Integration of Total-Sky Imager Data with a Physics-Based Smart Persistence Model for Intra-Hour Forecasting of Solar Radiation

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Why are we here?

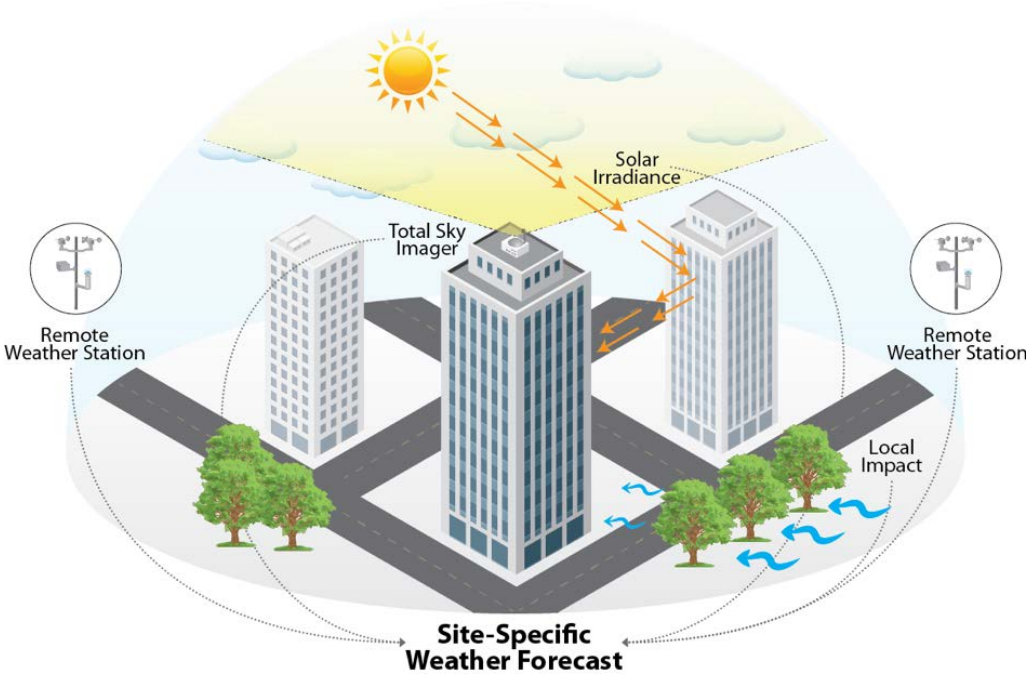
- Motivation:
  - Create a platform to provide site-specific weather forecasts for building energy management and control.
- Purpose:
  - Develop a short-term solar forecasting technique that can utilize total sky imager (TSI) data.
- Goals:
  - Provide intra-hour solar forecasts to improve energy forecasts for building energy management and control.

Motivation

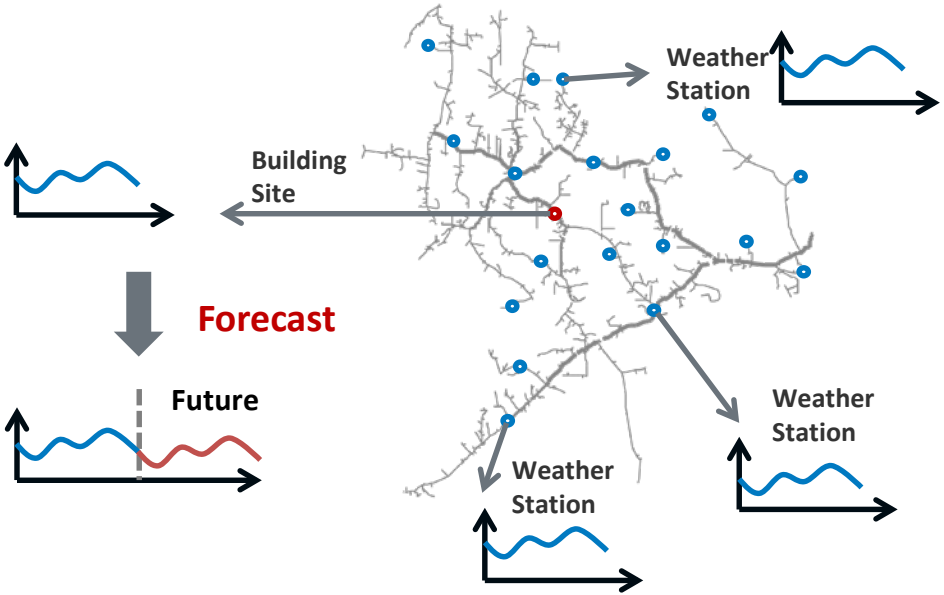
Create a platform to provide site-specific weather forecasts for building energy management and control.

Motivation/Background

- Part of bigger project to provide site-specific weather forecasts for buildings:
  - Weather stations, TSIs
  - Machine learning
  - Numerical weather prediction.
- Improved forecasts can be used for building controls, thus improving energy efficiency.

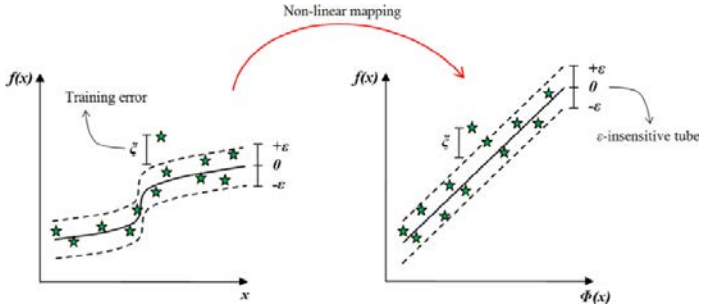


Site-Specific Weather Inference

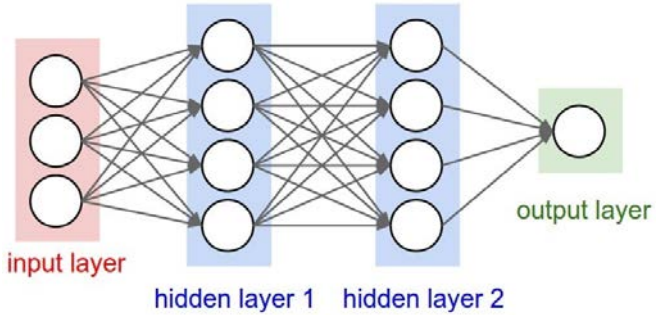


Learn the spatiotemporal correlation between weather conditions at nearby weather stations and the building site.

Support vector regression



Artificial neural networks



Purpose

Develop a short-term solar forecasting technique that can utilize total sky imager (TSI) data.

Problems to Solve

- For solar forecasting, clouds are the most difficult problem.
  - Type of cloud, duration of cover, etc.
- Observing clouds on short timescales usually requires a sky imager.
  - Problem: Access to the imager and cost.
- Computation time:
  - Is computation time > forecast horizon?

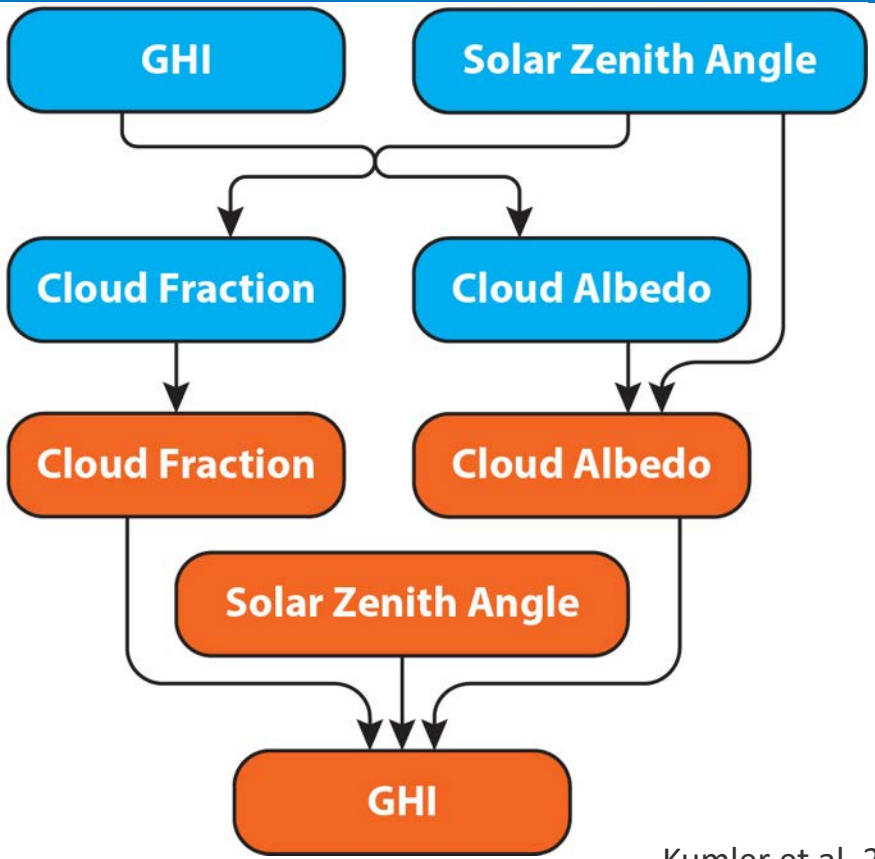
Solar Forecasting

- NREL developed a short-term (up to 60-min) physical smart-persistence solar forecasting model (Physics-Based Smart Persistence Model for Intra-Hour Solar Forecasting [PSPI]), Kumler et al. 2019):
  - Physical: Radiative transfer physics utilized (Xie and Liu 2013)
  - More intricate than the smart-persistence method, which provides no cloud information (e.g., GHI_{obs} / GHI_{CS})
  - Little input required:
    - Minimum of global horizontal irradiance (GHI) measurement, general site information.
  - Fast:
    - Can compute forecast almost instantaneously.
  - Highly customizable:
    - Adjust atmospheric variables depending on observations/data available.

Persistence vs. Smart Persistence vs. PSPI

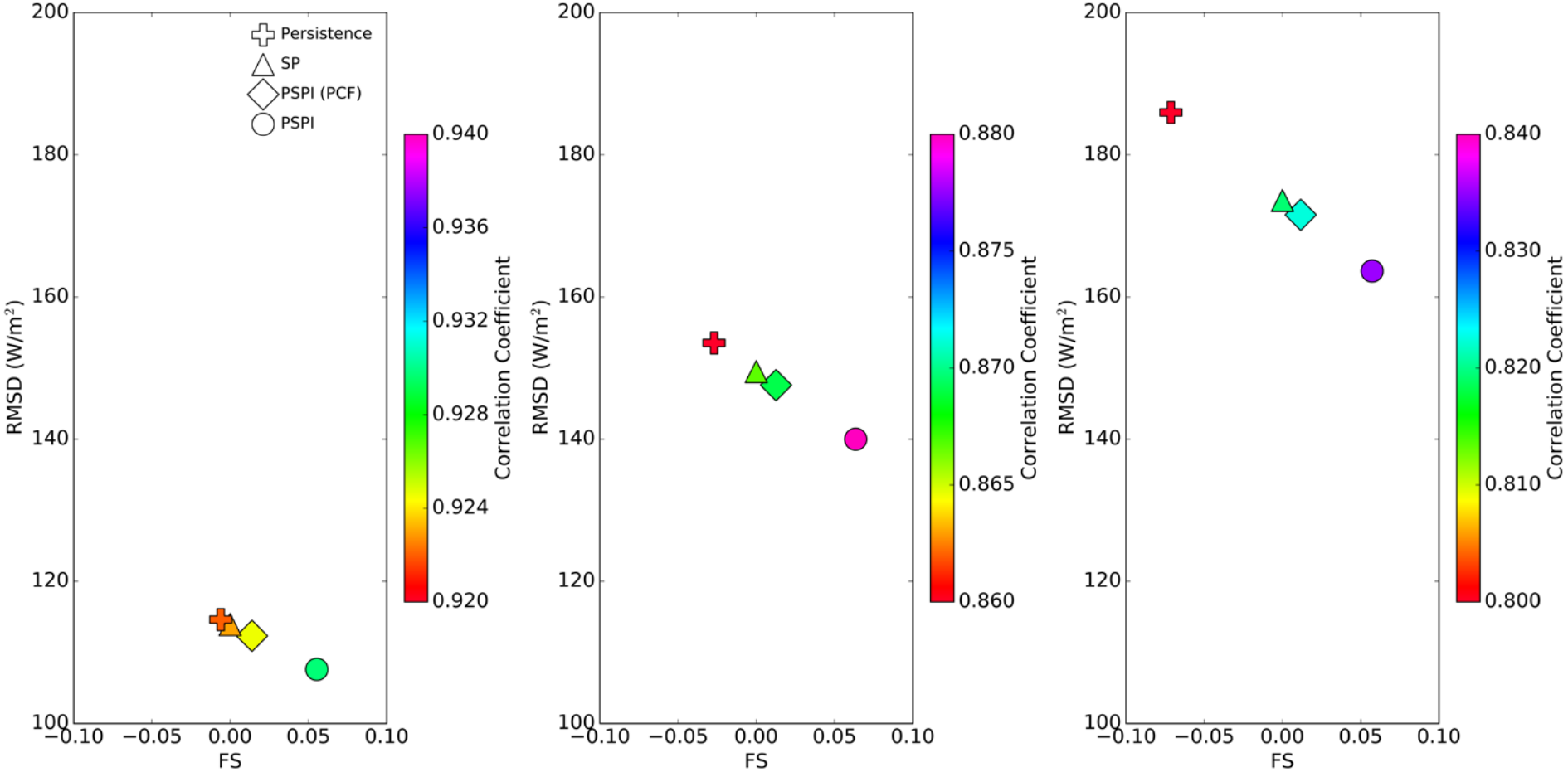
- Persistence is the simplest of solar forecasting techniques.
  - Projects the current GHI value to next time step (forecast horizon).
- Smart persistence takes the ratio of the current GHI against the theoretical maximum GHI (clear-sky).
  - This ratio is multiplied against a future clear-sky GHI value:
  - $GHI_{t+n} = \frac{GHI_t}{GHI_t^{CS}} \; x \; GHI_{t+n}^{CS}$
- PSPI improves upon smart persistence by breaking down the GHI into various physical components, such as cloud fraction.
  - This allows forecasting of separate variables that contribute to GHI.
  - A better cloud fraction forecast improves the GHI forecast.

Flowchart for PSPI



For physics breakdown, see Xie and Liu (2013).

Kumler et al. 2019


Persistence
SP
PSPI (PCF)
PSPI
RMSD (W/m^2)
FS
Correlation Coefficient
200
180
160
140
120
100
−0.10
−0.05
0.00
0.05
0.10
0.940
0.936
0.932
0.928
0.924
0.920
0.880
0.875
0.870
0.865
0.860
0.840
0.830
0.820
0.810
0.800

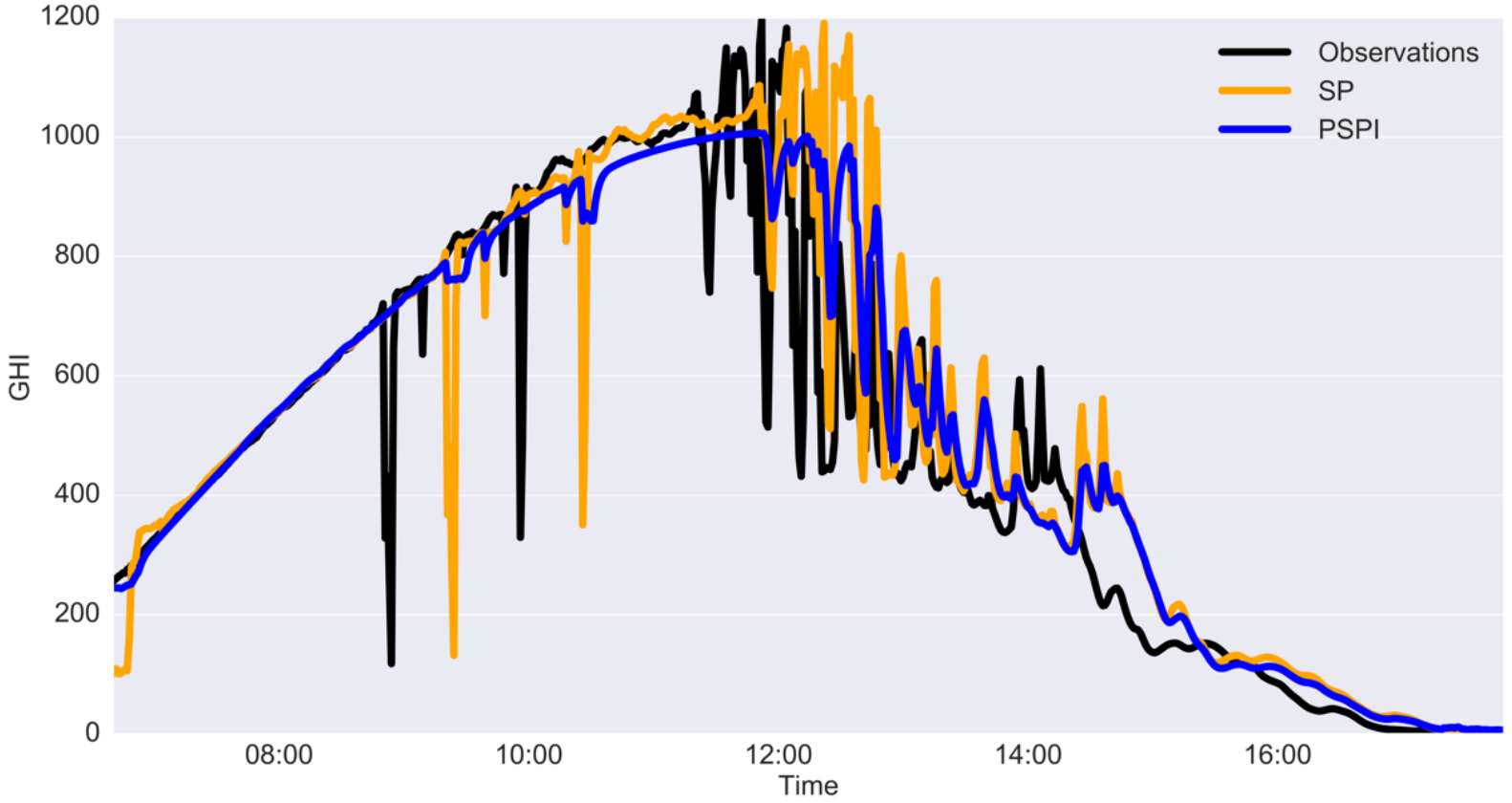
Goals

Provide intra-hour solar forecasts to improve energy forecasts for building energy management and control.

PSPI+TSI

- Replace cloud fraction approximation with actual TSI observations:
  - Removes source of uncertainty in algorithm.
- Access to more observations allows for more creative ways to forecast data:
  - Time-series forecasting
  - Machine learning, deep learning.

Example Results

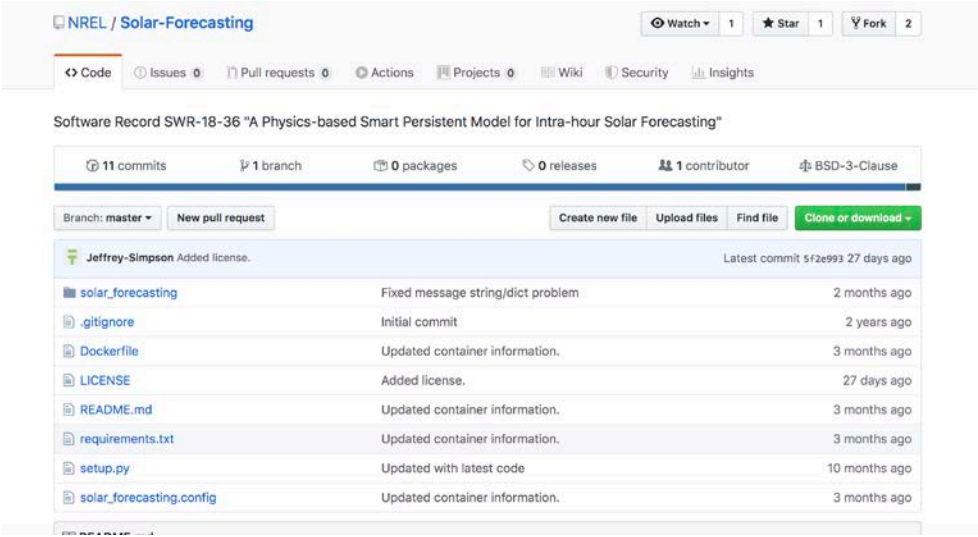


Advanced Forecasting Methods

- Plethora of meteorological data available at the National Renewable Energy Laboratory.
  - Time series forecasting (e.g., AutoRegressive Integrated Moving Average [ARIMA])
  - Machine learning/deep learning (e.g., neural networks).
- Difficult to beat persistence methods on short timescales
- Some advanced methods are more suitable than others.
  - Increased computation time for more sophisticated artificial intelligence methods
  - Changes application of forecasting software.

Code on GitHub

- Version 1 of the code is available today.
- It does not contain TSI data integration, but it will in future versions.
- The Code is easily adaptable for your intra-hour solar forecasting needs.



Xie, Yu, Andrew Kumler, and Yingchen Zhang. 2019. "A Physics-Based Smart Persistent Model for Intra-Hour Solar Forecasting." Computer software. https://www.osti.gov//servlets/purl/1580036. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Solar Energy Technologies Office (EE-4S). December 18, 2019. doi:10.11578/dc.20191220.2.

Q&A!

www.nrel.gov

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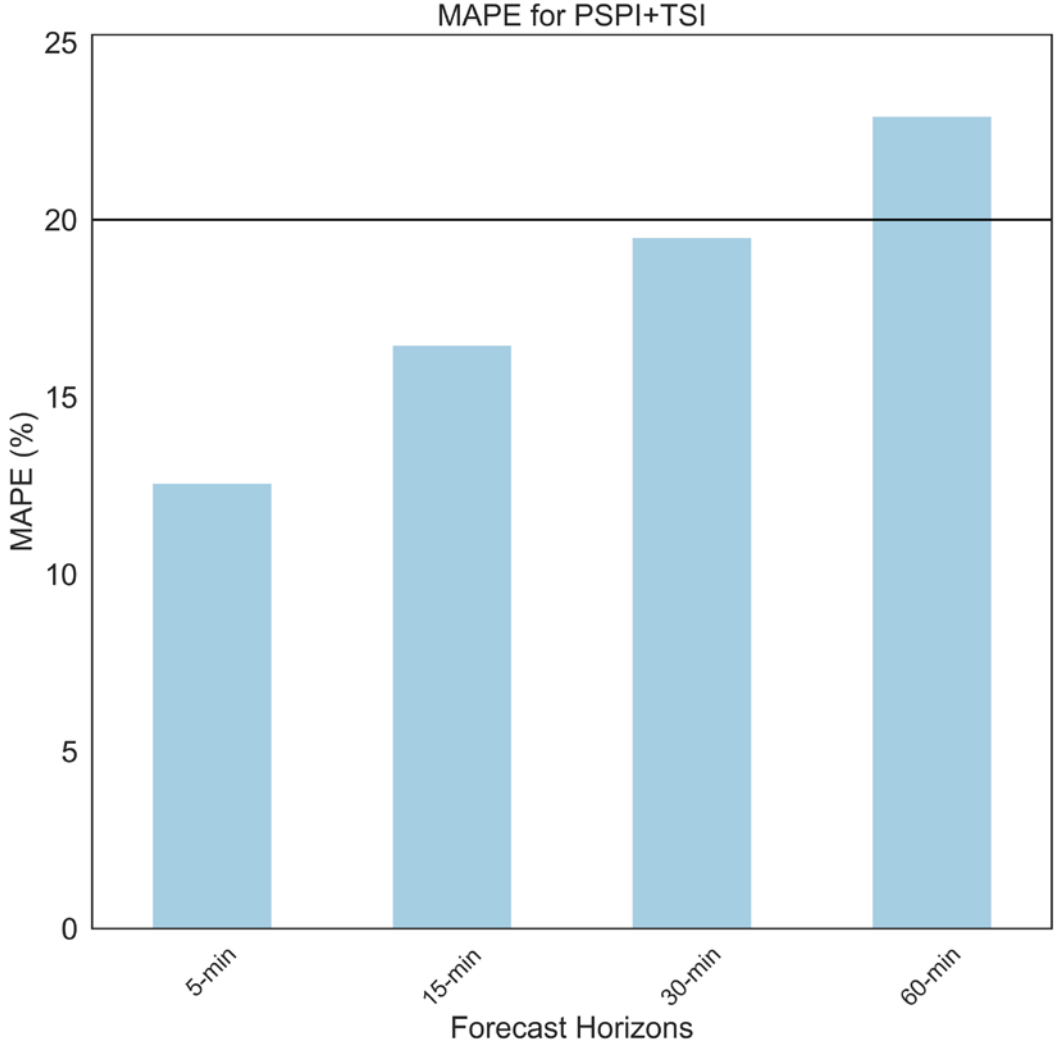
Extra Slides

Example Results

Model (5-min)	R	MBE	MAE	RMSE	FS
PSPI + TSI	0.93	-3.95	57.15	110.90	0.07
Smart Persist.	0.92	0.92	49.79	118.63	0
Model (15-min)	**R**	**MBE**	**MAE**	**RMSE**	**FS**
PSPI + TSI	0.88	-2.25	75.52	140.92	0.10
Smart Persist.	0.86	2.84	75.43	156.19	0
Model (30-min)	**R**	**MBE**	**MAE**	**RMSE**	**FS**
PSPI + TSI	0.84	0.45	90.98	163.69	0.10
Smart Persist.	0.81	5.79	94.63	181.06	0
Model (60-min)	**R**	**MBE**	**MAE**	**RMSE**	**FS**
PSPI + TSI	0.78	6.6	109.9	189.33	0.09
Smart Persist.	0.75	12.02	116.58	207.29	0


MAPE for PSPI+TSI
25
20
15
10
5
0
MAPE (%)
5-min
15-min
30-min
60-min
Forecast Horizons