Aerosol dry transfer above a forest canopy

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Fluid turbulence applications in both industrial and environmental topics
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Why studying the aerosol transfer onto the earth surface ?

- Air quality and its impact on human health
- Acidification of terrestrial ecosystems by atmospheric aerosol
- Climate change, as particles force the atmosphere radiative balance
- Spore spreading among crops (including GMO spores)
- Consequences of a nuclear accident : behaviour of particle-bound radionucleids

Impacts on human health

Two campaigns

- APHEA2 (Europe, 32 M people in 29 cities >5y)
- NMMAPS (USA, 50 M people in 20 cities 7y)

	Study	
	APHEA2	NMMAPS
Increase in total deaths per 10 $\mu g/m^3$ PM_{10} (95% confidence limits)	0.6% (0.4 – 0.8%)	0.5% (0.1 – 0.9%)
Increase in COPD (APHEA2: COPD + asthma) hospital admissions in persons > 65 yrs per 10 $\mu g/m^3$ PM_{10} (95% confidence limits)	1.0% (0.4 – 1.5%)	1.5% (1.0 – 1.9%)

Pulmonary disease

PM2.5 is more hazardous than coarser particles (Pope et al., 2002, JAMA, 287, 1132)

But the coarse mode is not innocious (WHO, 2003).

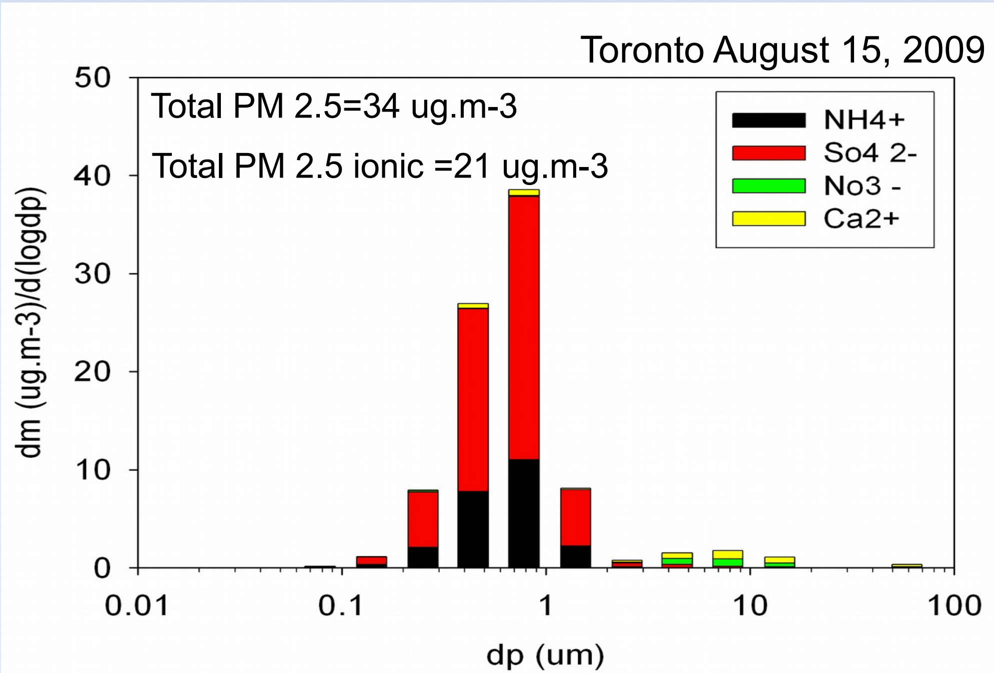
Little is known about the ultra-fine fraction -PM0.1- (Englert, 2004, Tox. Lett., 149, 235).

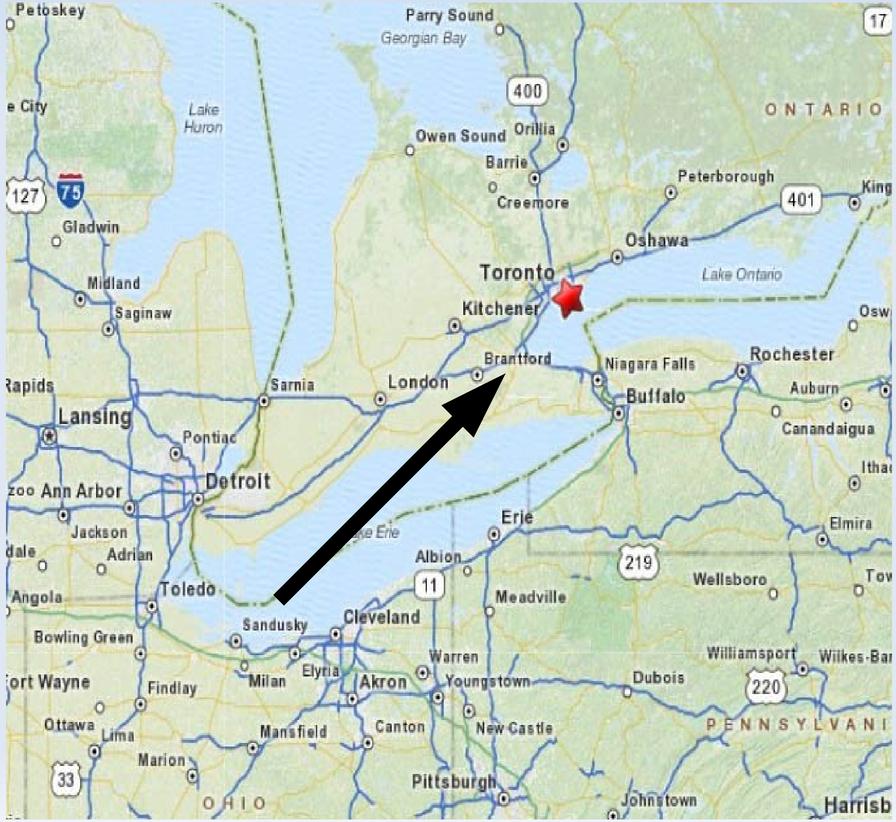
Effect on human health

Aerosol is a “container”. Not every compound is equal in term of health effects.

Need to determine both their size distribution AND their composition.

No single technique able to cover everything. Combined analysis.



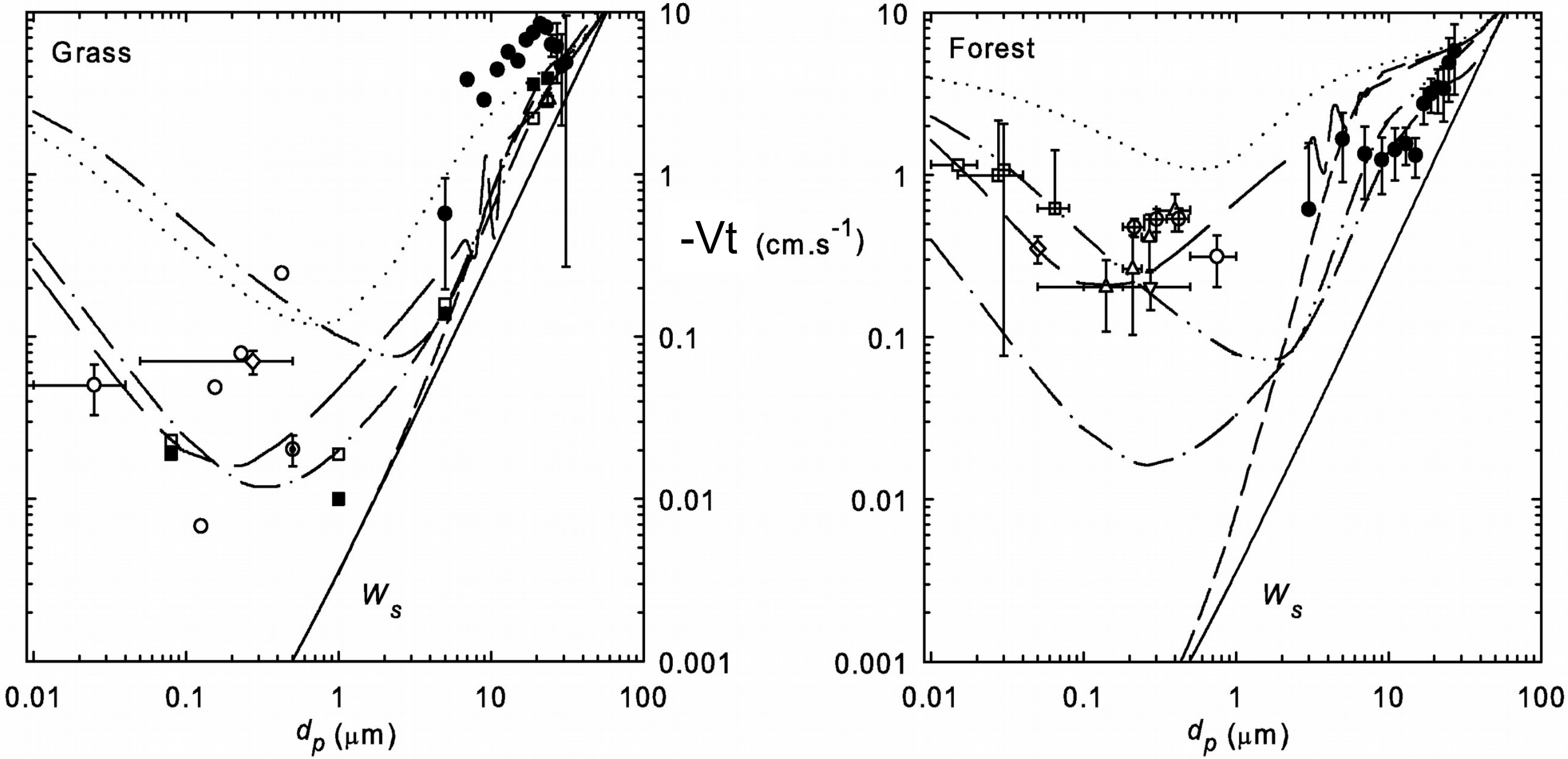


Aerosol transfer in dry conditions

- Without rain, mist or snow
- Accounts for a third to two-third of the total deposition of compounds monitored by air quality agencies.
- Problem is : these ratios depend on models that do not agree with one other
- The transfer velocity : a convenient boundary condition for the aerosol vertical flux

$$F = V_t \; c$$

Large discrepancies between the existing models and the measurements
….. And among these two groups



A. Petroff, A Mailliat, M. Amielh et F. Anselmet : Atmospheric Environment 42 (2008) 3625–3653

Aerosol mass balance above and within the canopy

Average over time and space to account for turbulence and the presence of obstacles

$$c = \langle c \rangle + c', \langle c' \rangle = 0$$

$$\frac{\partial \langle c \rangle}{\partial t} + \frac{\partial}{\partial x_i} \langle u_i \rangle \langle c \rangle + \frac{\partial}{\partial x_i} \langle u'_i c' \rangle - \frac{\partial}{\partial z} W_S \langle c \rangle = \langle S \rangle$$

Storage + Advection + Turbulent transport + Gravity effect = Sink + Source

Relating sink term to deposition on individual leaves

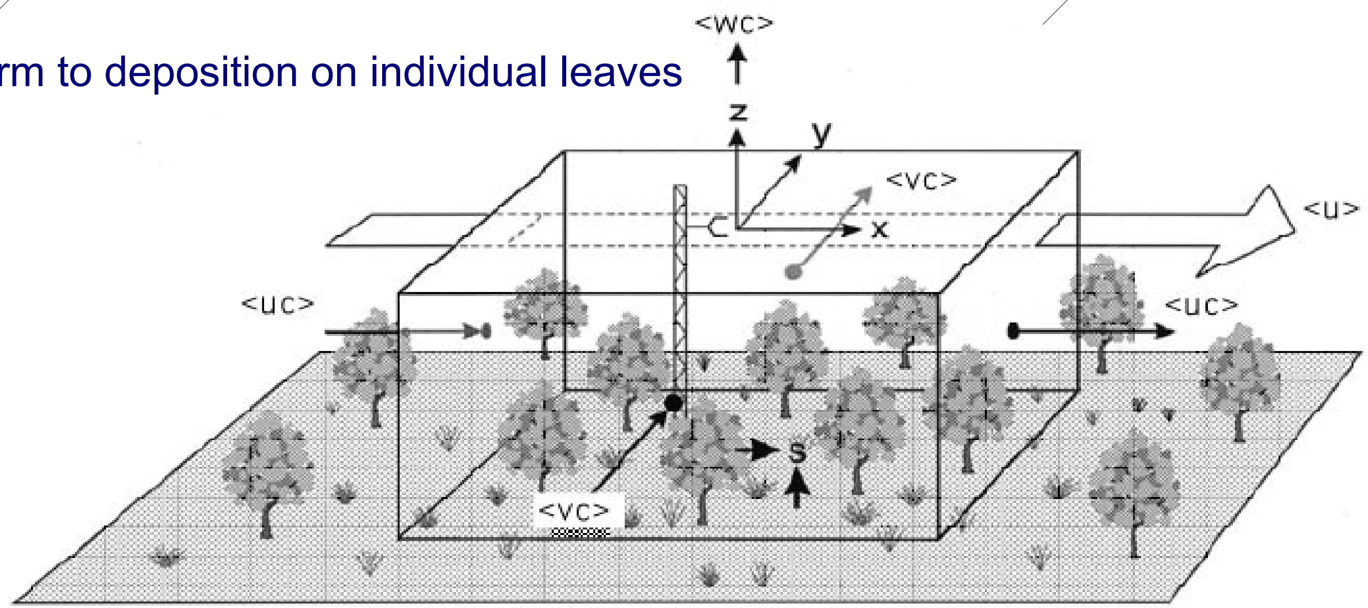
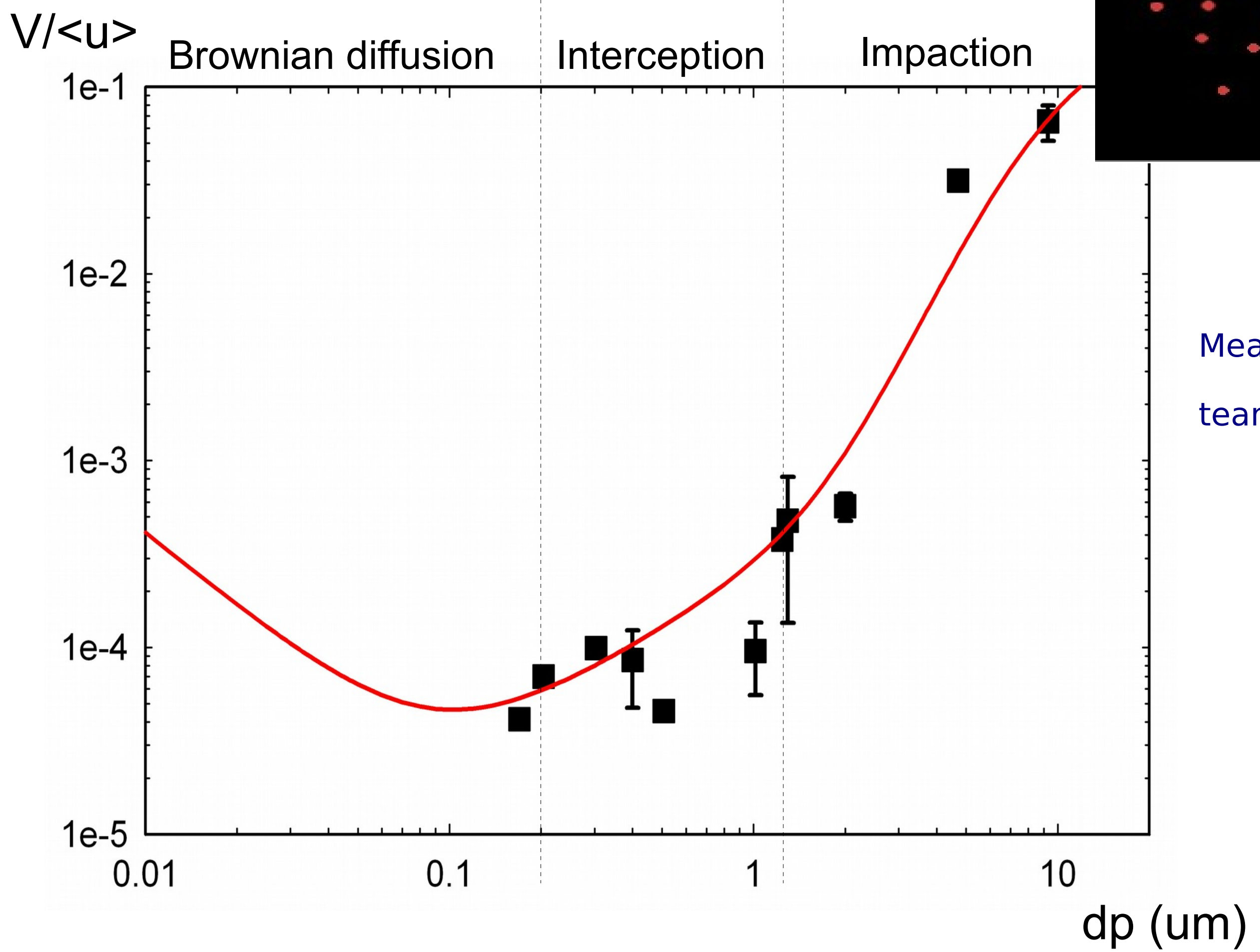
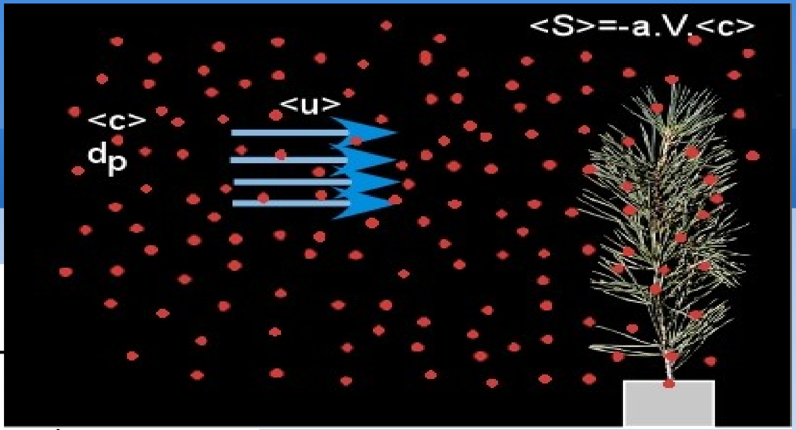


Figure modified from Finnigan et al., 2003 ,BLM, 107, 1

Collection on isolated twig





Measurements performed by Yves Belot's team between 1975 and 1994

A. Petroff, A Mailliat, M. Amielh et F. Anselmet, 2008b, Atmos. Env., 42, 3654

Dry deposition happening in an **homogeneous vegetation** cover is strongly dependent on

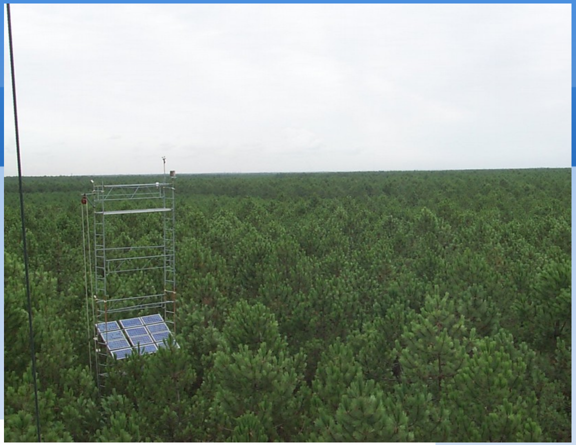
- the particle size distribution

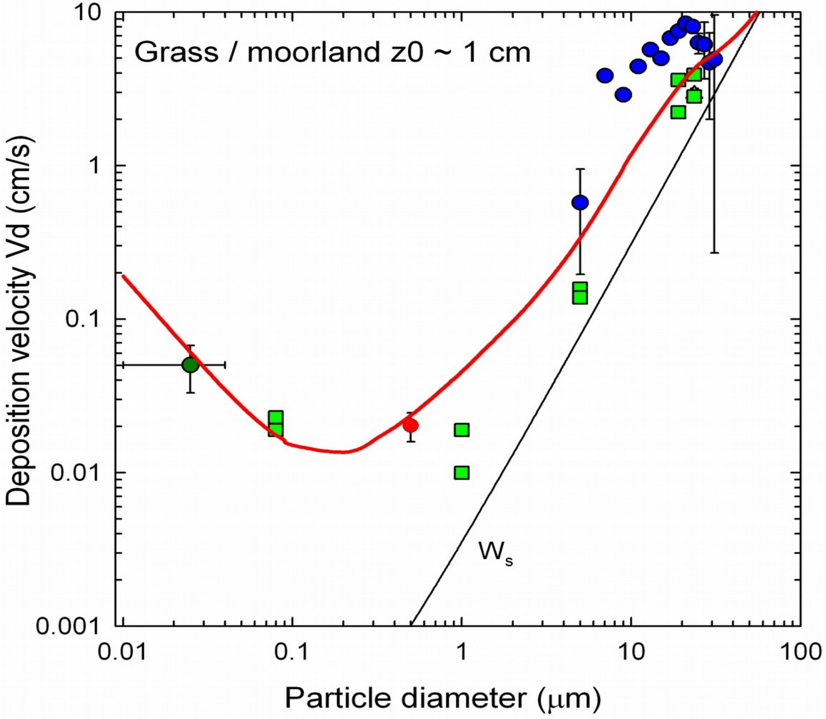
- the wind and turbulence level in the atmosphere

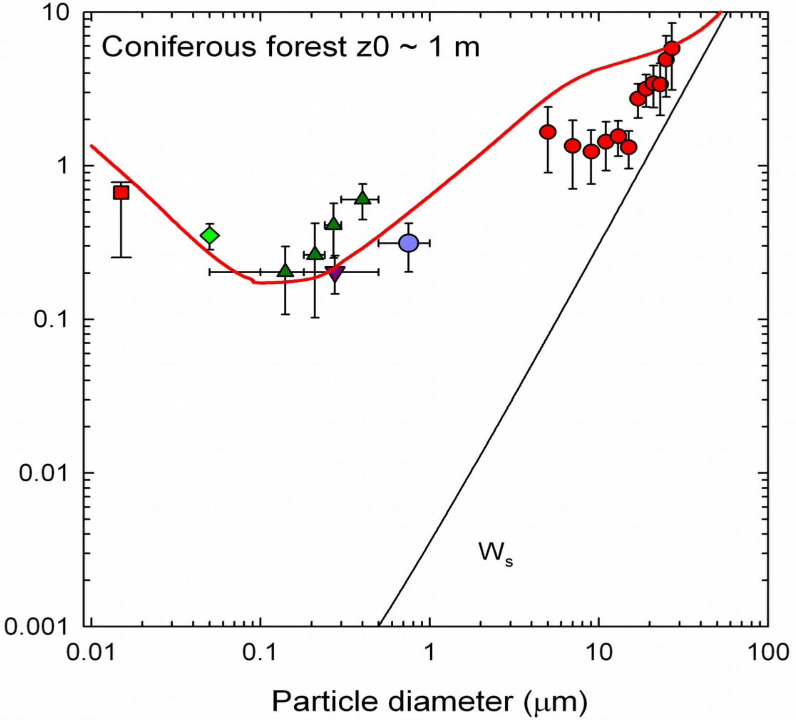
- the canopy collecting surfaces (shape, size of leaf, spatial density)

Aerosol transfer to the canopy

Influence of the surface







Reality check

Eddy-covariance measurements of particle fluxes

Instrumented flux tower in a forest of central Ontario

Carbon, nitrogen, water and energy fluxes

Focus on nitrogen :

Evidence of Nitrogen saturation of the forest and transition to Phosphorus limitation

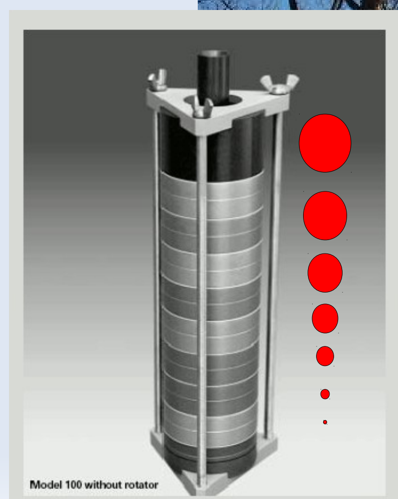
Need for evaluation of nitrogen containing particles and gases fluxes

Aerosol campaign for 2 months , extending into the autumn

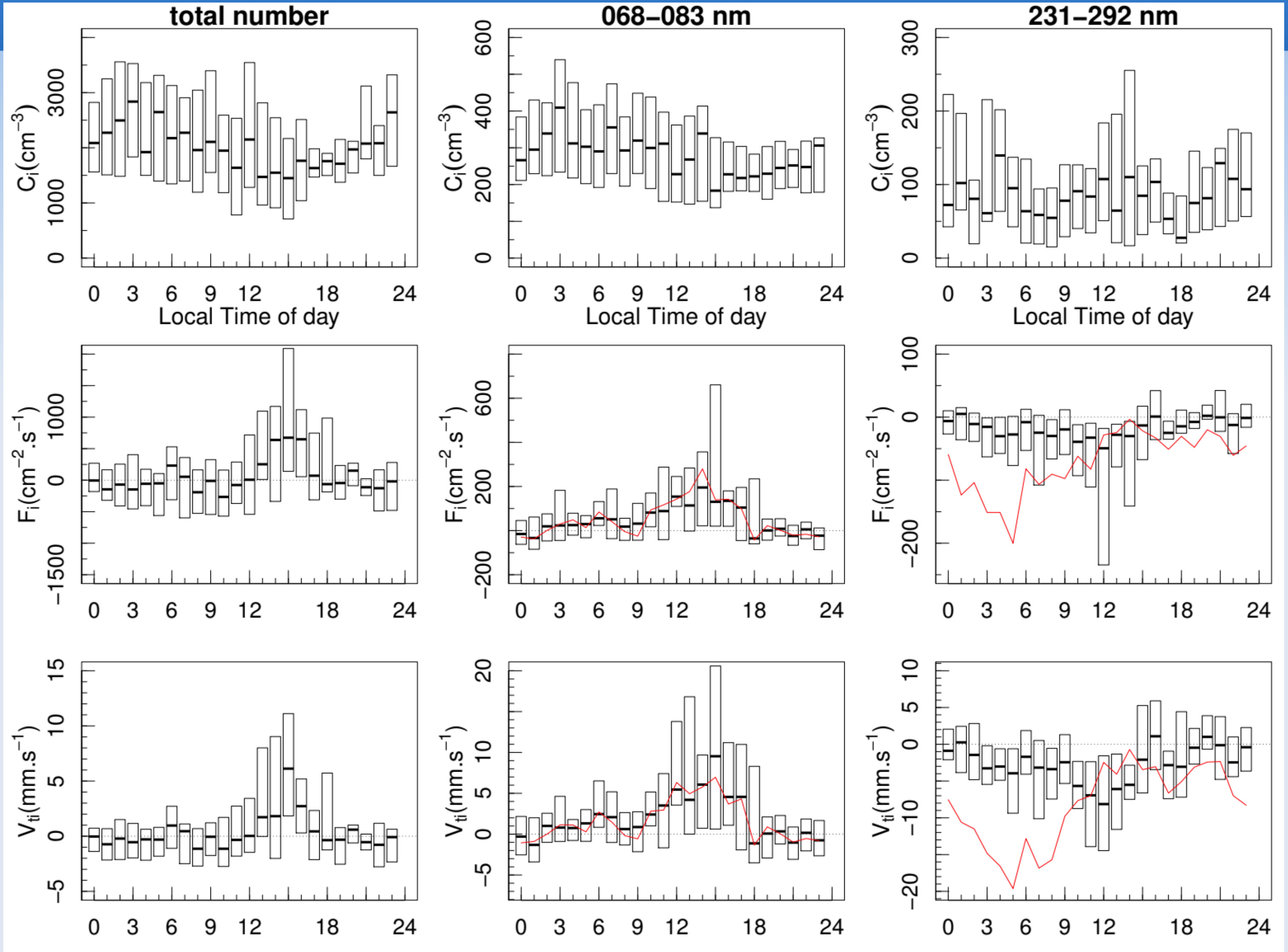
Eddy-correlation measurements 10 m above the forest crown

UHSAS spectrometer at 10 Hz
50 nm – 1 micron

Aerosol composition
Low-pressure impactor



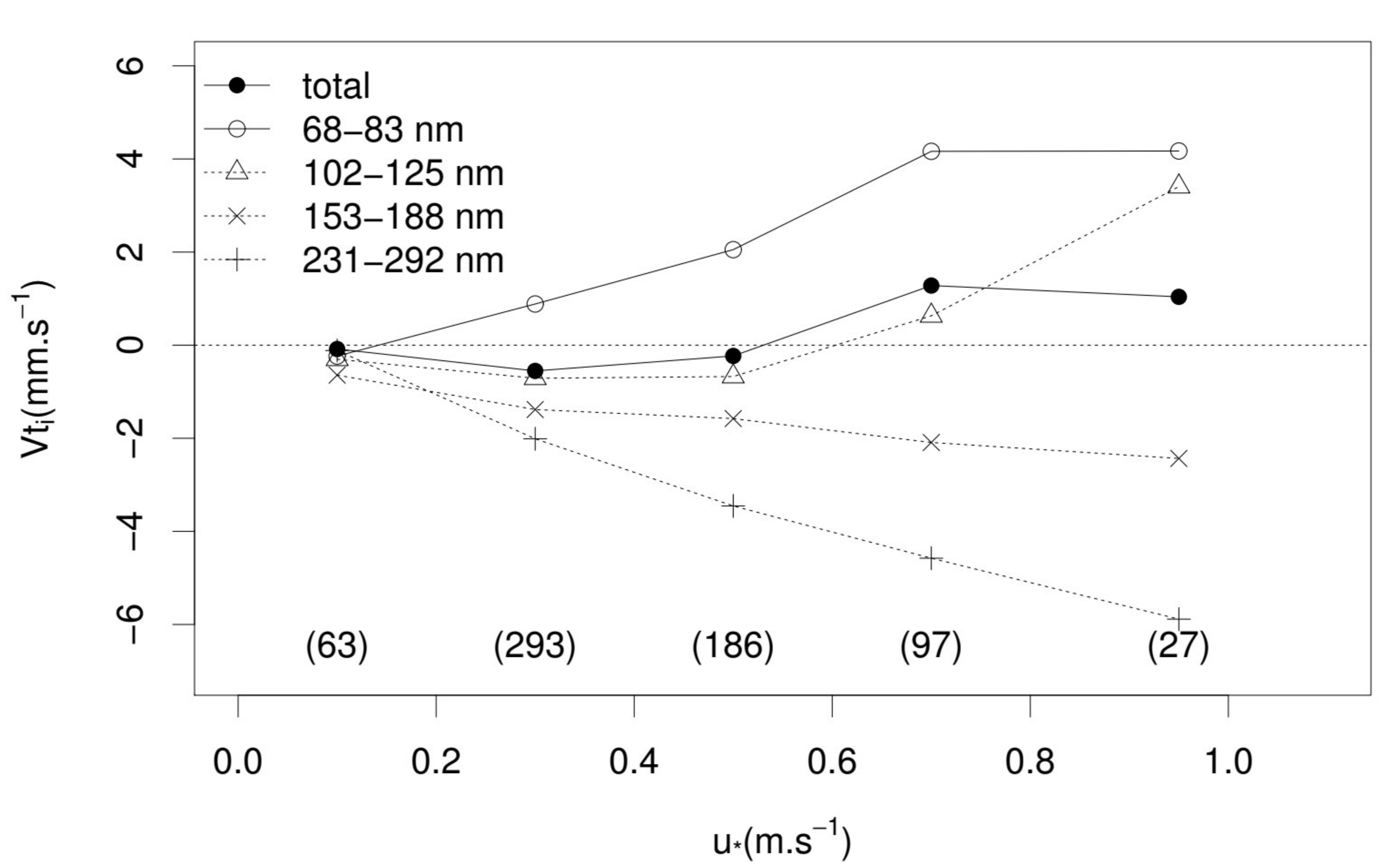
Diel cycles of concentration, flux and transfert velocity



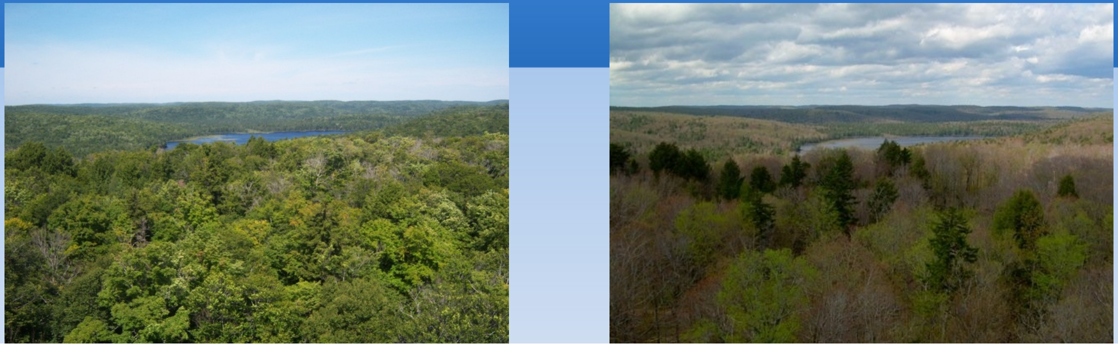
A. Petroff, J.G. Murphy, S.C. Thomas, J.A. Geddes, Atmospheric Environment 190 (2018) 359–375

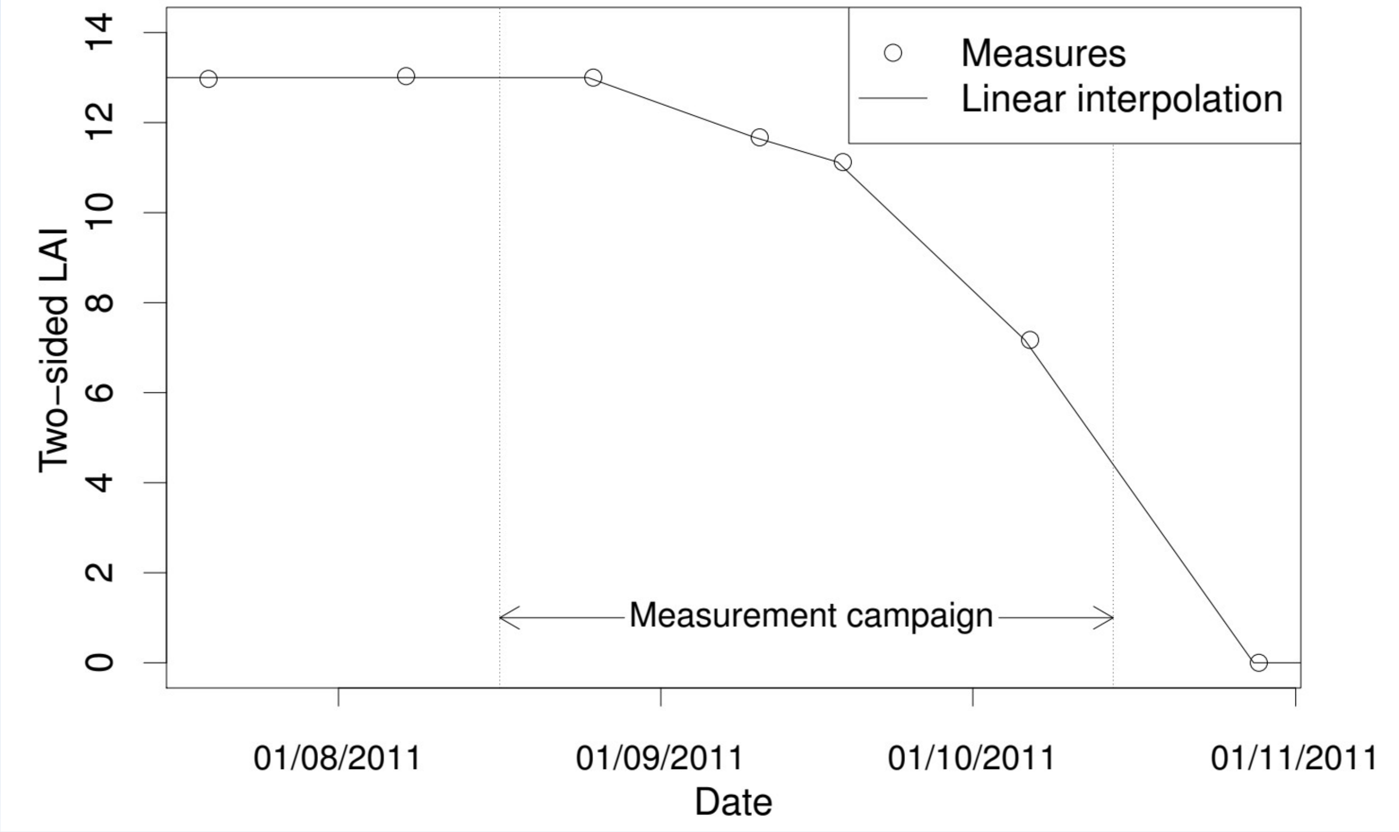
Friction velocity is a key driver of aerosol transfer

But there is a co-existence of processes leading to apparent emission or deposition



2 months campaign extending in the autumn : observation of leaf senescence

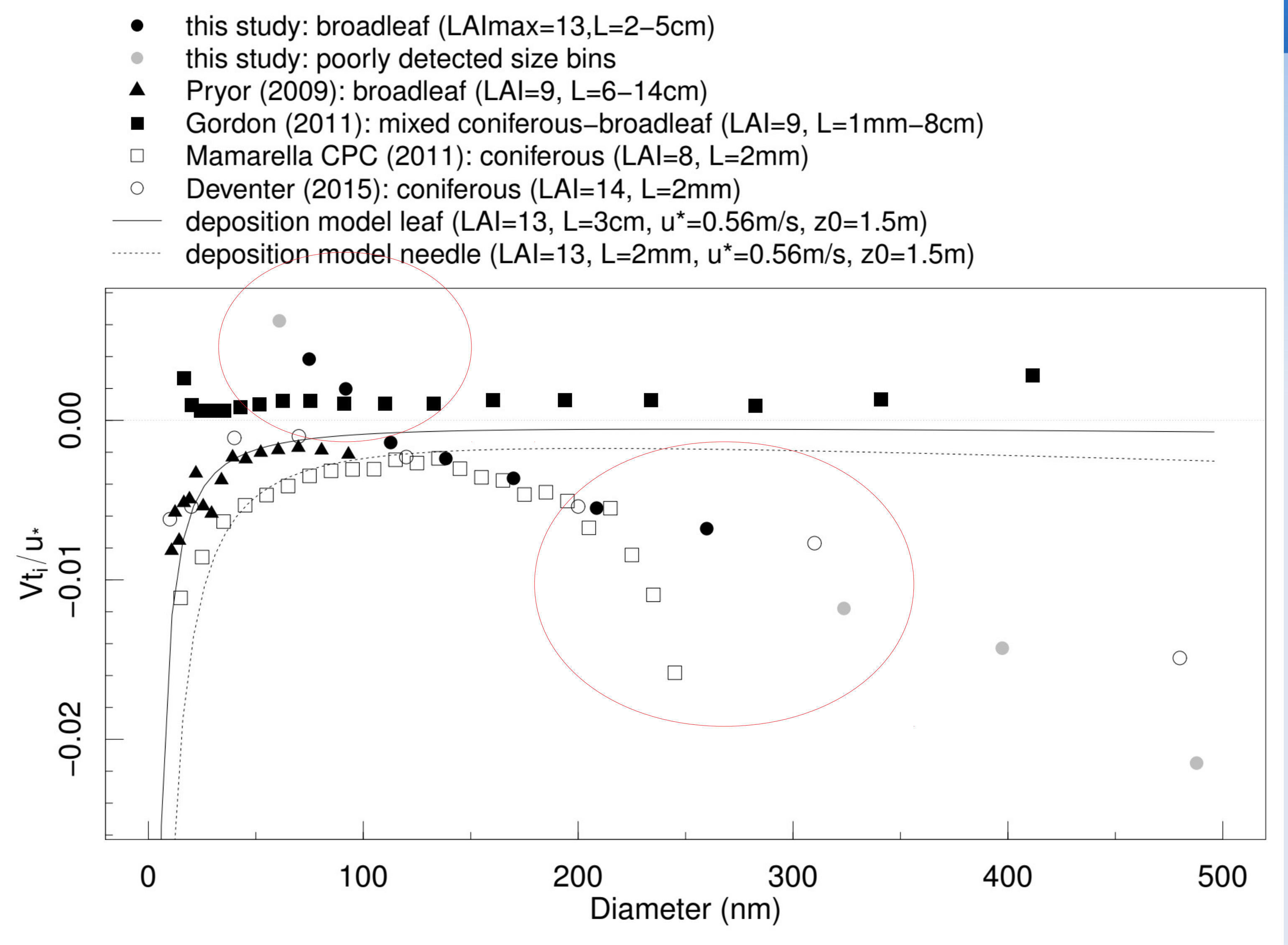




More leaves → more downward fluxes → more deposition

Size bin	Vt_i LAI $\in [5;11[$	Vt_i LAI$\in [11;13]$	p-value (Signif. level)	$\frac{\Delta Vt_i}{Vt_i}$ (%)	$\frac{\Delta Vt_{modi}}{Vt_{modi}}$ (%)
total count	0.09 (285)	-0.56 (384)	$4\ 10^{-4}$ (***)	312.4	NA
55-068 nm	2.62 (327)	1.79 (432)	0.018 (*)	39.4	42.2
68-083 nm	1.47 (288)	1.24 (376)	0.031 (*)	16.7	43.2
83-102 nm	1.12 (239)	0.39 (274)	0.111 ( )	103.3	41.4
102-125 nm	-0.02 (223)	-0.83 (256)	0.004 (**)	173.1	43.2
125-153 nm	-0.39 (223)	-1.26 (277)	$2\ 10^{-4}$ (***)	100.3	40.1
153-188 nm	-1.04 (232)	-1.75 (305)	$3\ 10^{-4}$ (***)	49	41.3
188-231 nm	-1.65 (227)	-2.51 (294)	0.011 (*)	39.5	34.9
231-292 nm	-2.53 (222)	-2.90 (305)	0.098 (.)	14.1	39.2
292-359 nm	-3.14 (239)	-7.21 (324)	$2\ 10^{-6}$ (***)	86.6	33.6
359-440 nm	-4.74 (265)	-7.68 (330)	0.005 (**)	48	37
440-541 nm	3.89 (300)	-16.65 (378)	$4\ 10^{-9}$ (***)	219.2	37.8
541-664 nm	11.12 (315)	17.91 (380)	$1\ 10^{-5}$ (***)	50.1	40.6
664-815 nm	29.97 (327)	56.04 (191)	$1\ 10^{-5}$ (***)	77.1	52.5
815-1000 nm	37.6 (266)	55.25 (108)	0.278 ( )	44.5	60.7

Comparison with model



Possible origins of the emission mecanisms :

- evolution of the aerosol size distribution, such as rapid oxidation of biogenic volatile organic compounds and growth of freshly nucleated aerosol

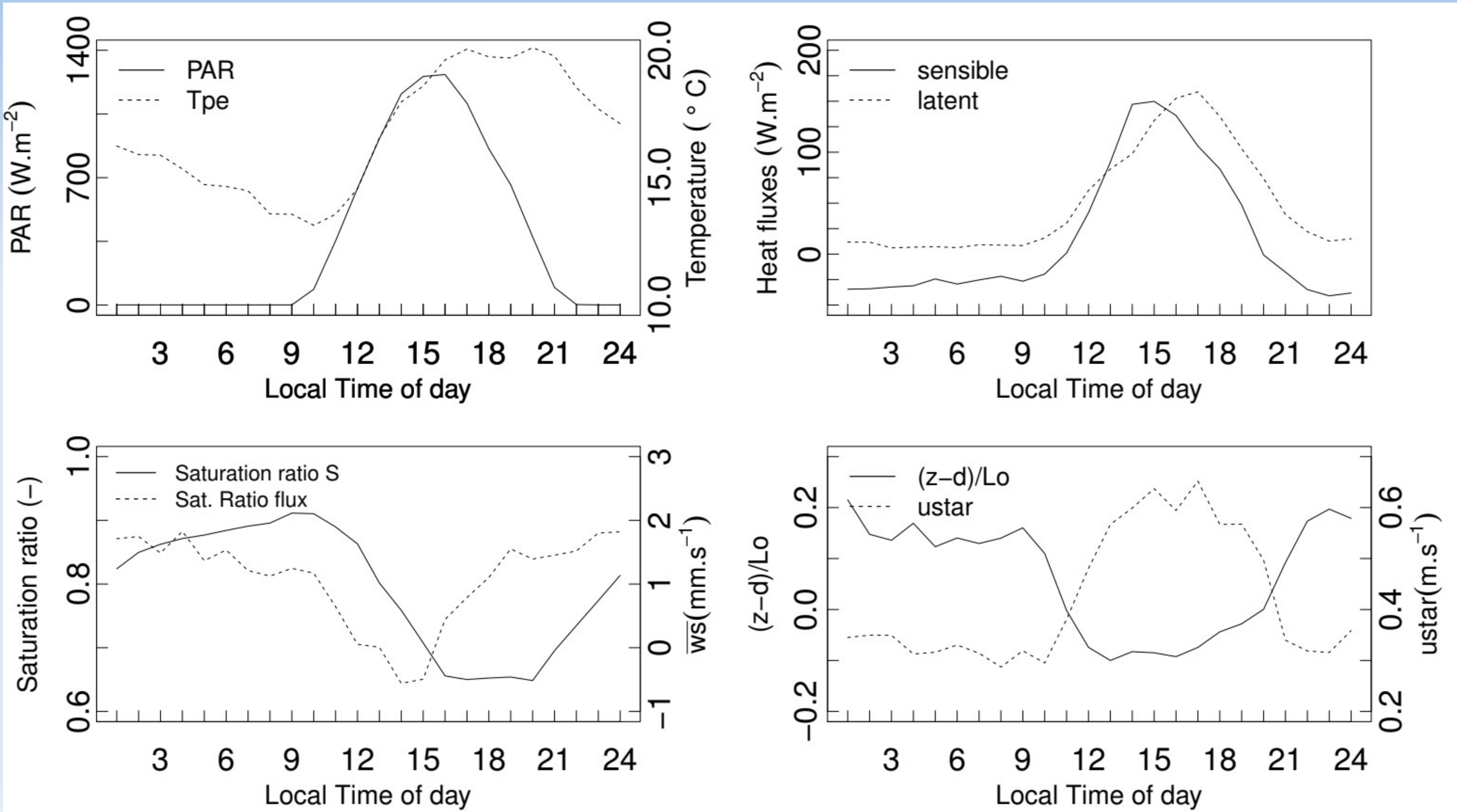
- thermal gradient inside the canopy altering the partitioning of nitrogen forms between gas and liquid forms

- other processes altering the aerosol distribution between the measurement height and the vegetation obstacles : coagulation, agglomeration, fragmentation

Areas of improvements for modelling

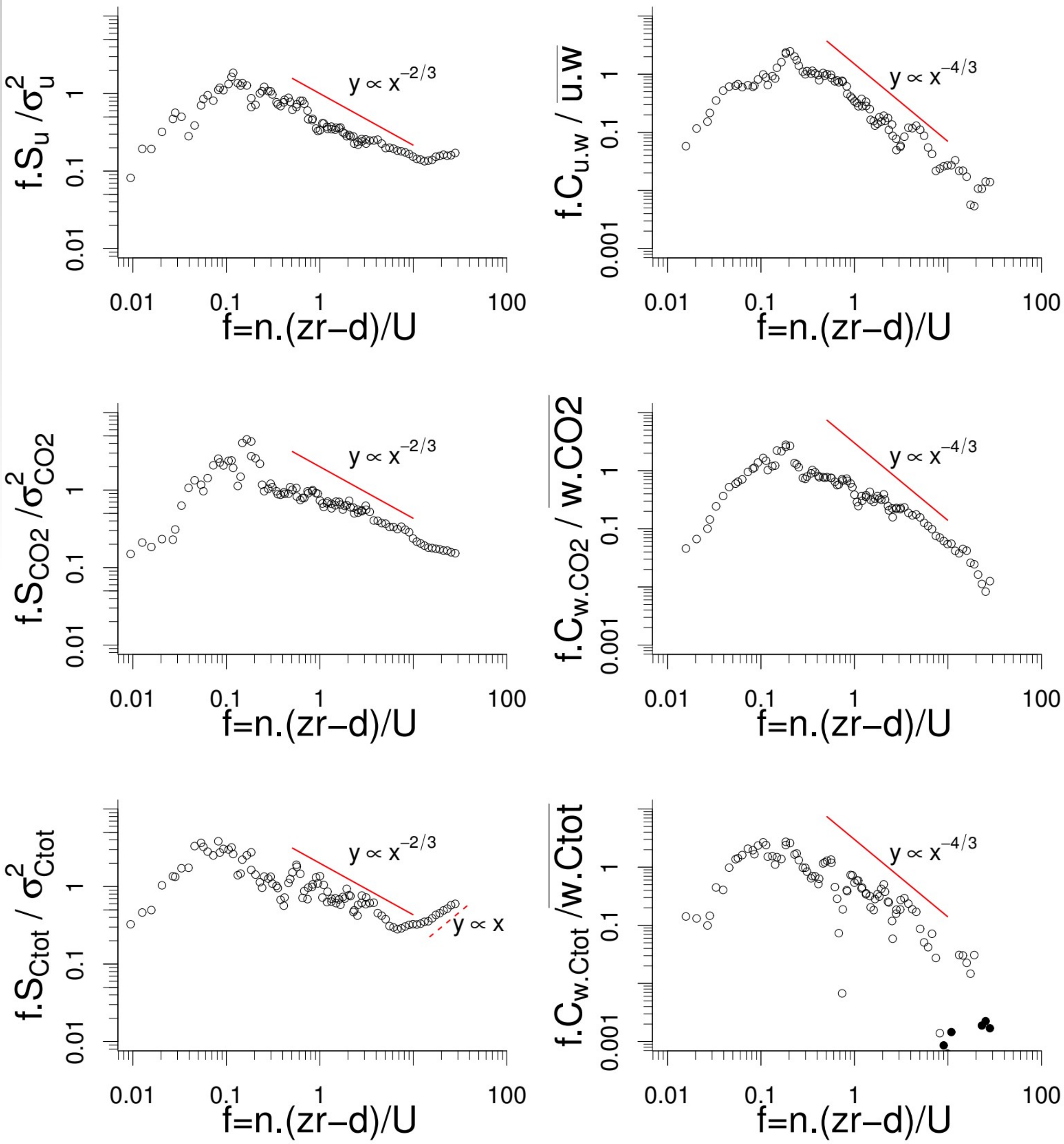
- more realistic description of the turbulence inside the canopy
- Air-particles and particle-particle interactions ….
- Aerosol chemistry, which means gas chemistry, which means dealing with time
- Describing all plant obstacles and their movement (leaf fluttering)
- Other processes, such as interception on leaf microroughness


Thank you for your attention
And thank you, Fabien, for your guidance



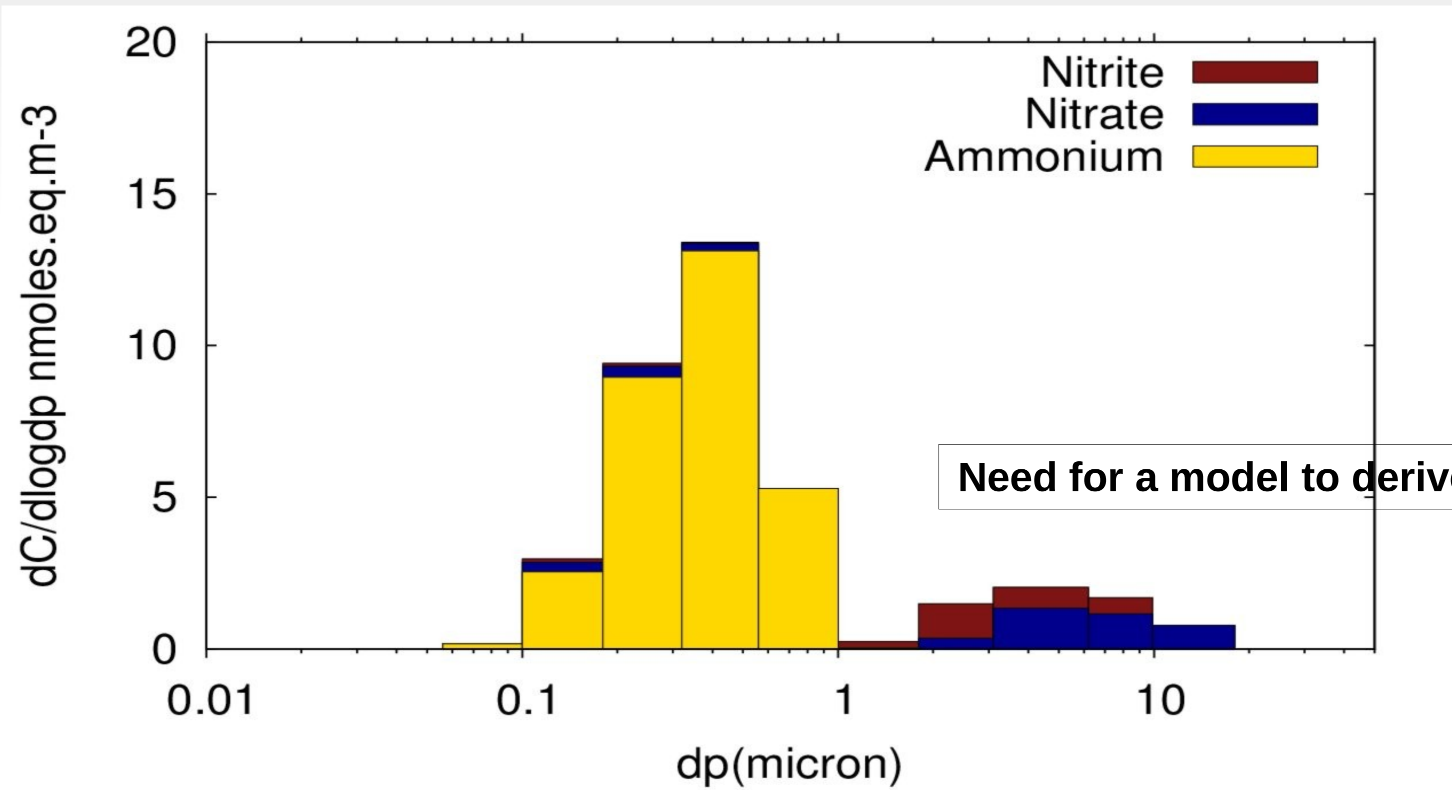
PAR
Tpe
PAR (W.m−2)
Temperature (° C)
1400
700
0
20.0
15.0
10.0
3 6 9 12 15 18 21 24
Local Time of day
sensible
latent
Heat fluxes (W.m−2)
200
100
0
Local Time of day
Saturation ratio S
Sat. Ratio flux
Saturation ratio (−)
ws(mm.s−1)
1.0
0.8
0.6
3
2
1
0
−1
Local Time of day
(z−d)/Lo
ustar
(z−d)/Lo
ustar(m.s−1)
0.2
0.0
−0.2
0.6
0.4
0.2
Local Time of day

Power spectra and cospectra



Nitrogen species
Ensemble median (15 samples)

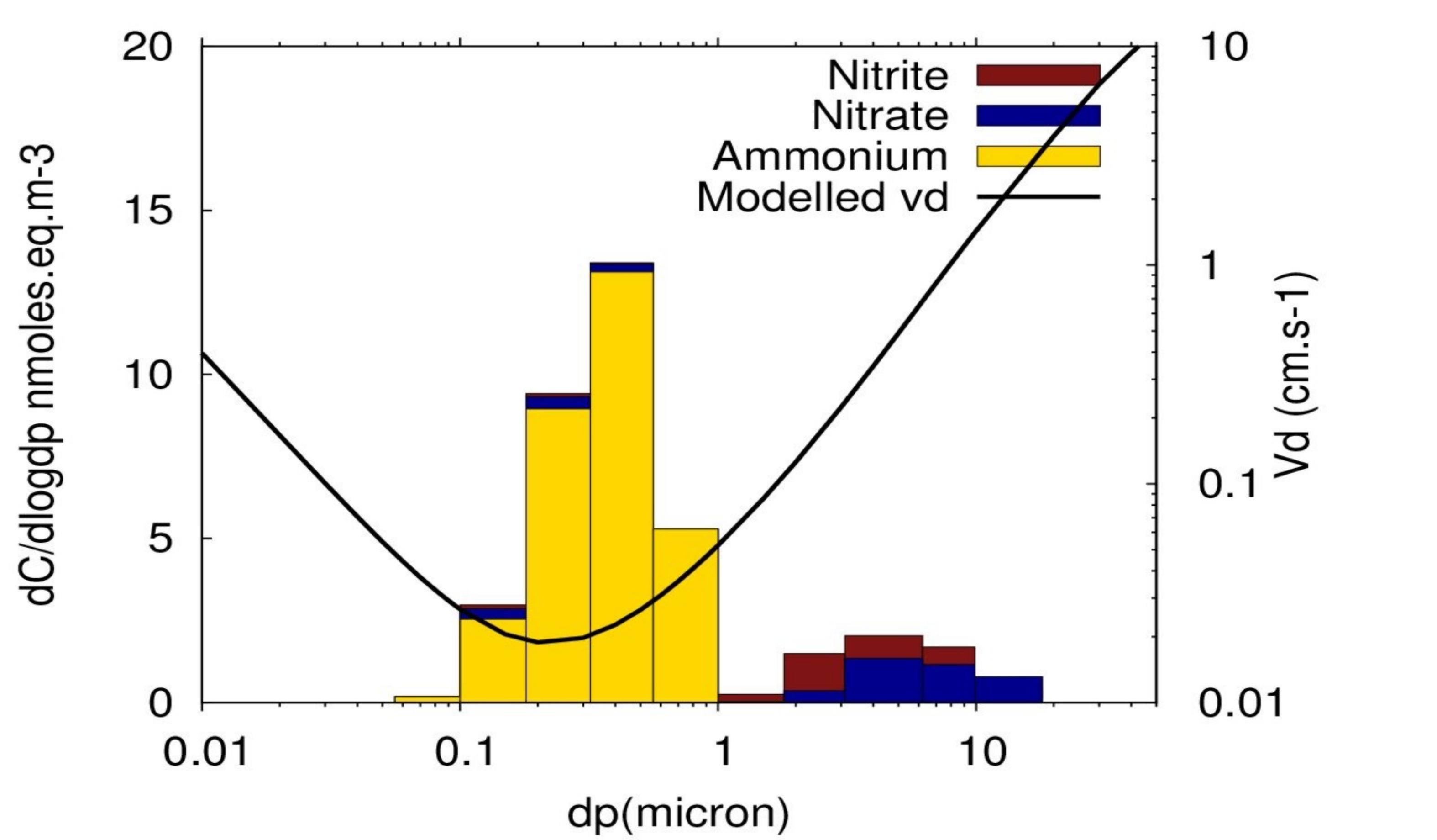
Ammonium fills 77% of the mass, mostly in the accumulation mode
Nitrate fills 12% of the mass, mostly in the coarse mode
Nitrite fills the rest, mostly in the coarse mode



Need for a model to derive the flux !

Particulate deposition

Inefficient deposition of the accumulation mode (vd ~ 0.2 mm/s)
1 order of magnitude between accumulation mode and coarse mode



Nitrogen fluxes

Ammonium represents only **18%** of the deposition flux
Nitrate represents **52%** of the flux
Nitrite represents **30%**