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The Impact of Microwave Sounder Radiance Assimilation in Convective-scale Limited-area NWP over the Nordic Region and in the Arctic

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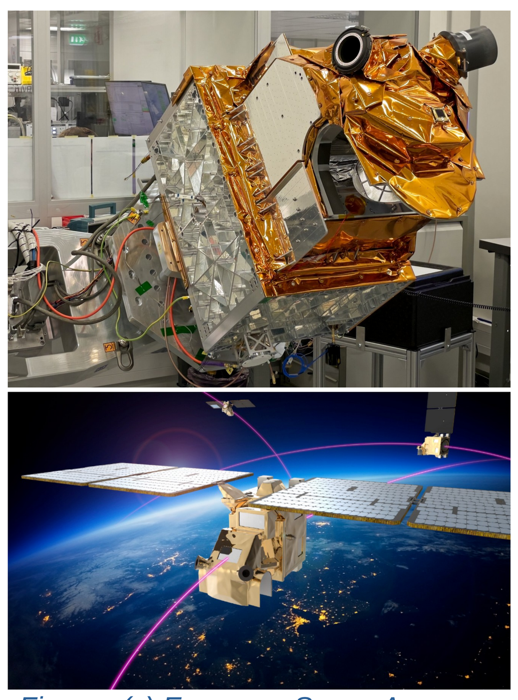
The Arctic Weather Satellite and the EPS-Sterna satellite constellation

– The 1st **Arctic Weather Satellite** (AWS) was launched into a polar orbit in August 2024
– AWS includes a microwave sounder with channel sensitivities to atmospheric temperature and humidity at the 54, 183, and 325 GHz absorption bands

– AWS serves as a demonstrator mission for the ***EPS-Sterna*** constellation:
→The constellation will include continued maintenance of six operational low-cost satellites in placed in three complementary orbital planes from 2029 onwards

– The Nordic NWP centres are receiving research funding from the European Space Agency (ESA) to support early exploitation of AWS satellite data
→SMHI is leading a four-year project that was kicked off in December 2021

– One of the project objectives is to evaluate *the expected EPS-Sterna constellation impact* on the basis of the impact that we get from *the currently operating microwave sounders*



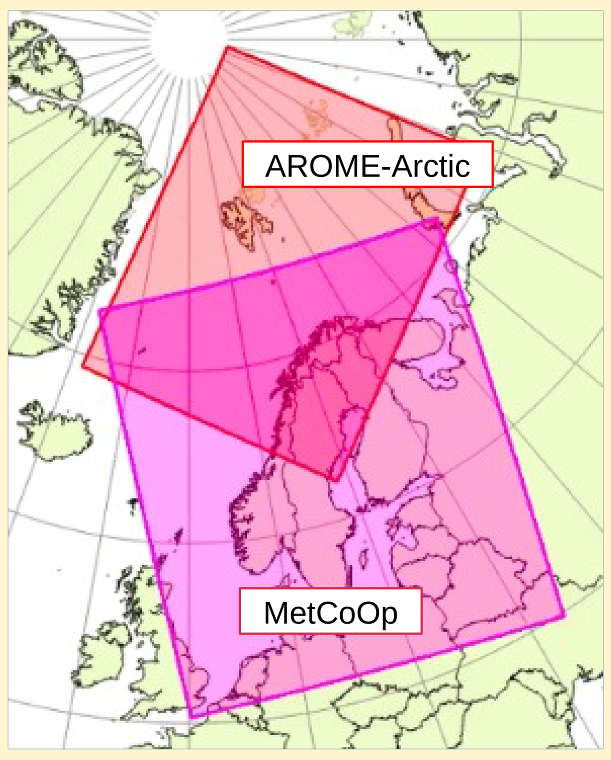
Figures (c) European Space Agency

Summary of the results

– The verification suggests a robust impact in the forecast of near-surface temperature and humidity as well as cloud cover, but evidence of impact in upper-air forecast fields is limited
– The microwave radiance impact is stronger in Winter than in Summer
– In terms of forecast RMSE reduction, the impact of the EPS-Sterna constellation may be up to 5-10% in cloud cover and humidity, but only up to 2-3% in temperature
– This evaluation is based on the current modelling and data assimilation system: there will be NWP developments in the coming years that may potentially enhance the impact further

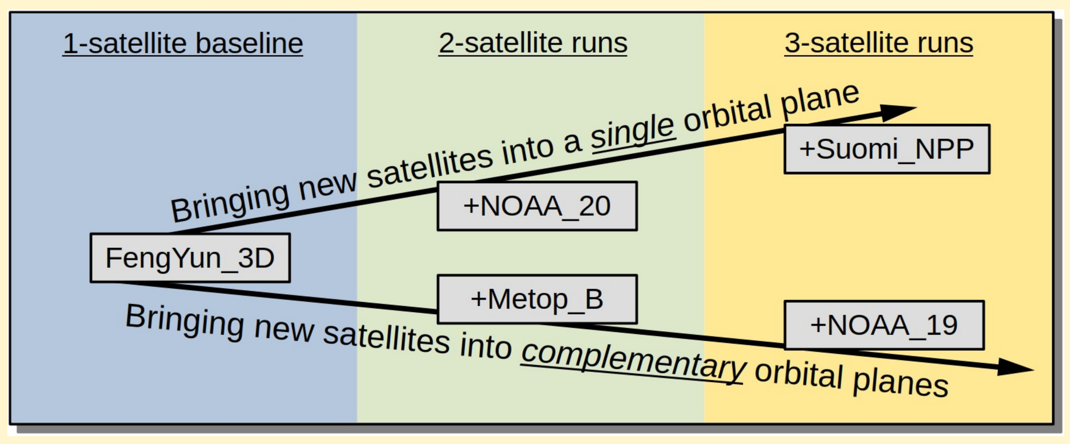
How do we evaluate the expected EPS-Sterna constellation impact using the currently operational microwave radiance data?

– We use NWP system setups that are similar to the operational configurations used at the Nordic meteorological offices:
→**MetCoOp** (joint effort of FMI, MET Norway, SMHI, and the Estonian and Latvian meteorological offices)
→**AROME-Arctic** (maintained and operated by MET Norway)
– The NWP systems are built on top of reference architectures provided by the International High Resolution Limited Area Model (HIRLAM) programme
– They use 2.5 km horizontal grids on 65 model levels that extend from approximately 12 meters to 10 hPa in the vertical
– The assimilation of microwave sounder radiance data is **only in clear-sky conditions** but includes the use of the **low-peaking channels** over all surface types
– The analysis of upper-air meteorological variables is done using the four-dimensional variational assimilation (4D-Var) method
– Maximum forecast range is +36 hours
– Lateral boundary forcing to the regional forecast is received from ECMWF



The experiment setup

– We evaluate the impact of bringing new satellites into the 4D-Var assimilation system one by one
– We make use of two alternative scenarios and go up to three satellites in each:
→***"Single orbit"***: all satellites go into the same orbital plane
→***"Complementary orbits"***: each satellite goes into a new orbital plane

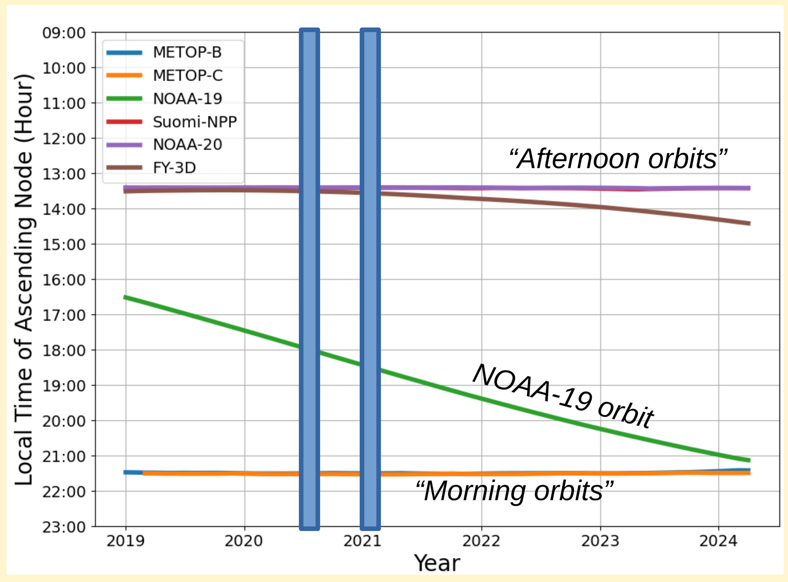


– Five NWP system runs are produced in both the MetCoOp and AROME-Arctic domains:
→1-satellite *baseline run* using microwave data from FengYun-3D only
→2- and 3-satellite runs in the single orbit scenario: adding NOAA-20 and S-NPP on top of the baseline
→2- and 3-satellite runs in the complementary-orbits scenario: adding Metop-B and NOAA-19 on top of the baseline

The initial set of model runs (6 weeks each)
– Running the complete set of five NWP system runs:
→29 June – 9 August 2020 in the AROME-Arctic domain
→28 December 2020 – 7 February 2021 in the MetCoOp domain

The additional set of model runs (4 weeks each):
– Running only the 1-satellite baseline and the 3-satellite run in the complementary-orbits scenario
→29 June – 26 July 2020 in the MetCoOp domain
→28 December 2020 – 24 January 2021 in the AROME-Arctic domain

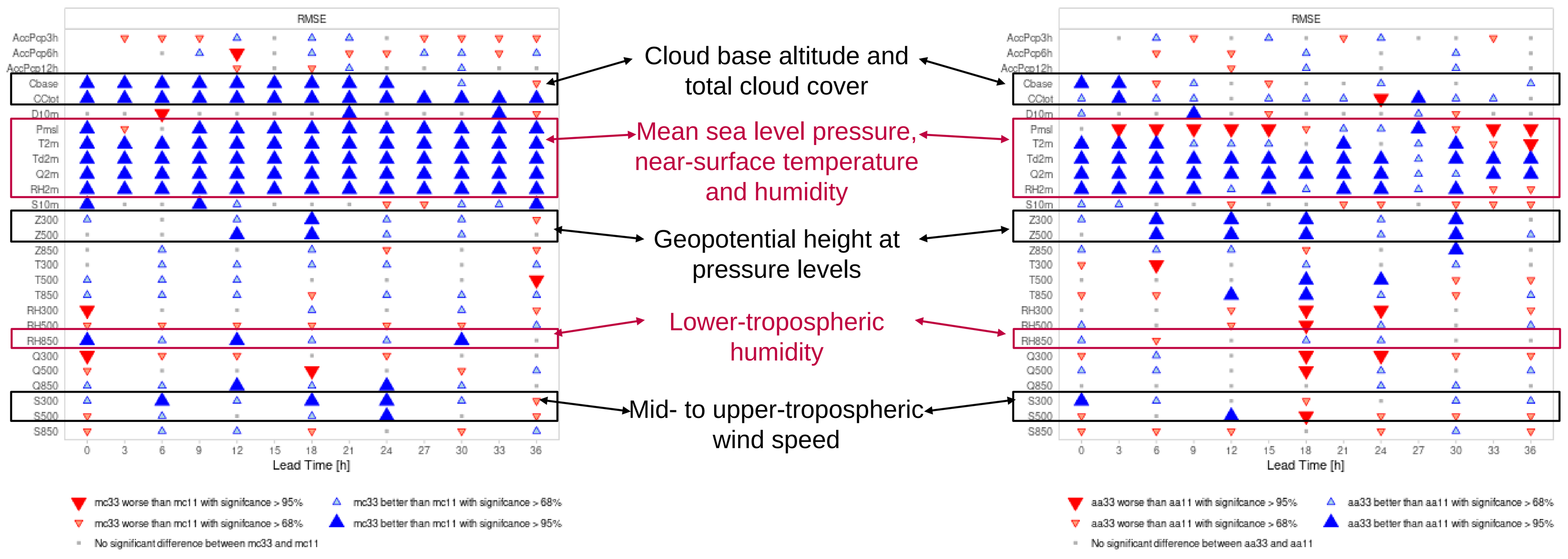
The experiment dates are chosen such that NOAA-19 is well separated from all the other satellites included in the study



FORECAST IMPACT FROM THE ASSIMILATION OF MICROWAVE RADIANCE DATA

*** Scorecard representation in the complementary-orbits scenario ***

– There is a robust and statistically significant impact on the forecast RMSE in near-surface temperature, humidity and cloud parameters
– The impact is particularly clear in the case of the Winter run in the MetCoOp domain
– ***Blue triangles*** indicate a positive impact from the microwave radiance data

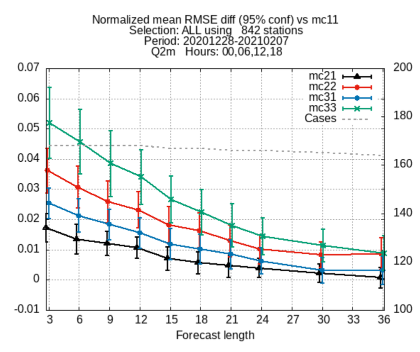


–Verification of *the 3-satellite run* in *the **complementary-orbits** scenario* against the 1-satellite baseline run in *the **MetCoOp** domain* in ***Winter***

–Verification of *the 3-satellite run* in *the **complementary-orbits** scenario* against the 1-satellite baseline run in *the **AROME-Arctic** domain* in ***Summer***

*** Building up of the impact from bringing in more satellites ***

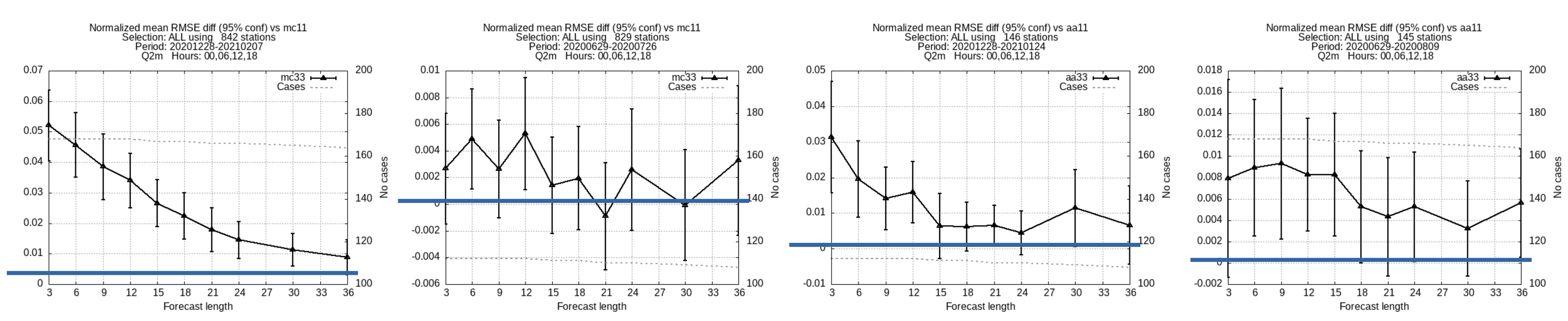
–The impact of 2 additional satellites is 50% larger than the impact of 1 additional satellite:
→In the single-orbit scenario: **blue** -vs- **black**
→In the complementary-orbits scenario: **green** -vs- **red**



–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**

*** There is more impact in winter than in summer ***

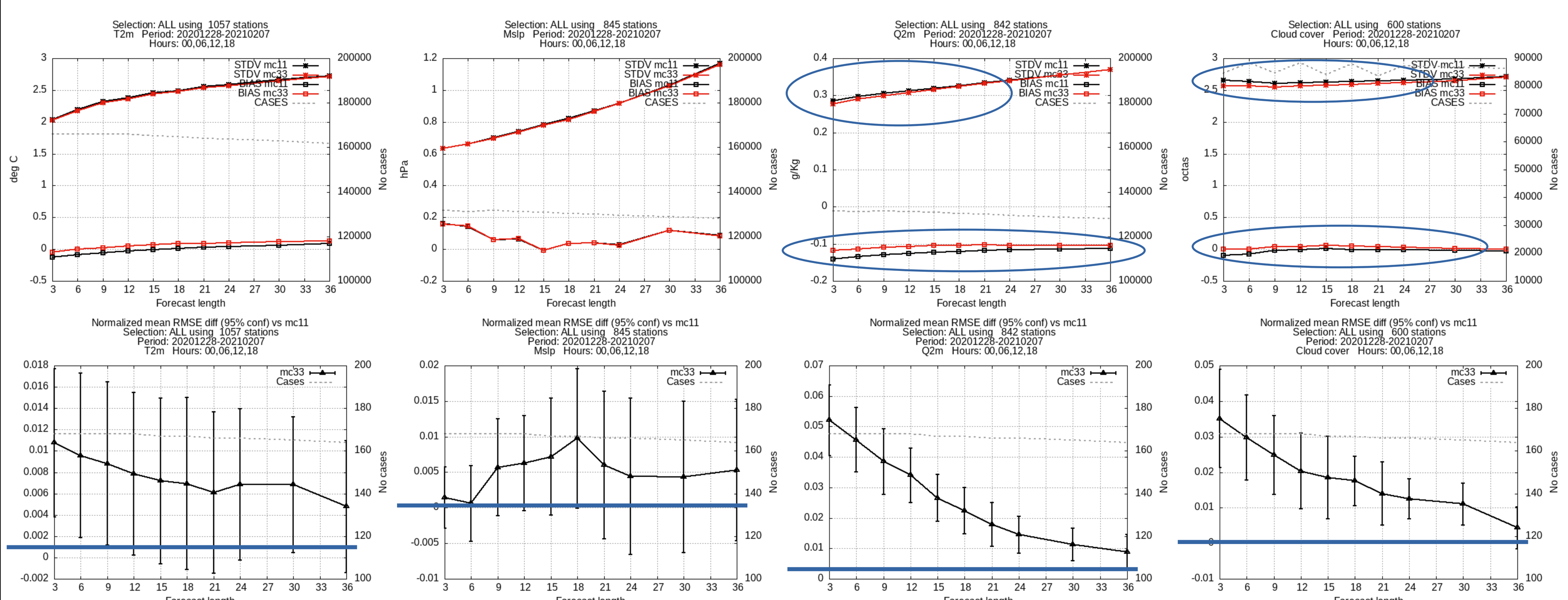
– This is evident in both the MetCoOp and AROME-Arctic domain runs



MetCoOp Winter run | MetCoOp Summer run | AROME-Arctic Winter run | AROME-Arctic Summer run

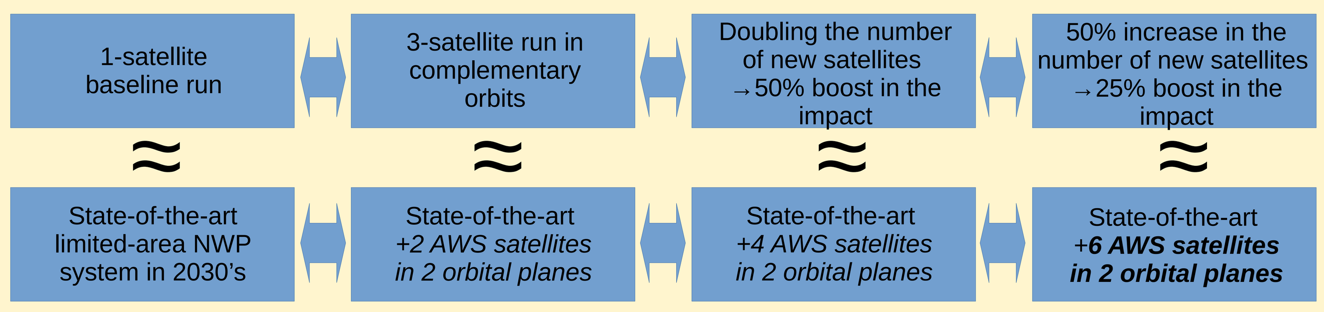
*** Quantifying the impact in the complementary-orbits scenario ***

– The positive impact is contributed by reductions in both systematic and random forecast errors and it extends beyond the 24-hour forecast range
– The reduction in the forecast RMSE is up to 5% in near-surface humidity and up to 3% in cloud cover
– **Black line** is the 1-satellite baseline run
– **Red line** is the 3-satellite run in the complementary-orbits scenario



Temperature at 2-m height | Pressure at mean sea level | Specific humidity at 2-m height | Cloud cover (octas)

How do these results extrapolate to the expected impact from the EPS-Sterna constellation?



– We assume that the 1-satellite baseline run is reasonably representative of a state-of-the-art limited-area NWP system in the 2030's
– We assume that the 3-satellite run in the complementary-orbits scenario os representative of a 2030's state-of-the-art NWP system enhanced by the assimilation of 2 EPS-Sterna satellites placed in 2 orbital planes
– We assume that doubling the number of EPS-Sterna satellites in the constellation with yield a 50% boost in the forecast impact
– We assume that another 50% increase in the number of EPS-Sterna satellites will yield another 25% boost in the forecast impact
→The EPS-Sterna constellation impact may be up to ~80% … 90% larger than the impact that we have demonstrated for the 3-satellite, complementary-orbits run against the 1-satellite baseline system
→Note that this reasoning corresponds to a hypothetical constellation of 6 satellites in 2 orbital planes, while the EPS-Sterna constellation will actually be 6 satellites in 3 orbital planes

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