Meteorologisk institutt
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Observations in Numerical Weather Prediction

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Observations for assimilation in NWP

What we have learned so far:

- We need to be able to model or estimate the observation from the state vector (observation operator), $H(\mathbf{x})$
- We need to specify an observation error covariance matrix $\mathbf{R}=\langle\boldsymbol{\varepsilon}_o\boldsymbol{\varepsilon}_o^T\rangle$ (usually assumed diagonal)

What we will get back to:

- Quality control (some observations have ”gross errors”, when something has ”gone wrong”)
- Some considerations on impact of wind observations vs ”mass field” (pressure, temperature) observations

What are the observations actually used in NWP assimilation?

(Observation techniques could have been a course in itself)

The observing system

- Conventional observations
  - Surface
  - Profile – radiosonde and aircraft
  - WMO – coordinates observation routines and data exchange globally, EUCOS in Europe
- Remote sensing observations
  - Satellite
  - Agencies: EUMETSAT, ESA, NOAA/NASA
  - Ground based radars, “wind profilers”

- ECMWF model now: 30 mill. obs. available for assimilation per day. (State vector dimension ~10^8)

Conventional observation types used in data assimilation

Surface

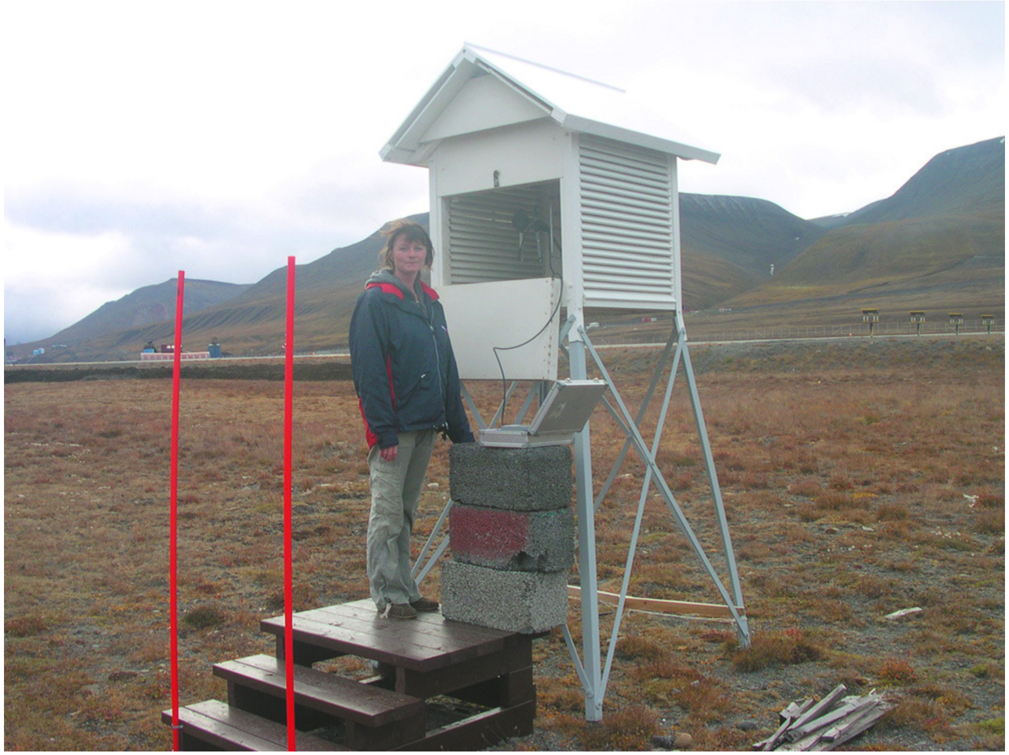
- Synop (manual and automated) and ship (over land mainly pressure is assimilated)
- Buoys on ocean

Profile and upper air

- Radiosondes (TEMPs and PILOTs)
- Aircraft (AIREP and AMDAR)

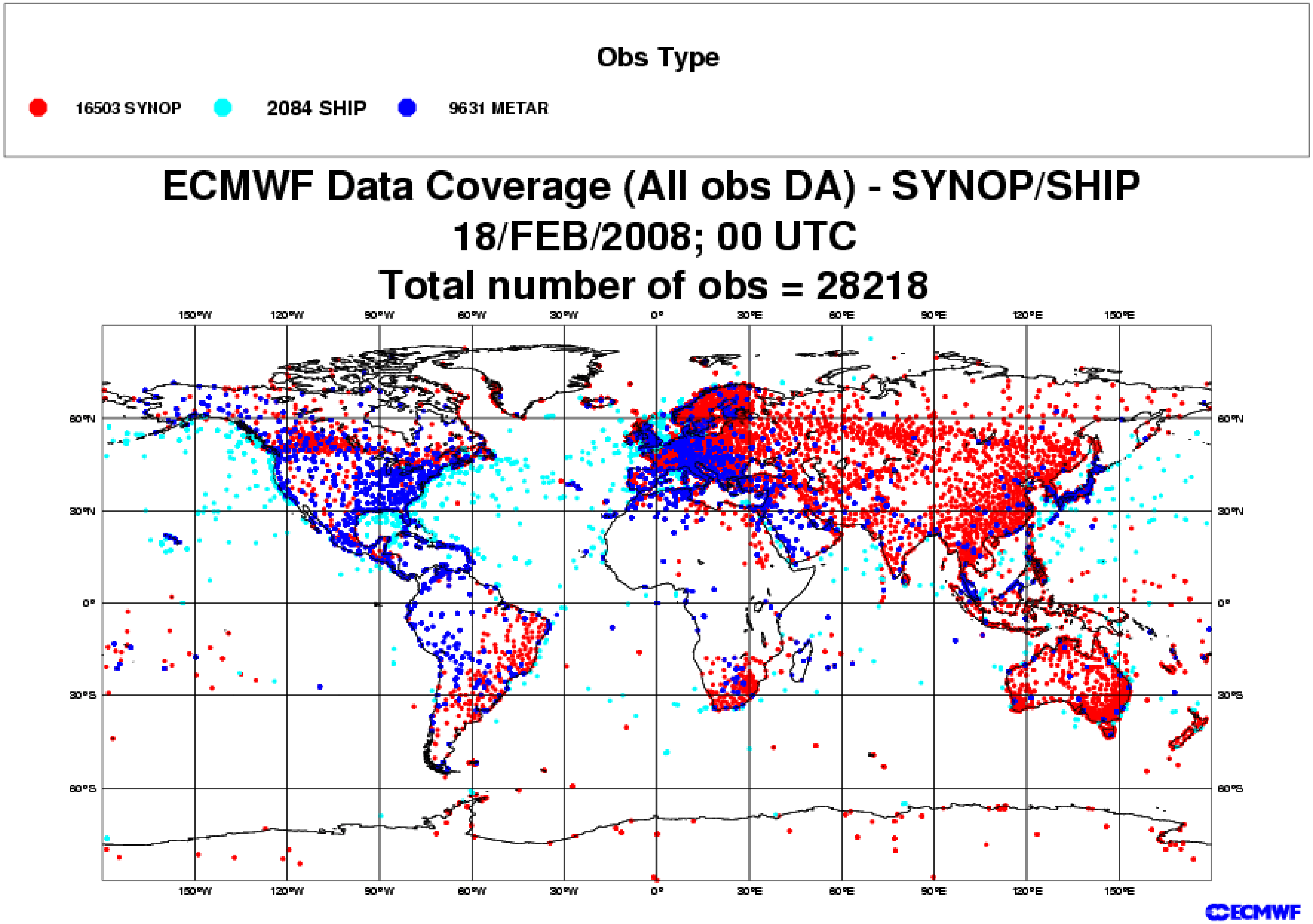
Not all observation types are easy or even possible to assimilate in NWP (like clouds, visibility, …)

Conventional observations: surface

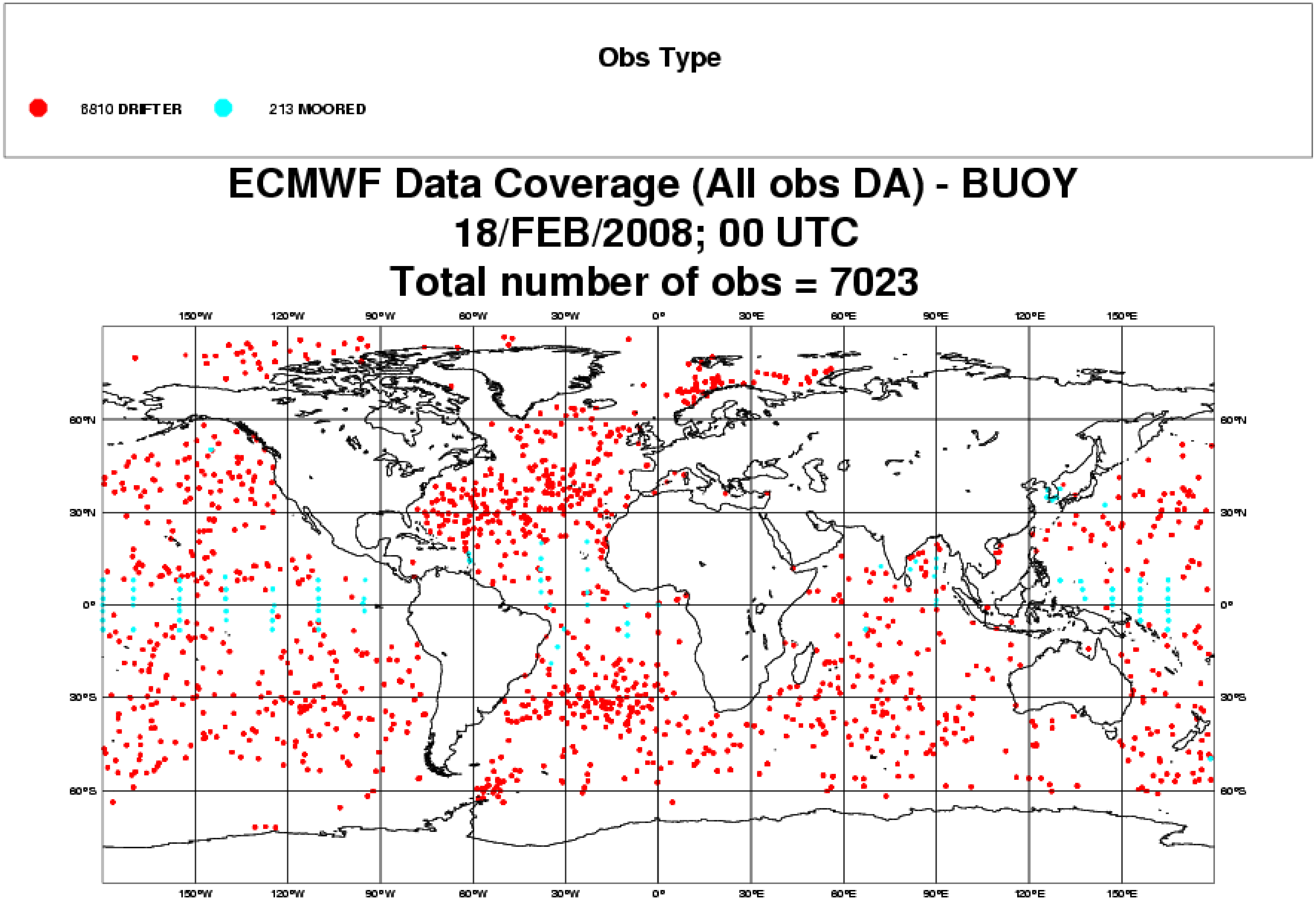


Example: Weather station Longyearbyen

SYNOP and ship
(example termin: 18 feb 2008 00 utc)



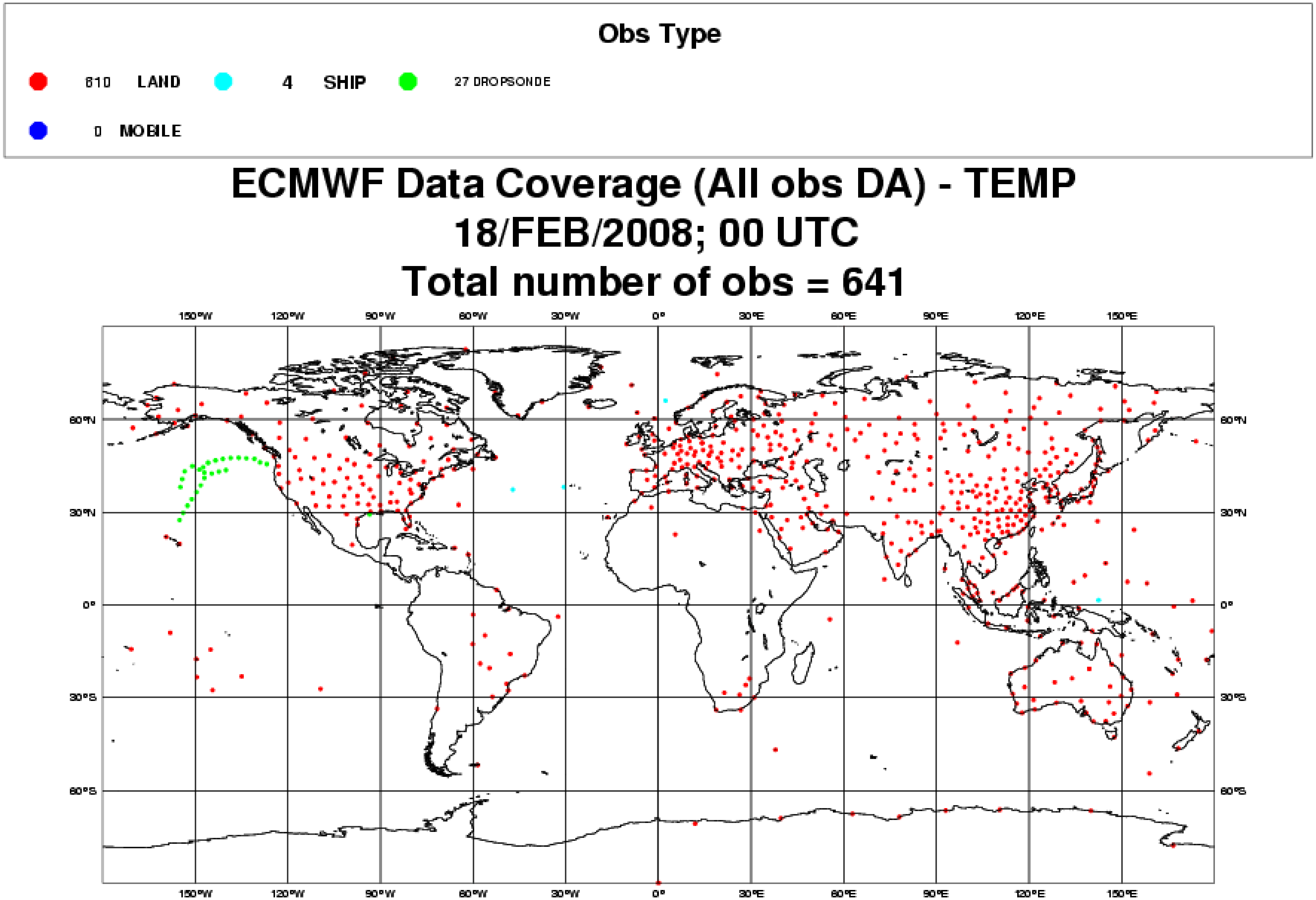
Buoys


Obs Type
6810 DRIFTER
213 MOORED
ECMWF Data Coverage (All obs DA) - BUOY
18/FEB/2008; 00 UTC
Total number of obs = 7023
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
60°N
30°N
0°
30°S
60°S

Conventional observations: Radiosonde

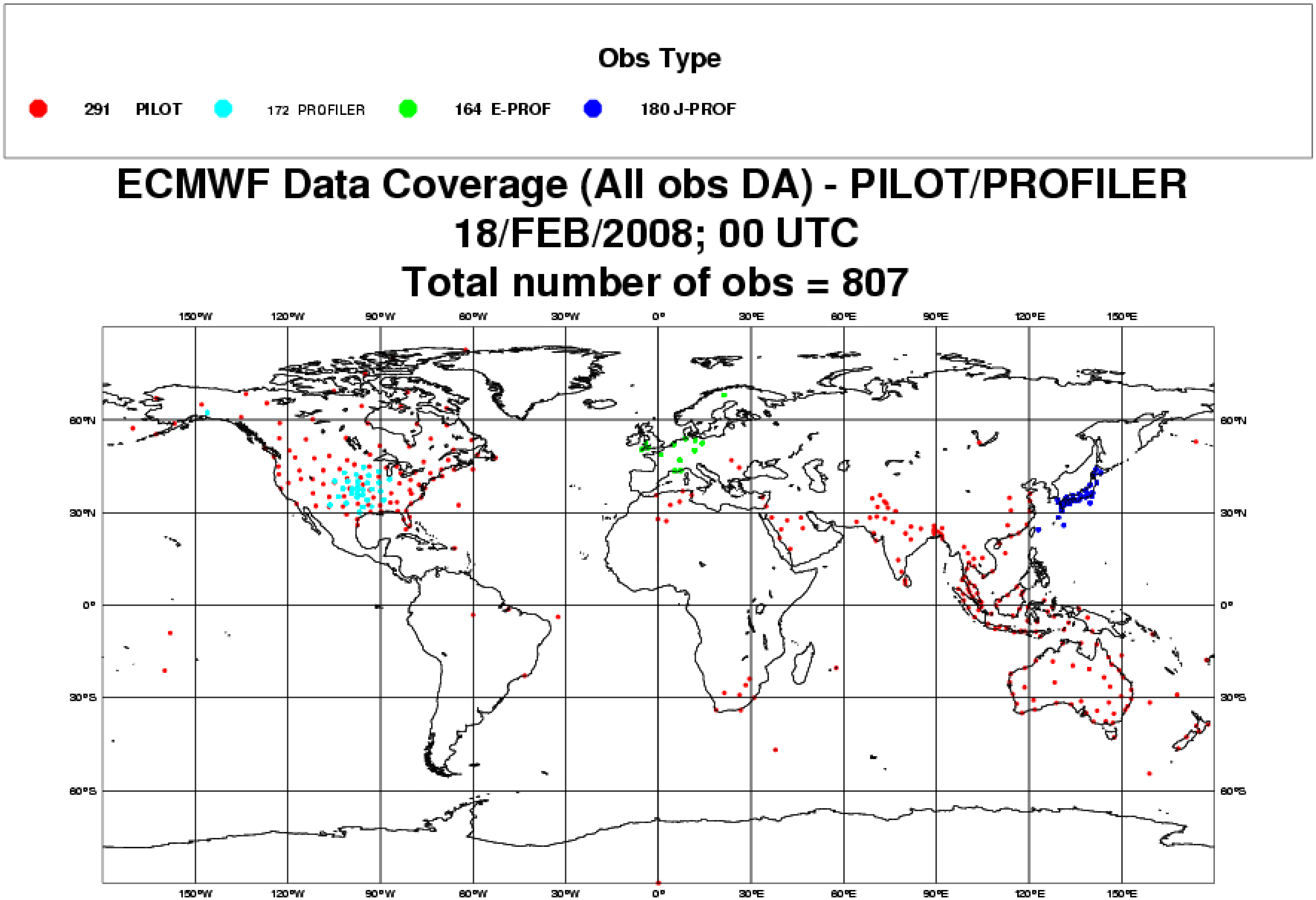
Bodø: automatic radiosonde

Radiosondes (TEMP)

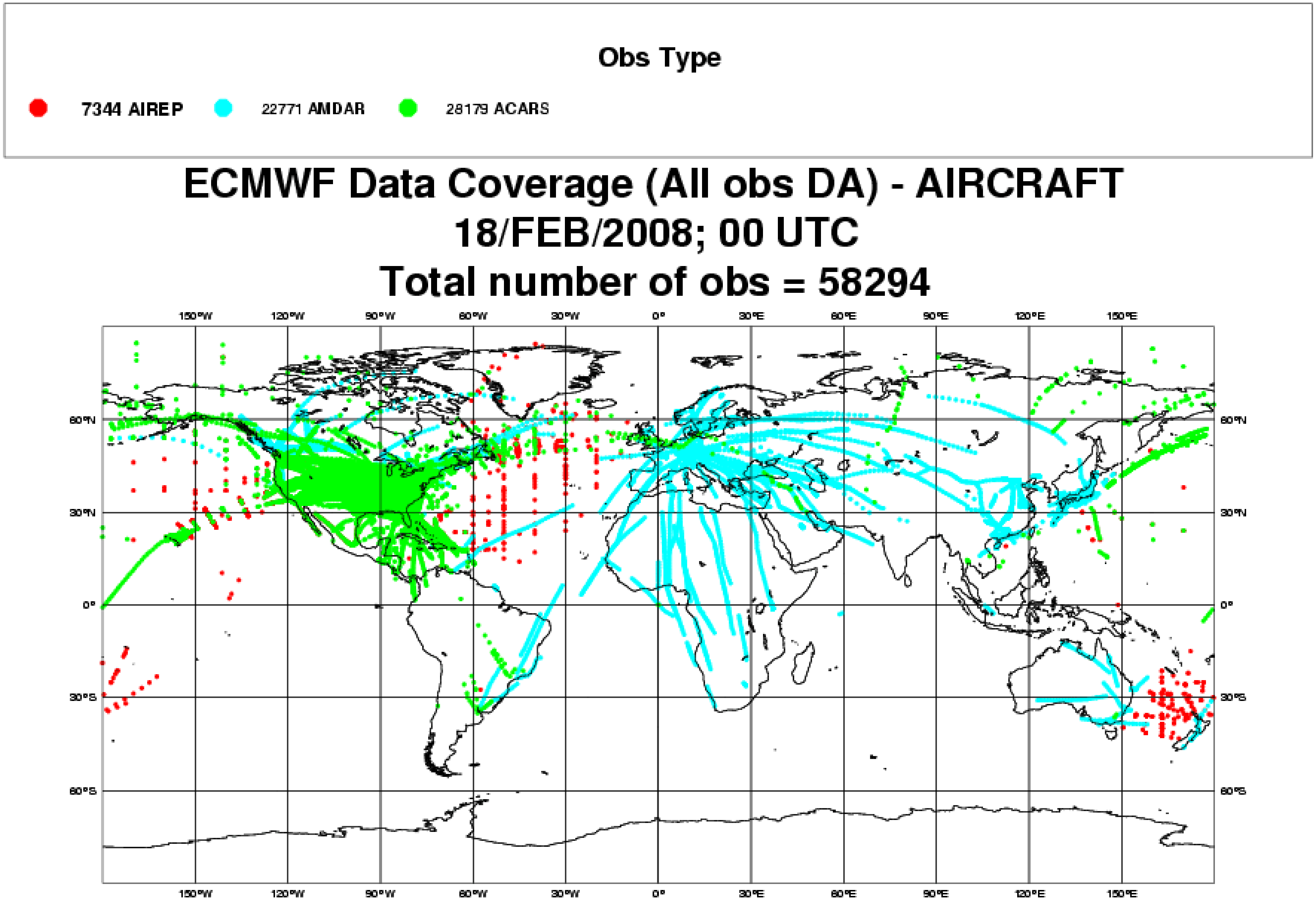


ECMWF t.no

PILOT /”Wind profiler”



Aircraft observations

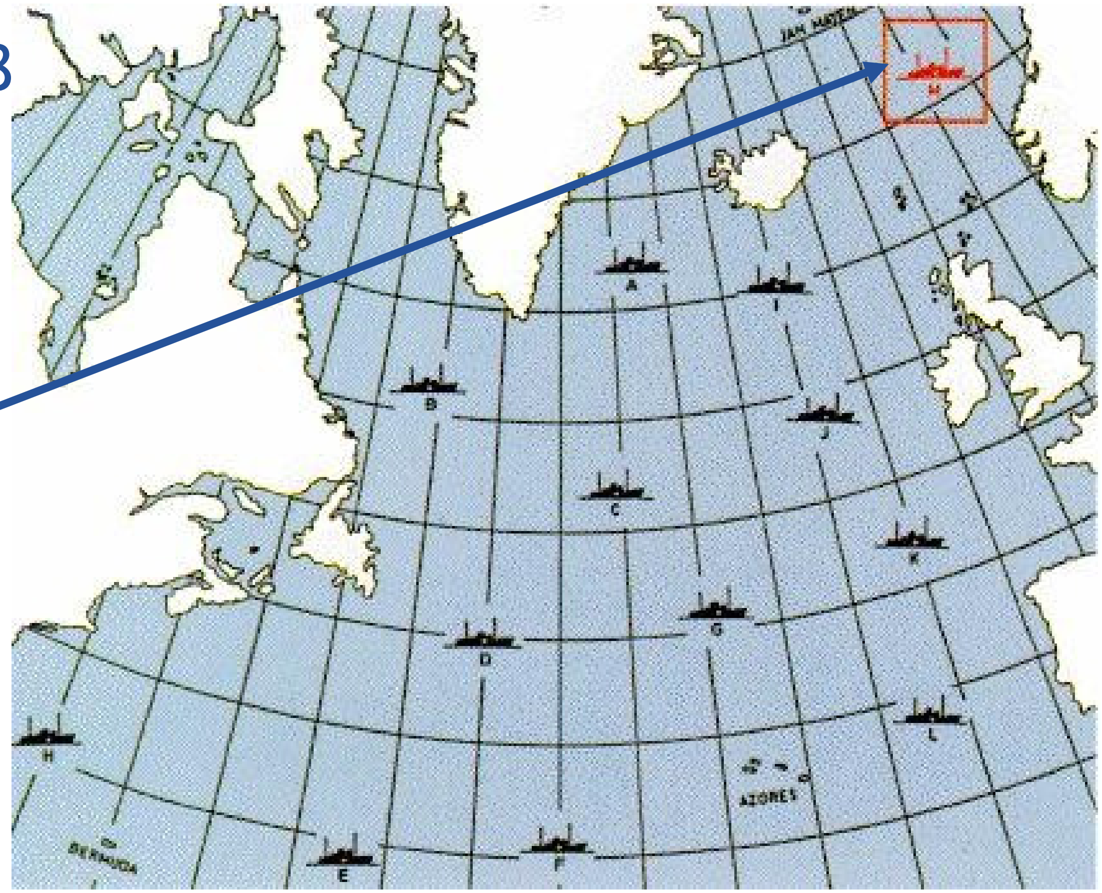


ECMWF

Dramatical change in the observing system since ca 50 years ago – more satellite data, but we have also lost something

Weather ships 1948

Last ship ended 2009



Increase in assimilated satellitte data (number of sensors) at ECMWF

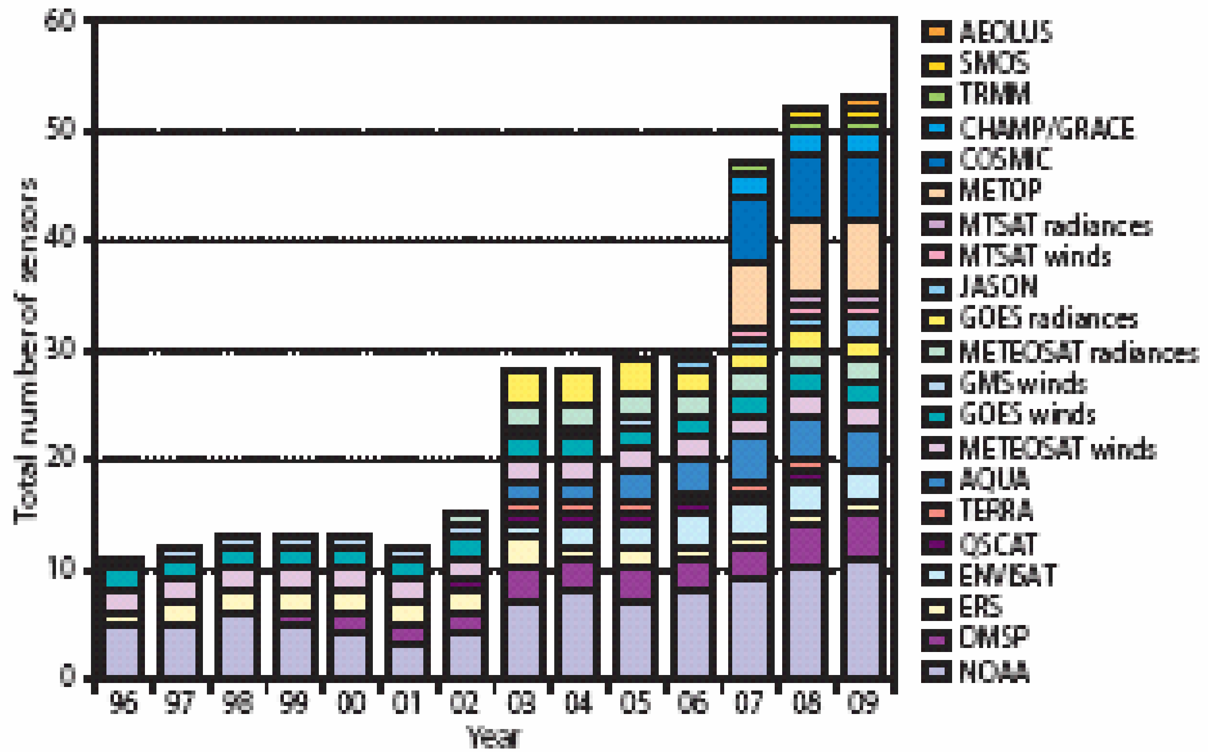


Figure 1 Number of satellite sensors that are or will be soon assimilated in the ECMWF operational data assimilation.

Satellite observations – divided into several groups

Passive (Top of Atmosphere radiances emitted from a surface-atmosphere column):

- Microwave
  - Profiling instruments: AMSU
  - Imaging instruments: SSM/I
- Infrared
  - Profiling instruments: HIRS, AIRS, IASI, CrIS
  - Imaging instruments: AVHRR, MODIS,
    - Atmospheric Motion Vectors

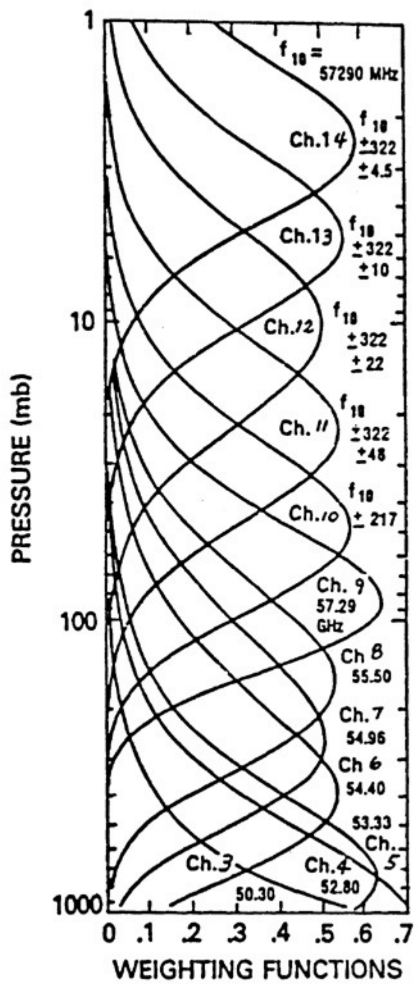
Active (RADAR, LIDAR, radio-signals):

- Scatterometer (ocean surface winds from radar)
- GPS (ground based from geodetic stations, radio occultation)

Passive sounding: Atmosphere's absorptivity varies with electromagnetic frequency

- Absorption and emission by well mixed gases with known concentration: Obs. operator depends on temperature profile (temperature is corrected in assimilation)
- Absorption and emission in water vapor bands: Obs. operator depends on both water vapor and temperature profile (water vapor profile is also corrected in assimilation)
- Window channels: Little absorption and emission in atmosphere, ”sees” surface (or cloud)
- IR is much affected by cloud, microwave is little affected by clouds

Satellite observations: AMSU-A “Advanced Microwave Sounding Unit”



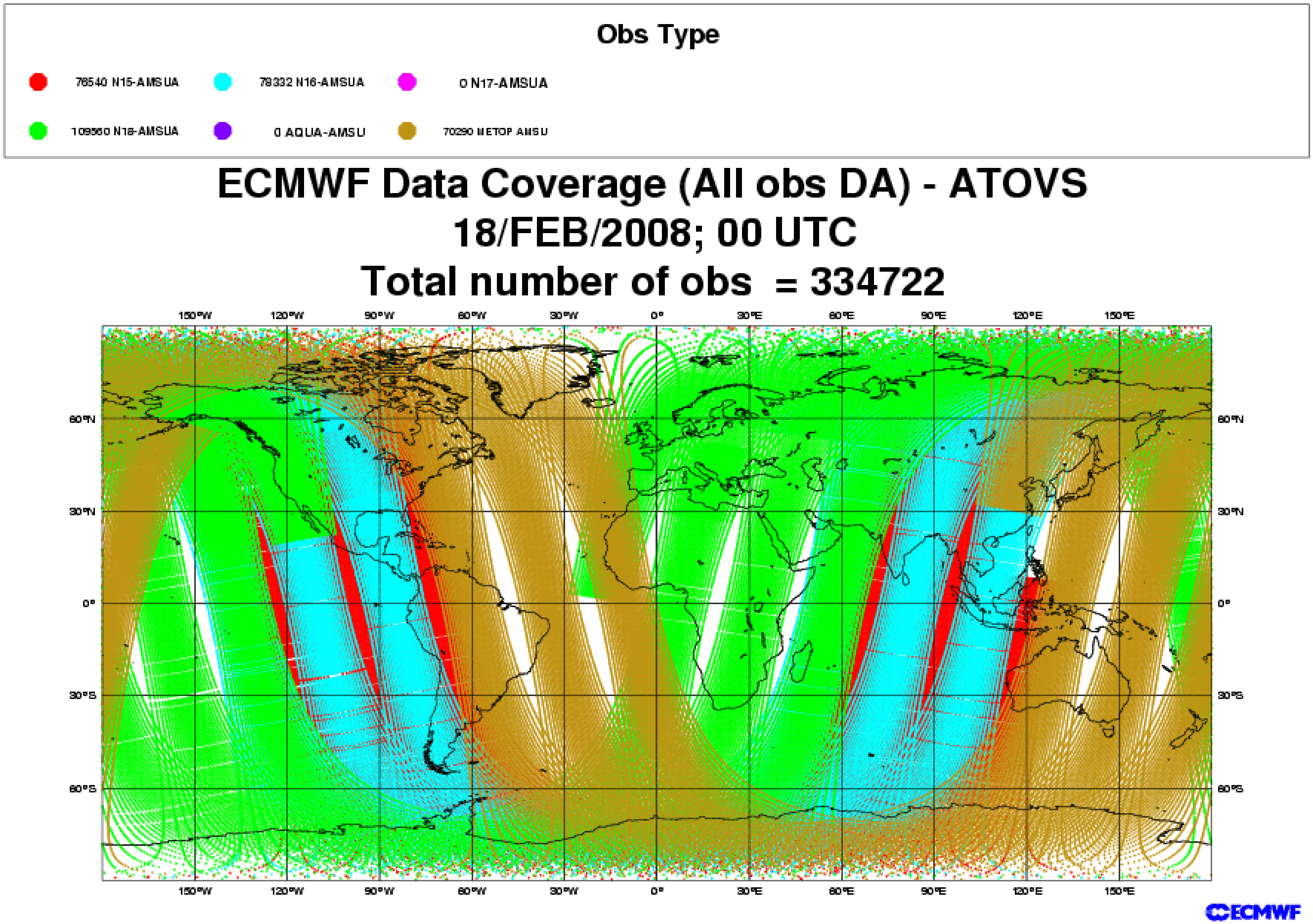
Temperature sounding channels

- Measures electromagnetic radiation emitted from the atmosphere at various frequencies, which is a function of temperature of emitting layers
- The less transparent the atmosphere is for the particular frequency, the higher up in the atmosphere will the radiation originate
- AMSU-A measures in the microwave part of the spectrum
- Weigthing functions (left) show which height ranges each AMSU-A channel sense

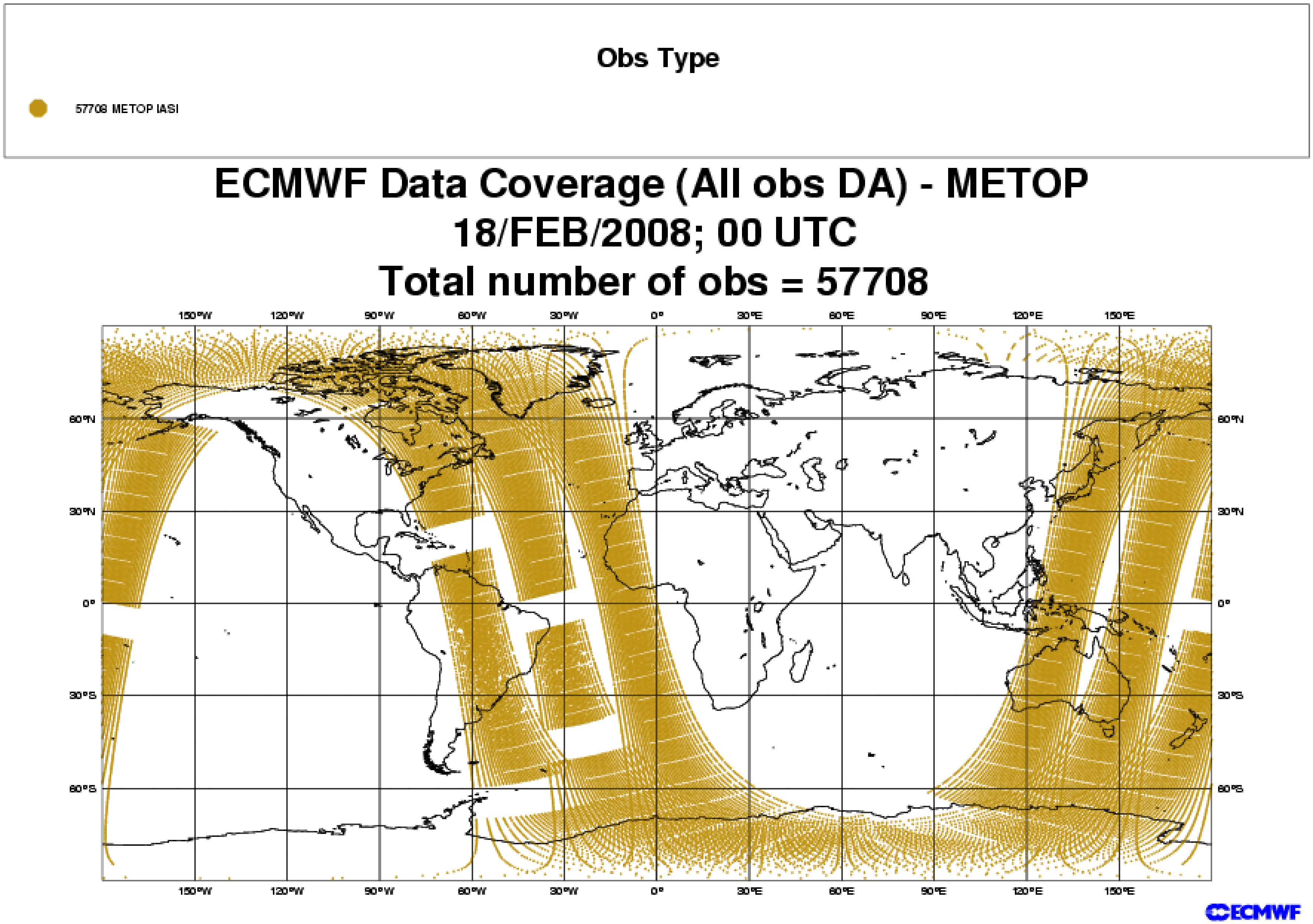
Other sensors using similar principles

- HIRS (High Resolution Infrared Sounder)
- IASI (Infrared Atmospheric Sounding Interferometer)
- AIRS (Atmospheric Infrared Sounder)

“Advanced Microwave Sounding Unit” (AMSU-A)

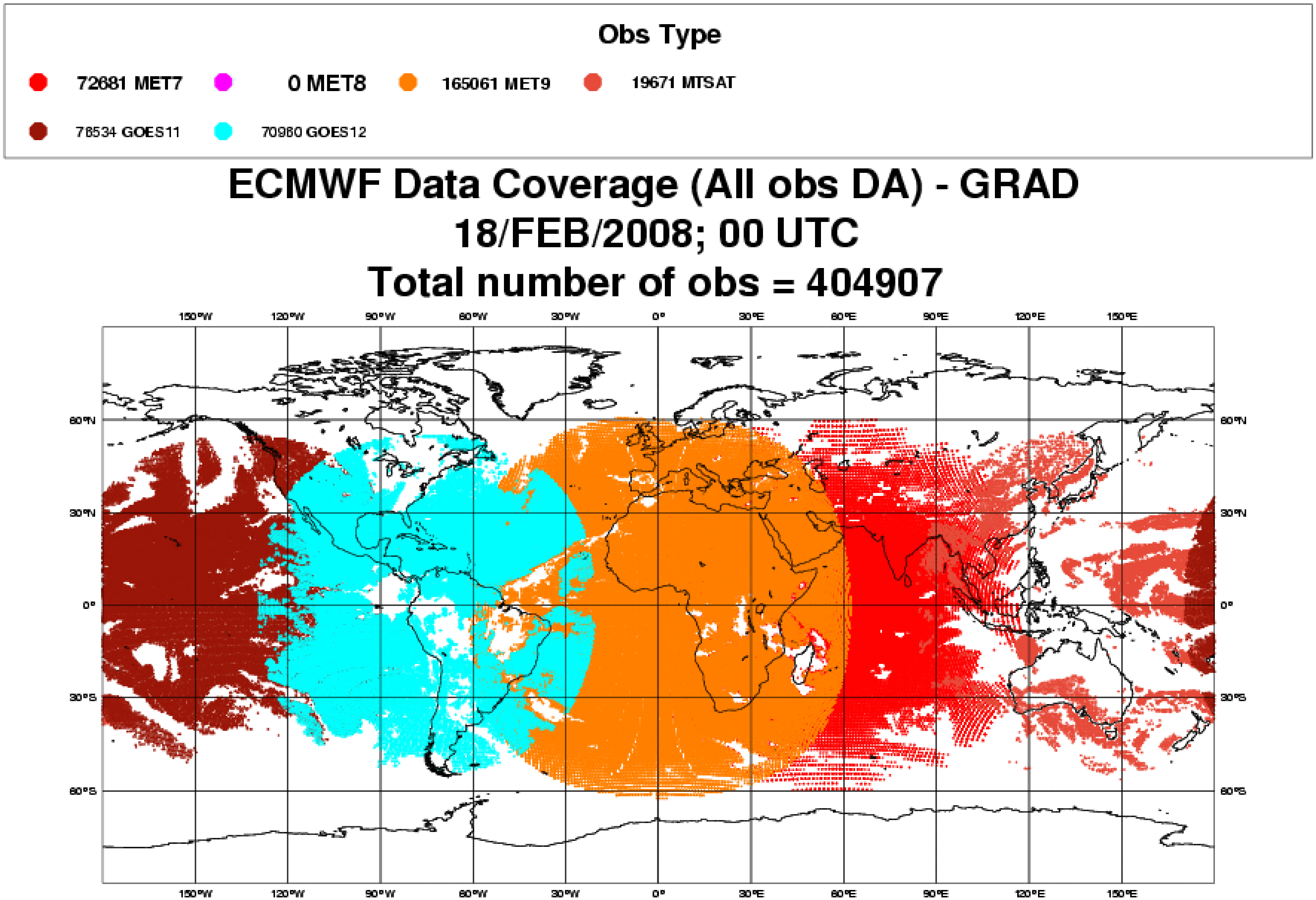


IASI

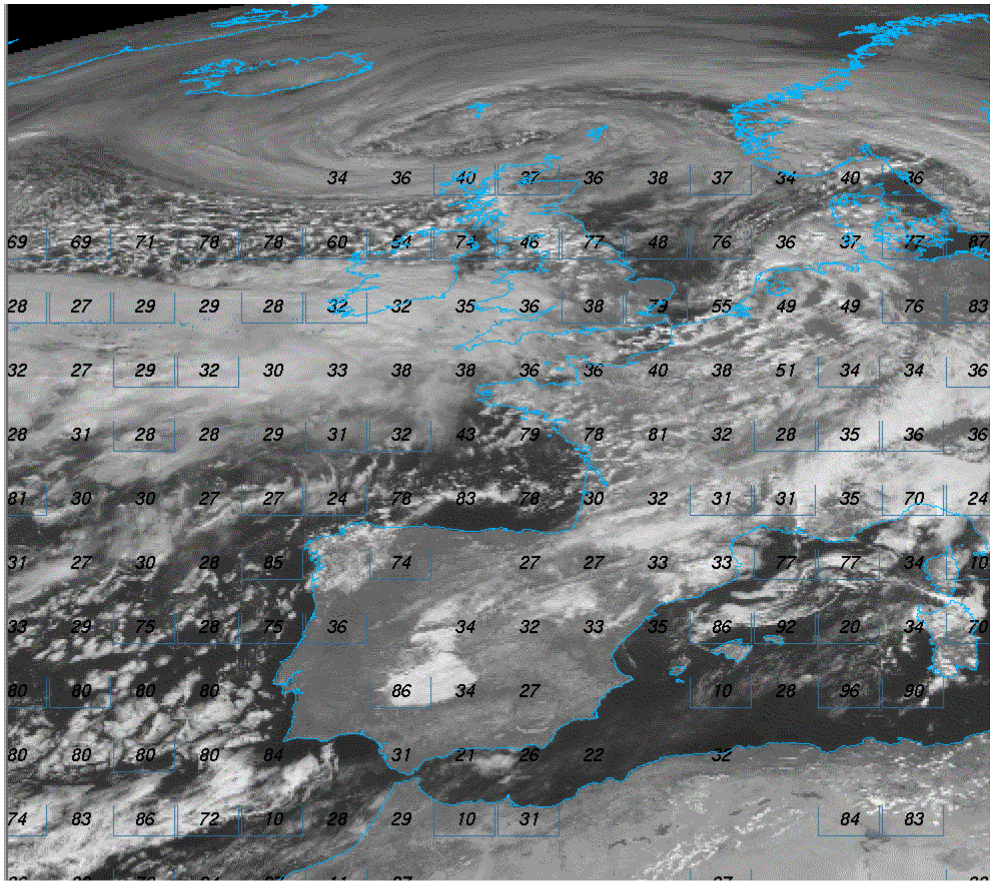


Obs Type
57708 METOP IASI
ECMWF Data Coverage (All obs DA) - METOP
18/FEB/2008; 00 UTC
Total number of obs = 57708
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
60°N
30°N
0°
30°S
60°S
ECMWF

Geostationary radiances (IR)

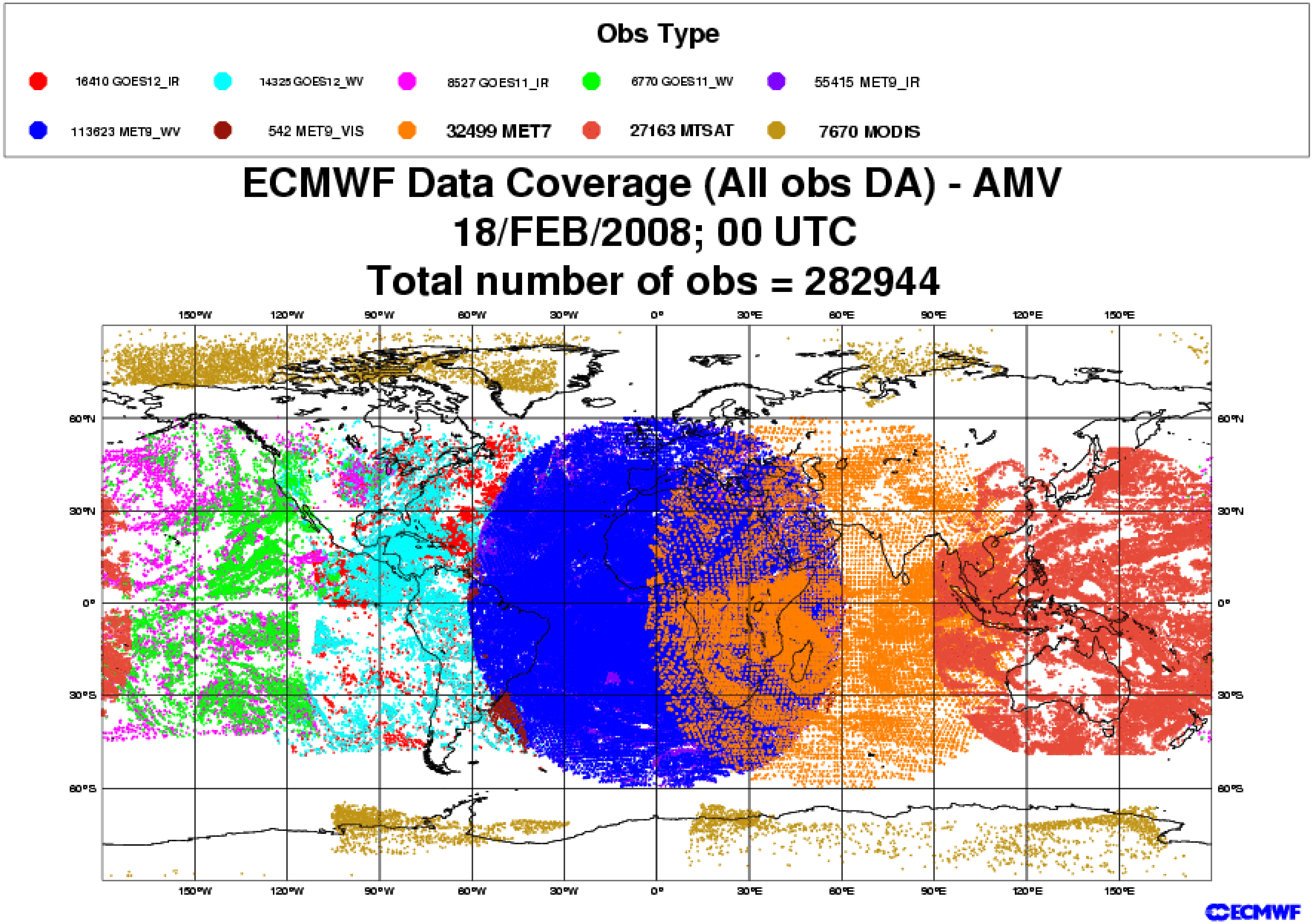


Atmospheric motion vectors

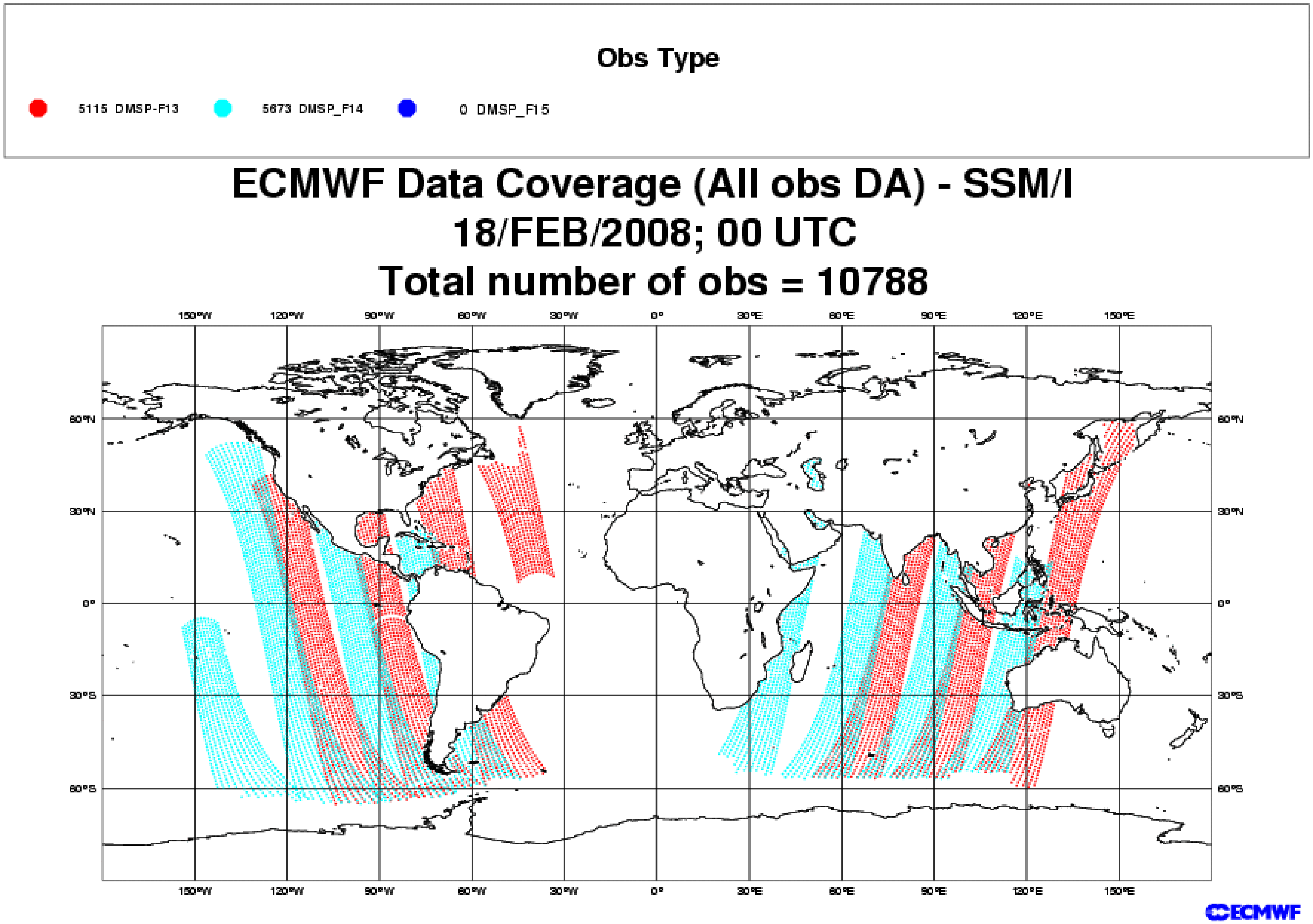


- Some satellites give timeseries of images:
  Geostationary or polar orbiting with frequent revisits
- Clouds or water vapor features can be tracked with automatic algorithms to derive displacement from one image to the next
- Height assignment problem

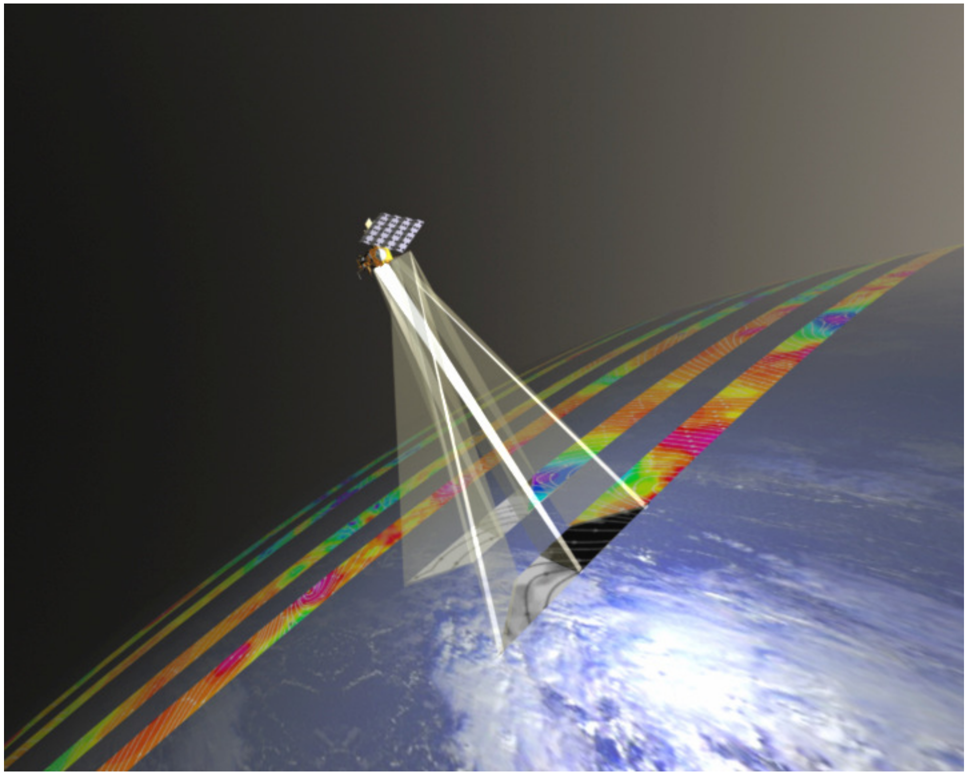
“Atmospheric Motion Vectors”



“Special Sensor Microwave Imager” (ocean surface windspeed and vertically integrated water vapour)

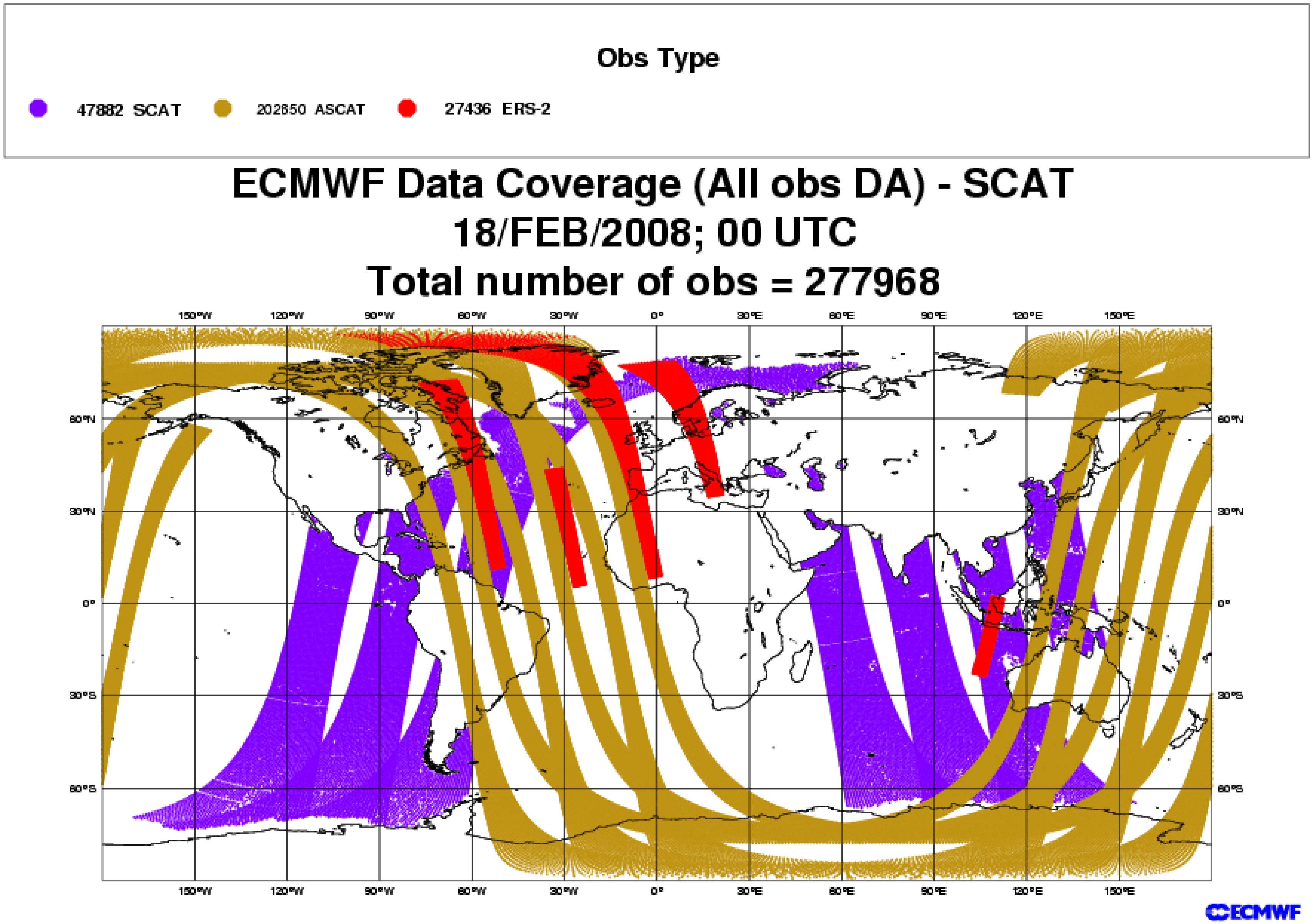


Remote sensing: Scatterometers



- Sense ocean surface wind vector
- Radar return dependent on ocean surface roughness
- 2 different satellites (sensors):
  Oceansat Scatt. and ASCAT (left)

Scatterometer (ocean surface wind from satellite)



Method for measuring the impact of the observing system components

- OSEs (“Observing System Experiments”)
  - Take the full observing system as a reference and remove a set of observations. Measure the reduction in forecast quality
  - Variant: Take a minimum, reduced observing system and add a set of observations. Measure the improvement in forecast quality
  - OSEs has a drawback: Can only assess the effect of already *existing* observations
    (cf OSSE – “Observing System Simulation Experiments”)

Example of some OSE's (ECMWF)

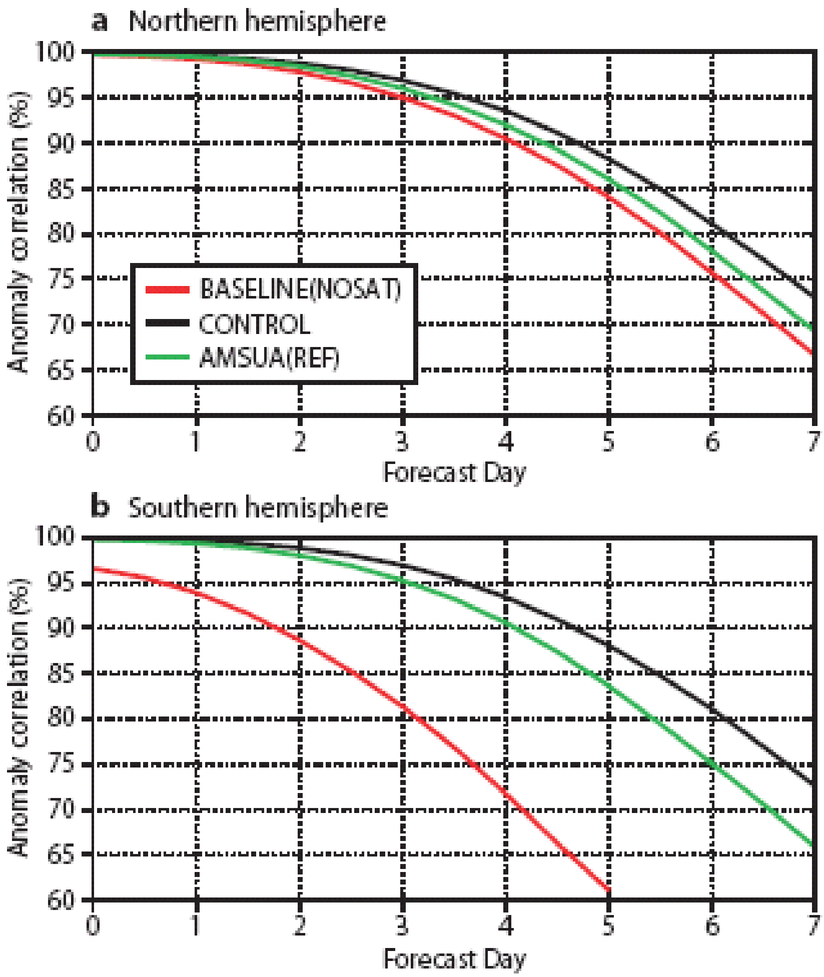


Figure 5 Comparison of *AMSUA(REF)* with *BASELINE (NOSAT)* and *CONTROL* for (a) northern hemisphere (20°–90°N) and (b) southern hemisphere (20°–90°S).

"Baseline": All conventional observations

"AMSU-A": "Baseline" with added AMSU-A

"Control": All conventional and all satellitte

Some conclusions from OSE's performed:

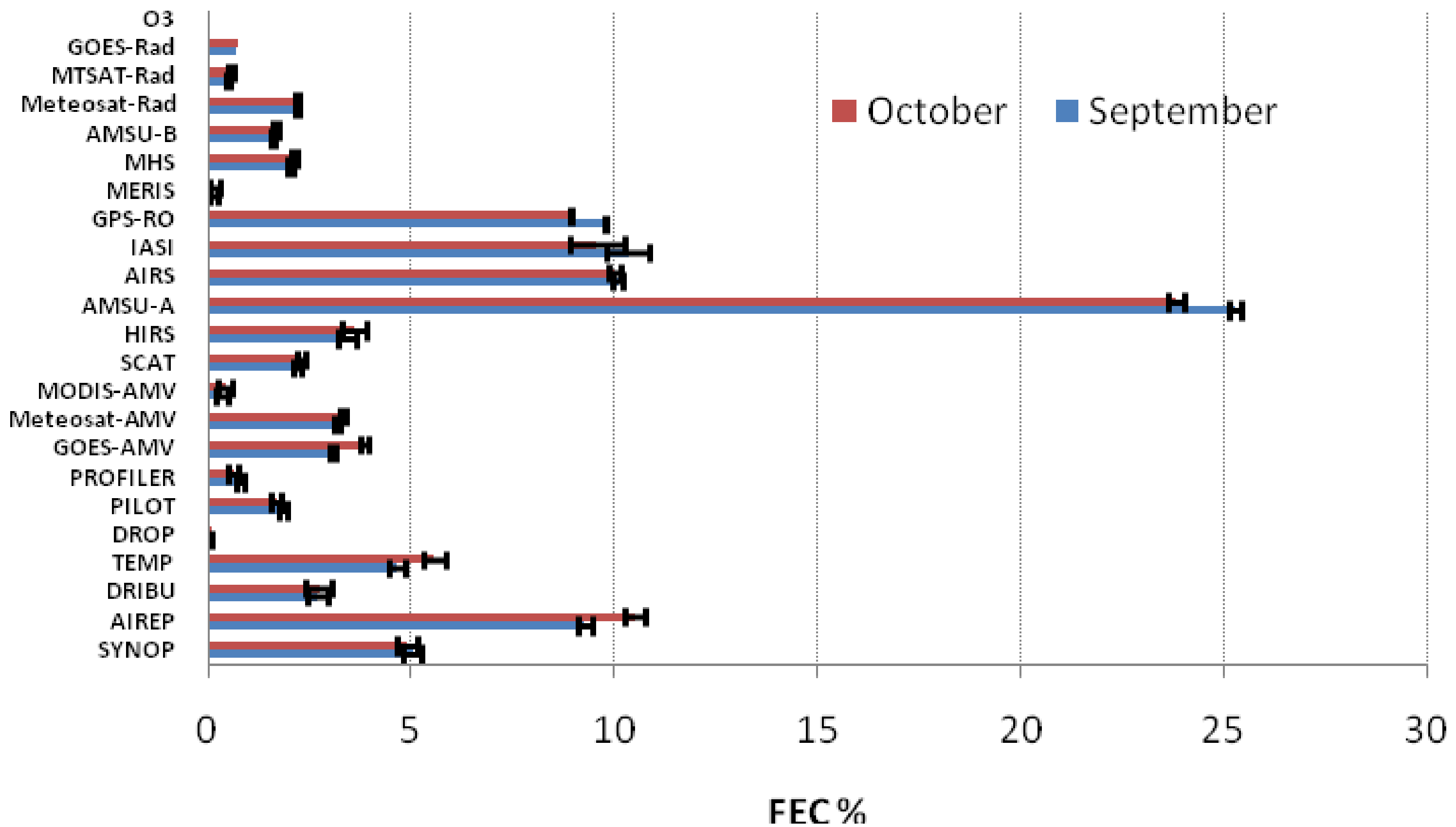
- Surface information insufficient, profile information needed
- Radiosondes still a key factor for forecast quality for the met.no HIRLAM forecasts (even if some satellite observations are being used)
- Aircraft observations supplement radiosondes and give a significant positive effect
- The total effect of satellite observations is now larger than total effect of conventional observations
- Redundance: Best effect of satellite data in areas of sparse coverage of conventional observations (for example Southern hemisphere, Arctic areas)

An ”information content” tool (C. Cardinali, ECMWF)

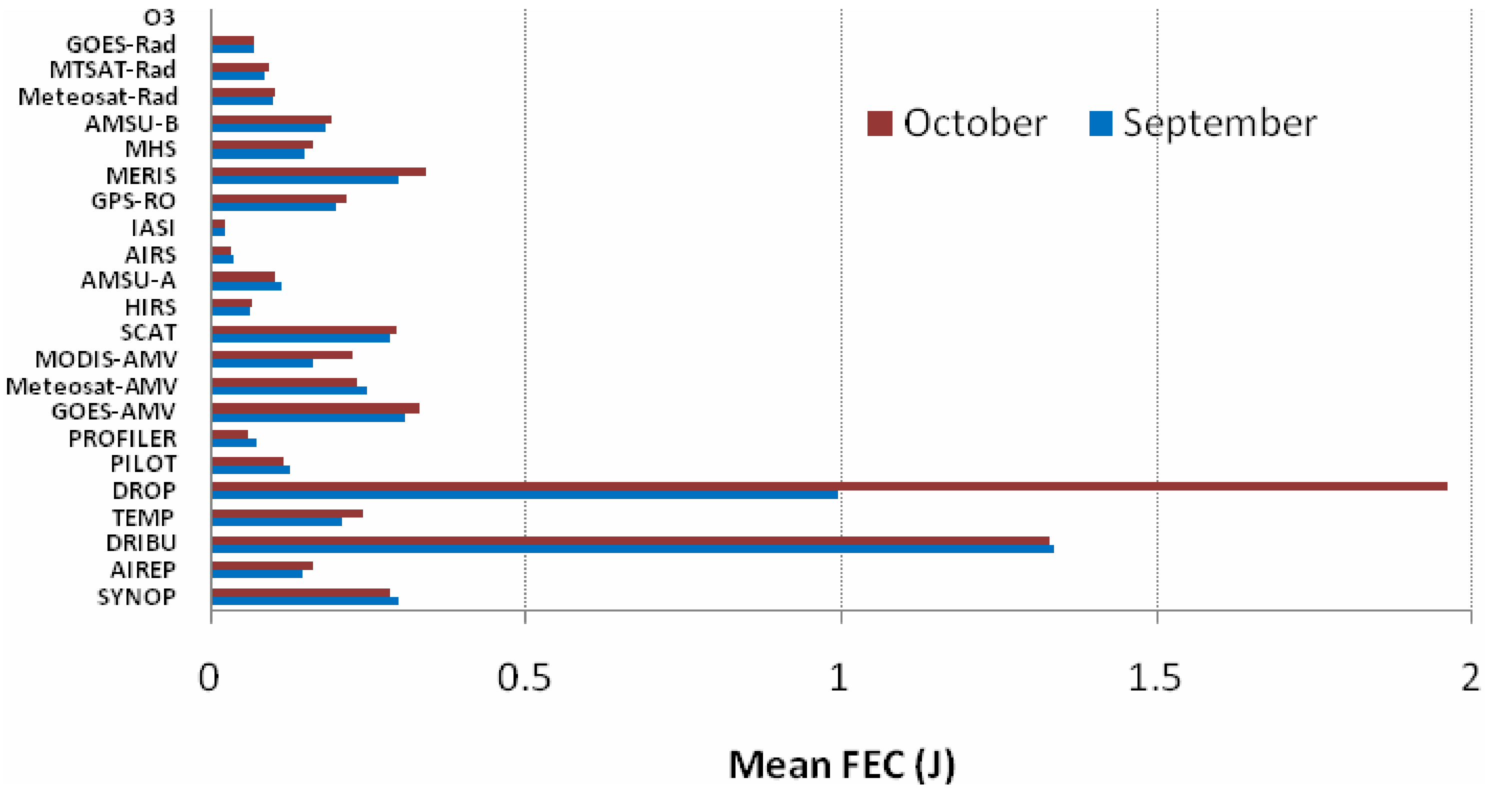
- Less accurate results than OSE’s, but easier to produce
- Assumes the B and R matrices are perfectly correct estimated (which is not possible in practise), uses adjoint sensitivity assuming linear model
- Measures forecast sensitivity to each observation in the analysis (theory and method not shown here)

- Can consider any grouping of observations or single ones

Recent data from ECMWF (C. Cardinali): Total impact (% contribution to forecast error reduction)

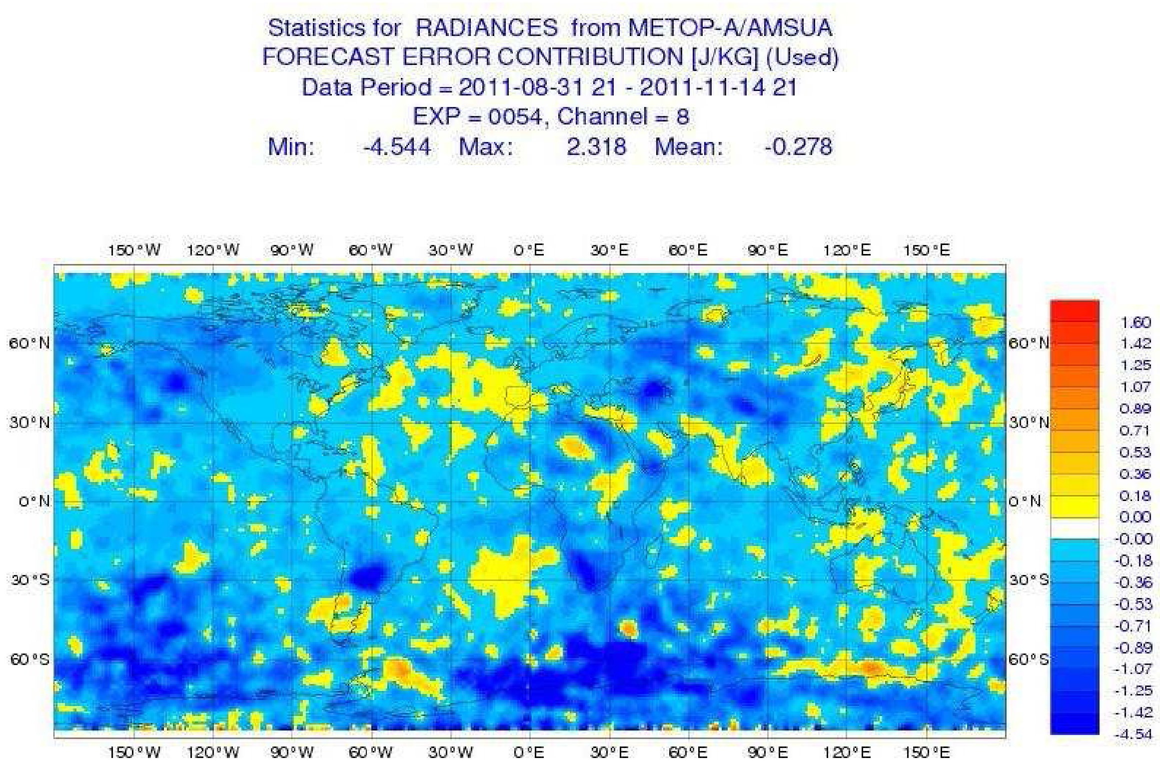


Data from ECMWF: Impact per observation



Example of spatial variability: Error reduction averaged over a 2 ½ month period, one satellite channel

Blue is positive effect, yellow negative (for AMSU-A channel 8)



Some remarks

- Large variations of ”impact” in space and time. But on average it tips to the positive side for each obs type
- For the ECMWF model satellite data gives much larger impact than conventional data in total
- But conventional observations give larger impact *per observation*