Solar irradiance and ramp events forecasting based on all-sky imagers

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This study was conducted under the framework of **IEA PVPS** Task 16

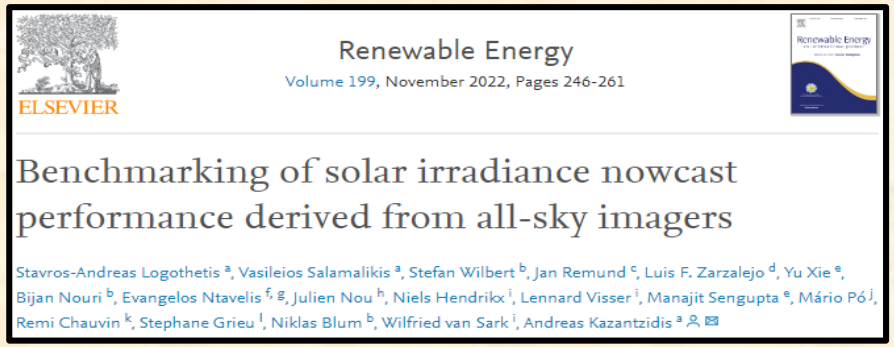
Aim

To evaluate the current and emerging solar forecasting techniques

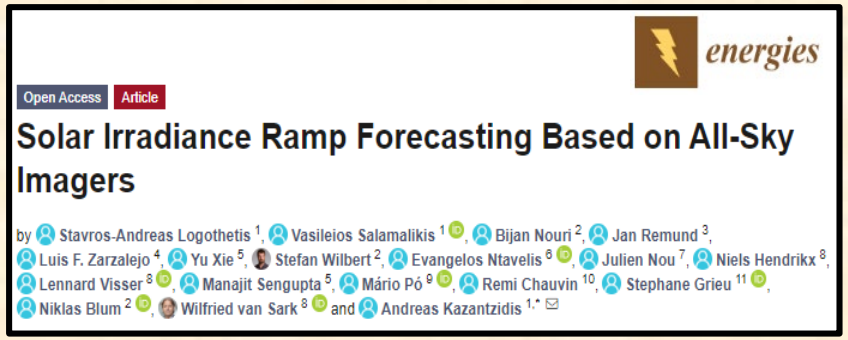
Our task

To qualify the current state-of-the-art of **all-sky imager** (ASI)-based solar nowcasting

Paper 1



Paper 2



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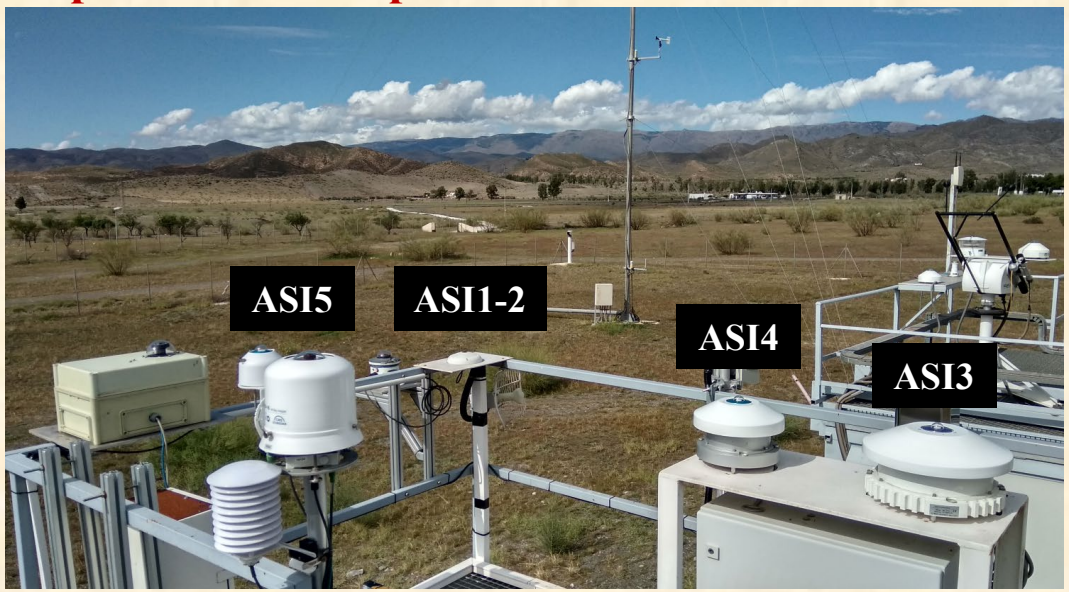
❑ Details of the campaign days and measurements

Experimental setup at METAS at CIEMATS's PSA



Information about the 5 ASI systems

Partners	Cameras Type	Number of Cameras	Image Acquisition time	Cloud detection method	Nowcast method
ASI1	Mobotix Q25 6MP	2	30s	Clear sky library (Wilbert et al., 2016)	Nouri et al. 2021
ASI2	Mobotix Q25 6MP	2	30s	Neural Network (Fabel et al., 2021)	Nouri et al. 2021
ASI3	Industrial	1	10s	N/A	Hybrid model (Knowledge/Neural Network)
ASI4	EKO 16	1	15s	Red/Blue Ratio (Ghonima et al., 2012)	LSTM (recurrent neural network) (Hendrikx et al., 2021)
ASI5	Prototype	1	10s	Deep learning (Pierer and Remund, 2019)	

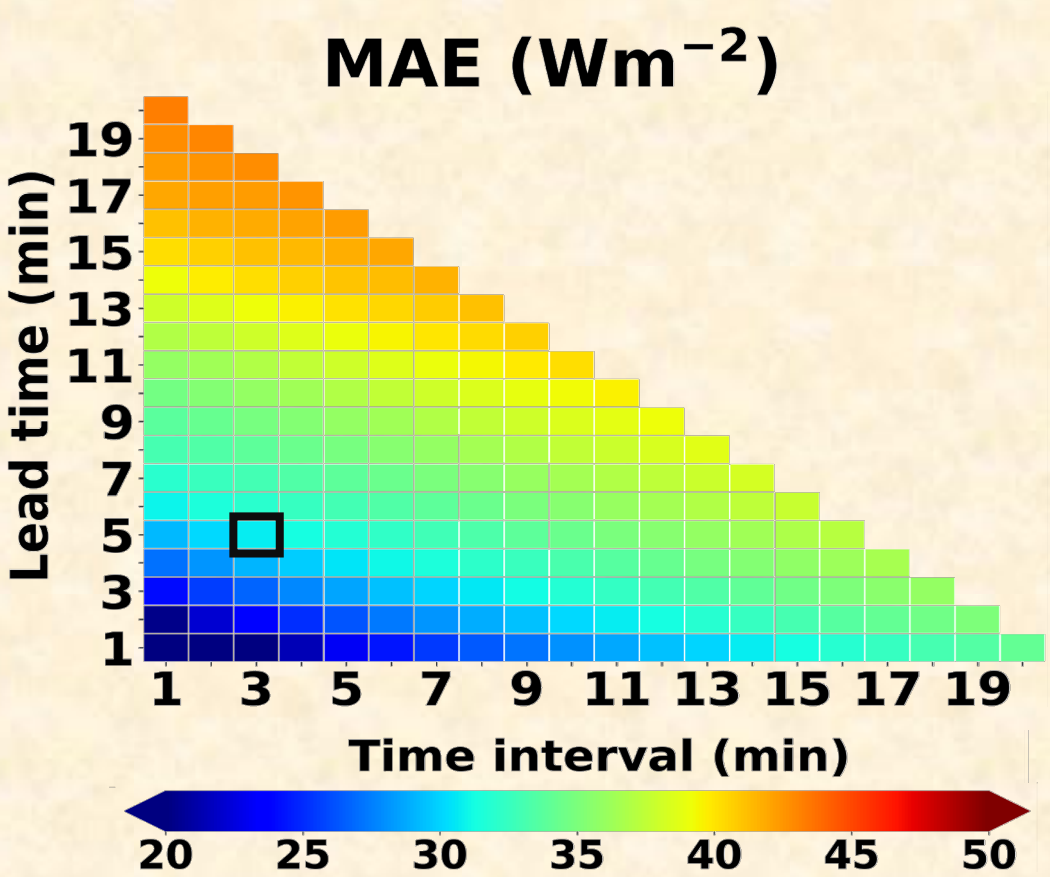
GHI nowcast systems

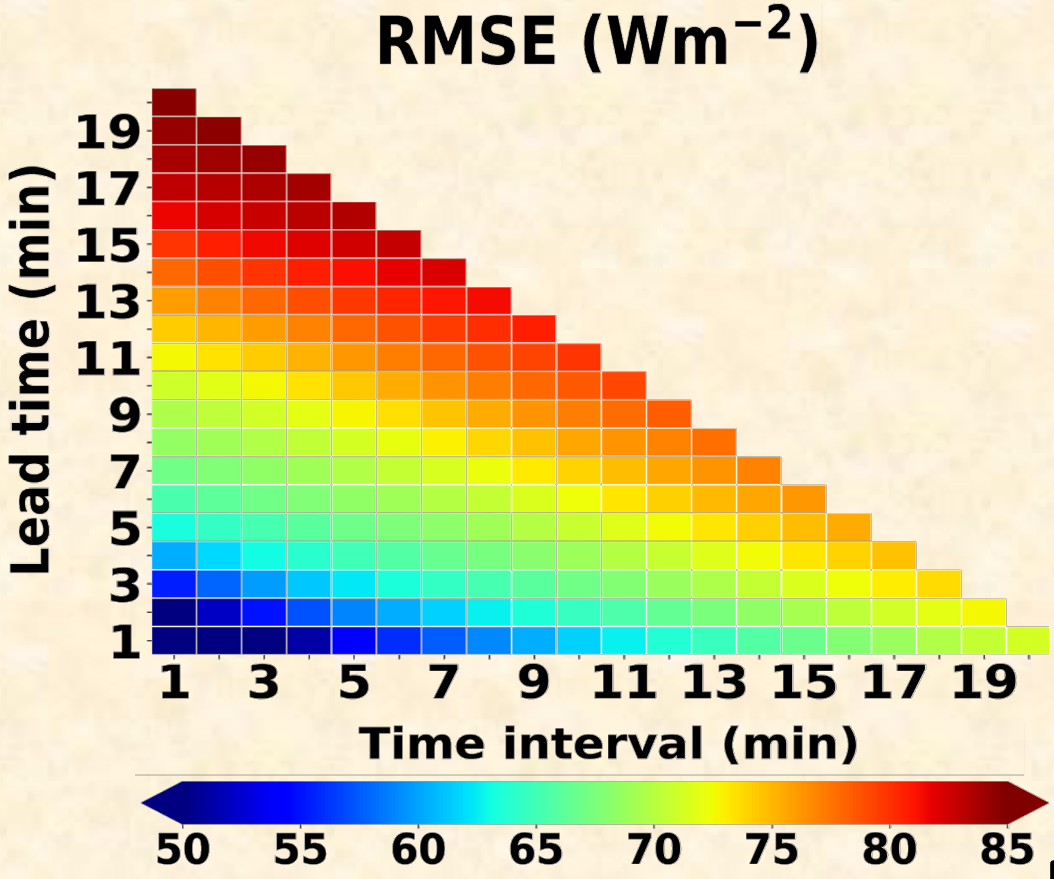
1) ASI: 4 camera setups, 5 nowcasting methods (ASI1−5).
2) Two persistence algorithms: PSPI and smart persistence

❖ Time horizon = Nowcasts up to 20 min with 1 min step

❖ Time period = from August to November 2019.

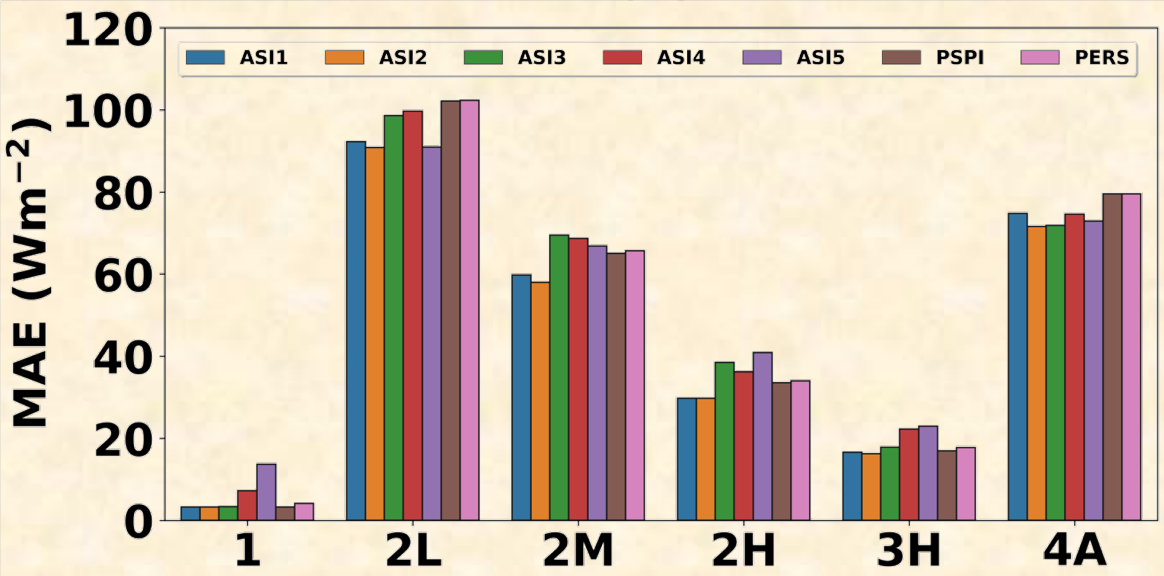
ASI2 system nowcast performance at various time intervals





The **vertical axis** shows **starting forecast minute (lead time).**
The **horizontal axis** shows the **number of minutes included (time interval).**

Nowcast performance at different cloud conditions



Summary of the algorithms with the **best performance** for each cloud cluster.

	Cloud Cluster					
	1	2L	2M	2H	3H	4A
Metric						
MAE	PSPI	ASI2	ASI2	ASI1	ASI2	ASI2
RMSE	ASI2	ASI5	ASI2	ASI2	ASI2	ASI3

Cloud clustering of campaign days

All campaign days were flagged in the following **6 cloud** classes:

1: Cloud-free (or almost cloud-free)

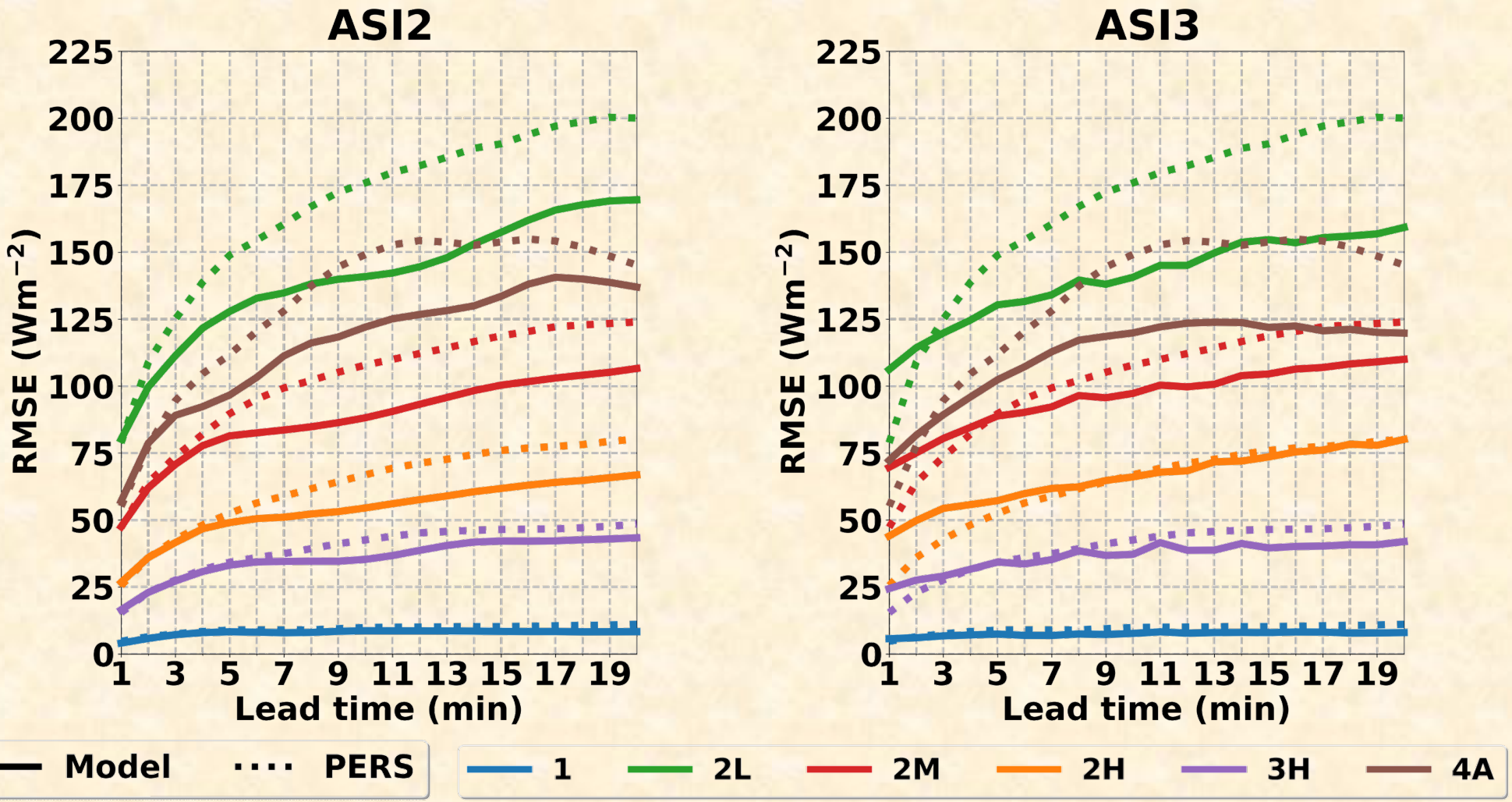
Scattered/broken cloudiness with:

2L: Low clouds | **2M:** Multiple clouds | **2H:** High/Middle clouds

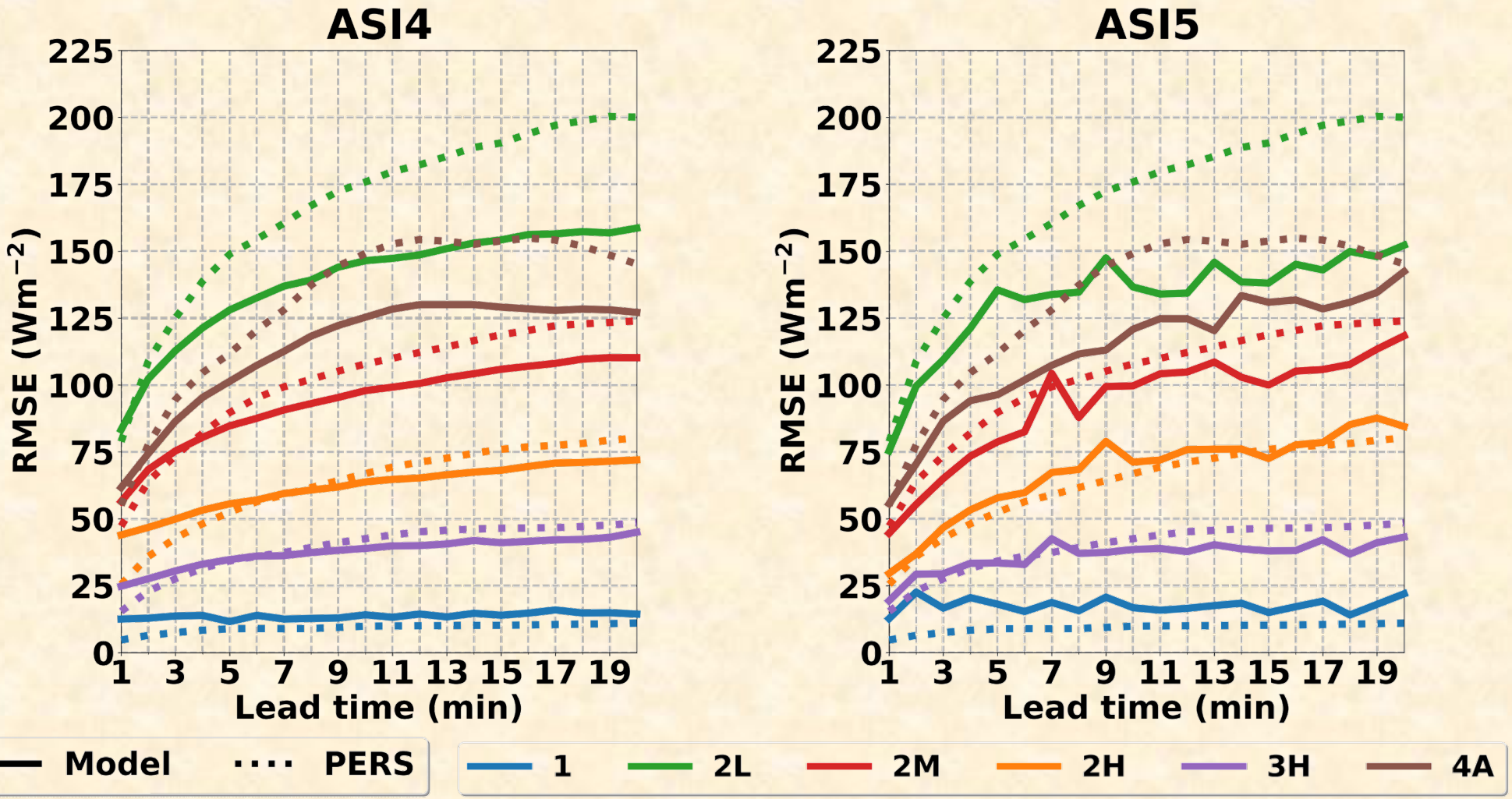
3H: Scattered/broken cloudiness with High/Middle clouds during half of the day, cloud-free during the other half.

4A: Overcast cloud conditions during half of the day, scattered/broken cloudiness during the other half

Nowcast performance at different cloud conditions and lead times against persistence



Nowcast performance at different cloud conditions and lead times against persistence



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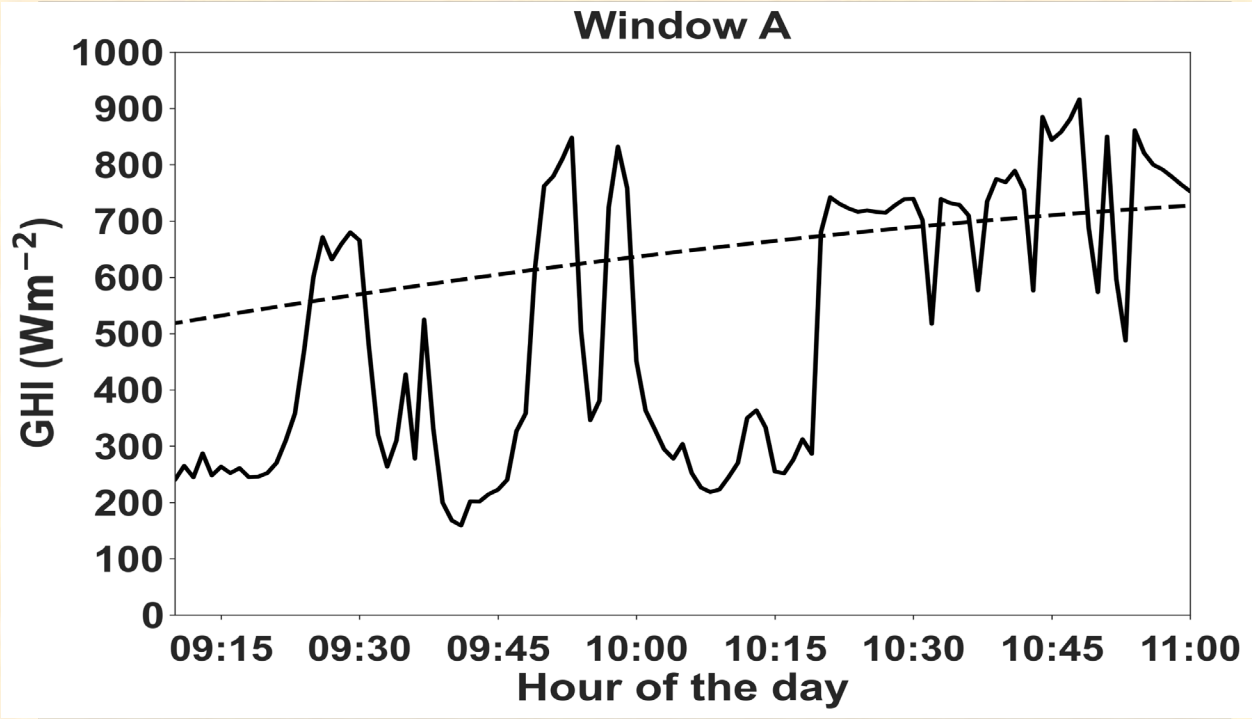
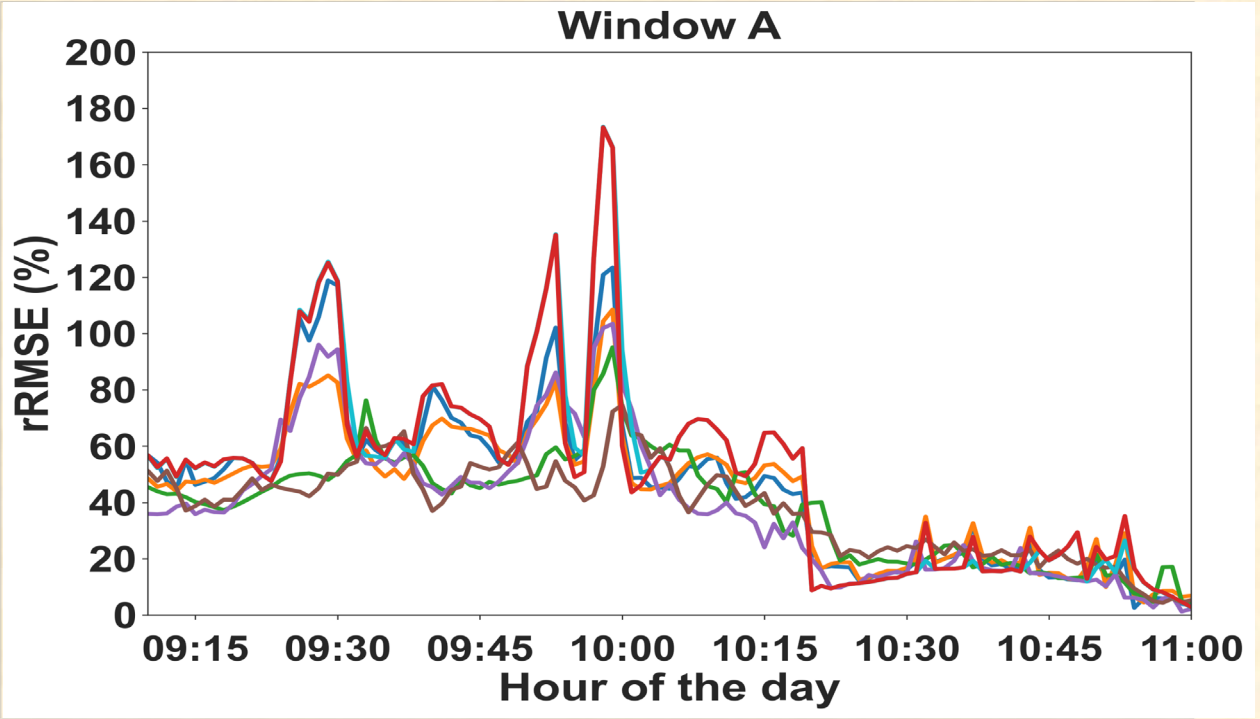
❑ Nowcast performance at different cloud conditions and lead times against persistence





Observations Clear sky ASI1 ASI2 ASI3 ASI4 ASI5 PSPI PERS

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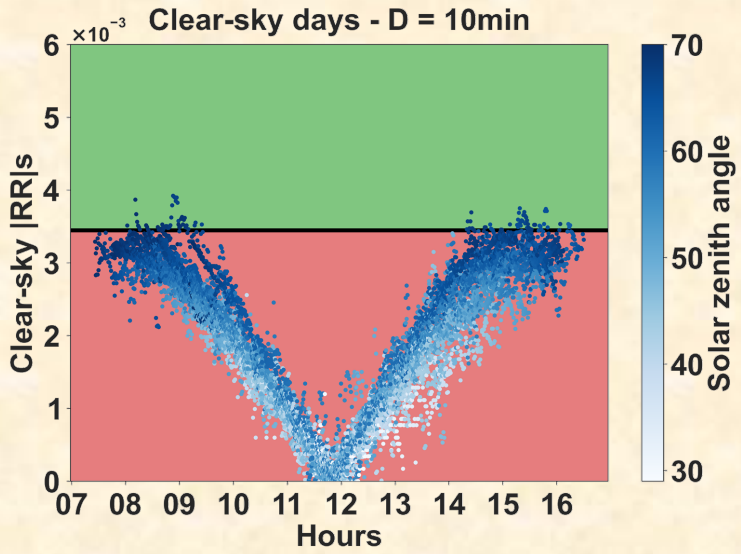
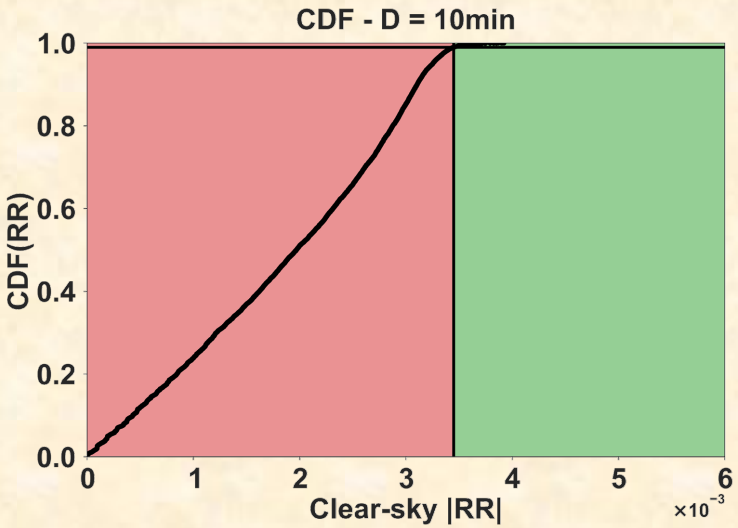
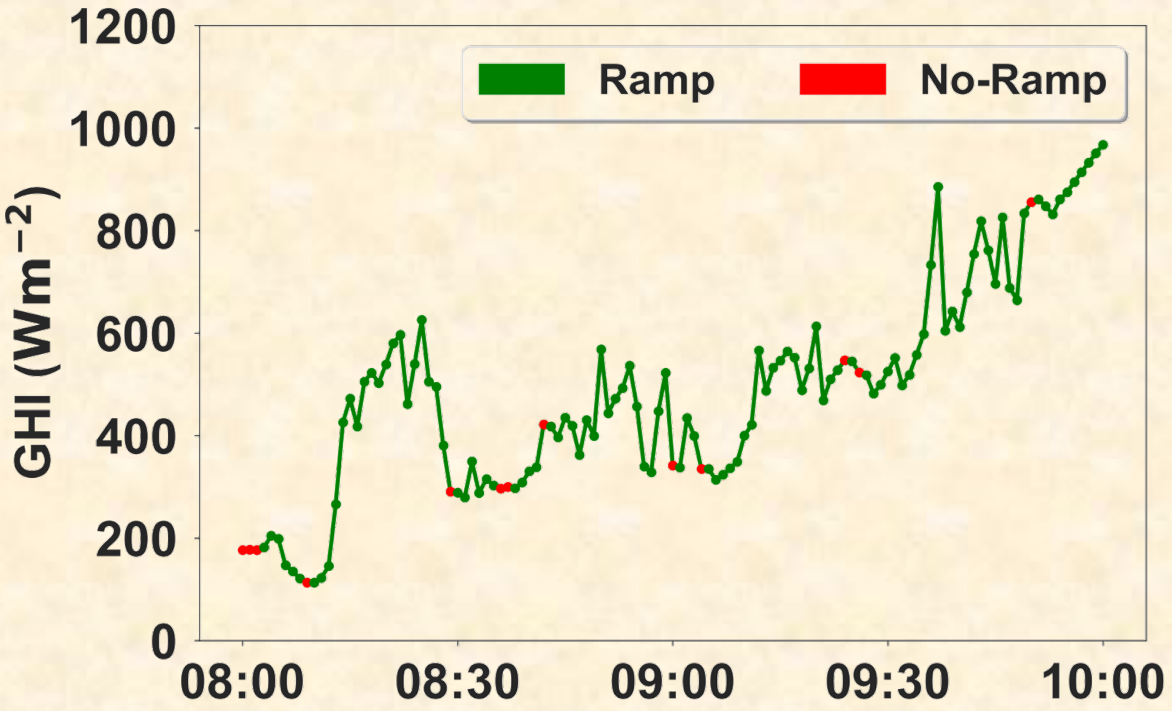
❑ Flowchart of the applied methodology

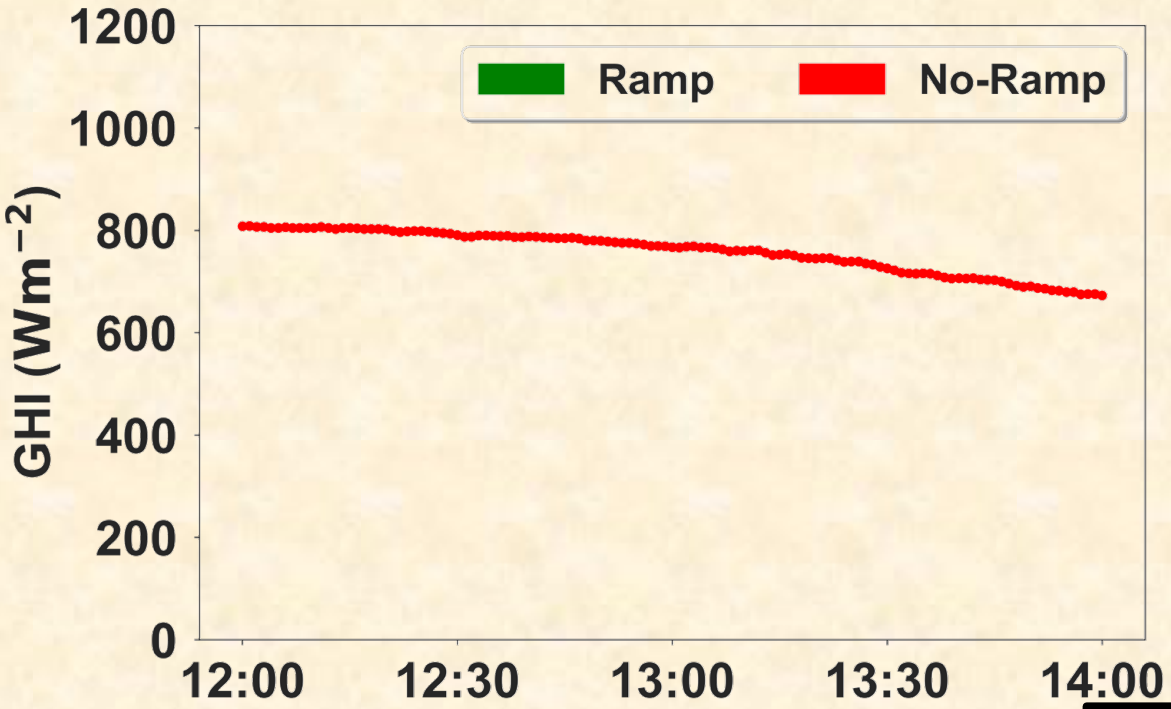
1. Solar Ramp Events
2. Ramp Rate Calculations (RR)
   - Source X (reference measurement or ASI system forecast)
   - $$RR(t, D) = \frac{d(nGHI_X)}{dt} = \frac{nGHI_X(t + D) - nGHI_X(t)}{D}$$
3. Selection of Time Horizon (D)
   - D = 1, 2, 3,⋯, 20 min
4. Determination of threshold limit (Thr)
   - Thr = 0.99 quantile
   - Using clear-sky |RR|s based on measurements
5. |RR| ≥ Thr → Ramp
   |RR| < Thr → No-Ramp





Verification of the applied methodology at a specific time horizon





❑ Possible cases

Predicted Ramp Events \ Observed Ramp Events	Ramp	No-Ramp
Ramp	True Ramp (TR)	False Ramp (FR)
No-Ramp	False No-Ramp (FNR)	True No-Ramp (TNR)

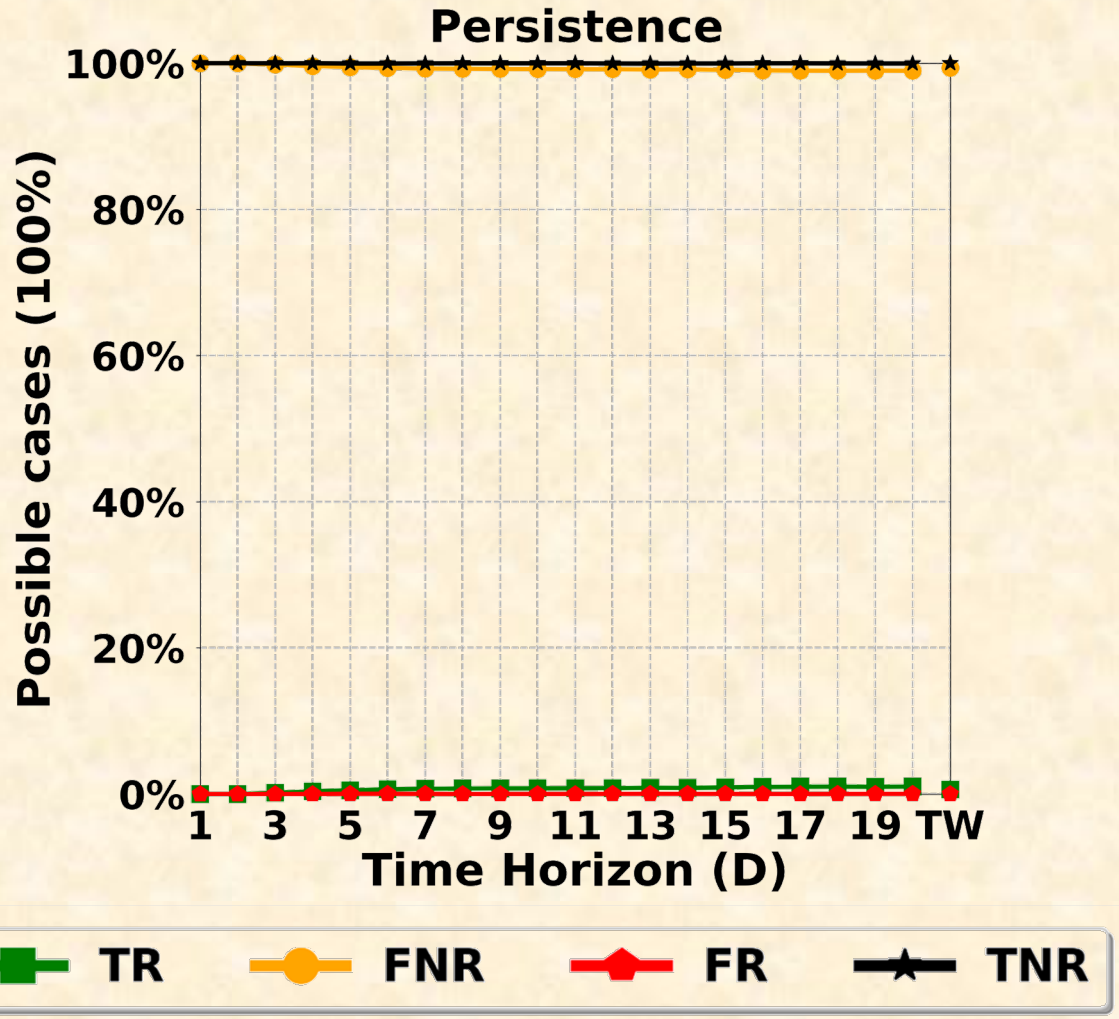
❑ Temporal analysis of ramp event detection

1) At each specific time horizon (from 1 to 20 min)
2) Over the whole 20-min time horizon (Time window, TW, analysis)

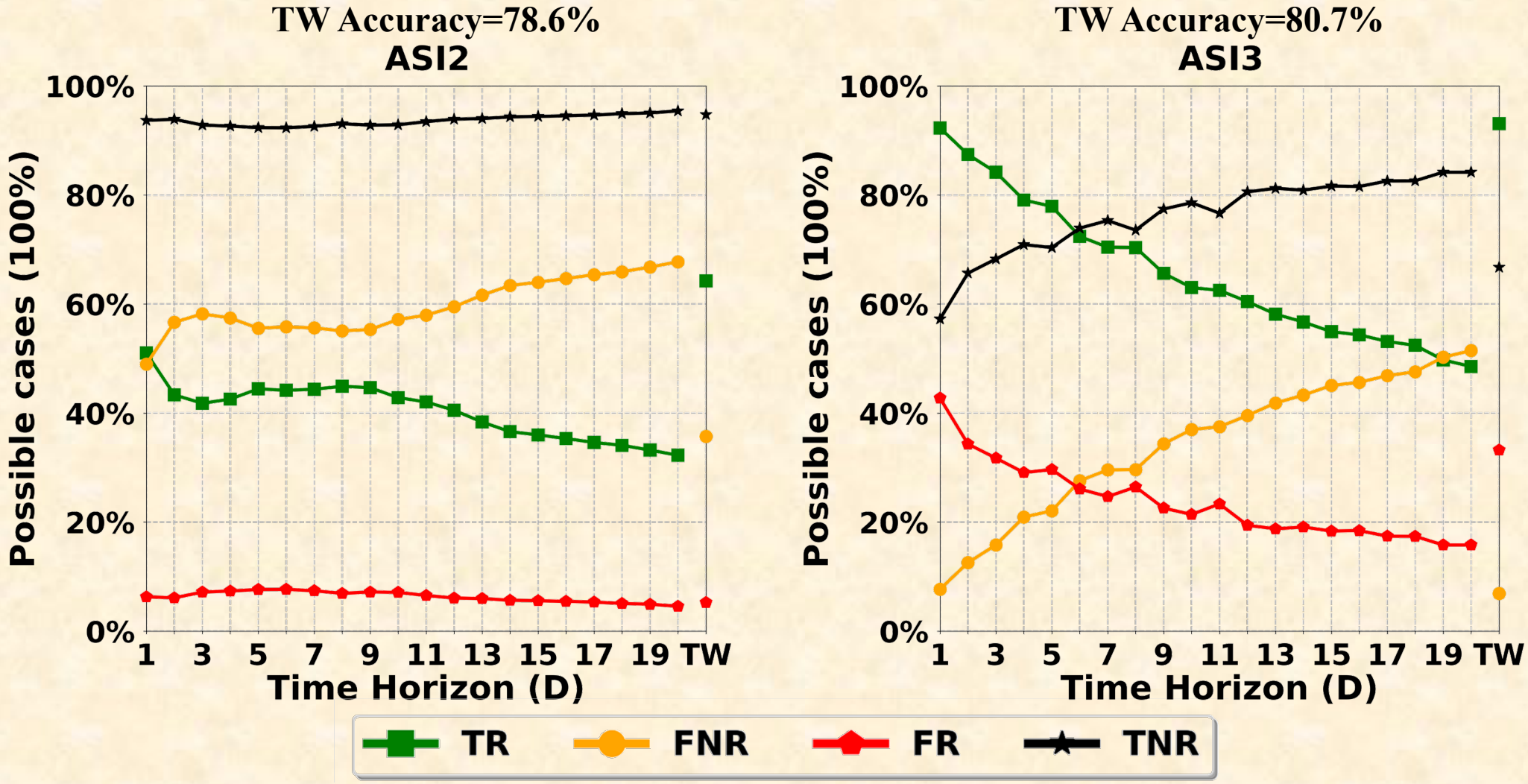
❑ Metric

$$\text{Total Accuracy} = \frac{\text{True cases}}{\text{Total cases}} = \frac{\text{TR} + \text{TNR}}{\text{TR} + \text{FR} + \text{FNR} + \text{TNR}}$$

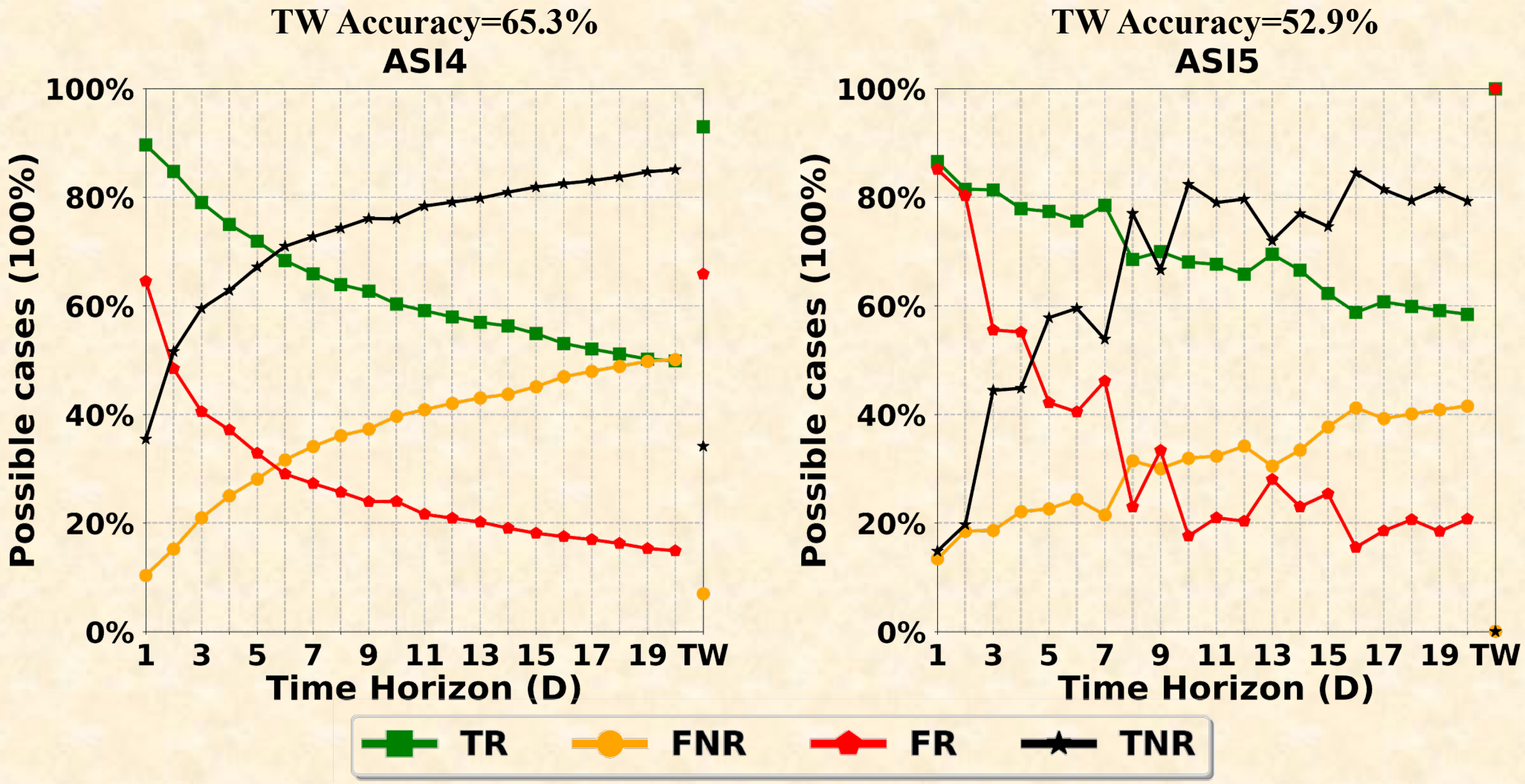
ASIs performance at each time horizon D and for the TW



ASIs performance at each time horizon D and for the TW



ASIs performance at each time horizon D and for the TW



Within the whole validation period

- ASIs 1-2 reported the lowest deviations among the ASIs.
- In general, ASIs deviations follow an increasing trend as the time horizon increases, with ASI 1 and 2 revealing the highest forecast accuracy either at low (<5 min) or at distant (>15 min) lead times.

Under specific cloud conditions

- ASI1 and 2 outperform the persistence models at all cloud clusters and lead times.
- For time horizons longer than 5 min, the other 3 ASIs (3-5) are also efficient to outperform the persistence model under cloudy skies.

Under cloud-free conditions

- Three ASIs (1-3) proved to be capable of providing better results than persistence.

Overall conclusion

- Specific ASIs **outperform** the persistence models even under clear, scattered, and overcast skies.

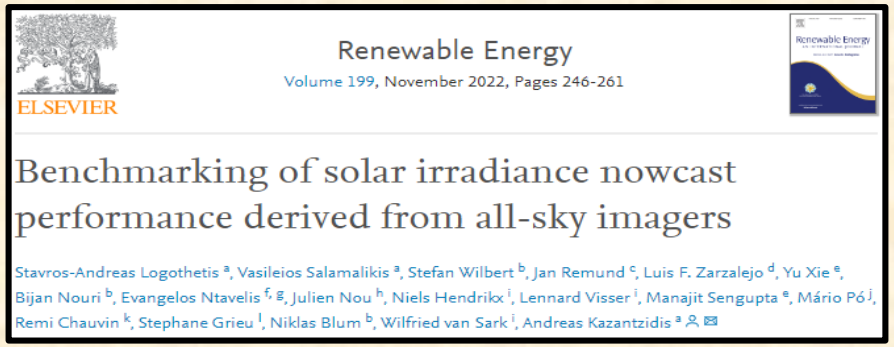
The performance of the detected ramp event is connected to the applied forecast algorithms.

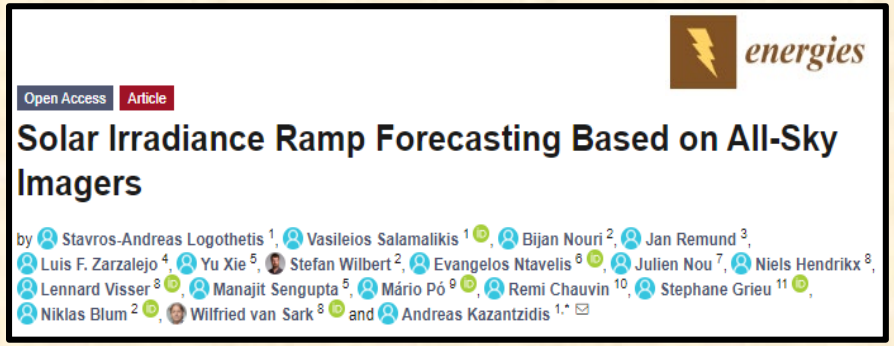
- The **true** predicted ramp event cases for all ASIs **decrease** as the time horizon increases.
- The ASI1 and ASI2, tend to **wrongly** record **no-ramp events** more often than ASI 3-5 systems.
- The ASI 3-5 show the tendency to **wrongly** predict **ramp events** which happens less often for ASI1 and ASI2.
- They can predict ramp events accurately from 30% to 95% of the cases.

Overall conclusion

- The selection of the most suitable ASI system for solar irradiance ramp event nowcasting **depends** on the **application**.

Thank you for your attention!!!





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