U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE

2021 Solar Forecasting Workshop

HAIMOS Ensemble Forecasts for Intra-day and Day-Ahead GHI, DNI and Ramps

Project Team

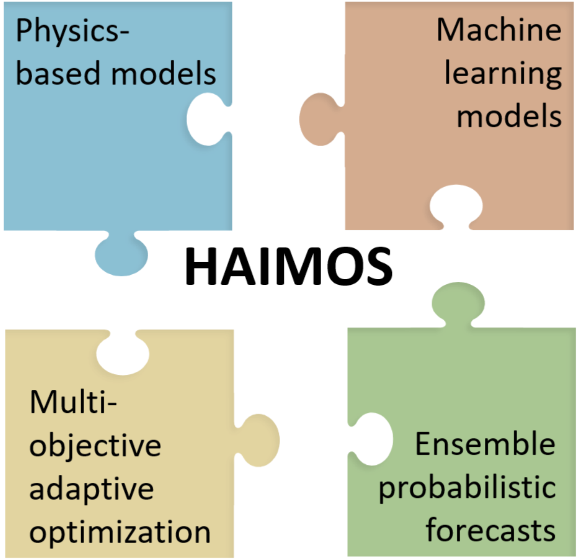
UC San Diego (prime)

Clean Power Research (sub)

Prof. Carlos Coimbra (PI), Dr. Hugo Pedro (Co-PI)

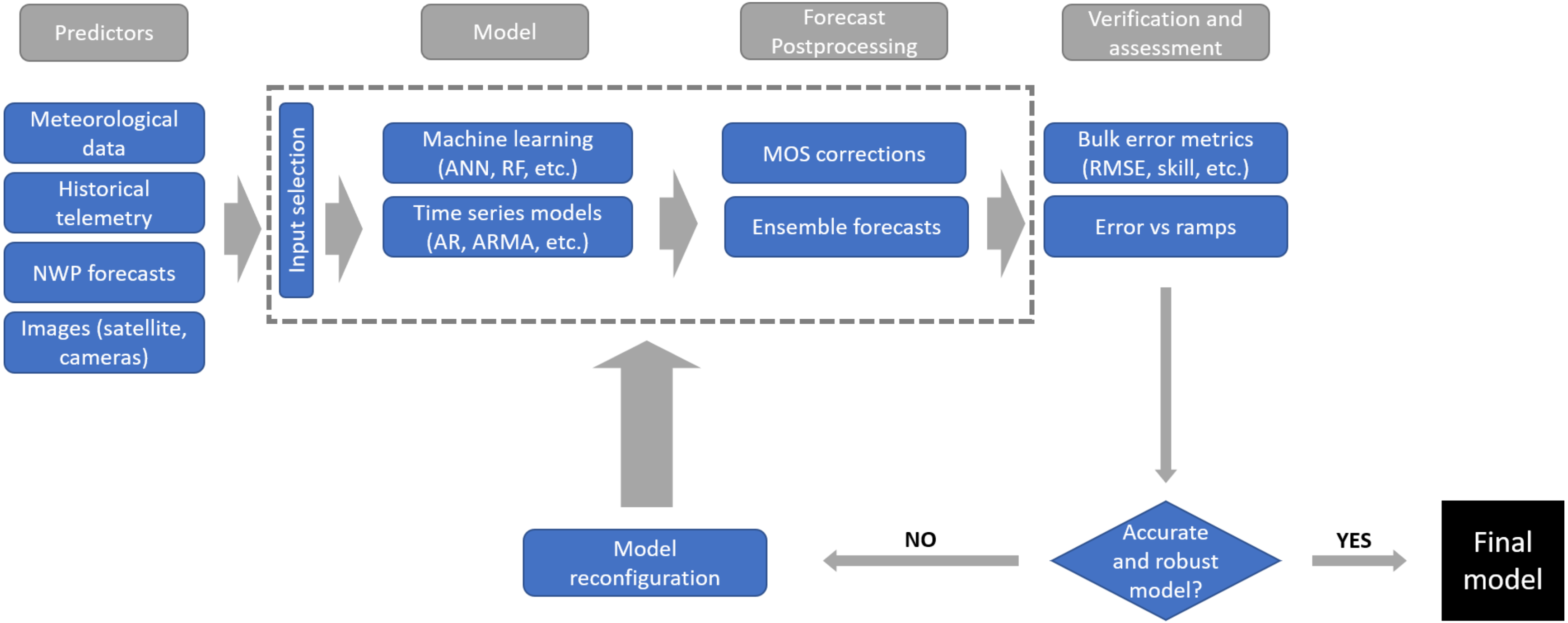
Mechanical and Aerospace Engineering, UC San Diego

Technical Approach

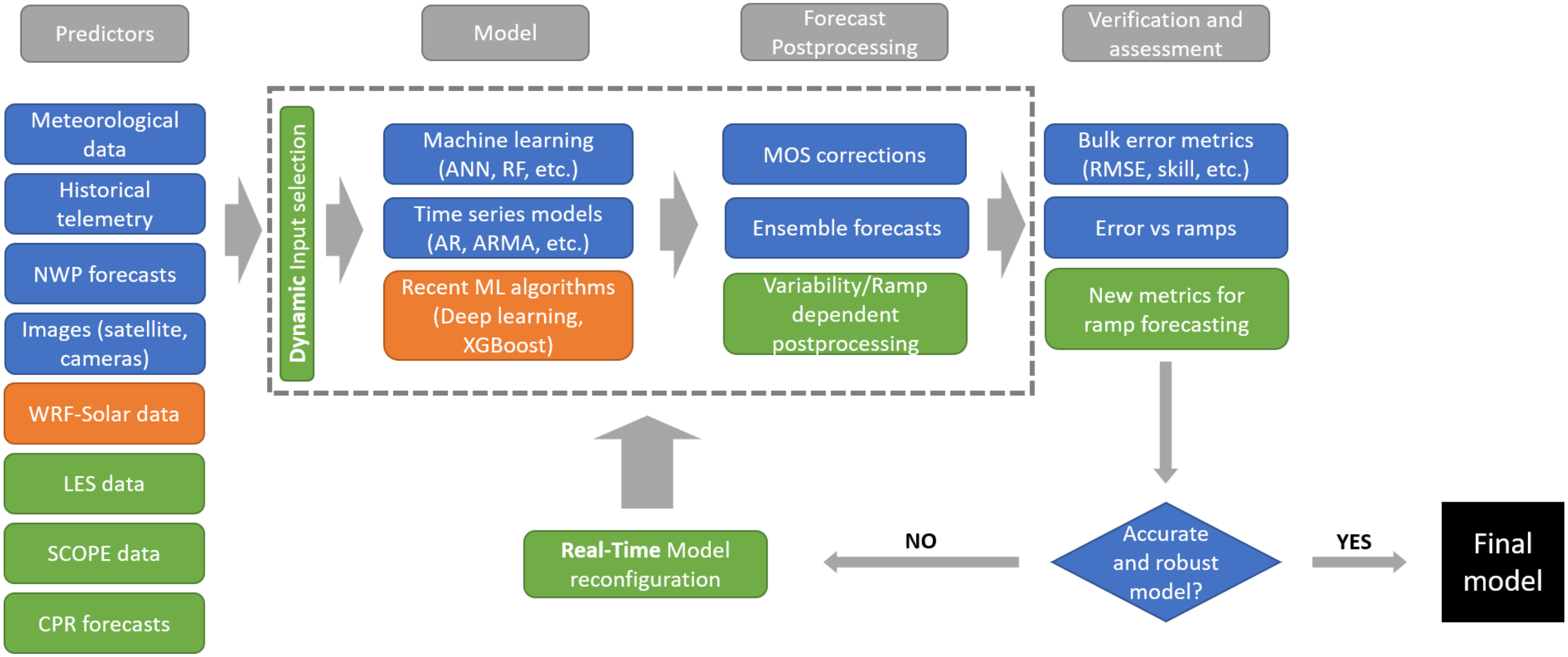


- Combines best practices in **machine learning** algorithms (deep-learning, feature engineering, etc.) with detailed **physics-based models** for cloud cover and cloud optical depth forecasts.
- Integrates information derived from the **new GOES satellites sensors and cloud cover simulations from LES**.
- Spatial and temporal sensing/modeling of clouds at much higher resolutions than previously available.

Traditional Approach



HAIMOS Approach



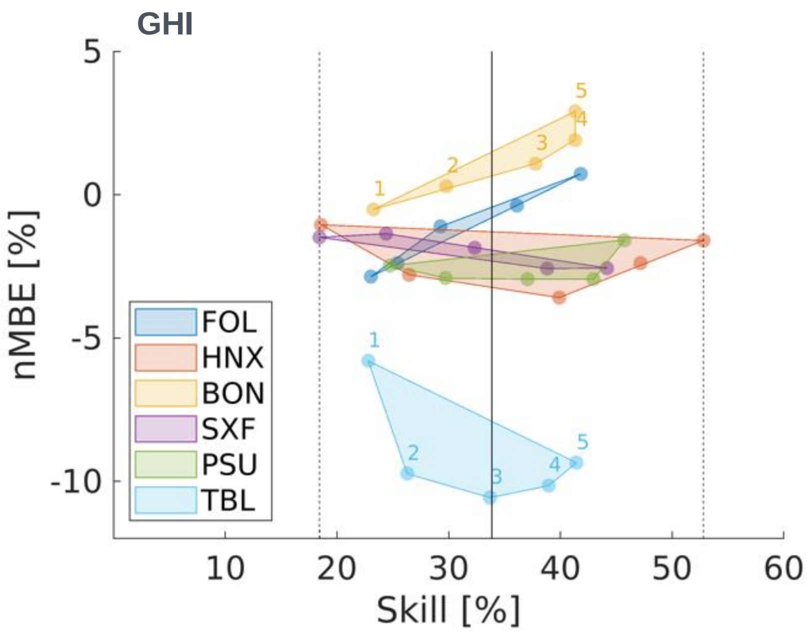
HAIMOS optimization

- Motivation: Improving the forecast skill during large variability periods.
- Input selection depending on the current (measured data) and future (NAM forecasts) irradiance variability.
  - Optimization model
  - Test inputs in terms of bias-variance metrics
  - Selects input that ranks highest
  - Iterates over unselected inputs until no improvements are observed.

Data	Description
Measured data	Irradiance data measured
Modeled irradiance	Satellite-derived irradiance data (CPR) for the target locations and neighboring nodes (49 in total)
CPR_i	Forecasted irradiance from CPR. Several forecasts are available, denoted by the subscript *i*.
NAM	GHI from the NAM model NAM
NAMcc	Total Cloud cover from NWP model NAM
SCOPE data	COD data for the target location (single node and extended domain)
LES data	COD and cloud fraction for the target location (single node and extended domain)
WRF-Solar data	COD and cloud fraction for the target location (single node and extended domain)
Other data	E.g. Cloud fraction from satellite images (broad band)

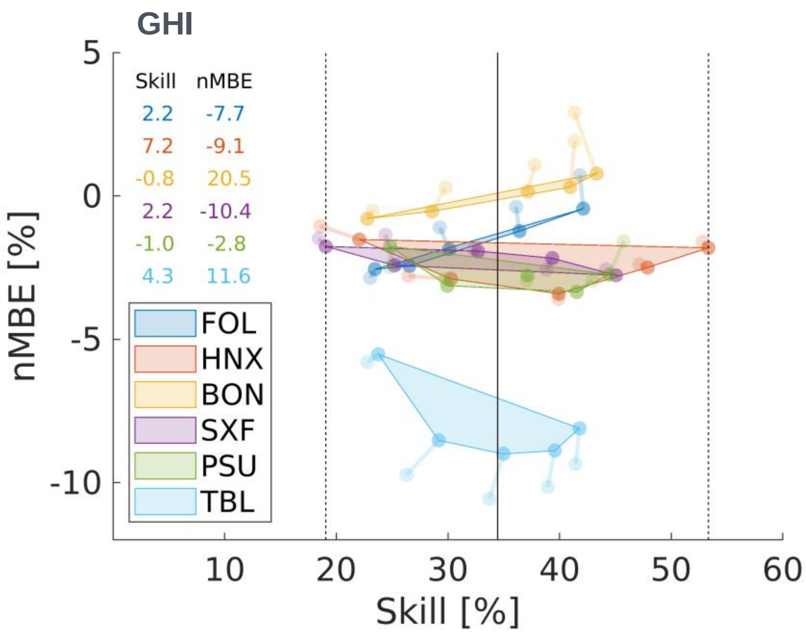
BP3 Results – HAIMOS

- Bias and forecast skill for GHI for the 6 SURFRAD and SOLRAD locations and forecast horizons ranging from 1 to 5 hours.
- On average HAIMOS can achieve a forecasting skill ~30% across different climate zones and forecasting horizons.



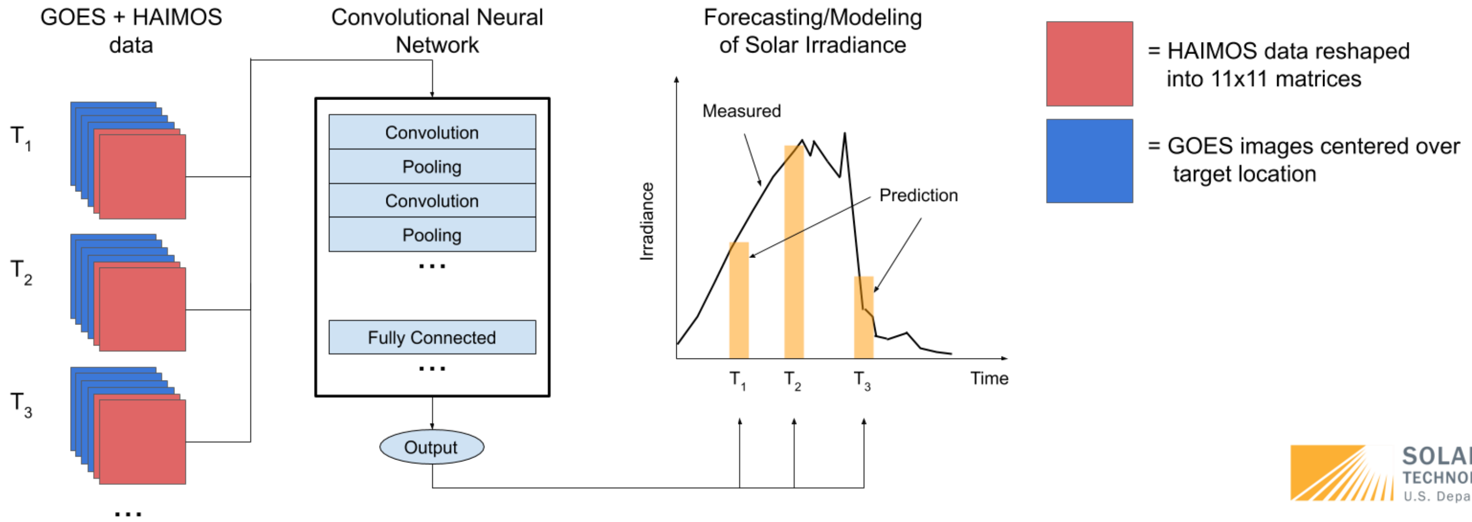
BP3 Results – Adaptive HAIMOS

- Adaptive protocols for HAIMOS as a function of the forecast variable (GHI or DNI) and the forecast horizon resulted in higher forecasts skills.
- As expected, improvements depend on the local irradiance variability (both skills and skill improvements are not uniform)
- Asymptoting to maximum possible skill, but still requires further study

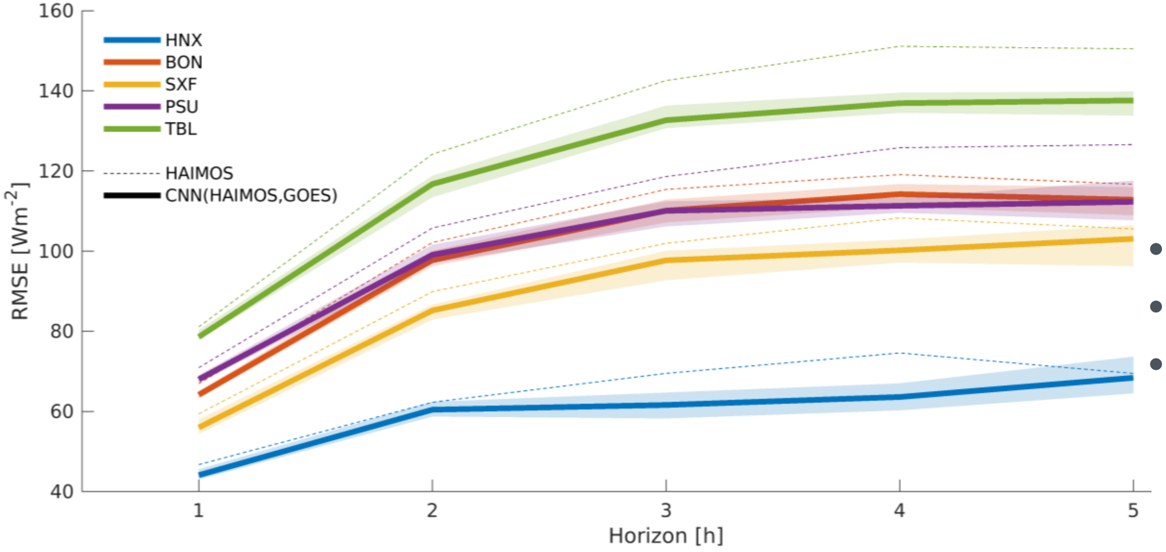


BP3 Results – CNN(HAIMOS + GOES-16 ABI)

- Explored merging GOES images and HAIMOS data
- The HAIMOS data produced in previous periods is formatted into a 11x11 matrix and concatenated with the 11x11 GOES image – see figure
- The models were trained 10 times for each location and forecast horizon in order to account for the random initialization of the CNNs.



BP3 Results – CNN(HAIMOS + GOES-16 ABI)

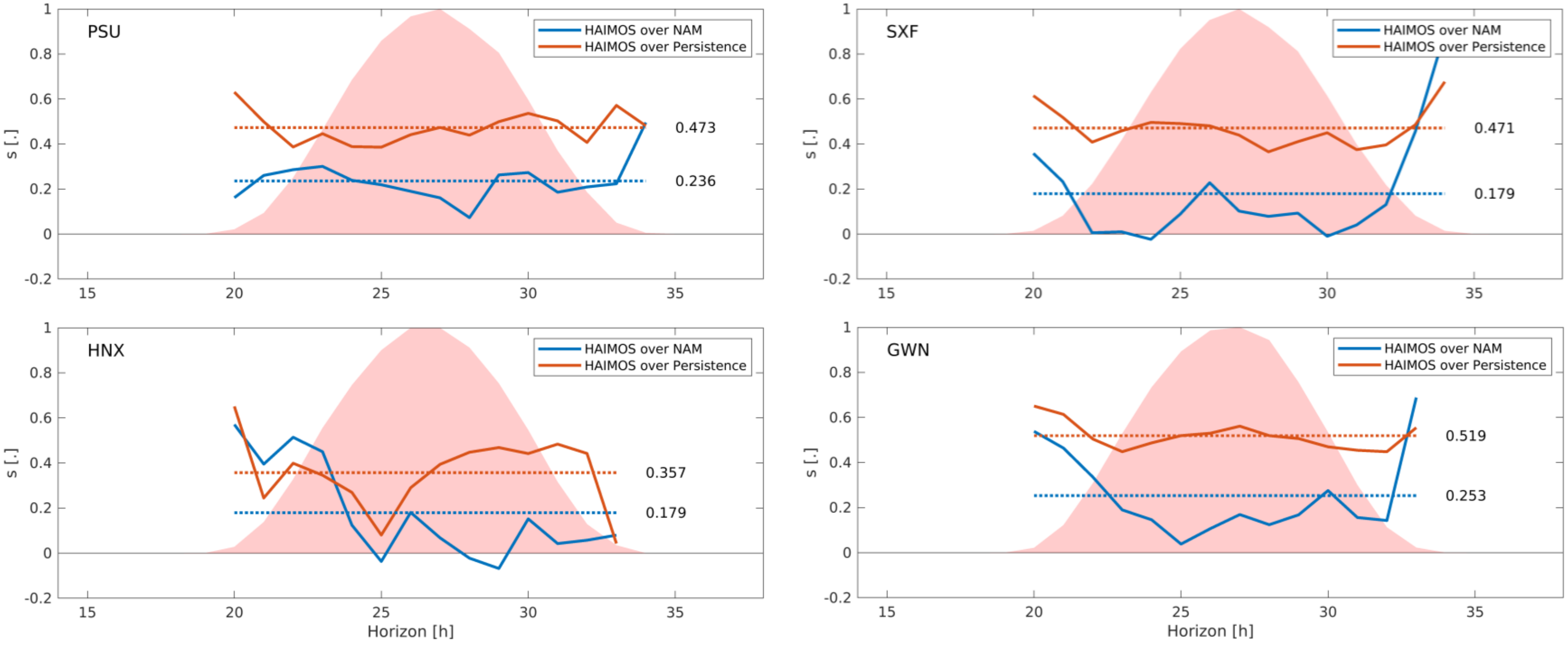


- The plot compares the forecasting accuracy for the validation set, in terms of RMSE, for all locations and horizons.
- Dashed lines = HAIMOS
- Solid lines = HAIMOS+GOES
- Merging HAIMOS data obtained from ground stations and CIF forecasts with GOES data results in a consistent RMSE reduction.

- The solid lines indicate the average RMSE for the 10 CNNs. The shaded band indicates the minimum and maximum RMSE obtained out of those 10 models.

BP3 Results – HAIMOS training for Area 1 test framework

- Validation of HAIMOS forecasts according Area 1 test framework.
- Day-Ahead GHI forecasts for SURFRAD and SOLRAD locations.



BP3 Results – HAIMOS training for Area 1 test framework

- Validation of HAIMOS forecasts using the Solar Forecast Arbiter (SFA) platform.
- Error metrics reported by SFA for Hanford and Goodwin Creek. HAIMOS forecasts identified as “UCSD”.

Table of total metrics

Forecast	MAE	MBE	RMSE	Skill
HNX_UCSD_2019	23	-7.66	46.9	0.311
Hanford California Current Day NAM ghi	34.5	-24.6	68	nan

Table of total metrics

Forecast	MAE	MBE	RMSE	Skill
GWN_UCSD_2019	43.3	-7.6	88.2	0.234
Goodwin Creek MS Current Day NAM ghi	55.4	-22.8	115	nan

BP3 Results – HAIMOS training for Area 1 test framework

- SFA comparison between ground data, HAIMOS forecasts and NAM forecasts for Hanford. SFA produces both timeseries and scatter plots for forecasted vs observed data. It is possible to zoom which allows for a detailed inspection of the data.