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The use of satellite data in limited-area NWP models of MetCoOp

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EUMeTrain
High-latitude Event Week 30 Jan – 3 Feb 2023

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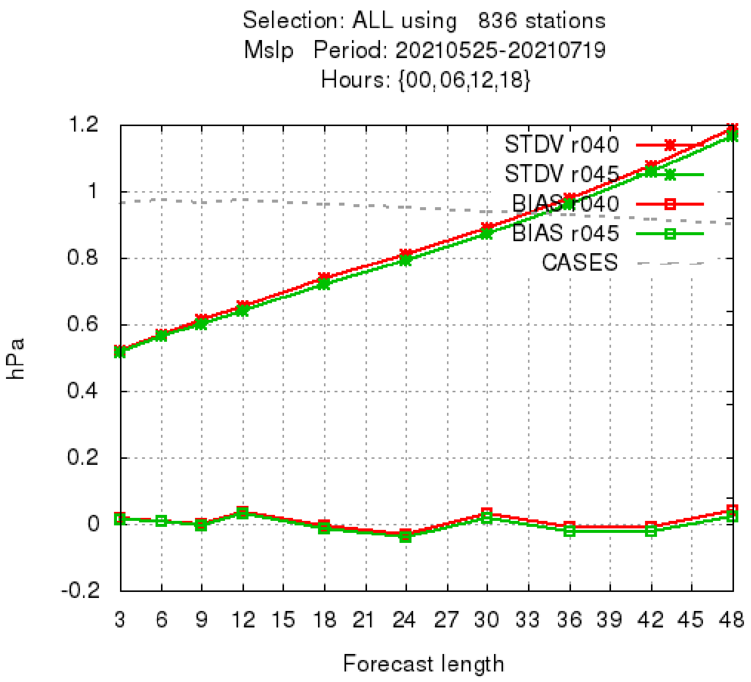
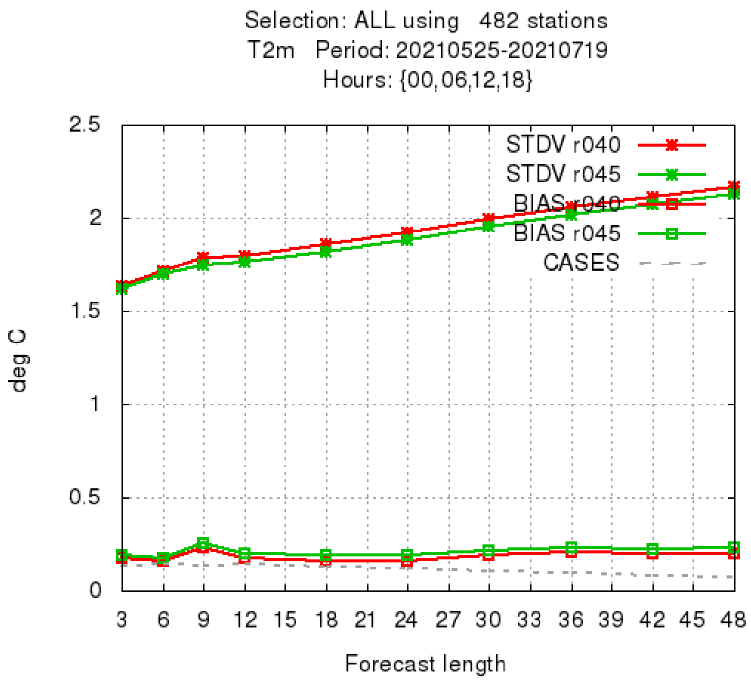
Meteorological Co-operation on Operational NWP

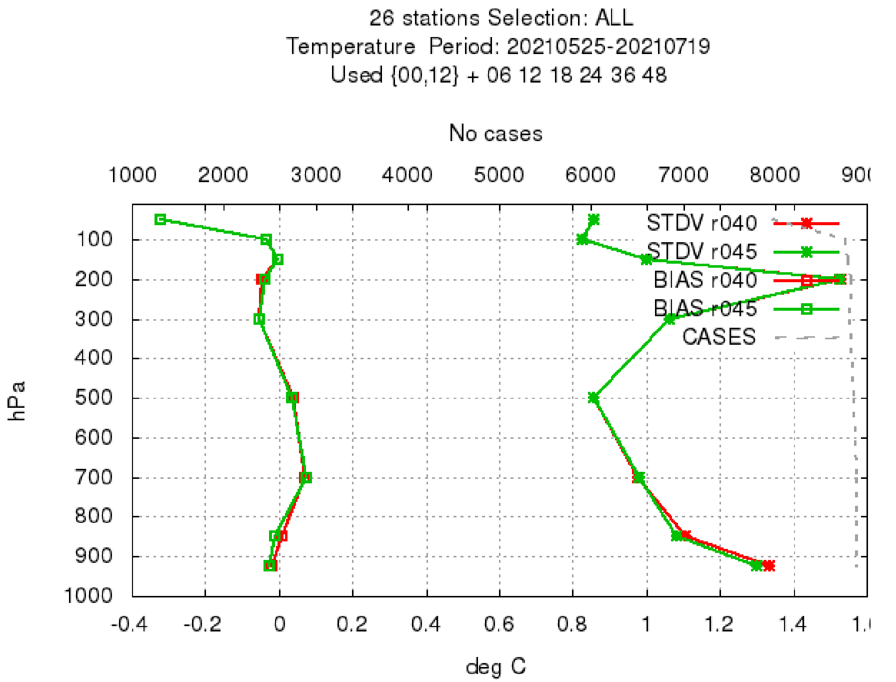
– *Operational production of short-range weather forecasts since 2014*

– Participating institutes include ESTEA (Estonia), FMI (Finland), SMHI (Sweden), and MET Norway

On the influence of satellite data in Numerical Weather Prediction







r040: Control run
r045: Control run + additional satellite data

Content

– Data assimilation in MetCoOp NWP systems

– Meteorological satellites in polar orbits today

– Meteorological information content in infrared and microwave sounding

– Handling of gross, systematic, and random observation errors

Ingredients of variational data assimilation

MetCoOp NWP suites employ three-dimensional variational data assimilation (3D-Var) at every analysis-forecast cycle

Variational data assimilation algorithms search for a statistically optimal analysis state **x** for given background $\mathbf{x}_b$ and observations **y**

$$J(\mathbf{x}) = \underbrace{(\mathbf{x}-\mathbf{x}_b)^T \mathbf{B}^{-1} (\mathbf{x}-\mathbf{x}_b)}_{\text{Background constraint}} + \underbrace{(\mathbf{y}-H[\mathbf{x}])^T \mathbf{R}^{-1} (\mathbf{y}-H[\mathbf{x}])}_{\text{Observation constraint}}$$

Background constraint *Observation constraint*

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Ingredients of variational data assimilation

Analysis state (temperature, humidity, wind etc)

(inverse of) background error covariance

(inverse of) observation error covariance

$$J(\mathbf{x}) = (\mathbf{x}-\mathbf{x}_b)^T \mathbf{B}^{-1} (\mathbf{x}-\mathbf{x}_b) + (\mathbf{y}-H[\mathbf{x}])^T \mathbf{R}^{-1} (\mathbf{y}-H[\mathbf{x}])$$

Background (a previous 3-hour forecast)

Observations

Conversion from analysis state to observation space (“observation operator”)

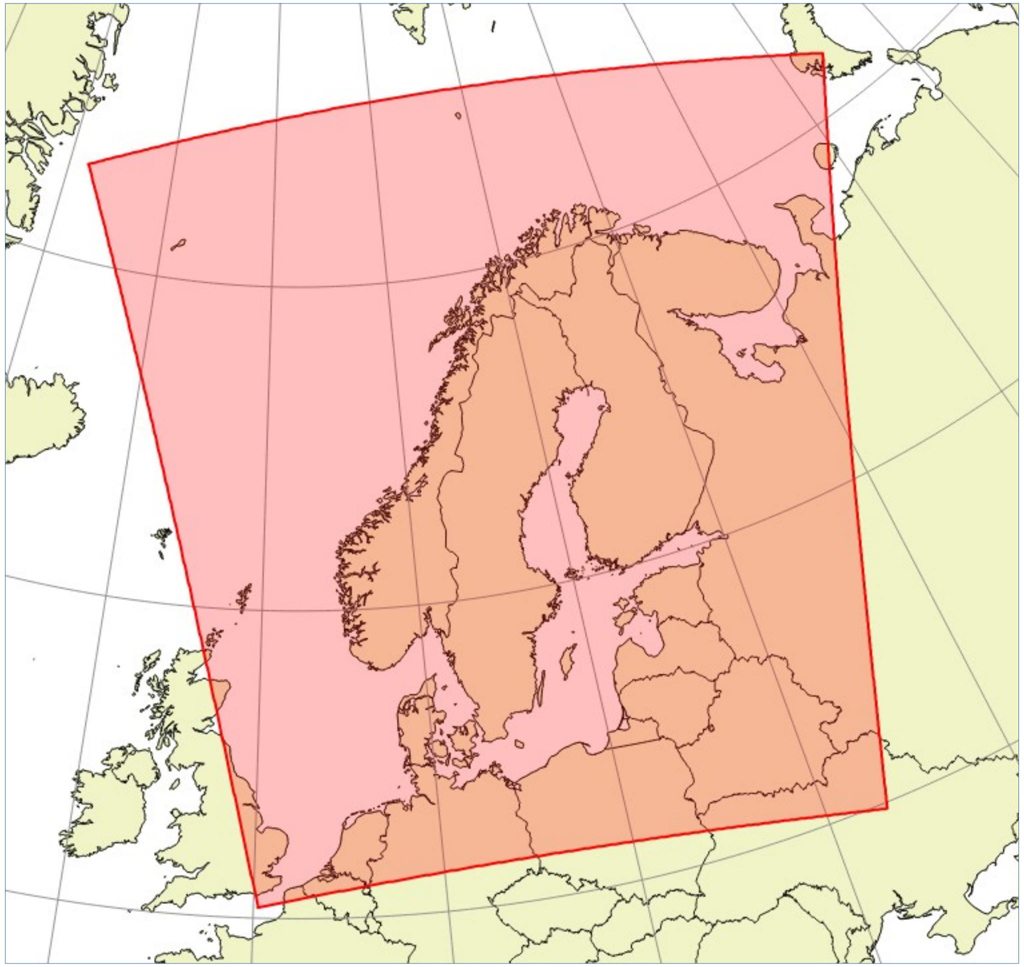
MetCoOp NWP systems

(January 2023)

→ **MetCoOp Ensemble Prediction System (MEPS_prod)**
  → *3-hour cycling with 75-minute observation cutoff*
  → Deterministic + 14 perturbed members
  → 5 new forecasts out to +66 hours at each hour

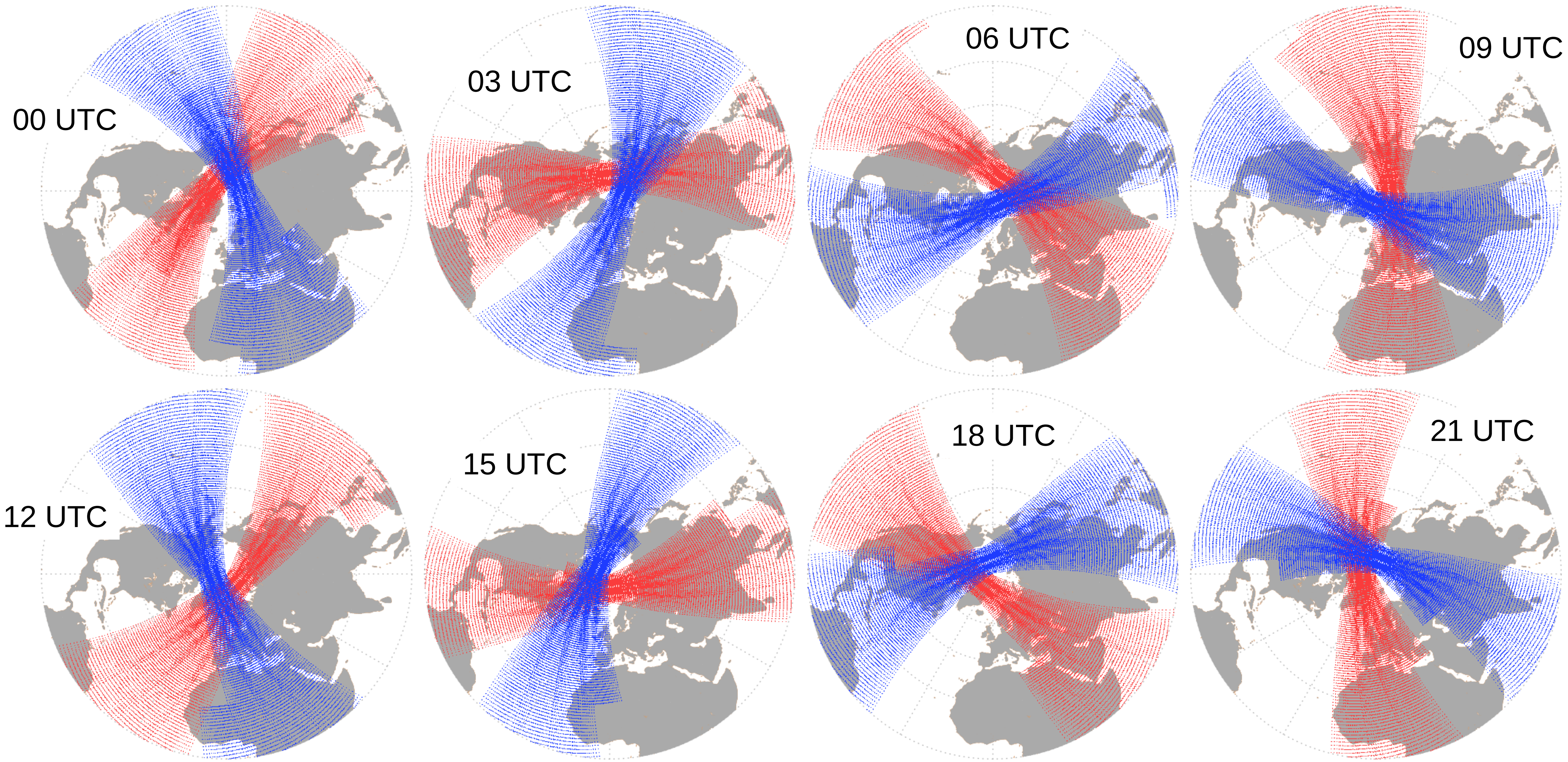
→ **MetCoOp Nowcasting System (MNWC_prod)**
  → *1-hour cycling with 25-minute observation cutoff*
  → Only a deterministic run out to +12 hours at each hour

*All MetCoOp NWP suites are based on Harmonie-Cy43h2**
All are run in a 2.5 km grid on 65 model levels
(with model top at 10 hPa)



*) Harmonie system releases are products of European-wide co-operation on short-range NWP development

Complementarity of "afternoon" and "morning" orbits



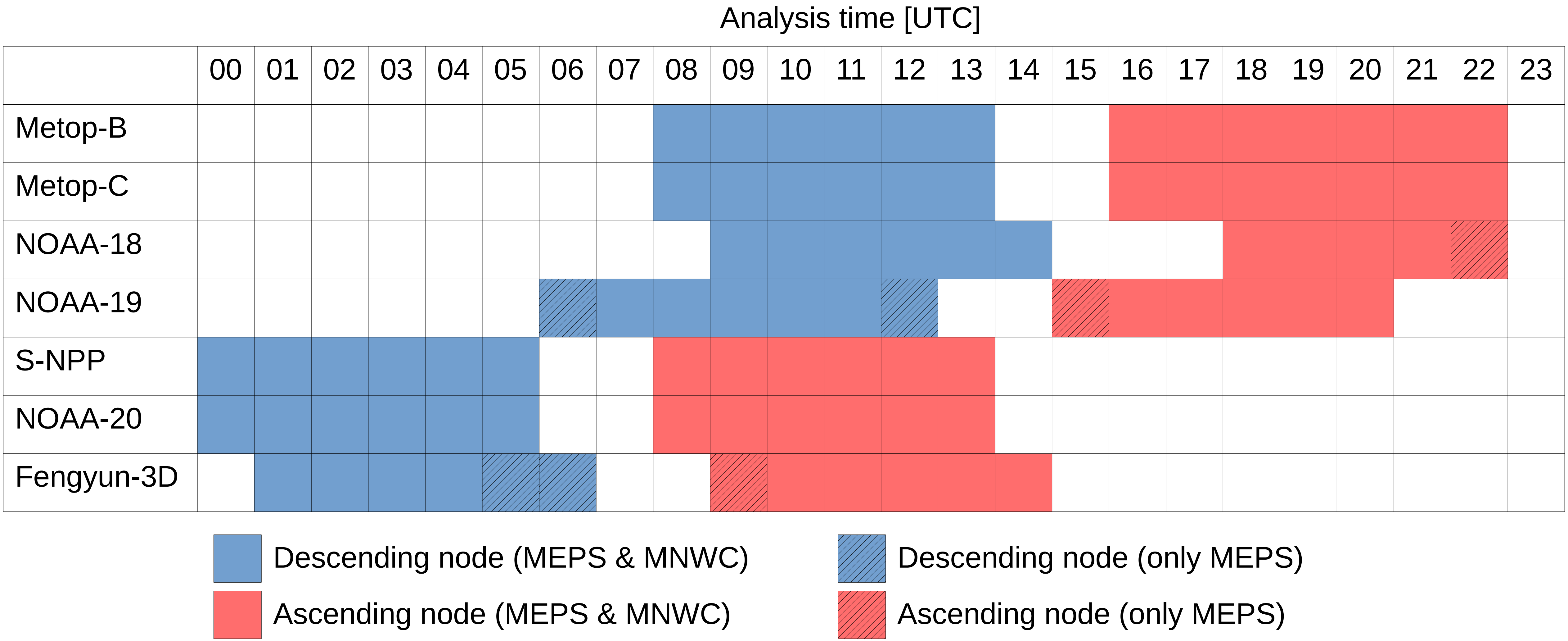
Polar-orbiting meteorological satellites used in MetCoOp

Daily overpasses at MetCoOp domain in UTC hours

	Ascending node overpass at Equator (local time)	Ascending at 63.5N, 16.7E [UTC]	Descending node overpass at Equator (local time)	Descending at 63.5N, 16.7E [UTC]
NOAA-18	22:25	20:05	10:25	10:30
NOAA-19	20:20	17:55	8:20	8:30
NOAA-20	13:25	11:05	1:25	1:25
S-NPP	13:25	11:10	1:25	1:25
Metop-B	21:30	19:15	9:30	9:30
Metop-C	21:30	19:15	9:30	9:35
Fengyun-3D	14:00	11:40	2:00	2:05

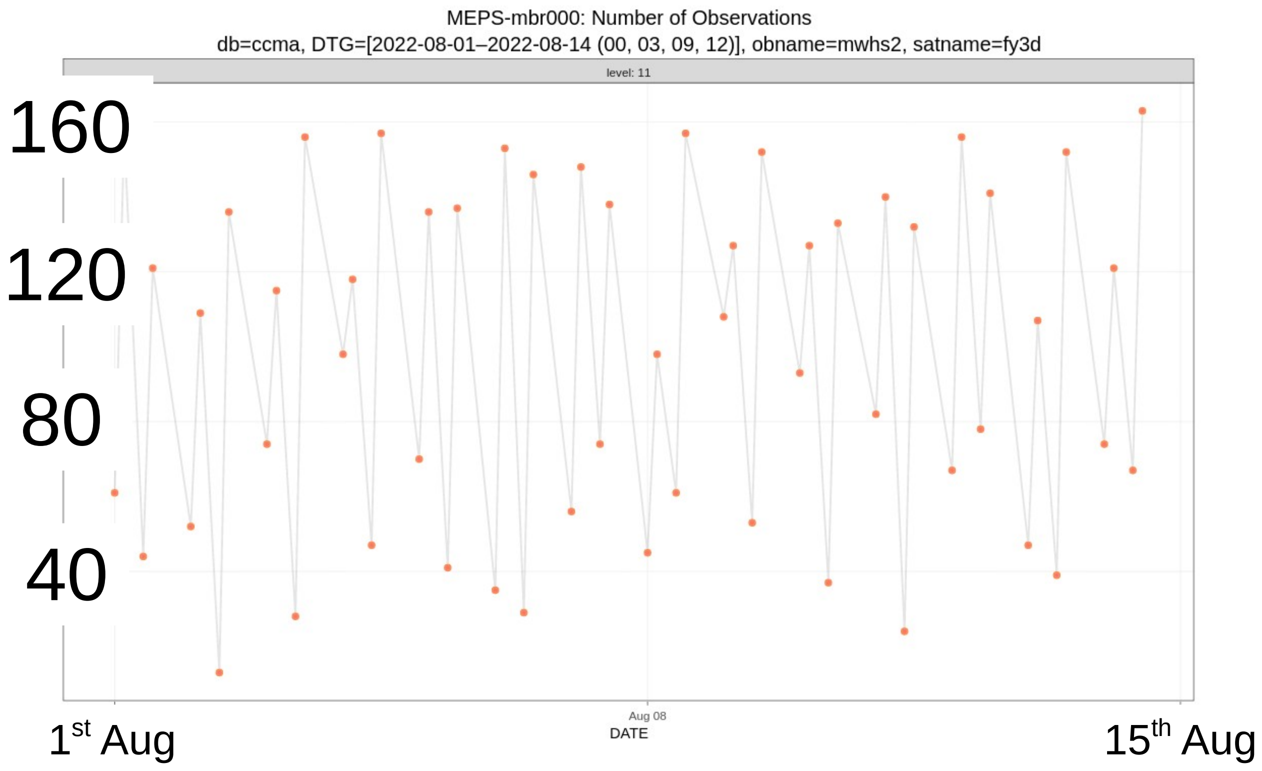
Satellite data use hours in MetCoOp

(January 2023)

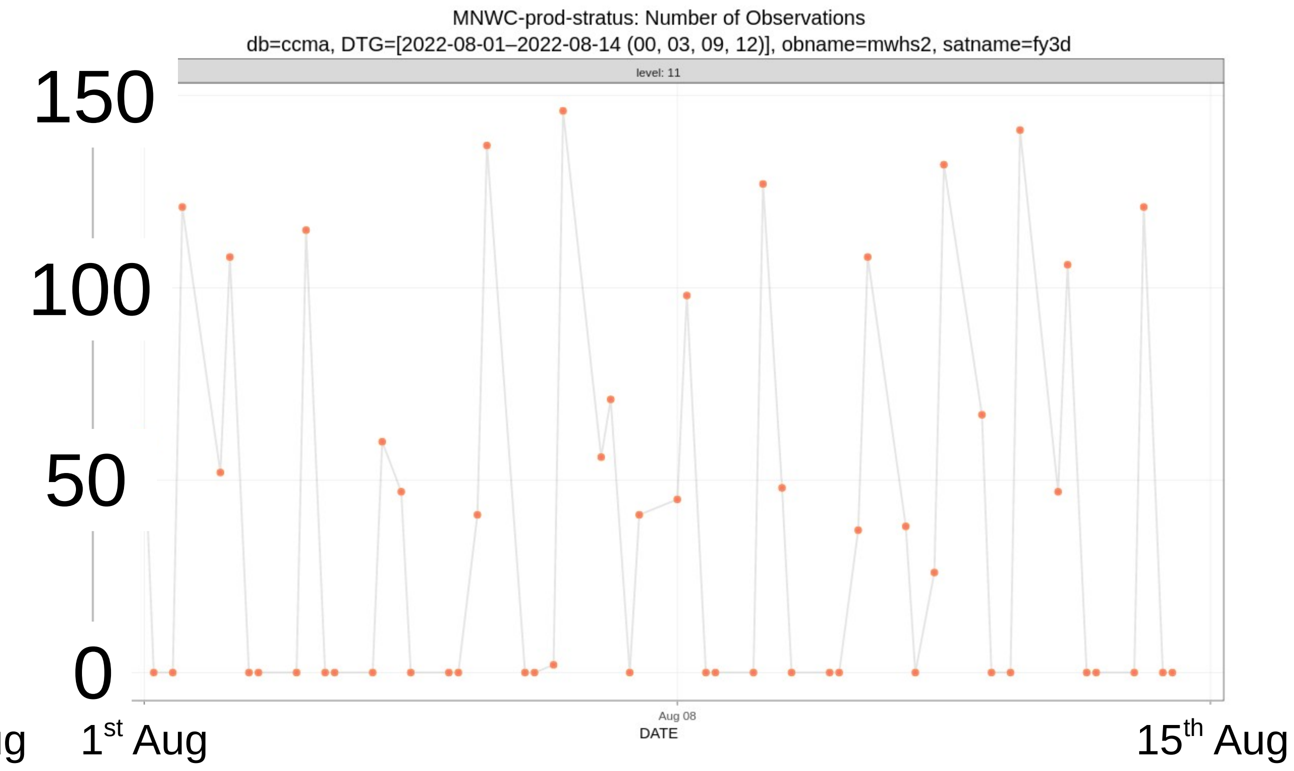


Shorter observation time cutoff means less stable data flow

Data count in MEPS
(3-hour analysis time window, 75 minutes cut-off)



Data count in MNWC
(1-hour analysis time window, 25 minutes cut-off)



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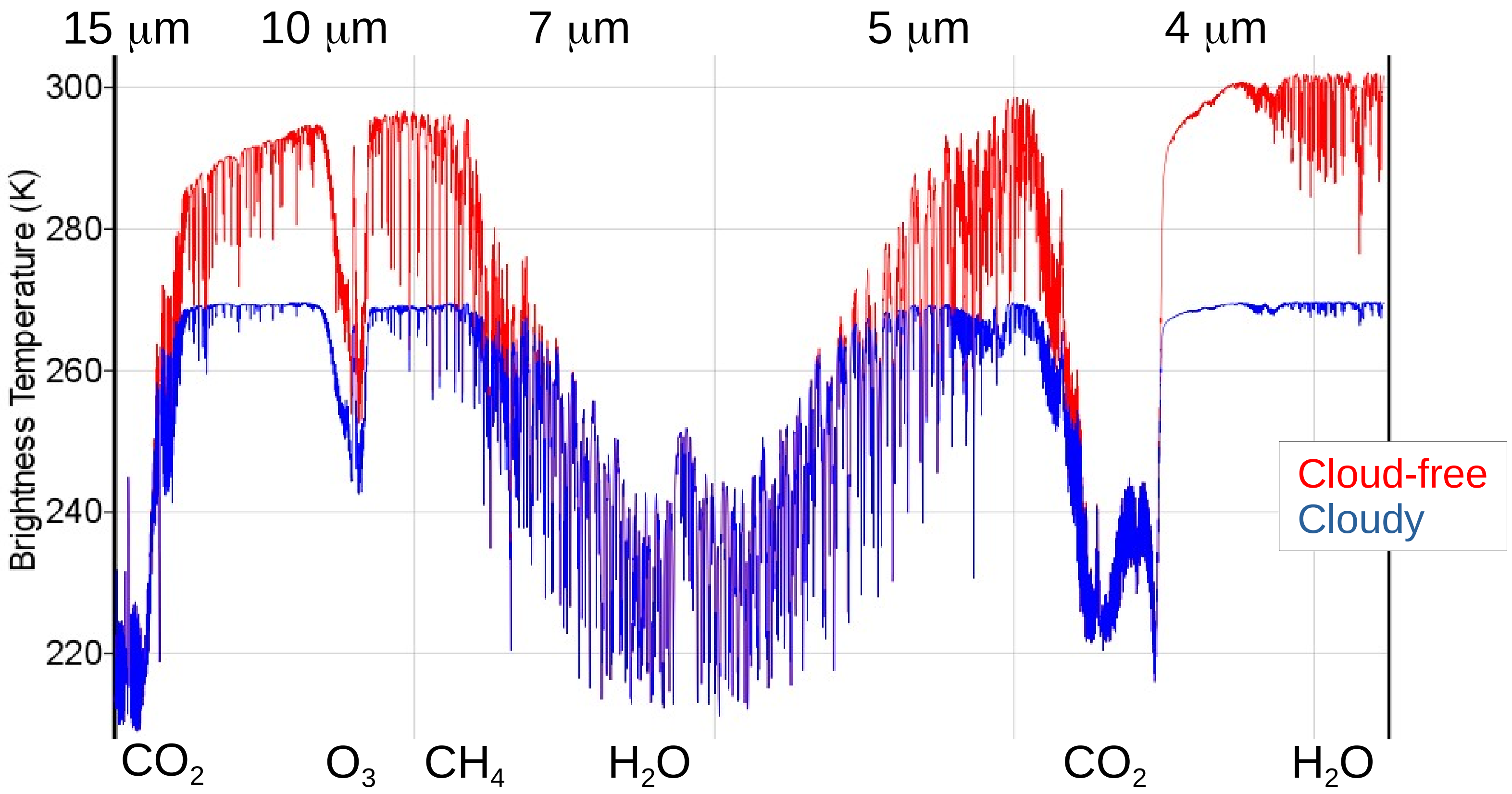
Polar-orbiting satellites used in MetCoOp

(January 2023)

Spacecraft	Launch date	Equatorial crossing in local time * indicates drift	Infrared sounding	Microwave temperature sounding	Microwave humidity sounding	Scatterometer
NOAA-18	**05 / 2005**	**10:25***	(HIRS)	AMSU-A	(MHS)	
NOAA-19	**02 / 2009**	**08:20***	(HIRS)	AMSU-A	MHS	
Suomi-NPP	**10 / 2011**	**01:25**	CrIS	ATMS		
Metop-B	**09 / 2012**	**09:30**	IASI	AMSU-A	MHS	ASCAT
FengYun-3D	**11 / 2017**	**02:00**	HIRAS	MWTS2	MWHS2	
NOAA-20	**11 / 2017**	**01:25**	CrIS	ATMS		
Metop-C	**11 / 2018**	**09:30**	IASI	AMSU-A	MHS	ASCAT

Currently in use	Preoperational	Lower priority	(No data access)

Infrared absorption spectrum



NWP applications rely primarily on

→ 15 μm CO_2 band for temperature sounding
→ 5-8 μm H_2O band for humidity sounding

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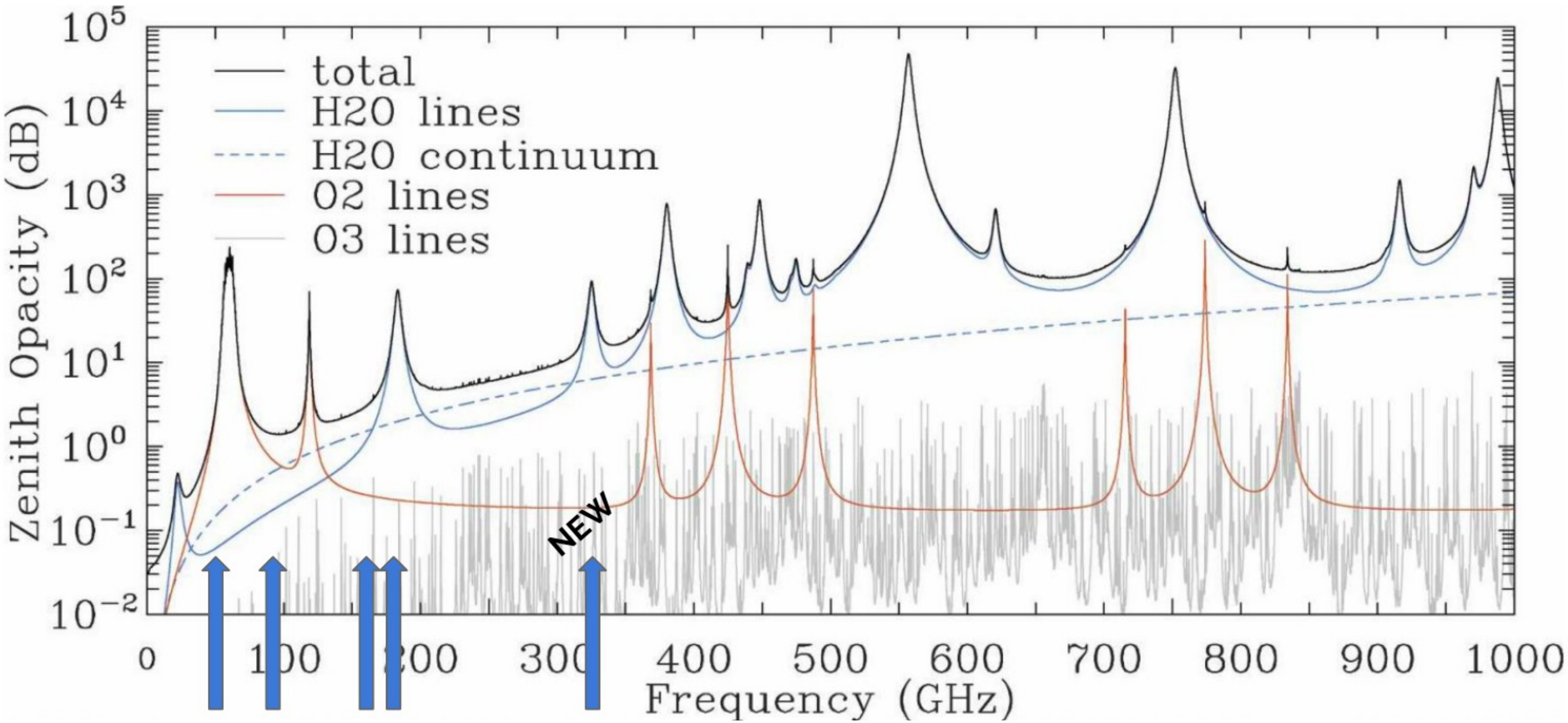
Microwave absorption spectrum



NWP applications rely primarily on

→ 54 GHz O_2 line for temperature sounding
→ 183 GHz H_2O line for humidity sounding

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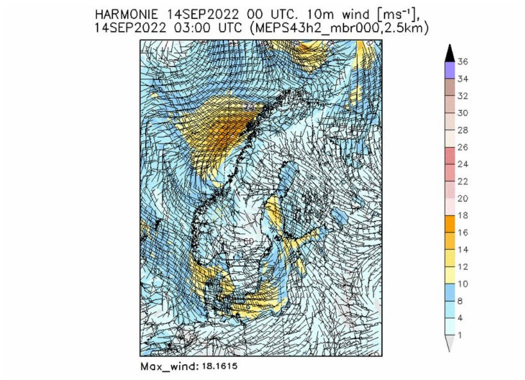
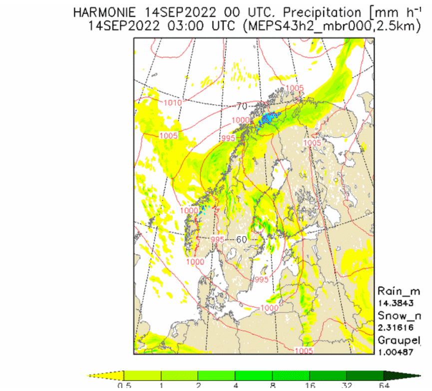
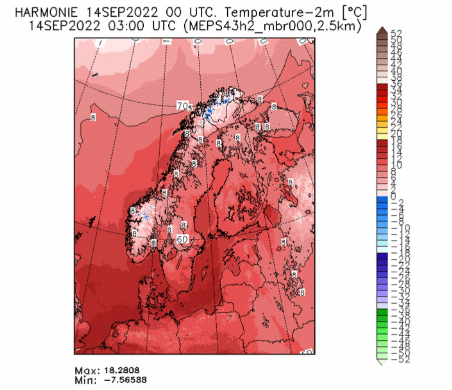
Forward modelling (conceptual)







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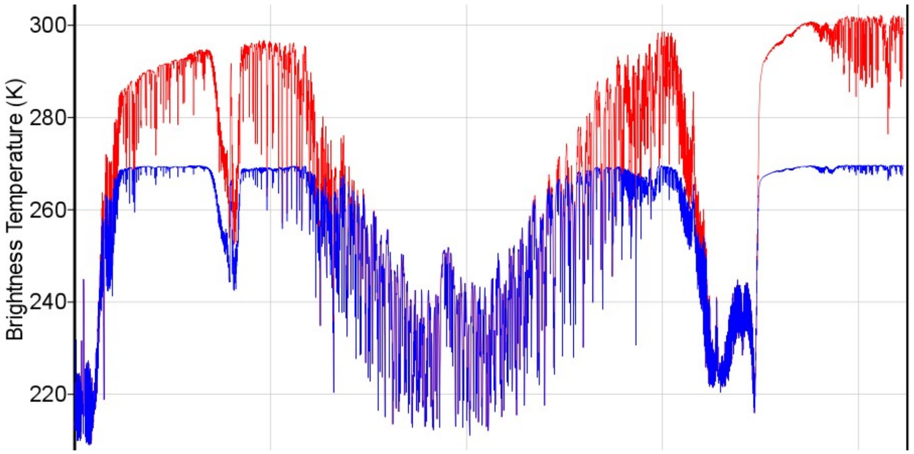

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Tip: compare real imagery with simulation at

https://nwp-saf.eumetsat.int/cssim

Introduction

Current version: v13.1 November 2021

RTTOV (Radiative Transfer for TOVS) is a very fast radiative transfer model for passive visible, infrared and microwave downward-viewing satellite radiometers, spectrometers and interferometers. It is a FORTRAN 90 code for simulating satellite radiances, designed to be incorporated within user applications. The following paper gives an overview of the model and should be used when citing RTTOV:

Saunders, R., Hocking, J., Turner, E., Rayer, P., Rundle, D., Brunel, P., Vidot, J., Roquet, P., Matricardi, M., Geer, A., Bormann, N., and Lupu, C., 2018: An update on the RTTOV fast radiative transfer model (currently at version 12), Geosci. Model Dev., 11, 2717-2737, https://doi.org/10.5194/gmd-11-2717-2018.

RTTOV Overview [hide]

Given an atmospheric profile of temperature, water vapour and, optionally, trace gases, aerosols and hydrometeors, together with surface parameters and a viewing geometry, RTTOV computes the top of atmosphere radiances in each of the channels of the sensor being simulated.

Satellite (radiance) instruments used in MetCoOp

Advanced <u>Microwave</u> Sounding Unit -A (**AMSUA**)
→ *Temperature* sounding

<u>Microwave</u> Humidity Sounding (**MHS**)
→ *Humidity* sounding

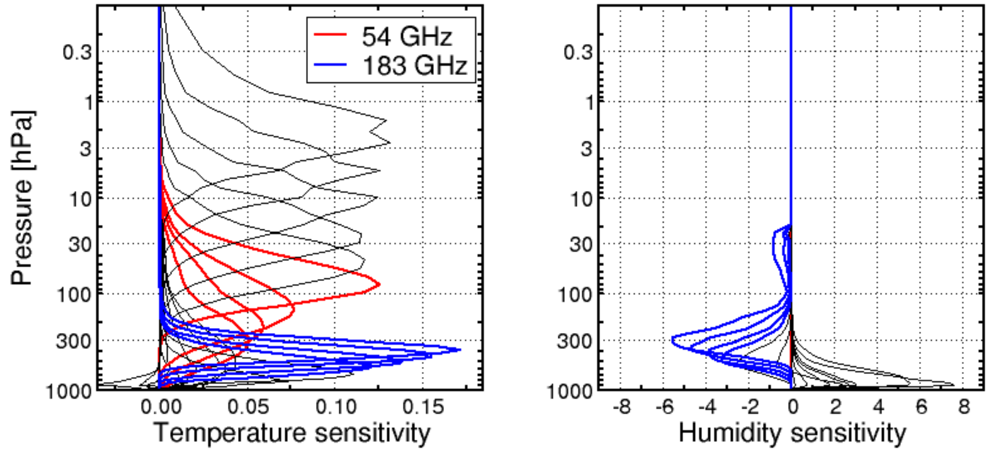
Advanced Technology <u>Microwave</u> Sounder (**ATMS**)
→ *Temperature* and *humidity* sounding

<u>Micro-Wave</u> Humidity Sounder -2 (**MWHS2**)
→ *Humidity* sounding

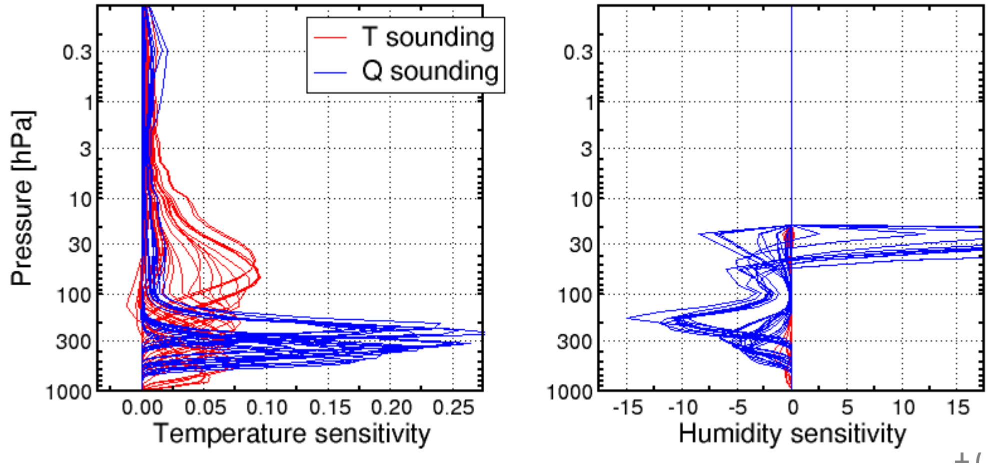
<u>Infrared</u> Atmospheric Sounding Interferometer (**IASI**)
→ *Temperature* and *humidity* sounding

Cross-track <u>Infrared</u> Sounder (**CrIS**)
→ *Temperature* and *humidity* sounding

ATMS weighting functions



IASI weighting functions



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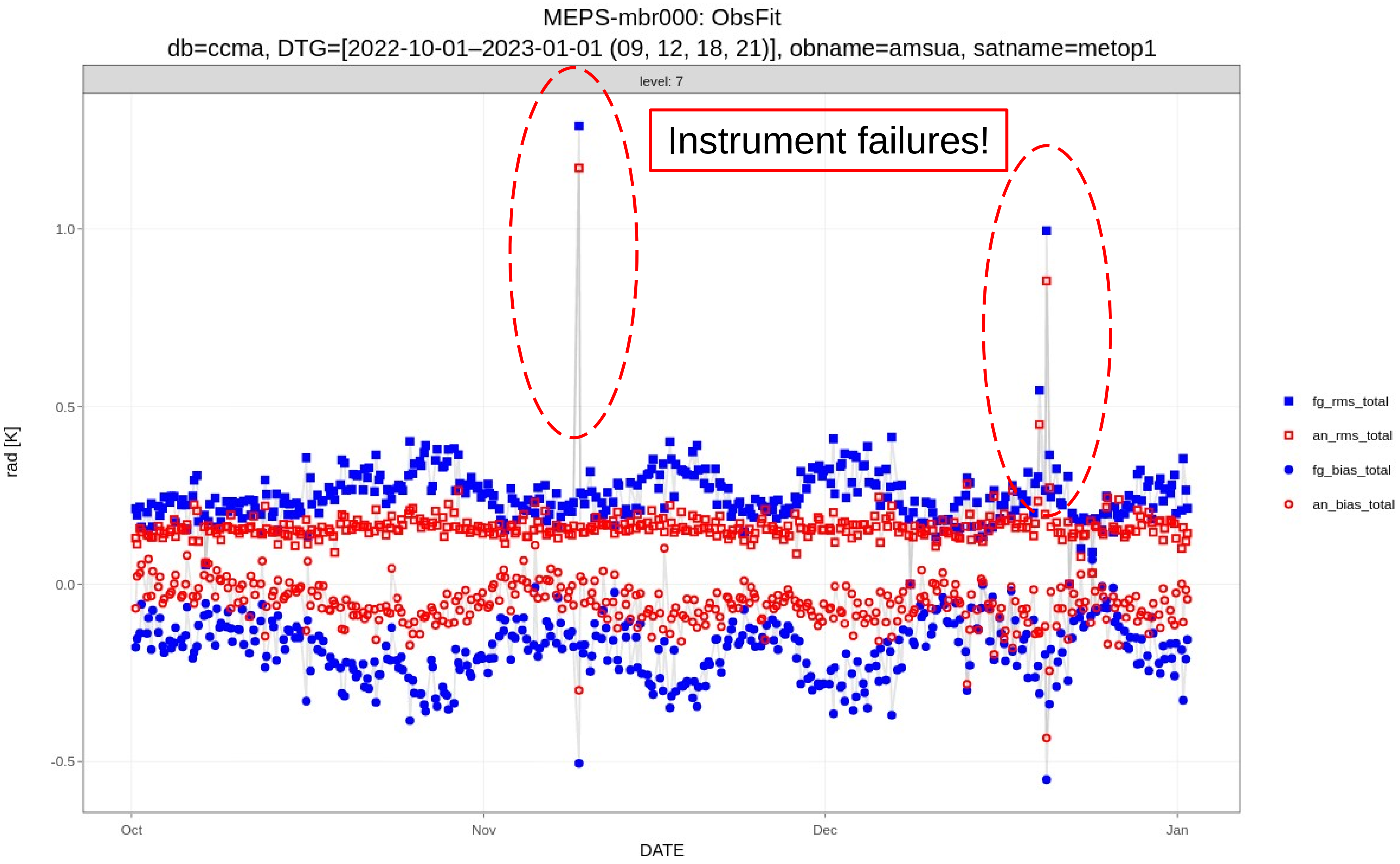
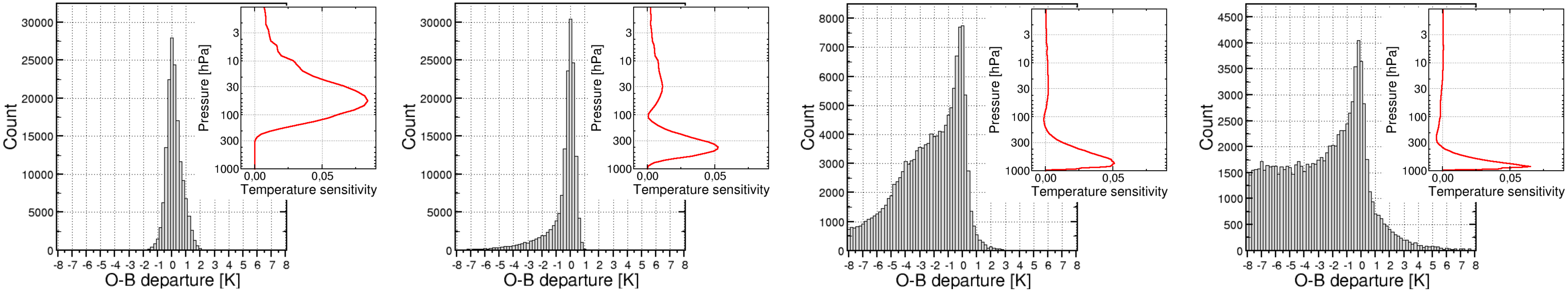
Handling of gross errors in radiance data



Handling of gross errors in radiance data



Cloud is the most significant source of gross error in infrared radiance data
→Particularly disturbing on channels that are sensitive to lower troposphere

In general, gross errors may originate from any such process that is not accounted for in the observation operator:

- Technical instrument failures
- Scattering of solar radiation
- Dust and other aerosol
- Rain and snow
- Radio frequency interference (RFI)

Handling of gross errors in radiance data

How to detect cloud contamination in infrared sounder data:

Following the ideas of McNally & Watts (2003):

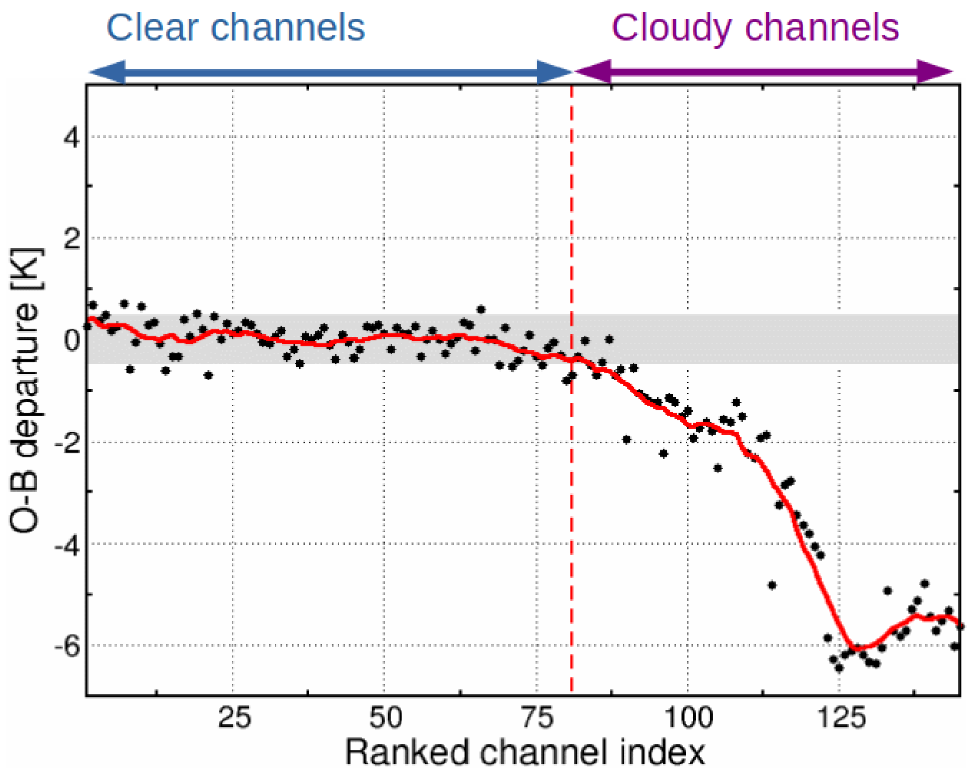
-Take a large number of channels in the 15 μm CO_2 absorption band

-Compute observation minus background (O-B) departures in each channel (using RTTOV)

-Rank the (O-B) departures in vertical and apply a smoothing filter

-Find the distinction between clear and cloud-affected channels: this is where the smoothed curve starts to “go down”

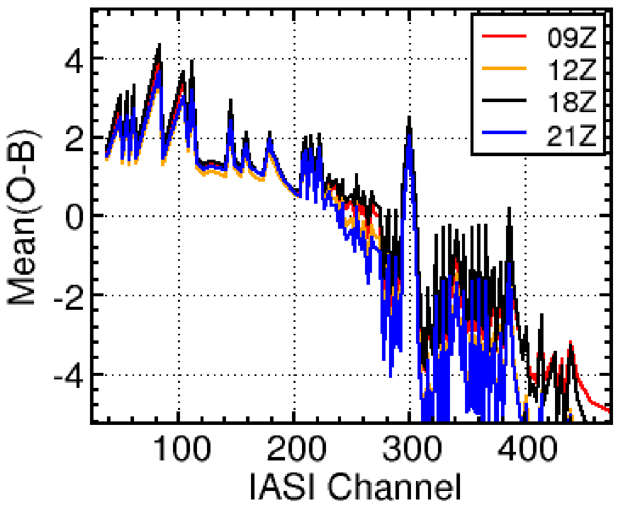
This process repeats at every observation location (up to several thousands of data points at each analysis time)



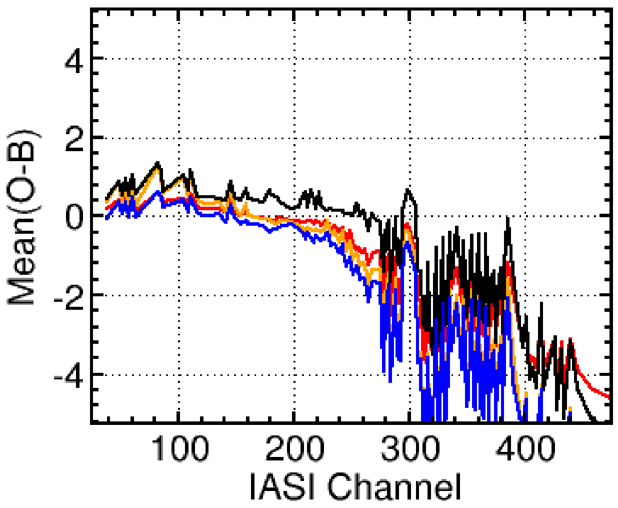
McNally & Watts (2003): *A cloud detection algorithm for high-spectral-resolution infrared sounders.* https://doi.org/10.1256/qj.02.208

Handling of systematic errors in radiance data

Before correcting for bias



After correcting for bias



Observation bias in radiance data can be due to special characteristics of microwave/infrared sounding instrument, or they can originate from inaccuracies in radiative transfer calculations or quality control processes.

In MetCoOp systems, limited ability to represent stratospheric radiance contributions is a major source of systematic error.

Handling of systematic errors in radiance data

$$b = \sum_{i=0}^{N^j-1} \beta_i^j p_i^j$$

Bias correction for one observation

Bias parameters

Bias predictors

Variational Bias Correction (VarBC) works by estimating the bias parameters internally during variational data assimilation.

TABLE 1. List of selected predictors in the ARPEGE/ALADIN models.

Predictor No.	Predictor
0	Constant
1	1000–300-hPa thickness
2	200–50-hPa thickness
3	Skin temperature
4	Total column water
5	10–1-hPa thickness
6	50–5-hPa thickness
8	Nadir-viewing angle
9	Nadir-viewing angle **2
10	Nadir-viewing angle **3
11	Nadir-viewing angle **4
15	Land or sea ice mask
16	View angle (land)
17	View angle **2 (land)
18	View angle **3 (land)

Benácek & Mile (2019) https://doi.org/10.1175/MWR-D-18-0359.1

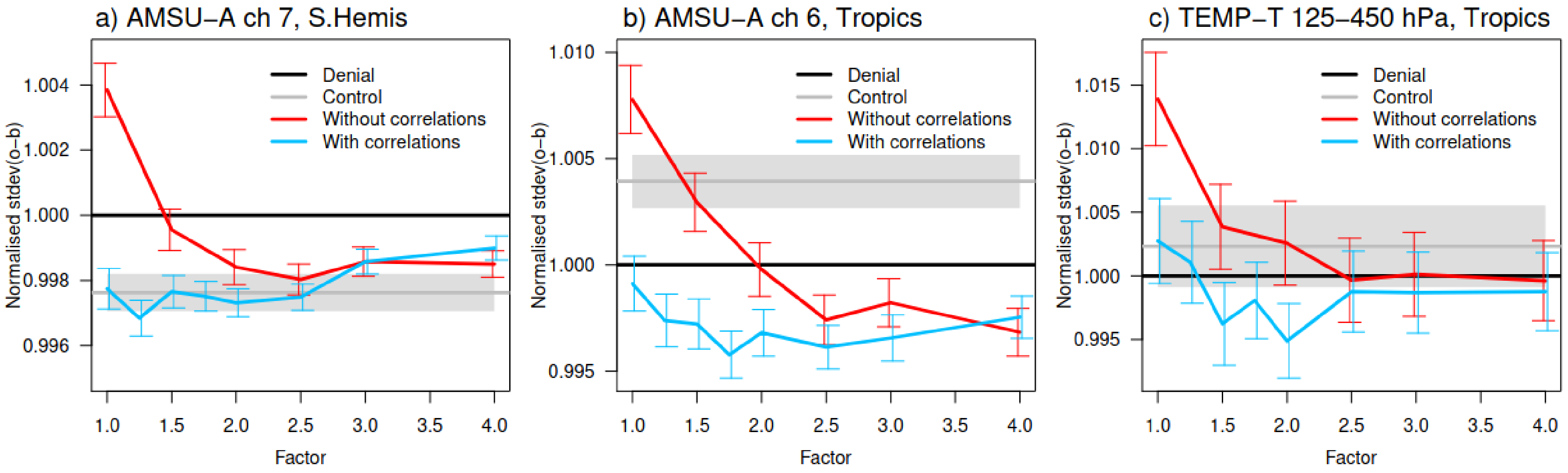
Handling of random errors in radiance data

(inverse of) observation error covariance

$$J(\mathbf{x}) = (\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}_b) + (\mathbf{y} - H[\mathbf{x}])^T \mathbf{R}^{-1} (\mathbf{y} - H[\mathbf{x}])$$

→ This is a relatively easy task, at least as long as observation errors are *mutually uncorrelated* and their *variances are known*

Handling of random errors in radiance data



→Forecast skill as a function of how much extra scaling is applied to IASI observation error variance on top of its diagnostic estimate

→Finding the optimal setting can be “trial and error”

From: Bormann et al. (2015), ECMWF Technical Memorandum 756

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Conclusion

Extensive use of microwave and infrared sounding radiances from polar-orbiting satellites

- Metop satellites
- NOAA and S-NPP satellites
- Fengyun 3 polar orbiters

The data is assimilated in terms of radiance (brightness temperature), using a fast radiative transfer software for conversion from NWP model state to observation space

It is essential to pay attention to proper handling of gross, systematic and random errors in observations