Understanding the Development and Evolution of Violent Tornadoes in Supercell Thunderstorms

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The problem

- Supercell thunderstorms produce the strongest tornadoes (Joplin, MO; Moore, OK; Greensburg, KS; El Reno, OK).
- We still don't understand why a very small subset of supercells produce long-path tornadoes producing surface winds in excess of 200 mph
- Worse yet, we don't really understand the processes leading to tornadoes in general; around one quarter of supercells are observed to produce tornadoes at all
- Overarching goal: *To understand the internal workings of nontornadic, weakly tornadic, and strongly tornadic supercell thunderstorms well enough to significantly improve our forecasting of supercell behavior*

Why it matters

- Currently the National Weather Service has a false alarm rate for tornado warnings of about 70%
- There are cases also where no warnings is given, and yet a tornado occurs
- Large majority of fatalities occur in EF4-EF5 strength tornadoes, which is why we are first focusing on simulating these rare, powerful storms
- Despite advances in observational and computational meteorology, why some supercells produce no / weak / strong tornado is not currently understood

Breakthrough tornado simulations

- Our team first accessed Blue Waters during the friendly user period
- Initially work focused on modifying the CM1 model code to improve I/O performance and an efficient visualization framework
- It was only at the very end of our first allocation in 2013 that we managed to simulate a supercell that produced a long-track EF5
- After some bumps in the road we managed to get good datasets with frequently saved data

Recent work

- We have simulated the 24 May 2011 EF5 tornado producing supercell at 30, 20, and 15 meter grid spacing
- Along the way I created a file system (LOFS) to manage all this data, utilizing HDF5 files and ZFP lossy floating point compression
- Our most impressive dataset is 67 TB, containing 32,400 times - saved *every model time step* throughout the entire life of the EF5 tornado

Recent work

- In addition to saving datasets with up to 1/6 second temporal resolution, we have also done temporal averaging of fields to reveal the persistent flow features, while “averaging out” the more sporadic ones.
- **A new theory for tornadogenesis is emerging where no downdraft “trigger” in the rear flank is required, and where there is no real distinction between genesis and maintenance**
- The fantastic simulation, the spatial and temporal resolution of the saved data, and the subsequent visualizations make this “breakthrough” work that only could have happened with long term access to a machine like Blue Waters

Key challenges

1. Getting the model to create the desired storm
2. Managing data - consider that the datasets we have created will be analyzed for many years
3. Making sense of the simulation - we have thus far focused primarily on 3D visualization to “tell a story” before we decide what quantitative techniques to apply to the storm

Accomplishments/Broader Impacts

- Simulations are having an impact on the severe storms community
- Field programs are being conducted that involve looking for the newly identified streamwise vorticity current (Orf et al 2017[1])
- CADENS / AMNH / lots of other PR
- Several journal articles, five grad students working on data
- Hundreds of thousands of views of animations on YouTube

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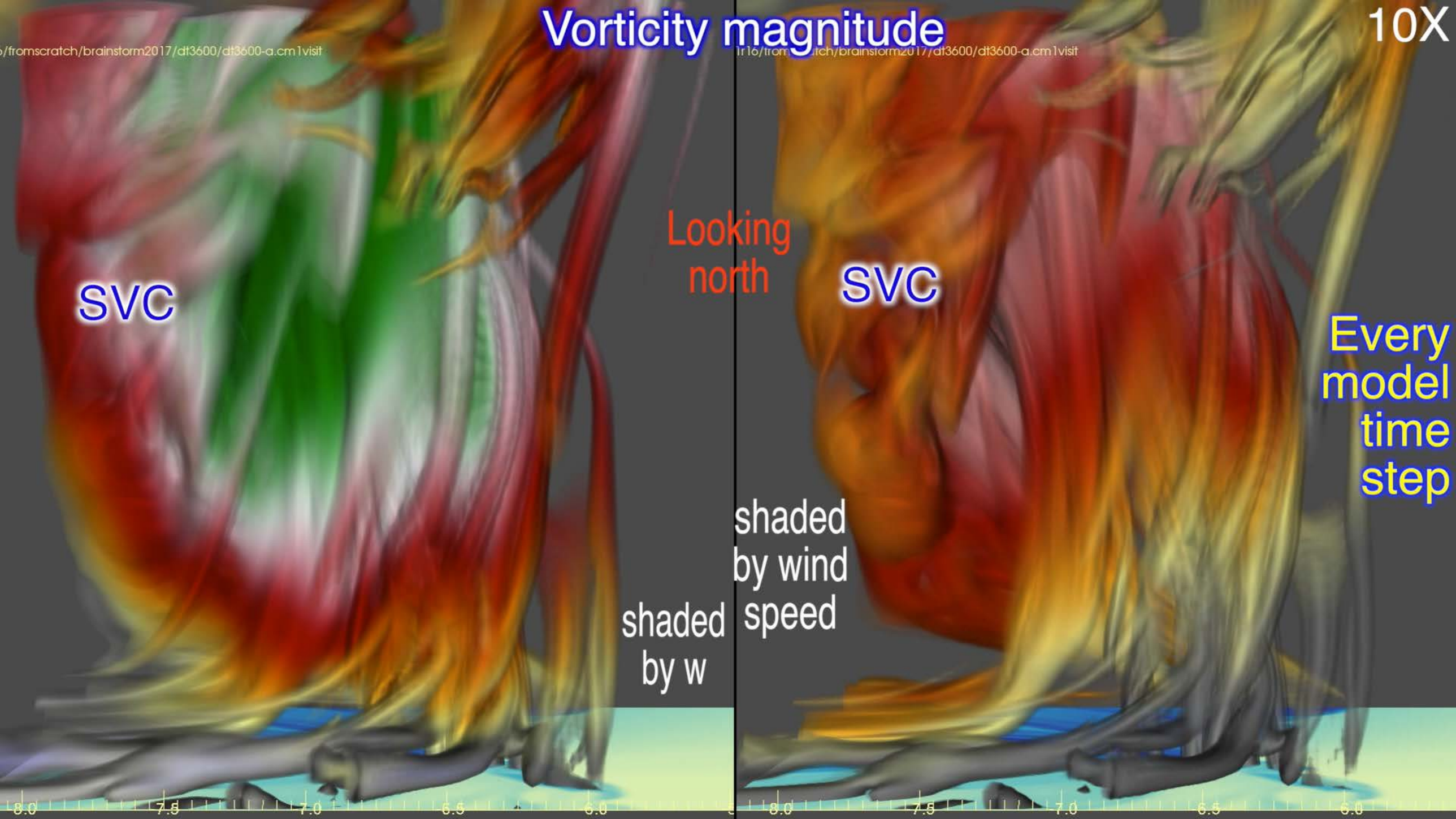
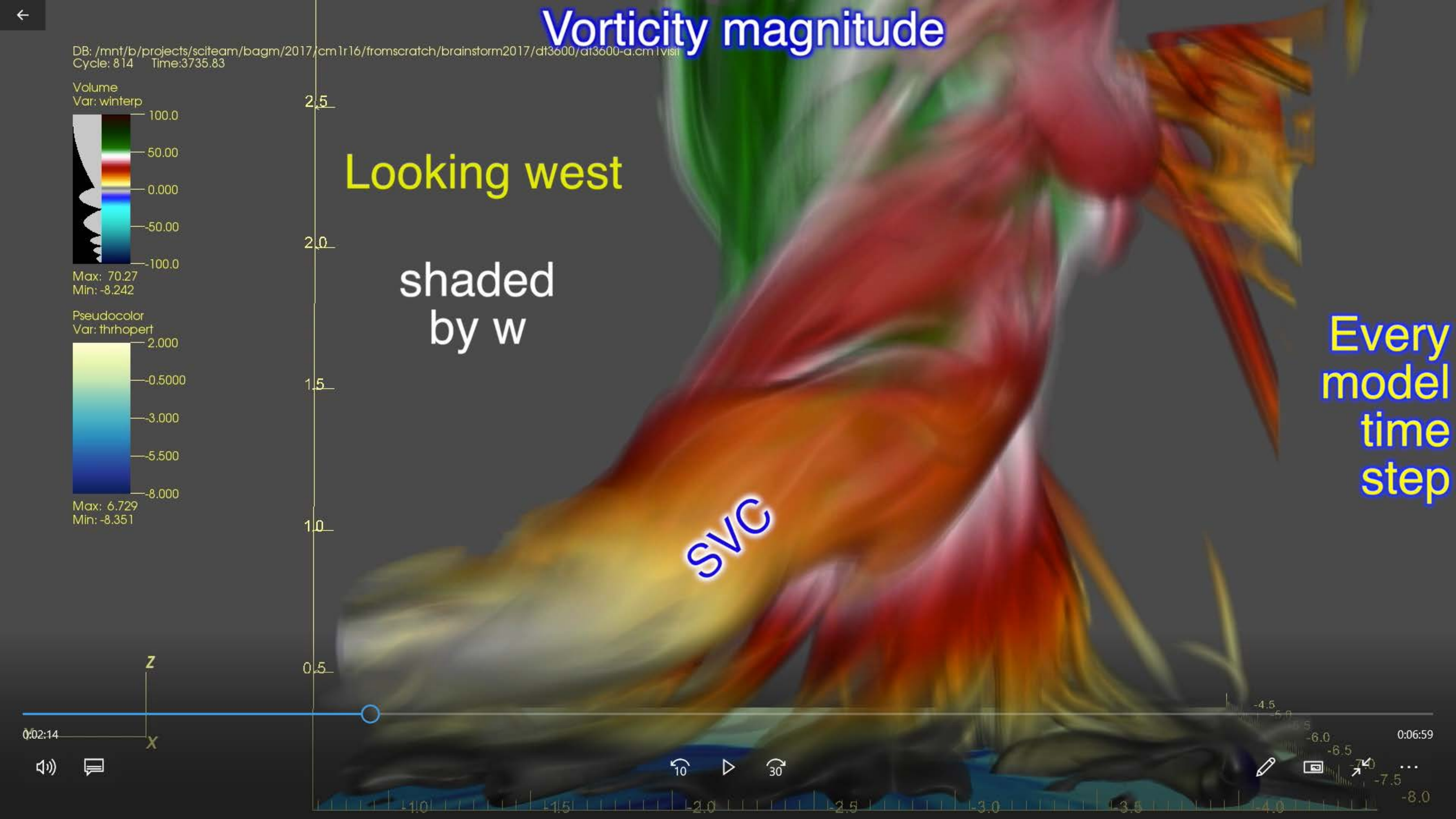
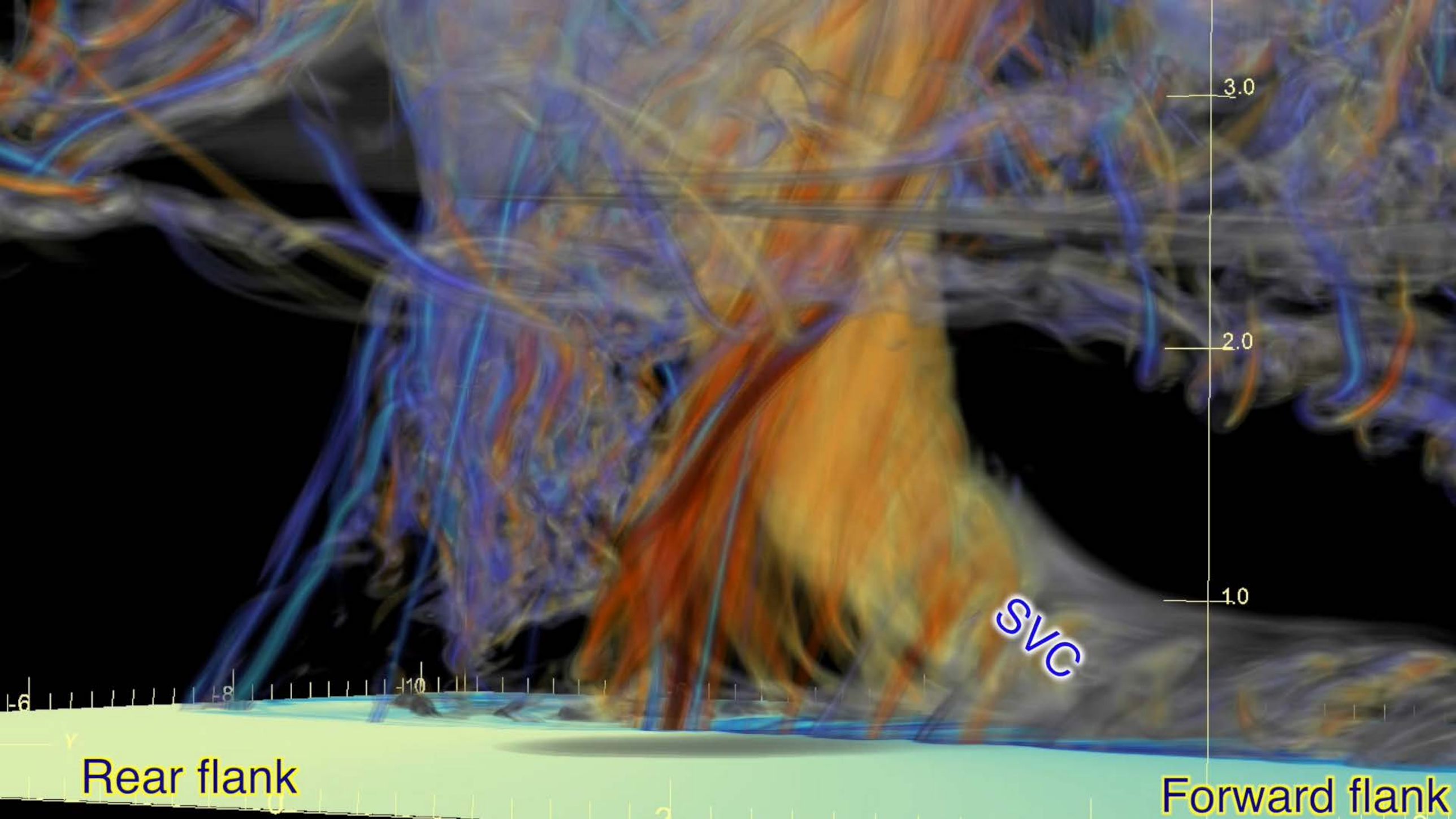
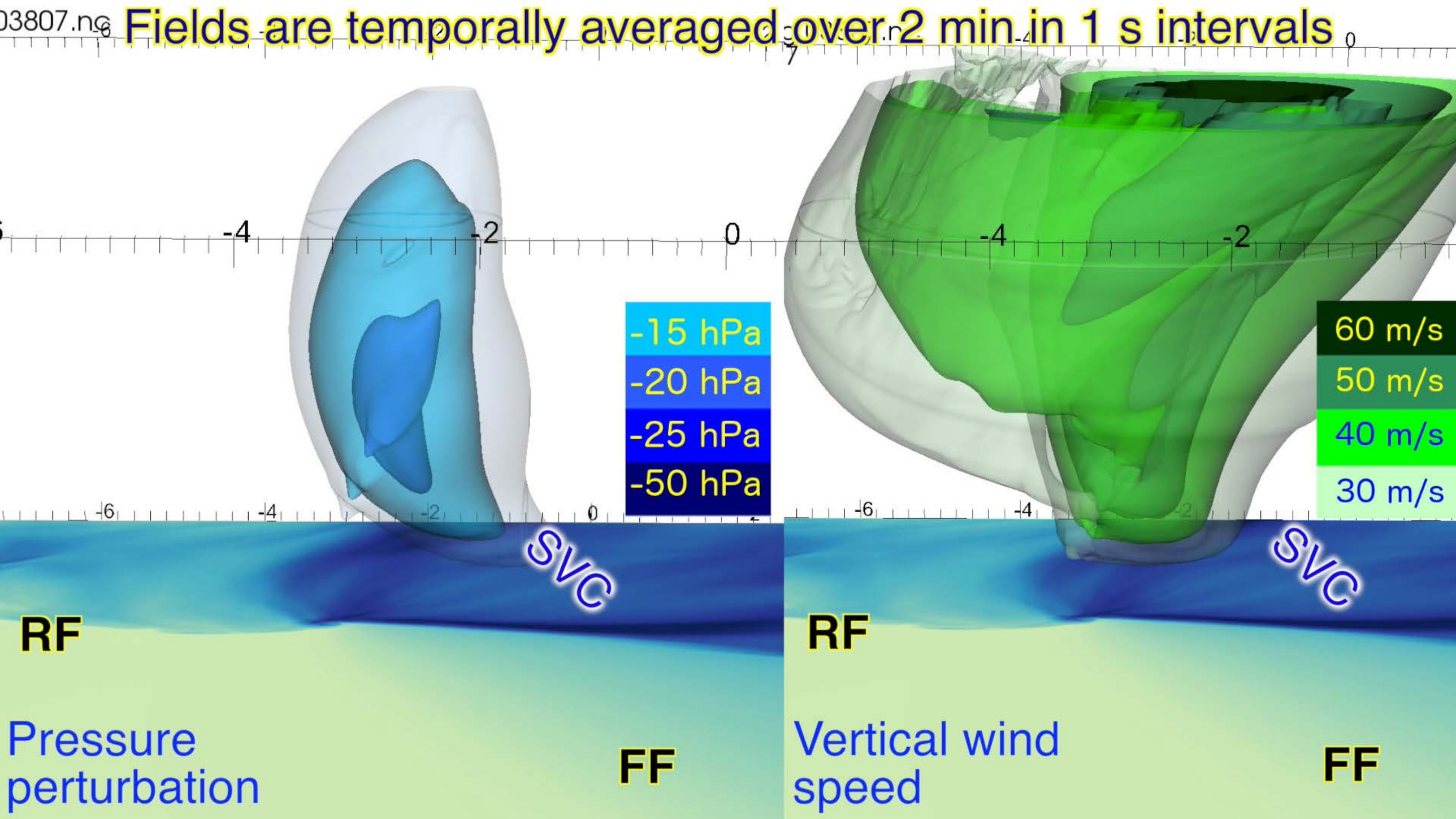
[1] Orf, L., R. Wilhelmson, B. Lee, C. Finley, and A. Houston, 2017: Evolution of a Long-Track Violent Tornado within a Simulated Supercell. Bull. Am. Meteorol. Soc., 98, 45–68.


Vorticity magnitude
10X
/fromscratch/brainstorm2017/dt3600/dt3600-a.cm1visit
SVC
Looking north
shaded by w
SVC
Every model time step
shaded by wind speed
8.0
7.5
7.0
6.5
6.0


Vorticity magnitude
DB: /mnt/b/projects/sciteam/bagm/2017/cm1r16/fromscratch/brainstorm2017/dt3600/dt3600-a.cm1visit
Cycle: 814 Time:3735.83
Volume
Var: winterp
100.0
50.00
0.000
-50.00
-100.0
Max: 70.27
Min: -8.242
Pseudocolor
Var: thrhopert
2.000
-0.5000
-3.000
-5.500
-8.000
Max: 6.729
Min: -8.351
Looking west
shaded
by w
SVC
Every
model
time
step
2.5
2.0
1.5
1.0
0.5
Z
X
0:02:14
0:06:59
10
30

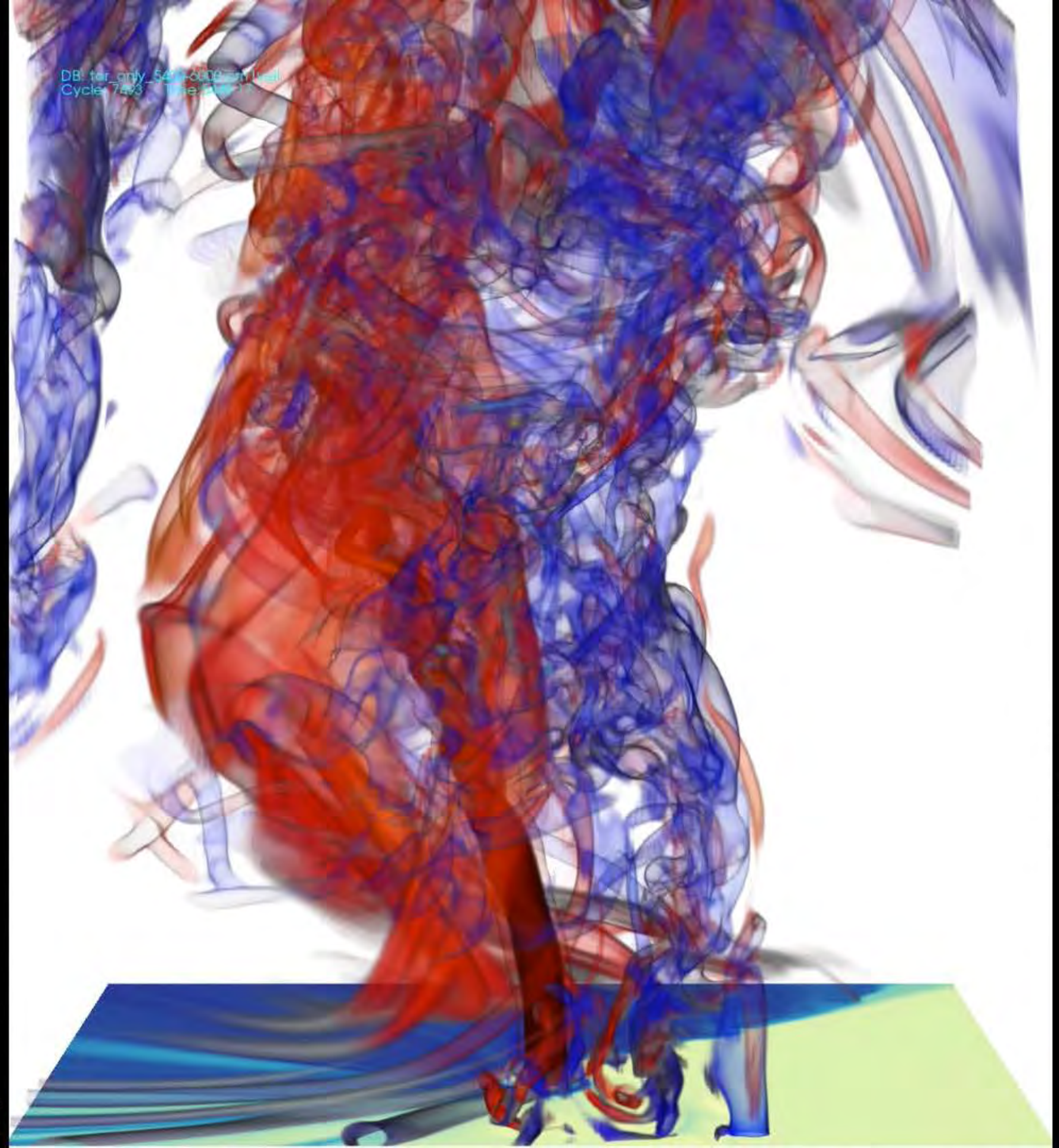

3.0
2.0
1.0
SVC
-6
-8
-10
Rear flank
Forward flank


Fields are temporally averaged over 2 min in 1 s intervals
-15 hPa
-20 hPa
-25 hPa
-50 hPa
60 m/s
50 m/s
40 m/s
30 m/s
SVC
SVC
RF
RF
Pressure perturbation
Vertical wind speed
FF
FF

Vorticity
magnitude
shaded
by zeta

Red=cyclonic
Blue=aniticyclonic

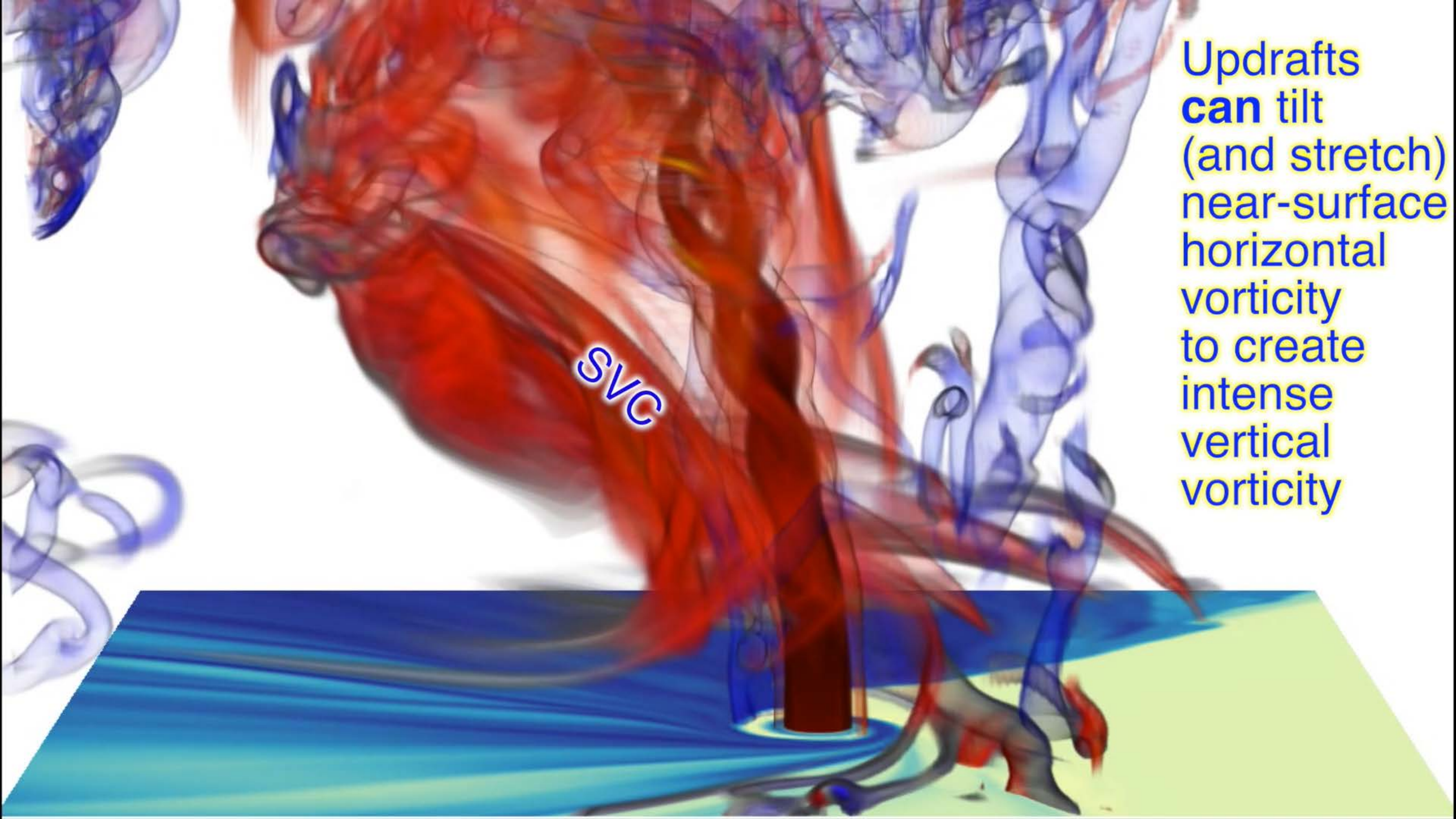
Looking
north

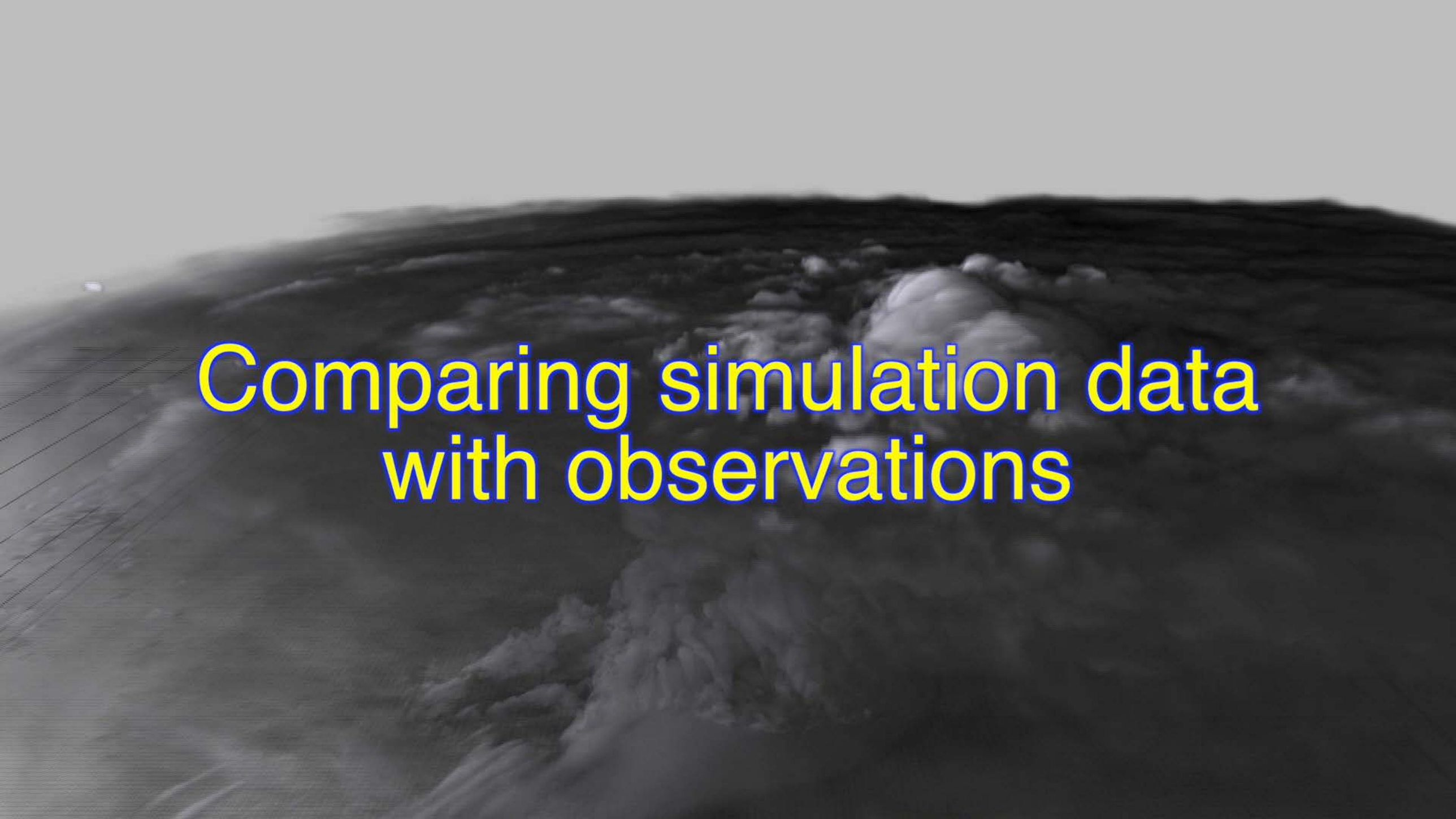


10X

Forward
Flank

Rear
Flank

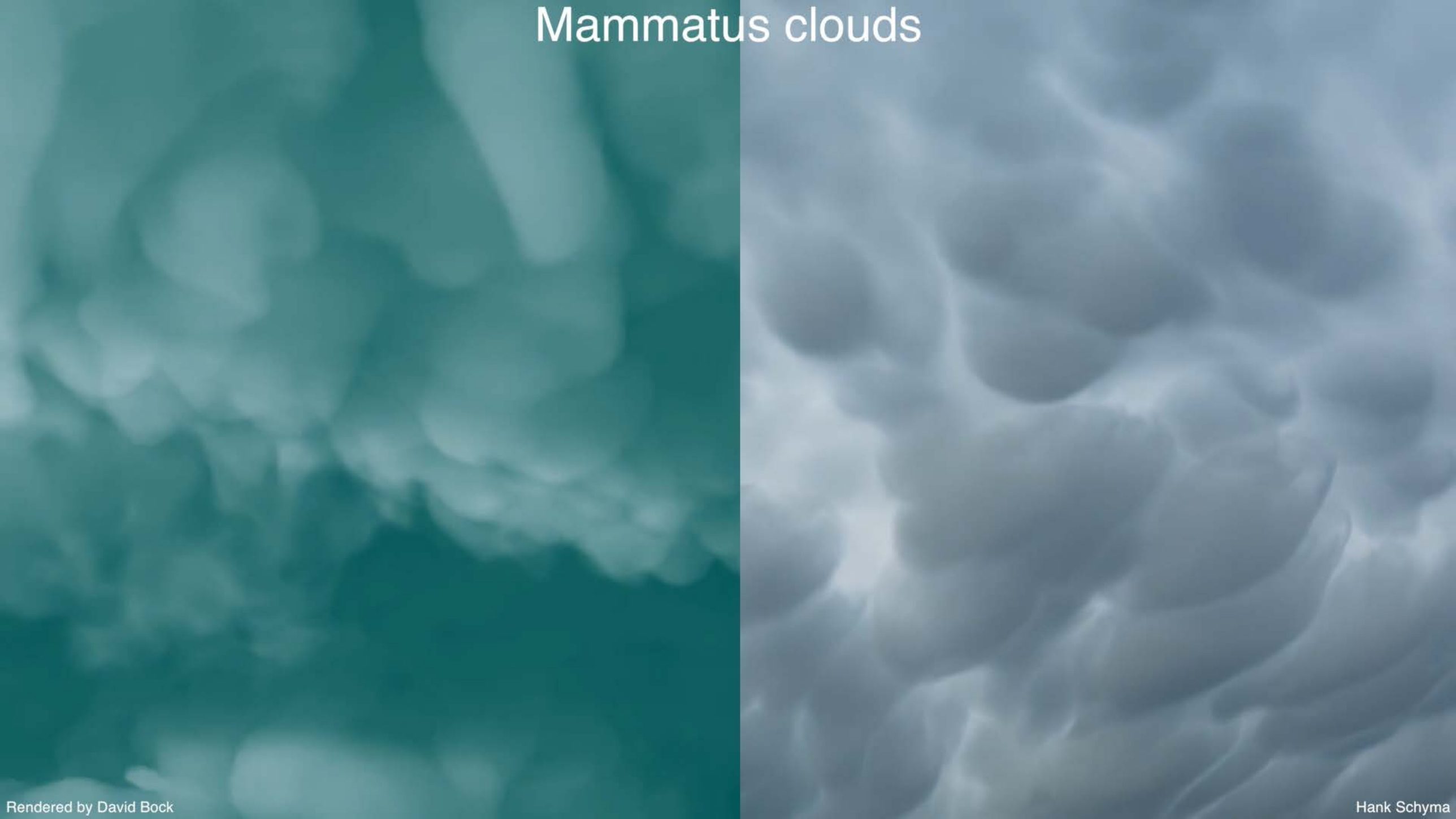

SVC
Updrafts
can tilt
(and stretch)
near-surface
horizontal
vorticity
to create
intense
vertical
vorticity


Comparing simulation data
with observations

Rendered by David Bock

Hank Schyma

Mammatus clouds



Rendered by David Bock

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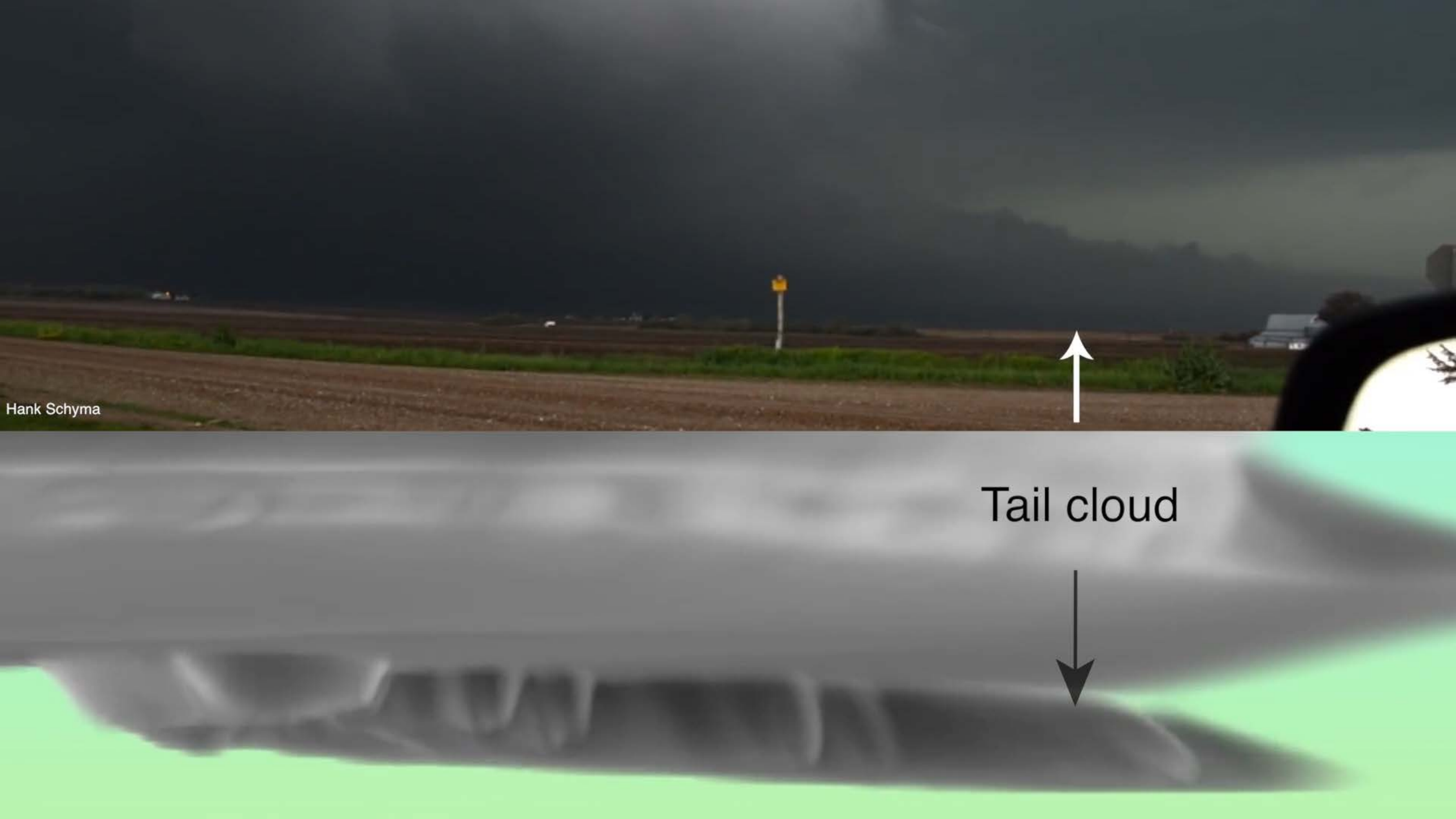
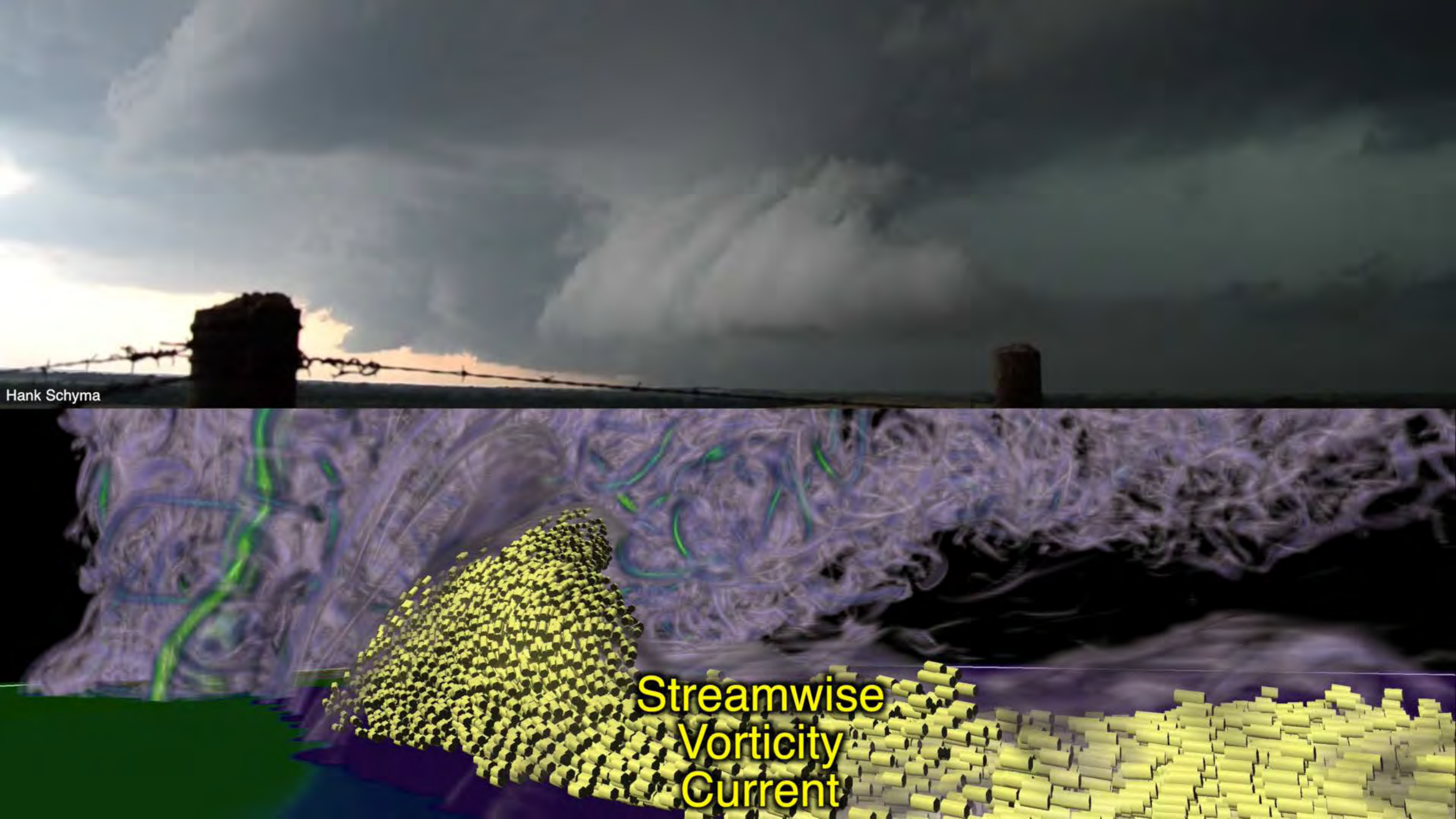
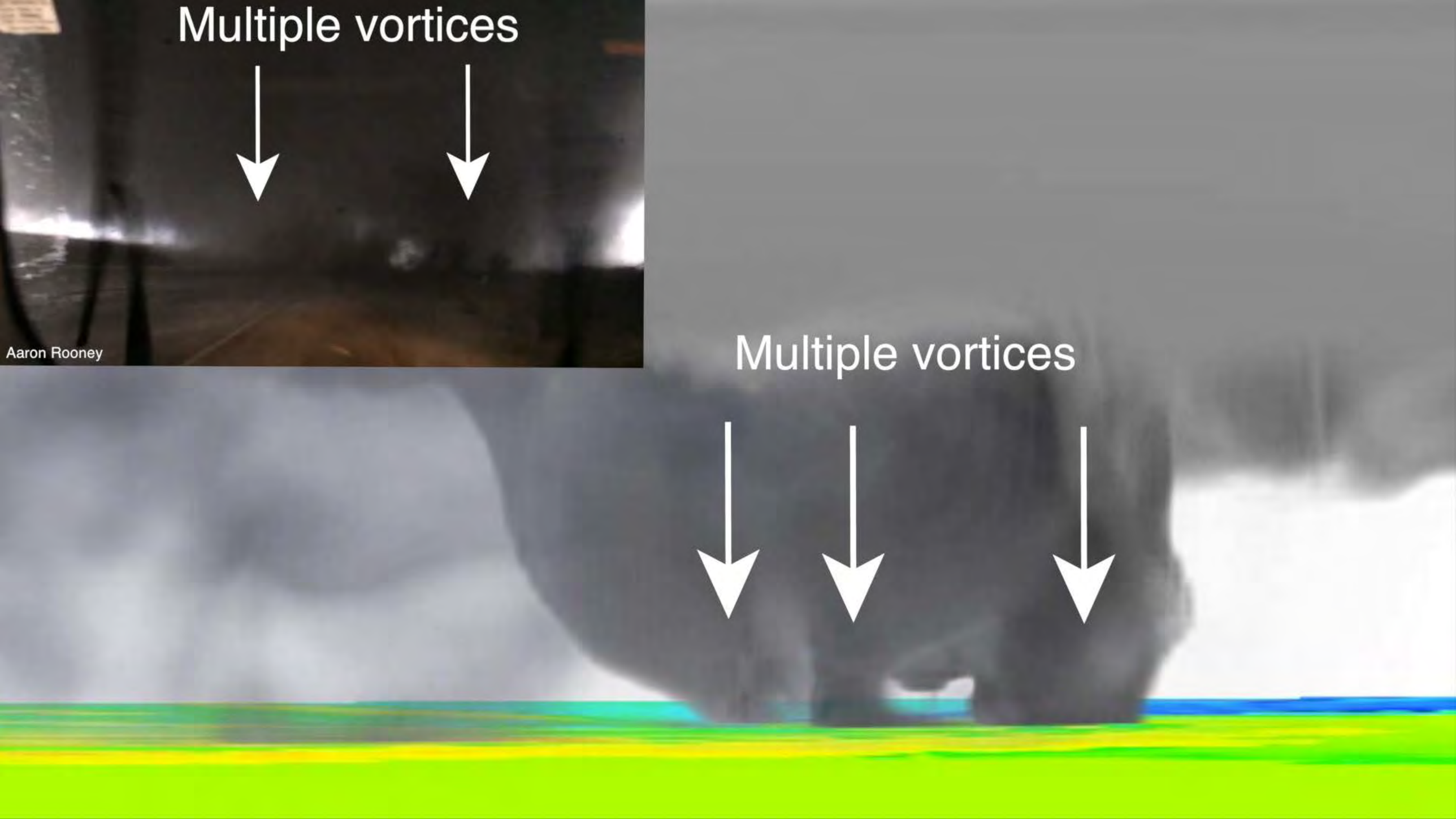
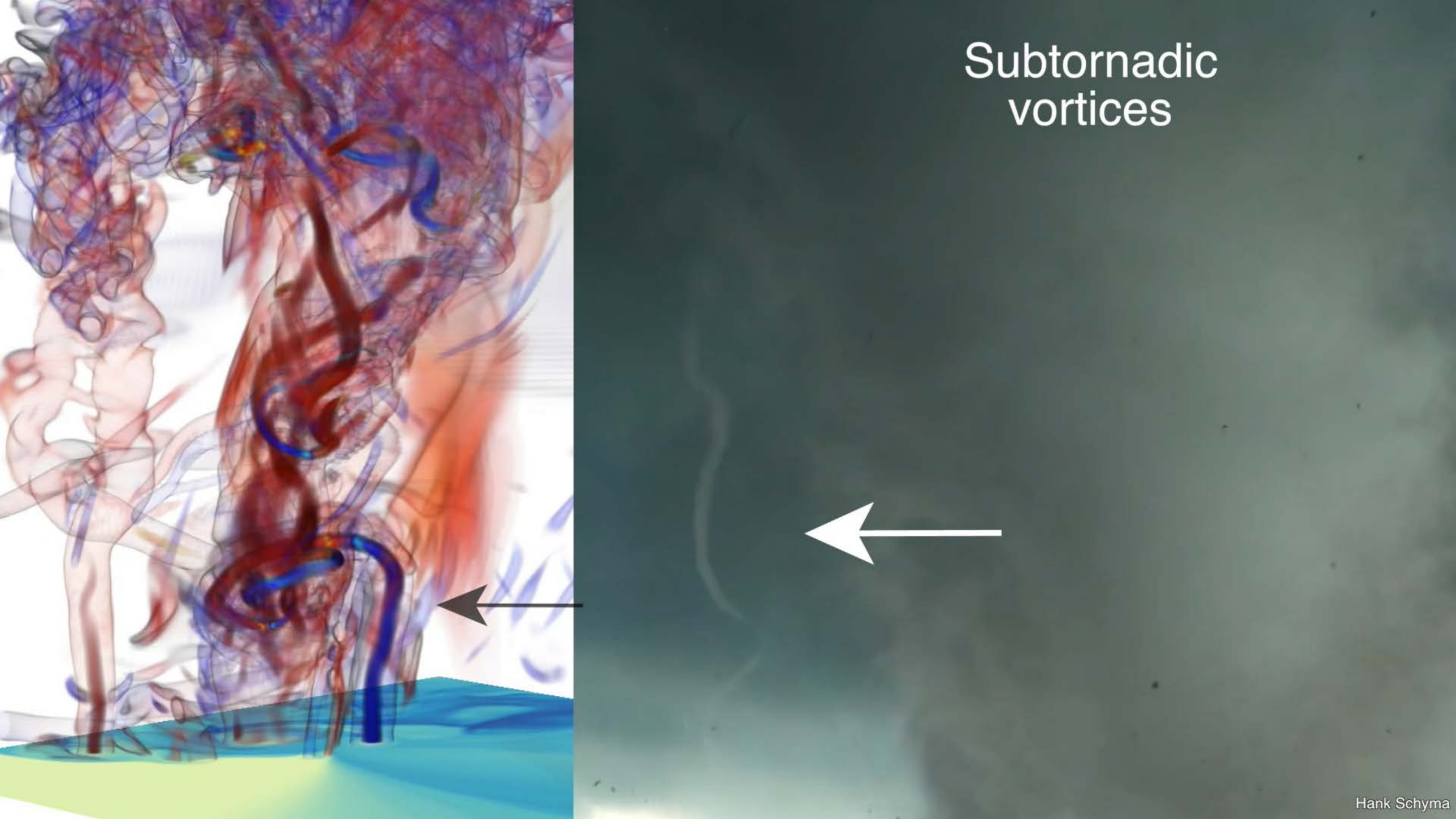

Hank Schyma
Tail cloud


Hank Schyma
Streamwise
Vorticity
Current

Hank Schyma


Multiple vortices
Aaron Rooney
Multiple vortices


Subtornadic
vortices
Hank Schyma

Parting thoughts

- Blue Waters has enabled breakthrough science in supercell/tornado modeling
- The tremendous amount of cloud model data produced on Blue Waters will be analyzed beyond Blue Waters - providing the motivation to take great care in massaging and curating data
- Our team is working on postprocessing/visualization code utilizing (massively parallel) GPU technology
- The portability of the LOFS data will enable us to do analysis on current and future supercomputers

Acknowledgments

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Thank you!

See `http://orf.media` for more

Questions?