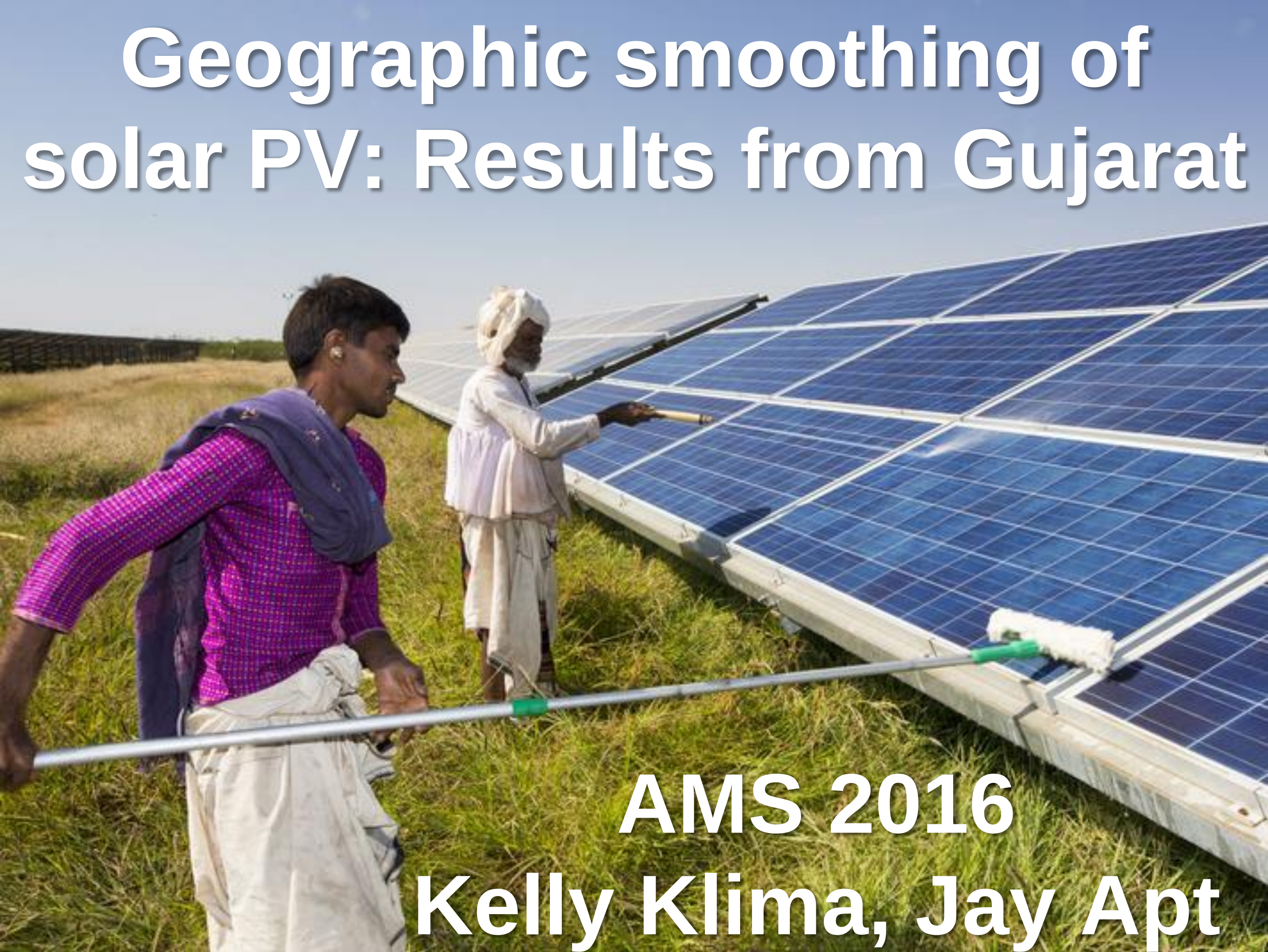
Geographic smoothing of solar PV: Results from Gujarat

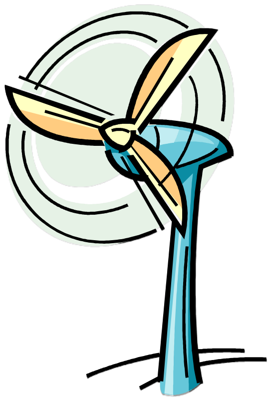


AMS 2016

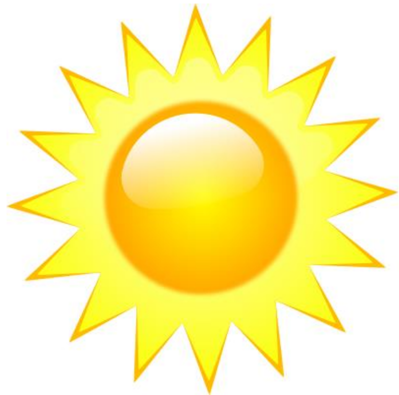
Kelly Klima, Jay Apt

Many forms of renewable energy exist. Some are variable, requiring smoothing.

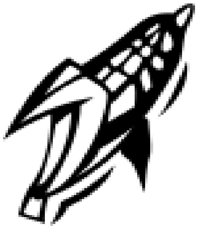
Wind



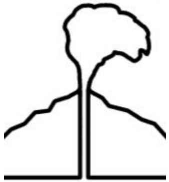
Solar



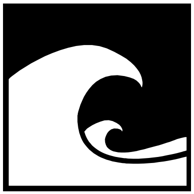
Biomass



Geothermal



Wave

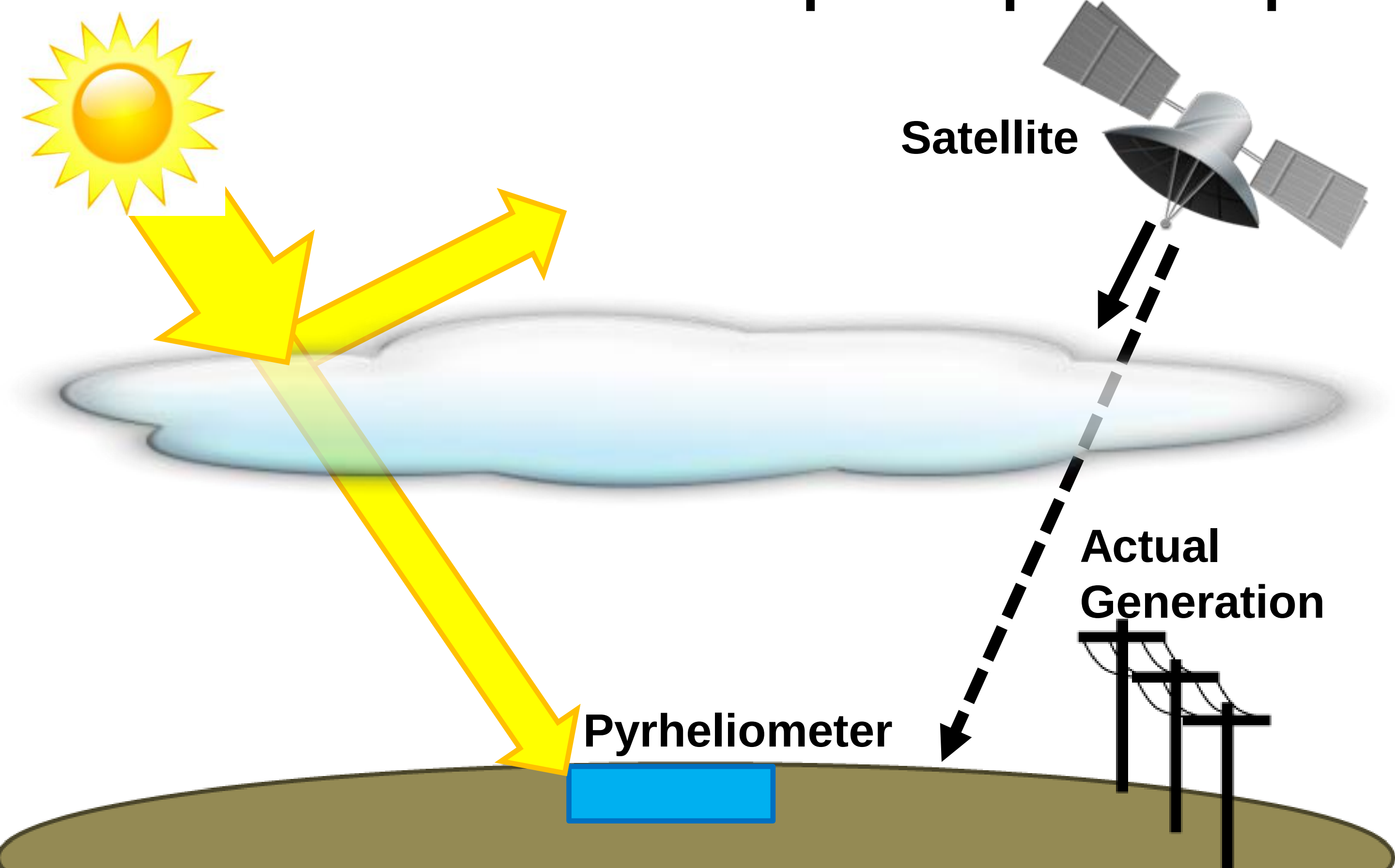


Hydropower

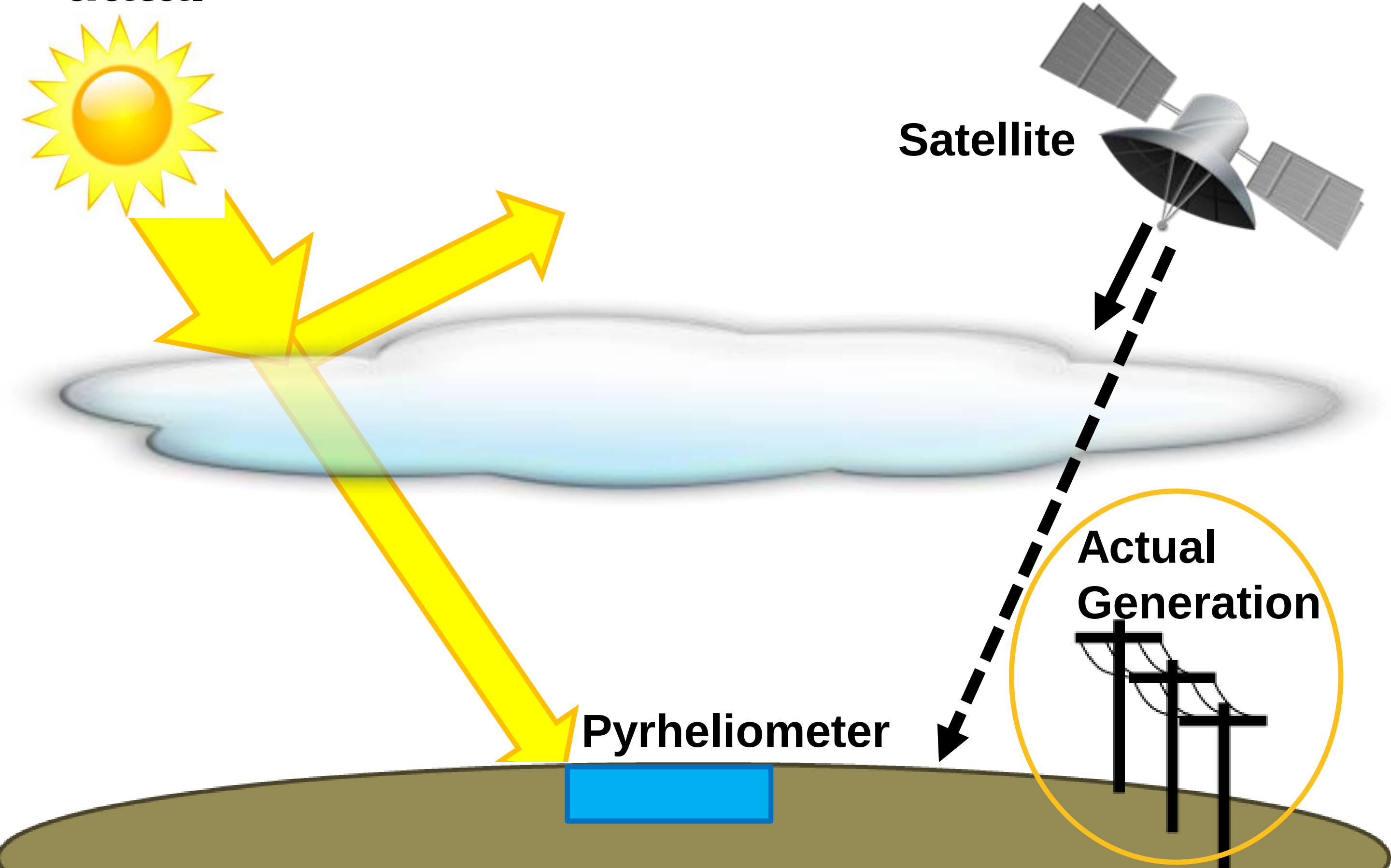
Can solar PV be smoothed?

- Examining Irradiance Data
  - Correlation measured at two locations decreases as the distance between the sites increases. **Long & Ackerman, 1995; Barnett et al., 1998; Lave & Kleissl, 2010, Hinkleman 2013.; Argonne National Labs 2013 etc.**
  - Changes in clear sky index for 23 locations show smoothing is likely for as few as 5 plants. **LBNL 2010.**
- Examining Generation Data
  - In Germany, 5-min ramps in normalized PV power may exceed +/- 50% for 1 plant but never exceed +/- 5% for 100 PV sites. **Wiemken et al., 2001.**
  - Correlation of real power output for three sites in Arizona is high, suggesting smoothing might not work here. **Curtright & Apt, 2008.**
  - Sites at hourly resolution show smoothing. **Rowlands 2014.**

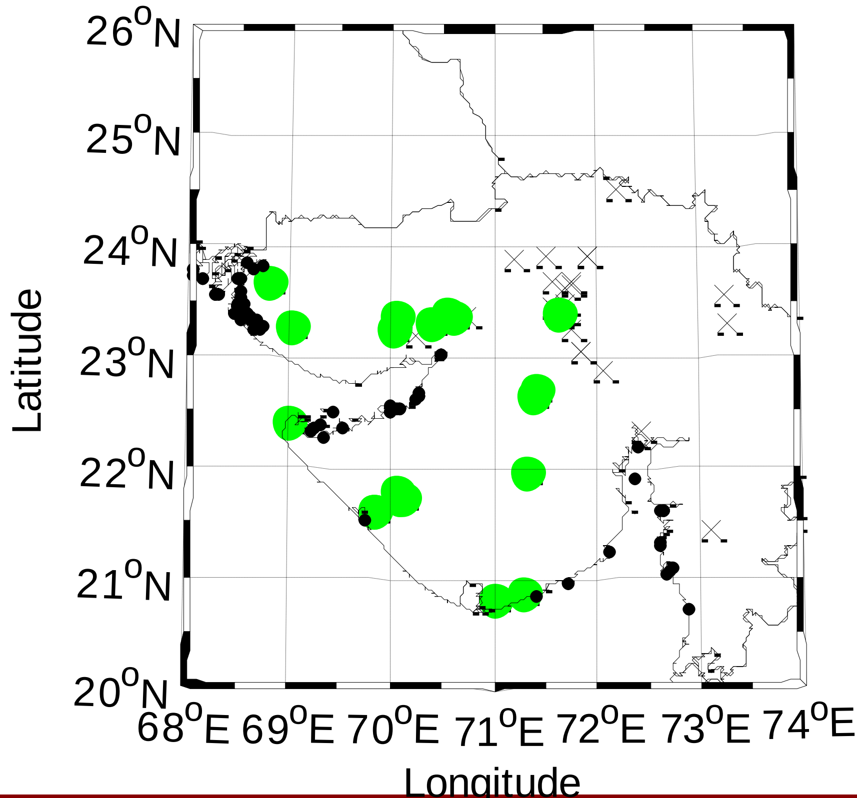
We can measure solar data at several points between the sun and the power plant output.



In this study we examined actual generation data.



We examined generation data from 50 power plants in Gujarat (eastern India).

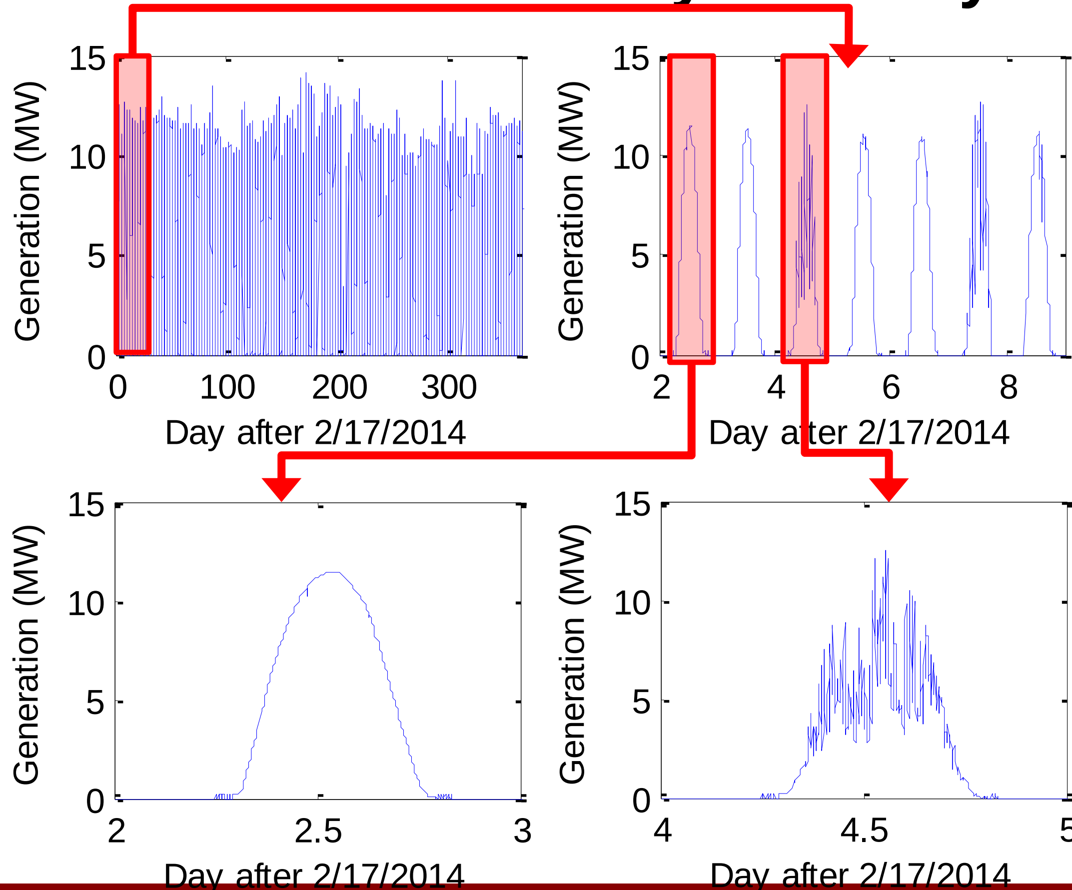


Green = Plants used in rest of presentation

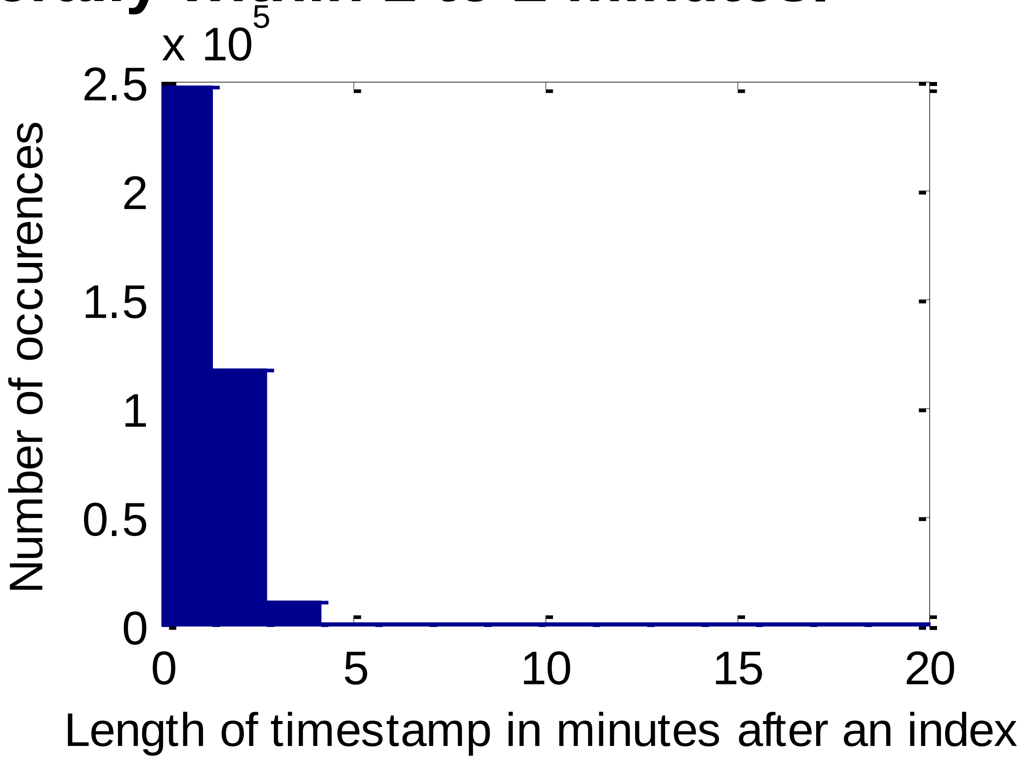
5-221 MW of installed capacity; changed over time.

Source: Gujarat State Load Dispatch Center, downloaded every minute.

Time series show sunny & cloudy days.

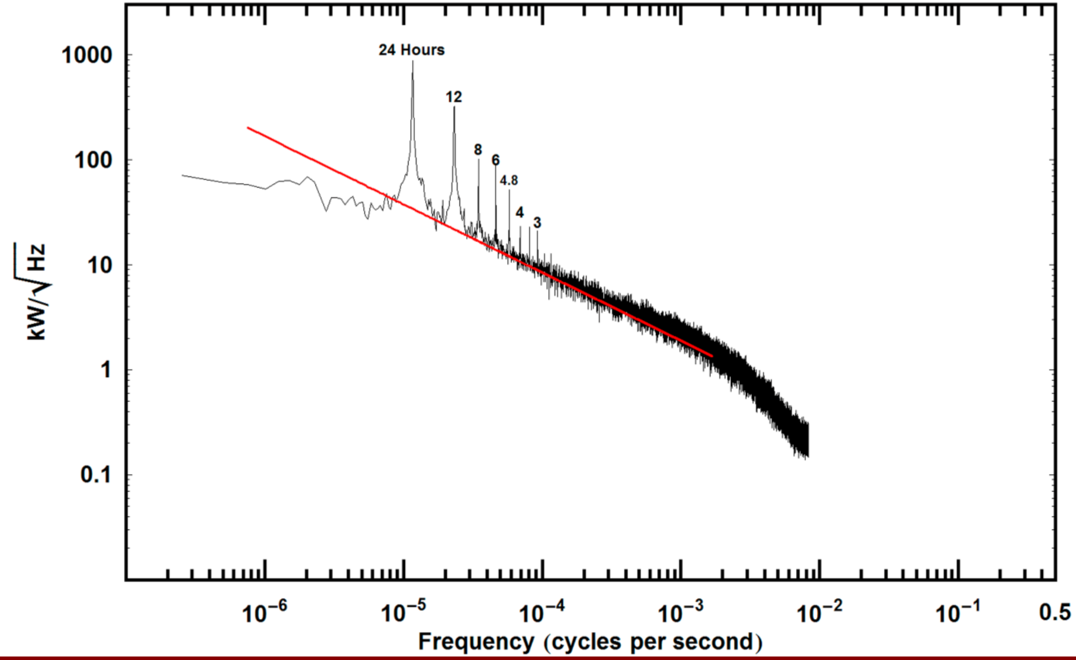


Time stamp intervals were uneven, and generally within 1 to 2 minutes.

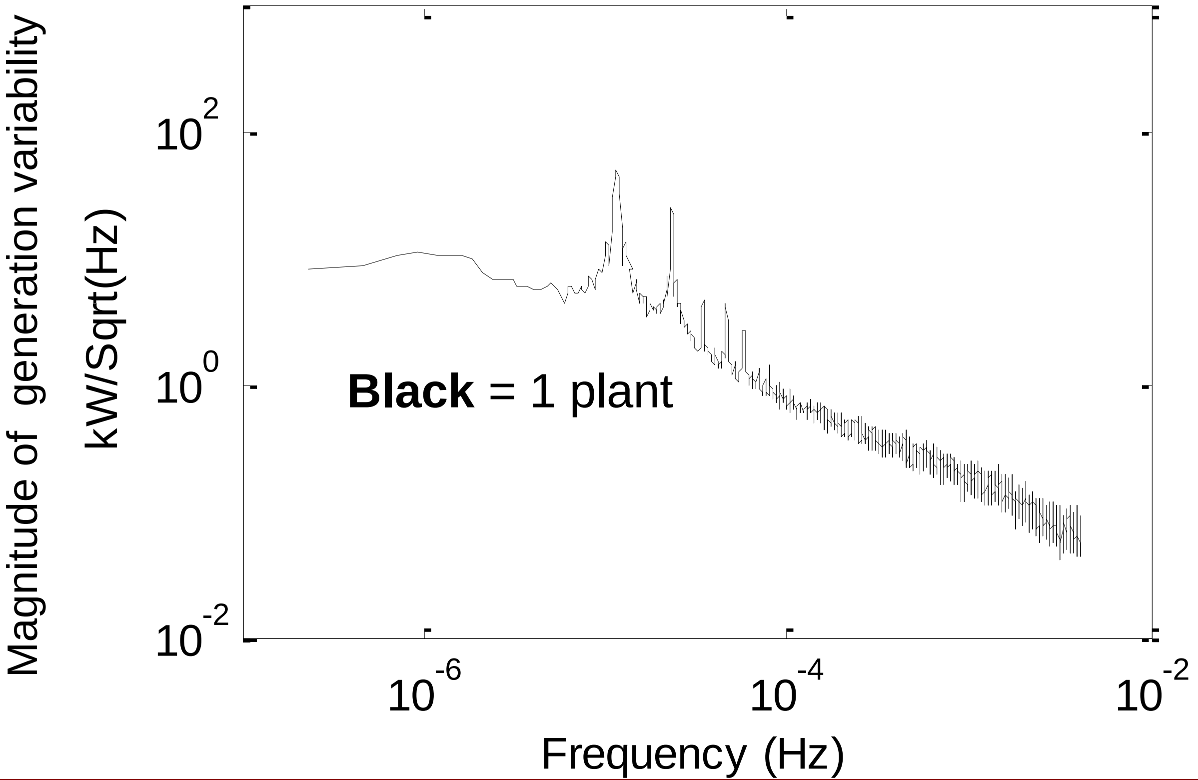


To understand the variability, we looked in the frequency domain.

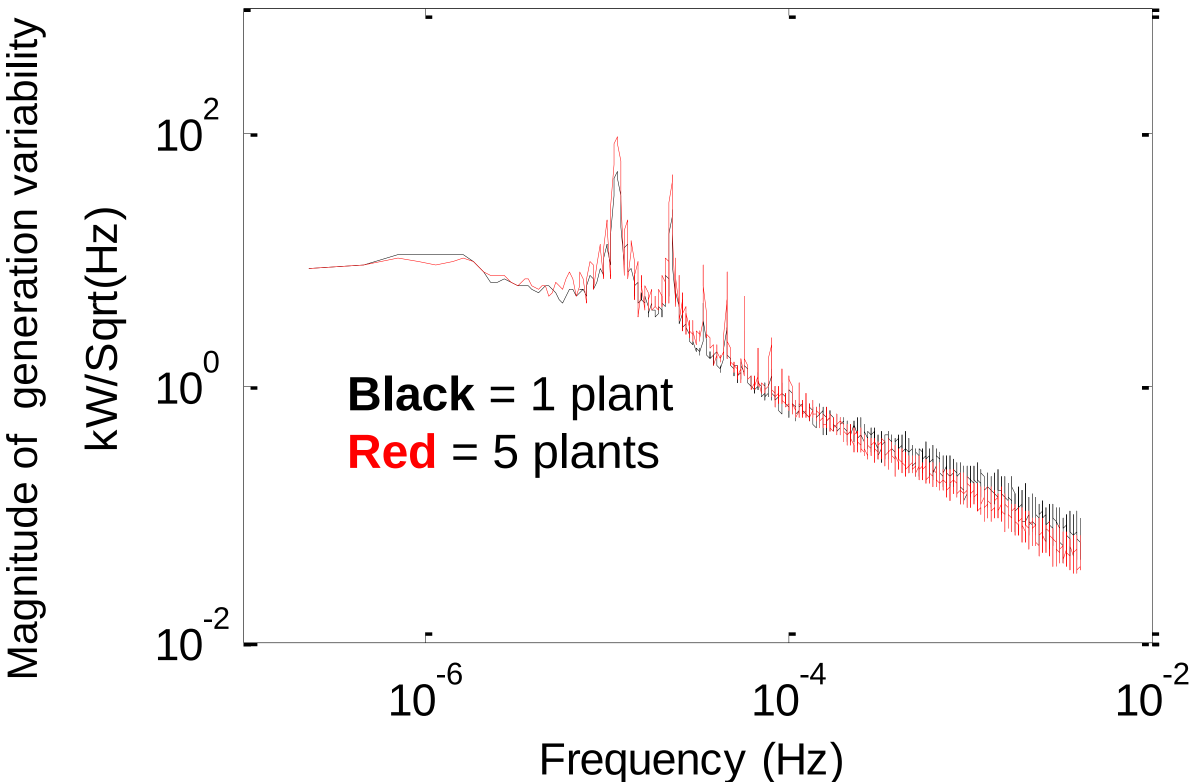
Curtright & Apt 2007: Sample power spectral density (PSD) of a Tucson Electric Power Array; red line is f^-1.3



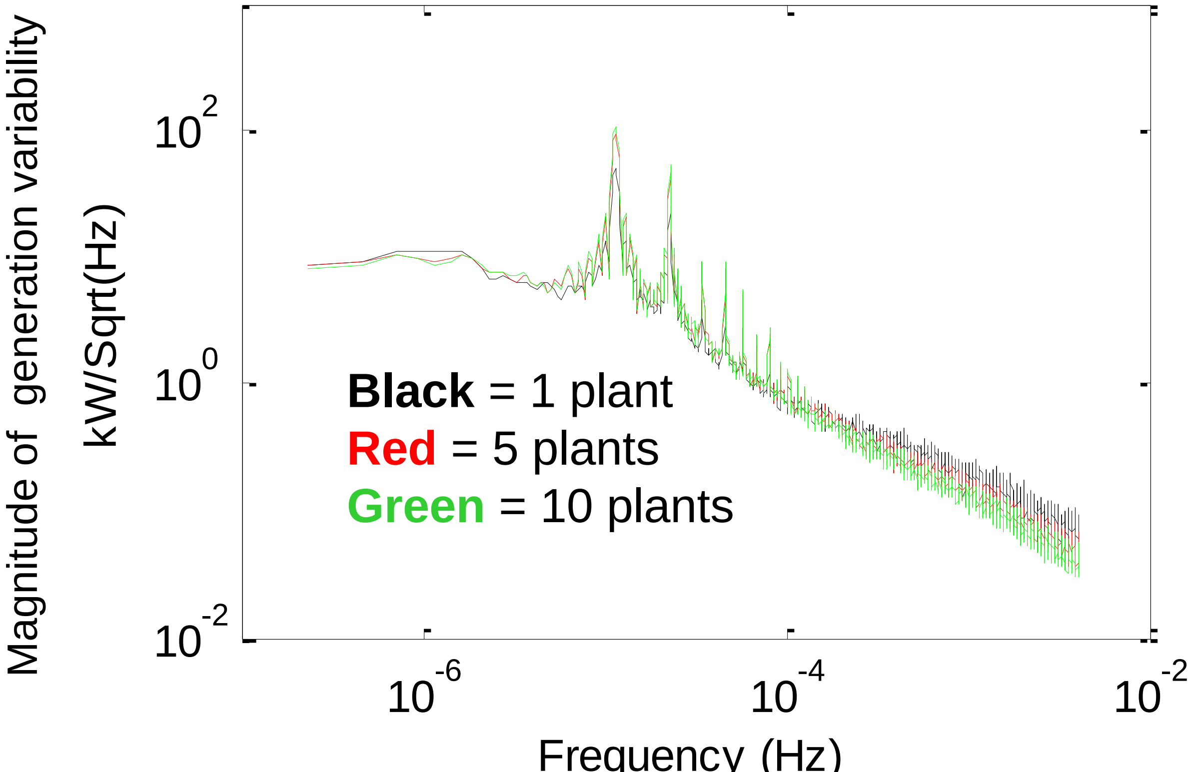
The PSD for one Gujarat plant has a f^1.3 spectra.



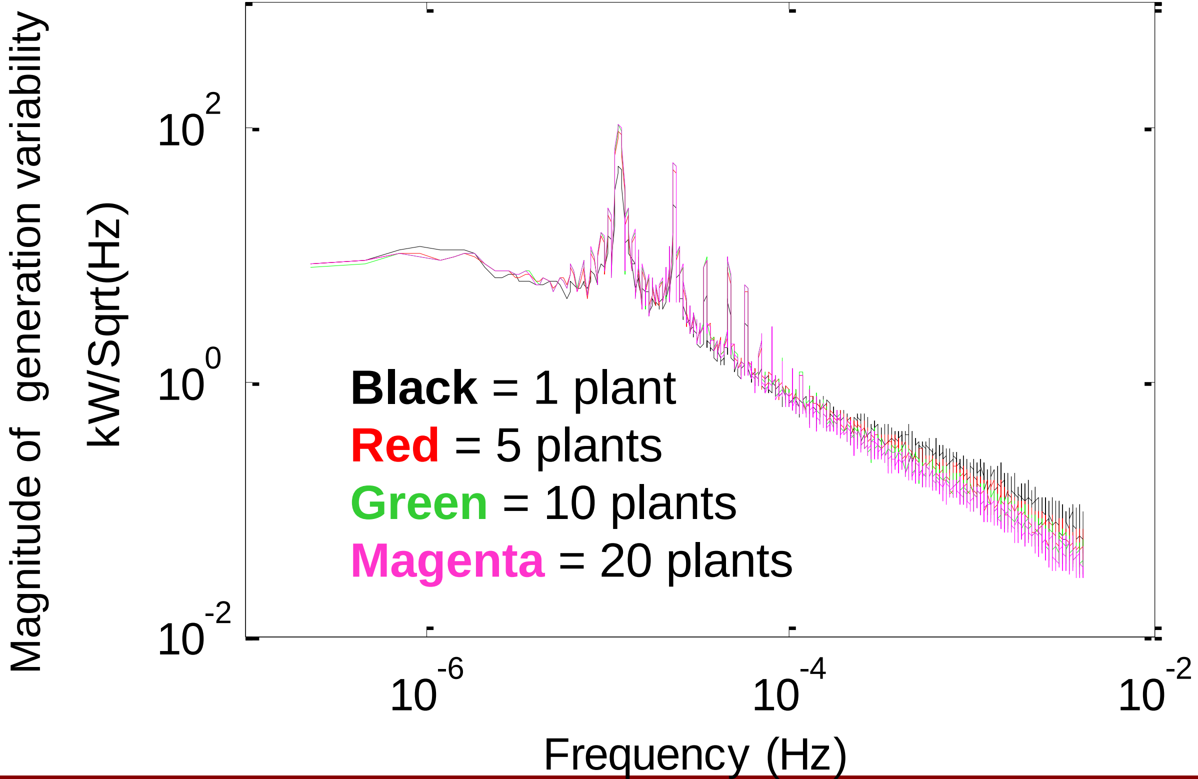
Summing the generation of the 5 closest plants smoothens higher frequencies.



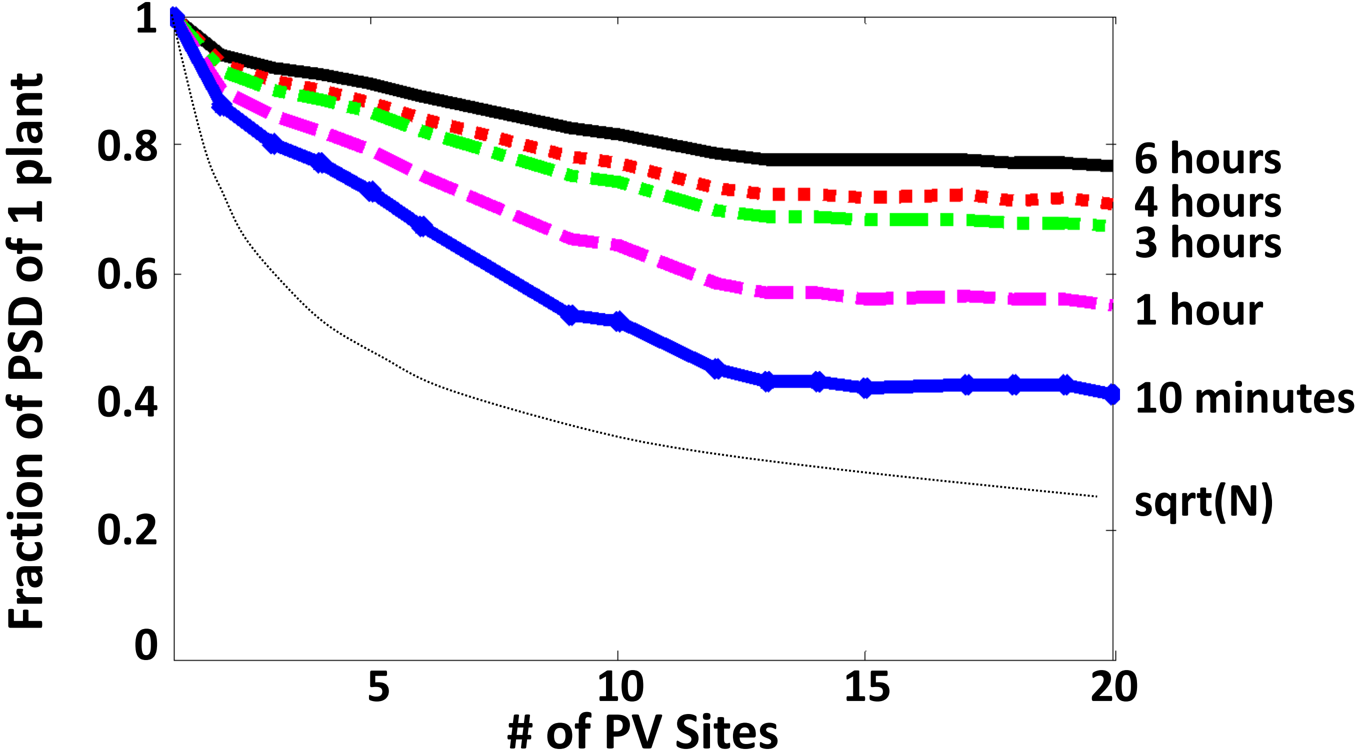
There appear to be diminishing returns with adding plants together.



The amount of smoothing achieved with 20 plants is almost the same as with 10 plants.

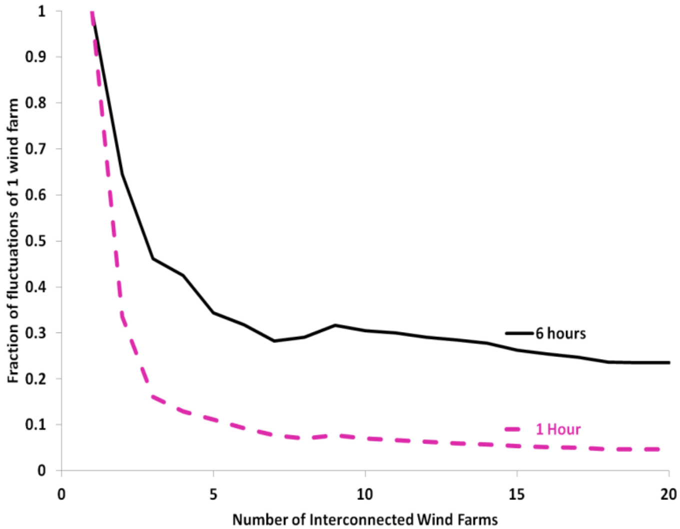


Interconnecting a few solar plants achieves the majority of smoothing.

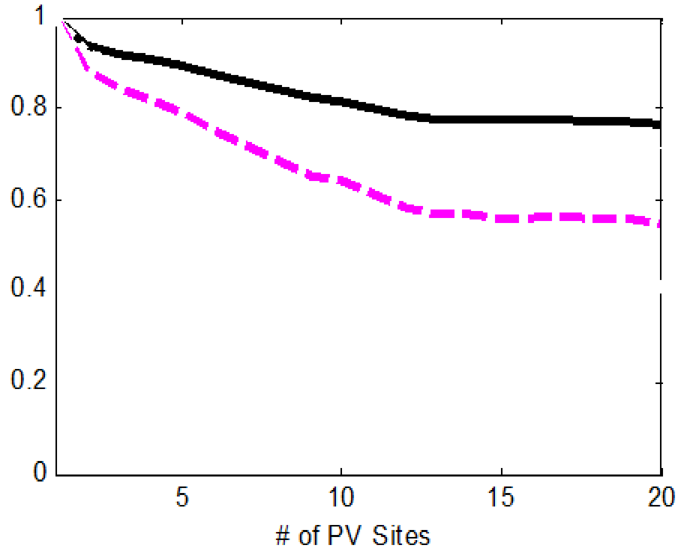


MUCH less smoothing than for wind

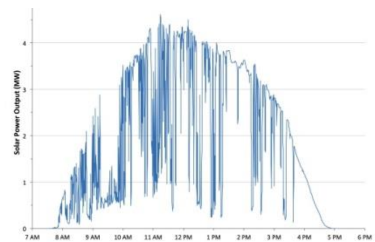
Wind



PV



That is probably because PV's deep power fluctuations lead to variability at many frequencies.



Conclusions

- Interconnecting 20 Gujarat plants yields a f^-1.66 spectrum and reduces fluctuations at frequencies corresponding to 6 hours and 1 hour by 23% and 45%, respectively. Half of this smoothing can be obtained through connecting 4-5 plants.

- The largest plant (322MW) showed an f^-1.76 spectrum. This suggests that in Gujarat the potential for smoothing is limited to that obtained by one large plant.

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Extra slides

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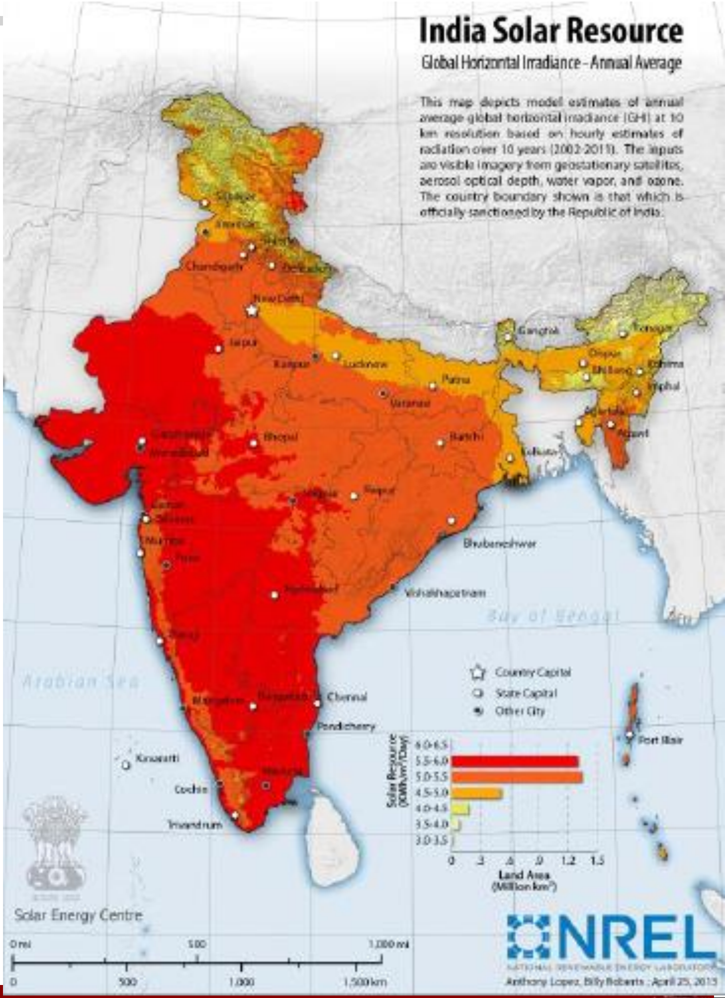
NREL calculated solar data from 2002-2011.

- SUNY model: created for U.S. observations
- 1° x 1°
- Calculated direct normal irradiance, direct horizontal irradiance, and global horizontal irradiance
- Values almost as high as Arizona.



Carnegie Mellon

We compared NREL calculated irradiance with generation data in Arizona.

- Pairwise correlation, Actual vs NREL. Values are given as: GHI correlation, (DNI correlation)

Springerville (1/1/2004-12/31/2005)	Cimarron (10/12/2010-12/31/2005)	NREL SUNY	NREL Metstat	8am-8pm LT	10am-6pm LT	Noon-4pm LT
✓		✓		0.79, (0.60)	0.79, (0.61)	0.79, (0.61)
✓			✓	0.77, (0.60)	0.76, (0.6)	0.76, (0.6)
	✓		✓	0.75, (0.69)	0.44, (0.41)	0.19, (0.35)

- This suggests that we might be able to use the NREL insolation data to predict generation data in India.

Since correlations were not 1-1, we decided to use actual generation data.

- **Data Locators:** IITB's Rangan Banjeree & Rhythm Singh
- **Data Source:** State Load Dispatch Center for Gujarat, India
- **Download and Conversion Advisors:** Eric Brundick, Terrence Wong, Joe Jewell, Jeremy Boulton, Eric Morganson.