ENHANCING INTRA-HOUR SOLAR IRRADIANCE FORECASTING FOR SOLAR APPLICATIONS: A BLENDED MODEL OF SATELLITE, SKY IMAGER AND PERSISTENCE

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Agenda

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- Methodology
  - Forecasting systems
  - Blending methods
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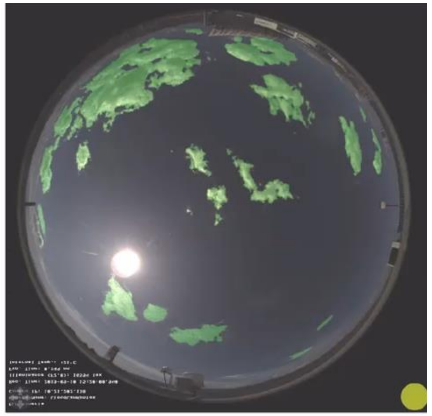
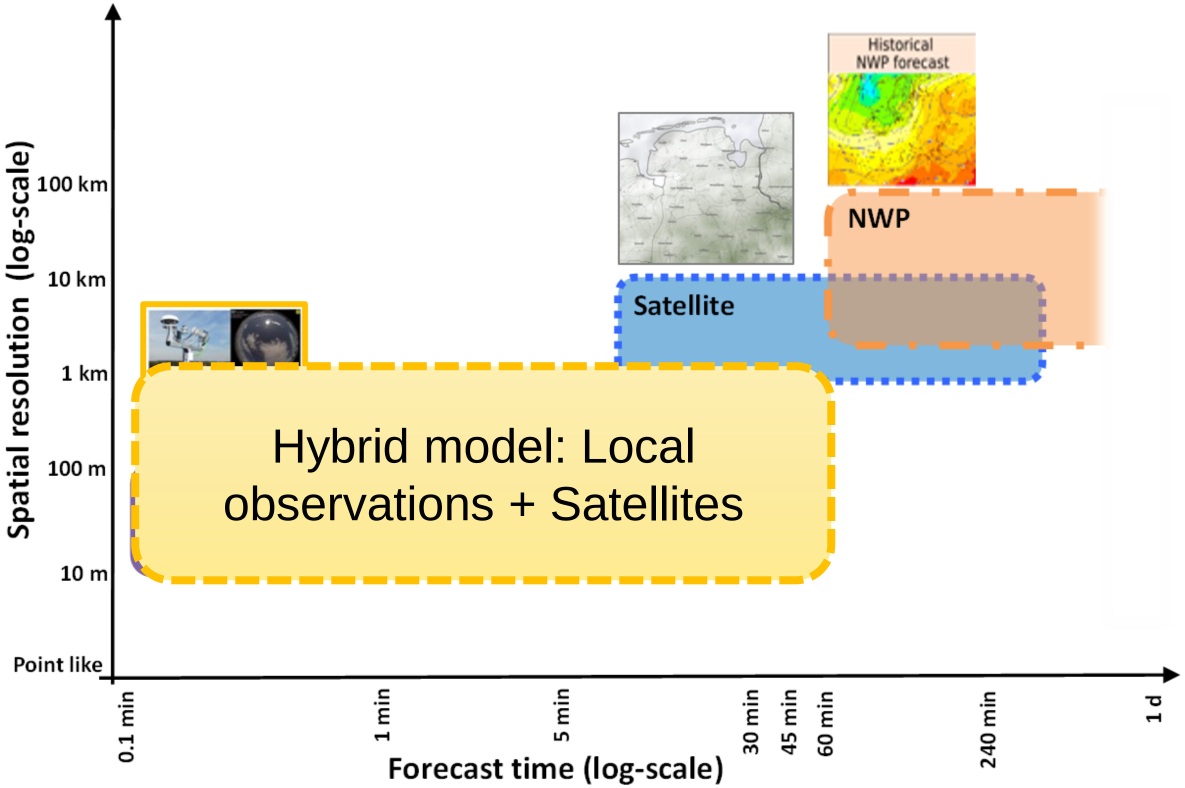
- Conclusion

Motivation

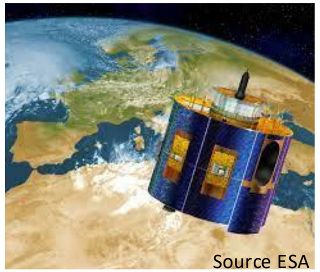
- Solar irradiance variabilities in space and time on the local scale occur due to cloud passing
- Forecasting could make it possible to anticipate changes
- Accuracy of forecasts is crucial for their applicability
- Complementary Methods
  - Local observations (e.g. sky cameras and radiometers) offer high temporal and spatial resolution, but have limited spatial coverage and a short forecast horizon.
  - Satellites provide broad coverage and an extended forecast horizon, but have a coarser resolution.
- A hybrid model that blends local and satellite forecasts to produce robust, high-resolution, intra-hour local forecasts.



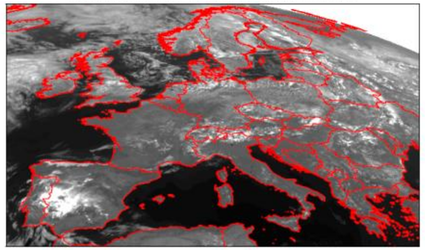


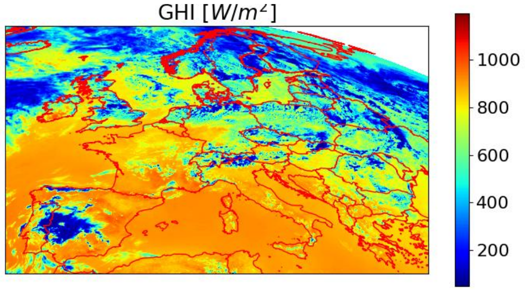
Forecasting systems

Meteosat based forecasts



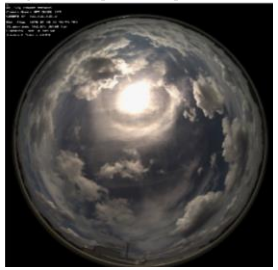
Heliosat method [1]



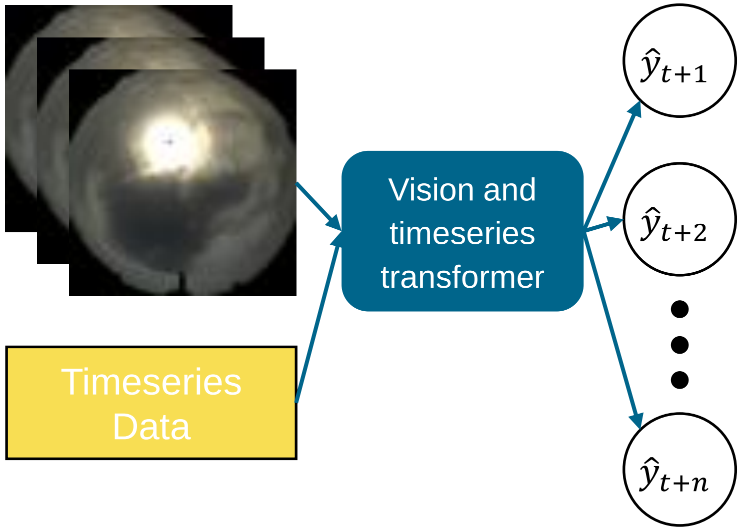


- Horizon ~6h
- Spatial resolution ~ 2km
- Temporal resolution and update rate 15 min

All sky imager (ASI) based forecast



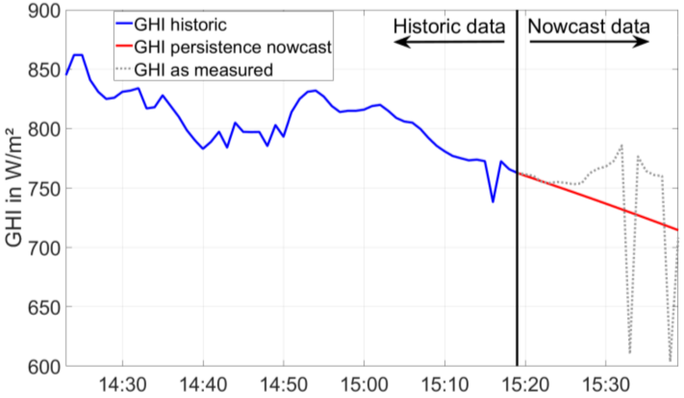
Deep learning transformer method [2]



- Horizon 1h
- Temporal resolution 1 min
- Update rate 30 s
- Model trained on data set in southern Spain
- >3000000 data points distributed over 7 years

Persistence forecast

Scaled persistence method [3]

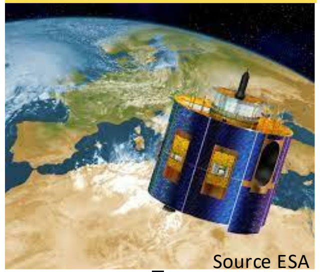


- Update rate 1 min

Blending methods

Ground measurements

Satellite



ASI

Ground measurements

Forecast

Ground truth

Training data

Testing data

Homogenization

Blending
- Linear regression
- XGBoost
- LSTM
- Transformer

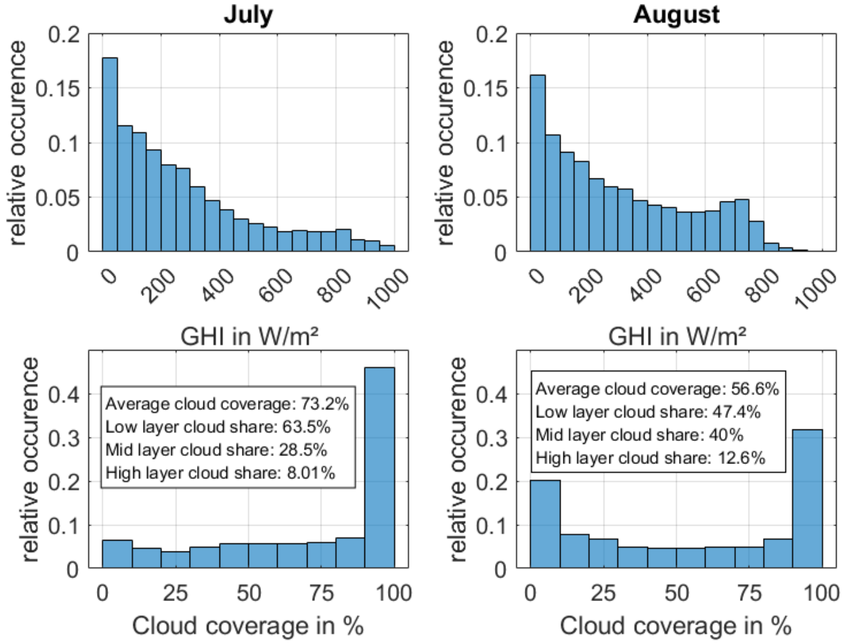
Hyperparameter tuning is performed

Inference blending

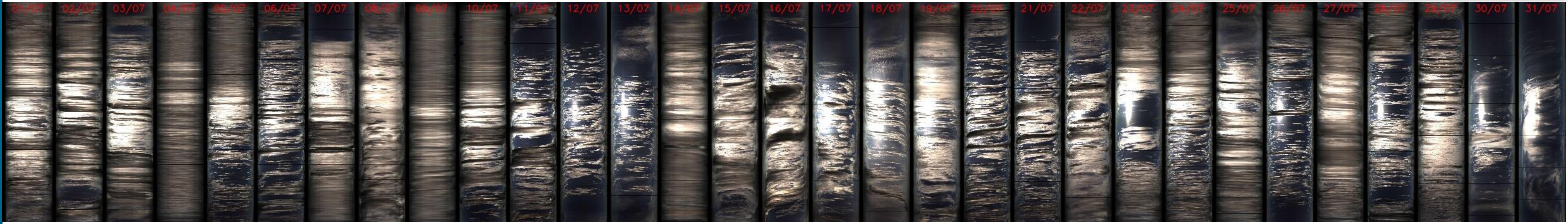
Blended forecasts
- Satellite+Persistence
- Satellite+ASI+Persistence

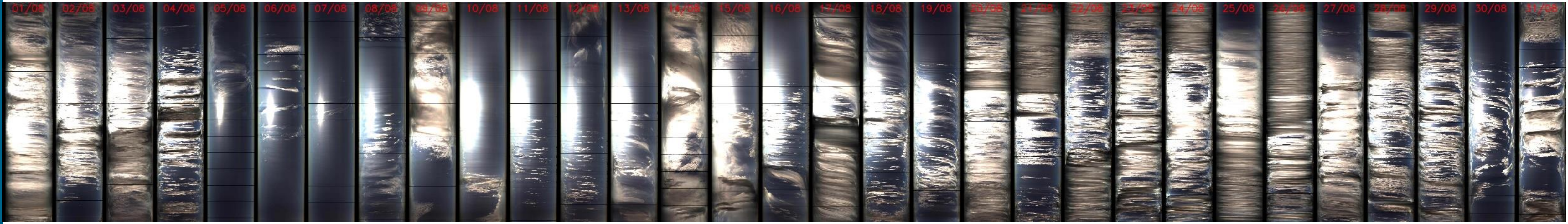
Used datasets

- Site: Oldenburg (Germany)
  - OLDON station of Eye2Sky Network [4]
  - 53°8´46.96´´N / 8°13´2.41´´E
- Used data
  - Training/Validation: July 2020 (50373 datapoints)
  - Testing: August 2020 (45163 datapoints)



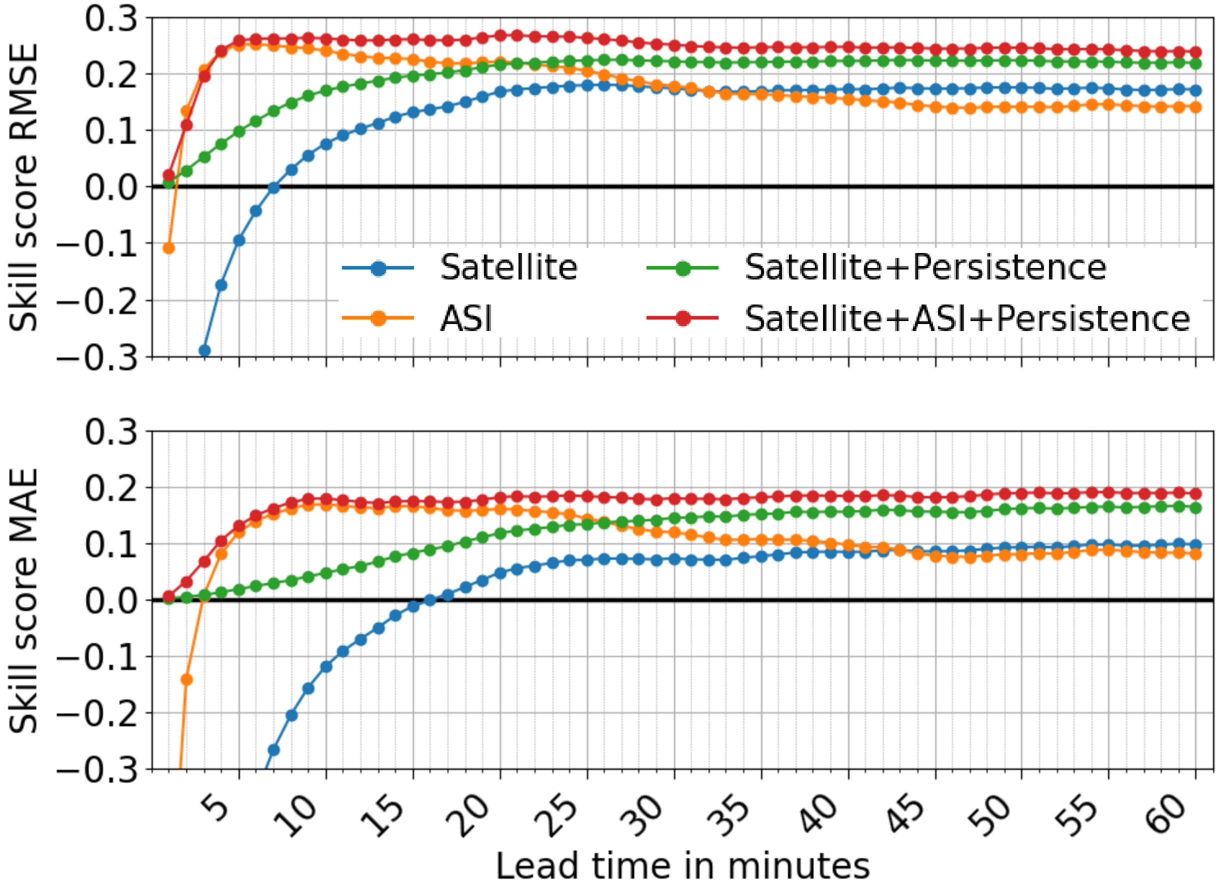
	July	August
$\overline{GHI}$	321.7 W/m²	358.1 W/m²
Max GHI	972.3 W/m²	840.0 W/m²
$\overline{DHI}$	192.1 W/m²	166.7 W/m²
Max DHI	505.4 W/m²	442.1 W/m²
$\overline{DNI}$	209.9 W/m²	323.5 W/m²
Max DNI	876.4 W/m²	847.7 W/m²





General benchmark forecasts

$$RMSE = \sqrt{1/n \sum_{i=1}^{n} (\hat{y}_i - y_i)^2} \qquad MAE = 1/n \sum_{i=1}^{n} |\hat{y}_i - y_i| \qquad Skill\ score = 1 - \frac{error_{model}}{error_{persistence}}$$



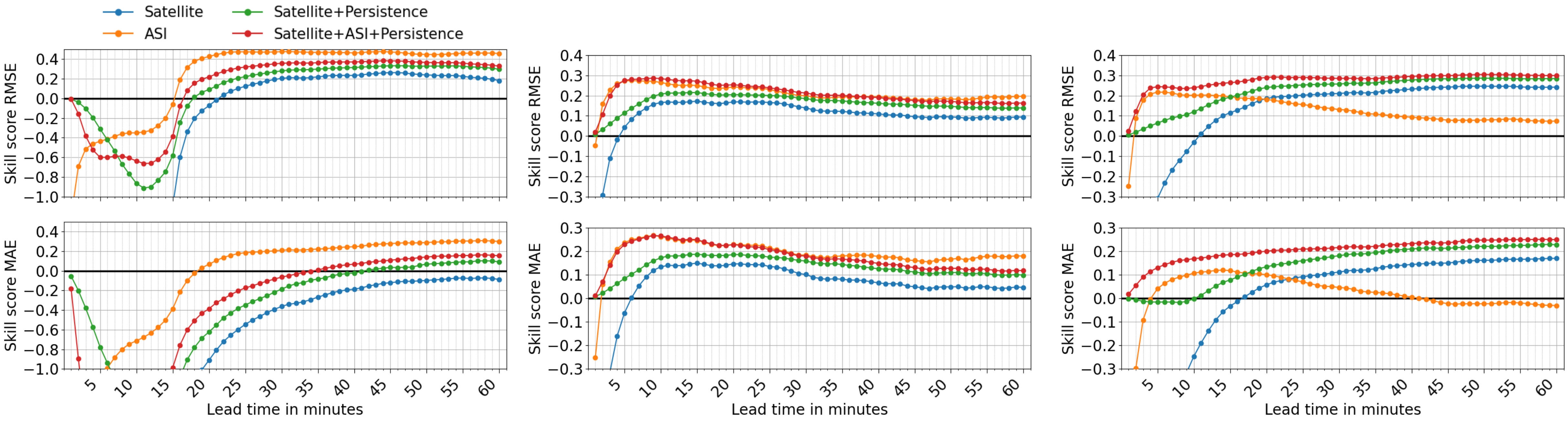
Satellite+ASI+Persistence

Error metric	LR	XGBoost	LSTM	Transfor-mer
RMSE [W/m²] ↓	121.8 ±16.9	120.8 ±17.2	119.7 ±17.4	120.4 ±17.2
MAE [W/m²] ↓	77.6 ±14.2	80.3 ±14.9	78.1 ±14.5	79.5 ±14.6
MBE [W/m²] ↓	-1.7 ±1.6	-5.5 ±1.5	-2.8 ±3.0	-1.8 ±5.1
Skill Score (RMSE) ↑	0.24 ±0.04	0.25 ±0.02	0.26 ±0.01	0.26 ±0.02
Skill Score (MAE) ↑	0.17 ±0.03	0.14 ±0.04	0.17 ±0.03	0.15 ±0.05

Averaged results over all lead times (± std)

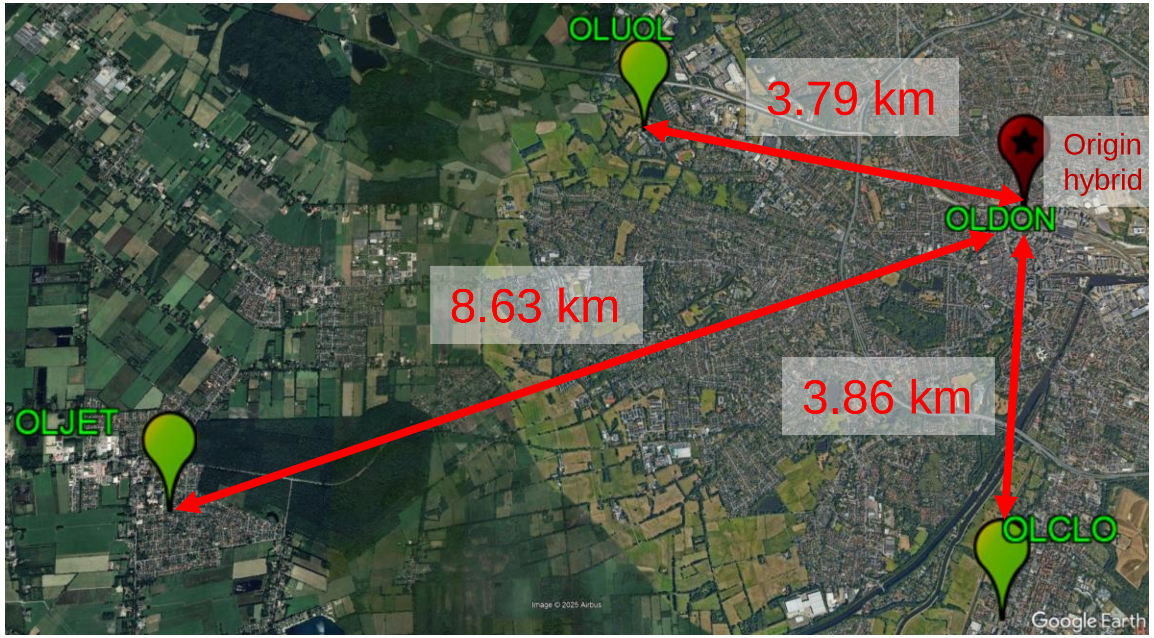
Influence of prevailing sky conditions

- Mostly/almost clear sky with high clear sky index
  - 27% of the dataset
  - Low variability
  - Average cloud coverage ≈ 11%
  - Average clear sky index ≈ 0.94
- Partly cloudy with intermediate clear sky index
  - 25% of the dataset
  - High/intermediate variability
  - average cloud coverage ≈ 53%
  - average clear sky index ≈ 0.57
- Almost/mostly overcast with low clear sky index
  - 48% of the dataset
  - Intermediate/low variability
  - average cloud coverage ≈ 85%
  - average clear sky index ≈ 0.08



Spatial influence

- Benchmark OLDON hybrid forecast against satellite forecasts at 3 additional sites
  - OLDON hybrid forecast remains unchanged.
  - Use site-specific satellite forecasts for comparison.
  - Sites are part of the Eye2Sky network with reference sensors.



$$Skill\ score = 1 - \frac{error_{Hybrid_{OLDON}@site(n)}}{error_{Satellite_{site(n)}}}$$

	Hybrid OLDON@OLCLO (Baseline: Satellite OLCLO)	Hybrid OLDON@OLUOL (Baseline: Satellite OLUOL)	Hybrid OLDON@OLJET (Baseline: Satellite OLJET)
Skill Score (RMSE) ↑	0.09±0.04	0.04±0.02	-0.01±0.06
Skill Score (MAE) ↑	0.14±0.03	0.07±0.02	0.05±0.03

Averaged results over all lead times (± std)

Conclusion

- Intra-Hour Boost: Ground measurements significantly enhance site-specific satellite forecasts in the intra-hour range.
- Hybrid Superiority: Satellite+ASI+Persistence model delivers lowest error metrics with top skill scores (RMSE: 0.24±0.04, MAE: 0.17±0.03).
- Cross-Climate Success: ASI, trained in desert climate, performs well in temperate regions.
- Short-Term Strength: ASI excels in short lead times and partly cloudy conditions, enhancing hybrid performance.
- Spatial Reach: Hybrid forecast shows a positive impact up to ~4 km away from the origin.
- Future Focus: Strong for overall irradiance, less for ramp events; generative ASI models to be explored.

References

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2. Fabel, Y., Nouri, B., Wilbert, S., Blum, N., Schnaus, D., Triebel, R., ... & Pitz-Paal, R. (2024). Combining Deep Learning and Physical Models: A Benchmark Study on All-Sky Imager-Based Solar Nowcasting Systems. Solar RRL, 8(4), 2300808.
3. Chu, Y., Li, M., Coimbra, C. F., Feng, D., & Wang, H. (2021). Intra-hour irradiance forecasting techniques for solar power integration: A review. Iscience, 24(10).
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THANK YOU FOR YOUR ATTENTION! QUESTIONS?

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