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

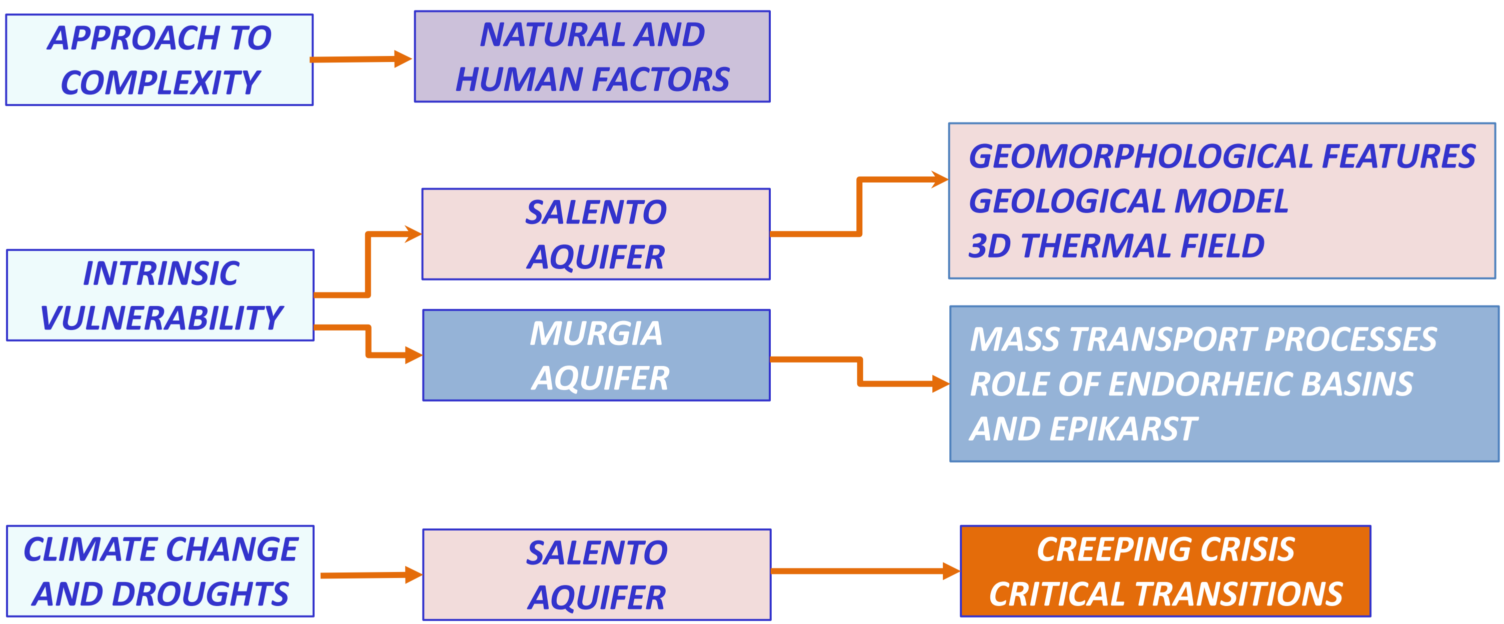
Protection of the Apulian karstic coastal aquifers between intrinsic complexity and anthropogenic effects

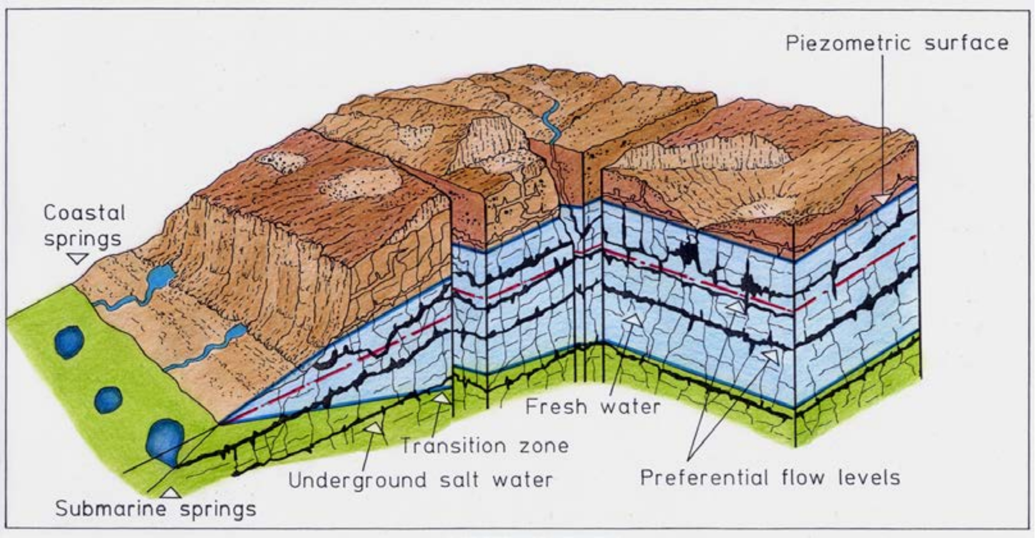
2) Department of Civil, Environmental, Land, Building Engineering and Chemistry Politecnico di Bari, Italy

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

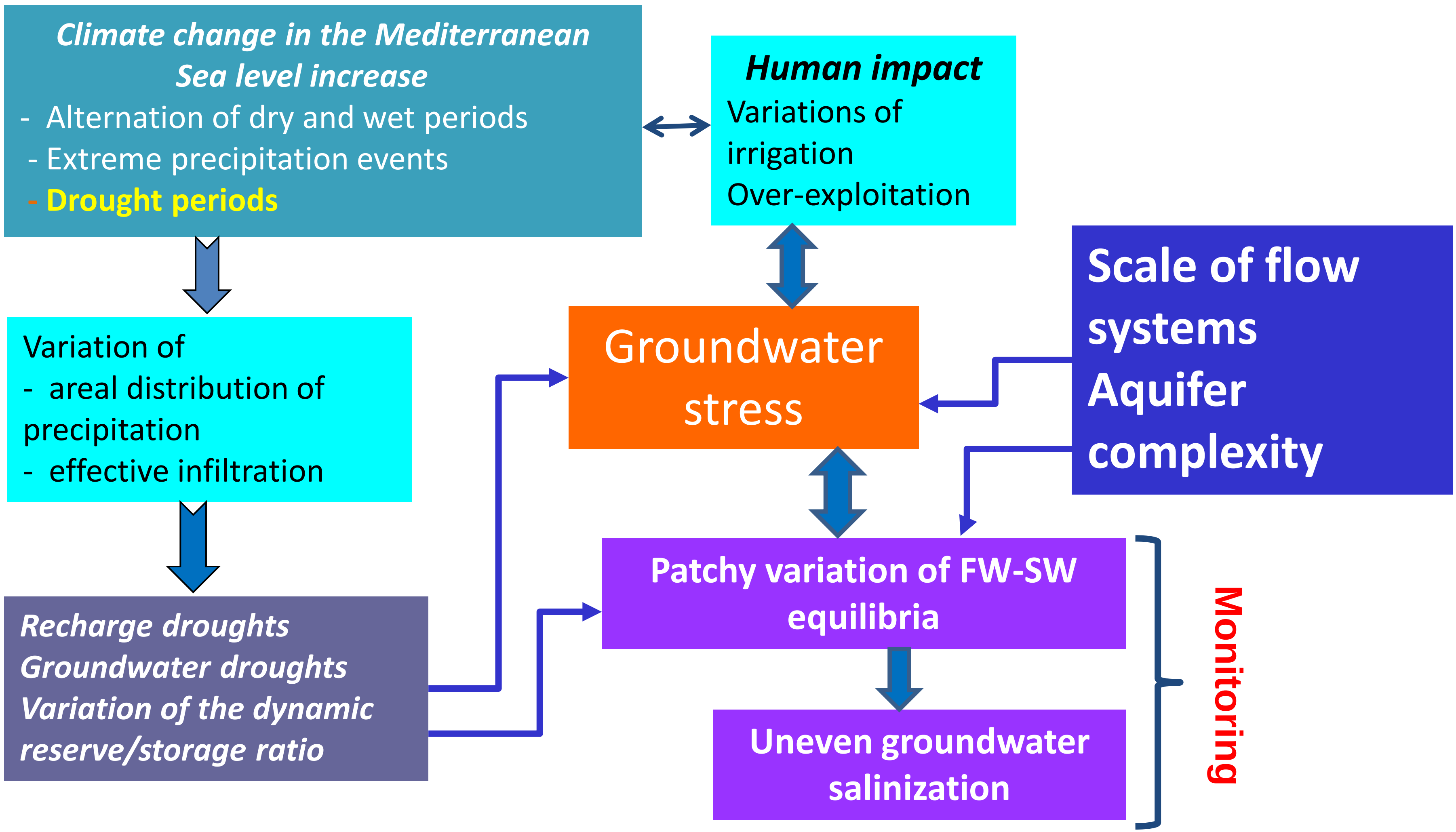


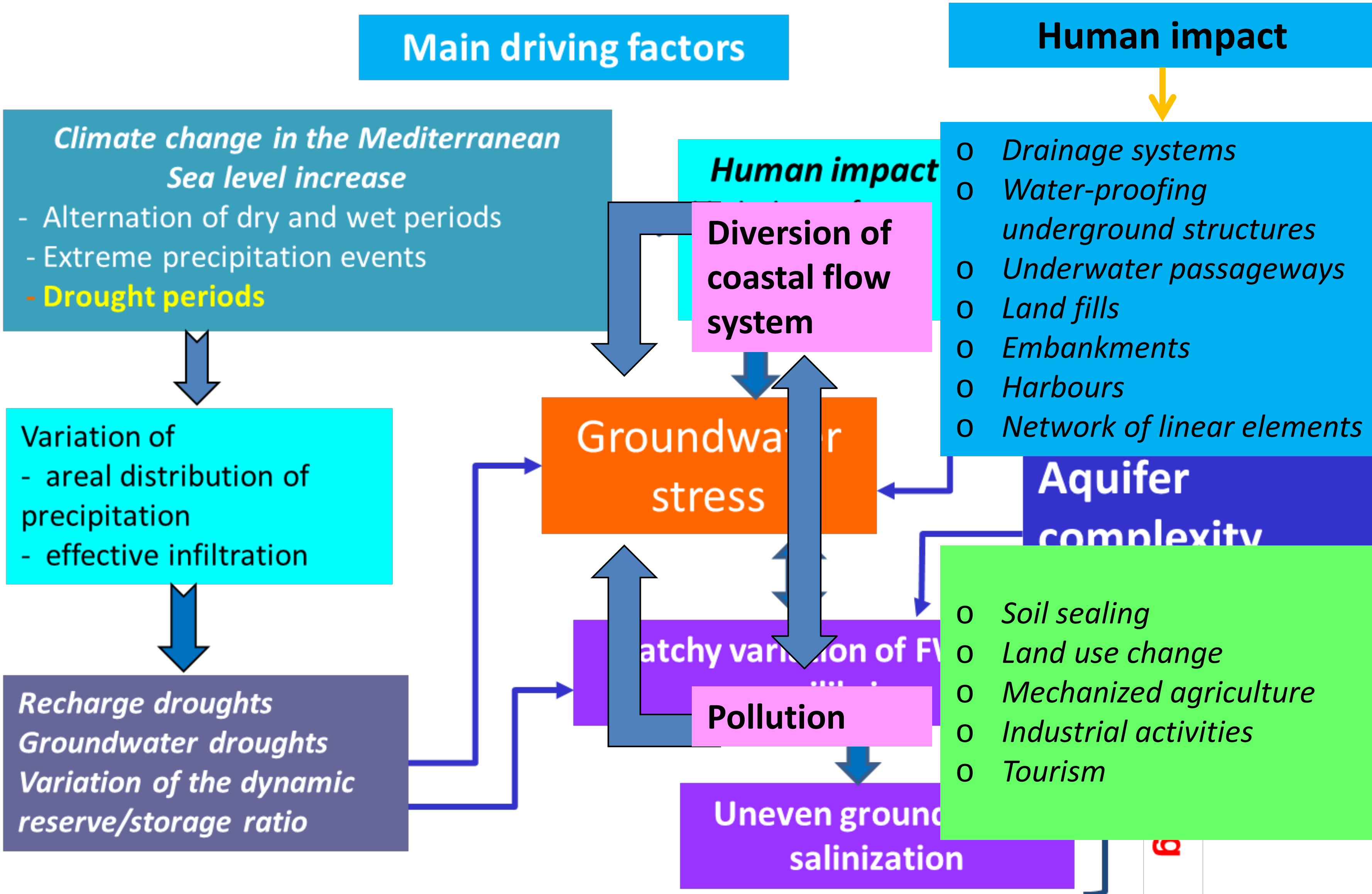


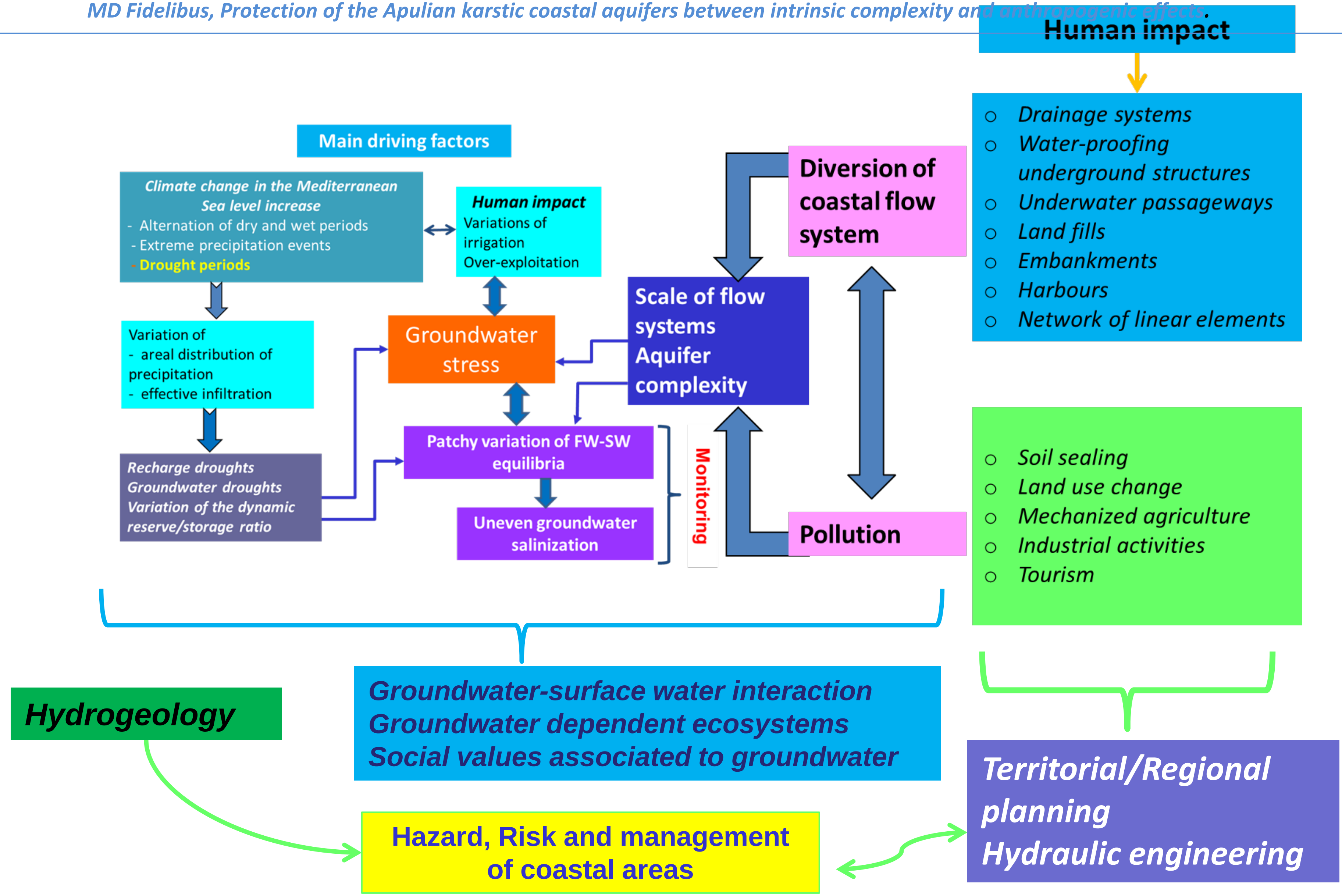
Murgia and Salento karst coastal aquifers belong to a ***platform karst*** characterized by thick and large sedimentary complex, formed by horizontal and gently sloping strata and platform relief

- *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




Main driving factors
Human impact
Climate change in the Mediterranean
Sea level increase
- Alternation of dry and wet periods
- Extreme precipitation events
- Drought periods
Human impact
Diversion of coastal flow system
o Drainage systems
o Water-proofing underground structures
o Underwater passageways
o Land fills
o Embankments
o Harbours
o Network of linear elements
Variation of
- areal distribution of precipitation
- effective infiltration
stress
Aquifer
Recharge droughts
Groundwater droughts
Variation of the dynamic reserve/storage ratio
Pollution
o Soil sealing
o Land use change
o Mechanized agriculture
o Industrial activities
o Tourism
salinization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Drainage systems
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Embankments
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Main driving factors
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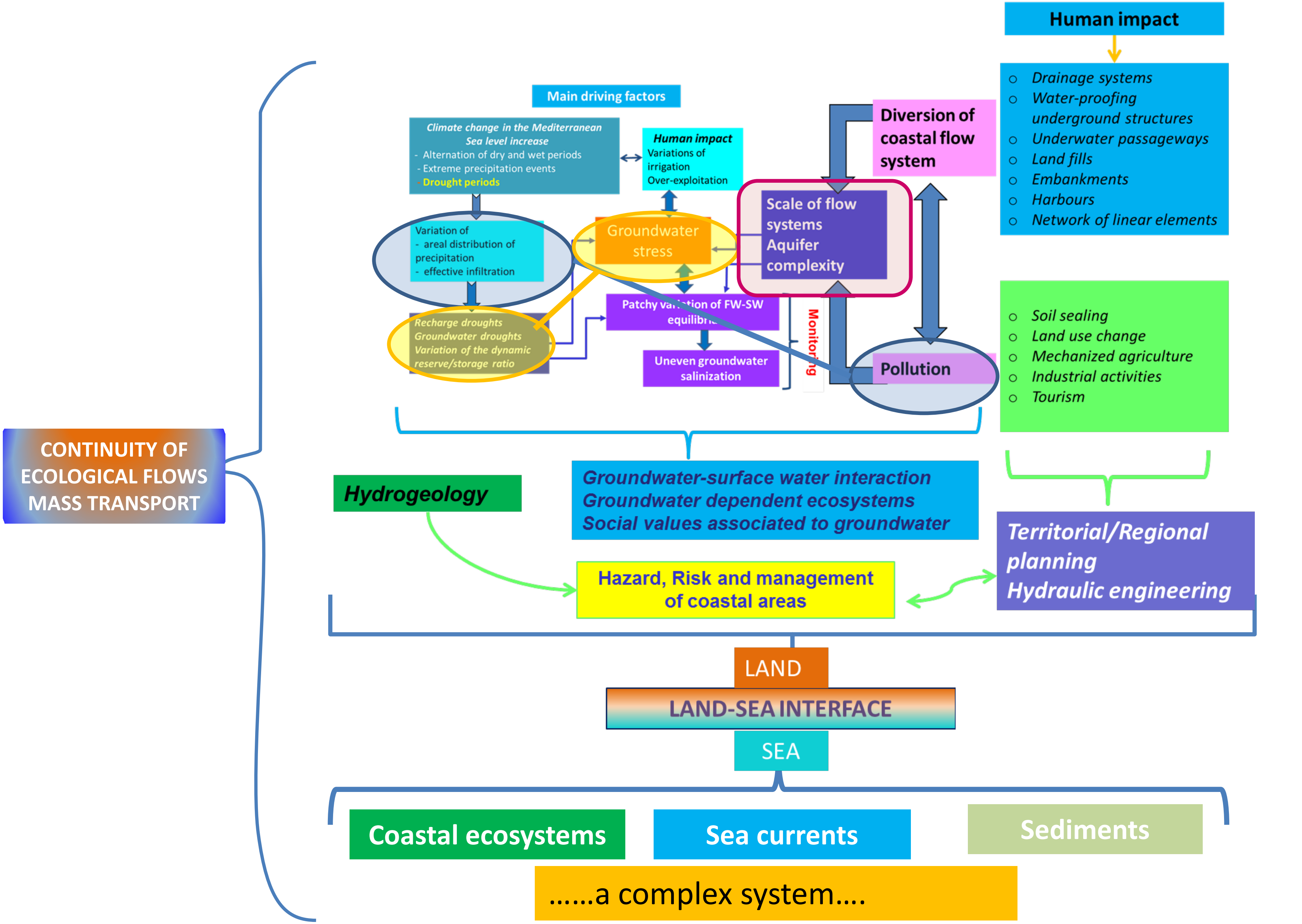
Sea level increase
- Alternation of dry and wet periods
- Extreme precipitation events
- Drought periods
Human impact
Variations of irrigation
Over-exploitation
Diversion of coastal flow system
Scale of flow systems
Aquifer complexity
Groundwater stress
Variation of
- areal distribution of precipitation
- effective infiltration
Recharge droughts
Groundwater droughts
Variation of the dynamic reserve/storage ratio
Patchy variation of FW-SW equilibria
Uneven groundwater salinization
Monitoring
Pollution
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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CONTINUITY OF ECOLOGICAL FLOWS MASS TRANSPORT
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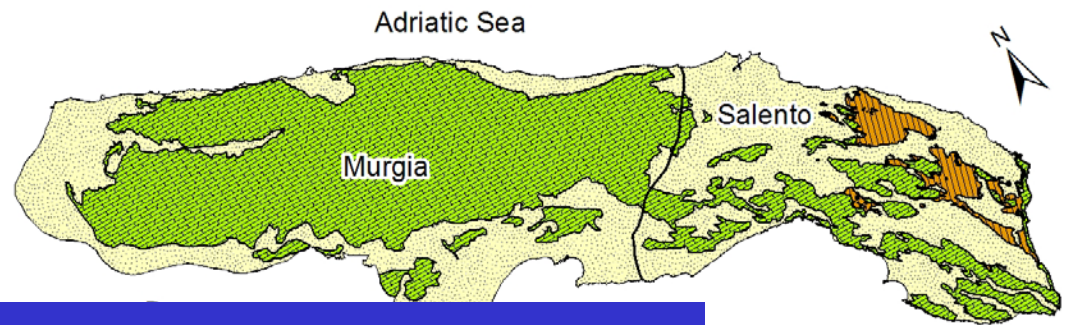
Hazard, Risk and management of coastal areas
LAND
LAND-SEA INTERFACE
SEA
Coastal ecosystems
Sea currents
Sediments
……a complex system….

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

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?

Murgia

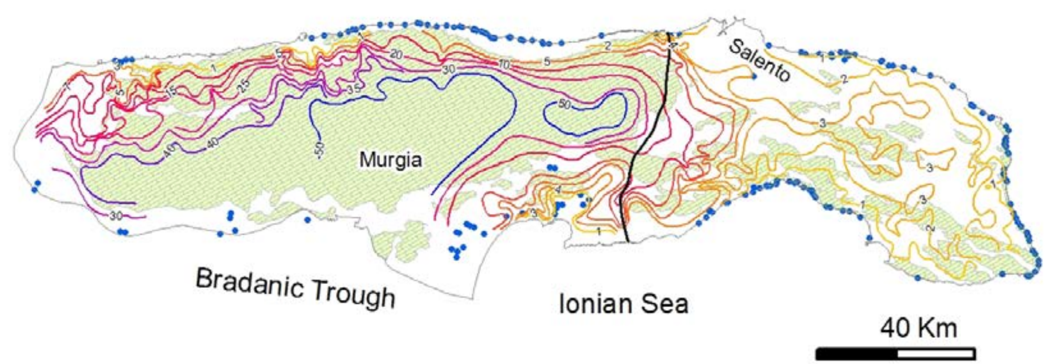
Mean recharge rate → 47 m^3/s

Hydraulic gradient → 2 $^0/_{000}$

Salento

Mean recharge rate → 28 m^3/s

Hydraulic gradient → 0.2 $^0/_{000}$



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**

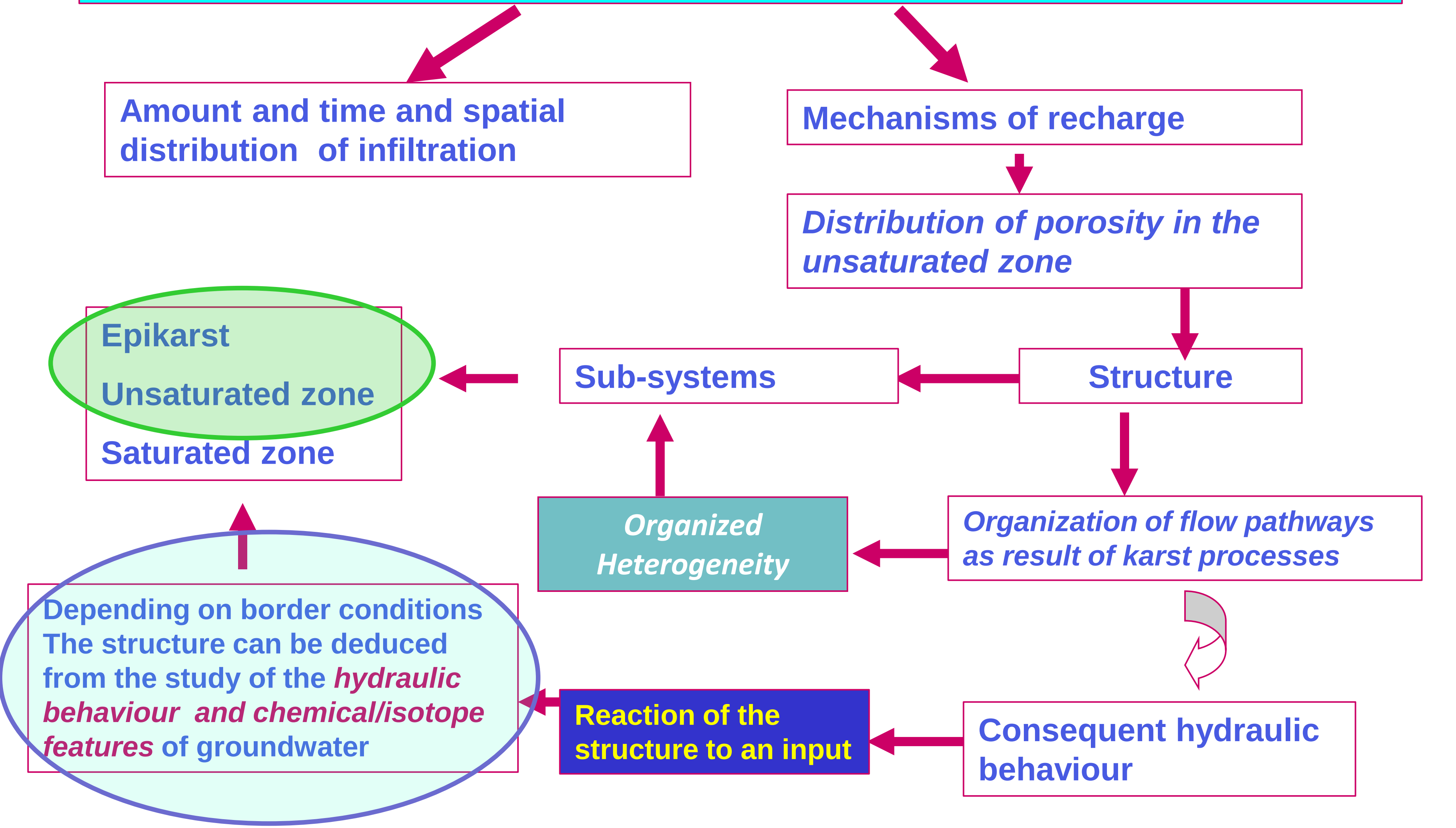
Target: the resource, the top of saturated zone

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

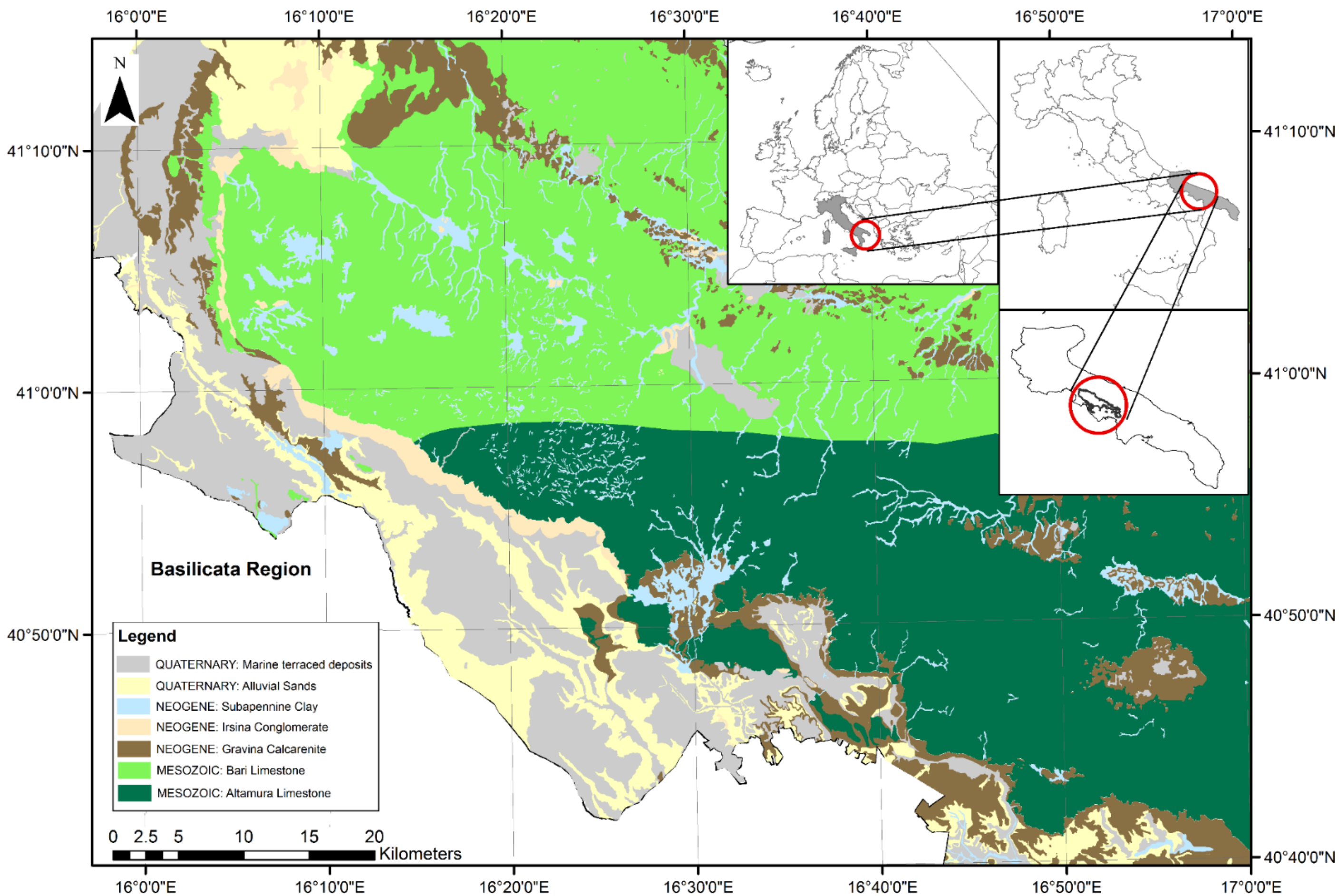
QUANTITATIVE IMPACT OF POLLUTANTS ON GROUNDWATERS AND PHYSICAL ATTENUATION EFFECTS IN THE KARST COASTAL AQUIFER



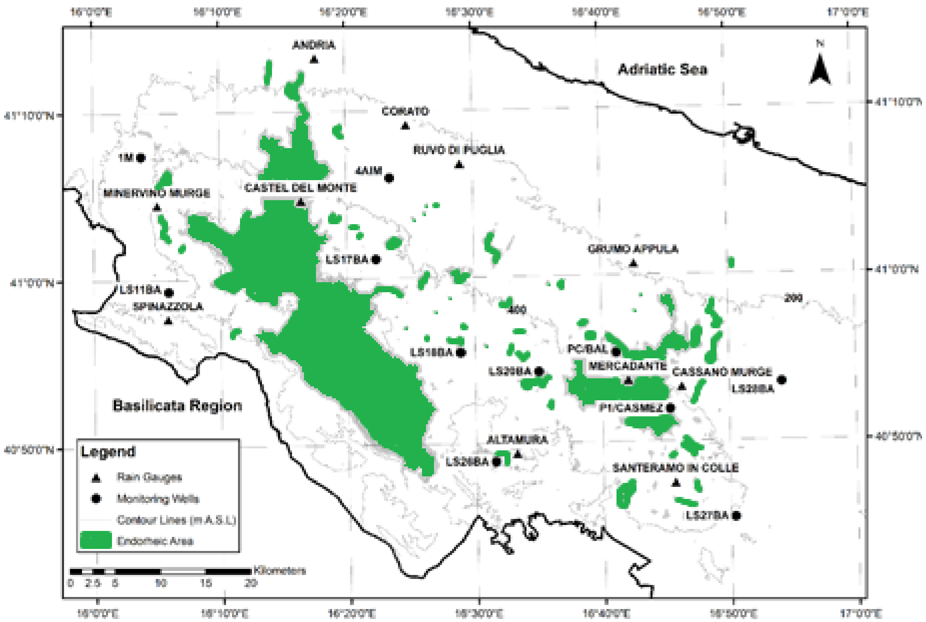
Study area:

Alta Murgia, far from the Adriatic coast

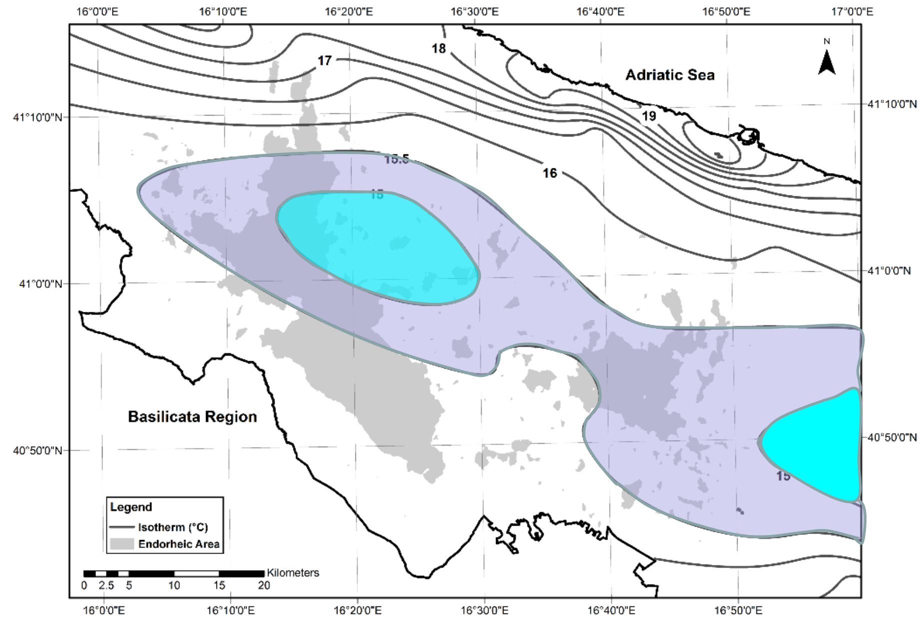
Circulation of fresh ground waters not affected by seawater intrusion due to the high hydraulic heads



Location and schematic geological features of the study area



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**

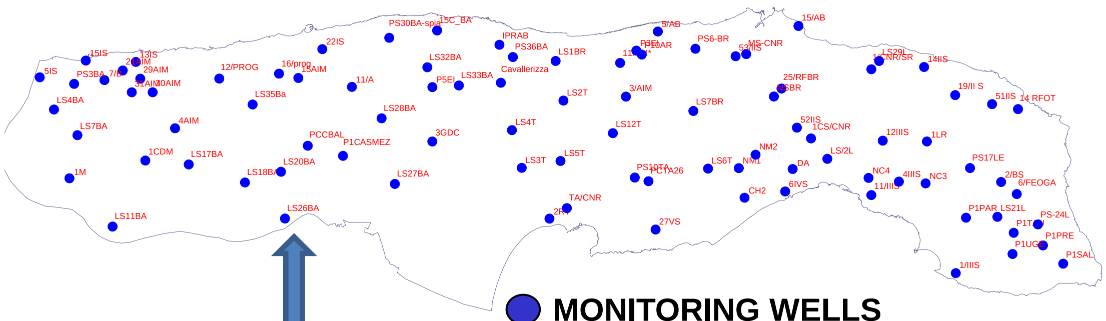


Horizontal ordinary kriging estimation of the temperature distribution at −5 m a.s.l.: **location of the main recharge areas** (included by the **isotherm 15.5°C**) compared to the location of endorheic areas

The more suitable zone to study the vertical paths from surface to saturated zone

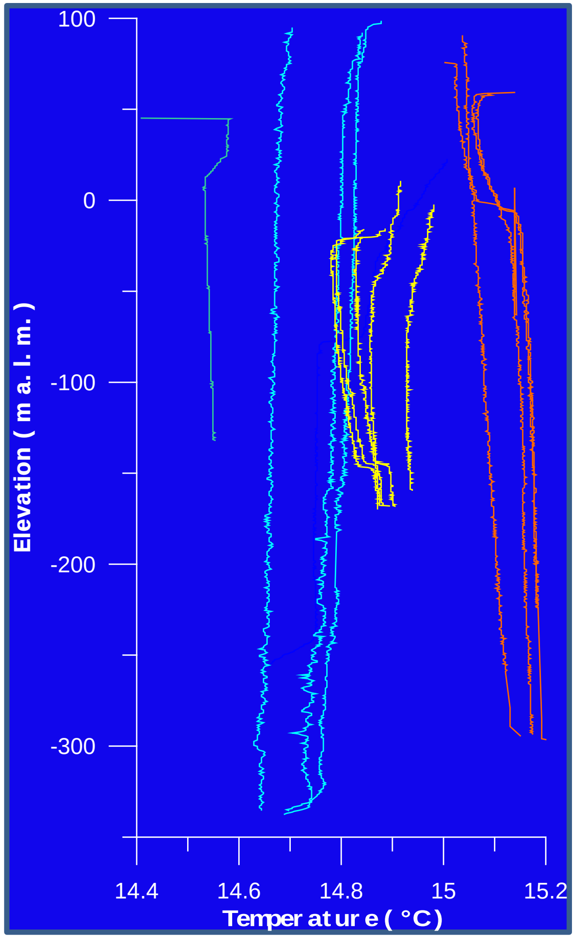
Which is the role of the geomorphological features in the mass transport processes from surface to groundwater?

Information from the thermal field…



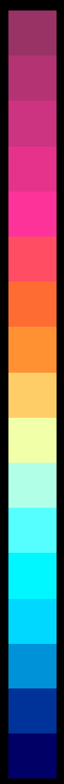
No. 107 Wells of the Monitoring net of Puglia Regional Government for the control of quantitative and qualitative status of groundwaters in karstic aquifers

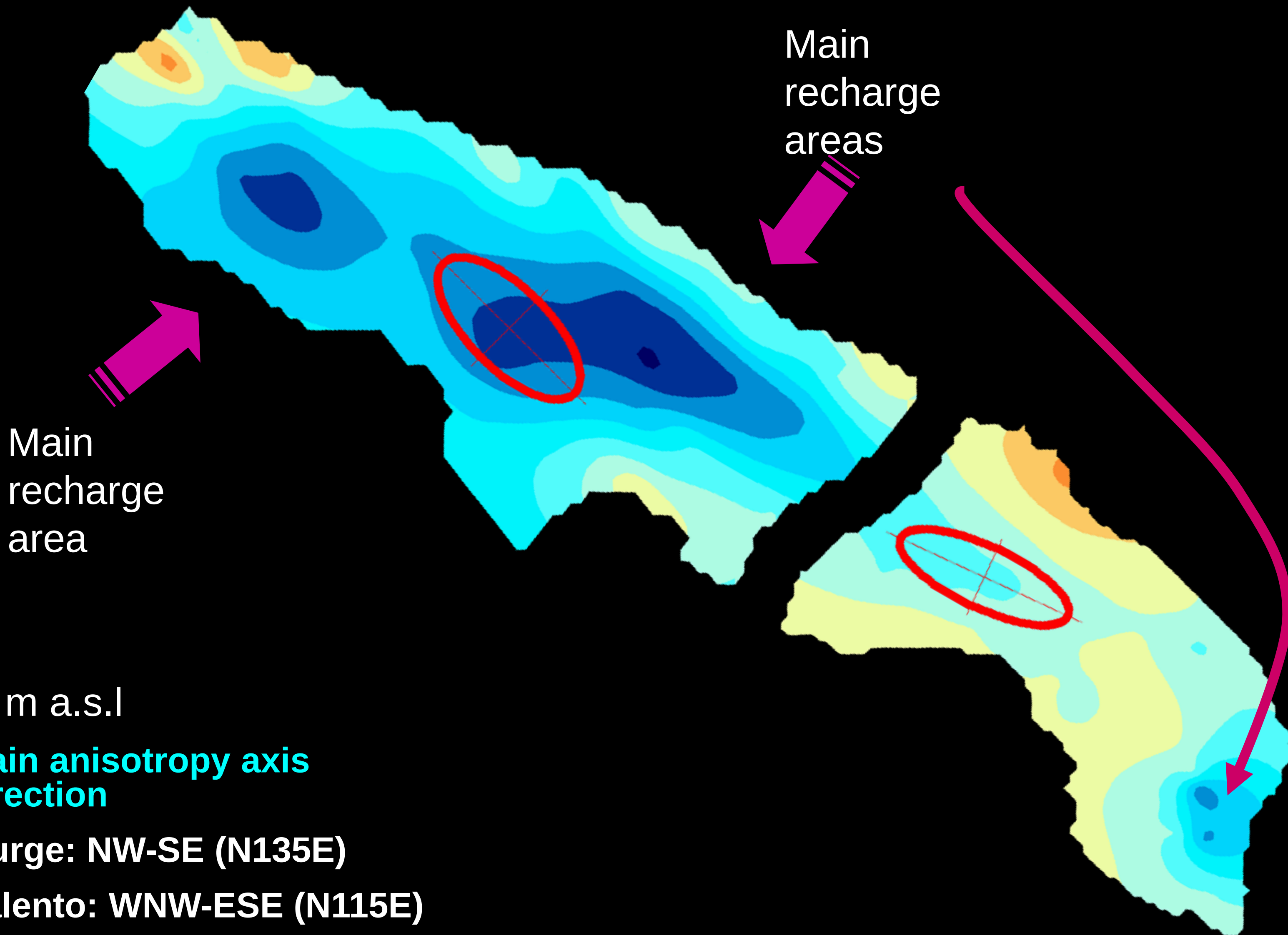
Temperature profiles typical of a recharge area



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

T (°C)



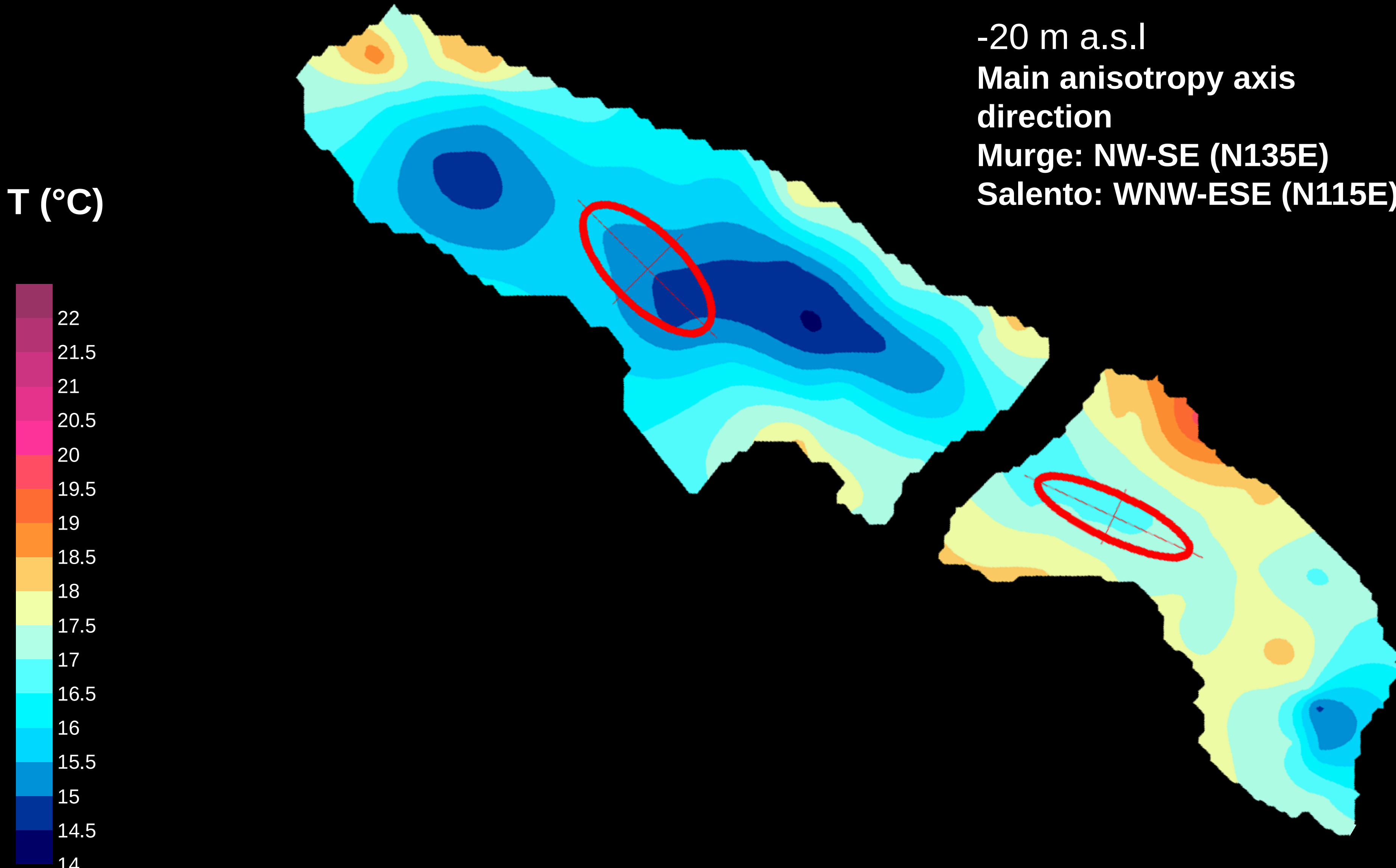


-5 m a.s.l

Main anisotropy axis direction

Murge: NW-SE (N135E)

Salento: WNW-ESE (N115E)

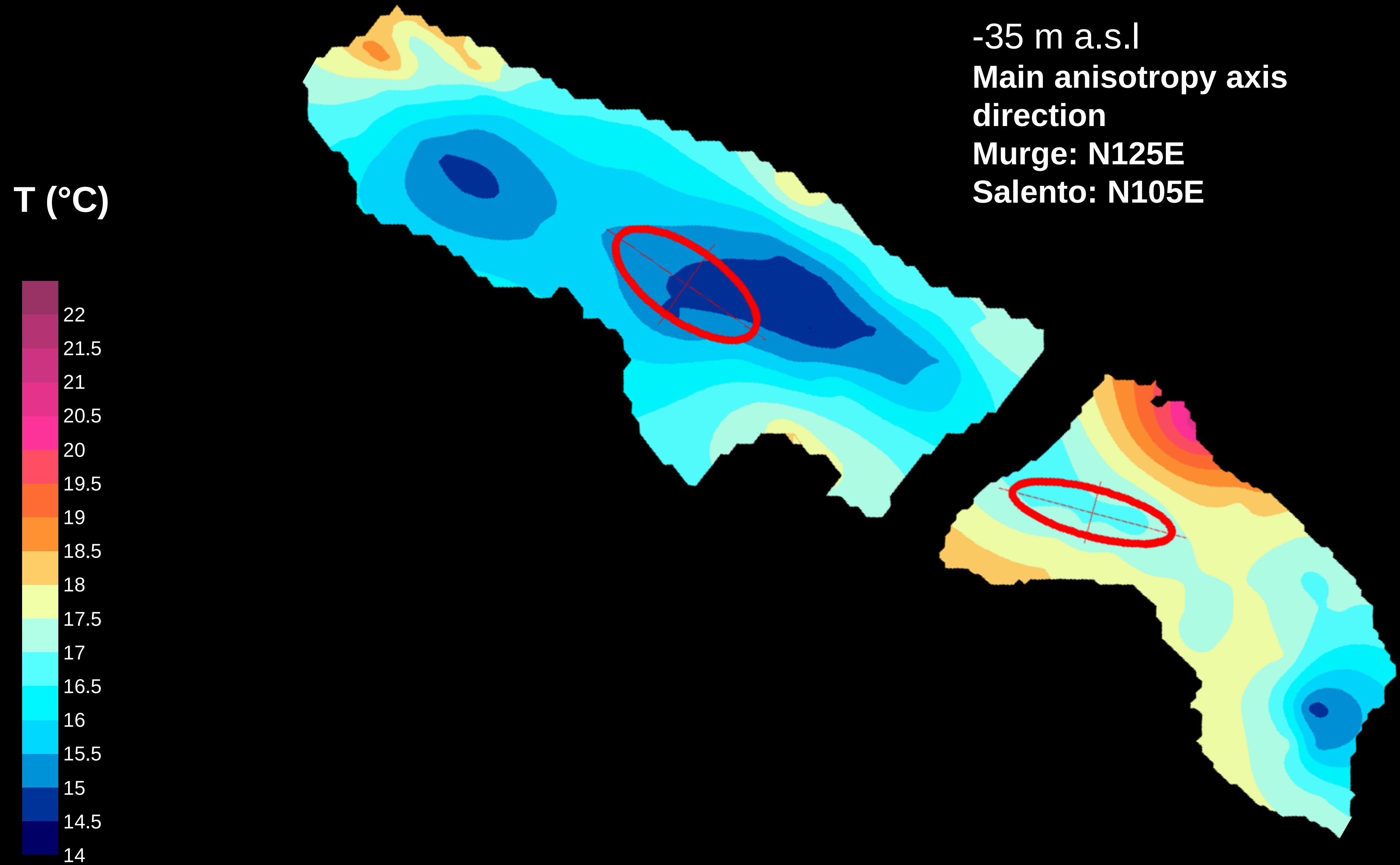


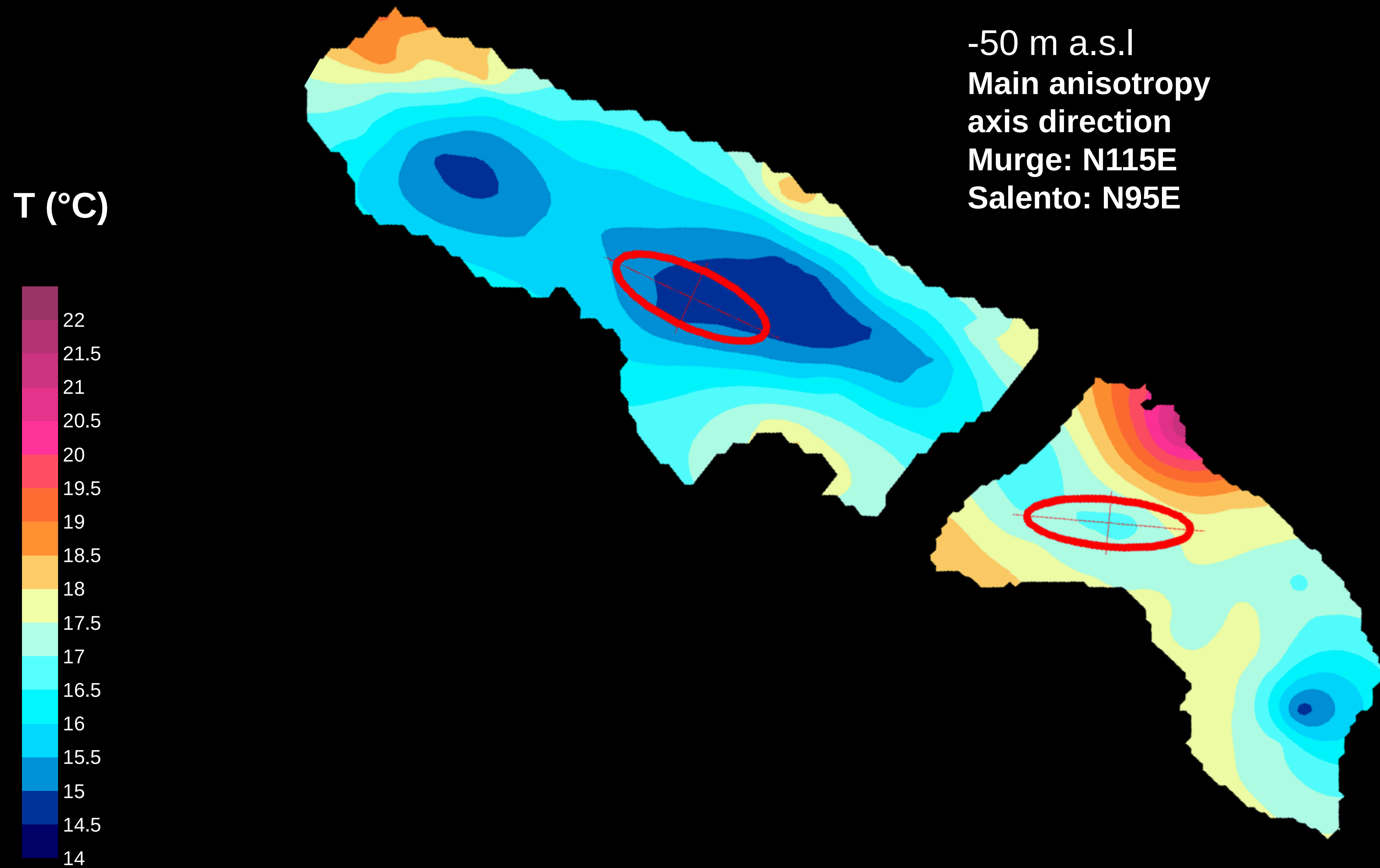
-20 m a.s.l

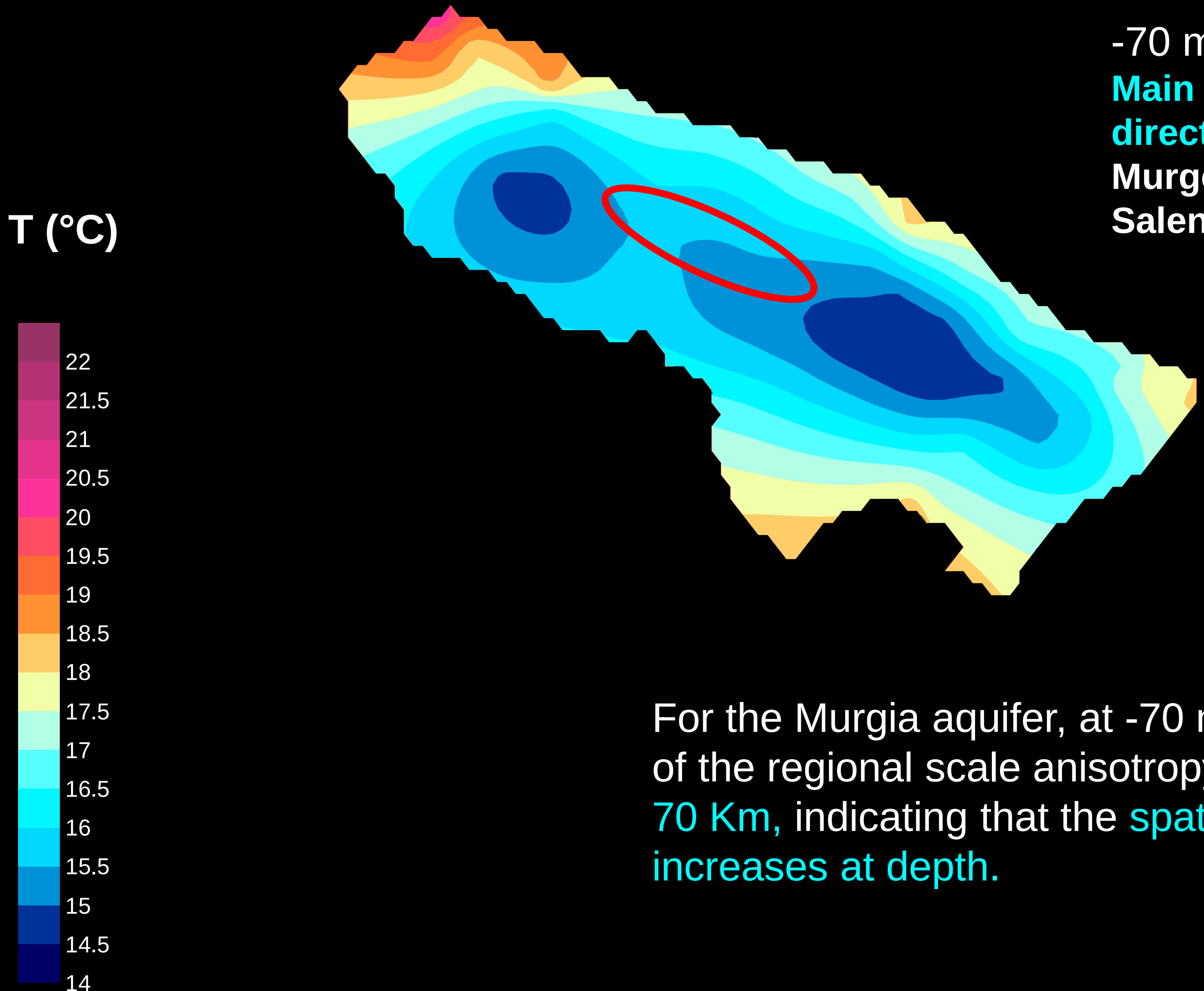
Main anisotropy axis direction

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

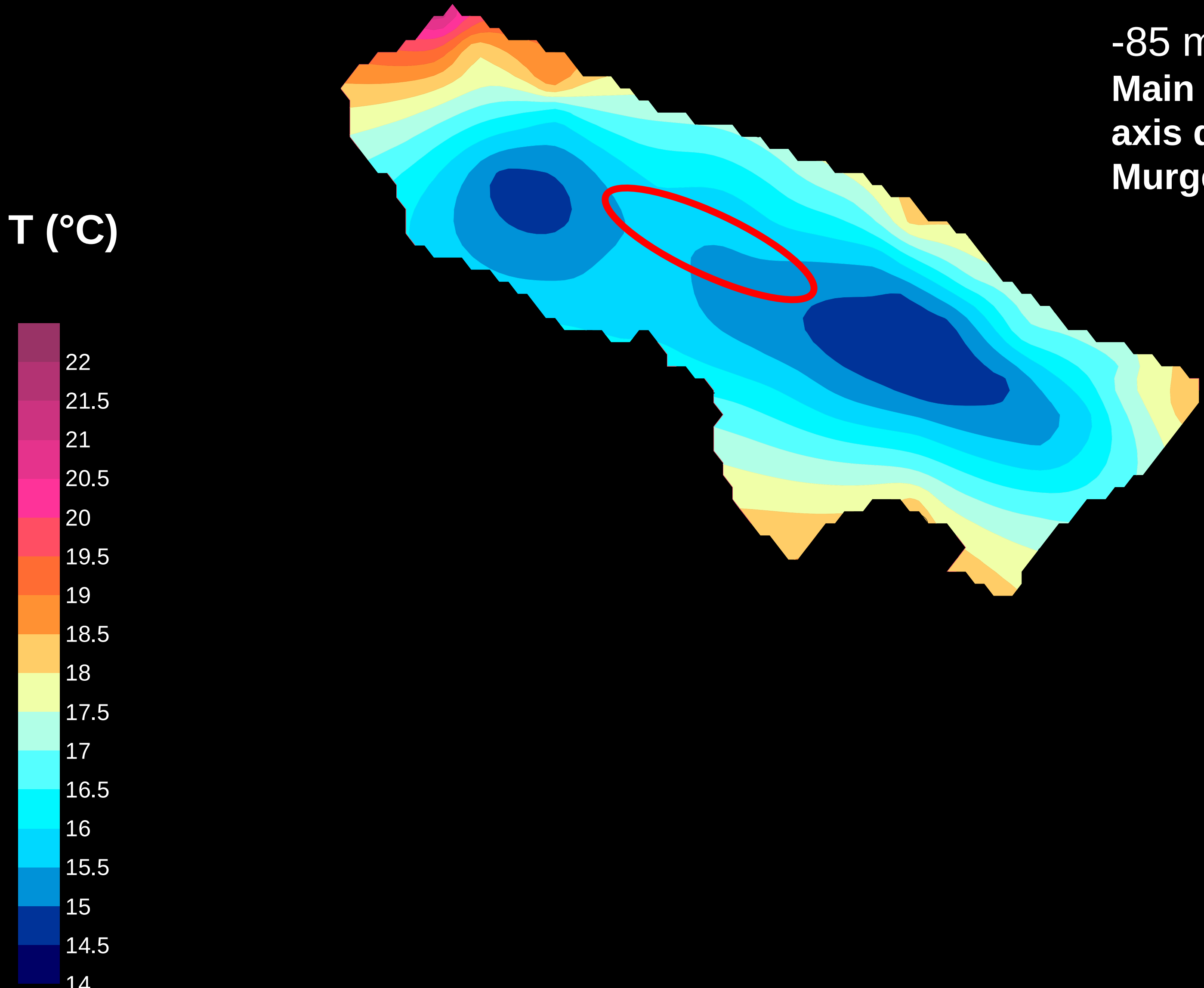
Murge: N115E

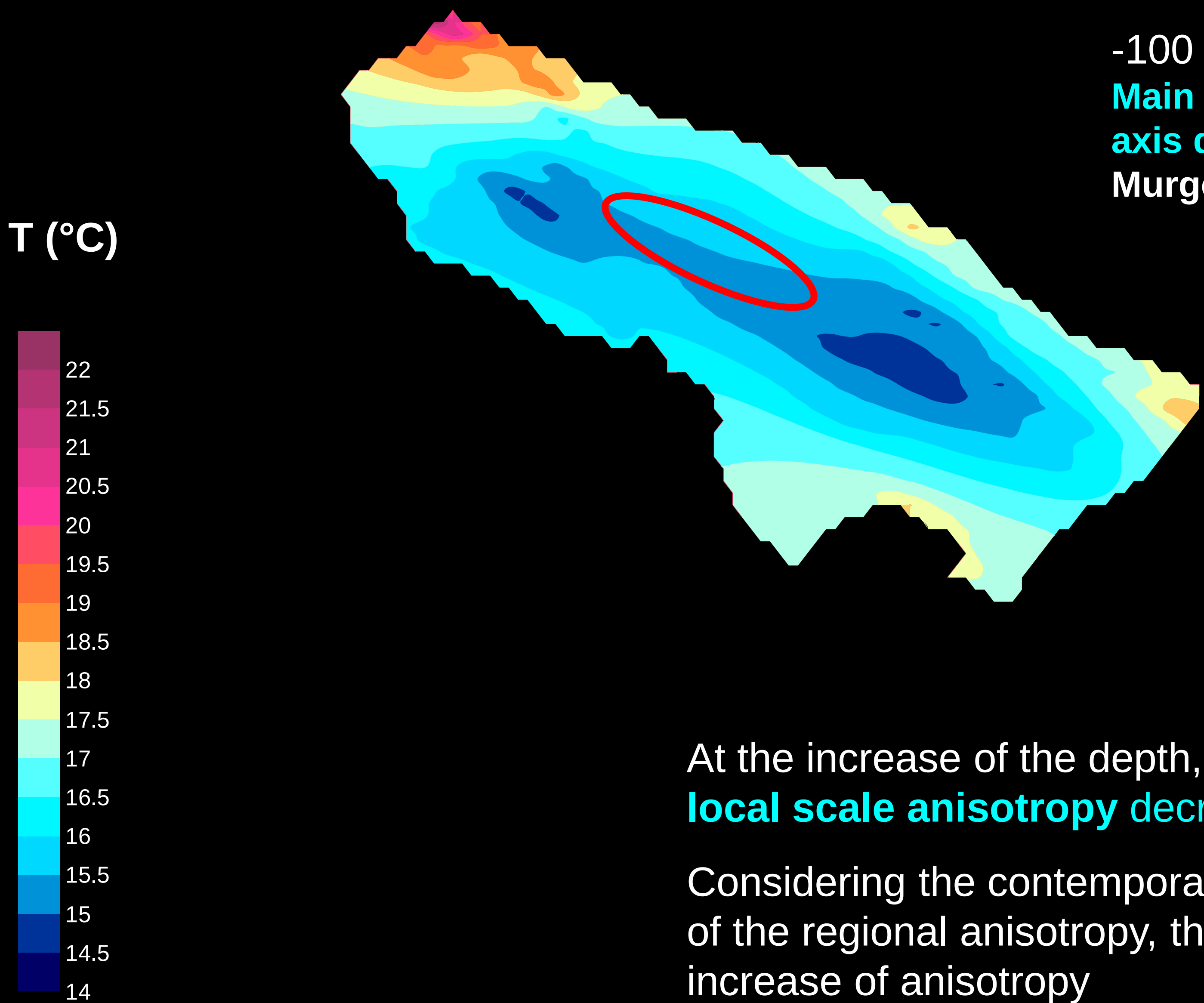
Salento: isotropic?

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





-100 m a.s.l

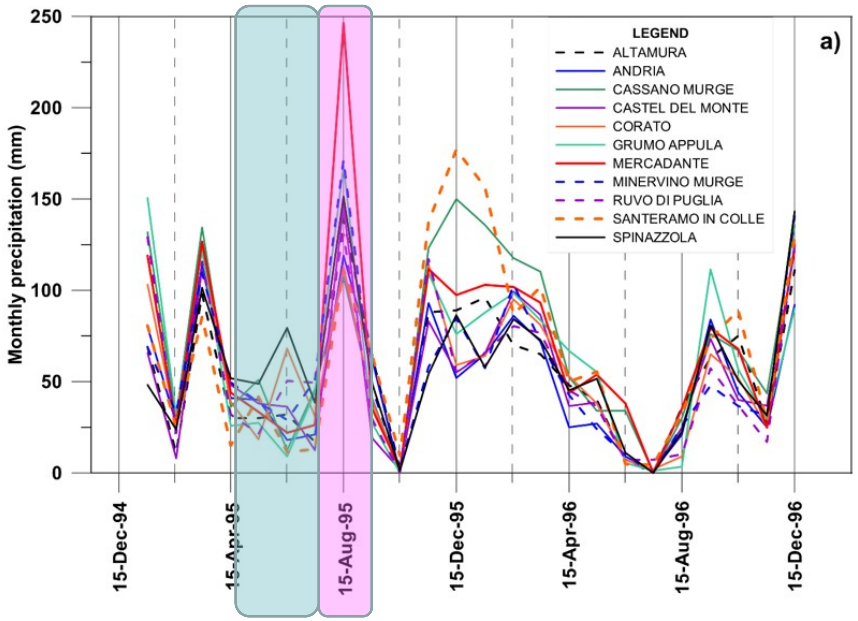
Main anisotropy axis direction

Murge: N115E

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

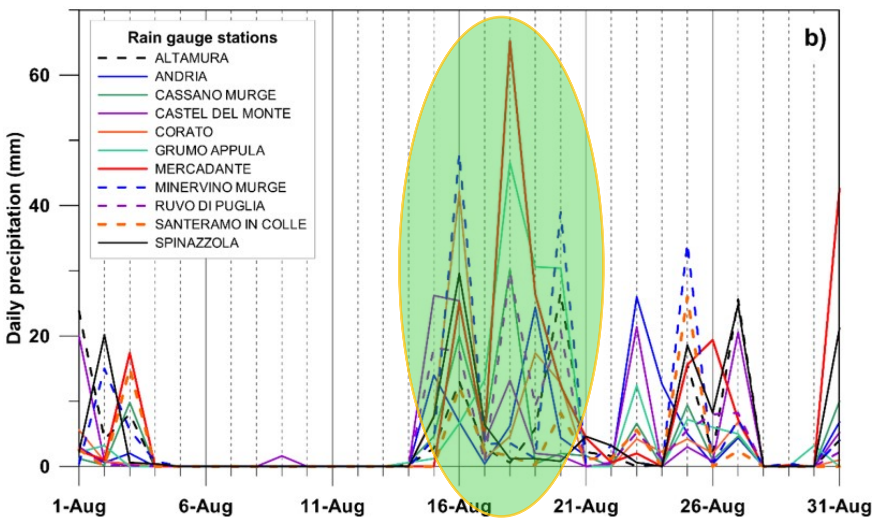
Considering the contemporaneous increase of the regional anisotropy, this indicates an increase of anisotropy

Concurrence of a peculiar climate sequence that favours the study



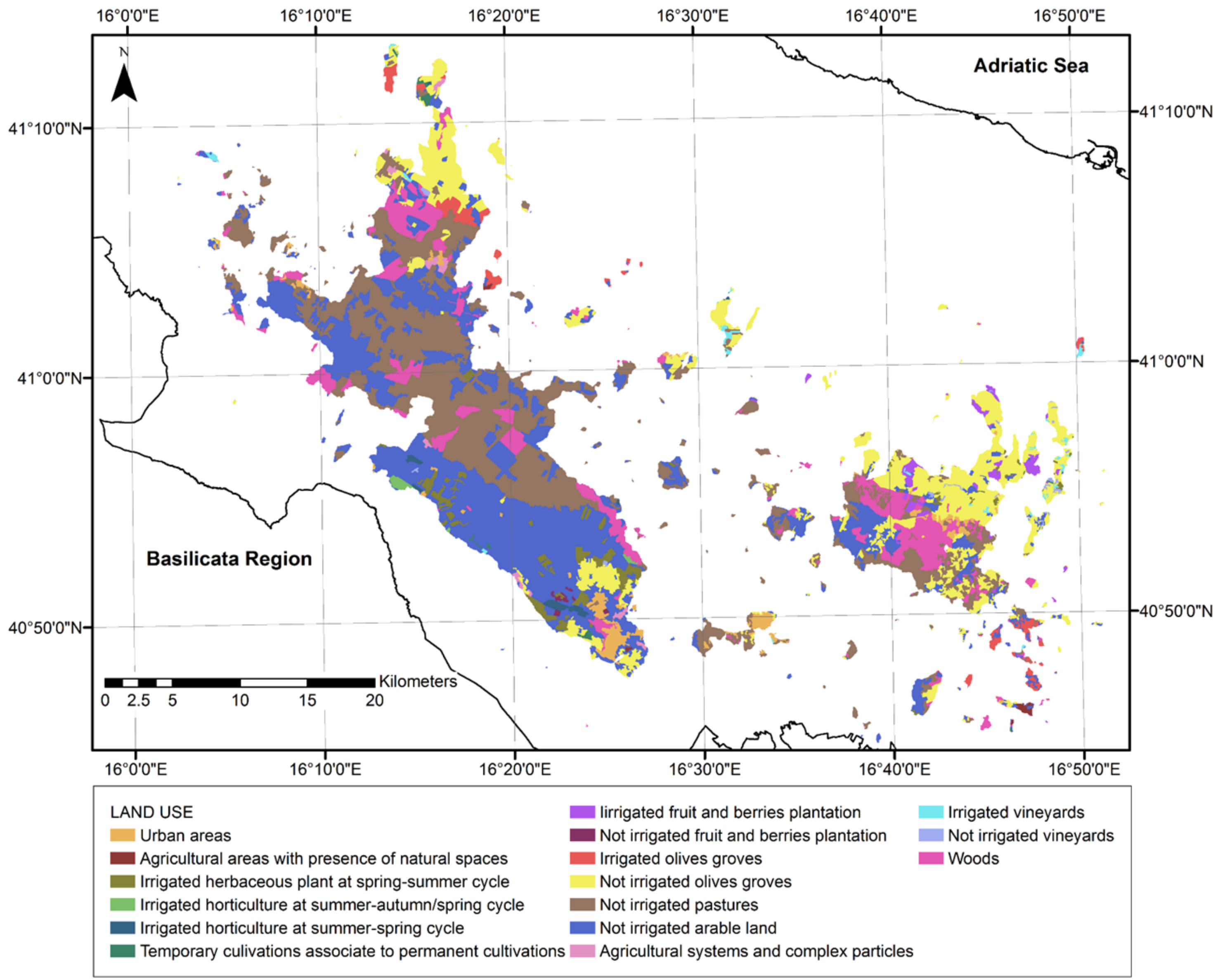
August 1995 was characterized by significant rainfall events: These rainfall events follow **a period of null recharge of 4 months**

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

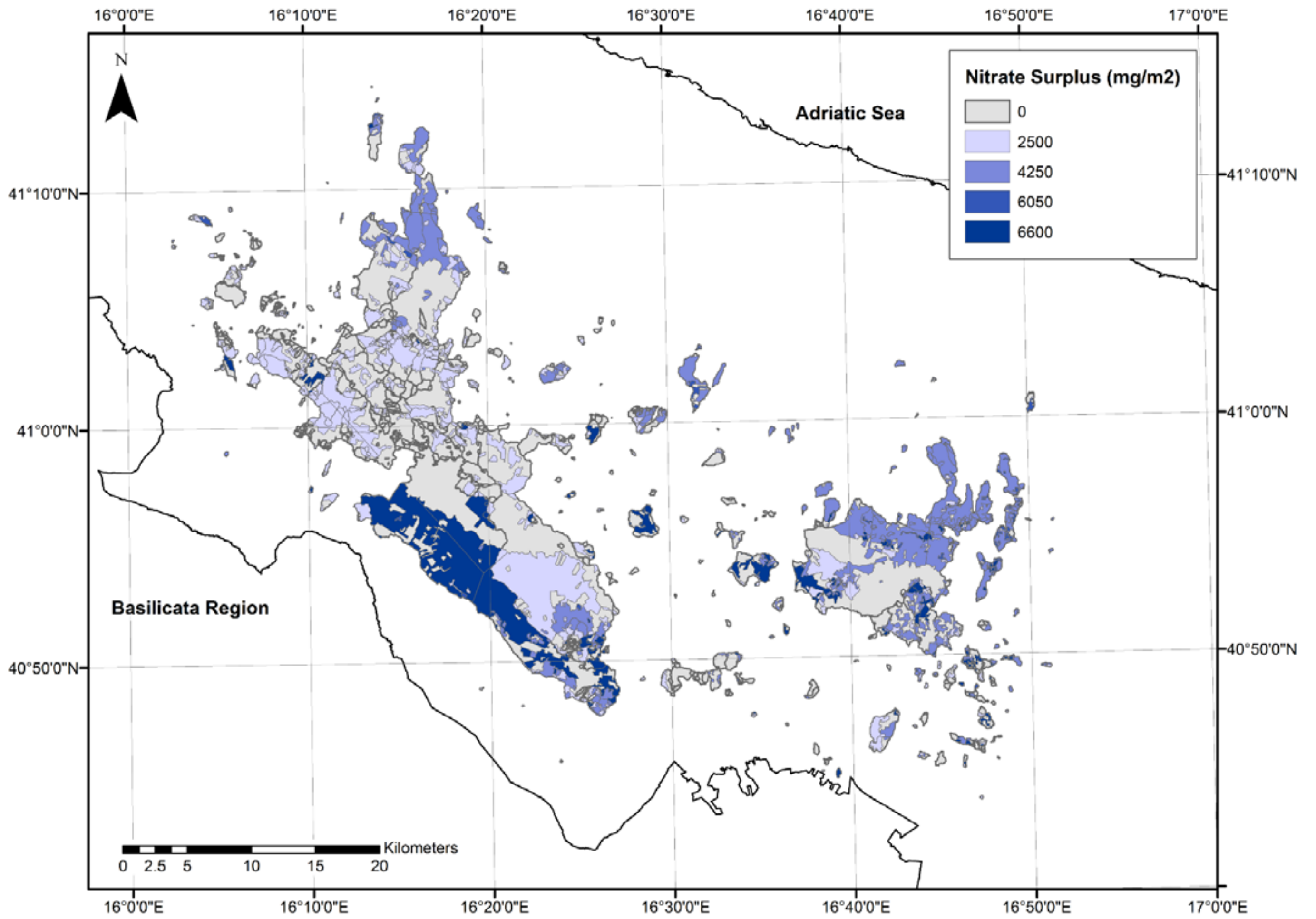


Assessment of the land use in the selected period

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



Evaluation of the nitrate surplus potentially avalaible for leaching



Nitrate surplus (mg/m^2)

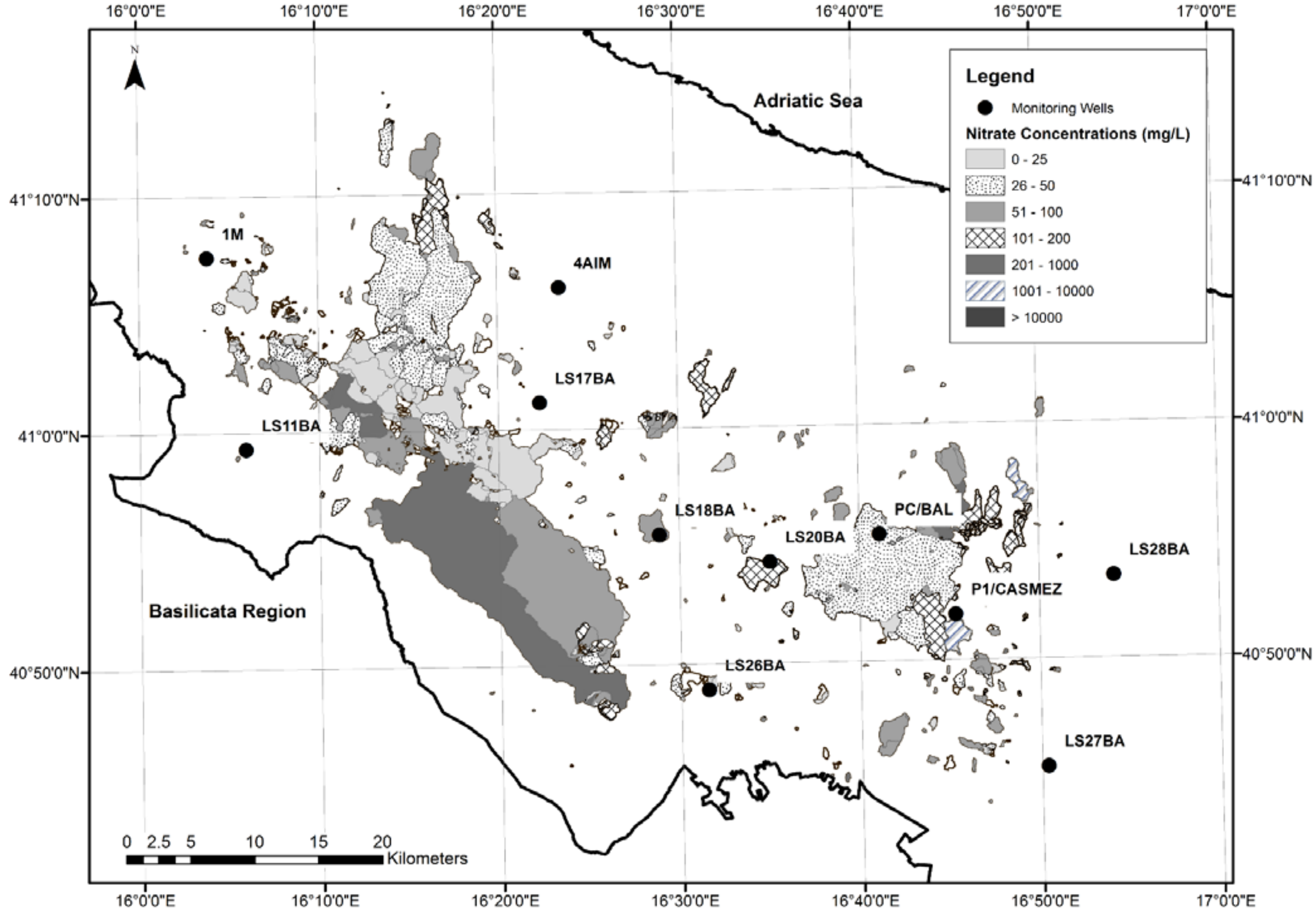
Calculation of nitrate concentration in recharge volumes

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.



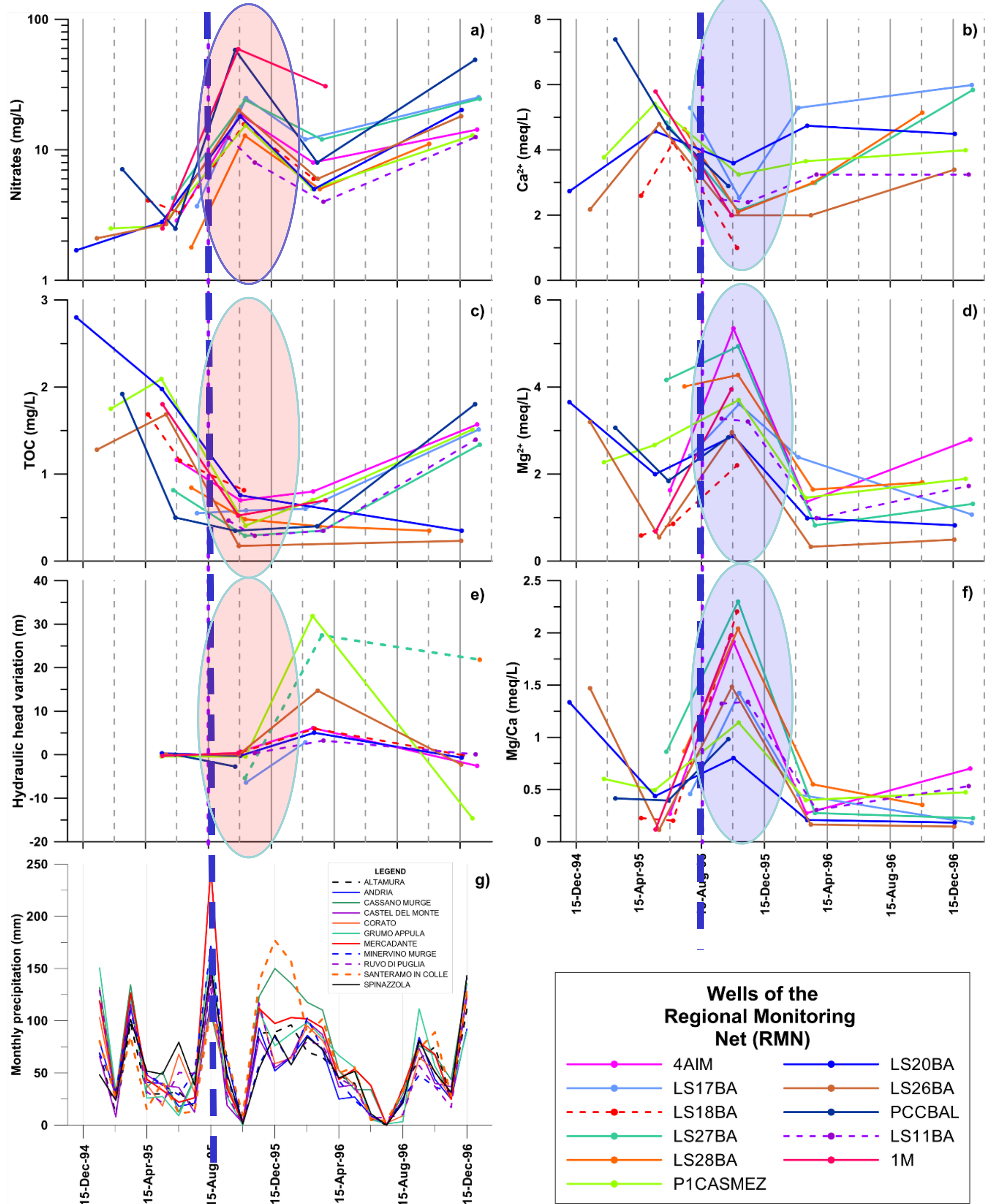
The **average concentration of nitrates in the whole volume of the autogenic recharge from endorheic basins of the period** is ***54 mg/L*.**

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***



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

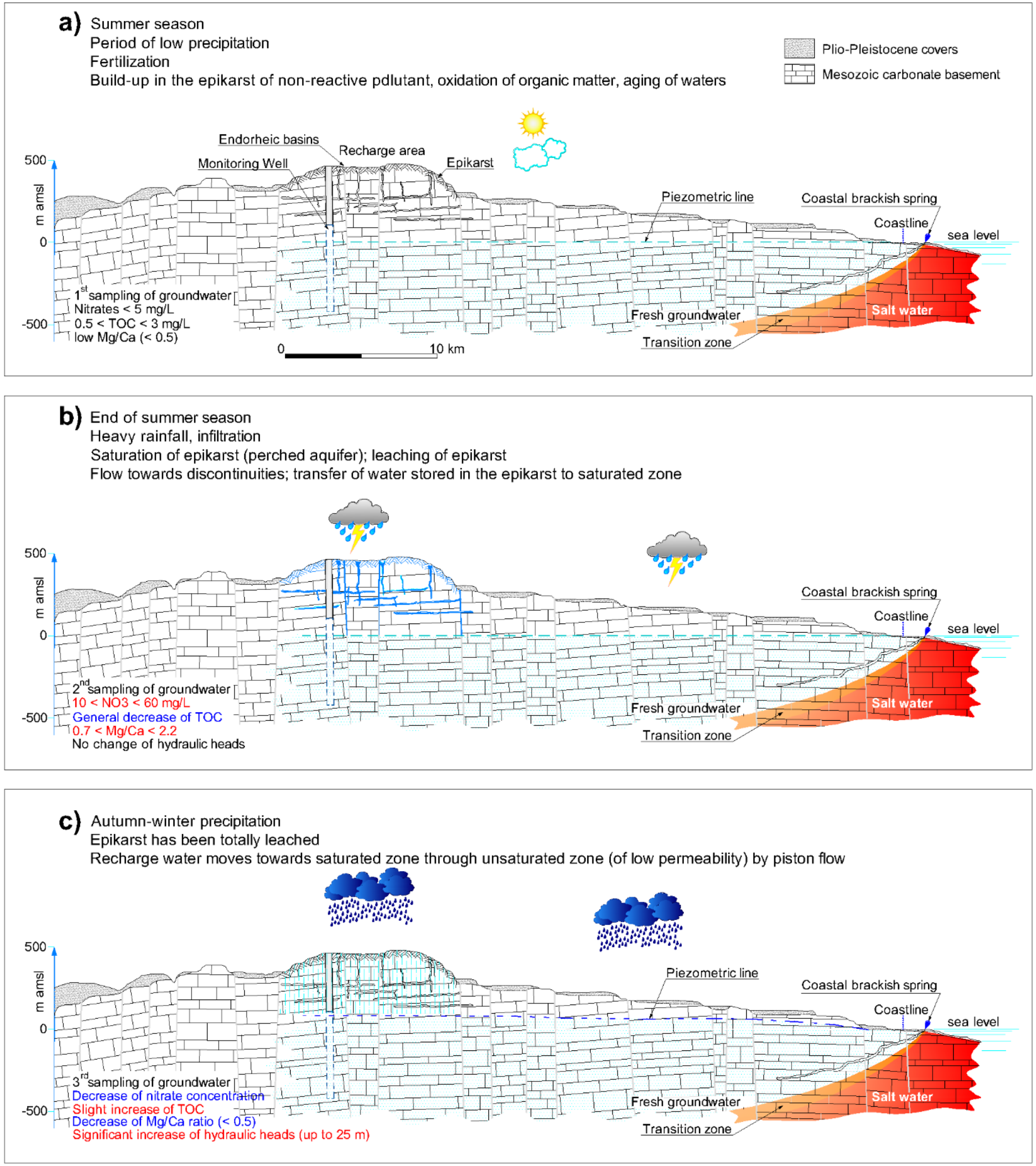
End of summer season - Heavy rainfall events

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***

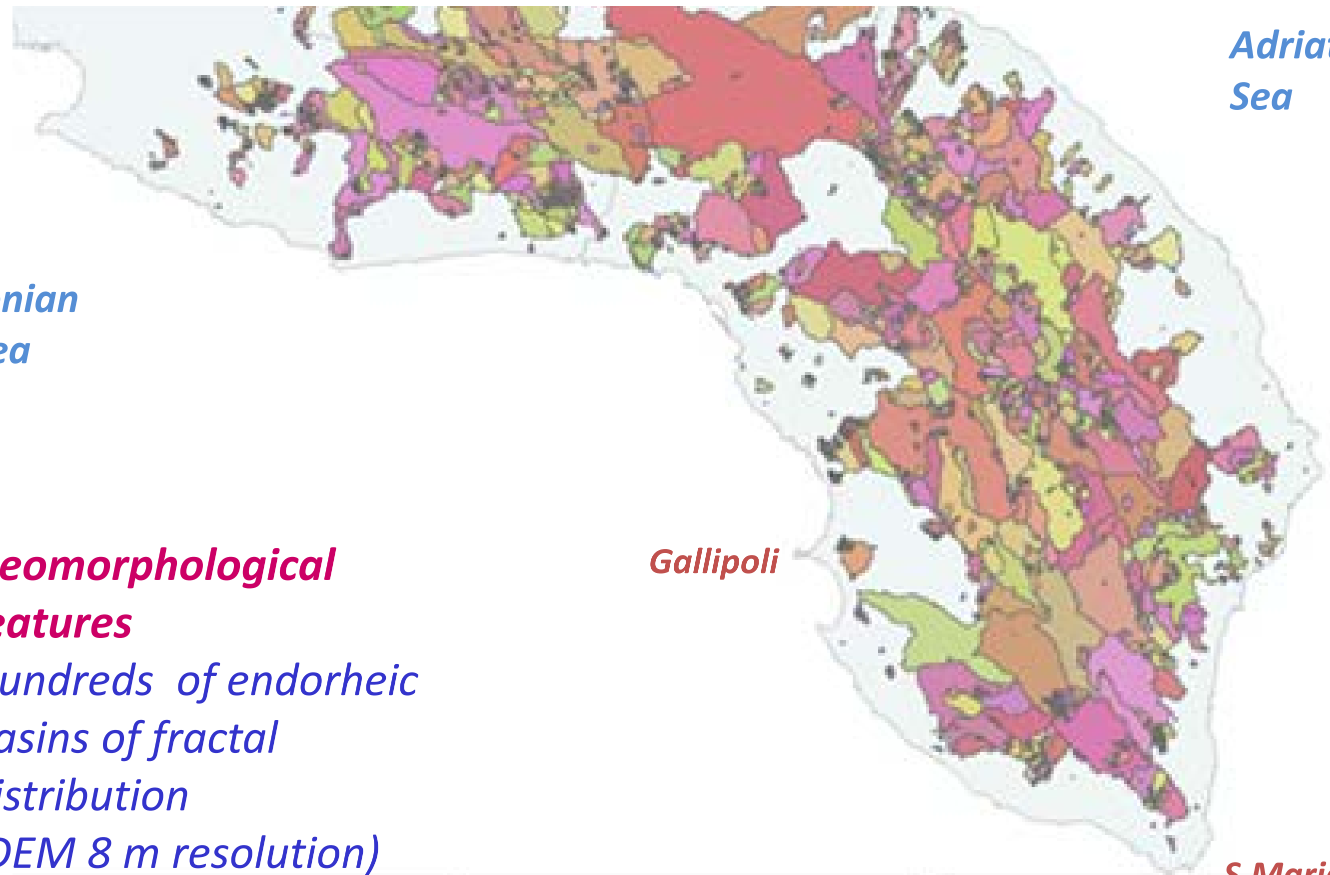
Autumn precipitation

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.

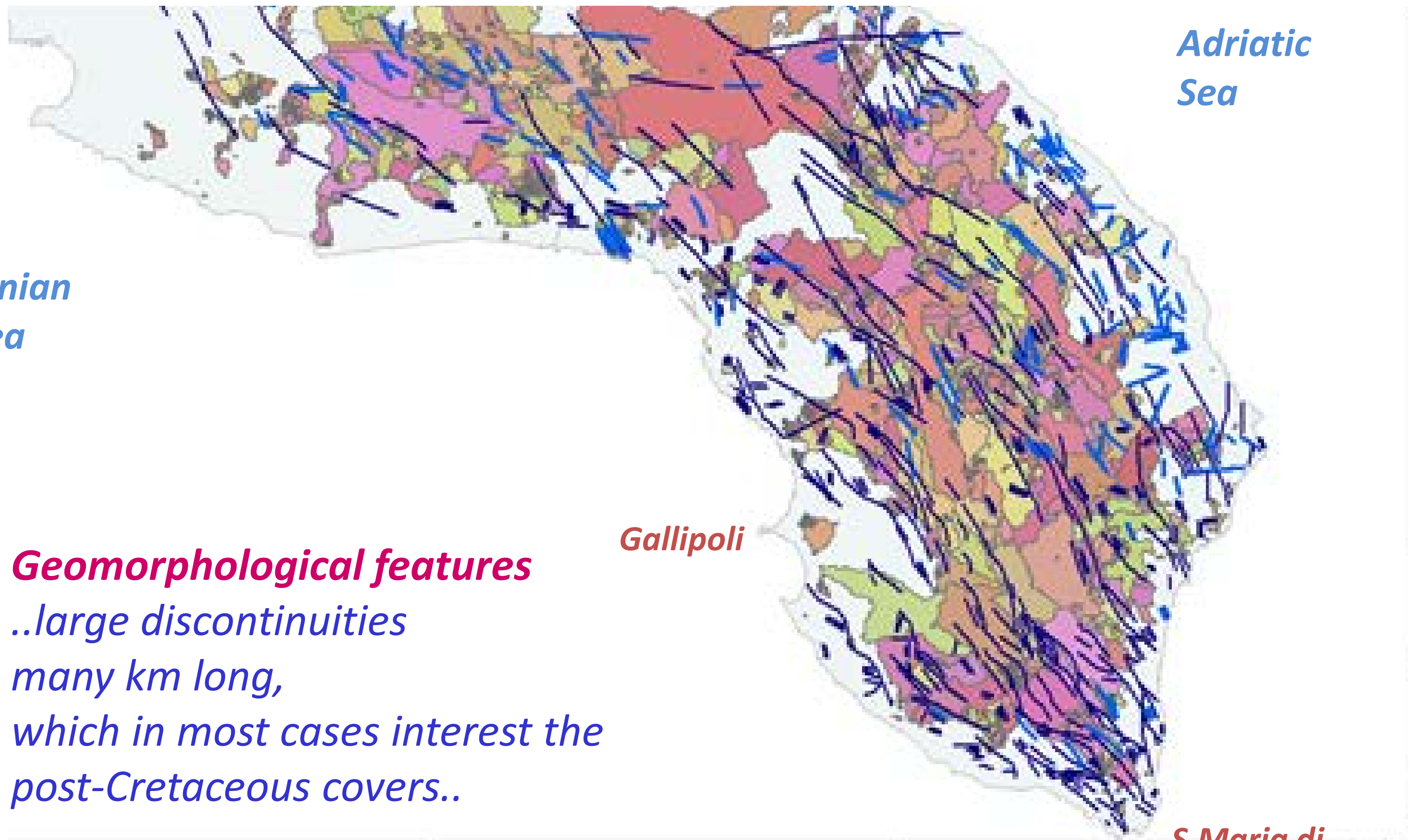


What about Salento intrinsic vulnerability?



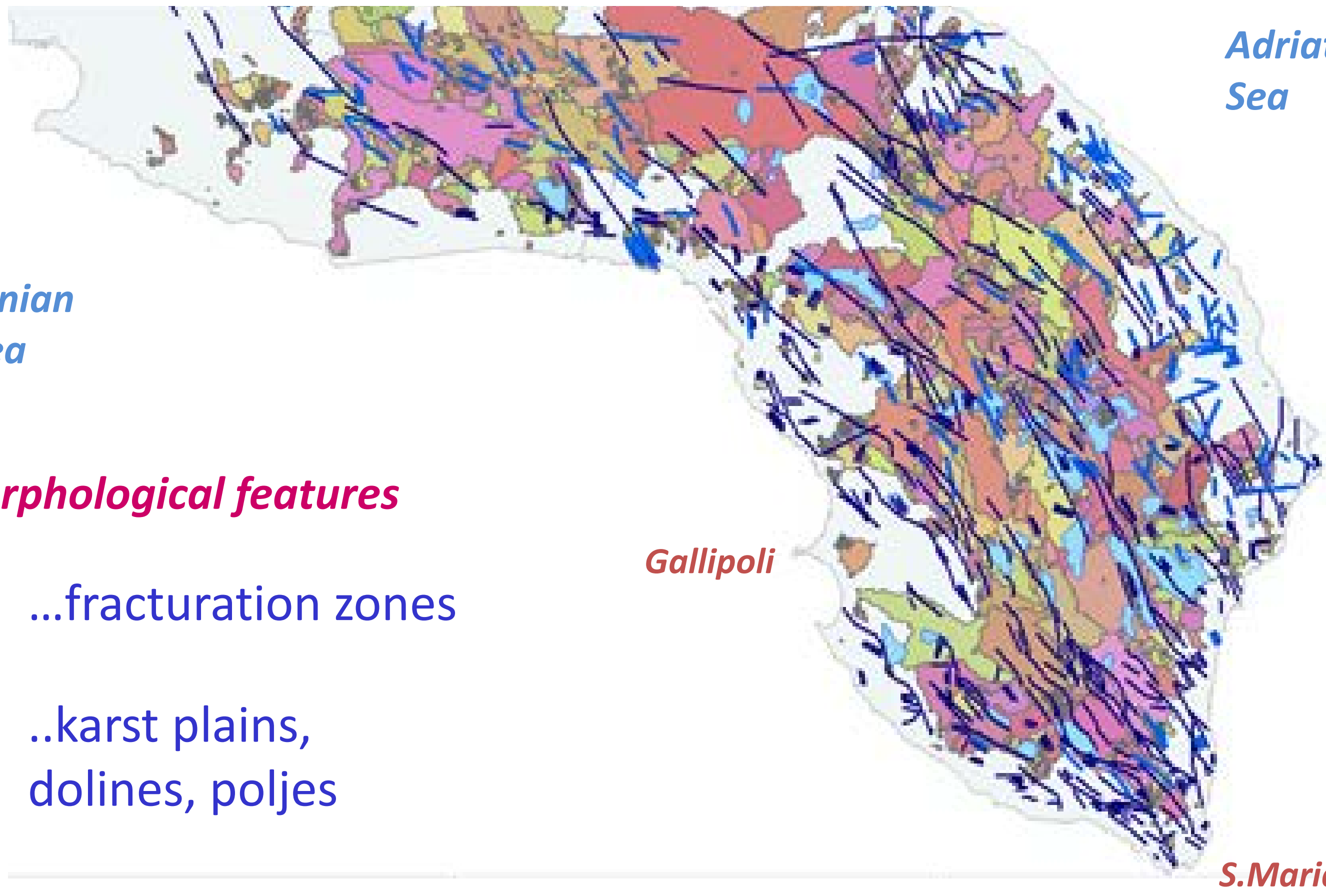
Geomorphological features

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



Geomorphological features

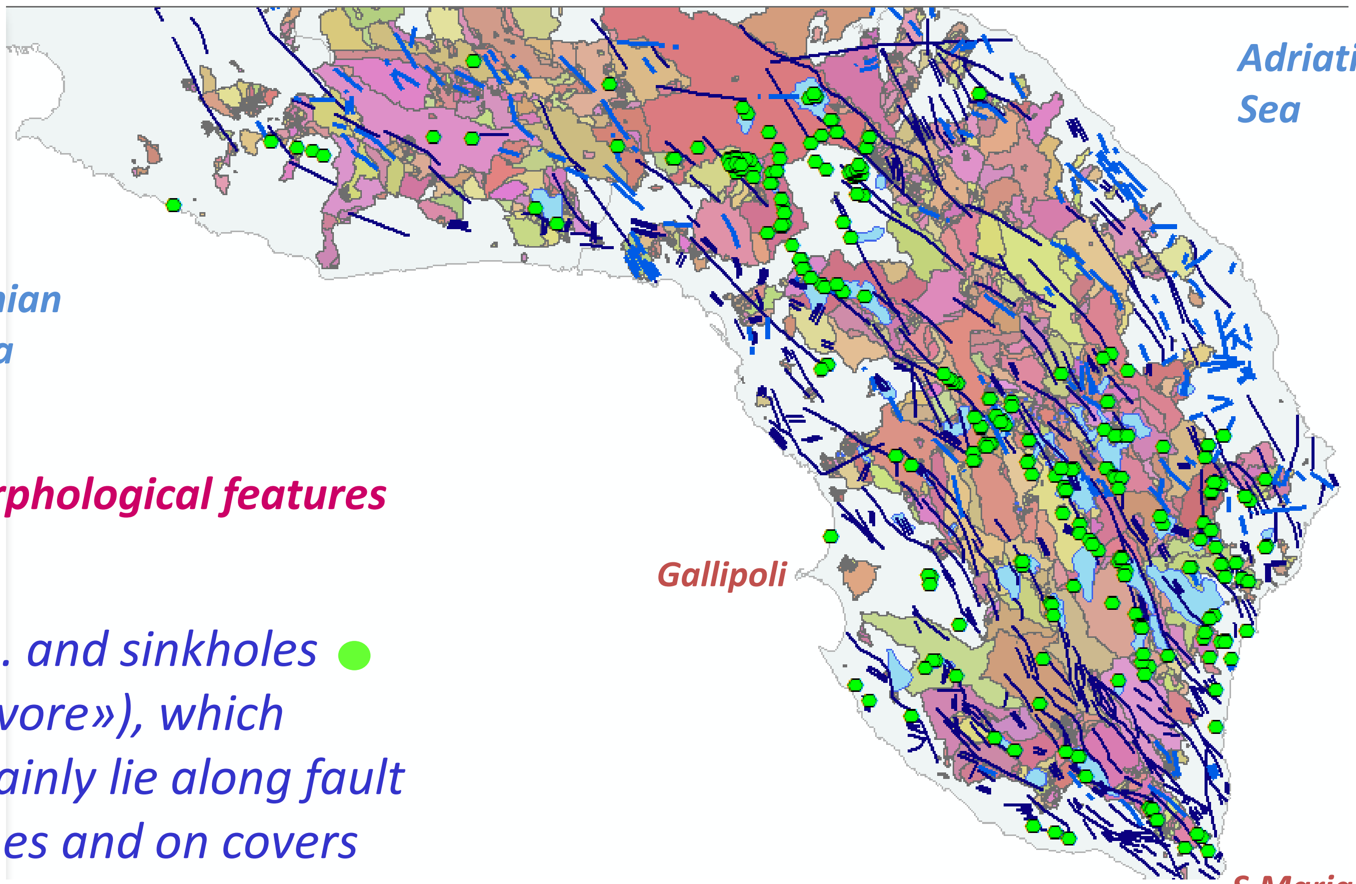
..large discontinuities many km long, which in most cases interest the post-Cretaceous covers..



Geomorphological features

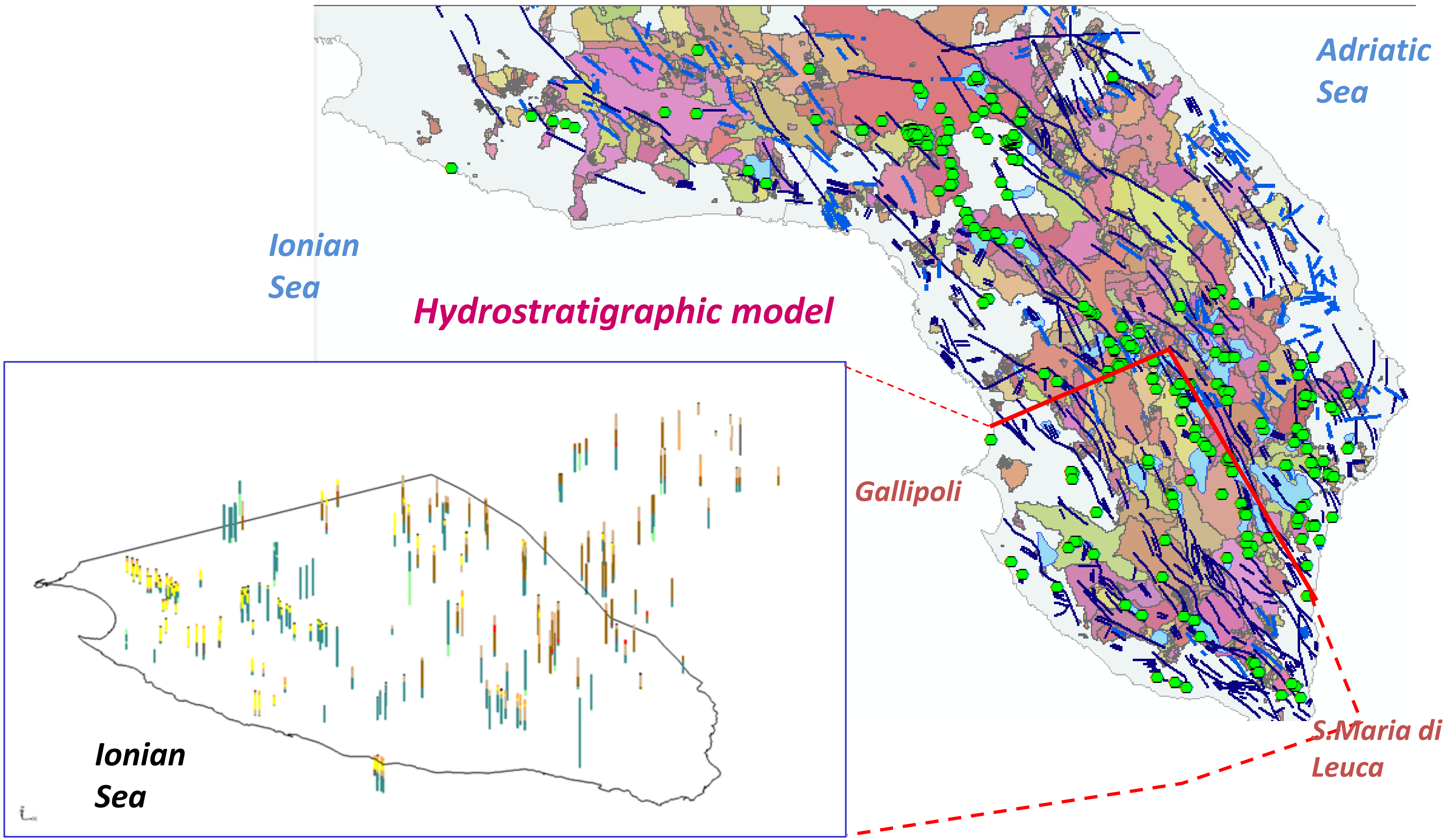
...fracturation zones

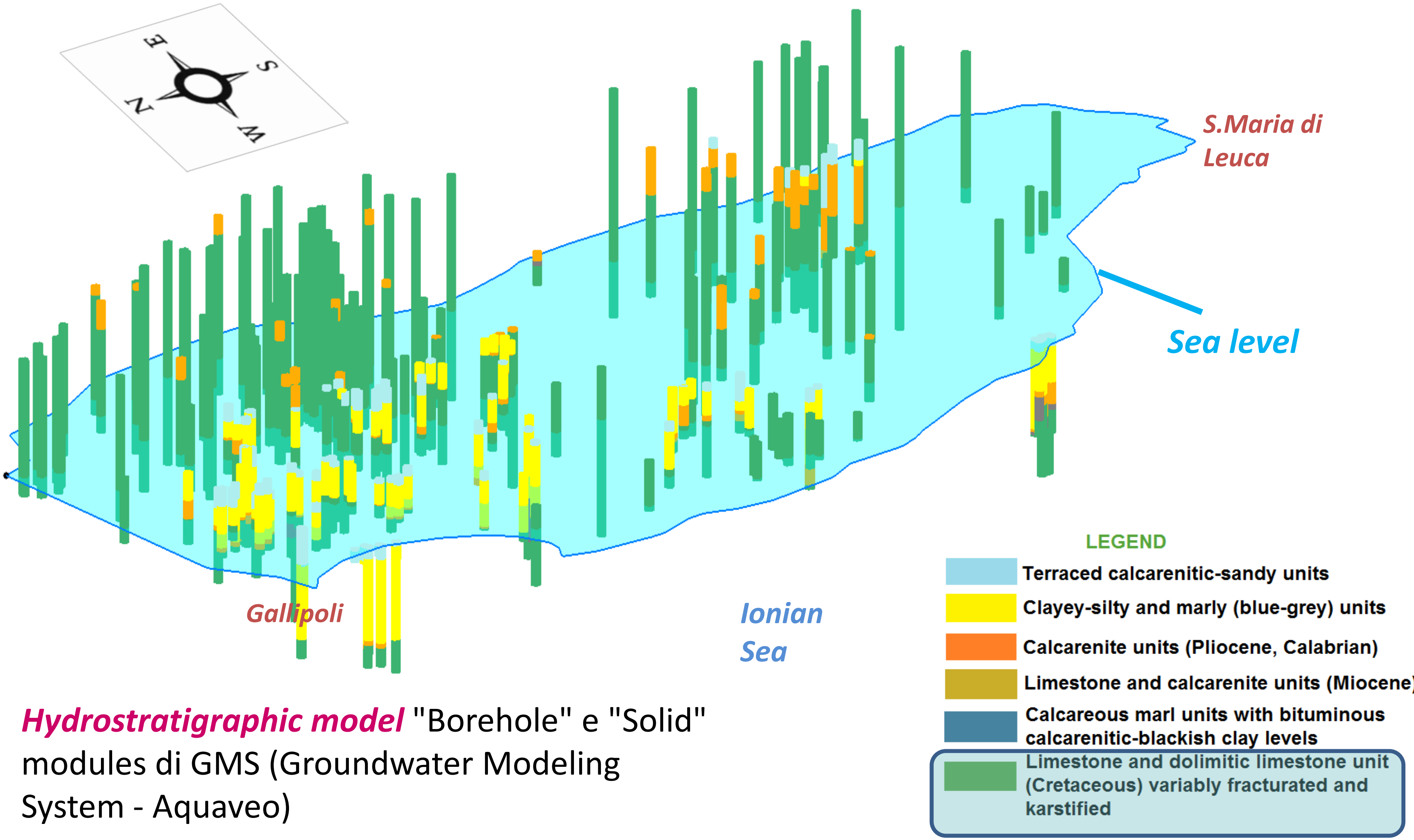
..karst plains, dolines, poljes



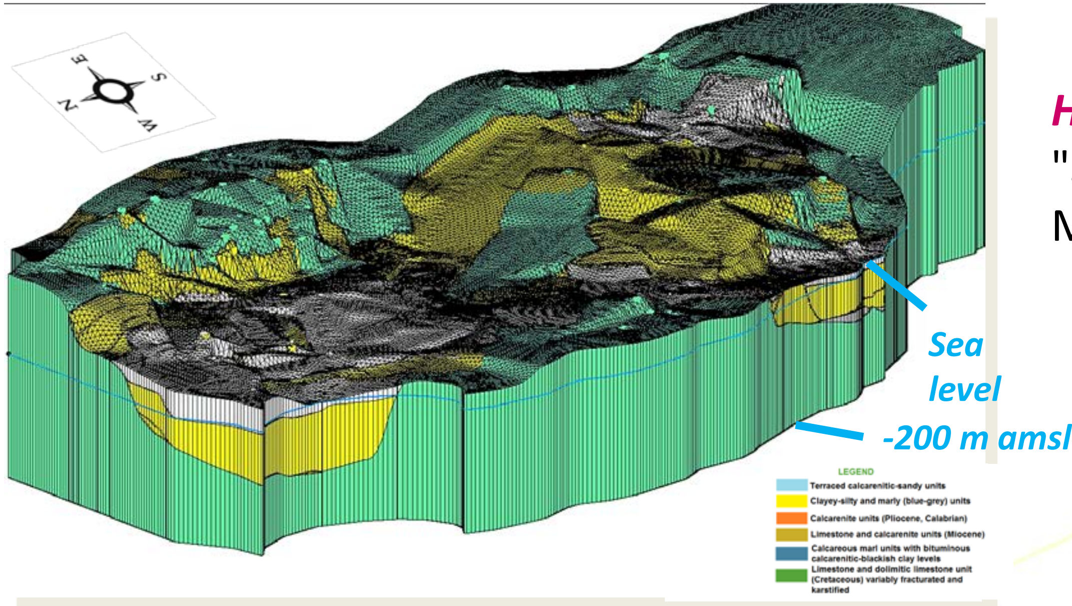
Geomorphological features

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


Adriatic Sea
Ionian Sea
Hydrostratigraphic model
Gallipoli
S.Maria di Leuca
Ionian Sea



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



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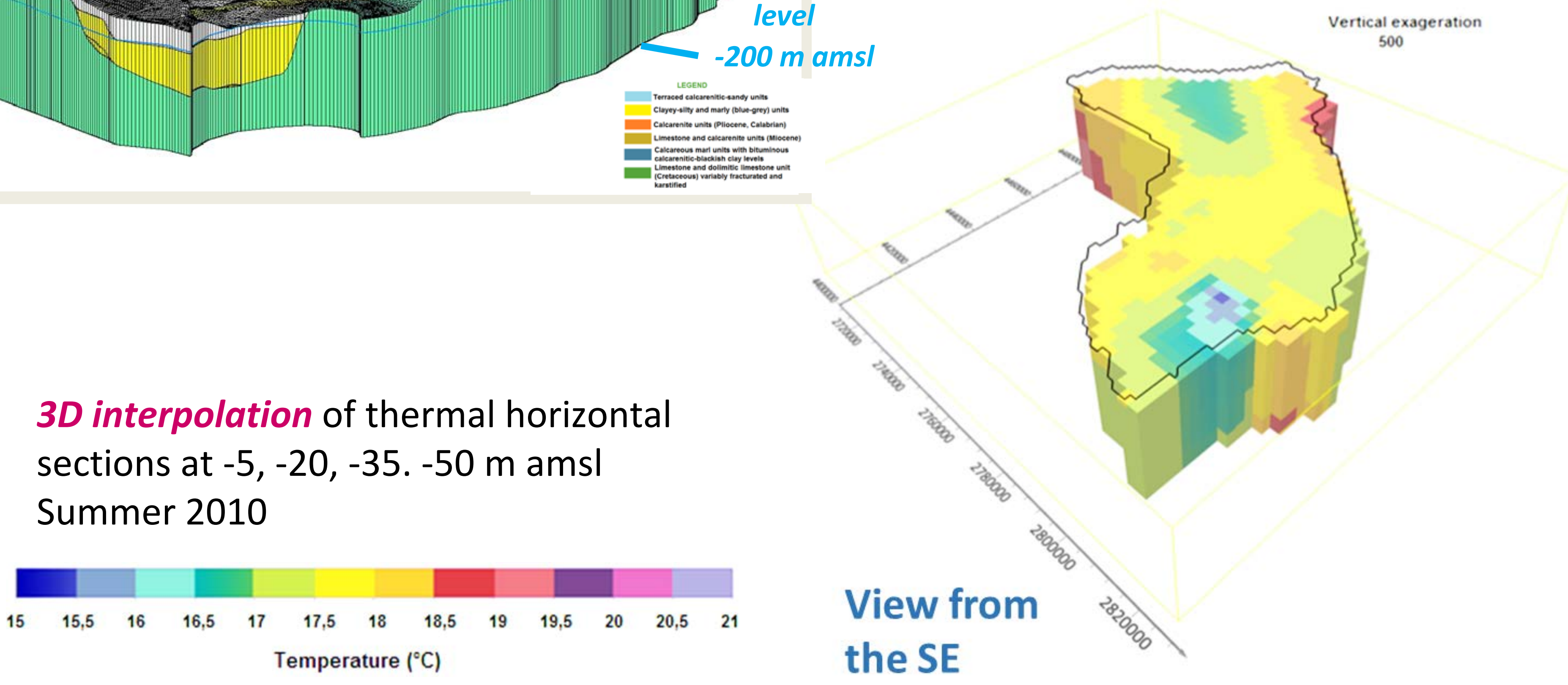
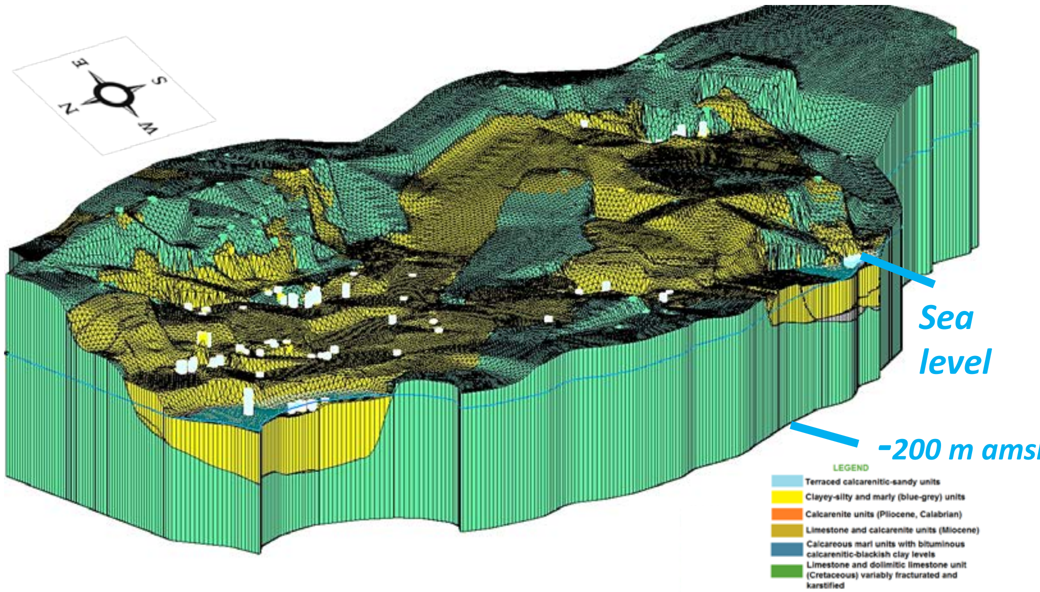
3D interpolation of thermal horizontal sections at -5, -20, -35. -50 m amsl Summer 2010





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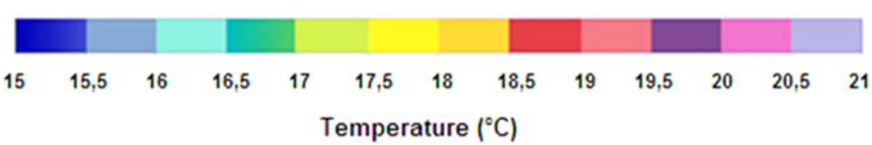

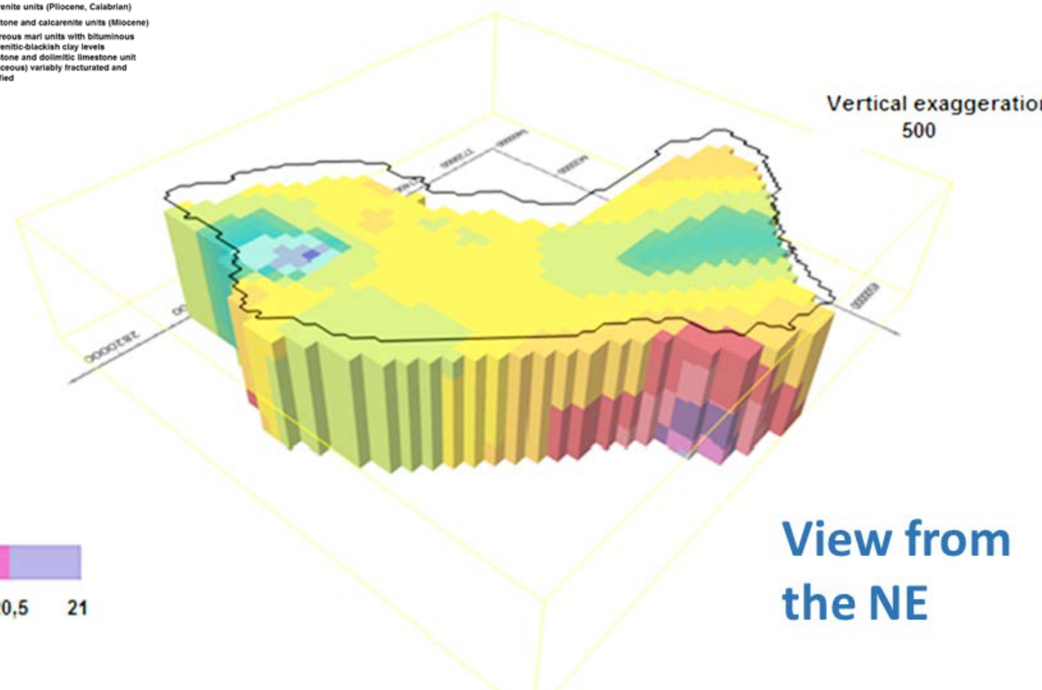

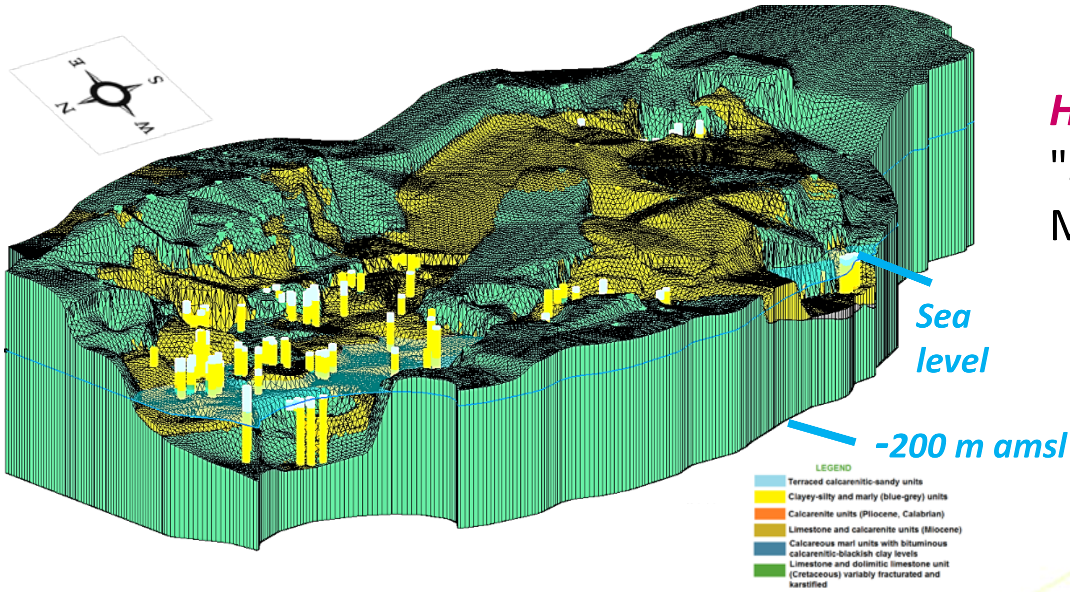

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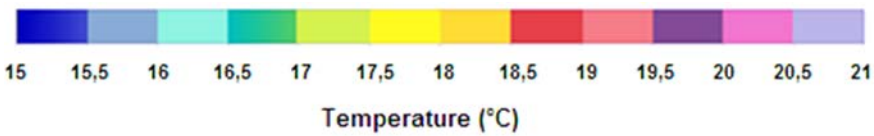
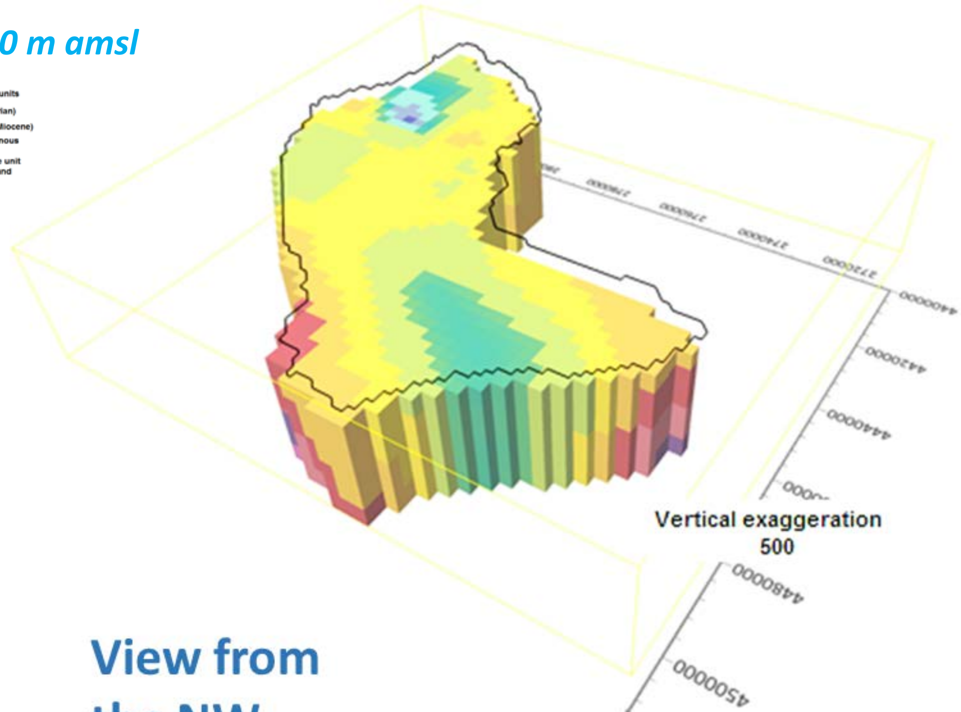
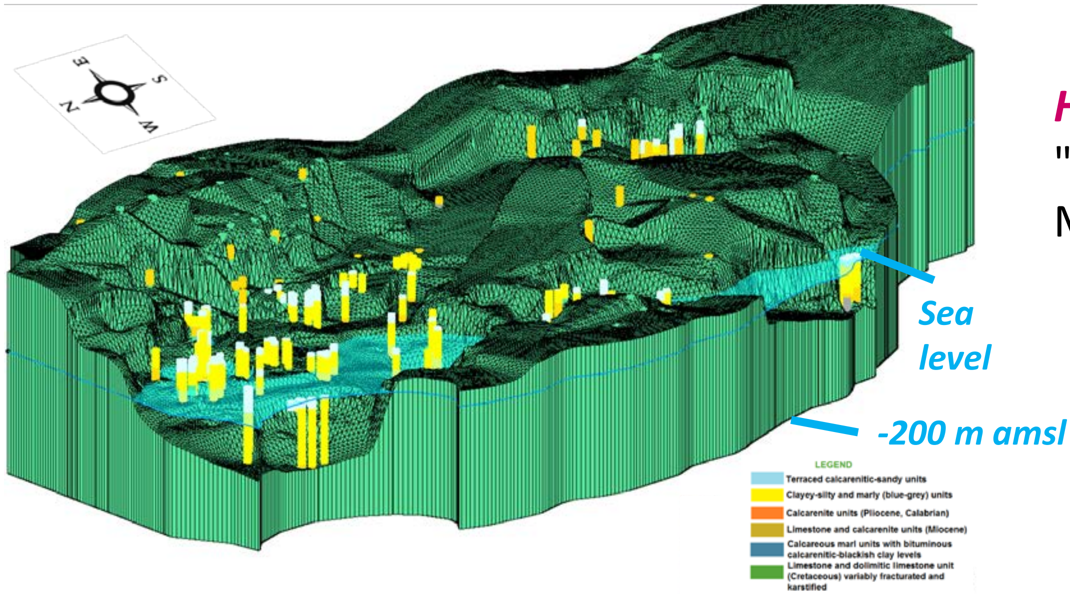




View from the NW



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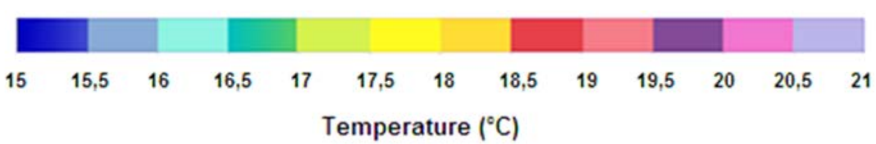
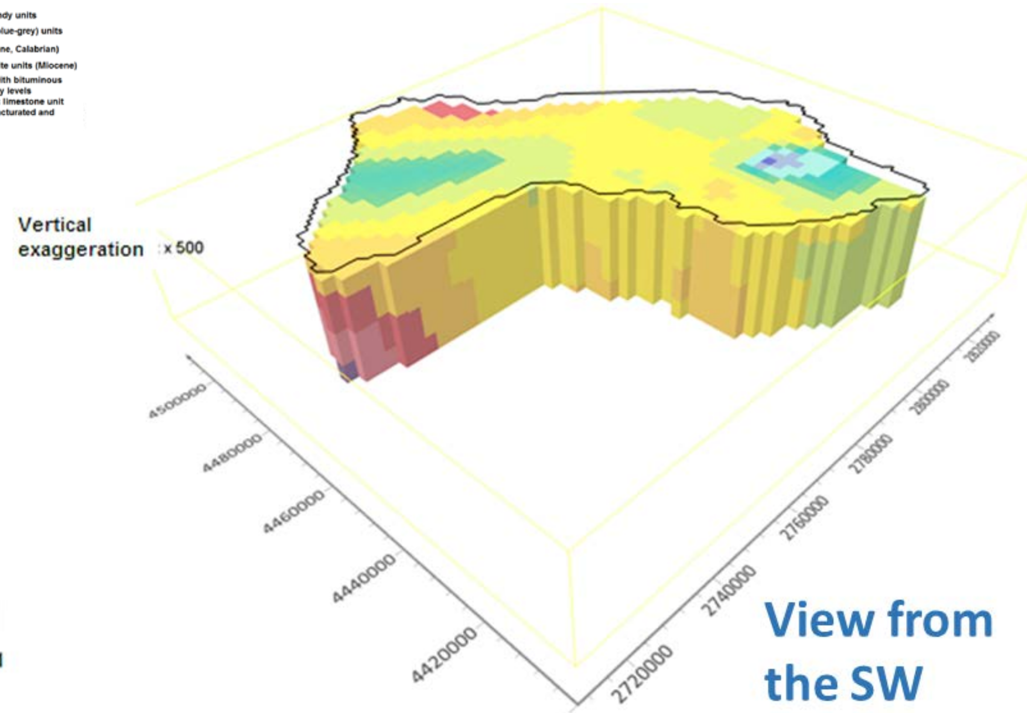
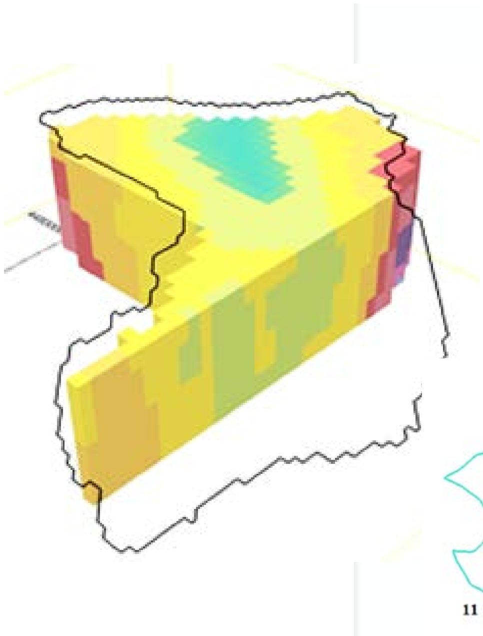
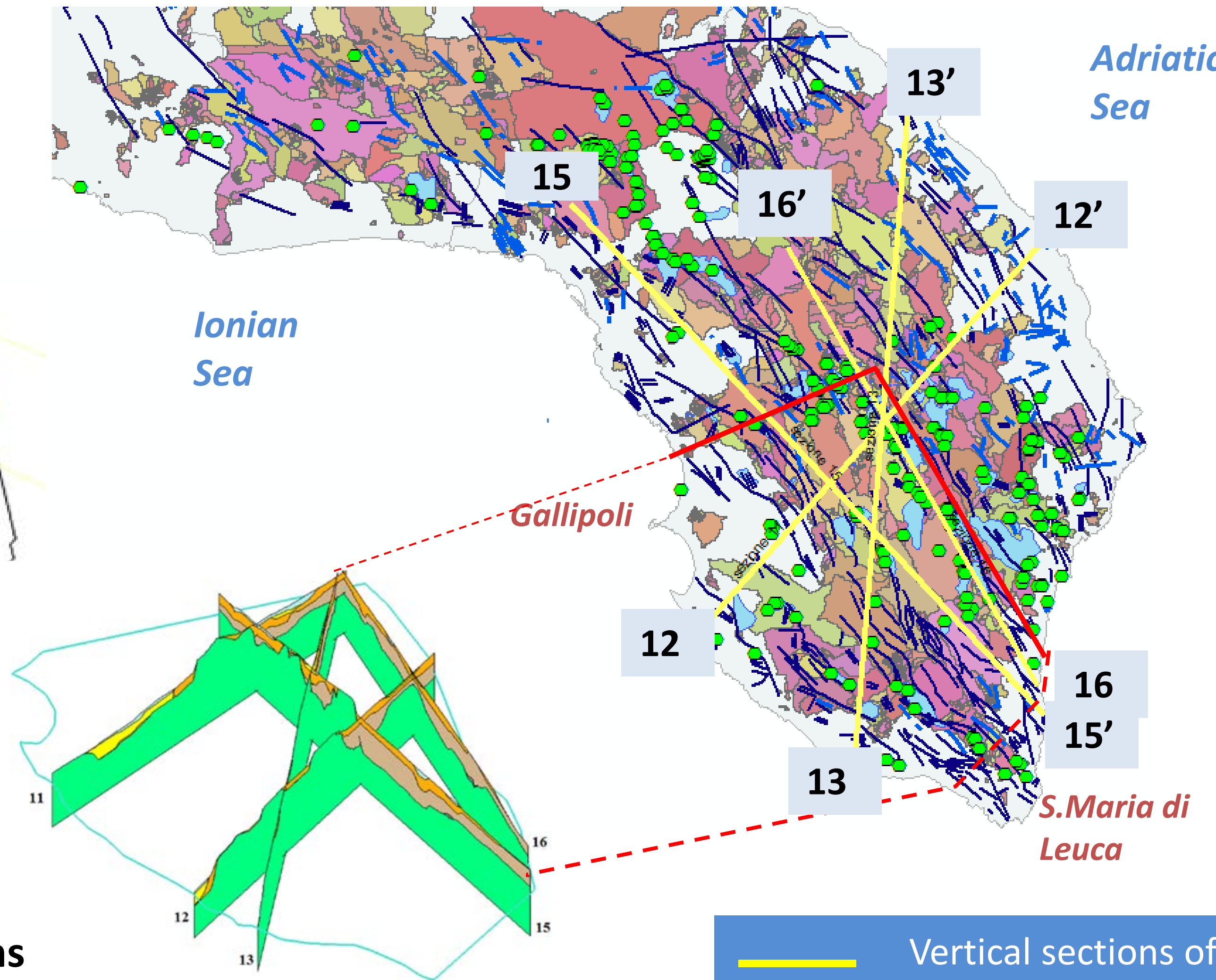




LEGEND

- Terraced calcarenitic-sandy units
- Clayey-silty and marly (blue-grey) units
- Calcarenite units (Pliocene, Calabrian)
- Limestone and calcarenite units (Miocene)
- Calcareous marl units with bituminous calcarenitic-blackish clay levels
- Limestone and dolimitic limestone unit (Cretaceous) variably fracturated and karstified





Geological sections from the 3D model

Vertical sections of the thermal field

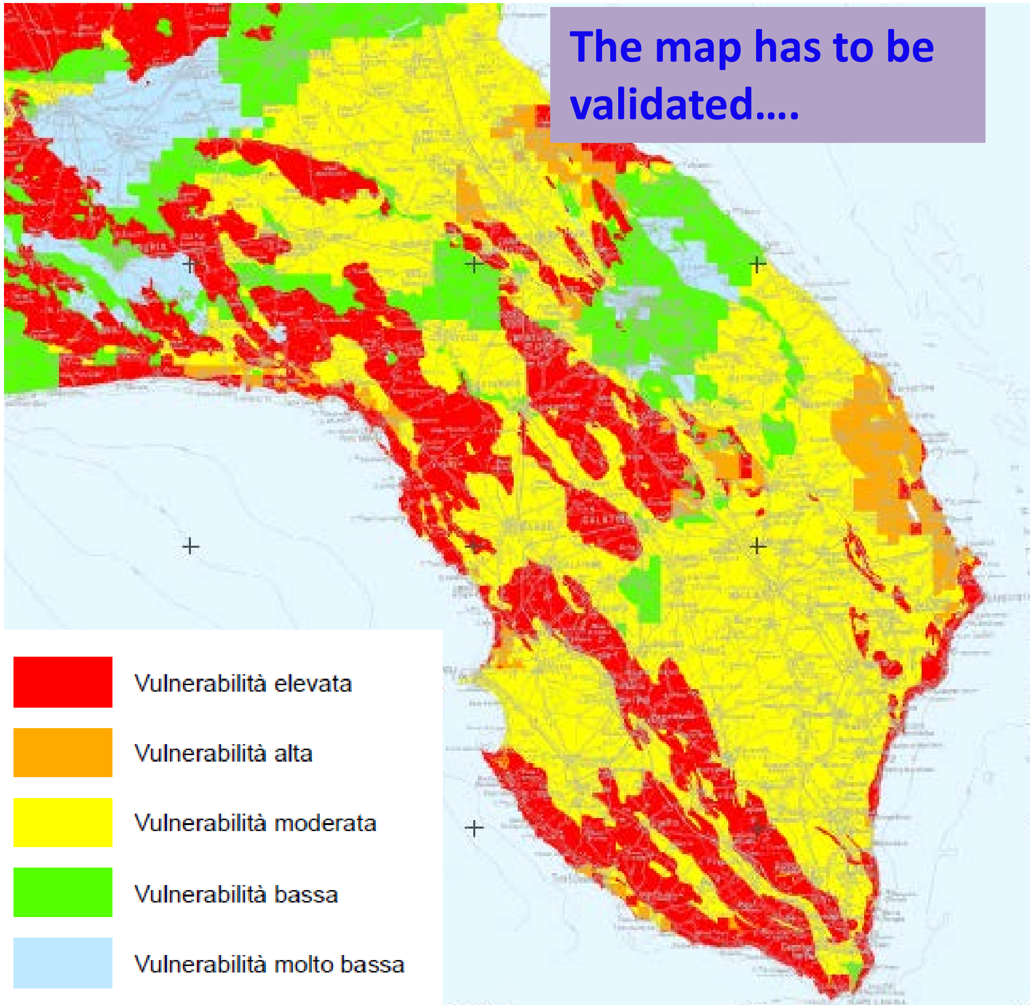
COP method developed in 2001 and 2002 by the Hydrogeology Group of the University of Malaga (Vías et al. 2002).

COP method takes into account the factor ***overlying layers (O),*** which refers to the protection of the unsaturated zone and to its capability to filter out or attenuate contamination.

the concentration of flow (C), which takes into account the ***surface conditions that control water flowing towards zones of rapid infiltration***.

the 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 (2005) - PTA

MD Fidelibus, Protection of the Apulian karstic coastal aquifers between intrinsic complexity and anthropogenic effects.

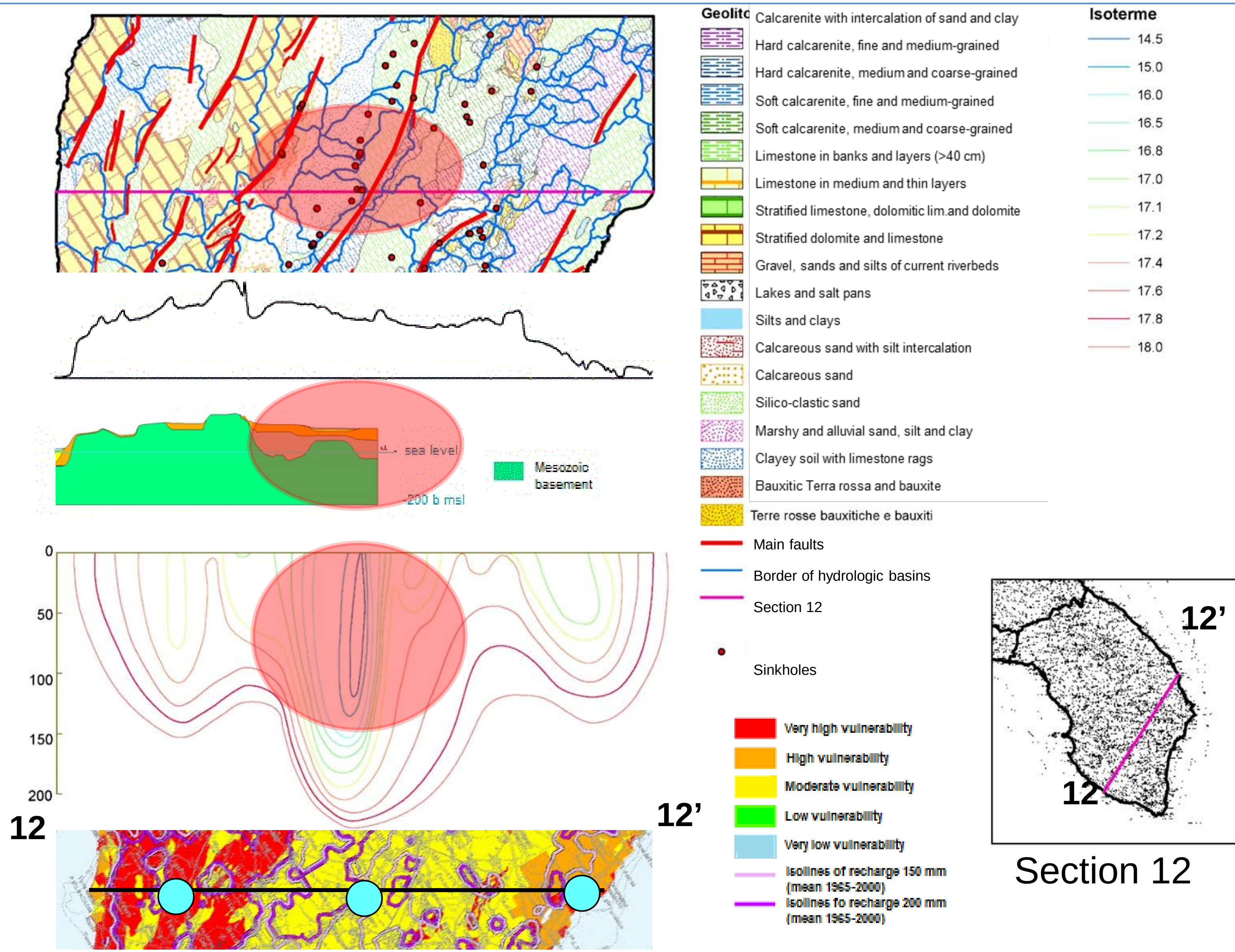
Geolithologic map

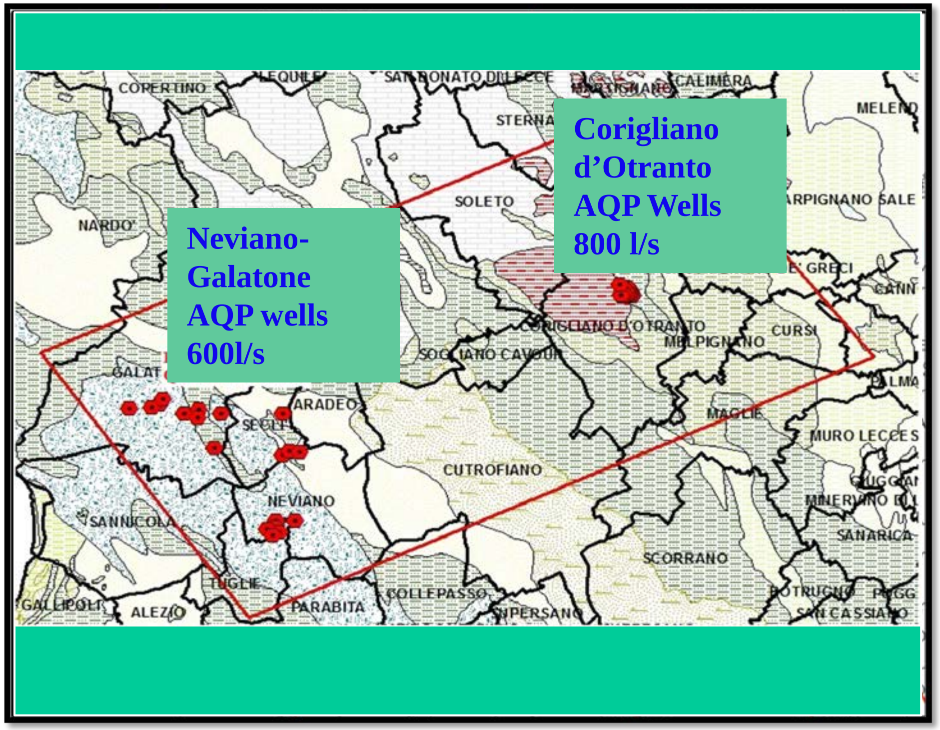
Topographic profile

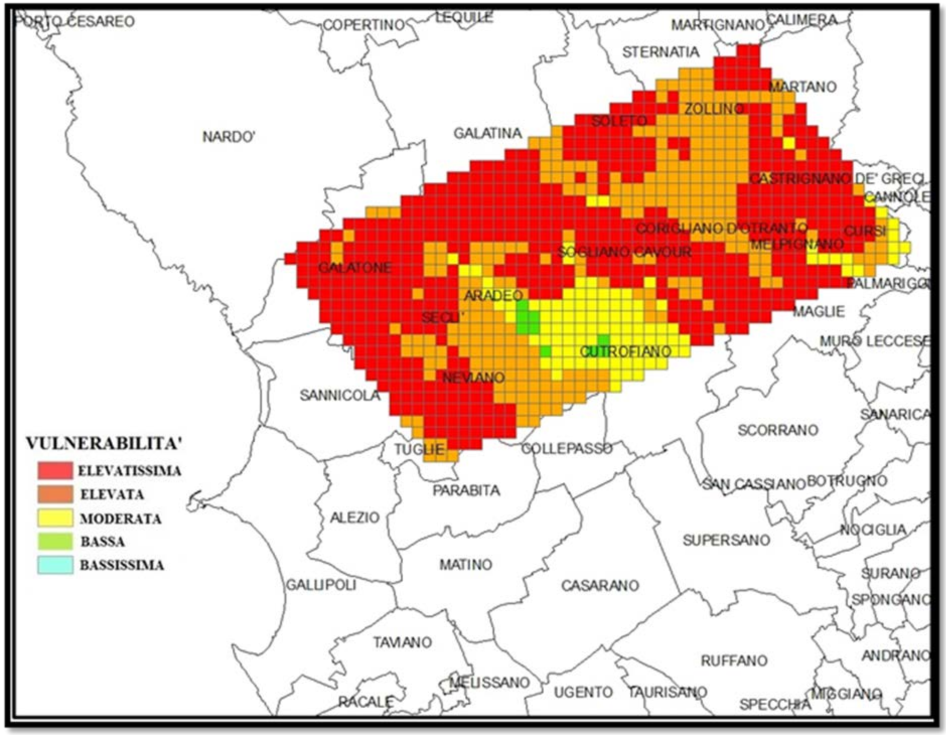
Geological section

Section of the thermal field

Intrinsic Vulnerability map (COP method)







Test zone for vulnerability mapping
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

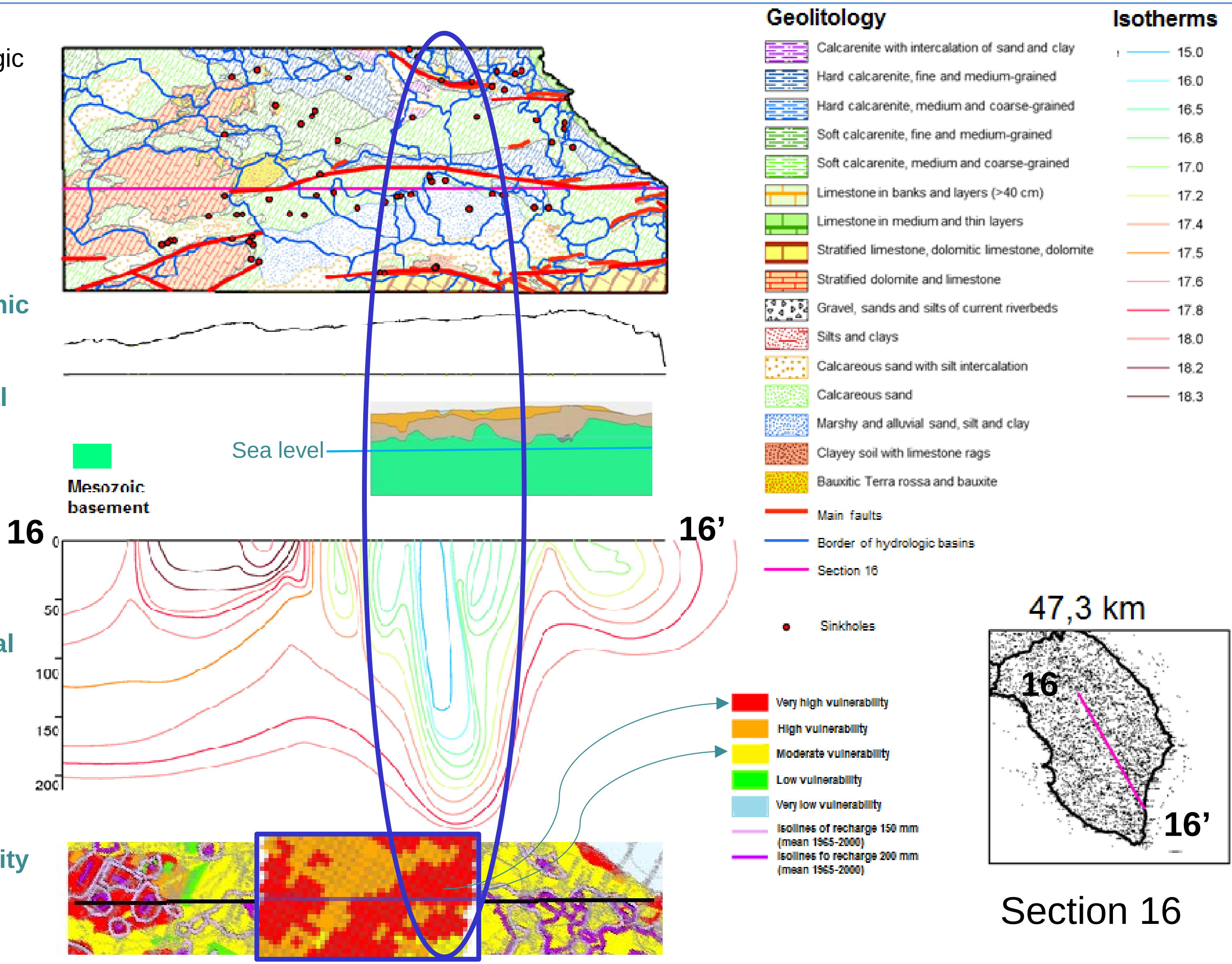
Geolithologic map

Topographic profile

Geological section

Section of the thermal field

Intrinsic Vulnerability map (COP method)



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 semi-arid climate***

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

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

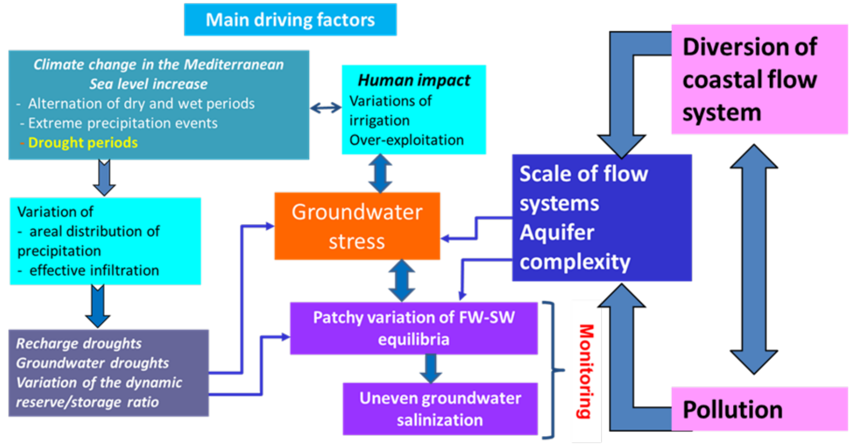
- The ***carbonate basement reveals to be more vulnerable in the sunken parts***, which at the same time, are the zones of ***more active groundwater circulation***: the correspondent ***surface areas, interested by covers, behaves in many cases as main recharge areas.***

- 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



Human impact

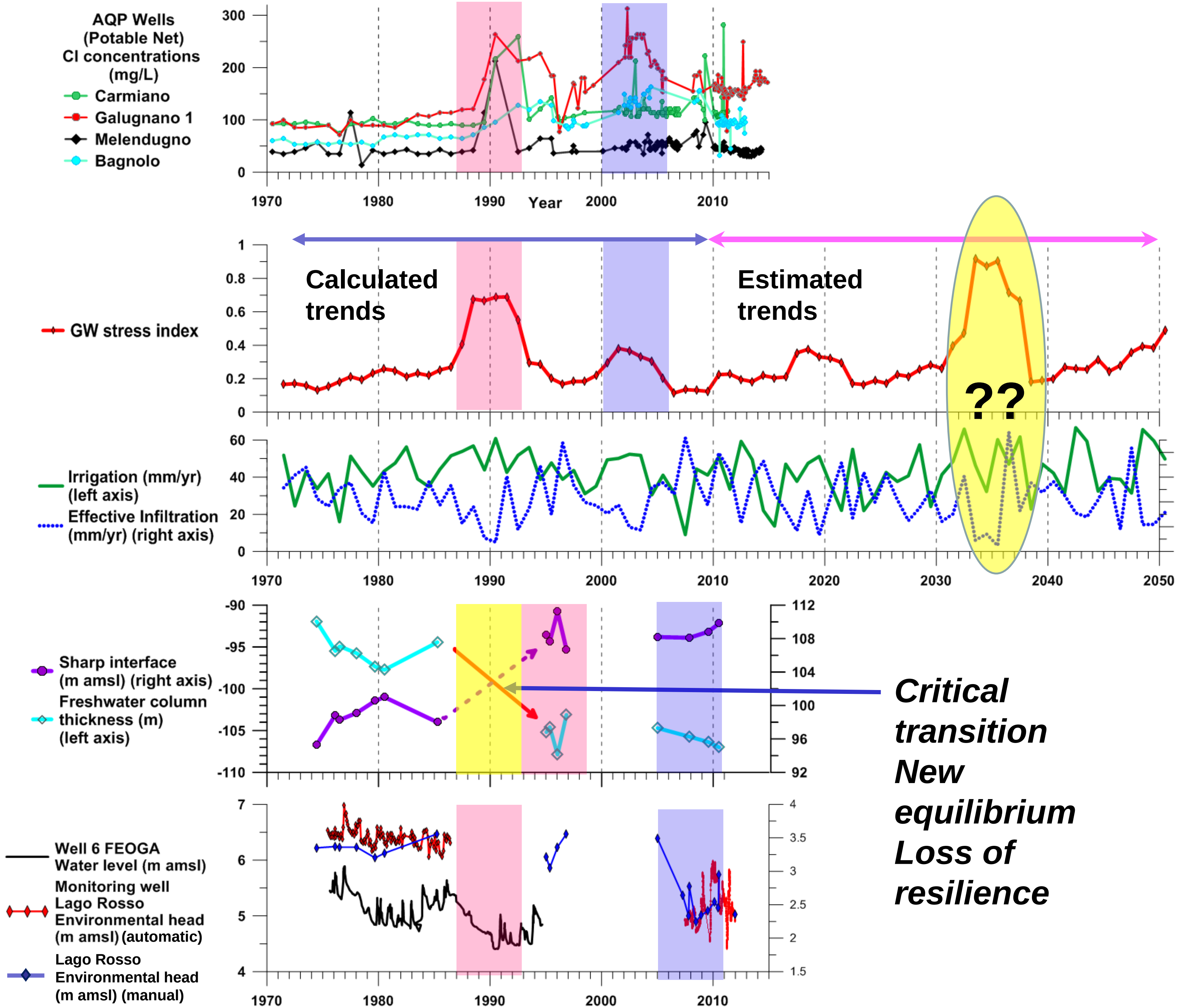
- *Drainage systems*
- *Water-proofing underground structures*
- *Underwater passageways*
- *Land fills*
- *Embankments*
- *Harbours*
- *Network of linear elements*

- *Soil sealing*
- *Land use change*
- *Mechanized agriculture*
- *Industrial activities*
- *Tourism*

We are facing, without knowing it, a «creeping disaster» that will develop on large spatial and time scales with «cascade effects» and «critical transitions» according to a nonlinear dynamics.
They will cause in the future irreversible damage to the socio-environmental systems.

What can we expect as potential effects of a sequence of droughts on these complex systems?

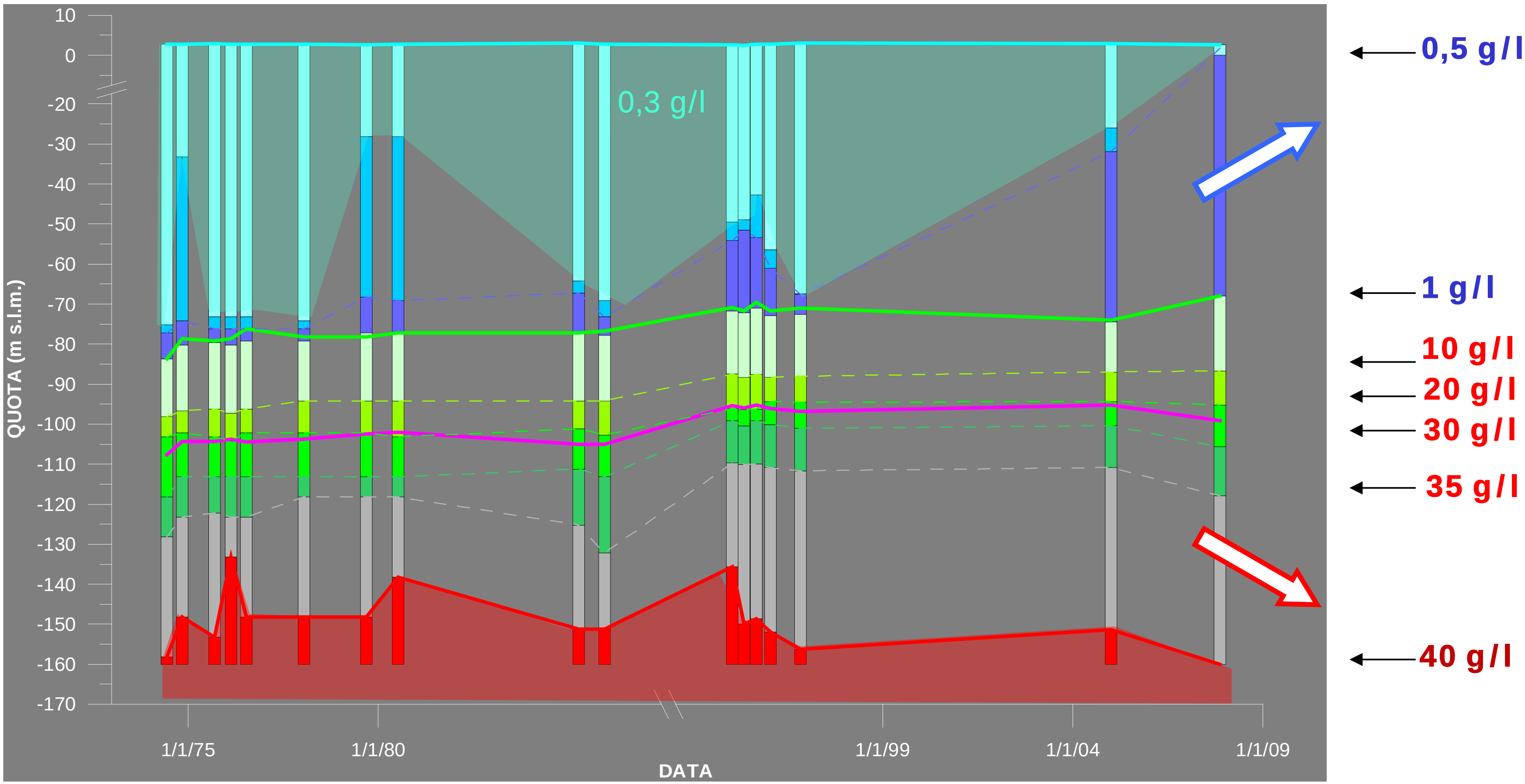
……a complex system….



AQP Wells
(Potable Net)
Cl concentrations
(mg/L)
Carmiano
Galugnano 1
Melendugno
Bagnolo
Year
Calculated trends
Estimated trends
GW stress index
??
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)
Critical transition
New equilibrium
Loss of resilience

Observation Well LR – Time variation of TDS

- Livello statico t_m
- Quota inizio zona di transizione h_{bt}
- Interfaccia netta h_{si}
- Quota inizio acqua salata h_{bt}



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 clearly with large time lags compared to recharge droughts***

THE END

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