# Solar Radiation and Sea ice Sea Ice dynamics from climate models

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# Outline

- Projections of future solar radiation for PV power
- Regional climate model uncertainty
- Challenges for functional data analysis
- Open water leads in sea ice simulations.
- Unsupervised learning.

Solar radiation project: Maggie Bailey, Soutir Bandyopadhyay
Manajit Sengupta, Aron Habte, Yu Xie (National Renewable Energy Laboratory)

Sea ice: Hannah Director ( Mines, Climate ), Cecilia Bitz (U Washington), Marika Holland ( NCAR).

# Planning for future photovoltaic (PV) power facilities.

Part of NRELs contribution to the energy community is National Solar Radiation Data Base (NSRDB).

- For the US 4km$\times$4km resolution, 1998–2014, hourly and 30 minute times.
- Uses a physical model for solar radiation at the surface and based on a variety of observations to create the gridded product.
- We might expect solar radiation to change over the lifetime of a facility along with the other changes to the climate system.

# Building off of NSRDB

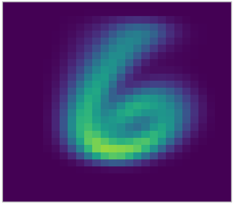
A PV facility can have a 30+ year life span

Goal: Characterize the distribution solar radiation at the same space and time resolution as NSRDB under scenarios of climate change.

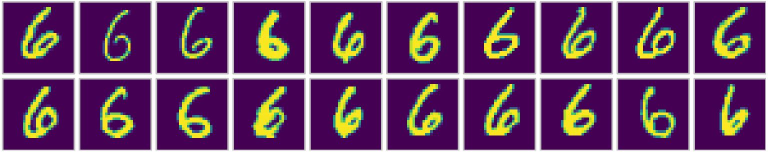
- Represent the distribution of solar radiation by a *statistical ensemble* of possible outcomes – all equally likely.
- Ensembles might be generated on demand to reduce the size of the stored results.

# MNIST – hand written digits

Mean across 60K samples

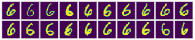


First 20 members



- Ensembles are useful to represent variation in complex objects.

# Workflow for modeling solar radiation

- Primary variable is Global Horizontal Irradiance (GHI) in watts/$m^2$.
- Use regional climate model projections to infer details of the distribution of GHI in time and space. 

Based on RCM projections

- *Regrid* Daily GHI from RCM on native grid $\rightarrow$ 20km NSRDB Grid
- *Predict daily total GHI* Regression model with RCMs, seasonality, elevation $\rightarrow$ to predict observed GHI based on NSRDB.

Based on NSRDB modeling

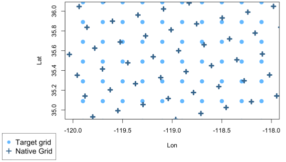
- *Disaggregation to hourly radiation* Daily totals of NSRBD $\rightarrow$ predict hourly solar radiation.
- *Downscaling to 4km* Hourly GHI at 20km $\rightarrow$ Hourly GHI at 4km

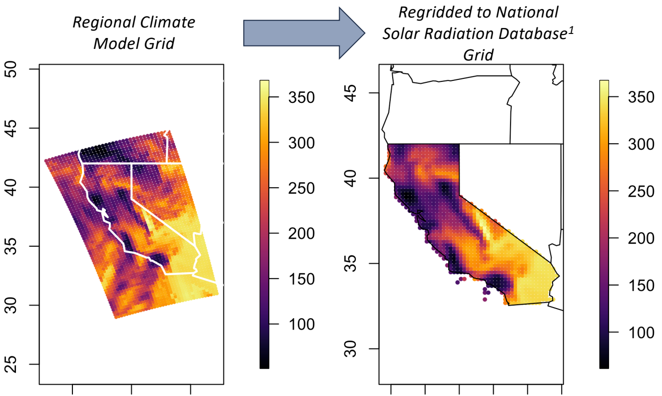
A hierarchical model to simulate high resolution hourly solar from RCM output.

*The variation in hourly GHI is as important as the point predictions.*

# Regridding and prediction

The RCM output is not on the same grid as the NSRDB product.



# Regridding and prediction

Regridding uncertainty (to out knowledge) is an often ignored issue in climate science.

Framework:

- A Bayesian linear model where the "X's" are uncertain.

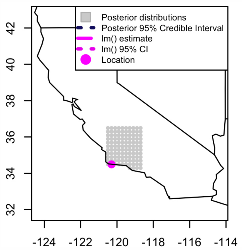
RCMs values have error based on regridding.

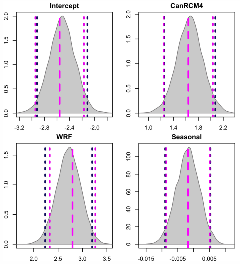
NSRDB $= \text{RCM}_1\beta_1 + \text{RCM}_2\beta_2 + \text{RCM}_3\beta_3 +$ Seasonality $+$ error

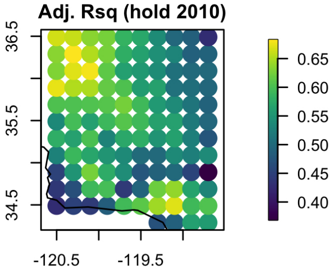
- Generate posterior draws from the RCM fields regridded to the NSRDB grid.
- Bayes posterior for regression coefficients and prediction and GHI conditional on draw.

# Regridding and prediction results

Parameters in the linear model for a coastal grid box.



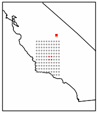



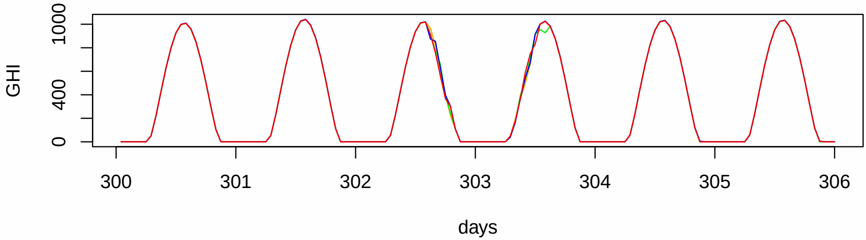

- NOTE RCMs are forced by reanalysis fields.
- Nominally we have a separate linear model for every grid box.

# Daily total → hourly at 20km

Use the NSRDB data to build this conditional distribution.

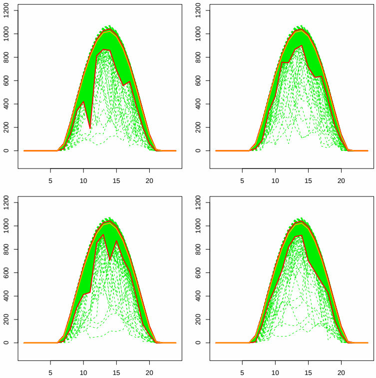


Hourly times series for June 1-6 2008, 4 grid boxes.



# Functional boxplots – diurnal cycle 20km

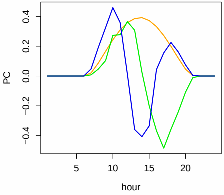
Hourly times series for June months over 1998- 2019

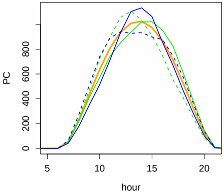



- Strong diurnal cycle around “deepest” curves
- Substantial variability for “shallow” curves – suggests a mixture model.

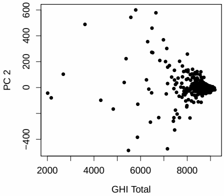
# Principle components at 20km

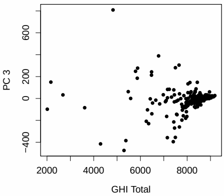
- First three PCs for a single grid box and PC1 $\pm$ PC2, PC1 $\pm$ PC3.




- Relationship of PC2 and PC3 to daily total GHI

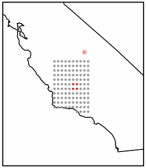


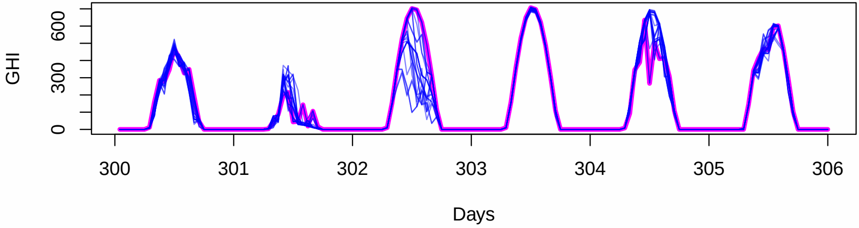

- Additional components tend to add more noise than structure.

# Downscaling to 4km

$5 \times 5 = 25$, 4km time series nested in a single 20km grid box.



June 1-6 2008 , 4km, 20km



# Summary

These are tentative based on preliminary analysis!

- Some skill in predicting total GHI from the RCMs
- Regridding process does not appear to inflate uncertainty.
- Diurnal patterns appear to be a mixture of a strong daily cycle and more variable, intermittent behavior. *(No surprises here.)*
  - Also true for 20km to downscaling to 4km.
- Diurnal and coefficients pattern appear to be coherent over space. Suggesting a multivariate spatial model on PCs.
- *LatticeKrig* spatial model and related SPDE work could be useful for the multivariate spatial and temporal models for the PC coefficients.

# Identification and Uncertainty of Sea Ice Leads

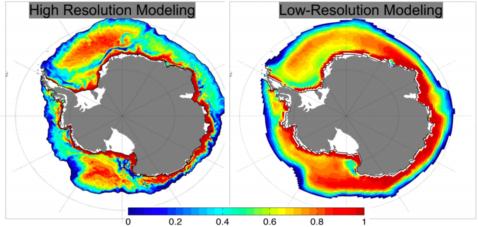
- Rapid decline in Arctic, more complex changes in Antarctica
- Understood via physics-based models, remote sensing, and direct measurement

# Deformation features

- Leads: long narrow cracks in sea ice
- Pressure ridges: small "mountains" that form on top of the ice
- Linear Kinematic Features (LKFs): discontinuities in kinematic features of sea ice (deformation), encompasses both leads and ridges


# Resolution

- Leads emerge in high-resolution simulations
- Leads are rarely present in typical low-resolution simulations
- Want to understand high-resolution leads to improve low-resolution approximations
- Statistics of leads interesting on their own as a coherent structure emerging from the model dynamics.




Daily growth rate (Antarctica, April/-May/June)

# Data

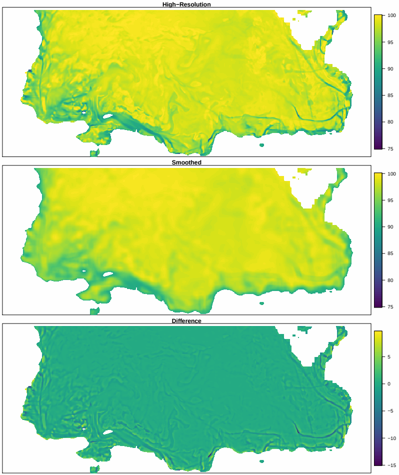
- High-resolution Community Earth System Model
  - Physical simulation of the whole Earth system
  - Widely-used and extensively tested
  - Focus on Sea Ice component.
- Pre-industrial control run
  - Stable climate
  - Useful for understanding sea ice physics and interactions of sea ice with surrounding environment

*Although leads are produced by the model they are not identified explictly as a coherent structure.*

# Data transformation: subgrid-scale leads

Sea ice concentration: proportion of area in each grid box that is ice-covered

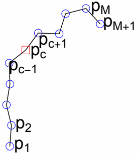
Model $\boldsymbol{y}$, the difference between high-resolution and smoothed output



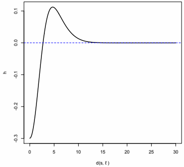

*Difference is the potential adjustment/parametrization for a low resolution simulation.*

# Finding Leads

Model the lead's path as a chain of $M + 1$ connected spatial points: $\ell = (p_1, \ldots, p_{M+1})$.



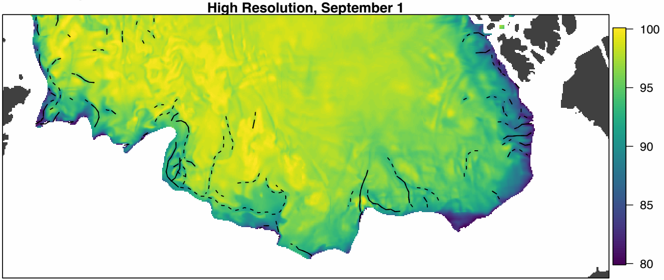

Model the expected difference in sea ice concentration at location $s$ as a function of the distance from $s$ to the lead path

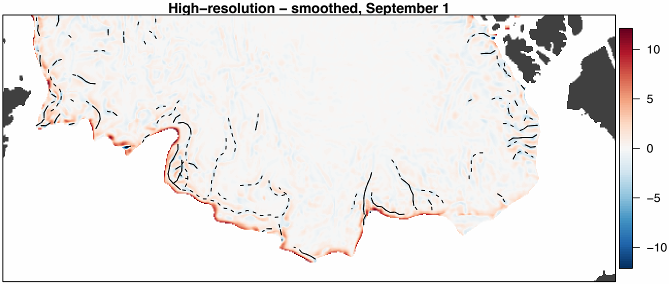



- The hardest part is estimating the end points because of the ambiguity of when a lead ends.
- Taken together provide a model for the ice concentration field localized around a lead.
- Difference function estimated using a nonparametric curve estimate.

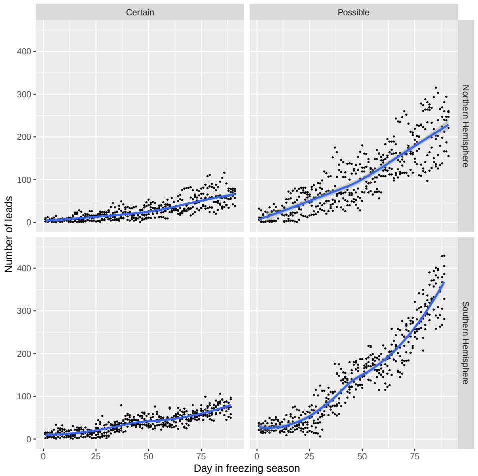
# Examples of identification

## Finding multiple leads



# Analysis of the ice model output




- Certain vs Possible based on amplitude of difference function.

# Summary

- Speedup Bayesian version to improve uncertainty quantification.
- Find difference function in fully objective manner.
- *One of the first times, leads have been explicitly quantified from the ice component of CESM.*

# Thank you