Forecasting Global Horizontal Irradiance Using the LETKF and a Combination of Advected Satellite Images and Sparse Ground Sensors

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Summary

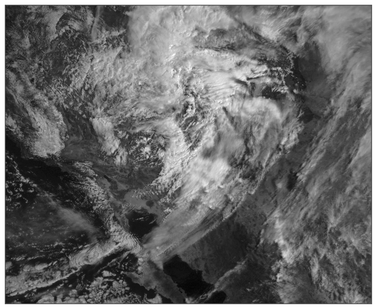
Motivation: Intra-hour irradiance forecasts are required for integrating PV power into the electrical grid.

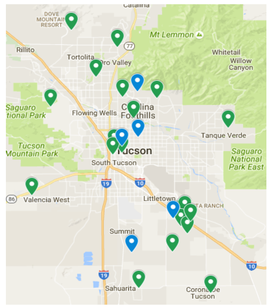
Idea: We combine satellite derived irradiance estimates with a cloud motion field in a data assimilation framework to create intra-hour irradiance forecasts.

Results: Combining cloud motion information from numerical weather prediction, optical flow, and satellite images can improve irradiance forecasts by 22% for 45 minute forecasts.

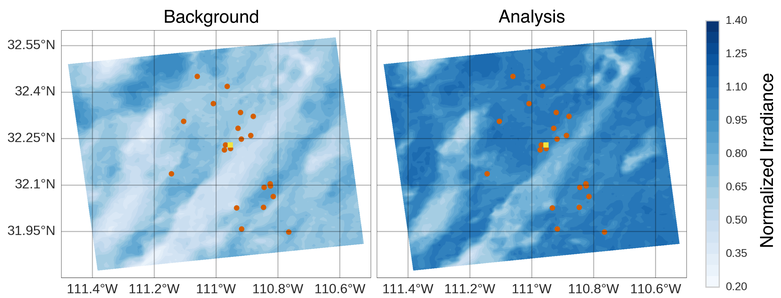
Previous work: satellite images & ground data

Normalized irradiance data are derived from two sources: geostationary satellite images and ground irradiance measurements from sensors and PV systems.





Optimal interpolation enables accurate but sparse ground data to improve the irradiance estimate over a large area (Tucson, AZ) by as much as 50% [1].



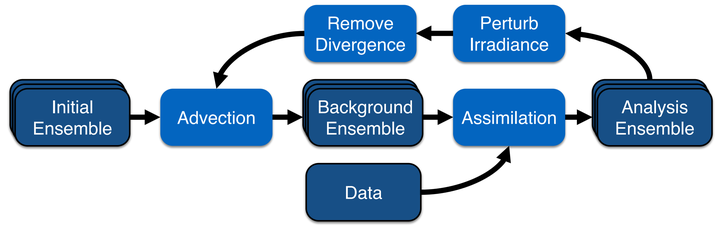
Forecasting irradiance

- An advection model is used to create forecasts from the satellite derived irradiance field, ψ, a two dimensional scalar field.
- This advection model requires a two dimensional vector field known as a cloud motion field, $\vec{C}$.

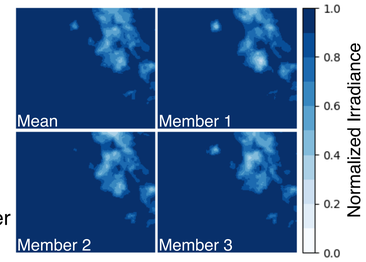
$$\frac{\partial \psi}{\partial t} = -\nabla \cdot (\vec{C}\psi)$$

- When forecasting only irradiance over short time scales (intra-hour) it is advantageous to use a simplified model rather than a full numerical weather model due to lower computational cost and ease of data assimilation.
- The forecasts produced by this model are sensitive to errors in the initial irradiance estimate and the cloud motion field.

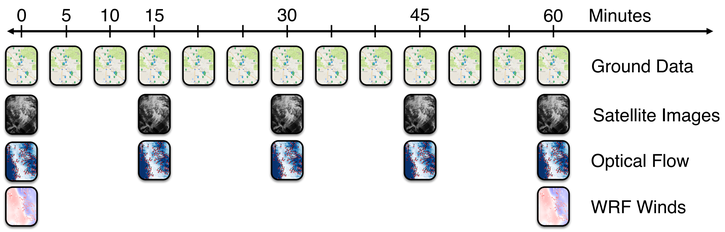
Ensemble forecasting system



- Ensemble includes irradiance and cloud motion fields.
- The Local Ensemble Transform Kalman Filter (LETKF) is used to reduce computational cost with a large state and small ensemble number [2].
- Irradiance fields are perturbed using a smooth random field targeting clouds in order to increase the ensemble variance.
- Data assimilation introduces additional divergence.
- Divergence is removed by solving Poisson's equation.

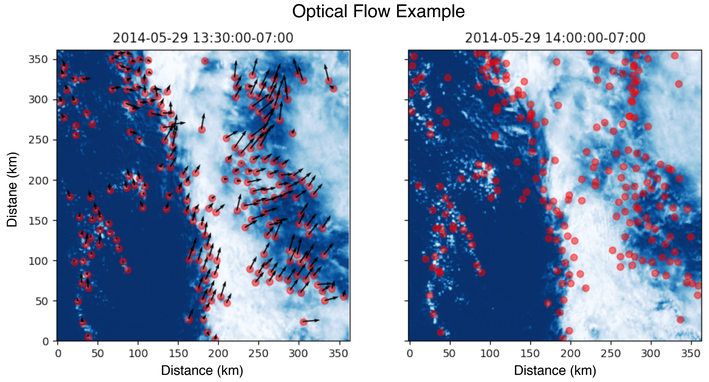


Data Availability



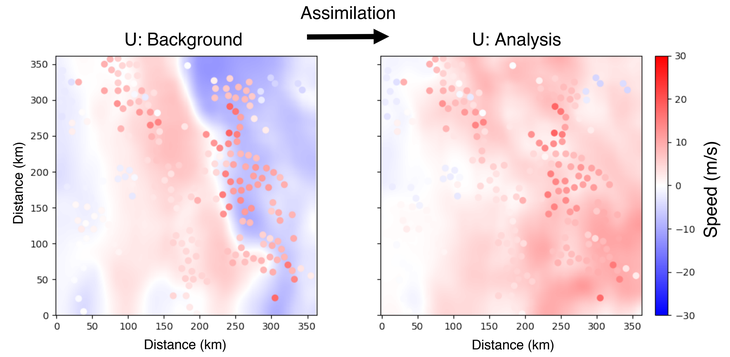
- Ground Data: rooftop solar, custom ground sensors, calibrated sensor.
- Satellite Images: GOES west visible band, 1 km^2 resolution.
- Optical Flow: uses current and previous satellite image to calculate flow [3].
- WRF Winds: from Arizona Regional WRF Model forecasts [4].
  - Assume clouds move with same velocity as WRF winds (U, V)
  - U and V taken from the model level with highest relative humidity
  - U and V then interpolated to the advection grid and smoothed

Optical Flow Example

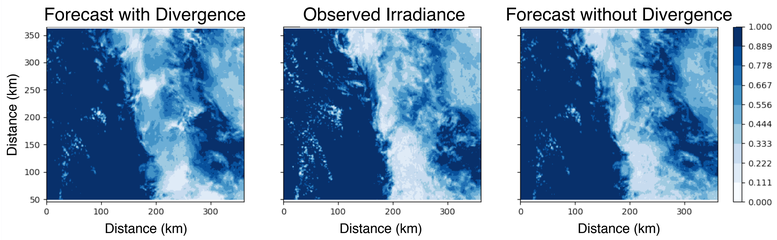


Preliminary results

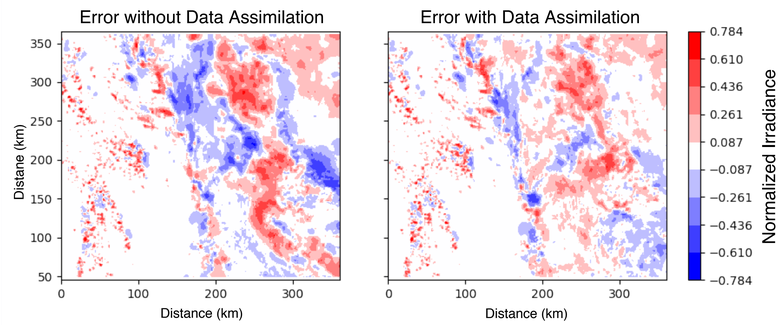
- Assimilation of optical flow vectors (scatter points) improves the accuracy of WRF derived cloud motion fields (Background).



- Examples of forecasts made from cloud motion fields



- RMSE is calculated based on the difference between the forecasted irradiance field and the observed satellite derived irradiance field.
- Error is calculated in a 45 by 60 km box containing all ground sensors.
- Error is reduced by 15%, 20%, and 22% for forecast horizons of 15, 30, and 45 minutes for the day shown here (5/29/2014).



References

1. Lorenzo, A., Morzfeld, M., Holmgren, W., Cronin, D., 2017. Optimal interpolation of satellite and ground data for irradiance nowcasting at city scales. Solar Energy 144, 466-474.
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3. Bradski, G., 2008. The OpenCV library. Dr. Dobb's Journal of Software Tools. https://github.com/opencv
4. Leuthold, M., 2017. Arizona Regional WRF Model Forecasts. http://www.atmo.arizona.edu/?section=weather&id=wrf

This material is based upon work supported by Tucson Electric Power, Arizona Public Service, the National Science Foundation under grant DMS-1619630, the Alfred P. Sloan Foundation, and by the Program in Applied Mathematics.
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