Application of Uncertainty Visualization Methods to Meteorological Trajectories

ESSI Workshop

August 5, 2009

Ryan Boller[12], Scott Braun[3], Jadrian Miles[1], David Laidlaw[1]

1: Brown University, Department of Computer Science
2: NASA/GSFC, Software Engineering Division
3: NASA/GSFC, Laboratory for Atmospheres

From VxO to Visualization *and* Application of Uncertainty Visualization Methods to Meteorological Trajectories

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Outline

- "From VxO to Visualization" (20%)
- "Applications of Uncertainty Visualization Methods…" (80%)

From VxO to Visualization

- Created link between Virtual Space Physics Observatory (VSPO) website and ViSBARD
  - http://vspo.gsfc.nasa.gov
  - http://spdf.gsfc.nasa.gov/research/visualization/visbard/

Traditional VxO Data Access

- "Pull" from server
  - Via WWW
  - Via Java Web Services
  - Etc.

Alternative VxO Data Access

- "Push" from Server
  - Dynamically generate application-launching script (JNLP) with URL to data
  - Subsequent data pushes go to same instance of application via Java SingleInstanceService

Demo

Takeaways

- Can force unsuspecting users to try tool
- Reduces initial learning curve
- Convenience of not manually managing downloads

Application of Uncertainty Visualization Methods to Meteorological Trajectories

Outline

- Uncertainty Visualization
- Motivation
- Contributions
- Methods
- Results
- Conclusions

Uncertainty Visualization

- Representing uncertainty in data (Griethe & Schumann, 2006)
  - Error
  - Imprecision
  - Lineage
  - Subjectivity
  - Noise
  - Etc.
- Easily applies to our observed and simulated data

Uncertainty Visualization (2)

- Importance (Johnson 2004)
  - Highly-respected sci/engr journals use error bars, standard deviations, etc.
  - Need to trust results of "new" visualization techniques

- Unimportance (Boukhelifa and Duke, 2009):
  - "Uncertainty visualization: why might it fail?"

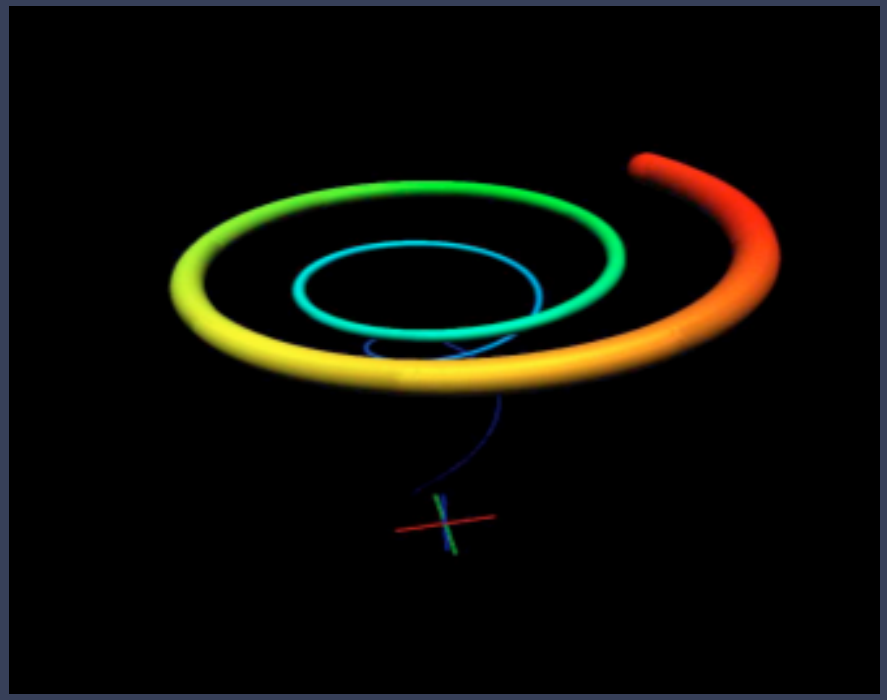
Uncertainty Visualization (3)

- Examples

Uncertainty of ocean current vectors (Pang et al, 1997)

Uncertainty Visualization (3)

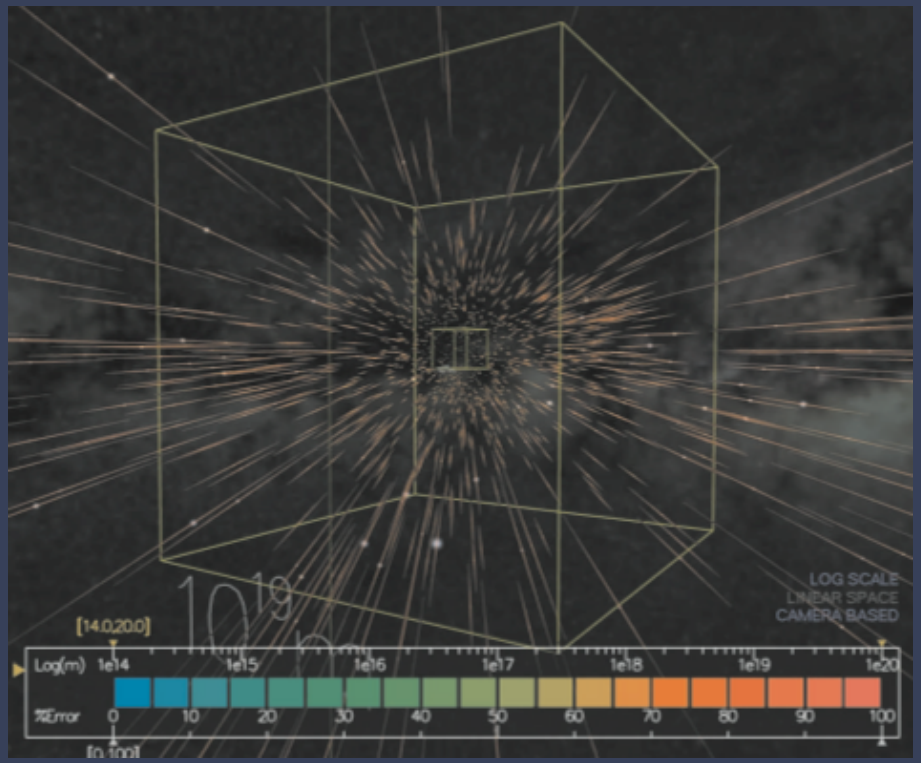
- Examples



"Envelope of Path Trajectory" (Lodha et al, 1996)

Uncertainty Visualization (3)

- Examples



Positional uncertainty of stars (Li et al, 2007)

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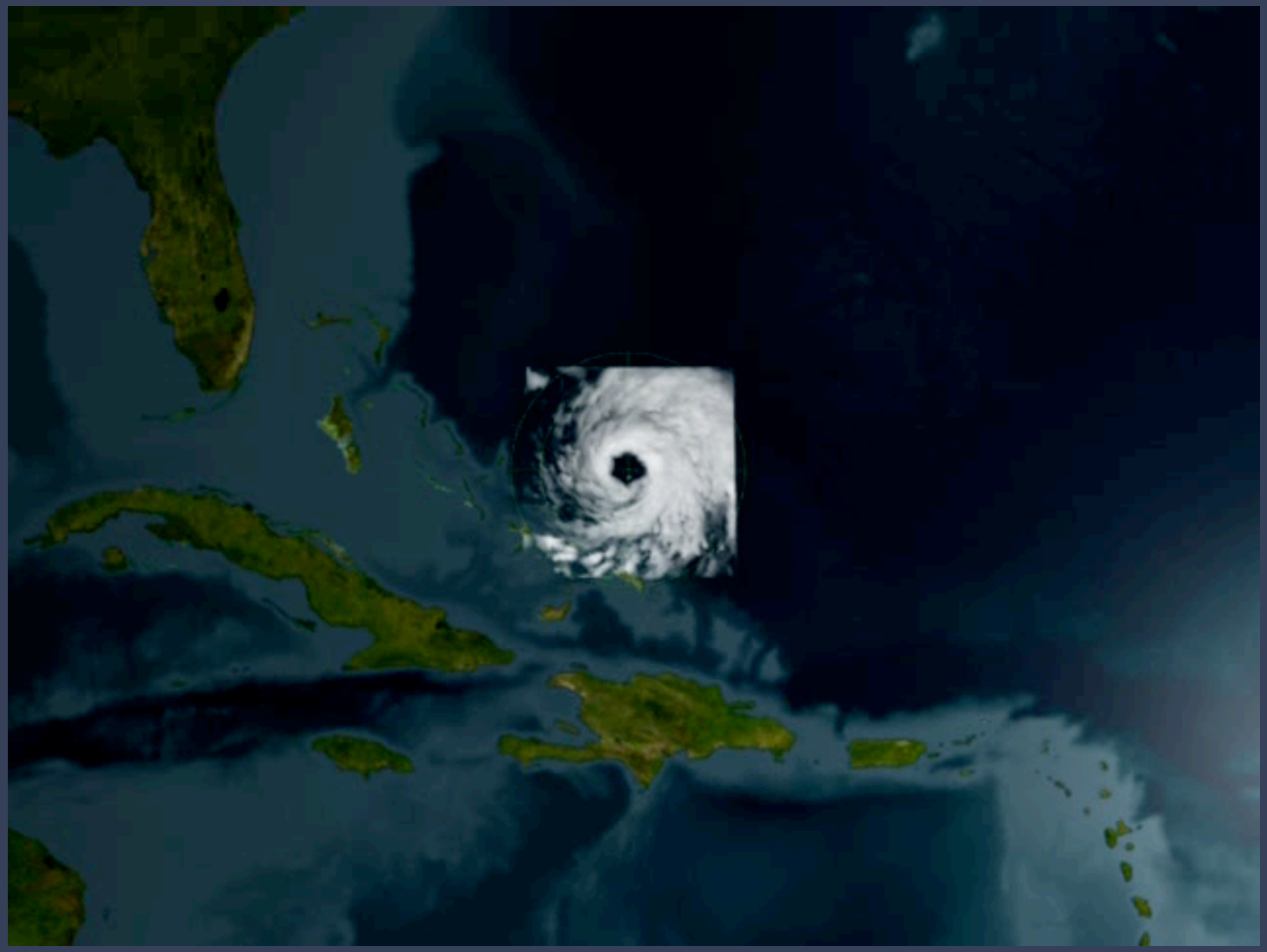
Motivation:

Understand interaction between a storm and its local environment; need to prioritize conflicting data

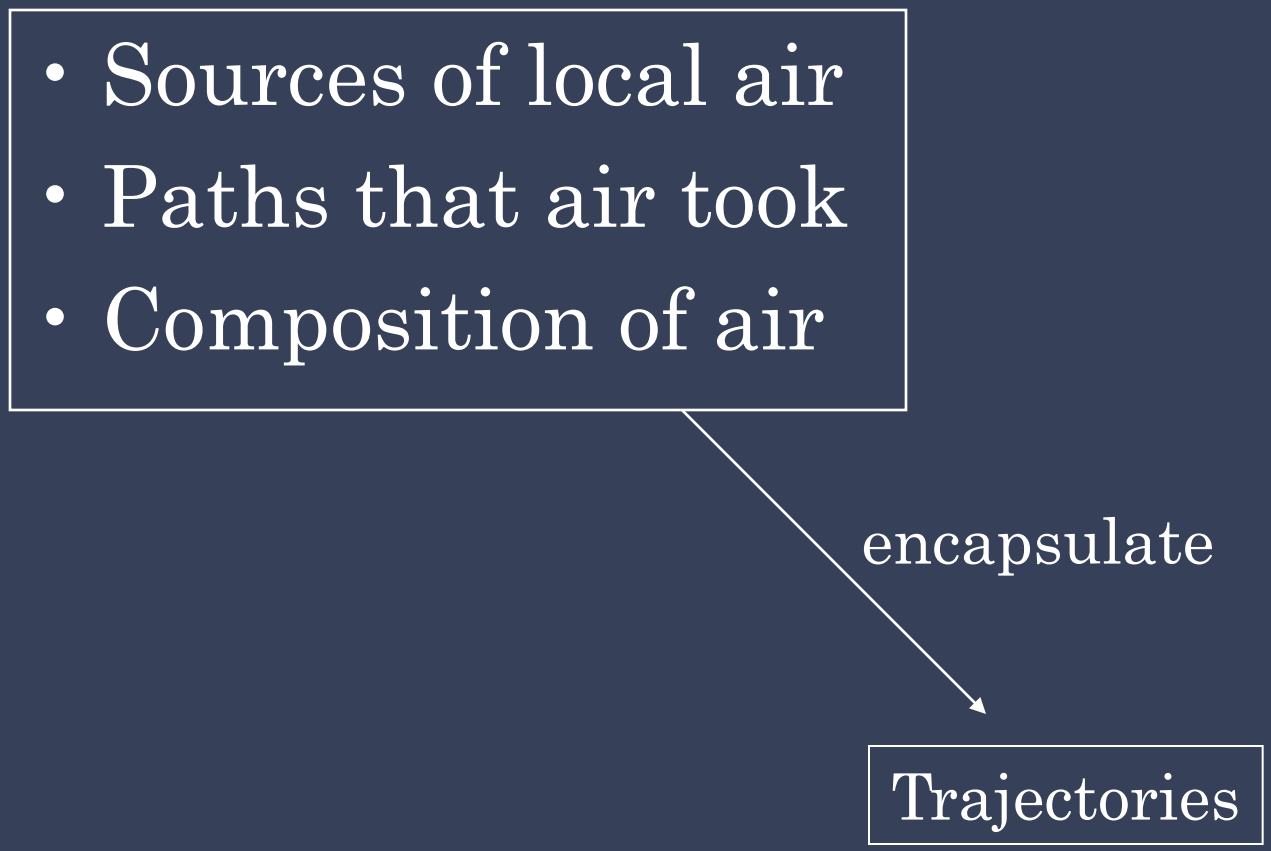
Better Understanding of Local Environment



http://svs.gsfc.nasa.gov/goto?3377

Important Environmental Factors

- Sources of local air
- Paths that air took
- Composition of air



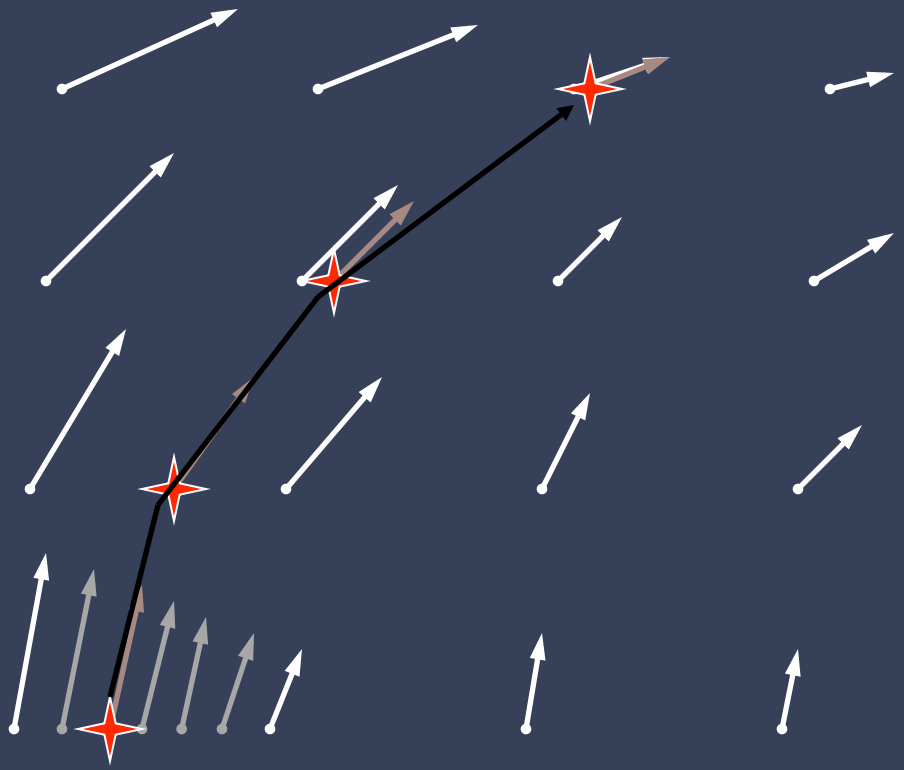
Trajectories = Pathlines = Particle Paths

- Trajectories, for massless particles, are lines tracing the path of the particle over time as it moves in the direction and speed dictated by the vector field.[1]

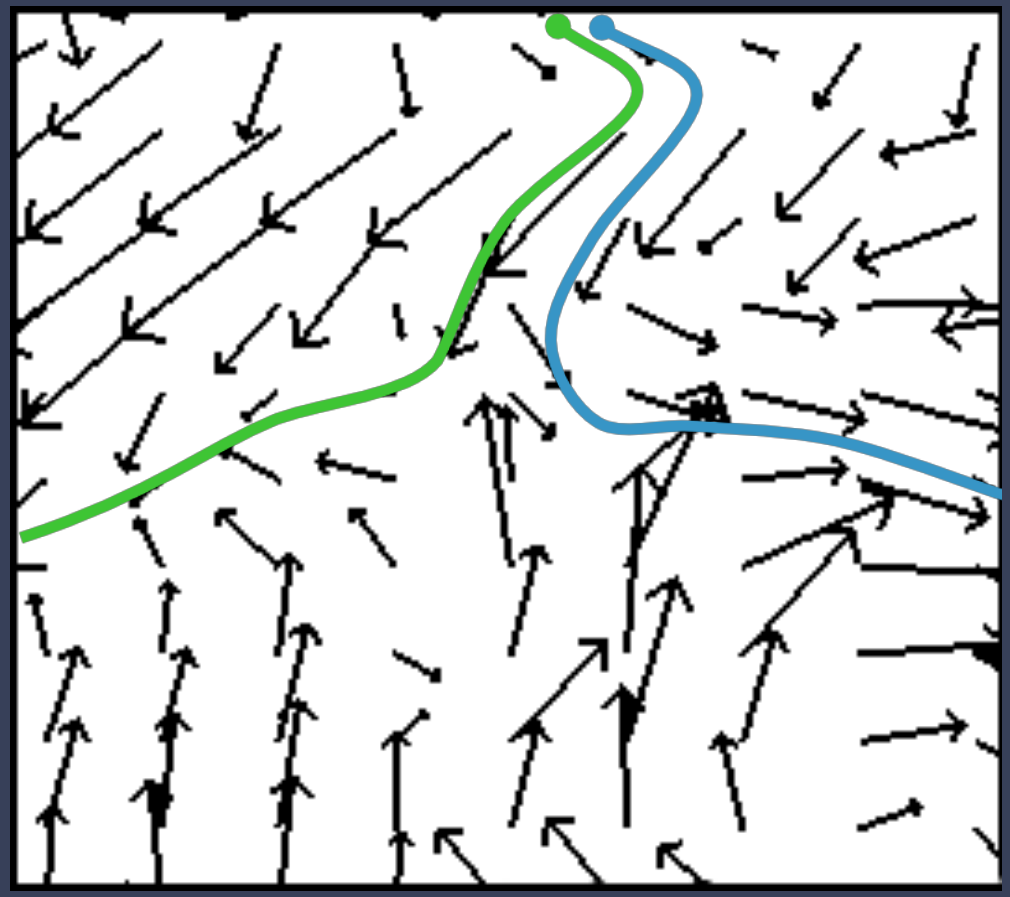
- Back trajectories: same, but flip vector field and go backward in time

[1] http://www.tecplot.com/showcase/contours/article.aspx?issue=35&article=2

Trajectories in Non-Shearing Flow



Trajectories in Shearing Flow



Data

- Data is coarse! Exacerbates uncertainty in areas of wind shear.

- NCEP global analyses (GRIB/NetCDF)
  - Variables: temperature, pressure, humidity, 3D wind, etc.
  - Resolution
    - Temporal: 6h
    - Spatial: 1˚ latitude, 1˚ longitude (~110km, approx 1/10 hurricane diameter)

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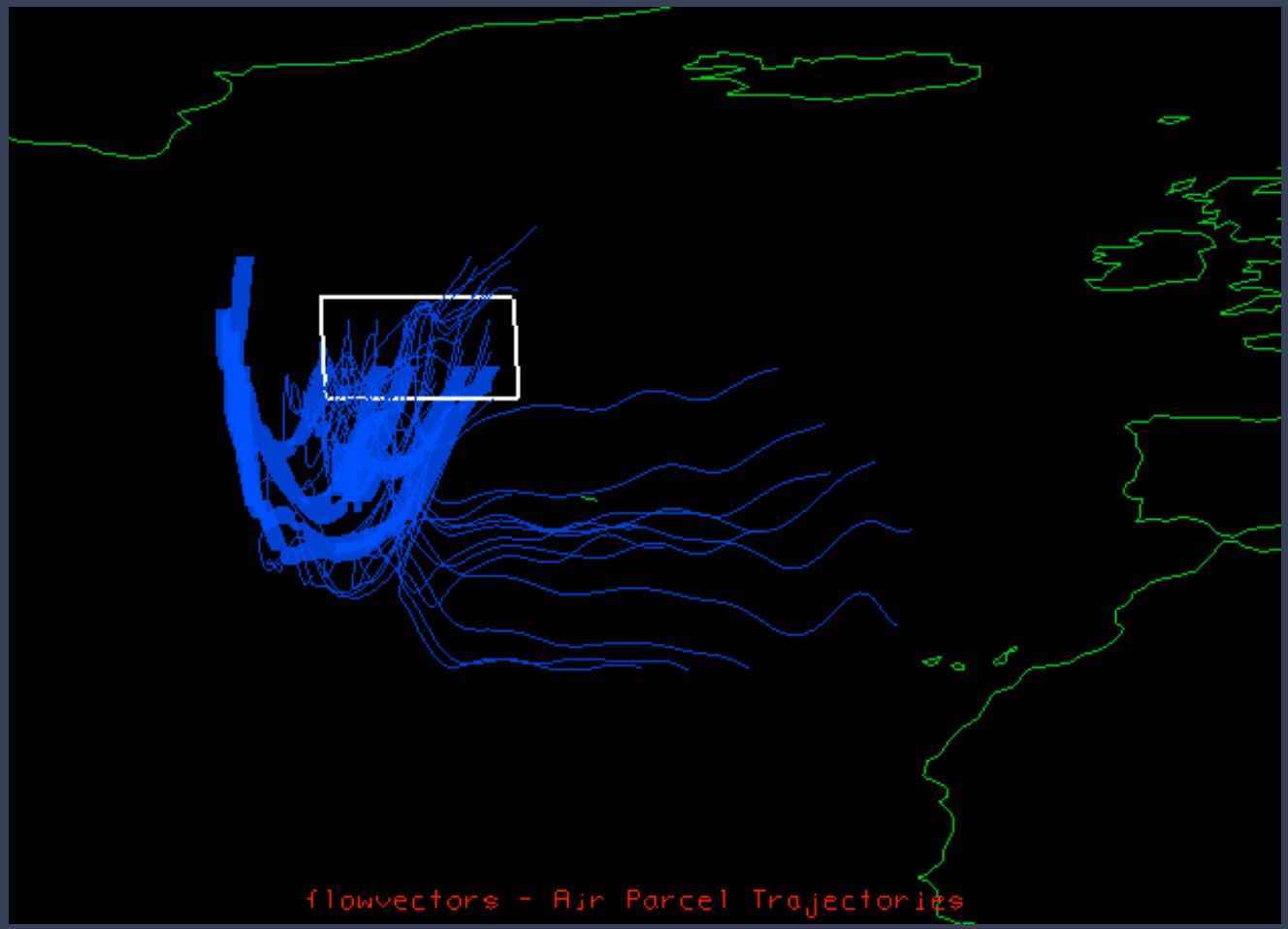
The Visualization



White box: trajectory seeding region
Thicker lines: more certain trajectories
Thinner lines: less certain trajectories

Contributions (1/3)

- Process-wise: enables efficient visual pruning of unlikely results

Contributions (2/3)

- Analysis-wise: bounds derived on advection uncertainty due to interpolation

Contributions (3/3)

- Science-wise: found supporting evidence for newly-developed meteorological theory

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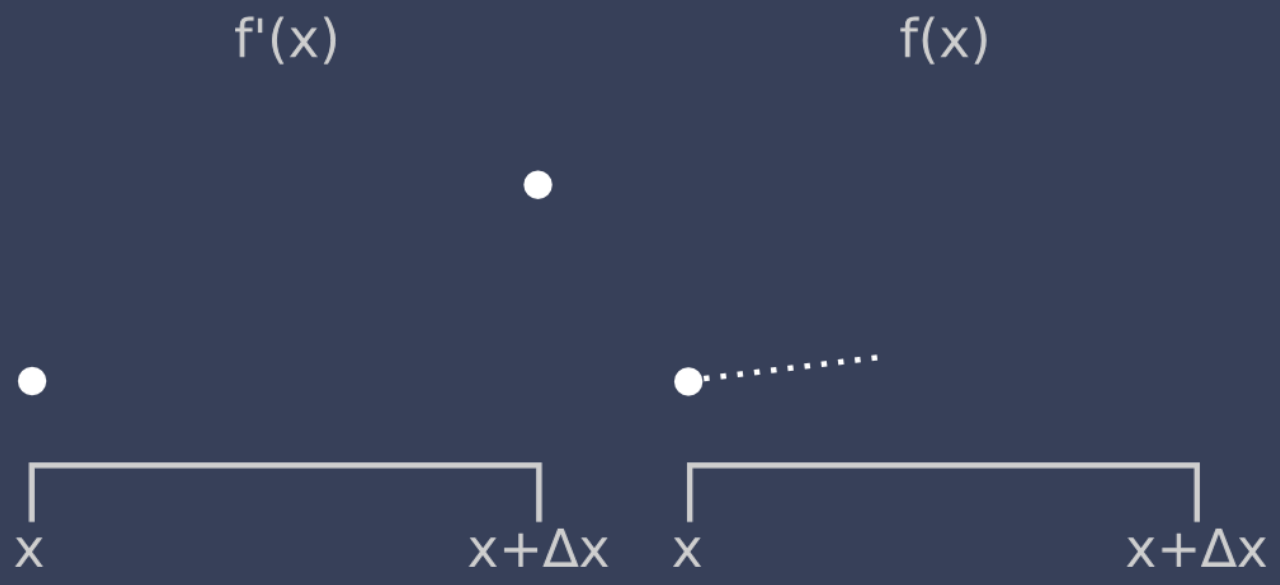
Trajectory Generation and Uncertainty Computation in 1-D



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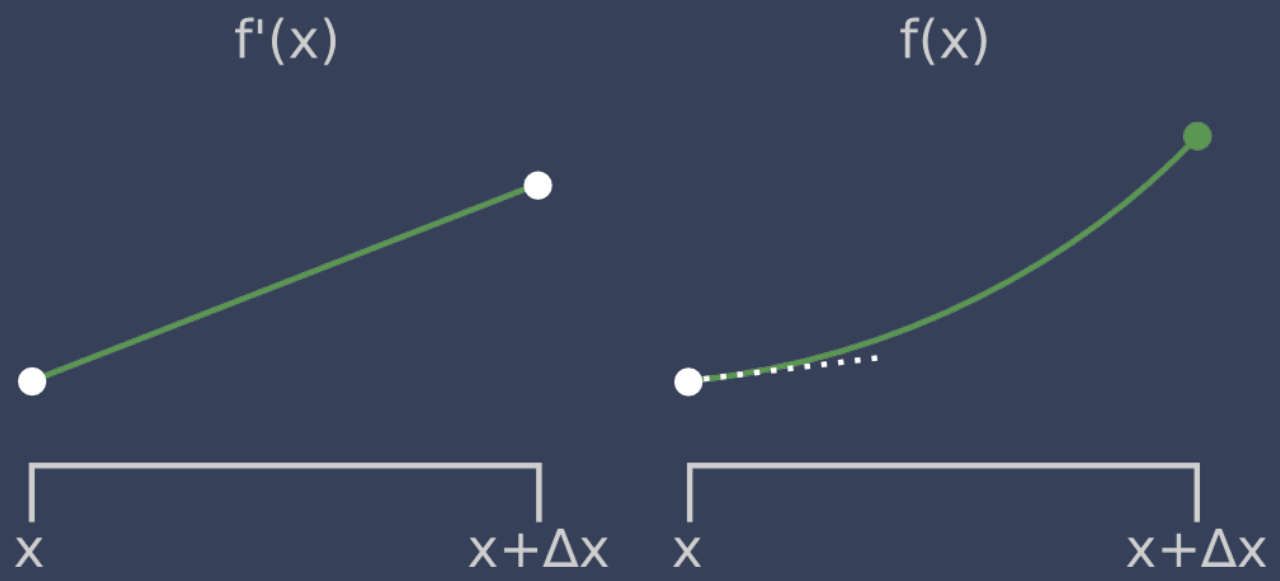

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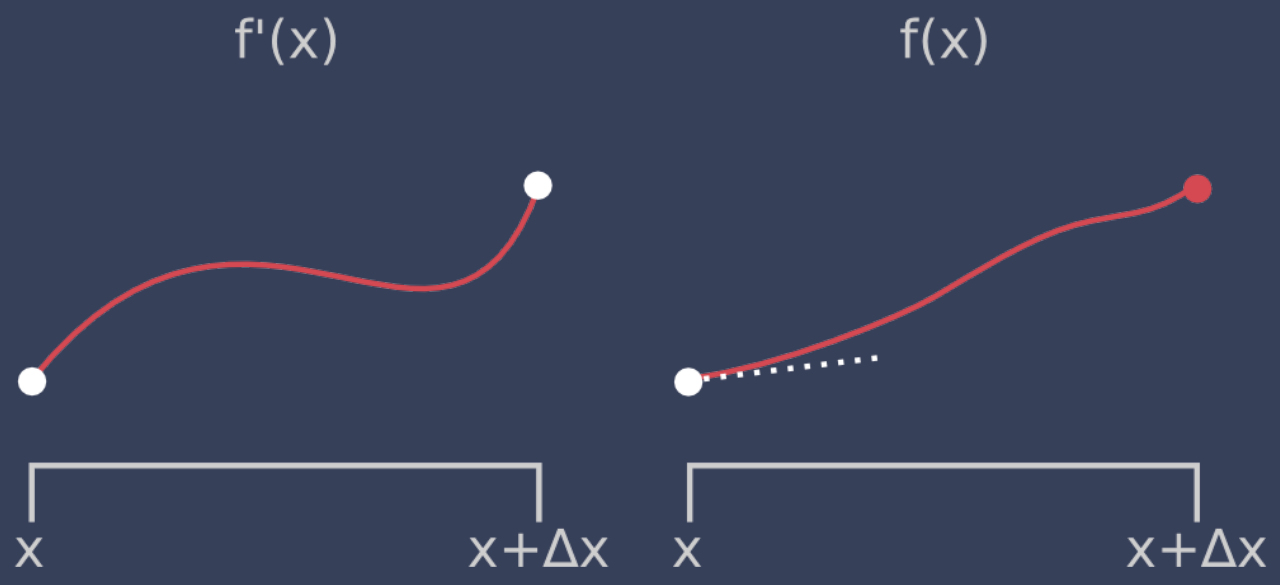

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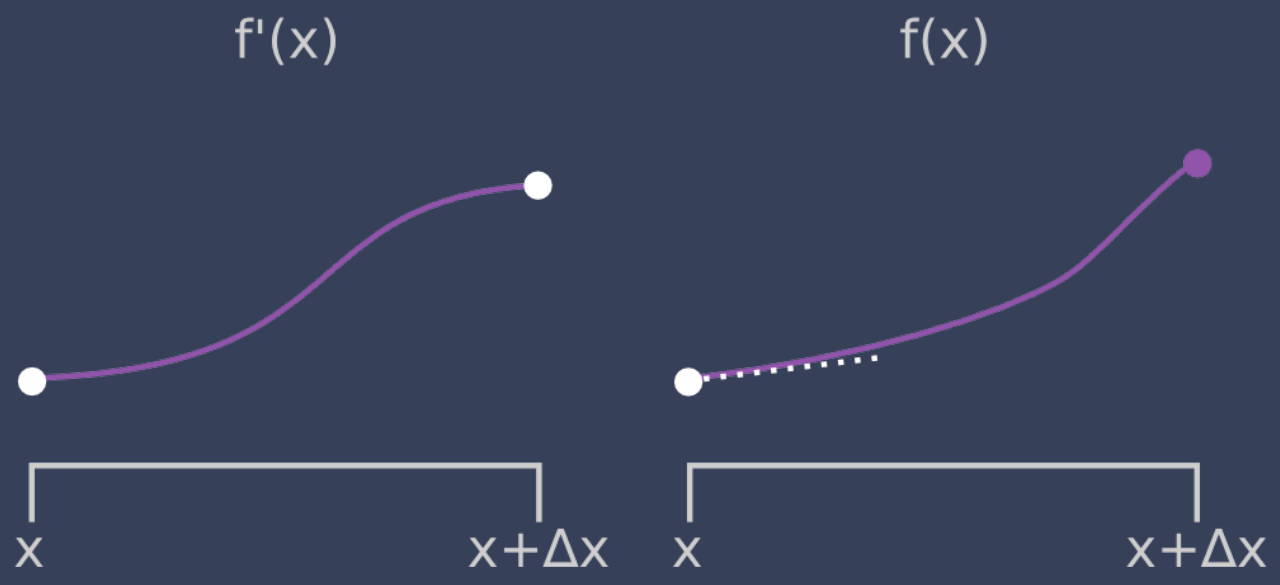

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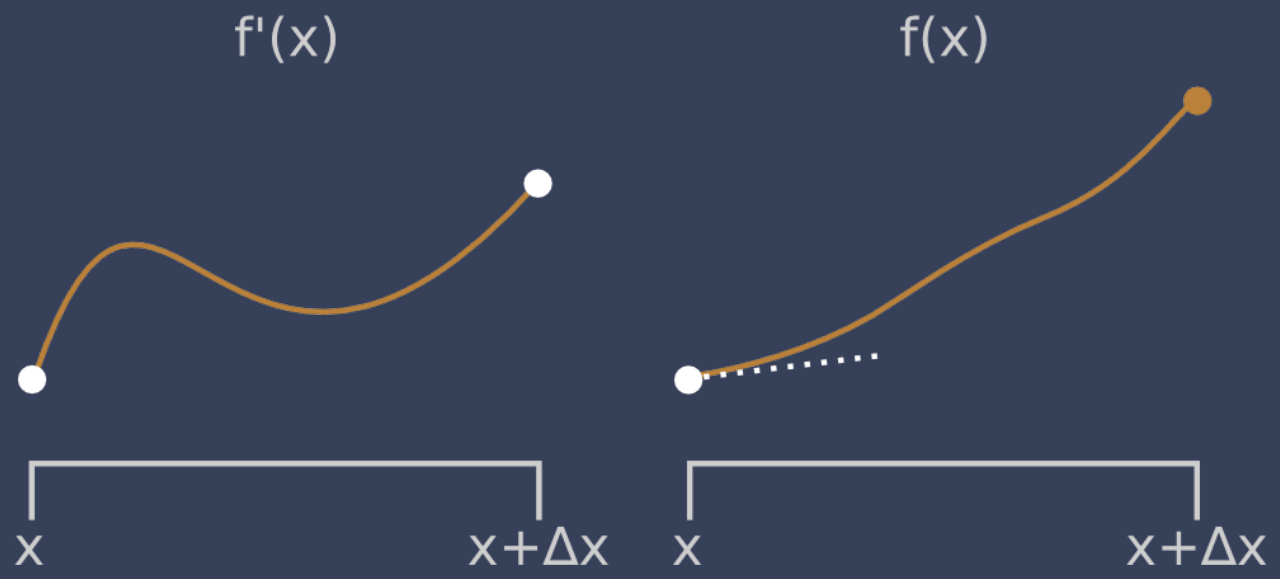

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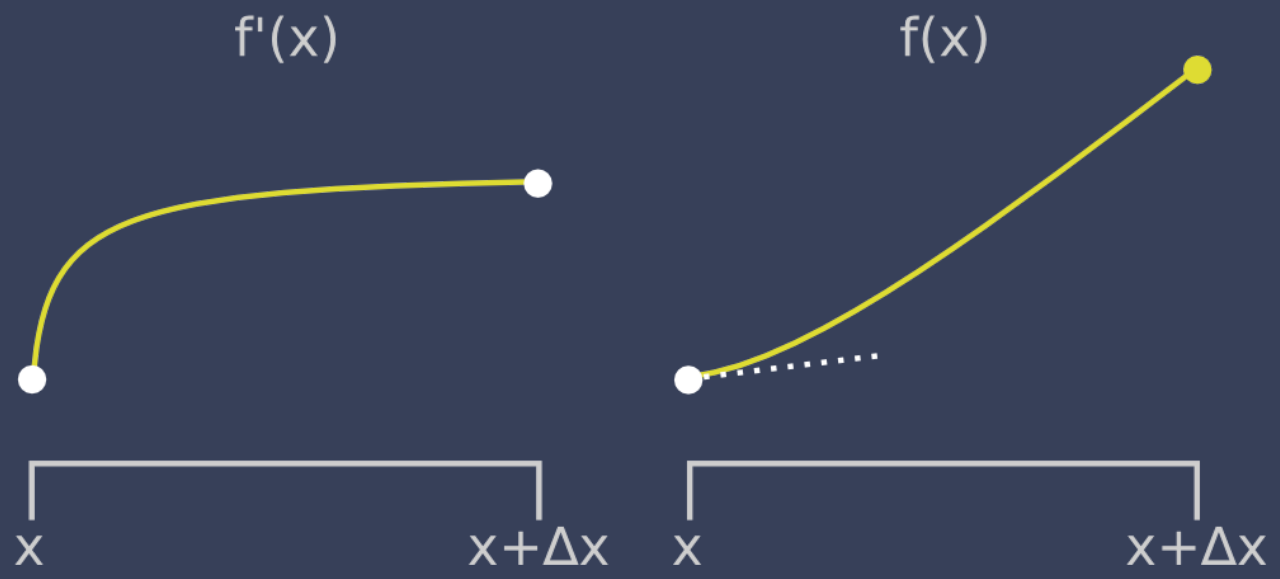

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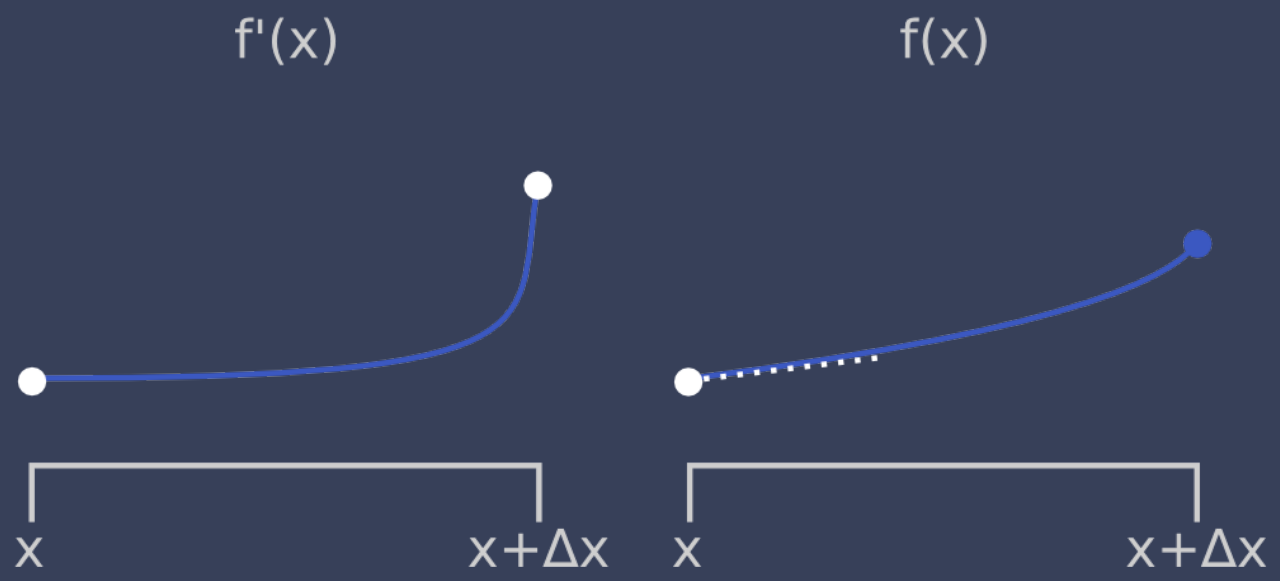

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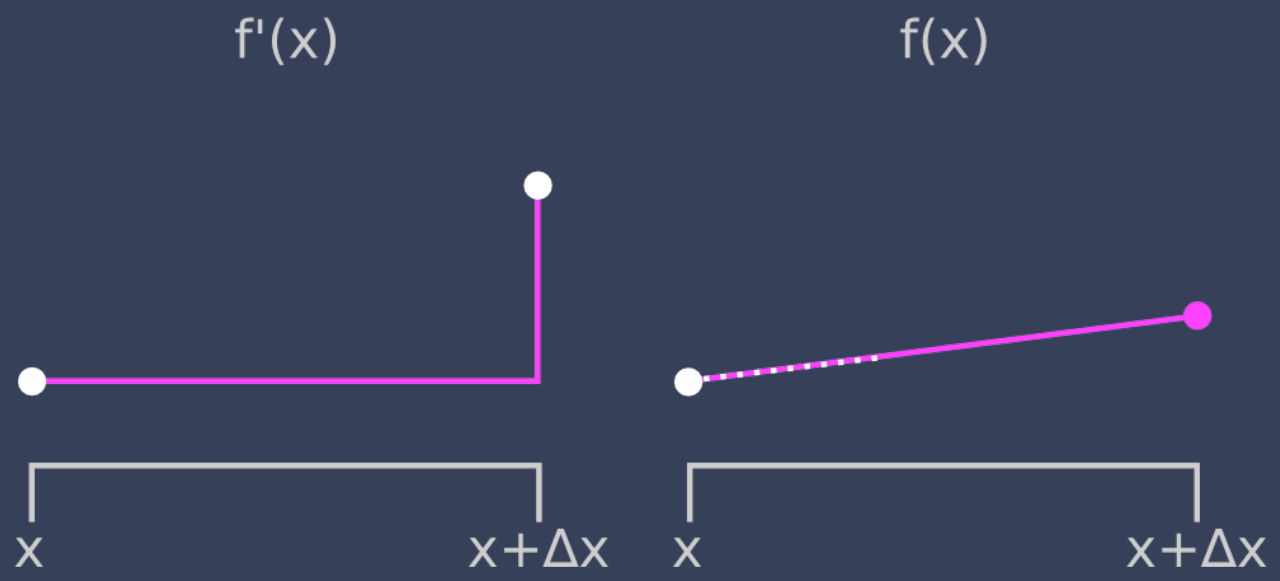

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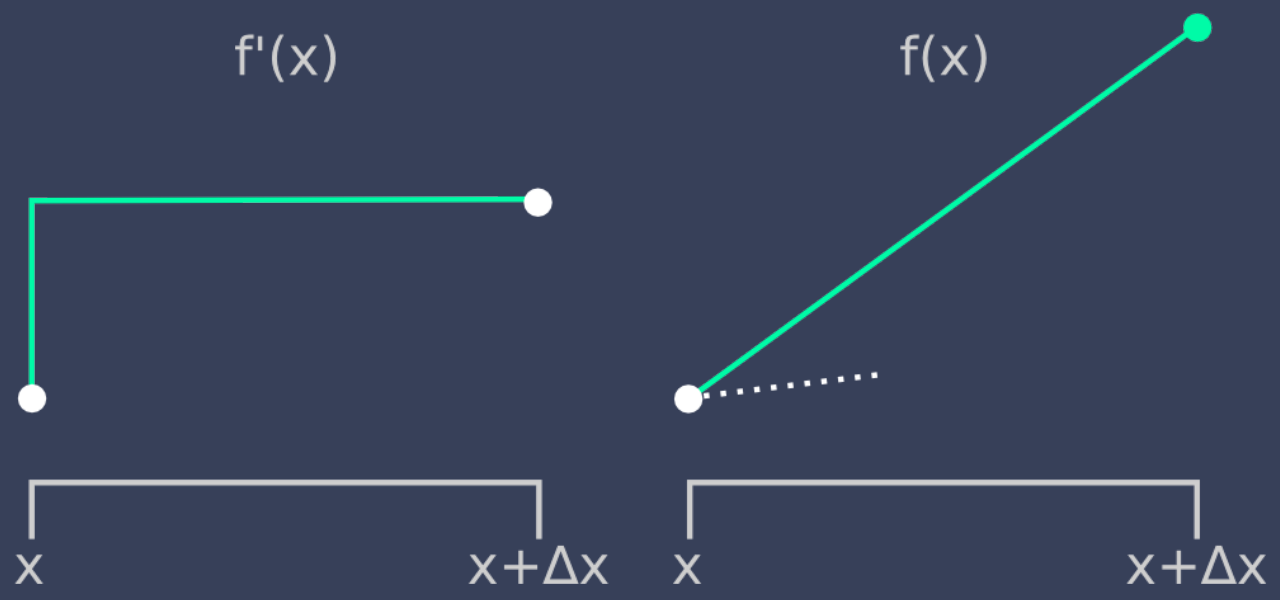

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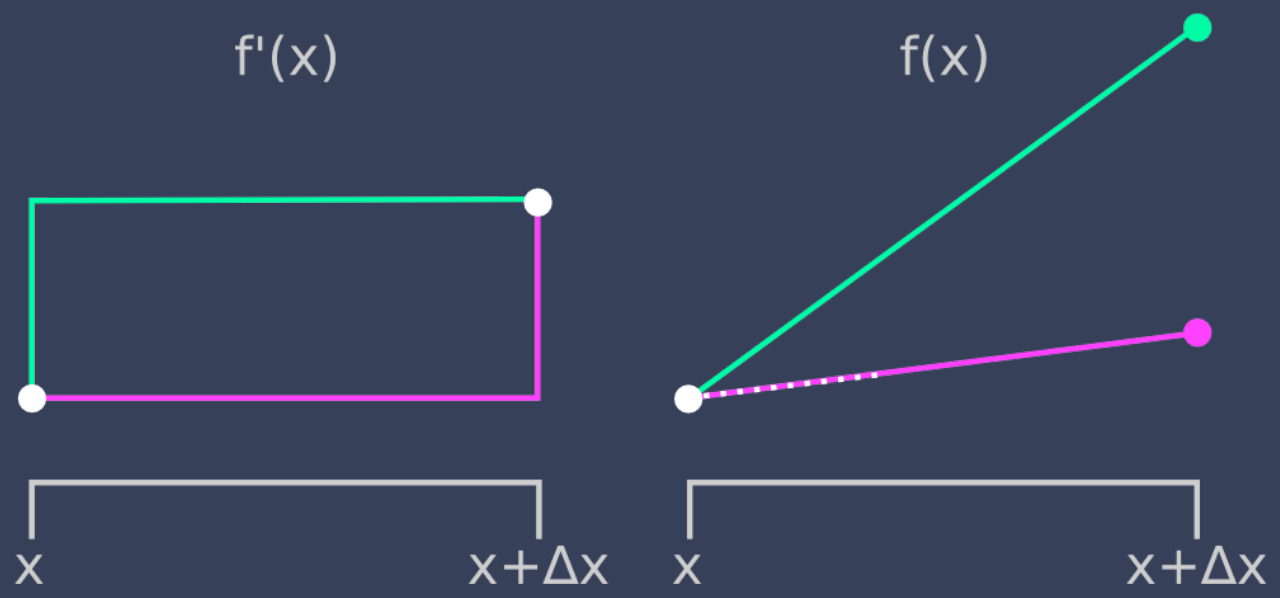

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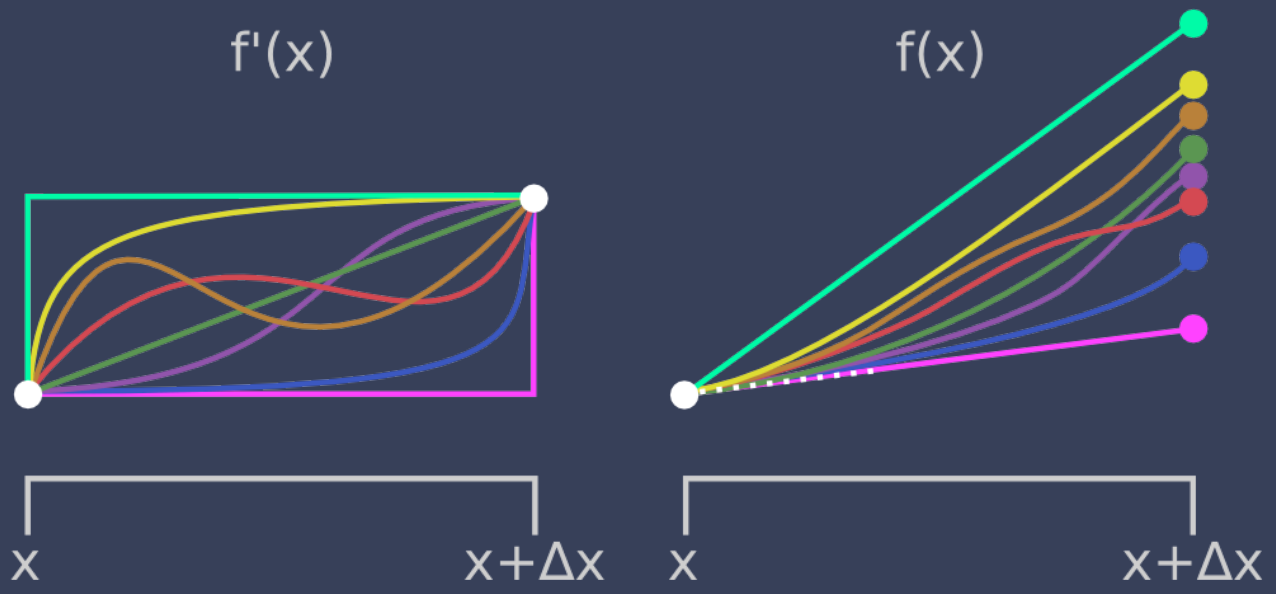

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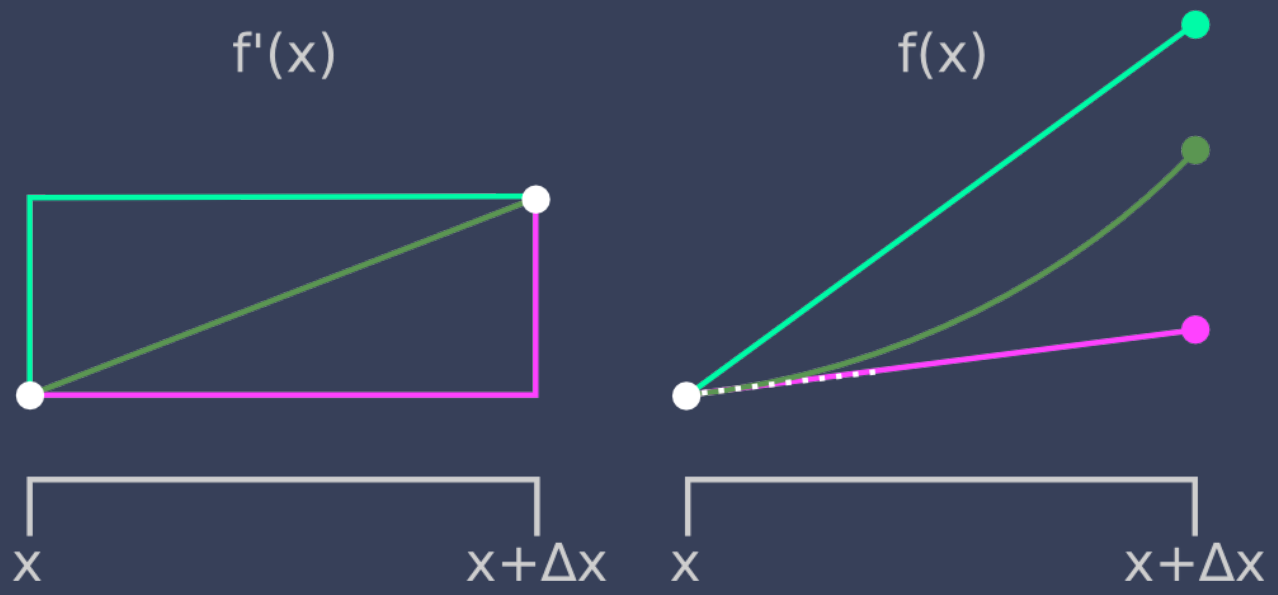
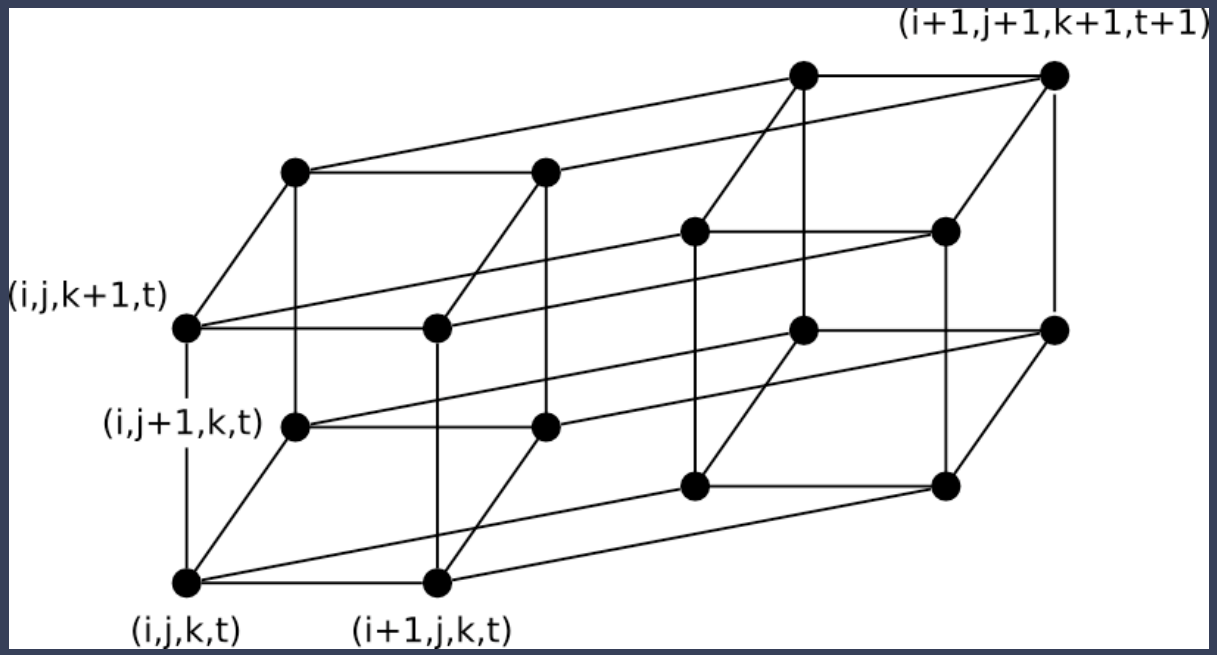


4-D Sample Lattice



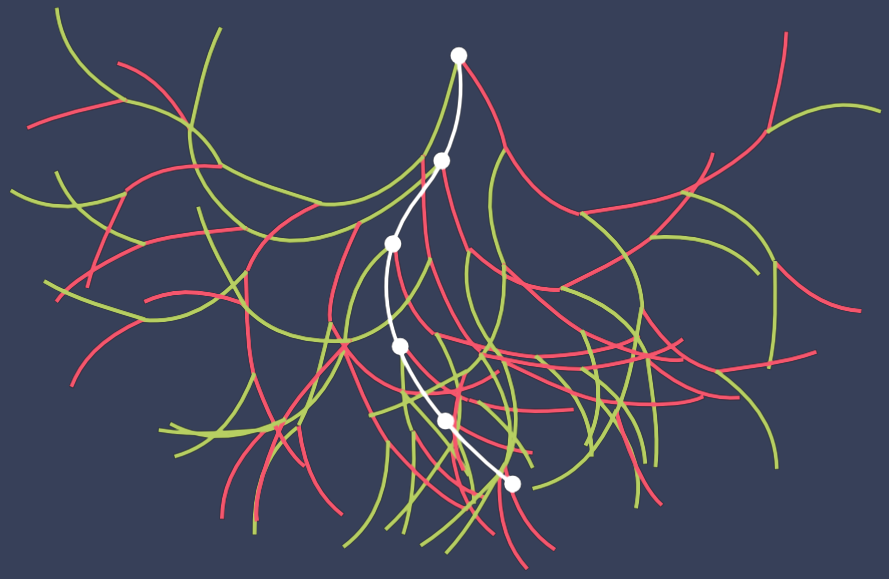
16 samples (vs. 2 for 1-D)

Trajectory Generation and Uncertainty Computation in 4-D

- "Master" trajectory with RK-4 & linear interpolation
- 8 "diverging" trajectories
  - min/max velocity in each of 3 dimensions

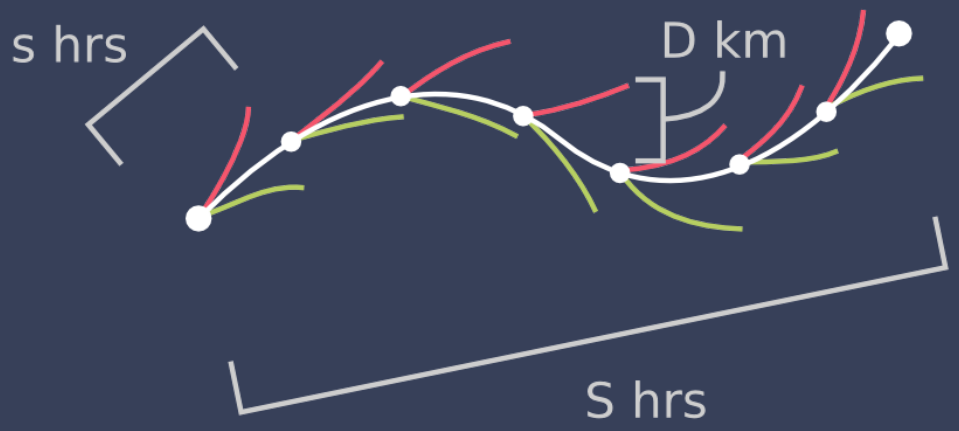
Combinatorial Explosion

- Main path through n hypercubes ⇒ $O(8^n)$ diverging paths
  - This is way too many!
- Would prefer an O(n) estimate



O(n) Uncertainty Estimate

- Divide main path into sub-paths; compute 8 fixed-length diverging paths each
  - (S/s)*8*s = O(n)
- Worst-case sub-path diverges by D
- Uncertainty = S/s * D

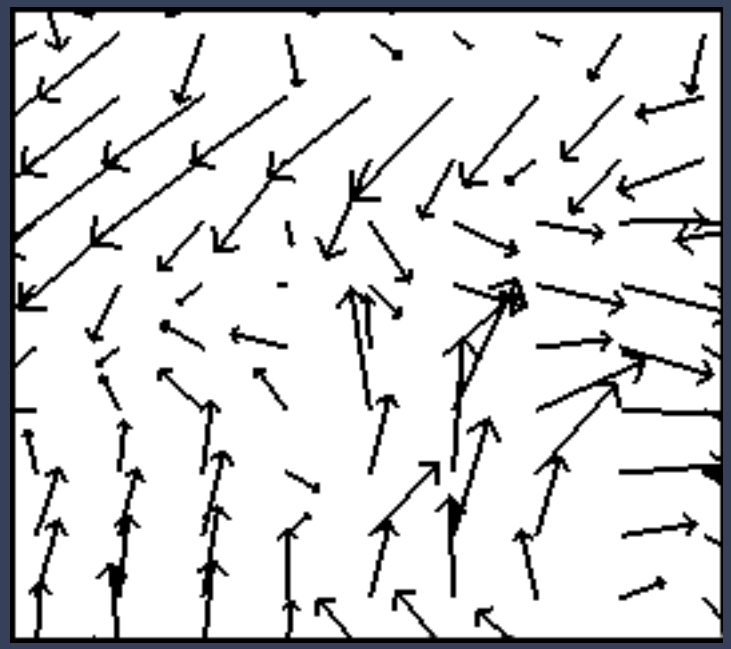


Implementation

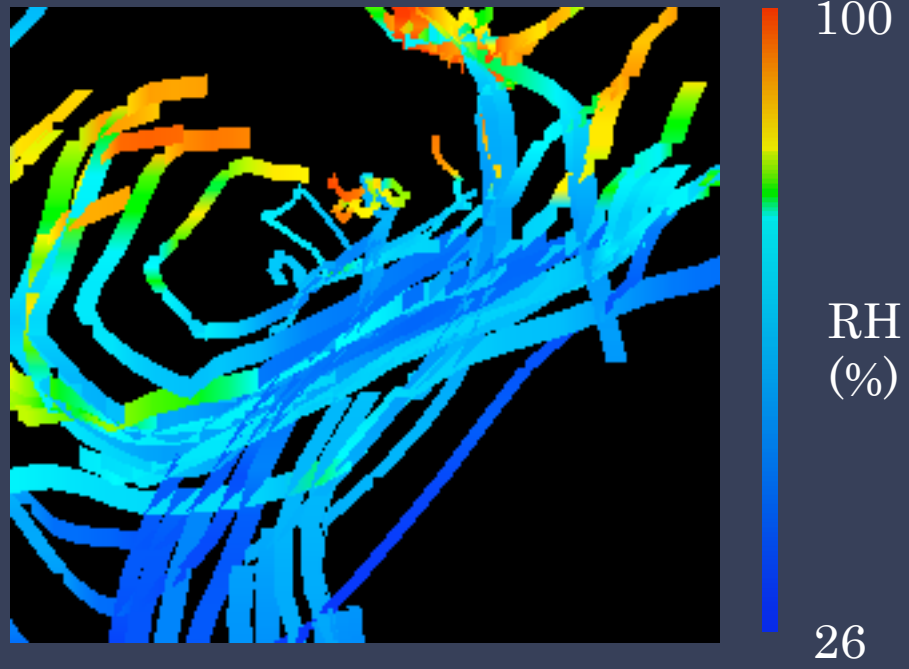
Implementation

- Built on Unidata's Integrated Data Viewer (IDV)
  - Open source
  - Java

Uncertainty Representation

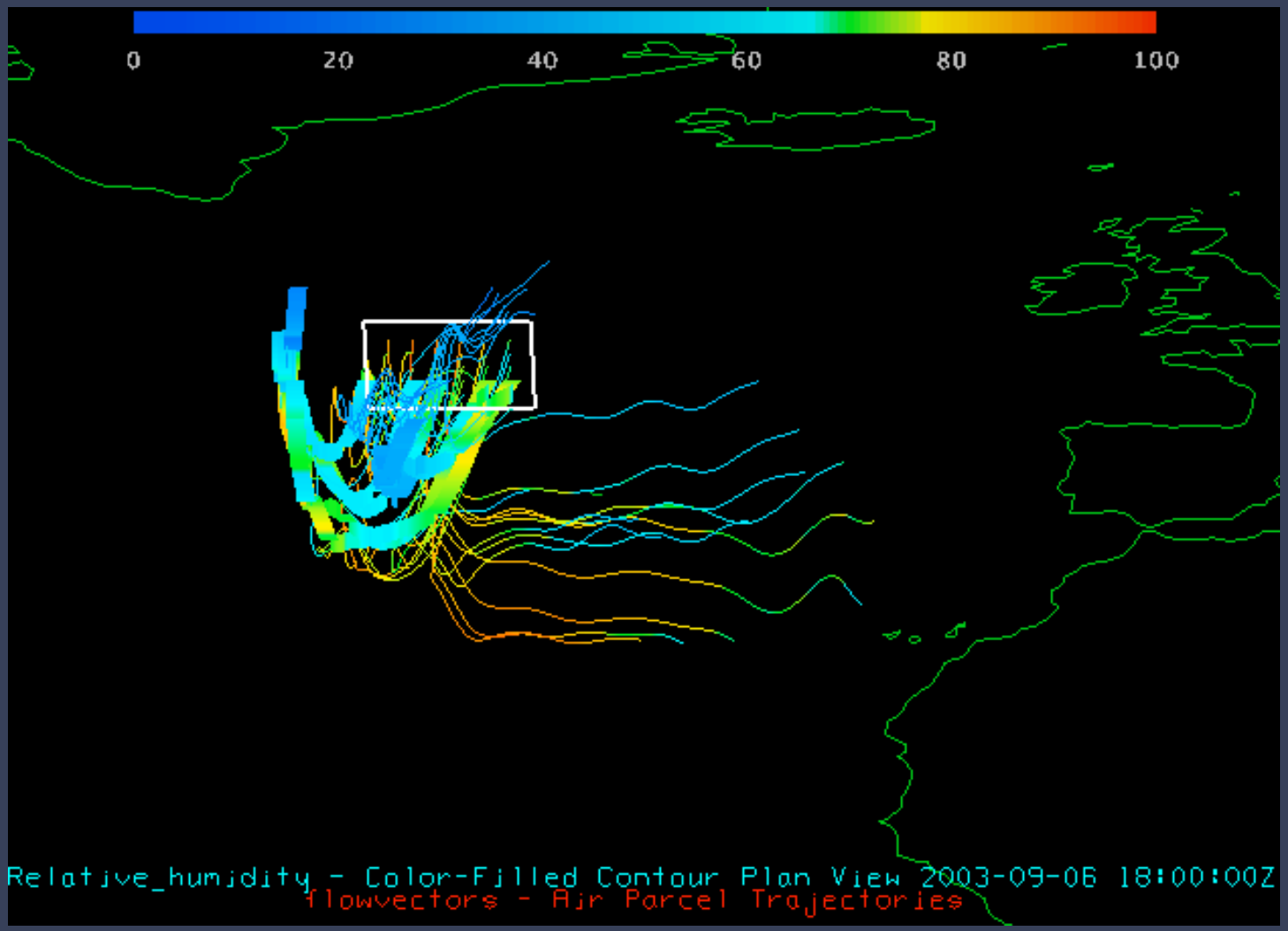


One time step of wind



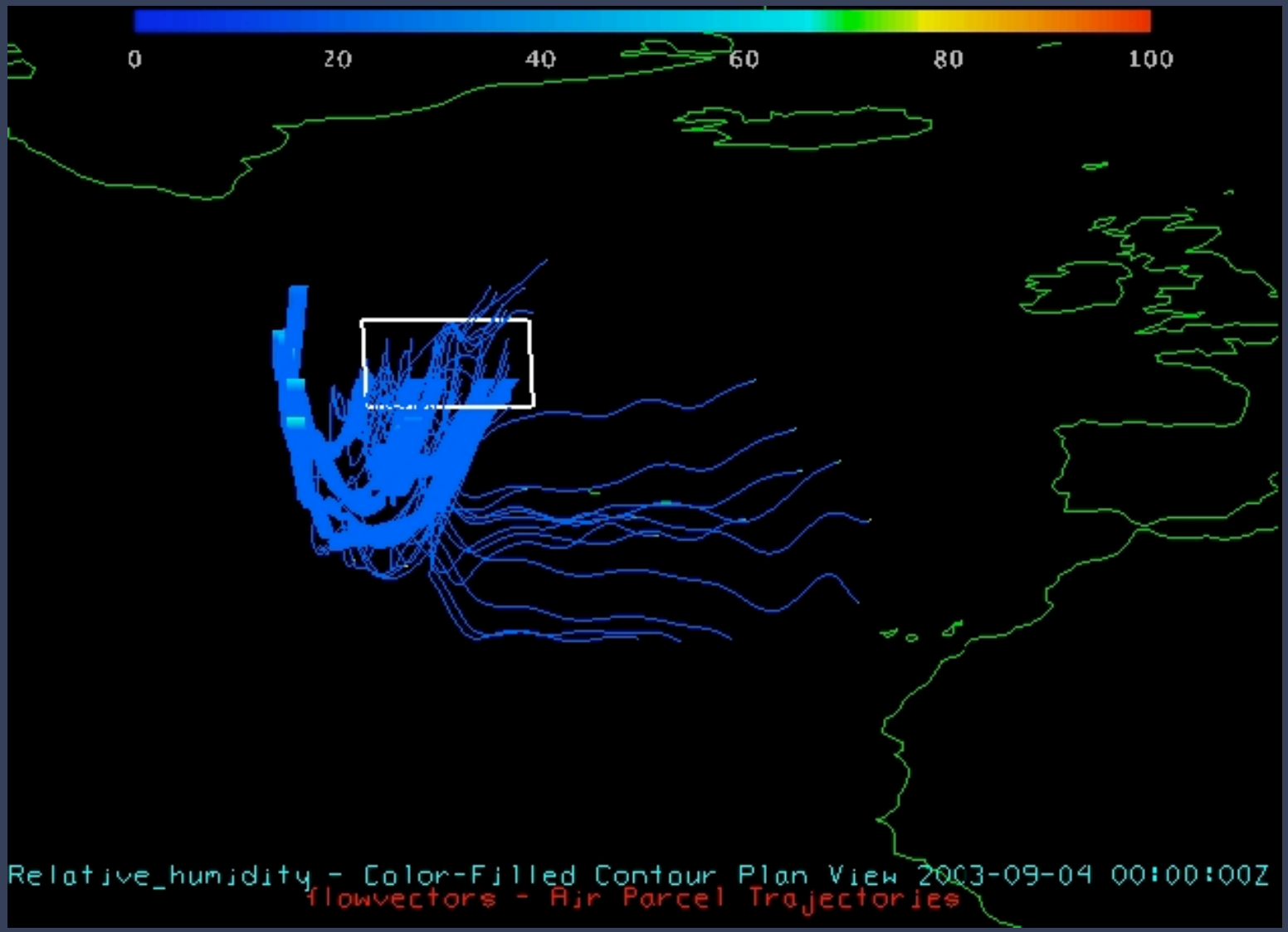
Resulting pathline uncertainty
(thicker is more certain)

Humidity Representation

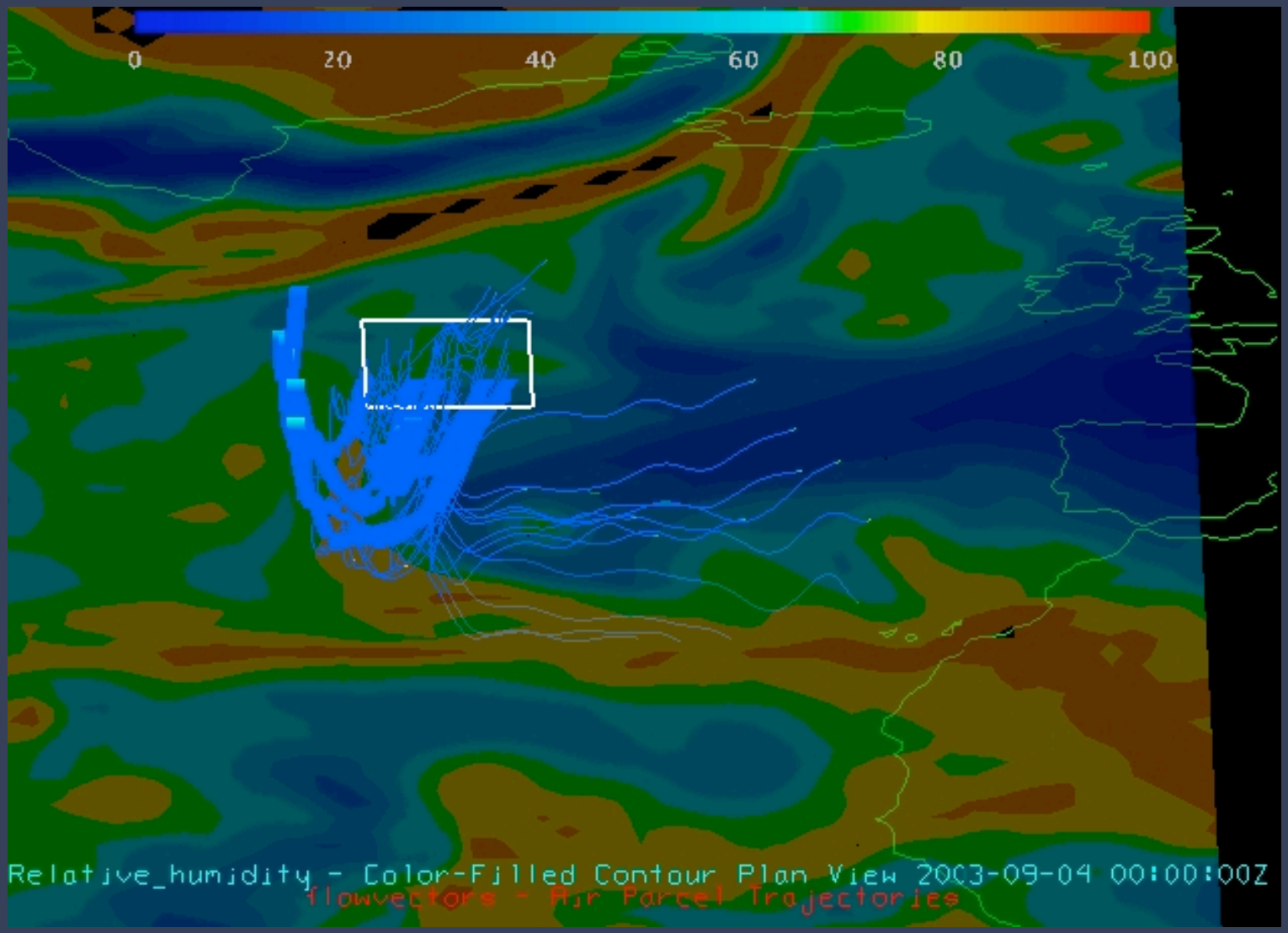


Humidity-colored trajectories

Incremental pathline coloring



Multi-field Context



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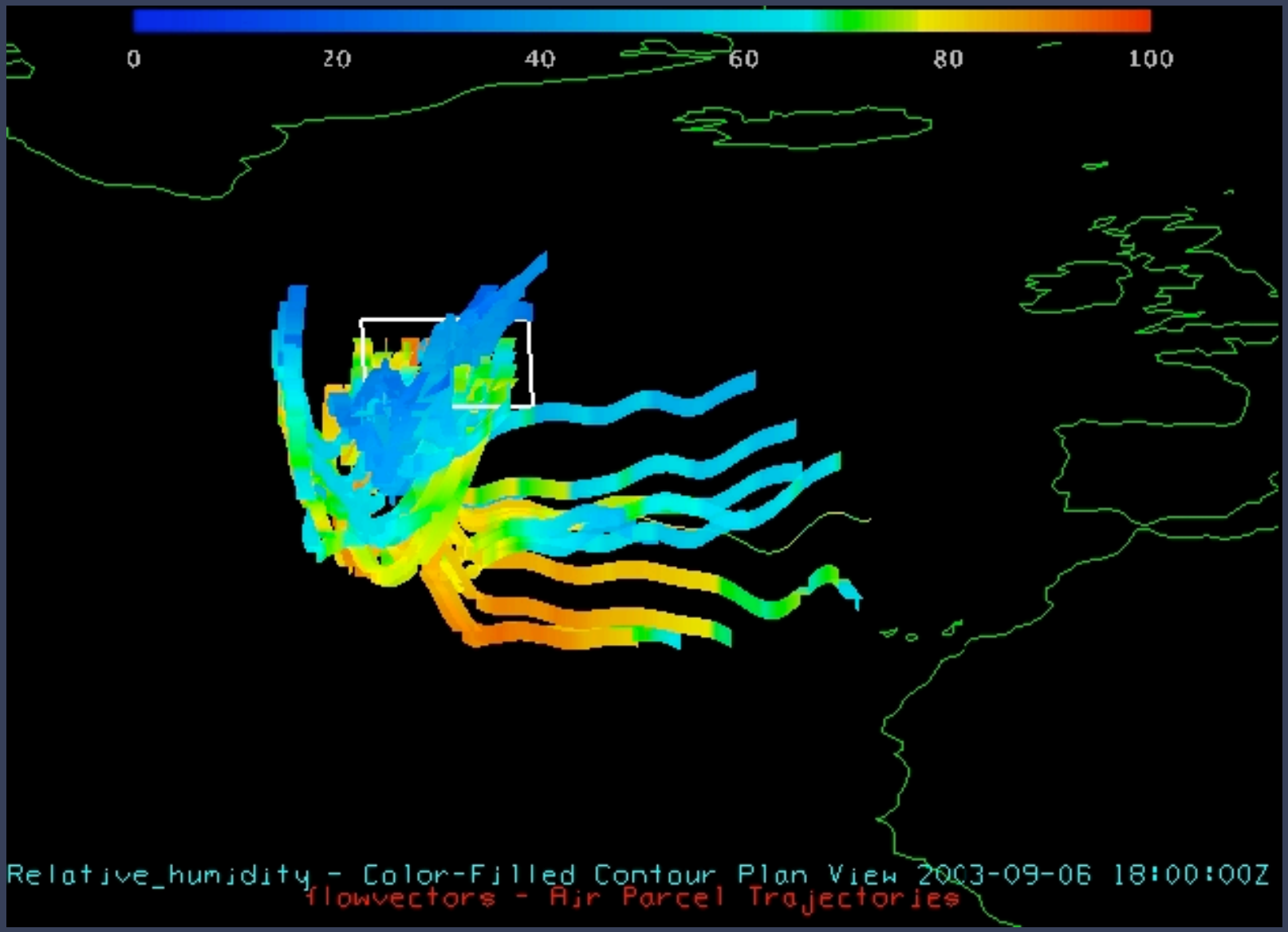
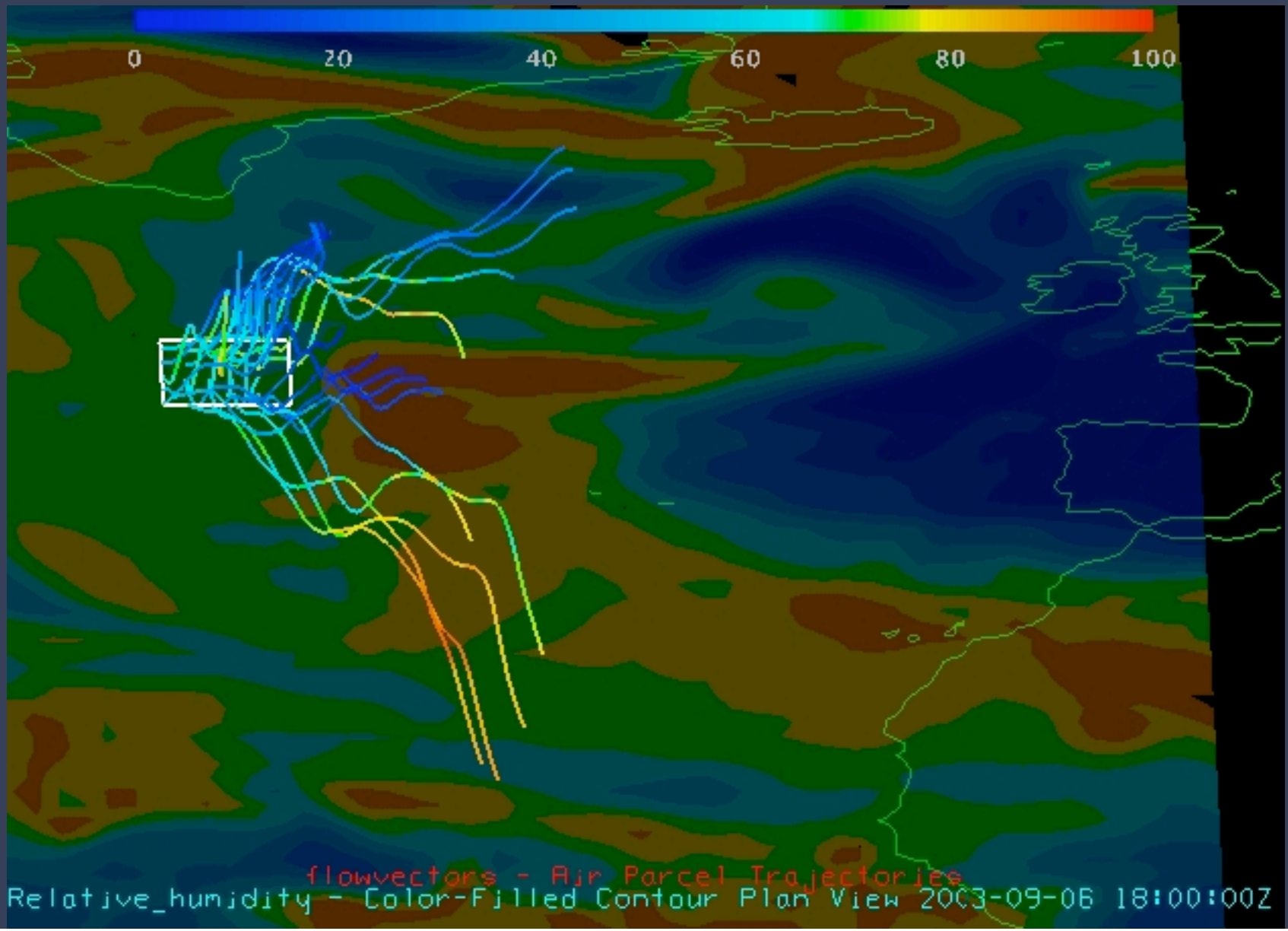
Efficient Visual Pruning

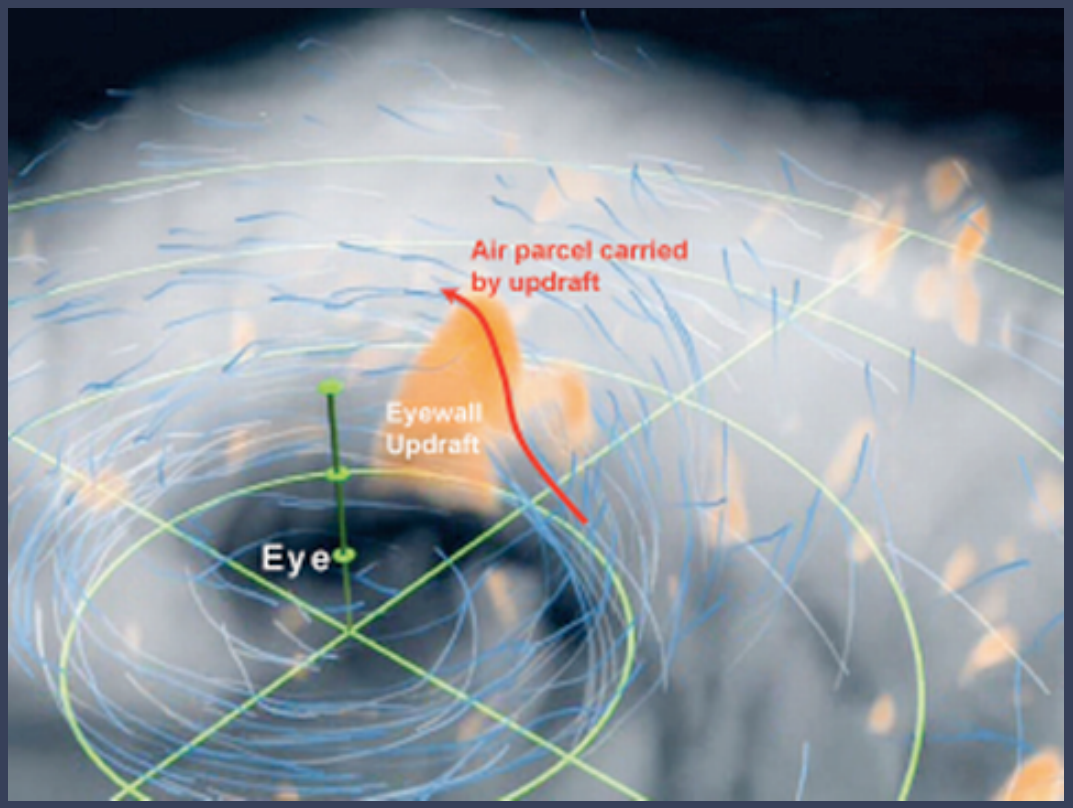


Efficient Search for Features



Other Applications

- Use higher resolution data, apply uncertainty concepts in different way



http://svs.gsfc.nasa.gov/goto?3377

- Obtain intermediate values from model computations for better uncertainty calculations

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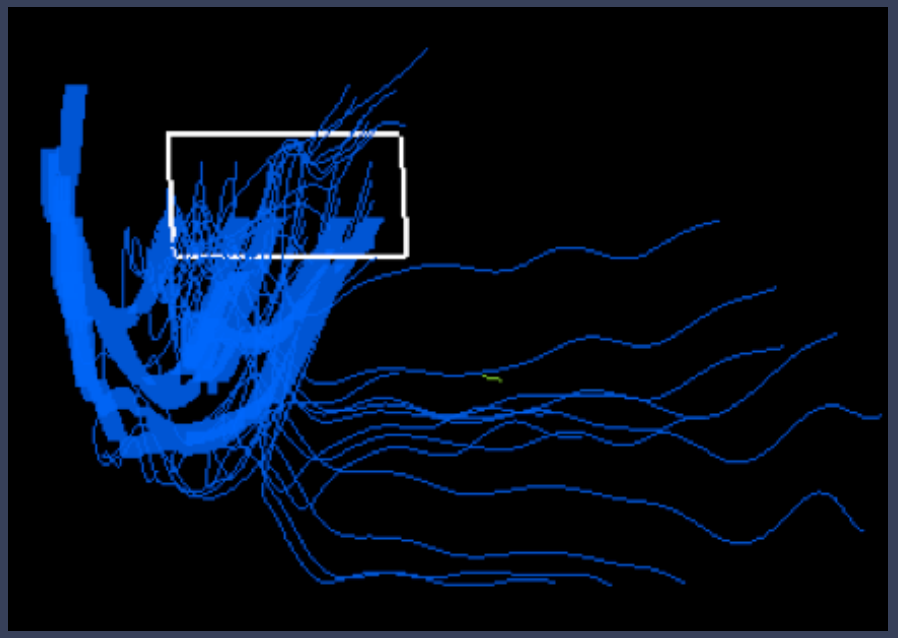
Conclusions

Original goal: improve understanding of local environment of developing hurricanes

- Enabled efficient generation and analysis of 3-D meteorological trajectories
- Derived an upper bound on uncertainty on these trajectories due to interpolation error
- Found preliminary evidence to support "marsupial" theory



Questions?