Norwegian Meteorological Institute

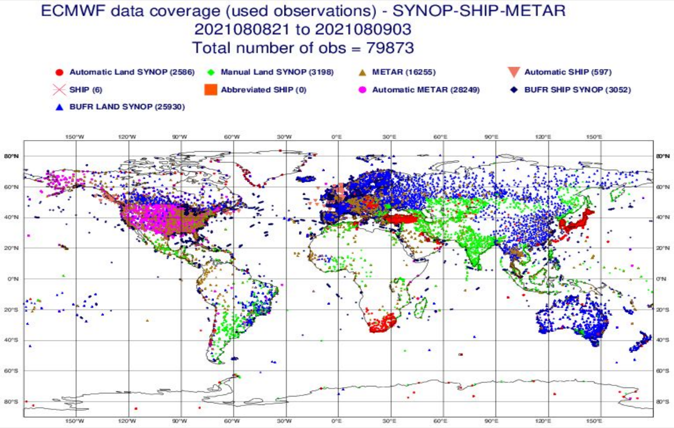
Role of non-operational observations today and in the future

Roger Randriamampianina

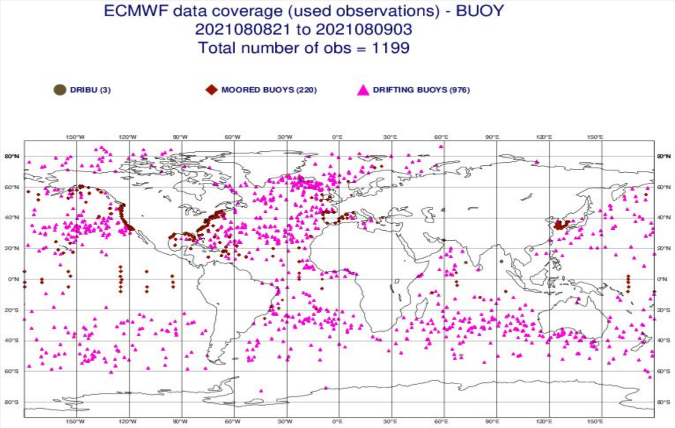
Michael Bender, Olivier Caumont, Stephen English, Frederic Fabry, Catherine Gaffard, Erik Gregow, Siebren de Haan, Kasper Stener Hintz, Martin Imrišek, Cristian Lussana, Claire Merker, Martin Osborne, Zoi Paschalidi, Martin Ridal, Roel Stappers, Kirien Whan

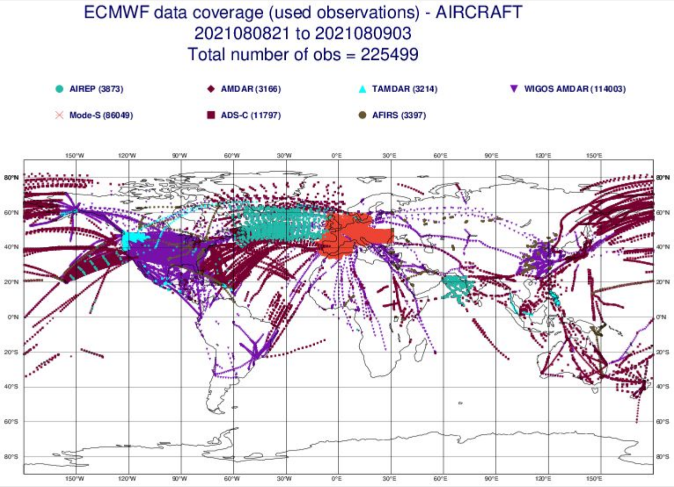
ECMWF annual seminar, 13-17 September 2021

Existing operational observations

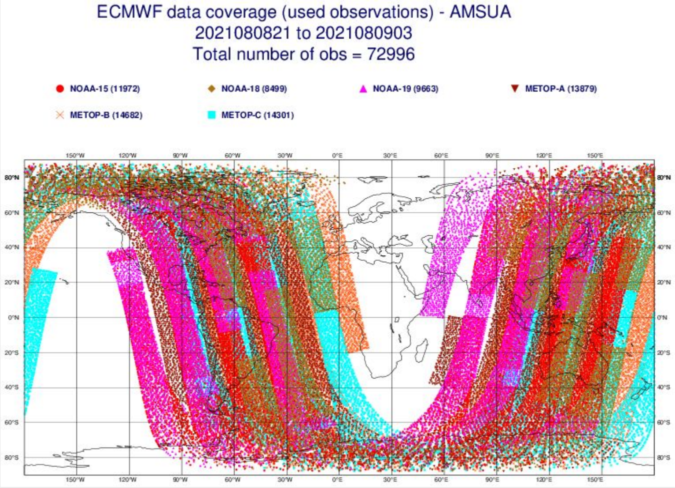


Example of assimilated surface observations

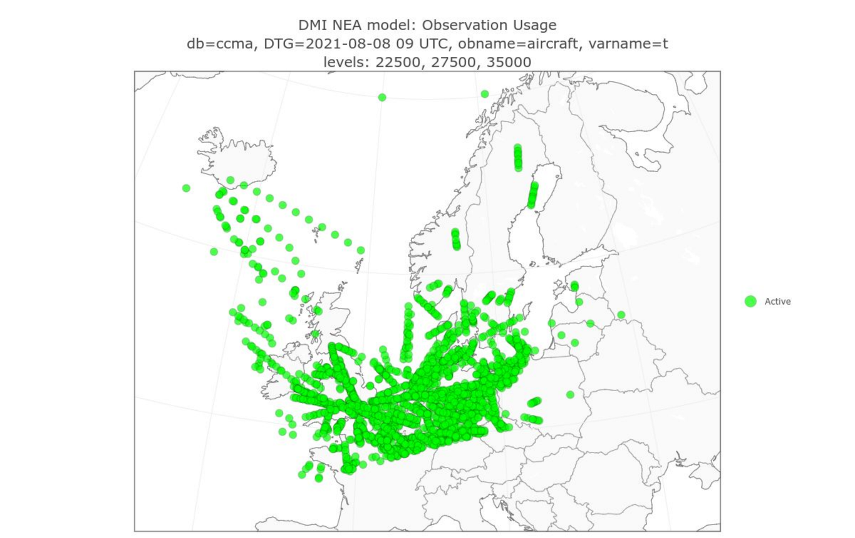




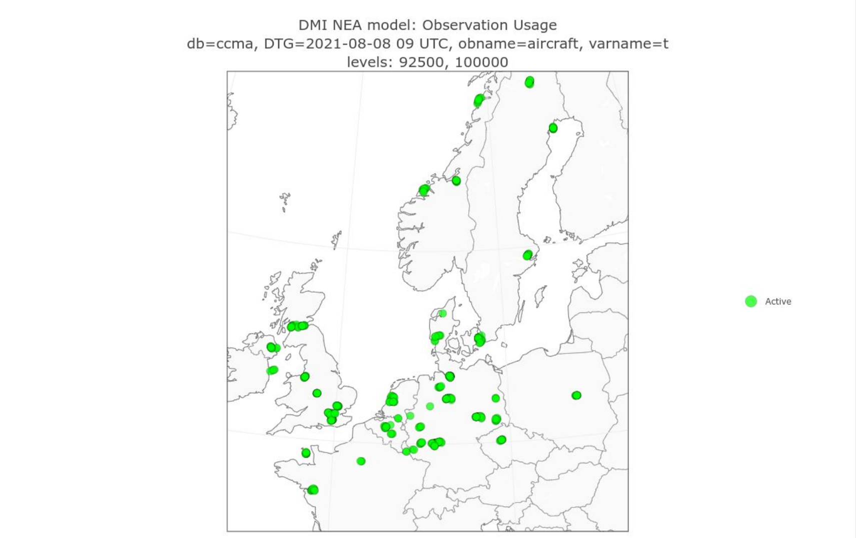
Example of assimilated upper-air observations



Existing operational observations



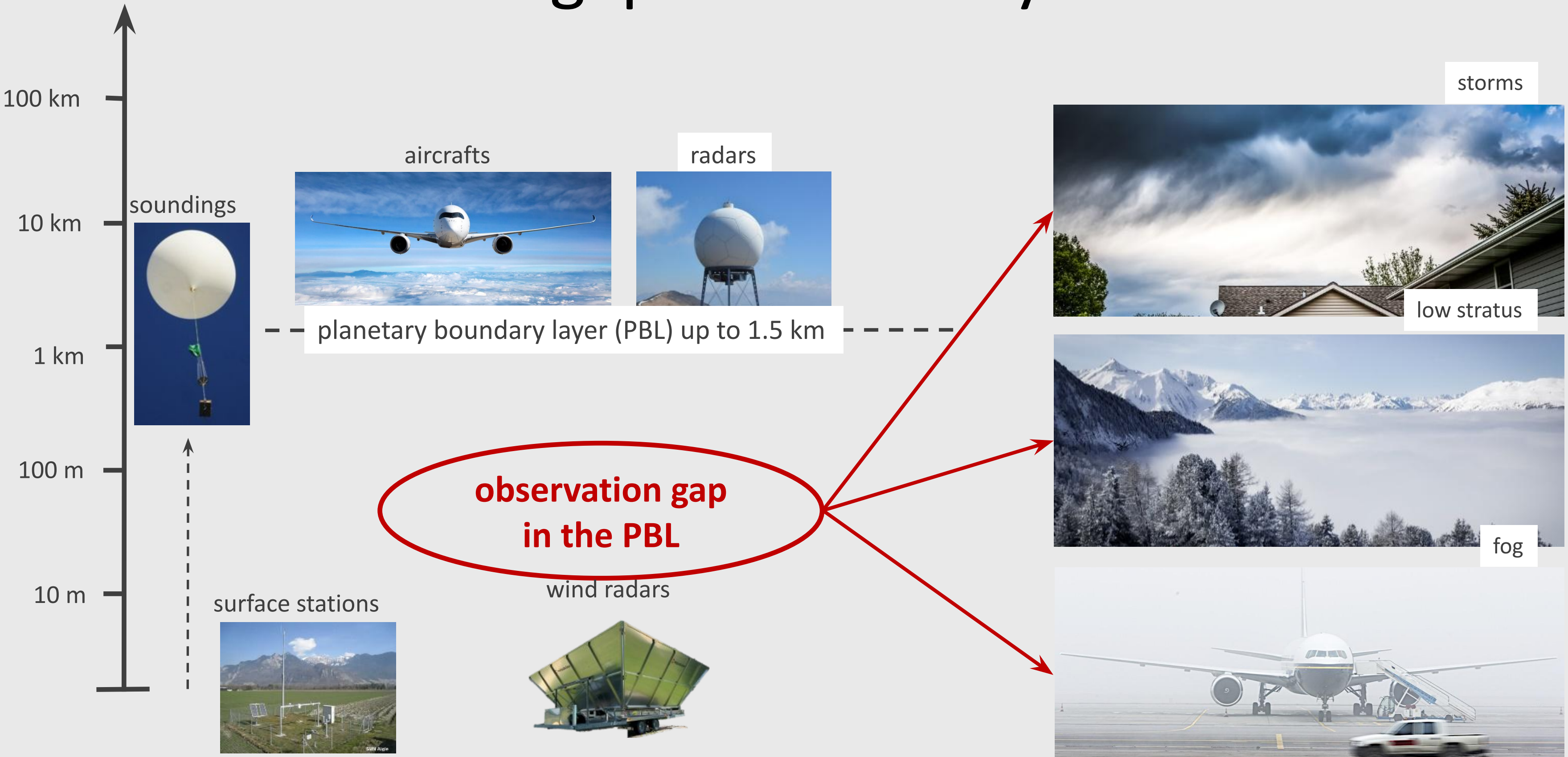
Flight level



Lower troposphere

Norwegian Meteorological Institute

Observation gap in our DA system



=> For example, ground-based radiometers can help

Merker et al., 2021

Outline

- Ground-based remote sensing observations:
  - Ceilometer observations
  - Microwave radiometer
  - GNSS slant total (path) delay
- Cars observations
- Personal weather station observations
  - Netatmo
  - WOW
- Smartphone observations

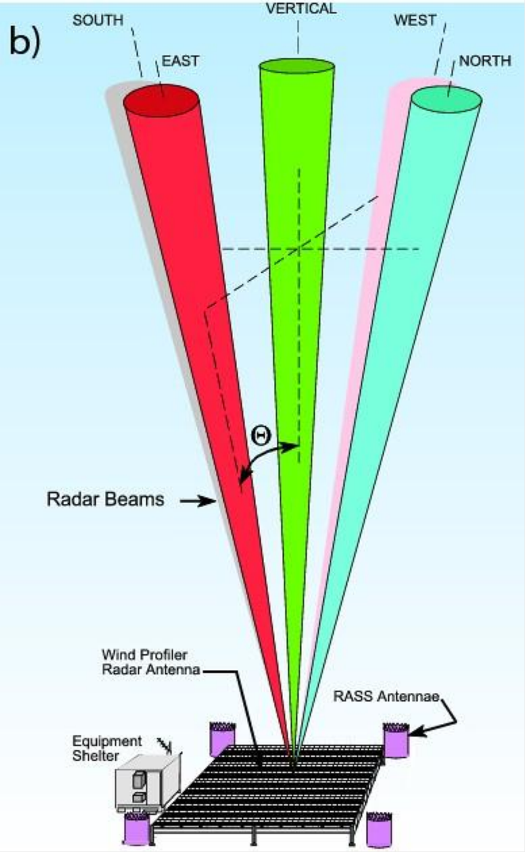
Focus on concrete field campaign, projects and studies in Europe

Norwegian Meteorological Institute

Ground-Based Remote Sensors

Weather radars (>1000 worldwide)

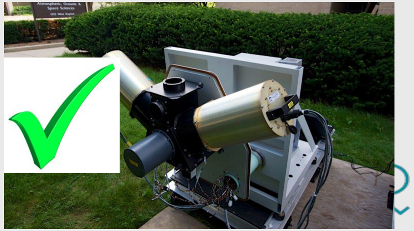
Winds profilers (~100 worldwide)
Wind, sometimes temperature



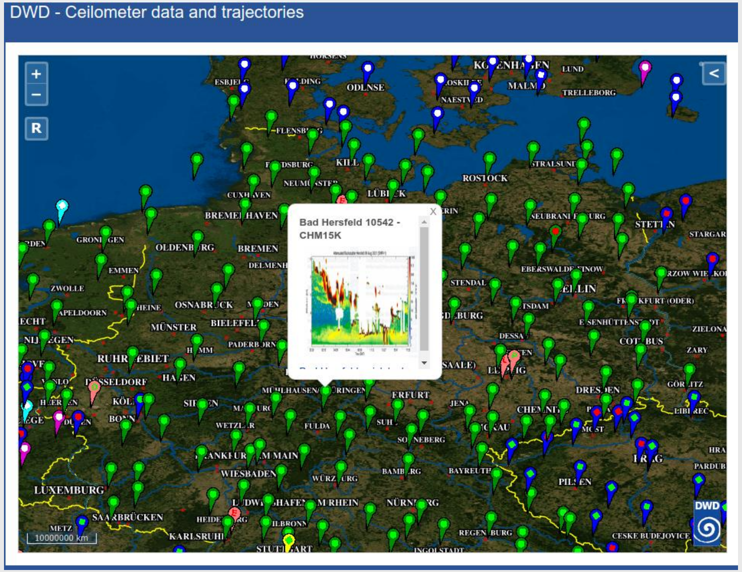
GNSS surface stations
Precipitable water

Ceilometers
Cloud base height

IR or μW radiometers
Temperature, humidity



Sodars, lidars
Wind, some lidars do vapor



Ceilometers & radiometers observations

Ground-base remote sensing: Ceilometer observations

<u>Ceilometers:</u>

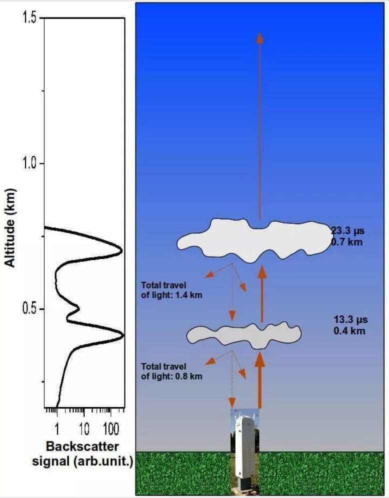
-- Use laser (LIDAR) or light source for detection of
  -- cloud ceiling or cloud base;
  -- aerosol concentration in the atmosphere (ex: volcanic ash and saharan dust);

-- Operate in the **near-infrared region** between 900 nm and 1064 nm, and **in the UV/VIS spectral region** at 355 nm and also at 387 nm;

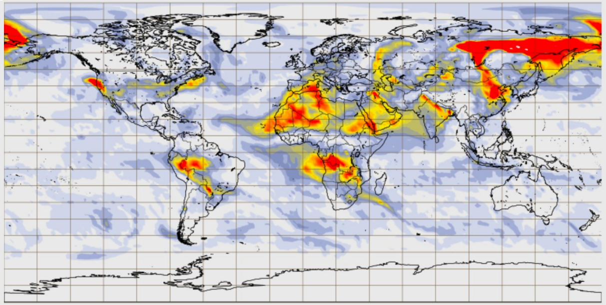
-- Most of them are fully automated and measure continuously;

-- Operated by
  -- NMHSs as potential replacement of personal observation of clouds;
  -- aviation entities to control runway at airports for fog and cloudiness

-- Used to validate model performance (ex. CAMS/Copernicus monitoring service)



Vaisala CL31 and CL51



Aerosol optical depth at 550 nm (provided by CAMS, the Copernicus Atmosphere Monitoring Service) Wednesday 11 Aug, 00 UTC T+60 Valid: Friday 13 Aug, 12 UTC

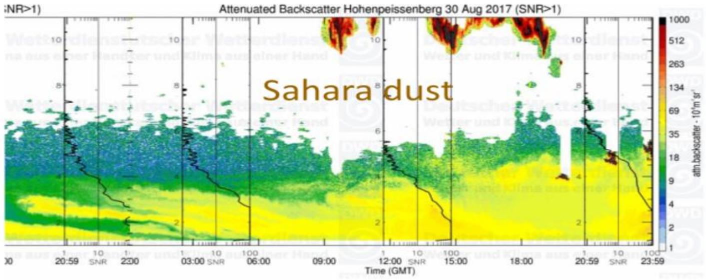
Role of ceilometer today, example at DWD

Aerosol „recognition“ by DWD

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

→ Sahara dust plumes

→ Happens frequently, ~ 40-50 times per year in Southern Germany

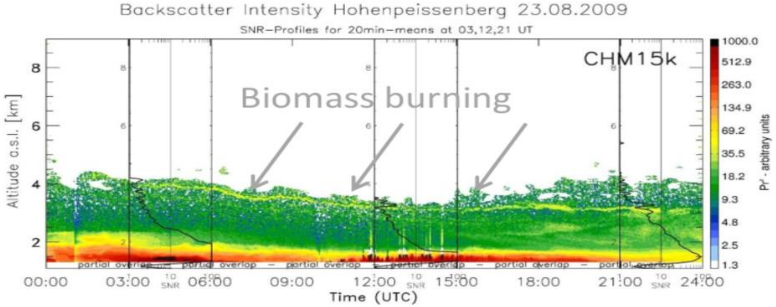


→ Biomass Burning plumes

→ Happens few days per year but really strong events in 2013, 2016, 2017…

→ Sea salt

→ Rarely, mostly at coastal stations



→ Volcanic Ash

→ Fortunately hardly the case, two events in 2010 and 2011

→ Anthropogenic aerosol burden in the PBL

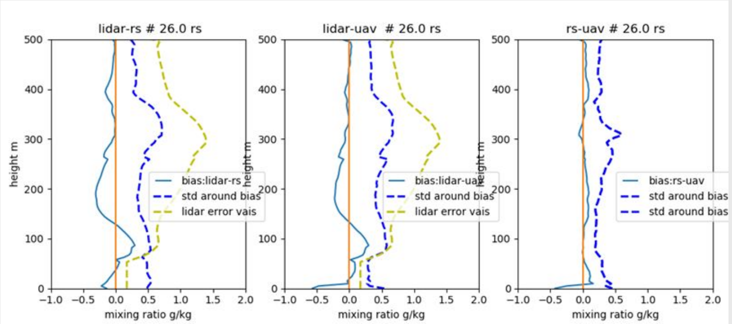
(Thomas, 2017)

Assessing the quality of the measurement (Gaffard et al. 2021)

DIAL (DIfferential Absorption Lidar) assessment at Cardington during 15 June – 14 July 2020

Using:

-- 93 radiosonde launches;
-- 27 UAV (drone) flights (but limited to 500 m altitude);
-- Hourly cycling 1.5 km UKV NWP model.



Results:

-- DIAL mixing ratio has similar characteristics against UAV (drone) and radiosonde.

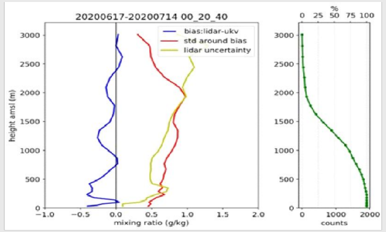
-- Bias for 1st 500m (likely to be DIAL bias)

-- Very good correlation with UKV of 0.90, with outliers being largely near the maximum height.

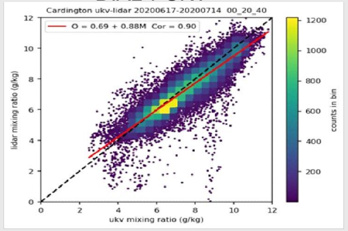
-- The accuracy of the observations meets the WMO OSCAR threshold requirement for high resolution NWP.

-- The reported error is a bit large, but meaningful.

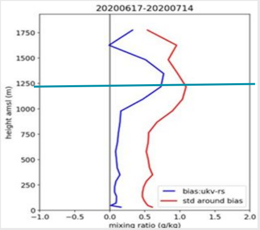
DIAL - UKV



DIAL v UKV



UKV - radiosonde



<u>Known issues</u>: Bias and higher standard deviation in lowest 500m; Spurious oscillations, particularly when little mixing ratio variability with height; Dry layer above fog or thick cloud.

=> DIAL observations could potentially improve the NWP model if assimilated

Microwave radiometer (Merker et al., 2021)

MeteoSwiss

<u>The instrument</u>: HATPRO (Humidity And Temperature PROfile) radiometer

-- Passive remote sensing instrument measuring brightness temperature from the atmosphere with 14 frequency bands (PBL temperature and humidity information)

- 7 K-band channels (22.24-31.40 GHz)
- 7 V-band channels (51.26-58.00 GHz)

-- 6 scanning elevations (zenith, 42.0°, 30.0°, 19.2°, 10.2°, 5.4°)

-- 3 devices in the Swiss Plateau (Payerne, Schaffhausen, Grenchen)

<u>The assimilation system</u>:

Model: COSMO-1E; 33 hour forecasts, 8x per day; 1.1 km grid size; 11 ensemble members

Ensemble data assimilation system: KENDA; (LETKF at 1.1km, 40+1 members)

Assimilated parameter: brightness temperature (not profiles of temperature and humidity)

Observation operator: RTTOV-gb radiative transfer model (upward-looking version of RTTOV)

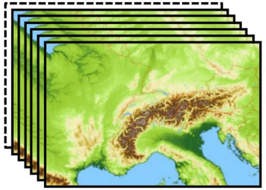
<u>Main challenges</u>:

-- vertical localisation of the integrated information on model columns

-- correct mapping of information to prognostic model variables

Ground-based microwave radiometer (HATPRO)

COSMO-1E (T, QV, …)
1.1 km grid size
40 ensemble members



+ RTTOV-gb
De Angelis et al., 2016

= brightness temperatures from the model

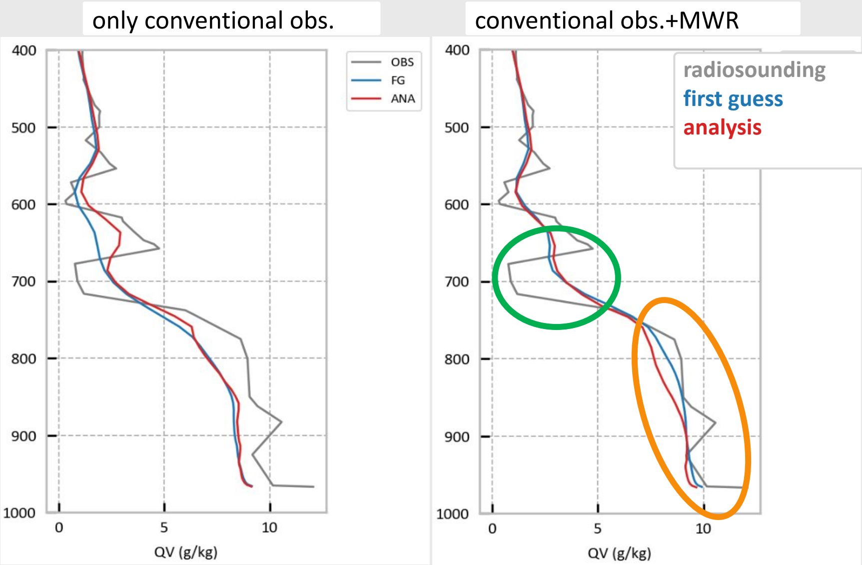
Norwegian Meteorological Institute

Data assimilation experiments

-- **72h data assimilation**, hourly cycle (20.07.2019-22.07.2019)
hourly MWR data

-- Temporally constant bias correction was used considering dependency on stations, elevations, channels

-- Only conventional observations vs conventional observations + MWR



Promising results:

-- The implemented system is technically working;

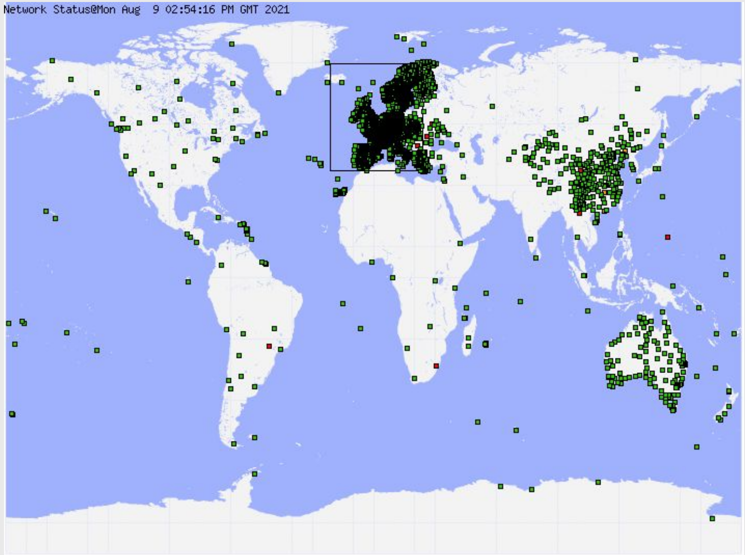
-- Better agreement between brightness temperature observations and model; expected behavior.

Further assessments:

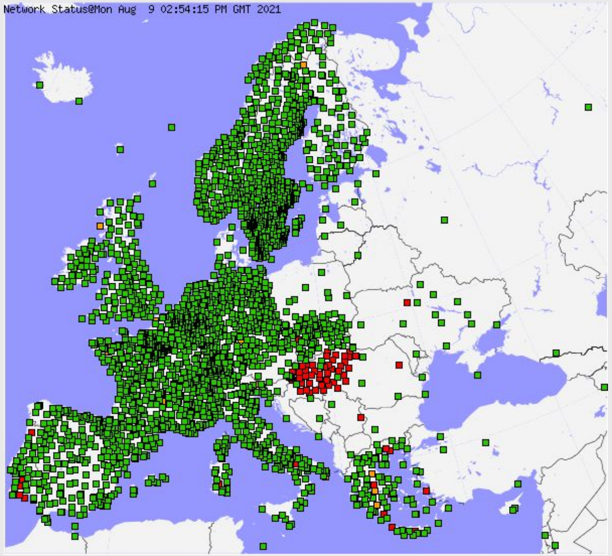
-- Assessment of impact in other model variables, assessment of impact on forecasts, longer experiments, tuning of observation error, improvement of bias correction, clear-sky vs. all-sky, benefit of slanted scans in addition to zenith scan…

Other results using microwave radiometer (Meteo France):

-- Successful retrieval of temperature, humidity, and liquid water path in fog via the 1DVar analysis of brightness temperatures measured by ground-based microwave radiometer (Martinet et al. 2020)



ZTD



GNSS slant delay observations

DWD

KNMI

SHMÚ

Norwegian Meteorological Institute

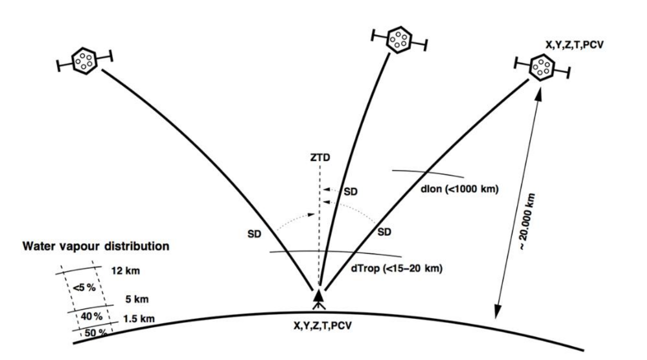
Global Navigation Satellite System(GNSS) slant total delay

GNSS signals are delayed and bent when propagating through the atmosphere (Guerova et al. 2016).
-- Travel time measurements from the GNSS satellite to the receiver: $T = \frac{L}{c}$

Optical path length : $L = \int_S n(s)\ ds$, n - refractive index, c - speed of light

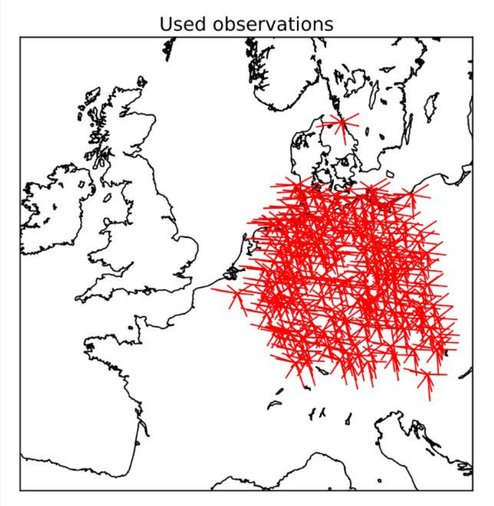
Excess path length due to the atmosphere:

Slant Total Delay: $STD \approx 10^{-6} \cdot \int_S N\ ds$ with $N = 10^6 \cdot (n-1)$



<u>GNSS atmospheric products</u>:
-- Slant total delay (STD)
-- Delay along individual transmitter and ground receiver paths

-- Zenith total delay (ZTD)
-- Spatially and temporally averaged delay in zenith direction based on many GNSS observations



<u>STD network in Europe</u>:
-- So far mainly in Germany

GNSS slant total delay - Observation operator

$$STD = 10^{-6} \cdot \int_S N(s)\ ds \quad \text{with} \quad N = k_1 \frac{p_d}{T} + k_2 \frac{e}{T} + k_3 \frac{e}{T^2}$$

The STD assimilation operator H STD consists of 2 parts which are called by the COSMO interface (Bender et al. 2021) :

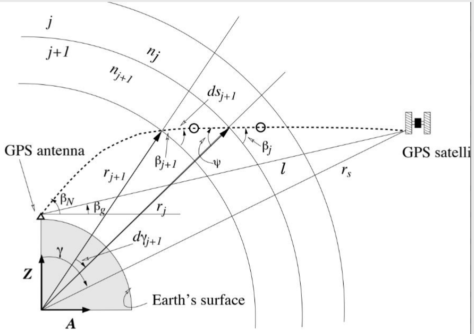
1) <u>Setup of the observation geometry</u>:
   - -- Computes connecting line between satellite and receiver
   - -- Definition of supporting points on the signal path

2) <u>Computation of the signal path estimation and delay</u>:
   - -- Interpolation/extrapolation of the model data on the supporting points
   - -- Call of the raytracer, iterative estimation of the curved signal path
   - -- Delay computation - integration of the refractive index along the signal path

STD operator

$$\begin{aligned} \tau &= \int_{H_a}^{r_s} n(s)ds - L \\ &= \int_{H_a}^{r_s} (n(s)-1)ds + S - L \\ &= \int_{H_a}^{r_s} 10^{-6} N(s)ds + S - L \end{aligned}$$

At low elevations S and L differ!



Refractivity between layers:

$$N(h; H_k \le h < H_{k-1}) = N_k \left(\frac{N_{k-1}}{N_k}\right)^{\frac{h-H_k}{H_{k-1}-H_k}},$$

Similar implementation was done in AROME based DA (de Haan and Imrišek, 2021)

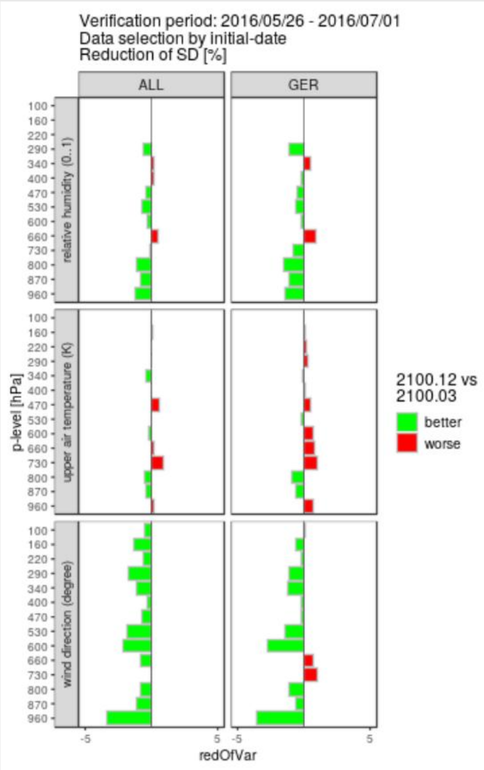
GNSS slant total delay - Impact assessment

In COSMO (Bender et al. 2021)**:**

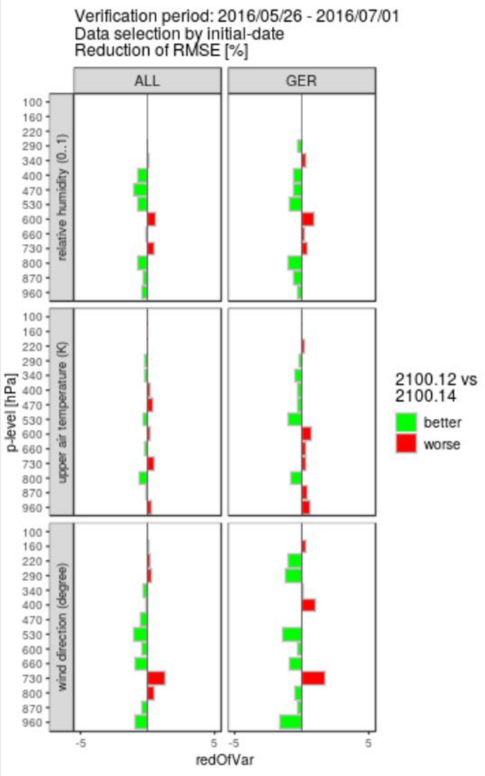
-- Temporal thinning: Last observation(s) within hour per station
-- No spatial thinning
-- Elevation thinning: Per station one ZTD and all STDs with $\varepsilon < 25^\circ$
-- Horizontal localisation for LETKF: 20 km
-- Weak vertical localisation for LETKF: 2.5 km
-- One constant ZTD error assumed for all stations (mapped for STDs): 12 mm
-- Bias correction per station/provider/product
-- Ranking and whitelisting per product
-- Blacklisting per station/provider/product

Three experiments for May/June 2016:

1. Reference experiment with conventional observations
2. Reference + ZTD
3. Reference + ZTD + (STD at low elevations)



STD+ZTD vs REF
Improvement 1 - 4 %

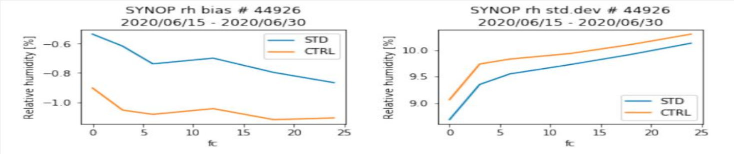


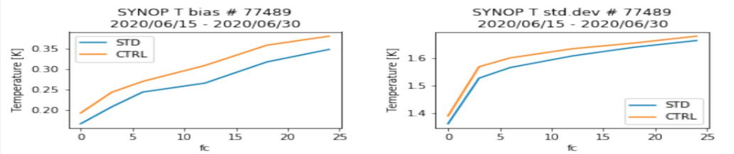
STD+ZTD vs ZTD
Improvement 1 - 2 %

Very promising results!

GNSS slant total delay - Impact assessment

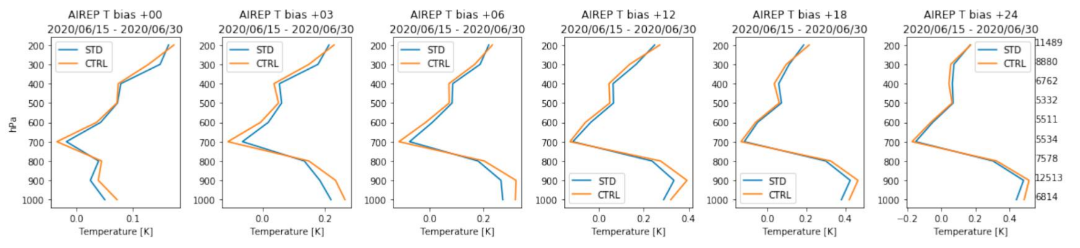
In HARMONIE-AROME (de Haan and Imrišek, 2021)**:** Two weeks experiments including all available STD & ZTD

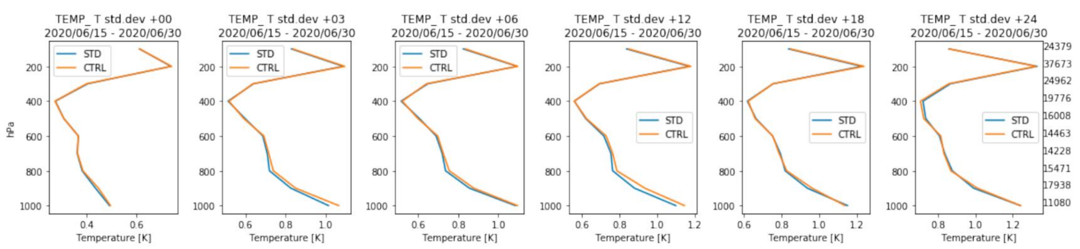


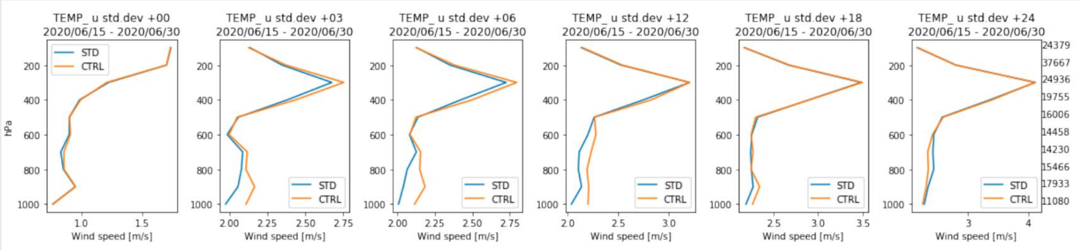


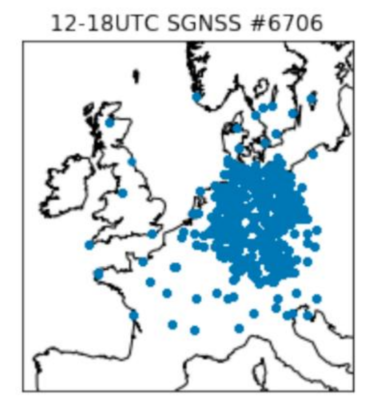
Very promising results!

We need all producers to provide also STD.









KNMI

SHMÚ

Observations measured by cars

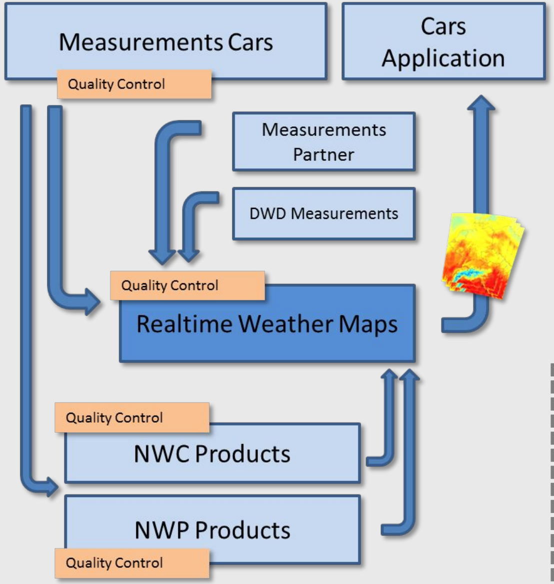
Observations by Cars - FloWKar („Fleet Weather Maps“) project

A collaboration of the German Weather Service & the car manufacturer AUDI AG

→ Real time weather maps for road applications and autonomous driving

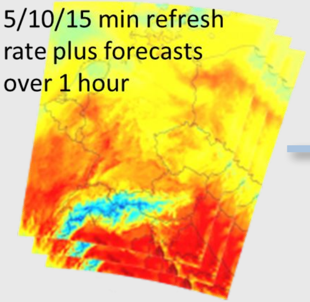
Real Time Weather Maps @ DWD

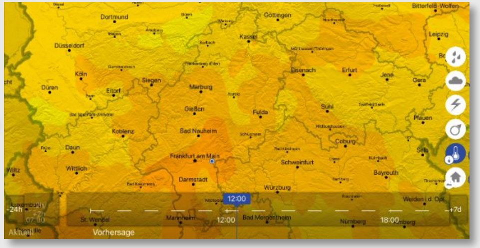
Based on seamless integration of ultra-rapid data assimilation and nowcasting



Realtime Weather Maps

5/10/15 min refresh rate plus forecasts over 1 hour





Variables (optional/scenario)

- Ground temperature
- Wind gusts/Wind
- Visibility
- Precipitation
- …

Publication available: **Hellweg et al.,** 2020

Norwegian Meteorological Institute

FloWKar Observation Network & Processes

DWD

- → Vehicle data
- → Conventional sources
- → Reference sources (Mobile weather units, weather boxes)
- → Road weather stations
- → Citizen weather stations (Netatmo)
- → 10’ SYNOP data

- ✔ Data calibration
- ✔ Quality control
- ✔ Bias correction of measured data
- ✔ Checks on Points Of Interest (eg. bridges, tunnels etc.)
- ✔ Data assimilation

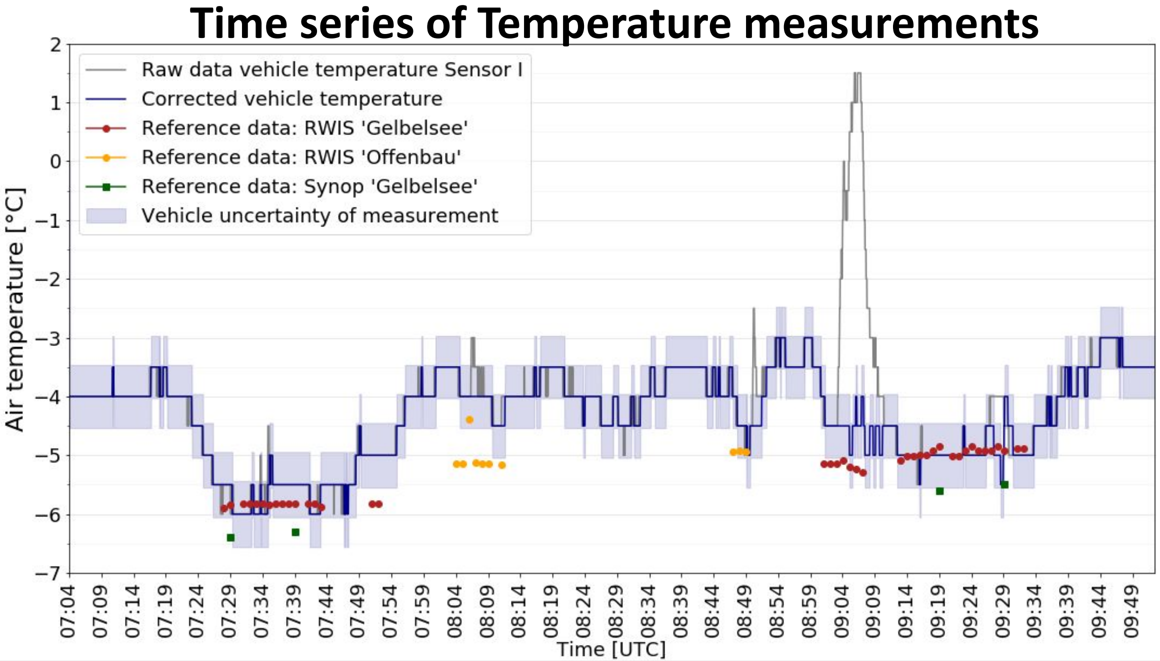
AUDI

- → Car data
- → Mobile weather stations

- ✔ Bias correction of measurement; uncertainty of vehicle sensors
- ✔ Correction due falsifying effects included by dynamics of vehicle
- ✔ Correction of physically explicable effects
- ✔ Machine Learning approaches for bias correction

FloWKar: Bias Correction of Temperature

Bias correction of temperature car measurements via Artificial Intelligence techniques



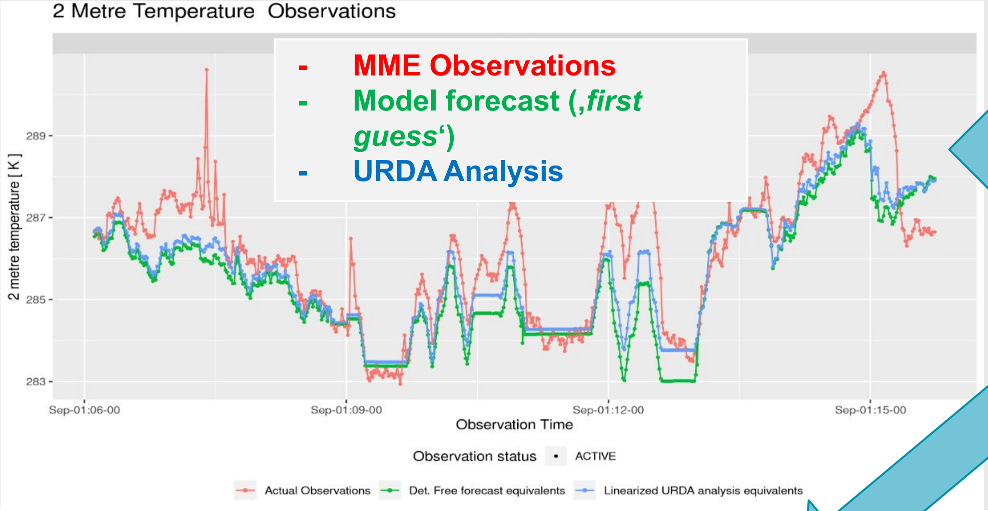
- Correction of car measured temperature
- Approach: dealing with measurement errors by physical and mechanical processes
- Corrected temperature is in agreement with the reference data

Publication available: **Hellweg et al.**, 2019

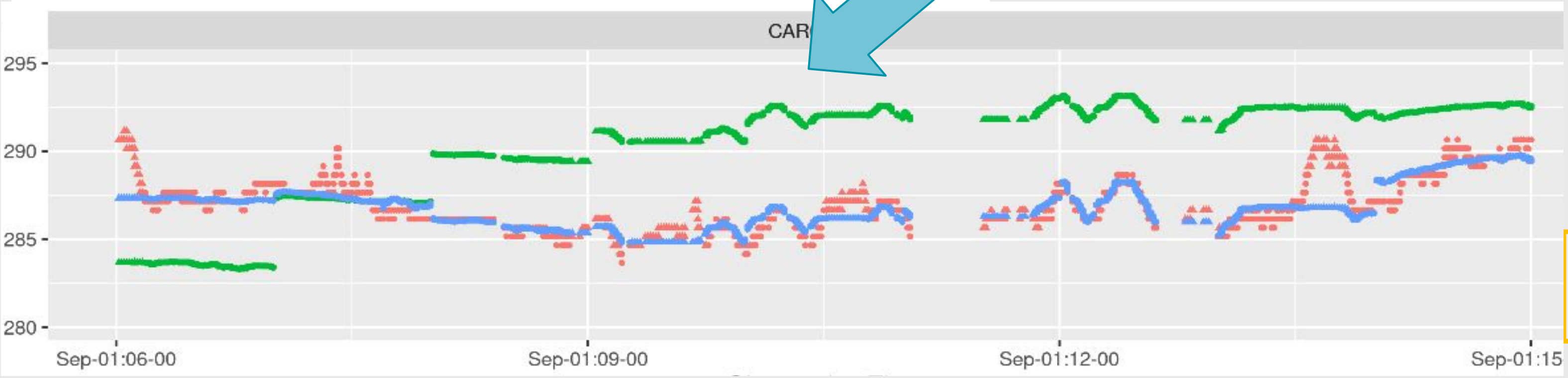
Norwegian Meteorological Institute

FloWKar: Ultra Rapid DA for Mobile Data

URDA for Temperature observations



- ✔ URDA application with high quality mobile meteorological measurements (MME data) & car measurements (AUDI A6 project vehicle)
- ✔ successful assimilation of high resolution data with URDA
- ✔ URDA improves the forecast



Publication **in progress**

Personal weather station observations

FMI

Norwegian Meteorological Institute

SMHI

CSC

DMI

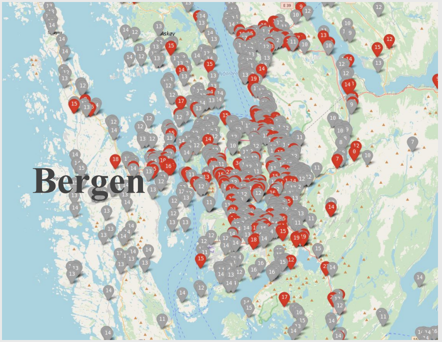
KNMI

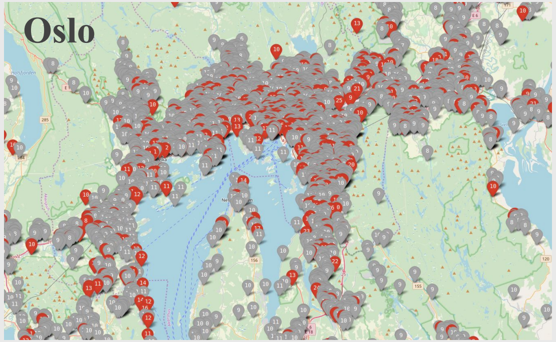
METEO FRANCE

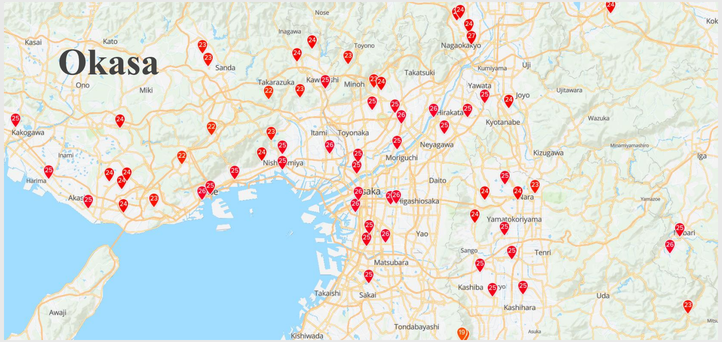
Personal weather stations

Very fast growing networks...

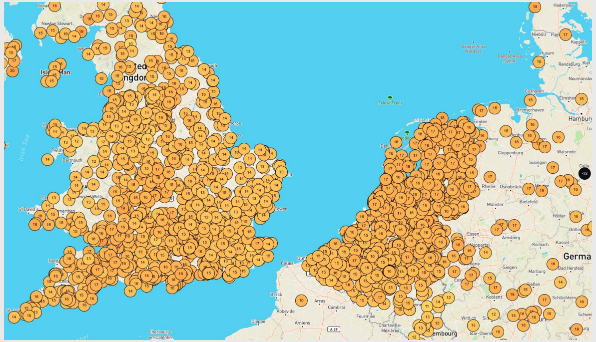
Netatmo

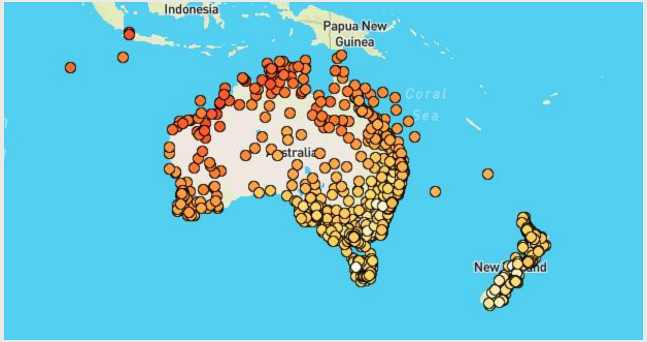






WOW -- weather observation website





Personal weather stations

Measuring:

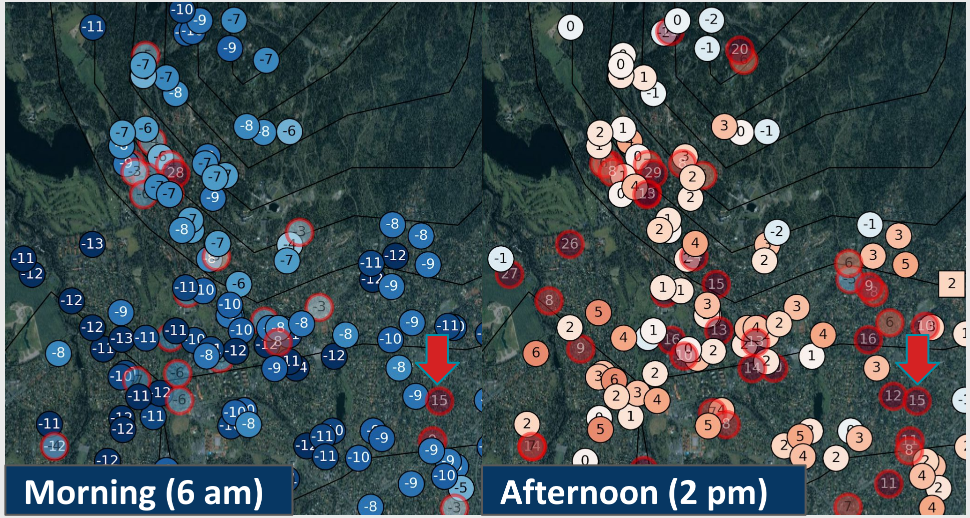
-- Temperature, Humidity, Pressure, Wind, Precipitation

Advantage:

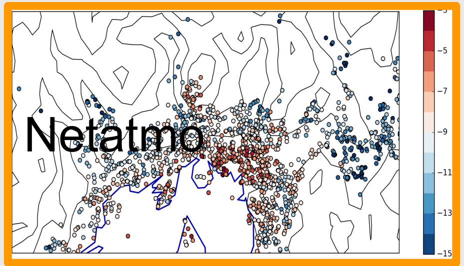
-- Private weather stations are becoming popular
-- Low-cost and off-the-shelf devices
-- Data in real-time
-- Fast growing network, fills the gaps
-- Quality controlled network (Netatmo web site)

Known issues:

-- Poorly located device (such as in direct sunlight, next to building, or even inside), incorrect location and altitude information, uncalibrated/calibration errors, possible drifting/biasing...
-- The quality of the device is not guaranteed (WOW)



Use of netatmo at MET Norway



Data assimilation — NWP model (forecast) — Post-processing → End users

Nipen et al., 2020

Norwegian Meteorological Institute

Good to have multiple sources

To confirm “no rain” event

2019-09-14 13:00 UTC

Oslo

1-hour acc. precipitation

citizen observations

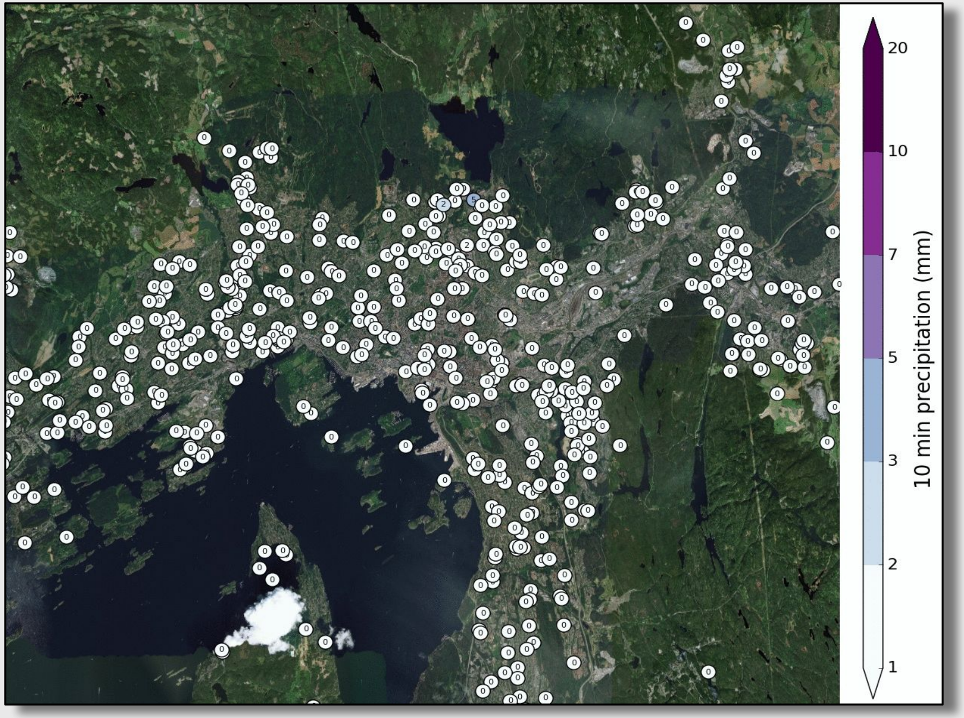
radar estimates

no rain.

Norwegian Meteorological Institute

...citizen observations turn out to be useful even when it is raining...

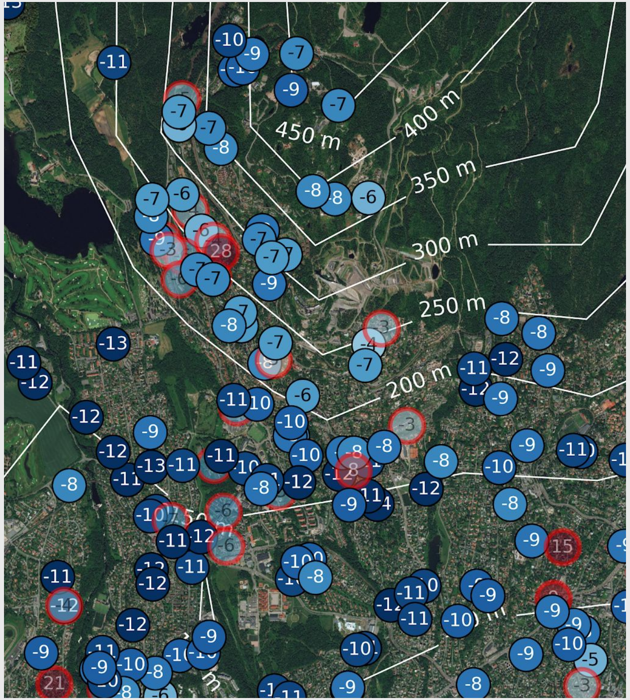
Extreme local precipitation in Oslo (Aug 4, 2019)

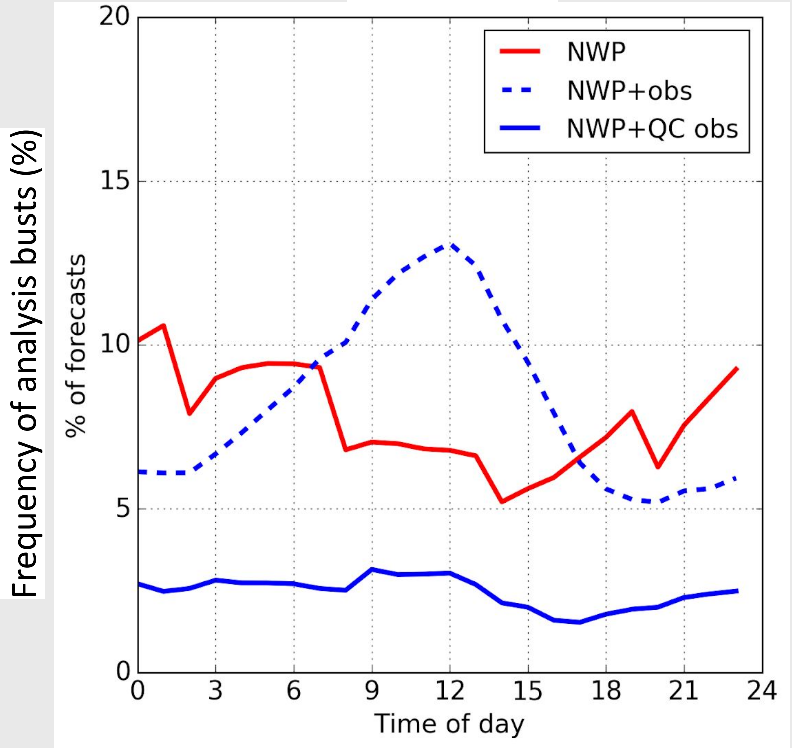


Quality control is essential to get value!

Network should be treated as a whole, not as individual stations

Only 20% are removed in conservative QC





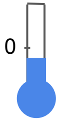
Quality control - the TITAN Library (1)

-- Use neighbouring stations to remove suspicious values (21%)

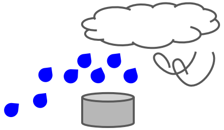
-- Each hour is checked independently

Sequential tests for climate datasets (precipitation) (Nipen et al., 2020)

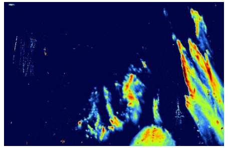
Cross-check temperature and precipitation



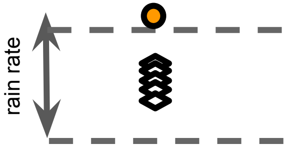
Adjust for wind-induced undercatch



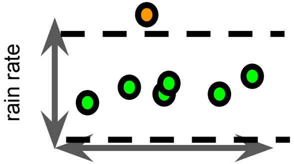
Check against radar data



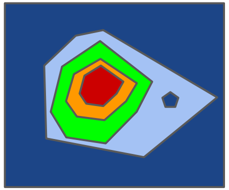
Check against NWP ensemble



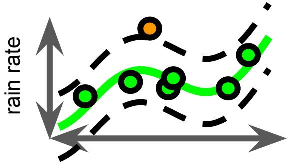
Buddy check
(r = 10 km, minimum 4 stations)



Check for holes in the field

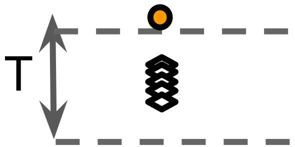


Spatial consistency test
(first guess, 20 closest stations)

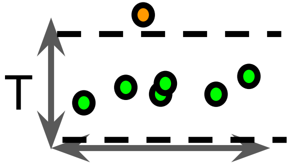


Sequential tests for climate datasets (temperature) (Nipen et al., 2020)

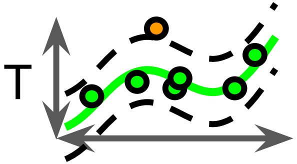
Check against NWP ensemble



Buddy check
(r = 10 km, minimum 4 stations)



Spatial consistency test
(first guess, 50 closest stations)



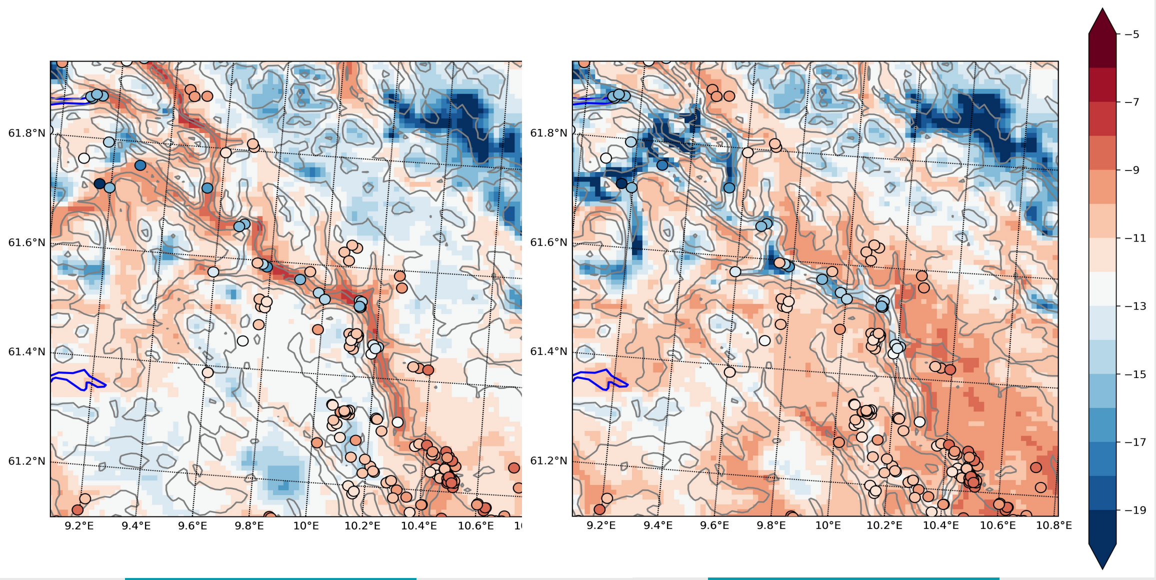
Norwegian Meteorological Institute

Interpolation / assimilation tool - GridPP Library

Correction are spread in space, but limited by:

- Distance (~30km)
- Elevation (~200m)
- Land/ocean
- MEPS covariance structure
    - E.g. will not spread across a front

(Lussana et al., 2019)



No correction

With correction

Ongoing (in MetCoOp nowcasting system):

-- Apply TITAN and GriPP Libs to assimilate netatmo observations (T2m, Hu2m) to improve analysis of soil variables in NWP.

Norwegian Meteorological Institute

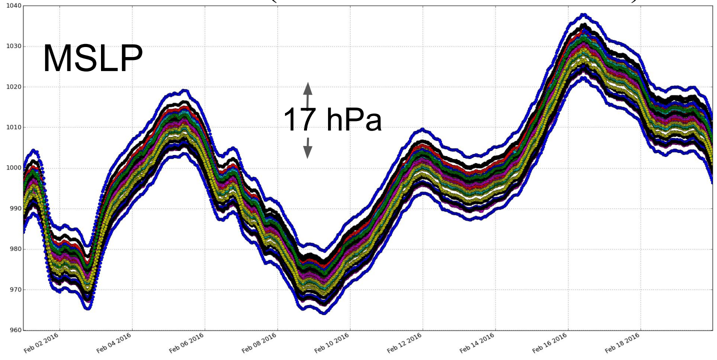
Pressure observations from Netatmo (iOBS project -- Ridal et al., 2021)

iOBS is a Nordic collaboration between **FMI, MET Norway, SMHI & CSC** (→ Q2 2021) (https://neic.no/iobs/)
Objective:
Develop QC algorithms for crowd-sourced data (Netatmo) and investigate the potential of using high resolution QC-ed pressure data in the Harmonie-AROME data assimilation.

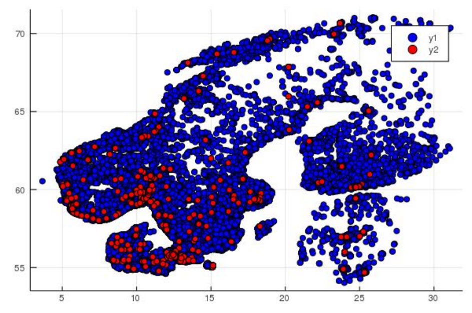
<u>Known issues</u>:

- Inaccurate altitude (17 hPa ~ 130 m)
- Data needs to be bias corrected.

Netatmo (1km x 1km box in Oslo)



Duplicate coordinates (lat lon values)



Each red dot marks a place where there are two or more Netatmo stations with exactly the same lat, lon coordinates.
In some cases (e.g. at Oslo Domkirke) there are more than 50 stations at the same location.
All these stations are blacklisted (approx 1000 stations)

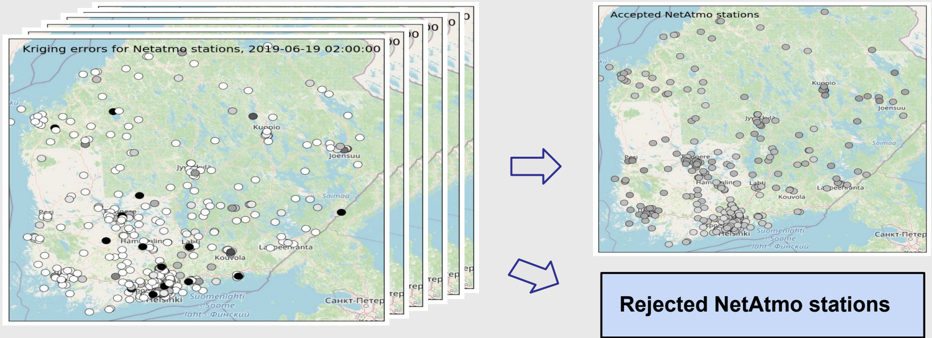
Pressure observations from Netatmo - Data processing

Pre-processing using 3 QC methods:

1) **Baseline QC**
   - -- remove duplicates and stations with missing data
   - -- Relies on existing background checks in Harmonie-AROME DA

2) **Clustering/grouping method**
   - -- Unsupervised machine learning:
     - -- Find clusters of similar obs; Accept obs with high degree of confidence and belong to a cluster
     - -- Reject obs that look like outliers or just don't belong to any cluster

3) **Kriging Method**
   - -- Conventional weather stations (CVS) used as ground truth
   - -- Kriging or Gaussian Process regression in spatial domain (2D)
   - -- Interpolate CWS measurements, record errors for personal weather stations (PWSs)
   - -- Run the spatial consistency test for multiple timestamps
   - -- Reject PWSs that have too often, too high interpolation errors



Need for data thinning:

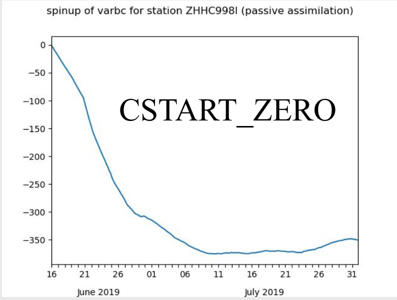
- -- Netatmo stations are concentrated in populated areas
- -- Thinning is needed
- -- Thinning to either 20kmx20km or 10kmx10km grid in Lambert conformal conic projection
- -- Select station closest to the predefined grid

Format conversion:

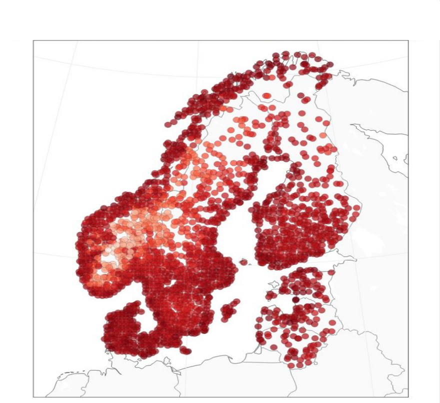
- -- Use of surface pressure (Ps) instead of geopotential (Z)
- -- Netatmo MSLP converted to Ps
- -- CSV converted to input format (ascii) of the Harmonie-AROME

Variational bias correction (VarBC):

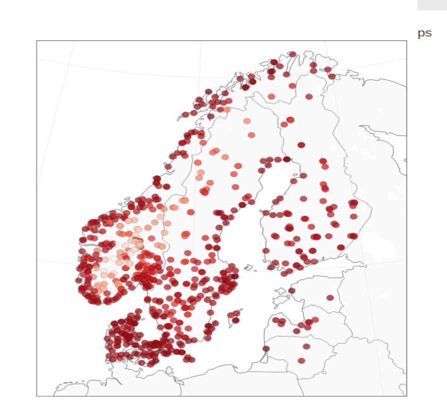
- -- Bias parameters set to zero (CSTART_ZERO) at the start of spinup
- -- Bias parameters set to mode (CSTART_MODE) of the first-guess at the start of spinup



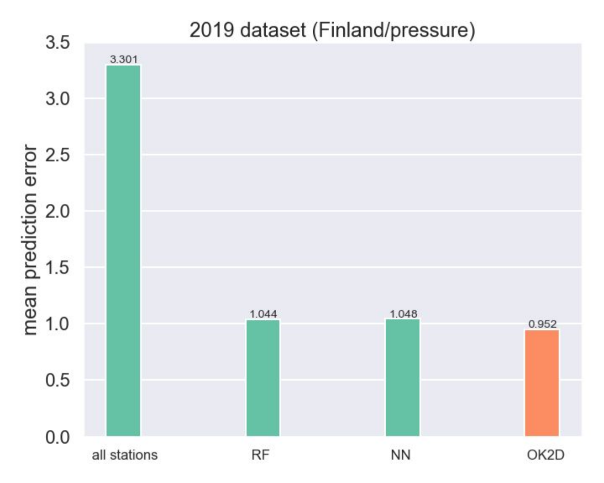
Data after QC and thinning



Use nearest good observation to the grid (~ 1850 stations)



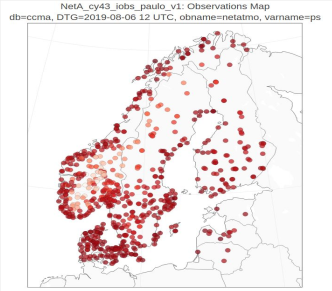
Clustering and rejection; use nearest observation to the grid (~ 520 stations)

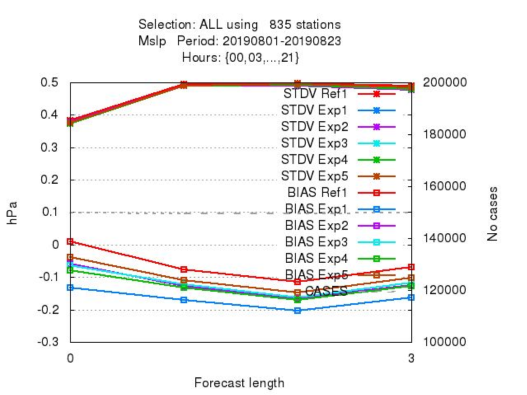


No QC (all stations); random forest regression (RF); nearest neighbor regression (NN); 2D kriging (OK2D)

Norwegian Meteorological Institute

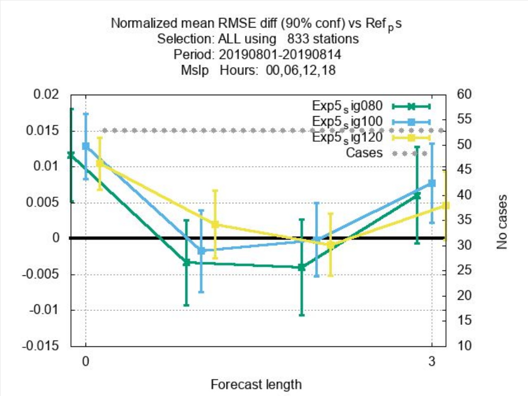
-- Verification scores over 3,5 weeks period (and short period);
-- Data Assimilation : 3D-Var
-- Assimilating station surface-pressure (PS) instead of geopotential (Z).
-- Confirmed that reference with PS and Z does give very similar results/scores.
-- Verification is against Synop stations





Experiment	QC method	VARBC	Obs. error (Pa) sigma_o	Station distance (km) Thinning
Reference (Ref)	-	-	-	-
Experiment 1 (Exp1)	Baseline	CSTART_MODE	80	20
Experiment 2 (Exp2)	Baseline	CSTART_ZERO Long spinup	80	20
Experiment 3 (Exp3)	ML clustering method	CSTART_MODE	80	20
Experiment 4 (Exp4)	ML clustering method	CSTART_MODE	80	10
Experiment 5 (Exp5)	Kriging	CSTART_MODE	80	20
Experiment 6 (Sig_100) Short Exp	Kriging	CSTART_MODE	100	20
Experiment 7 (Sig_120) Short Exp	Kriging	CSTART_MODE	120	20

Important:
-- Careful implementation and setup of VarBC
-- Choice of the QC technique



Ref - no netatmo Ps assimilation
Sig_80 - kriging & 80 Pa obs error
Sig_100 - kriging & 100 Pa obs error
Sig_120 - kriging & 120 Pa obs error

Important:
-- Well defined observation error

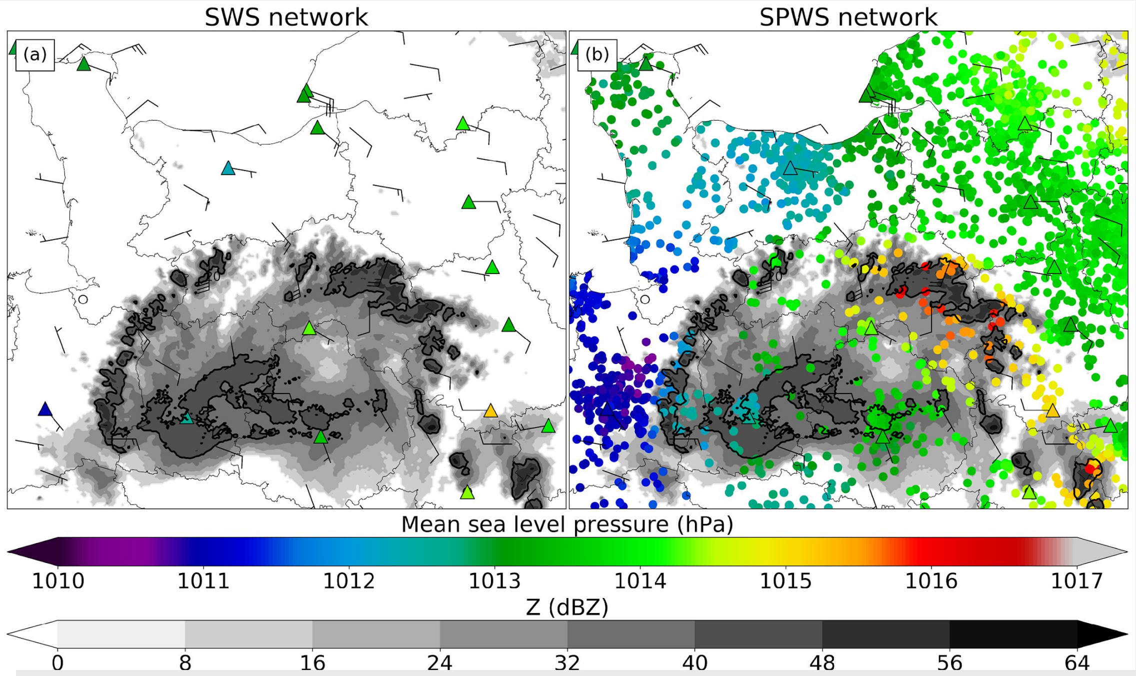
Norwegian Meteorological Institute

Towards the assimilation of PWS data at Météo-France

The design of a specific quality control (correction & rejection) for the PWS data (pressure, temperature, and humidity) has shown that these data provide relevant information and paves the way for the assimilation of these data.

Current efforts in assimilating temperature are focused on the implementation of VarBC (selection of predictors) and its evaluation (Alan Demortier's PhD).

The group is in touch with MET Norway experts (C Lussana and T Nipen) regarding the possible use of TITAN: a preliminary evaluation was carried out on several deep-convection cases over France

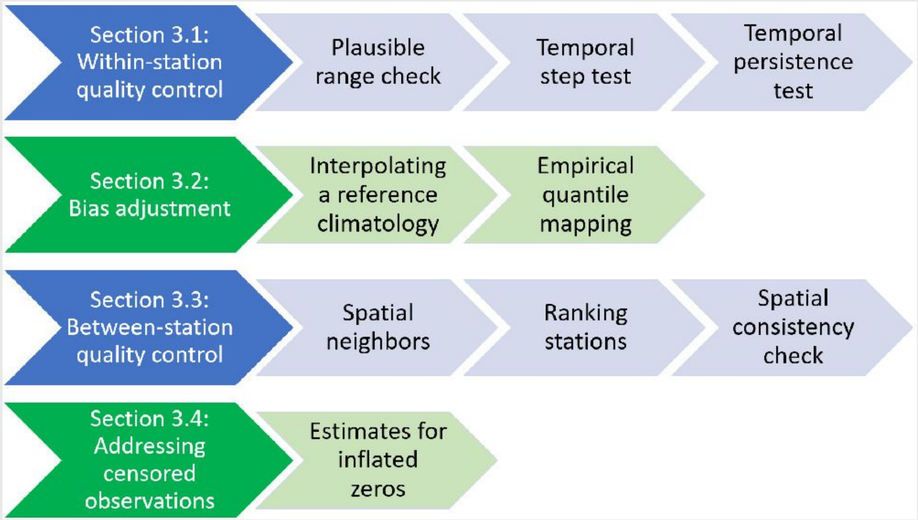


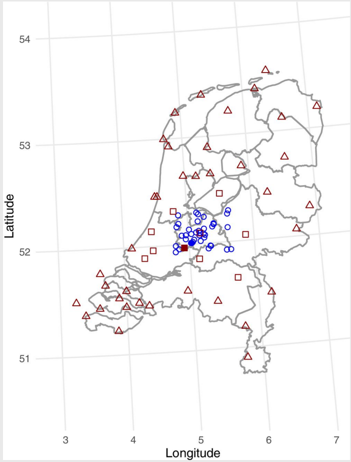
Comparison between mean sea-level pressure at 18:15 UTC on 26 May 2018 from (a) Standard Weather Stations and (b) Standard + quality-controlled Personal Weather Stations. Reflectivity in grey shades. (from Mandement and Caumont 2020)

Wind observations from WOW-- WOW NL (Chen et al., 2021)
QCwind

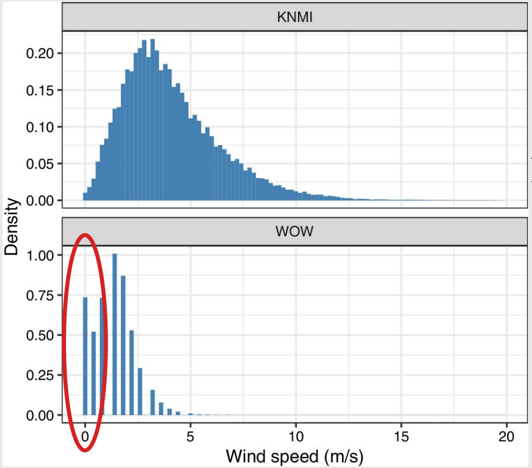
Known issues:
- -- Bias
- -- Too many zeros
- -- Credibility of individual observations

Quality control:



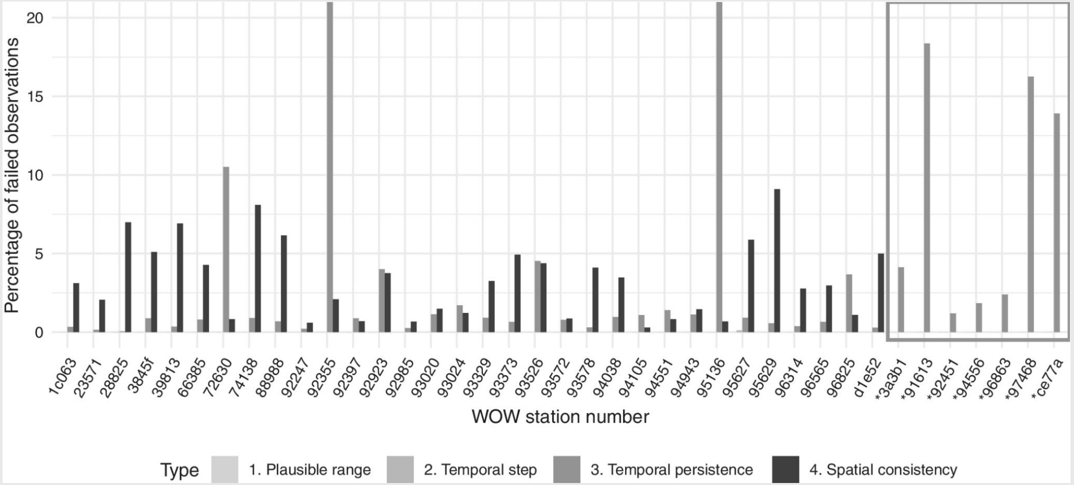


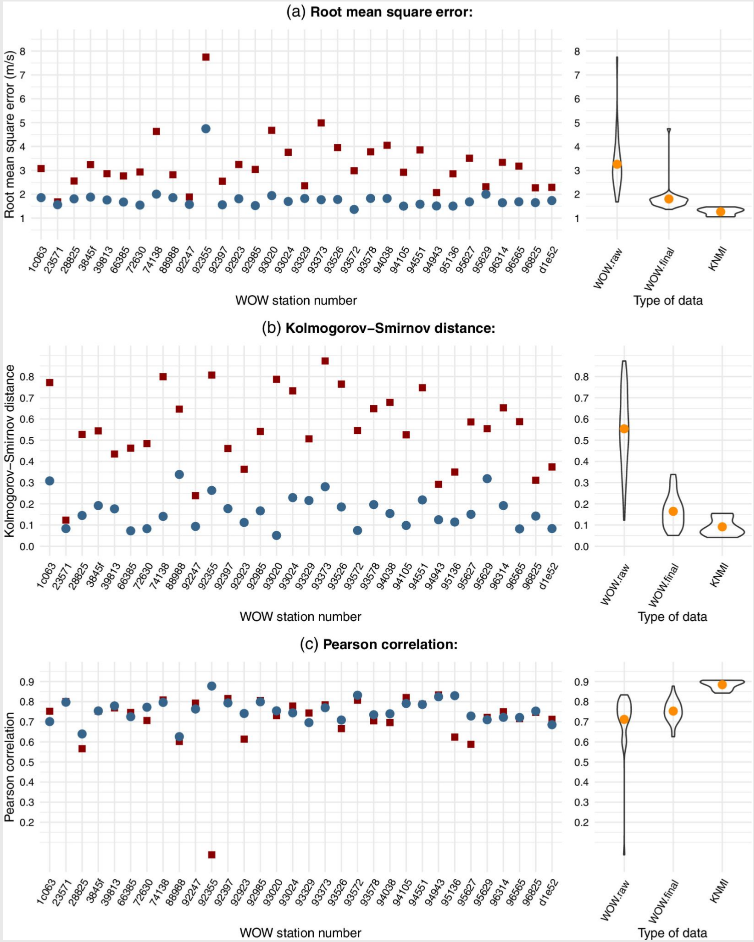
39 WOW stations considered in the study (circles) and the 47 KNMI stations (squares and triangles)



Density frequency histograms of wind speed observations from a KNMI station (Cabauw) and an example WOW

Wind observations from WOW-- WOW NL (Chen et al., 2021)





Depending on the application:

-- Valuable wind information can be extracted from the WOW-NL network

Further improvements:

-- Bias adjustment (BA) per wind direction

-- Improvements to the climatology - surface roughness

-- Develop a data-driven method - can we include more metadata?

-- Transferable to other regions - need a ’truth’ for the BA

Smartphone observations

DMI

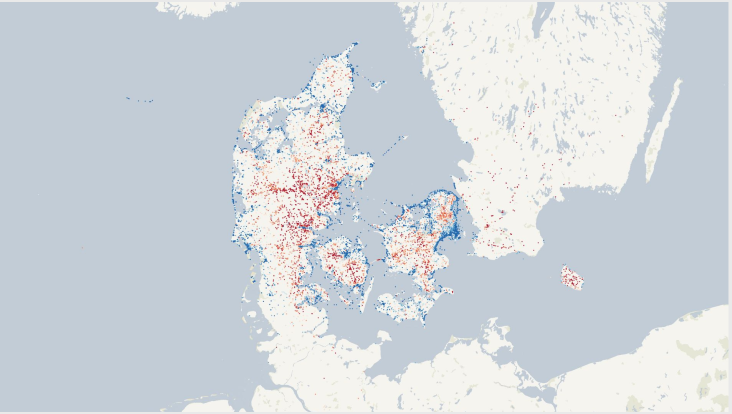
Norwegian
Meteorological
Institute

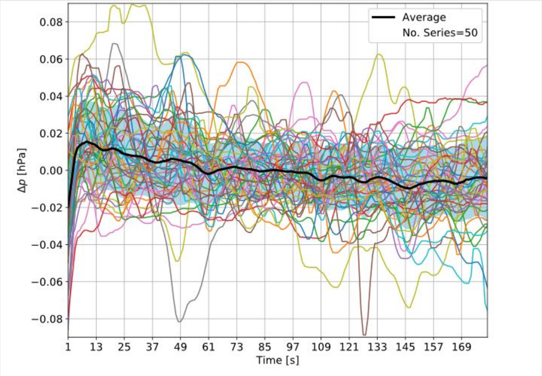
Pressure observations from Smartphones (SPOs)

(Hintz et al., 2019, Hintz, 2021)

How does data look?

Surface pressure during one hour
20th of June 2020, 5 - 6 UTC





Issues and solutions:

-- Data not just ready for download as other types of crowdsourced data
=> Had to write a software for collecting the data
=> A short spin-up time of 5s was found on average during which the pressure should not be logged

-- General Data Protection Regulation (GDPR)
=> Had to remove the unique identifier (UID) and blur the location of the device

-- Data processing:
=> Observation correction and quality control (QC)

Current status:

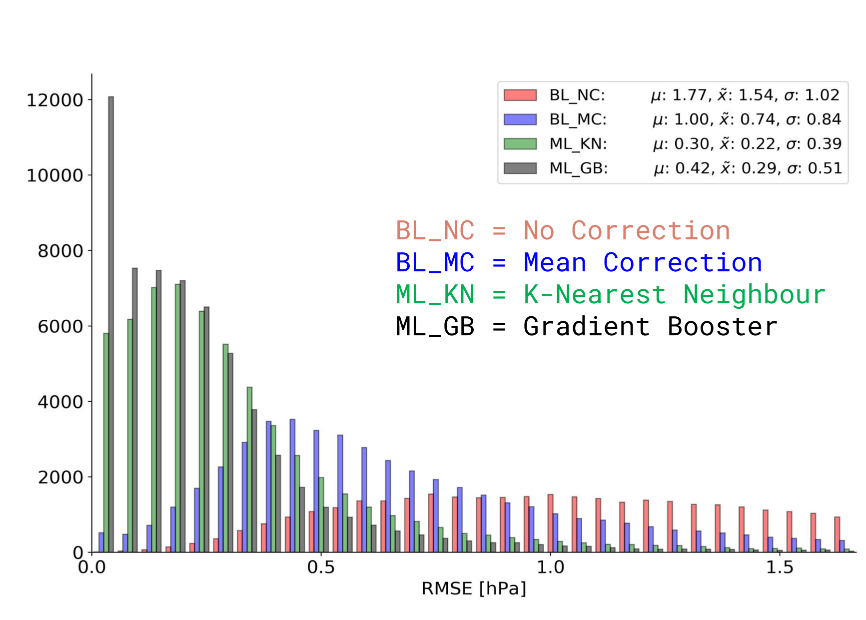
-- Testing TITAN lib for QC
-- Assimilating in Harmonie-AROME 750 m resolution and testing configurations
-- Making data collection software (SMAPS) easier to integrate into native software development kits (SDKs)
-- iOS: Completed
-- Android: Needs refactoring

DMI

Norwegian Meteorological Institute

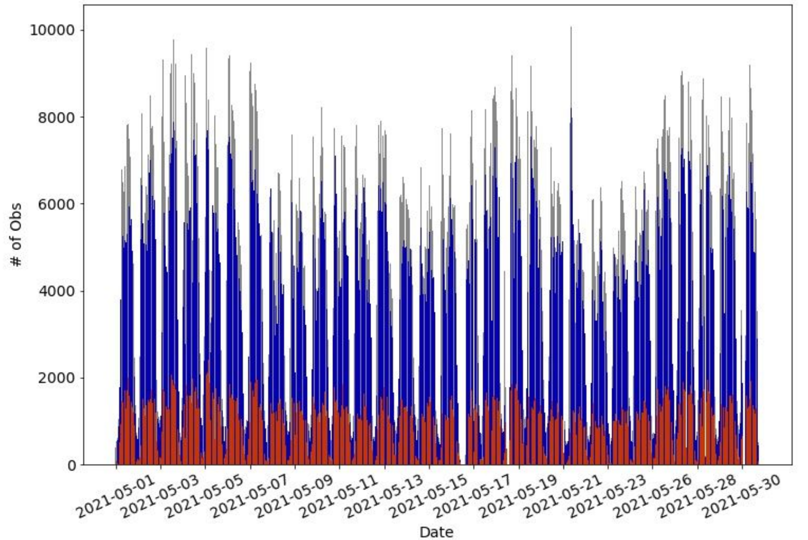
SPOs data processing

Observation Correction



Testing to evaluate results using TITAN on moving platforms.

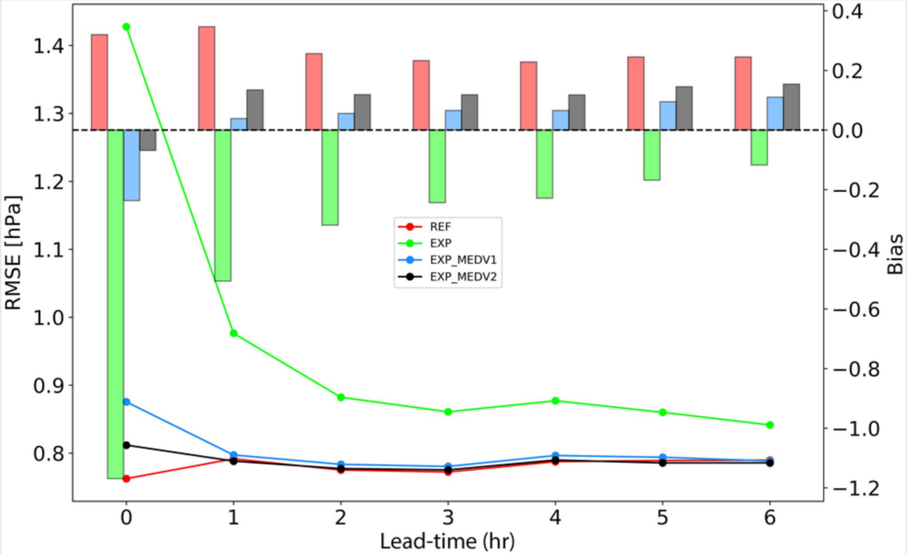
For one month of data TITAN flagged 20.2 % of all observations.



Norwegian Meteorological Institute

SPOs data assimilation

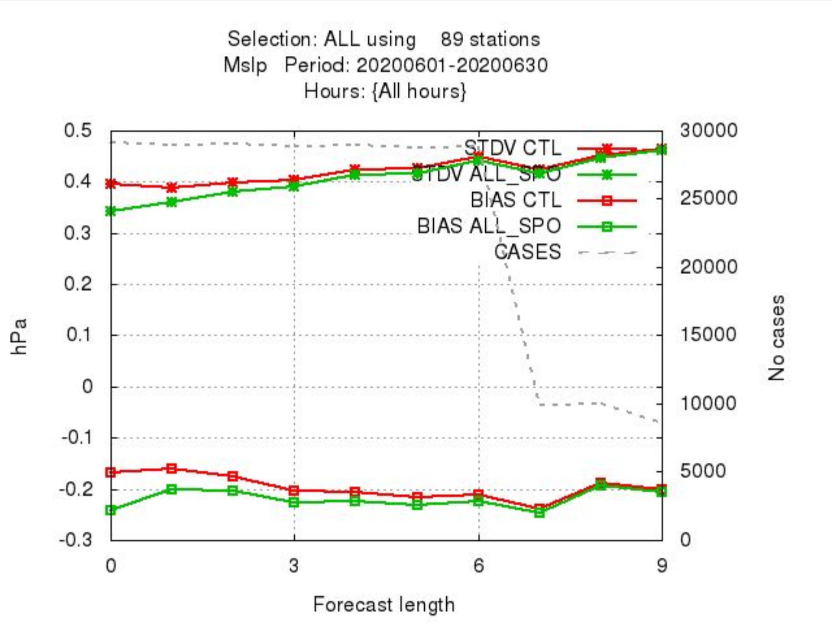
Old-Neutral Results (Hintz, et. al., 2019)



REF (Red): No SPOs
EXP (Green): No thinning
EXP* (Blue and Black): thinning applied

3DVar 2.5 km Harmonie-AROME
Period: 2 weeks

New-Promising Results (2021)

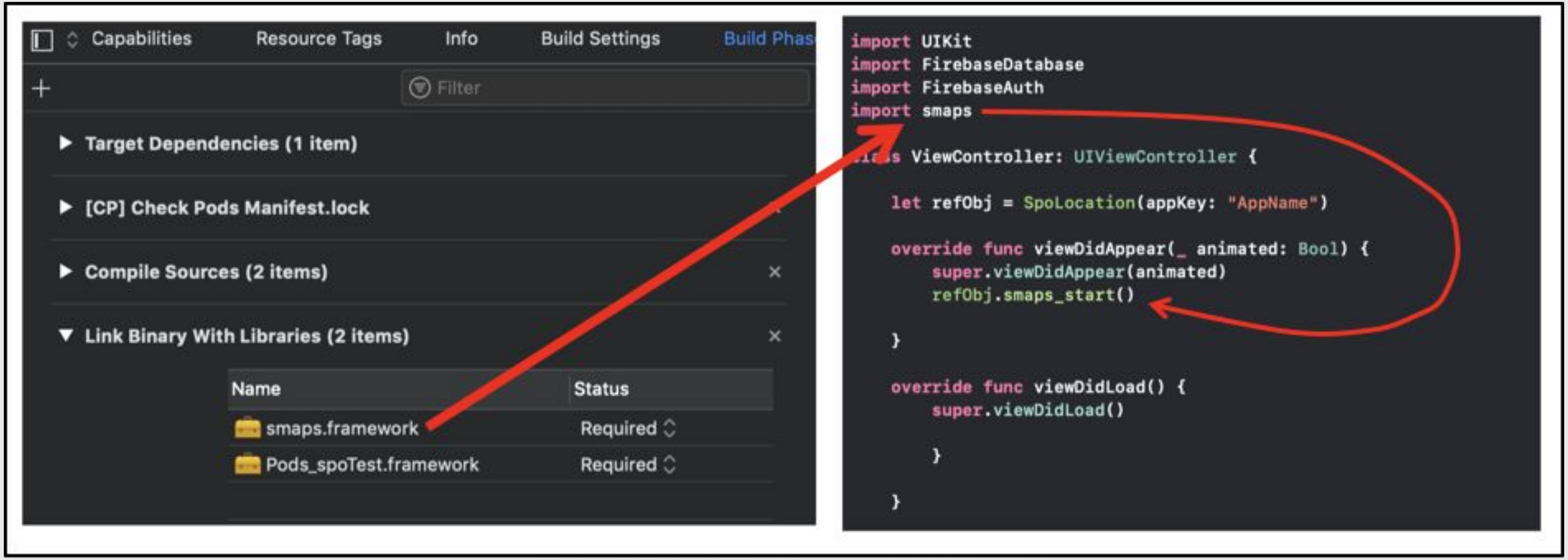


3DVar 750 m Harmonie-AROME
Period: 4 weeks
Red: No SPOs
Green: No thinning (inflated obs error)

=> Plan to use TITAN QC'ed SPOs

Getting SPOs accessible for NWP applications in Europe

The SMAPS framework can be included as a module.
The module is being used in the DMI app operationally.
Data is not personal anymore, thus we can share data across borders.



https://github.com/Hirlam/smaps (Contact HIRLAM Management Group for access)

Concluding remarks (1)

Ceilometer/Lidar (DIAL):

-- Provide observation in all weather conditions with good vertical range (up to 3 km).
-- The accuracy meets the WMO OSCAR threshold requirement for high resolution NWP.
-- Lidar observations could potentially improve the model if assimilated.
=> Observation operator needs to be developed.
=> Campaign will take place in autumn 2022 over the coastal regions of the north-western Mediterranean basin in order to evaluate the benefit of assimilating water vapour data measured by a Raman lidar network

-- Operated by NMHSs and aviations.
=> (Global/European) Operational network is needed for further exploration in NWP.

Radiometers:

-- Assimilation using RTTOV-gb technically works; many remain to be done.
-- 1D-Var scheme successfully used to retrieve temperature, humidity, and liquid water path.

=> (Global/European) Operational network is needed for further exploration in NWP.
=> EUMETNET plans to establish an operational network of ground-based microwave radiometers by 2023 (Rüfenacht et al. 2021).

Concluding remarks (2)

GNSS slant path delay:

-- The developed observation operators (in KENDA and in Harmonie-AROME) provide clear positive impact on forecasts.

-- Would be good to have (robust) bias correction approach. For example: VarBC (?)

-- (Global/European) network is needed.

-- (in Europe) Next request to E-GVAP: provide also STD available at all receiver stations.

Observations from cars:

-- FloWKar project shows that collaboration between NMHSs and car manufacturers (DWD and AUDI) is essential for an efficient data collection and processing.

-- Provide valuable observation for NWP applications.

-- Successful quality control, bias correction, and data assimilation.

=> EUMETNET (WMO) to collect and distribute European (global) data.

Concluding remarks (3)

Private weather station (Netatmo, WOW):

-- Valuable data but good quality control and bias correction are needed.

-- TITAN (https://github.com/metno/titanlib) and QCWind (https://github.com/jieyu97/QCwind) are open source codes.

-- iOBS project showed that

-- Machine learning approaches can be used to quality control data from PWS.

-- A robust bias correction solution is needed to assimilate efficiently the pressure observations.

=> EUMETNET is preparing a sandbox dataset with long enough period for testing different tools.

Smartphone observations:

-- Solution for data collection found.

-- Robust quality control is needed (TITAN QC showed good results).

-- Assimilation in high resolution with inflated observation error showed promising results in hectometric NWP and DA.

=> EUMETNET (WMO) to collect and distribute European (global) data.

For discussion

Fast growing stations and bias correction / quality control:

-- VarBC requires stationID, which is not trivial for PWS and crowdsourced observations.

-- Robust on the fly quality control and bias correction approaches are needed without strong dependency to StationID.

Thank you for your attention!

References (1)

Bender et al. 2021: Assimilation of GNSS Slant Delays with COSMO-D2/Kenda, EUMETNET annual Obs-SET meeting, 15-18 June, 2021.

Chen et al., 2021: Quality control and bias adjustment of crowdsourced wind speed observations. Q.J.R. Meteorol. Soc, 1–18. Available from: https://doi.org/10.1002/qj.4146

Gaffard et al., 2021: DIAL Assessment results, EUMETNET annual Obs-SET meeting, 15-18 June, 2021.

Guerova et al. 2016: Review of the state of the art and future prospects of the ground-based GNSS meteorology in Europe, Atmos. Meas. Tech., 9, 5385–5406

Haan and Imrišek, 2021: GNSS slant total delays in the ALADIN NWP system: Phasing of the source code from cy40h1 to cy43t2, available at: https://www.rclace.eu/File/Data_Assimilation/2019/repStay_MImrisek_STDphasing_2019.pdf

Hellweg et al., 2019"Fleet Weather Map: a project to integrate floating car weather data into the field of automated driving", TAC-ITS Canada Joint Confluence, 2019

Hellweg et al., 2020: Using floating car data for more precise road weather forecast, 2020 IEEE 91st Vehicular Technology Conference.

Hintz et al., 2019: Collecting and processing of barometric data from smartphones for potential use in numerical weather prediction data assimilation. Meteorological Applications,2019, 1–14. https://doi.org/10.1002/met.1805

Hintz, 2021: Processing and assimilation of surface pressure from smartphones, EUMETNET annual Obs-SET meeting, 15-18 June, 2021.

References (2)

Lussana et al., 2019: Spatial interpolation of two-meter temperature over Norway based on the combination of numerical weather prediction ensembles and in-situ observations. Quarterly Journal of the Royal Meteorological Society. DOI: 10.1002/qj.3646

Nipen et al., 2020: Adopting citizen observations in operational weather prediction. Bull. Amer. Meteor. Soc., 101, E43–E57, https://doi.org/10.1175/BAMS-D-18-0237.1.

Martinet et al. 2020: Improvement of numerical weather prediction model analysis during fog conditions through the assimilation of ground-based microwave radiometer observations: a 1D-Var study, Atmos. Meas. Tech., 13, 6593–6611, https://doi.org/10.5194/amt-13-6593-2020, 2020.

Merker et al., 2021: Microwave radiometer data assimilation at MeteoSwiss, EUMETNET annual Obs-SET meeting, 15-18 June, 2021.

Thomas, Werner, 2017: European ceilometer and lidar networks for aerosol profiling and aviation safety – the German contribution, Aeronautical Meteorology Scientific Conference, 6-10 November, Toulouse.

Ridal et al., 2021: use of surface pressure from netatmo stations in the iOBS project, EUMETNET annual Obs-SET meeting, 15-18 June, 2021.

Rüfenacht et al. 2021: EUMETNET opens to microwave radiometers for operational thermodynamical profiling in Europe. Bull. of Atmos. Sci.& Technol. 2, 4 (2021). https://doi.org/10.1007/s42865-021-00033-w