Use of Satellite Data at ECMWF

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What satellites are used for NWP ?

- **Two different type of satellite (orbit)**
  - ➔ GEO (geostationary satellites)
  - ➔ LEO (low earth observing satellites)

GEOSTATIONARY (GEO) satellites

(36 000 km from the earth)

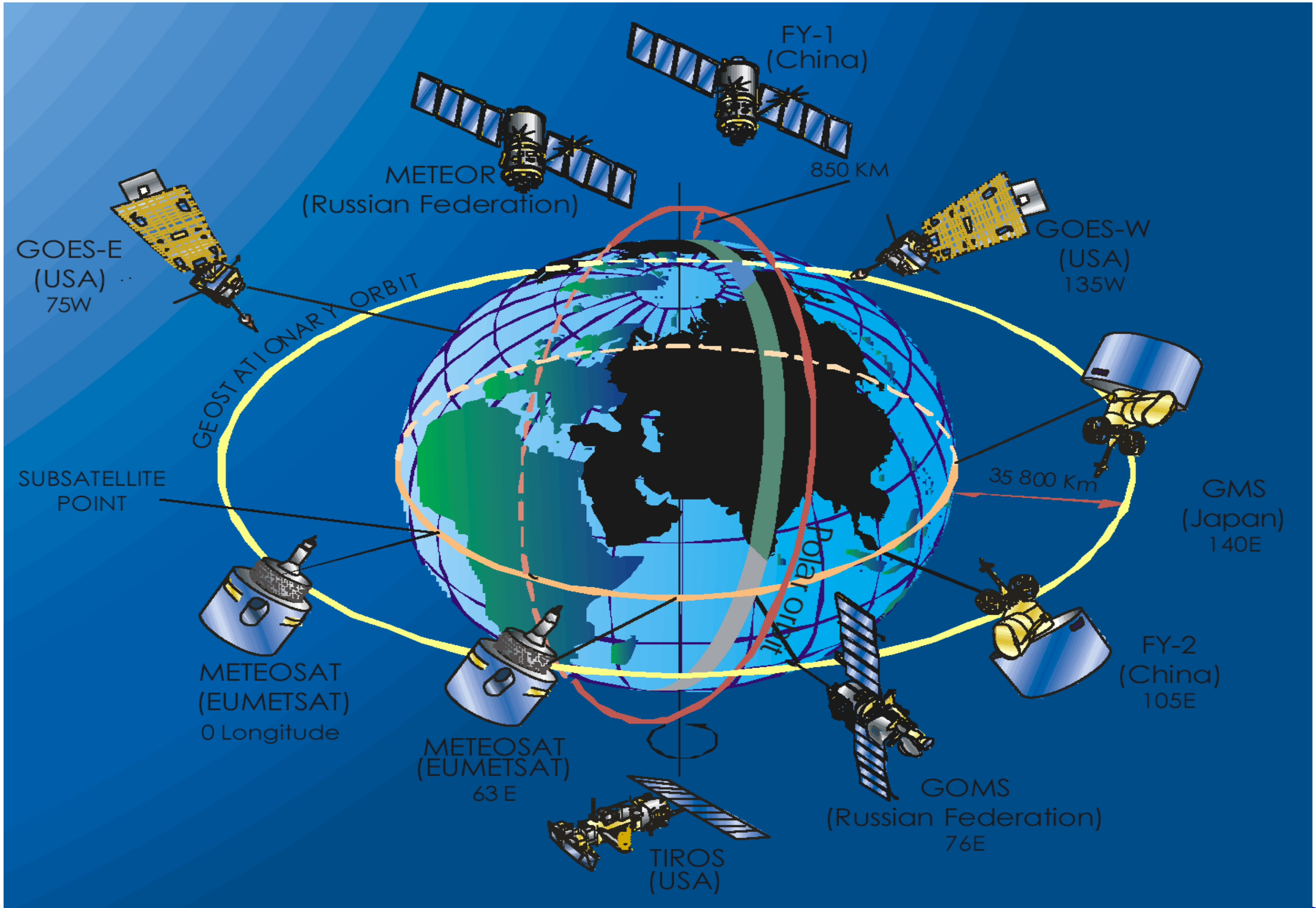
- **Advantages:**
  - **Wide space coverage (whole disk)**
  - **Very high temporal coverage (a few minutes)**
    - ➔ Particularly suitable for short-range NWP and Now-casting applications
    - ➔ Suitable also for meteorological feature tracking
      - (**Atmospheric Motion winds**)
    - ➔ Suitable for applications in which the diurnal cycle representation is crucial
- **Drawbacks:**
  - **Spatial coverage limited to the disk (need for constellation)**
  - **Unsuitable to observe the polar regions**

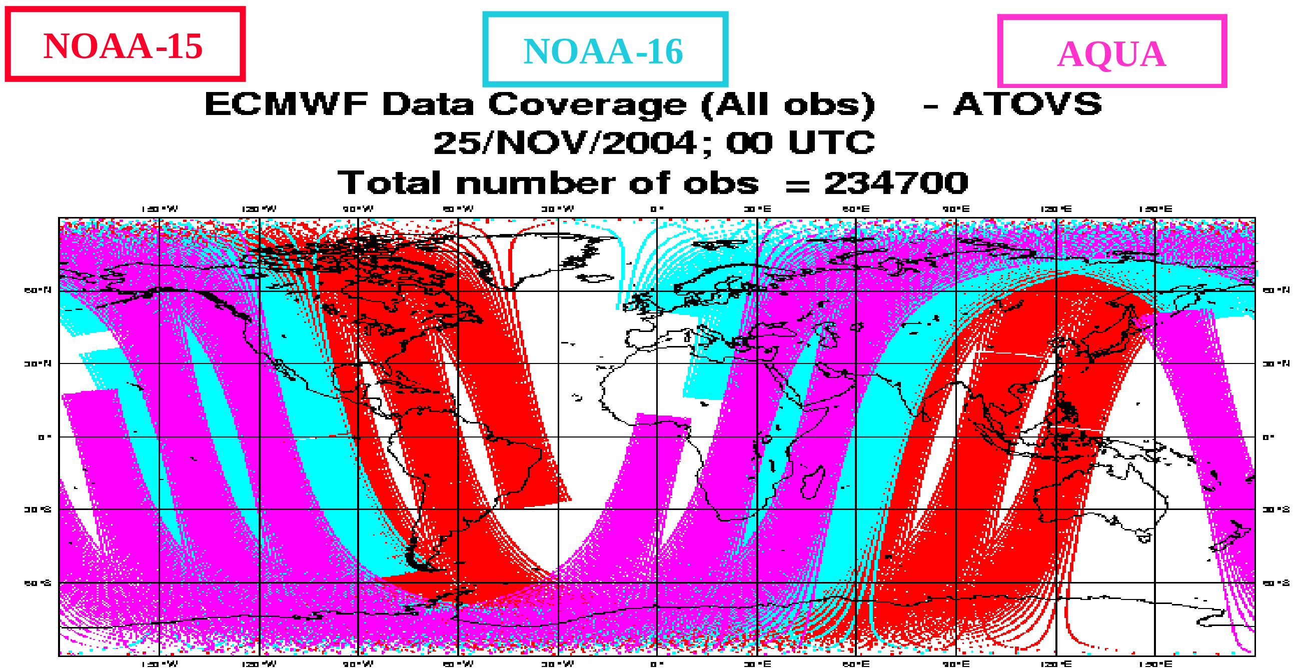
Low Earth Orbiting (LEO) satellites

(400 to 800 km from the Earth)

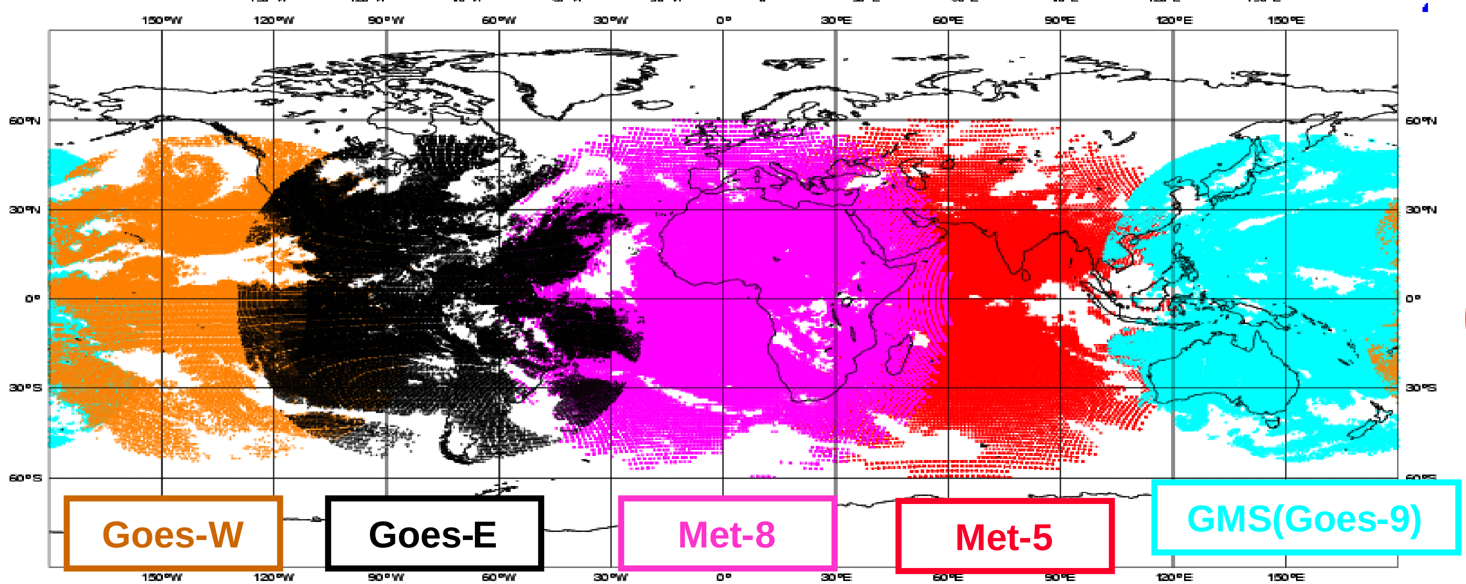
- **Advantages:**
  - Cover the whole earth after several cycles (polar orbiting satellites)
  - More suitable to sound the atmosphere in the microwave spectrum.
- **Drawbacks:**
  - Moderate temporal sampling (several hours to go back to the same point)
  - Requires constellation to ensure a reasonable temporal sampling

Mixed GEO and LEO Observing System




NOAA-15
NOAA-16
AQUA
ECMWF Data Coverage (All obs) - ATOVS
25/NOV/2004; 00 UTC
Total number of obs = 234700

LEO


Goes-W
Goes-E
Met-8
Met-5
GMS(Goes-9)

GEO

What do the instruments on board satellites measure ?

- Satellite instruments are specific in that they **do not** measure geophysical quantities (temperature, moisture, ozone, wind,…)

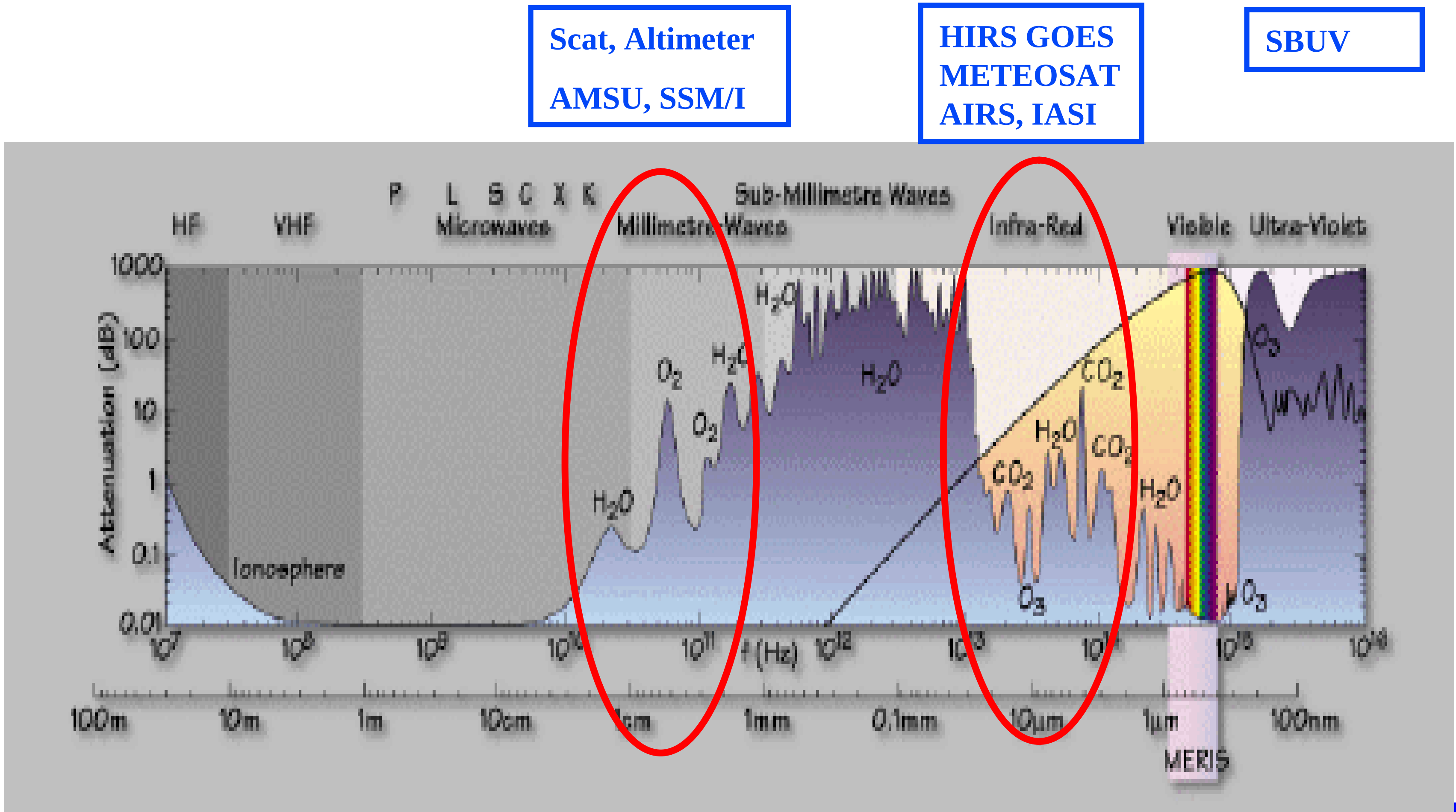
- Satellite instruments measure the **radiation** emitted by the Earth/Atmosphere

- The conversion of this measurement into a geophysical information is an **inverse/retrieval** problem

$Y_b = H(X_b)$ **Forward modelling problem (Radiative Transfer Equation)**

$X_a = H^{-1}(Y_{obs})$ **Inverse problem (need for prior information)**

- Depending on the wavelength, the radiation reaching the satellite is sensitive to different atmospheric constituents and different altitudes



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Different measurement techniques

- **Passive technologies**
  - **Passive instruments sense the:**
    - ➔ natural radiation emitted by the Earth/Atmosphere
    - ➔ solar radiation reflected by the Earth/Atmosphere
- **Active technologies**
  - **Active instruments:**
    - ➔ Emit radiation towards the Earth/Atmosphere
    - ➔ Sense how much is scattered (or reflected) back
- **GPS technologies**
  - **GPS receivers:**
    - ➔ Measure the phase delay of refracted through the atmosphere

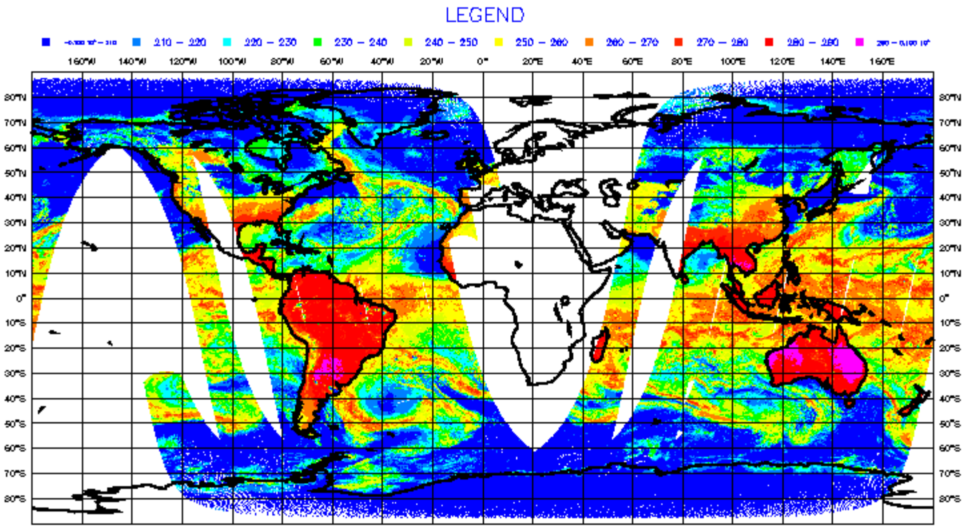
Passive imaging

- “Imaging” instruments
  - Sense in spectral “window” regions where the atmosphere is close to transparent, therefore sense essentially the surface emission
  - Provide indirectly information on:
    - ➔ VIS/IR: surface temperature, cloud top, wind (through cloud motion), snow/ice, vegetation
    - ➔ μW: surface ocean wind speed, sea-ice, total column water vapour, cloud liquid water, rain
  - **Vis/IR instruments: AVHRR on NOAA, MODIS on TERRA/AQUA, GOES+METEOSAT/MSG,…**
  - **Microwave instruments: SSM/I on DMSP, TMI on TRMM, AMSR on AQUA and ADEOS-2,…**

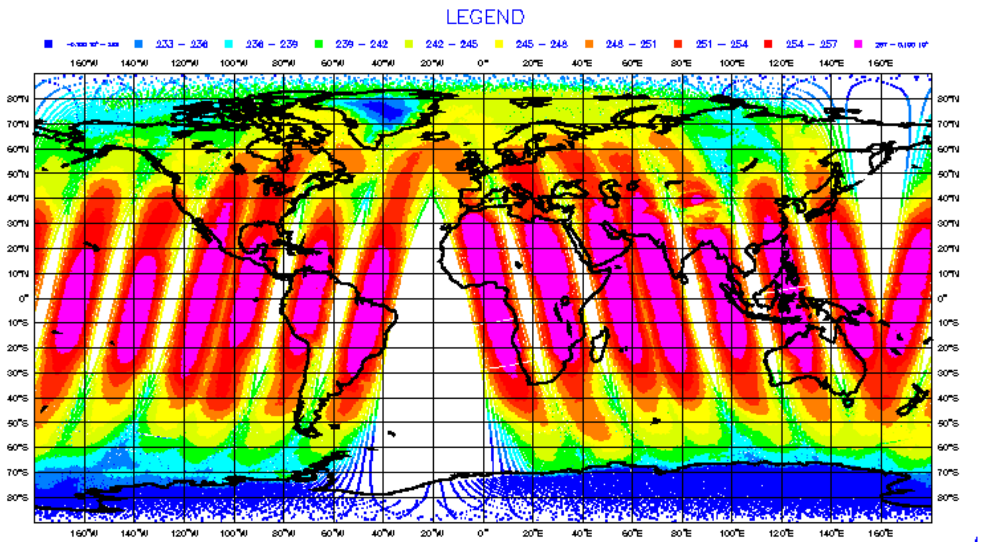
Passive sounding

- "sounding" instruments
  - Sense in spectral regions where the contribution from the surface is negligible (strong atmospheric absorption bands)
  - Provide indirectly information on:
    - ➔ IR: profiles of temperature-humidity-ozone, surface temperature (limited to non cloudy areas)
    - ➔ µW: temperature and humidity profiles (limited to non rainy areas)
  - IR instruments: HIRS on NOAA, AIRS on AQUA, GOES,…
  - Microwave instruments: AMSU-A, AMSU-B on NOAA,…

Passive Imager and Sounder

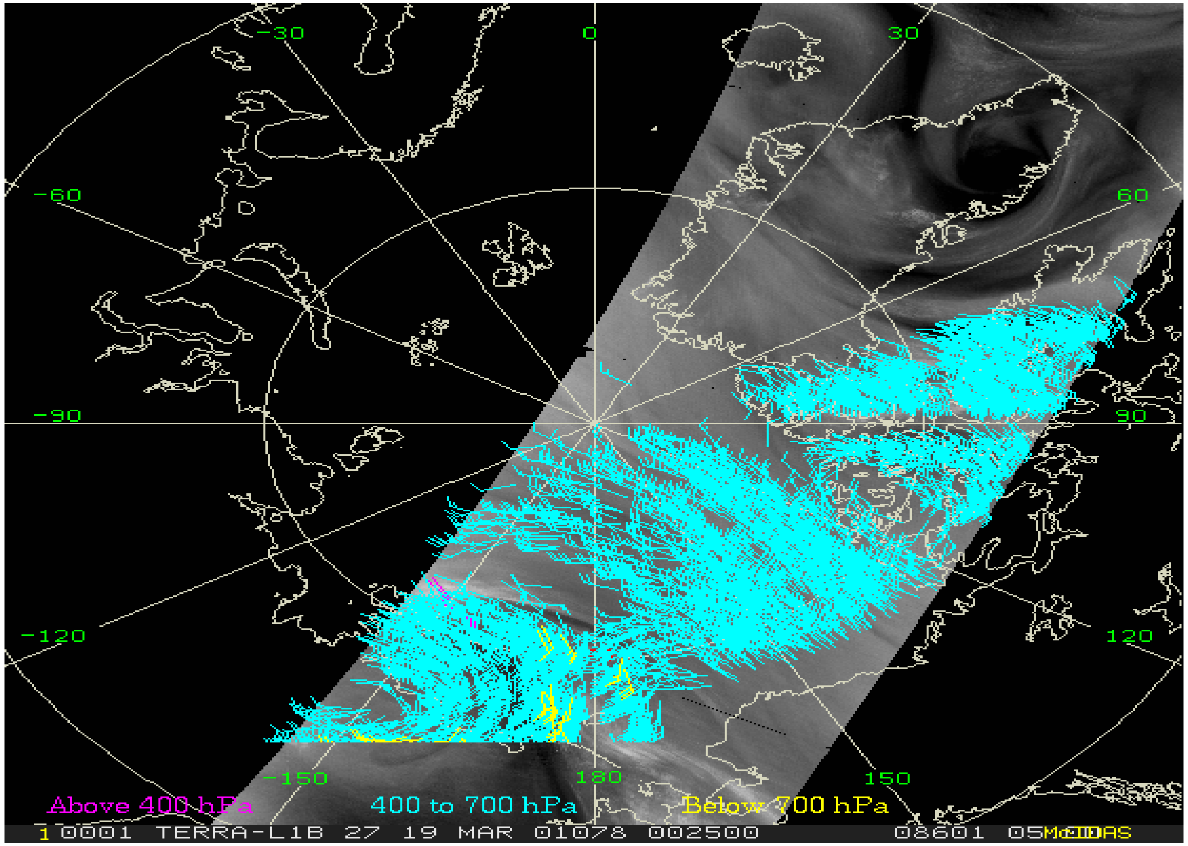


SSM/I microwave imager sensing the surface / clouds



AMSUA microwave sounder sensing the atmosphere

Passive imaging instruments:
example MODIS Atmospheric Motion Vectors

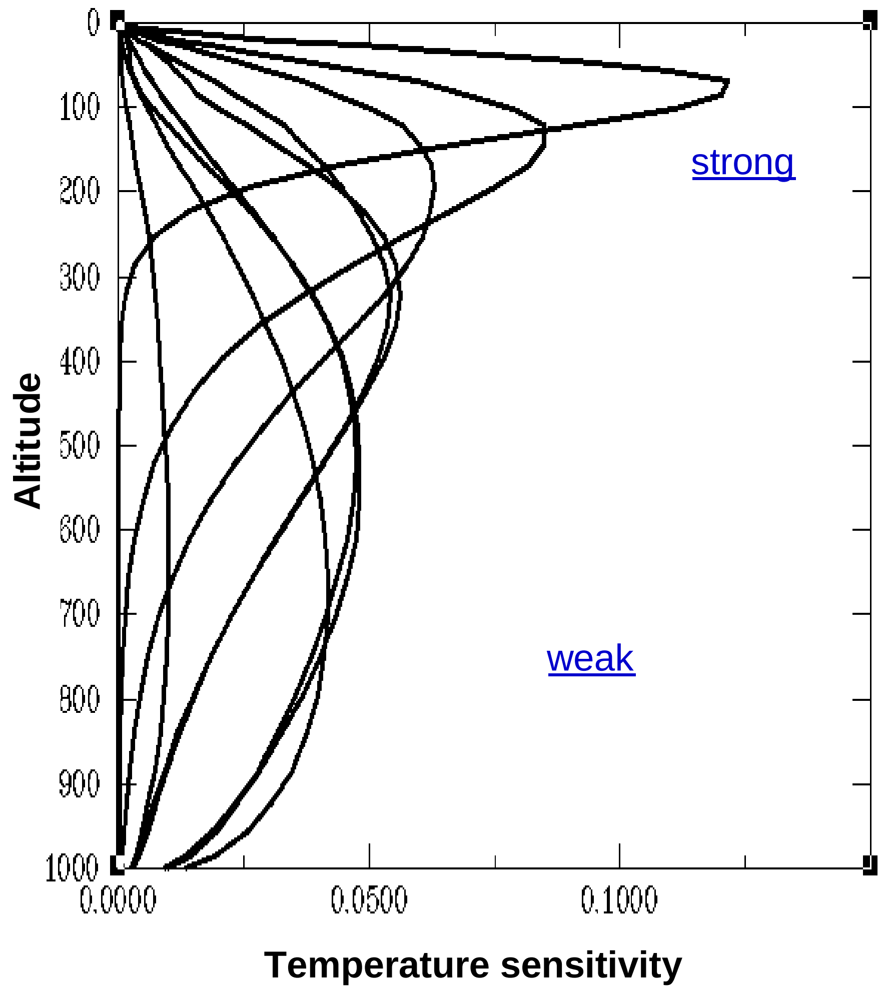


- Use water vapour and cloud features to infer winds
- Polar regions from polar orbiting platforms; tropical and temperate from geostationary

Passive sounding instruments: example AMSU-A

- Sense radiation from different atmospheric layers by selecting different channels with strong and weak absorption

- In practice the radiation in a particular channel is sensitive to temperature at many altitudes (ill posed inverse)



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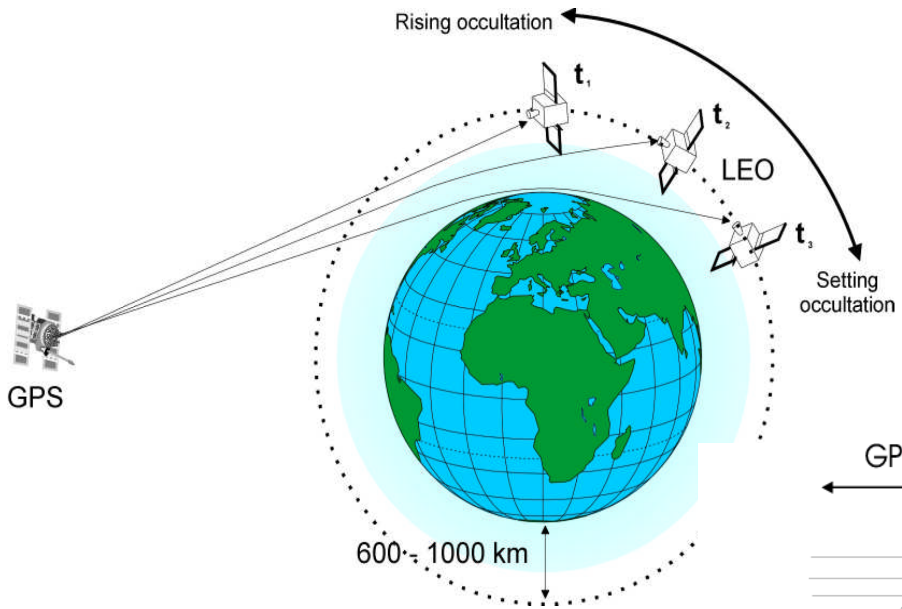
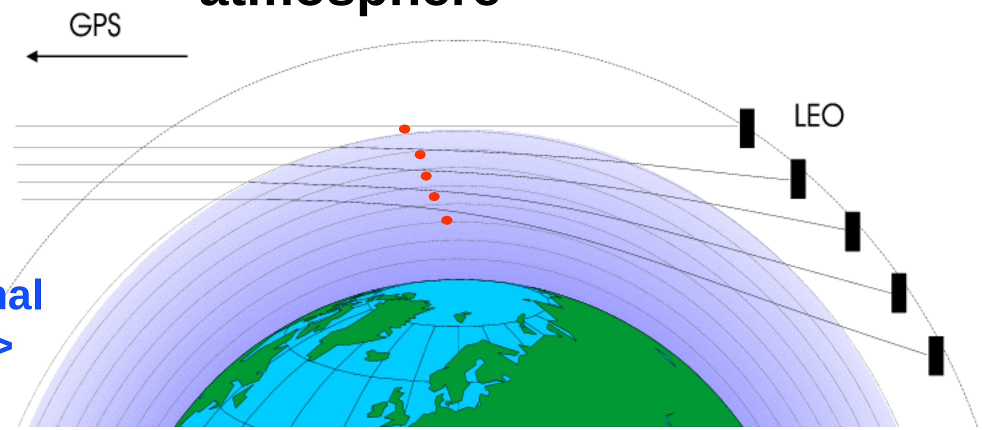
Active technologies

- **Active instruments**
  - **Send radiation to a target (Earth/Atmosphere) and measure what is back reflected/scattered.**
  - **Provide indirectly information on:**
    - ➔ Surface wind (scatterometers, radar altimeter)
    - ➔ Sea surface height, wave height and spectra (altimeters, SARs)
    - ➔ Rain, cloud and aerosol profiles (radars, lidars)
    - ➔ Atmospheric wind profiles (Doppler lidars)
    - ➔ Moisture profiles (DIALS)
  - **TRMM-PR, ERS-2 (Scat/RA/SAR), SeaWinds on QuikScat and ADEOS-2, ENVISAT (RA-2, ASAR)**

GPS radio occultation technologies



- = the path of the ray perigee through the atmosphere



- GPS-MET, CHAMP

- The impact of the atmosphere on the signal propagation depends on the refractivity => the vertical profile of the refractivity (and further down temperature, humidity and pressure) at the location of the ray perigee can be inverted from the observation

Converting the satellite radiance measurements to the quantities we require (e.g. temperature)

Inversion Problem: Example

Given one observation y (radiance), a background x_b (temperature/moisture/ozone/surface pressure/…) , R and B the associated error covariances,

The analysis equation reads:

$$x_a = x_b + \frac{BH^T}{HBH^T + R}\left[y - H(x_b)\right]$$

The convolution of B and H will determine how information from a given radiance measurement (deep layer) will be distributed in the vertical (e.g. for temperature sounding)

Inversion problem: Importance of *B*

- ***B*** **together with H will propagate the information coming from the satellite radiances that can sense very broad atmospheric layer. Modelling of *B* is therefore crucial for a proper assimilation of satellite radiances**

- **Problem even more complicated when:**

  ➔ radiance information has to be distributed in temperature and moisture

- **Problem even even more complicated when:**

  ➔ Radiance information has to be distributed in temperature, moisture, ozone, CO2, cloud, rain,…

- **Problem even even even more complicated when:**

  ➔ Radiance information has to be distributed in space and time

Inversion Techniques

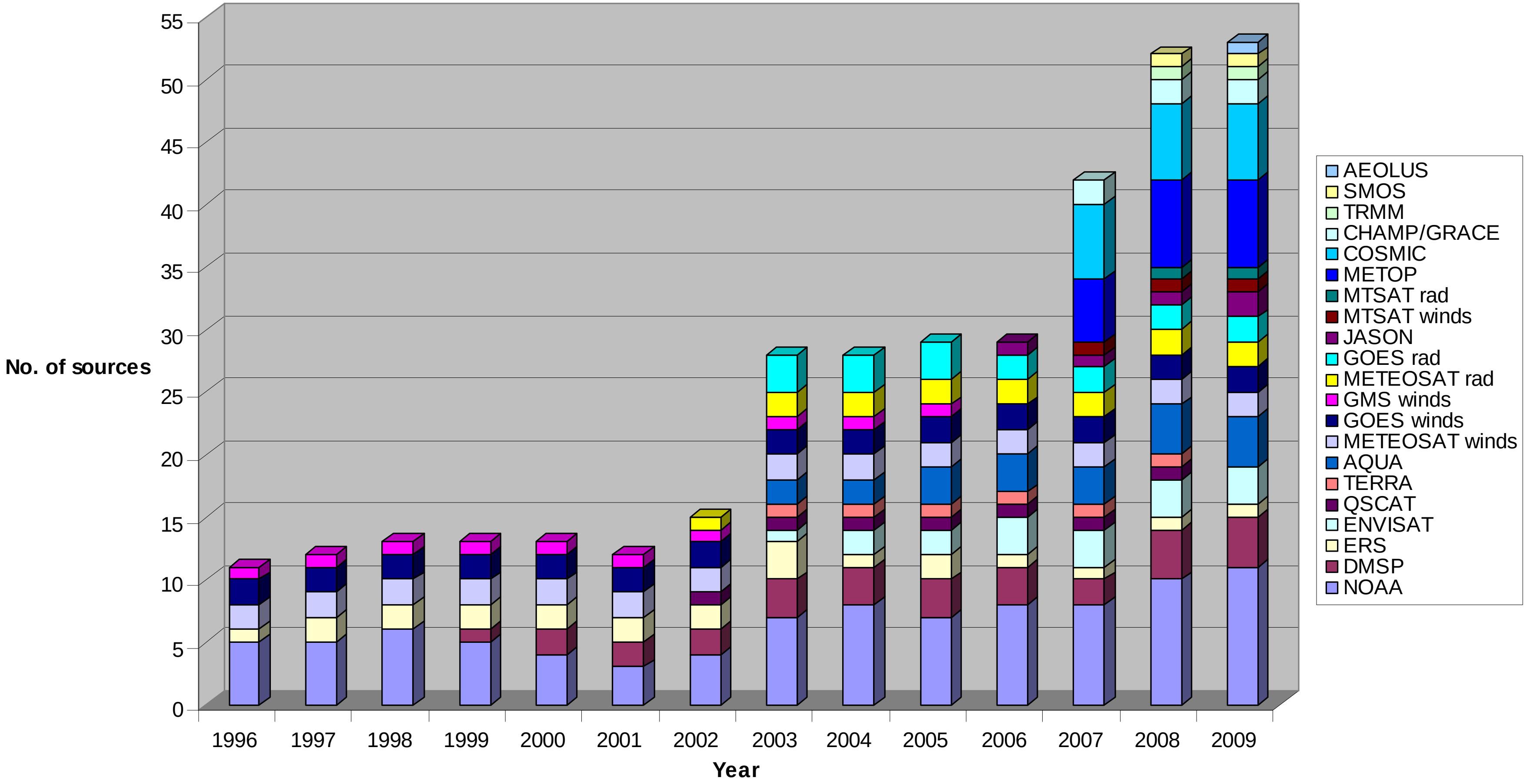
- Data assimilation in some way or another inverts radiance measurements in temperature/moiture/winds,…
- Different possibilities
  - Use of externally generated retrievals
  - Use of interactive retrievals (e. g. 1D-Var retrievals)
  - Direct use of radiances (e.g. 3D-Var or 4D-Var)
- In NWP at least, the direct assimilation of satellite raw radiances has progressively replaced the assimilation of retrievals

Inversion Techniques

- **The direct assimilation of radiances has several advantages over that of retrievals:**
  - ➔ avoid the contamination by external background information for which error characteristics are poorly known
  - ➔ Avoid further complicated errors entailed by the processing of the data provider
  - ➔ Avoid vulnerability to changes in the processing of the data provider
  - ➔ Allow a faster implementation of new data (no delay due to readiness of pre-processing)
  - ➔ 3D and 4D-Var allow for some (weak) non linearities in the observation operator
  - ➔ Increments further constrained by many other observations/information

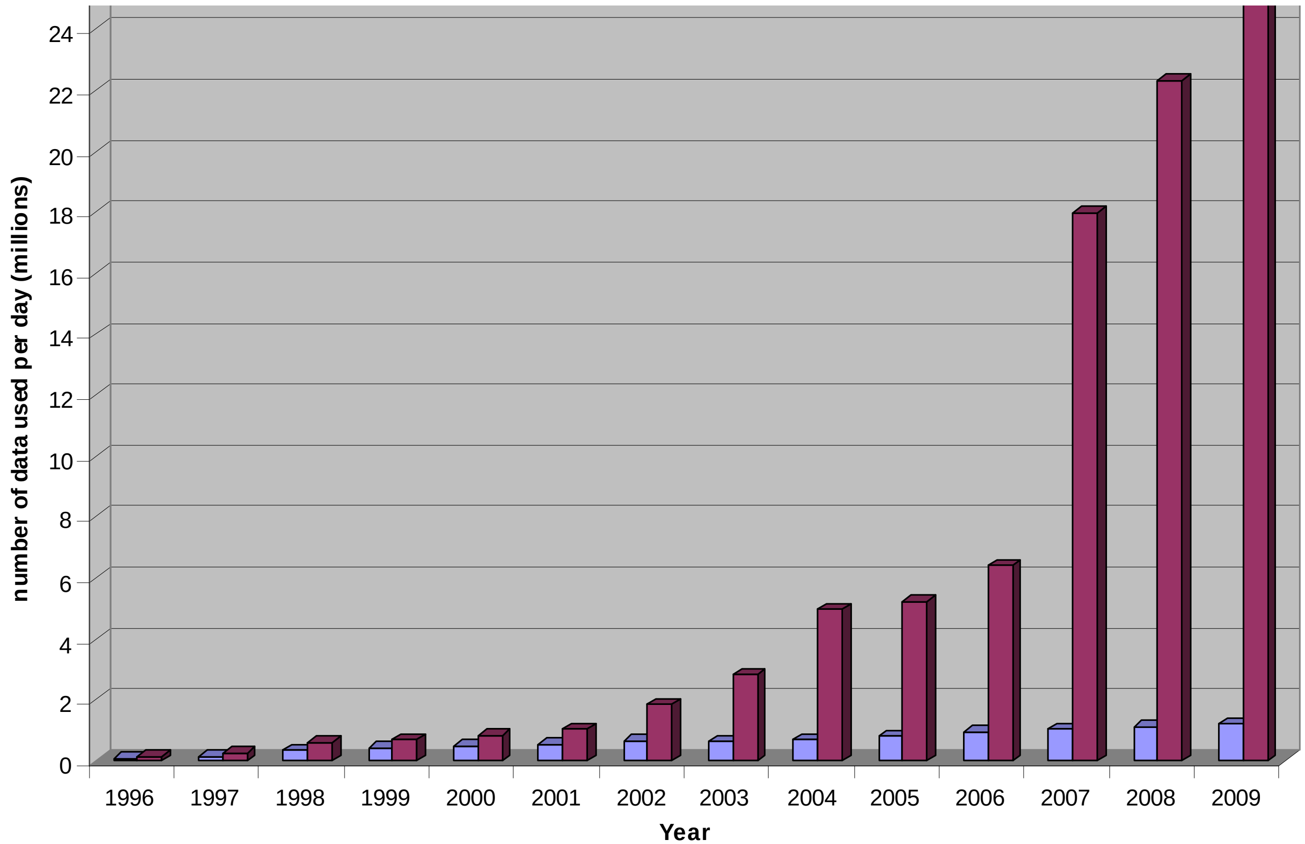
How important is satellite data for NWP ?

Evolution in the number of instruments used



Mid 2007 we use 41 different satellite data sources, and by 2009 we should use more than 50

Large increase in number of data used



Mid 2007: Satellite data volumes used: around 18 millions per day today, and probably around 25 millions by 2009

Conventional + Satellite Winds
Total

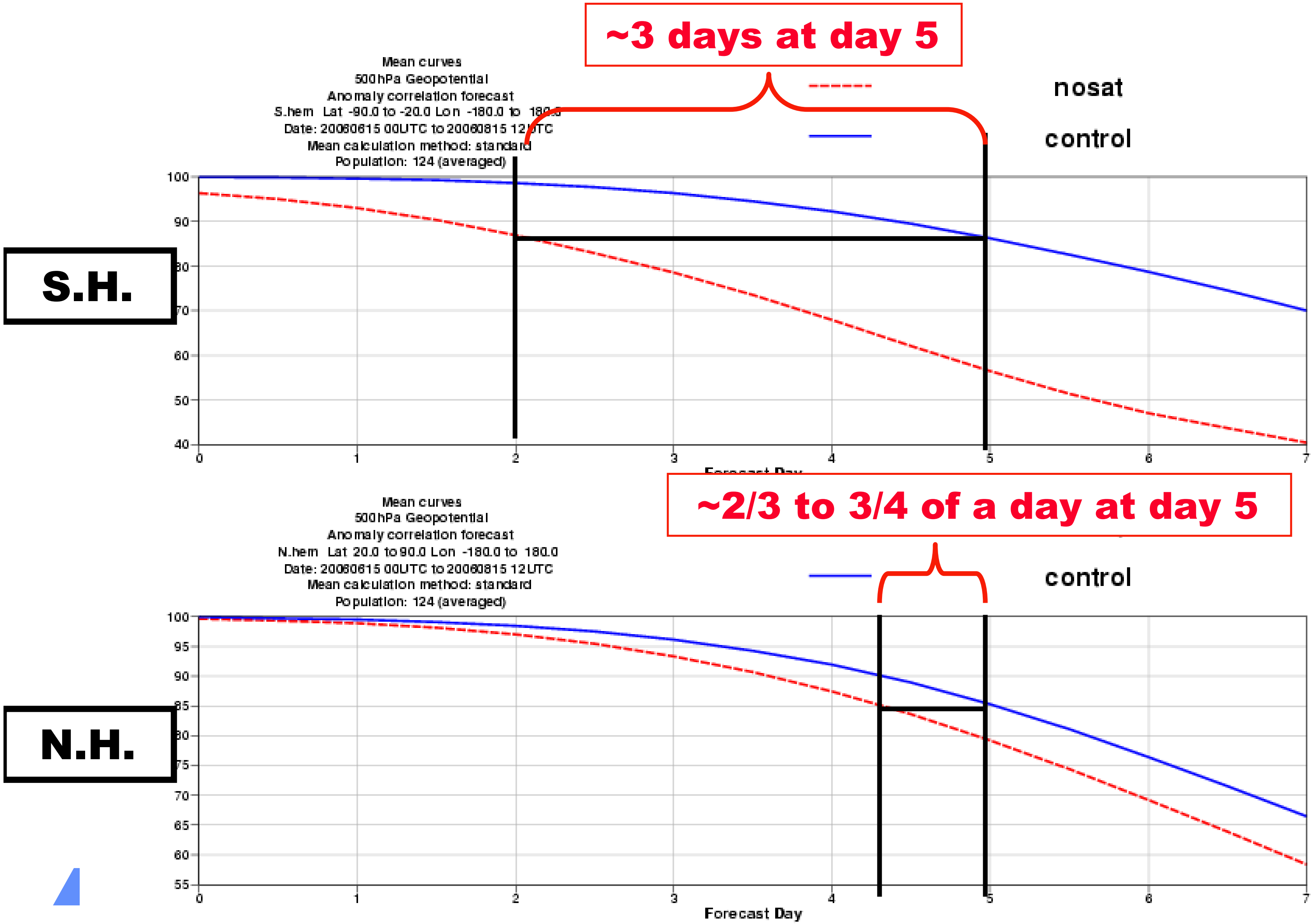
Forecast Impact studies

...what if we did not have satellites ...?

- **Observing System Experiments (OSEs) are a very useful sanity check for both the data assimilation and the observing system**

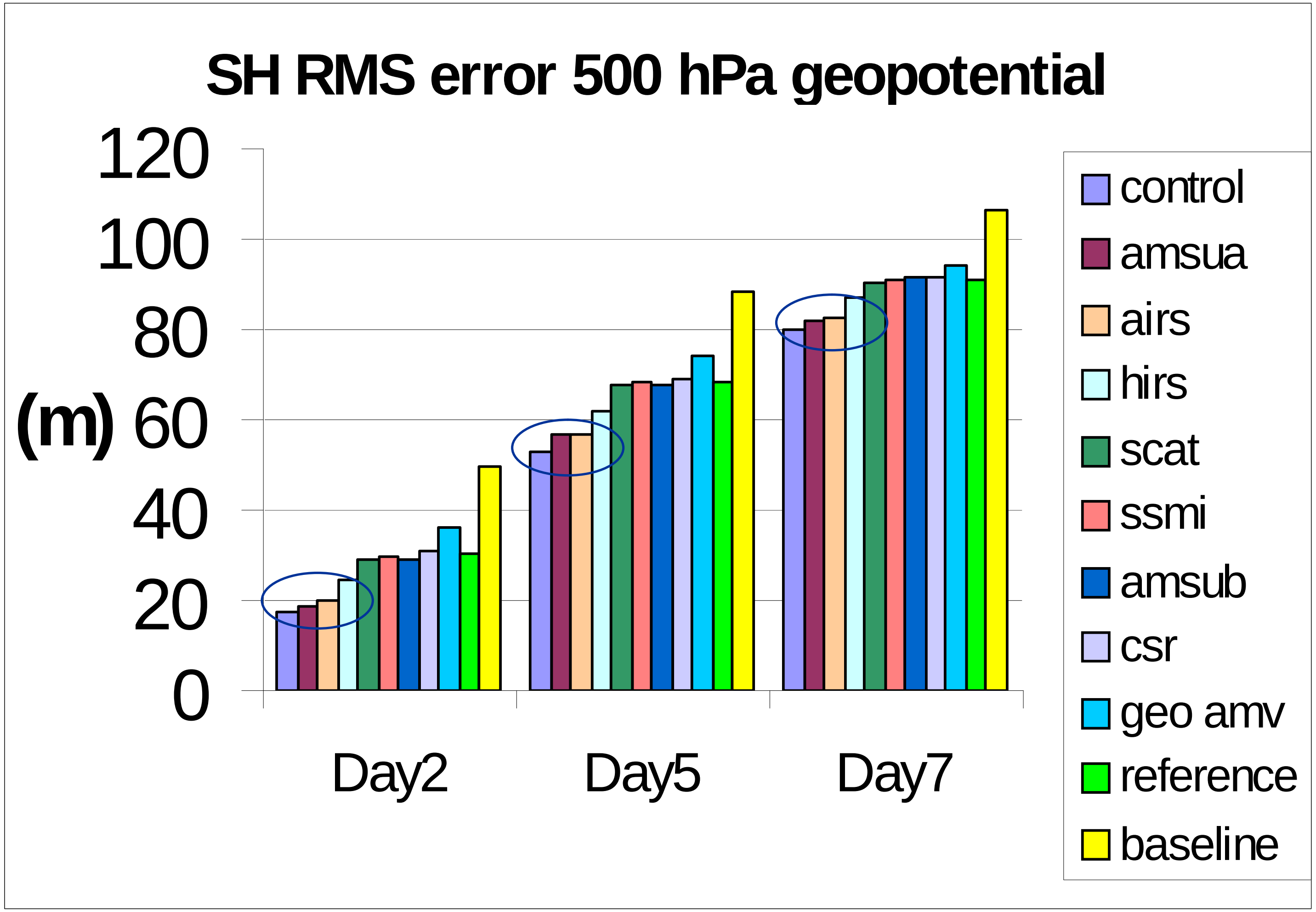
- **A 120 case OSE has been undertaken at ECMWF (Kelly, 2003) to evaluate the quality of the different major Observing Systems**

What happens if we lose all satellites?



Instruments have been ranked:
Geopotential 500 hPa Southern Hemisphere

- **Control:**
  all
- **Baseline:**
  conv only
- **Reference:**
  baseline +
  all AMVs
- **Geo AMV:**
  reference –
  Modis AMVs
- **Others:**
  reference +
  instrument



What are the current problems / issues for using satellite data ?

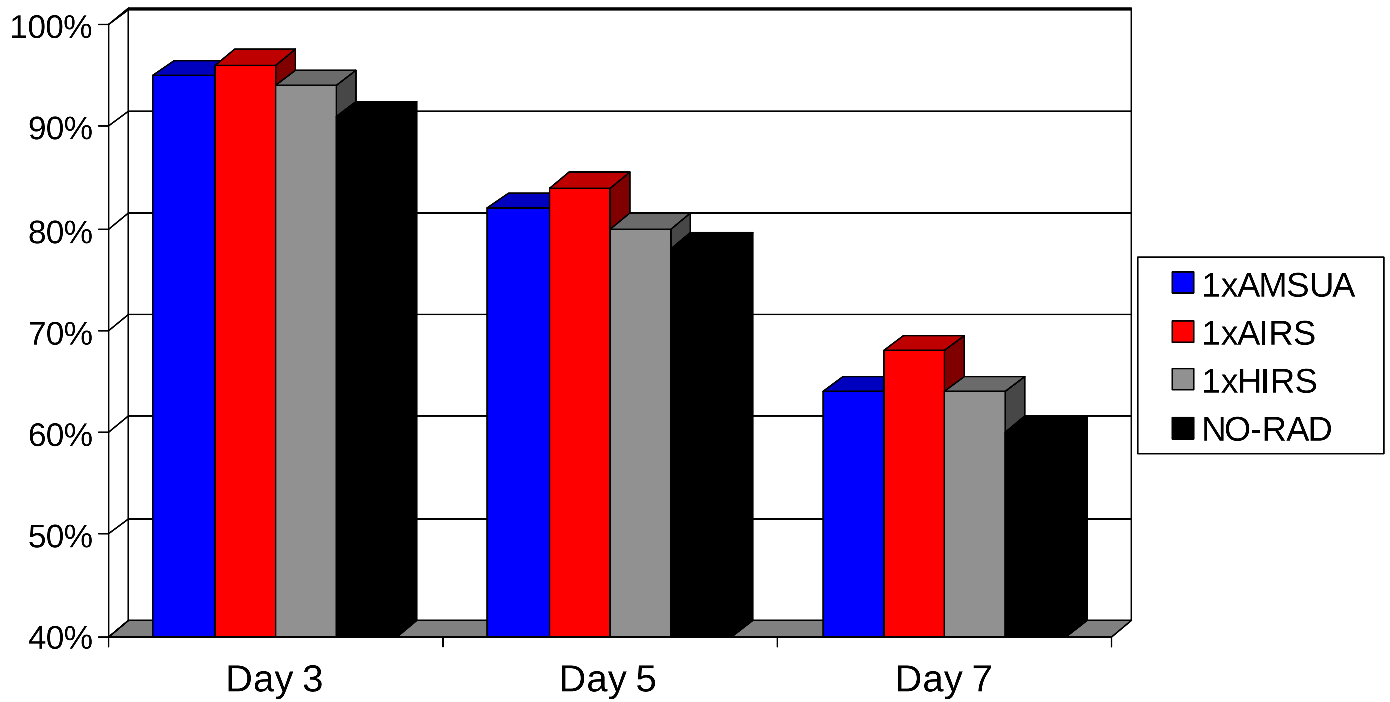
Important issues for the assimilation of satellite radiances

- **Bias removal**
- **Observation error understanding**
- **Background error understanding**
- **Quality control / screening**
- **Data selection / volume reduction**

Future challenges ….

Future space program planning …what are the most useful satellite instruments ?

Anomaly correlation of 500hPa height for the **Southern Hemisphere**
(average of 50 cases summer and winter 2003 verified with OPS analyses)



Use of cloudy / rainy radiances

- **Assimilation of clouds and precipitation**
  - **Currently, the assimilation of satellite information concerns only 20% of the globe**
  - **The ability of atmospheric models to describe cloud and precipitation is continuously improving**
  - **A number of space missions are already up and major others will come (GPM)**
  - **Issues:**
    - **Representativeness errors**
    - **Predictability of the cloudy/rainy systems**
    - **Radiative transfer and background error modelling**

Concluding remarks …

- Satellite data have been very succesfully exploited by new data assimilation schemes (DA schemes are such that introducing additional well characterised satellite data improves the system)
- The combined availability of new accurate satellite observations and improvement of models will allow an improved extraction of information content from these new data (parallel upgrades of *B* and *Y)*
- The proliferation of new satellite instruments makes it hard for end-users to keep up (choices will have to be done)
- Massive investment in data handling and monitoring should be done (or pursued)
- Short-loop dialogue between users and space agencies is vital!