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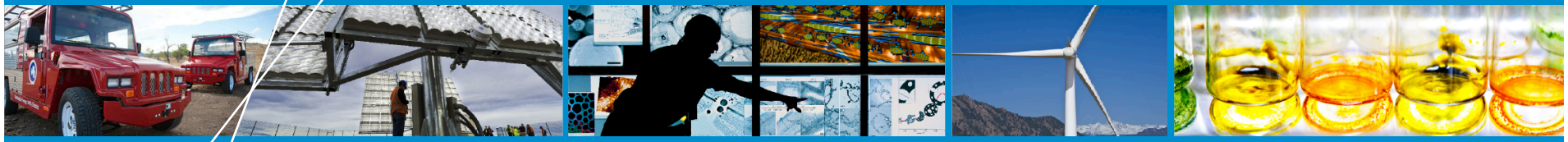
Changing How We Look at Things:

Are There Opportunities That We're Overlooking?



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PV Solar Resource Workshop

February 27, 2015

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Outline

- **Goal: Reduce uncertainty in PV investments**
- **Options for quantifying irradiance data**
  - For predicting output of a future PV plant
  - For verifying output of an installed PV plant
  - Key question is horizontal vs plane-of-array irradiance
- **Can we avoid taking risk twice for the uncertainty of the transposition?**
- **Can we change the way we communicate historical data to enable more precise validation of PV plant performance?**
- **Solar resource vs PV resource – what would it take to change the paradigm?**

Investors want to know the ROI

- **If you buy a Certificate of Deposit, would you buy the one for**
  - 2%/year return or
  - 2.5%/year return?
- **When investing in PV, each reduction in uncertainty (risk) is valuable to the investor**
- **Risk is included in contract for**
  - The available sunshine
  - The plant performance

For a new project, what are options?

- **Quantify solar resource:**
  - Deploy sensors in the proposed location and configuration and wait 30 years

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For a new project, what are options?

- **Quantify solar resource:**
  - Deploy sensors in the proposed location and configuration and wait ~~30 years~~ a year
  - Use historical data sets derived from > 30 years of data (e.g. TMY = Typical Meteorological Year*) to provide horizontal (GHI, direct, diffuse) irradiance, transpose that to plane-of-array (POA) irradiance

*www.nrel.gov/rredc/

Why GHI rather than POA Irradiance?

- **Why not include POA irradiance in weather files?**
- **Practical questions for POA irradiance in weather data files:**
  - How many tilts and azimuths might we want data for?
  - When creating a POA irradiance data set,
    - What albedo would one assume?
    - What transposition model?
    - Isotropic or anisotropic diffuse radiation?
- **Conclusion: Horizontal data are easier to document (though less useful than POA data).**

For monitoring plant operation, what options?

- **Quantify solar resource using:**
  - Thermopile in horizontal plane
    - This is consistent with the data used for the original prediction
  - Reference cell or module in POA
    - This is known to more closely correlate with system performance

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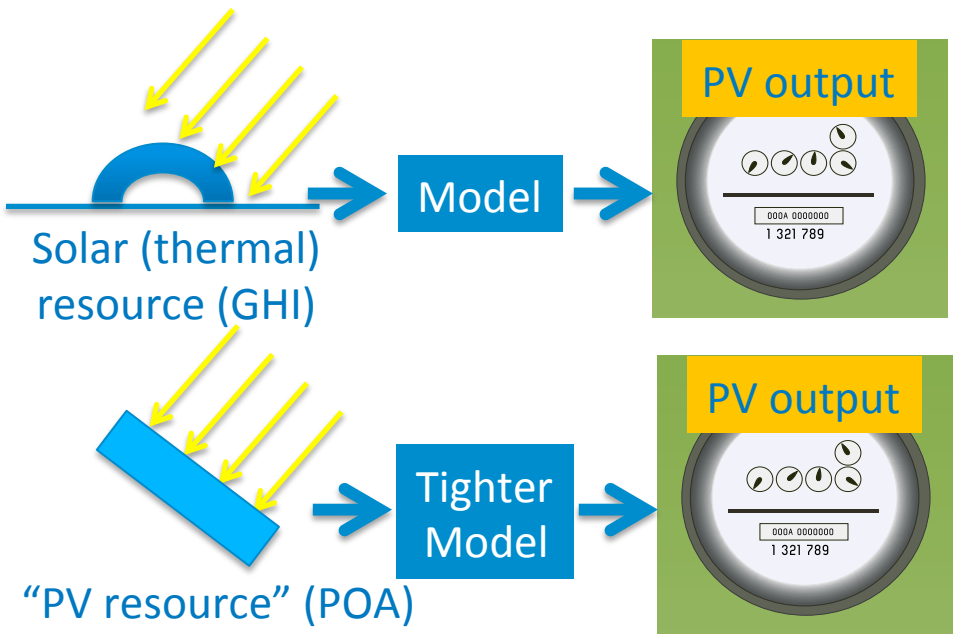
- **Which is preferred?**
  - Some say that the only "correct" way is the thermopile



Double counting risk

- **Investor wants to know kWh at the end of the year. Risk includes:**
  - Accuracy of historical data
  - Sunny or cloudy weather relative to historical average
  - Accuracy of transposition to POA
  - Risk of plant performance relative to predicted for measured weather is transferred to installer
- **Installer's risk includes:**
  - Accuracy of measurement of GHI
  - Accuracy of transposition to POA
  - Plant performance relative to predicted for measured weather

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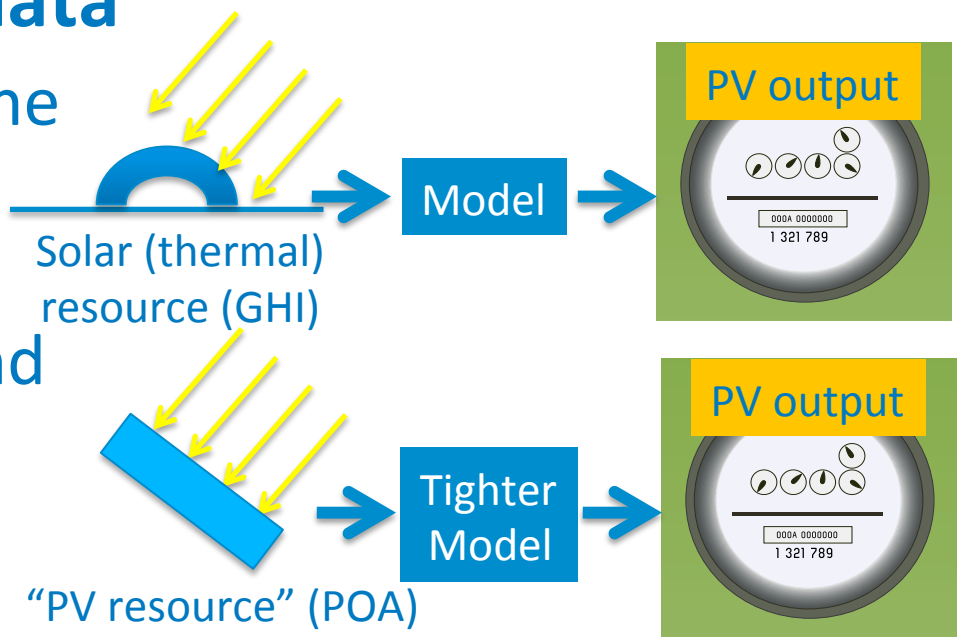
- **Installer's risk includes:**
  - Accuracy of measurement of horizontal irradiance
  - Accuracy of transposition to POA
  - Plant performance relative to predicted for measured weather

Both the investor and the installer often take risk for inaccurate transposition!

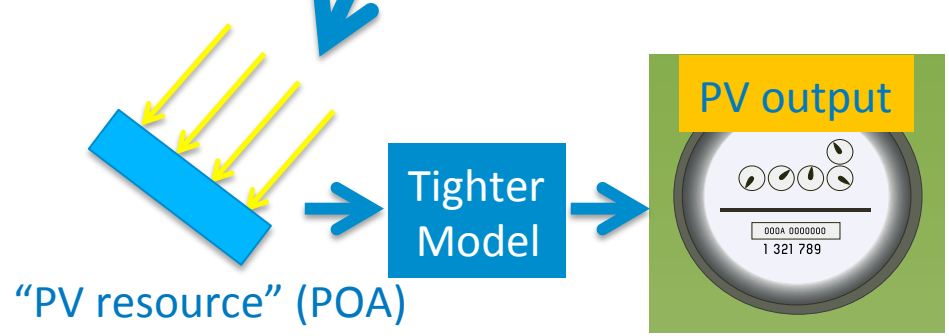
Can we use POA data to verify plant performance?

- **Reasons for using horizontal data**
  - Historical POA data is not available in many cases
  - POA may not be well defined
  - Performance model may use horizontal rather than POA irradiance
- **Reasons for using POA data**
  - Avoids double counting the risk for transposition
  - Allows a tighter contract between the investor and the installer

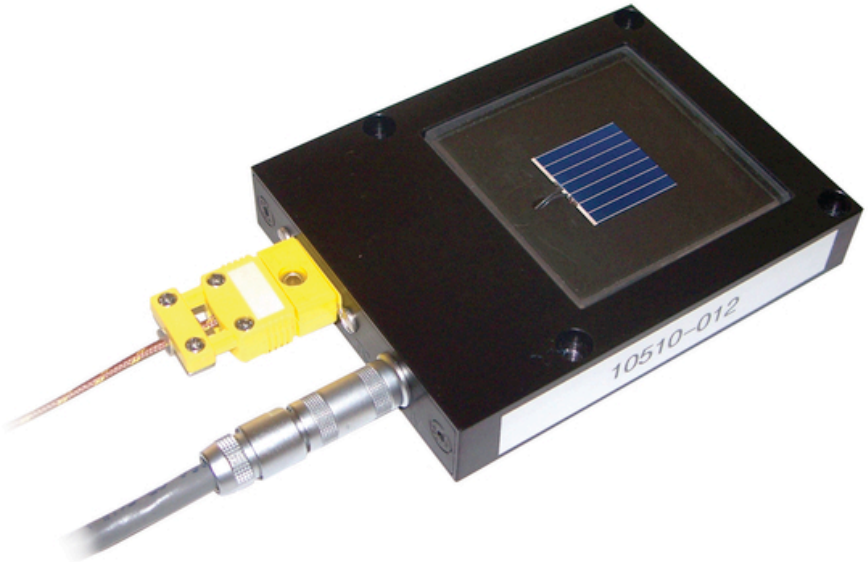


What if?

- **What if the satellite data could be used to create TMY files for any POA?**
  - Would need to be validated against ground data at a range of POAs.
  - May use satellite images to improve understanding of anisotropy of diffuse light
  - What if?????



What sensor for POA? Thermopile vs Reference cell vs ?

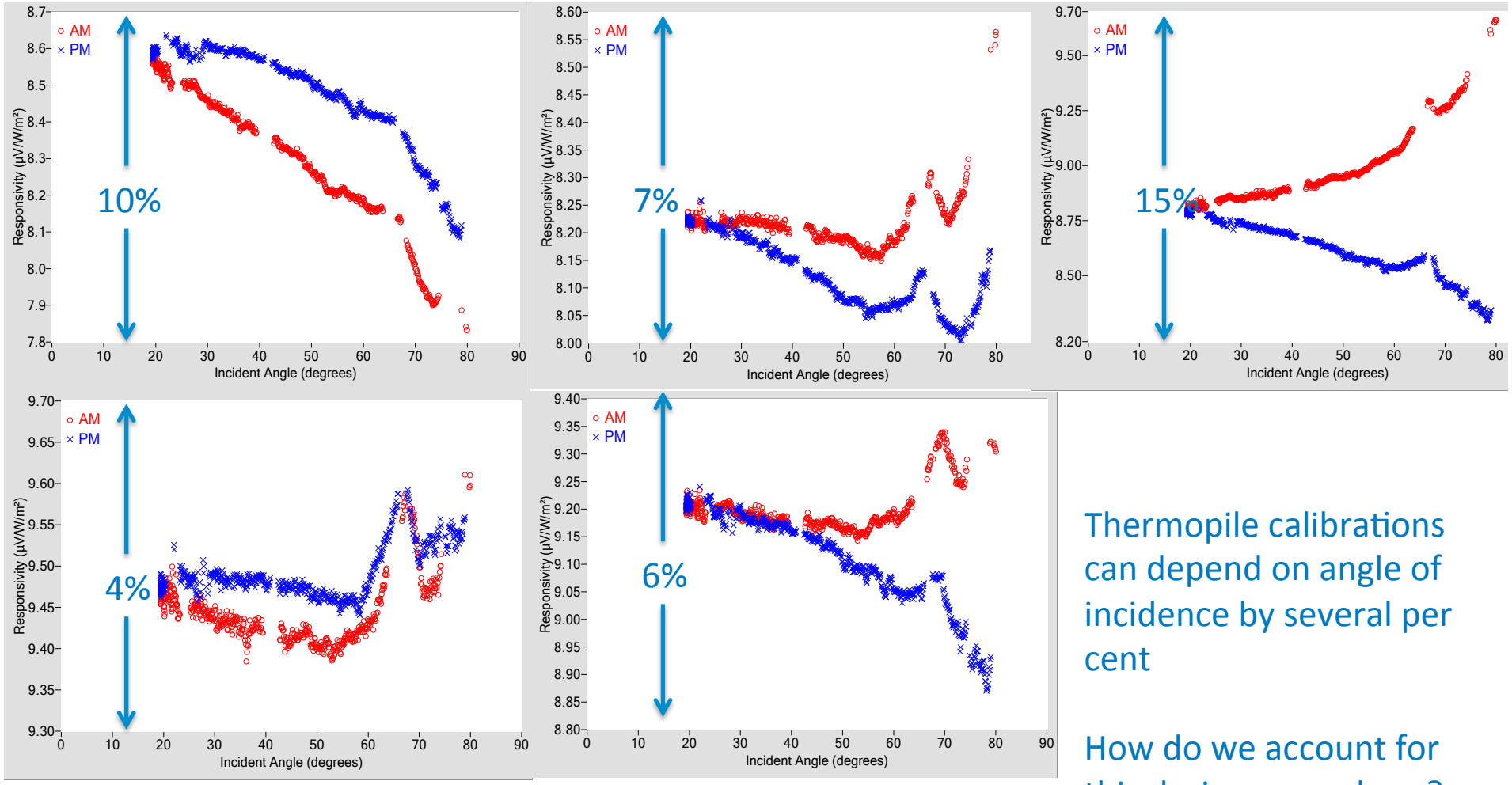


Many options for irradiance sensors.

Which is the best for which purpose?

Do they differ enough for us to care?

Calibration of Thermopiles – angular effects

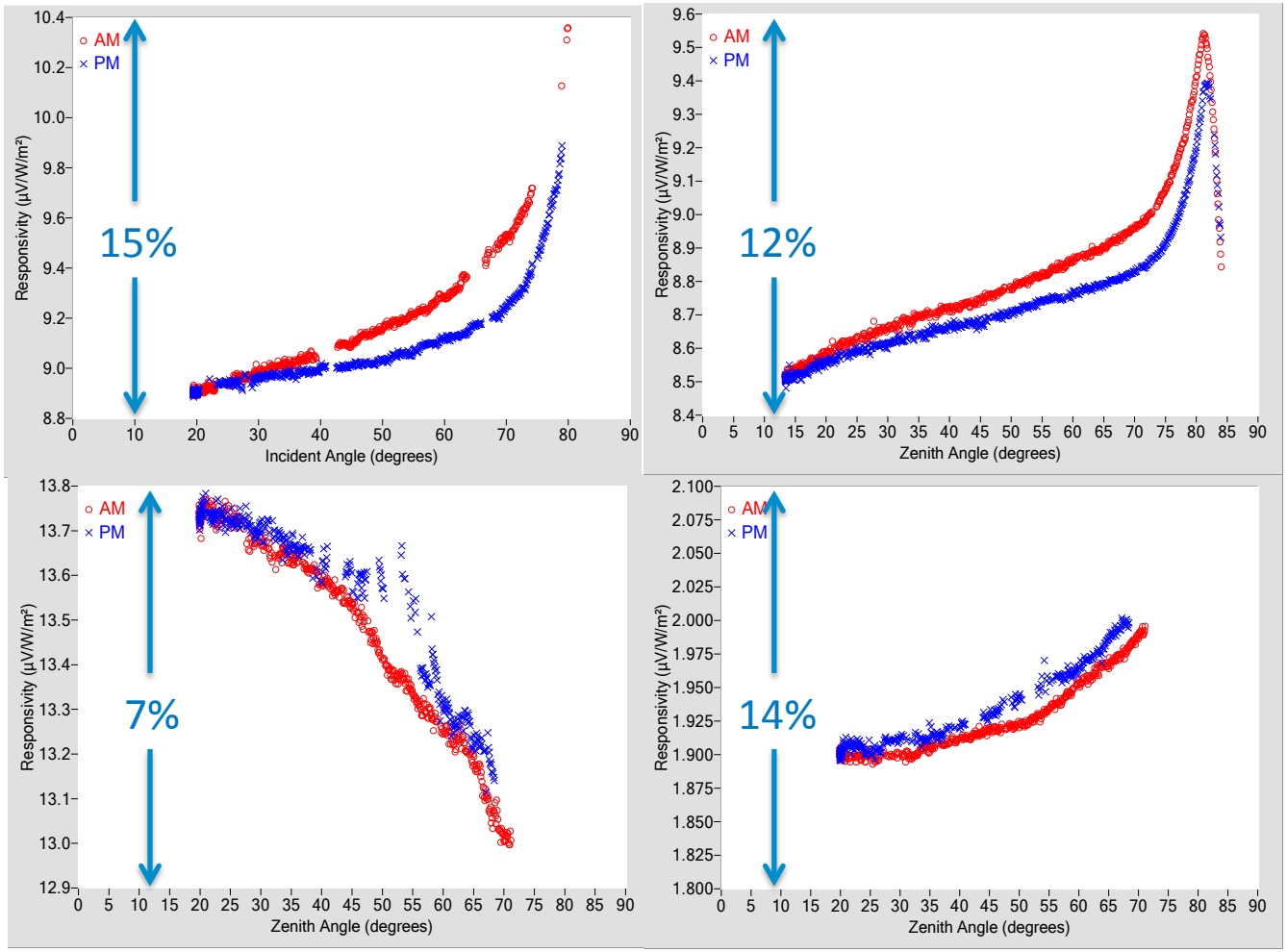


Thermopile calibrations can depend on angle of incidence by several per cent

How do we account for this during normal use?

BORCAL data from http://www.nrel.gov/aim/Calibrations/BORCAL/

Calibration of LI200,LI201 – angular effects



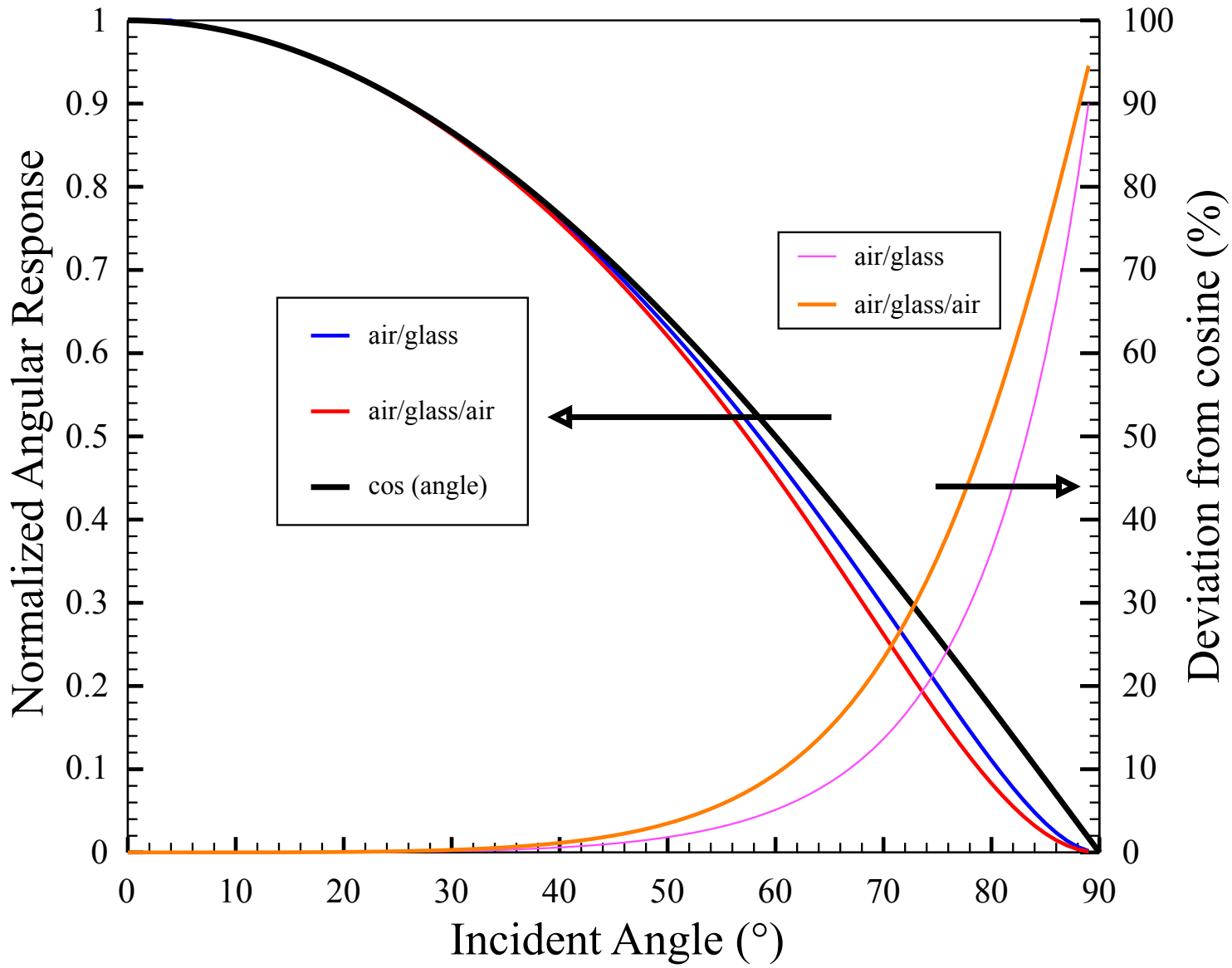
Almost ALL irradiance sensor calibrations depend on the angle of incidence by several per cent

How do we account for this during normal use?

Is this dependence from angle of incidence or spectral effects?

BORCAL data from http://www.nrel.gov/aim/Calibrations/BORCAL/

Angular response – depends on interface

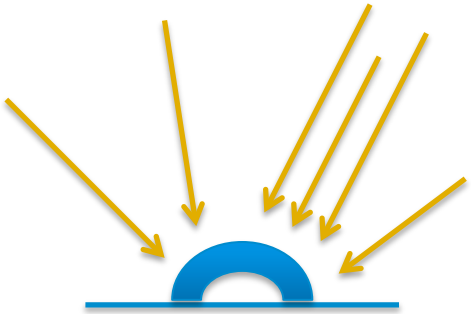


How should we calibrate irradiance sensors?

- **Normal incidence (collimated) light**
- **Diffuse light**
- **Mixture of diffuse and normal light?**

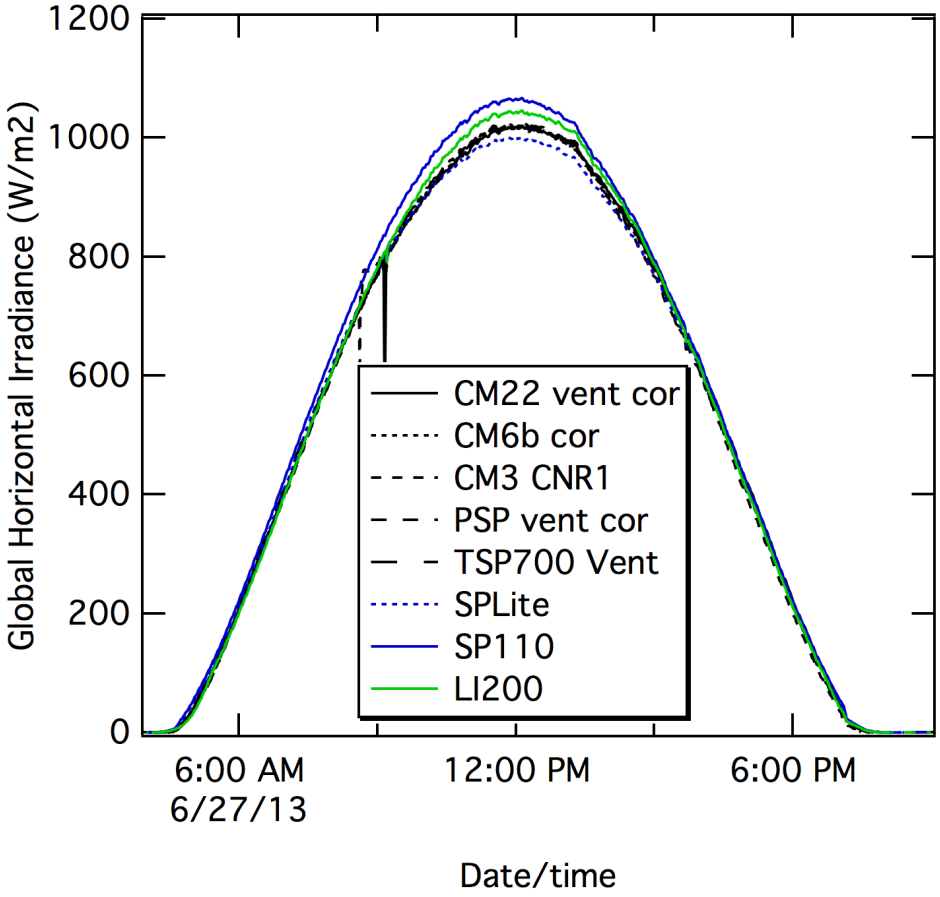
Winter, et al (25 EUPVSEC, pp. 4304-4306, 2010) reported 0.5%-1.2% error

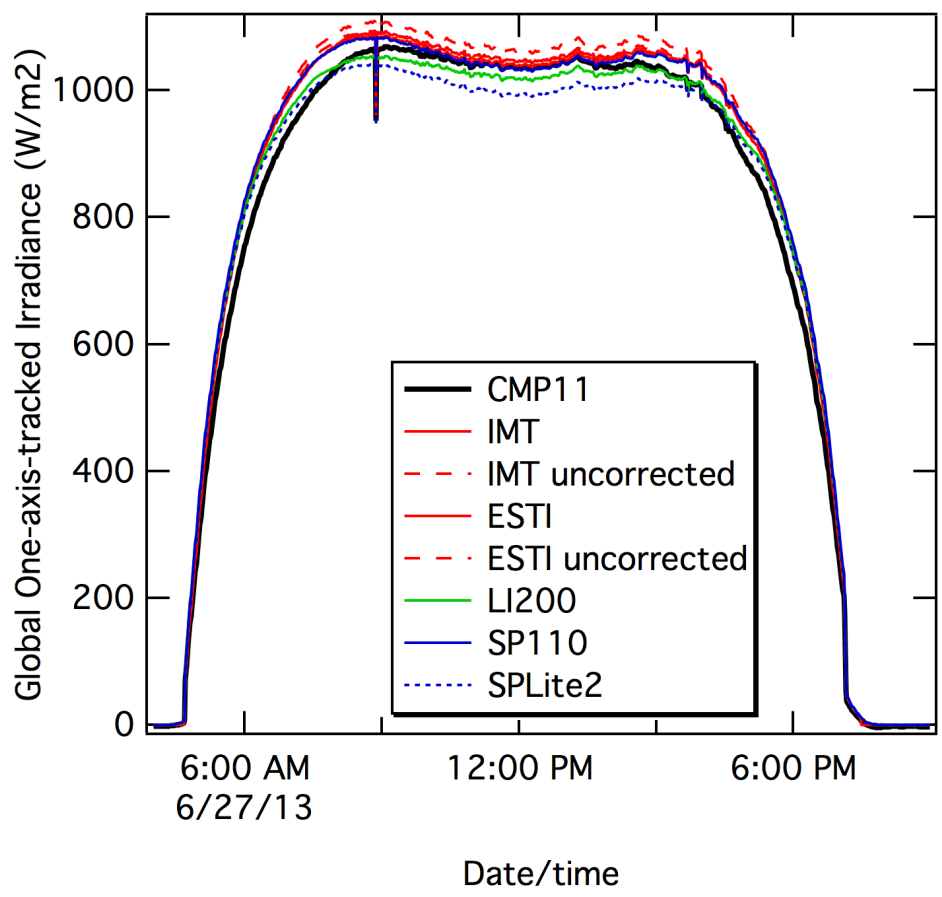
Reference cell calibration: normal incidence



Thermopile calibration: BORCAL uses variable angle; others use normal incidence

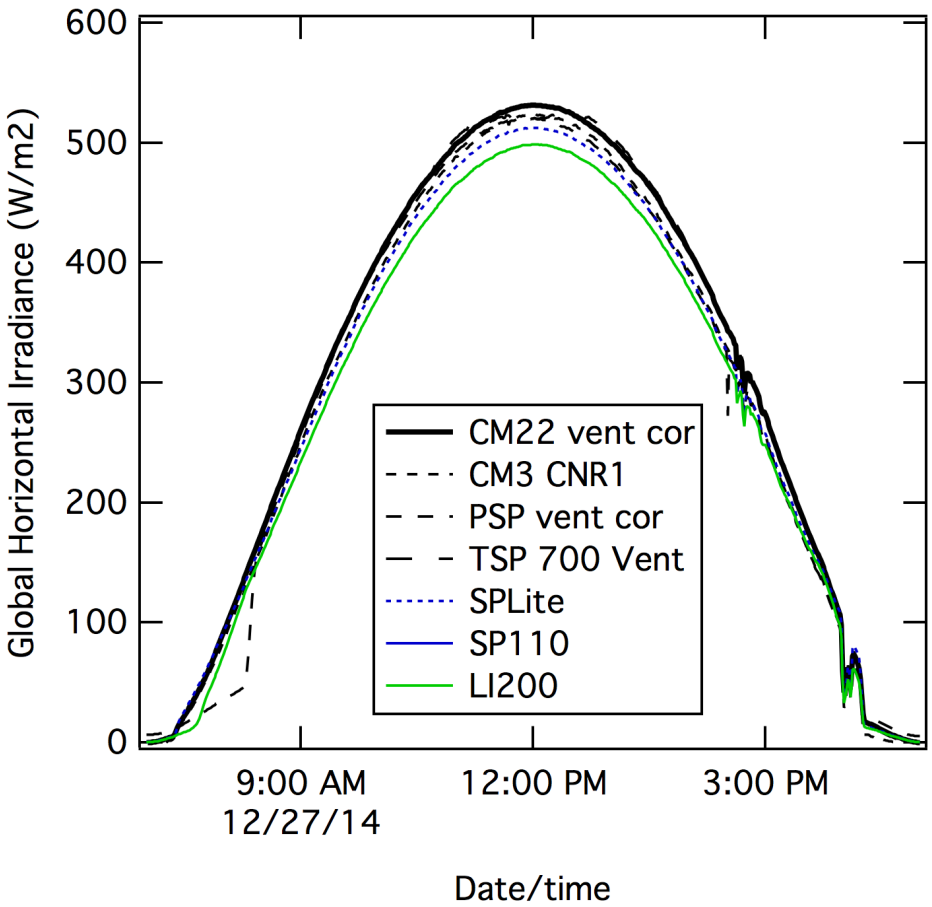
Irradiance sensors may respond similarly

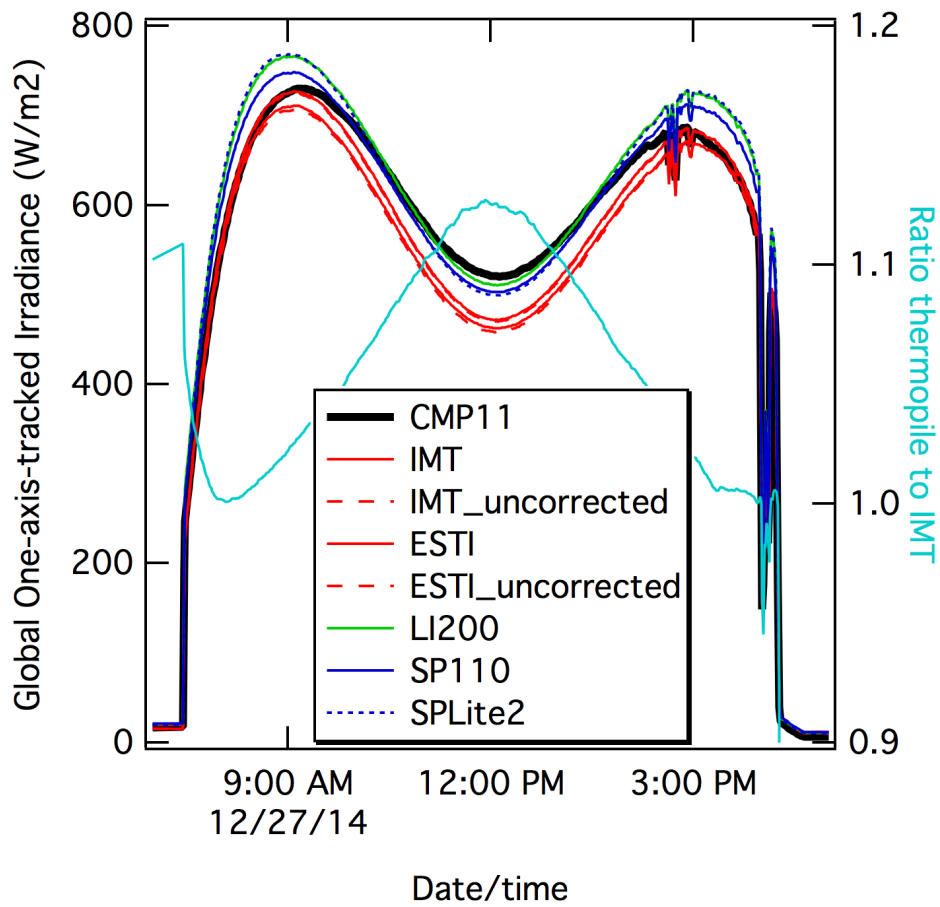




Collection of irradiance sensors give results, typically within ~5%

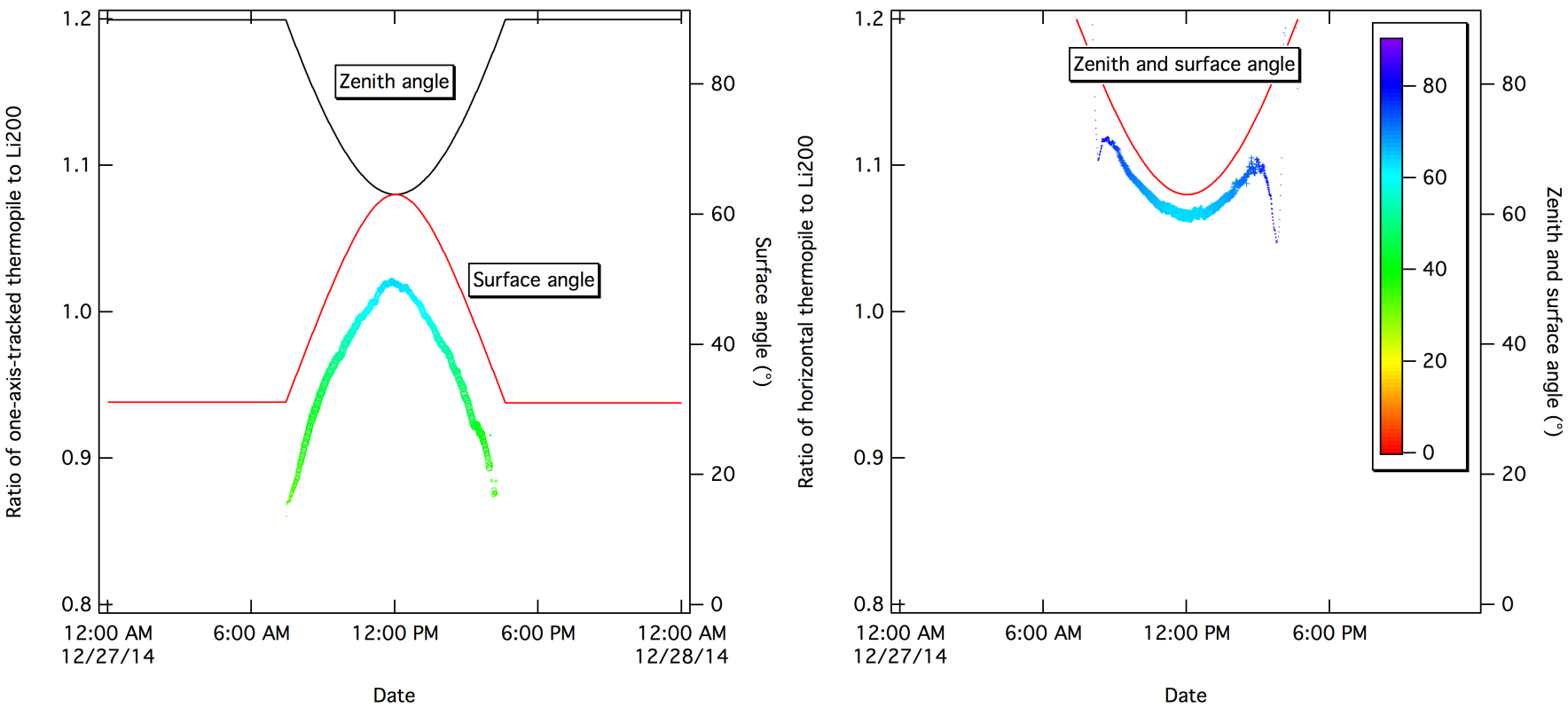
Irradiance sensors sometimes don't agree





Ratio of thermopile to reference cell may vary by more than 10%!

Difference may be both angle and spectrum



Ratio of thermopile to Li200 may vary by more than 10%; Difference correlates with angle of incidence, but also depends on spectrum!

Solar Resource vs PV Resource

- **Thermopiles measure W/m^2 – traceable to world reference standards**

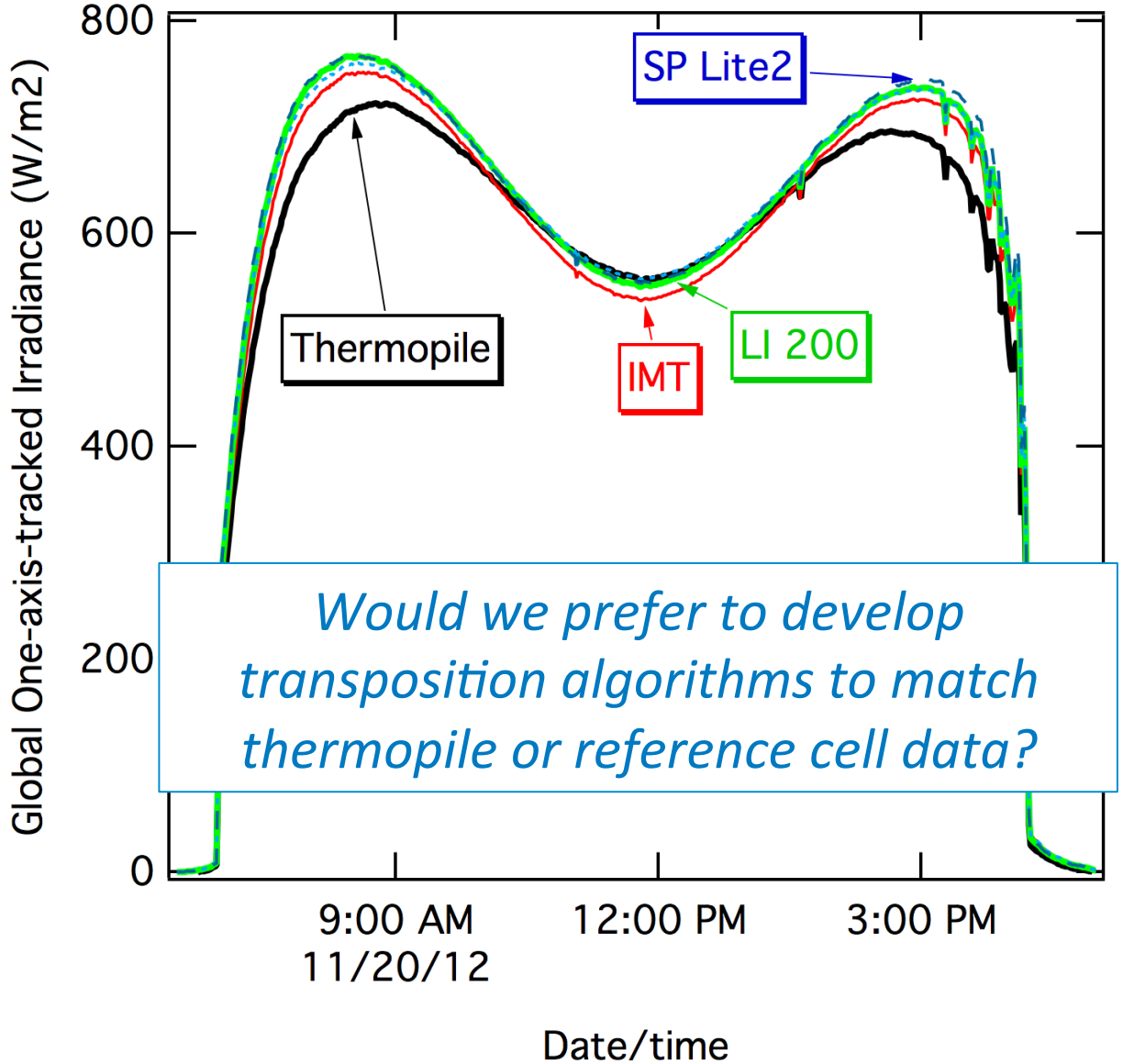
- **What do reference cells measure?**
- **PV module power output measurements are adjusted to Standard Test Conditions – the actual W/m^2 during the measurement may differ from the thermal 1000 W/m^2 because of the spectral correction**

Should we define a new unit?

- **Irradiance as "total energy" = W/m^2**
- **Irradiance as "the eye sees" = Lumens**
- **Irradiance as "a PV cell sees" = "Solmens?" IEC calls this "effective" irradiance**

- ***Can we differentiate "Solar Resource" from "PV Resource" so that we are measuring the quantity most relevant to PV?***

Transposition to thermopile or reference cell?



Would we prefer to develop transposition algorithms to match thermopile or reference cell data?

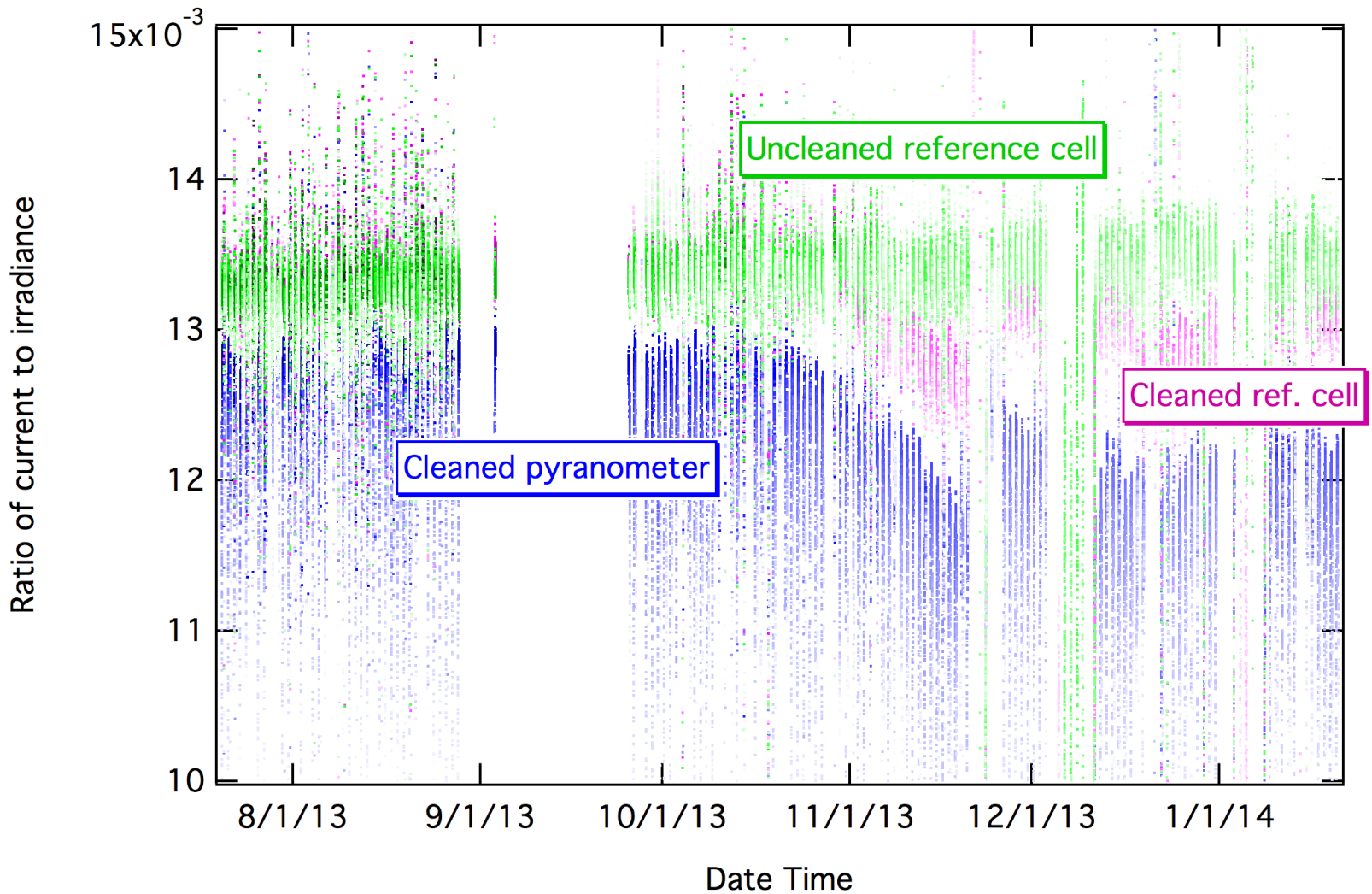
Do we calibrate PV modules and irradiance sensors similarly?

- **Angle**
  - Normal incidence (in collimating tube or using a solar simulator with a long path)
  - Typical global (clear-sky day with sun overhead)
  - Diffuse (cloudy day or some simulators)
  - If calibrated in one condition is adjustment made for different angles of incidence?
- **Spectrum**
  - Modules and reference cell measurements are adjusted for spectrum
  - Thermopile calibrations are independent of spectrum
  - When used outdoors, do we want to adjust for spectrum?

How do we measure irradiance? Depends!

- Module manufacturer: irradiance reaching cells (uncleaned reference cell)
- Investor expecting MWh consistent with original prediction: (thermopile for GHI)
- O&M provider: compare cleaned and uncleaned reference modules to determine need for cleaning
- Degradation rates: uncleaned reference cell?

Sensors for measuring degradation



When measuring degradation, an uncleaned reference cell correlates most closely

Conclusions

- **What if?**
  - Satellite data could quantify irradiance on any POA with accuracy as good or better than what we can do now? Could we use this data as the basis for our predictions?
  - Spectra could be derived from satellite data to adjust for any reference cell?
- **Would it make sense to:**
  - Verify plant performance using POA data?
  - Model plant performance from POA rather than horizontal data?
  - Use matched or semi-matched reference cell data?
- **What would it take?**

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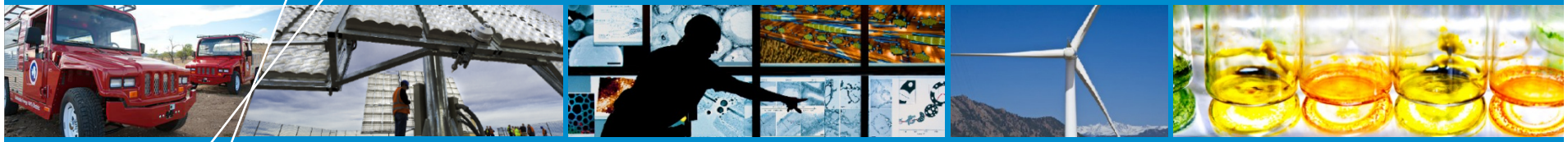

Thank you. Questions?