

# Quantifying PV Output Variability

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# Why This Topic is Important to Utilities

## **System Planning**

Maximizing the benefits while minimizing grid impacts of PV requires utilities to influence where PV systems are installed

## **System Operation**

Optimize utility system operation once systems are installed requires the ability to forecast PV variability

# Intermittency Questions

1. What is the effect of short-term output variability?
2. What needs to be done to forecast short-term output variability?

## Question #1

What is the effect of short-term output variability?



# Objective

Quantify relative power output variability  
for a fleet of identical PV systems

# Key Findings

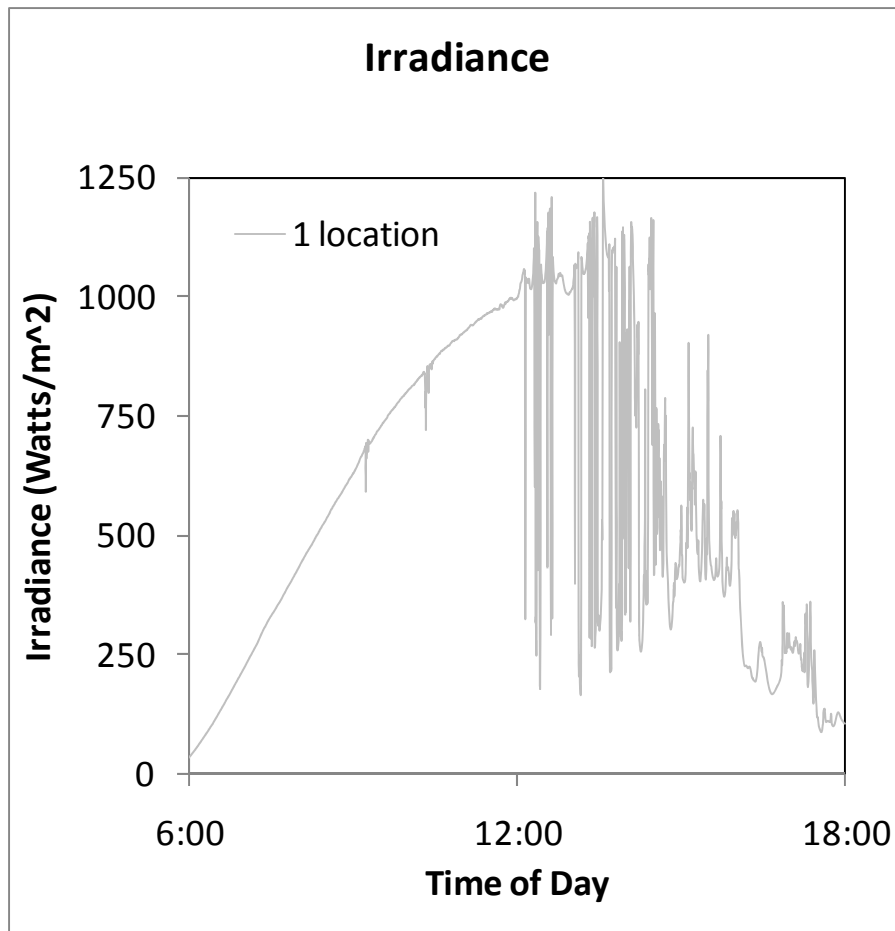
Relative Output Variability is based on:

1. Number of PV systems
2. Dispersion Factor

## **Relative Output Variability**

Output variability for fleet / Output variability at single location

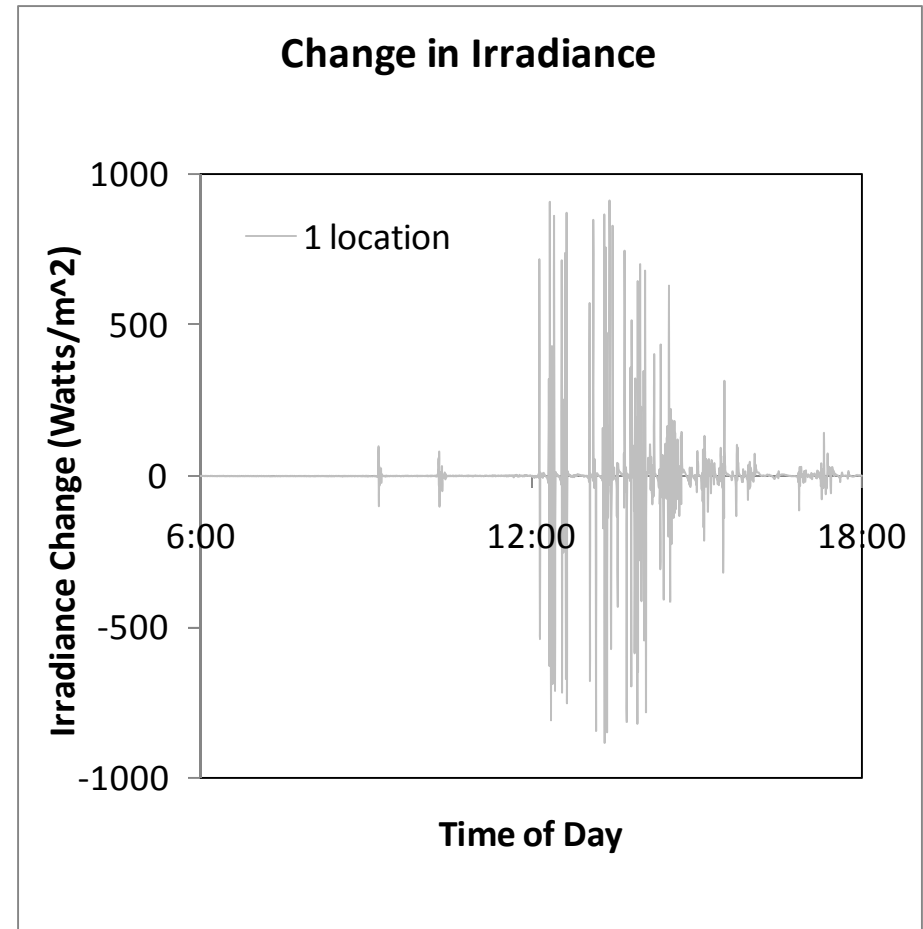
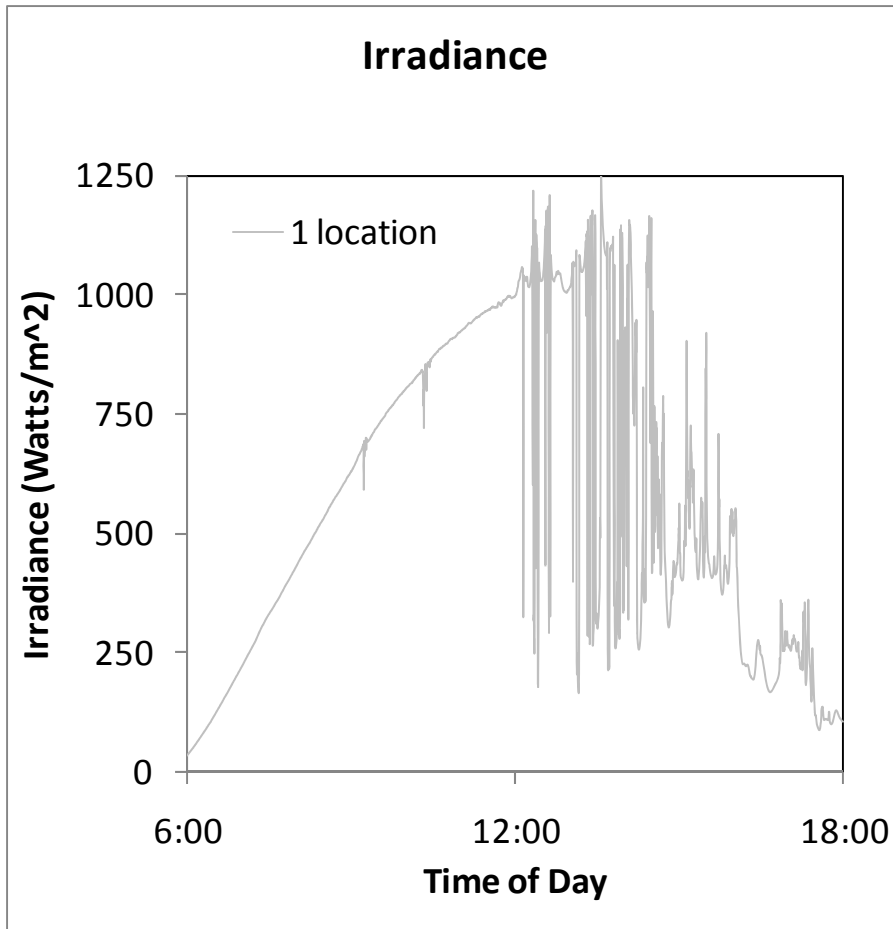
# What is Meant by Variability?



## Relative Output Variability

Output variability for fleet / Output variability at single location

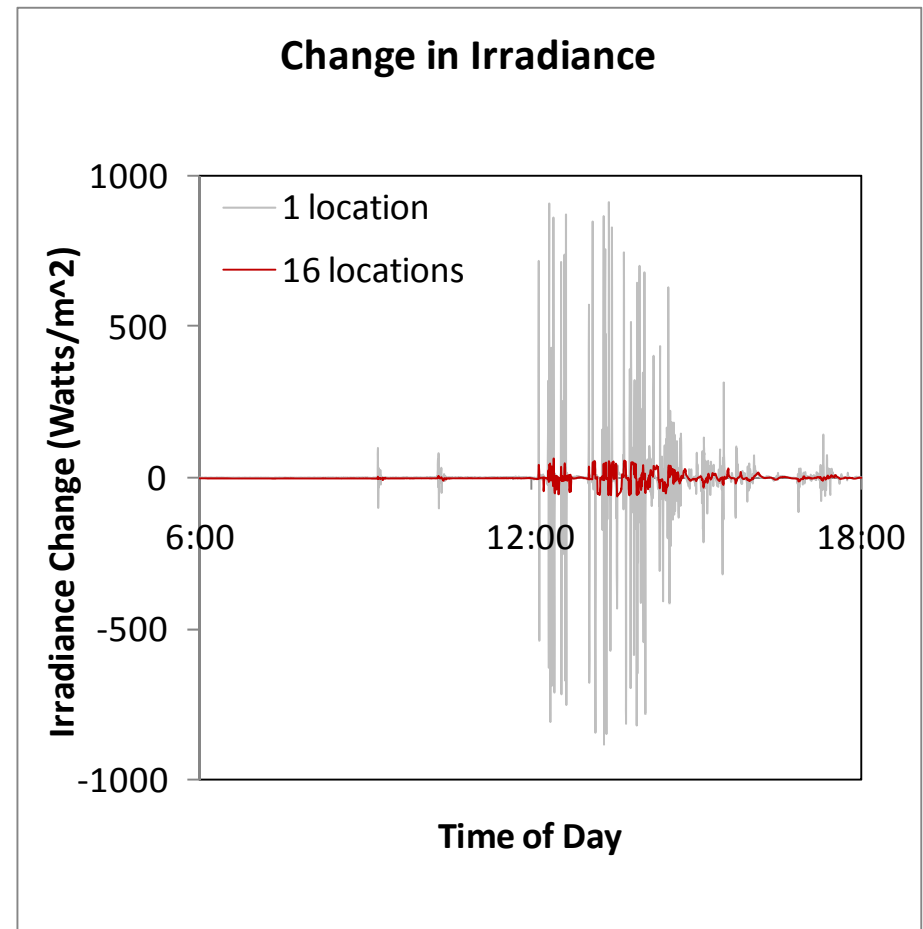
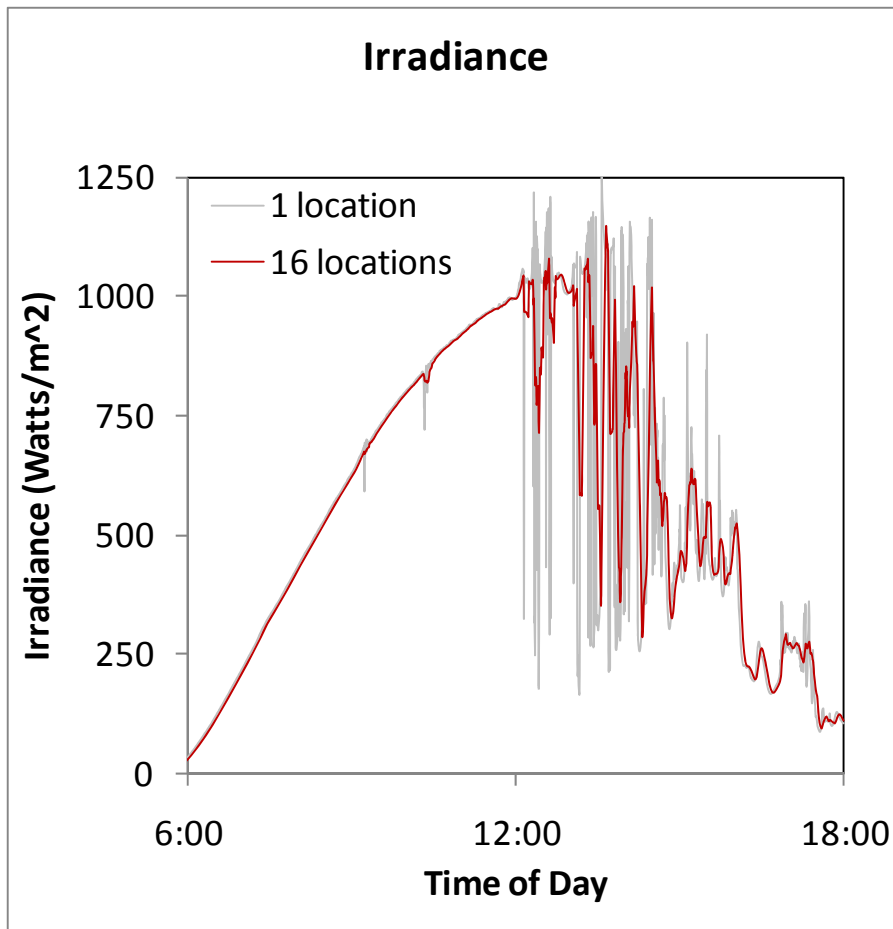
# What is Meant by Variability?



## Relative Output Variability

Output variability for fleet / Output variability at single location

# How Number of Systems Affects Variability



## Relative Output Variability

Output variability for fleet / Output variability at single location

# What is Dispersion Factor

- Dispersion Factor is the number of Time Intervals for a cloud to pass across the distance of the entire PV Fleet

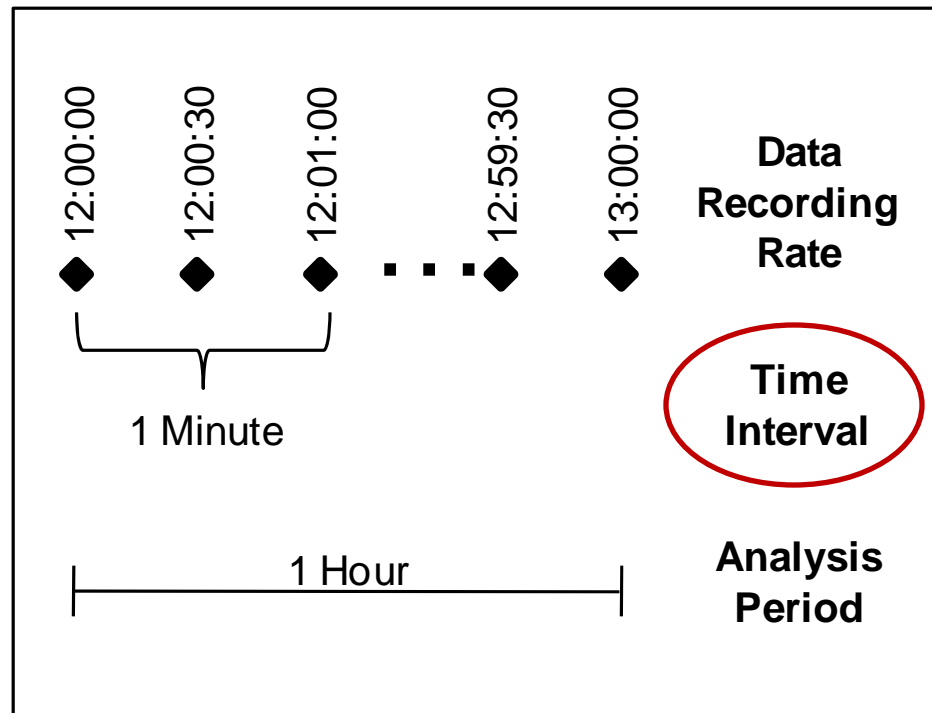
## **Relative Output Variability**

Output variability for fleet / Output variability at single location

## **Dispersion Factor**

Number of Time Intervals for cloud to pass across the PV Fleet

# What is Time Interval?



## Relative Output Variability

Output variability for fleet / Output variability at single location

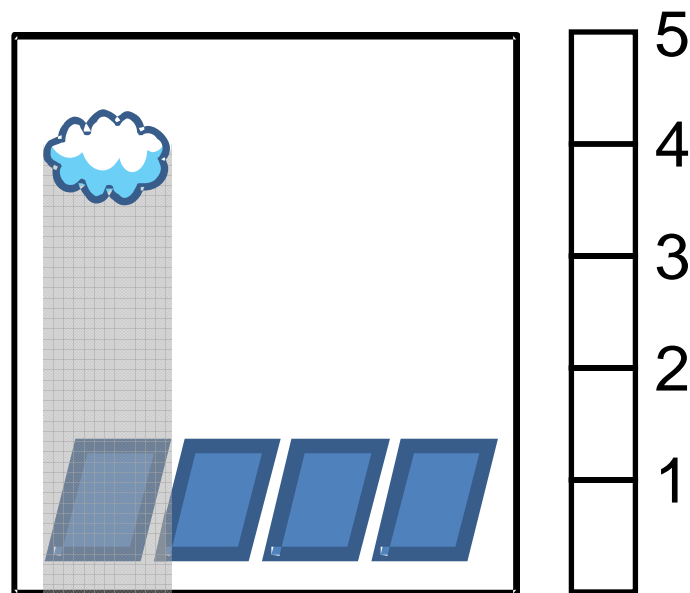
## Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

# Dispersion Factor For Moderate Cloud Transit Speed

**Moderate Cloud Transit Speed  
(Dispersion Factor = 4)**

12:00



**Dispersion  
Factor**

**Relative Output Variability**

Output variability for fleet / Output variability at single location

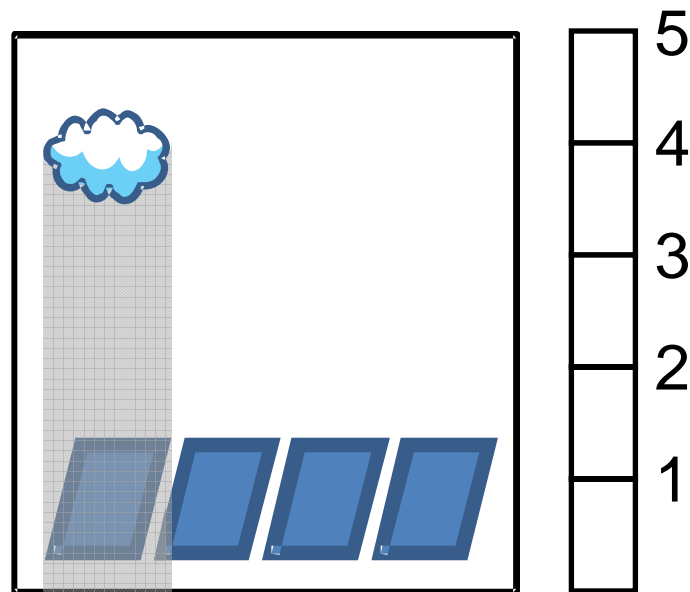
**Dispersion Factor**

Number of Time Intervals for cloud to pass across the PV Fleet

# Dispersion Factor

**Fast Cloud Transit Speed  
(Dispersion Factor = 2)**

12:00



**Dispersion  
Factor**

**Relative Output Variability**

Output variability for fleet / Output variability at single location

**Dispersion Factor**

Number of Time Intervals for cloud to pass across the PV Fleet

# Model Results Categorized in 4 Regions

<b>Crowded</b>	Number of Systems $>$ <i>Dispersion Factor</i>
<b>Optimal</b> (Point)	Number of Systems $=$ <i>Dispersion Factor</i>
<b>Limited</b>	Number of Systems $<$ <i>Dispersion Factor</i>
<b>Spacious</b>	Number of Systems $\ll$ <i>Dispersion Factor</i>

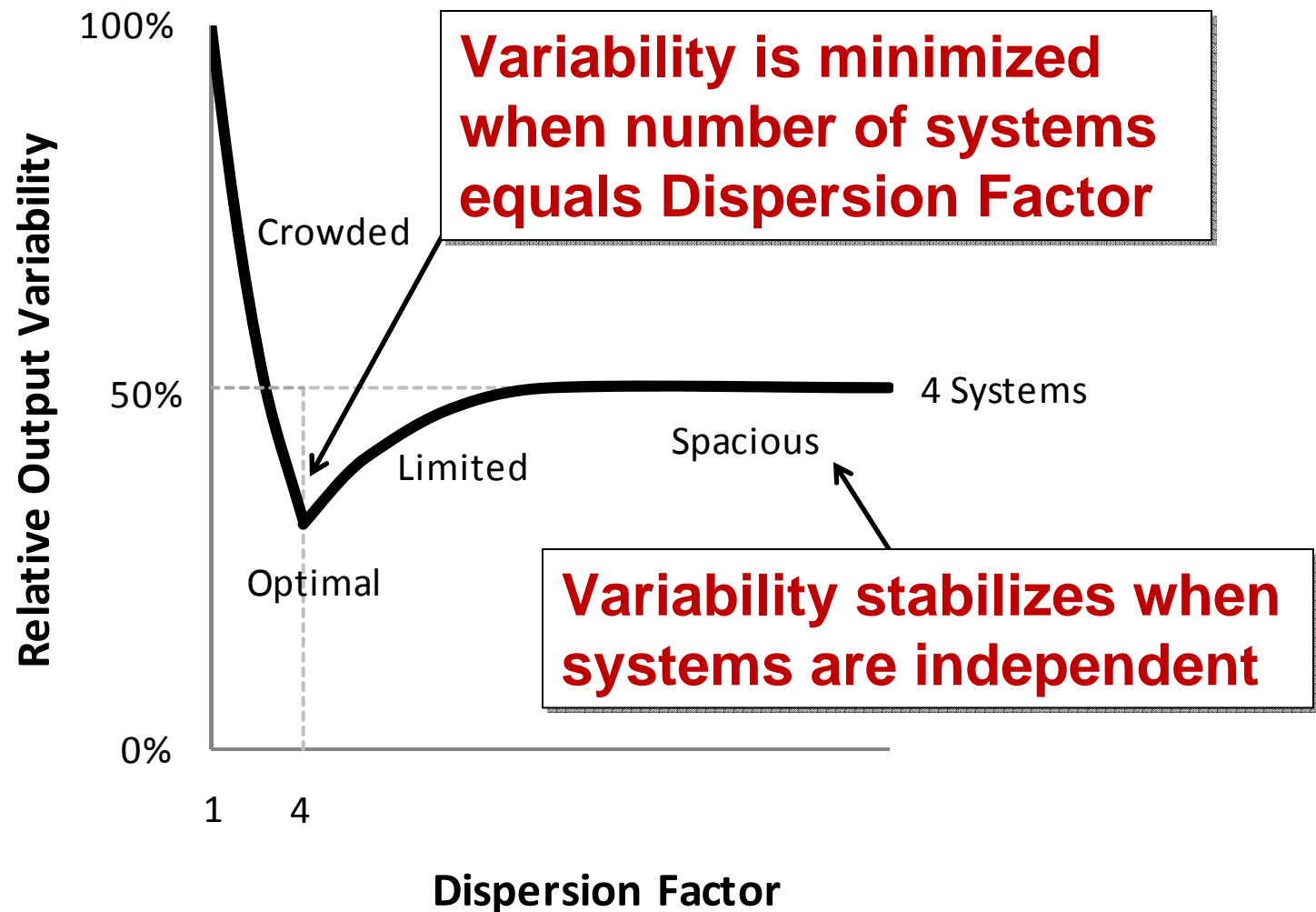
## Relative Output Variability

Output variability for fleet / Output variability at single location

## Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

# Relative Output Variability: 4 Systems



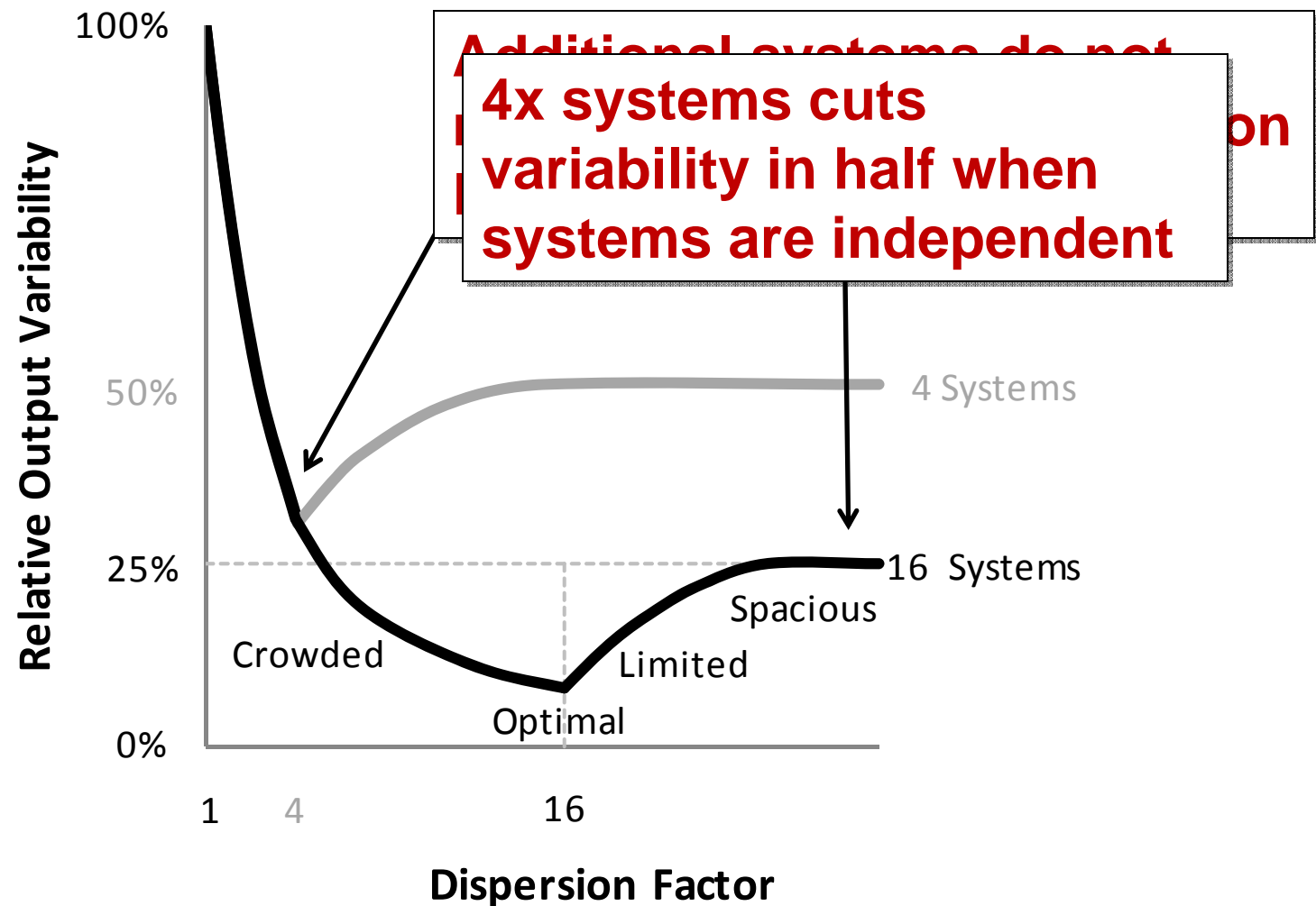
**Relative Output Variability**

Output variability for fleet / Output variability at single location

**Dispersion Factor**

Number of Time Intervals for cloud to pass across the PV Fleet

# Relative Output Variability: 16 Systems



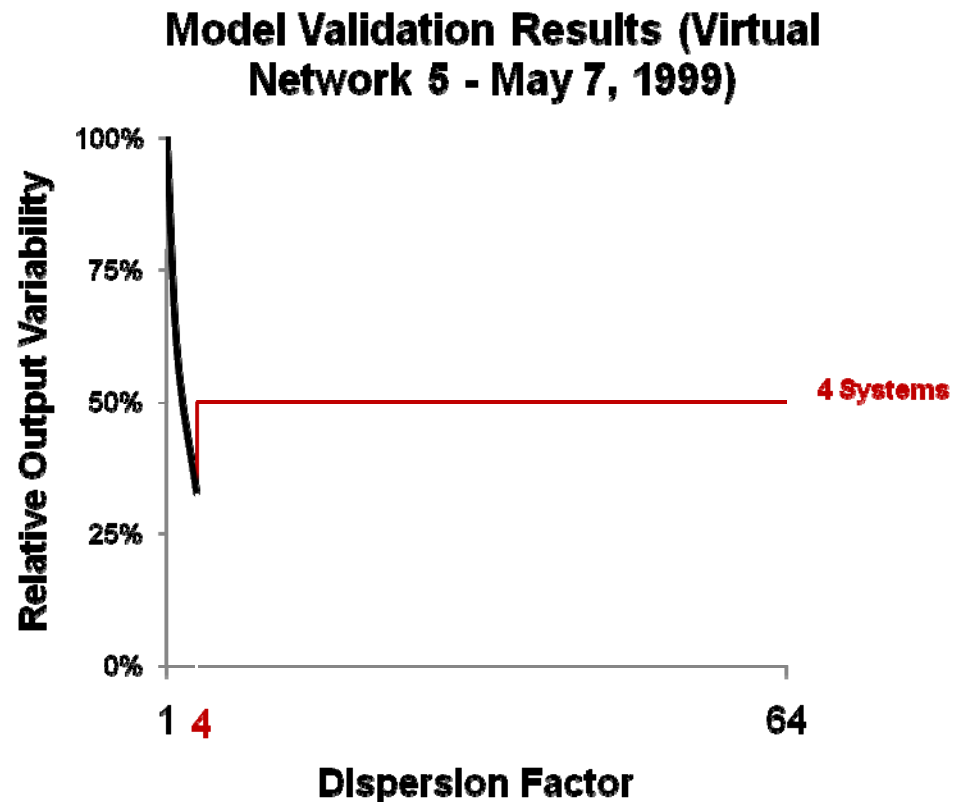
**Relative Output Variability**

Output variability for fleet / Output variability at single location

**Dispersion Factor**

Number of Time Intervals for cloud to pass across the PV Fleet

# Validation: Construct Model for 4 Systems



60-second Time Interval (Solid)

**Relative Output Variability**

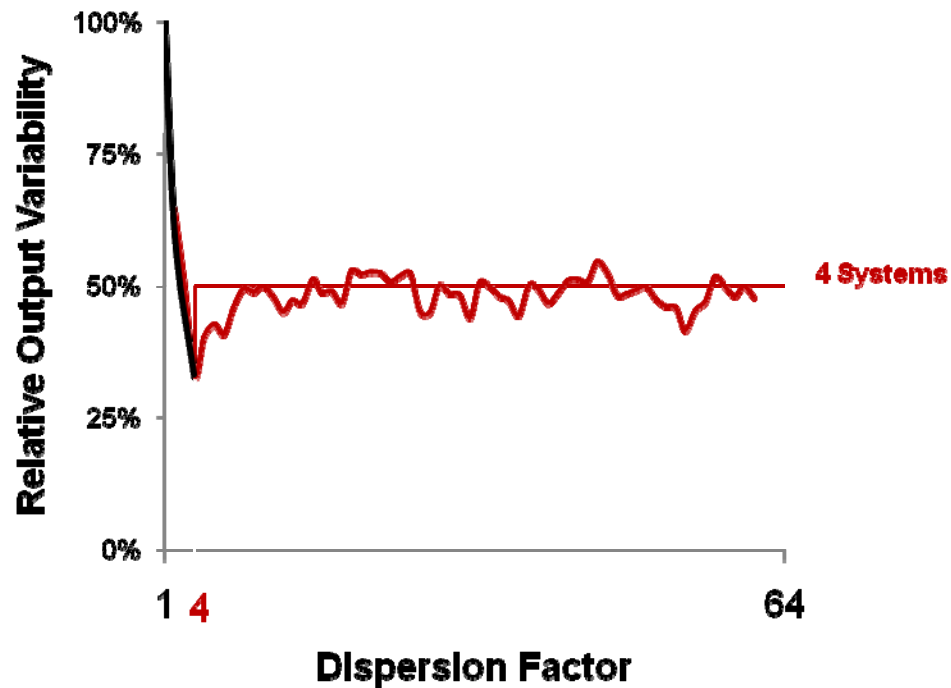
Output variability for fleet / Output variability at single location

**Dispersion Factor**

Number of Time Intervals for cloud to pass across the PV Fleet

# Add Measured Data

**Model Validation Results (Virtual Network 5 - May 7, 1999)**



60-second Time Interval (Solid)

**Relative Output Variability**

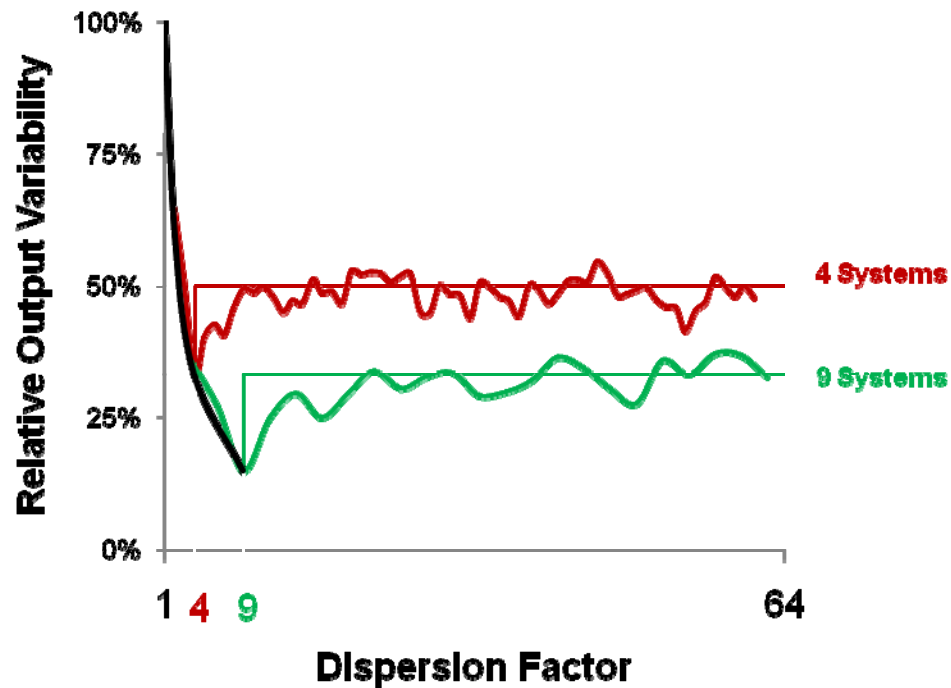
Output variability for fleet / Output variability at single location

**Dispersion Factor**

Number of Time Intervals for cloud to pass across the PV Fleet

# Repeat for 9 Systems

**Model Validation Results (Virtual Network 5 - May 7, 1999)**



60-second Time Interval (Solid)

**Relative Output Variability**

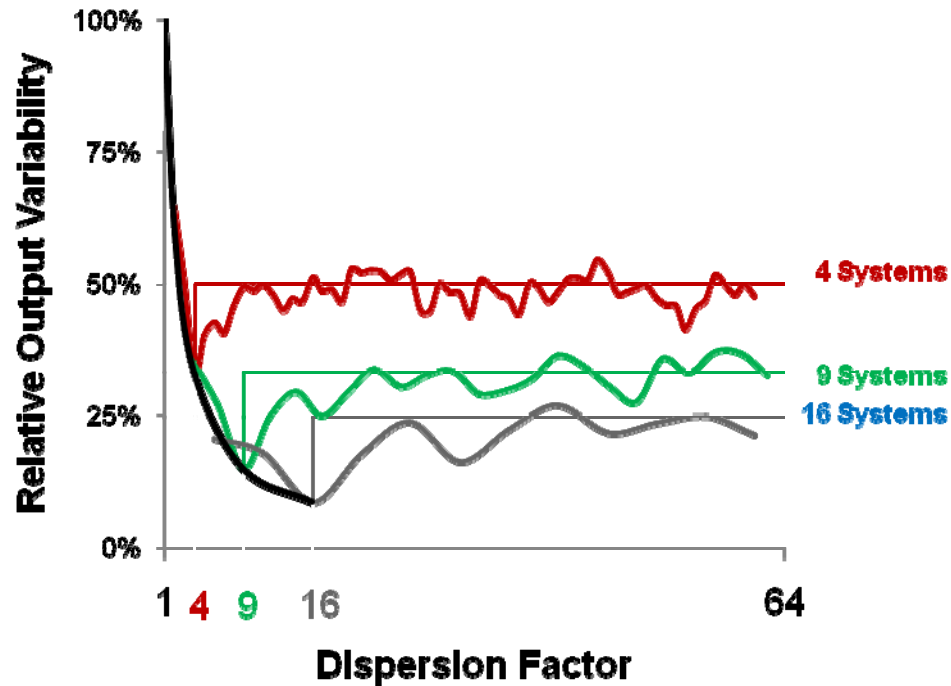
Output variability for fleet / Output variability at single location

**Dispersion Factor**

Number of Time Intervals for cloud to pass across the PV Fleet

# Repeat 16 Systems

**Model Validation Results (Virtual Network 5 - May 7, 1999)**



60-second Time Interval (Solid)

**Relative Output Variability**

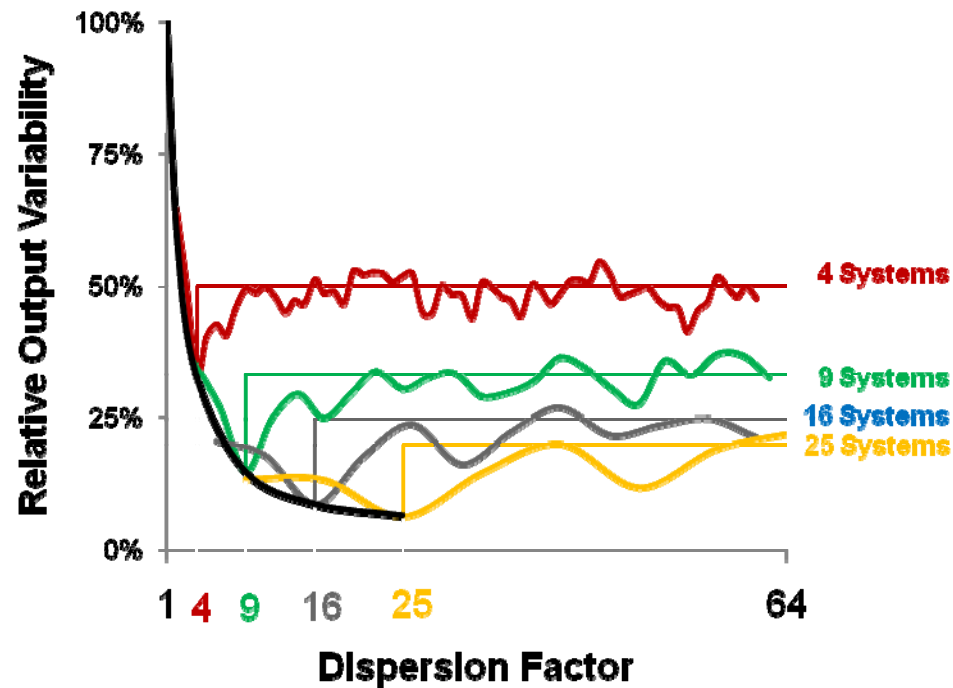
Output variability for fleet / Output variability at single location

**Dispersion Factor**

Number of Time Intervals for cloud to pass across the PV Fleet

# Repeat for 25 Systems

## Model Validation Results (Virtual Network 5 - May 7, 1999)



60-second Time Interval (Solid)

### Relative Output Variability

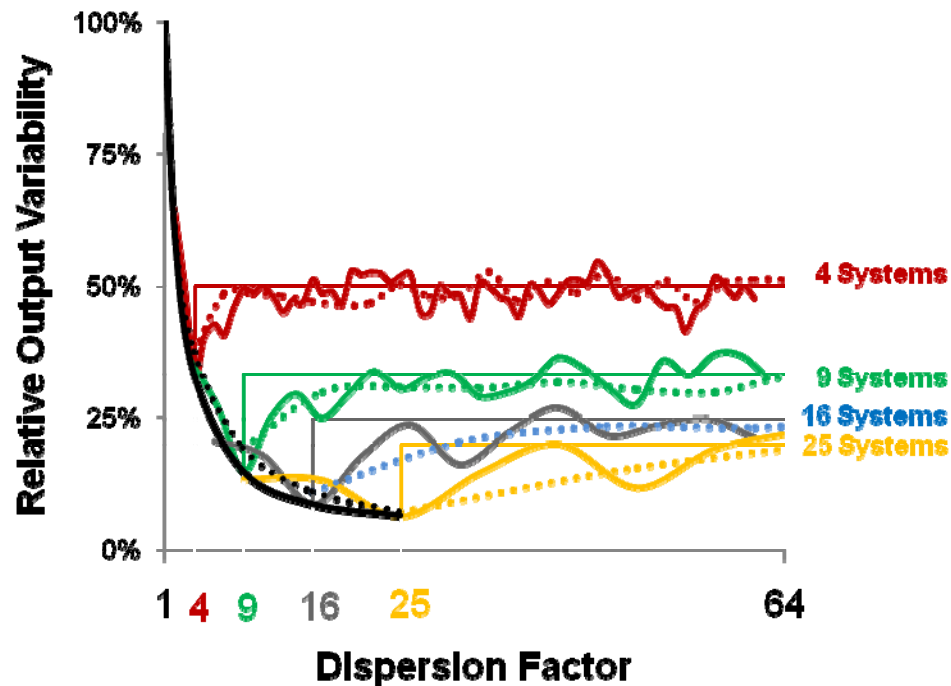
Output variability for fleet / Output variability at single location

### Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

# Repeat w/ 20 Second Time Interval

## Model Validation Results (Virtual Network 5 - May 7, 1999)



20-second Time Interval (Dashed) 60-second Time Interval (Solid)

**Relative Output Variability**

Output variability for fleet / Output variability at single location

**Dispersion Factor**

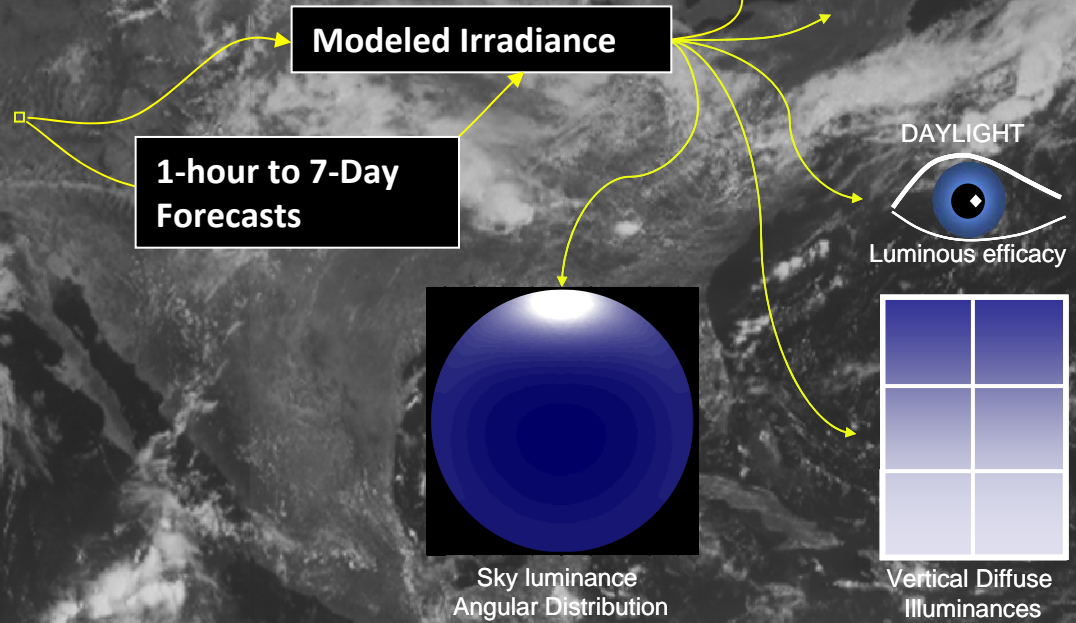
Number of Time Intervals for cloud to pass across the PV Fleet

## Question #2

What needs to be done to forecast short-term output variability?

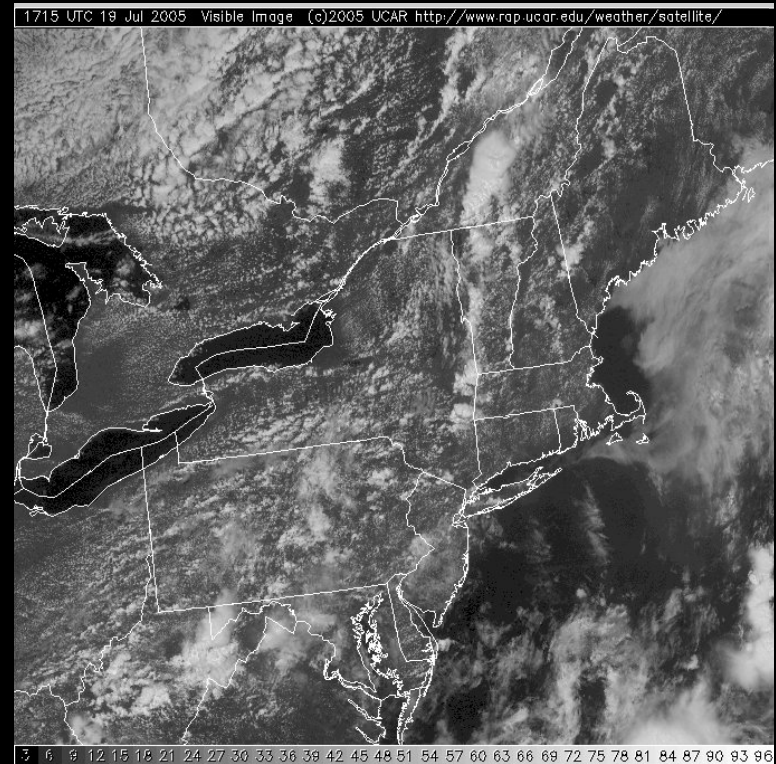
**SOLARANYWHERE®**

**DNI** **PV**  
TILTED IRRADIANCE



# Current-to-5 hours CLOUD MOTION

Patterned after Lorenz et al.



# How This Relates To Output Variability

Relative Output Variability is based on:

1. Number of PV systems
2. Dispersion Factor

Dispersion Factor is the number of Time Intervals for a cloud to pass across the distance of the entire PV Fleet

## Conclusions: Relative Output Variability

- Can be quantified based on the number of PV systems and the Dispersion Factor
- Equals inverse of the square root of the number of systems for dispersed PV systems
- Can be minimized for optimally-spaced PV systems for a given Cloud Transit Speed

## Next Steps

- Further model validation
- Extend model to arbitrary fleet configuration
- Integrate with SolarAnywhere<sup>®</sup>  
([www.solaranywhere.com](http://www.solaranywhere.com)) forecasting



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