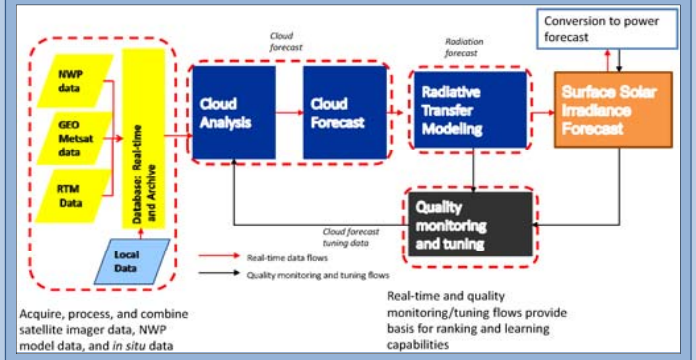
Prototyping and Validating a Solar Irradiance Forecasting System

Marisa Gioioso, Robert d'Entremont, Mike Iacono, Mary Ann Glennon, Hilary E. Snell
and George Modica

Atmospheric and Environmental Research, Inc., Lexington, MA

1. Overview

➢As solar and wind energy resources supply a greater share of electricity production, it will become increasingly necessary to develop controls to handle these variable energy sources and balance supply cycles that are at times out of sync with demand cycles. These power grid controls must enable maximum exploitation of the renewable energy sources when they are active and productive, while allowing traditional power plants to provide energy during off-peak production times, for example overcast skies and light winds. Detection (nowcast) and forecast of these changes will provide information which allows power production from conventional power plants to be adjusted to meet demand.



Our solar irradiance forecast system integrates cloud remote sensing, mesoscale forecast modeling and rapid radiative transfer calculations. The resulting product can forecast solar irradiance on hours-to-days time scales for power production analysis between solar and other power generation sources.

SUMMARY

• Solar power production is limited by cloud attenuation.

• Accurate power production forecasts require accurate cloud-cover forecasting coupled with appropriate radiative transfer modeling.

•AER has developed a solar irradiance forecast system which combines state-of-art cloud analysis and forecast products with accelerated radiative transfer modeling.

•Prototype forecasts over the Iberian Peninsula and the ARM site in Oklahoma presented here.

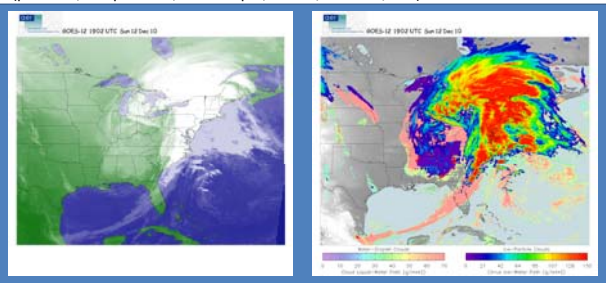
Features

➢ Leverages models developed by AER for cloud detection, analysis and forecasting encompassing 30+ years of research and development.

➢Input data provided from both satellite observations (short-term) and NWP model runs (medium-term); local in-situ data used when available

➢Satellite-based cloud analysis allows for global forecast coverage and is not limited by ground-based cloud detection stations.

➢Radiative transfer models used to compute surface solar irradiance for given atmospheric state (pressure, temperature, water vapor, clouds, aerosols, etc.).



Example of AER cloud analysis. The left panel shows a GOES-12 thermal IR band image of the eastern and central U.S. The right panel shows the retrieved liquid and ice water path .

2. Cloud Forecasting

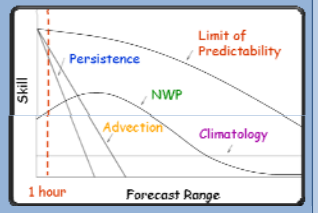
➢ Techniques have varying skill at different forecast ranges.

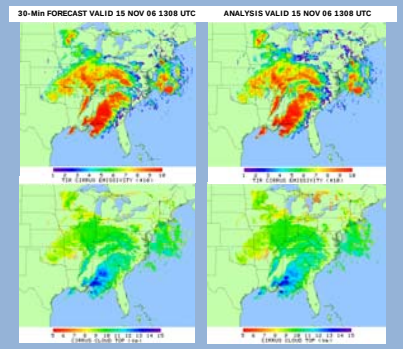
➢Theoretical limit to predictability due to chaotic nature of atmosphere.

➢ 1 hour or less: NWP models less skillful than the advection model for predicting clouds and precipitation

➢NWP model variables suffer from dynamic and thermodynamic inconsistencies during an adjustment period after the initial time.

➢Cloud forecasting software built from work done for AFWA





Cloud advection model is validated by comparison of predicted cloud field with the subsequent analysis.

3. Radiative Transfer Modeling

➢ AER is a world leader in radiative transfer modeling, with over 25 years of peer-reviewed design, development and validation

➢Highly-accurate (slow) models are used to develop and validate faster models

➢LBLRTM (slow) is industry-standard model used for validation

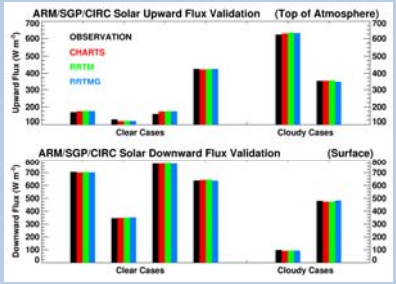
➢RRTM (fast) is used in numerical weather prediction and climate models (where a real-time solution is required).

➢The solar irradiance forecast product uses RRTM-G as the radiative transfer model.

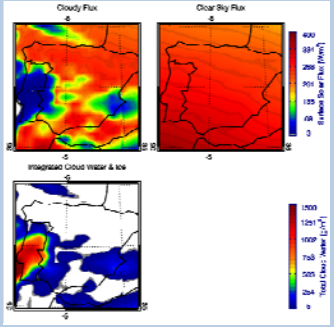
Extensive Application of RT Model

RRTMG Global and Regional Model Applications

- ECMWF (European Centre for Medium-Range Weather Forecasts), Reading, UK
  - **Integrated Forecast System (IFS), ERA40 Reanalysis**
    Began operational use of LW on 27 June 2000 (version prior to LW_v2.0).
    Began operational use of LW and SW with McICA on 5 June 2007.
    Upgrade to v4.84 in progress as of April 2010
- MPI (Max Planck Institute), Hamburg, Germany
  - **ECHAM5**
    Began operational use of LW in 2002 (prior to LW_v2.0 from ECMWF).
    Upgrade to v4.84 in progress as of April 2010
- NCEP (National Centers for Environmental Prediction)
  - **Global Forecast System (GFS)**
    Began operational use of RRTM3_LW at 12Z on 28 August 2003.
    Began operational use of RRTM3_SW at 12Z on 27 July 2010
- NCEP (National Centers for Environmental Prediction)
  - **Climate Forecast System (CFS)**
    Began operational use of LW in 2004.
    Update to include SW and newer LW expected in September 2010
- NCEP (National Centers for Environmental Prediction)
  - **Rapid Update Cycle Forecast Model (RUC)**
    Began operational use of LW in November 2008 (prior to LW_v2.0)
- NCAR (National Center for Atmospheric Research)
  - **Weather Research and Forecasting Model (WRF-ARW)**
    Released as LW and SW radiation option in WRF_v3.1 in April 2009
- NCAR (National Center for Atmospheric Research)
  - **Community Atmosphere Model (CAM5) and Community Earth System Model (CESM1, formerly CCSM)**
    CAM5 and CESM1 released with RRTMG/MJECA (LW and SW) on 25 June 2010
- NASA/GSFC (Goddard Space Flight Center)
  - **Goddard Earth Observing System (GEOS-5) Data Assimilation System**
    Implementation and testing of LW_v4.83 and SW_v3.8 began in 2009
- LMD (Laboratory for Dynamical Meteorology), France
  - **LMDZ climate model**
    Began operational use of LW in 2008-09 (prior to LW_v2.0 from ECMWF).
- CMA (China Meteorological Administration), China
  - **Global/Regional Assimilation and Prediction System (GRAPES)**
    Implementation and testing of LW_v4.71 and SW_v3.8 began in February 2009
- Meteo-France (French National Meteorological Service), France
  - **Meso-NH (Non-hydrostatic Meso-scale atmospheric model)**
    included LW as radiation option in 2009 (prior to LW_v2.0 from ECMWF).

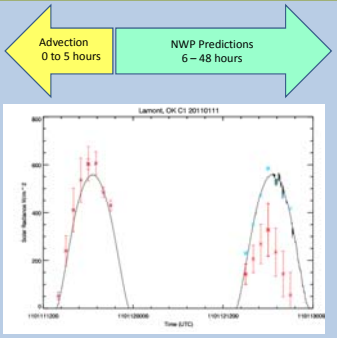


RRTMG model compared to solar observations and other radiative transfer models.



Demonstration of the radiative transfer model applied to the forecast cloud fields for a scene covering the Iberian Peninsula. The surface downwelling solar flux is plotted in the upper left, and the clear sky-equivalent solar flux is plotted on the right, for comparison. The lower left panel shows the total ice and liquid water path for this scene.

4. Preliminary Validation



➢Short-wave broadband Solar Radiation Infrared System (SIRS) measurements at the Central Facility Station (C1) for January 11-14, 2011 shown in W/m² (black solid curve). Standard deviations (not shown) are generally < 10 W/m². Ground measurements courtesy of the ARM (Atmospheric Radiation Measurement) data archive.

➢Solar radiation model predictions calculated hourly (red). No predictions for solar zenith angle > 90 (nighttime hours).

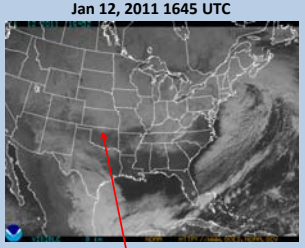
➢Advection-based cloud forecast predictions calculated over 51 x 51 grid centered on the Central Facility site (C1) with 4 km pixels corresponding to GOES 12 satellite data for hours 0-5. Later predictions use the spatially coarser NWP forecast parameters to model solar fluxes.

➢Error bars represent the standard deviation of the predicted surface solar radiation within the model grid. A large standard deviation indicates that significant variation in cloud cover exists within the model area.

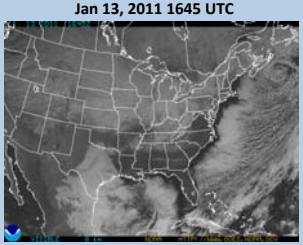
➢Model predictions utilizing cloud forecasts are shown in red. Blue symbols show clear sky predictions with the current atmosphere and represents the maximum solar radiation predicted for that hour.

➢Differences between the predicted and surface measured solar radiation can be attributed to different spatial scales of the measurements.

Jan 12, 2011 1645 UTC



Jan 13, 2011 1645 UTC



Approximate Location: Lamont, OK

CONTACT: **Hilary E. ("Ned") Snell** • Atmospheric and Environmental Research, Inc. • 131 Hartwell Ave • Lexington, MA 02421 • hsnell@aer.com • (781) 761-2288

Acknowledgements
Ryan Aschbrenner, Gary Gustafson and Eli Mlawer for technical advice and support
This work was partially funded by AER IR&D 2010-0029.