Les traits d'histoire de vie de la bactérie phytopathogène et glaçogène *Pseudomonas syringae*:

un lien entre l'agriculture et les processus atmosphériques

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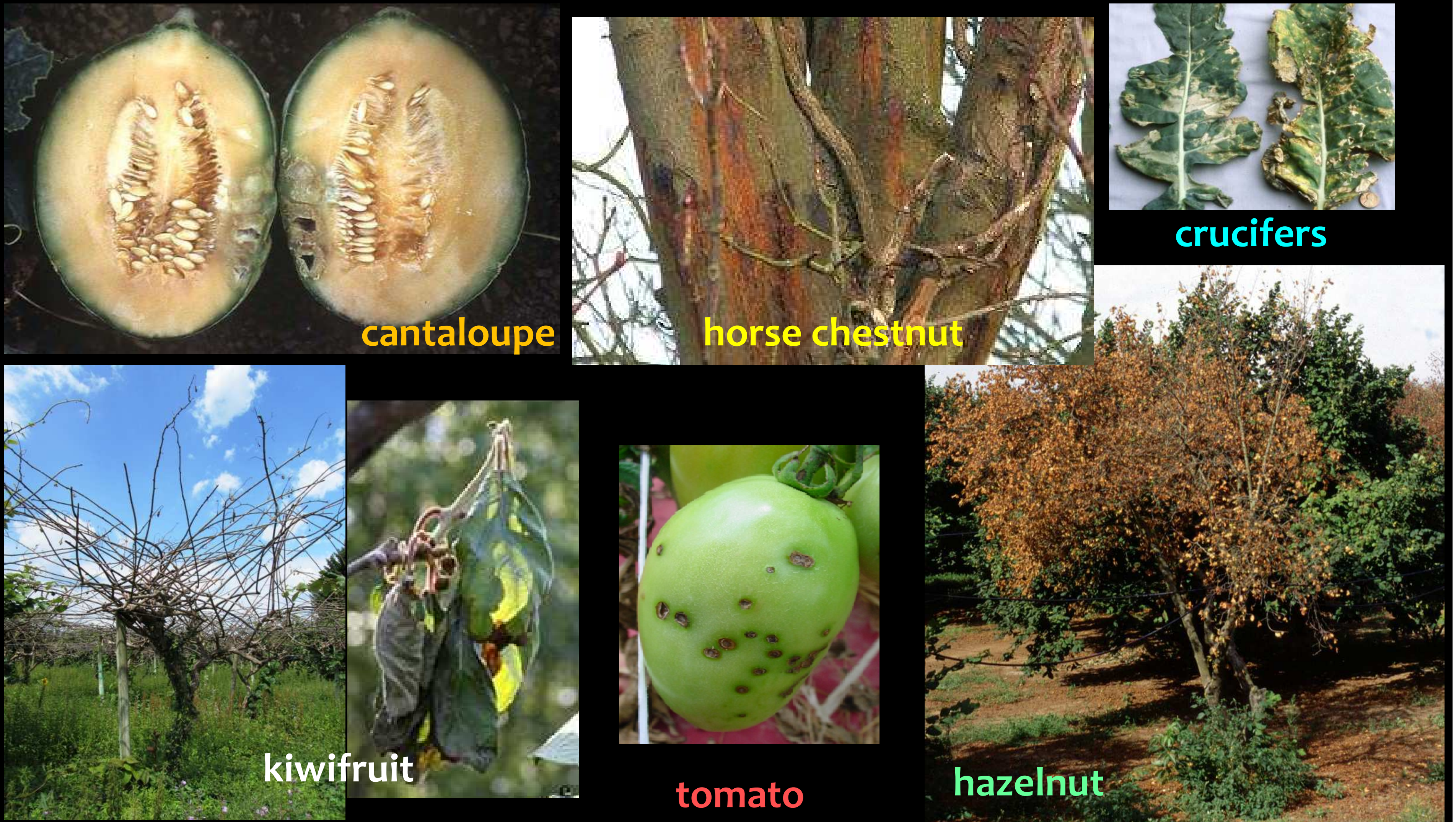
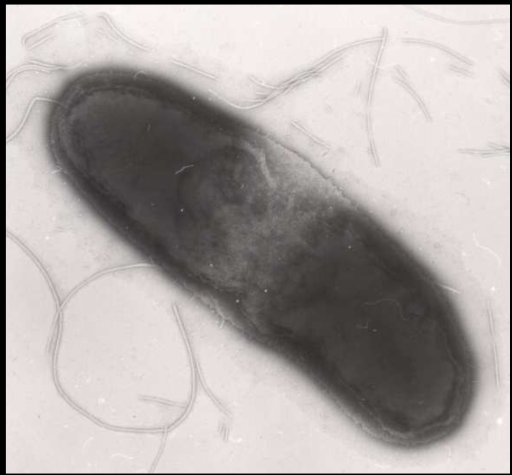
INRA SCIENCE & IMPACT

Pseudomonas syringae, an important plant pathogen



Aspects of the ecology of *P. syringae* suggest it is ubiquitous in the environment …….



- Ubiquitous epiphyte
- Cool weather opportunist
- Multiple means of dissemination including airborne
- Ice nucleation active

(*watch INA movie*)

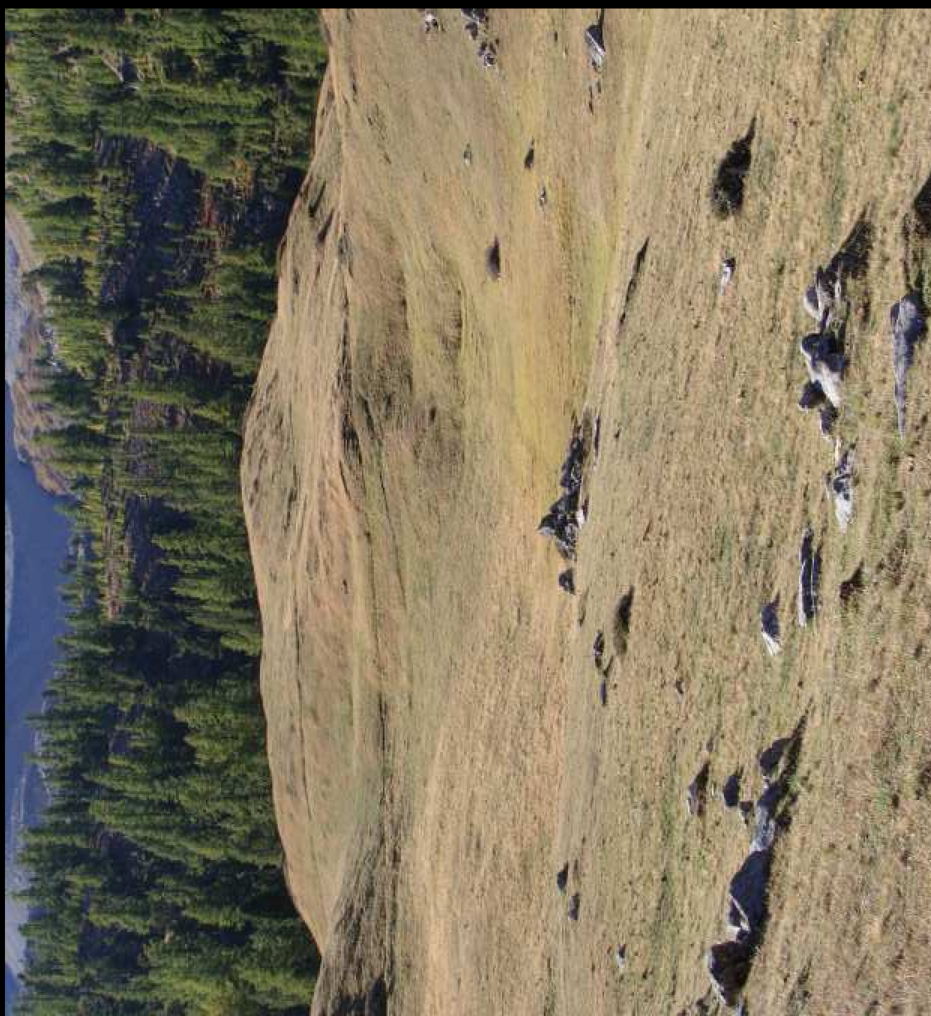


Are there habitats of *P. syringae* outside of agriculture?

The search for *P. syringae* beyond agriculture


2800 m, Oetzal Valley, Austria



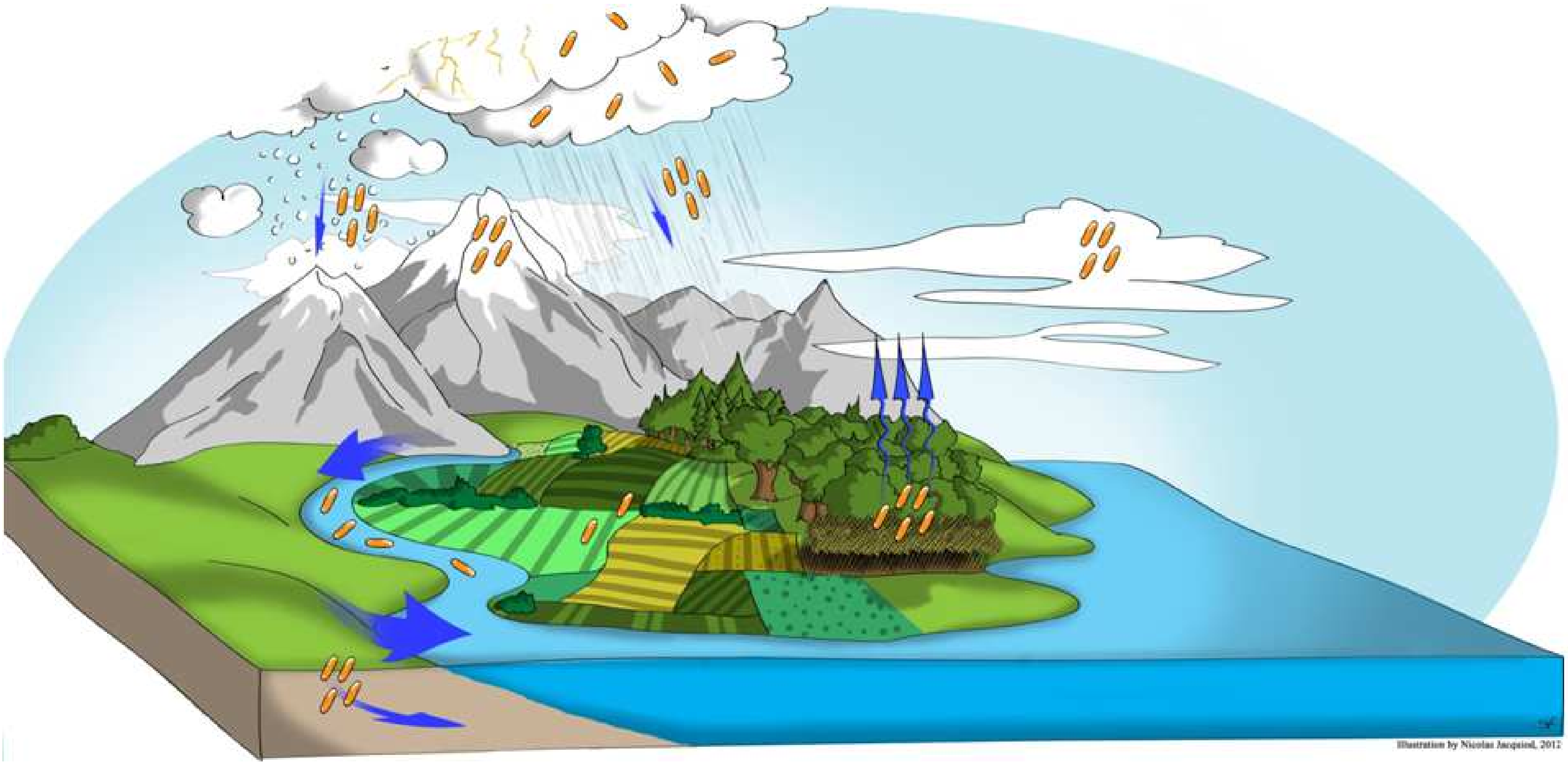



The search for *P. syringae* – agriculture and beyond . . . . .

Crops (reported in the literature)	$10^2 – 10^8$ b / leaf (or /g)
Wild plants (healthy)	$500 – 10^7$ b / g
Cloud water (Sands 1982; Amato et al 2007)	ca. 10^4 b / L
Rain	$100 – 10^4$ b / L
Snow	$100 – 10^5$ b / L melt water
Leaf litter in alpine prairies	10^8 b/m2 of ground cover
Alpine lakes and rivers	$100 – 10^4$ b / L
Irrigation water basins	12 – 70 b / L
Epilithic biofilms in rivers	$50 – 10^4$ b / g
Aerosols (Lindemann et al 1982)	↑ 30 b / m^2 / sec

The life history of *P. syringae* is linked to the water cycle

P. syringae inhabits multiple substrates associated with the water cycle and is disseminated among them.



Morris et al. 2008. The life history of the plant pathogen *Pseudomonas syringae* is linked to the water cycle. *ISME Journal* 2:321-334.

New lessons about *P. syringae* ecology from an expanded view of its life history

1. "Natural" environments and non-plant substrates can be significant reservoirs of *P. syringae.*

2. Hydrological and atmospheric circulation transport *P. syringae* over large spatial scales.

3. Pandemic populations are disseminated over long ranges and co-exist with endemic populations.

4. Genetic diversification of *P. syringae* occurs in environmental reservoirs.

5. Ice nucleation activity links pathogen dissemination and evolution – with potential impact on the water cycle

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2. Dissemination with atmospheric circulation and the water cycle

P. syringae trajectory:

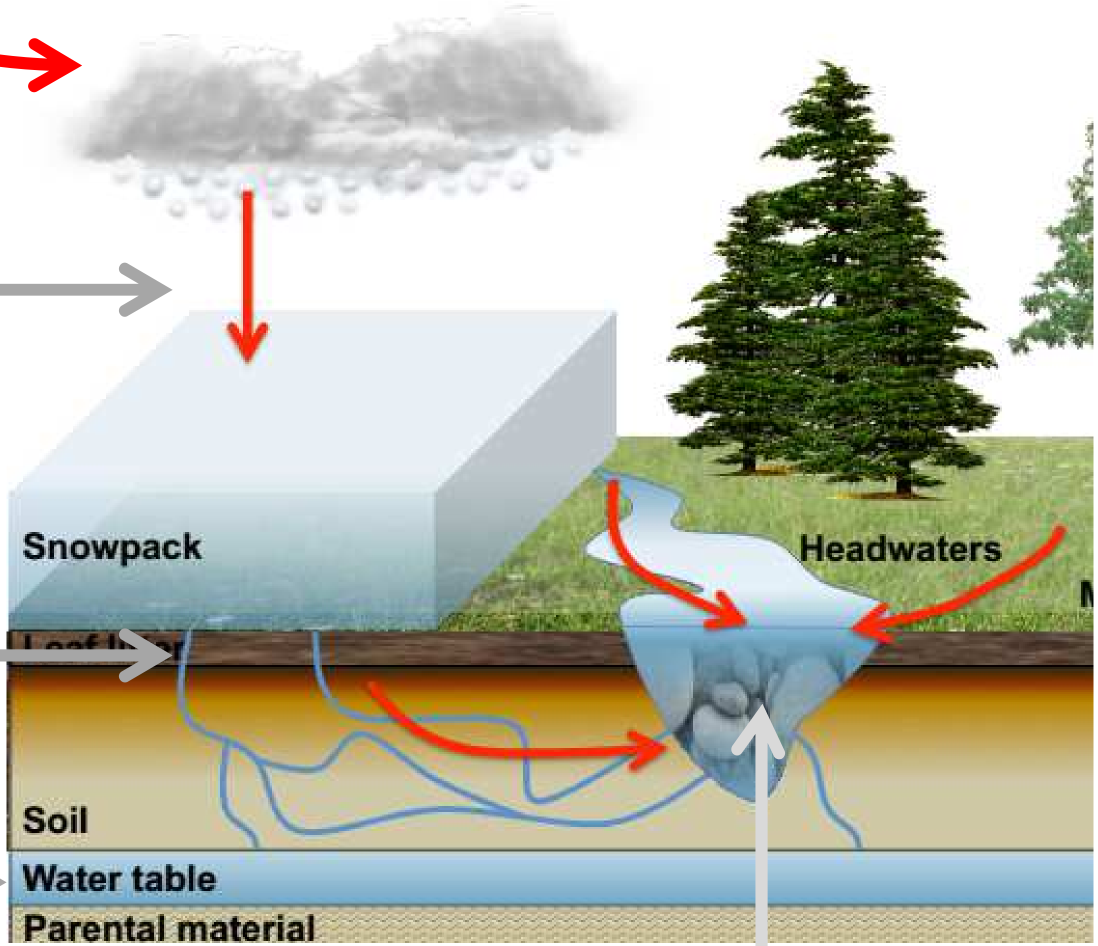
Clouds

Precipitation

Percolation water

Ground water

Rivers

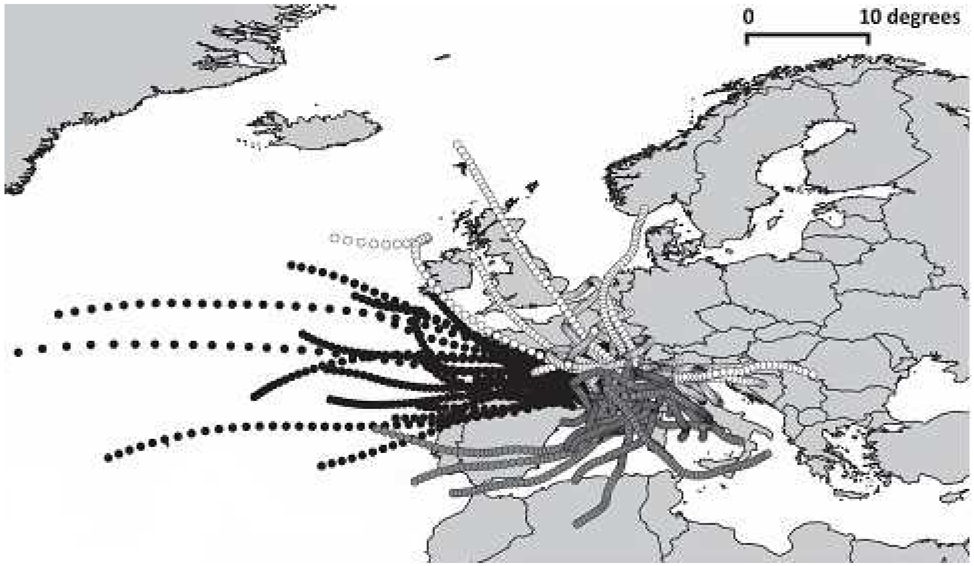


Falling rain and snow carry *P. syringae*, depending on the origin of air masses and precipitation chemistry.

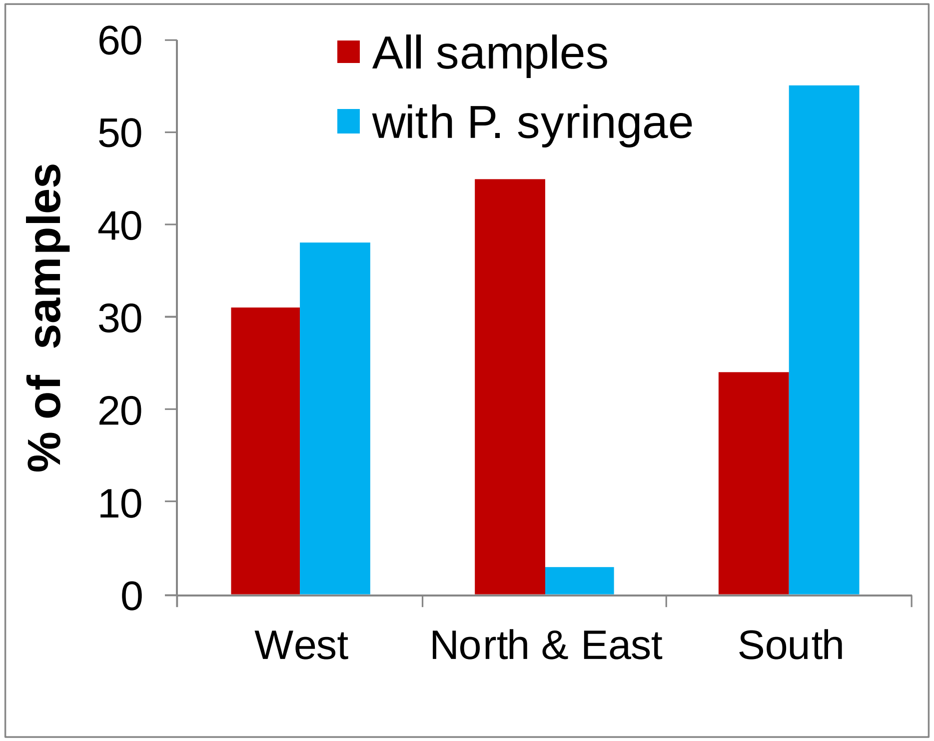
In southern France:

	% w/Ps	*P. syringae* / L
Rain	65.2	500
Snow	12.3	5000

88 precipitation events 2006 - 2010



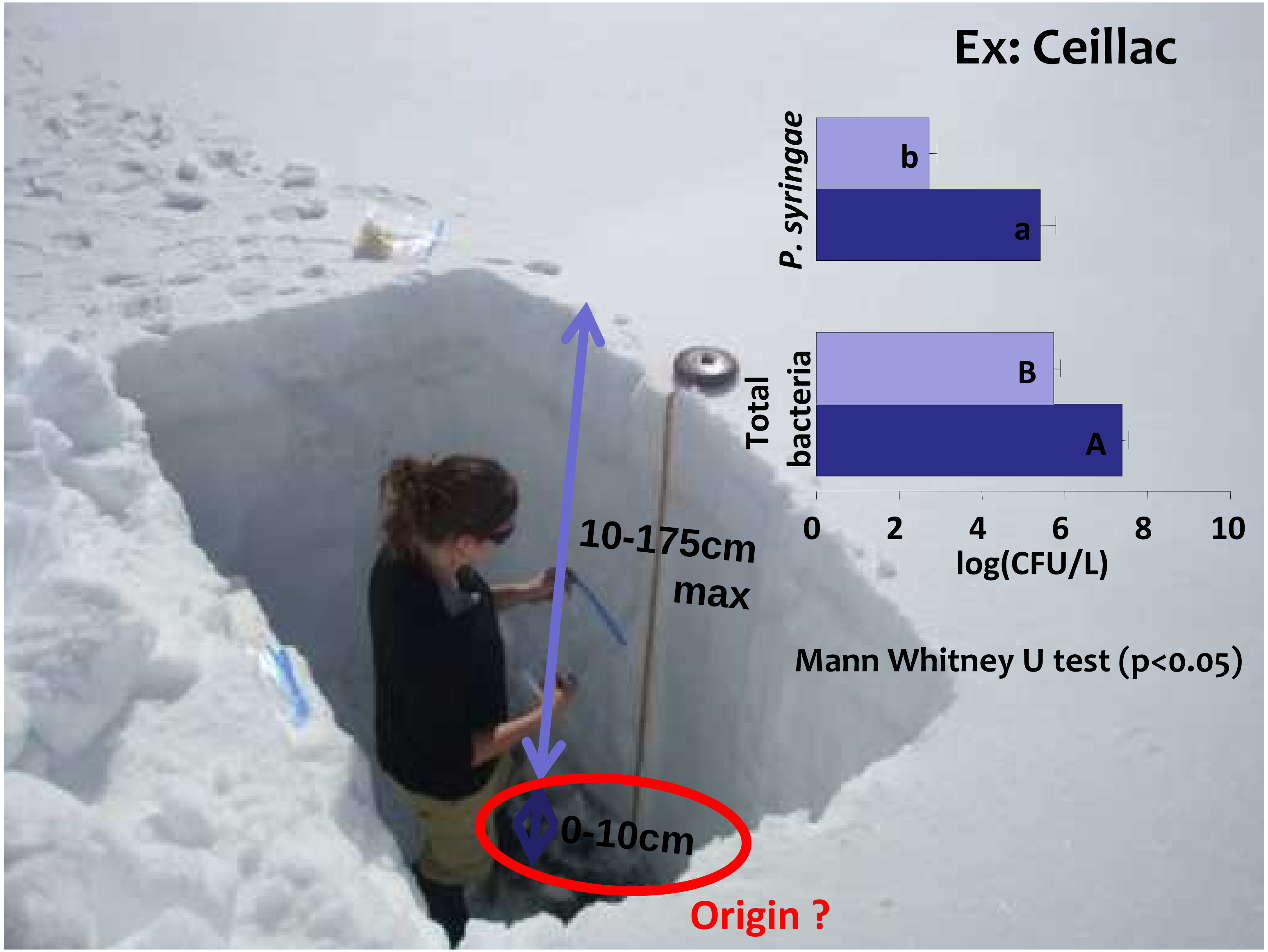
Monteil et al. 2014 *ISME J.* doi:10.1038/ismej.2014.55



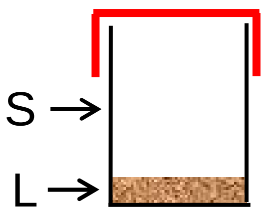
	pH*	Conductivity*
Present	6.21	13 µS.cm^{-1}
Absent	5.76	8 µS.cm^{-1}

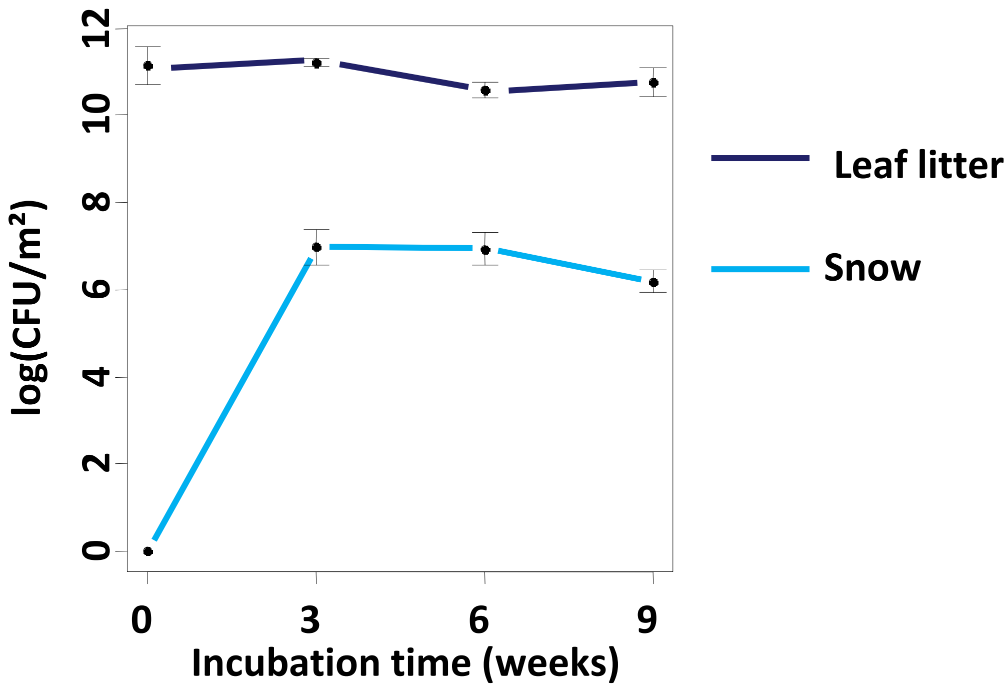
*Mann Witney U test ($p<0.05$)

P. syringae survives in snowpack during the winter
The population density in snowpack is stratified



Emigration of *P. syringae* from litter to snowpack contributes to a stratified population density



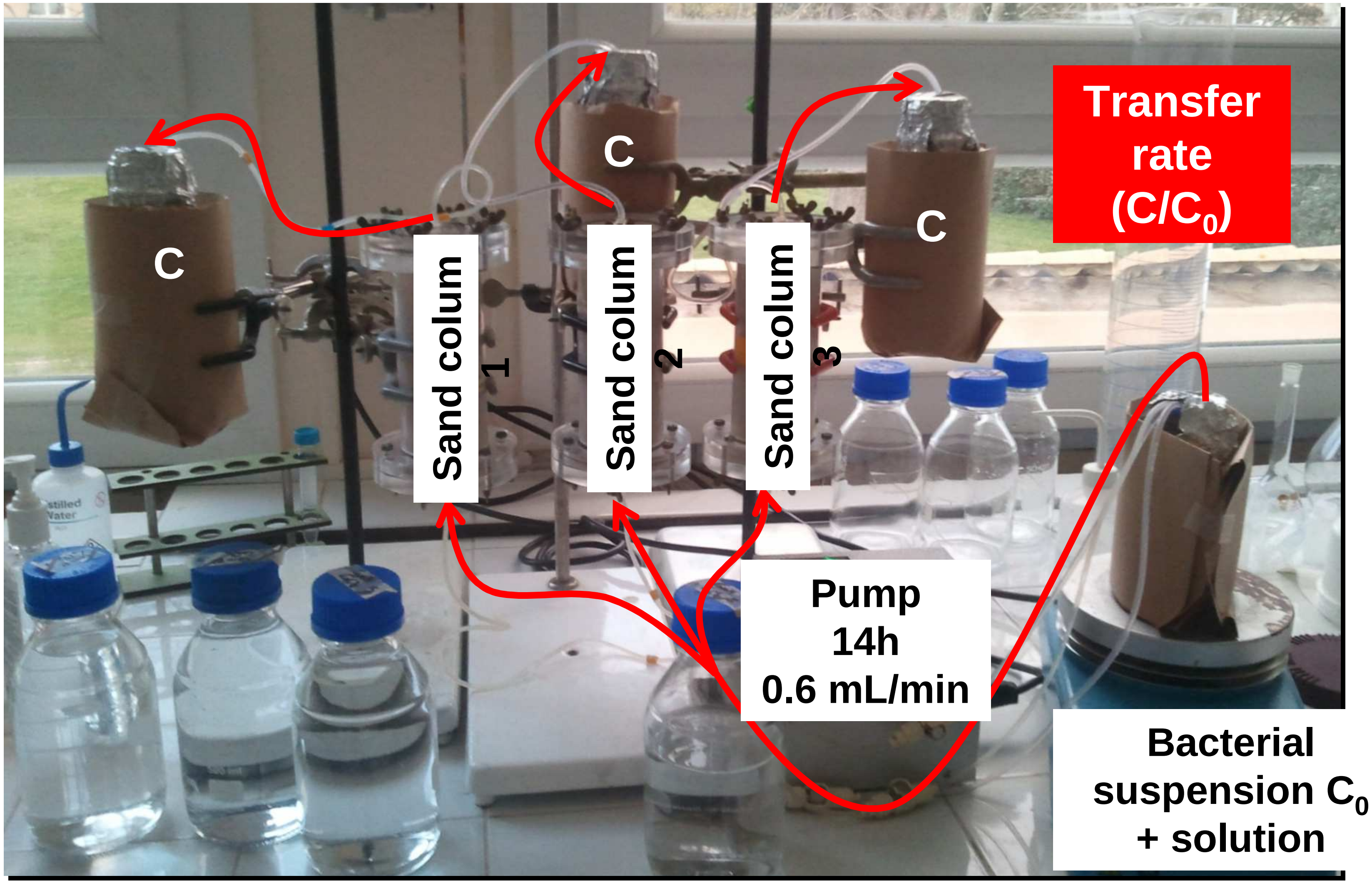


Kruskall Wallis ($p<0.05$)

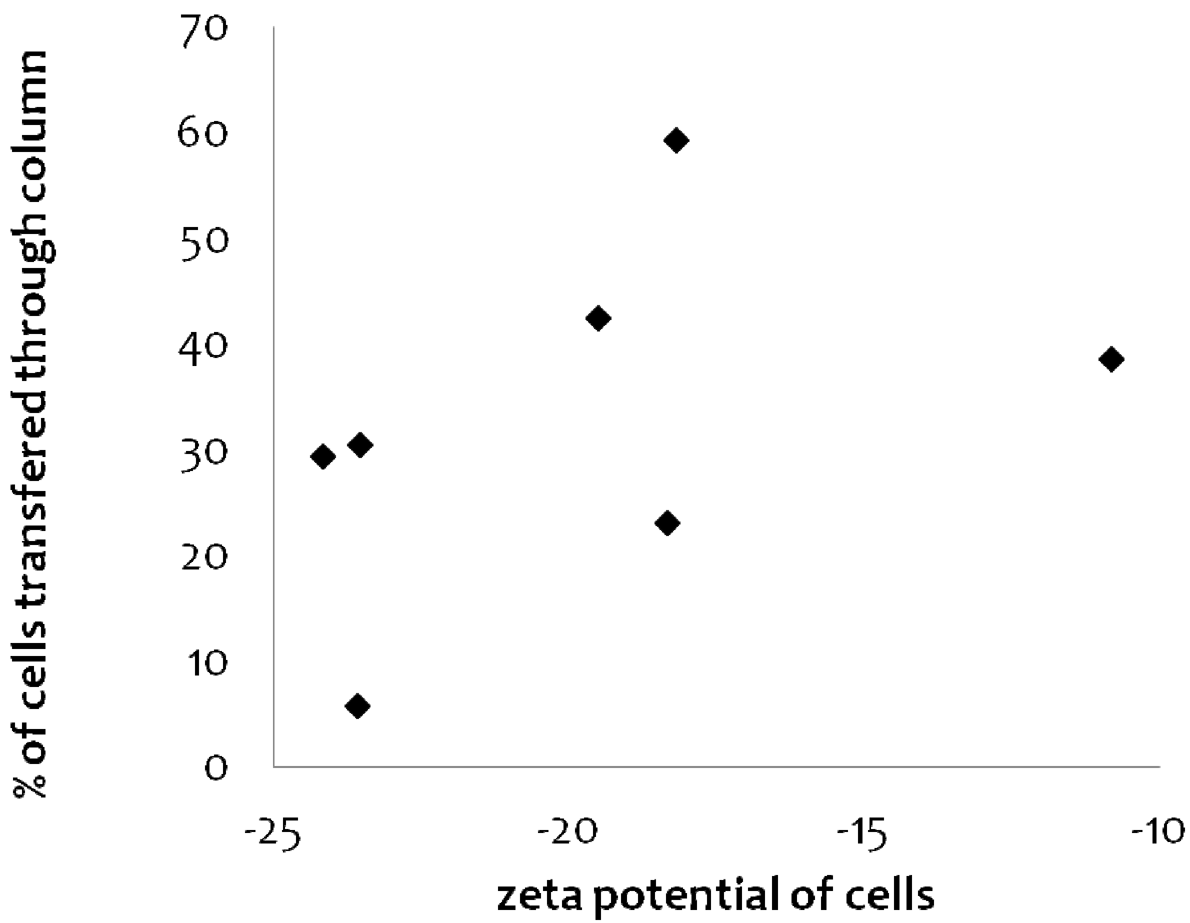
P. syringae passes through the soil into surface and ground waters.

Monteil et al. 2013
Environ. Microbiol. **16:**2038–2052..

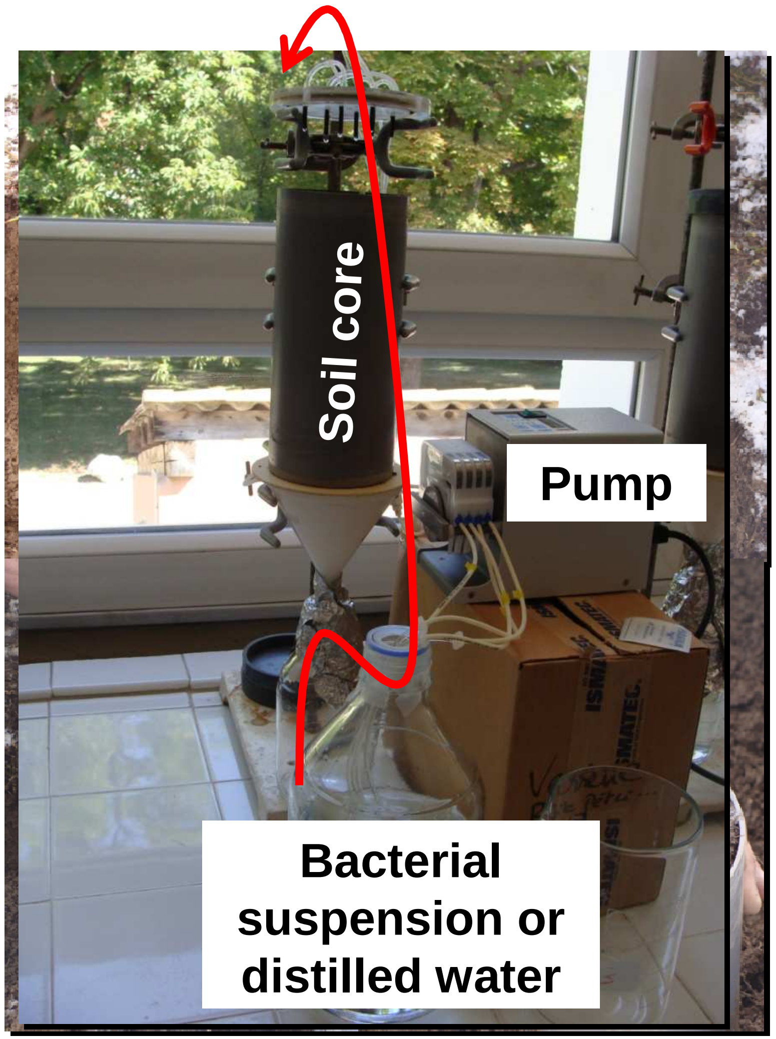
P. syringae transport rate through sand columns



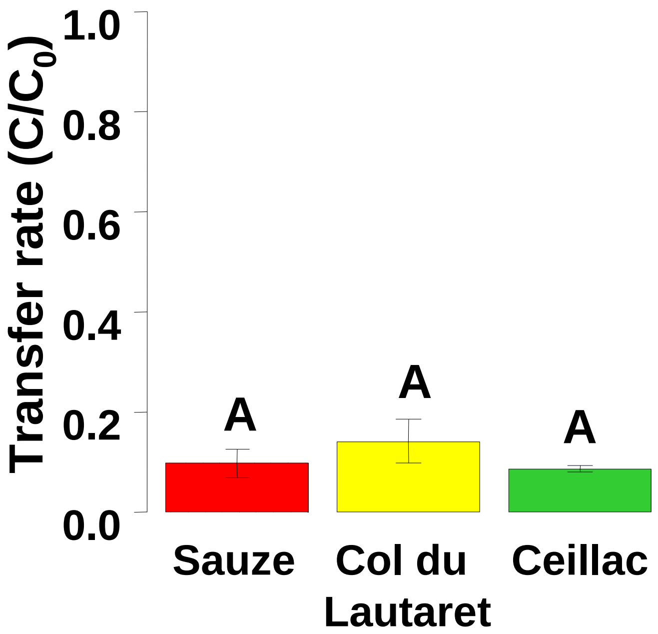
P. syringae transport rate through sand columns: 7 strains representing the rage of zeta potential



The rate of transfer of *P. syringae* through soil columns is comparable to that in sand columns



Strain TA022 resistant to rifamycin



Kruskall Wallis test ($p<0.05$)

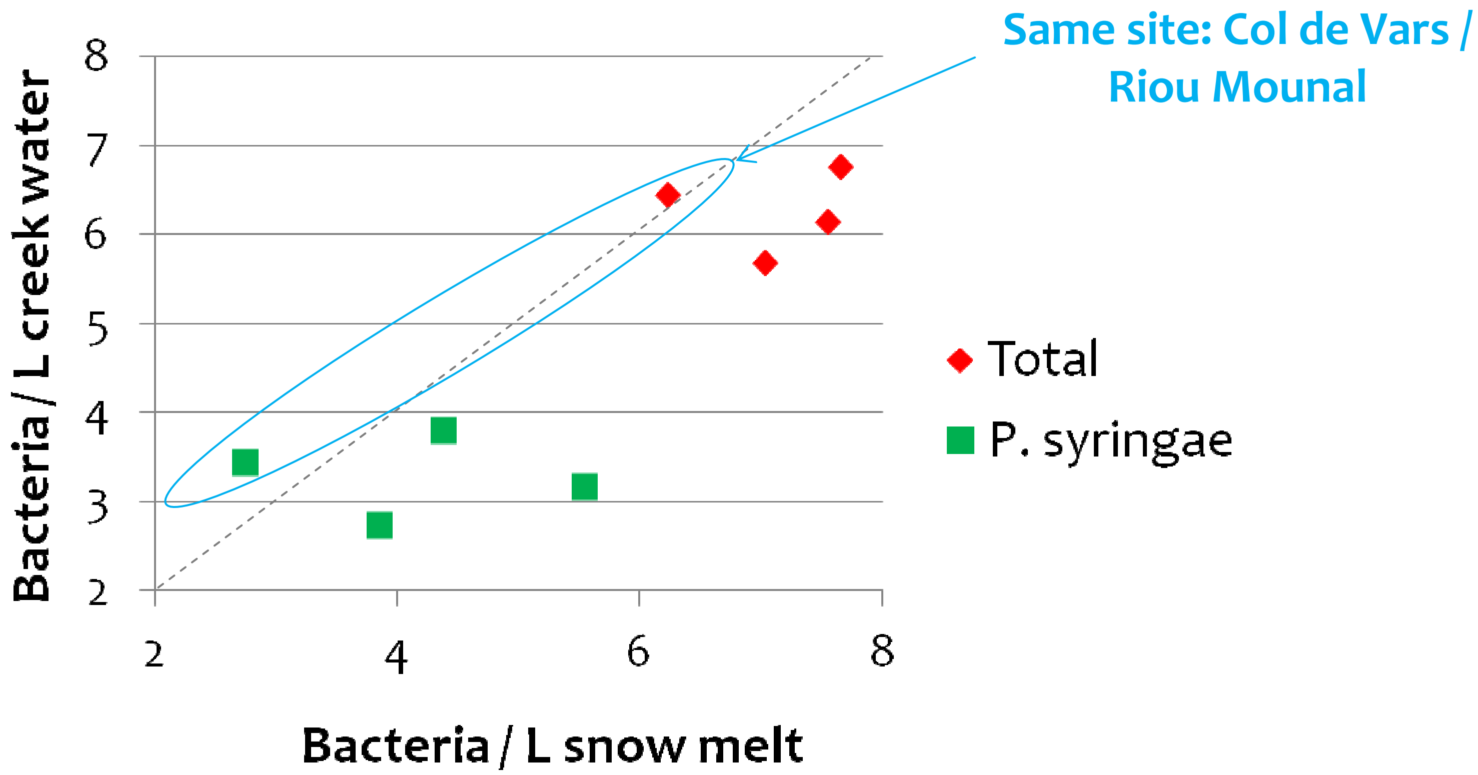
Soil core also leached indigenous *P. syringae*

Concentrations of bacteria in creeks are usually less than those in snowmelt

Catchment basin, creek	Substrate	pH	EC (µs/cm)	Population densities (CFU/L) Total bacteria	*P. syringae*
Ceillac, Pisse					
	Snow	5.62 c	3 e	7.03 a	3.85 bc
	Water	7.90 a	609 a	5.67 dvv	2.73 e
Col de Vars, Riou Mounal					
	Snow	5.40 bcd	4 de	6.23 abcd	2.74 bc
	Water	7.89 a	216 c	6.46 cvv	3.43 ce
Col du Lautaret, Roche Noire					
	Snow	6.30	6	7.55 a	5.54 a
	Water	7.78 ab	143 d	6.13 bcd	3.16 cde
Super Sauze, Soudane					
	Snow	5.30 d	4 e	7.65 a	4.38 b
	Water	7.88 a	324 b	6.75 bvv	3.79 c

Mann Whitney ($p<0.05$)

Concentrations of bacteria in creeks are usually less than those in snowmelt – but not always



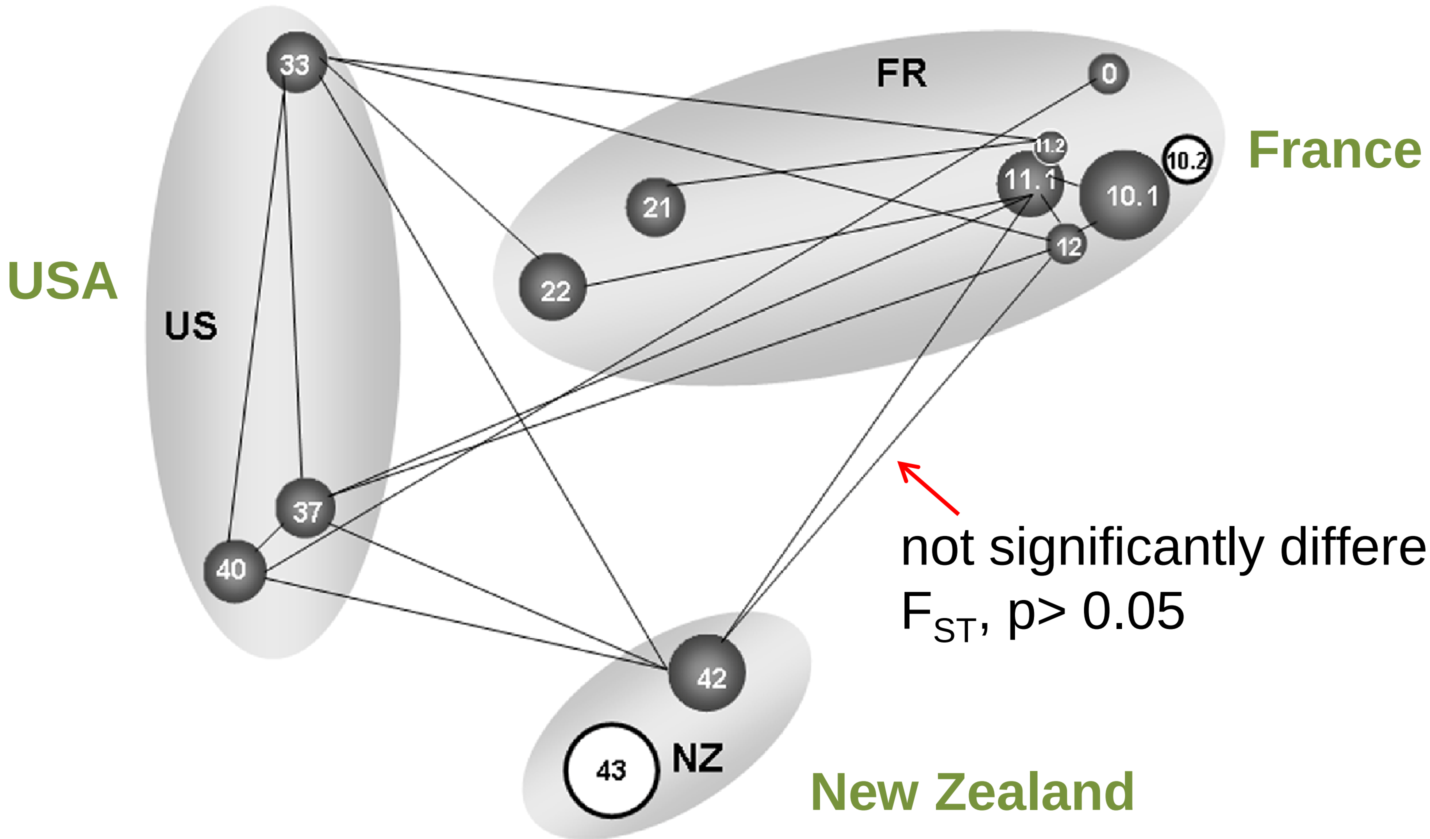
Association of *P. syringae* with the water cycle contributes to pandemic and endemic biogeography

Population structure of *P. syringae* populations in water:

236 strains, 11 sites, 3 continents

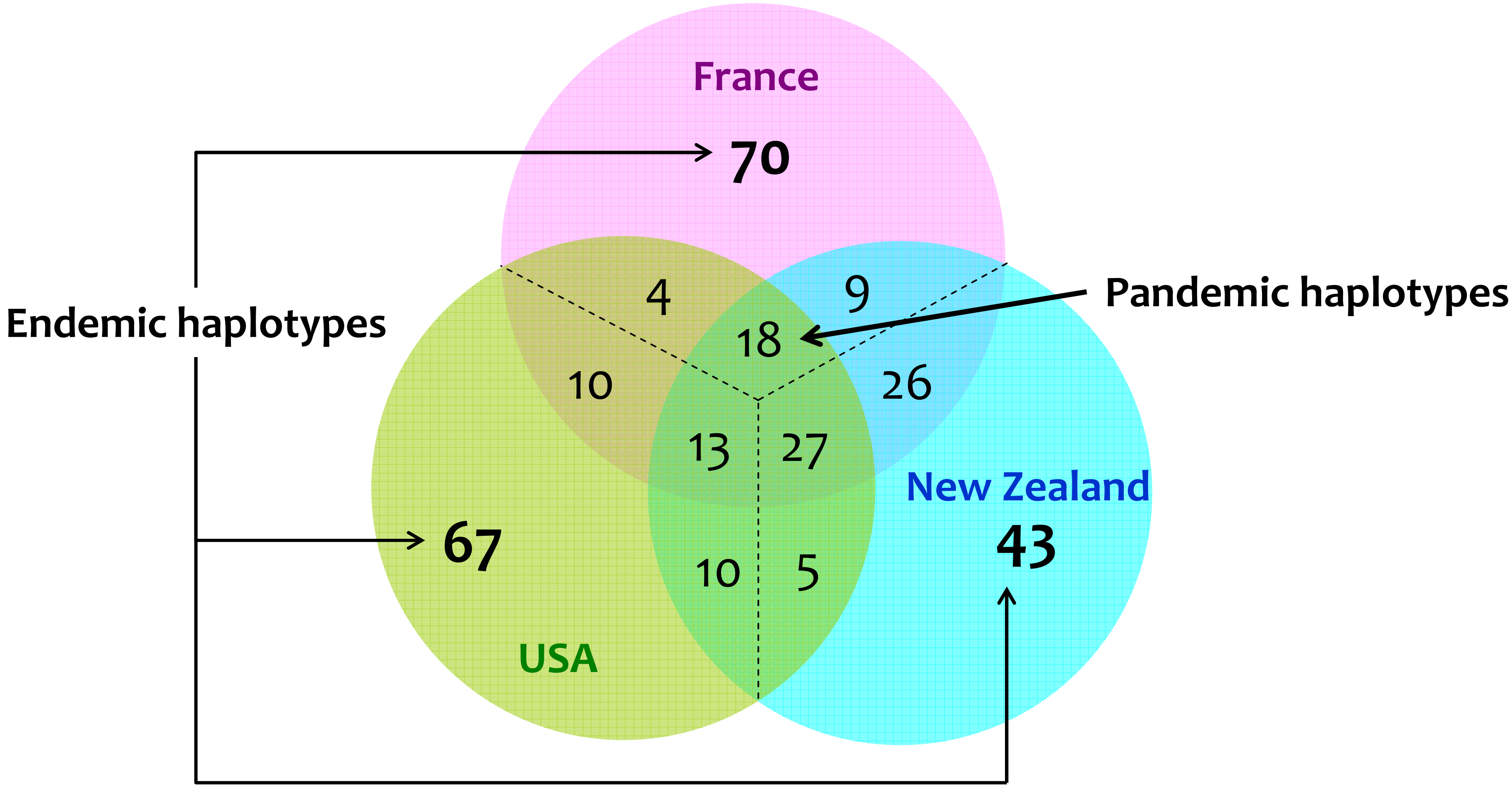
population genetics based on conserved housekeeping genes

Pandemic genetic structure .... ..



not significantly different, F_{ST}, p> 0.05

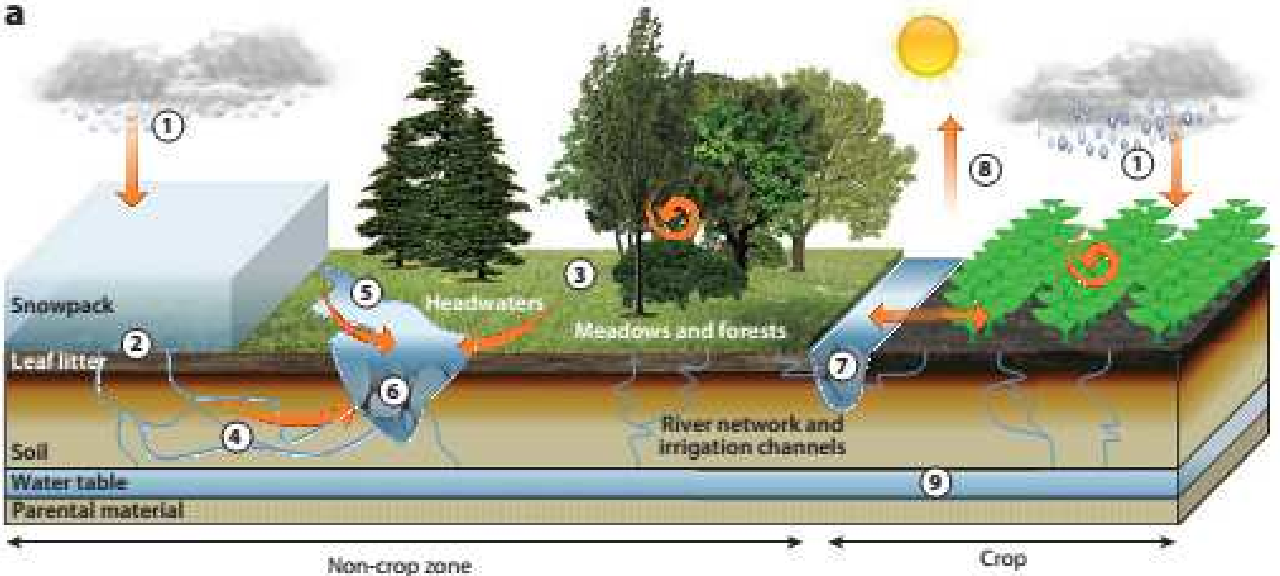
… with an endemic component



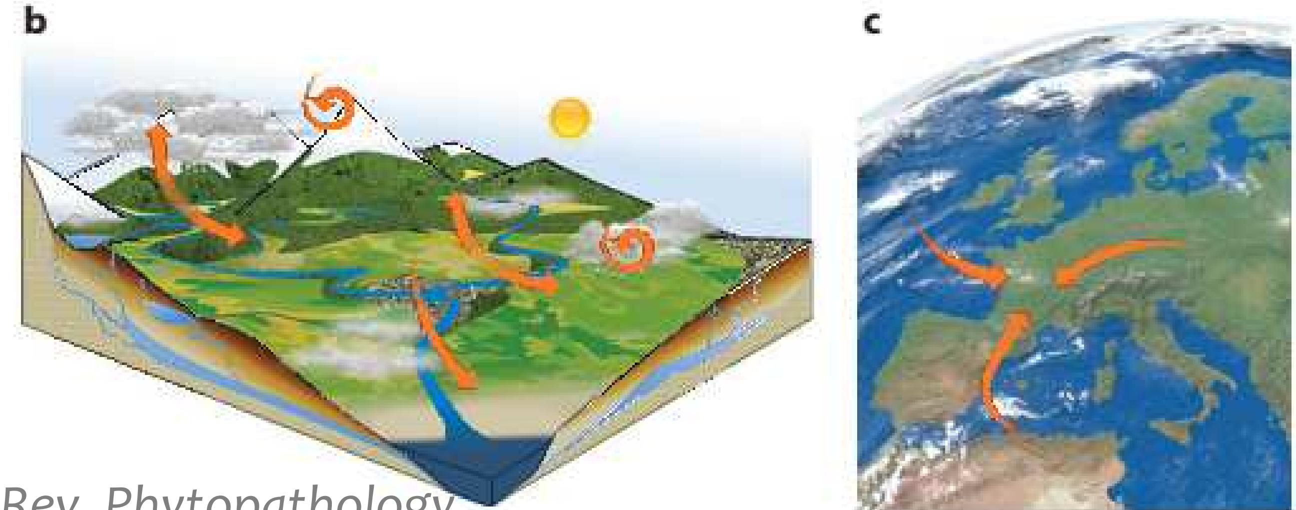
Percent of haplotypes that are unique to each region and in common between regions.

The water cycle links agricultural and natural habitats

at a range of scales



We have detected *Ps* in the water table at 7m depth



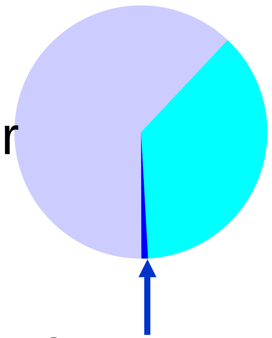
Morris et al. 2013. *Annu. Rev. Phytopathology*

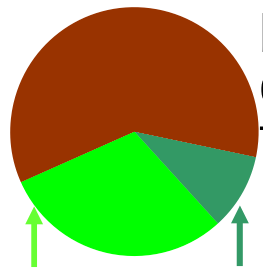
Fresh water: a major reservoir of *P. syringae*

Comparison of metapopulation sizes of *P. syringae*:

fresh-water vs. plant-associated

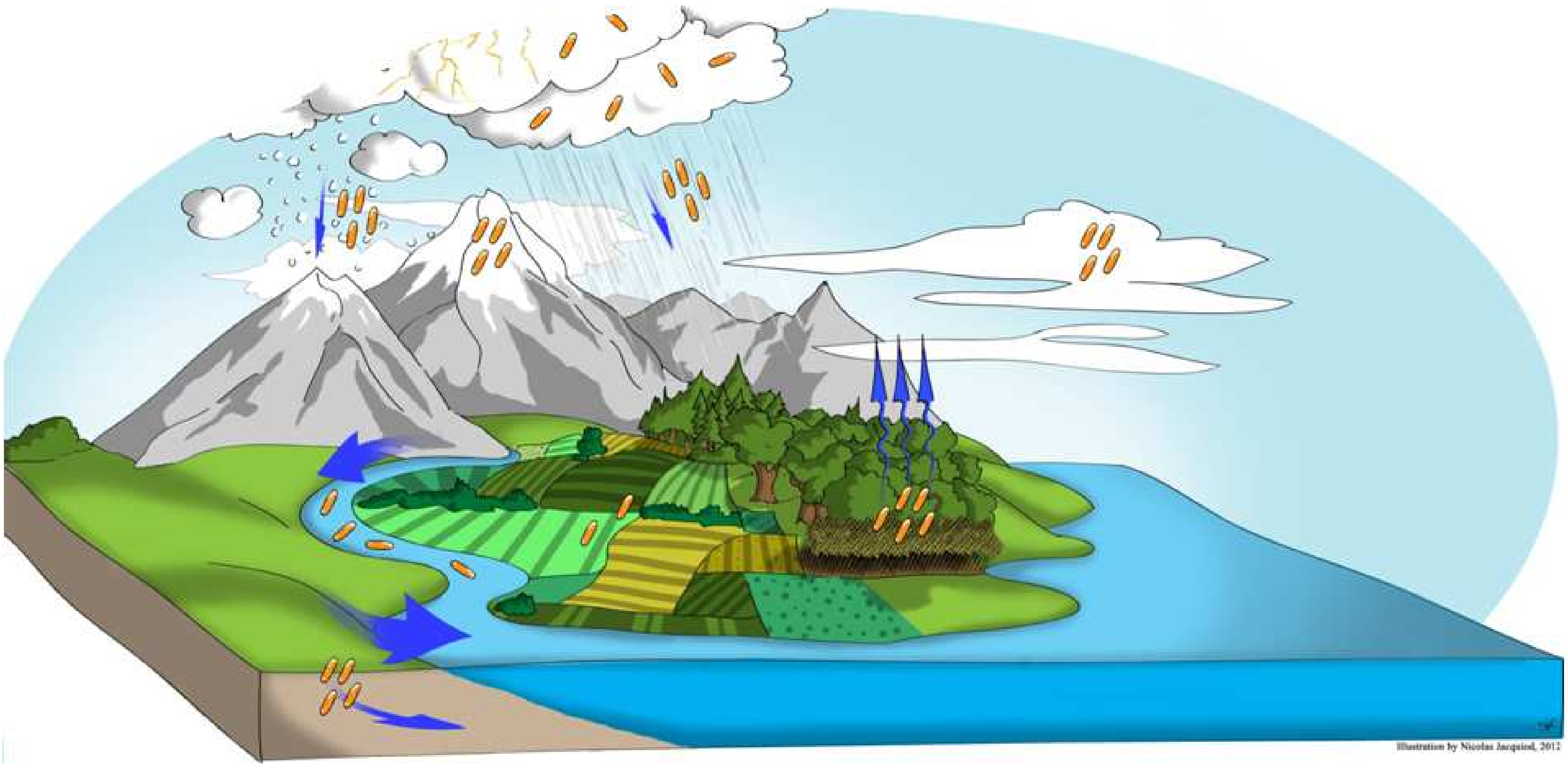
	fresh-water	plant-associated
Total potential habitat:	**5×10^{7} km^{3}**	**10^{9} km^{2}**





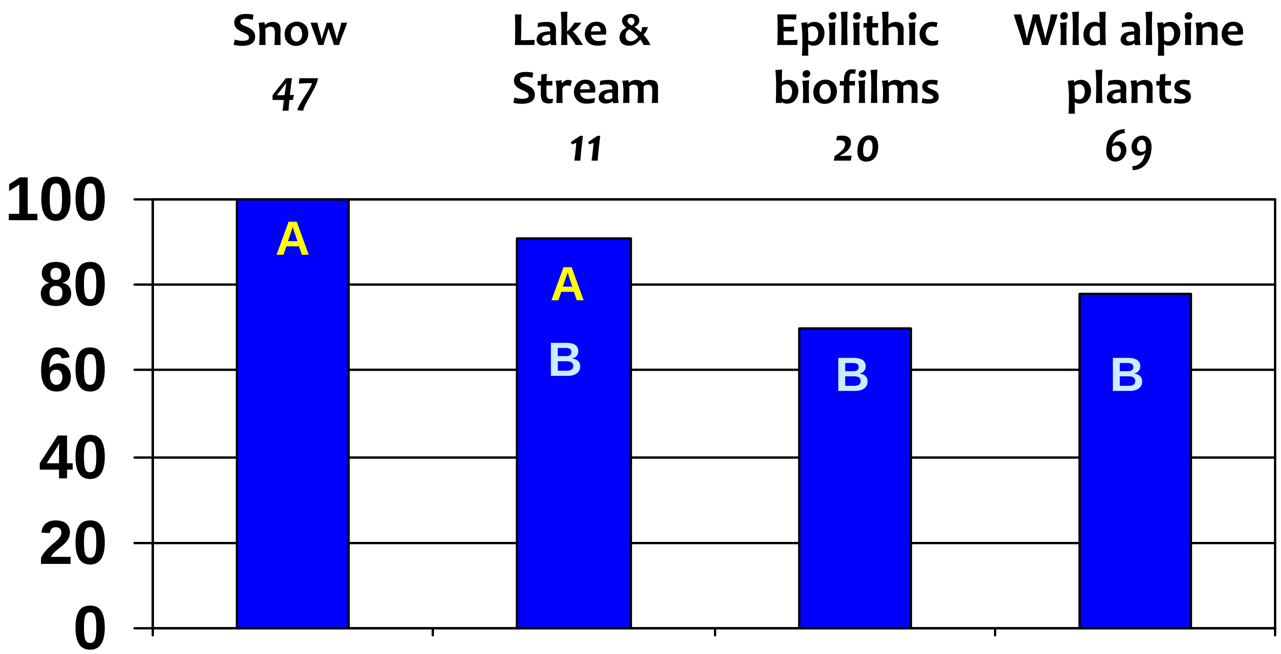
	fresh-water	plant-associated
Known to be colonized:	**2×10^{5} km^{3}**	**4×10^{8} km^{2}**
Density:	1000 cfu / L **10^{15} cfu / L**	100 – 10^{4} cfu / cm^{2} **10^{12} – 10^{14} cfu / km^{2}**
Population size: cfu	**2×10^{20} cfu**	**4×10^{20} – 10^{22}**

5. Ice nucleation activity links pathogen dissemination and evolution – with potential impact on the water cycle



Precipitation positively selects for INA *P. syringae*

% ice nucleation active (-2° to -6°)



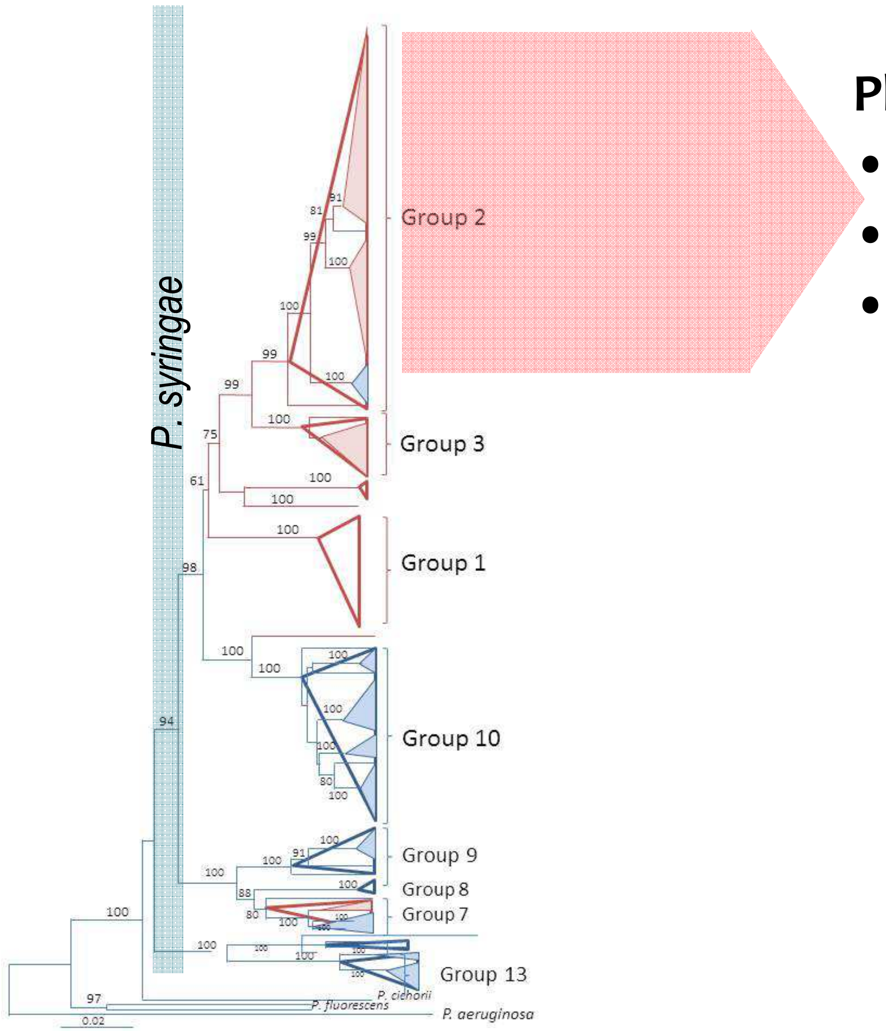
pair-wise χ^2, $p \leq 0.05$

Morris et al. 2008. ISME Journal 2:321-334

In clouds, only ca. 10% of *P. syringae* strains are INA

Joly et al. 2013. *Atmospheric Environment* 70:392–400

Precipitation positively selects for INA and highly aggressive *P. syringae* with broad host ranges



Phylogroup 2 contains

- **the most ubiquitous strains**
- **with the broadest host range and**
- **the most frequently INA**

Broad host range is correlated with ice nucleation activity

Number of strains

	Ice nucleation activity		
Host range (proxy)	0	1	2
0	24	22	37
1	3	10	35
2	3	12	54

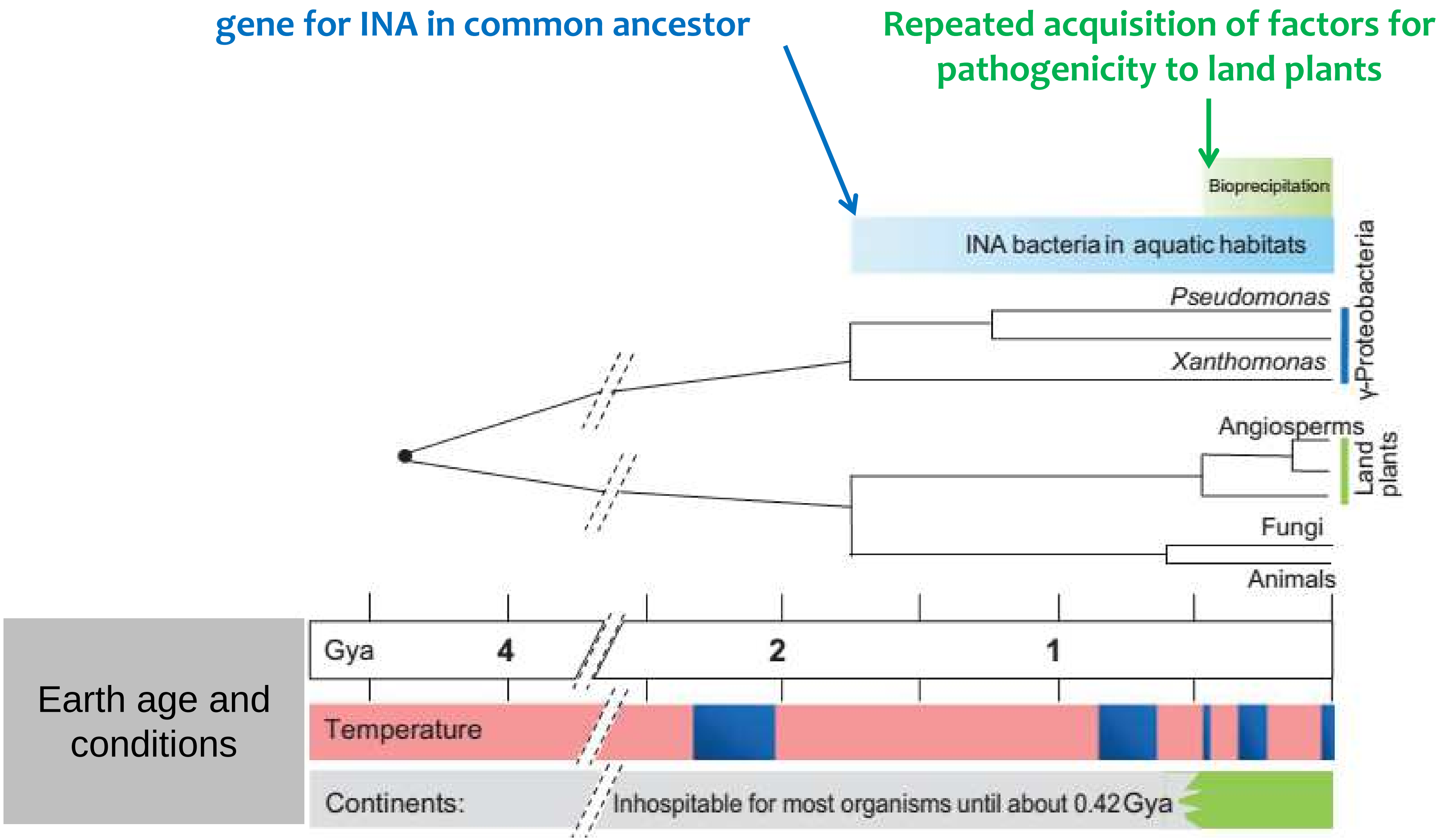
$p < 0.0001$, Fisher's exact test

Broad host range is correlated with ice nucleation activity

Pathogenicity and INA are NOT related mechanistically.

How have they co-evolved?

Evolution of ice nucleation activity and pathogenicity



Bioprecipitation: a feedback cycle linking Earth history, ecosystem dynamics and land use through biological ice nucleators in the atmosphere

Global Change Biology

Morris et al. 2014. Global Change Biology 20:341-351