CERMAK
PETERKA
PETERSEN

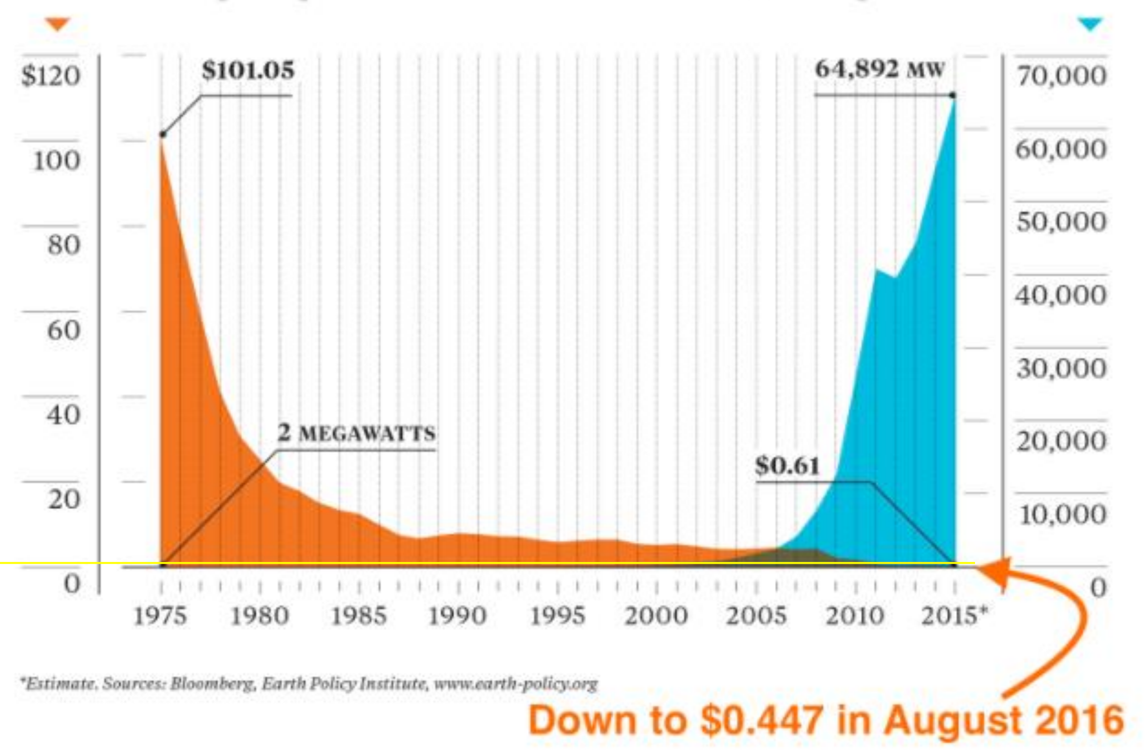
Wind Loads on Solar Racking

David Banks

Solar Energy is

- cheap(est?)
- fastest growing

Parity with fossil fuels
at 50-90 cents per Watt.



*Estimate. Sources: Bloomberg, Earth Policy Institute, www.earth-policy.org

Down to $0.447 in August 2016

Solar Energy is

- the cheapest
- the fastest-growing
- the most popular

43 per cent of Australians expected solar to be "our primary source of electricity 10 years from now.” (2015 Lowry)

US adults who favour or oppose expanding Solar

Wind loads are critical

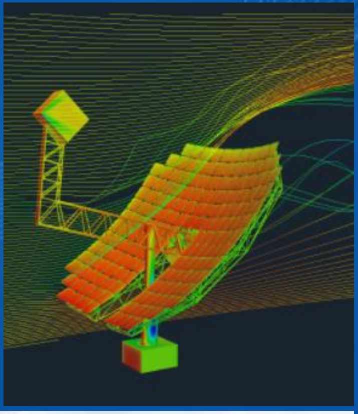
Failures

'It is in shambles': St. Thomas solar farm destroyed by Irma

A s Play arm in St. Thomas was destroyed by Hurricane Irma last week.
Reporter: Ken Smith
Photographer: Richard Adkins
Web editor: Janine Bowen
2:37 p.m., Sep 16, 2017

Oil train wreck in Quebec.

Ad hoc testing NDA




© 2009 GeoBasis-DE/BKG
© 2018 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
US Dept of State Geographer
Google Earth

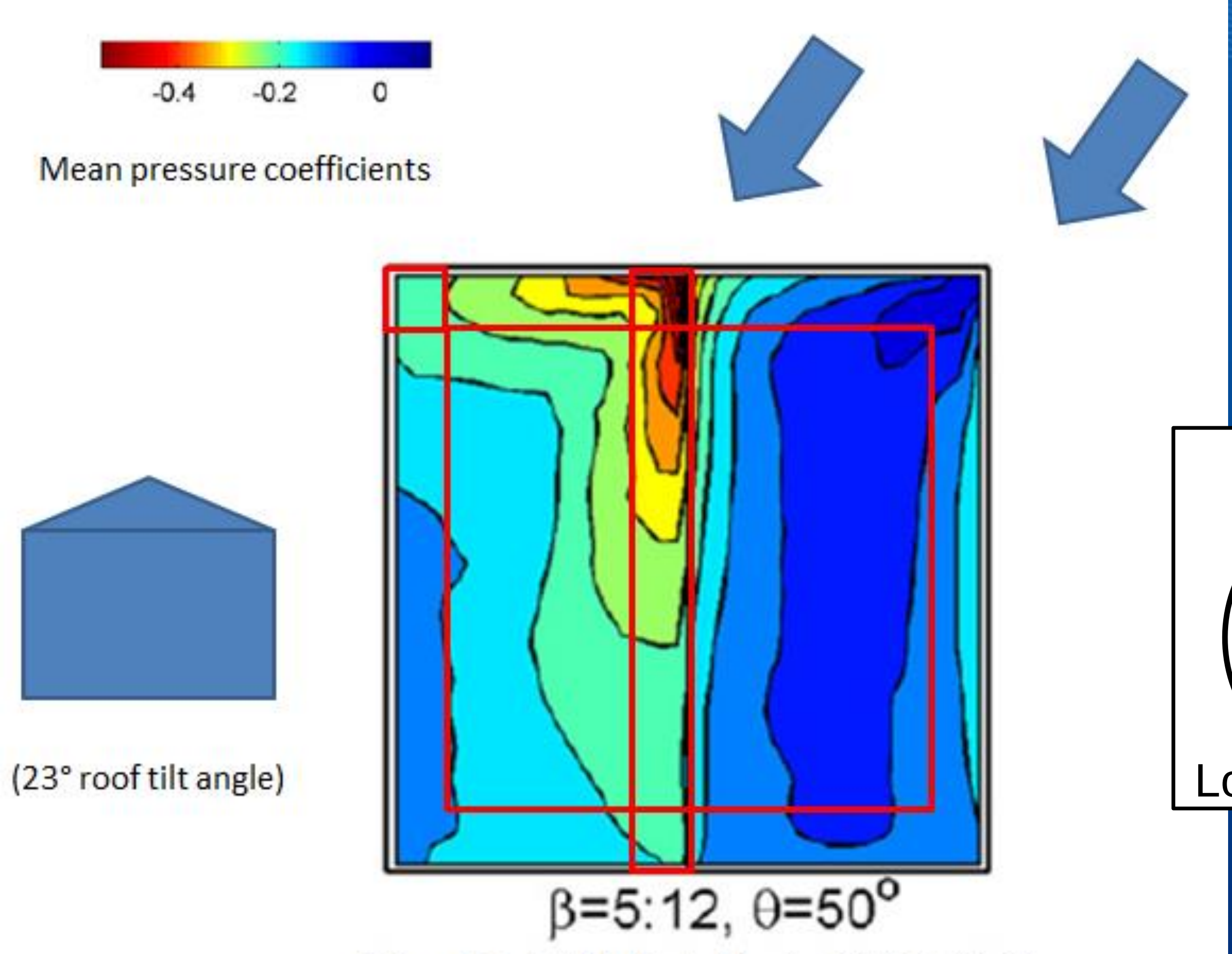
Why does Solar need wind engineers?

- So the best designs win

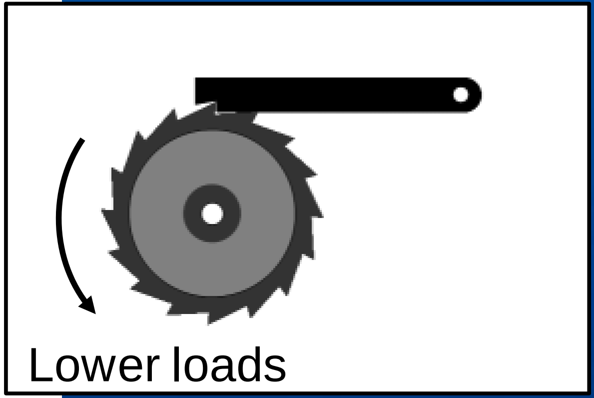
What have we learned?

- Residential roof mounts
  - Equalizing
  - Roof zones…

Code isn't perfect, but followed slavishly.

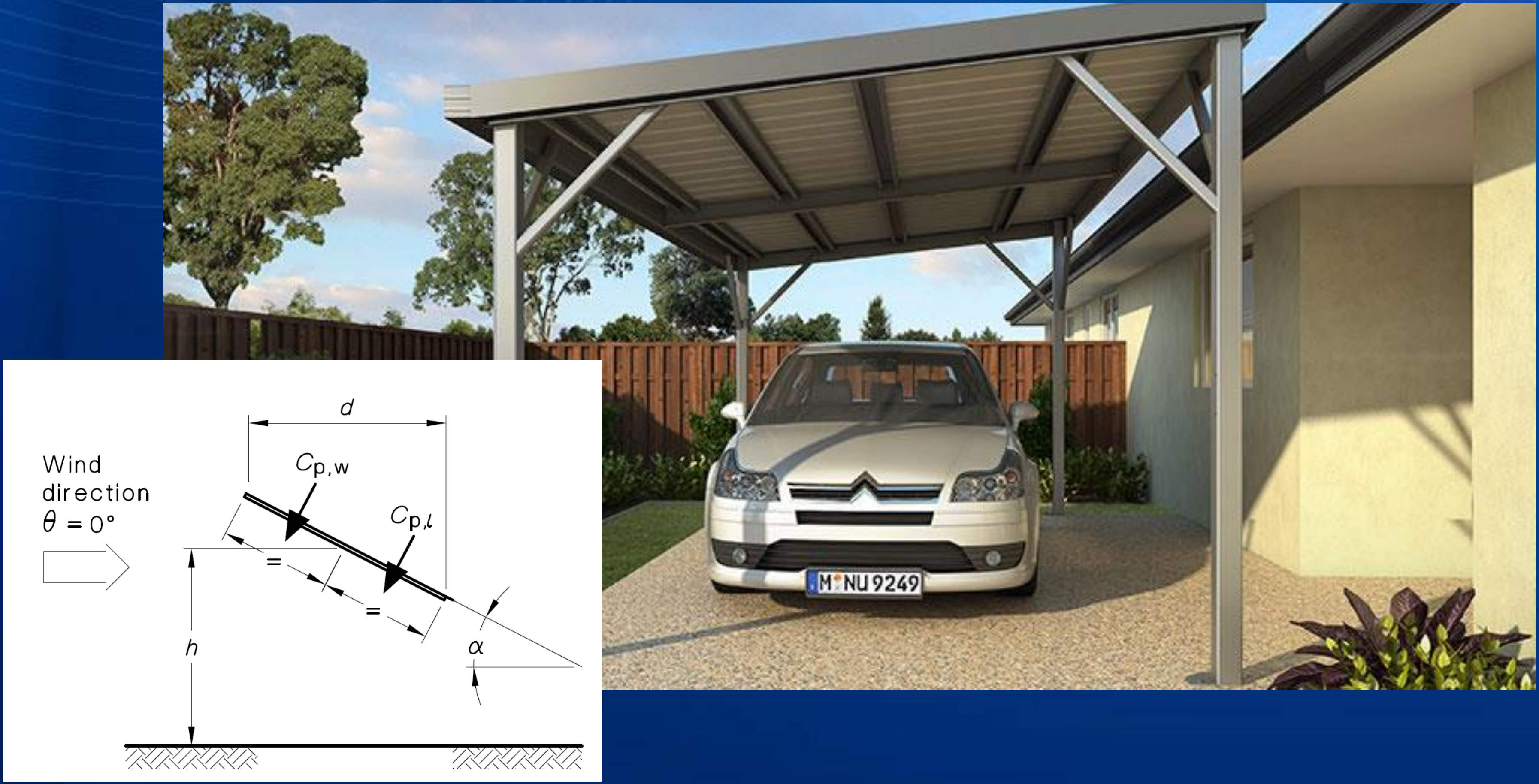


E. Gavanski et al. / J. Wind Eng. Ind. Aerodyn. 114 (2013) 106–121



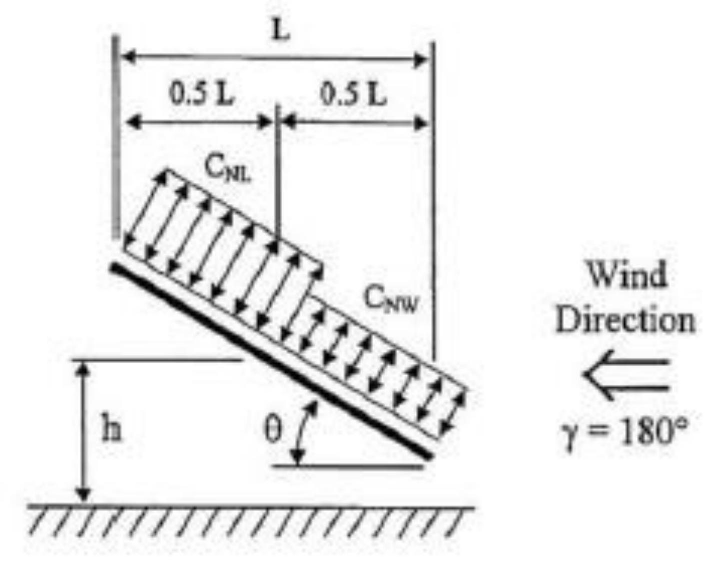
What have we learned?

- Carport



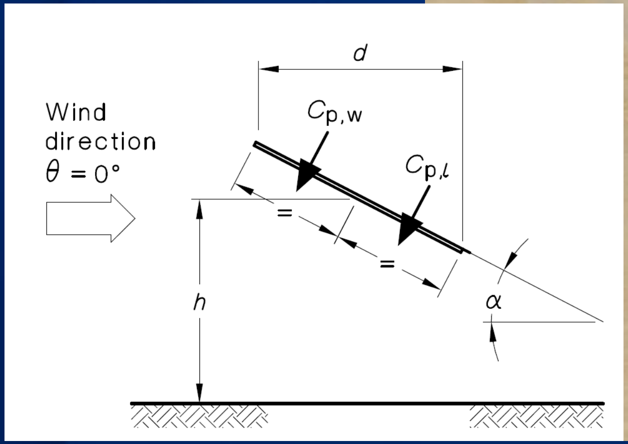
What have we learned?

- Carport
  - Aspect ratio
  - Multi-row
  - structure



What have we learned?

- Fixed tilt
  - Gaps

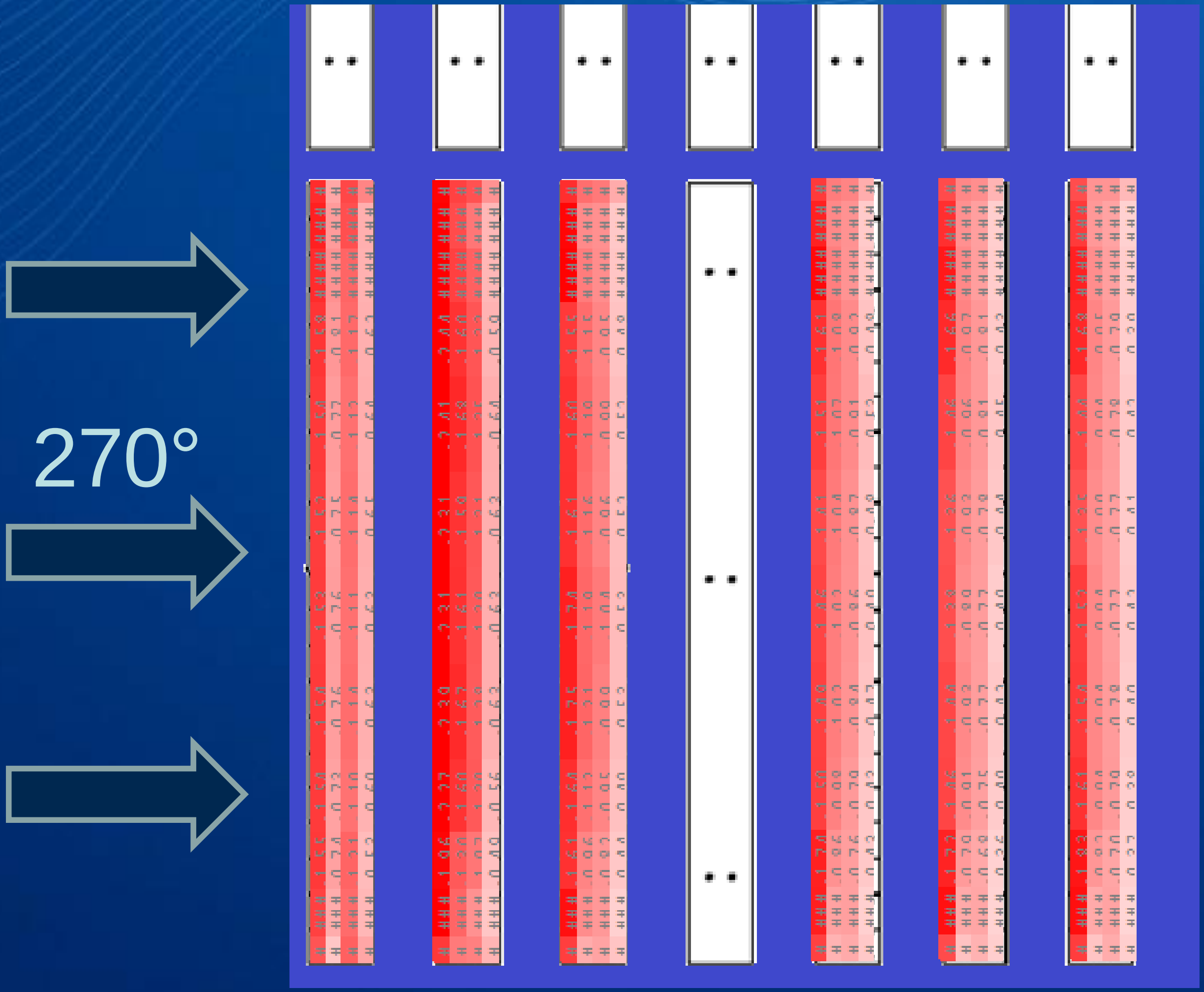


What have we learned?

- Fixed tilt
  - Gaps
  - Cantilever

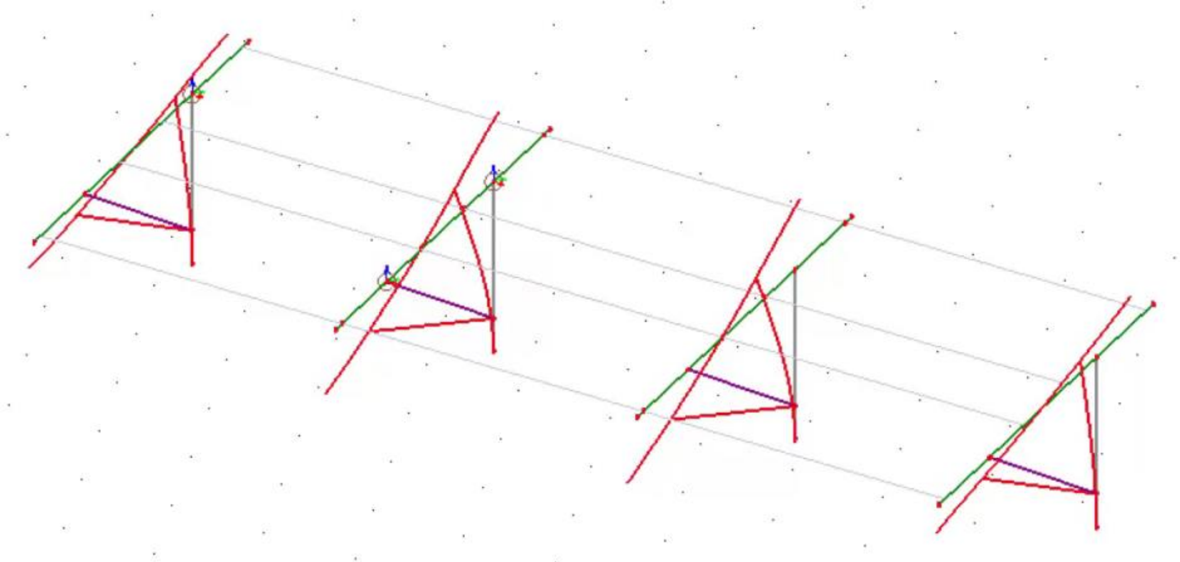
What have we learned?

- Fixed tilt
  - Gaps
  - Cantilever
  - Second row



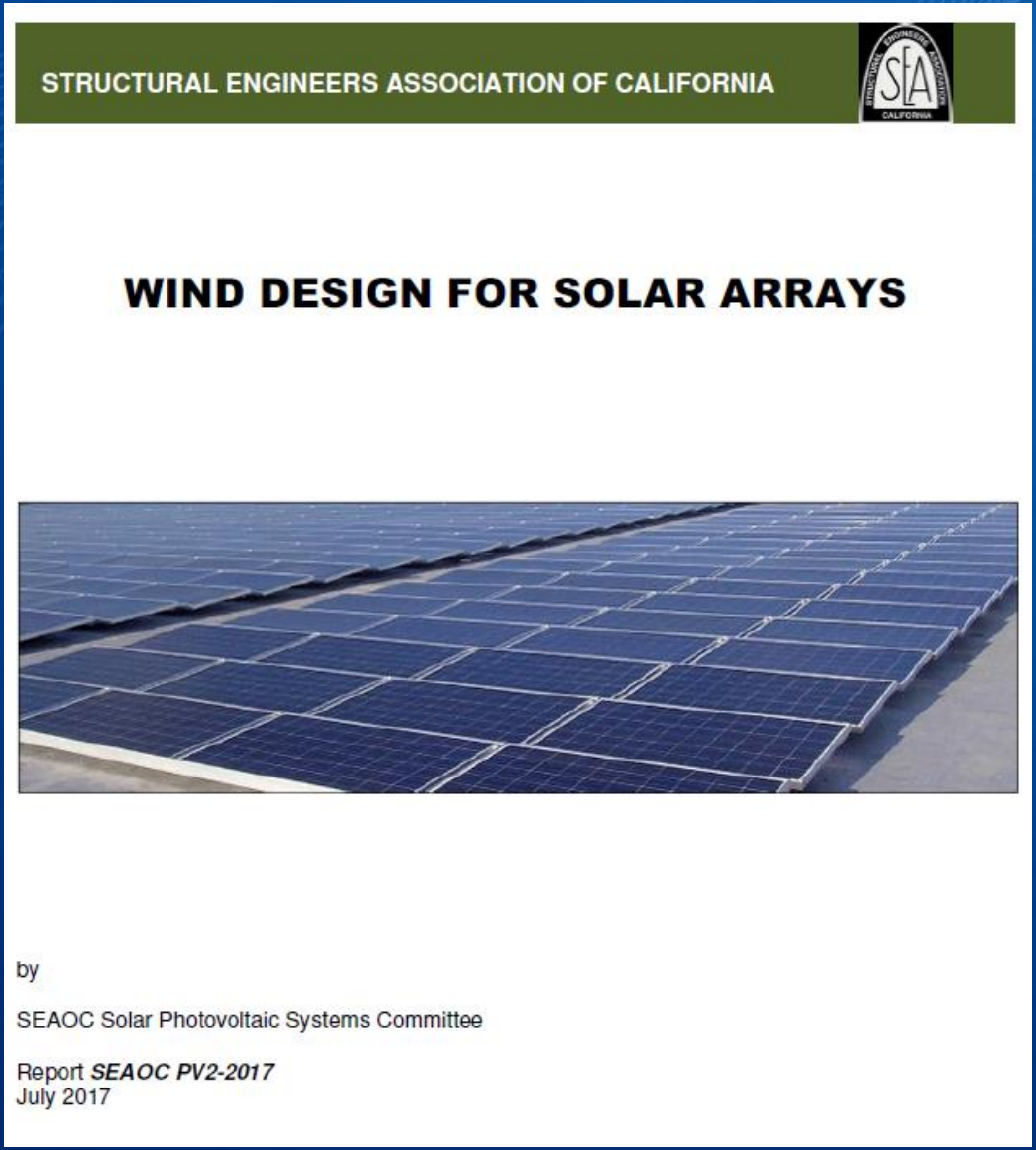
What have we learned?

- Fixed tilt
    - Gaps
    - Cantilever
    - Second row
    - Dynamics



What have we learned?

- Roof Mounts
  - how to test



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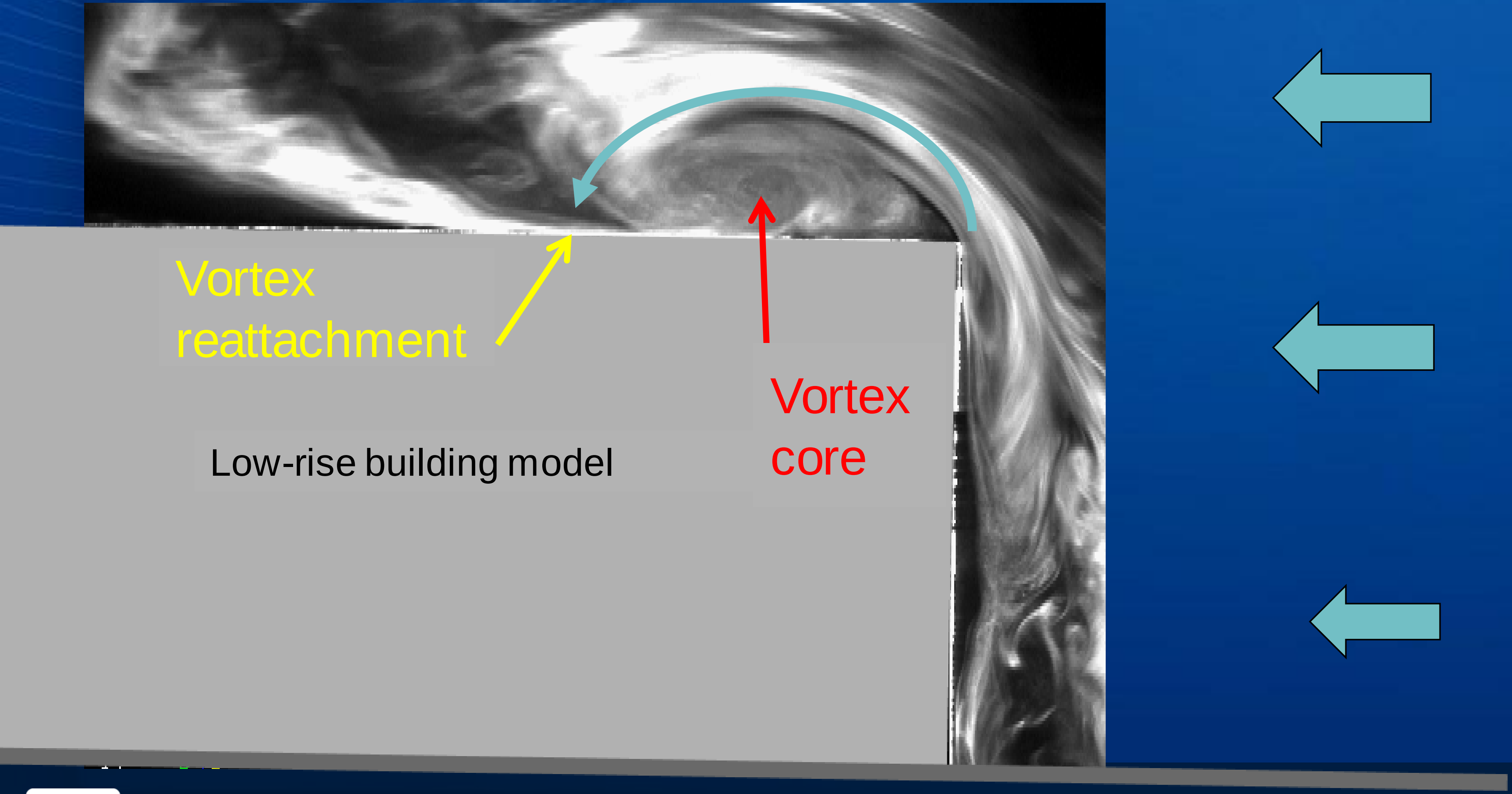
WIND DESIGN FOR SOLAR ARRAYS

by

SEAOC Solar Photovoltaic Systems Committee

Report ***SEAOC PV2-2017***
July 2017

We know a lot about these vortices



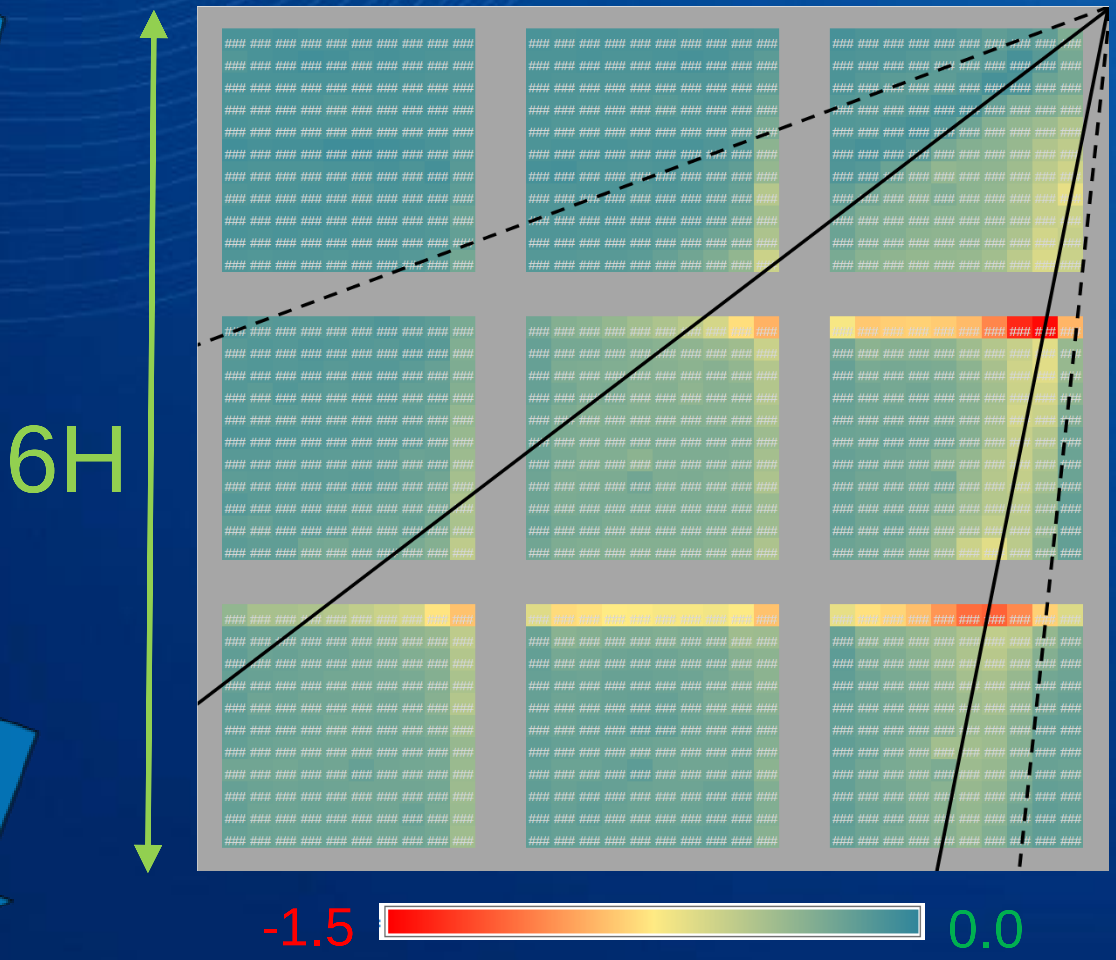
Wind tunnel test

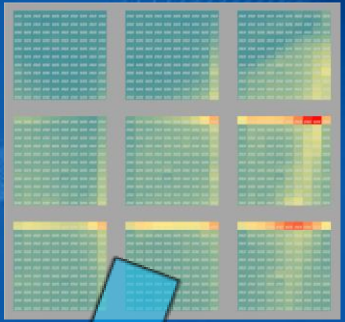
- 1:50 scale
- H = 10 m tall
- W = 60 m wide
- 9 positions
  - One at a time
- 1 m parapet
- 10 x 10 array
- Single tilt

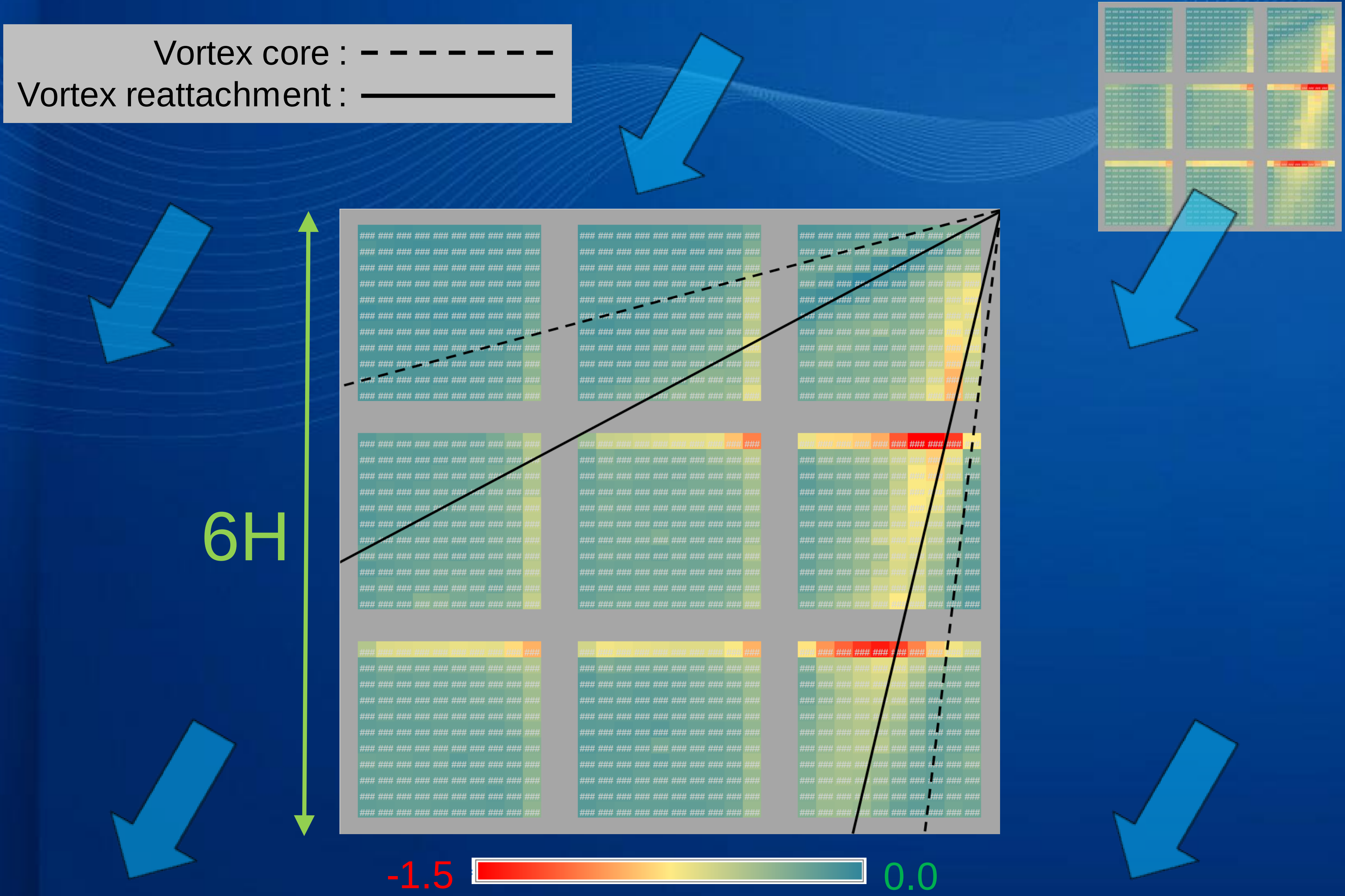
Lift Coefficients 20°

Vortex core : - - - - - - - -

Vortex reattachment : ————



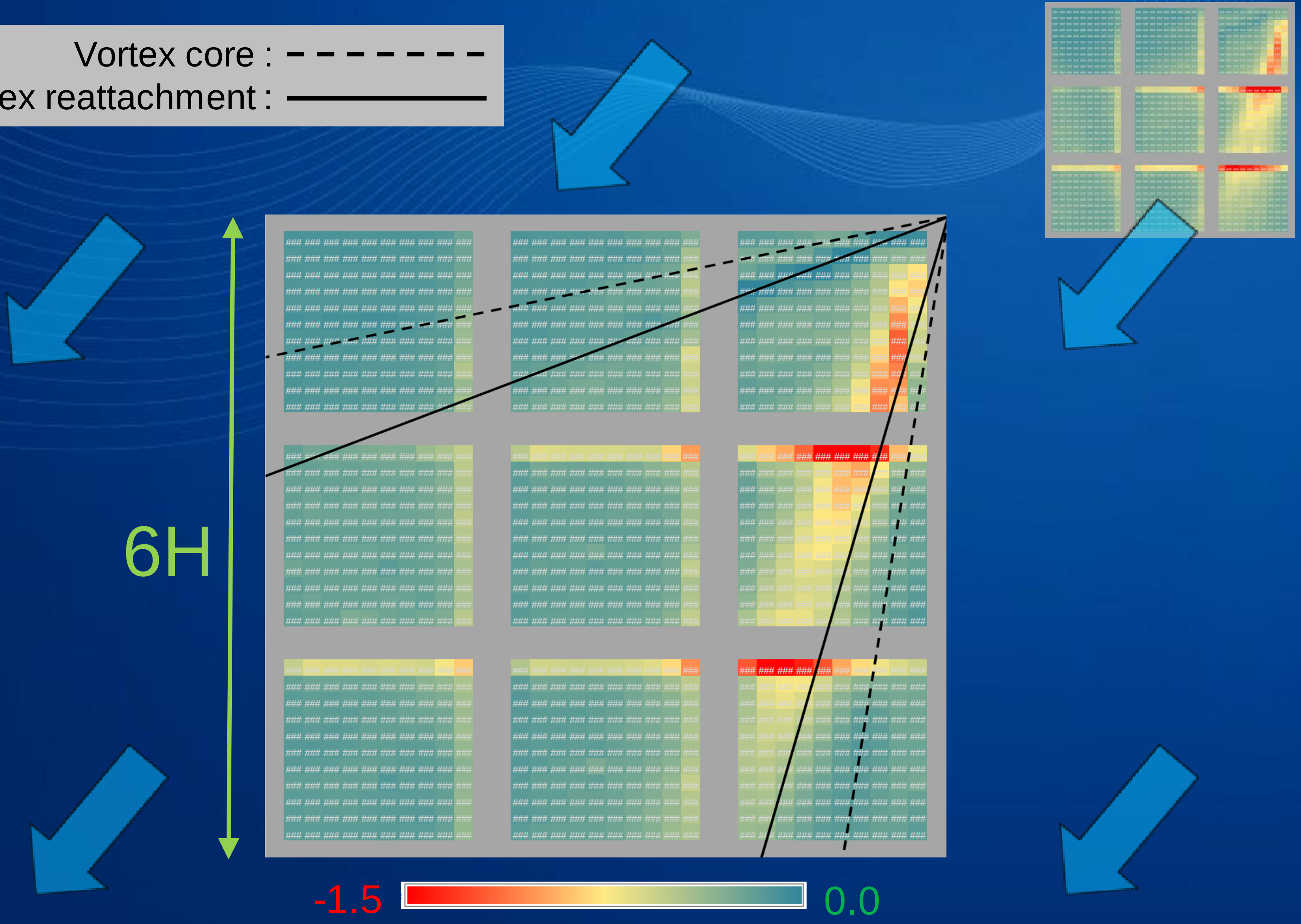


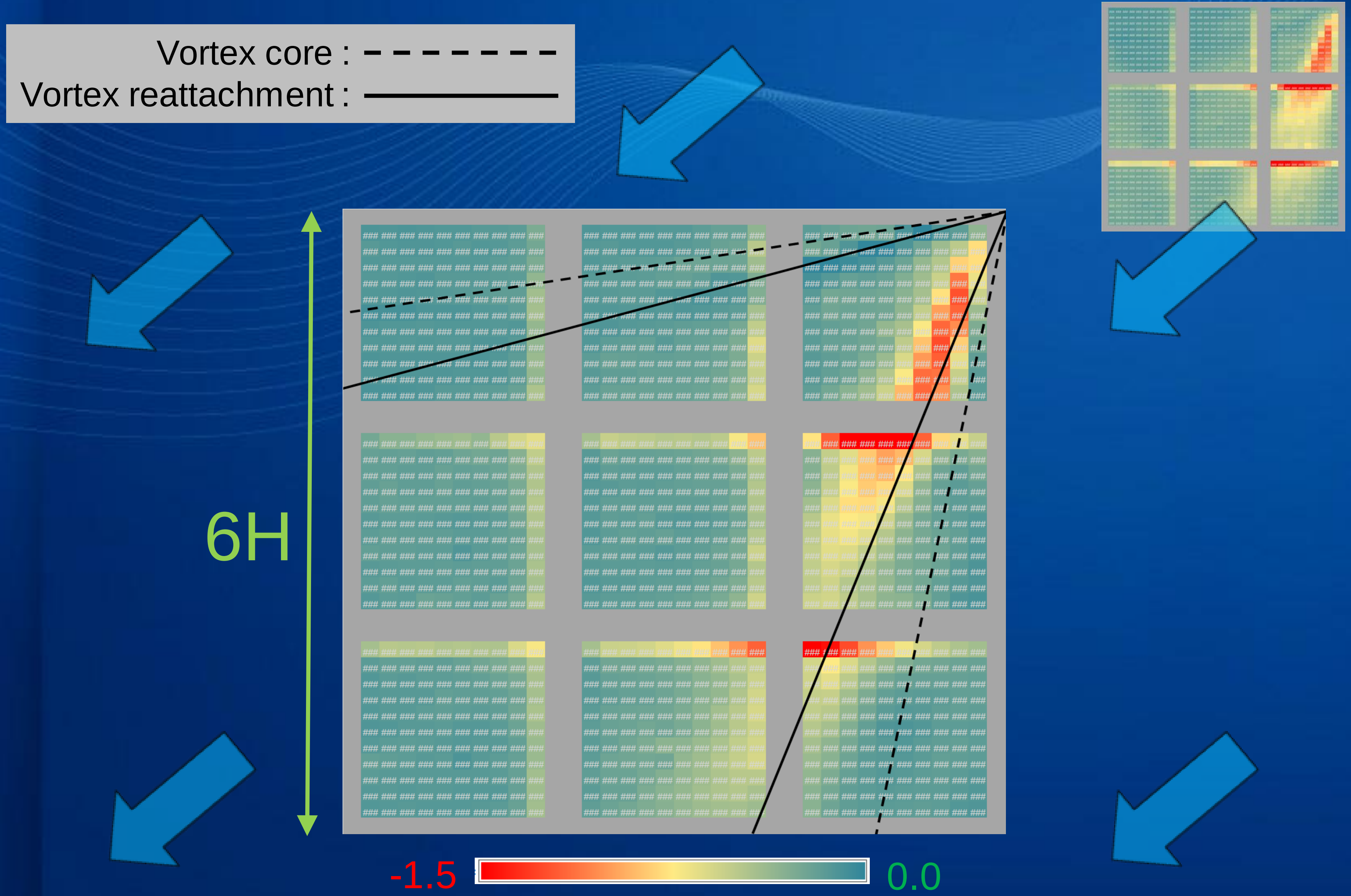


Lift Coefficients 30°

Lift Coefficients 40°

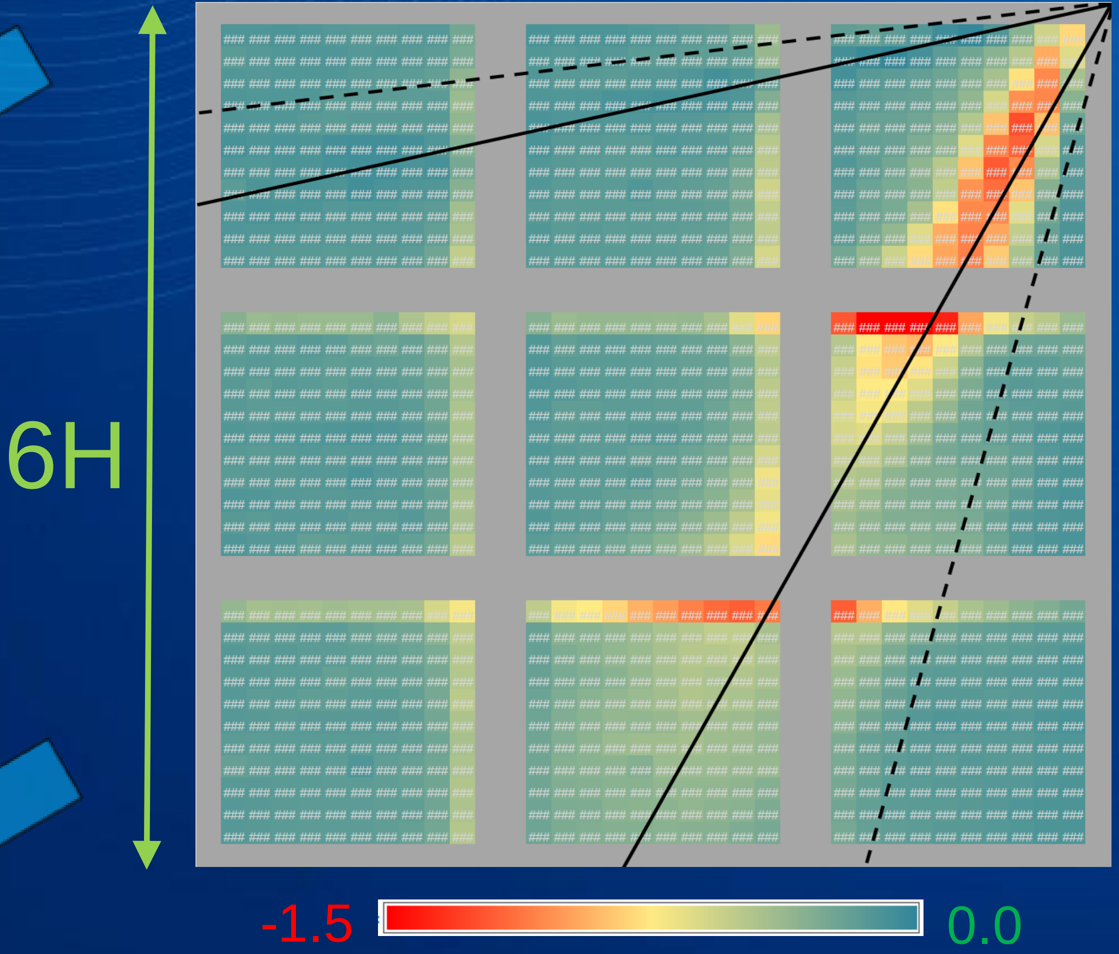
Vortex core : - - - - - - - -
Vortex reattachment : ————

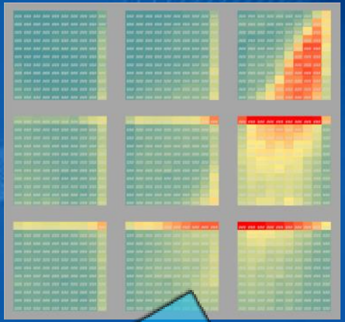




Lift Coefficients 50°

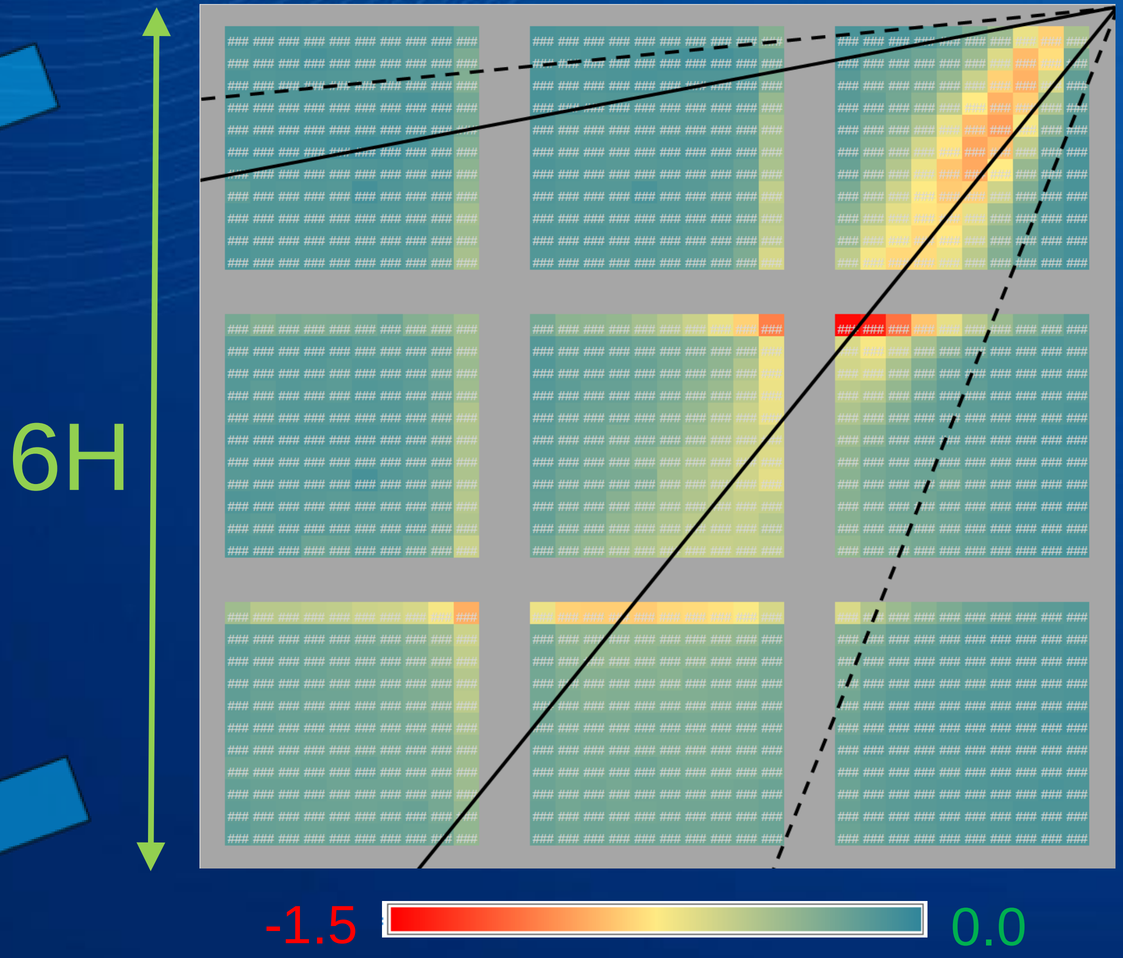
Vortex core : - - - - - - - -
Vortex reattachment : ———————

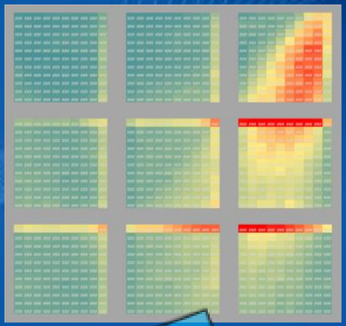




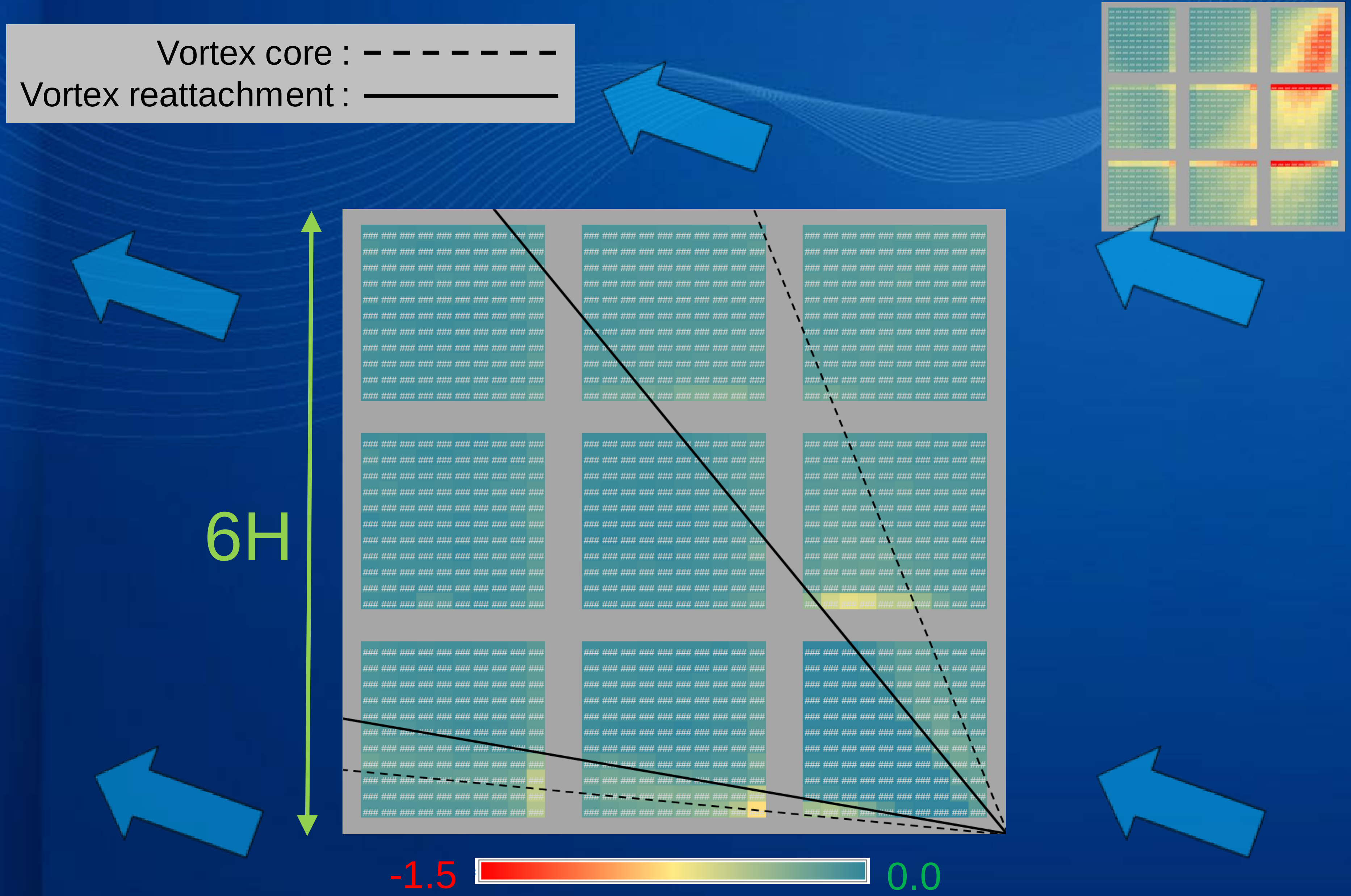
Lift Coefficients 60°

Vortex core : - - - - - - - -
Vortex reattachment : ————————



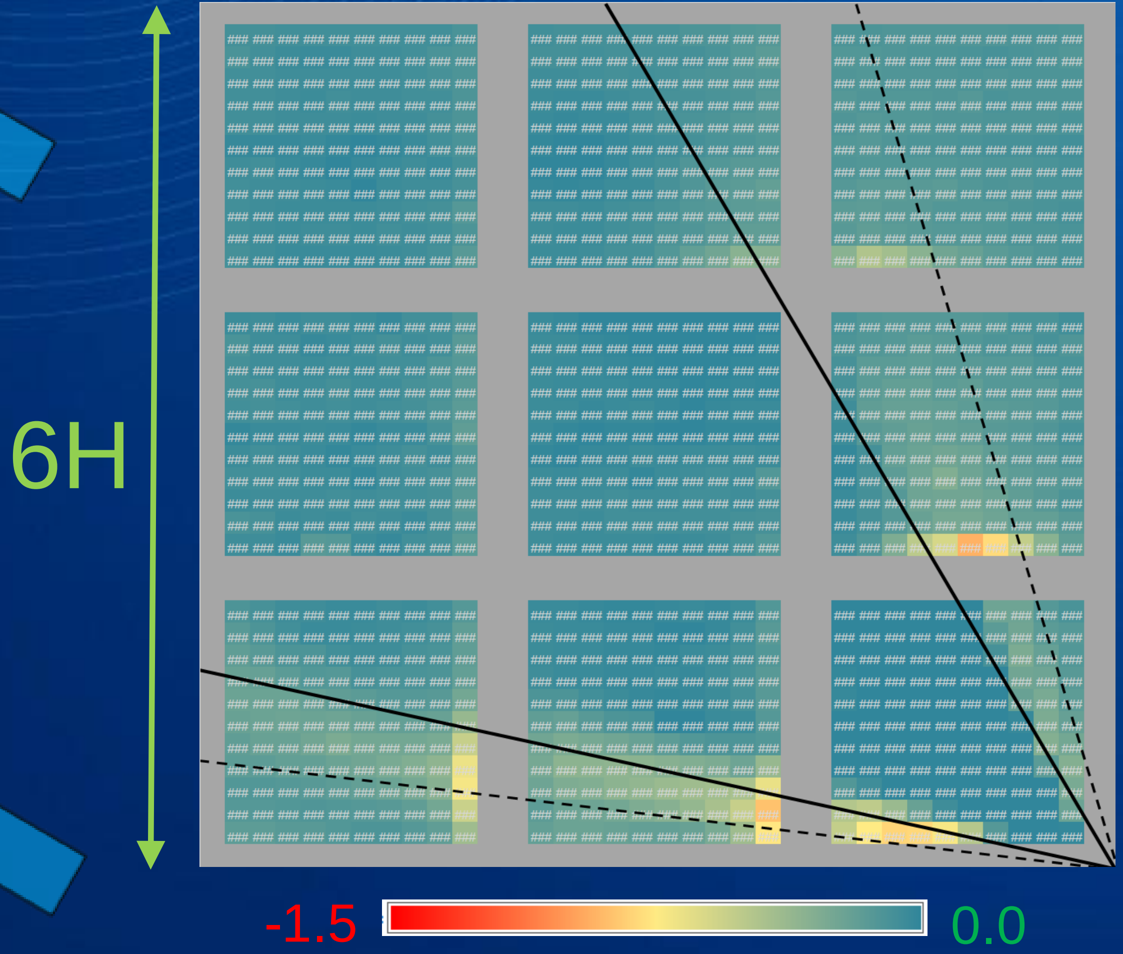


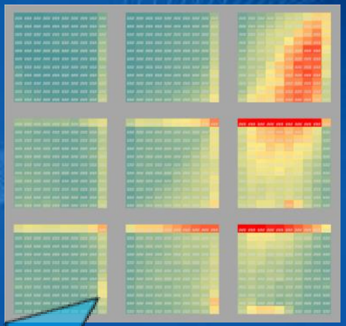
Lift Coefficients 70°



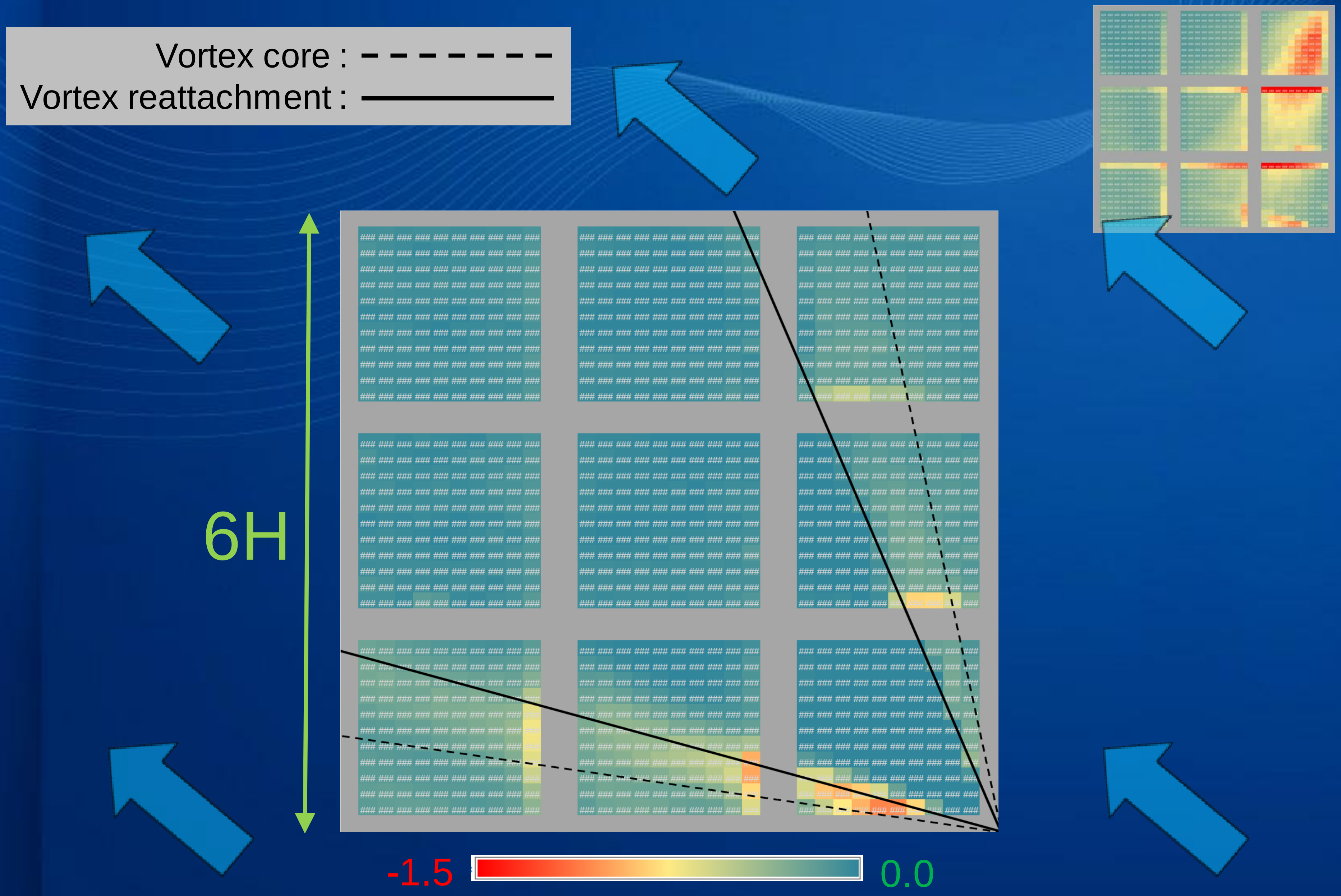
Lift Coefficients 110°

Vortex core : - - - - - - - -
Vortex reattachment : ———————

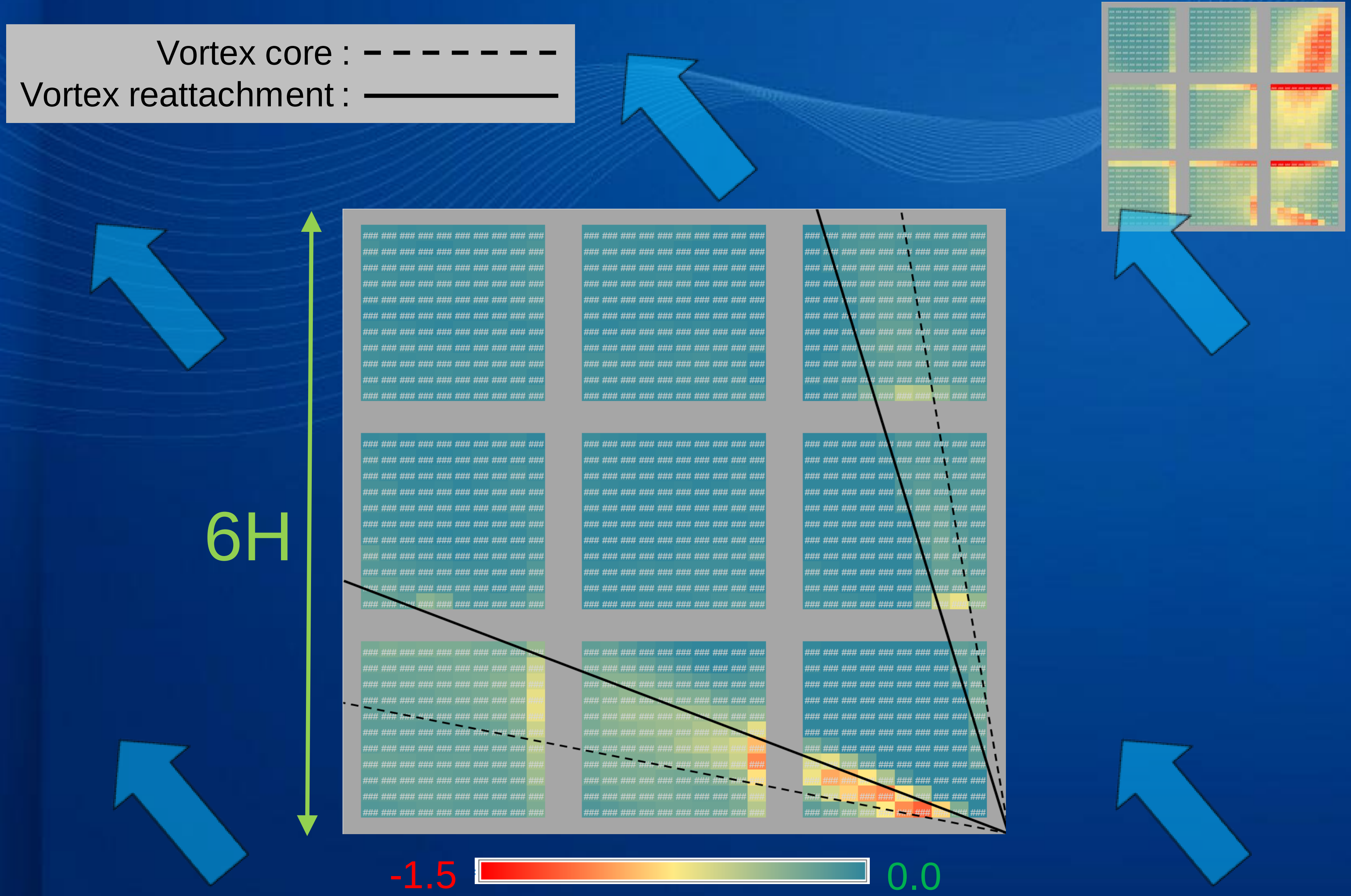




Lift Coefficients 120°

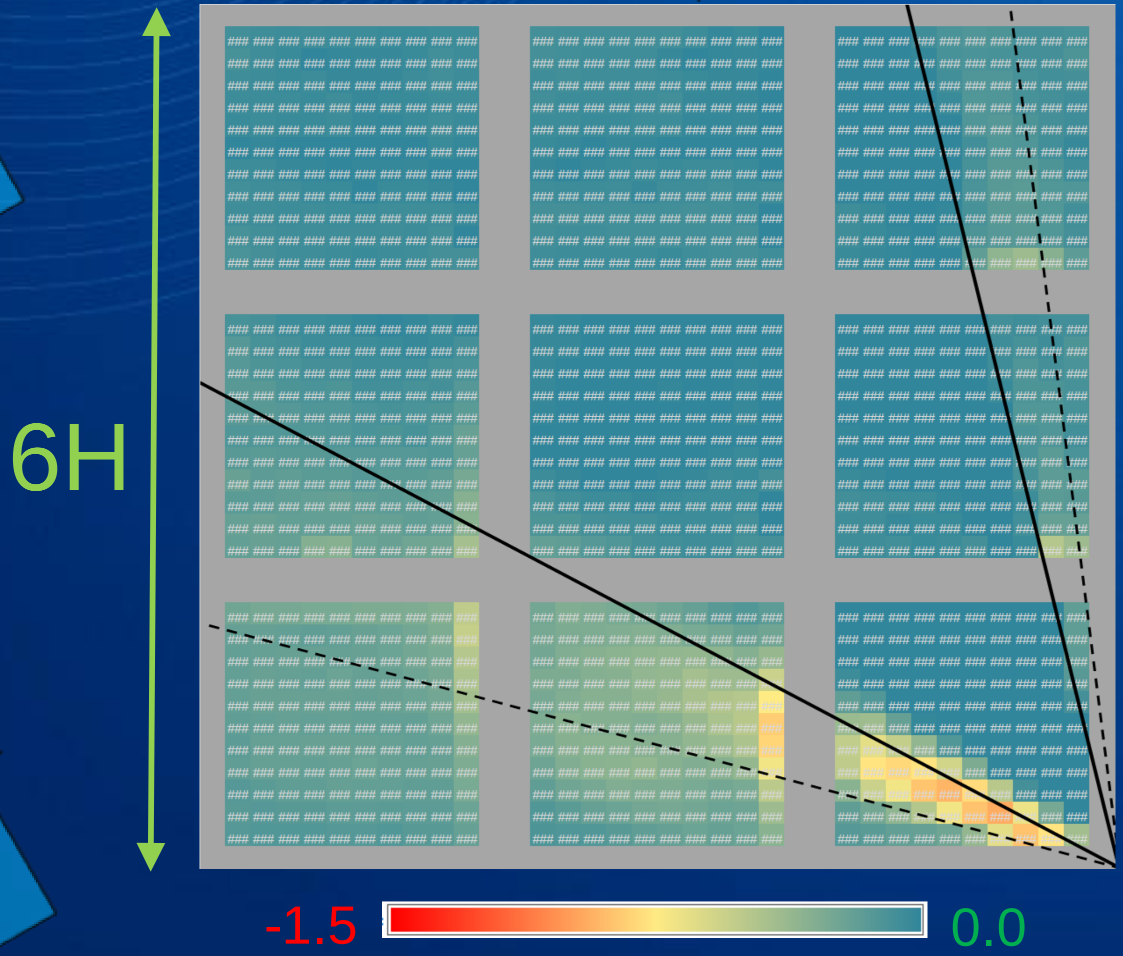


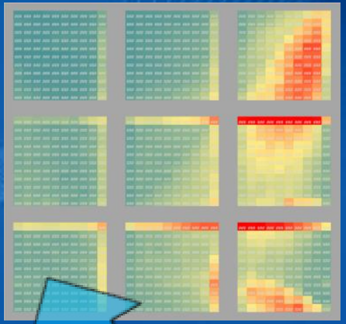
Lift Coefficients 130°



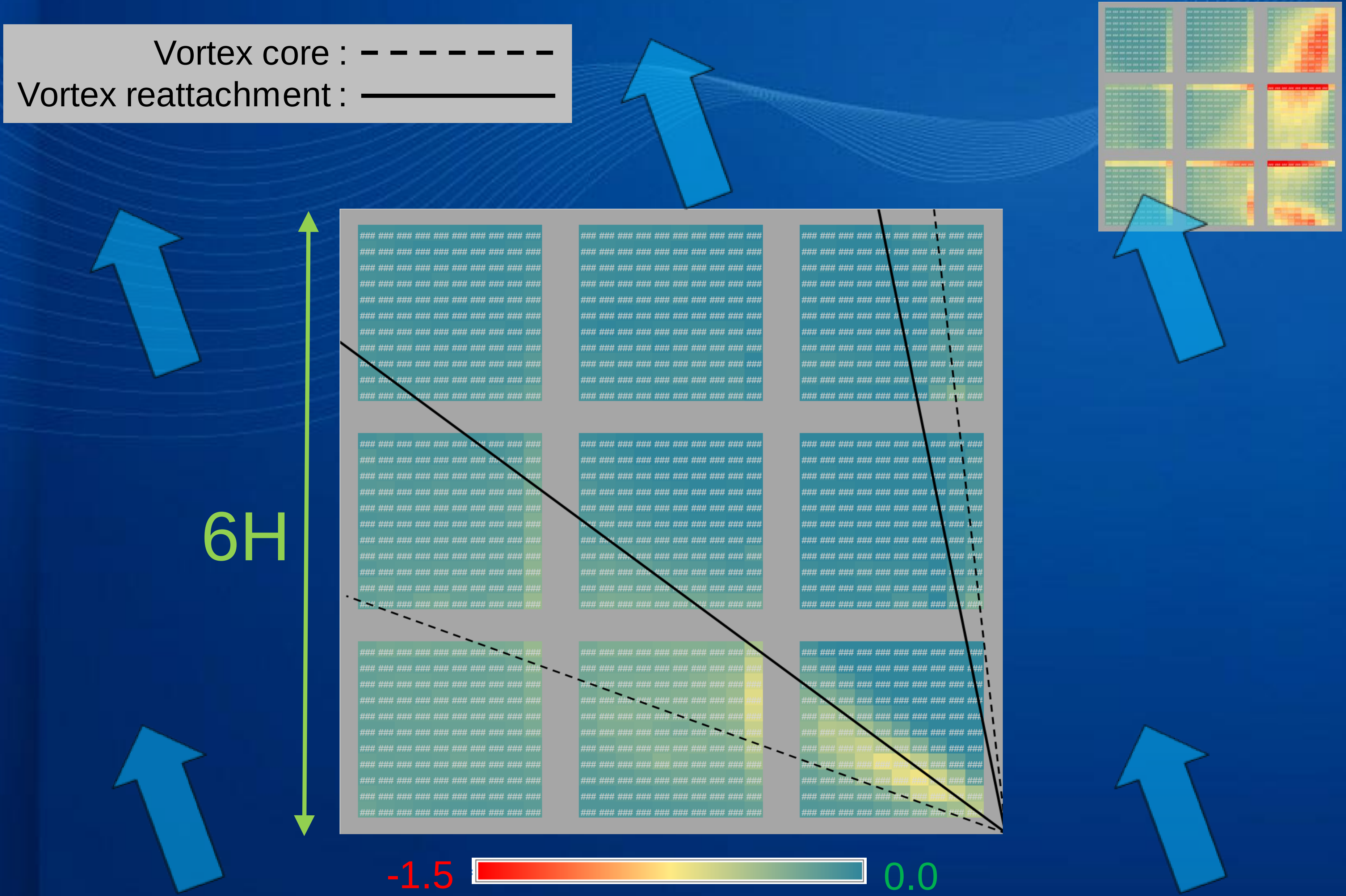
Lift Coefficients 140°

Vortex core : - - - - - - - -
Vortex reattachment : ———

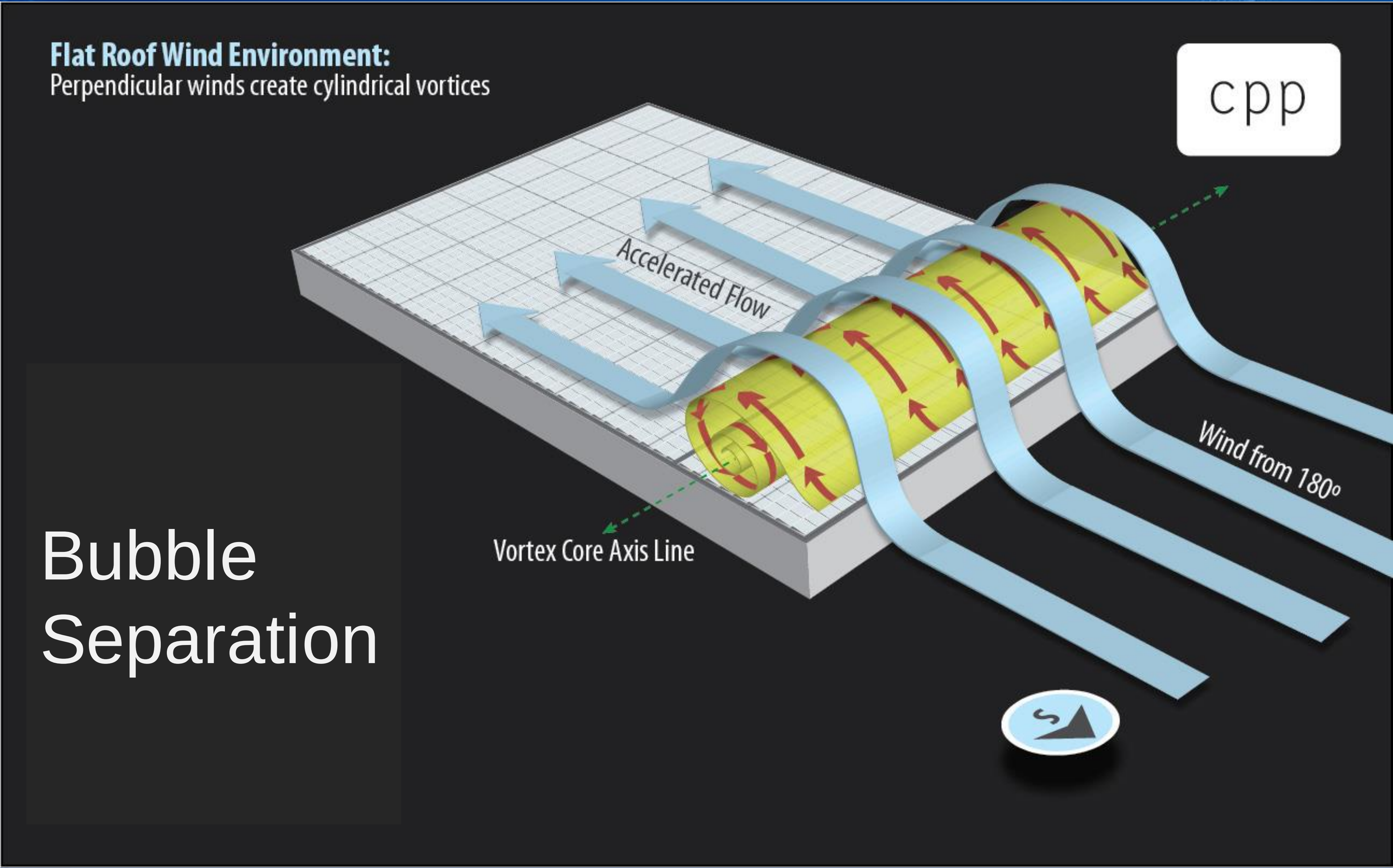




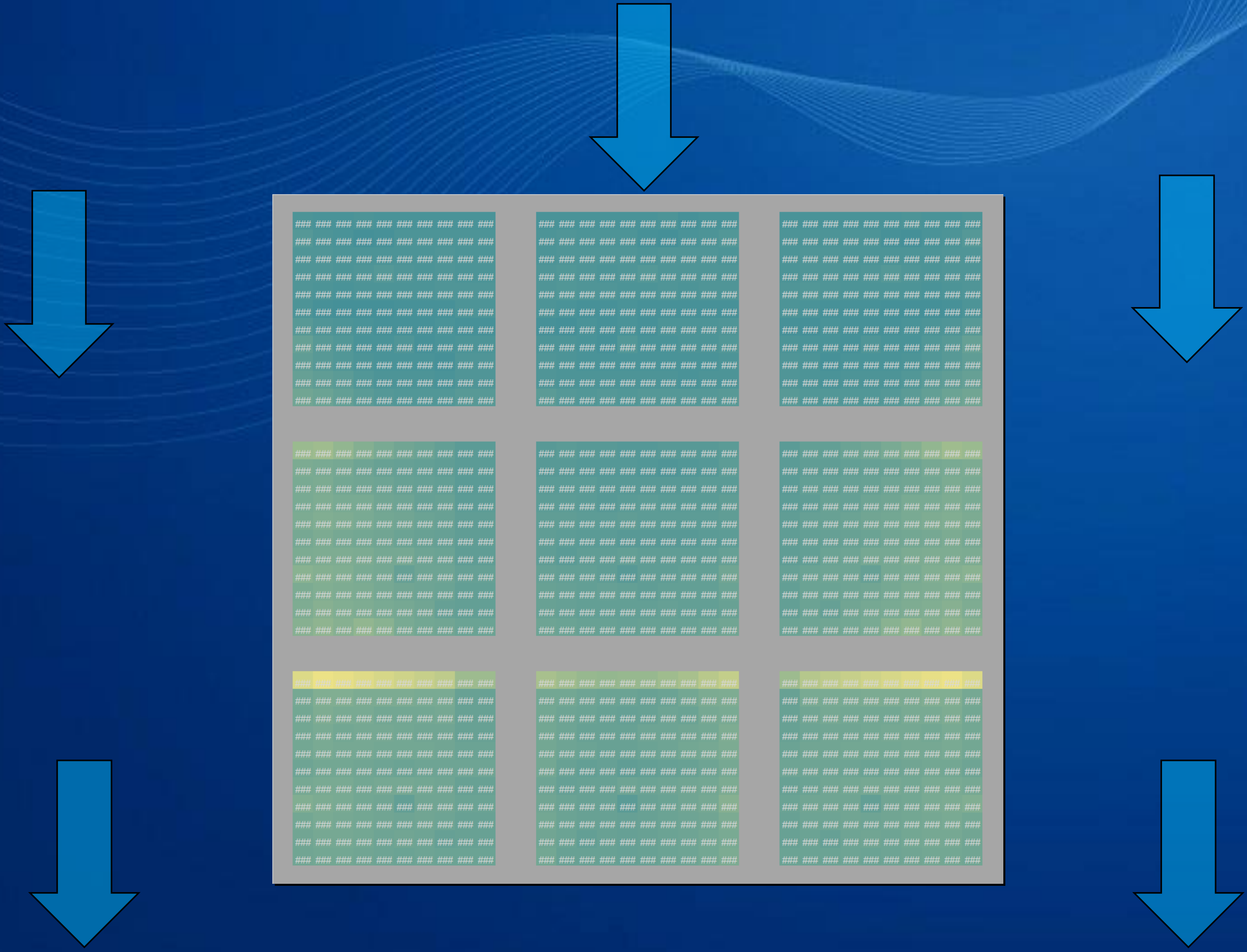
Lift Coefficients 150°



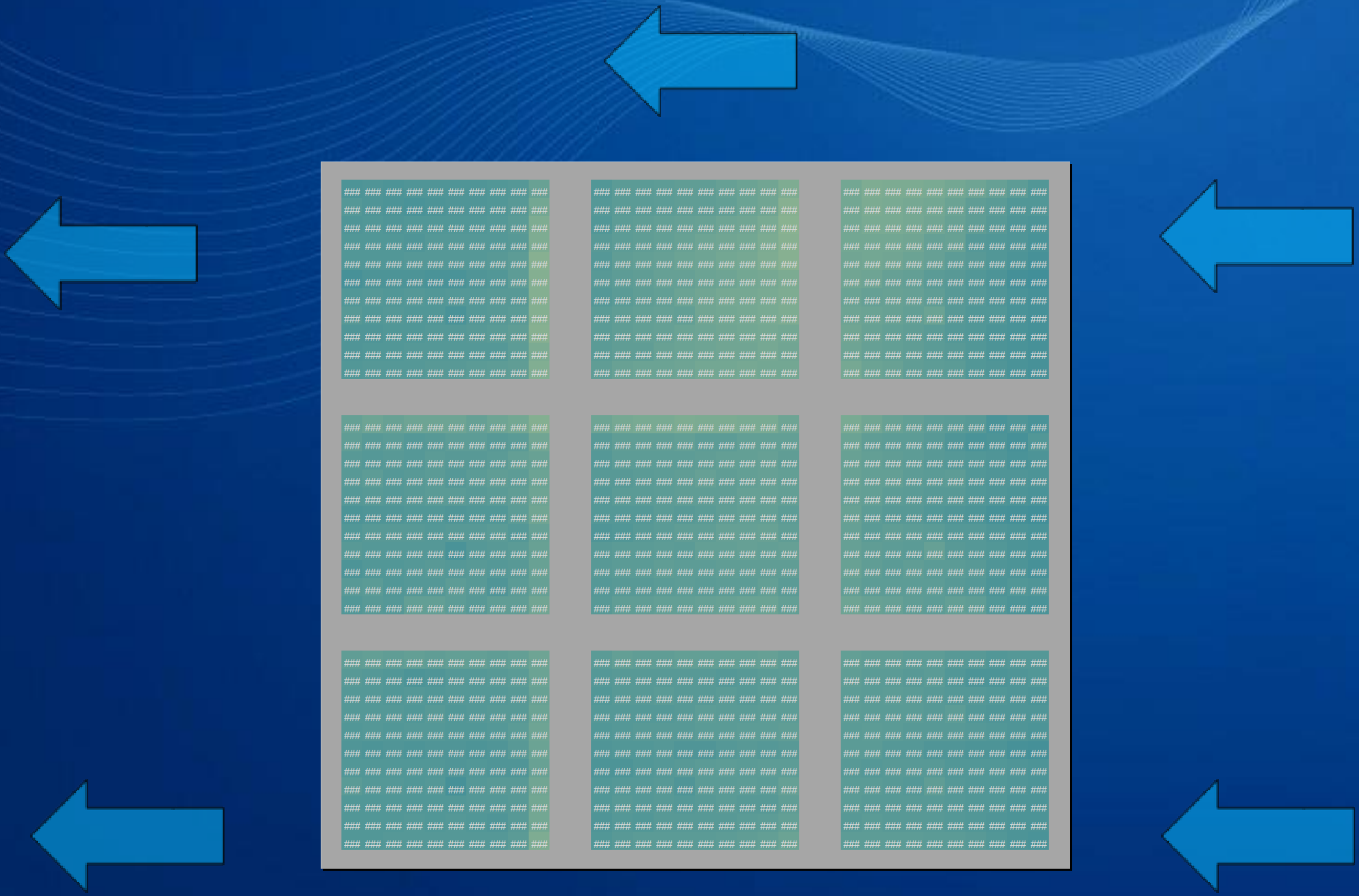
Lift Coefficients 160°



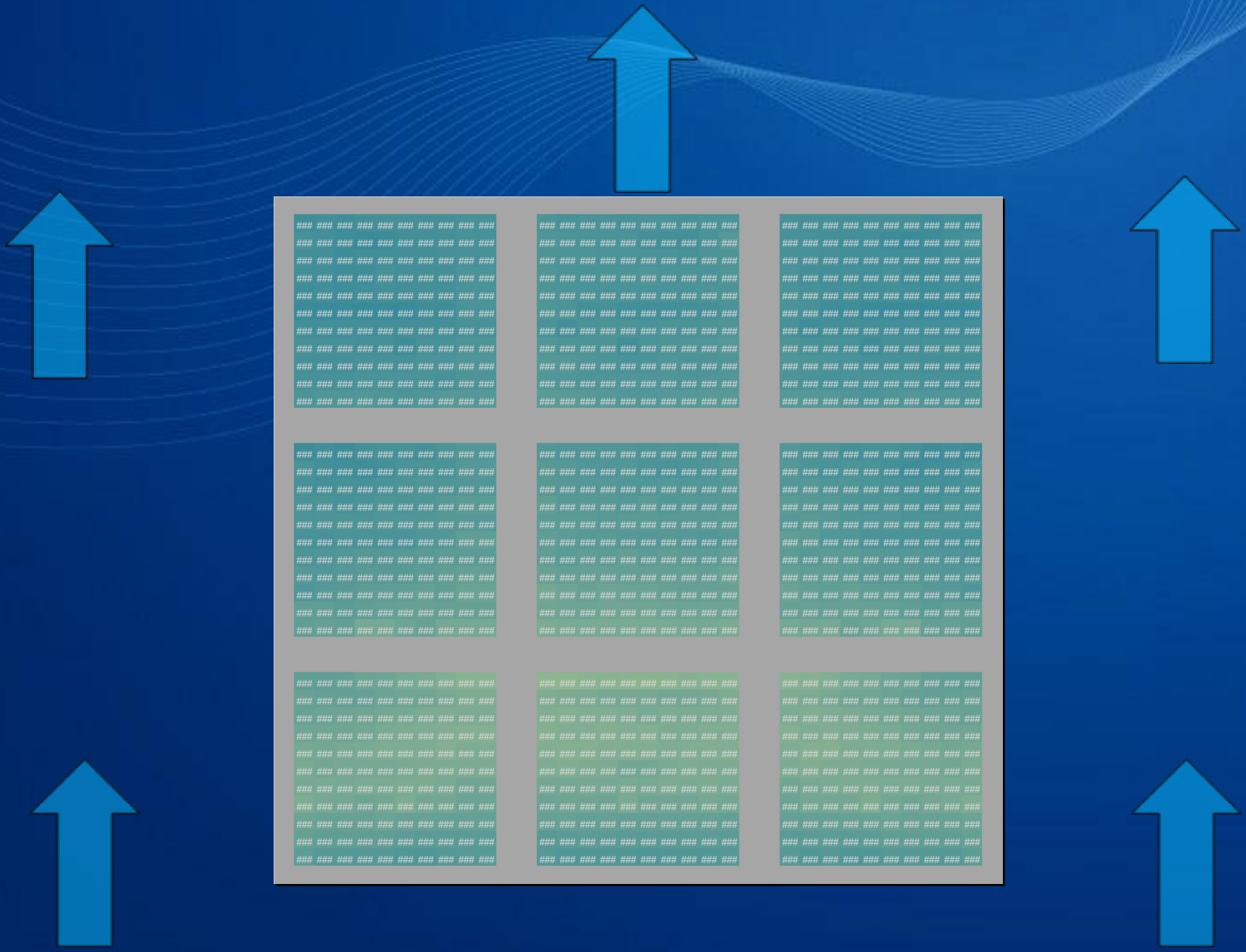
Bubble Separation



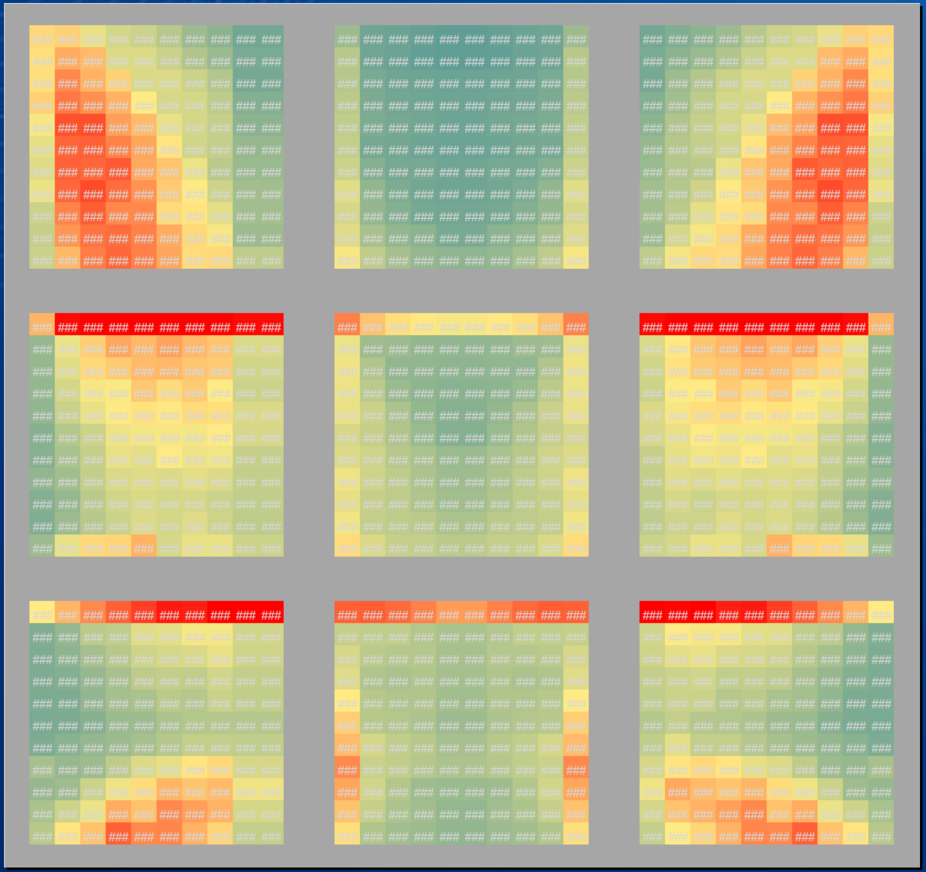
Lift Coefficients 0°



Lift Coefficients 90°



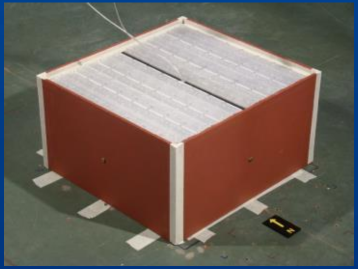
Lift Coefficients 180°



Lift Coefficients All directions

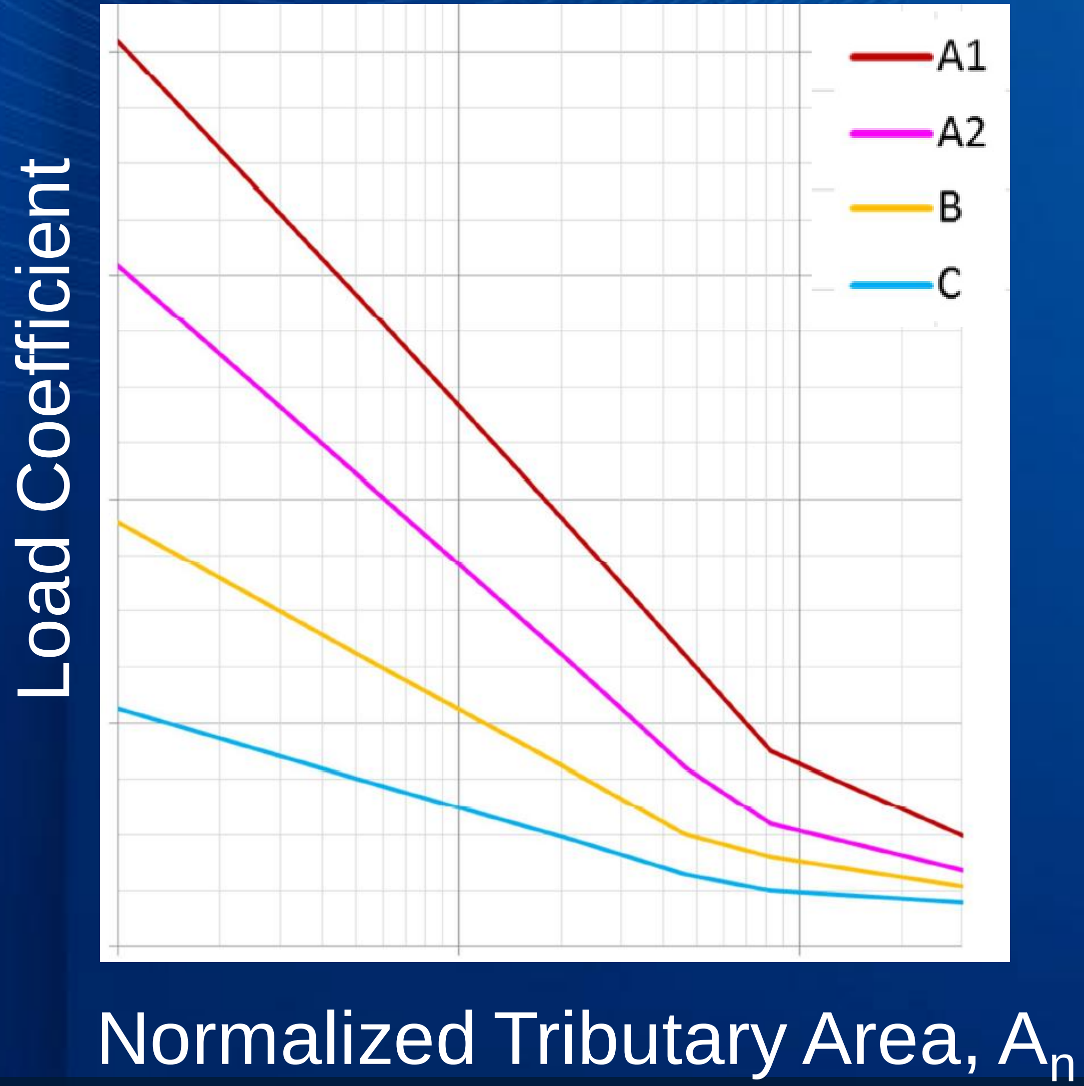
Building size predicts loads

6H X 6H



2H X 2H

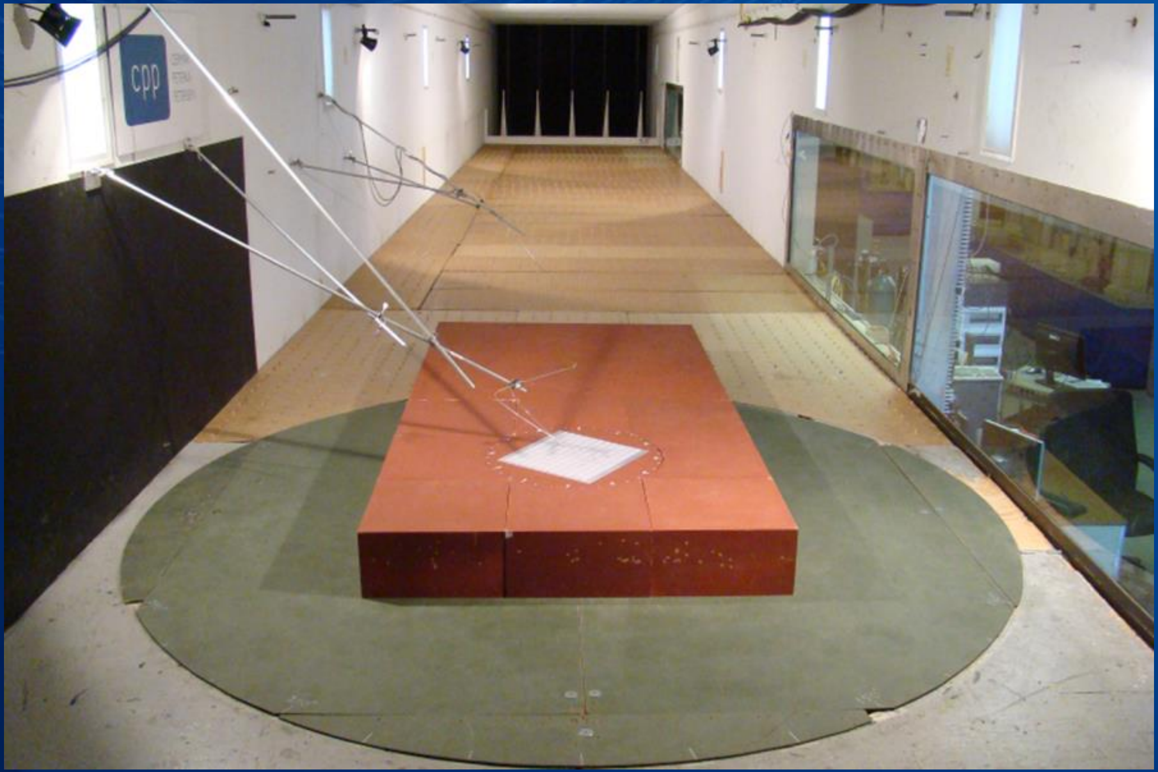
The Outputs: Generic coefficients

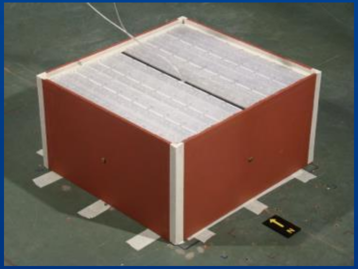


- $An \sim A_{tributary}/A_{wall}$

This of course is not just true for roof mounted solar, it applies to the roof itself.

Far interior



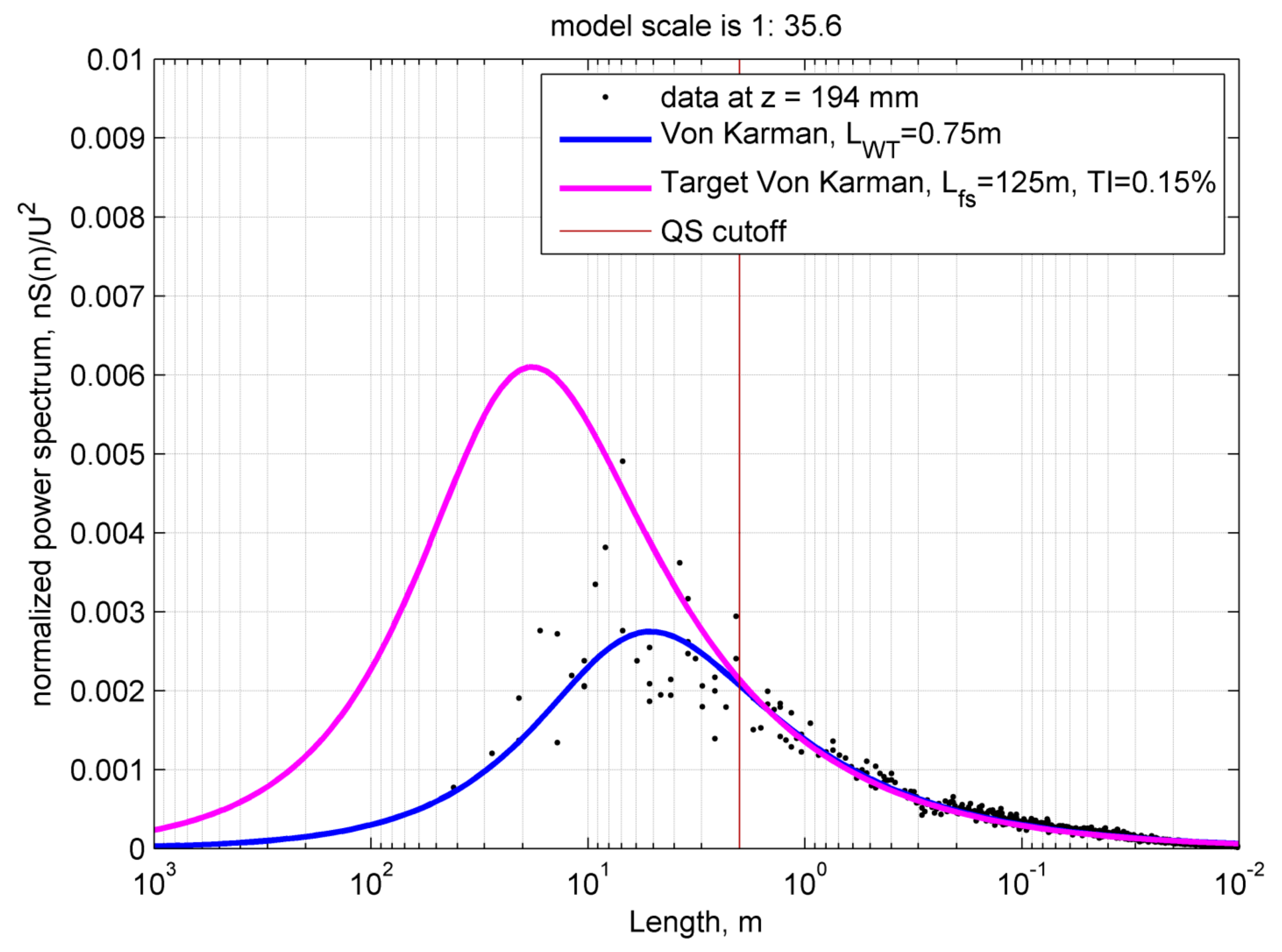


12H X 6H

2H X 2H

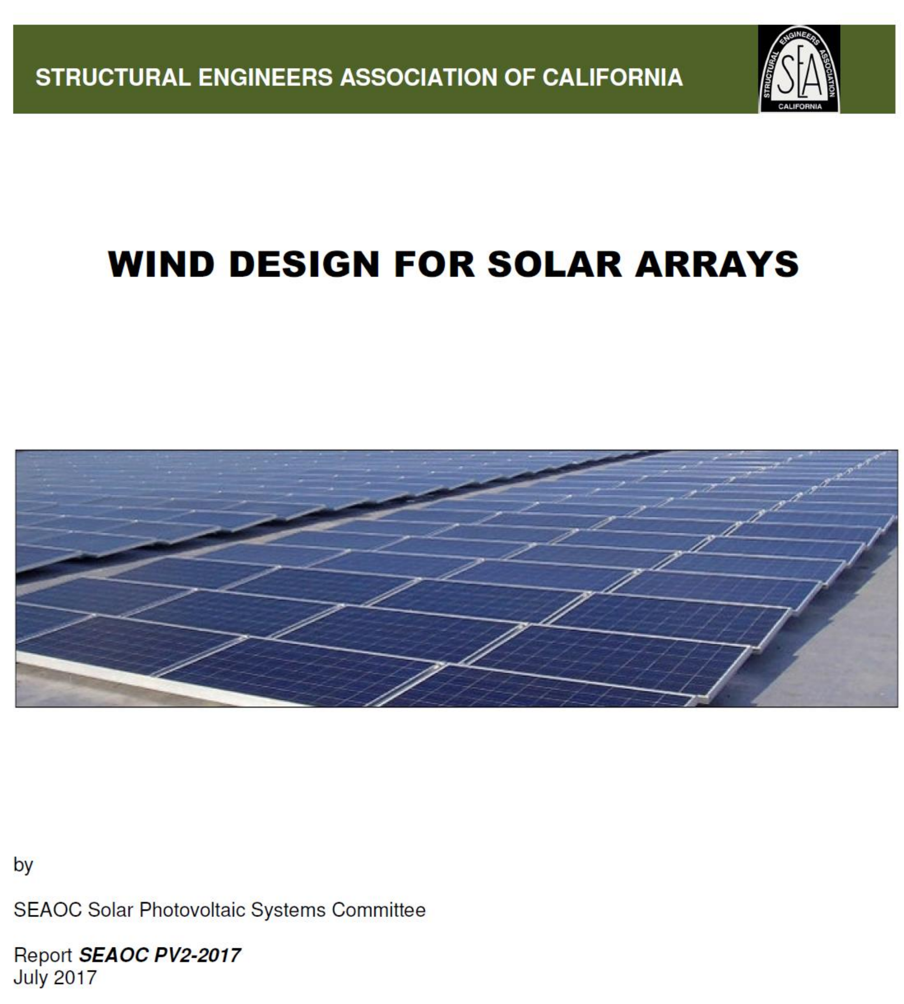
The turbulence spectrum: effect on peaks

- Ensure that GCp > mean Cp



SEAOC PV2

- Too complex?



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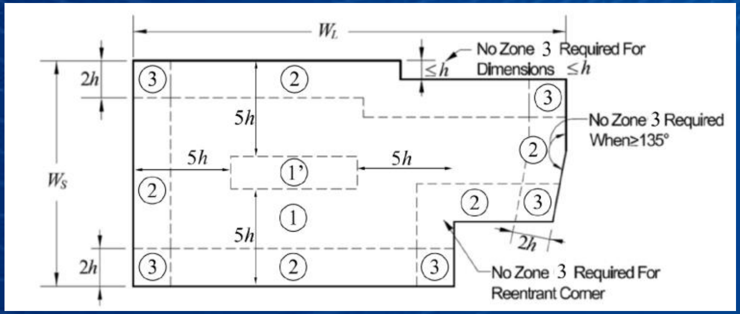
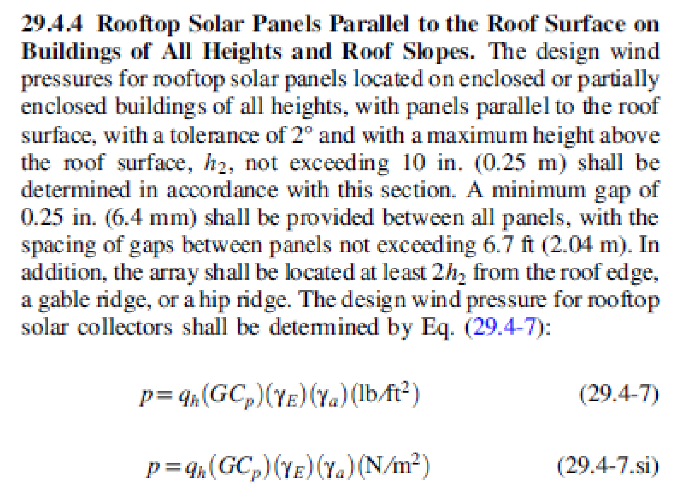
What if we could simplify?

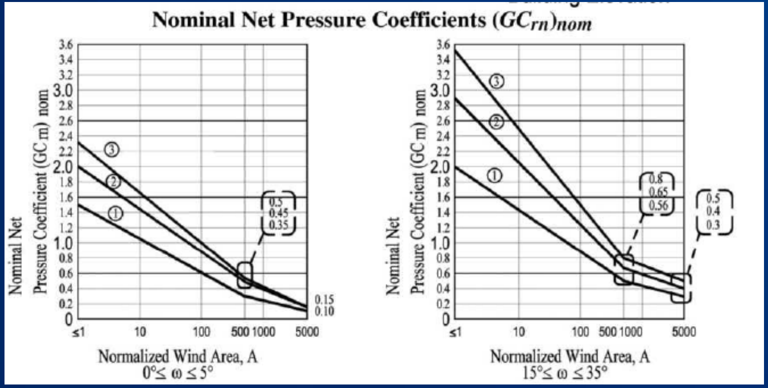


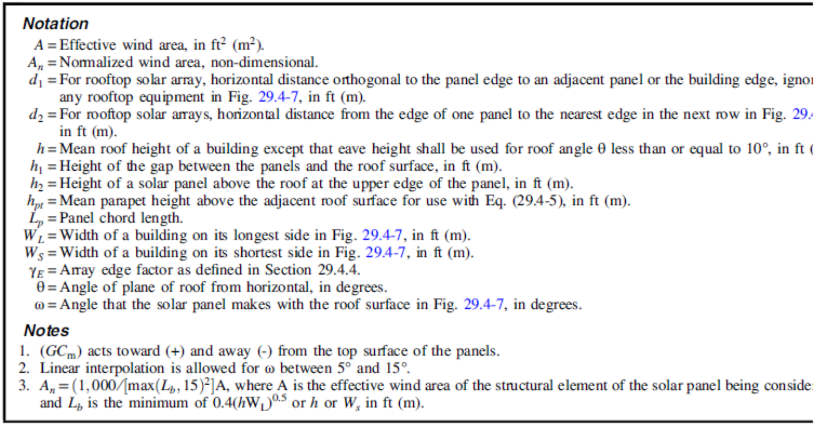


29.4.4 Rooftop Solar Panels Parallel to the Roof Surface on Buildings of All Heights and Roof Slopes. The design wind pressures for rooftop solar panels located on enclosed or partially enclosed buildings of all heights, with panels parallel to the roof surface, with a tolerance of 2° and with a maximum height above the roof surface, h_2, not exceeding 10 in. (0.25 m) shall be determined in accordance with this section. A minimum gap of 0.25 in. (6.4 mm) shall be provided between all panels, with the spacing of gaps between panels not exceeding 6.7 ft (2.04 m). In addition, the array shall be located at least $2h_2$ from the roof edge, a gable ridge, or a hip ridge. The design wind pressure for rooftop solar collectors shall be determined by Eq. (29.4-7):

$$p = q_h(GC_p)(\gamma_E)(\gamma_a)\,(\text{lb/ft}^2) \qquad (29.4\text{-}7)$$

$$p = q_h(GC_p)(\gamma_E)(\gamma_a)\,(\text{N/m}^2) \qquad (29.4\text{-}7.\text{si})$$





Notation

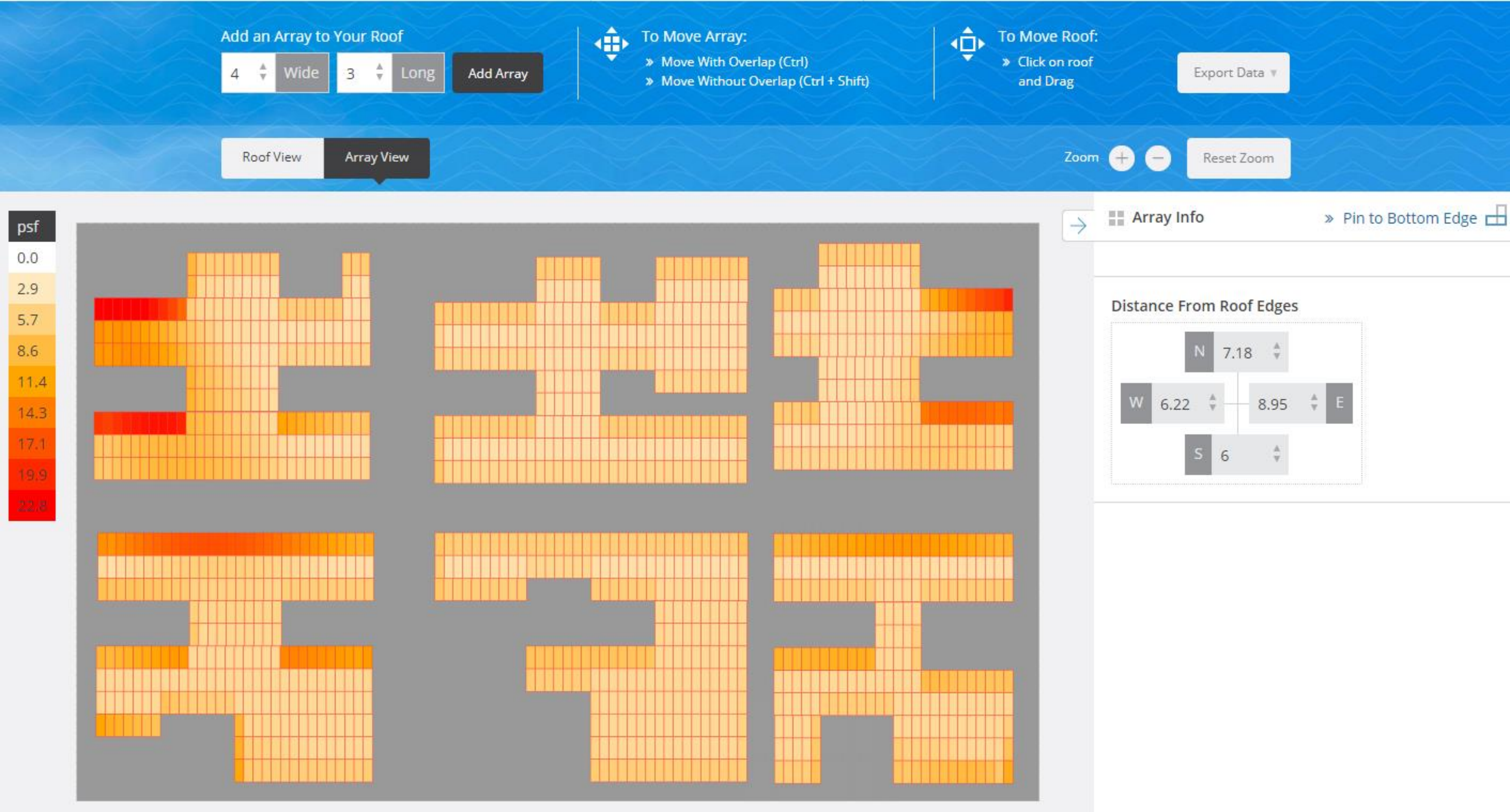
A = Effective wind area, in ft^2 (m^2).
A_n = Normalized wind area, non-dimensional.
d_1 = For rooftop solar array, horizontal distance orthogonal to the panel edge to an adjacent panel or the building edge, igno any rooftop equipment in Fig. 29.4-7, in ft (m).
d_2 = For rooftop solar arrays, horizontal distance from the edge of one panel to the nearest edge in the next row in Fig. 29. in ft (m).
h = Mean roof height of a building except that eave height shall be used for roof angle θ less than or equal to 10°, in ft (
h_1 = Height of the gap between the panels and the roof surface, in ft (m).
h_2 = Height of a solar panel above the roof at the upper edge of the panel, in ft (m).
h_{pt} = Mean parapet height above the adjacent roof surface for use with Eq. (29.4-5), in ft (m).
L_p = Panel chord length.
W_L = Width of a building on its longest side in Fig. 29.4-7, in ft (m).
W_S = Width of a building on its shortest side in Fig. 29.4-7, in ft (m).
γ_E = Array edge factor as defined in Section 29.4.4.
θ = Angle of plane of roof from horizontal, in degrees.
ω = Angle that the solar panel makes with the roof surface in Fig. 29.4-7, in degrees.

Notes

1. (GC_m) acts toward (+) and away (-) from the top surface of the panels.
2. Linear interpolation is allowed for ω between 5° and 15°.
3. $A_n = (1{,}000/[\max(L_b, 15)^2]A$, where A is the effective wind area of the structural element of the solar panel being conside and L_b is the minimum of $0.4(hW_L)^{0.5}$ or h or W_s in ft (m).

FIGURE 29.4-7 (*Continued*). Design Wind Loads (All Heights): Rooftop Solar Panels for Enclosed and Partially Enclosed Buildings, Roof

On line calculator and layout tool



Add an Array to Your Roof

4 Wide 3 Long Add Array

To Move Array:

- Move With Overlap (Ctrl)
- Move Without Overlap (Ctrl + Shift)

To Move Roof:

- Click on roof and Drag

Distance From Roof Edges

N 7.18

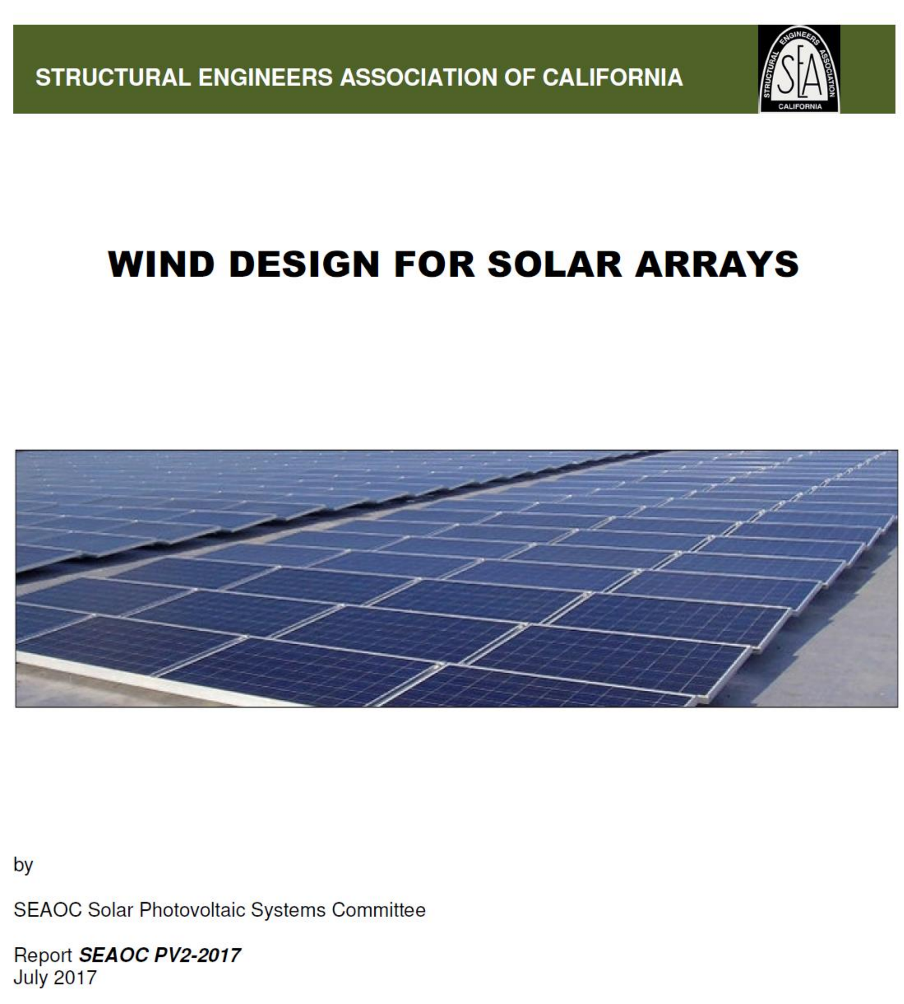
W 6.22

E 8.95

S 6

SEAOC PV2

- Too complex?
- Loads too high?



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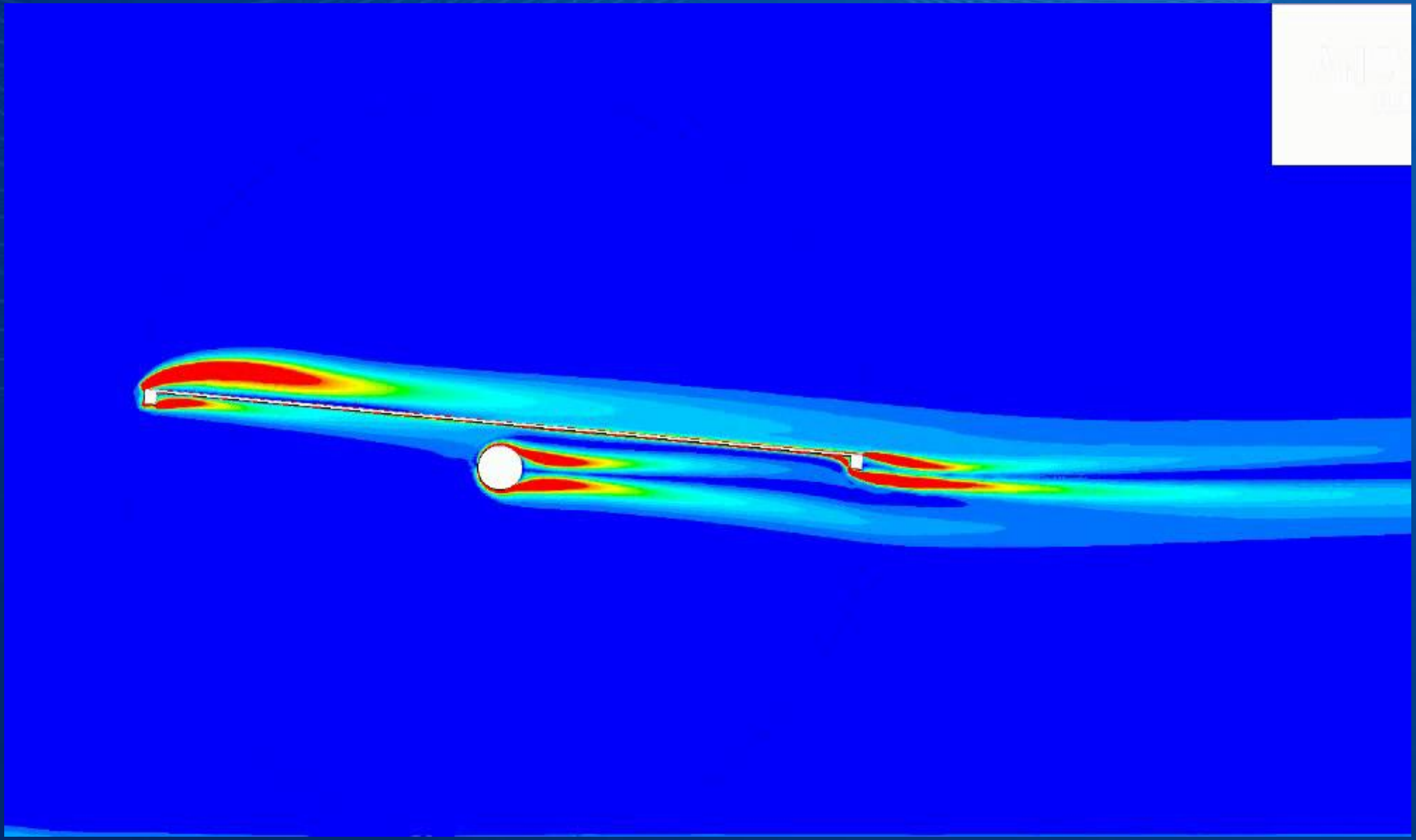
Single Axis Trackers

- Tap density
- Structure
- Instability

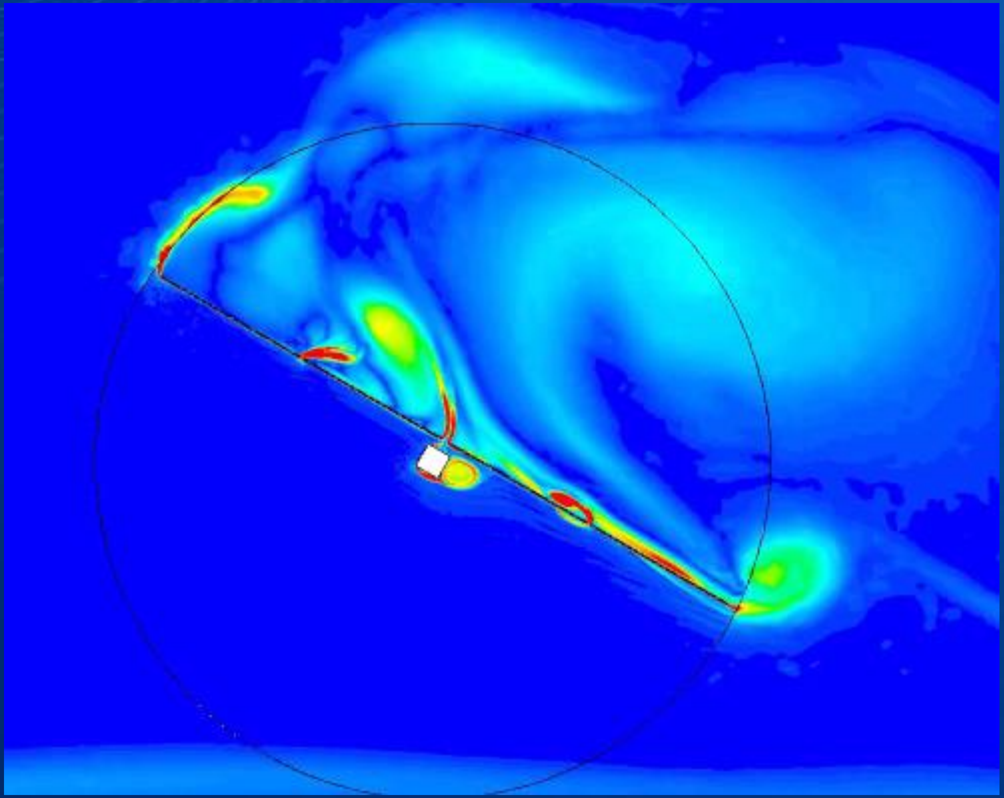
STOW POSITION

- Will it go unstable?
  - Classical Flutter
  - Torsional divergence
  - Galloping
  - Torsional galloping
  - Vortex lock-in

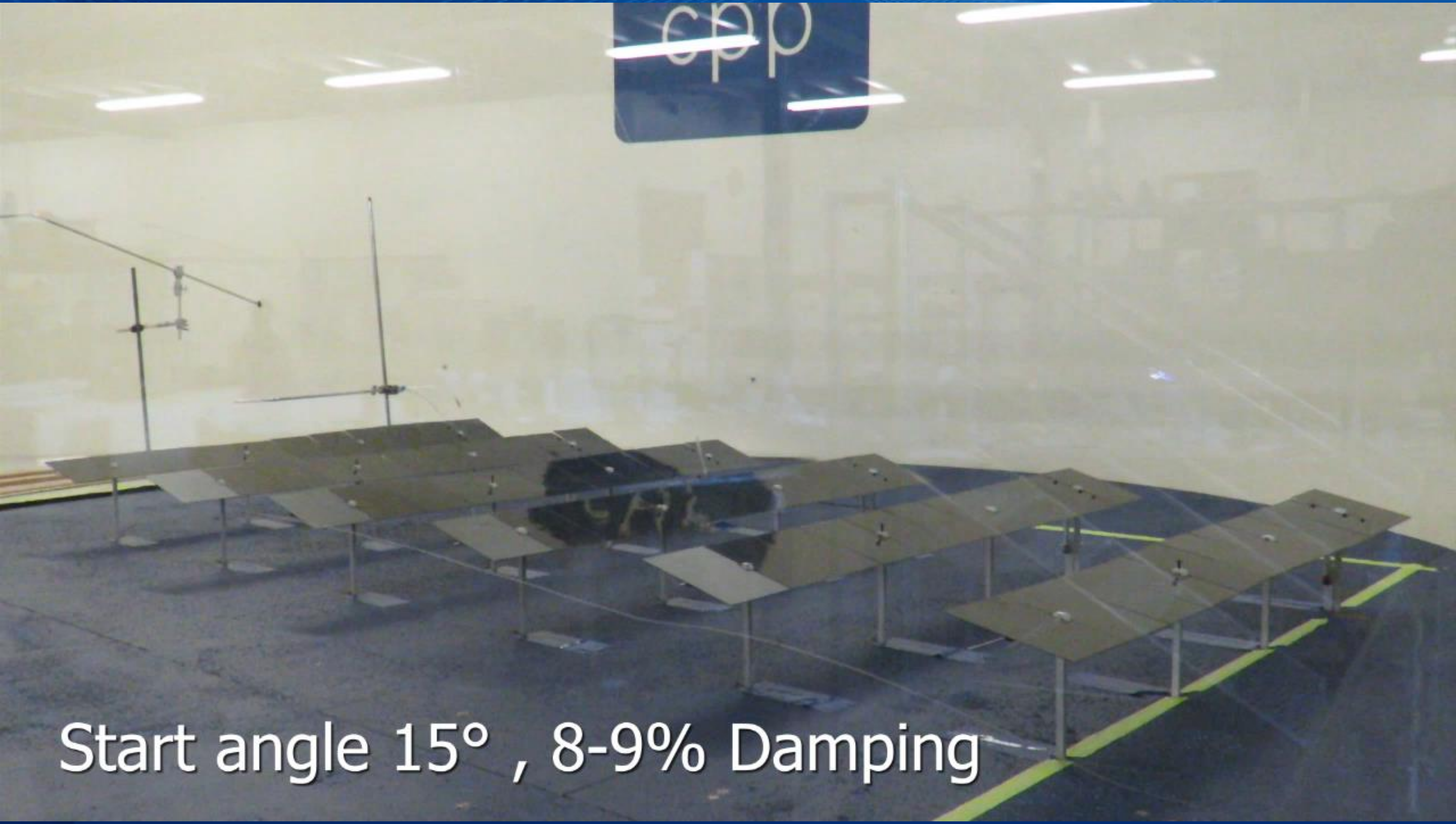
Torsional Galloping



Vortex lock-in



Aeroelastic wind tunnel test



Start angle 15° , 8-9% Damping

Still happening in 2018

- Stowed at 0°
- Ucr < 20 m/s
- dampers

Responsibility

- We determine who wins and who loses
    - It’s not as simple as it appears
- Best-before date on reports?

How can we help good design to win?

- Good testing

How can we help good design to win?

- Good testing
- Proper penalties

How can we help good design to win?

- Good testing
- Proper penalties
- Thorough peer reviews
- Good codes
    - No limits
    - Performance based?

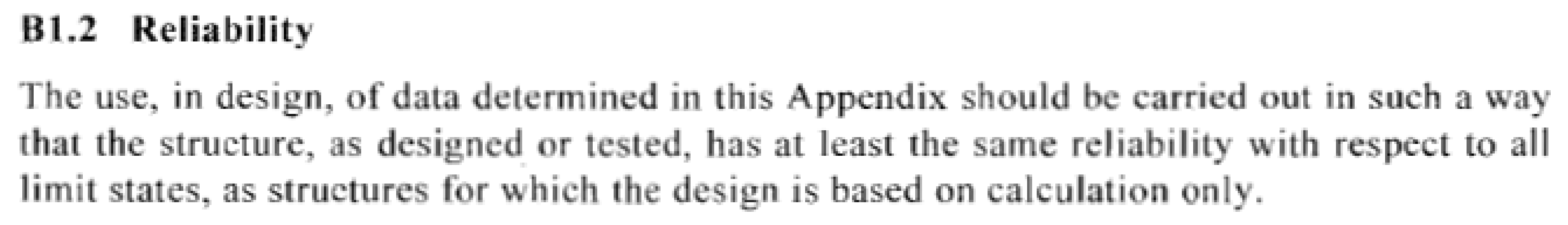
Achieve 1-in-700 chance of failure next year.

Show your work.

How can we help good design to win?

- Good testing
- Proper penalties
- Thorough peer reviews
- Good contracts
  - Performance, not compliance

What if?



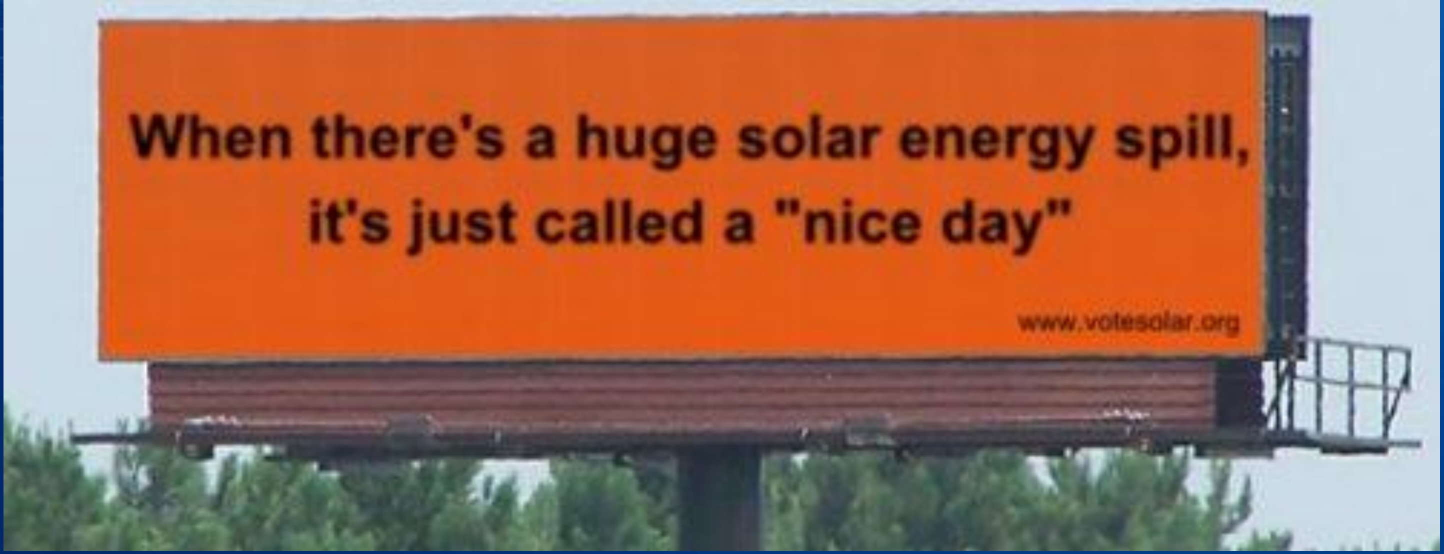
B1.2 Reliability

The use, in design, of data determined in this Appendix should be carried out in such a way that the structure, as designed or tested, has at least the same reliability with respect to all limit states, as structures for which the design is based on calculation only.

AS/NZS 1170.0 2002 Appendix B

What if we had a “black box”?

Are codes helpful? Is there a better way?
What if risk was consistent ?


When there's a huge solar energy spill,
it's just called a "nice day"
www.votesolar.org