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GameChange Solar

Choose the right direction: Designing for wind directionality and extreme weather for solar assets

pv magazine webinars

4 September 2024

7:00 am – 8:00 am | PDT, Los Angeles
10:00 am – 11:00 am | EDT, New York City
4:00 pm – 5:00 pm | CEST, Berlin, Madrid

Ryan Kennedy
Editor
pv magazine USA

Scott Van Pelt
Chief Engineer
GameChange Solar

Yarrow Fewless
Principal, Solar Structures Group
CPP Wind Engineering

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Welcome!

Do you have any questions? ❓ 🙋

Send them in via the Q&A tab. 👉 We aim to answer as many as we can today!

You can also let us know of any tech problems there.

We are recording this webinar today. 🎥

We‘ll let you know by email where to find it and the slide deck, so you can re-watch it at your convenience. 👀 💡

GAMECHANGE SOLAR
REPOWERING THE PLANET

Choose the Right Direction:
Designing for wind directionality and extreme weather for solar assets

SEPTEMBER 4, 2024

Scott Van Pelt – Chief Engineer

Agenda

1

GameChange Speaker Introduction

Meet your speaker, Scott Van Pelt.

2

Understanding Stow

Learn background information on what “stow” is and how it can vary.

3

CPP: Wind Engineering

How wind direction can change during hurricanes and thunderstorms

4

Extreme Weather Mitigation

- Wind
- Hail
- Flood
- Snow

5

Construction

Understand design considerations during construction.

6

Conclusion

Review key takeaways.

Speaker Introduction

Get to know your speaker for this presentation

Scott Van Pelt, P.E.

As the Chief Engineer, oversees the customer-facing engineering team at GameChange Solar. In this role, he is responsible for the execution, accuracy, and timeliness of all technical deliverables.

He is a Professional Engineer licensed in two dozen states, and functions as the Structural Engineer of Record for many GameChange projects.

With over a decade of experience in the renewable energy space, Scott has served as a voting member of multiple national and international standards committees.

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Understanding Stow

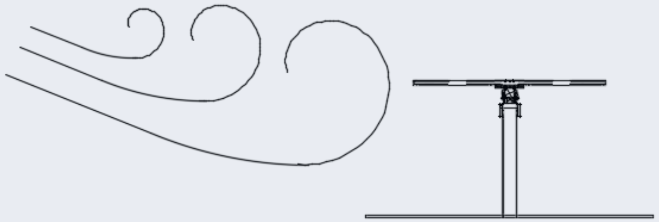
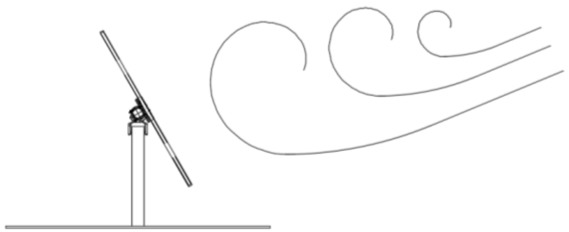
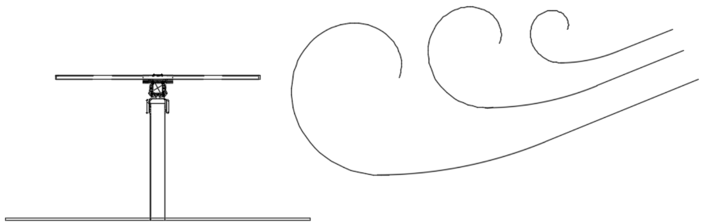
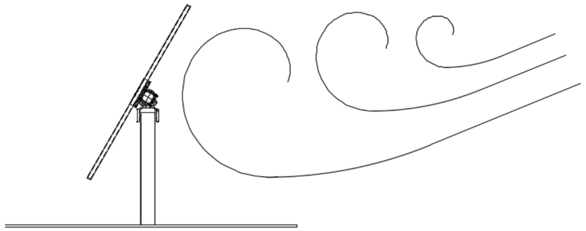
Stow Overview

Stow is the safety position that tracker tables turn to withstand extreme wind

- Tracker tables turn throughout the day to follow the sun, increasing energy yield
- Sensors are triggered actively or passively to detect wind, snow, hail, and other events
- Tables are turned to a previously specified stow angle to better withstand the extreme weather
- Stow tilt angle can vary based on the extreme weather events observed
- Structural loading is determined by the pressures caused by these weather events at these stow angles

Stow Options | Wind Direction

Tracker systems use differing stow strategies to mitigate wind loading

	Nose Down Into Wind	**Flat**	**Omni-directional Wind**
Wind from West			
Wind from East			

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Choose the Right Direction: Designing for wind directionality and extreme weather for solar assets

PV Magazine Webinar - September 4, 2024

cppwind.com

Presented by

Yarrow Fewless
Principal, CPP Wind Engineering Consultants
yfewless@cppwind.com

Yarrow is a Principal in the Solar Structures Group at CPP Wind Engineering, focusing on the effects of the wind on solar structures. He has been in the field of wind effects on structures since 2005, with significant experience consulting on wind loads on ground-mounted and roof-mounted solar structures, wind issues related to tall buildings (structural dynamics, cladding pressures, door operability, and pedestrian comfort), and more unique situations such as wind loads on air-supported radomes and launch vehicles (prelaunch, on the launch pad).

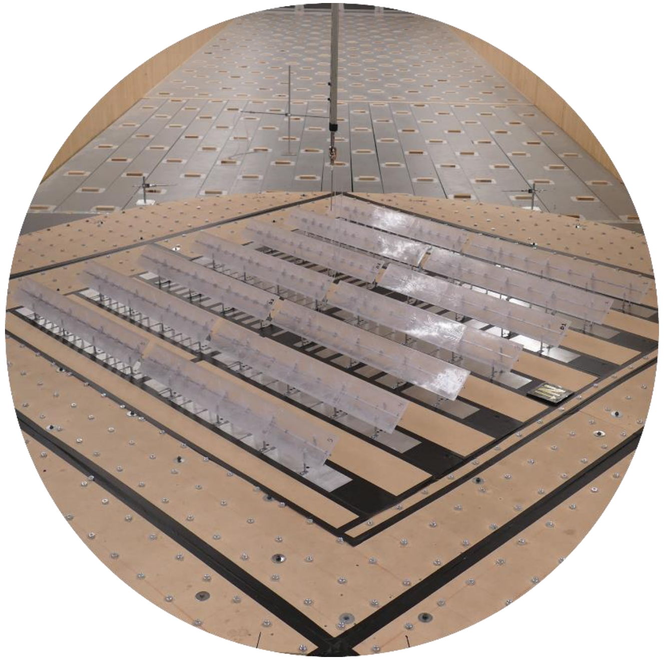
CPP Wind Engineering Consultants

Wind Effects on Solar Structures

- Wind climate analysis (site)
- Wind tunnel testing (product):
  - Scale-model measurements
  - Analysis for:
    - Structural/component loads
    - Instability for single-axis trackers
- Consulting on
  - Topographic effects
  - Sand drifting
  - Snow drifting

WIND CLIMATE ANALYSIS

WIND TUNNEL TESTING



SCALE WIND TUNNEL MODELING

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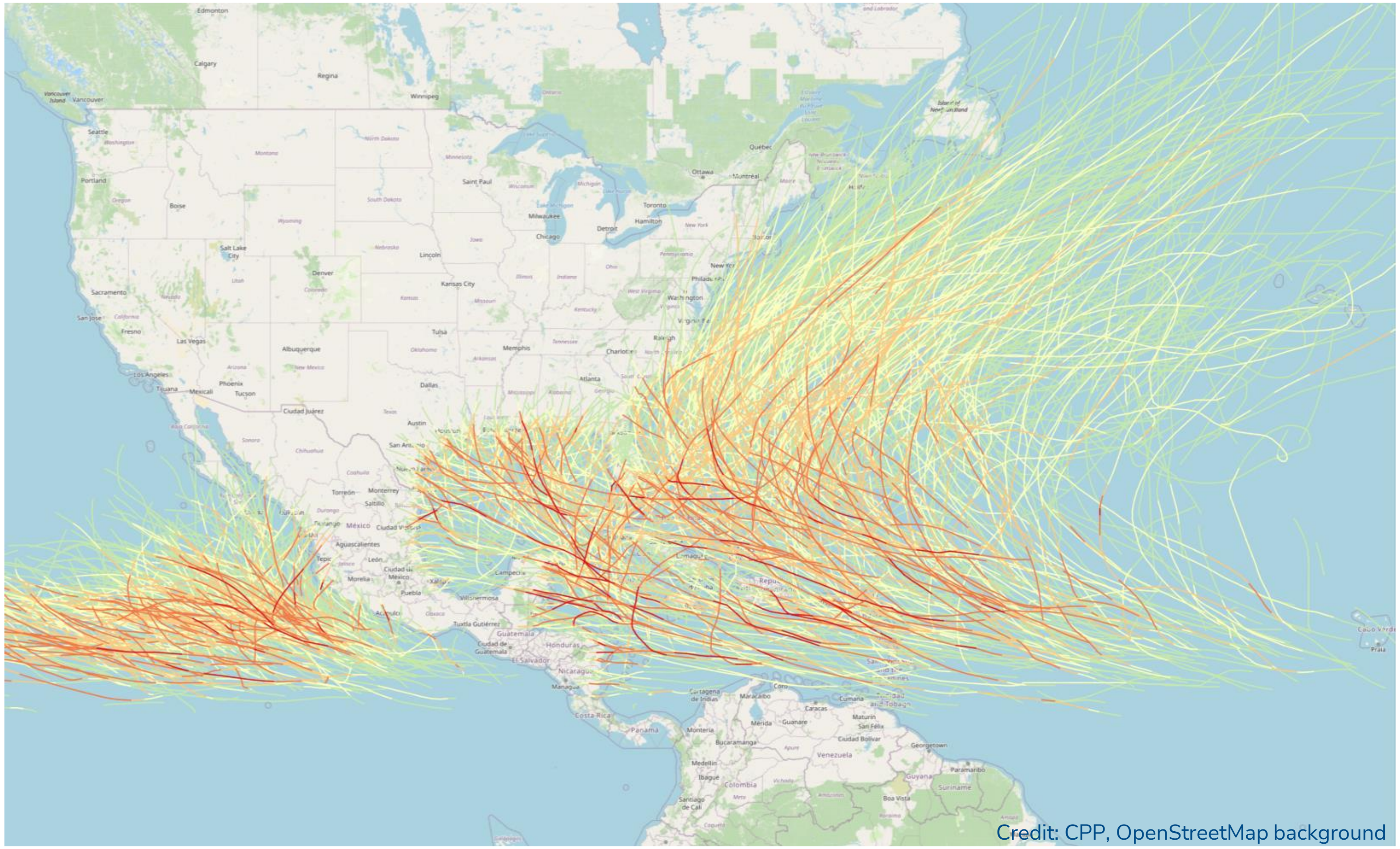
Hurricanes

Design

- Wind speed simulations
- Directionality possible

Operational considerations:

- Relatively slow translation speed. Not hard to see it coming.
- Wind direction changes as the storm passes
- Severity varies by location relative to eye

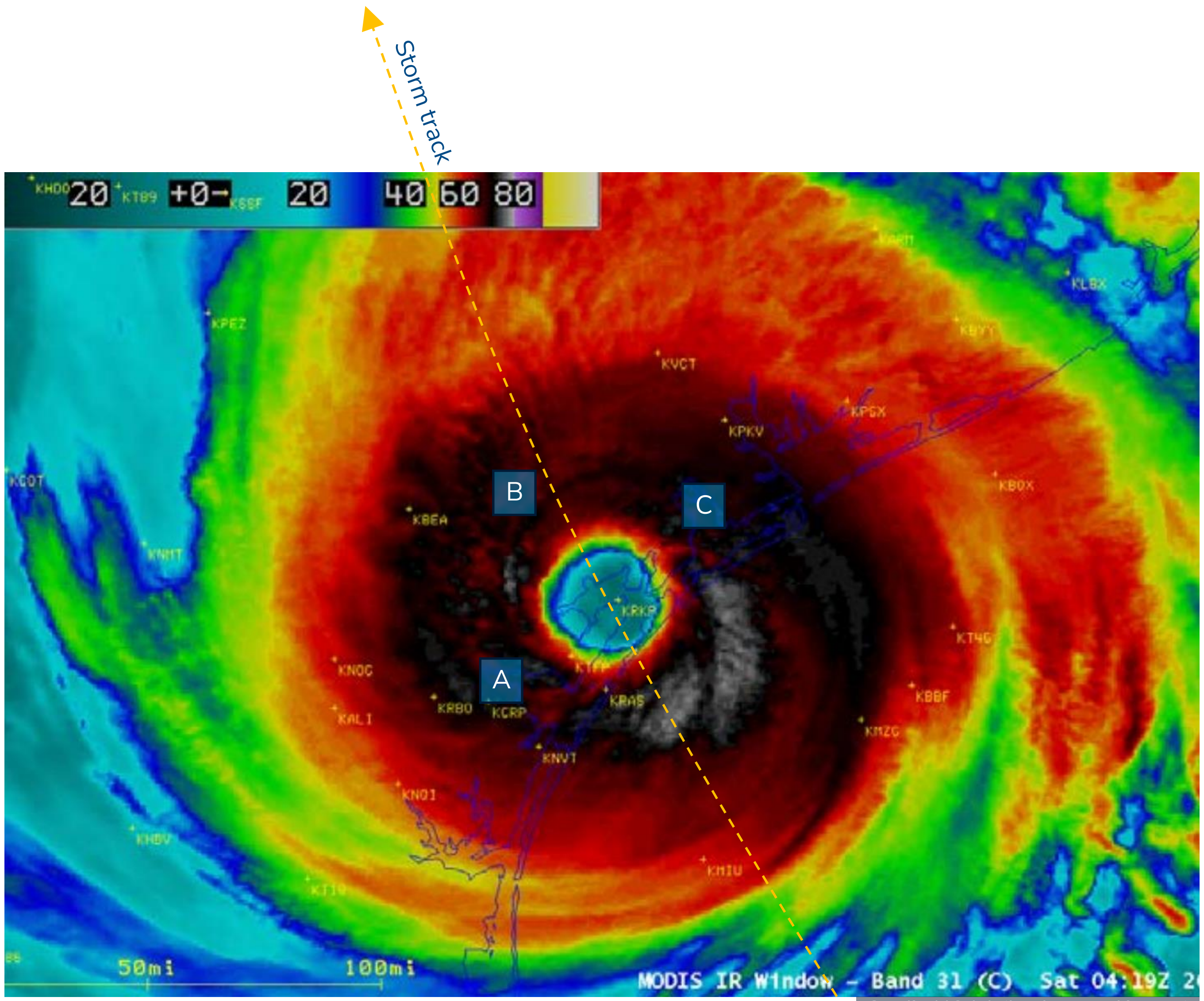


Credit: CPP, OpenStreetMap background

Historical Hurricane Tracks, North America

Storm Passage

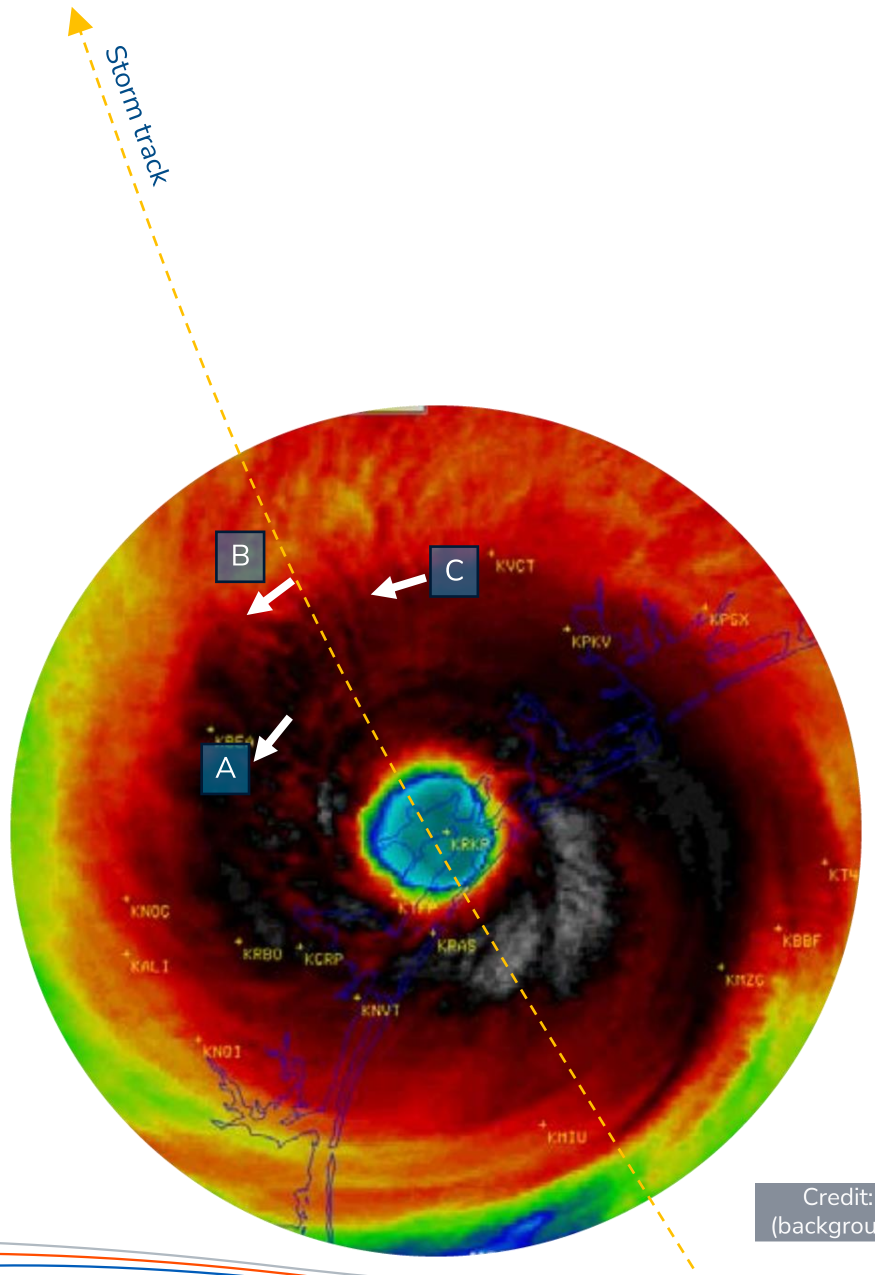
- Hypothetical example based on Hurricane Harvey, 2017, Houston, Texas, USA
- Three hypothetical sites: A, B, and C
- Showing time around landfall



Credit: NOAA (background image)

Storm Passage

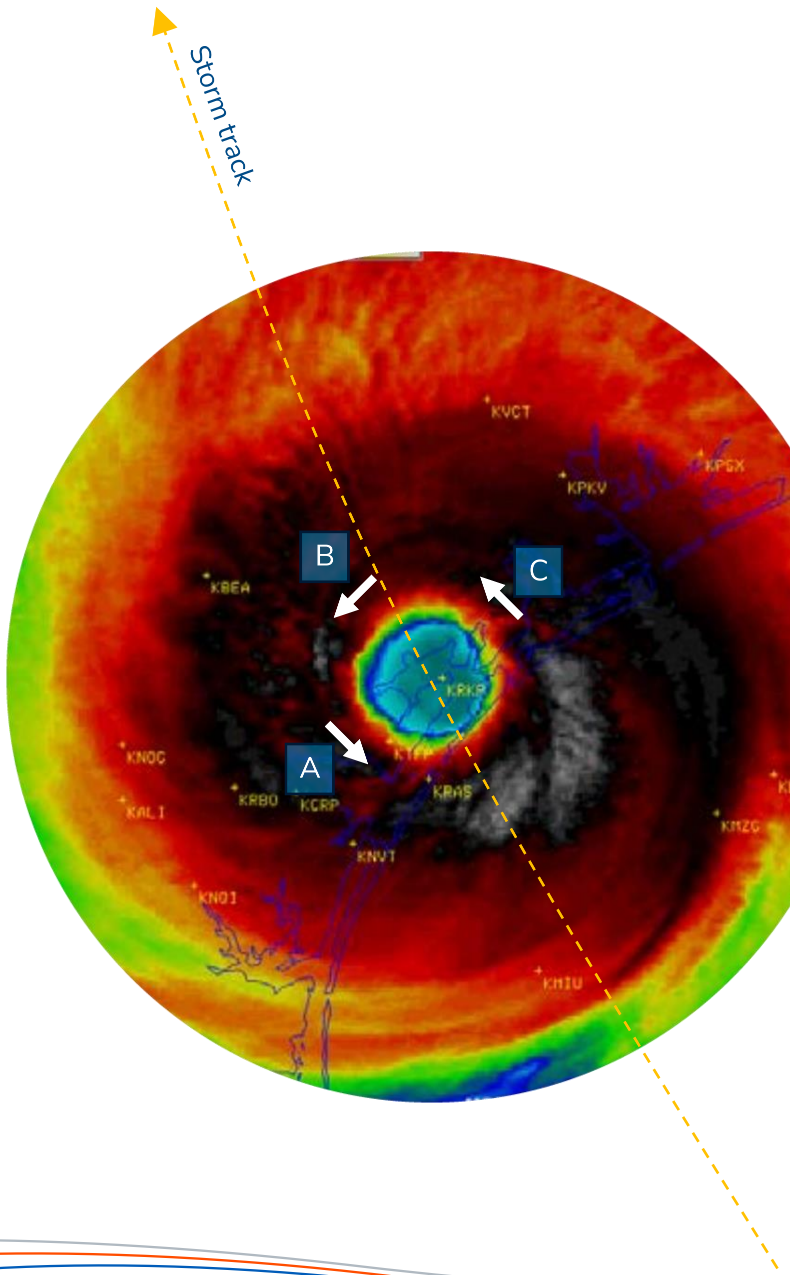
- An hour or two <u>before</u> landfall (image shifted for demonstration):
  - Site A, NE winds
  - Site B, NE winds
  - Site C, E winds



Credit: NOAA (background image)

Storm Passage

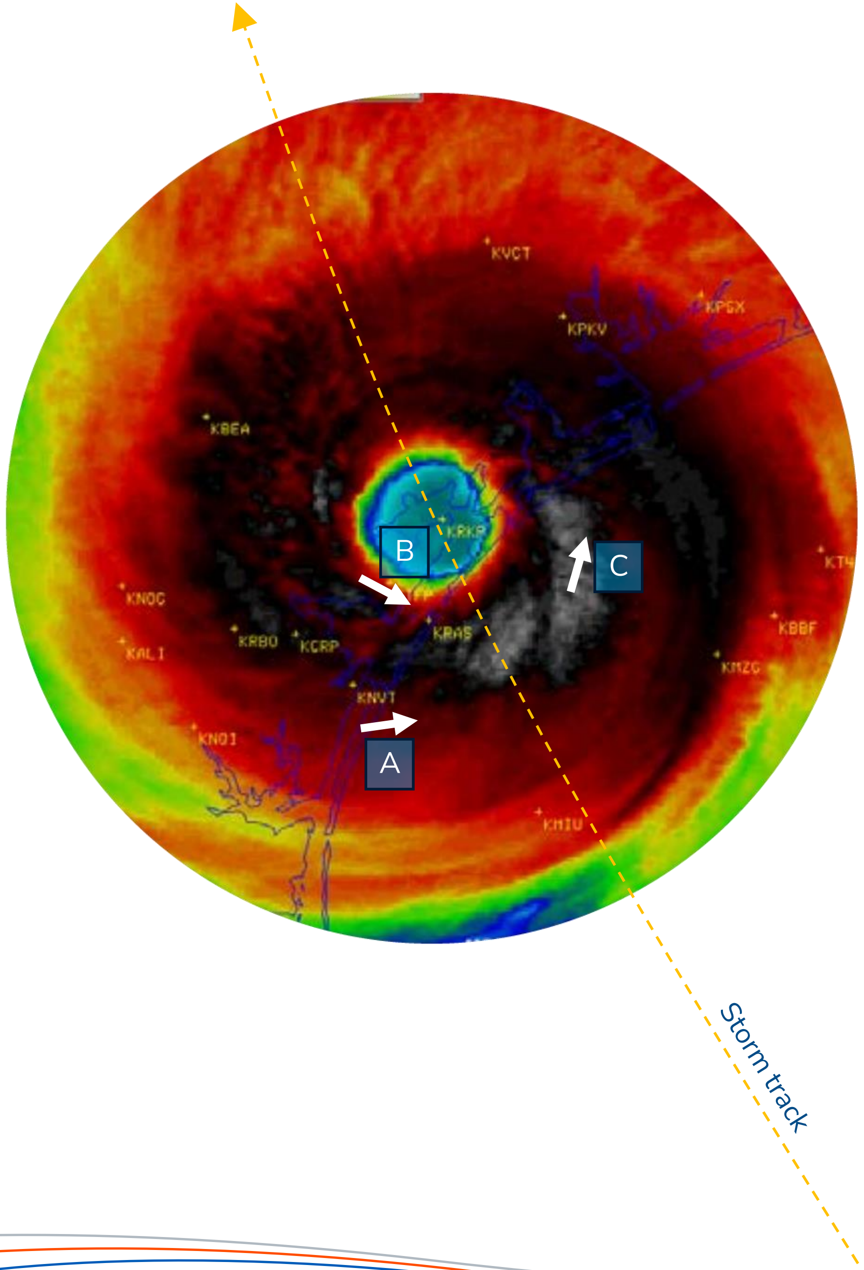
- Landfall:
  - Site A, NW winds. Big shift in direction and increase in speed as it is now closer to eyewall
  - Site B, still NE winds
  - Site C, SE winds



Credit: NOAA (background image)

Storm Passage

- An hour or two after landfall
  - Site A, W winds
  - Site B, WNW winds
  - Site C, SSW winds

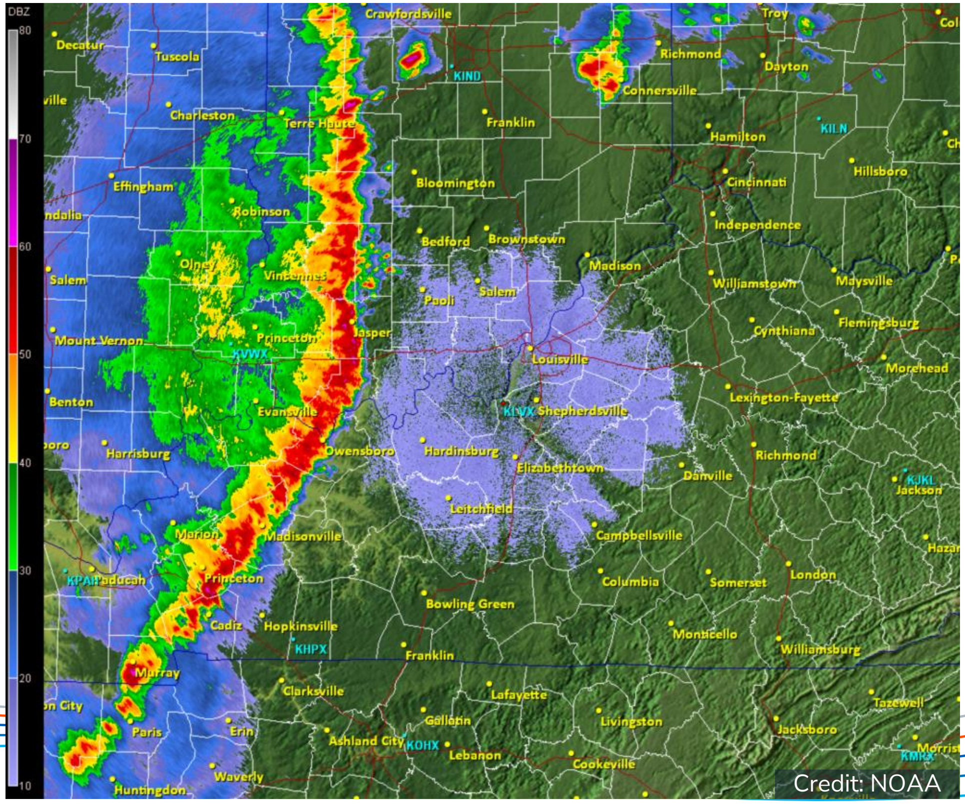


Credit: NOAA (background image)

Thunderstorms

- Thunderstorms are common in much of the US and the world
- They can drive the design wind speed outside of hurricane/cyclone/typhoon-prone regions
- Could appear as a cluster or squall line with an obvious approach, or could be isolated thunderstorms that seem to "pop up" on a radar image
- Weather services typically alert when the atmospheric conditions are ripe for strong thunderstorms
- Wind speed increases much faster than in a hurricane, called the 'ramp rate'
- Direction can change rapidly during the storm

Credit: Roger Riggin



Credit: NOAA

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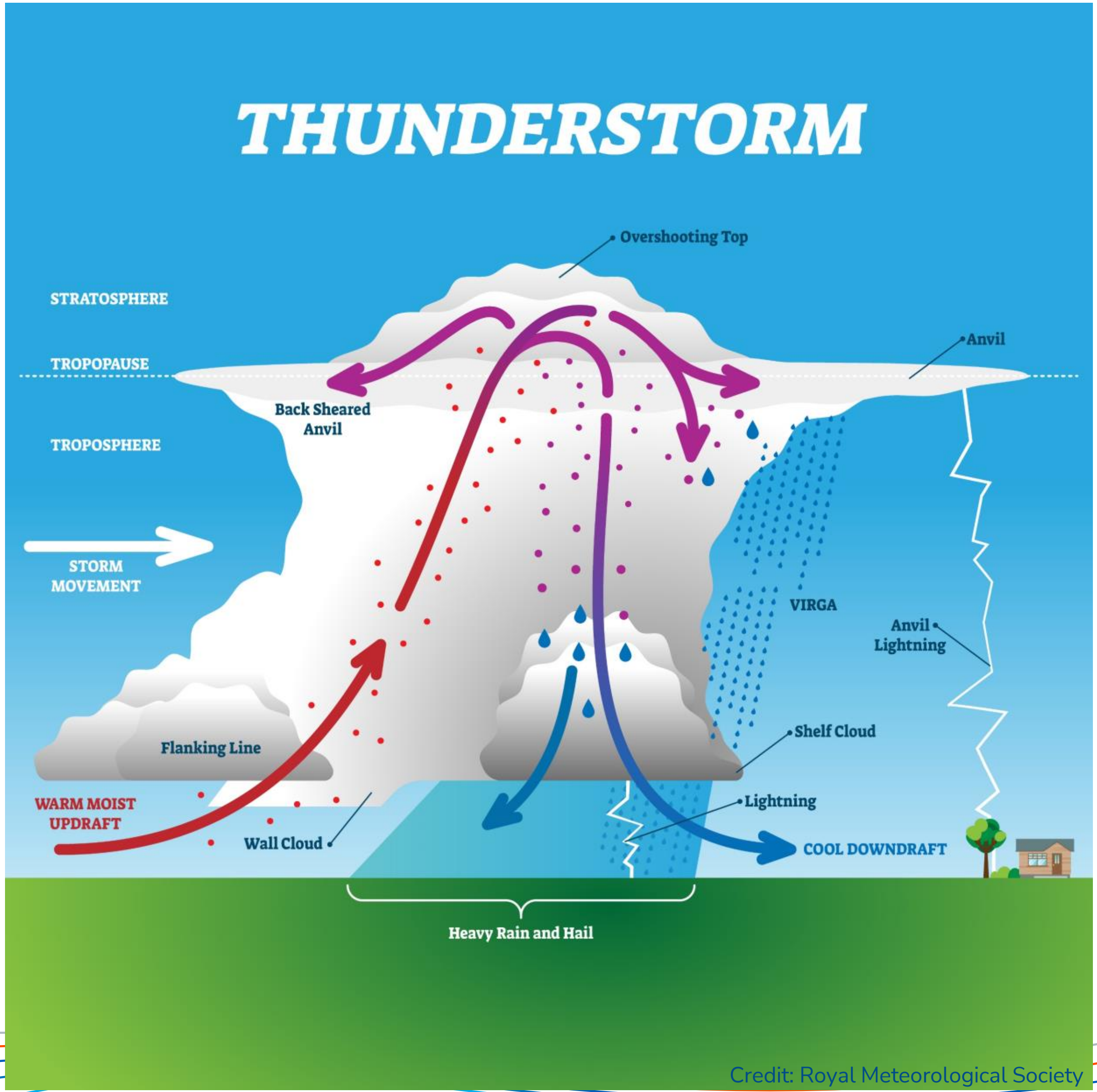
Thunderstorms

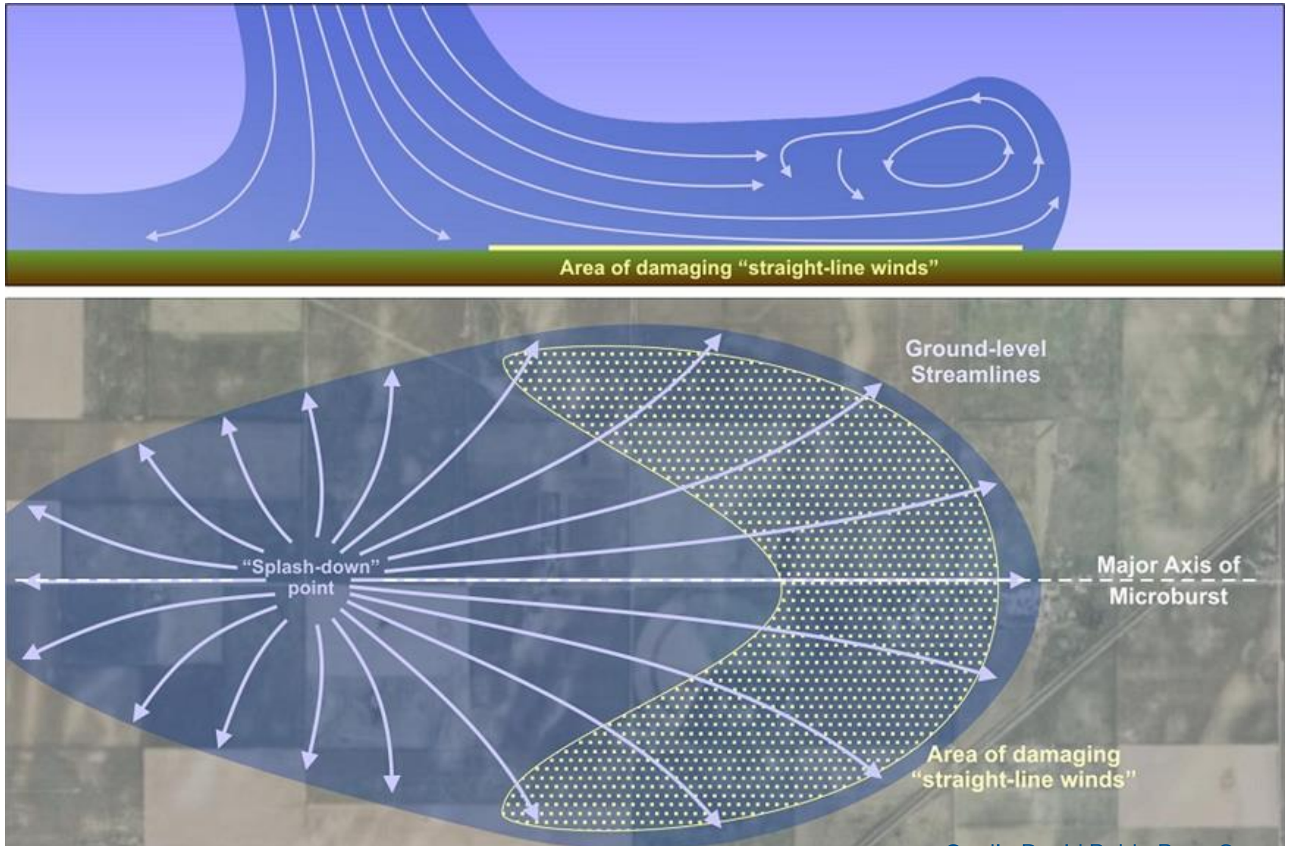
- Unstable atmosphere, it just takes a nudge to move air upwards and it accelerates into a strong updraft
  - Warm air rising on a hot day
  - A cold front pushing in underneath
- Warm air is lifted or forced upward
- As it's lifted it naturally cools and can't hold as much moisture, so water droplets form
- The droplets form into rain or hail and are held up by the updraft
- Raindrops/hail grows until the mass is too much to support with the updraft and the flow reverses
- Downburst!



Credit: Royal Meteorological Society

Thunderstorms

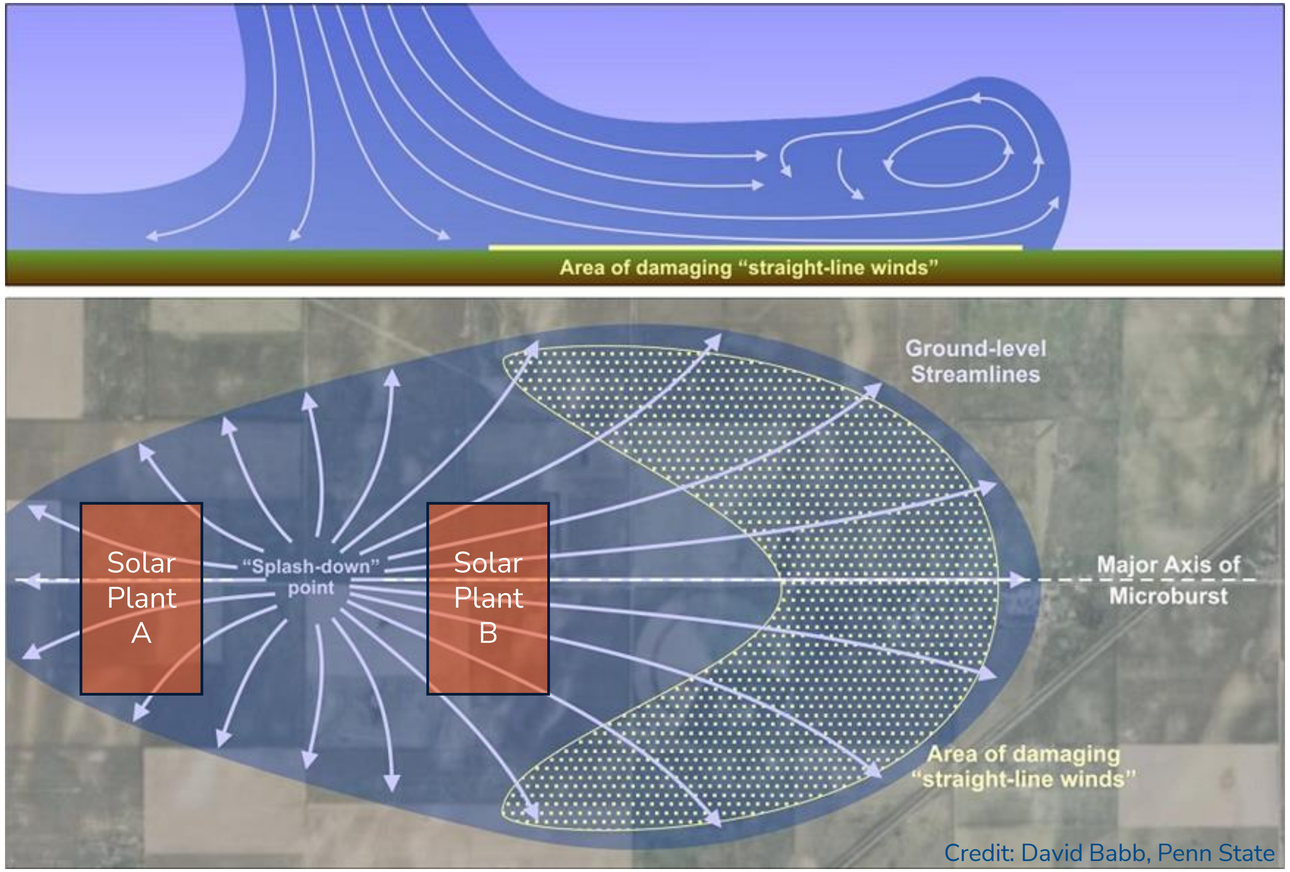
- Where the winds come from depends on where you are when a downburst/downdraft occurs
- Strong/damaging winds on the forward flank
- Strong/damaging winds on the rear flank are also possible



Credit: David Babb, Penn State

Thunderstorms

- Whatever the wind direction was 10 minutes earlier, Solar Plant A sees strong winds from the east and Solar Plant B sees strong winds from the west.



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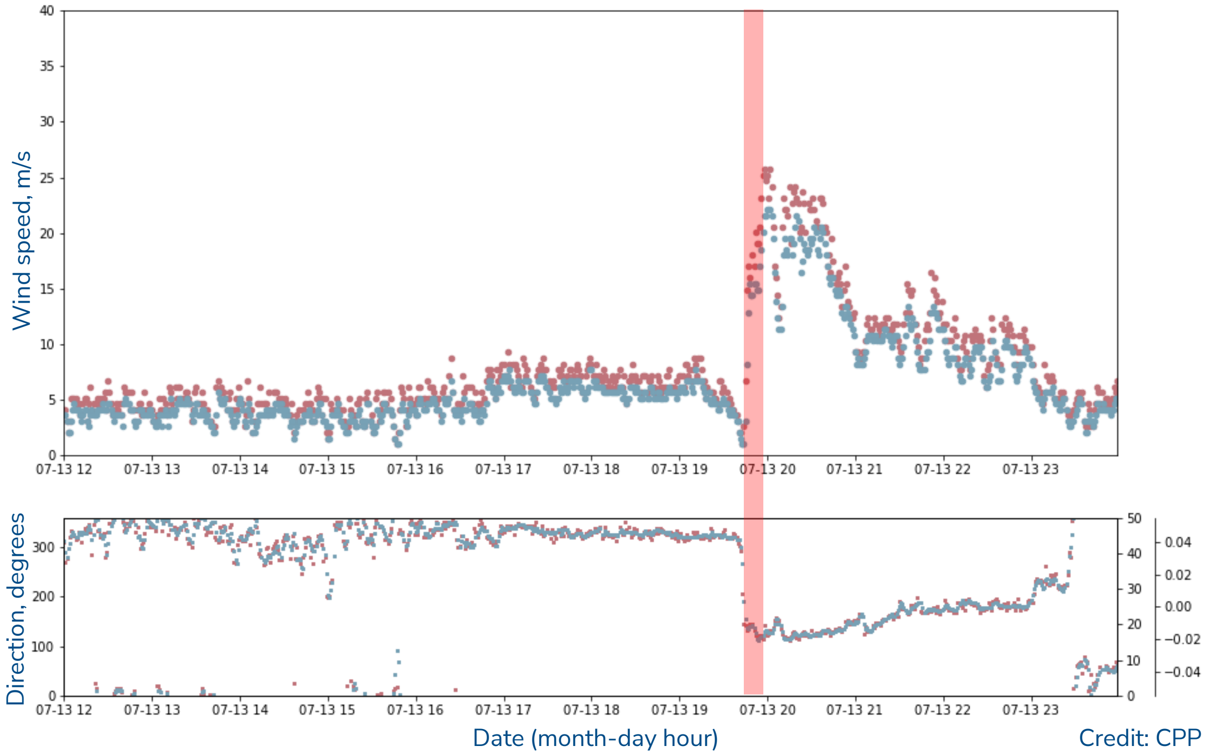
Thunderstorms

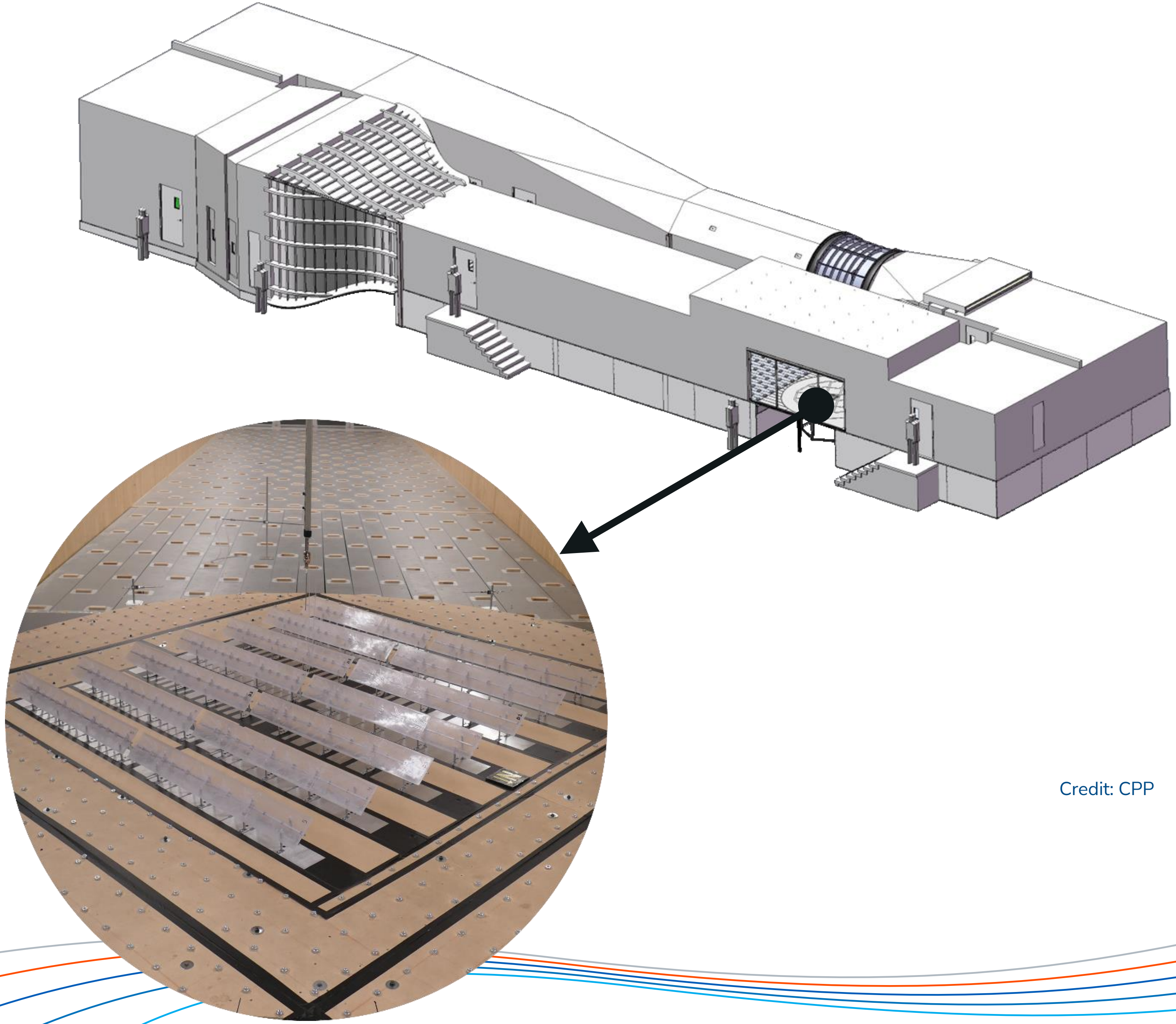
- Storm passage data from Tucson, Arizona, USA
- Pink strip is approximately 12 minutes
- Note sudden shift in direction, changing from NW to SE



Credit: CPP

Wind Tunnel Testing

- Develop the turbulent properties of the wind at model scale
- Test scale models of a generic array for surface pressures
- Analyze the raw data for loads on all components of the system
- Can also test for instability using aeroelastic models (mass, stiffness, and damping at model scale).



Credit: CPP

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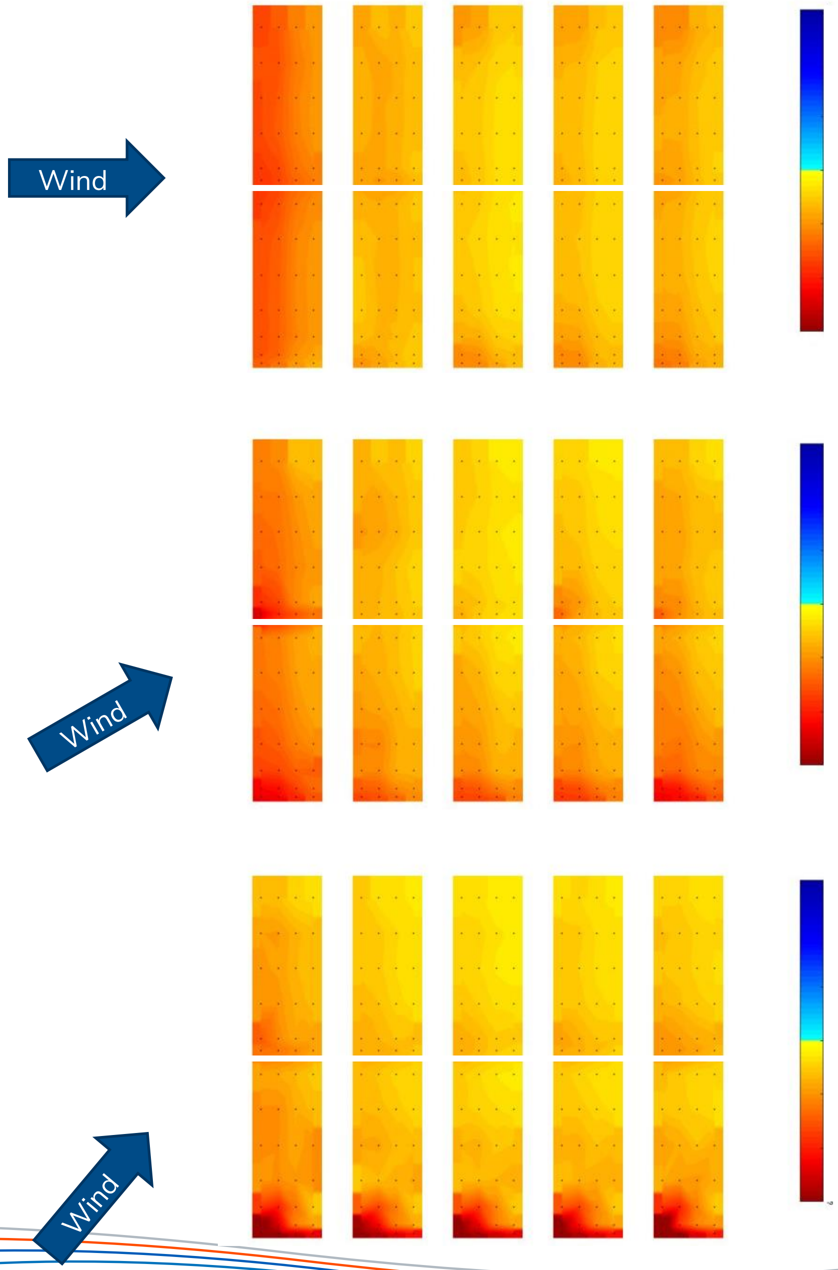
Highest Pressures in Array

- Example: 45° tilt, leading edge up
- Highest pressures occur at exposed end of rows, and come for cornering wind
- Highest pressures are concentrated at the exposed end



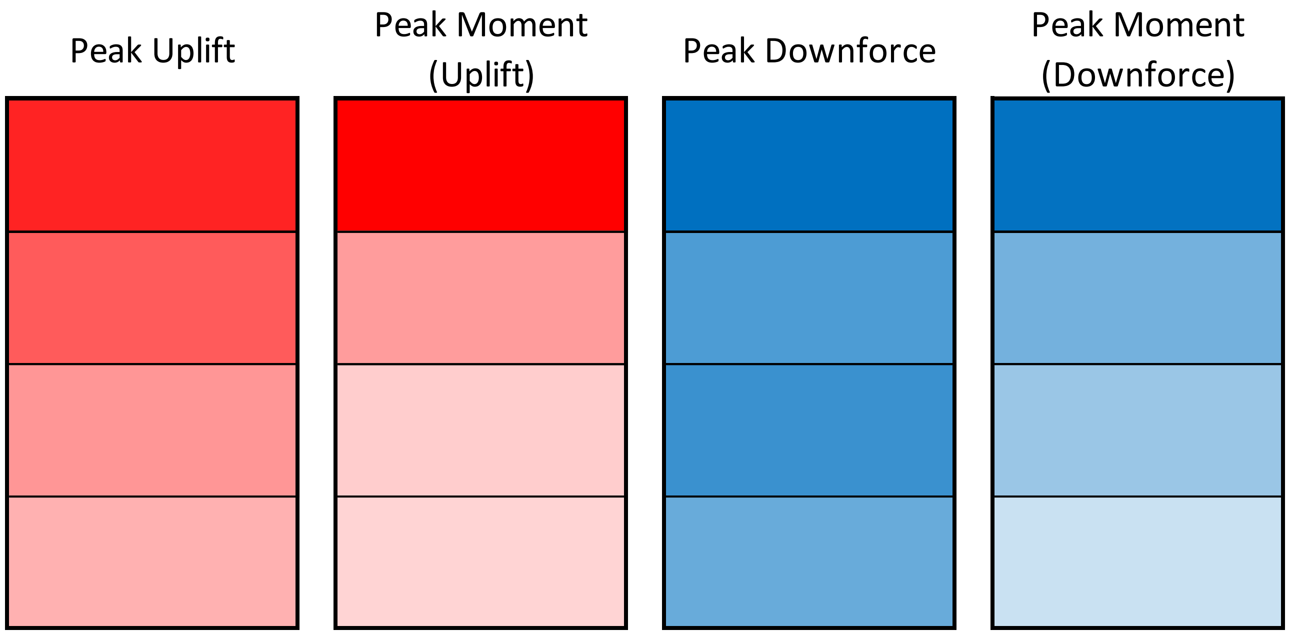
Solar Module Wind Loading

Load Cases Can focus on greatest module load or greatest moment about the torque tube.

Asymmetric Loads Pressures don't tend to be uniform across the modules.

Assuming an even load can change the failure mechanism.

Steady vs Fluctuating Load Pressures fluctuate so assuming a sandbag-style test is approximate.



TYPICAL MODULE LOAD CASES
(RED = UPLIFT NET PRESSURE; BLUE = DOWNFORCE NET PRESSURE)

Key Take-aways

Hurricanes pass over a site and wind direction changes throughout the storm passage, over a time scale of hours. No interim time to change stow angle.

Thunderstorms also pass over a site, but the strong wind speeds develop very quickly, and the direction from which they come depends on where the downburst came down, not the wind direction prior to the increase.

Wind Tunnel Testing is the state-of-the-art method for determining wind loads, coupled with site-specific wind speeds for the best accuracy.

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Thank You!

CPP WIND ENGINEERING CONSULTANTS

7365 Greendale Road
Windsor, CO 80550
USA

T: +1 970 221 3371

cppwind.com

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Extreme Weather Mitigation

Wind

Calculating Wind Pressures | Application of Wind Tunnel Results

Wind pressures are calculated per equations in building code

Velocity pressure (**q_z**) is site-specific based on wind speed

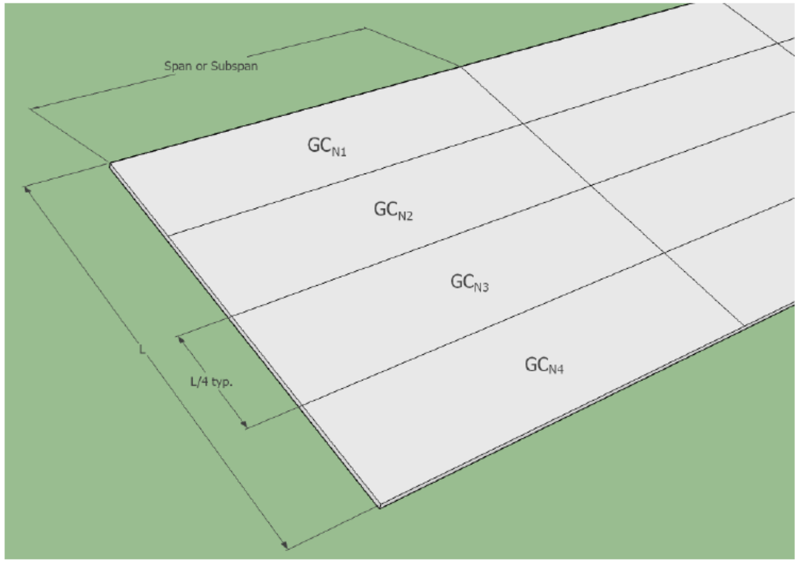
$$q_z = 0.00256 K_z K_{zt} K_e V^2 (\text{lb/ft}^2)$$

Force on panels and racking components are calculated by multiplying **q_z** by Gust Coefficient (GC) from the wind tunnel test

$$F = q_z K_d G C_f A_f \ (\text{lb})$$

Dynamic Amplifications Factors (DAFs) are used to account for stresses due to dynamic movement of the structure

Aeroelastic instability: torsional divergence and vortex lock-in, can cause system damage when the structure oscillates due to wind at unacceptable amplitudes



Segments of PV module in wind tunnel

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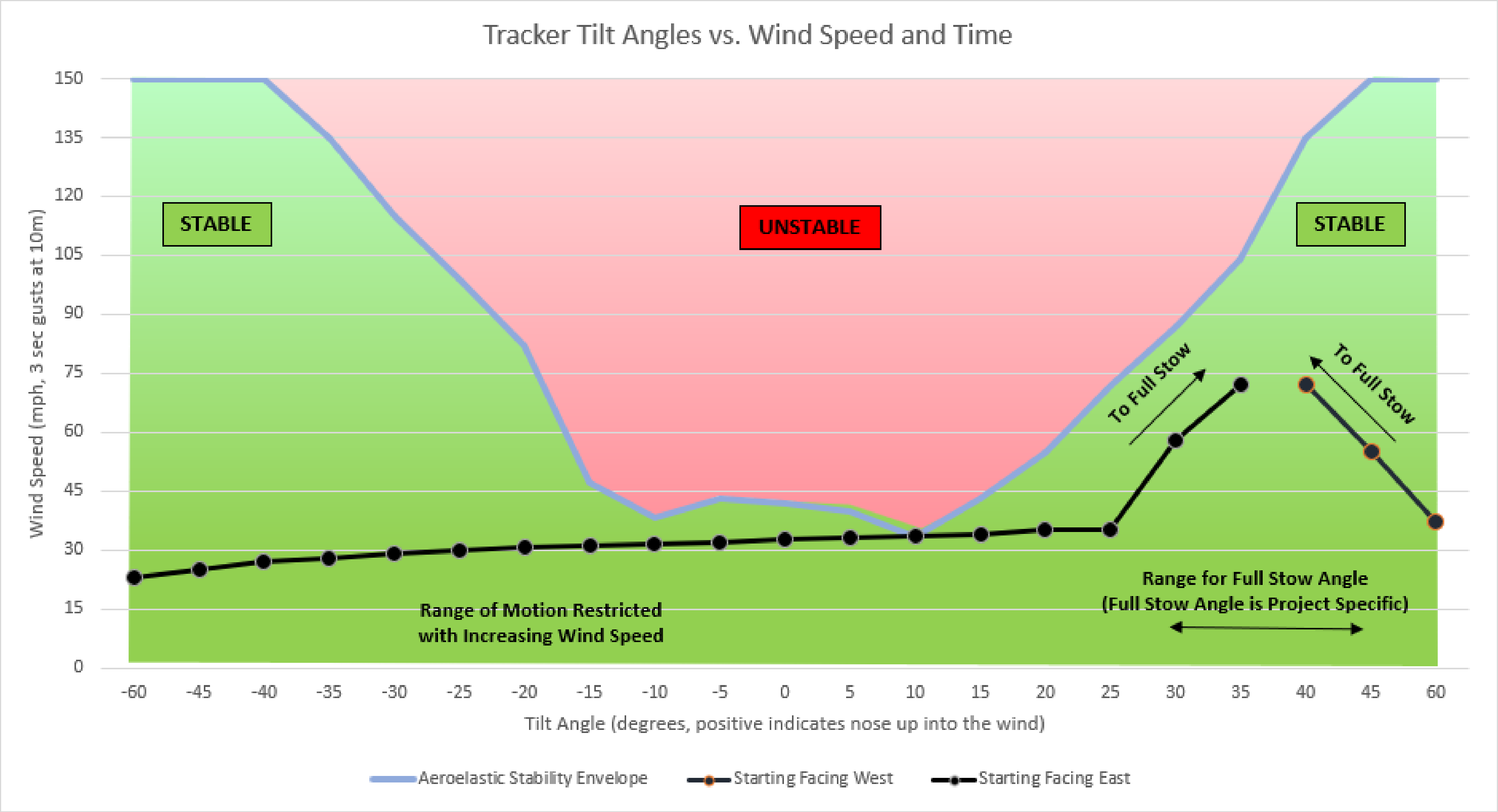
Calculating Wind Pressures | Aeroelastic Stability

Torsional Divergence is most likely at flat tilt angles



Calculating Wind Pressures | Load Combinations

Building codes account for both downforce and uplift wind directions

Load combinations from ASCE7:

1. D
2. $D + L$
3. $D + (L_r \text{ or } S \text{ or } R)$
4. $D + 0.75L + 0.75\,(L_r \text{ or } S \text{ or } R)$
5. $D + (0.6W)$
6. $D + 0.75L + 0.75\,(0.6W) + 0.75\,(L_r \text{ or } S \text{ or } R)$
7. $0.6D + 0.6W$

Where:
D = Dead Load (structure self-weight)
L = Snow Load
S = Snow Load
R = Rain Load
W = Wind Load

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4. $D + 0.75L + 0.75\ (L_r \text{ or } S \text{ or } R)$
5. $D + (0.6W)$ ← **Wind Down**
6. $D + 0.75L + 0.75\ (0.6W) + 0.75\ (L_r \text{ or } S \text{ or } R)$ ← **Wind Down + Snow**
7. $0.6D + 0.6W$ ← **Wind Up**

Where:
D = Dead Load (structure self-weight)
L = Snow Load
S = Snow Load
R = Rain Load
W = Wind Load

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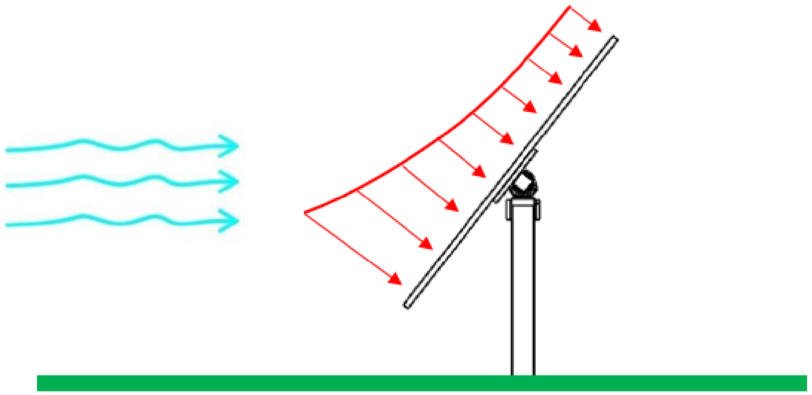
Designing for Directionality | Stow Approaches

Some tracker vendors turn tables towards oncoming wind, lowering calculated loading



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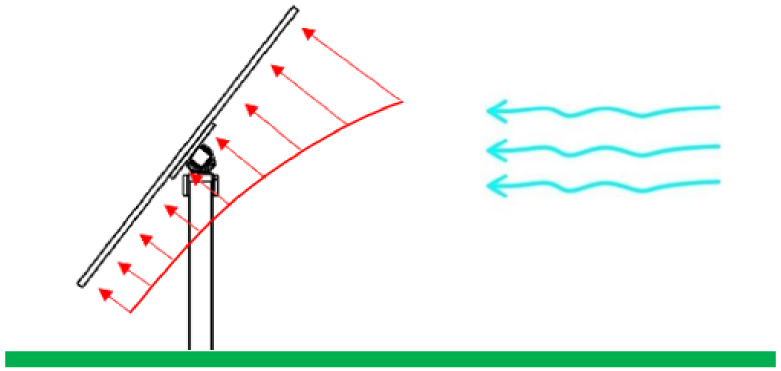
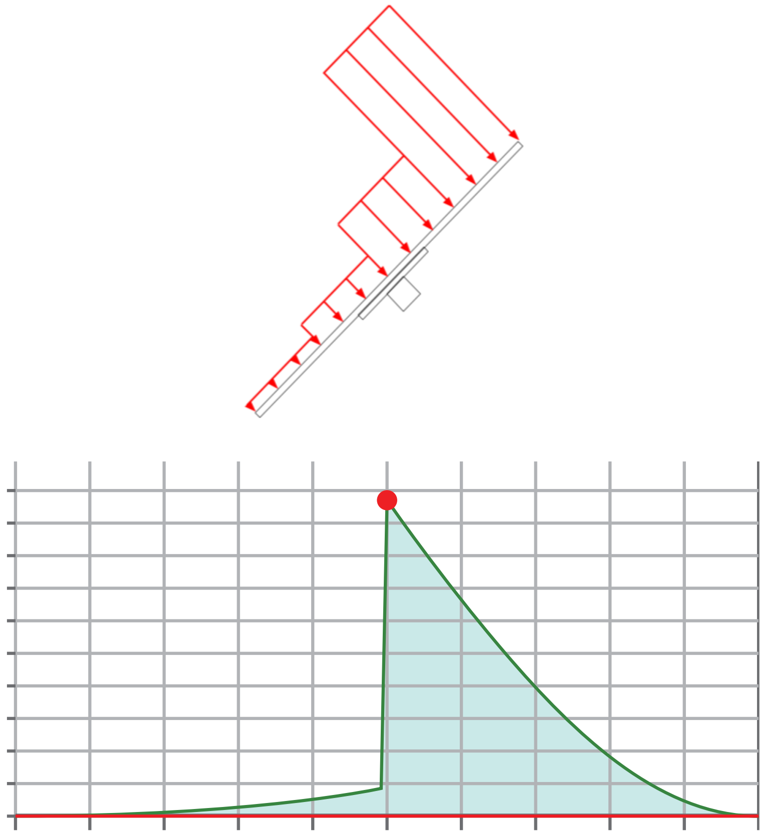


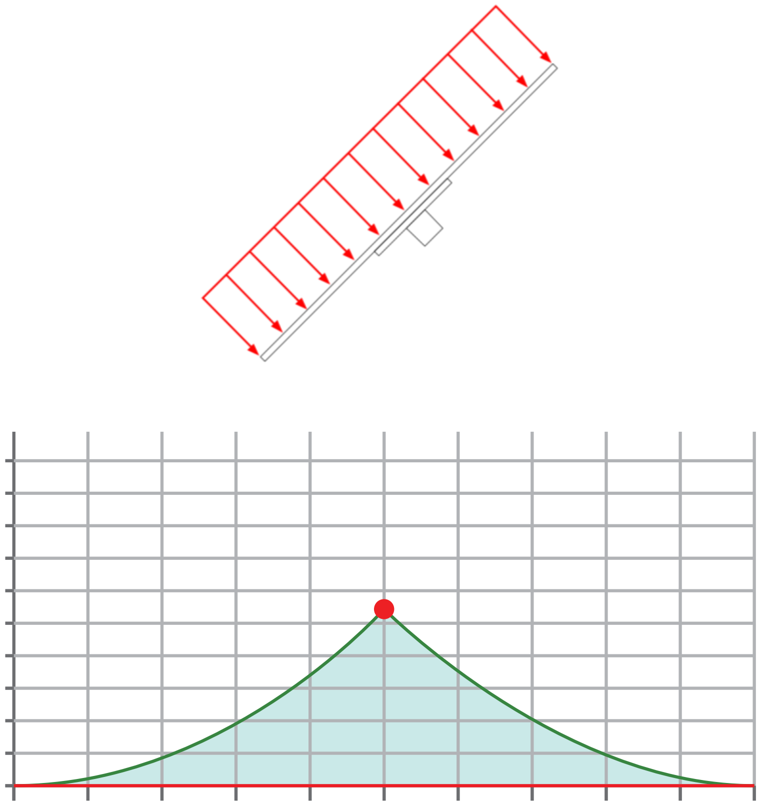
Calculating Wind Pressures | Unbalanced Loading

Averaging wind pressure artificially lowers the maximum load accounted for in the design

*Rail bending from **quadrant** pressure*



*Rail bending from **average** pressure*



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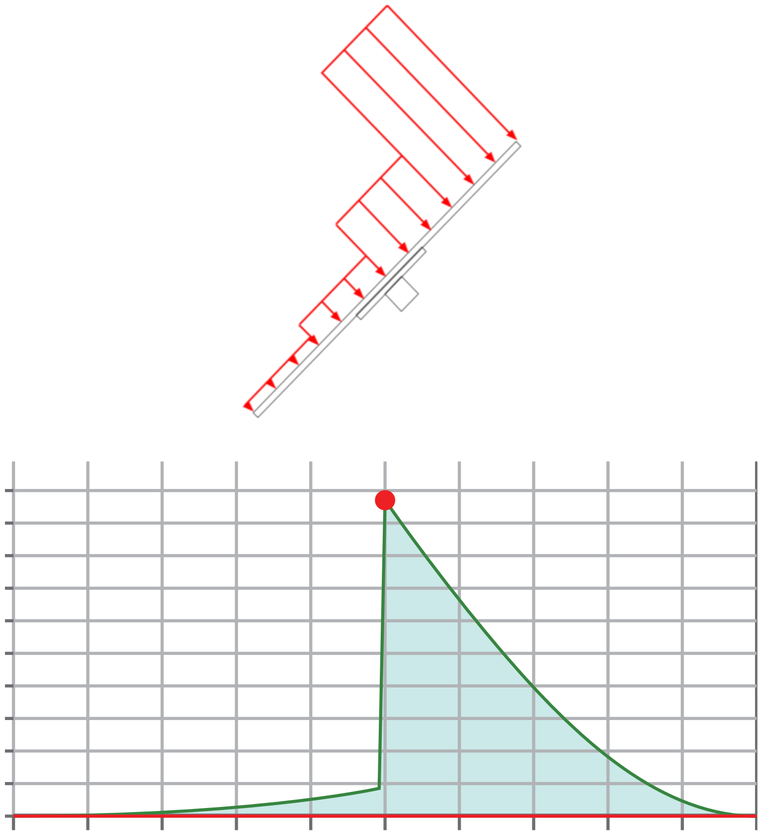

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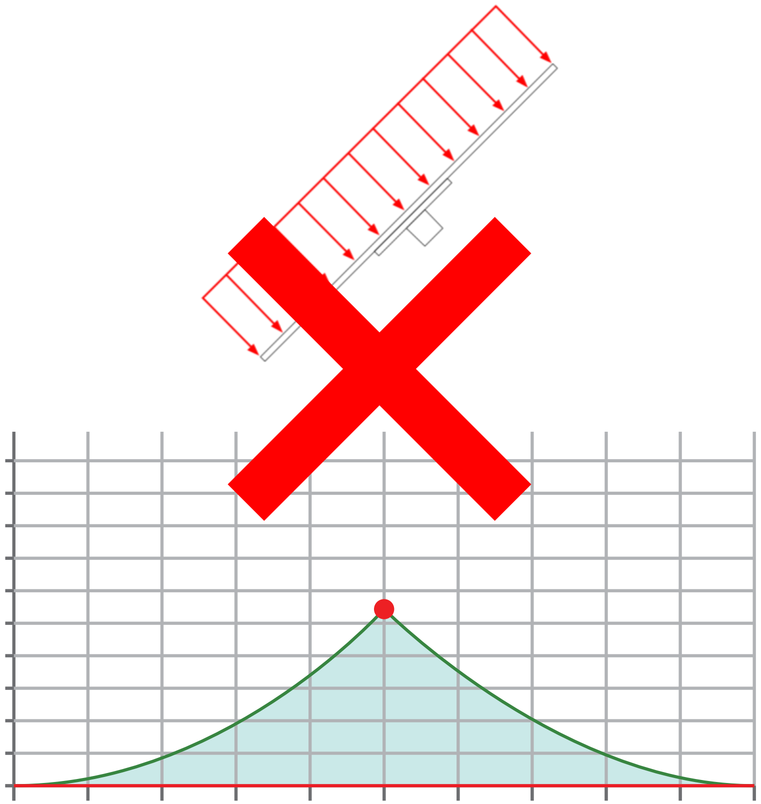

Mechanical Load Testing

Unbalanced testing more accurately reflects real-world loading of modules on a tracker

Failure modes:

- Glass cracking
- Glass to module frame connection failure
- Module frame shear
- Bolt pry out through module frame bottom flange
- Fatigue failure
- Stress concentration in glass at junction box
- Racking mounting rail (purlin or speedclamp) failure

Loading on modules to match pressure gradient

Mechanical Load Testing

Unbalanced testing more accurately reflects real-world loading of modules on a tracker

Failure modes:

Independent of Rack

- Glass cracking
- Glass to module frame connection failure
- Module frame shear
- Bolt pry out through module frame bottom flange
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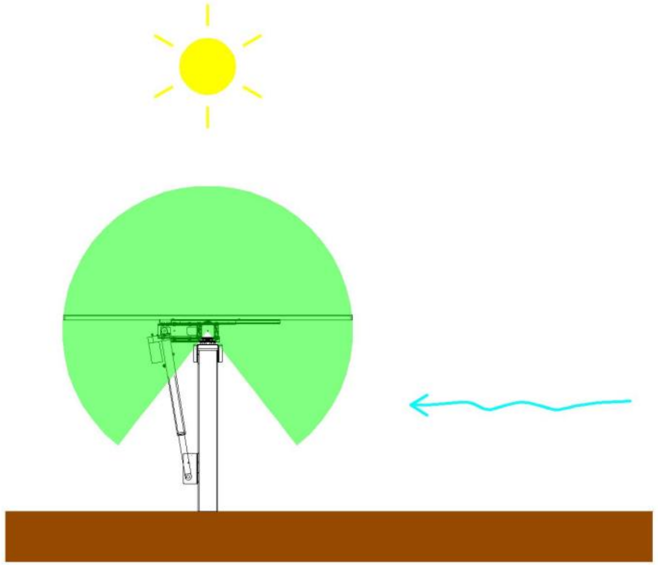
Loading on modules to match pressure gradient

Stow Options | Binary vs. Progressive

Taking a nuanced approach to wind stow can help solar modules generate more energy

Progressive Stow:

Multiple trigger windspeeds are used to gradually close off allowable tracker range.



SmartStow™ Trigger Wind Speeds	
Trigger Wind Speed 3s Gust 10m Above Grade	Rotational Range at Wind Speed
0 mph	Full East to Full West
27 mph	35 East to Full West
28 mph	30 East to Full West
29 mph	20 East to Full West
30 mph	10 East to Full West
31 mph	Flat to Full West
32 mph	10 West to Full West
33 mph	20 West to Full West
34 mph	25 West to Full West
36 mph	30 West to Full West
45 mph	35 West to 45 West
72 mph	Full Stow

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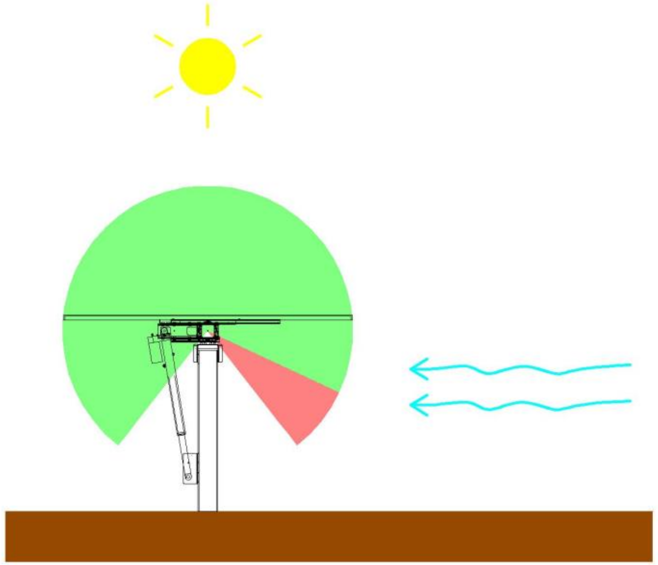

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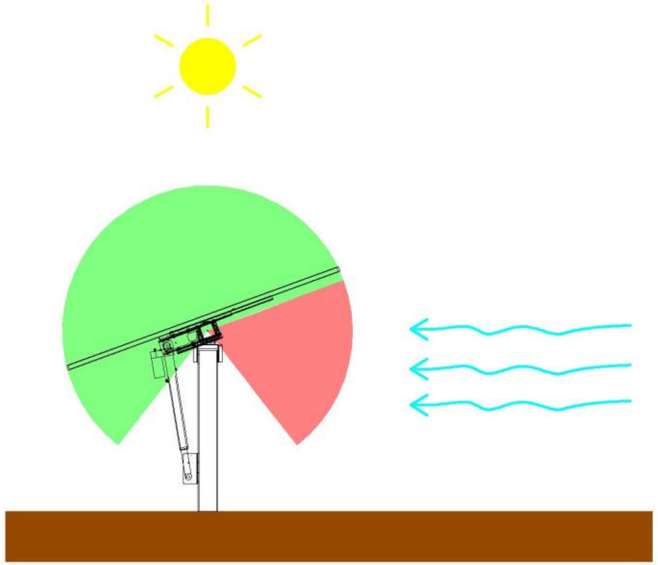

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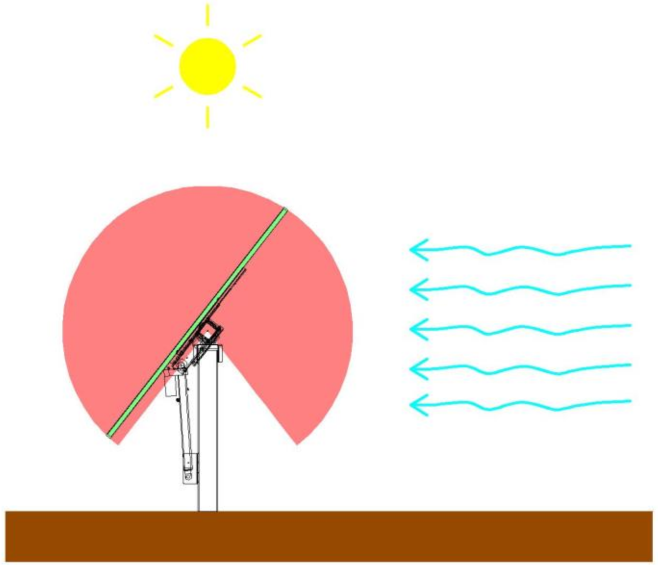

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34 mph	25 West to Full West
36 mph	30 West to Full West
45 mph	35 West to 45 West
72 mph	Full Stow

Wind Mitigation | Summary

Best practices for designing single axis trackers:

1. Account for real-world wind direction
2. Select tracker OEM which accounts for potential for wind uplift
3. Test modules based on wind gradient with unbalanced load
4. Implement progressive wind stow to maximize energy production

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Extreme Weather Mitigation

Hail

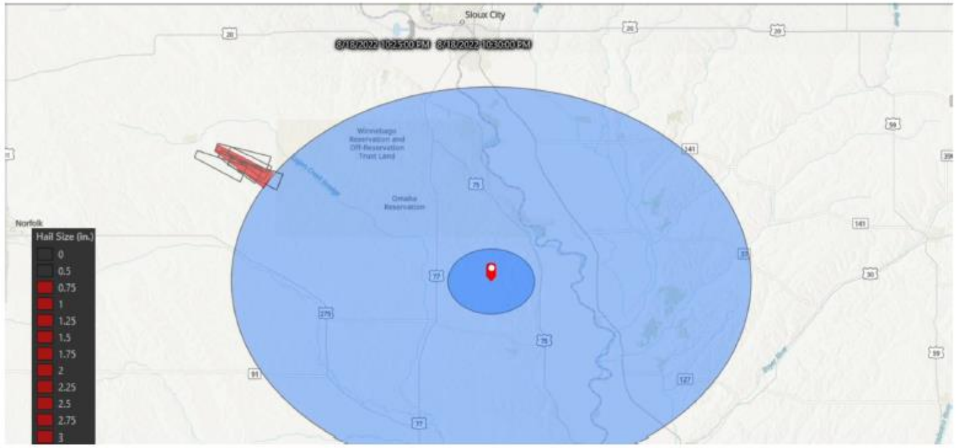
Methods of Detection

Each hail detection method offers differing benefits

On-site Sensor

- **Does not allow time to go to stow**
- **Ground truth**

Weather Forecasting



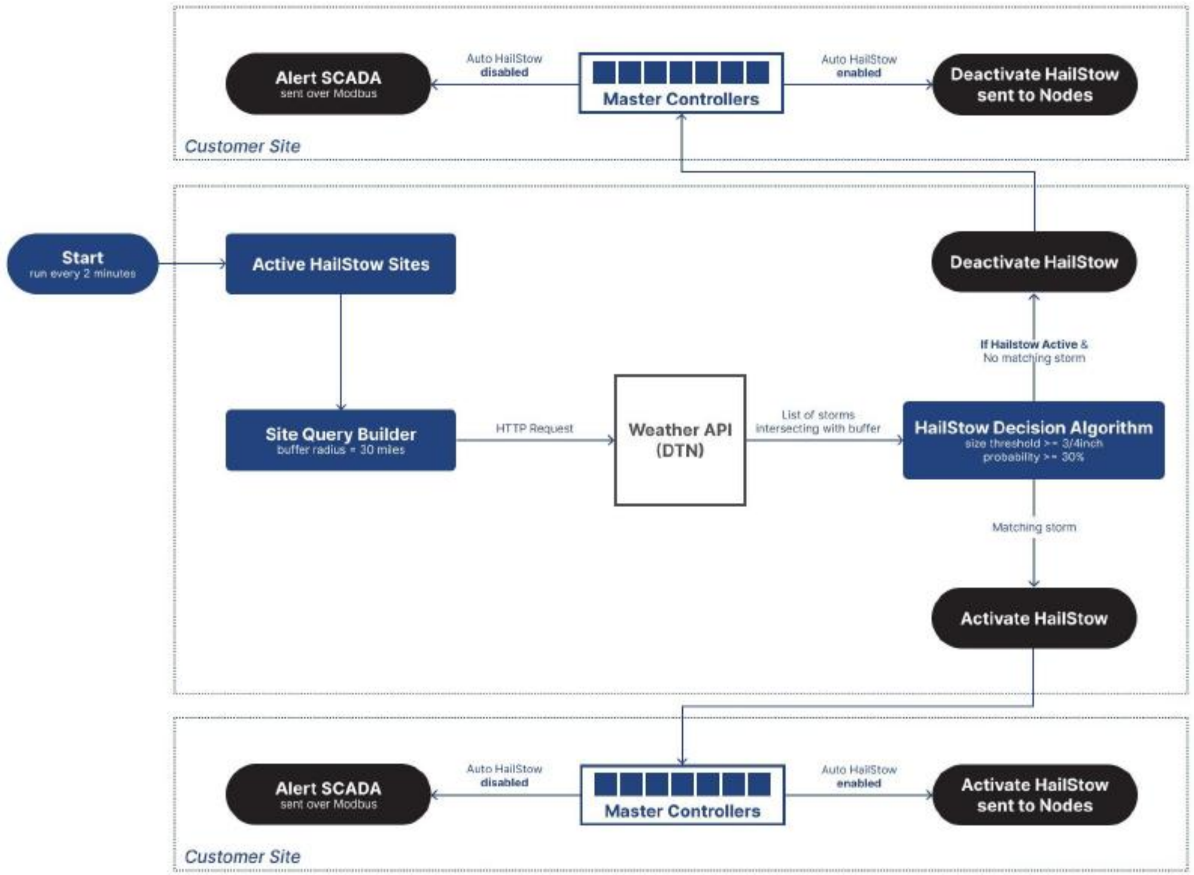
- **Allows for time to go to stow**
- **Prediction**

HailStow™ Process

For NERC Compliant sites, semi-autonomous HailStow protects the tracker system and panels in case of a hailstorm in a preventative manner
Using a hail API provider, HailStow notifies the customer SCADA if the site is in the path of an incoming hailstorm

Requirements:

- SCADA to provide VPN to access to the MCU on the local site network to send automated hail stow
- SCADA provider must build out the ability to read active HailStow active status and set hail stow through the Modbus registers
- SCADA must verify the read/write functionality of HailStow through the SCADA HMI
- SCADA must verify they receive alerts from the static IP of HailStow
- Weather API event logs
- HailStow flags in the modbus



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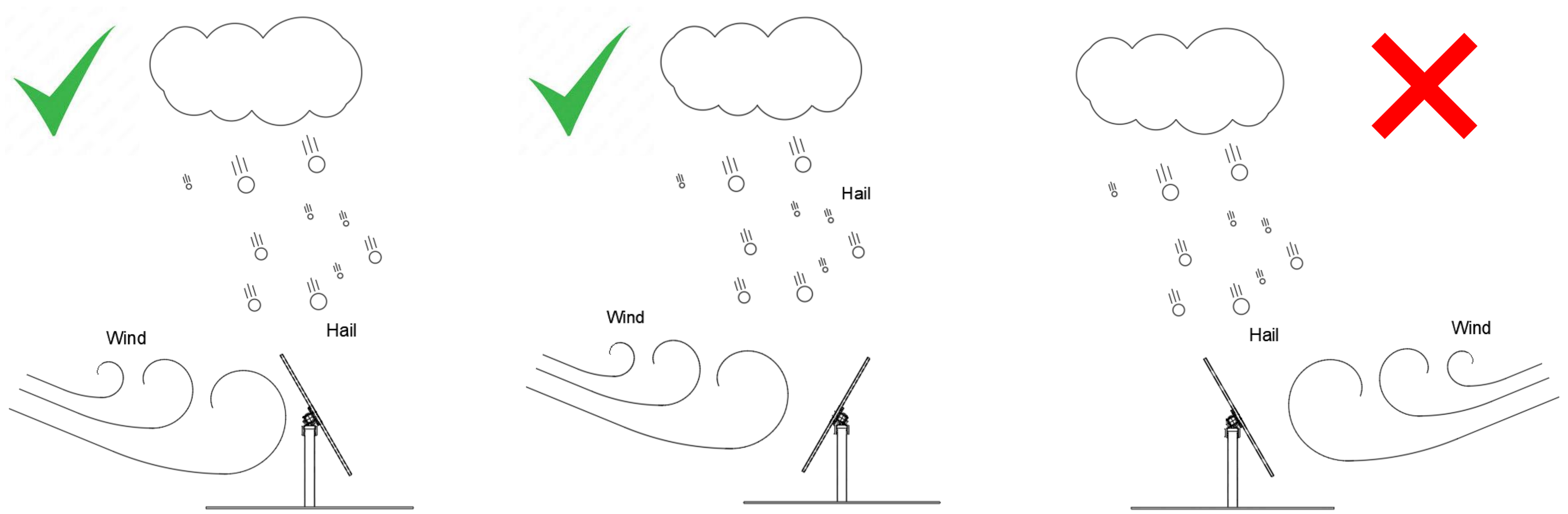
Hail & Wind Stow Considerations

It is not advisable to stow away from hail and nose down into wind simultaneously

Differing orientations for hail and wind can cause conflicting priorities for tracker systems



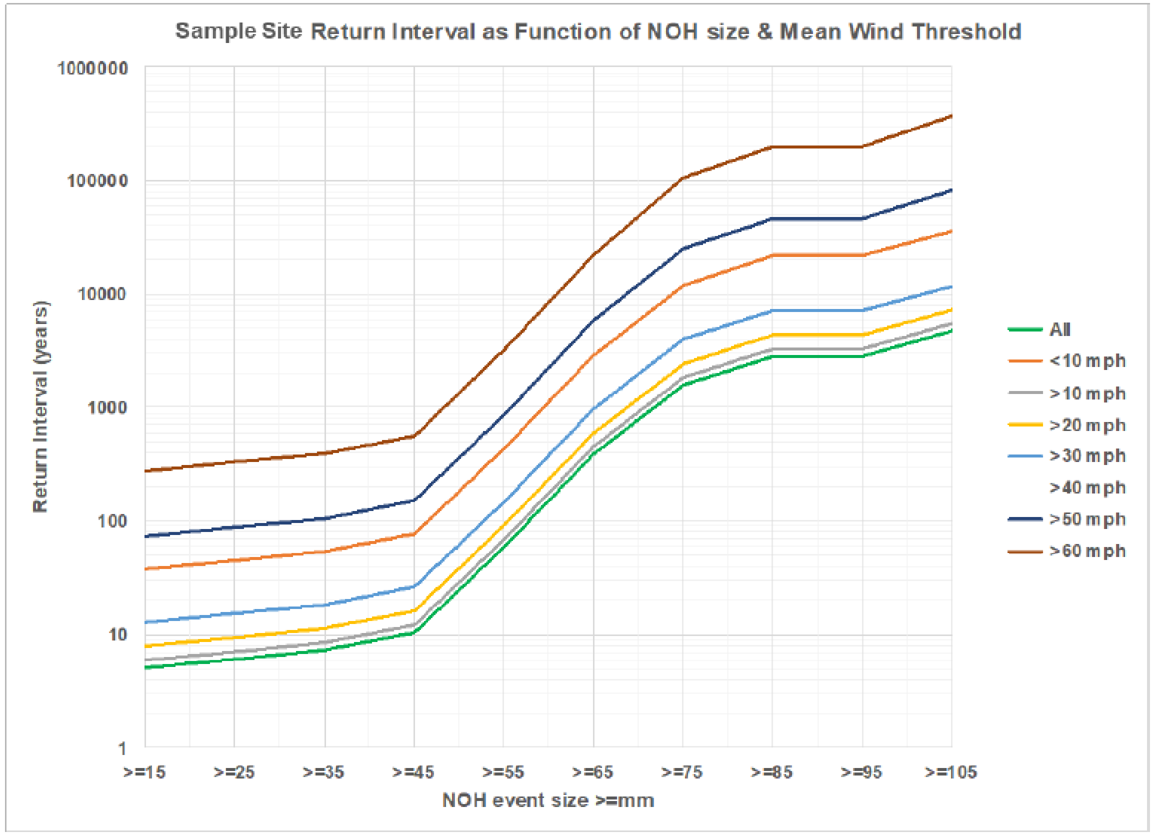
Wind	Nose Up	Nose Down	Nose Down
Hail	Nose Up	Nose Down	Nose UP

Lowering Hail Damage on Modules

Turning to a steep stow angle helps lower the potential damage from hail

Best Practices:

- Do not stow flat: When modules are flat, they absorb 100% of impact energy from hail vertically falling hail
- Assume wind will occur at the same time as hail
- Turning modules away from hail is optimal however:
  - Wind changes direction
  - Not all trackers are designed for uplift wind loads
  - Tracker may stow nose down into wind at start of weather event (cannot move through flat due to aeroelastic instability)



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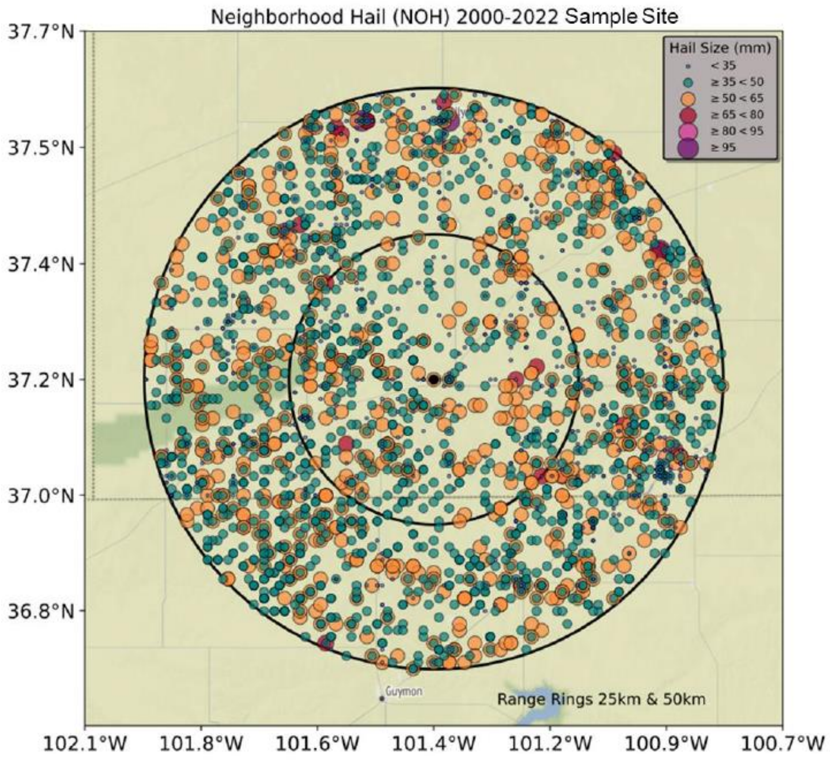
Financial Modeling & Analysis

Generation of economic models based on historical hail data can provide quantifiable impacts to owners and insurers

- Site-specific economic analysis based on module and tracker system used
- Quantitatively demonstrates benefits of a robust hail stow procedure
- Can lower Average Annual Loss (AAL) and Probable Maximum Loss (PML) by over 98%

VDE suggests, out of caution, using the “Facing into the Wind” PML and AAL values



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Hail Mitigation | Summary

Best practices for designing single axis tracks:

1. Use weather forecast services to ensure trackers have time to turn to a safer angle before impact of hail event
2. Turn to steep angles to reduce impact energy of hailstones
3. Plan for varying wind and hail directions during concurrent events
4. Accurately model hail risk for owners and insurers

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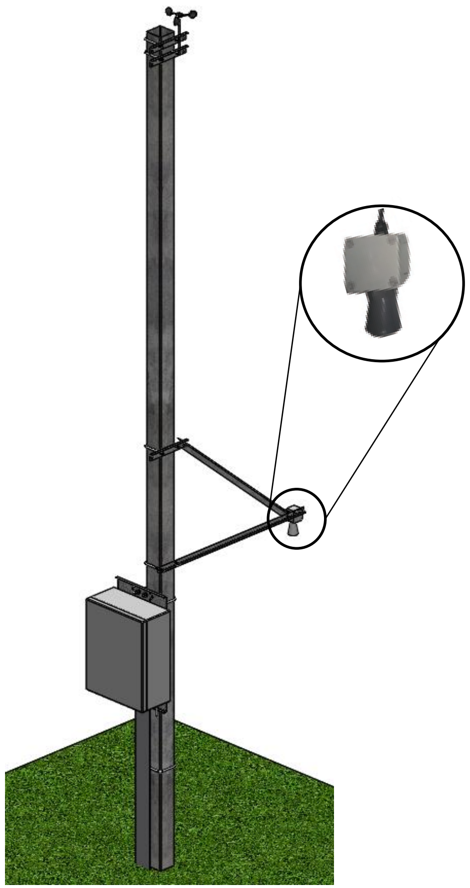
Extreme Weather Mitigation

Flood

Detection of Flood vs. Snow

Splitting flood and snow strategies allows for optimized design and system safety

- Ultrasonic sensor used to measure distance from center to ground
- Snow or flood event will cause effective ground elevation to increase triggering sensor
- Temperature sensors can be used to delineate between flood and snow triggers of the depth sensor
- Send tables to shallow angle for flood stow for warm temperatures
- Send tables to steep angle for snow stow for freezing temperatures



Minimum Freeboard

Freeboard = clearance from electronic device to surface of flood waters

- ASCE24 requires 12” [305mm] freeboard
- Project freeboard may be driven by owner requirements

Table 2-1 Minimum Elevation of the Top of Lowest Floor—Flood Hazard Areas Other Than Coastal High Hazard Areas,[a] Coastal A Zones,[a] and High Risk Flood Hazard Areas[a]

Flood Design Class[b]	Minimum Elevation, Relative to Base Flood Elevation (BFE) or Design Flood Elevation (DFE)
1[c]	DFE
2[d]	BFE + 1 ft or DFE, whichever is higher
3[d]	BFE + 1 ft or DFE, whichever is higher
4[d]	BFE + 2 ft or DFE, or 500-year flood elevation, whichever is higher

[a] Minimum elevations shown in Table 2-1 do not apply to Coastal High Hazard Areas and Coastal A Zones (see Table 4-1). Minimum elevations shown in Table 2-1 apply to other high risk flood hazard areas unless specific elevation requirements are given in Chapter 3 of this standard.
[b] See Table 1-1 for Flood Design Class descriptions.
[c] Flood Design Class 1 structures shall be allowed below the minimum elevation if the structure meets the wet floodproofing requirements of Section 6.3.
[d] For nonresidential buildings and nonresidential portions of mixed-use buildings, the lowest floor shall be allowed below the minimum elevation if the structure meets the dry floodproofing requirements of Section 6.2.

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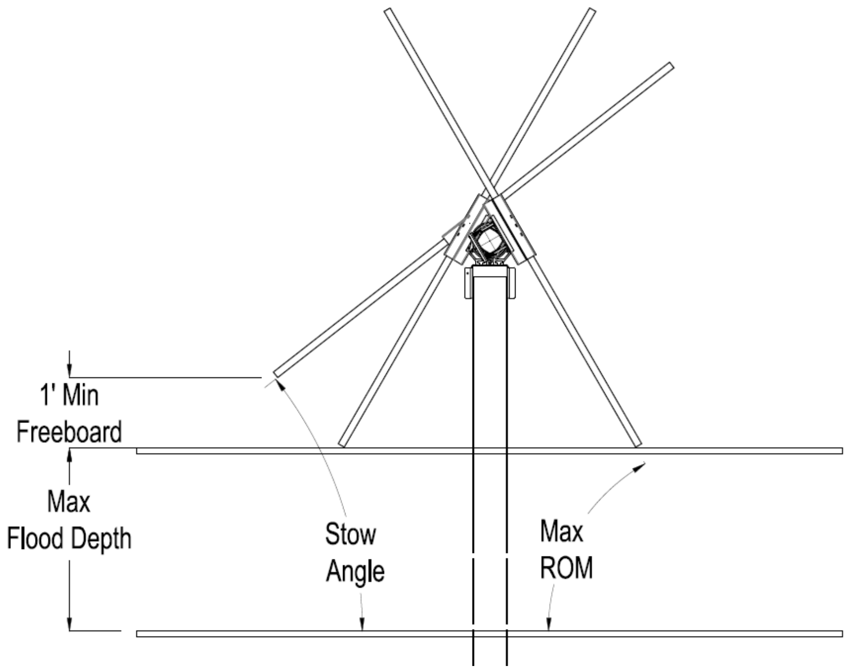
Designing for Flood & Wind

Wind loading must still be considered when implementing flood stow

- Tables can only be flat if they maintain aeroelastic stability
- Stowing flat for flooding severely increases risk of aeroelastic instability even in moderate winds
- Tilt angles > 30 degrees minimize instability risk
- Max Flood Load and Max Wind Load do not need to be considered concurrently (per ASCE7):

$$0.9D + 0.5W + 1.0F_a$$



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Extreme Weather Mitigation

Snow

Designing for Snow & Wind

Stow at high tilt angles allow snow to slide off modules

- Snow slides off modules at steep angles without need for manual process
- Reduced snow load accounted for in system design
- For high snow load sites there will still be some snow on the modules. Must account for downforce wind and the downward oriented snow load
- Put system back in operation after snow load is reduced

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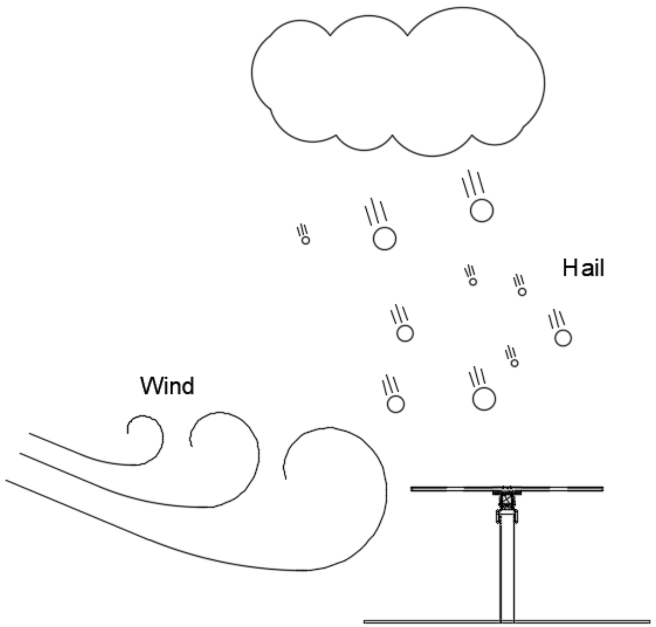
Construction

Designing for Directionality | Construction

Tracker design must account for the project's construction phase to mitigate risk when the trackers are built, but not yet tracking

- EPC's have interest in leaving tables flat during install
  - Easy install of modules
  - Easy access to install wire management
- Falling hail imparts greatest impact energy on flat modules
- Tables which are not designed to maintain aeroelastic stability when flat will go unstable
- Tables kept at stow during install must still be designed for wind from either direction



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Conclusion

Key Takeaways

Accounting for Wind Direction is critical for ensuring the longevity of the solar power plant

- Assuming the tracker can always stow nose down into the wind is not appropriate for:
  - Hurricane prone sites
  - Downbursts from thunderstorms
- Uplift wind loads on the tracker and modules should be considered in the design
- Trackers cannot simultaneously stow nose down into the wind and nose up into the hail
- Risk of hail damage can be minimized by using systems that stow at a high tilt
- Aeroelastic Stability should be considered for shallow flood tilts
- Wind downforce adding to snow loads should be considered for snow events
- Uncommissioned trackers should be in stow when not being actively worked on during construction

Stow Options | Wind Direction

Omni-directional stow is the only strategy that accounts for all extreme weather conditions and combinations

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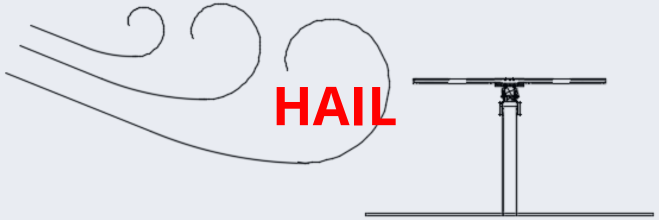
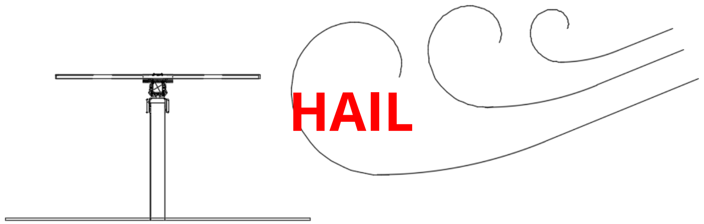
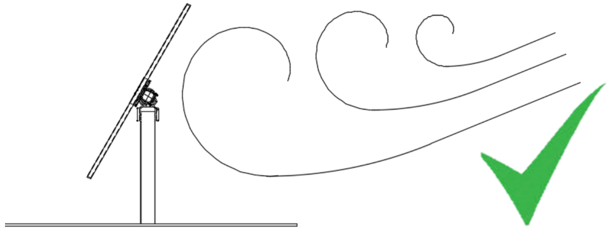
	Nose Down Into Wind	Flat	Omni-directional Wind
Wind from West			
Wind from East			

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Q&A

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