Using Satellite-Based Solar Insolation for Estimating Long-Term Regional Evapotranspiration

Simon J. Paech[1], John R. Mecikalski[1], David M. Sumner[2], Jennifer M. Jacobs[3]

[1]Atmospheric Science Department, University of Alabama in Huntsville, Huntsville, Alabama
[2]United States Geological Survey, Altamonte Springs, Florida
[3]University of New Hampshire, Durham, New Hampshire

1. MOTIVATION

- **Incoming short-wave solar radiation (insolation) is the largest determinant of temporal variation in potential and reference evapotranspiration (PET & RET).**
- **PET & RET are critical variables for water management, both in hydrologic flow simulations and water allocation.**
- **Satellite estimation of solar insolation provides significant advantages over traditional ground-based measurements:**
  - Seamless spatial coverage over large geographic regions
  - High spatial resolution (2-20 km)
  - Data availability:
    - In remote, inaccessible, or potentially hazardous regions
    - Over oceans and large water bodies
    - In countries that don't have the means to install a ground-based measurement network.

2. THIS STUDY AND AFRICA

- **As an example of what may be performed over Africa, we present a study performed over the state of Florida in the United States.**
- **Estimates of solar insolation from satellite data have been produced over a 10-year period (1995-2004) at 2 km spatial, 30 min and daily temporal resolution.**
- **A model calibration and validation of the daily insolation product was undertaken using ground-based pyranometer data, resulting in a refined, high quality product.**
- **The resulting dataset has been used by State of Florida Water Management Districts to produce 2 km resolution PET & RET estimates.**
- **A similar solar insolation product could be generated and utilized in the same way to improve groundwater management in African regions.**

3. SOLAR INSOLATION ESTIMATION

- **The Gautier-Diak-Masse (GDM) model was employed:**
  - **A fairly simple physical representation of cloud and atmosphere radiative processes.**
  - **Has been shown by various studies to perform as well as, or even better than, more complex methods over a variety of land surface and climatic conditions.**
  - **See Gautier et al. (1980), Diak and Gautier (1983), Diak et al. (1996) for details.**
- **National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellite (GOES) visible satellite data (2 km resolution) was used as model input.**

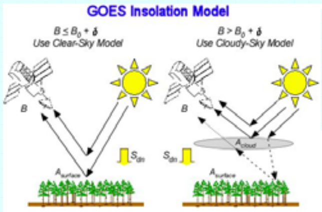


Figure 1. Graphical depiction of the GDM model under clear-sky conditions (left) and cloudy conditions (right). B refers to the brightness observed by the satellite, S_{dn} is the downward shortwave radiation flux, and $A_{surface}$ and A_{cloud} refer to the surface and cloud albedos, respectively.

4. MODEL CALIBRATION & VALIDATION

- **A cumulative 3-step calibration of the daily insolation product was undertaken to fine-tune the data & remove temporal- and cloudiness-related biases. This was achieved via comparison with "truth" measurements from ground-based pyranometer data.**
  - **Step 1: Clear-day Comparison**
    - Comparison of satellite-estimated and pyranometer-measured data under clear-sky reference conditions.
    - Multiplier coefficients determined.
  - **Step 2: Cloudiness Bias Correction**
    - Satellite-estimated data regressed against pyranometer data
    - Linear bias correction for each data point computed based on a "cloudiness index".
  - **Step 3: Temporal (monthly) Bias Correction**
    - Monthly bias corrections determined via comparison of monthly-averaged satellite-estimated and pyranometer-measured insolation.
- **Model validation (performance assessment) was achieved by comparison of calibrated data with additional pyranometer data. Figures 2 and 3 and Table 1 show the progression of model performance from the initial, un-calibrated product ("DAILY_A"), through to the fully calibrated ("DAILY_D").**

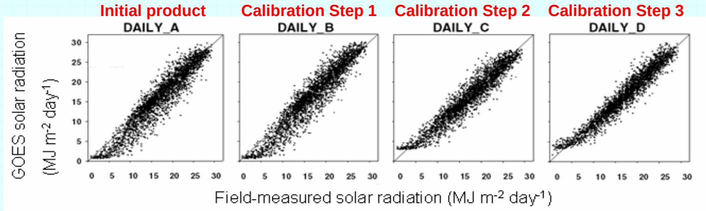


Figure 2. Comparison of satellite-estimated and pyranometer-measured daily mean solar insolation for an individual representative pyranometer location (Floral City, Florida).

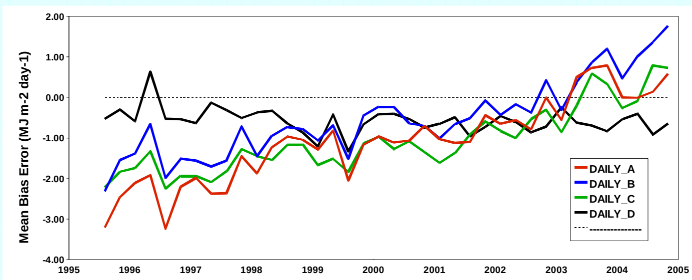


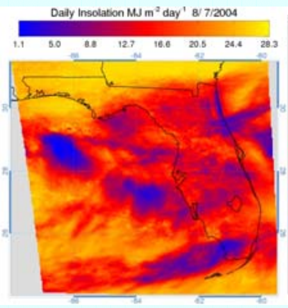
Figure 3. Seasonal bias of satellite-estimated daily mean solar insolation relative to pyranometer data; values represent time- and station-averaged values for the nine validation stations; bias equals GOES-estimated minus measured solar radiation.

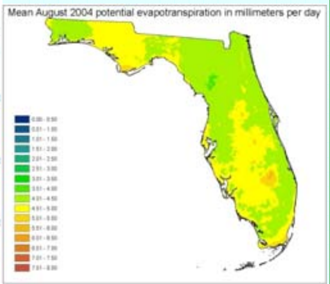
	DAILY_A	DAILY_B	DAILY_C	DAILY_D
RMSE MJ m^{-2} day^{-1} (%)	2.2 (13%)	2.2 (13%)	1.9 (11%)	1.7 (10%)
MBE MJ m^{-2} day^{-1}	-0.7	-0.2	-0.8	-0.5
R^2	0.90	0.91	0.92	0.93

Table 1. Model validation/assessment statistics. Average over entire data period and nine validation stations. Root mean square error (RMSE) (as a percentage of the mean pyranometer value in parentheses), mean bias error (MBE), and correlation coefficient (R^2).

5. EXAMPLE & APPLICATION

- **An example of the final, calibrated daily solar insolation product is shown below (left), with application toward estimating mean monthly PET (right).**





6. GENERATION OVER AFRICA

- **The GDM model is portable - it is not bound to data from GOES satellites, nor to regions within the United States.**
- **To generate an equivalent solar insolation product over Africa, high-resolution data from the Meteosat Second Generation satellites (MSG1 and MSG2) would be utilized.**
- **For calibration, only a single pyranometer is necessary (with two to ten being ideal).**
- **With these data, a high resolution, high-quality solar insolation dataset could be produced for Africa toward estimating potential and reference evapotranspiration (PET & RET).**

7. KEY REFERENCES:

- Gautier, C., G.R. Diak, and S. Masse, 1980: *A simple physical model to estimate incident solar radiation at the surface from GOES satellite data.* J. Appl. Meteor., 19, 1007–1012.
- Diak, G. R., and C. Gautier, 1983: *Improvements to a simple physical model for estimating insolation from GOES data.* J. Climate. Appl. Meteor., 22, 505- 508.
- Diak, G. R., W.L. Bland, and J. Mecikalski, 1996: *A note on first estimates of surface insolation from GOES-8 visible satellite data.* Agric. For. Meteorol., 82, 219-226.

Contacts: Simon Paech: *simon_paech@hotmail.com,* John Mecikalski: johnm@nsstc.uah.edu, Research funded under USGS grant 05ERAG0027.

Groundwater and Climate in Africa, an international conference. Kampala, Uganda, 24-28 June, 2008