Development of WRF-Solar v2—Improving Solar Forecasts

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Project summary

- **Objectives:** Reduce forecast errors of Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI) by **25%** and provide better forecasts of irradiance ramps, estimates of sub-grid scale variability, and more accurate estimates of forecast uncertainty
- **Technical Approach:** WRF-Solar v2 will have improved treatments of
  - Boundary-layer clouds
  - Cloud microphysics and entrainment
  - Sub-grid temporal variability of solar irradiance
  - Absorbing aerosol
  - UQ and model calibration
- **Team:** PNNL, NCAR, Vaisala, NOAA
- **Outcomes:**
  - Reduce the MAE, RMSE, and other error metrics of the DNI and GHI forecasts
  - New industry standard for intra-day and day ahead forecasts

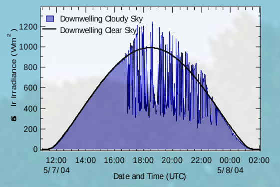
Project motivation and objective

- NWP models are the backbone of many intra-day (4-6 hours) and day ahead forecasts
- WRF-Solar v1 improved solar forecasts, addressing for the first time:
  - Output of key variables such as GHI and DNI
  - Inclusion of aerosol-radiation feedbacks
  - Cloud-aerosol feedbacks
  - Cloud-radiation feedbacks
- Address remaining biases associated with partly cloudy periods, absorbing aerosol, and winter time conditions

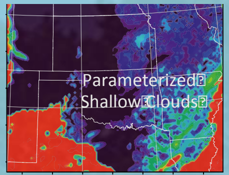
Project Goal: Reduce forecast errors in DNI and GHI by 25% compared to WRF-Solar v1.

Development of WRF-Solar v2

Treatment of fine scale variability



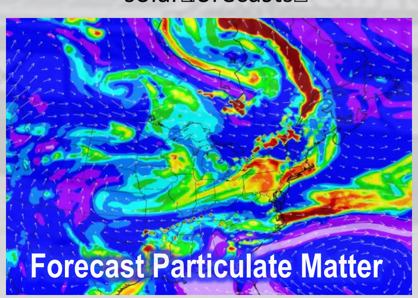
Enhanced methodologies for simulating shallow clouds



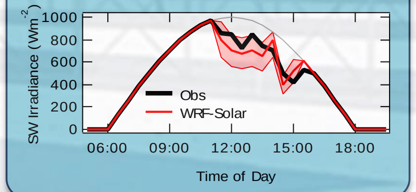
New treatment of cloud microphysics and cloud/aerosol interactions

WRF-Solar v2

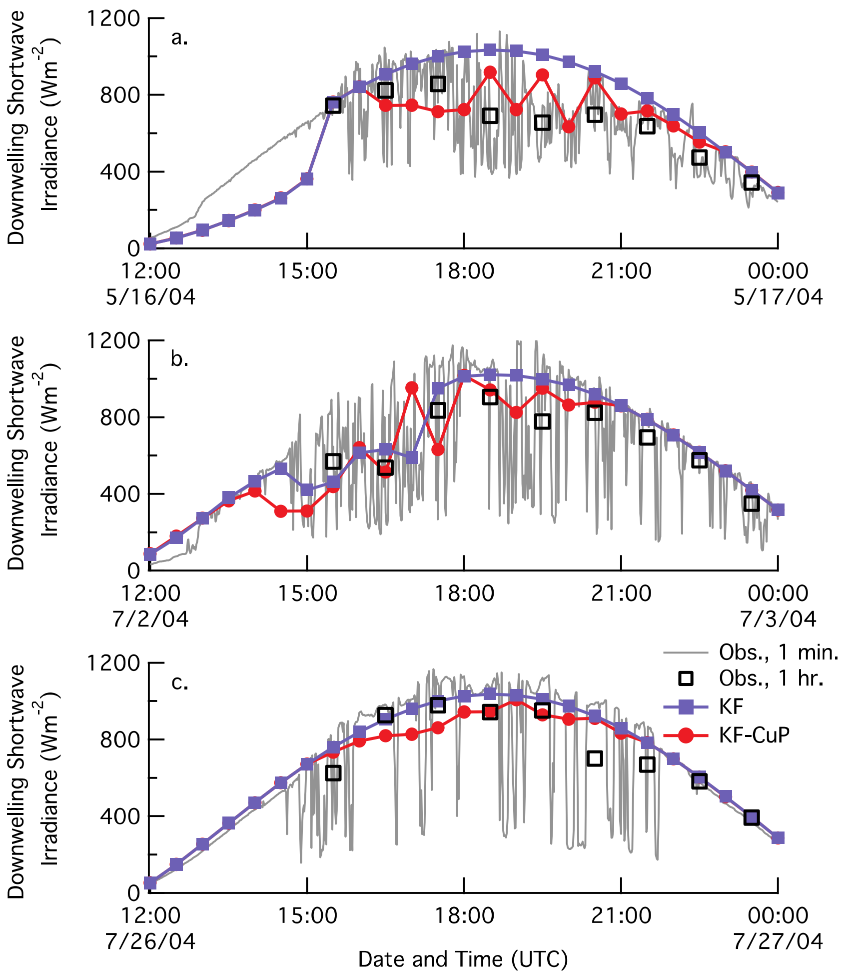
WRF-Chem Explicit Aerosol: Evaluation of impact of aerosol on solar forecasts

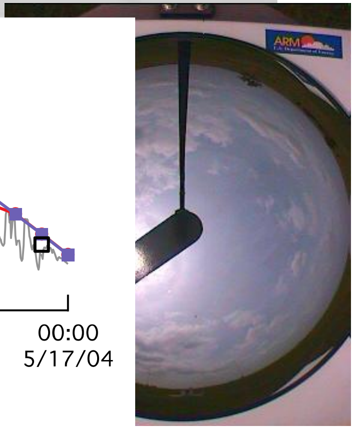


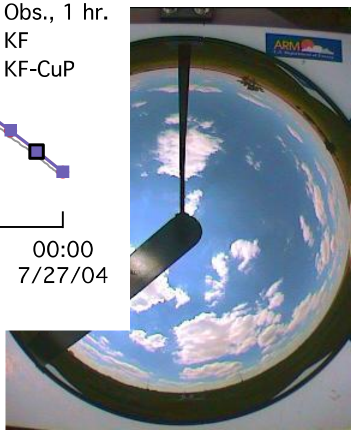
UQ analysis to investigate forecast sensitivity

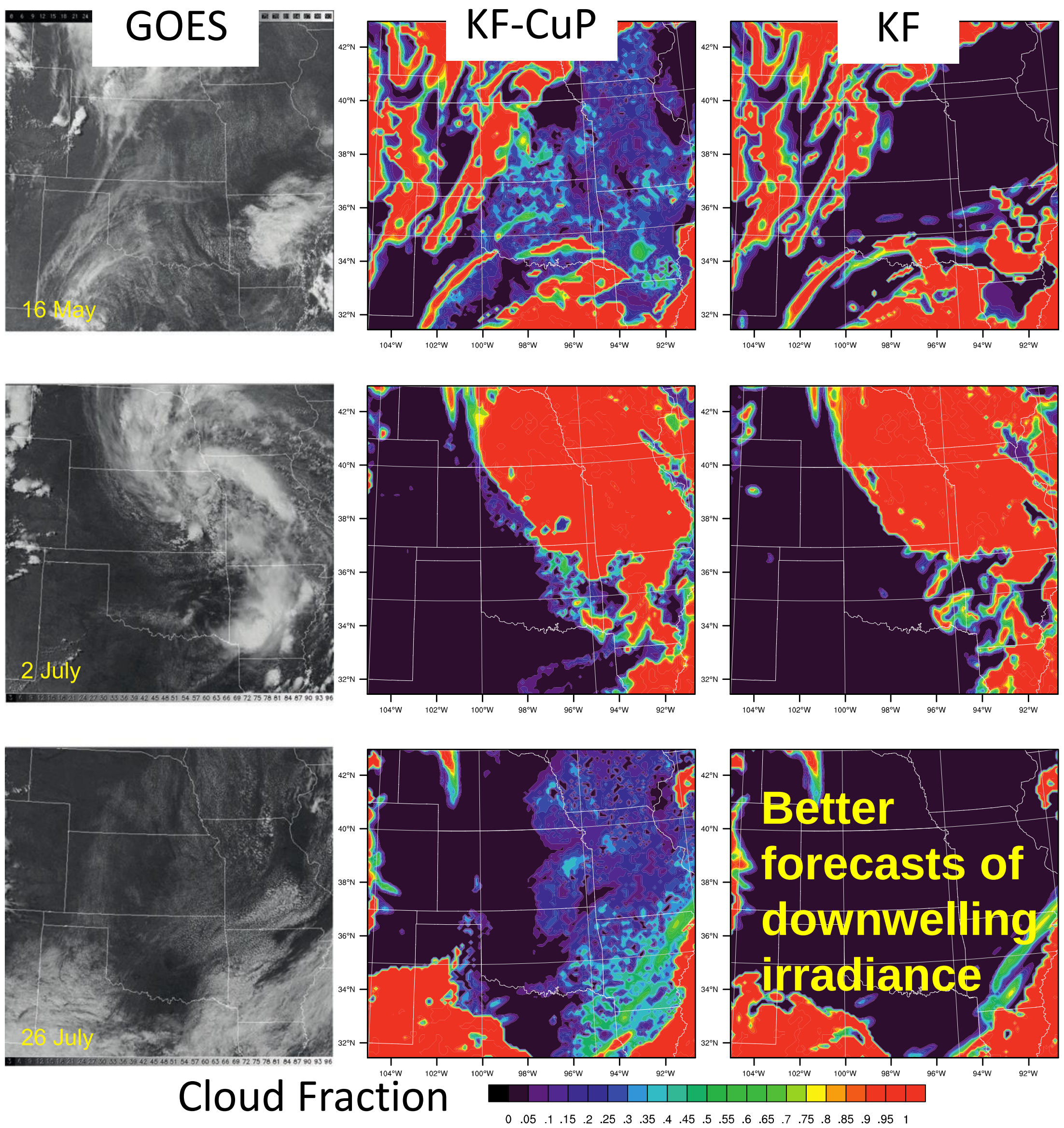


Improved treatment of shallow cloud fraction in the KF cumulus parameterization





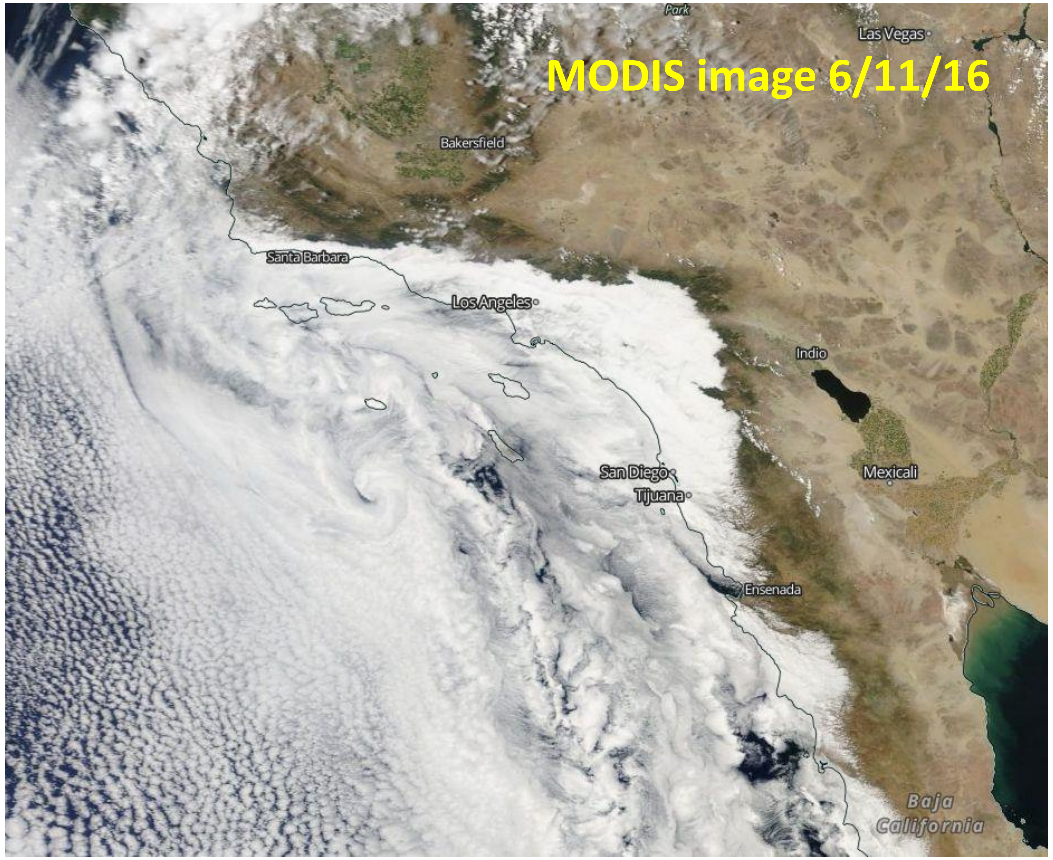


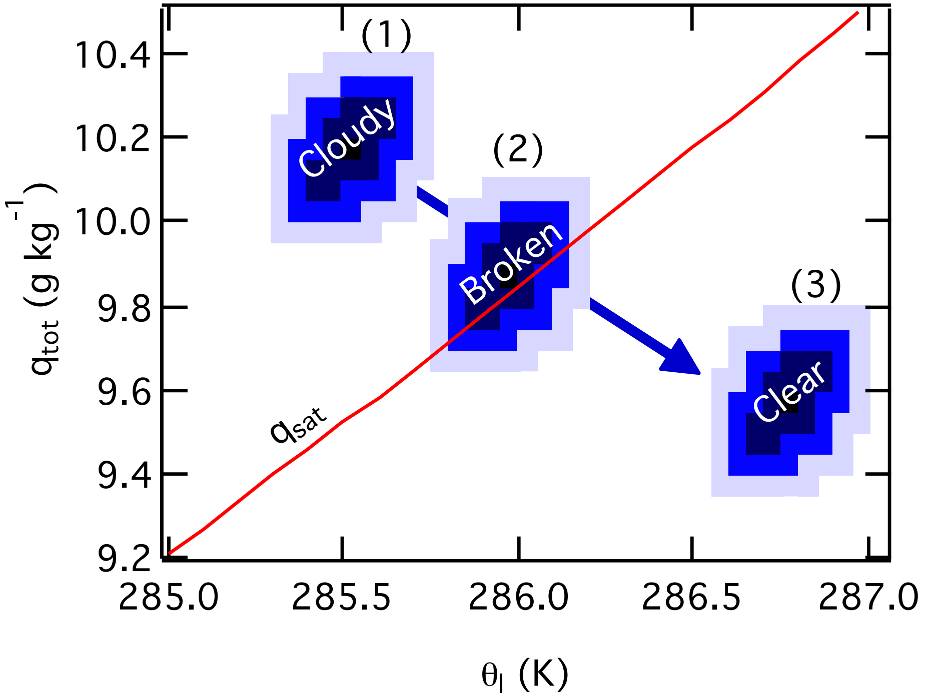


Berg and Stull (2004, 2005), Berg et al. (2013, 2015)

Better forecasts of stratocumulus breakup

- Stratocumulus are common over the west coast of North America, including areas with large solar penetration





- Mixing diagram approach developed by Berg and Stull (2005) will allow us to better simulate cloud break up

Improved representation of cloud-top entrainment and liquid/ice partitioning

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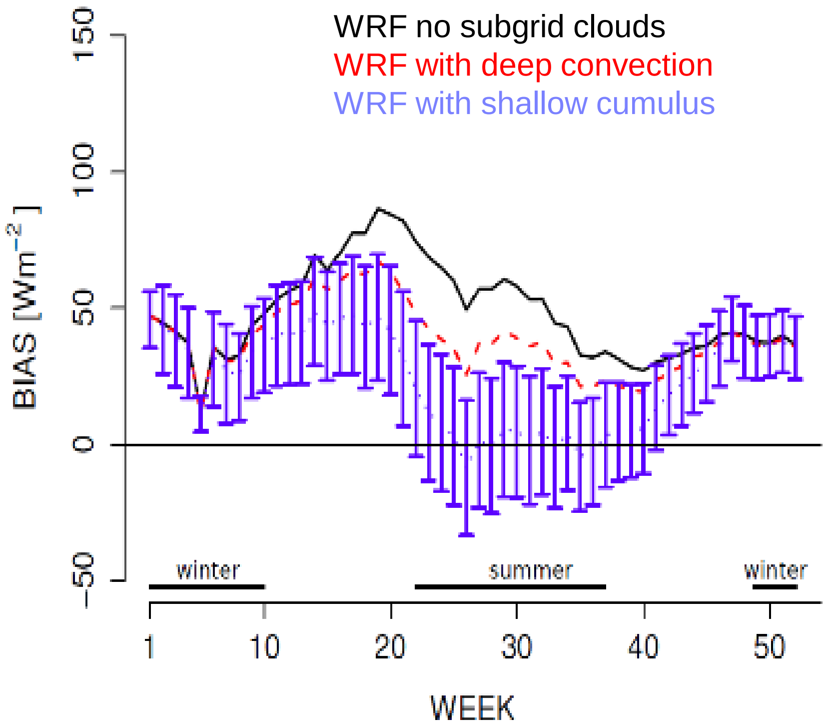
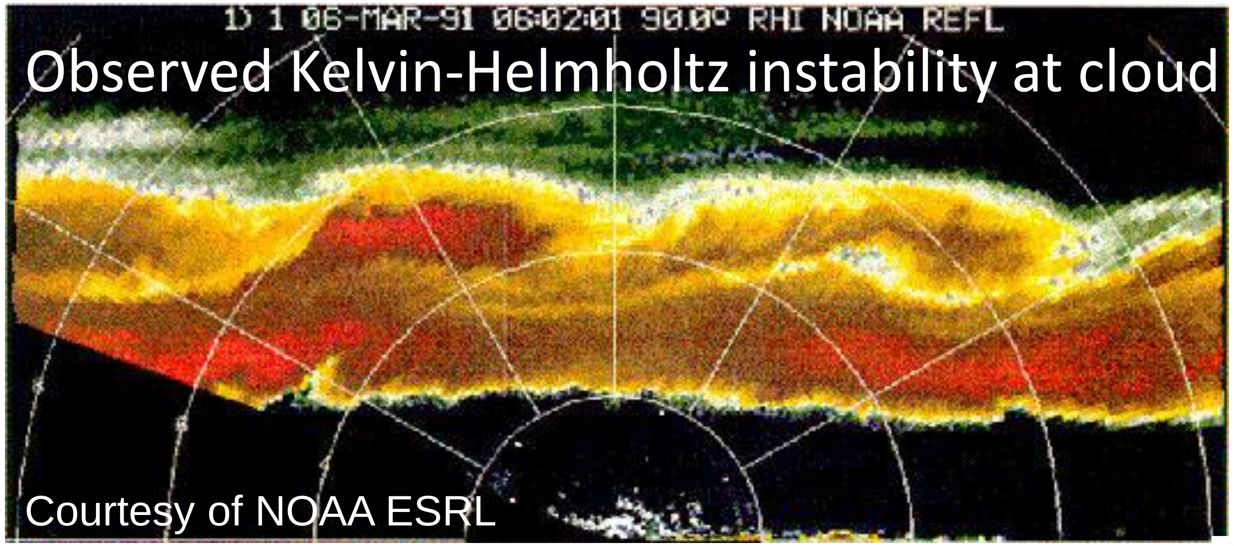
- Wintertime irradiance bias can be attributed to inaccurate cloud fraction and partitioning of liquid and ice water content (Thompson, 2017 AMS)
  - Liquid/ice water partitioning is controlled by cloud-top entrainment that is driven by turbulent mixing
  - At the subgrid level entrainment can be considered inherently random and will be represented using a stochastic parameterization





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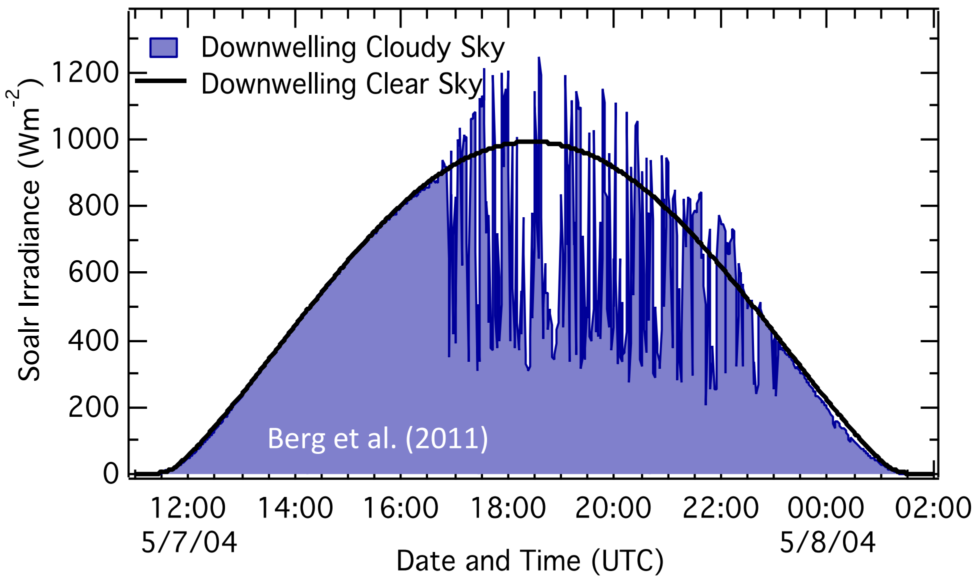
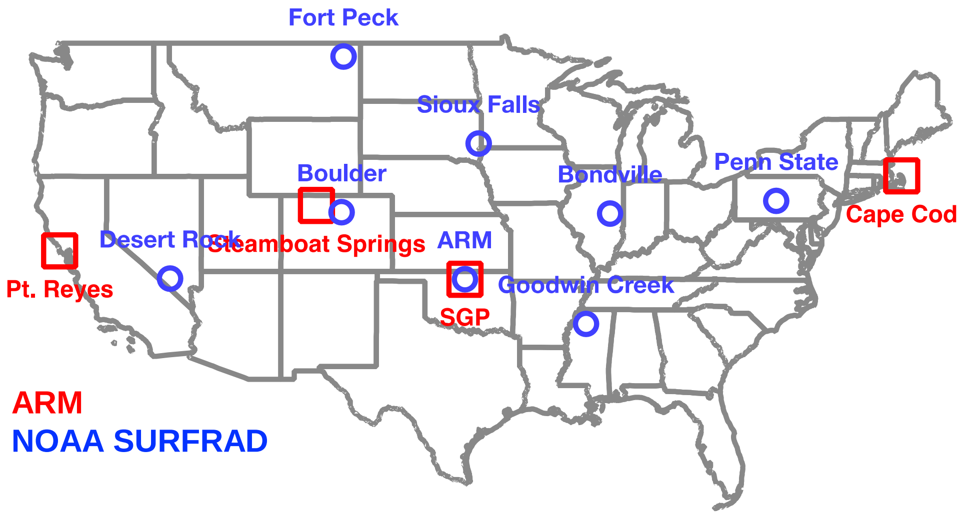
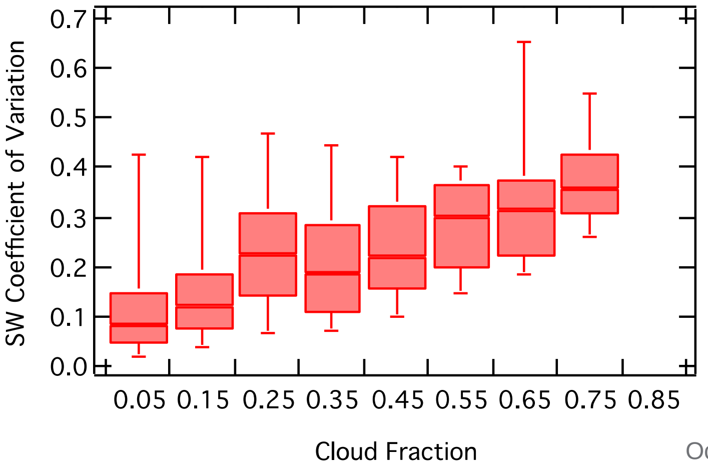
Treatment of temporal variability of solar irradiance

- Observations show large variability in irradiance with broken clouds
- Develop a new parameterization
  - Variability will be related to cloud fraction and cloud base height
  - Requires measurements of cloud fraction, cloud-base height, and irradiance

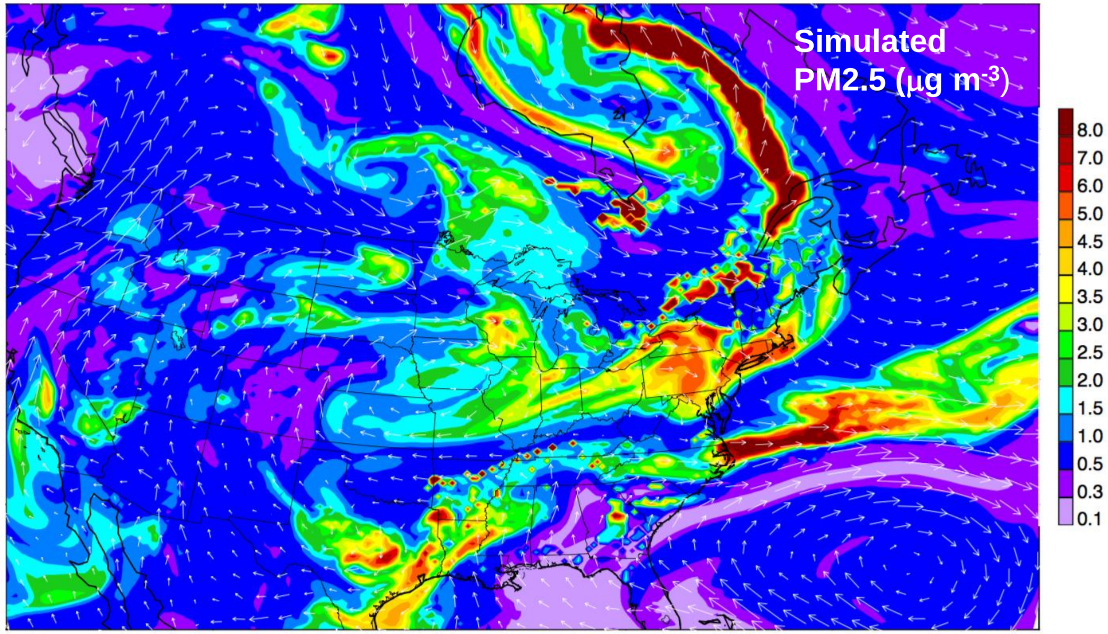






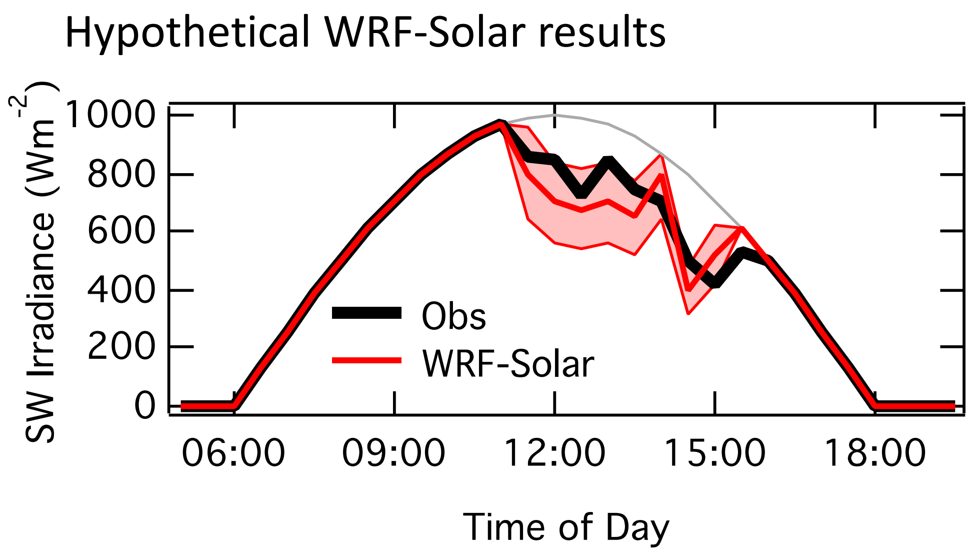
Including impact of absorbing aerosol

- In absence of clouds, aerosol accounts for up to 100% of the total attenuation (Schroedter-Homscheidt et al. 2013)
- WRF-Solar v1 **ignored** absorbing aerosol
  - Add treatments consistent with representation of other aerosol with changes to the Thompson and Eidhammer (2014) approach
  - Aerosol are obtained from climatological values, global forecast, or ignored
- Test specific cases with output from WRF-Chem
  - Detailed calculations of all aerosol types (Barnard et al. 2010; Fast et al. 2016)



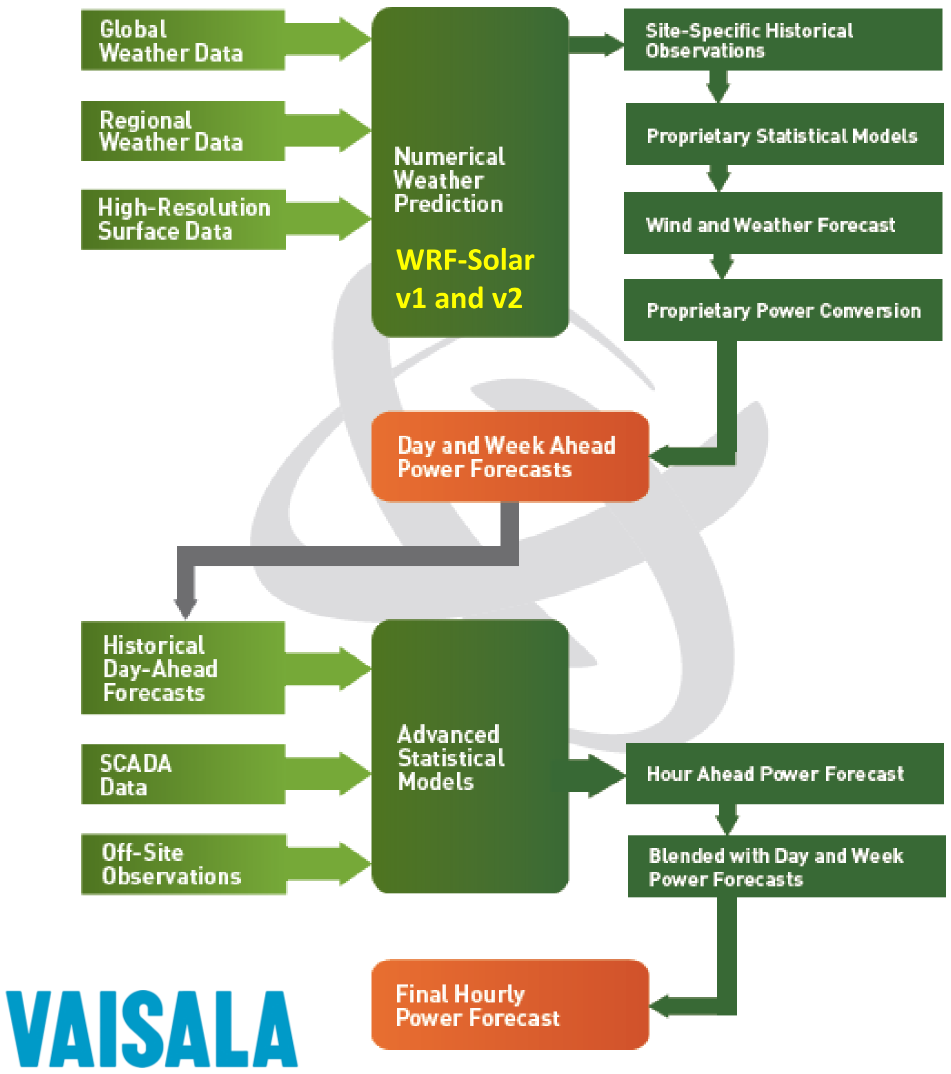
Application of UQ techniques to better understand forecast uncertainty

- Sensitivity Analysis (SA) provides a way to investigate uncertainty associated with parameters or physics packages
  - Focus on parameters used in boundary-layer, microphysics, radiation, and convective parameterizations
  - Follow Yang et al. (2017) and construct surrogate model to determine sensitivities
  - Points to new ways to improve model and reduce uncertainty
- Calibration (tuning) is often accomplished using a trial and error approach
  - UQ methods can be used to find optimal values and calibrate models
- Focus on geographic areas identified by Topic Area 1 Team



Integration with operational systems

Vaisala Forecast System Flow Diagram

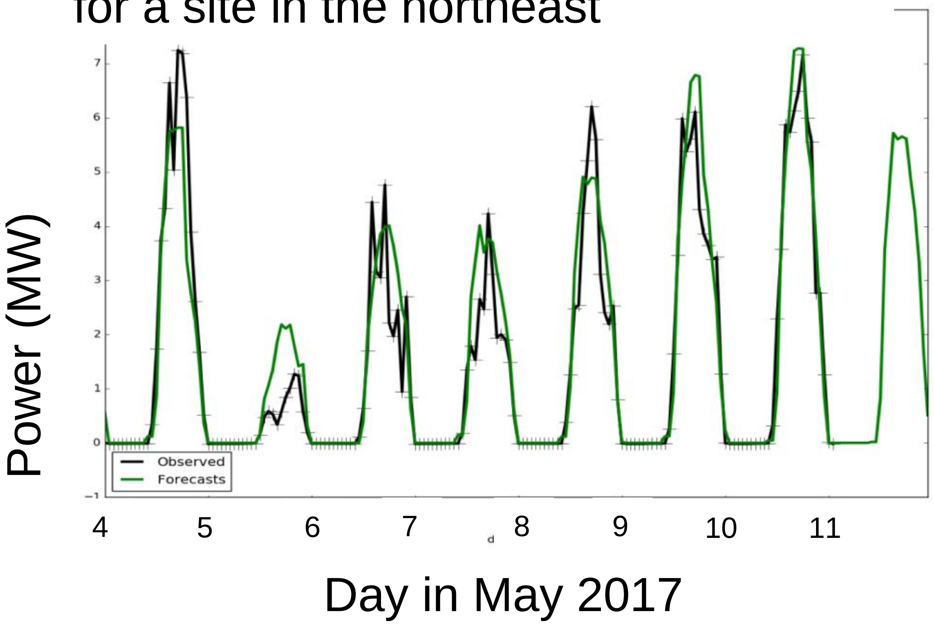


- Use of multiple NWP models (including WRF-Solar)
- System has reduced emphasis on one particular statistical modeling approach—several machine learning methods are in the Vaisala toolbox and hierarchical setup improves robustness
- Generalized power conversion approach rather than power curve application
- NWP integrated with statistical model inputs reducing need for blending day/week ahead power forecasts

Integration with operational systems: Model evaluation

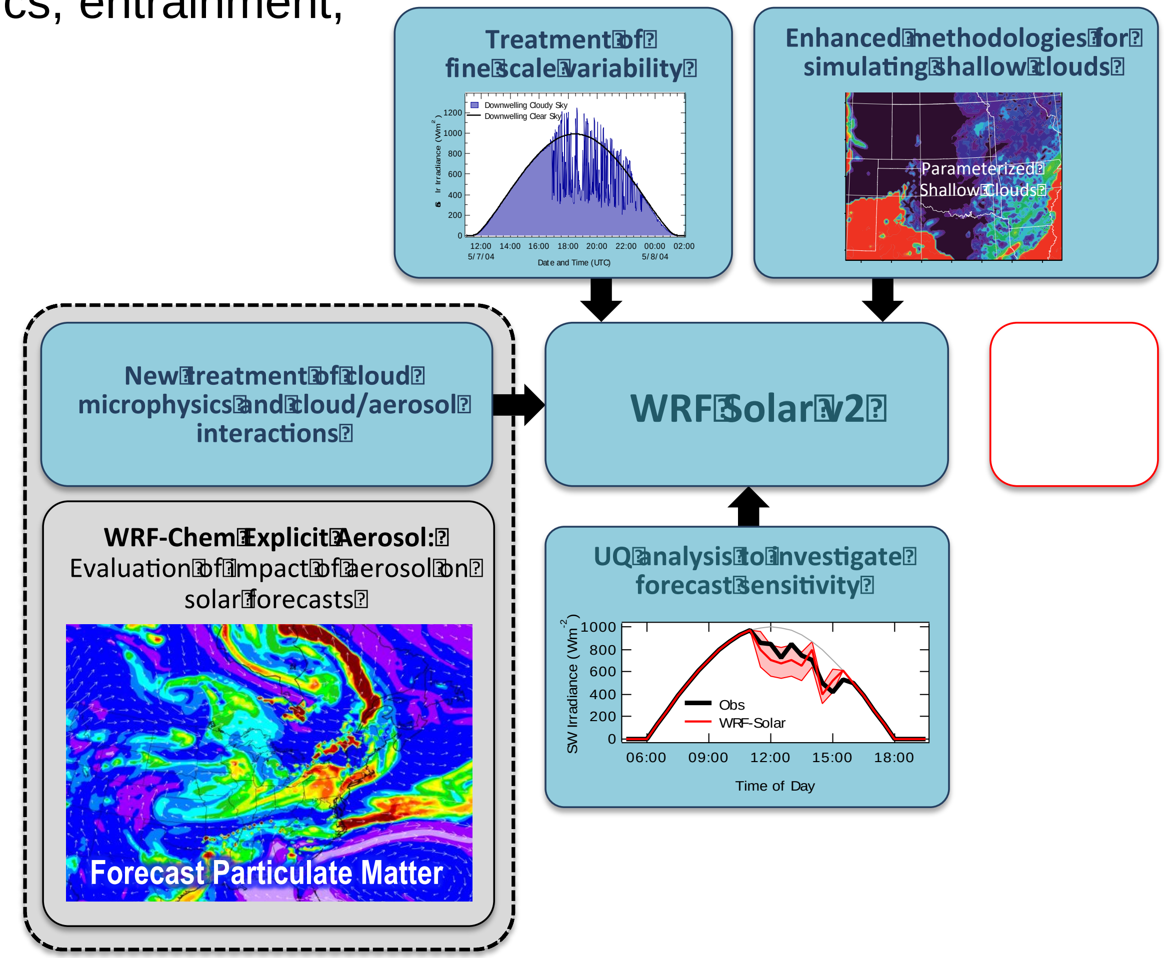
- WRF-Solar v2 will lead to improved intra-day and day ahead forecasts that can be used by the community
- Model improvement will be measured using a range of metrics in collaboration with other teams
  - Mean absolute error (MAE)
  - Root mean square error (RMSE)
  - Characterization of error distributions
  - Categorical statistics for solar power ramps [e.g., Haupt et al. (2016)]
  - New metrics developed by Topic Area 1 Team
- Tested by Vaisala in their operational system
- A community model for all users

Sample Vaisala Irradiance Forecast for a site in the northeast



Overview of research plan

- Improvements in WRF-Solar v2
  - Shallow cumulus, stratocumulus breakup, microphysics, entrainment, and absorbing aerosol
  - Representation of sub-grid variability
- Uncertainty quantification and calibration
- Two types of simulations
  - Focused analysis at specific locations with research-grade observations (NOAA and ARM sites)
  - Regional retrospective simulations of irradiance and aggregate solar power—regions selected in collaboration with other teams
- Evaluation
  - Standard metrics
  - Project specific metrics determined in collaboration with other teams



Backup material

Project Metrics: Year 1 Model Development

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	Metric Definition
Milestone 2.1	Improvement over WRF-Solar v1 in simulated GHI for case studies developed from DOE ARM data sets focused on shallow cumuli.
Milestone 2.2	Improvement in simulated GHI and DNI with improved treatment of cloud entrainment.
Milestone 2.3	Data analysis related to variability of solar irradiance at three DOE ARM sites, forming the basis of the new parameterization of variability.
Milestone 2.4	Perform base-line simulations for specific regions which will form basis for documenting model improvements.

Project Metrics: Year 2 Model Development

	Metric Definition
Milestone 2.1	Verification of new estimates of subgrid variability of DNI and GHI from WRF-Solar simulations using new parameterization at three SURFRAD, and sites defined by the Topic Area 1 team. .
Milestone 2.2	Improvement in forecasts of irradiance using new parametrization for breakup of stratocumulus.
Milestone 2.3	Improvement in forecasts using new treatment of absorbing aerosol for selected case studies with large amounts of absorbing aerosol.
Milestone 2.4	Achieve overall improvement for forecasts of DNI and GHI for selected areas and times relative to WRF-Solar v1. Release working version of WRF-Solar v2 for testing.
	Milestone for release of functioning version of WRF-Solar v2.

Project Metrics: Year 2 and Year 3 Model Application

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	Metric Definition
Milestone 3.1	Document parametric sensitivity of model results to new parameters introduced in WRF-Solar v2 for 2 to 5 regions determined by Topic Area 1 Team.
Milestone 3.2	Improvement in forecast irradiance through model calibration at nine specific locations distributed among 2 to 5 regions determined by the Topic Area 1 Team.

	Metric Definition
Milestone 4.1	Achieve improvement in DNI and GHI using framework developed by, and five regions selected by, the topic Area 1 team.