

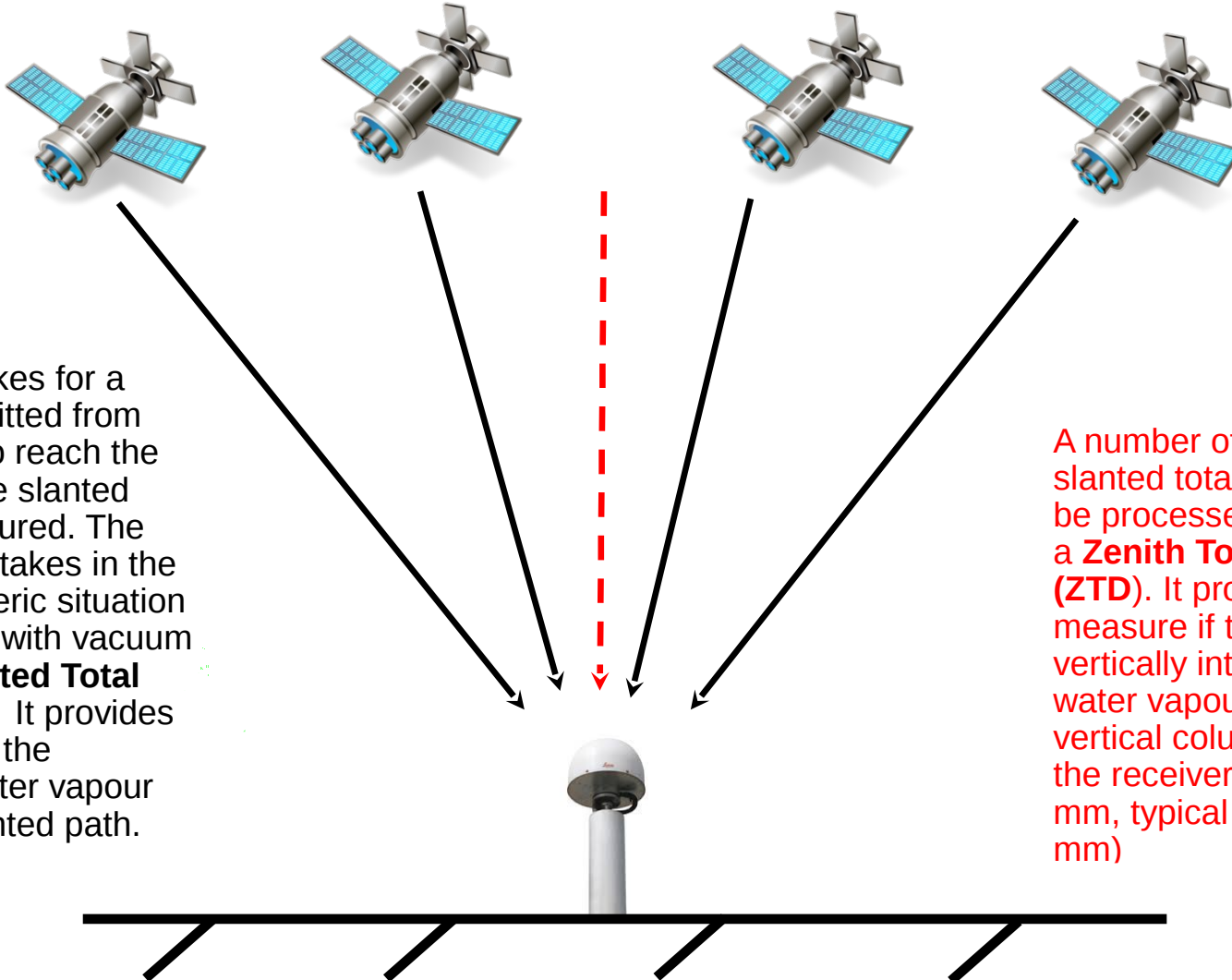
DATA ASSIMILATION OF GNSS ZTD FROM THE NGAA PROCESSING CENTRE

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Magnus Lindskog, Sigurdur Thorsteinsson and Tong Ning

GNSS derived moisture

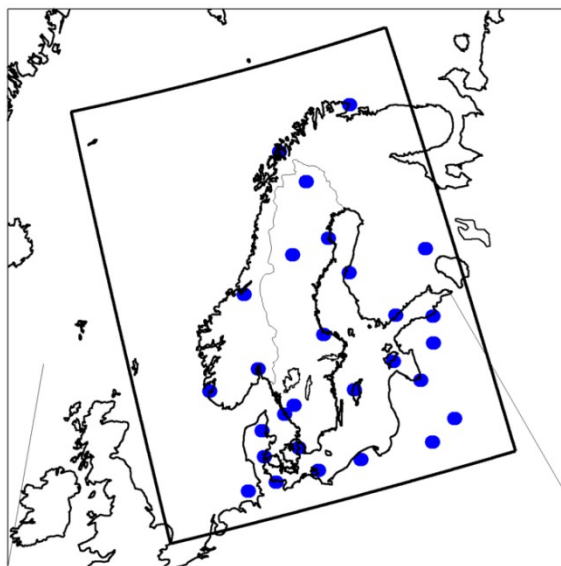
Global Navigation Satellite System
GPS, GLONASS, GALILEO, COMPASS



The time it takes for a signal transmitted from the satellite to reach the receiver in the slanted path is measured. The longer time it takes in the real atmospheric situation as compared with vacuum is called **Slanted Total Delay (STD)**. It provides a measure of the integrated water vapour along the slanted path.

A number of such slanted total delays can be processed to obtain a **Zenith Total Delay (ZTD)**. It provides a measure of the totally vertically integrated water vapour in a vertical column above the receiver. (unit: s or mm, typical value 2500 mm)

- An operational km-scale NWP system based on AROME.
- Ensemble system with 10 ensemble members.
- Upper-air data assimilation based 3D-Var to obtain the best possible initial state for the atmosphere.
- Observations used are conventional types of in-situ measurements, radar reflectivities, satellite radiances (AMSU A, AMSU-B/MHS and IASI), advanced scatterometer surface winds and GNSS ZTD.

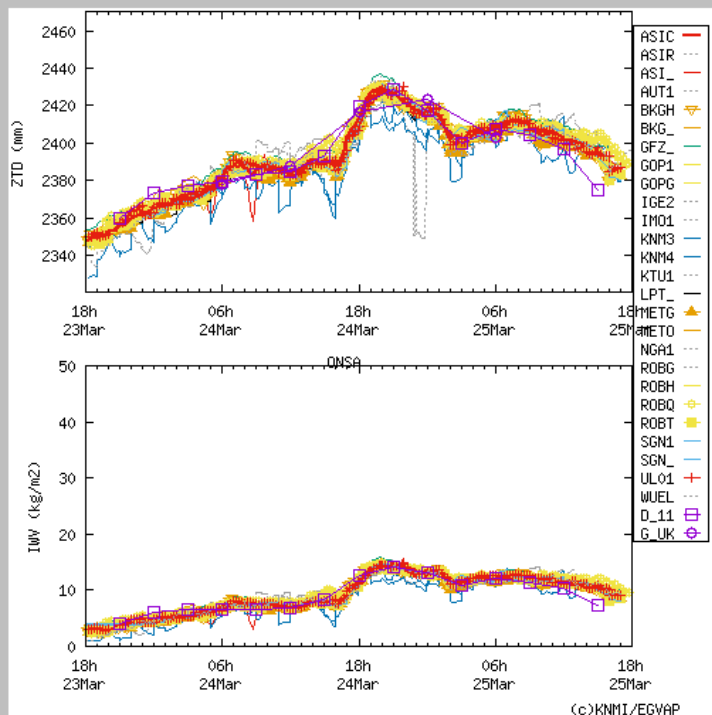


MetCoOp model domain and
GNSS stations (28 stations
from ROBH and METO
processing centres).

MetCoOp

- Due to quality issues MetCoOp did not assimilate NGAA data but rather the few (28) stations over the MetCoOp domain processed by METO and ROBH processing centres.
- In June, 2015, Lantmäteriet (the Swedish mapping, cadastral and land registration authority) took over the NGAA data processing which includes two parts of work:
 1. Move and modify GIPSY solution to Lantmäteriet servers.
 2. Prepare a new Bernese solution.
- Since 2016, Lantmäteriet send data to SMHI:
 - Sweden – 383 sites
 - Finland – 88
 - Denmark – 10
 - Norway – 192
 - IGS – 10In total 683 sites
- Both Bernese (v 5.2) solution (**NGA1**) and GIPSY (v 6.2) solution (**NGA2**) are uploaded to SMHI. Only Bernese solution are further uploaded to E-GVAP due to longer time delay (more than 1.5 hour) of the GIPSY solution caused by long waiting time of JPL ultra rapid orbit and clock product.

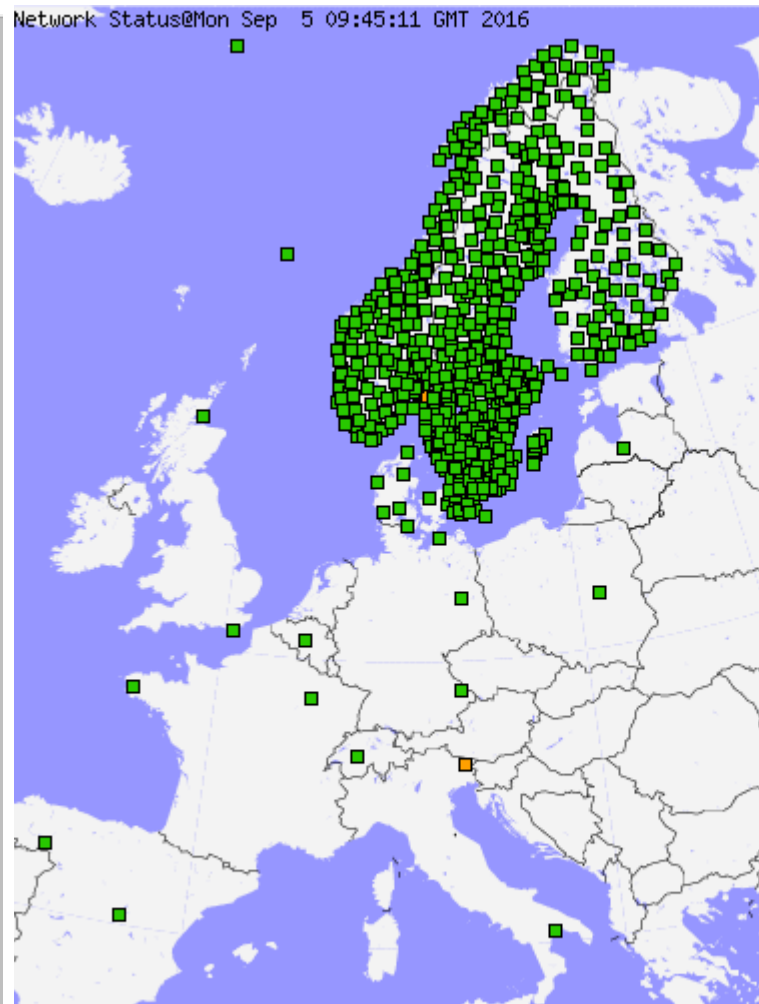
Onsala, Sweden (ONSA)



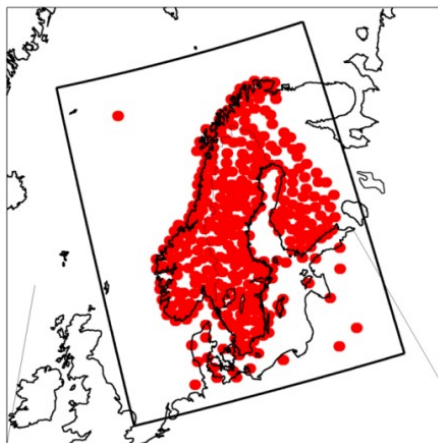
HIRLAM(KNMI) AN - GPS ZTD
7day stat. 2017/03/09 - 2017/03/17

AC	num	bias	RMS	stddev
ASIC	56	-3.3	8.9	8.2
ASIR	56	-2.8	9.0	8.6
AUT1	56	-2.2	9.2	8.9
BKGH	56	-0.0	8.4	8.4
GFZ	56	1.4	9.0	8.8
GOP1	56	-4.5	10.1	9.0
IGE2	56	-0.7	7.3	7.2
IMO1	56	-3.0	9.6	9.1
KNM3	56	-3.2	10.4	9.9
KNM4	56	-11.7	17.0	12.2
KTU1	56	-4.2	10.0	9.0
LPT	56	-3.7	10.1	9.3
METG	56	-4.3	9.9	8.9
ROBG	56	-2.2	9.0	8.7
ROBH	56	-3.8	9.6	8.8
SGN1	56	-3.3	9.9	9.4
SGN1	55	-4.2	9.9	8.9
TEST				
ASIR	56	-1.6	9.4	9.2
BKGH	56	-2.2	8.7	8.4
IGE2	56	-1.0	9.5	9.4
METG	56	-3.8	9.3	8.5
NGA1	56	-4.4	9.2	8.1
ROBQ	56	-0.8	9.8	9.8
ROBT	56	-3.9	9.6	8.8
WUEL	56	-4.9	10.9	9.8

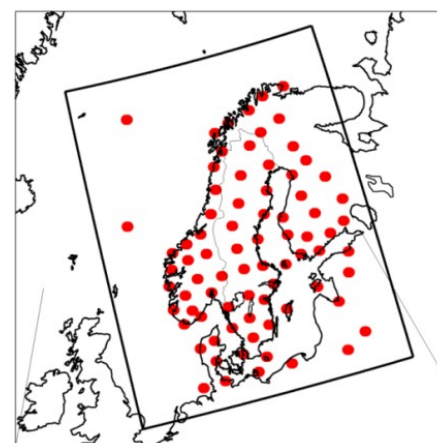
The NGA1 data sent to E-GVAP



Spatial thinning of observations



Before spatial thinning



Spatial thinning ~100 km
(~80 stations)

Variational Bias Correction

Linear predictor model:

$$b(x, \beta) = \sum_{i=0}^{N_p} \beta_i p_i(x)$$

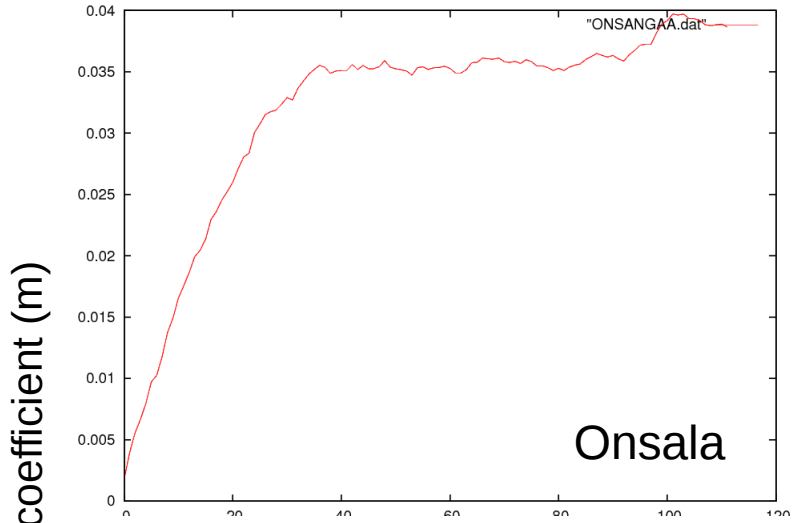
Modified cost function:

$$J(x, \beta) = \frac{1}{2} (x - x^B)^T B^{-1} (x - x^B) + \frac{1}{2} (\beta - \beta^B)^T B_\beta^{-1} (\beta - \beta^B) + \frac{1}{2} (Hx + b(x, \beta) - y)^T R^{-1} (Hx + b(x, \beta) - y)$$

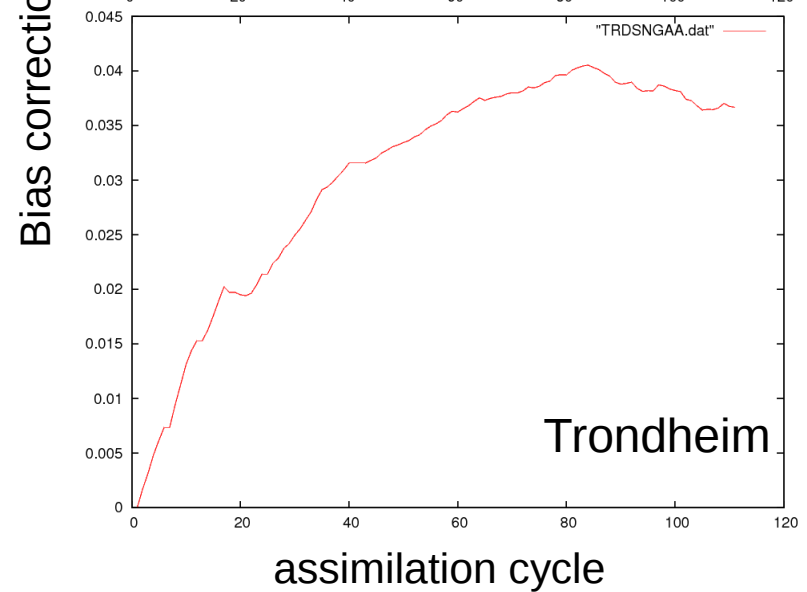
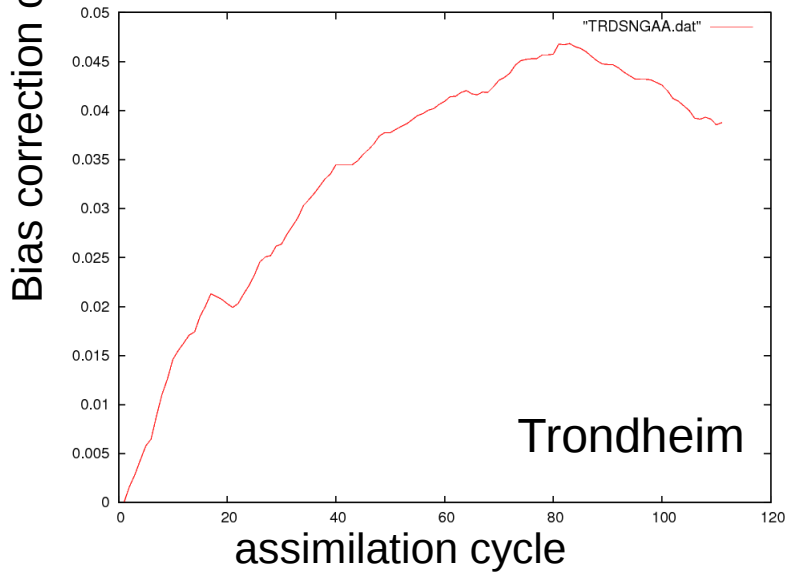
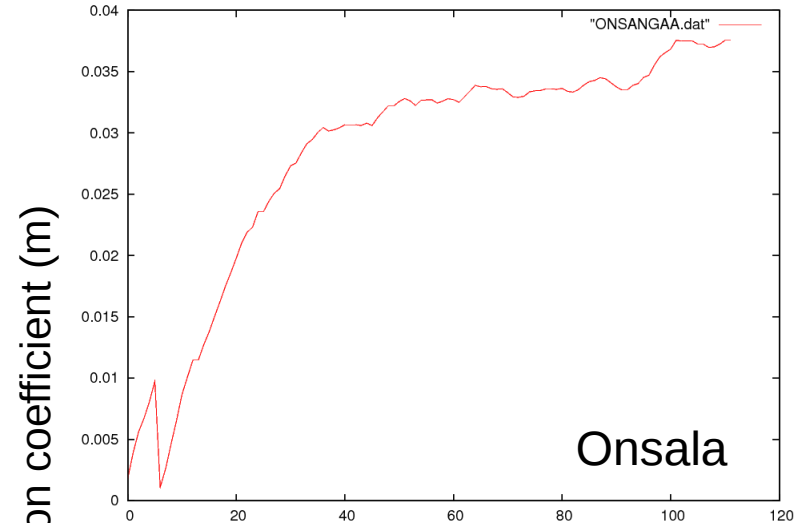
Spin-up of NGA GNSS VARBC-coefficients 20160215-20160229



NGA1



NGA2



Four one-month parallel data assimilation and forecast experiments for June 2016

- **Impact of introducing NGAA GNSS ZTD**

Operational, NGA1 GNSS usage, NGA2 GNSS usage
(all runs with ~80-100 km thinning distance and one VARBC predictor)

- **Impact of different VARBC predictor choices**

offset , offset and 1000-300 hPa thickness, offset and TCWV
(all runs with ~80-100 km thinning distance and NGA1)

- **Impact of modifying thinning distance**

NGA1 observation usage ~80-100 km thin. dist. , NGA1 observation usage 40 km thin. dist.

- **Impact of modified background error statistics (B matrix)**

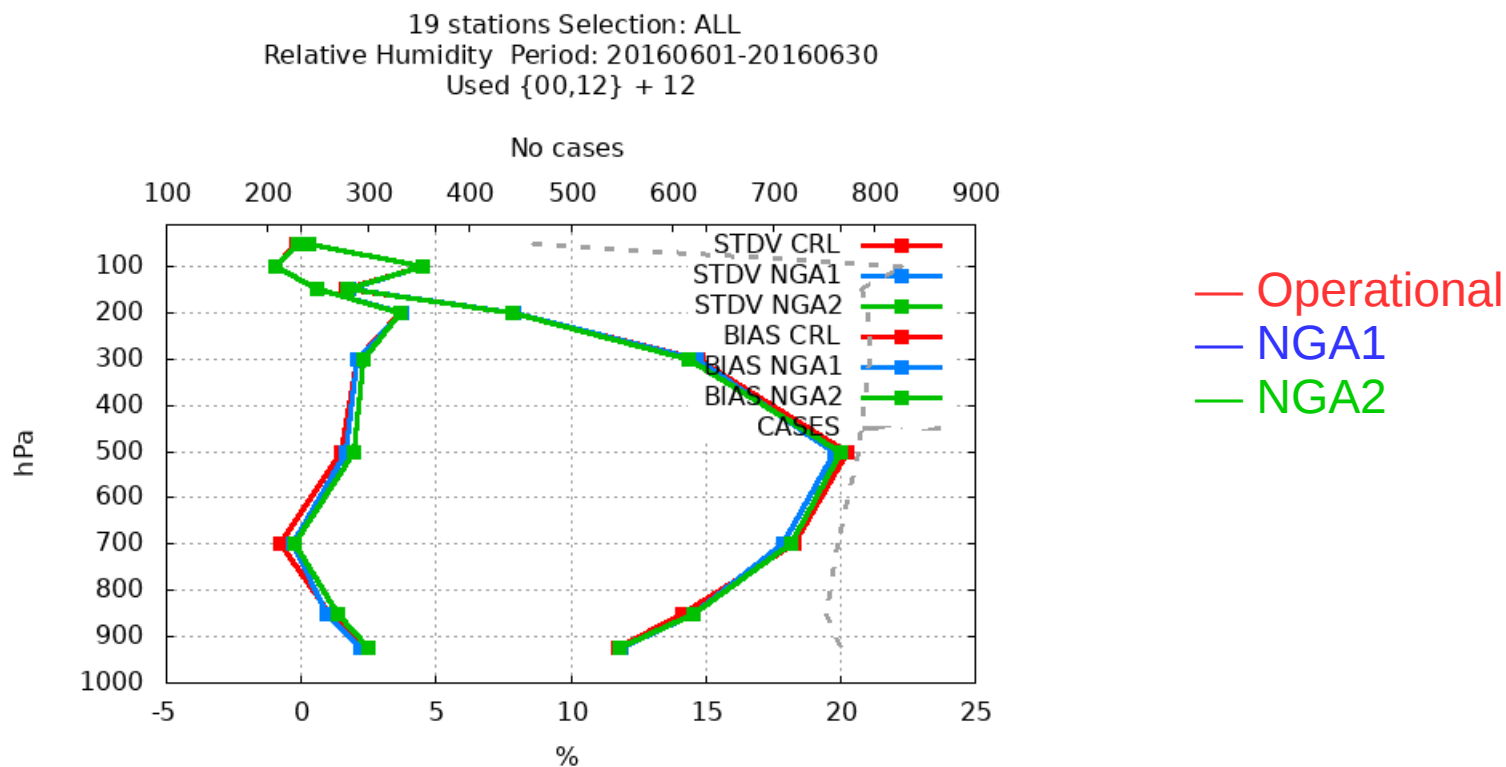
Original and modified B (both runs with ~80-100 km thinning distance and NGA1)

B-matrix derived using cy40h1.1 (MetCoOp) and ECMWF ensemble (EDA) with cubic grid of ~20 km

Impact of introducing NGAA GNSS ZTD

Time-averaged verification scores over MetCoOp domain

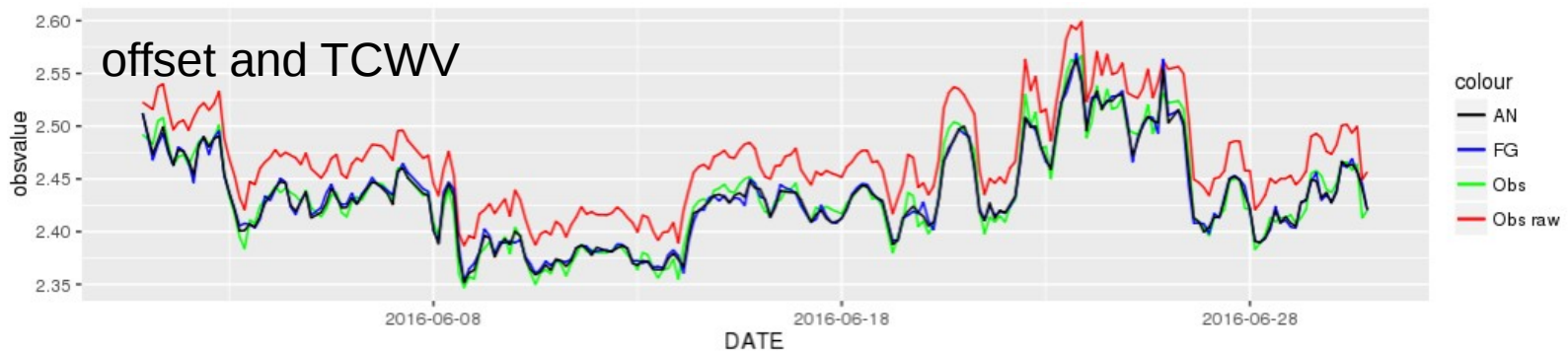
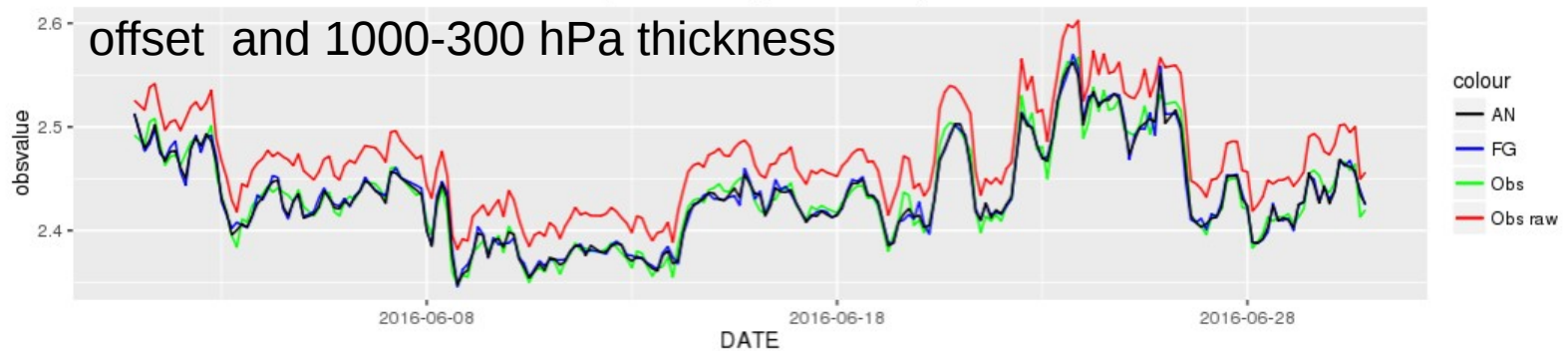
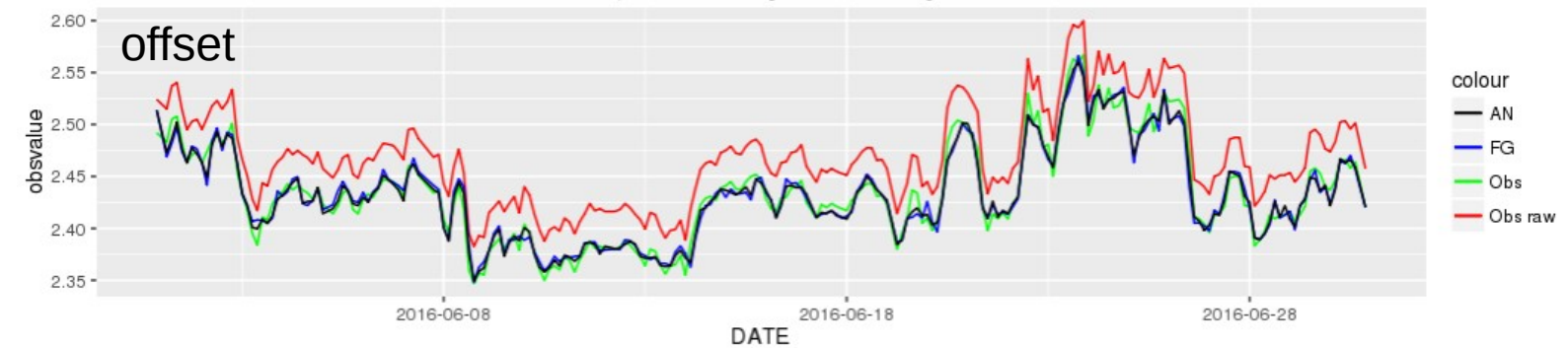
Bias and RMSE for +12 hour relative humidity forecasts



Introduction of NGAA with Bernese (NGA1) solution was more beneficial.

Impact of different VARBC predictor choices

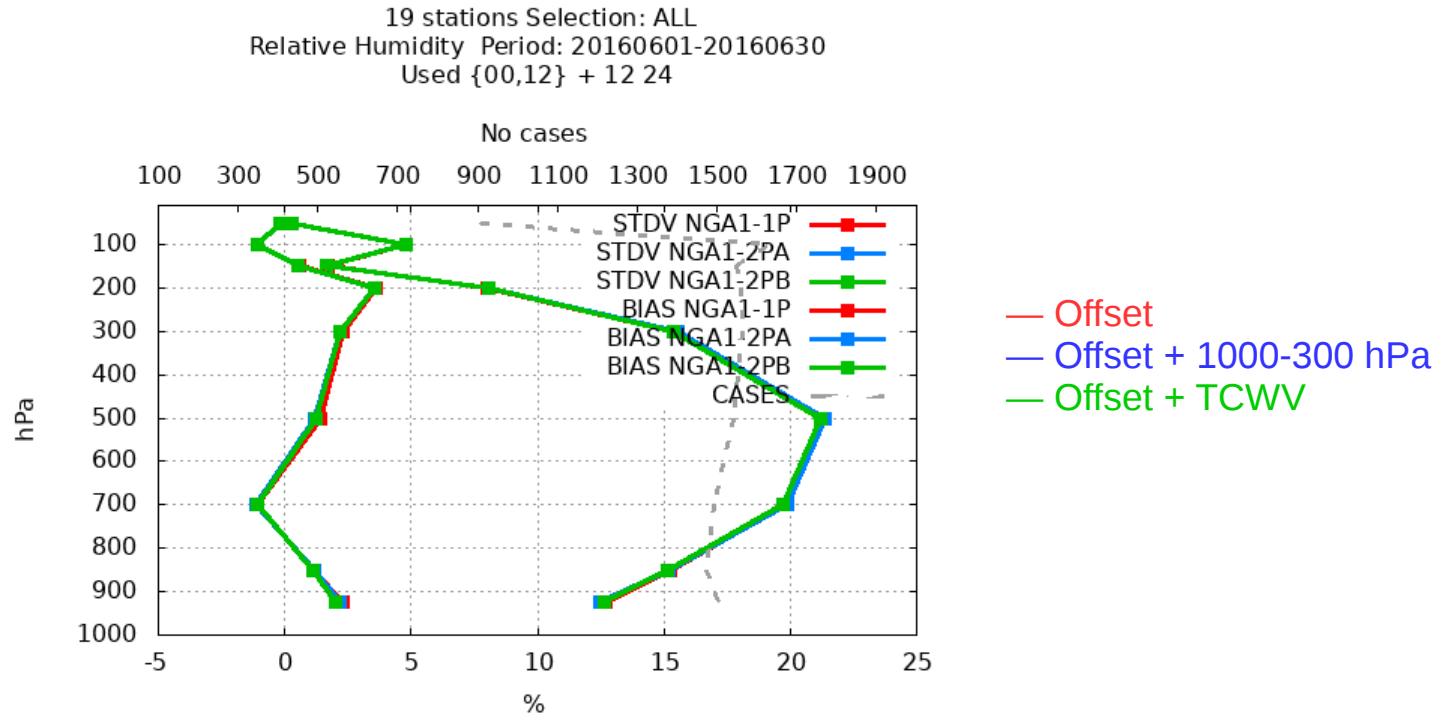
Time-series of GNSS ZTD from Onsala receiving station



Impact of different VARBC predictor choices

Time-averaged verification scores over MetCoOp domain

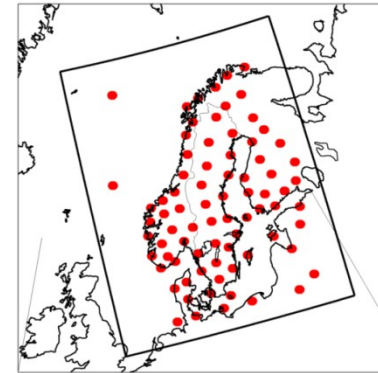
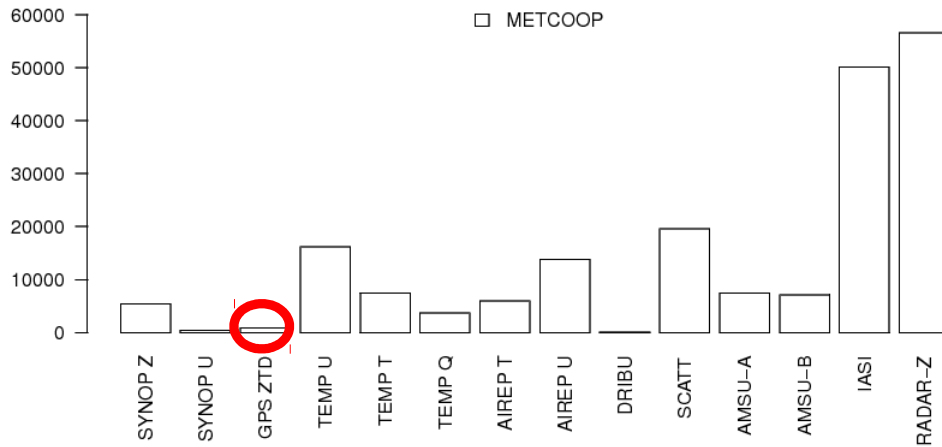
Bias and RMSE for +12,24 hour relative humidity forecasts



Small impact of introducing one more predictor in GNSS VARBC.

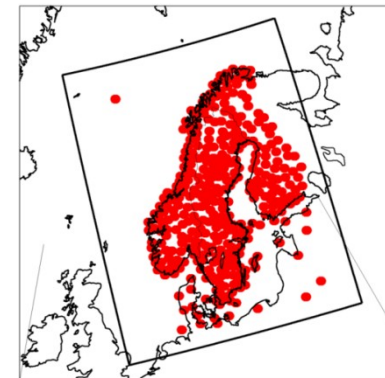
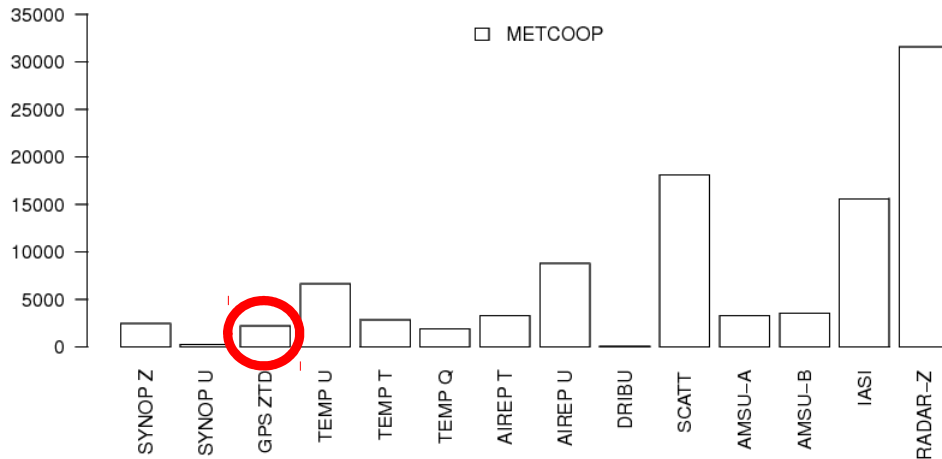
Effect of modified GNSS ZTD thinning distance on Impact on analysis separated into observation types (20160612-20160616)

Absolute Degree of Freedom for Signal (DFS)



80-100 km (~80 stations)

Absolute Degree of Freedom for Signal (DFS)



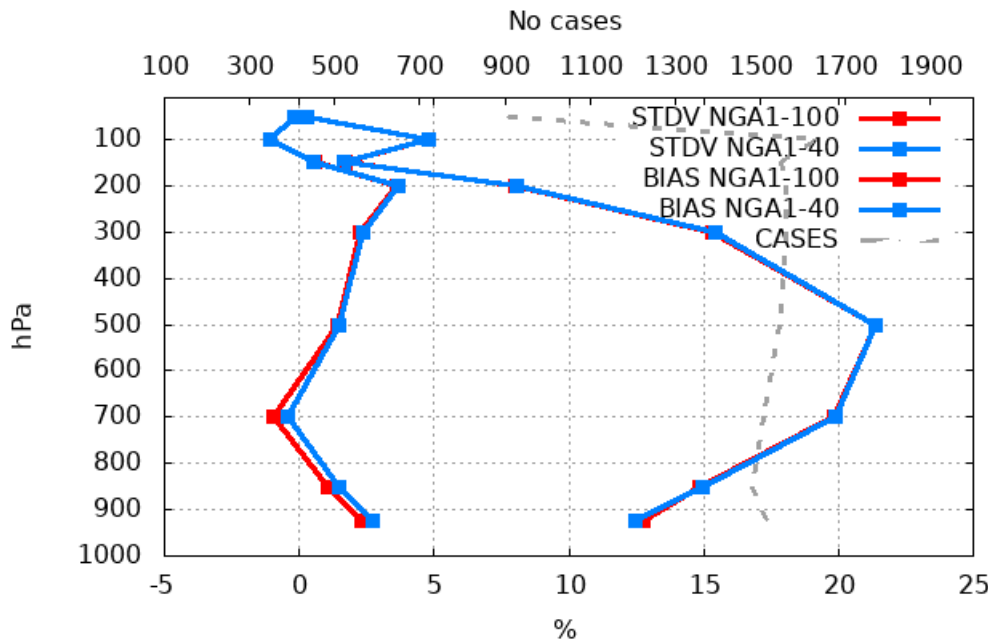
40 km (~330 stations)

Impact of introducing modified GNSS ZTD thinning distance

Verification scores over MetCoOp domain

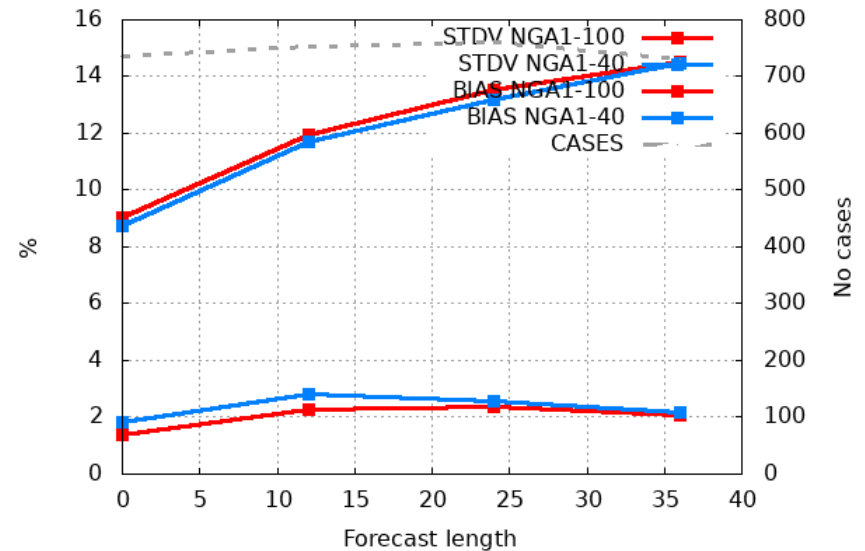
Relative humidity for +12,24

19 stations Selection: ALL
 Relative Humidity Period: 20160601-20160630
 Used {00,12} + 12 24



Relative humidity at 925 hPa.

Selection: ALL using 19 stations
 Relative Humidity 925hPa Period: 20160601-20160630
 Hours: {00,12}



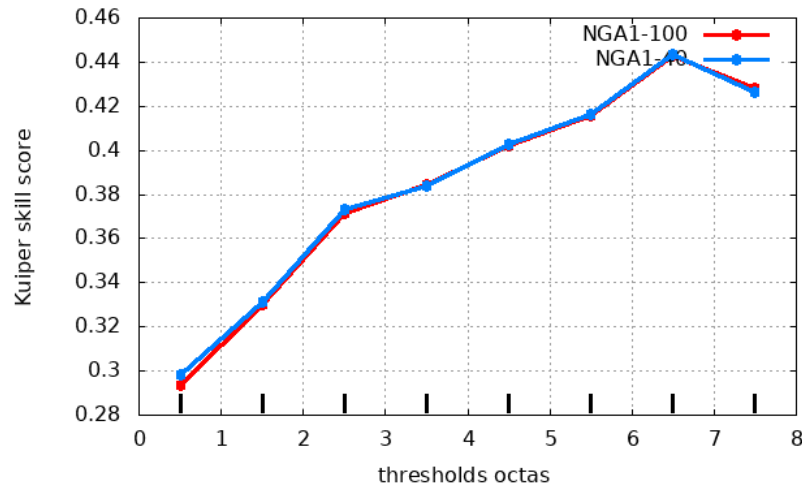
Larger bias and smaller standard deviation at lowest levels for NGA1-40, otherwise neutral.

Impact of introducing modified GNSS ZTD thinning distance

Time-averaged verification scores over MetCoOp domain Kuiper skill score

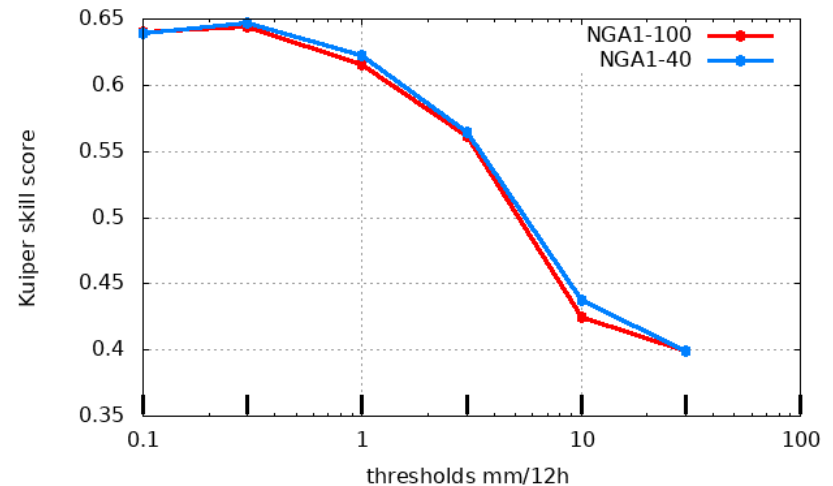
Cloud cover

Kuiper skill score for Cloud cover (octas)
Selection: ALL 432 stations
Period: 20160601-20160630
Used {00,12} + 06 18



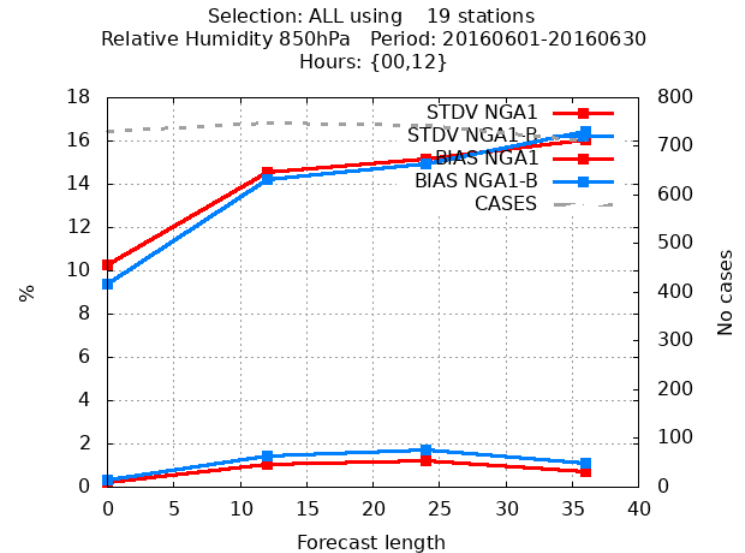
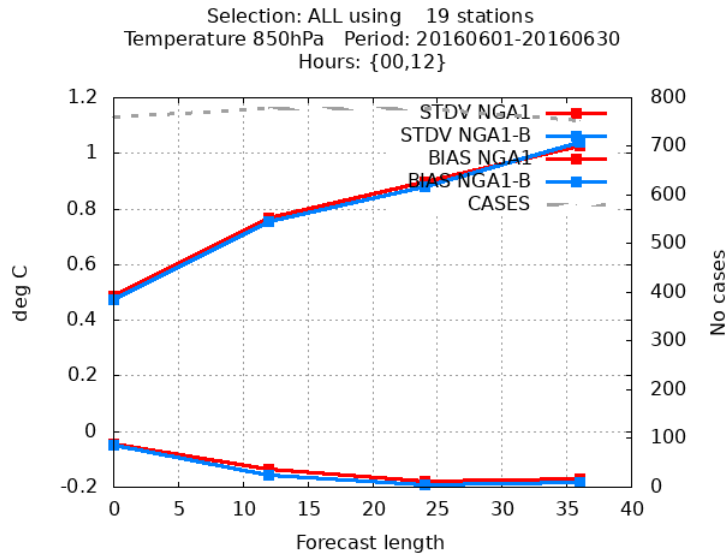
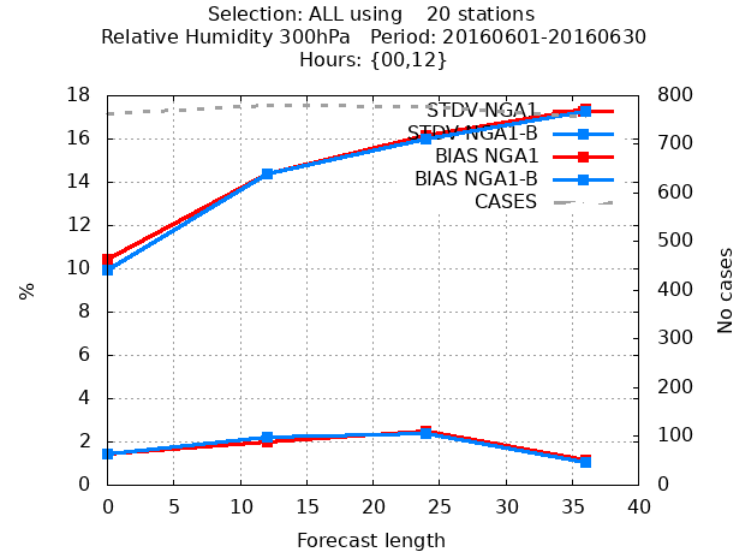
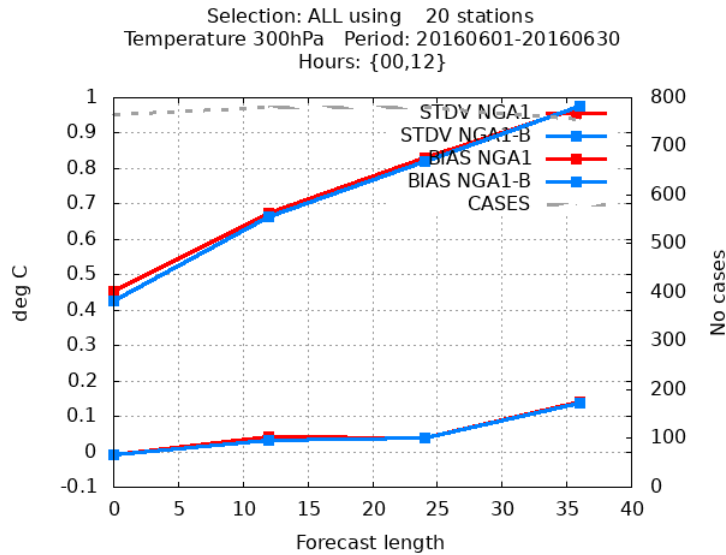
Precipitation 12h

Kuiper skill score for 12h Precipitation (mm/12h)
Selection: ALL 602 stations
Period: 20160601-20160630
Used {00,12} + 18-06



Slightly better precipitation forecasts for NGA1-40.

Impact of modified background error statistics (B matrix)



- GNSS ZTD from the NGAA processing centre is now of a good quality and these are planned to be introduced in the MetCoOp operational data assimilation (now in pre-op).
- We have earlier demonstrated that use of GNSS ZTD observations together with a variational bias correction do improve the short range weather forecasts. The findings of the present study indicate however that it is enough to use one predictor, in the form of a constant offset.
- Rather encouraging results were obtained with a reduced thinning distance. The introduction of many different sources of humidity information seem to alleviate problems earlier noticed related to use of variational bias correction and small GNSS ZTD thinning distances. Some further investigations of low level biases are however needed.
- Within the data assimilation a clear interaction of GNSS ZTD with other types of humidity observation was noticed.
- The benefit of GNSS ZTD observations can be enhanced by improving various aspects of the NWP data assimilation in general, demonstrated here by modifying the B-matrix.