Exploring a method to estimate real-sky global solar radiation in mountainous areas at high resolutions with an open-source geospatial solar radiation model and GOES-13 geostationary meteorological satellite data.

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Objective

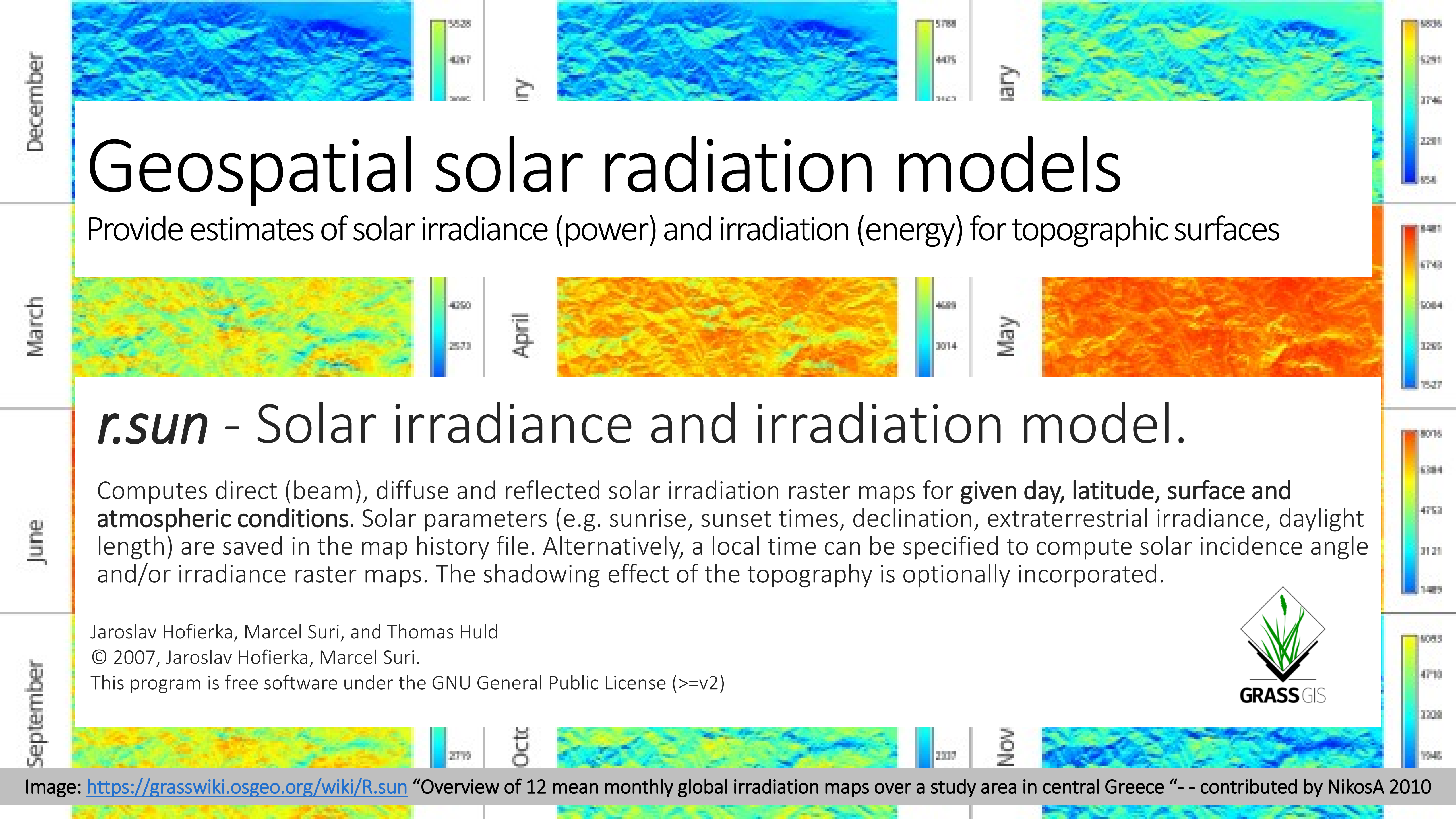
spatially and temporally explicit estimates of solar radiation for a montane area with complex topography and dynamic atmospheric conditions

Data:

- high spatial and temporal resolution
- continuous across large extents and long time frames
- publicly available, reasonably accessible

Model:

- Open source and free
- Accessible to a range of users (e.g. GUI and command line interfaces)
- Capable of handling high spatial and temporal resolution data over large extents (!)



Geospatial solar radiation models

Provide estimates of solar irradiance (power) and irradiation (energy) for topographic surfaces

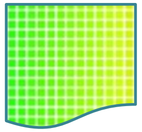
r.sun - Solar irradiance and irradiation model.

Computes direct (beam), diffuse and reflected solar irradiation raster maps for **given day, latitude, surface and atmospheric conditions**. Solar parameters (e.g. sunrise, sunset times, declination, extraterrestrial irradiance, daylight length) are saved in the map history file. Alternatively, a local time can be specified to compute solar incidence angle and/or irradiance raster maps. The shadowing effect of the topography is optionally incorporated.

Jaroslav Hofierka, Marcel Suri, and Thomas Huld

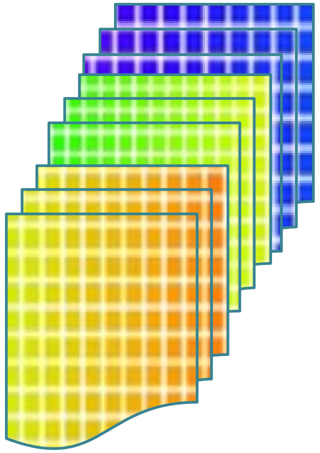
GRASS GIS

Image: https://grasswiki.osgeo.org/wiki/R.sun "Overview of 12 mean monthly global irradiation maps over a study area in central Greece "- - contributed by NikosA 2010

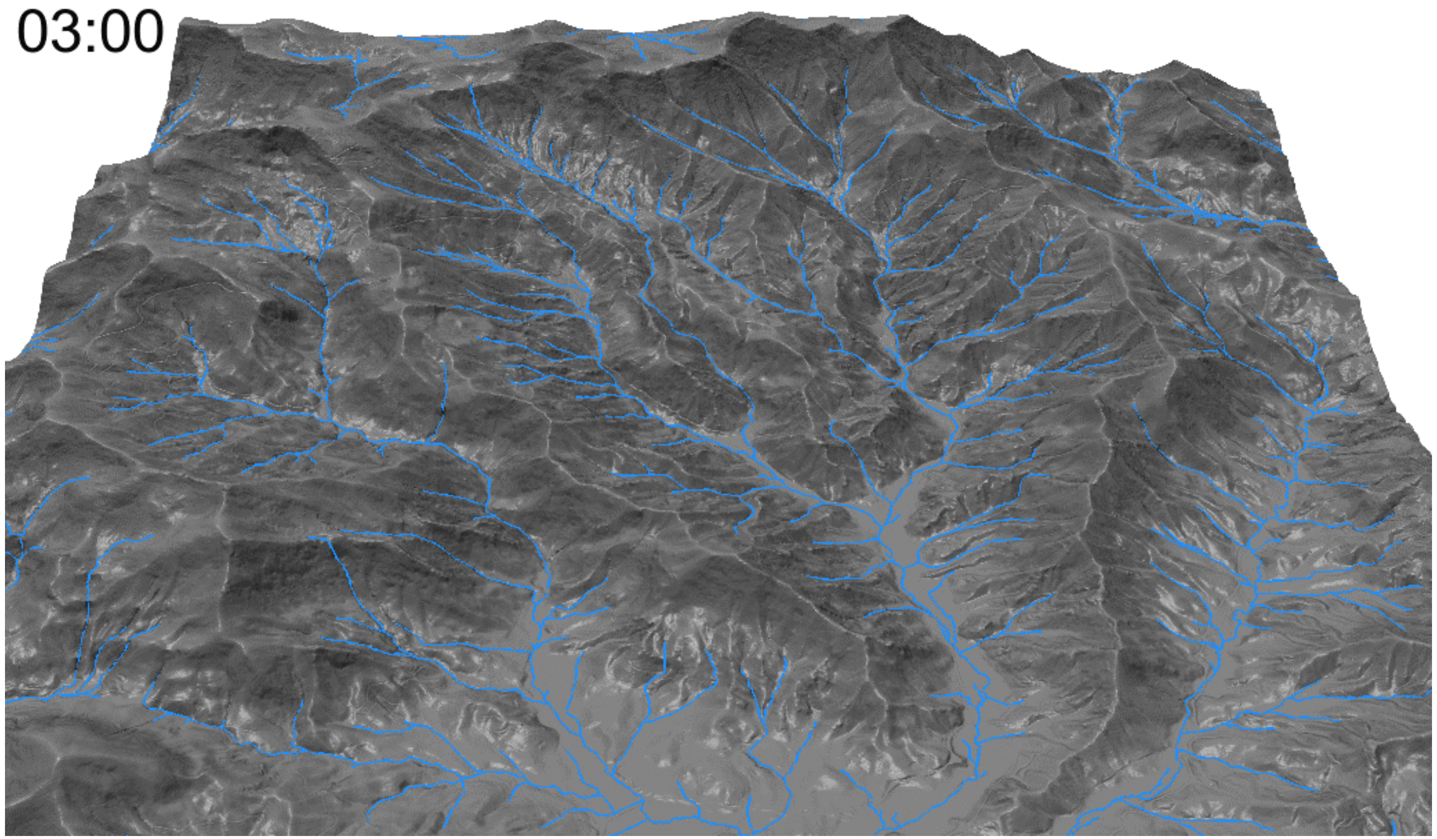


r.sun - … Alternatively, **a local time** can be specified to **compute** solar incidence angle and/or **irradiance raster** map.

r.sun.hourly - Runs r.sun in loop for given time range within one day.



Time-series of
irradiance raster maps



r.sun.hourly written (2013) and modified (2019) by Anna Petrasova
Available as a GRASS GIS Addon https://grass.osgeo.org/download/addons/

atmospheric parameters

Linke Turbidity Coefficient (linke)

Real-Sky Beam Radiation Coefficient (coeff_bh) – thick cloud

Real-sky Diffuse Radiation Coefficient (coeff_dh) - haze

The 2019 modifications of r.sun.hourly included enabling temporal raster series for coeff_bh and coeff_dh and spatially and temporally explicit atmospheric conditions to be incorporated in the estimates of irradiance and irradiation.

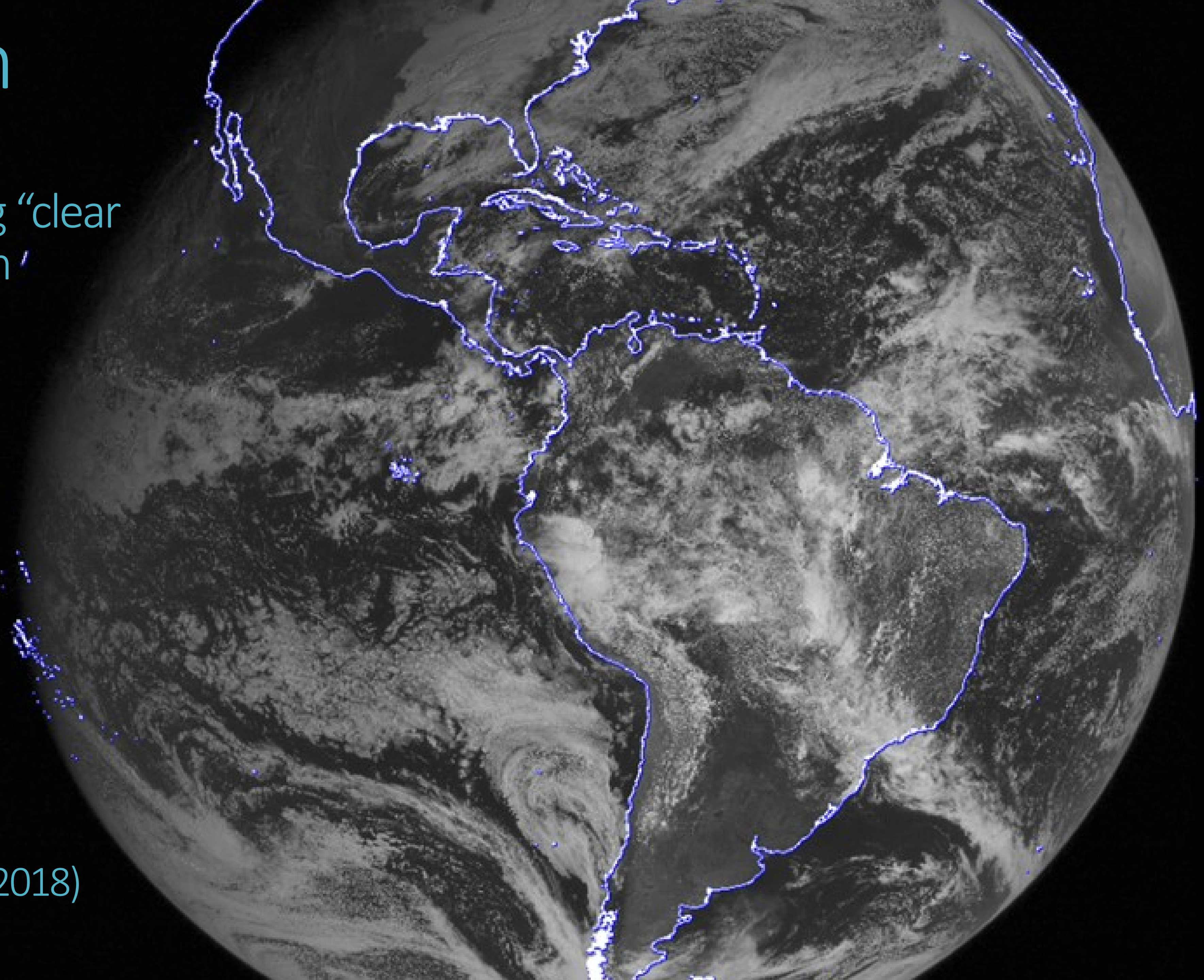
coeff_bh

estimated using "clear sky index" from "cloud index"

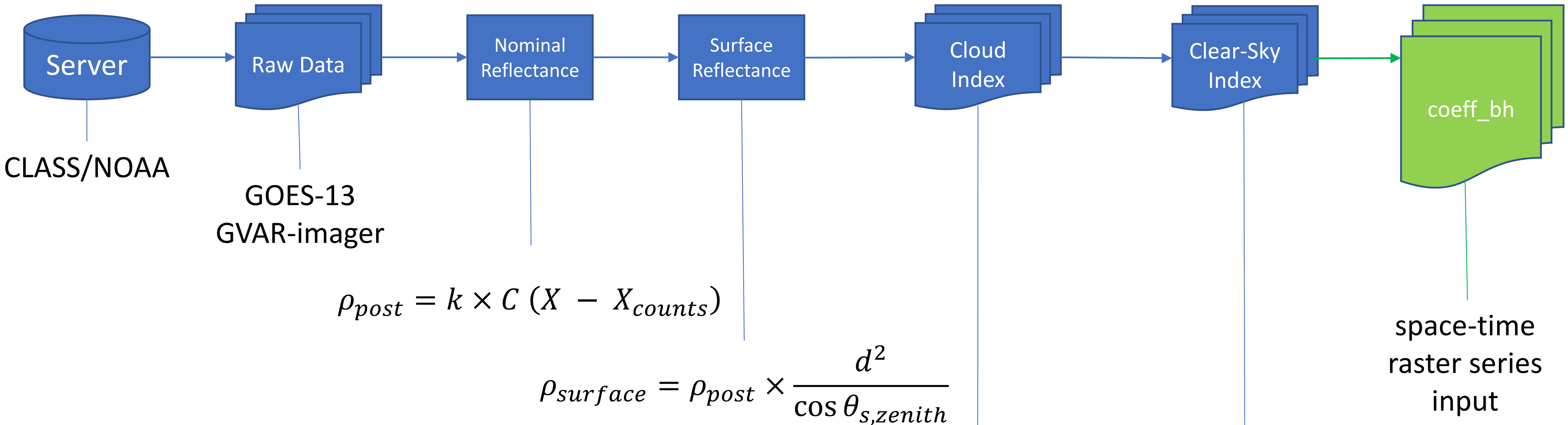
GOES 13 geostationary satellite GVAR imager

resolution:
1 km
15 minute

(operated 2006 – 2018)



Workflow for coeff_bh



$$\rho_{post} = k \times C\,(X - X_{counts})$$

$$\rho_{surface} = \rho_{post} \times \frac{d^2}{\cos\theta_{s,zenith}}$$

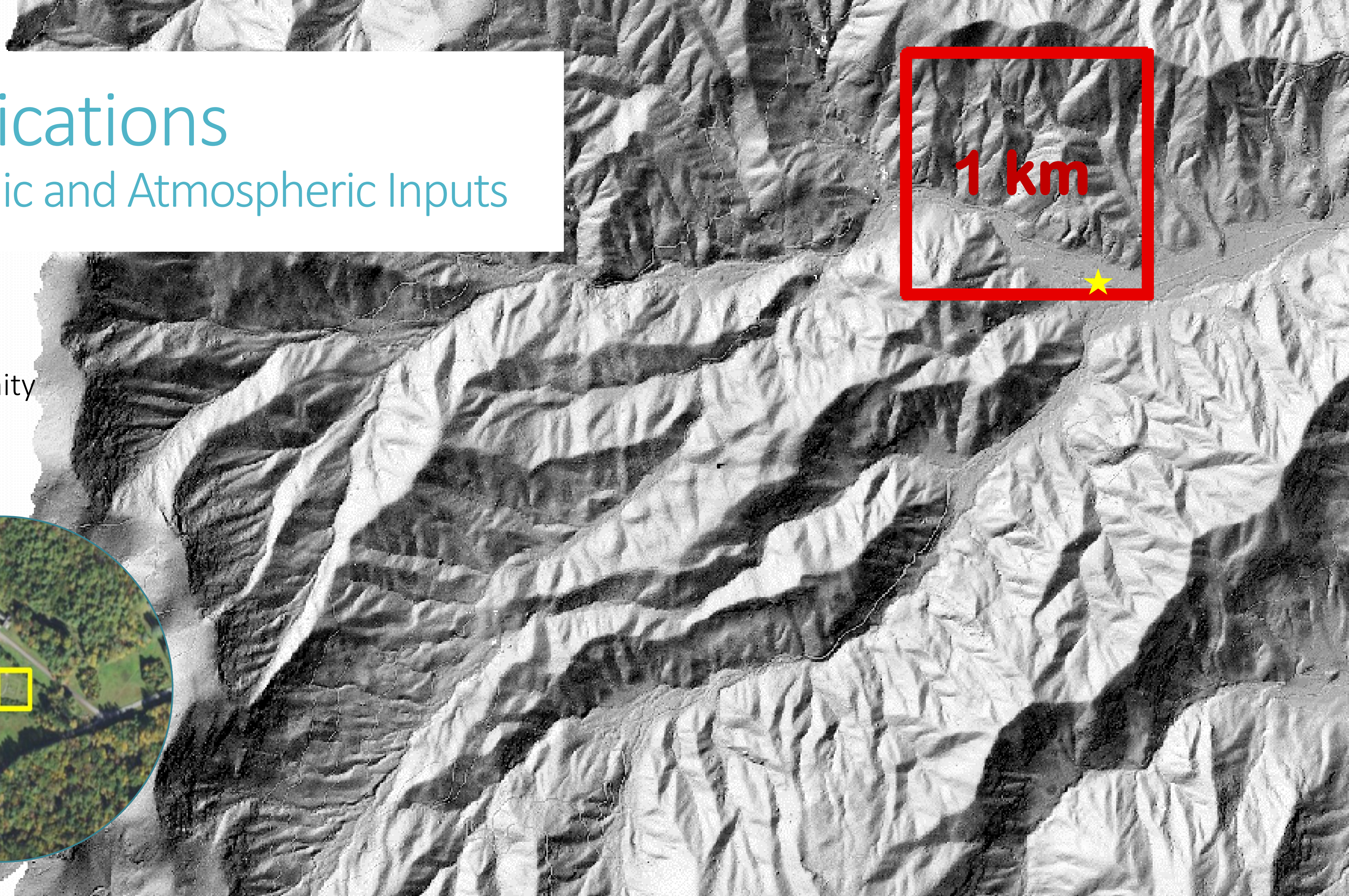
$$n_i = \frac{\rho_i - \rho_{cloud-free}}{\rho_{cloud} - \rho_{cloud-free}}$$

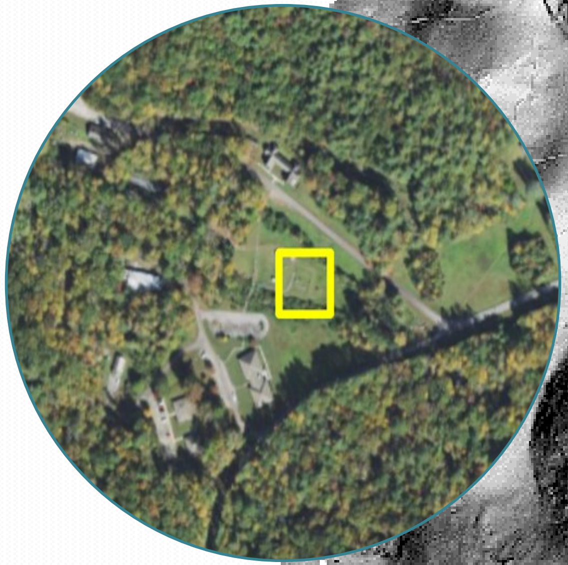
$$K_{c,i} = 1 - n_i$$

Complications

Topographic and Atmospheric Inputs

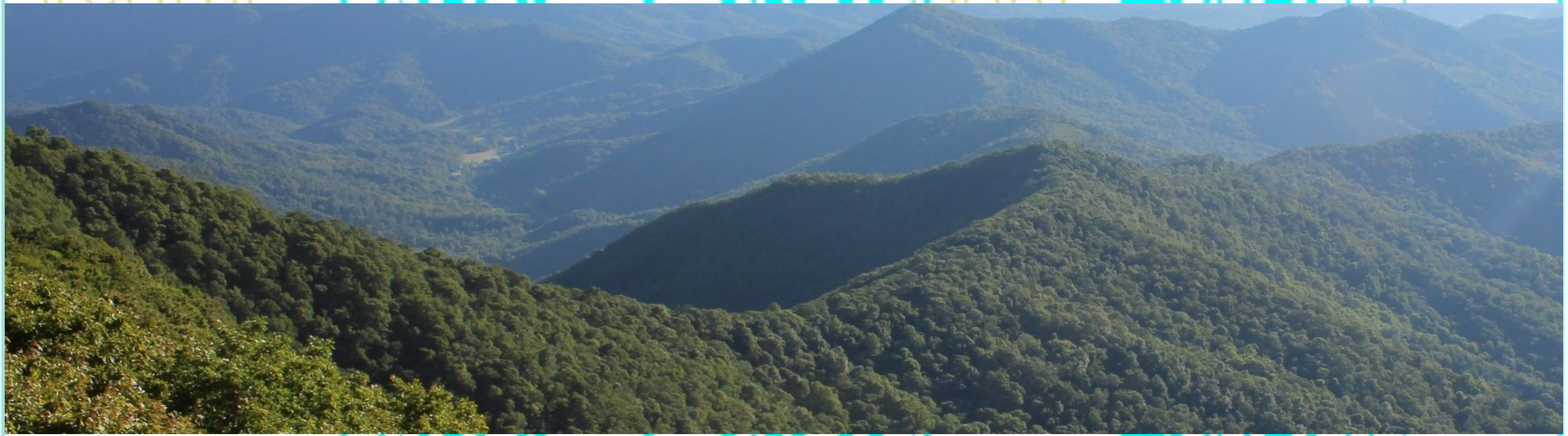
- ❑ Resolutions
- ☆ Edge proximity
- ○ Land cover?





Validation data set

144 “summer” days, 48 measurements/day



Date	Daylight Duration (at 35°N)
1 May	13:39:54
22 June	14:34:38
30 September	11:53:53

1 May to 30 September (153 days, 5 months)

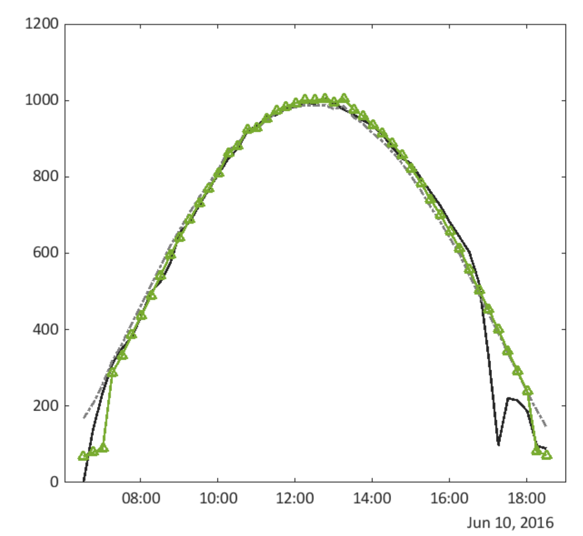
0:630 to 18:30 EST *, 15-minute intervals (48 measurements or images/day)

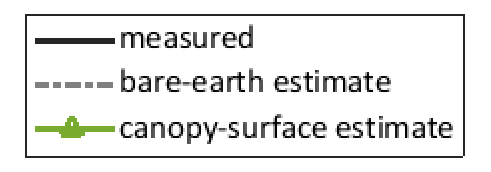
2 years (**2016 and 2017**)

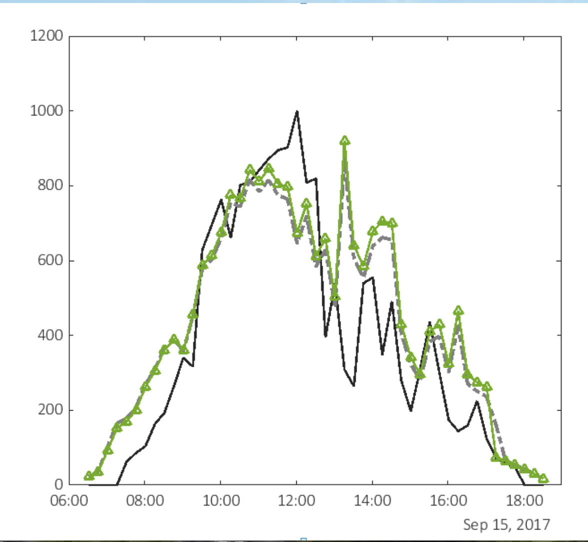
Screened out 162 dates with daytime rain or incomplete imagery

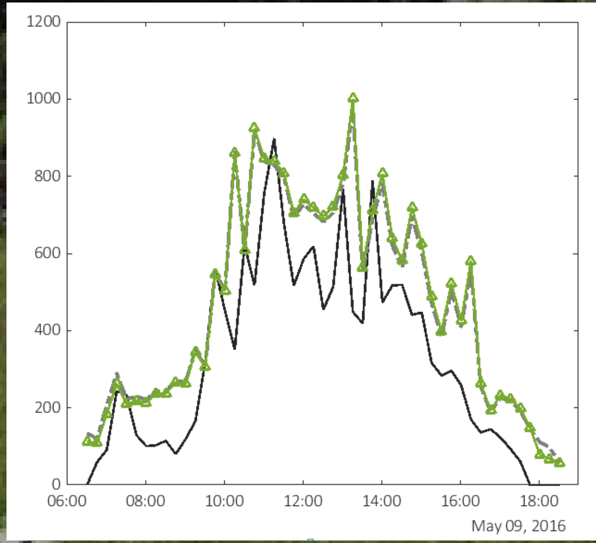
**solar noon ~ 12:30 local standard time*

Estimates v. Measurements









Mean (std dev)	CS01	Bare-earth	Canopy surface
Irradiance(W/m^2) N = 7055	500.4 (308.7)	542.4 (271.1)	546.3 (288.0)
Irradiation(kJ/m^2) N = 144	22068 (4161.7)	23916 (3105)	24084k (2826)

Accuracy of estimates

DEM vs DSM, irradiance vs daily irradiation

Irradiation (J/m^2) N = 144		
	Bare-earth	Canopy surface
RMSE	2498346	2643813
MAPE	10.7%	11.5%
SMAPE	2.4%	2.6%
modSMAPE	4.9%	5.2%

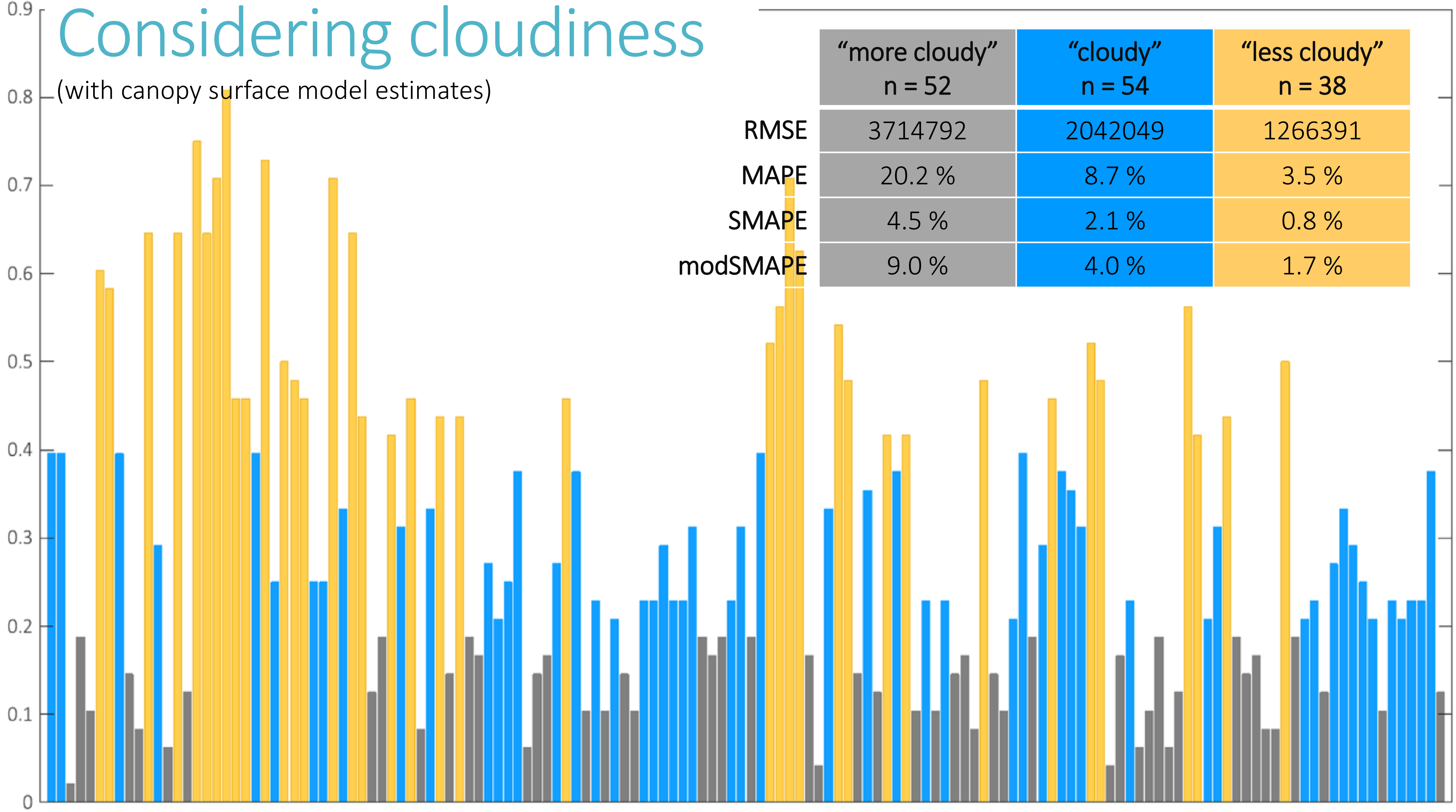
Irradiance (W/m^2) N = 7055		
	Bare-earth	Canopy surface
RMSE	140.9	141.7
*	-	-
SMAPE	9.2%	8.9%
modSMAPE	18.4%	17.7%

* MAPE undefined if a measurement = 0

Considering cloudiness

(with canopy surface model estimates)

	"more cloudy" n = 52	"cloudy" n = 54	"less cloudy" n = 38
RMSE	3714792	2042049	1266391
MAPE	20.2 %	8.7 %	3.5 %
SMAPE	4.5 %	2.1 %	0.8 %
modSMAPE	9.0 %	4.0 %	1.7 %



Initial assessment and next steps

- Not bad, given the challenging climatic conditions of the site and spatial resolution of the GOES 13/GVAR imager
- Share the workflows /open science
- Assess accuracy in different conditions (seasons and regions) …
- Assess the accuracy of estimates with higher spatial, temporal, and spectral resolution imagers deployed since…

	Spatial Resolution for CONUS		
Characteristics	**GOES 15**	**GOES 16/17 - ABI**	**GOES 18/19**
VIS Channel	1 km	0.5 km	0.5 km
Spectral Coverage	5 bands	16 bands	16 bands

References and Acknowledgements

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