I Giornata AIGA di Approfondimento

Lo studio e la tutela delle acque sotterranee – 25 Ottobre 2016

Salvaguardia degli acquiferi carsici costieri pugliesi tra complessità intrinseca e impatto antropico

Protection of the Apulian karstic coastal aquifers between intrinsic complexity and anthropogenic effects

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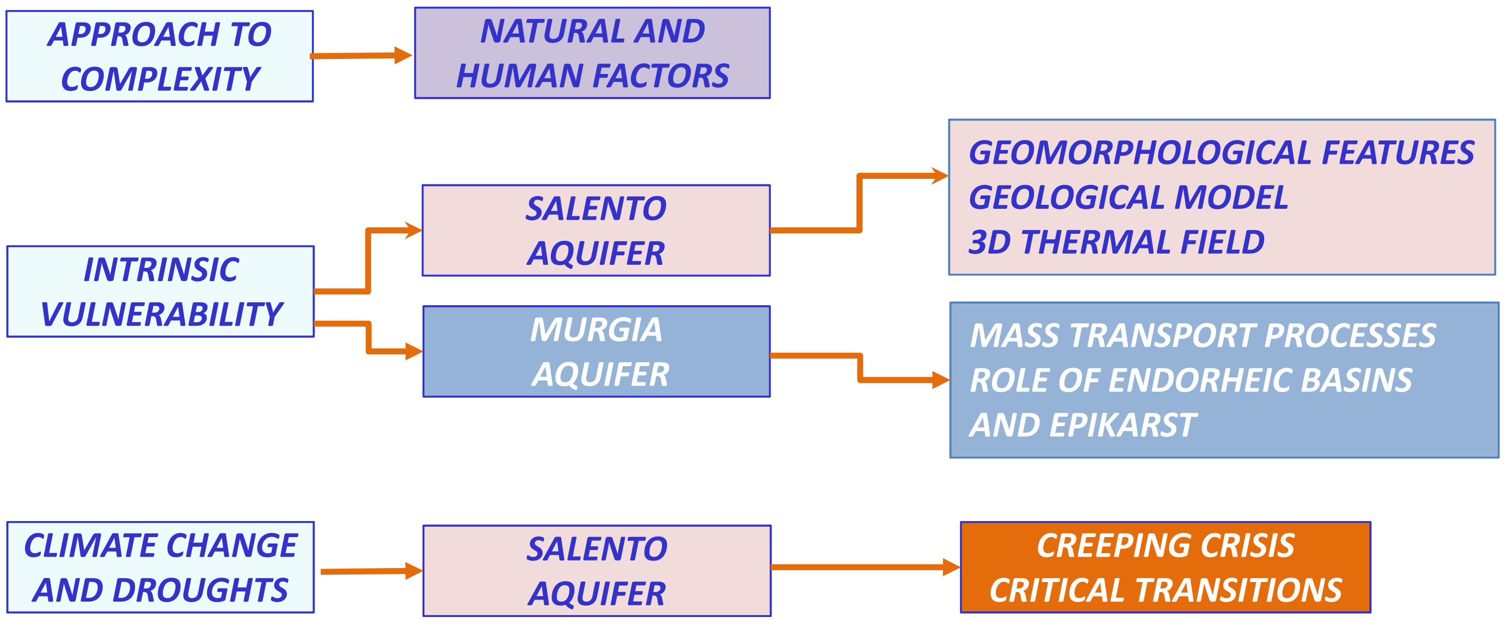
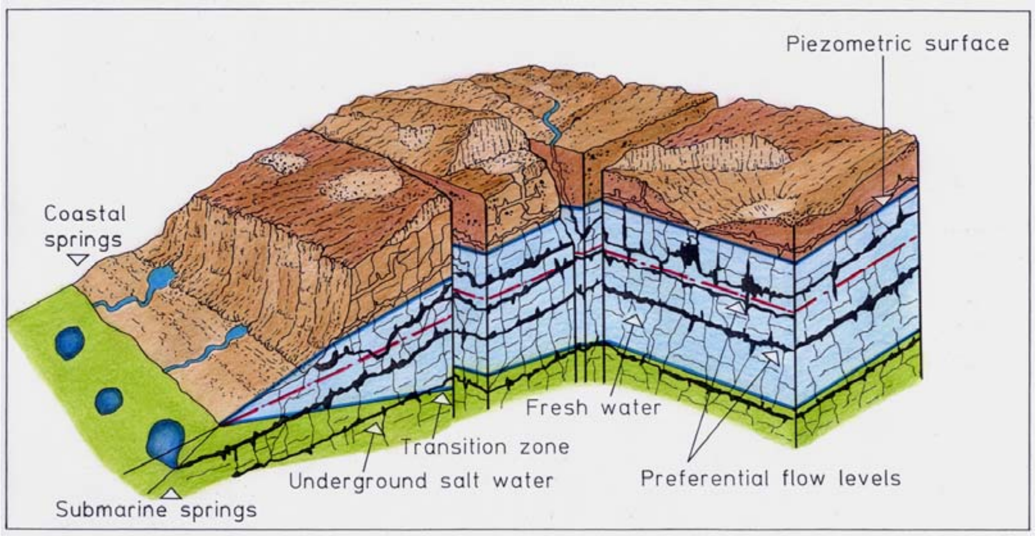
Politecnico di Bari, Italy

M.D. Fidelibus

Objective

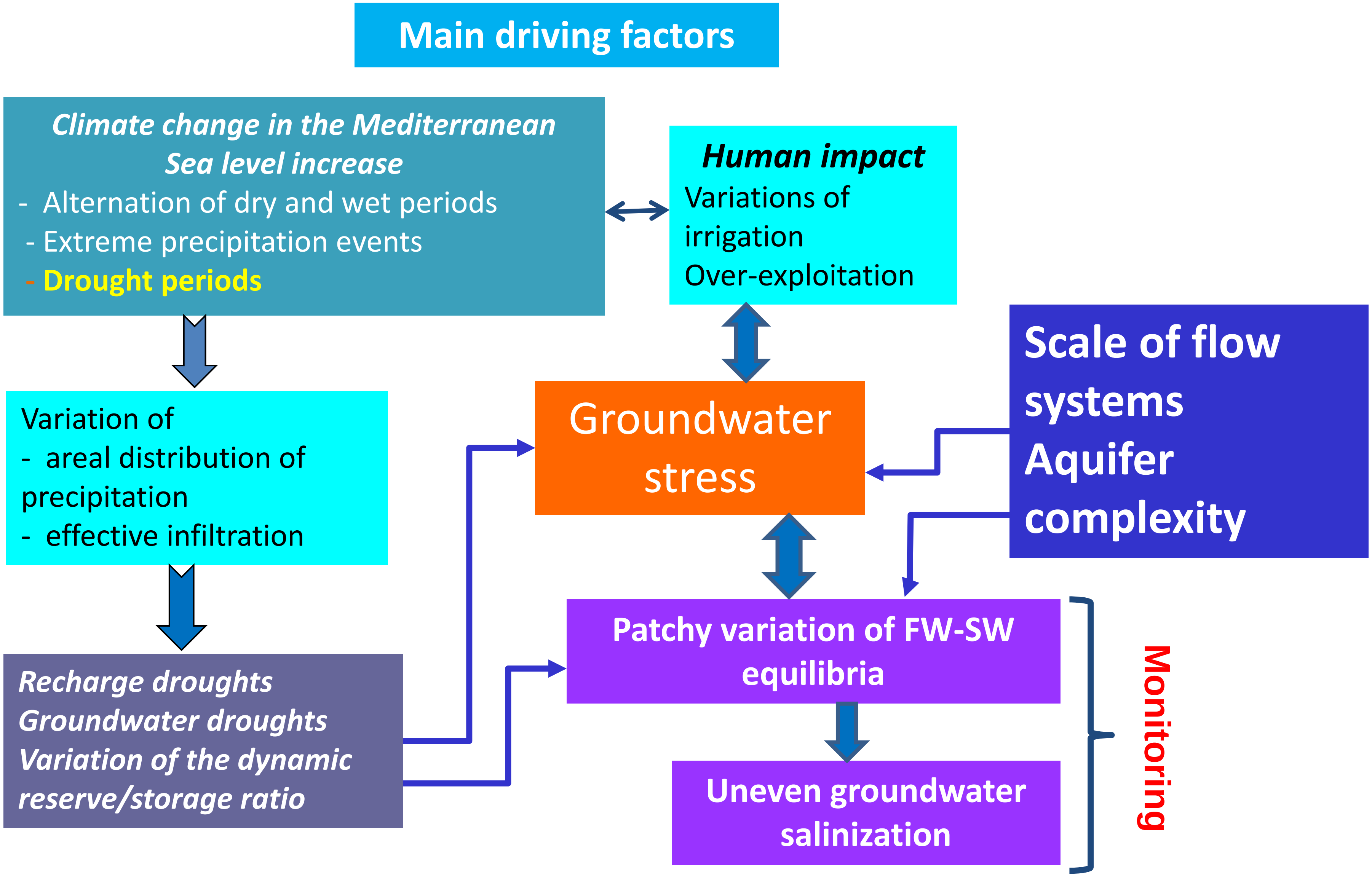
The final aim of the current research activity is to define a ***methodological approach*** for the solution of management issues related to the ***safeguard of the qualitative and quantitative status*** of groundwater in the main coastal karst aquifers of Puglia Region

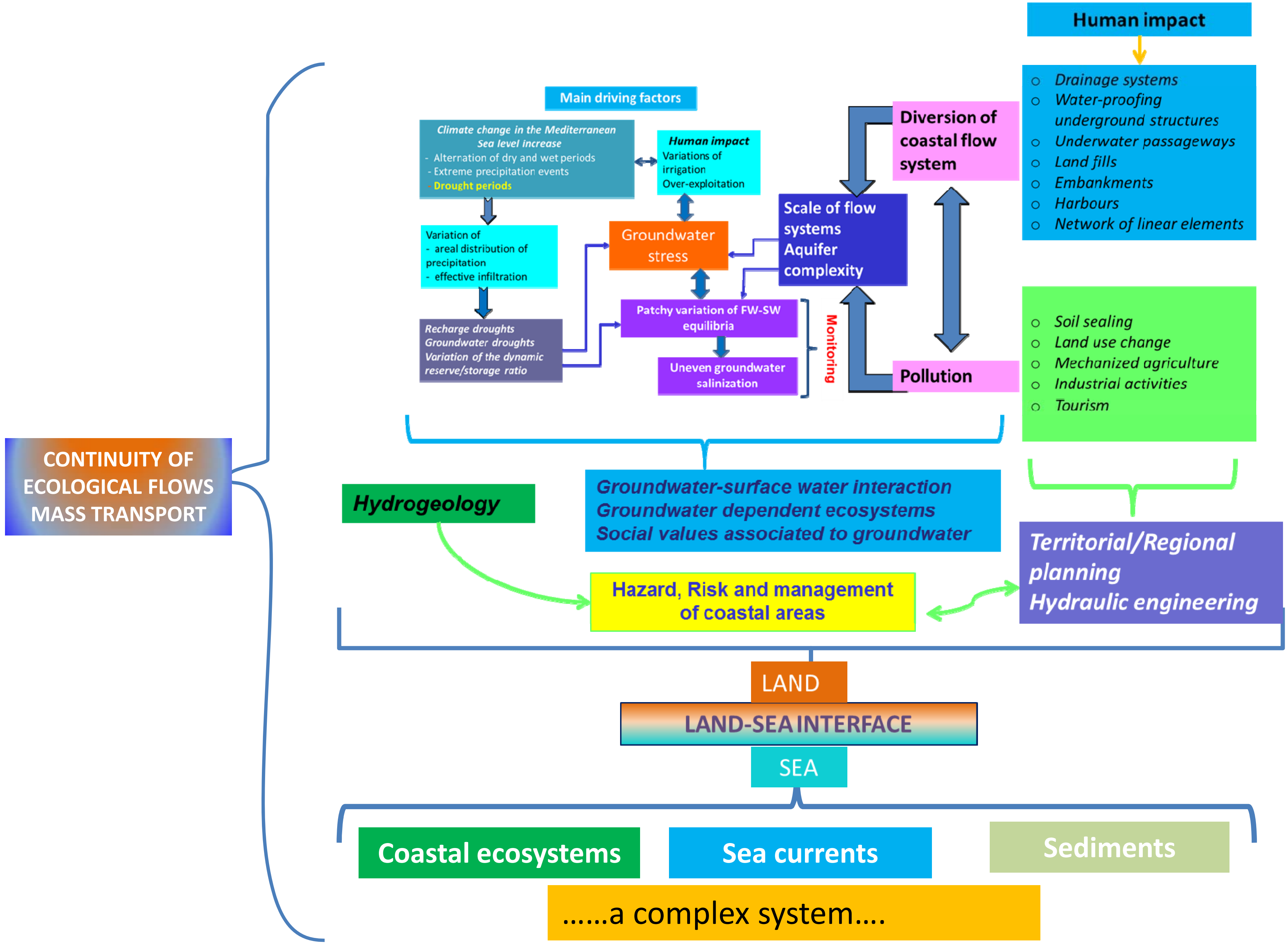




Murgia and Salento karst coastal aquifers belong to a ***platform karst*** characterized by thick and large sedimentary complex, formed by horizontal and gently sloping strata and platform relief

- *The sea partially borders the karst aquifers (coastal aquifers): **a transition zone and salt waters** are found at the bottom of fresh groundwater depending on the hydraulic heads.*
- *The aquifers show a high anisotropy of the intrinsic permeability, due to the **complex network of discontinuities, and surface and subsurface karst forms**.*
- *The **groundwater flow systems are of regional size**.*
- *Groundwater discharge occurs only along the coast as **diffuse flow or through coastal and submarine brackish springs.***
- *The karst coastal systems are **complex systems** that respond to inputs arising from spatial and temporal scales larger than those outlined by their local boundaries.*


Main driving factors
Climate change in the Mediterranean
Sea level increase
- Alternation of dry and wet periods
- Extreme precipitation events
- Drought periods
Human impact
Variations of irrigation
Over-exploitation
Scale of flow systems
Aquifer complexity
Variation of
- areal distribution of precipitation
- effective infiltration
Groundwater stress
Recharge droughts
Groundwater droughts
Variation of the dynamic reserve/storage ratio
Patchy variation of FW-SW equilibria
Uneven groundwater salinization
Monitoring


CONTINUITY OF ECOLOGICAL FLOWS MASS TRANSPORT
Main driving factors
Climate change in the Mediterranean
Sea level increase
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Uneven groundwater salinization
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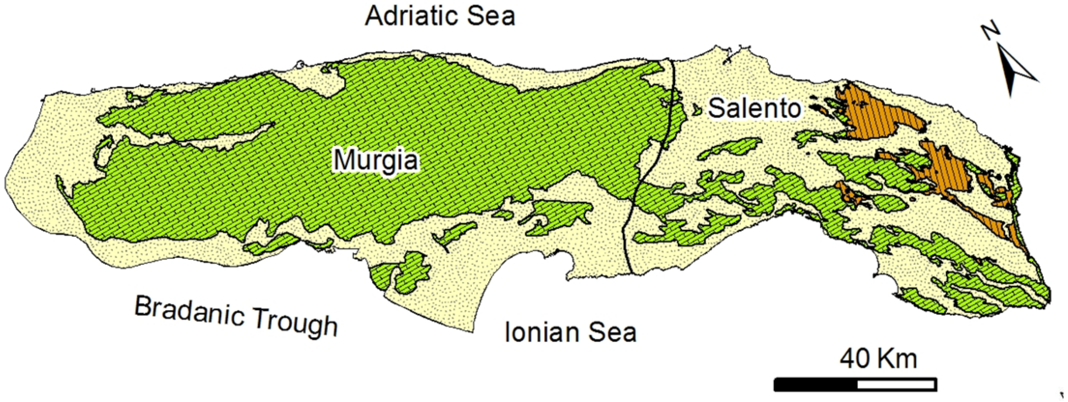
Scale of flow systems
Aquifer complexity
Diversion of coastal flow system
Pollution
Human impact
Drainage systems
Water-proofing underground structures
Underwater passageways
Land fills
Embankments
Harbours
Network of linear elements
Soil sealing
Land use change
Mechanized agriculture
Industrial activities
Tourism
Hydrogeology
Groundwater-surface water interaction
Groundwater dependent ecosystems
Social values associated to groundwater
Territorial/Regional planning
Hydraulic engineering
Hazard, Risk and management of coastal areas
LAND
LAND-SEA INTERFACE
SEA
Coastal ecosystems
Sea currents
Sediments
......a complex system....

Calcarenites, sands and clays (Pliocene-Quaternary);

Calcarenites and marly calcarenites (Miocene);

Limestones and dolomitic limestones (Cretaceous)



NORMAL FAULT

PROBABLE NORMAL FAULT

BURIED NORMAL FAULT

PROBABLE BURIED NORMAL FAULT

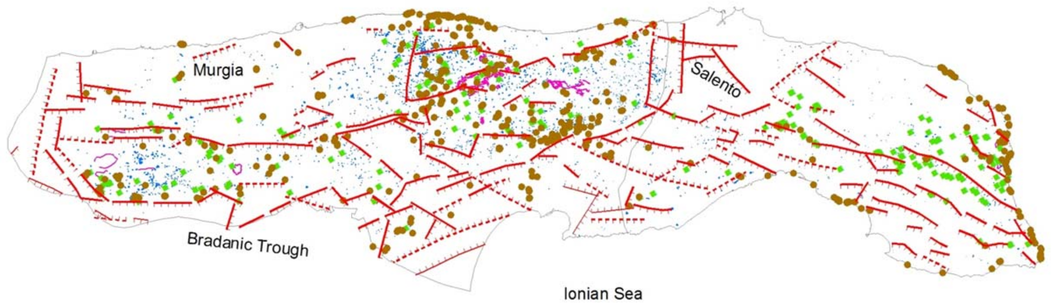
VERTICAL FAULT

CAVES

SINKHOLES

DOLINES

POLJE



Murgia

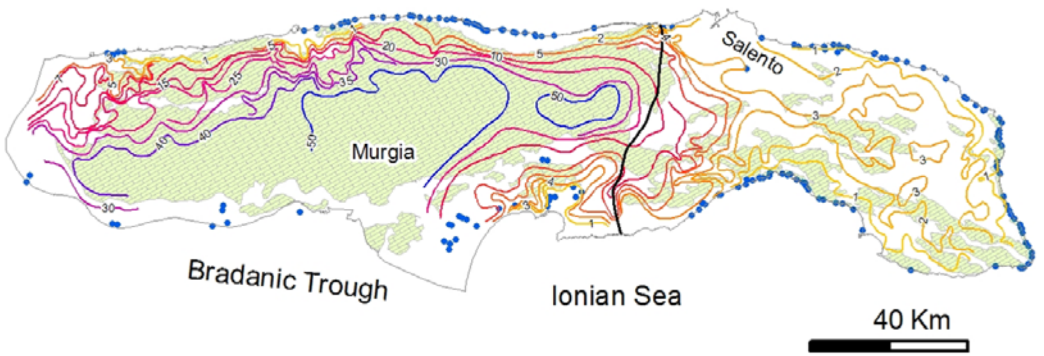
Mean recharge rate → 47 m^3/s

Hydraulic gradient → 2 $^0/_{000}$

Salento

Mean recharge rate → 28 m^3/s

Hydraulic gradient → 0.2 - 2 $^0/_{000}$



Questions:
- which is the role of the geomorphological features in the mass transport processes from surface to groundwater?
- is the bare karst more vulnerable than the covered karst?

THE QUANTITATIVE IMPACT OF POLLUTANTS ON GROUNDWATERS AND PHYSICAL ATTENUATION EFFECTS IN KARSTIC AQUIFERS….

…depends on the Intrinsic and Groundwater Vulnerability…

Intrinsic vulnerability

- covers
- aquifer properties in the parts interested by the vertical pathway (track)
- hydrogeological conditions
- indipendent from chemical characteristics of pollutants

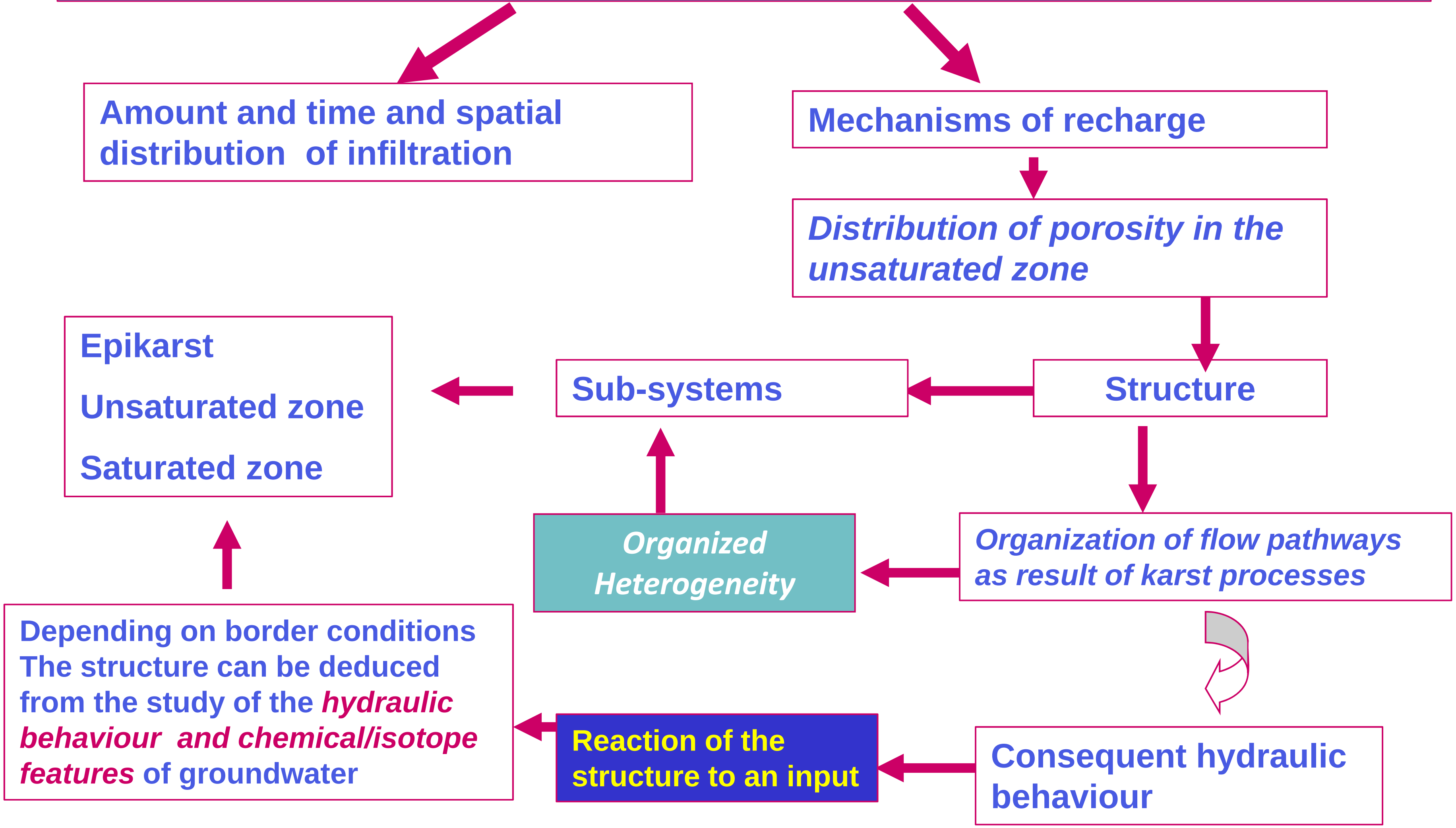
Target: the resource, the top of saturated zone

Groundwater vulnerability

- intrinsic vulnerability of the aquifer
- proximity to the pollution sources
- pollutant characteristics
- factors that increase or decrease the total pollution load during transport

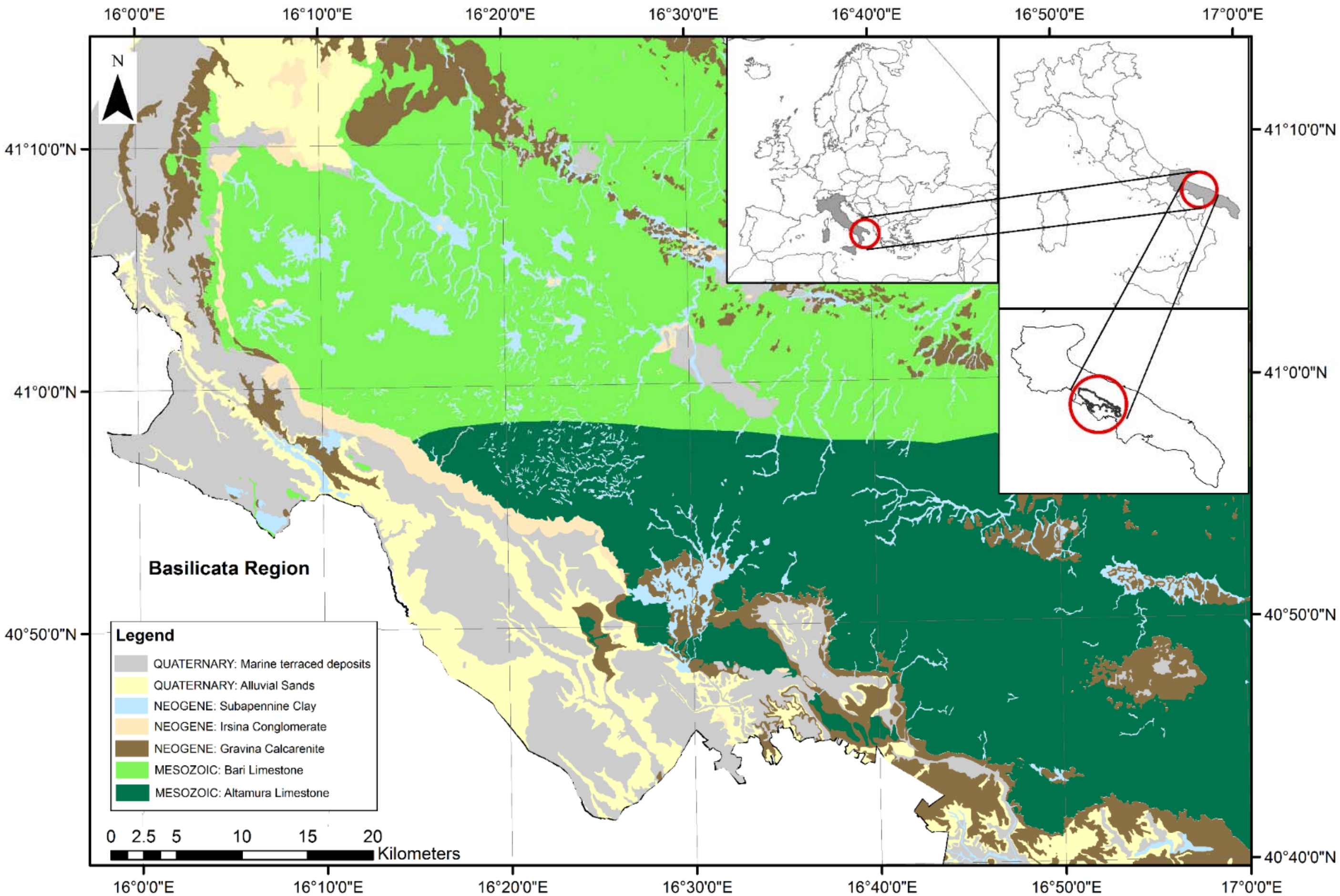
Target: a precise point within the saturated zone

QUANTITATIVE IMPACT OF POLLUTANTS ON GROUNDWATERS AND PHYSICAL ATTENUATION EFFECTS IN THE KARST COASTAL AQUIFER



Choice of the study area*:
Alta Murgia, far from the Adriatic coast

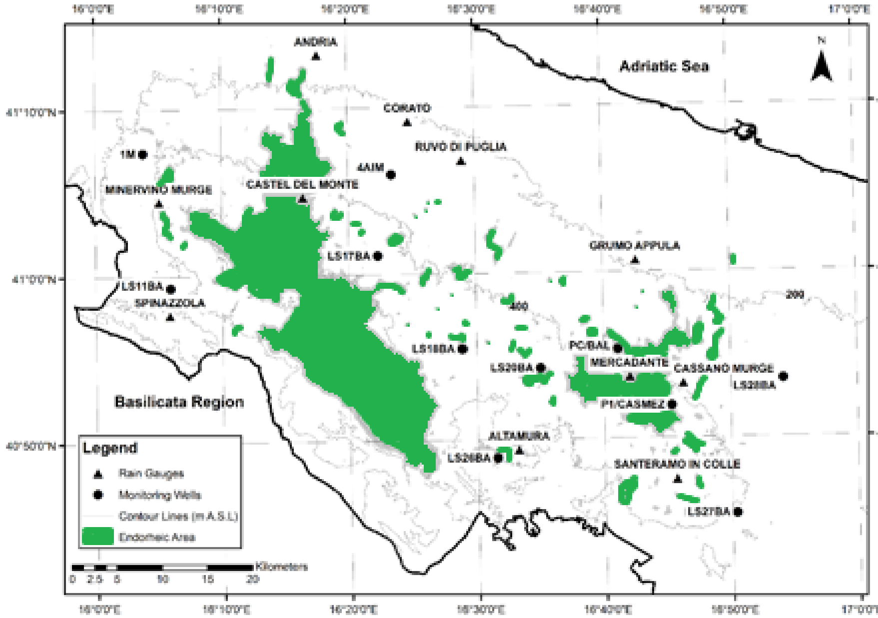
Reason:
Circulation of fresh ground waters not affected by seawater intrusion due to the high hydraulic heads

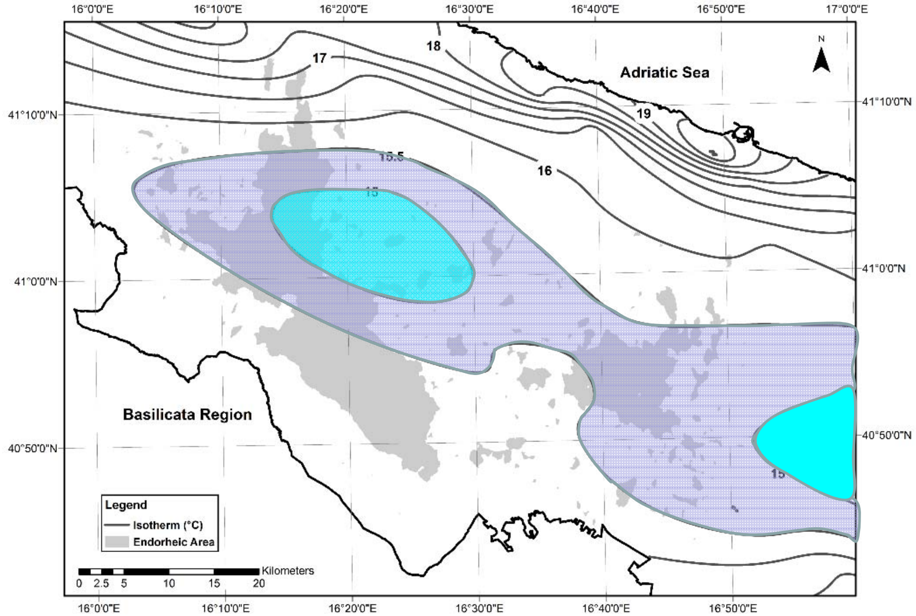


Location and schematic geological features of the study area

Fidelibus M.D., Balacco G., Gioia A., Iacobellis V., Spilotro G.(2016) Mass transport triggered by heavy rainfall: the role of endorheic basins and epikarst in a regional karst aquifer, Hydrological Processes, DOI 10.1002/hyp.11037

The Alta Murgia is the more appropriate zone for the study of the vertical paths from surface to saturated zone (recharge area)

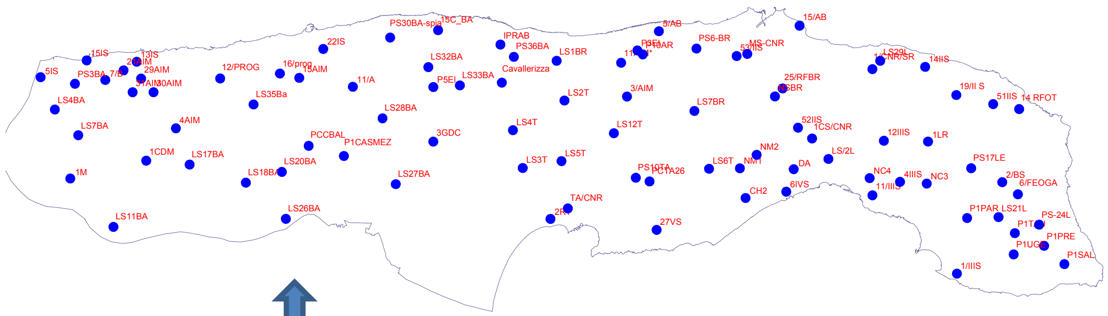




Outline of the endorheic areas in Alta Murgia (GIS Modelling of 8 m resolution DEM): **986 endorheic basins** and sub-basins, with a highly variable geometry and **areal extensions ranging from a few square kilometers to 99.5 km2**

Horizontal ordinary kriging estimation of the temperature distribution at −5 m a.s.l.: **location of the main recharge areas** (included by the **isotherm 15.5°C**) compared to the location of endorheic areas

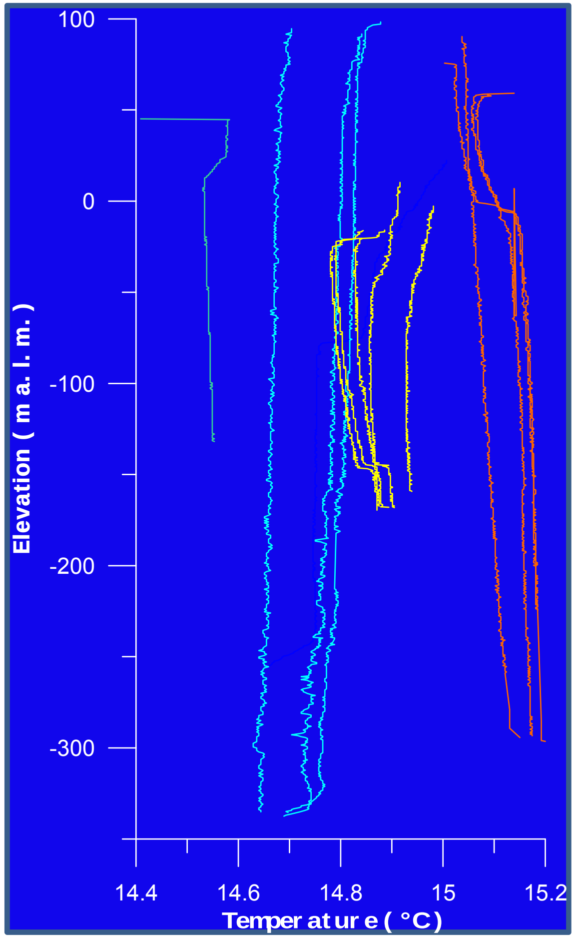
The thermal field is the best tool to recognize recharge areas in anysotropic aquifers



MONITORING WELLS

No. 107 Wells of the Monitoring net of Puglia Regional Government for the control of quantitative and qualitative status of groundwaters in karstic aquifers

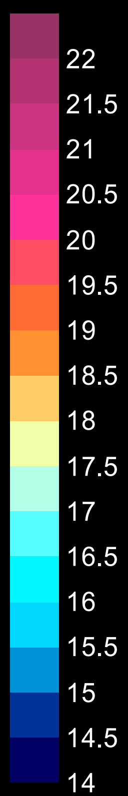
Temperature profiles typical of a recharge area

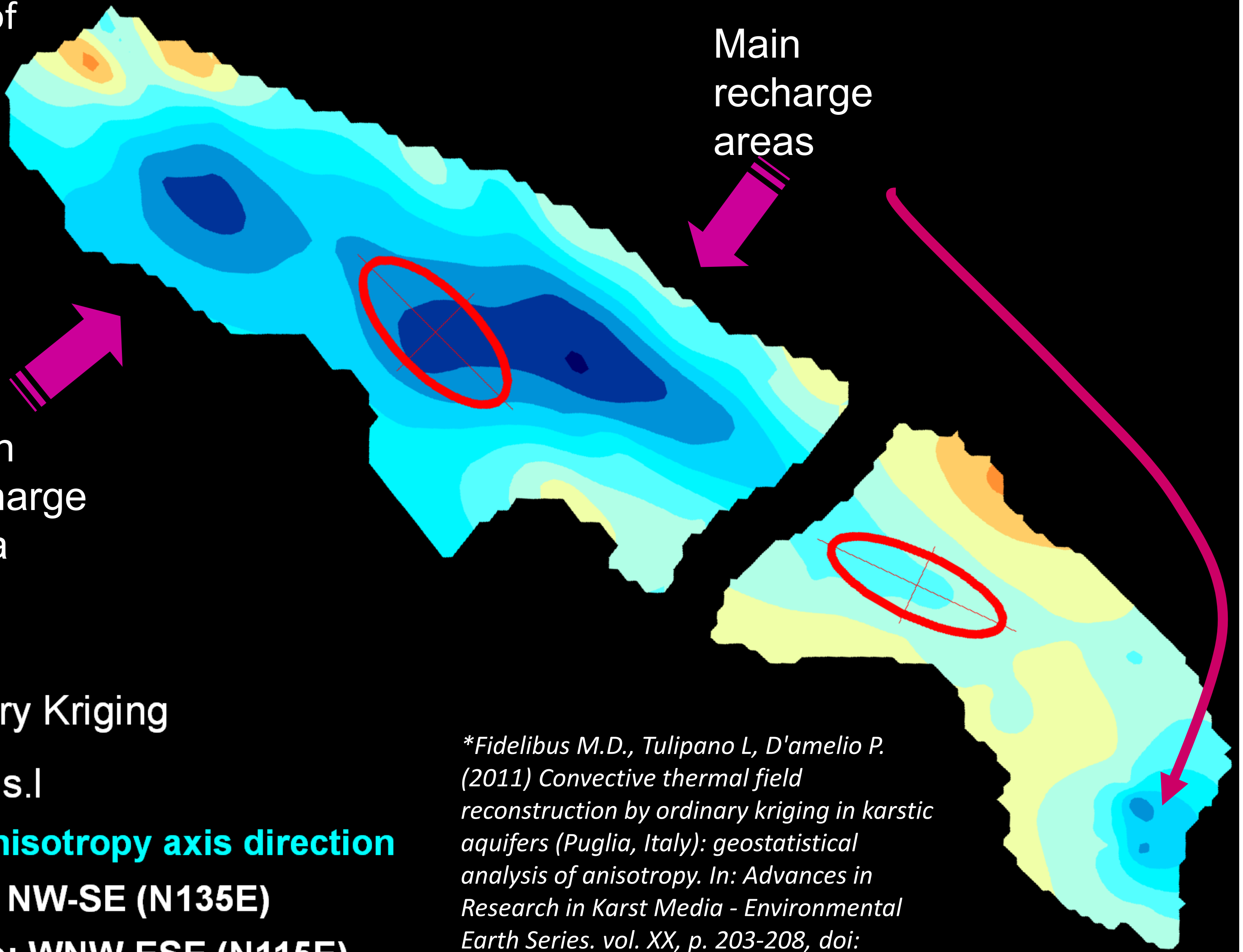


Monitoring period: 1995-1996;
no. 428 temperature (and EC, pH, Eh and O2) profiles (107 wells x 4 profiles)
Selected time horizon for the geostatistical study: 107 profiles of winter 1995

Horizontal sections of the thermal field*

T (°C)





Ordinary Kriging

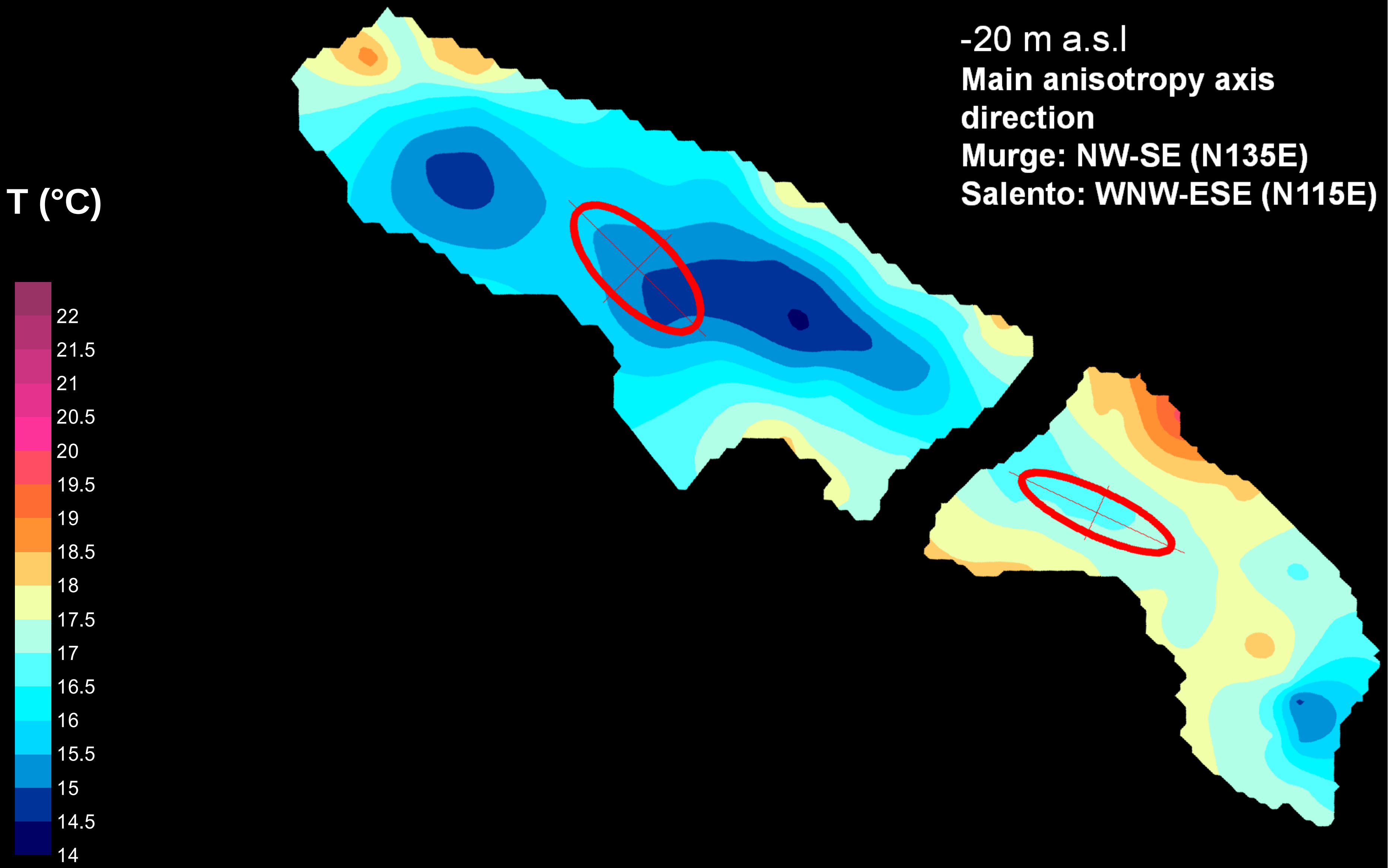
-5 m a.s.l

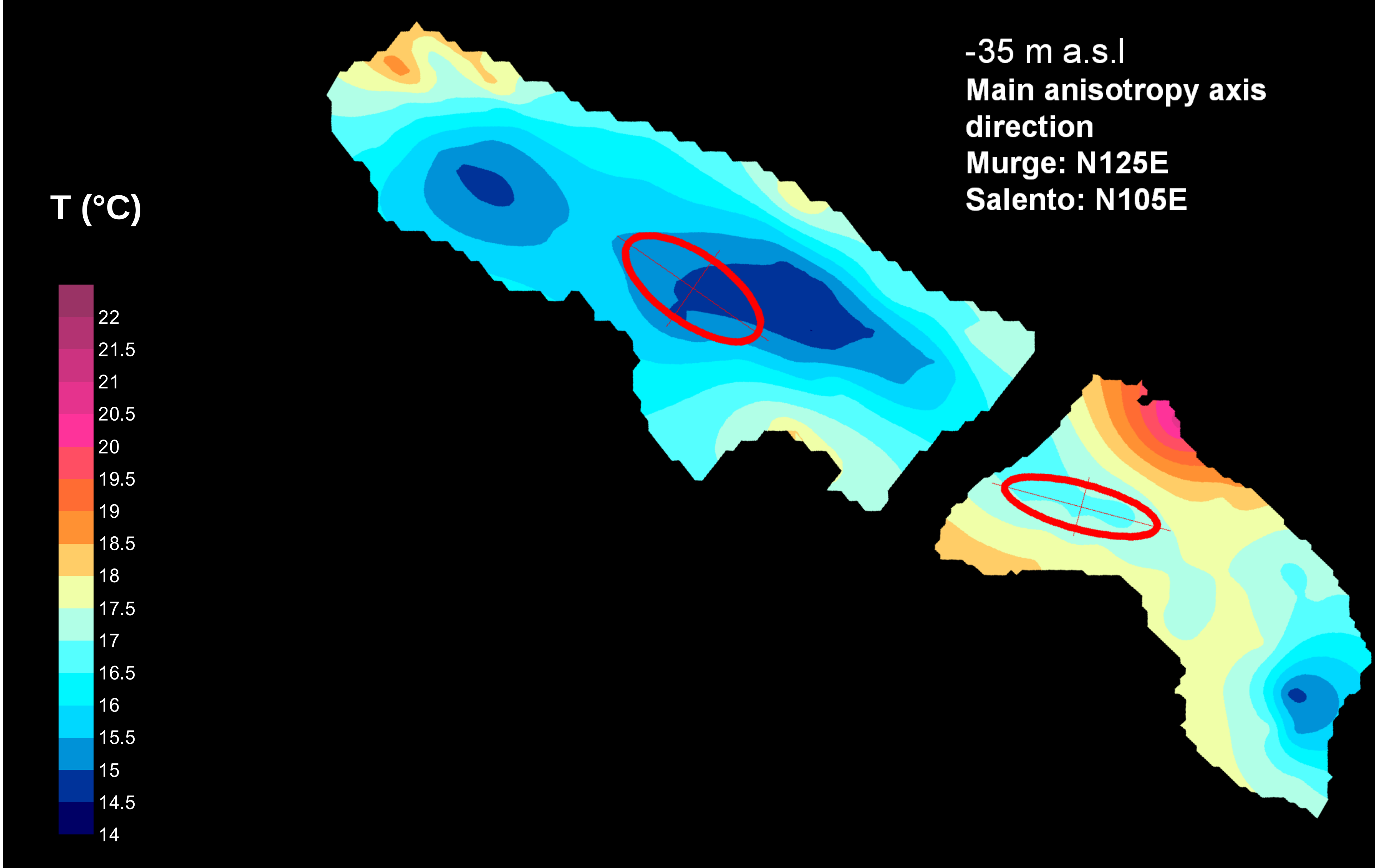
Main anisotropy axis direction

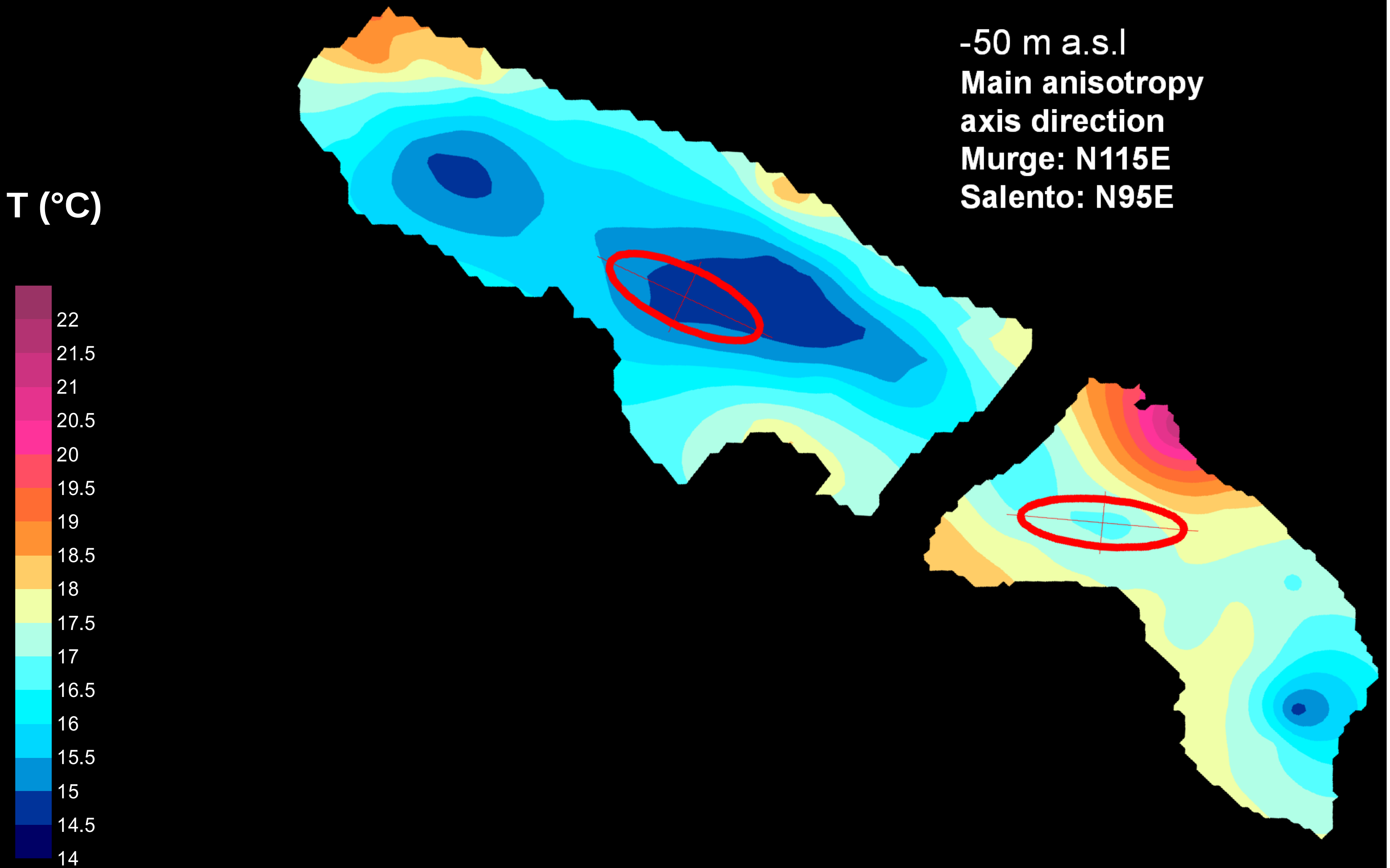
Murge: NW-SE (N135E)

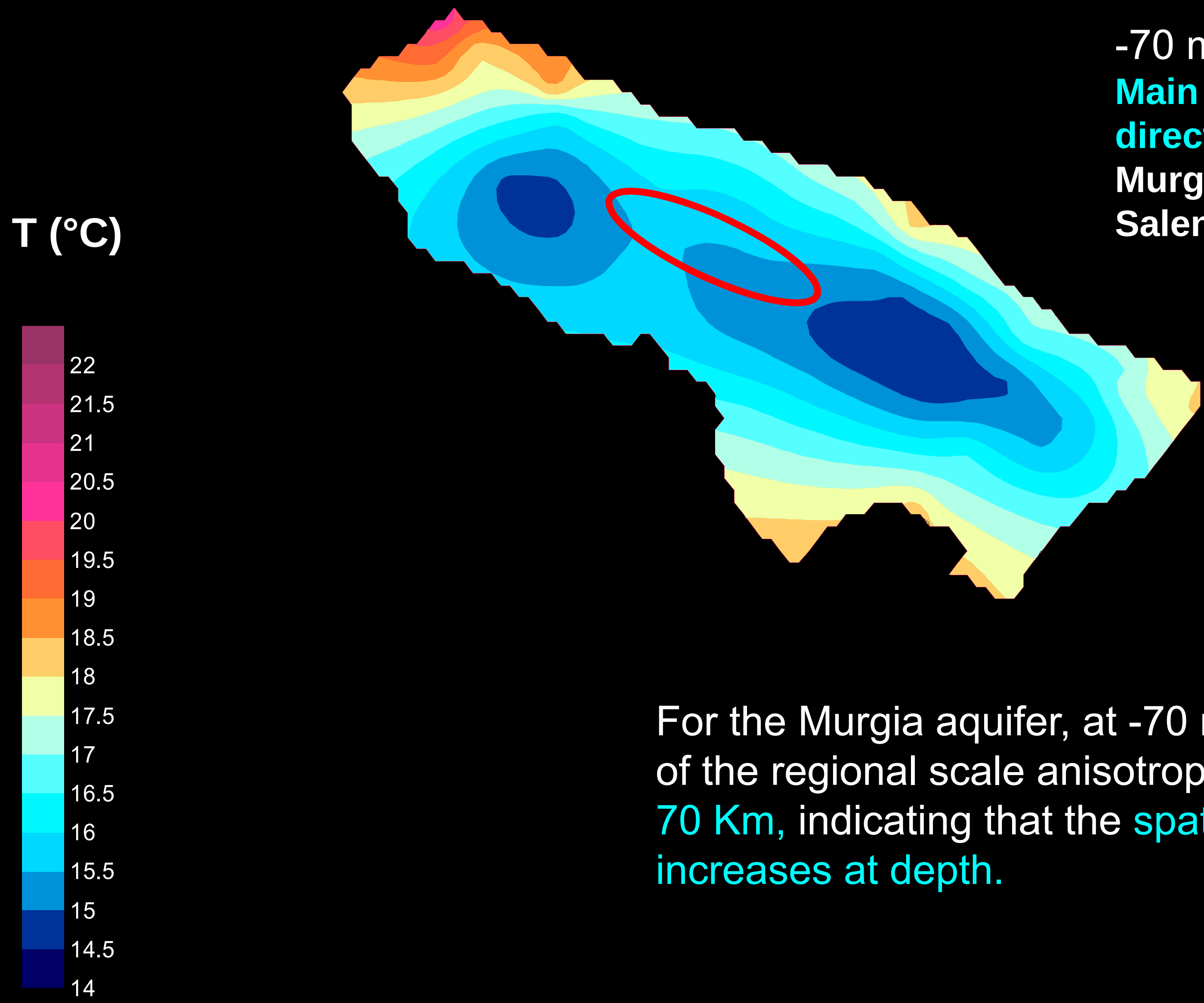
Salento: WNW-ESE (N115E)

**Fidelibus M.D., Tulipano L, D'amelio P. (2011) Convective thermal field reconstruction by ordinary kriging in karstic aquifers (Puglia, Italy): geostatistical analysis of anisotropy. In: Advances in Research in Karst Media - Environmental Earth Series. vol. XX, p. 203-208, doi: 10.1007/978-3-642-12486-0_31*


T (°C)
22
21.5
21
20.5
20
19.5
19
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14
-20 m a.s.l
Main anisotropy axis direction
Murge: NW-SE (N135E)
Salento: WNW-ESE (N115E)


-35 m a.s.l
Main anisotropy axis direction
Murge: N125E
Salento: N105E
T (°C)
22
21.5
21
20.5
20
19.5
19
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14


T (°C)
22
21.5
21
20.5
20
19.5
19
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14
-50 m a.s.l
Main anisotropy axis direction
Murge: N115E
Salento: N95E



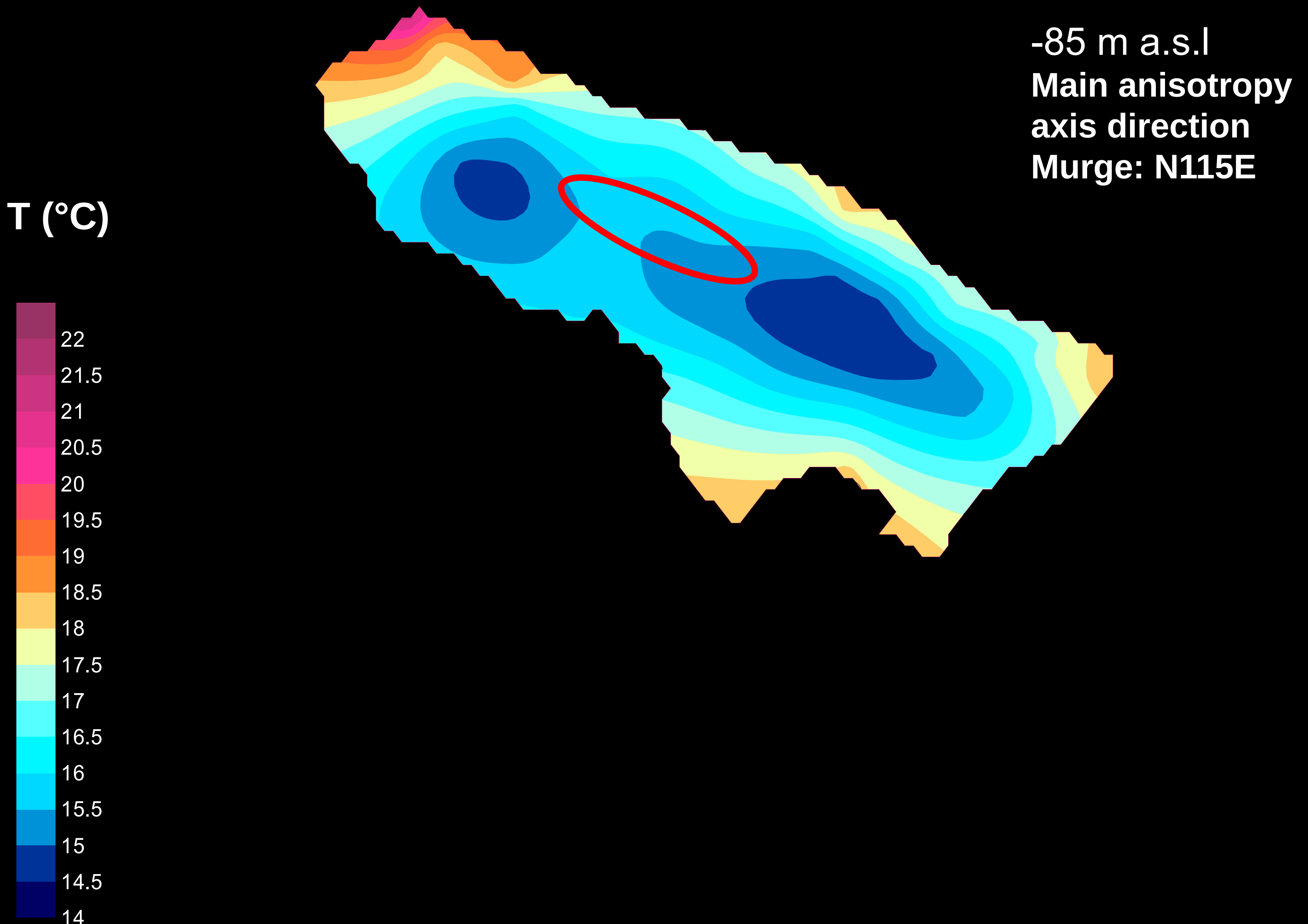
-70 m a.s.l

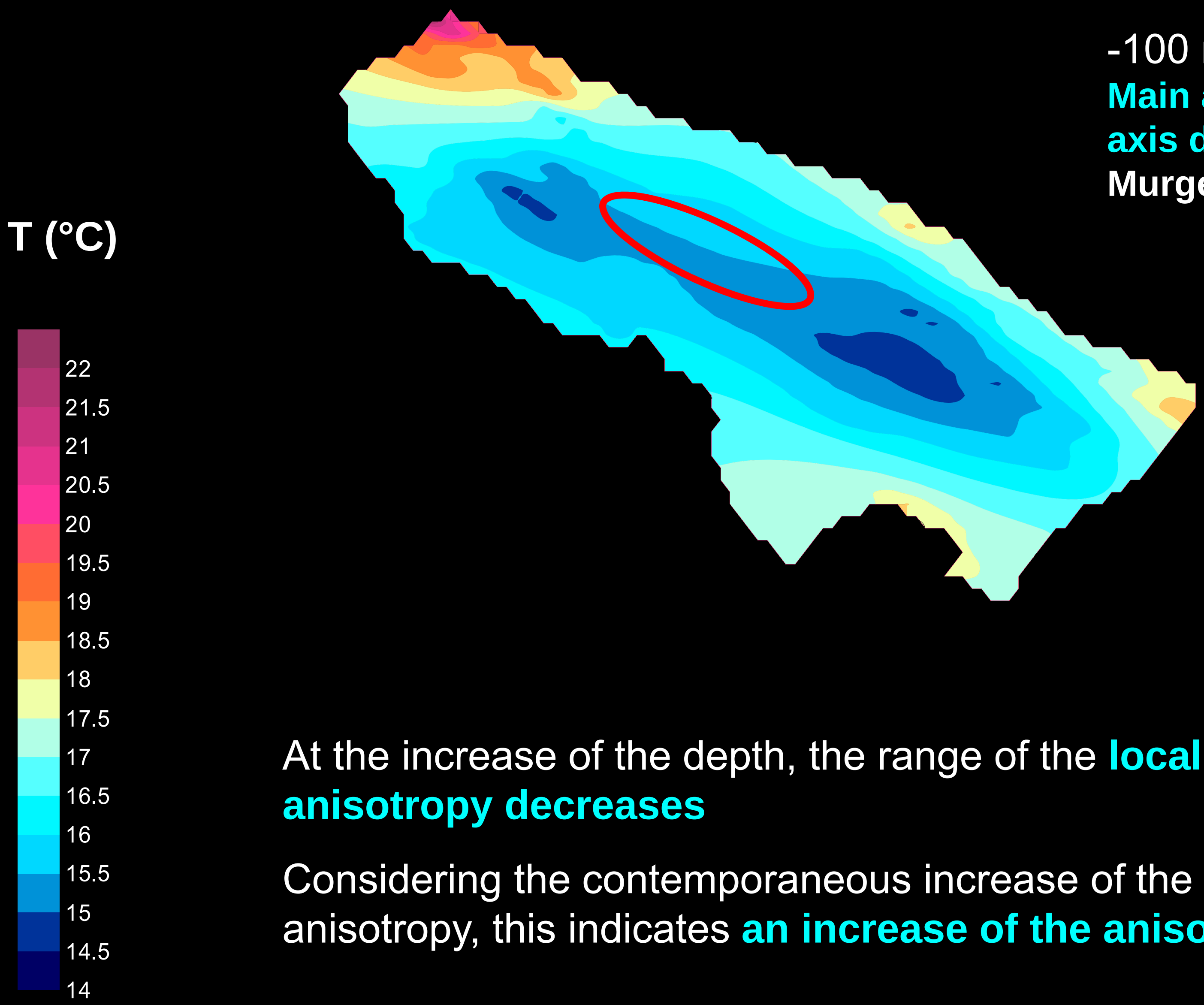
Main anisotropy axis direction

Murge: N115E

Salento: isotropic?

For the Murgia aquifer, at -70 m AMSL, the range of the regional scale anisotropy jumps from 48 to 70 Km, indicating that the spatial continuity increases at depth.


-85 m a.s.l
Main anisotropy axis direction Murge: N115E
T (°C)
22
21.5
21
20.5
20
19.5
19
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14



-100 m a.s.l

Main anisotropy axis direction

Murge: N115E

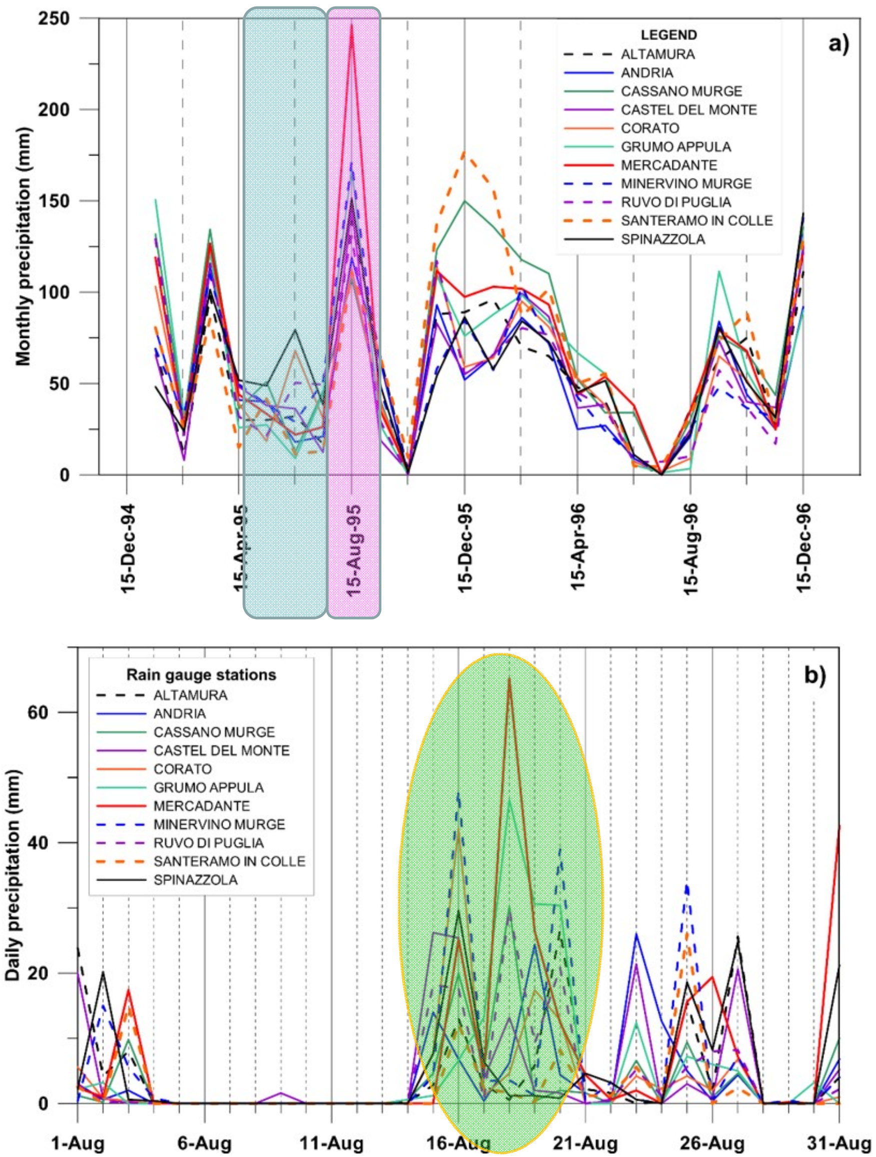
At the increase of the depth, the range of the **local scale anisotropy decreases**

Considering the contemporaneous increase of the regional anisotropy, this indicates **an increase of the anisotropy**

The study in Alta Murgia relies on a period of groundwater monitoring, which included a peculiar climate sequence (August 1995): a dry period followed by a hydrological stress

August 1995 was characterized by significant rainfall events: These rainfall events follow **a period of null recharge of 4 months**

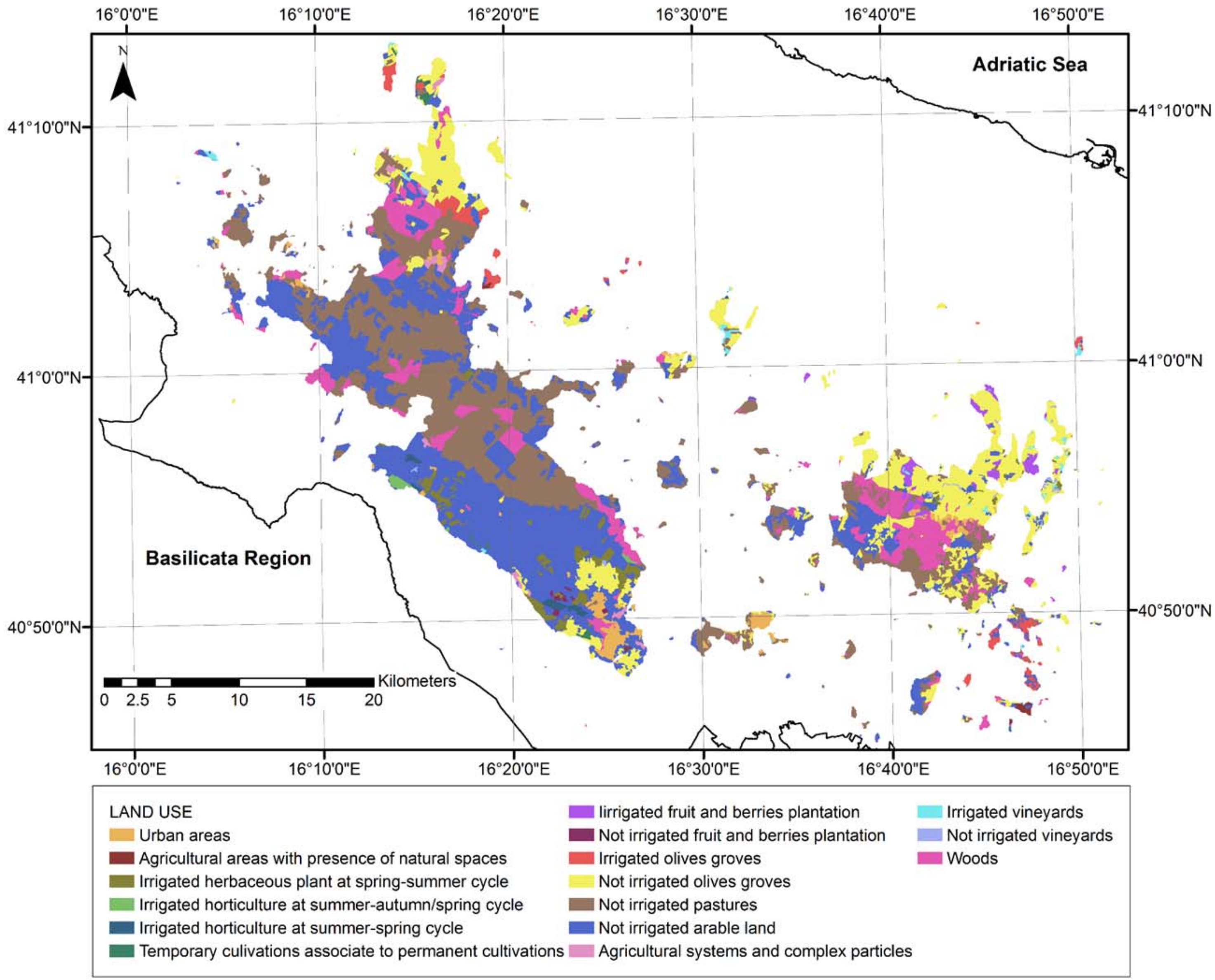
The rainfall events occurred between 16 and 20 of August 1995 were **quite significant for their spatial extent and interested the entire endorheic area**



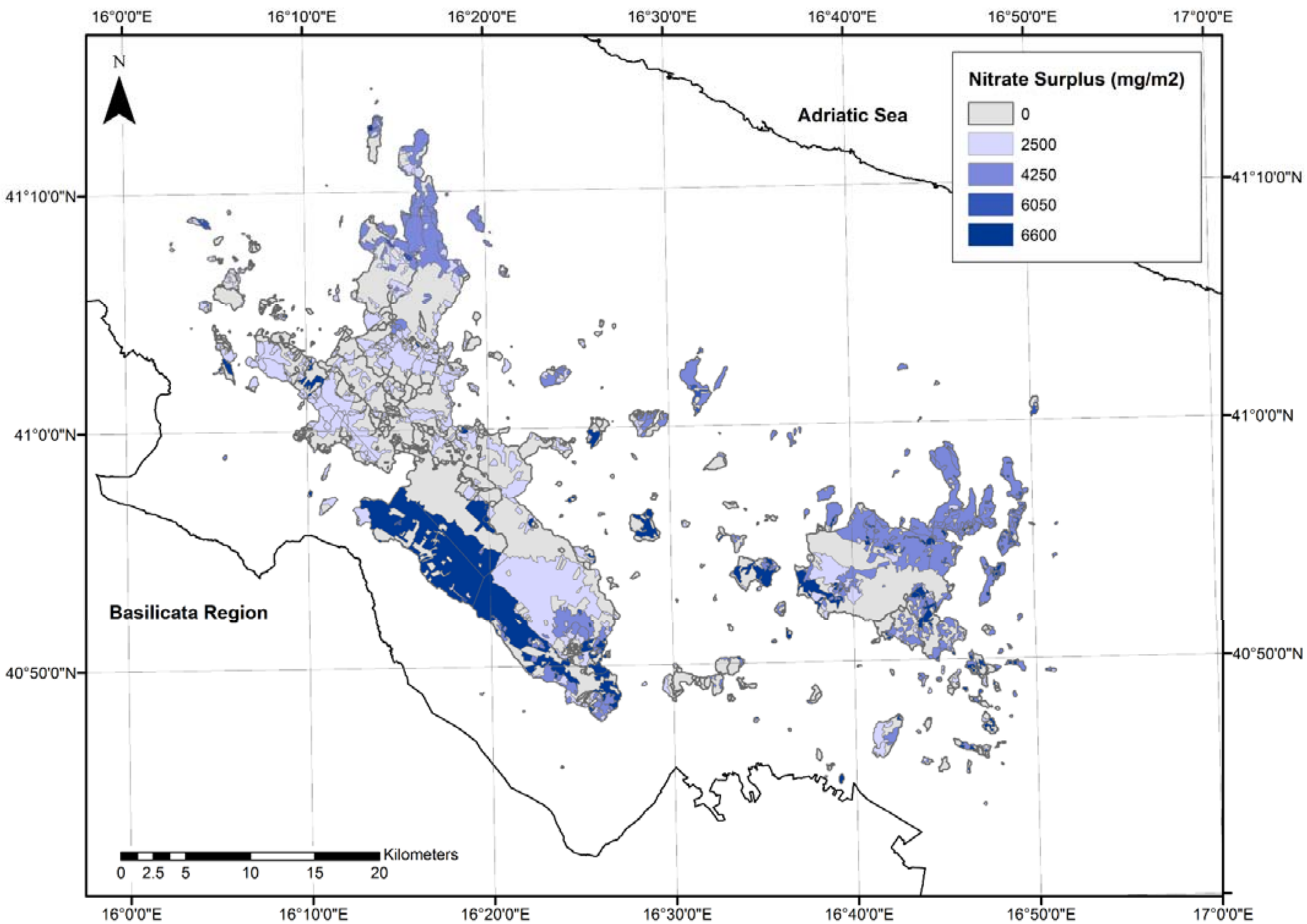
Calculation of nitrate load in the effective infiltration waters of August 1995

a - Assessment of the land use in the selected period.

The land use map of the endorheic area derive from the SIGRIA (Information System for Water Management for Irrigation, INEA, 2001).



b) Evaluation of the nitrate surplus potentially avalaible for leaching



Nitrate surplus (mg/m^2)

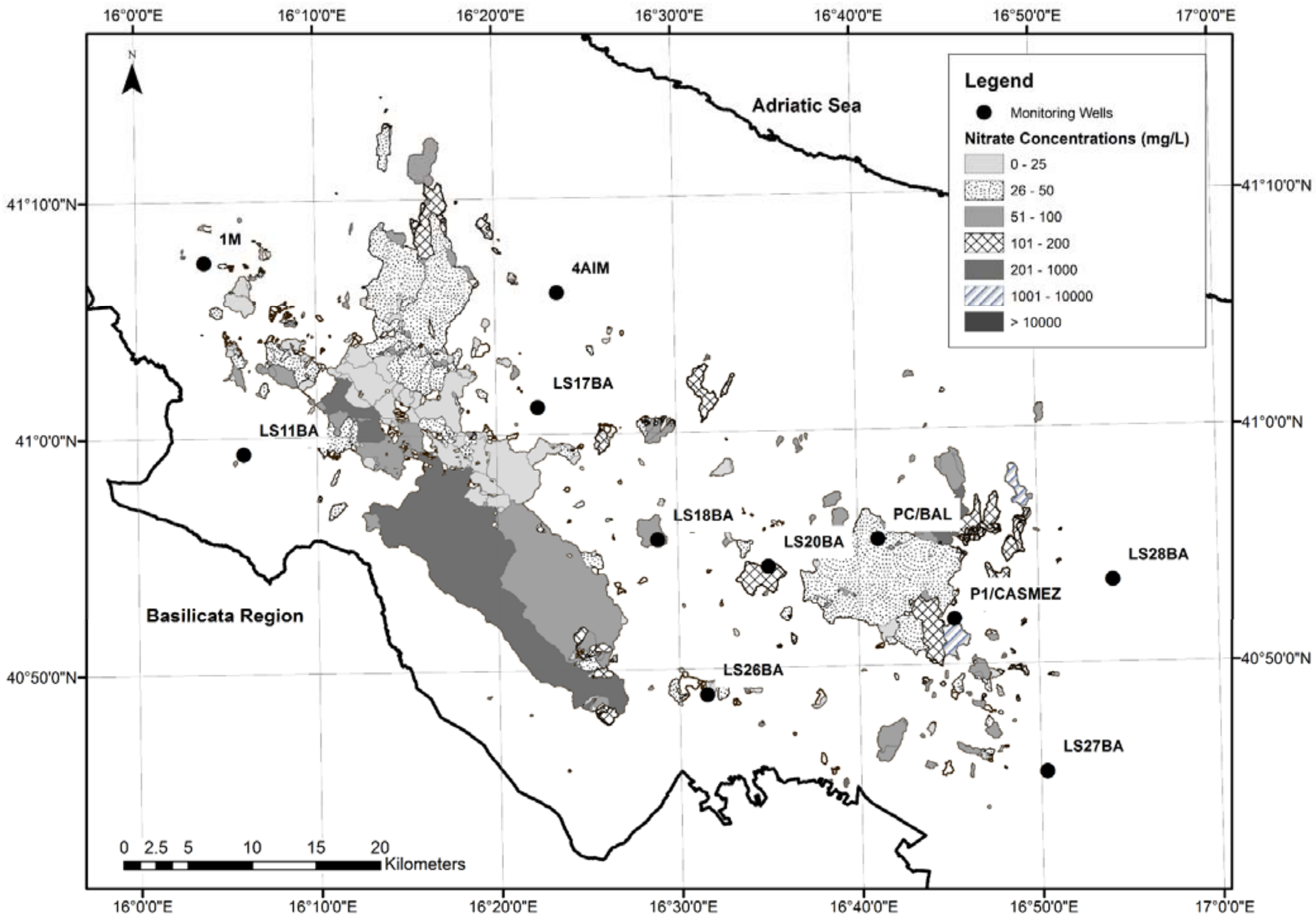
c) - Calculation of nitrate concentration in recharge volumes

Assumptions:

(a) all runoff and precipitation exceeding evapotranspiration infiltrate;

(b) nitrate surplus before precipitation events is set equal to the total annual nitrate surplus;

(c) all the nitrate surplus is leached by the total effective infiltration of August 1995.



The **average concentration of nitrates in the whole volume of the autogenic recharge from endorheic basins of the period** is ***54 mg/L*.**

d) – Rection of groundwater to the hydrological stress

The wells considered for the validation of the previous modeling were selected among those of the Regional monitoring net located in the recharge area
They are even 800 m long
They have the highest chance to directly catch the autogenic recharge: the selected wells are close to (or in direct correspondence of) the endorheic basins.

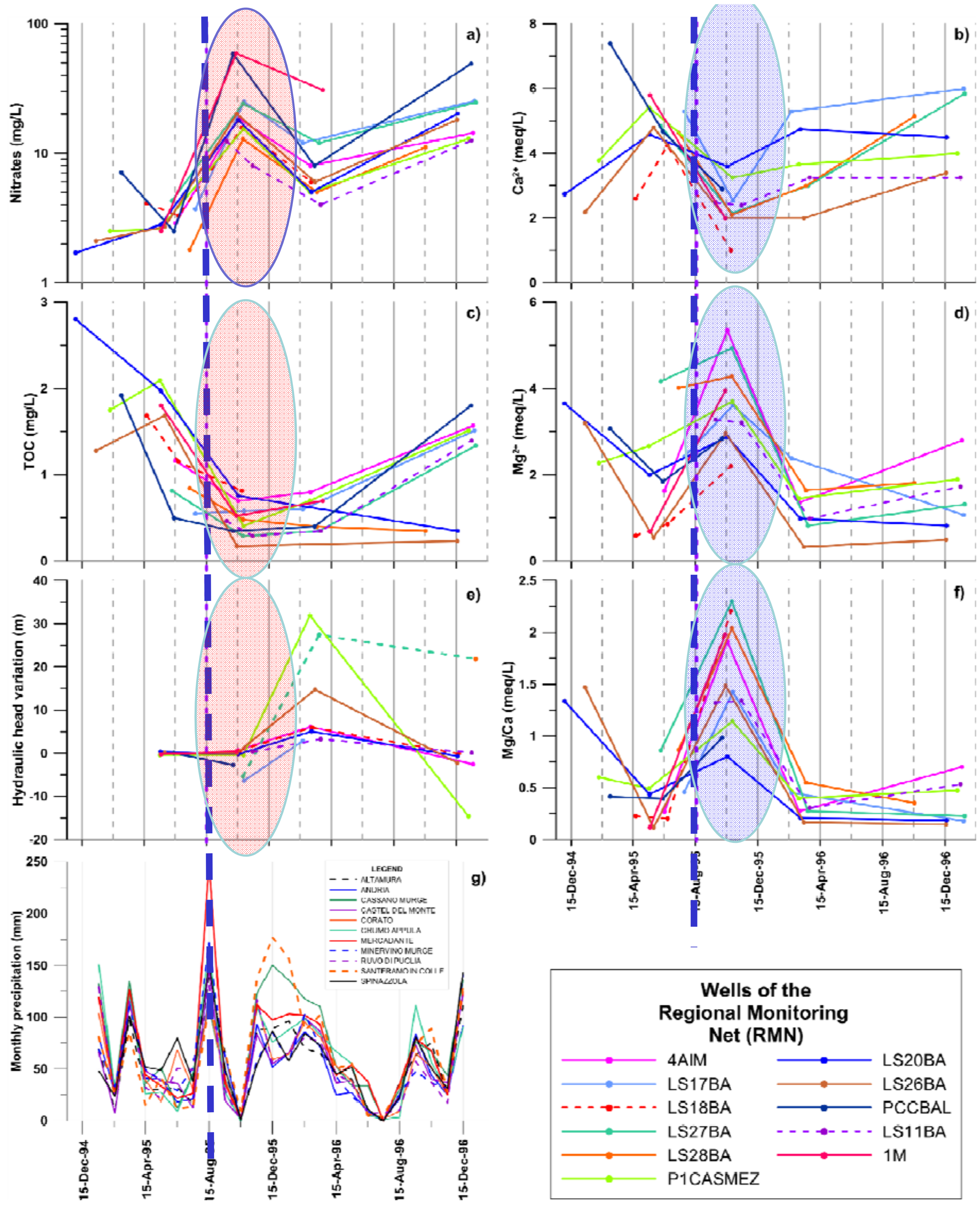
The following figure shows the time trend of nitrates, calcium, TOC, magnesium concentrations, and Mg/Ca ratio with reference to groundwater samples taken at the selected wells of the RMN during the monitoring period.
Moreover, it shows the variation of the hydraulic heads measured at the same wells during the same period.

Nitrate concentrations are around **5 mg/L** (background) before the rainfall event (May–June 1995. They increase up to maximum values of ***60 mg/L*** after the hydrological stress

Variations In the post-event period,

- **magnesium** concentrations increase,
- **-calcium and TOC** concentrations **decrease, Mg/Ca (molar) ratio increases**
- **h**ydraulic heads do not show variation

The nitrate concentrations measured in ground waters during the post-event time are in the **range 10–60 mg/L**. These concentrations ***are comparable to the nitrate concentrations of the autogenic recharge waters resulting from modeling***



Conceptual model

Summer season

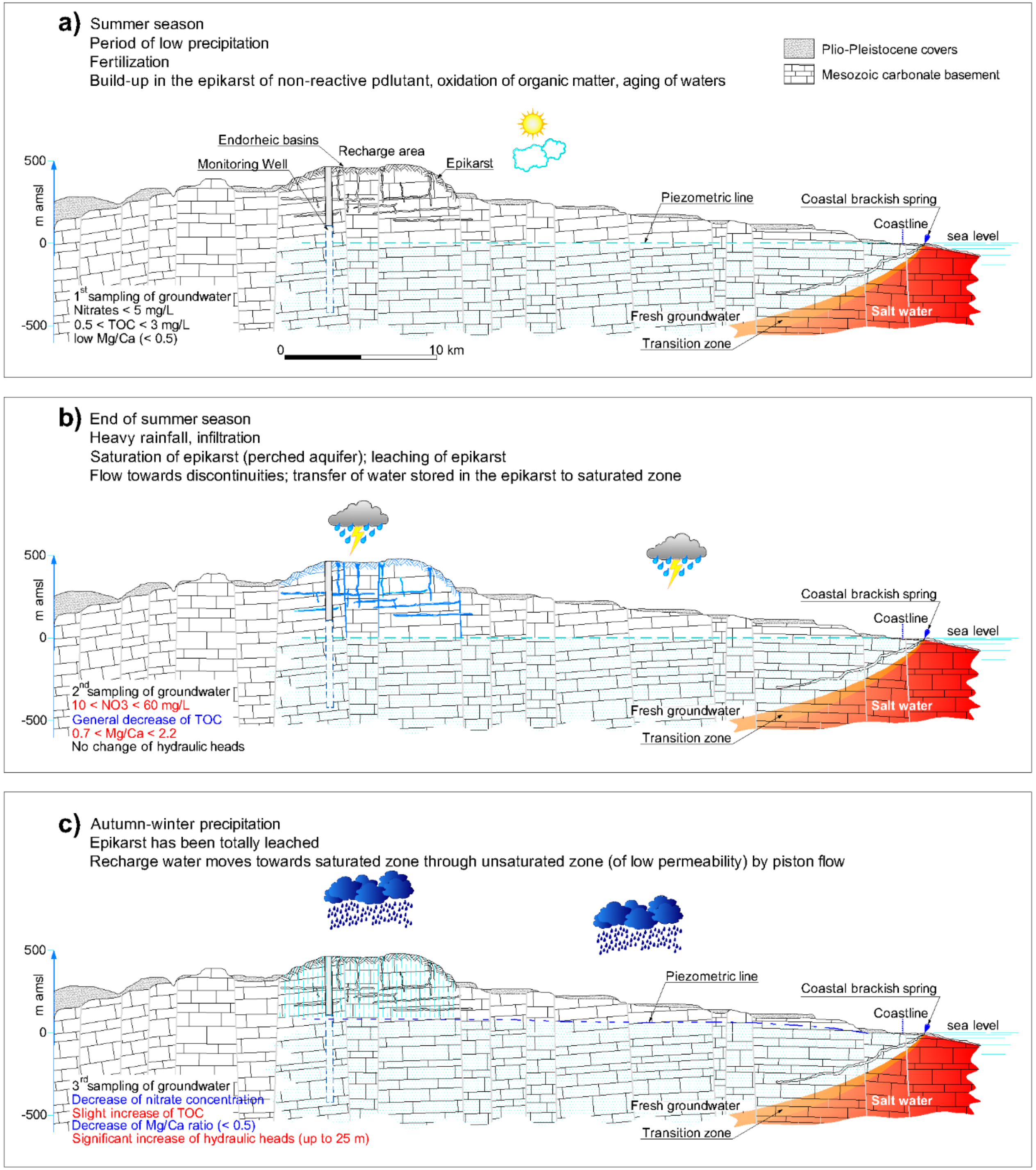
Period of low recharge: non-reactive pollutants, as nitrates, ***accumulate in the epikarst***, while organic matter oxidises and water-rock interaction determine progressive evolution of waters

End of summer season - Heavy rainfall events

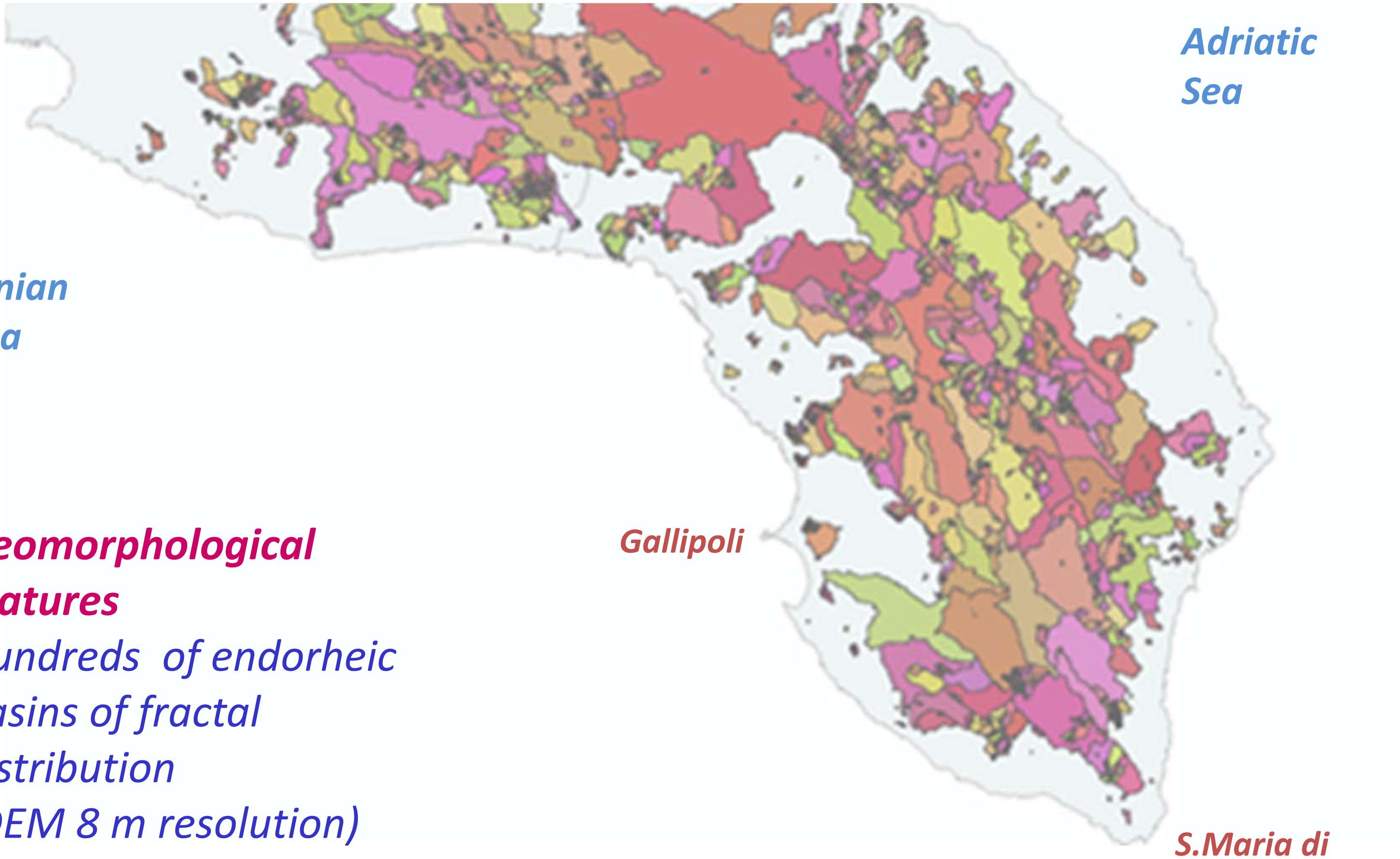
Saturation of the epikarst. Water stored in epikarst and conduits flows towards saturated zone, ***conveying reactive and non-reactive pollutant load***. NO3 and Mg/Ca ratios are both higher than the pre-event period, while TOC decreases. ***Hydraulic heads do not significantly increase***

Autumn precipitation

progressively leaches the epikarst; recharge waters move through the low permeability unsaturated zone. NO3 and Mg/Ca ratio decrease. TOC decreases ***The hydraulic heads increase***.

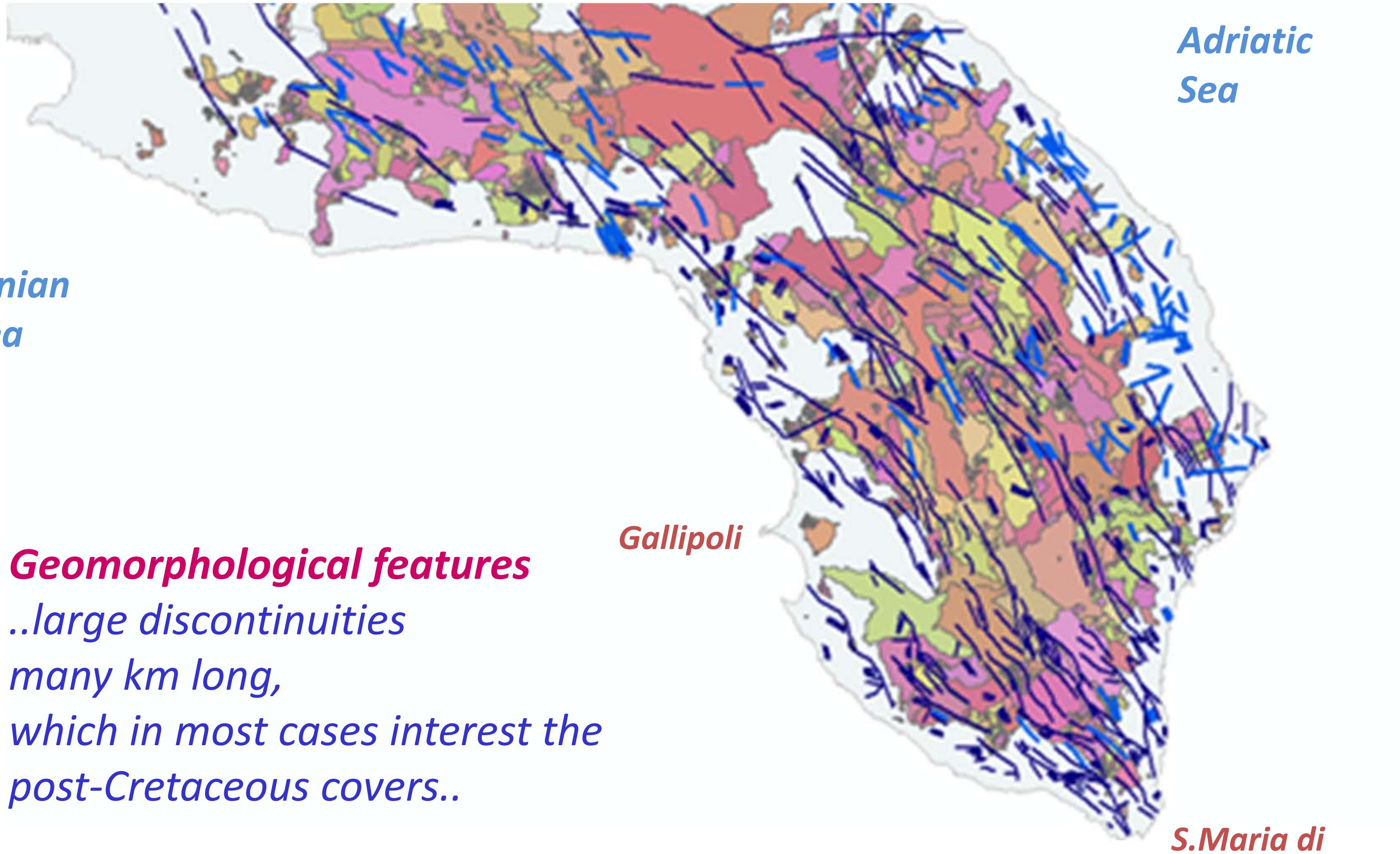


What about Salento intrinsic vulnerability?



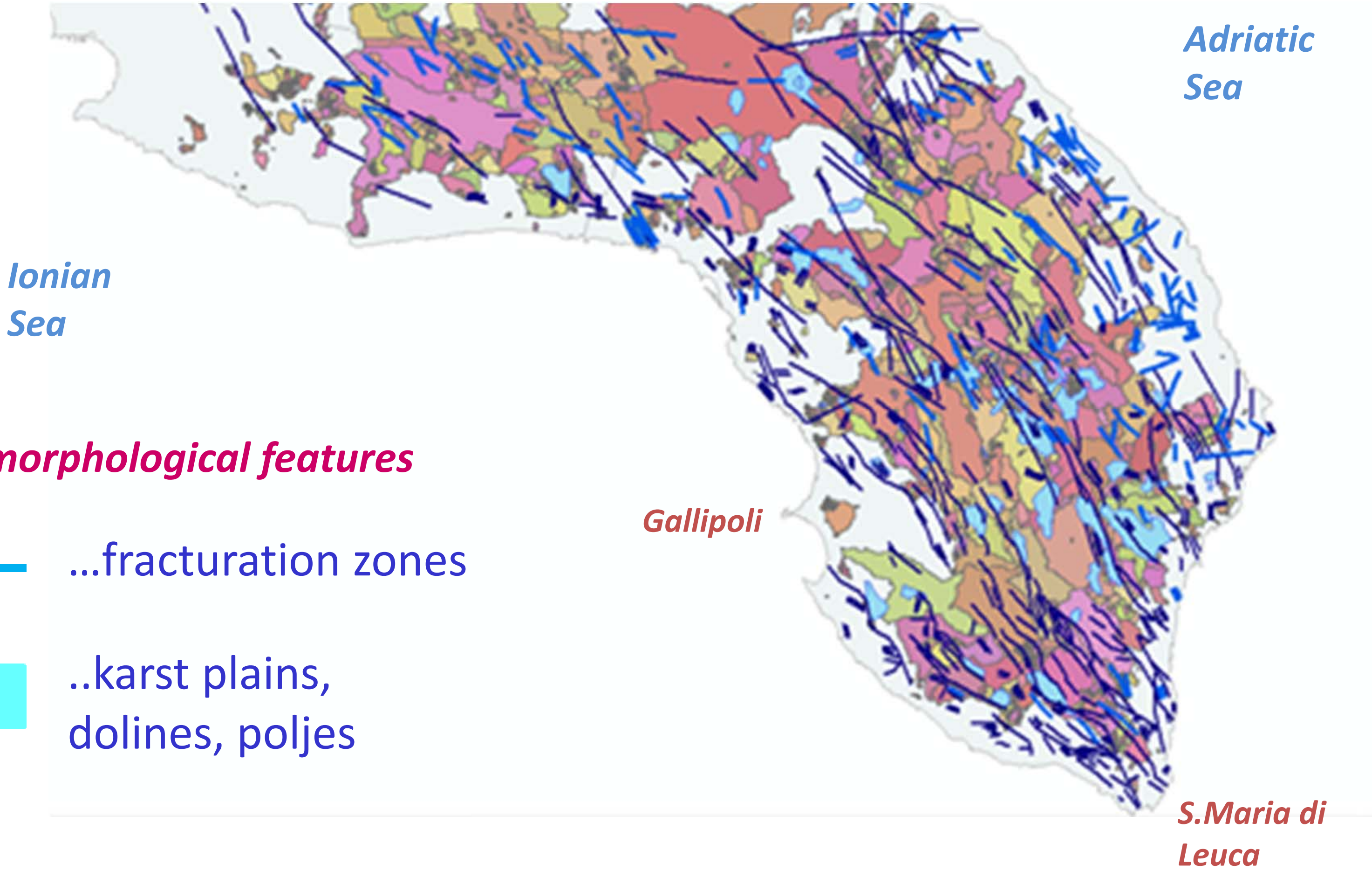
Geomorphological features

Hundreds of endorheic basins of fractal distribution (DEM 8 m resolution)



Geomorphological features

..large discontinuities many km long, which in most cases interest the post-Cretaceous covers..



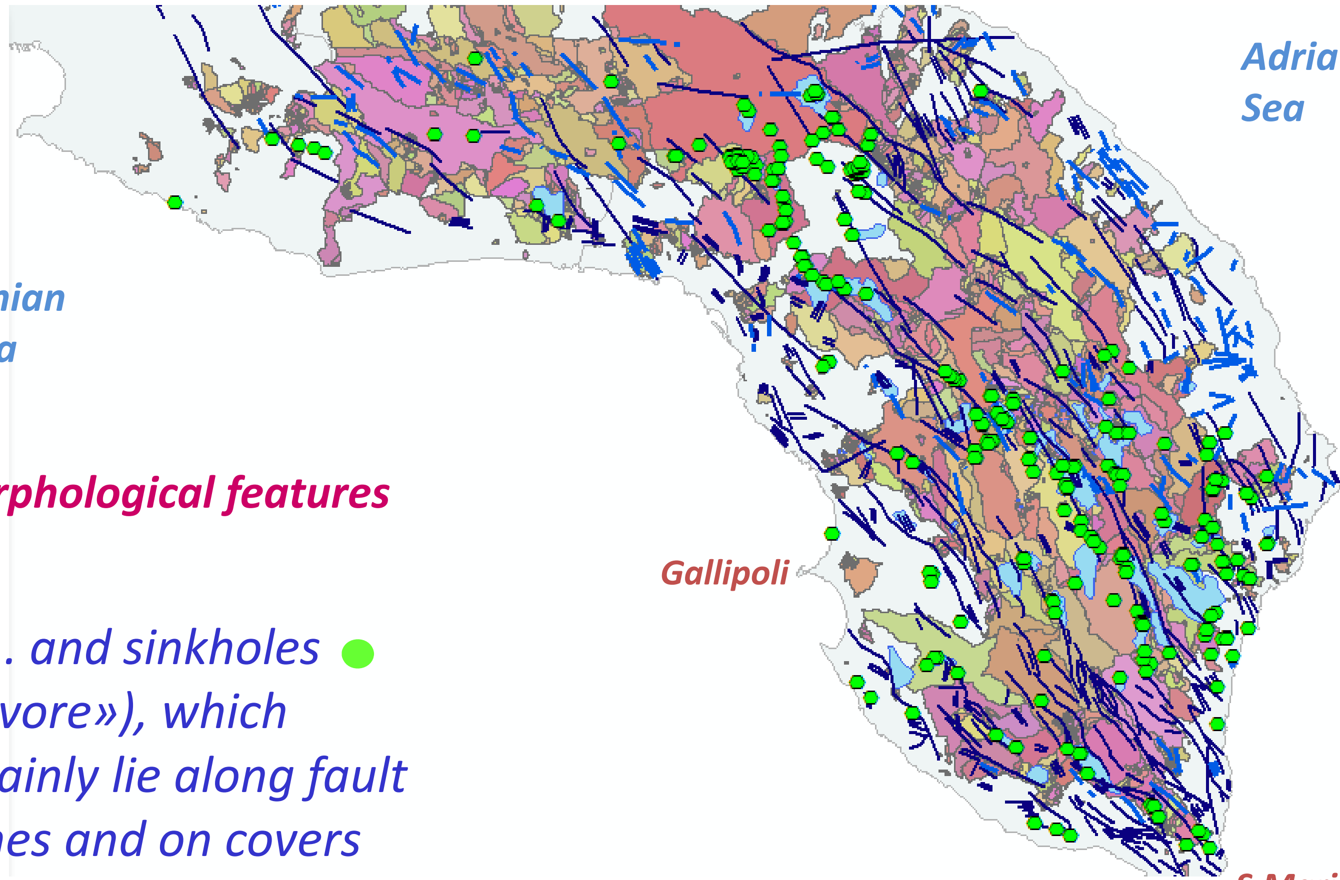
Geomorphological features

…fracturation zones

..karst plains, dolines, poljes

Adriatic Sea

Ionian Sea

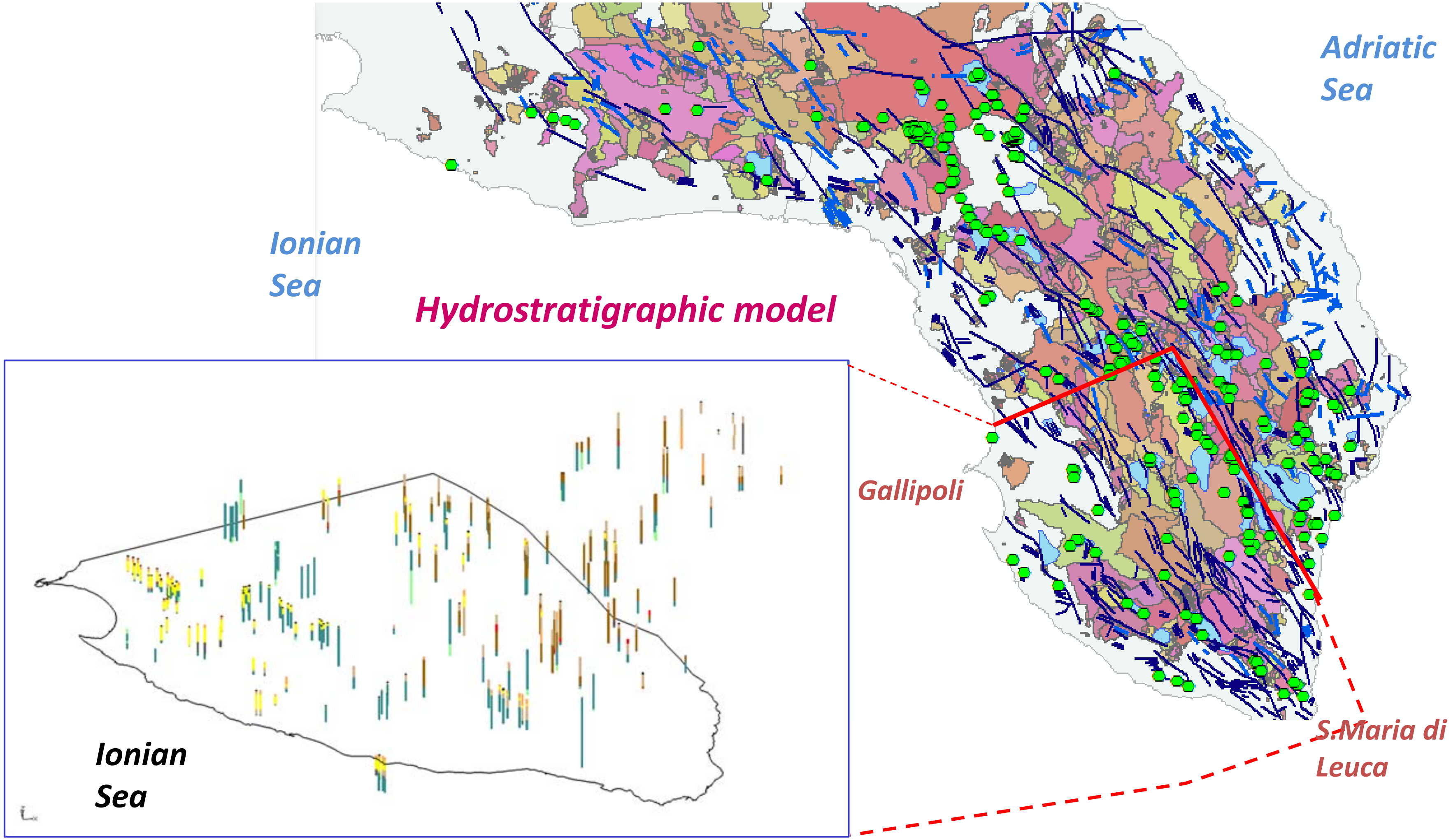


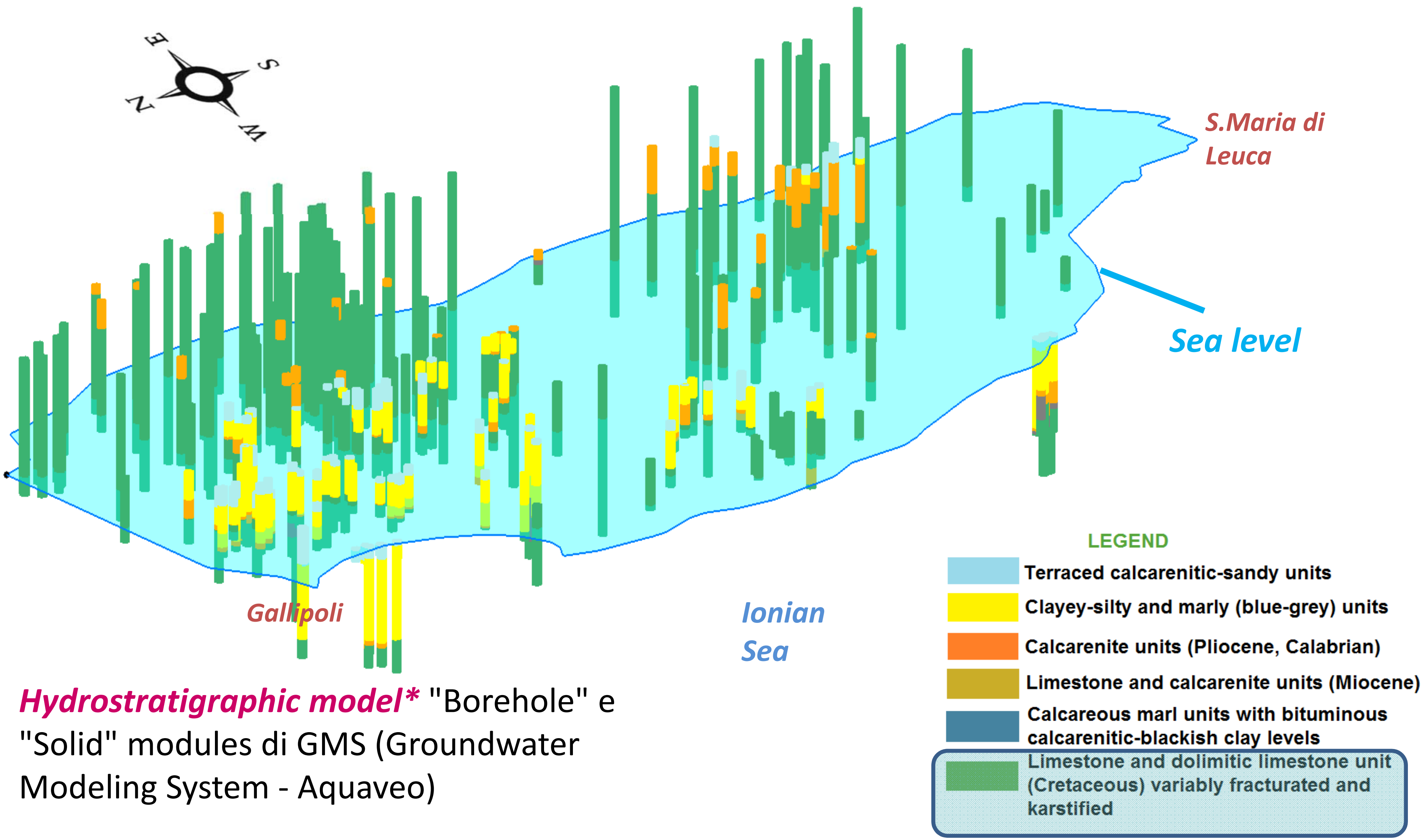
S.Maria di Leuca

Geomorphological features

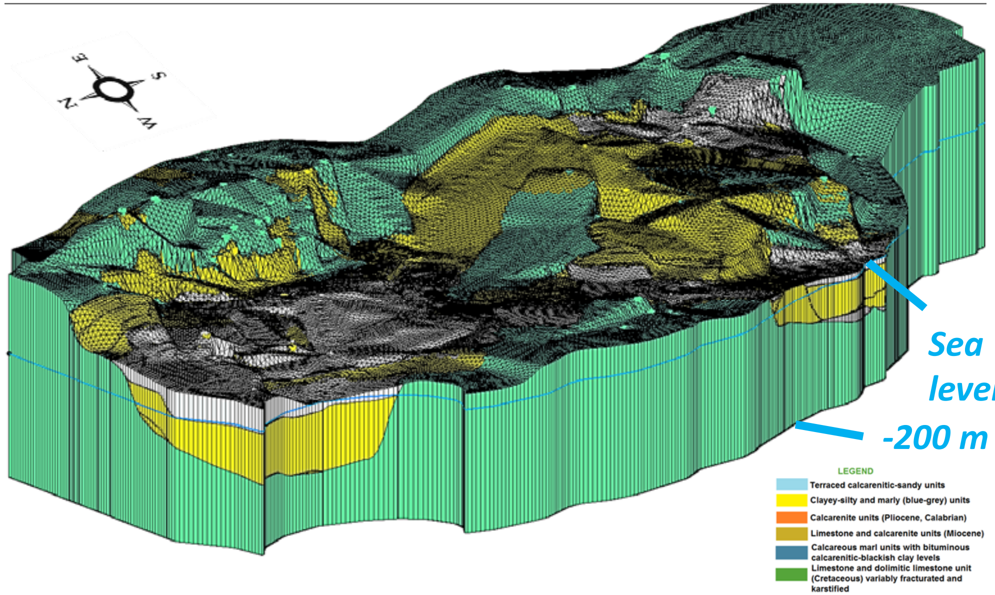
….. and sinkholes (« vore »), which mainly lie along fault lines and on covers

Hydrostratigraphic model





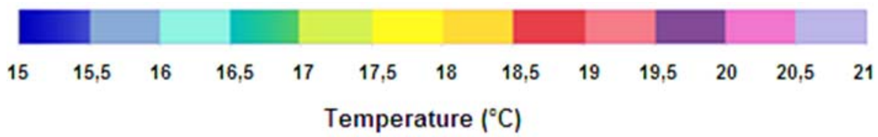
Hydrostratigraphic model* "Borehole" e "Solid" modules di GMS (Groundwater Modeling System - Aquaveo)

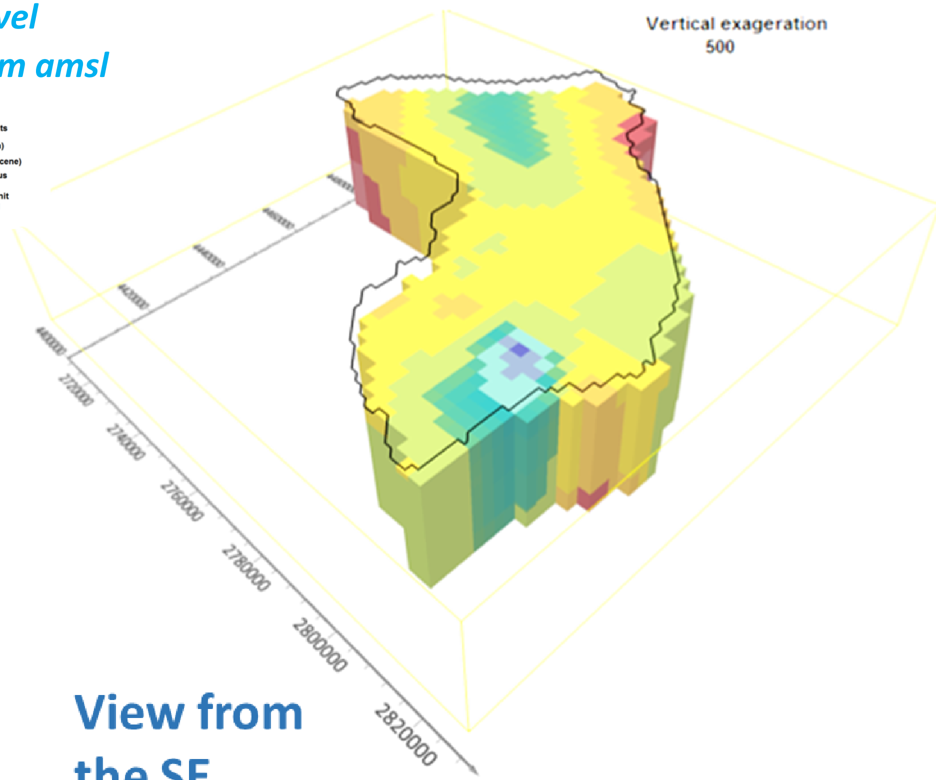


Hydrostratigraphic model "Borehole" e "Solid" modules di GMS (Groundwater Modeling System - Aquaveo)

Courtesy of D.Sollitto – AdB Puglia

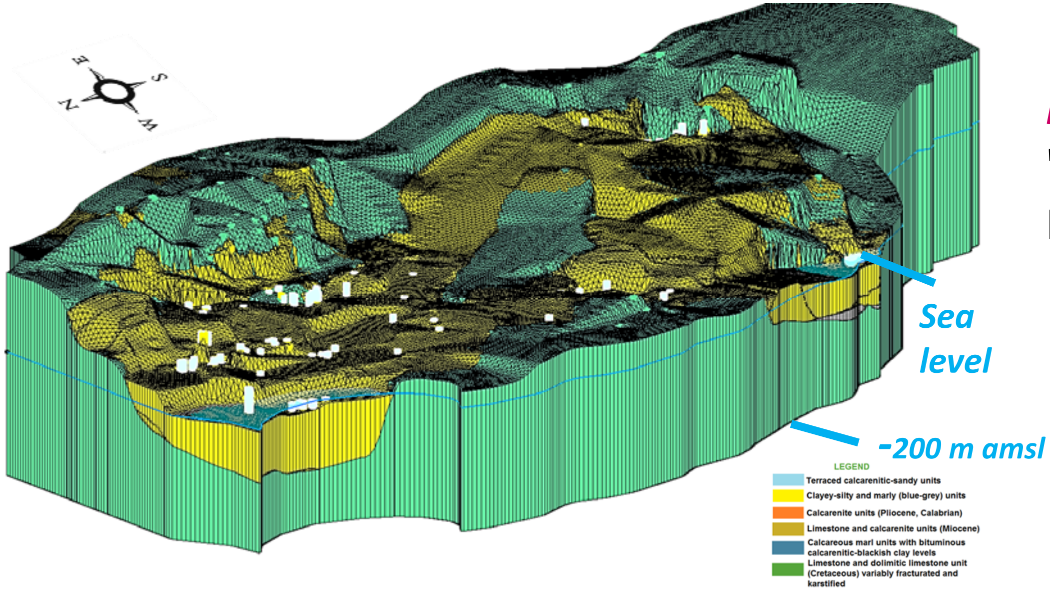
3D interpolation of thermal horizontal sections at -5, -20, -35. -50 m amsl Summer 2010*





View from the SE

Courtesy of E.Barca and G. Passarella – IRSA CNR Bari



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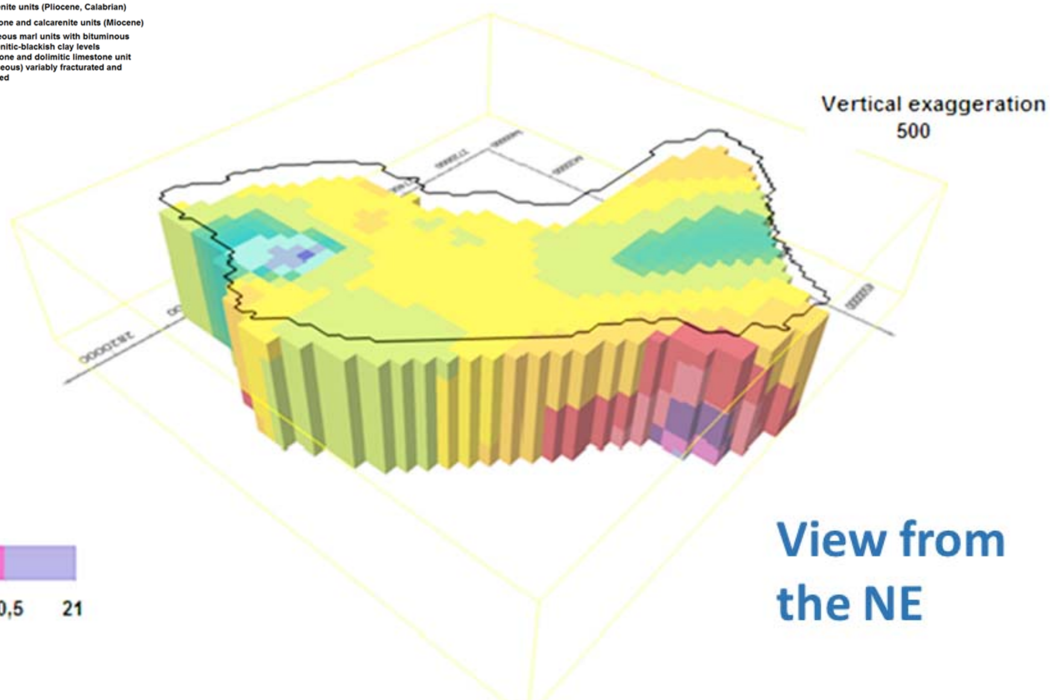
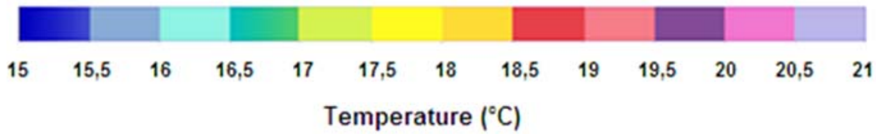
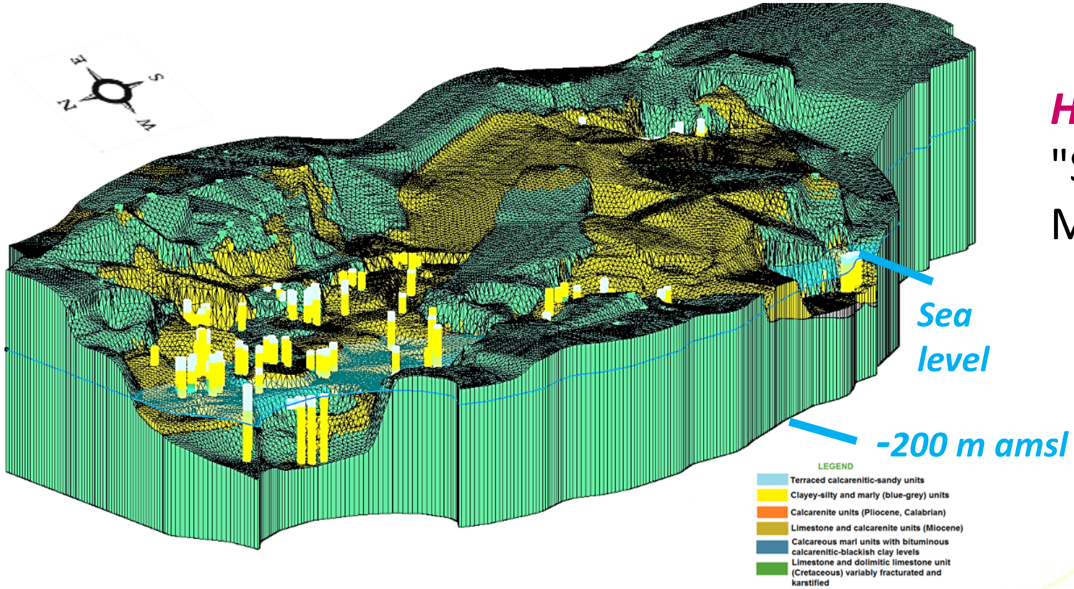


3D interpolation of thermal horizontal sections at -5, -20, -35. -50 m amsl Summer 2010





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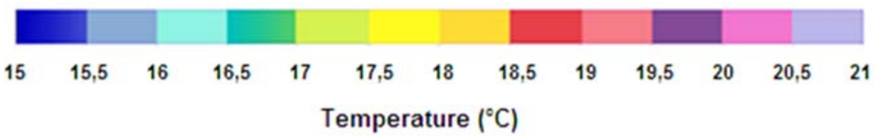
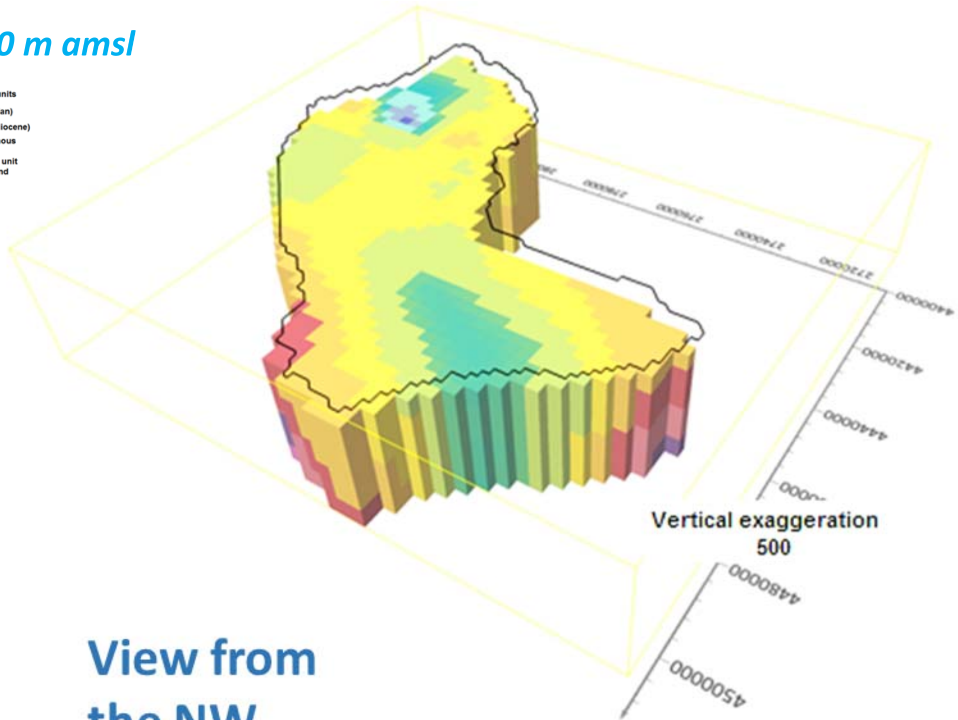
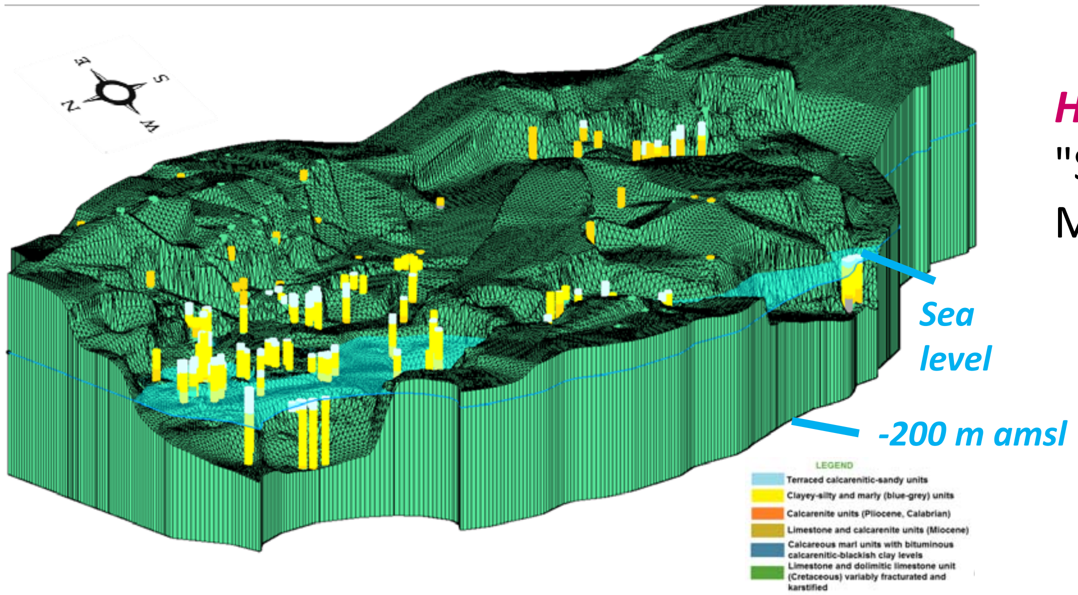


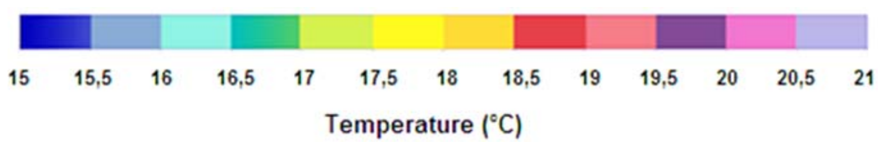


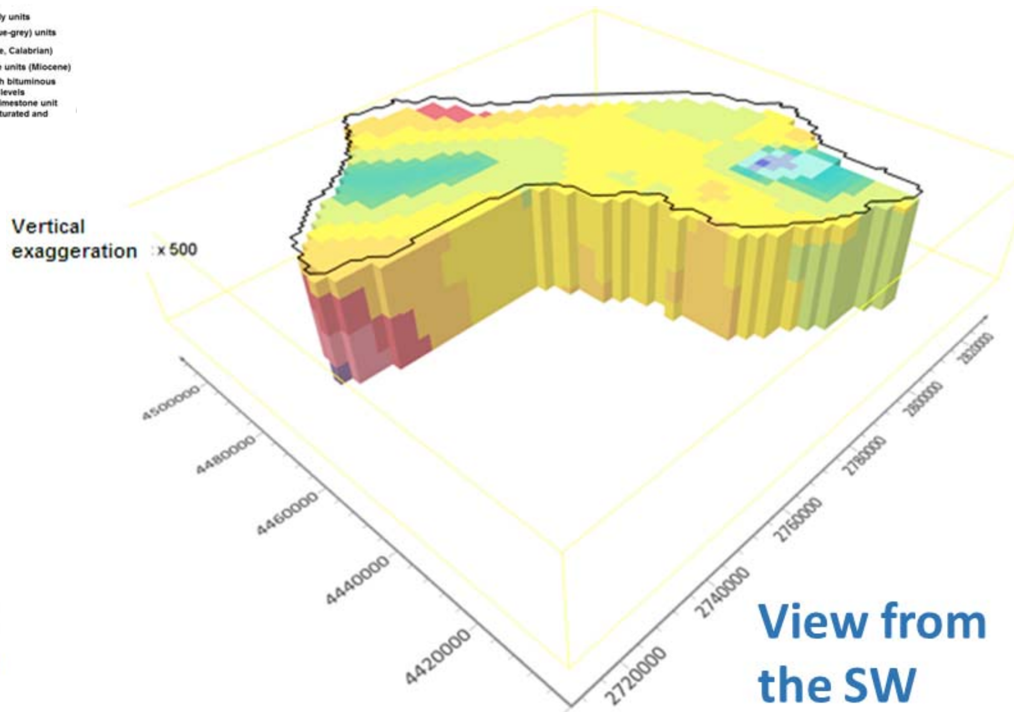
View from the NW

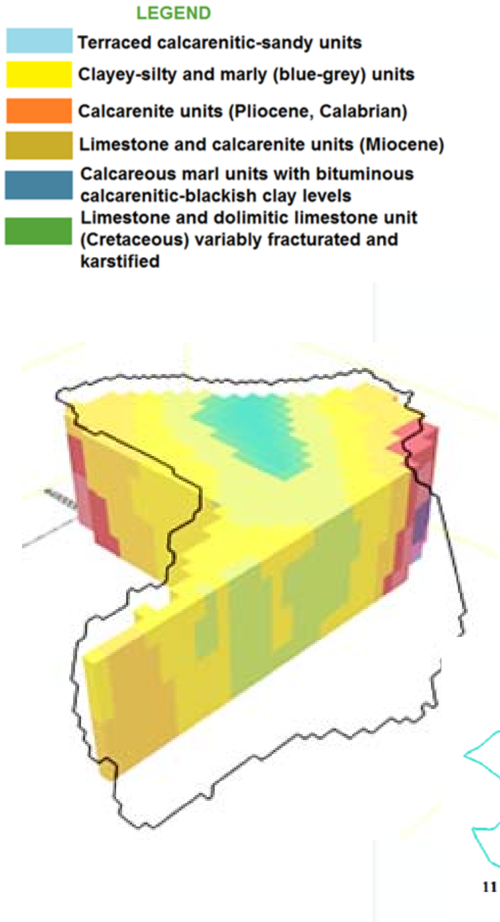


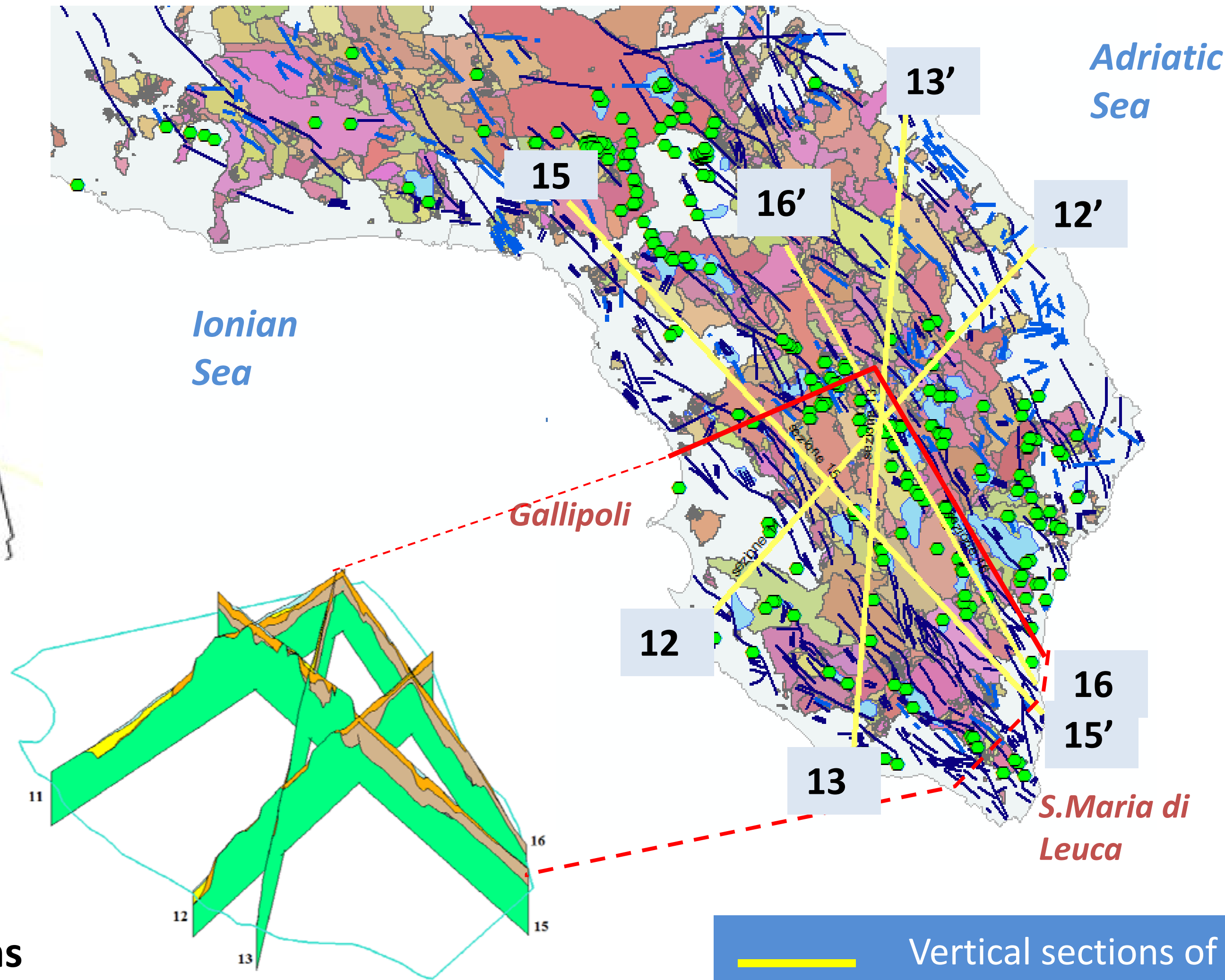
Hydrostratigraphic model "Borehole" e "Solid" modules di GMS (Groundwater Modeling System - Aquaveo)

3D interpolation of thermal horizontal sections at -5, -20, -35. -50 m amsl Summer 2010









Geological sections from the 3D model

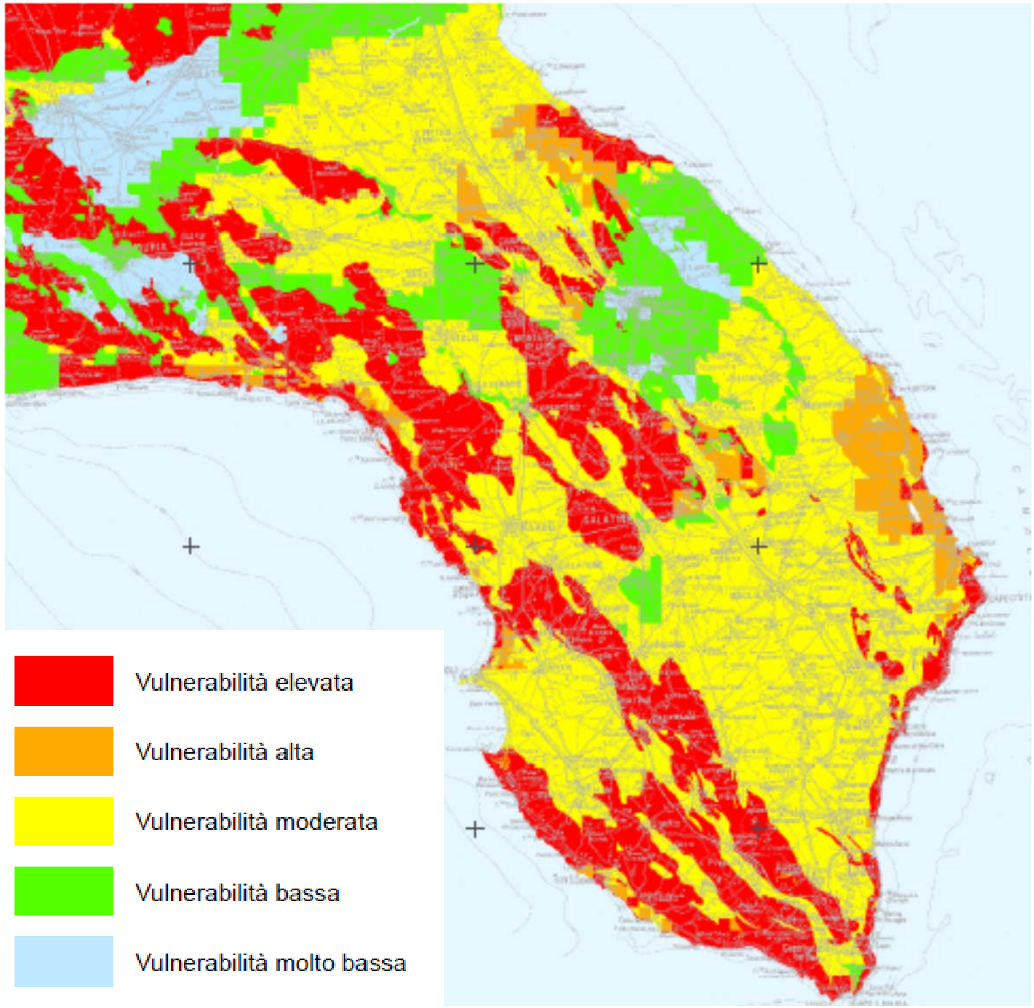
Vertical sections of the thermal field

COP method developed in 2001 and 2002 by the Hydrogeology Group of the University of Malaga (Vías et al. 2002).

COP method takes into account the fectors

- ***overlying layers (O),*** which refers to the protection of the unsaturated zone and to its capability to filter out or attenuate contamination.
- ***concentration of flow (C), which*** takes into account the ***surface conditions that control water flowing towards zones of rapid infiltration***.
- ***precipitation (P),*** which is assessed on the basis of annual precipitation depth and rainfall intensity

The map has to be validated….



Intrinsic vulnerability map (COP Method)
Regione Puglia – Sogesid (2007) - PTA

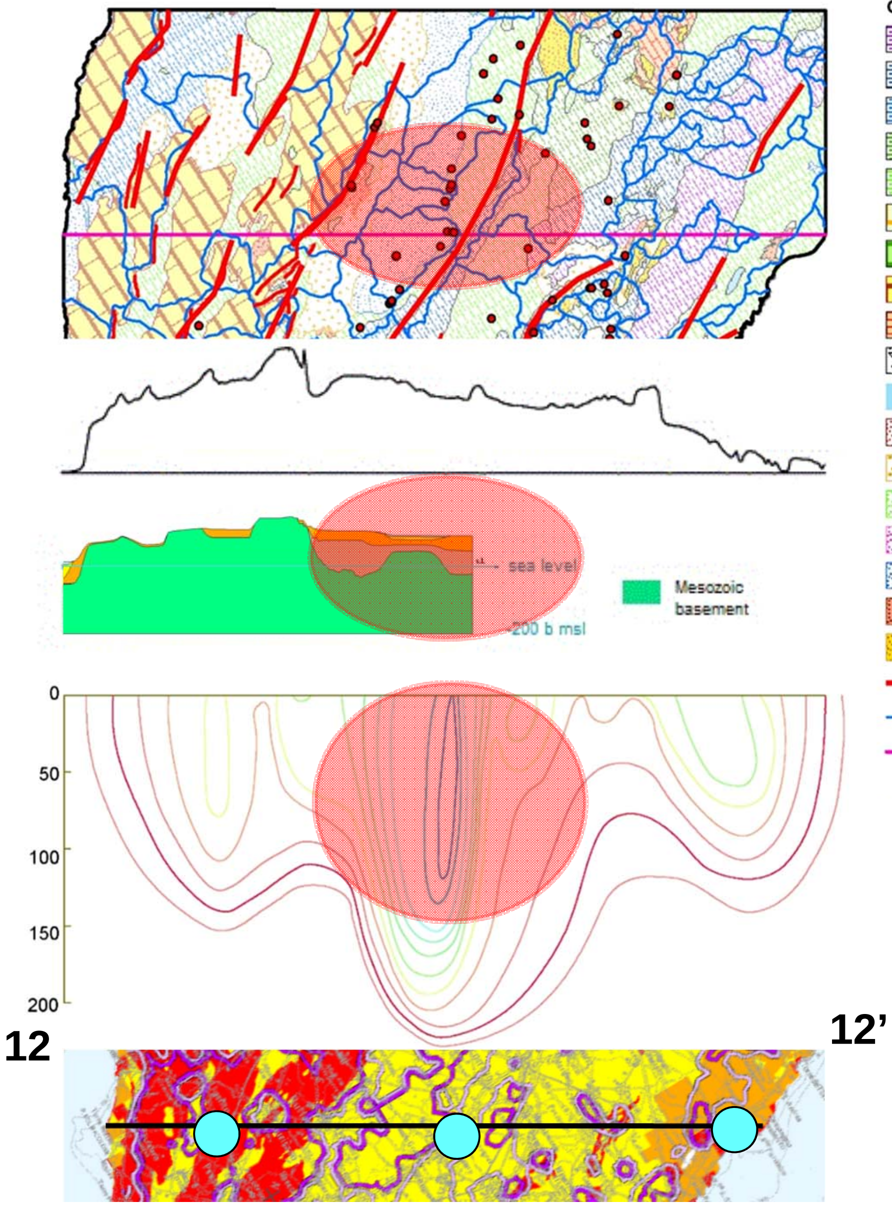
Geolithologic map

Topographic profile

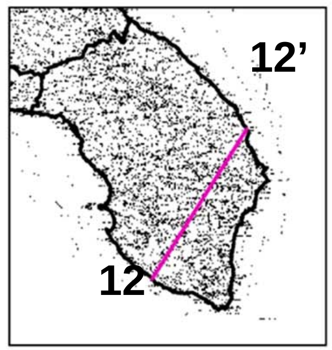
Geological section

Section of the thermal field

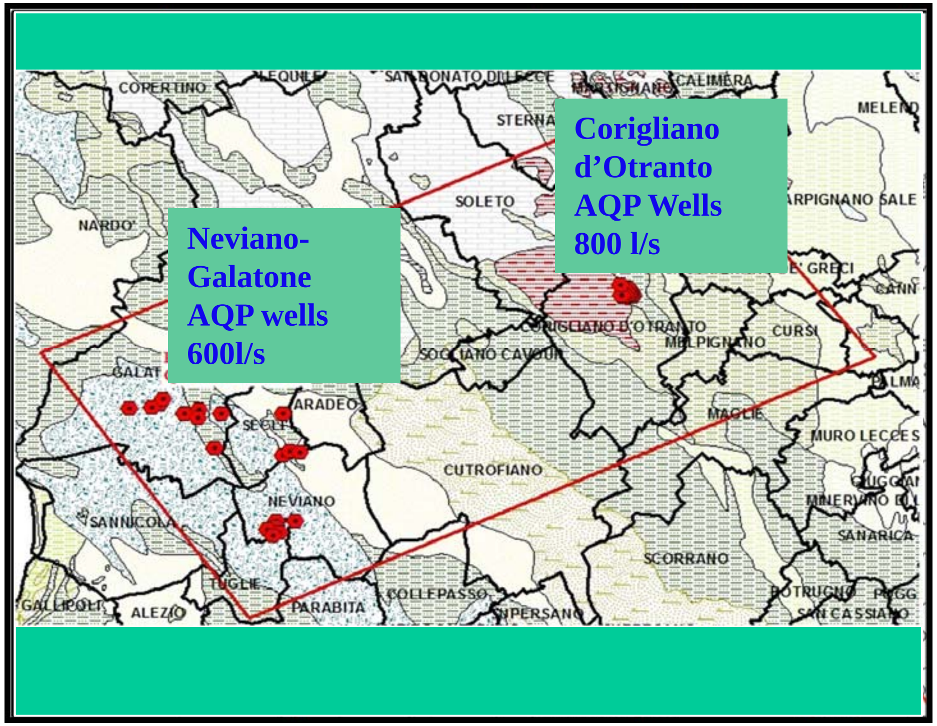
Intrinsic Vulnerability map (COP method)

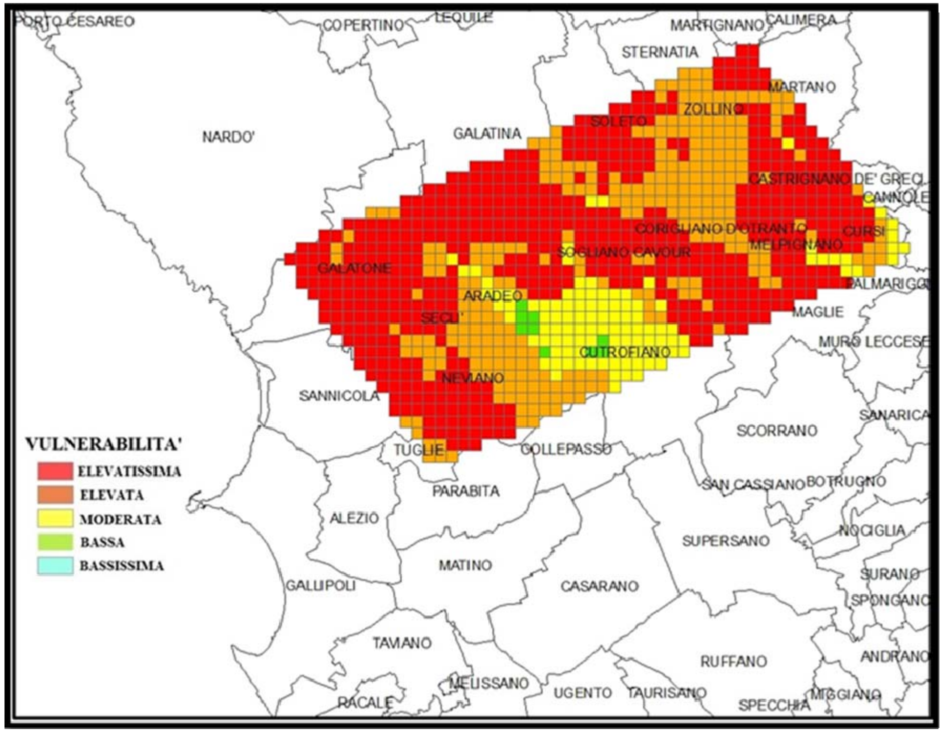


Validation of vulnerability map through geological model and thermal sections



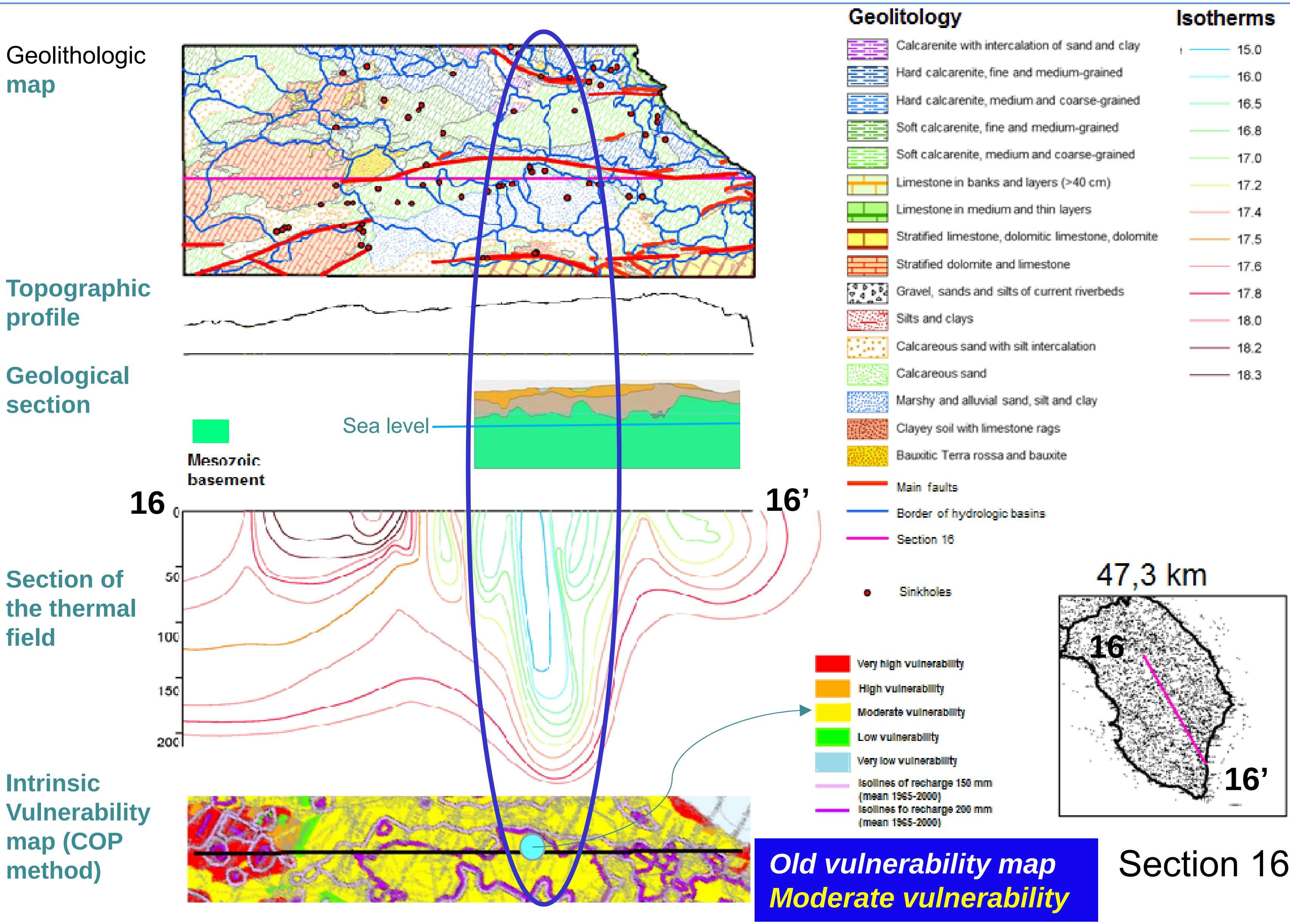
Section 12

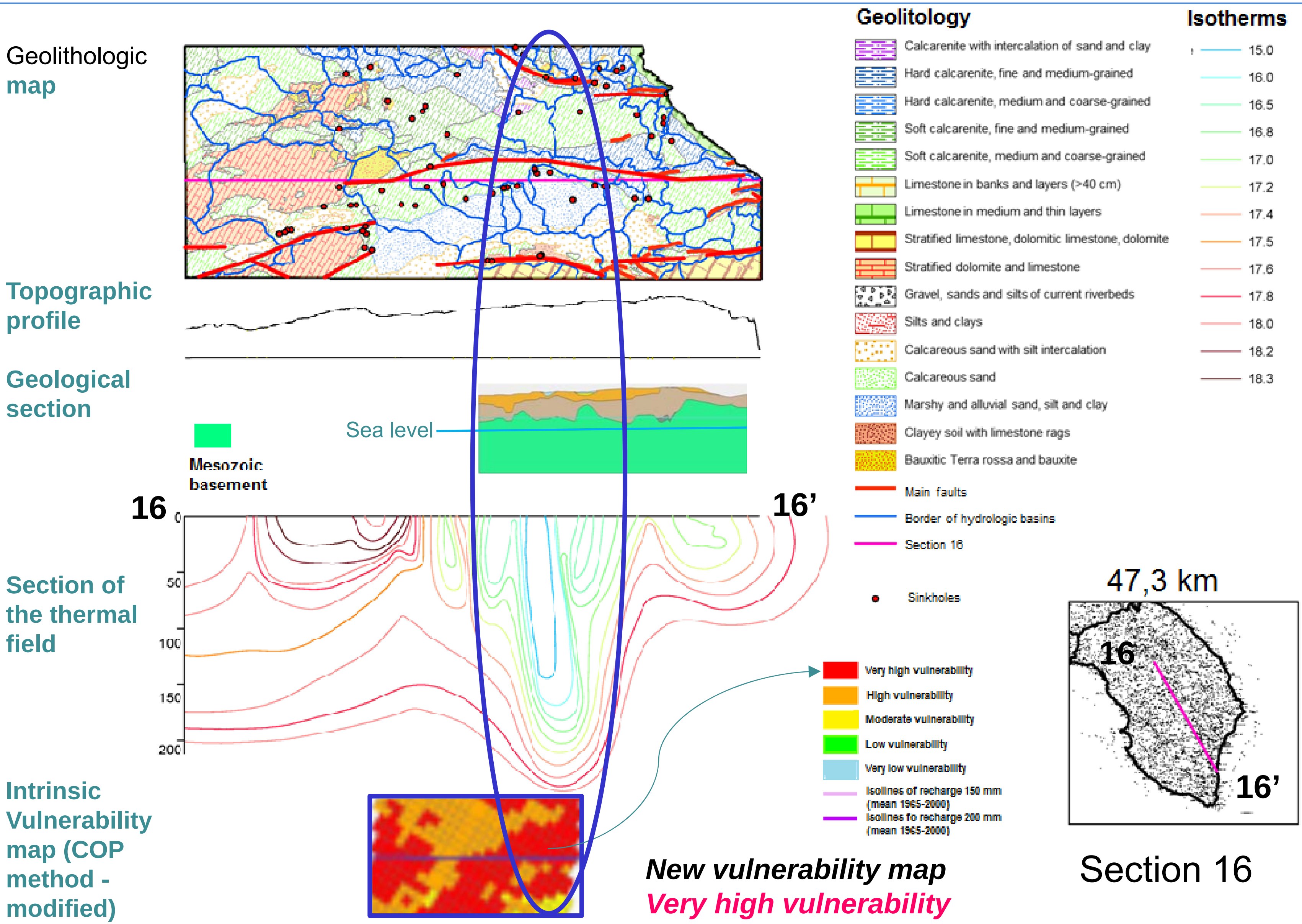




Test zone for vulnerability mapping, which tkes into account the elements of validation
It includes two important areas of drinking water exploitation

Vulnerability map
COP modified for the factor C
High weight to main discontinuities, endorheic basins, sinkholes, dolines, karst fields


Geolithologic map
Topographic profile
Geological section
Section of the thermal field
Intrinsic Vulnerability map (COP method)
Sea level
Mesozoic basement
16
16'
0
50
100
150
200
Geolitology
Calcarenite with intercalation of sand and clay
Hard calcarenite, fine and medium-grained
Hard calcarenite, medium and coarse-grained
Soft calcarenite, fine and medium-grained
Soft calcarenite, medium and coarse-grained
Limestone in banks and layers (>40 cm)
Limestone in medium and thin layers
Stratified limestone, dolomitic limestone, dolomite
Stratified dolomite and limestone
Gravel, sands and silts of current riverbeds
Silts and clays
Calcareous sand with silt intercalation
Calcareous sand
Marshy and alluvial sand, silt and clay
Clayey soil with limestone rags
Bauxitic Terra rossa and bauxite
Main faults
Border of hydrologic basins
Section 16
Sinkholes
Isotherms
15.0
16.0
16.5
16.8
17.0
17.2
17.4
17.5
17.6
17.8
18.0
18.2
18.3
47,3 km
16
16'
Very high vulnerability
High vulnerability
Moderate vulnerability
Low vulnerability
Very low vulnerability
Isolines of recharge 150 mm (mean 1965-2000)
Isolines fo recharge 200 mm (mean 1965-2000)
Old vulnerability map
Moderate vulnerability
Section 16


Geolithologic map
Topographic profile
Geological section
Section of the thermal field
Intrinsic Vulnerability map (COP method - modified)
Sea level
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Isolines fo recharge 200 mm (mean 1965-2000)
47,3 km
16
16'
Section 16
New vulnerability map
Very high vulnerability

Conclusions I

Question: which is the role of the geomorphological features in the mass transport processes from surface to groundwater?

- Information on mass transport processes indicates that the ***epikarst*** mediates the transfer from surface; ***endorheic basins, vertical discontinuities, and karst forms*** are the most relevant factors in determining a ***high intrinsic vulnerability*** with a ***hazard of exposition to pollutant peak concentrations that depends on the fluctuations of the semi-arid climate***

Question: is the bare karst more vulnerable than the covered karst?

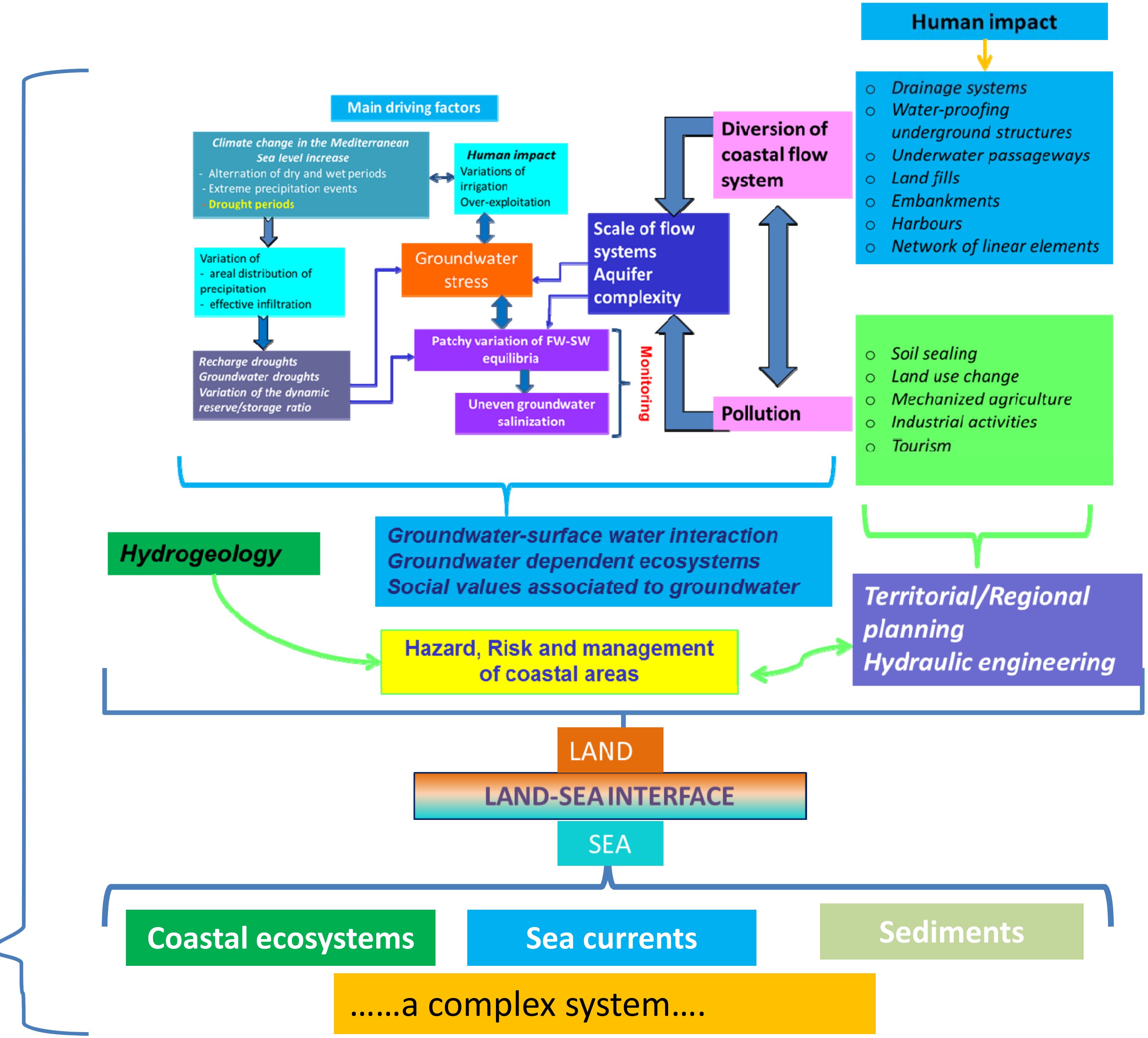
- The 3D information on hydrostratigraphy, geomorphology and thermal field points out that the ***covers on karst surface, when intersected by discontinuities and karst forms, do not guarantee the protection of groundwater resource.***

- The ***carbonate basement reveals to be more vulnerable in the sunken parts***, which at the same time, are the zones of ***more active groundwater circulation***: the correspondent ***surface areas, interested by covers, behaves in many cases, as main recharge areas.***

- Moreover, the ***large discontinuities drive most of the groundwater flow.***

The feedback of the complex interconnection between human impact and natural system intervene ***negatively often with extensive time lags***

The ***short-term management solutions*** attempt to control the ecological dynamics (in the broad sense) ***without understanding the complexity*** of the systems.



CONTINUITY OF ECOLOGICAL FLOWS MASS TRANSPORT

The feedback of the complex interconnection between human impact and natural system intervene ***negatively often with extensive time lags***
The ***short-term management solutions*** attempt to control the ecological dynamics (in the broad sense) ***without understanding the complexity*** of the systems.

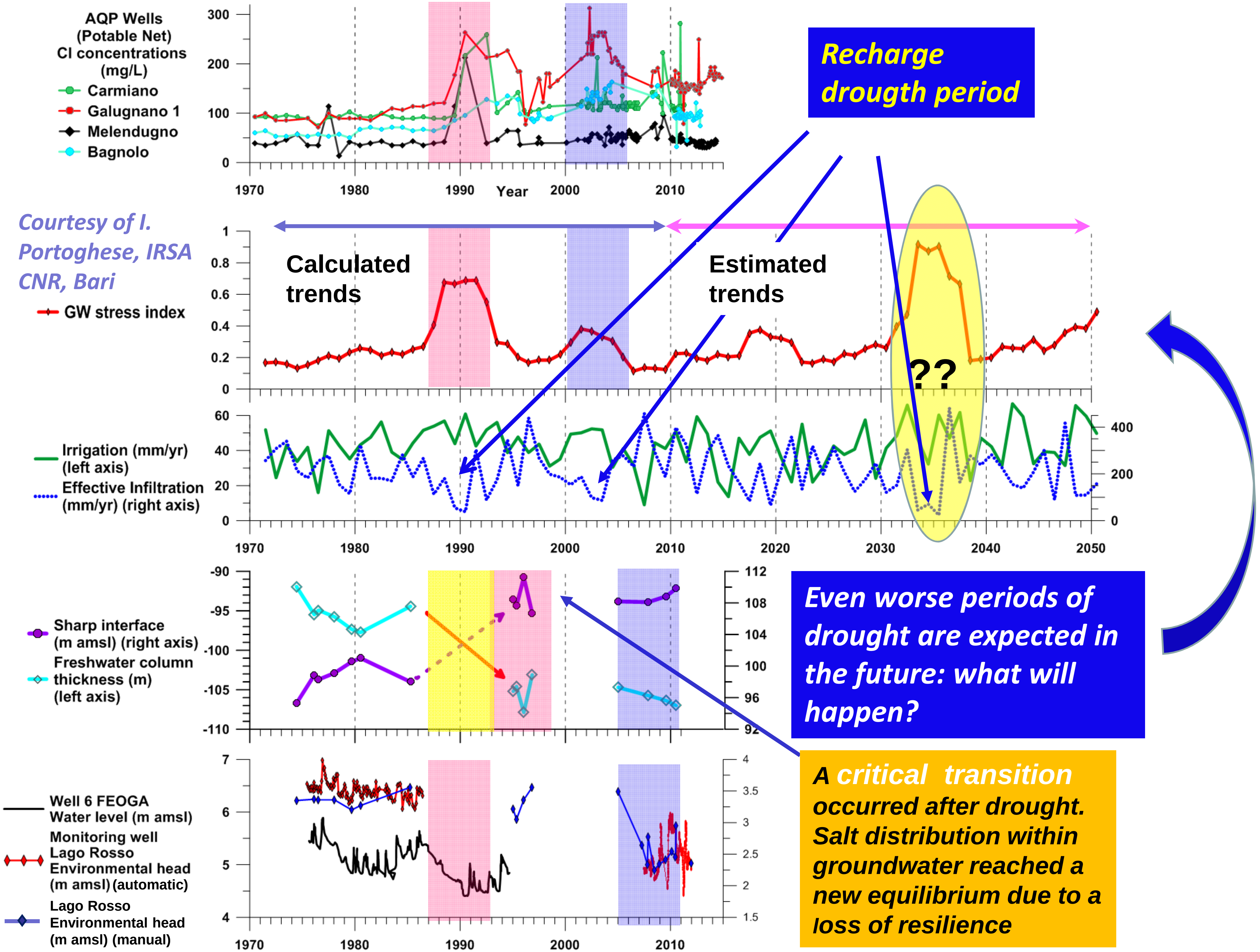
CONTINUITY OF ECOLOGICAL FLOWS MASS TRANSPORT

……a complex system….

In Puglia we are facing, without knowing it, a «creeping disaster» that is developing on large spatial and time scales with «cascade effects» and «critical transitions» according to a nonlinear dynamics.

These critical transitions and cascade effects have the potential to cause in the future irreversible damage to the socio-environmental systems.

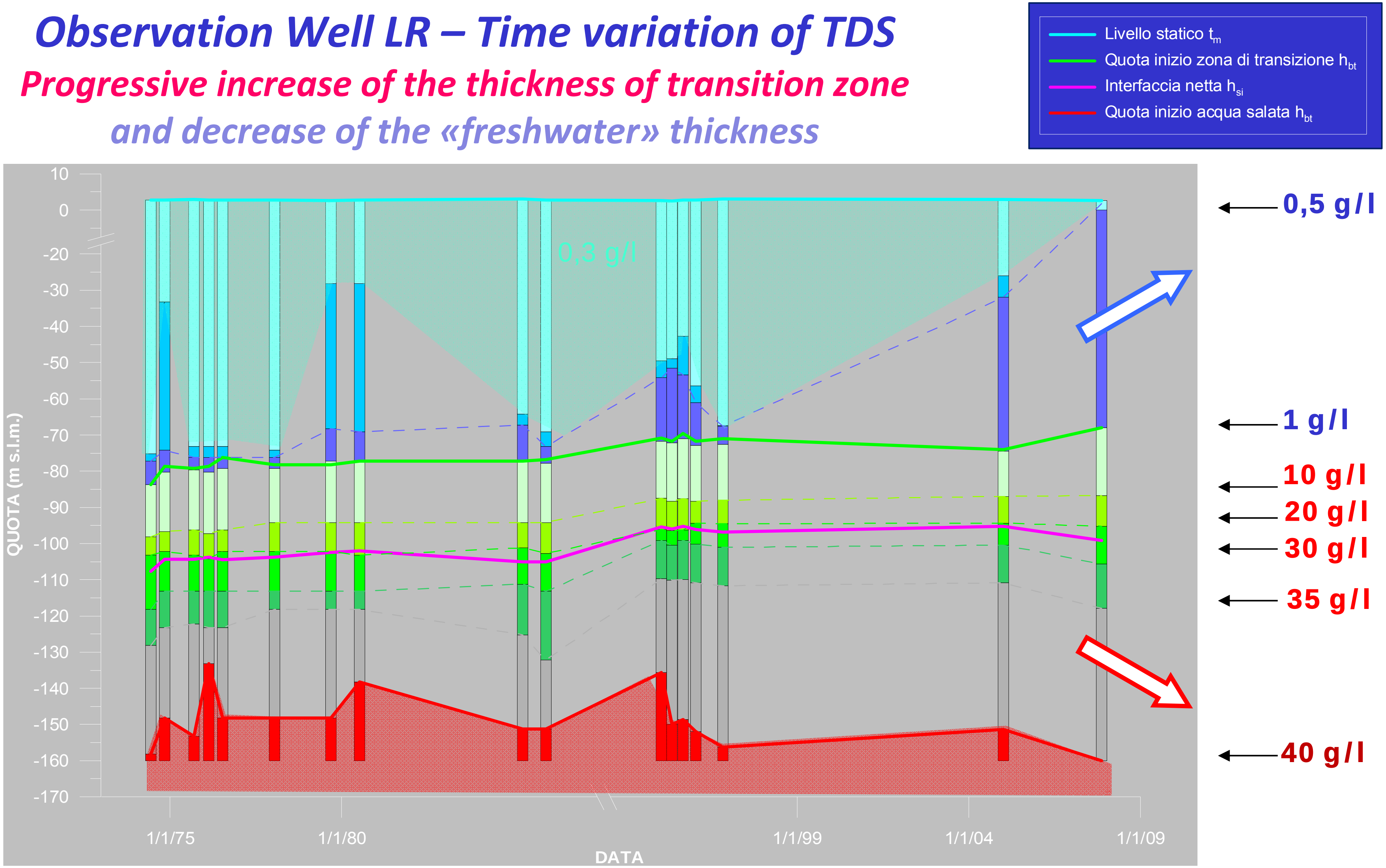
What effects can we expect from the forecasted sequences of droughts on such systems?


AQP Wells (Potable Net) Cl concentrations (mg/L)
Carmiano
Galugnano 1
Melendugno
Bagnolo
Year
Courtesy of I. Portoghese, IRSA CNR, Bari
GW stress index
Calculated trends
Estimated trends
??
Irrigation (mm/yr) (left axis)
Effective Infiltration (mm/yr) (right axis)
Sharp interface (m amsl) (right axis)
Freshwater column thickness (m) (left axis)
Well 6 FEOGA Water level (m amsl)
Monitoring well Lago Rosso Environmental head (m amsl) (automatic)
Lago Rosso Environmental head (m amsl) (manual)
Recharge drought period
Even worse periods of drought are expected in the future: what will happen?
A critical transition occurred after drought. Salt distribution within groundwater reached a new equilibrium due to a loss of resilience

Observation Well LR – Time variation of TDS

Progressive increase of the thickness of transition zone

and decrease of the «freshwater» thickness



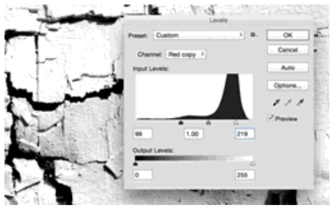
Conclusions II

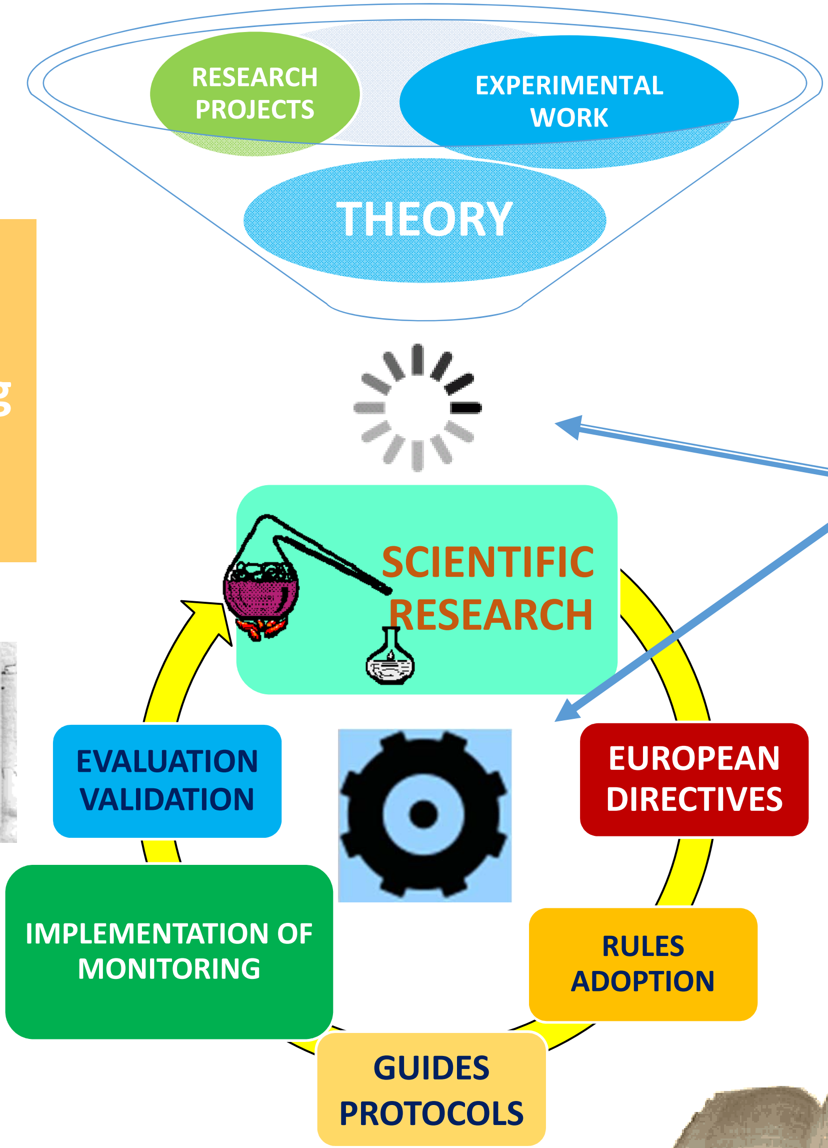
- Exploitation, climate change and droughts are part of a ***creeping crisis: other "Critical transitions" toward new equilibrium states*** due to ***loss of resilience*** can be expected in correspondence to future drought periods

- These critical transitions could be forecast and prevented in their effects only if ***managers will understand that in our large coastal systems groundwater droughts (and parallel salinization processes) appear with large time lags compared to recharge droughts***

THE END

Life is what happens when you're busy making other plans…
John Lennon





DIFFERENT SPEED