Université Mohammed V
Ecole Mohammadia
d'Ingénieurs Rabat

WSTA 12th Gulf Water
Conference
28 - 30 March 2017

Modeling the Impact of Climate Change on Groundwater Resources in Arid and semi-Arid Areas

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***WSTA 12th Gulf Water Conference, Bahrain**, 28-30 March 2017*

OVERVIEW

- Introduction
- Climate Change (CC) Analysis
- Trends of CC in Morocco
- Modeling the Impacts of CC on Groundwater Resources (Downscaling and future projections)
- Coupling CC models with Classical Modeling
- Case Studies.

INTRODUCTION

Key Elements for Decision Makers in Water Resources to build Strategies

- Water Budget based on Input and Output.
- These Input/Output are assessed based on physical parameters (stochastic/deterministic): P, T, Sea Level fluctuations…
- Due to Climate Change (CC), the mean values of these parameters are varying in time and space.
- Need to recalculate the Water Budget to assess the impact of CC for better Planning and Optimal Management.

Problems and Chalenges for the Coastal Water Resources and Oasis Systems

- Dense Population installed in the coastal zones very close to rivers and seas;

- Available water resources are overexploited, including surface water & groundwater;

- High risk of Floods & Pollution from upstream

- Seawater intrusion in the coastal aquifers,

- Soil salinization,

- Climate Change: Tincrease, P, ETR, Sea Level Rise

- Abandoned Farms and rural population

The MAGHREB-MEDITERRANEAN REGION

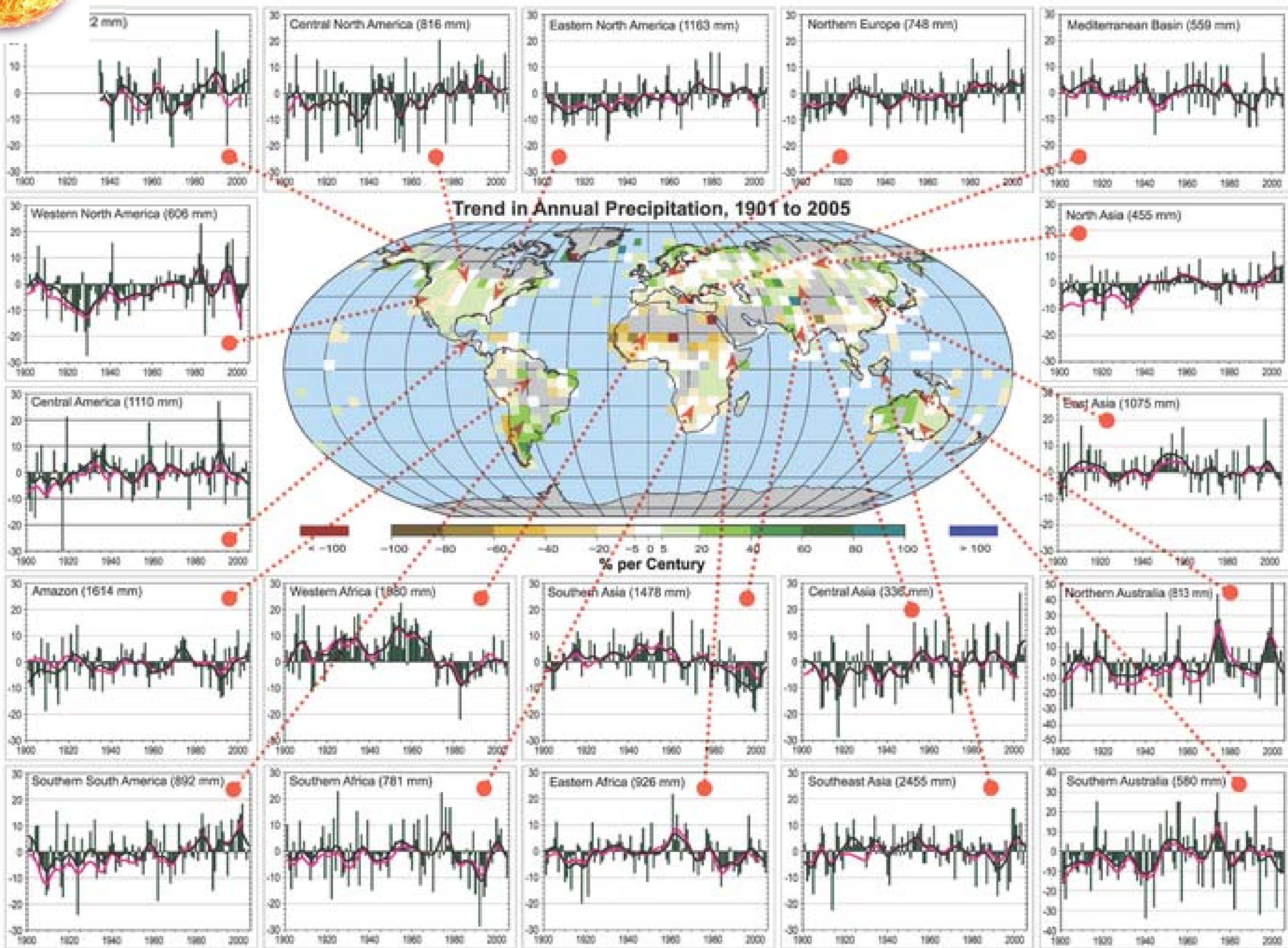
Challenges

- This region is more sensitive to climate change extremes. The coastal sites share common water management problems due to their overexploitation, fresh water pollution, sea level rise, seawater intrusion and land losses.

- Increased complexity of policy making in the Maghreb sites presents an ongoing challenge to managers.

- The main objective is to identify & quantify the impacts of climate change on water resources in coastal zones/oases, and how they imply, in turn, socio-economic vulnerability and sustainable development.

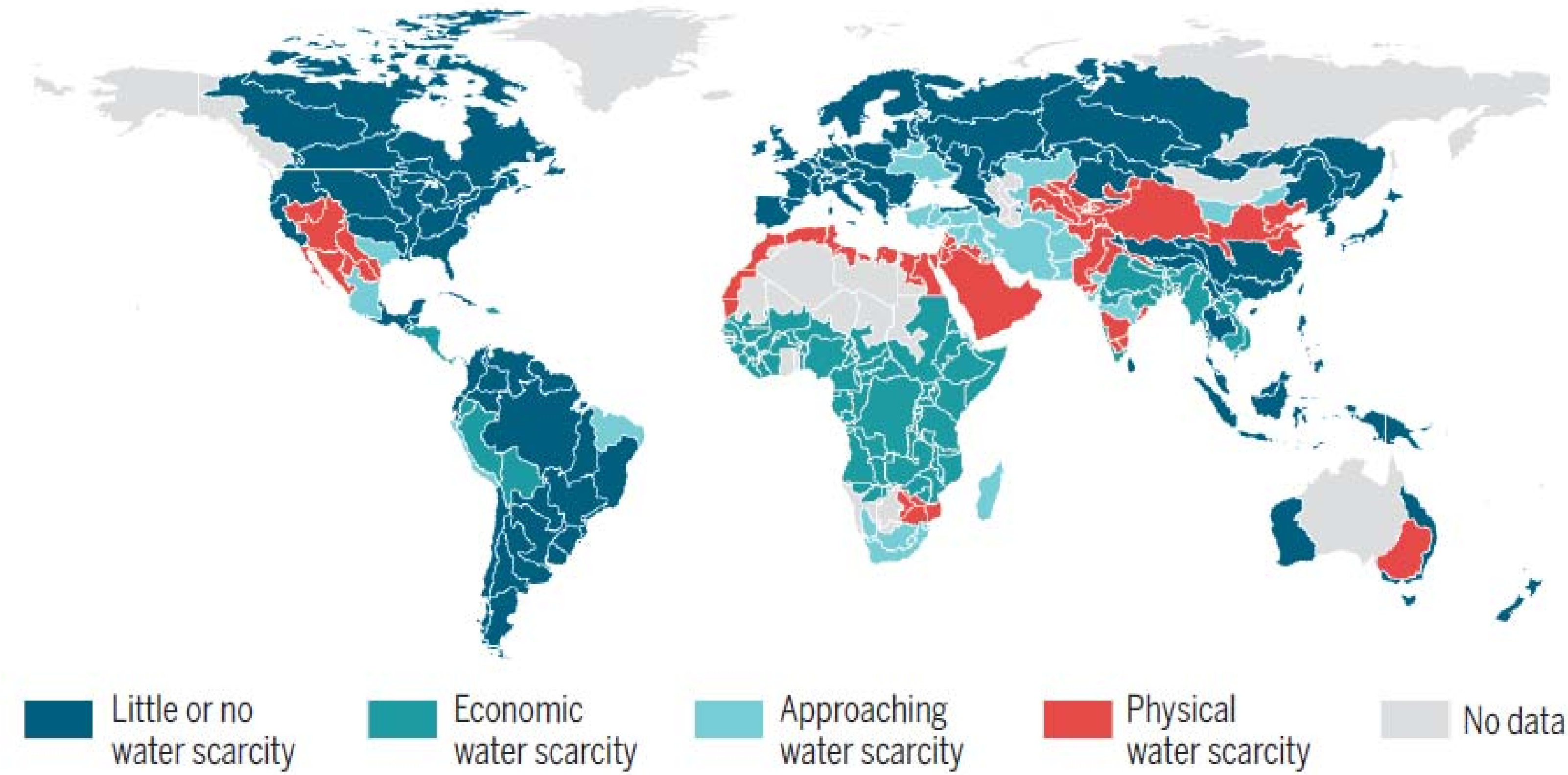
Observed Climatic Variations



Source: IPCC AR4

Water Scarcity Areas

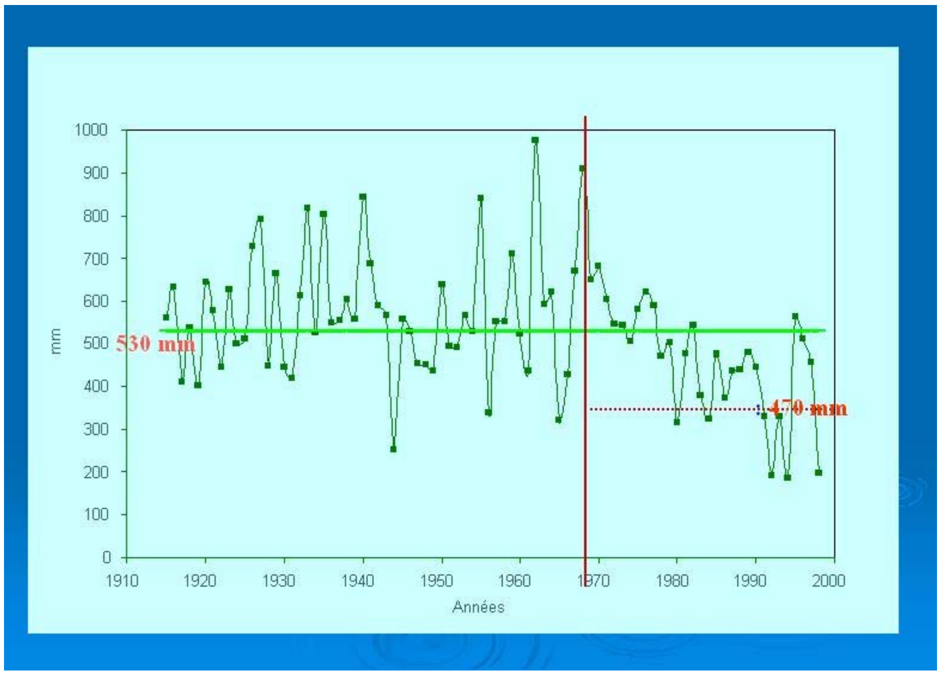
Maghreb belongs to the most important physical water resources scarcity area in the world, due to arid and semi-arid conditions

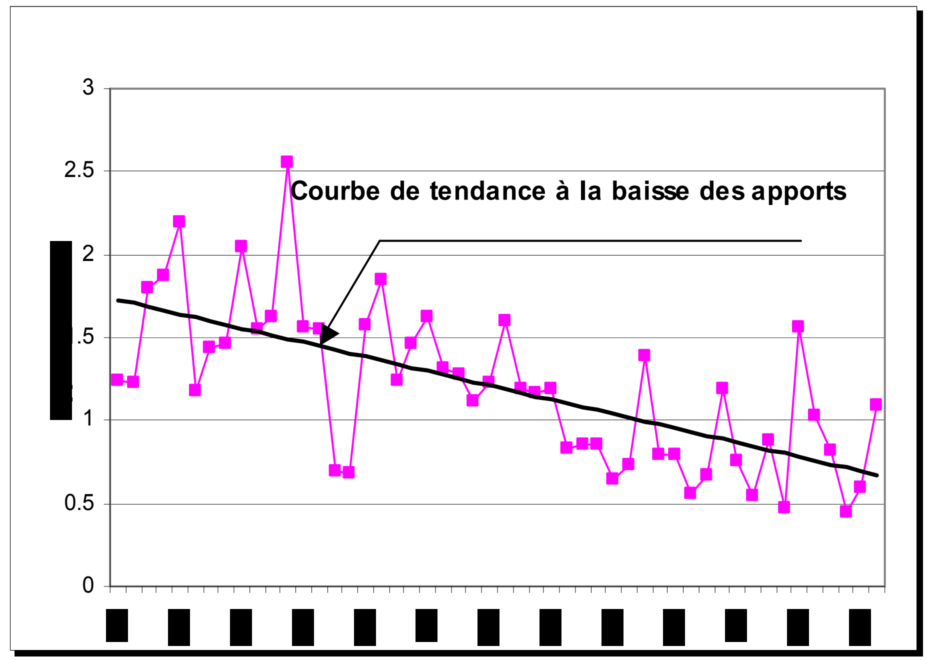


Areas of physical and economic water scarcity in the world.

CLIMATE CHANGE: a Local Reality?

Rainfall -Ifrane (Atlas Mountans)





Source : DRPE

Trends of Climate Change in Morocco :

Statistical downscaling of precipitation for a region covering the western parts of Northern Africa shows rainfall increases in December/January of up to about 60 mm in the period 2071-2100 compared to the time period 1990-2019.

The results are based on assessments of precipitation changes under the ***SRES B2 scenario*** assumptions using a statistical downscaling technique (canonical correlation analysis).

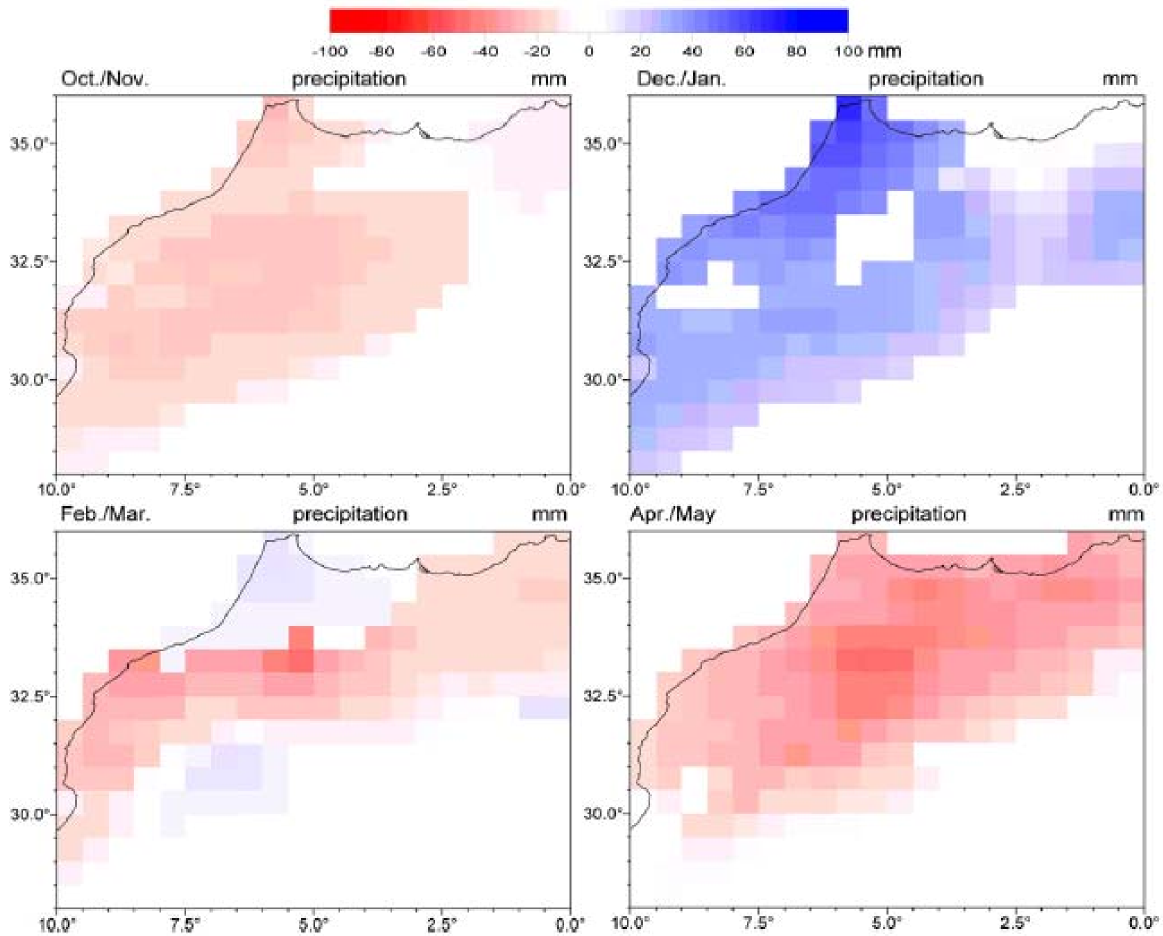


Fig. 2. Changes of Mediterranean precipitation for the main rainy season from October to May according to statistical downscaling assessments using ECHAM4/OPYC3 predictors (1000 hPa-/500 hPa- geopotential heights and 1000 hPa-specific humidity). Differences of the mean 2-month precipitation between the periods 2071–2100 and 1990–2019 in mm. Statistical downscaling technique: canonical correlation analysis. Scenario: SRES-B2.

Source : Schilling J. et al.

Case of Souss Massa Basin (1)

❖ *Rainfall variation*

The variation of rainfall is very important in **time** and **space** showing a clear decrease from the mountains to the plains and towards the desert zone in the south. The monthly values indicate a decrease over the last three decades after the most important intensity during the 1960's. The variation shows a clear seasonal irregularity.

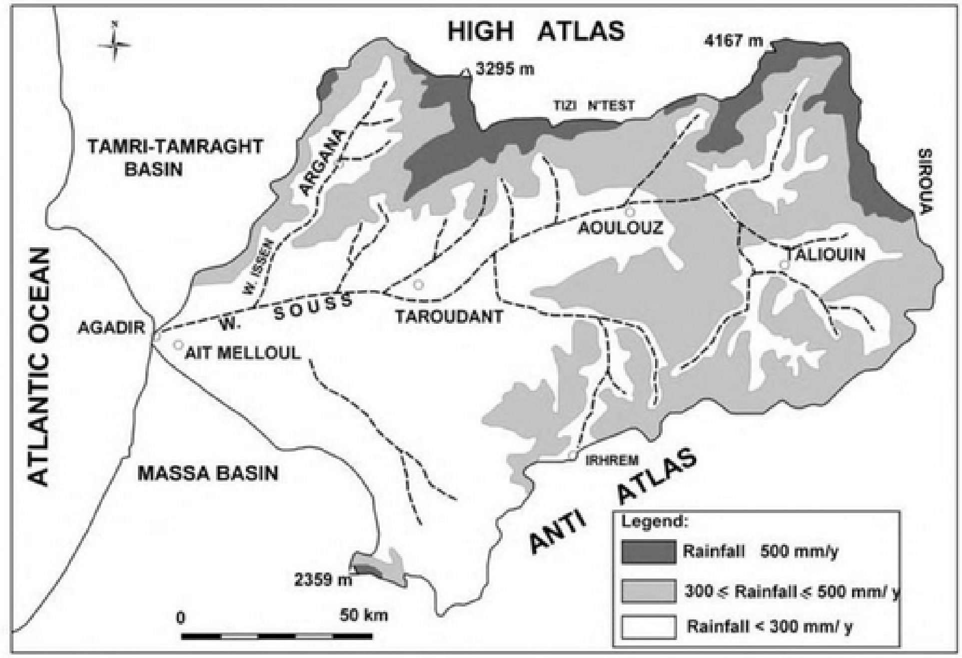


Figure 8.2. Altitude and rainfall distribution (Elmouden et al. 2005).

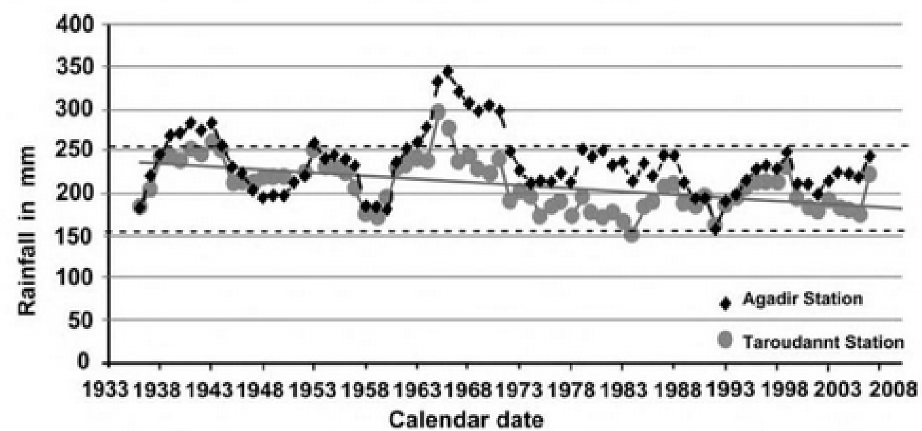


Figure 8.3. Monthly variation of precipitation in two main stations (Agadir and Taroudant) in the Souss-Massa basin.

Source : Bouchaou L.et al.

Case of Souss Massa Basin (2)

❖ ***Temperature***

The variation using 12-month moving average shows that the monthly values of the temperature indicate an increase during the last decades since the **I970's**.

The inter-annual evolution of T shows the same trend with strong increase in temperature. Mean annual temperature is plotted versus time. *The solid black line represents a locally-weighted polynomial regression using kernel smoothing*.

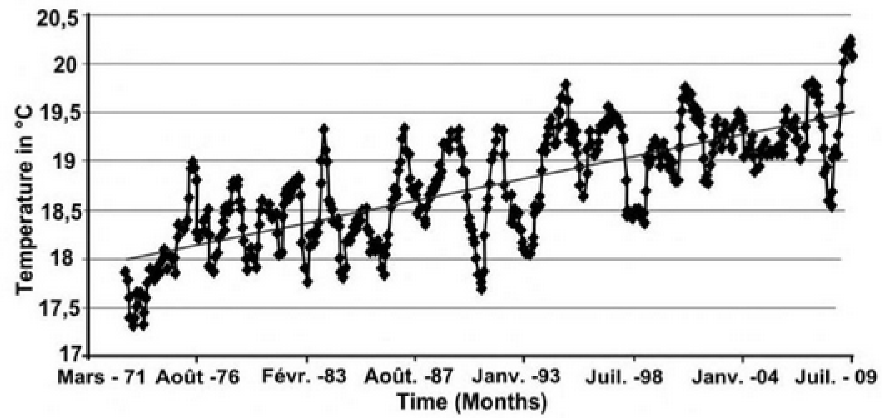


Figure 8.5. Seasonal variation of the monthly temperature in Agadir station: moving average.

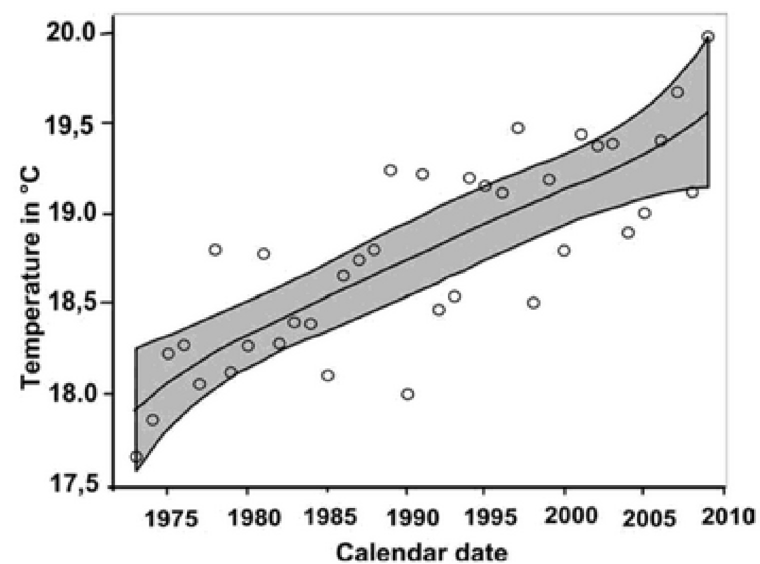


Figure 8.6. Seasonal variation of the temperature in Agadir station: inter-annual trend evolution. The solid black line represents a locally-weighted polynomial regression using kernel smoothing.

Source : Bouchaou L.et al.

Case of Souss Massa Basin (3)

❖ *Impacts on groundwater leve*

The reaction of the water table to the rainfall recharge is very variable in space and time within the basin. The major trend indicates an overall decrease in water resources, due to the combination of the natural decreased recharge and human activities (extractions). This depletion affects directly the water availability in the Souss-Massa basin.

According to water monitoring and simulation established by the hydraulic department, the scenario for the 2020 predicts a possible water crisis in the area.

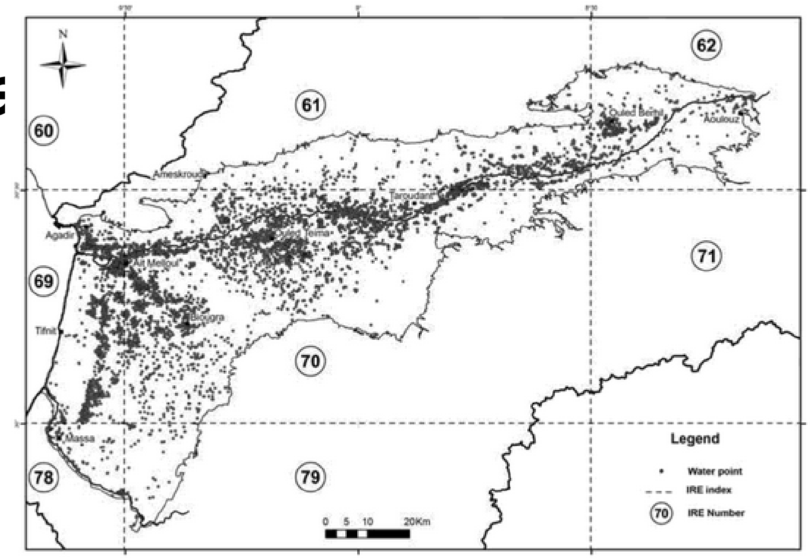


Figure 8.7. Wells and boreholes in Souss-Massa plain aquifer (more than 25,000 wells).

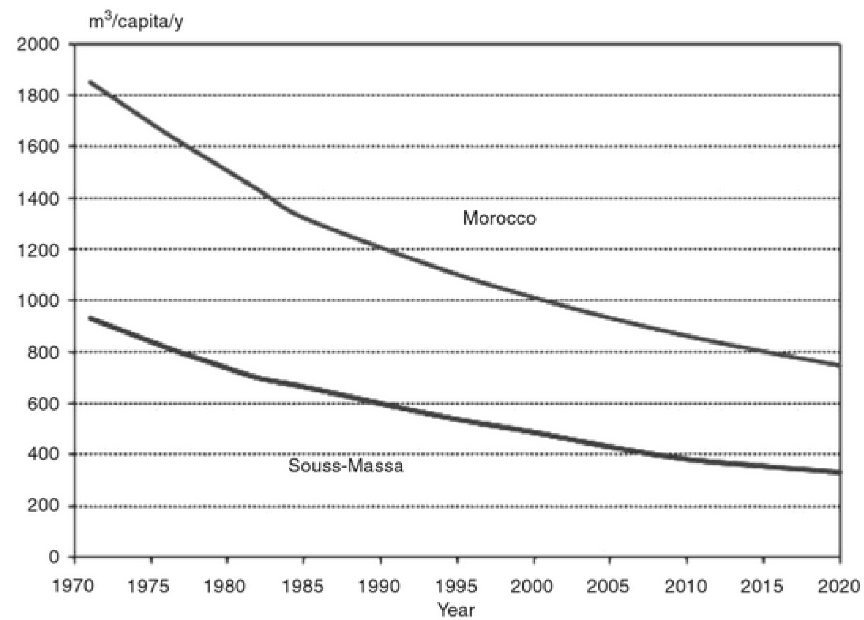


Figure 8.9. Scenarios evolution of water availability in Morocco and in Souss-Massa region (ABHSM 2008).

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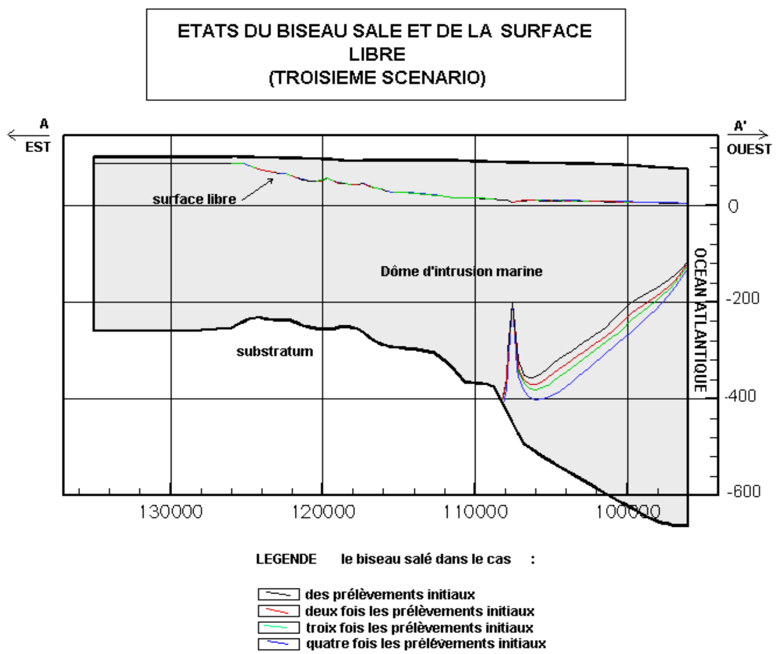
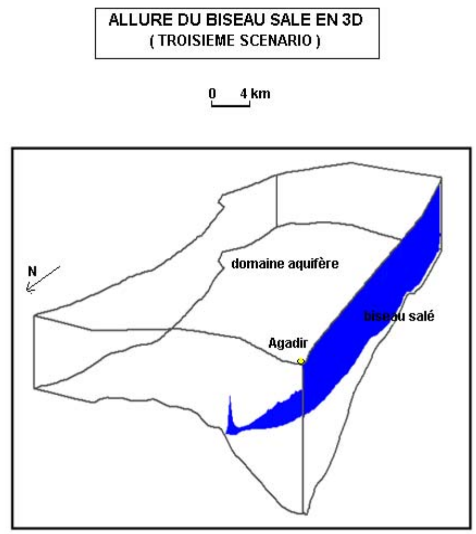
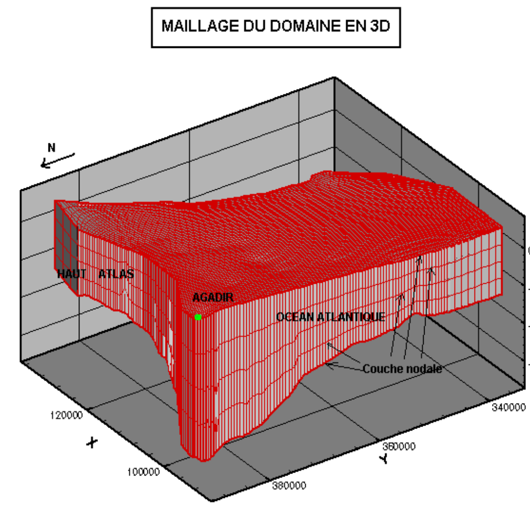
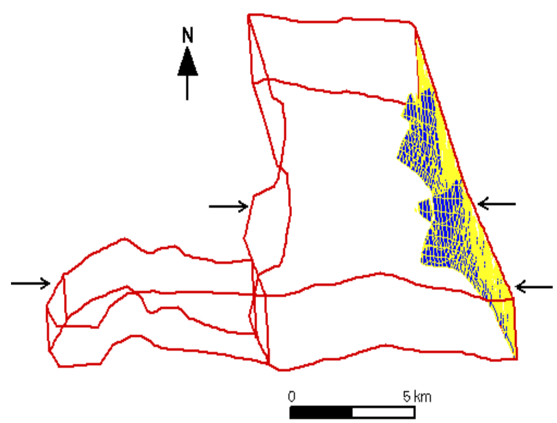
☑ Seawater intrusion in coastal aquifers (Souss and Martil aquifers)

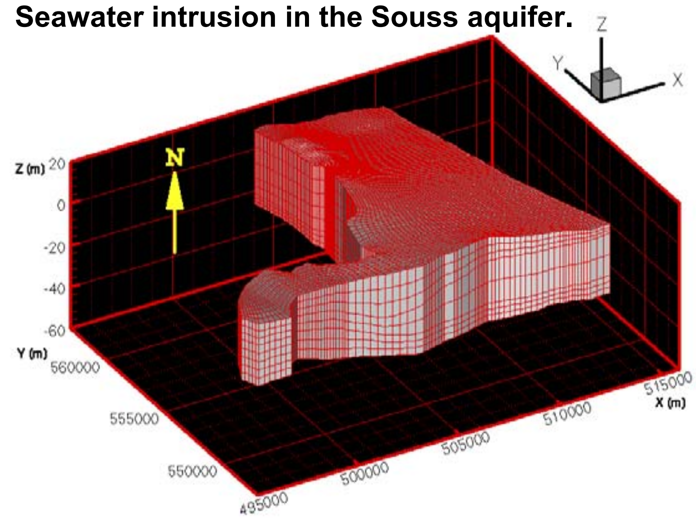






Seawater intrusion in the Souss aquifer.

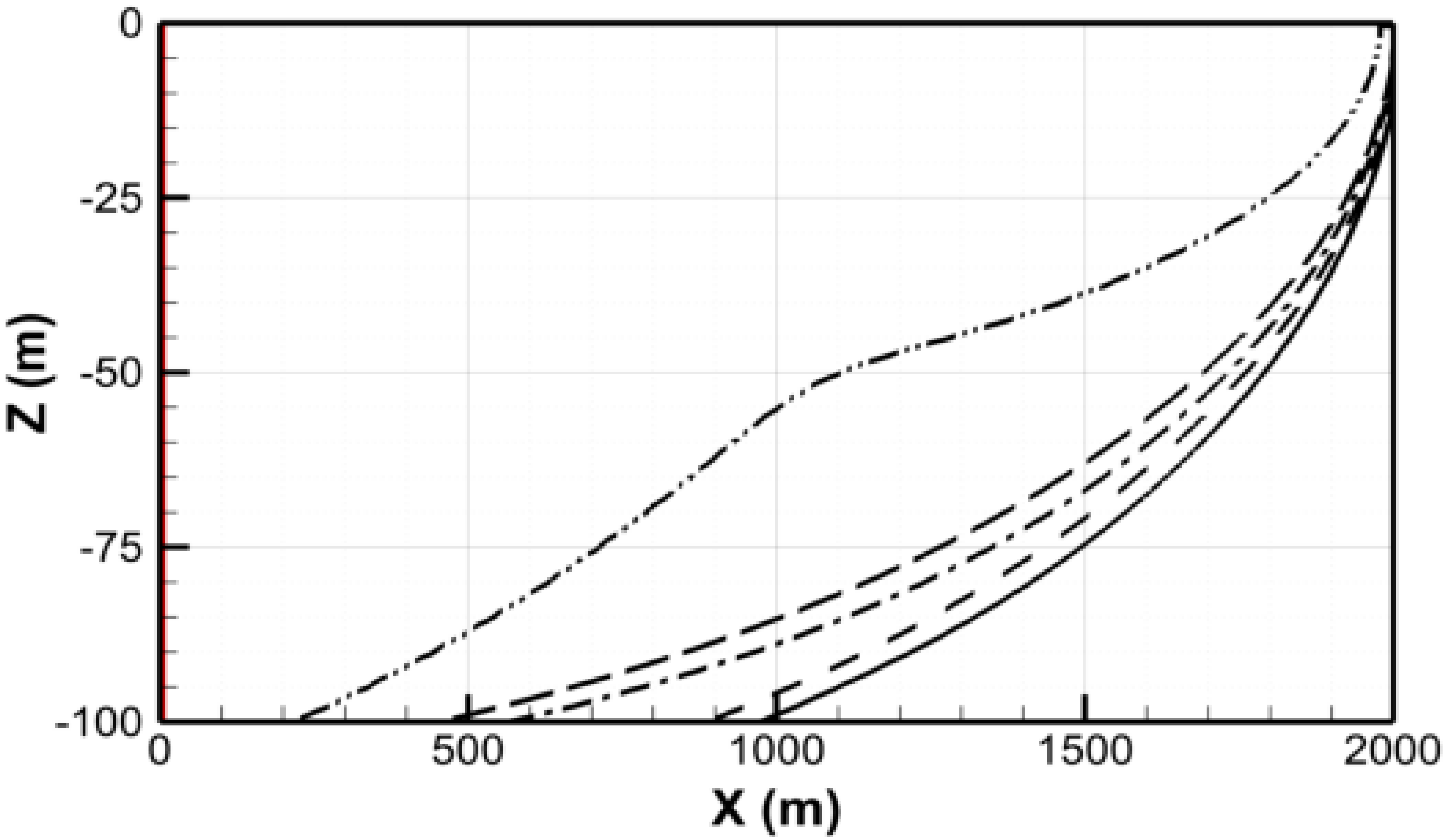




Seawater intrusion in the Martil aquifer.

Sea Level Rise due to CC and its impact

☑ Impact of CC on the Seawater intrusion interface in a hypothetical coastal aquifer: Natural conditions versus SLR and pumping?

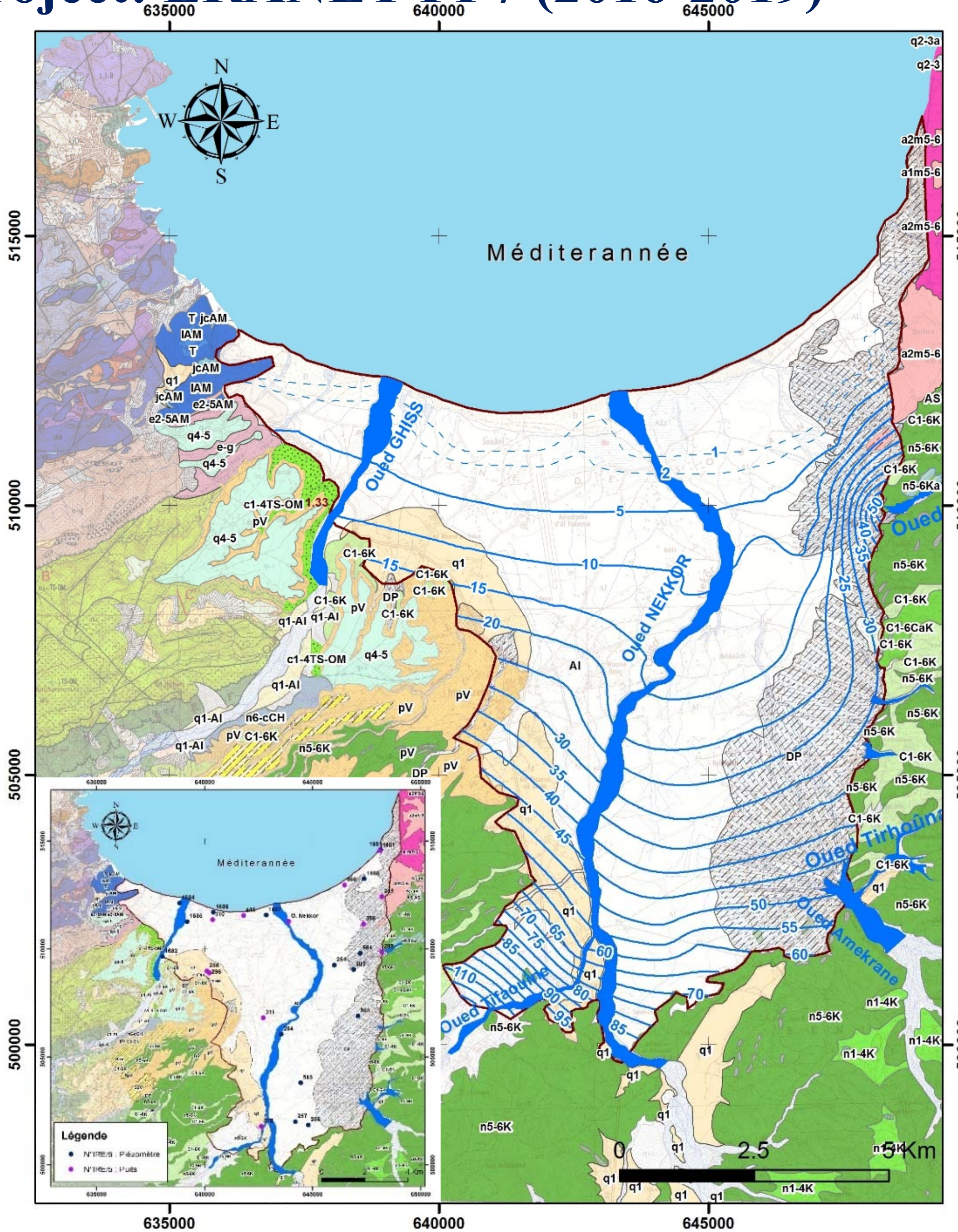


Modeling Climate Change Impact on the Ghiss Nekkor Aquifer System (Sea water level , recharge, ET)

MEDACQLIM Project: ERANET-FP7 (2016-2019)

Groundwater balance for the Ghiss-Nekkor aquifer in 2014

Entrées (en Mm³/an)		Sorties (en Mm³/an)	
Apports latéraux	5.26	Sorties vers la mer	2.57
Infiltration des pluies	1.95	Prélèvements ONEE Pompages agricoles	3.58 3.3
Apports des oueds	2,97		
Retours des pompages agricoles	0.66	Pertes par évaporation	5.16
Total	**10.84**	**Total**	**14.61**
Variation du Stock (en Mm³/an) : - 3.77 Mm³/an			



DRAINAGE NETWORK OF THE CATCHMENT

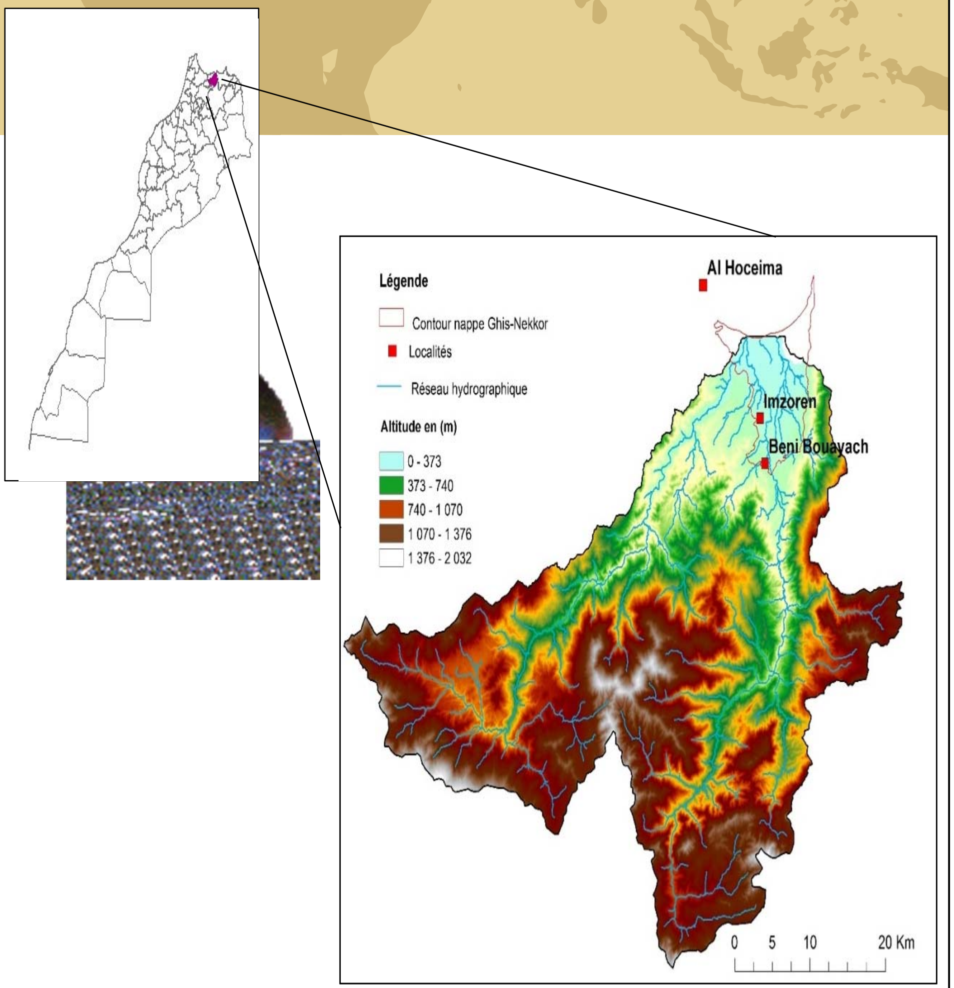


Figure 1: Drainage Network

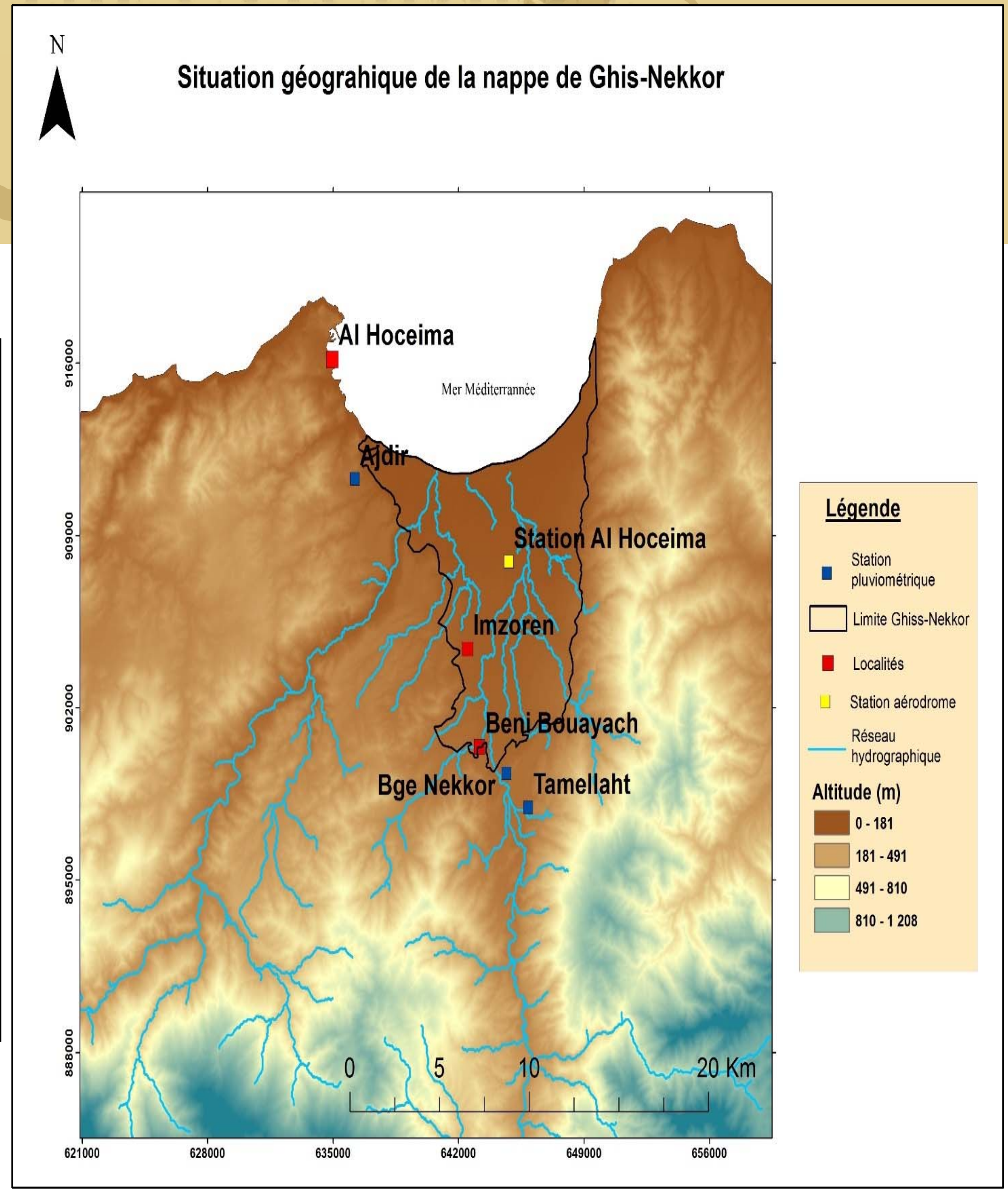


Figure 2: Location of the coastal aquifer

Visualization of Tmax at the closed node (août 1982)

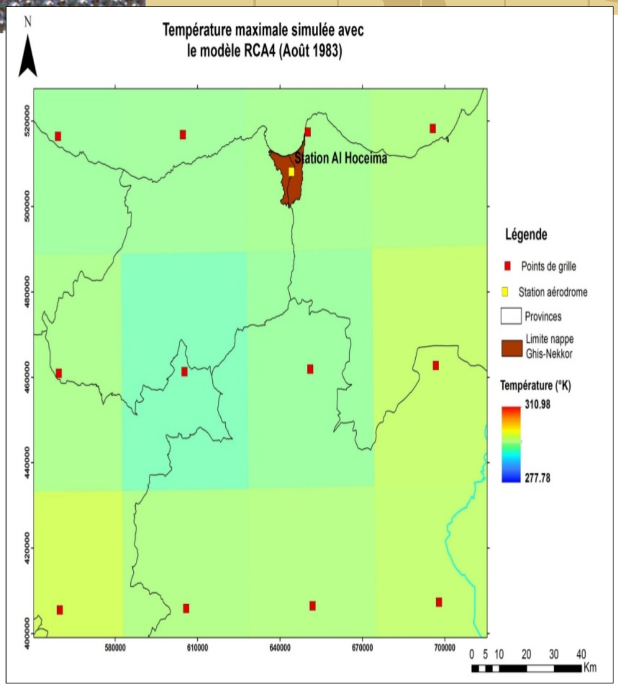
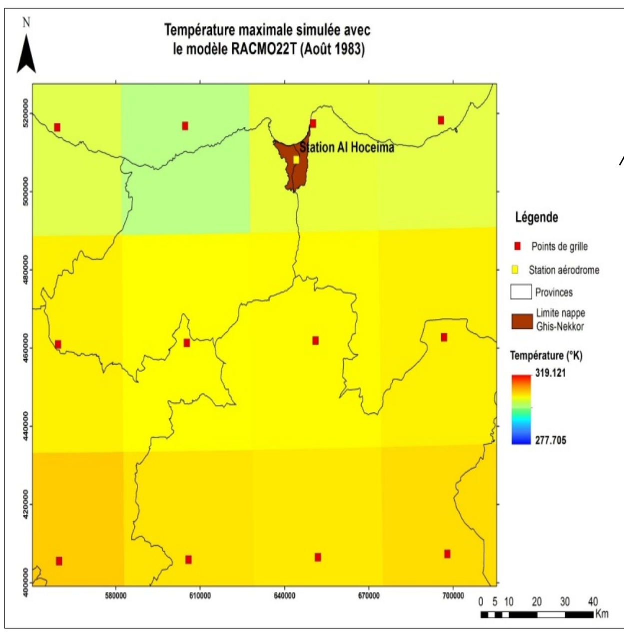
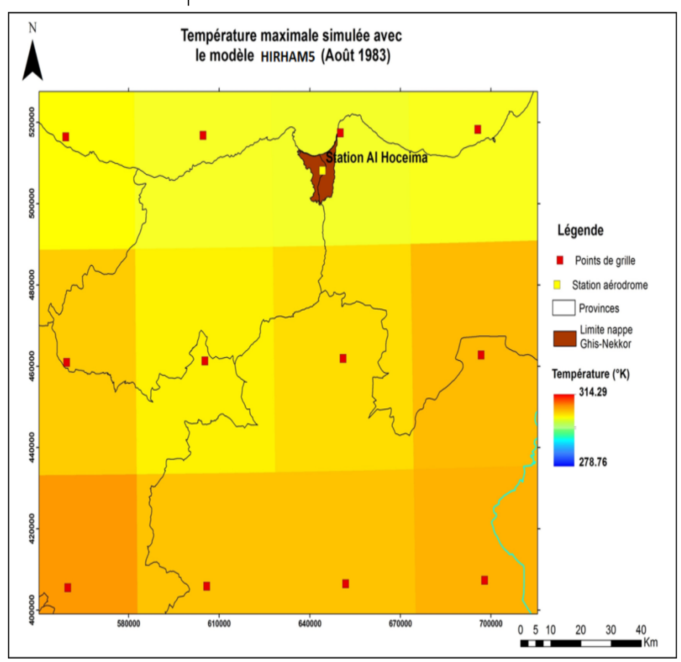


Tableau 4: valeurs de la température maximale de la période août 1982 sous les trois MCR

Models	Tmax value at the closed node (août 1982)
RCA4	25.12 °C
RACMO22T	28.22 °C
HIRHAM5	30.01°C
Observation (August 1982)	27.85 °C

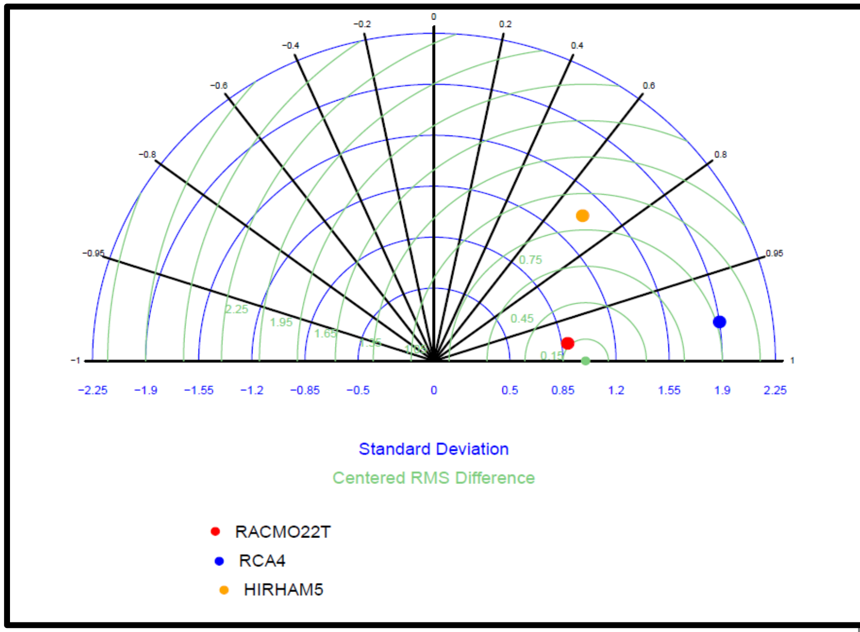




Example of visualization of Tmax with the 3 CRM (Août 1982)

Selected CRM Models to simulate (Tmax,Tmin, P)

-Statistical Analysis: Linear regression and Taylor Diagram



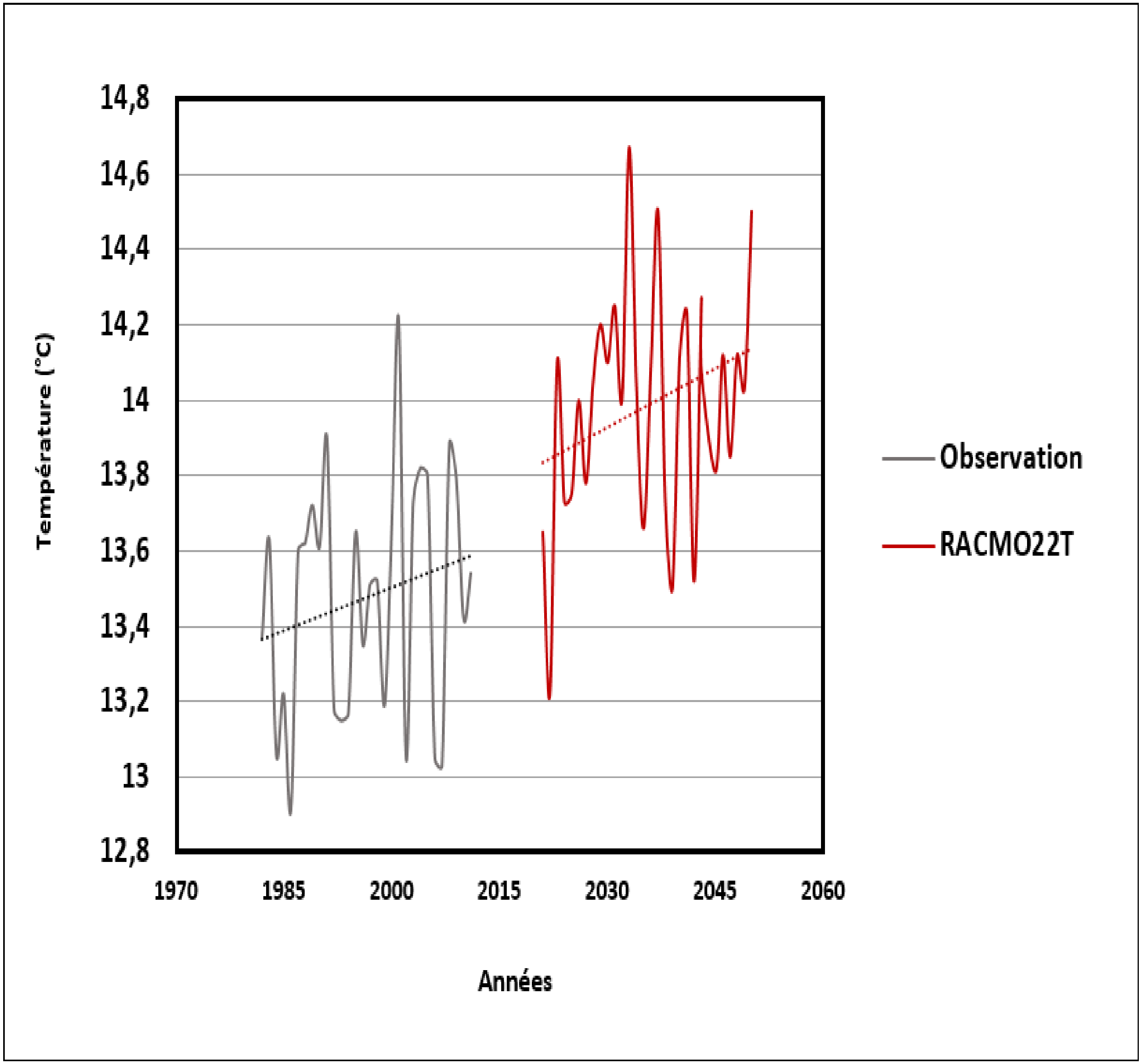
- Example of Results for Tmin in the Taylor Diagram

Paramètre	Modèle	RMSE	R	STD
Tmin	RACMO22T	0.15	0.98	0.85
Tmax	RACMO22T	0.42	0.96	1.45
Pr	HIRHAM5	0.74	0.8	0.78

- Selected of the best CRM Models to simulate (Tmax,Tmin, P)

Future Projections for Tmin (2050)

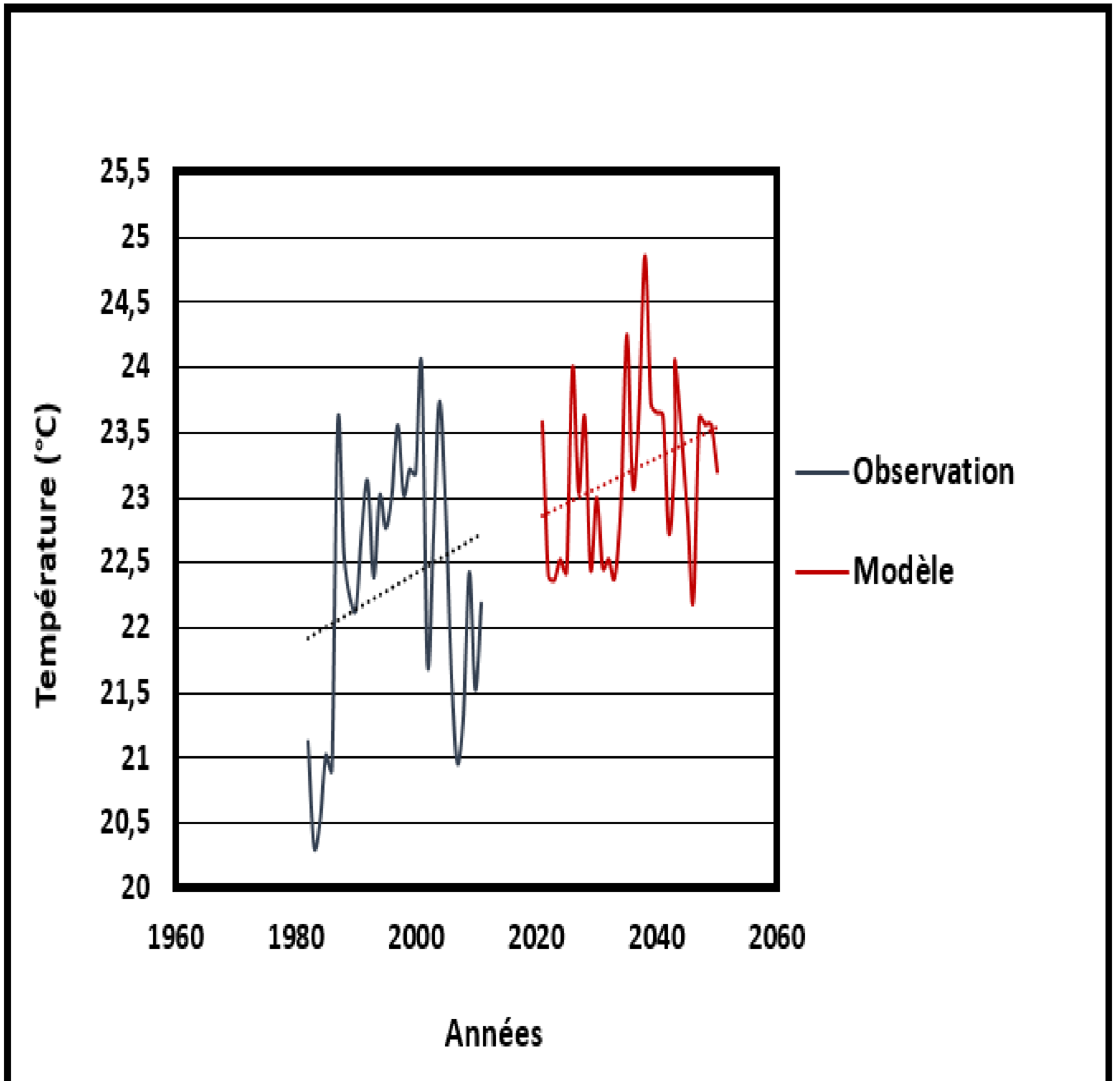
High fluctuation of Tmin (2050) which would increase indicating a local warming.



Tmin prediction (2050) with RACMO22T

Future Projections for Tmax (2050)

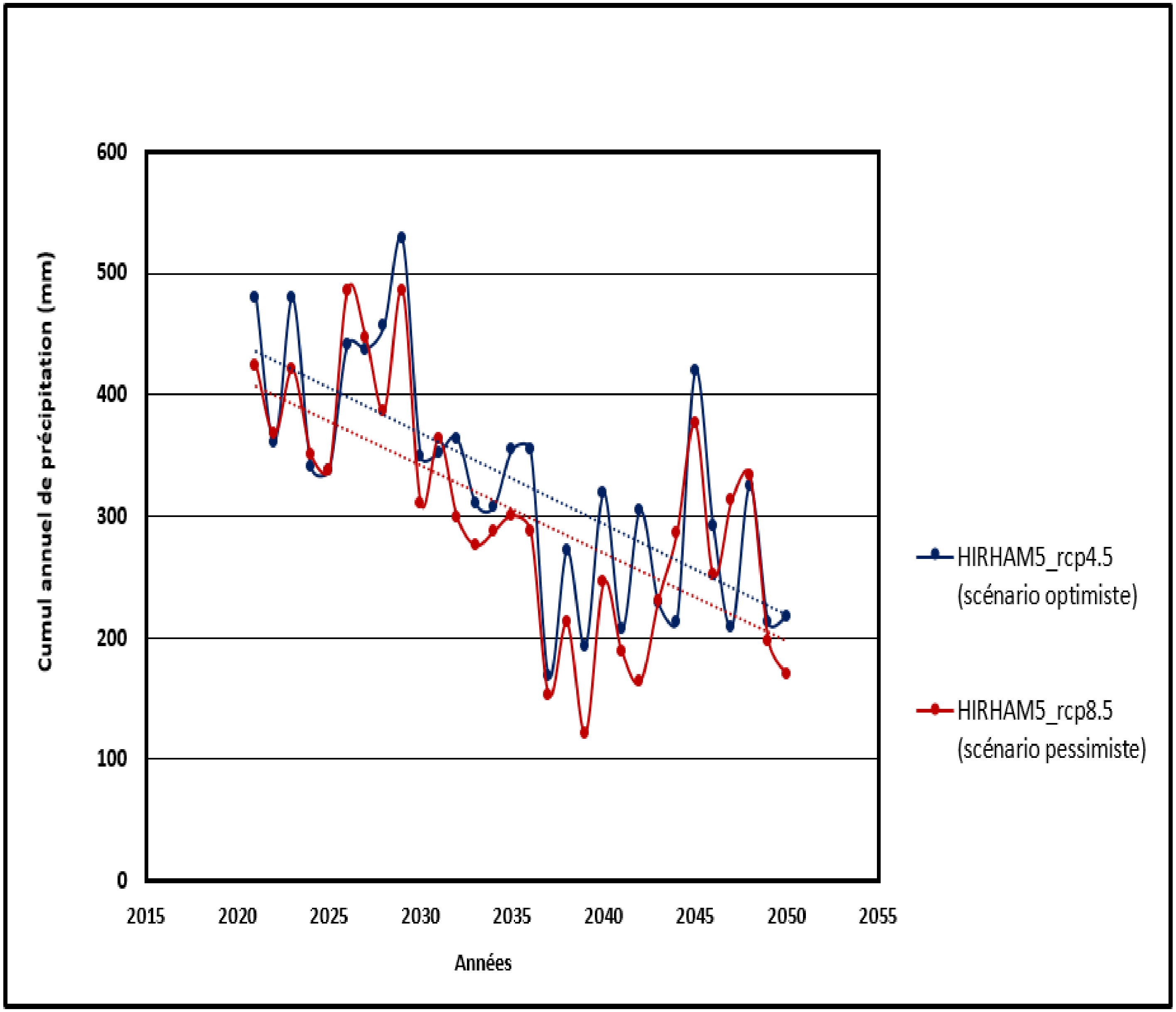
Tmax would also increase with less fluctuation than Tmin.



Tmax prediction (2050) with RACMO22T

Future Projections for P (2050)

For both scénarios (RCP 4.5 ; RCP 8.5) P would decrease



Prediction of precipitation (2050) with HIRHAM (rcp 4.5 &8.5)

Modeling the Impacts of CC on GW

- Coupling CC models with Classical Modeling:

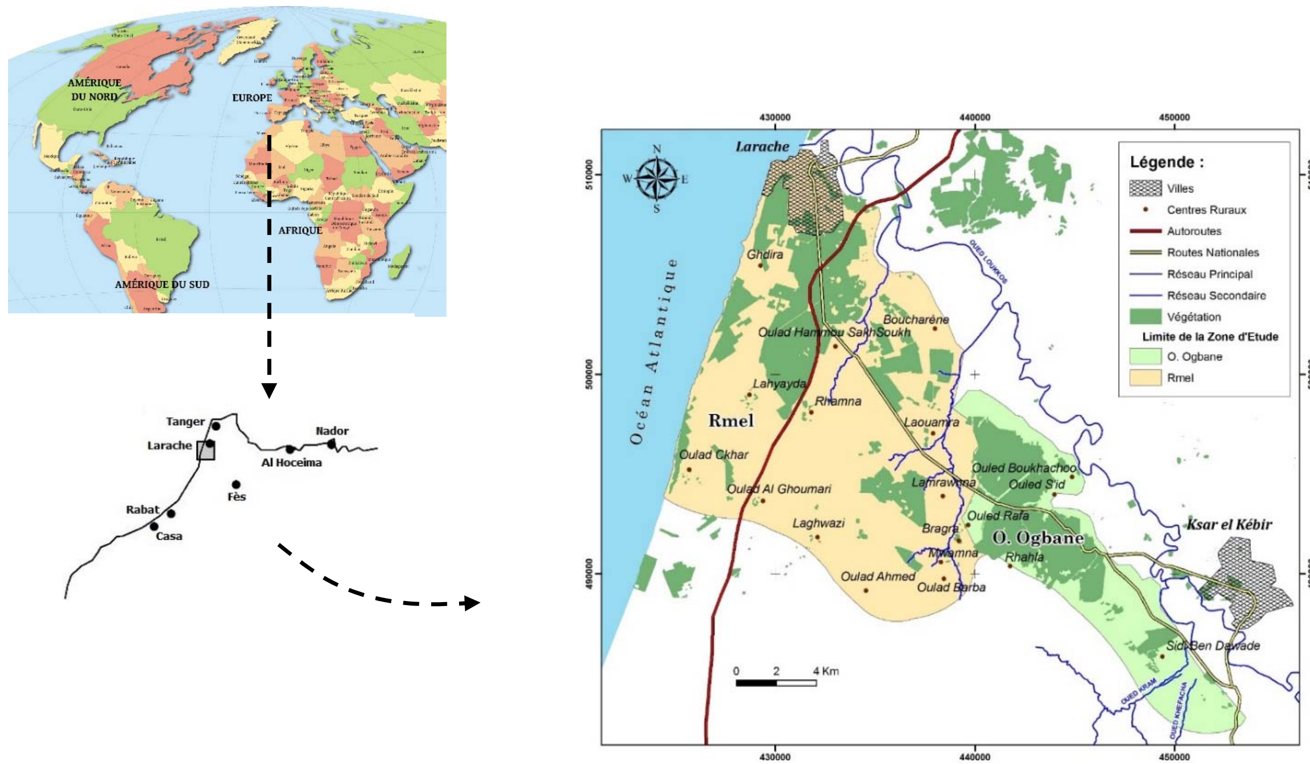
- Tmean can be calculated, in addition to P and Sea Level Rise from circulation Models,

- The New Recharge can also be calculated taking into account CC,

- Use Classical Modeling,

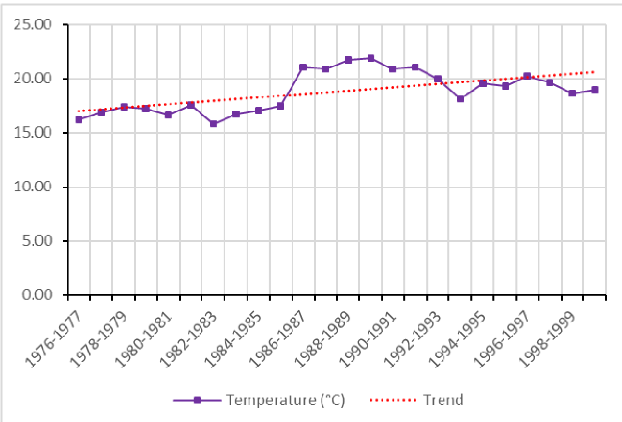
- Application to Case Studies.

Case of the Loukkos basin (1)

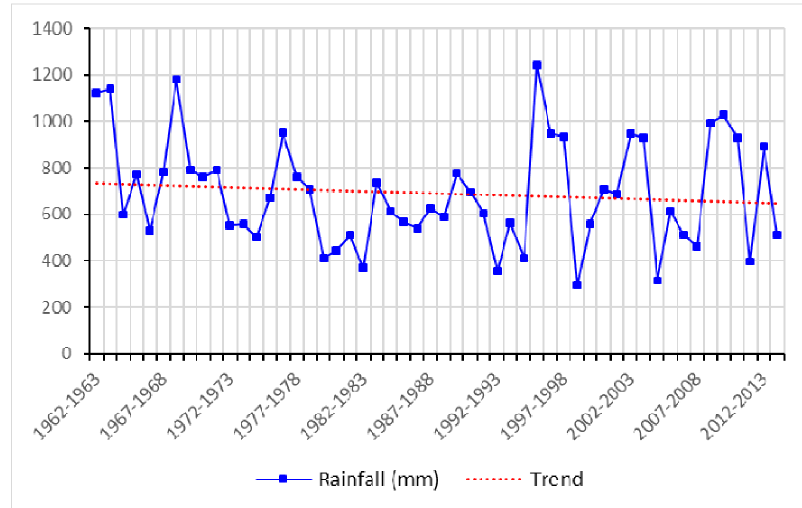


Location map of the study area

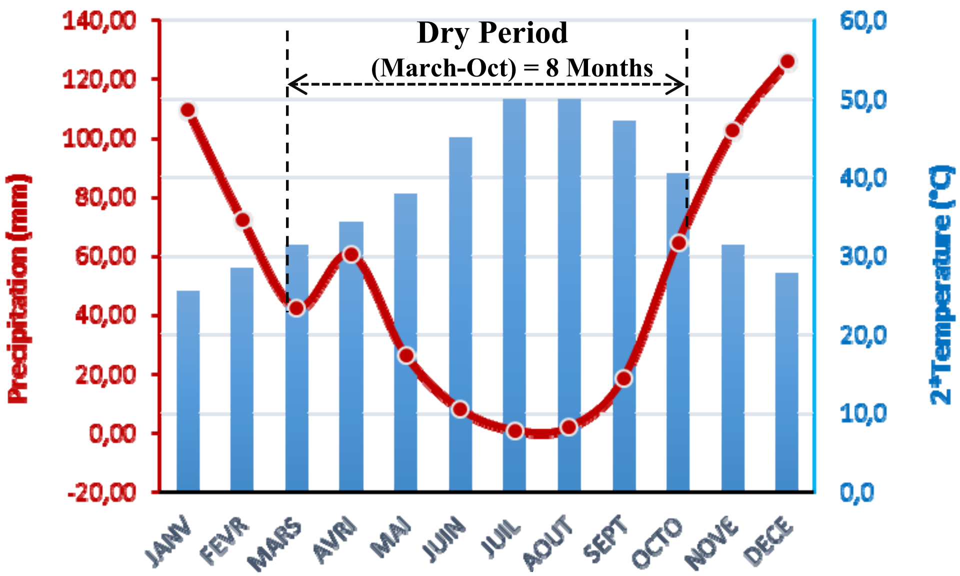
Case of the Loukkos basin (2)



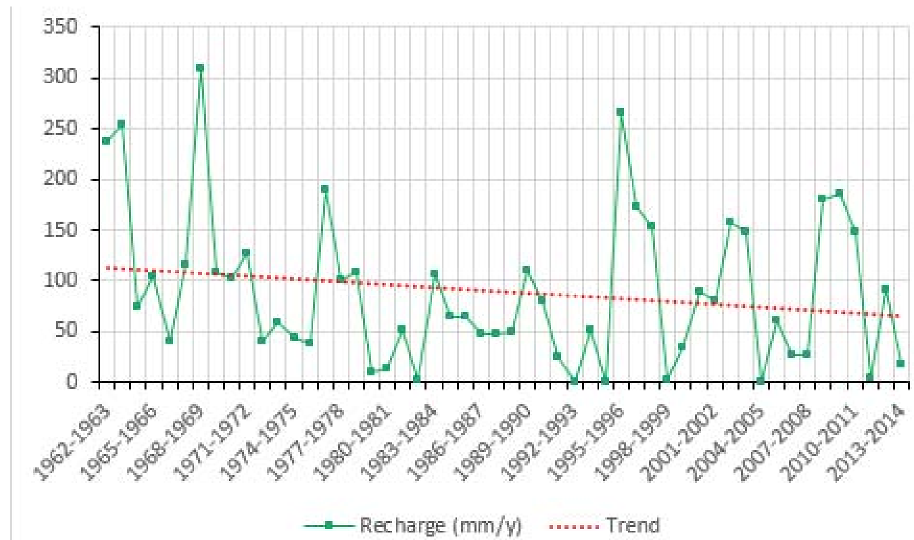
Monthly variation of temperature (1977 – 2000)



Monthly variation of precipitation (1963 – 2014)

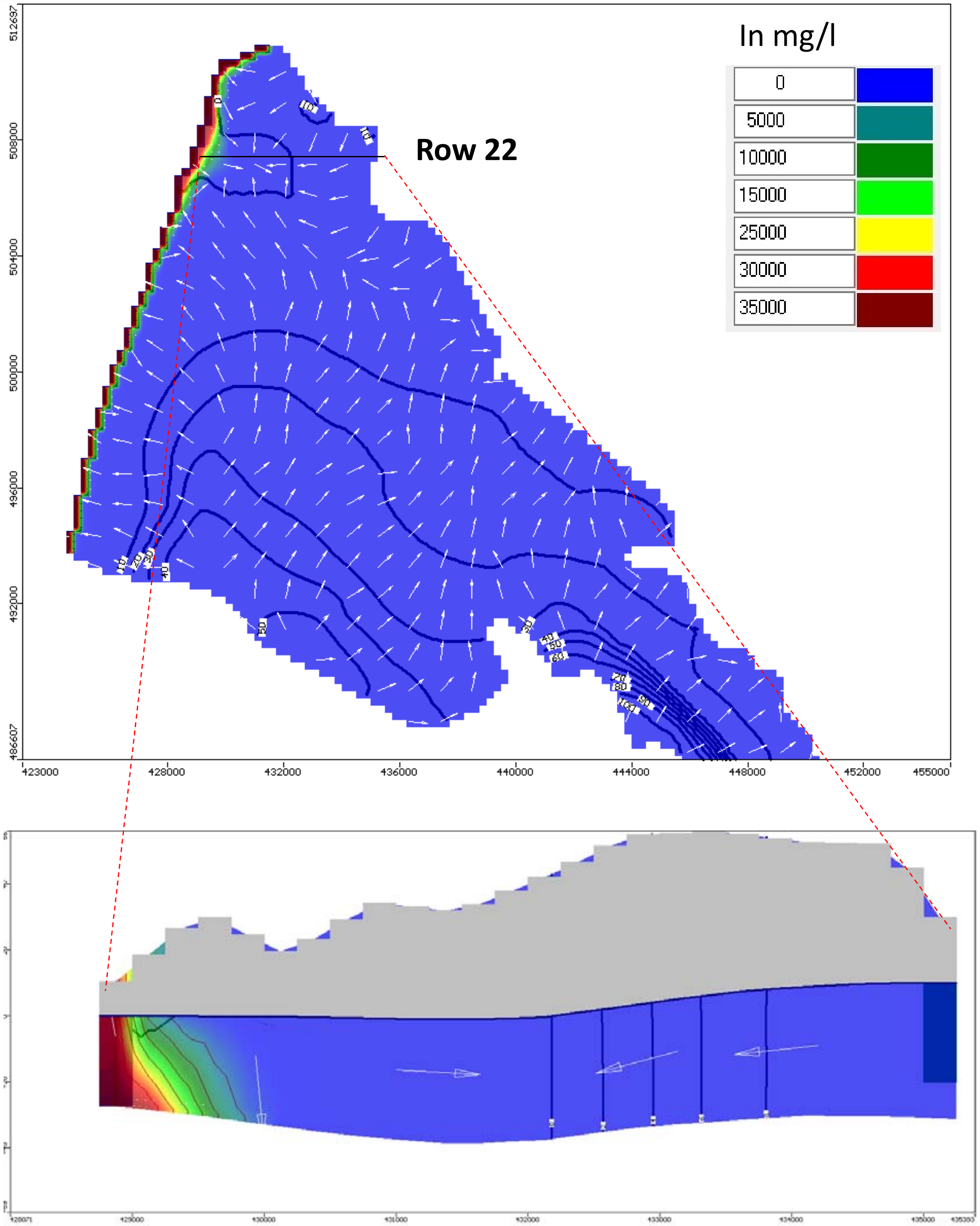


Ombrothermic chart at Larache station (1977-2000) by Gaussen and Bagnouls (1952)



Monthly variation of natural recharge of aquifer Rmel-O. Ogbane calculated by Thornthwaite method (1948).

Case of the Loukkos basin (3)

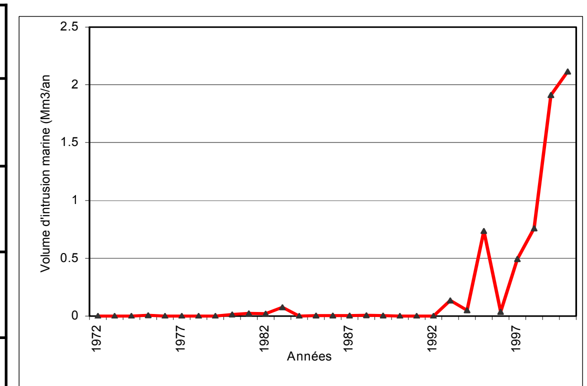


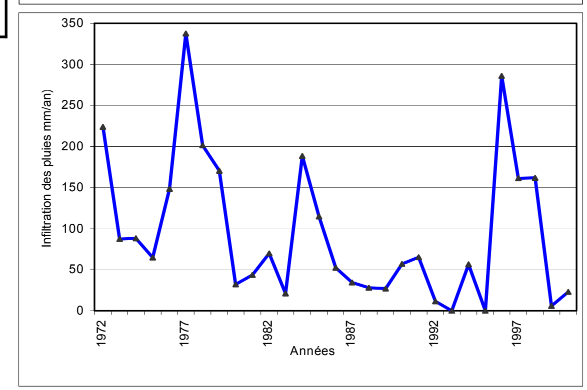
Seawater intrusion in the Rmel-O. Ogbane coastal aquifer was studied in terms of qualitative and quantitative aspects, under a distribution of salt concentrations values in the coastal area, ranging from sea salt (35 g/l) in red color and freshwater concentration which is almost 0 g/l in blue color. The seawater intrusion edge extended 2 Km in the bottom of the aquifer. The results showed also that seawater intrusion increased in 2000 in the northwestern sector (Fig.11), due to mainly to (1) *Less recharge caused by CC and the recurrent droughts*; (2) *Overexploitation of groundwater by intensive pumping from a well field used for drinking water supply of the Larache city and rural areas.*

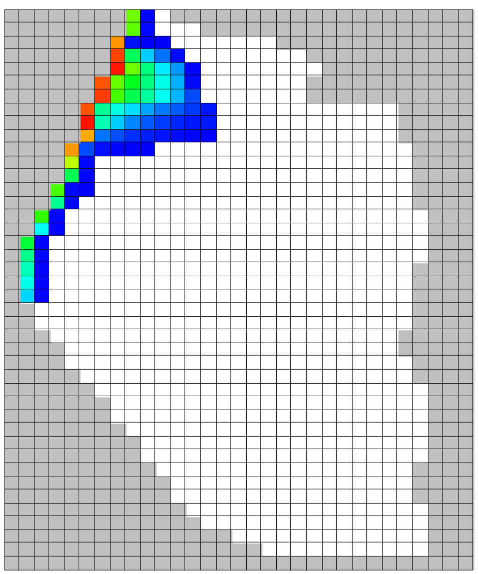
☑ Regional Model to deal with Seawater Intrusion in Coastal Aquifers:

Année / Scénarios	Volume en Mm³/an 2004	2005	2010	2015	2020
Scénario 1	1.5068	1.248 0	0.790 8	0.4492	0.3905
Scénario 2	2.9996	3.754 4	4.545 7	4.7273	4.9428
Scénario 3	3.0139	3.814 5	4.786 0	5.0961	5.7462

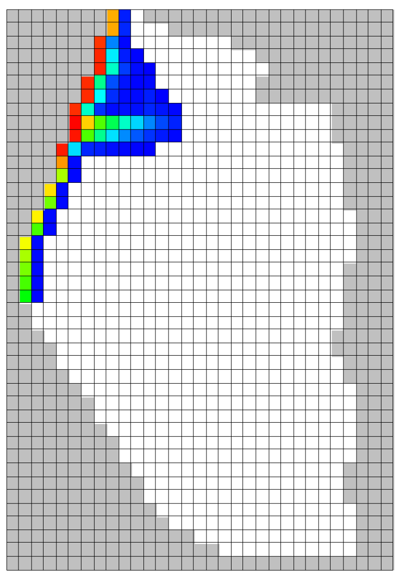
a) Location of the study area , e) Predicted SWI Volumes





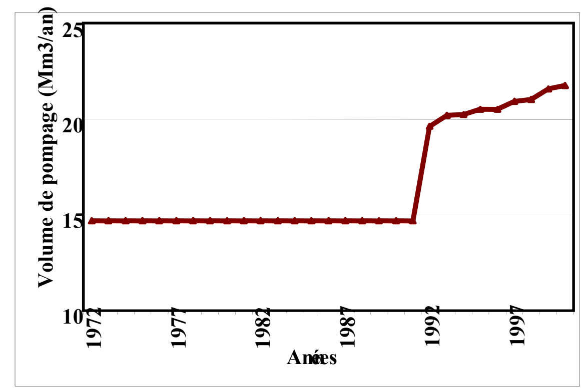


b) Distribution of Salinity for layer 2 (Scénario 1, 2020)



c) Distribution of Salinity for layer 4 (Scénario 1, 2020)

d) Seawater intrusion is more sensitive to the recharge and GW abstractions



Climate Change in the Tafilalet Oasis

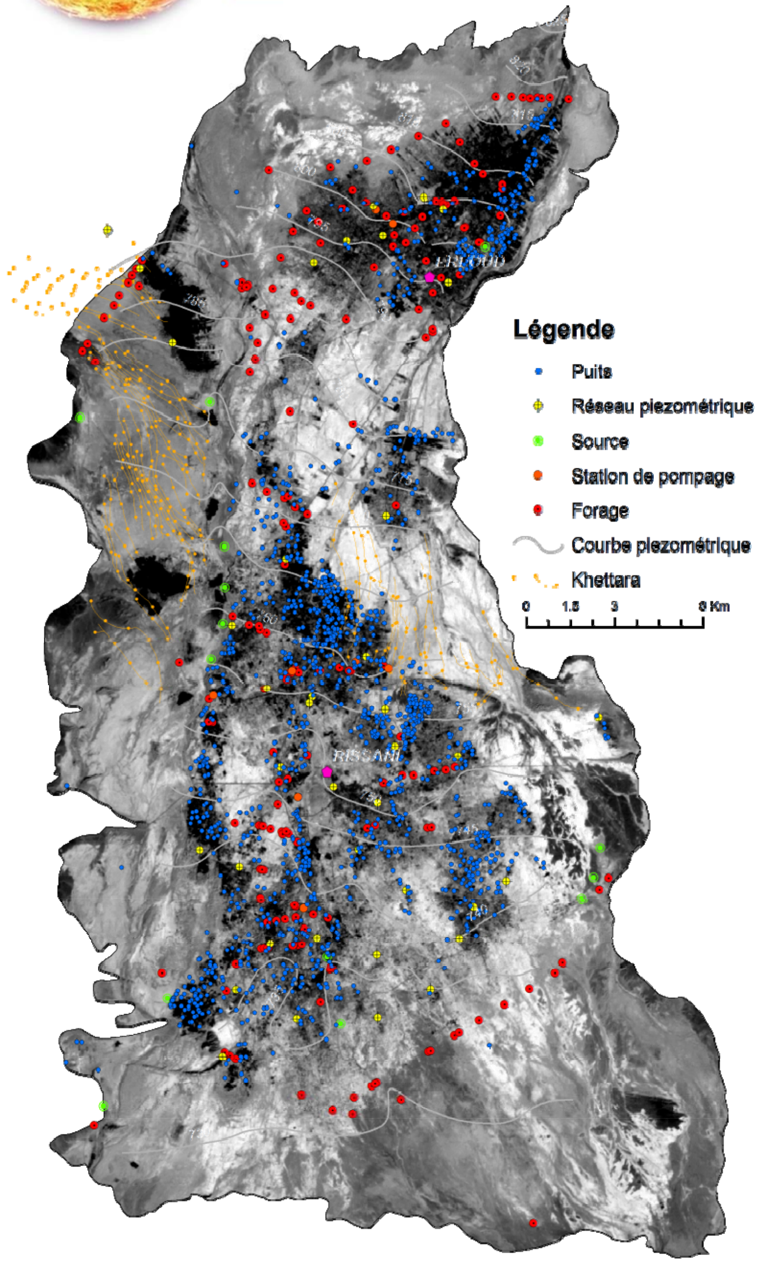
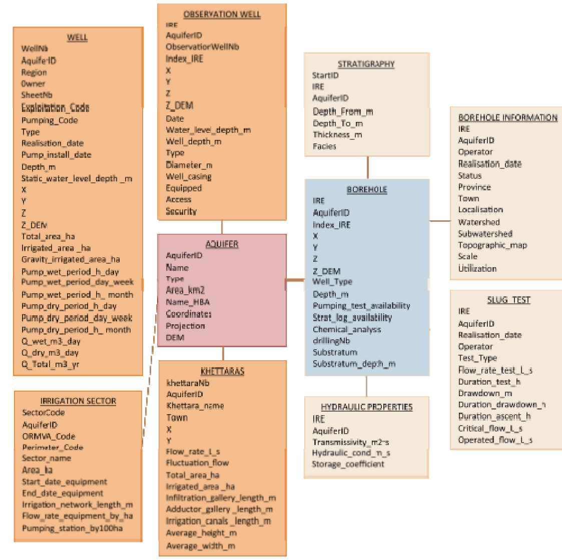
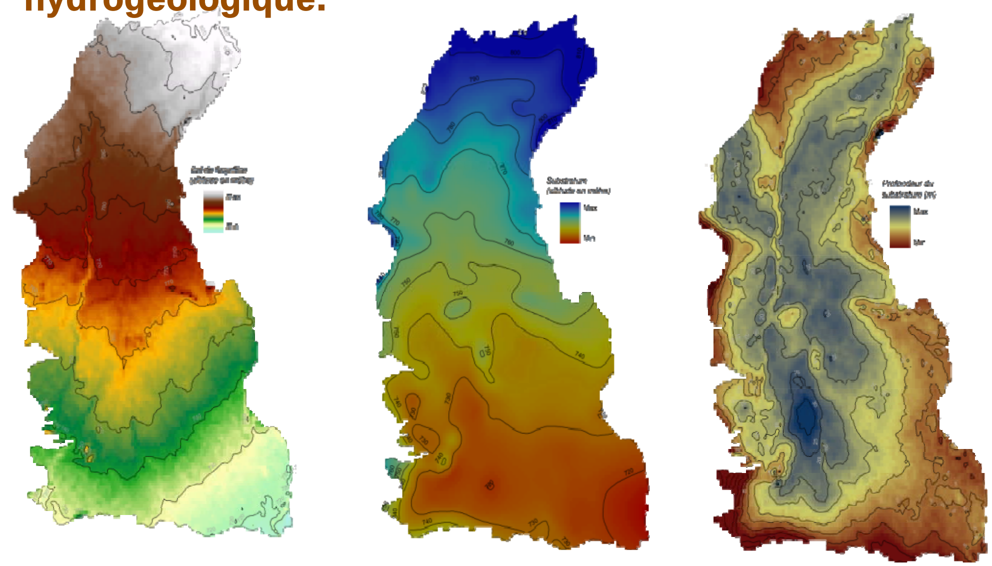


image Landsat (*spectral radiance of band 3*) de la plaine de Tafilalet avec les différents points d'eau d'observation ou d'éxploitation. La surface piézometrique de la nappe phréatique correspond à une période relativement humide (fèvrier 2011). les tâches sombres au centre de la plaine sont des palemeraies. Les drains articiels (Khettras) ont été aussi dressés à partit de l'image.



Base de données relationnelles de Tafilalet représentant les données disponibles et nécessaires pour le modèle hydrogéologique.



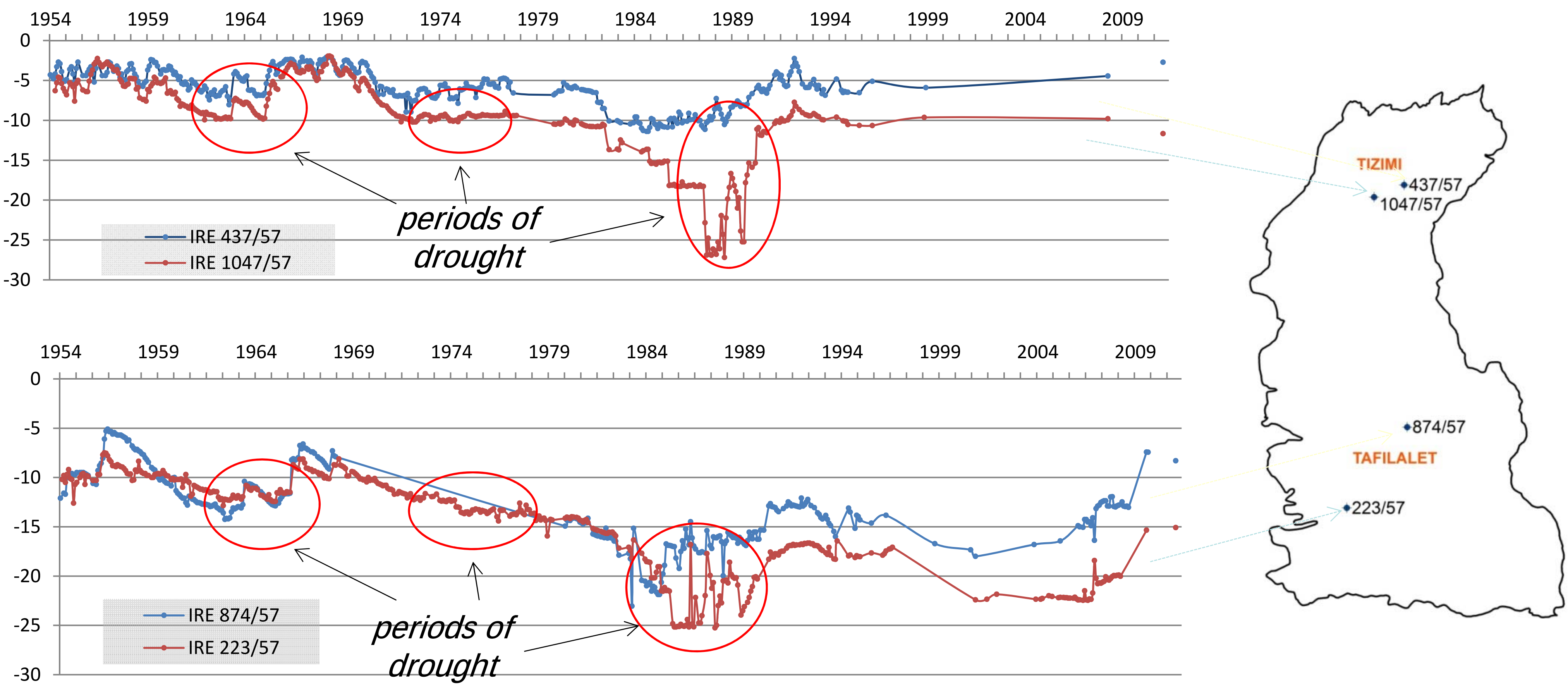
exemple de données d'entrée au modèle numérique obtenues par modélisation géostatistique des données spatiales.

Piezometric Records and evolution for the Tafilalet aquifer-Droughts

Analysis of the piezometric graphs shows some fluctuations of great amplitude with periods of strong reductions of stored volumes (early 1960s, mid-1970s and 1980) and periods of natural replenishment of groundwater (the end of 1960s, 1970 and 1980).

The amplitudes of the interannual variations can reach 5m.

It is mainly the succession of dry periods causing the lowering of the piezometric level and the development of groundwater abstraction has not prevented the wound of water table in 2011.



Piezometric Records and evolution of Tafilalet aquifer- Droughts

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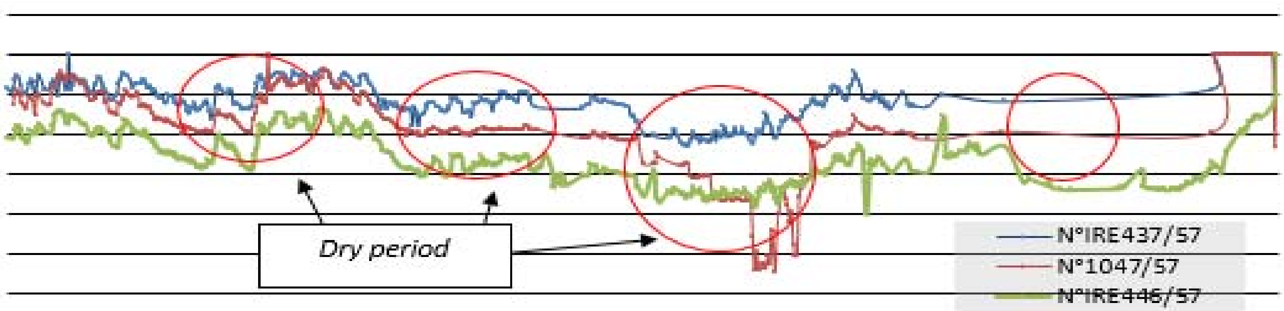
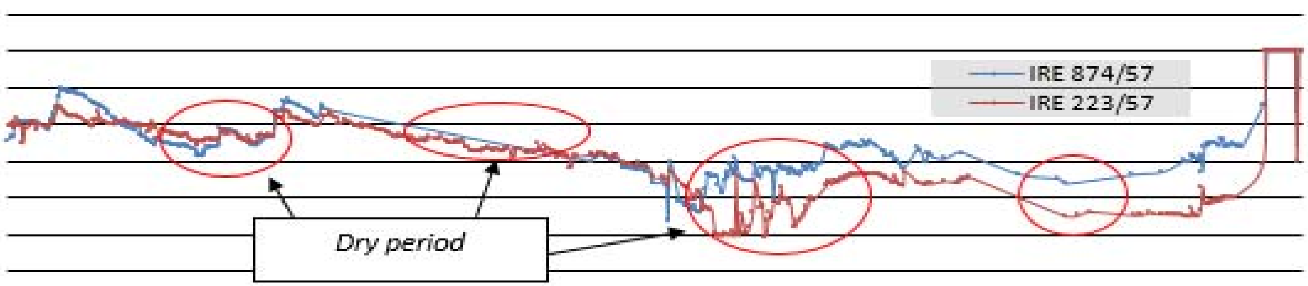
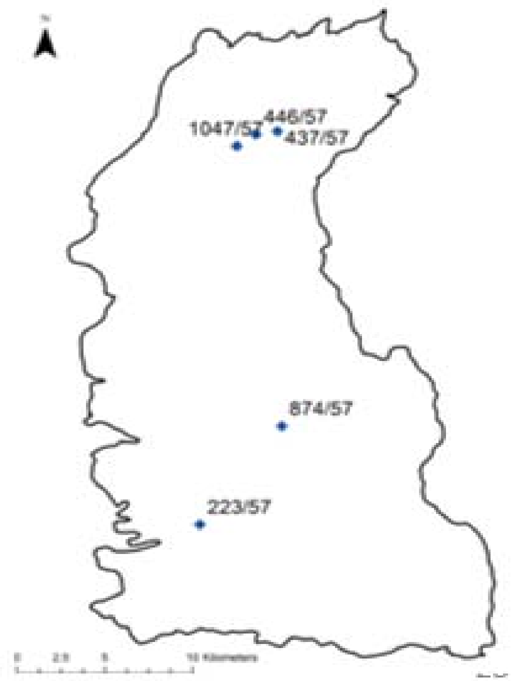


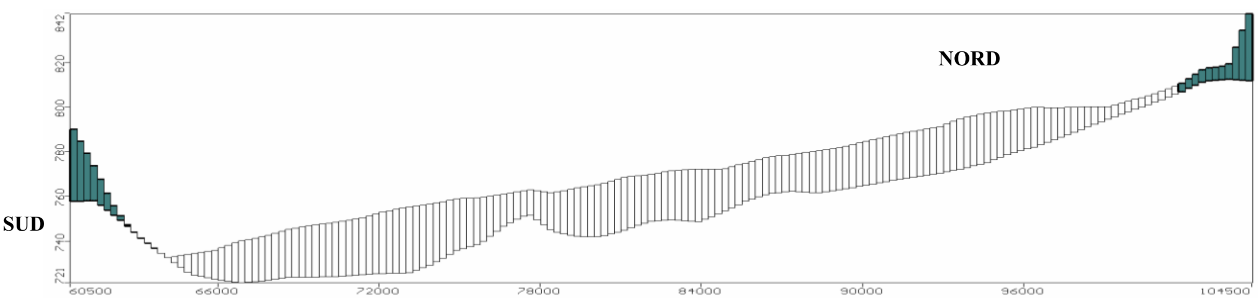


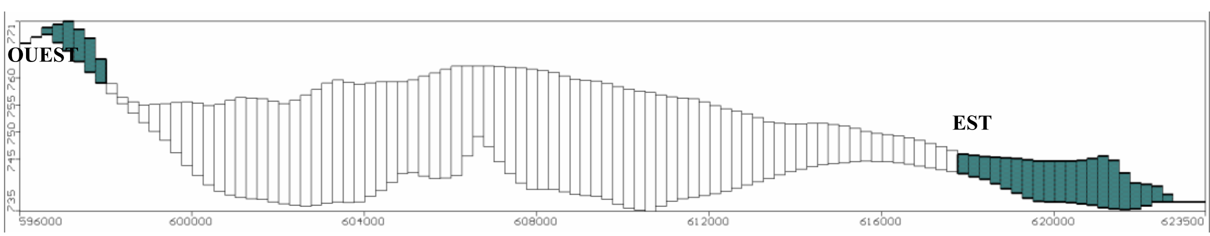


3D Groundwater Flow Model (Mesh Network)

Le domaine modélisé correspond à la nappe alluviale du Quaternaire de la plaine de Tafilalet (y compris le Tizimi) couvrant une superficie de 637 km².

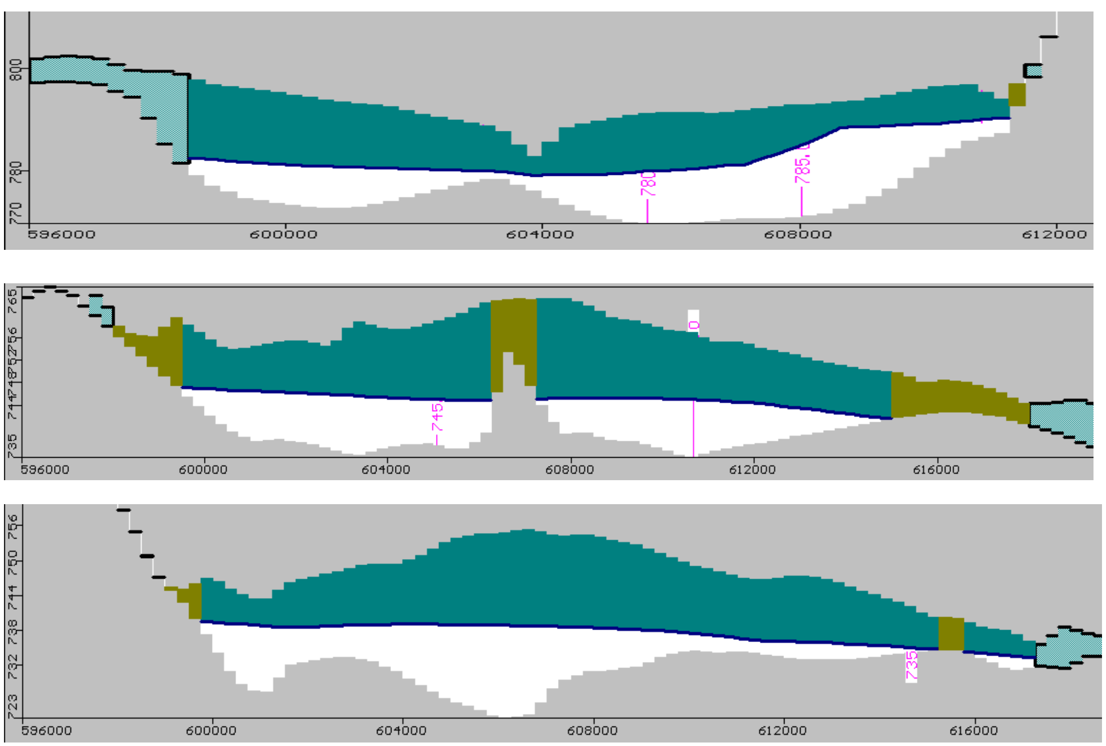
Maillage: un réseau de mailles carrées de 250m de coté. La zone modélisée est constituée de 7900 mailles, dont 10190 mailles actives.

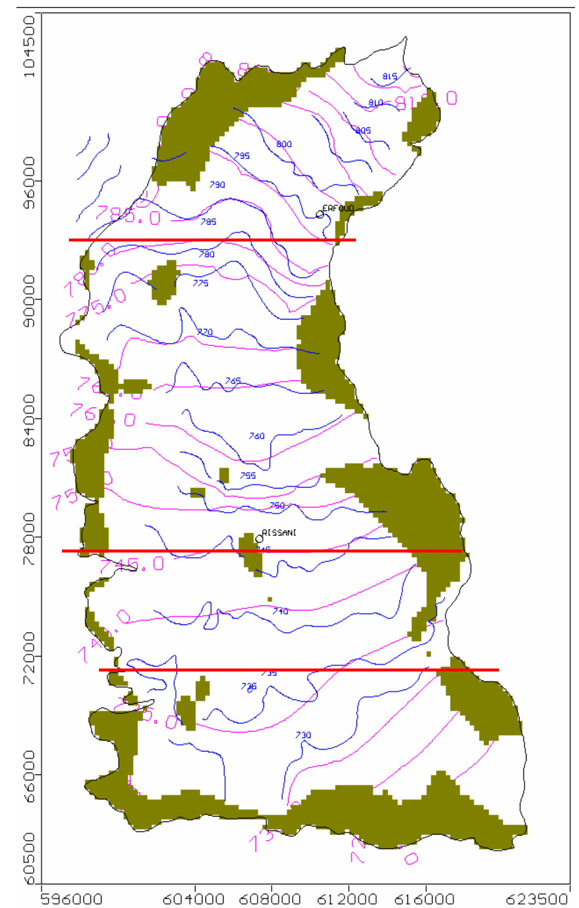




Regional Model in Steady state *(1960)*

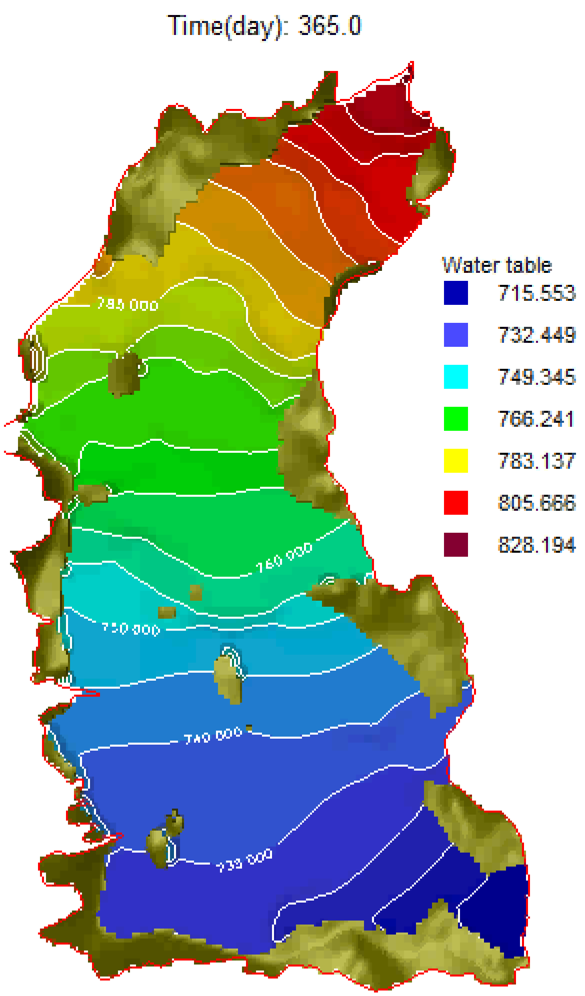
Water balanc term	m3 yr-1	%
lateral groundwater recharge	13942088	19.89
Infiltration from River flow		
Infiltration from irrigation	56145480	80.11
Rainfall		
Spring		
Traditional wells	6949252	9.92
Pumping wells		
Khettaras	10767369	15.36
Tafilalet outflow	1968755	2.81
Evapotranspiration	50401972	71.91
Total IN	70087568	100
Total OUT	70087344	100

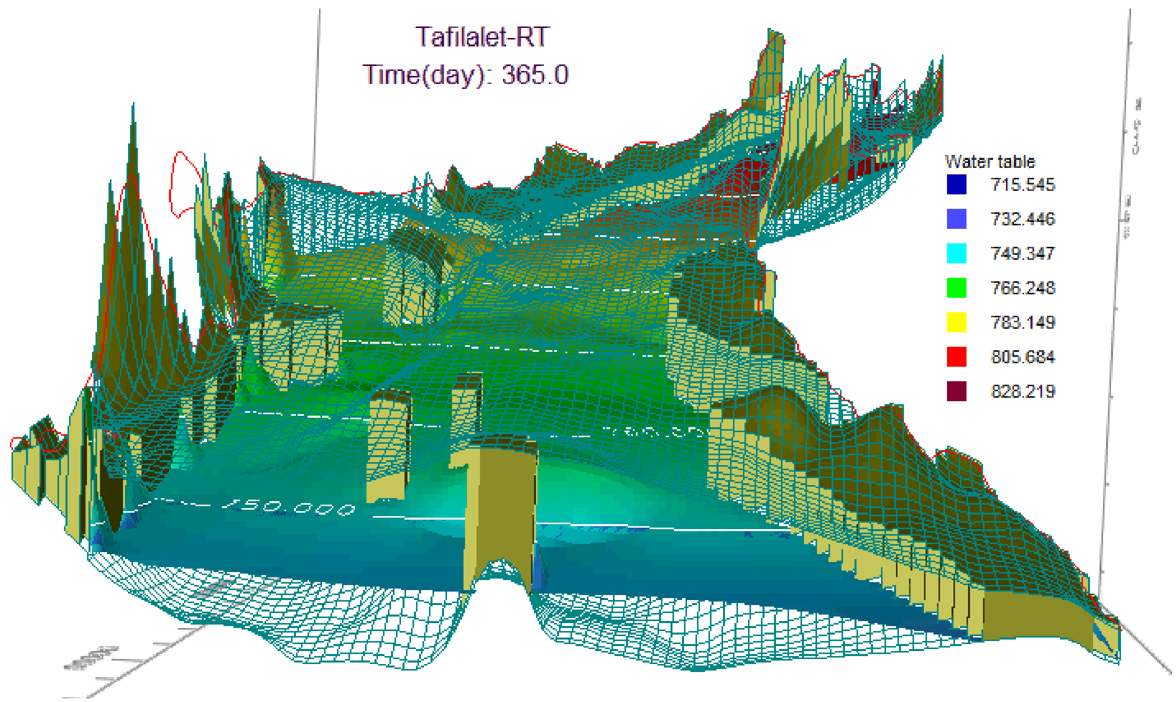




Coupes transversales de la nappe à l'état du regime permaent.

Regional Model in Transient Conditions





Le Modèle simulé entre 1960 et 2011 est caractérisé par deux périodes de sécheresses.

Conclusions - Recommendations

Need of optimal IWRM :

- **Build series of underground dams upstream of the Oasis ecosystems to recharge the aquifers and maintain the traditional drainage systems (Kettras, Aflaj),**

- **Irrigation of the coastal areas from surface water to mitigate seawater intrusion in the coastal aquifers,**

- **Conjunctive use of conv. Water and Desalination water in the coastal zones,**

- **Participative water management through a contract concept, including all the stakeholders for monitoring, exploitation & management.**


THANK YOU FOR YOUR ATTENTION
شكرا على انتباهكم