Developing Solar Forecasting Model Diagnostics of Cloud Impacts on Solar Variability

Laura D. Riihimaki[1], Joseph Sedlar[1], Kathy Lantz[1], Larry Berg[2]

1. CIRES at GMD Global Radiation Group
2. Pacific Northwest National Laboratory

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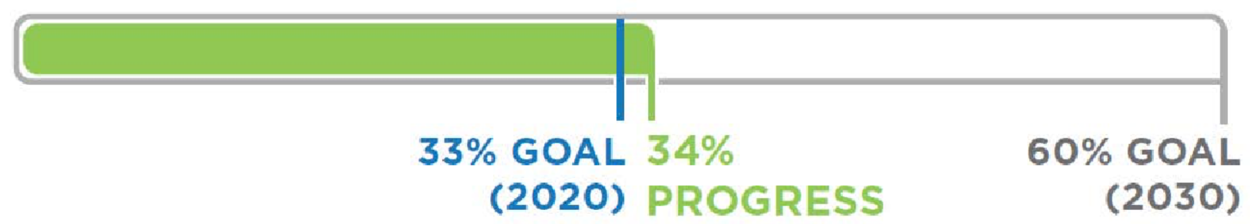
Increasing use of renewables in US electric grid

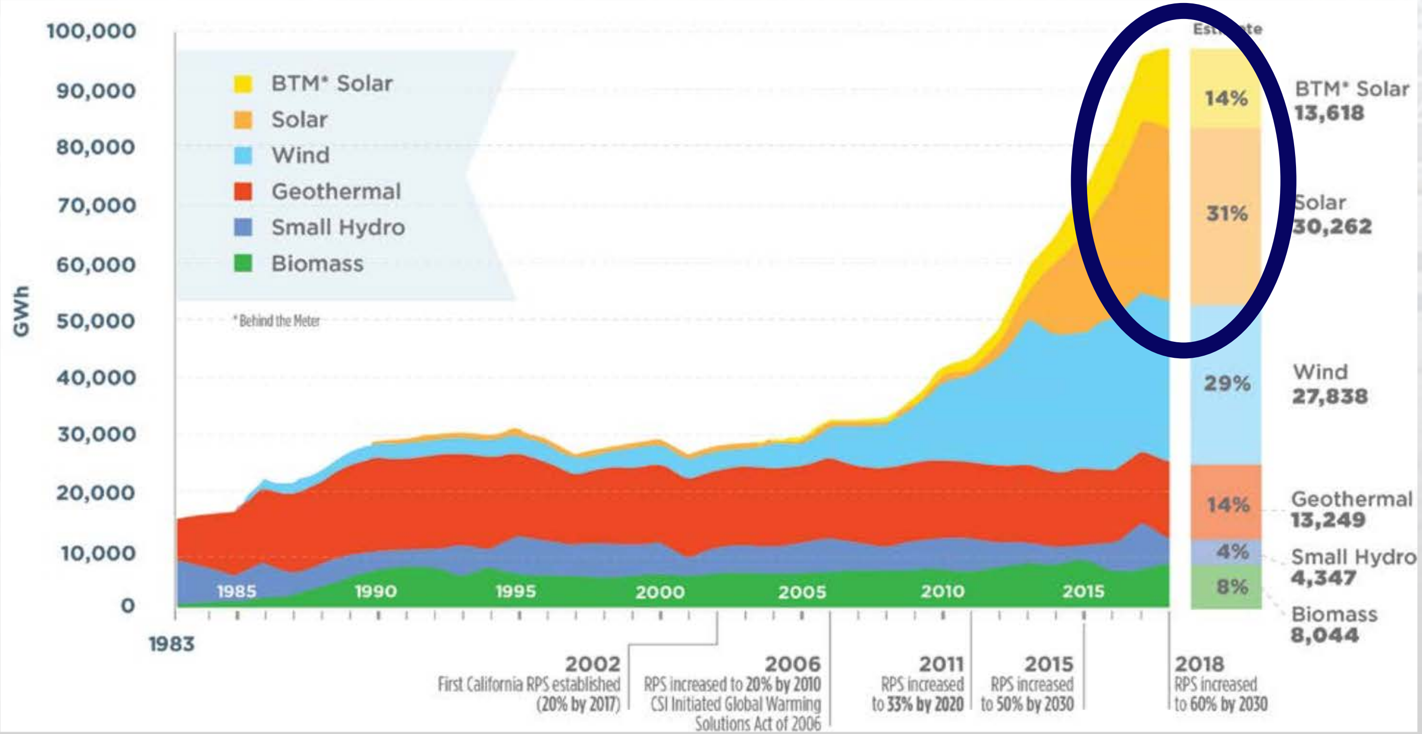
Figure 1. Estimated Current Renewables Portfolio Standard Progress



Source: California Energy Commission, staff analysis November 2018

California now has > 10% of electricity from Solar!

Figure 4. Total Renewable Generation Serving California Load by Resource Type



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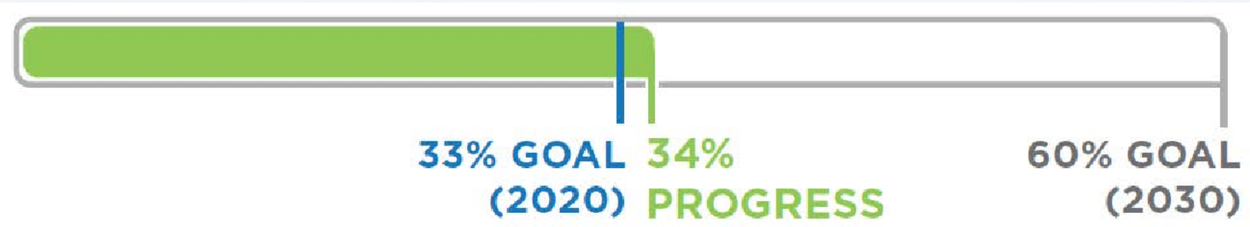

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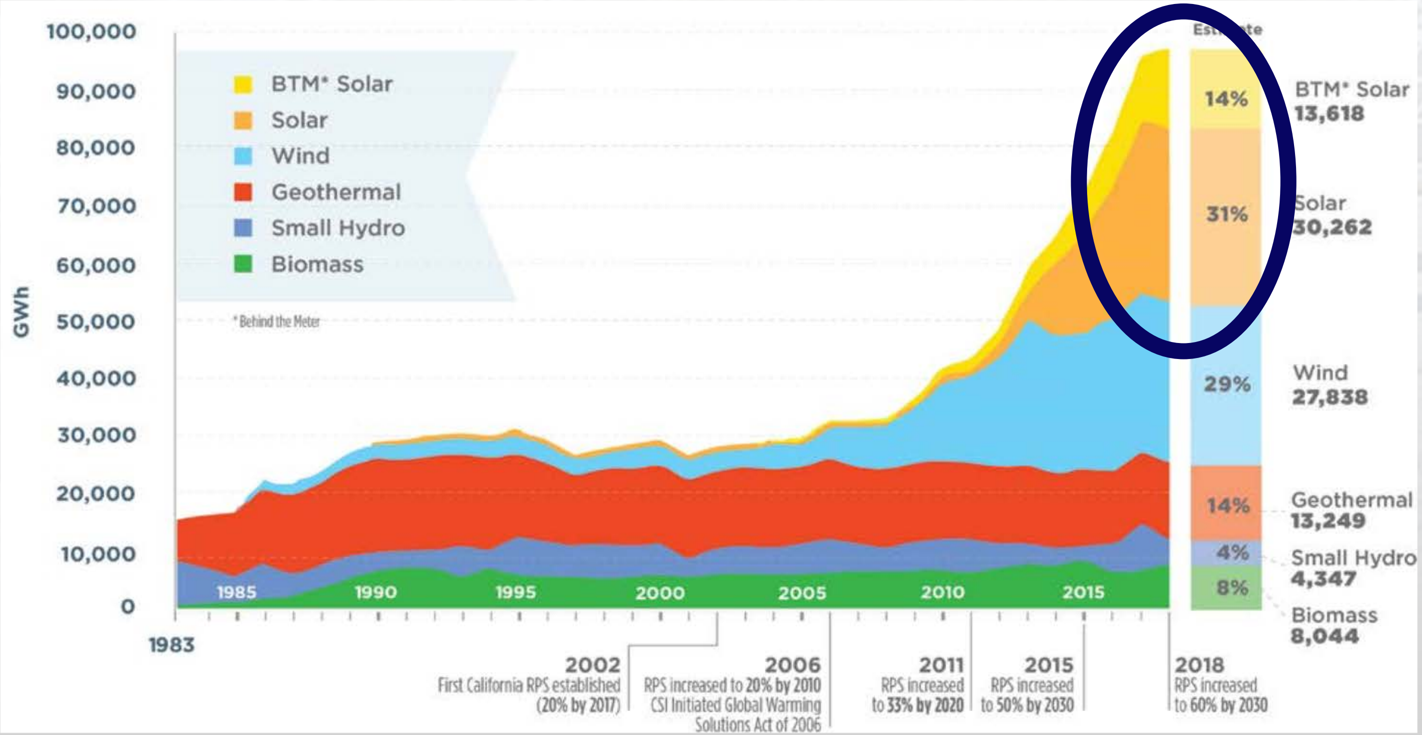
California now has > 10% of electricity from Solar!

Figure 4. Total Renewable Generation Serving California Load by Resource Type



Source: California Energy Commission, staff analysis November 2018

Significant challenge in incorporating a high penetration of solar energy into the electric grid is variability!

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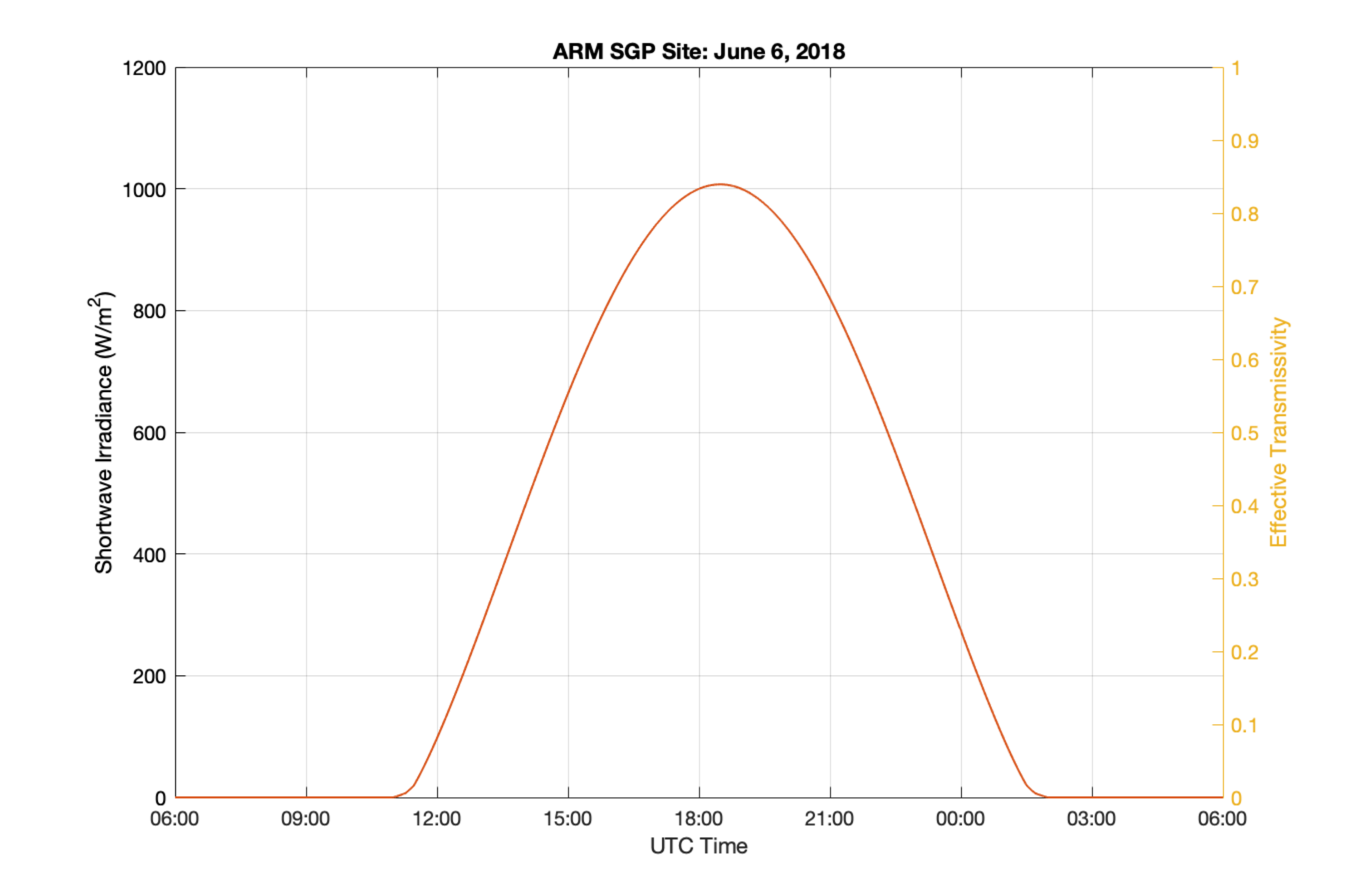
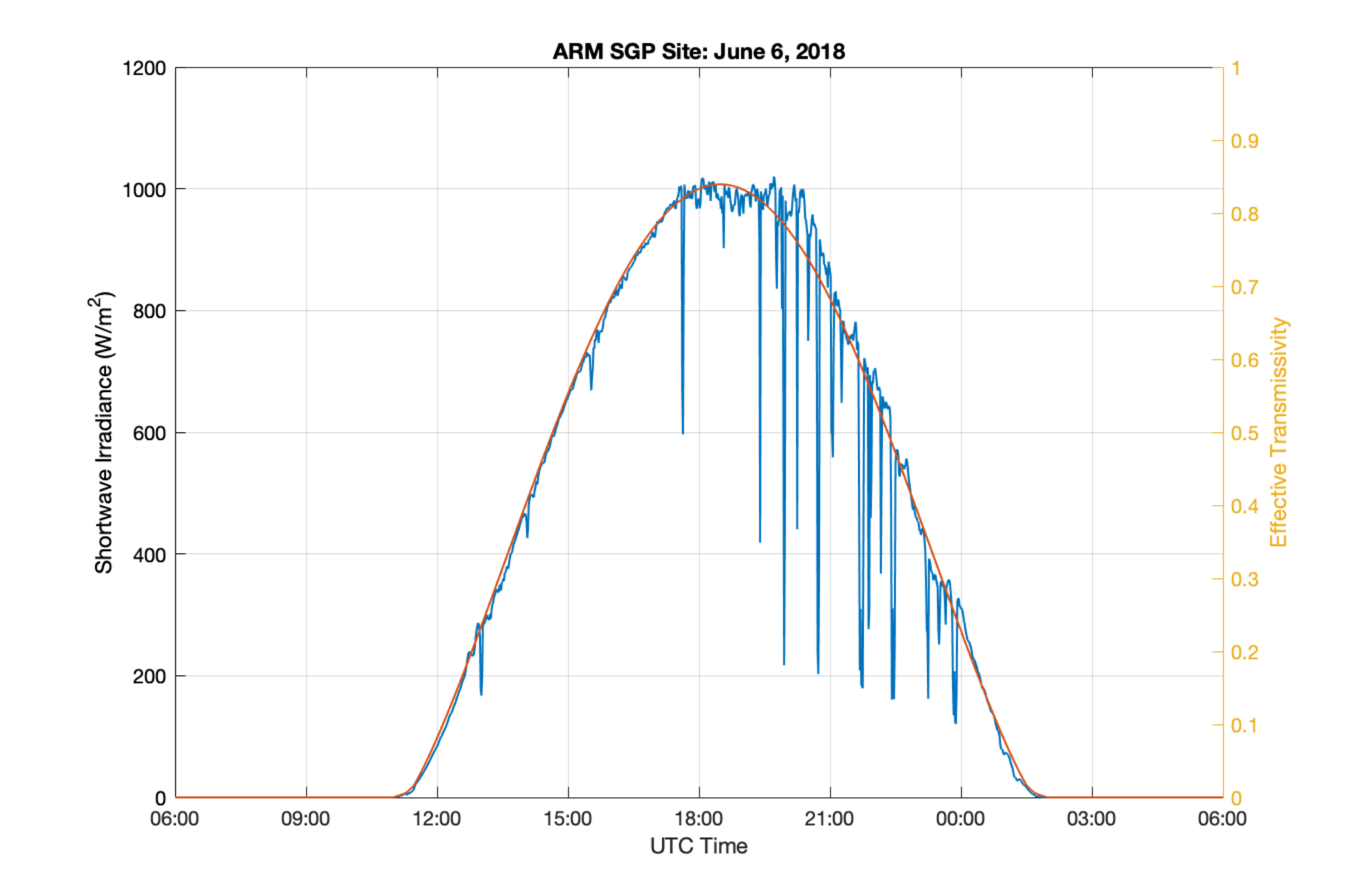
Variability can be better managed if we can predict it

- Clear sky surface solar radiation is variable but predictable



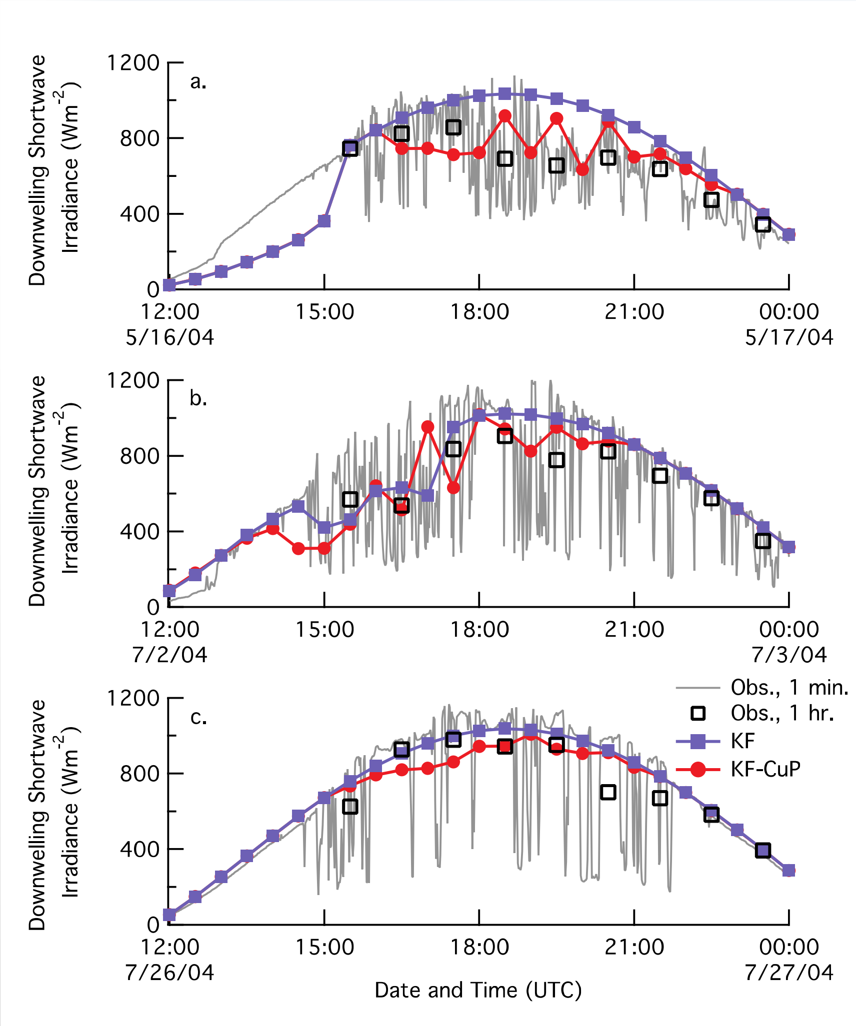
Variability can be better managed if we can predict it

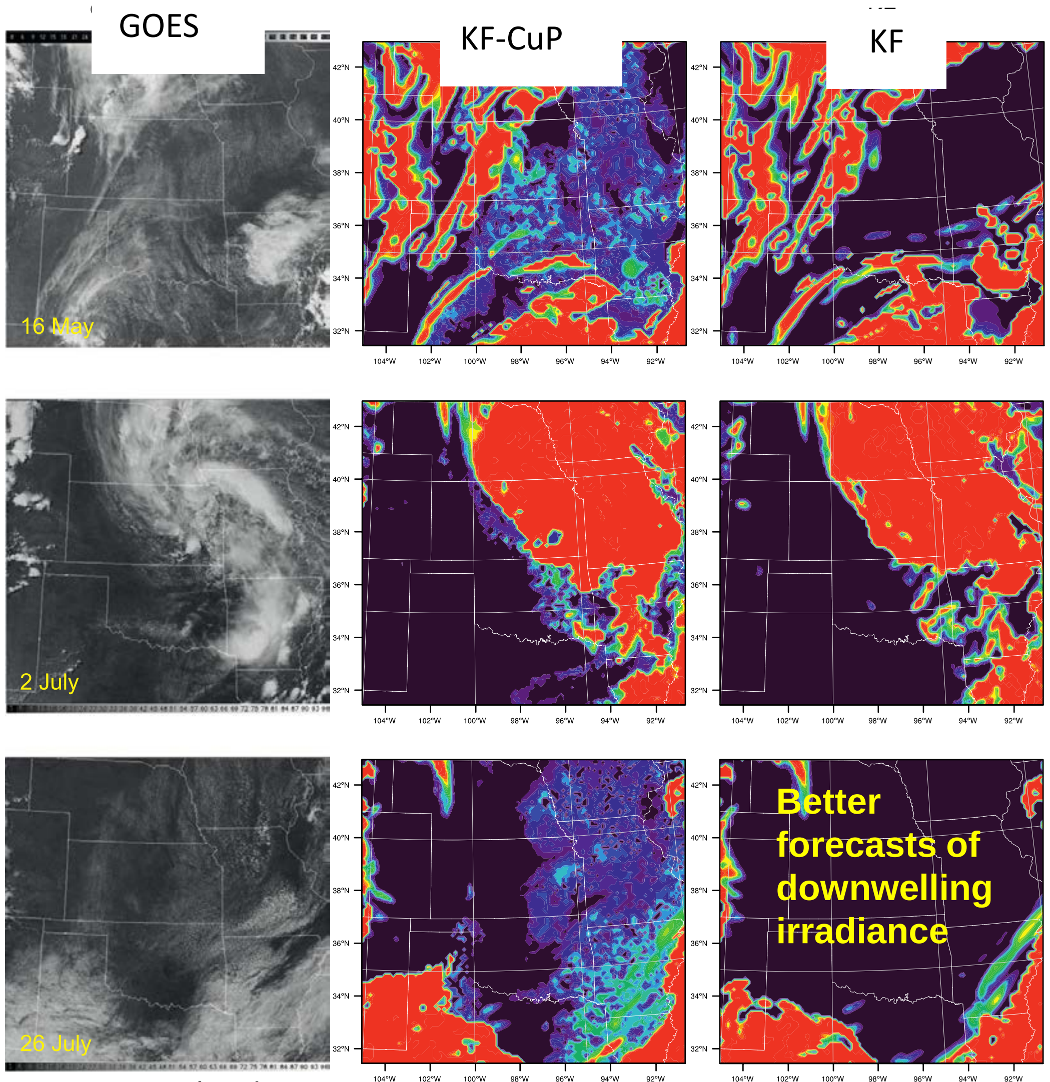
- Clear sky surface solar radiation is variable but predictable
- Cloud effects are the toughest challenge to predict well!



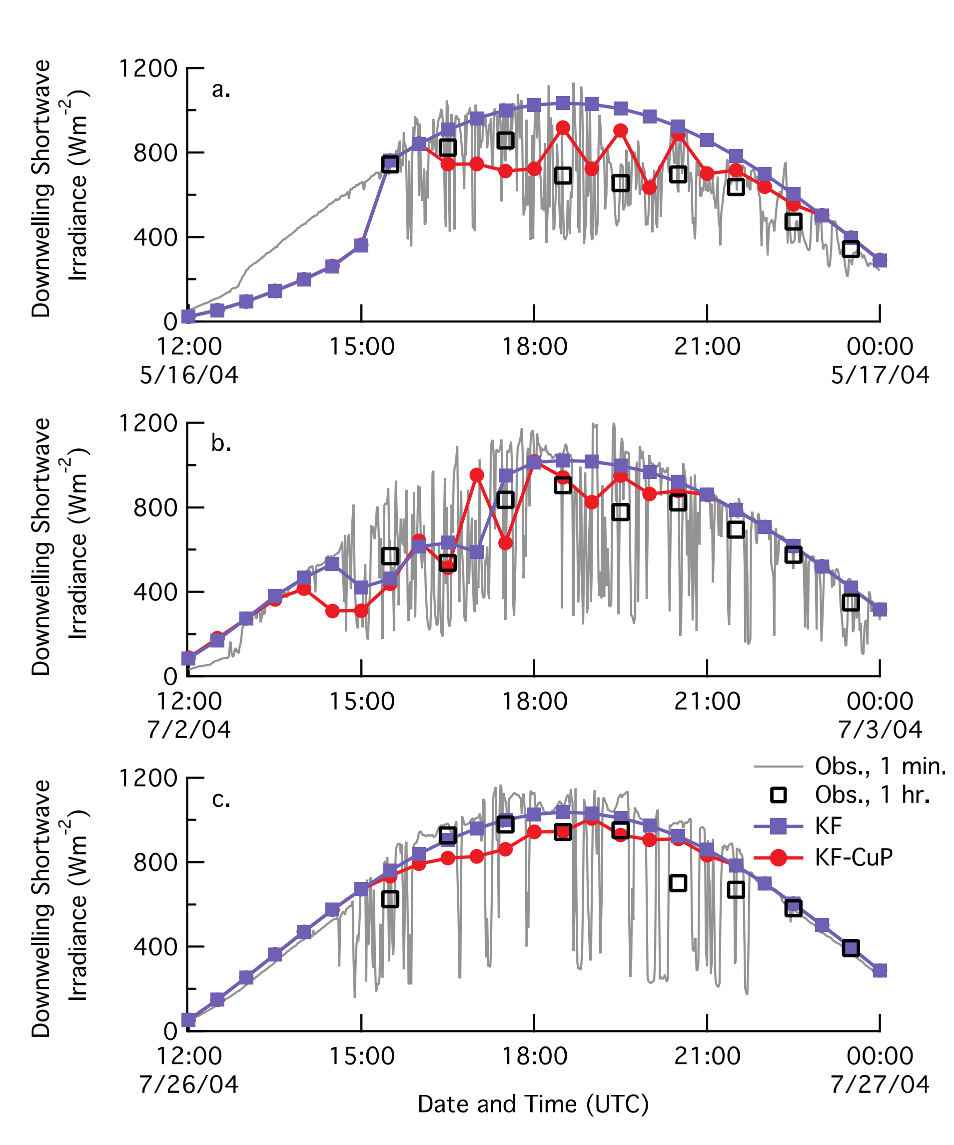
Assessing and improving the utility of weather forecast models for solar forecasting using ground-based observations

Using surface irradiance measurements to evaluate model improvements in cloud parameterizations



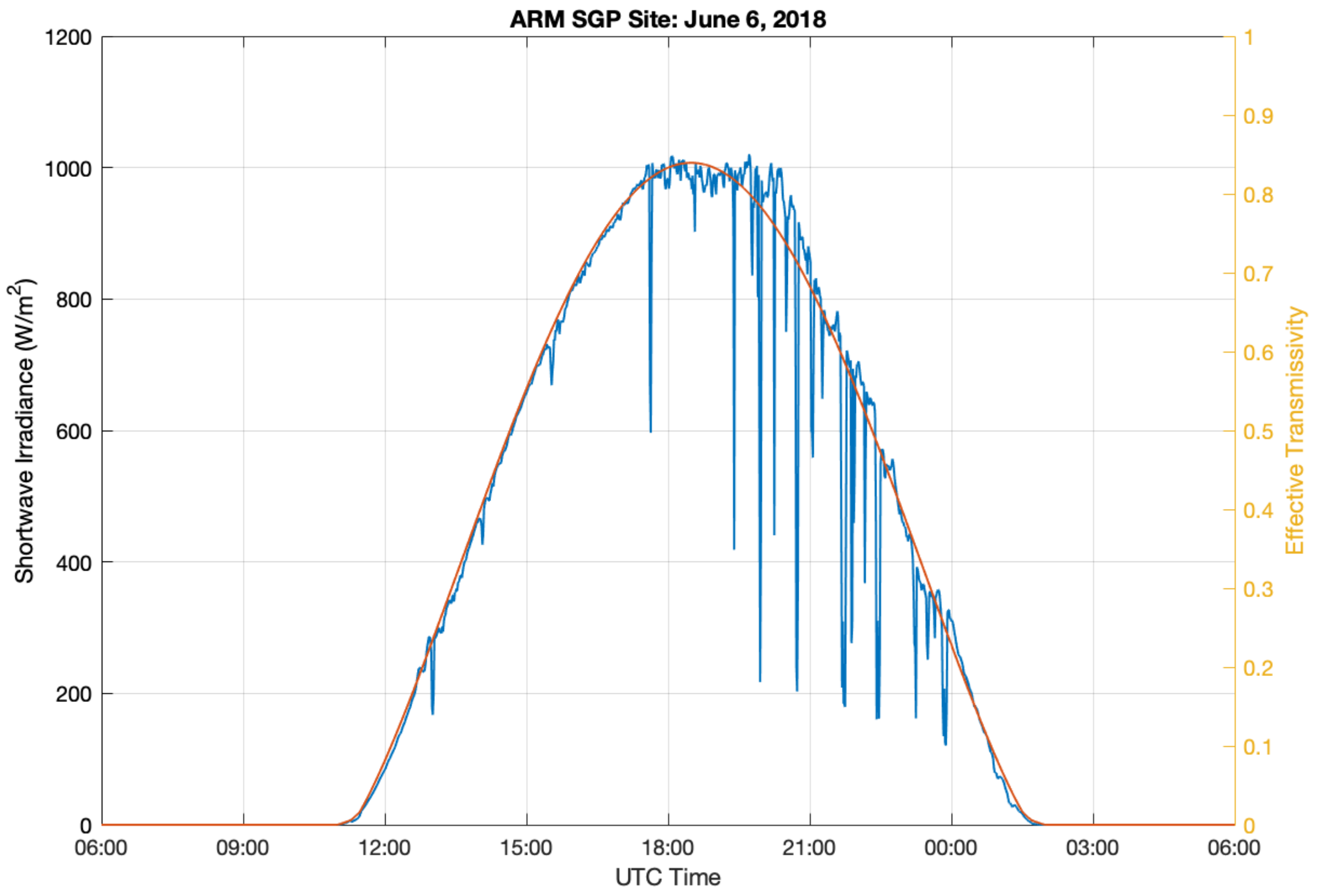


Need new ways to predict variability from models



- Observations show large variability in irradiance with broken clouds
- That variability is not currently captured in the model
- Develop a new parameterization to include that variability in the model

Approach: Build observational metrics of surface shortwave variability under different cloud types that can be incorporated into forecast models

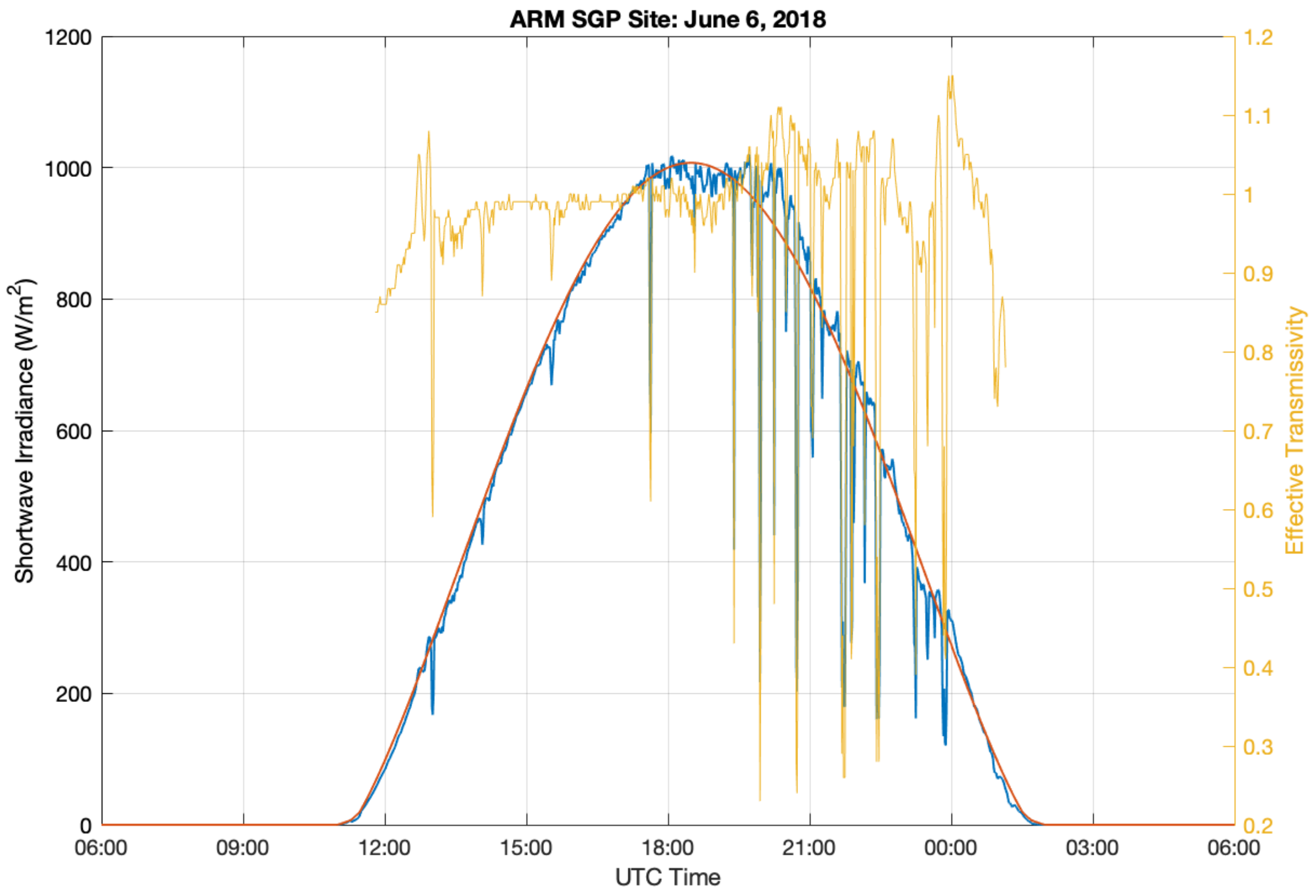


Approach: Build observational metrics of surface shortwave variability under different cloud types that can be incorporated into forecast models

1. Separate the variability due to clouds from solar geometry.

Effective Transmissivity:

$$ET = \frac{Measured\ SW\ Irradiance}{Clear\ Sky\ SW\ Irradiance}$$



Clear Sky calculated using Chuck Long's Radiative Flux Analysis, Long and Ackerman (2000)

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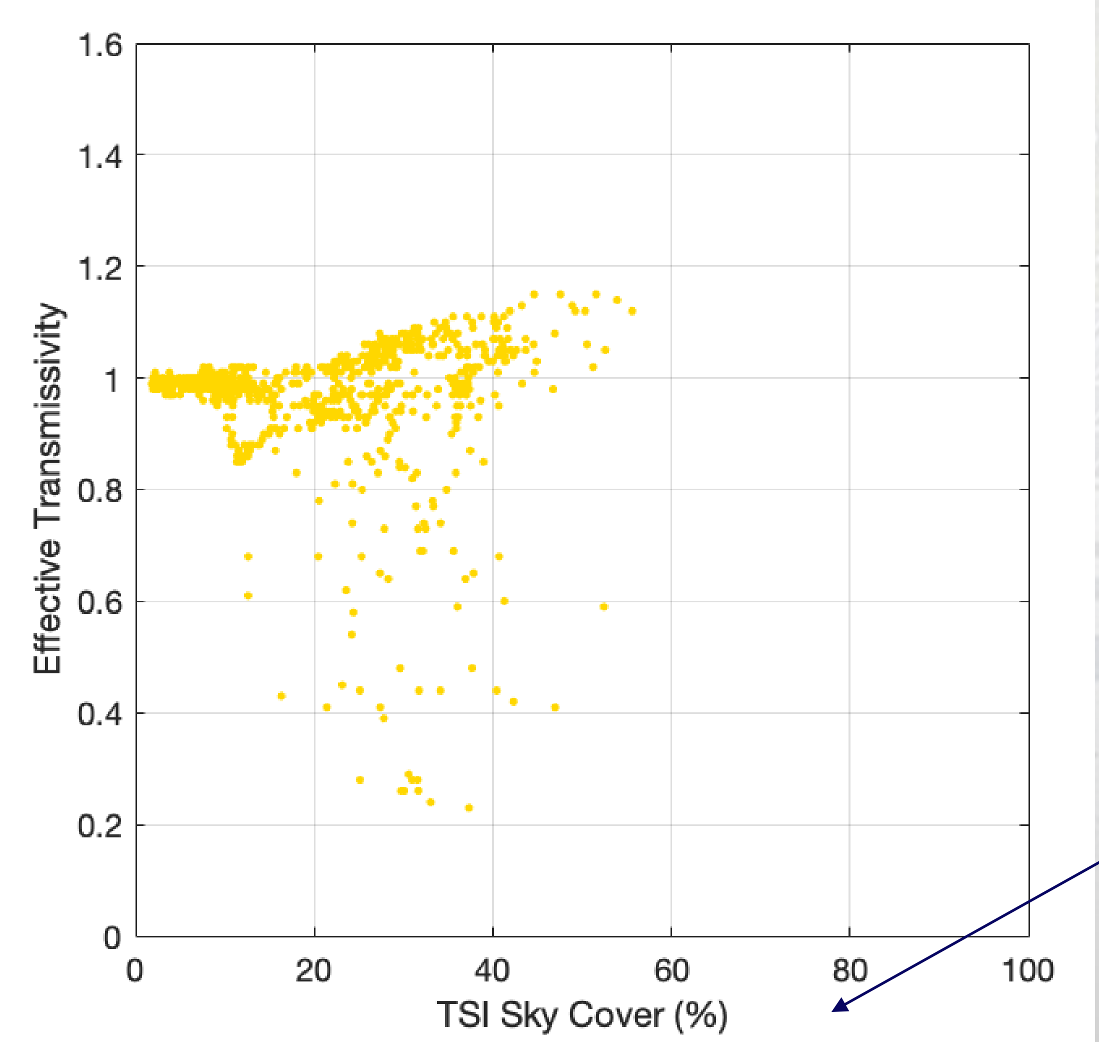
Approach: Build observational metrics of surface shortwave variability under different cloud types that can be incorporated into forecast models

2. Characterize the relationship between Effective Transmissivity and cloud fraction



Total Sky Imager measures fractional sky cover (cloud fraction)

Approach: Build observational metrics of surface shortwave variability under different cloud types that can be incorporated into forecast models

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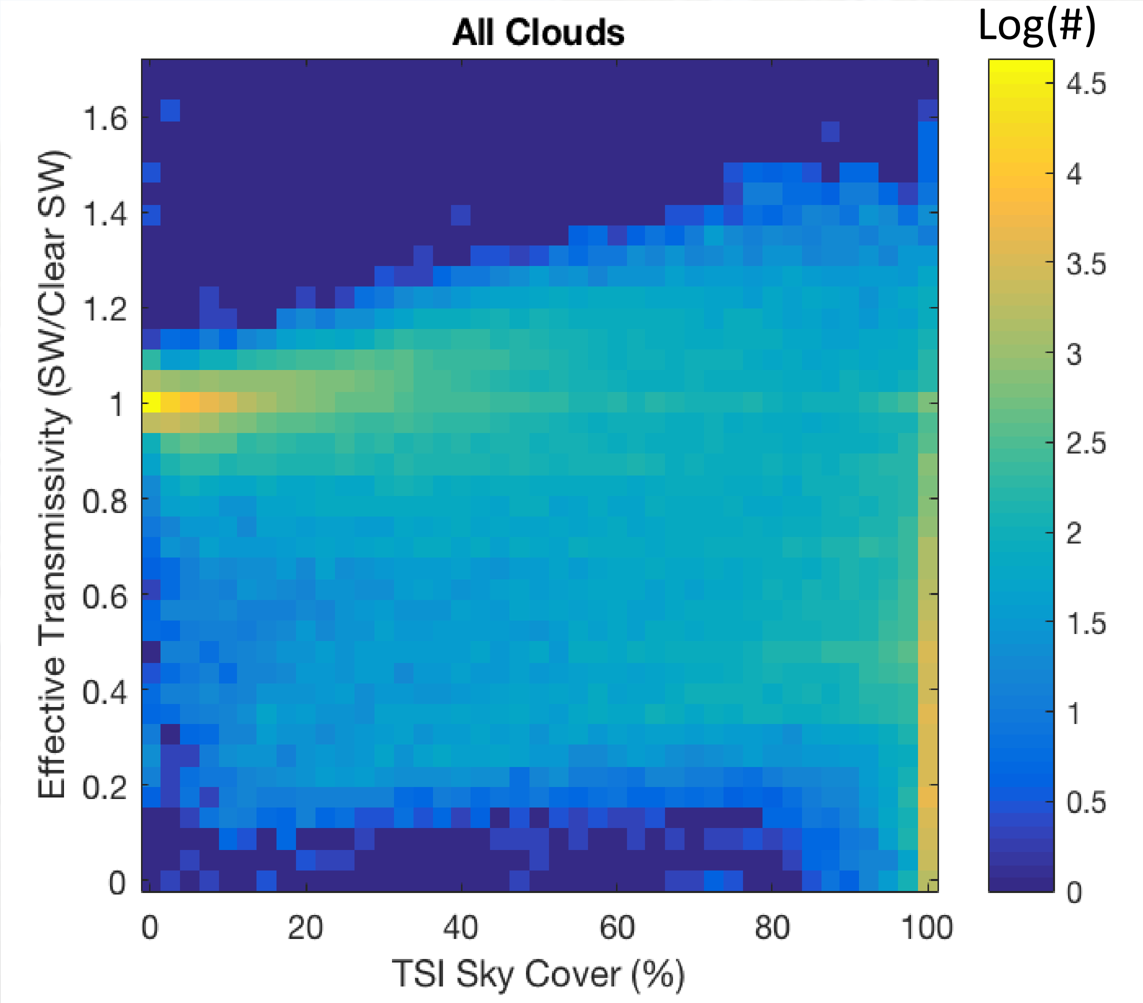
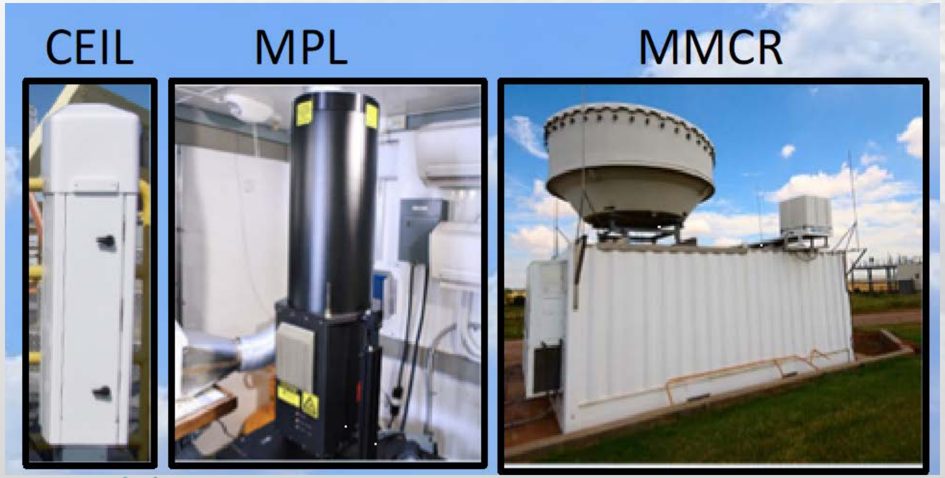
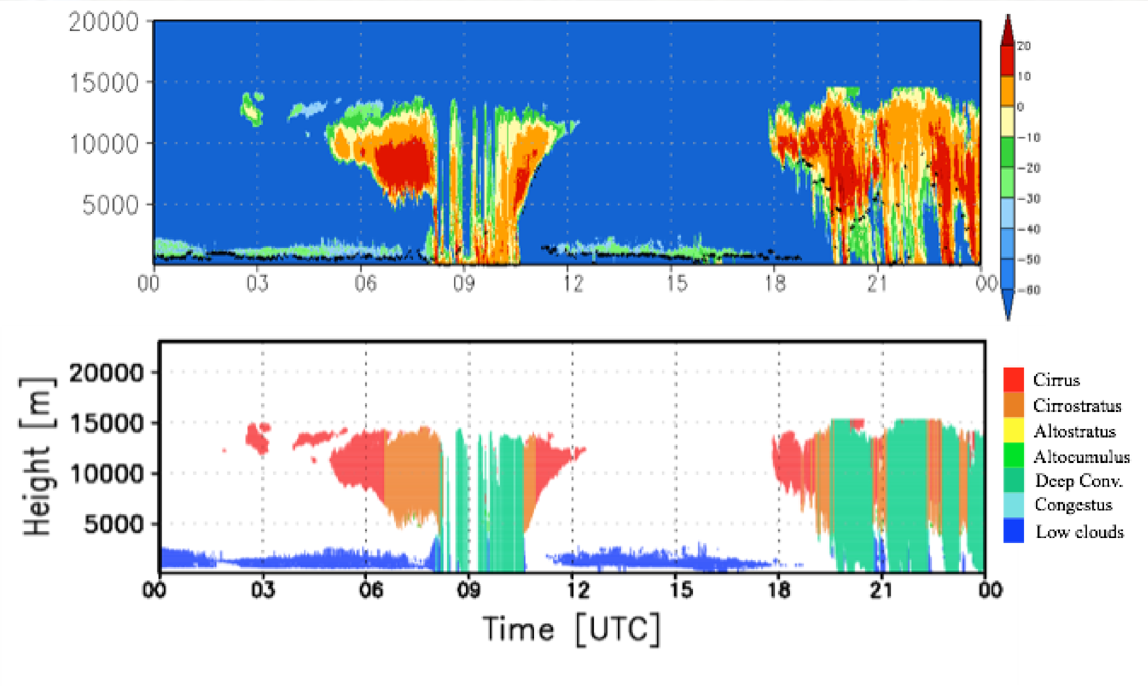


Density plot of 1 year of data, all sky conditions

Approach: Build observational metrics of surface shortwave variability under different cloud types that can be incorporated into forecast models

3. Use active remote sensors to identify cloud types based on height





Example of time-height evolution of radar reflectivity from Millimeter wavelength Cloud Radar (MMCR) (shaded) (top) and classified cloud types at the ARM SGP C1 site on 24 May 2008. From Lim et al. (under review in *J. Tech*).

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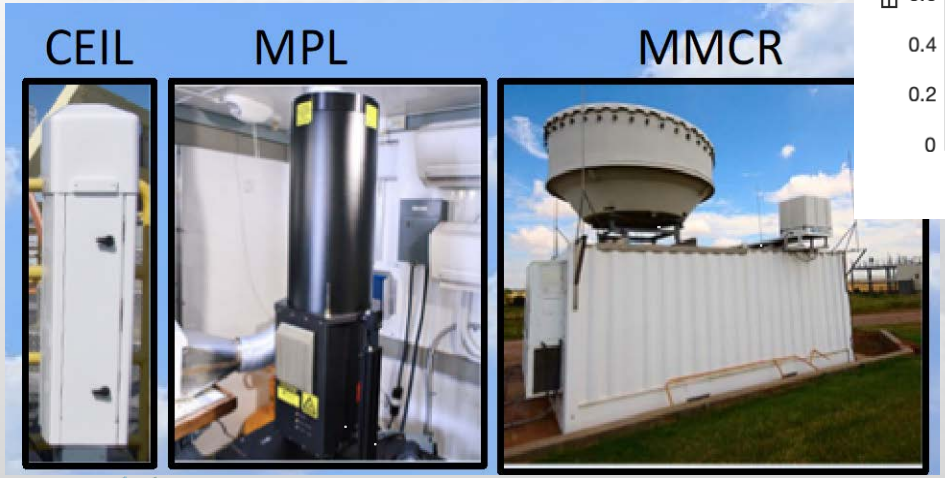

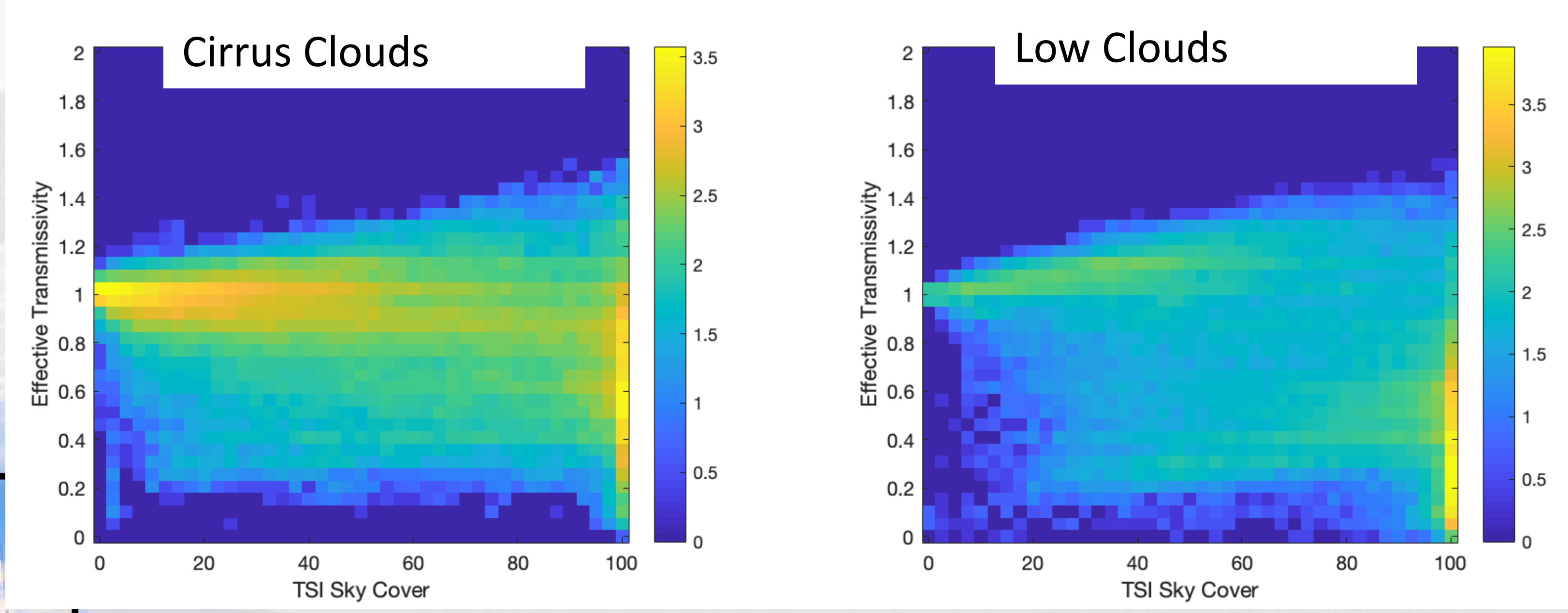

Cloud type classification allows us to quantify cloud effects by cloud type.

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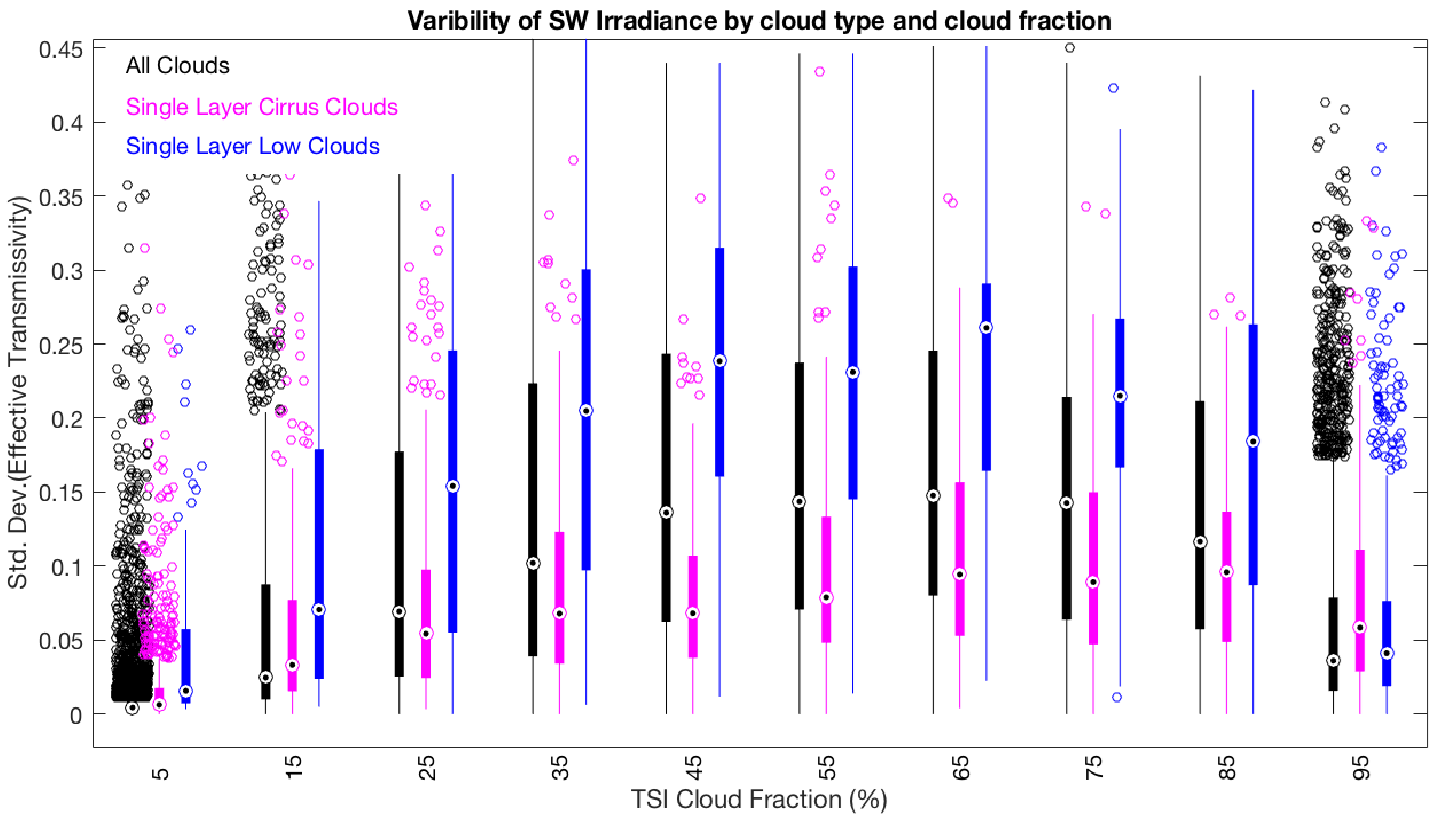
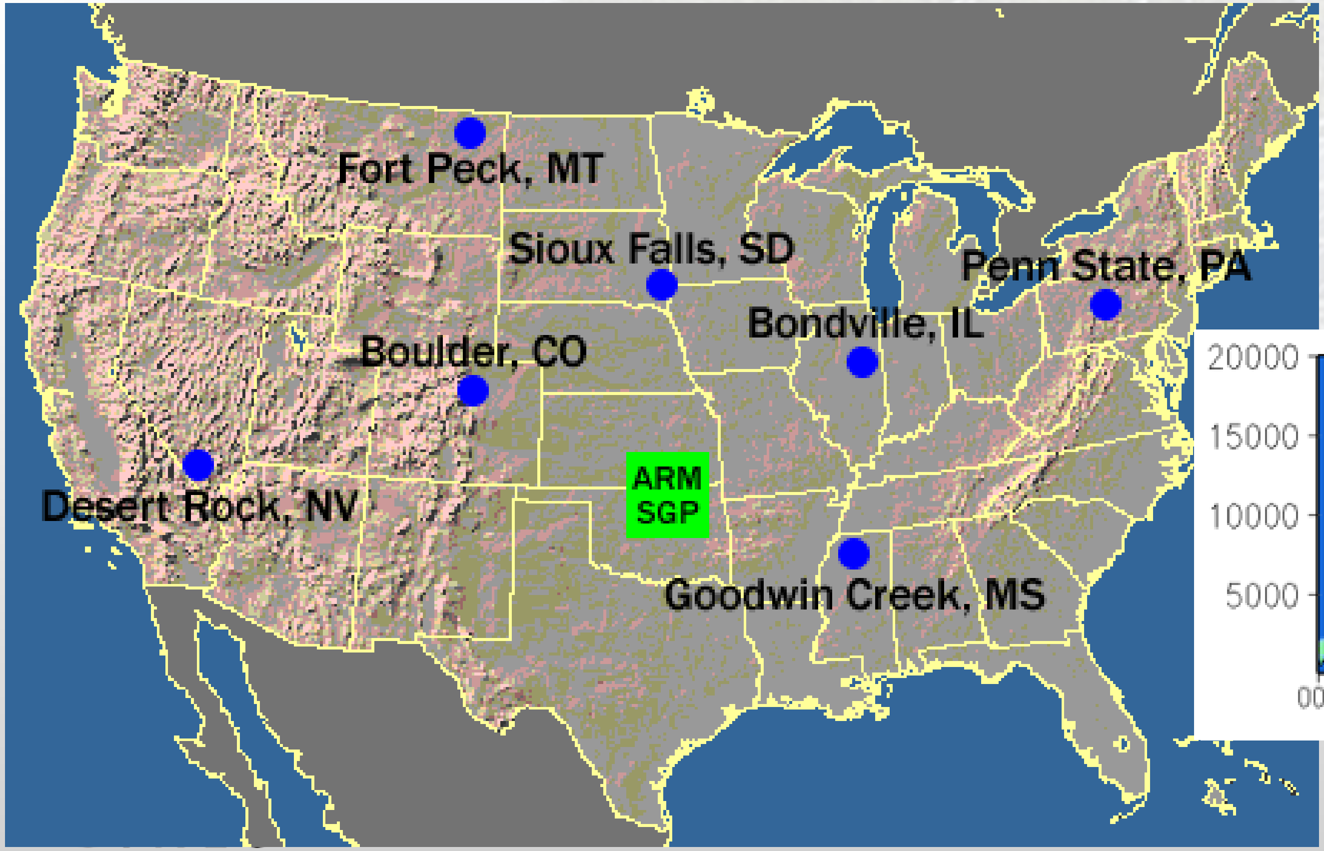
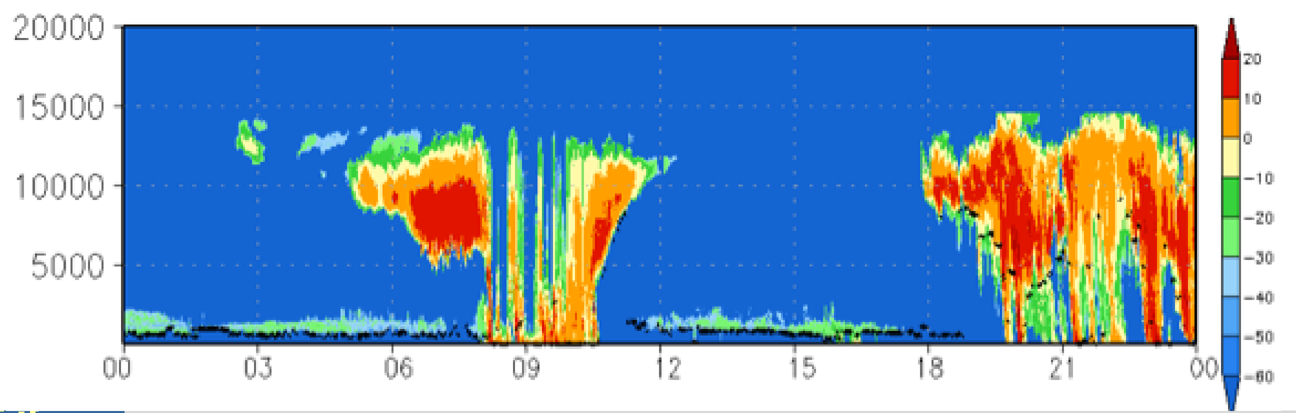
Measures of irradiance variability differ by cloud type



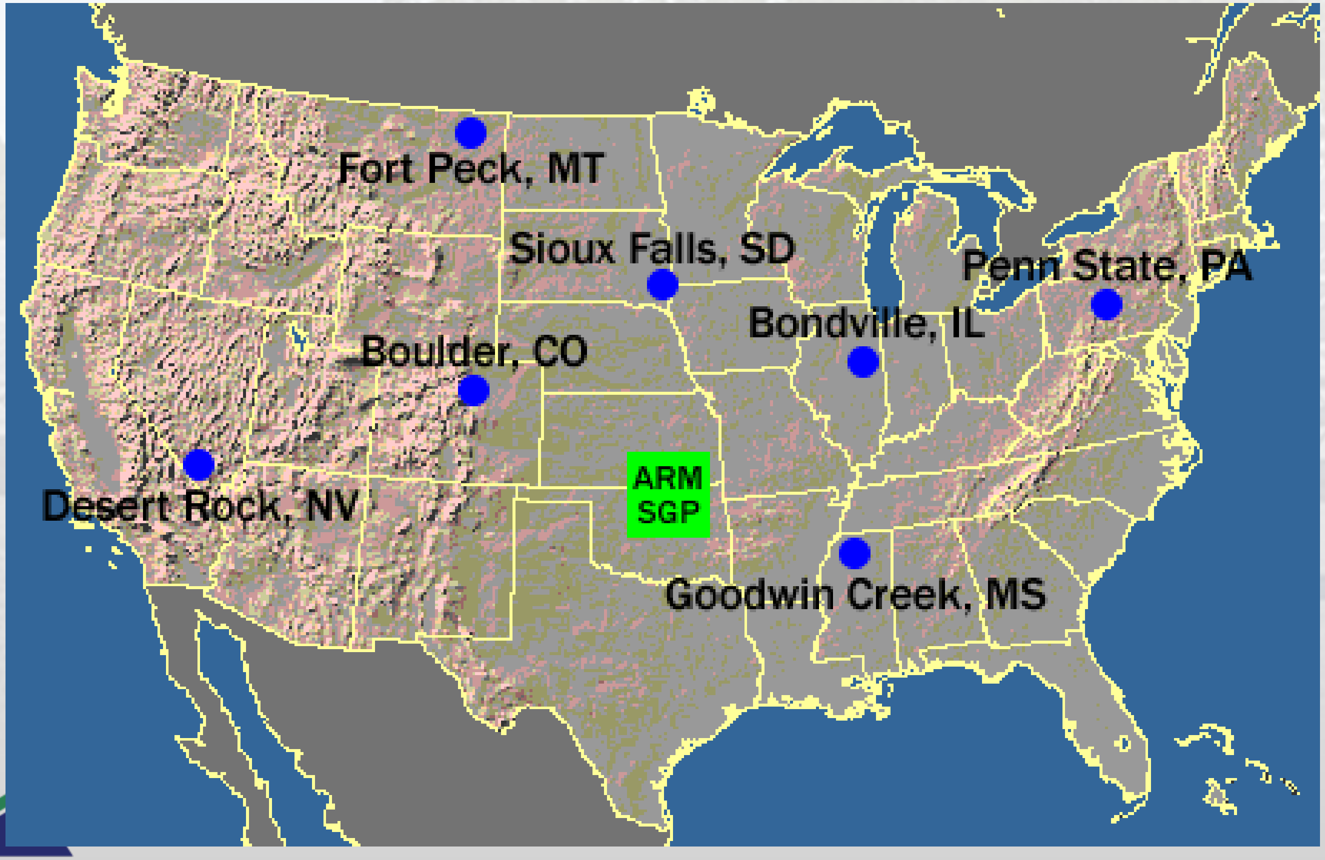
Distributions of the 15-min standard deviation of effective transmissivity in 10% cloud fraction bins. Median values are shown in the circles, solid bars show 25/75 percentiles, full range in thin lines. Colors: different cloud types.

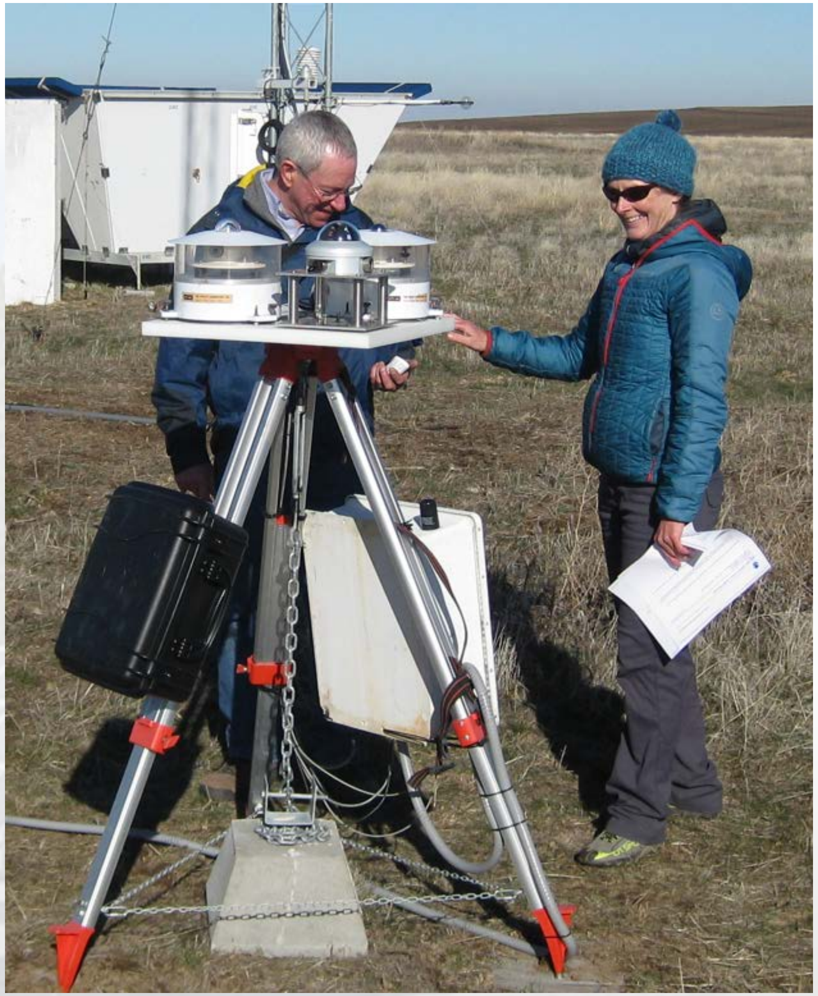
Outlook: Installation of ceilometers at SurfRad stations will allow for cloud type variability metrics in different climate regimes!





Outlook: Incorporate spatial variability as well as temporal variability measurements.





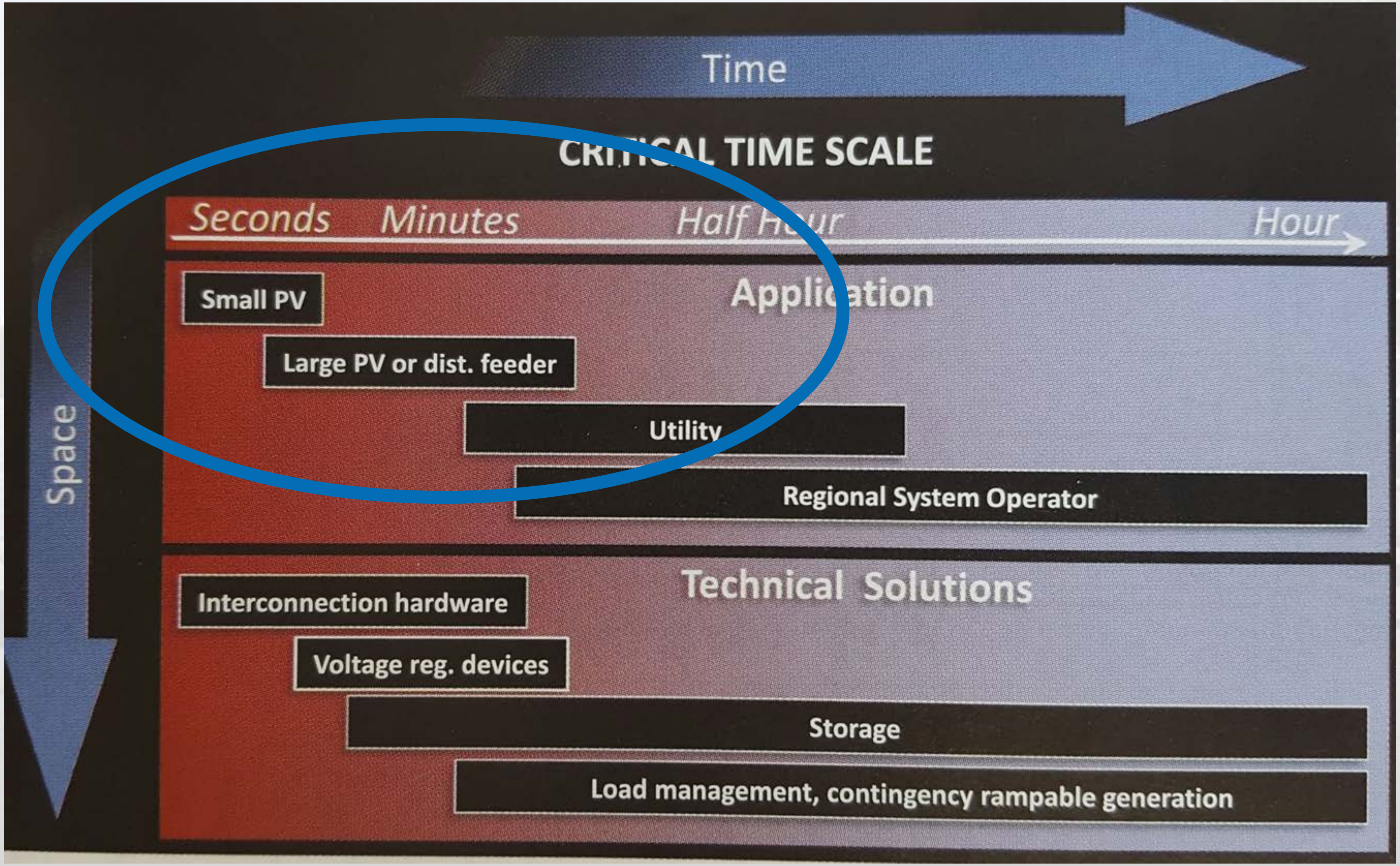
G-Rad built 3 portable radiometer systems (RADSYS) to measure spatial variability around sites

Summary

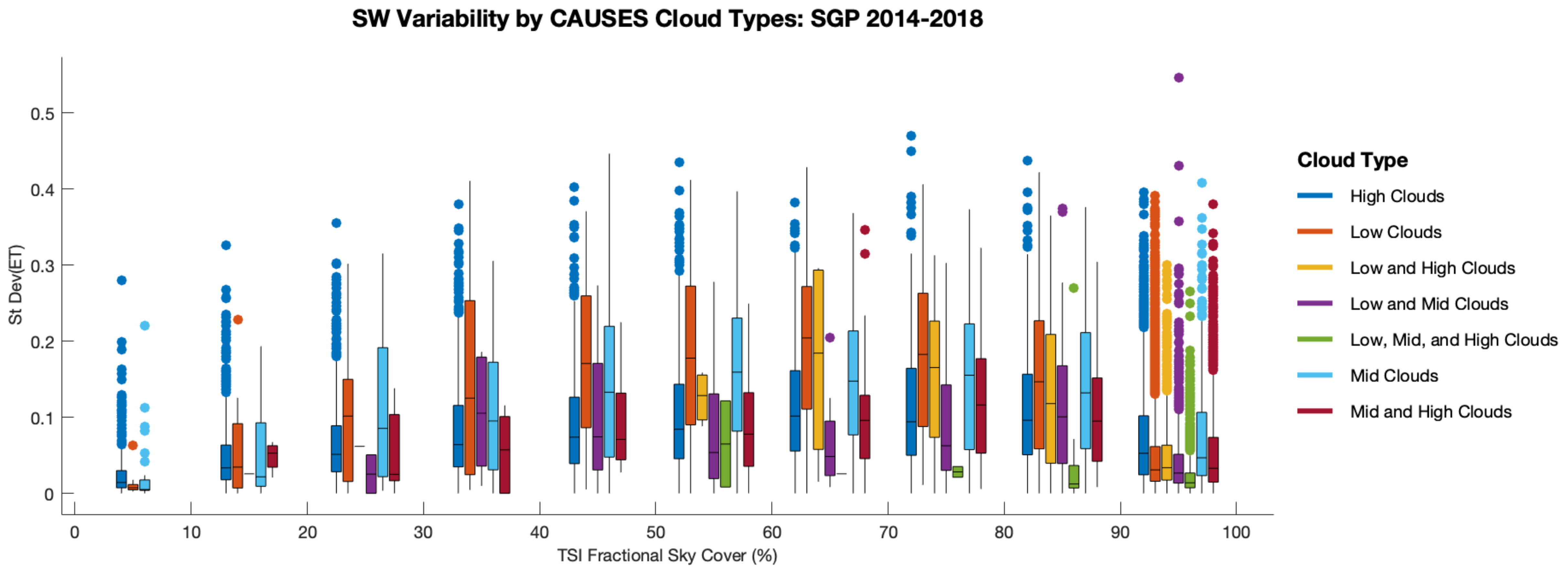
1. Improved shallow cumulus parameterizations being tested in WRF to improve simulations of broken cloudy conditions. This is a necessary but not sufficient condition to capture irradiance variability in solar forecasts.
2. Developing observational products to quantify irradiance variability in SGP observations:
   - Separating cloud impact from solar geometry allows better statistics of short-term variability
   - Using automated identification of cloud types shows utility in classifying irradiance variability in order to give more accurate variability statistics.
3. New measurements (ceilometers, radsys) at SURFRAD stations will allow calculation of spatial and temporal variability in multiple climate regimes!

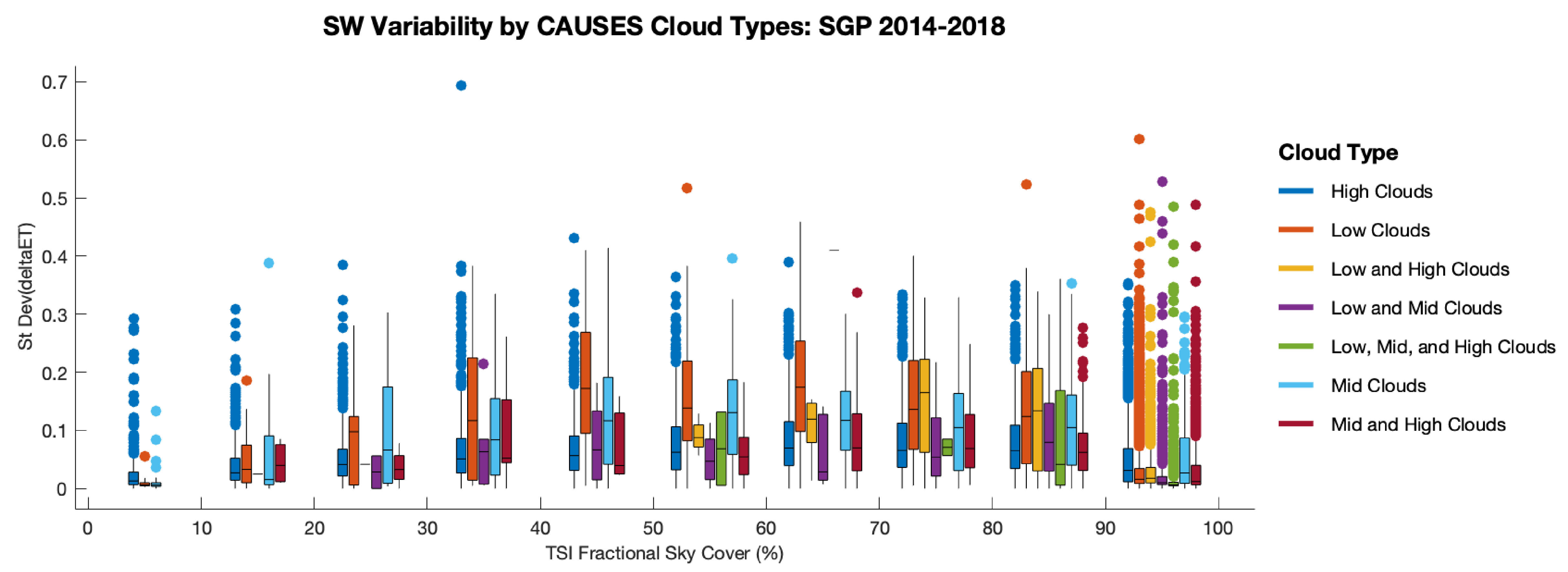
Extra Slides

Significant challenge in incorporating a high penetration of solar energy into the electric grid is variability!



From: J. Kleissl, *Solar Energy and Forecasting and Resource Assessment*


SW Variability by CAUSES Cloud Types: SGP 2014-2018
St Dev(ET)
0
0.1
0.2
0.3
0.4
0.5
0
10
20
30
40
50
60
70
80
90
100
TSI Fractional Sky Cover (%)
Cloud Type
High Clouds
Low Clouds
Low and High Clouds
Low and Mid Clouds
Low, Mid, and High Clouds
Mid Clouds
Mid and High Clouds


SW Variability by CAUSES Cloud Types: SGP 2014-2018
St Dev(deltaET)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
TSI Fractional Sky Cover (%)
Cloud Type
High Clouds
Low Clouds
Low and High Clouds
Low and Mid Clouds
Low, Mid, and High Clouds
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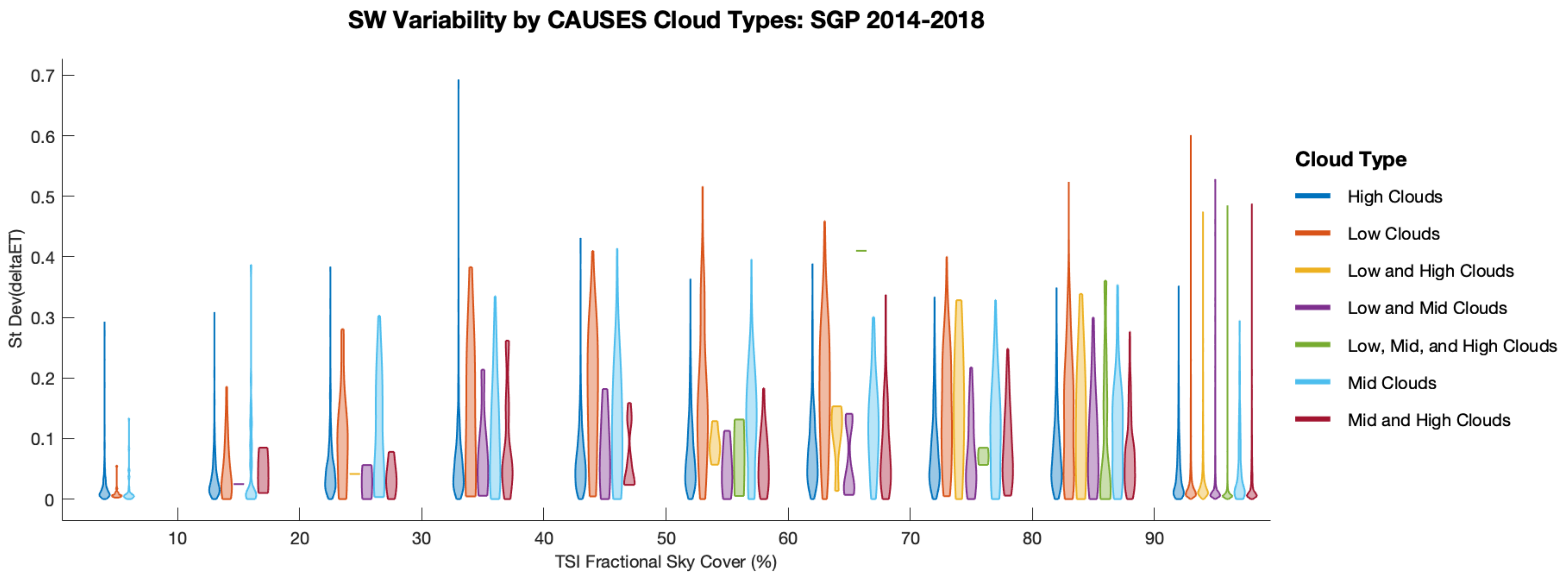
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0.7
0.6
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20
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70
80
90
TSI Fractional Sky Cover (%)
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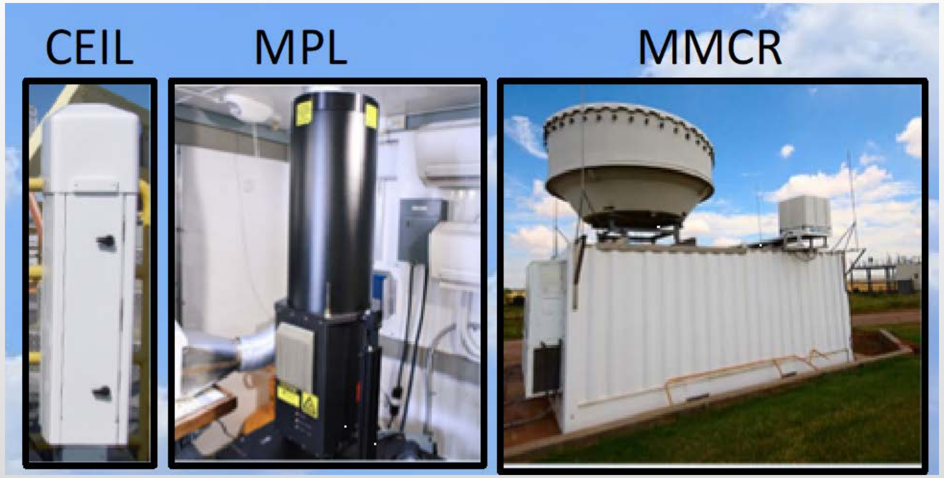
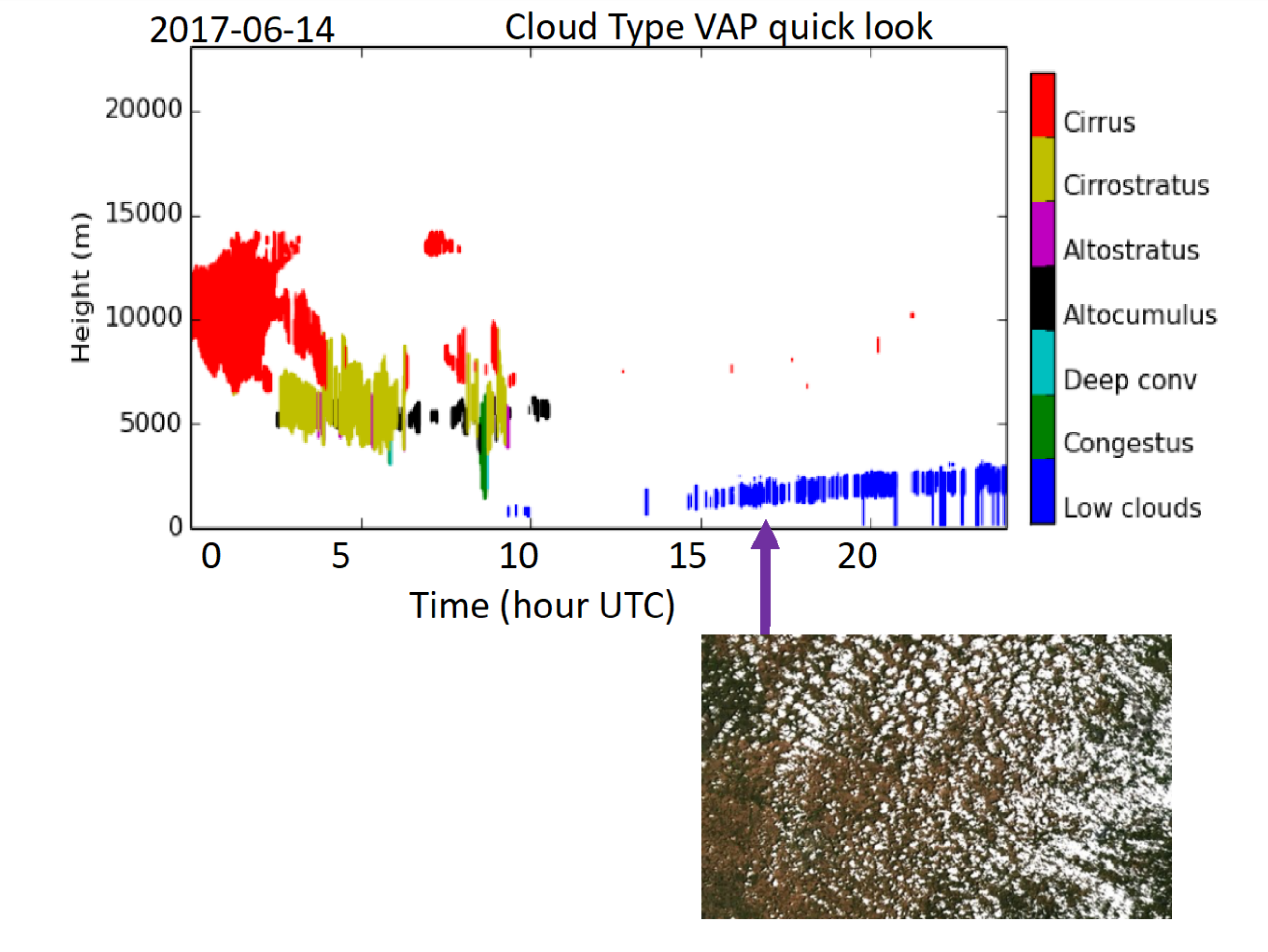
Low Clouds
Low and High Clouds
Low and Mid Clouds
Low, Mid, and High Clouds
Mid Clouds
Mid and High Clouds

Treatment of temporal variability of solar irradiance: Development using sites with cloud instrumentation

- Vertically pointing active sensors are used to classify clouds by cloud heights
- Multiple instruments (ceilometer, lidar, radar) are used to determine a comprehensive picture of multiple cloud layers



Active sensors at US DOE ARM sites



Motivation: Solar Forecasting for solar energy most challenging in broken cloud conditions

Development of WRF-Solar v2—Improving Solar Forecasts

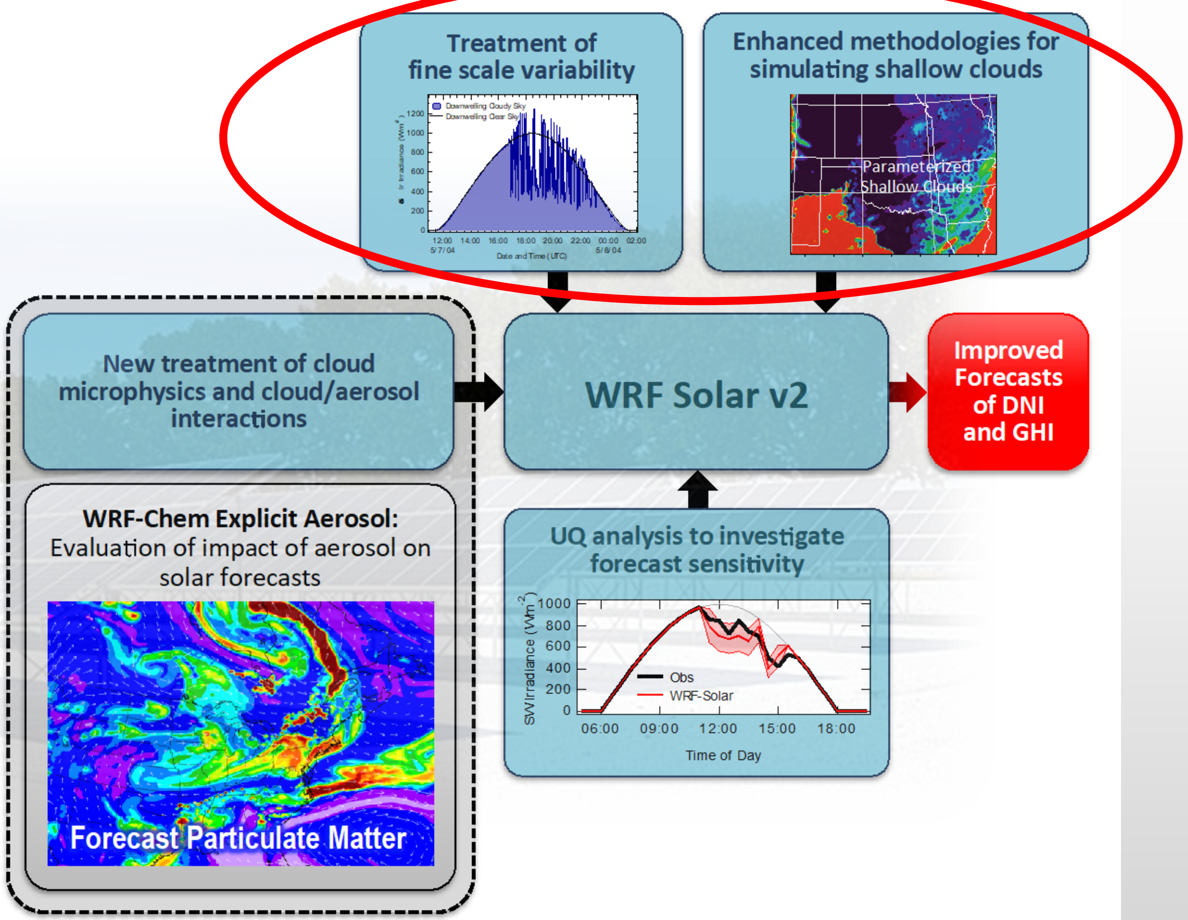
- PI Larry Berg

Pacific Northwest NATIONAL LABORATORY

VAISALA

NCAR

NOAA



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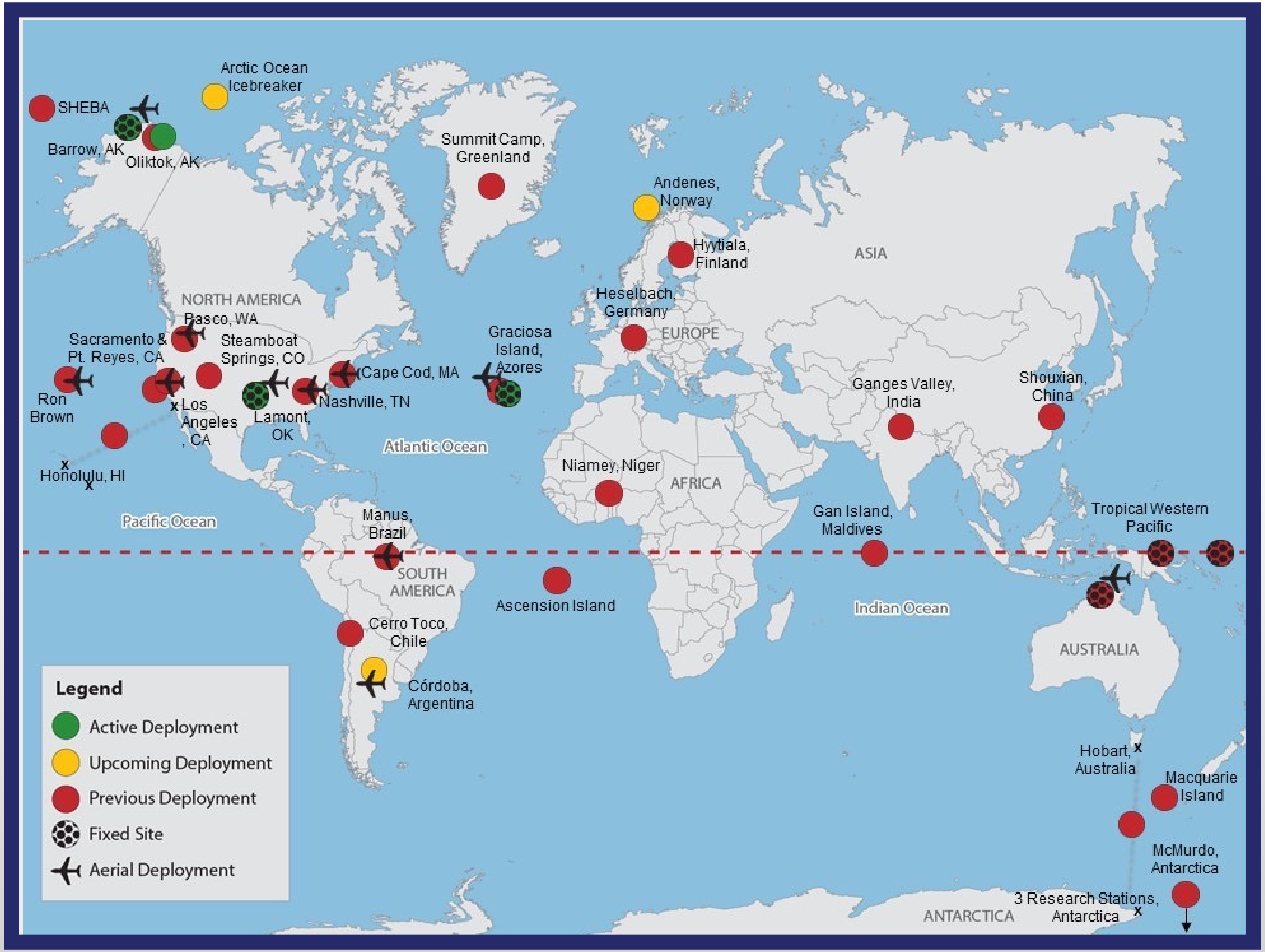
Project Goal: Reduce forecast errors in DNI and GHI by 25% compared to WRF-Solar v1.

ARM Site Map


Arctic Ocean
Icebreaker
SHEBA
Barrow, AK
Oliktok, AK
Summit Camp,
Greenland
Andenes,
Norway
Hyytiala,
Finland
ASIA
Heselbach,
Germany
EUROPE
NORTH AMERICA
Pasco, WA
Sacramento &
Pt. Reyes, CA
Steamboat
Springs, CO
Cape Cod, MA
Graciosa
Island,
Azores
Ron
Brown
Los
Angeles
, CA
Lamont,
OK
Nashville, TN
Ganges Valley,
India
Shouxian,
China
Atlantic Ocean
Honolulu, HI
Niamey, Niger
AFRICA
Pacific Ocean
Manus,
Brazil
Gan Island,
Maldives
Tropical Western
Pacific
SOUTH
AMERICA
Ascension Island
Indian Ocean
Cerro Toco,
Chile
AUSTRALIA
Córdoba,
Argentina
Legend
Active Deployment
Upcoming Deployment
Previous Deployment
Fixed Site
Aerial Deployment
Hobart,
Australia
Macquarie
Island
McMurdo,
Antarctica
3 Research Stations,
Antarctica
ANTARCTICA