Improving Solar Radiation Forecasting

Betsy Weatherhead, U. Colorado
Craig S. Long, NOAA/NWS/NCEP/CPC

NCAR Wind Forecasting Meeting, May 12, 2010
Needs of Renewable Energy Community


- Maximum production during the middle of the day.

- Passive maintenance of many systems.

- PV plants depend on total solar radiation.
  - Fixed angle
  - Single axis
  - Full rotation

- Concentrated Solar Energy highly dependent on direct beam radiation
  - Various forms of energy storage

- Time scales from seconds to decades with a strong focus on minutes to days.
Solar Radiation - Basics

- Solar radiation reaching the surface of the Earth is affected by many factors:
  - Sun angle
  - Clouds
  - Aerosols
  - Surface reflectivity
  - Water vapor
  - Ozone

- All of these factors can change dynamically on a day-to-day basis.
- Each part of the solar spectrum is affected differently by these factors.
Technologies are still developing

- **Wavelength matters.**
- **Clouds, aerosols, ozone, water vapor all matter.**
Technological Improvements

Best Research-Cell Efficiencies

Efficiency (%)


Multijunction Concentrators
- Three-junction (2-terminal, monolithic)
- Two-junction (2-terminal, monolithic)

Single-Junction GaAs
- Single crystal
- Concentrator
- Thin film

Crystalline Si Cells
- Single crystal
- Multicrystalline
- Thin film

Thin-Film Technologies
- Cu(In,Ge)Se₂
- CdTe
- Amorphous Si:H (stabilized)
- Nano-, micro-, poly-Si
- Thin film polycrystalline

Emerging PV
- Dye-sensitized cells
- Organic cells (various technologies)

Courtesy of NREL
Multiple paths to making solar forecasts

- Proprietary
- Data extrapolation
- Statistical modeling
- Physical modeling
- Ensemble forecasts
- Data assimilation, rapid refresh
NOAA’s NWS Model Production Suite

- Climate
  - CFS
  - MOM3

- North American Mesoscale
  - WRF NMM

- Hurricane
  - GFDL
  - HWRF

- North American Ensemble Forecast System
  - GFS, Canadian Global Model

- Short-Range Ensemble Forecast
  - WRF: NMM+ARW
  - ETA, RSM

- Global Forecast System

- Global Data Assimilation

- Oceans
  - HYCOM
  - WaveWatch III

- Dispersion
  - ARL’s HYSPLIT

- Severe Weather
  - WRF NMM
  - WRF ARW

- Air Quality
  - NAM+CMAQ

- Rapid Update for Aviation, Severe Weather

- Courtesy Stan Benjamin
Forecasting Solar UV Radiation

- UV Forecasts have taken place for fifteen years in support of human health.
- NOAA, various weather services, Accu-Weather
- Private monitoring offers Nowcasts.
Solar radiation is affected by a variety of factors—all of which must be understood and properly forecasted.
UV Index Algorithm

**Old** *(virtually unchanged since 1994)*
- Weight UV relationship w/total ozone and SZA derived from delta Eddington RT model.
- Total ozone forecasts from GFS.
- Surface UV albedo held constant at 5%, *(no allocation for snow or ice cover).*
- Aerosols: AOD is constant at 0.2 and SSA = 1.0.
- Elevation increases UV flux by ~6% per km.
- UVI clear sky field on 1x1 grid up to this point.
- Relationship between NGM MOS cloud prob and cloud attenuation of UV flux.
- Cloudy UV Index values at all (~800) MOS locations.
- Bulletin, Eta grid 211 and 207 are created by interpolation from MOS cities.
- Products are limited to next day solar noon over US.

**New**
- Weight UV relationship with total ozone, and SZA derived from NCAR-TUV RT model.
- Total ozone forecasts from GFS.
- Surface UV albedo held constant at 3% for non-snow conditions.
  - GFS albedo is used when > 30% *(where snow is possible).*
- Aerosols: AOD and SSA vary, derived from seasonal global climatology grids.
- Elevation increases UV flux by ~ 6% per km.
- Ratio of GFS down-welling UVB flux w & w/o clouds determines cloud attenuation.
- Output remains on gaussian grid.
- GFS inputs available at 3hr interval.
- UV Index products are outputted globally at 1 hr intervals out to 96 hours.
Cloud Impacts

- Broken clouds can be difficult to forecast. Within a balancing area, this may not be important. Defining appropriate areas is unclear.

- Very light cirrus clouds can have a large impact on direct beam efficiency.

- Both types of clouds can be difficult to predict.
25 mWatts/sq m = 1 UV Index unit

Diurnal trace of observed UV

| St Dev of obs +/- 0.5 hr about 18 UTC

o 18 hr FCST from 00Z run valid at 18 UTC

Erythema Dose Rate - (Old)
Bondville, IL

NOAA/SRRB Surface Radiation Budget Network
Improvements in NWS’ solar UV forecast

- Improvements in cloud and ozone forecasts result in a much improved solar forecast.

- Verification depends strongly on time period of averaging when single locations are considered.
Significant improvements in solar radiation forecasts

- Cloud modeling has improved significantly over the past twenty years.
- Inclusion of “cloud optical depth” and “cloud height” are of considerable importance to assessing transmission.
- Aerosol forecasts are currently under consideration in NWS.
Erythemal Dose Rate - Bondville, IL - October 13 & 14, 2003
40.04N, 88.36W

Fine temporal structure is extremely difficult.
Improved forecasts are necessary for optimal use of solar energy integration.

Multiple factors must be considered to make accurate forecasts: clouds, aerosols, water vapor.

NWS currently makes solar radiation forecasts for 57 locations for UV index. Significant improvements have been achieved using state of the art cloud forecasting.

Fundamentally, improvements require accurate measurements of both direct and diffuse radiation.
Actual hourly variation of solar energy potential - accurate forecasts are essential

Long-term estimates of solar radiation will need to take into multi-year factors including El Nino, solar cycles, NAO, changes in climate, including in changes in the jet stream.

Predictions of long-term changes will require research into past long-term datasets as well as best available climate models.
Foundation for Model Improvement--Measurements

- Surface Radiation monitoring
- Direct beam separate from total solar radiation.
- DOE’s Atmospheric Radiation Measurement, National Renewable Energy Laboratory
- NOAA’s SurfRad, Central Calibration Facility
- USDA’s UV Monitoring Network
- Direct beam measurements are difficult, but not impossible.
Summary

- Data are the foundation for improving forecasts.
- Current solar monitoring is inadequate, but can be easily adapted and expanded.
- Multiple modeling approaches will be needed to address the multiple needs of the renewable energy communities.