



# Estimation statistique et réanalyse des précipitations en montagne

Thèse soutenue le 27 janvier 2009





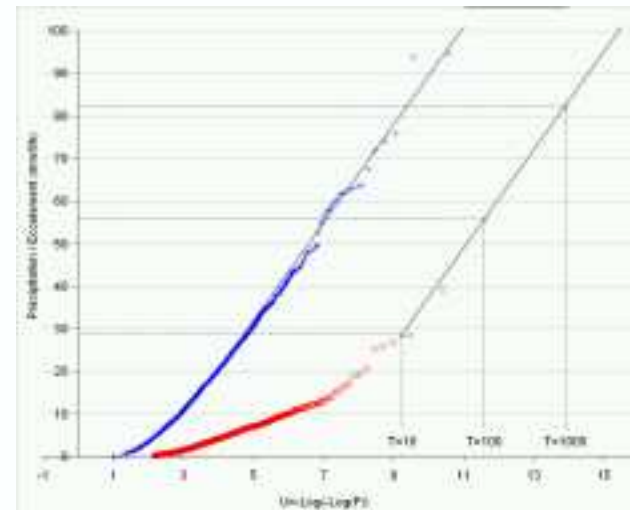
# Un besoin croissant en données spatialisées



## Prévisions

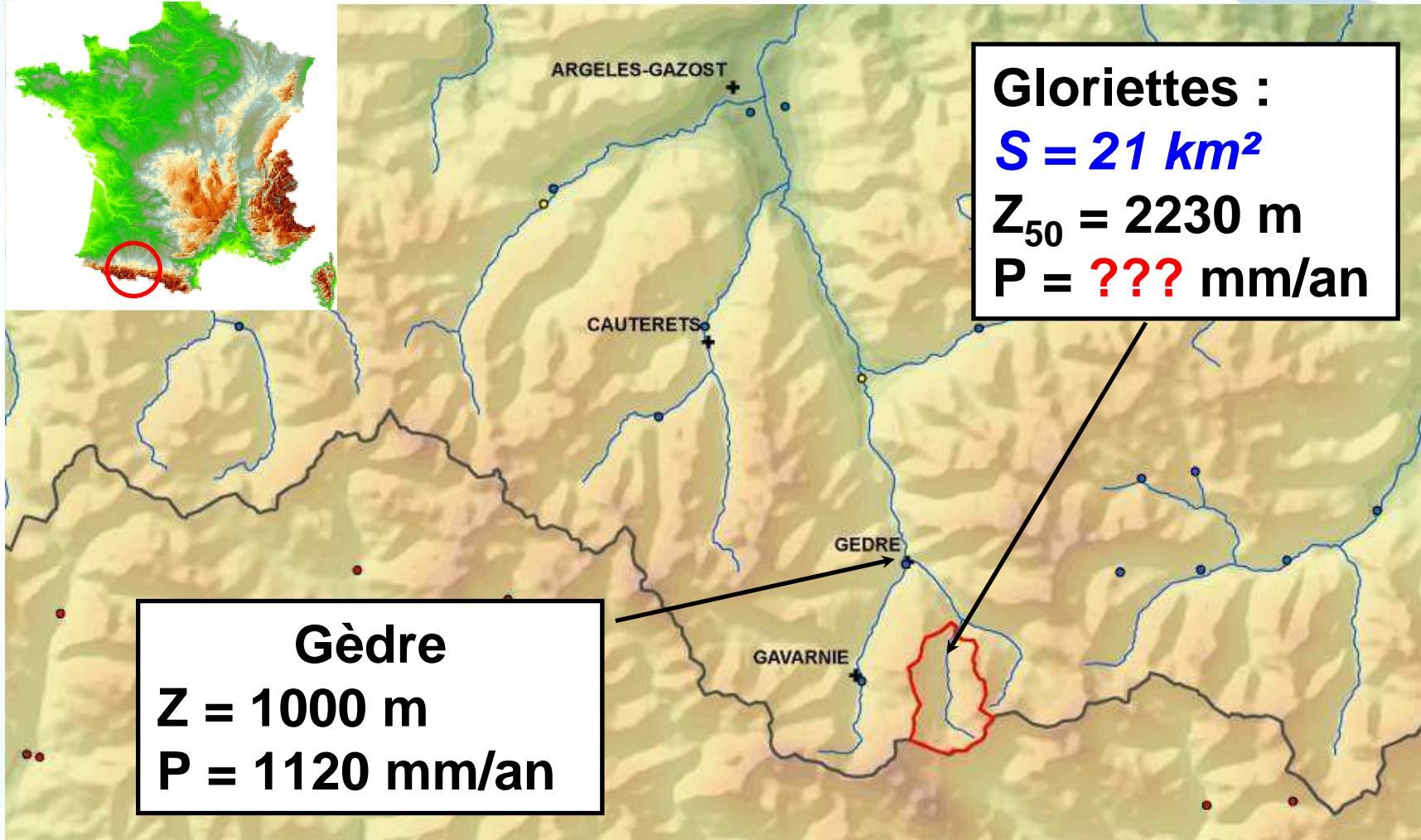
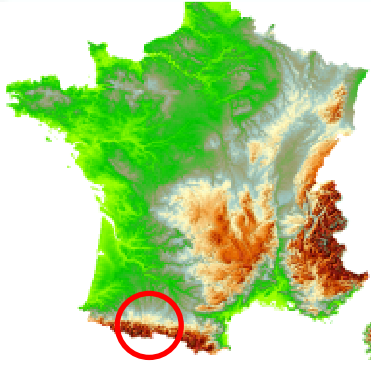


## Études





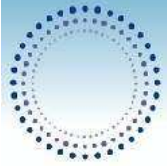
# Exemple : Estimation des extrêmes Pb des précipitations en altitude





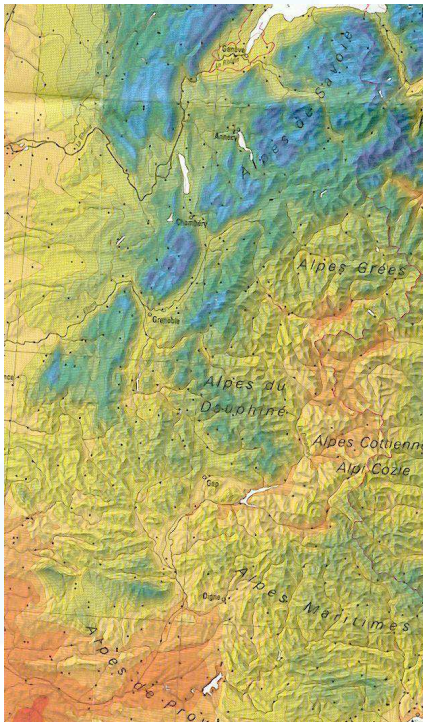
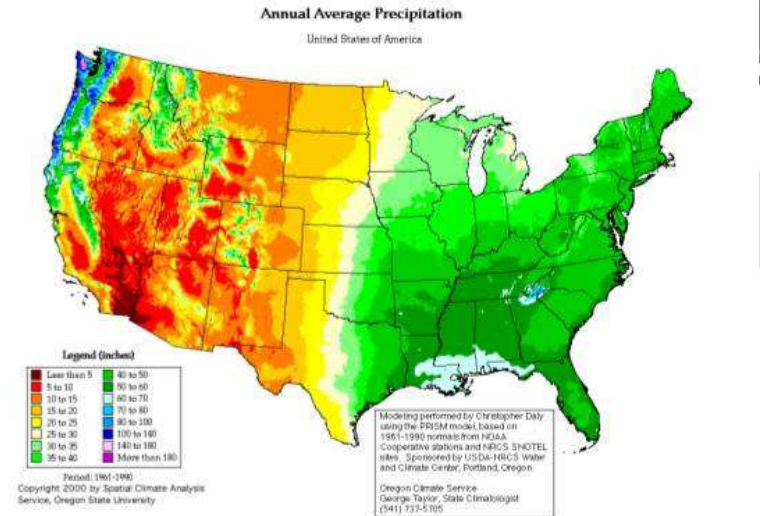
## Question scientifique

Quelles estimations **spatiales** des précipitations peut-on réaliser en **montagne** à partir de mesures **ponctuelles** souvent réalisées en **vallée** ?



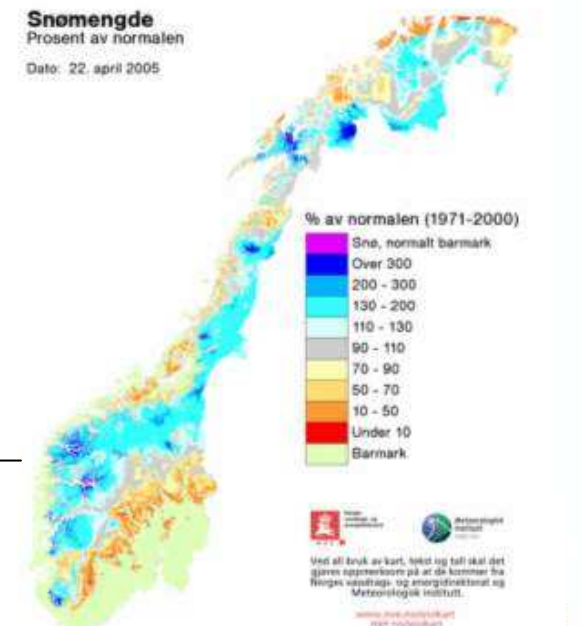
# PRISM

## Precipitation-elevation Regressions on Independent Slopes Model (Daly et al., 1994)



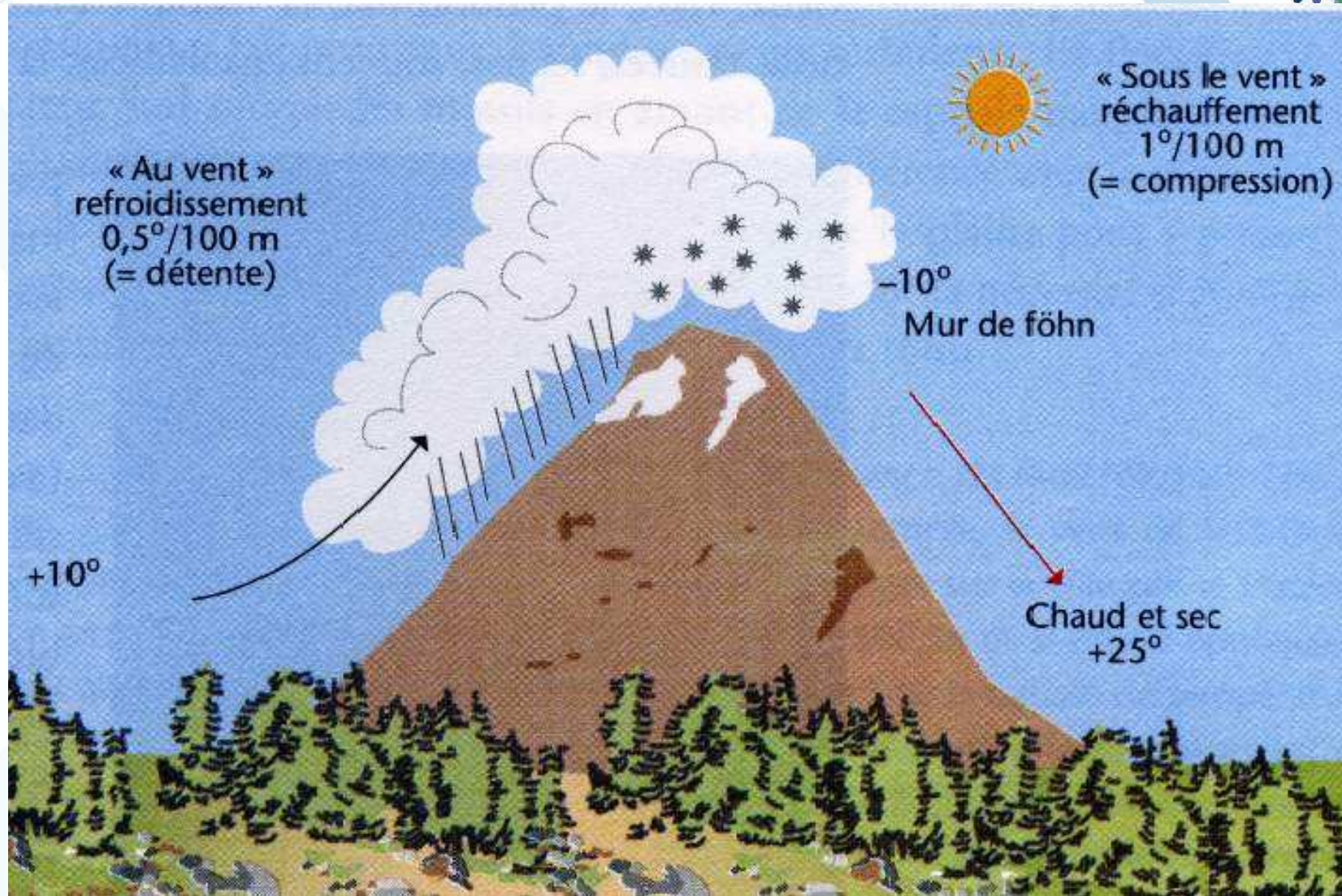
## Suisse (Frei and Schär, 1997)

## Norvège (Tveito et al., 2004)

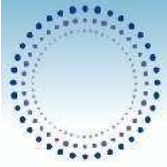




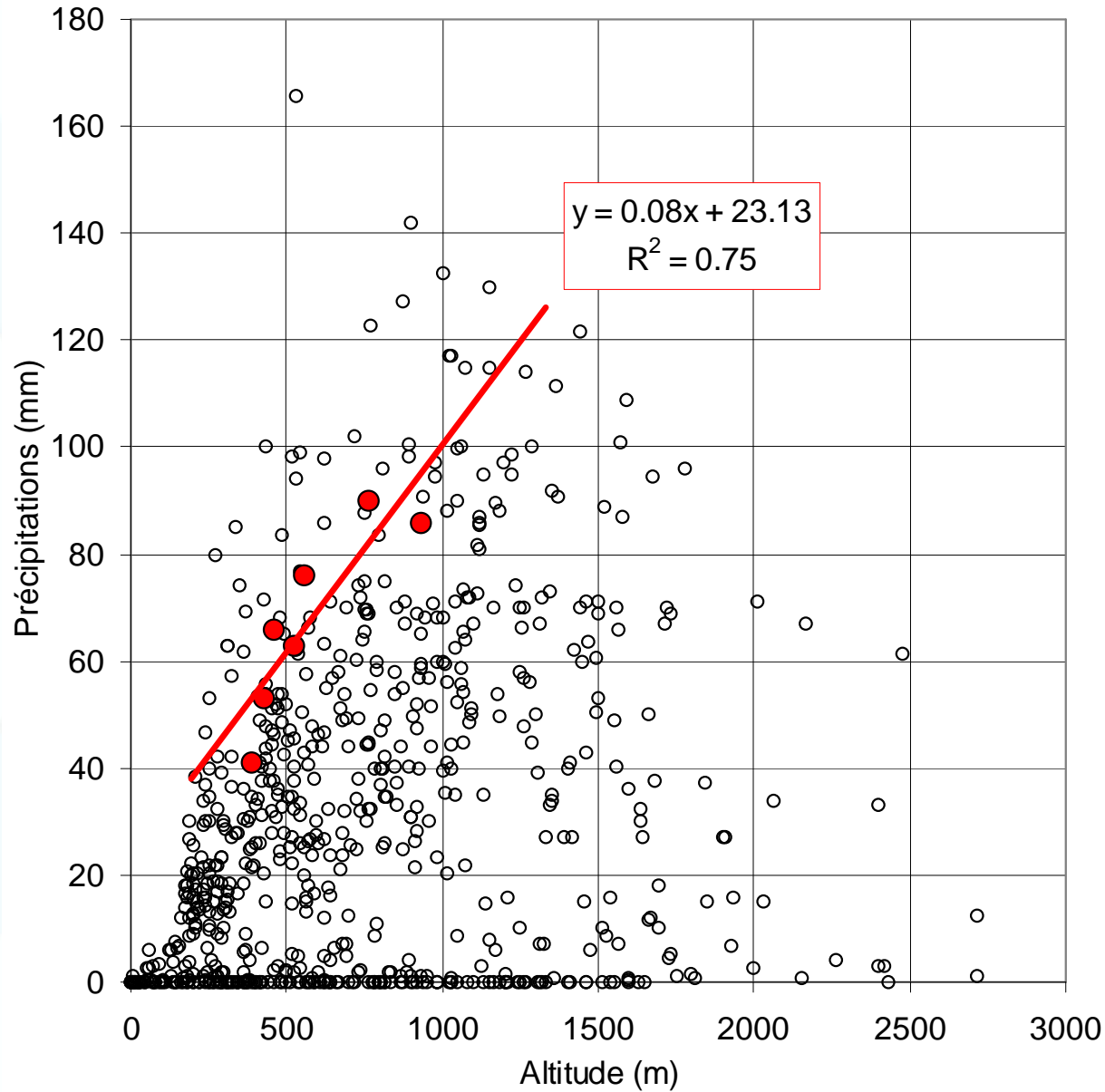
# Modélisation de l'effet orographique



D'après *La météo de montagne*, Thillet (1997)



# Régression linéaire locale



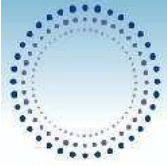
Précipitations  
du 26/11/1983  
sur les Alpes



# Plan de l'exposé







# Plan de l'exposé

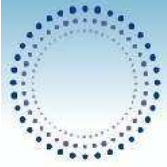


- ① Base de données
- ② Première estimation des précipitations journalières
- ③ Validations
- ④ Assimilation des données d'enneigement
- ⑤ Seconde estimation des précipitations journalières

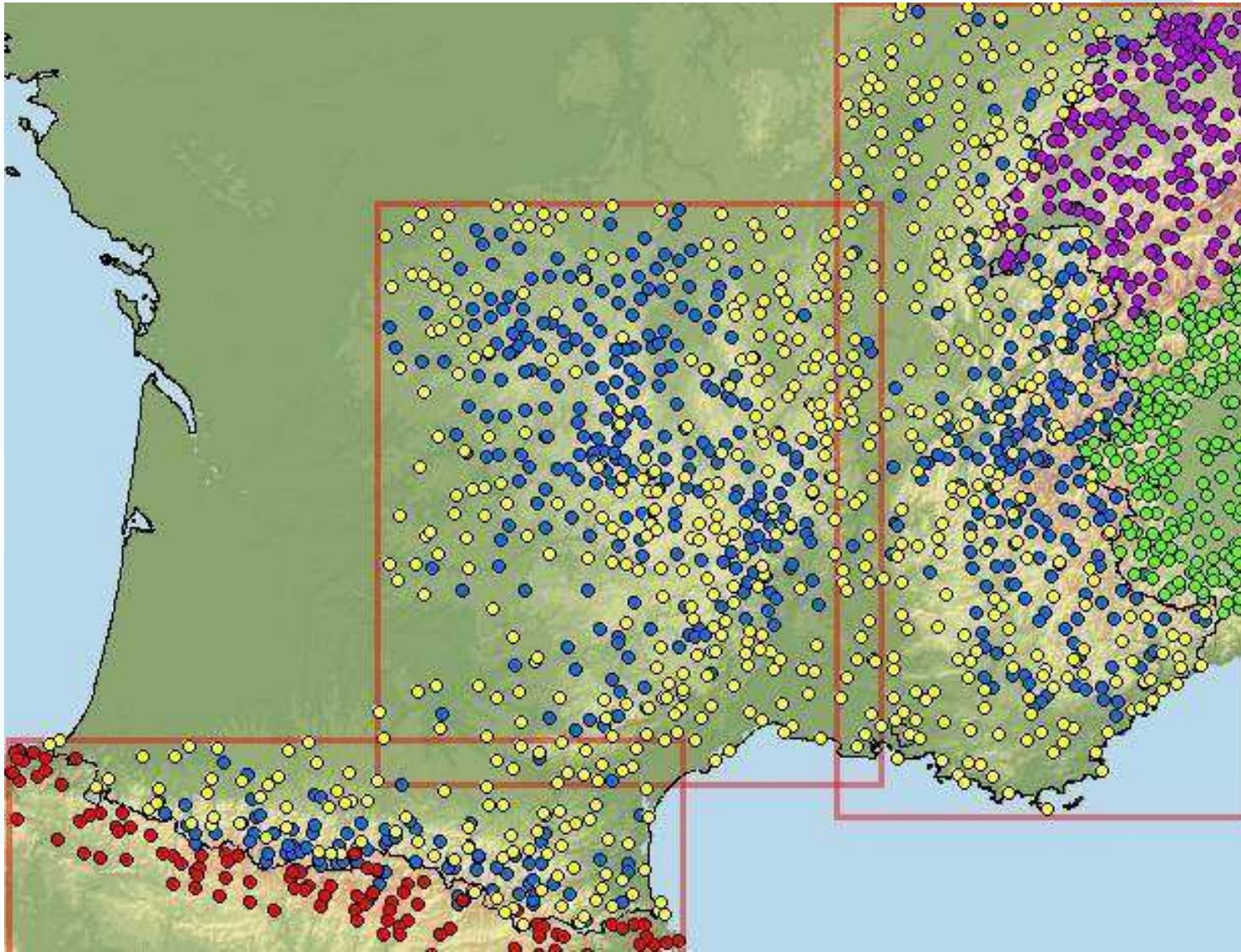


# Base de données





# Pluie : Réseau EDF + Nationaux

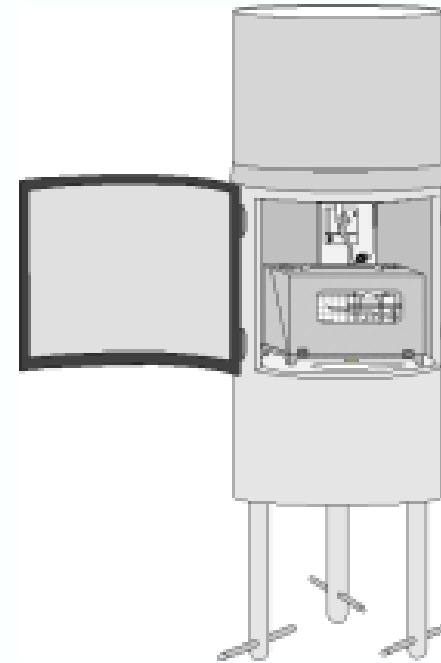




# Synthèse, base de données pluies

## 1885 postes pluviométriques :

- 603 postes EDF/DTG
- 555 postes Météo France
- 213 postes Météo Suisse
- 383 postes ARPA Piémont (Italie)
- 131 postes de l'INM (Espagne)

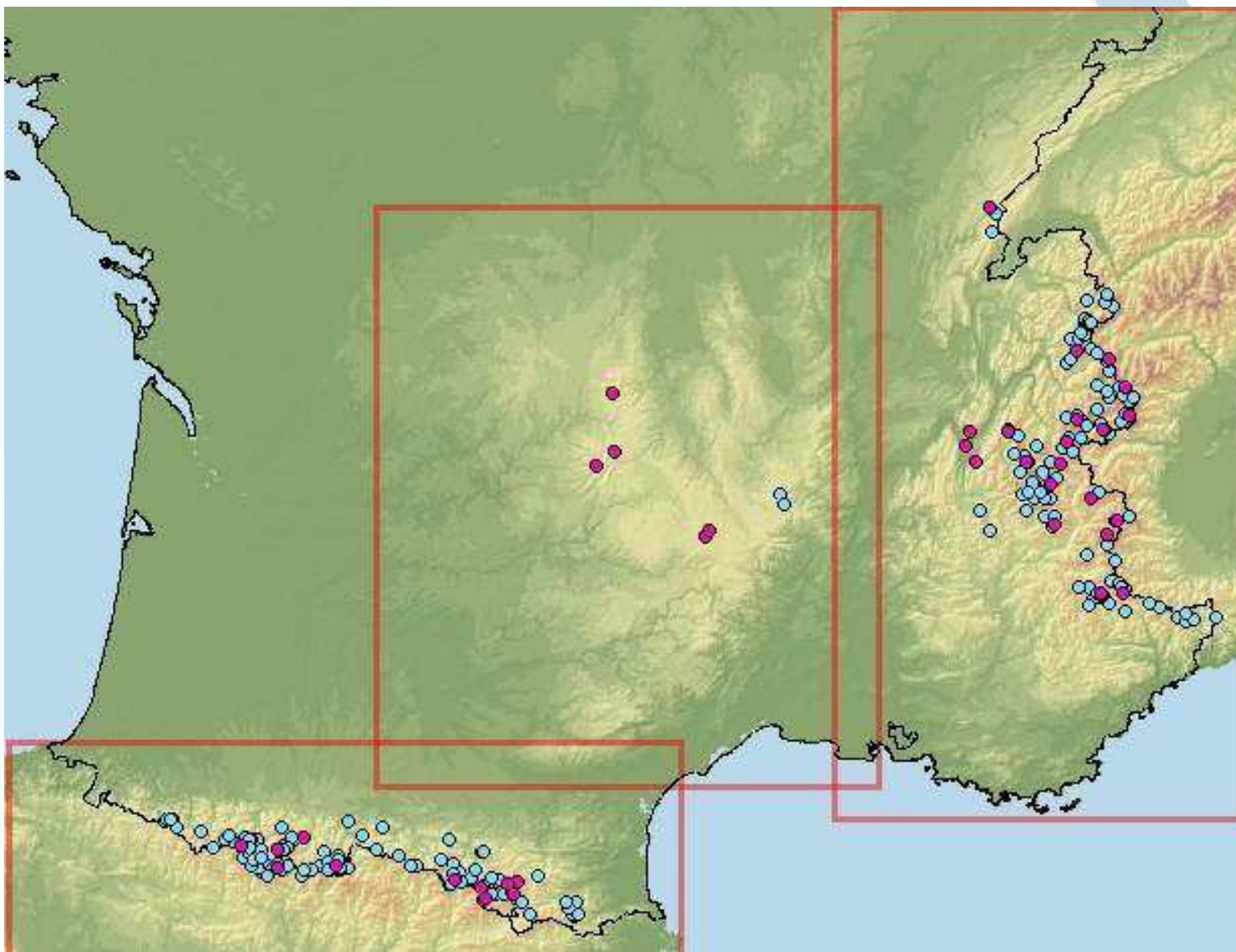


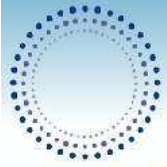
**Séries journalières**

**Période cible : 1948 - 2005**



# Neige : Réseau EDF



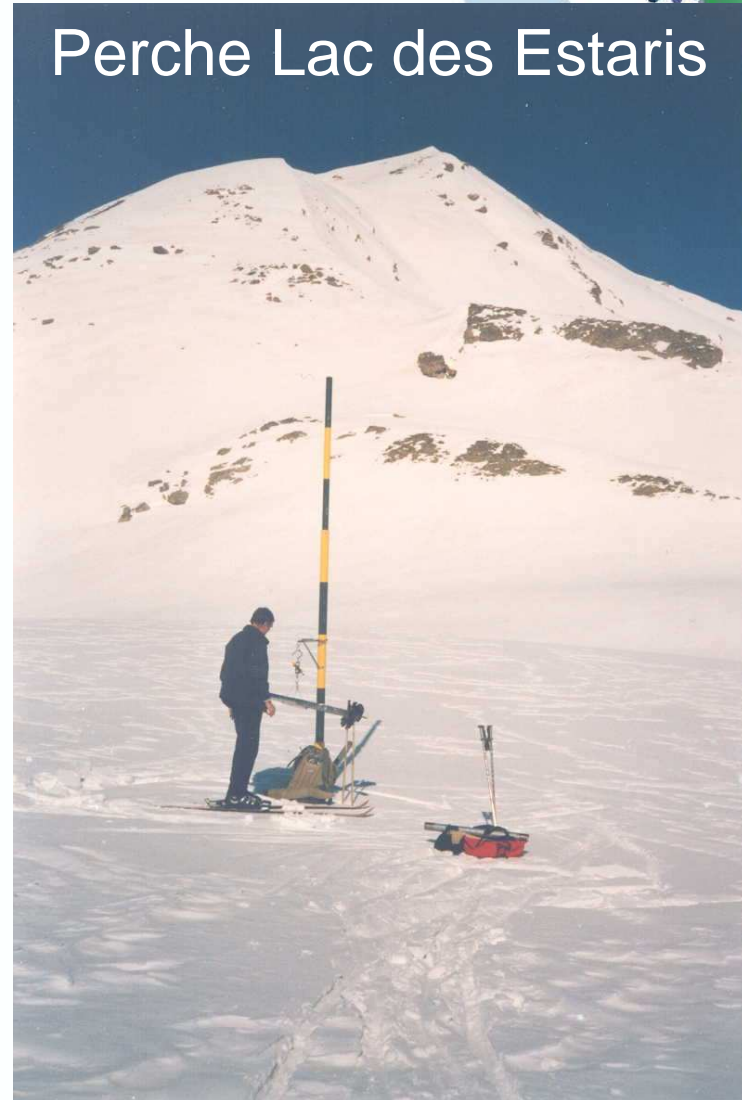


# La perche

Perche Roche Polie



Perche Lac des Estaris





# Le NPT (Nivo-Pluviomètre Totalisateur)

NPT Tré la tête



NPT Izoard



NPT





# Le Télénivomètre

## TLNM des Marrous

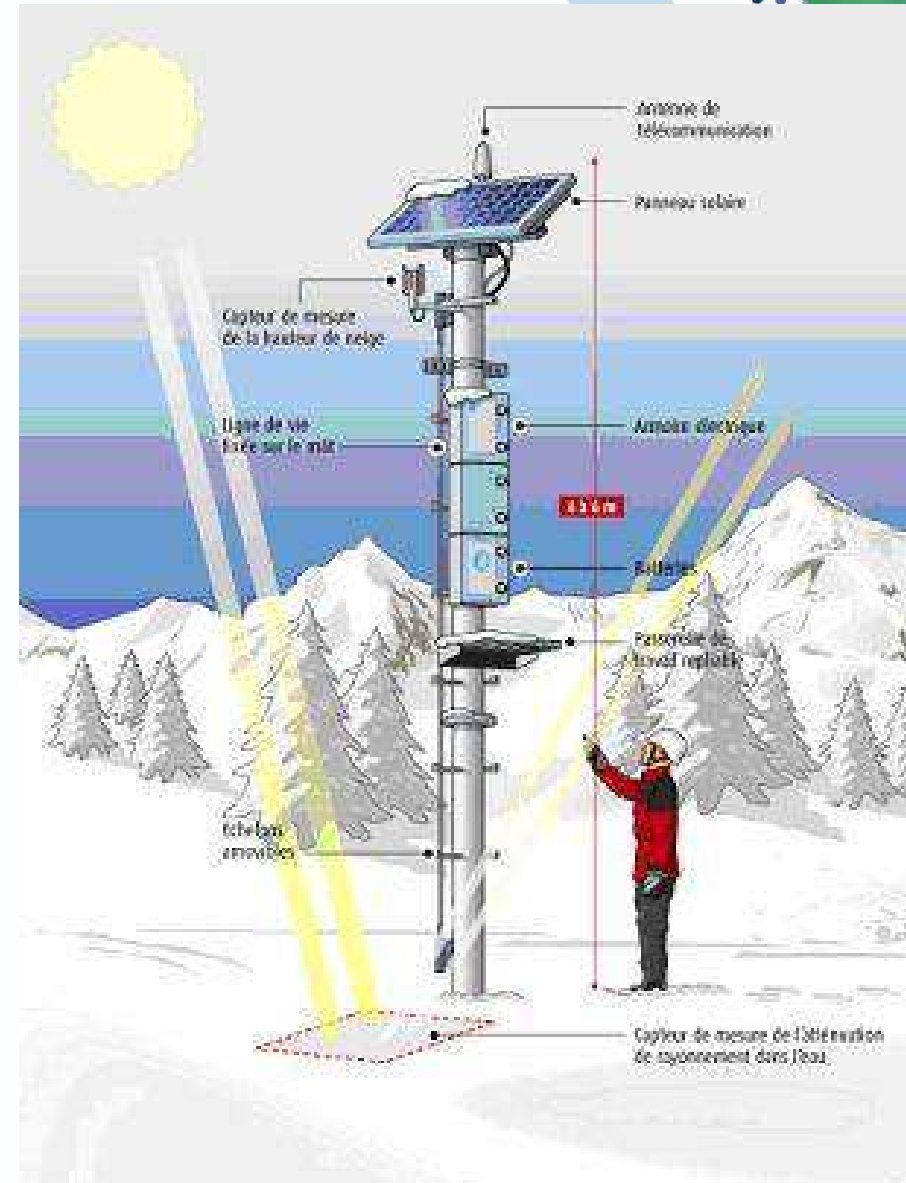






# Le Nivomètre à Rayonnement Cosmique NRC

## NRC Barrada (Pyrénées)





# Synthèse, base de données neige



## ~ 650 postes d'observation EDF :

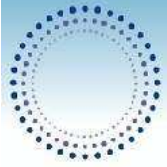
- |   |            |                  |
|---|------------|------------------|
| ▪ ~ 325 Sondages (Perches)                  | Mensuel    | <b>1948-2008</b> |
| ▪ ~ 230 NPT (Nivo Pluvio Totalisateur)      | Annuel     | <b>1948-1975</b> |
| ▪ 48 Télénivomètres                         | Journalier | <b>1983-2003</b> |
| ▪ 36 NRC (Nivomètre à rayonnement cosmique) | Journalier | <b>1999-2008</b> |





# Première estimation des précipitations journalières



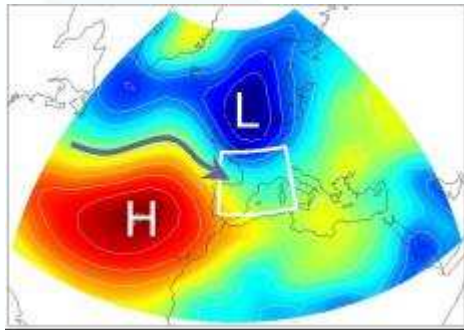


# Une Classification en *Types de Temps*

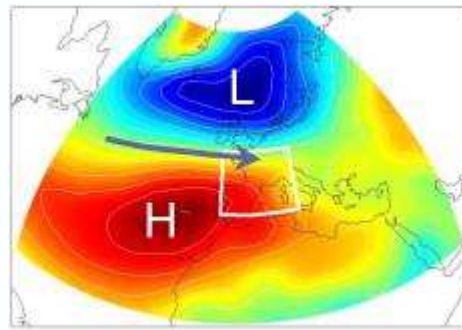
(Paquet et al., 2006)



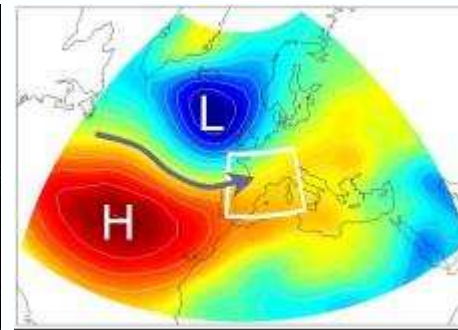
Classe 1  
**Onde atlantique**



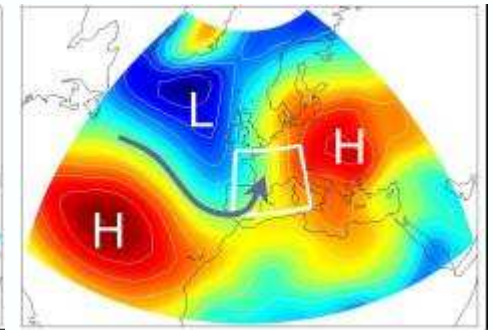
Classe 2  
**Flux atlantique stationnaire**



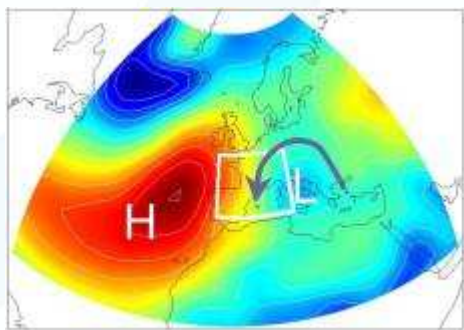
Classe 3  
**Circulation de Sud-Ouest**



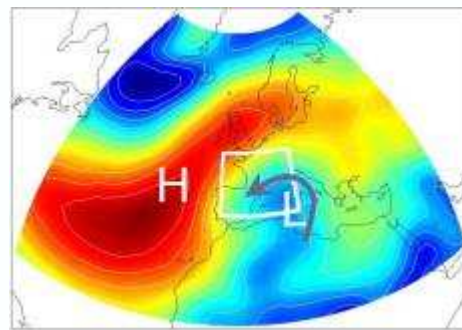
Classe 4  
**Circulation de Sud**



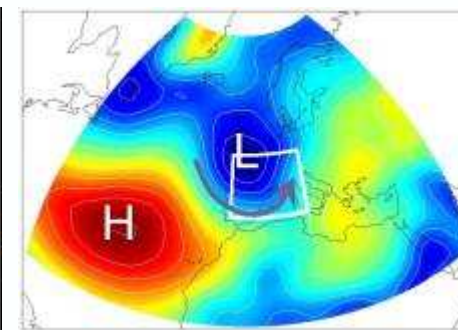
Classe 5  
**Circulation de Nord-Est**



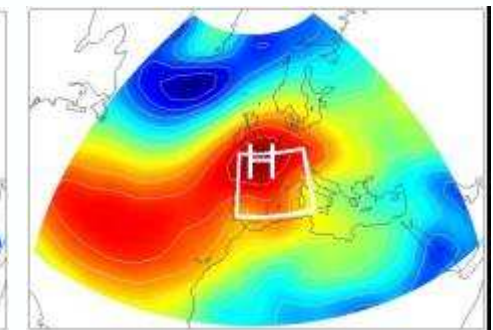
Classe 6  
**Retour d'Est**

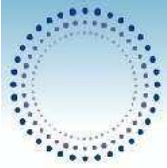


Classe 7  
**Dépression centrale**



Classe 8  
**Anticyclonique centrale**

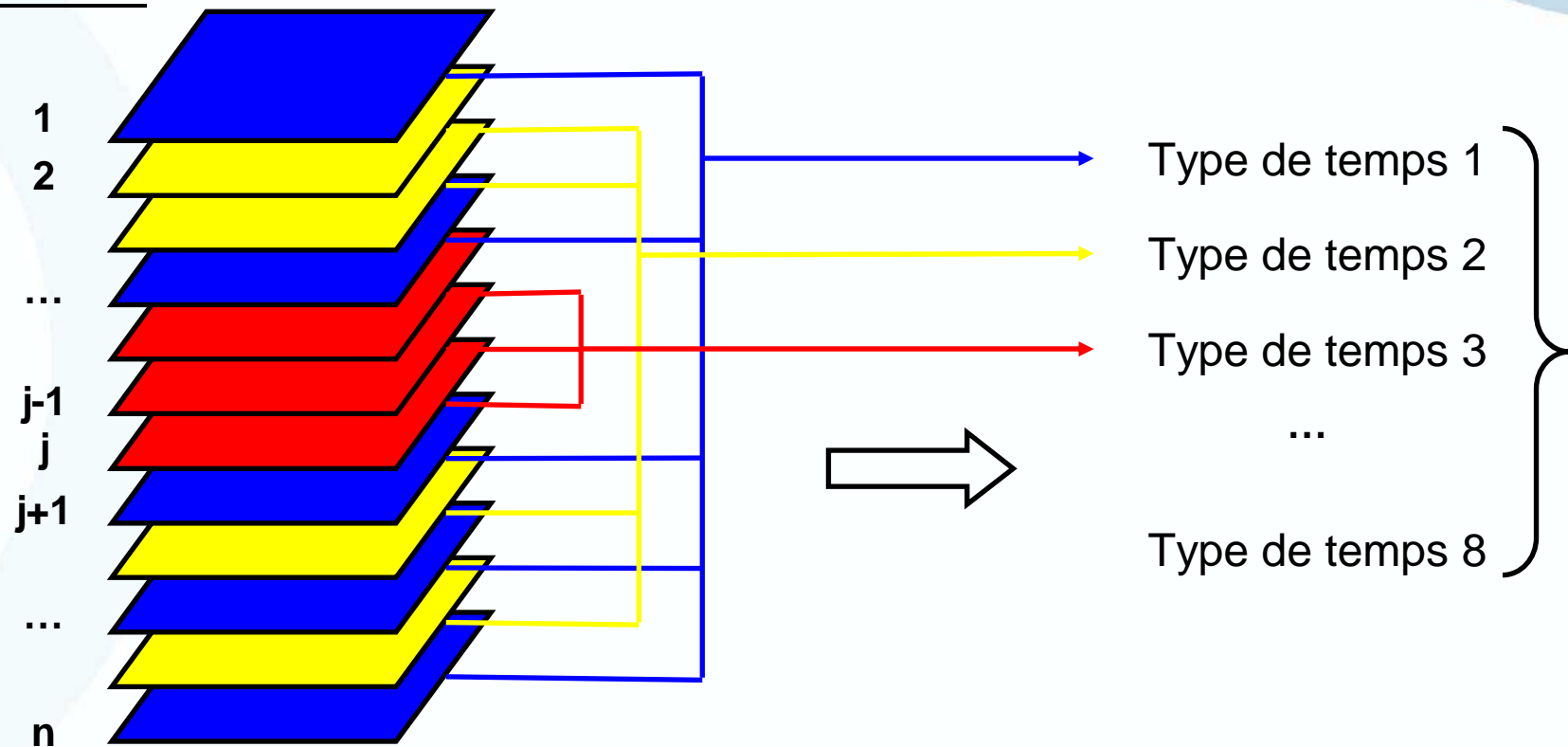




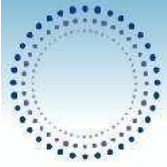
# Ébauche de précipitation par type de temps

**Ébauche** = champ de précipitation moyen journalier estimé sur toutes les journées d'un **type de temps**

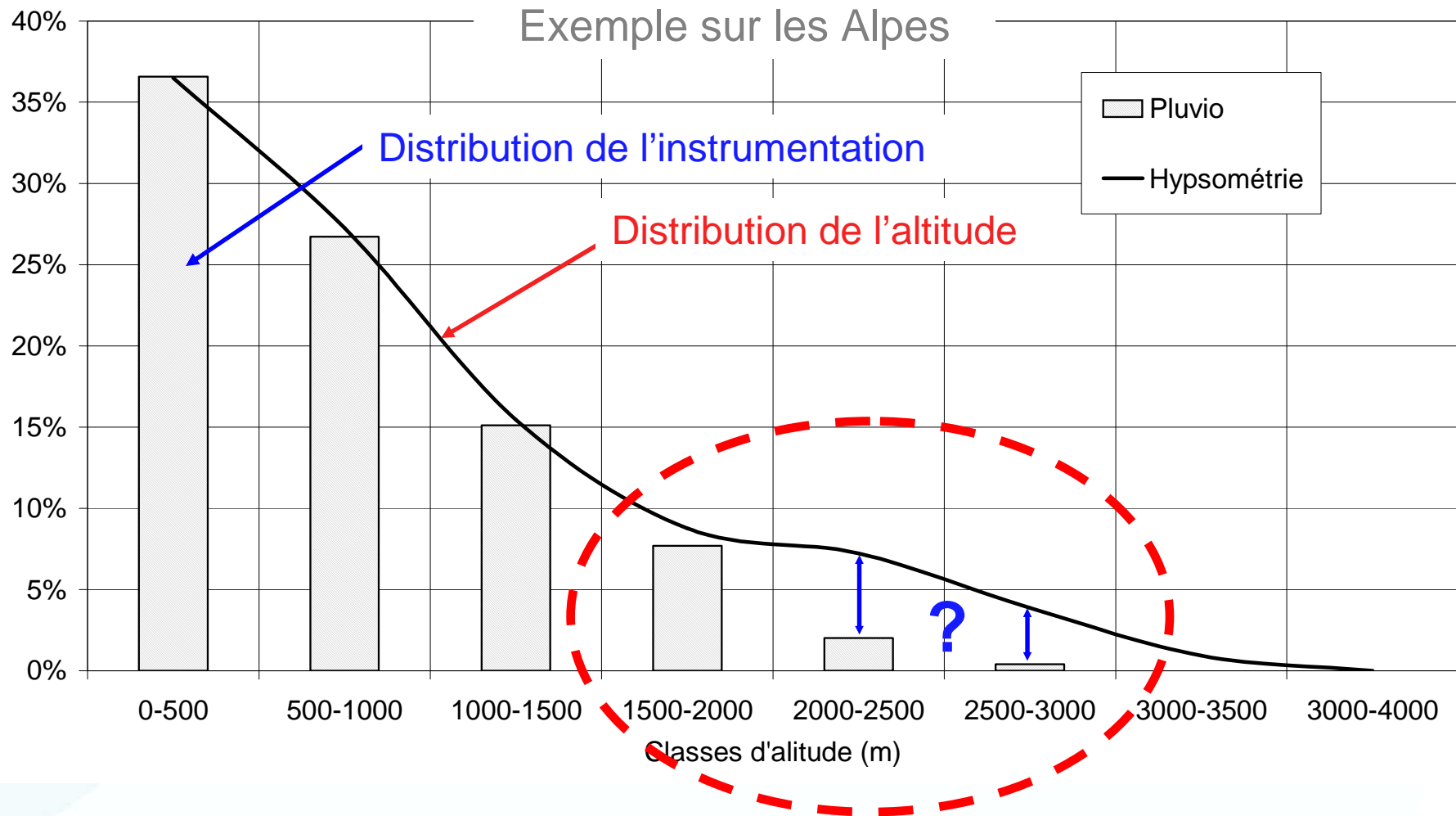
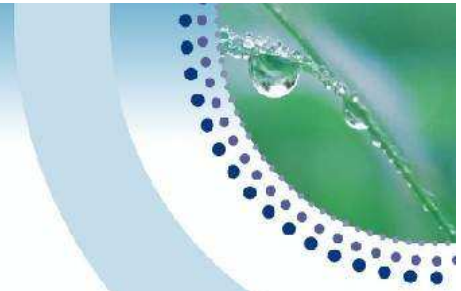
Journées

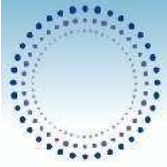


⇒ Construction de 8 Ébauches

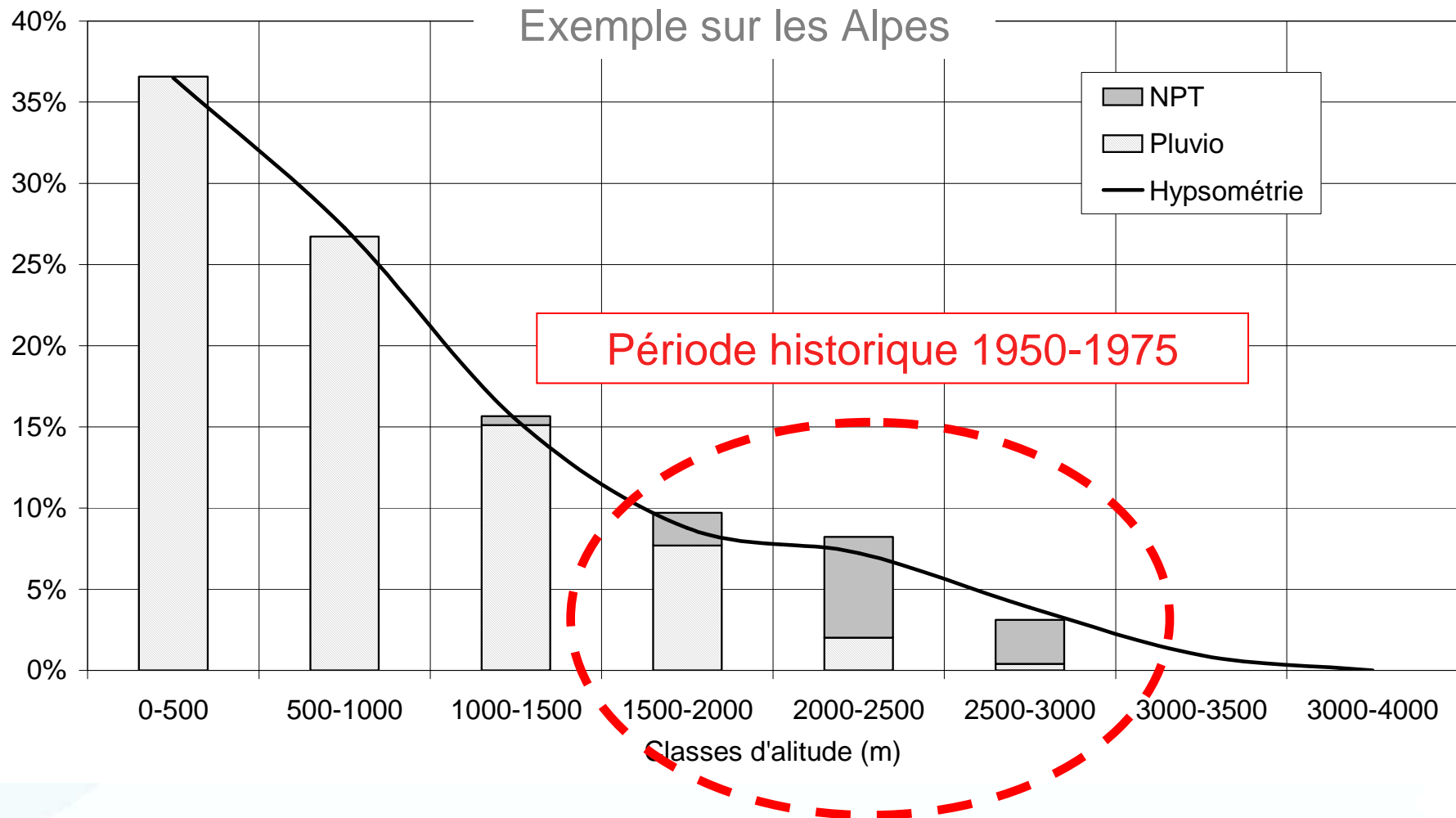
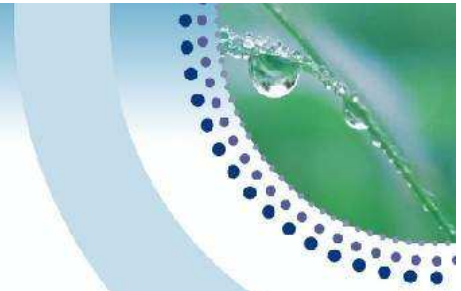


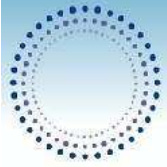
# Avec quelles données ?



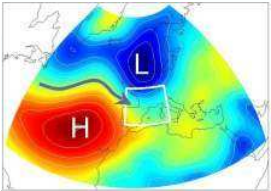


# Avec quelles données ?

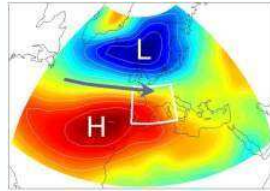




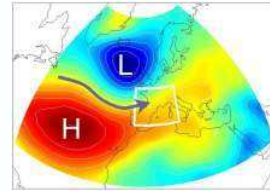
# 8 ébauches par type de temps



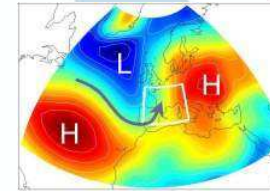
TT1



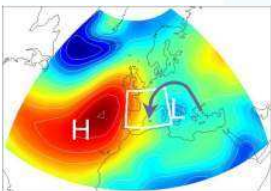
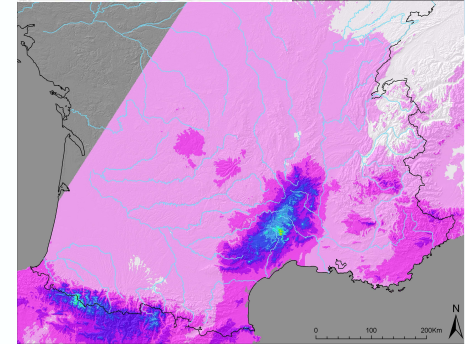
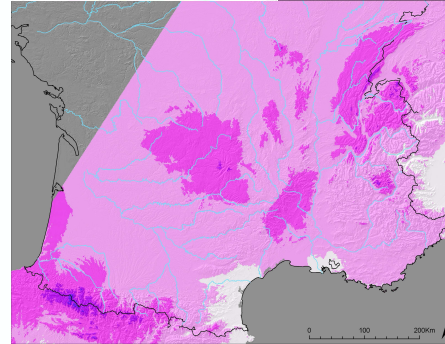
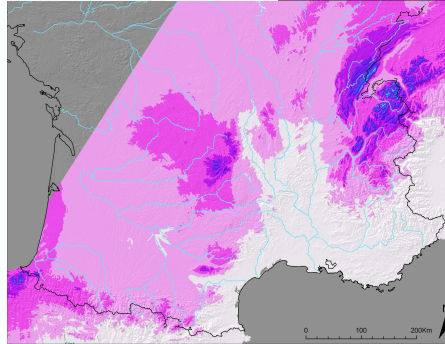
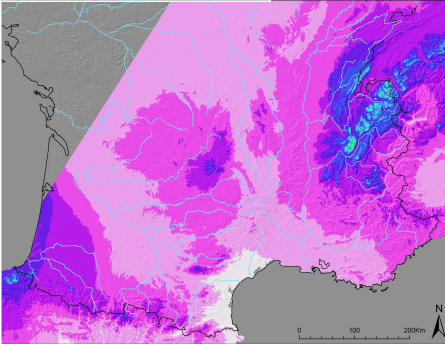
TT2



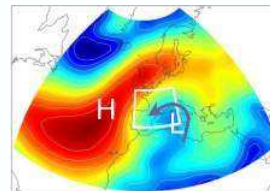
TT3



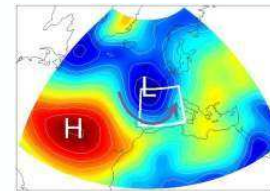
TT4



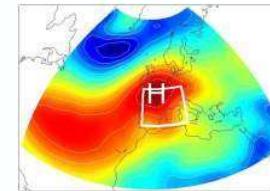
TT5



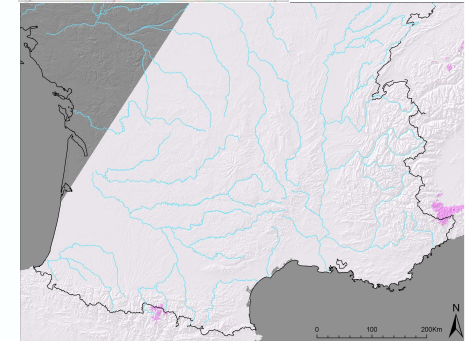
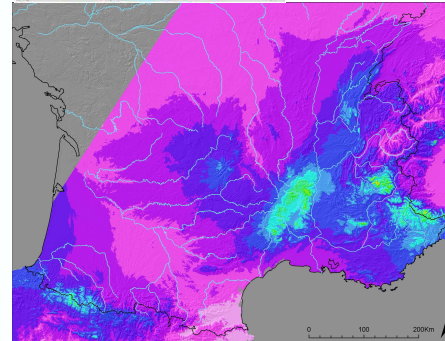
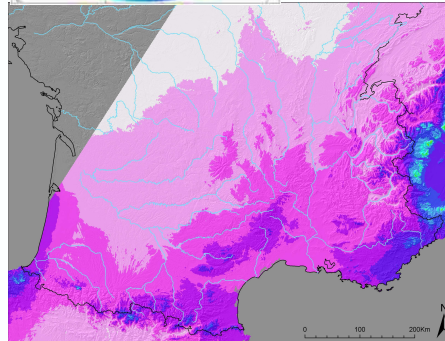
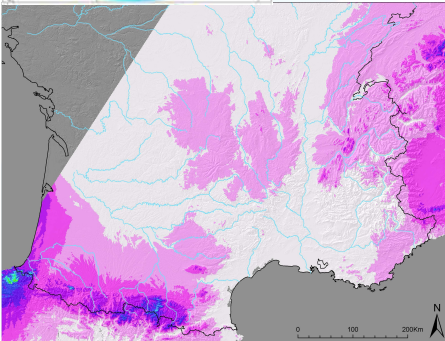
TT6



TT7



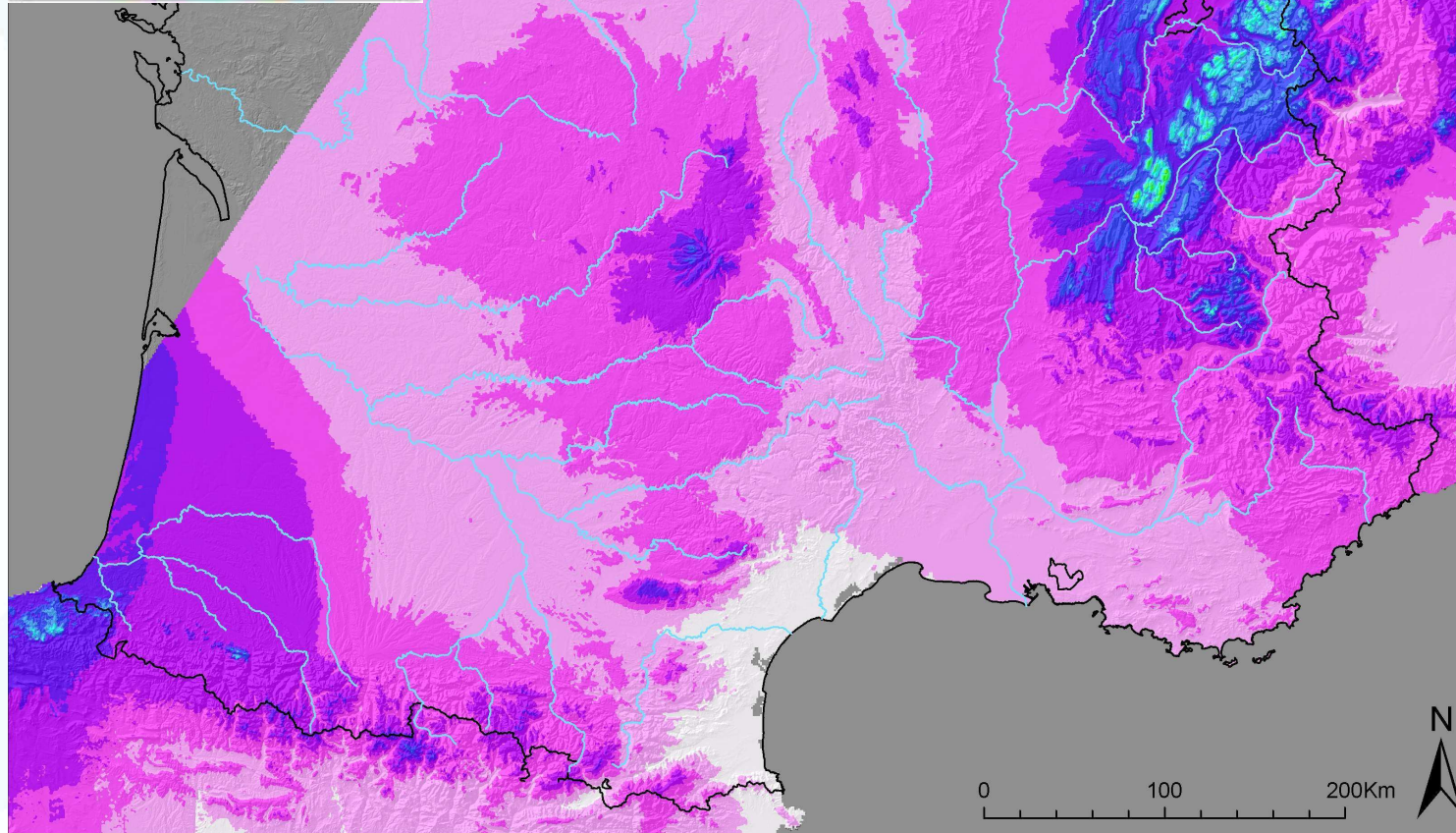
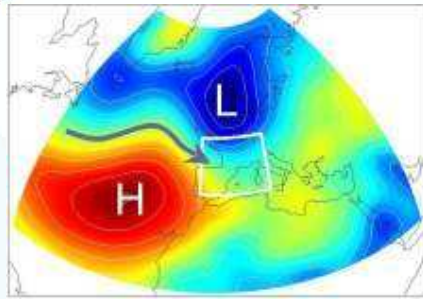
TT8



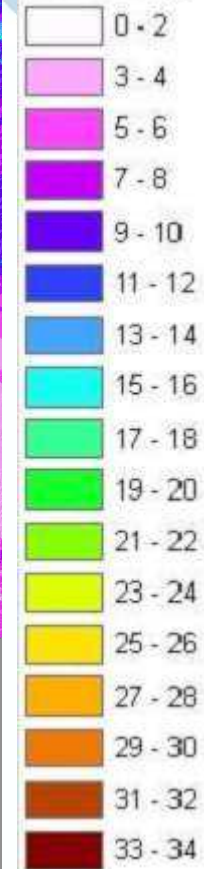


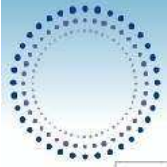


# Ébauche TT1 : Onde Atlantique

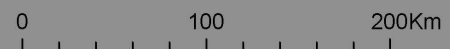
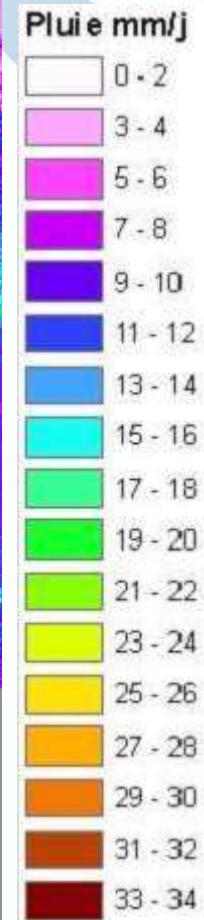
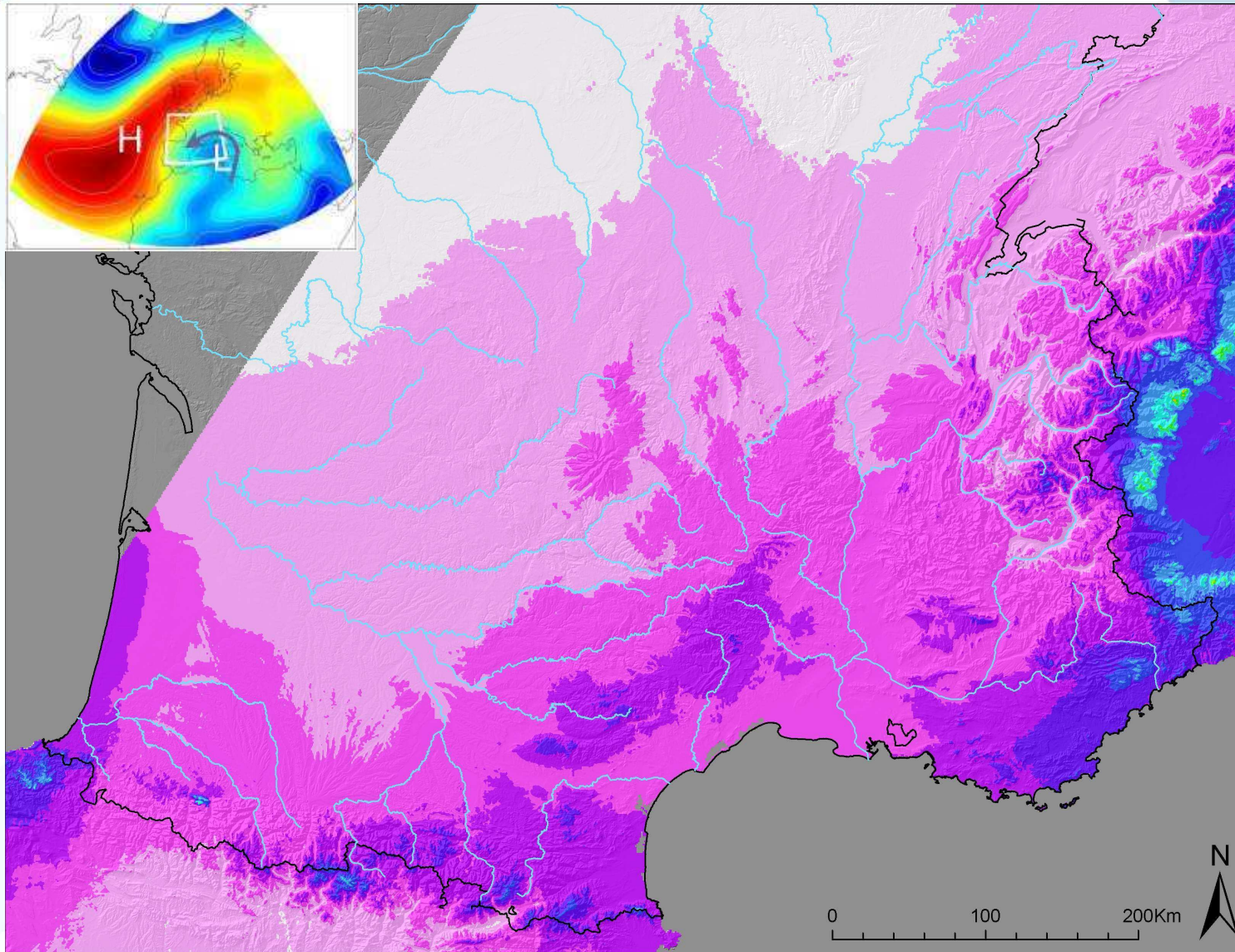
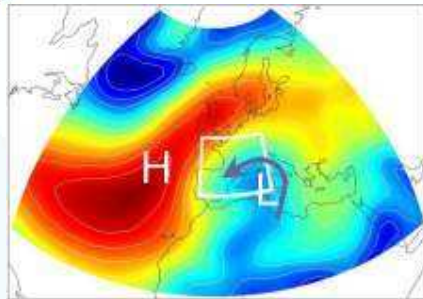


Pluie mm/j



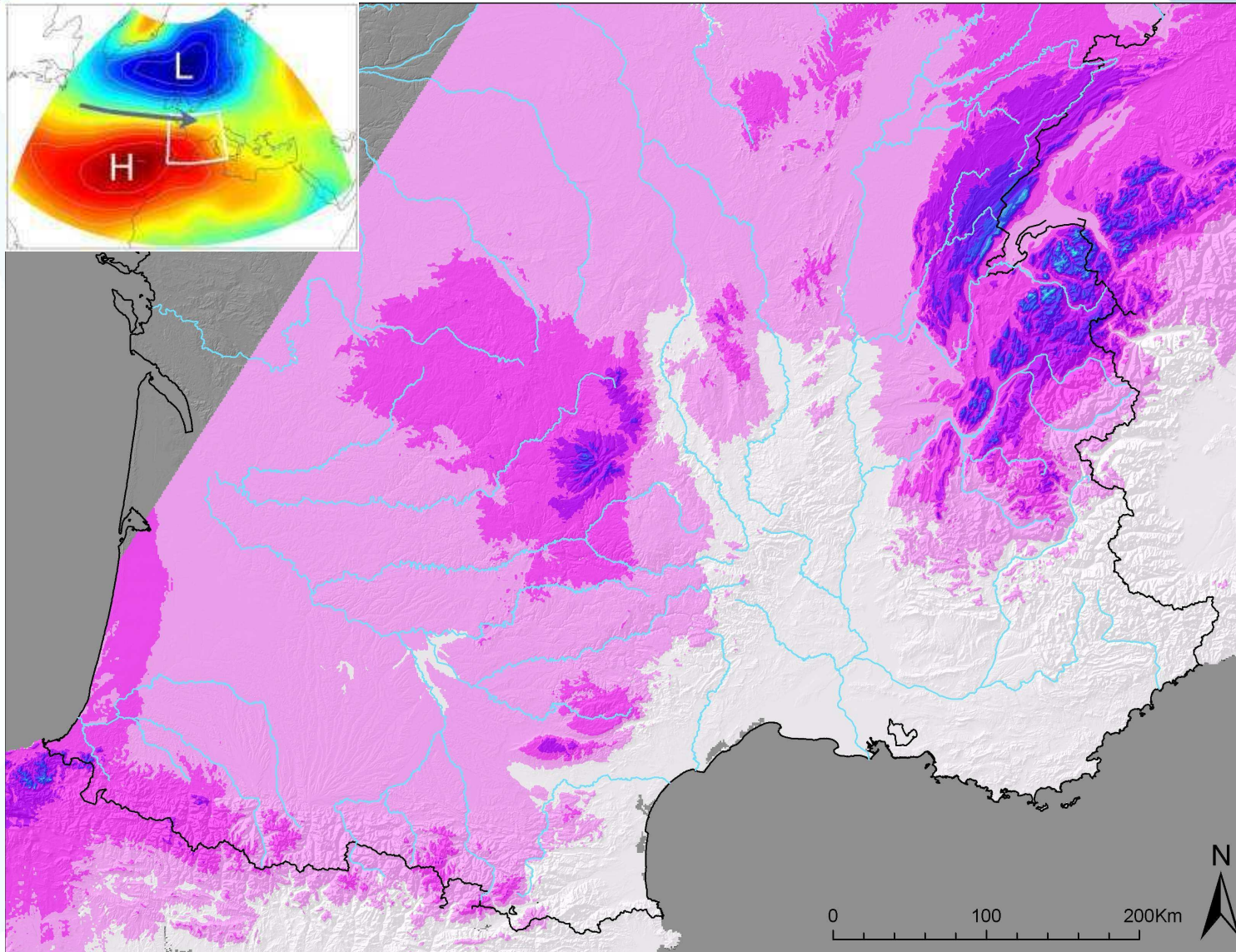
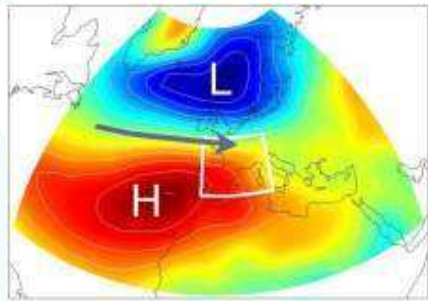


# Ébauche TT6 : Retour d'Est

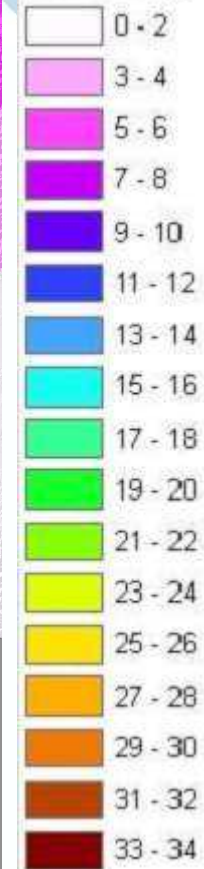




# Ébauche TT2 : Flux atlantique stationnaire



Pluie mm/j

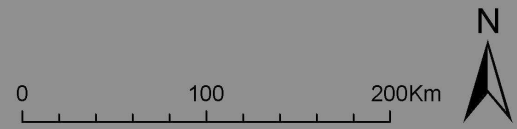
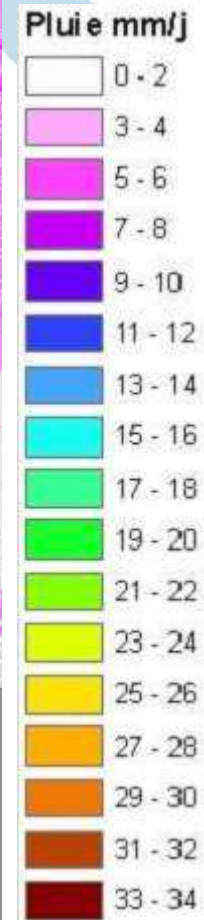
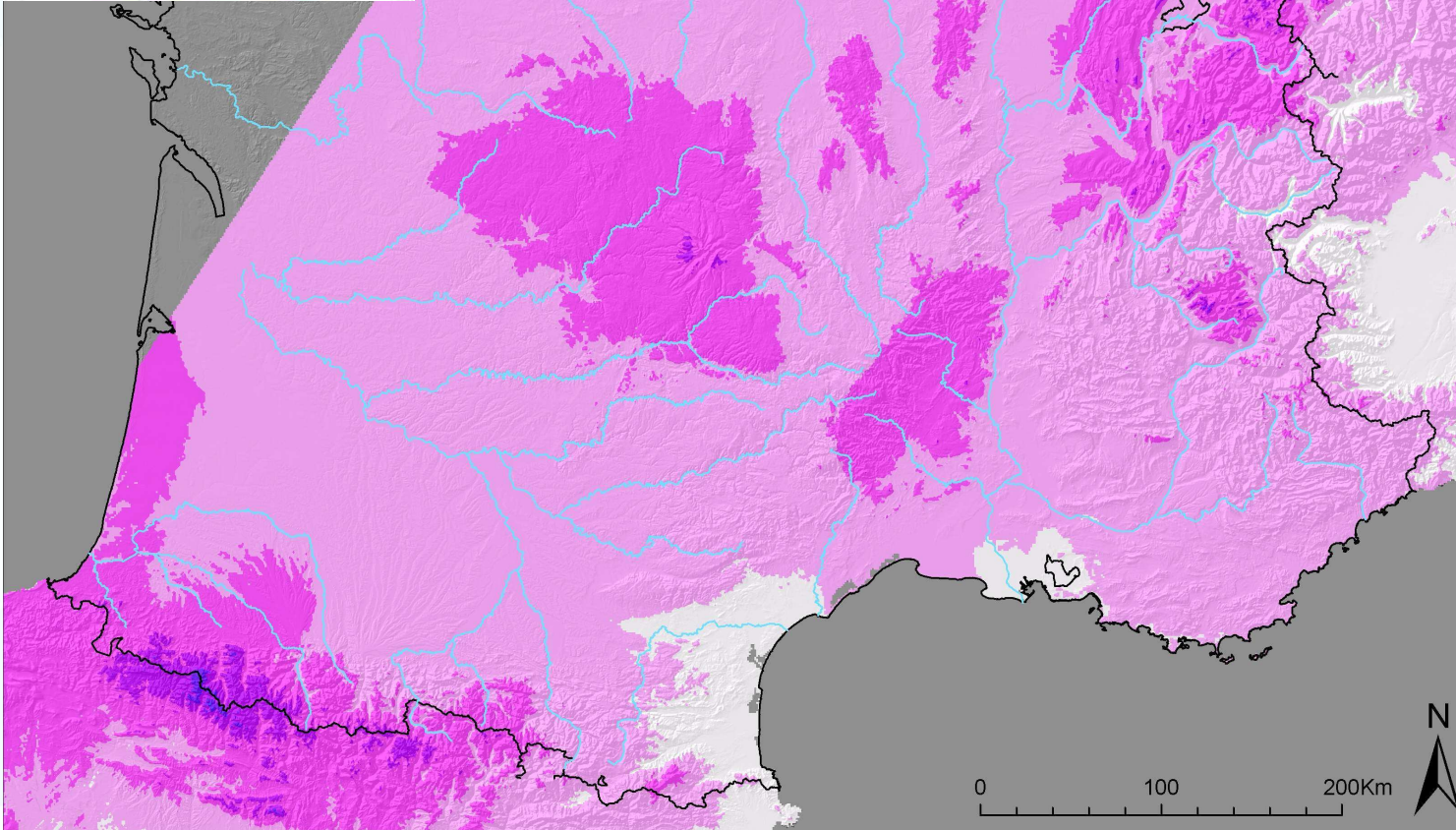
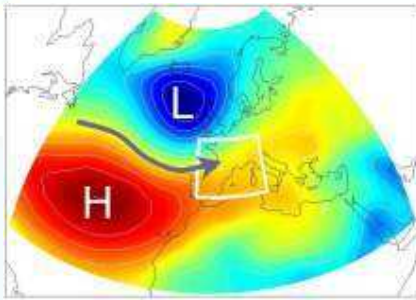


0 100 200Km



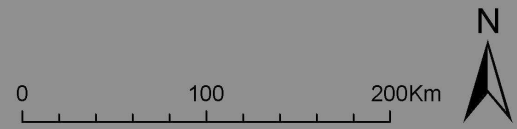
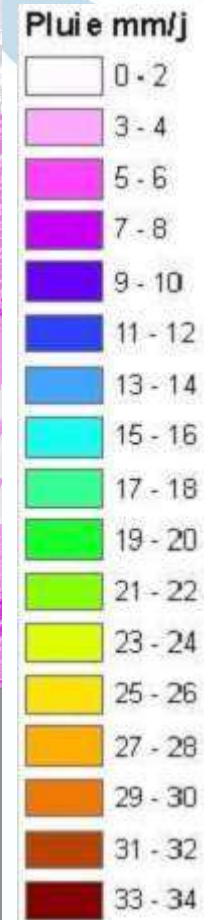
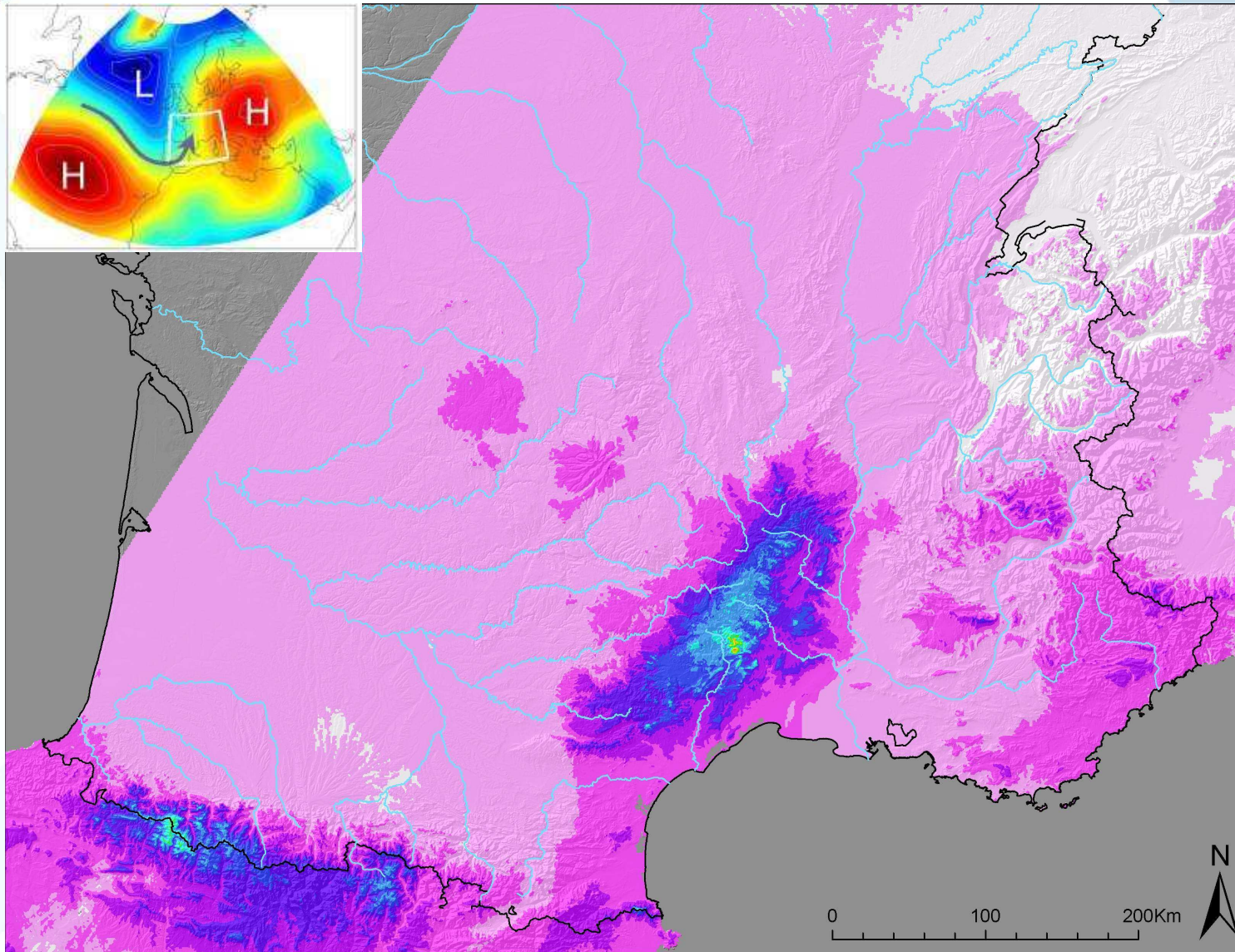
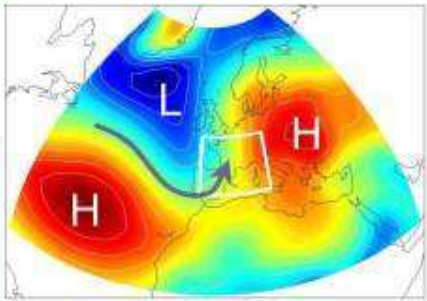


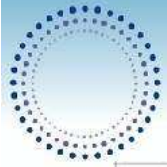
# Ébauche TT3 : Circulation de Sud-Ouest



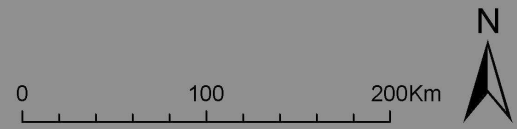
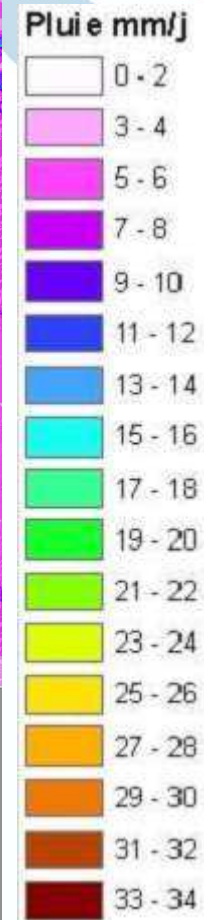
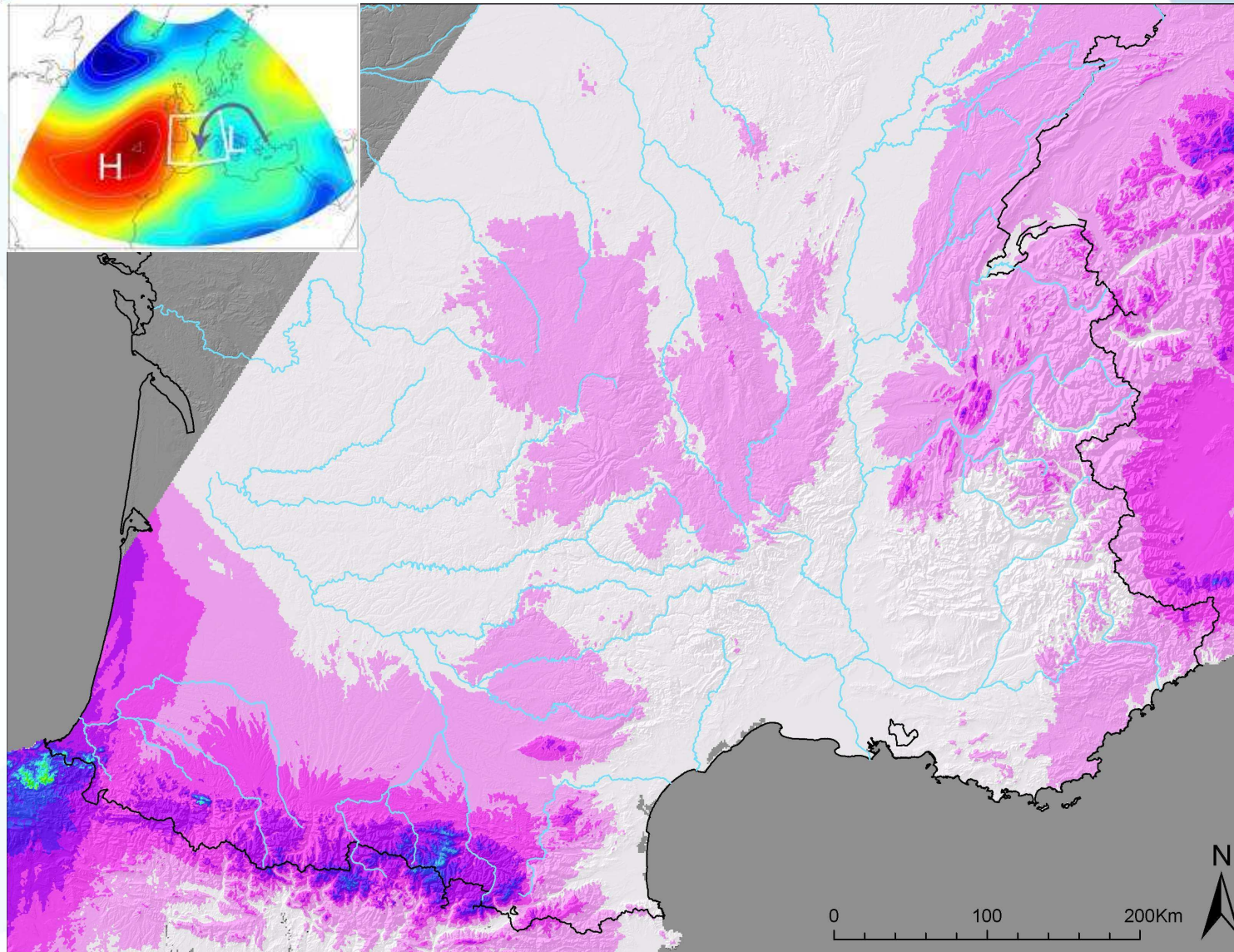
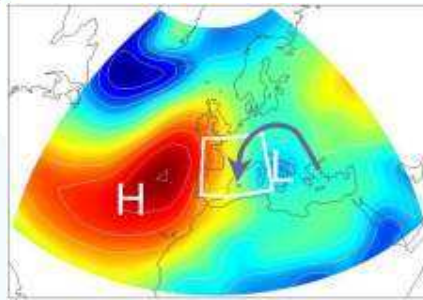


# Ébauche TT4 : Circulation de Sud



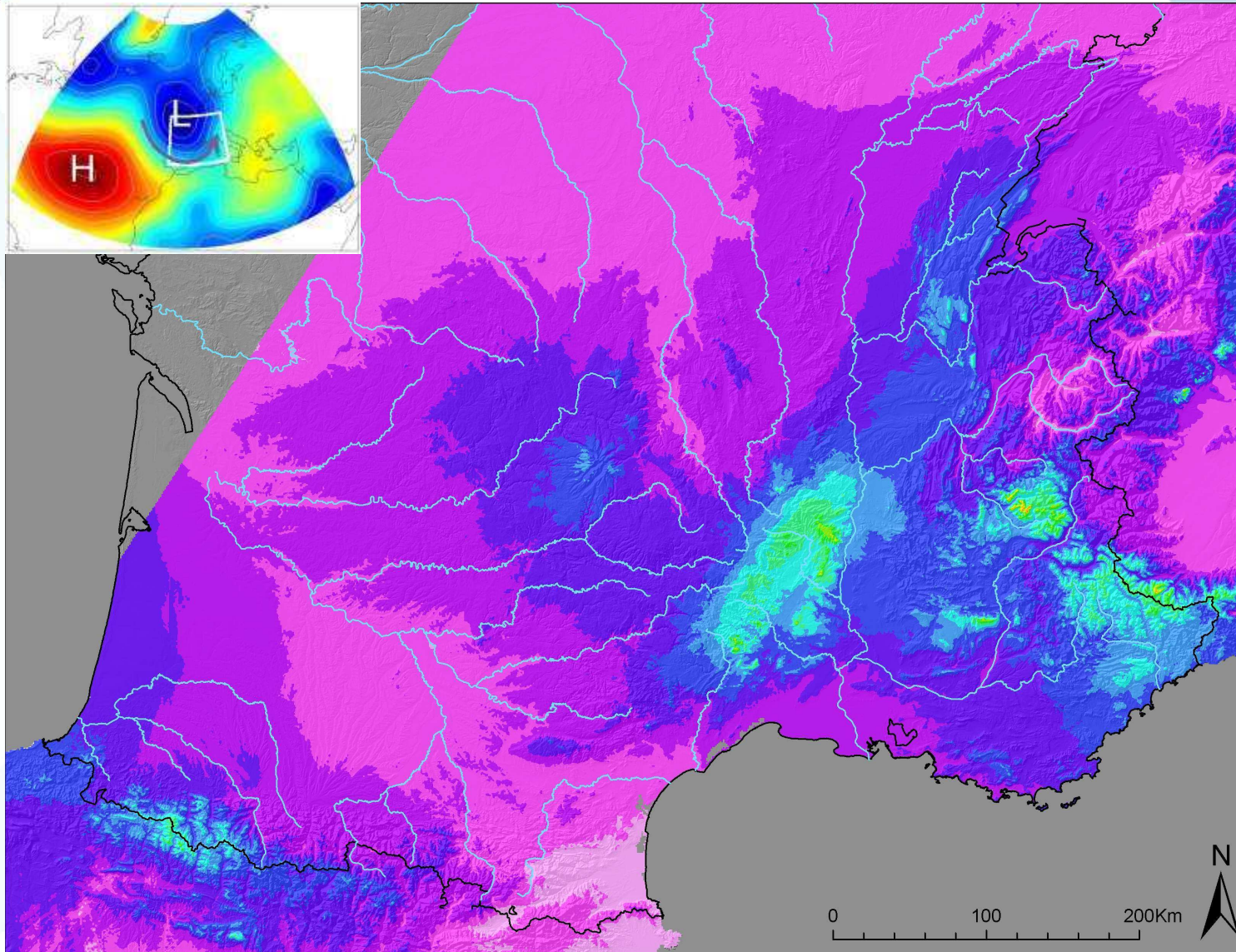
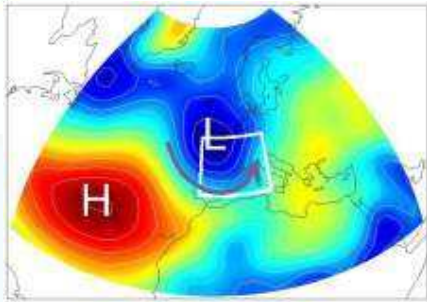


# Ébauche TT5 : Circulation de Nord-Est

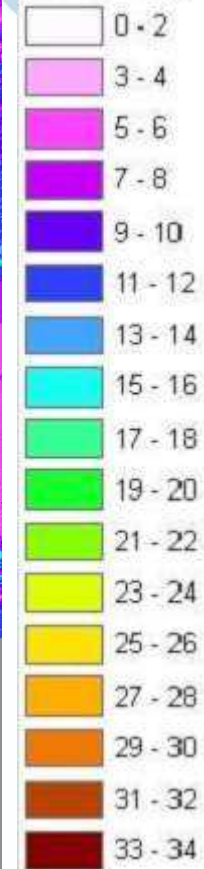




# Ébauche TT7 : Dépression Centrale



Pluie mm/j

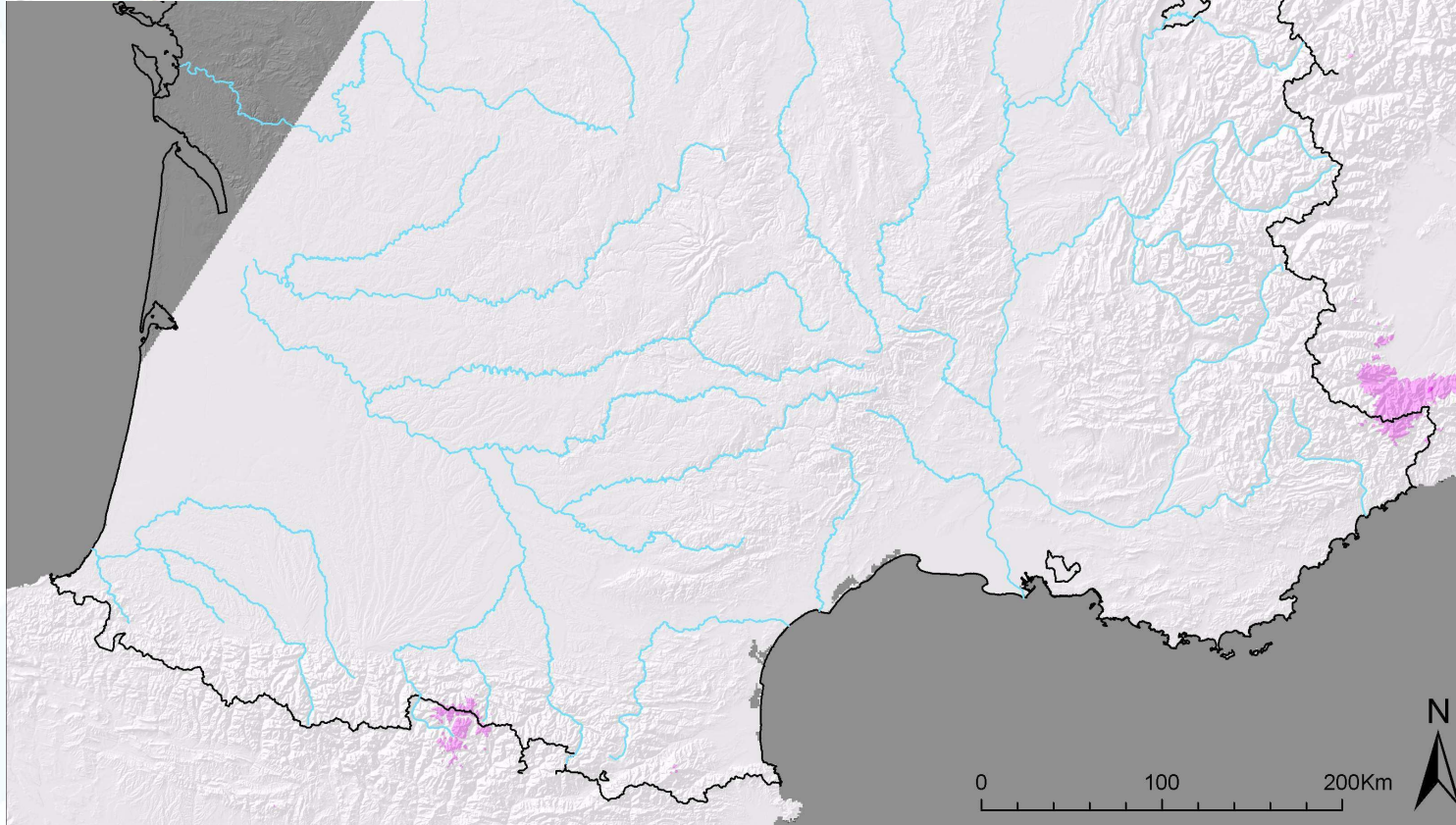
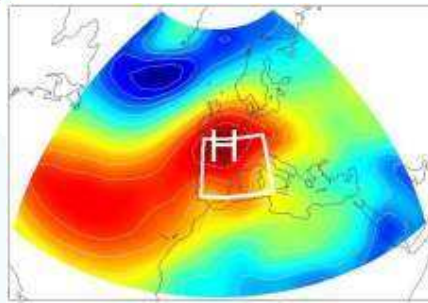


0 100 200Km

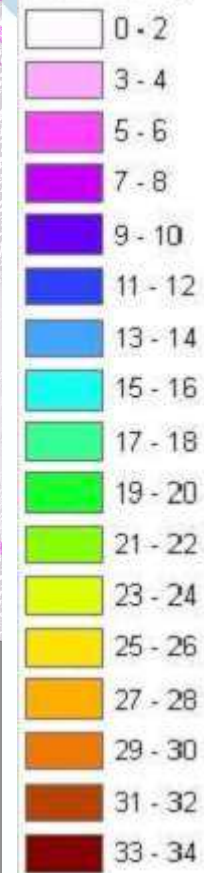




# Ébauche TT8 : Anticyclonique



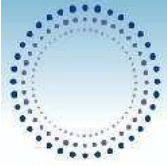
Pluie mm/j



0 100 200Km







# Ébauches de précipitation

Identifier les structures moyennes par type de temps sur un **historique** bien instrumenté (1957-1973)

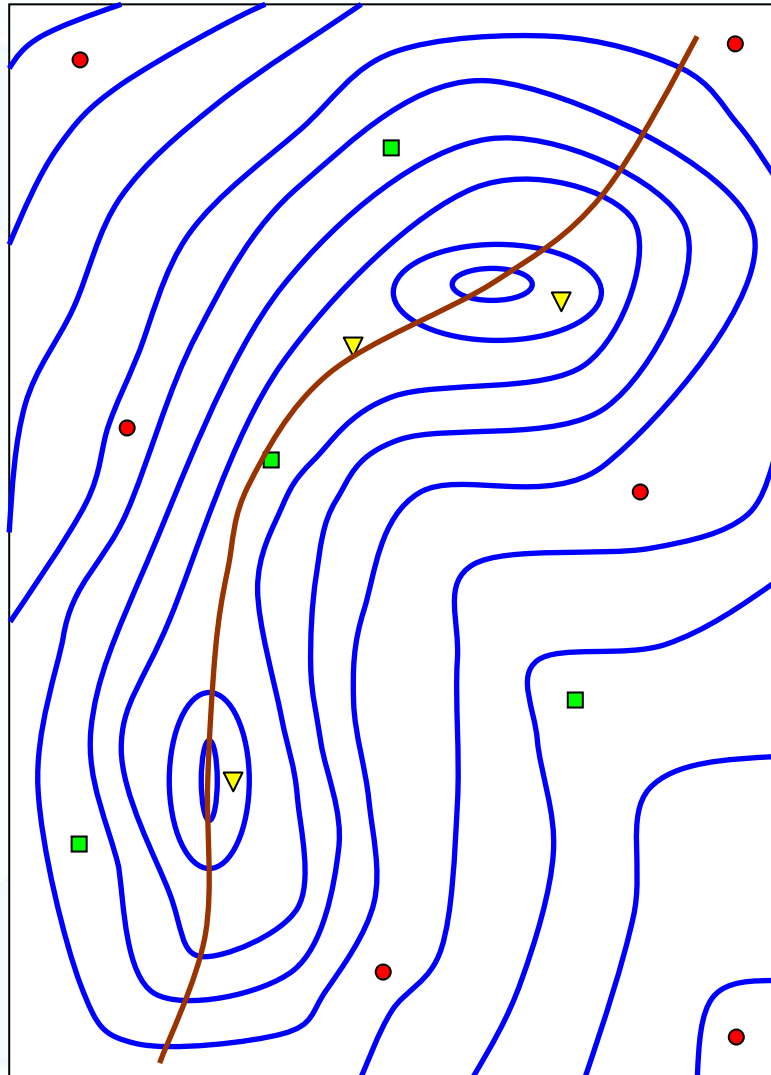
Structures = Ébauches

Utiliser ces ébauches  
pour estimer les précipitations journalières

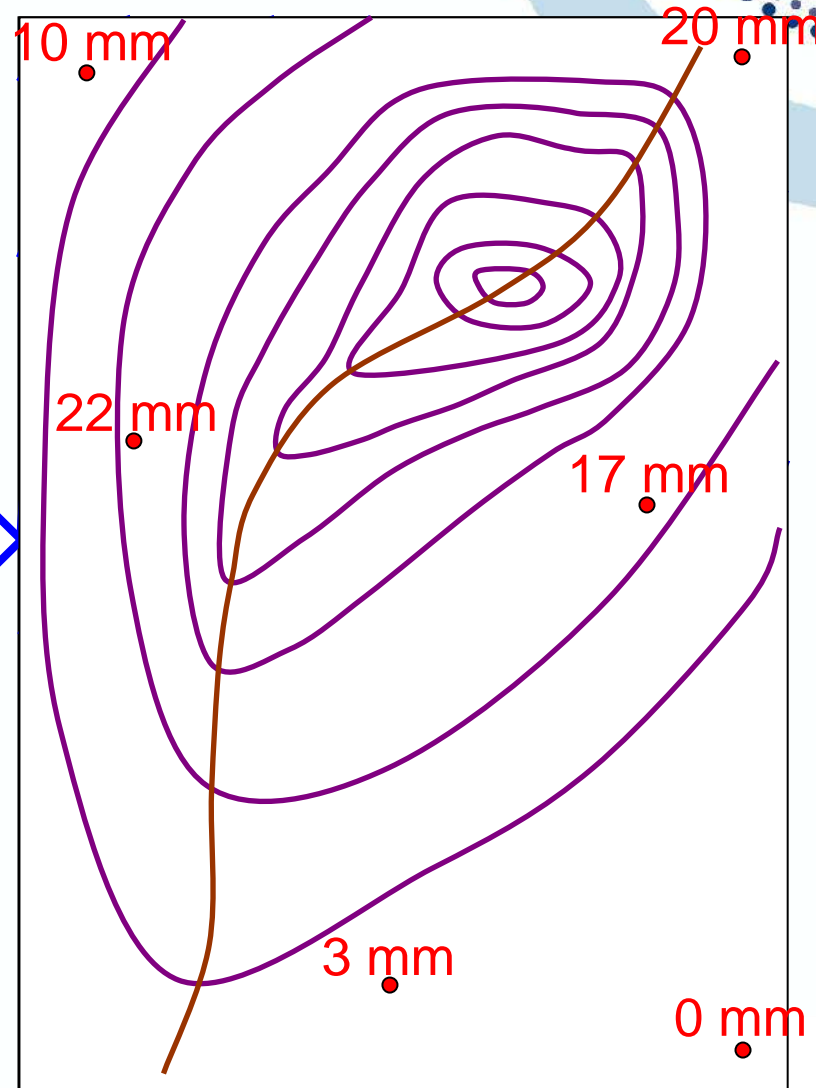


# Utilisation des ébauches

Ébauche TTK



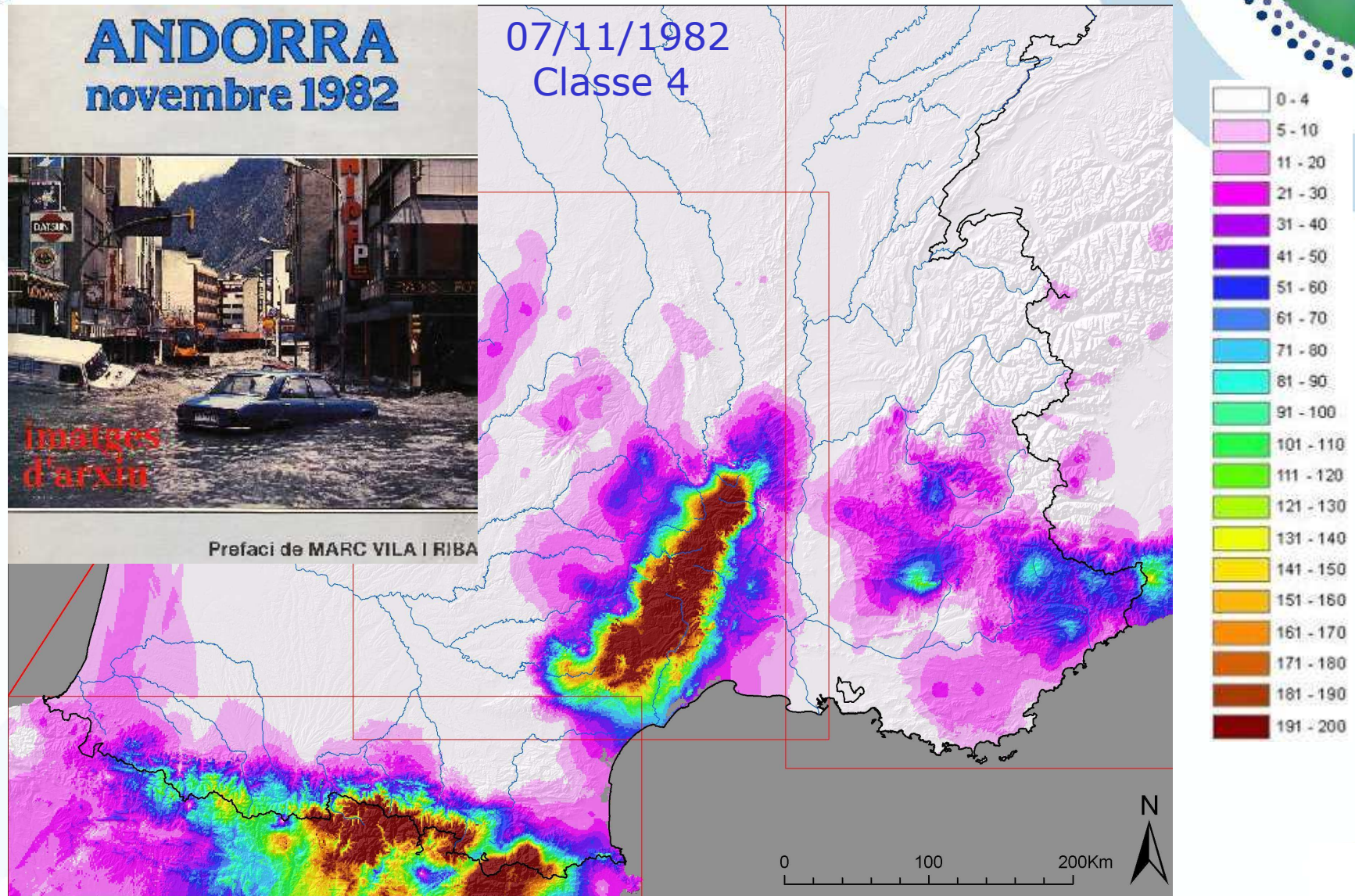
Jour J (TTk)



**+ krigeage des résidus**

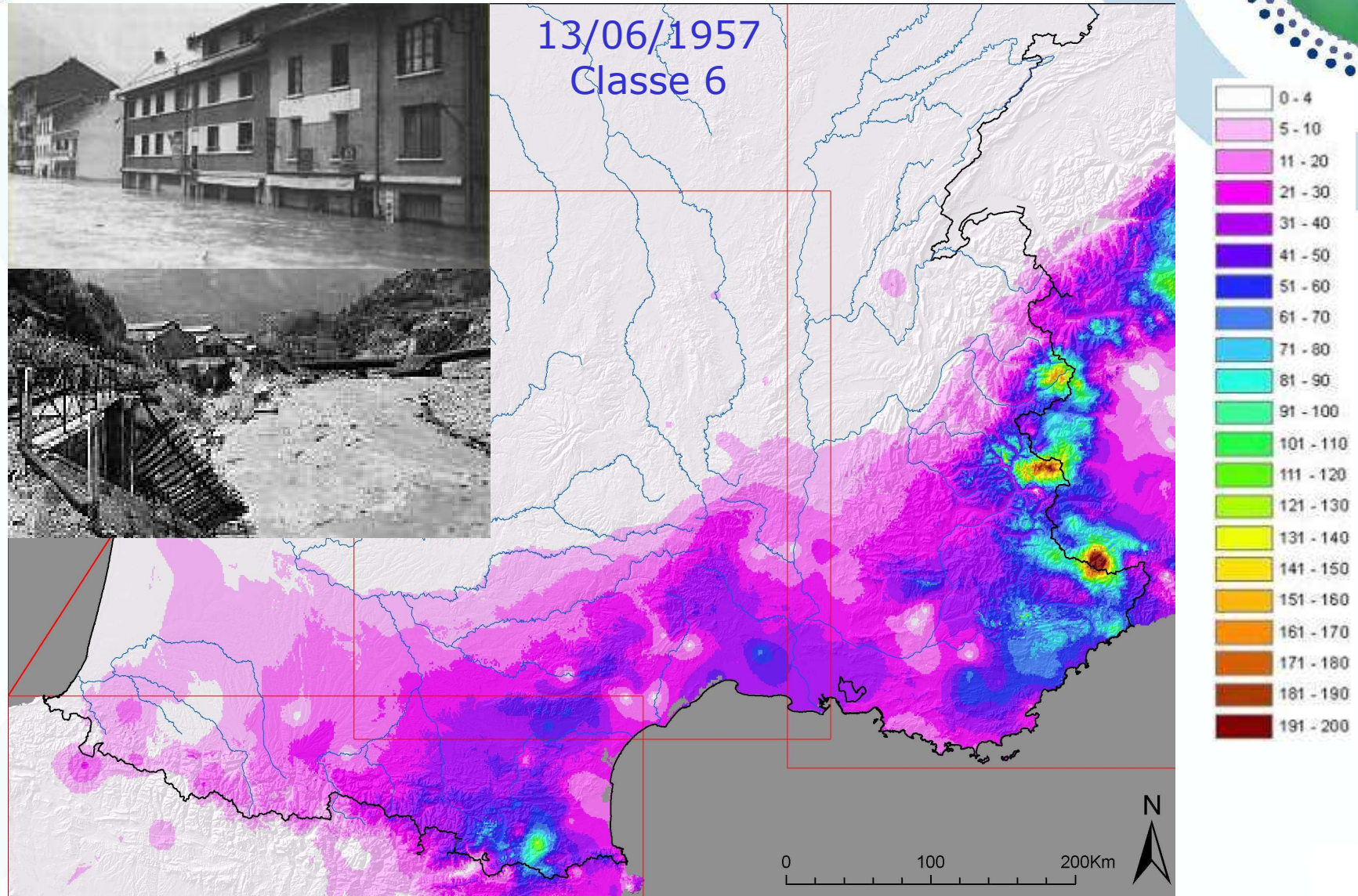


# Cartographie journalière des précipitations (1)



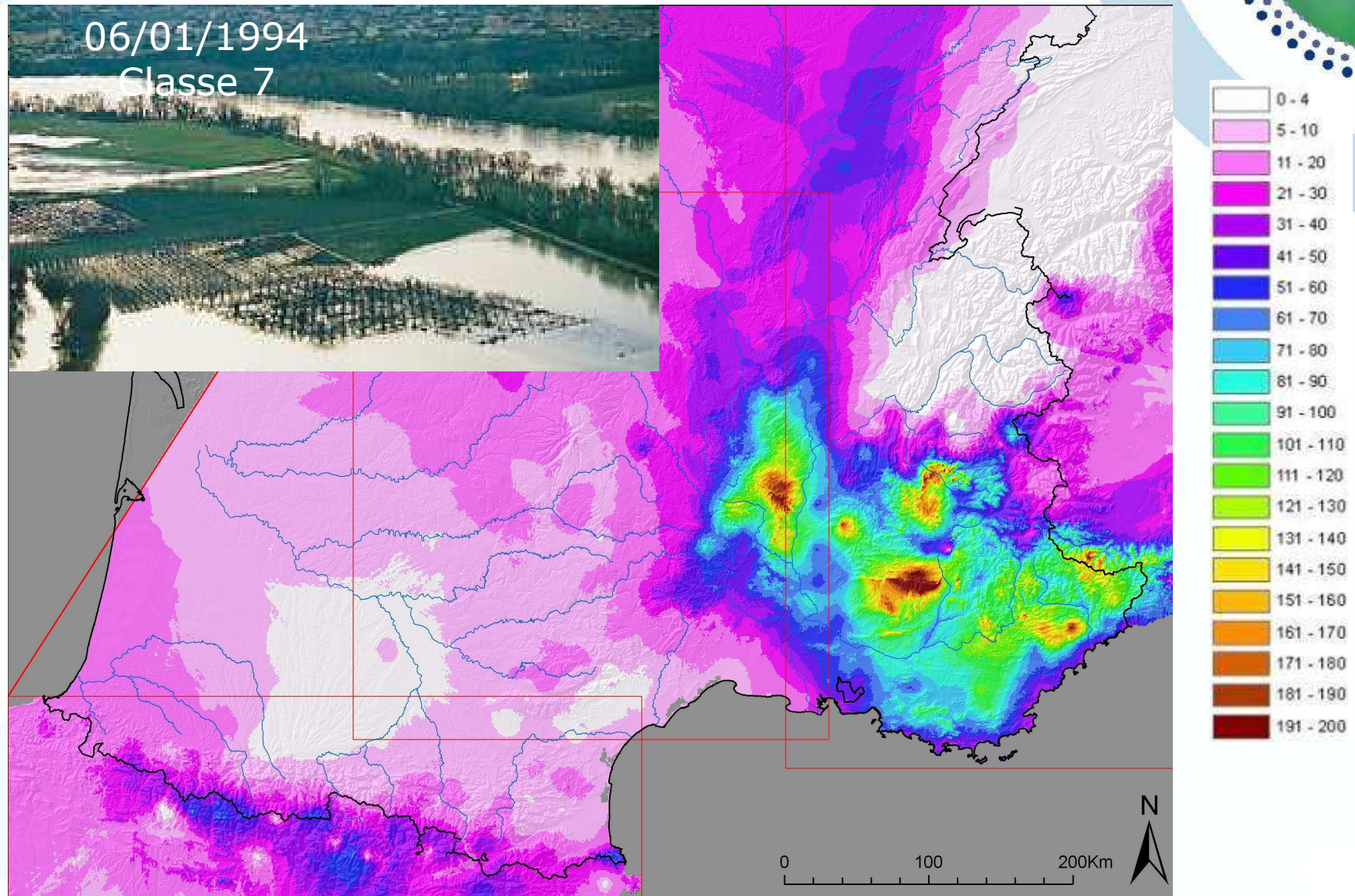


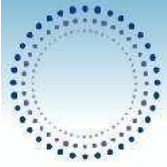
# Cartographie journalière des précipitations (2)





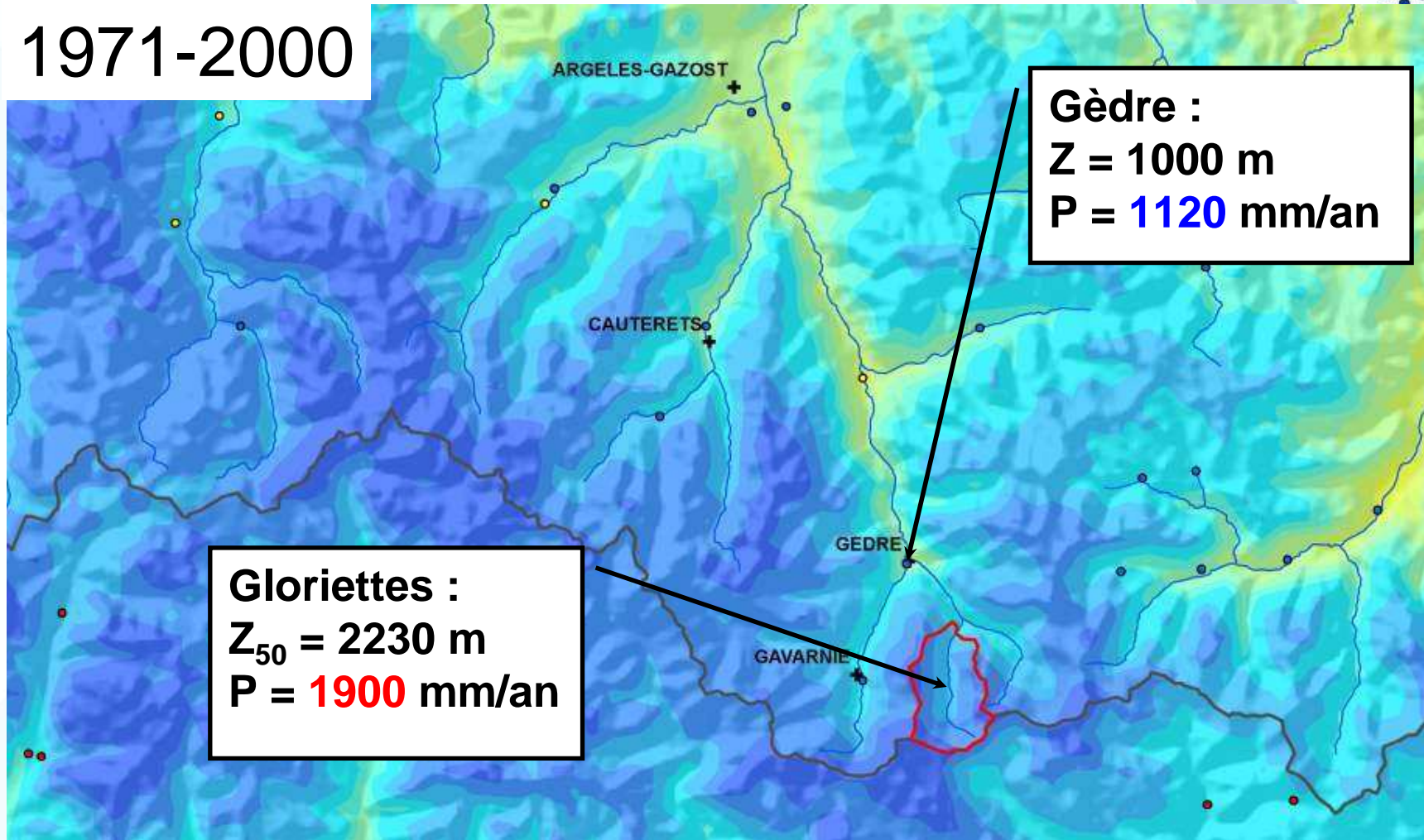
# Cartographie journalière des précipitations (3)





# Zoom sur le bassin de Gloriettes (Pyrénées)

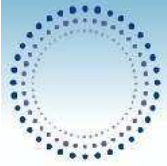
1971-2000



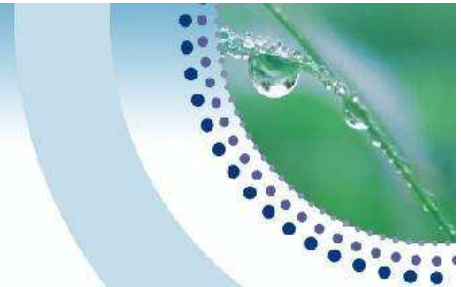


# Validations





# Deux approches de validation



## 2 approches de validation

### **Données d'enneigement**

Équivalent en eau – EQN

(validation **locale** et journalière  
potentiellement)

### **Bilan hydrologique**

mesures de débit

(validation **spatiale**  
agrégée sur un bassin)

## **MAIS**

Neige – pluie/fusion

⇒ modèle neige

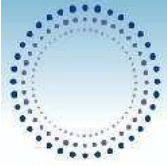
⇒ modèle température

Apport = Precip – ETR ±  $\Delta$ stock

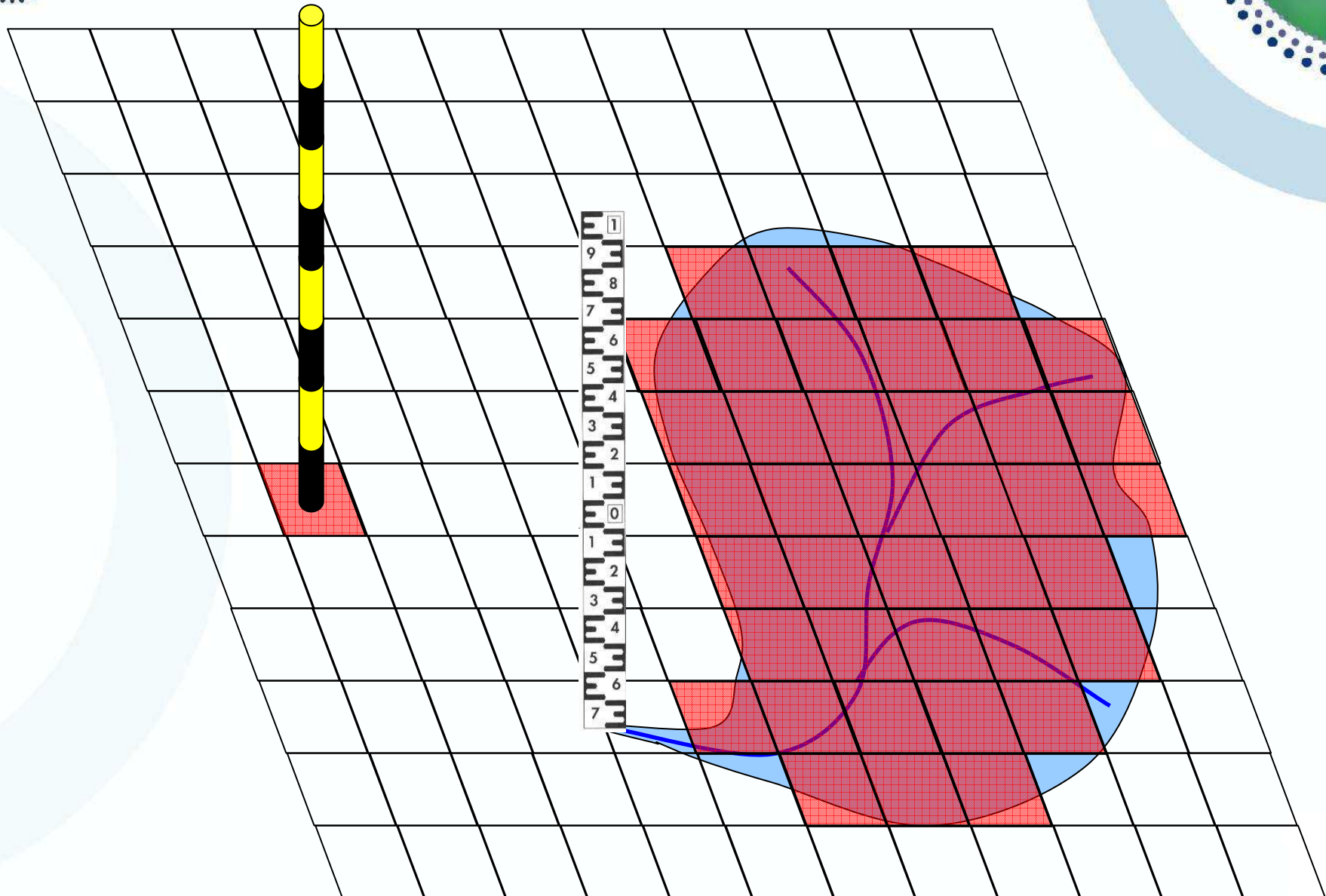
⇒ modèle d'évaporation

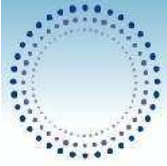
⇒ modèle de température





# Validations

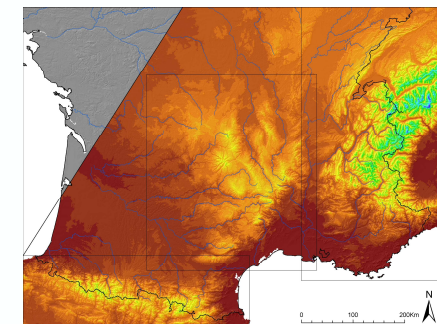
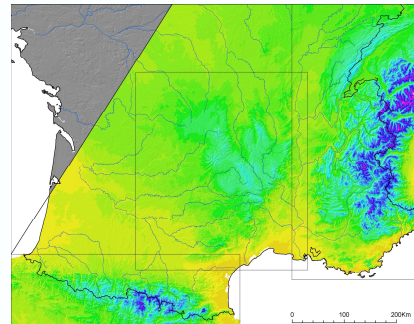
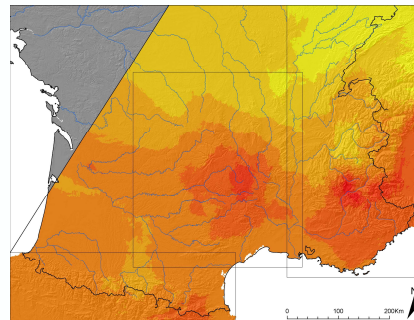
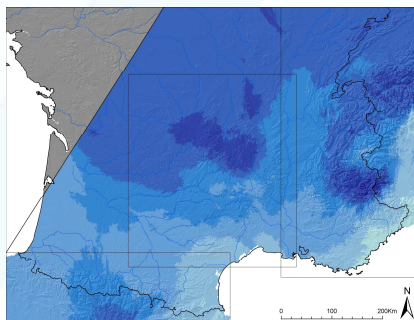
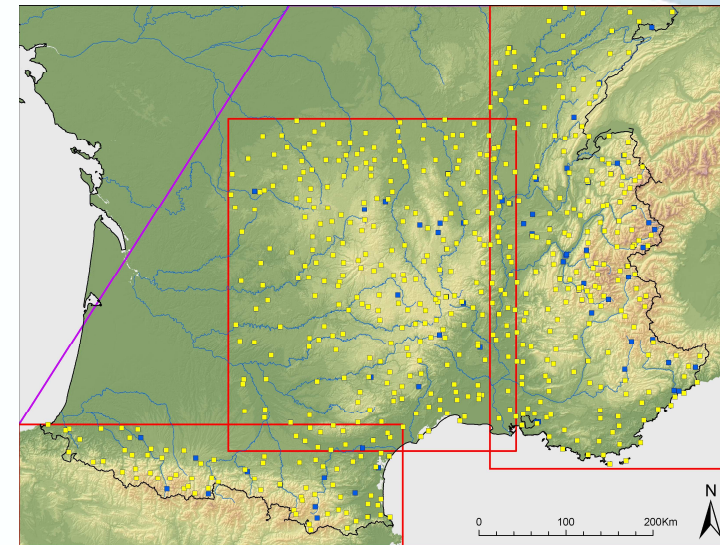


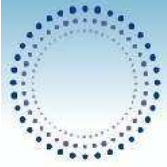


# Modèle de *température*

- ⇒ Phase des précipitations journalières
- ⇒ Fusion du stock de neige
- ⇒ Estimation de l'évapotranspiration réelle

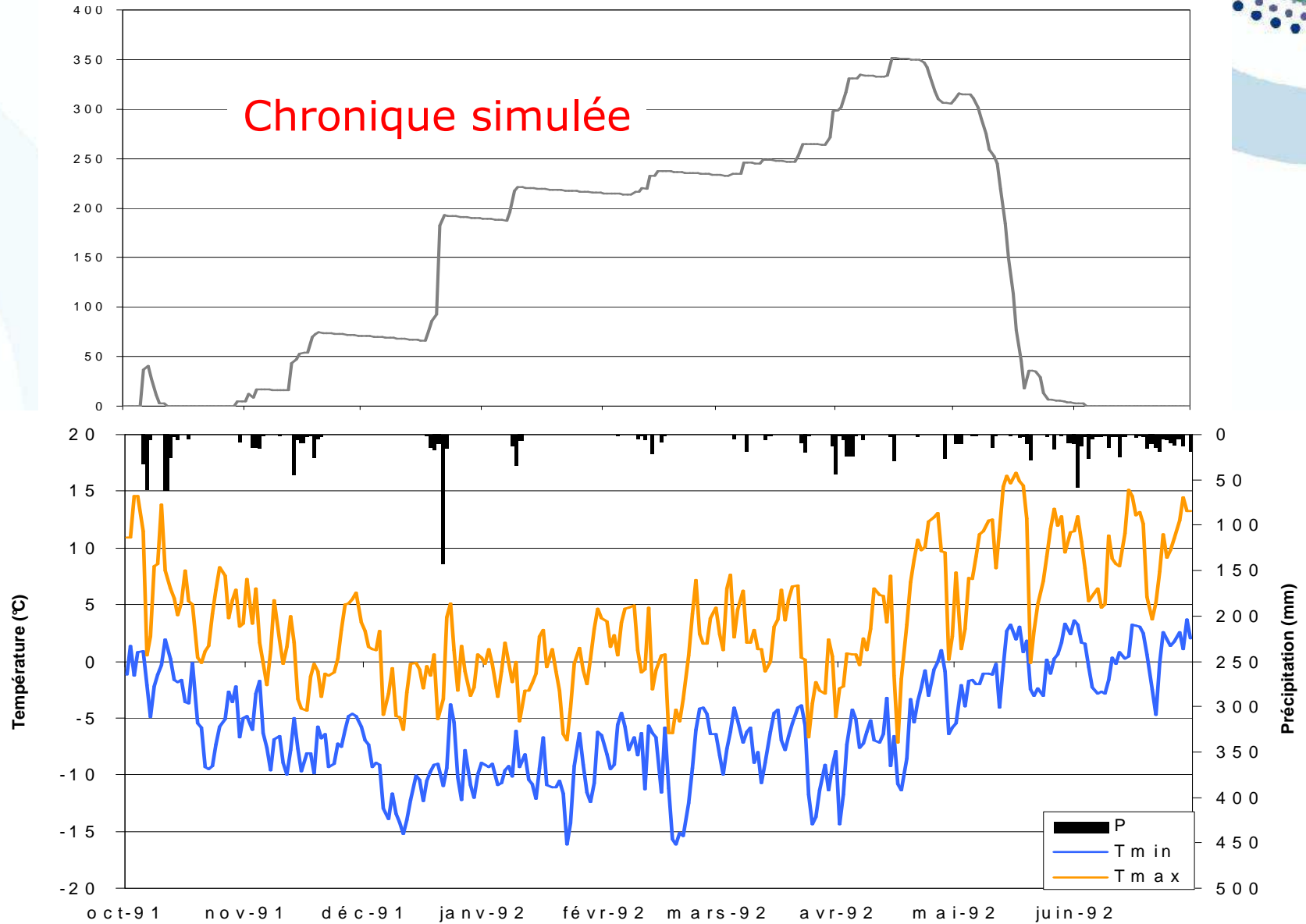
## Cartographie des Tmin et Tmax journalières 1953-2005

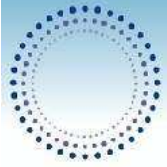




# Modèle Neige

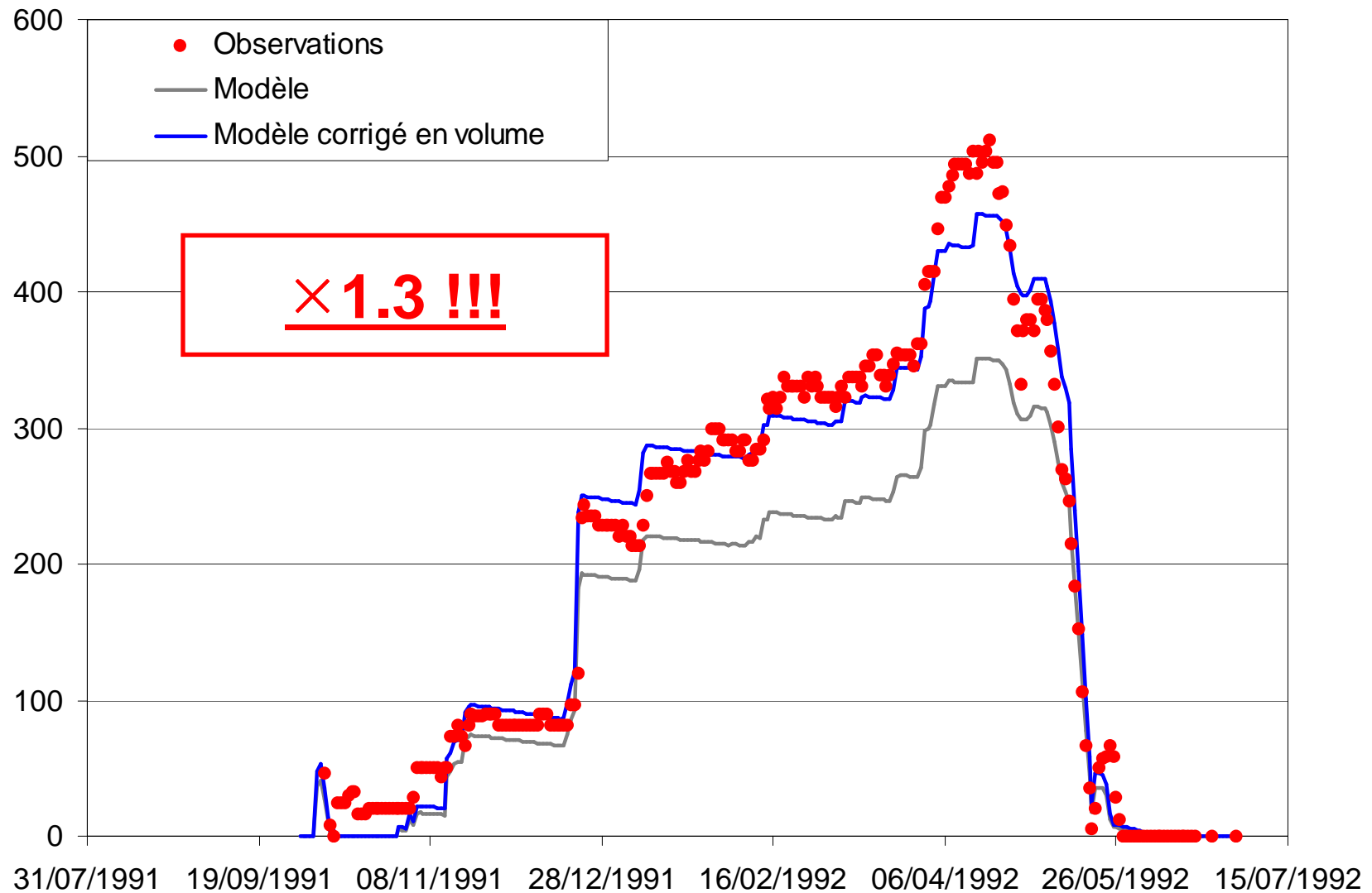
NRC de Chardonnet, saison 1991-1992

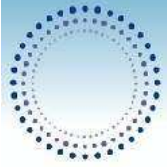




# Modèle Neige

NRC de Chardonnet, saison 1991-1992





# Modèle Neige

**Entrée :** Précipitation  
Interpolée au pixel

Facteur multiplicatif

**Nouvelle entrée**  
du modèle neige

...  
0  
8  
0  
32  
16  
20  
0  
0  
...

× Cp =

↓  
**Optimisé**

tq: EQN modélisé ↔ EQN observé

...  
0  
10  
0  
40  
20  
25  
0  
0  
...

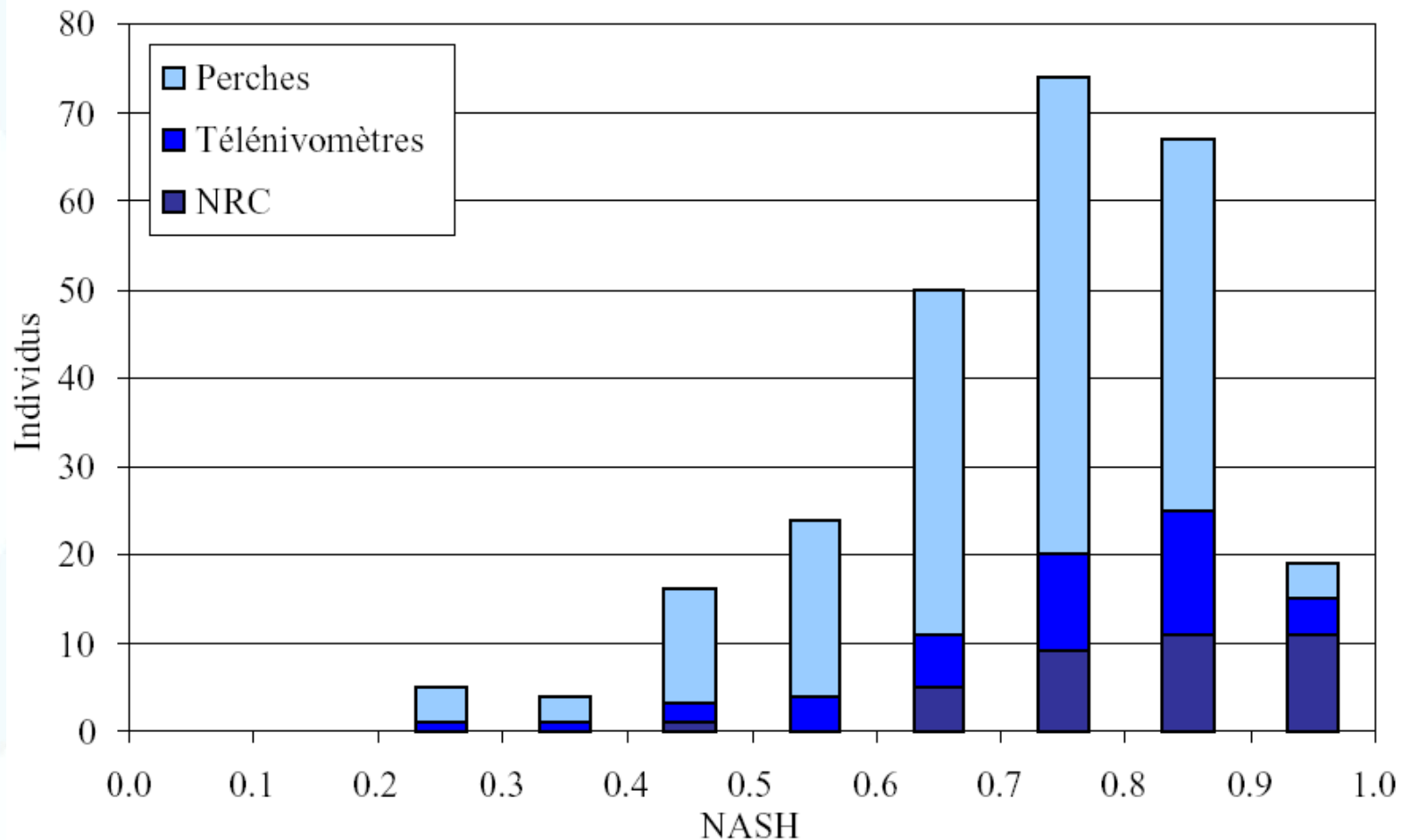
Une « bonne » estimation de précipitation ↔ **Cp ≈ 1**

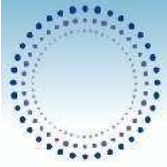


# Validation aux postes de neige

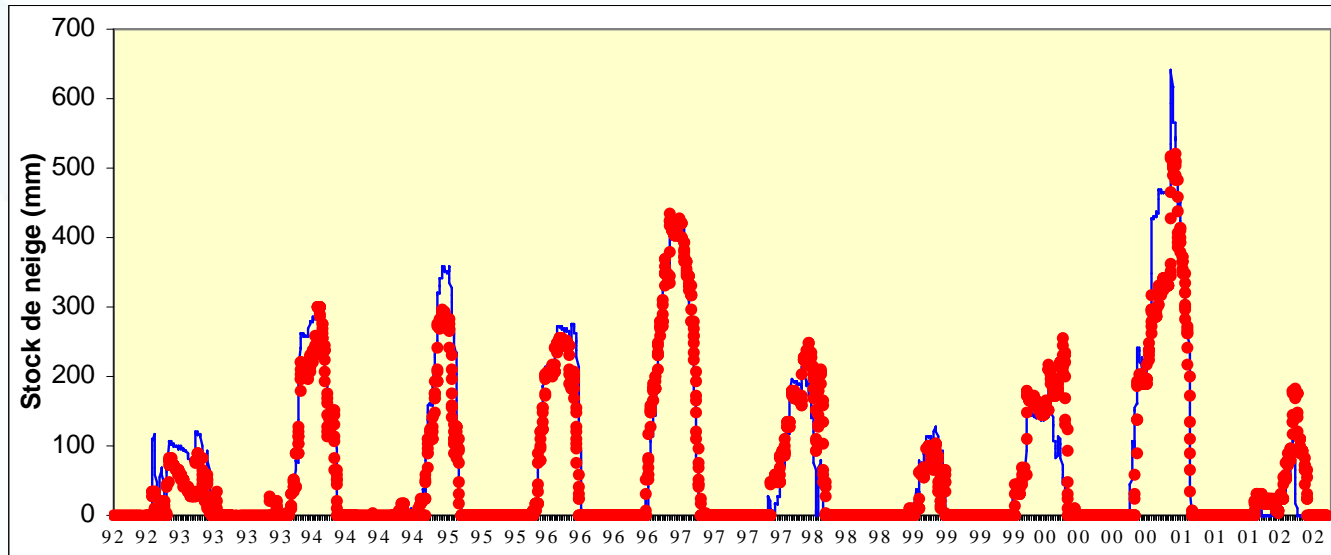
267 chroniques modélisées (sondages, TLNM, NRC)

153 séries le sont avec un NASH > 0.7

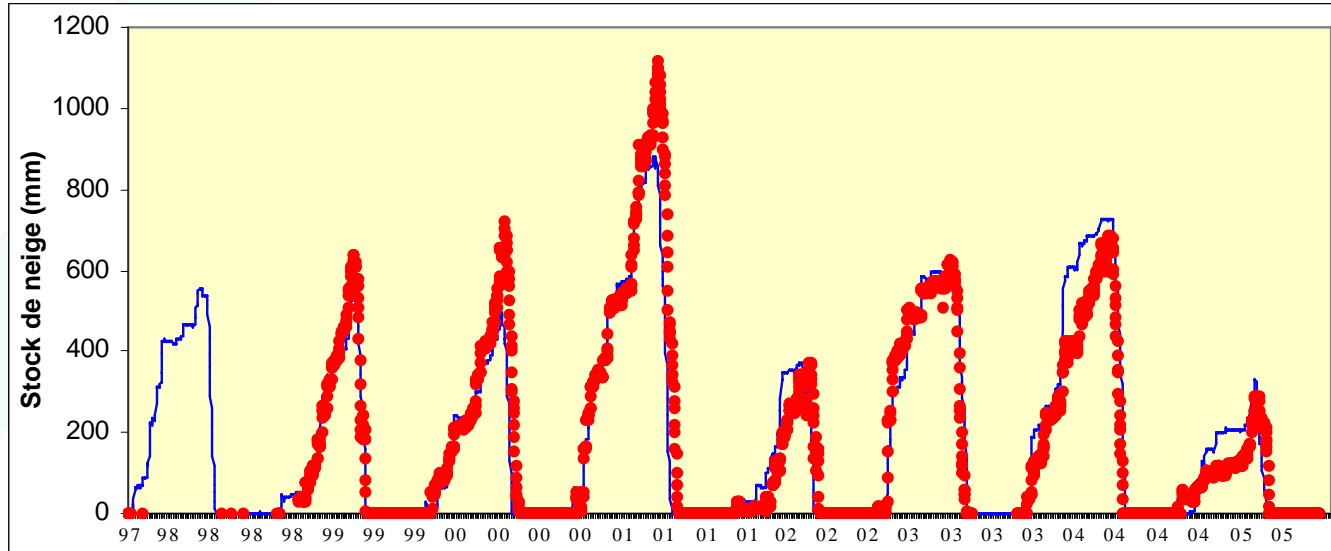




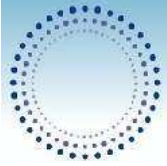
# Validation aux postes de neige



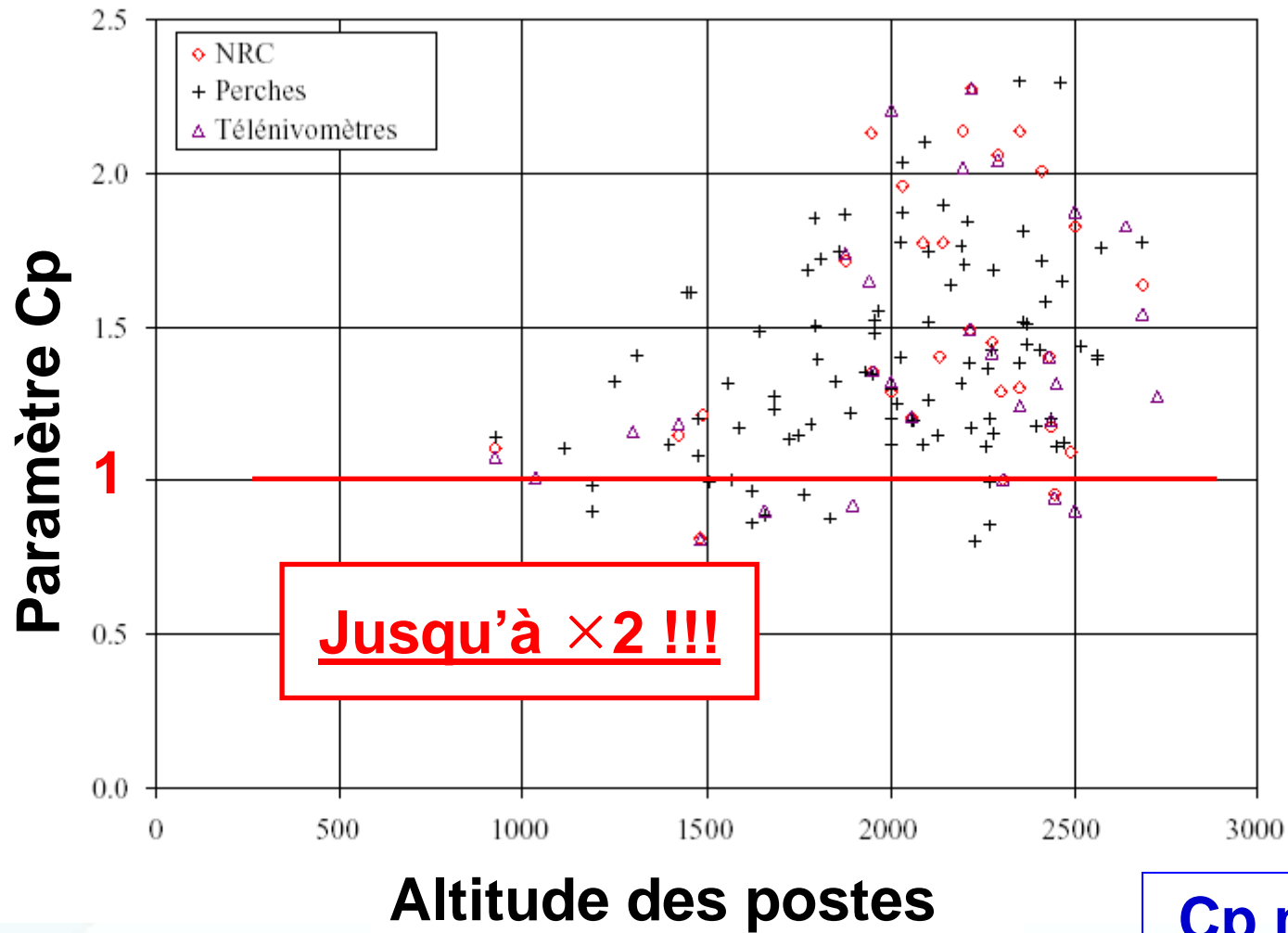
TLNM/NRC  
de Passaur  
*Nash = 0.87*



NRC de  
Chardonnet  
*Nash = 0.83*



# **Mais** : utilisation d'un facteur correctif !



**Cp moyen = 1.41**  
**écart type = 0.36**





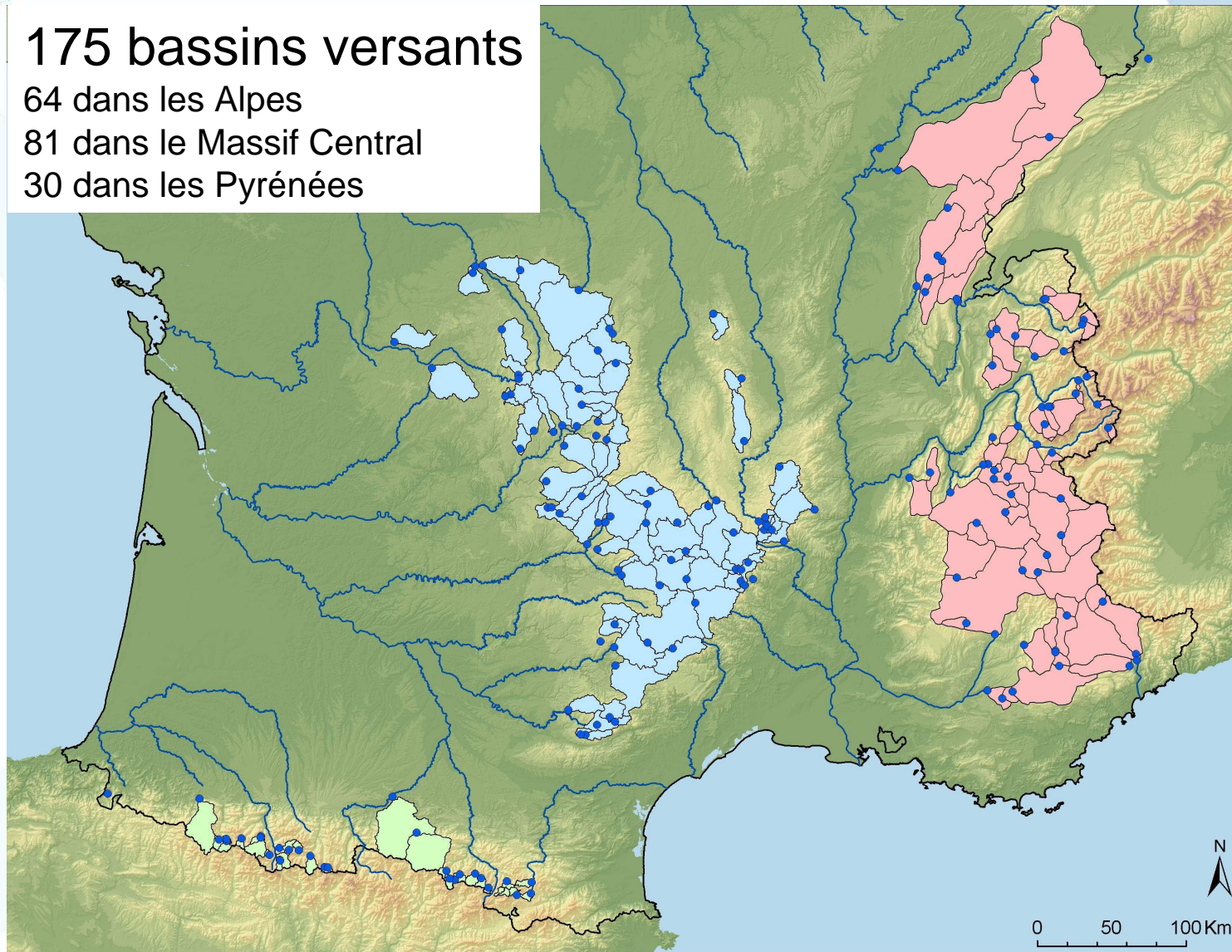
# Validation par *bilans hydrologiques annuels*

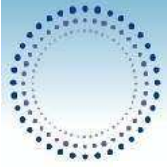
175 bassins versants

64 dans les Alpes

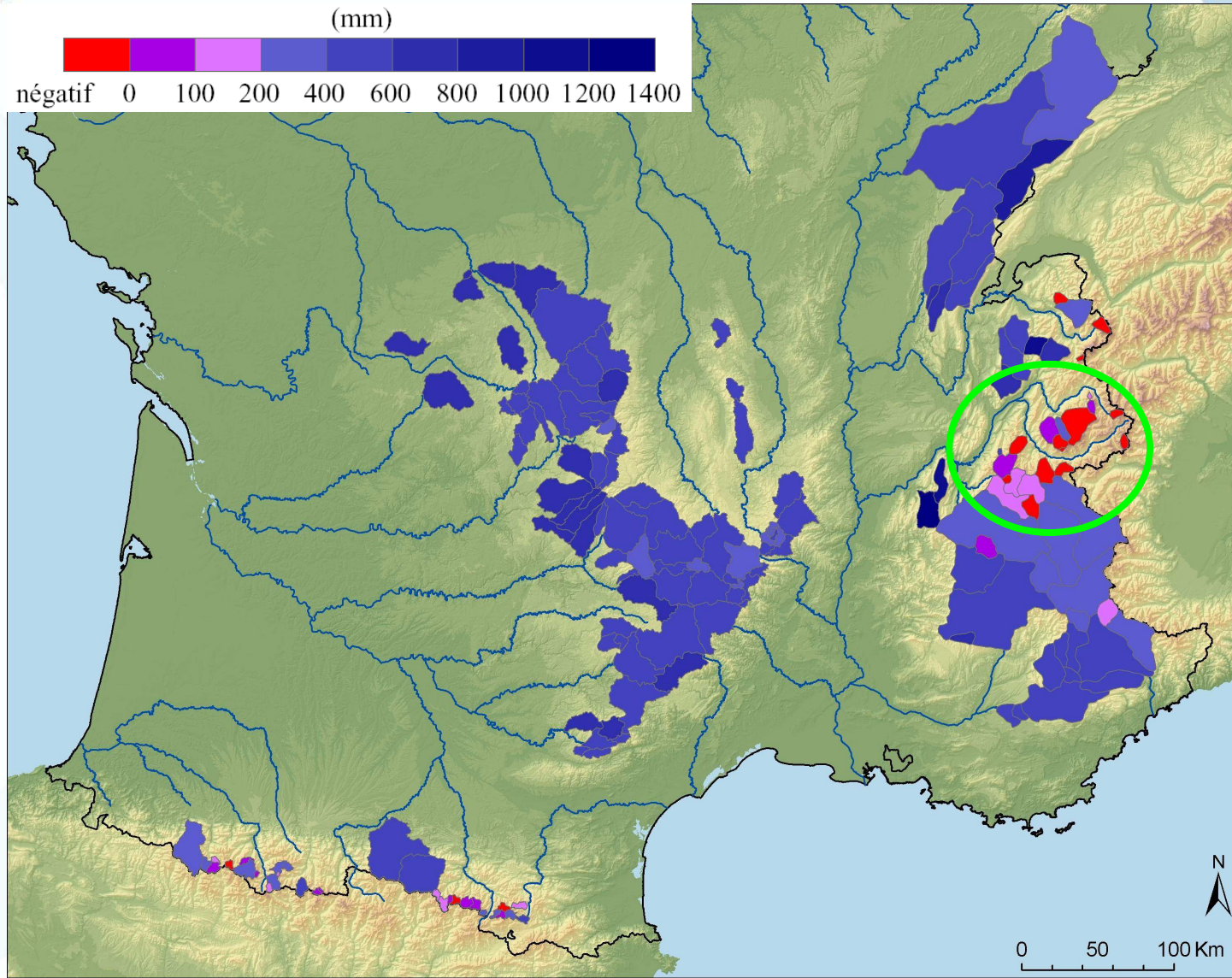
81 dans le Massif Central

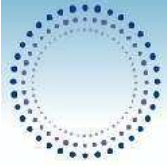
30 dans les Pyrénées





# Cartographie des déficit moyens



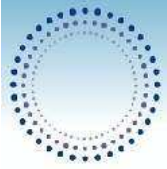


# Assimilation des données d'enneigement ?

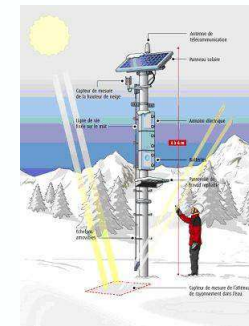
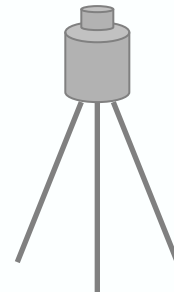
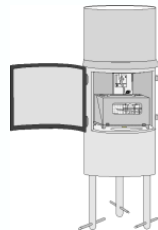
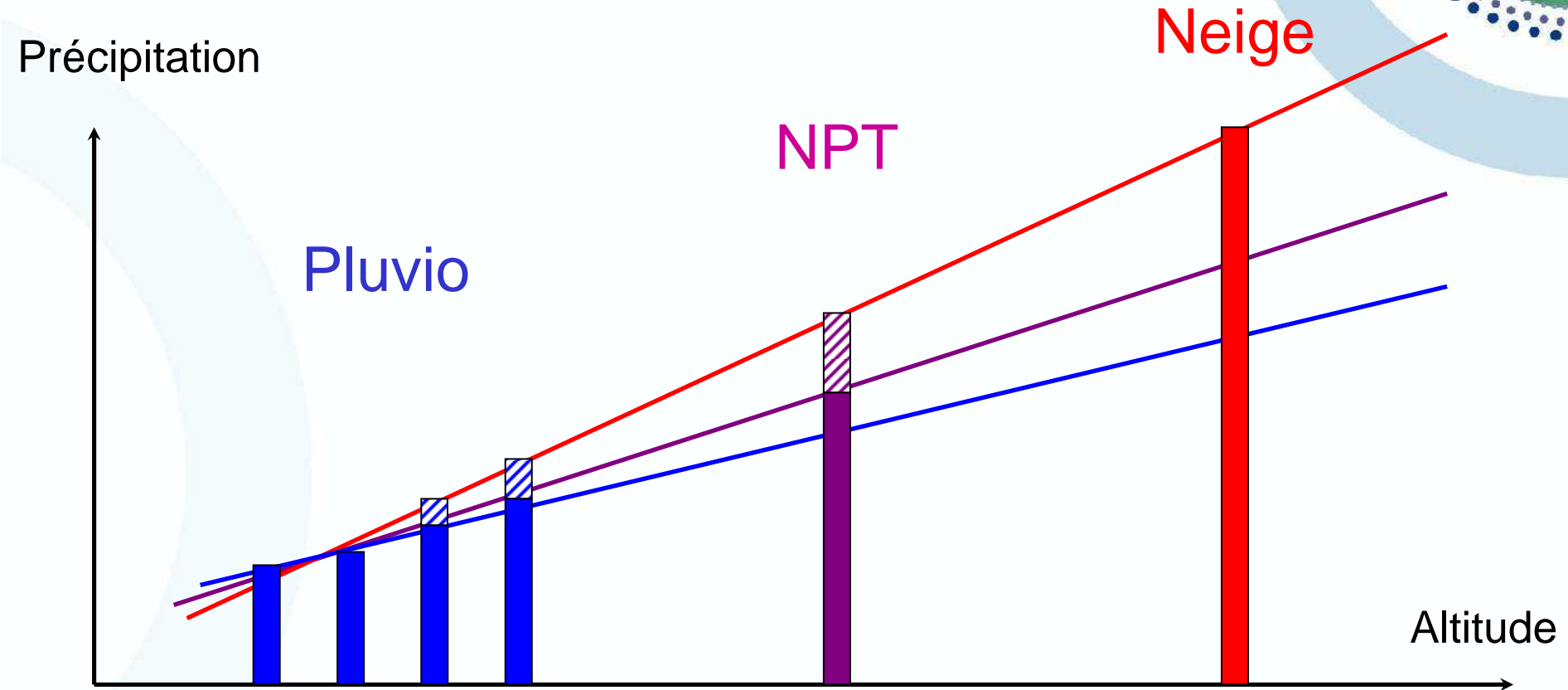


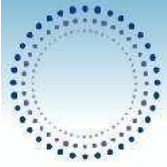
# Assimilation des données d'enneigement





# Introduction des mesures de neige





# Comme

→ Deux f

✓ La p

✓ Le v

→ 5% en  
30% e

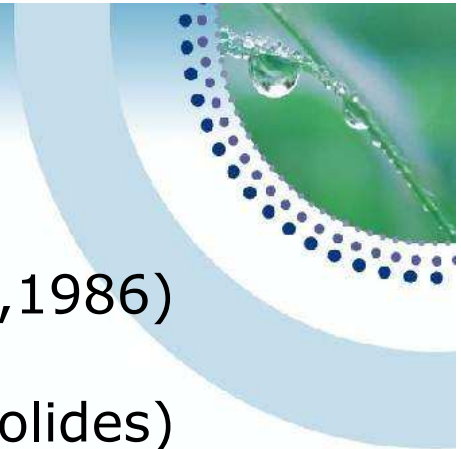
→ Correc



uk, 1986)

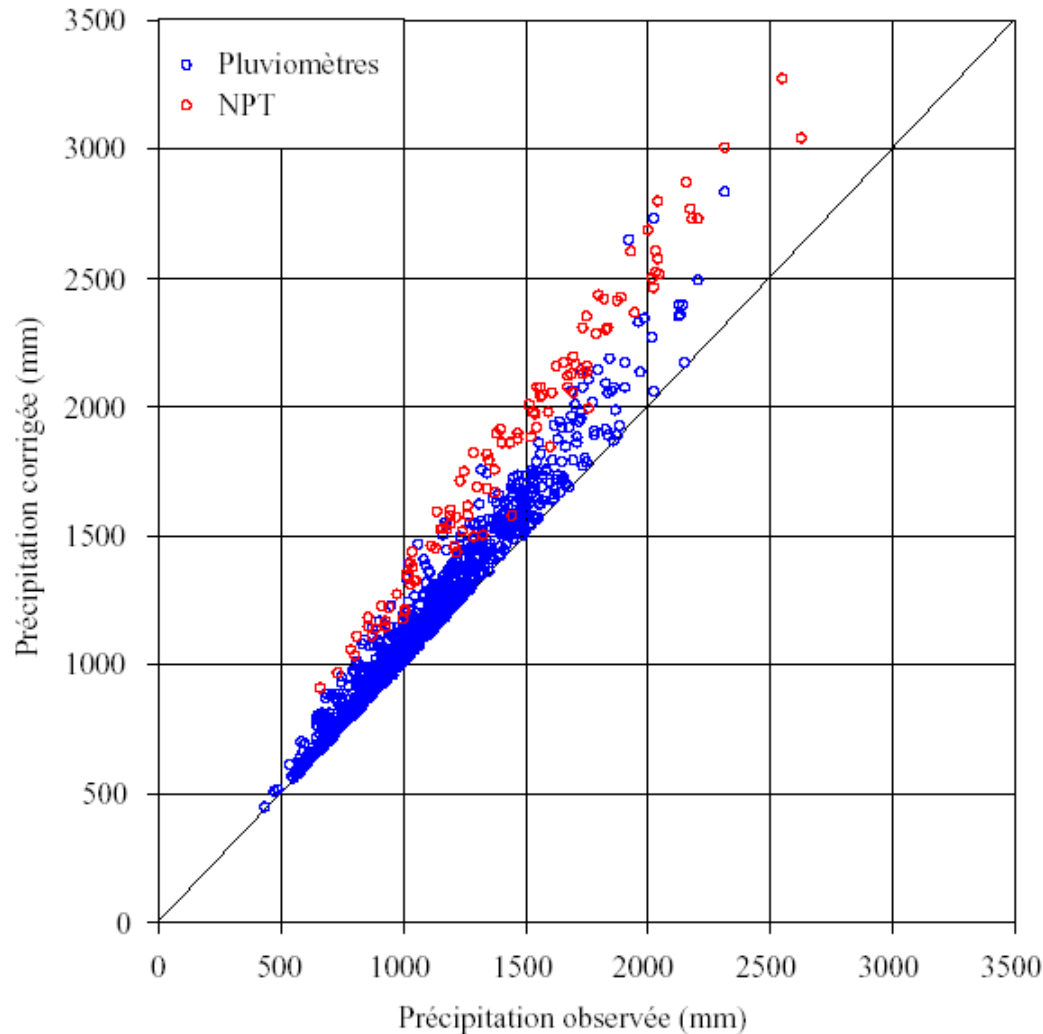
solides)

nt avec l'altitude !





# Modèle correctif des précipitations *fonction* de la fraction solide ***FS***



$$P_j^* = C(FS_j) \cdot P_j$$

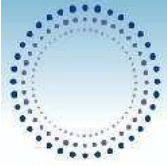
$$C(FS_j) = 1 + 0,6 \cdot FS_j$$



# Estimations améliorées



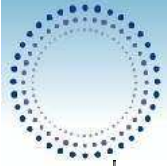




# On rejoue tout depuis le début...

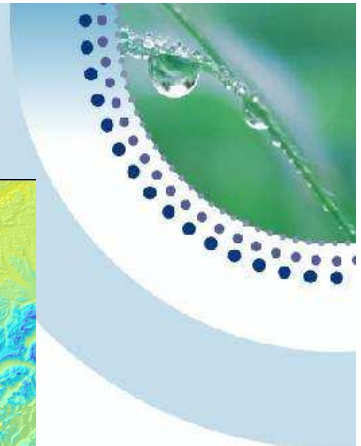
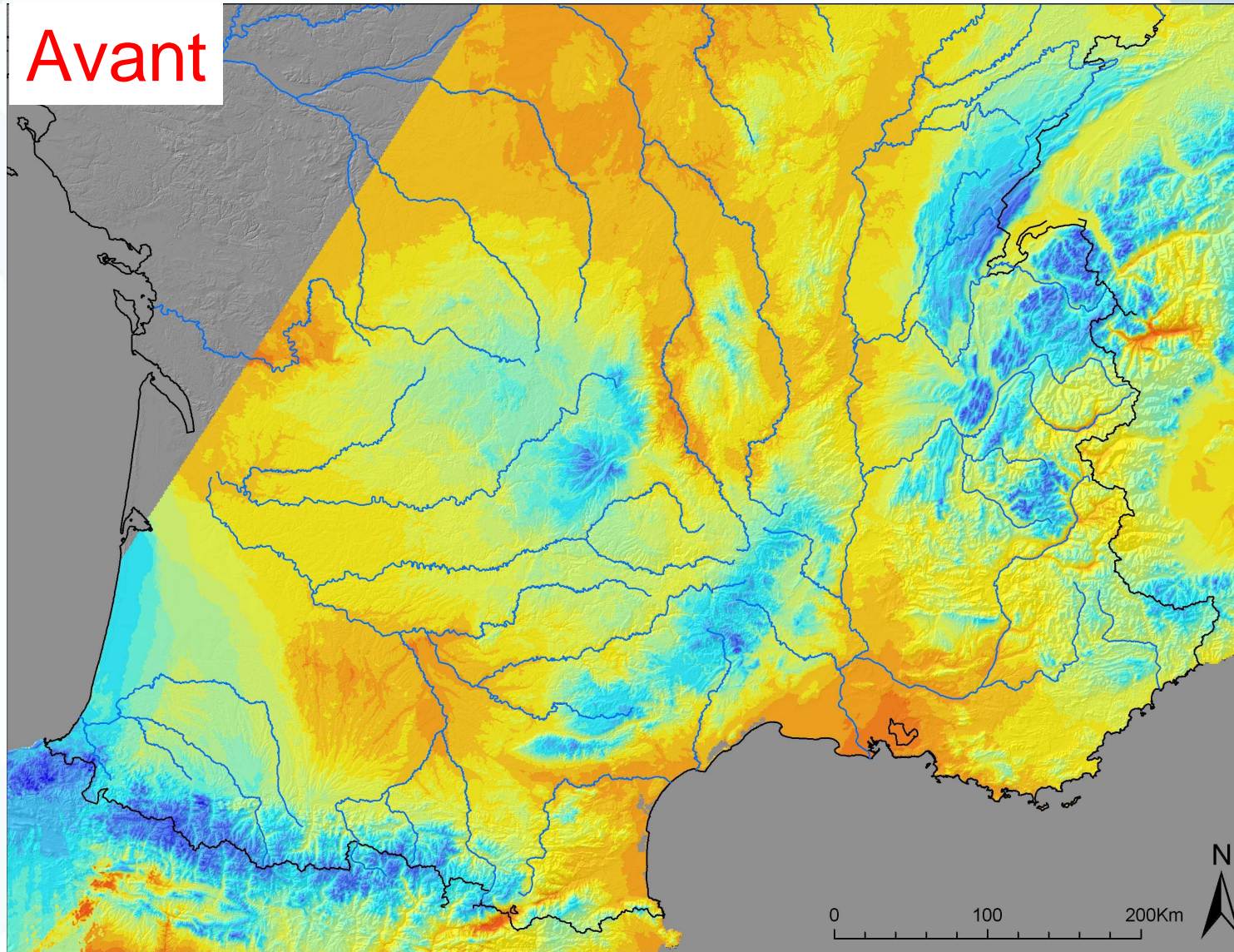


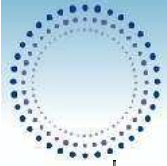
- ⇒ De nouvelles **ébauches enrichies** :  
des postes de neige,  
des pluviomètres **corrigés**,  
des NPT **corrigés**.
- ⇒ De nouvelles estimations journalières
- ⇒ De nouvelles validations



# Nouvelle normale 1971-2000

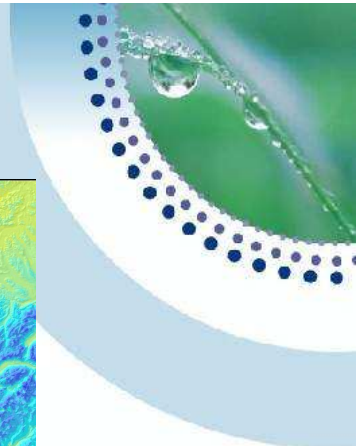
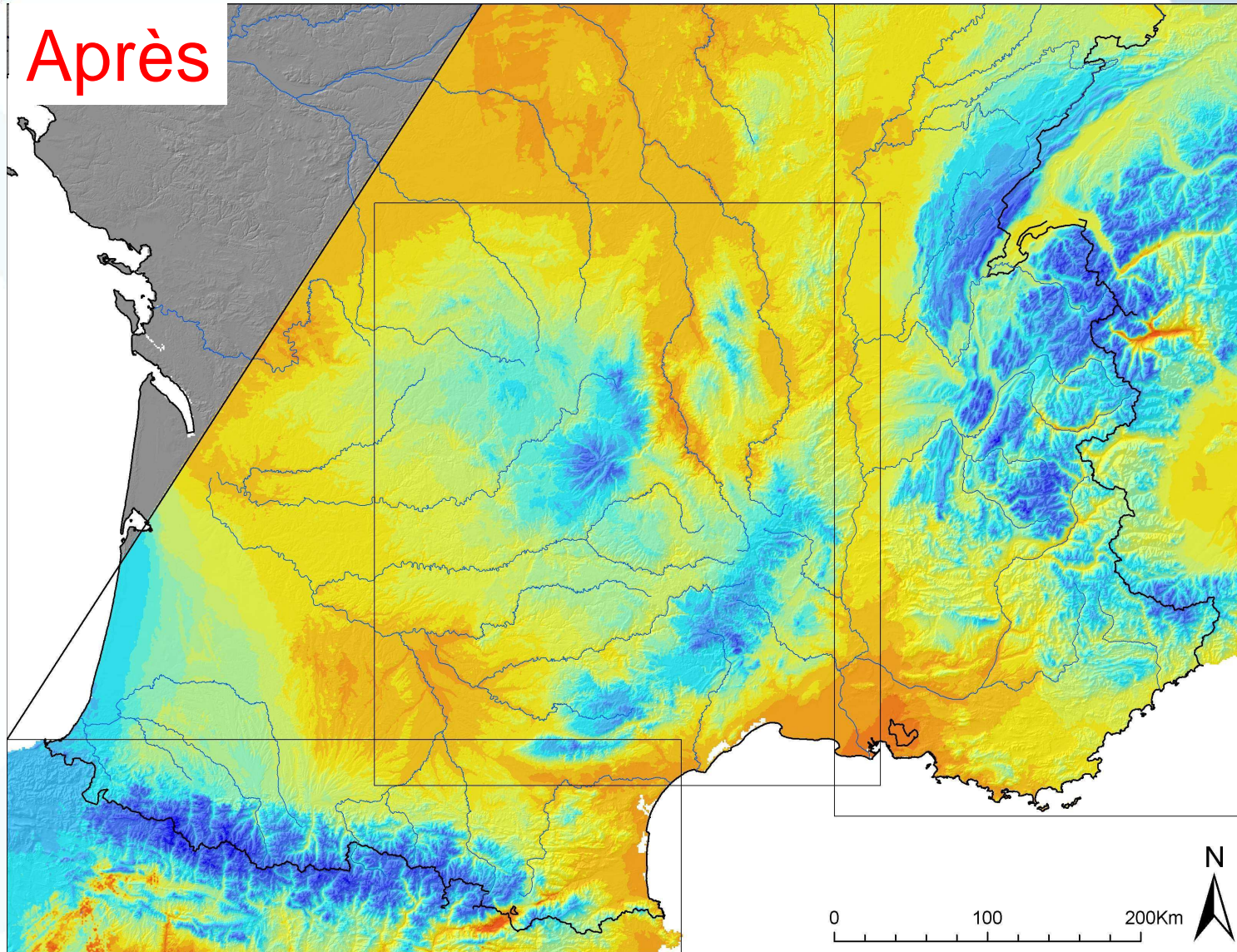
Avant

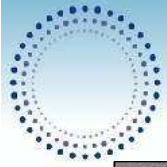




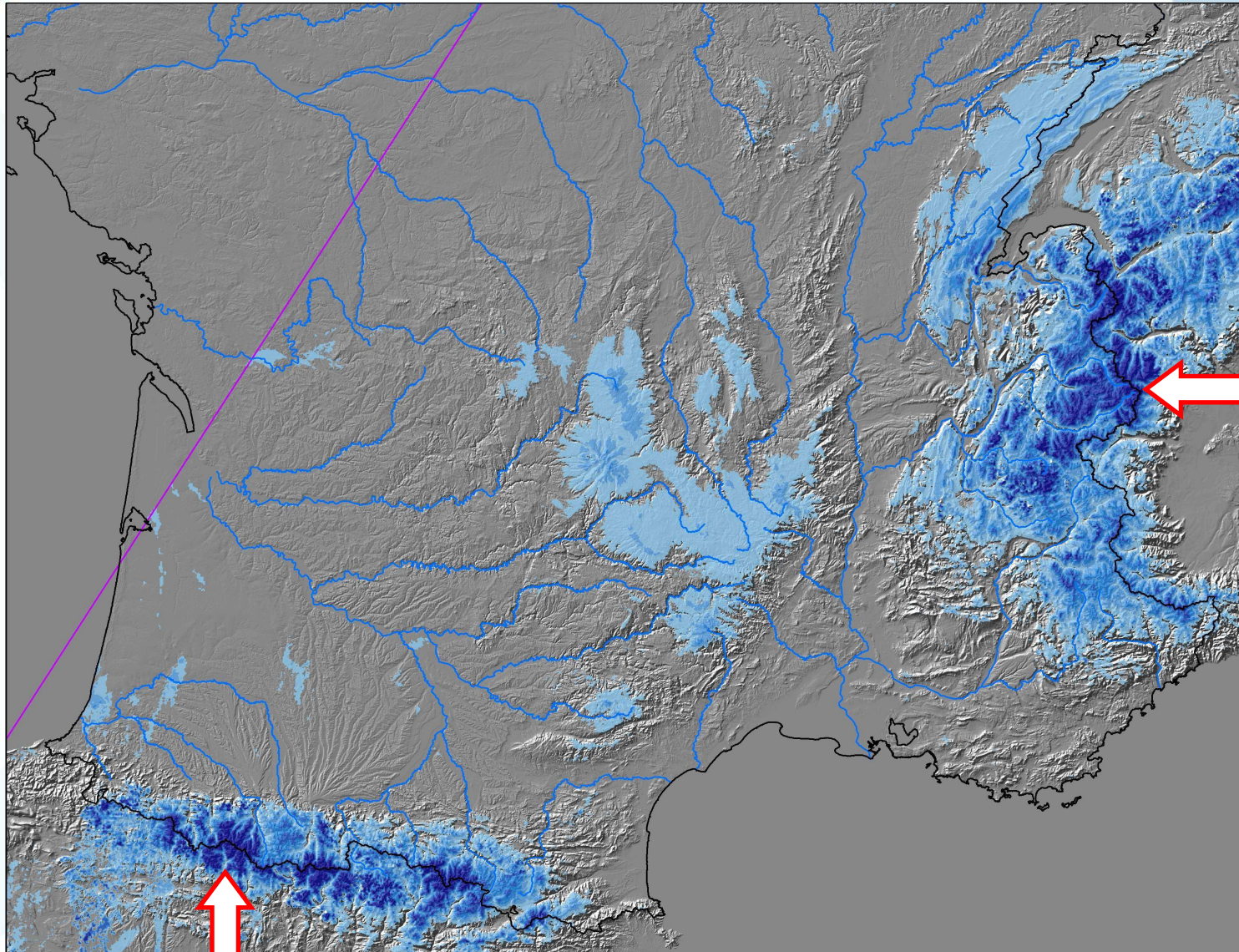
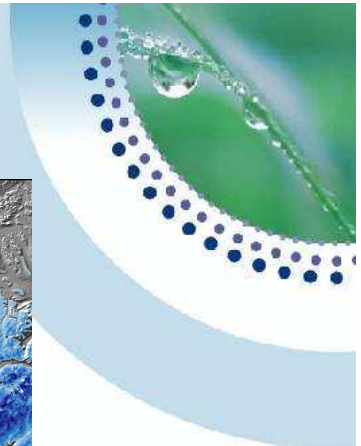
# Nouvelle normale 1971-2000

Après

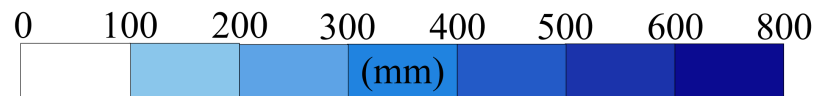




# Différence en mm



60





# Modélisation nivale

153 séries modélisées (Perches, Télénivomètres, NRC)

Pour reproduire le stock au sol :

Avant



Cp moyen = 1.41  
écart type = 0.36

Après

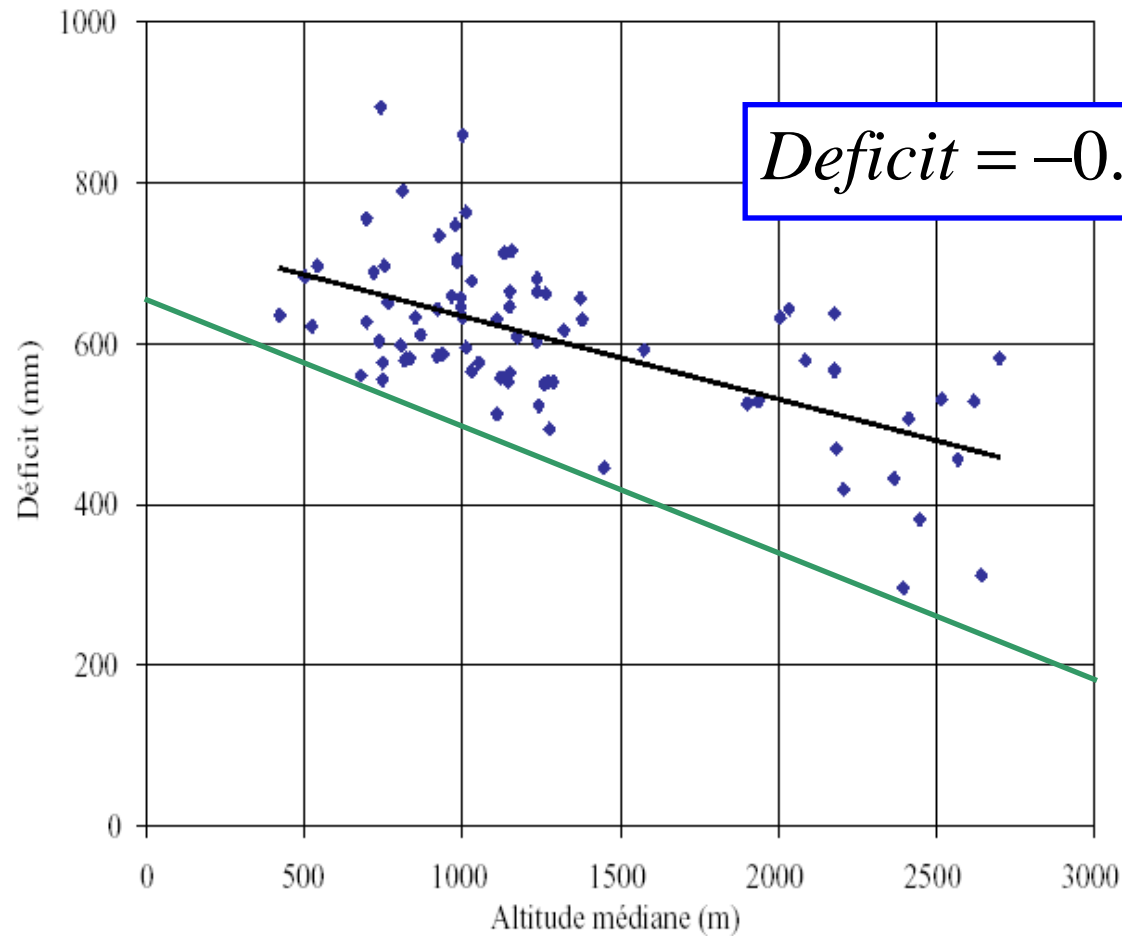
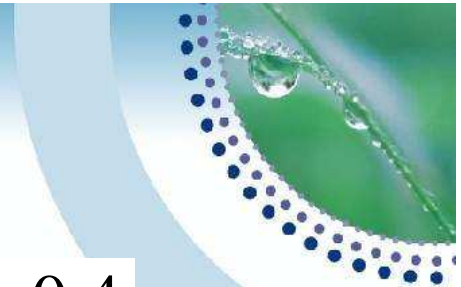


Cp moyen = 0.96  
écart type = 0.18





# Bilan hydrologique



$R^2 = 0.4$

$$Deficit = -0.10 \cdot Z_{50} + 740$$

(en mm/an)

$$ETR_{Menzel} = -0.15 \cdot Z_{50} + 640$$

(en mm/an)

(Menzel et Lang, 1998)

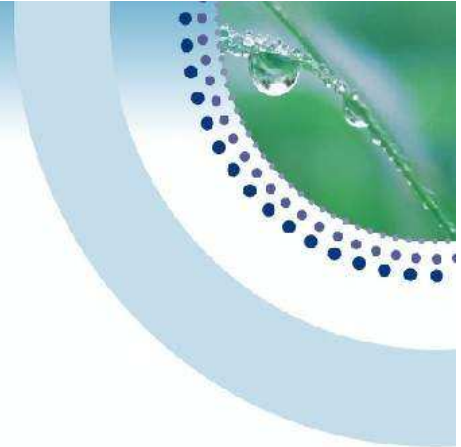


**Conclusions,  
discussions,  
perspectives...**





## **Conclusions** & discussions



➡ Réanalyses des précipitations journalières...

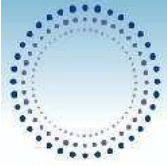
- à la maille 1km
- sur la période 1953-2005 (Prolongement ?)
- sur les principaux massifs montagneux français

➡ Synthèse de toutes les informations sol disponibles en montagne

➡ ...Cohérentes avec :

- Mesures de précipitation,
- Mesures de neige,
- Mesures de débit,
- (Pourquoi pas bientôt) **les mesures Radar !**





# Conclusions & *discussions*



Mesures Radar vs mesures sol ?

Instrumentation en zone de montagne ?

Importance de la mesure sol  
Qualité de la mesure – Archives longues et homogènes  
(Pluviomètres, NPT, Réseau neige)



**Merci de votre attention...**