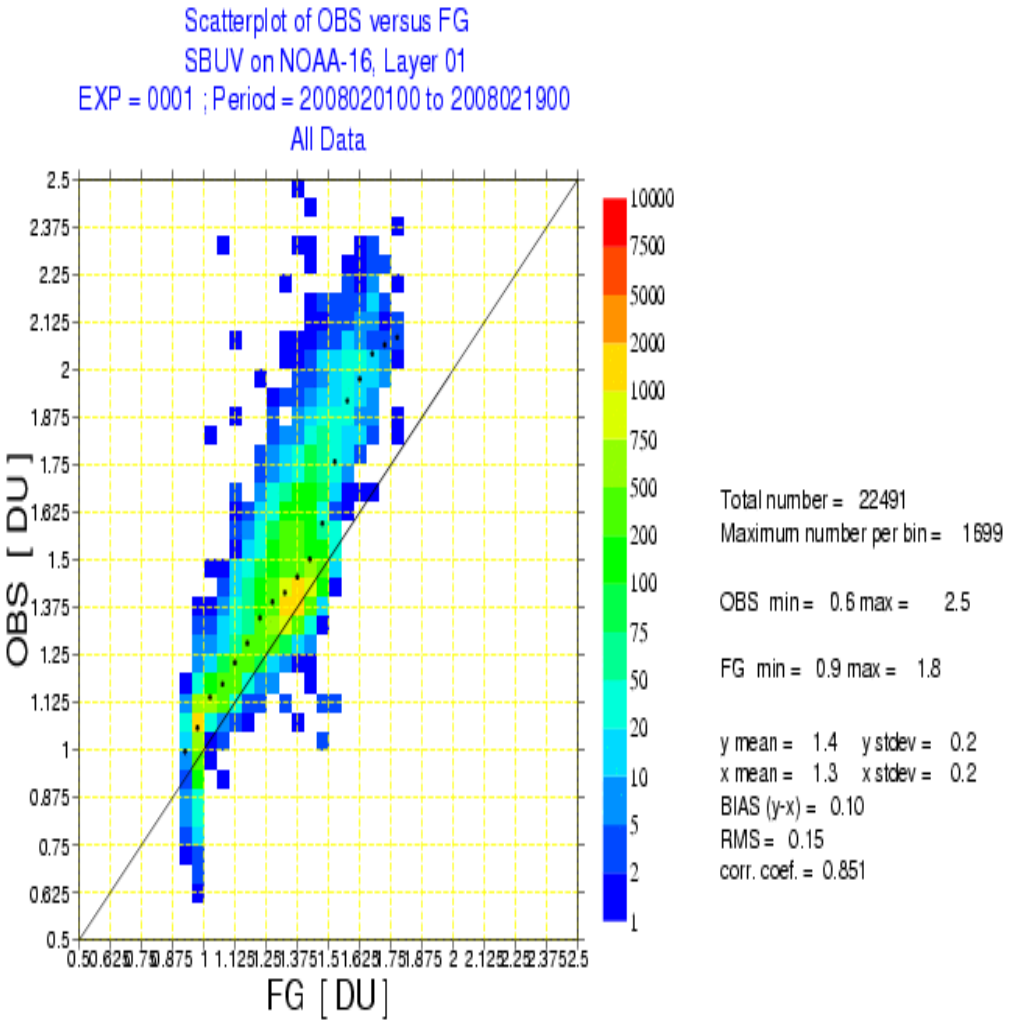
Assessment of the geographical variability of statistics:

- location effect
- air mass effect



Scatter plots

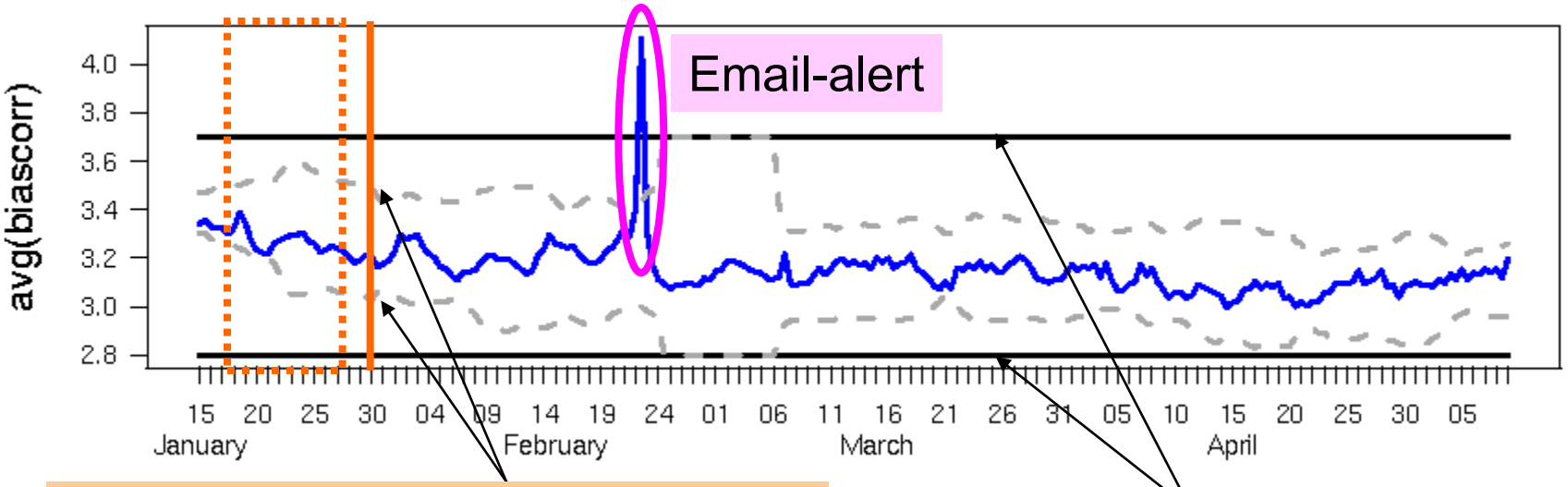
comprehensive way to compare observed values against model ones



Alarm system

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)

Alarm system

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

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Satellite Data Automatic Checking

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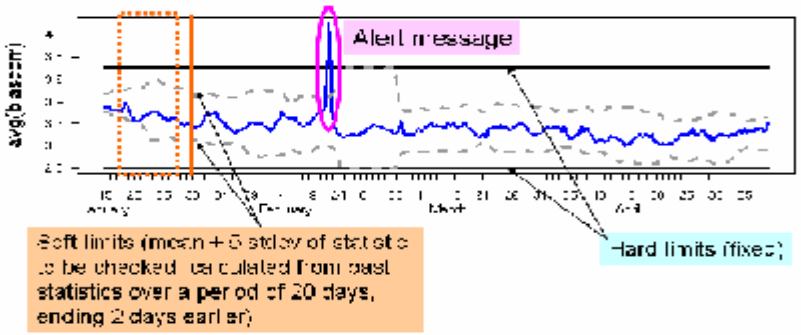
An experimental automatic satellite data checking system has been implemented recently at ECMWF. It triggers the production of alarm messages if an anomaly is detected in the quality or the availability of the satellite data assimilated by the model.

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/

Diagnosing model problems (1/4)

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.

Diagnosing model problems (2/4)

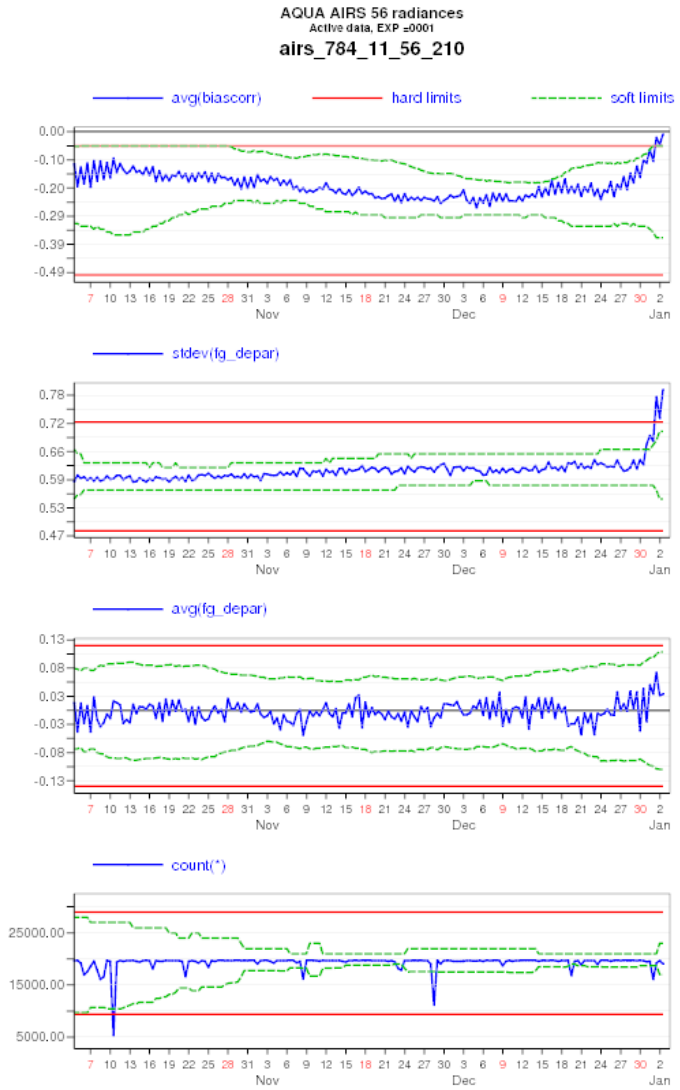
Early January 2013, the automatic alarm system generated severe alarms associated to an increase of the noise for infrared and microwave stratospheric peaking channels

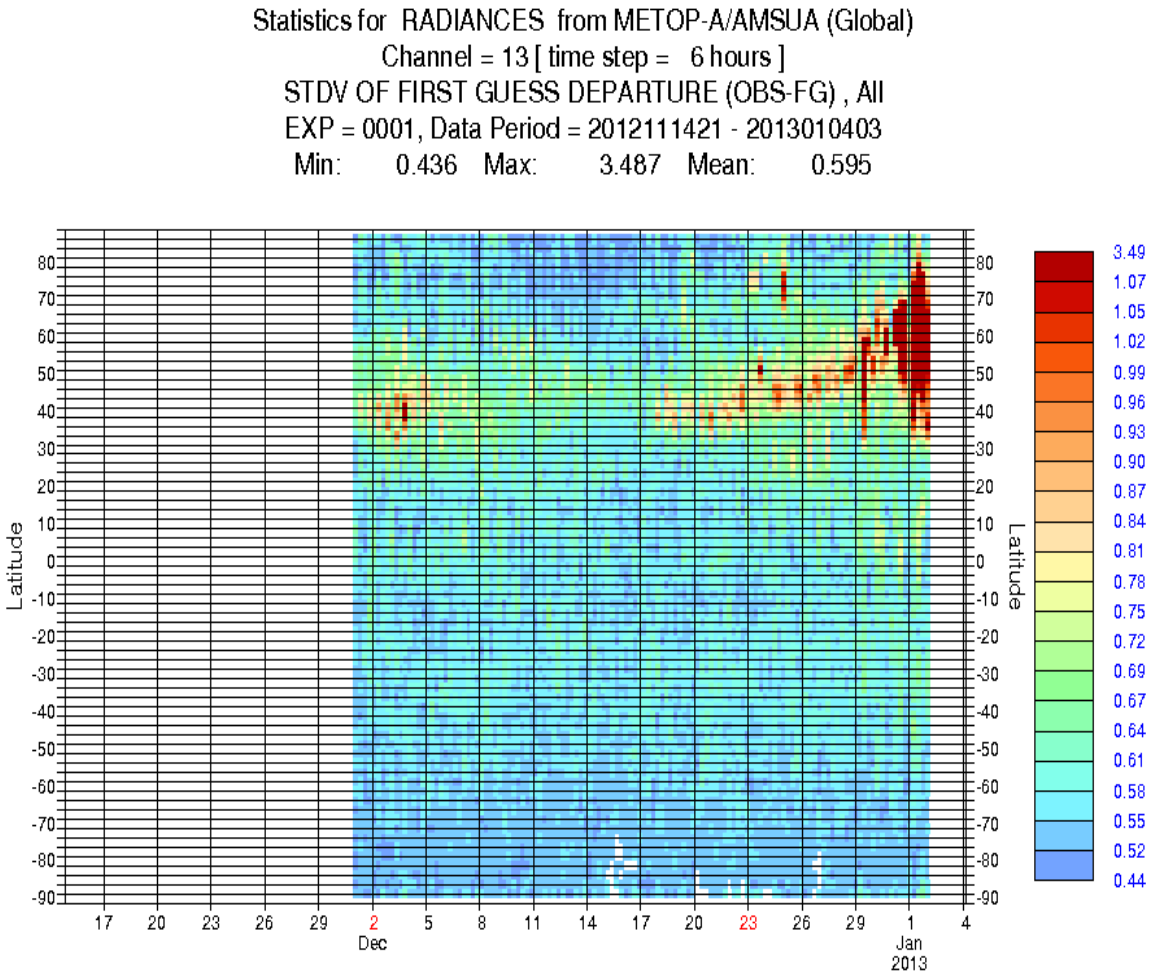
Checking 0001 DCDA 2013010212
==========

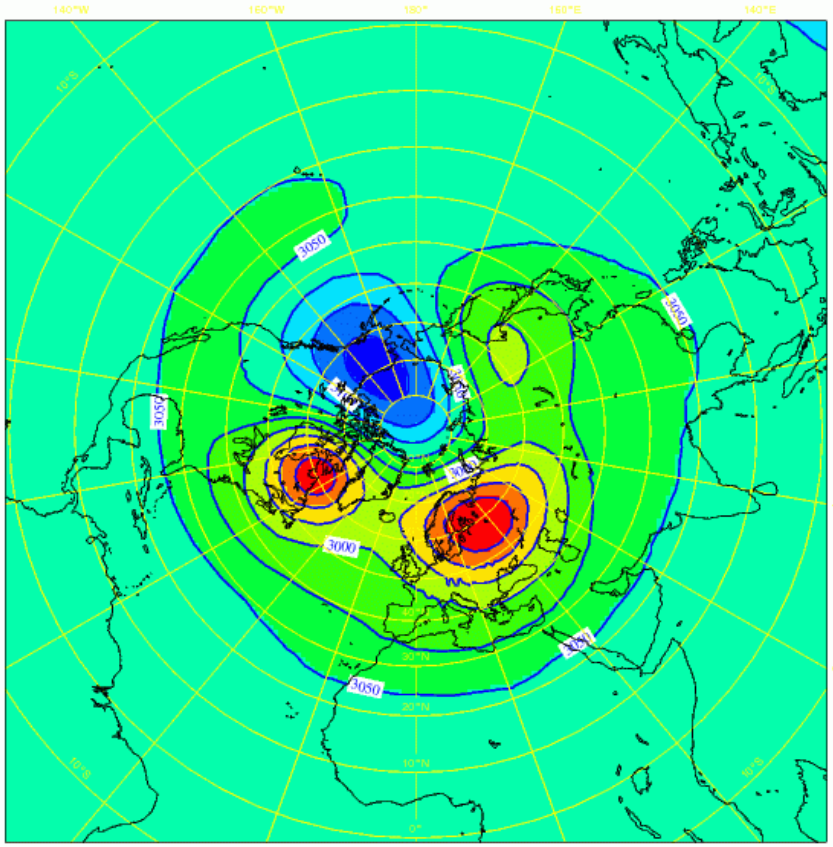
AQUA AIRS 56 radiances : out of range:
(3 times in last 10 days for at least one item)
http://www.ecmwf.int/products/forecasts/satellite_check//do/get/satcheck/3215/110485?showfile=true
Severely: stdev(fg_depar)=0.777, expected range: 0.57 0.68
Slightly: avg(biascorr)=-0.02000005, expected range: -0.37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

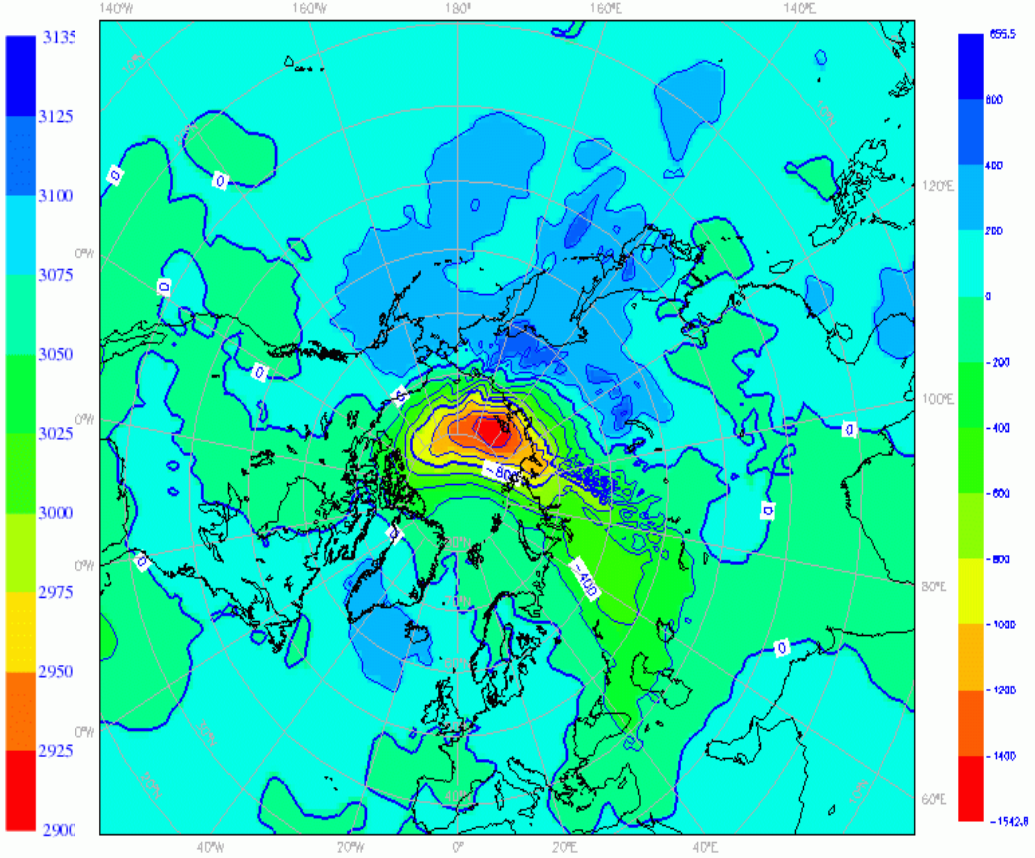
METOP-A IASI 89 radiances : out of range:
(6 times in last 10 days for at least one item)
http://www.ecmwf.int/products/forecasts/satellite_check//do/get/satcheck/3217/111259?showfile=true
Severely: stdev(fg_depar)=0.459, expected range: 0.33 0.41

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.

Thank you for your attention