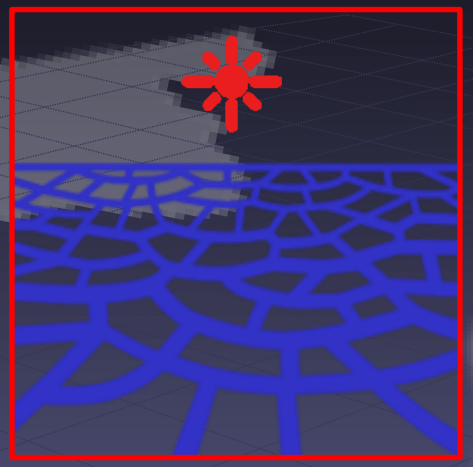
# Intensification du cycle hydrologique en Afrique de l'Ouest

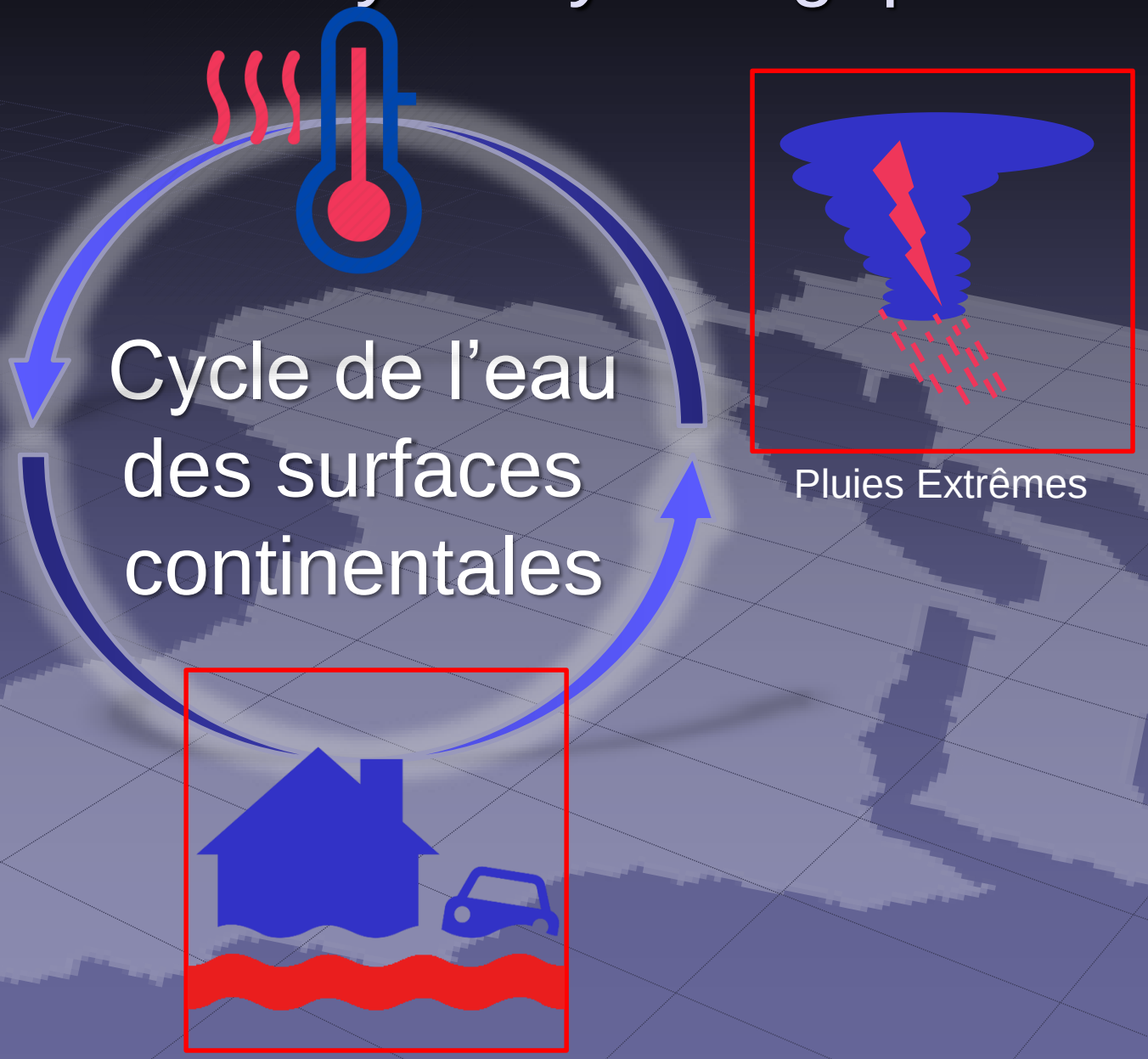
Vischel T.*, Panthou G.*, Wilcox C.*, Quantin G.*, Harris P.▲, Blanchet J.*, Aly C.*, Taylor C. ▲, Berthou S. ♦, Vanderveare J-P.*, Sané Y. ■, Lebel T.*, Stratton R. ♦ , Miller J. ▲,Tazen F.●, Bouvier C.

*Cycle de l'Eau et Changement Climatique, Atelier de lancement Dakar, 29 mars 2022*

# Intensification du cycle hydrologique



Sécheresses

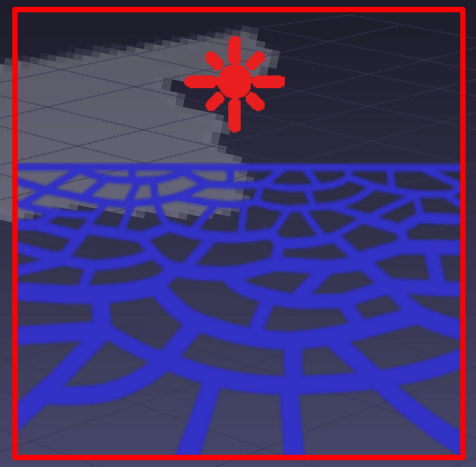




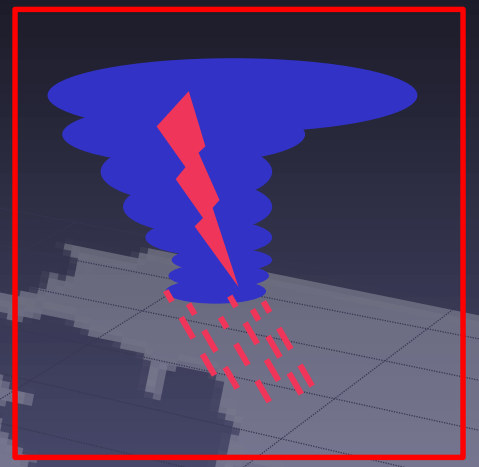

Pluies Extrêmes

Crues

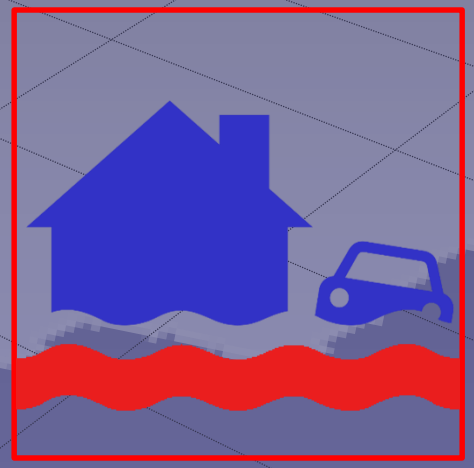
# Intensification du cycle hydrologique



Sécheresses



Pluies Extrêmes

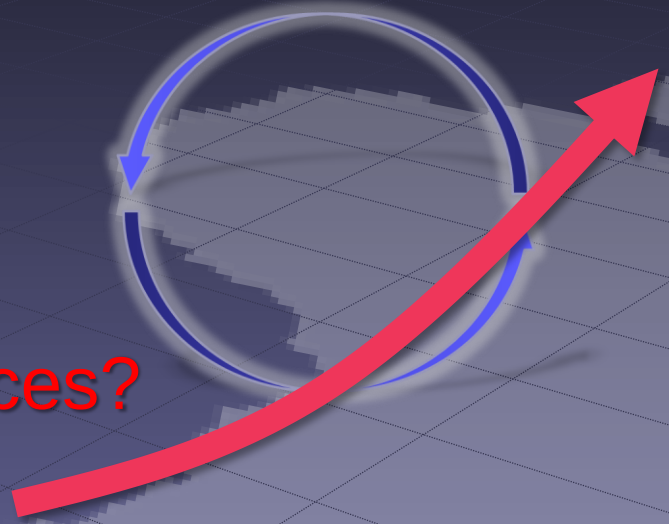


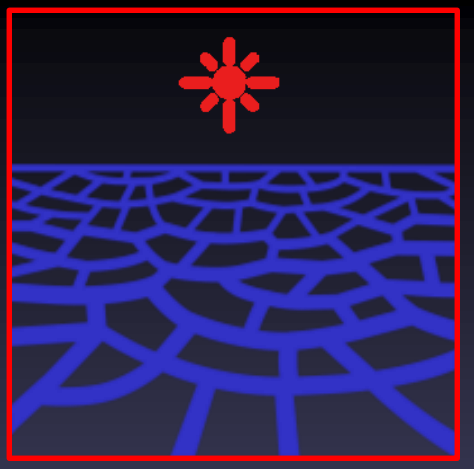
Crues

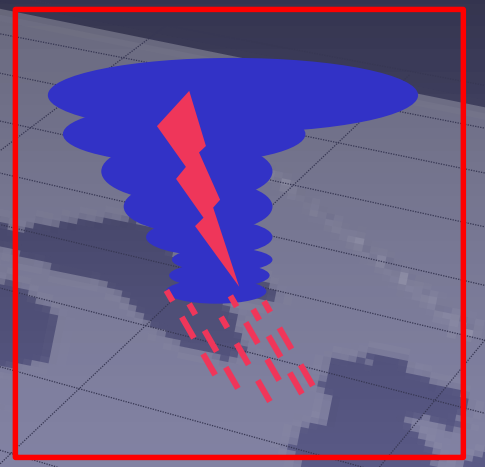
# Intensification du cycle hydrologique
## Trois défis

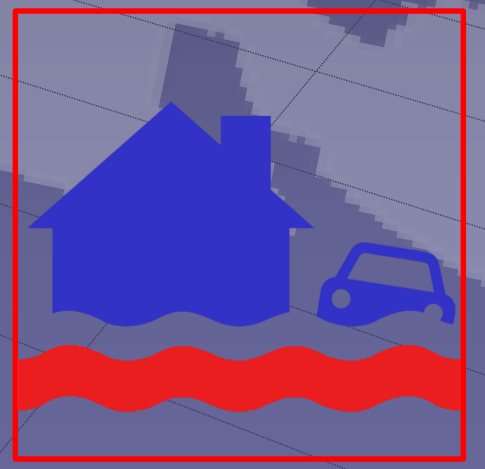
1

**Détection**



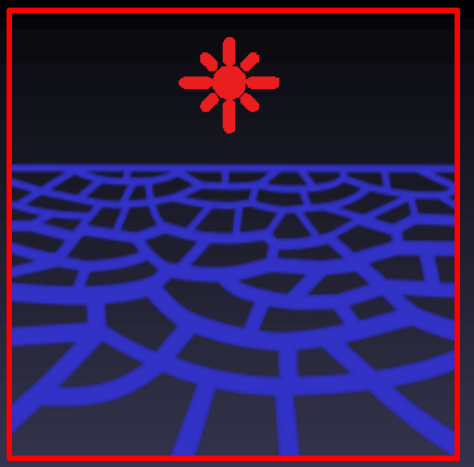



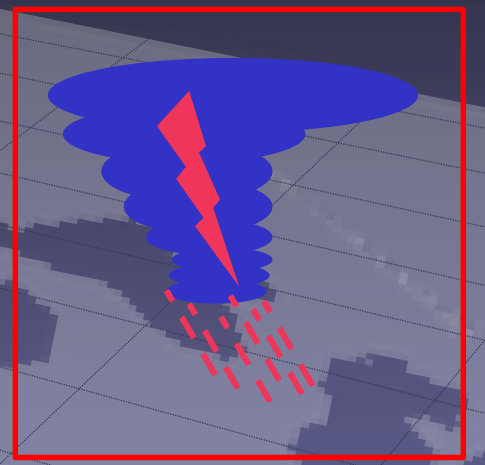


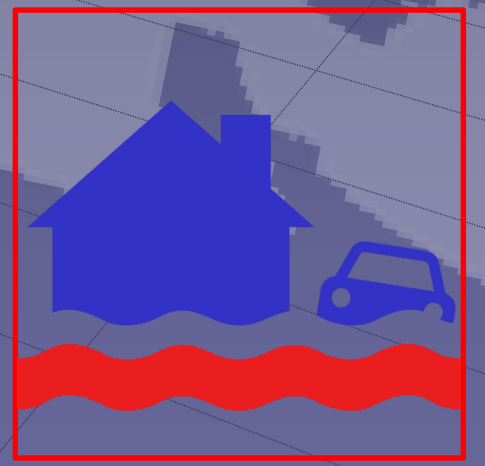


# Intensification du cycle hydrologique
## Trois défis

1. Détection
2. Attribution

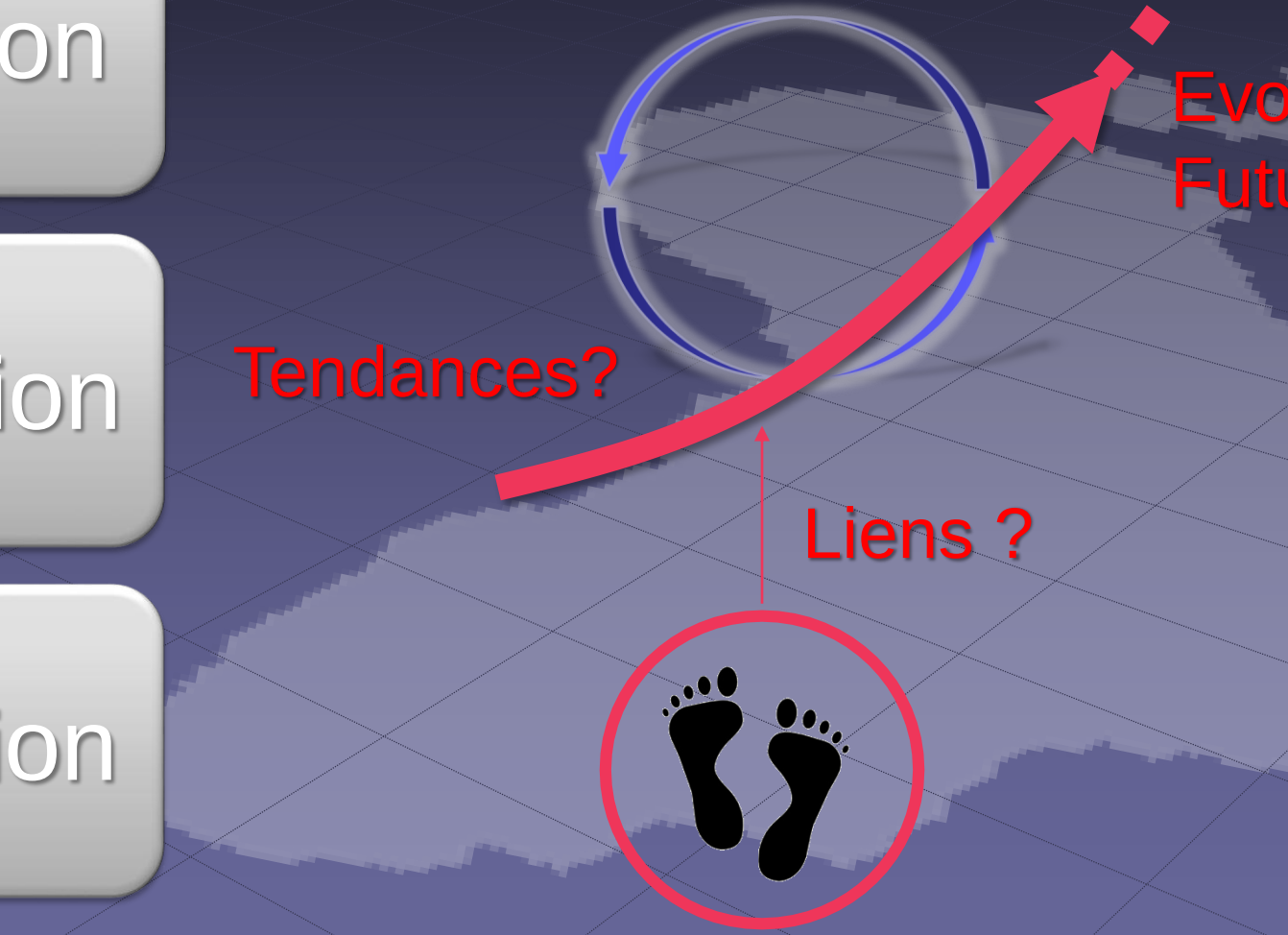



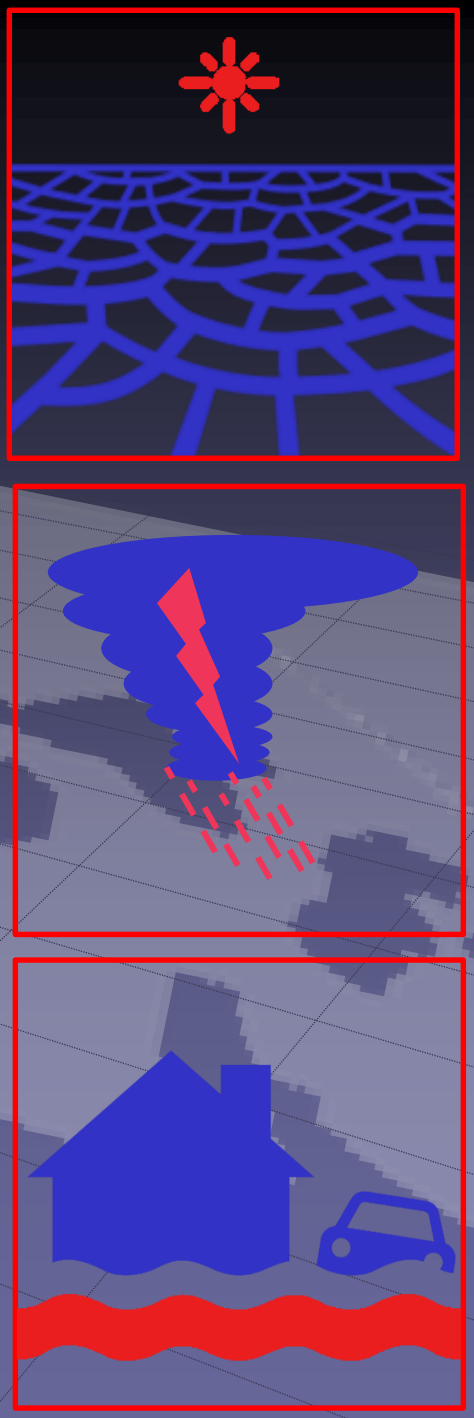




# Intensification du cycle hydrologique
## Trois défis

1. Détection
2. Attribution
3. Projection



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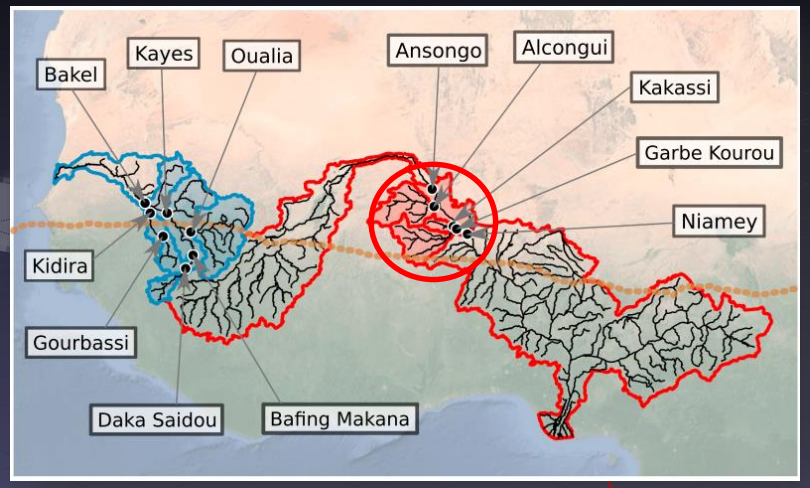
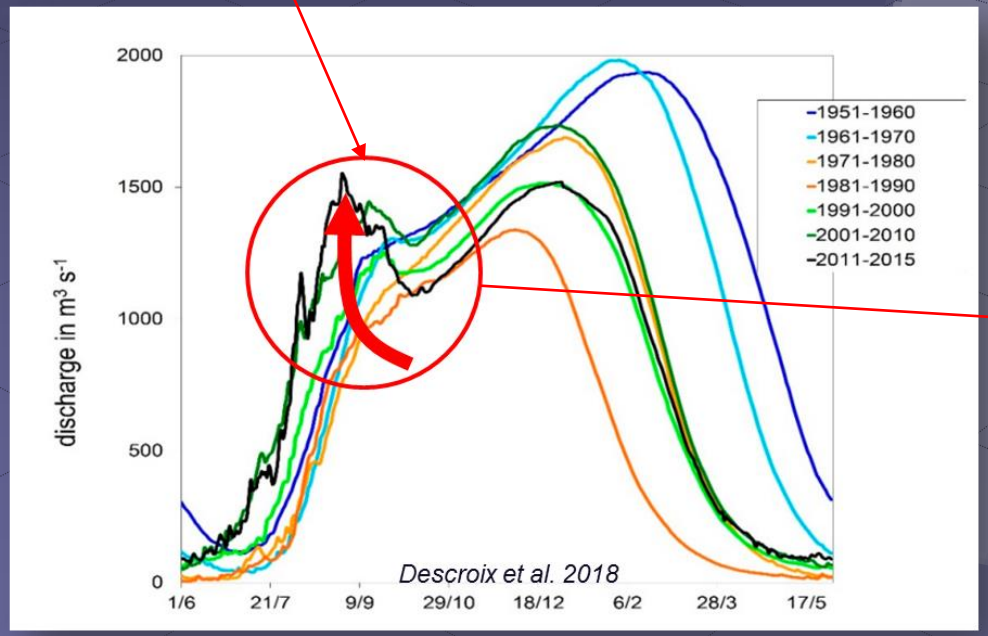
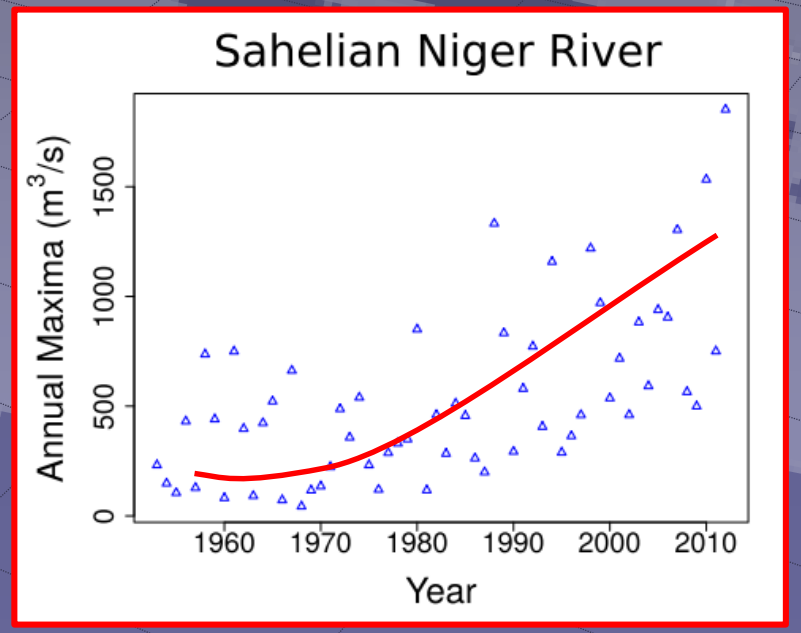



*Wilcox et al. 2018, J. of. Hydrol.*



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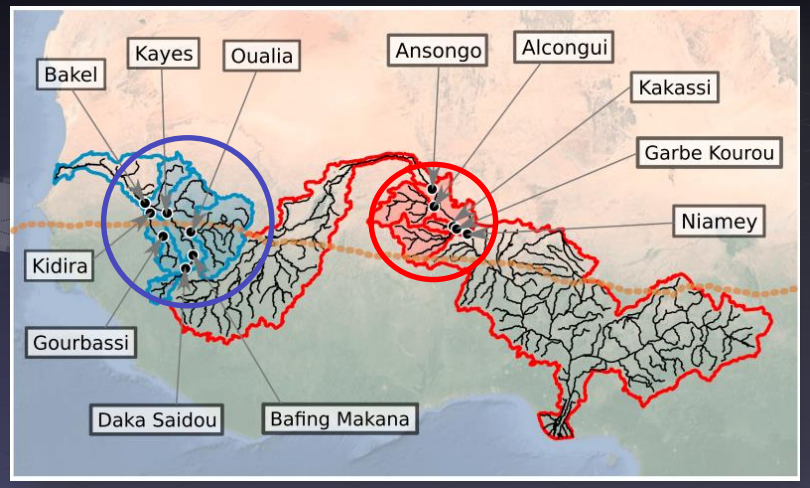
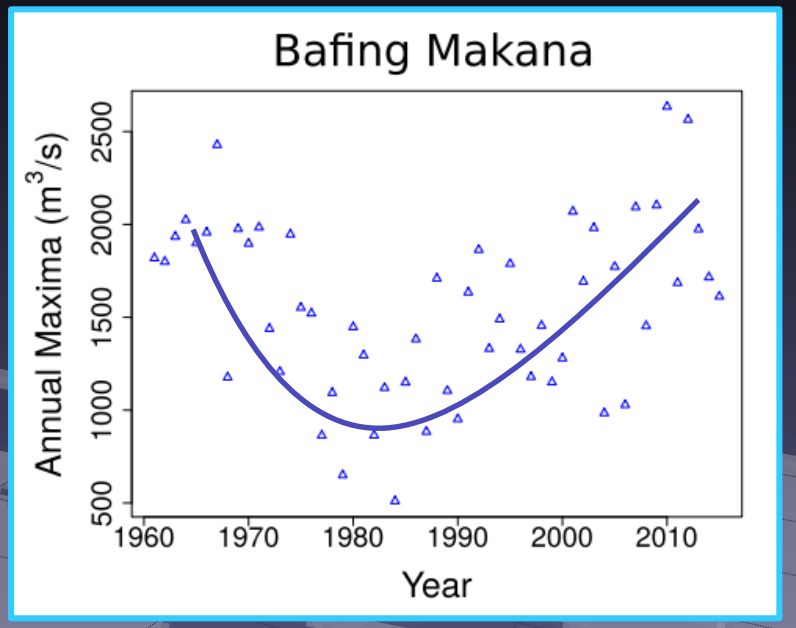
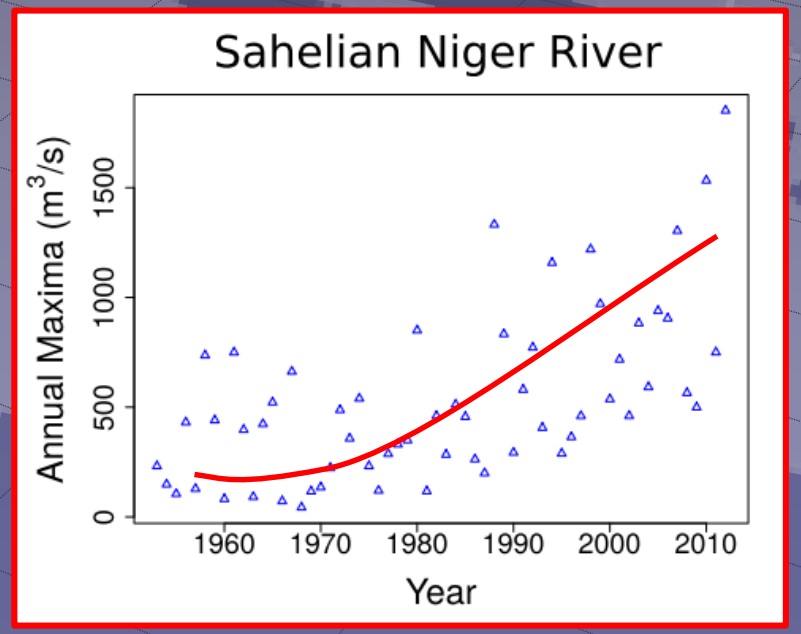


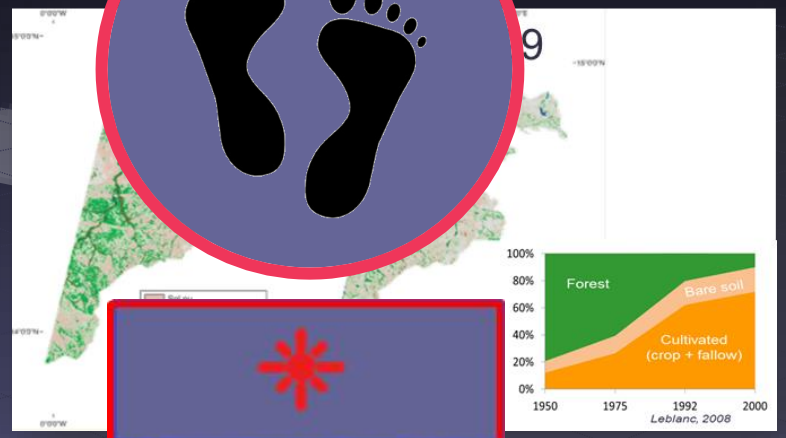

*Wilcox et al. 2018, J. of. Hydrol.*



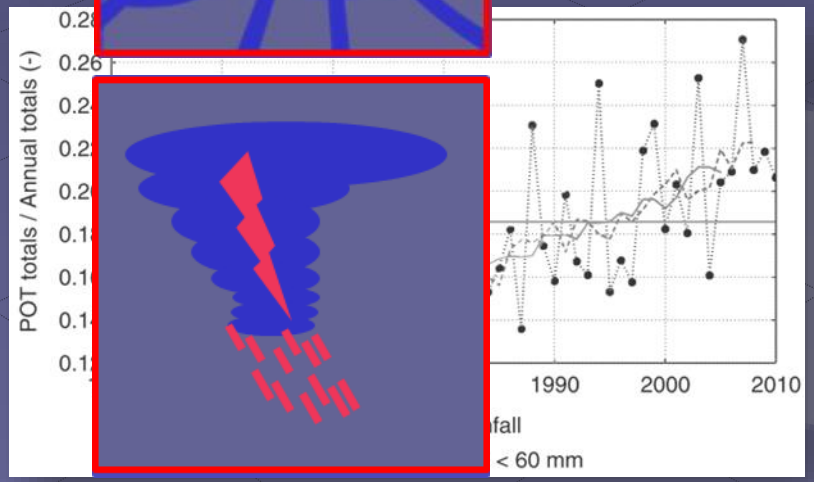
## Fa… l'influence

… s sols



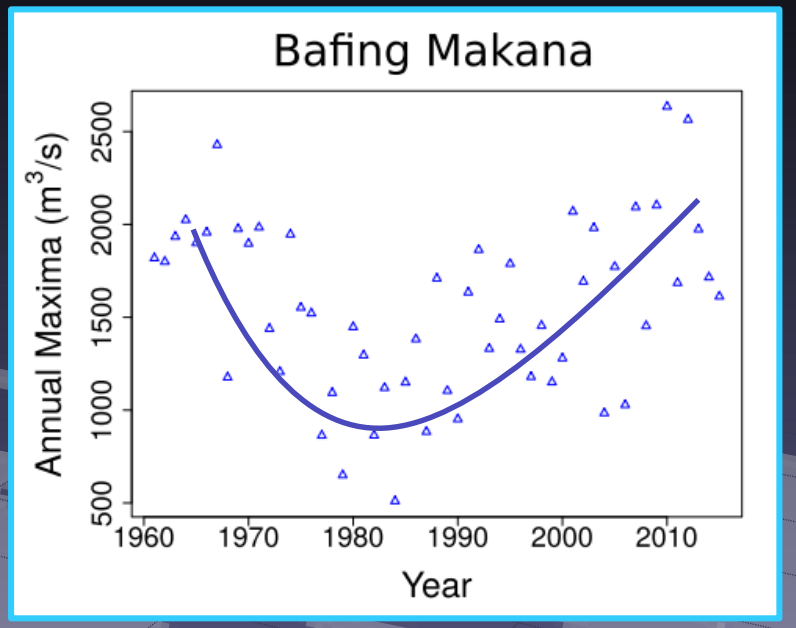

*Favreau … et al. 2009 JH, 2018 Water*

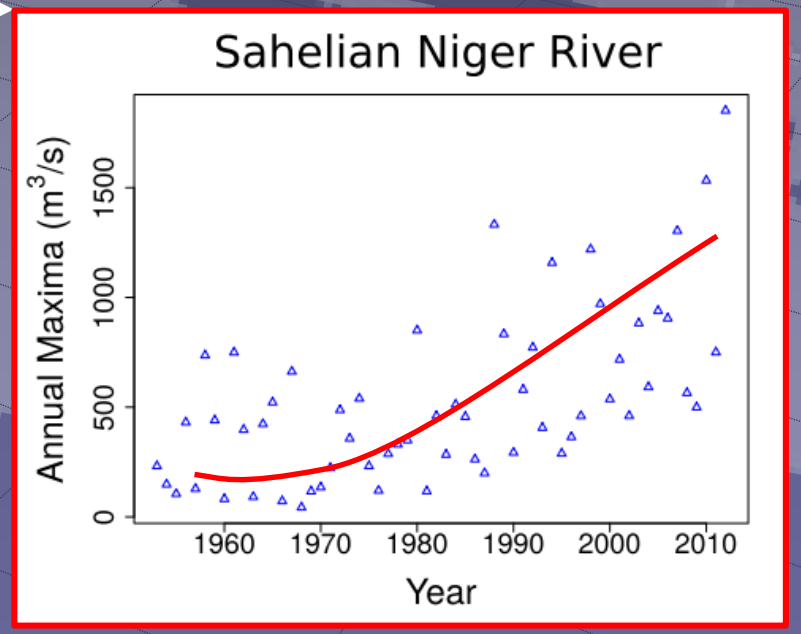
## In… précipitations



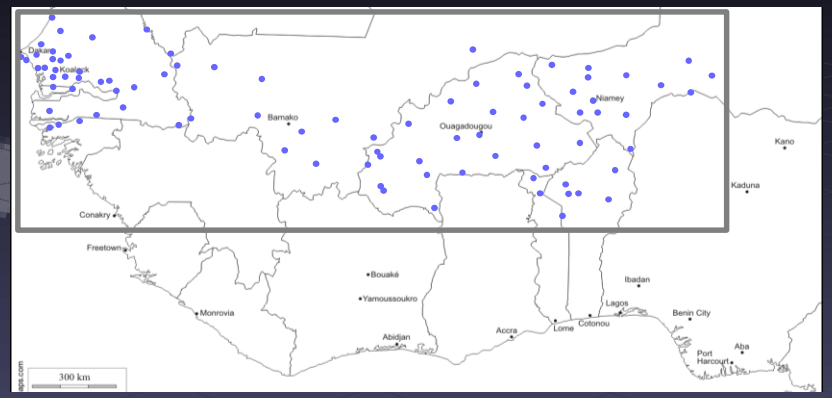

*Panthou et al. 2014 IJOC*

## Attribution

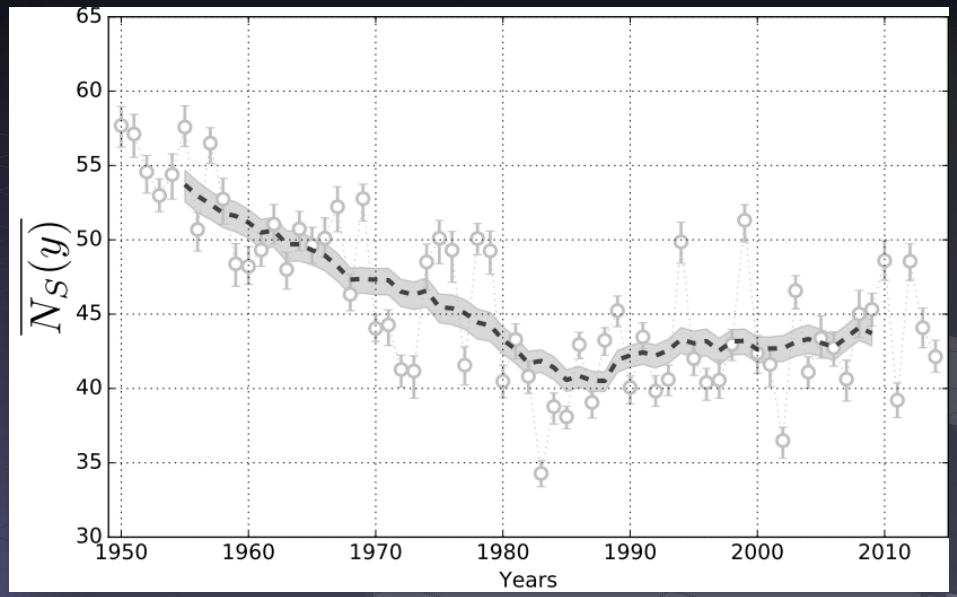


## Nombre de jours pluvieux



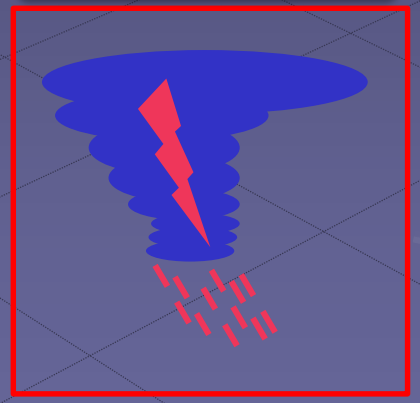

*Panthou et al. 2018, ERL*

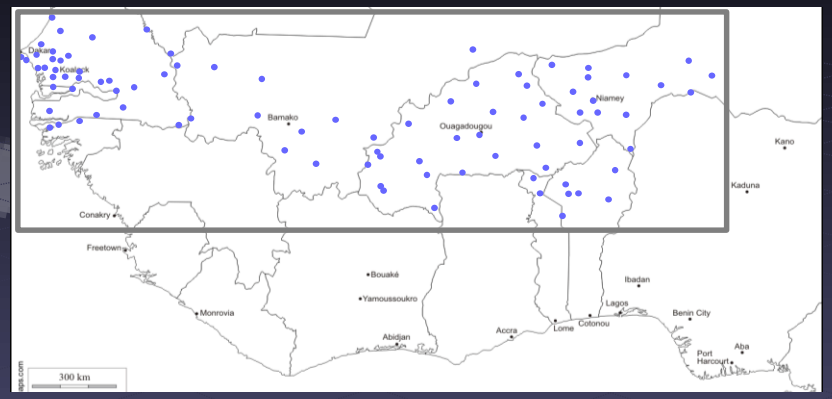



Depuis les années 80

- Stable
- A un niveau proche de ceux de la grande sécheresse

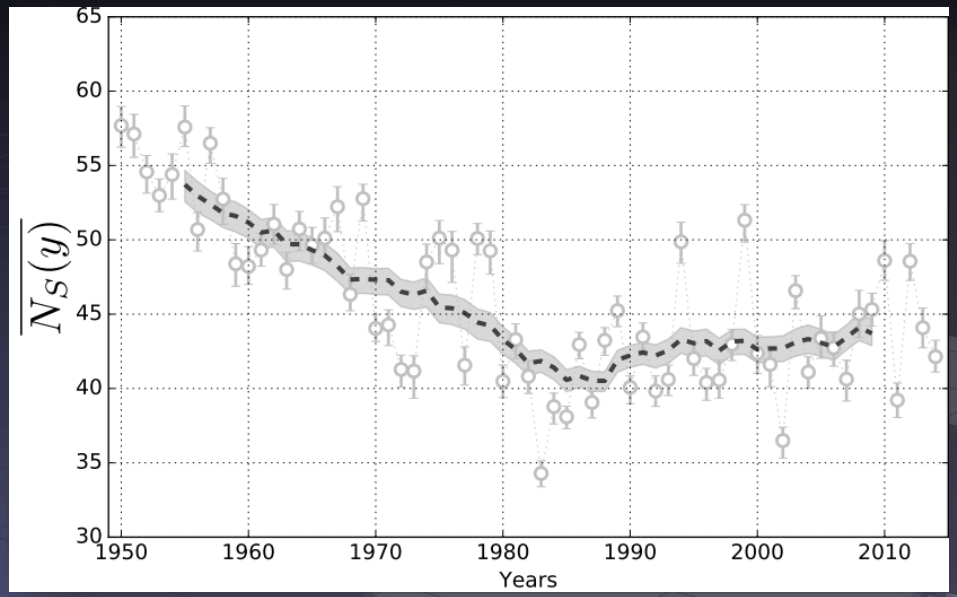
Détection





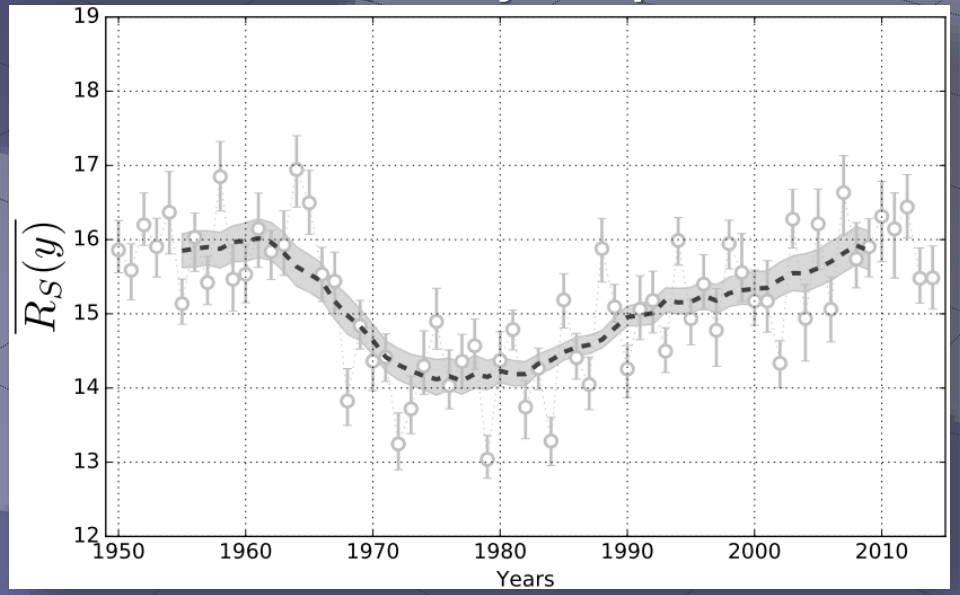

*Panthou et al. 2018, ERL*

## Nombre de jours pluvieux



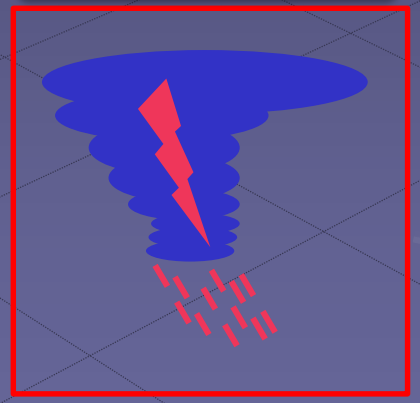

Depuis les années 80
- Stable
- A un niveau proche de ceux de la grande sécheresse

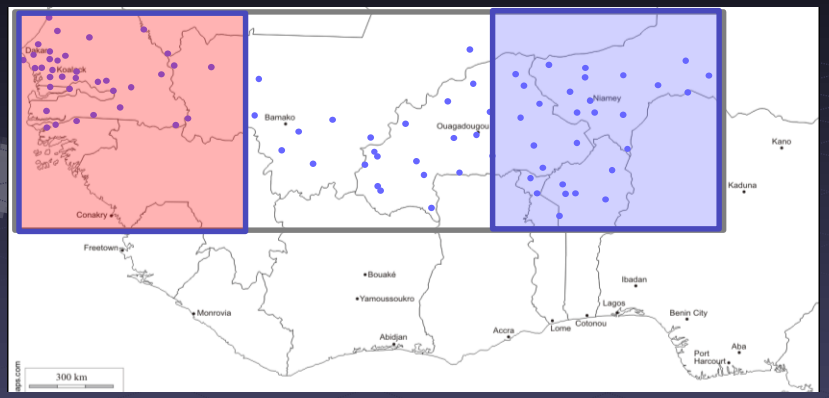
## Intensité des jours pluvieux



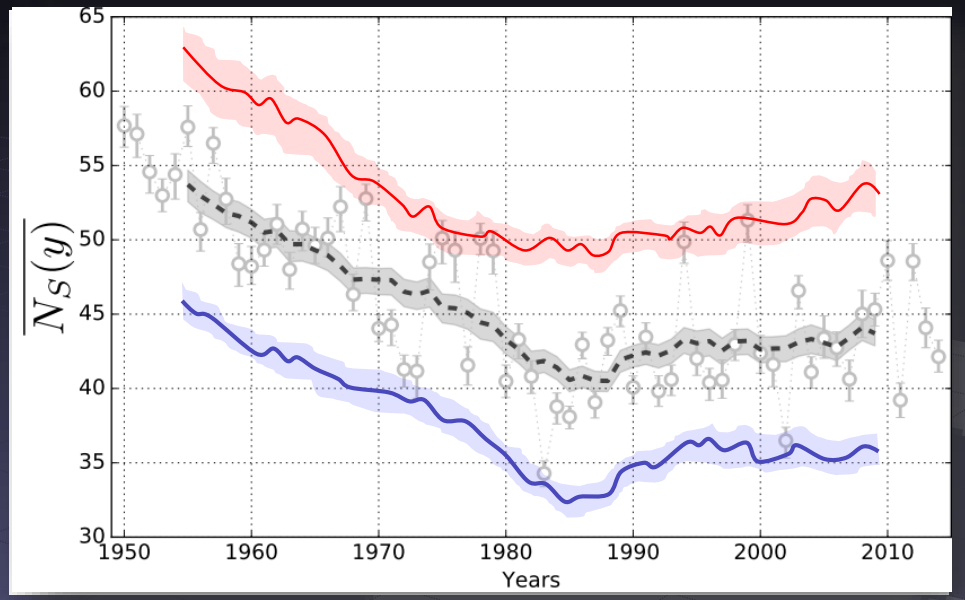

Depuis les années 70-80:
- Forte augmentation
- Parfois à des niveaux jamais atteints depuis les années 50.

Détection

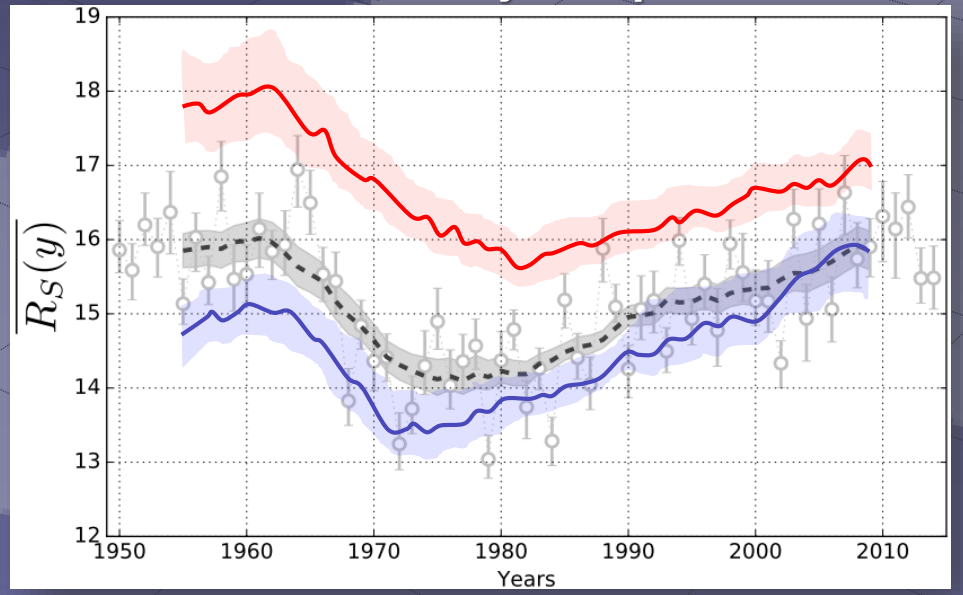





*Panthou et al. 2018, ERL*

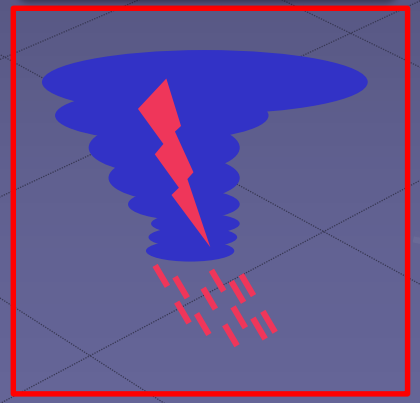



**Intensité des jours pluvieux**

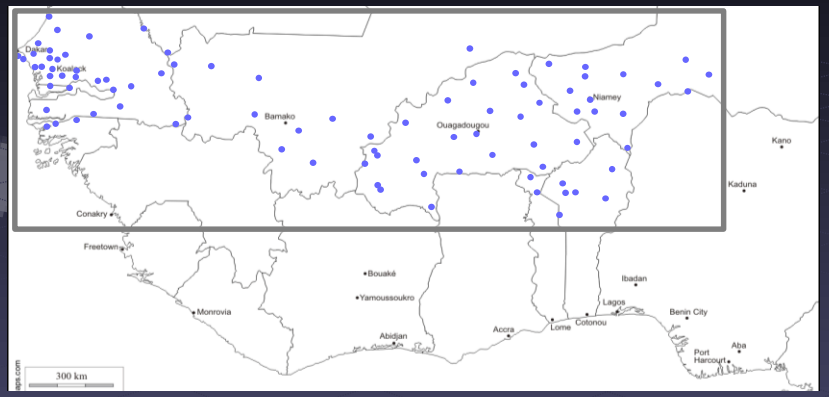



Différences Est-Ouest

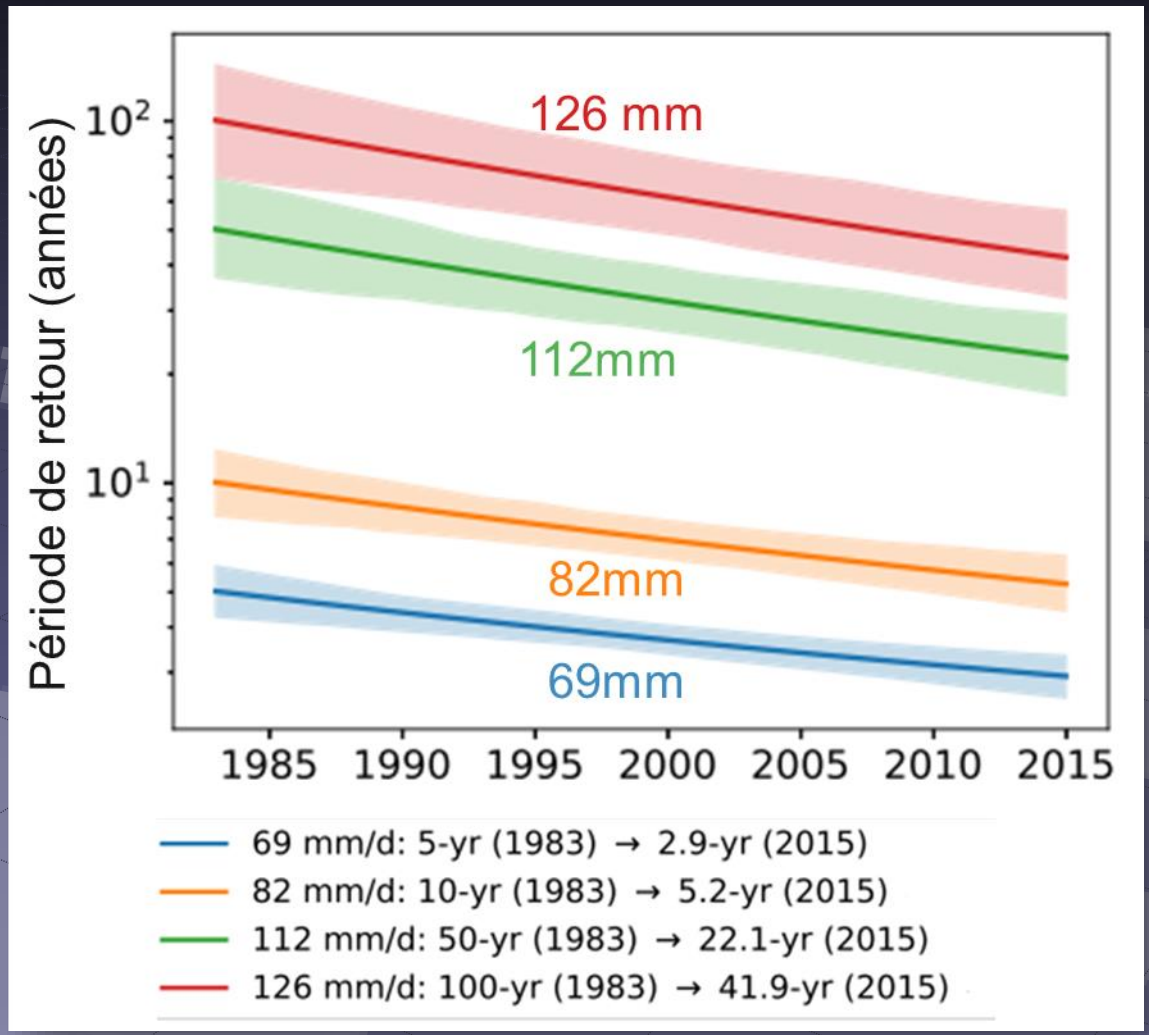
Détection



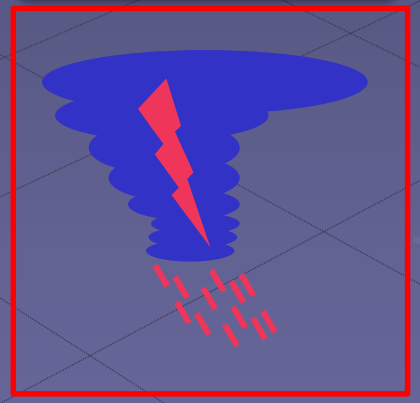
## Impact sur les temps de retour
## Pluie journalières

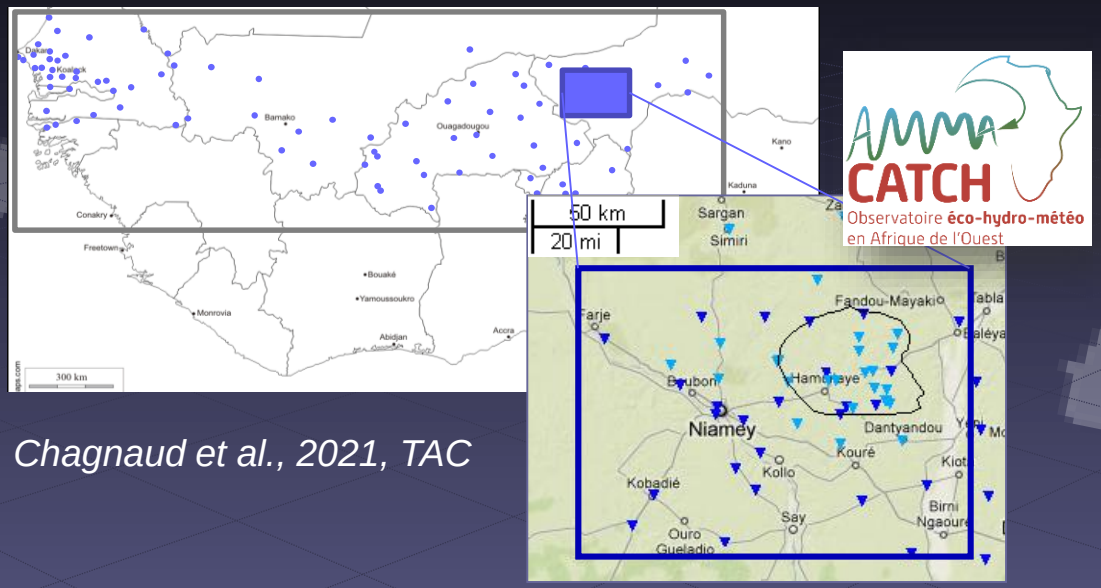



*Chagnaud et al., 2022, ERL*




Détection

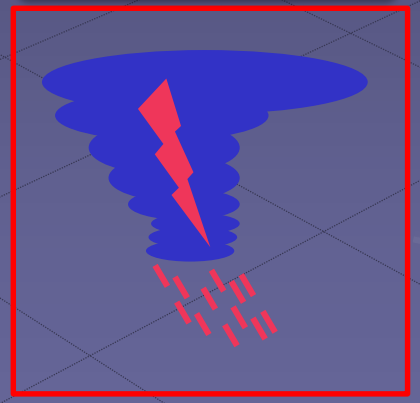




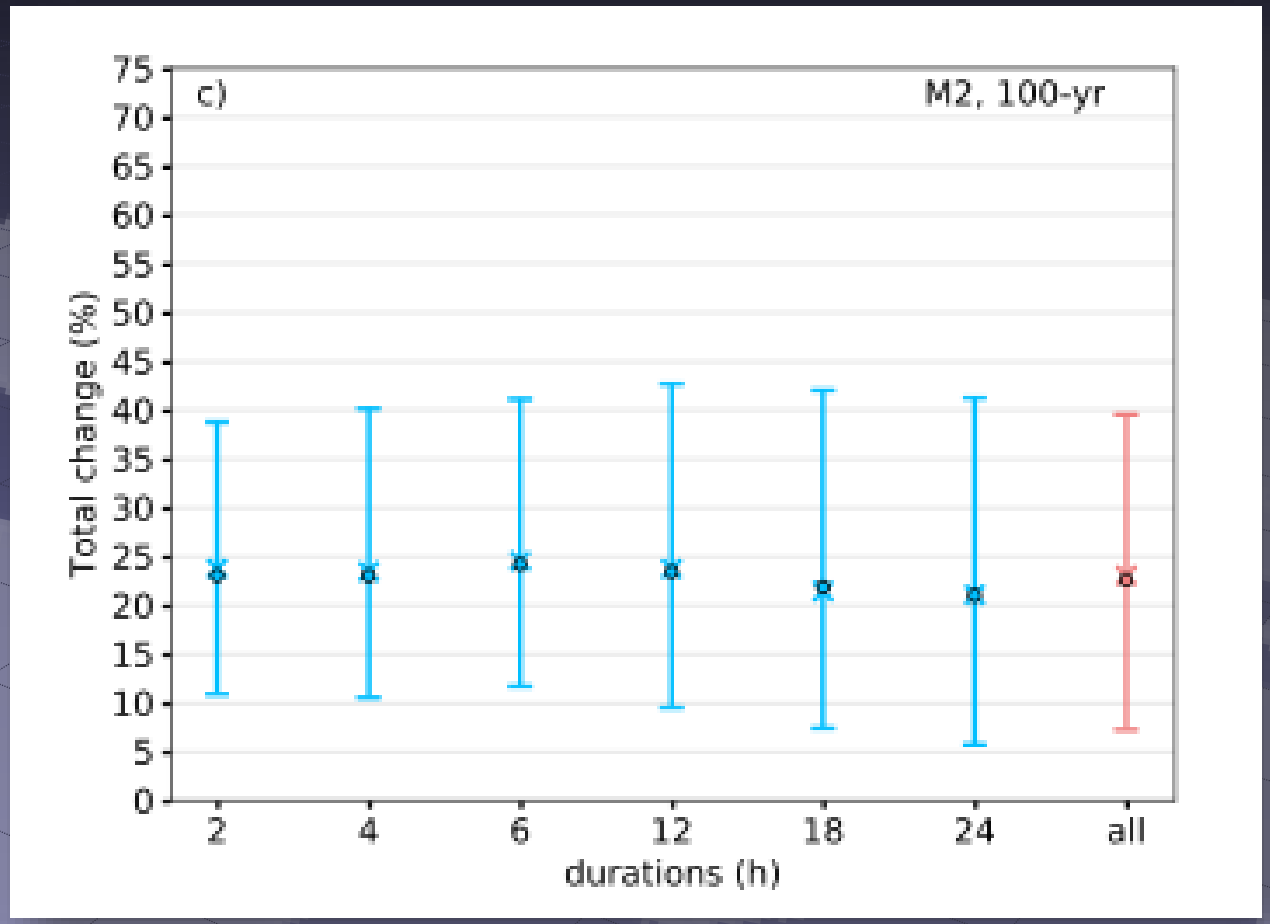

*Chagnaud et al., 2021, TAC*

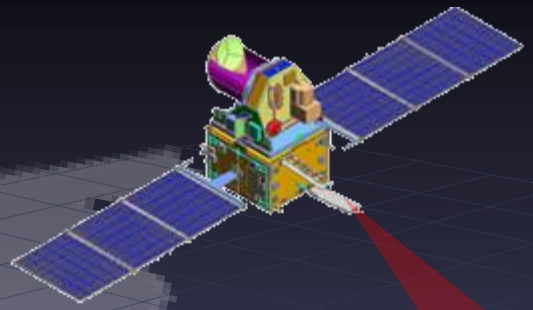
AMMA CATCH
Observatoire éco-hydro-météo en Afrique de l'Ouest

Détection



Tendance (%) pluie centennale 1990-2017

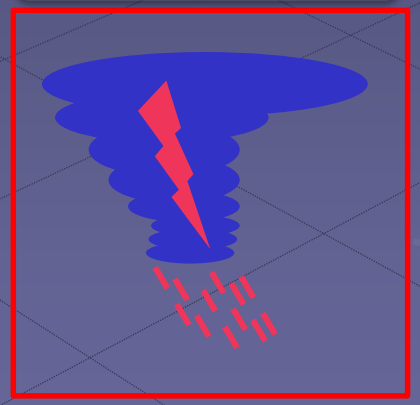




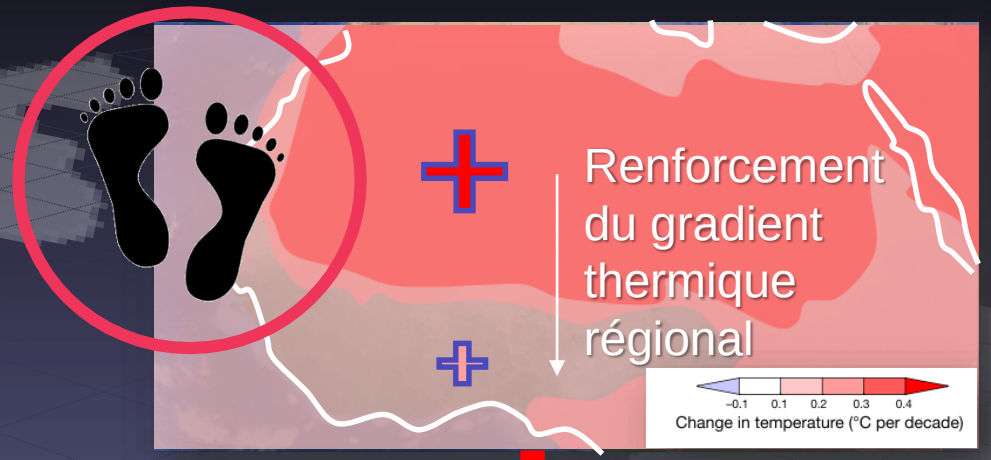
Des orages
- plus développés
- plus intenses
- plus fréquents

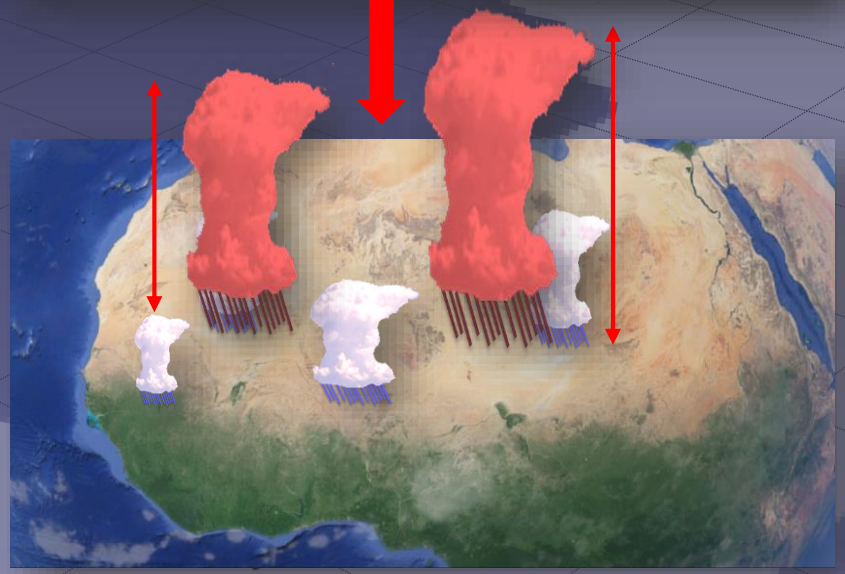
*Taylor et al. 2017, Nature*

Attribution



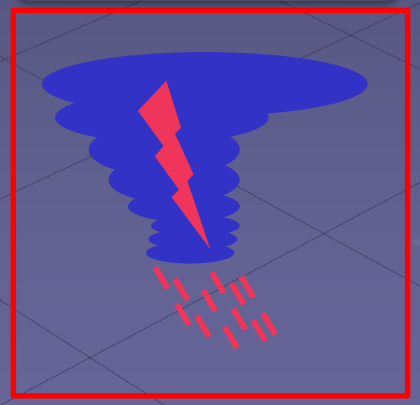
## Causé par le réchauffement du Sahara



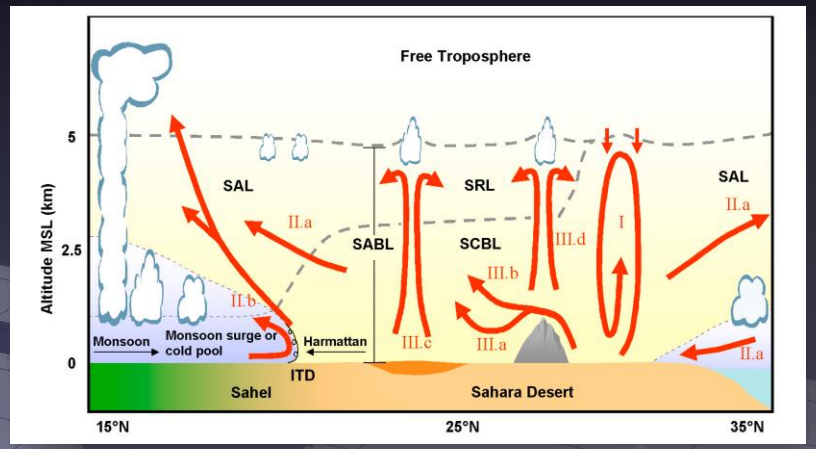



*Taylor et al. 2017, Nature*

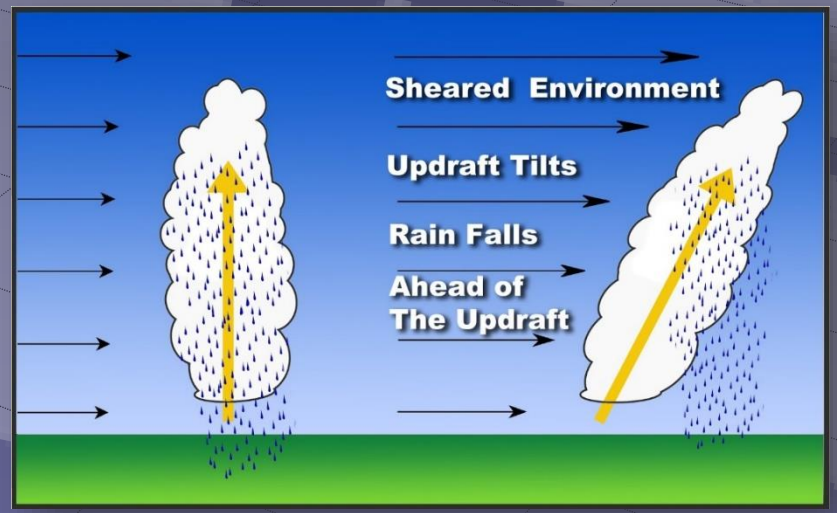
## Attribution

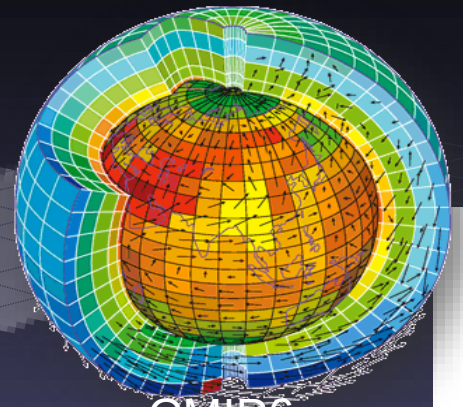


## Renforcement du SAL




## Renforcement du cisaillement

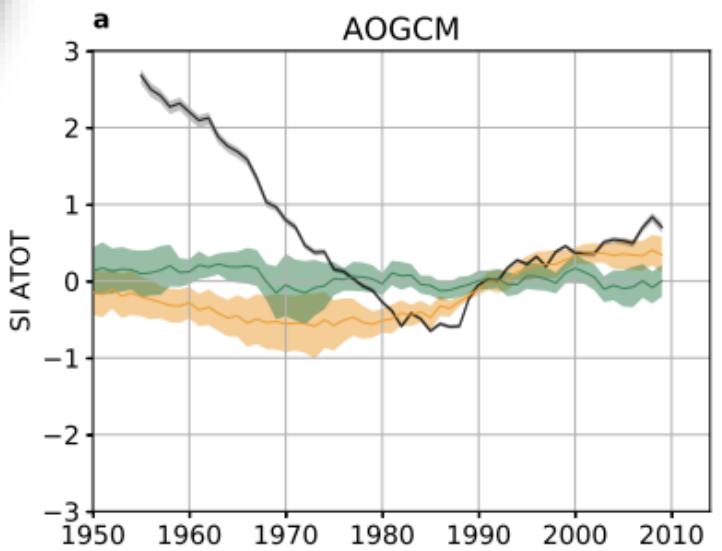




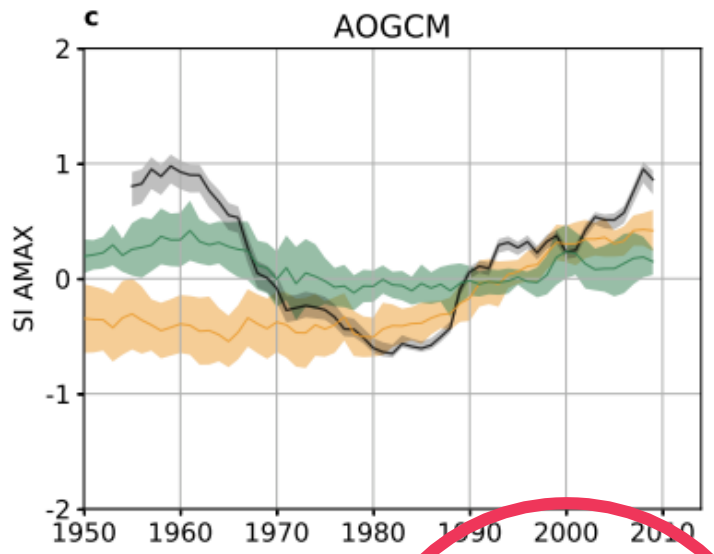
CMIP6

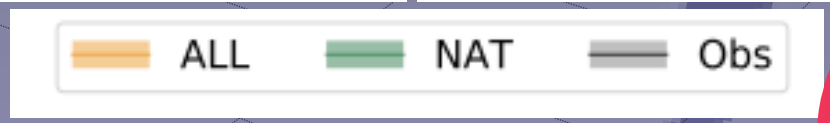
Les modèles de climat simulent l’intensification des pluies…

Pluie cumul annuel



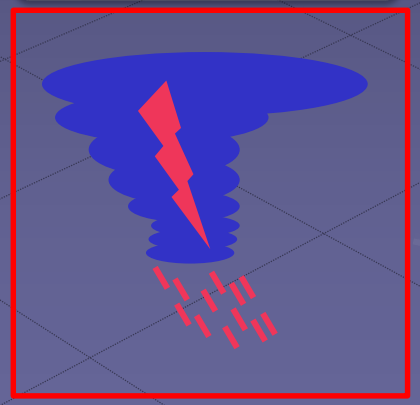

Pluie journalière maximale annuel

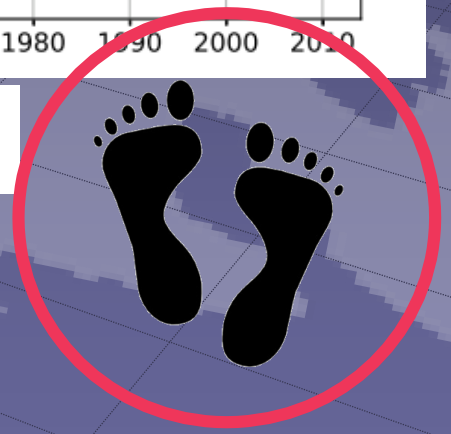



*Chagnaud et al. In prep*

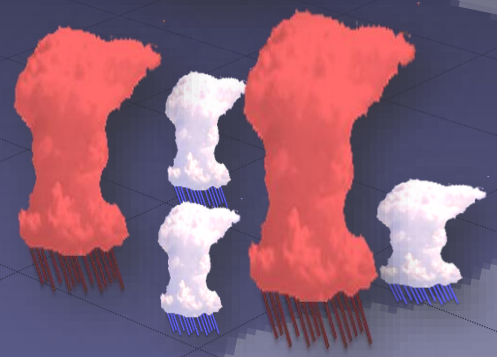
Attribution





# Trois approches

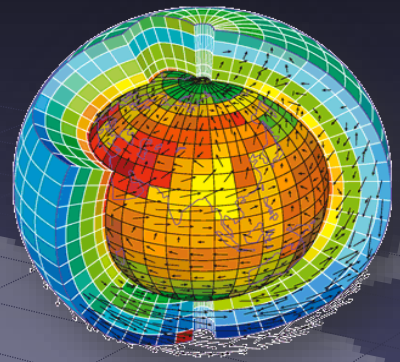
1

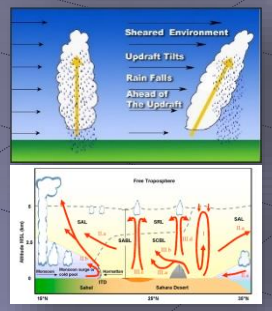


Modèles Climatiques Régionaux
Convection Explicite

*CP4-Africa*
*Stratton et al. 2018, J. Clim*
*Berthou et al. 2019, GRL, Clim. Dyn.*

2

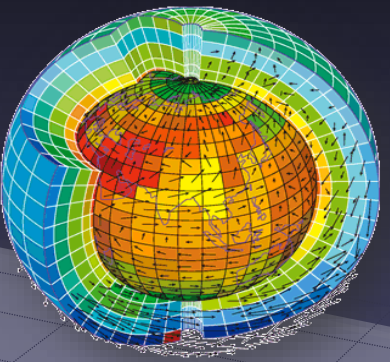


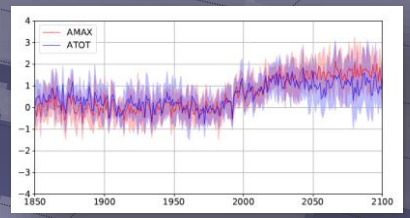



Modèles Climatiques Globaux
Evolution des mécanismes
associés aux extrêmes

*Rowell et al. 2020, J. Clim*
*Klein et al. 2021, ERL*

3

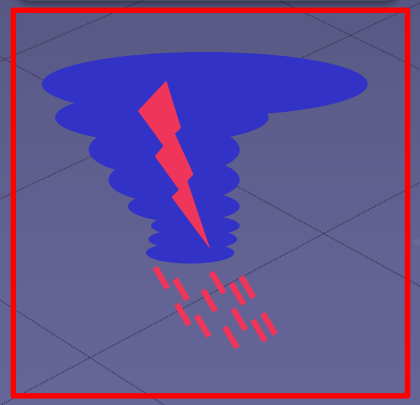


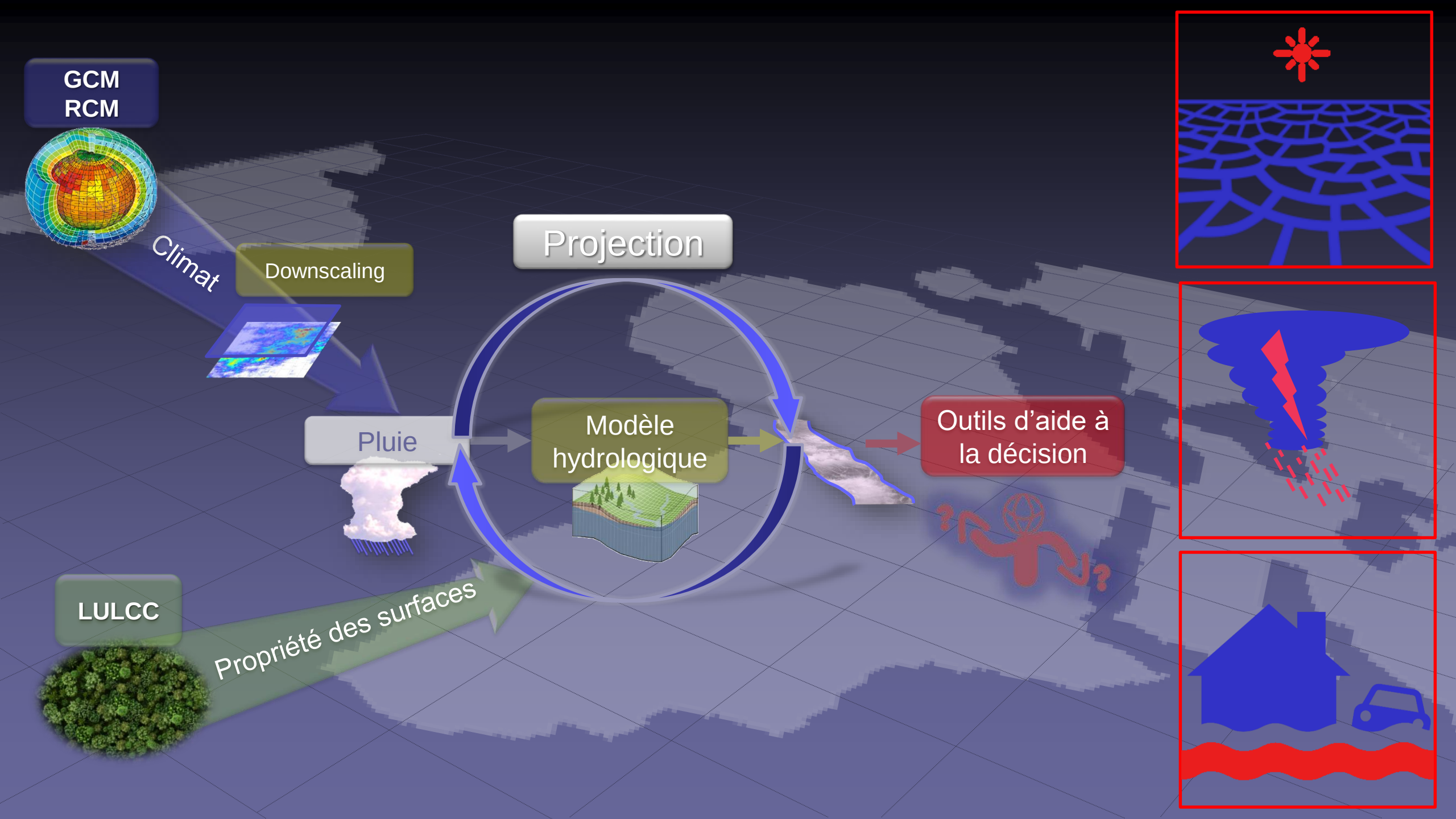



Modèles Climatiques Globaux
Analyse des
extrêmes de pluie simulés

*Chagnaud et al. In prep*

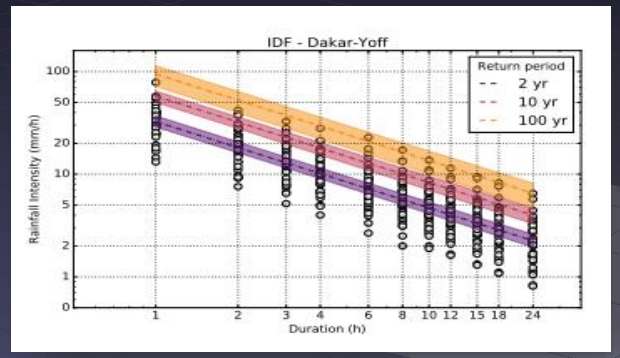
Projection




GCM
RCM
Climat
Downscaling
Projection
Pluie
Modèle
hydrologique
Outils d'aide à
la décision
LULCC
Propriété des surfaces

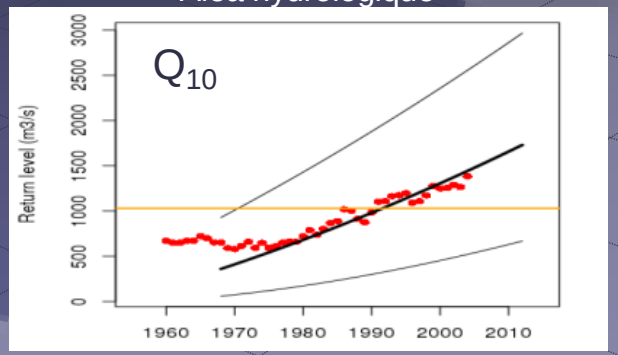
# Défi n°4 SERVICES CLIMATIQUES

Courbes intensité-durée-fréquence




*Panthou et al. 2014, HESS*
*Sané et al. 2018, NHESS*

Alea hydrologique




*Wilcox et al. 2018, JH*

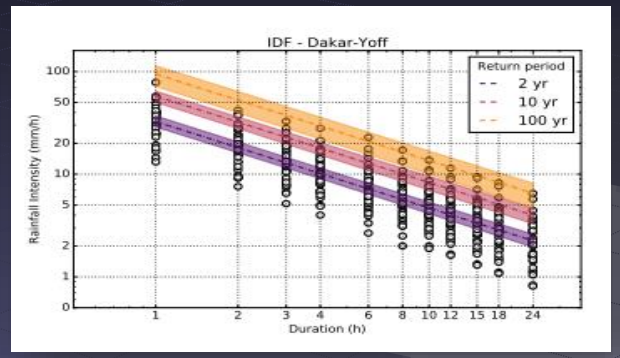
Cartes d' inondations

*Miller et al. in prep.*

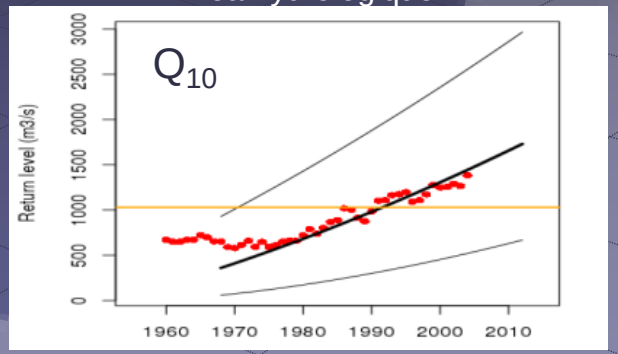
OUTILS D'AIDE À LA DÉCISION

# Défi n°4
# SERVICES CLIMATIQUES

Courbes intensité-durée-fréquence




Alea hydrologique

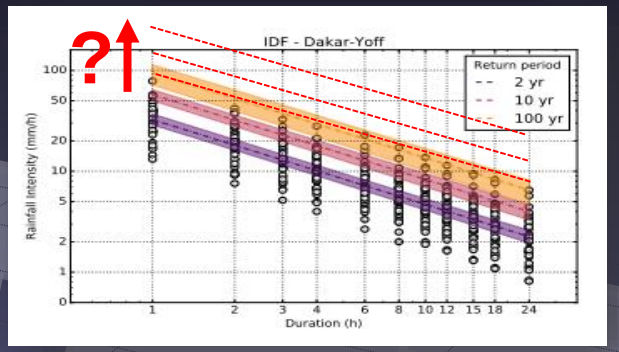



Cartes d' inondations

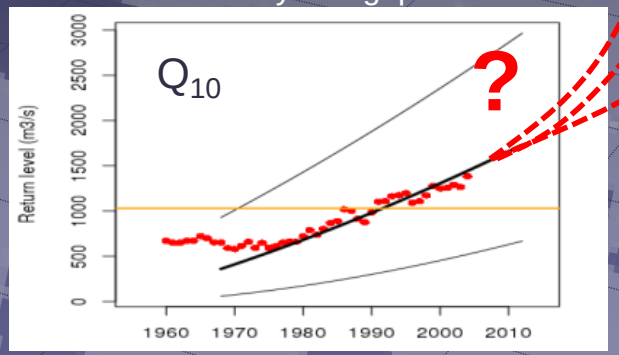
en 2050?

en 2100?

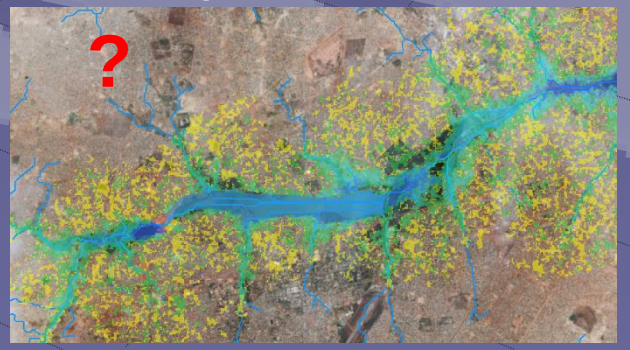
Courbes intensité-durée-fréquence




Alea hydrologique




Cartes d'inondations



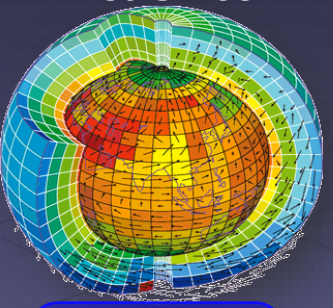
**Défi n°1 PROBLEMES D'ECHELLES**

**Défi n°2 EXTREMES**

**Défi n°3 MODELES PROCESS-BASED**

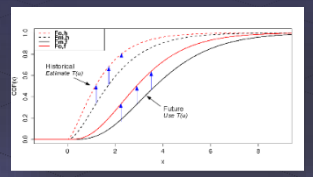
**Défi n°4 CO-CONSTRUCTION**

Unif. Mod. Met Office

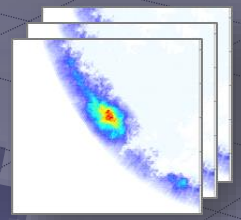


CP4-Africa

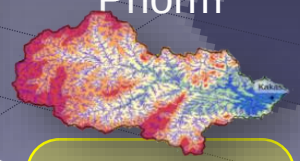
CDF-t

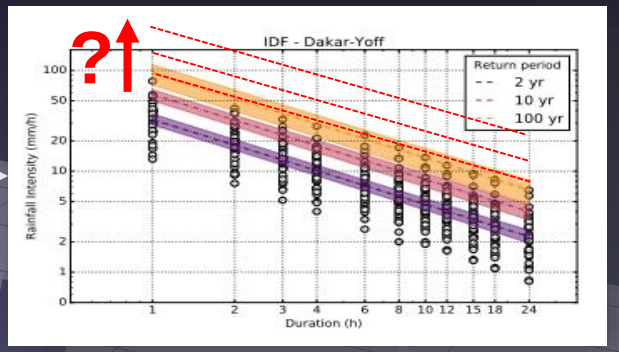


Stochastorm

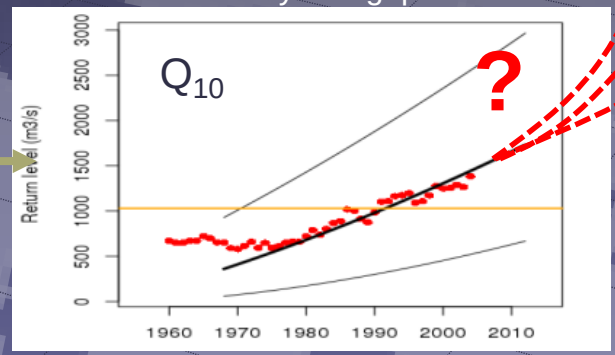


Phorm

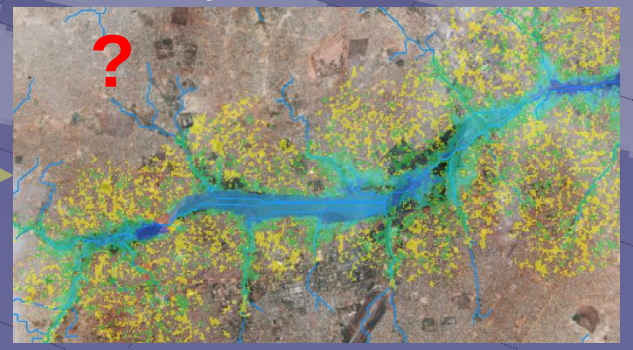




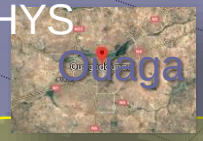

Alea hydrologique

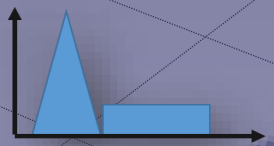



Cartes d'inondations




ATHYS



**GCM**

**RCM**

**Bias correction**

**Stochastic Rainfall Generator**

**Mesoscale Rain fields**

**Rural Hydrologi cal model**

**Design storms**

**Urban Hydrologi cal model**

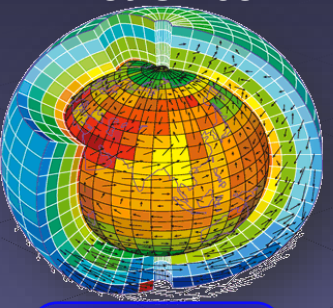
**Défi n°1 PROBLEMES D'ECHELLES**

**Défi n°2 EXTREMES**

**Défi n°3 MODELES PROCESS-BASED**

**Défi n°4 CO-CONSTRUCTION**

Unif. Mod. Met Office

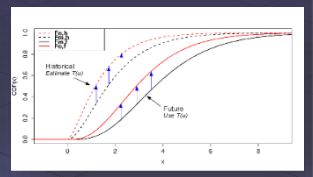


**GCM**

CP4-Africa

**RCM**

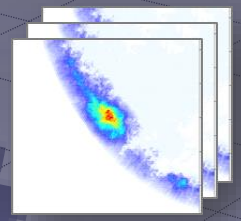
CDF-t



**Bias correction**

Stochastorm

**Stochastic Rainfall Generator**

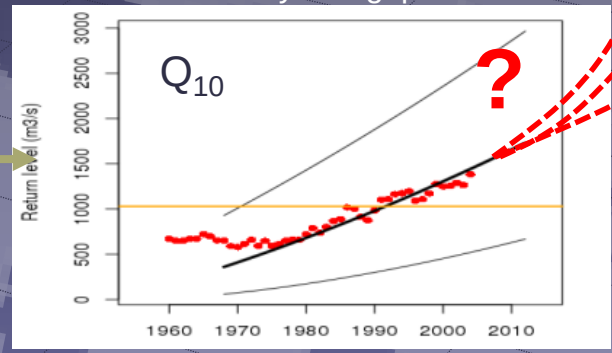


**Mesoscale Rain fields**

Phorm

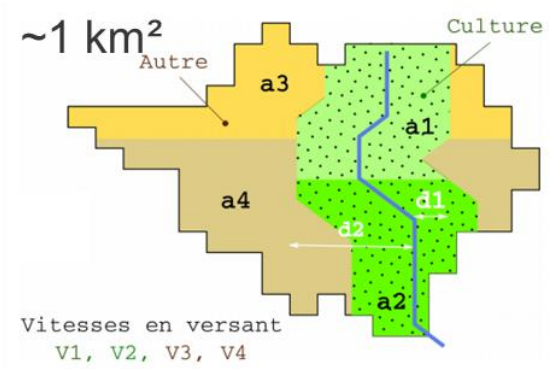
**Rural Hydrologi cal model**

Alea hydrologique

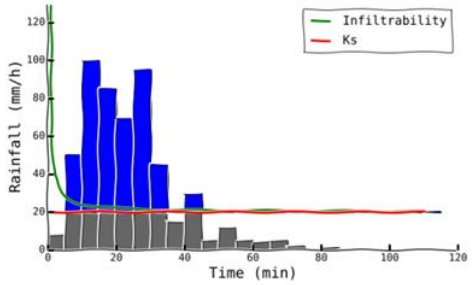


***PHORM***
***Purely HOrtonian Runoff Model***

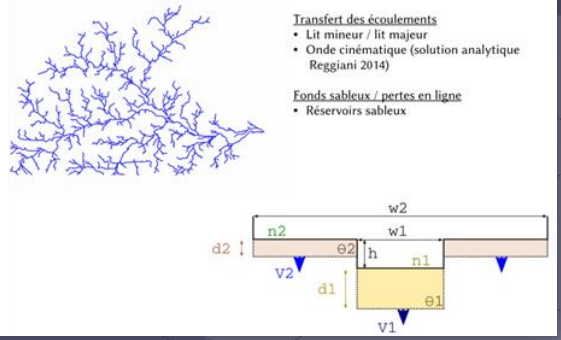
Discretization



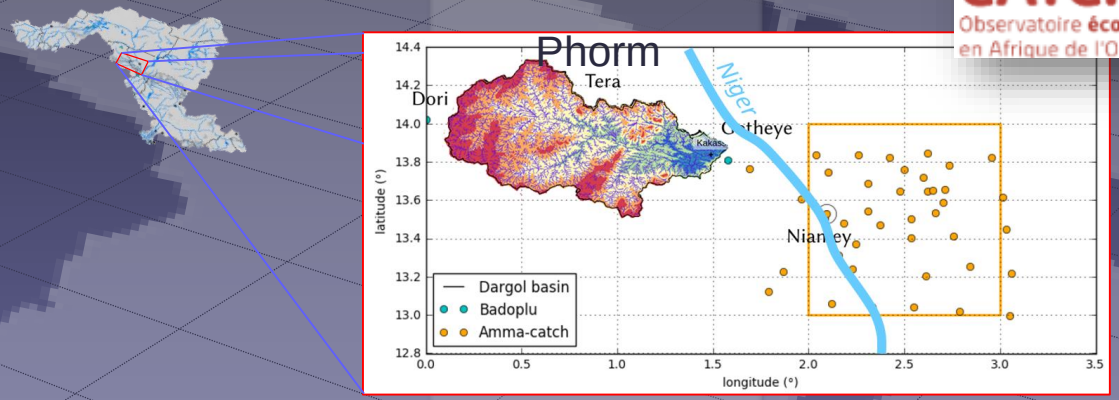

Production




Transfer




*Quantin et al. in prep.*




AMMA CATCH
Observatoire éco-hydro-météo en Afrique de l'Ouest

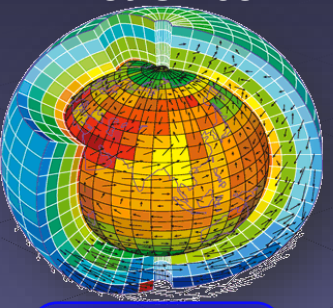
**Défi n°1 PROBLEMES D'ECHELLES**

**Défi n°2 EXTREMES**

**Défi n°3 MODELES PROCESS-BASED**

**Défi n°4 CO-CONSTRUCTION**

Unif. Mod. Met Office

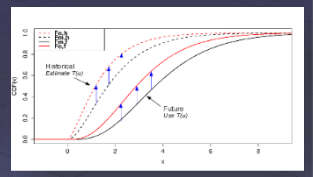


**GCM**

CP4-Africa

**RCM**

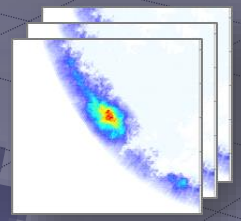
CDF-t



**Bias correction**

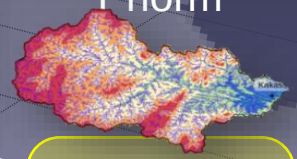
Stochastorm

**Stochastic Rainfall Generator**



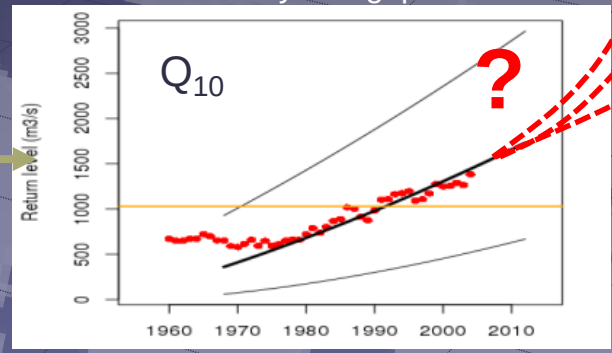
**Mesoscale Rain fields**

Phorm



**Rural Hydrologi cal model**

Alea hydrologique



| | Object | Function | Parameters | | f(t) degree | Fitting method |
|---|---|---|---|---|---|---|
| Occurrence | Start Date | Gauss | mean | $\mu_s$ | - | likelihood |
| | | | std | $\sigma_s$ | - | |
| | End Date | Gauss | mean | $\mu_e$ | - | likelihood |
| | | | std | $\sigma_e$ | - | |
| | IET | Gamma | shape | $\alpha$ | 3 | likelihood |
| | | | rate | $\beta$ | 2 | |
| | Big vs small | Bernoulli | ratio | $\kappa$ | - | moment |
| Event Rain field – Marginal | Big events | F0-Gamma | atom | $F_0$ | 3 | Censored likelihood |
| | | | shape | $\alpha_B$ | 1 | |
| | | | rate | $\beta_B$ | 3 | |
| | | GPD | threshold | $\lambda$ | - | likelihood |
| | | | scale | $\sigma_{GPD}$ | - | |
| | | | shape | $\xi_{GPD}$ | - | |
| | Small events | F0-Gamma | atom | $F_0$ | 3 | likelihood |
| | | | shape | $\alpha_S$ | 3 | |
| | | | rate | $\beta_S$ | 2 | |
| Event Rain field – Variogram | Big events | Double exponential | range | $\varphi_1$ | - | Censored likelihood |
| | | | range | $\varphi_2$ | - | |
| | | | anis. coef. | $a_1$ | - | |
| | | | anis. coef. | $a_2$ | - | |
| | | | variance ratio | $\nu$ | - | |
| | Small events | Exponential | Range | $\varphi$ | - | Censored likelihood |

| | | | |
|---|---|---|---|
| Sub-event Rain field | Big events | Hyetogram shape | - |
| | | Propagation | Mean speed |
| | | | Mean direction |
| | Small events | Hyetogram shape | - |

**Stochastorm**

**Stochastic Rainfall Generator**

*Guillot and Lebel, 1999, JGR*
*Vischel et al. 2009, JH*
*Wilcox et al. in prep, JHM*

Inter-event time
Big events
Small events

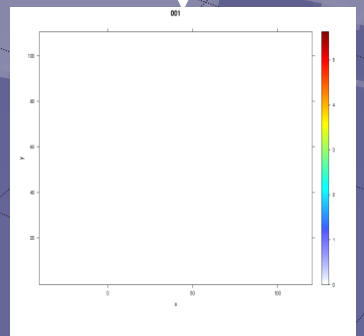
*1st of April*

Time within the rainy Season

CDF
Spatial covariance

Synthetic hyetograph

Propagation



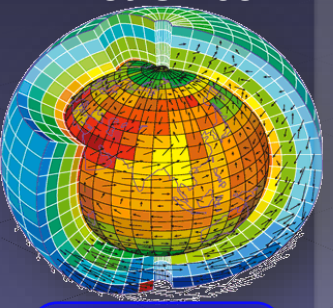
**Défi n°1 PROBLEMES D'ECHELLES**

**Défi n°2 EXTREMES**

**Défi n°3 MODELES PROCESS-BASED**

**Défi n°4 CO-CONSTRUCTION**

Unif. Mod. Met Office

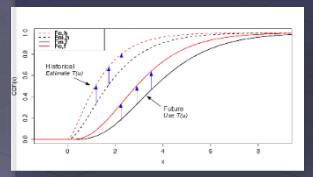


**GCM**

CP4-Africa

**RCM**

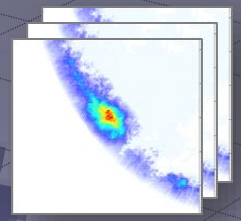
CDF-t



**Bias correction**

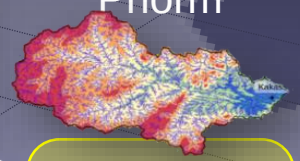
Stochastorm

**Stochastic Rainfall Generator**



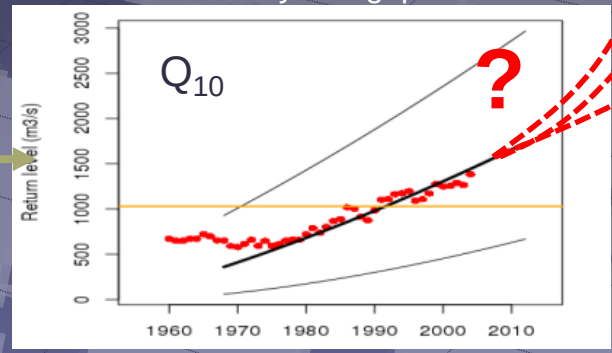
**Mesoscale Rain fields**

Phorm

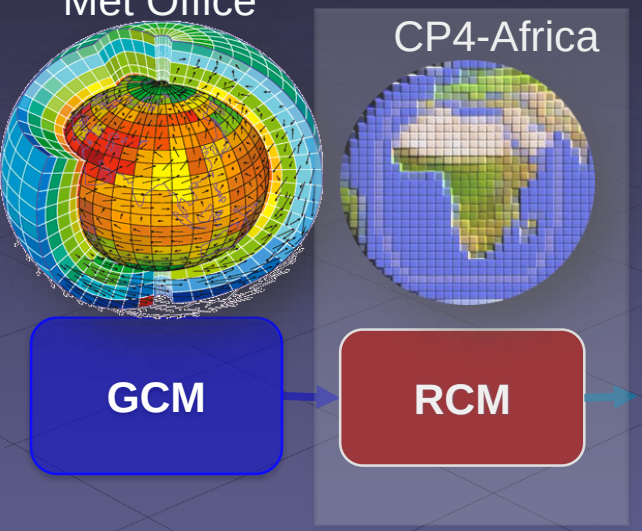


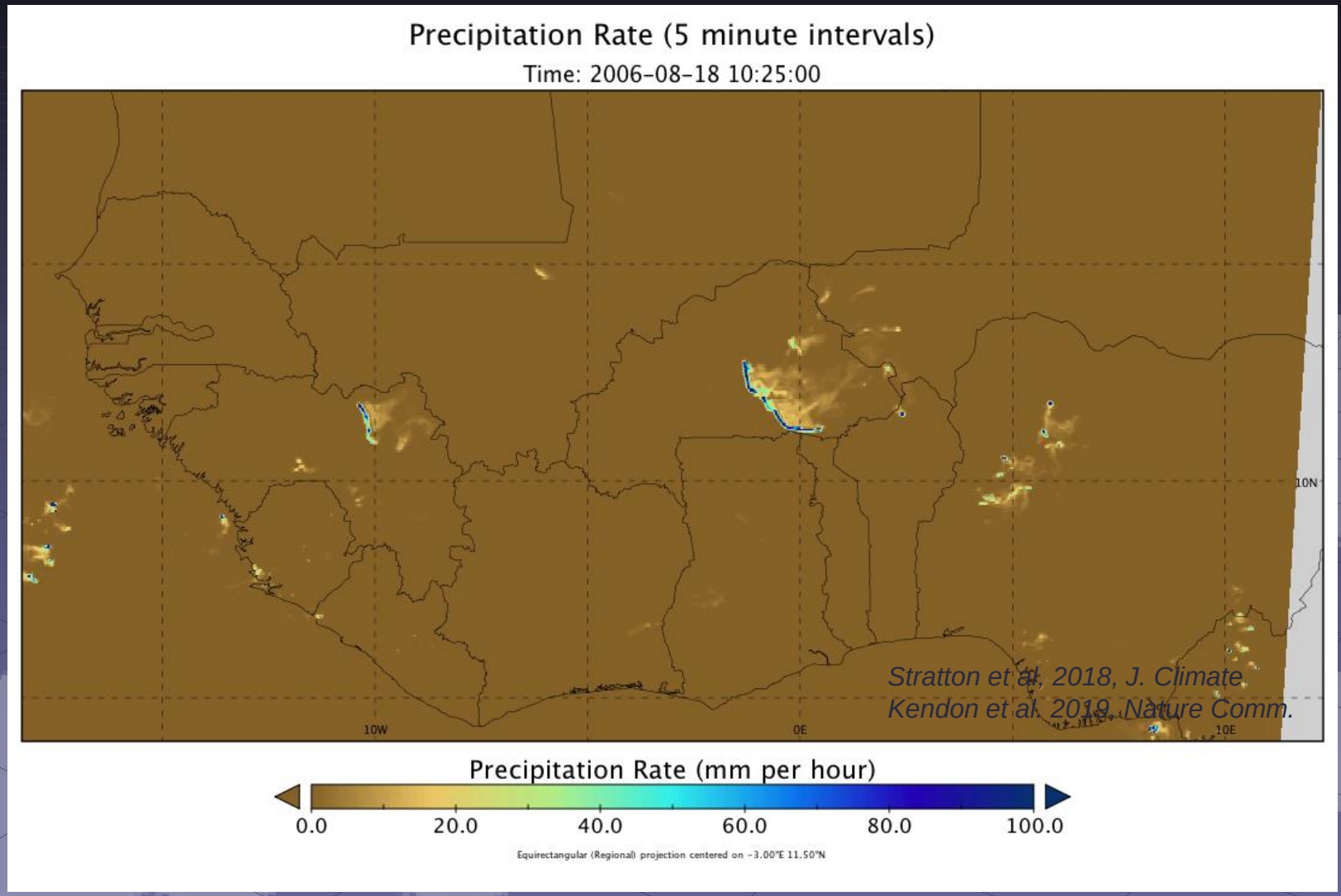
**Rural Hydrologi cal model**

Alea hydrologique



# Convection-Permitting atmospheric model for Africa




*Stratton et al. 2018, J. Climate*
*Kendon et al. 2019, Nature Comm.*

**Simulation plan:**

- **10-years in control period 1997-2006**
- **10-years future climate ~2080-2100**

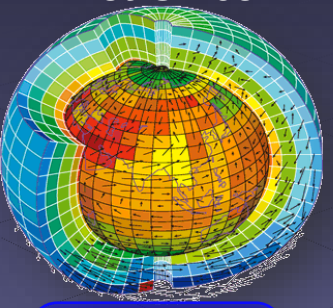
**Défi n°1 PROBLEMES D'ECHELLES**

**Défi n°2 EXTREMES**

**Défi n°3 MODELES PROCESS-BASED**

**Défi n°4 CO-CONSTRUCTION**

Unif. Mod. Met Office

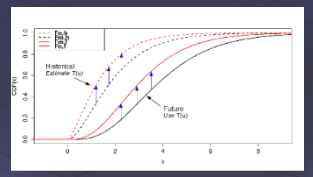


**GCM**

CP4-Africa

**RCM**

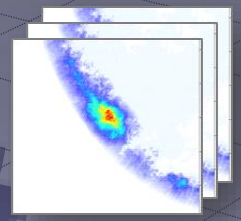
CDF-t



**Bias correction**

Stochastorm

**Stochastic Rainfall Generator**

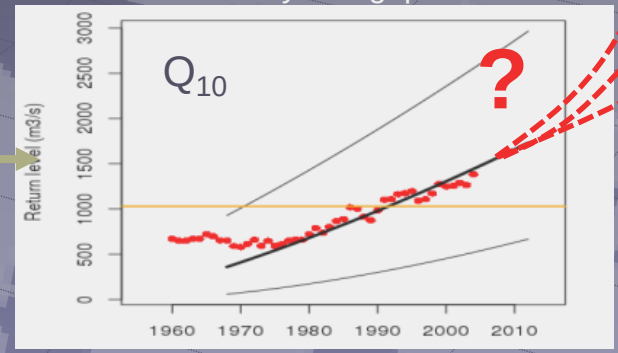


**Mesoscale Rain fields**

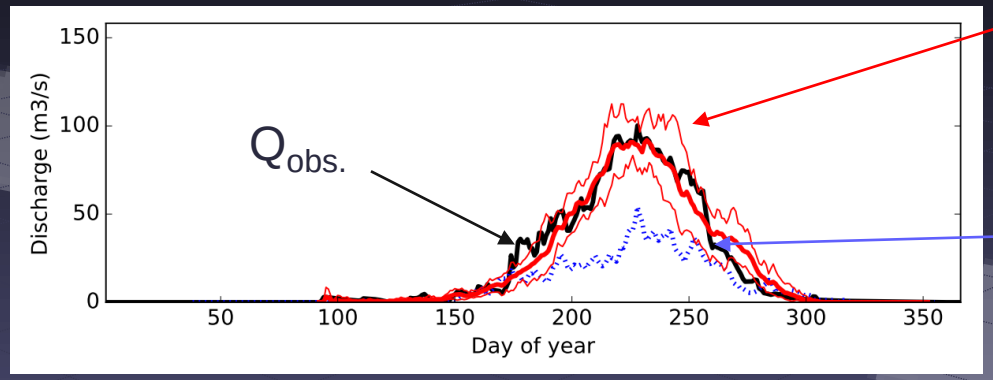
Phorm

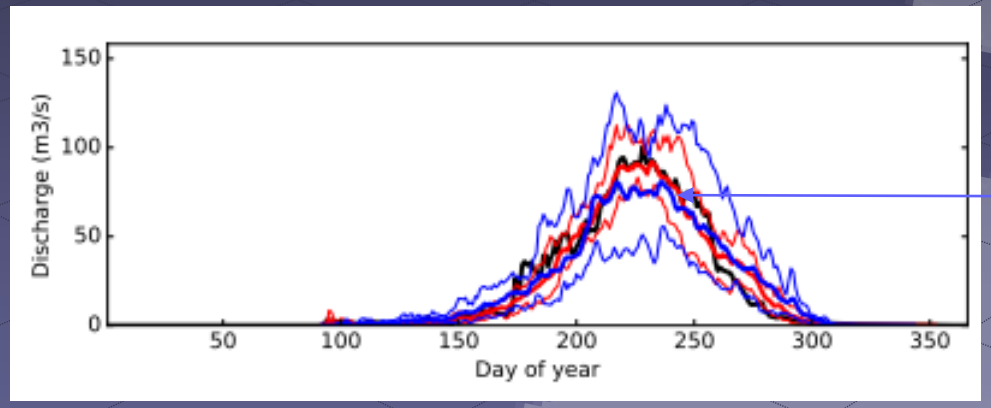
**Rural Hydrologi cal model**

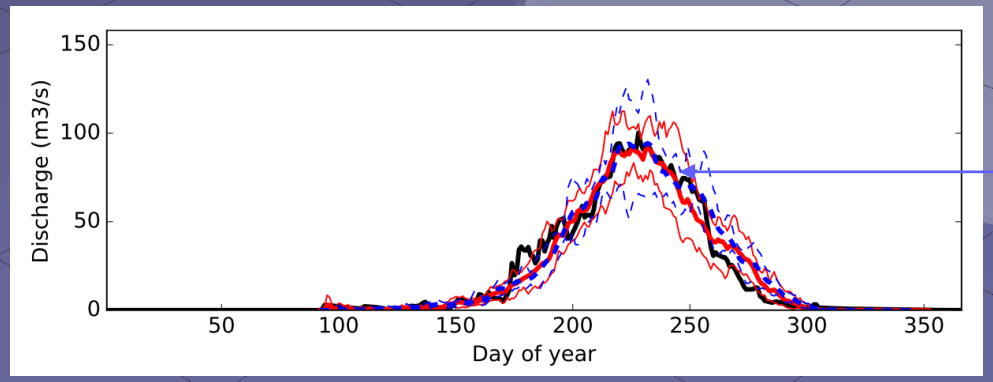
Alea hydrologique



# Régime hydrologique Dargol (Période de contrôle)




AMMA CATCH
Observatoire éco-hydro-météo en Afrique de l'Ouest

Stochastorm

CP4-Africa

CP4-Africa

Stochastorm

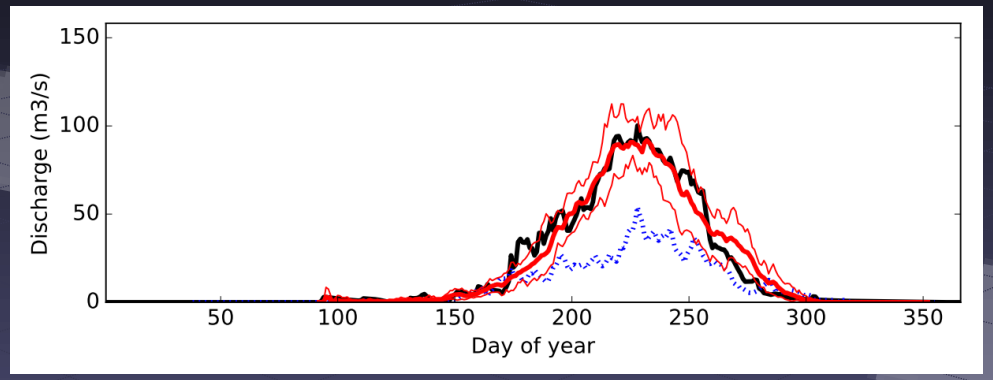
CP4-Africa

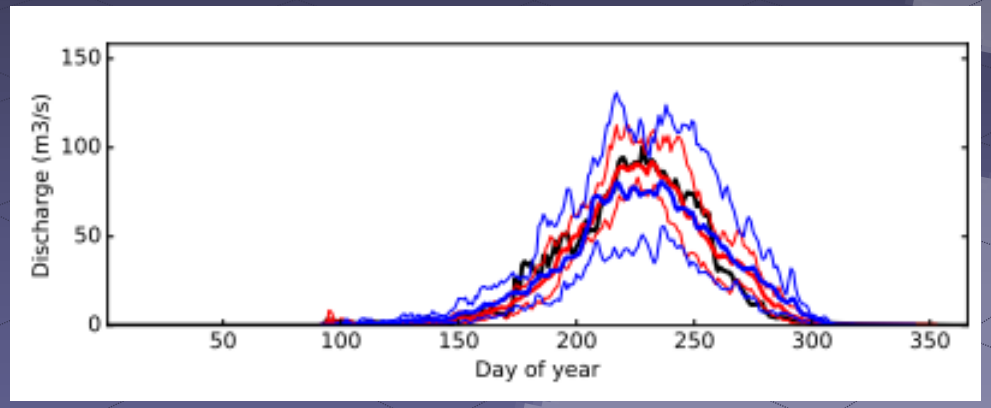
CDF-t

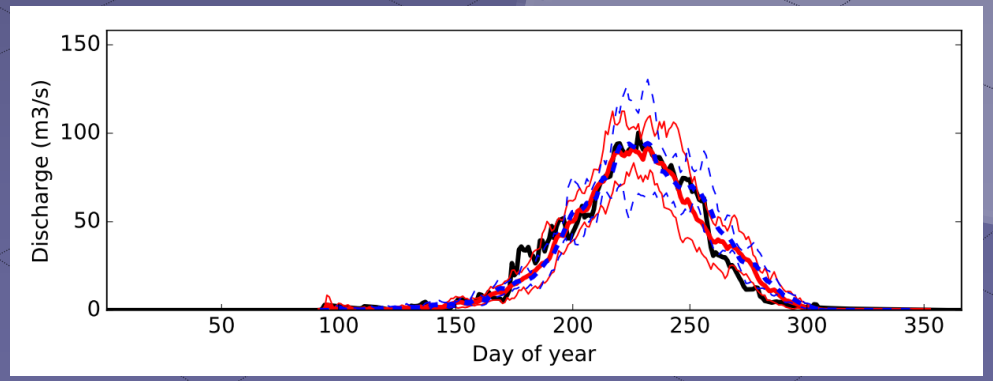
Stochastorm

*Wilcox, 2019 (PhD); Wilcox et al. in prep.*

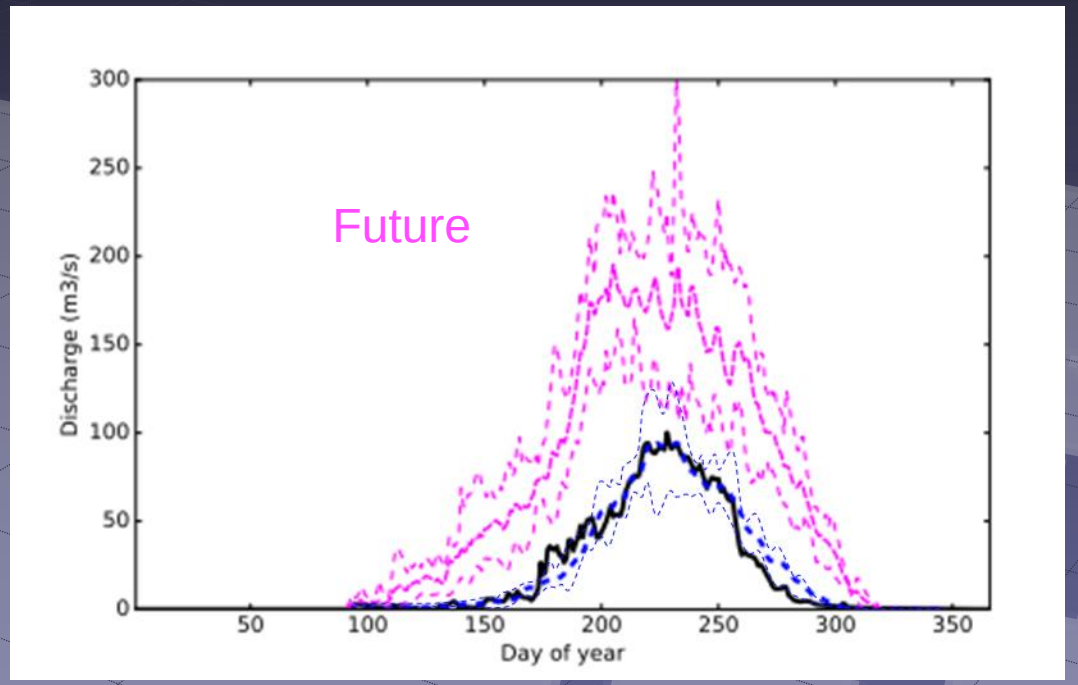
Régime hydrologique Dargol
(Période de contrôle)




Régime hydrologique Dargol
(Période future ~2080-2100)




*Wilcox, 2019 (PhD); Wilcox et al. in prep.*

# Bilan

- Mise en place d'une chaine de modélisation climat-impact
  - Répondre à une demande pressante d'outils d'aide à la gestion structurelle du risque inondation
  - Prise en compte des échelles et processus clé de la variabilité hydrologique
- Preuve de concept…Résultats incertains.

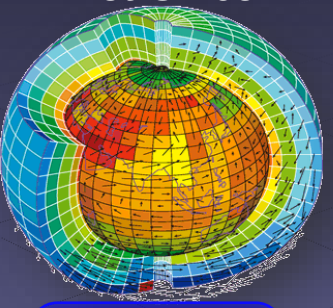
**Défi n°1**
**PROBLEMES D'ECHELLES**

**Défi n°2**
**EXTREMES**

**Défi n°3**
**MODELES PROCESS-BASED**

**Défi n°4**
**CO-CONSTRUCTION**

Unif. Mod. Met Office

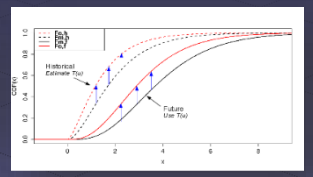


**GCM**

CP4-Africa

**RCM**

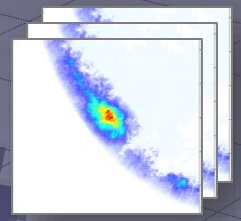
CDF-t



**Bias correction**

Stochastorm

**Stochastic Rainfall Generator**

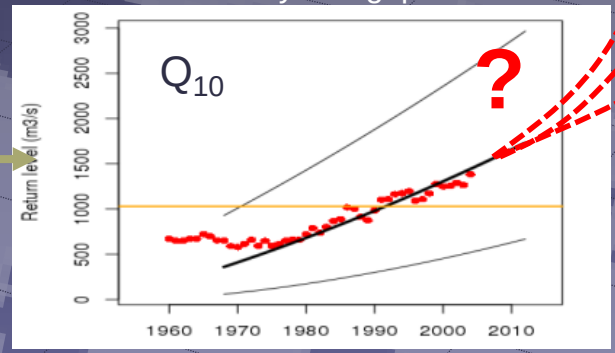


**Mesoscale Rain fields**

Phorm

**Rural Hydrological model**

Alea hydrologique




**Défi n°5**
**INCERTITUDE CLIMATIQUE**

**Défi n°6**
**INTERACTIONS HYDROLOGIE-SOCIETE**


MERCI POUR VOTRE ATTENTION

**Facteurs d'influence**

Dégradation des sols

Société (local)

**Attribution hydrologique**

Climat

Intensification des précipitations

**Attribution climatique**

Société (global)

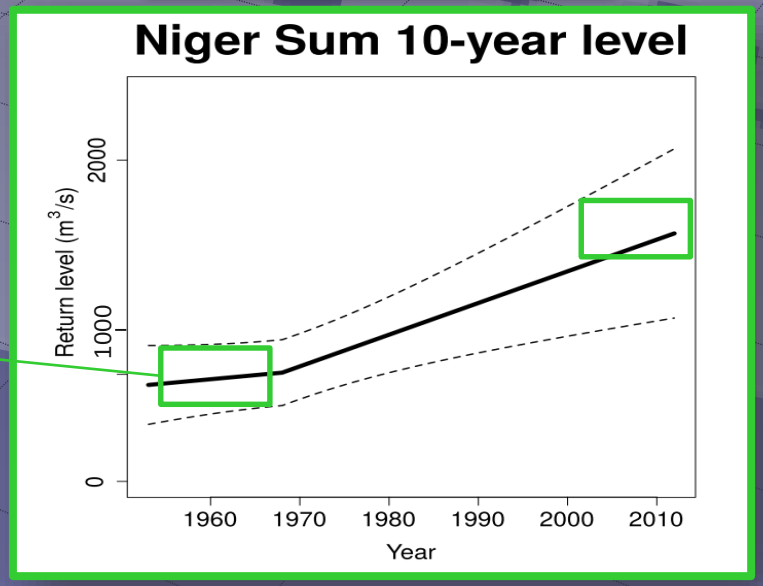
Intensification du cycle hydrologique

**Evolution de régime hydrologique**

**Projection hydrologique**

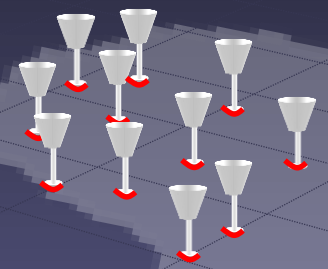
**Outils d'aide à la décision**

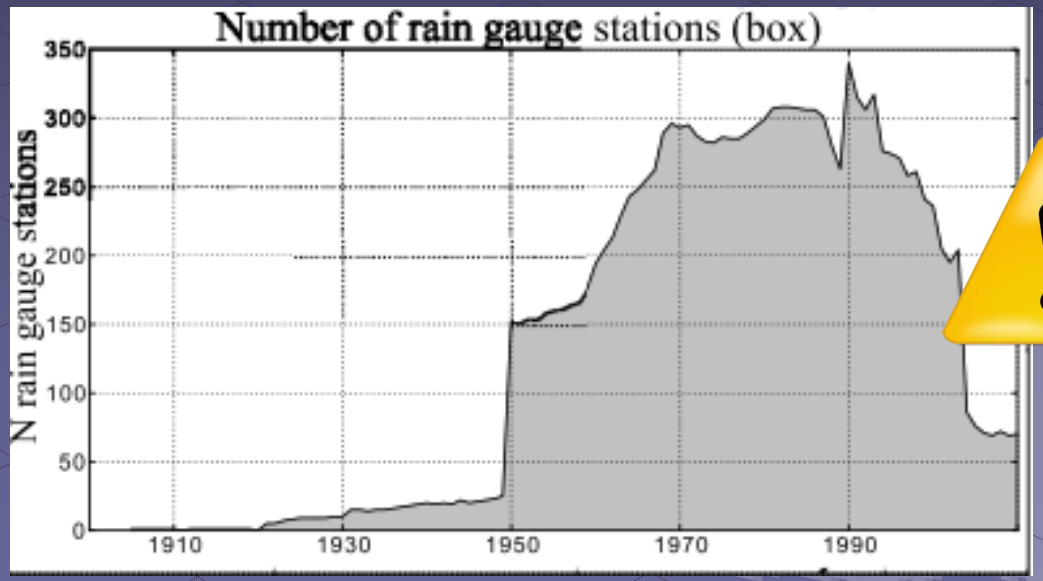
Normes Hydrologiques Années 1970

# Observations

**Défi n°2**
**EXTREMES CLIMATIQUES**

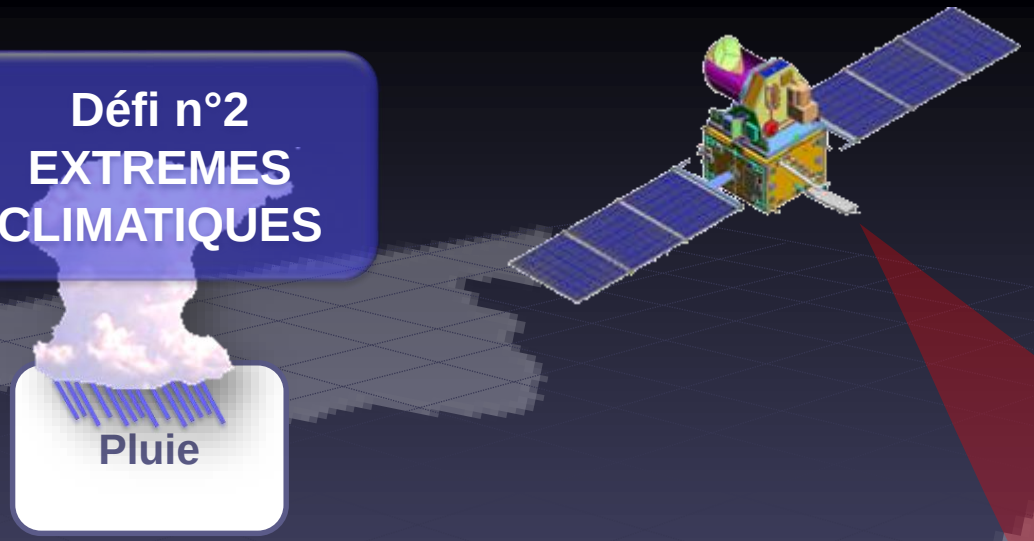





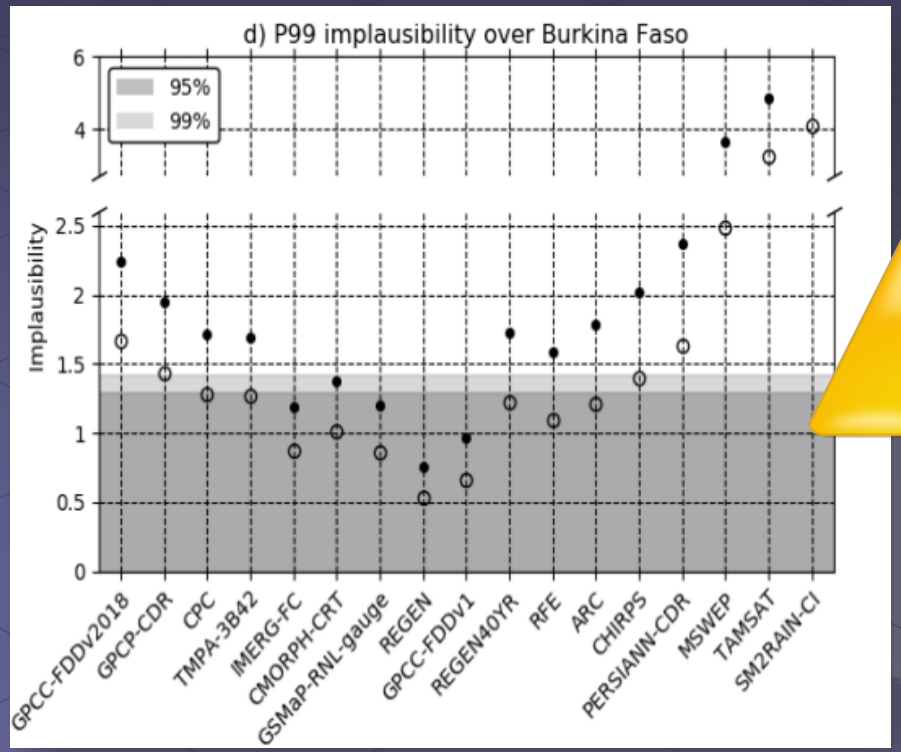

**→ Développer des approches statistiques adaptées aux problèmes d'échantillonnage spatio-temporel**

# Observations

**Défi n°2**
**EXTREMES CLIMATIQUES**




**Produits Satellites**




*Sanogo et al. 2022, J. Clim*

- **Difficultés pour l'estimation quantitative de la climatologie des pluies extrêmes**
- **Pas d'études systématiques fiables pour les tendances sur les extrêmes**