Concentration fluctuations above a vegetation canopy, a wind tunnel simulation.

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Context of the study

Accelerated Forest Fire (AFF)

- Sudden and strong events:
  - high increase of the fire propagation speed (cm/s to m/s)
  - hectares can be burned in a few minutes
  - fireballs
  - unpredictable events
  - very dangerous for firemen

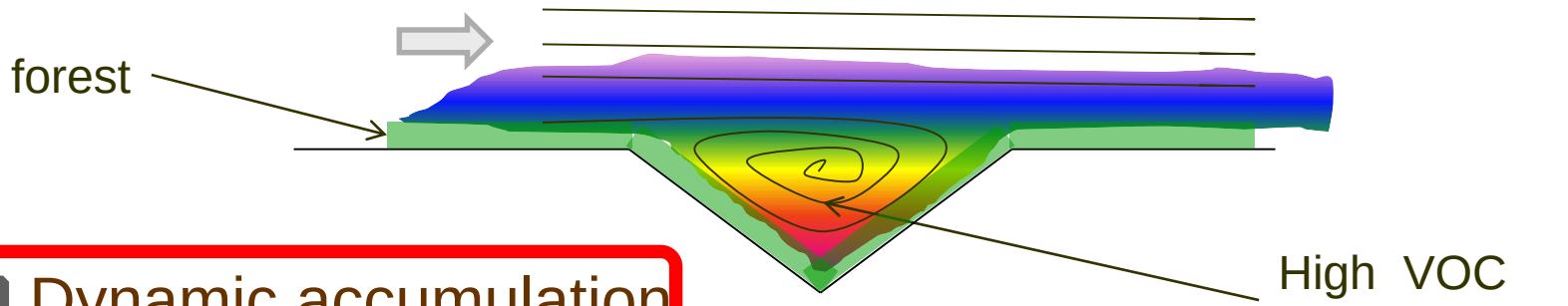
- Causes not completely understood (multiple)
  - can happen in sloppy terrain, canyon, valley but also flat terrains
  - wind driven? thermal effects?
  - **Accumulation of VOC (Volatile Organic Compound)?**

Context of the study

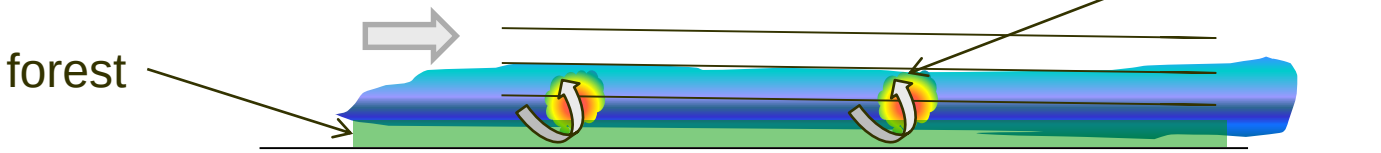
Can local VOC accumulation promote AFF?

Forest vegetation continuously emits flammable VOC.

- Topographic accumulation
  - Wind recirculation in a valley/canyon

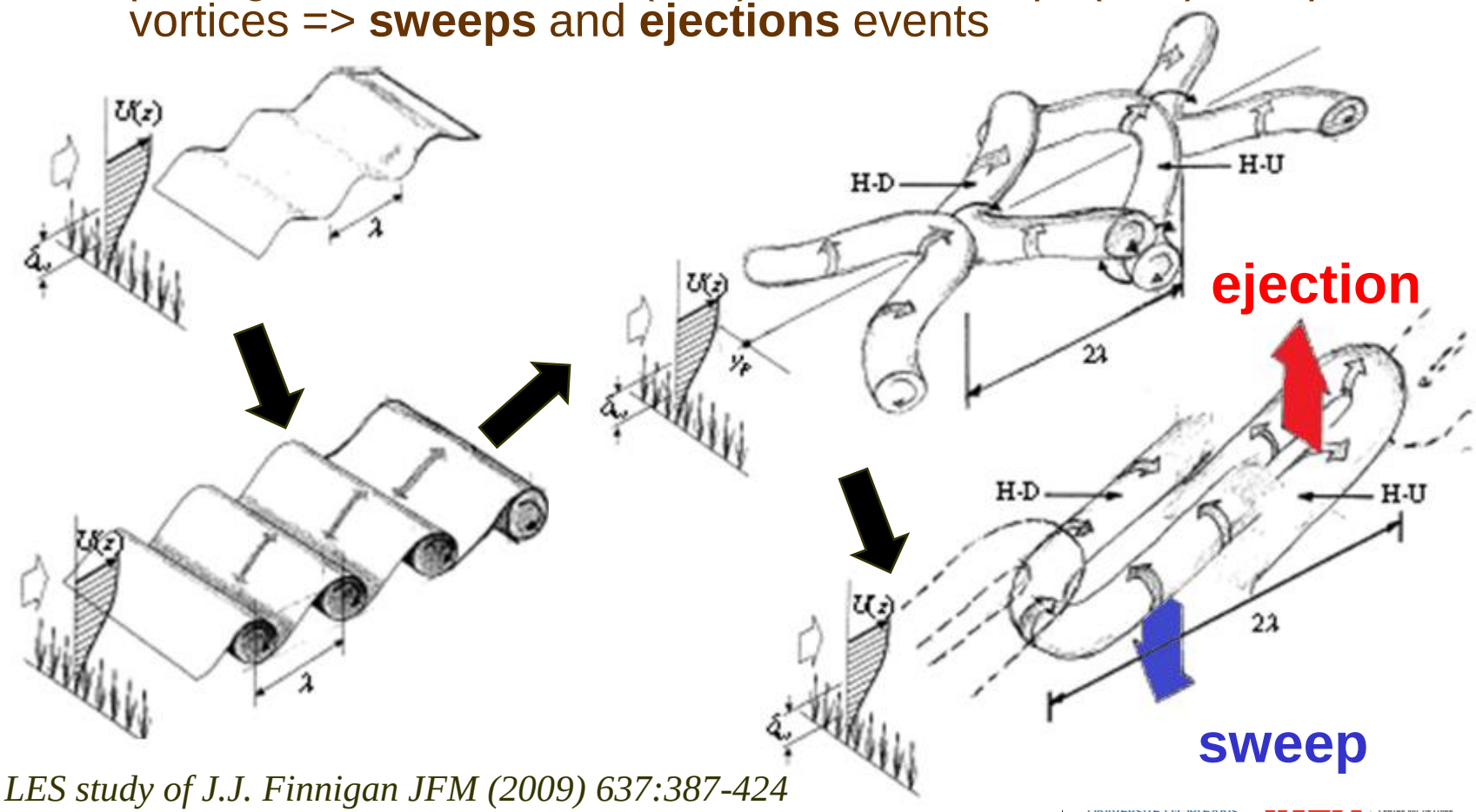


- Dynamic accumulation
  - Local accumulation of gas in the shear layer due to shear layer instabilities



Context of the study

- Shear layer instabilities above a vegetation canopy:
  - Scenario proposed by *Finnigan (2009)* : K-H instability => pairing => head-down (H-D) and head-up (H-U) hairpin-like vortices => **sweeps** and **ejections** events



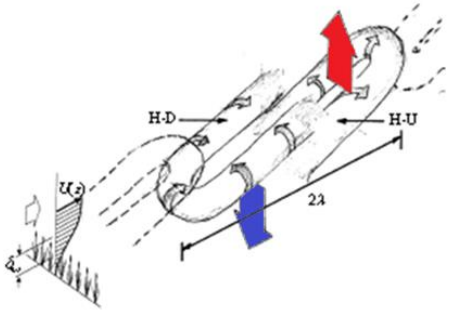
LES study of J.J. Finnigan JFM (2009) 637:387-424

Context of the study

- Shear layer instabilities above a vegetation canopy:
  - Ejection and sweeps are predominant in the shear production (field measurements, wind-tunnel simulations and CFD) and are linked in observations of temperature ramps.

    Field measurements of C. Thomas, (2007) BLM 123:317-337

  - They must have an important rule in the transport of gas through the forest canopy



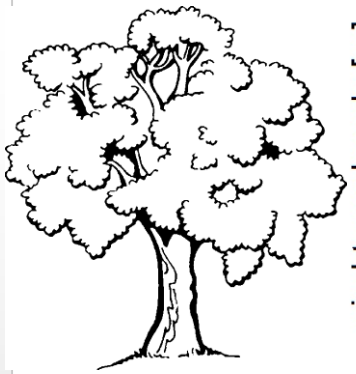
- **Objective:** evaluate the contribution of *coherent structures* in releasing high concentration gas pockets above the vegetation canopy

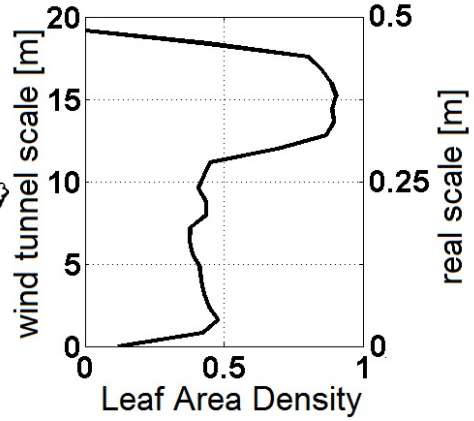
Contents

- AFF and instabilities above forest canopy
- **Reproduction of the forest and the VOC emission in the wind tunnel**
- Time averaged measurements
- Velocity and concentration fluctuations
- Conclusions et perspectives

Wind tunnel set-up

- Forest modeled by metallic mesh rings in staggered arrangement in the atmospheric wind tunnel



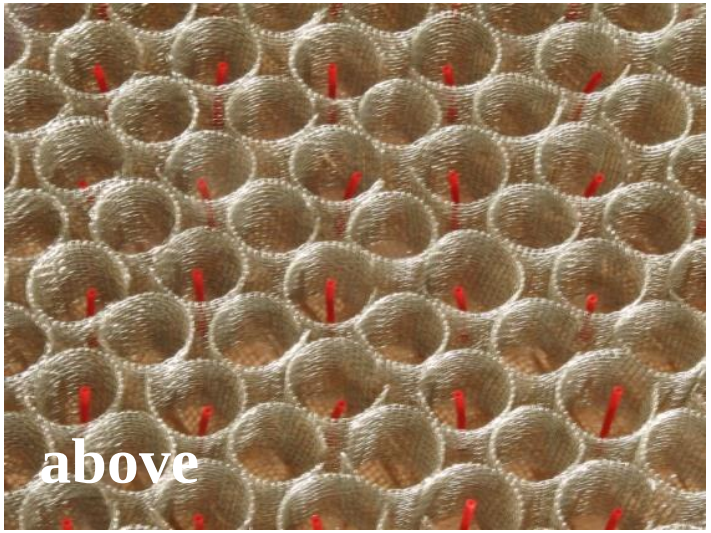


- porous media
- LAD representative of a real tree
- metallic rings covering a 2 m wide x 3 m long area on the ground
- h = 5 cm high
- **1/400 scale**

S. Aubrun (2004), Atm.Env. 38:2797-2801

Wind tunnel set-up

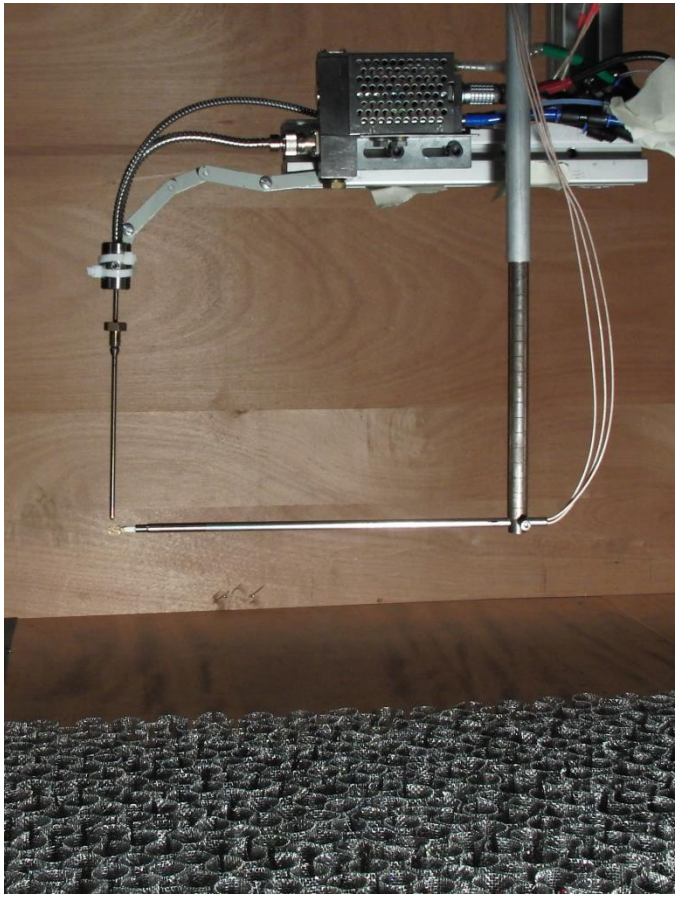
❑ VOC emission



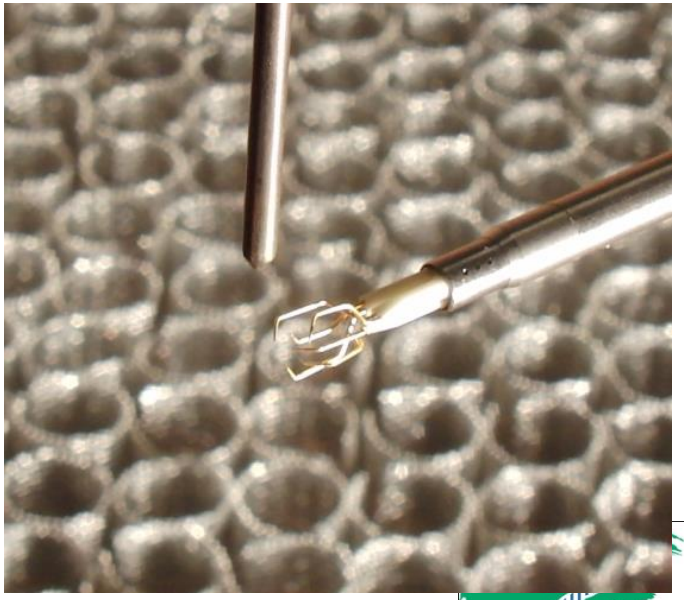
- emission tubes rise at 4/5h to mimic the tree crown emission
- adjustable flow rate
- high pressure drops to ensure homogeneous gas emission
- emission velocity ≈20% of u*
- ethane is used to study only aerodynamics mechanism (density close to the air) (no Buoyancy)

Wind tunnel set-up

- Measurement techniques
  - Three component hot-wire velocity measurement (**> 5 kHz**)
  - Fast Flame Ionization Detector (F-FID **50 Hz**)

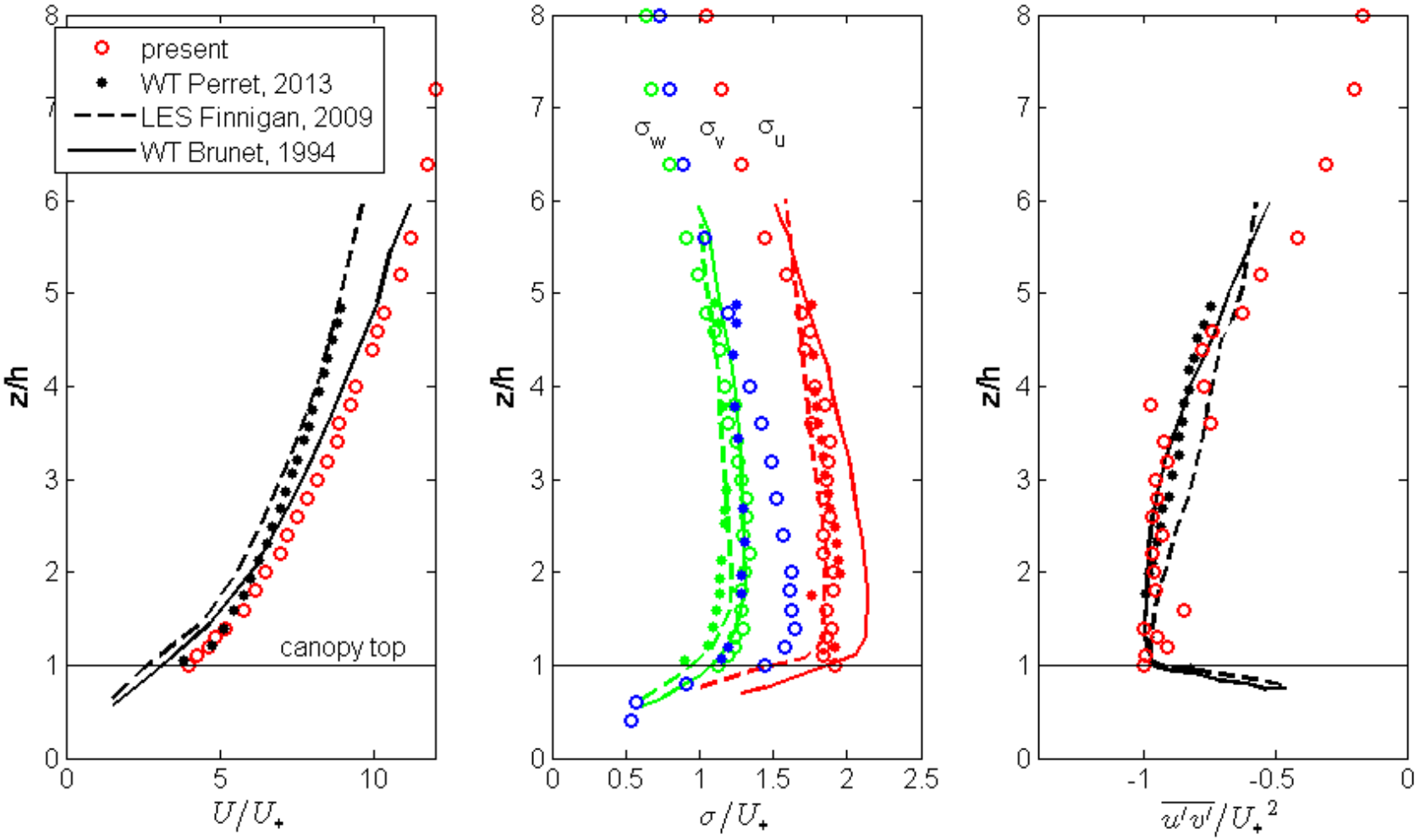


- simultaneous, time resolved and *nearly punctual* velocity and concentration measurements



Time averaged measurements

- Time averaged velocity in the three directions at x = 50h
  - Comparison to literature

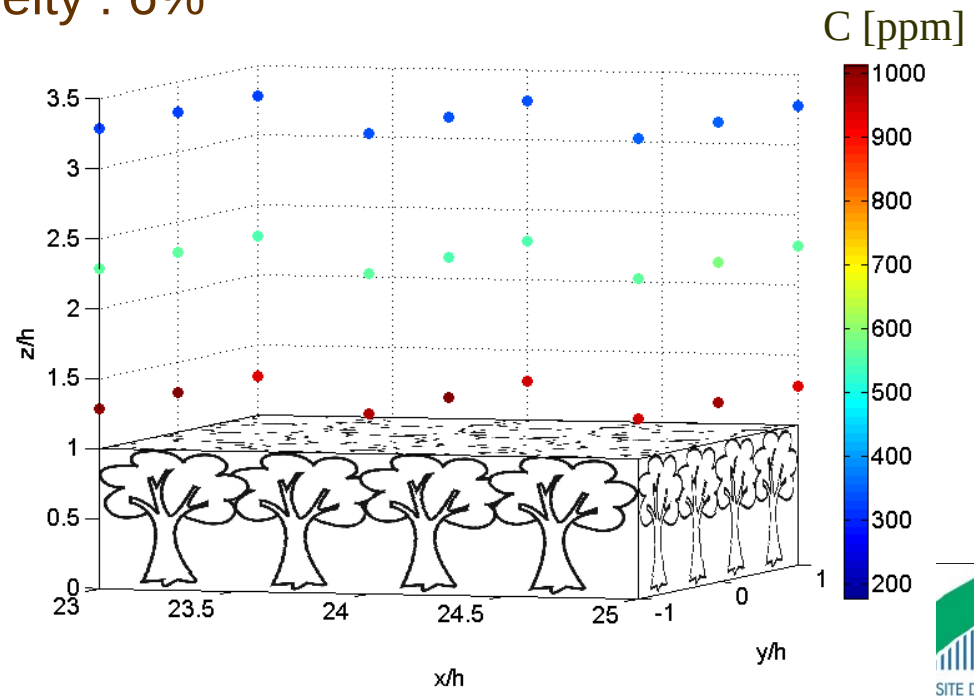


Time averaged measurements

- Concentration reproduction and homogeneity
  - Normalization of the concentration C* by the speed at h and the surface flow rate:

$$C^* = \frac{C.U}{Qs}$$

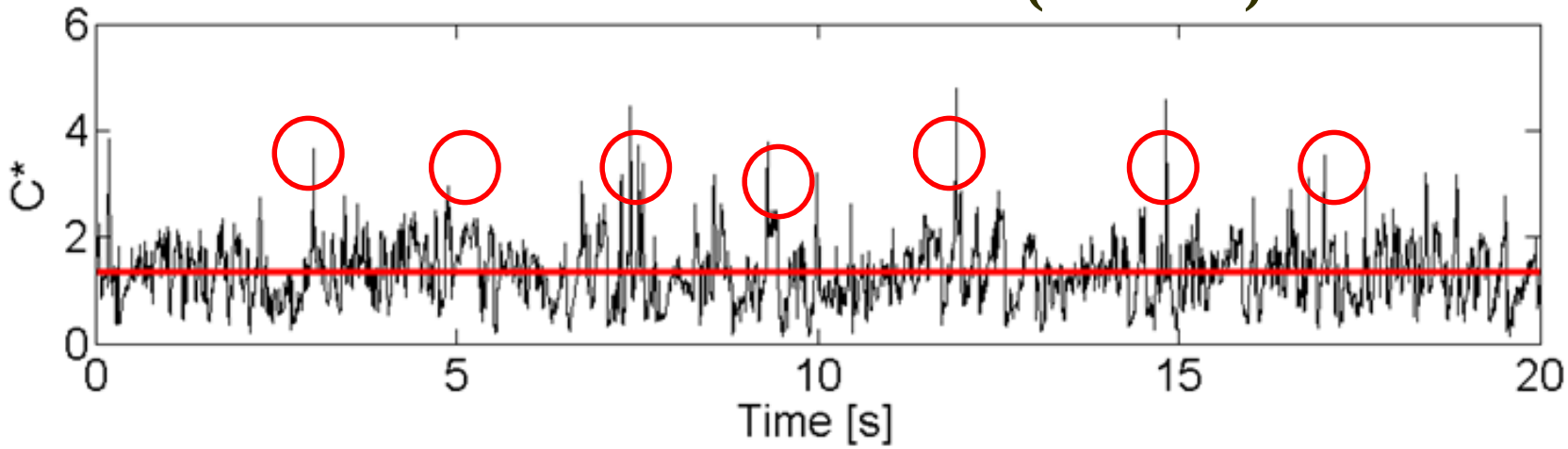
  - Measurement repeatability : 5-10%
  - homogeneity : 6%



Time averaged measurements

- Time averaged results consistent to literature
- But it is necessary to study time series to account for concentration peak that may reach the flammability limit

Concentration time series (z = 1.5h)

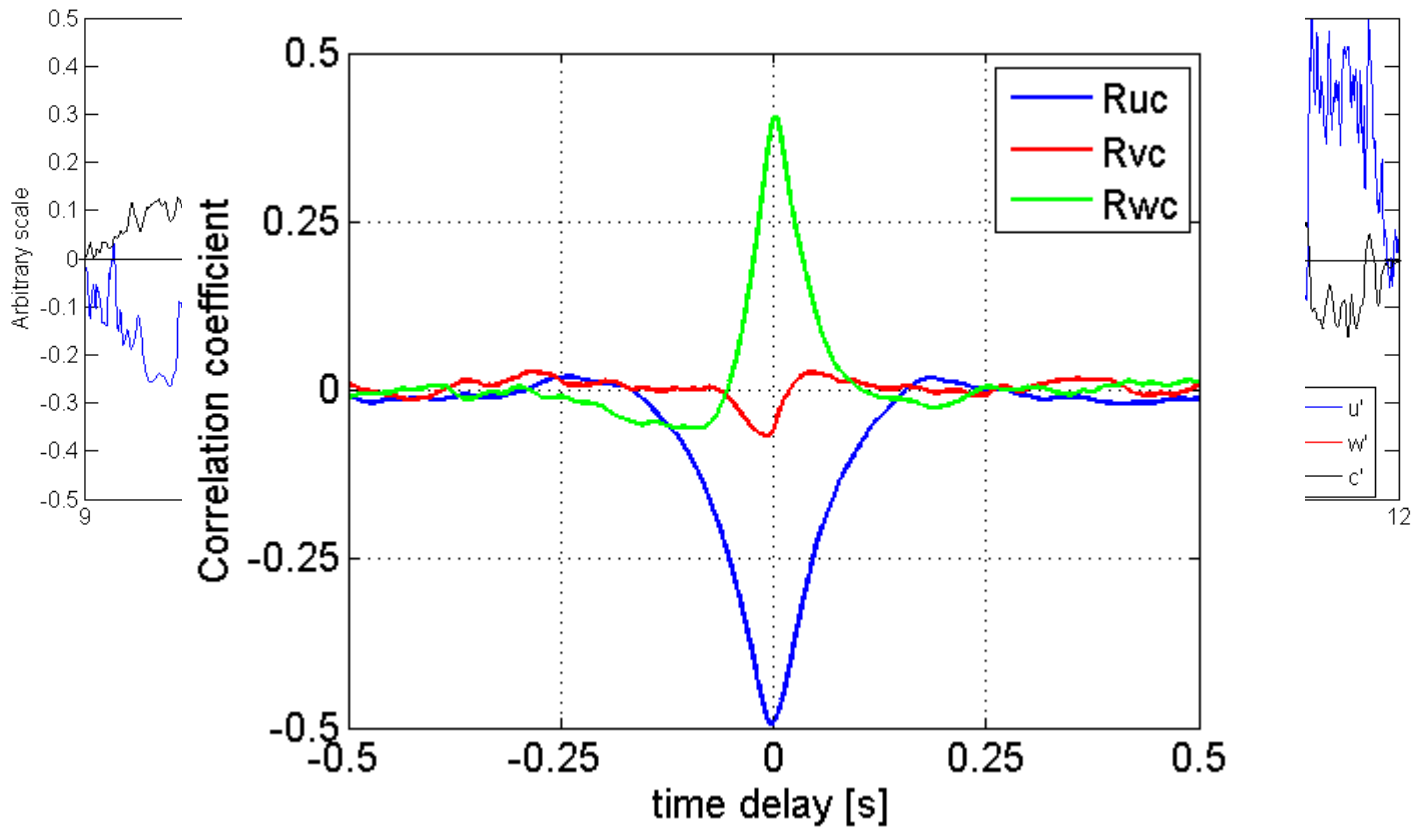


- Similar behavior observed for passive transport in the field

Field measurements from A.L. Steiner Atm. Chem. Phys., 11, 11921-11936

Flow instabilities

- Velocity and concentration correlation

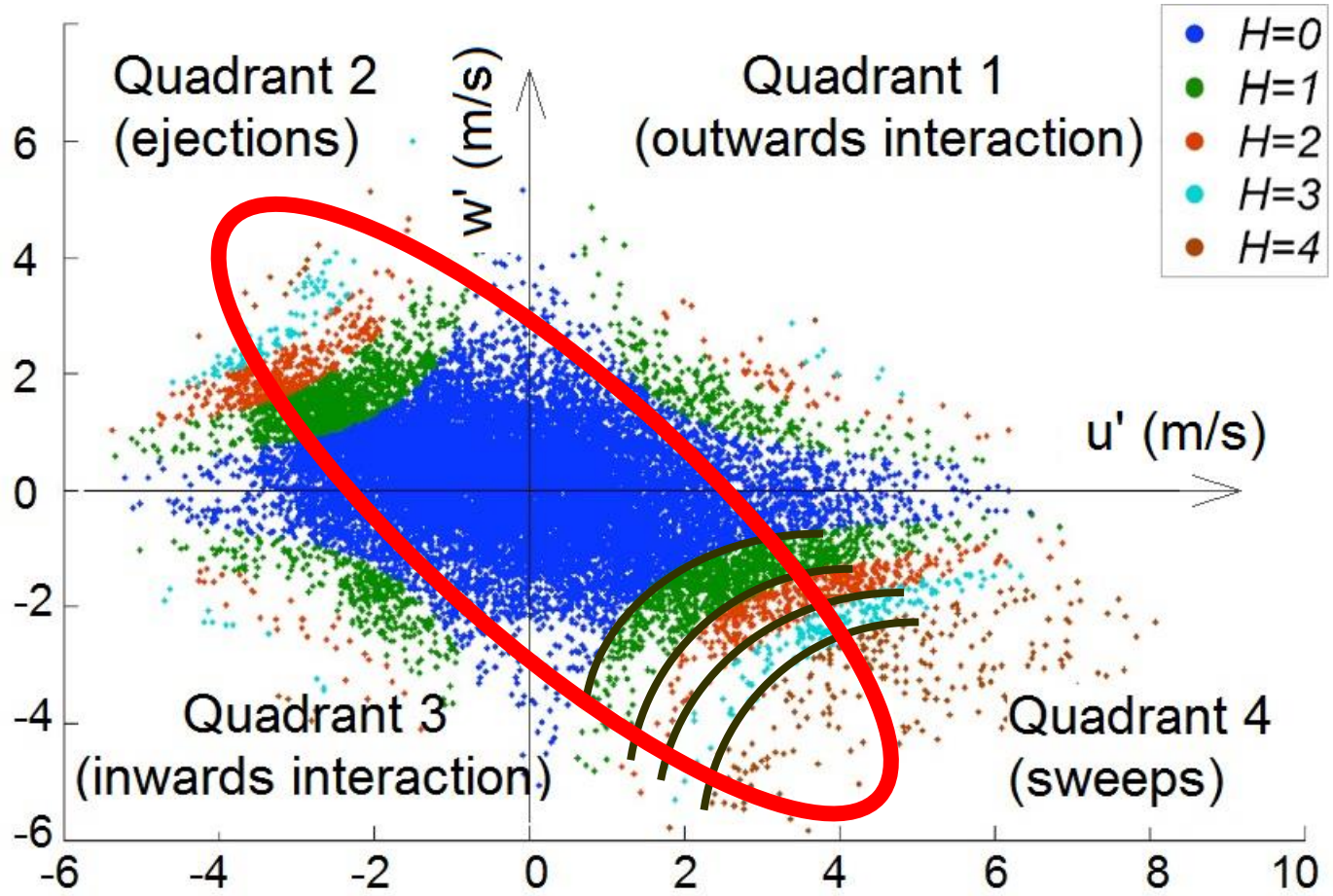


Concentration is closely liked to longitudinal and vertical velocity fluctuations

Flow instabilities

- Quadrant-Hole technique to characterize wind flow

  A hole (*H*) filters fluctuations below $H.\sigma_u\sigma_w$



Field measurements from A.L. Steiner Atm. Chem. Phys., 11, 11921-11936

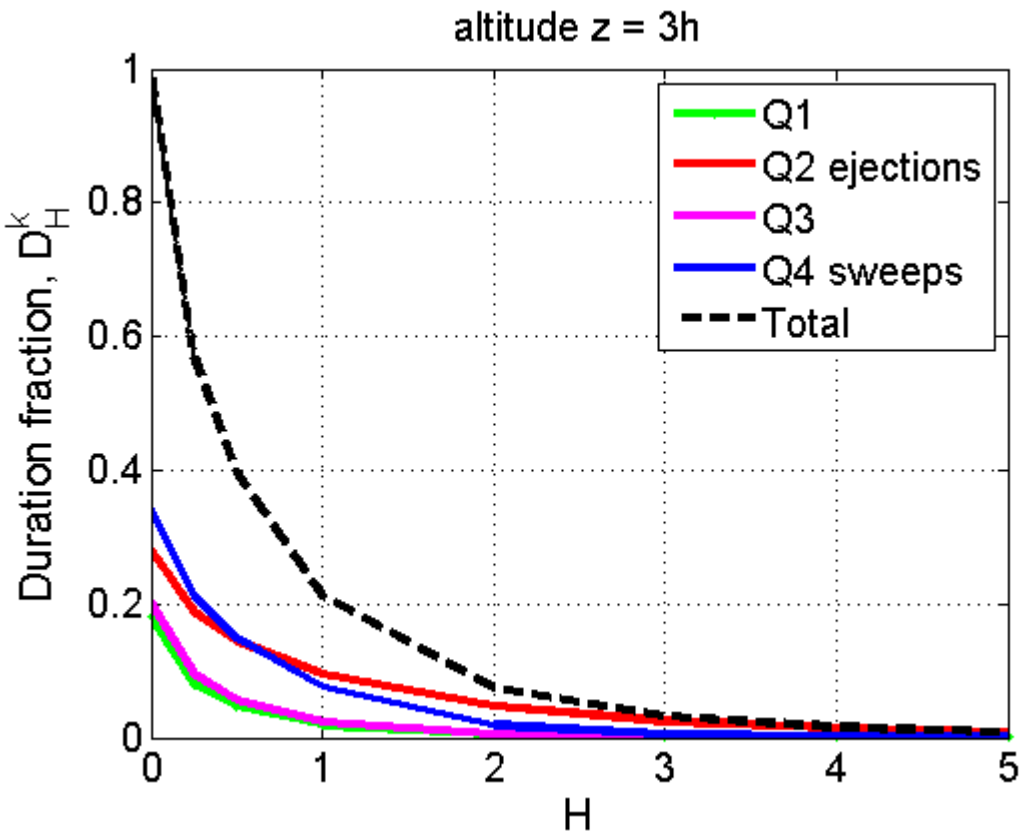
Flow instabilities

- Duration fraction of a quadrant defined by:

$$D_H^k = \frac{1}{N}\sum_{n=1}^{N} I_{H,n}^k$$

with k: quadrant, H: hole size

I^k_H =1 if (u'w') belongs to Q_k and $u'w' > H.\sigma_u\sigma_w$ (conditional average)
otherwise, $I^k_H = 0$



For H=0, Q2+4 weakly dominant (60%)

For H=1, only 20% of the time is left, Q2+4 = 18% and Q1+3 =2%

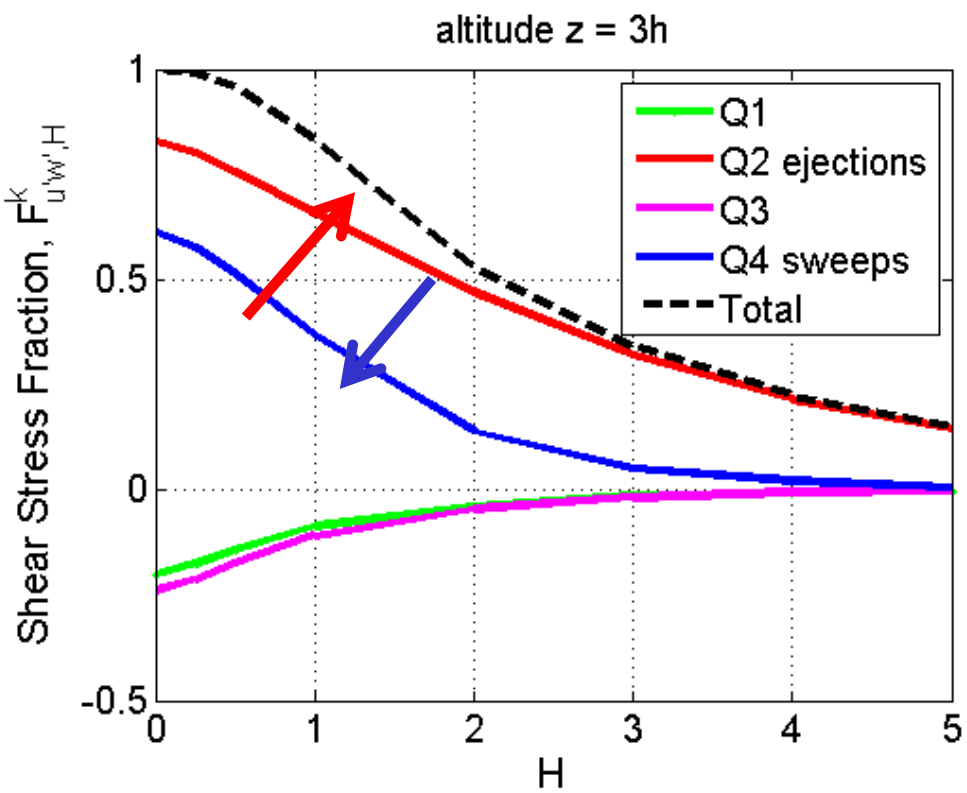
Weak influence of the height

Flow instabilities

- The fractional contribution of the quadrant *k* to the variable *X* is then defined as:

$$F^k_{X,H} = \frac{\overline{X^k_H}}{\overline{X}} D^k_H$$

  - For the shear stress $\overline{u'w'}$ we have:



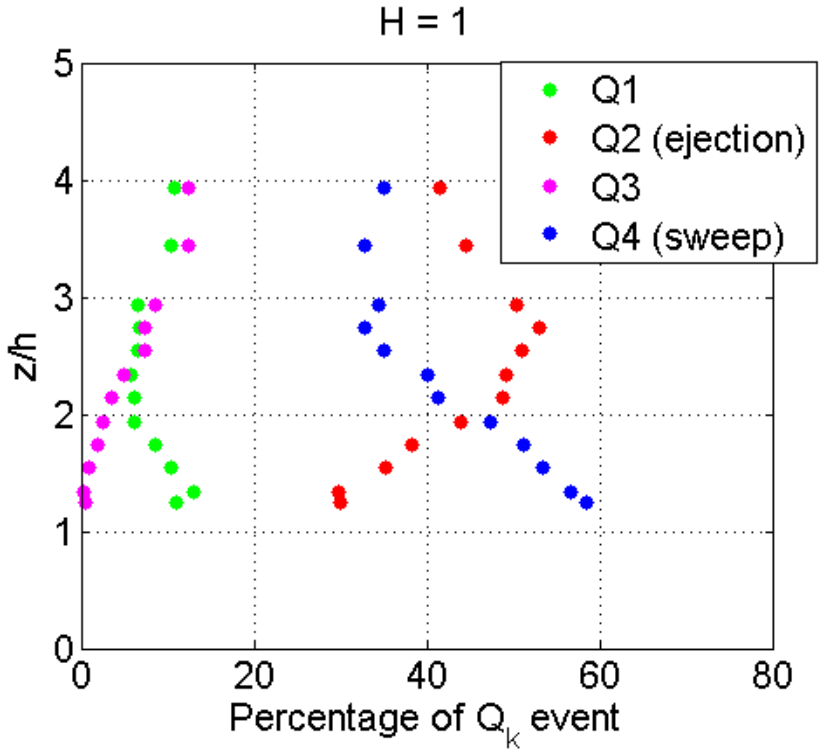
Clear predominance of Q2+4 events in the shear production

Extreme events are only sweeps and ejections

Sweeps dominate in near canopy but the contribution of ejections increases with height at the expense of the sweeps

Flow instabilities

- Velocity fluctuations



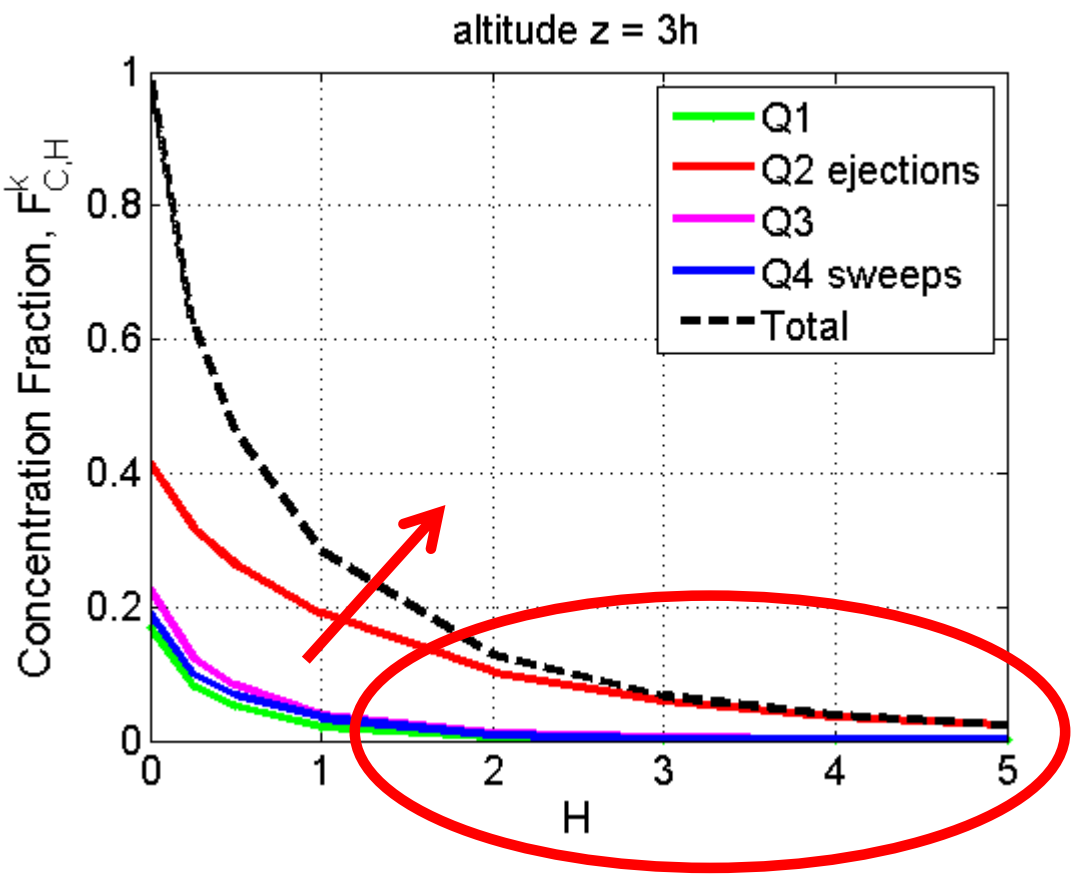
« ejections » dominates above

« sweeps » dominate near canopy top

- Ejections and sweeps are the main contributors to the shear
- **Sweeps are stronger near the canopy**
- **How are they linked to the concentration fluctuations?**

Flow instabilities

- The fractional contribution to the mean concentration *C* is computed with the Quadrant-Hole technique:



- Clear domination of ejection quadrant (40% @ H=0)

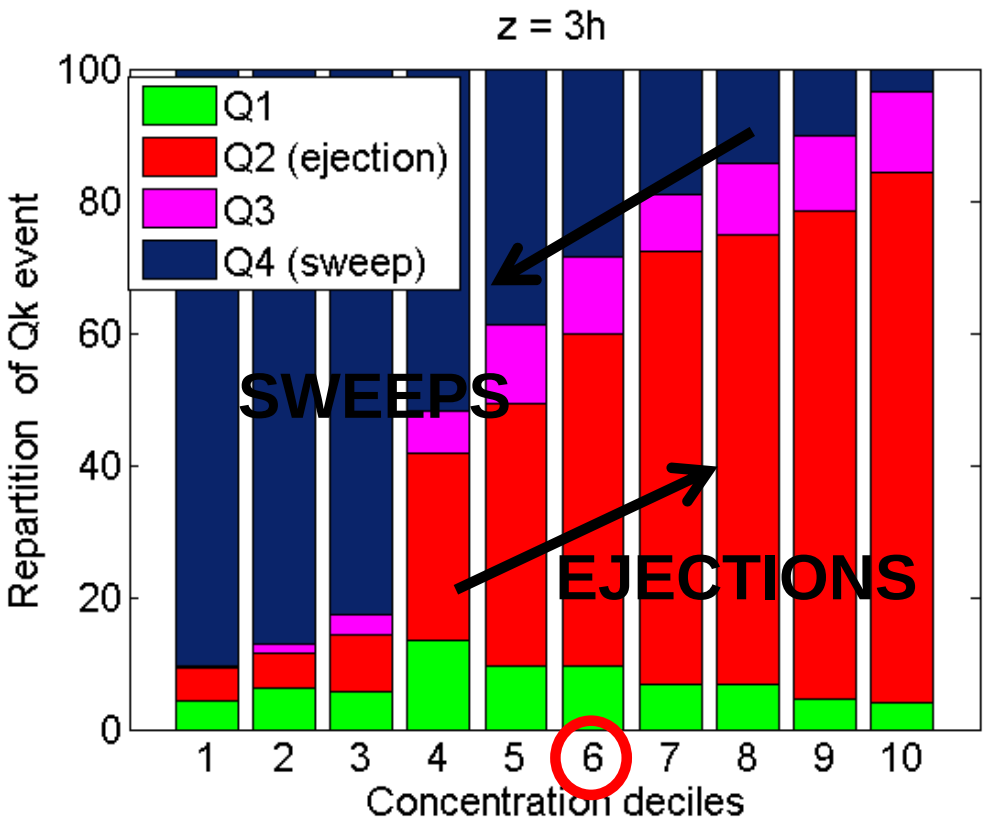
Ejection contribution increases with height

For H=1, the ejection quadrant still contribute to 10% to 20% of the mean concentration

Ejections responsible of extreme concentration events

Flow instabilities

- Another way to enlighten the contribution of ejections and sweeps:
  - Instantaneous C*' are sorted in ascending order and divided in decils. Relative ratios of Qk events are then calculated for each decile.



- Concentrations above the mean are mainly linked to an ejections process in the shear layer.
- Concentration can rise up to 300% of the mean!
- On the other side, low concentrations are associated to sweeps.

Conclusions

- The ejection / sweep mechanism is closely associated to the transport of gas through the forest canopy
- Ejections are not very frequent close to the canopy but they can release concentration pockets more than three times more concentrated than the mean!

Perspectives

- Concentration found in gas pockets has to be compared to real field data to assess their flammability
- A more precise detection of the coherent structures (EMD, wavelet…) may bring more accurate data on the averaged size and concentration of the high concentration gas releases.
- CFD is being performed to increase the understanding of the physical phenomena

Concentration fluctuations above a vegetation canopy, a wind tunnel simulation.

THANK YOU FOR YOUR ATTENTION

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