

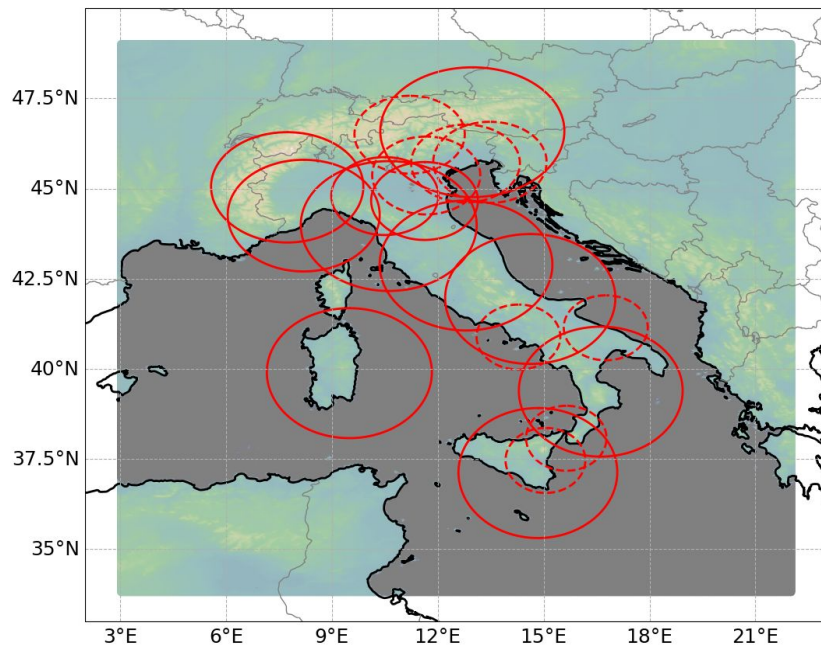
# Data Assimilation at Arpae: recent updates

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## ICON-2I model (2.2 km)

Maintained and developed by Arpae and Agenzia ItaliaMeteo



## KENDA implementation

- 40 members + deterministic run
- 1h assimilation cycles, employing IAU
- RTPS
- Assimilation up to 200 hPa
- IAU with 10 minutes window
- Control vector:  $pf, t, q, u, v, qcl, qci, qr, qs, qg$

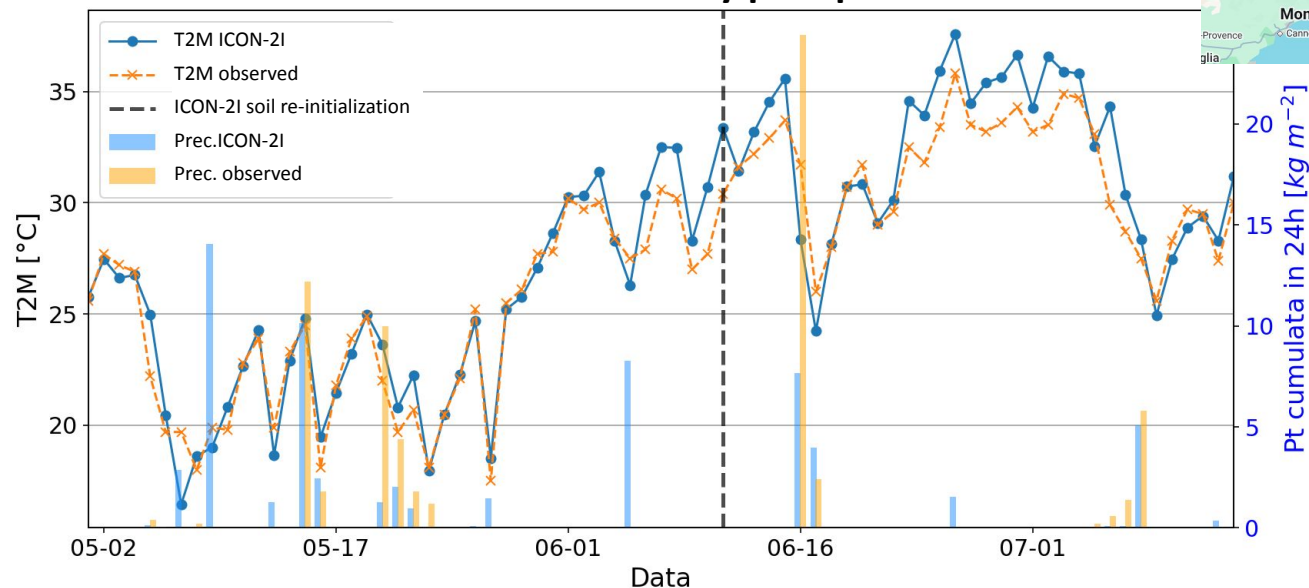
## Assimilated observations

- AIREP, TEMP, SYNOP (wind and surface pressure) and radar volumes (solid lines) of reflectivity and radial wind through KENDA
- SRI via LHN using the composite of all radars (solid+dashed lines)

# Soil moisture (SM) nudging: motivation

ICON-2I overestimates maximum temperature in summer. As an example, the plot compares T2M forecast of ICON-2I (run init. at 00 UTC, so lead time +12h) with the corresponding observations in San Pietro Capofiume.

**T2M at 12 UTC + daily precipitation**



Good agreement during/after rainy days; increasing overestimation with the persistence of stable anticyclonic conditions

## Implementation

- Applied daily to the **03 UTC analysis**, employing the +3h forecast from the ICON-EU run initialized at 00 UTC
- **Weighting of 50%** at each level: the deterministic 03 UTC analysis combines 50% soil moisture from ICON-EU and 50% from the ICON-2I first guess
- The other members of KENDA ensemble nudged towards deterministic member every hour, with a daily weight of 0.5.

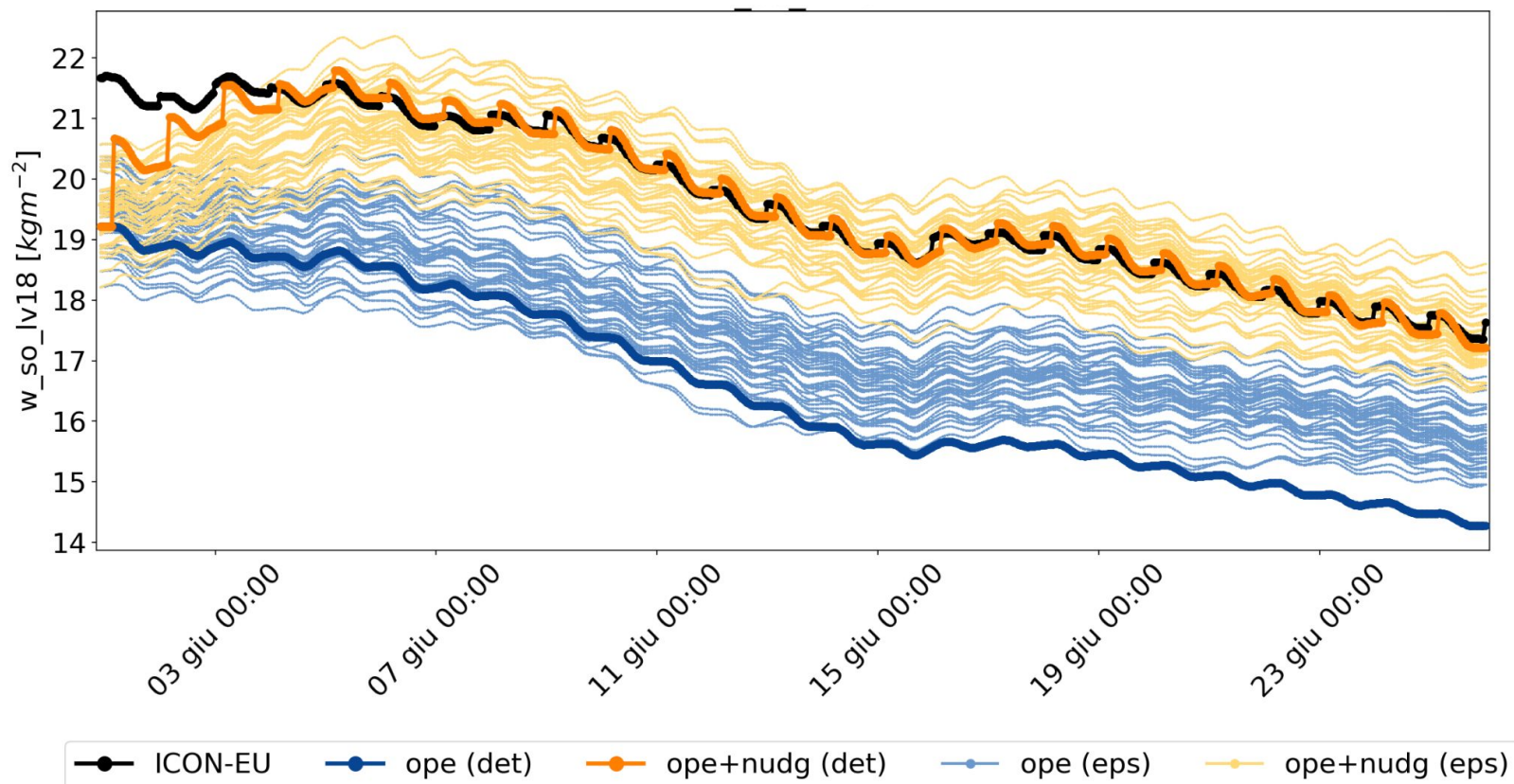
## Experiments

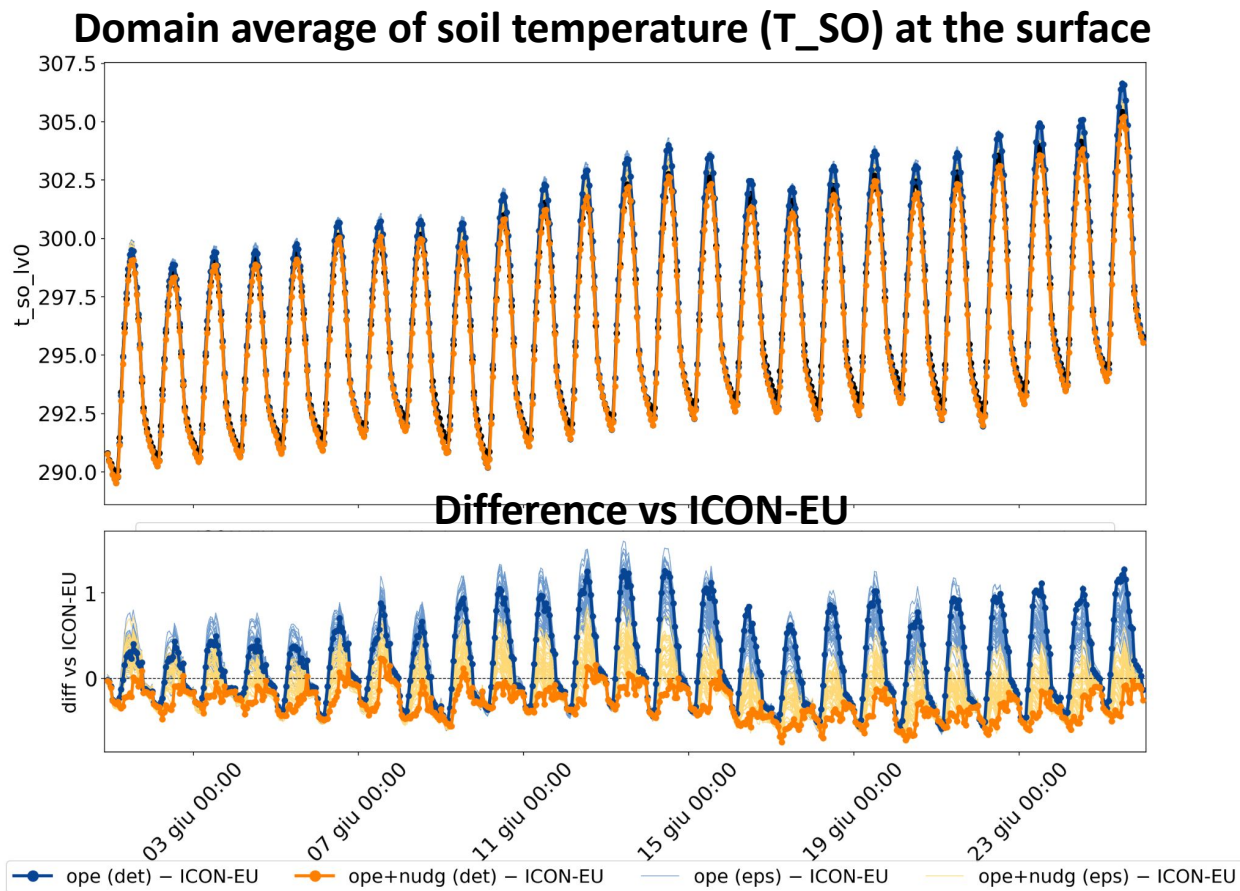
- ***ope***: as operational setup
- ***ope+nudg***: as *ope* but with:
  - Updated ICON model version: 2025-04-1 → **2025.10-2** (no namelist modifications).
  - Updated DACE version: 2.15 → **2.27** (no namelist modifications)
  - **Soil moisture nudging at 03 UTC**, as described before.

## Test period

From 31/05/2025 at 21 UTC to 26/06/2025 at 00 UTC: stable anticyclonic conditions with few relevant precipitating events. A 60h forecast is initialized every 3 hours from deterministic analysis. In total, **201 forecasts** for each experiment.

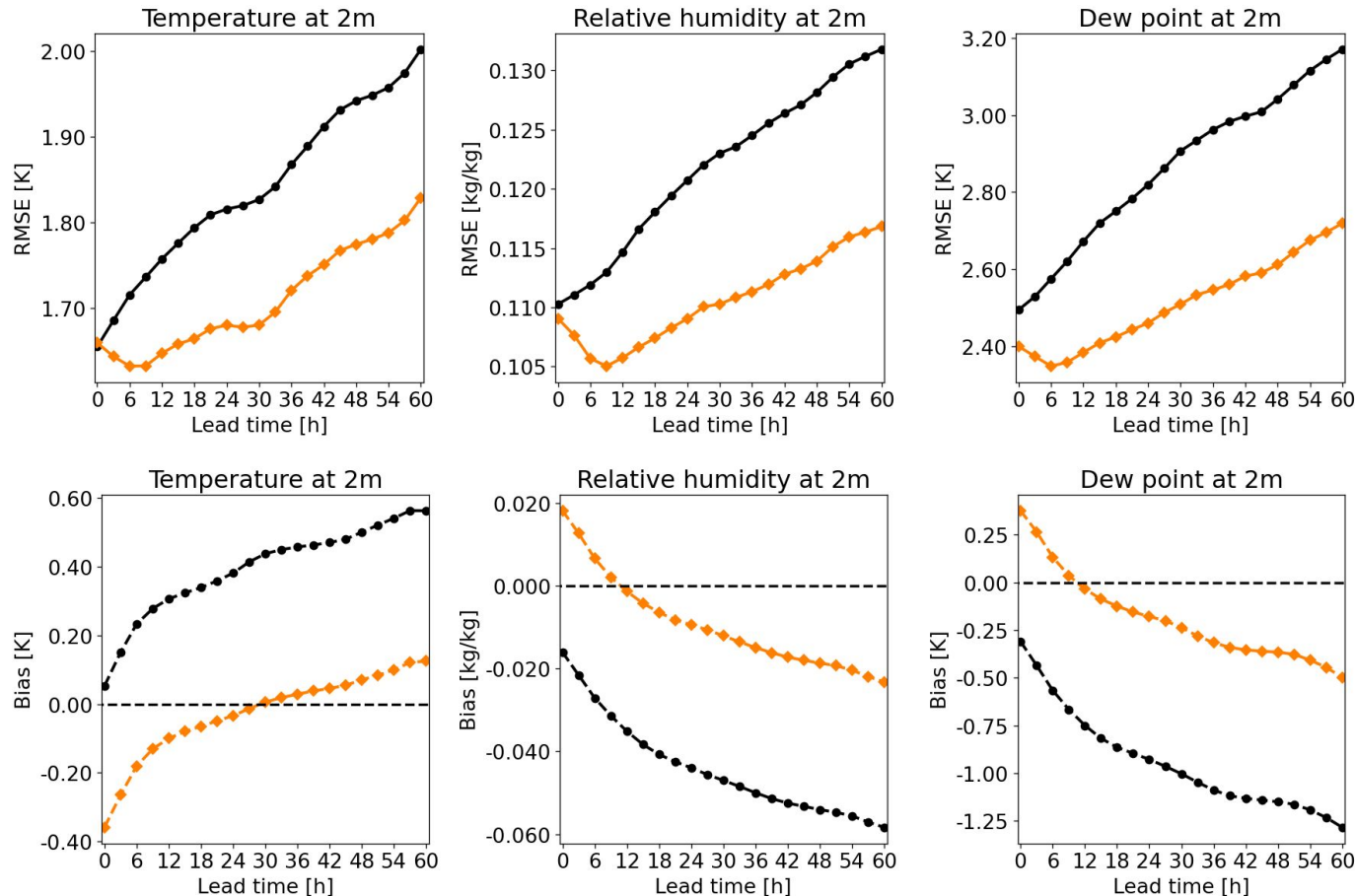
## Domain average of column-integrated soil moisture ( $W_{SO}$ ) between 9 and 27 cm





# SM nudging: near-surface variables

All forecast init.  
times, whole domain



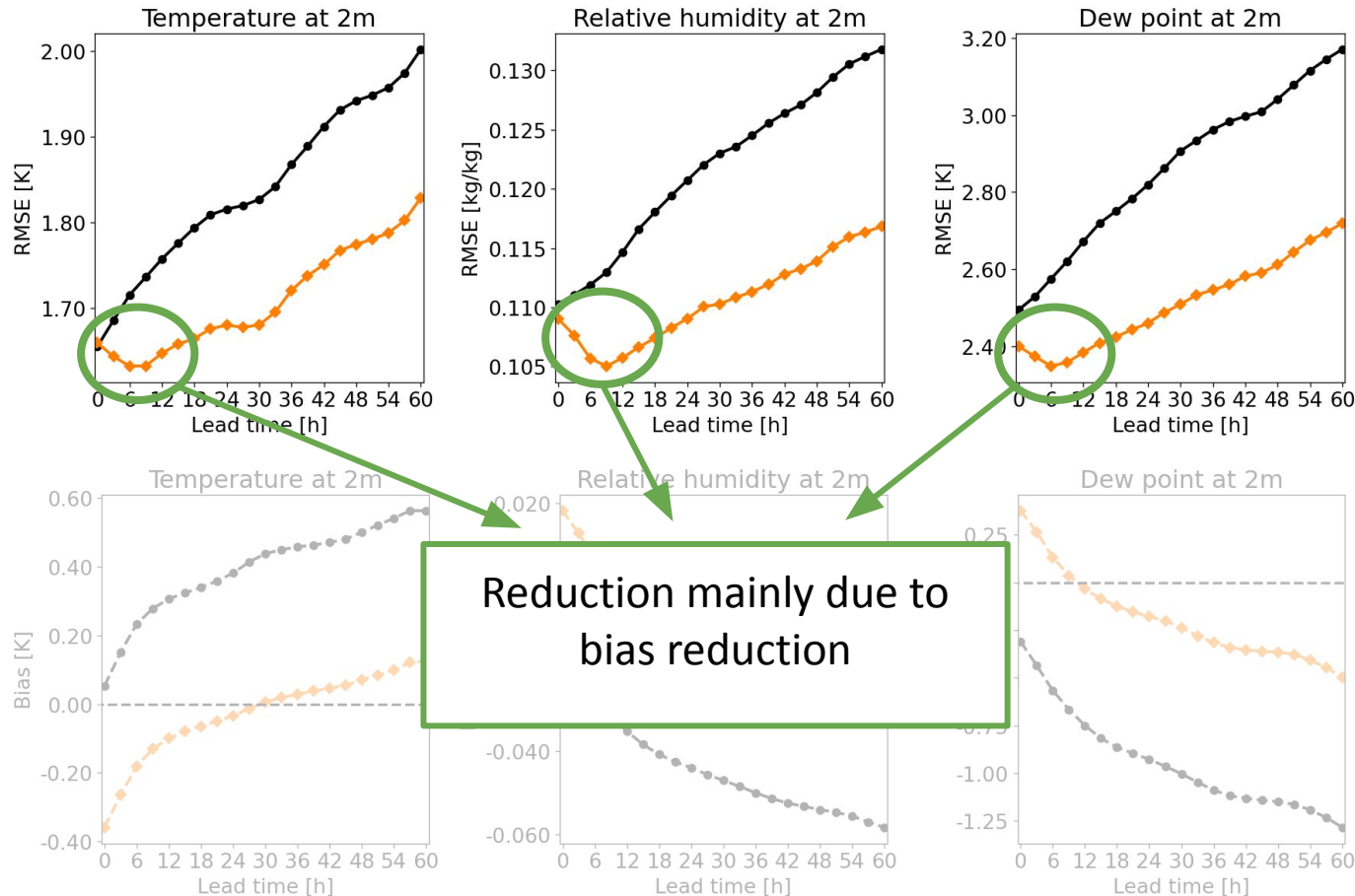
RMSE

ope  
ope+nudg

BIAS

# SM nudging: near-surface variables

All forecast init.  
times, whole domain



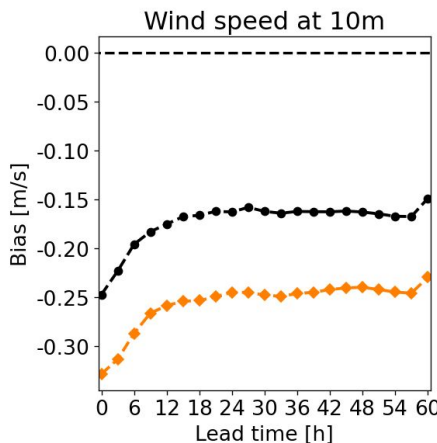
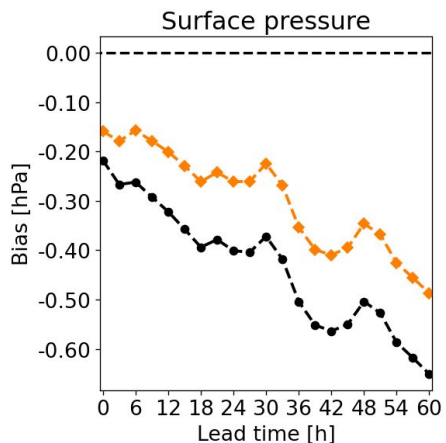
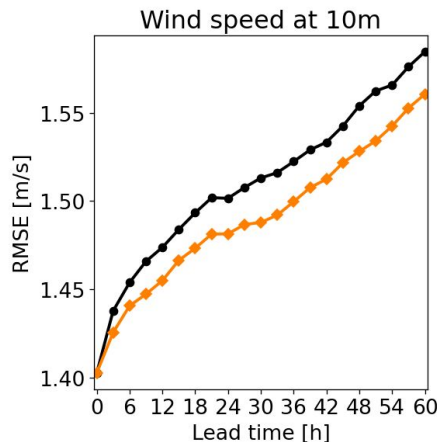
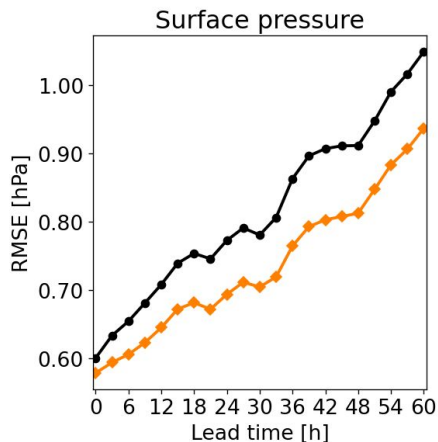
RMSE

ope  
ope+nudg

BIAS

# SM nudging: near-surface variables

All forecast init.  
times, whole domain



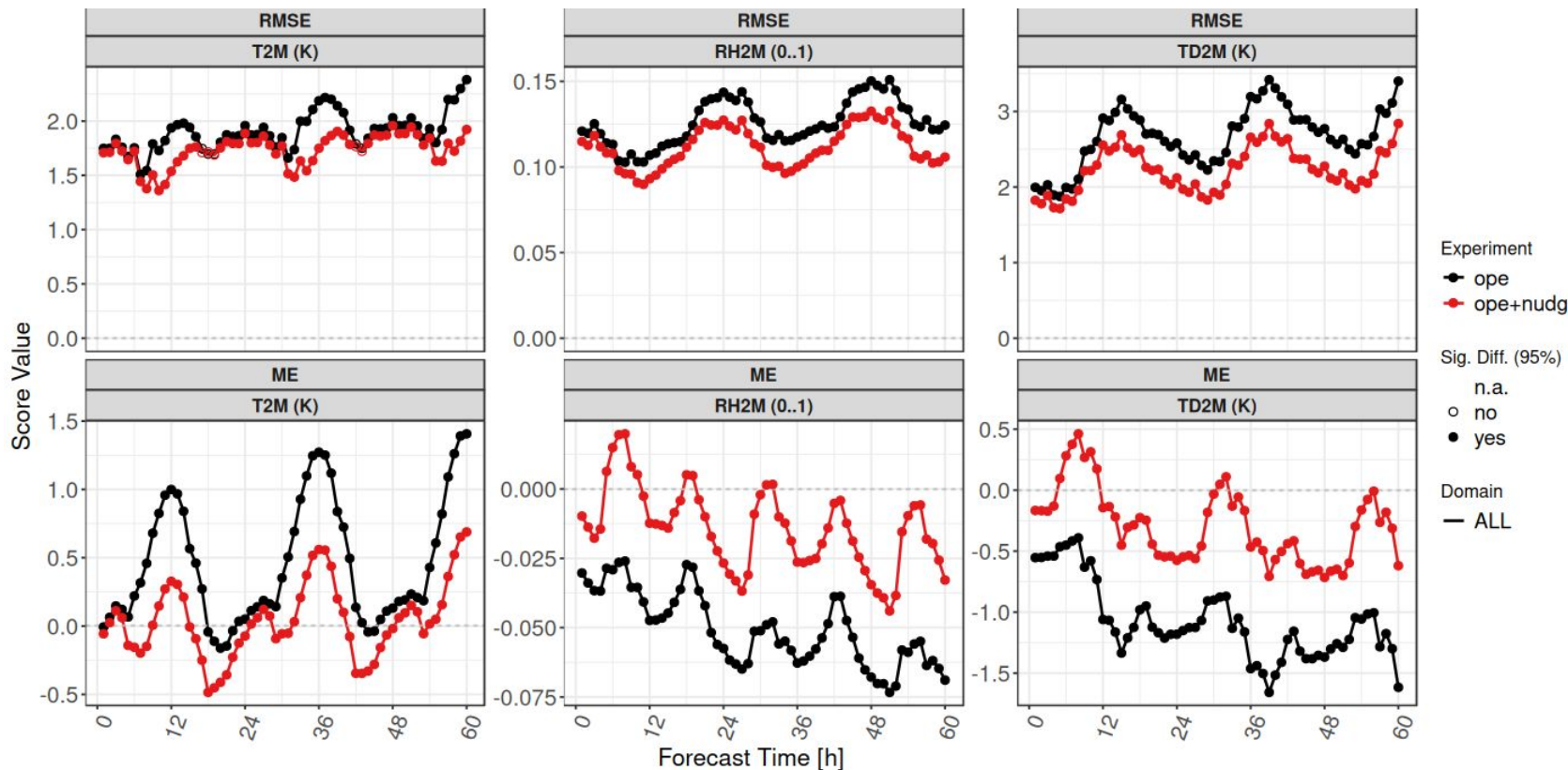
RMSE

—●— ope  
—◆— ope+nudg

BIAS

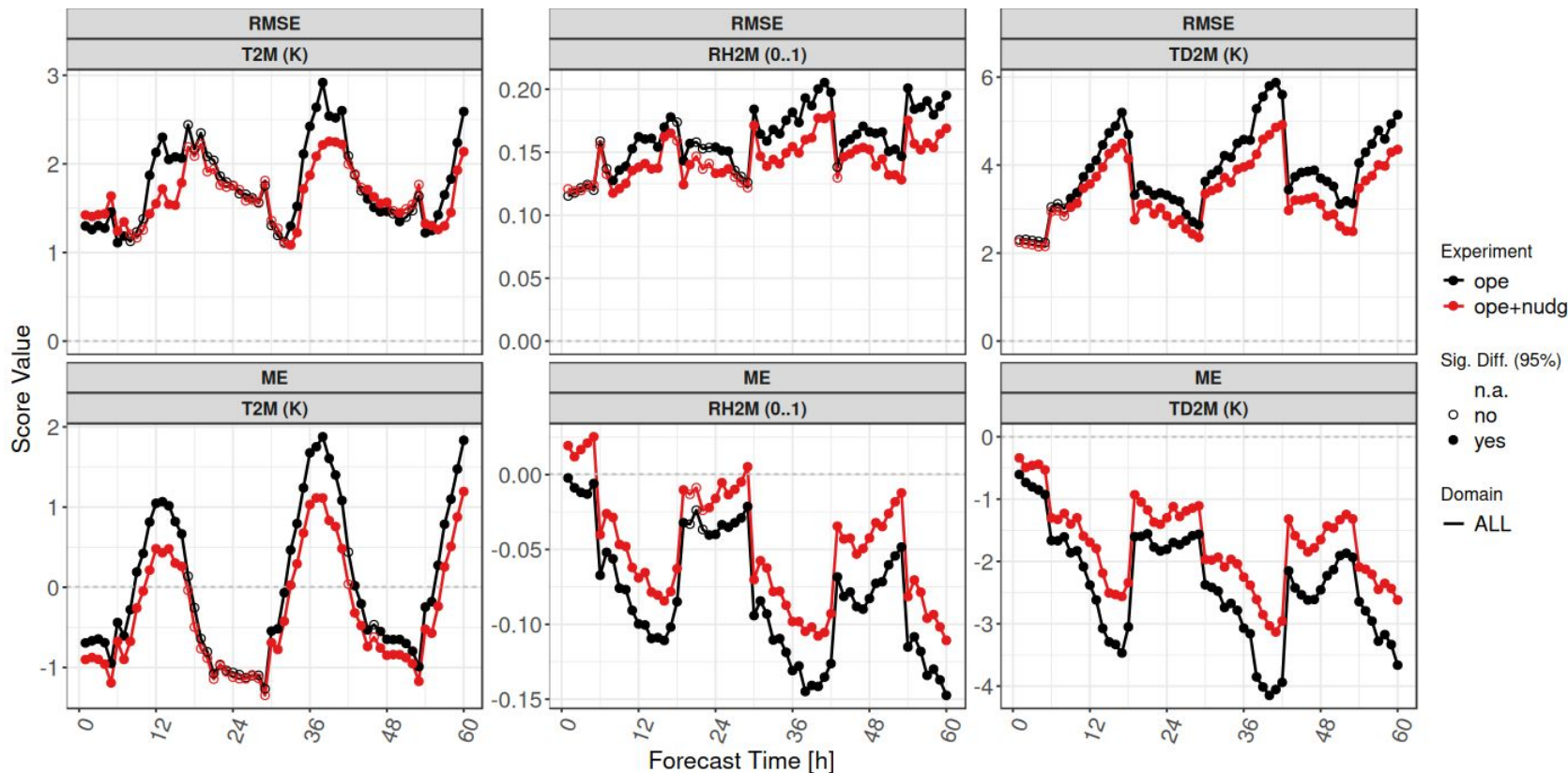
# SM nudging: near-surface variables

Forecast init. at 00 UTC, whole domain



# SM nudging: near-surface variables

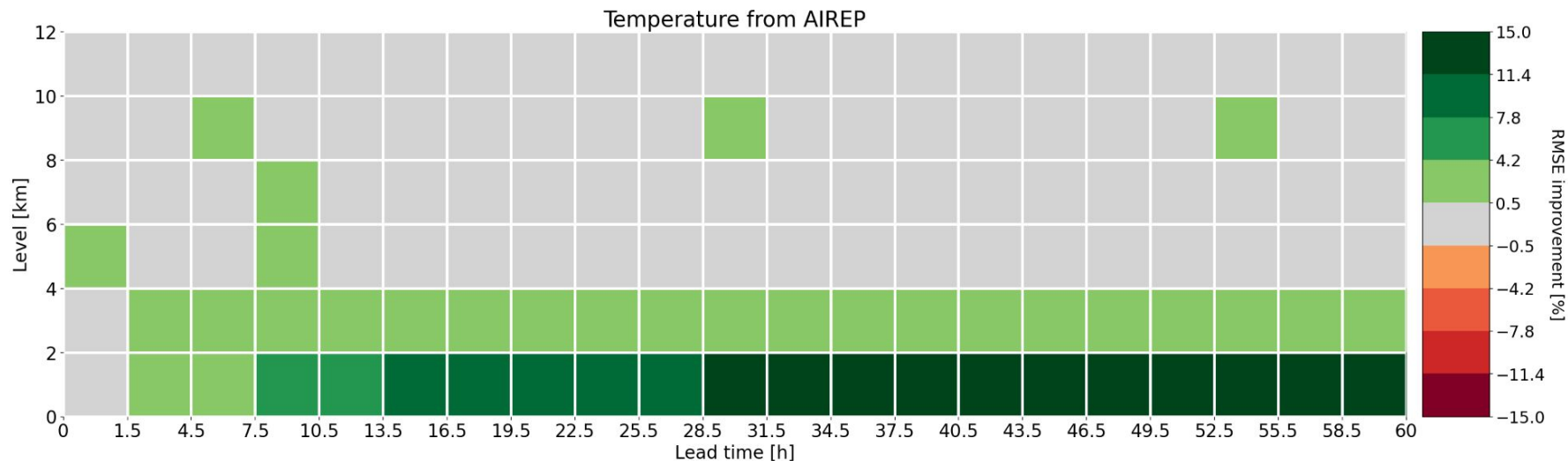
Forecast init. at 00 UTC, Po Valley stations



# SM nudging: upper-air temperature (RMSE)

Plot difference:  $RMSE(ope) - RMSE(ope+nudg)$ .

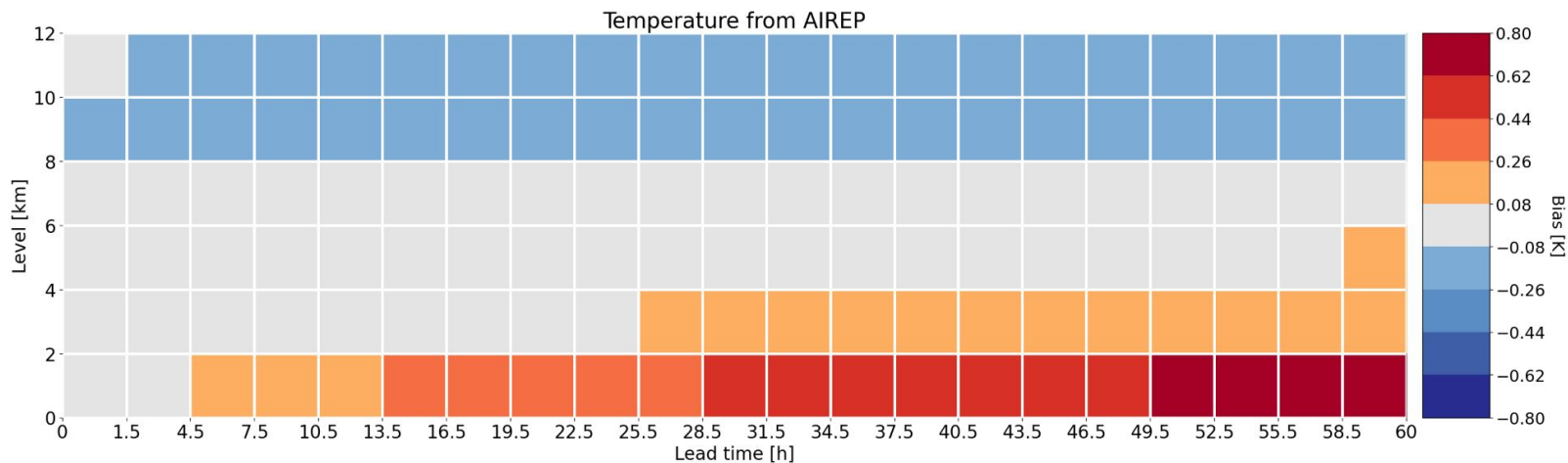
Positive values (green)  $\rightarrow$  *ope+nudg* better than *ope*



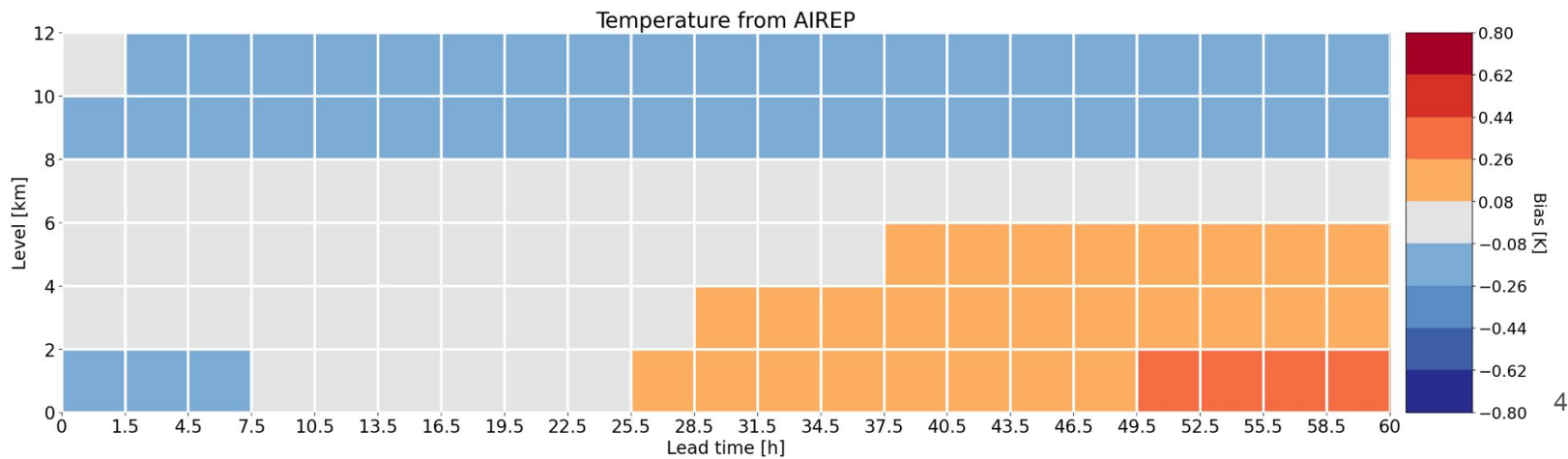
Average number of obs.: 54049 (ranging from 12174 to 164575)  
Average RMSE for ope: 0.898 K (ranging from 0.629 K to 1.430 K)  
Average RMSE for ope+nudg: 0.873 K (ranging from 0.626 K to 1.224 K)

# SM nudging: upper-air temperature (bias)

*ope*



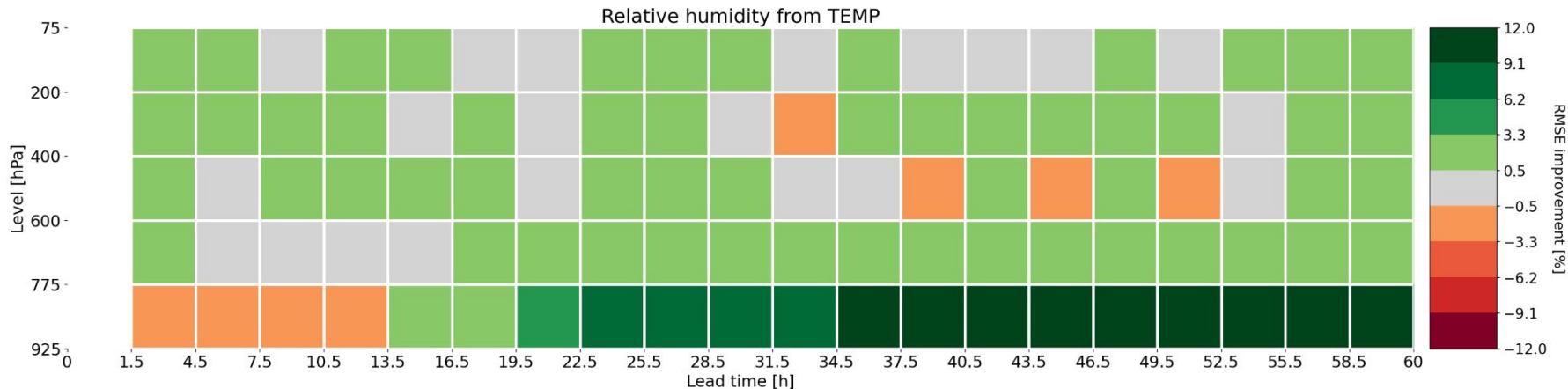
*ope+nudg*



# SM nudging: upper-air relative humidity (RMSE)

Plot difference:  $RMSE(ope) - RMSE(ope+nudg)$ .

Positive values (green)  $\rightarrow$  *ope+nudg* better than *ope*



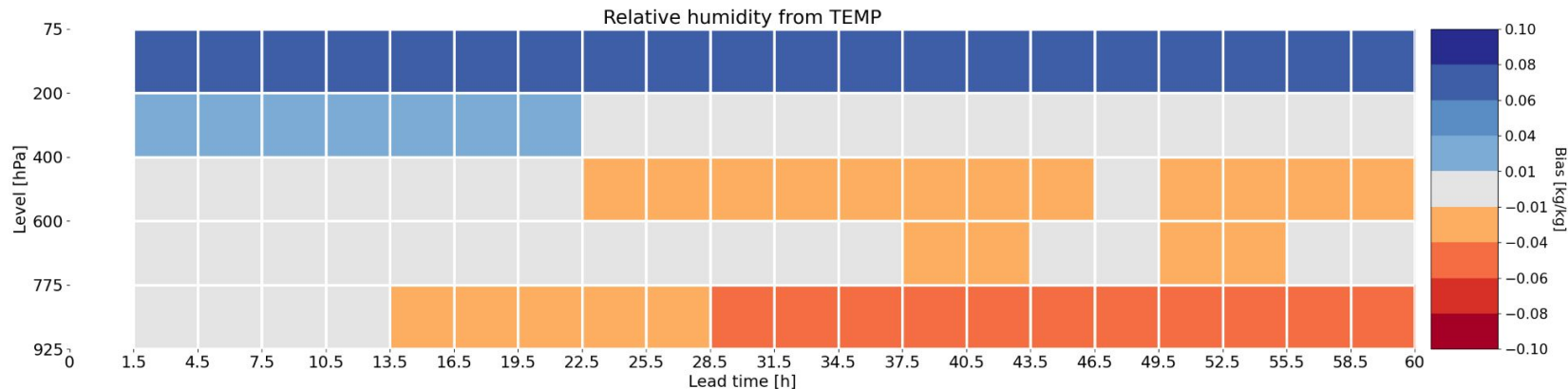
Average number of obs.: 15158 (ranging from 11670 to 19104)

Average RMSE for ope: 0.139 kg/kg (ranging from 0.101 kg/kg to 0.178 kg/kg)

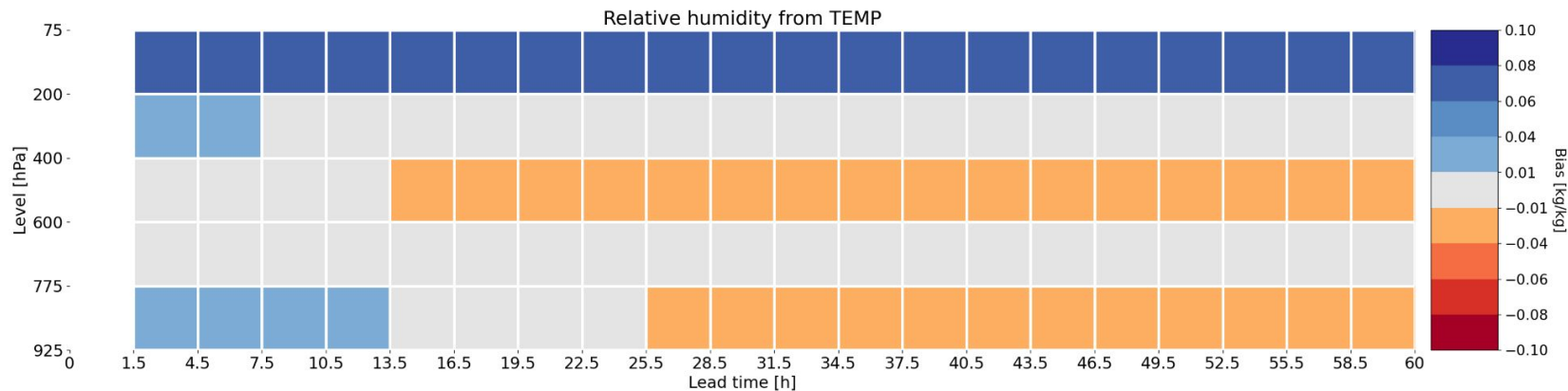
Average RMSE for ope+nudg: 0.137 kg/kg (ranging from 0.102 kg/kg to 0.177 kg/kg)

# SM nudging: upper-air relative humidity (bias)

*ope*



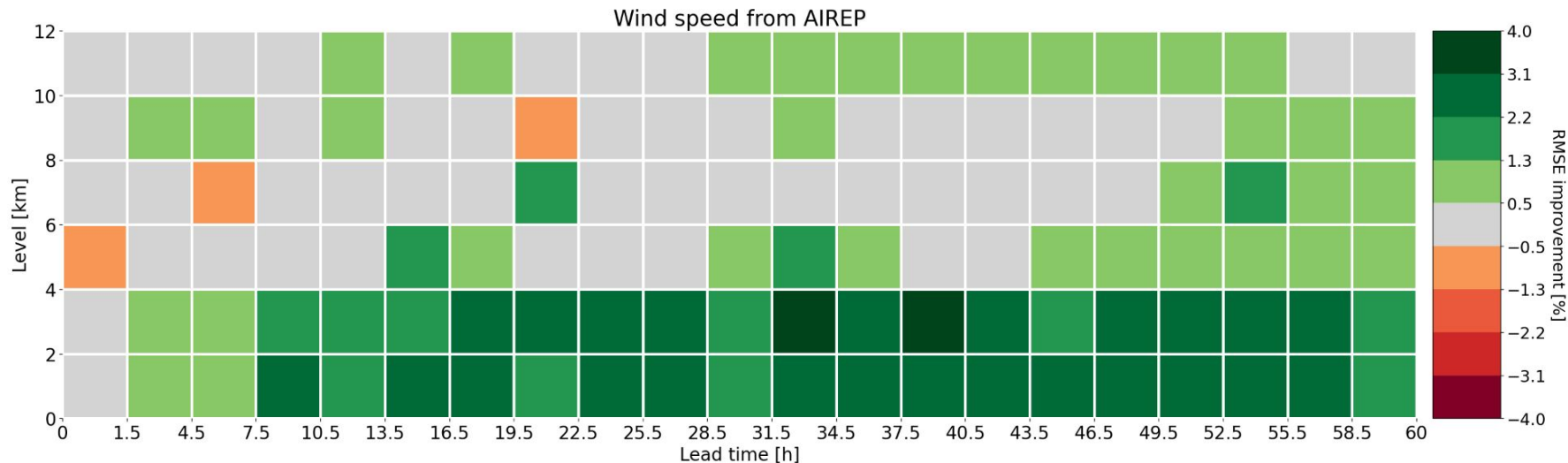
*ope+nudg*



# SM nudging: wind speed (RMSE)

Plot difference:  $RMSE(ope) - RMSE(ope+nudg)$ .

Positive values (green)  $\rightarrow$  *ope+nudg* better than *ope*



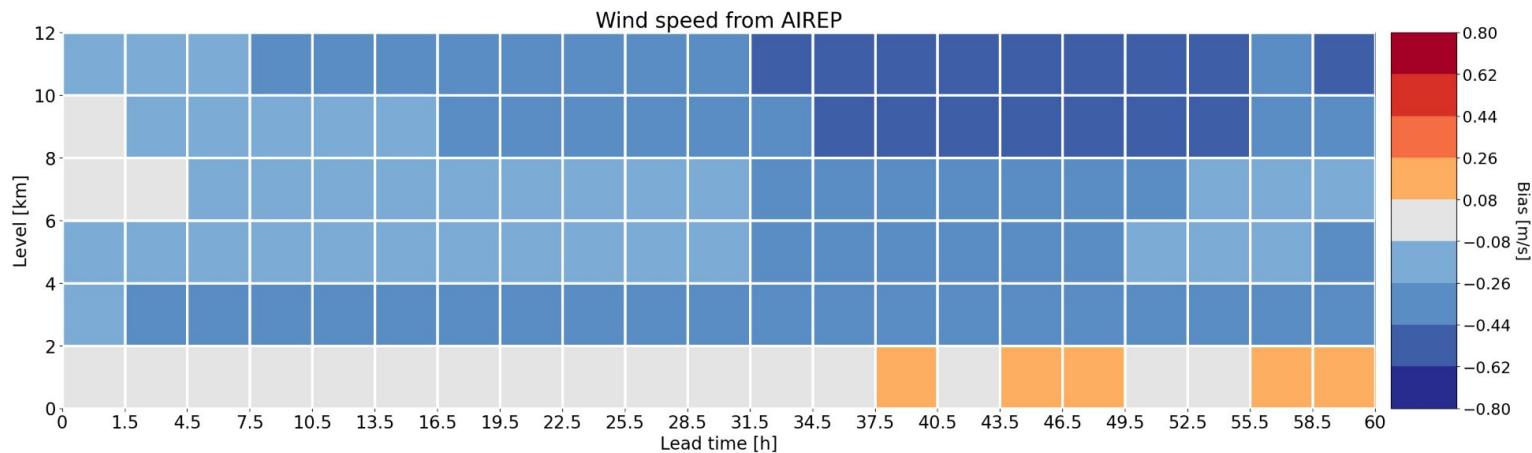
Average number of obs.: 33265 (ranging from 8733 to 92158)

Average RMSE for *ope*: 2.495 m/s (ranging from 1.742 m/s to 4.011 m/s)

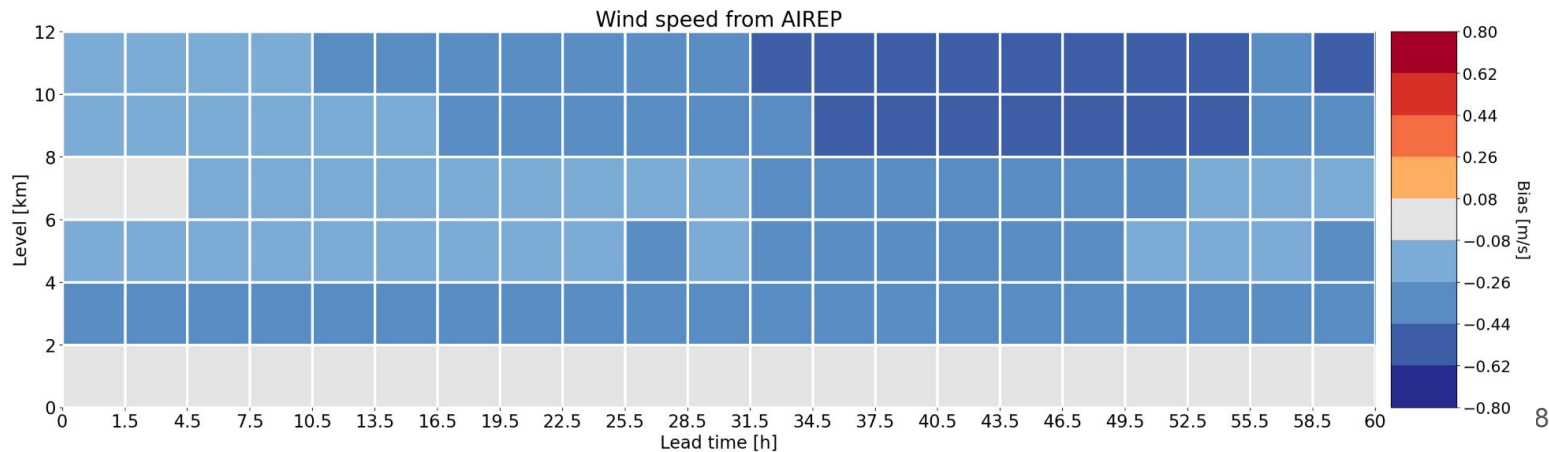
Average RMSE for *ope+nudg*: 2.470 m/s (ranging from 1.746 m/s to 3.995 m/s)

# SM nudging: wind speed (bias)

*ope*

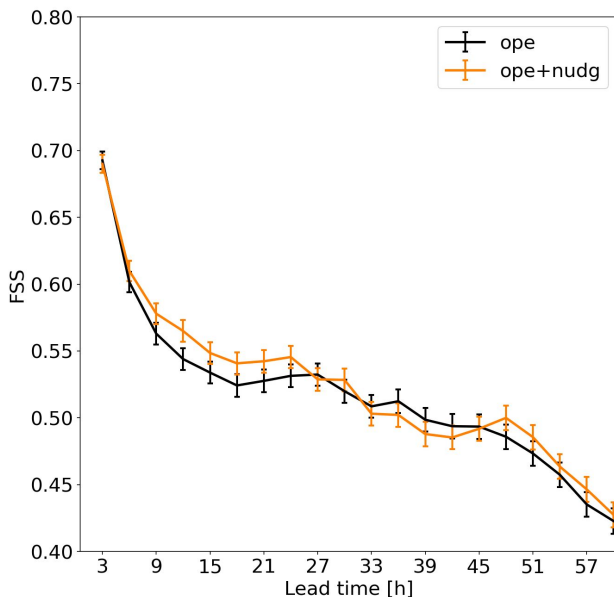


*ope+nudg*

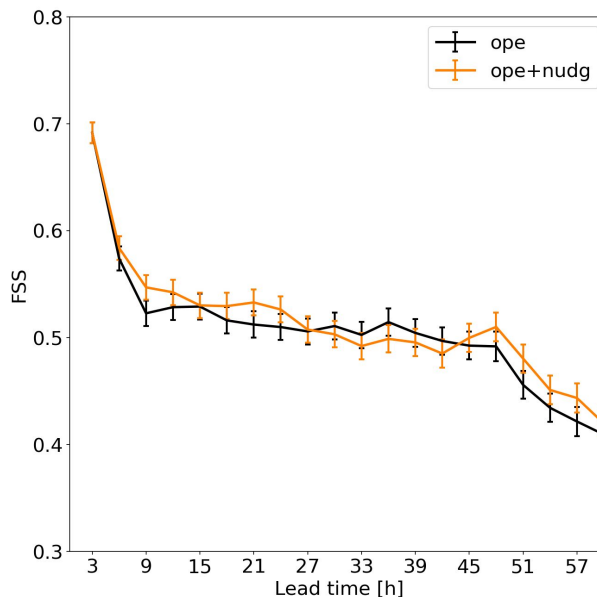


# SM nudging: forecast precipitation (FSS)

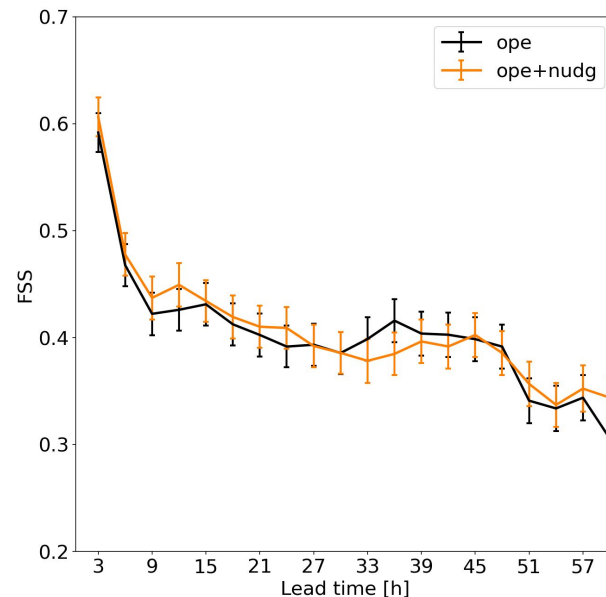
thr = 0.1 mm



thr = 1.0 mm



thr = 5.0 mm

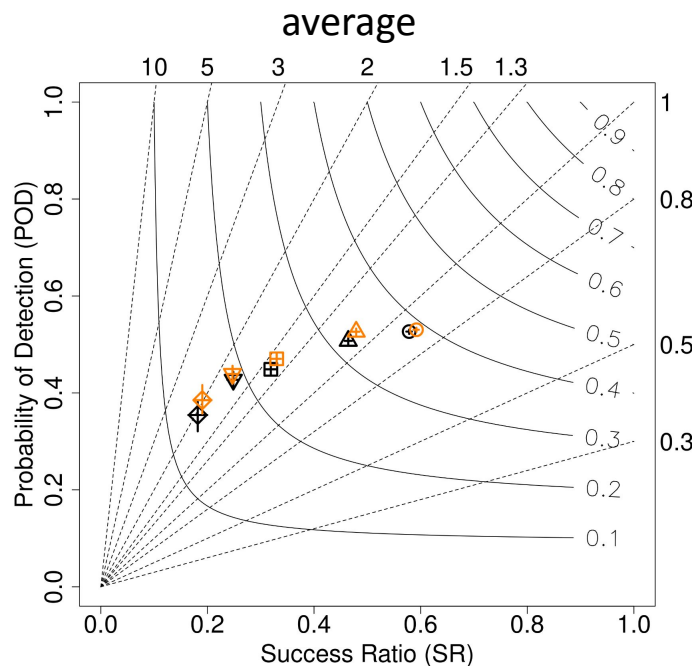


Observations: hourly radar-estimated precipitation over Italy corrected with rain-gauges.

Boxes:  $0.2^\circ \times 0.2^\circ$

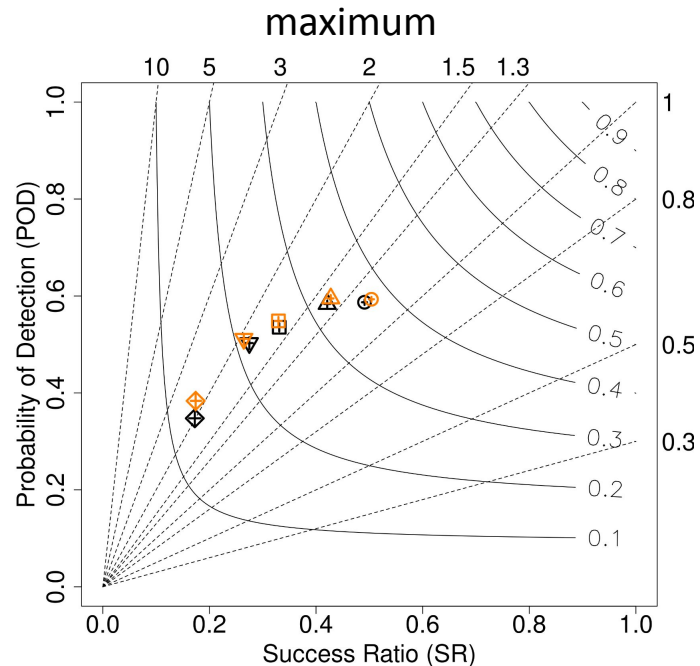
# SM nudging: forecast precipitation (perf. diagram)

Verification of 3h precipitation over the alerting areas of Italy, using radar-estimated prec. corrected with rain-gauges as observations. Scores are aggregated over the whole forecast (from +0h to +60h)



- thr = 0.2 mm
- △ thr = 1 mm
- thr = 3 mm
- ▽ thr = 5 mm
- ◇ thr = 10 mm

— ope  
— ope+nudg



- thr = 5 mm
- △ thr = 10 mm
- thr = 20 mm
- ▽ thr = 30 mm
- ◇ thr = 50 mm

— ope  
— ope+nudg

Implementation of soil moisture nudging:

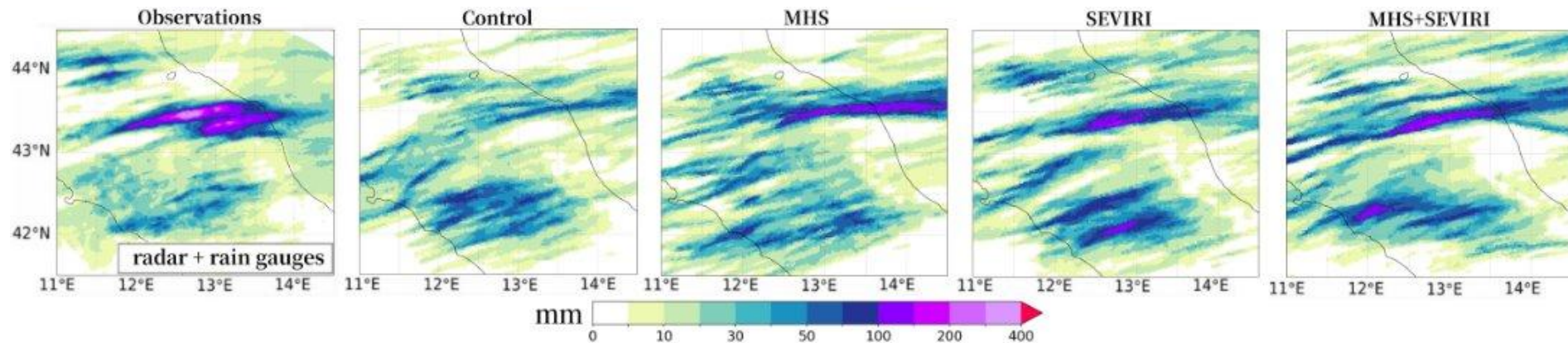
- strongly improves forecast of 2m temperature, 2m dew point and surface pressure, while the impact is neutral on 10m wind speed.
- improves upper-air temperature, relative humidity and wind speed, in particular below 2-4 km.
- slightly improves precipitation.

Accordingly, **ope+nudg configuration became operational from 17/06/2026** to overcome the issue of overestimation of maximum temperatures during summer.

However, experiments are running to evaluate its impact on the other seasons.

Extension of the work carried out by Marcello Grenzi on the assimilation of observations from the Microwave Humidity Sounder (MHS):

- Polar orbit, 6 passages per day over Italy (METOP-B, METOP-C, NOAA-19)
- 16x16 km<sup>2</sup> resolution
- 3 channels in clear-sky, sensitive to water vapour in low, mid and high troposphere.



Activity in collaboration with Francesca Vittorioso (CMCC) and with the support of DWD.

## Experiments

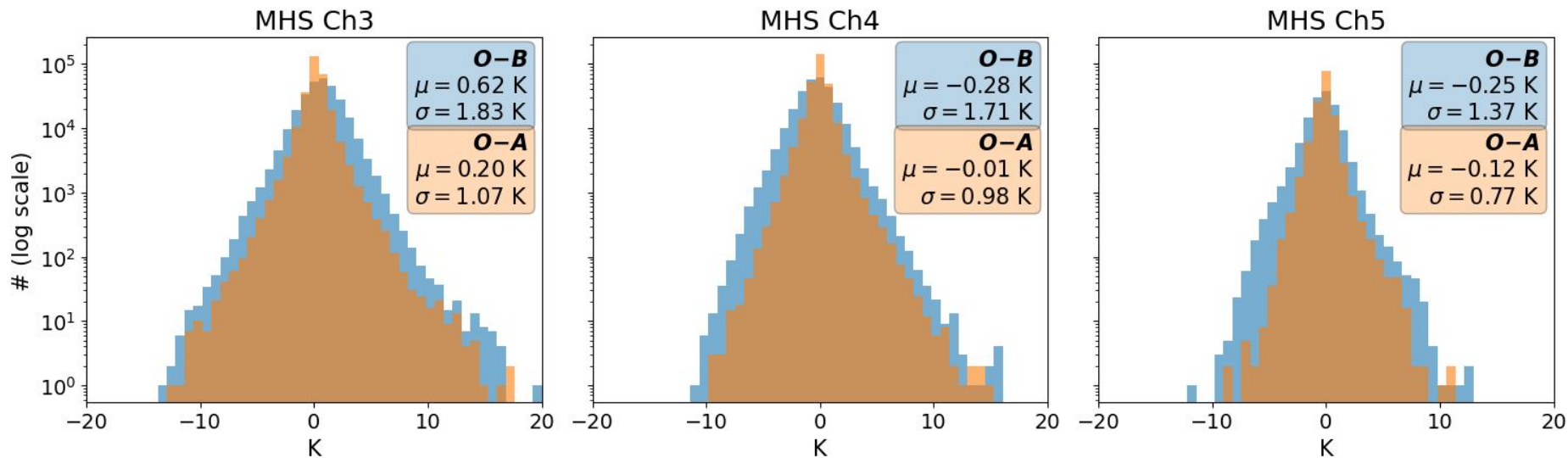
- **ope**: as new (*ope+nudg* in the previous slides) operational setup
- **ope+MHS**: as *ope* but assimilating MHS using the following setup:
  - data from METOP-B and METOP-C in **clear-sky** (**4 passages** per day over Italy)
  - channel 3 and 4 over sea and land (with surface influence check “surfinfl”), channel 5 only over sea.
  - Observation error equal to 2 K

This is the same setup adopted by Marcello Grenzi, but with **MEC applied offline** in both experiments (thanks to Thomas Deppisch for providing his branch of DACE).

## Test period

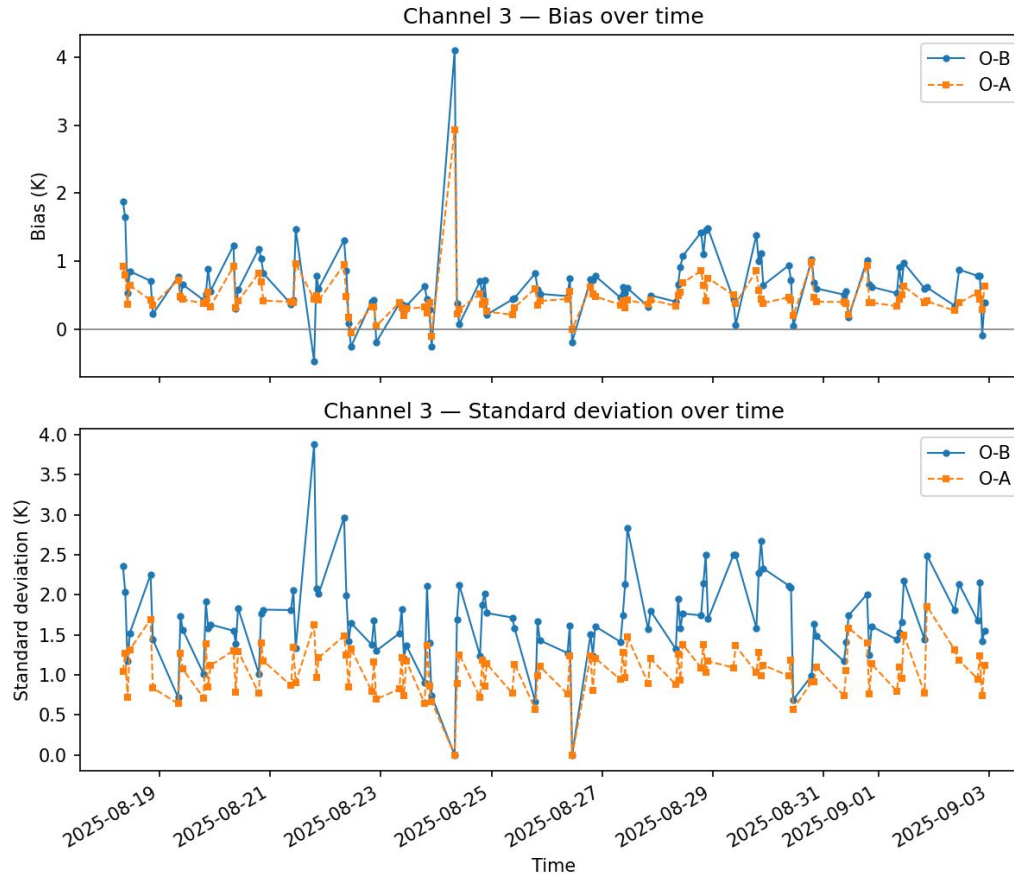
From 17/08/2025 at 21 UTC to 03/09/2025 at 00 UTC; few days of heavy but localized rainfall. A 24h forecast is initialized every 3h from deterministic analysis. In total, **128 forecasts** for each experiment. 23

## Residuals for satellites METOP-B+METOP-C



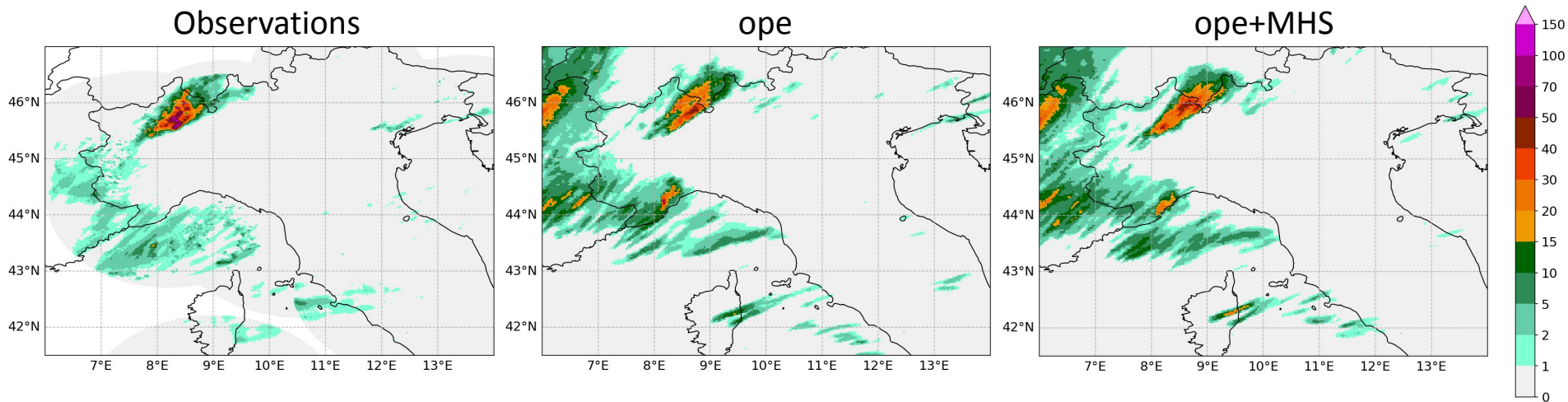
Bias are in general quite small and distributions symmetric. Both bias and standard deviation for increments are smaller than for innovations.

# MHS: innovations and increments (time series)



In general, no strong impact on the events of localized heavy precipitation during the test period, but with some exceptions.

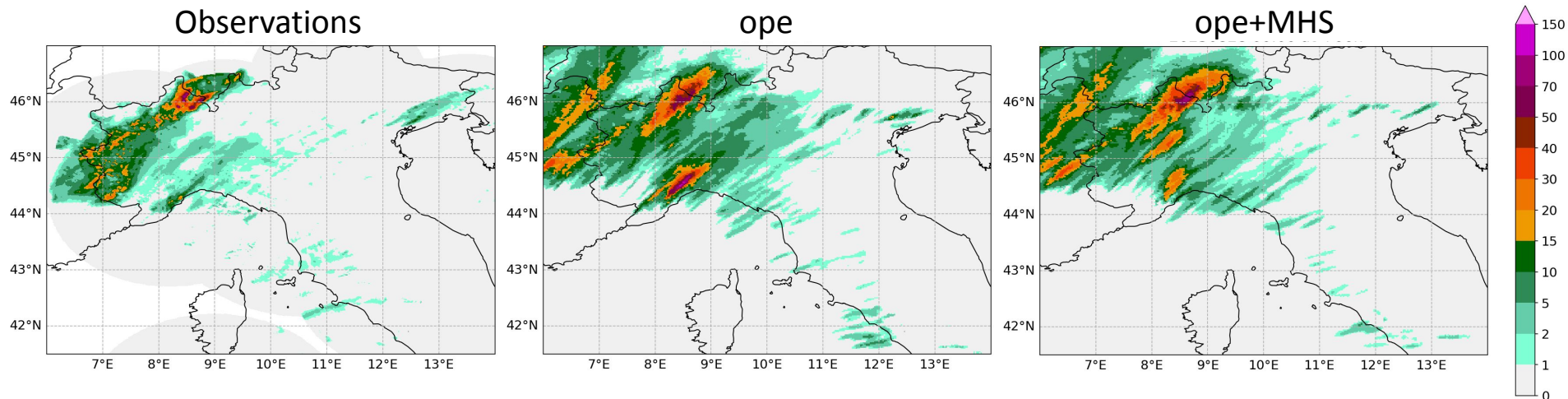
For example, forecast initialized at 00 UTC on 28/08/2026:



3h accumulated precipitation, forecast at +3h

In general, no strong impact on the events of localized heavy precipitation during the test period, but with some exceptions.

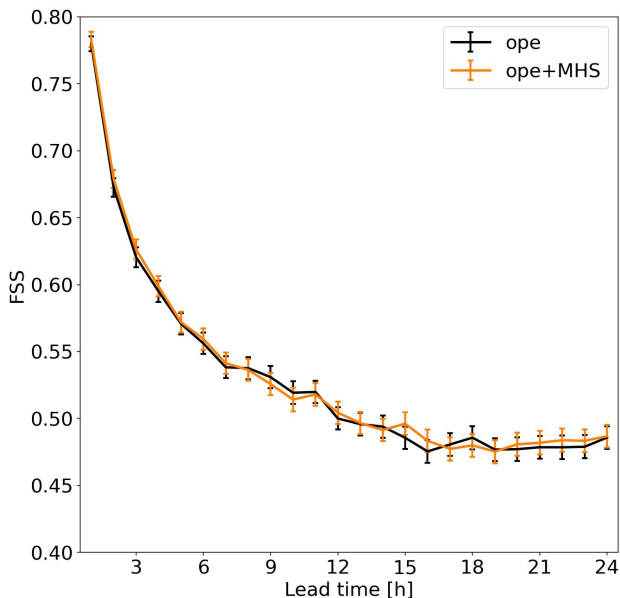
For example, forecast initialized at 00 UTC on 28/08/2026:



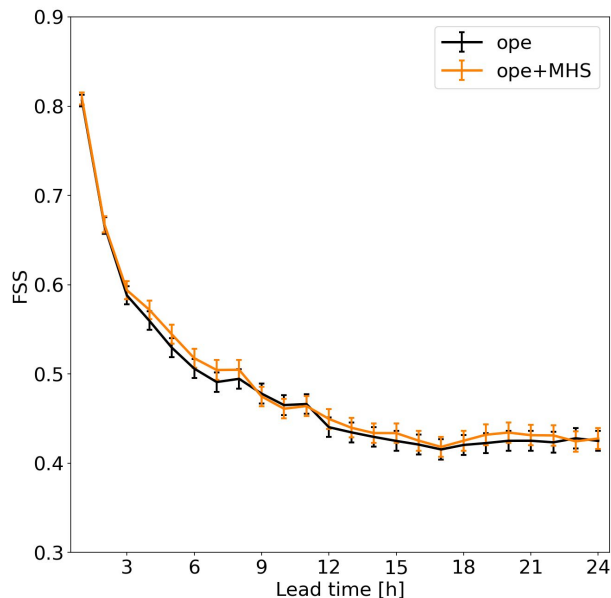
3h accumulated precipitation, forecast at +6h

# MHS: forecast precipitation (FSS)

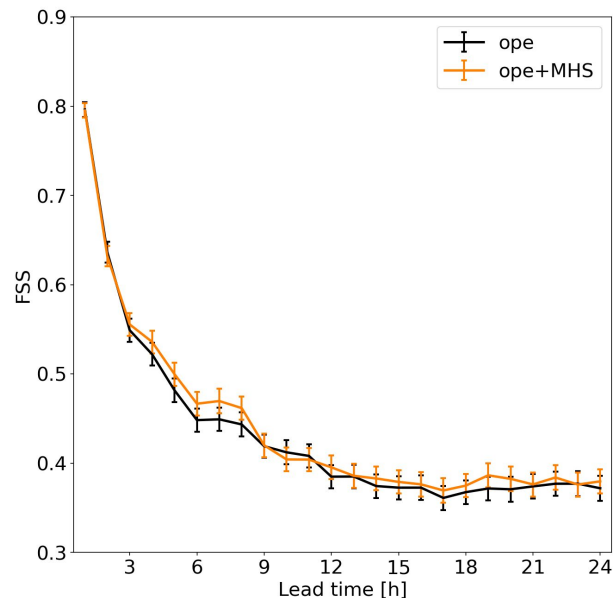
thr = 0.1 mm



thr = 0.5 mm

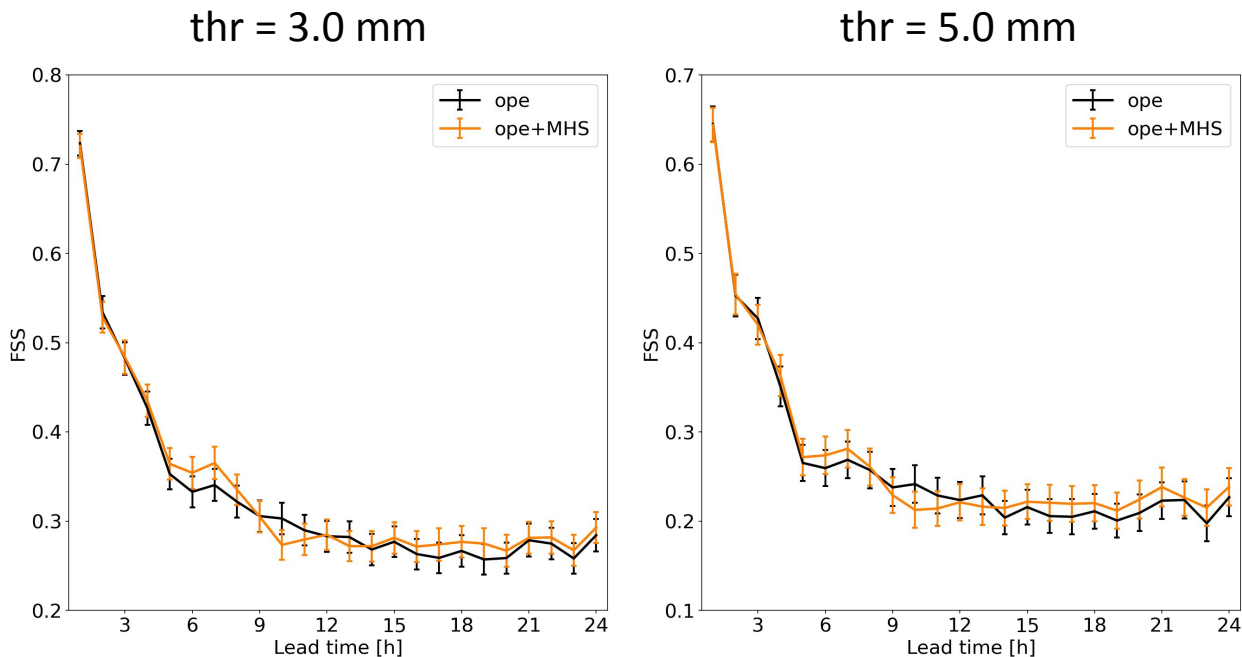


thr = 1.0 mm



Observations: hourly radar-estimated precipitation over Italy corrected with rain-gauges.

Boxes:  $0.2^\circ \times 0.2^\circ$



Observations: hourly radar-estimated precipitation over Italy corrected with rain-gauges.

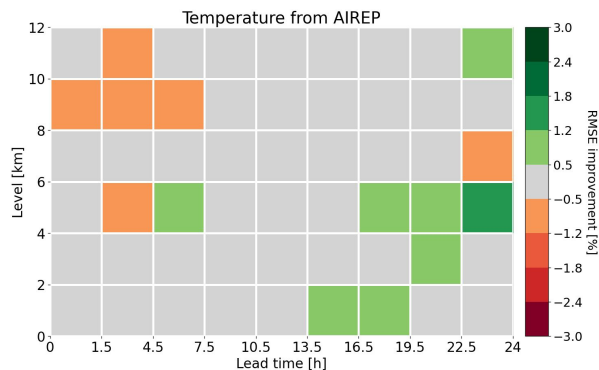
Boxes:  $0.2^\circ \times 0.2^\circ$

# MHS: upper-air variables (FSS)

Plot difference:  $RMSE(ope) - RMSE(ope+MHS)$ .

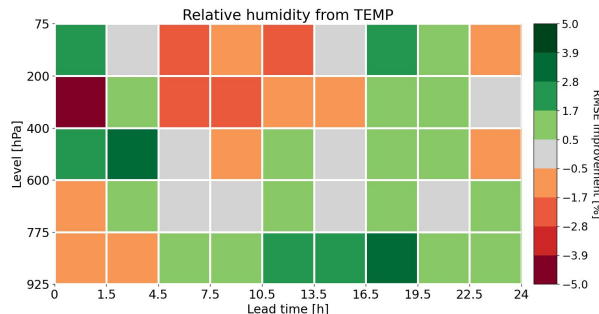
Positive values (green)  $\rightarrow$   $ope+MHS$  better than  $ope$

## Temperature



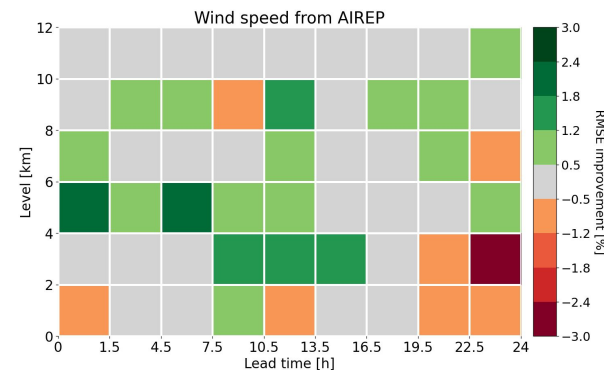
Average number of obs.: 32038 (ranging from 7690 to 97574)  
Average RMSE for ope: 0.866 K (ranging from 0.675 K to 1.146 K)  
Average RMSE for ope+MHS: 0.865 K (ranging from 0.673 K to 1.142 K)

## Relative humidity



Average number of obs.: 8710 (ranging from 983 to 11391)  
Average RMSE for ope: 0.140 kg/kg (ranging from 0.103 kg/kg to 0.178 kg/kg)  
Average RMSE for ope+MHS: 0.140 kg/kg (ranging from 0.104 kg/kg to 0.178 kg/kg)

## Wind speed



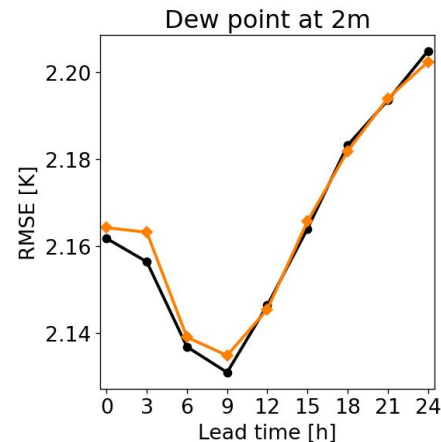
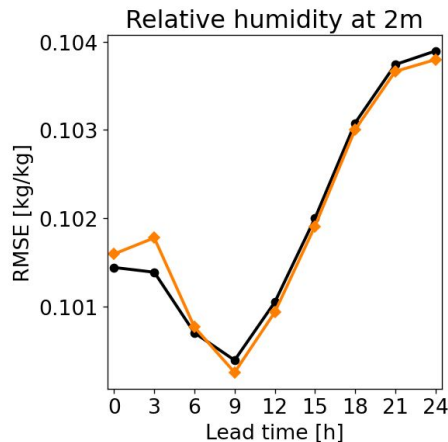
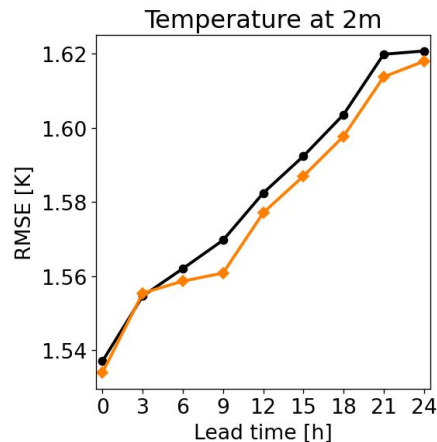
Average number of obs.: 18958 (ranging from 5084 to 53146)  
Average RMSE for ope: 2.514 m/s (ranging from 2.087 m/s to 3.325 m/s)  
Average RMSE for ope+MHS: 2.508 m/s (ranging from 2.053 m/s to 3.310 m/s)

Slight positive impact on wind speed and on RH below 400 hPa, neutral for T.

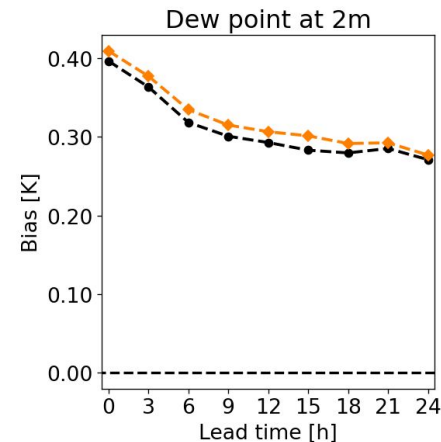
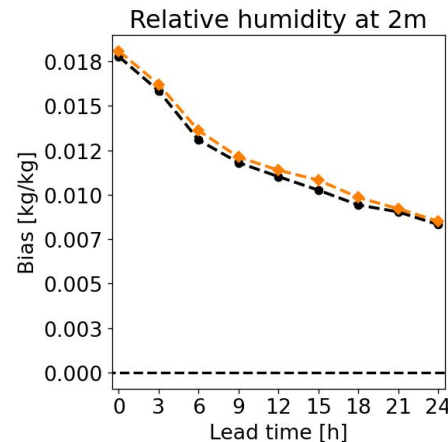
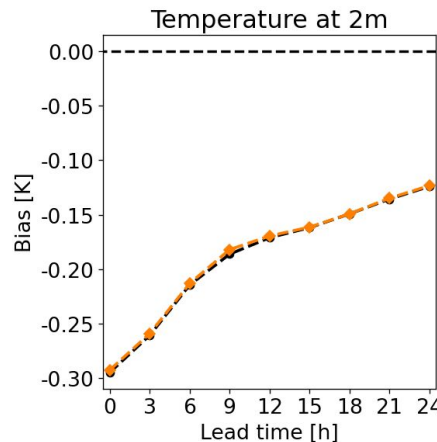
Bias (not shown): neutral impact for all variables

# MHS: near-surface variables

All forecast init.  
times, whole domain

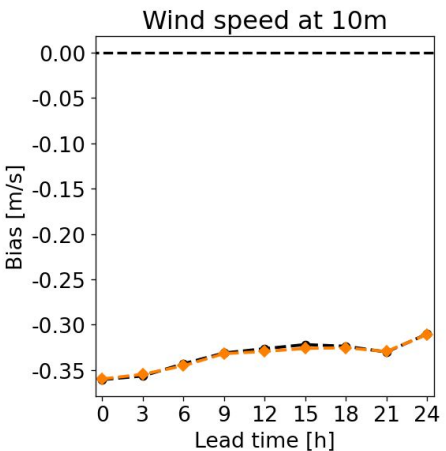
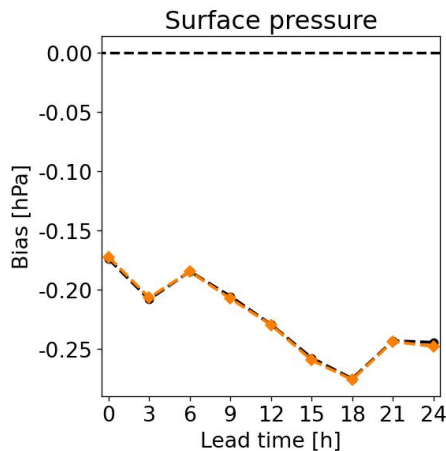
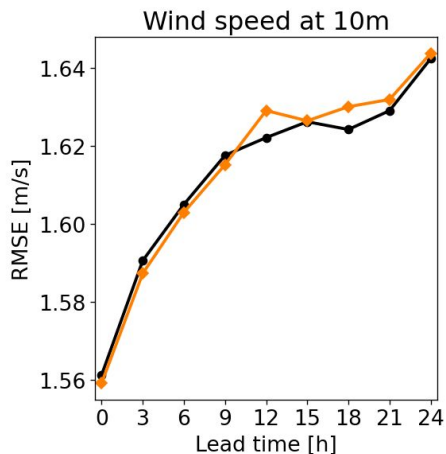
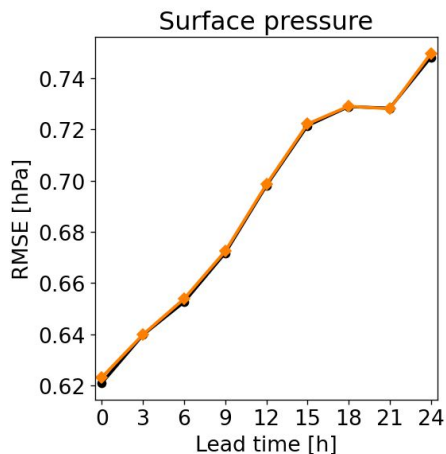


RMSE



BIAS

All forecast init.  
times, whole domain



RMSE

—●— ope  
—◆— ope+MHS

BIAS

First results on a longer period evaluation show slightly positive impact of assimilating MHS

- evaluate the impact of applying MEC online/offline
- extend to other periods

Overall on satellite DA, we aim to assimilate SEVIRI/FCI data and, later on, IRS, in collaboration with Francesca Vittorioso (CMCC) and with DWD.

- Partial analysis increments: see presentation by Virginia and Marcello.
- Assimilation of T2M/RH2M from SYNOP: experiments have to be re-run due to the operational implementation of soil moisture
- Assimilation of radar data: refine the operational configuration due to the renewal of the Italian network; extend to OPERA data.