Geographic generalization of sky image-based solar forecasting models

Solar R&D Program
TotalEnergies

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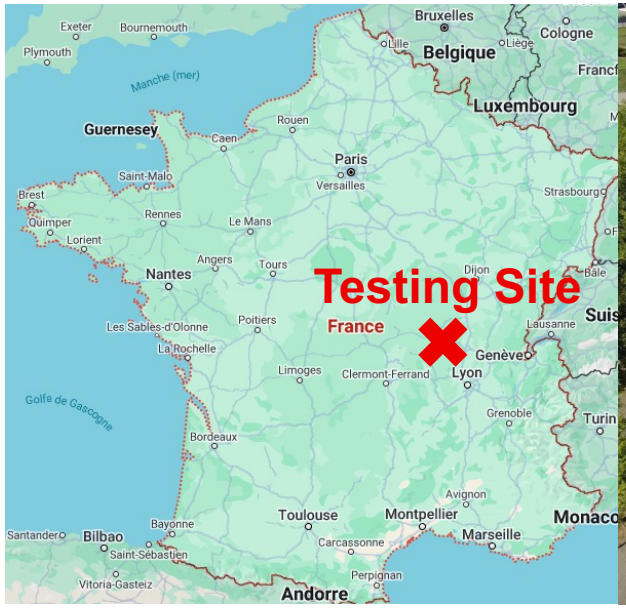
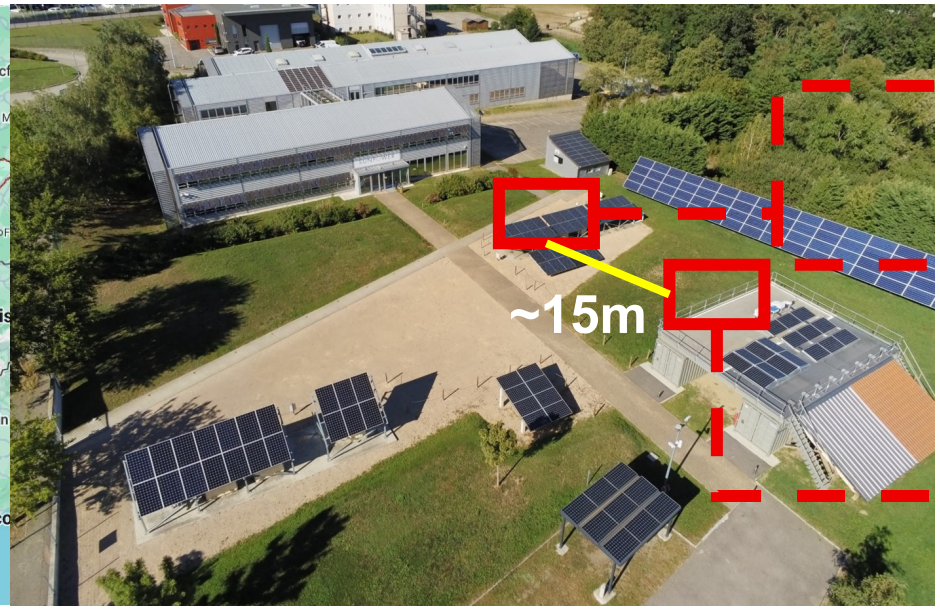
Motivation

1. **Geographic Generalization**: Model's ability to keep consistent level of performance across distinct geographic locations (climate, orography, etc.).
2. A challenge for sky image-based models:
   - **Preferred**: Deploy a standardized data acquisition setup globally.
   - **Alternative**: Utilize open-source data, noting issues with camera specifications, temporal resolution, and data quality etc. (Nie et al., 2022).
3. The market offers commercial forecasting services (sky imager + forecasting model).
4. **How do commercial forecasting services generalize on sites with no historical data compared to models developed with extensive site-specific data?**

Experimental Setup

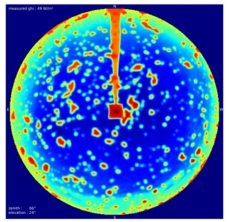
- We installed two distinct sky imagers equipped with different technologies.
- We embedded two commercial forecast algorithms (“black box”).
- We adapted a standard ML forecasting methodology on the visible camera (Sun et al, 2019).
- **Objective**: 5-minute GHI forecast.





Pyranometer (GHI)
Reference Measurements

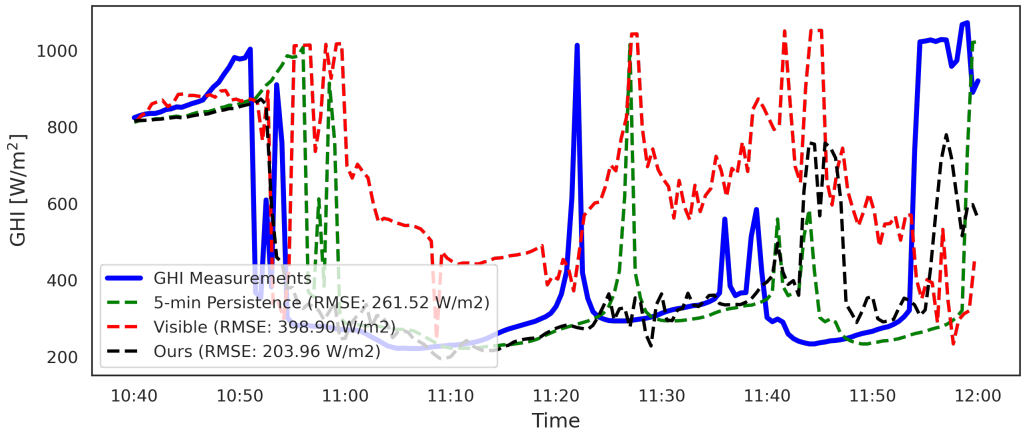
Camera 1 (Visible Spectrum)
A: Commercial Solution (10 weeks)[1]
Ours: Our Model

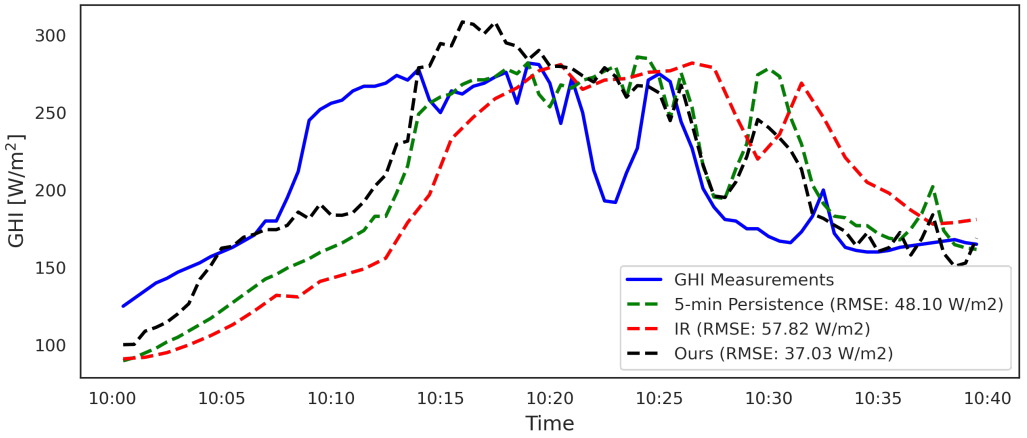


Camera 2 (Infrared Spectrum)
B: Commercial Solution (17 weeks)[2]

[1][2020-09-01 to 2020-11-09] [2][2022-11-15 to 2023-03-06]

Comparative Performance Analysis





Skill-Score / RMSE [W/m2]

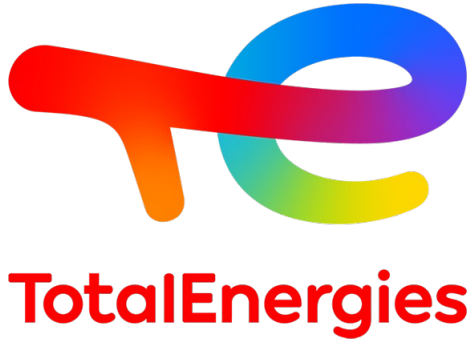
Transferred Model (Visible): -16.90% / 141.19
Local Model: **+15.05% / 77.09**

Transferred Model (Infrared): -6.80% / 88.78
Local Model: **+16.15% / 34.74**

- Local Model Training
- Testing (Local Model + Visible Model)
- Testing (Local Model + Infrared Model)

Conclusion

- External forecasting providers have encountered difficulties in generalizing the skill score on our test site, which implies problems of geographic generalization.
- Site-specific model better adapted to testing period (align w/ Nie et al., 2022).
- Future Directions (PhD Project O.I.E – Mines Paris – PSL & TotalEnergies)
  - Deploy our model across various geographic locations to assess its performance consistency.
  - The scope will broaden to include diverse image-based forecasting approaches (both sky and satellite), while **identifying factors that influence model generalization**.



Thank you!

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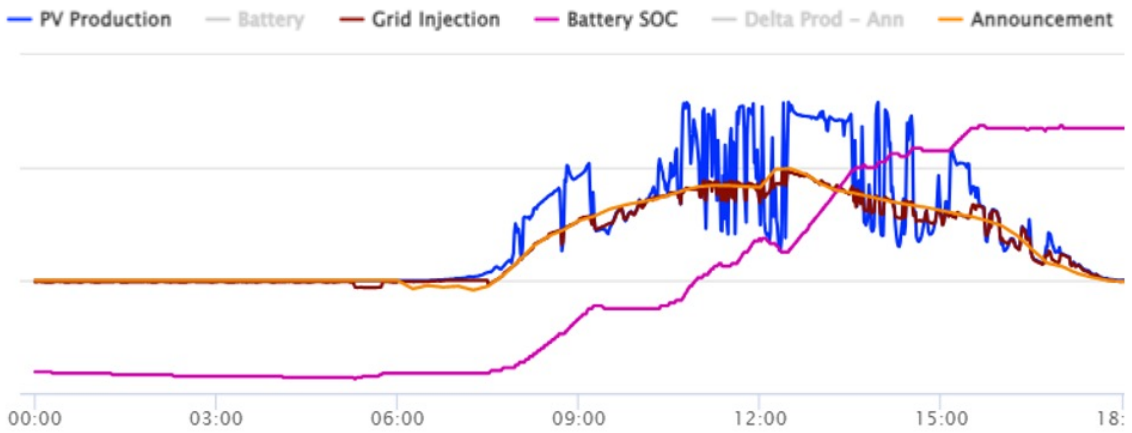
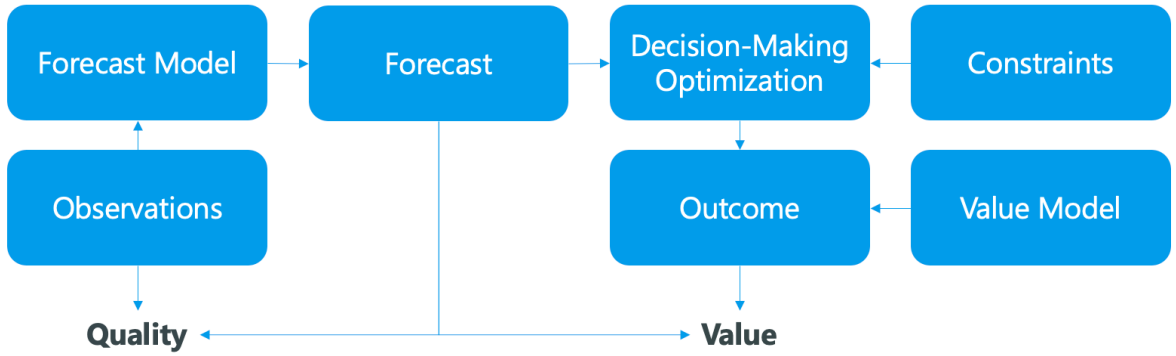
(Appendix) Operational Benefits of Sky-Imager Based Forecasting Models

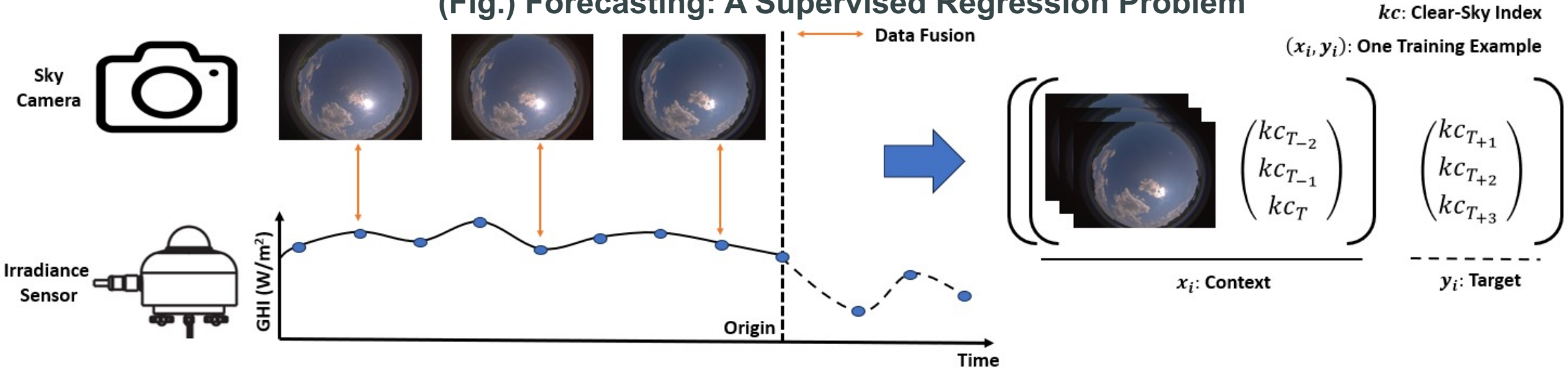
- PV assets commonly leverage day-ahead forecasts which are periodically updated and also provide "intra-hour" data.
- Such forecasts, albeit at a lower fidelity, indicate minute-scale irradiance variability, which may be further refined using satellite or sky-imager-based techniques.
- What additional operational value can higher frequency, higher fidelity forecasts bring to application-specific contexts?
- We are currently evaluating various segments within the value chain, modeling and determining the operational value of these detailed forecasts.



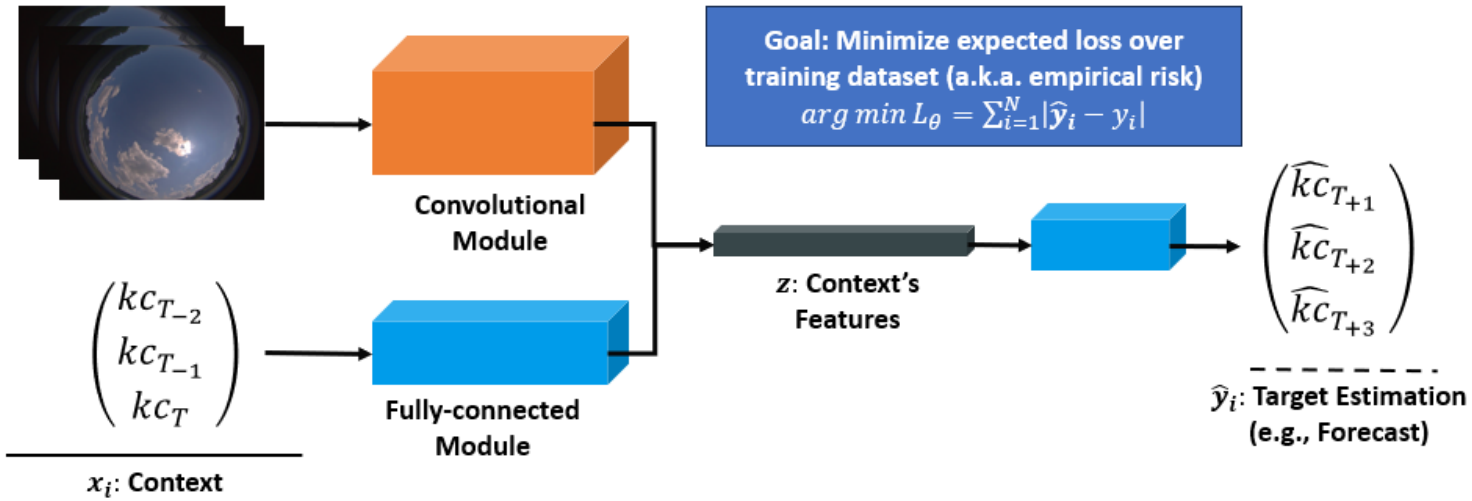


(Appendix) Model

(Fig.) Forecasting: A Supervised Regression Problem

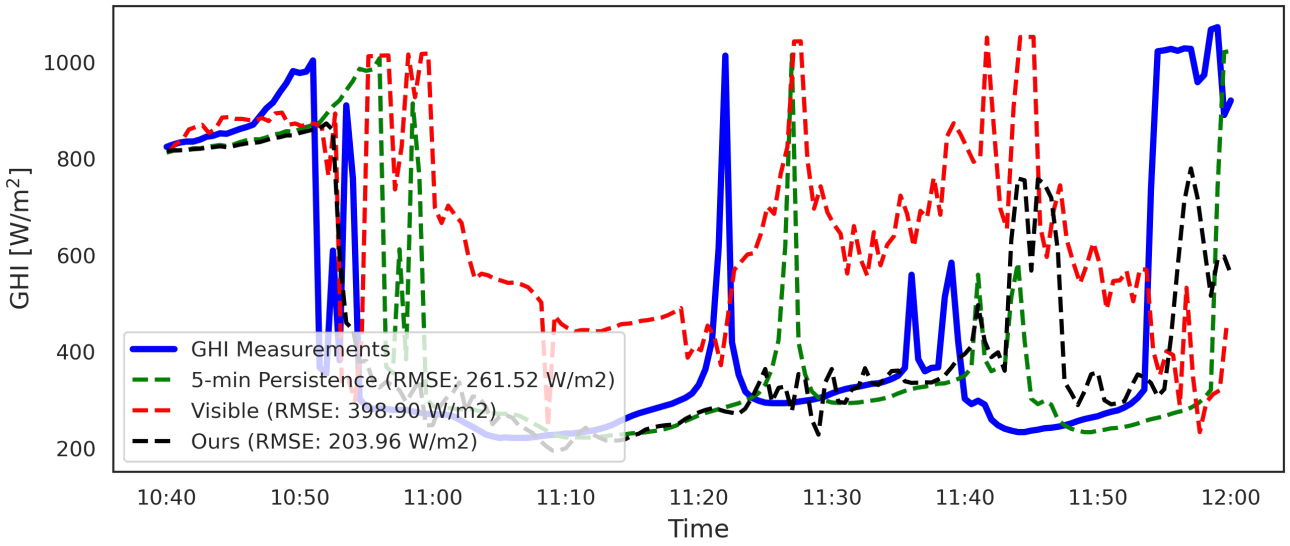


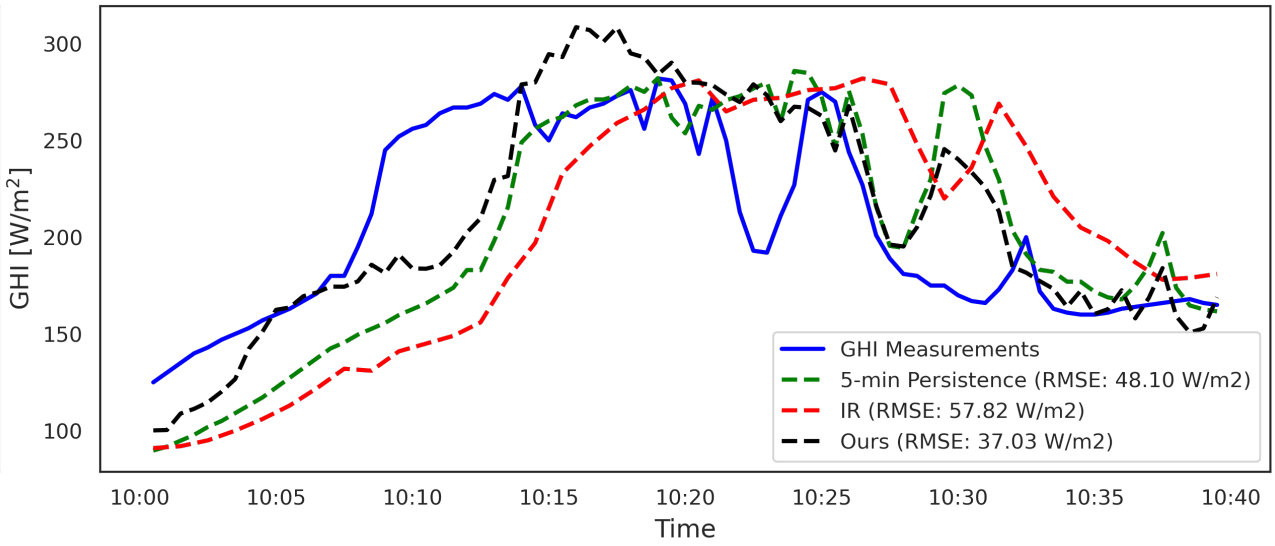
(Fig.) Neural Network Modeling



(Appendix) Full results

(Fig.) Comparative GHI forecasts displayed over time.





	Testing Set A (10 weeks)			Testing Set B (17 weeks)		
Metric	RMSE [W/m2]	nRMSE [%]	Skill-Score [%]	RMSE	nRMSE	Skill-Score
Forecaster A (Visible Imager)	141.19	36.14	−16.90	N/A	N/A	N/A
Forecaster B (Infrared Image)	N/A	N/A	N/A	88.78	35.59	-6.80
Ours	**77.09**	**23.22**	**15.05**	**34.74**	**25.28**	**16.15**