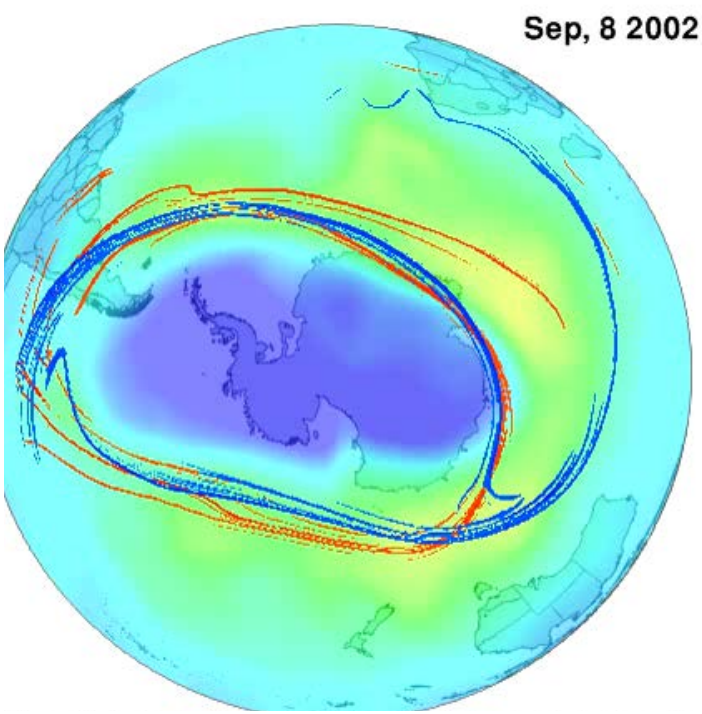
Geophysical transport structure and ecology: challenges and opportunities

Shane Ross

Joint work with David Schmale, Amir BozorgMagham, Binbin Lin, A.J. Prussin, Phanindra Tallapragada, Shibabrat Naik

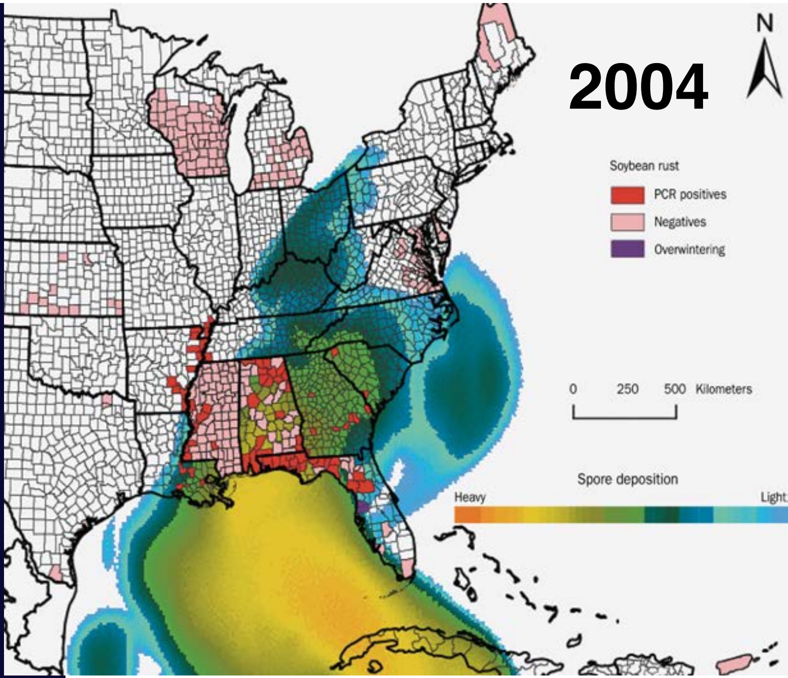
Virginia Tech



Invasive species riding the atmosphere

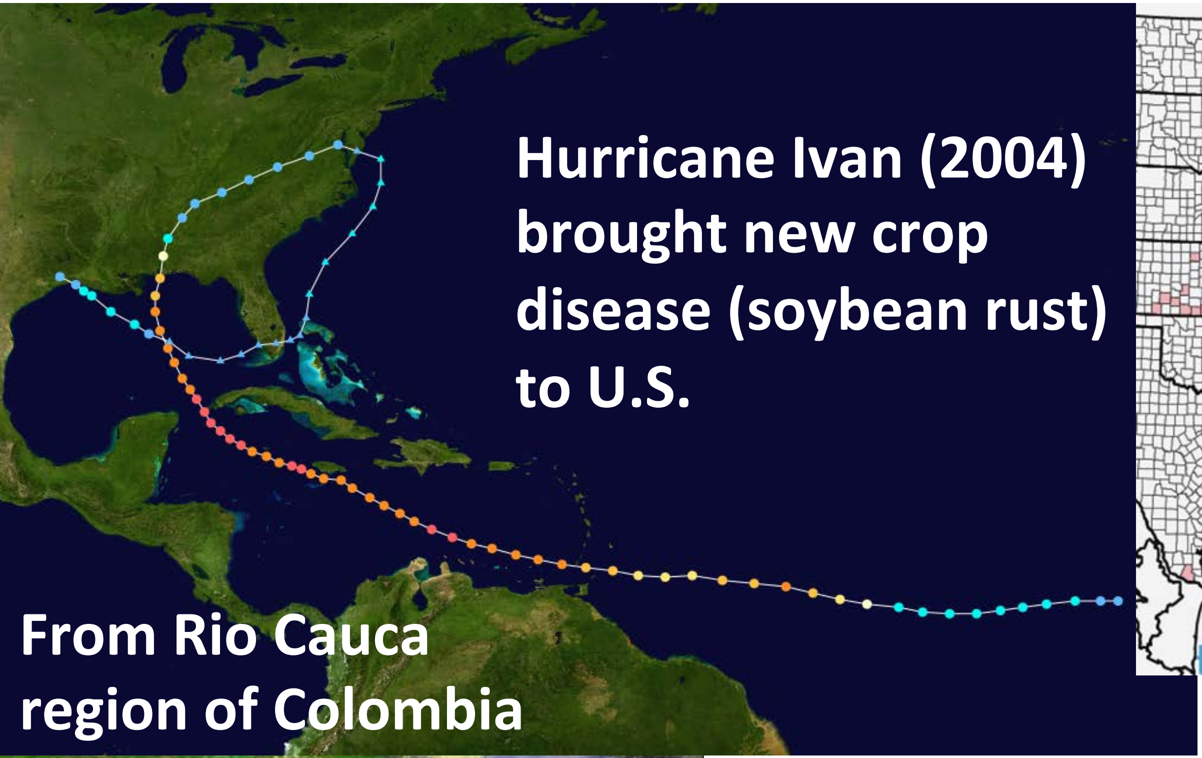
Hurricane Ivan (2004) brought new crop disease (soybean rust) to U.S.

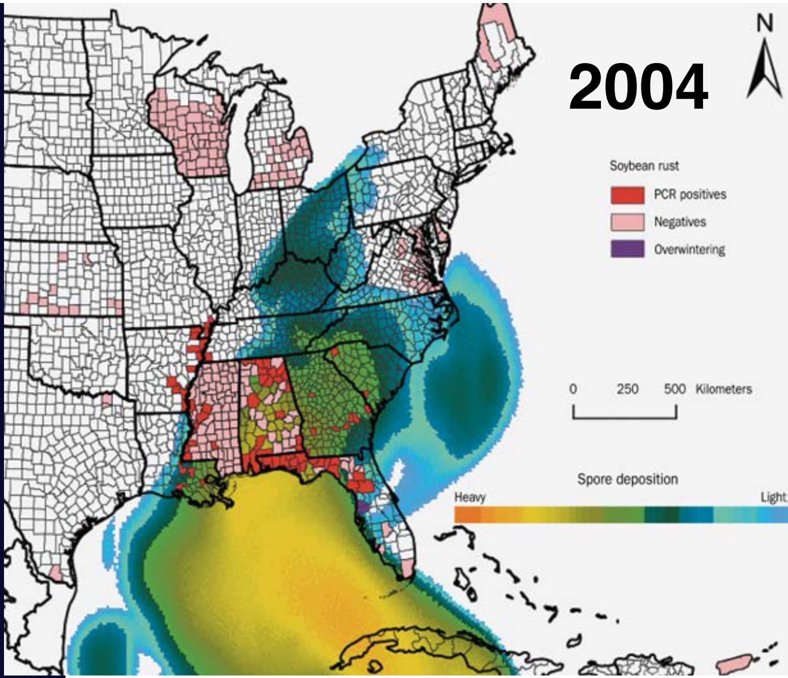
From Rio Cauca region of Colombia



Red=infected US regions

Invasive species riding the atmosphere





Cost of invasive organisms is
<u>$137 billion</u> **per year in U.S.**

Food supply concerns, bioterrorism

Wheat scientists seek to slow crop fungus in Africa, Asia

Thu Aug 30, 2012 10:00pm EDT

* Stem rust, originating in Uganda, spreads to Yemen, Iran

* Fears that it could sweep eastwards in Asia

By Alister Doyle

OSLO, Aug 31 (Reuters) - Wheat experts are stepping up monitoring of a crop disease first found in Africa in 1999 to minimise the spread of a deadly fungus that is also a threat in Asia, experts said on Friday.

A "Rust-Tracker", using data supplied by farmers and scientists, could now monitor the fungus in 27 developing nations across 42 million hectares (103 million acres) of wheat - an area the size of Iraq or California.

"It's the most serious wheat disease," Ronnie Coffman, vice-chair of the Borlaug Global Rust Initiative (BGRI), told Reuters ahead of a meeting of wheat experts in Beijing from Sept. 1-4.

"If it gets started...it's like a biological firestorm," he said. Experts will review progress in combating the disease, with fungicides and 20 new resistant varieties developed in recent years.

Related News

Australia says signs El Nino weather pattern forming
Tue, Aug 14 2012

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Non-Cyclical Consumer Goods »

Annu. Rev. Phytopathol. 2003. 41:155–76
doi: 10.1146/annurev.phyto.41.121902.102839

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THE THREAT OF PLANT PATHOGENS AS WEAPONS AGAINST U.S. CROPS

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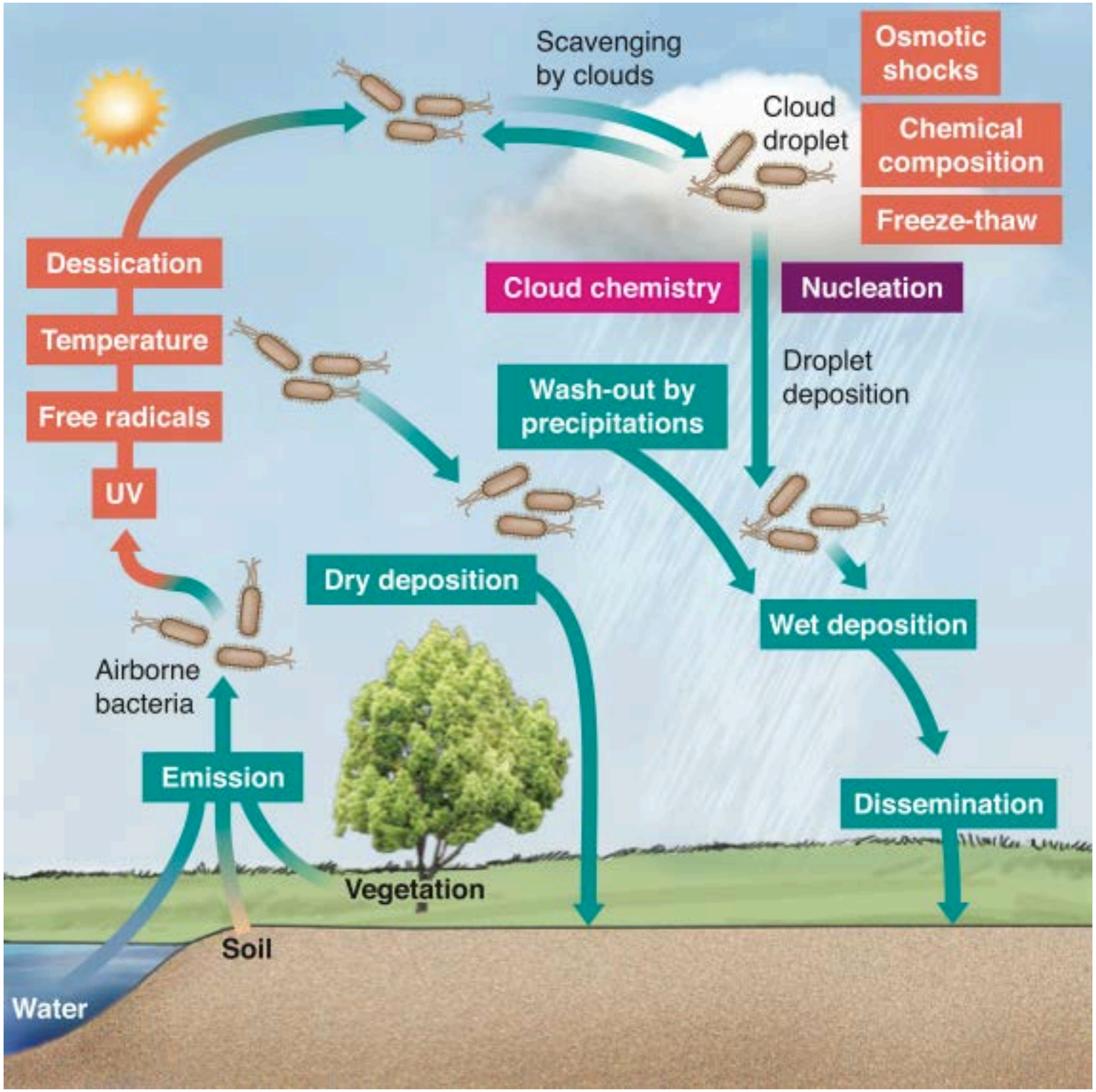
Key Words agricultural vulnerability, biological weapons, bioterrorism, crop biosecurity, plant disease invasion, plant disease persistence and spread, risk analysis

■ **Abstract** The U.S. National Research Council (NRC) concluded in 2002 that U.S. agriculture is vulnerable to attack and that the country has inadequate plans for dealing with agricultural bioterrorism. This article addresses the vulnerability of U.S. crops to attack from biological weapons by reviewing the costs and impact of plant diseases on crops, pointing out the difficulty in preventing deliberate introduction of pathogens and discovering new disease outbreaks quickly, and discussing why a plant pathogen might be chosen as a biological weapon. To put the threat into context, a brief historical review of anti-crop biological weapons programs is given. The argument is made that the country can become much better prepared to counter bioterrorism by developing a list of likely anti-crop threat agents, or categories of agents, that is based on a formal risk analysis; making structural changes to the plant protection system, such as expanding diagnostic laboratories, networking the laboratories in a national system, and educating first responders; and by increasing our understanding of the molecular biology and epidemiology of threat agents, which could lead to improved disease control, faster and more sensitive diagnostic methods, and predictions of disease invasion, persistence, and spread following pathogen introduction.

INTRODUCTION

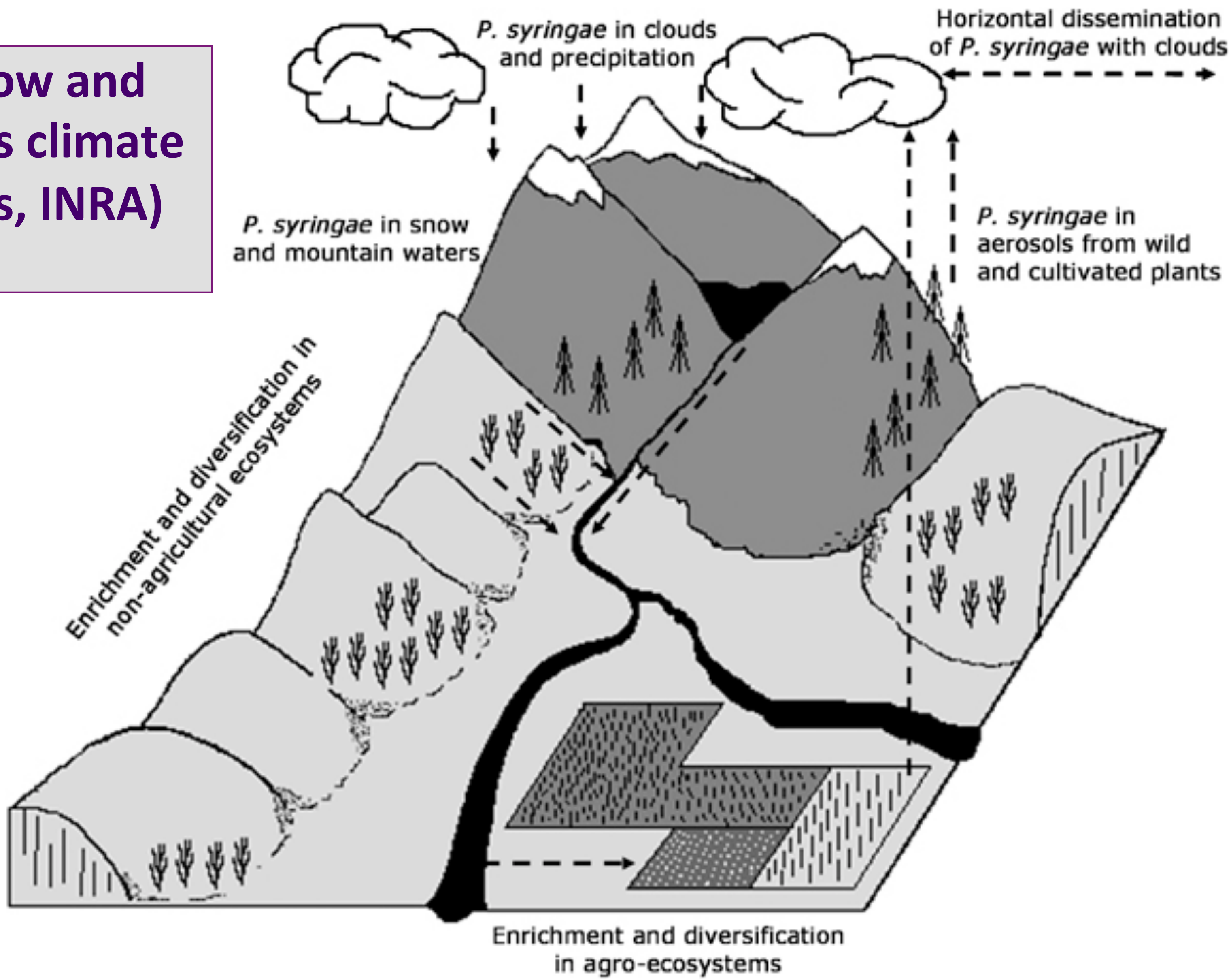
Using [biological weapons] to attack livestock, crops, or ecosystems offers

Microbes ride in clouds, catalyze rain

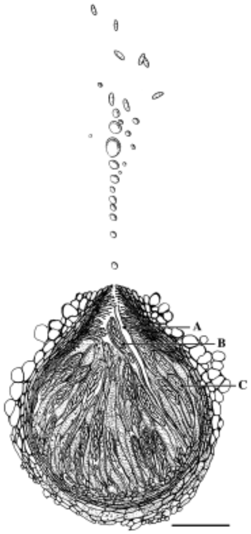


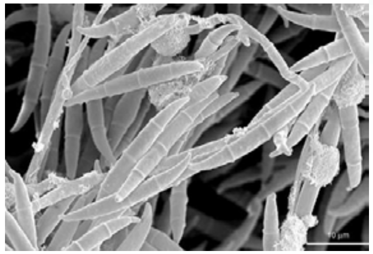
Plant pathogens linked to water cycle

What you grow and where affects climate (Cindy Morris, INRA)

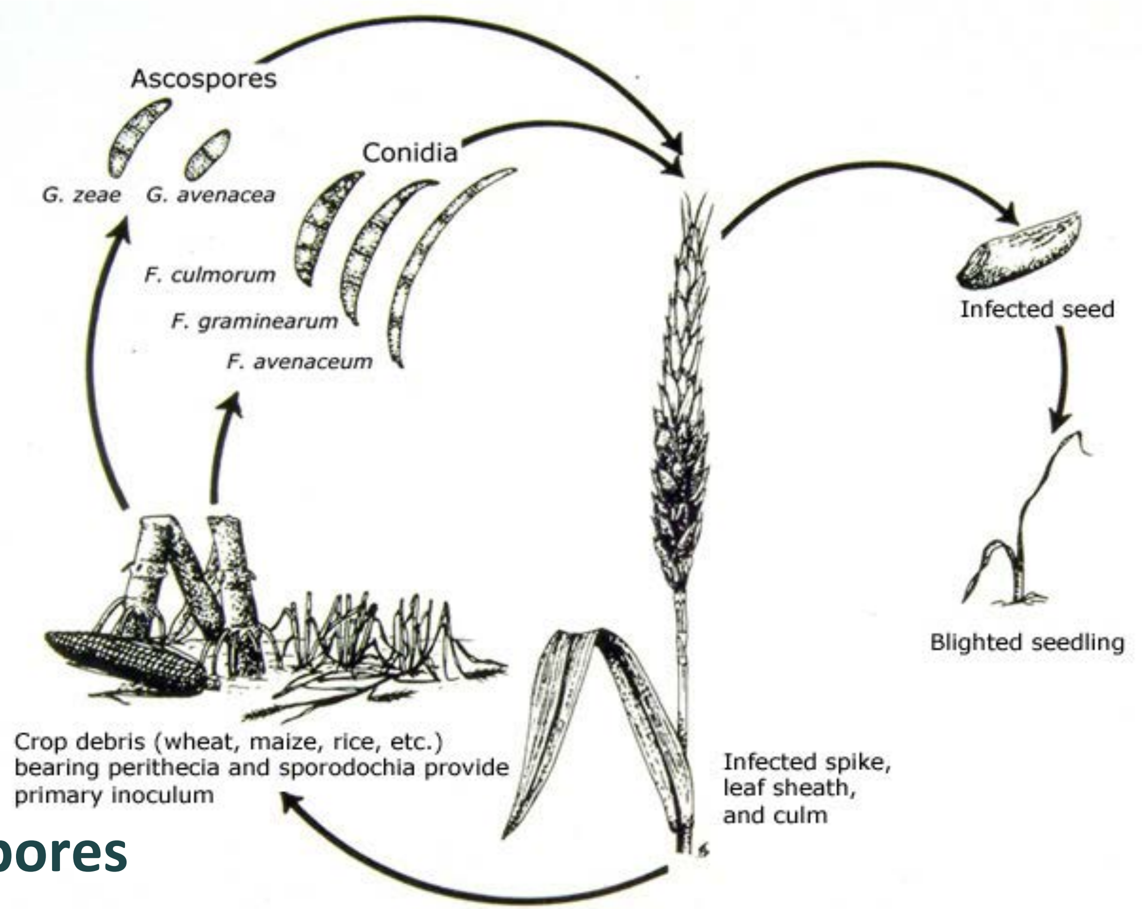


Atmospheric transport of microorganisms





$$a \approx 10^6 g$$

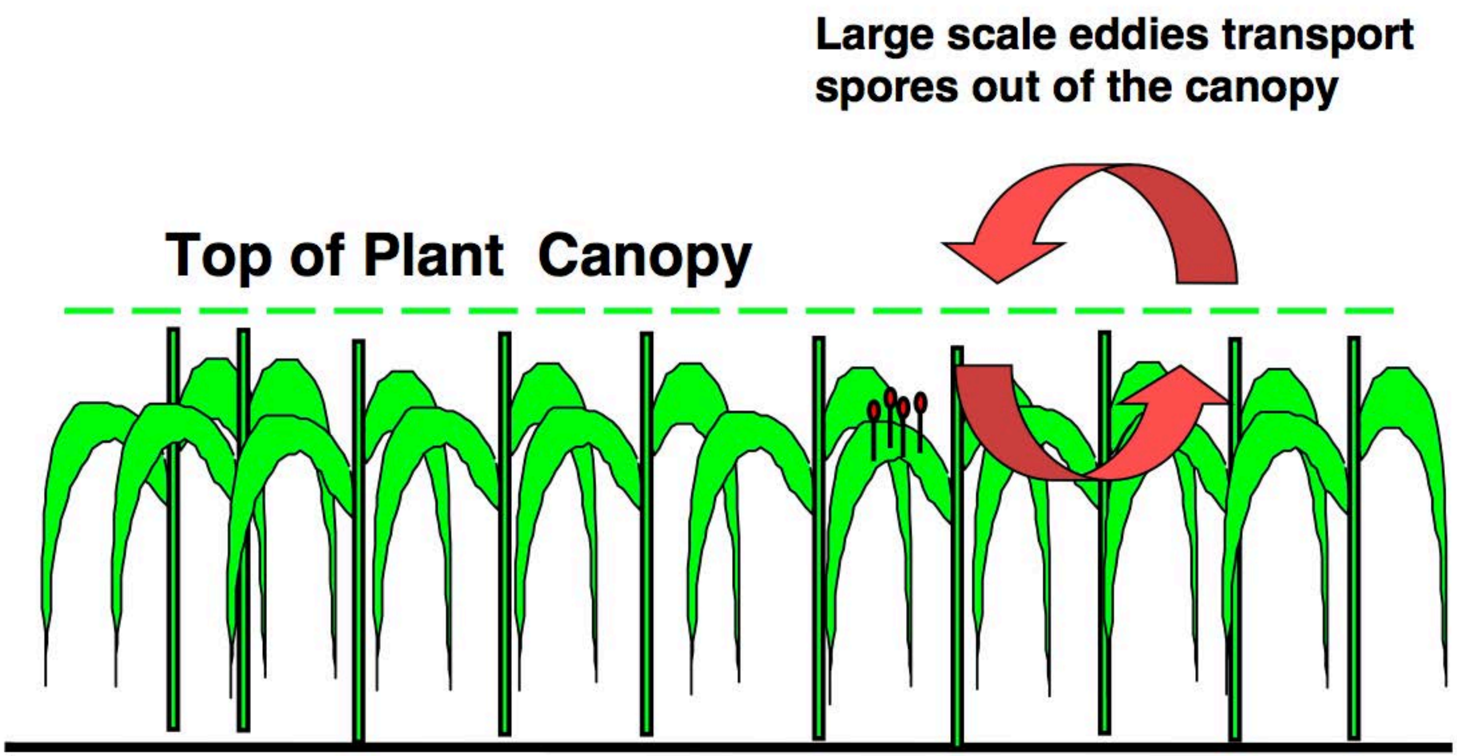


e.g., *Fusarium* fungal spores

- **Spore production, release, escape from surface**
- **Long-range transport (time-scale hours to days)**
- **Deposition, infection efficiency, host susceptibility**

Schmale & Bergstrom [2003], Trail et al. [2005]

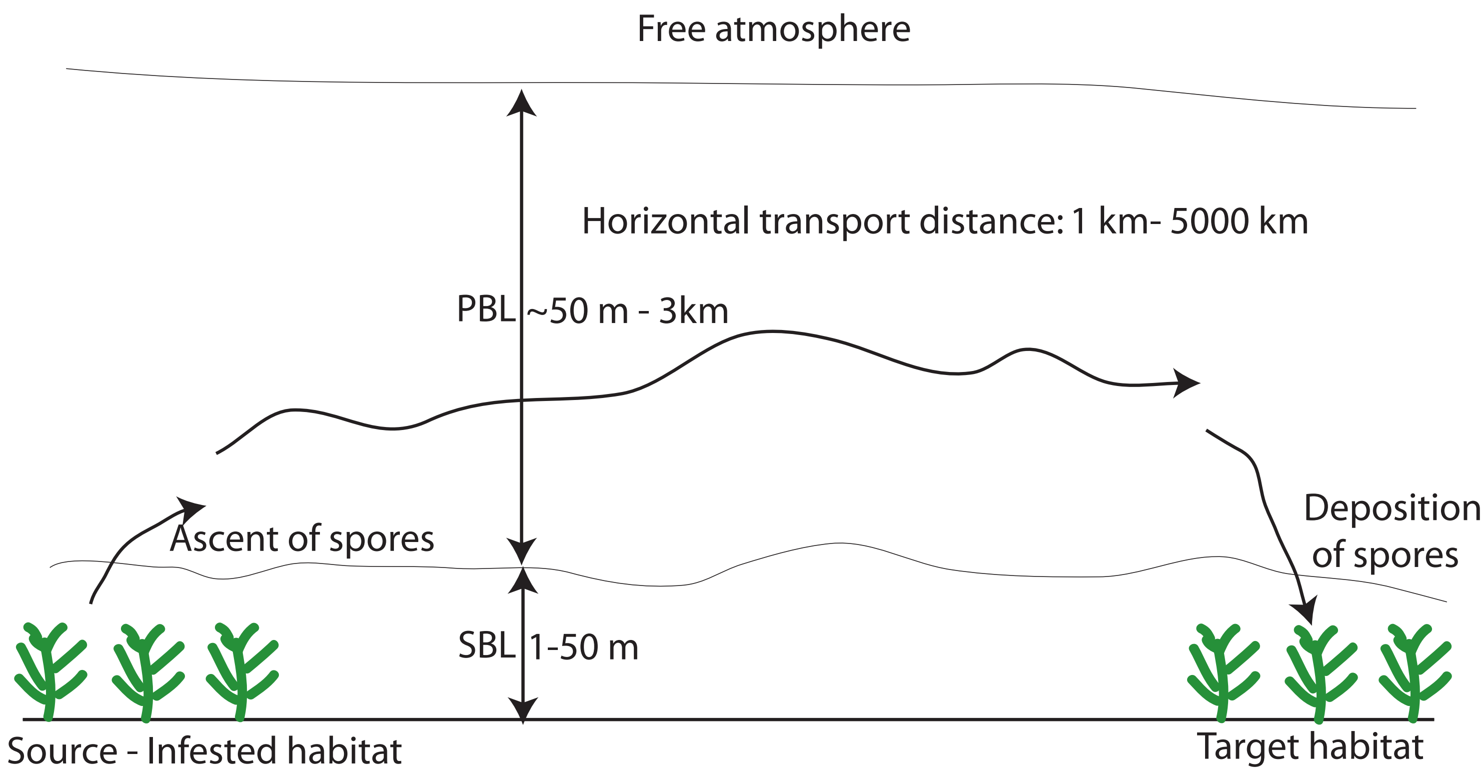
Atmospheric transport of microorganisms



- Spore production, release, escape from surface
- Long-range transport (time-scale hours to days)
- Deposition, infection efficiency, host susceptibility

Aylor [1999]

Atmospheric transport of microorganisms



- **Spore production, release, escape from surface**
- **Long-range transport (time-scale hours to days)**
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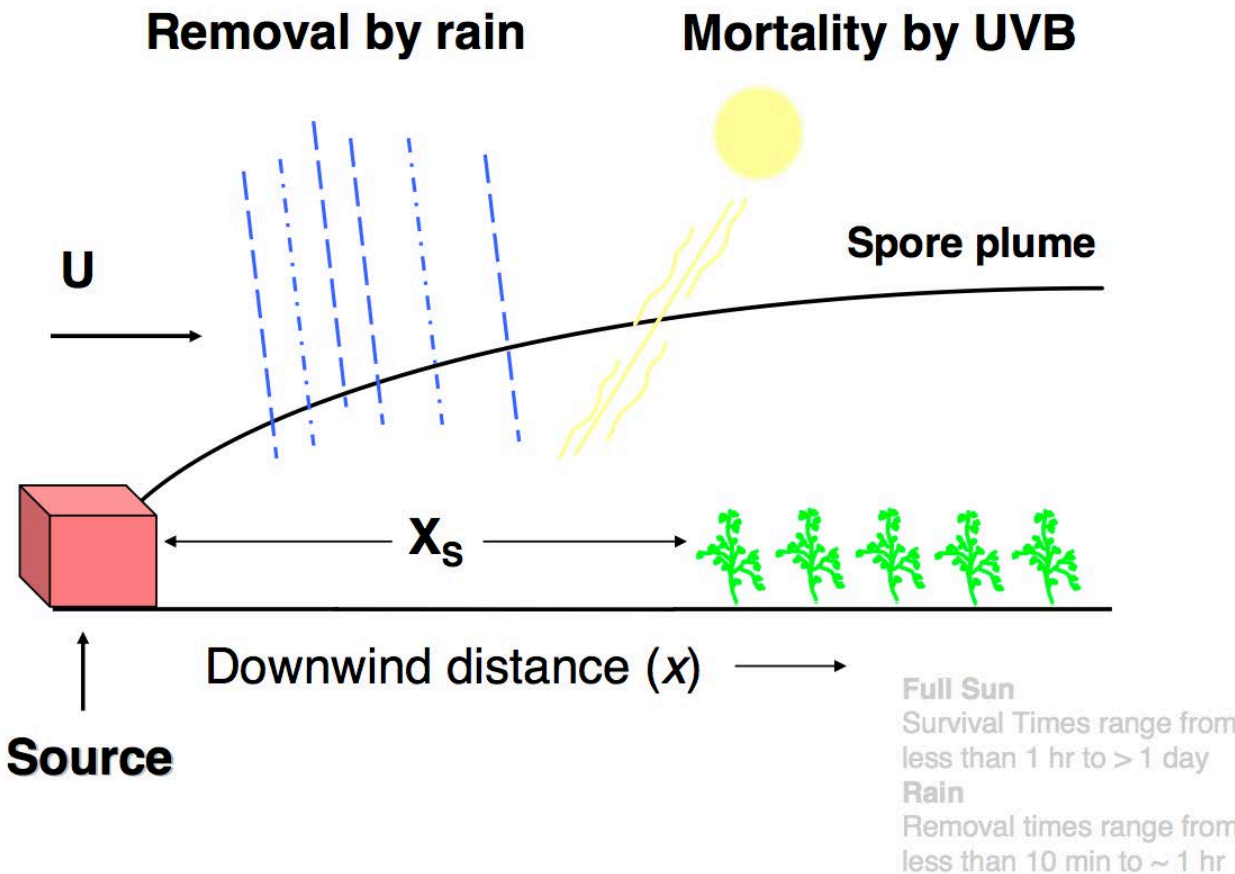
Isard & Gage [2001], Tallapragada, Ross, Schmale [2011]

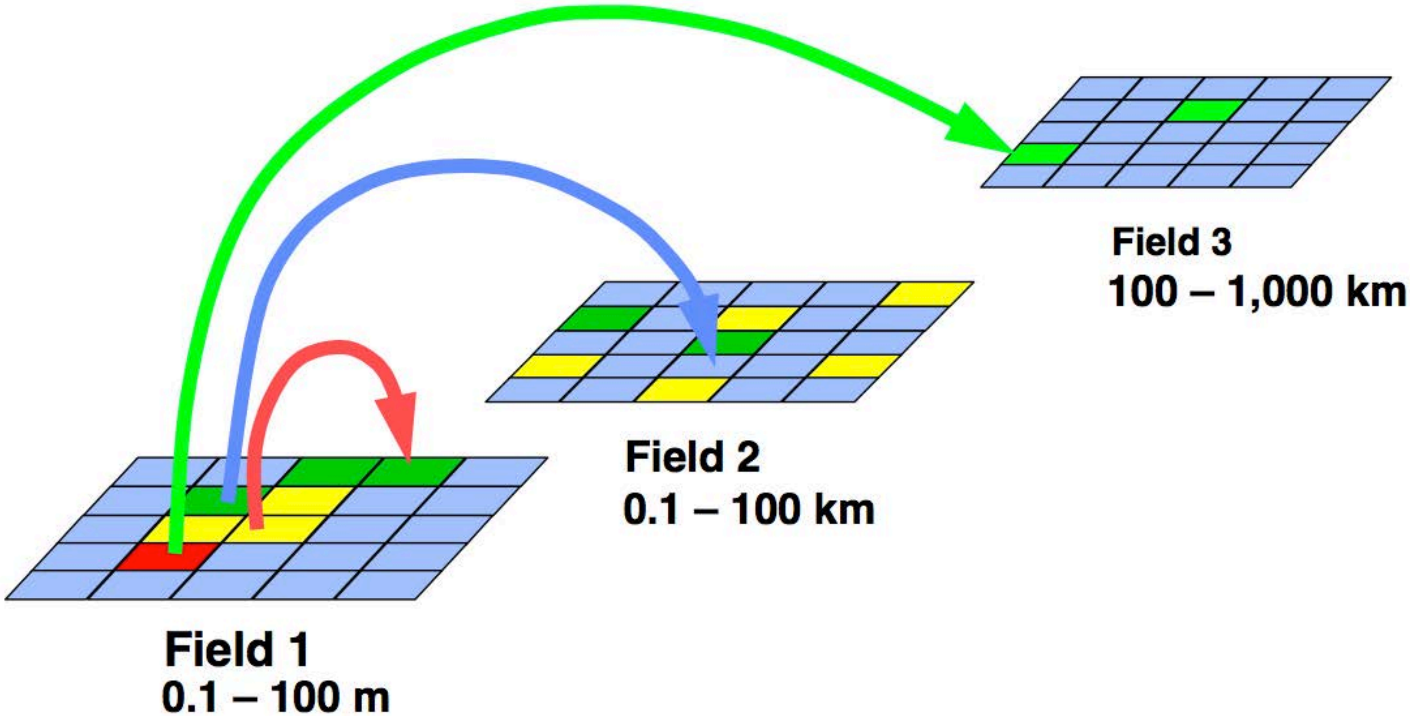
Atmospheric transport of microorganisms



- **Spore production, release, escape from surface**
- **Long-range transport (time-scale hours to days)**
- **Deposition, infection efficiency, host susceptibility**

Aylor [1999]; Prussin et al [2013]

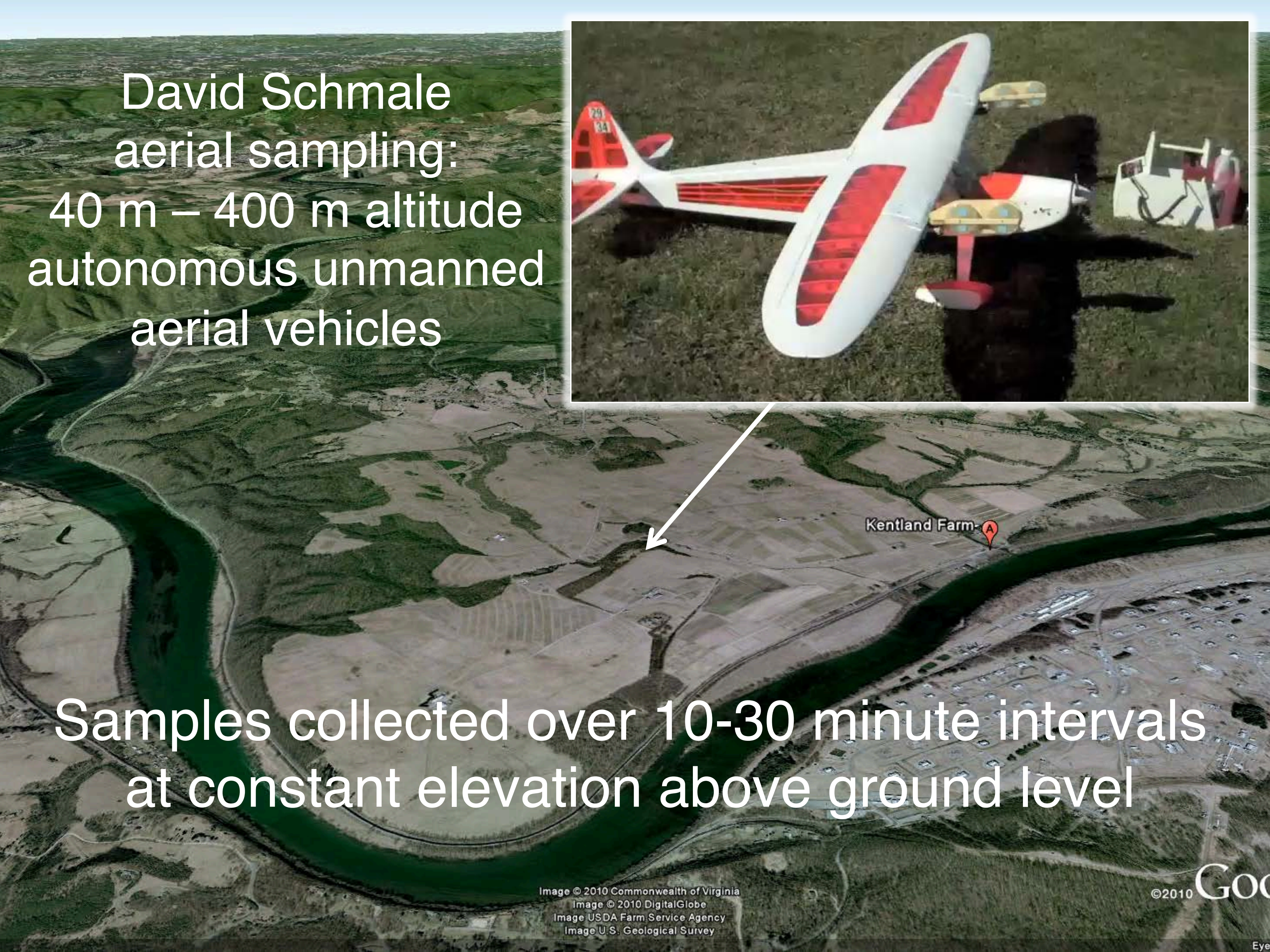
Atmospheric transport of microorganisms



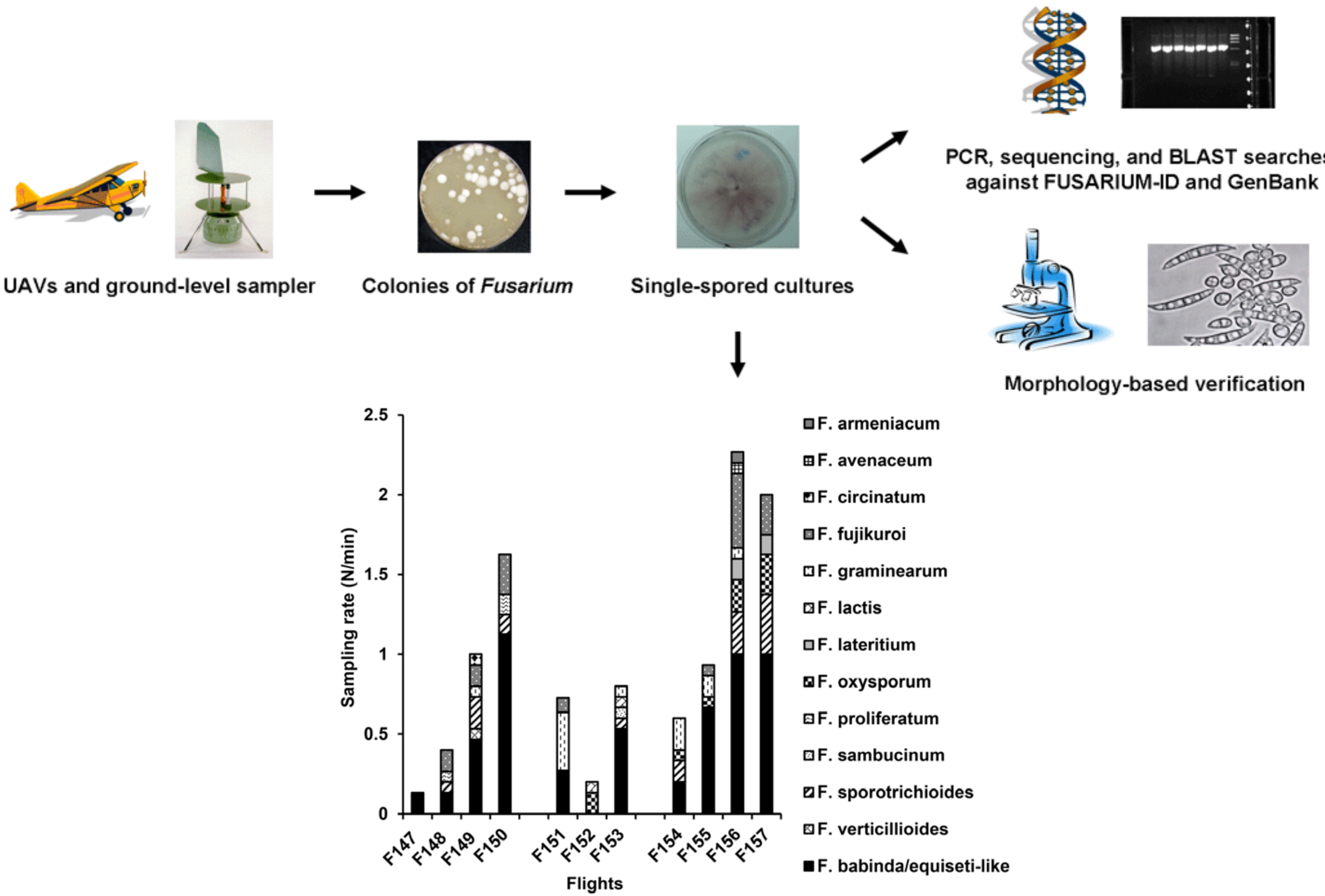
Deposition patterns can be patchy

- Spore production, release, escape from surface
- Long-range transport (time-scale hours to days)
- Deposition, infection efficiency, host susceptibility

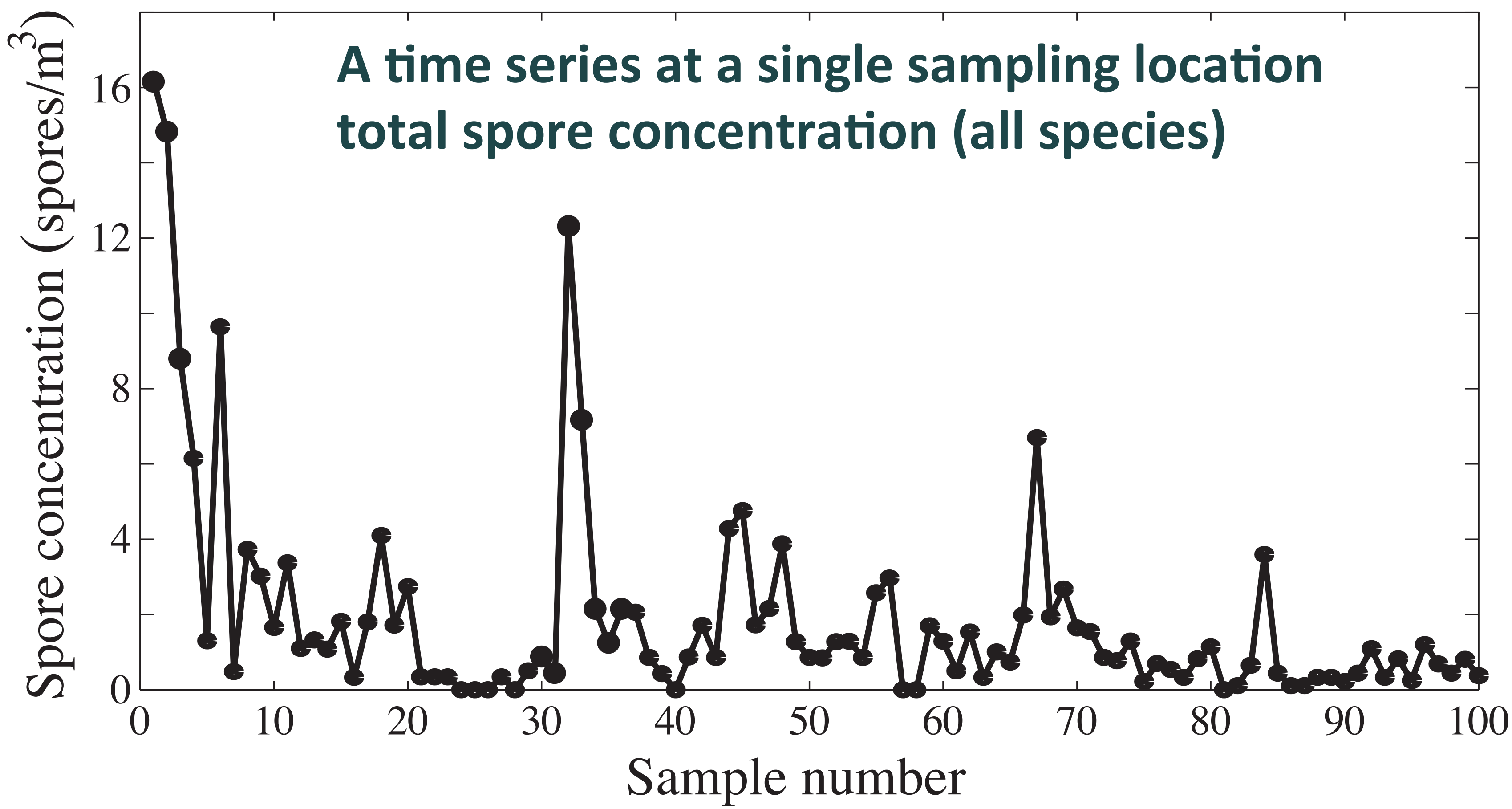
Aylor [1999]


David Schmale
aerial sampling:
40 m – 400 m altitude
autonomous unmanned
aerial vehicles
Kentland Farm
Samples collected over 10-30 minute intervals
at constant elevation above ground level
Image © 2010 Commonwealth of Virginia
Image © 2010 DigitalGlobe
Image USDA Farm Service Agency
Image U.S. Geological Survey
©2010

Count spores, identify down to level of species



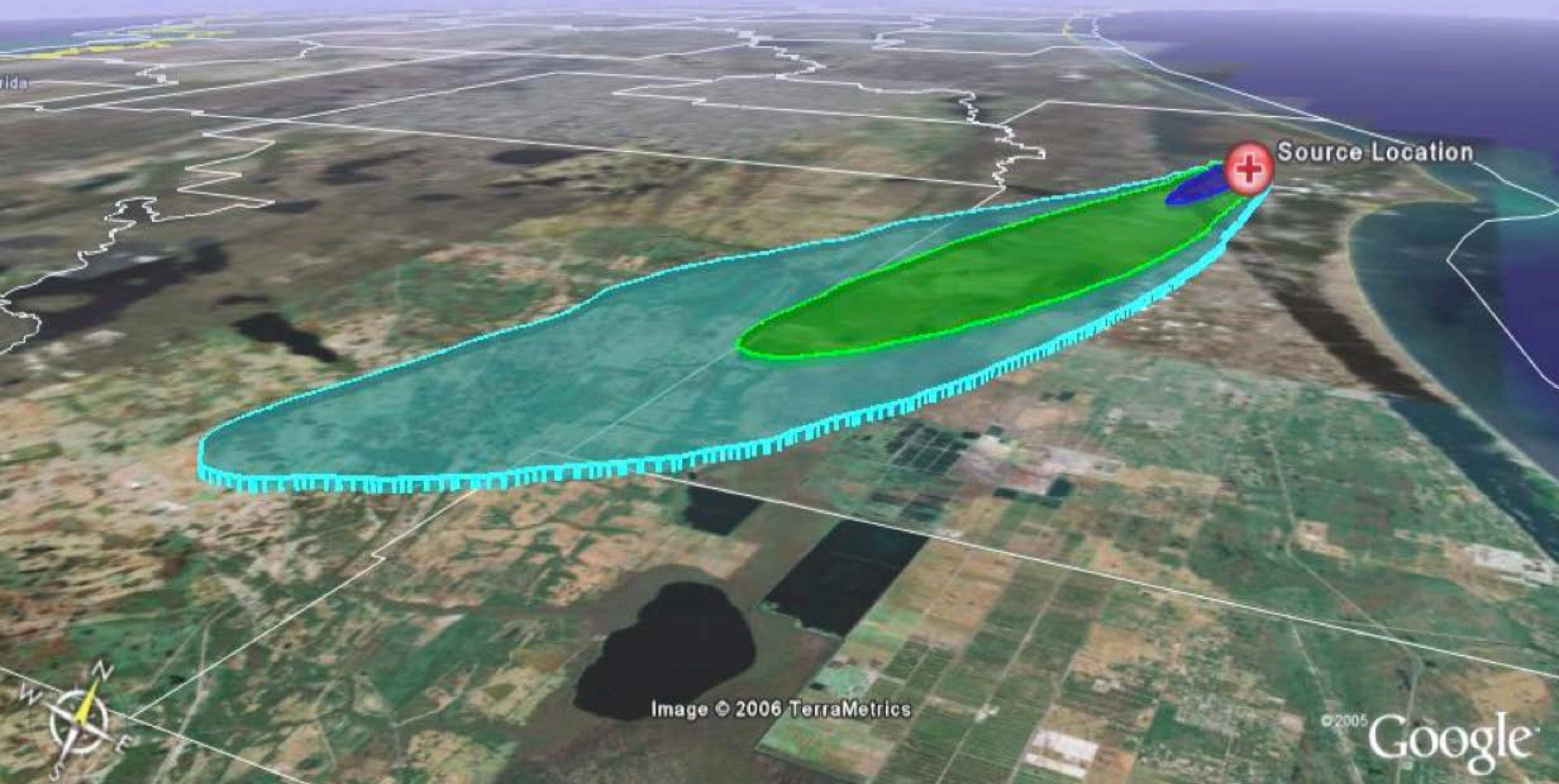
Fluctuations in fungal spore concentration



Concentration of *Fusarium* spores (number/m^3) for samples from 100 flights conducted between August 2006 and March 2010.

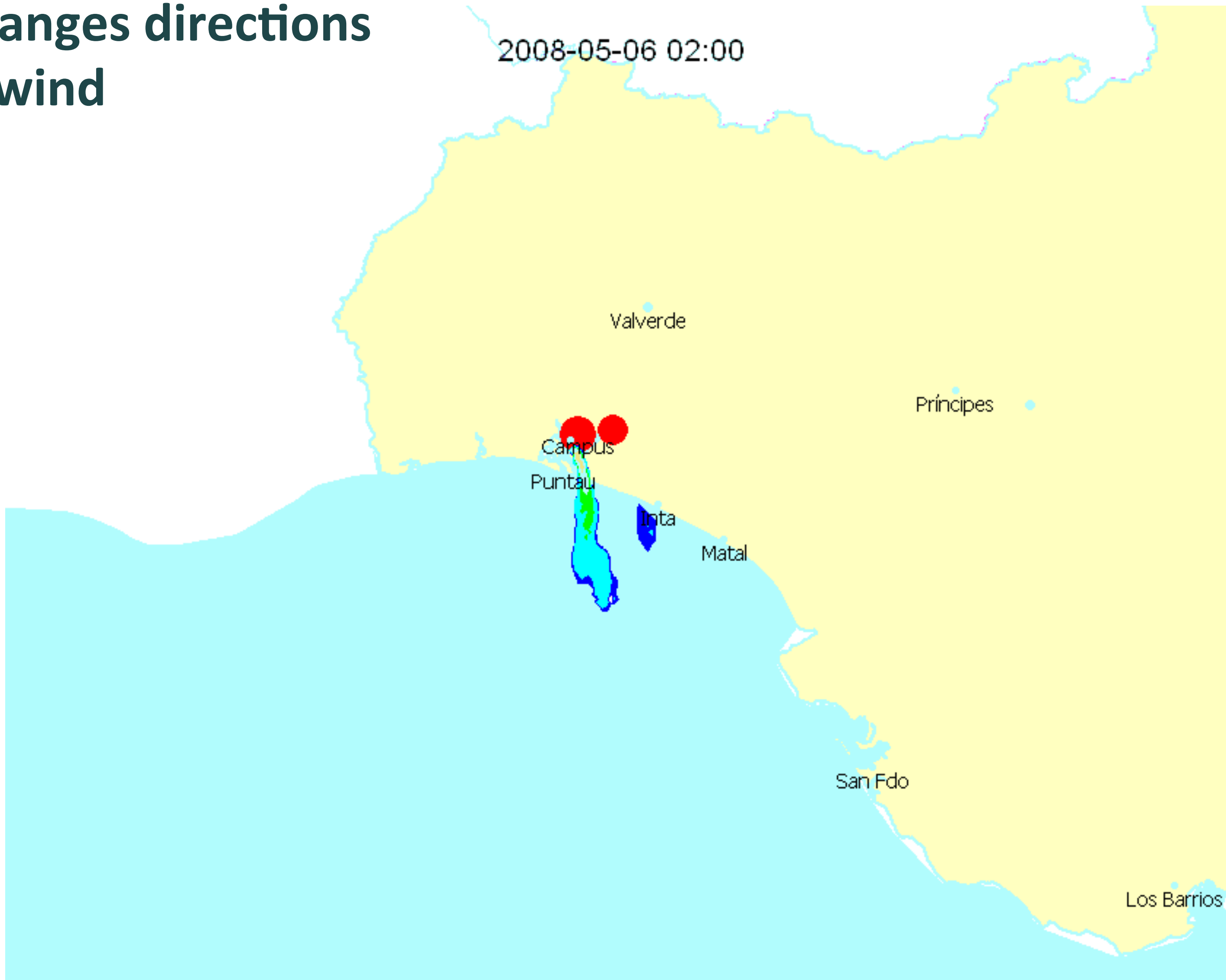
Sources are unknown

If sources were known, could model plume



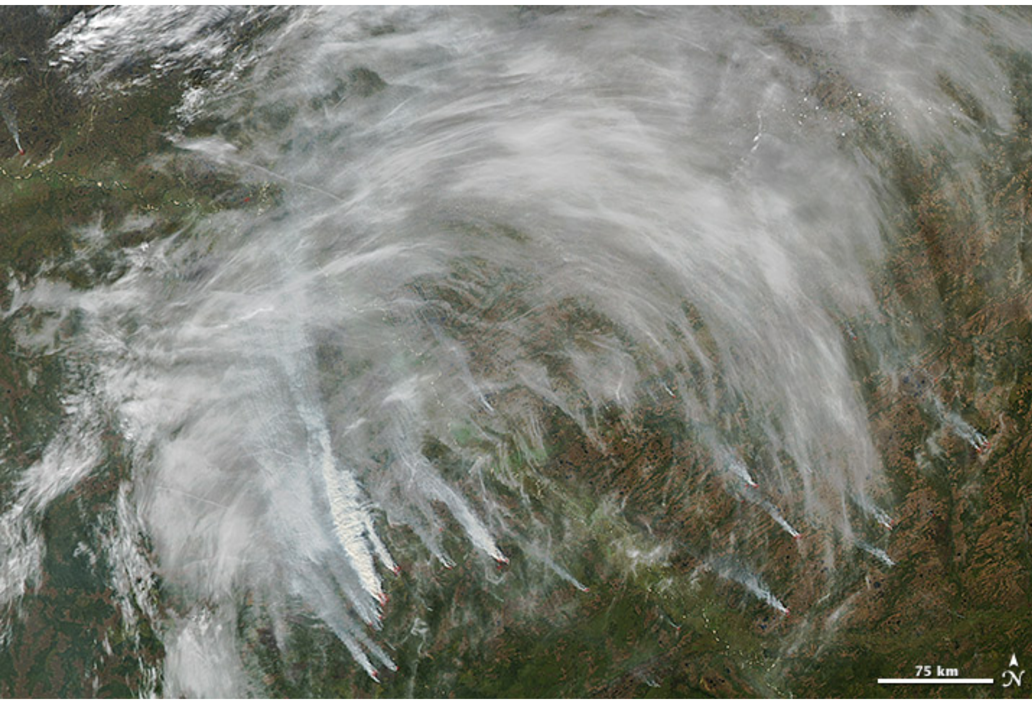
Sources are unknown

Plume changes directions with the wind



Sources are unknown

We are sampling from many sources

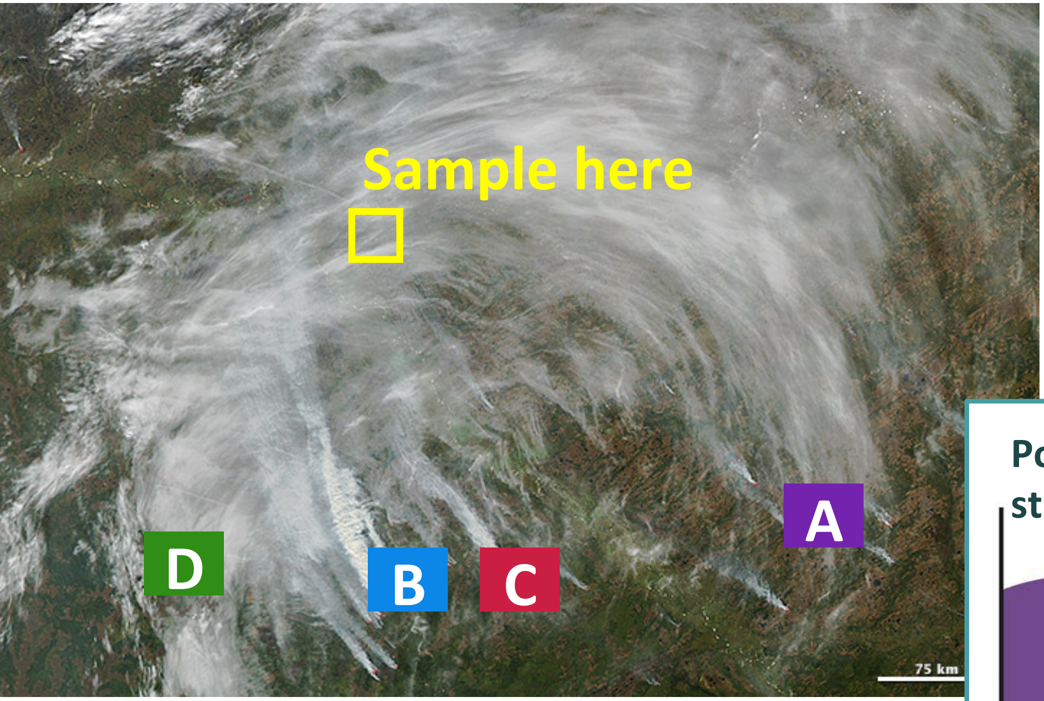


We are sampling a superposition of plumes from various distant sources (e.g., diseased fields)

e.g., can imagine 'invisible' smoke plumes

Sources are unknown

We are sampling from many sources



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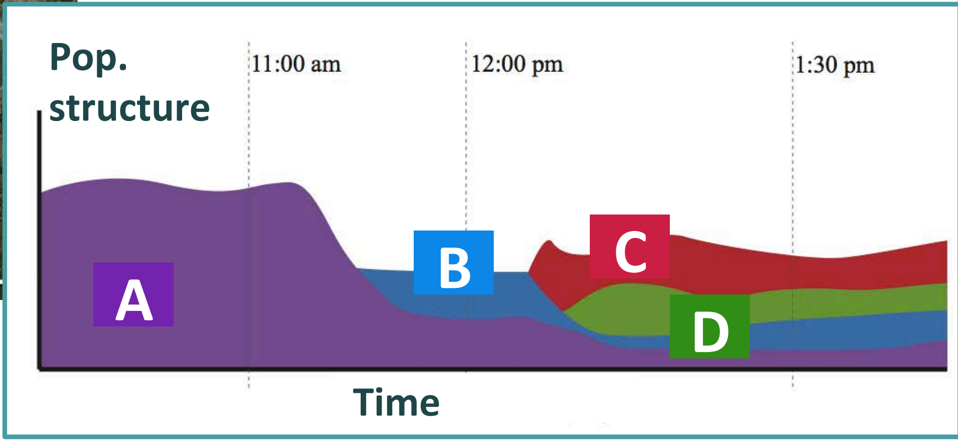
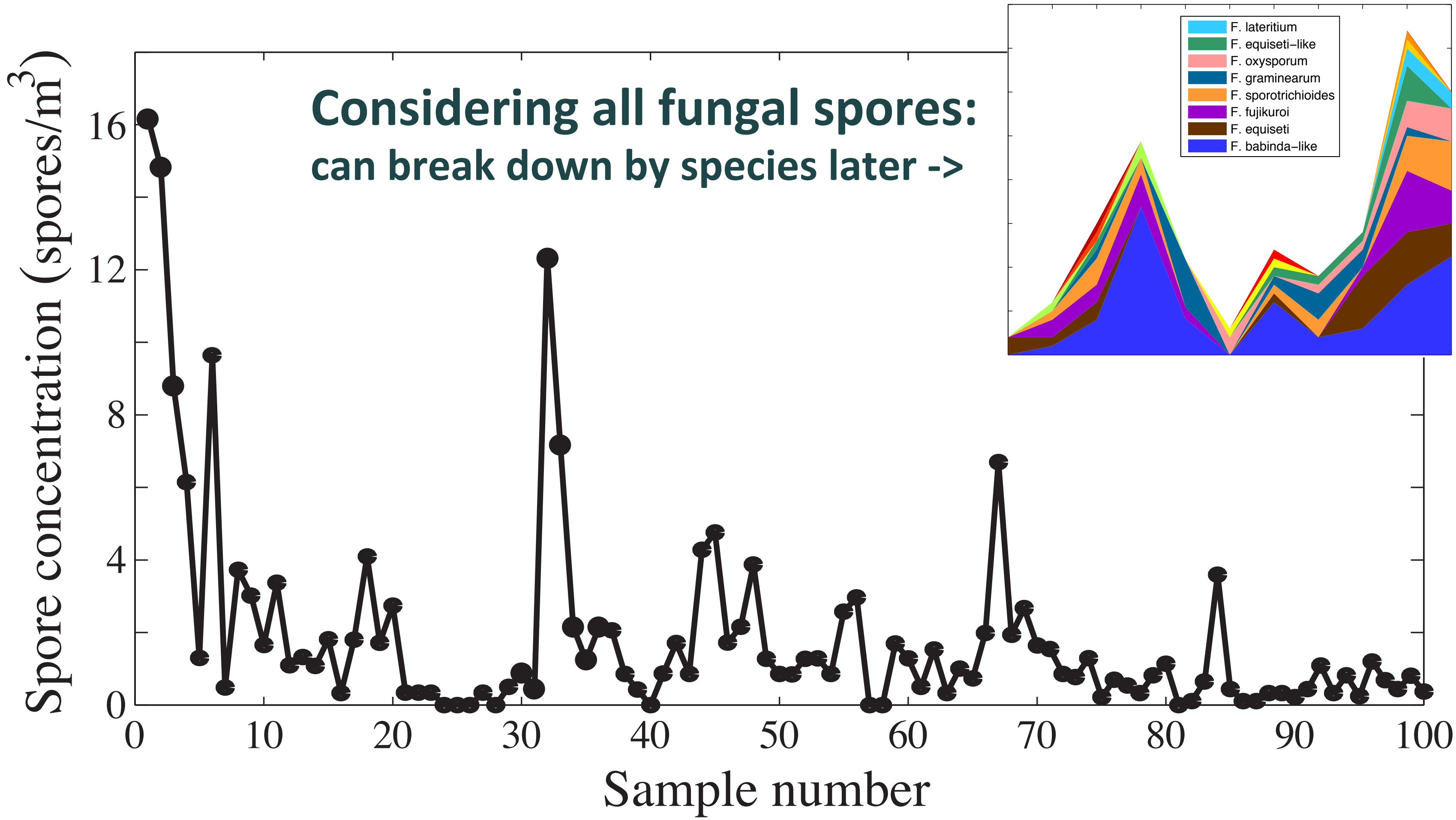


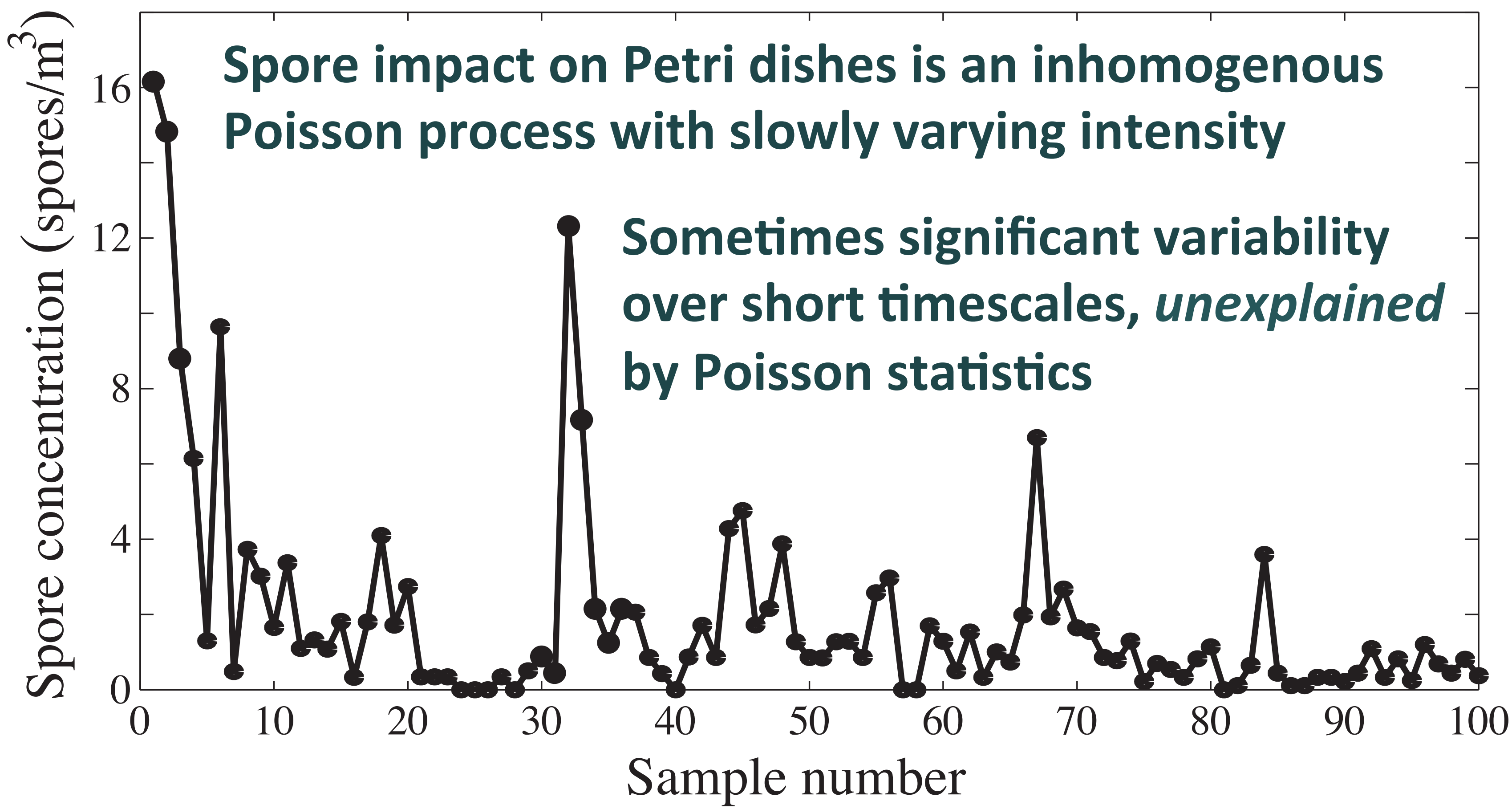
e.g., can imagine 'invisible' smoke plumes

Fluctuations in fungal spore concentration



Concentration of *Fusarium* spores (number/m^3) for samples from 100 flights conducted between August 2006 and March 2010.

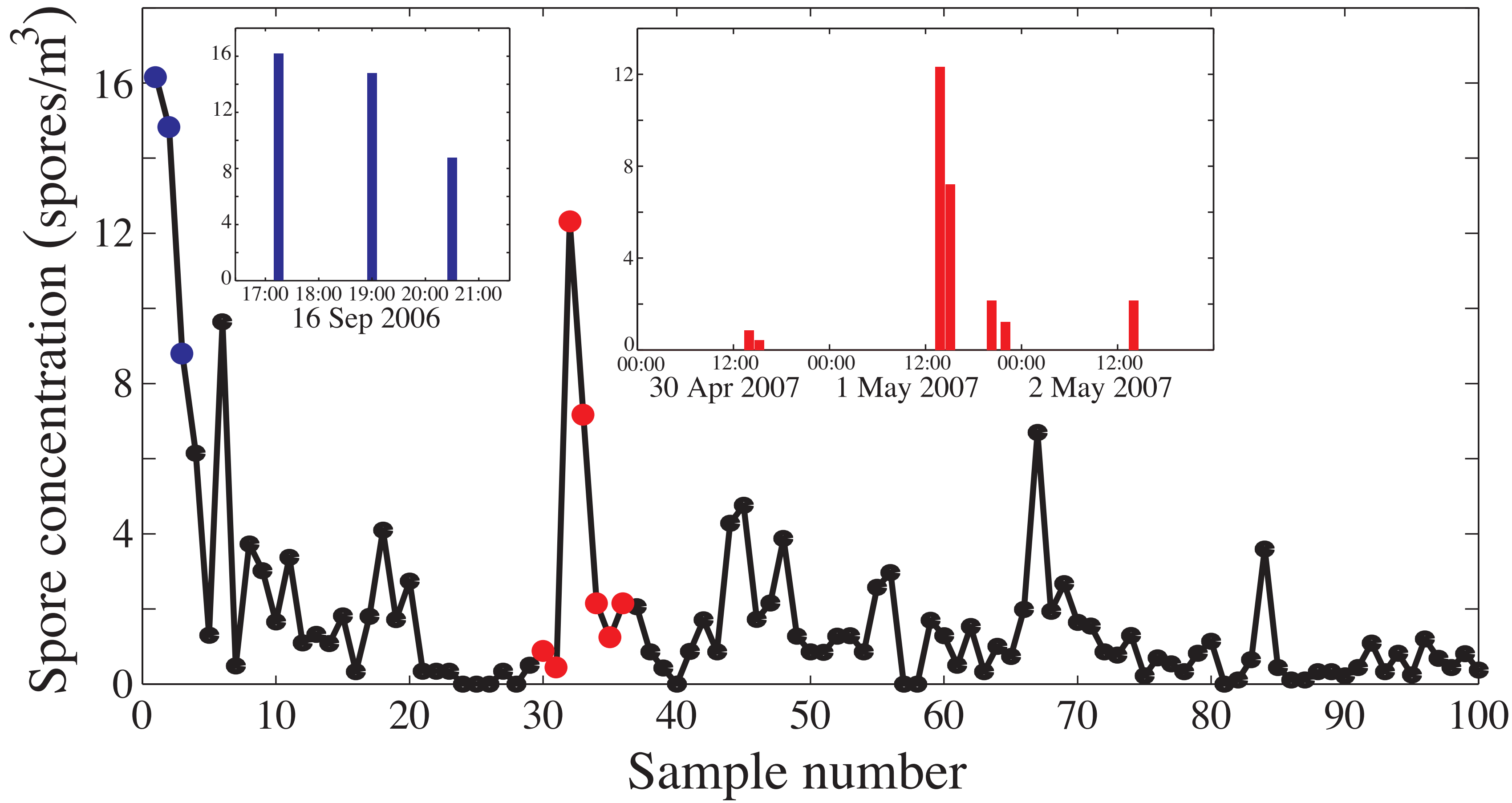
Fluctuations in fungal spore concentration



Concentration of *Fusarium* spores (number/m^3) for samples from 100 flights conducted between August 2006 and March 2010.

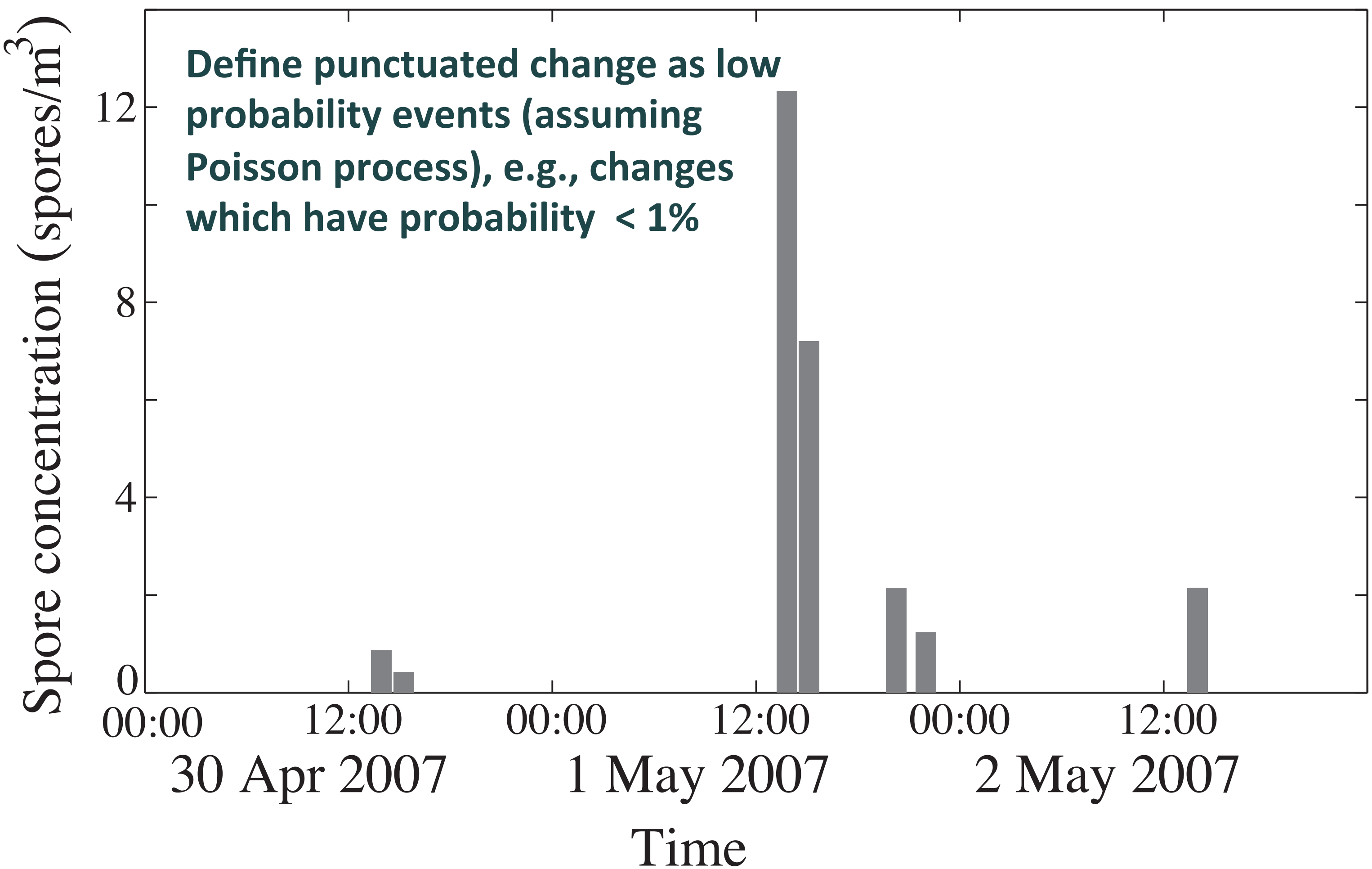
Lin et al. [2012]

Punctuated changes in fungal spore concentration



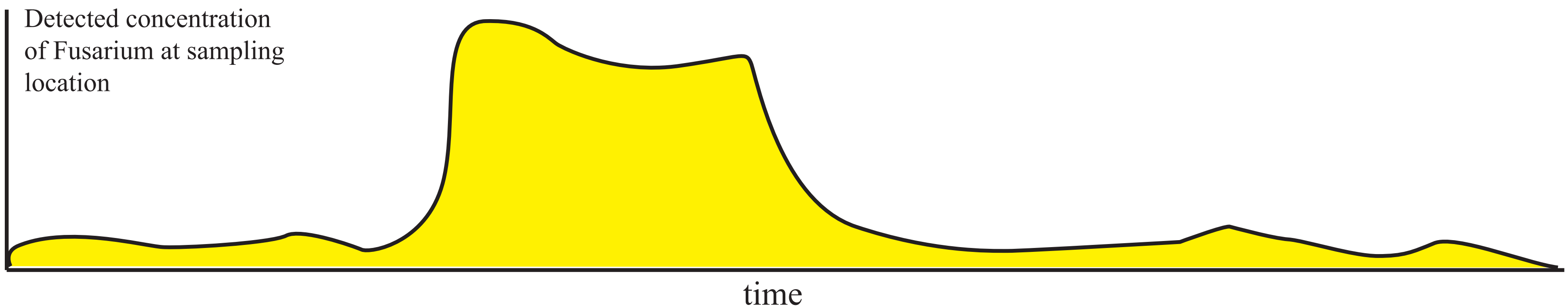
Concentration of *Fusarium* spores (number/m^3) for samples from 100 flights conducted between August 2006 and March 2010.

A classic punctuated change

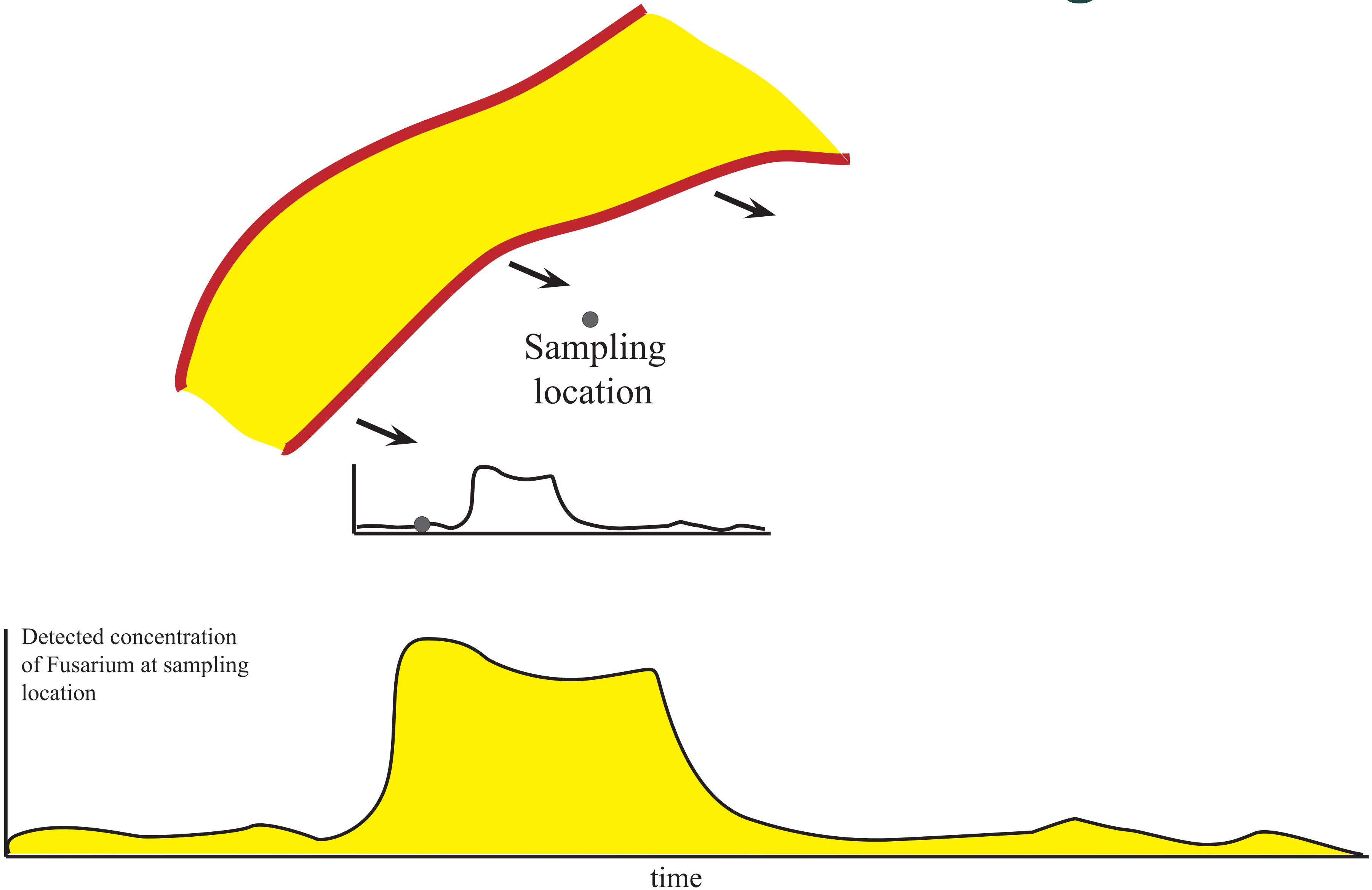


Time series of concentration $\{(t_0, C_0), \ldots, (t_{N-1}, C_{N-1})\}$

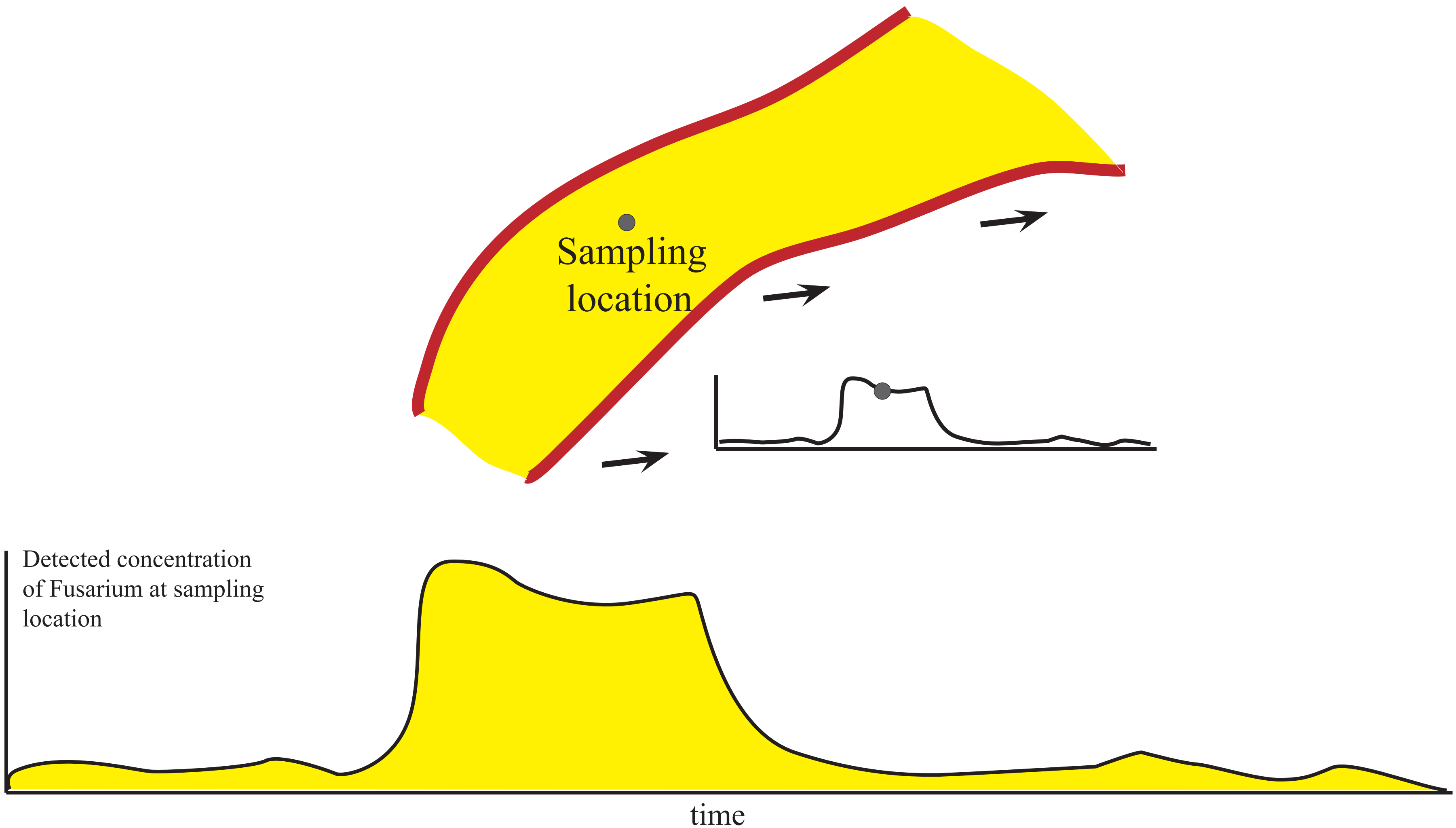
Punctuated changes:
How to understand cloud edges?



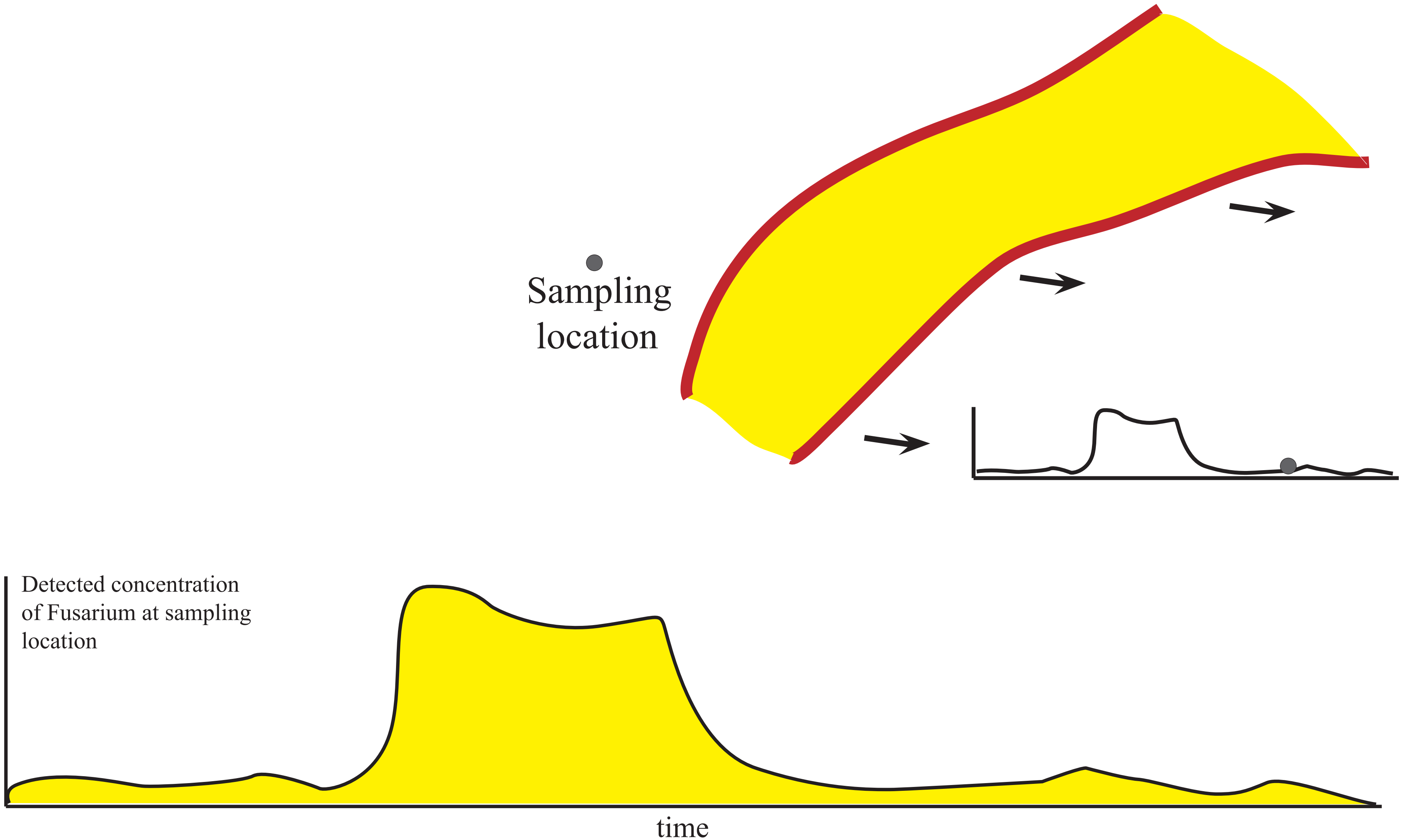
Punctuated changes:
How to understand cloud edges?



Punctuated changes:
How to understand cloud edges?



Punctuated changes: How to understand cloud edges?

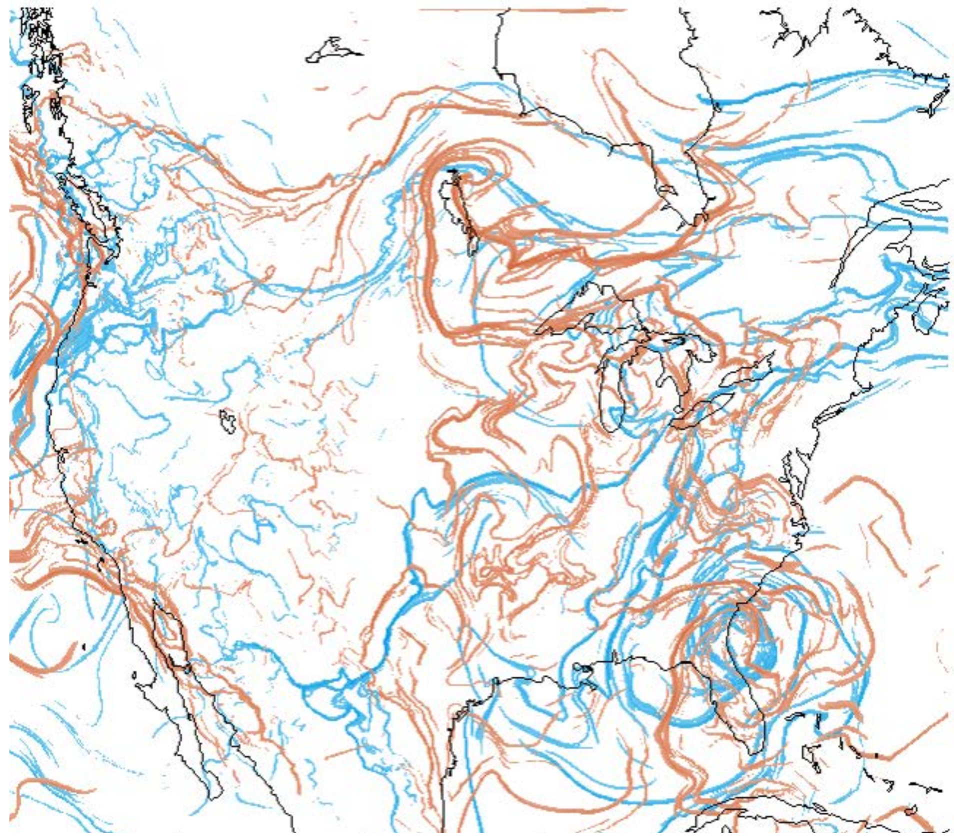


Atmospheric transport network

LCS, repelling (orange) and attracting (blue)

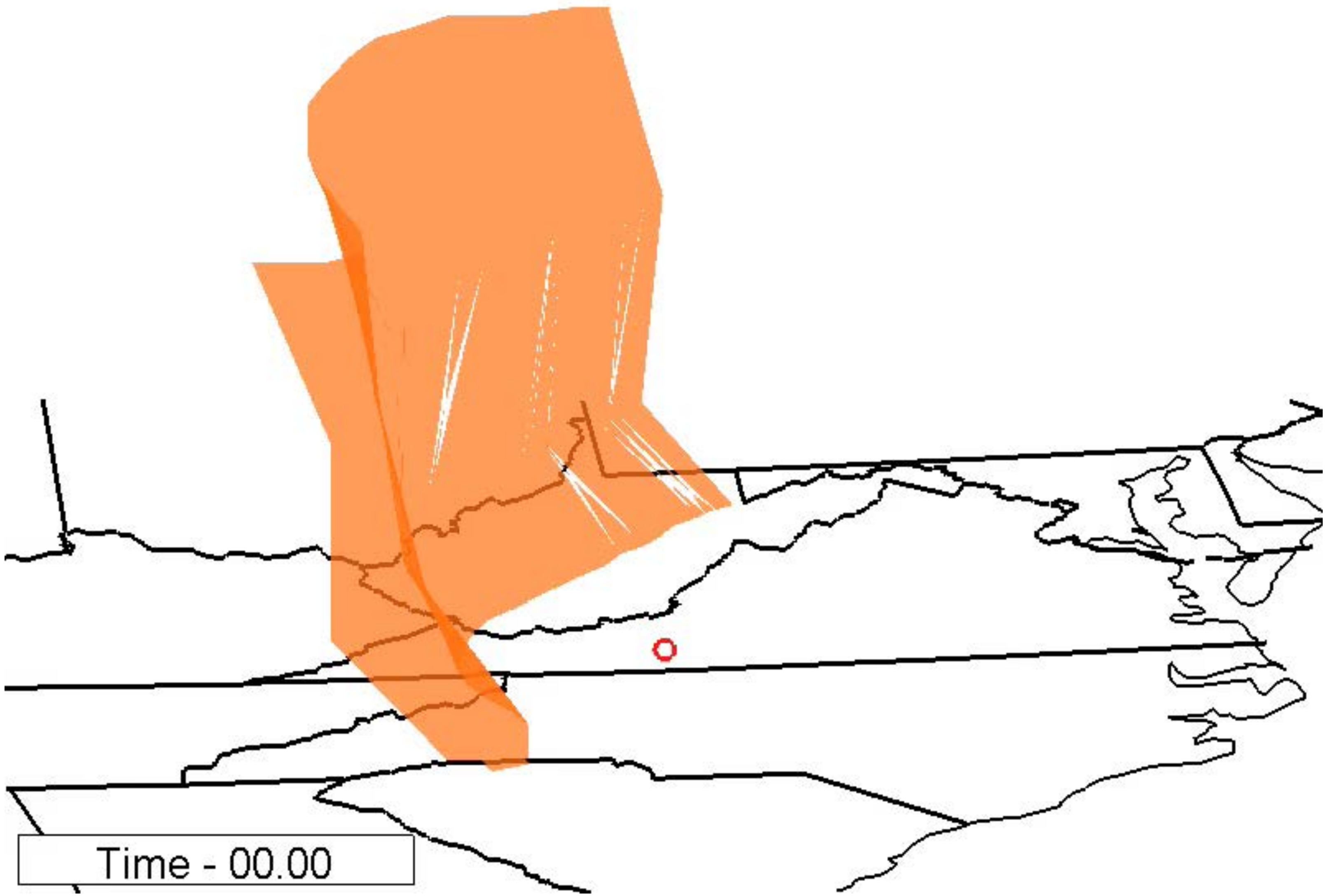
Atmospheric Superhighway, a skeleton of large-scale horizontal transport

Relevant for large-scale spatiotemporal patterns of pollution but also **biological agents**



orange = repelling LCSs, blue = attracting LCSs

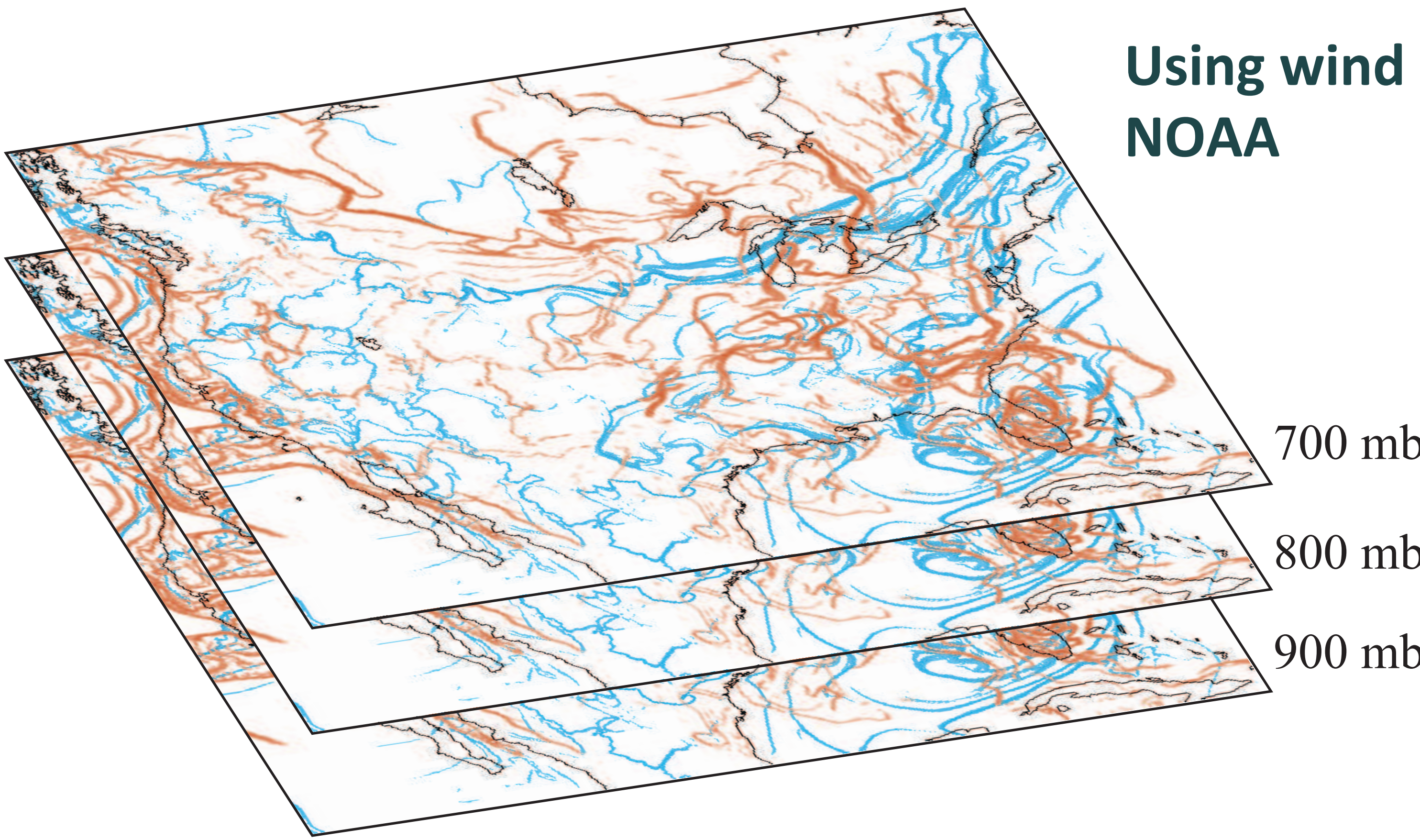
Curtain-like partitions moving over landscape



Mesoscale to synoptic scale motion

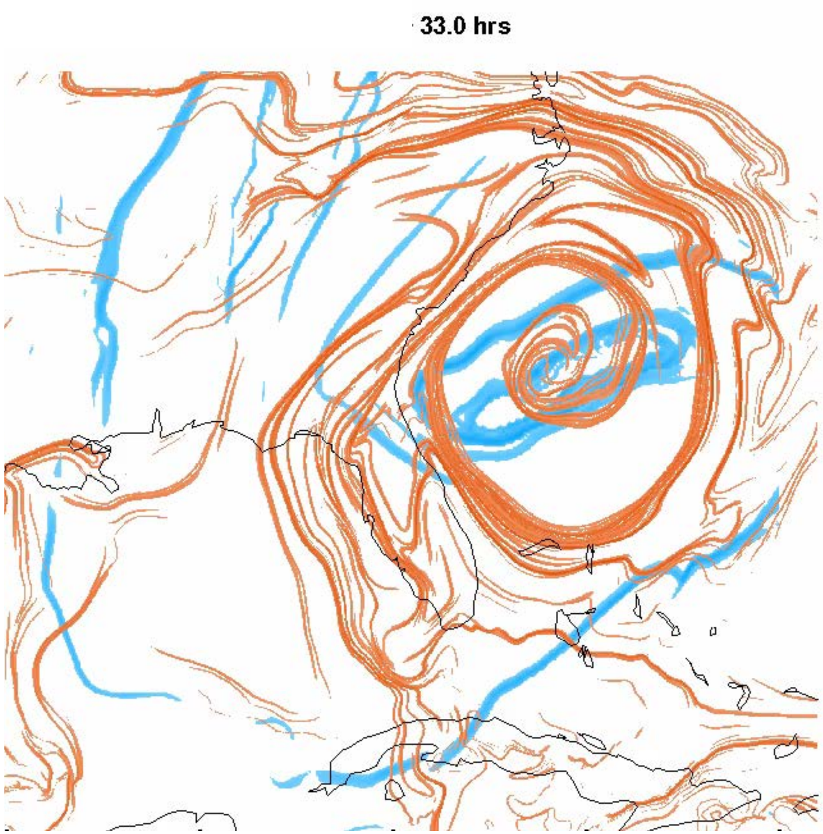
- Consider first 2D motion, then fully 3D
- Quasi-2D motion (isobaric) over timescales of interest, < 12-24 hrs, given by fungal spore viability

Using wind fields from NOAA

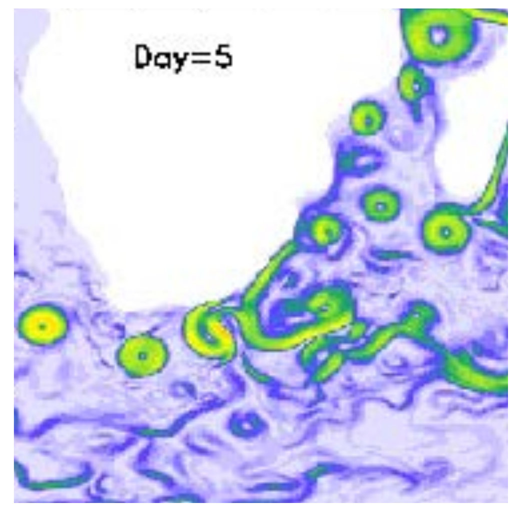


Identify 'atoms' of transport bounded by LCS

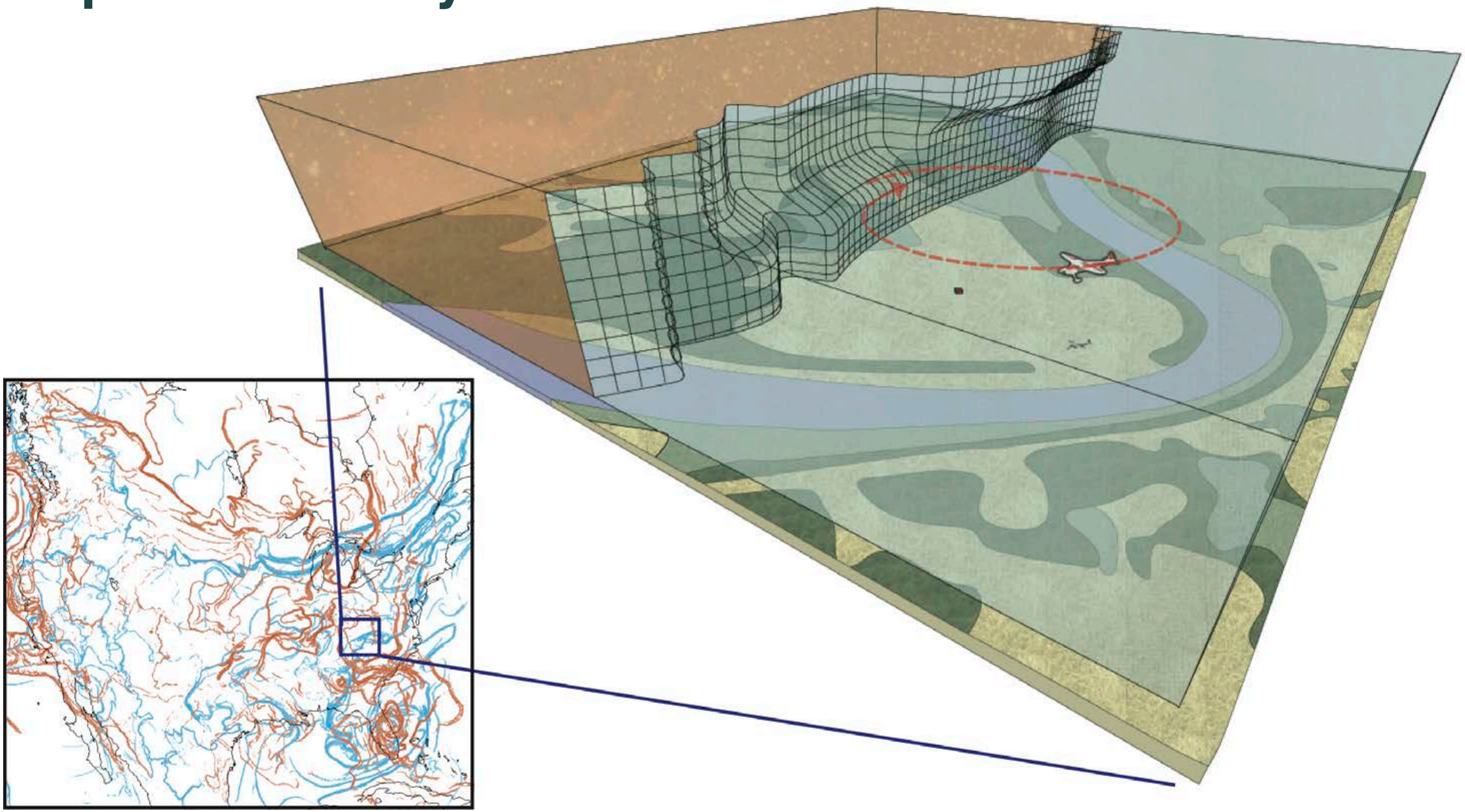
- **Coherent atmospheric filaments or vortices which mix little with surroundings, analogous to ocean eddies**



- **Temporarily isolated sub-systems**

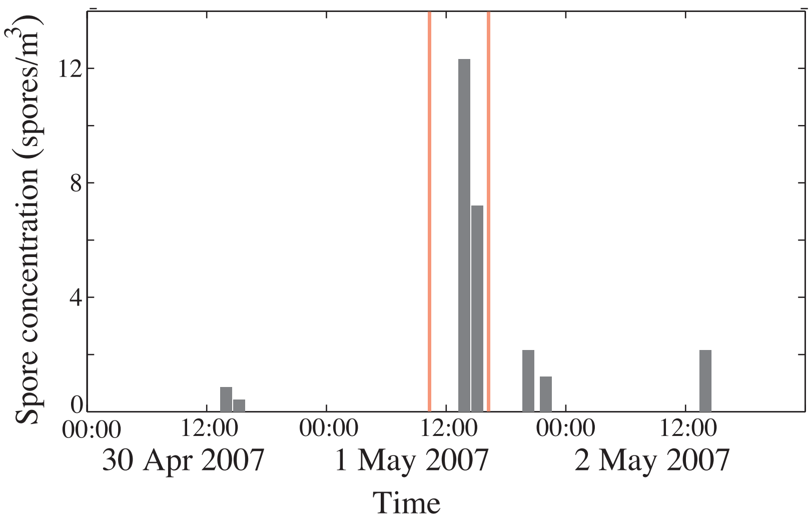


Volumes of differing spore composition partitioned by LCS

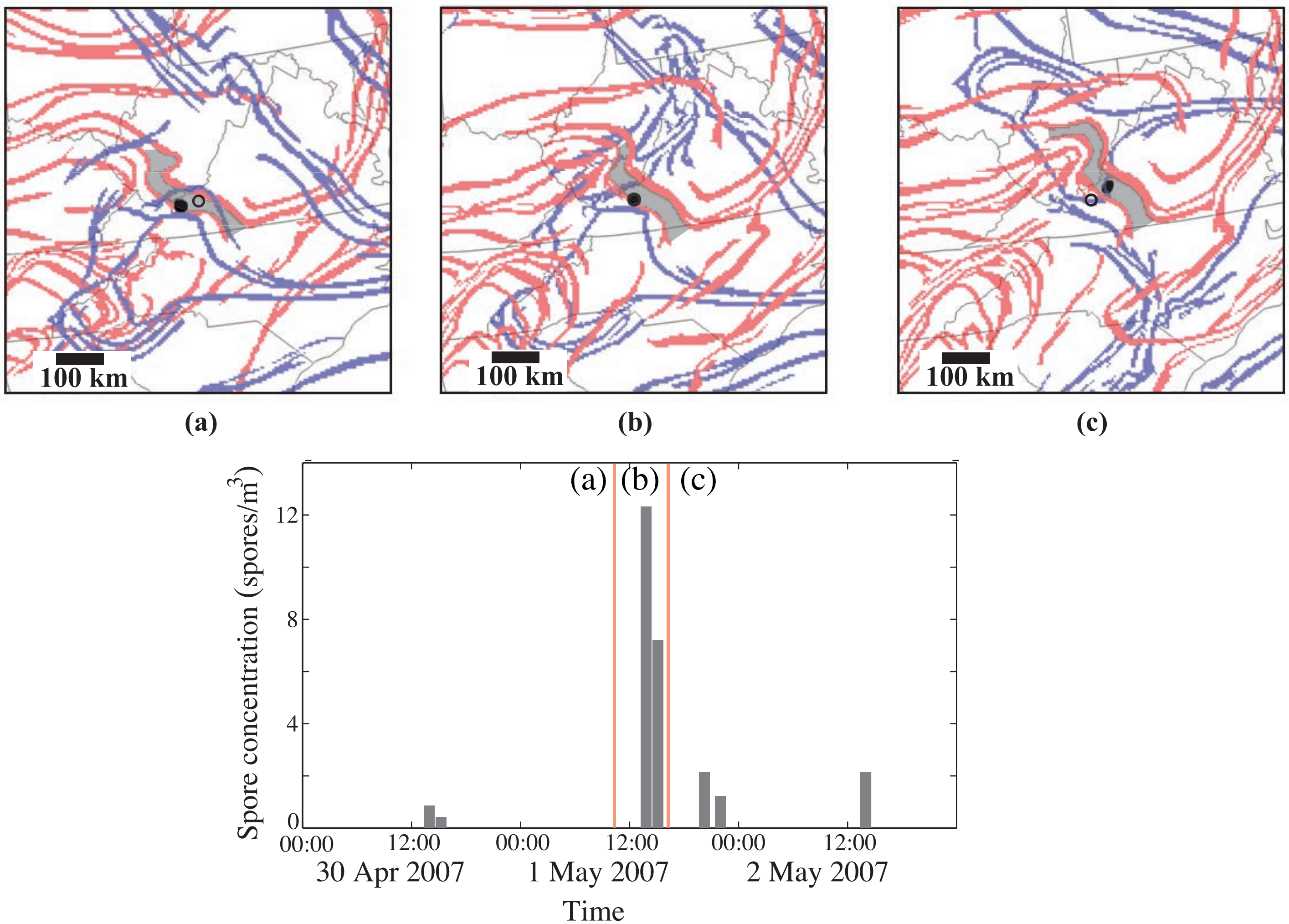


Our unmanned aerial vehicles (UAVs) are usually sampling one side or the other

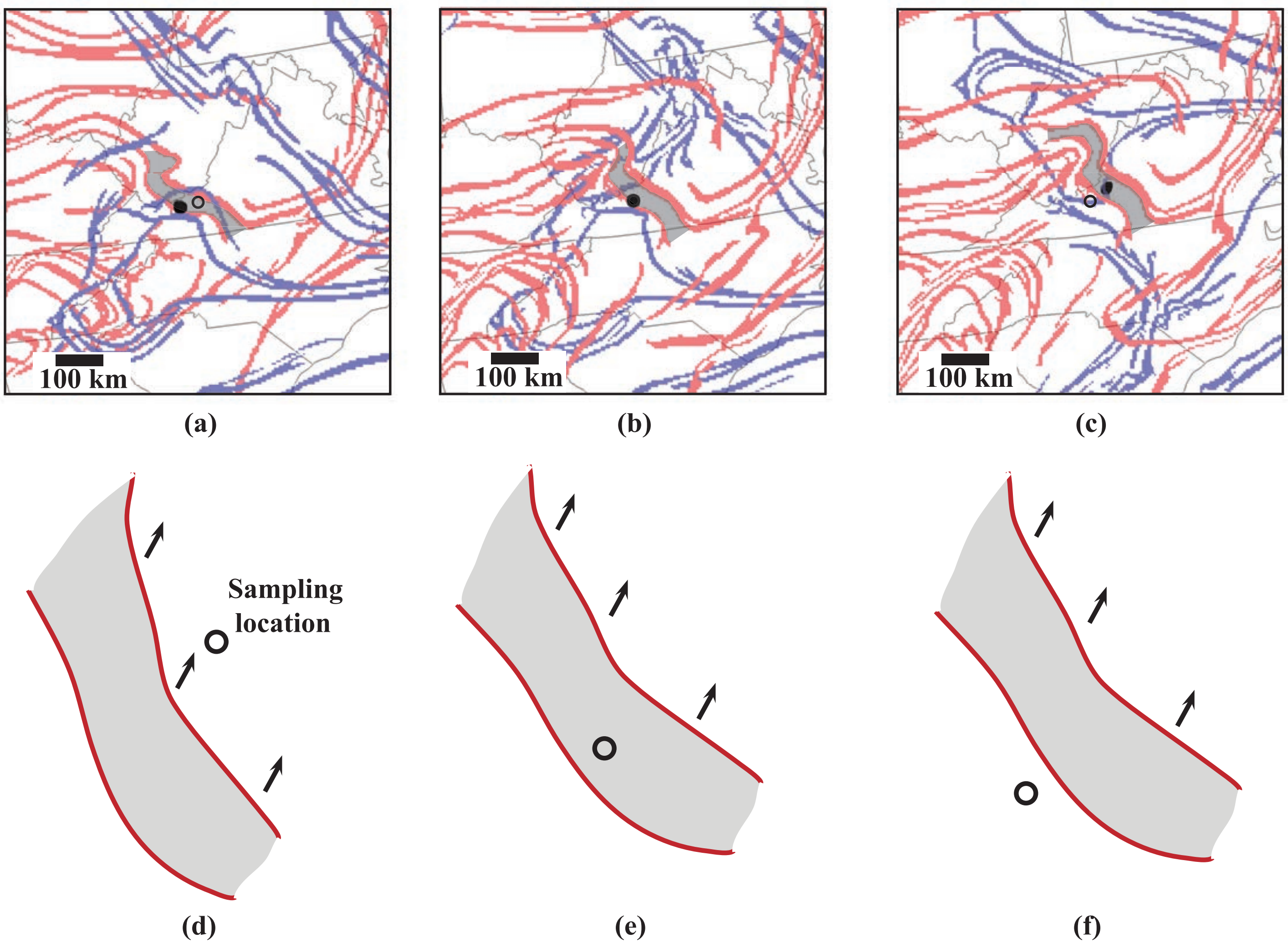
Filament with high pathogen values 'sandwiched' by LCS



Filament with high pathogen values ‘sandwiched’ by LCS



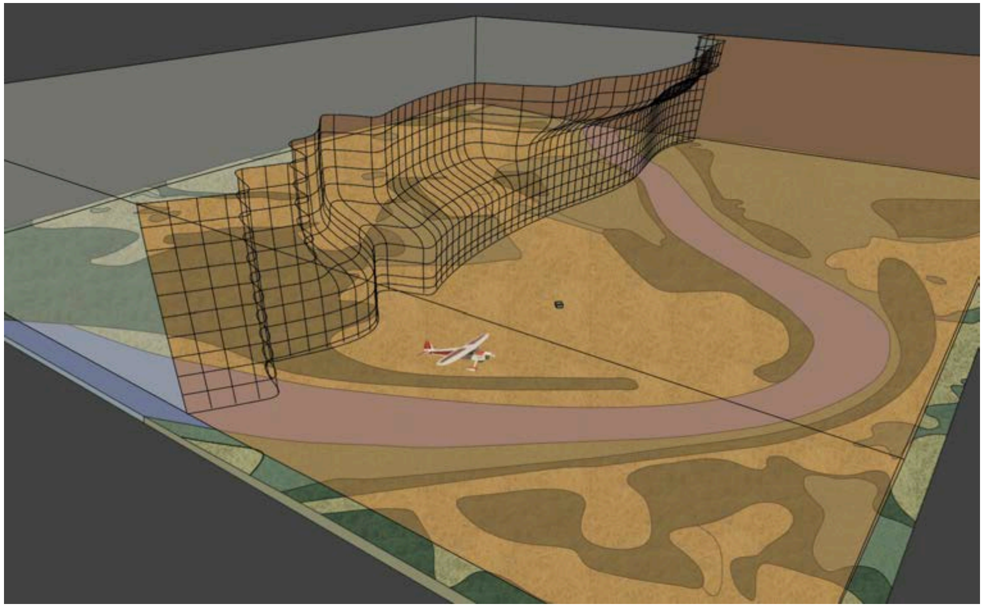
Filament with high pathogen values ‘sandwiched’ by LCS



12:00 UTC 1 May 2007 15:00 UTC 1 May 2007 18:00 UTC 1 May 2007

Microbe fluctuations associated with LCS

- Punctuated change was associated with a LCS passage **>70% of the time**

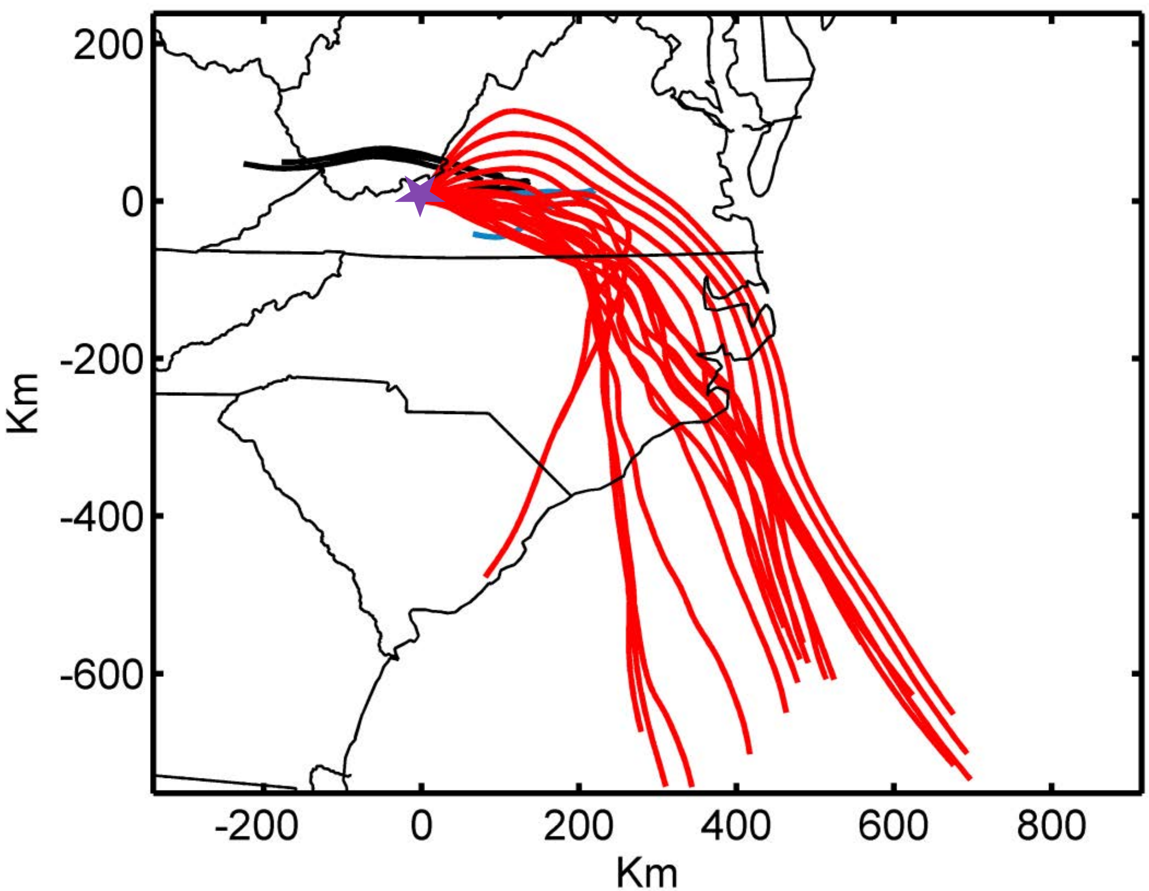


- **Airborne biological agent concentrations can provide a proxy for measuring Lagrangian transport structure**

Tallapragada, Ross, Schmale [2011] *Chaos*

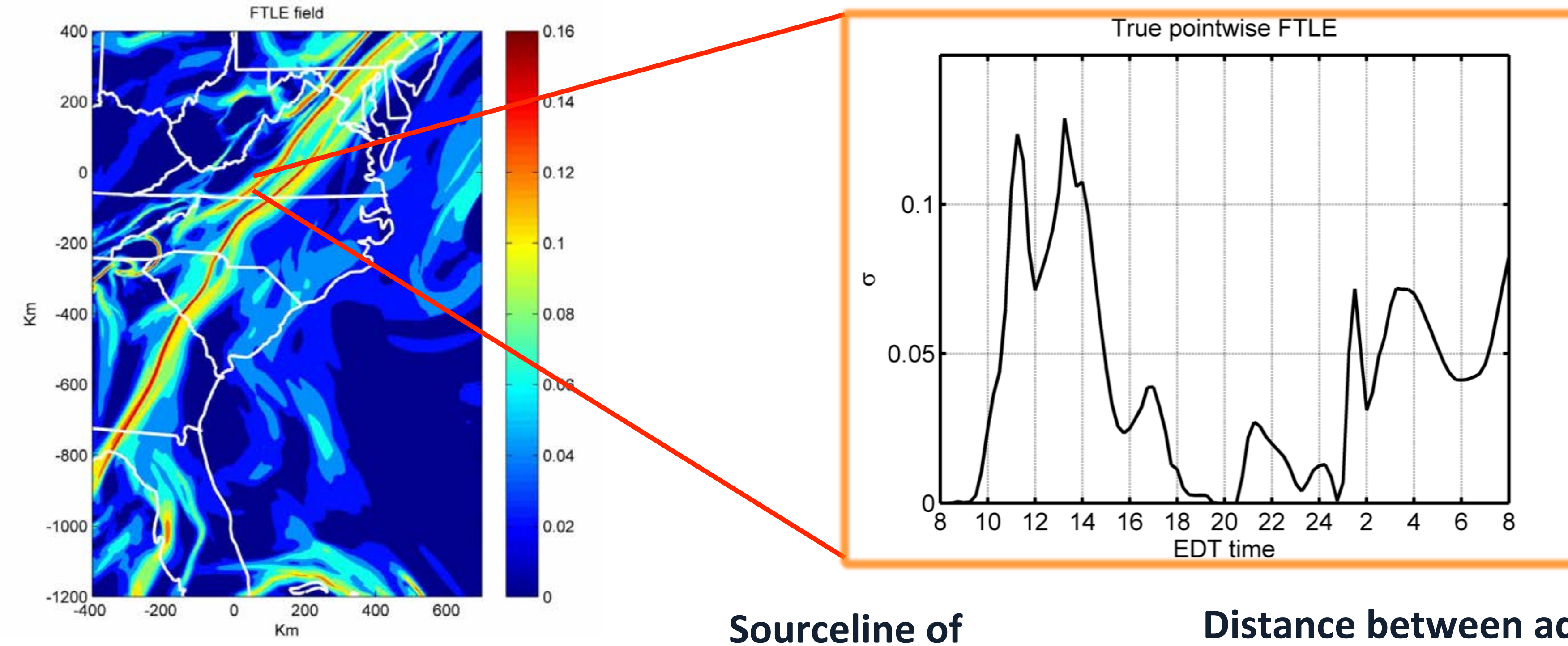
Sampling biological tracers at a fixed location

Backward trajectory of particles, time delay = 1h

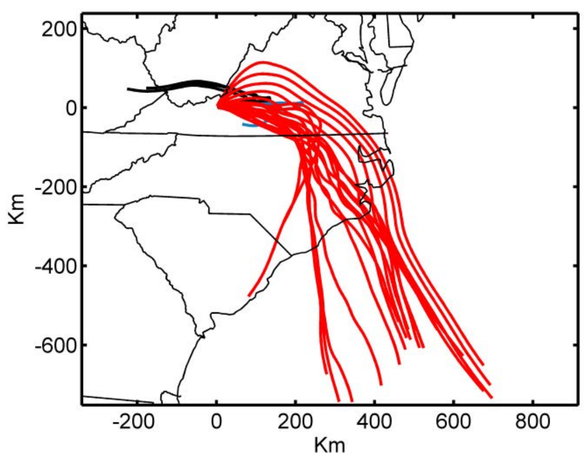


- Sampling point: Virginia Tech campus
- Sampling times: 8AM – 8AM, Sep 29 & 30, 2010
- Integration time: - 24 h.

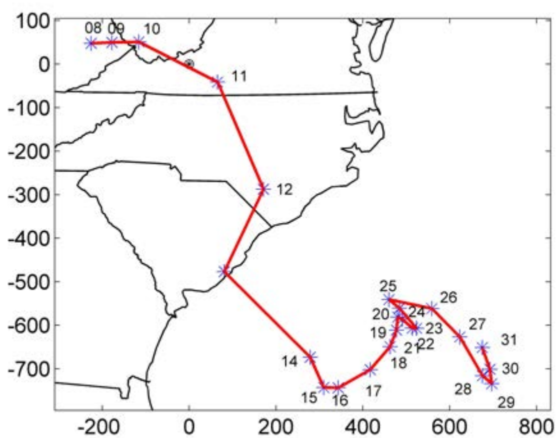
Sampling biological tracers at a fixed location



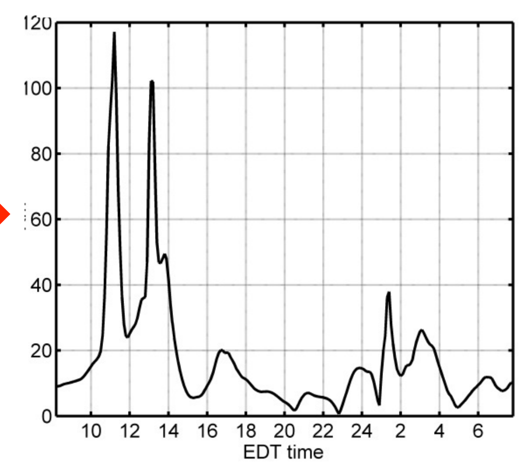
24 hour back-trajectories



Sourceline of sampled points

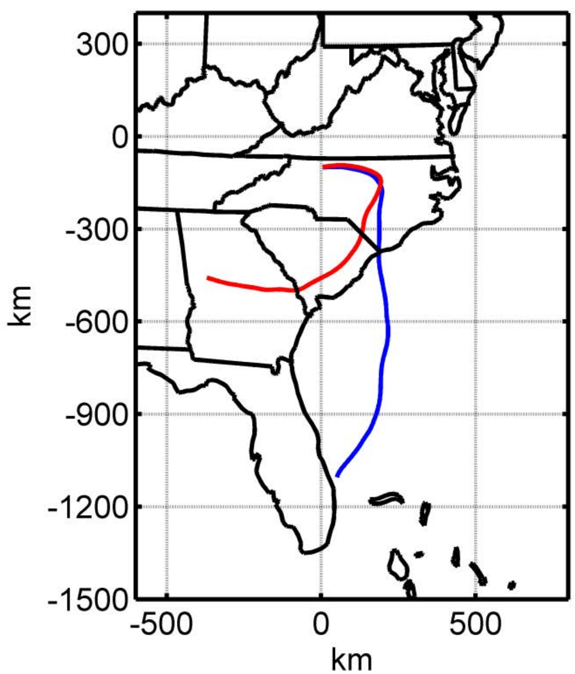


Distance between adjacent points along sourceline

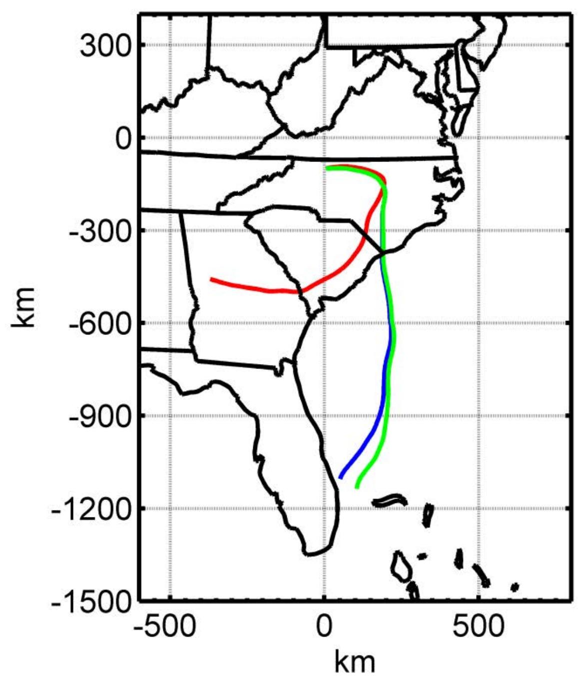


Sampling on either side of a LCS

$$\delta s(t_0+T) \approx \lambda_{\max}^{1/2}\left[C_{t_0}^{t_0+T}(\mathbf{x}_0)\right] u(\mathbf{x}_0,t_0)\delta t$$

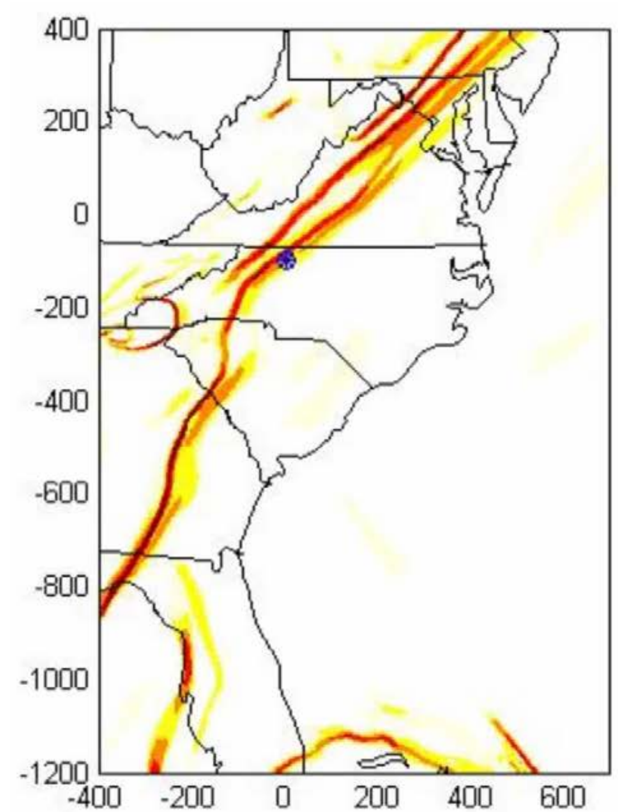


Red: sample time: 1315 UTC
Blue: sample time: 1415 UTC



Red: sample time: 1315 UTC
Blue: sample time: 1415 UTC
Green: sample time 1515 UTC

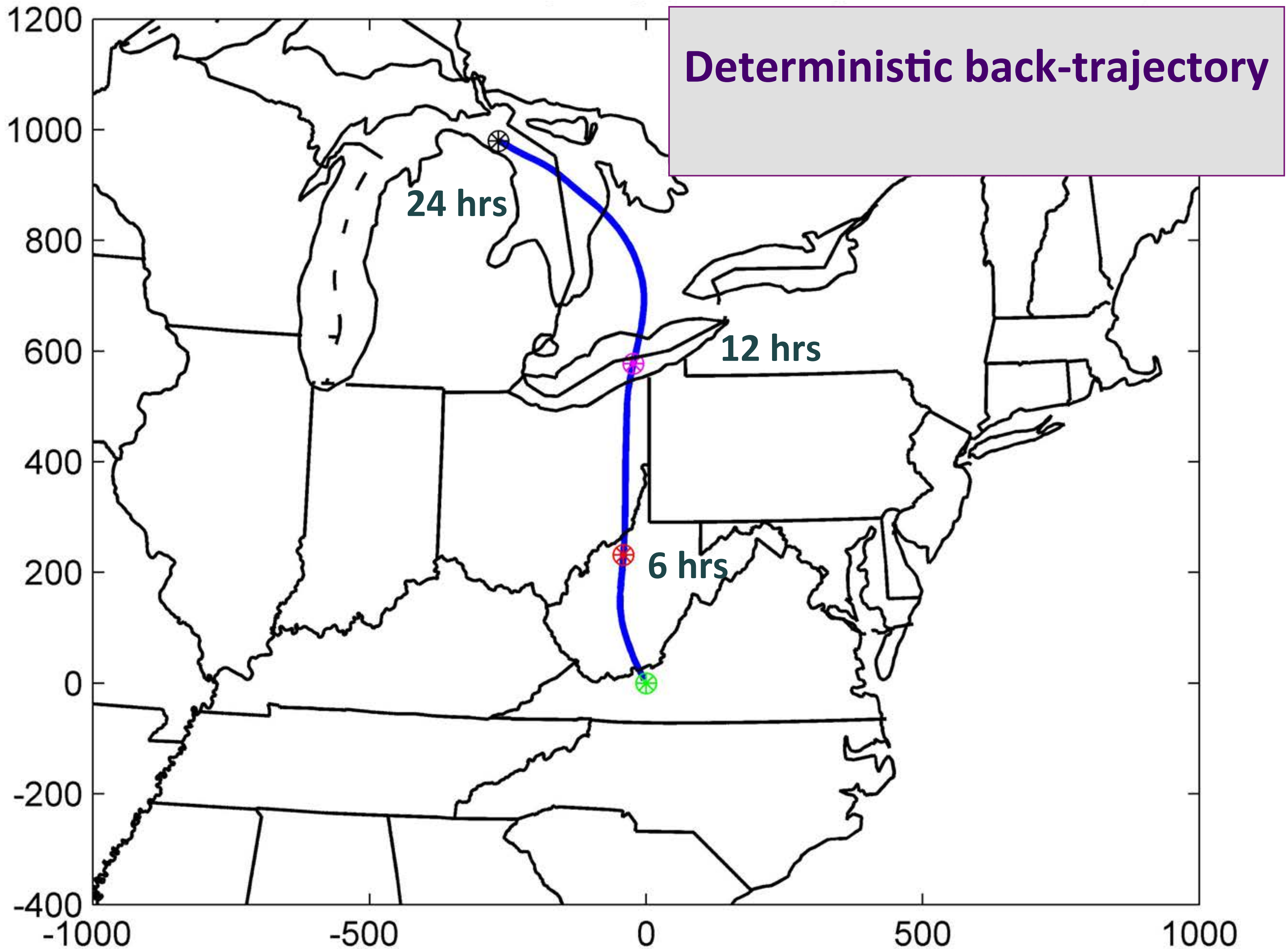
Back trajectories with attracting LCS



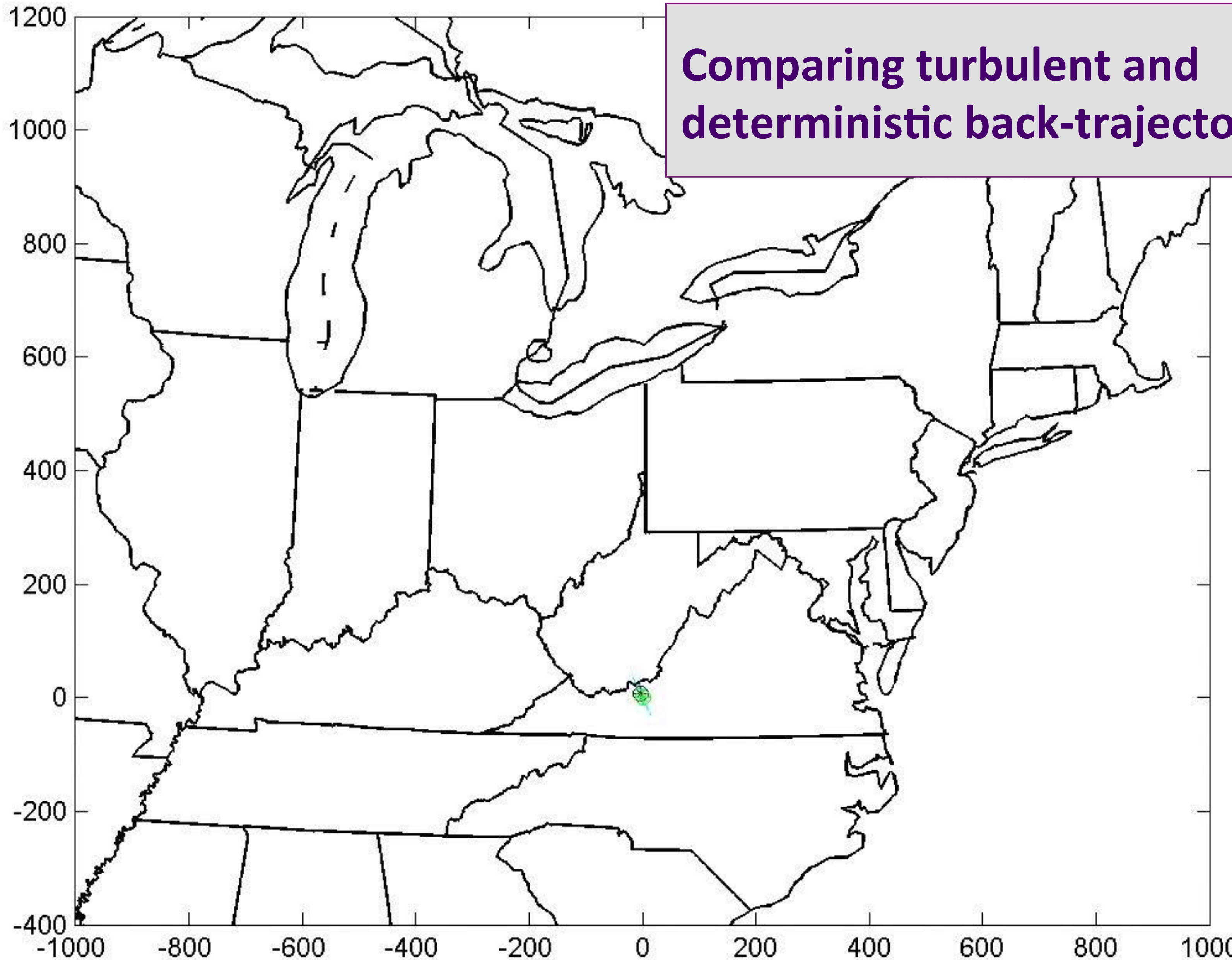
Movie is showing time backwards

Back-trajectories shown

Effect of turbulence

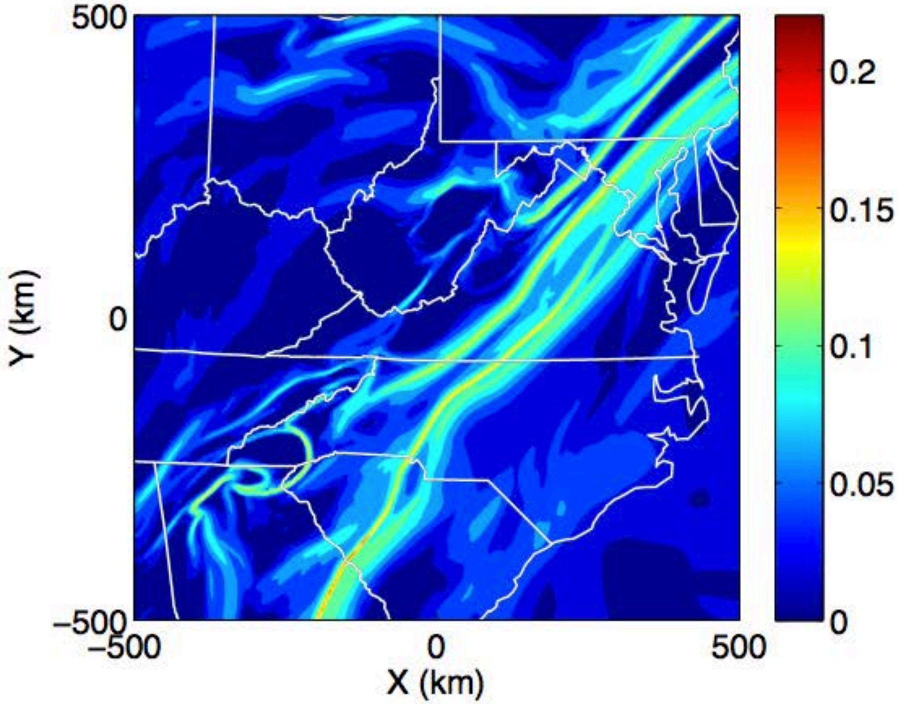


Effect of turbulence

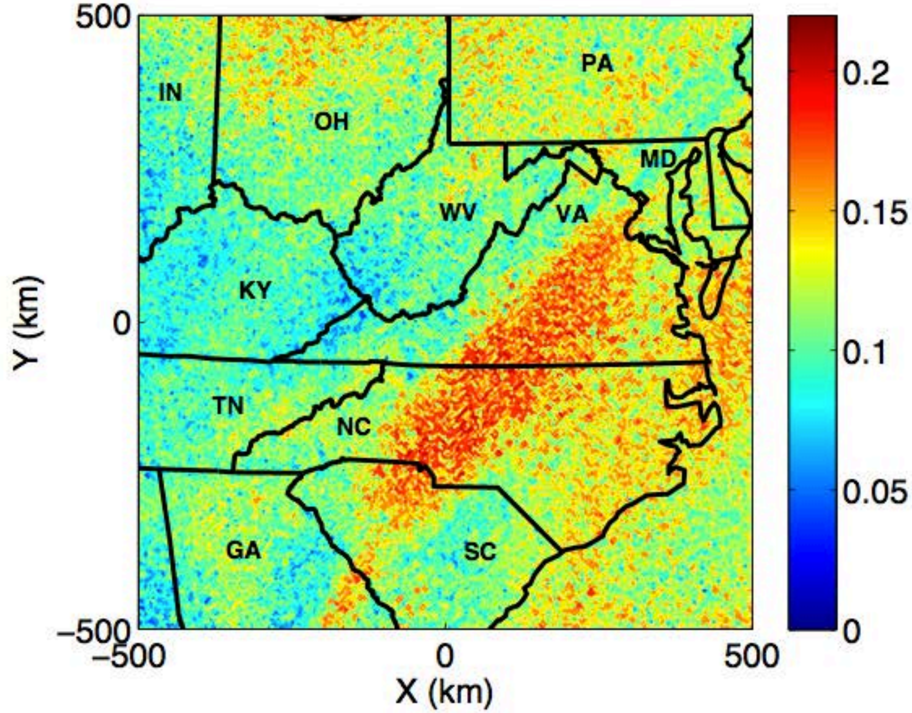


Comparing turbulent and deterministic back-trajectory

FTLE including sub-grid scale turbulence



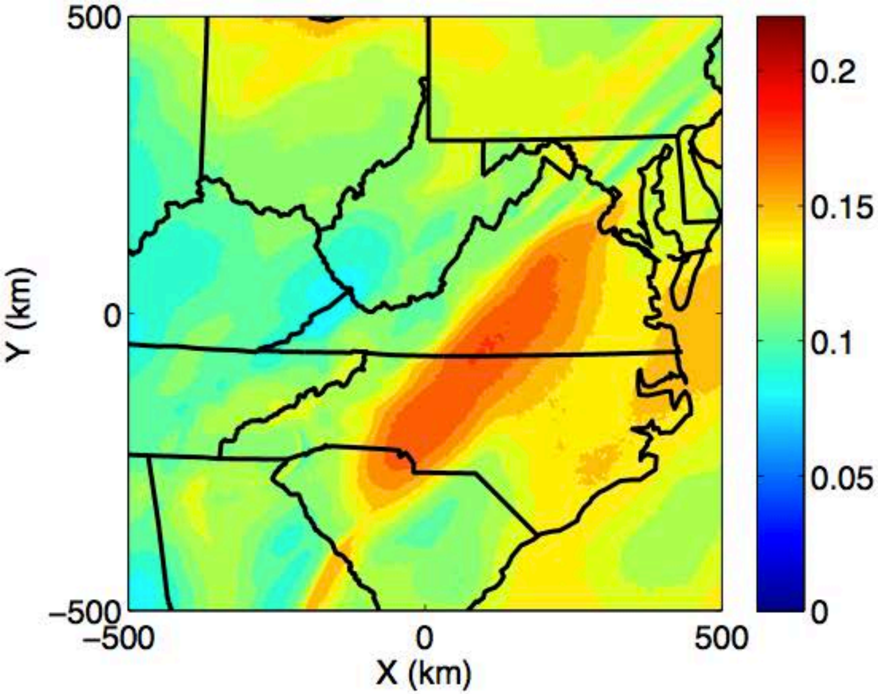
Deterministic



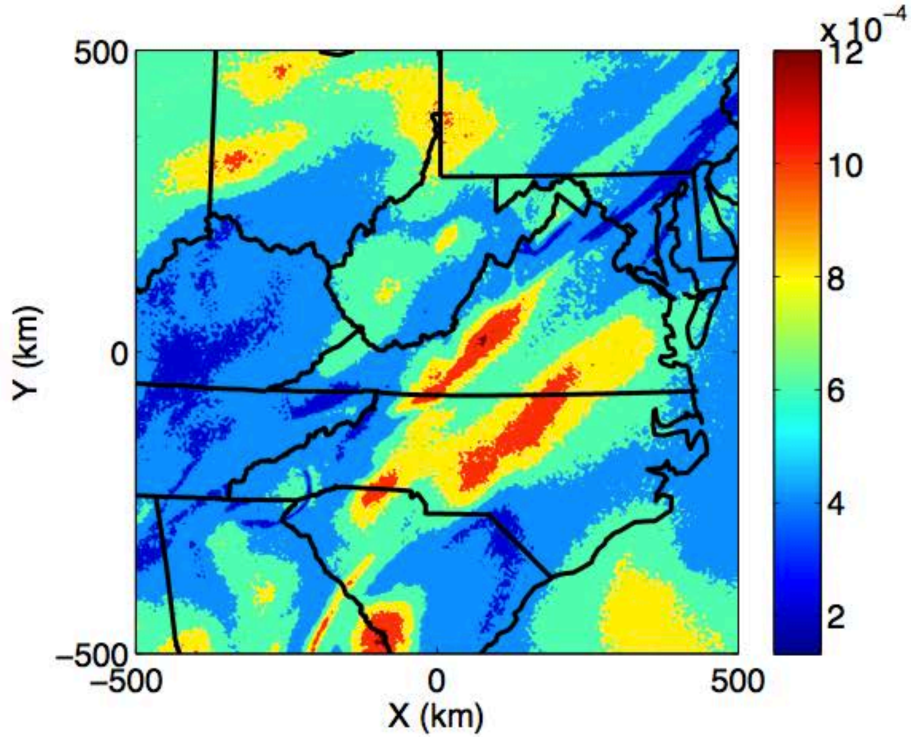
incl. turbulent diffusion

BozorgMagham, Ross [2013]

FTLE including sub-grid scale turbulence



Ensemble average

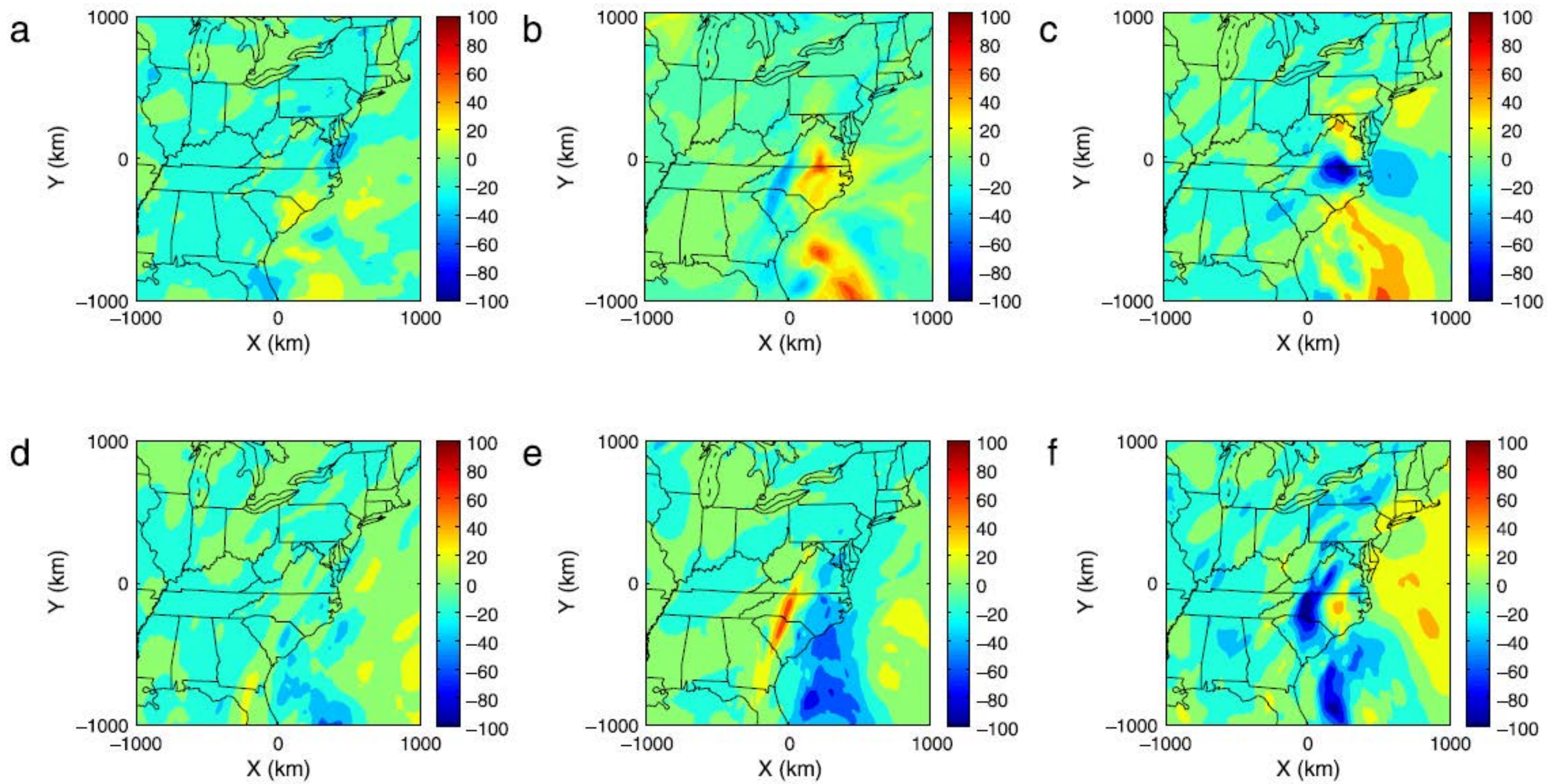


Standard deviation

BozorgMagham, Ross [2013]

Forecasting atmospheric LCS

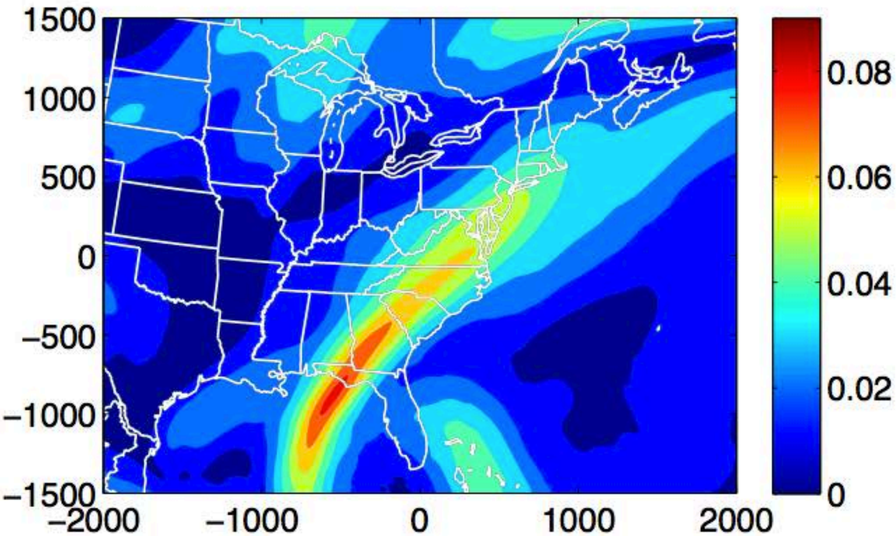
Wind field errors are not small or localized in time



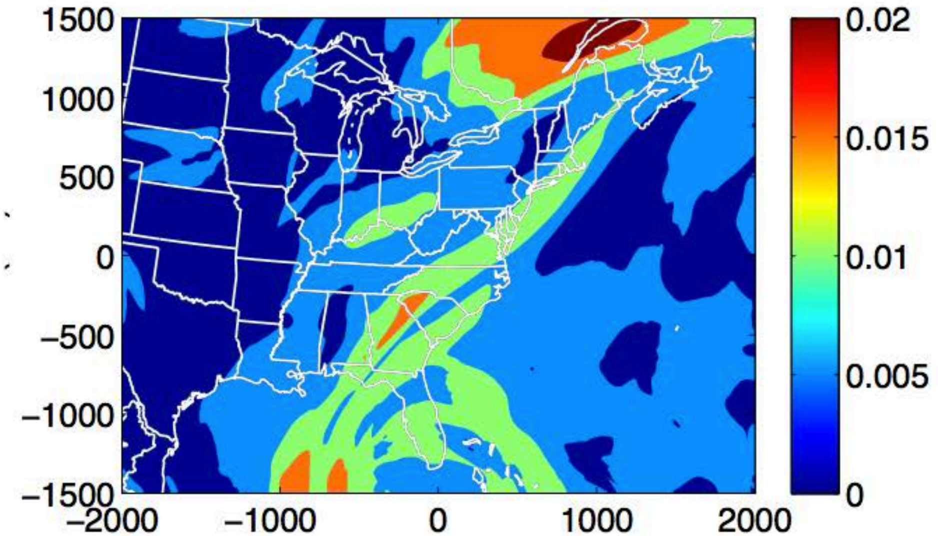
BozorgMagham, Ross, Schmale [2013] *Physica D*

Forecasting atmospheric LCS

Using an ensemble forecasting approach



Ensemble average

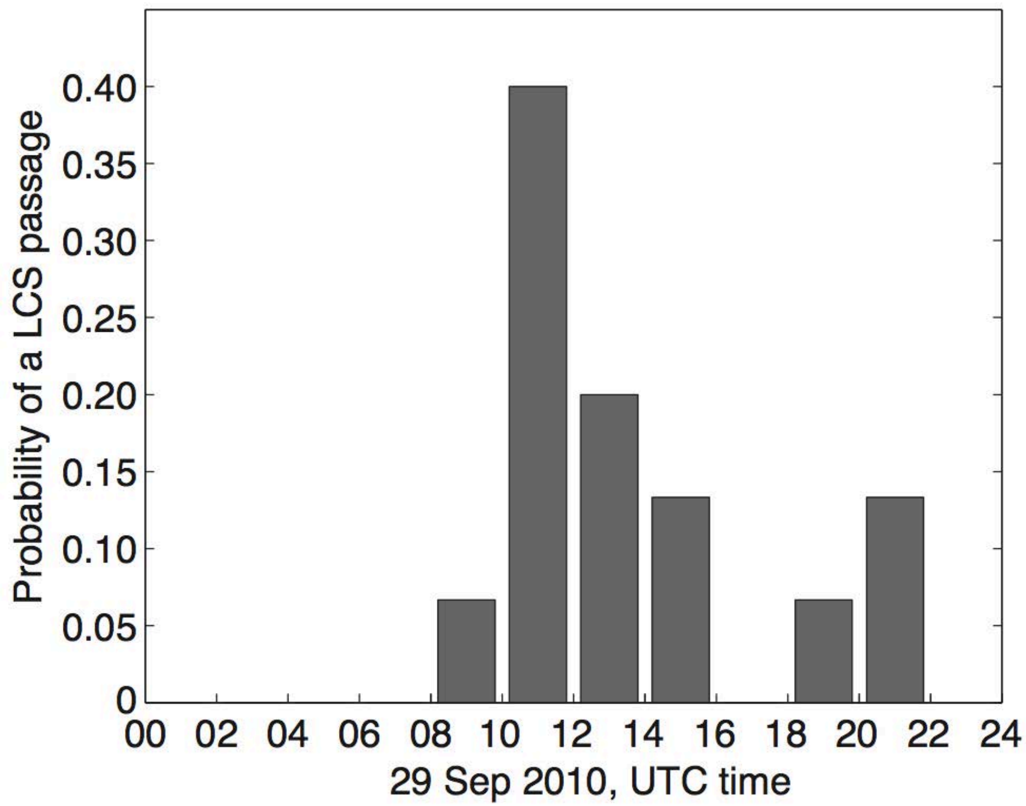


Standard deviation

BozorgMagham, Ross [2013]

Forecasting atmospheric LCS

Forecasting an LCS passage time

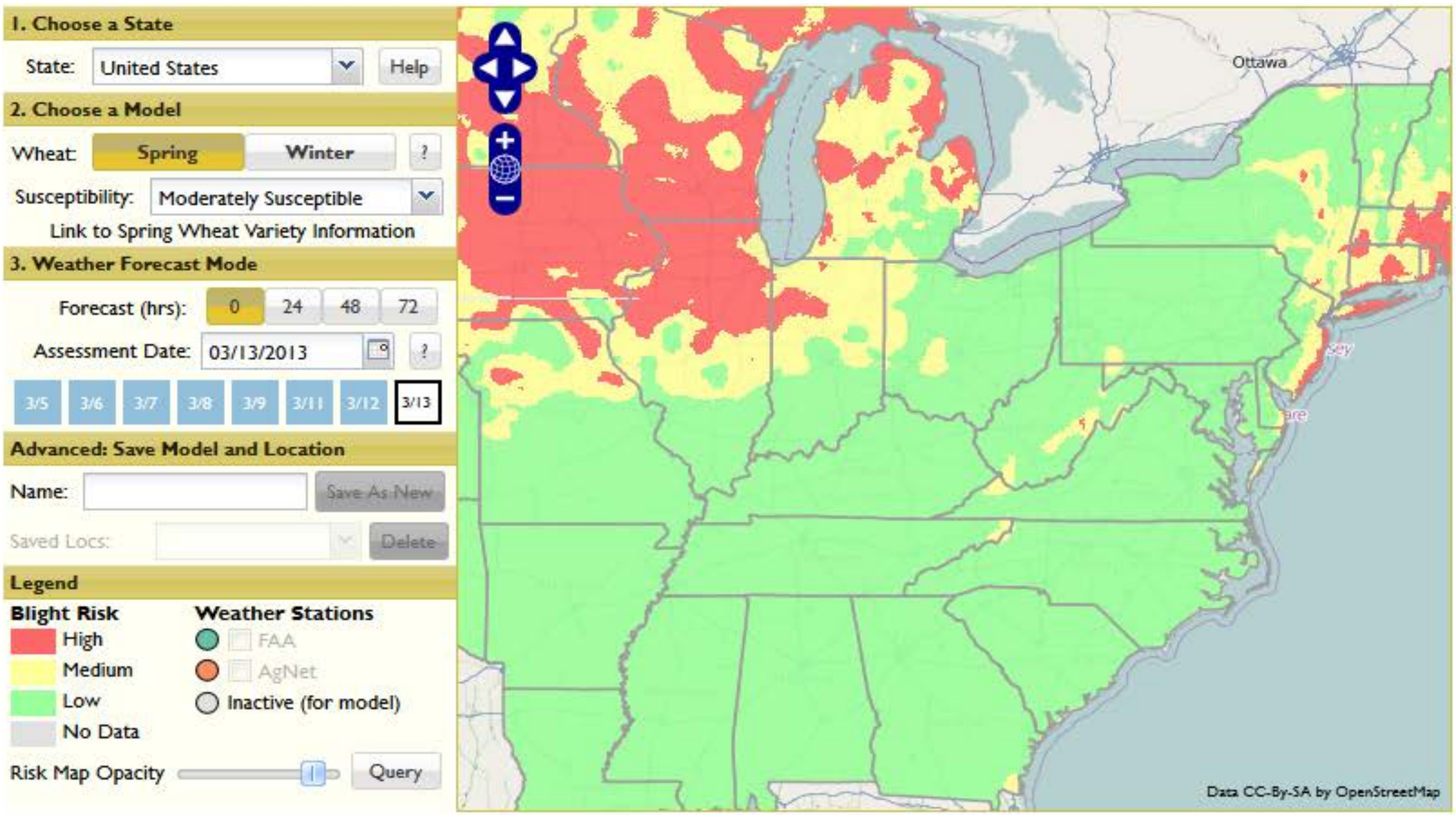


Can correctly forecast within 2 hours 60% of the time

BozorgMagham, Ross [2013]

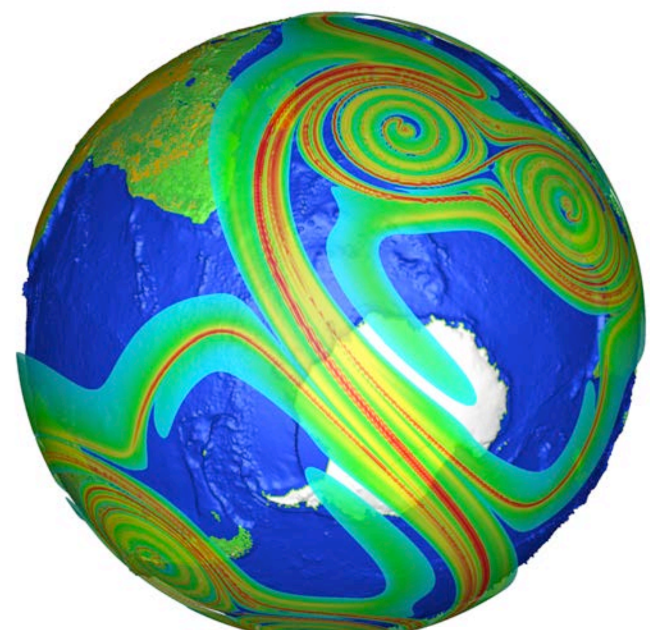
Practical application: early warning systems

LCS or other transport methods could help inform farmers regarding possible zones of disease spread

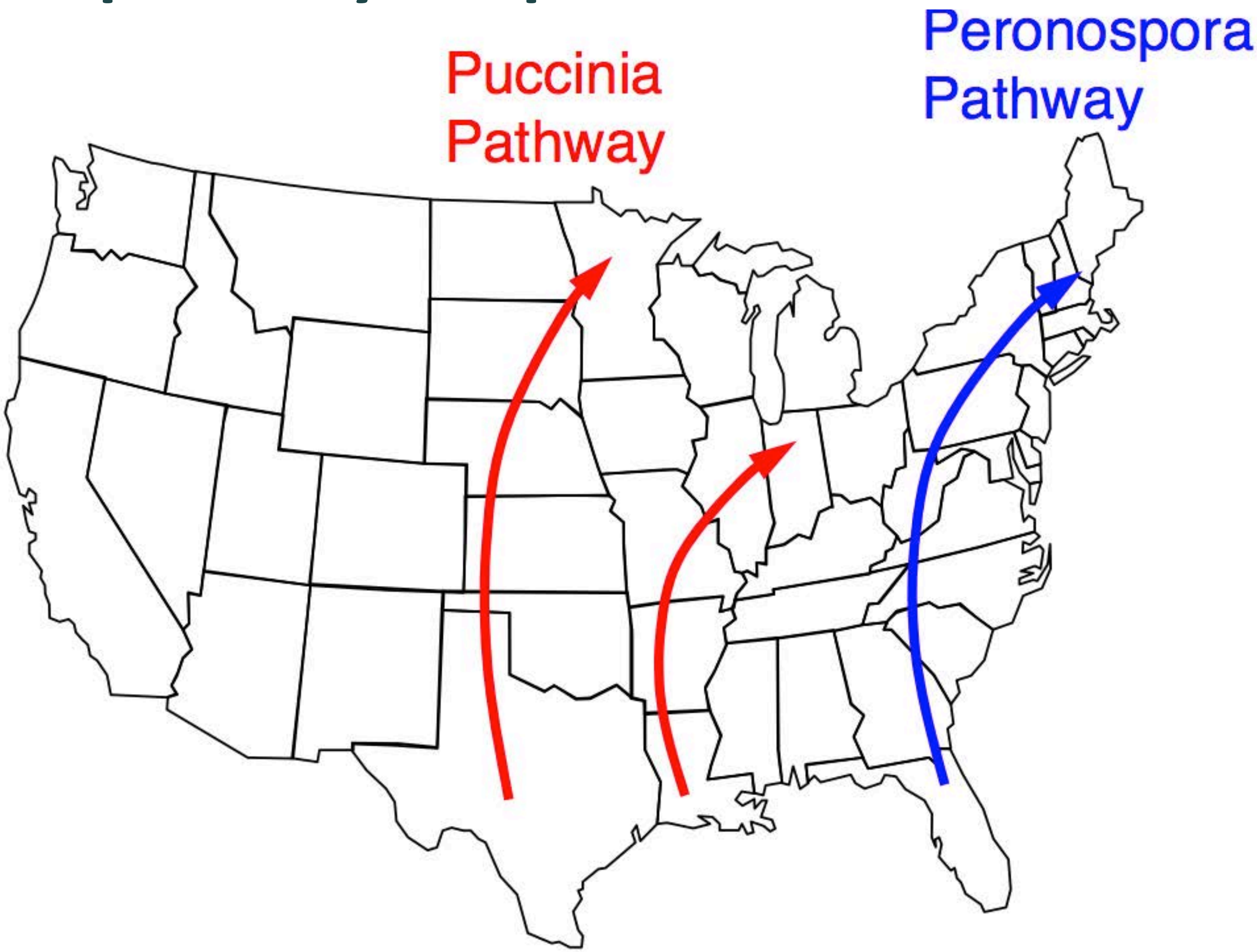


Lagrangian transport structure and ecology

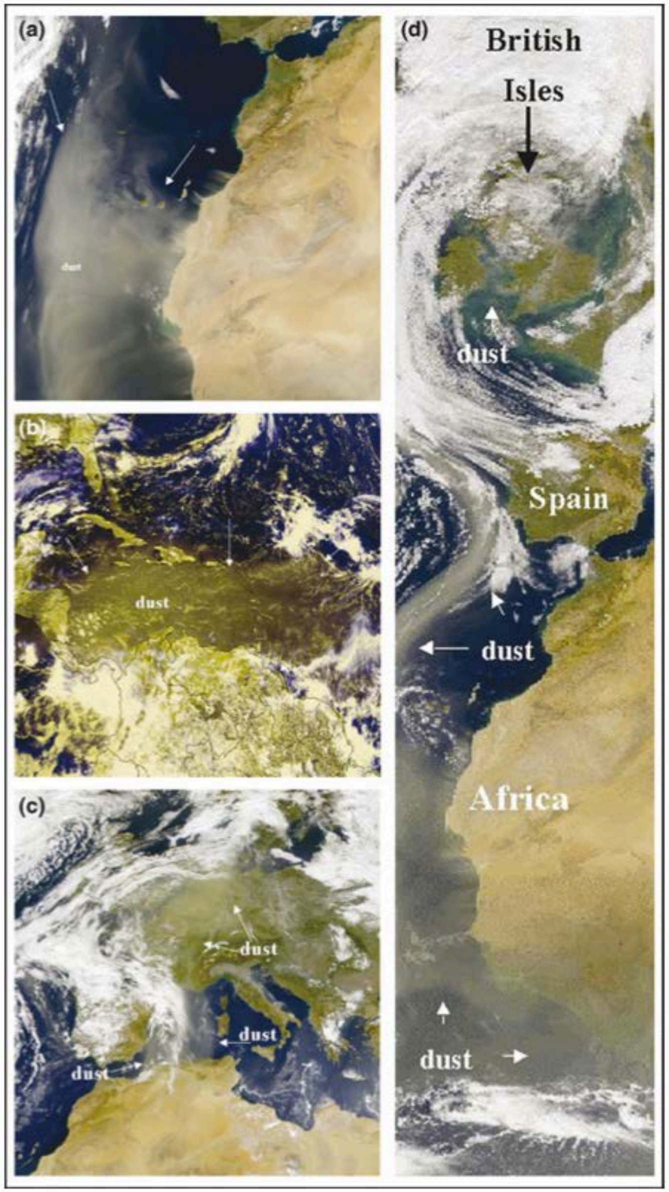
- **Could provide insight to spatiotemporal data and models in ecology**
- **Role of rare transport events**
- **Bifurcations changing the global tr structure (e.g., due to climate cha**
- **Universal principles for fluid regimes: oceans, rivers, lakes, …**

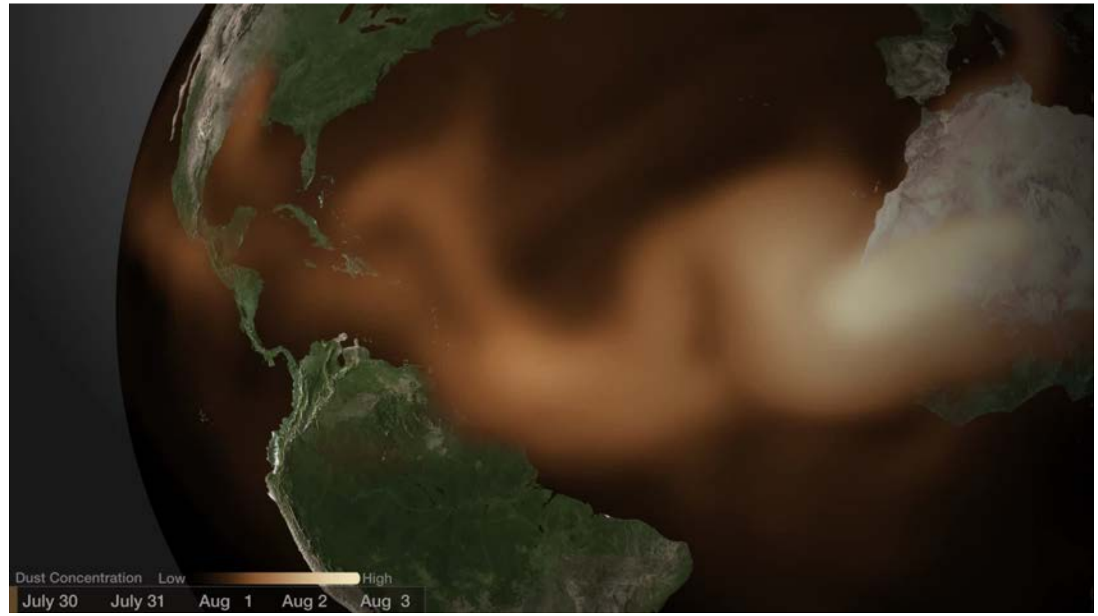


In aeroecology, concerns about likely pathways or persistent barriers

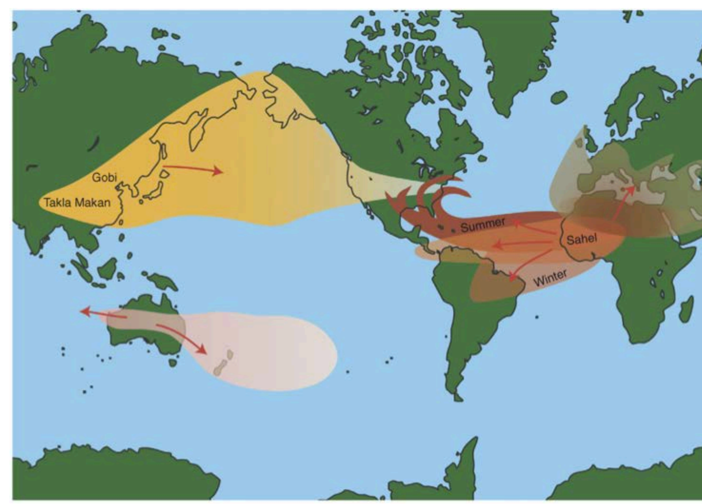


Aeroecology and the global transport of desert dust





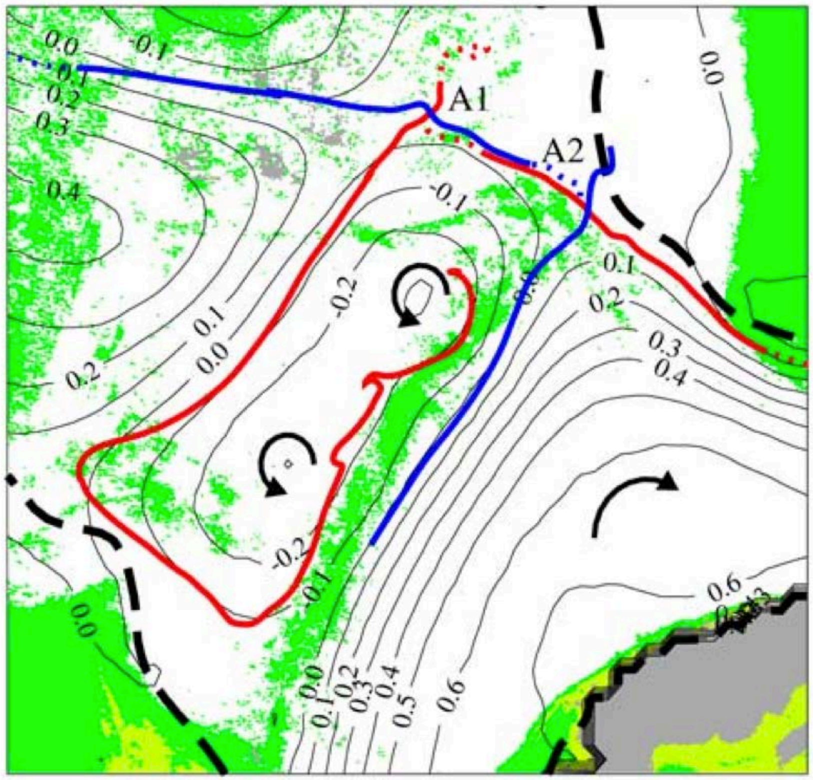
Lagrangian bridge connecting distant ecosystems

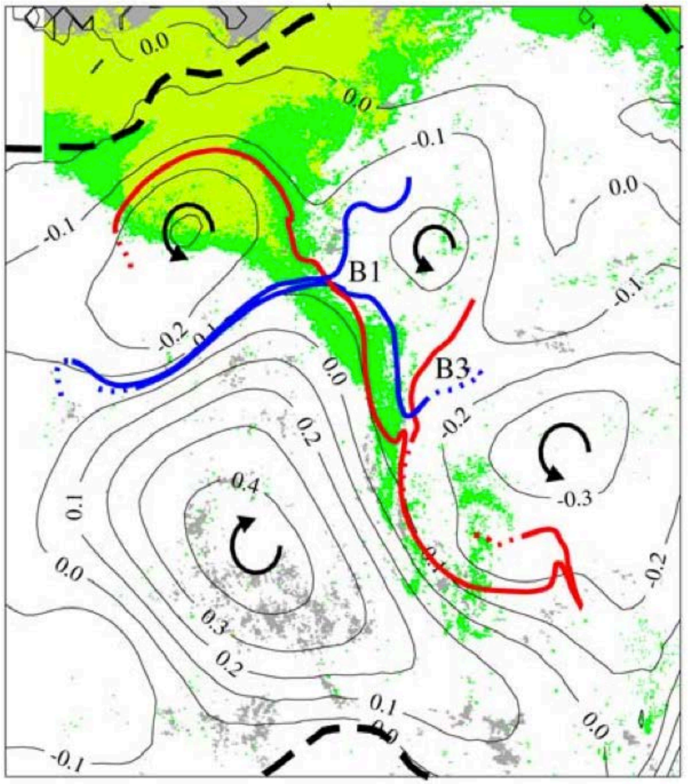


Kellogg, Griffin [2006]

Connectivity between vastly separated ecosystems

Chlorophyll transport in the Gulf of Mexico



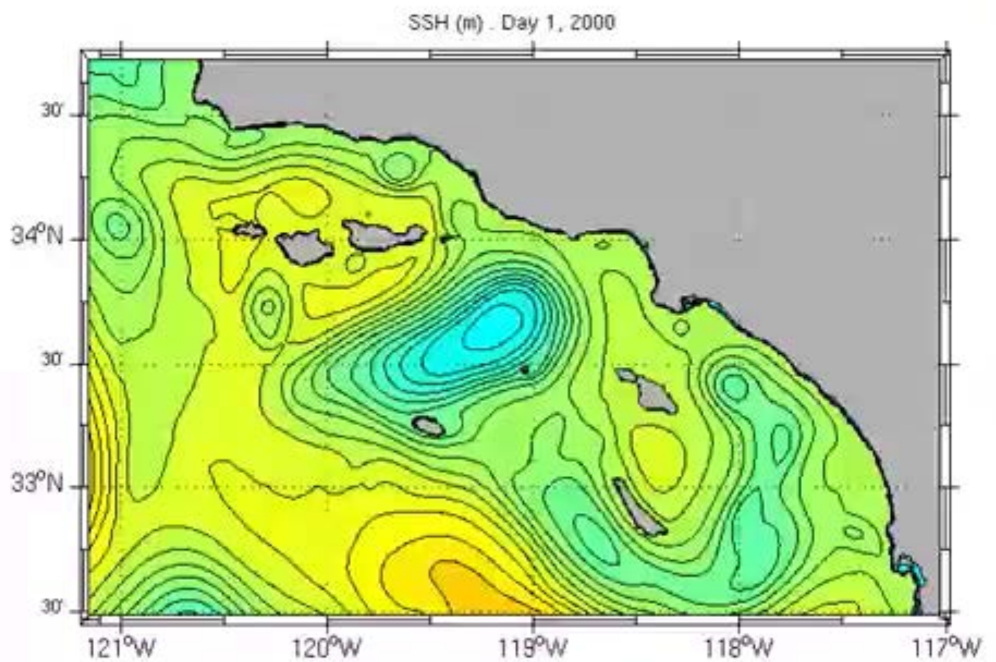


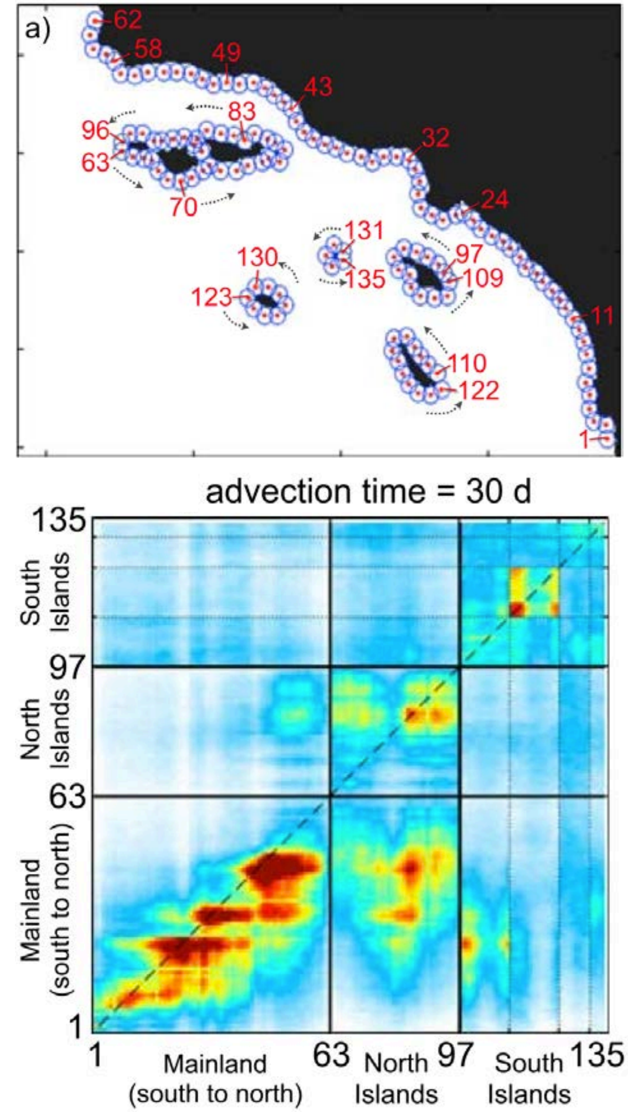
Chlorophyll as a tracer of biological advection and connectivity

Toner, Kirwan, Poje, Kantha, Muller-Karger, Jones [2003]

Connectivity and mixing in Southern California Bight

Relevant for marine ecosystem, larval transport, nutrient mixing



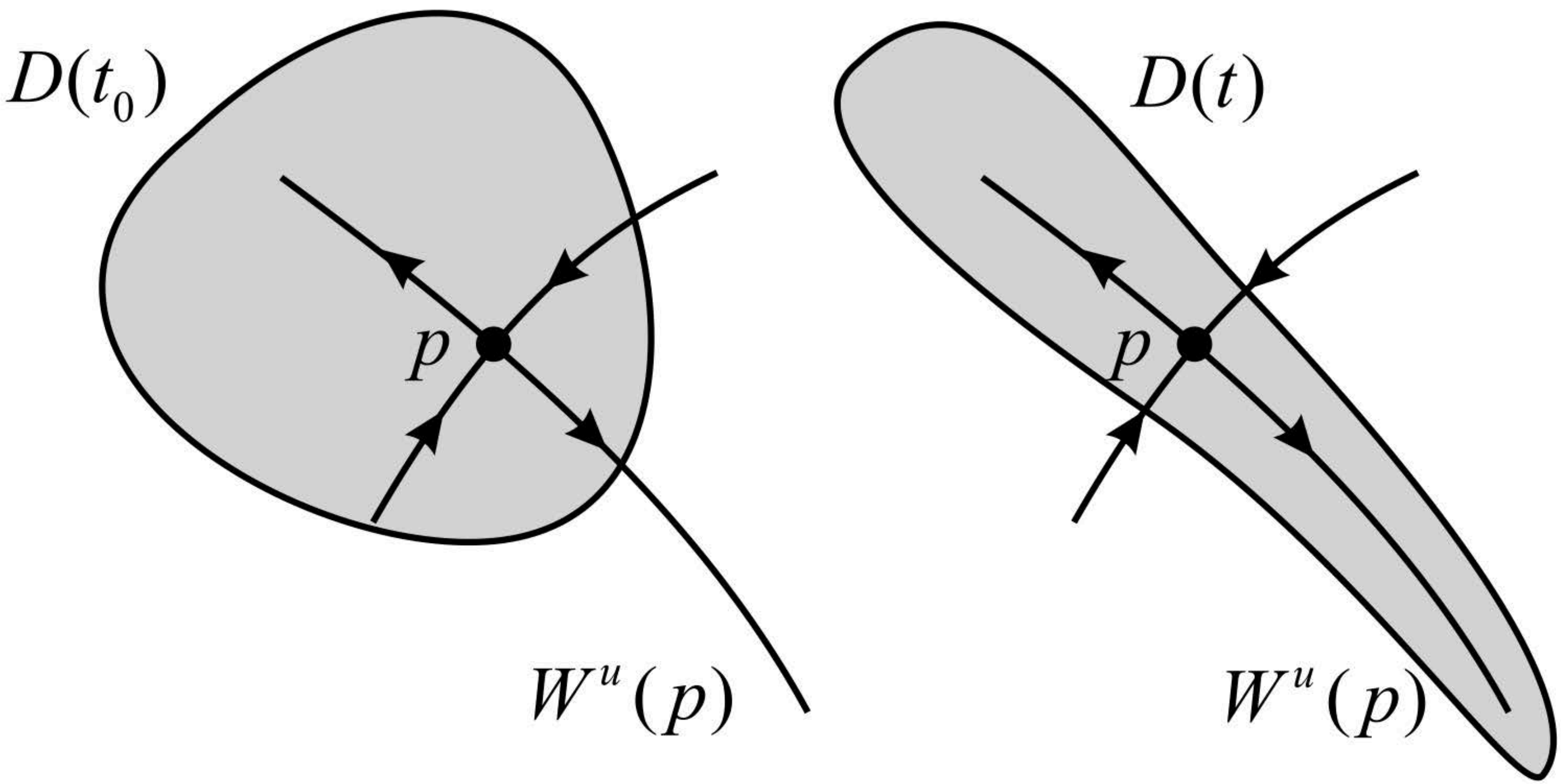


Applications of transition matrices, transfer operator, graph theoretic approaches? Ghost rod stirring around islands?

Mitarai, Siegel, Watson, Dong, McWilliams [2009]; Harrison, Siegel, Mitarai [2013]

Forecasting sudden *ecosystem* changes

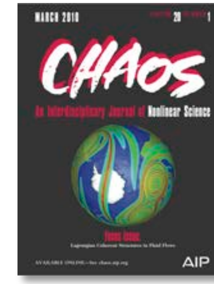
Application of, e.g., the LCS-core analysis of Olascoaga & Haller [2012] to predict rare biological incursions, drastic changes in connectivity?



Provide early warning of rapid long-distance dispersal events

The End

Sponsors: NSF DEB-0919088
NSF CMMI-1100263



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Main Papers:

- BozorgMagham, Ross, Schmale [2013] Real-time prediction of atmospheric Lagrangian coherent structures based on forecast data: An application and error analysis. *Physica D* 258, 47-60.
- Lin, BozorgMagham, Ross, Schmale [2013] Small fluctuations in the recovery of fusaria across consecutive sampling intervals with unmanned aircraft 100 m above ground level. *Aerobiologia* 29(1), 45-54.
- BozorgMagham, Ross [2013] Atmospheric Lagrangian coherent structures considering unresolved turbulence and forecast uncertainty, *submitted*.
- Prussin, Marr, Schmale, Ross [2013] Experimental validation of a long-distance transport model for plant pathogens: Application to Fusarium graminearum. *Agricultural and Forest Meteorology*, accepted.
- Tallapragada, Ross, Schmale [2011] Lagrangian coherent structures are associated with fluctuations in airborne microbial populations. *Chaos* 21, 033122.
- Lekien & Ross [2010] The computation of finite-time Lyapunov exponents on unstructured meshes and for non-Euclidean manifolds. *Chaos* 20, 017505.