# The impact of observations in the latest ECMWF reanalysis system

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special thanks to Carla Cardinali for the interpretation of the DFS results

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European Commission

Copernicus
Europe's eyes on Earth

Implemented by ECMWF

# *Initial remarks*

**It is the first (and hopefully not the last) reanalysis talk in the history of the „WMO workshops on the impact of various observing systems on NWP"!**

**BUT: might be interesting, since it provides information about the evolution of the observing system from the NWP perspective → some of the results discussed earlier this week will be recalled/confirmed**

# Table of content

- Brief introduction to the ECMWF's Copernicus ERA5 reanalysis system (this is the new generation ECMWF reanalysis system succeeding ERA-Interim)

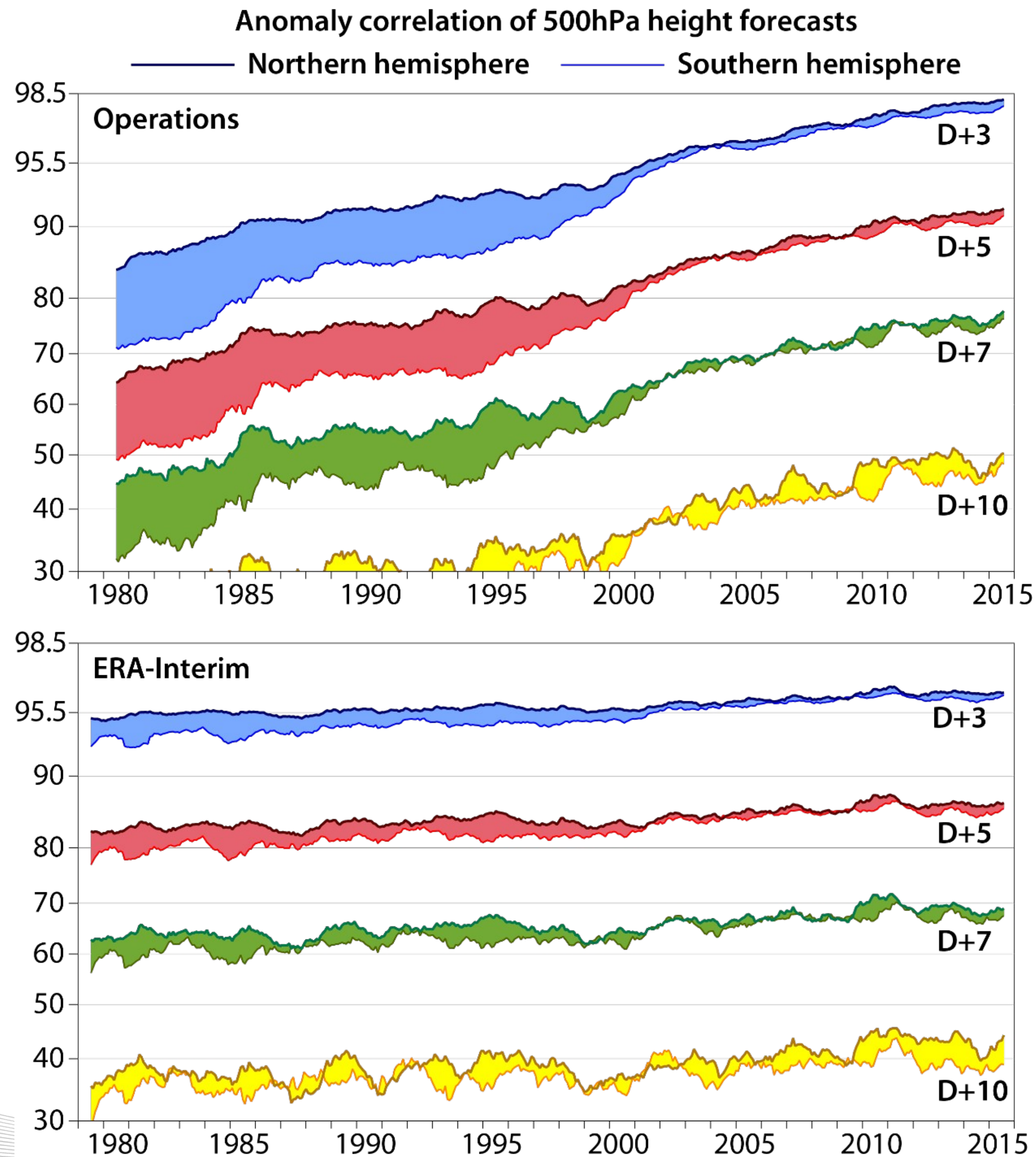
- Impact of observations in the early ERA5 reanalysis suites

# Reanalysis: consistency

**Consistent reconstruction of the atmosphere, waves (and ocean):**

- merge observations into ***global fields,***
- using the ***laws of physics***
- and appropriate ***bias correction*** scheme
- maintain the ***same up-to-date system*** over the entire reanalysis period.

At lower resolution to ***keep affordable***



# What is new in ERA5 as compared to ERA-Interim?

| | ERA-Interim | ERA5 |
|---|---|---|
| Period | 1979 – present | 1979 – present |
| Start of production | August 2006 | Jan 2016, 1979-NRT: end 2017 |
| Assimilation system | 2006 technology | Current state of the art (12h 4D-Var with EDA) |
| Model input (radiation and surface) | As in operations, (inconsistent sea surface temperature) | Appropriate for climate, e.g., evolution greenhouse gases, volcanic eruptions, sea surface temperature and sea ice |
| Spatial resolution | 79 km globally<br>60 levels to 10 Pa | 32 km globally (T639)<br>137 levels to 1 Pa |
| Uncertainty estimate | | Based on a 10-member ensemble at 64 km (T319) |
| Land Component | 79km | <32km, TBC |
| Output frequency | 6-hourly Analysis fields | Hourly (three-hourly for the ensemble),<br>Extended list of parameters<br>~ 5 Peta Byte |
| Extra Observations | Mostly ERA-40, GTS | Various reprocessed CDRs, latest instruments |
| Variational Bias corrections | Satellite radiances<br>Radiosondes: RASE | Also ozone, aircraft, surface pressure,<br>Radiosondes: RICH + Solar-Elevation (RISE)<br>operational bias control from 2015 |

# The evolving observing system

## Newly reprocessed data sets

Radiances: SSM/I brightness temp from CM-SAF
METEOSAT from EUMETSAT

Atmospheric motion vector winds: METEOSAT, GMS/GOES-9/MTSAT, GOES-8 to 15, AVHRR METOP and NOAA

Scatterometers: ASCAT-A, ERS 1/2 soil moisture

Radio Occultation: METOP GRAS, COSMIC, CHAMP, GRACE, SAC-C, TERRASAR-x

Ozone: NIMBUS-7, EP TOMS, ERS-2 GOME, ENVISAT SCIAMACHY, Aura MLS, OMI

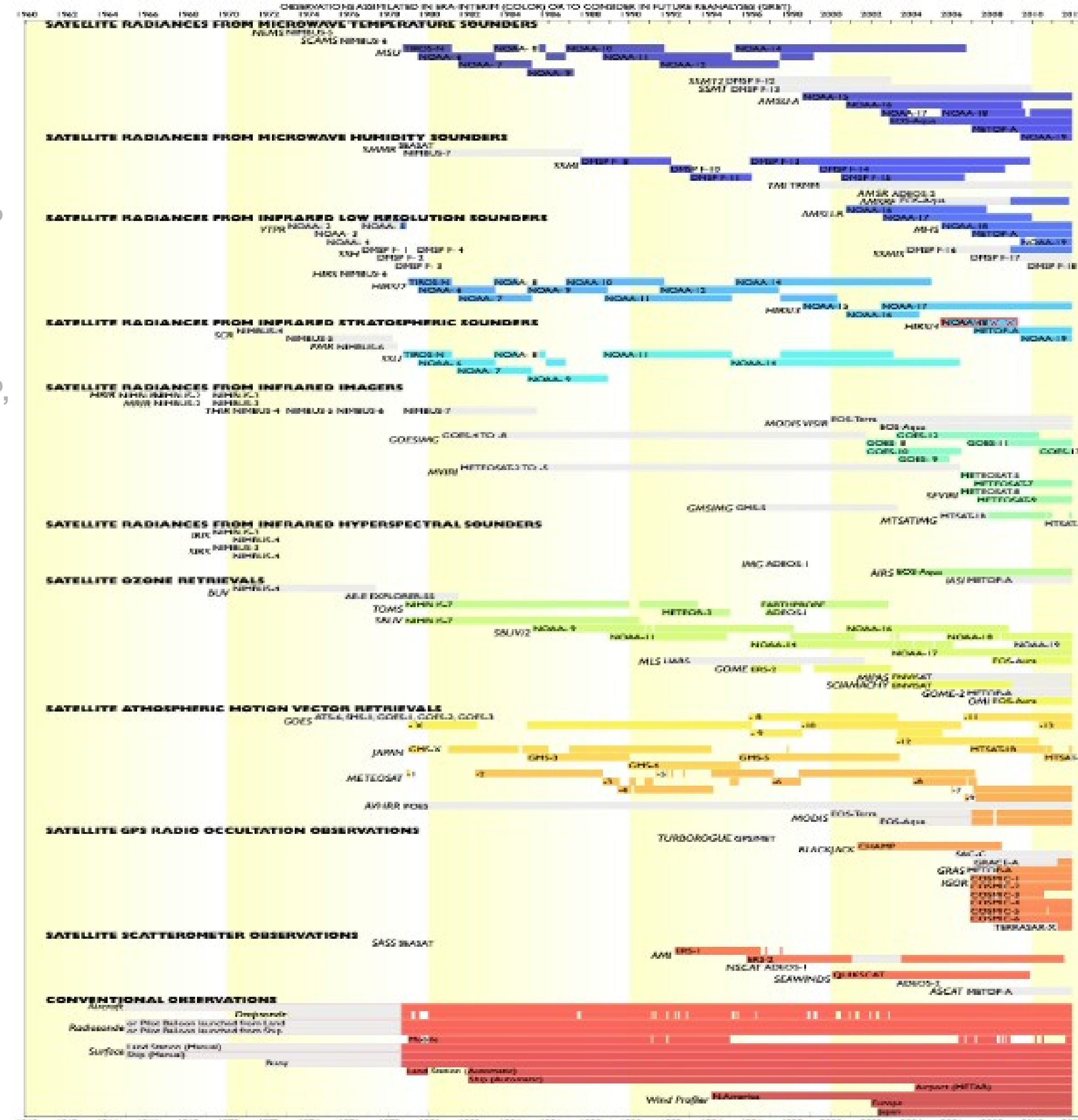
## Data not used by ERA-Interim
### (due to lack of infrastructure)

IASI, ASCAT, ATMS, Cris, Himawari, FY-3 …

*Typically the latest instruments:*
*ERA5 is more future proof!*

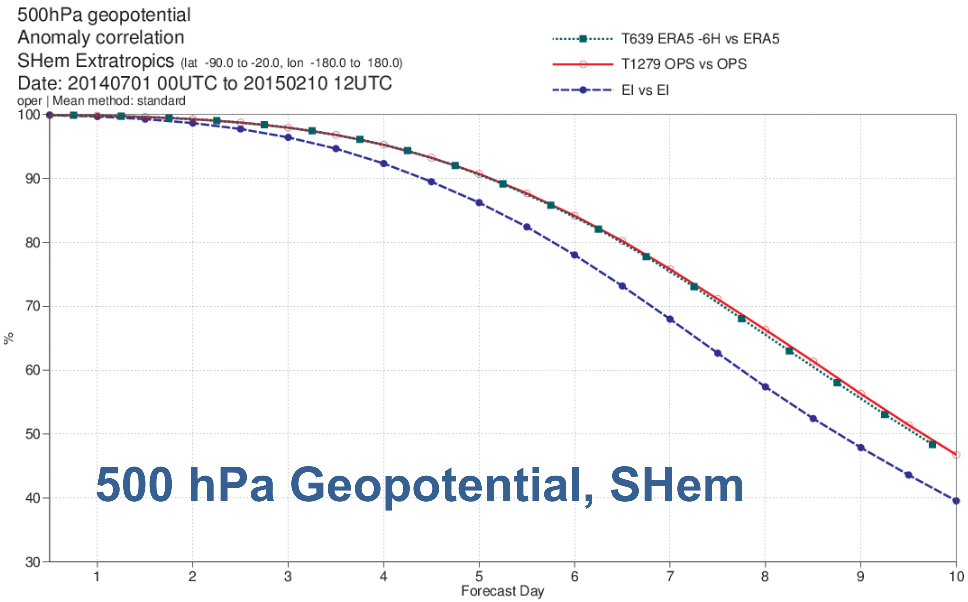
## Improved data usage

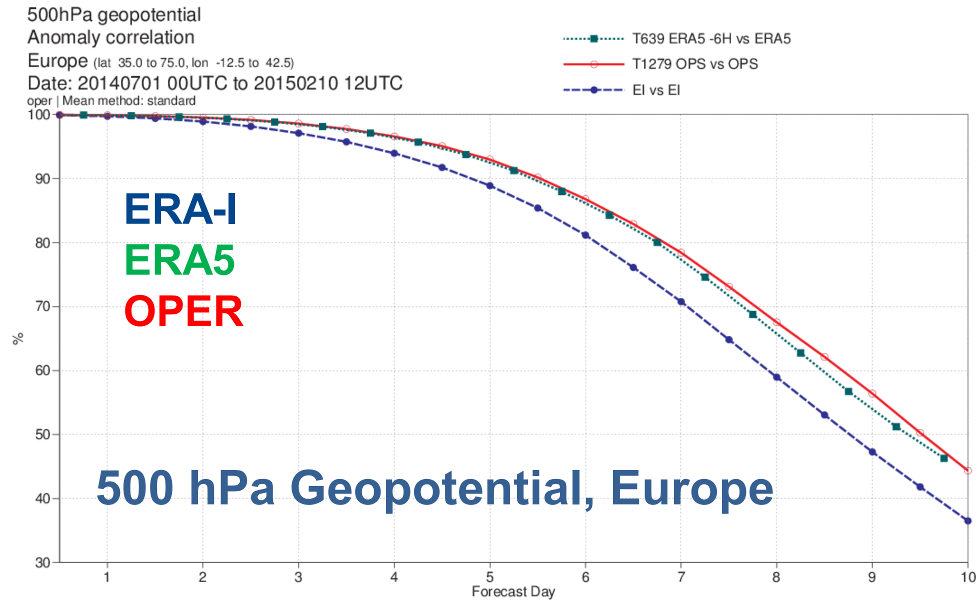
all-sky vs clear-sky assimilation,
latest radiative transfer function,
…



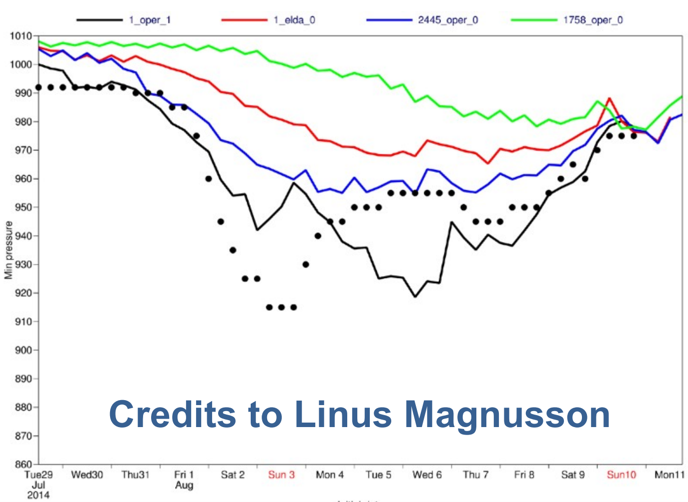
# ERA5: forecast skill

## Some initial verification of the 2014-NRT stream




**Scores not far from ECMWF operational, much better than for ERA-Interim**




**Tropical cyclone "Halong": evolution of the minimum pressure (much better than ERA-Interim, comparable to operations)**

**OPER, ERA5, EDA, ERA-INTERIM**

European Commission | Copernicus Europe's eyes on Earth ECMWF

# ERA5: preparations and streams

- ★ We have started the the early suites of ERA5 (scan and check the observations for the 40 years, develop monitoring tools, archiving, post-processing etc.)

- ★ ERA5 to be completed until the end of 2017 (and continue the near real time production beyond)

- ★ ERA5 streams: 1979-1990, 1989-2000, 1999-2010, 2009-2017, 2014- (Near Real Time Production)
  - ★ Note: these suites are just started…

# *Impact of observations in reanalysis*

- How to quantify it?
  - OSE-type of assessment: very costly (though there will be some experiments for GNSS-RO)
  - EDA: might be an option for information content studies since EDA is used to compute background error covariances
  - Adjoint observation diagnostics:
    - **DFS (Degree of Freedom for Signal; analysis impact):** practically free of charge
    - FSOI (Forecast Sensitivity Observation Impact; forecast impact): too costly (but might be considered for shorter periods)

# Forecast/analysis sensitivity to observations

**Aim: quantify the impact of observations**

$$\boxed{\frac{\partial J_e}{\partial \mathbf{y}} = \frac{\partial \mathbf{x}_a}{\partial \mathbf{y}} \frac{\partial J_e}{\partial \mathbf{x}_a}}$$

$J_e$ is a measure of the forecast error e.g in energy

$$\frac{\partial J_e}{\partial \mathbf{x}_a}$$

Forecast error sensitivity to the analysis (Rabier *et al*, 1996) → Forecast Sensitivity Observation Impact (FSOI)

$$\frac{\partial \mathbf{x}_a}{\partial \mathbf{y}} = \mathbf{K}^T = \mathbf{R}^{-1}\mathbf{H}(\mathbf{B}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H})^{-1}$$

Cardinali et al, 2004; Lupu & Gauthier, 2010

Degree of Freedom for Signal (DFS) and Observation Influence (OI; DFS per datum)

Observation Influence is complementary to Background Influence (impact/weight of observations in the analysis)

# DFS and OI results: some remarks

- ★ These are **VERY preliminary results** based on initial "scout reanalysis runs" (some suites are to be improved)

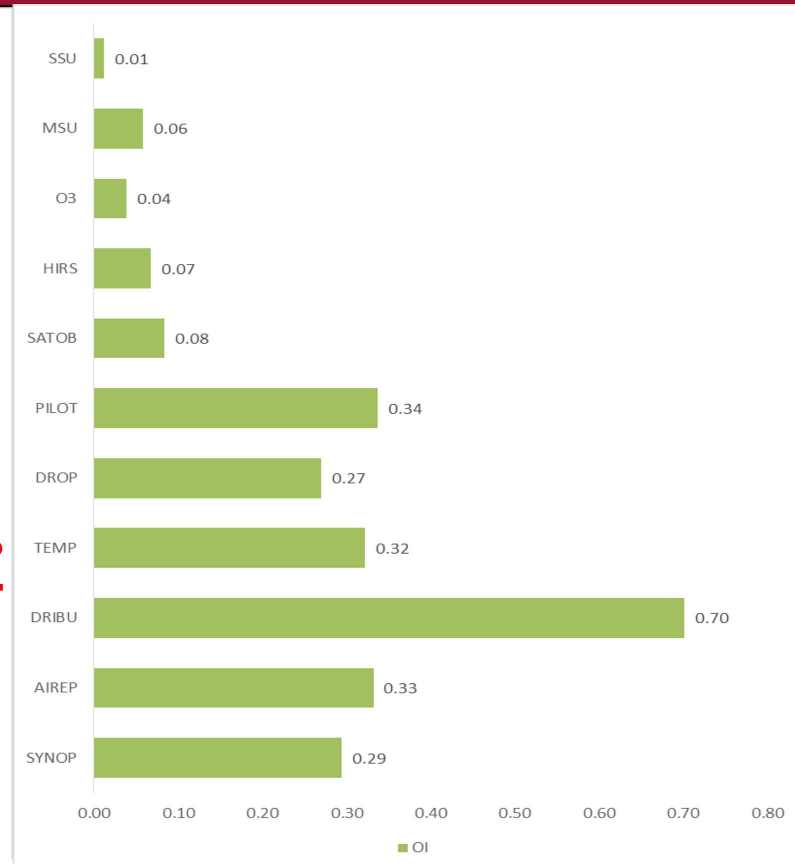
- ★ The results depend on the observing and model systems used (they are not absolute)

- ★ DFS (OI) provides information only about the influence of observation into the analysis, but does not tell if the impact is positive or negative (though: DFS and FSOI fractional impacts are generally similar)

- ★ Error bars are not shown, but only „large scale" issues will be discussed

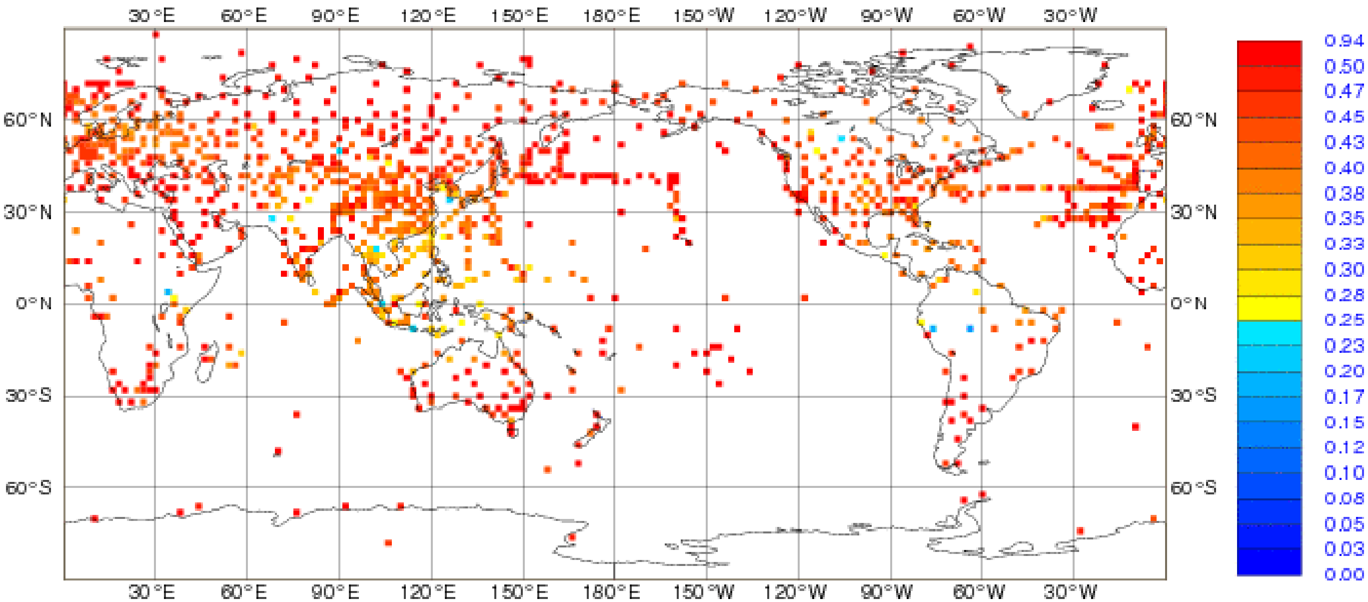
**IN THE NEXT FIGURES FRACTIONAL OBSERVATION AMOUNTS/DFS, AND OI WILL BE SHOWN AND ALSO SOME OI CHARTS**

# 1979 suite: DFS (%), OBS (%) and OI

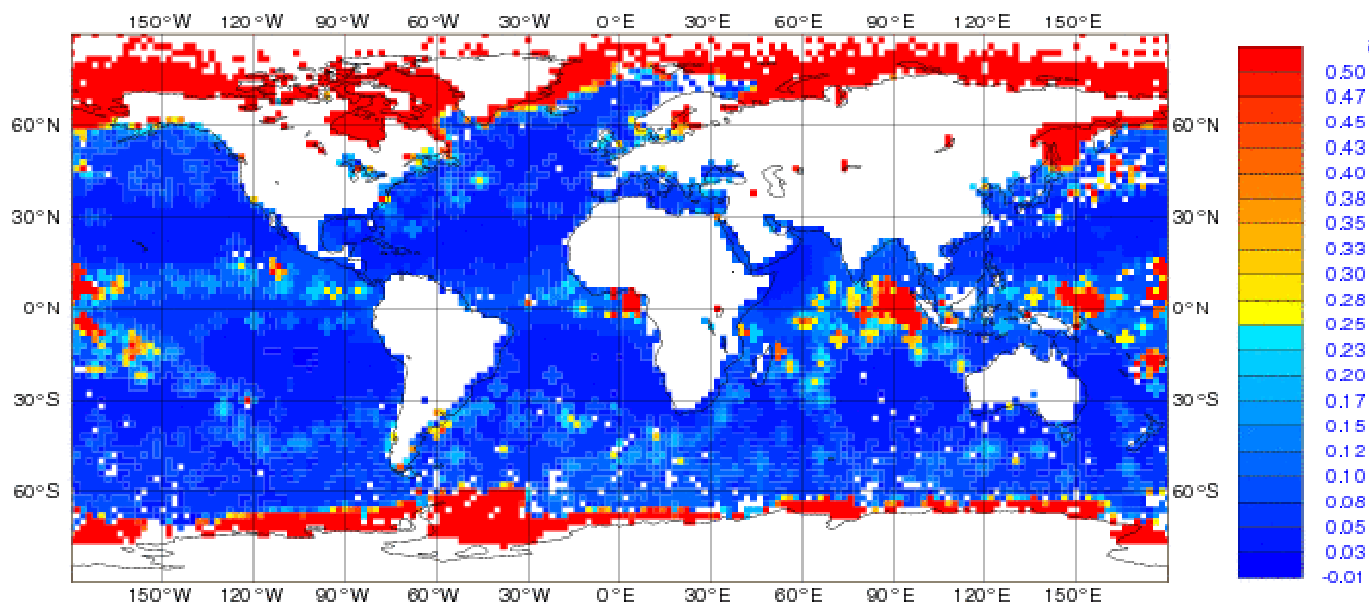

- ★ **Conventional vs. satellite observations: 35%-65%**
- ★ **Conventional vs. satellite DFS: 75%-25%**
- → **The conventional observations have an overwhelming impact!**
- → **The radiosondes are the most influential**
- → **The buoys have the largest impact per observation (as today), small weight is given to the satellite data**

# 1979 suite – Observation Influence: radiosondes vs. HIRS




**Radiosonde winds for 0-400 hPa**

**Uniformly large impact → the overall impact is large**



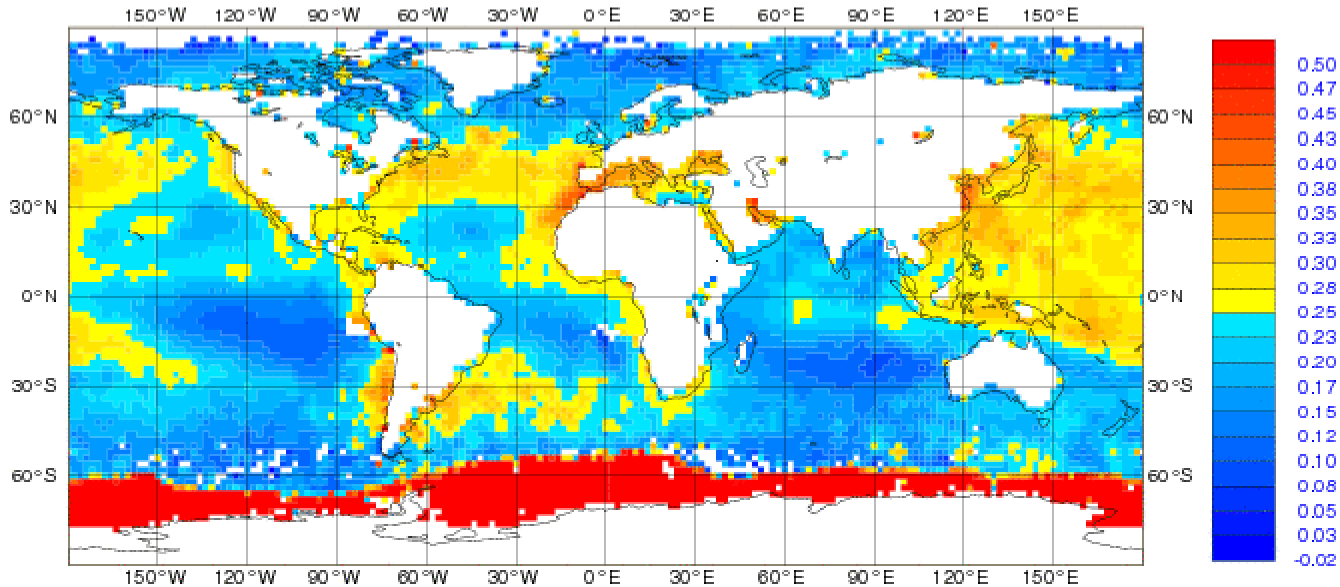

**TIROS-N HIRS channel 6 radiances**

**Large impact at the polar regions (to be checked) → the overall impact is smaller (but still more than 10%)**

# 1989 suite: DFS (%), OBS (%) and OI


- ★ **Conventional vs. satellite observations: 22%-78%**
- ★ **Conventional vs. satellite DFS: 40%-60% (<u>satellites take over</u>)**
- → **The satellite observations are getting larger overall impact**
- → **HIRS have the largest impact (closely followed by radiosondes)**
- → **The per observation impact of satellite data largely increased**

# 1989 suite –Observation Influence: HIRS vs. radiosondes

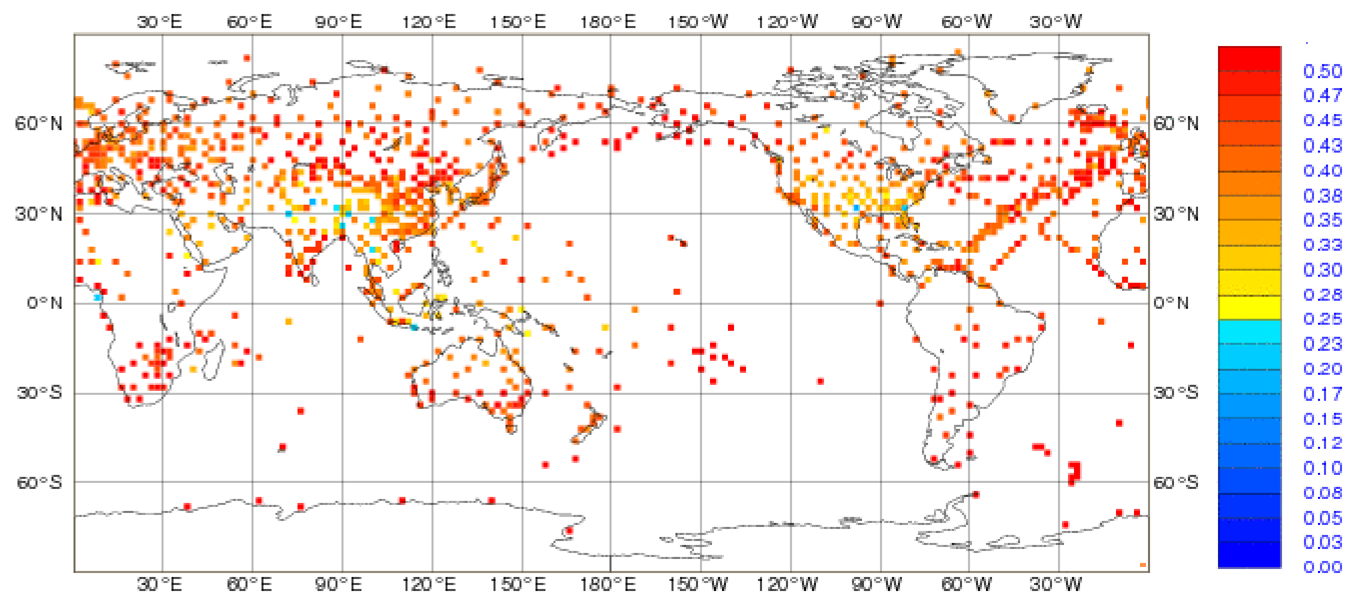



**NOAA-11 HIRS, channel 11 radiances**

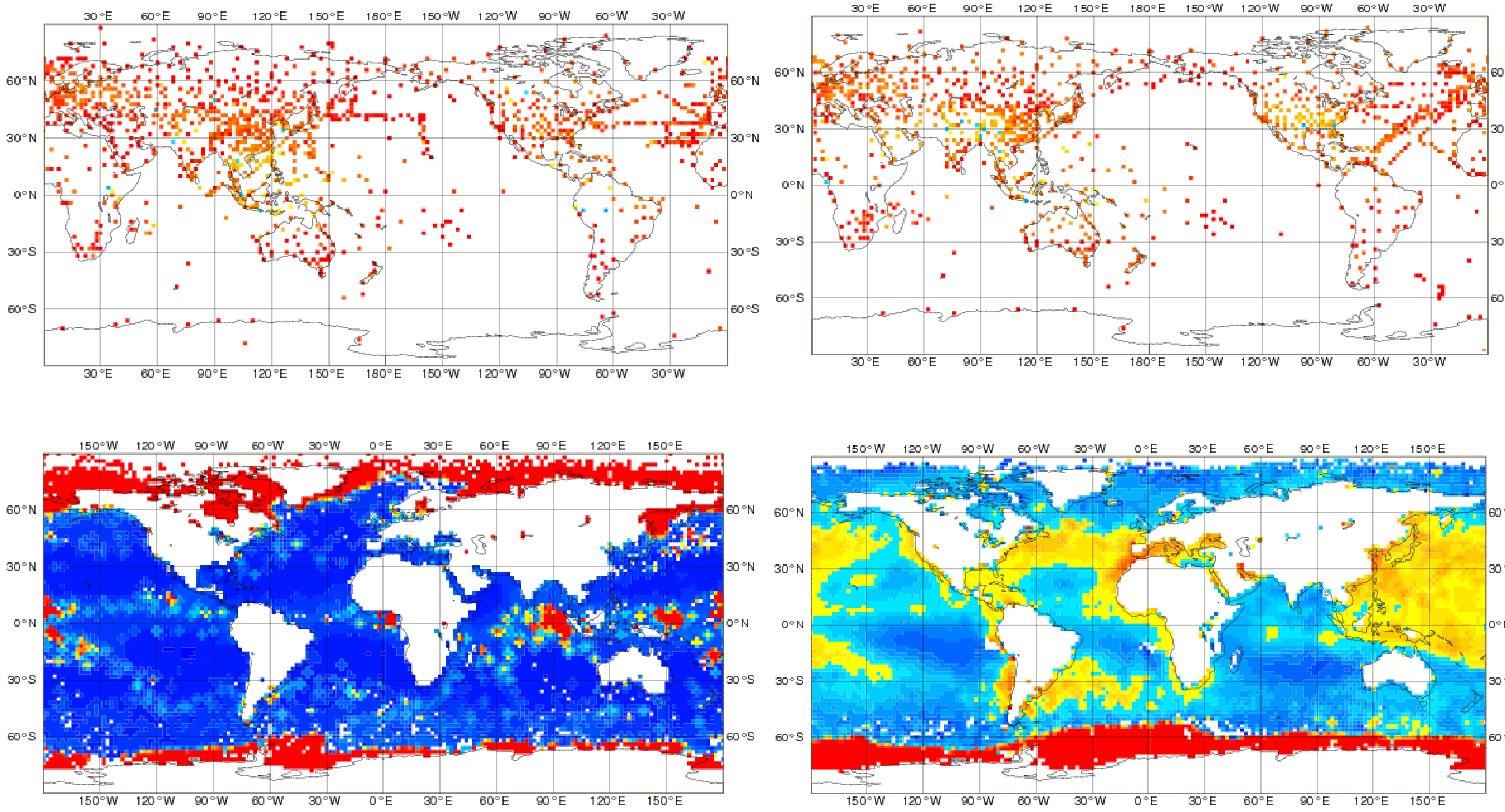
**Increased impact at the mid-latitudes → the overall impact had been increased (more than 30% by now)**

**Radiosonde winds for 0-400 hPa**

**Similarly large impact than for the previous stream**



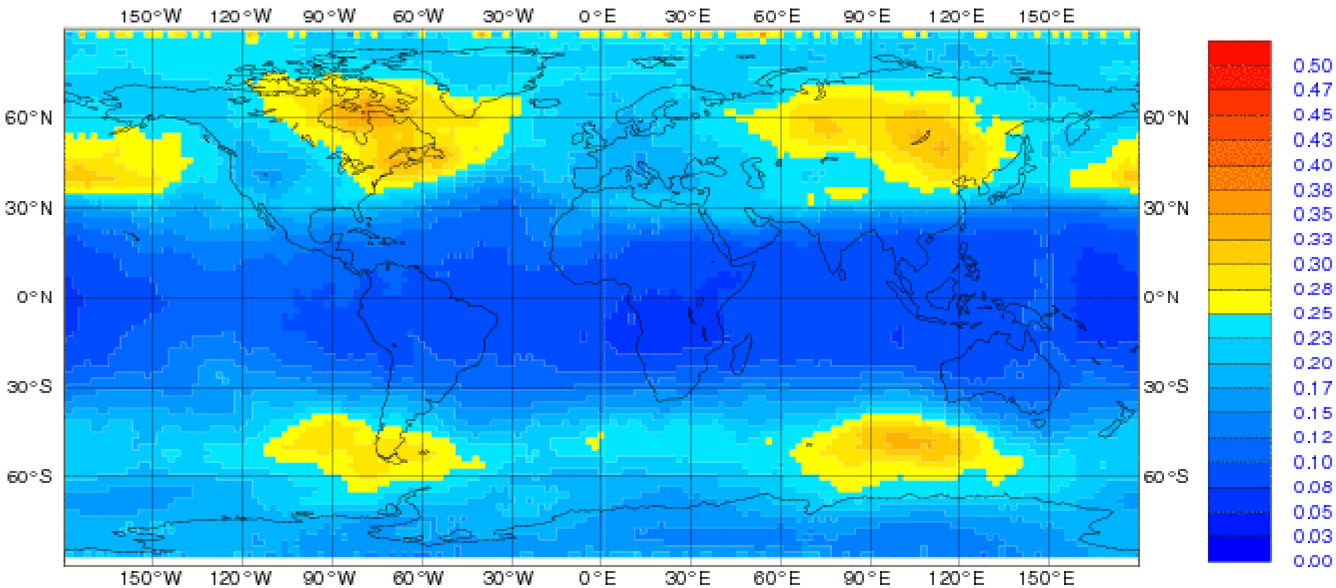
# 1979 vs 1989 suite – Observation Influence: radiosondes vs. HIRS



# 1999 suite: DFS (%), OBS (%) and OI


- ★ **Conventional vs. satellite observations: 15%-85%**
- ★ **Conventional vs. satellite DFS: 28%-72%**
- → **The satellite observations are dominating (quantity and impact)**
- → **AMSU-A, SSMI, HIRS and SATOB: the largest sat. contributors**
- → **Aircraft data are getting equally important than radiosondes**

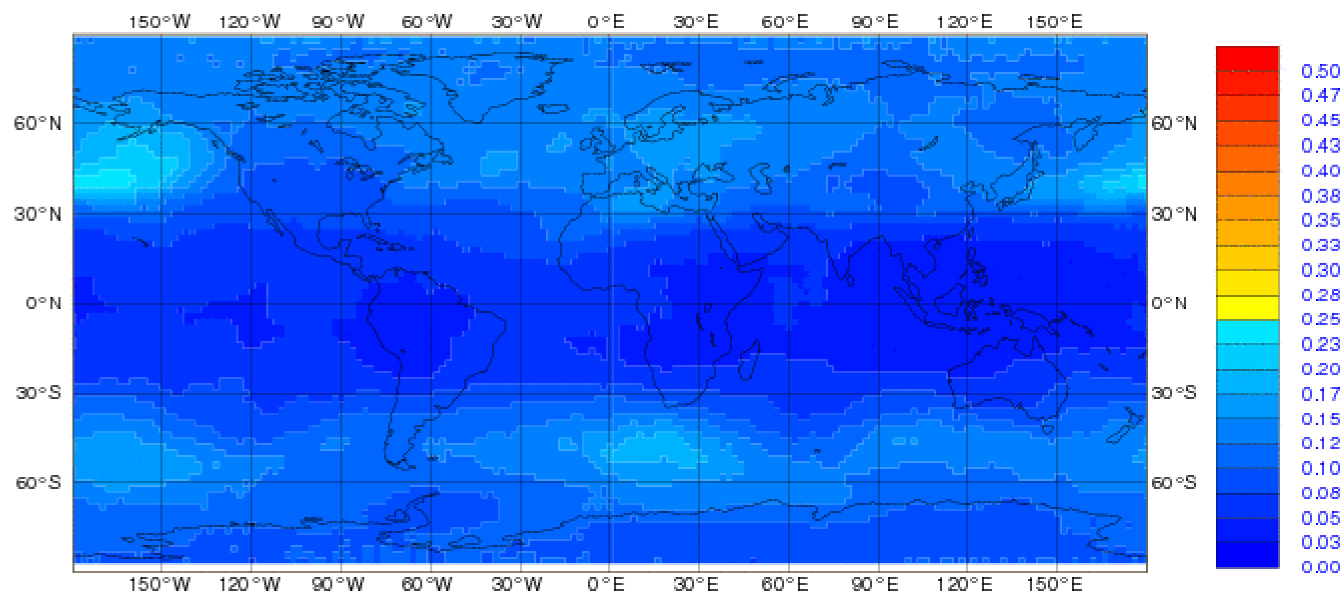
# 1999 suite - Observation Influence: AMSU-A for two satellites



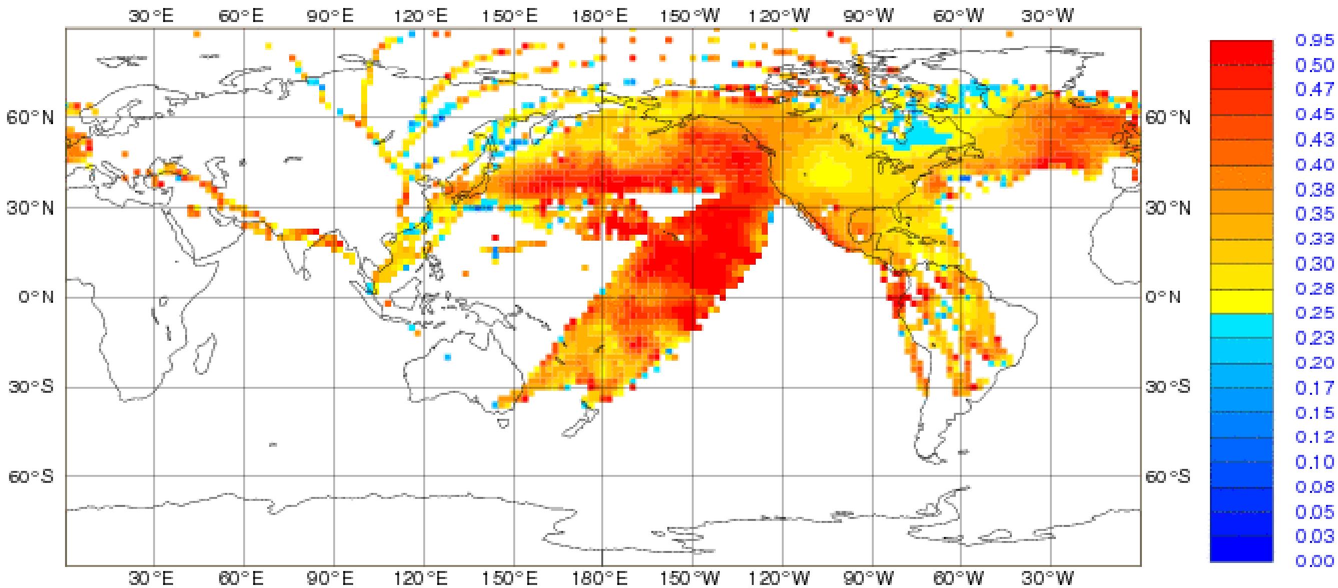

**NOAA-15 AMSU-A, channel 8 radiances**

**Reasonably large per observation impact especially at mid-latitudes (overall 24%)**

**NOAA-16 AMSU-A, channel 8 radiances**



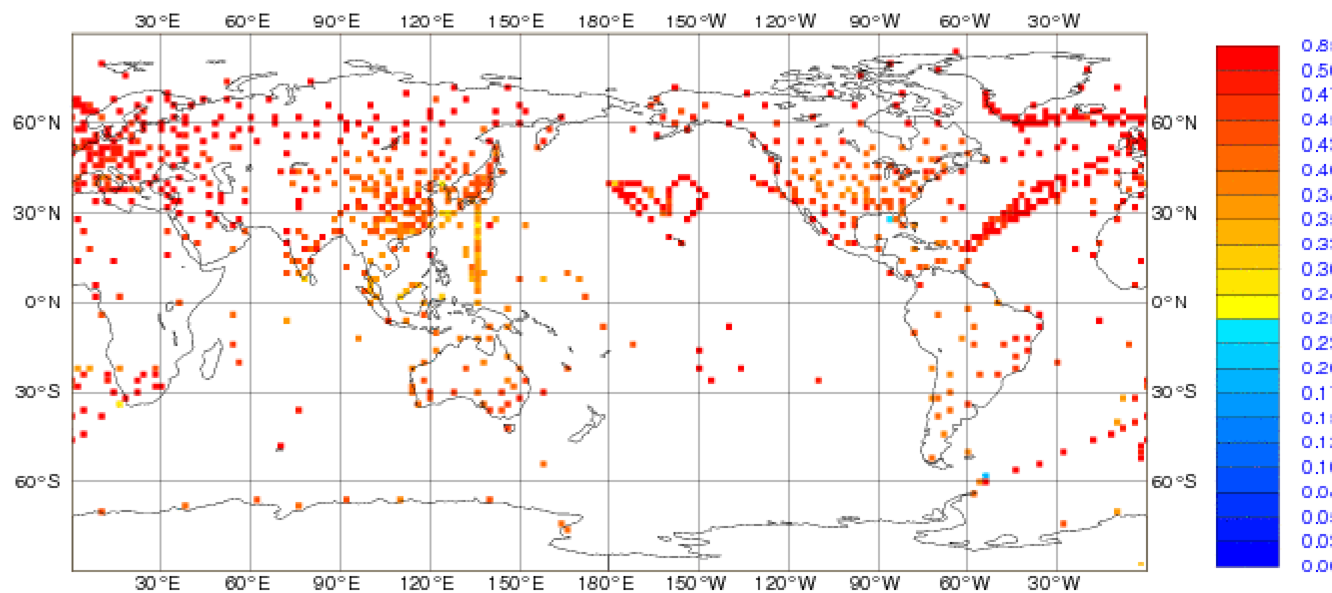
# 1999 suite – Observation Influence: ACAR vs. radiosondes



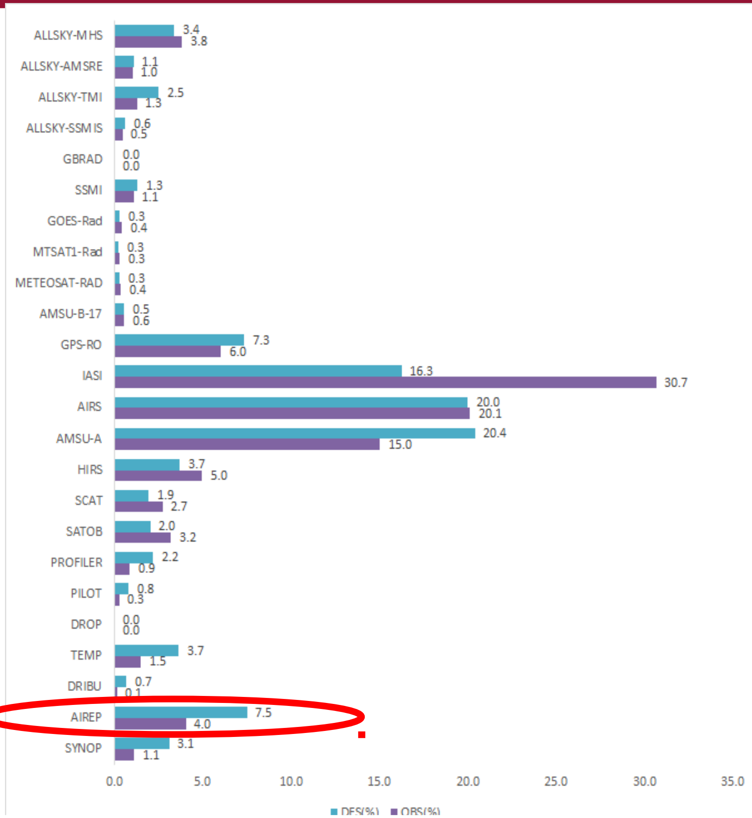

**ACAR windspeed at 0-400 hPa**

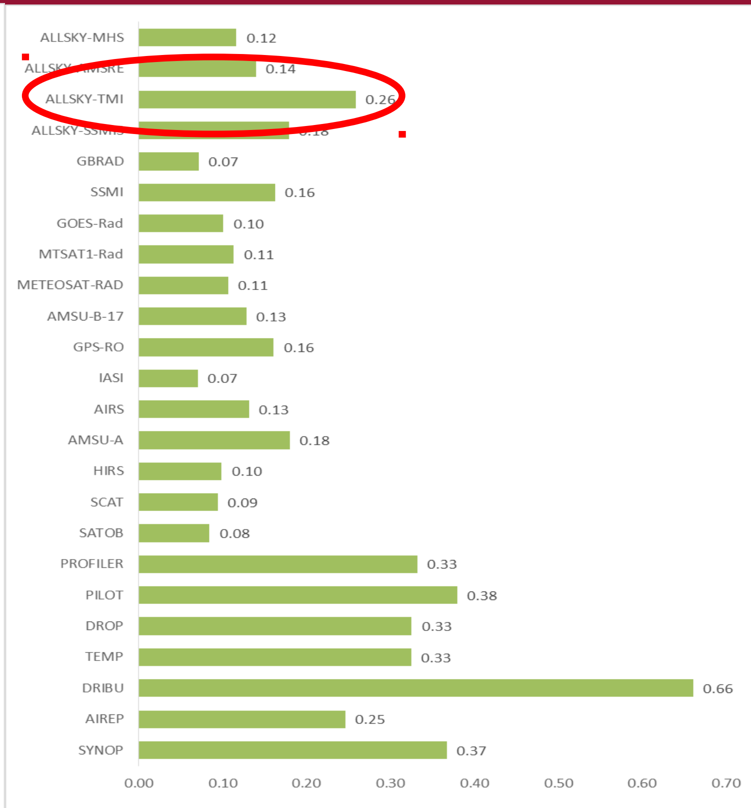
**Good ACAR coverage and impact particularly in areas with less radiosondes (Pacific)**

**Radiosonde winds for 0-400 hPa**



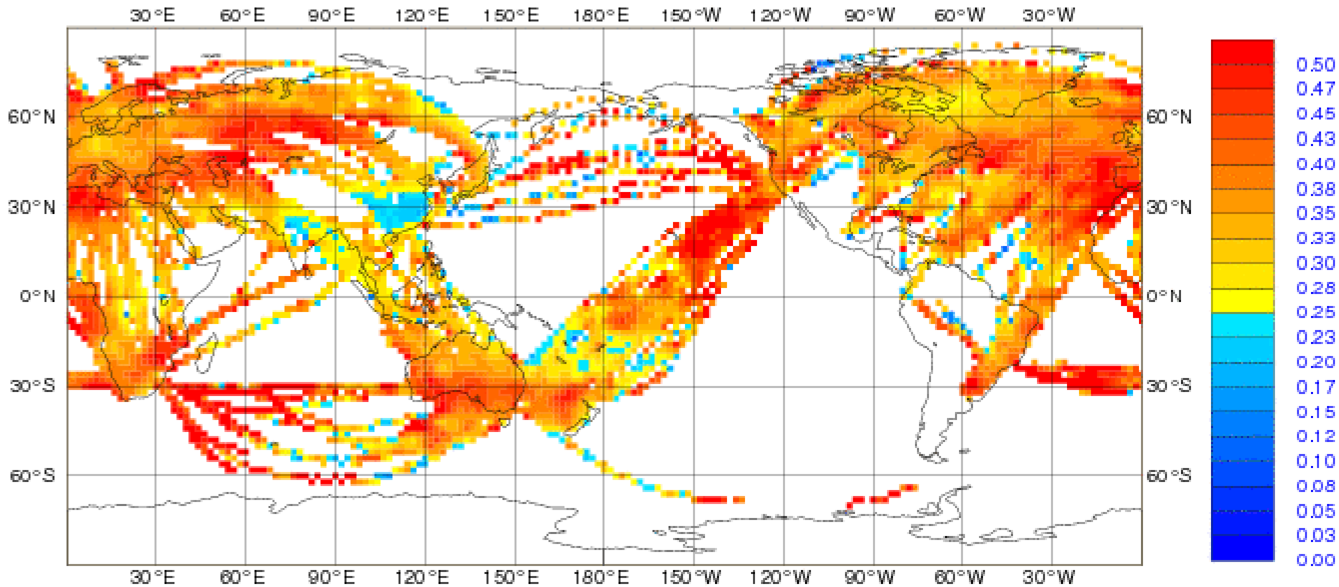
# 2009 suite: DFS (%), OBS (%) and OI




- ★ **Conventional vs. satellite observations: 8%-92%**
- ★ **Conventional vs. satellite DFS: 18%-82%**
- → **AMSU-A, AIRS, IASI and GNSS-RO: largest satellite contributors**
- → **Large OI for allsky-TMI (MW humidity sounder), also GNSS-RO**
- → **Aircraft are the most influential conventional observation (due to its growing number)**

# 2009 suite – Observation Influence: AMDAR vs. all-sky radiances

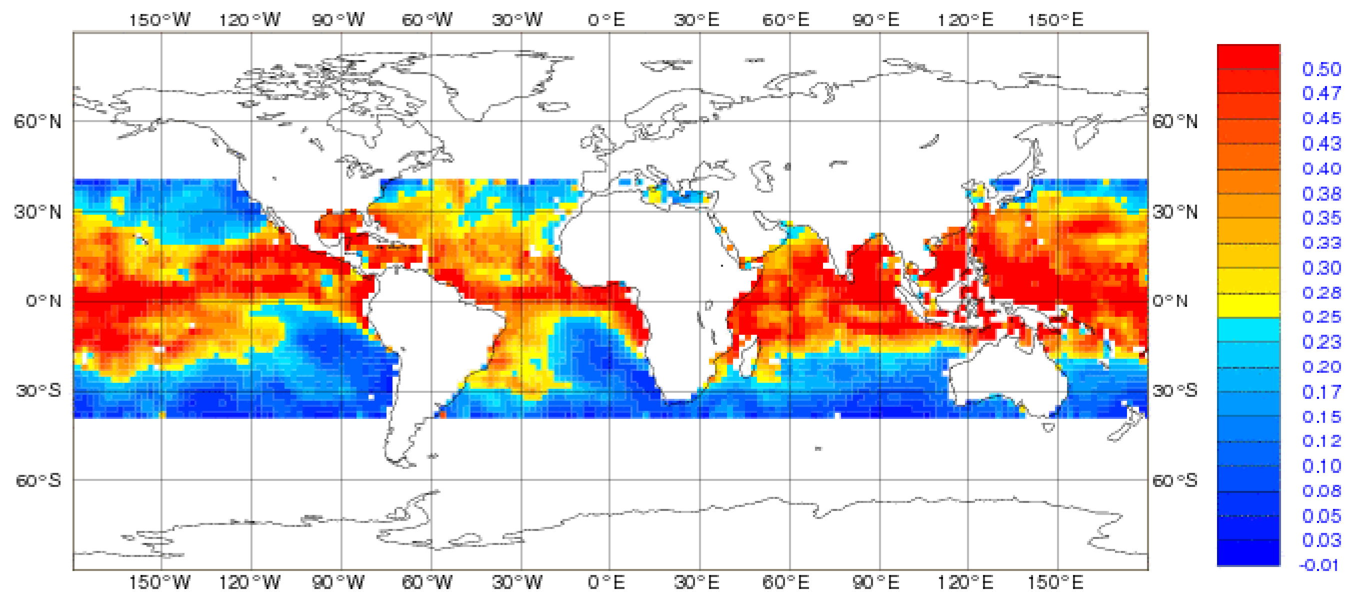



**AMDAR winds at 0-400 hPa**

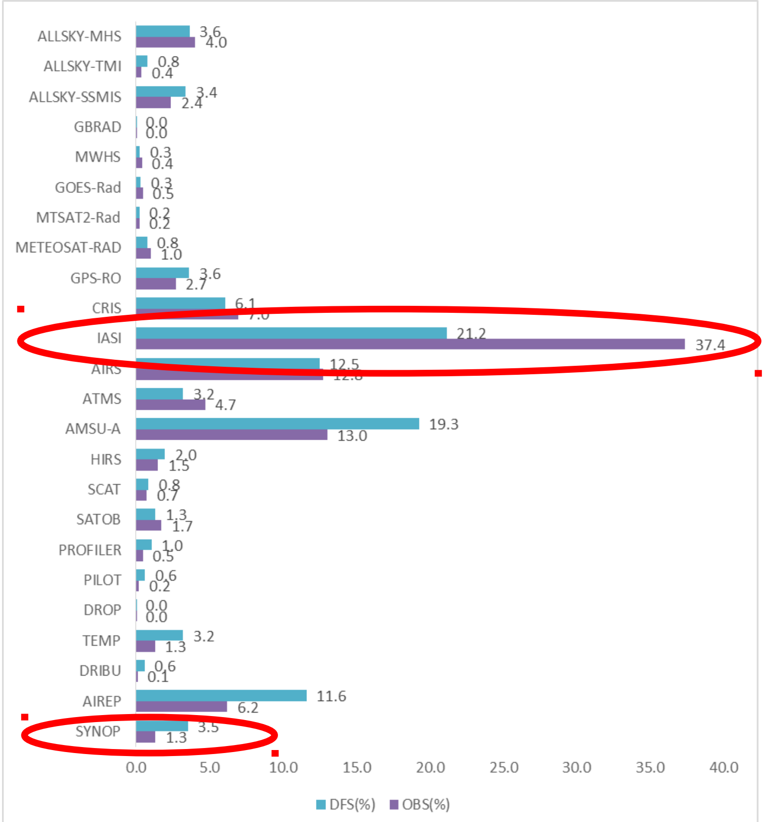
**Uniformly large impact**

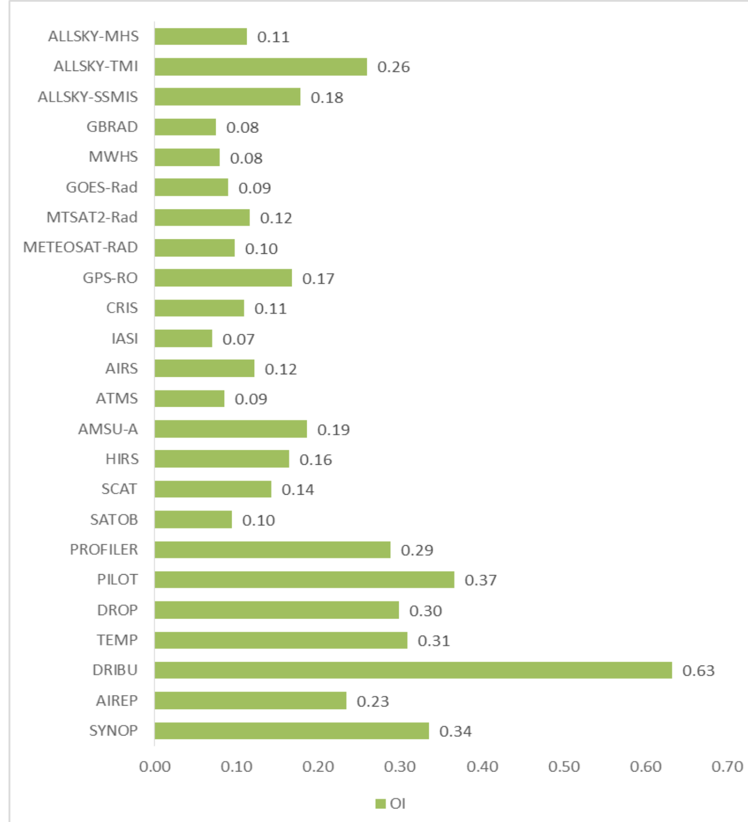
**All-sky TRMM/TMI channel 6 radiances**

**Strong tropical impact**



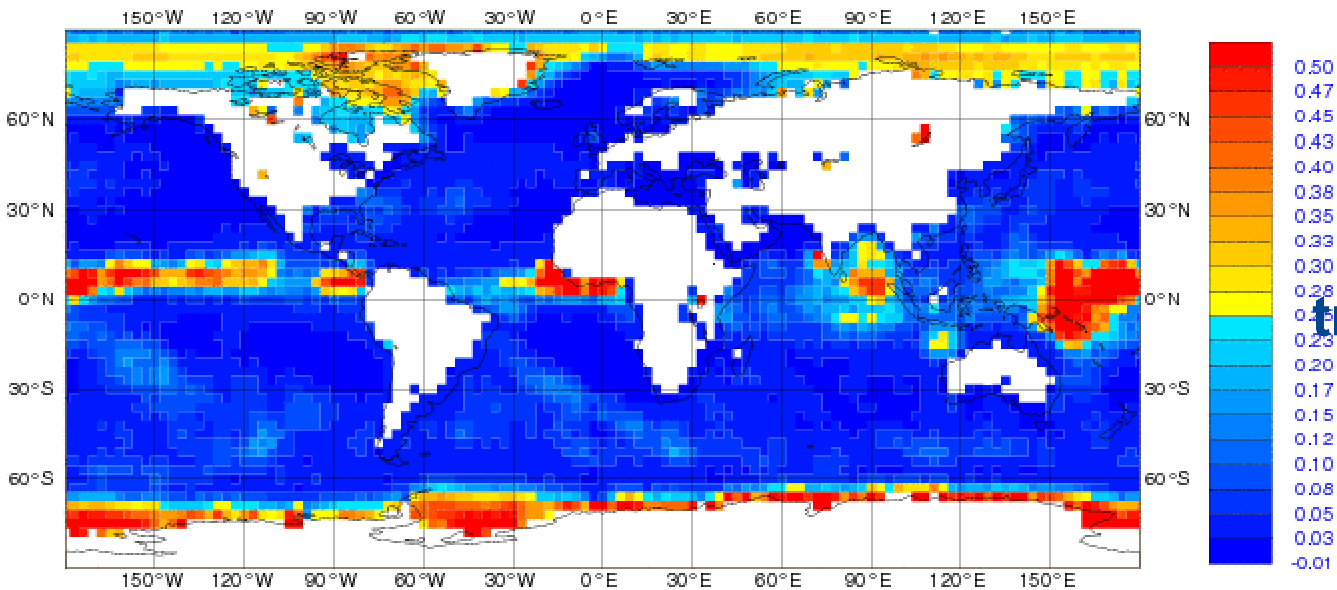
# 2015 suite: DFS (%), OBS (%) and OI




- ★ **Conventional vs. satellite observations: 10%-90%**
- ★ **Conventional vs. satellite DFS: 20%-80%**
- → **IASI, AMSU-A, AIRS and CRIS as largest satellite contributors**
- → **Impact of SYNOPs is getting similar than radiosondes (aircraft are clearly dominant among the convntional observations)**

# 2015 suite –Observation Influence: IASI vs. SYNOP pressure

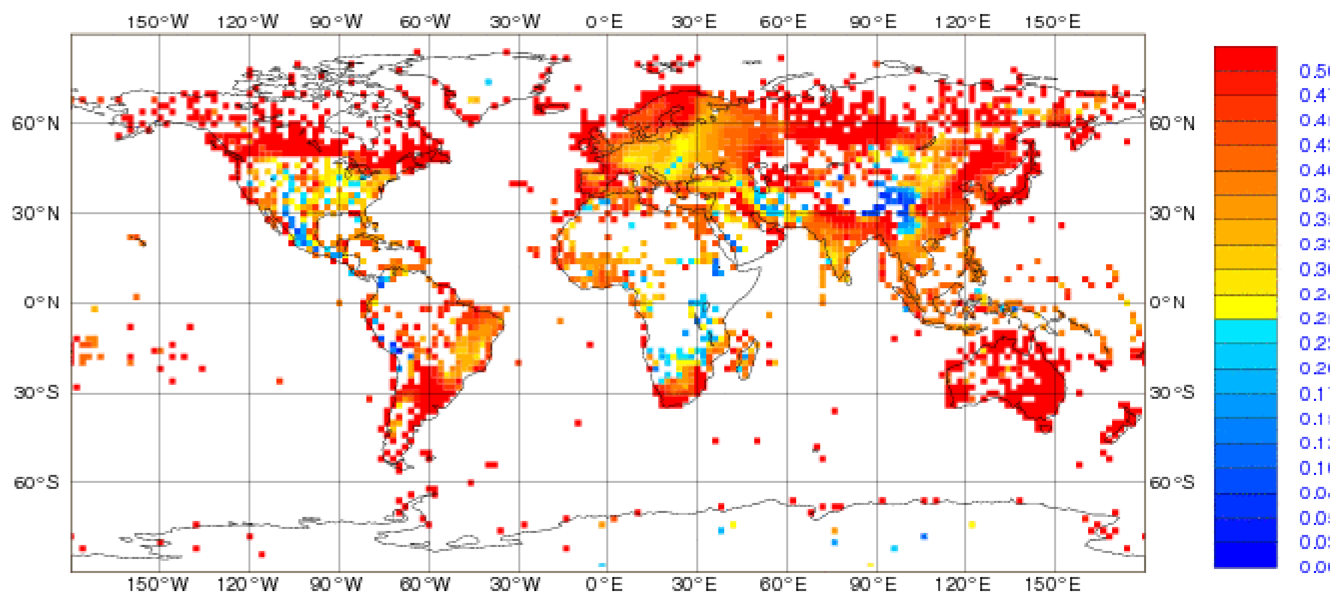



**METOP-A IASI channel 335 radiances**

**Large impact at the tropical and polar regions**

**SYNOP pressure**

**Uniformly large impact**



# ERA5: observation amounts and influence (%)

| | OBSERVATION AMOUNT (%) | | DFS (%) | |
|---|---|---|---|---|
| | CONVENTIONAL | SATELLITE | CONVENTIONAL | SATELLITE |
| 1979 suite | **35** | **65** | **75** | **25** |
| 1989 suite | **22** | **78** | **40** | **60** |
| 1999 suite | **15** | **85** | **28** | **72** |
| 2009 suite | **8** | **92** | **18** | **82** |
| 2014 suite | **10** | **90** | **20** | **80** |

# Summary, conclusions (1)

- ERA5 reanalysis covers the „satellite era", i.e. the **satellite observations are always dominating in observation quantities** (reaching 90% today)

- The **total influence of conventional observations are always and still large** (now: double than their observation amount would suggest)

- The **per observation impact of conventional observations are always larger than that of the satellites**

- The **per observation impact of satellite observations had been increased** (especially for the all-sky radiances, for GNSS-RO it was always large)

# *Summary, conclusions (2)*

- The **influence of the aircraft and surface observations had been increased** with time (with respect to radiosondes, which was dominant at the early times).

- History of satellite observation influences: **HIRS** (80s, 90s) → **AMSU-A** (end of 90s) → **IASI** (AIRS)

# ERA5 outlook

- ERA5 availability:
  - End of 2016: 2010 to NRT available
  - 2-years from now: 1979-2009
  - Afterwards: continuation in near real time

**Thank you!**