# LATE REQUEST FOR A SPECIAL PROJECT 2025–2027

**MEMBER STATE:** Croatia

**Principal Investigator**[1]**:** Suzana Panežić (panezic@cirus.dhz.hr)

**Affiliation:** Croatian Meteorological and Hydrological Service

**Address:** Ravnice 48, 10000 Zagreb, Croatia

**Other researchers:**

Benedikt Strajnar (ARSO; benedikt.strajnar@gov.si)

**Project Title:**

Assimilation of all-sky infrared radiances from IASI and MTG-IRS in C-LAEF AlpeAdria system

To make changes to an existing project please submit an amended version of the original form.)

| | | |
|---|---|---|
| If this is a continuation of an existing project, please state the computer project account assigned previously. | **SP** ………….. | |
| Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.) | 2025 | |
| Would you accept support for 1 year only, if necessary? | YES ☒ | NO ☐ |

| **Computer resources required for project year:** | | **2025** | **2026** | **2027** |
|---|---|---|---|---|
| High Performance Computing Facility | [SBU] | 5M | 45M | 45M |
| Accumulated data storage (total archive volume)[2] | [GB] | 10000 | 100000 | 200000 |

| **EWC resources required for project year:** | | **2025** | **2026** | **2027** |
|---|---|---|---|---|
| Number of vCPUs | [#] | | | |
| Total memory | [GB] | | | |
| Storage | [GB] | | | |
| Number of vGPUs[3] | [#] | | | |

*Continue overleaf.*

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

[3] The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

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# Extended abstract


Accurate short-range weather prediction over Europe is increasingly important due to the rise of high-impact weather events, especially in regions with complex orography and coastal influences. Convection-permitting numerical weather prediction systems can significantly improve forecasts, but their performance depends on high-quality initial conditions and the effective assimilation of dense, frequently updated observations. Hyperspectral infrared radiances from next-generation geostationary and polar-orbiting satellites offer substantial potential, yet the assimilation of cloud-affected ("all-sky") radiances remains challenging due to scene-dependent errors and strong inter-channel correlations.

This proposal is related to the PhD topic of Suzana Panežić, done under the supervision of Benedikt Strajnar (ACCORD Data Assimilation Area Leader). The research focuses on improving short-range weather forecasts over Europe by assimilating all-sky hyperspectral infrared radiances into a regional numerical weather prediction system. The Meteosat Third Generation InfraRed Sounder (IRS, currently in commission phase), delivering high-resolution hyperspectral radiances every 30 minutes, represents a major opportunity for improving regional NWP. While MTG-IRS data are not yet available, proxy radiances from the IASI instrument are used to implement and calibrate a cloud-dependent observation error model following the Okamoto methodology within the AROME (Applications of the Research to Operations at Mesoscale) model. The work includes the introduction of a new cloud-dependent predictor in the variational bias correction (VARBC), extensive quality control for cloud-affected radiances, and the diagnosis of statistically consistent observation-error covariances. The technical setup will be developed and evaluated using both passive and active data assimilation experiments within the C-LAEF AlpeAdria regional ensemble system (collaboration between Austria, Slovenia and Croatia). The final stage transitions the developed system from IASI to MTG-IRS, enabling the first evaluation of all-sky IRS radiances in a European convection-permitting ensemble system. The expected outcome is a prototype of an all-sky data assimilation system suitable for future operational implementation in C-LAEF AlpeAdria. Due to the high computational and storage demands of these experiments, this research requests additional SBU and disk resources.


**Objectives:**

The objective of this research is to investigate (1) the feasibility of assimilating all-sky infrared radiances from hyperspectral sounders into a regional convection-permitting numerical weather prediction system over Europe using the Okamoto methodology, (2) the impact of combining cloud-dependent observation error modeling with the 3D-EnVar flow-dependent background errors instead of static climatological covariances, and (3) the impact of assimilating high spatial and temporal resolution data in all-sky conditions on short-range weather forecasts, particularly in cases of high-impact weather.

**Introduction and overview of prior research**

Accurate short-range weather forecasts from such models highly depend on the representation of the atmospheric state from which the model is initialized. The optimal initial atmospheric state is estimated through the process of data assimilation, which combines prior information from the model background with observation data, using the Bayesian framework (Lorenc, 1986).

The assimilation of satellite radiance data has led to significant improvements in weather prediction, particularly in regions where in-situ measurements are unavailable. Creating a high-quality initial state at a convection-permitting scale requires frequent and dense observations, such as radar reflectivities and satellite radiances. In July 2025, the Meteosat Third Generation (MTG) mission of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) launched Europe's first hyperspectral infrared sounding instrument, designed for operation in geostationary orbit. InfraRed Sounder (IRS) on top of MTG-S1 satellite is expected to provide radiance measurements over Europe every 30 minutes in 1960 channels with a spatial sampling of 4 km at nadir (Holmlund et al., 2021). While this offers considerable potential for advancing high-resolution convection-permitting numerical models, data assimilation faces several challenges due to constraints related to the currently used algorithms and underlying hypotheses. Firstly, the vast number of channels in mid- and long-wave infrared spectral bands (4.44–6.25 µm and 8.26–14.70 µm) is almost unmanageable for the minimisation step of the currently used variational algorithms. Secondly, the observations are not independent due to overlapping weighting functions. A channel selection procedure based on the information content is typically applied to address both issues (Collard, 2007). Benefiting from the heritage of the Infrared Atmospheric Sounding Interferometer (IASI) on top of the Metop polar satellite series (Hilton et al., 2012), the preparation research for IRS began in the pre-launch period (Coopman et al., 2023). It progressed in parallel with preparations for IASI-NG, a new-generation polar infrared sounder within the EUMETSAT Polar System Second Generation (EPS-SG). Coopman et al. (2022) performed a channel selection procedure for synthetic IRS data using simulated data based on the 1D-Var assimilation technique proposed by Rodgers (1998). To fully exploit the potential of high-resolution IRS observations in regional numerical weather prediction systems, assimilating radiances in all-sky conditions is essential.

Due to unresolved cloud microphysics in the model, satellite radiance data assimilation has traditionally been limited to clear-sky conditions. However, the development of high-resolution convection-permitting models that can explicitly resolve cloud-related processes has provided the necessary framework for revisiting the use of cloud- and precipitation-affected observations. The introduction of all-sky data assimilation, which incorporates information from both clear and cloud-affected scenes, has shown significant potential to improve short-range weather prediction. It allows cloud, precipitation, moisture, and temperature state estimates to be updated simultaneously during the data assimilation process (Bauer et al., 2011). However, it also presents challenges due to the larger variances and strong inter-channel error correlations of cloud-affected data compared to clear-sky data (Bormann et al., 2011), which conflicts with the underlying hypothesis that covariance structures are homogeneous and isotropic.

The first observation error model for assimilating all-sky microwave imager radiances was developed by Geer and Bauer (2011). They applied a piecewise linear fit to the first-guess standard deviation as a function of cloud amount, estimated from either the observations or their model equivalents. For the application of all-sky data assimilation methods to infrared radiances from IASI, Geer (2019) proposed a combination of variational quality control with correlated inter-channel errors. This study led to the development of a new methodology for handling observation error inflation for cloud-affected data, while highlighting the high sensitivity of results to the choice of inflation method during the minimization process.

Okamoto et al. (2023) proposed a simplified and robust method for representing cloud-dependent observation errors, taking into account both observed and simulated clouds (Okamoto et al., 2014). This method combines the use of observation error modeling, extensive data quality control, and cloud-dependent predictors in the variational bias correction method. By assimilating infrared radiances from the Himawari-8 geostationary satellite, it was demonstrated that incorporating cloud-affected data into the assimilation process led to improvements in the humidity, temperature, and wind fields in the middle and upper troposphere when compared to assimilation using only clear-sky radiance data. This method was extended to assimilate IASI data into the operational Japan Meteorological Agency's Global Spectrum Model, demonstrating huge potential for broader applicability to various infrared instruments (Okamoto et al., 2024). It provides a solid base for further advancements in regional all-sky data assimilation, especially in the context of high-resolution infrared radiance data from IRS.

**Materials, participants, methodology and research plan**

The initial phase of this research will evaluate the applicability of the Okamoto method for all-sky infrared data assimilation within a regional numerical weather prediction system over Europe. As the Infrared Sounder (IRS) aboard the Meteosat Third Generation Sounding (MTG-S1) satellite is currently undergoing calibration, its data will not become available before 2026. In the meantime, radiance observations from the IASI instrument on the Metop polar-orbiting satellites will be used as a proxy, owing to the similar design of a hyperspectral infrared Fourier-interferometer on board. However, due to the limited temporal and spatial coverage of polar-orbiting platforms such as Metop-B and Metop-C, extended time periods will be required (at least 1 month long) to accumulate a sufficient number of observations for robust calibration and testing of the all-sky data assimilation setup.

The technical implementation will take place within the CY48T3 version of the ALADIN (Aire Limitée Adaptation Dynamique Développement International; Bubnová et al., 1995) model, which represents the latest export cycle within the ACCORD (A Consortium for COnvection-scale Modelling Research and Development). Radiance simulations will be performed using the Radiative Transfer for TOVS (RTTOV) model (Saunders et al., 2018), with cloud-sensitive settings enabled to accurately account for cloudy-sky radiances. A cloud detection algorithm developed by McNally and Watts (2003) will be applied to identify cloud-affected channels, enabling the formulation of a scene-dependent observation error model using the methodology of Geer and Bauer (2011). Additionally, a new cloud-dependent predictor will be incorporated into the variational bias correction (VARBC) scheme (Auligné et al., 2007) and used to distinguish between the background error and the observation biases. Following the initial technical implementation, computational stability and timeliness of a modified data assimilation system will be assessed.

Calibration of the setup and further evaluation will be performed within the 1 km version of the C-LAEF (Convection-permitting Limited-Area Ensemble Forecasting system; Wastl et al., 2021), which is based on the non-hydrostatic spectral model AROME (Applications of Research to Operations at Mesoscale; Seity et al., 2011). It has 16 ensemble members (15 perturbed and one unperturbed) using a 3D-Var assimilation scheme and one member using the 3D-EnVar scheme (Montmerle et al., 2018; Michel & Brousseau, 2021). Boundary conditions for the perturbed members are taken every hour from the global ensemble system IFS-ENS. Numerical experiments will be carried-out mainly using computational and storage resources of ECMWF, using national shares at their HPC.

To minimize contamination from surface emissivity, the all-sky assimilation will focus on water vapor channels whose weighting functions peak in the mid-to-upper troposphere. Initial evaluation of the observation error model will be performed using IASI radiances in passive mode during data assimilation. Since satellite data are not currently assimilated operationally in C-LAEF, this passive experiment will additionally enable the assessment of observation biases and the predictor values within the VARBC scheme. Following this, an active assimilation experiment will be conducted using the same configuration to assess the impact of the all-sky observation error model and validate its effectiveness in a fully coupled assimilation system.

Observation errors associated with cloud-affected radiances typically exhibit non-Gaussian and asymmetric distributions, resulting in a pronounced cold bias in the analysis. This conflicts with the core assumption in data assimilation variational schemes that errors have normal distributions, potentially degrading the analysis and consequently, the forecast. To address this issue, a detailed evaluation will be conducted to identify observations that the C-LAEF AlpeAdria system cannot accurately reproduce. Following this, a quality control procedure will be adapted to filter out poorly simulated data, ensuring that only physically consistent and well-represented observations are retained in the assimilation process. The remaining cold bias associated with the introduction of cloud-affected data will be addressed by introducing a new cloud-dependent predictor within the VARBC scheme. Following the implementation of observation error modeling, a full observation error matrix will be diagnosed using the method of Desroziers et al. (2005), ensuring that the assumptions of the assimilation system remain consistent with the statistical properties of the data.

As demonstrated by Menetrier et al. (2014), forecast errors at convection-permitting scales are flow-dependent, and a climatological background-error covariance matrix is insufficient to represent high-impact weather features. The 3D-EnVar method is an advanced hybrid data assimilation technique that combines variational assimilation with ensemble-derived, flow-dependent background error covariances. Unlike standard 3D-Var, it uses an ensemble to capture more realistic, situation-specific error structures, improving the assimilation of complex observations without relying on adjoint models. Due to its modular implementation and flow-dependent setup, the 3D-EnVar control variable vector can be extended with further prognostic variables of the model such as hydrometeors, which are expected to capture significant part of the information from all-sky observations. Flow-dependence in 3D-EnVar comes at the cost of sampling noise and long-distance correlations due to limited ensemble size; these will be damped using various implementations of localization (Menetrier et al., 2015) such as vertically dependent horizontal localization and scale-dependent localization.

The joint performance of the 3D-EnVar method and adaptive all-sky observation error modeling will be explored, as they are expected to complement each other. The 3D-EnVar method provides dynamically evolving background error structures, while the observation error modeling accounts for the scene-dependent nature of satellite radiance errors in cloudy conditions. Together, they are expected to enhance the assimilation of cloud-affected observations and improve short-range forecasts in convection-permitting models. A comparison will be made between 3D-Var and 3D-EnVar schemes to evaluate their relative skill in handling cloud-affected radiances.

Unlike global models, regional models are sensitive to seasonal variability, which can influence both background and observation error behavior. Consequently, it is expected that the performance of the all-sky assimilation system might depend on the time of year. To capture these potential differences, all experiments will be conducted over two extended periods, representing both warm and cold seasons. This approach will enable the assessment of seasonal dependencies in both the 3D-EnVar and observation error modeling components, ensuring robustness of the final configuration. Additionally, the impact of all-sky infrared radiances on other assimilated observations will be explored by evaluating their root mean square departures and other statistical properties.

Finally, the last part of the research will focus on an optimal exploitation of IRS data for data assimilation over Europe. Preparatory work with IASI will provide the required error characteristics and tuning of the assimilation setup, allowing for an impact study of IRS observations in the 1 km convection-permitting model using the final refined configuration.

**Following experiments will be performed for 2x1 month long periods (winter and summer):**

1) Reference experiment with no IASI data assimilation
2) Clear-sky assimilation of IASI data
3) All-sky assimilation of IASI data with tuned observation error model and scene-dependant quality control
4) All-sky assimilation of IASI data with tuned observation error model, scene-dependant quality control and scene-dependant VARBC predictor
5) All-sky assimilation of IASI data with tuned observation error model, scene-dependant quality control and scene-dependant VARBC predictor + 3DEnvar with extended control variable vector

All experiments will be repeated with MTG-IRS data when available instead of IASI data

| **Task:** | SBU consumption | Storage requirement |
|---|---|---|
| 3D-Envar Assimilation & 6h forecast /run | 15000 | 5 GB |
| 3D-Envar Assimilation & 69h forecast /run | 23000 | 50 GB |

SBU consumption per day -> (23000 * 4 runs) + (15000 * 4 runs) -> 92000 + 60000 = 152000

Net SBU consumption -> 152000 * 4 weeks * 2 periods * 10 experiments  = 91200000

**Cited literature**


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