SUNY Satellite-to-Solar Irradiance Model Improvements

Higher-accuracy in snow and high-albedo conditions with SolarAnywhere Data v3

SolarAnywhere

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Executive Summary

Clean Power Research has released a new version of SolarAnywhere® Data to address limitations of previous models in conditions of snow cover, high-ground reflectance and persistent clouds. This paper validates improvements that are the result of incorporating four infrared (IR) geostationary satellite channels into the SUNY satellite-to-solar irradiance model.

By incorporating satellite IR channels, the new SUNY model better detects snow cover and high-albedo conditions, and modulates the model background accordingly to more accurately report actual irradiance. The overall reduction in the model uncertainty is reflected by multi-annual comparisons of total insolation. The new model shows a more accurate, less uncertain approach to determining available insolation as compared with a wide range of climactic conditions.

The new SUNY model has been implemented operationally as SolarAnywhere Data v3, and is available exclusively as a commercial software product via SolarAnywhere Data. Previous SUNY models have comprised the gridded dataset used by NREL to produce the 2005 (SUNY v1) and 2010 (SUNY v2.3) National Solar Radiation Database (NSRDB) releases. SolarAnywhere irradiance data is used to reduce the risk of solar asset ownership by quantifying renewable resource potential with associated uncertainty.

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Understanding Risk Assessment in Snow and High-Albedo Conditions

The SUNY satellite model was selected by NREL to produce the 2005 and 2010 National Solar Radiation Database (NSRDB) releases, and is available throughout North America in the commercial software platform SolarAnywhere® Data. The SUNY satellite model uses a one-time satellite device calibration to enable high spatial consistency, alleviating the need for regional irradiance sensor input to maintain accuracy.

Developers, system owners/operators, utilities, grid operators and state governments use SolarAnywhere irradiance data to reduce the risk of solar asset ownership by quantifying renewable solar resource and associated uncertainty. The main uses of this data are to:

- Qualify prospective solar sites by quantifying a typical year's solar resource and PV production.
- Assess project economics and feasibility by quantifying long-term risk.
- Correlate with ground-measured data to reduce long-term risk.
- Forecast solar production to meet PPA and off-taker requirements.

The SUNY satellite model has historically yielded irradiance measurements with low bias and minimal error in most climatological conditions, leveraging visible (VIS) channel images from the Geostationary Operational Environmental Satellites (GOES) operated by the National Oceanic and Atmospheric Administration (NOAA). The model bias and error increase, however, when measuring terrestrial irradiance in conditions of snow cover or when the background visible image is predominantly bright (i.e., high albedo surfaces and persistent cloud cover).

SUNY model improvements have been developed and proven by Perez et al. [1] to address the limitations of previous models (SolarAnywhere versions 1.0 through 2.4) in circumstances of snow cover, and certain conditions that exhibit high ground reflectance and persistent clouds. The model improvements have been made operational exclusively through Clean Power Research and its SolarAnywhere software product family.

The accuracy of the SUNY model, in practice, relies heavily on the ability to recognize the difference between cloudy and clear sky background conditions. In older versions of the SUNY model (SolarAnywhere v2.4 and previous models), the ability to distinguish between cloudy and clear sky conditions within the visible model diminishes when certain weather or geological conditions exist:

1) Regions with non-negligible snow cover and minimal forest or building cover (e.g. northern tundra, or northeastern non-pine forest).

2) Locations with persistent or long-lasting cloud cover, termed the "Eugene Syndrome" [2] (e.g. Pacific Northwest and Pacific Coastal marine stratus).

3) Ground characteristics that include elements of highly reflective or bright material, (e.g. desert sand or salt pans).

This report summarizes the result of validating a new SUNY model that incorporates both visible and infrared (IR) satellite image channels to better distinguish between clouds and snow cover or other high albedo surfaces, and that has been implemented operationally as SolarAnywhere Data v3.

SolarAnywhere v3 Model Improvements

The SUNY models used in SolarAnywhere v2.4 and earlier versions were designed to account for ground snow cover using an external snow mask and the GOES visible channel. This approach is more accurate than considering only the visible channel, since snow and bright clouds are difficult to discern in visible channel images. Adding infrared (IR) channels to the set of inputs improves the model further by providing additional information about the temperature of the ground and clouds, which better characterizes irradiance levels when snow is present.

Incorporating IR data from GOES satellites is possible because of overlapping coverage of both the IR and visible images. Visible satellite images represent the solar radiation reflected by the earth's surface and the atmosphere (in the visible light spectrum), whereas the IR radiation captured by the satellite represents the temperature of the earth's surface, clouds and atmosphere.

Combining different IR channels can therefore distinguish between most cloud layers and the ground. This distinction is shown below in Figures 1 and 2. Figure 1 shows the GOES Visible channel, and thus no distinction between cloud and snow cover. Figure 2 shows a combination of GOES Infrared channels, and exhibits the potential to only capture clouds.

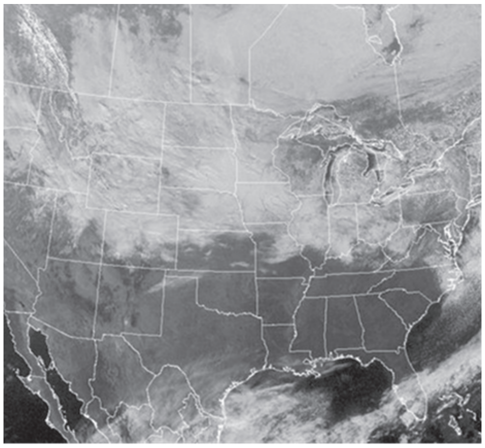

Figure 1: GOES Visible (VIS) channel image shows no distinction between cloud and snow cover

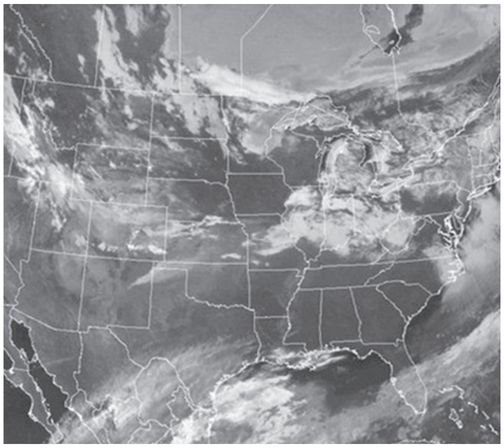

Figure 2: Combination of GOES Infrared (IR) channel images shows only cloud coverage

The SolarAnywhere v3 model incorporates all four GOES IR channels listed in Table 1 through a pseudo-empirical approach that matches channel readings to a wide range of high quality irradiance measurements from the Surface Radiation Budget Network (SURFRAD [3]), covering distinct climactic environments across North America.

IR Channel	Wavelength
2	3.9 µm
3	6.7 µm
4	10.7 µm
5/6*	12 µm / 13.3 µm

** IR Channel 5 used for GOES 8-11 and IR channel 6 used for GOES 12-15 satellite data, respectively*

Table 1: GOES Satellite IR Channels

The pseudo-empirical approach is retained because: (1) the physical processes linking surface downwelling irradiance and IR channels are not as clear-cut as those linking surface downwelling with reflected radiances [4]; and (2) it is an effective approach (existing operational satellite-based snow detection algorithms rely in part on empirical thresholds in their implementation, e.g. reference [5]).

While the current visible model is self-calibrating and does not depend on evolving satellite calibrations [1], the IR model assumes that the satellite IR channels are properly calibrated and do not drift over time. This is a safe assumption because these channels, which are essentially temperature sensors, are constantly calibrated onboard from an absolute temperature source with an operational accuracy of ± 1K [6].

In addition to the four IR satellite channels, the model also uses operational inputs already available as part of the SolarAnywhere Data production stream, including solar zenith angle, surface temperature and ground elevation. Surface temperature is a particularly important input that provides real time ground-truth reference to the remotely sensed brightness temperatures, which are temperatures of the atmospheric layers seen by each IR channel. The IR channel data may or may not include the ground temperature, depending on the channel and meteorological conditions.

SolarAnywhere v3 Validation

The improved IR+VIS SUNY model used to generate SolarAnywhere v3 data is validated in this study against 5 years (2010-2014) of surface-measured irradiance data from 14 U.S. ISIS and SURFRAD sites (a total of 70 site-years). Significant snow cover was present at the Fort Peck, Sioux Falls, Pennsylvania State, Bondville and Boulder sites during this validation period, ranging from 12% to 25% of all hours.

Figures 3 and 4 depict the relative hourly Mean Absolute Error (MAE) for GHI and DNI, respectively, at the fifteen reference ground sites. Relative hourly MAE is expressed as a percentage of the observed mean value (¯(x^obs)), and calculated by the equation:

$$MAE = \frac{\sum_{i=1}^{N} \left| x_i^{SA} - x_i^{obs} \right|}{N} \frac{100\%}{\overline{x^{obs}}}$$

where x stands for the variable being considered (either GHI or DNI), N is the number of data points used, and the superscripts SA and obs stand for SolarAnywhere and ground observed data respectively.

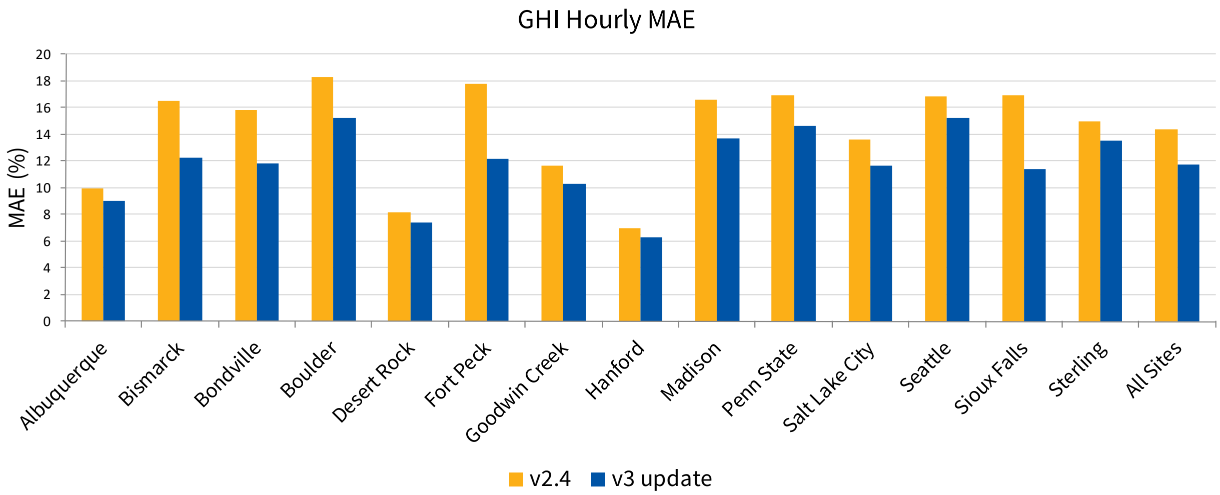

Figure 3: Hourly averaged MAE for GHI from the VIS only (v2) and IR + VIS (v3) SUNY models for 2010-2014

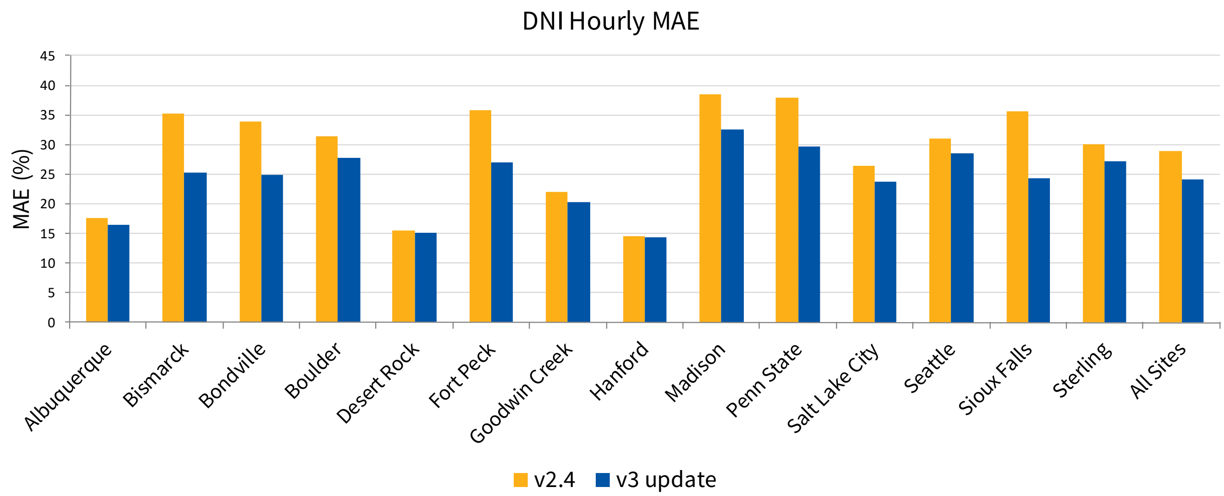

Figure 4: Hourly averaged MAE for DNI from the VIS only (v2) and IR + VIS (v3) SUNY models for 2010-2014 for all stations except Sterling, which only had DNI data available for 3 years (2012-2014)

Composite benchmarked Root Mean Square Error RMSE and Mean Absolute Error MAE metrics for the ground versus satellite-based results are shown in figures 5 and 6, where RMSE and MAE are also expressed relative to the observed mean value and calculated by the following equations:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(x_i^{SA} - x_i^{obs})^2}{N}}\,\frac{100\%}{\overline{x^{obs}}}$$

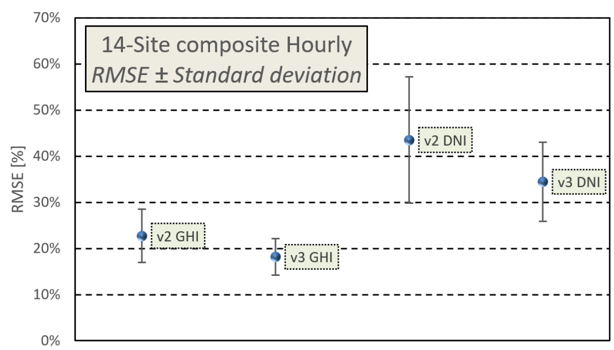

Figure 5: Hourly RMSE, all sites, v2 and v3

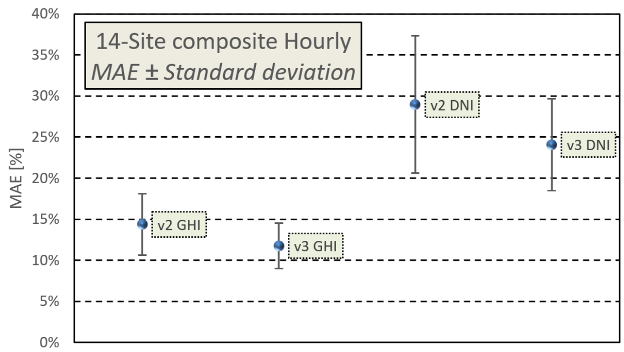

Figure 6: Hourly MAE, all sites, v2 and v3

Additional comparisons can be made showing improvements in snow cover conditions by looking specifically at each site referenced against the ground measurements. For the studied period, the Fort Peck site exhibited the highest percentage of snow cover out of the five selected sites.

Figure 7 shows the scatter of modeled GHI against ground for the v2.4 visible-only model. Figure 8, which compares SolarAnywhere v3 modeled GHI against ground shows a large reduction in the scatter in the lower right and lower center of the figure. The improvements seen in Fig. 8 correspond to more accurate estimates of GHI on clear days (high measured GHI) with snow on the ground that was mistaken as cloudy conditions (low modeled GHI) in the previous model.

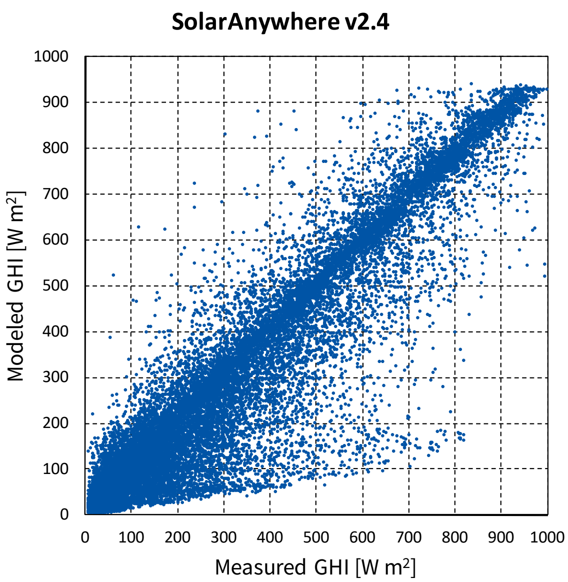

Figure 7: Comparison of modeled versus measured GHI for Fort Peck, using the VIS-only (v2) SUNY model for 2010-2014

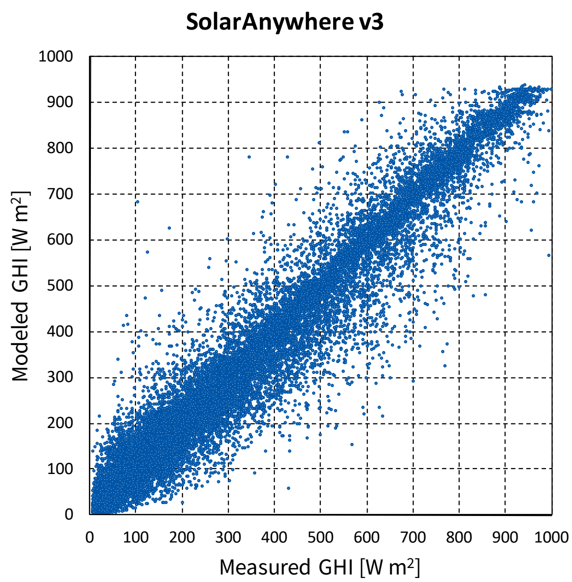

Figure 8: Comparisons of modeled versus measured GHI for Fort Peck, using the IR+VIS (v3) SUNY model for 2010-2014

The use of the IR channel model was also effective in addressing conditions with persistent cloud coverage and high ground reflectivity. Madison, Wis., was used as an example location with persistent cloud cover. Here, a comparison was made using daylight measurements from 2010 to 2014. The relative Mean Bias Error (MBE) over this time period decreases from -3.2% to -1.1% for GHI measurements, whereas the GHI RMSE also decreased from 87 to 70 W/m2. MBE is also expressed relative to the observed mean value and calculated by the following equation:

$$MBE = \frac{\sum_{i=1}^{N}\left(x_i^{SA} - x_i^{obs}\right)}{N} \frac{100\%}{\overline{x^{obs}}}$$

Albuquerque, N.M., is a location that presents specific challenges in high ground reflectivity due to low vegetation and surface material coverage that is highly reflective, such as sand. For SolarAnywhere v1.0 through v2.4 that use the visible satellite model, direct normal irradiance measurements are particularly challenging in regions of high ground reflectivity.

For comparison at this location, we compared the modeled versus measured direct using all daylight hour data from 2010 to 2014. The comparison of the existing visible model and the new IR + VIS model to ground results in a decreased DNI relative MBE from 1.3% to 0.1%, and a decrease in RMSE from 176 to 159 W/m2.

SolarAnywhere v3 Uncertainty in the Yearly GHI and DNI

To calculate model uncertainty, five years of data from 14 sites across the United States were analyzed. The aggregated number of 70 annual values for GHI and 68 for DNI provide wide temporal and geographic coverage. Two site-years of DNI data were removed for poor ground observed data quality. Table 2 shows average and standard deviation (σ) of the annual values of MBE and MAE, and the standard error of the mean (SE). These metrics are generally used to assess uncertainty and are defined by the following equations:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}\left(MBE_i - \overline{MBE}\right)^2}{N}}$$

$$SE = \frac{\sigma}{\sqrt{N}}$$

Where N equals 70 for GHI and 68 for DNI and DHI.

Metric	Average	Standard Deviation (σ)	Standard Error (SE)
MBE_{GHI}	0.5%	2.4%	0.3%
MBE_{DNI}	1.7%	6.8%	0.8%
MBE_{DHI}	-4.7%	5.5%	0.7%
MAE_{GHI}	1.5%	2.0%	0.2%
MAE_{DNI}	4.6%	5.3%	0.6%
MAE_{DHI}	5.8%	4.3%	0.5%

Table 2: Annual uncertainty metrics associated with SolarAnywhere Data v3

Assuming the bias error is normally distributed, then the SolarAnywhere Data v3 bias will fall with a 95% probability within [-4.3, 5.3]% for GHI, [-11.9, 15.3]% for DNI and [-15.7, 6.3]% for DHI. The 95% confidence intervals for the mean value of the bias will also be [-0.1, 1.1]% for GHI, [0.1, 3.3]% for DNI and [-6.0, -3.4]% for DHI.

Reduced Risk in Snow and High-Albedo Conditions

The results of this study confirm that the new IR-based SUNY model used in the generation of SolarAnywhere Data v3 enables considerable operational improvement over previous models, significantly reducing bias and error in modeled GHI and DNI results. Specifically, GHI and DNI hourly MAE showed a 17% and 15% average reduction respectively. Regions with the most consistent snow cover show the most improvement, while locations with significant ground cover (e.g., vegetation, trees) show modest improvement in the error statistics. Regions with bright surfaces (e.g., deserts) and persistent cloud cover also show improvement on the modeled irradiance error.

The overall reduction in uncertainty in the model is reflected by multi-annual comparisons of total insolation. The SolarAnywhere Data v3 model shows a more accurate, less uncertain approach to determining available insolation over a wide range of climactic conditions when compared with previous versions.

References

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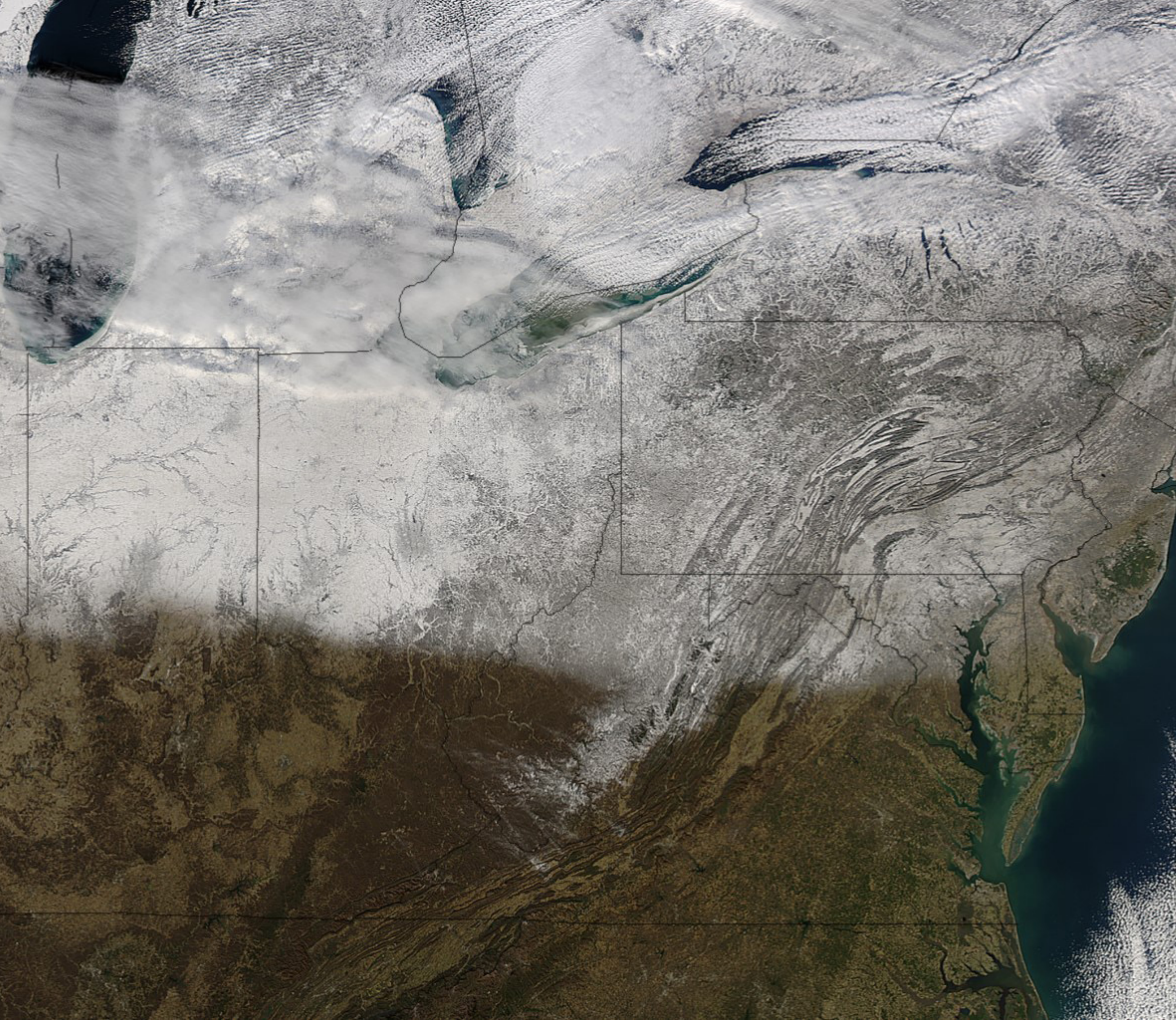
[6] NOAA-NESDIS, US Department of commerce, http://www.nesdis.noaa.gov/, 2010



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