REQUEST FOR A SPECIAL PROJECT 2026–2028

MEMBER STATE:	Austria
Principal Investigator[1]:	Adhithiyan Neduncheran (adhithiyan.neduncheran@geosphere.at)
Affiliation:	GeoSphere Austria
Address:	GeoSphere Austria, Hohe Warte 38, 1190, Vienna, Austria
Other researchers:	Florian Meier (florian.meier@geosphere.at), Christoph Wittmann (christoph.wittmann@geosphere.at), Philipp Scheffknecht (philipp.scheffknecht@geosphere.at)
Project Title:	AllSky assimilation of MTG FCI in high-resolution regional Ensemble Prediction System of GeoSphere Austria

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.)	2026	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for project year:	**2026**	**2027**	**2028**
High Performance Computing Facility [SBU]	34.1M	34.1M	34.05M
Accumulated data storage (total archive volume)[2] [GB]	70000	170000	240000

EWC resources required for project year:	**2026**	**2027**	**2028**
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

The rapid evolution of satellite remote sensing and numerical weather prediction (NWP) demands innovative approaches to harness high-resolution observational data for improving forecast accuracy. This proposal aims to advance severe weather prediction by implementing the assimilation of Meteosat Third Generation (MTG) Flexible Combined Imager (FCI) water vapor and visible channel data into AROME (Applications of the Research to Operations at Mesoscale) model using the state-of-the-art, high-resolution 3D-Ensemble Variational (3D-EnVar) algorithm, in the convection-permitting Limited-Area Ensemble Forecasting at 1 km, (C-LAEF1k) framework being run at GeoSphere Austria in operations. MTG FCI's unprecedented 10-minute temporal refresh rate, 1 km spatial resolution at nadir, and spectral diversity offer transformative potential for capturing rapidly evolving atmospheric processes, particularly in data-sparse regions. However, current operational NWP systems underutilize these channels due to challenges in handling non-linear observation operators, cloud-affected radiance. This work addresses these gaps by integrating a state-of-the-art 3D-EnVar system tailored to exploit MTG FCI's capabilities within C-LAEF1k's convective-scale framework. Key innovations include the development of flow-dependent ensemble-based error covariances to better represent mesoscale dynamics, advanced observation error modelling techniques for visible/infrared channels, and a high-performance computing strategy to ensure operational feasibility. By improving the characterization of moisture fields and cloud initiation, this research seeks to enhance the initialization of high-impact weather systems in C-LAEF1k, with anticipated gains in forecast skill for extreme events and localized precipitation. The proposed transition of this research into operational infrastructure will bridge critical gaps between satellite innovation and NWP performance, fostering resilience in weather dependent decision-making.

This project aims to develop and operationalizing an advanced 3D-EnVar assimilation framework tailored to integrate MTG FCI's high-resolution WV and visible channel data into C-LAEF1k.

Specific goals include:

1. <u>Enhancing mesoscale analysis</u>: Leveraging FCI's rapid refresh rate to resolve moisture gradients, convective initiation, and cloud dynamics at 1 km scales.
2. <u>Optimizing non-linear observation operators</u>: Addressing biases in cloud-affected radiances via advanced radiative transfer modelling and machine learning-assisted visible channel assimilation.
3. <u>Improving ensemble-based uncertainty quantification</u>: Developing flow-dependent error covariances to better represent mesoscale processes.
4. <u>Operational transition</u>: Ensuring computational efficiency for real-time deployment.

By transitioning MTG FCI's cutting-edge observations into operational workflows, this work will advance GeoSphere Austria's mandate to mitigate weather-related risks in Central Europe.

1. Introduction

Accurate prediction of high-impact weather events relies on precise initial conditions derived from advanced DA systems. Despite significant progress in NWP, challenges persist in resolving convective-scale processes and moisture gradients that drive severe thunderstorms, flash floods, and other mesoscale phenomena. The launch of MTG FCI, a next-generation geostationary satellite provides a transformative dataset with 16 spectral bands (including high-frequency water vapor and visible channels), sub-kilometric spatial resolution, and sub-hourly temporal sampling. Yet, many operational systems, currently lack frameworks to fully exploit these observations due to limitations in traditional 3D-Variational (3D-Var) methods and insufficient representation of non-Gaussian error statistics in cloudy regions.

Current assimilation of satellite radiances in AROME focuses primarily on microwave and infrared sounders, leaving untapped potential in MTG FCI's visible/infrared channels for detecting low-level cloud structures using visible channels, convection triggers using the infrared channels. Meanwhile, the shift toward ensemble-based DA methods like 3D-EnVar offers a pathway to leverage ensemble-derived flow-dependent covariances, which better capture rapidly evolving error structures in complex terrain and unstable atmospheres. This proposal posits that synergistic use of MTG FCI's observational revolution and modern ensemble-variational techniques will revolutionize C-LAEF1k's ability to initialize convective-scale weather systems.

The core objective of this work is to implement a high-resolution 3D-EnVar framework within AROME to assimilate MTG FCI water vapor (6.3 µm, 7.3 µm) and visible (0.6 µm) channel radiances. the project aligns with global efforts to maximize the societal value of satellite investments. Expected outcomes include improved short range forecasts skill for severe weather and a blueprint for assimilating future geo-stationary sensors in convection-permitting models. Success will be measured through verification against the in-house operational forecast metrics, with broader implications for NWP communities such as ACCORD(**A** **C**onsortium for **CO**nvection-scale modelling **R**esearch and **D**evelopment) and RC-LACE(**R**egional **C**ooperation for **L**imited **A**rea modelling in **C**entral **E**urope) fostering international collaboration.

2. Relevant experience

GeoSphere Austria has established a robust foundation in satellite data assimilation over many years, with a proven track record of advancing meteorological forecasting through innovative techniques. Over the past two years, we have focused extensively on the AllSky assimilation of Meteosat Second Generation (MSG) Spinning Enhanced Visible and Infrared Imager (SEVIRI) water vapor (WV) channels and pioneered exploratory work on visible channel assimilation. This effort has equipped us with unparalleled expertise to tackle cutting-edge challenges in satellite data utilization, positioning us in the advancements in this field and ensuring readiness for the proposed project. Successfully implemented AllSky assimilation for SEVIRI WV channels, integrating data under all weather conditions (clear-sky, cloudy, and precipitating). This required overcoming significant technical hurdles, including modelling cloud-radiation interactions, mitigating biases in cloud-affected radiances, and refining quality control algorithms.

Our team has rigorously validated the fidelity of the NWP system through high-resolution model simulations of SEVIRI water vapor (WV) channel radiances, achieving good agreement with observed brightness temperatures (BTs) under diverse atmospheric conditions. As illustrated in Figure 1, simulations of SEVIRI's 6.2 µm, as an example for one such case study.

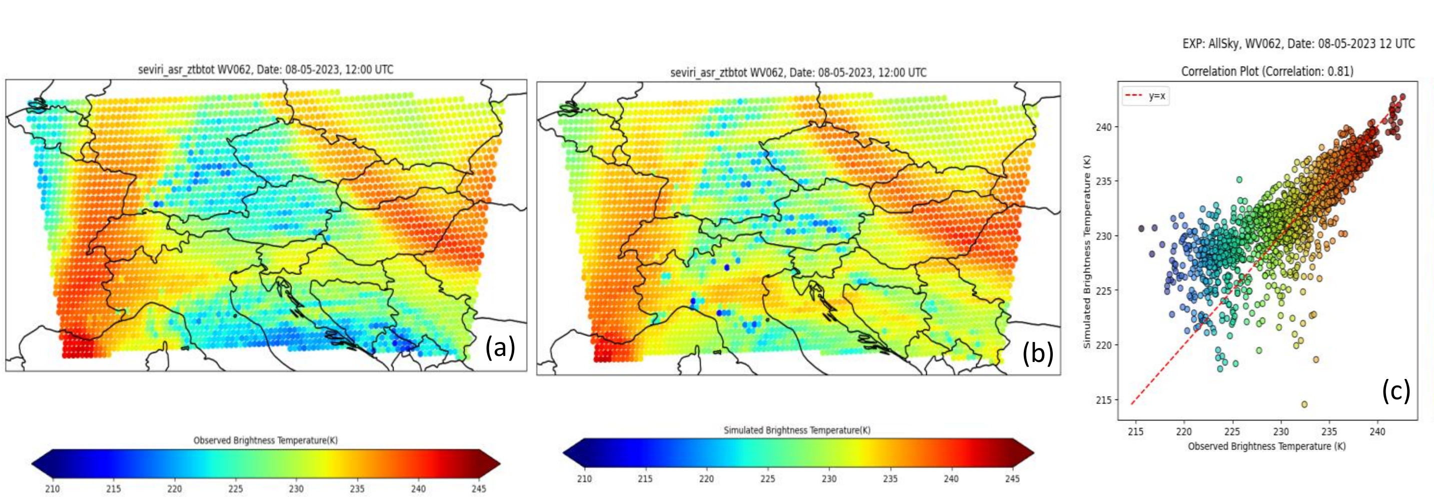

Fig 1: WV6.2 µm channel from MSG SEVIRI, (a) Observed brightness temperature, (b) Simulated brightness temperature, (c) correlation between observed and simulated brightness temperature

With a decade of cumulative experience in satellite data assimilation, validated by measurable advancements in weather prediction and technical infrastructure, we are well positioned to lead this project. Our past successes in AllSky assimilation for SEVIRI provide a springboard to address even more complex challenges, ensuring rapid integration of MTG FCI observations.

3. Model and software package

The proposed framework integrates AROME as the foundational modeling architecture, configured to assimilate high-temporal-resolution observations from MTG FCI. Operating at an unprecedented 1 km horizontal grid spacing, AROME enables the explicit representation of fine-scale atmospheric processes and convective systems, leveraging lateral boundary conditions sourced from the European Centre for Medium-Range Weather Forecasts (ECMWF) Integrated Forecasting System (IFS) to maintain synoptic-scale consistency. The assimilation engine employs a 3D-EnVar algorithm, combining flow-dependent ensemble-derived background error covariances with deterministic variational optimization to maximize observational information content. This system is executed on ECMWF's HPC infrastructure. Workflow automation and job orchestration are managed through ECMWF's EcFlow suite, enabling robust scheduling of data ingestion, quality control, minimization algorithms, and forecast initialization phases.

The implementation will utilize AROME Cycle 49 (Cy49), which incorporates Radiative Transfer for TOVS (RTTOV) version 13 as a natively integrated component of the observation operator. This configuration ensures compatibility with MTG FCI's spectral channel characteristics while exploiting the latest advances in radiative transfer modelling, including optimized absorption coefficients and cloud-scattering parameterizations. Particular emphasis is placed on the deployment of the Multispectral Forward Assessment of Surface-Independent Signatures Neural Network (MFASIS-NN) visible-channel operator, a machine learning-enhanced component specifically tailored for simulating MTG FCI visible channel radiances under diverse aerosol and hydrometeor conditions. The technical integration of these components demonstrates a sophisticated capacity to harmonize cutting-edge NWP system, next-generation satellite data streams, and high-performance computing resources into a coherent assimilation framework capable of extracting maximum predictive value from MTG FCI's observational capabilities.

4. Planned research work

The research plan involves conducting an initial investigation, followed by adapting existing codebases or developing new algorithms tailored to the problem. Implementation includes rigorous testing in controlled environments to ensure functionality, followed by experiments to evaluate performance. Results undergo validation using established in-house verification tools.

i) **Source code modifications/adaptations:** Develop and integrate required changes into existing codebase. This mainly involves the auditing the existing code for compatibility with research goals, and identify the modules requiring modifications. As part of the code development, we shall add new features to the existing model source code and validate individual components.

ii) **Implementation & preliminary experimentation:** This involves performing feasibility tests and refine workflows. Firstly, the environment is configured to automate the workflow. Secondly, individual case studies will be performed for selected extreme weather events to compare the performance with our operational model. Finally, we try to optimize the forecasts by fine-tuning the model.

iii) **Month long experiments:** Validate the robustness under the extended study period, once during the summer and once during the winter season, six weeks each. This involves an in-depth analysis and post-processing of the model results.

iv) **Validation study:** To ensure the reliability and reproducibility, we shall compare and verify against the in-house verification tools and nowcasting system. Finally, compiling the results into visualizations.

v) **Deliverables:**
a) Experiment logs and analysis results.
b) Validation and technical reports.
c) Code modifications (if requested).

Following experiments will be carried out, twice:
a) Reference run from operations (***at no additional computational cost***)
b) ClearSky assimilation of MTG FCI IR/WV channels
c) AllSky assimilation of MTG FCI WV channels
d) AllSky assimilation of MTG FCI visible channel
e) AllSky assimilation of MTG FCI WV channels + visible channel

5. Computational cost and data storage estimate

S.No.	Task	SBU consumption	Storage requirement
1	Source code compilation(s)	2000	-
2	3D-Envar Assimilation & 6h forecast / run	15000	5 GB
3	3D-Envar Assimilation & 69h forecast / run	23000	50 GB
4	Miscellaneous technical tests	1000000	-

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

Each experiment will be run for 2+4 week, allowing a 2 week spinup period, for one summer and one winter month(4 week) each.

Net SBU consumption -> 152000 * 6 weeks * 2 periods * 4 experiments * 2 = **102144000 SBU**

Access is required for following researchers involved:
Christoph Wittmann (christoph.wittmann@geosphere.at),
Florian Meier (florian.meier@geosphere.at),
Adhithiyan Neduncheran (adhithiyan.neduncheran@geosphere.at),
Philipp Scheffknecht (philipp.scheffknecht@geosphere.at).

**There is a possibility to add more researchers during the course of this project.*

6. References

Geer, A.J., Migliorini, S. and Matricardi, M., 2019. All-sky assimilation of infrared radiances sensitive to mid-and upper-tropospheric moisture and cloud. *Atmospheric Measurement Techniques*, *12*(9), pp.4903-4929.

Geer, A. J., Lonitz, K., Weston, P., Kazumori, M., Okamoto, K., Zhu, Y., Liu, E. H., Collard, A., Bell, W., Migliorini, S., Chambon, P., Fourrié, N., Kim, M.-J., Köpken-Watts, C., and Schraff, C.: All-sky satellite data assimilation at operational weather forecasting centres, Q. J. Roy. Meteor. Soc., 144, 1191–1217.

Geer, A.J. and Bauer, P., 2011. Observation errors in all-sky data assimilation. *Quarterly Journal of the Royal Meteorological Society*, *137*(661), pp.2024-2037.

Montmerle, T., Michel, Y., Arbogast, E., Ménétrier, B. and Brousseau, P., 2018. A 3D ensemble variational data assimilation scheme for the limited-area AROME model: Formulation and preliminary results. *Quarterly Journal of the Royal Meteorological Society*, *144*(716), pp.2196-2215.

Okamoto, K., Ishibashi, T. and Okabe, I., 2023. All-sky infrared radiance assimilation of a geostationary satellite in the Japan Meteorological Agency's global system. *Quarterly Journal of the Royal Meteorological Society*, *149*(755), pp.2477-2503.

Bauer, P., A. J. Geer, P. Lopez, and D. Salmond, 2010: Direct 4D-Var assimilation of all-sky radiances. Part I: Implementation. *Quart. J. Roy. Meteor. Soc.*, **136**, 1868–1885.

Li, J., Geer, A.J., Okamoto, K., Otkin, J.A., Liu, Z., Han, W. and Wang, P., 2022. Satellite all-sky infrared radiance assimilation: Recent progress and future perspectives. *Advances in Atmospheric Sciences*, *39*(1), pp.9-21.

Okamoto, K., McNally, A.P. and Bell, W., 2014. Progress towards the assimilation of all-sky infrared radiances: An evaluation of cloud effects. *Quarterly Journal of the Royal Meteorological Society*, *140*(682), pp.1603-1614.

Okamoto, K., 2017. Evaluation of IR radiance simulation for all-sky assimilation of Himawari-8/AHI in a mesoscale NWP system. *Quarterly Journal of the Royal Meteorological Society*, *143*(704), pp.1517-1527.

Okamoto, K., Hayashi, M., Hashino, T., Nakagawa, M. and Okuyama, A., 2021. Examination of all-sky infrared radiance simulation of Himawari-8 for global data assimilation and model verification. *Quarterly Journal of the Royal Meteorological Society*, *147*(740), pp.3611-3627.

Kugler, L., Anderson, J.L. and Weissmann, M., 2023. Potential impact of all-sky assimilation of visible and infrared satellite observations compared with radar reflectivity for convective-scale numerical weather prediction. *Quarterly Journal of the Royal Meteorological Society*, *149*(757), pp.3623-3644.

Kugler, L. and Weissmann, M., 2025. Effects of Observation-Operator Nonlinearity on the Assimilation of Visible and Infrared Radiances in Ensemble Data Assimilation. *Quarterly Journal of the Royal Meteorological Society*, p.e4970.

Harnisch, F., Weissmann, M. and Periáñez, Á., 2016. Error model for the assimilation of cloud-affected infrared satellite observations in an ensemble data assimilation system. *Quarterly Journal of the Royal Meteorological Society*, *142*(697), pp.1797-1808.