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The impact of microwave sounder radiance assimilation in the Nordic and Arctic regions

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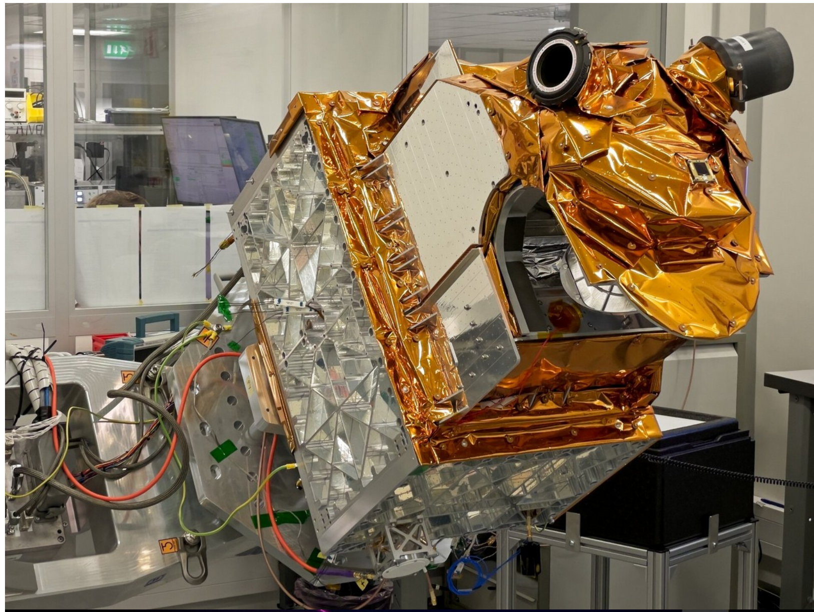
Arctic Weather Satellite (AWS) is coming – are we ready?

– Launch 2024/Q3
– AWS will include *microwave sounding* capability with channels sensitive to atmospheric temperature and humidity

– Serves as a demonstrator mission for the EUMETSAT *EPS-Sterna constellation*:
→ Targeting continued maintenance of six operational low-cost satellites in a constellation of three complementary orbital planes from 2029 onwards

– Research funding from the European Space Agency (ESA) to support early exploitation of AWS satellite data in NWP
→ *"Performance evaluation of the Arctic Weather Satellite data"*
→ *A four-year project kicked off in December 2021*
→ *WP2: Preparing the HARMONIE-AROME system for AWS radiances (see Magnus Lindskog's presentation)*
→ ***WP3: Constellation Impact Studies***

– As a 1st step, we evaluate the <u>*expected constellation impact*</u> on the basis of the impact we get from the <u>*currently operating*</u> microwave sounders



Figures (c) ESA

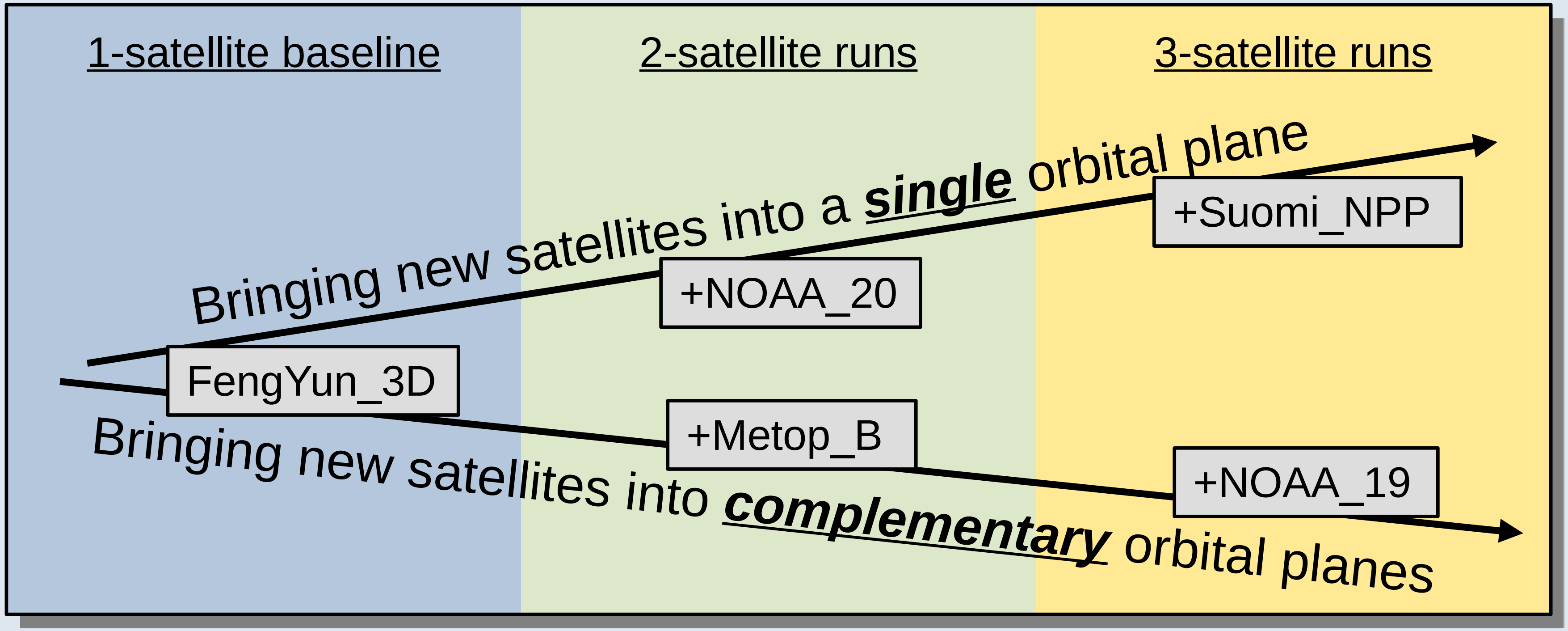
The currently operating satellites with microwave sounding capability

Orbit group	Spacecraft	Launch date	Equatorial crossing in local time	Microwave temperature sounding	Microwave humidity sounding
*Satellites in **drifting** orbits (no orbit maintenance)*	NOAA-18	05 / 2005	((10:40))	AMSU-A	(MHS)
	NOAA-19	02 / 2009	((09:10))	AMSU-A	MHS
	FengYun-3D	11/ 2017	((02:25))	(MWTS2)	MWHS2
*Satellites in maintained "**afternoon** orbits"*	Suomi-NPP	10 / 2011	01:30	ATMS	
	NOAA-20	11 / 2017	01:30	ATMS	
	NOAA-21	10 / 2022	01:30	ATMS	
*Satellites in maintained "**morning** orbits"*	Metop-B	09 / 2012	09:30	AMSU-A	MHS
	Metop-C	11 / 2018	09:30	AMSU-A	MHS
*A satellite in a maintained "**early-morning** orbit"*	FengYun-3E	07 / 2021	05:30	(MWTS2)	MWHS2

Currently in use (at MetCoOp)	In passive monitoring (at MetCoOp)	(no support in Harmonie-Arome)	(no fast data access)

Can we simulate the EPS-Sterna constellation using the satellites that are already in orbit?

– Short answer: no, we can’t
– Instead, we will evaluate the impact of bringing new satellites into the assimilation system one by one
– We repeat the exercise in two scenarios:
  → ***”Single orbit”***: all satellites will go into the same orbital plane
  → ***”Complementary orbits”***: satellites will each go into a new orbital plane
– We can go up to 3 satellites in either scenario



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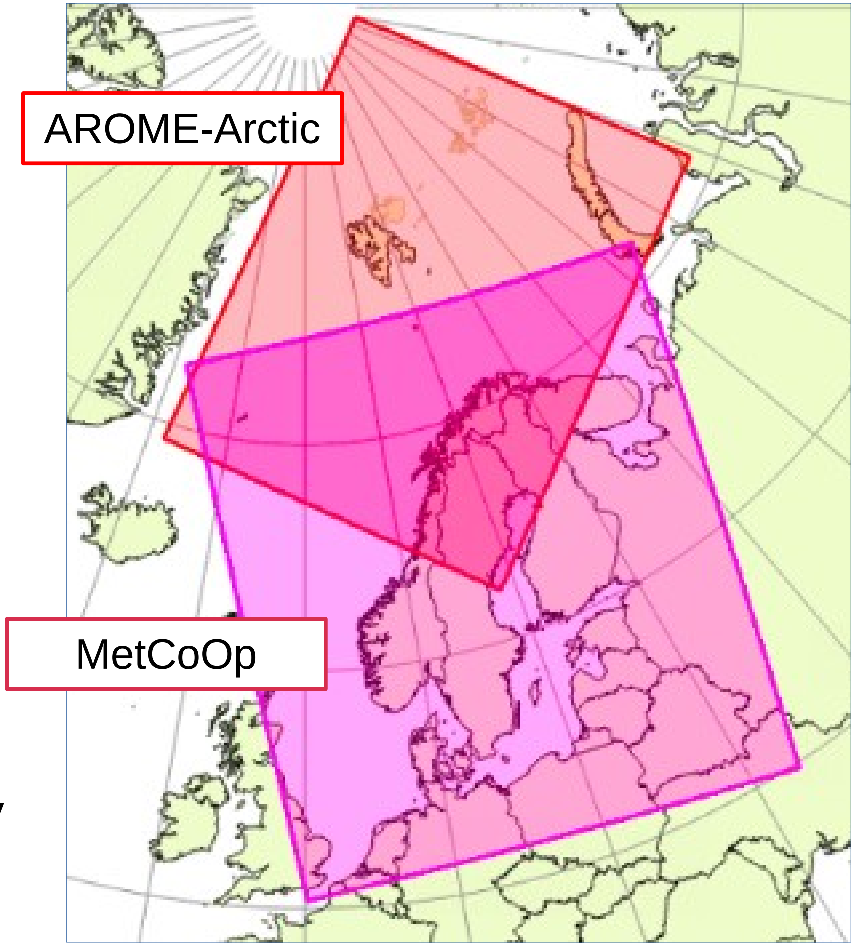
The experiment setup

- We use NWP system settings that are (for most parts) similar to the operational setups at MetCoOp and AROME-Arctic
  - → Harmonie-Arome Cy43
  - → 2.5 km grid and 65 model levels (model top at 10 hPa)
  - → Microwave sounder radiance assimilation in clear-sky conditions only but including the low-peaking channels over sea, sea ice and land

  <u>However:</u>
  - → 4D-Var upper-air data assimilation (rather than 3D-Var as in operations)
  - → Only deterministic runs (omitting the ensemble system characteristics)
  - → Forecast is run out to +36 lead time four times a day (00, 06, 12, 18 UTC)
  - → Forecast only out to +3 hours at the intermediate 3-hourly cycles

- Five model runs in each domain:
  - → 1-satellite baseline run using microwave-sounder data from FengYun-3D only
  - → 2-satellite run in the single-orbit scenario: add NOAA-20
  - → 3-satellite run in the single-orbit scenario: add NOAA-20 and Suomi-NPP
  - → 2-satellite run in the complementary-orbits scenario: add Metop-B
  - → 3-satellite run in the complementary-orbits scenario: add Metop-B and NOAA-19



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On the choice of experiment dates

– The cost of running 4D-Var limits the time span of the experiment
– But, we also want to run long enough to allow for statistically robust evaluation of the impact
– We are interested in evaluating the impact in winter and in summer
– *To maximize the separation between the three orbital planes, it is useful to choose dates around 2020*

<u>The initial set of model runs</u> (six weeks each):
→ From 29 June to 9 August 2020 in the AROME-Arctic setup
→ From 28 December 2020 to 7 February 2021 in the MetCoOp setup

– The model runs are warm-started from a spun-up model state that includes appropriate initial bias correction coefficients for satellite data

Table 1: Evolution of the equatorial crossing times

	09/2020	09/2021	09/2022	Tendency
Metop_B	09:30	09:30	09:30	~0
NOAA_19	6:20	7:10	8:00	+50 min/year
Suomi_NPP	1:30	1:30	1:30	~0
NOAA_20	1:30	1:30	1:30	~0
FengYun_3D	1:25	1:40	1:55	+15 min/year

On the choice of experiment dates

- To maximize the separation between the three orbital planes, it is useful to choose experiment dates earlier than 2021
- The cost of running 4D-Var limits the time span of the experiment
- But, we also want to run long enough to allow for statistically robust evaluation of the impact
- We are interested in evaluating the impact in winter and in summer

The initial set of model runs (six weeks each):
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Table 1: Evolution of the equatorial crossing times

	09/2020	09/2021	09/2022	Tendency
Metop_B	09:20	09:25	09:30	+5 min/year
NOAA_19	6:20	7:10	8:00	+50 min/year
Suomi_NPP	1:25	1:25	1:25	~0
NOAA_20	1:30	1:30	1:25	~0
FengYun_3D	1:25	1:40	1:55	+15 min/year

+An additional set of model runs (three weeks each):
→ From 29 June to 19 July 2020 in the MetCoOp setup
→ From 28 December 2020 to 17 January 2021 in the AROME-Arctic setup

- The additional model runs include only the 1-satellite baseline and the 3-satellite run in the complementary-orbits scenario

Results

Near-surface temperature, humidity, and cloud forecasts benefit from the satellite data assimilation

–*Verification of the 3-satellite run in the **complementary-orbits** scenario against the 1-satellite baseline run in the MetCoOp domain in winter*

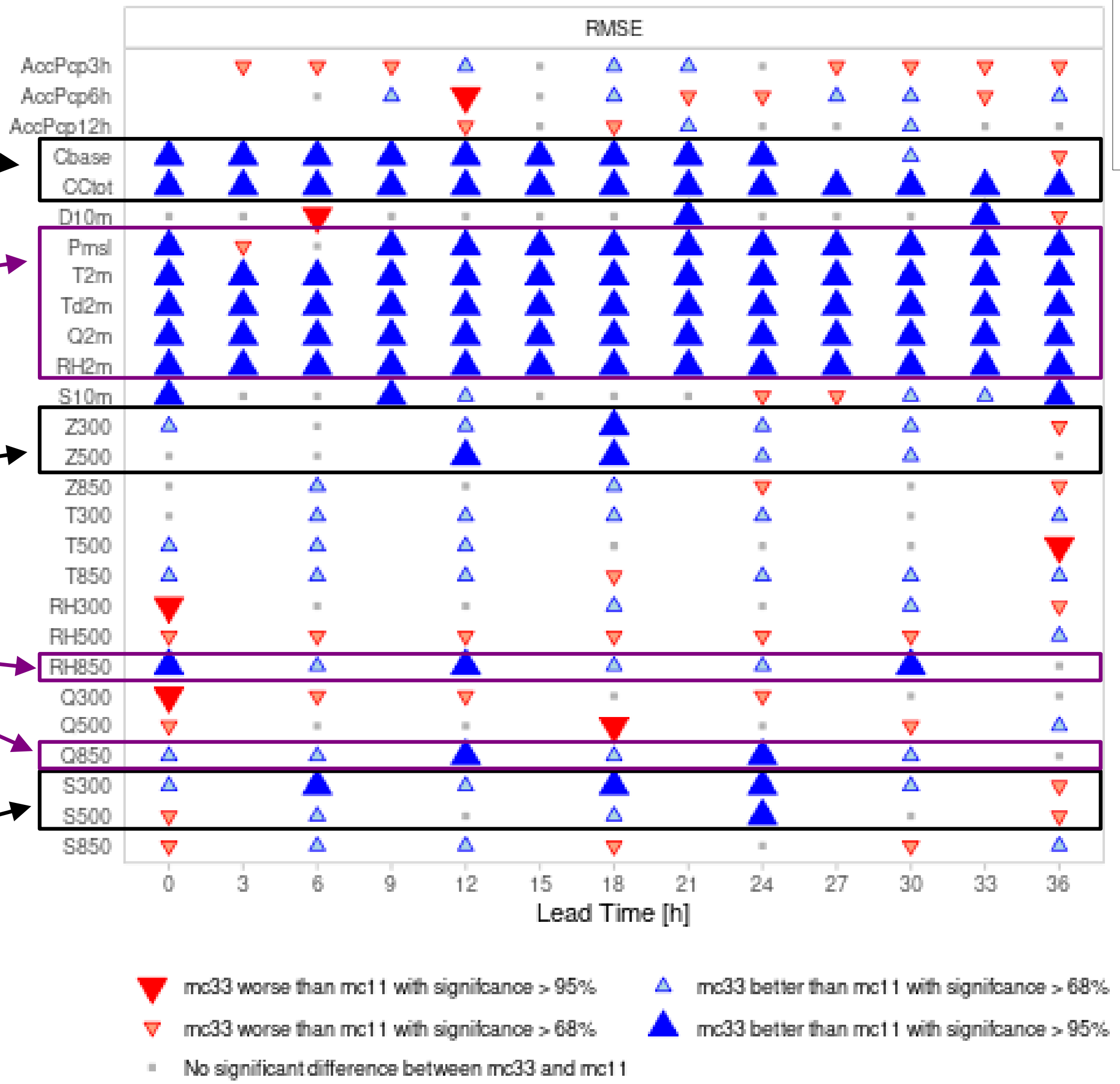
Cloud base altitude and total cloud cover

Mean sea level pressure, near-surface temperature and humidity

Geopotential height at pressure levels in the upper air

Lower-tropospheric humidity

Mid- to upper-tropospheric wind speed



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Near-surface temperature, humidity, and cloud forecasts benefit from the satellite data assimilation

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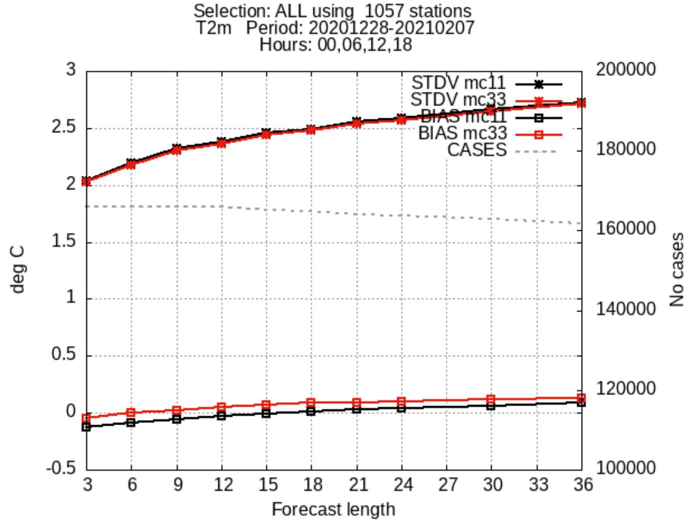
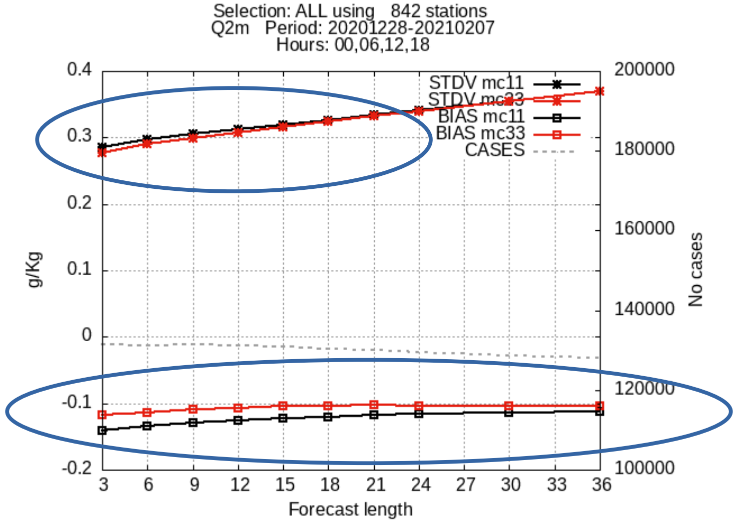
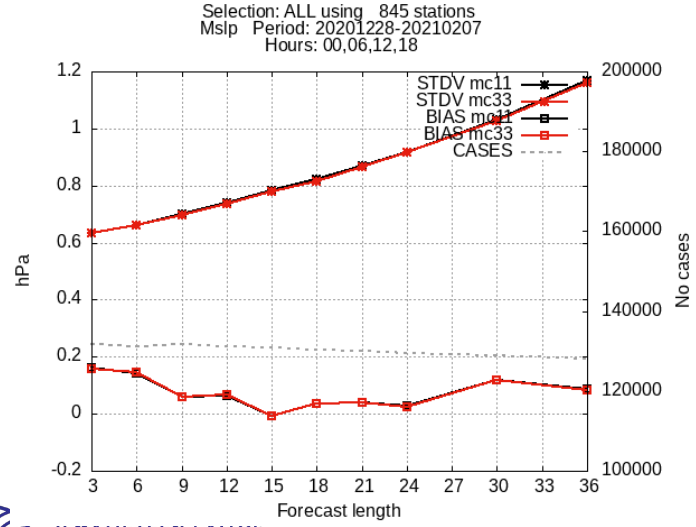
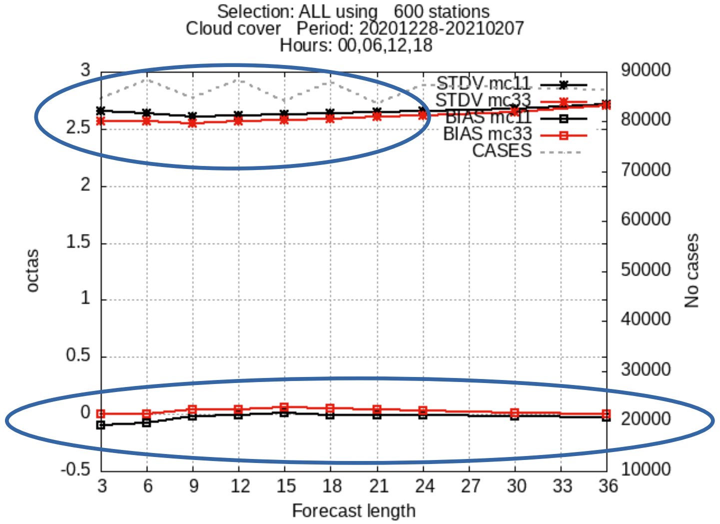
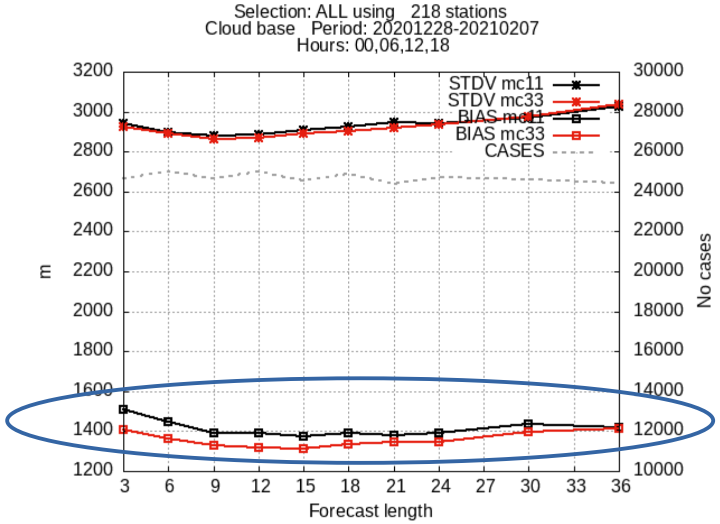




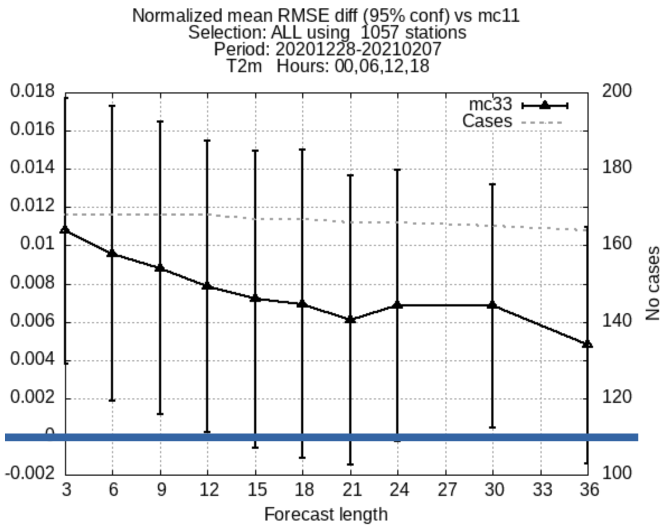


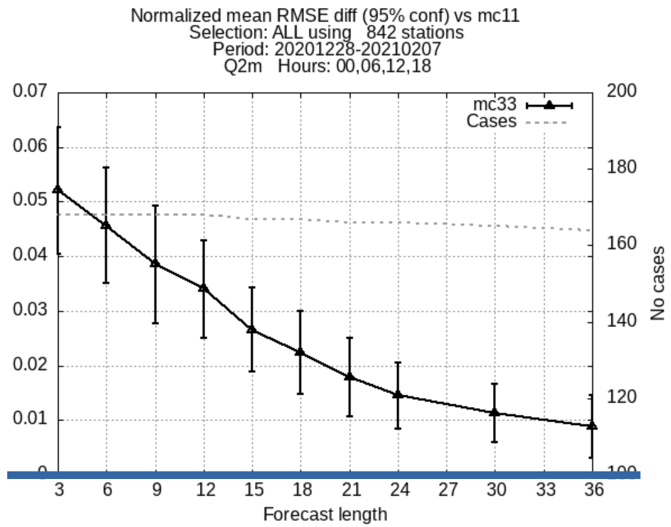


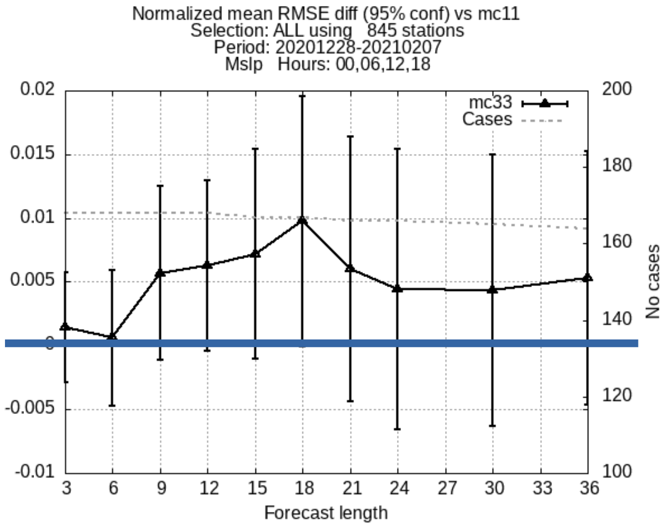


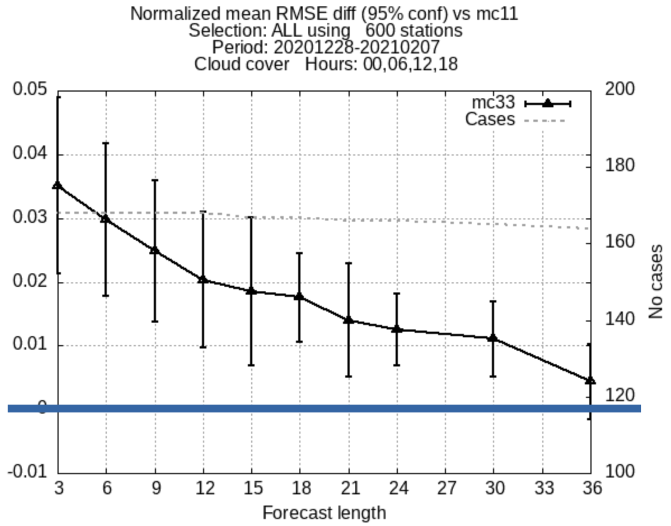
Near-surface <u>temperature</u>, <u>humidity</u>, and <u>cloud</u> forecasts benefit from the satellite data assimilation

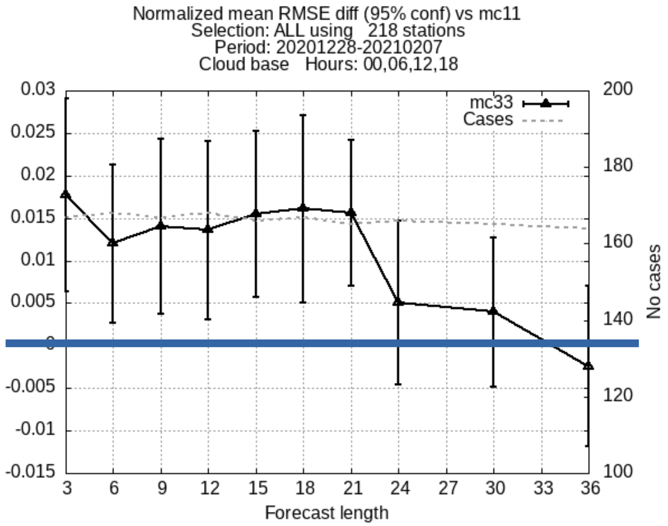
–*Verification of the 3-satellite run in the **complementary-orbits** scenario against the 1-satellite baseline run in the <u>MetCoOp</u> domain in <u>winter</u>*









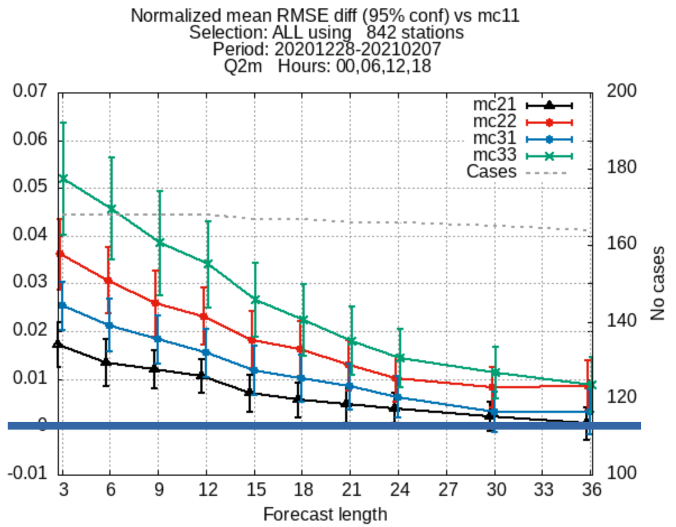


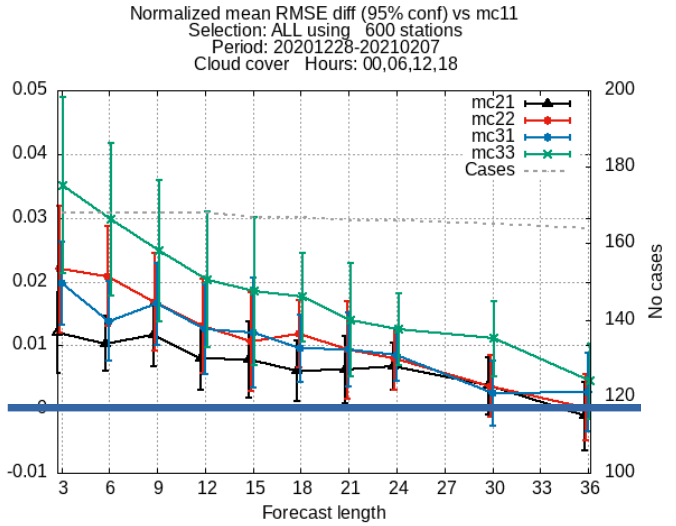
How does the impact from different satellites build up?

–The impact in the "complementary-orbits" scenario is twice as large as the impact in the "single-orbit" scenario:

→In 2-satellite runs: *red* -vs- *black*

→In 3-satellite runs: *green* -vs- *blue*





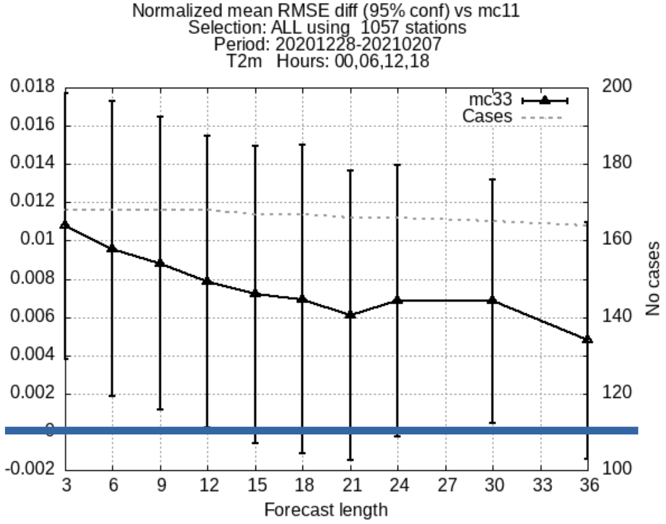
–The impact of 2 additional satellites is <u>50% larger</u> than the impact of 1 additional satellite:

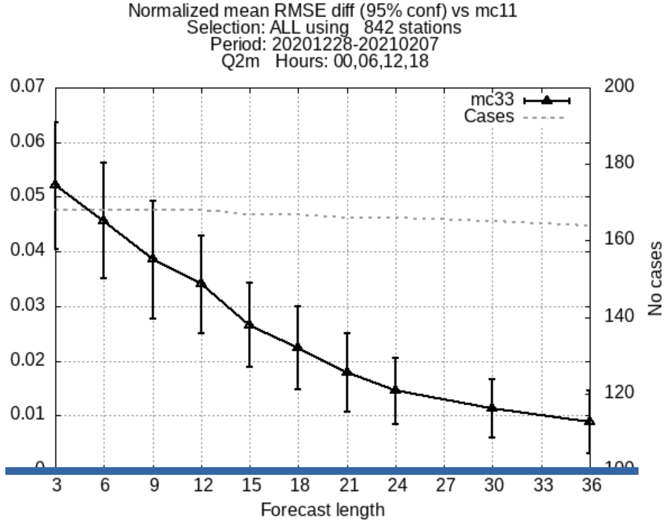
→In the single-orbit scenario: *blue* -vs- *black*

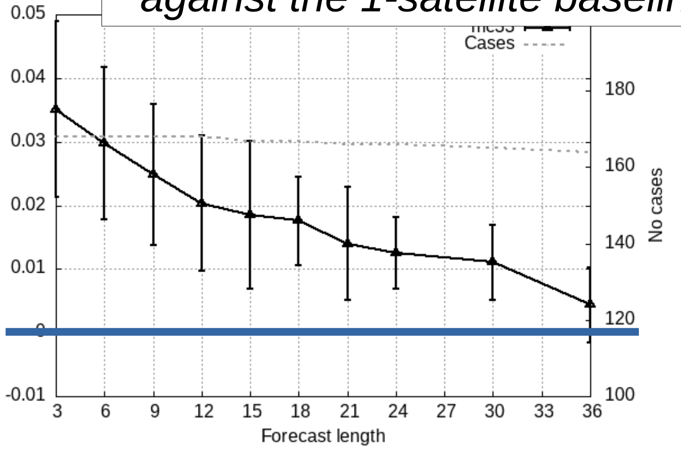
→In the complementary-orbits scenario: *green* -vs- *red* ;

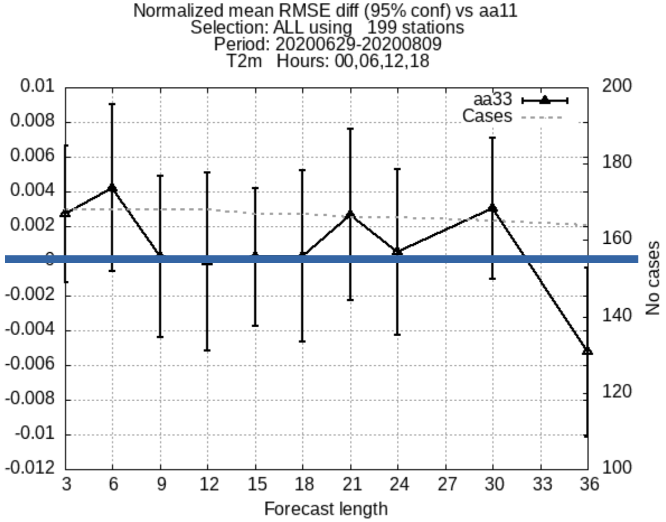
There is more impact in __the MetCoOp domain in winter__ (panels at top) than in __the AROME-Arctic domain in summer__ (panels at bottom)

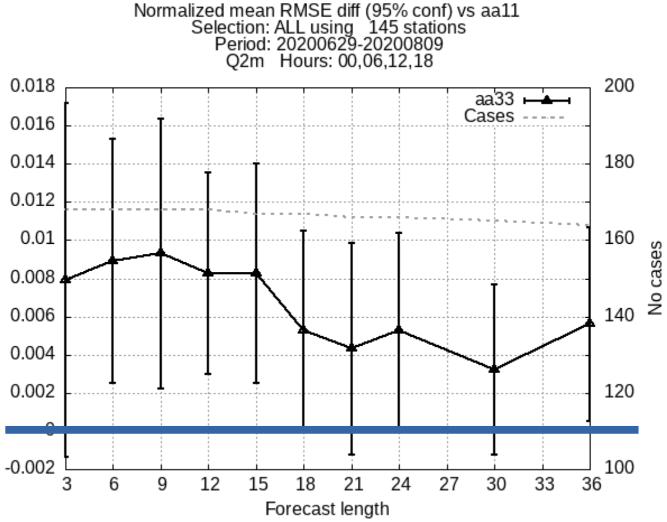
–*Verification of the 3-satellite run in the __complementary-orbits__ scenario against the 1-satellite baseline run*

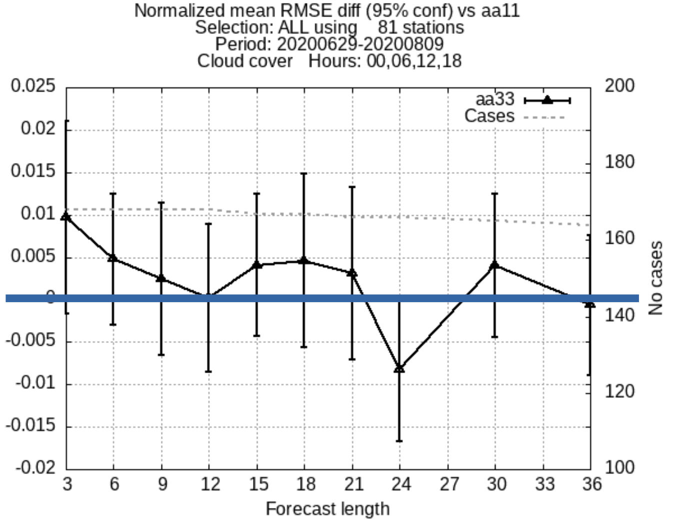






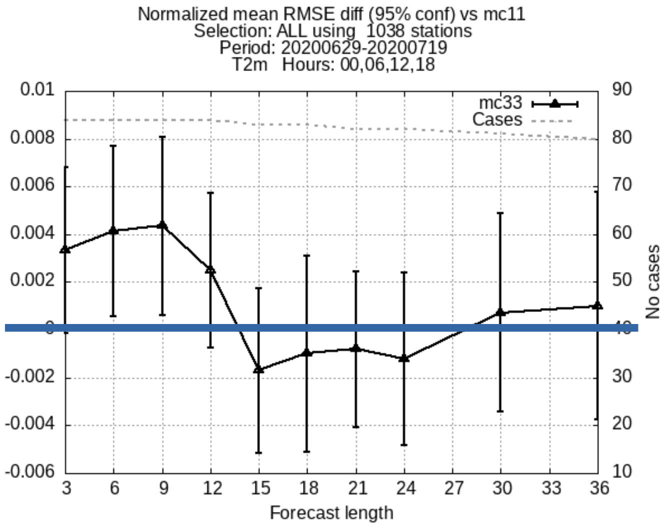


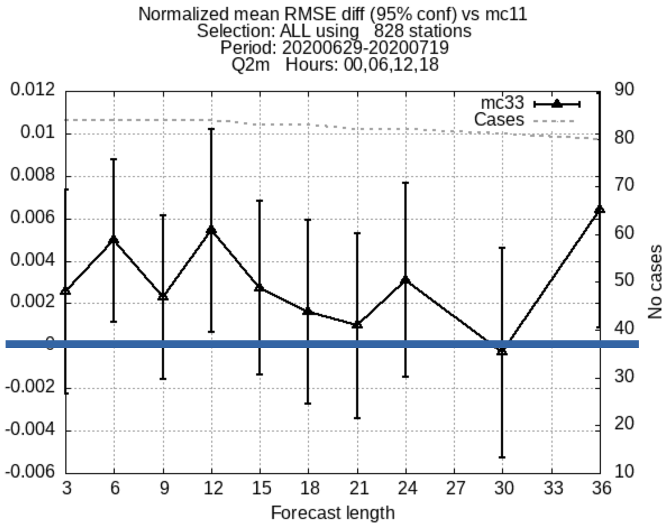


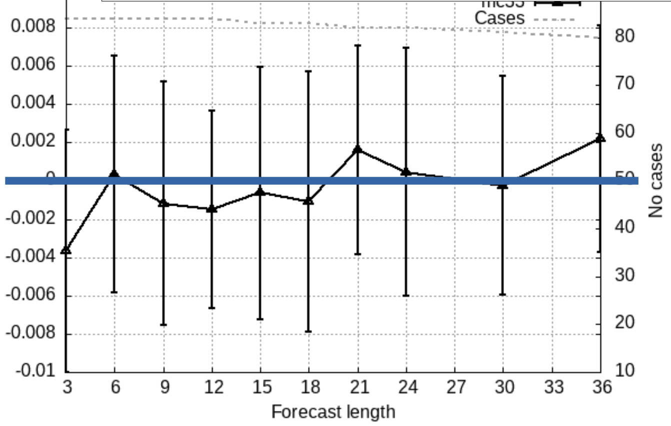


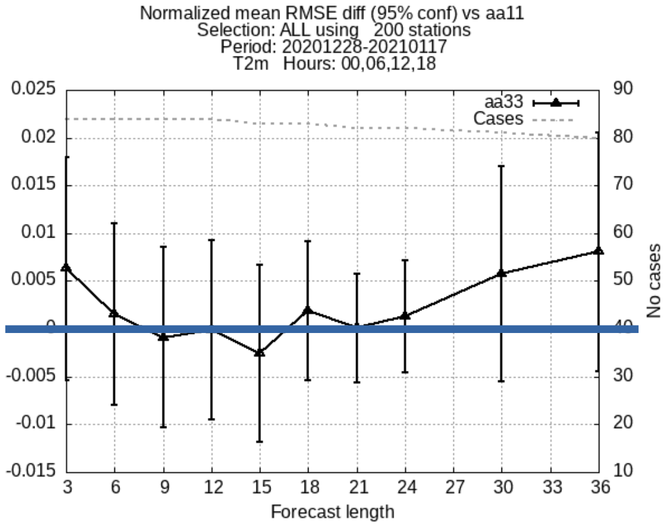
<u>The additional set of model runs</u> shows more impact in the AROME-Arctic domain in winter (bottom) than in the MetCoOp domain in summer (top)

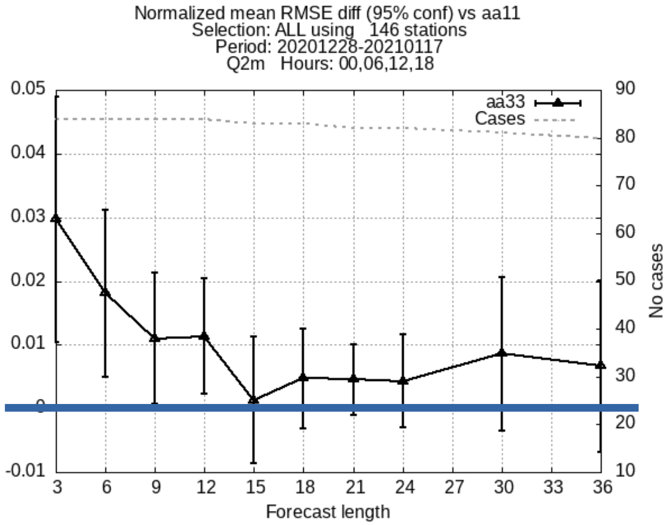
–*Verification of the 3-satellite run in the **<u>complementary-orbits</u>** scenario against the 1-satellite baseline run*

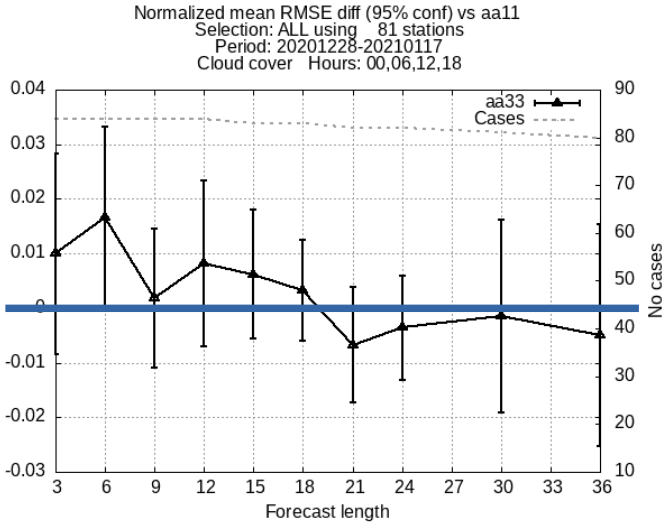












The anticipated impact from the EPS-Sterna constellation in the North

We can expect the following:

→ A boost in the forecast performance in near-surface temperature, humidity and cloud cover

→ The greatest benefit is in the forecast of humidity and cloud cover out to +24 hour lead time

→ The positive impact will be more pronounced in winter than in summer

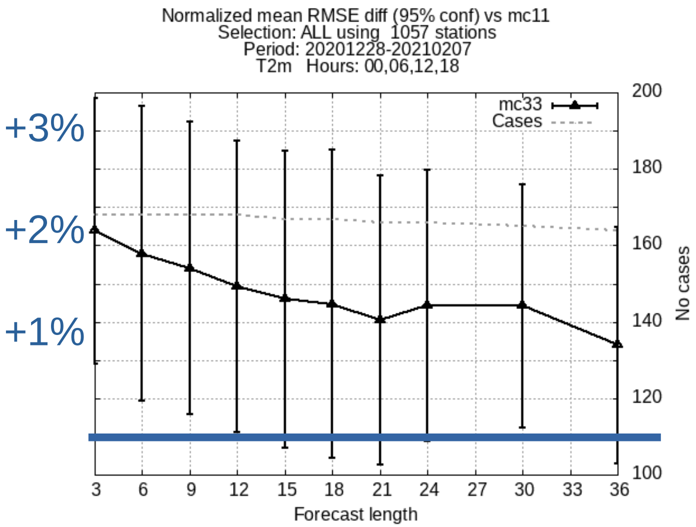
How do we produce a quantitative estimate of the constellation impact?

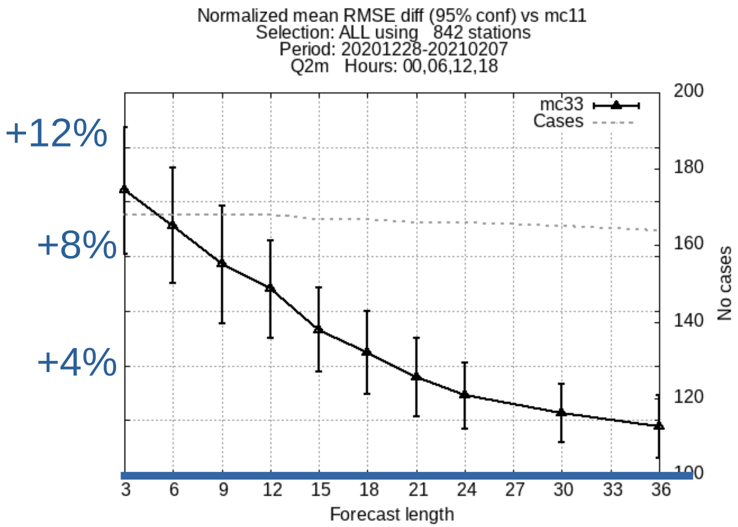
Let's make a series of assumptions:

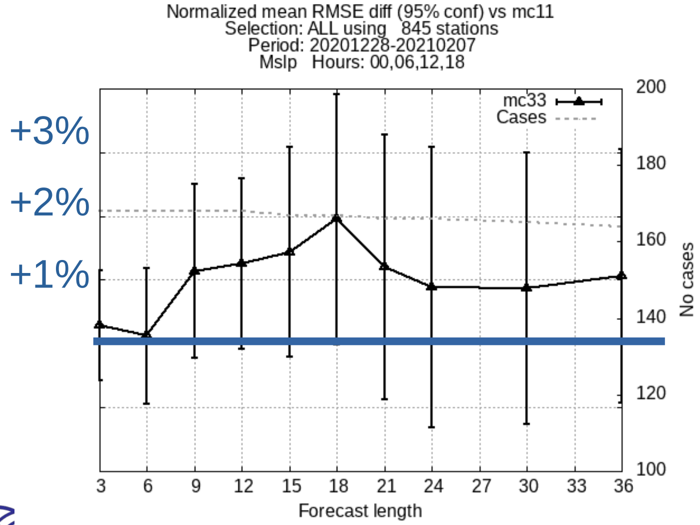
1. The *1-satellite baseline* run of this work is representative of a *state-of-the-art limited-area NWP system* at the time when the EPS-Sterna constellation becomes operational
2. The EPS-Sterna constellation will consist of *six satellites placed in two complementary orbital planes* (i.e. three satellites in each plane)
3. The impact of *two satellites added into complementary orbits* is representative of a hypothetical impact from a combination of *two AWS satellites operated in complementary orbital planes*
4. *Doubling the number of added satellites* will enhance the constellation impact *by 50%*
5. Another *50% increase* in the number of new satellites will enhance the constellation impact by *another 25%*

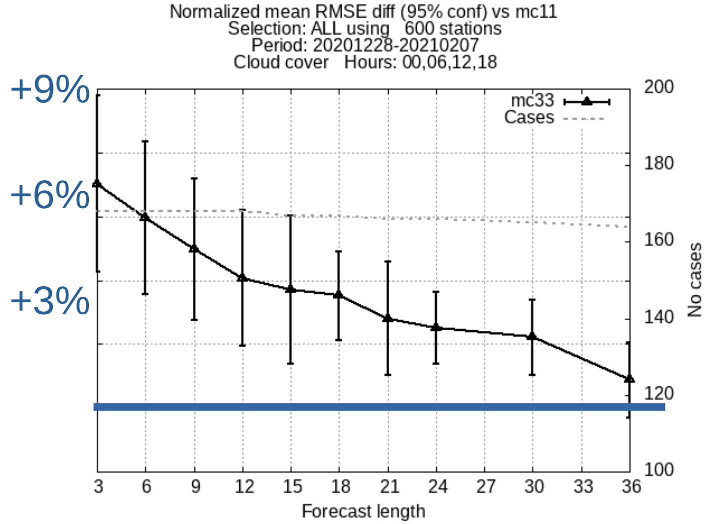
The constellation impact may be *up to ~80...90% larger* than the impact we have demonstrated for the three-satellite, complementary-orbits run against the one-satellite baseline

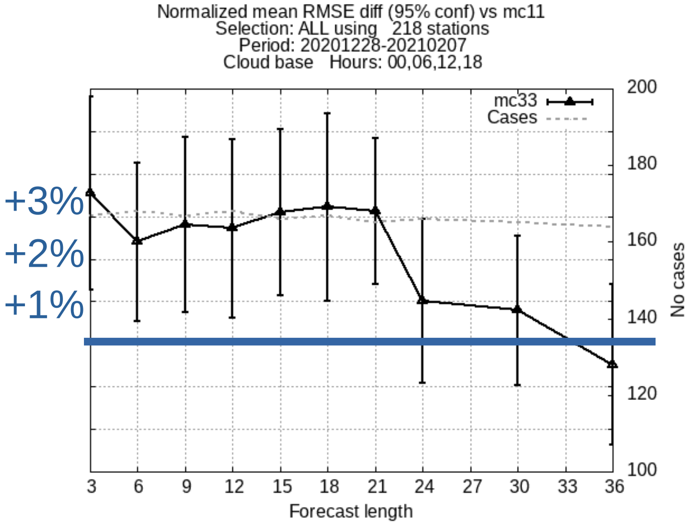
The anticipated impact from the EPS-Sterna constellation in the North











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Summary

–The verification suggests a stronger impact from microwave sounders in winter than in summer

–There is a robust impact in the forecast of near-surface temperature and humidity as well as cloud cover, but no solid evidence of impact in upper-air forecast fields

–In terms of forecast RMSE reduction, the EPS-Sterna constellation impact may be up to 5-10% in cloud cover and humidity, but only up to 2-3% in temperature

–This impact evaluation is based on the current modelling and assimilation system: there will be NWP developments in the coming years that may potentially enhance the impact further.