Satellite Observations

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Outline

- Data sources and role of satellite observations
- What do satellites measure ?
- Satellite data usage
- Monitoring of satellite data

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- **Data sources and role of satellite observations**
- What do satellites measure ?
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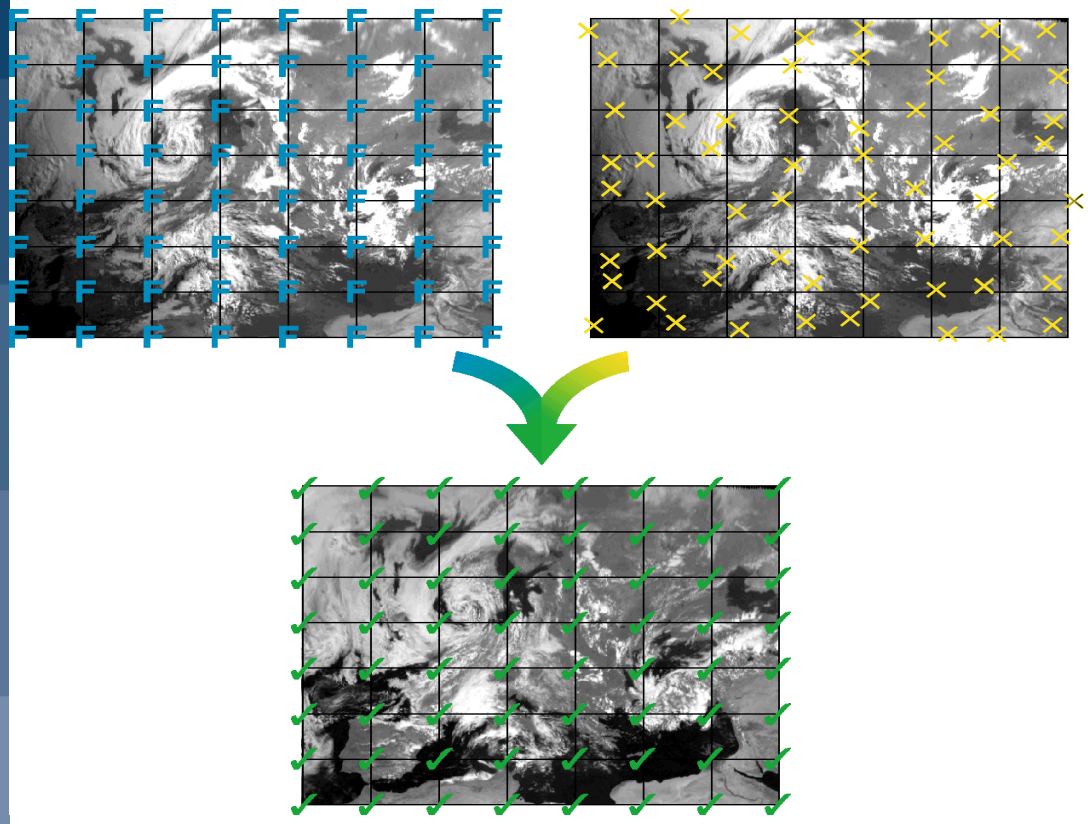
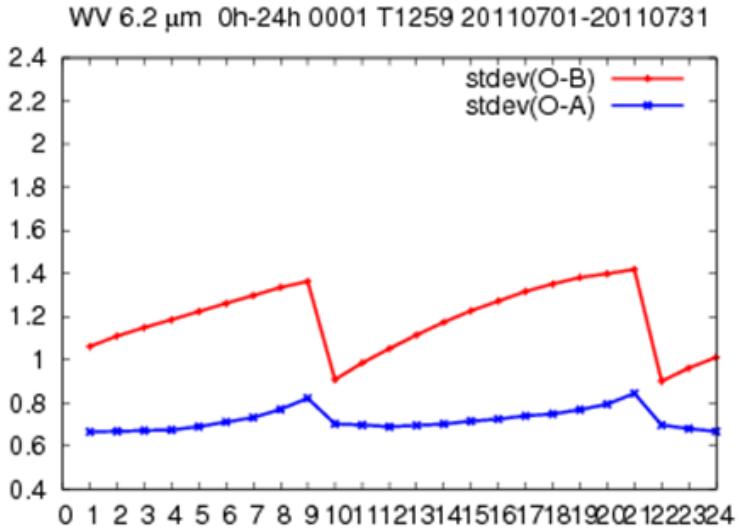
Role of observations

Twice a day we assimilate ~20,000,000 observations to correct the 80,000,000 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*

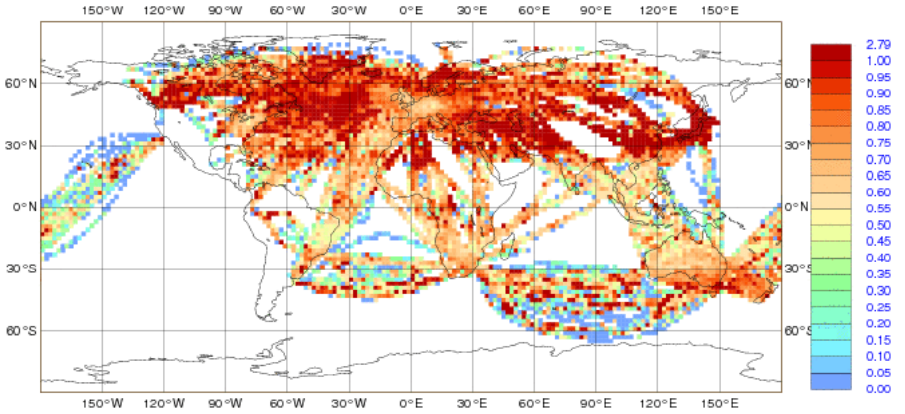
PROFILERS:

→ wind *profiles*

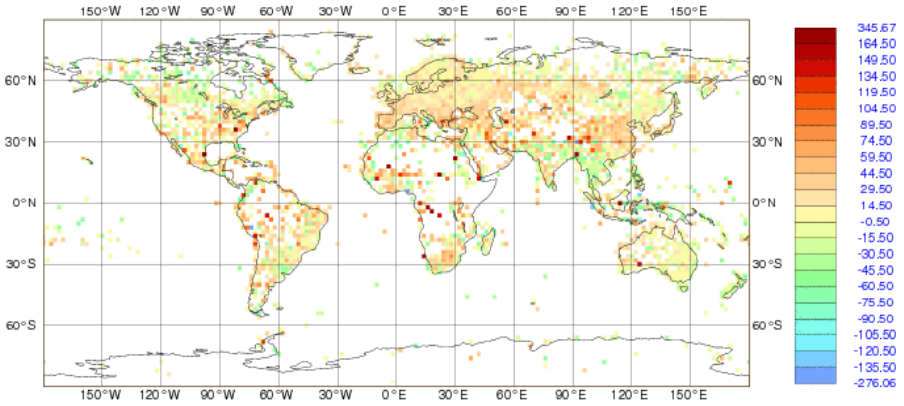
Aircraft:

→ temperature, pressure, wind *profiles*

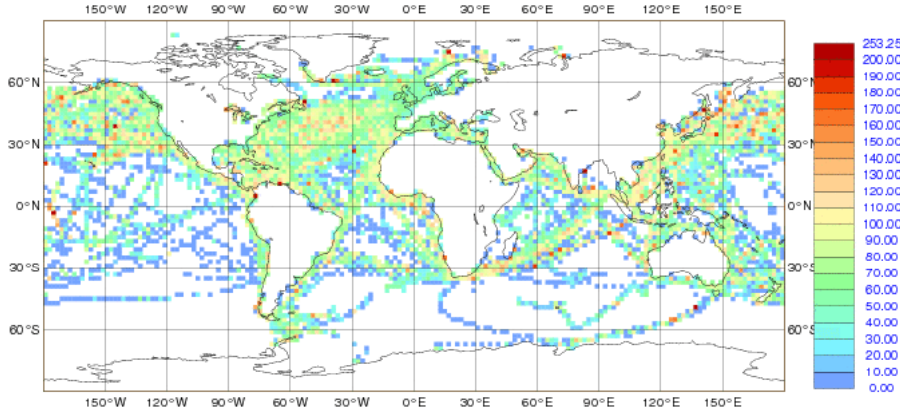
Example of conventional data coverage (one month)



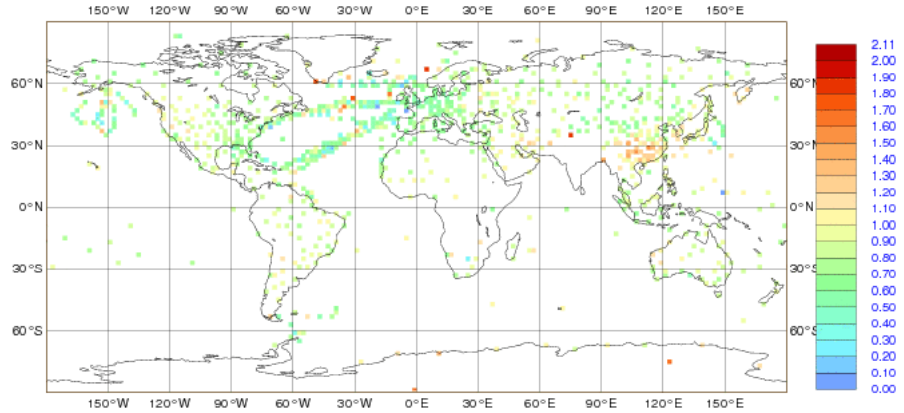
Aircraft – AMDAR



Synop



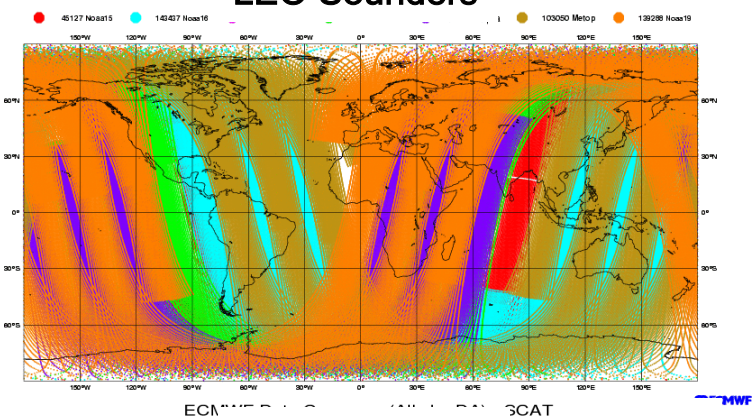
ship



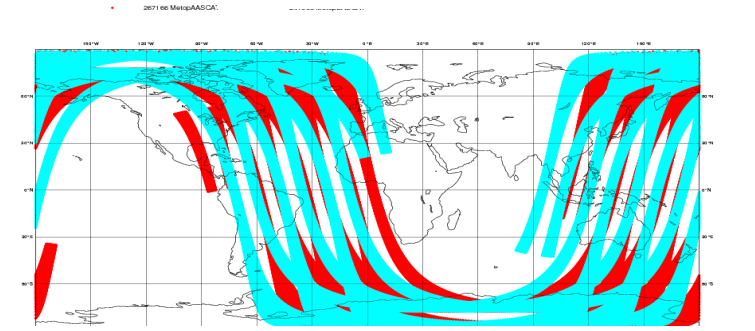
Temp

Example of 6-hourly satellite data coverage

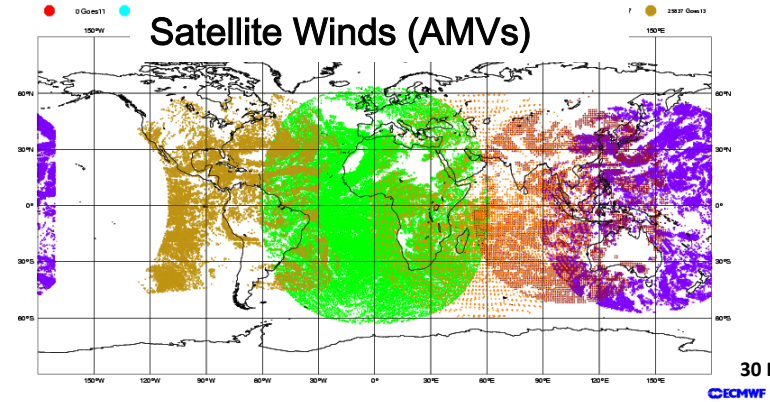
LEO Sounders



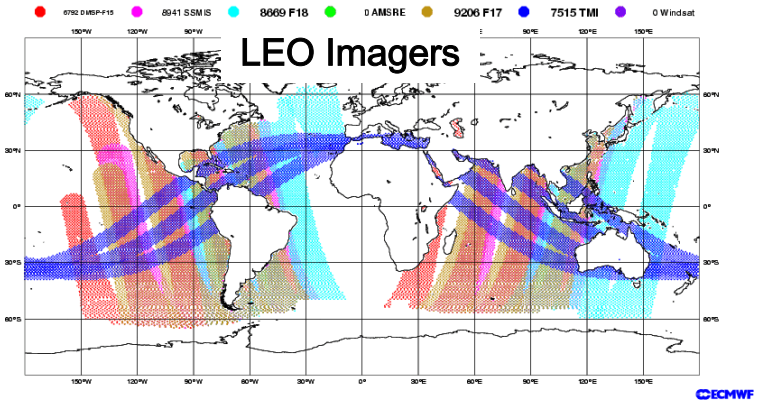
Scatterometers



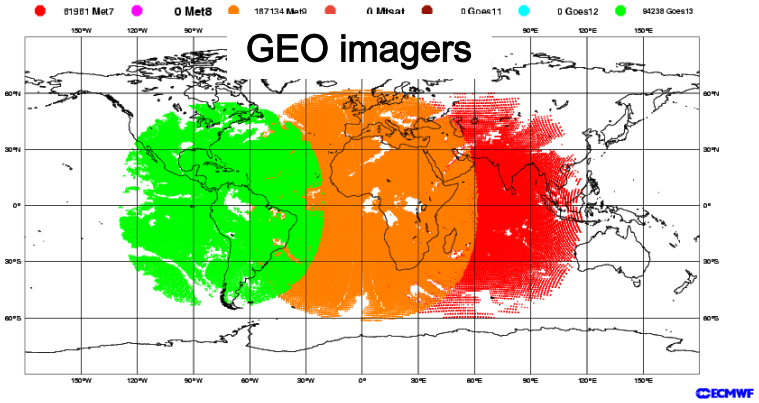
Satellite Winds (AMVs)



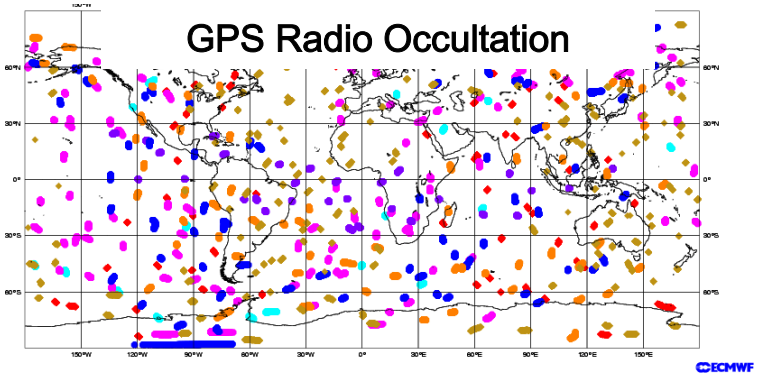
LEO Imagers



GEO imagers

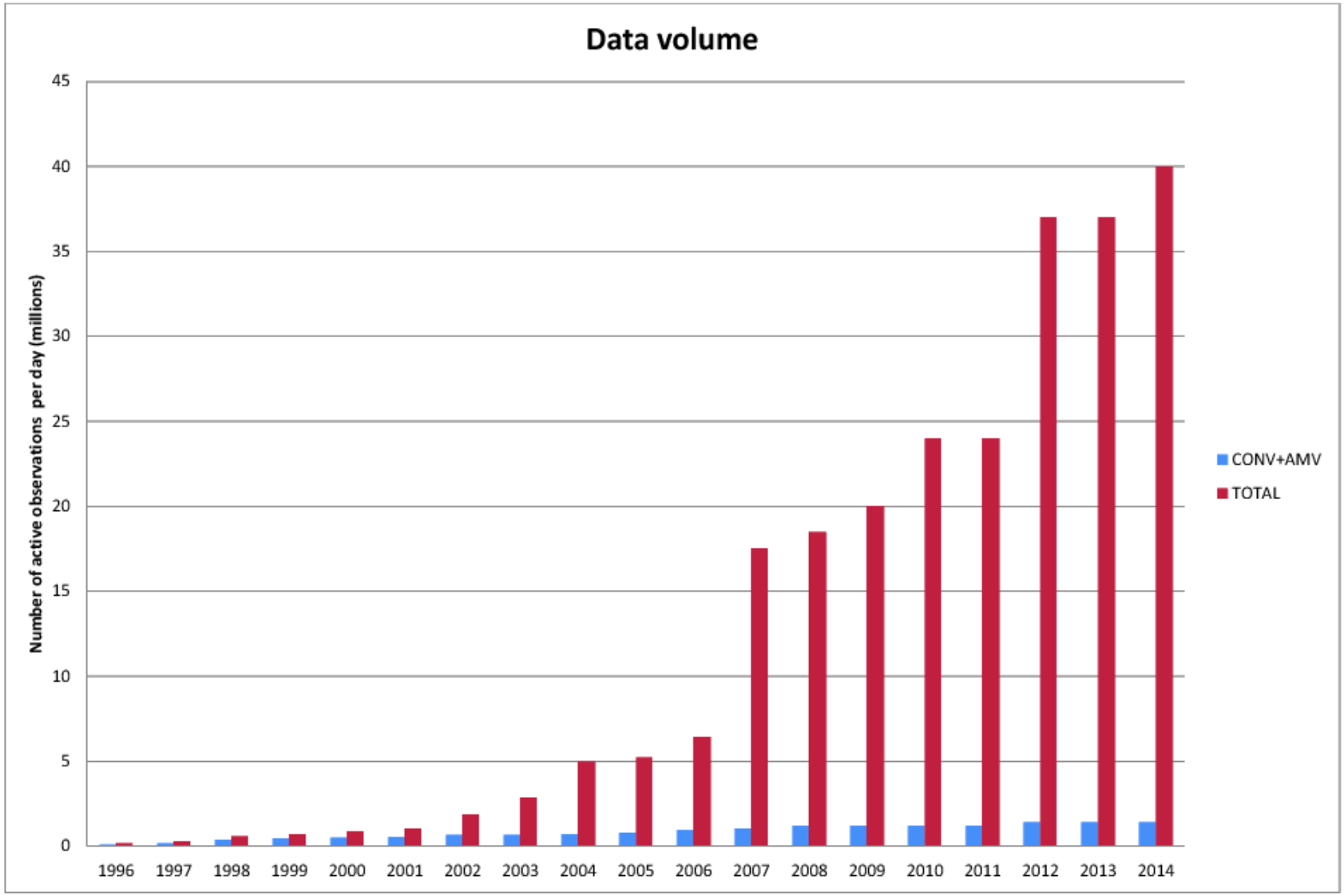


GPS Radio Occultation

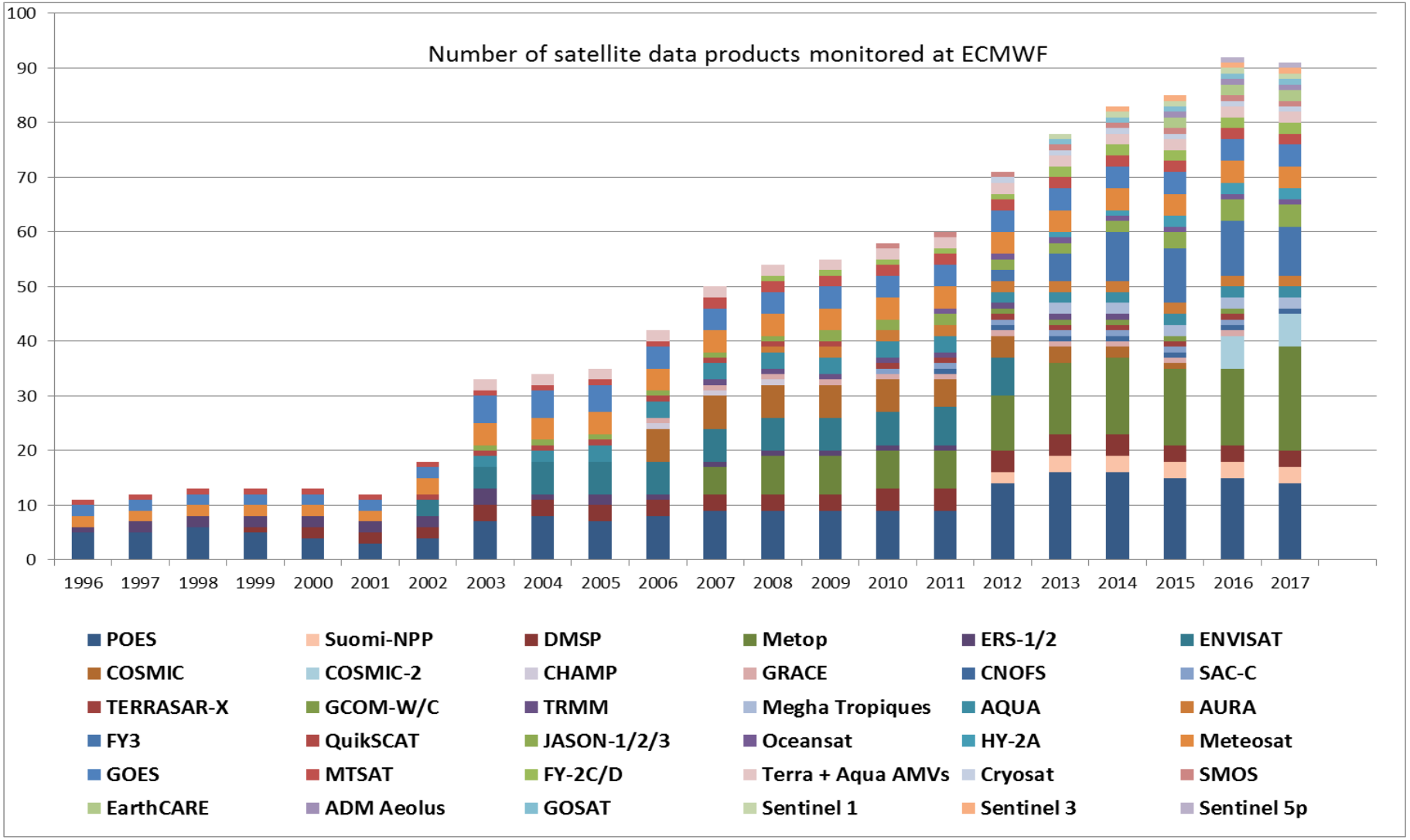


30 March 2012 00 UTC

Number of used satellite data is increasing



Number of used satellite data is increasing



Slide from S. English

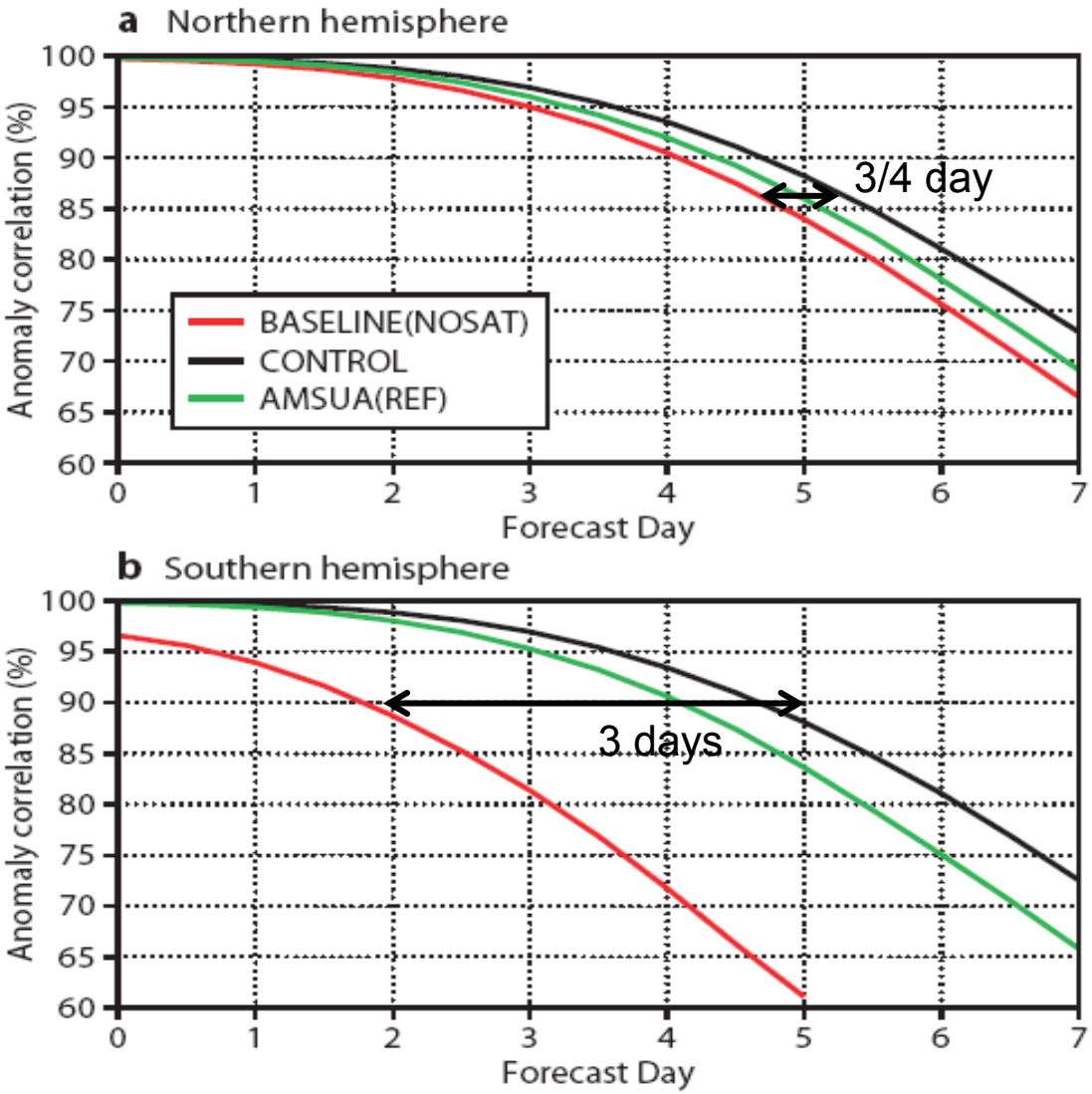
Why important ?

- **Vital for less observed regions (oceans, deserts).**

- **global coverage with a high spatial and temporal resolution.**

- **Consistent positive impact everywhere: Capacity to correct small-amplitude large scale errors**

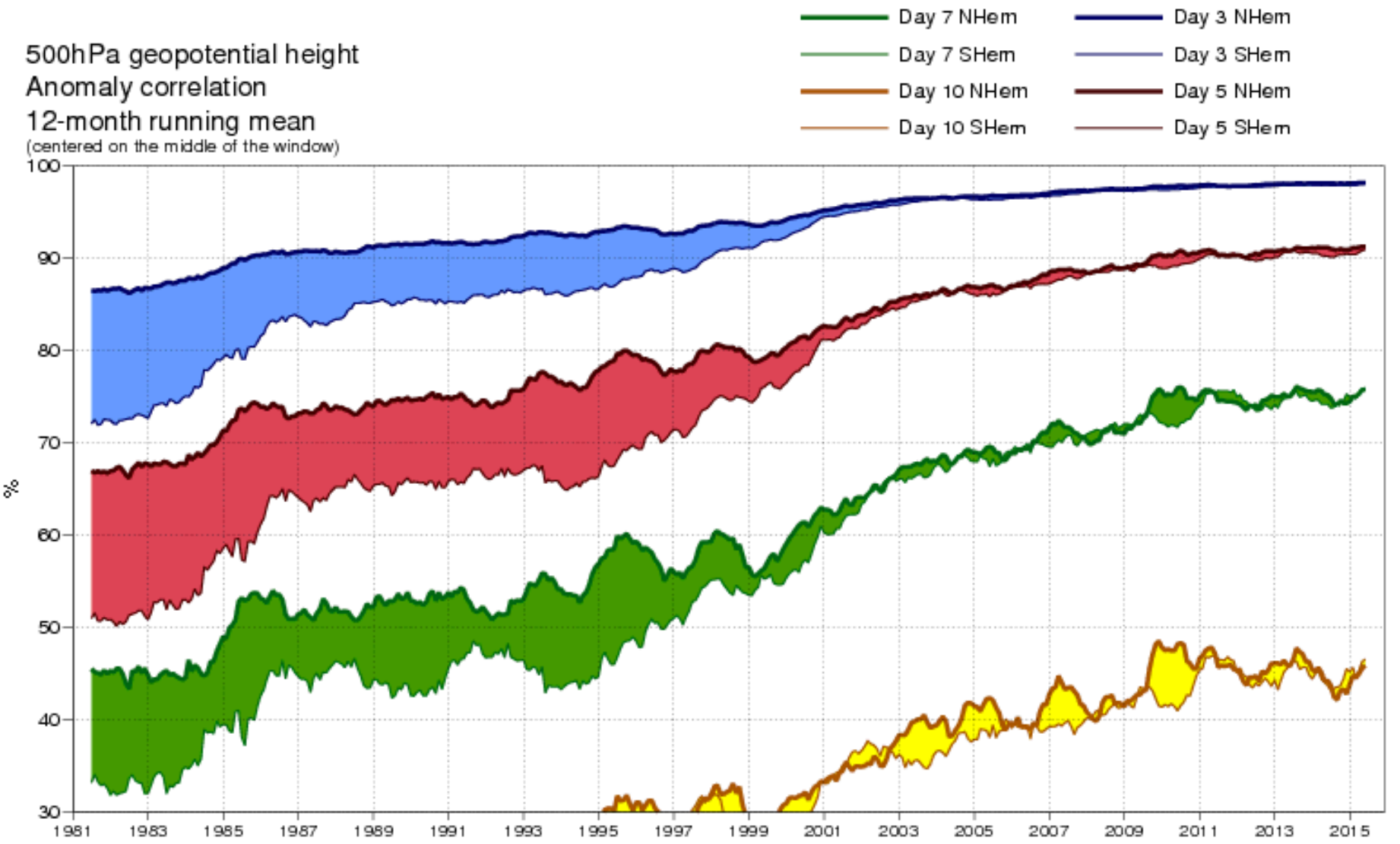
Why important ?



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 ?



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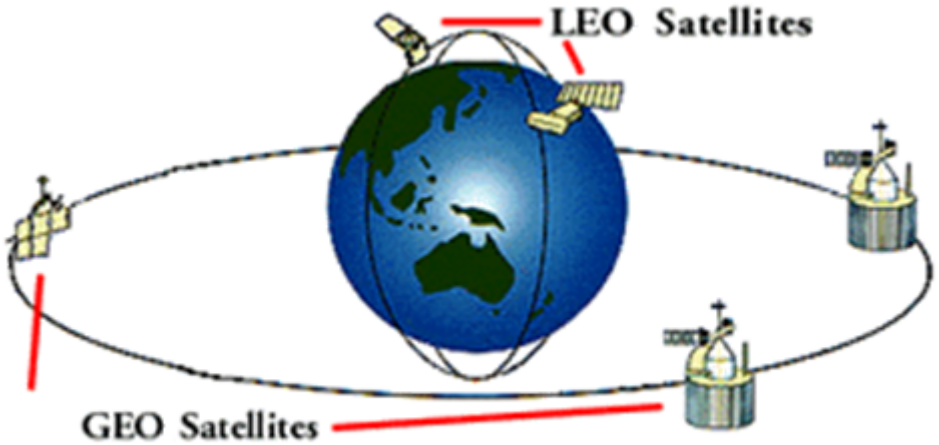
Types of satellites used in NWP

- **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

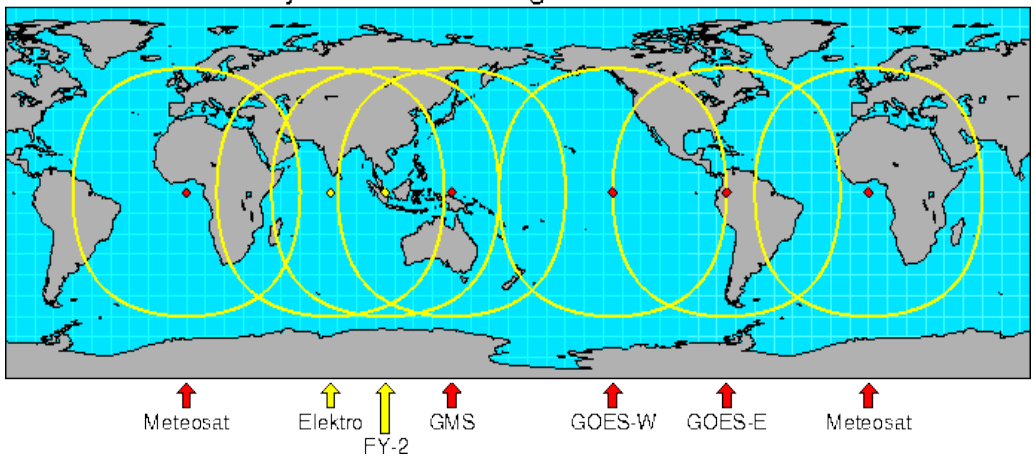
Advantages

- 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
- Limited spectral resolution

Global Geostationary Satellite Coverage



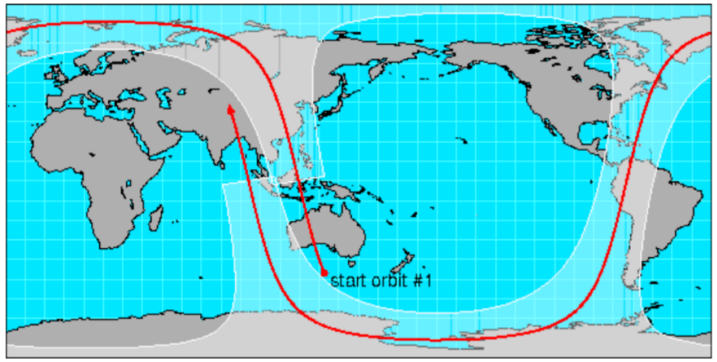
LEO satellites

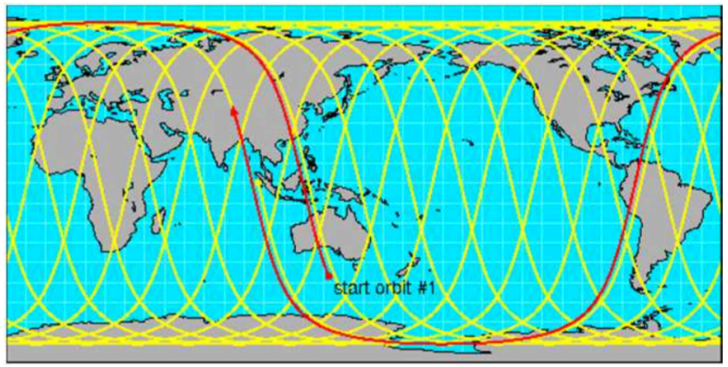
Advantages

- 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)





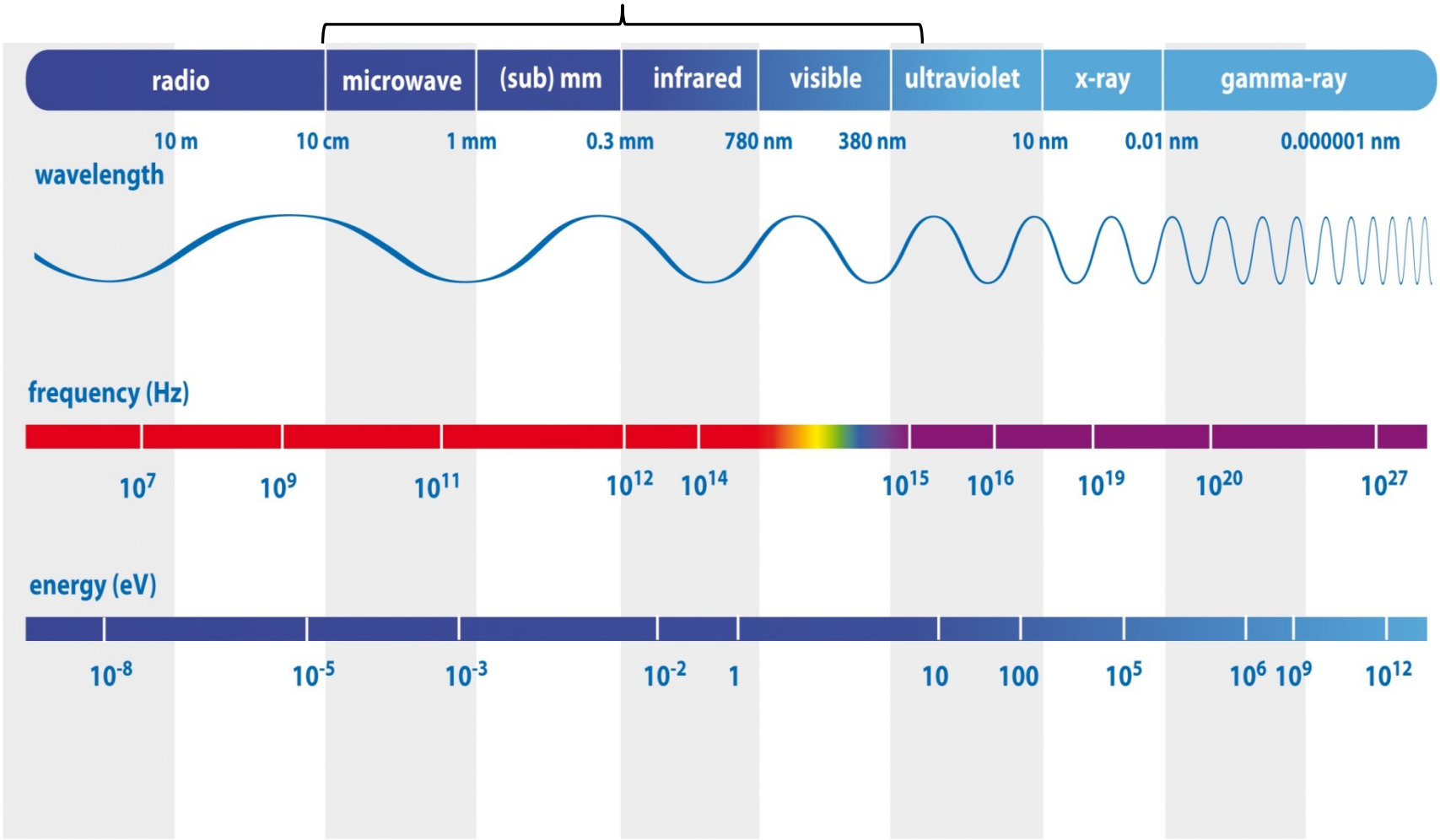
What's measured ?

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

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

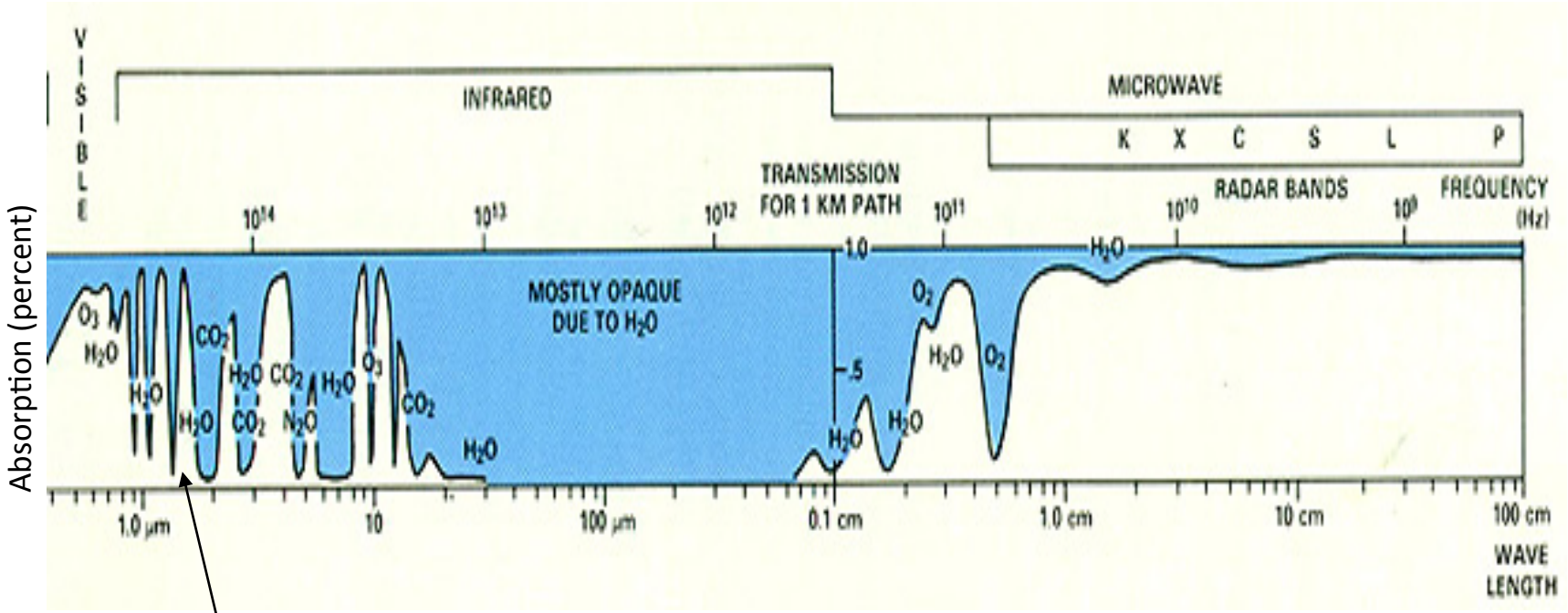
Measured radiance is related to geophysical atmospheric parameters by the radiative transfer equation

Electromagnetic radiation



Electromagnetic radiation

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



Atmospheric Windows

Radiative transfer

measured by the satellite

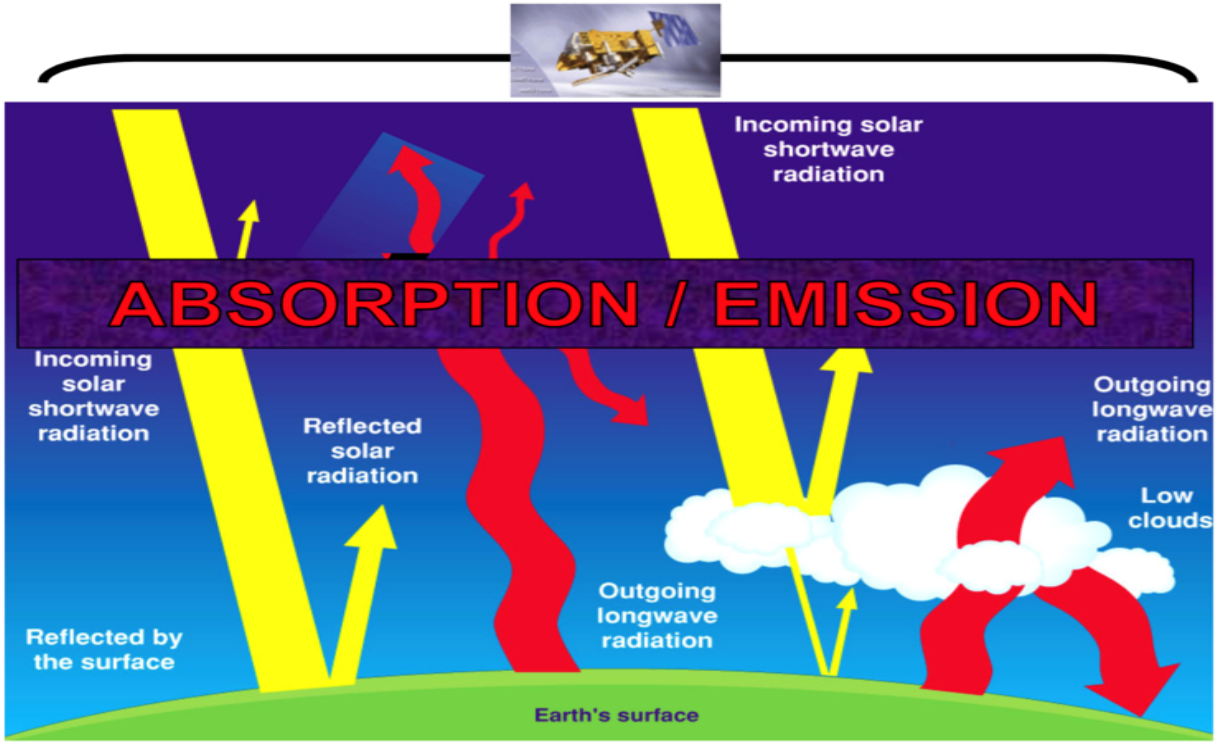
Our description of the atmosphere

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

Planck source term* depending on temperature of the atmosphere

Absorption in the atmosphere

Other contributions to the measured radiances



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**
- **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 (e.g. CO2).

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 channels 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

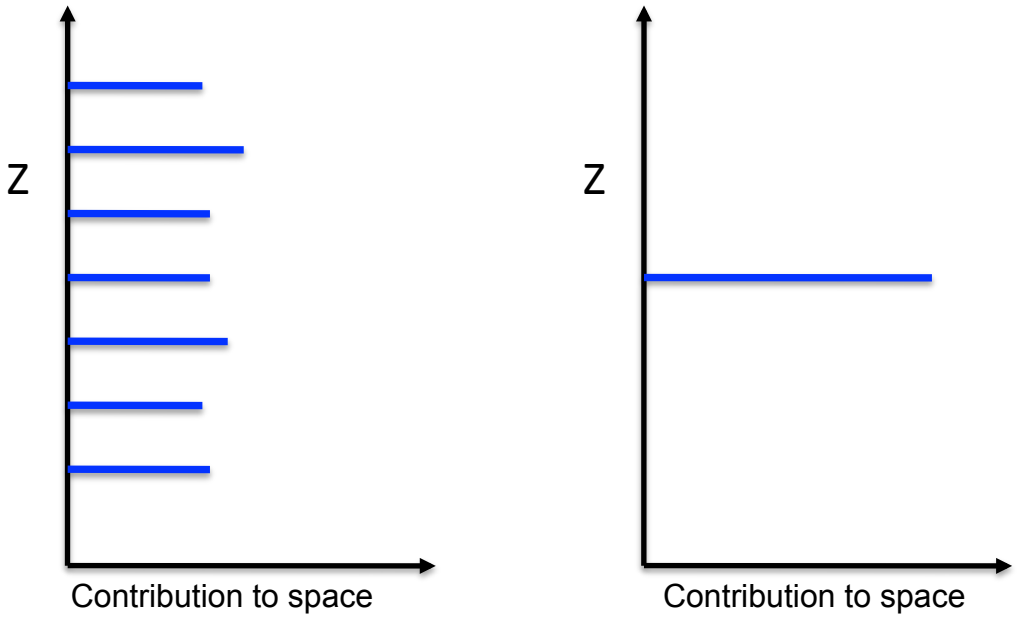
To measure the humidity or ozone we need to select channels for which Water vapor or ozone are a potential absorbers.

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

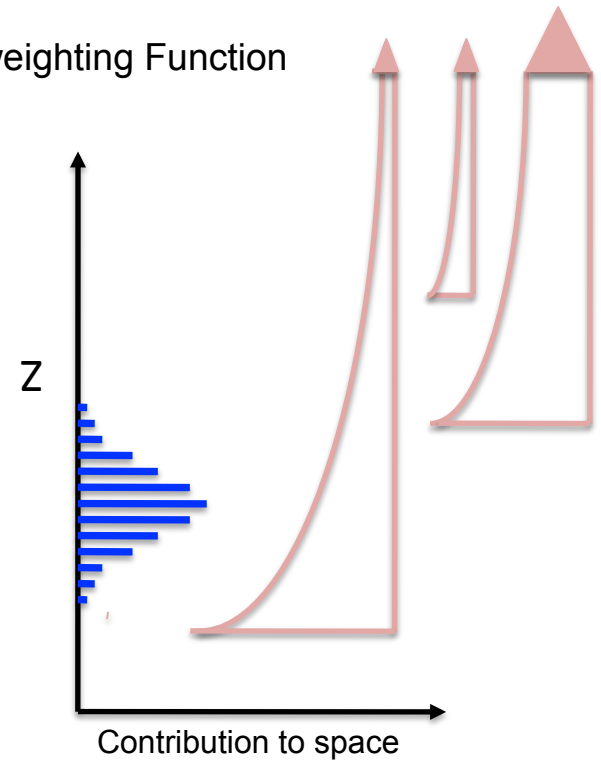
Atmospheric Passive Sounding

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

Ideal weighting function



Real weighting Function

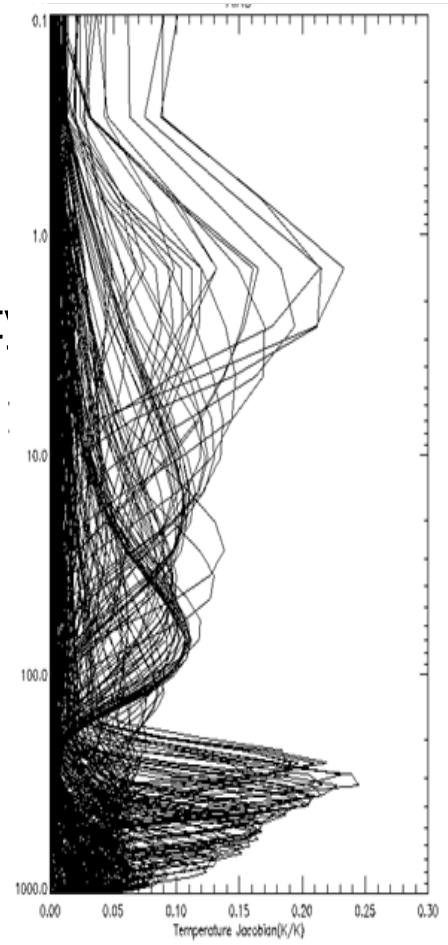


Atmospheric Passive Sounding

- 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:

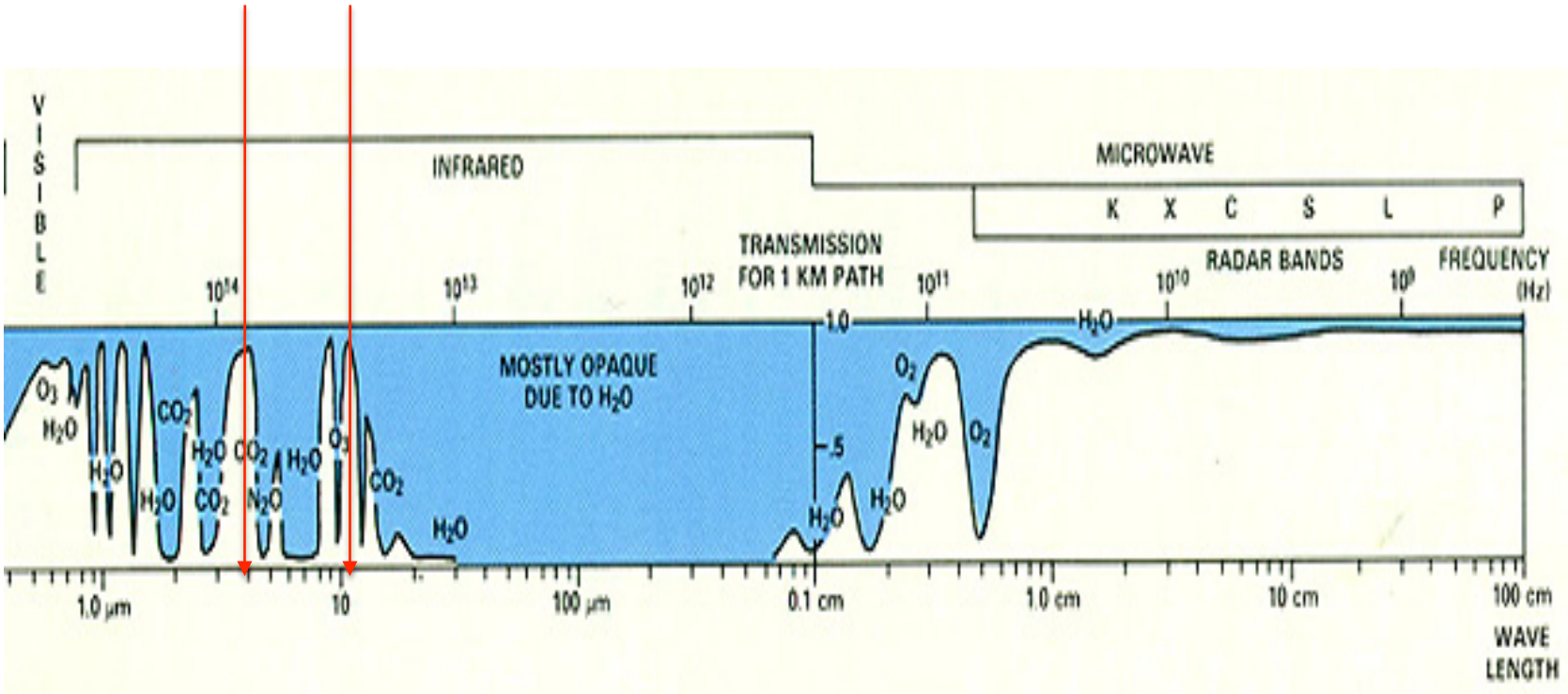
$$L_v = \int_0^{\infty} B(v, T(z)) \left[\frac{d\tau(v)}{dz} \right] dz$$ + *Surface emission* + *Surface reflection* + *Cloud/Rain interaction*

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

T_{surf} = *skin 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).

Surface sensing (passive)



Surface sensing (Active)

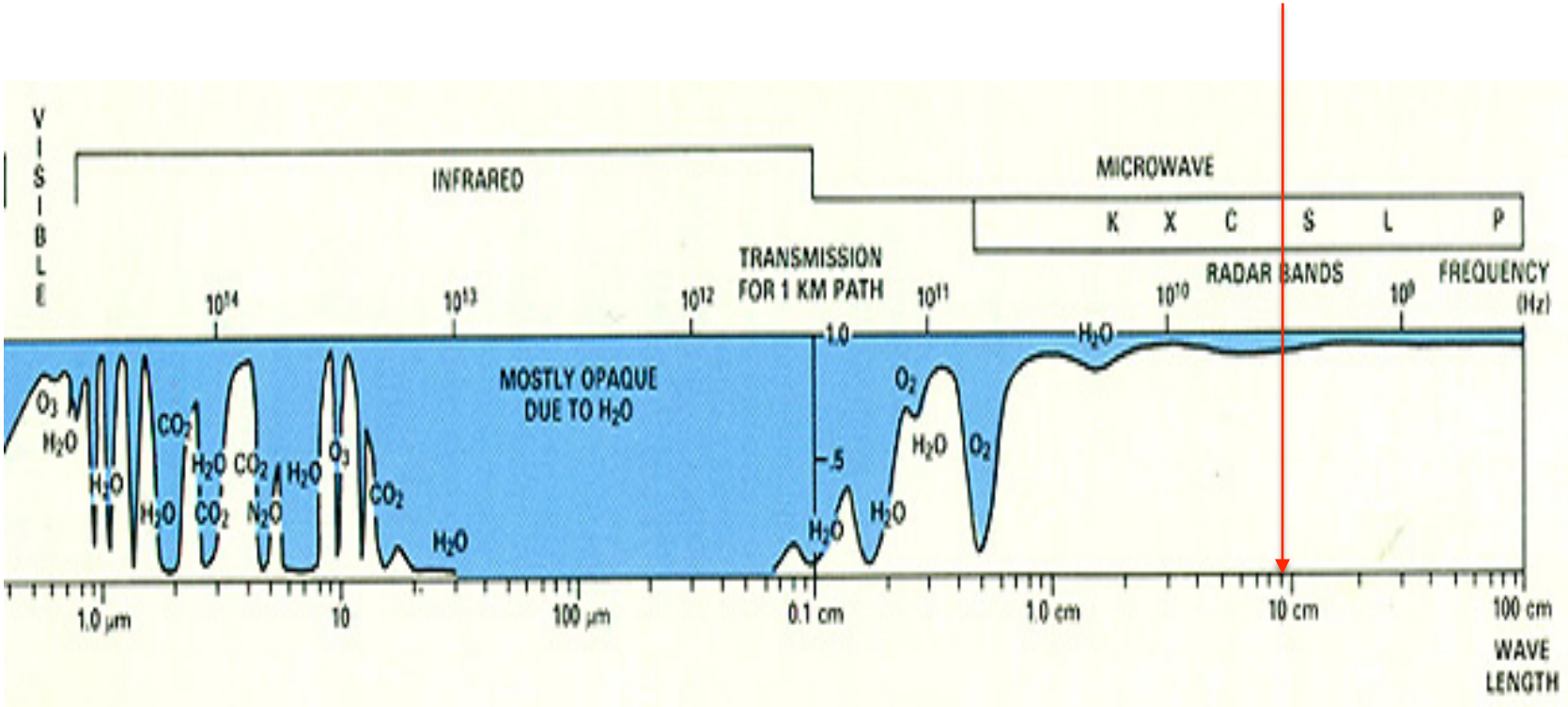
- Selecting channels where there is no contribution from the atmosphere or emission from the surface.

- 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.

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

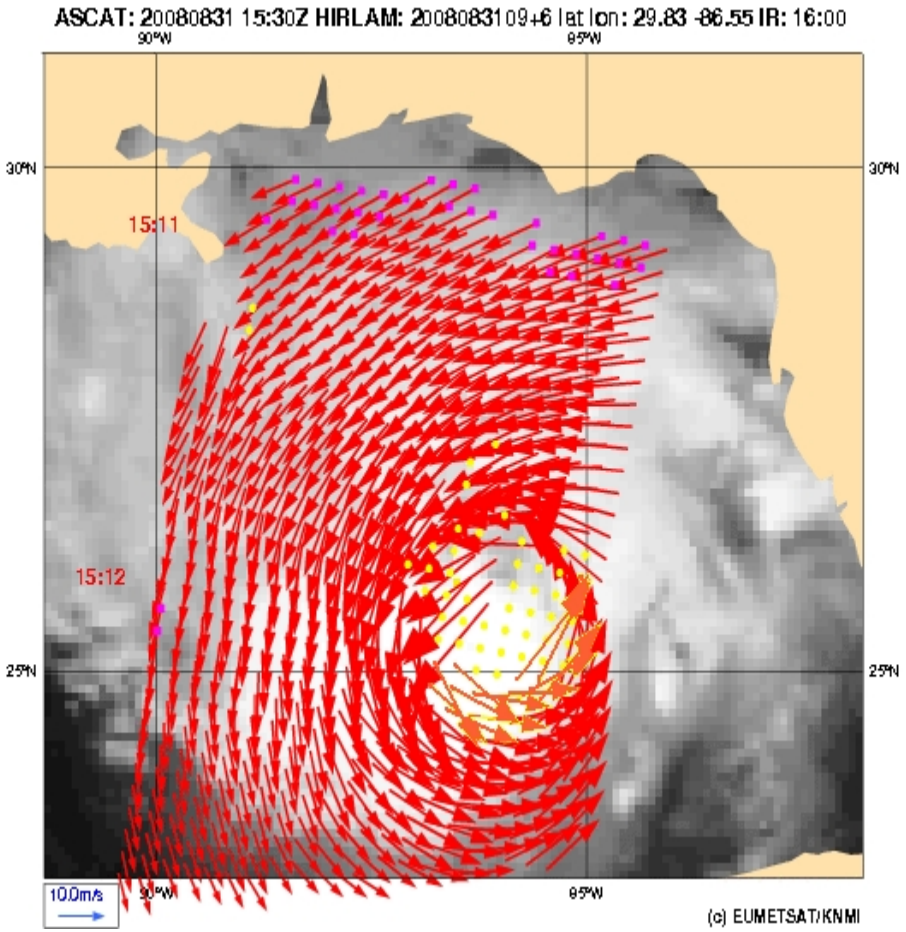
Provide information on surface winds, waves (over sea) and soil moisture (over land),

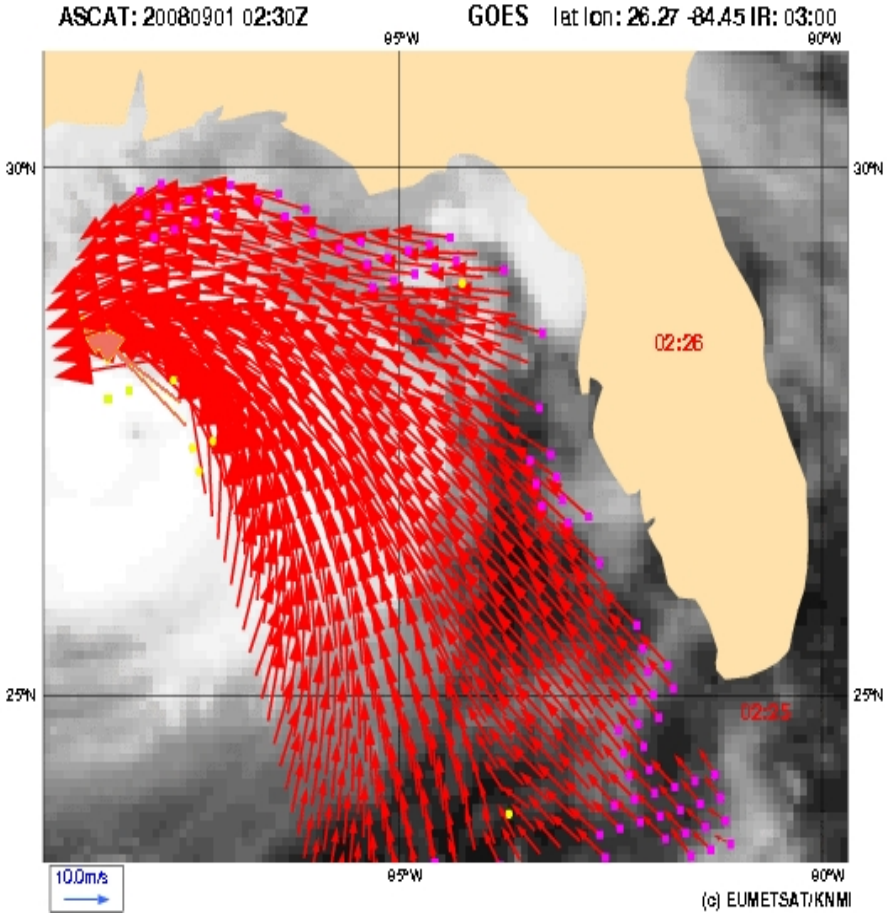
Surface sensing (passive)



Active Surface sensing

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

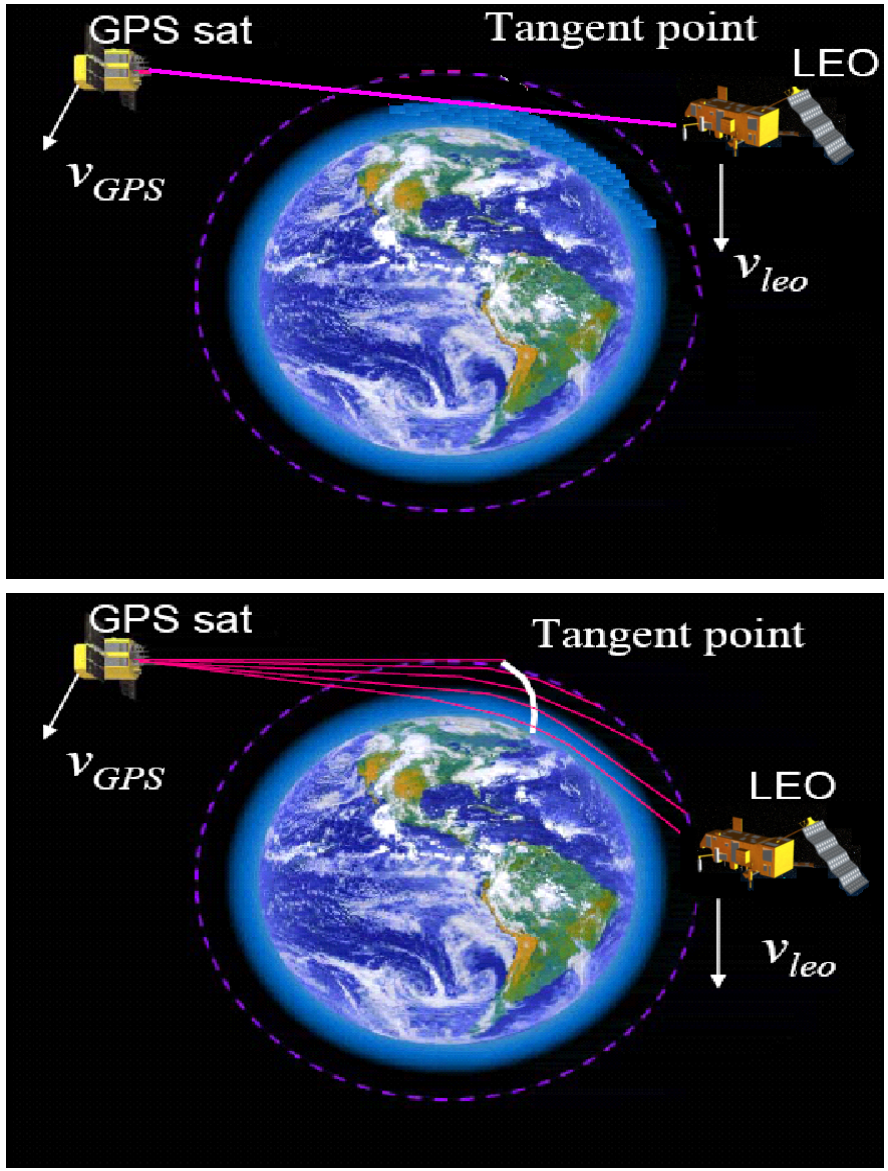




GPS Radio occultation

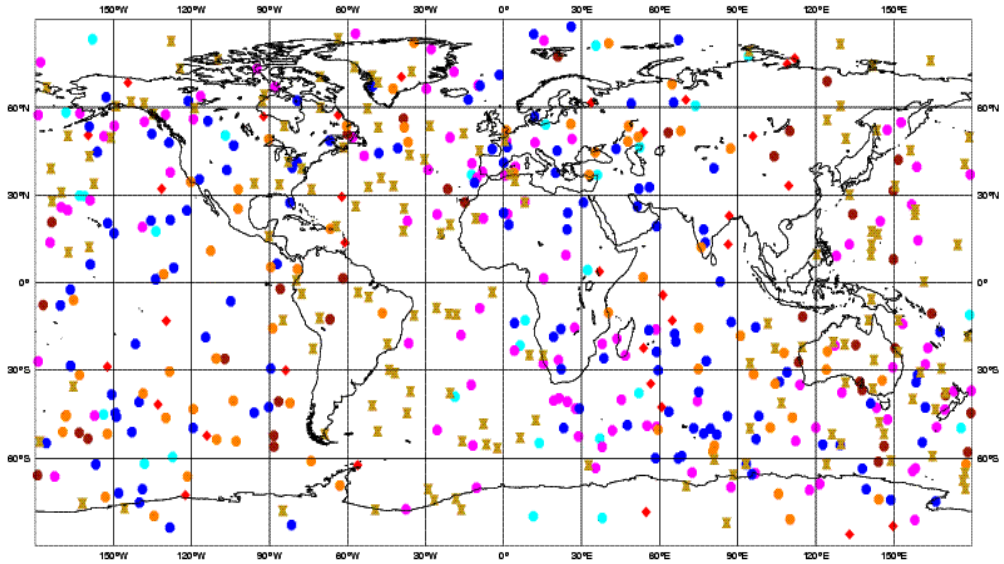
- The impact of the atmosphere on the radio signal (emitted by GPS satellites) propagation depends on the refractivity which is dependent of temperature and humidity.

- 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),



Instruments	Satellites
HIRS (Infrared)	NOAA satellites, METOP A&B
AMSU-A, AMSU-B/MHS (microwave)	NOAA, METOP-A, METOP-B, AQUA
ATMS (microwave)	NPP
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
SSMI, SSMIS, TMI, WINDSAT, AMSR2 (microwave)	DMSP series, TRMM, WINDSAT, GCOM-W1
MODIS (AMVs)	AQUA, TERRA
Scaterrometer (surface winds, soil moisture)	METOP-A/ASCAT, METOP-B/ASCAT
Altimeter (surface winds, waves)	Jason
SBUV, OMI, GOME-2	NOAA, AURA, METOP
Geostationary instruments (Radiances & derived AMVs)	METEOSAT, MSG, GEOS, MTSAT, Himawari-8

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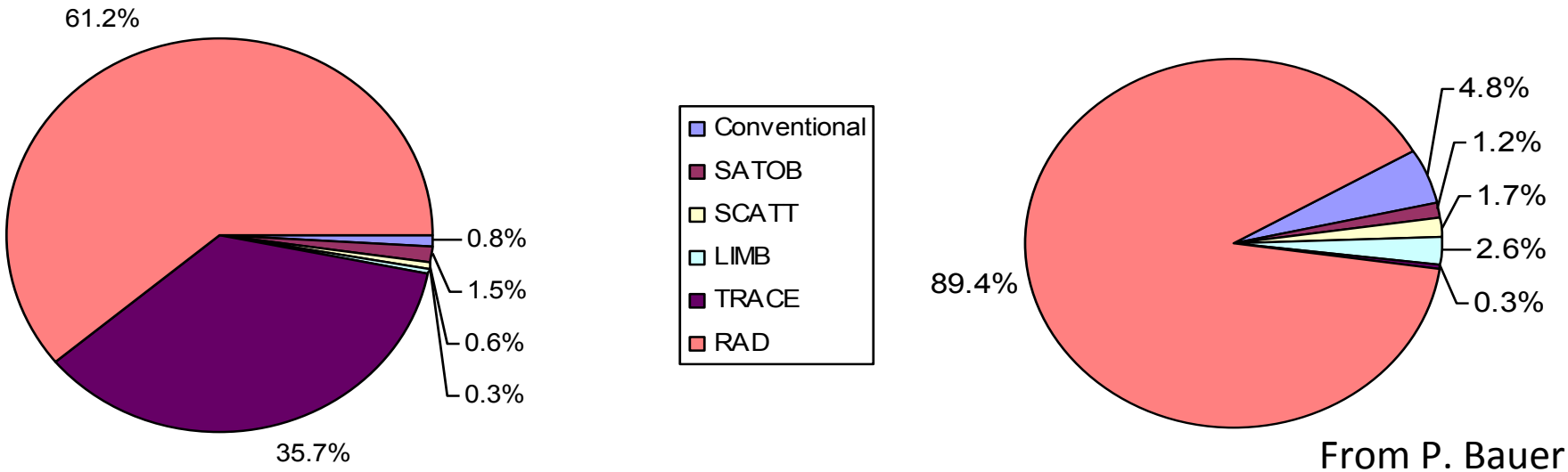
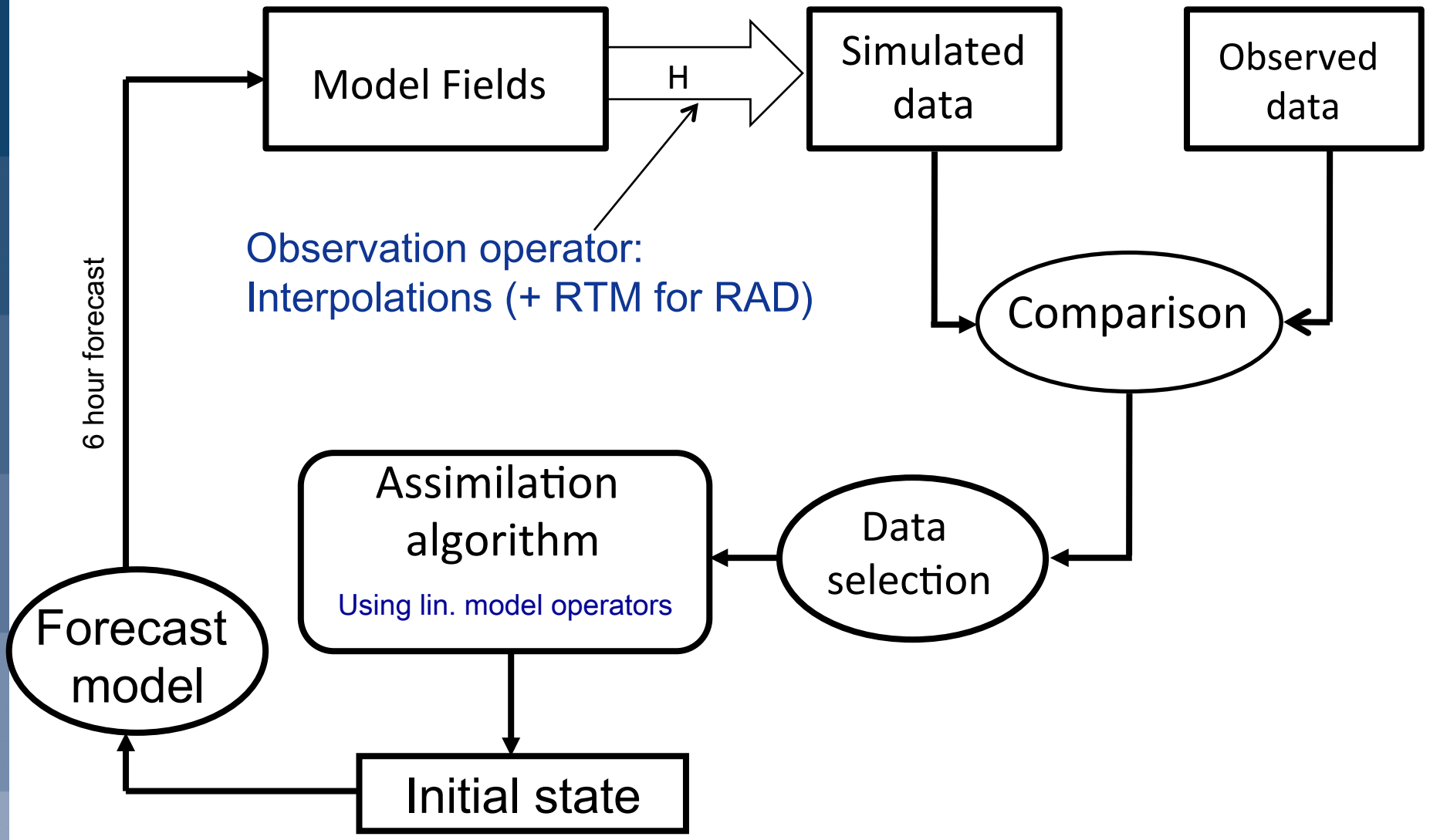
- **Satellite data usage**
- Monitoring of satellite data

- 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.



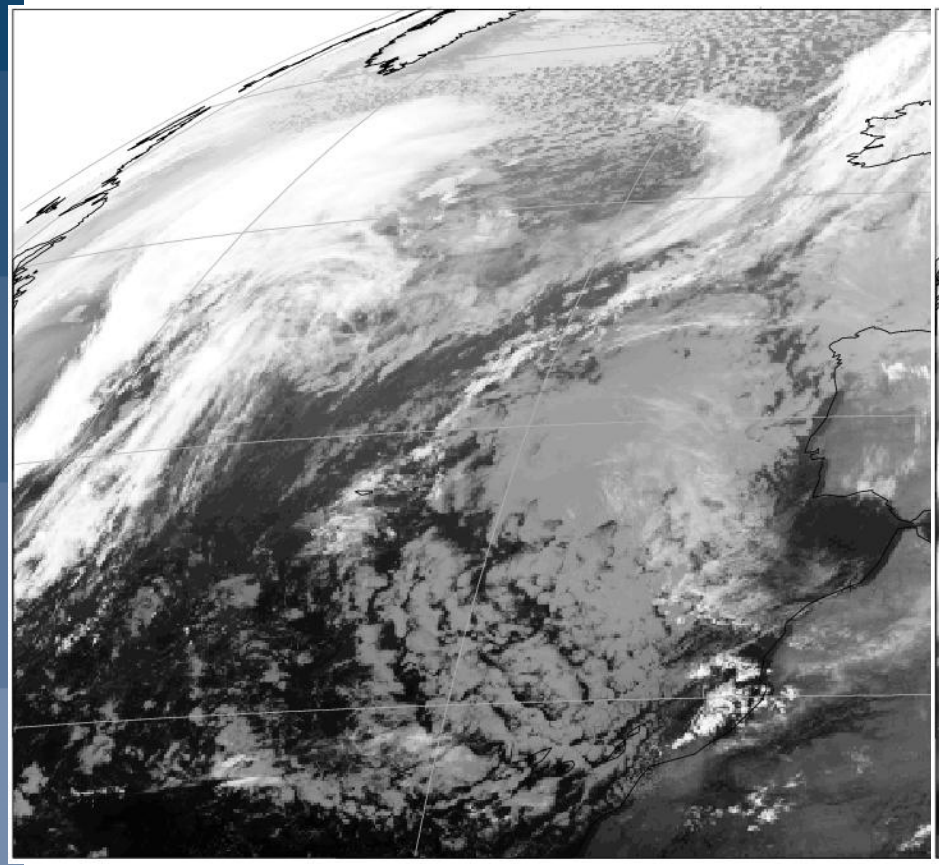
From P. Bauer

Assimilation of satellite data

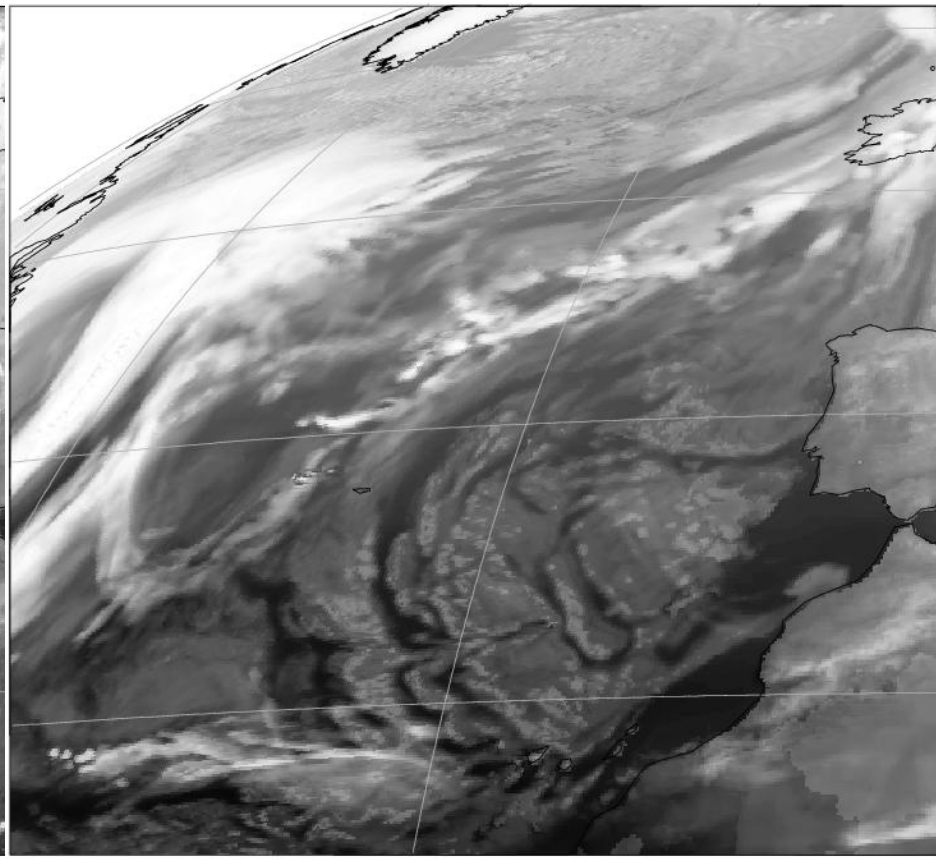


Observation operator

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:

- 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

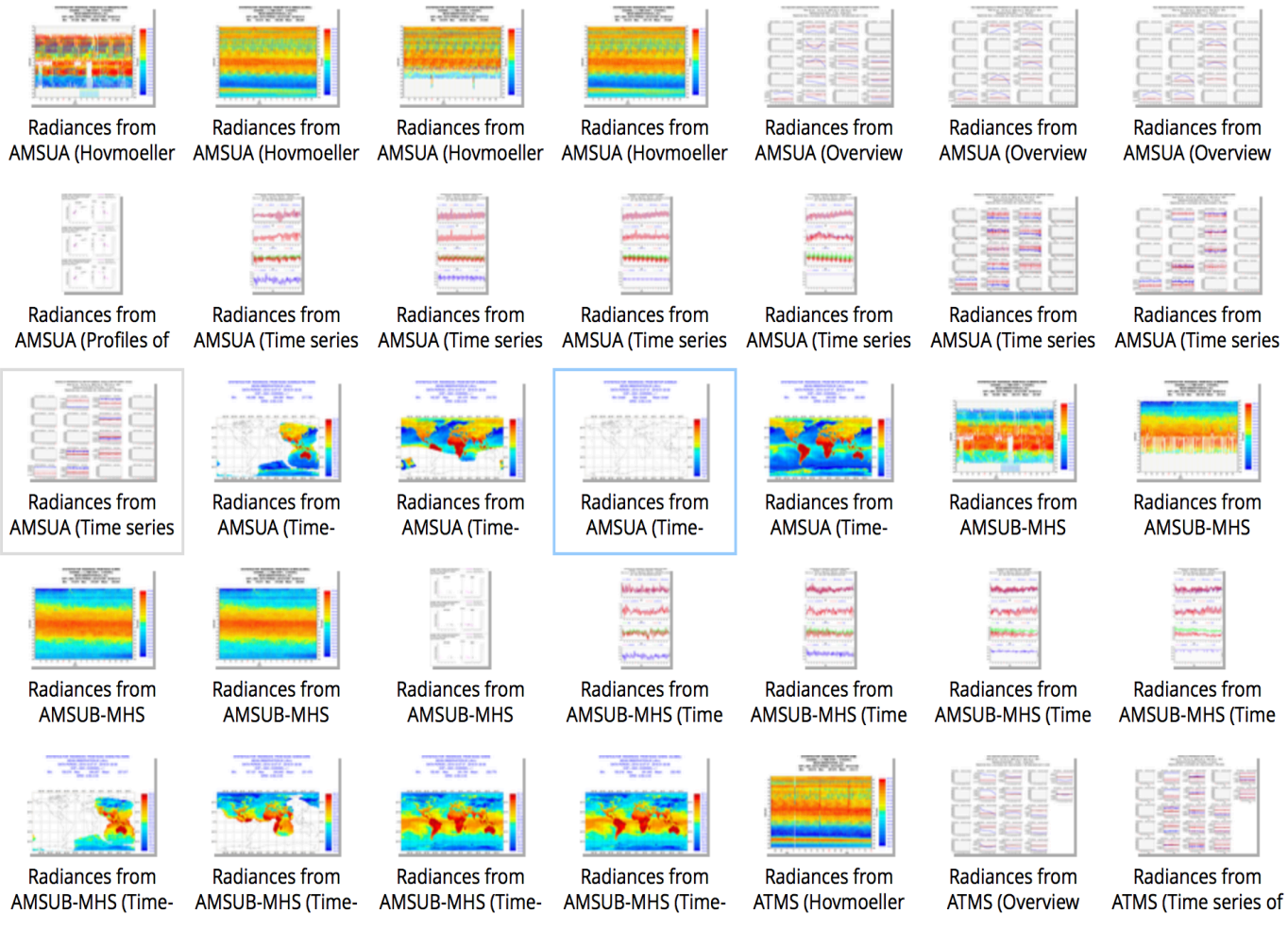
- [ ] AMSUA (19)
- [ ] AMSUB-MHS (13)
- [ ] ATMS (5)
- [ ] MWHS (4)

Data Stream

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

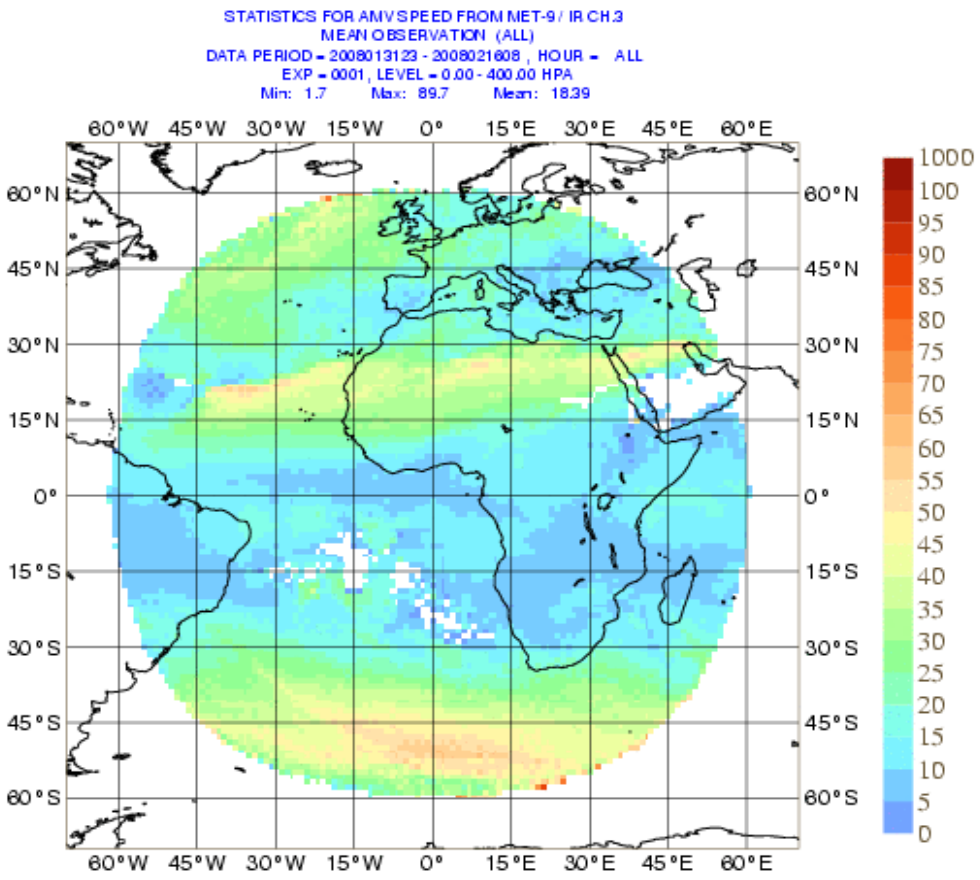
41 matching items

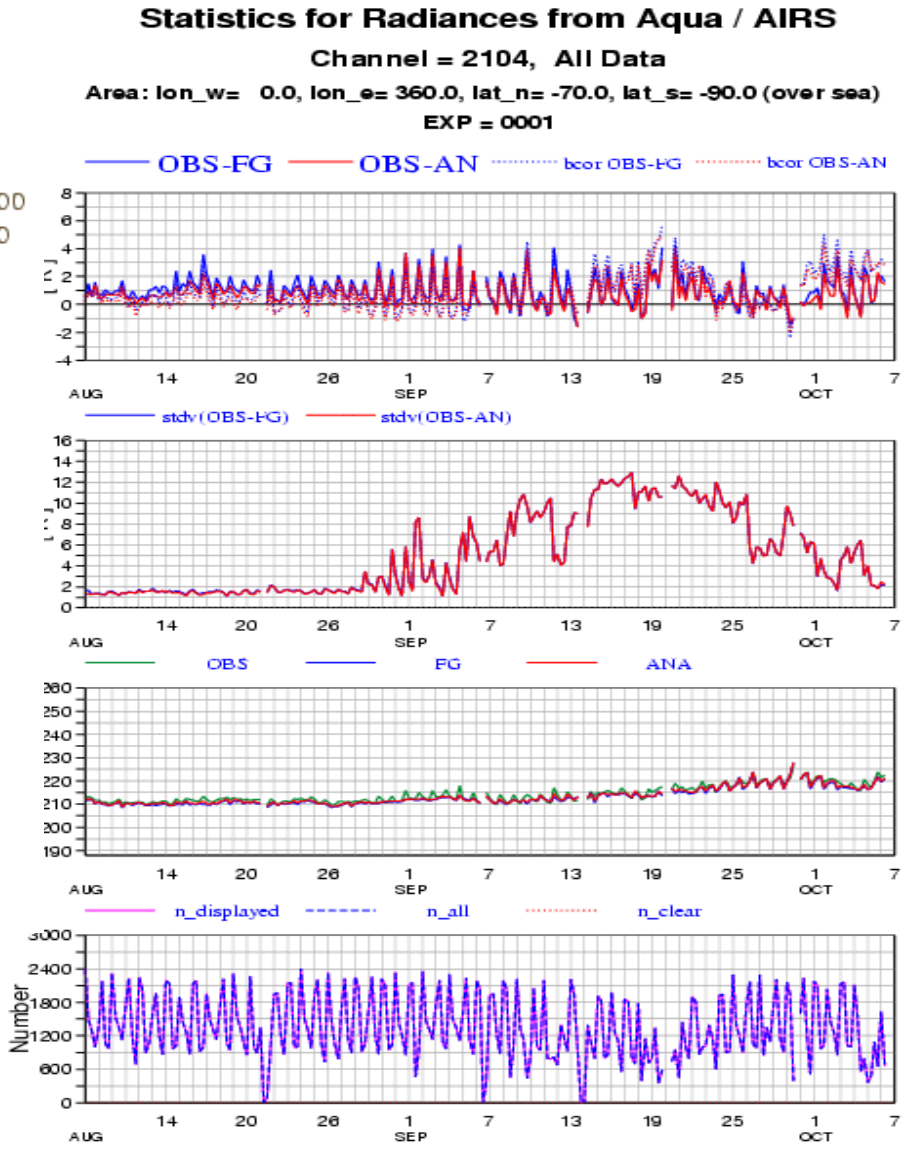
Parameter: Radiances / Data type: Microwave radiances



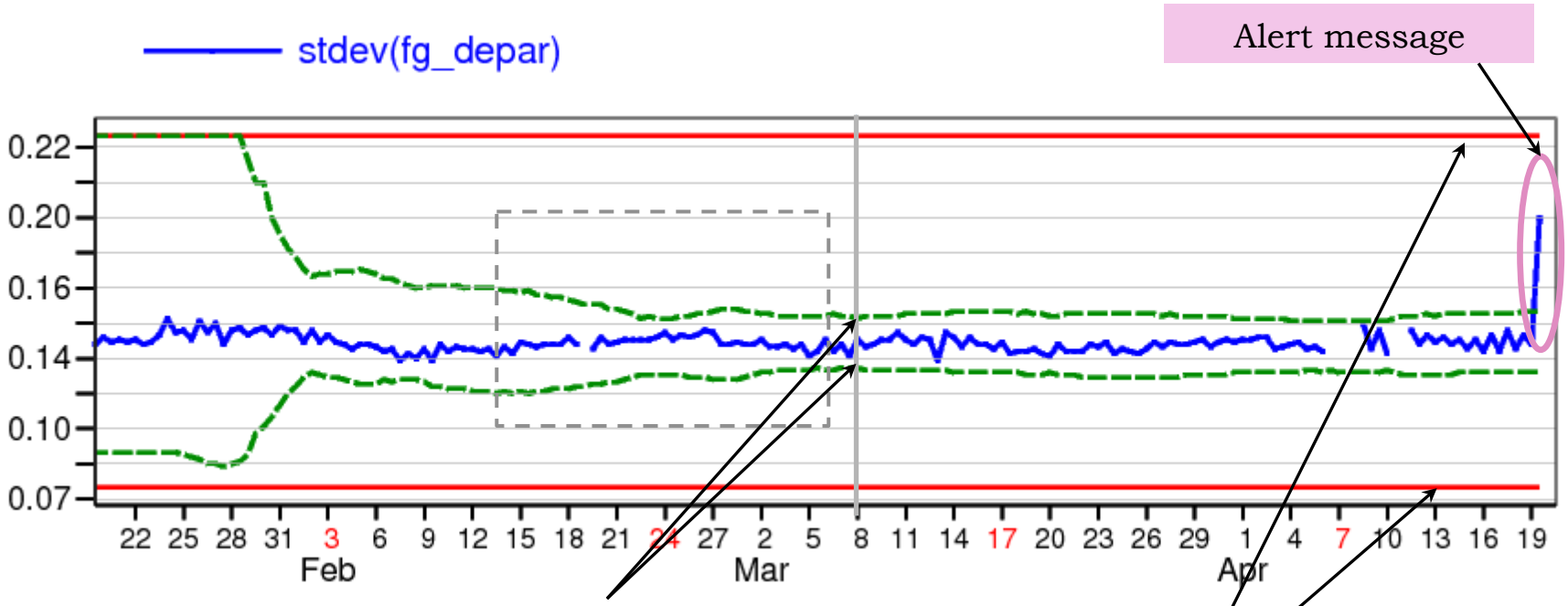
Time series

Time evolution of statistics over predefined areas/surfaces/flags





Automatic Alarm system



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

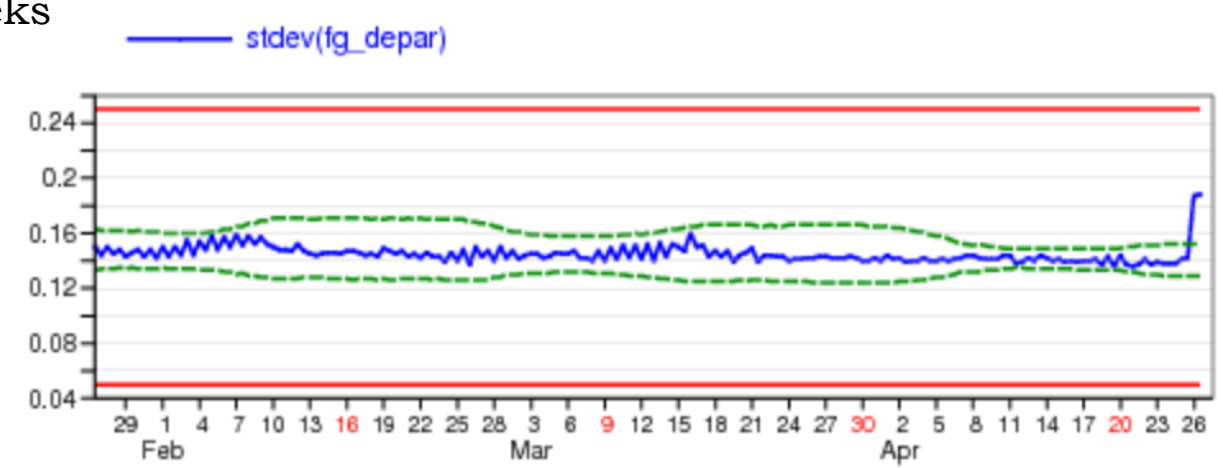
Hard limits (fixed)

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

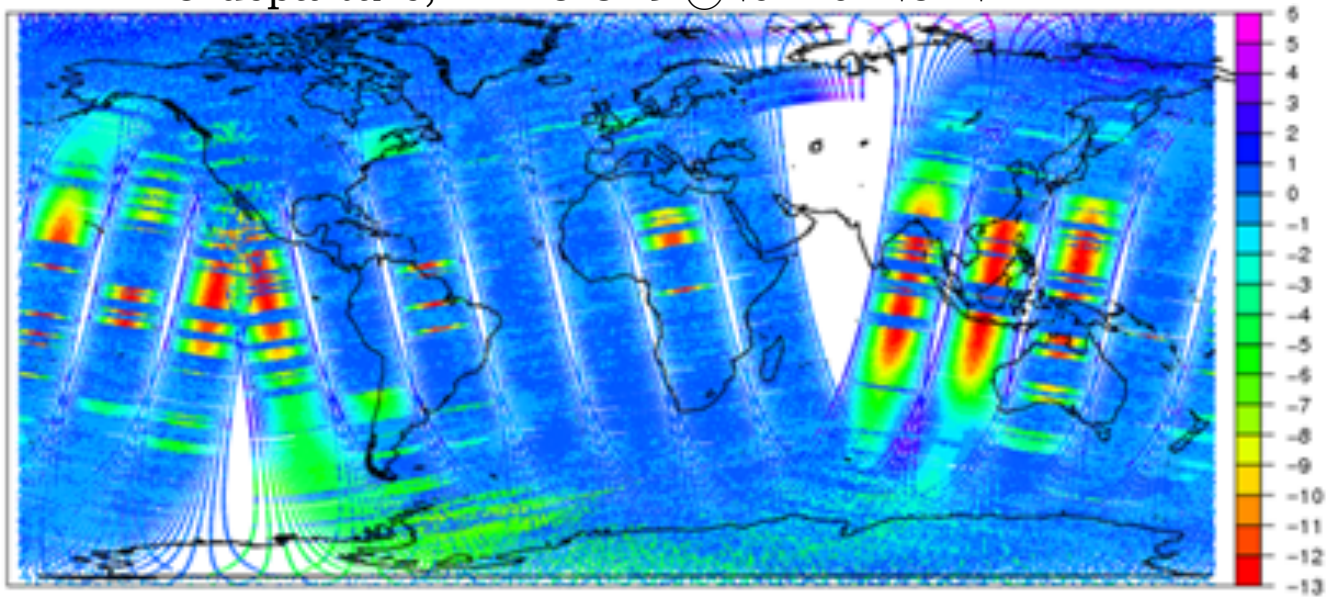
ATMS Ch9 @2014042612

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