Reducing Solar Performance Uncertainty

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Head of Solar Product Development

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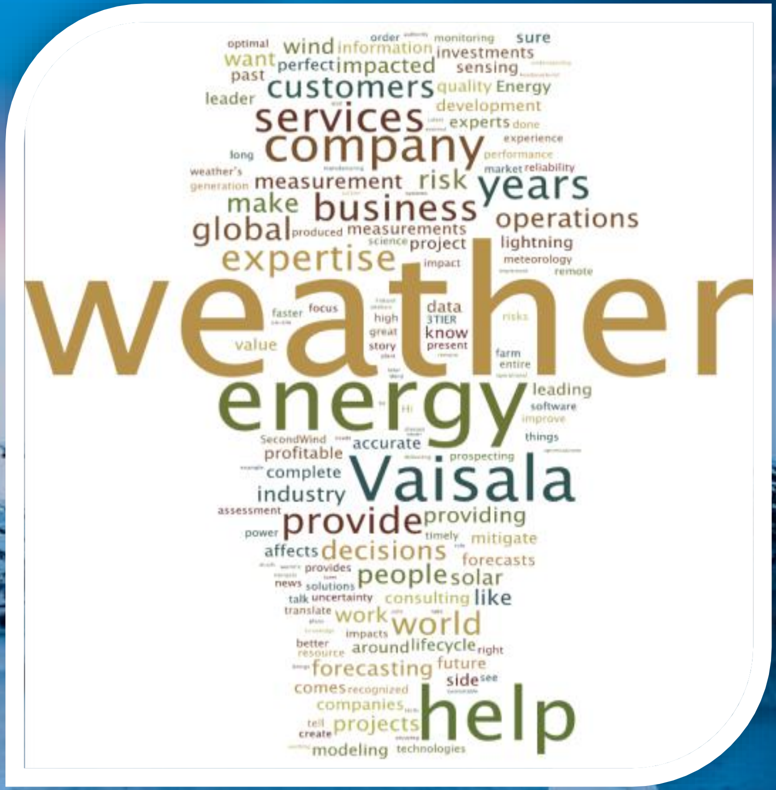
Vaisala | Measurement, Assessment, Forecasting

- **Over 80 years** helping industries manage the impact of weather
- **Develop and operate your projects** better, faster, and more efficiently
- Analysis and consulting services are **based on proven science**



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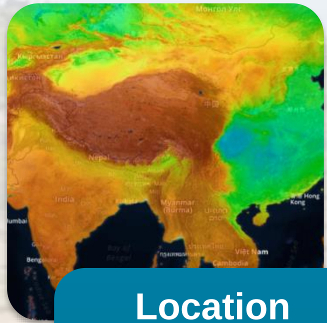
- **2013** acquisitions to serve the renewable energy marketplace

3TIER by Vaisala

Solar resource feasibility studies	800 (42 GW), 6 continents
Due diligence assessments	5 GW
Wind and solar site specific forecasting	18GW, 4 continents

Project Development Road Map



Location Prospecting

Where is the best place to build a solar project?

Confirm that land can be used for the project and that an off-taker is available

Project Design

What is the expected generation of my solar project?

Create initial energy production estimates and decide on technology / basic project design

Due Diligence

What are my long-term production estimates for financing?

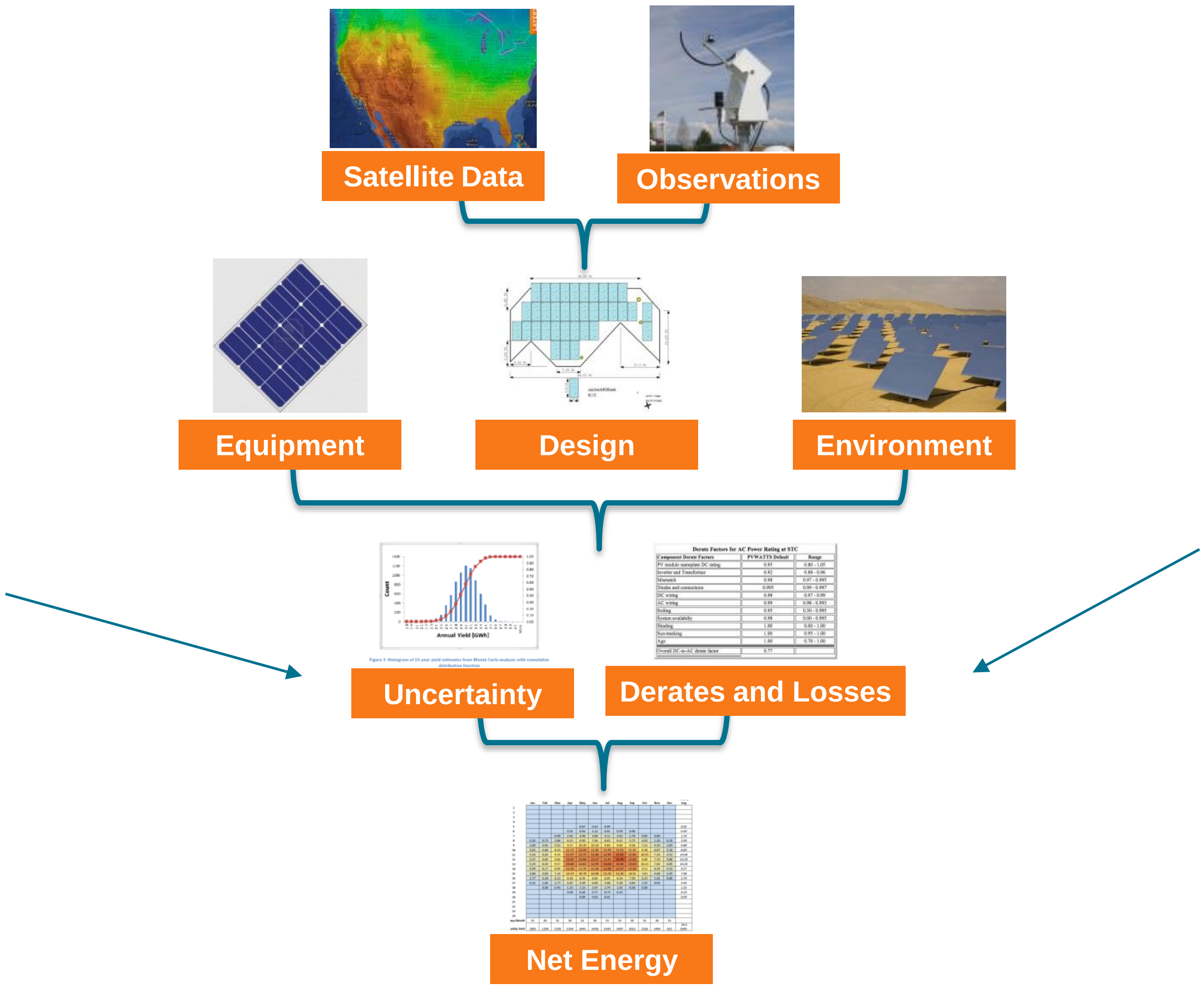
Finalize project design and secure financing and land

Construction

How do I guarantee a quality project?

Verify that all provisions of EPC contract is met and that independently verifiable performance metrics are met

Solar Energy Assessment Process



The Difference Between Losses and Uncertainty

Losses

- The difference between ideal production and actual production
- Some are inherent in the system (ex: atmospheric losses)
- Some can be reduced with good design (ex: wiring losses)
- Included in your "net energy" values

Uncertainty

- The measure of how certain we are a project will perform the way we say it will
- Usually expressed as a ranged estimate (ex: +/- 5.6%)
- Used to create the Probability of Exceedance Values for project financing
- Can be influenced by project development choices

Where Do Losses Come From?

Some losses that are calculated in the energy modeling process that are inherent in the location or system.

Some losses that can be influenced by plant design and maintenance plans

Loss Factors	
Irradiance	
Global Incident in Collector plane	18.3 %
Far shadings / Horizon	-0.3 %
Near shadings: Irradiance loss	-2.8 %
IAM Factor on global	-2.0 %
Soiling loss factor	-1.0 %
Snow loss factor	0.0 %
Array Operating Losses	
PV Loss due to irradiance level	0.0 %
PV Loss due to temperature	-8.6 %
Spectral loss	0.0 %
Shadings: Electrical Loss according to strings	0.0 %
Module quality loss	0.8 %
LID - Initial light induced degradation	-1.5 %
Mismatch loss	-0.5 %
Ohmic wiring loss	-1.1 %
Inverter efficiency loss during operation	-1.3 %
Inverter Loss over nominal inverter power	0.0 %
Inverter Loss due to power threshold	0.0 %
Inverter Loss over nominal inverter voltage	0.0 %
Inverter Loss due to voltage threshold	0.0 %
Auxiliaries	-0.8 %
AC ohmic loss	-0.6 %
External transformer	-0.8 %
Transmission loss	-1.0 %
Curtailment loss	0.0 %
Unavailability	-2.0 %

Technology Selection Considerations

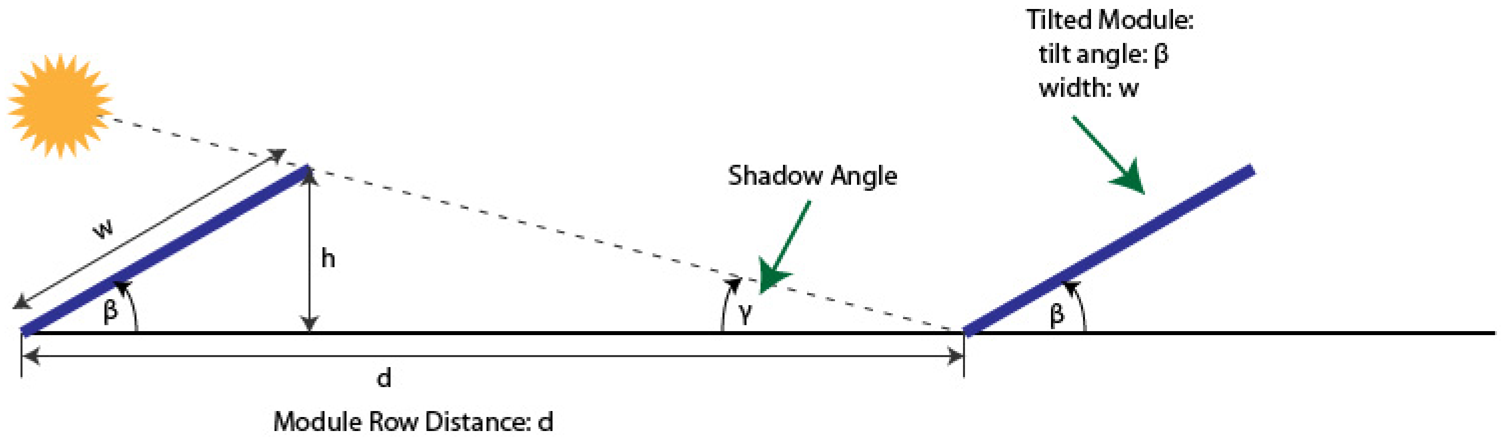
Modules

1. Monocrystalline
   - *Expensive but rugged and efficient*
2. Polycrystalline
   - *A good choice*
3. Thin film (including CIGS)
   - *Cheapest*
   - *Requires the largest amount of land area*

Mounting

1. Fixed Mount
   - Cheapest but least efficient
   - Most adaptable to different types of terrain
2. 1-axis tracking
   - ~11-25% more energy than fixed depending on latitude
   - Requires more land and moderate slopes
3. 2-axis tracking
   - Most expensive option
   - ~35-40% more energy than fixed

Cross-Shading Optimization



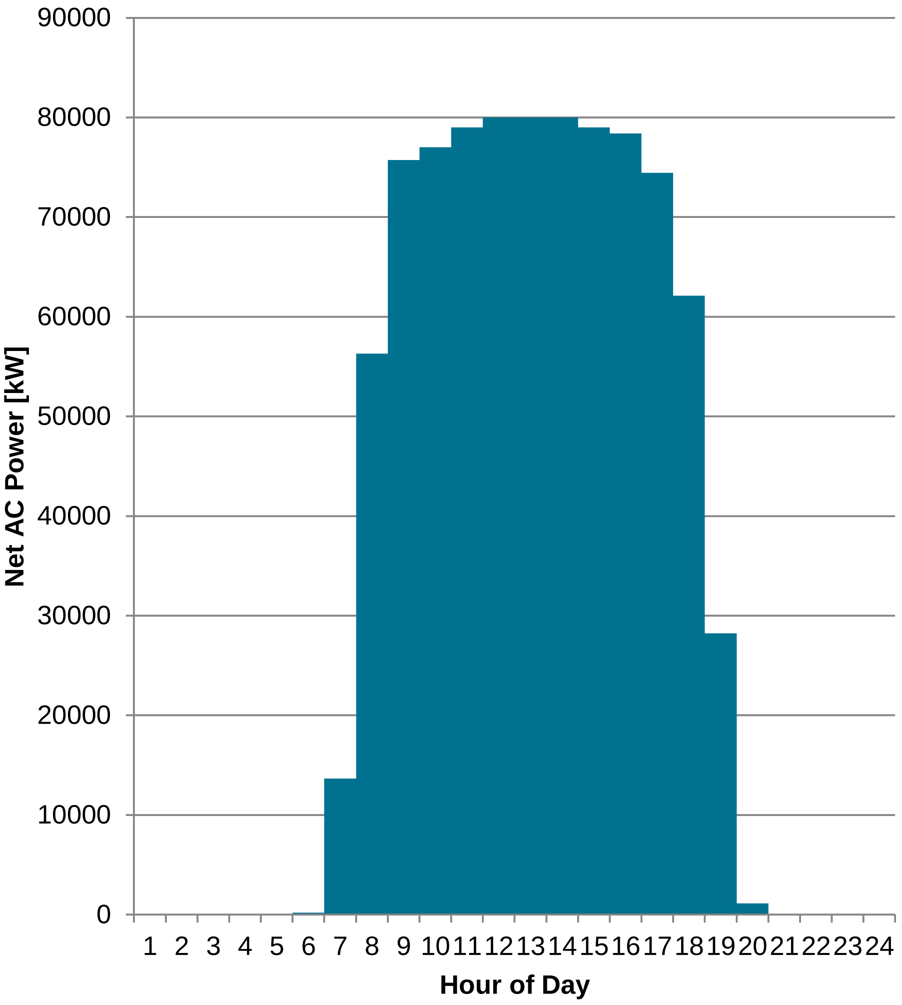
- What happens when distance between rows is small or the sun is low in the sky. Also called ground cover ratio.
- Happens for certain sun angles, tilt angles, and row pitches.
- Minimizing cross-shading is a major aspect of plant layout.

Clipping, Overbuilds, and DC/AC Ratio

- Both the AC and DC sides of the plant have losses
- By increasing the ratio of DC to AC (increasing the number of modules, without changing the inverter capacity) we can make sure that the plant outputs at rated capacity over a larger part of the day.
- In utility-scale plants, the DC/AC ratio varies from about 1.05 to about 1.40.
- The higher the DC/AC ratio the more days of the year the plant will hit rated capacity, and the plant will produce at rated capacity during more hours of the day.
- High DC/AC ratio, or overbuild factor, imply a lot of clipping.
- Clipping and high overbuilds do no harm, but they do mean that money is used to purchase DC capacity which is only occasionally used.

Clipping Losses

- Modern inverters clip at their maximum rated capacity.
- Clipping is when DC output exceeding inverter capacity is then shed and only the max AC capacity is fed to the grid.
- All plants will experience clipping to some level as determined by the DC/AC ratio



Soiling Losses

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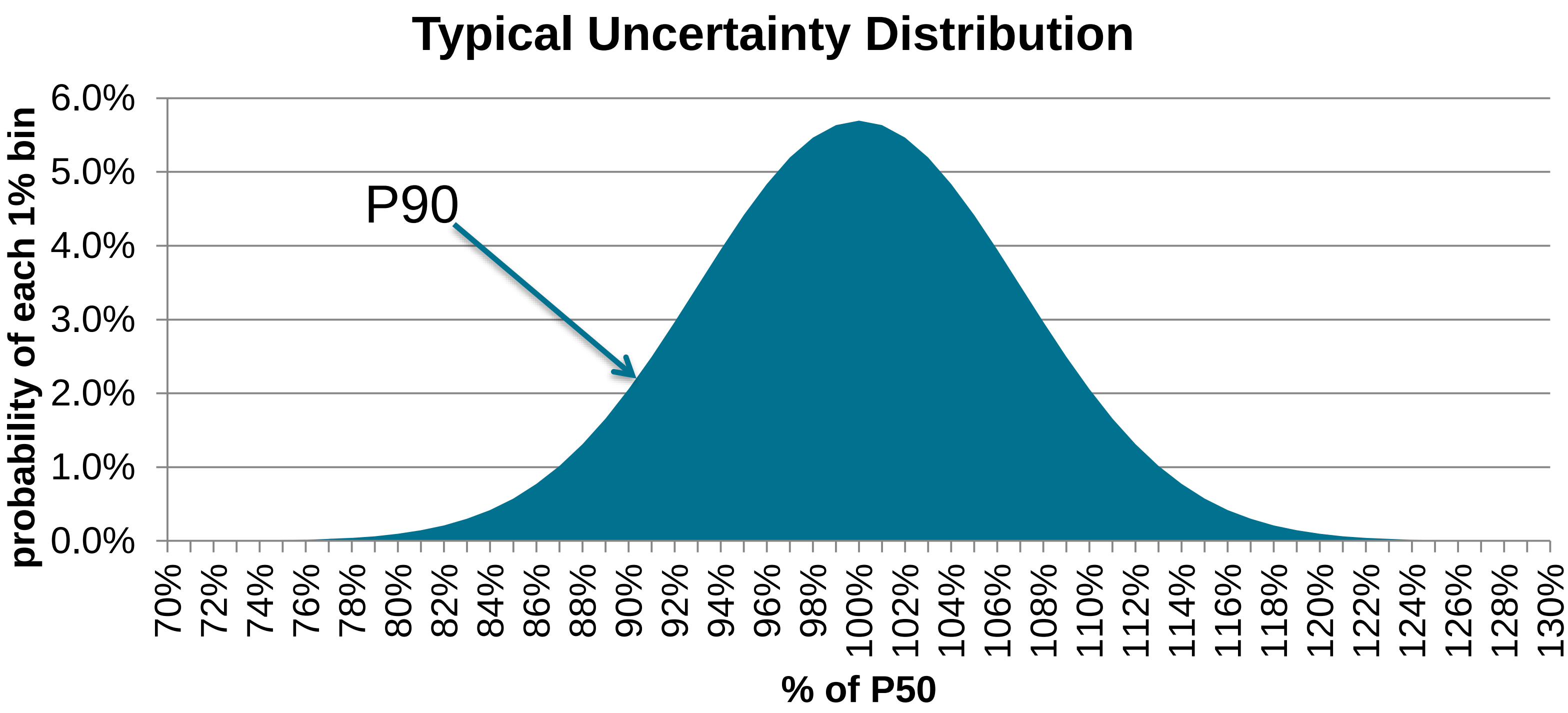
Where Does Uncertainty Come From?

	1-Year	10-Year	25-Year
Resource	4.1	4.1	4.1
Climate	2.5	0.9	0.7
Power Modeling	5.0	5.0	5.0
Aging	0.1	0.7	1.7
Total Uncertainty	6.9	6.5	6.7

Defining Uncertainty



- PXX values defined to be the probability that average generation will *exceed* the specified generation over the associated time period and are the basis for many financing decisions

Two Ways to Calculate P-Values

TMY Distribution

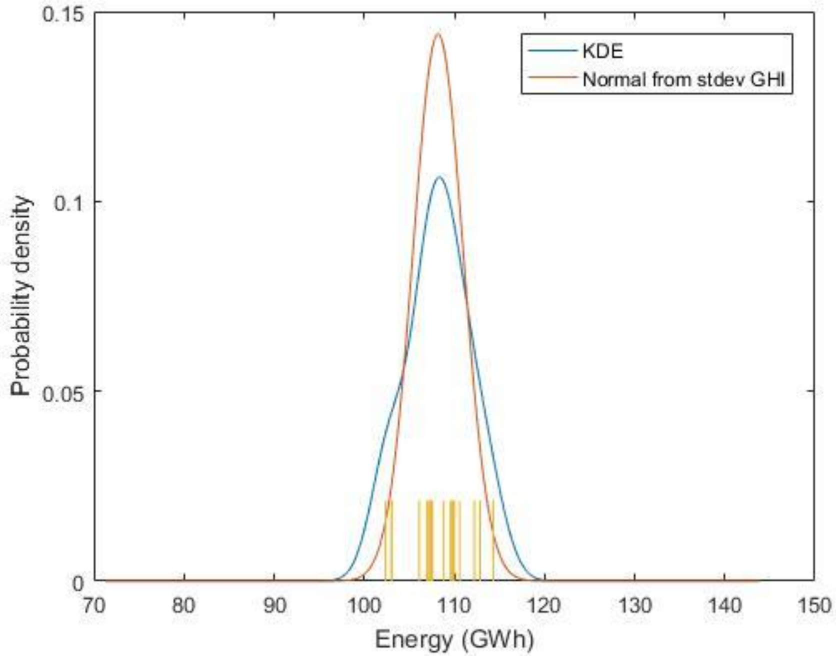
- When using a TMY to calculate energy production you have to assume a standard distribution around the P50 because that's all you have
- We set the distribution primarily based on the resource variability as that is the largest driver of energy variability
- The p-values are chosen using a standard deviation

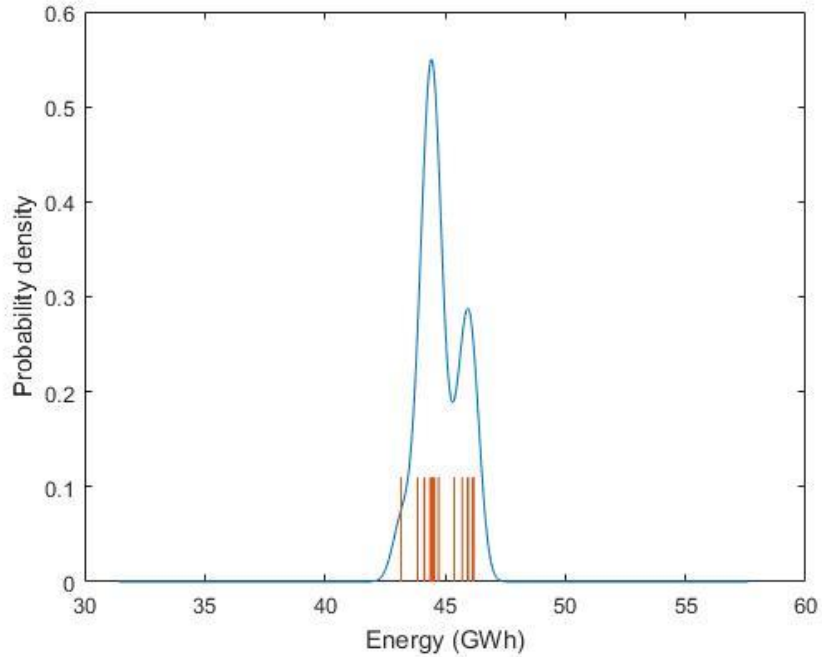
17+ Year Distribution

- When using the long-term time series you do not have to assume the distribution you set the curve based on the actual energy production modeled
- Because we do not have 20+ years of resource data to model with we use a Kernel Density statistical method to set the distribution around the modeled data to get 20 year P90 values

The P50's are the same with both methods but the P90's often vary by 1% but can be as high as 3-5% at resource variable locations

Comparing year-1 yield distributions from TMY and full time series

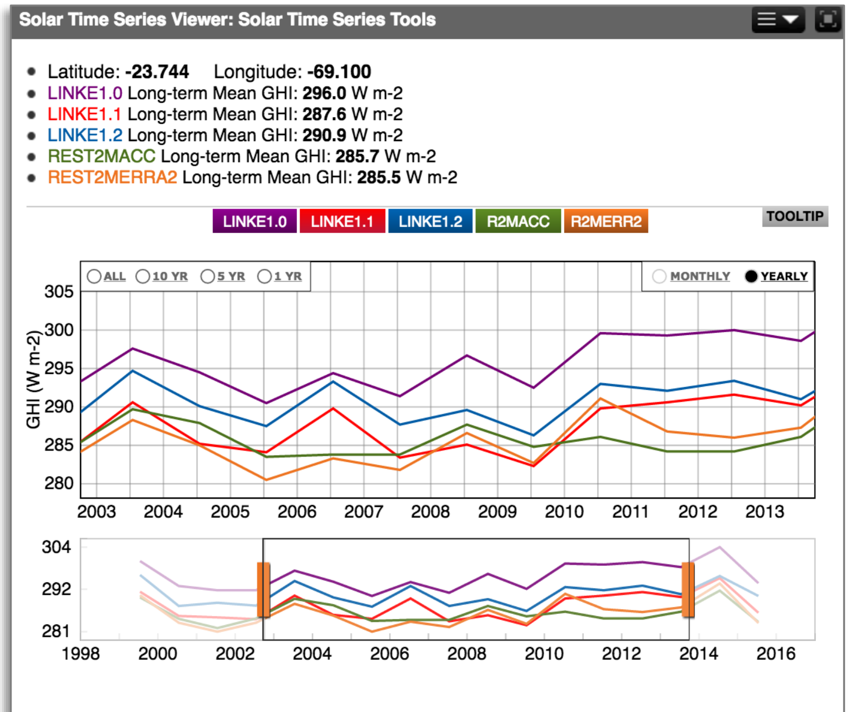




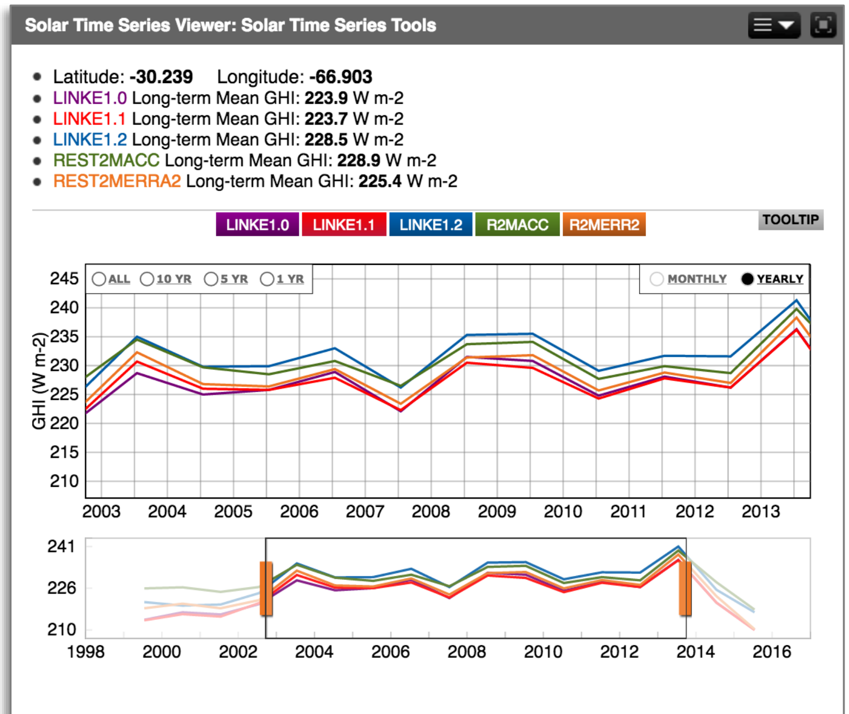
- KDE distributions tend to have fatter tails
- KDE distributions often have different shapes than normal distributions, so not possible to match these up completely

Resource Uncertainty

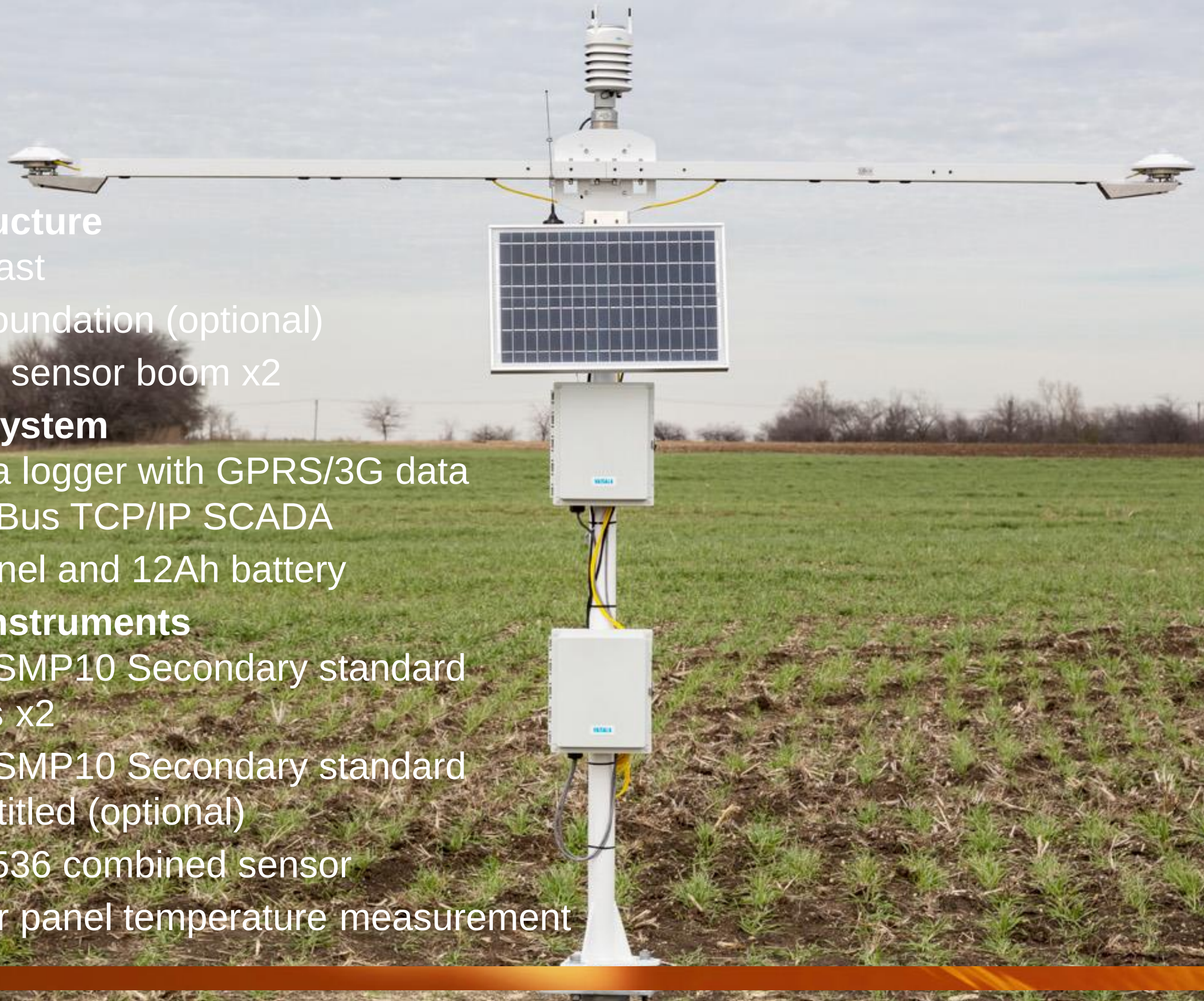
High Risk



Low Risk



Solar Measurement Station



Mechanical Structure
- 2m tubular mast
- 1.3m screw foundation (optional)
- 1m horizontal sensor boom x2

Measurement System
- Nomad 3 data logger with GPRS/3G data transfer, ModBus TCP/IP SCADA
- 20W solar panel and 12Ah battery

Measurement Instruments
- Kipp&Zonen SMP10 Secondary standard pyranometers x2
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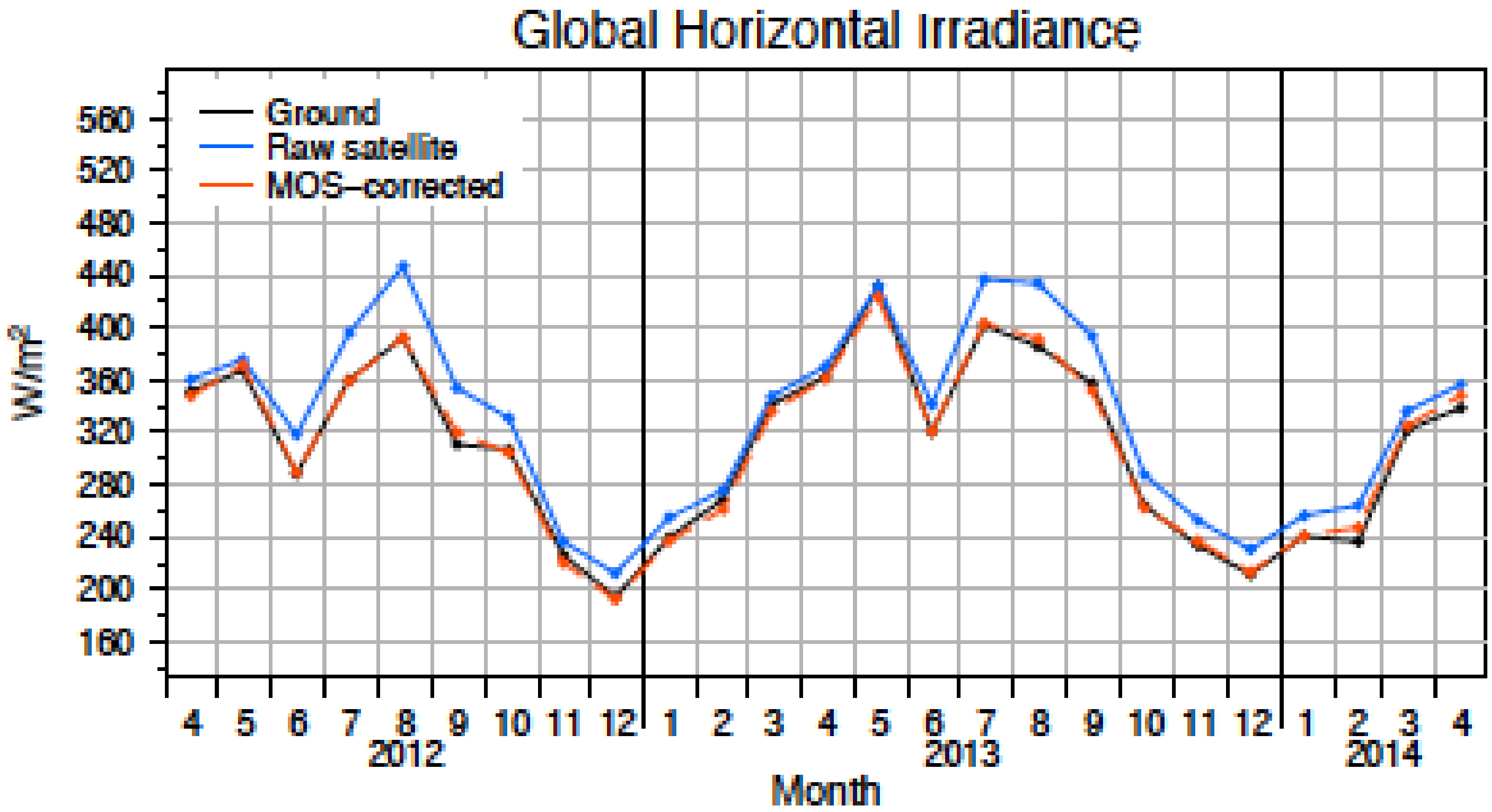
- Vaisala WXT536 combined sensor
- Thermistor for panel temperature measurement

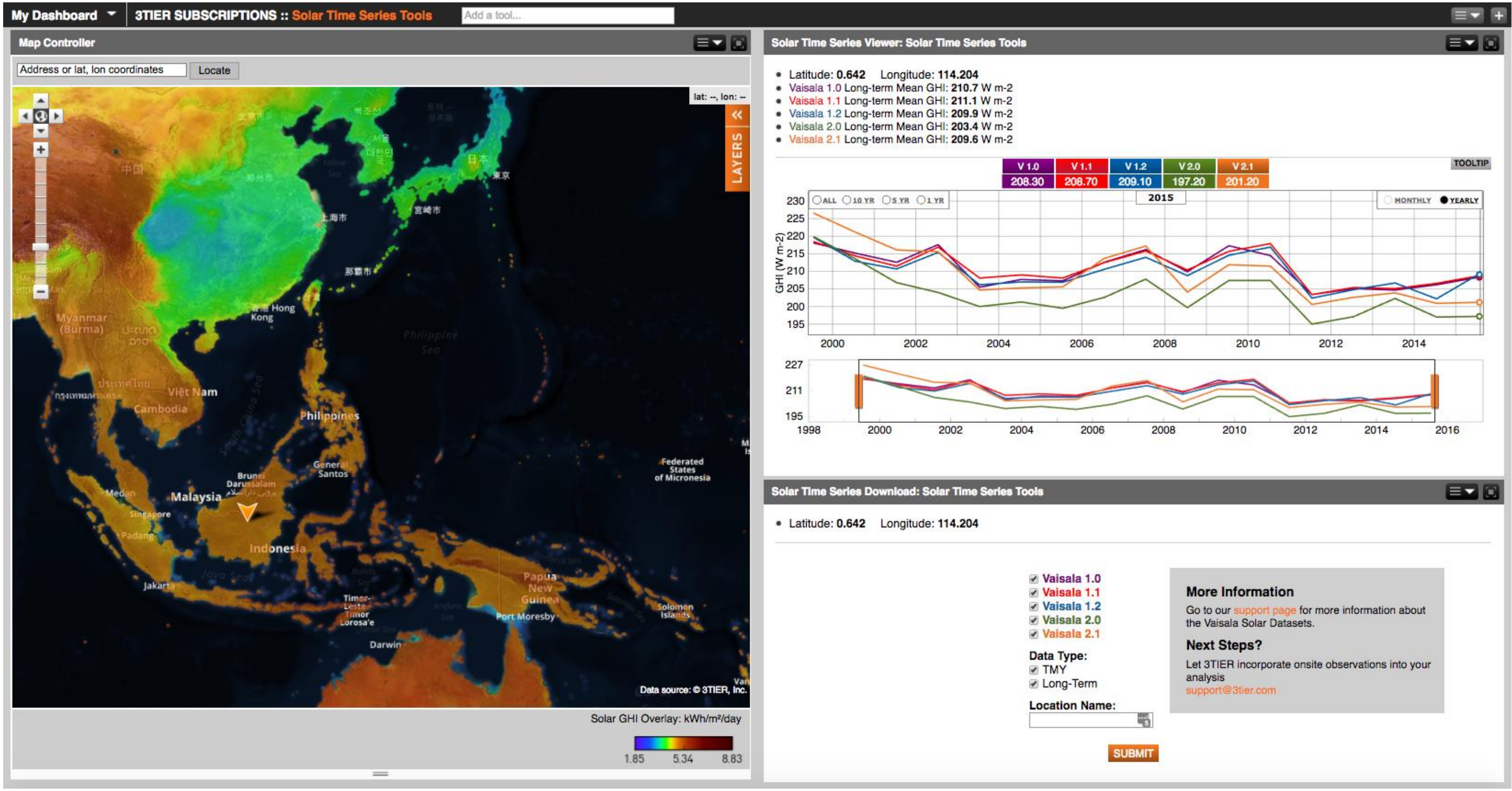
How Does Vaisala Combine Ground Observations and Modelled Data?



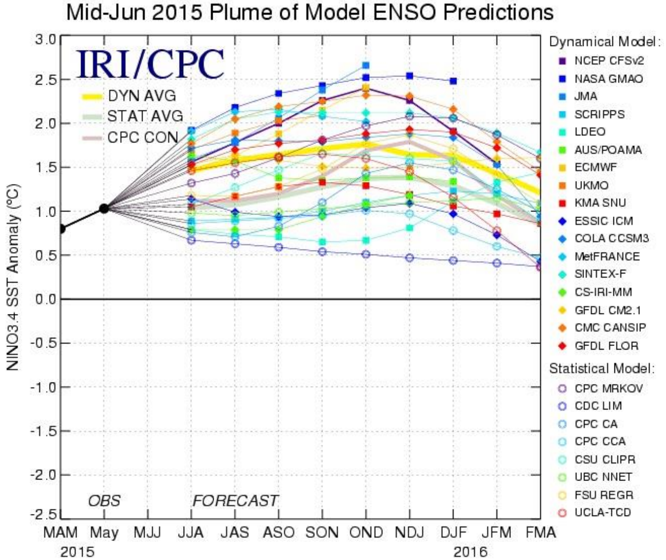
Reduction In Resource Uncertainty

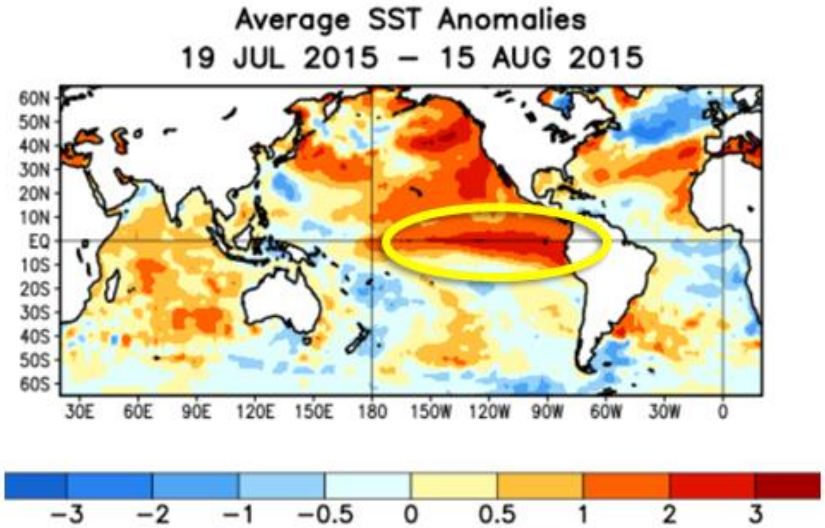
Months of Observations	GHI (%)	DNI (%)	DIF (%)
0 months	5.00	9.00	15.00
4 months	2.88	5.94	11.69
8 months	2.41	4.68	10.32
12 months	2.17	4.08	8.96
18 months	1.95	3.55	6.90
24 months	1.81	3.21	4.85

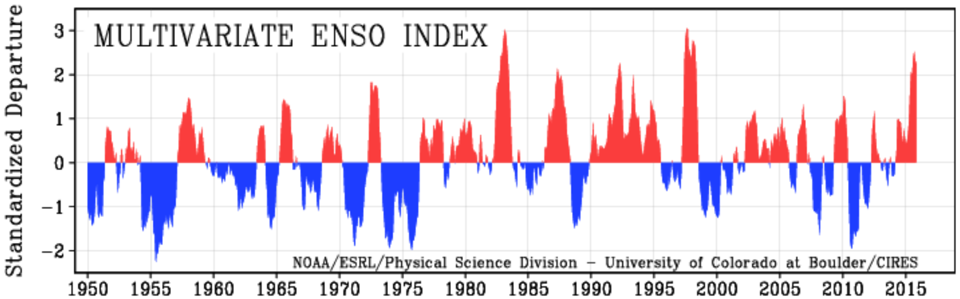
Climate Uncertainty

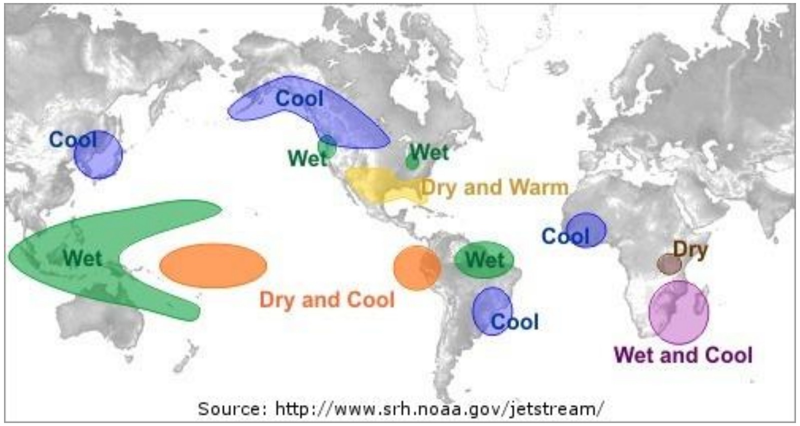


Climate Change

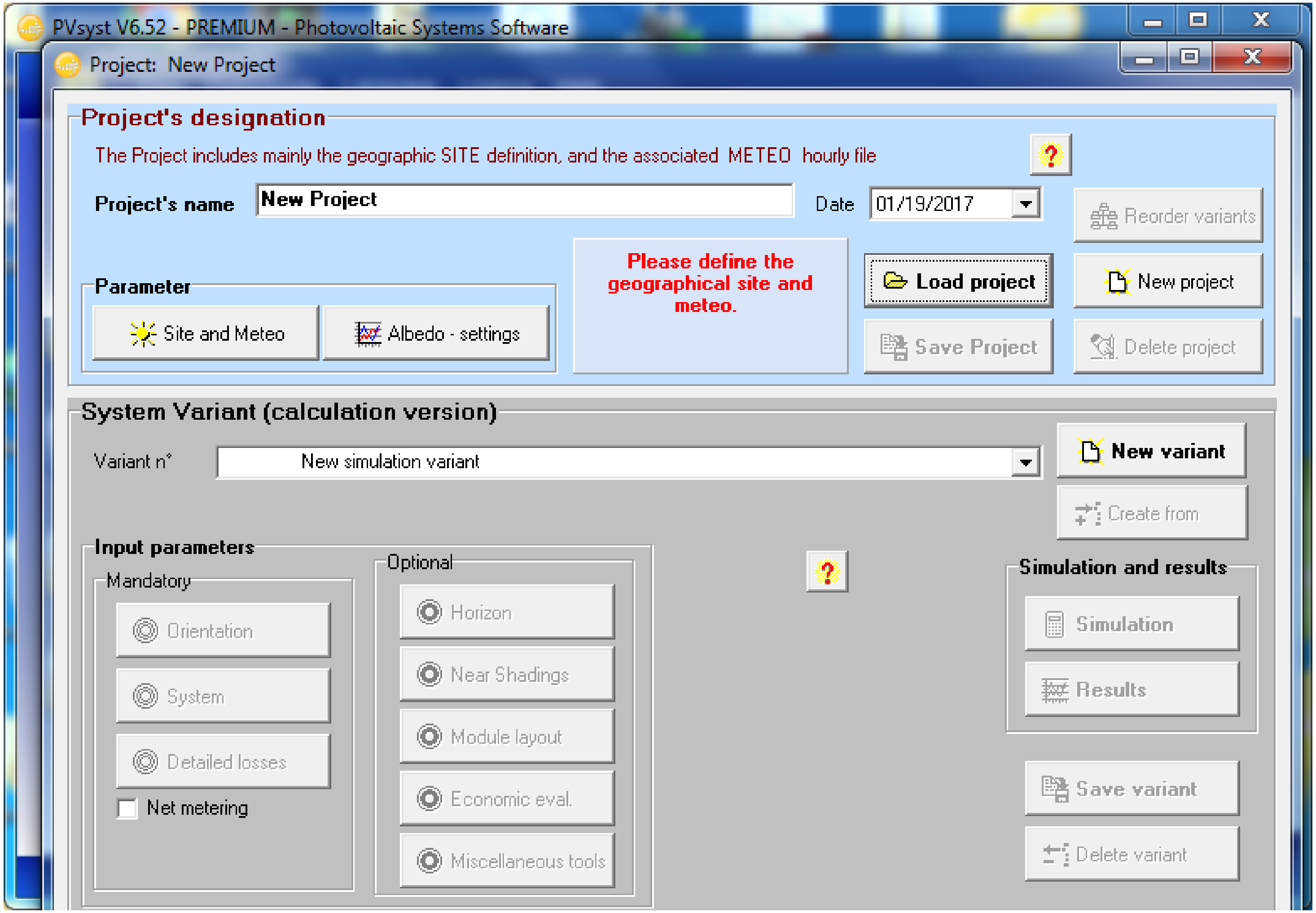








Power Modeling Uncertainty



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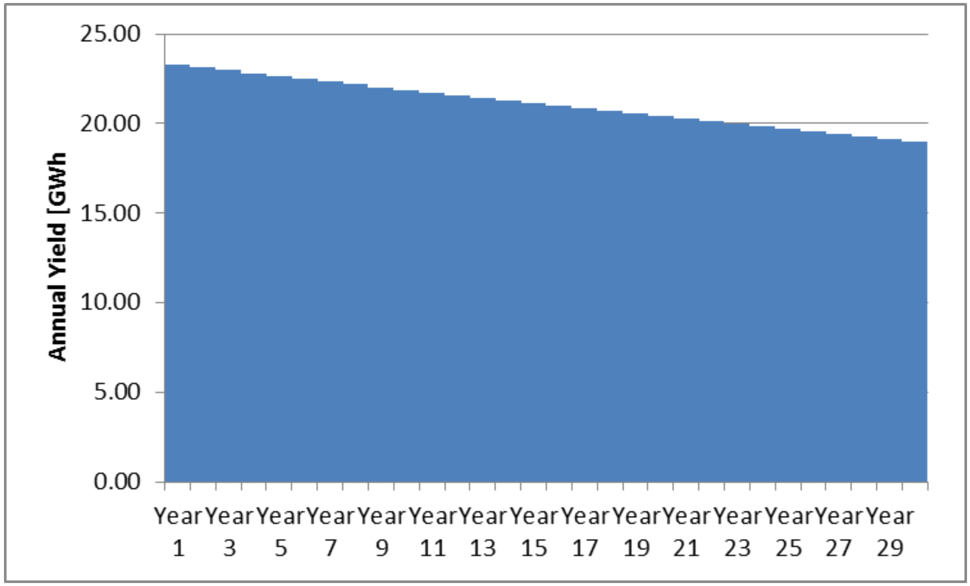
Technology Modeling Uncertainty

Unusual technology or location choices carry greater uncertainty which may or may not be offset by gains in energy or cost reductions

Aging Uncertainty From Long-term Degradation

- **Solar cell aging** is known to cause a decrease in output with age.
- The primary mechanism is **repeated heating and cooling cycles** which cause cracks in the metal leads as well as in the semi-conductor material.
- **Estimates for the rate of degradation vary between manufacturers.** Vaisala evaluates the manufacturer warranty claims and assumes the degradation will not exceed that value.



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Takeaways

Approaching the project development process with a **view to the end goal** will help you reach it

- A high quality project that will meet performance goals

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Get the project financed by **reducing uncertainty**

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Using **high quality data and analytics from the beginning** means less rework

- It's less expensive than you think to gain insight into your project or portfolio!

For product information or trial access to the online tools contact: energy@vaisala.com

Questions about the content shown here contact: gwendalyn.bender@vaisala.com

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