Lagrangian Coherent Structures in High-Frequency Satellite Winds of an Atmospheric Kármán Vortex Street

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Motivation

ABI Observations [Horváth et al. 2020]

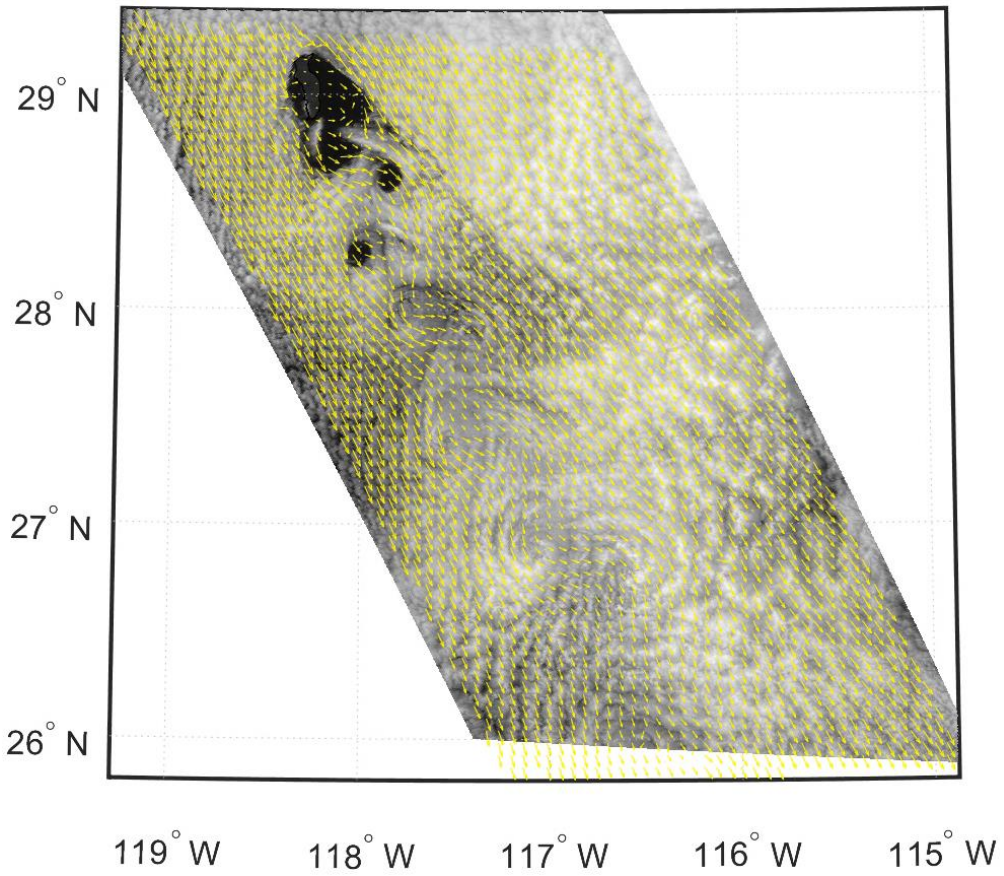
- Reconstruction of wind vectors at km/minute scale became possible

Challenge

- There is no ground truth!
- **How to validate?**

Approach

- Look deeper into the **fluid dynamics**!
- Are cloud patterns correlated to fluid dynamical processes?



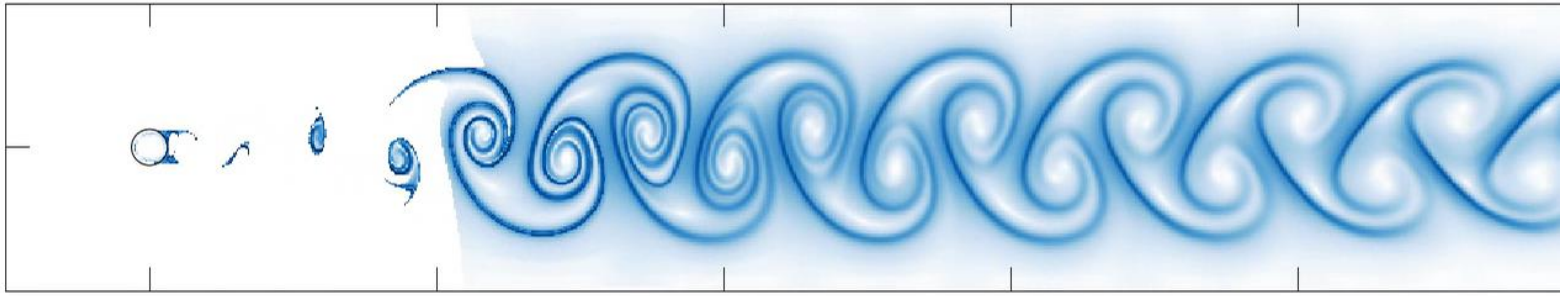
Reconstructed wind vectors from ABI observations.

Lagrangian Coherent Structures [Haller 2015]

Distinguished material lines that govern the fluid motion

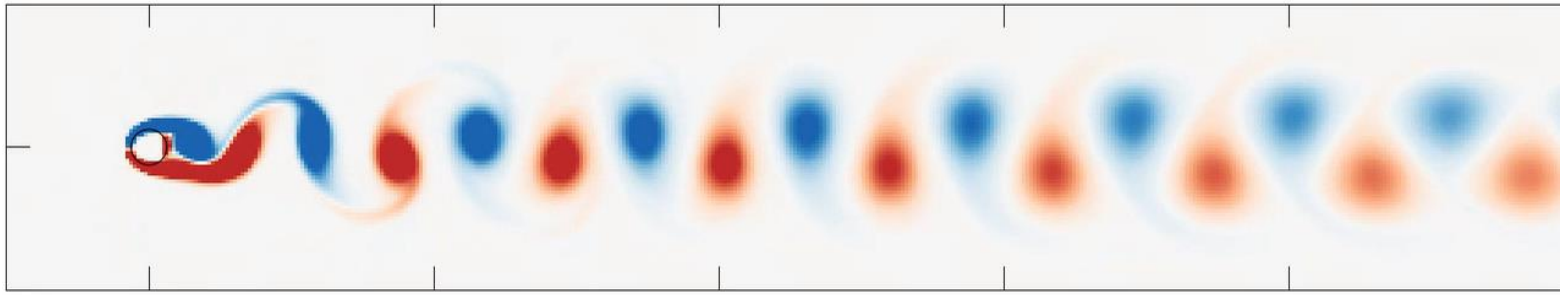
Hyperbolic LCS

Transport barriers



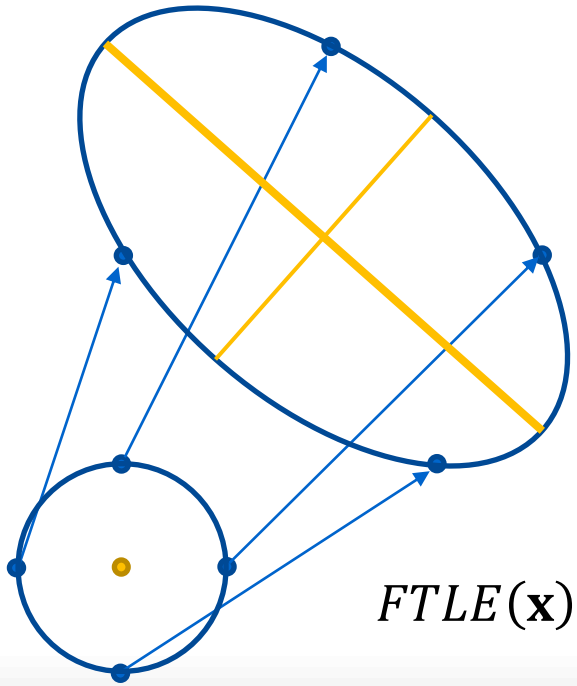
Elliptic LCS

Vortices

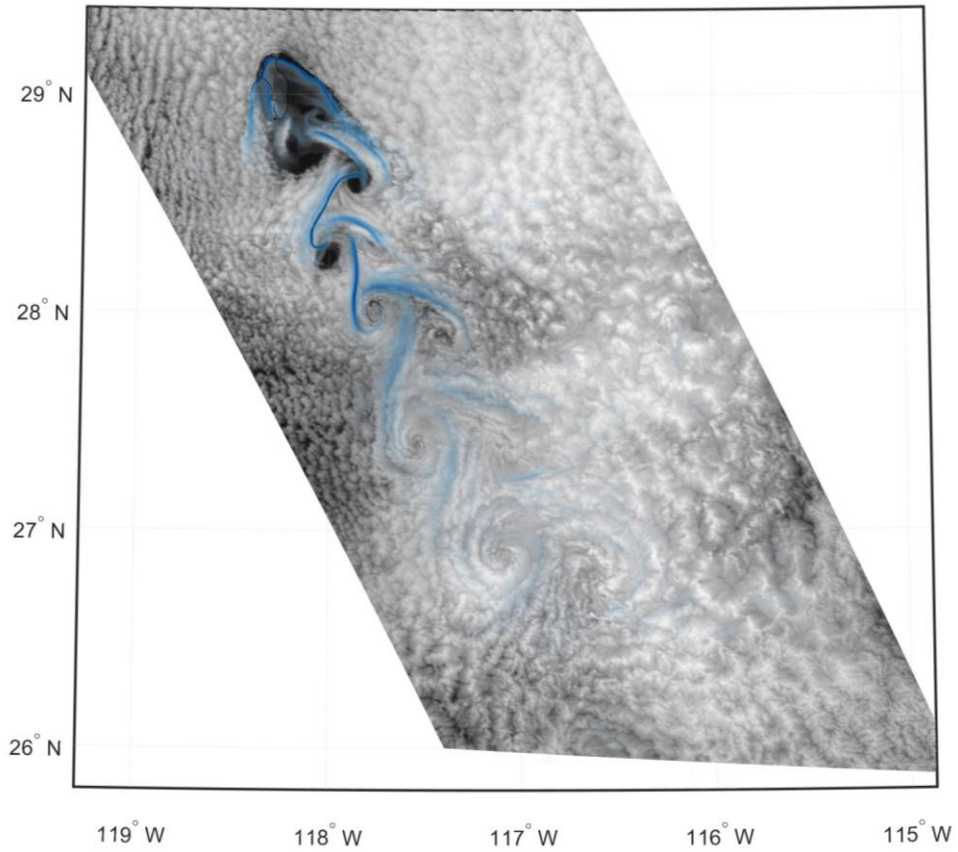


Transport Barriers [Shadden 2005]

- Where are particles **repelled** away?
- Where are particles **attracted** to?



$$FTLE(\mathbf{x}) = \frac{1}{|\tau|} \ln \sqrt{\lambda_{max}\left(\Phi(\mathbf{x})^{\mathrm{T}} \Phi(\mathbf{x})\right)}$$



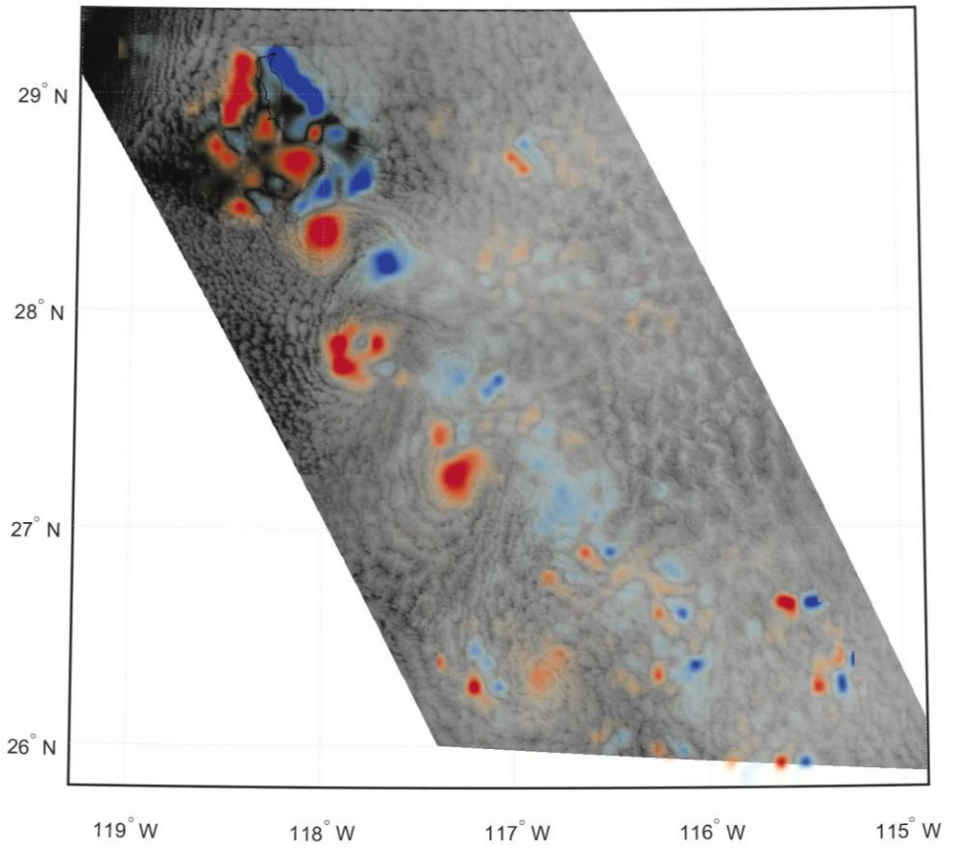
Finite-Time Lyapunov Exponent (FTLE) in backward direction shows attracting material lines.

Vorticity

- Rotating motion of particles

$$\omega(x,y) = \frac{\partial v(x,y)}{\partial x} - \frac{\partial u(x,y)}{\partial y}$$

- **Problem**:
  - Very sensitive to noise



Vorticity

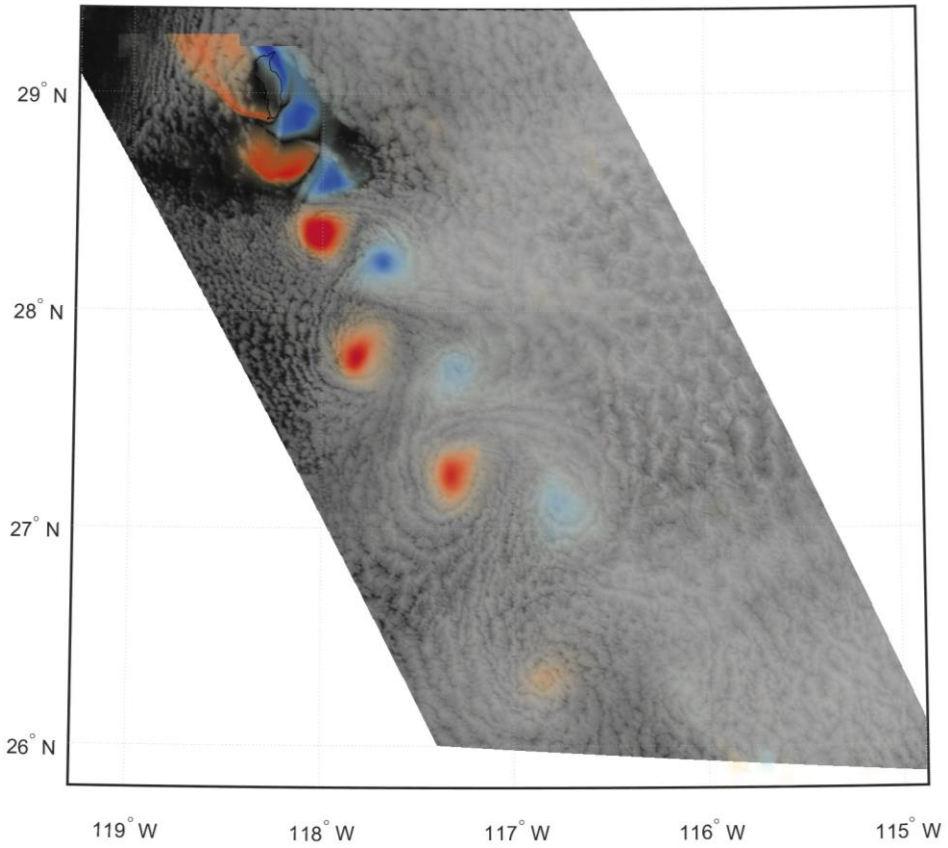
- Rotating motion of particles

$$\omega(x,y) = \frac{\partial v(x,y)}{\partial x} - \frac{\partial u(x,y)}{\partial y}$$

Lagrangian-averaging [Haller 2016]

$$LAVD(\mathbf{x}) = \int_t^{t+\tau} \left|\omega\big(\mathbf{p}(\tau)\big) - \omega_{avg}\big(\mathbf{p}(\tau)\big)\right| \mathrm{d}s$$

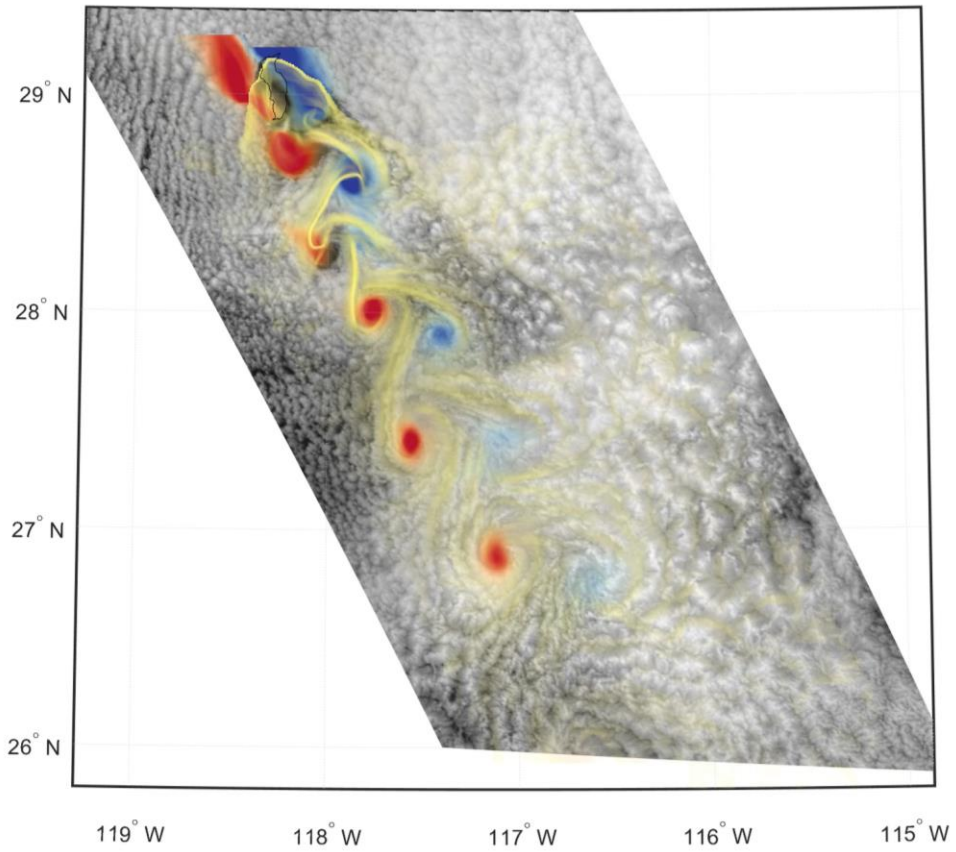
Particle trajectory $\mathbf{p}(t)$ started from $\mathbf{x}$.



Finally, we visualize both

- Separating structures via backward **FTLE** (hyperbolic LCS),
- and vortices via **LAVD** (elliptic LCS).

LCS evolve coherently with clouds



Conclusions

Feature-based Verification of Wind Retrievals

- Observing a strong correspondence, or lack thereof, between visible cloud structures and flow features derived from satellite wind retrievals is a useful verification tool

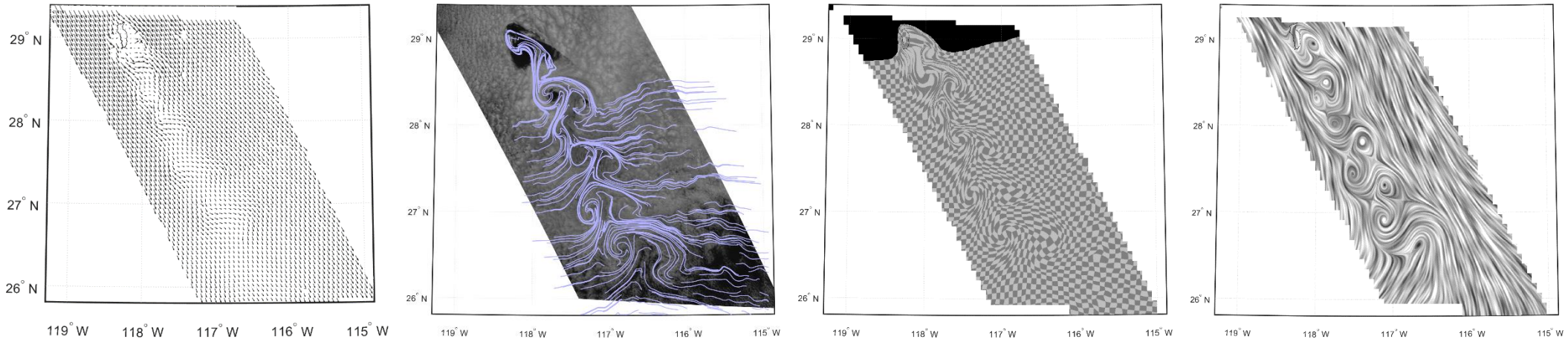
Lagrangian Coherence

- Smoothing along pathlines is more meaningful than smoothing in space, as temporal smoothing reveals structures that live for a longer period of time

Coming Soon...

More techniques in „JGR: Atmosphere“ submission

- Arrow plots, integral curves, texture advection, line integral convolution, ...



Matlab Code is available!

- https://github.com/tobguent/vislcs-guadalupe

GitHub