Inferring groundwater ages in complex aquifers using gas tracers and tritium

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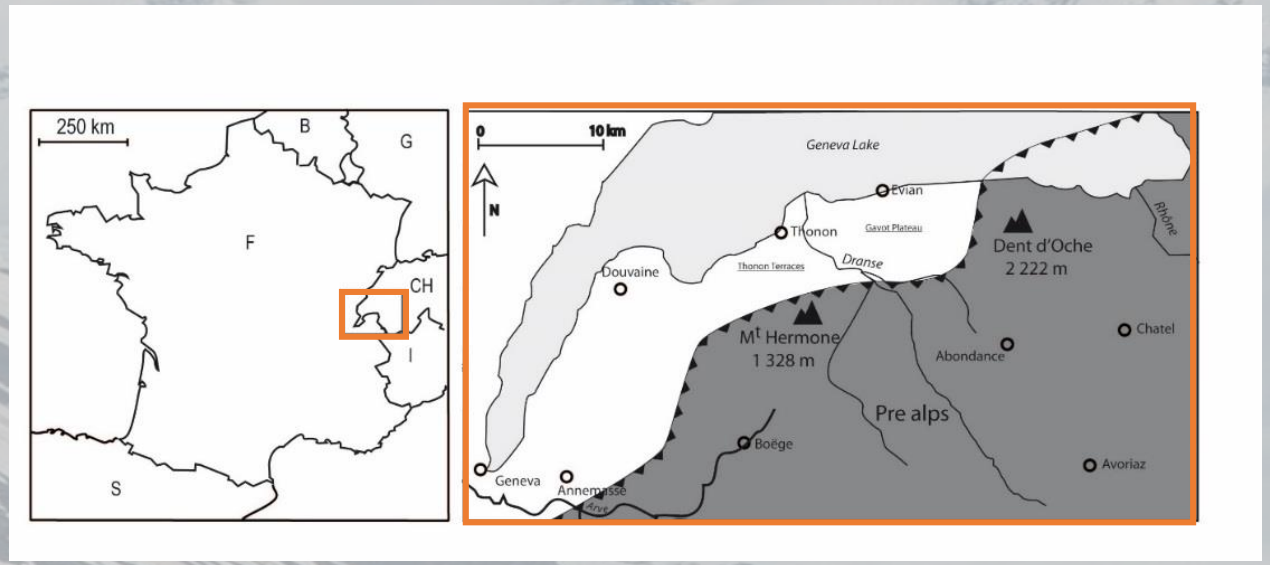
General framework

- Site with long ^{3}H time series
- Existing LPM

- Need for validation of the LPM (^{3}H only)
- New set of tracers

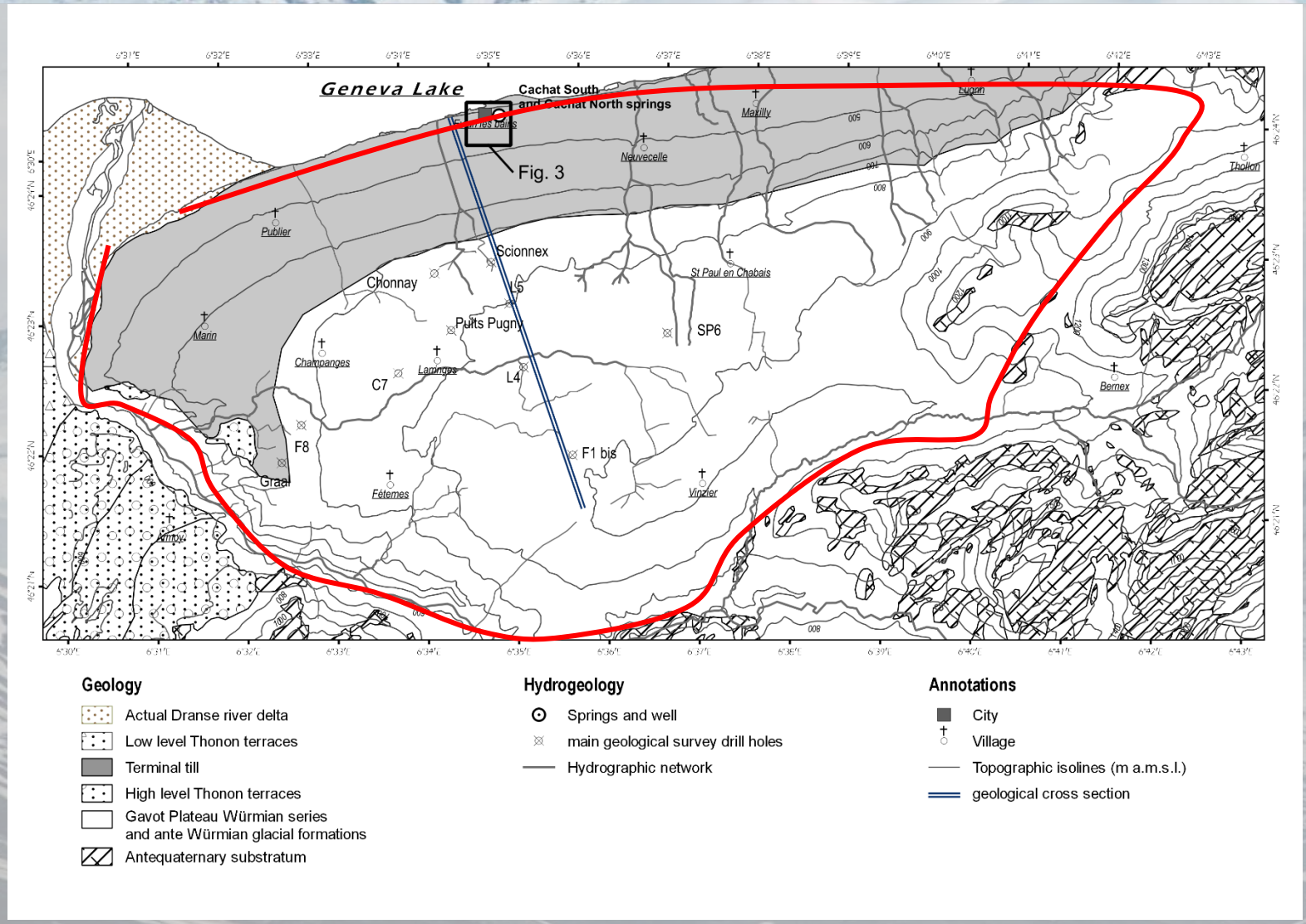
- What can we learn when comparing :
  - Long time series interpretation on only one tracer
  - Snapshot one several tracers

General settings



General settings

Glacial aquifer



Geological settings

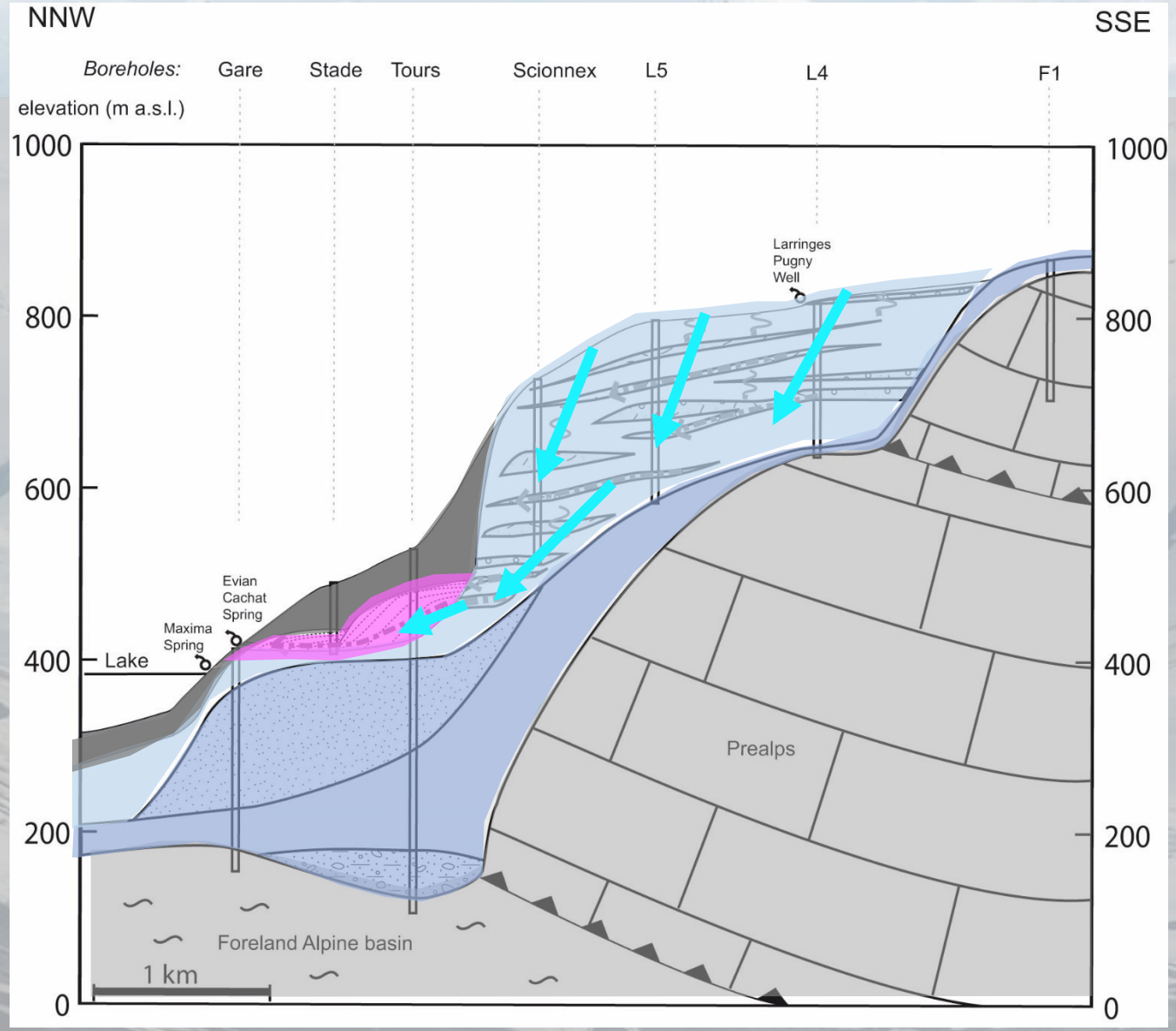
Terminal till, Nested Complex
25 – 21 ka BP

Kame terraces, Nested Complex

Gavot Plateau Complex
30-27 ka BP

Inferior Complex
>30 ka BP

Alpine Rocks



Blavoux et al, 2013

Problematic :

- One main spring : Cachat South
- Flow rate is about stable trougth time
- Overflow, no pumping
- Existing lumped model for ^{3}H

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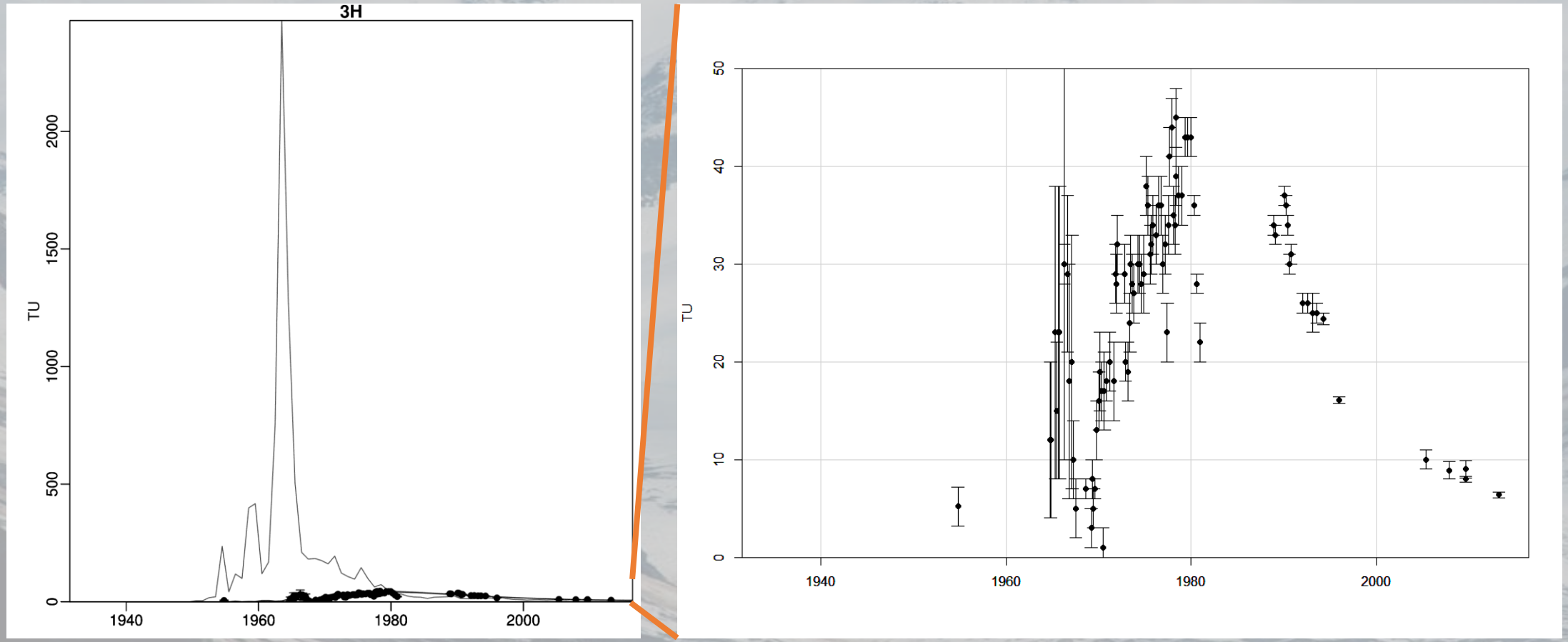
❖ Is the lumped model suited for other tracers, e.g. gases ?

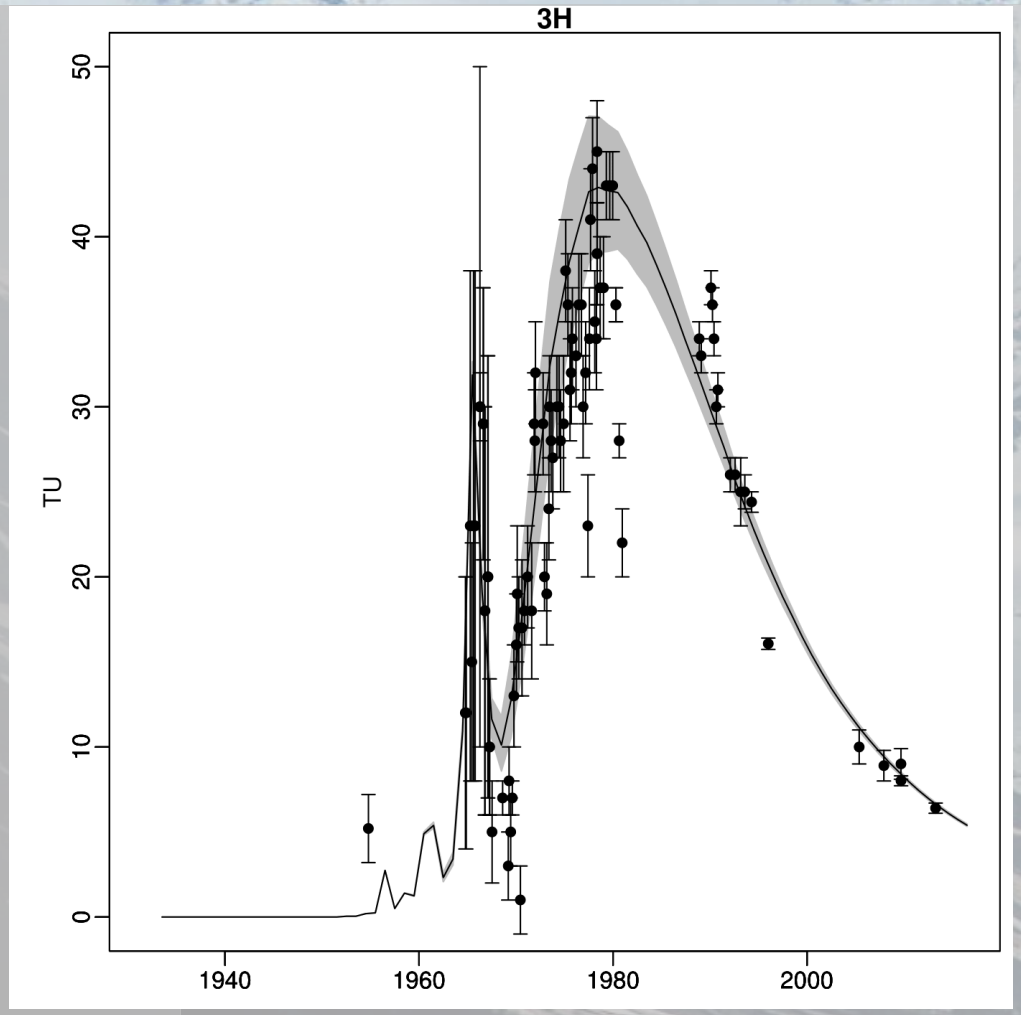
❖ Is it straitforward to apply existing model for gaseous tracers ?

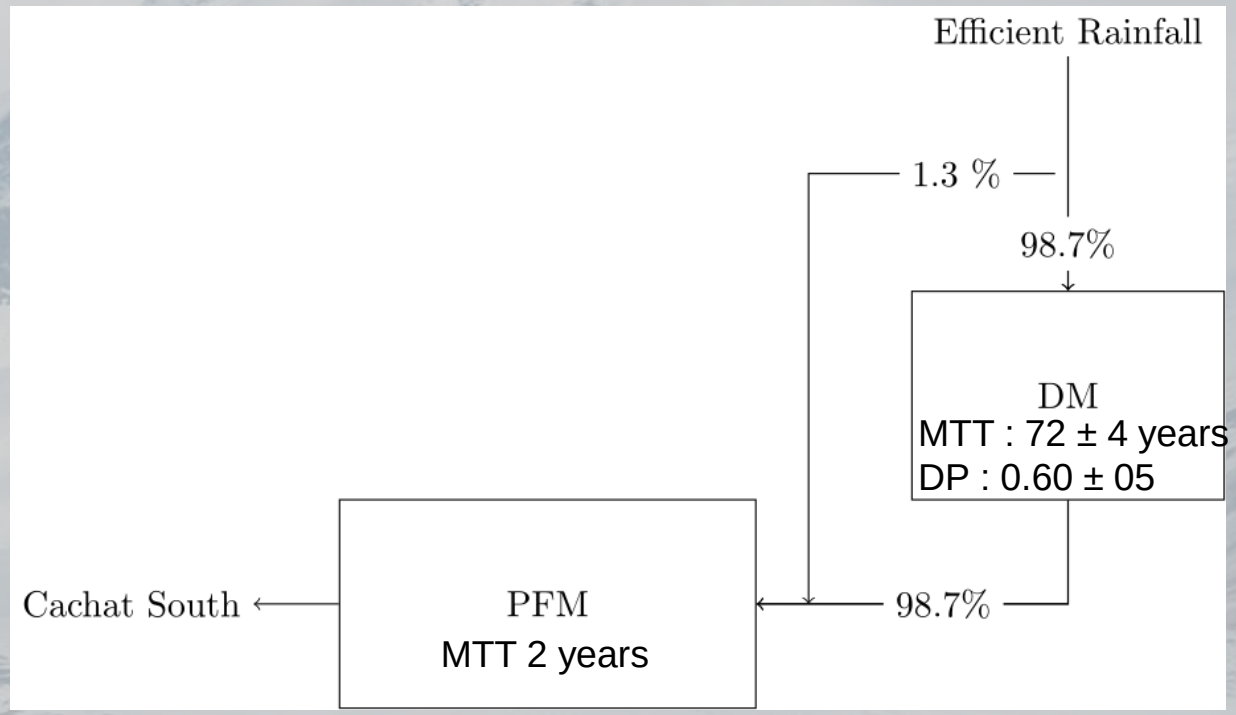
❖ What supplementary information do they provide ?

Age distribution : the 3H time series at Cachat South

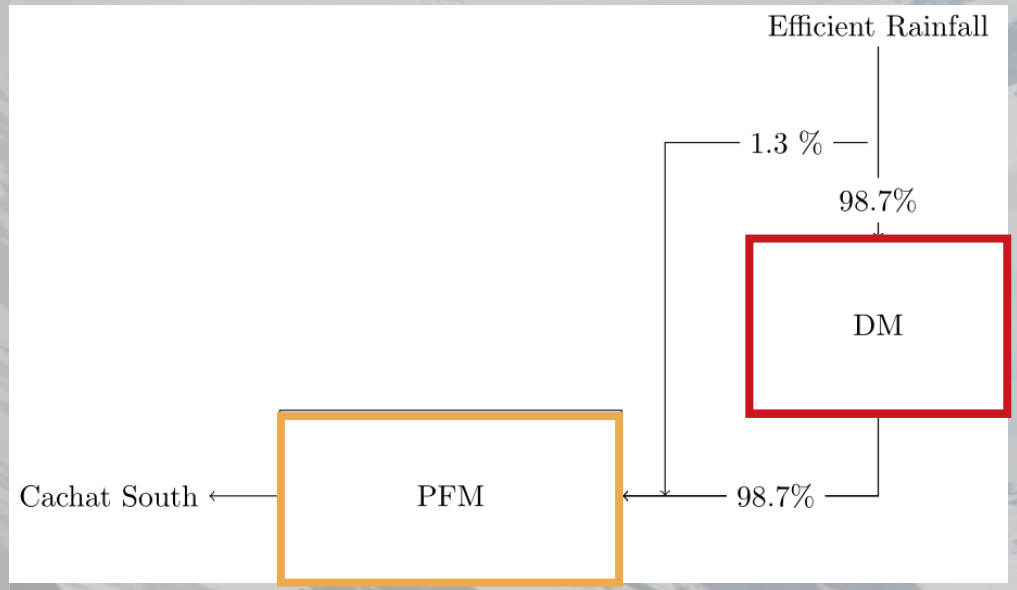


Modelling with lumped model



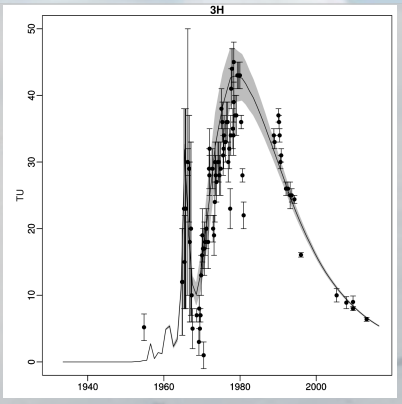


Modelling with lumped model



Extending LPM for other tracers

- One tracer, long time series
- Confidence : medium



Extending LPM for other tracers

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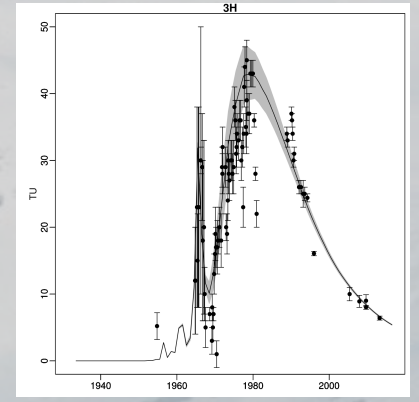
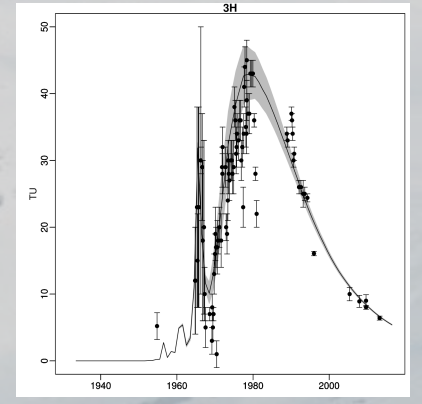
- First trial to modelize CFC's :
  - high uncertainties
  - big discrepancies (not shown)
  - low values, close to detection limits



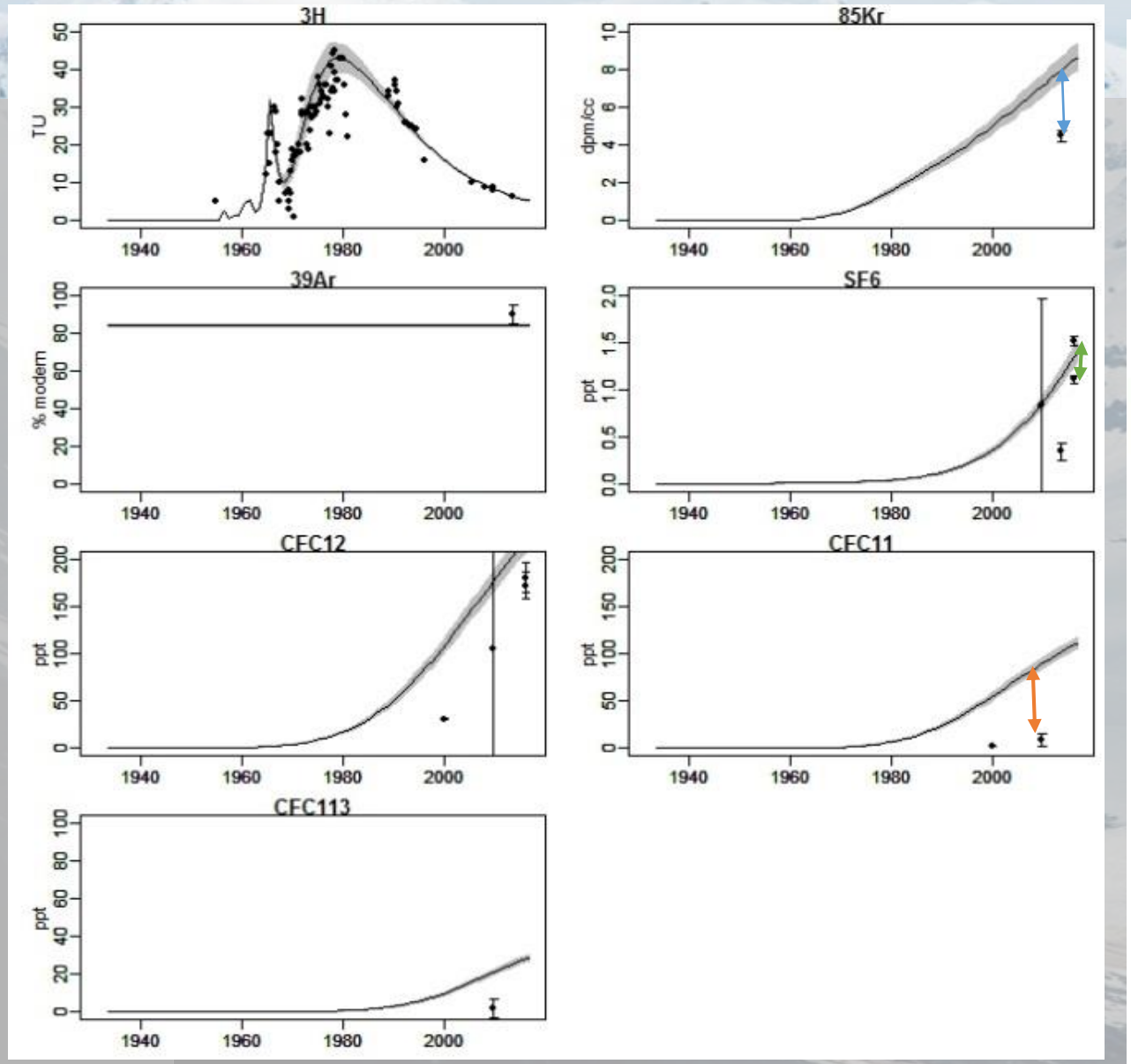
Extending LPM for other tracers

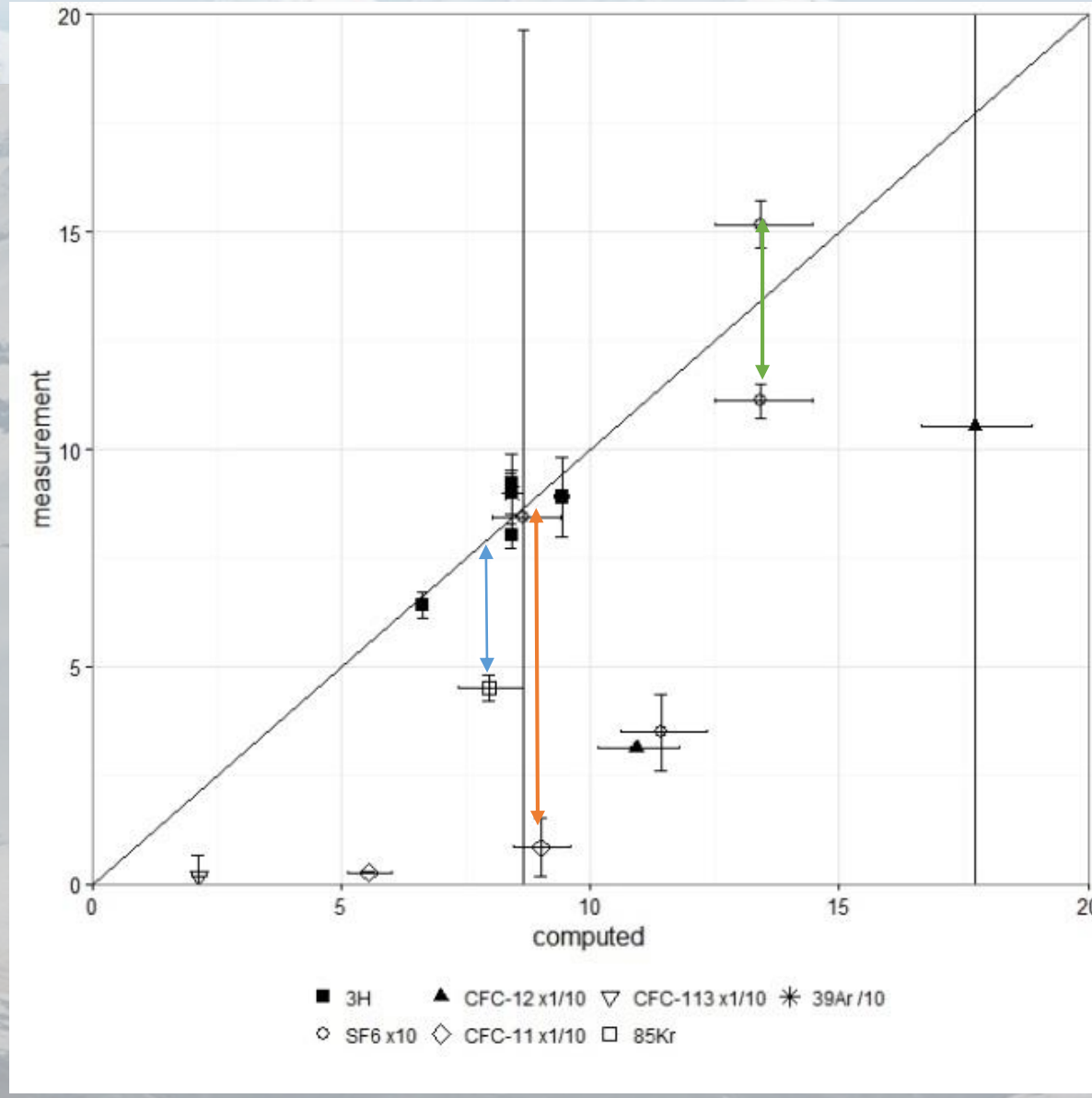
- One tracer, long time series
- Confidence : medium
- First trial to modelize CFC's :
  - high uncertainties
  - big discrepancies (not shown)
  - low values, close to detection limits
- New data (2013) : 85Kr, 39Ar, noble gases
- NG :
  - correction for excess air
  - Estimated recharge temperature



	Cachat South		
^{3}H	Time series 1963-2013		
	2000	2009	2013
^{39}Ar			X
^{85}Kr			X
CFC	X	X	X
SF6		X	X
NG			X

First interpretation : new set of data, unchanged LPM





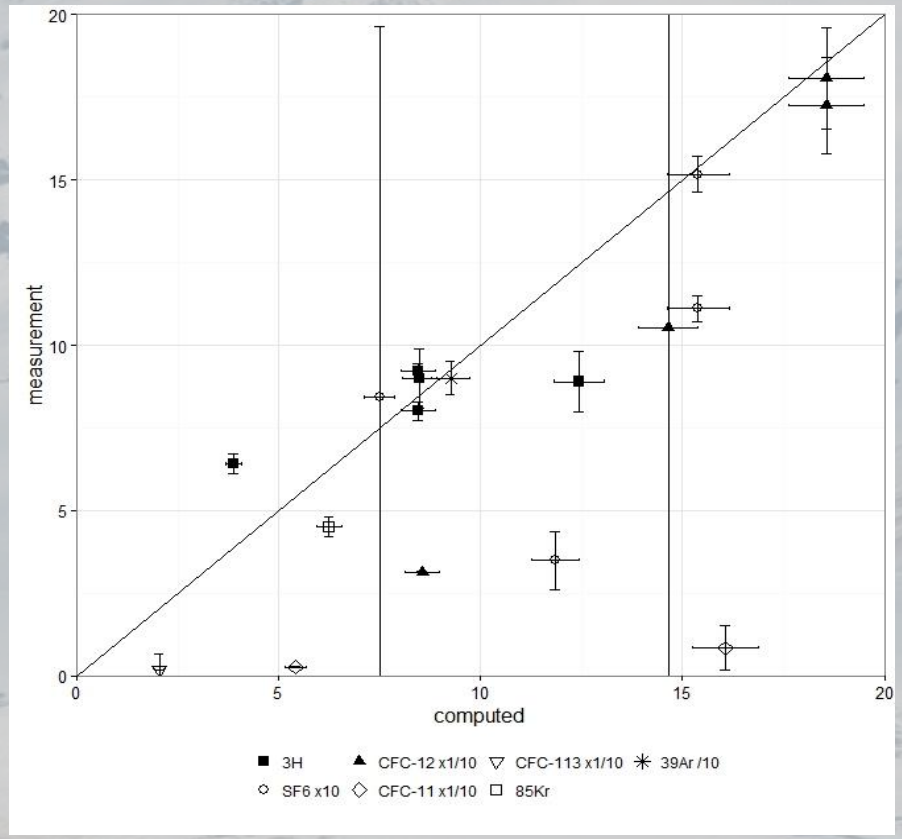
New set of data, unchanged LPM

	Cachat South			Model
^{3}H	Time series 1963-2013			
	2000	2009	2013	
^{39}Ar			X	Too high
^{85}Kr			X	Too low
CFC	X	X	X	Too low
SF6		X	X	High variability

Was the LPM suited ?

Trial to interpret with only one model for all tracers :

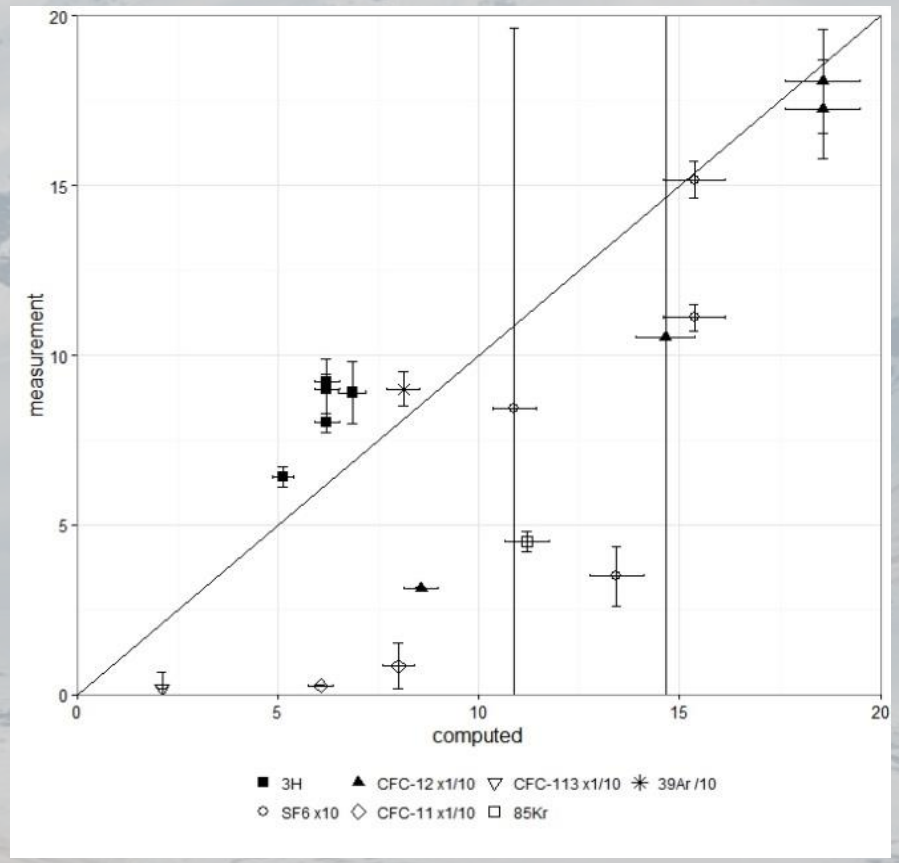
- PFM : 30 years



Was the LPM suited ?

Trial to interpret with only one model for all tracers :

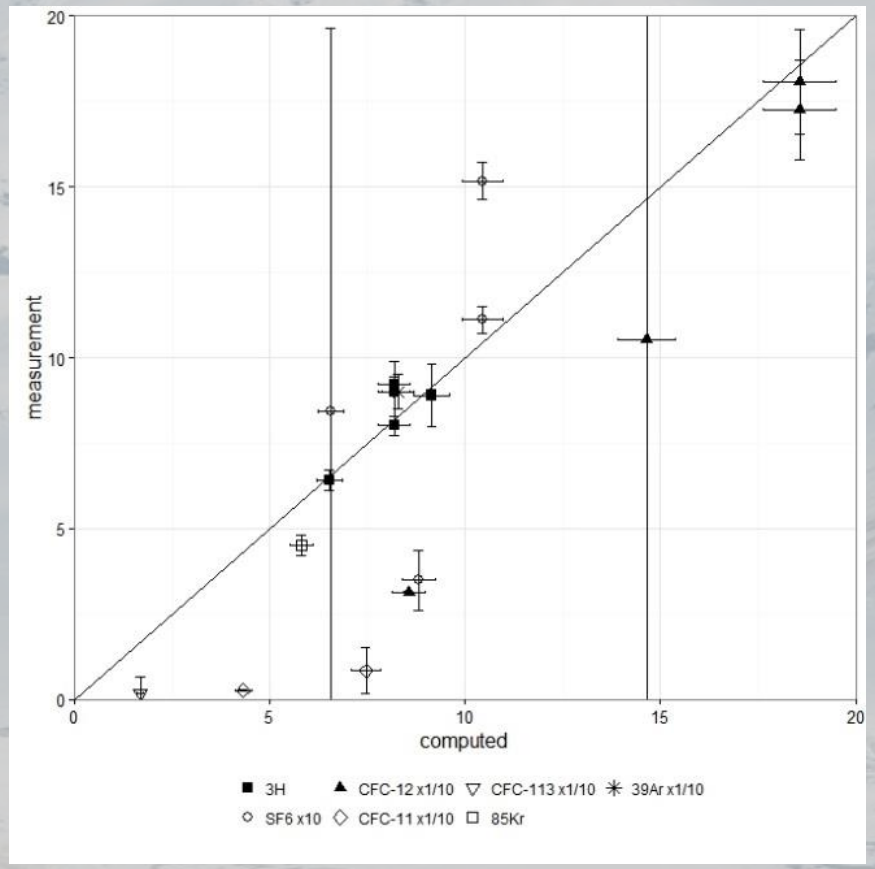
- EM : MTT=90 years



Was the LPM suited ?

Trial to interpret with only one model for all tracers :

- DM : (MTT=80 years, DP=0.5)



Was the LPM suited ?

Trial to interpret with only one model for all tracers :

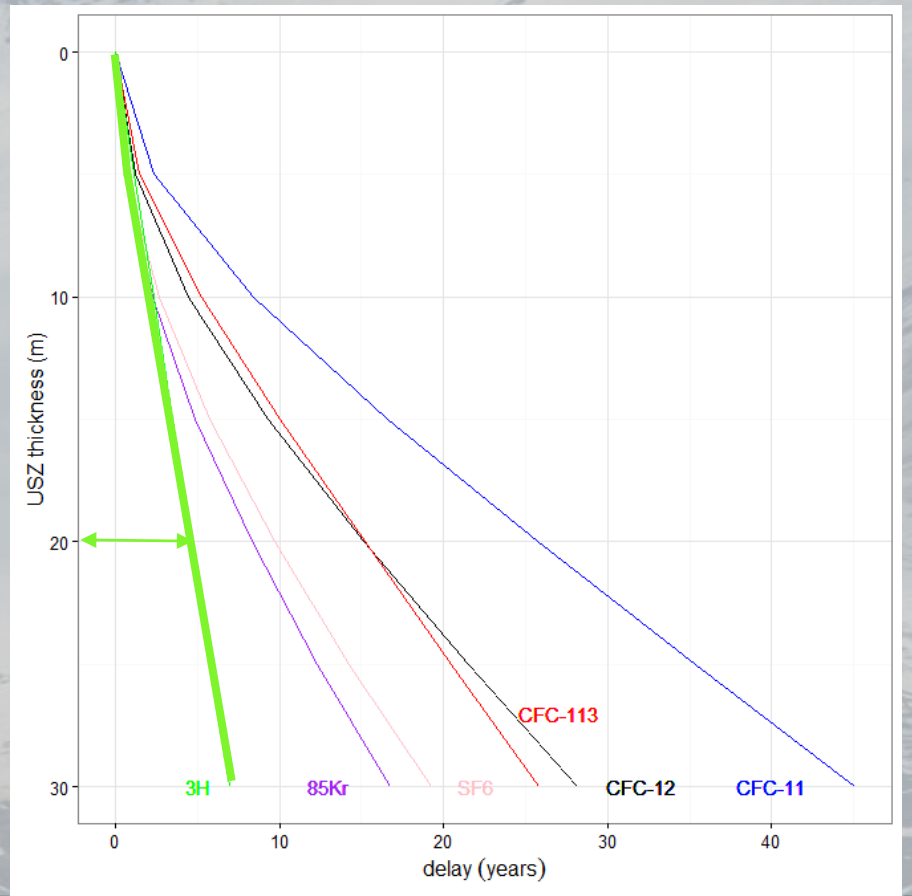
DM :	MTT=80 years, DP=0.5
EM :	MTT=90 years
PFM :	MTT=30 years

- Back to previous model
  - Trial do understand discrepancies

What role plays the USZ :

USZ delay from literature (Engesgaard et al., 2004, Cook and Solomon, 1995)

^3H	$t_t = \frac{\theta_w}{R} \times Z$	θ_w : **porosity** **R : recharge rate** **Z : USZ thickness**



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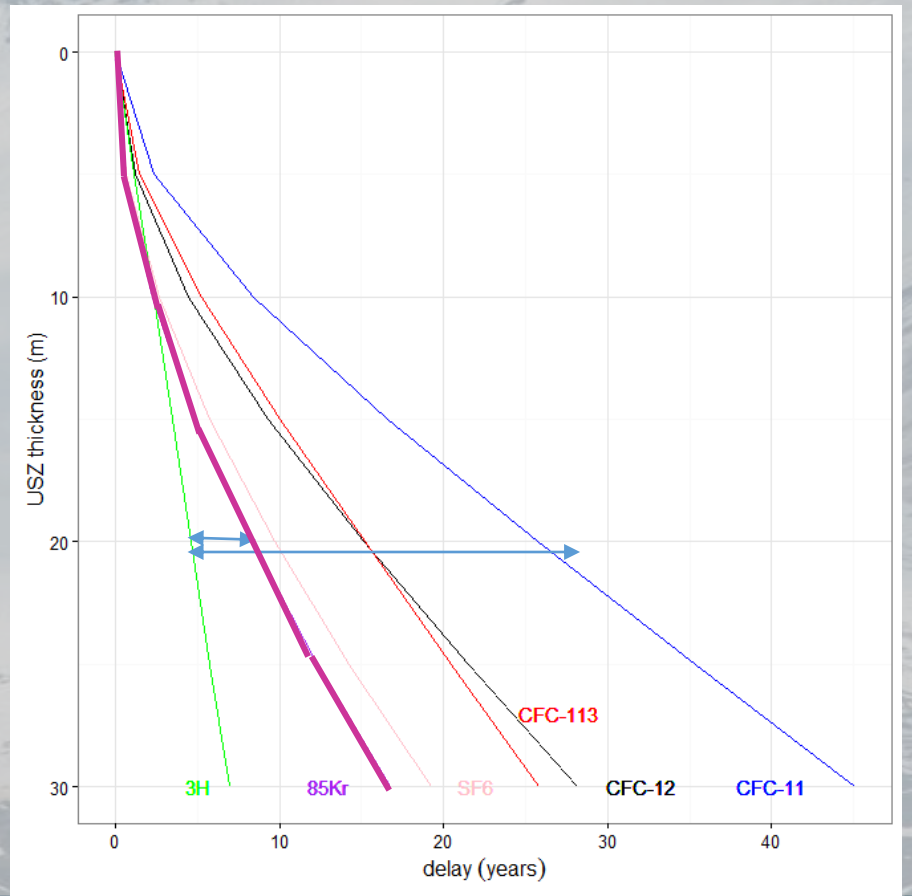
Gaseous traceurs	$t_l = \frac{\ln\left(\cosh\left(H\sqrt{k/D_g^0 \tau_g}\right)\right)}{k}$	k : growth rate of the atmospheric tracer τ_g : tortuosity D_g^0 : diffusion coefficient

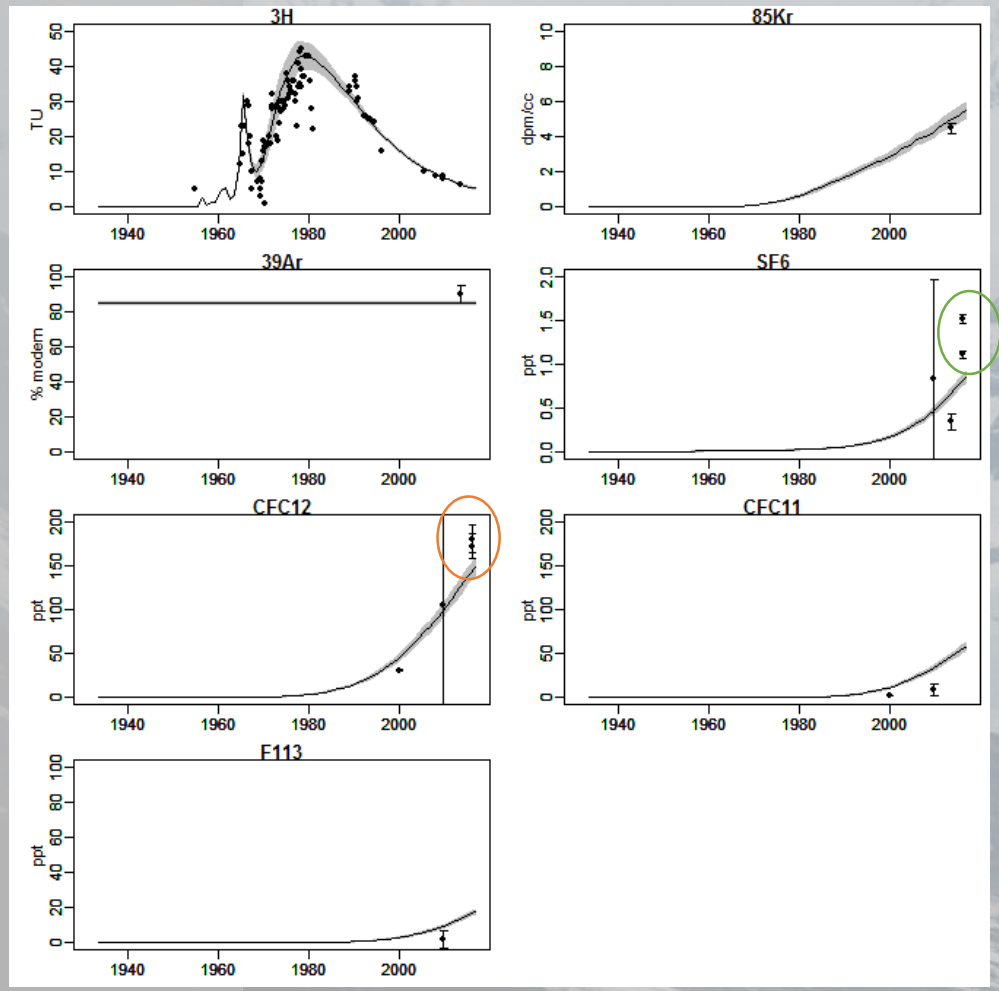


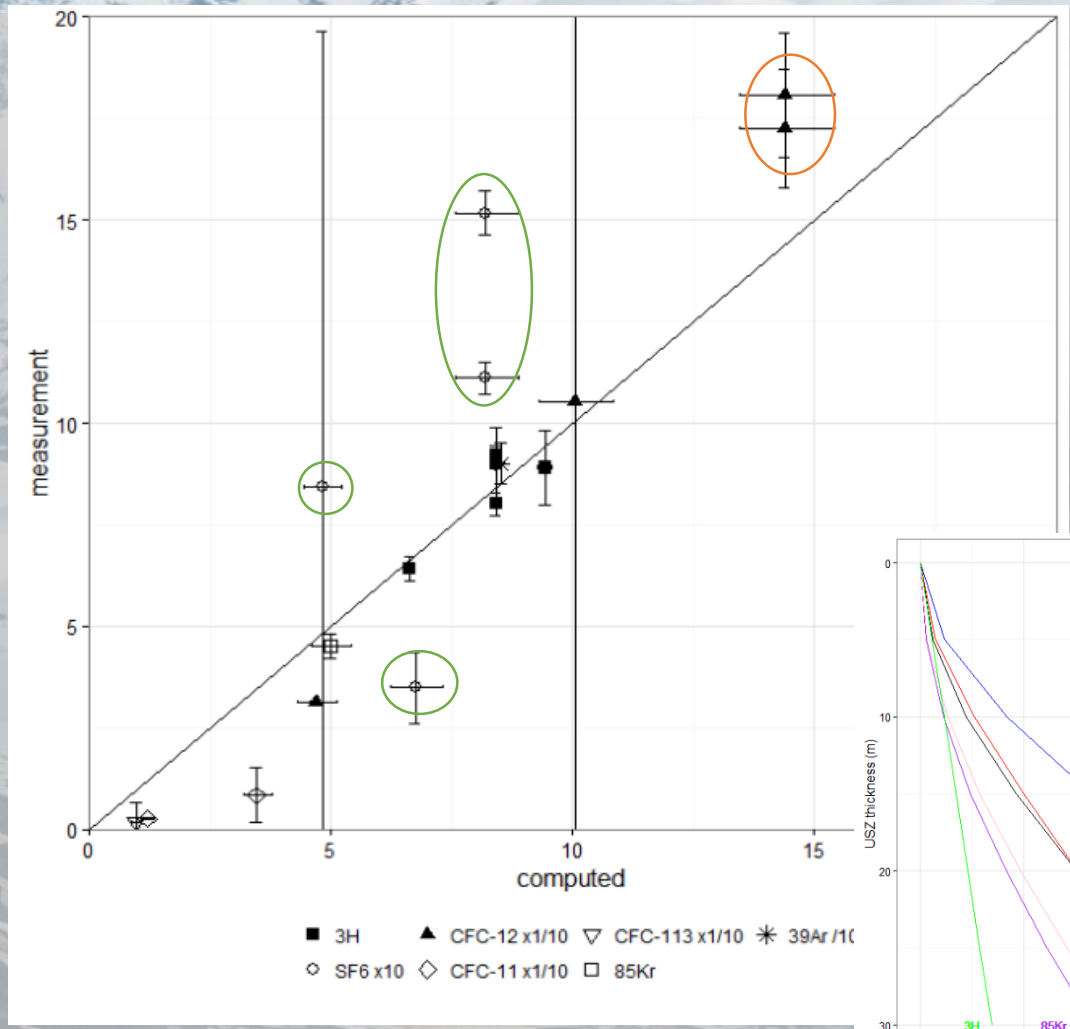
^{39}Ar :

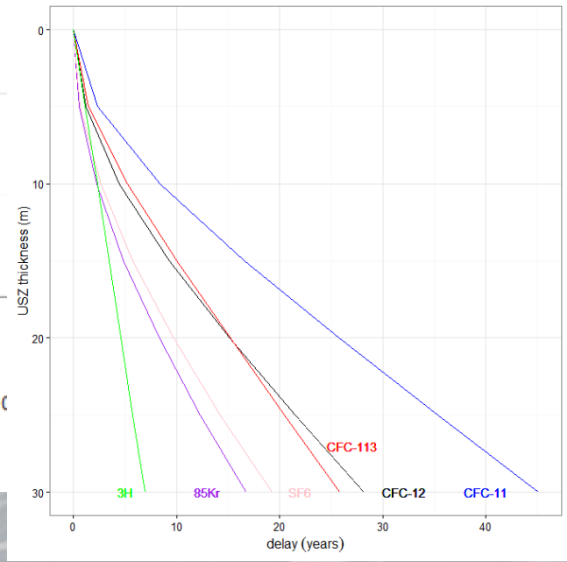
In situ production :

- ✧^{39}Ar cosmogenically produced in the USZ
- ✧neutron activation of potassium : $^{39}K + neutron \rightarrow {}^{39}Ar + proton$
- ✧USZ thickness about 20 to 30 m : 200 % of ^{39}Ar modern (IAEA, 2008)

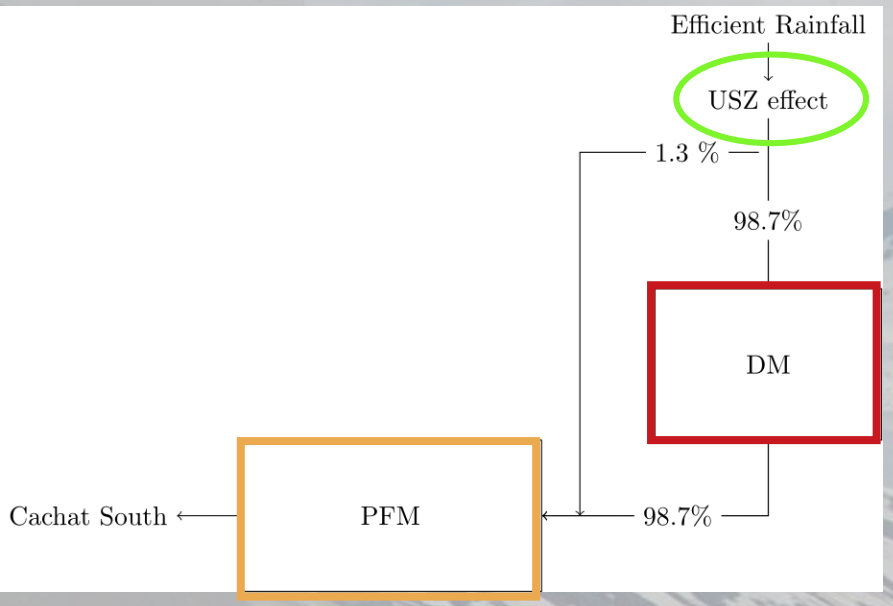
LPM with USZ taken into account

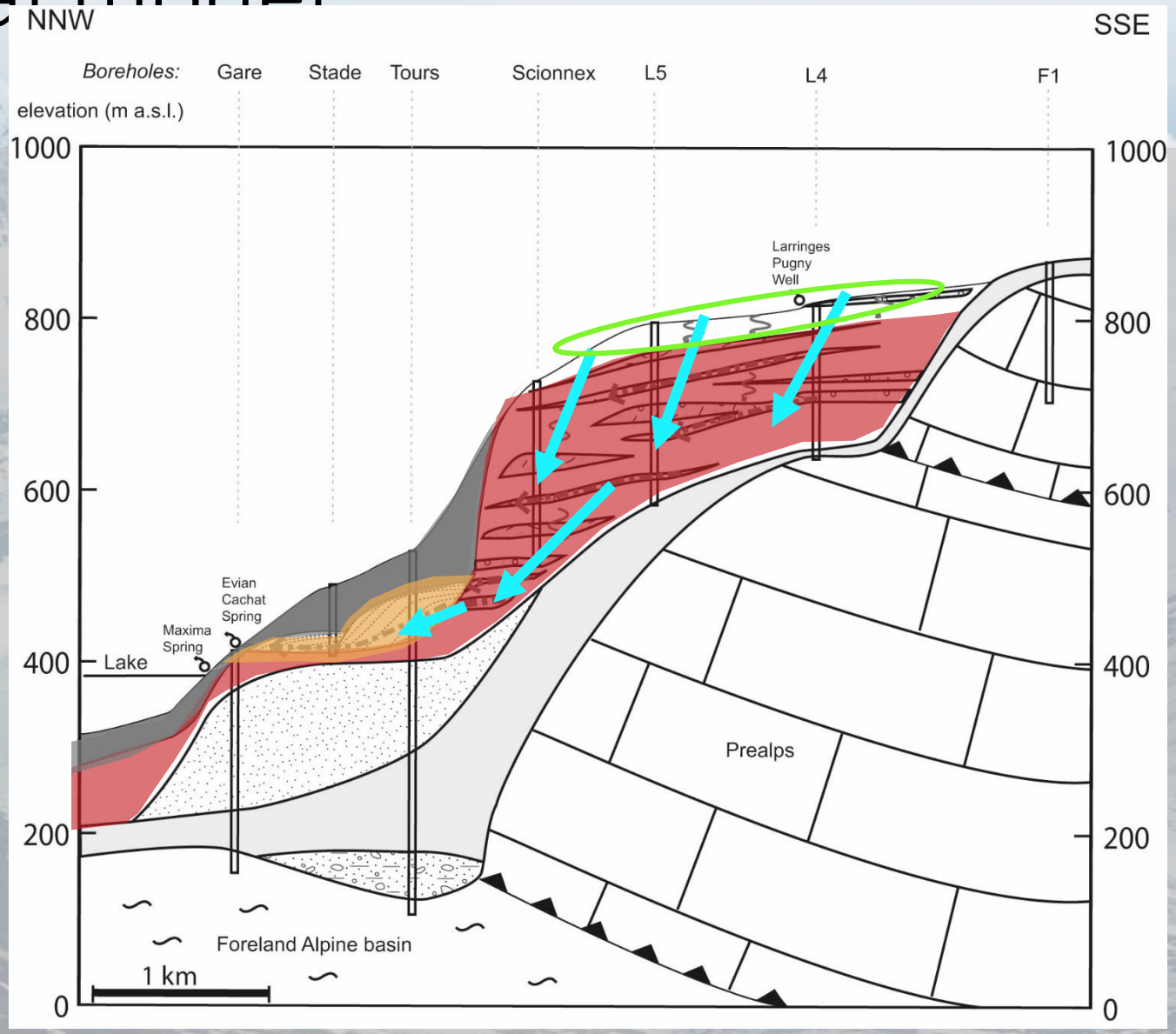






Ehanced conceptual model

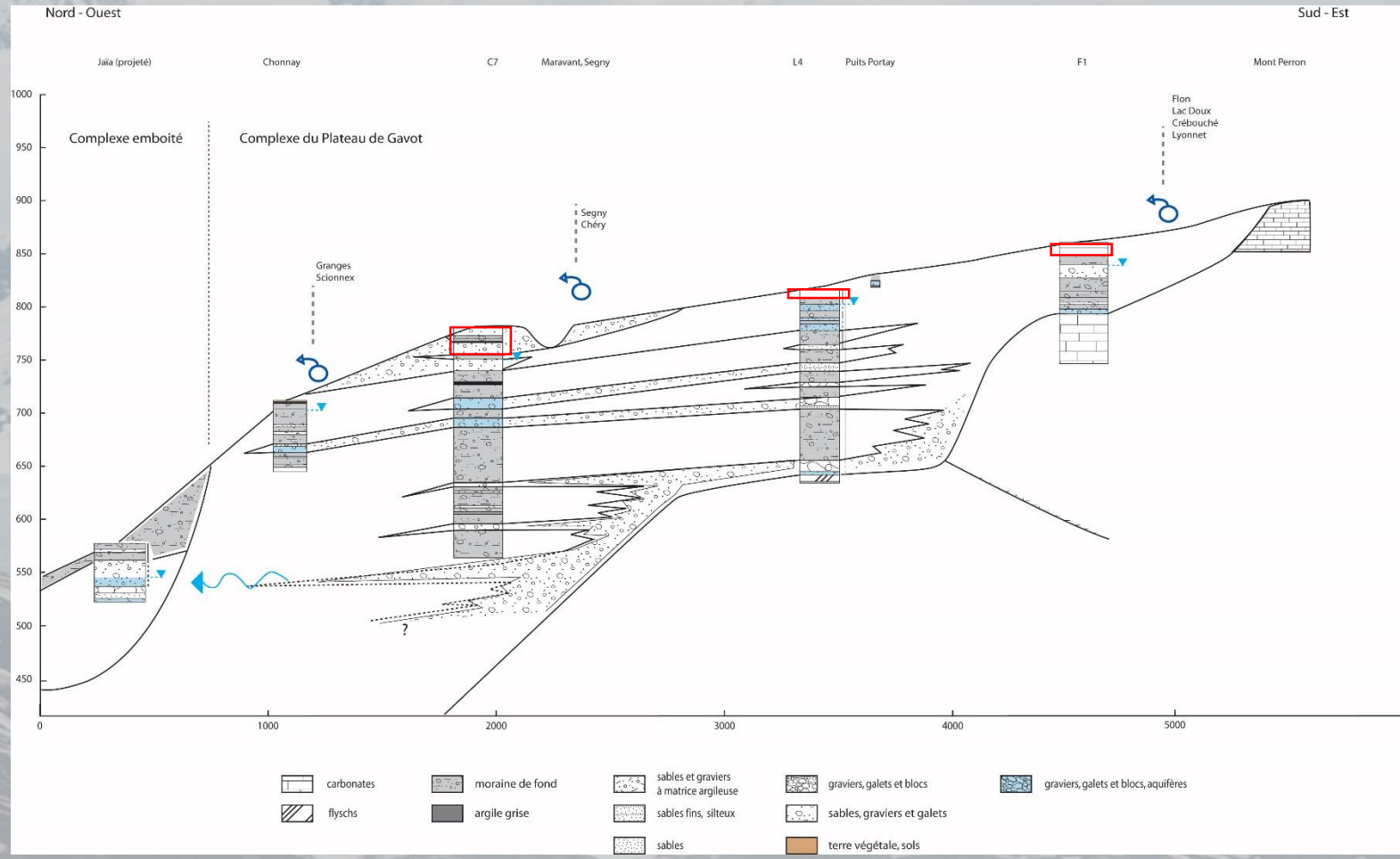




USZ thickness on the recharge area

Observed USZ thickness :

10 – 50 m



Conclusions

Conclusion :

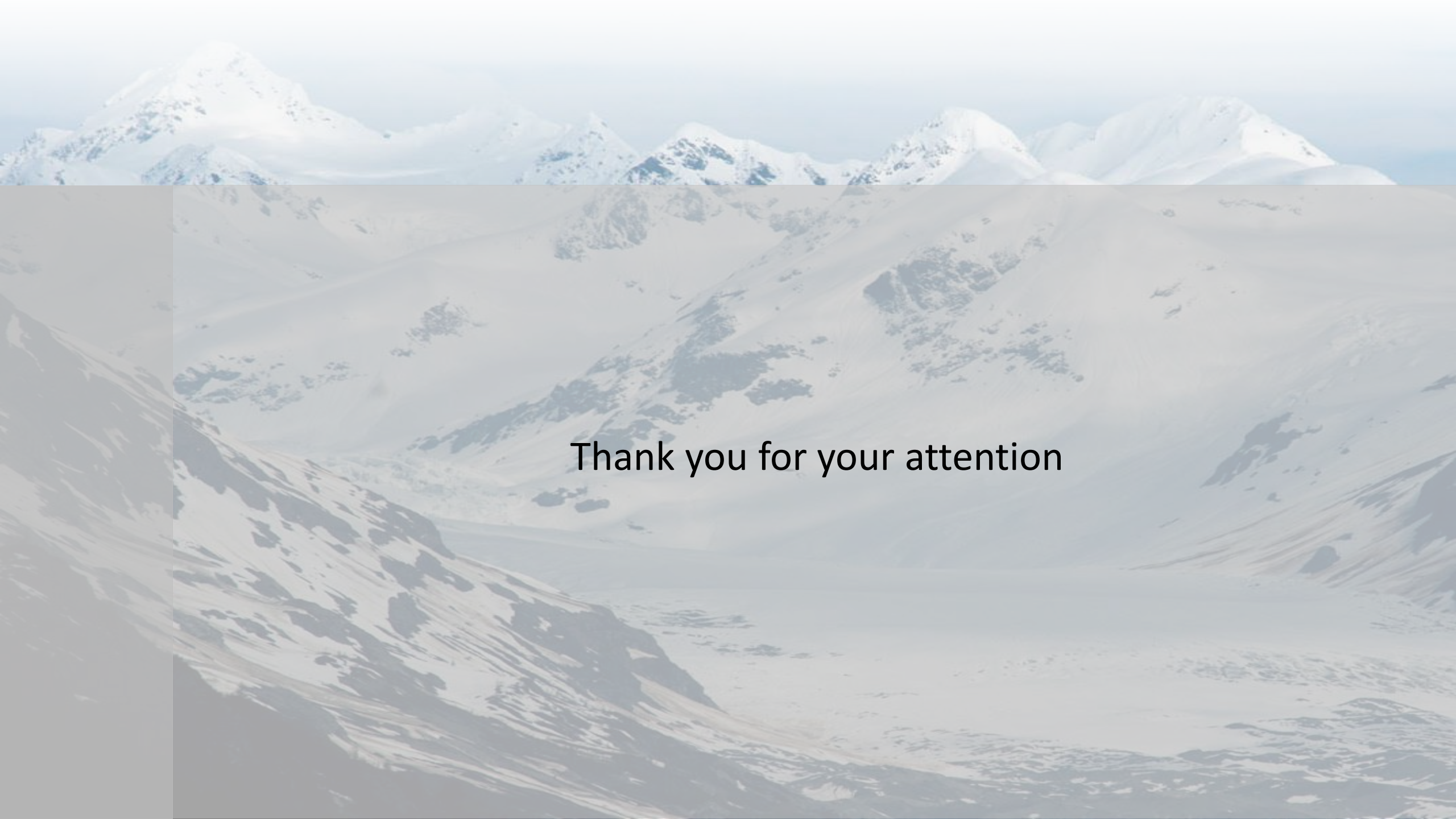
- ✧ ^{3}H only : long time series : good estimation of the distribution of transit time
  - ↳ No evidence of the effect of the USZ
- ✧ ^{3}H + Gaseous tracers as a snapshot :
  - ↳ Need for extra comprehension of distribution of transit time
  - ↳ Simple LPM model not suited
  - ↳ No
- ✧ ^{3}H time series LPM + gaseous tracers
  - ↳ Possible estimation of the USZ effect
  - ↳ CFC's : delay rather than degradation
  - ↳ ^{39}Ar in situ production

Take home message

Conclusion :

- ✧Complex system : need for both time series and snapshot of several tracers
- ✧Each tracer provide a new insight on the functionning :
- ✧^{85}Kr : USZ thickness (range), good order of magnitude compared to observation
- ✧CFC's : medium to strong delay.
  - ↳CFC-11, CFC-113 : degradation could append, no strong evidence of it
- ✧SF6 : high variation, still not properly understood
- ✧^{39}Ar : need for in-situ production

- ✧Good agreement with known geology
- ✧Ehanced conceptual hydrogeological model

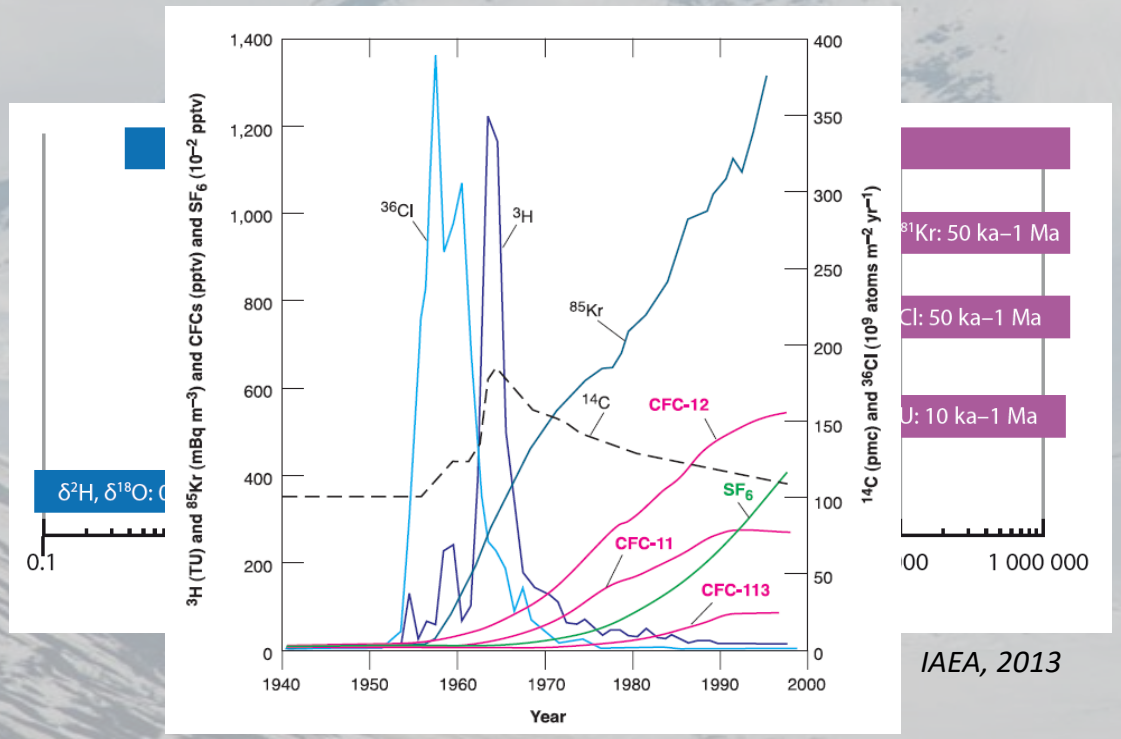

Thank you for your attention

The determination of transit time distributions in complex aquifers with environmental tracers might be affected by a series of processes. We compare results from a 50-years' time series of a water-bound tracer (^{3}H) and a complete set of gaseous environmental tracers (^{85}Kr, ^{39}Ar, CFCs, SF_6) sampled at a single date. Study area is the complex aquifer system of Evian (French Alps).The interpretation using lumped parameter models and ^{3}H data is not sensitive to distinguish between residence times in the unsaturated (USZ) and saturated zone. Since gas tracers behave differently in the USZ they provide a differenced view on the water flow path including some estimates about the recharge area and process. The comparison of ^{85}Kr data with CFCs allow for a quantification of degradation processes of the latter.Due to the prolonged gas residence time in the USZ the initial ^{39}Ar activity is possibly affected by cosmogenic production by the $^{39}K(n,p)^{39}Ar$ reaction.

It is concluded that the combination of time series measurements and a multi tracer snapshot in time complete each other and provide also an assessment of the transient behavior of a groundwater flow system. Furthermore, hydrogeological conceptualization in order to pre-design the possible schemes for the lumped parameter models (e.g. models in series or in parallel), highly helps to converge towards more realistic sets of parameters.

- Traceurs environnementaux

I. Introduction
I-1 Contexte et objectifs
I-2 Site d'étude
II. Résultats
II.1-1 Aire de recharge
II. 1-2 Aquifères terminaux
II. 2-1 Traceurs environnementaux



IAEA, 2013

Alley et. Al., 2002

LPM with USZ taken into account