InStaFlex

Report D4.2 – Meteorological forecasts

Submitted to: FOD Economy
Lead Partner: RMI Belgium

InStaflex Project – Results Report

1. Project Information

Project Title	InStaFlex
Client	FOD Economy
Lead Partner Report	Royal Meteorological Institute Belgium
Partner Organisations	University of Antwerp, Oktow, PropheSea

2. Document Version History

Version	Date	Author(s)	Description / Changes
0	20/10/2025	J. Van den Bergh, D. Van den Bleeken, G. Smet	Executive summary + document sent to consortium for comments
1	27/10/2025	J. Van den Bergh, D. Van den Bleeken, G. Smet	Final version

3. Executive Summary

This report lists the meteorological data provided by RMI to InStaFlex partners within the context of WP4. We give a brief overview of the weather models, their spatio-temporal resolution, and the meteorological variables provided. We also present a few verification results to give an idea of the overall forecast accuracy of the data provided. Since this deliverable mainly concerns data provision towards other members of the InStaFlex consortium, it has been kept quite short. Additional information is available on request.

4. Objectives and Scope

Deliverable 4.2 aims to provide a set of deterministic meteorological forecasts of variables relevant for on-site load and energy consumption forecasting (ensemble forecast provision will be handled in a future deliverable). Air temperature is the most important weather variable in terms of its effects on load, through building heating and cooling (Gross & Galiana, 2005). Other variables such as wind speed and humidity also play a role on building cooling, solar radiation impacts lighting demand, and snow or rain may impact person attendance. In this report, we focus on air temperature at 2 meters (T2M) and wind speed at 10 meters (S10M) as main variables. Surface solar radiation (SSRD) and its direct component (FDIR) have been included as supplementary parameters due to their their further use towards InStaFlex PV forecasting tasks in other Work Packages.

5. Methodology

5.1 Meteorological forecasts

Meteorological forecasts have been made available for 11 industrial sites in Belgium agreed upon with Oktow, which are anonymized in this report. In addition, we have added Ukkel (where RMI is located) as an extra site for validation purposes, since RMI operates a quality-controlled automatic weather station (AWS) and wind mast with anemometer there. Forecasts have been made available for the European Centre for Medium range Weather Forecasts (ECMWF) deterministic HRES model with ~9 km resolution (ECMWF, 2025), the RMI in-house Alaro model at 1.3 km resolution (Termonia et al., 2018). Table 1 shows the selected numerical weather prediction (NWP) models, their resolution, forecast horizon and available model runs. Forecasts are provided at hourly lead times; the Alaro1.3 forecasts have been further interpolated to 15-minute lead times also. Variables are bilinearly interpolated for T2M and S10M, while radiation is taken from nearest grid point.

Table 1: Selected numerical weather prediction models.

Model	Spatial resolution	Time resolution	Forecast horizon	Forecast runs
ECMWF HRES	9 km	hourly	60 hours	0, 12 UTC
Alaro1.3	1.3 km	hourly	48 hours	1, 6, 12, 18 UTC

Table 2 shows the selected weather parameters and units. Radiation parameters are expressed fluxes at the surface, representing the energy that passes through a square-meter of a flat horizontal plane since the start of the forecast run. The diffuse component can be extracted from the two other components as the difference SSRD – FDIR (Hogan, 2025).

Table 2: Selected meteorological parameters from NWP models in Table 1.

Parameter	Abbrev	Unit	Accumulated
2-meter air temperature	T2M	Degrees Celsius	no
10-meter wind speed	S10M	m/s	no
Surface solar radiation downwards	SSRD	J/m^2	yes
Direct surface solar radiation downwards	FDIR	J/m^2	yes

For Alaro1.3 forecasts only, the following parameters have been made available as well, in case they are needed for future InStaFlex application, e.g. sites with wind turbine assets, or to investigate their use as additional predictors for load forecasts:

- 10-meter wind gust speed
- 100-meter wind speed and direction
- Relative humidity
- Total accumulated precipitation (rain + snow)
- Accumulated snow

Current data is available for **1 January 2024 – 28 February 2025** for **Alaro1.3**, and **1 June 2024 – 28 February 2025** for **ECMWF HRES**. Scripts and tools were also developed to quickly extract the same variables for further future periods, and to perform automatic validation and verification on the forecast data sets.

Data is provided to consortium partners through the RMI NextCloud cloud storage platform. Since it concerns point locations only, storage space is not an issue. The chosen format is **zarr** (Cranmer et al., 2022). In a later phase, integration with the PropheSea ForeSight platform could be implemented.

Figure 1 shows the ECMWF HRES grid points on the native O1280 grid (~ 9km) over Belgium. The grid is a so-called cubic reduced Gaussian grid O*T*, where *T*=1280 refers to the spectral truncation (Malardel et al., 2016).

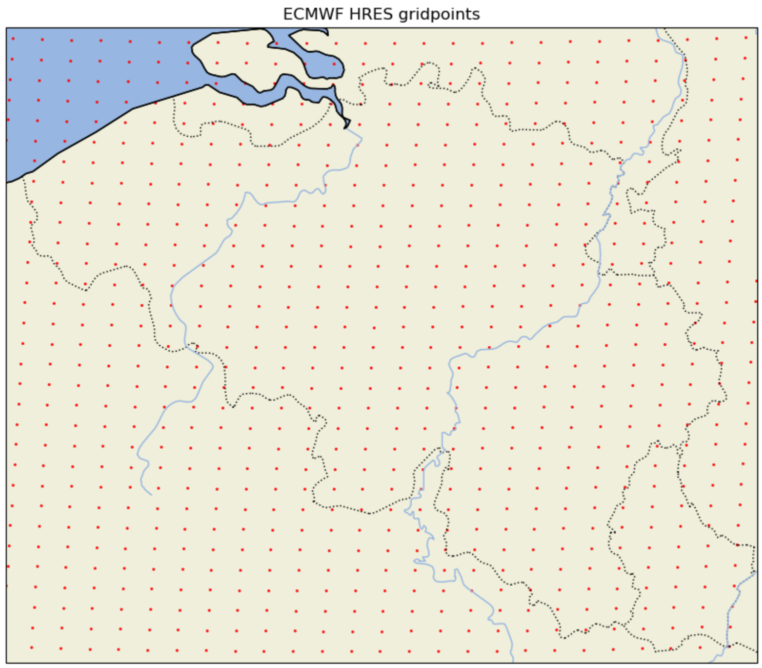

Figure 1: ECMWF HRES O1280 grid points.

Figure 2 shows a zoomed in region over the province of Antwerp, comparing the high-resolution Alaro 1.3 grid with the comparatively coarser ECMWF HRES grid.

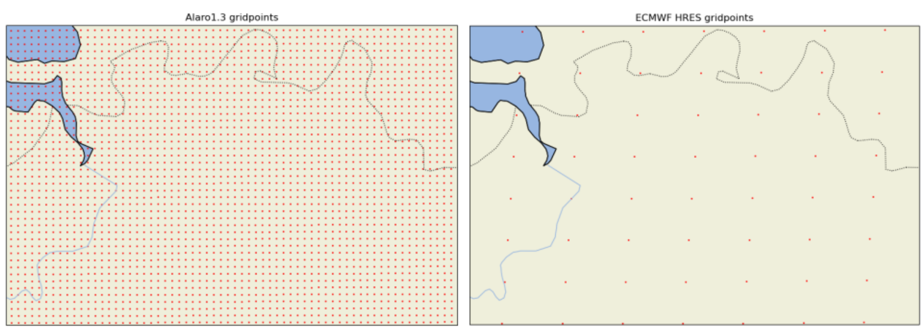

Figure 2: Alaro1.3 (left) and ECMWF HRES (right) grid points over Antwerp region.

5.2 Meteorological observations

To validate our forecasts, we also provide observations for the same period. This also enables the testing of the load forecasting models developed in WP4.3 in a "perfect model" setup. The following data are provided:

- Hourly T2M and S10M from the ERA5 reanalysis (~ 30 km grid; Hersbach et al., 2020).
- Hourly SSRD and FDIR from the gridded RMI product (~ 5 km grid) of merged satellite and pyranometer observations (Journée & Bertrand, 2010).

For InStaFlex purposes, the ERA5 grid was deemed to suffice for wind and temperature, while the higher-resolution gridded solar radiation observations are expected to be advantageous for PV applications. Additionally, wind and temperature observations from the RMI synoptic and AWS weather station network are available on request.

6. Key Results

6.1 Validation framework

We validate the provided forecasts for the period 01 June 2024 – 28 Febr 2025. We compute standard deterministic verification skill scores (Jolliffe & Stephenson, 2012) such as Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Bias, and Pearson Correlation Coefficient (PCC) as function of lead time for T+0 to T+48 hours, comparing the forecast models with ERA5 wind speed and temperature observations, and with RMI SSRD and FDIR observations. For radiation, we also provide normalized scores, using the maximum observed values SSRD_nmax, FDIR_nmax as normalization constants. We compute skill scores for each InStaFlex site separately, and averaged over all sites.

Below, we present the site-averaged RMSE and Bias for T2M and S10M 0:00 UTC forecasts, and the normalized MAE and Bias for 0:00 FDIR and SSRD forecasts at Ukkel (site 6447). This is not intended as an extended verification study, but to have an idea of the typical forecast errors. Scores for all sites will be made available through the RMI cloud drive, and can be computed for other periods as well when the need arises within the project.

6.2 Results

Figure 3 shows the scores for temperature forecasts. Both Alaro and ECMWF have a diurnal cycle in the bias. Alaro forecasts have a slight negative bias overall, while ECMWF has a positive bias in the afternoon and negative bias at night. One should be careful with interpreting model skill however, due to the ERA5 ground truth used here favoring ECMWF HRES, and the fact that Alaro1.3 has a much higher resolution than ECMWF HRES.

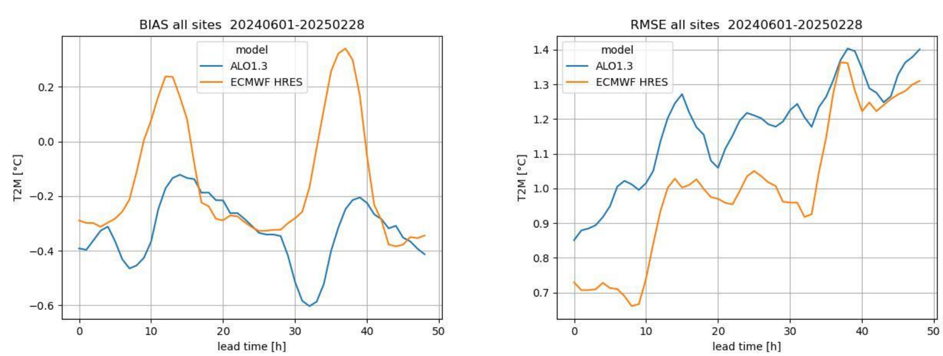

Figure 3: Bias and RMSE for Alaro1.3 and ECMWF HRES temperature forecasts (0:00 UTC).

Figure 4 shows the scores for the wind speed forecasts, which are very similar between Alaro and ECMWF , with Alaro/ECMWF slightly over/under-estimating the wind speed respectively.

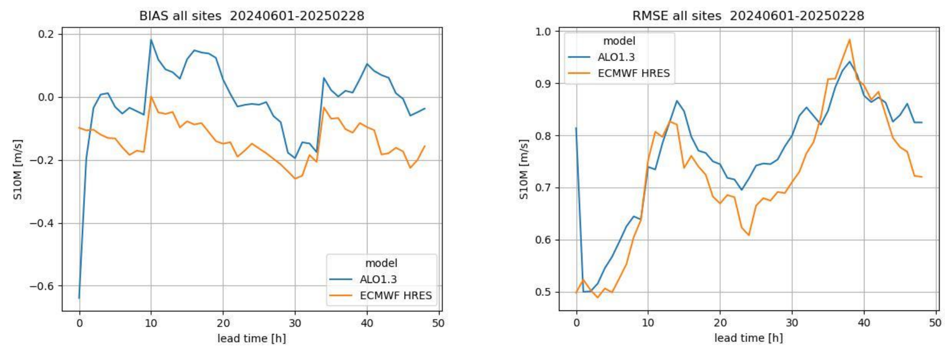

Figure 3: Bias and RMSE for Alaro1.3 and ECMWF HRES wind speed forecasts (0:00 UTC).

Finally, Figure 5 and Figure 6 show the scores for FDIR and SSRD respectively. Both models overestimate the global radiation SSRD and underestimate the direct component FDIR. Normalized errors at noon are around 13% and 15% for intraday and day-ahead FDIR respectively and 10% and 11% for intraday and day-ahead SSRD.

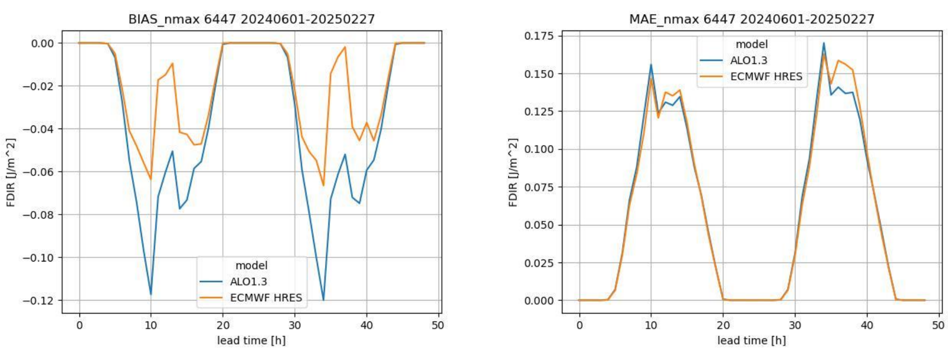

Figure 5: normalized Bias and MAE for Alaro1.3 and ECMWF HRES forecasts of FDIR (0:00 UTC).

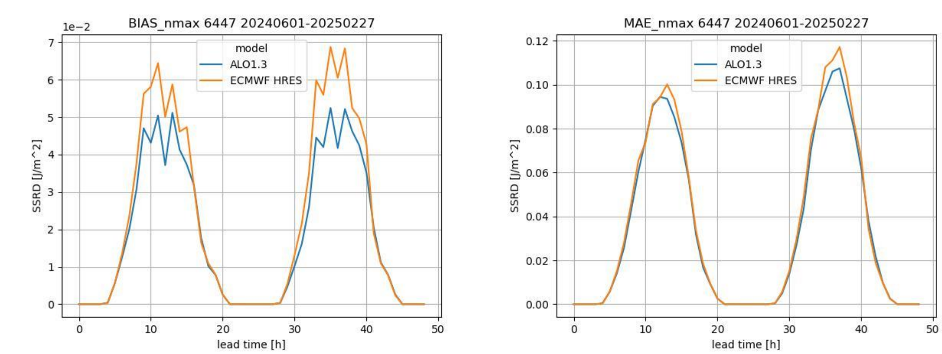

Figure 6: normalized Bias and MAE for Alaro1.3 and ECMWF HRES SSRD forecasts of SSRD (0:00 UTC).

7. Discussion and insights

Deterministic weather forecasts from two numerical weather prediction models at resolutions of 9 km and 1.3 km are available to the InStaFlex consortium partners for load forecasting applications at all chosen industrial sites. Model skill is very similar for both models, with a higher T2M accuracy for ECMWF HRES when compared to ERA5, and very similar S10M and radiation forecast accuracy.

8. Recommendations

For on-site applications, we recommend that both models be tested. Since on-site meteorological observations are typically not available, further direct verification of load forecasts, and photovoltaic power (PV) forecasts for sites with PV assets will reveal further information. For later multi-site optimization, we expect added value from the higher-resolution Alaro1.3 forecasts, which should be verified with multivariate scores such as the Energy Score. Finally, statistical postprocessing techniques will enable reduction of systematic biases revealed in the previous section, and together with the provision of ensemble forecasts will also enable uncertainty quantification.

9. Annexes

None

10. Contact and Acknowledgements

Organisation	Contact Person	Email
PropheSea	Tomas Van Oyen	tomas.vanoyen@prophesea.eu
Oktow	Brecht Zwaenepoel	brecht@oktow.be
University of Antwerp	Peter Hellinckx	peter.hellinckx@uantwerpen.be
Royal Meteorological Institute	Joris Van den Bergh	joris.vandenbergh@meteo.be

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