Wind Farm Wake Loss Analysis and Mitigation Techniques

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Background Information

- Why is wind power important? Why should we be doing wind power research?
- Wind power is still in its infancy
  - By the end of 2012, wind power was capable of supplying only 3% of worldwide electricity demand[1]

1. Gsänger, S., & Pitteloud, J. *2012 Annual Report.* World Wind Energy Association.

Background Information

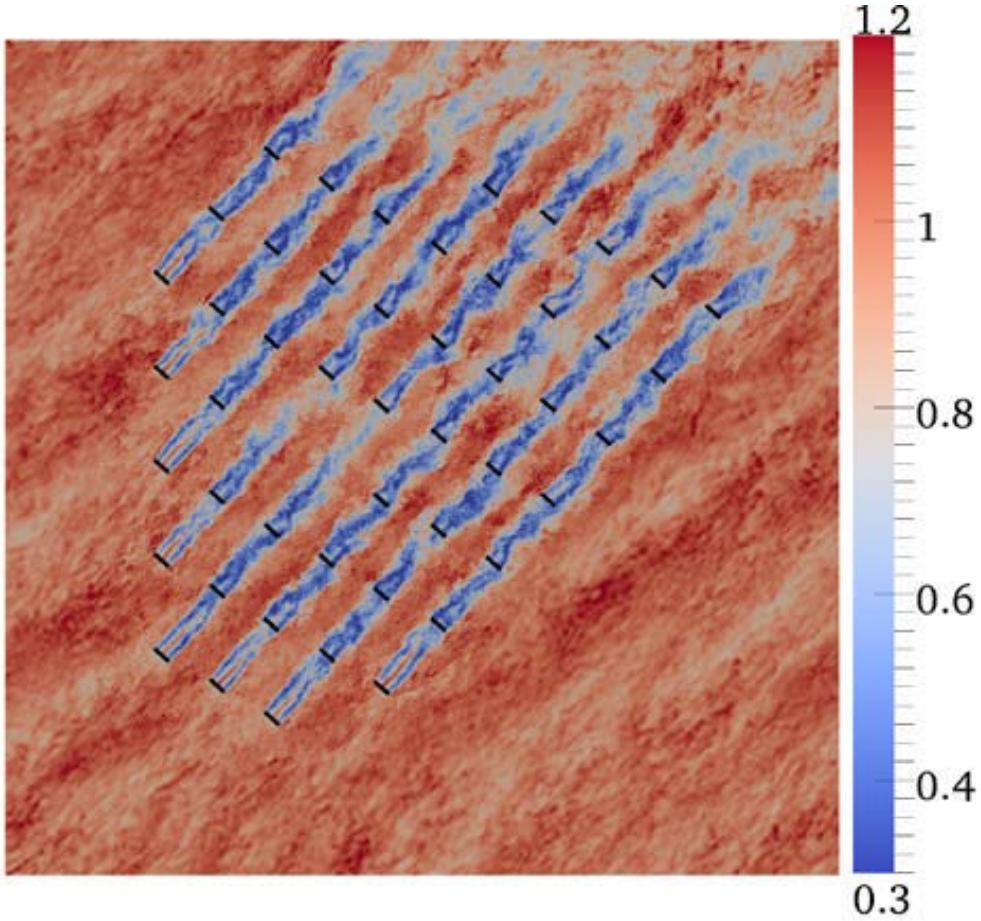
- But wind power is growing
  - New wind power capacity in 2012[2]
    - US: 13,124 MW
    - China : 12,960 MW
    - Germany: 2,415 MW
  - Wind power capacity expected to grow by about 13.7% per year to 2017[2]

2. *Global Wind Report - Annual Market Update 2012*. Global Wind Energy Council.

Problem

- Land cost is a major component of total wind energy cost
  - Turbines are placed relatively close together

Problem



- Wake effect

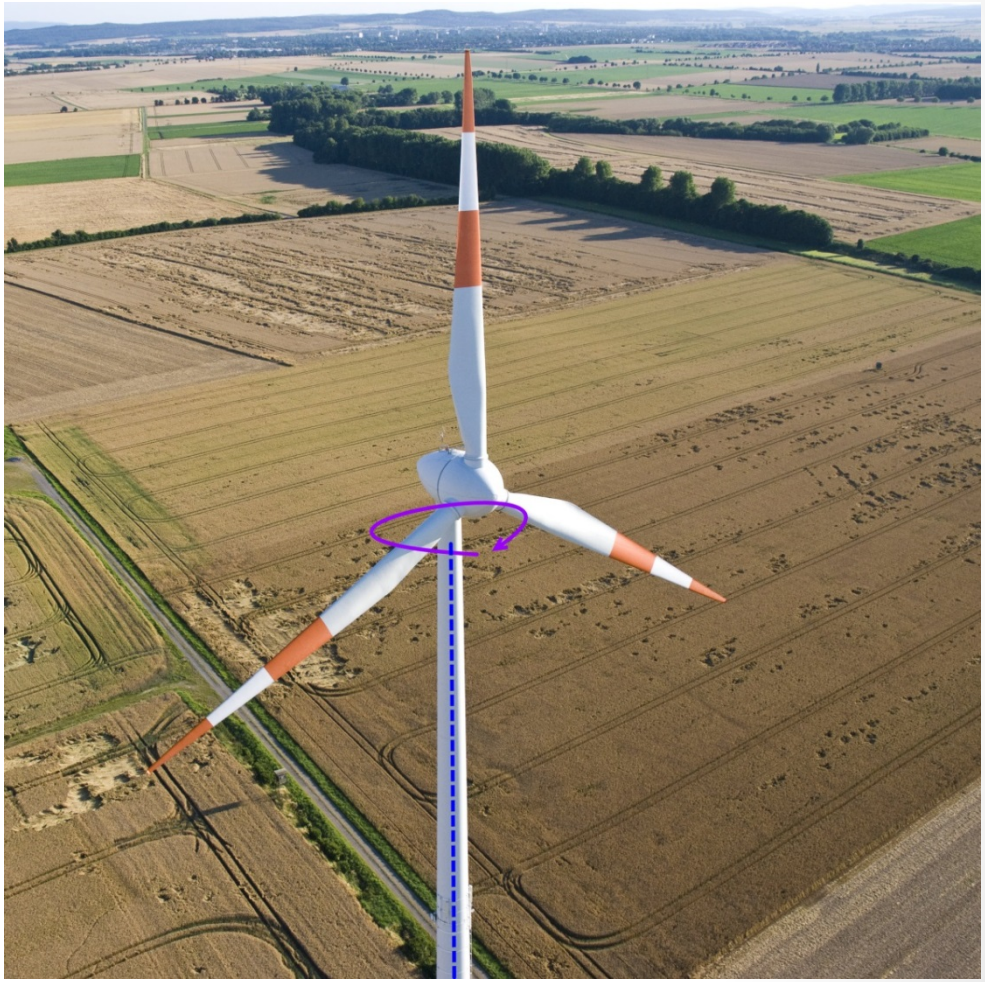
Churchfield, M., et al. *A Large-Eddy Simulation of Wind-Plant Aerodynamics.* National Renewable Energy Laboratory.

Problem

In the Wake of a Wind Turbine. National Oceanic and Atmospheric Administration. http://www.noaanews.noaa.gov/stories2011/20110426_windwakes.html

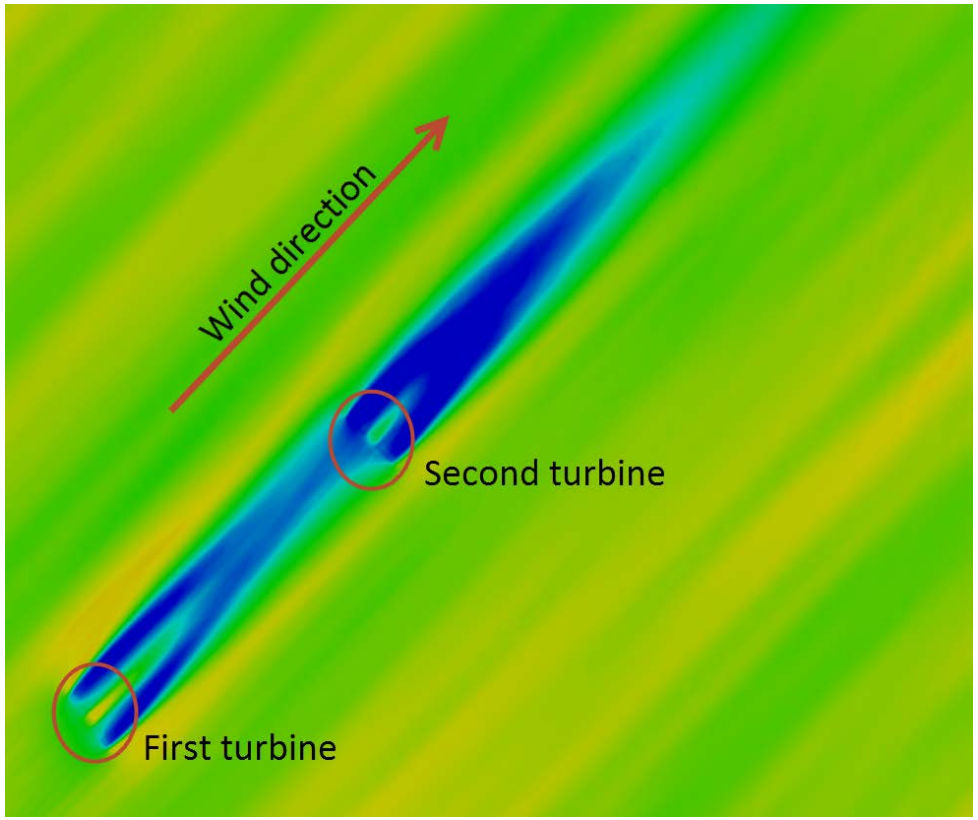
Proposed Solution

- Yawing
  - Rotating the turbine so it's not directly facing the wind
  - 0° yaw means the turbine is facing the wind
  - **Reduce wake loss, therefore increase power output**



https://commons.wikimedia.org/wiki/File:Windrad-Wind-Turbine.jpg

Methodology



- In this study, a two turbine layout was tested
  - First turbine: constant yaw of 10° clockwise
  - Second turbine: yawed from 0° to 50° in steps of 5° (also clockwise)

Methodology

- Computer simulations
  - OpenFOAM
    - Open Source Field Operation and Manipulation
    - Computational fluid dynamics (CFD) simulator
  - SOFWA
    - Simulator for Offshore Wind Farm Applications
    - Add-in for OpenFOAM
    - Developed by the National Renewable Energy Laboratory

Methodology

- Two steps to performing simulation
  1) Atmospheric Background Layer (ABL) generated
     - No turbines present
     - Model of typical wind conditions at the wind farm site
     - The ABL was generated before this study

Methodology

- Two steps to performing simulation
  2) The two turbines were added to the site
     - The ABL data serves as the initial conditions
     - Simulation was run for 500 seconds
       - Only the last 400 seconds of data was used in order to allow transients to die out

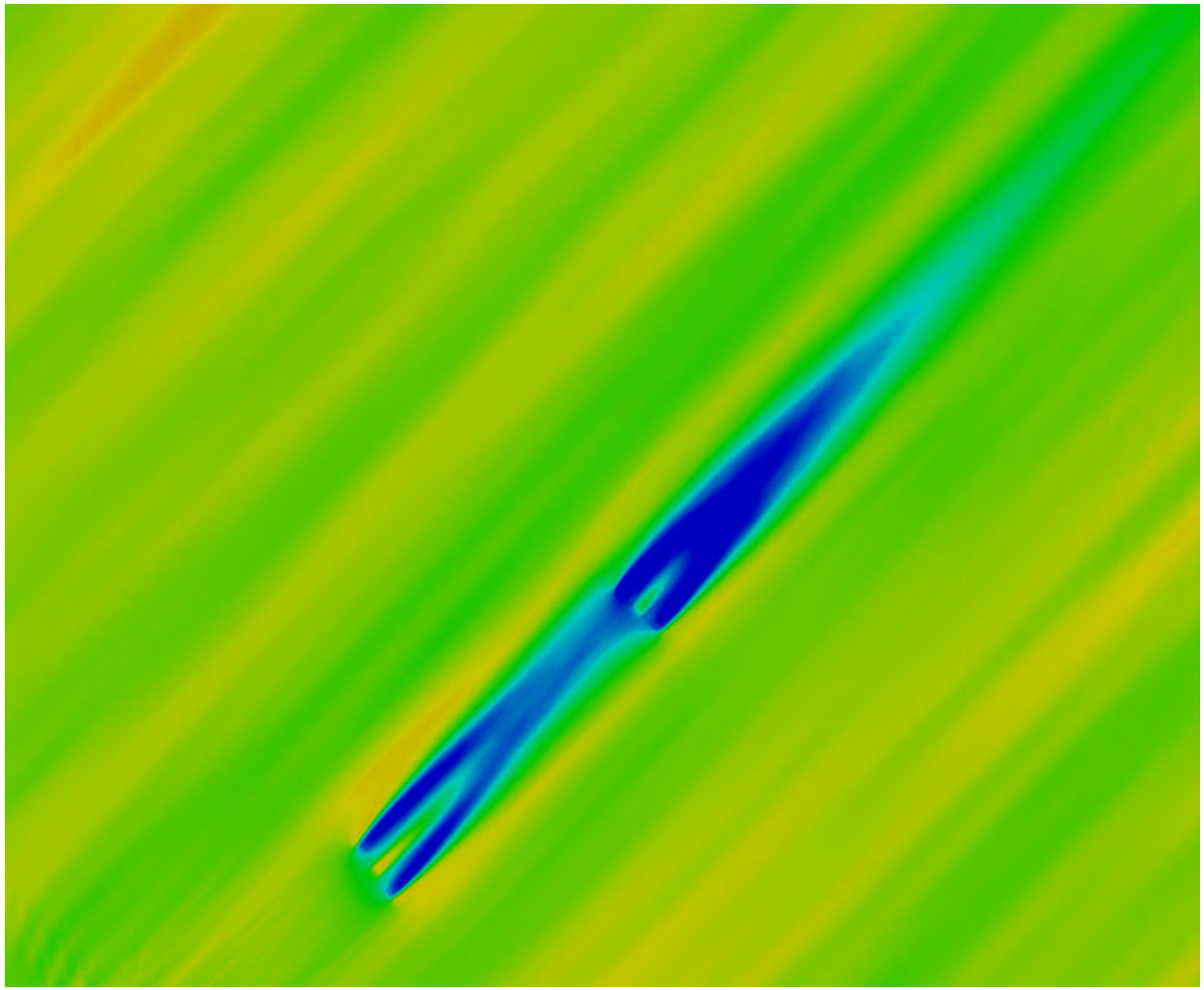
Methodology

- Computing resources
  - UNCC high performance computing cluster VIPER
    - 492 computing cores
    - 1600 GB RAM
    - 39 TB storage space
  - Each simulation was run on 48 cores
  - Each simulation took about 36 hours to complete

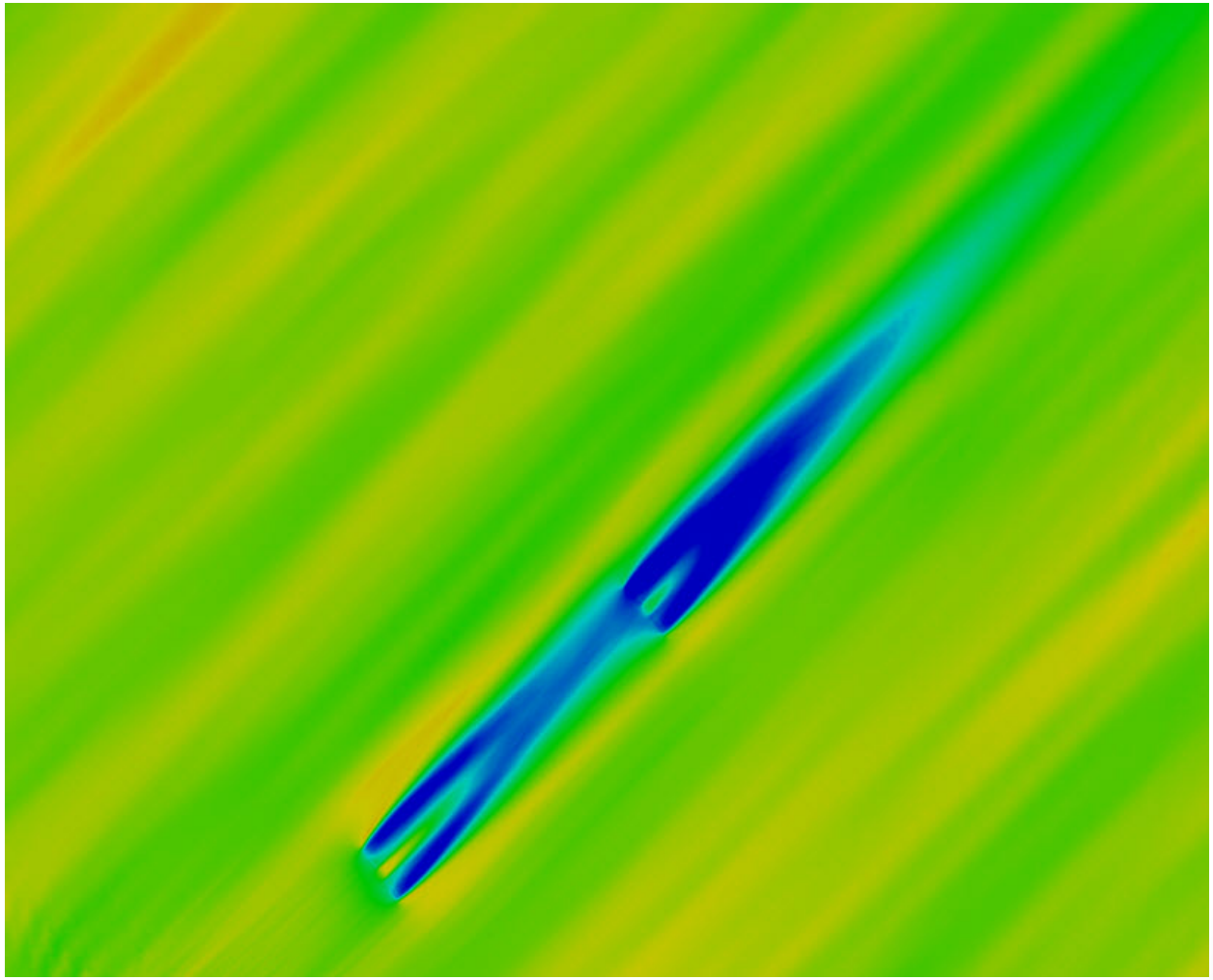
Results

1) Power output of the second turbine decreased with increasing yaw angle
2) The wake intensity behind the second turbine decreased with increasing yaw angle
3) The wake deflection behind the second turbine increased with increasing yaw angle

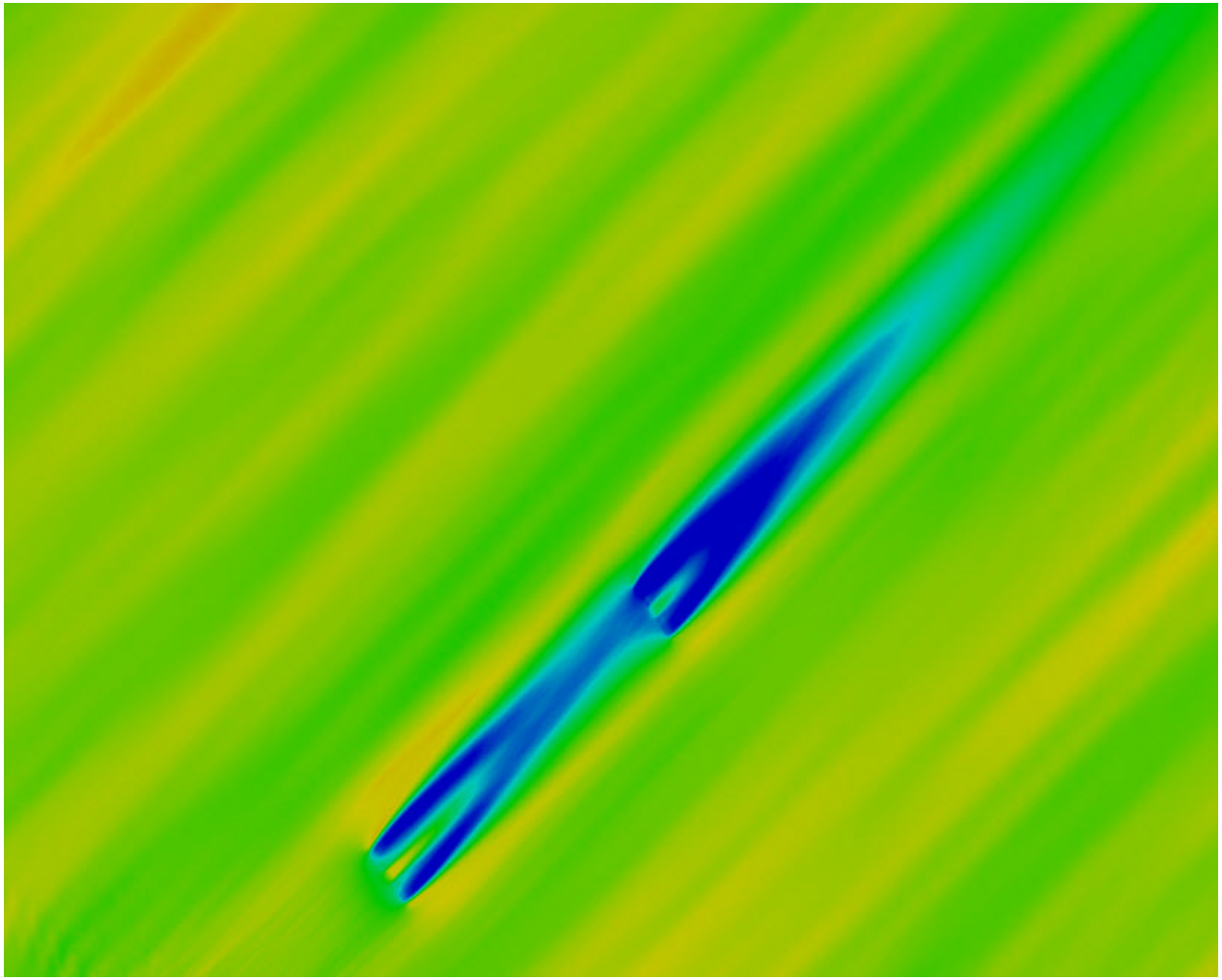
Results - 0° yaw



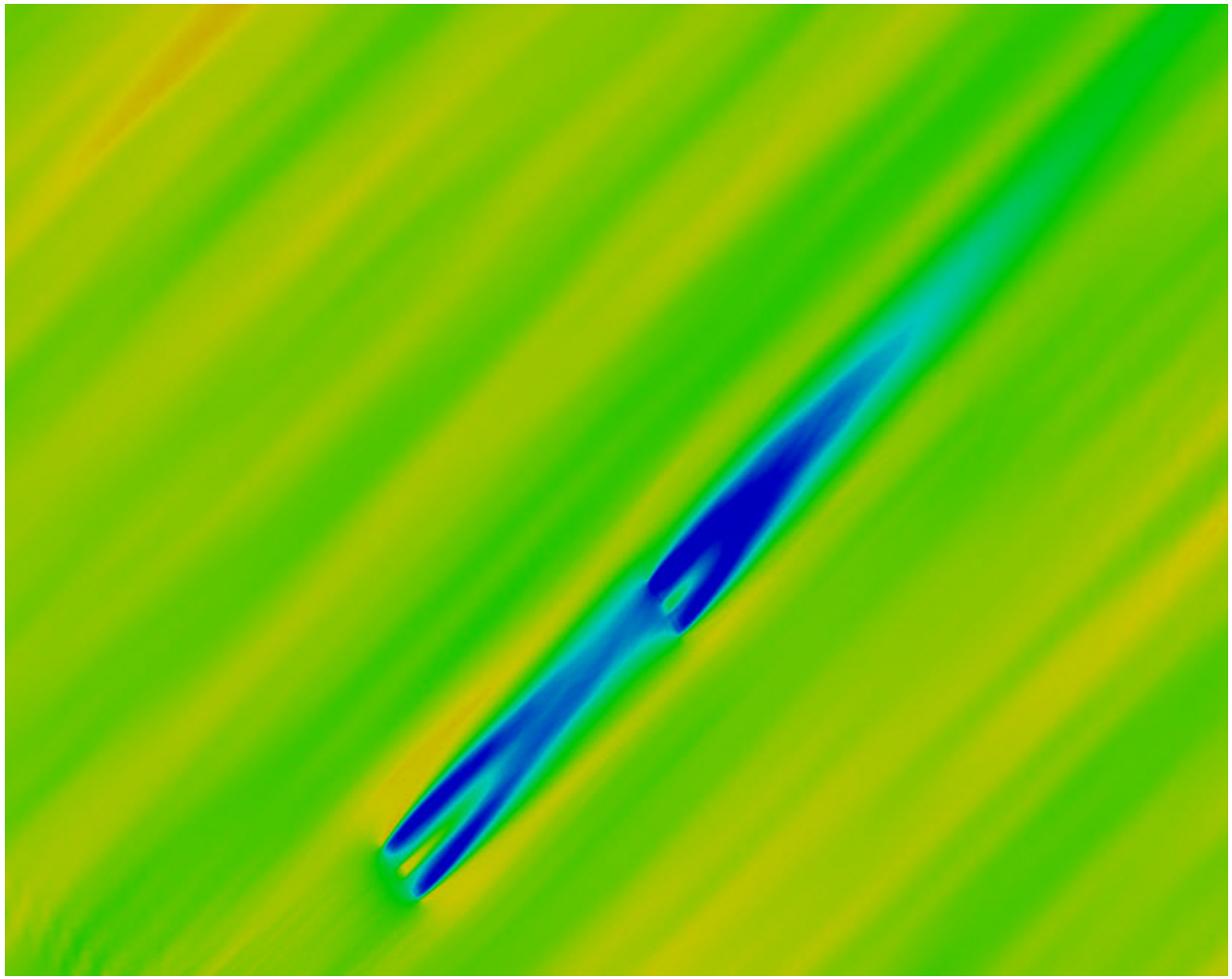
Results - 5° yaw



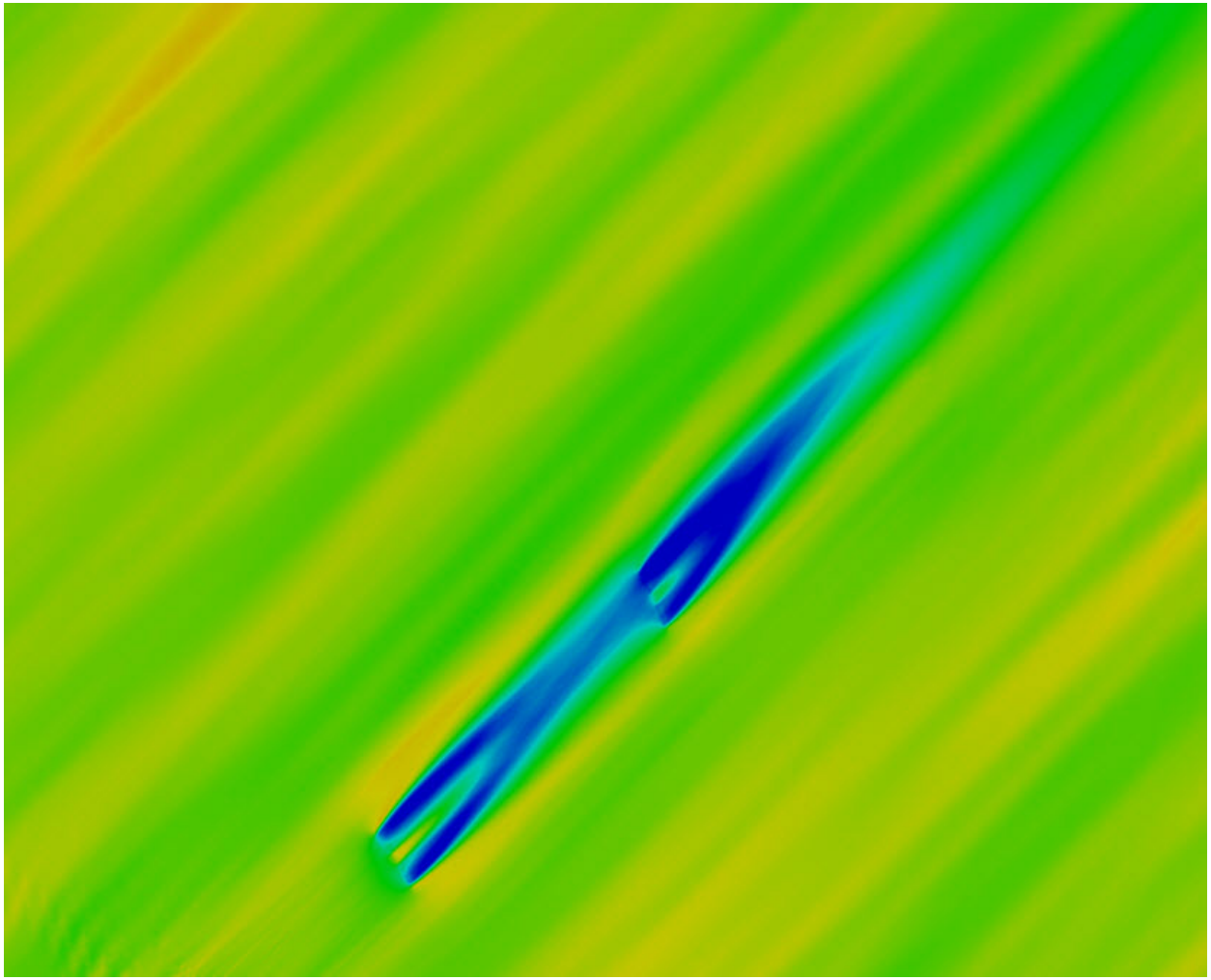
Results - 10° yaw



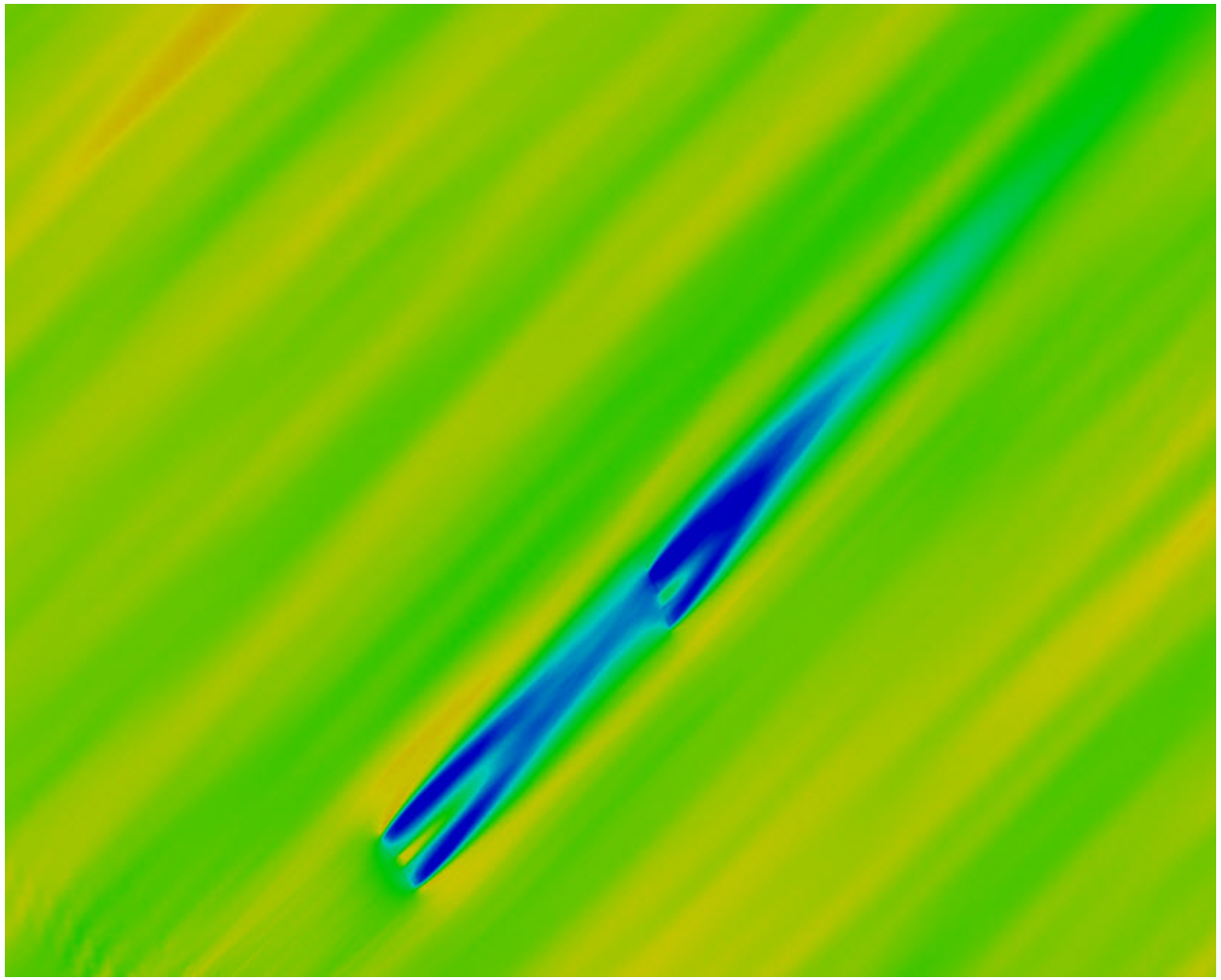
Results - 15° yaw



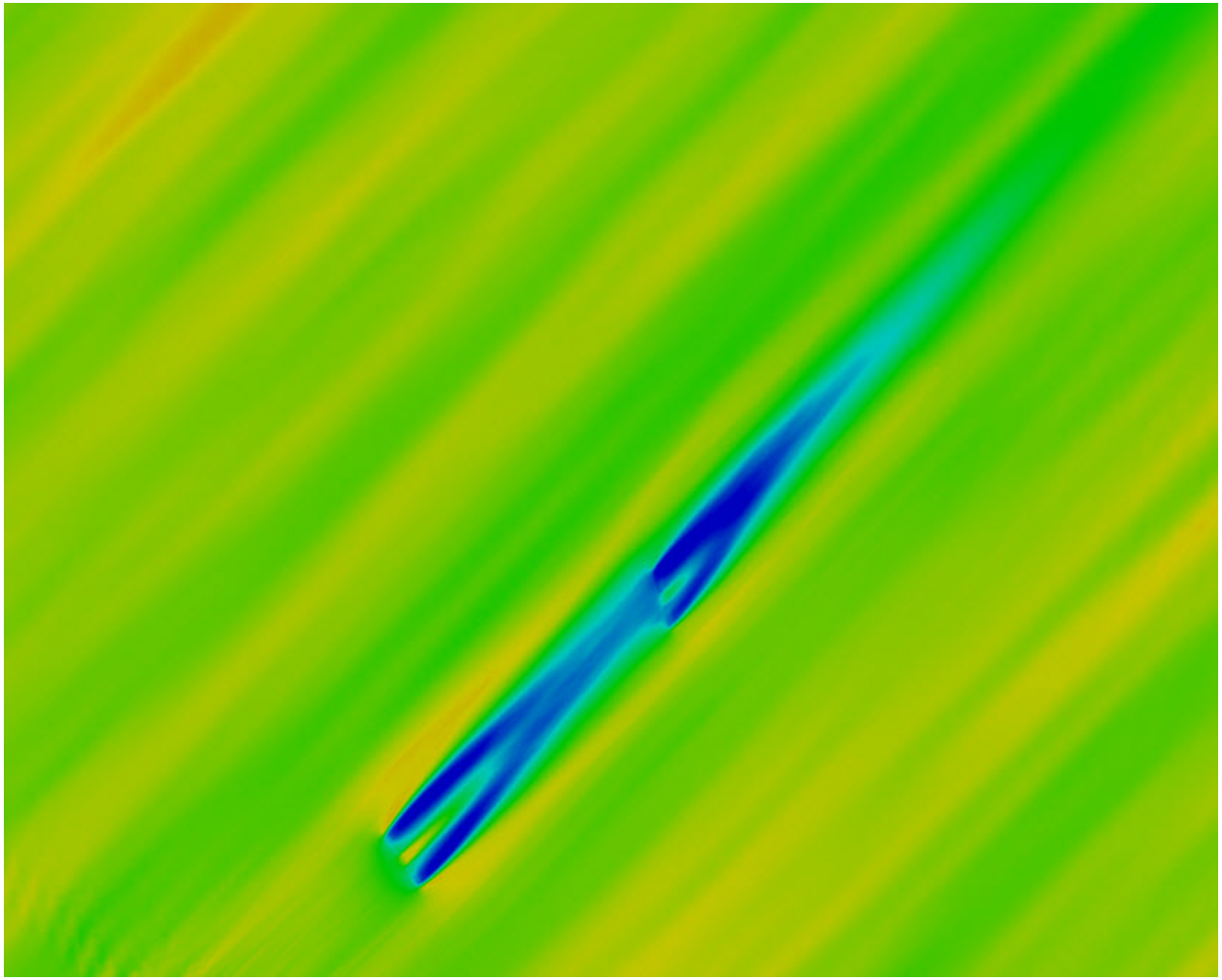
Results - 20° yaw



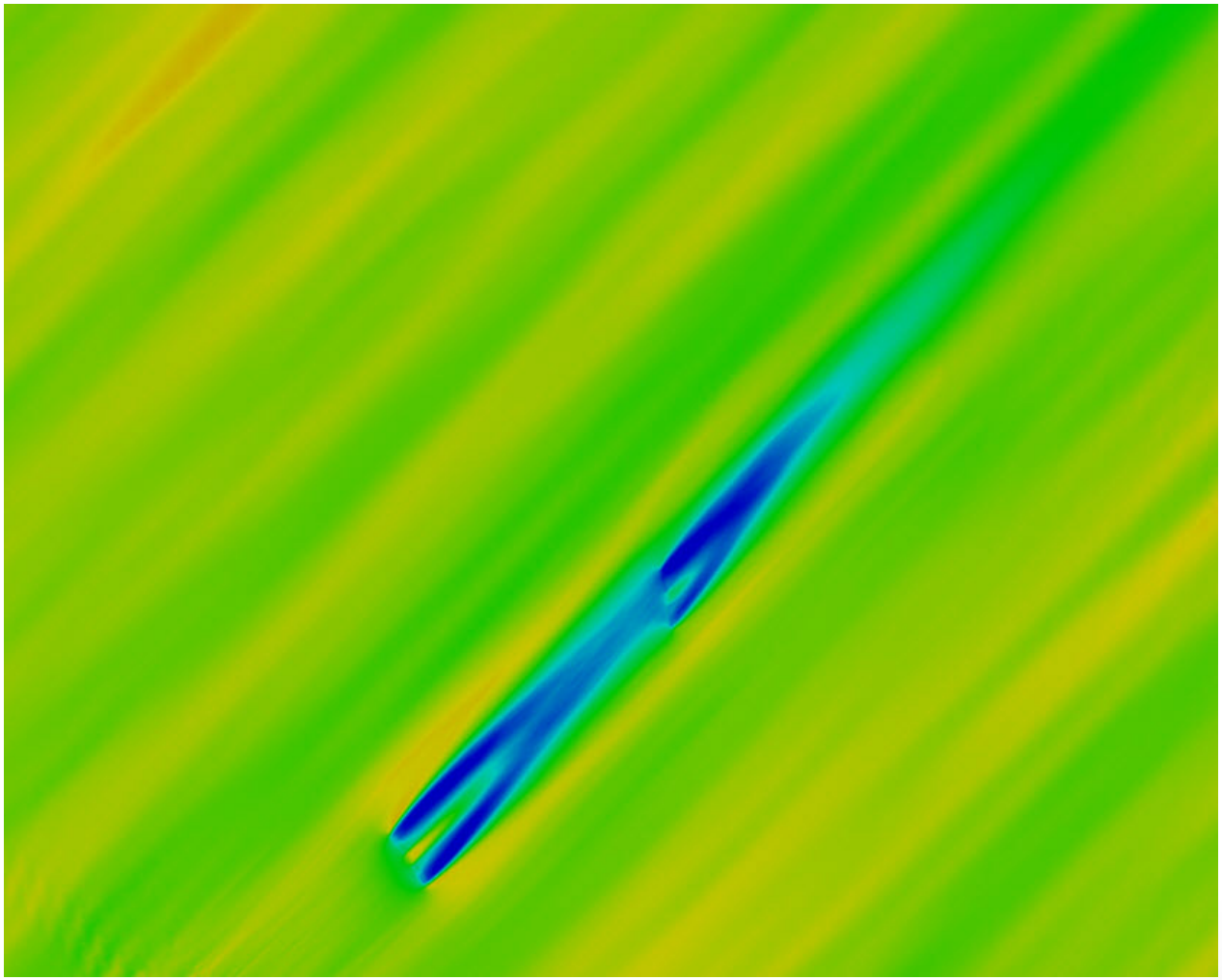
Results - 25° yaw



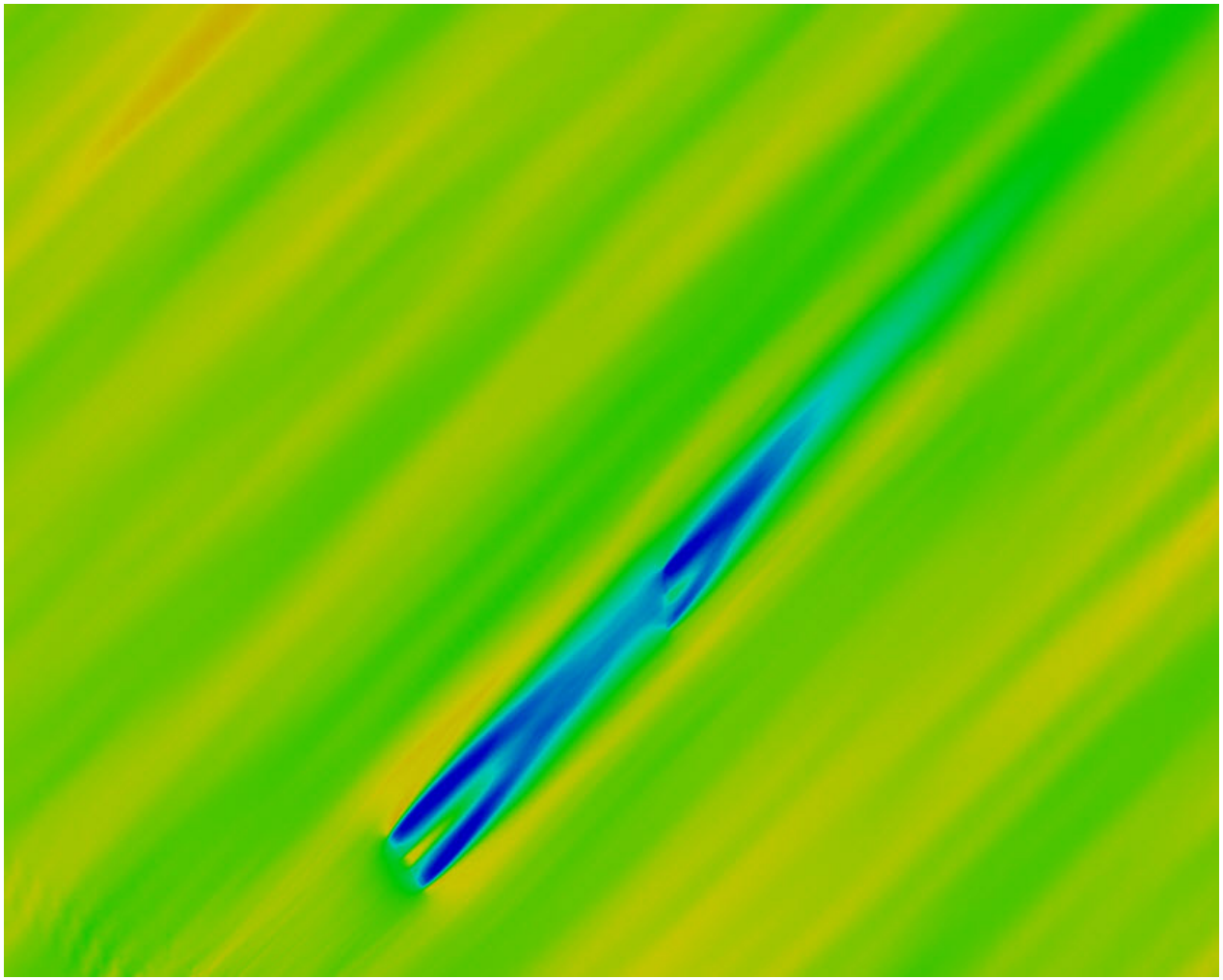
Results - 30° yaw



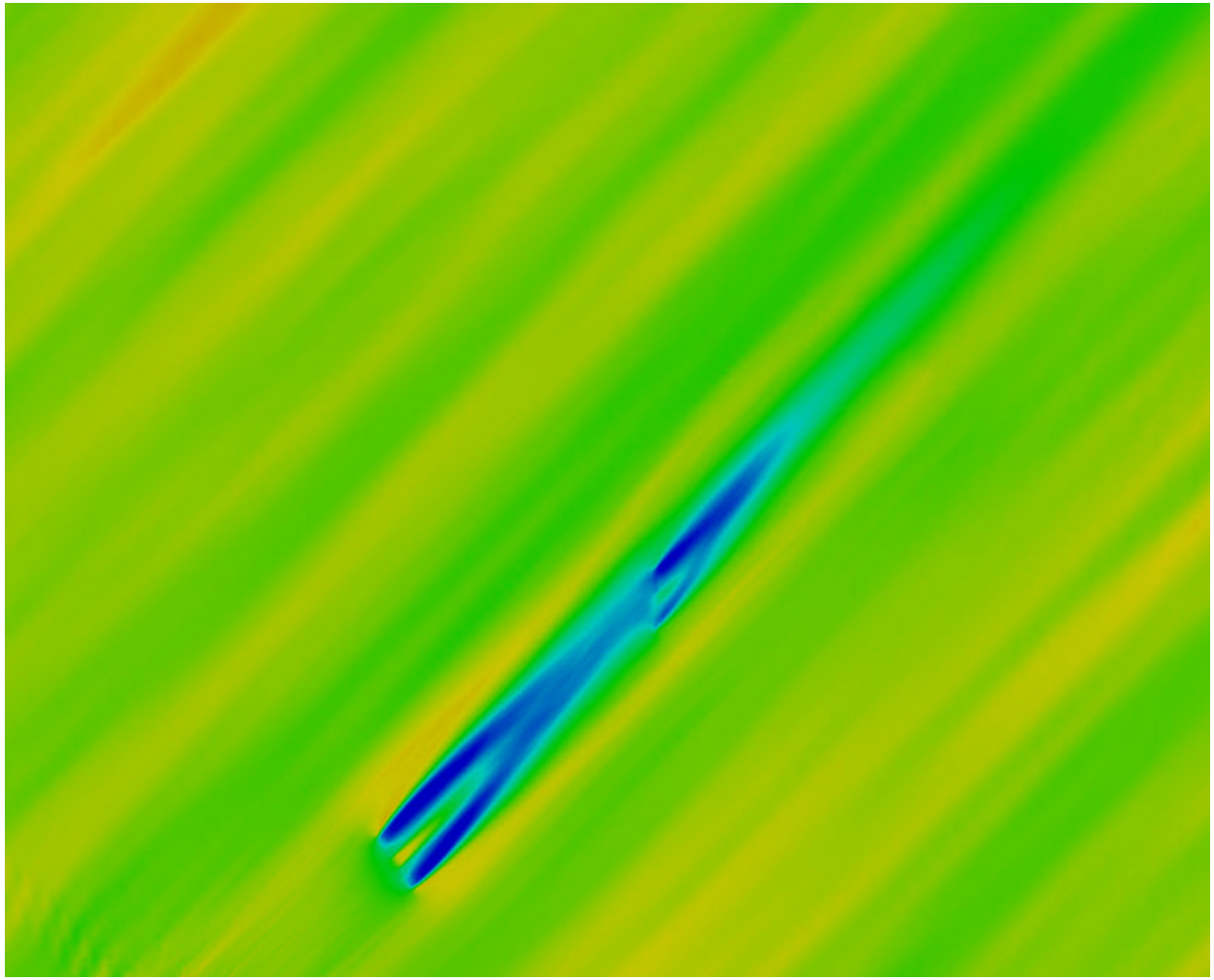
Results - 35° yaw



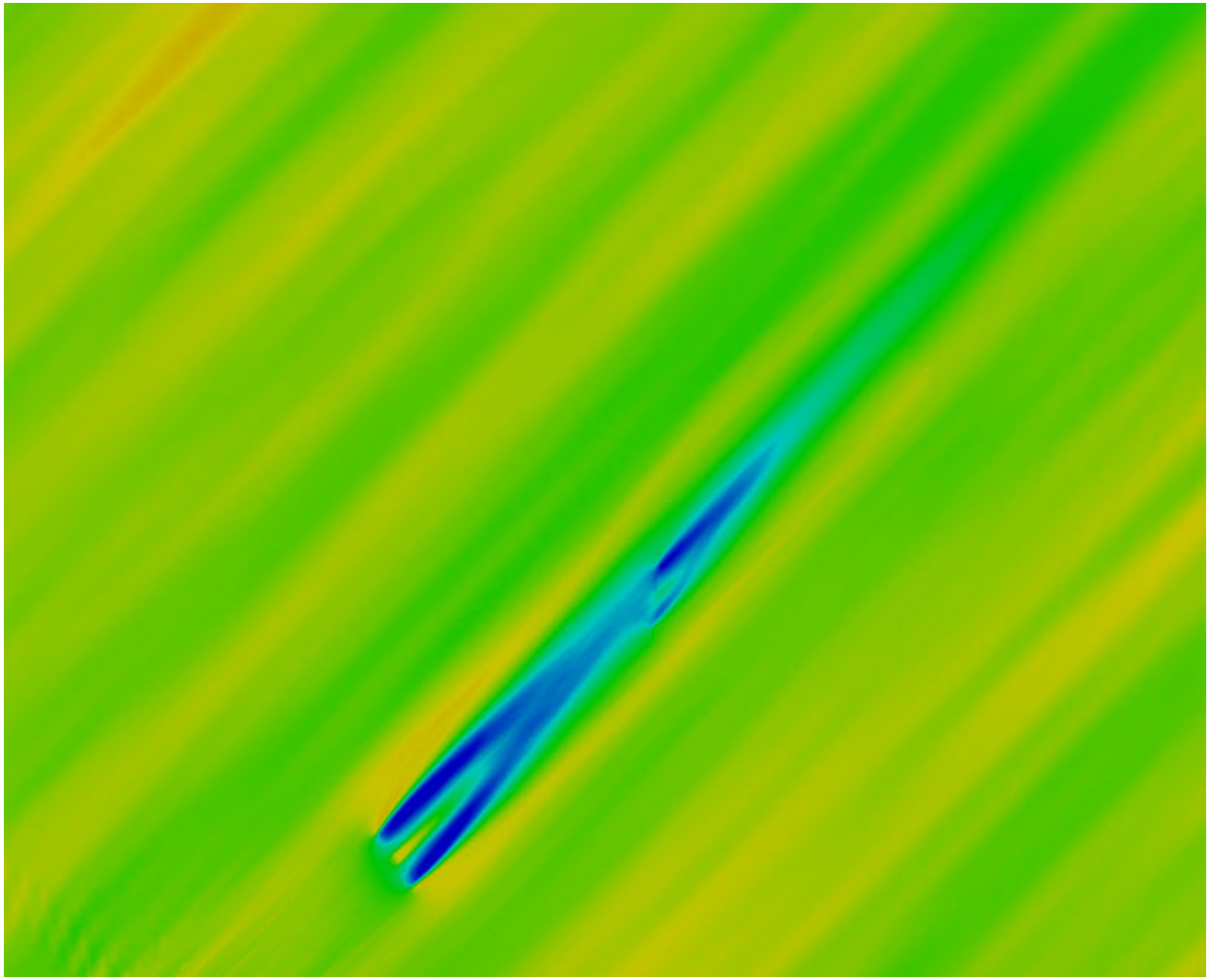
Results - 40° yaw



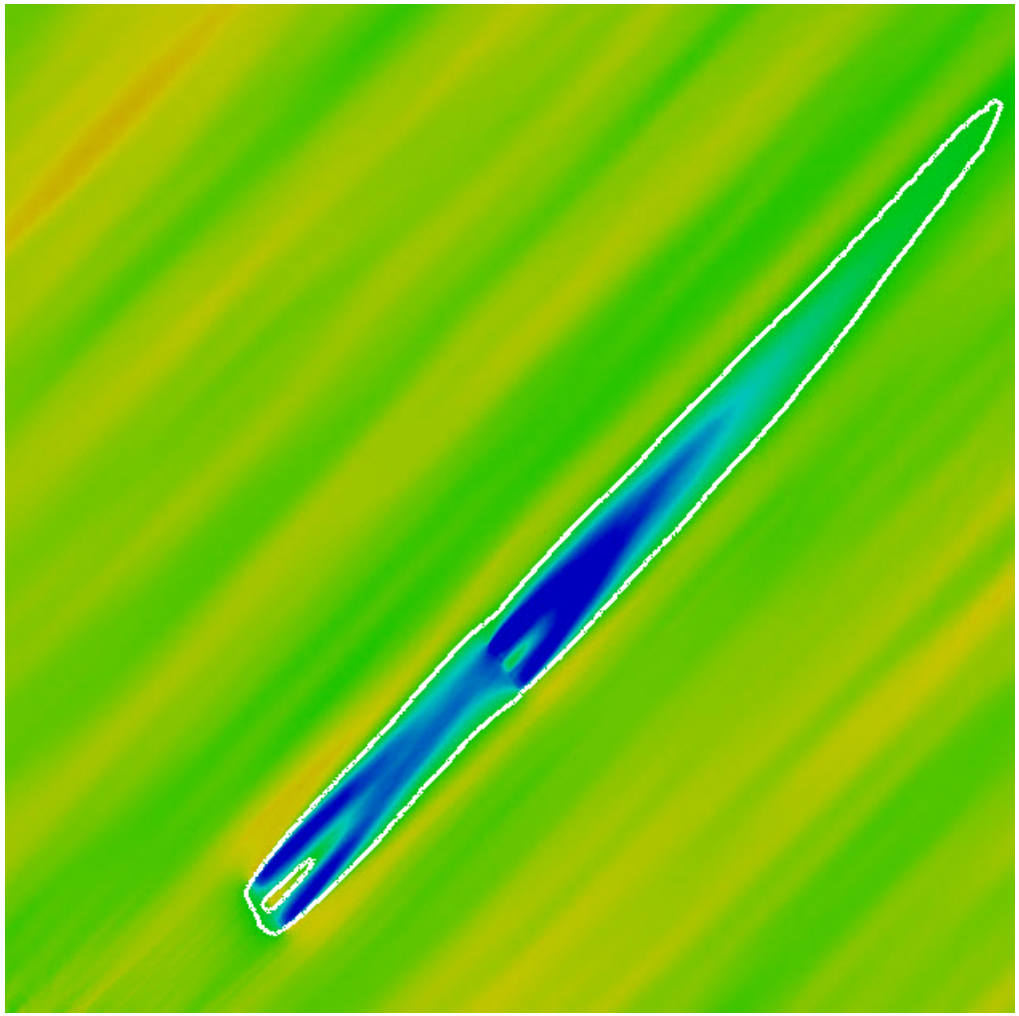
Results - 45° yaw



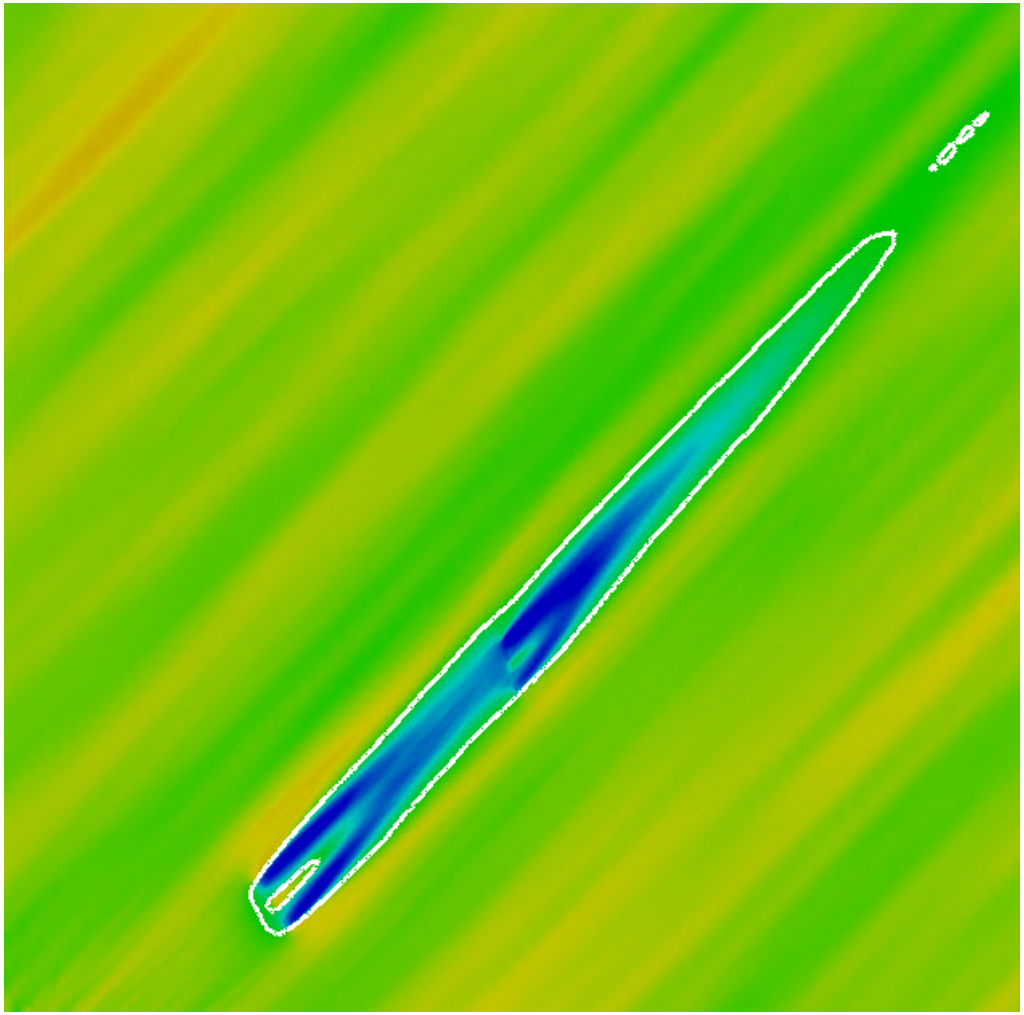
Results - 50° yaw



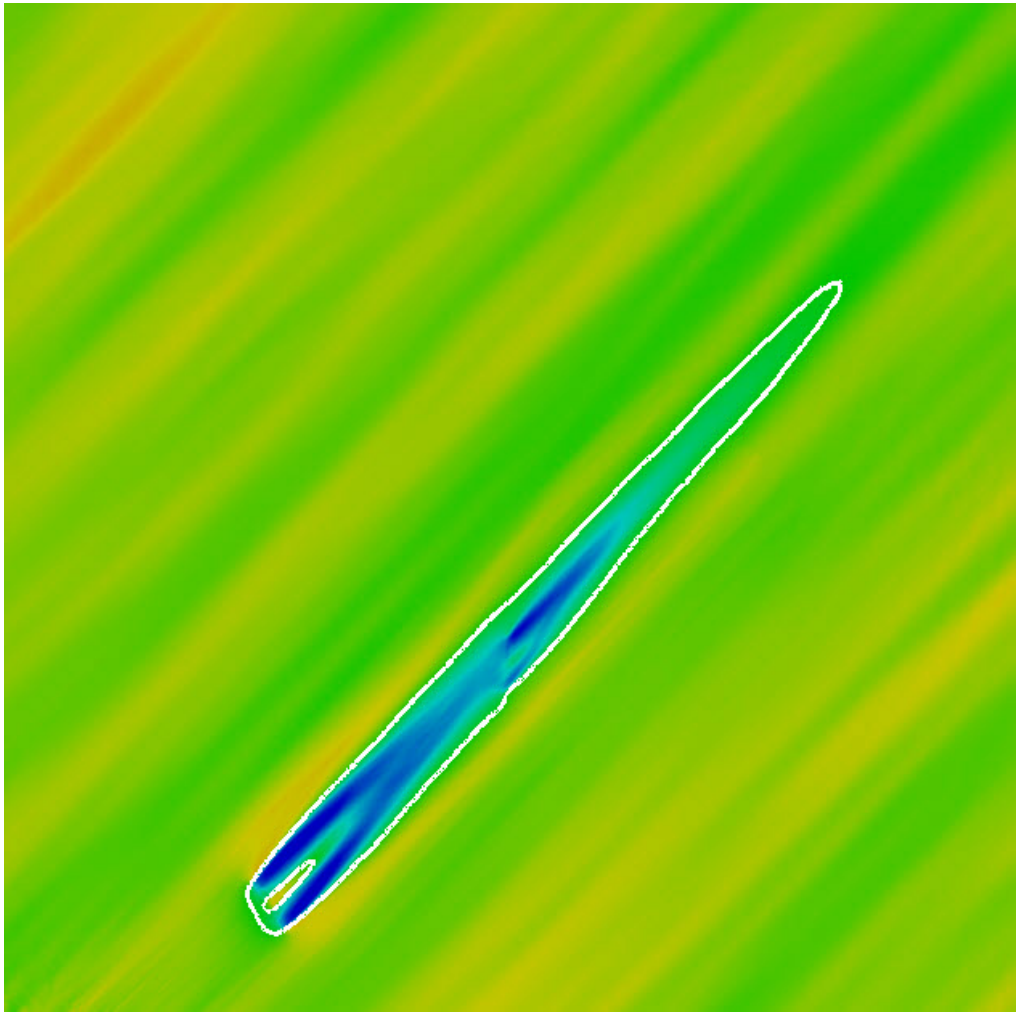
Results - 10° yaw, 8 m/s contour



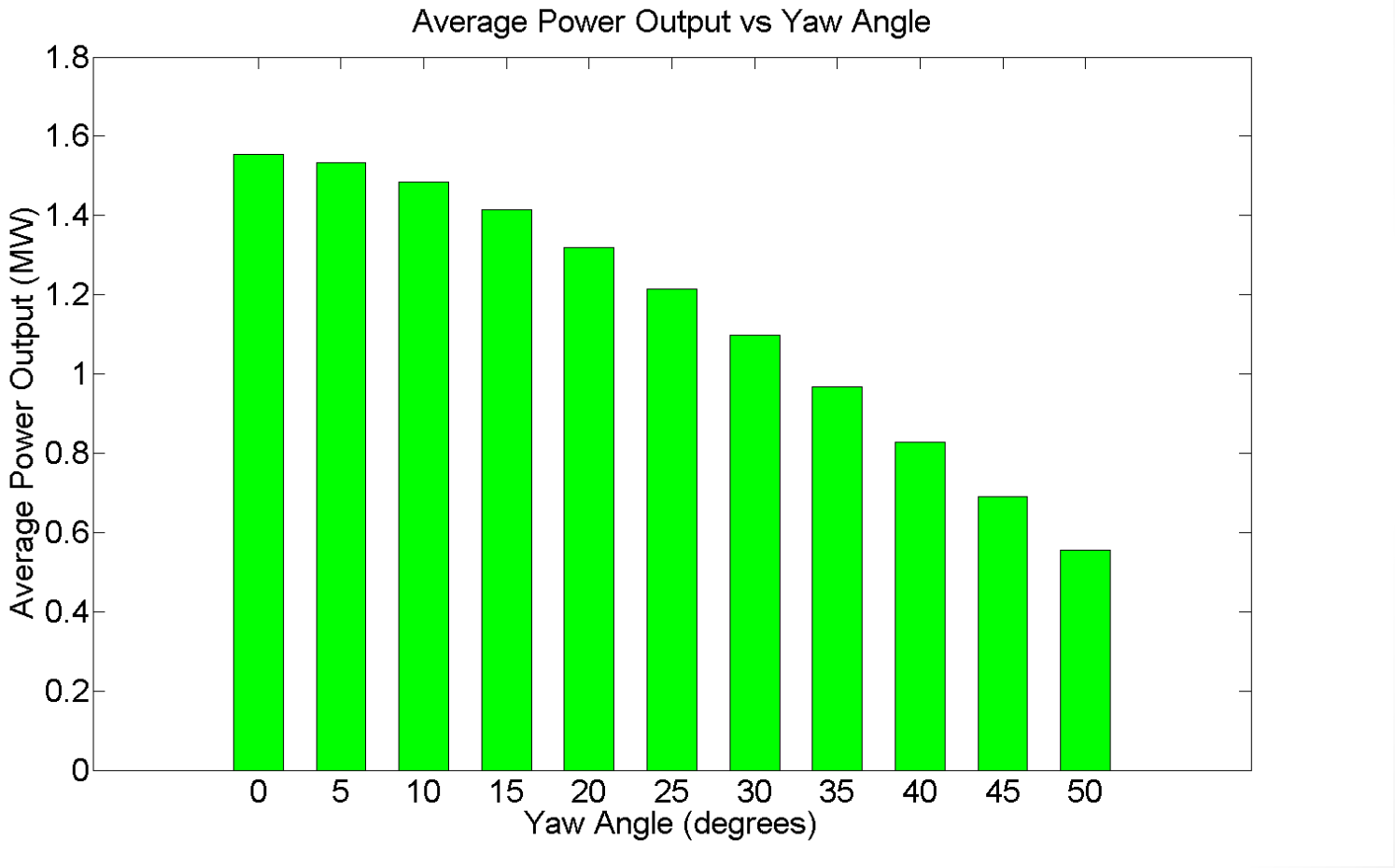
Results - 30° yaw, 8 m/s contour



Results - 50° yaw, 8 m/s contour



Results


Average Power Output vs Yaw Angle
Average Power Output (MW)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40
45
50
Yaw Angle (degrees)

Conclusions

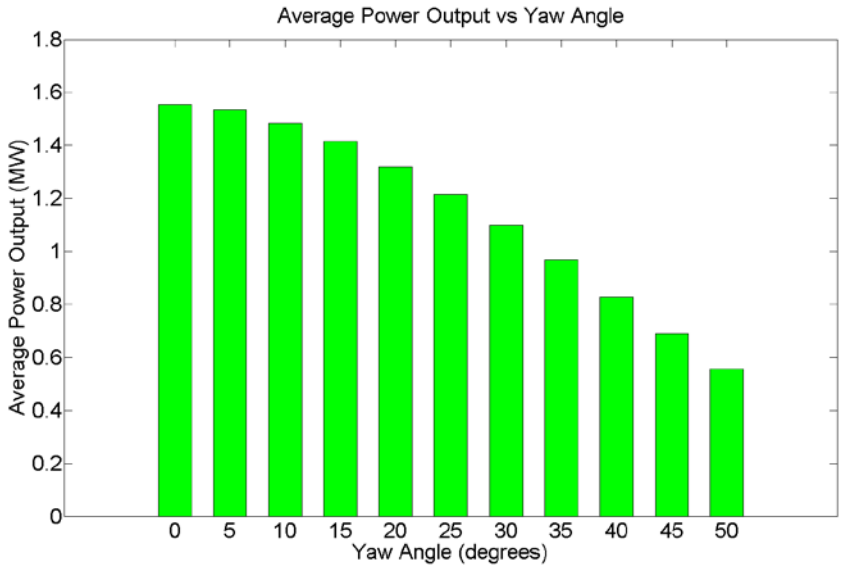
- While yawing a wind turbine will deflect and reduce the intensity of its wake, it will also reduce its power output

Conclusions

- This suggests that **large yaw angles** throughout a wind farm are undesirable
  - The wake effect would be reduced
  - But, it probably wouldn’t compensate for the reduced power output of each turbine
  - Most likely a net power decrease compared to a wind farm whose turbines aren’t yawed

Conclusions

- What about **small yaw angles**?
- Small yaw angles reduce the wake effect, but power output is still somewhat decreased in the turbine being yawed
- Our goal is to increase power output!



Conclusions

- Small yaw angles could be used in multiple turbines in a line
  - Each turbine could deflect the wake a little bit, adding to the wake deflection caused by the turbine before it
- Could result in a net power increase compared to a wind farm whose turbines aren’t yawed

Other Considerations

- Turbulence Intensity (TI)
  - A measure of fluctuations in wind flow
  - Higher TI = more “unstable” wind
- High TI upstream of a turbine
  - Excessive fatigue loads on blades

Questions