Ground-based Image Analysis for Solar Energy Applications

Joint work with Florian Savoy, Yee Hui Lee, & Stefan Winkler

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Why are we looking at clouds?

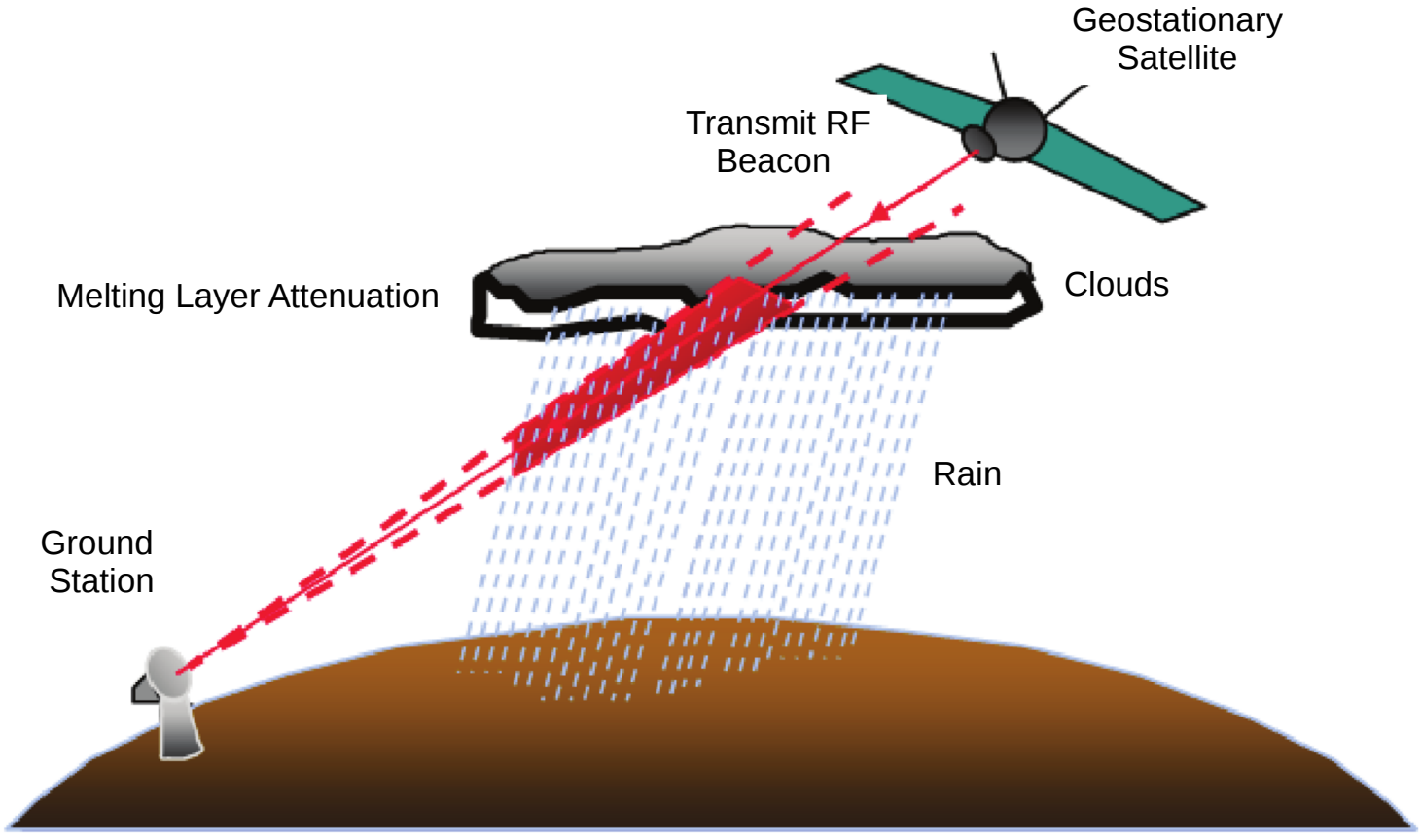
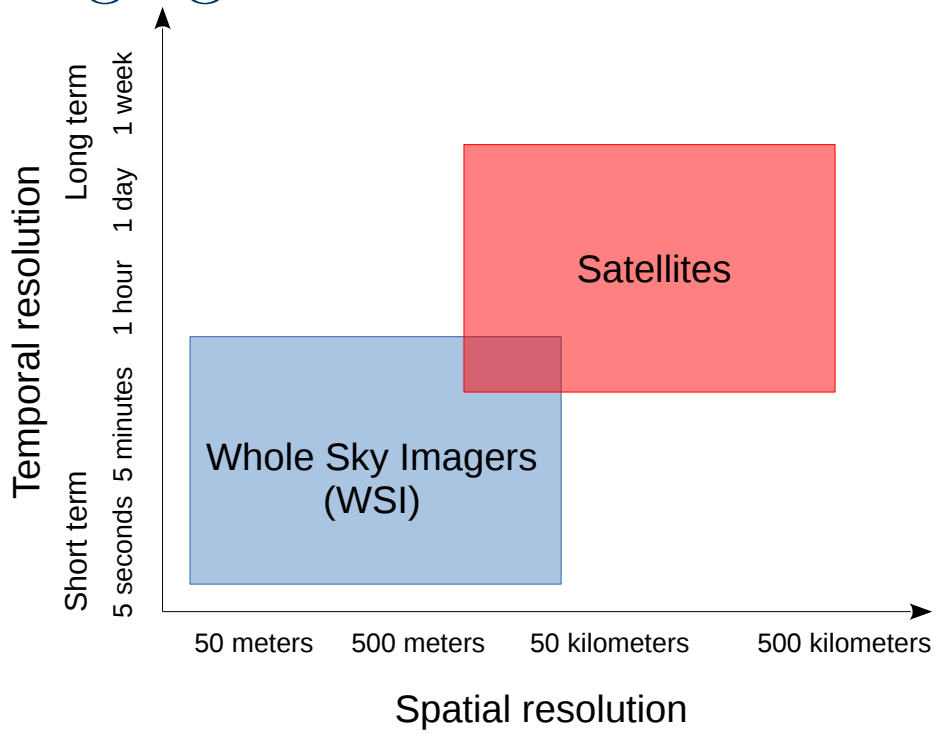
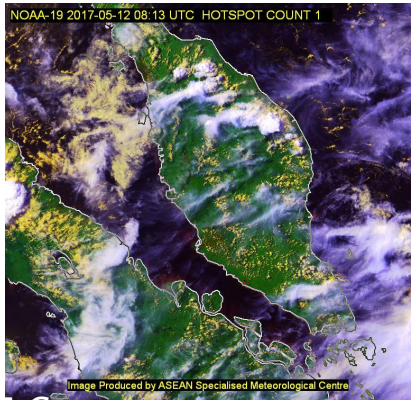


Fig: Illustration of cloud attenuation in satellite communication links. Image is archived from NASA, Glenn Research Center.

Ground-based Imaging



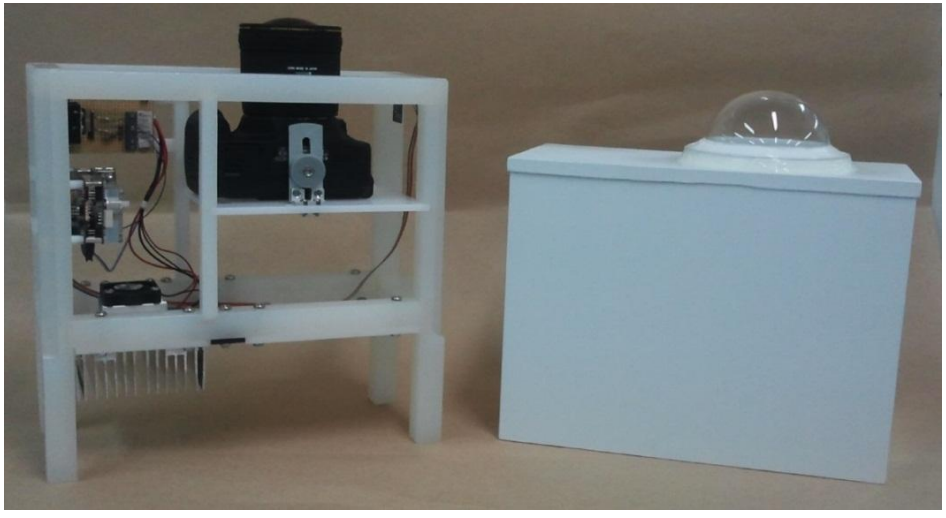
Satellites



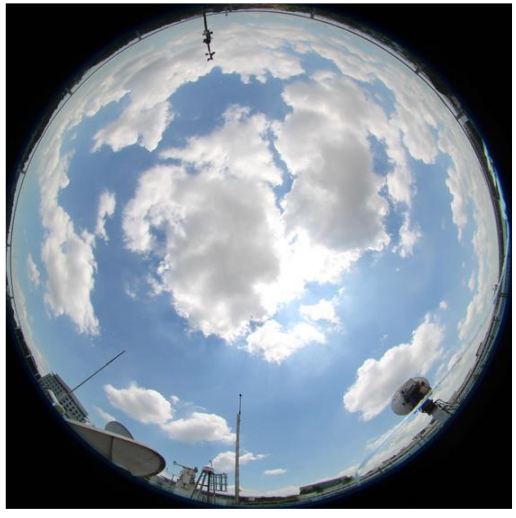
Whole Sky Imagers (WSIs)

Whole Sky Imager Design

- Commercial WSIs are expensive(35K USD), have a low image resolution and sophisticated machinery.
- WAHRSIS: Wide Angle High-Resolution Sky Imaging System
  - Easy-to-design model [1].
  - Low-cost (2000USD) and high image-resolution (18MP).



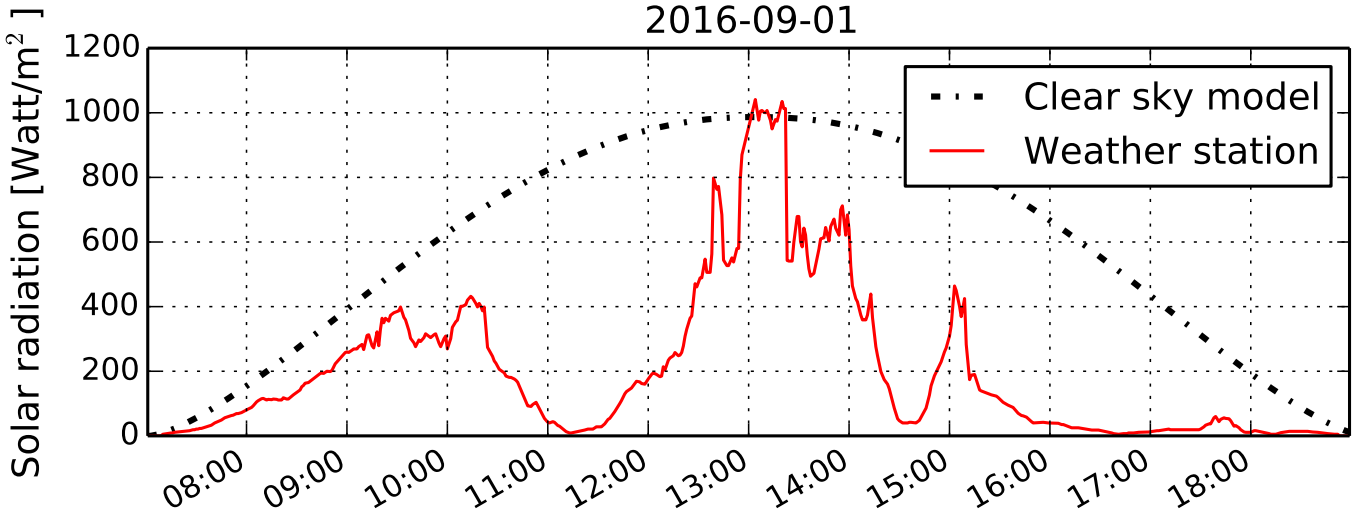
(a) WAHRSIS



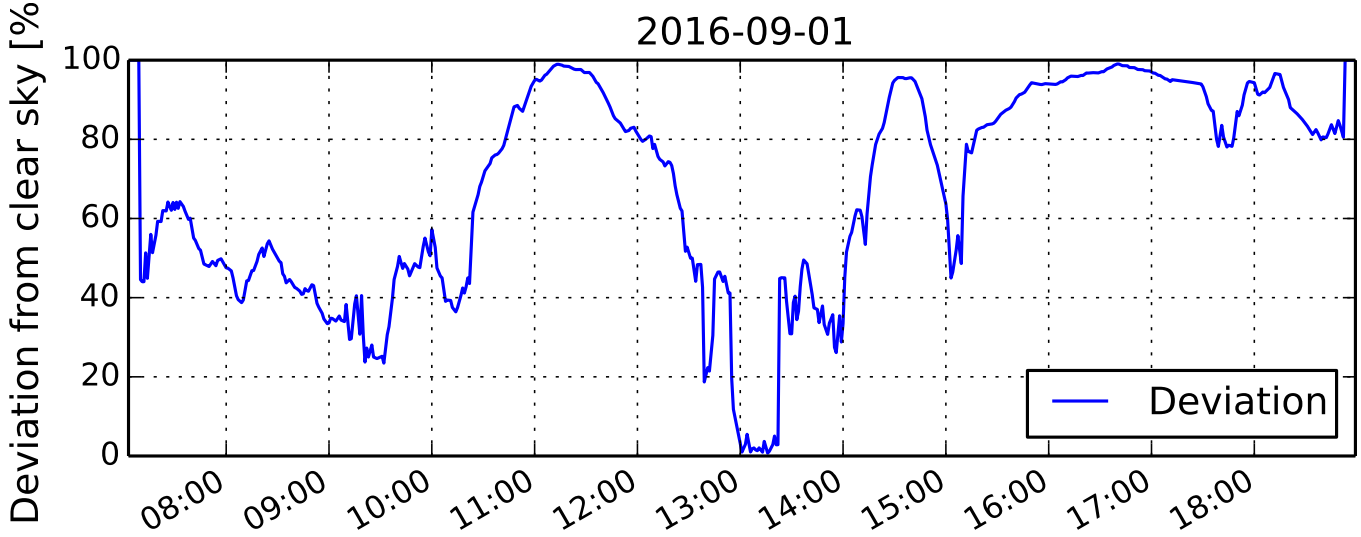
(b) Captured image

[1] S. Dev, F. M. Savoy, Y. H. Lee and S. Winkler, DIY Sky Imager For Weather Observation: A complete guide to build a ground-based sky imager using off-the-shelf components with automatic cloud coverage computation, SPM Student Design Project Series Documents, *IEEE Signal Processing Society*, 2016

Measured Solar Radiation



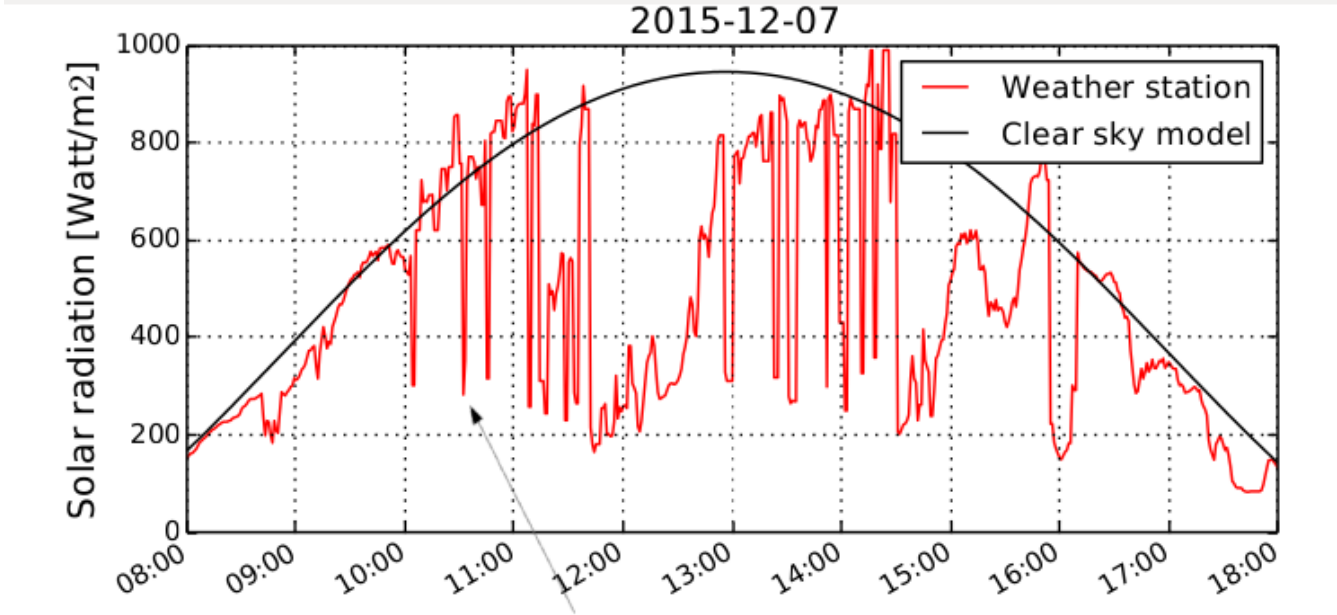
(c) Measured solar radiation along with clear-sky model.



(d) Percentage deviation of solar radiation from clear sky.

Solar Irradiance Fluctuation

Clouds are *mostly* responsible for solar irradiance fluctuations.



10:30 (758 W/m^2) 10:32 (283 W/m^2) 10:34 (714 W/m^2)

Fig: Impact of clouds on direct solar irradiance.

Challenges

Engaging Content
Engaging People

- In what ways can the rapid fluctuations of the solar irradiance be best captured?
- Existing solar estimation methods consist of using:
  - Daily temperature variations [Hargreaves and Samani].
  - Daily precipitation data [Hunt et al.].
  - Also including clear sky transitivity [Donatelli and Campbell], atmospheric transmission coefficient [Bristow and Campbell].

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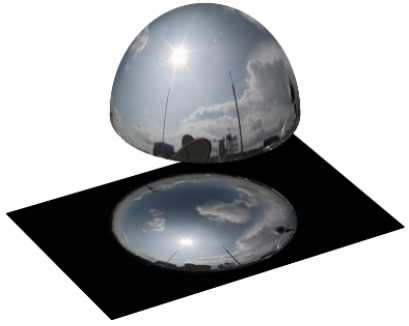
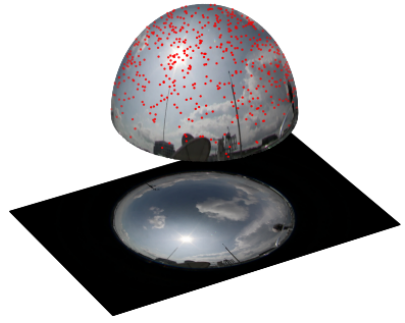
We propose solutions by:

- Using ground-based sky camera images to estimate solar irradiance with highest accuracy;
- First step towards short-term solar energy generation forecasting.

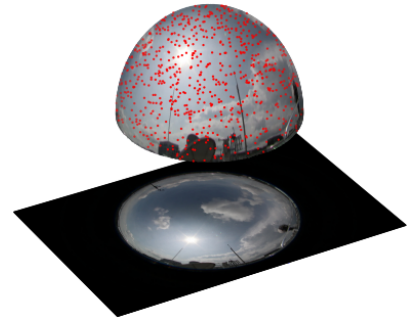
Proposed Methodology



(a) Projection on a hemisphere of the original image

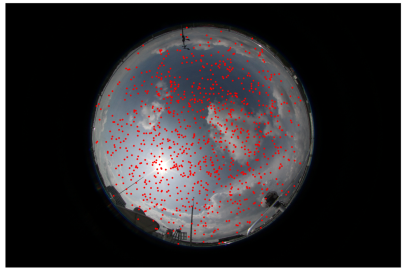


(b) Cosine hemispheric sampling of the hemisphere with origin on the top

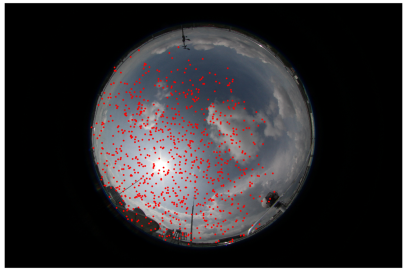


(c) Applying a rotation matrix to center at the sun location

(d) Original image with detected sun location in red



(e) Projection on the image of the sampled points



(f) Projection on the image of the rotated sampled points

Fig: Cosine weighted hemispheric sampling process used to select the pixels used for solar irradiance estimation.

Modeling Irradiance

WAHRSIS images captured during the time period from January 2016 till August 2016 (7:00 am till 7:00 pm).

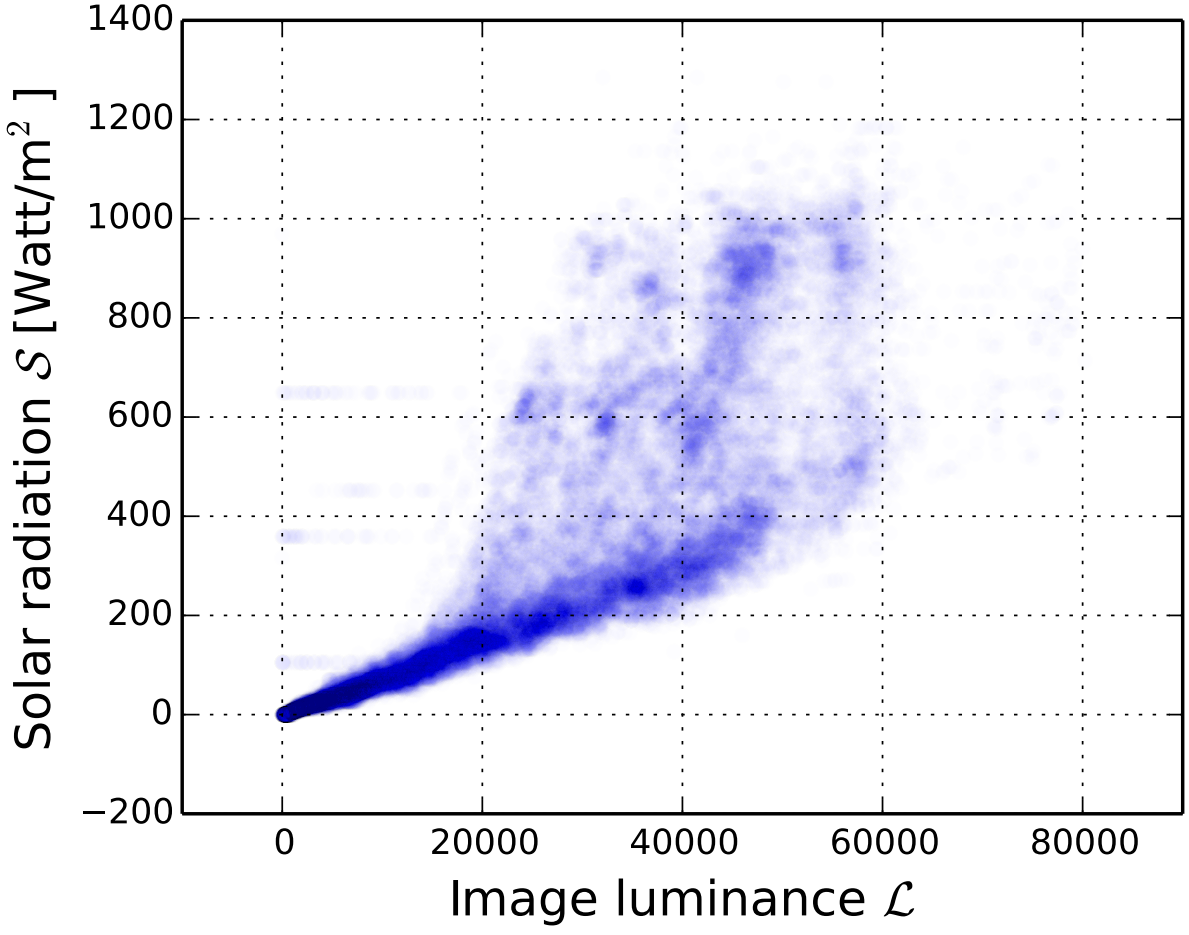


Fig: Modeling the solar radiation using the luminance computed from sky camera images.

Performance Evaluation

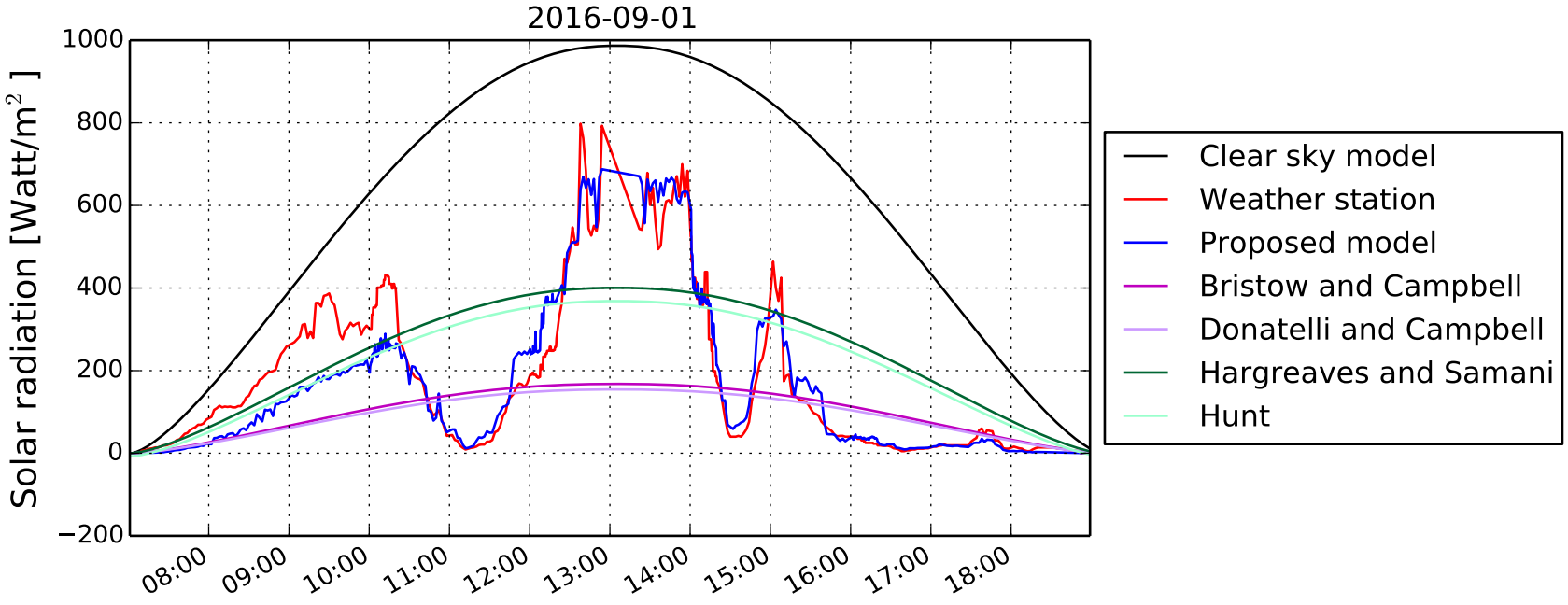


Fig: We show our estimated solar radiation (in blue), measured weather station data (in red), and the clear sky radiation (in black) as on 01-Sep-2016.

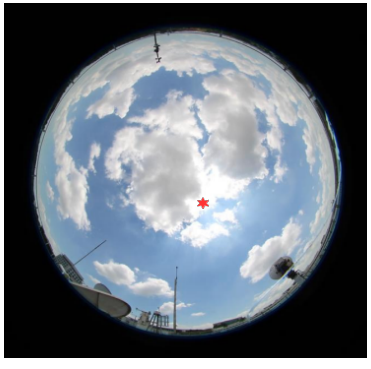
Our proposed [2] has the highest correlation (0.86), amongst all estimation methods.

[2] S. Dev, F. M. Savoy, Y. H. Lee, S. Winkler, Estimation of solar irradiance using ground-based whole sky imagers, *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, 2016.

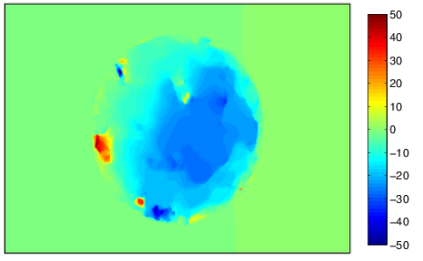
Solar Forecasting

Unlike point-measurement devices, sky cameras provide additional information about cloud movement [3] and coverage.

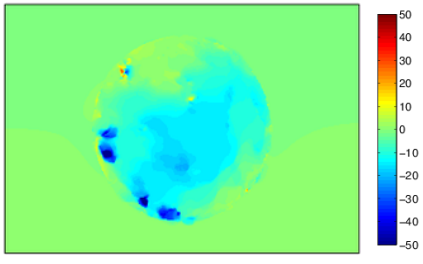
Input at $t - 2$'



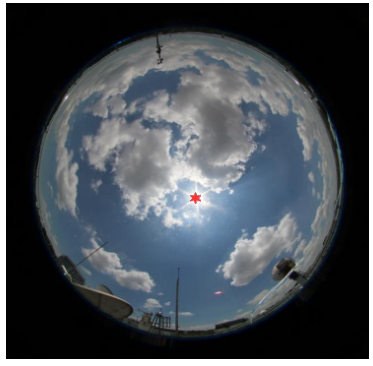
Input at t'



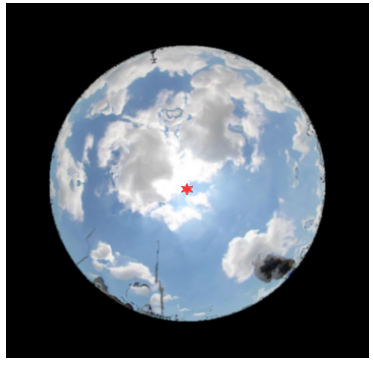
Horizontal translation



Vertical translation



Actual at $t + 2$'



Predicted at $t + 2$'

[3] S. Dev, F. M. Savoy, Y. H. Lee, S. Winkler, Short-term prediction of localized cloud motion using ground-based sky imagers, *Proc. TENCON 2016 - 2016 IEEE Region 10 Conference*, 2016.

Summary

- Using whole sky imagers to reliably estimate the total solar irradiance.
- Proposed model to track the fluctuations of solar irradiance.
- Useful in reliable and robust short-term solar energy forecasting.

Thank You!