Variabilitate spatio-temporala in sistemele fluviale

Descriptori si modele de abordari multidisciplinare
Hidrologie – Biogeochimie
Hidraulica - Geomorfologie

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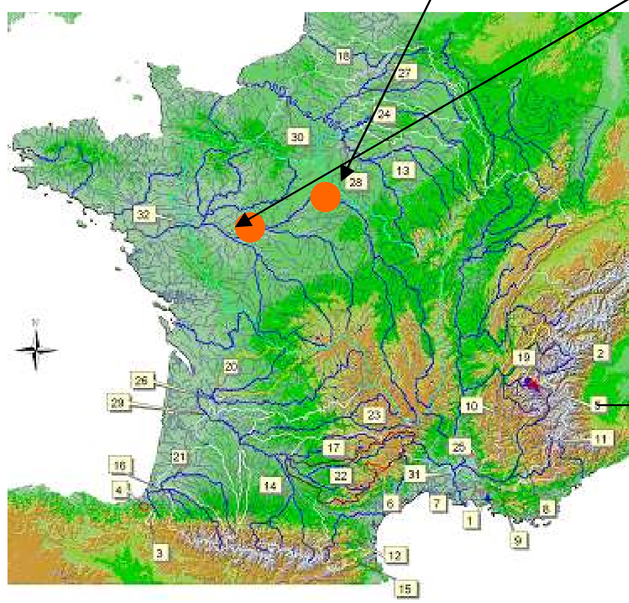
Institut Sciences de la Terre d'Orléans et Tours



PROGRAMME VARIFLUX
CNRS/ECCO/INSU
Situri pilot de masuratori
Ale materiilor in suspensii
In riuri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Live Search
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Master ST2E Tours
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UNIVERSITÉ FRANÇOIS - RABELAIS TOURS
Départements:
Géosciences et Environnements
IMACOF
Parcours BV-Transferts
Parcours IMACOF
M2 Recherche
Master Mention : Sciences de la Terre, de l'Eau et de l'Environnement
Spécialité Pro : Ingénierie des Hydrosystèmes et des Bassins Versants
Spécialité Recherche : Géo - Transferts
Organisation générale des études
La formation comporte un tronc commun, des enseignements spécifiques a chacun des deux parcours ...
suite ...
Admission
Les étudiants susceptibles d'intégrer le Master proviennent de L3 Sciences de la Terre, Sciences de la vie, ...
suite ...
Insertion professionnelle
La formation entend doter ces futurs professionnels de compétences ...
suite ...
Equipe pédagogique
L'équipe pédagogique est constituée d'enseignants-chercheurs de l'Université de Tours et de nombreux professionnels d'autres organismes ...
suite ...
La spécialité Pro Ingénierie des Hydrosystèmes et des Bassins Versants comprend deux parcours :
- Ingénierie des transferts dans les bassins versants (BV-Transferts)
- Ingénierie des milieux aquatiques et des corridors fluviaux (IMACOF)
Les deux parcours forment aux métiers de l'ingénierie des hydrosystèmes et des bassins versants : études, réalisation, maîtrise d'ouvrage et maîtrise d'oeuvre, gestion intégrée, en mettant l'accent sur des compétences distinctes suivant les deux parcours.
La spécialité Recherche (Géo-Transferts) vise à former des spécialistes ayant une vision innovation et recherche dans les domaines de l'environnement touchant le sol, les hydrosystèmes et les sédiments continentaux.
Parcours BV-Transferts
Parcours IMACOF

UMR 6113 CNRS/INSU

Institut National des Sciences de la Terre Orléans – Tours

~ 100 permanents, ~ 40 doctorants et post-doctorants

2008-2011 - 5 Programmes et 15 projets

- **Processus organo-minéraux**

  Réactivité de la Matière organique

- **Transferts continentaux**

  Discrimination des forçages géodynamiques, Climatique et anthropique

  → Systèmes fluviaux acutels

  → Archives sédiment. Holocène

  → Tectonique – Climat – Erosion Cénozoique

- **Géodynamique**

  Dynamique lithosphérique

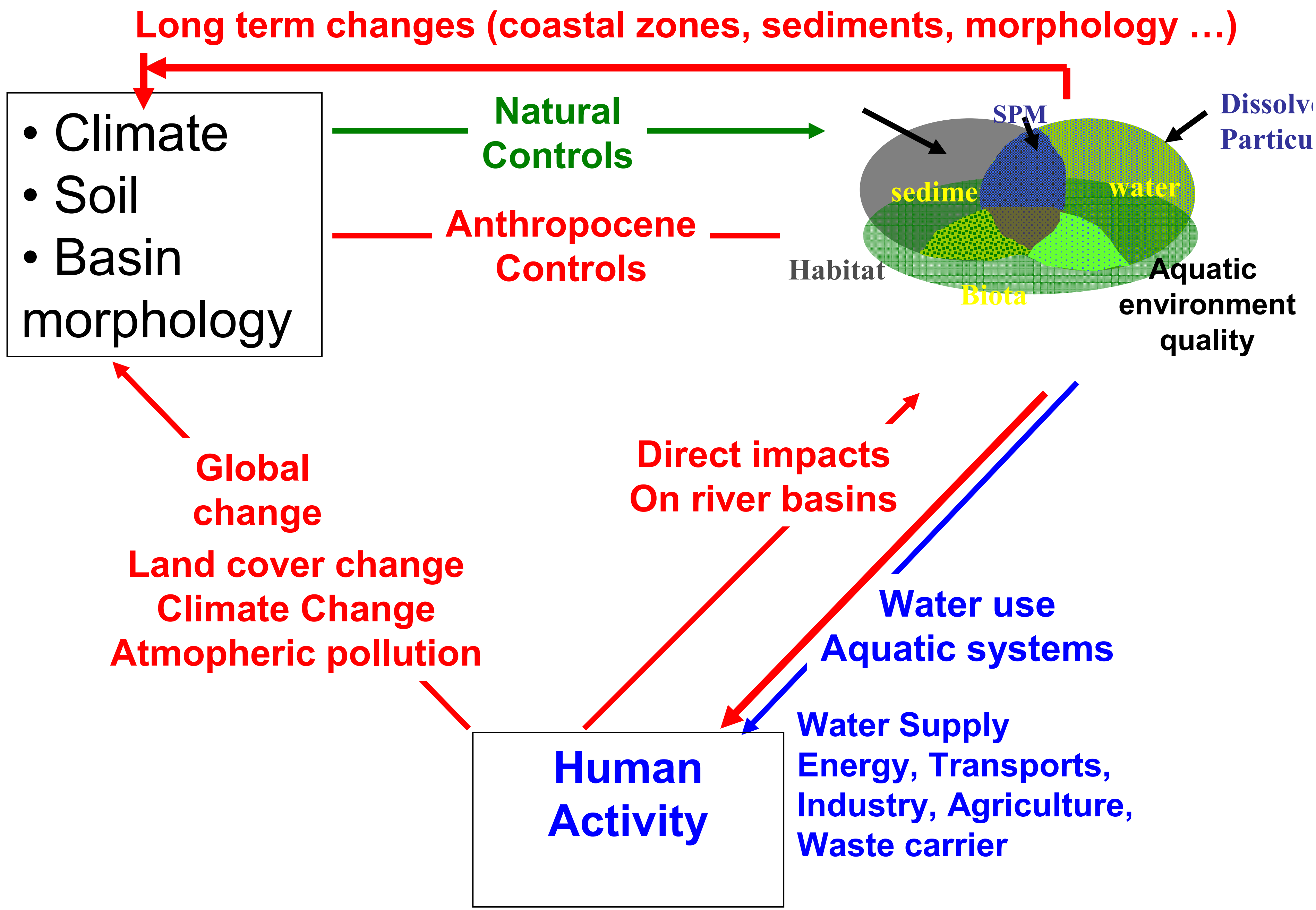
- **Propriétés des géomatériaux**

  Transferts des fluides (pierres monuments, Sols, croûte terrestre

- **Magma**

  Rhéologie des magmas

Introd. (1) Complex interactions in fluvial systems



Introd. (2)

Deciphering human impacts

- Human impact on river systems are transferred, altered, or even amplified from headwater to coastal zone

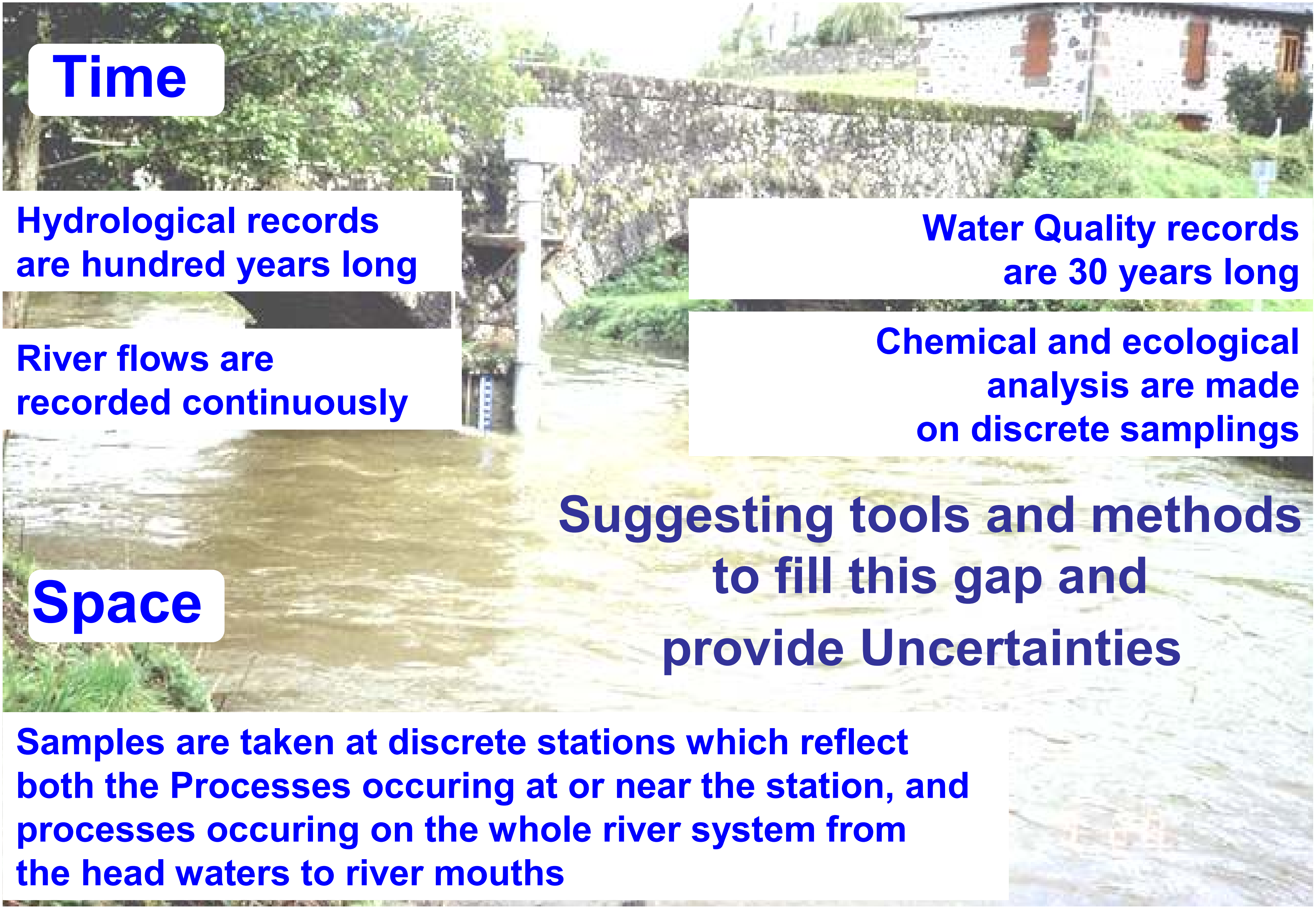
- Knowledge of natural processes and human impact therefore need to be deciphered patiently and carefully through our knowledge of river systems

- **Two complementary approaches :**

  - Scientific studies of control processes at various scales (BVRE – Bassins Versants de Recherche Expérimentaux)
  - Environmental state survey and assessment by official bodies such as Ministries, Water Agencies, Local authorities

Introd. (3)

Two limitations in time and space



Time

Hydrological records are hundred years long

River flows are recorded continuously

Water Quality records are 30 years long

Chemical and ecological analysis are made on discrete samplings

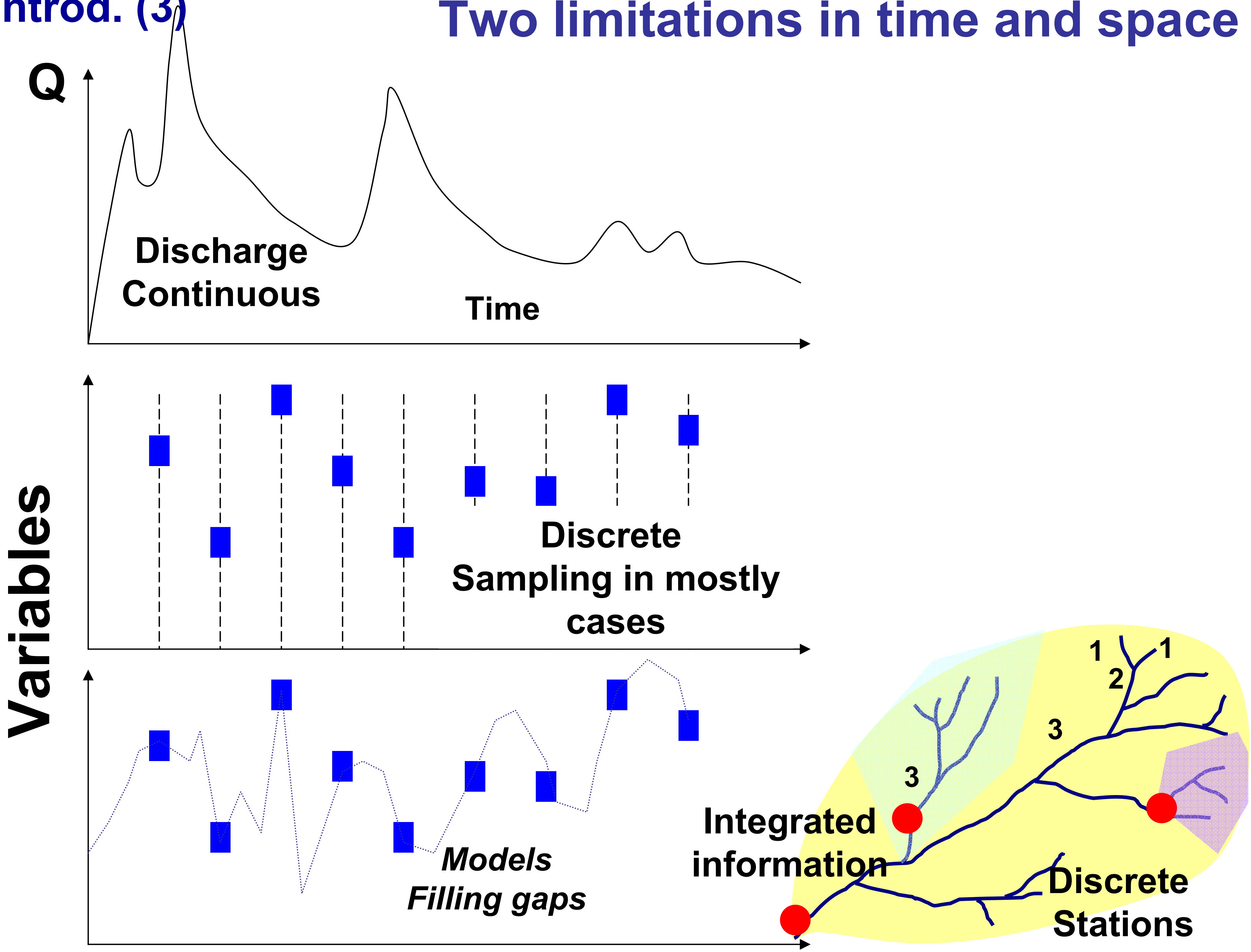
Suggesting tools and methods to fill this gap and provide Uncertainties

Space

Samples are taken at discrete stations which reflect both the Processes occuring at or near the station, and processes occuring on the whole river system from the head waters to river mouths

Introd. (3)

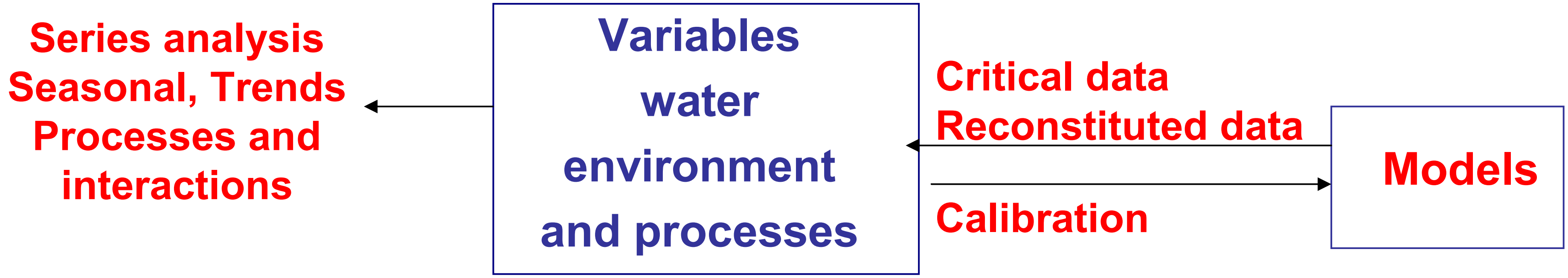
Two limitations in time and space :



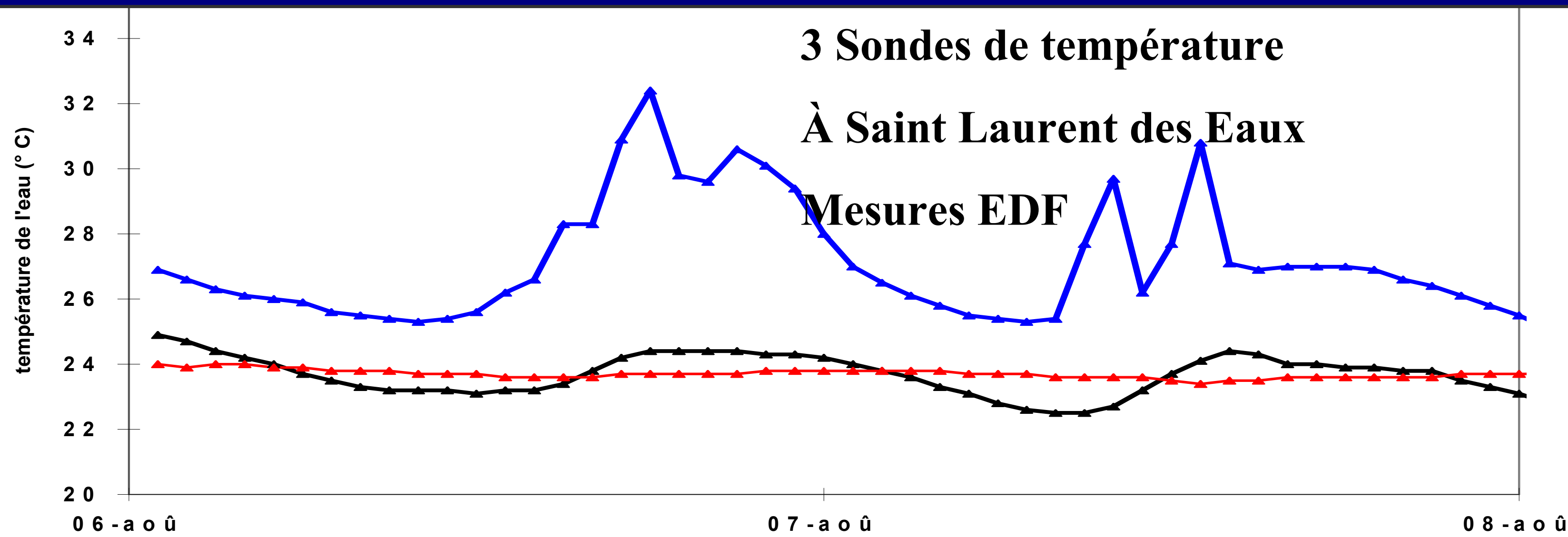
Introd. (4)

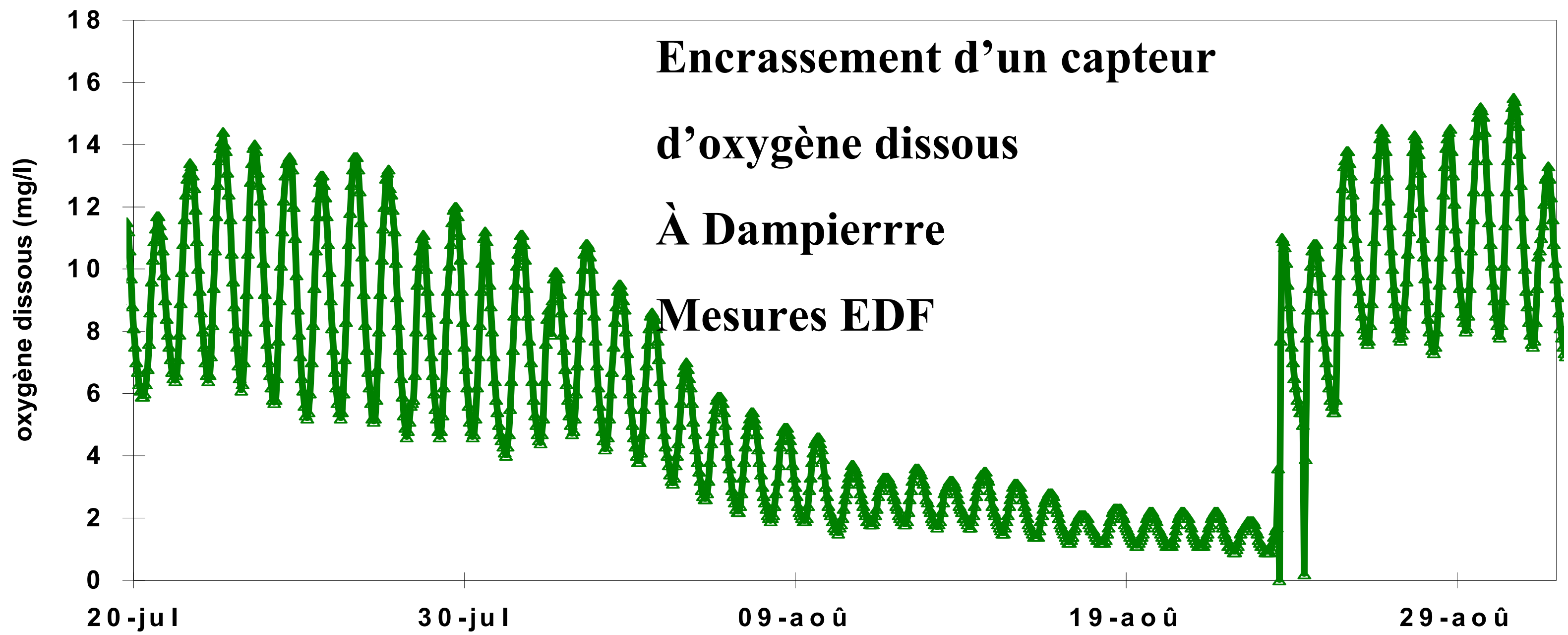
Defining, synthesising, prioritising hydrological, biogeochemical, morphological variability

Our contribution



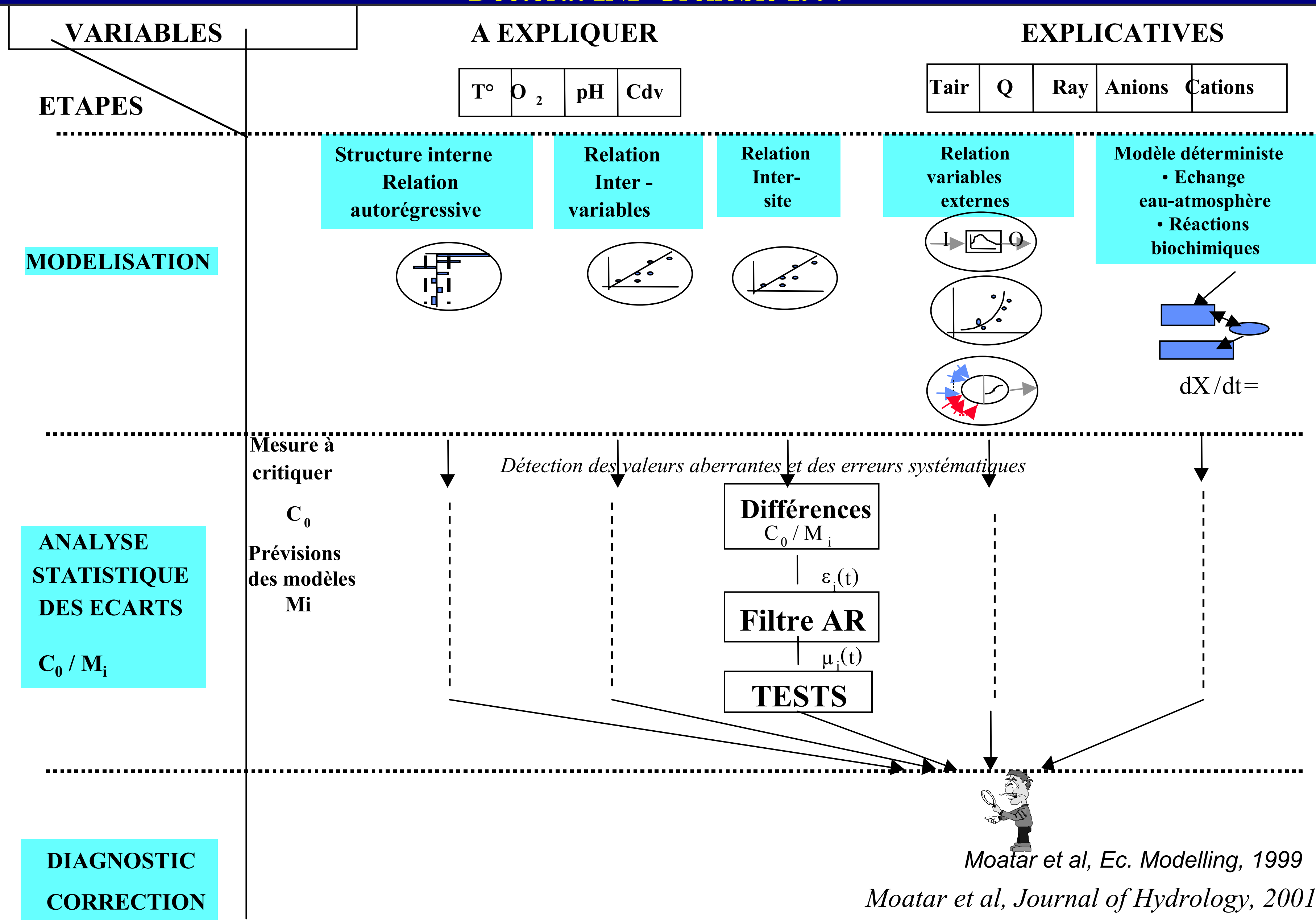
Exemple 1 : critique des données





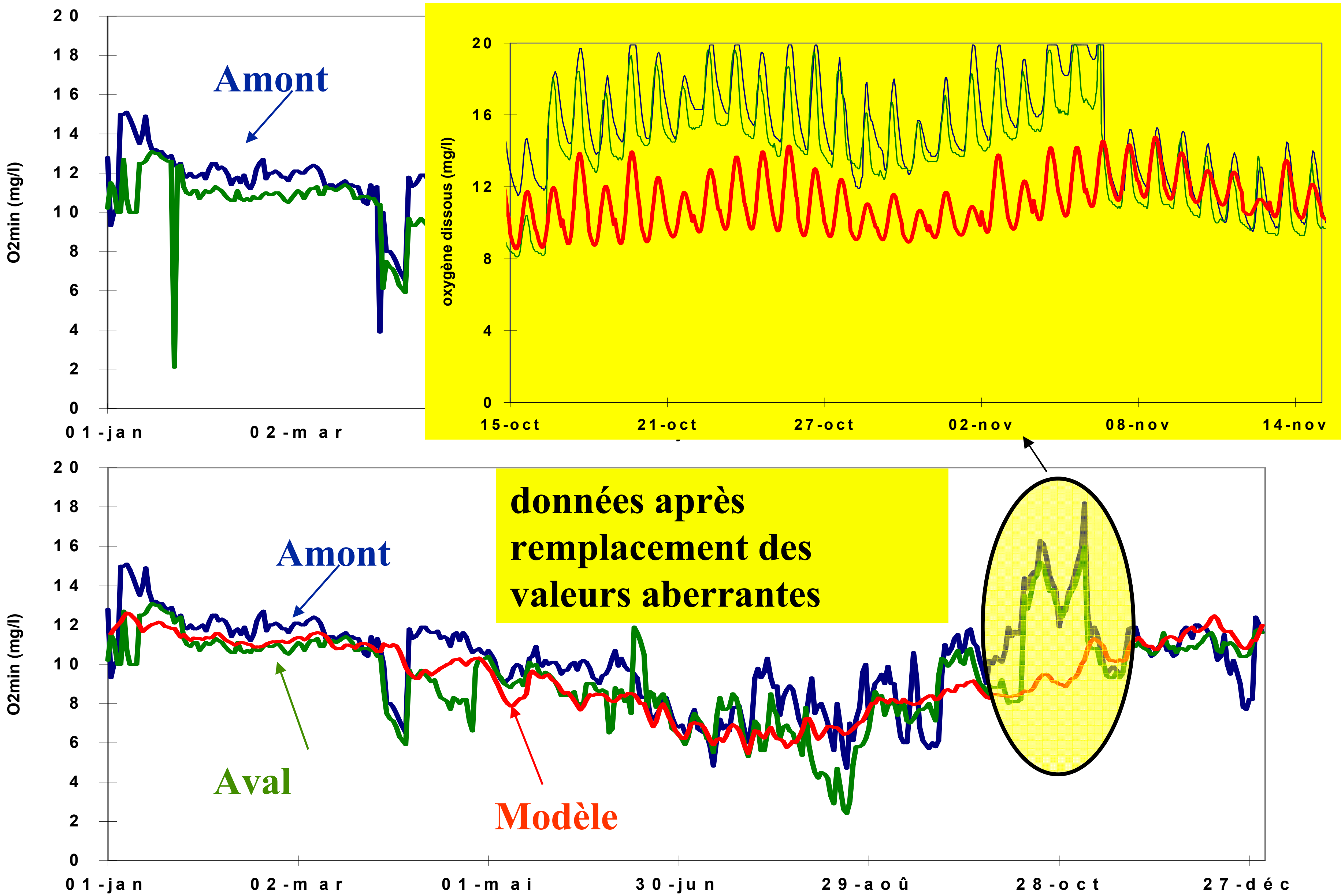
Mise au point d'une méthode de critique de mesures en continu

Doctorat INP Grenoble 1997



Résultats : année test 1995

O2min



Fluvial System functionning	Queries	Temporal Scale	Spatial Scale
Thermal regime		Daily Seasonal Since 1976, 19th century	Middle Loire reach : 250 km
Eutrophication		Hourly, Daily Seasonal Since 1980	Middle Loire reach : 350 km
Nutrients		Inter-annual Since 1980	Loire catchment Stream Order 120 catchments (< 200 km²)
Water and Material fluxes		Daily Seasonal	60 U.S. Rivers 30 E.U. Rivers 100 to 600 000 km²
Morphological dynamics		Daily Flood Multi-year	Middle Loire Brehemont site 5 km

Fluvial System functionning	Queries	Temporal Scale	Spatial Scale
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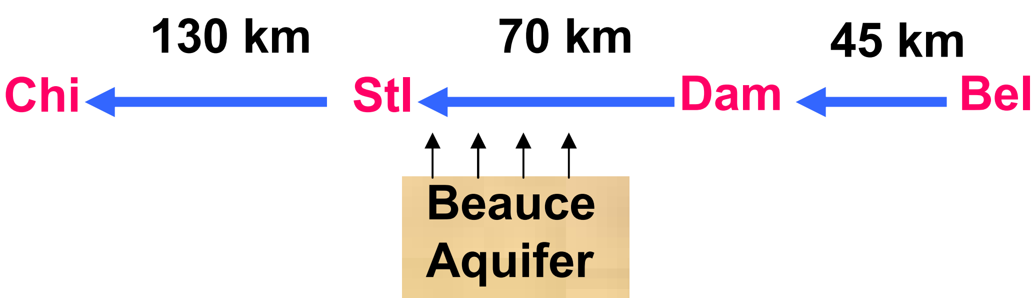
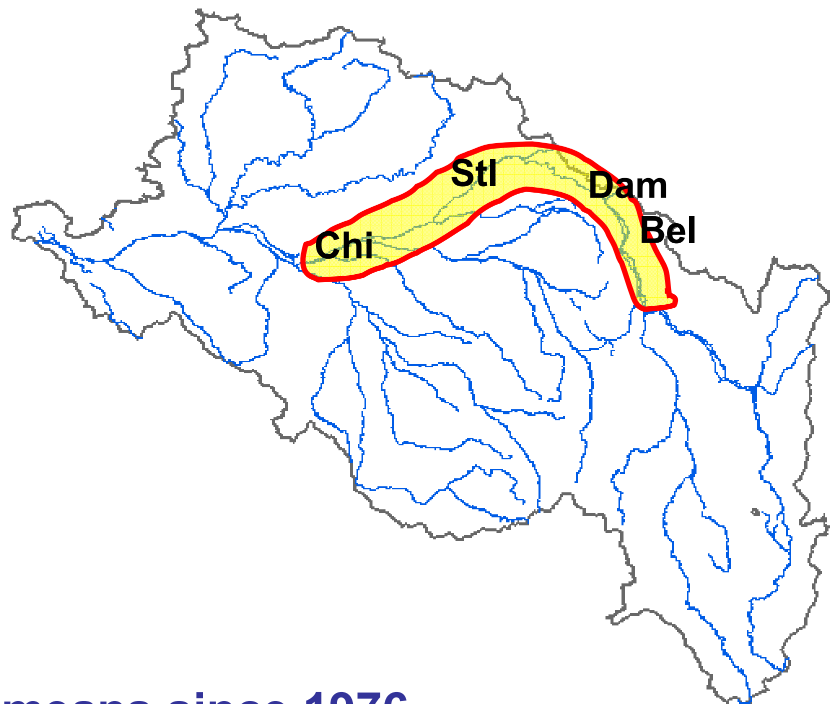
Thermal Regime (1)

Loire Middle reach : 250 km
4 monitoring stations, hourly, 28 y
Upstream Nuclear Power Plants (NPP)

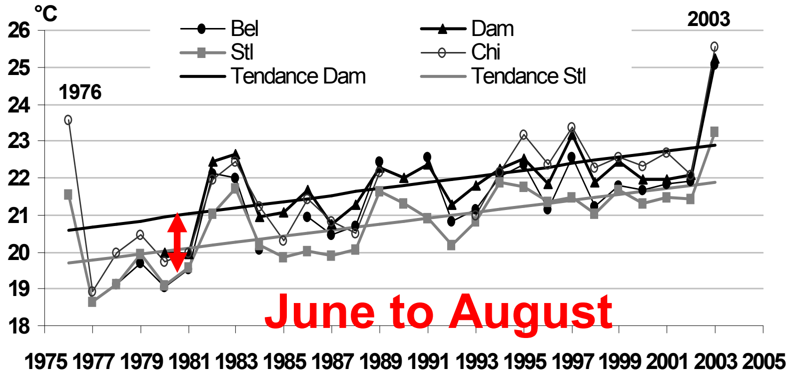


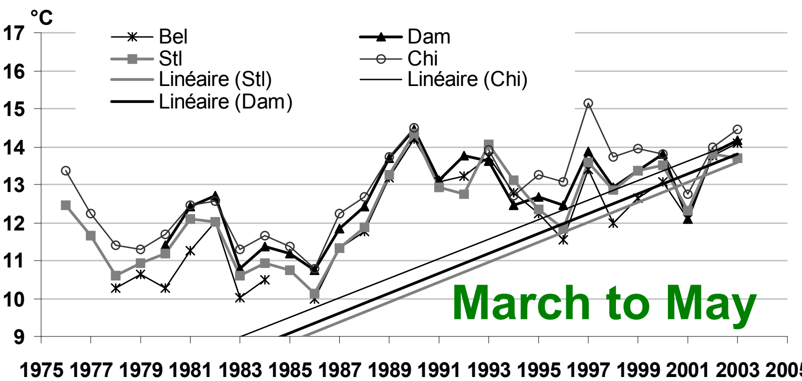


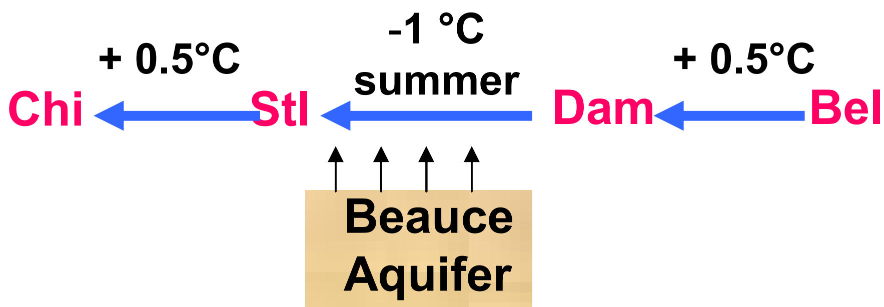
- trends on seasonal variations and annual means since 1976
- influence of groundwater inputs from the Beauce sub-karstic aquifer
- reconstruction and analyse of river water temperature since 1881
- characterize the exceptional 2003 hot year in relation to the very long-term temperature series since 1881

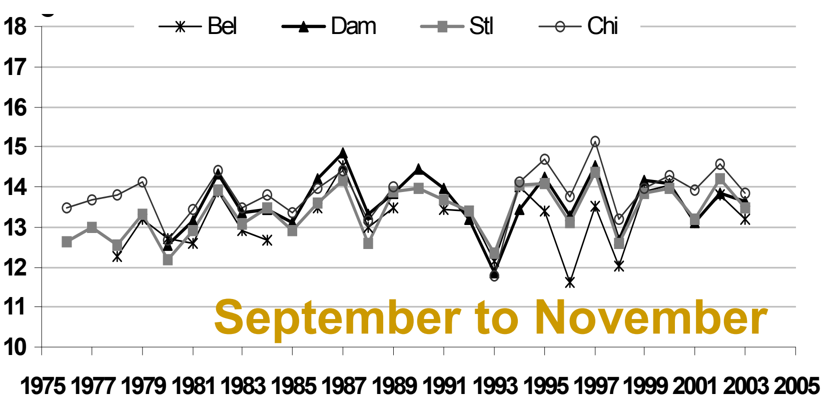
Thermal Regime (2)

How has the temperature regime changed since 1976 ?









Seasonal increases at all stations, but only in Spring and Summer

Same level of increase for Belleville station, upstream of any NPP

Decrease of water temperature in summer between Dampierre and St Laurent Station, about 1° C (mean summer)

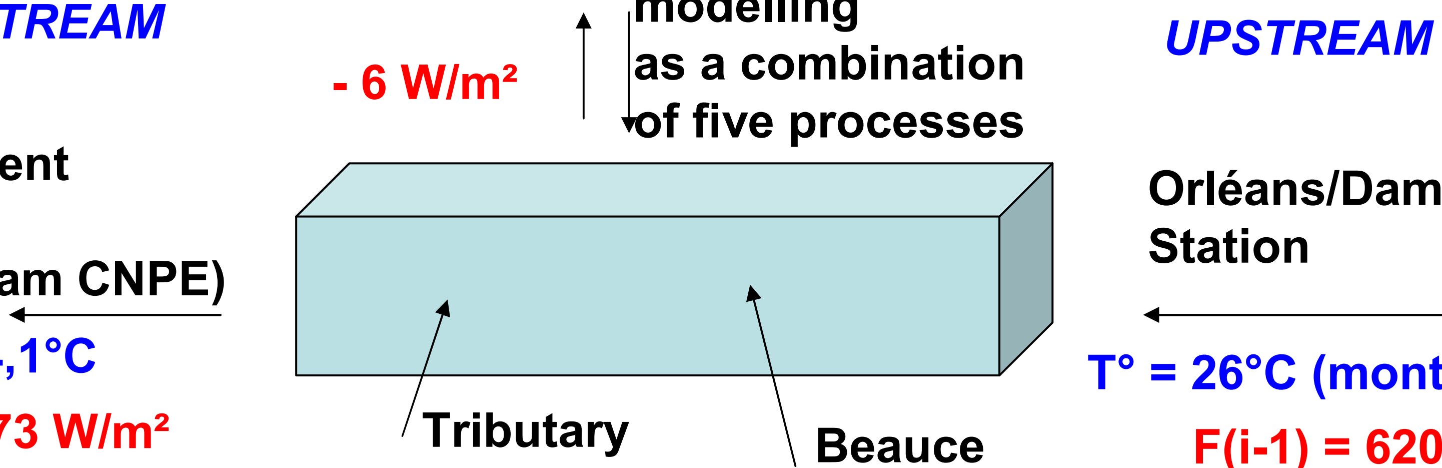
Moatar and Gailhard, 2006,C.R. Geoscience

Thermal Regime (3)

Energy balance for Orléans – St. Laurent Reach

August 2003 : very severe drought

Observed $\Delta T = -1.9°C$

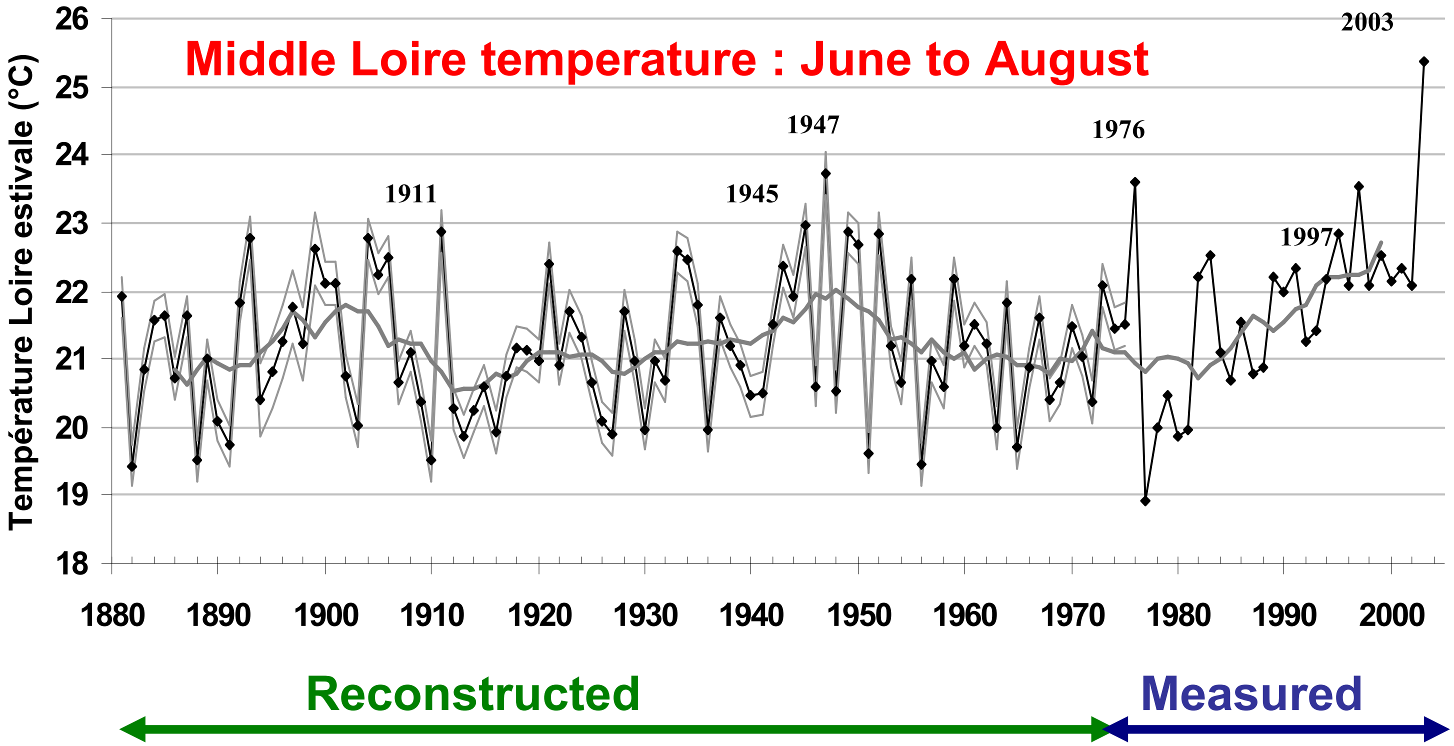


Incoming underground water of Beauce aquifer is shown by a heat balance model

Moatar and Gailhard, 2006,C.R. Geoscience

Thermal Regime (4)

How Summer temperature has changed since 1881 ?



Residuals
Std= 0.33°C
R^2= 0.94

Summer Loire T° = 13.1(±1.9) + 0.737(±0.07) AirT° - 0.95 (±0.15) Ln(Q)

Three warm periods: around 1900, 1950 and the current period

Summer that combined drought and a heat wave are particularly remarquable

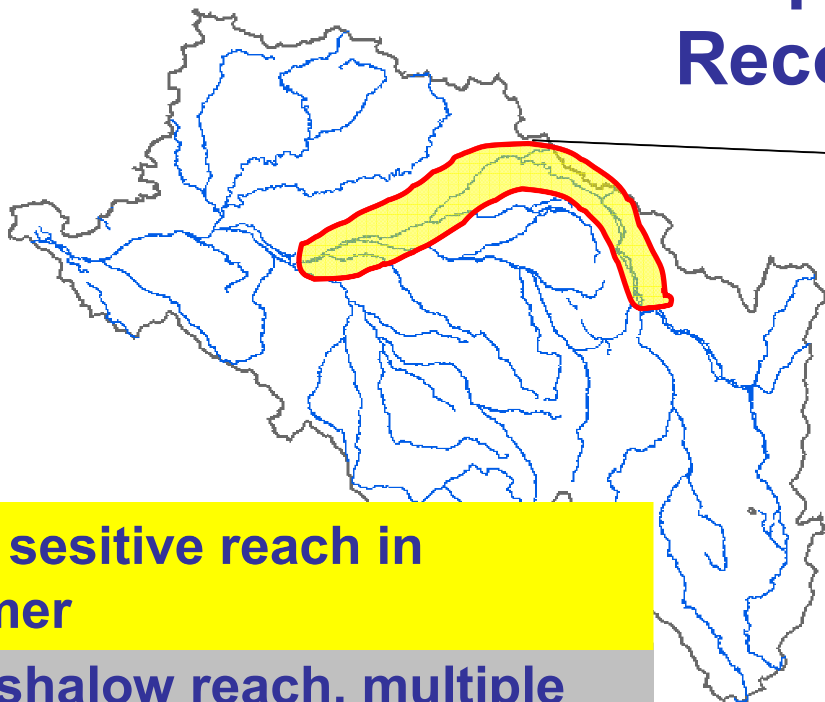
2003 (+4°C) 1976 and 1947 (+2°C)

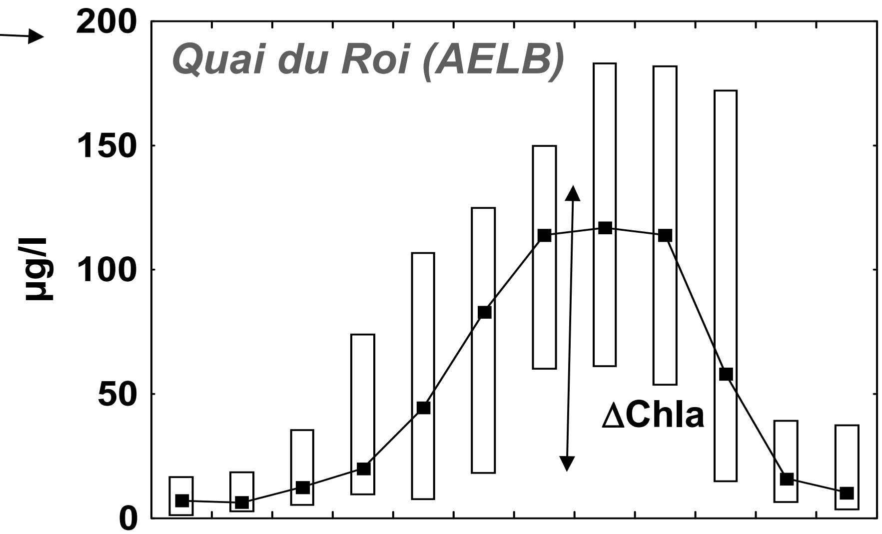
Moatar and Gailhard, 2006,C.R. Geoscience

Fluvial System functionning	Queries	Temporal Scale	Spatial Scale
Thermal regime	120 year - trends Hydrological, Meteorolog. controls NPP impact	Daily Seasonal Since 1976, 19th century	Middle Loire reach : 250 km
Eutrophic.	25 year-trends Hydrological, Algal developp. controls	Hourly, Daily Seasonal Since 1980	Middle Loire reach : 250 km
Nutrients		Inter-annual Since 1980	Loire catchment Stream Order 120 catchments (< 200 km²)
Water and Material fluxes		Daily Seasonal	60 U.S. Rivers 30 E.U. Rivers 100 to 600 000 km²
Morphological dynamics		Daily Flood Multi-year	Middle Loire Brehemont site 5 km

Eutrophication (1)

Middle Loire Reach : Chlorophylle regime : 1981 – 2003 Record level of eutrophication





Moatar et Meybeck, Hydrological Processes, 2005

Higly sesitive reach in summer

Very shalow reach, multiple channels

Very low water velocity

High residence time

Average summer temperature exceeding 21°C

- Has eutrophication state been improved since 1981 ?
- What is the impact of eutrophication on daily variations of pH and O_2 ?
- How does eutrophication determine the Cyclicity of seasonal variations in N, P

Conclusions — Middle Loire Reach

- We have demonstrated a great range of temporal variability from Hourly scale to secular : T°, O2, pH, Chla, nutrients, particularly due to Important eutrophication

- This 300 km reach is remarquably homogeneous

- Eutrophication is now slowly decreasing : δO_2, pH, PO_4^{3-}, chlorophylle

- 2003 Summer temperature is the hotest since 1881

Fluvial System functionning	Queries	Temporal Scale	Spatial Scale
Thermal regime	120 year - trends Hydrological, Meteorolog. controls NPP impact	Daily Seasonal Since 1976, 19th century	Middle Loire reach : 250 km
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Nutrients	**Pressure – Impact catchment analysis Zones of homogeneous agricultural pressure**	**Inter-annual Since 1980**	**Loire catchment Stream Order 120 catchments (< 200 km²)**
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Nutrients (1) Spatial analysis – methodological steps

RNB
Data base
Regular sampling
1971(1987) - 2005

↓

Reviewing and validating time series

↓

<u>Analyse 1</u>
Temporal Variability at stations

<u>Analyse 2</u>
Spatial analysis of temporal descriptors in relation with catchment caracteristics

Strahler Order
Hydroecoregions

→

Selection 2
BV < 200 km², dpop < 40 hab/km²

→

<u>Analyse 3</u>
Small catchments low point sources
PCA
Cluster Analysis

↓

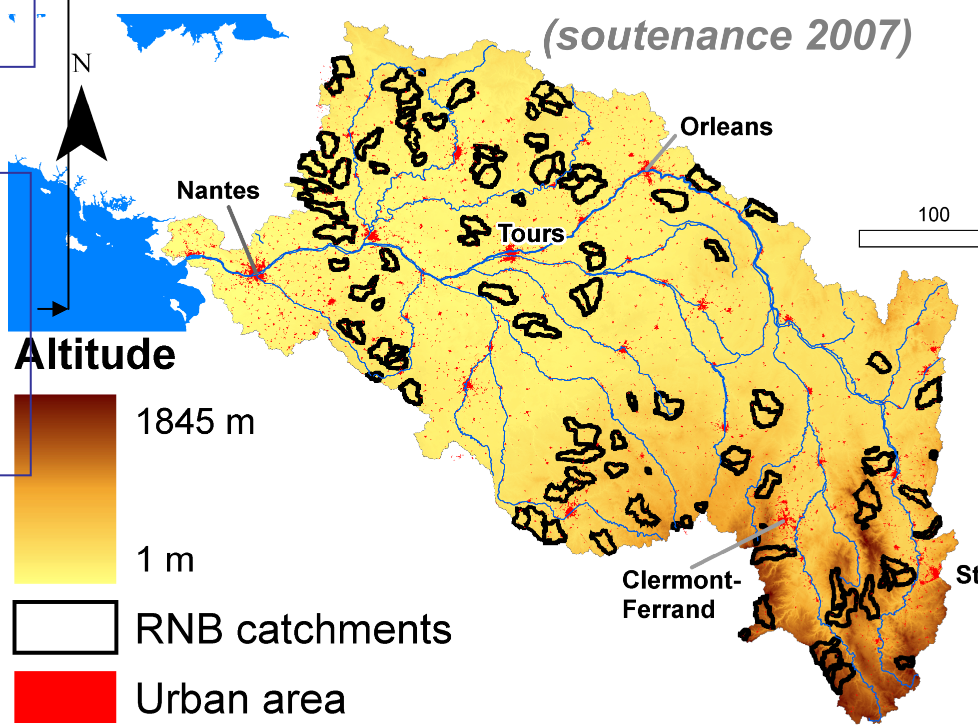
Analyse 4
Nitrates and landuse

Fuzzy clustering approach

- **5 classes based cereals, grassland, livestock density**
- **fit probability functions on the distribution of the three variables**
- **extrapolation for unsurveyed small river basins**

AGRO-ZONES

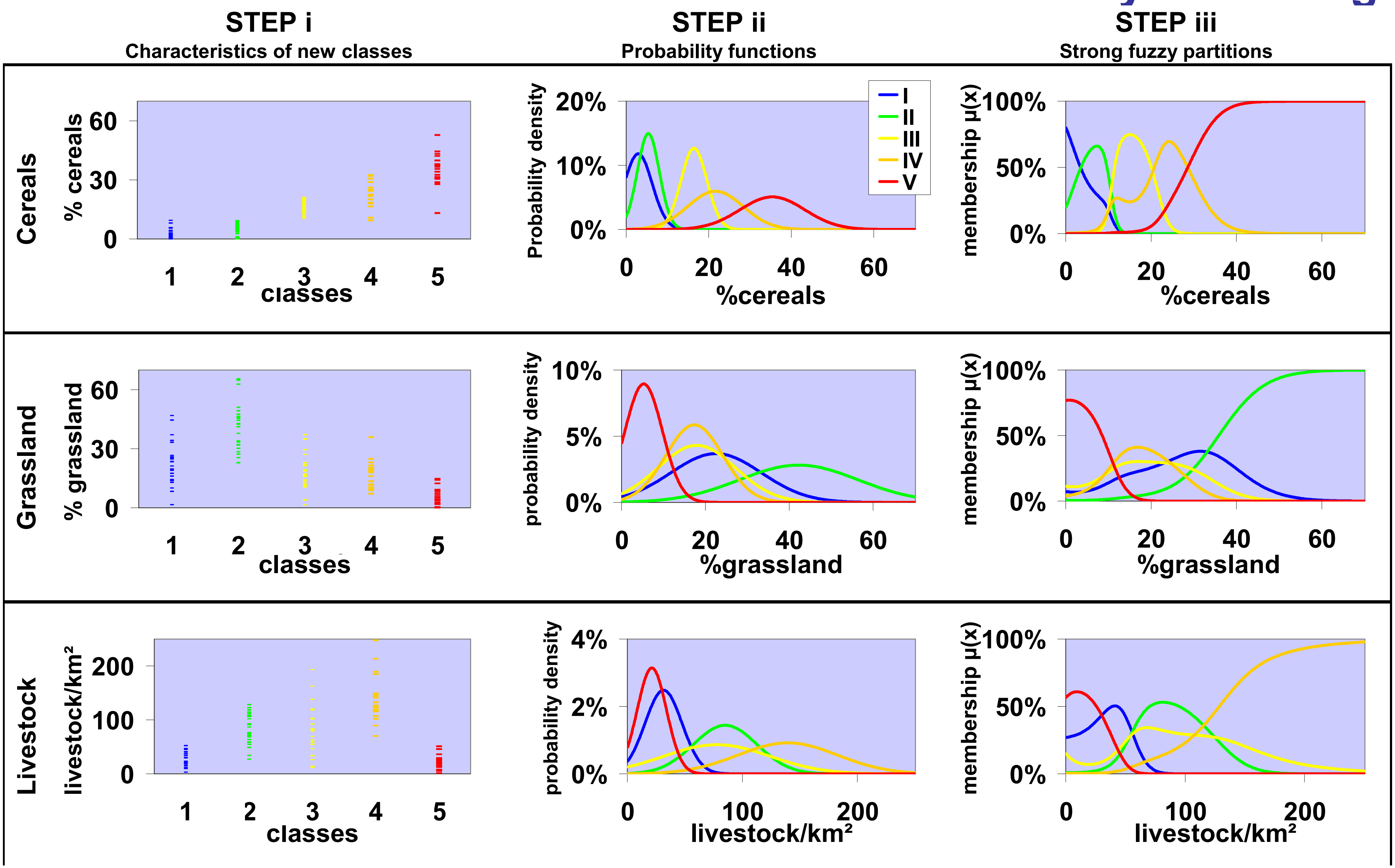
Thèse Ch. Blanchard (soutenance 2007)



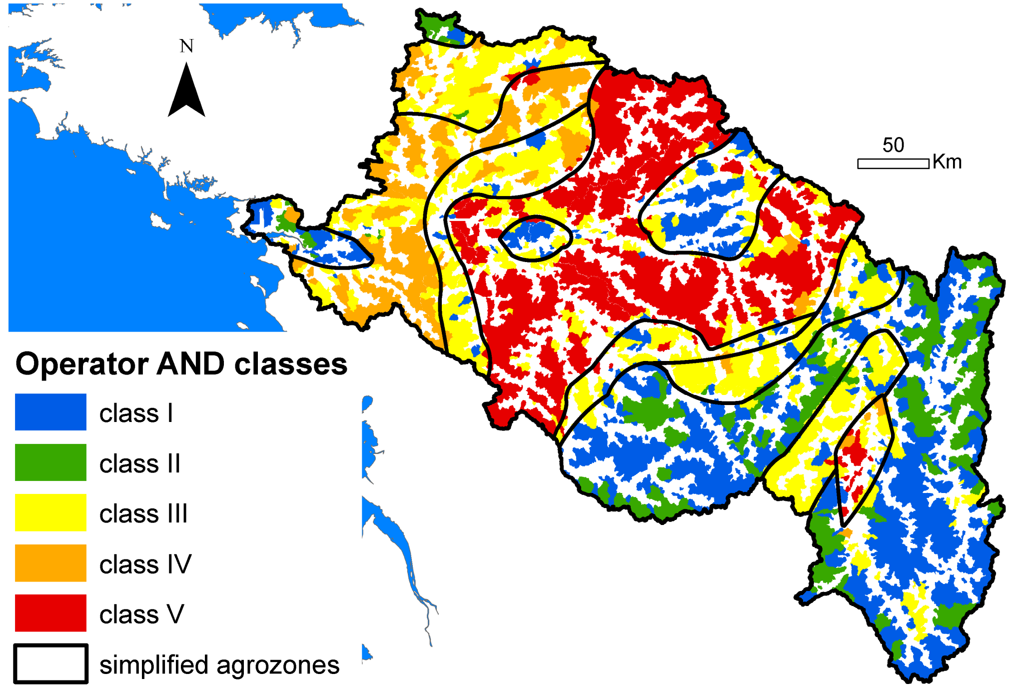
Nutrients (2)

Blanchard et al,
Man and River Systems,
Paris 4-6 December 2006

Agro-Zonation in five classes
Based on nitrate and landuse
Fuzzy clustering



Conclusions Agro-Zones of the Loire catchement



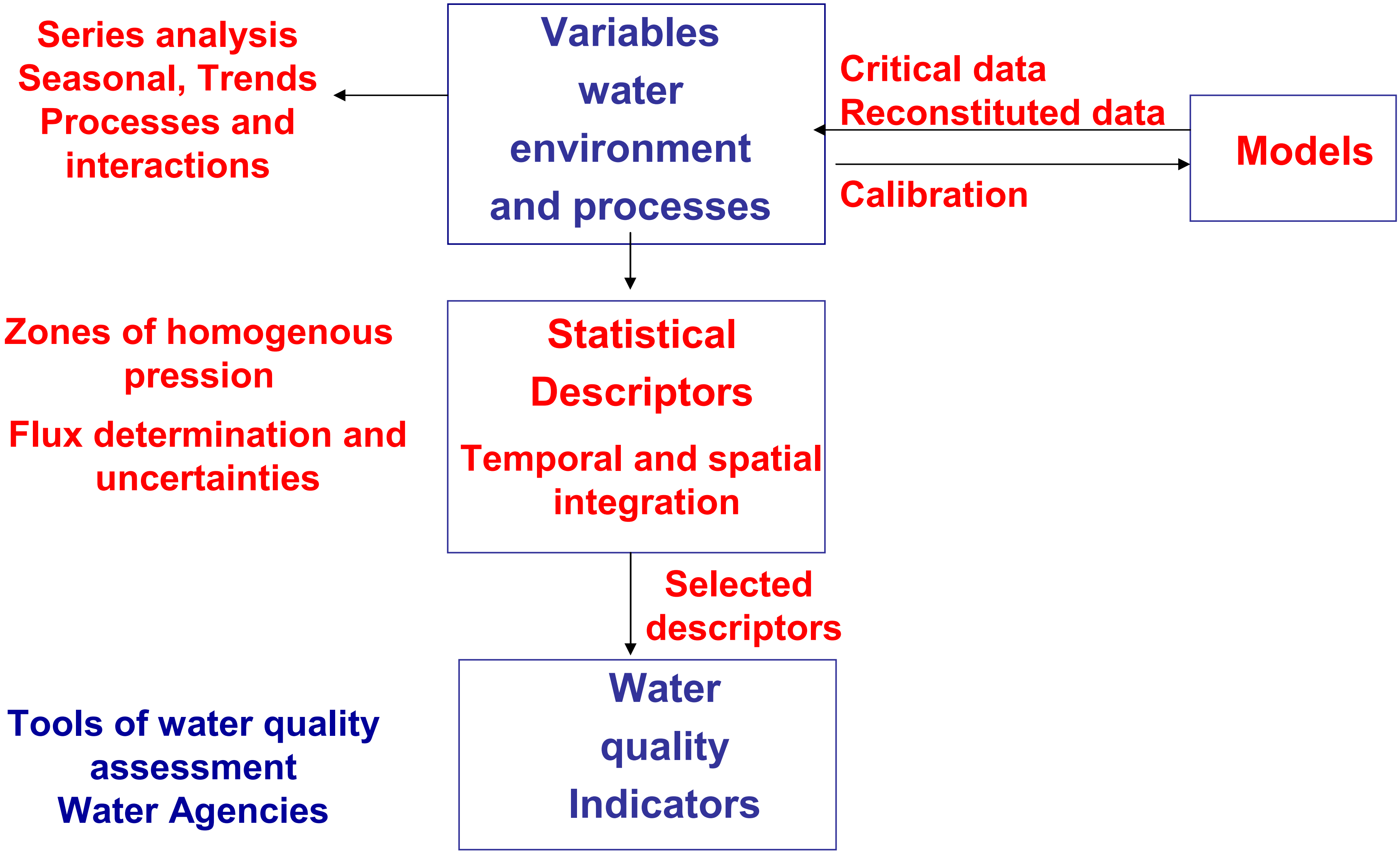
- In order to combine fuzzy partitions, we use the optimistic Operator AND, which takes into account the minimum membership of the three partitions.
- The AND Operator applied on the 119 catchments, 103 catchments results in the same classes as obtained by Cluster Analysis

- The fuzzy approach helps to define transitional areas (22% of the whole Loire catchment
- These new agrozones present some differences with hydroecoregions (level 1) as the agricultural pressures are here taken into account

Introd. (4)

Defining, synthesising, prioritising hydrological, biogeochemical, morphological variability

Our contribution



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Nutrients	Pressure – Impact catchment analysis Zones of homogeneous agricultural pressure	Inter-annual Since 1980	Loire catchment Stream Order 120 catchments (< 200 km²)
Water and Material fluxes	**Variability in contrasted catcments** **Optimize sampling** **Predict uncertainties**	**Daily** **Seasonal**	**60 U.S. Rivers** **30 E.U. Rivers** **100 to 600 000 km²**
Morphological dynamics		Daily Flood Multi-year	Middle Loire Brehemont site 5 km

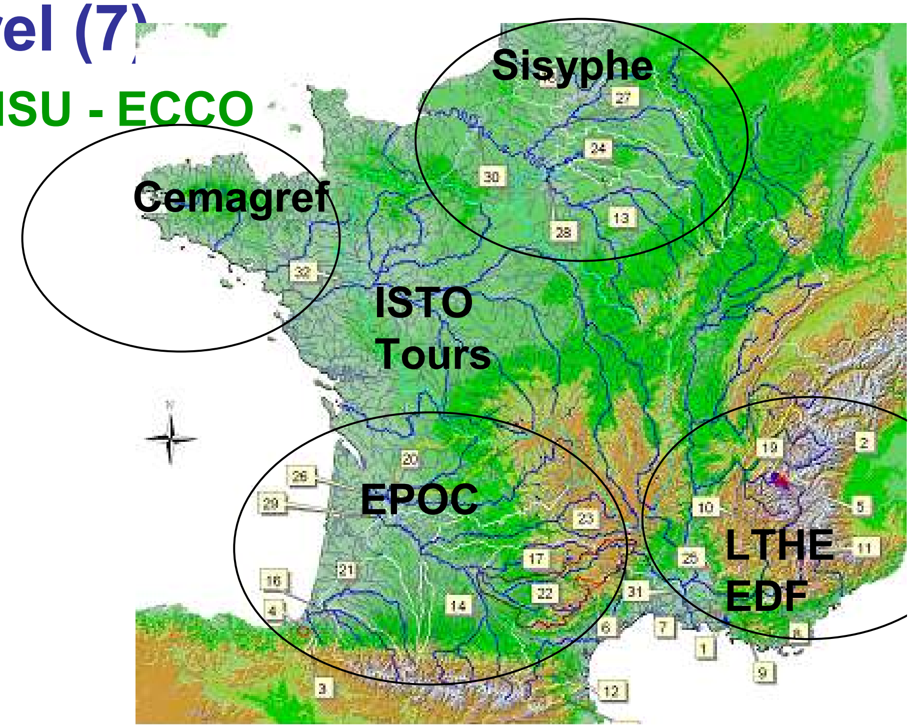
Caractérisation de la variabilité des transports fluviaux (MES, nutriments, ions dissous) à fine résolution temporelle et prédiction des incertitudes liées à la fréquence des suivis

F. Moatar(1), M. Meybeck(2), A. Coynel(3), H. Etcheber(3), V. Mano (4), J. Néméry (4), F. Birgand(5), W. Ludwig (6), A. Poirel (7)

Projet VARIFLUX (2004-2008) : CNRS/INSU - ECCO

1) UMR 6113 ISTO-Tours
2) UMR Sisyphe, Paris VI
3) UMR EPOC, Bordeaux I
4) UMR LTHE, Grenoble
5) Cemagref, Transfeau, Anthony
6) UMR CEFREM, Perpignan

EDF/ DTG, Grenoble; USGS



Objectifs

Variabilité des matériaux fluviaux à fine résolution temporelle au travers de bassins versants de nature contrastée
(100 à 1 000 000 km²)

- **établir les relations entre les variabilités des concentrations et des flux et la taille des bassins, la spécificité des matières fluviales considérées, les régimes hydrologiques, les caractéristiques des bassins**

- **établir les méthodes de calcul des flux les plus appropriées à partir des suivis discrets,**

- **quantifier les incertitudes sur les flux en fonction de la variabilité (Matières en suspension (MES), nutriments, ions diss.) et de la fréquence**

  affecter les incertitudes aux suivis actuels

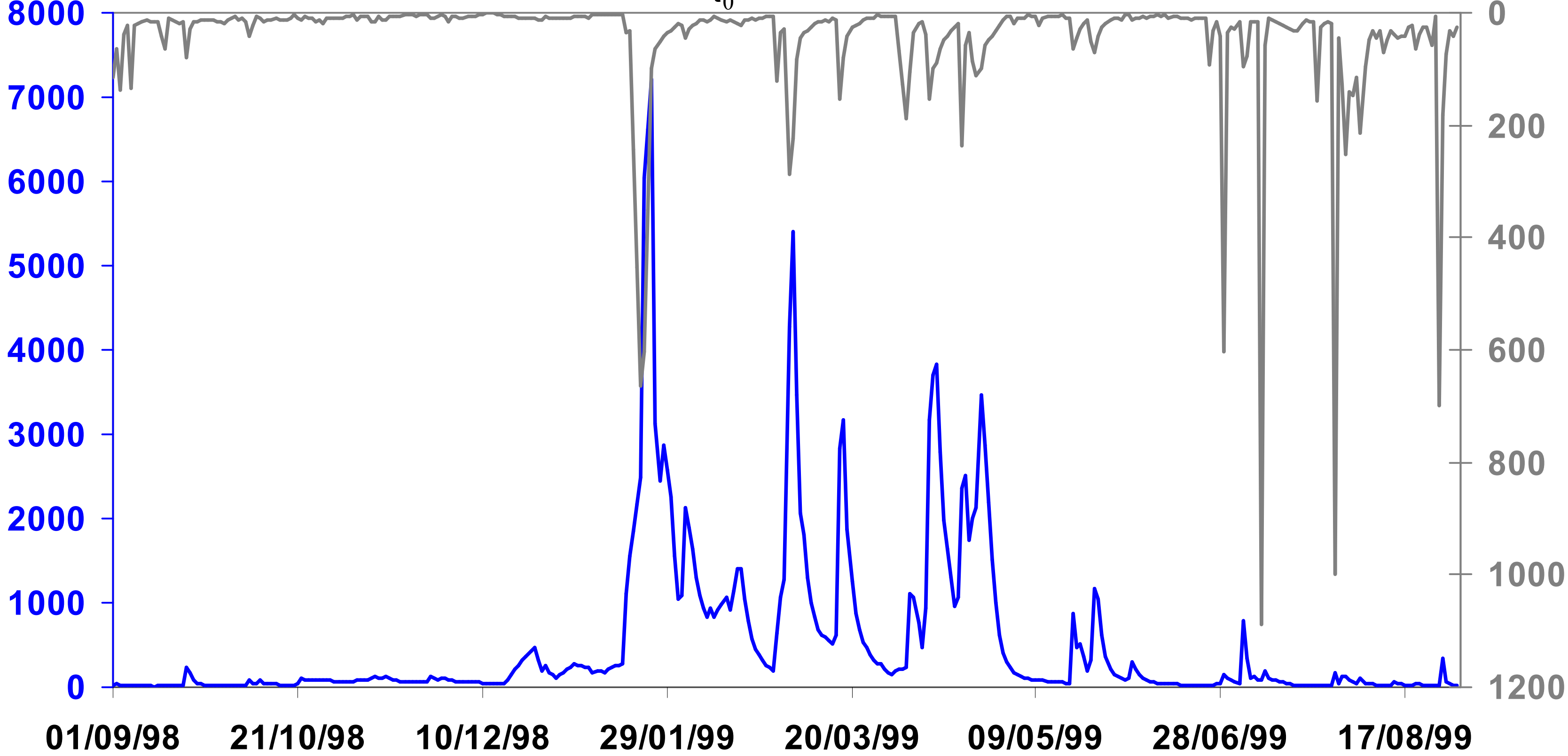
  optimiser les surveillances compte tenu des contraintes opérationnelles

Riverine fluxes (1)

Calculating nutrient annual loads

Definition : $$L = K\int_{t_0}^{T} L(t)dt$$

$$L = K\int_{t_0}^{T} Q(t)C(t)dt$$

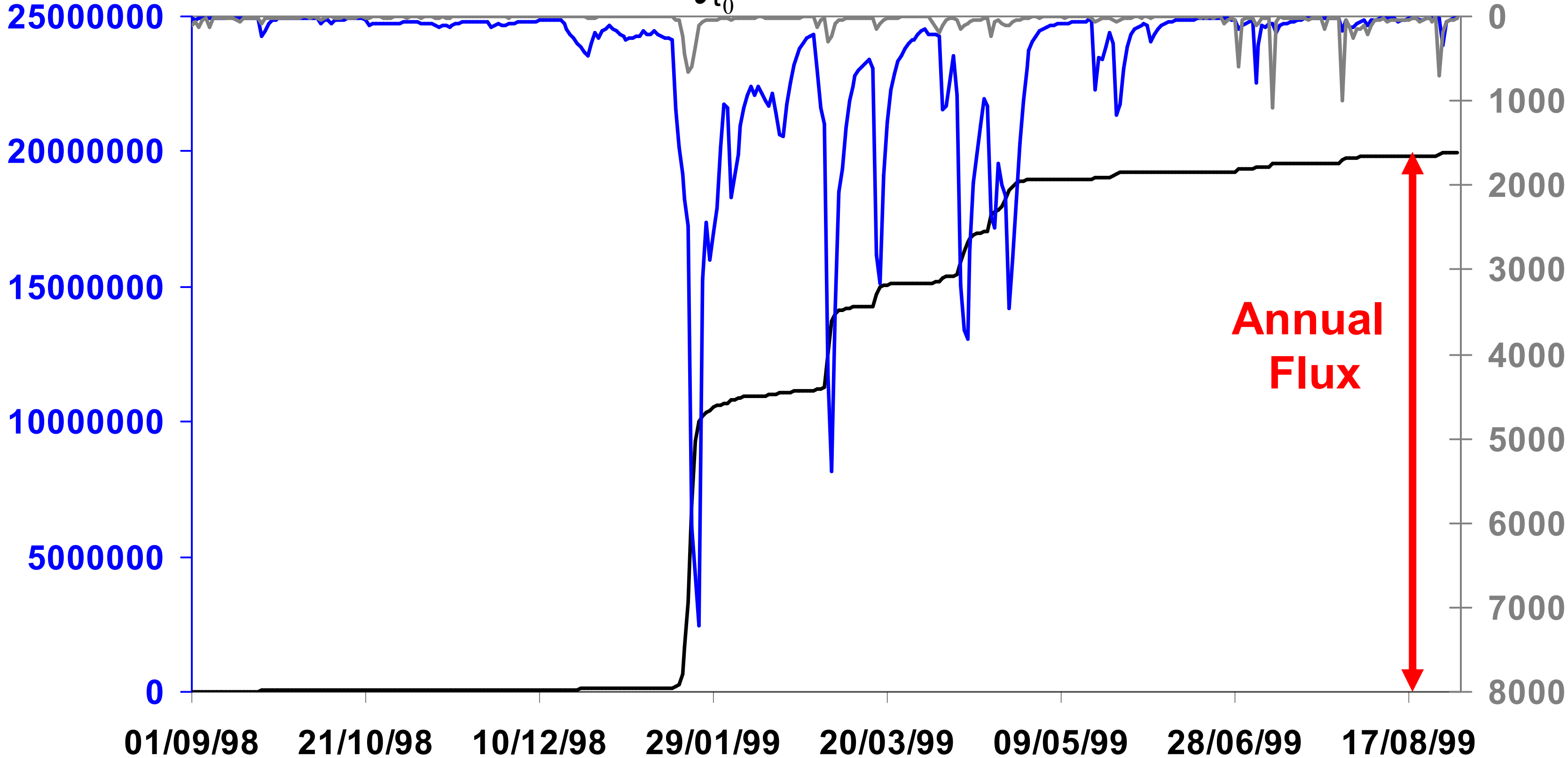


Riverine fluxes (2)

Calculating nutrient annual loads

Definition : $L = K\int_{t_0}^{T} L(t)dt$

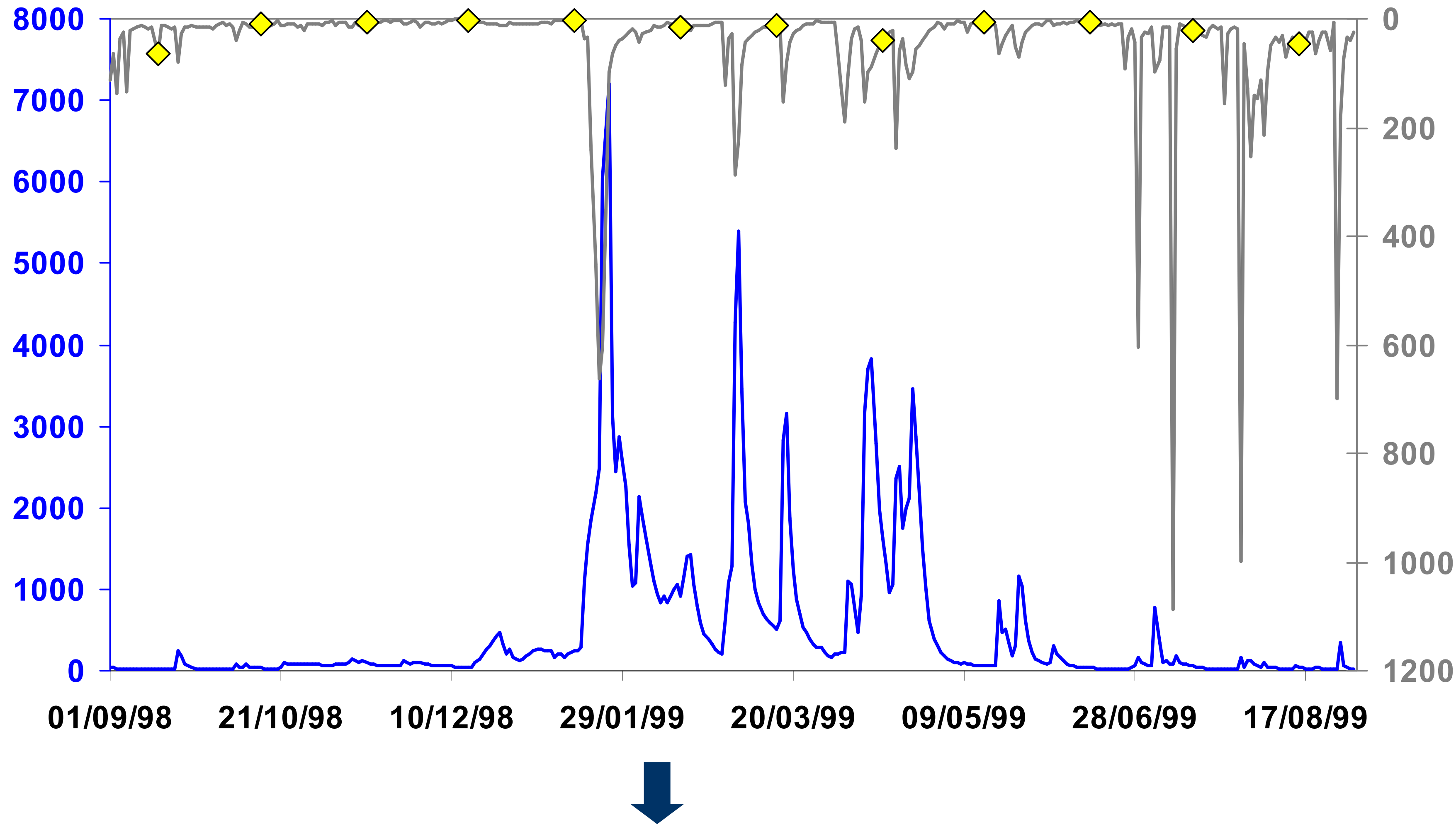
$$L = K\int_{t_0}^{T} Q(t)C(t)dt$$



$$L = \sum_{i=1}^{N} \frac{C_{i+1}Q_{i+1} + C_iQ_i}{2}\delta t$$

Riverine fluxes (3)

Discrete sampling…



Possible errors on estimating actual annual load

Riverine fluxes (4)

Queries

Specific sites

- **Flux computation methods**

  Walling and Webb, 1981; 1985

  22 methods, Philipps et al, 1999

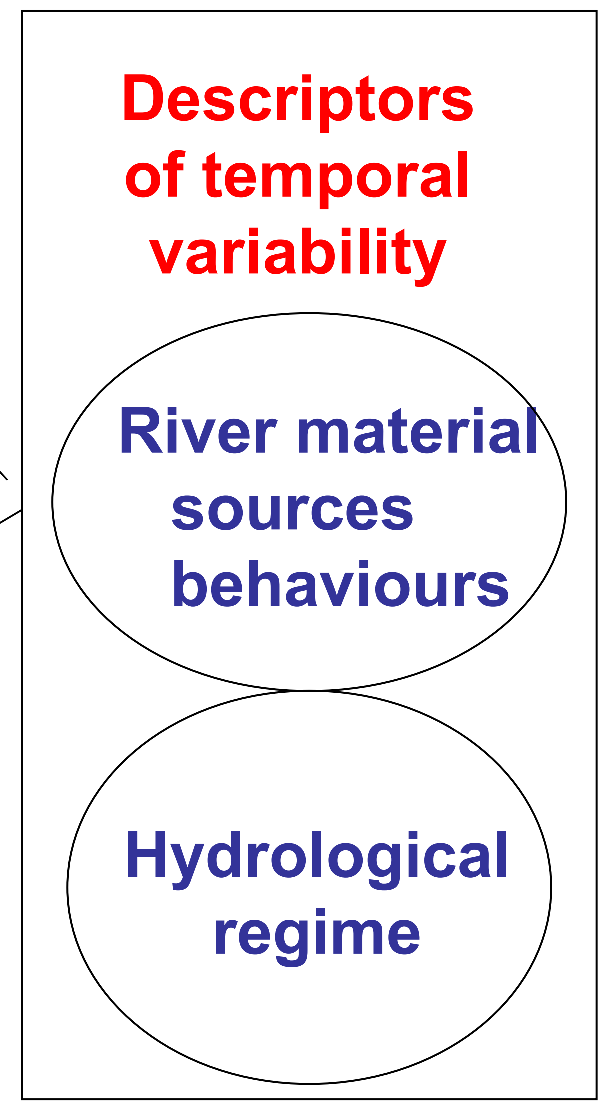
- **Sampling optimization**

  Littlewood, 1995

- **Predicting uncertainties**

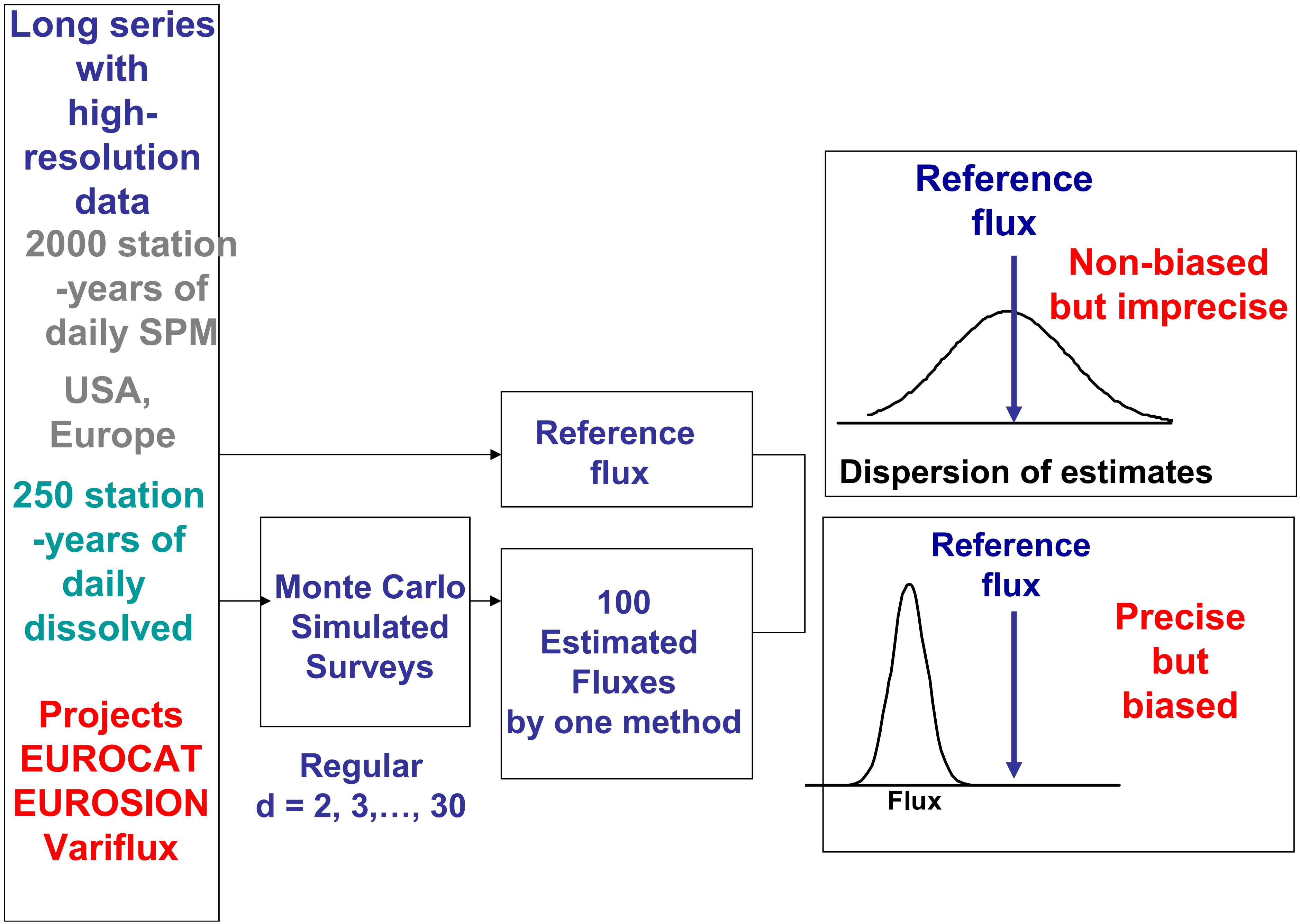
  influence of basin size
  Philipps et al, 1999

Contrasted catchments



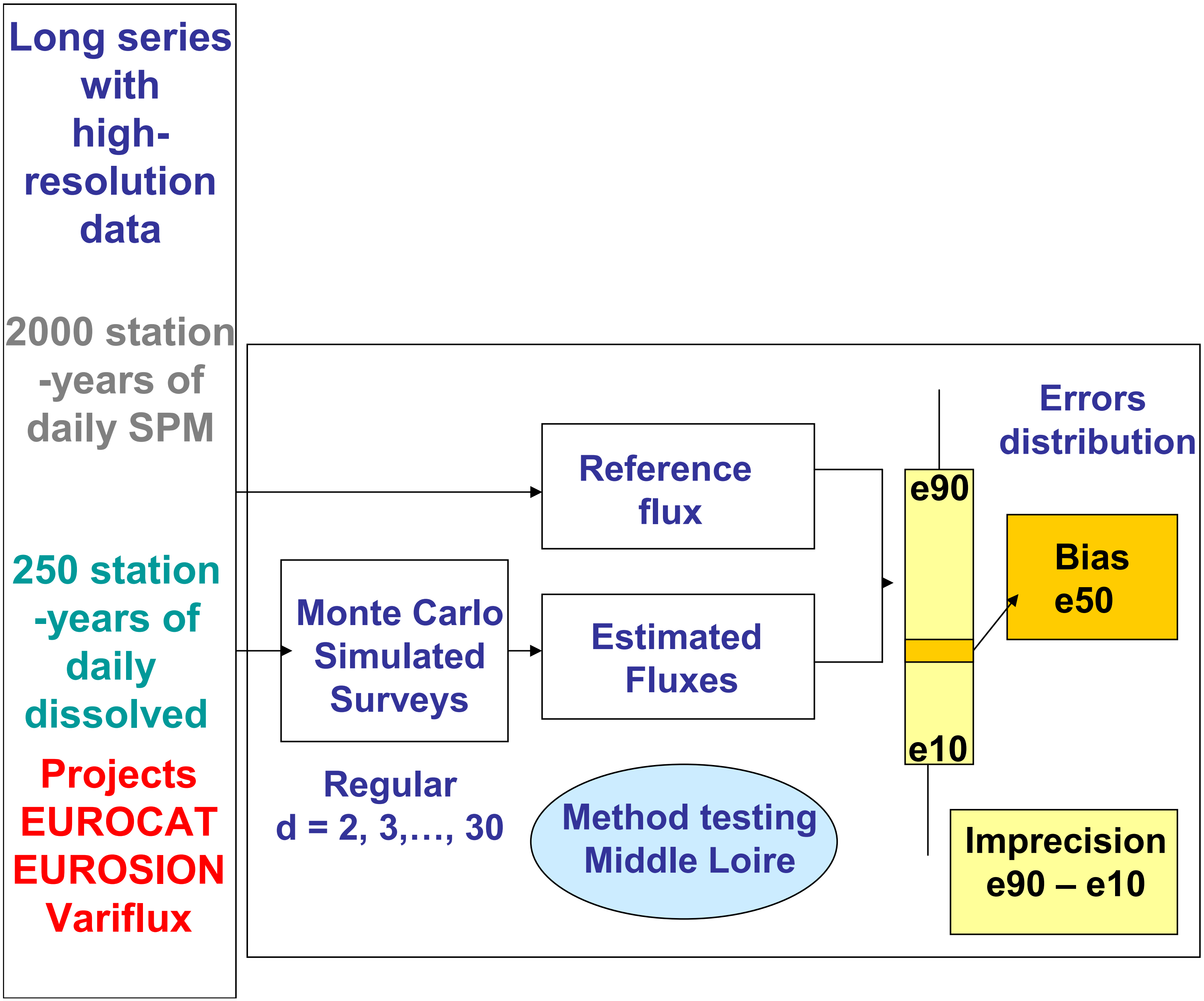
Riverine fluxes (5)

Methodological steps



Riverine fluxes (5)

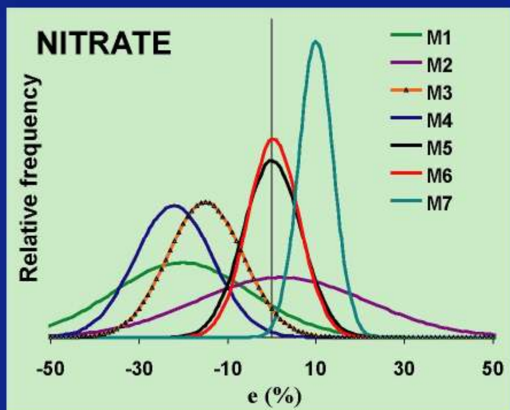
Methodological steps

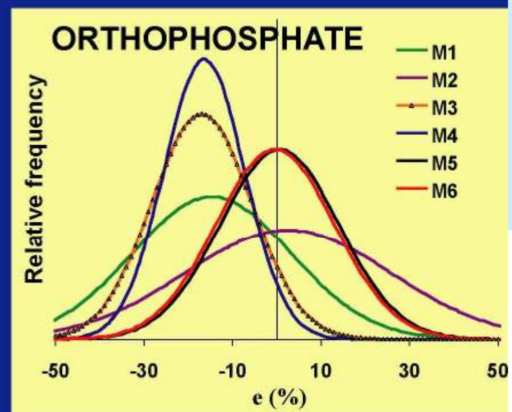


Riverine fluxes (6)

Evaluation of 7 Methods Nutrient fluxes

Middle Loire at Orléans: 35 670 km²





Nitrate	Bias %	Precision %	RMSE %
M6	0.4	12	5.8
M5	0.1	13	6.5
M7	10.0	8	10.8

Ortho-P	Bias %	Precision %	RMSE %
M6	- 0.4	27	13.4
M5	0.6	27	13.5

Which is the best method for monthly frequency ?

M2 : arithmetic mean of instantaneous flux

M5 : Flow-weighted mean concentration

M6 : Linear interpolation

M7: Rating curve stratified (winter and summer)

M2 is always imprecise (Walling & Webb, 1981)

M7 produces precise but inaccurate flux estimates

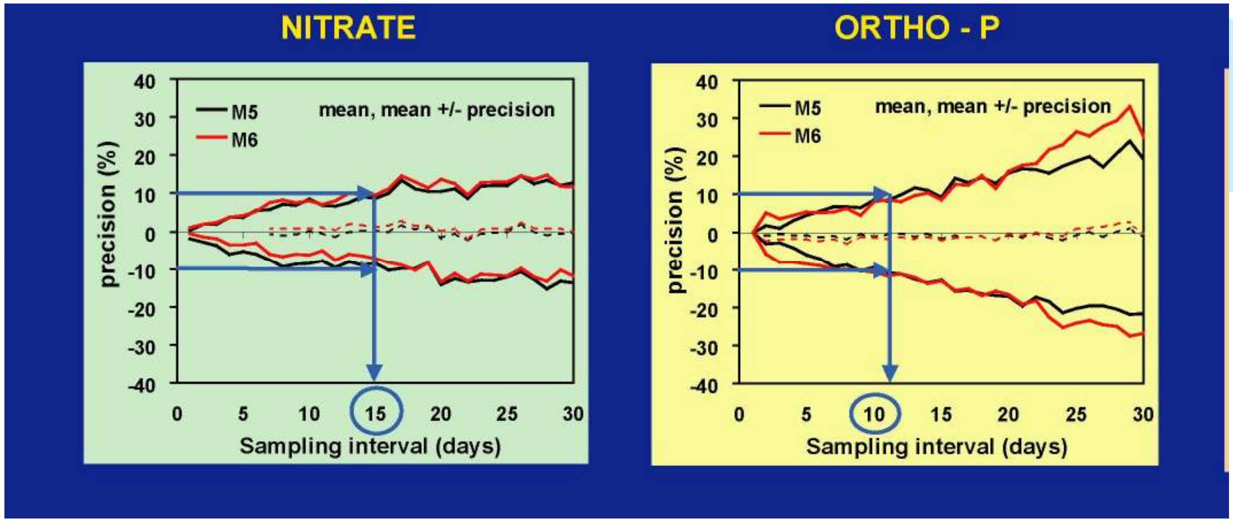
M5 and M6 provide very close results and are preferable for NO_3^- and PO_4^{3-}

Moatar et Meybeck, Monitoring Tailor Made-IV, 2003, Hydr. Processes, 2005

Riverine fluxes (7)

Uncertainties versus sampling interval (M5 and M6 methods)

Middle Loire at Orléans: 35 670 km²



Which is the best frequency ?

Annual Flux errors ± 10% is obtained for :

15 days for nitrate

10 days For othophosphate and Total phosphorus

5 days for Particulate - P

Middle Loire → Can we optimize sampling frequency at a given station And for any rivermaterial ?

Riverine fluxes (8)

Time series analysis

Long series with high-resolution data

2000 station-years of daily SPM

250 station-years of daily dissolved

Projects
EUROCAT
EUROSION
Variflux

→

Analyse of data series
Variability
C, Q, Flux

→

Variability descriptors
Metrics
Graph.
Repres.

→

River material
River Regime
Basin size

Riverine fluxes (9)

Time series analysis
Concentrations, C, Discharge, Q

- Discharge weighted average C*, q*
- Frequency statistics: C_{50}, q_{50}, C_{99}, q_{99}, **ratios**

  C_{99} corresponds to different periods and/or functionnning
  SPM (floods), TDS (low flows), nitrate (winter high flow)

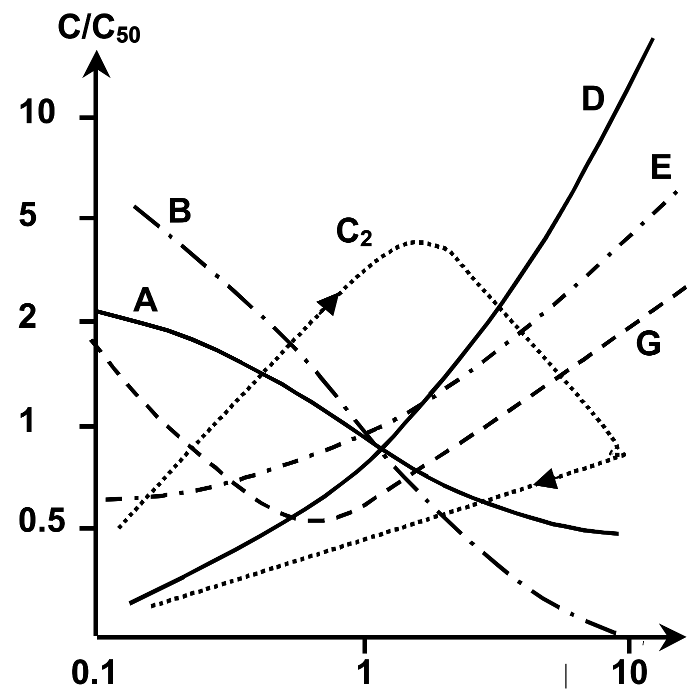
- Seasonality : Δ, r²

  Predictible seasonal change

- Slope of autocorrelation function

  « memory » of the time series

- C vs. Q pattern normalised



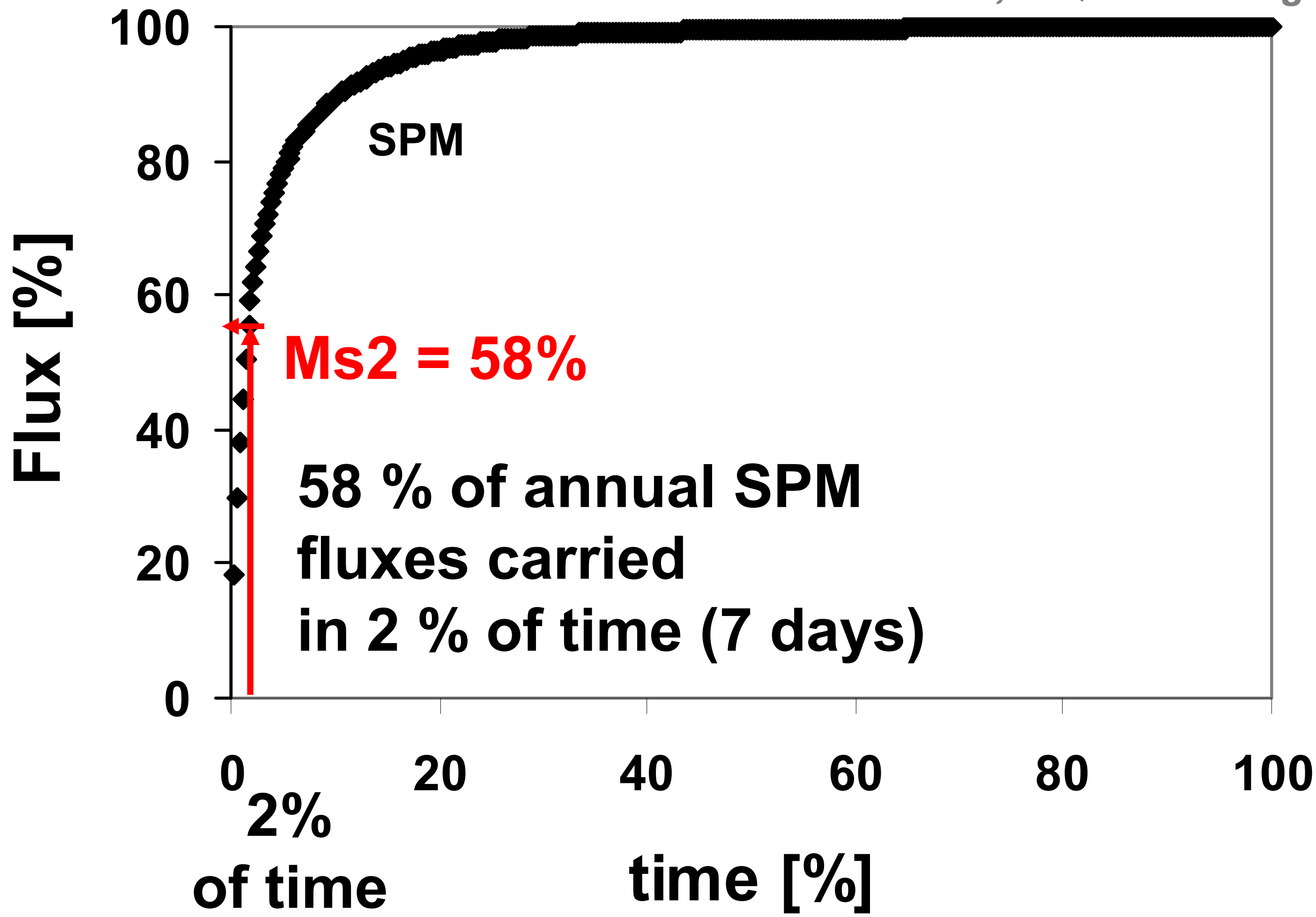
Riverine fluxes (10)

Time series analysis
Flux duration curve

Grand River (1773 km²)

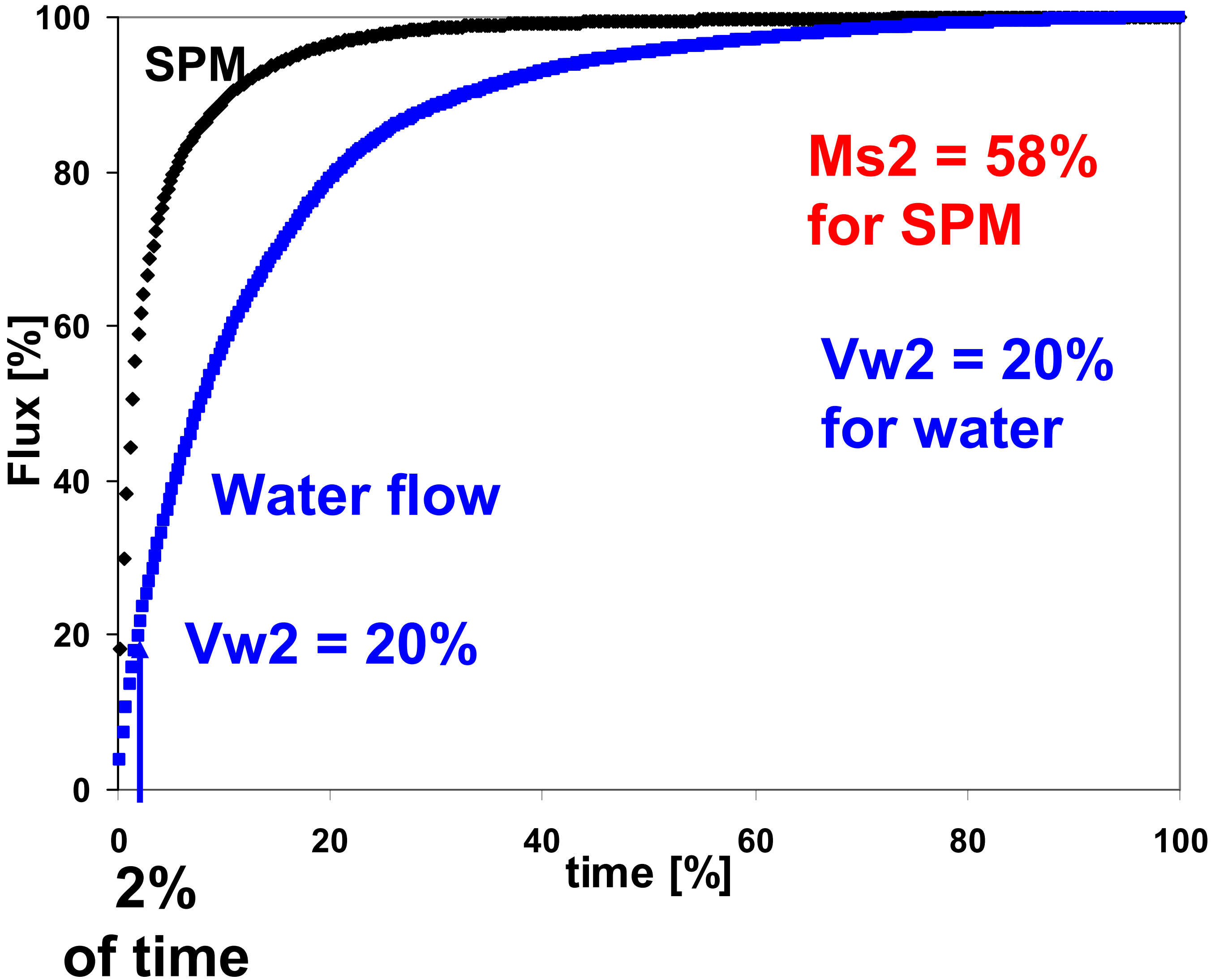
Ohio tributary Monitoring Program

Richards and Baker, WQ Heidelberg College, Ohio



Walling & Webb, 1981

Time series analysis
Flux duration curve



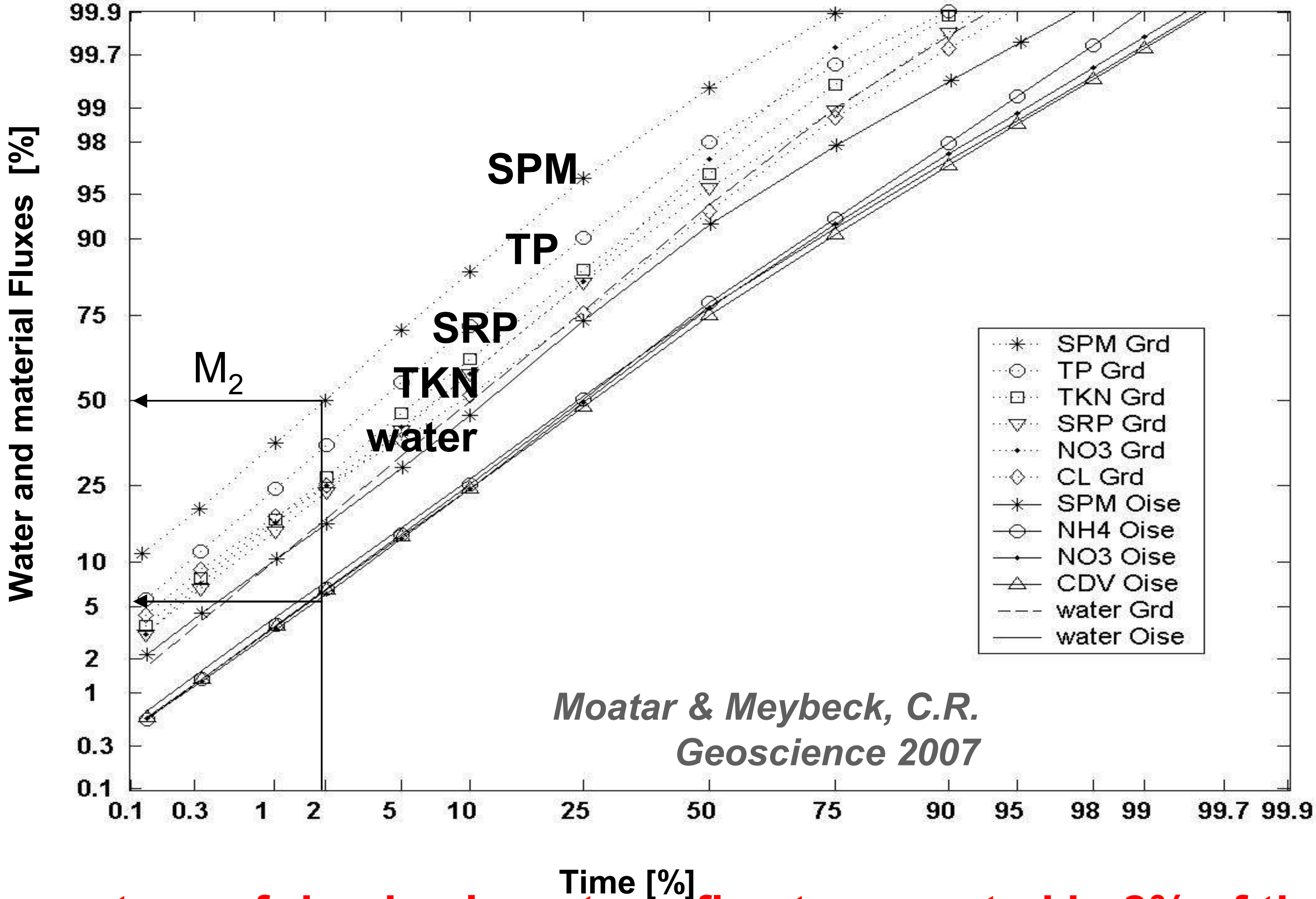
Riverine fluxes (10)

Flux duration curve

New graphical representation

Meybeck et al, 2003

Double Probability Scale : Linearisation of Flux duration curve

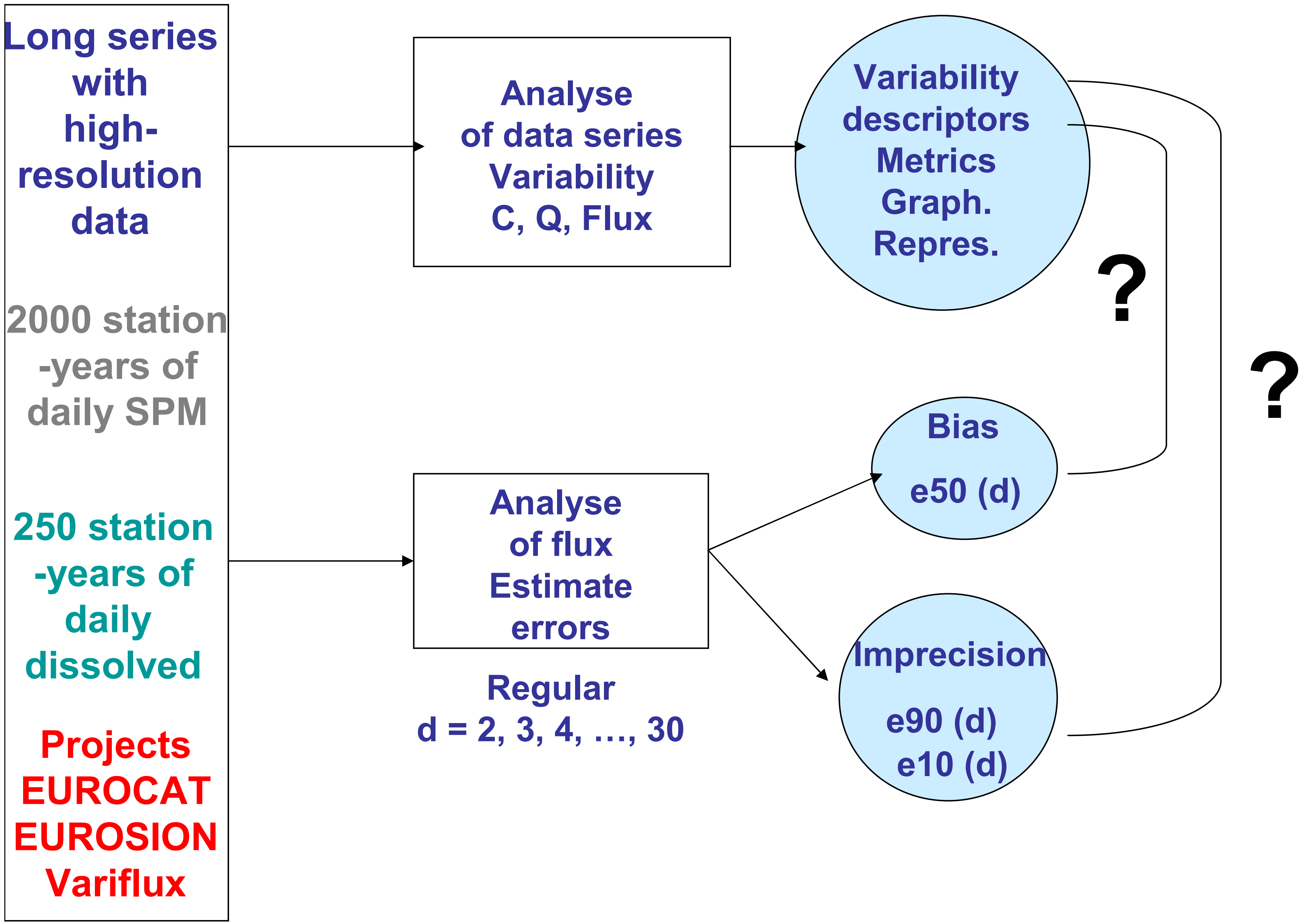


M_2 = pourcentage of riverine long-term flux transported in 2% of time

m_2 = pourcentage of riverine long-term flux transported in 2% of time

Riverine fluxes (11)

Towards prediction of uncertainties



Riverine fluxes (12)

SPM Flux error nomograph Construction and validation

56 U.S. sites
U.S.Geological Surveys data

↓

Selection of 27 U.S. sites
4 to 26 years of daily records
DEA G. Person (2004)

↓

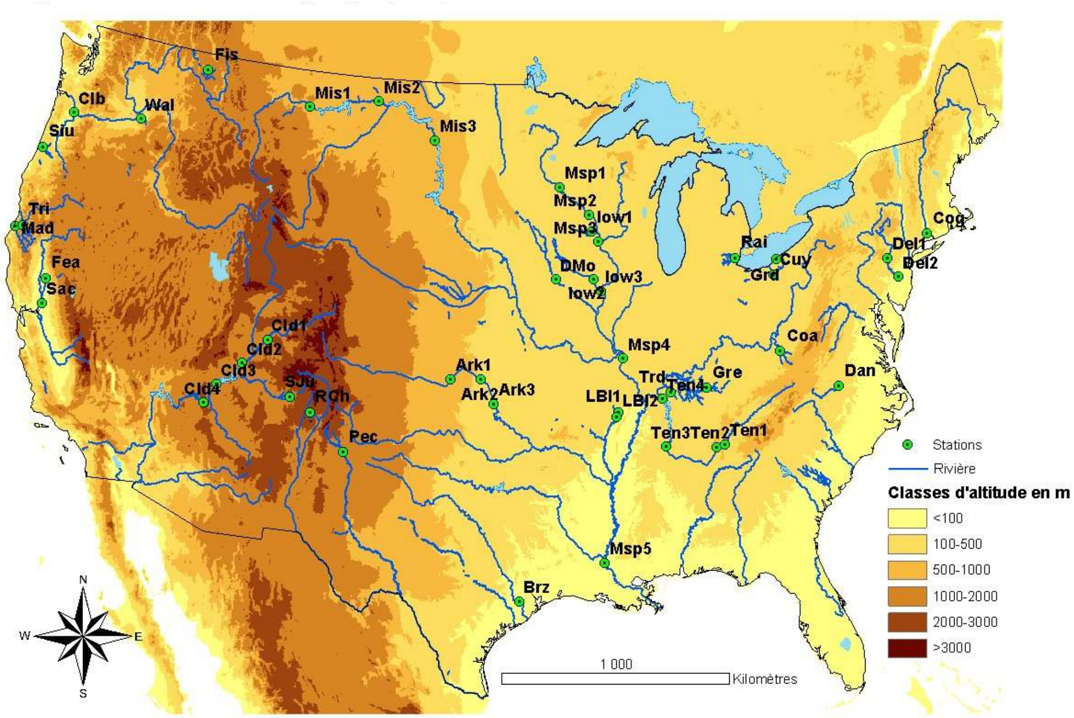
Test of 4 groups of descriptors
slopeQ, DQ95%, Ms2, Vw2

↓

Ms2

↓

Construction of SPM flux errors nomographs At interannual scale → Validation of SPM error nomogr. For 9 European Rivers



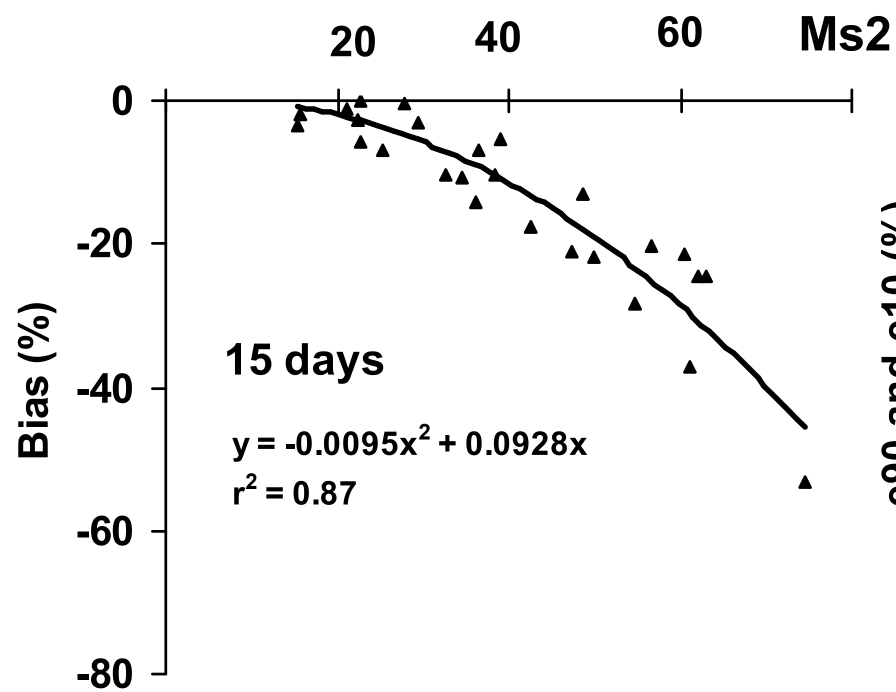
Moatar et al, 2006, Sci. of Total Env.

Riverine fluxes (13)

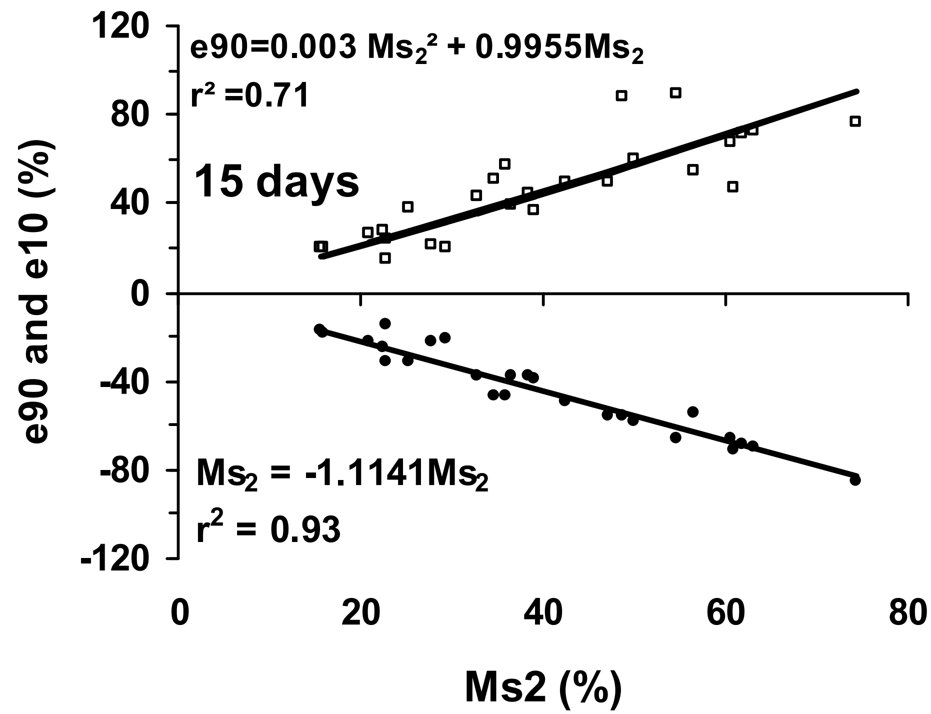
Interstation comparison
Errors vs. Ms2 duration indicator
for given sampling intervals (15 days)
U.S. Stations

Discharge-weighted concentration method

Biais vs. Ms2



Imprecision vs. Ms2

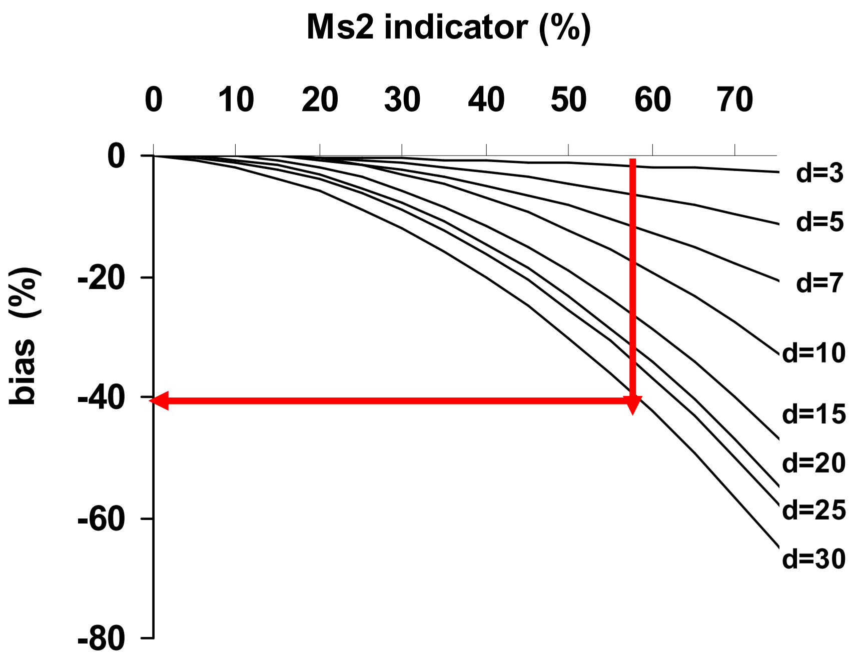


Moatar et al, 2006, Sci. of Total Env.

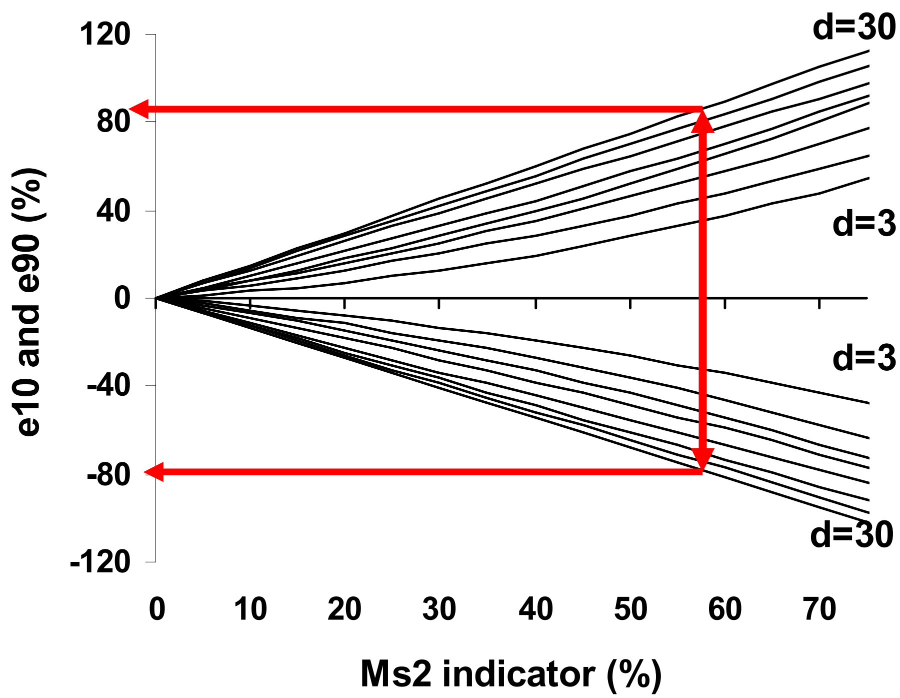
Riverine fluxes (14)

SPM flux error nomographs for increasing sampling intervals U.S. stations

Biais vs. Ms2



Imprecision vs. Ms2

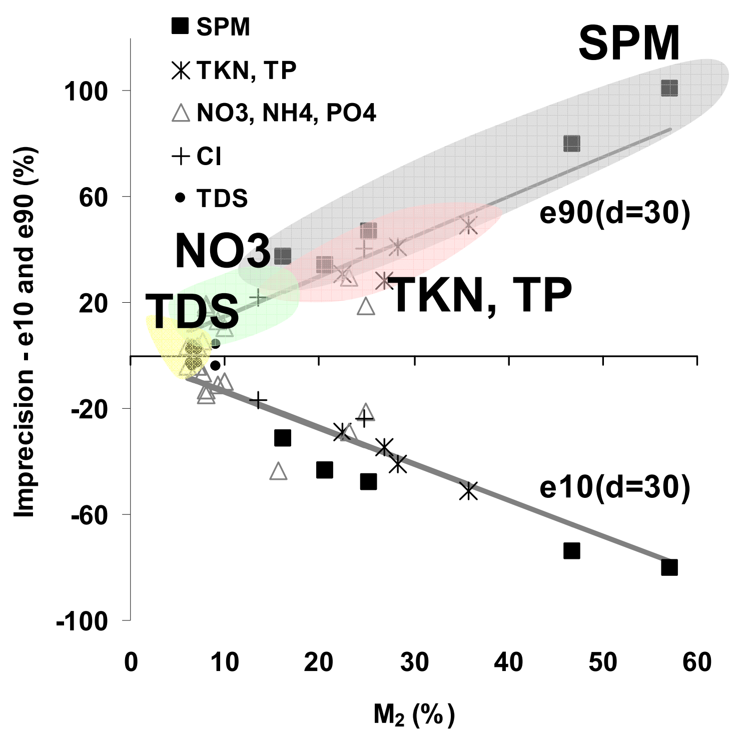


Moatar et al, 2006, Sci. of Total Env.

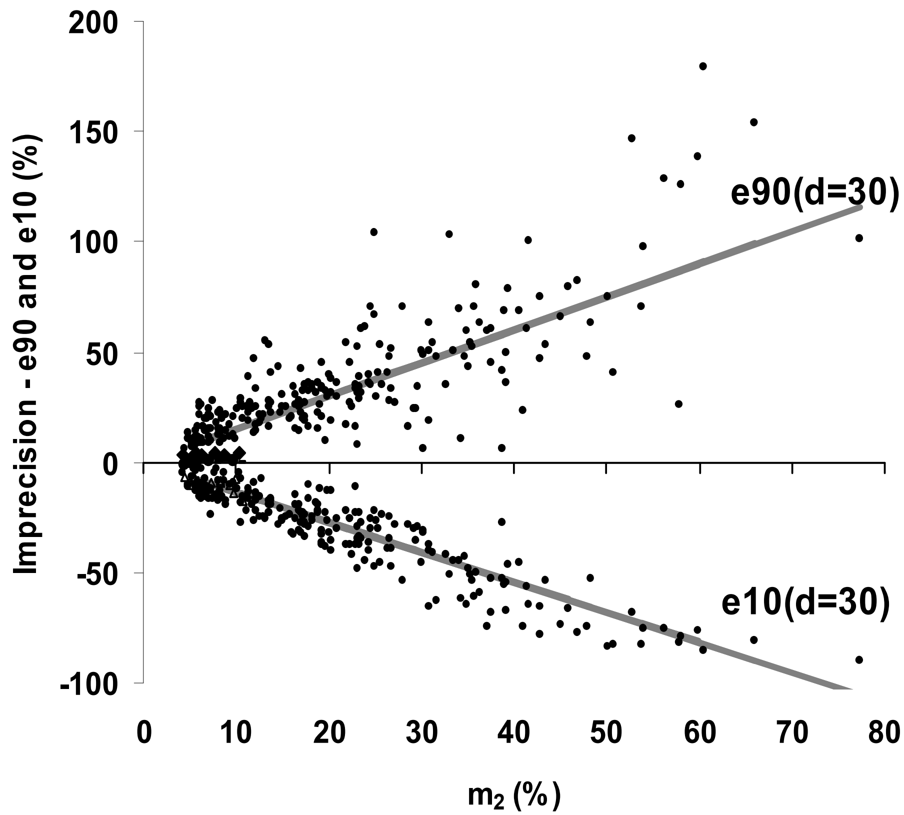
Riverine fluxes (15) **Flux error nomograph : Imprecision**

Application to Lake Erie tributaries, Seine, Loire
8 variables

Can be applied to any rivermaterial at inter-annual scale (10 years)



Can be applied at the annual scale



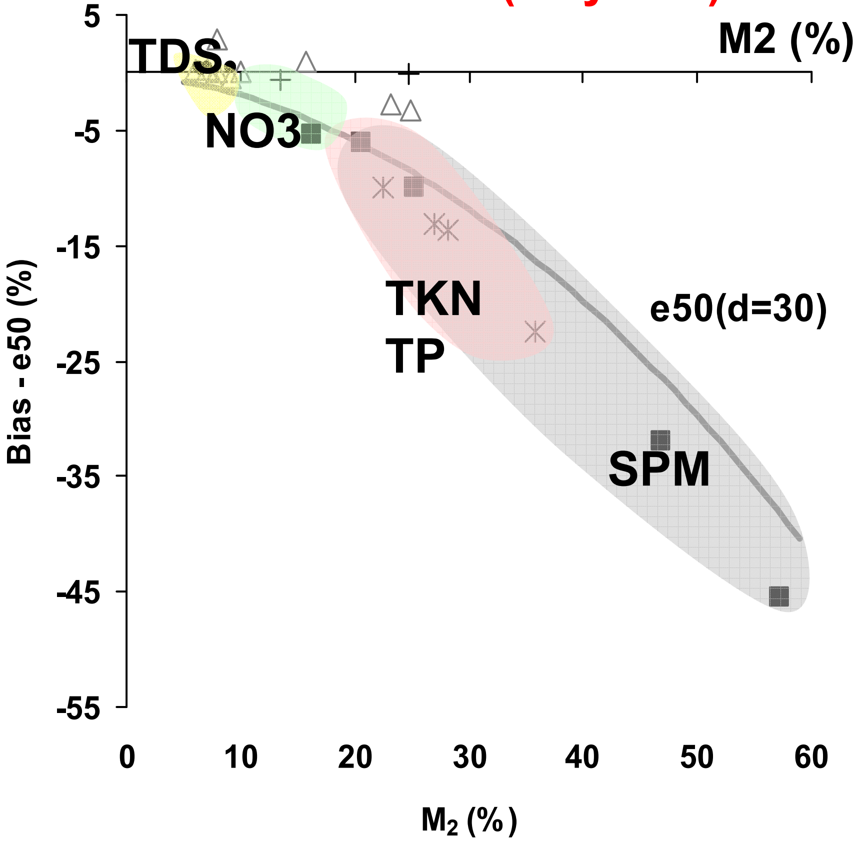
Moatar and Meybeck, C.R. Geoscience,2007

Riverine fluxes (16)

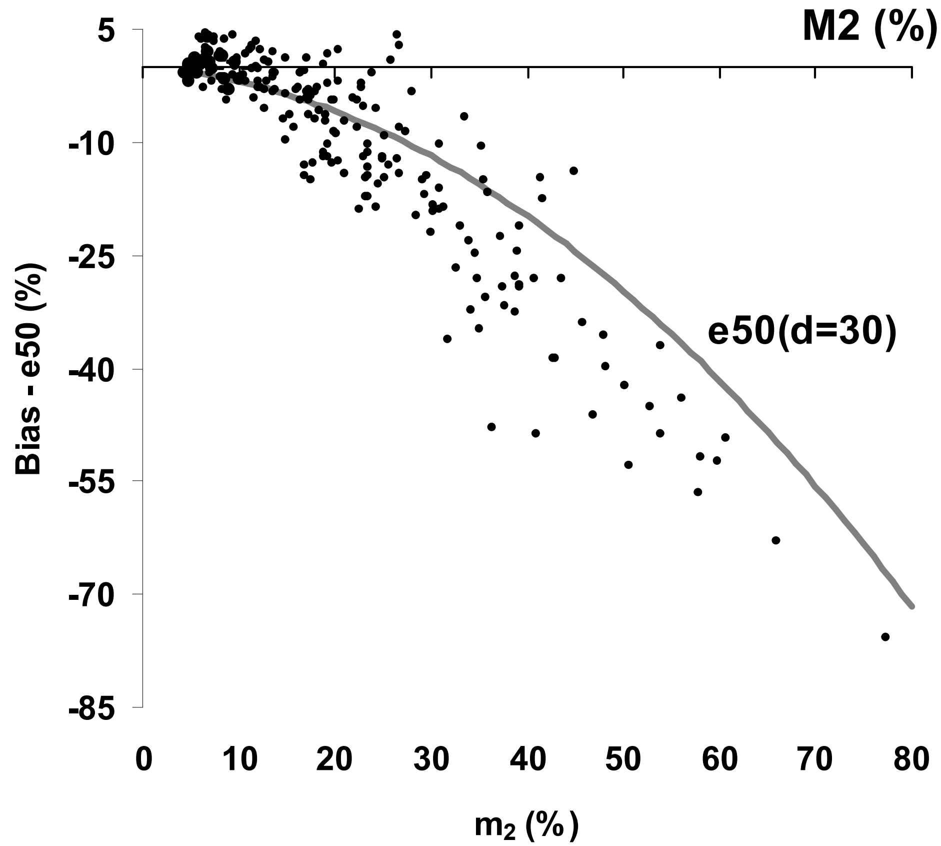
Flux error nomograph : Bias

Application to Lake Erie tributaries, Seine, Loire
8 variables

Can be applied to any rivermaterial at inter-annual scale (10 years)



Can be applied at the annual scale



Moatar and Meybeck, C.R. Geoscience, 2007,
Moatar, Meybeck, in press Water Ress. Resources

Objectifs et Méthodes

Compléter les incertitudes dans le calcul des flux (à partir des échantillons Ponctuels et discrets) par les incertitudes liées à la prise des échantillons elle-même.

➡ **Est-ce que la mesure de la turbidité est une alternative pour évaluer les flux de MES en continu ?**

➡ **Est-ce que la mesure de l'aDcp est une alternative pour évaluer les flux de MES de façon spatialisée dans la section transversale ?**

- **Isère, prélèvements ponctuels, turbidimétrie, aDcp**

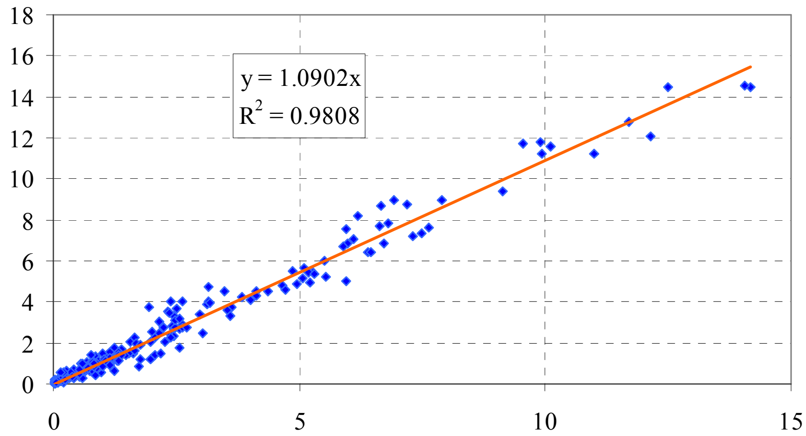
  Campagne mars 2007 *LTHE, Cemagref HHLY*

- **Rhône-Saône, prélèvements ponctuels, aDcp**

  Campagne février 2006 *Cemagref HHLY, CNR*

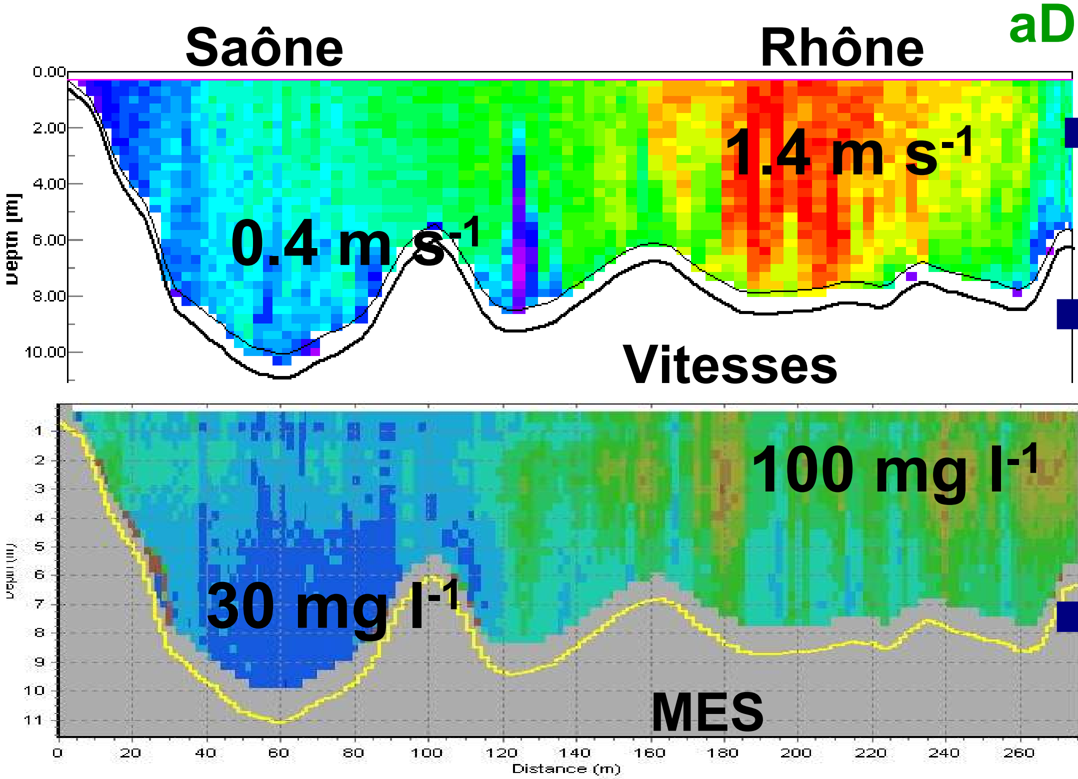
Turbidimétrie et aDcp

MES vs. Turbidité : Isère



- La relation MES – NTU reste constante de 20 à 15 000 mg/l, permettant la mesure en continu
- L'écart moyen entre les mesures par turbidimétrie et par pesée : 23 %

aDcp : Confluence Rhône - Saône

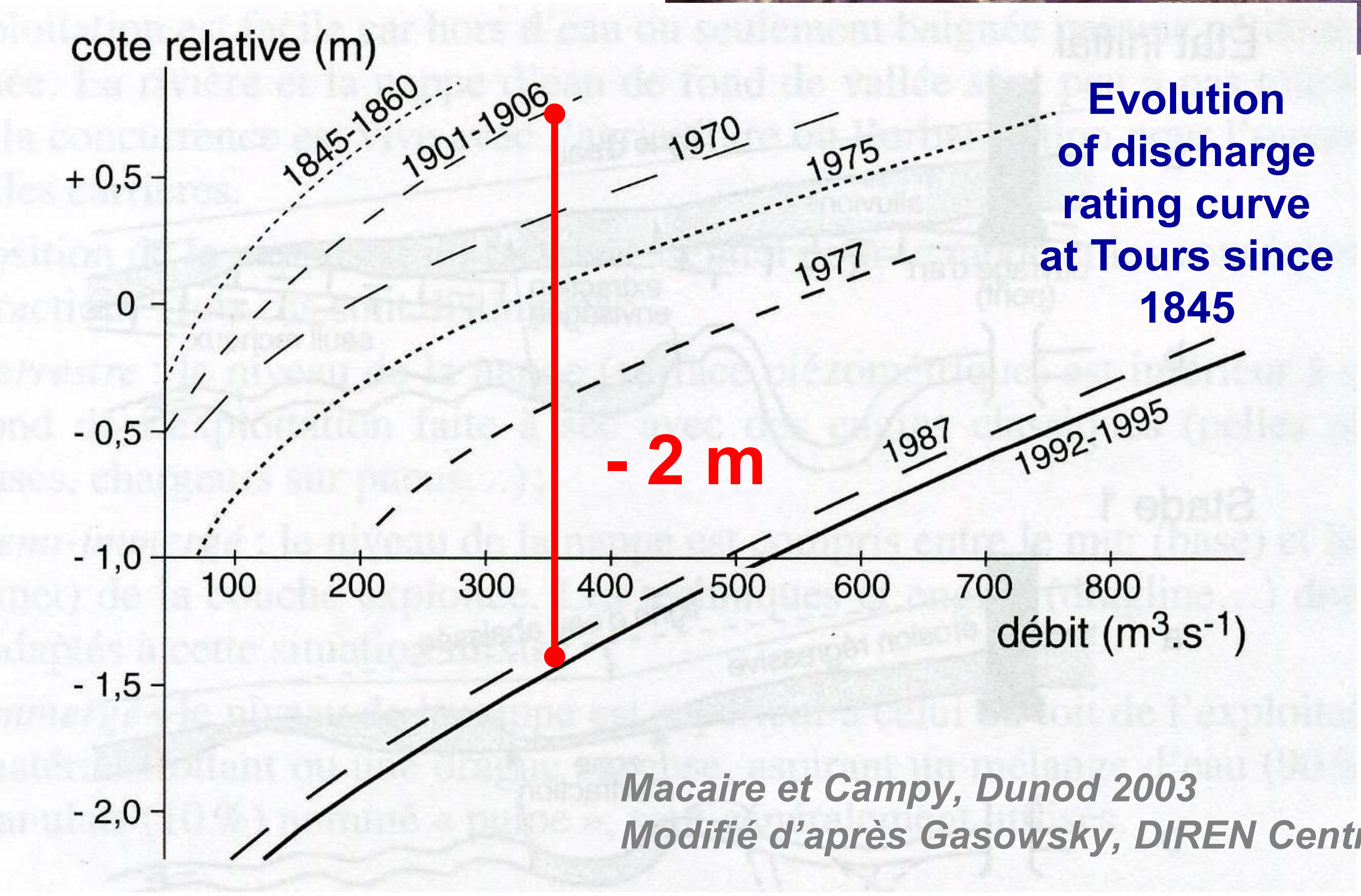


- L'aDcp permet d'explorer avec finesse le champ des vitesses et des MES
- Il met en évidence la grande hétérogénéité des confluences et la non représentativité des échantillons ponctuels (type RNB) dans un tel contexte.
- Les essais sur l'Isère ont été beaucoup moins concluants

LTHE, Cemagref HHLY

Fluvial System functionning	Queries	Temporal Scale	Spatial Scale
Thermal regime	120 year - trends Hydrological, Meteorolog. controls NPP impact	Daily Seasonal Since 1976, 19th century	Middle Loire reach : 250 km
Eutrophic.	25 year-trends Hydrological, Algal developp. controls	Hourly, Daily Seasonal Since 1980	Middle Loire reach : 350 km
Nutrients	Pressure – Impact catchment analysis Zones of homogeneous agricultural pressure	Inter-annual Since 1980	Loire catchment Stream Order 120 catchments (< 200 km²)
Water and Material fluxes	Variability in contrasted catcments Optimize sampling Predict uncertainties	Daily Seasonal	60 U.S. Rivers 30 E.U. Rivers 100 to 600 000 km²
Morphological dynamics	**Sediment budgets** **Hydraulic conditions and secondary channels**	**Daily** **Flood** **Multi-year**	**Anabranched Middle Loire** **Brehemont site** **5 km**

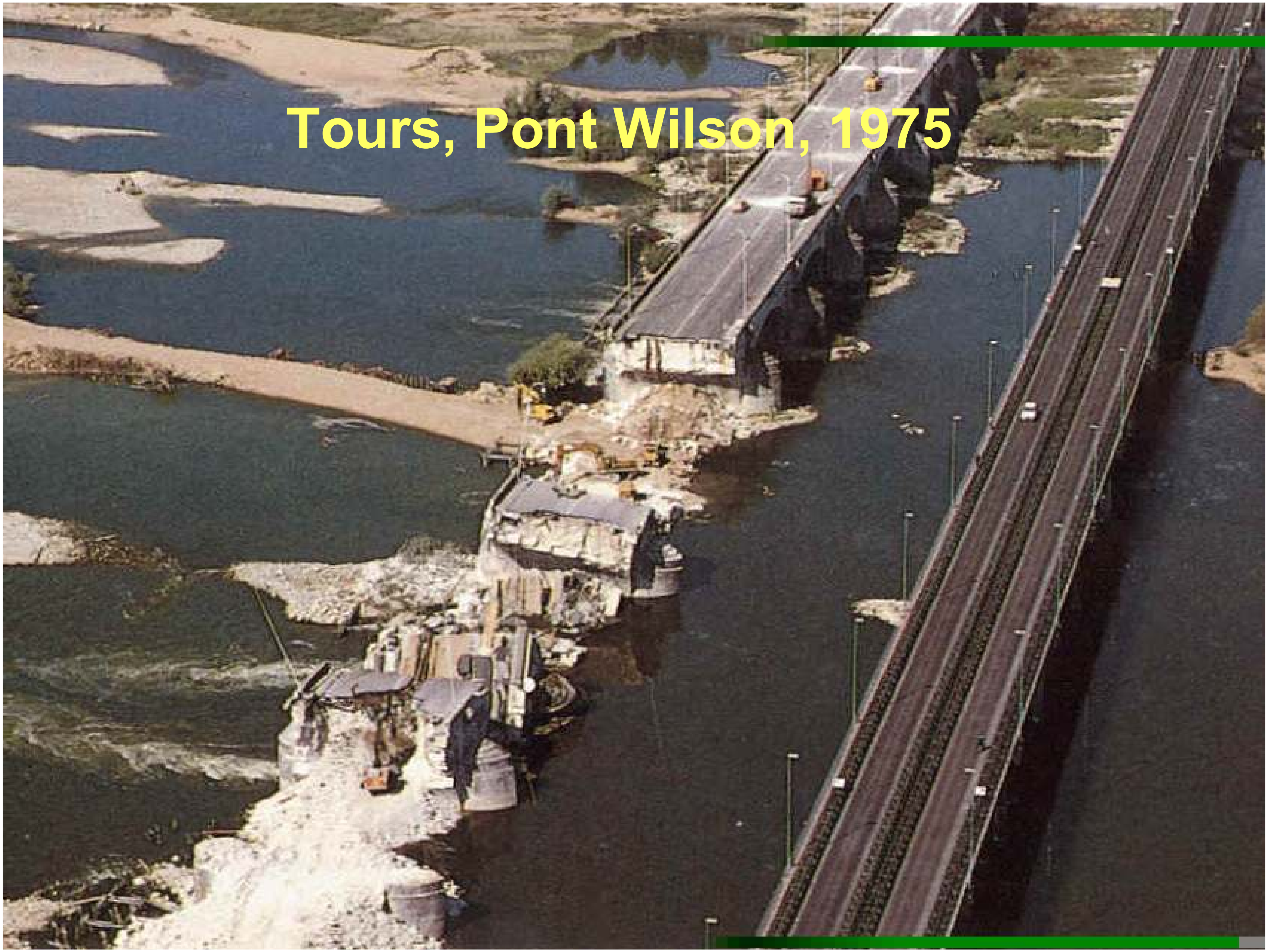
Morphological dynamics (1)



Evolution of discharge rating curve at Tours since 1845

Macaire et Campy, Dunod 2003
Modifié d'après Gasowsky, DIREN Centre

Tours, Pont Wilson, 1975



Morphological dynamics (2)

These S. Rodrigues, 2005

Colonisation végétale

Colmatage sédimentaire

Quelle est l'évolution morphologique des différents chenaux au cours des crues ?

Existe-t-il des zones préférentielles de stockage ou de destockage ?

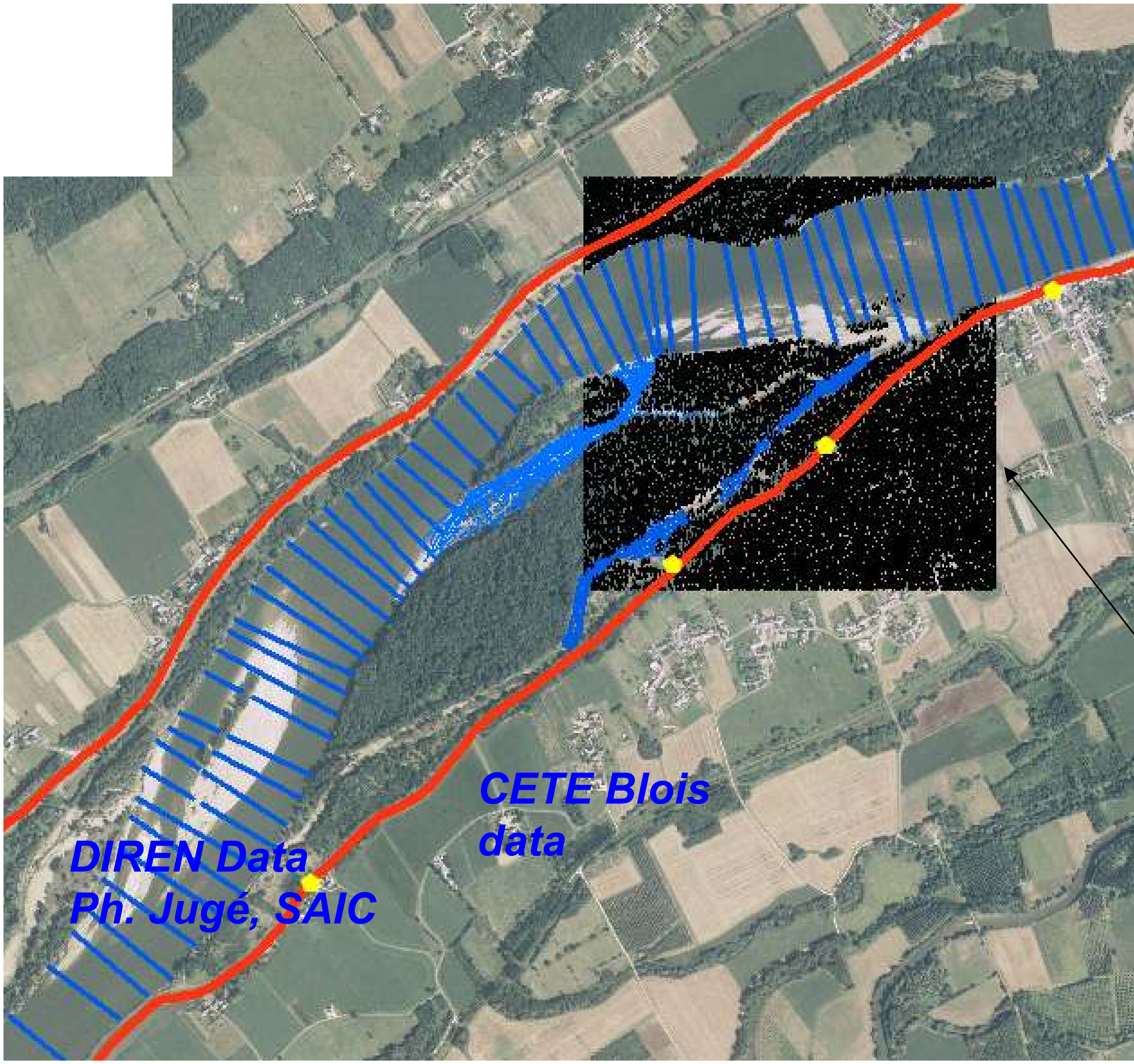
Lien entre paramètres hydrauliques et transport solide ?

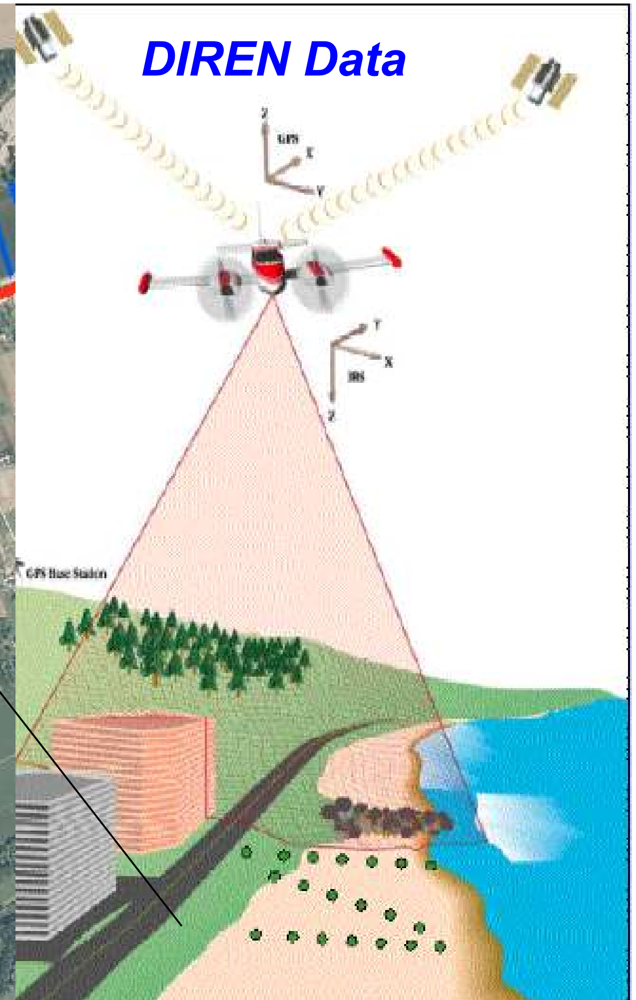
Collaboration D. Nistoran, INP Bucarest

Morphological dynamics (3)

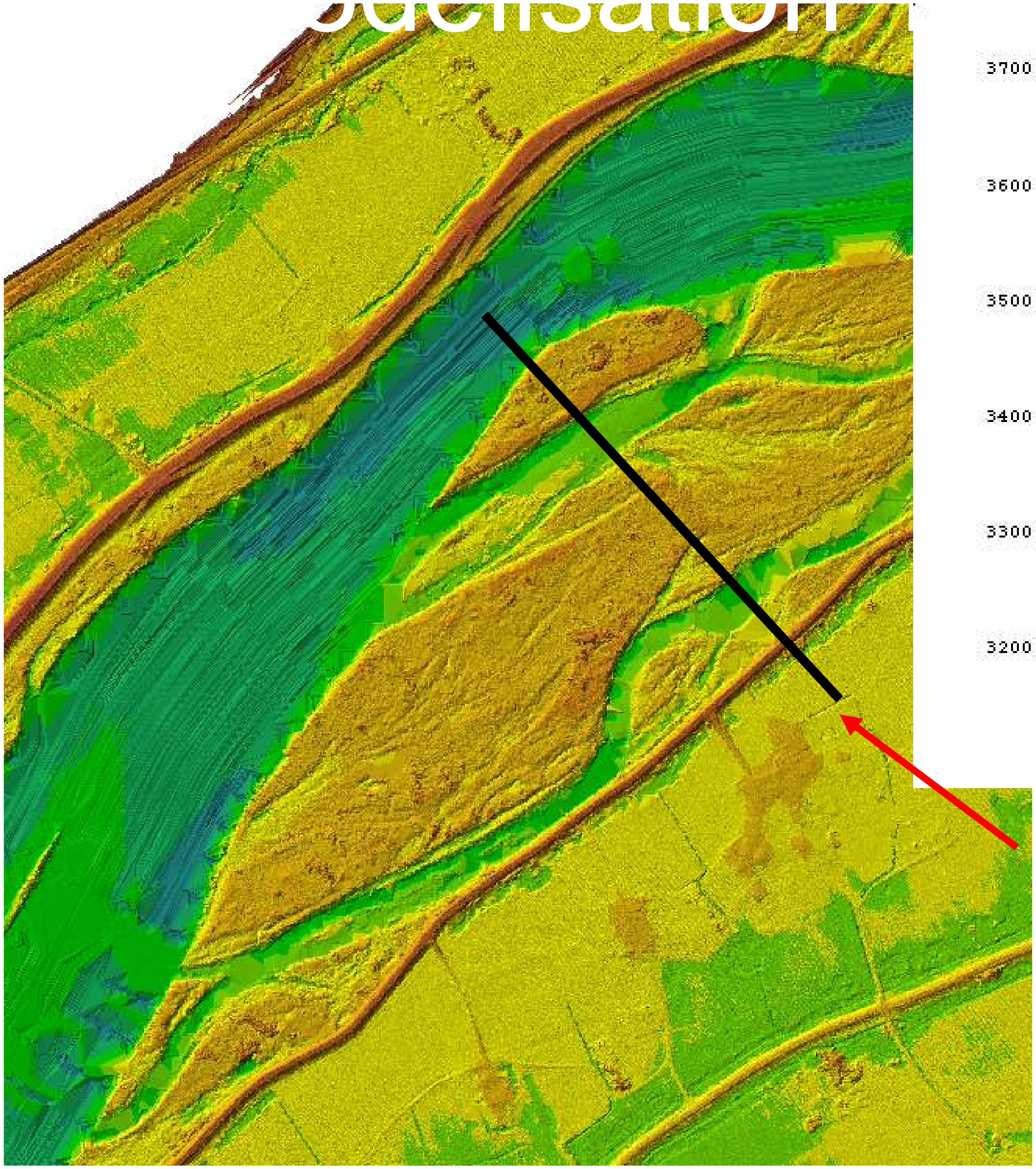
Bathymetric and Lidar Data 5 km

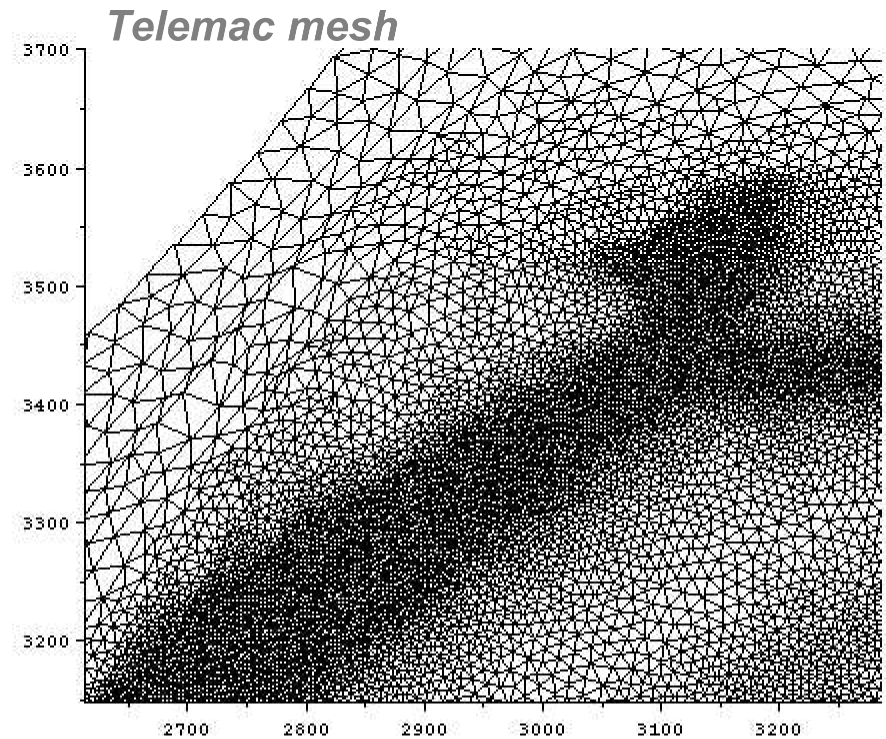
Collaboration D. Nistoran, INP Bucarest , Chaire d'Hydraulique et Machines Hydr.

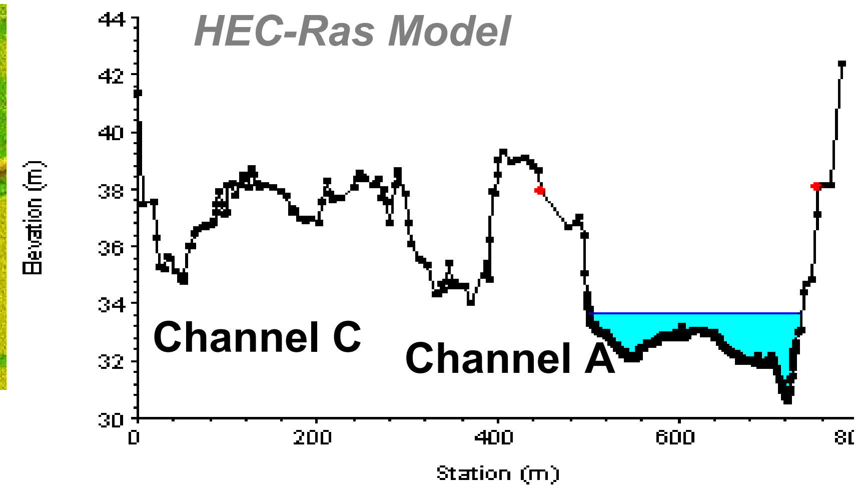




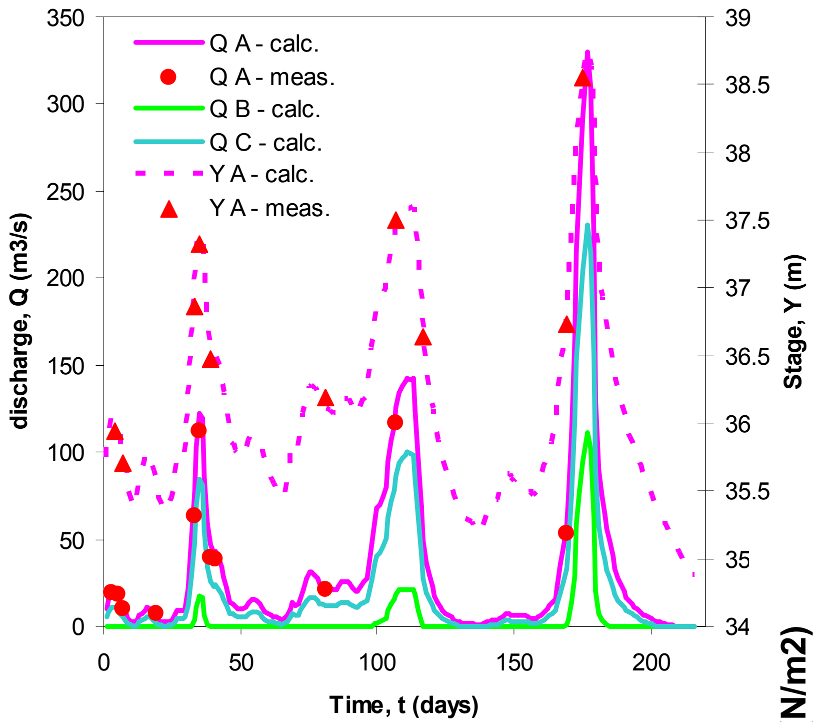
Morphological dynamics (4) Construction of the Geometry





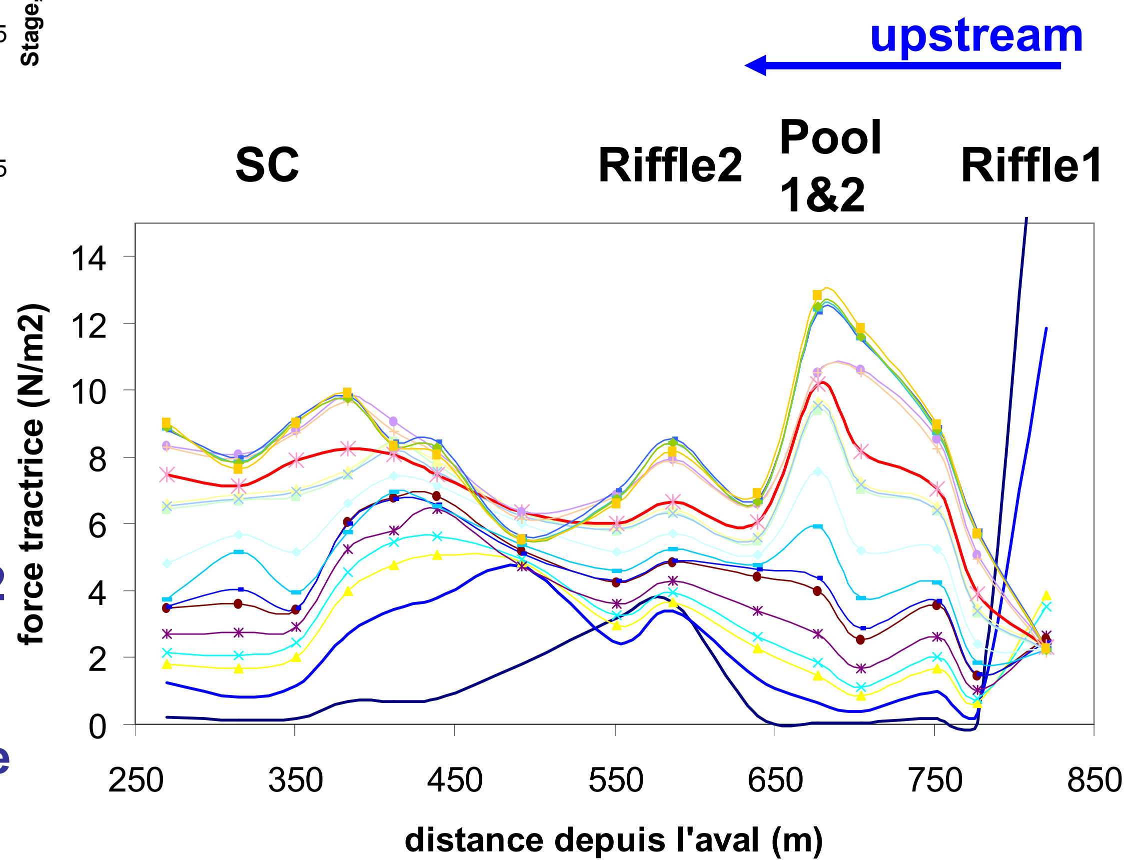


Morphological dynamics (5) 1D – Unsteady flow Modelling



• Flow and stage hydrographs errors less than 12 cm (6%)
12 m3/s (17%)

• Flow velocity and bed shear stress allong the secondary channel



• At low flows (<1300 m3/s) peak valeus of velocities and shear stresses are found on R1 and R2

• At high flows peak values of velocities and shear stresses are in P1 and P2

Collaboration D. Nistoran, INP Bucarest, Rodrigues et al, Sedimentology, 2005

Conclusions

Processus hydro-sedimentaires en Loire moyenne

- la modélisation a permis de mettre en évidence le phénomène Inversion des vitesses et forces tractrices (Velocity reversal) au sein des Unités seuils - mouilles

- d'estimer les débits nécessaires pour la rupture des couches d'armures (environ 1600 m3/S) par une approche couplée de modélisation et d'observation « chaines d'érosion » et bathymétrie

- elle complète les lacunes temporelles et spatiales d'échantillonnage sur le terrain

- Le modèle TELEMAC, en cours de calage, permettra de mieux comprendre les processus à l'entrée du chenal (zone clef)

Perspectives (2)

Riverine fluxes Uncertainties

Our Successful approach has been validated on

For one method

- Any stations > 1000 km²
- 8 Water Quality (WQ) Variables with varying C vs. Q patterr
- annual and interannual basis
- But can not be used in most cases !

And Needs:

- to estimate M2 from existing discrete WQ data and continuous flow data
- to estimate the sensibility of M2 to the length of the period of record
- to test new temporal descriptors
- to test calculation new methods (ANN)

Moatar et al, 1999, 2005

Perspectives (3)

Other Water Quality issues

Developpement of statistical methodologies to test Water Quality issues and variables

- Uncertainties on quantiles analysis and WQ standard
(« SEQ – Eau » - Water Quality Evaluation System)

- Monitoring station optimization
(WQ Variable and Stations redundancing)

- Duration – frequency – intensity analysis of worst water quality

- Trend analysis from discrete sampling with uncertainties

- Spatial analysis : Fuzzy clustering approach
Geostatistical developments for incorporating river network dependencies

Sauquet, 2006, de Fouquet et Bernard-Michel, 2006

Hydro-sedimentary dynamic

Apply hydro-sedimentary models to understand Morphological changes at different temporal and Spatial scales

- **key zones : bifurcation zones between the main and secondary channels**

  Estimate the distribution of flow and solid transport in the Different channels

  How long sediments remain in the secondary channels ?

  Telemac, Sogreah, Sysiphe, LTHE

- **large stretches of the Middle Loire on a multi-annual scale**

  Analyse morphological evolution and predict river bed changes

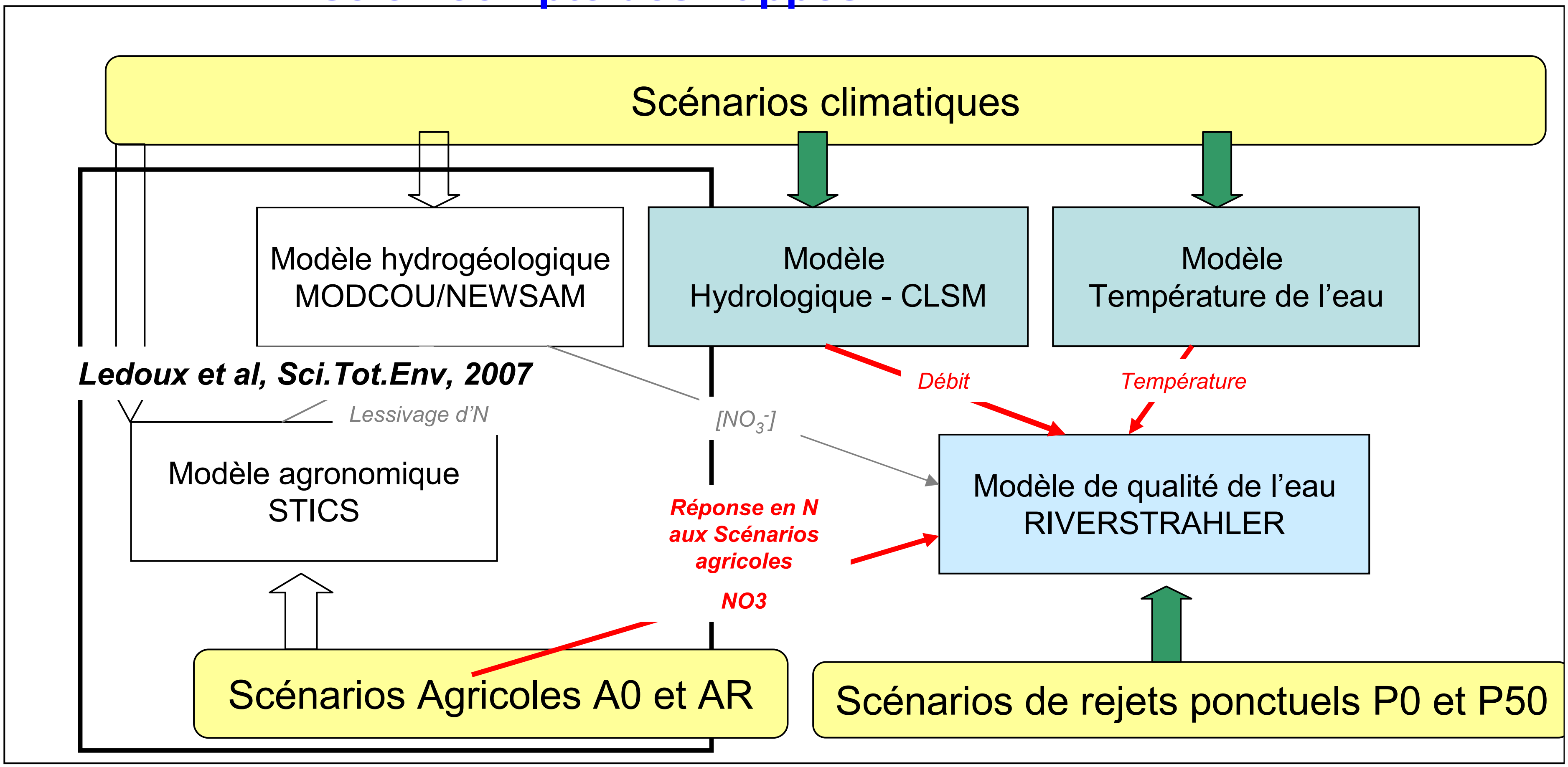
  EDF, Model developpement Cemagref

Conclusions / Perspectives – Modélisation prospective

➜ **Modélisation à l'échelle globale (BV de la Loire)**

➜ **Hydrologie + qualité des eaux**

➜ **Prise en compte des nappes**



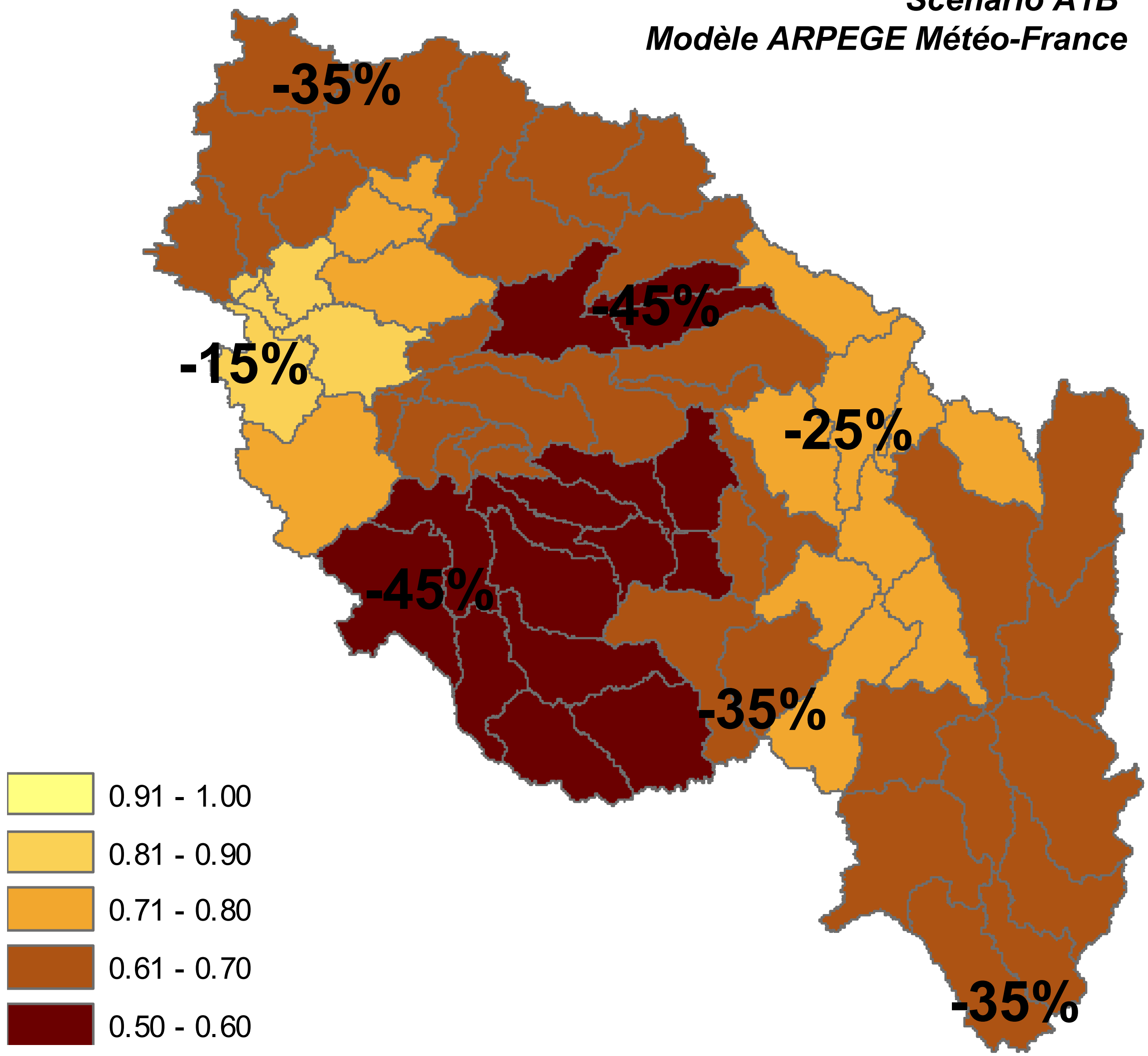
➜ **D'autres modèles à l'échelle globale (évaluation des incertitudes)**

Scénarios climatiques
Anomalies de Précipitation - Valeurs moyennes pour 68 sous-bassins

Scénario A1B
Modèle ARPEGE Météo-France

Moyenne cumul
(Juin – Juillet- Août)

Futur : 2080 – 2100
Présent : 1970-1990



V. Bustillo et al, en cours

Scénarios climatiques
Anomalies de Précipitation - Valeurs moyennes pour 68 sous-bassins

Moyenne Cumul
(Décembre – Janvier- Février)

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Modèle ARPEGE Météo-France

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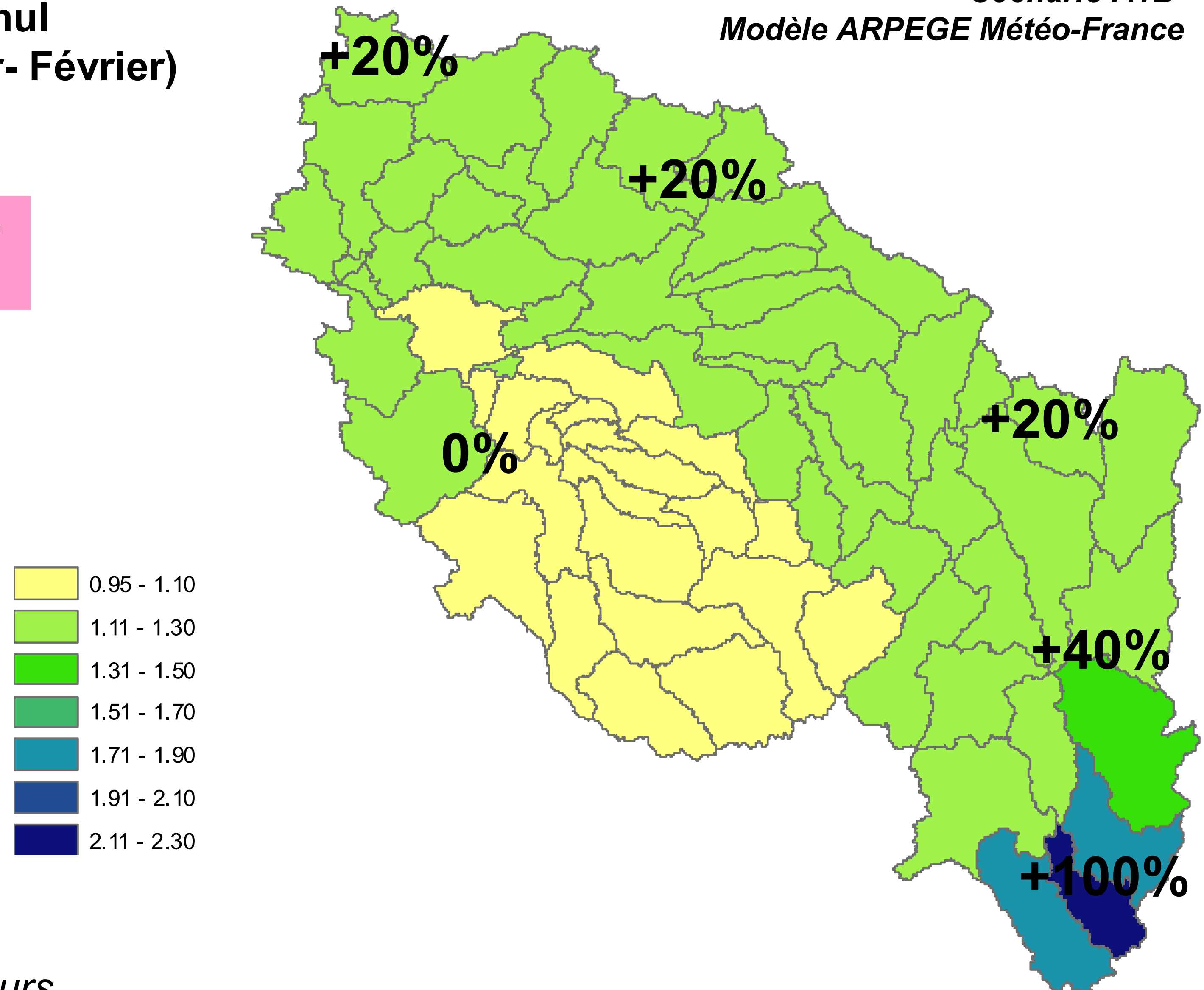
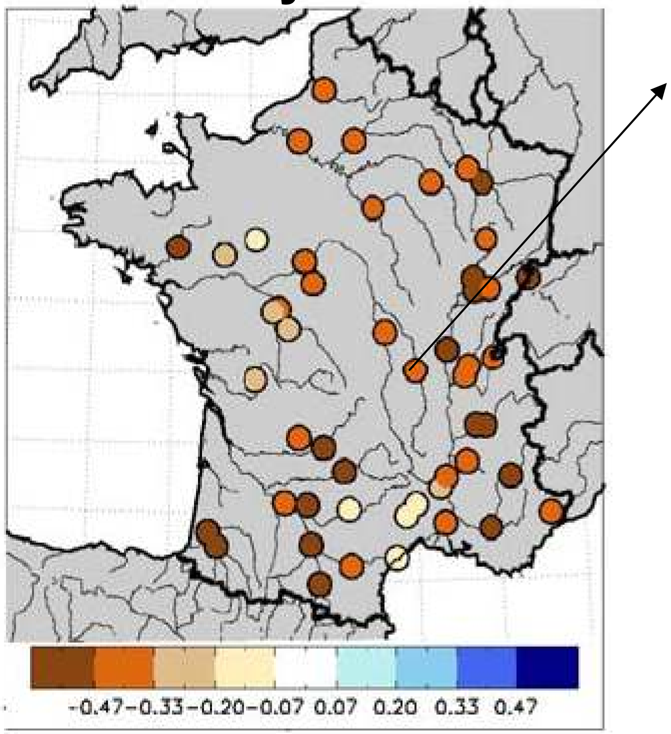


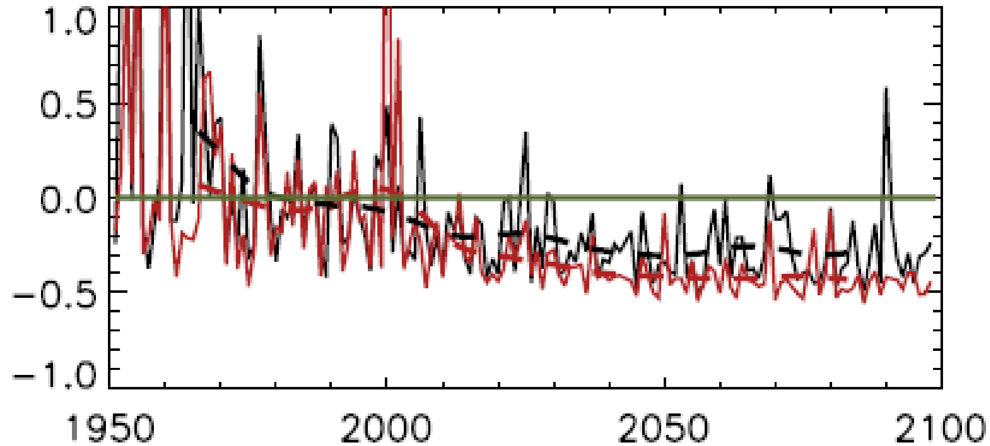
V. Bustillo et al, en cours

Changement global et cycle hydrologique : Régionalisation sur la France, *J. Boe, thèse 2007*

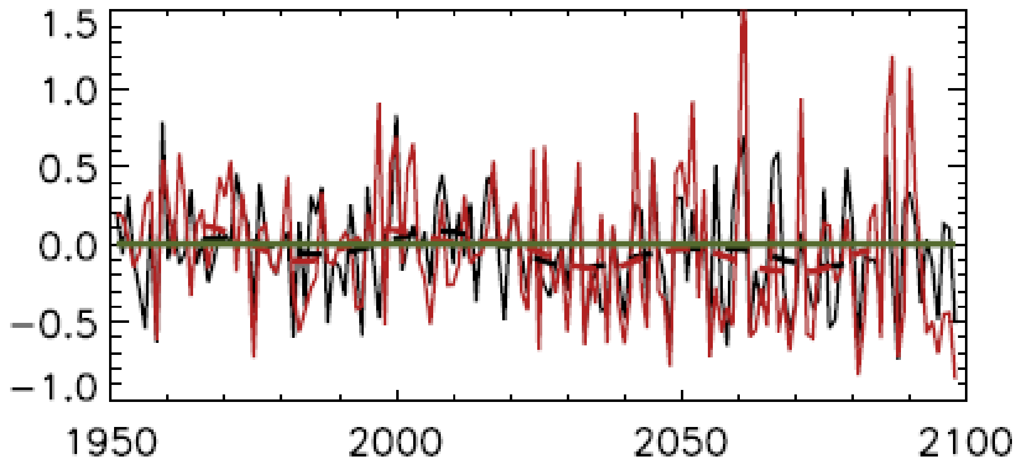
Débits moyens J J A



Loire à Villerest, Débit moyen été



Loire à Villerest, Débit maximum annuel

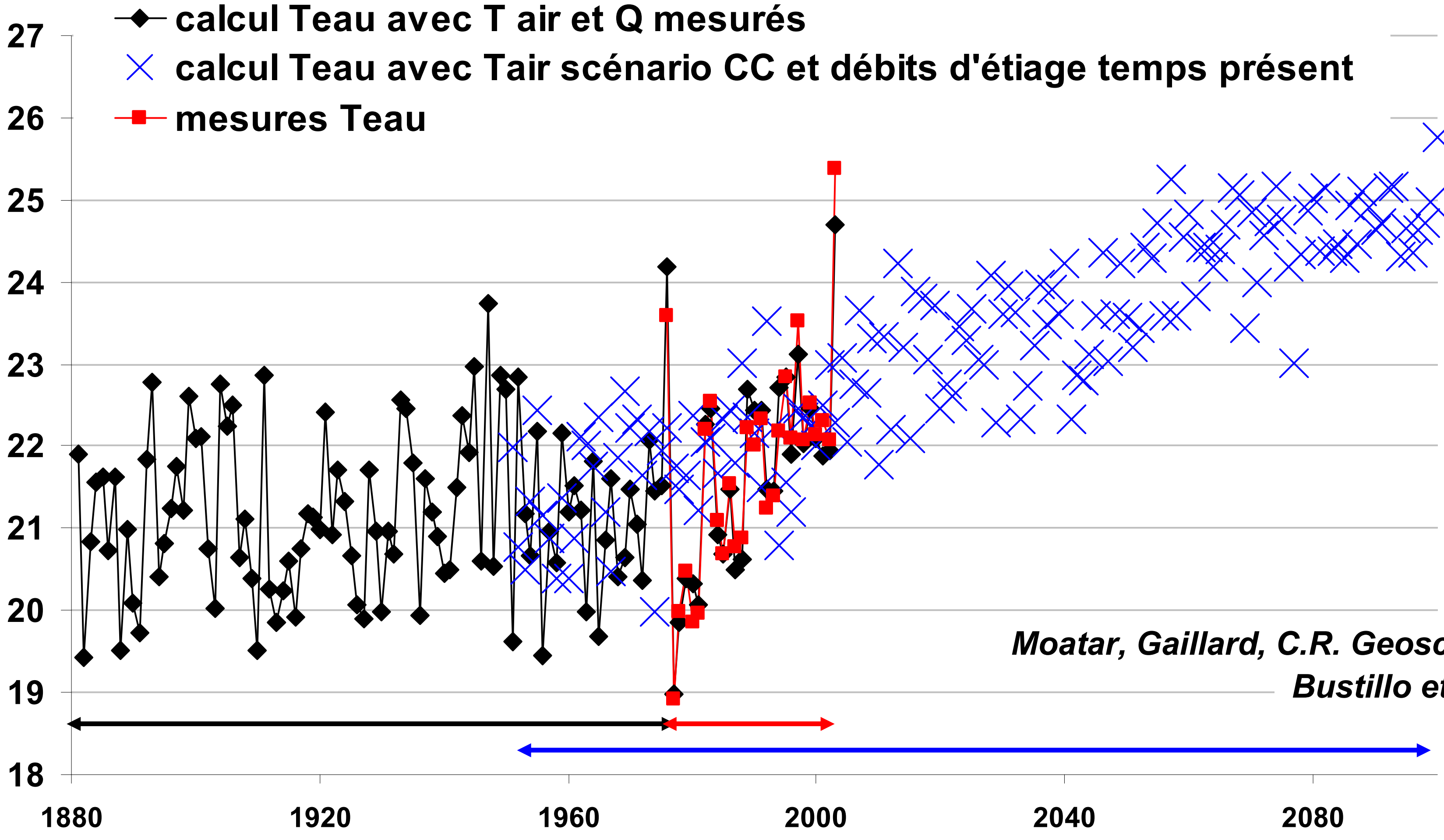


Figures tirées de la thèse de J. Boé, 2007, Toulouse

Utilisation du modèle Thermique Loire Moyenne (Moyenne estivale – Juin à Août)

Même distribution Statistique des débits d'étiage
(gestion identique des barrages)

Apports identiques nappe des Calcaires de Beauce
(ex. Bassin Parisien, diminution des alimentations par les nappes MODCOU)



Moatar, Gaillard, C.R. Geosciences, 2006
Bustillo et al, en cours