Contextual Compression of Large-Scale Wind Turbine Array Simulations

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Motivation

buoyant plume:
entailing dryer air, as a result of
downward momentum, temperature, and moisture fluxes
and stronger winds near the surface

narrower wake
growth due to
stronger winds

significant lateral
wake growth likely
due to weaker
winds at right

Vertical velocity in wake
cools air forming cloud.
Latent heat is released
creating vertical buoyant
plumes and wave motions.

strong 3-D turbulent
mixing region

moist area near sea surface
capped by marine inversion

horizontal wind speed gradient?

conceptual analysis by N. Kelley, NREL
Background: Turbine Wake Effects

Downstream turbines
• Reduced power performance (50-60%)
• Higher gearbox forces (30%)
• Shorter lifespans
Data

- Minimum size: 3000m x 3000m x 1000m
- Uniform grid w/ wesolution ~1m
  - ~ 100 GB/timestep/variable

- Unstructured “nested” grid
  - 10m atmosphere
  - 1m to capture wake dynamics
  - ~4 GB/timestep/variable + ~40 GB of metadata
Objective

Show the detailed flow of the turbine wakes in the context of the atmospheric conditions.
Visualization and Analysis Platform for Ocean, Atmosphere, and Solar Researchers

www.vapor.ucar.edu
Example: Two Turbine Uniform Case

<table>
<thead>
<tr>
<th>Original (Full) Fidelity</th>
<th>Block-wise Compressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>112 GB</td>
<td>5.8 GB</td>
</tr>
</tbody>
</table>

3008m x 3008m x 1024m @ 1m resolution
9.2 billion cells
### 48 Turbine Case

<table>
<thead>
<tr>
<th></th>
<th>Unstructured grid</th>
<th>Uniform grid</th>
<th>Mixed Resolution VDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconstruction</td>
<td>n/a</td>
<td>CPU</td>
<td>CPU</td>
</tr>
<tr>
<td>Frame rate</td>
<td>*</td>
<td>0.5 fps</td>
<td>0.5 fps</td>
</tr>
<tr>
<td>Render time</td>
<td>*</td>
<td>2s</td>
<td>2s</td>
</tr>
<tr>
<td>Time to frame</td>
<td>hours</td>
<td>360s</td>
<td>300s</td>
</tr>
<tr>
<td>ū volume size</td>
<td>3.9 GB</td>
<td>38.7 GB</td>
<td>3.7 GB</td>
</tr>
<tr>
<td>Metadata size</td>
<td>39.9 GB</td>
<td>673 KB</td>
<td>674 KB</td>
</tr>
</tbody>
</table>
Custom GPU Renderer

Low Fidelity Texture

High Fidelity Texture
## 48 Turbine Case

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</tr>
</thead>
<tbody>
<tr>
<td>Reconstruction</td>
<td>n/a</td>
<td>CPU</td>
<td>CPU</td>
<td>GPU</td>
</tr>
<tr>
<td>Frame rate</td>
<td>*</td>
<td>0.5 fps</td>
<td>0.5 fps</td>
<td>3-12 fps</td>
</tr>
<tr>
<td>Render time</td>
<td>*</td>
<td>2s</td>
<td>2s</td>
<td>0.08-0.33s</td>
</tr>
<tr>
<td>Time to frame</td>
<td>hours</td>
<td>360s</td>
<td>300s</td>
<td>70s</td>
</tr>
<tr>
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Contextualized Compression

Original Fidelity

- expanding lateral wake growth
- strong 3D turbulent mixing
- low-velocity flow

Compression Boundary

- high-velocity flow
- approaching low-velocity turbulent flow

Compressed Context

- narrow lateral wake growth

`t = 12210`

`t = 12230`
Acknowledgements

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