Data assimilation of rooftop solar power data to improve satellite derived irradiance nowcasts

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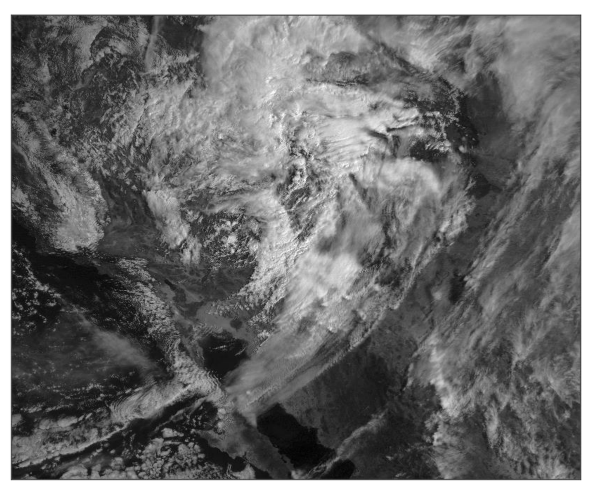
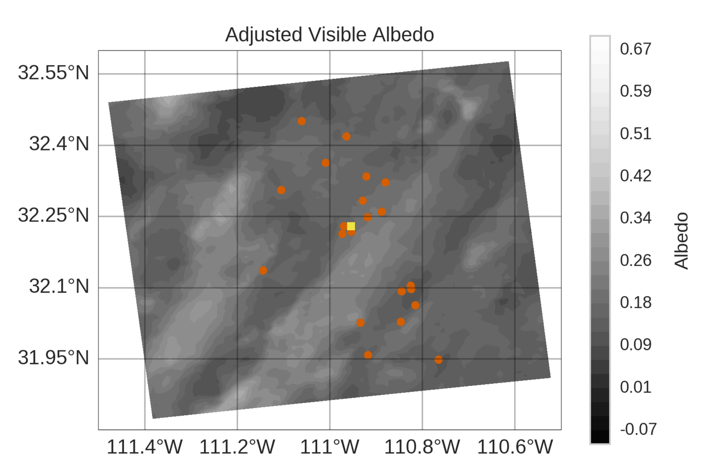
Summary

- Motivation: Accurate irradiance estimates are needed for resource assessment and real-time estimates and forecasts of PV power generation.
- Idea: Combine satellite derived irradiance estimates over a large area with sparse, accurate irradiance measurements through optimal interpolation.
- Results: Optimal interpolation reduces root mean square error (RMSE) by over 50% and nearly eliminates mean bias error (MBE).

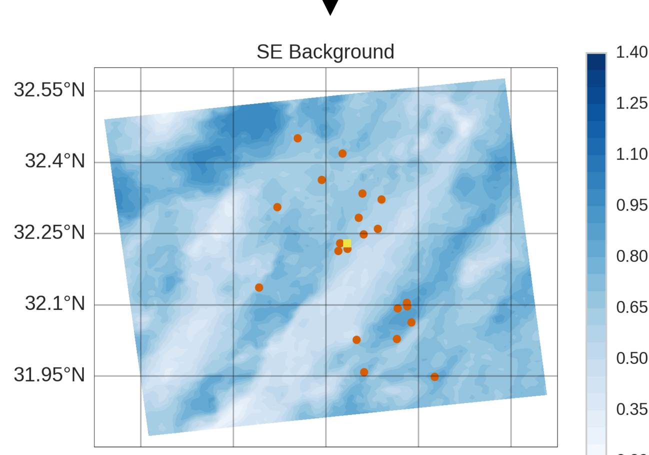
Optimal interpolation

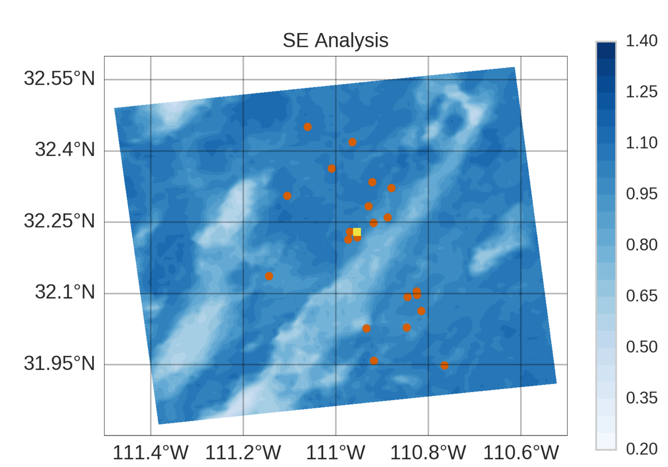
- Data are derived from two sources, geostationary satellite images and ground irradiance measurements from sensors and PV cells.
- Optimal interpolation enables accurate but sparse ground data to improve the irradiance estimate over a large area (in this case, Tucson and southern AZ).





Visible satellite images are converted to a surface irradiance estimate using two models: a physical model and a semi-empirical model. The background, $\mathbf{x}_b$, is this surface irradiance divided by the clear sky expectation. Optimal interpolation (OI) combines measurements, $\mathbf{y}$, with this background to form the analysis, $\mathbf{x}_a$.





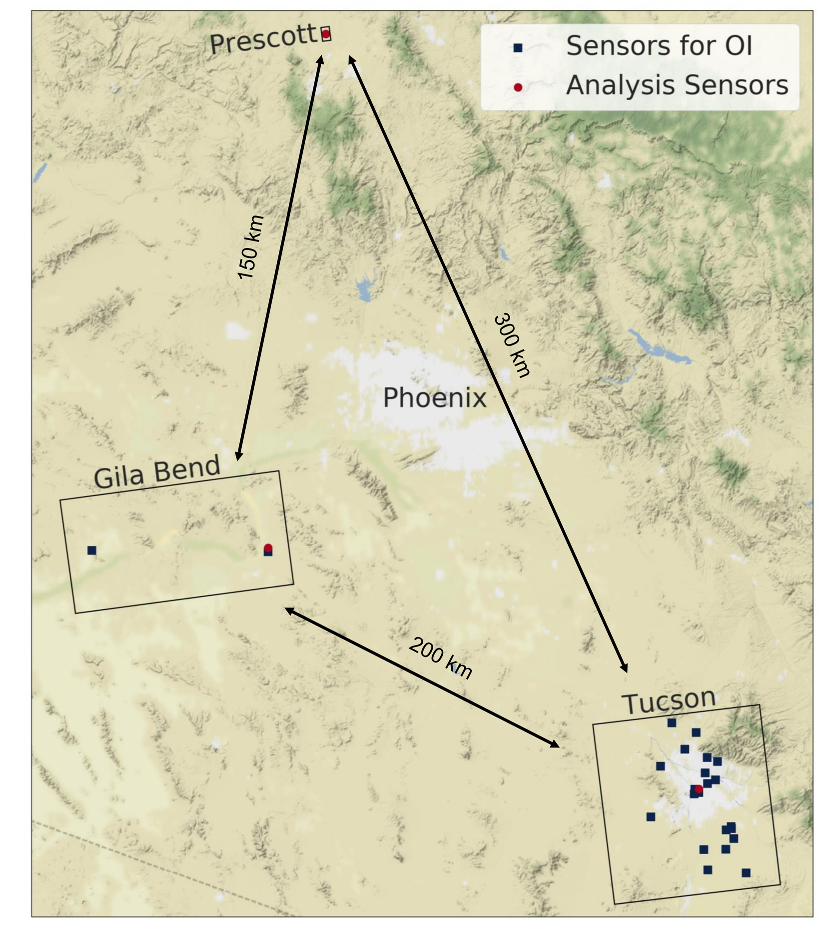
$\mathbf{x}_b$ $\mathbf{x}_a$

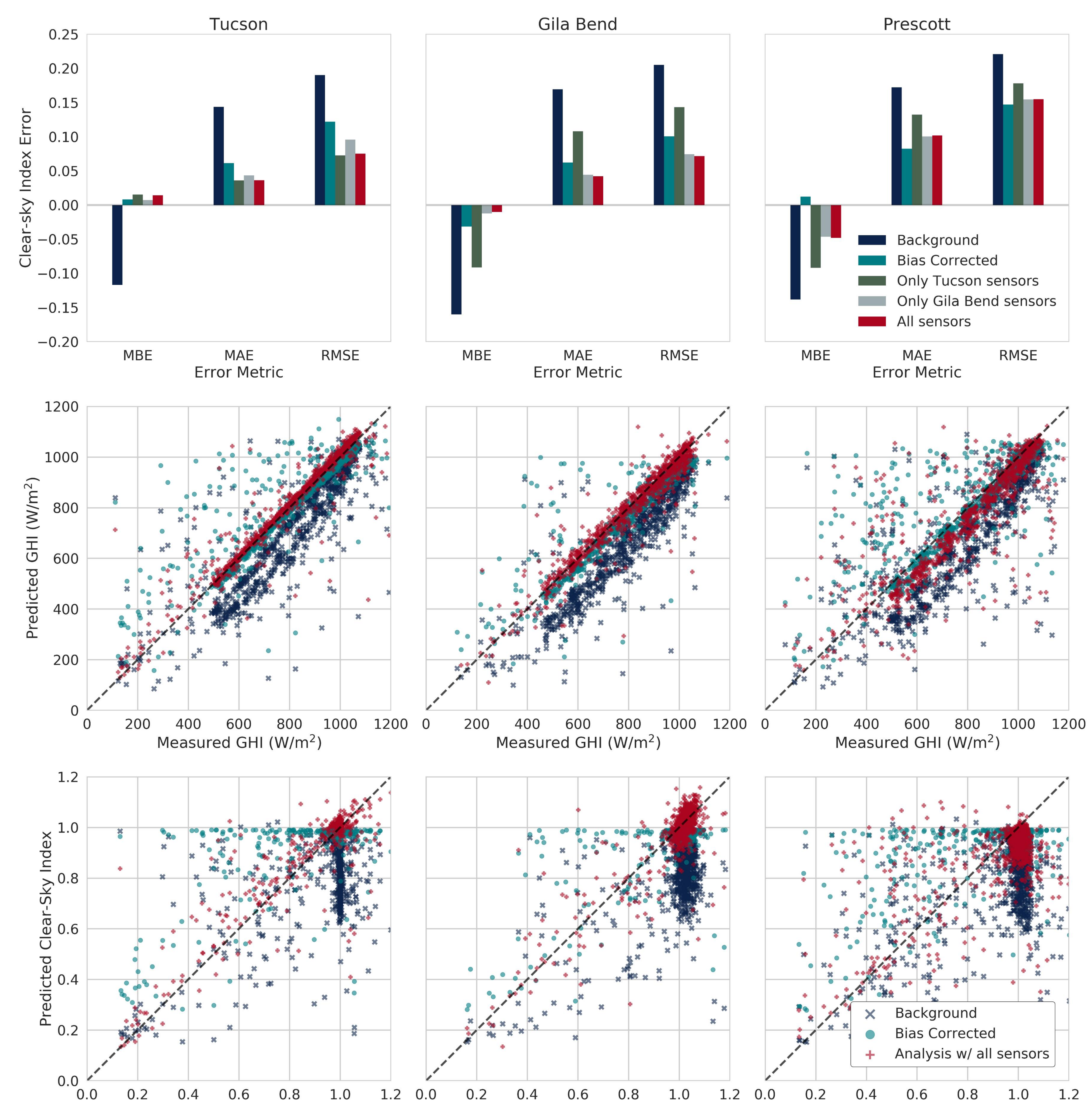
$$\mathbf{P} = \mathbf{D}^{1/2}\mathbf{C}\mathbf{D}^{1/2}$$
$$\mathbf{W} = \mathbf{P}\mathbf{H}^T(\mathbf{R} + \mathbf{H}\mathbf{P}\mathbf{H}^T)^{-1}$$
$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{W}(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

- **C** is the satellite correlation matrix. Points in the background are more correlated if they have a similar satellite image pixel value.
- **D** is the background (satellite derived irradiance) error variance.
- **H** maps points in the satellite image to sensors on the ground.
- **P** and **R** are the satellite and sensor error covariance matrices which enable information to spread throughout the image
- **W** is the weight matrix, also known as the Kalman gain matrix
- Parameters for **C** and **D** are optimized on a set of test images.

Results

- Errors are calculated for sensors not included in the OI routine for 3 months of data.
- A bias-corrected nowcast calculated from the test data is shown as a reference.
- Summary statistics are shown for the semi-empirical model. Error improvements for the physical model are similar.
- For locations with nearby sensors used in OI (Tucson and Gila Bend), RMSE is reduced by over 50% and MBE is nearly eliminated.
- Scatterplots of predicted vs measured GHI and clear-sky index illustrate the improvements of the analysis (after OI) over the background (before OI).
- Including sensors located hundreds of km away can improve the estimates.





Case studies

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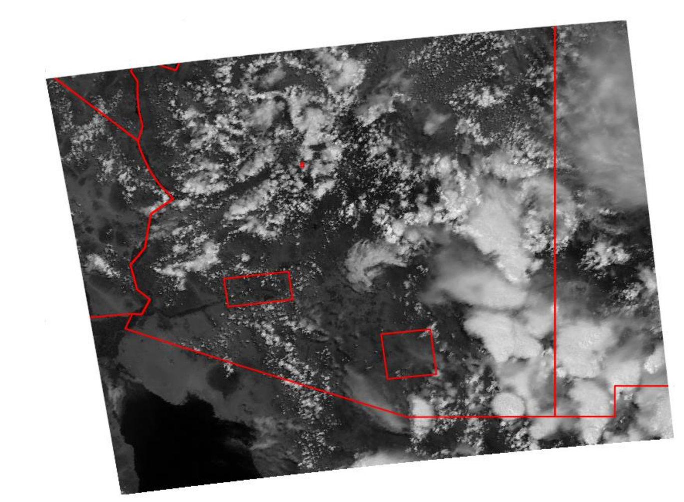
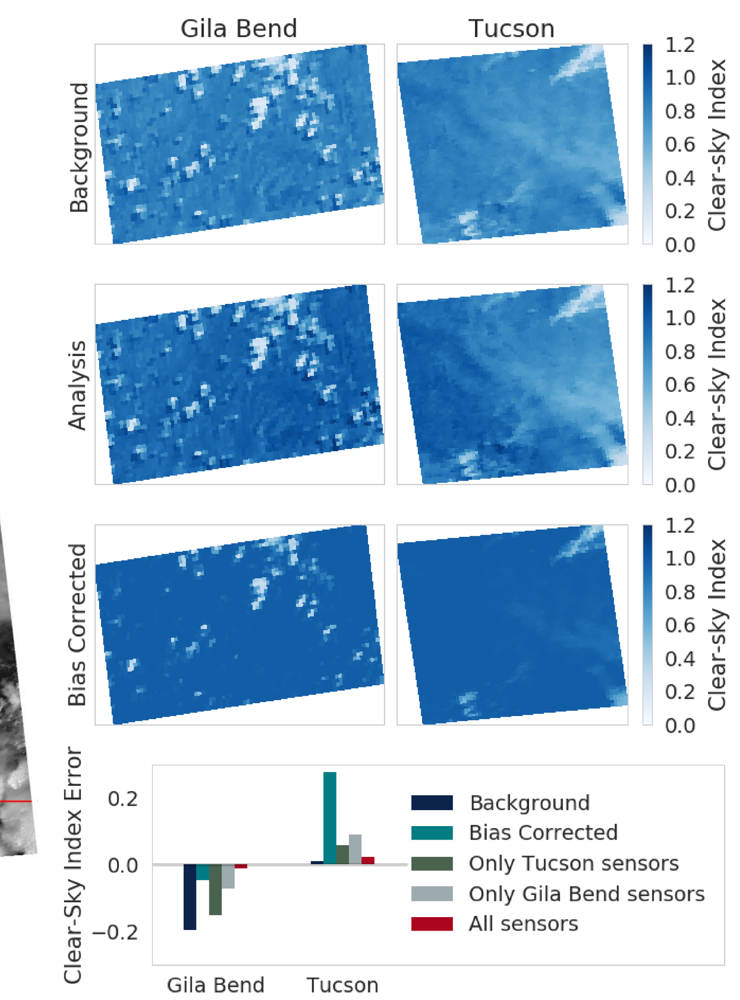
Deep convection near Tucson and shallow cumulus over Gila Bend. Tucson sensors reduce errors in Gila Bend, likely as a result of better parallax correction.





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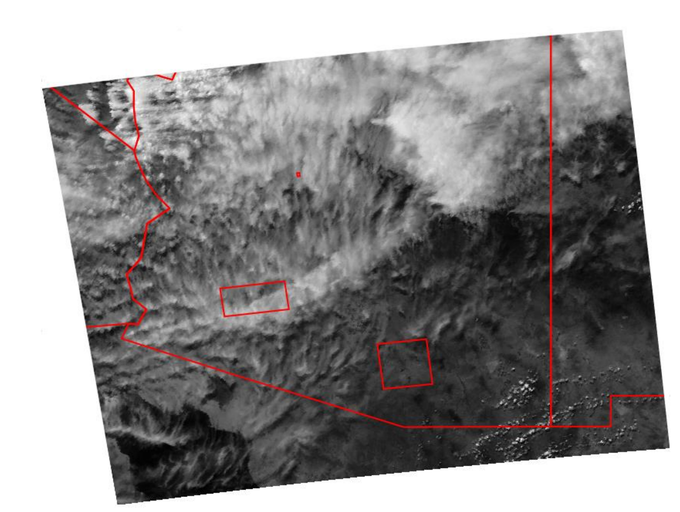
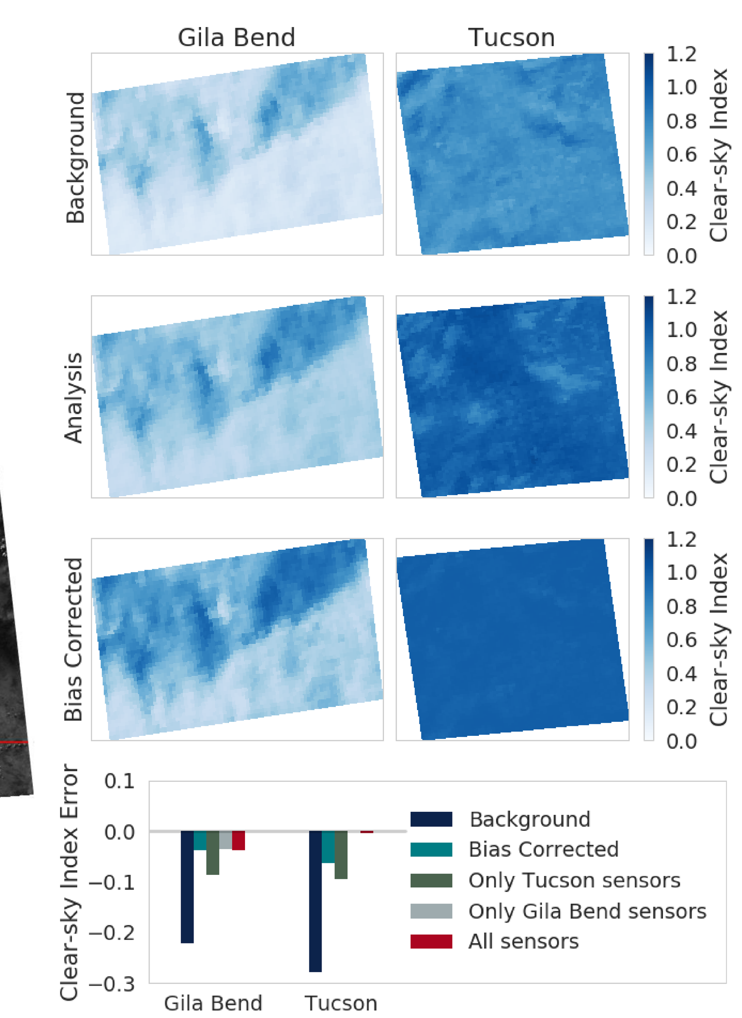
Frontal system moving over AZ. Here information from Gila Bend improves estimation of thin clouds over Tucson.





Conclusions

- OI can improve satellite derived irradiance nowcasts using a mix of irradiance sensors and rooftop PV systems.
- Parallax correction is an important component of improved estimates; calculating cloud height that minimizes OI RMSE is one effective correction technique.
- Results are likely to improve if parameters (correlation length, error variances) can be tuned based on the weather of the day.
- Future work includes extending OI to produce forecasts via an ensemble Kalman filter; see poster #750.

Further details: A. T. Lorenzo, M. Morzfeld, W. F. Holmgren, and A. D. Cronin, "Optimal interpolation of satellite and ground data for irradiance nowcasting at city scales," Sol. Energy, vol. 144, pp. 466—474, 2017.

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