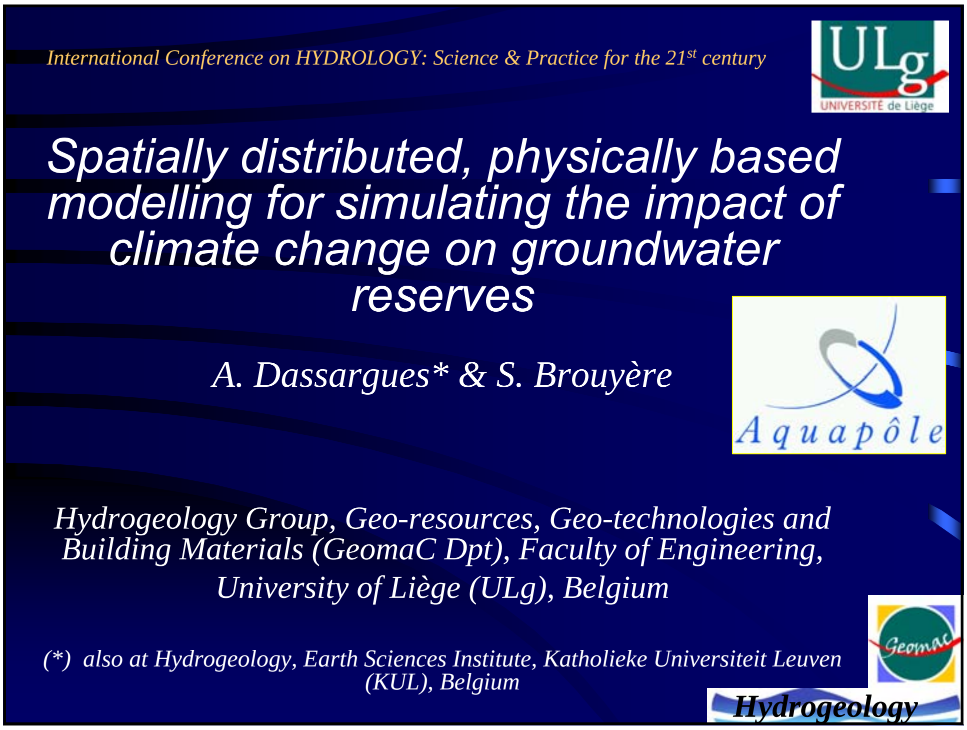


International Conference on HYDROLOGY: Science & Practice for the 21st century

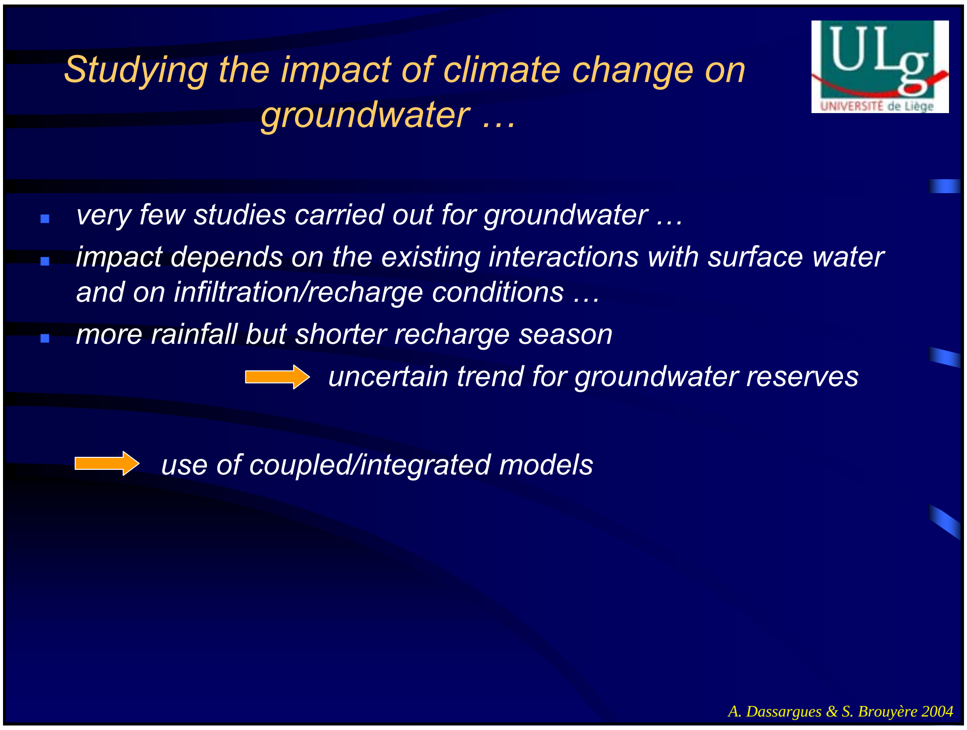
Spatially distributed, physically based modelling for simulating the impact of climate change on groundwater reserves

A. Dassargues* & S. Brouyère

Hydrogeology Group, Geo-resources, Geo-technologies and Building Materials (GeomaC Dpt), Faculty of Engineering, University of Liège (ULg), Belgium

(*) also at Hydrogeology, Earth Sciences Institute, Katholieke Universiteit Leuven (KUL), Belgium

Hydrogeology



Studying the impact of climate change on groundwater …

- very few studies carried out for groundwater …
- impact depends on the existing interactions with surface water and on infiltration/recharge conditions …
- more rainfall but shorter recharge season

→ uncertain trend for groundwater reserves

→ use of coupled/integrated models

Outline

- *Coupled and integrated modelling*
  - *general principles*
  - *soil model*
  - *groundwater model*
  - *surface water model*
  - *integration and coupling*
- *Example in Walloon Region of Belgium: Geer basin*
  - *groundwater model: construction, calibration, validation*
  - *results of the integrated model*
- *Climatic scenarios and chosen assumptions*
- *Results in terms of groundwater reserves*
- *Conclusions and challenges*

Coupled and integrated modelling

Application of a
deterministic, spatially distributed, physically-based model, …
… composed of three interacting sub-models:

→ *soil model*
→ *groundwater model*
→ *surface water model*

… linked dynamically and operated in a global structure.

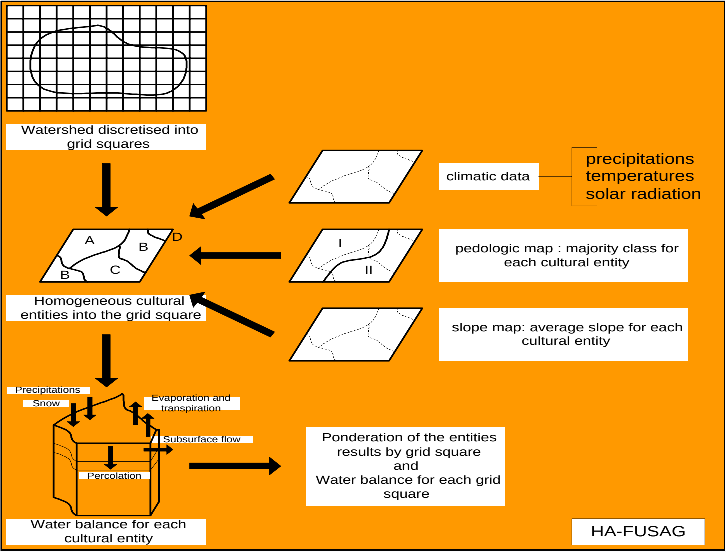
… required

→ *adaptation of the different sub-models in order to run together*

→ *construction of a meta-structure which controls all the integrated model running operations*

Coupled and integrated modelling

‘Soil model’ C. Sohier & S. Dautrebande
Hydraulique agricole, HA-FUSAGx, Gembloux, Belgium


Watershed discretised into grid squares

Homogeneous cultural entities into the grid square

climatic data
precipitations
temperatures
solar radiation

pedologic map : majority class for each cultural entity

slope map: average slope for each cultural entity

Water balance for each cultural entity

Ponderation of the entities results by grid square and Water balance for each grid square

HA-FUSAG

Reference: Sohier C., Moeremans B., Deglin D. and Dautrebande S., 2000, Validation of the new catchment hydrological model EPIC-GRID for soil moisture evaluation and discharges simulation. Presented at the Workshop “The future of distributed hydrological modelling”, Leuven, Belgium, April 2000.

Coupled and integrated modelling

‘Groundwater model’

Hydrogeology Group, GeomaC Dpt , Faculty of Engineering, ULg

SUFT3D (Saturated Unsaturated Flow and Transport in 3D)
is a finite-element code,
- for modelling of the unsaturated and saturated zones in 3D;
- allowing local mesh refinements depending on local geological characteristics;
- seawater intrusions;
- realistic tracer injection conditions;
- data and results processing by GMS © and full GIS compatibility

References:
- Brouyère S., 2003, Modeling tracer injection and well-aquifer interactions: a new mathematical and numerical approach, Water Resources Research 39(3), 1070, doi:10.1029/2002WR001813
- Carabin, G., Dassargues A., 1999, Modeling groundwater with ocean and river interaction, Water Resources Research, 35(8), 2347-2358.
- Carabin G., Dassargues A. and Brouyère S., 1998, 3D flow and transport groundwater modelling including river interactions, in Computational Methods in Water Resources XII, Vol. 1: , pp. 569 - 576.

Coupled and integrated modelling

‘River Model’

J-F. Deliège & J. Smitz
Environment Centre (CEME), ULg

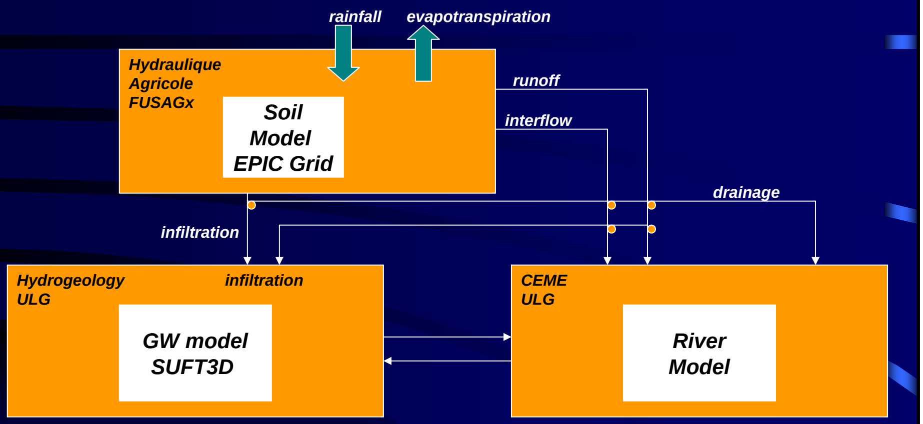
River model
sub-model simulates water dynamics
in the river network, as the result of input of
water fluxes from the soils and of transfers
water fluxes from / to the groundwater
based on Saint-Venant equations (mass and momentum balances)
in a one-dimensional channel.

… the surface water sub-model is applied to the entire river network, including the main river and its tributaries.
The channel characteristics (slopes, sections, widths, roughness, …) are determined during the pre-processing operations.

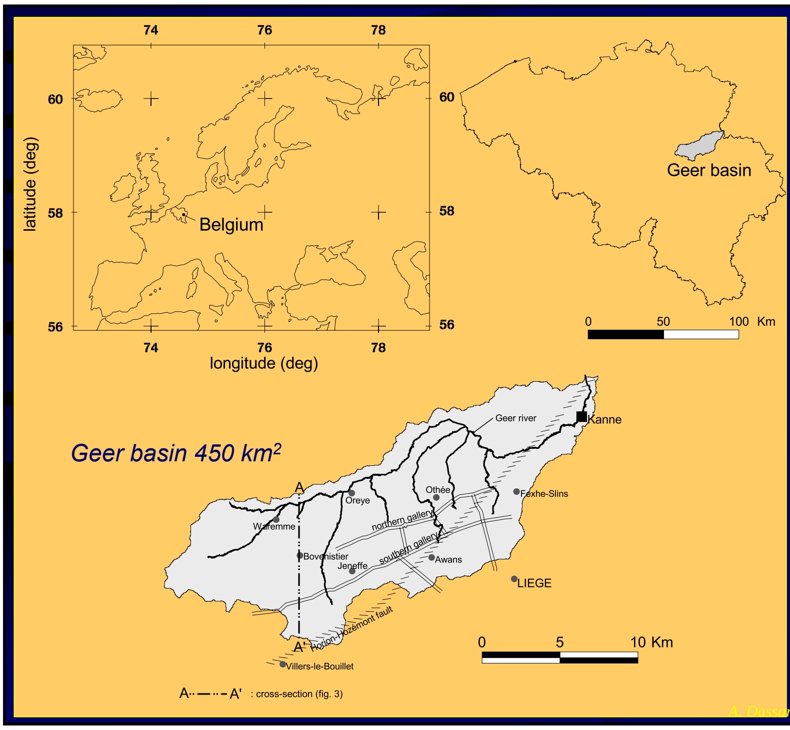
Reference:
- Smitz, J., Everbecq, E., Deliège, J.-F., Descy, J.-P., Wollast, R. and Vanderborght. J.-P., 1997, PEGASE, une méthodologie et un outil de simulation prévisionnelle pour la gestion de la qualité des eaux de surface (PEGASE : a methodology and a forecasting simulation tool for surface water quality management). Tribune de l'Eau. 588, 73-82

Coupled and integrated modelling

Simplified general schema … for water quantity



- models are implemented in a parallel processing environment
- data exchange protocol MPI



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Geer basin : hydrology et hydrogeology

$P \;\; = ETR + Q_{GEER} + Q_{OUT} + \Delta_{Reserves} + \Delta_{Losses}$

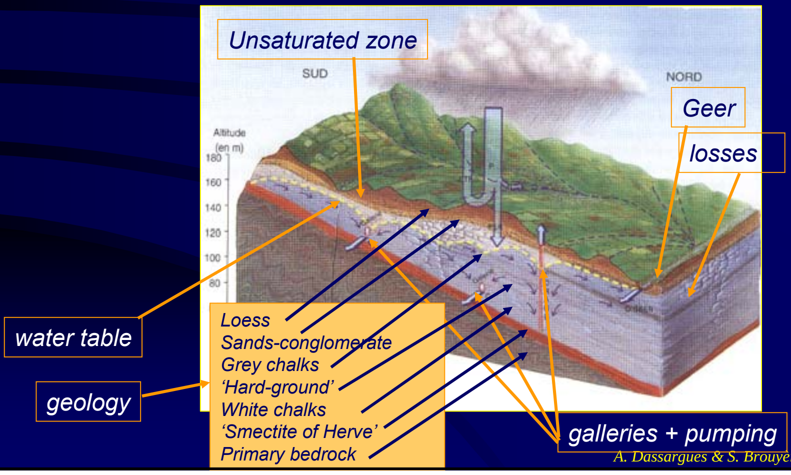
810 = 508 + 145 + 88 + 7.5 + 61.5 mm

(between 1975 and 1994, after Hallet, 1999)

740 = 525 + 120 + 65 + 15 + 15 mm

(between 1951 and 1965, after Monjoie, 1965)

Geer basin 450 km²



Unsaturated zone

Geer

losses

water table

geology

Loess
Sands-conglomerate
Grey chalks
'Hard-ground'
White chalks
'Smectite of Herve'
Primary bedrock

galleries + pumping

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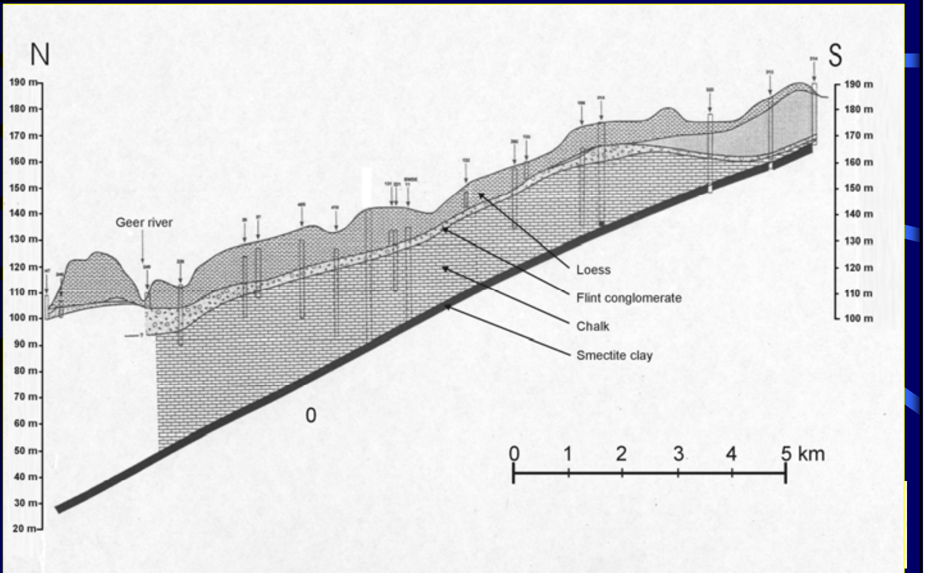
Geer basin : hydrogeology and modelling

Main characteristics



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Geer basin : hydrogeology and modelling

Main characteristics

- *piezometric fluctuations up to 15 m: ability of SUFT3D code for considering a highly variable unsaturated zone*
- *seven layers of finite elements, from bottom to top (in general) :*
  - *- three layers of chalk ;*
  - *- one layer of hardened chalk named 'hard ground'';*
  - *- one layer of fractured chalk;*
  - *- one layer of conglomerate / residual sands;*
  - *- one layer of loess.*
- *the 'hardground' is not found in the whole domain;*
- *the conglomerate is replaced northwards by sands;*
- *the thickness of the unsaturated zone can reach 40 m and, when piezometric levels are varying only in the chalk, in this case the 7 layers of finite elements are in the chalk;*

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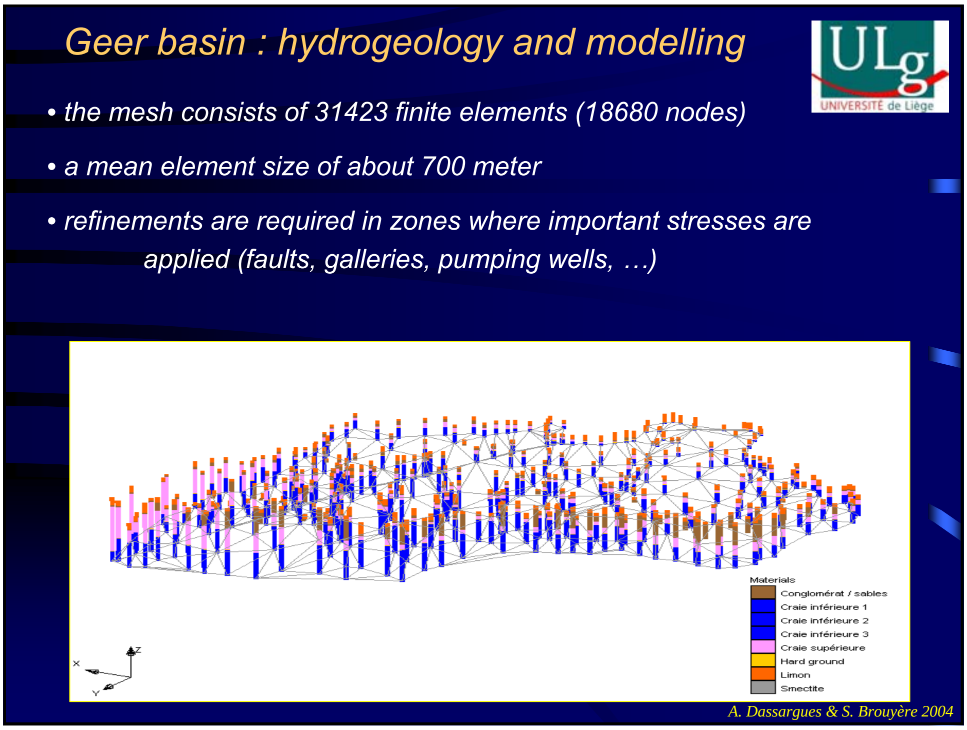

Geer basin : hydrogeology and modelling

- the mesh consists of 31423 finite elements (18680 nodes)
- a mean element size of about 700 meter
- refinements are required in zones where important stresses are applied (faults, galleries, pumping wells, …)

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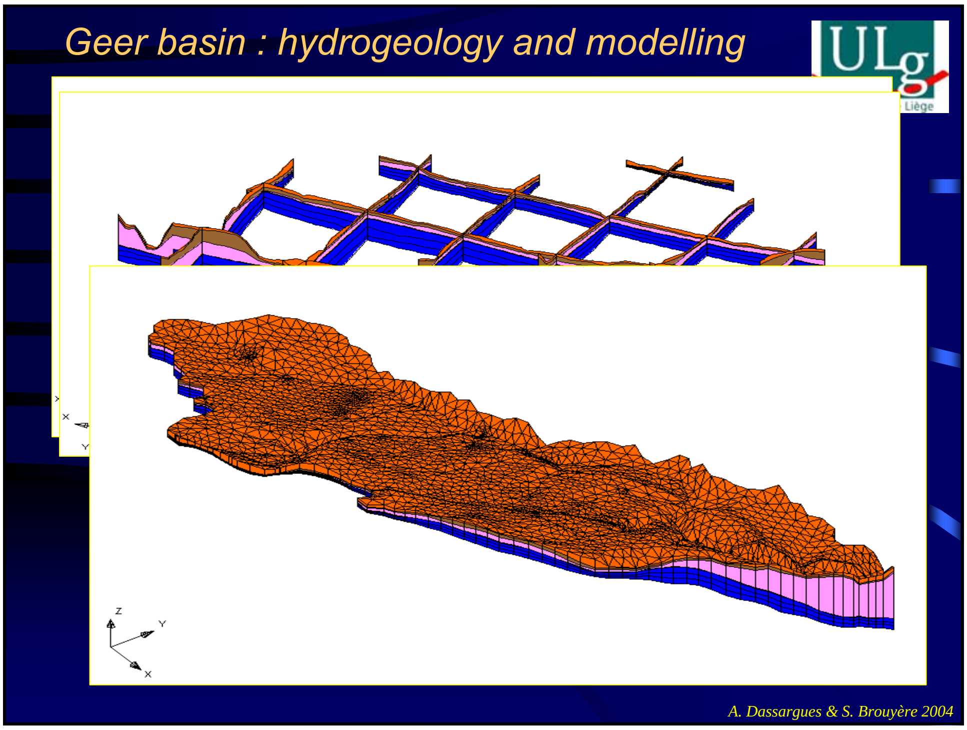

Geer basin : hydrogeology and modelling

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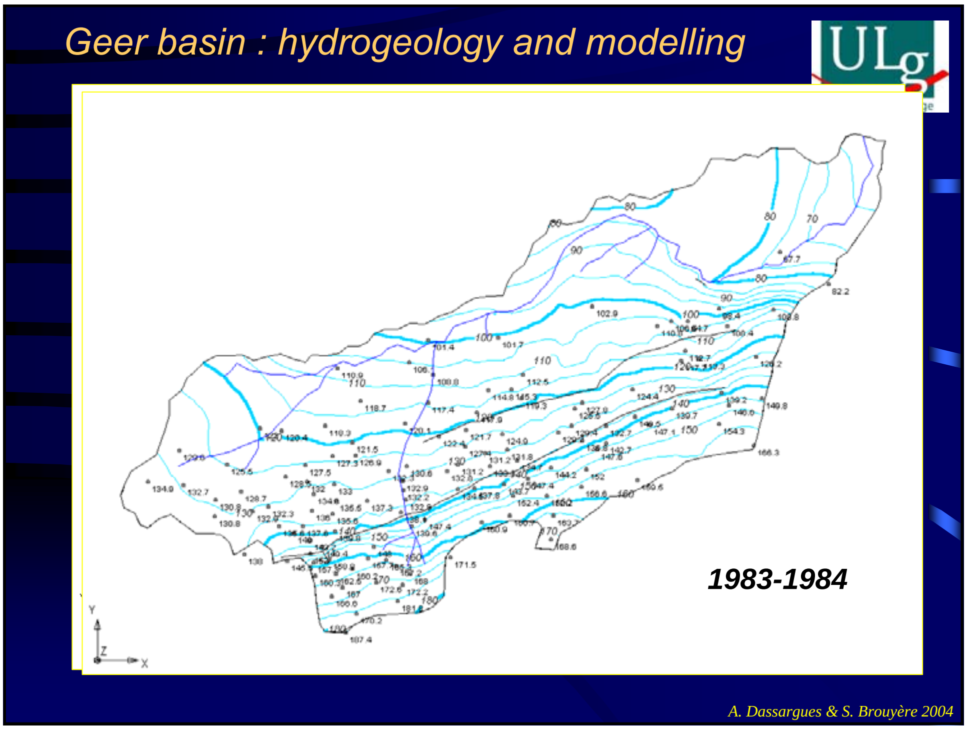

Geer basin : hydrogeology and modelling

1983-1984

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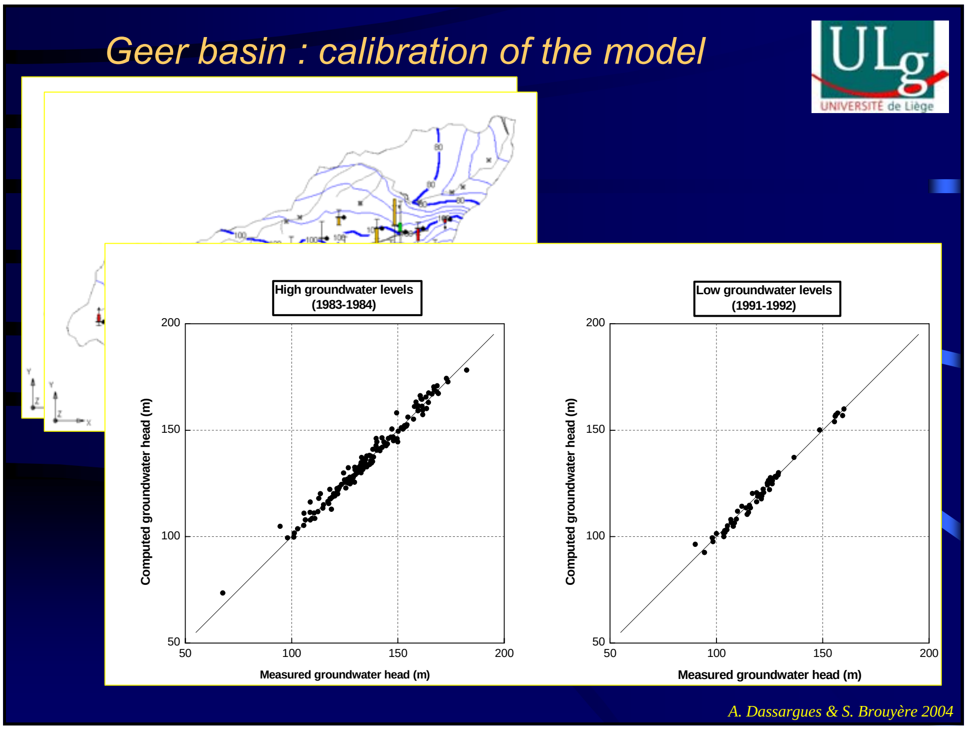

Geer basin : calibration of the model

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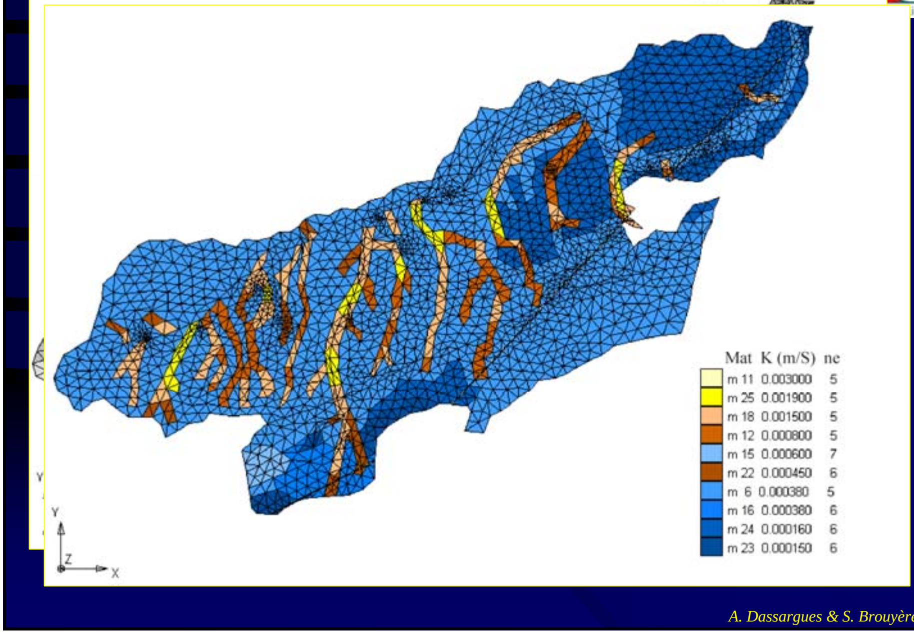
Geer basin : calibration of the model



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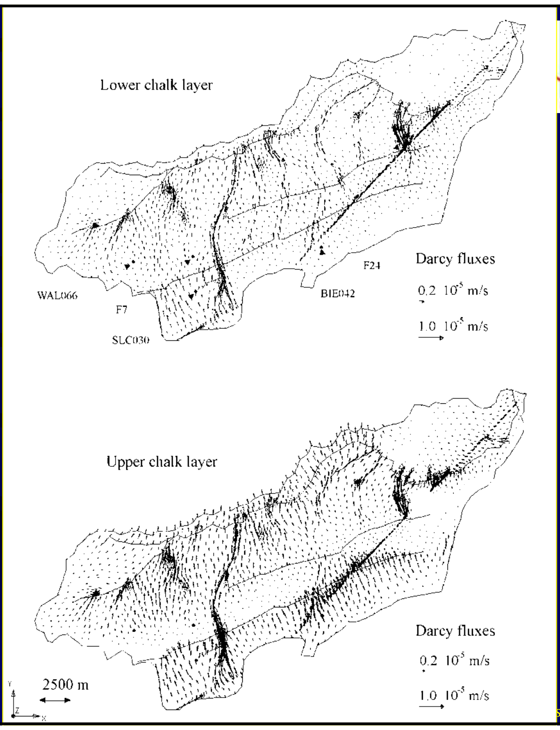
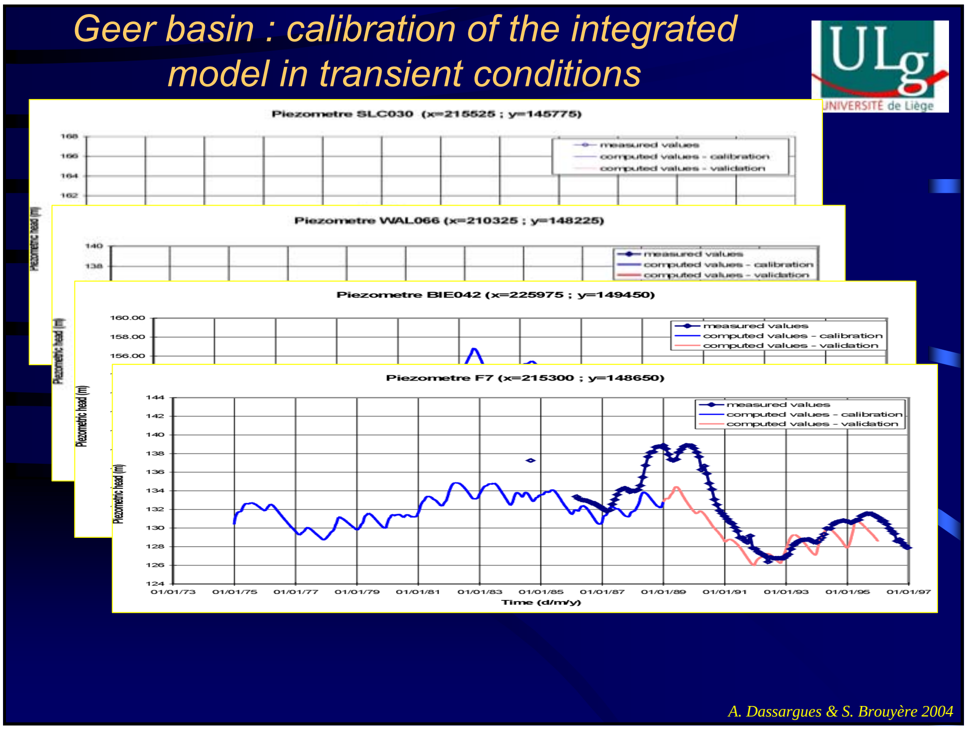
Calculated Darcy's fluxes



s & S. Brouyère 2004



Geer basin : calibration of the integrated model in transient conditions

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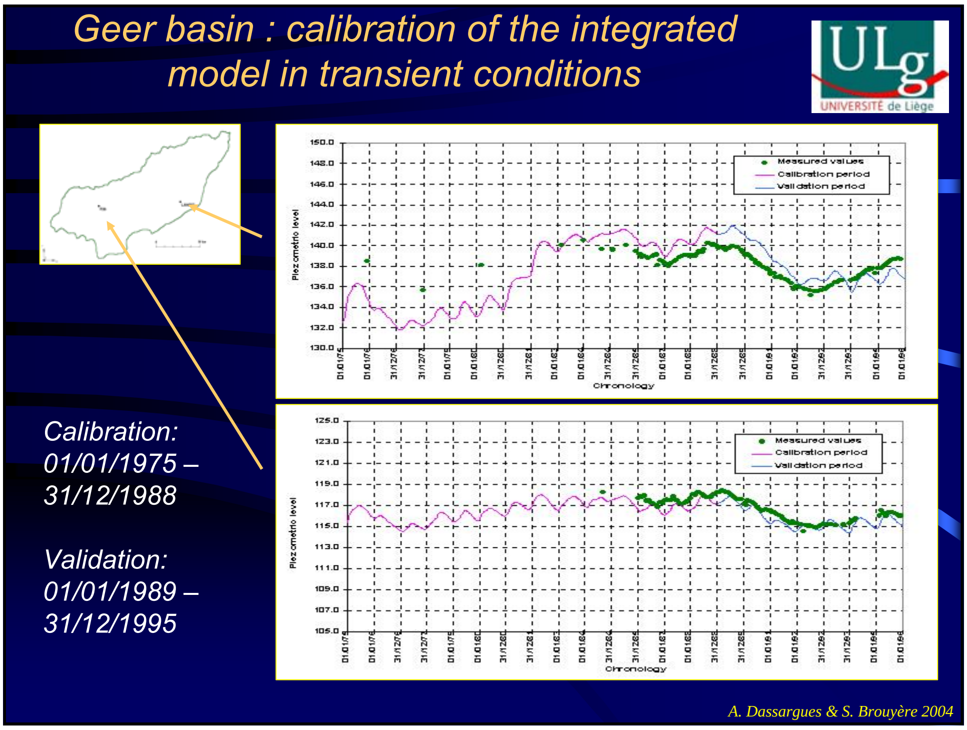
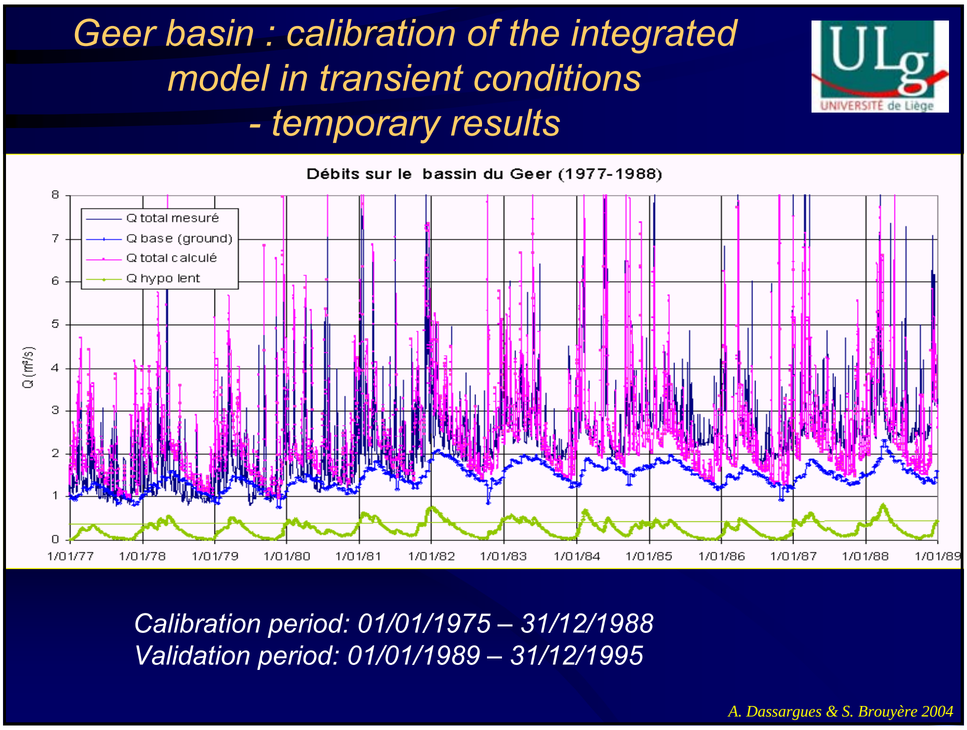


Geer basin : calibration of the integrated model in transient conditions

Calibration:
01/01/1975 –
31/12/1988

Validation:
01/01/1989 –
31/12/1995



Geer basin : calibration of the integrated model in transient conditions - temporary results

Calibration period: 01/01/1975 – 31/12/1988
Validation period: 01/01/1989 – 31/12/1995

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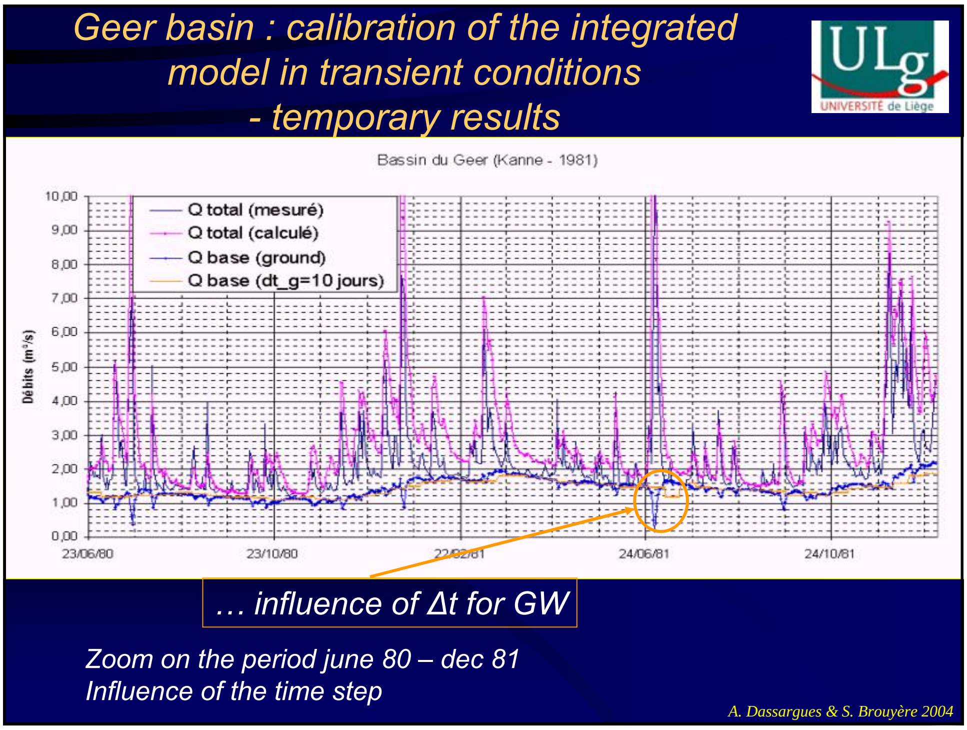

Geer basin : calibration of the integrated model in transient conditions - temporary results

… influence of Δt for GW

Zoom on the period june 80 – dec 81
Influence of the time step

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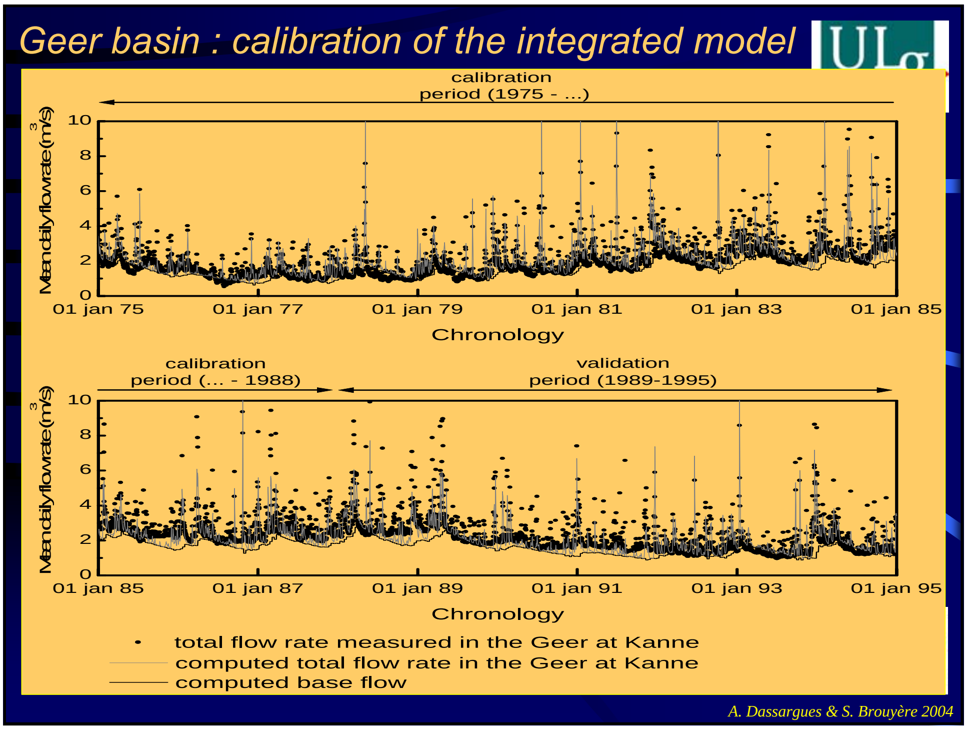

Geer basin : calibration of the integrated model

- • total flow rate measured in the Geer at Kanne
- computed total flow rate in the Geer at Kanne
- computed base flow

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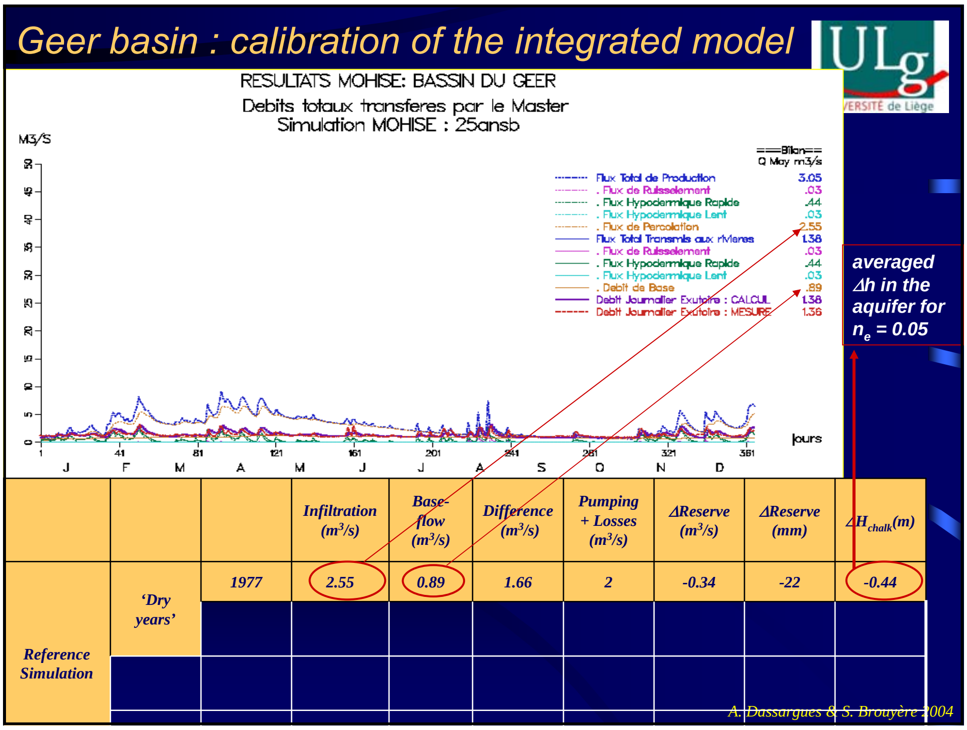

Geer basin : calibration of the integrated model

RESULTATS MOHISE: BASSIN DU GEER
Debits totaux transferes par le Master
Simulation MOHISE : 25ansb

===Bilan== Q Moy m3/s	
Flux Total de Production	3.05
. Flux de Ruisselement	.03
. Flux Hypodermique Rapide	.44
. Flux Hypodermique Lent	.03
. Flux de Percolation	2.55
Flux Total Transmis aux rivieres	1.38
. Flux de Ruisselement	.03
. Flux Hypodermique Rapide	.44
. Flux Hypodermique Lent	.03
. Debit de Base	.89
Debit Journalier Exutoire : CALCUL	1.38
Debit Journalier Exutoire : MESURE	1.36

averaged Δh in the aquifer for $n_e = 0.05$

			Infiltration (m^3/s)	Base-flow (m^3/s)	Difference (m^3/s)	Pumping + Losses (m^3/s)	ΔReserve (m^3/s)	ΔReserve (mm)	ΔH_{chalk}(m)
Reference Simulation	'Dry years'	1977	2.55	0.89	1.66	2	-0.34	-22	-0.44

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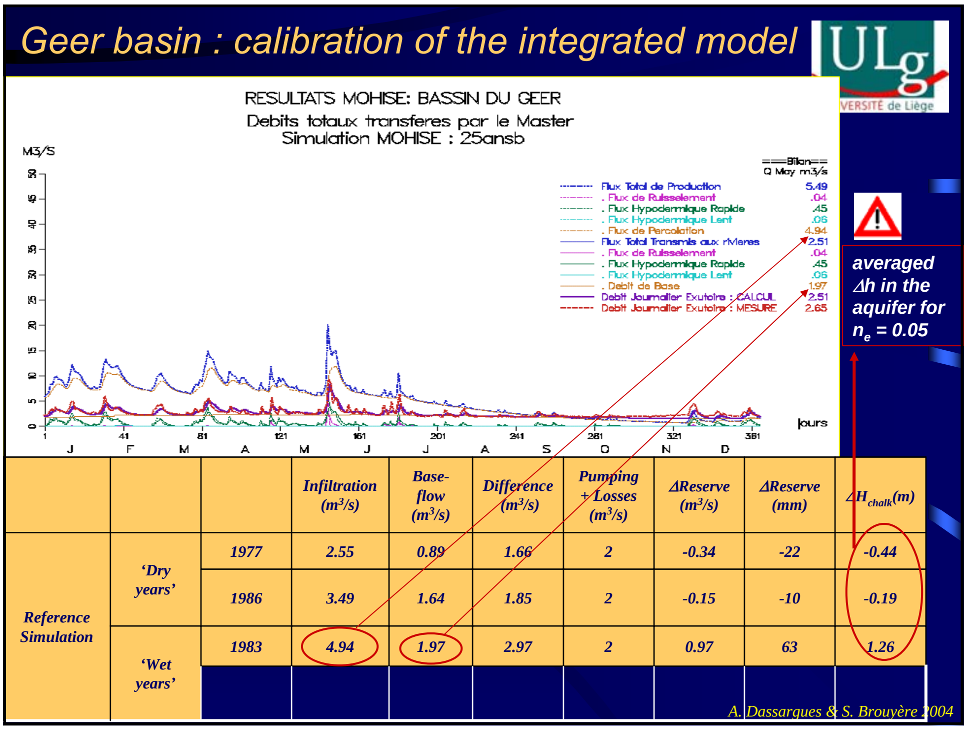

Geer basin : calibration of the integrated model

			Infiltration (m^3/s)	Base-flow (m^3/s)	Difference (m^3/s)	Pumping + Losses (m^3/s)	ΔReserve (m^3/s)	ΔReserve (mm)	ΔH_{chalk}(m)
Reference Simulation	'Dry years'	1977	2.55	0.89	1.66	2	-0.34	-22	-0.44
		1986	3.49	1.64	1.85	2	-0.15	-10	-0.19
	'Wet years'	1983	4.94	1.97	2.97	2	0.97	63	1.26

averaged Δh in the aquifer for $n_e = 0.05$

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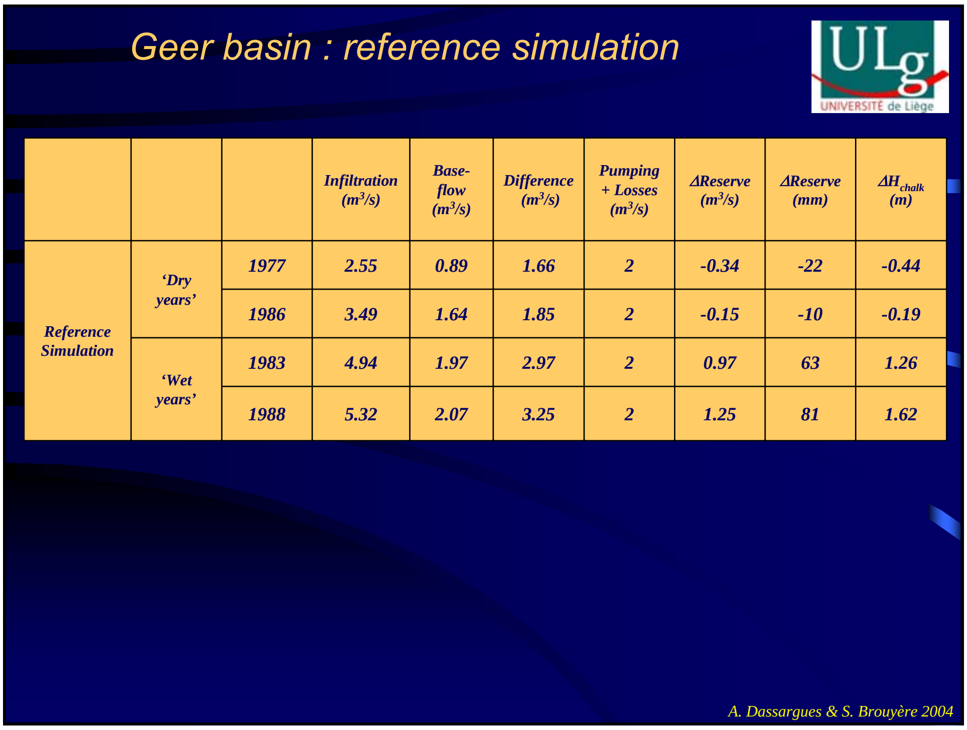

Geer basin : reference simulation

			Infiltration (m^3/s)	Base-flow (m^3/s)	Difference (m^3/s)	Pumping + Losses (m^3/s)	ΔReserve (m^3/s)	ΔReserve (mm)	ΔH_{chalk} (m)
Reference Simulation	'Dry years'	1977	2.55	0.89	1.66	2	-0.34	-22	-0.44
		1986	3.49	1.64	1.85	2	-0.15	-10	-0.19
	'Wet years'	1983	4.94	1.97	2.97	2	0.97	63	1.26
		1988	5.32	2.07	3.25	2	1.25	81	1.62

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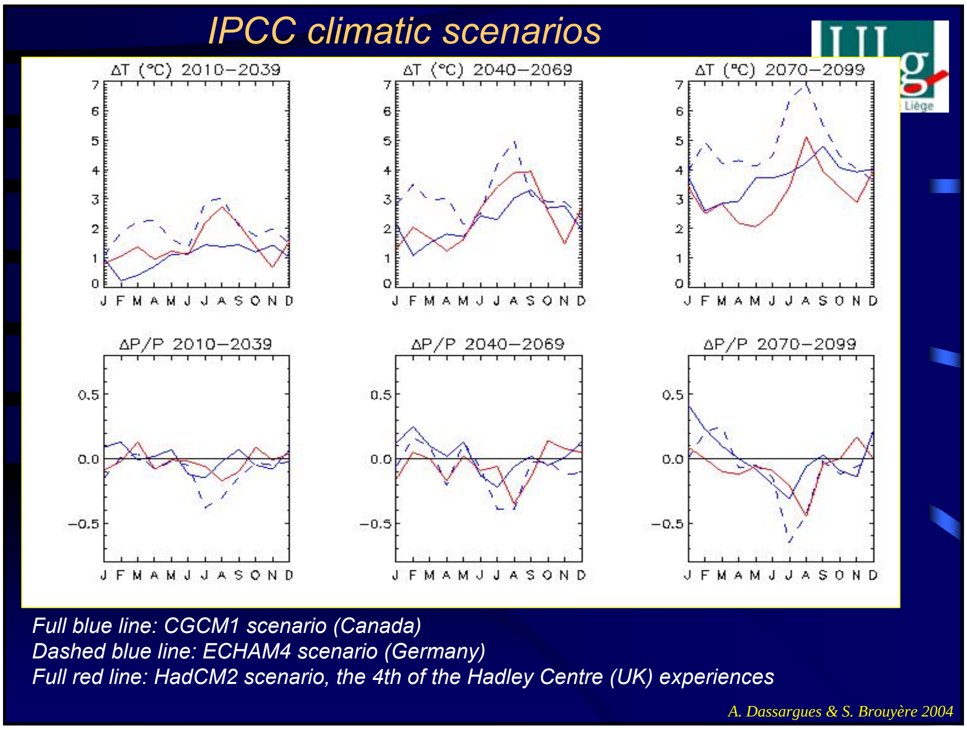

IPCC climatic scenarios

Full blue line: CGCM1 scenario (Canada)
Dashed blue line: ECHAM4 scenario (Germany)
Full red line: HadCM2 scenario, the 4th of the Hadley Centre (UK) experiences

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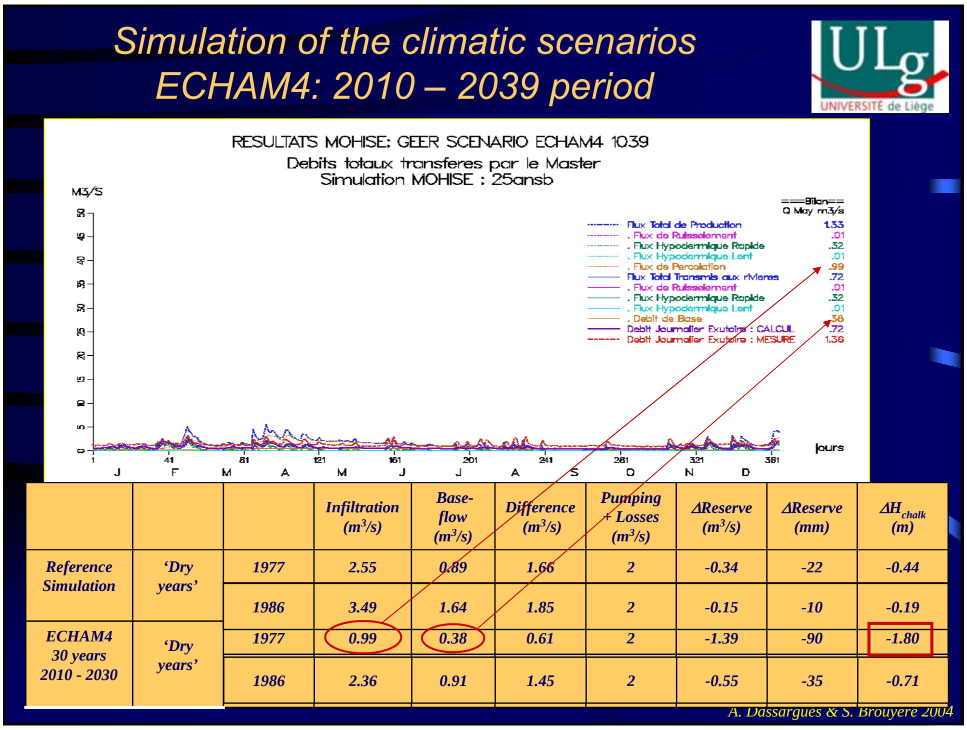

Simulation of the climatic scenarios ECHAM4: 2010 – 2039 period

			Infiltration (m^3/s)	*Base-flow (m^3/s)*	*Difference (m^3/s)*	*Pumping + Losses (m^3/s)*	*ΔReserve (m^3/s)*	*ΔReserve (mm)*	*ΔH_{chalk} (m)*
Reference Simulation	*'Dry years'*	*1977*	*2.55*	*0.89*	*1.66*	*2*	*-0.34*	*-22*	*-0.44*
		1986	*3.49*	*1.64*	*1.85*	*2*	*-0.15*	*-10*	*-0.19*
ECHAM4 30 years 2010 - 2030	*'Dry years'*	*1977*	*0.99*	*0.38*	*0.61*	*2*	*-1.39*	*-90*	*-1.80*
		1986	*2.36*	*0.91*	*1.45*	*2*	*-0.55*	*-35*	*-0.71*

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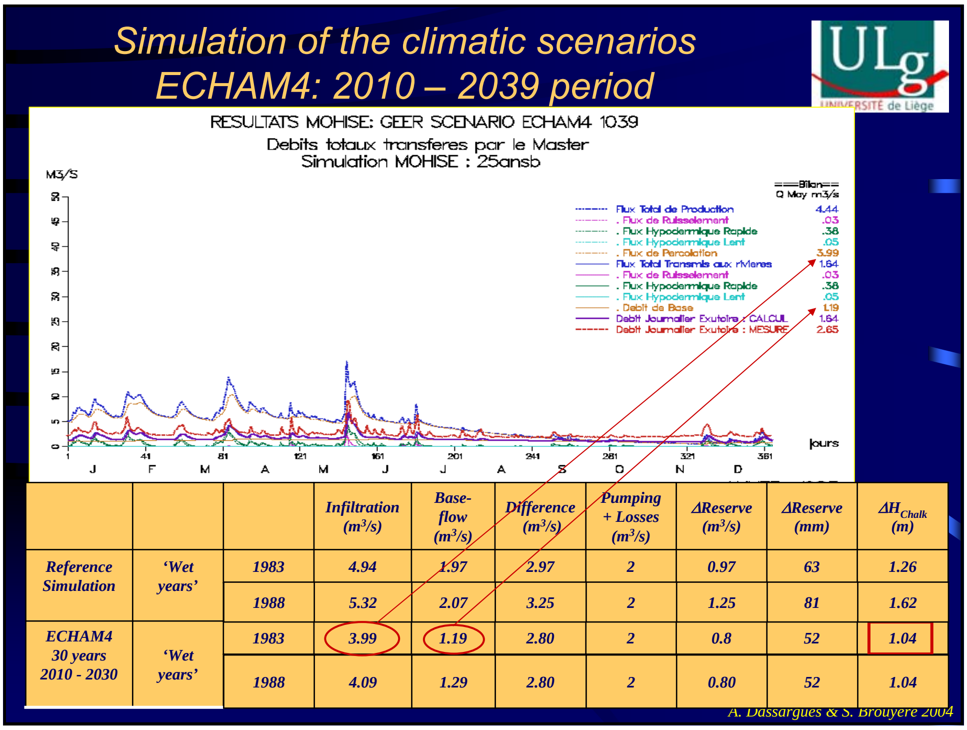

Simulation of the climatic scenarios ECHAM4: 2010 – 2039 period

			Infiltration (m^3/s)	Base-flow (m^3/s)	Difference (m^3/s)	Pumping + Losses (m^3/s)	ΔReserve (m^3/s)	ΔReserve (mm)	ΔH_{Chalk} (m)
Reference Simulation	*'Wet years'*	*1983*	*4.94*	*1.97*	*2.97*	*2*	*0.97*	*63*	*1.26*
		1988	*5.32*	*2.07*	*3.25*	*2*	*1.25*	*81*	*1.62*
ECHAM4 30 years 2010 - 2030	*'Wet years'*	*1983*	*3.99*	*1.19*	*2.80*	*2*	*0.8*	*52*	*1.04*
		1988	*4.09*	*1.29*	*2.80*	*2*	*0.80*	*52*	*1.04*

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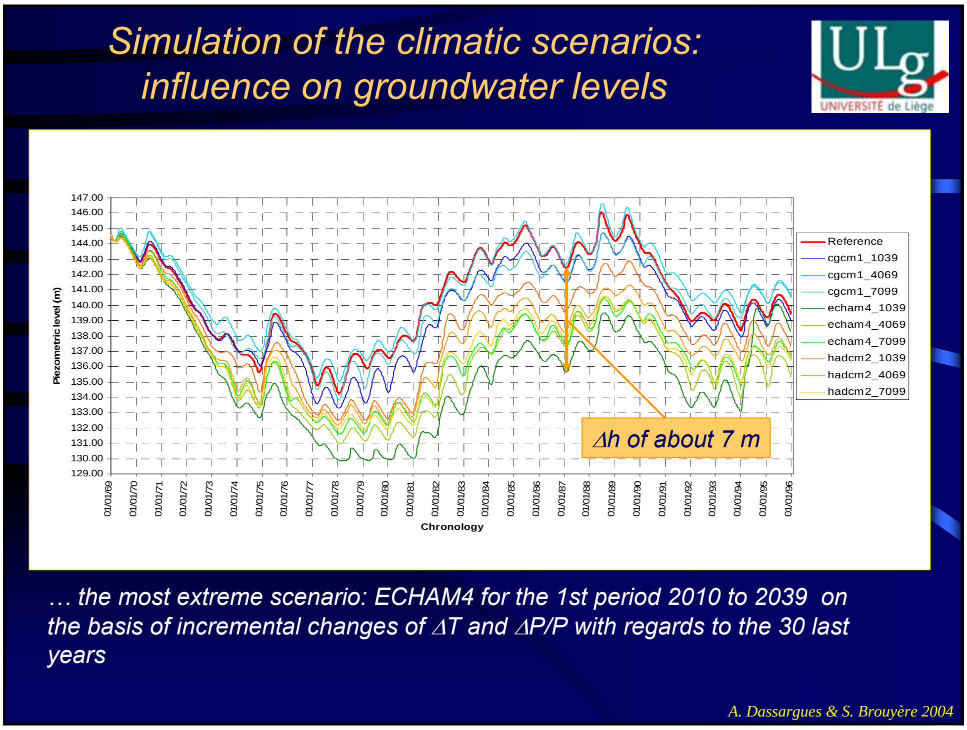


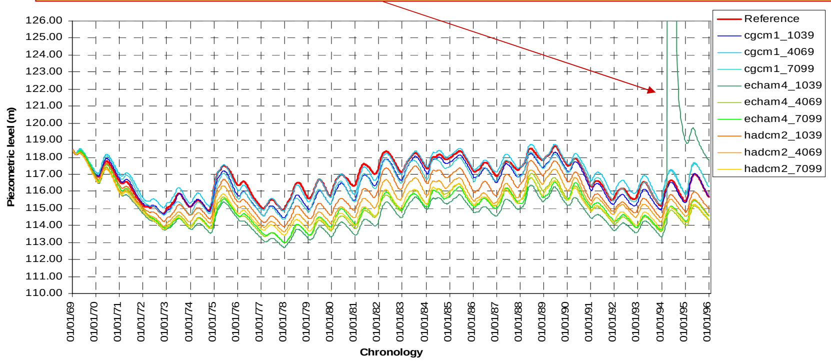
Simulation of the climatic scenarios: influence on groundwater levels

… the most extreme scenario: ECHAM4 for the 1st period 2010 to 2039 on the basis of incremental changes of ΔT and $\Delta P/P$ with regards to the 30 last years

A. Dassargues & S. Brouyère 2004

Simulation of the climatic scenarios: influence on groundwater levels

…galleries are out of the saturated zone, … inducing numerical problems



… the most extreme scenario: ECHAM4 for the 1st period 2010 to 2039 on the basis of incremental changes of ΔT and $\Delta P/P$ with regards to the 30 last years

Conclusions

- *for reliable and detailed predictions … 'physically consistent' and 'spatially distributed' simulations ;*
- *the impact of climate changes on groundwater reserves is far from easy to be predicted: here, strong assumptions were chosen:*
  - *unchanged pumping;*
  - *unchanged land use;*
  - *climatic scenarios taken into account by incremental changes with regards to the situation of now;*
  - *scenarios uncertainty is not taken into account;*
- *trends are showing deficits: bad news because it will be probably worst with the introduction of increasing irrigation and introduction of the more frequent climatic extremes, etc.*
- *what about impact on the groundwater quality ?*

➡ *still a lot of work and lot of challenges !*

Thank you

Credits

- S. Brouyère & G. Carabin, Hydrogéologie et Géologie de l'Environnement, Dpt GéomaC, ULg
- C. Sohier & S. Dautrebande, Hydraulique agricole, HA-FUSAGx, Gembloux
- J-F. Deliège & J. Smitz Centre Environnement (CEME-ULg)

More details in

Brouyère, S., Carabin, G. and Dassargues, A., 2004, Climate change impacts on groundwater reserves: modelled deficits in a chalky aquifer, Geer basin, Belgium, Hydrogeology Journal, DOI 10.1007/s10040-003-0293-1, 12(2), pp.123-134

A. Dassargues & S. Brouyère 2004