Session HS8.2.6

EGU23-17249

EGU General Assembly 2023

New developments of global coastal groundwater salinity modelling and mapping

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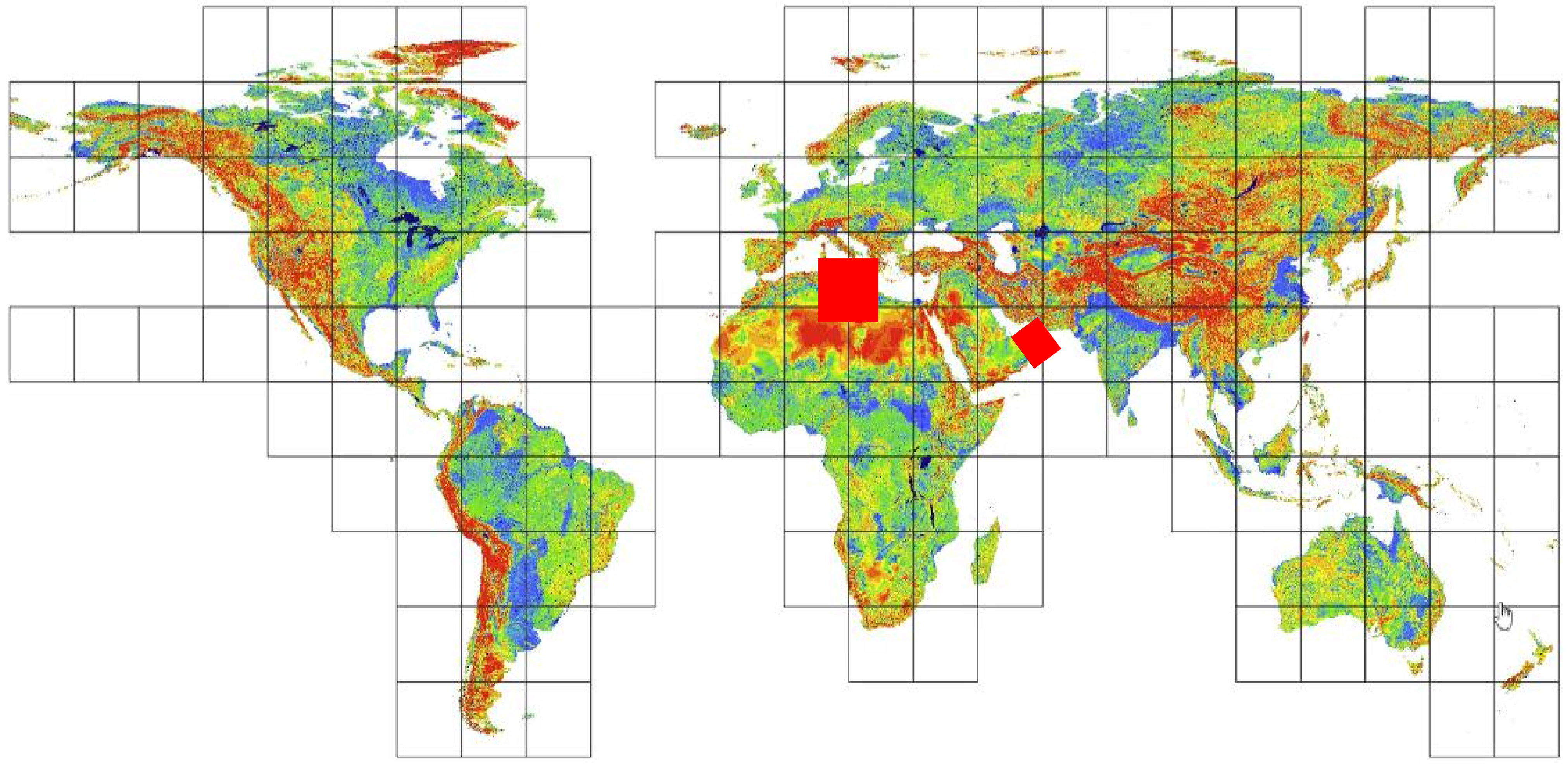
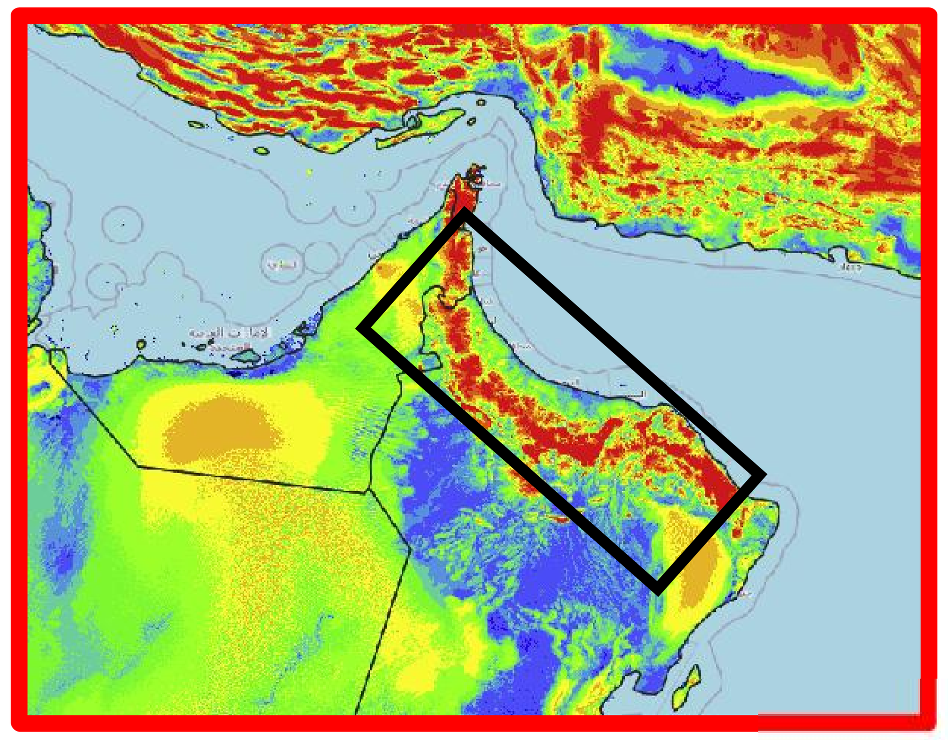
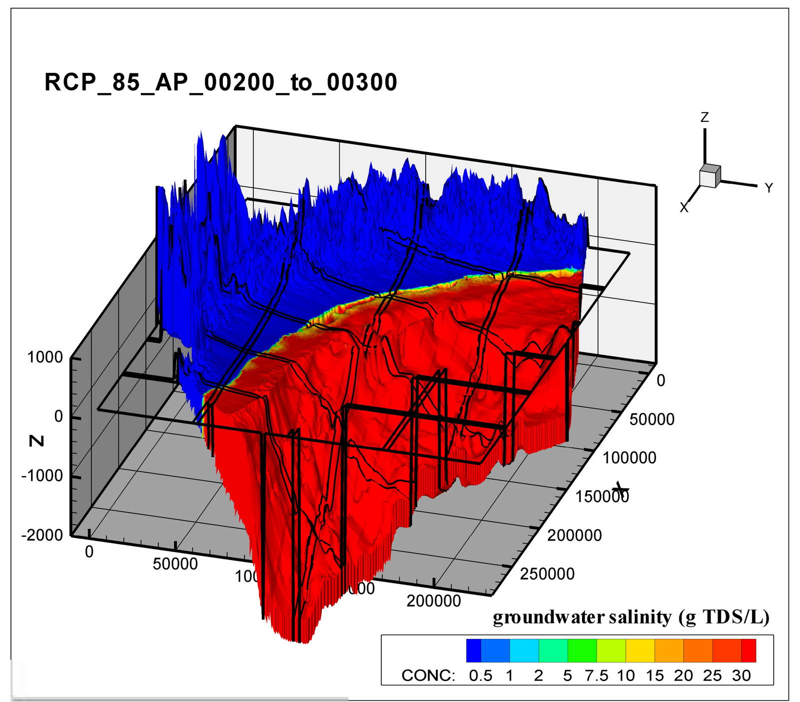
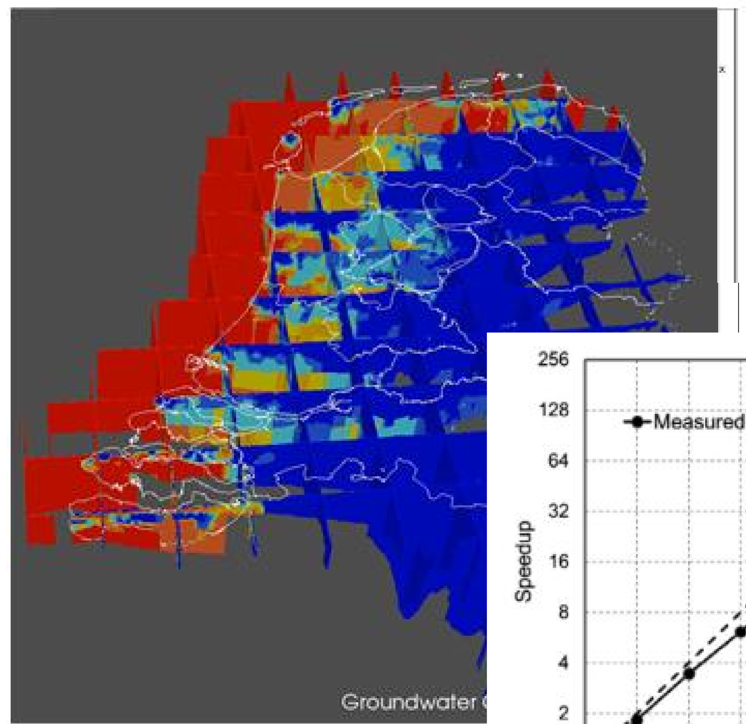
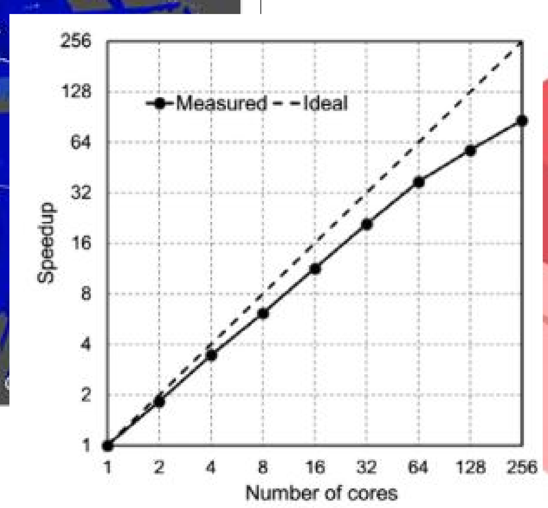
[2] Utrecht University [1] Deltares

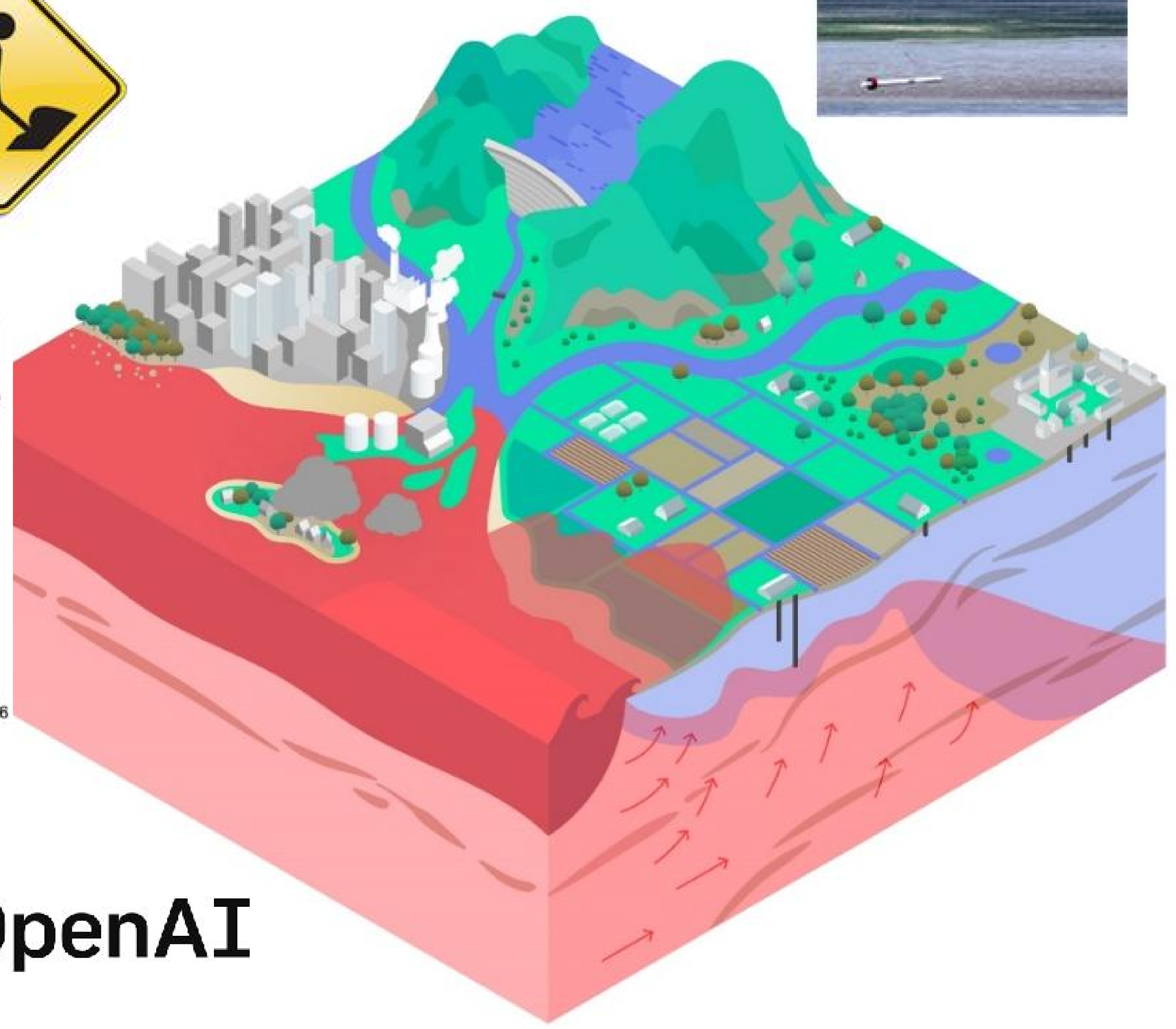












Tesseract OCR

PyMuPDF

OpenAI

Why this global coastal groundwater model initiative?

- We need quantified **storylines** on fresh groundwater availability under stress in coastal zones
- Storylines should to **link** coastal groundwater **to droughts, land subsidence, flooding, health, biodiversity**
- Coastal fresh groundwater is **main water resource** for ~50% of the world population in the coastal zone
- Groundwater is important for **agriculture**, **industry**, as well as **ecosystems & river baseflows**
- Resources are threatened by **excessive pumping**, climate change induced **sea-level rise**, and **sealing**
- E.g., for **Water Peace & Security** issues, groundwater resources are often part of the water **solution**

Image credit: wikipedia

50% *of our drinking water is fresh groundwater*

Image credit: USGS

Image credit: Piyaset/Shutterstock.com

38% *of irrigable area is irrigated with fresh groundwater*

Image credit India Water Portal

Possible applications coastal global groundwater model (1km^2 scale)

- Components:
  - groundwater quantity
  - groundwater salinity
  - subsidence (2024)
  - heat transport (later, >2024)
  - groundwater quality (later, >>2024)

- Themes like:
  - drinking water quality and health in the coastal zone
  - damages to crops (drought, salinity)
  - anthropogenic activities (limits of groundwater use, sustainable rates, sealing aquifers due to urbanization, effectiveness of regional Managed Aquifer Recharge pilots)
  - sea-level rise and climate change
  - combining land subsidence and overexploitation with salinisation
  - Submarine Groundwater Discharge, Offshore Fresh Groundwater
  - Water Peace and Security / refugee camps

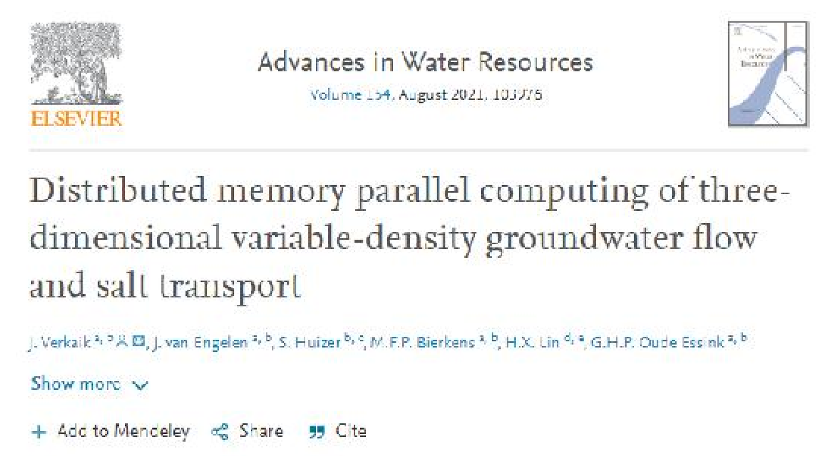
Example: storyline on Pathways to demonstrate the future Mekong delta: linking groundwater extraction ➡ subsidence ➡ increased flood risk

Among others based of this research, 'Decree 167' is implemented in Vietnam in the Law of Water Resources: On developing and implementing zoning plans to **restrict groundwater overexploitation!**

Why now?

Creating high-resolution global 3D coastal groundwater salinity models is now possible:

1. **Parallel groundwater salinity modelling** (iMOD-WQ / SEAWAT).


Advances in Water Resources
Distributed memory parallel computing of three-dimensional variable-density groundwater flow and salt transport

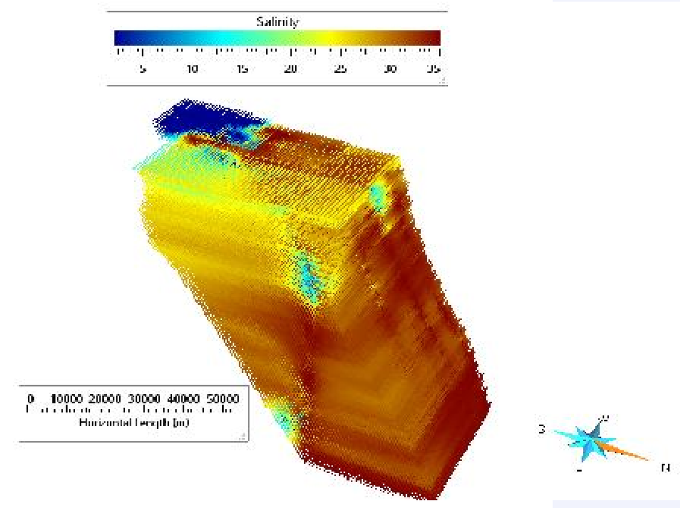
2. **Fast Airborne EM groundwater salinity mapping in 3D**, (e.g., FRESHEM), citizen science data collection at high TRL.

3. **Paleo reconstructions of past hydrogeological conditions in data-poor areas**, (possible due to parallel computer), resulting in improved understanding of present groundwater salinity.

4. **More open hydrogeologic data available** (advanced **text mining**, open-source webportals).

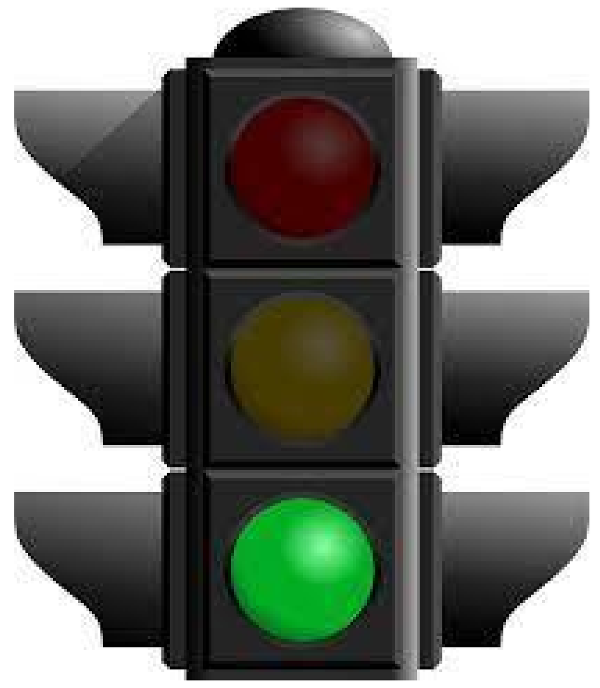
5. **Advanced interpolation techniques for rapid 3D interpolation** of coastal geology and groundwater salinity, and model parameters.

6. **Fully scripted reproducible modelling workflows, clipping & refining** (e.g., iMOD-Python), aiding regular updating and stakeholder trust in model results.



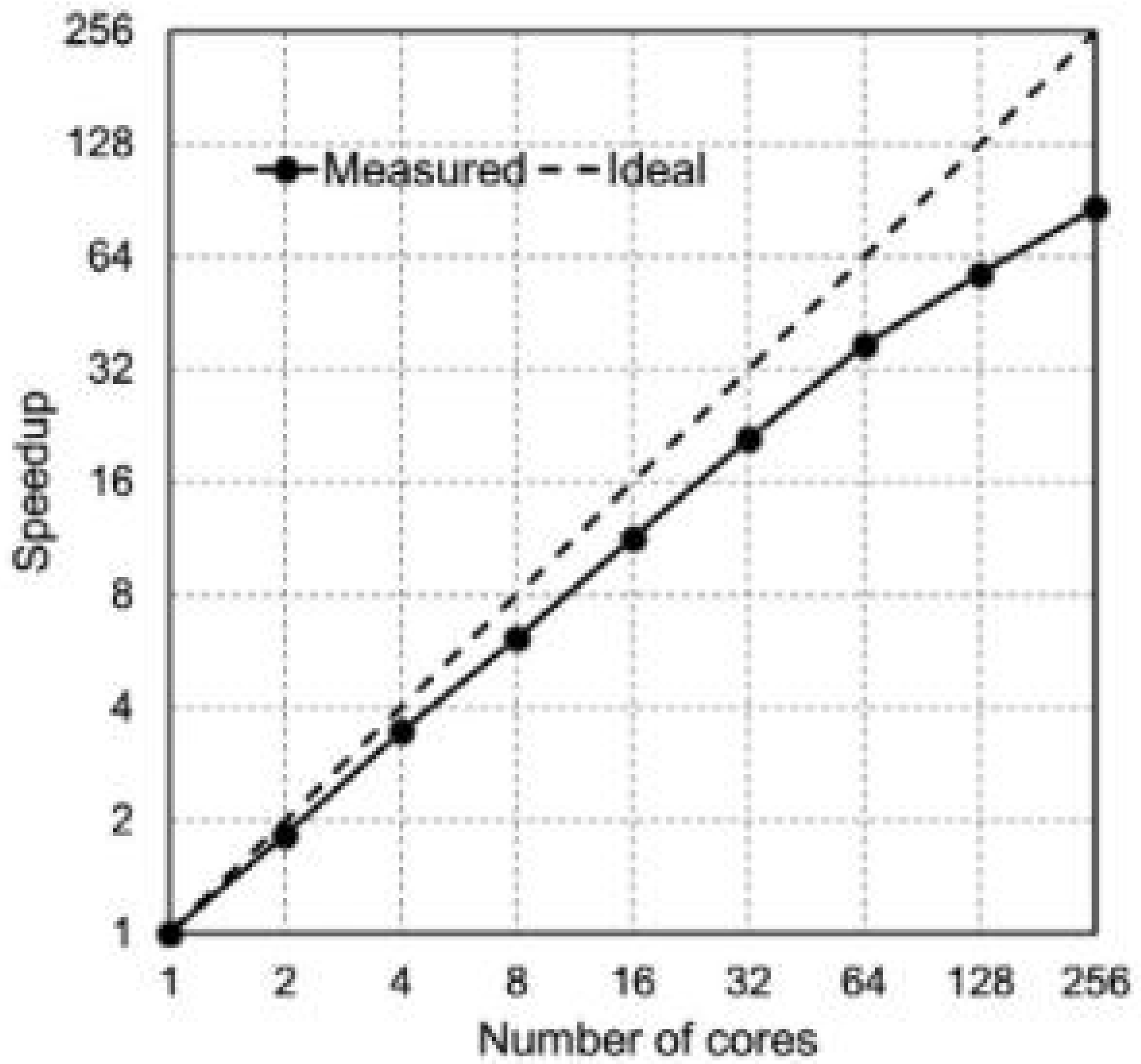
7. **And: groundwater community initiatives**, like Groundwater Model Portal (GroMoPo) (e.g. poster EGU23-12340)

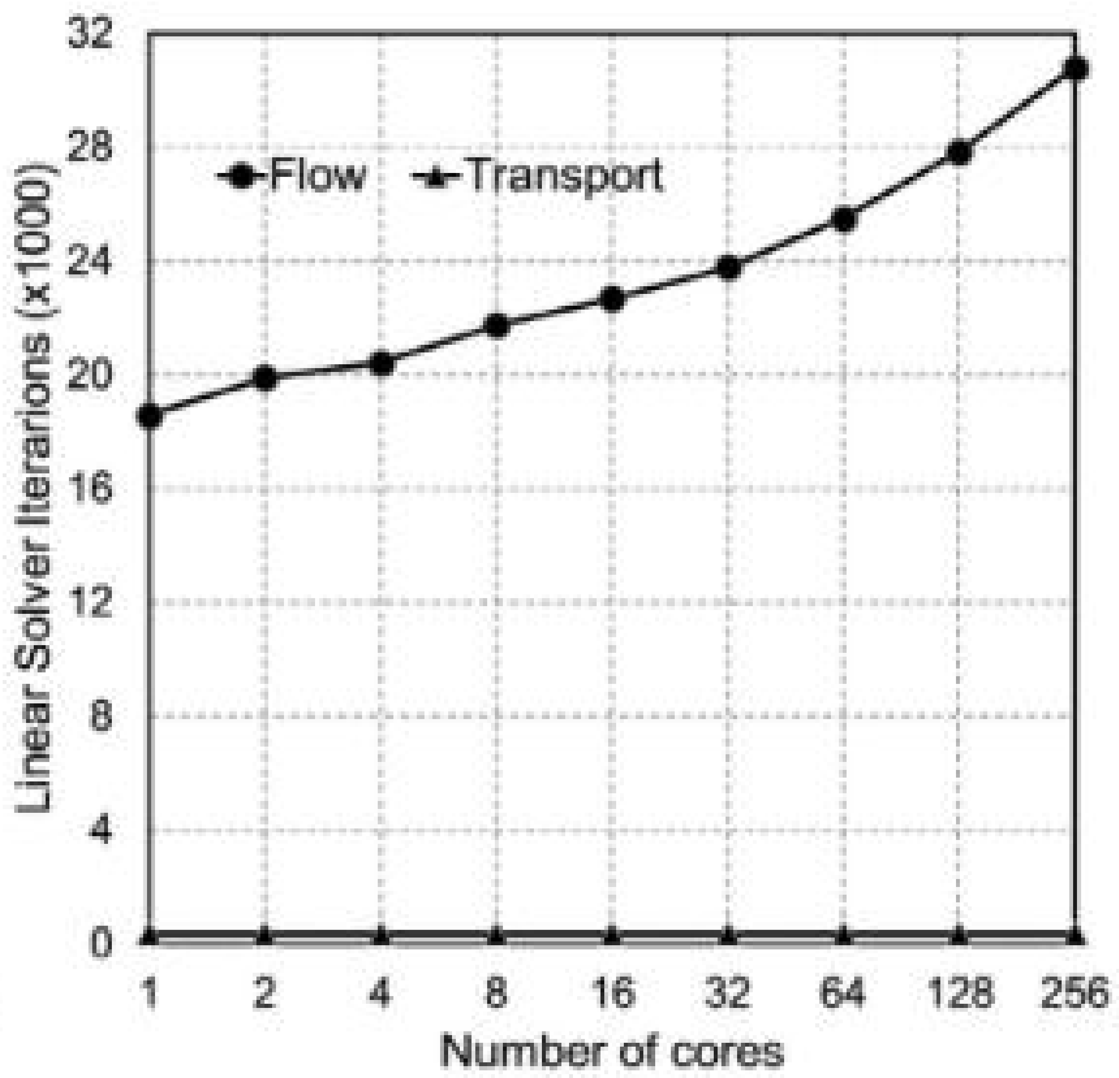
Parallel groundwater salinity modelling



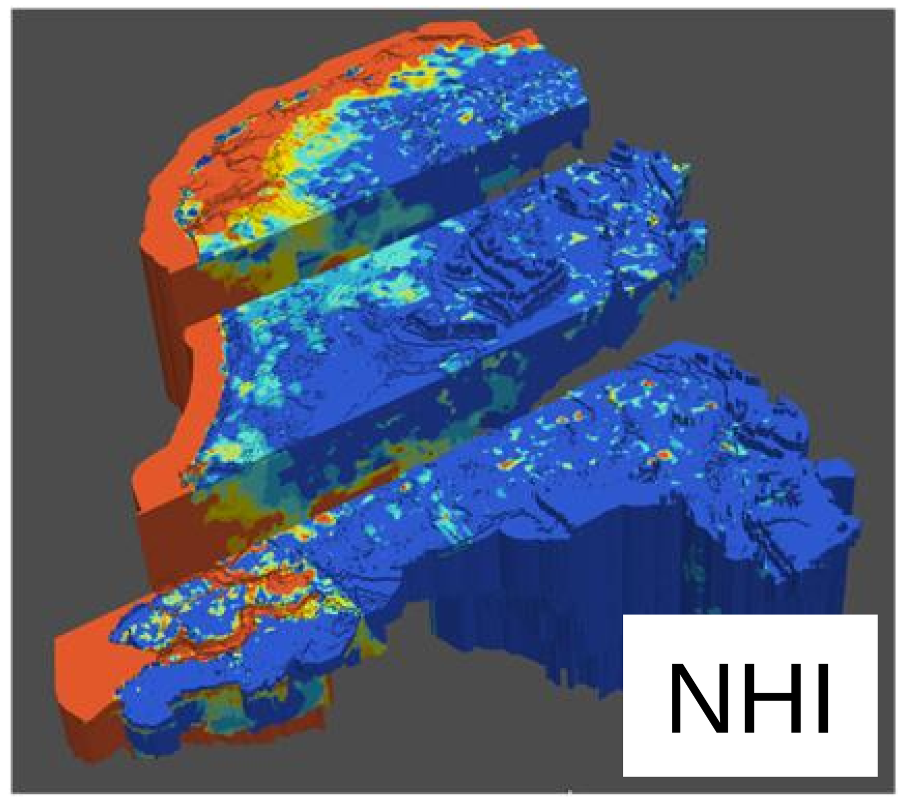
Speed-ups up to at least 10 – >100 times, depending on cores, iterations and data exchange efficiencies

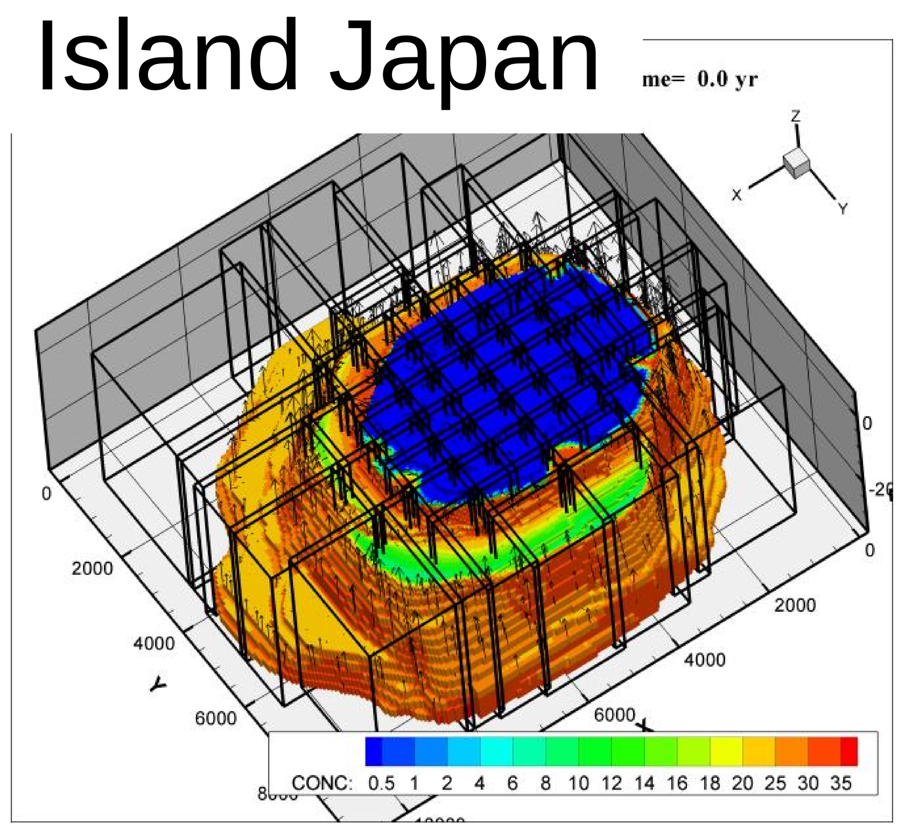
Verkaik, J. et al., 2021. Adv.WR

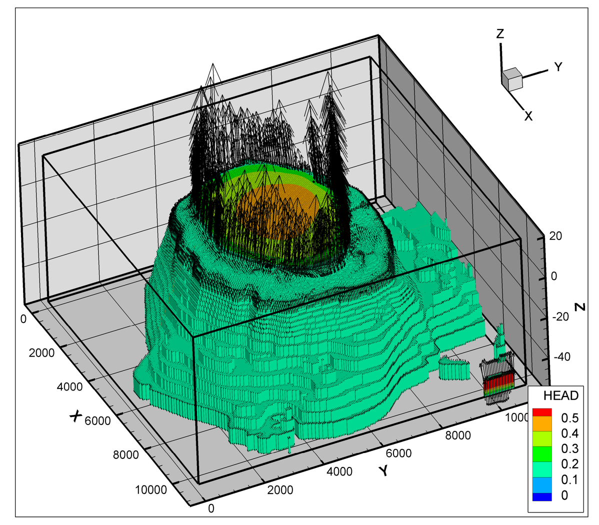


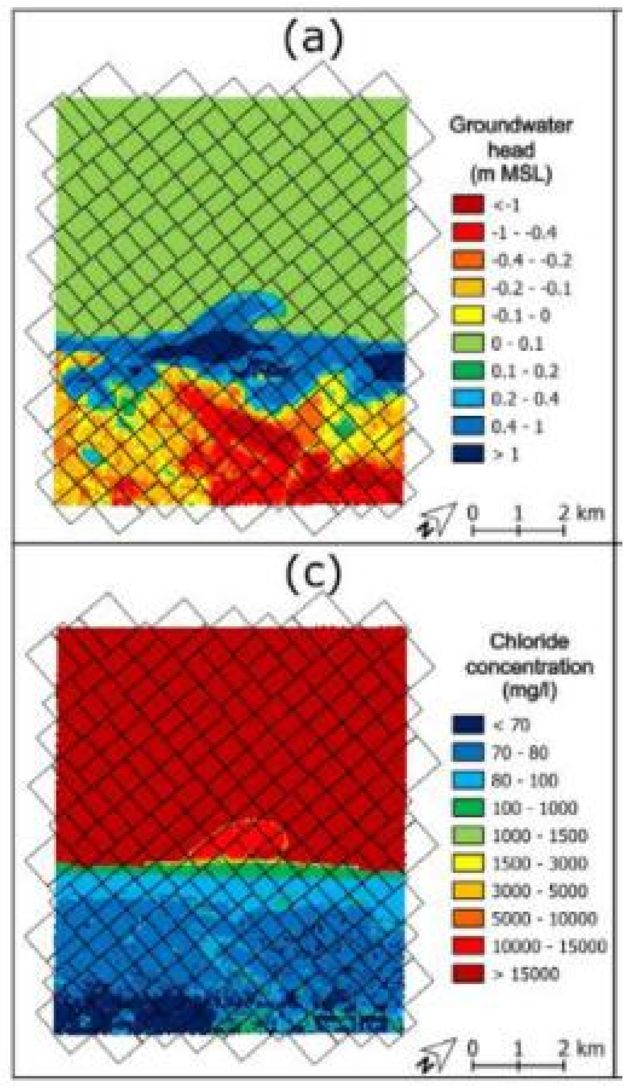


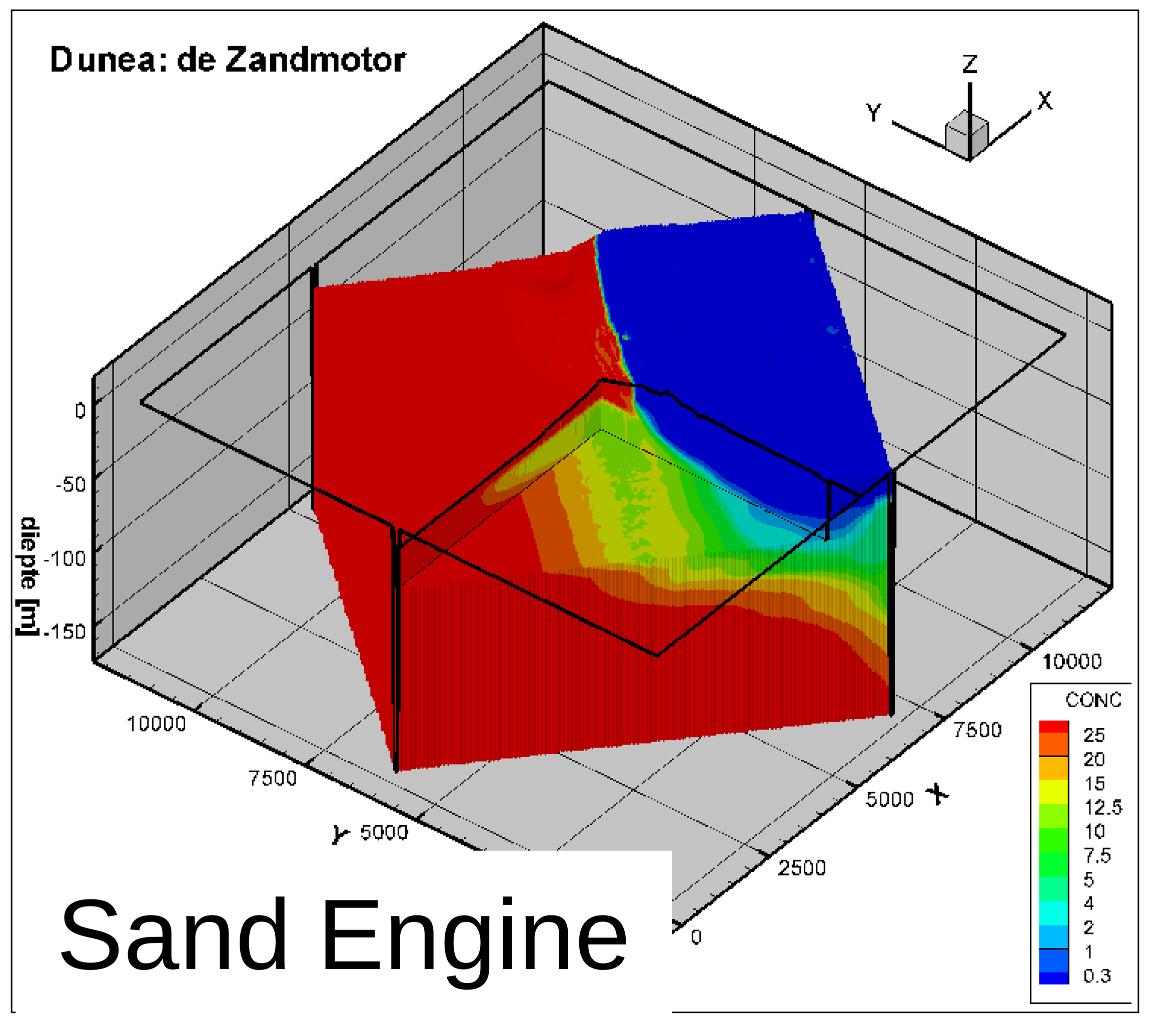
- Sand Engine: from 1hr 47min 55sec -> 2min 40sec: 40*
- NHI fresh-salt: from ~30 days to ~2days: 15*
- Island Japan: from 5d0h36m to 5m59s: 1209*

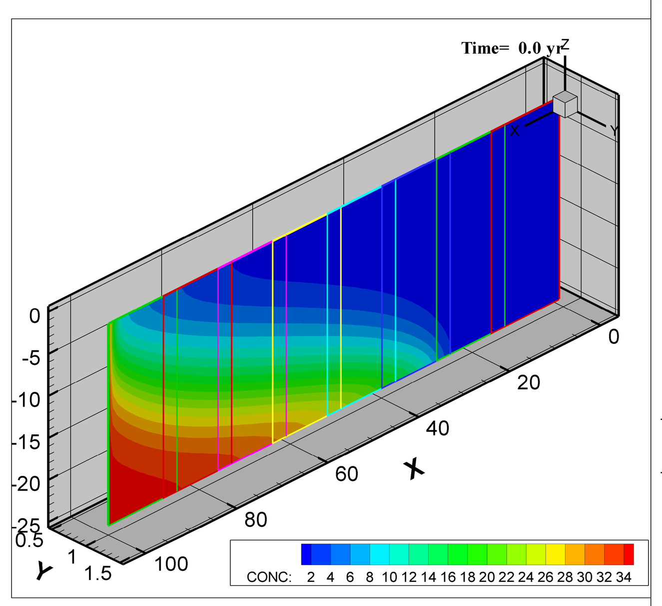


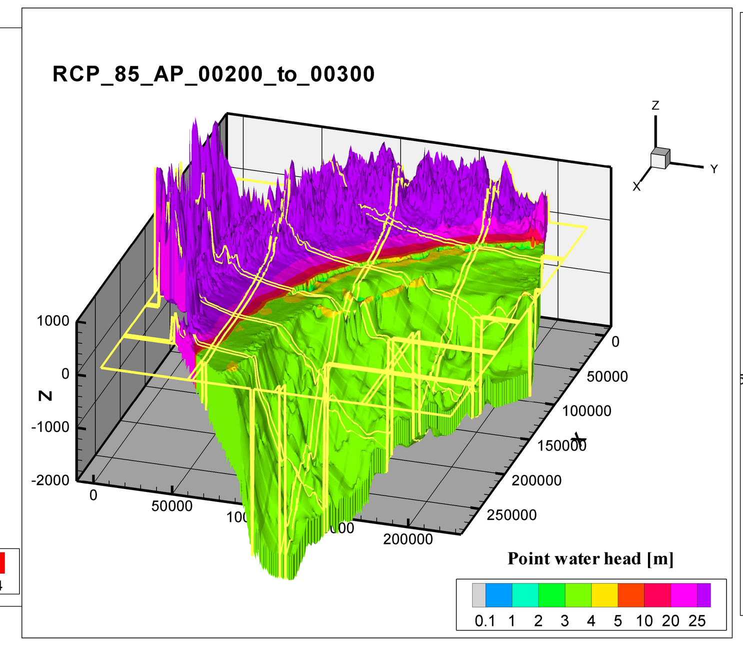


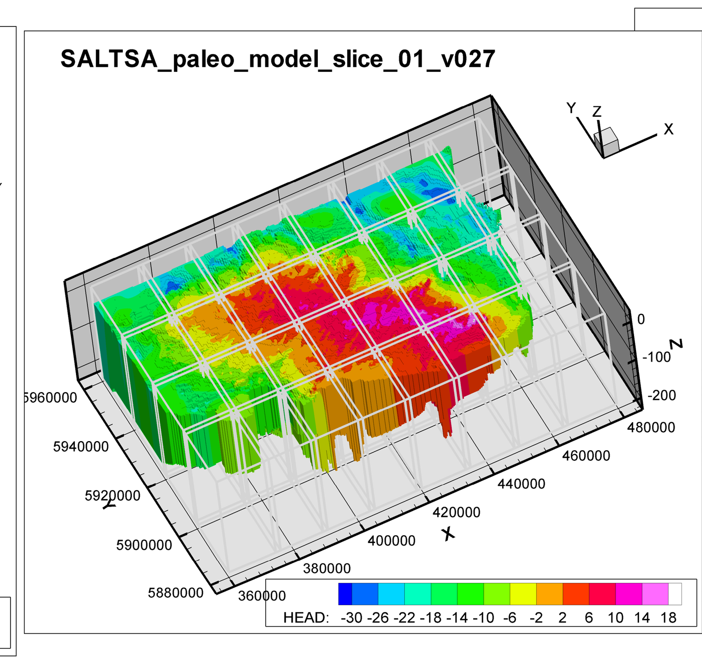


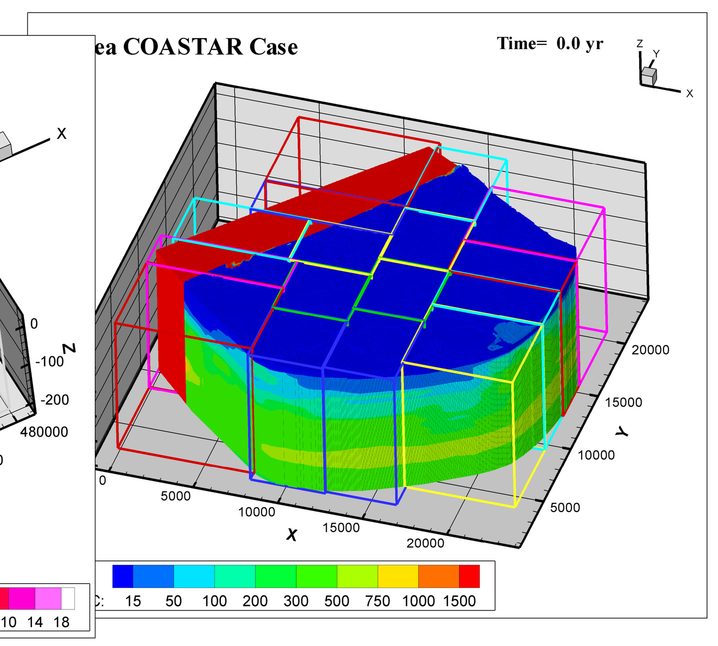










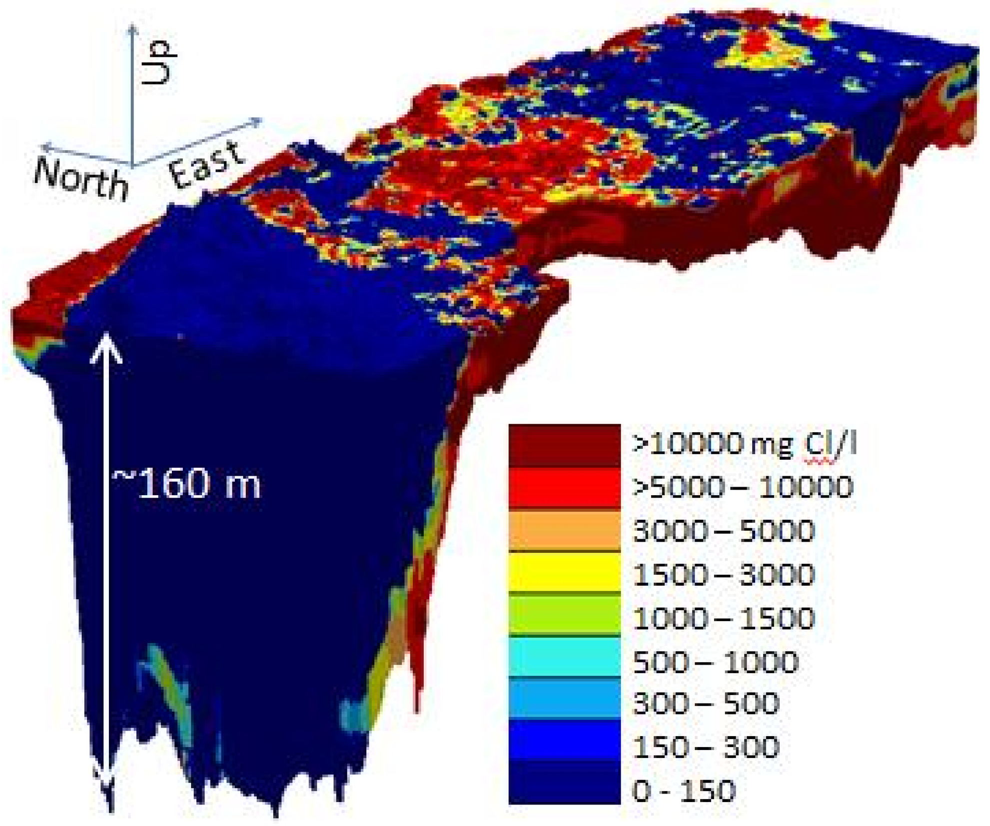


Airborne groundwater salinity mapping FRESHEM

Deltares

TNO innovation for life

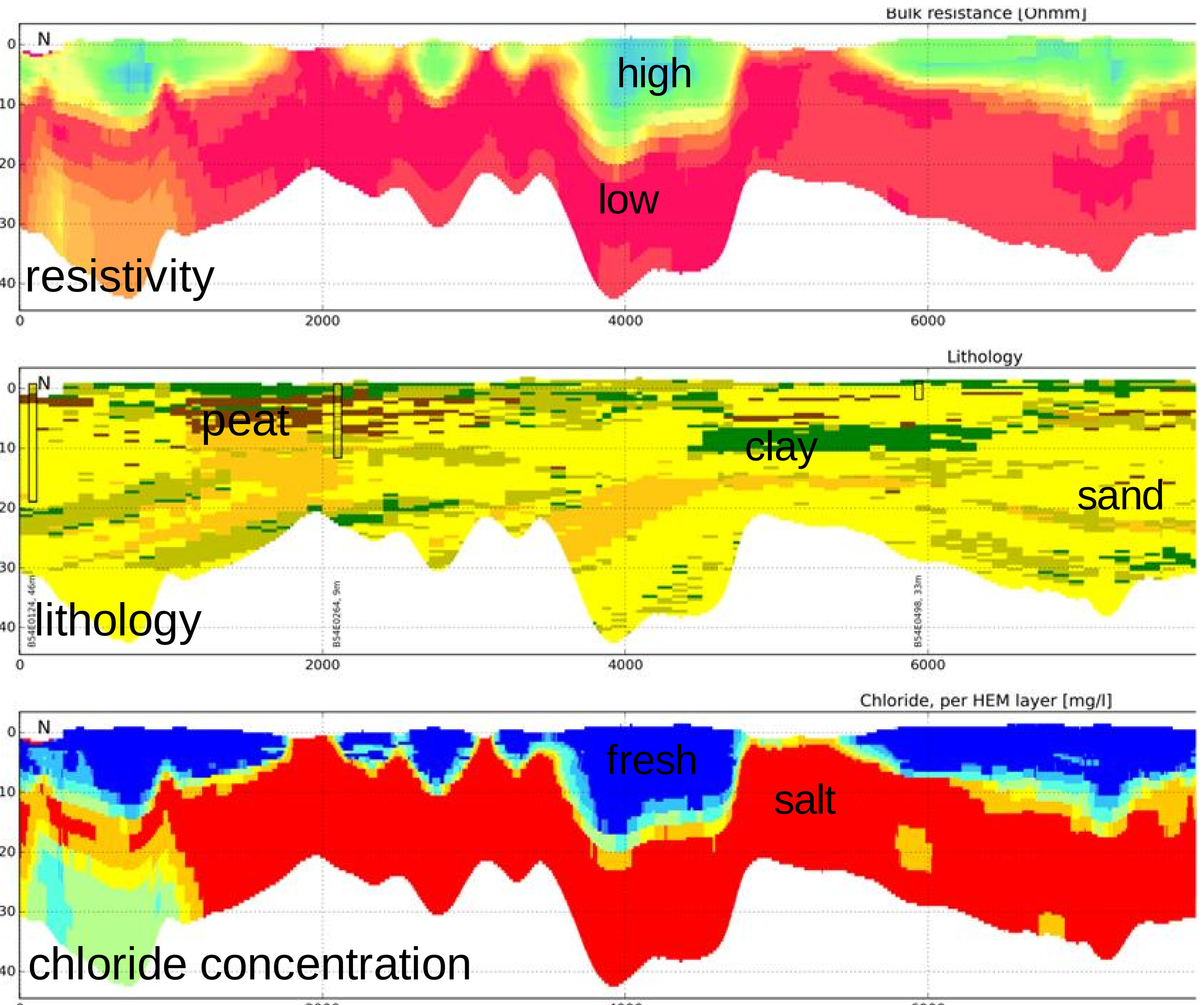
BGR



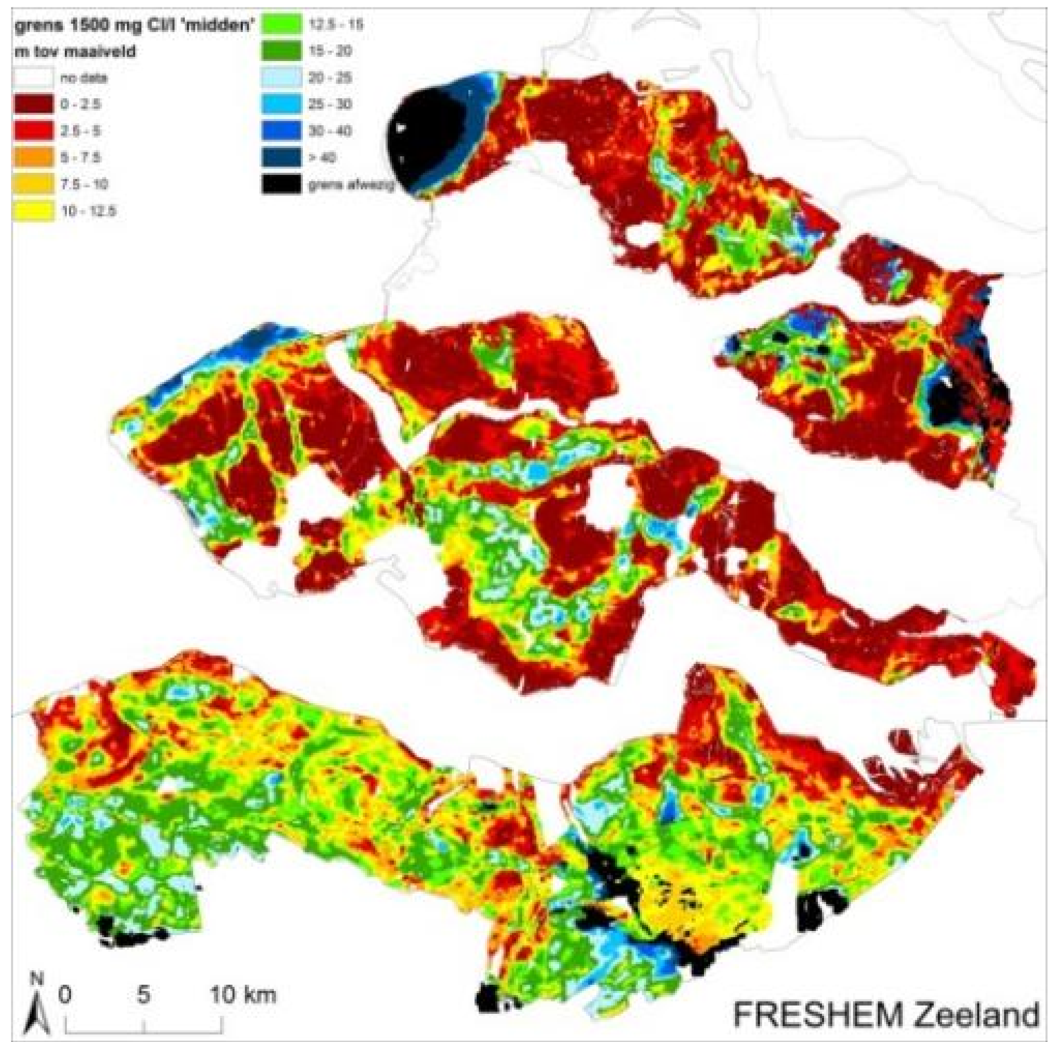
Method:
Combination helicopter measurements with data and knowledge about subsurface and processes in fresh-saline groundwater, and geostatistical mapping via (multiple) indicator kriging.

Results:
- Mapping of 3D groundwater salinity
- Mapping of clay layers

FRESHEM Zeeland

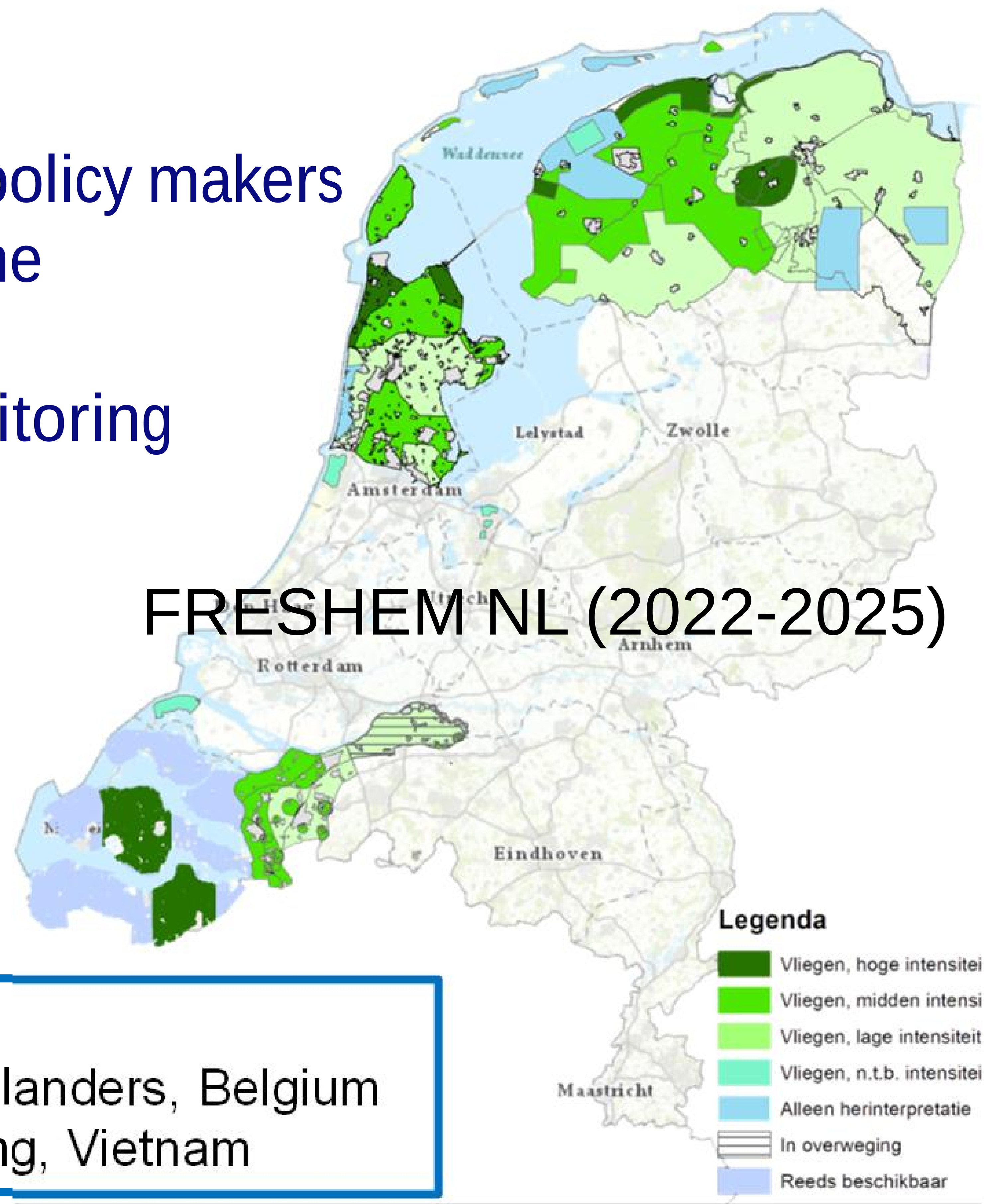


Applications:
- strategic fresh groundwater users & policy makers
- support ASR (COASTAR) in coastal zone
- identify brackish water potential
- improve groundwater models & monitoring

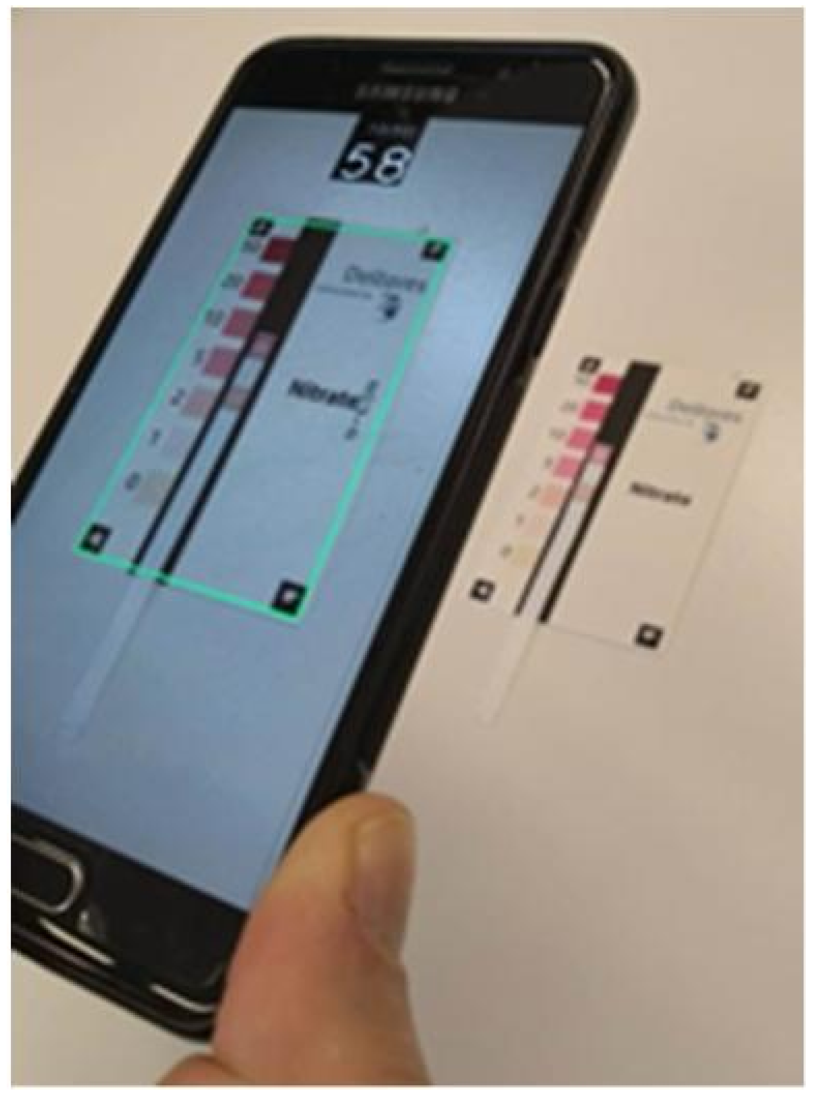


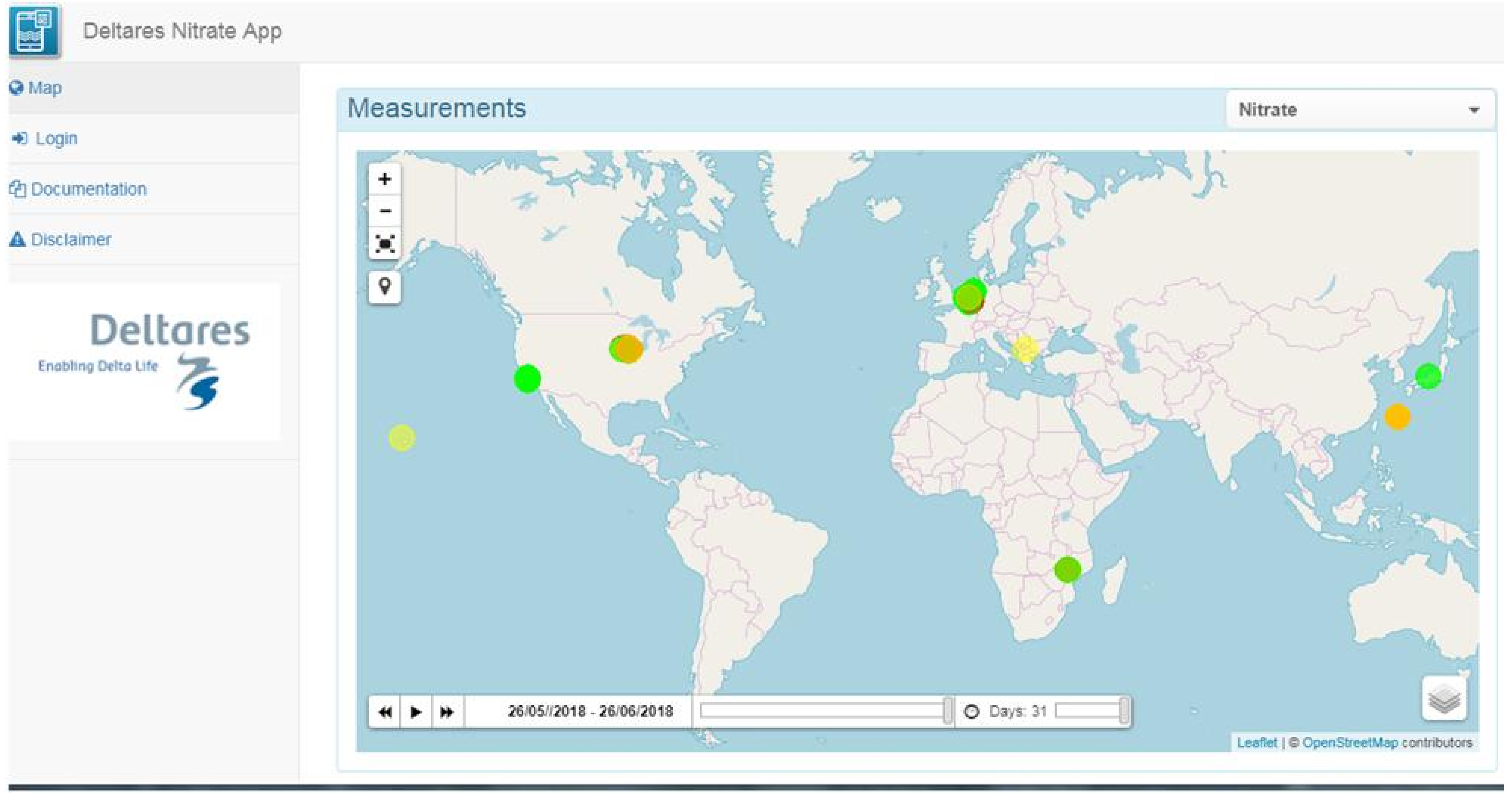
International:
- Project in Flanders, Belgium
- Pilot Mekong, Vietnam

FRESHEM NL (2022-2025)

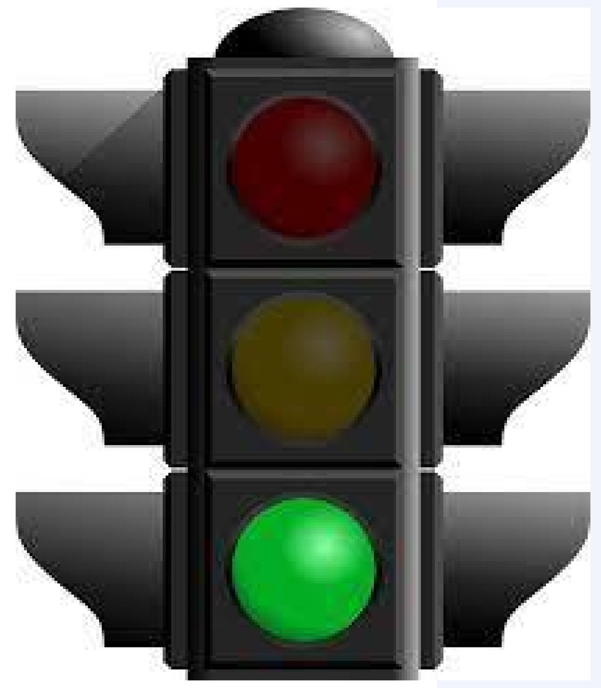


Citizen science, using simple devices and webportals

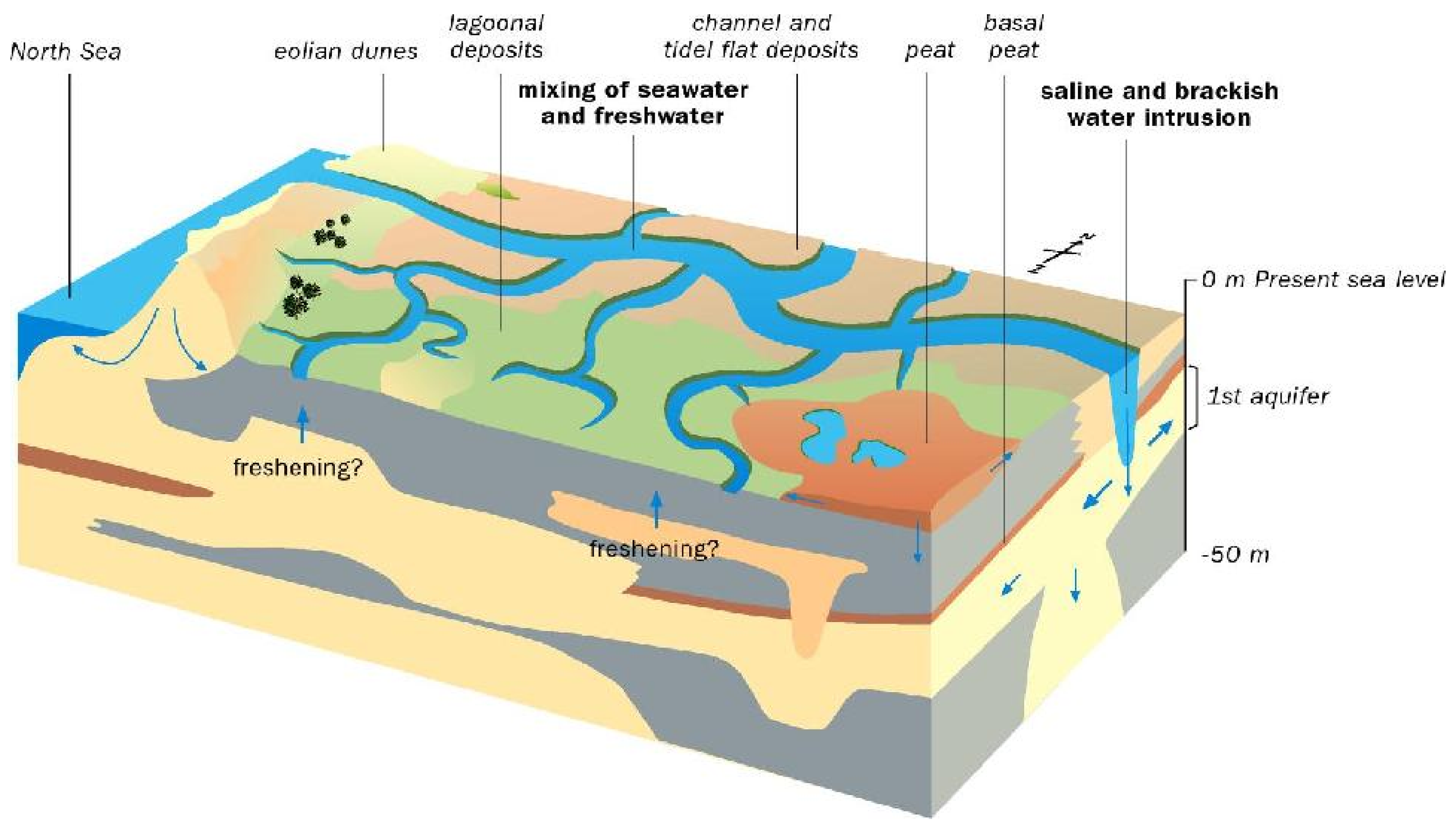


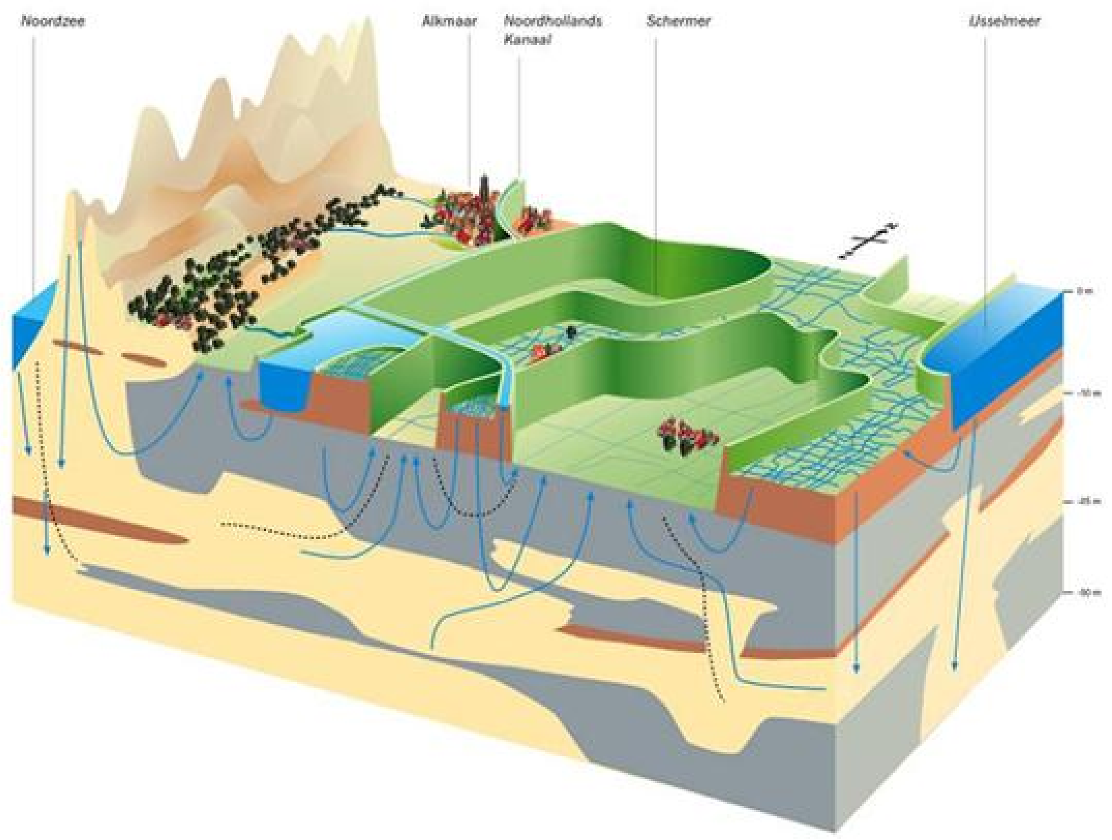


Paleo-reconstructions groundwater salinity

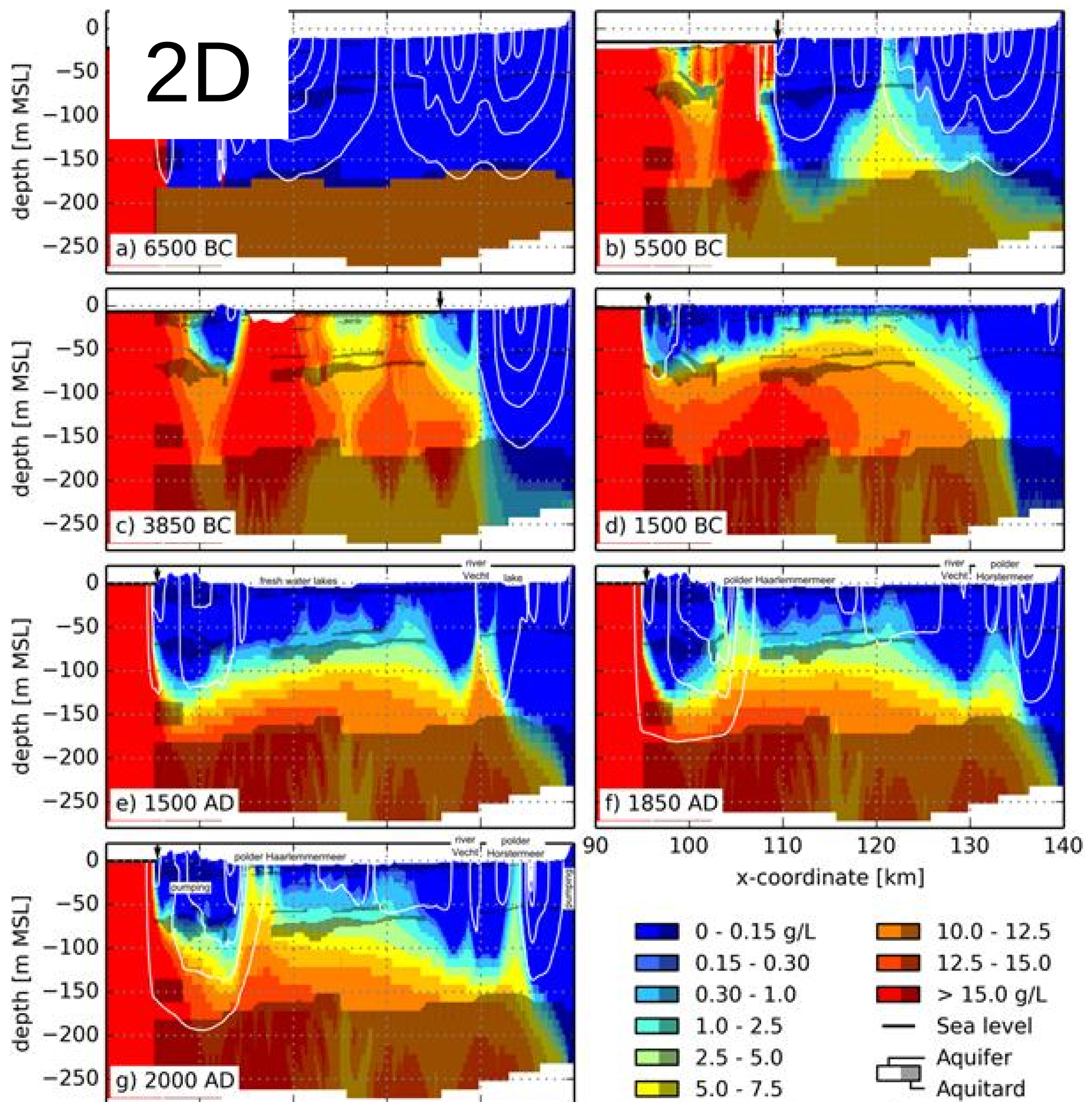


Parallel computer power is utilized to simulate 3D reconstructions of past hydrogeological conditions in (data-poor) areas, improving understanding of present groundwater salinity.

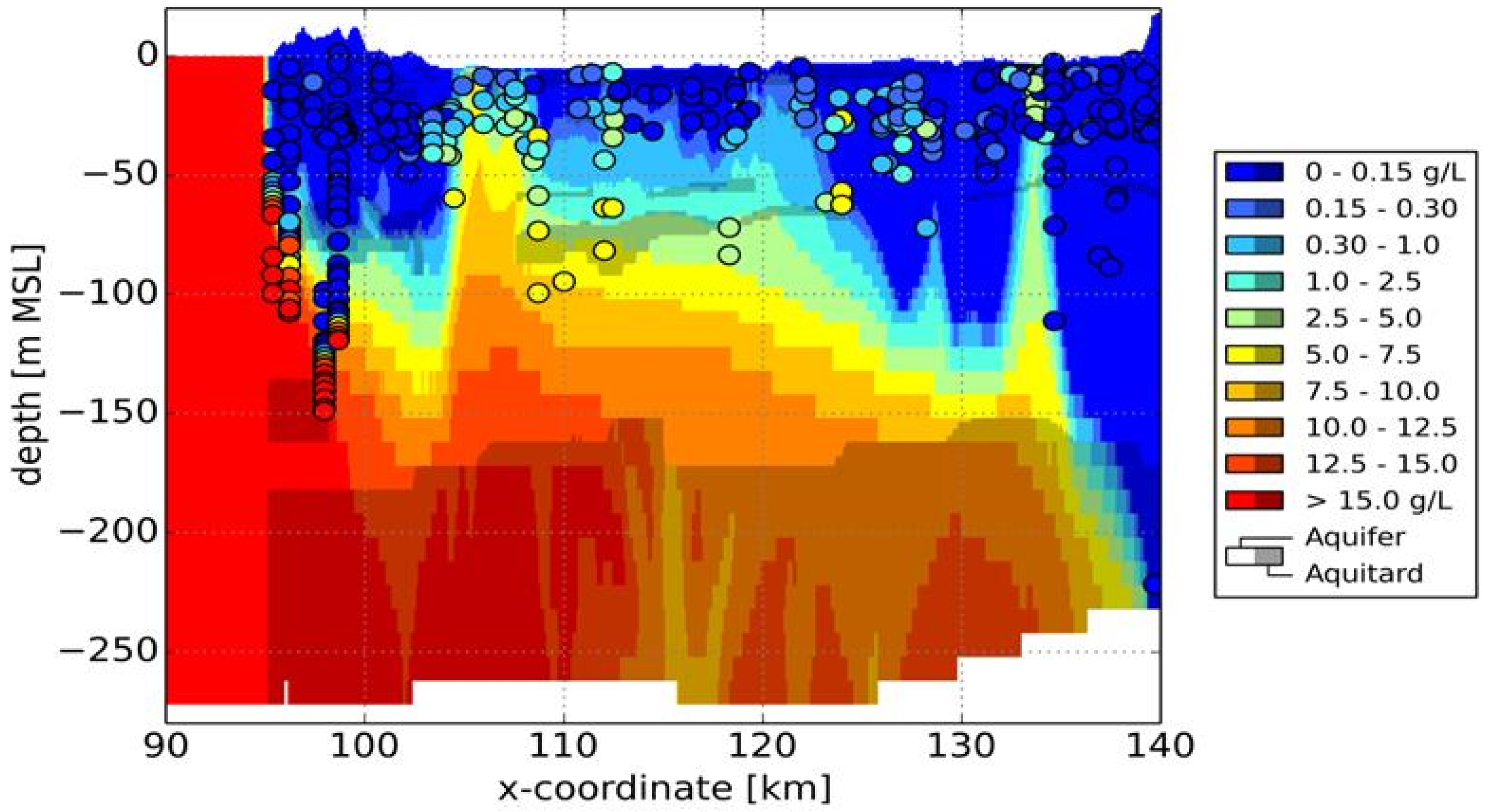




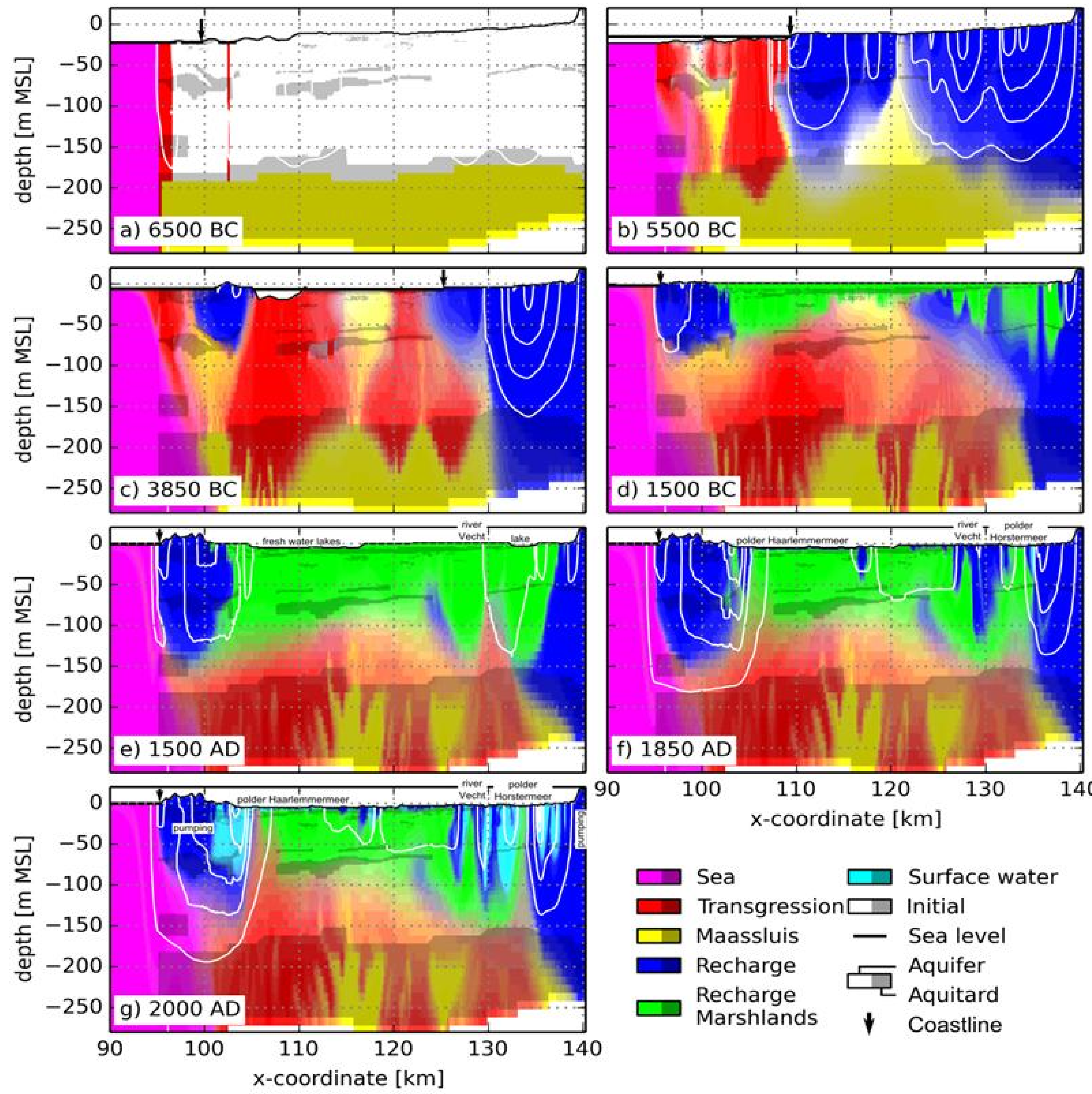
2D → 3D



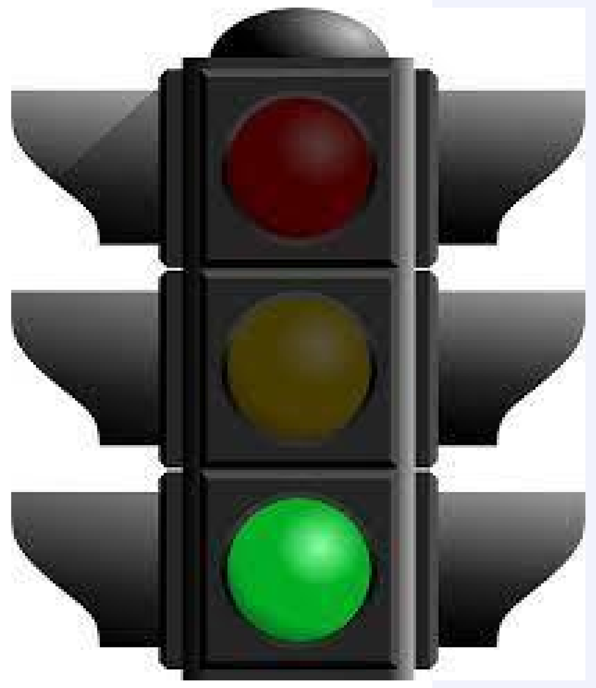
Delsman et al., 2014. HESS



Origin



Paleo-reconstructions groundwater salinity



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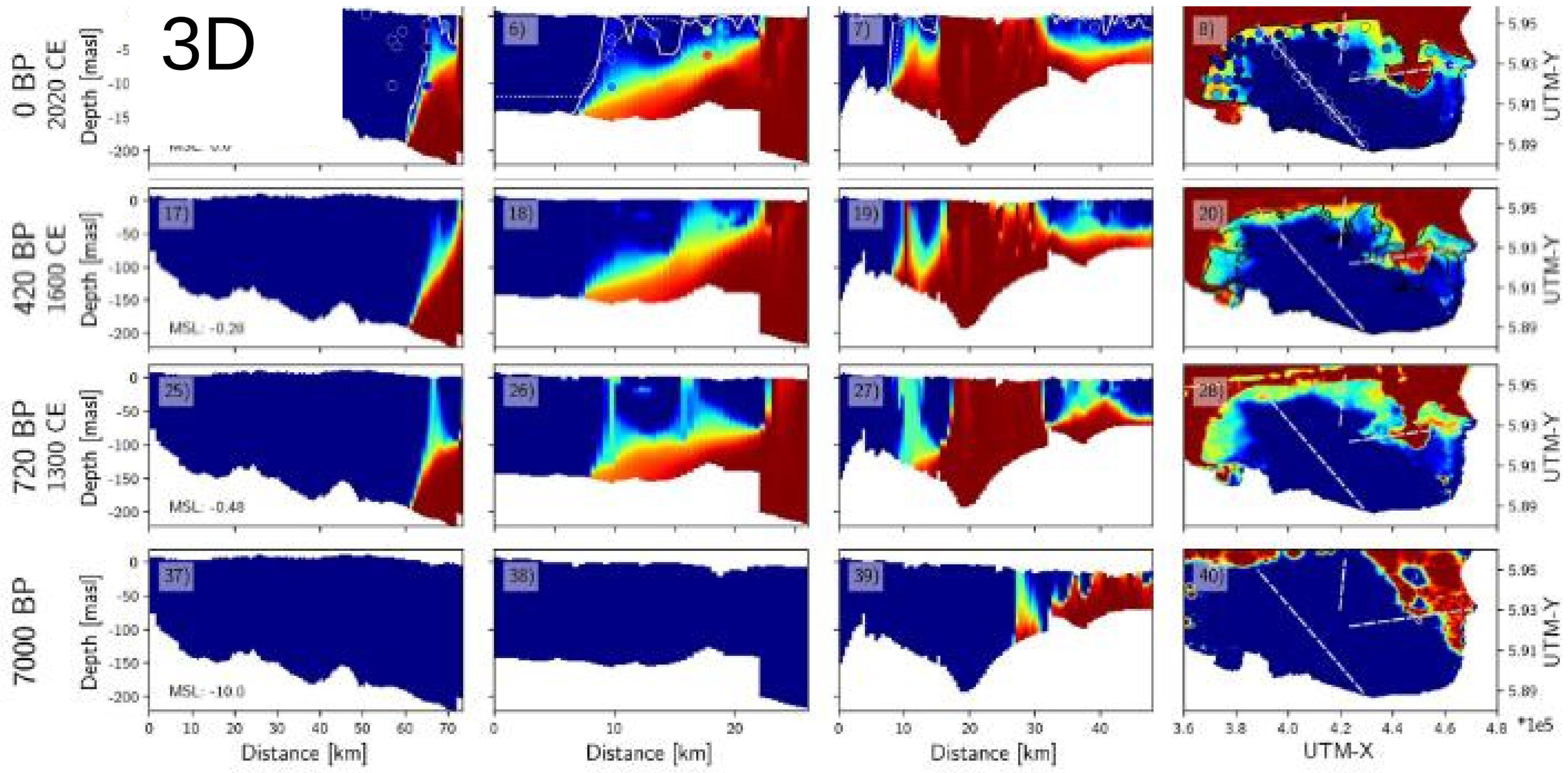
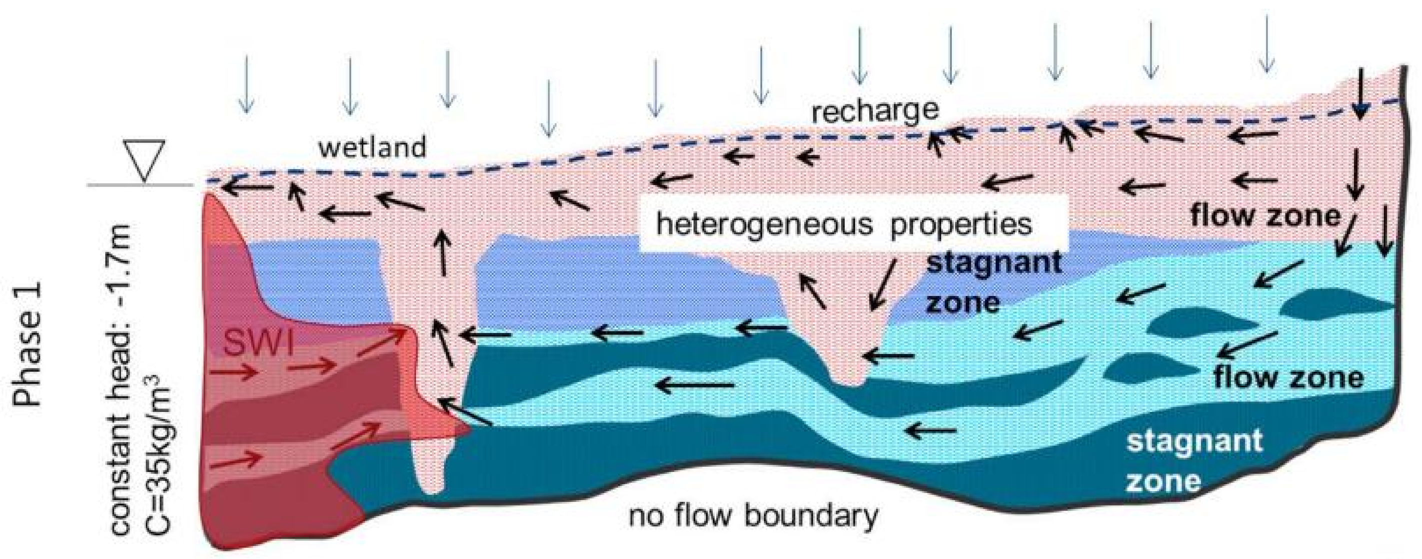
Northwest Germany



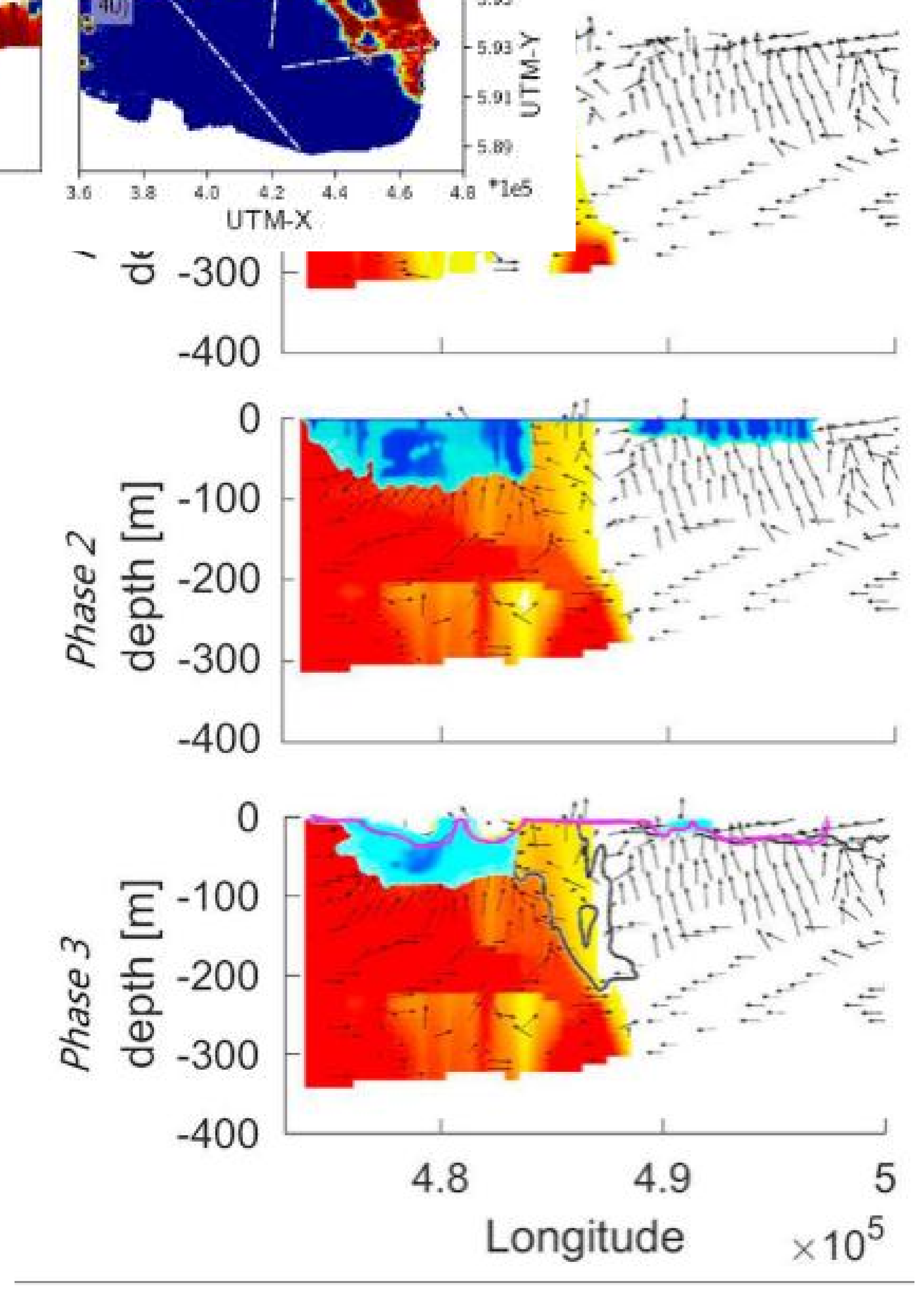
Seibert et al., 2023 WRR

Origin of sources and ~age dating

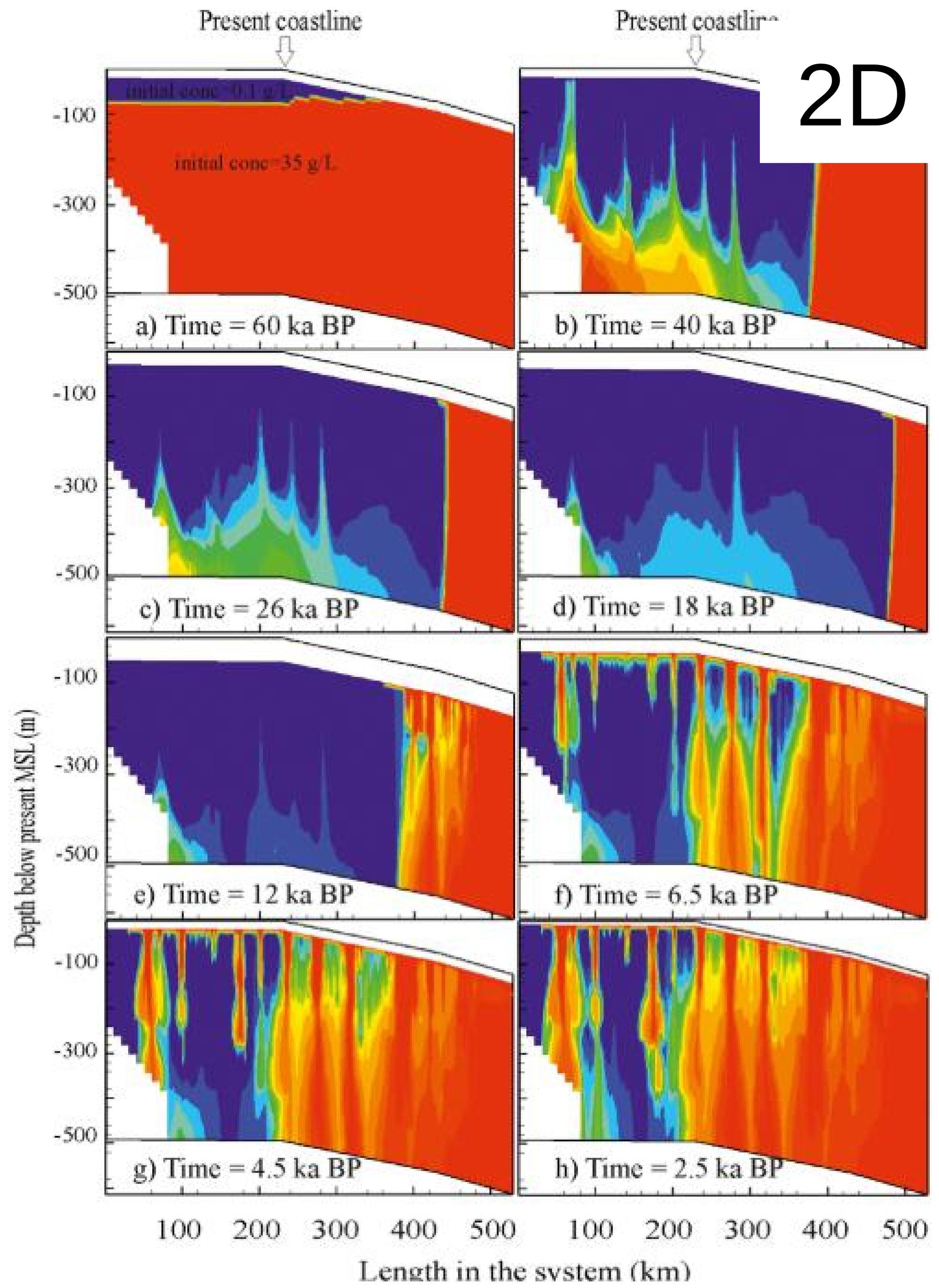
Denmark



Meyer, et al., 2019

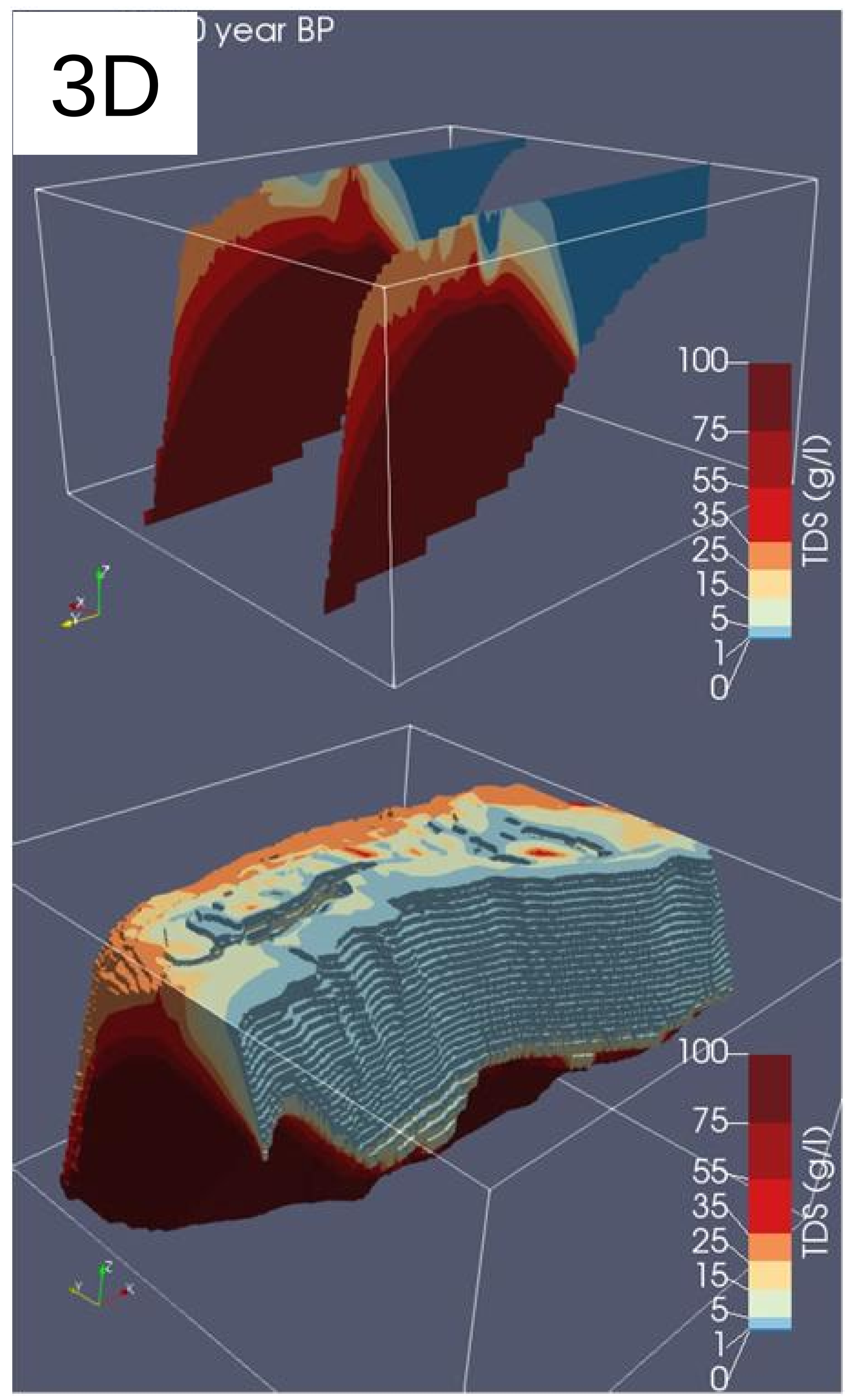


Mekong delta



Hung et al., 2019 JoH, RS

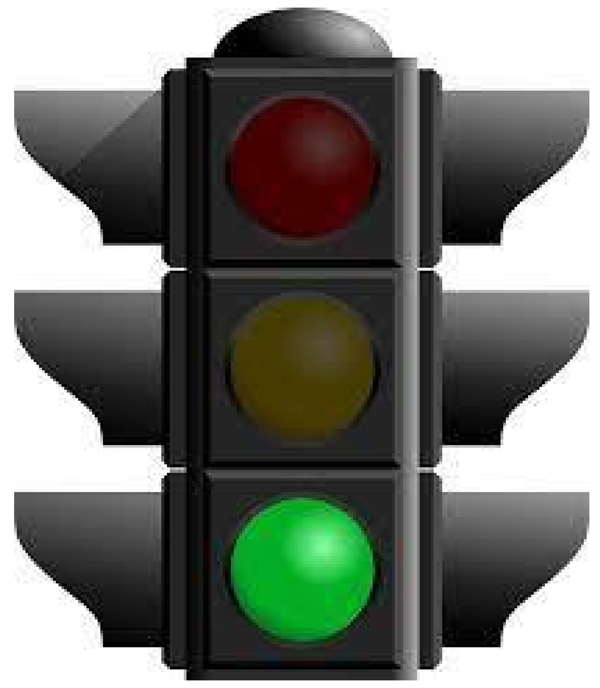
Nile delta

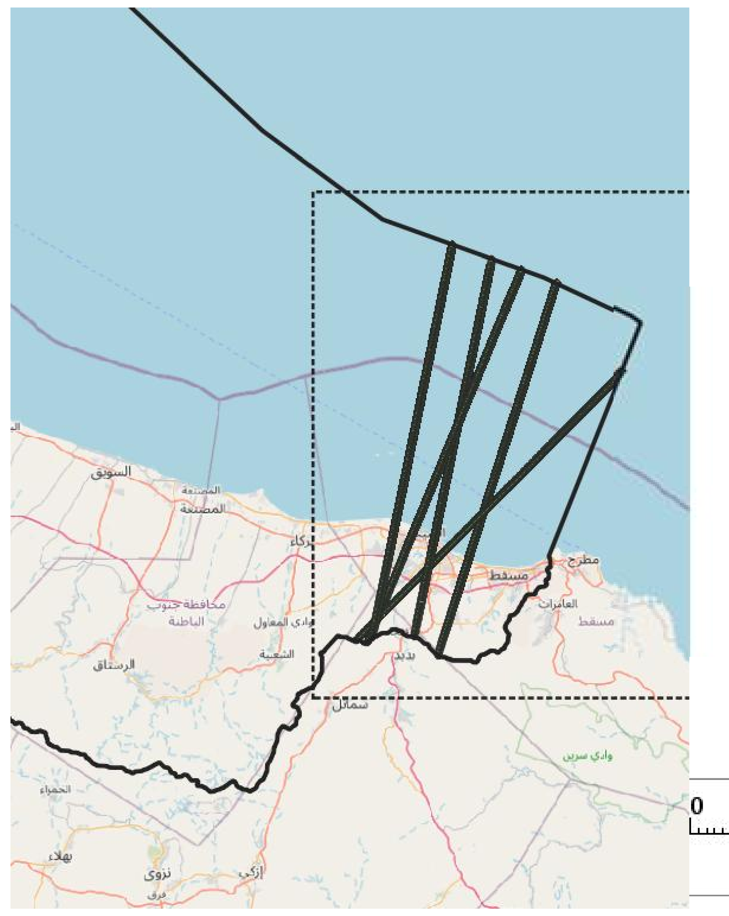


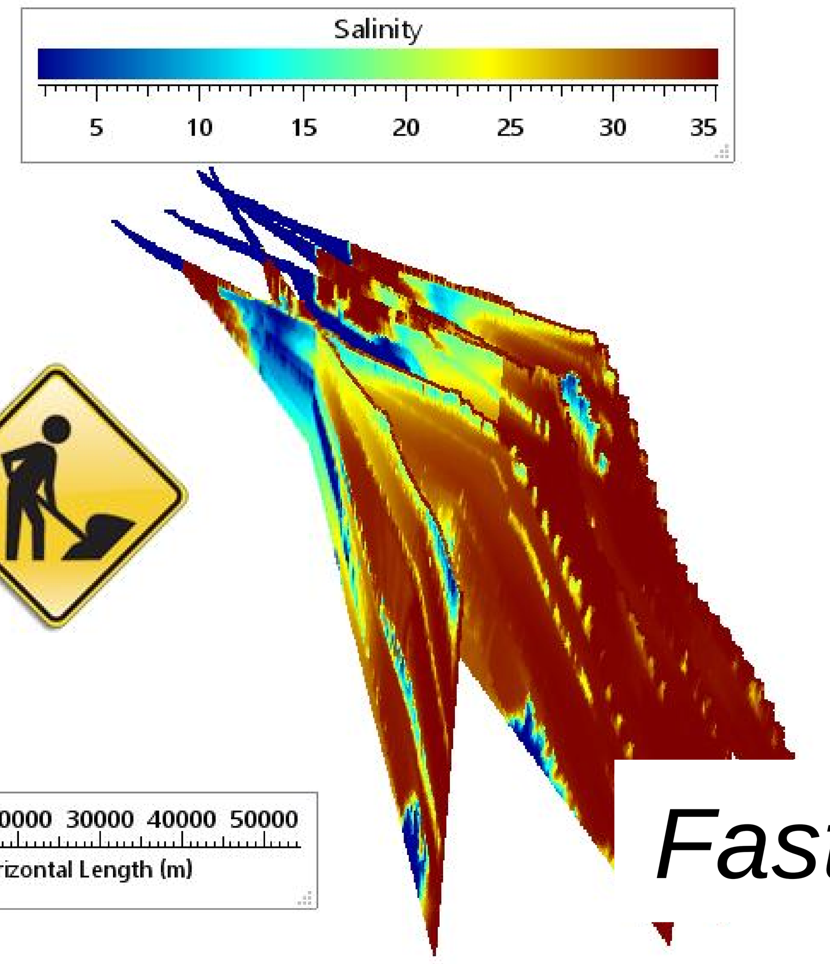
Van Engelen et al., 2019. HESS

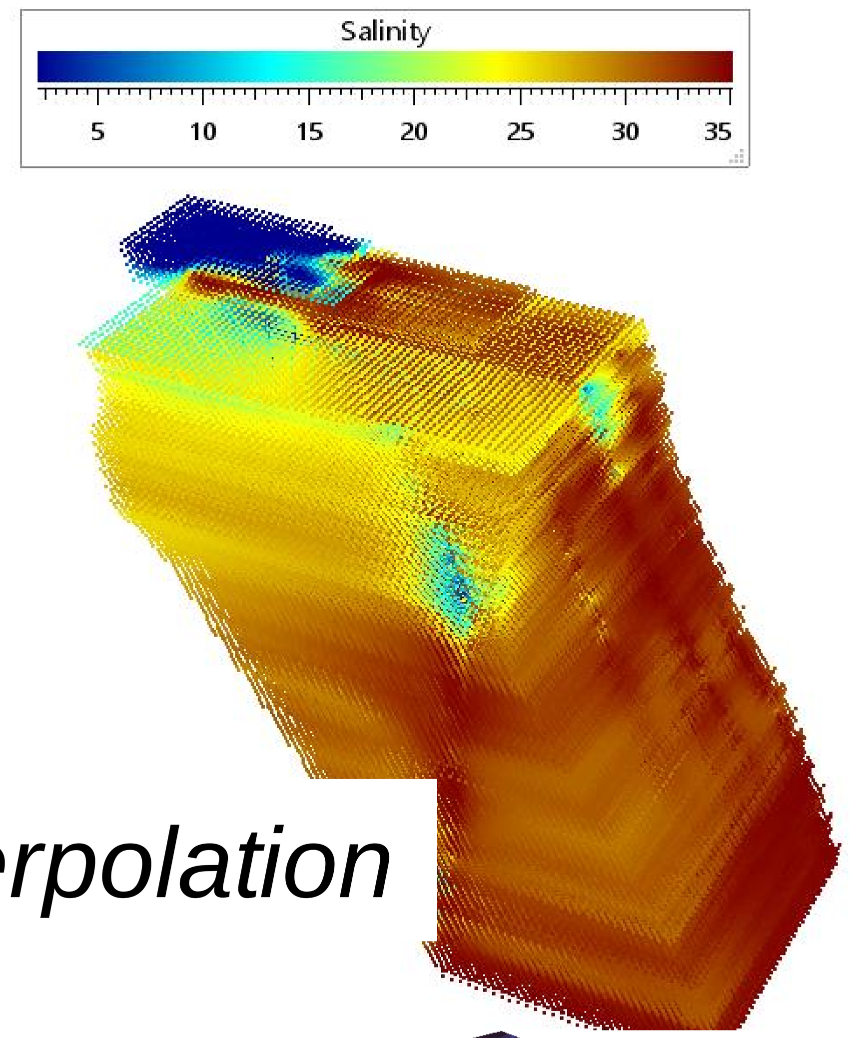
Combining groundwater salinity data

- Airborne surveys
- Webportals, text mining (pdf)
- Rapid, automated interpolations
- Paleo reconstructions modelling
- (Citizen science salinity monitoring)

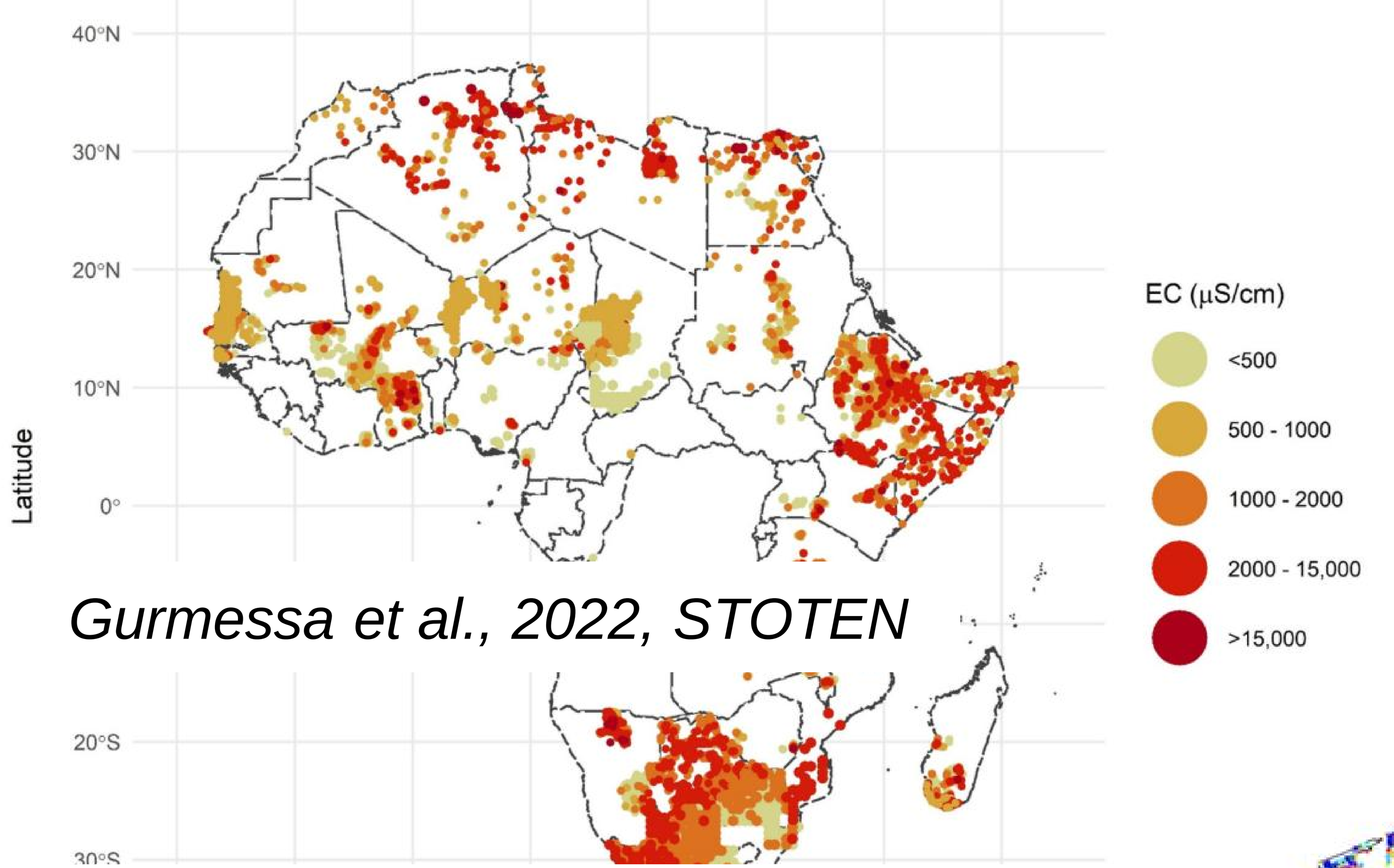




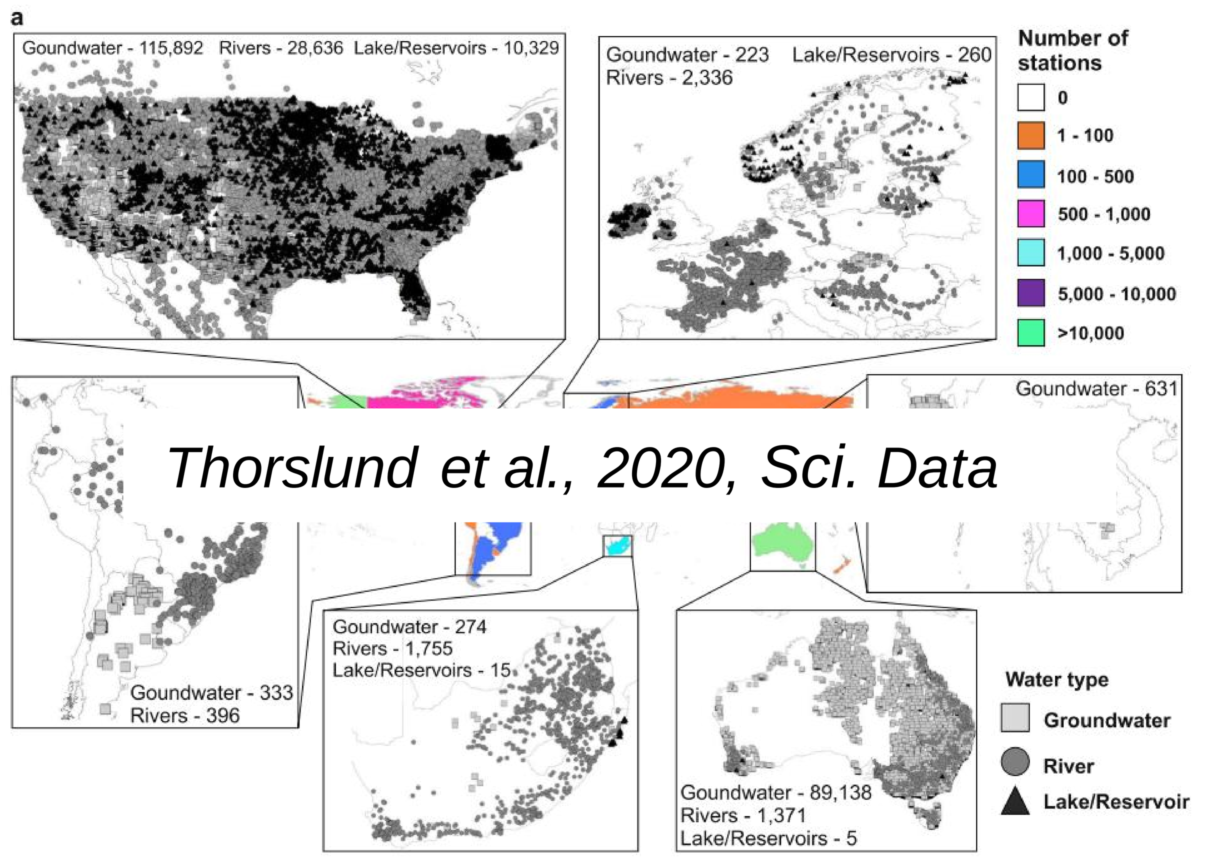




Fast interpolation

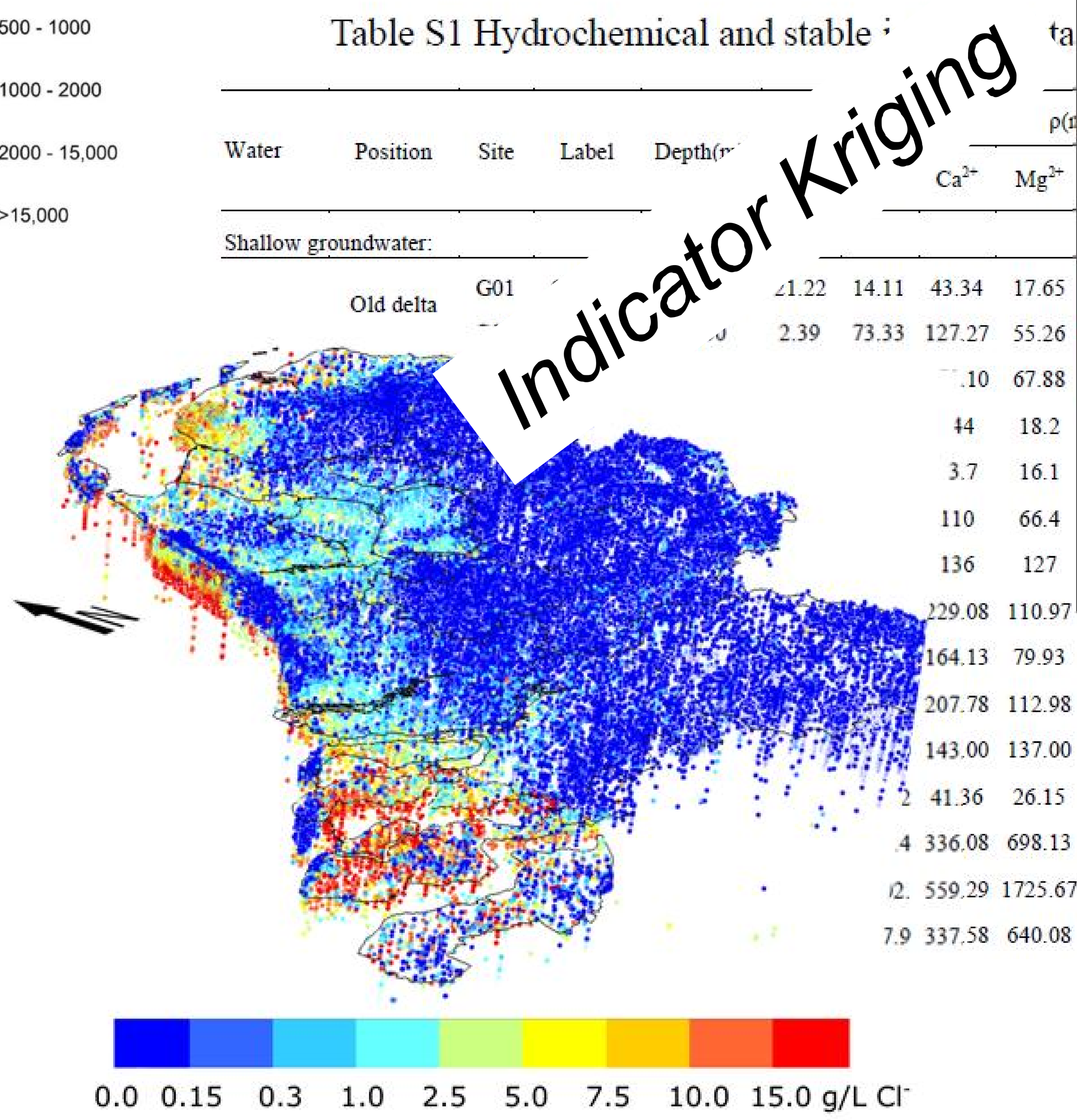


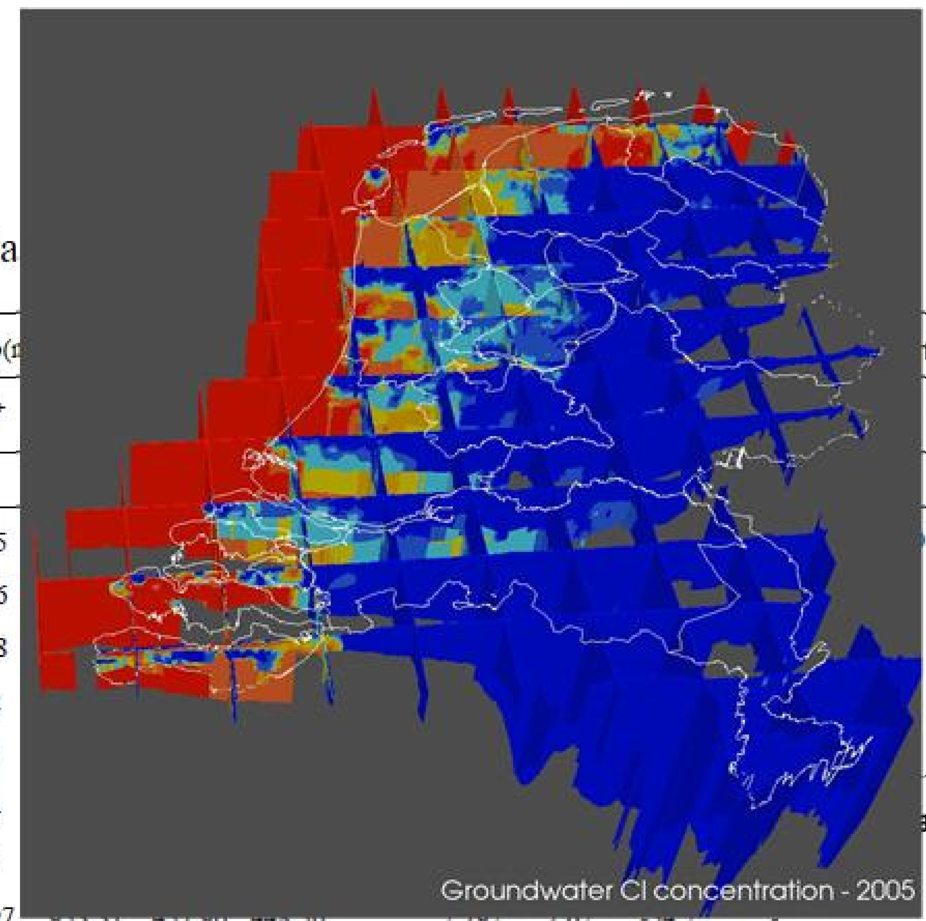
Gurmessa et al., 2022, STOTEN

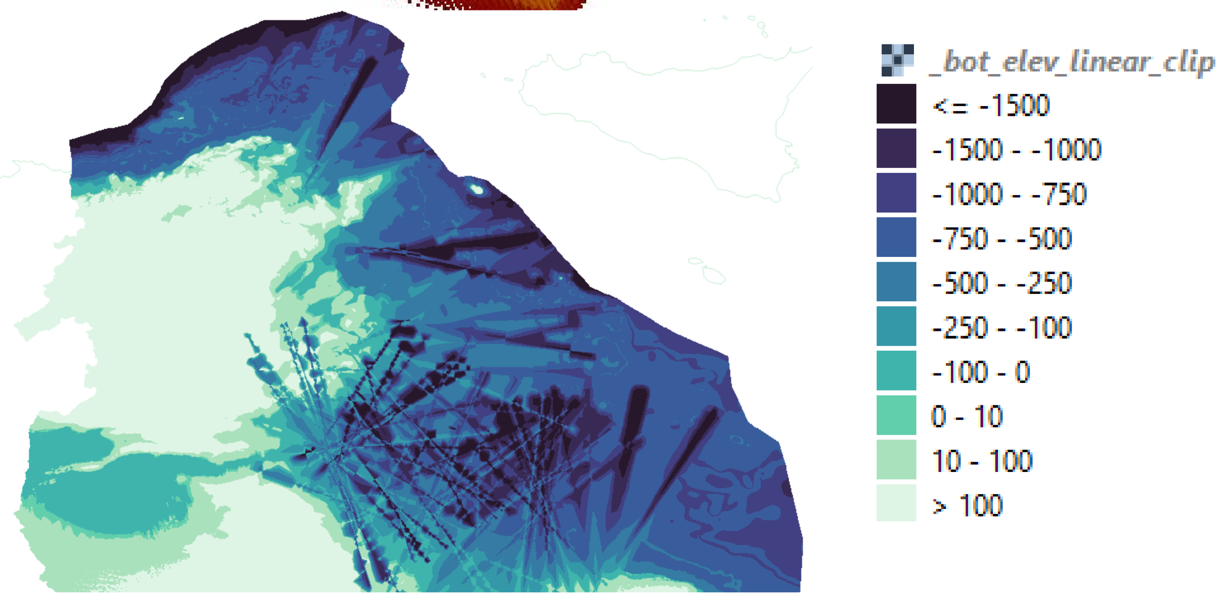


Thorslund et al., 2020, Sci. Data

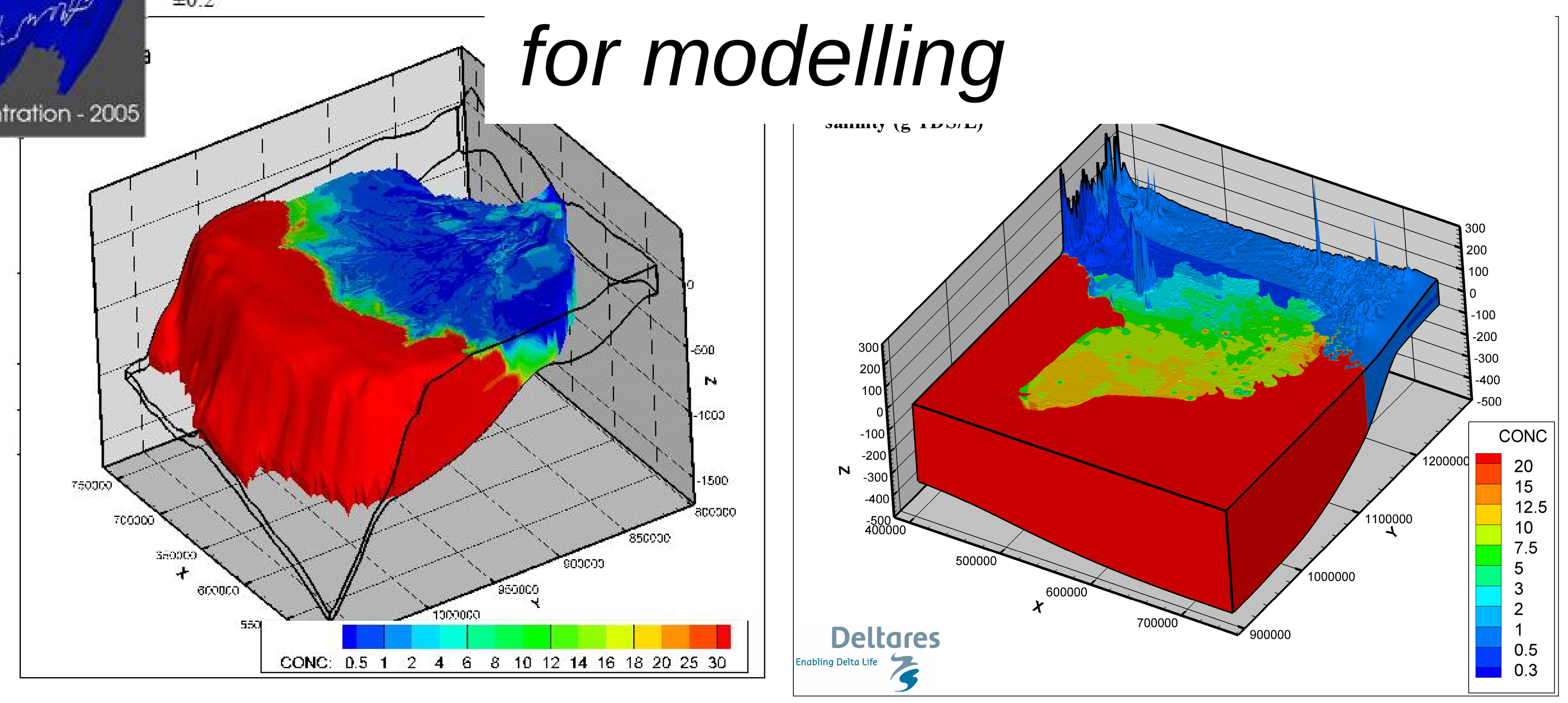
Indicator Kriging



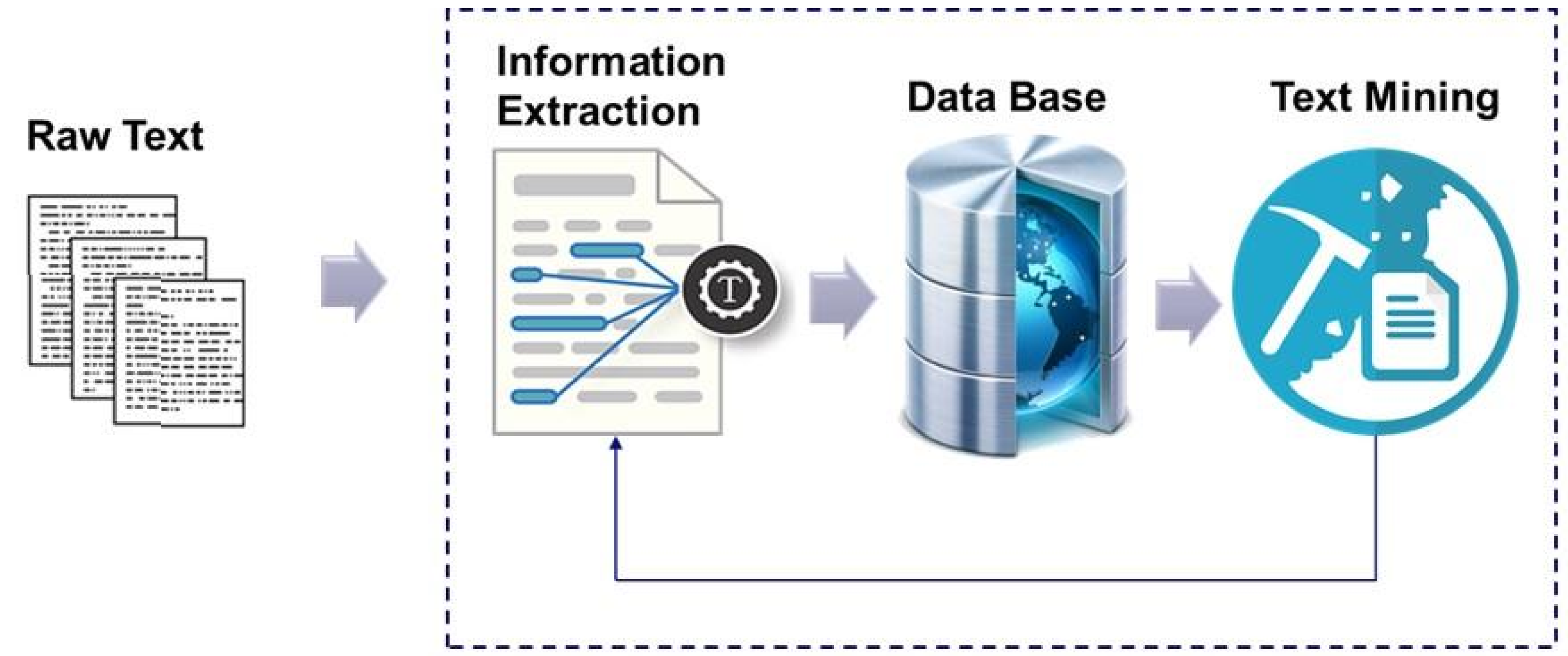


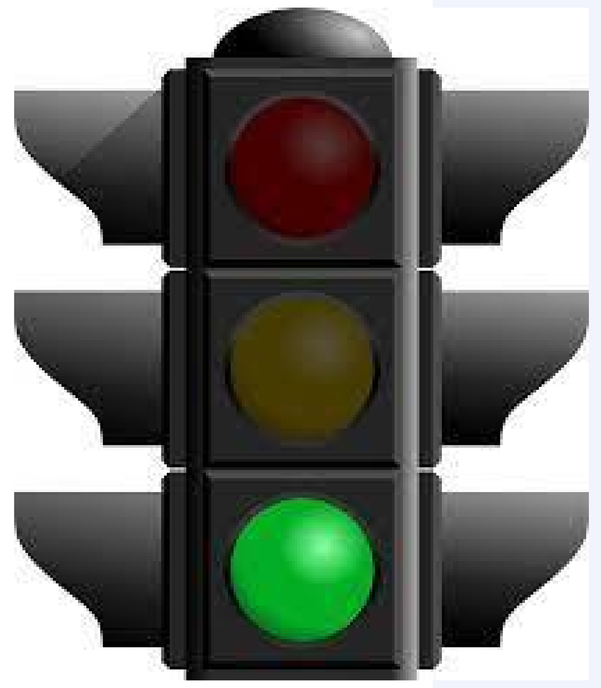


Estimate bottom elevation for modelling



Data mining hydrogeology



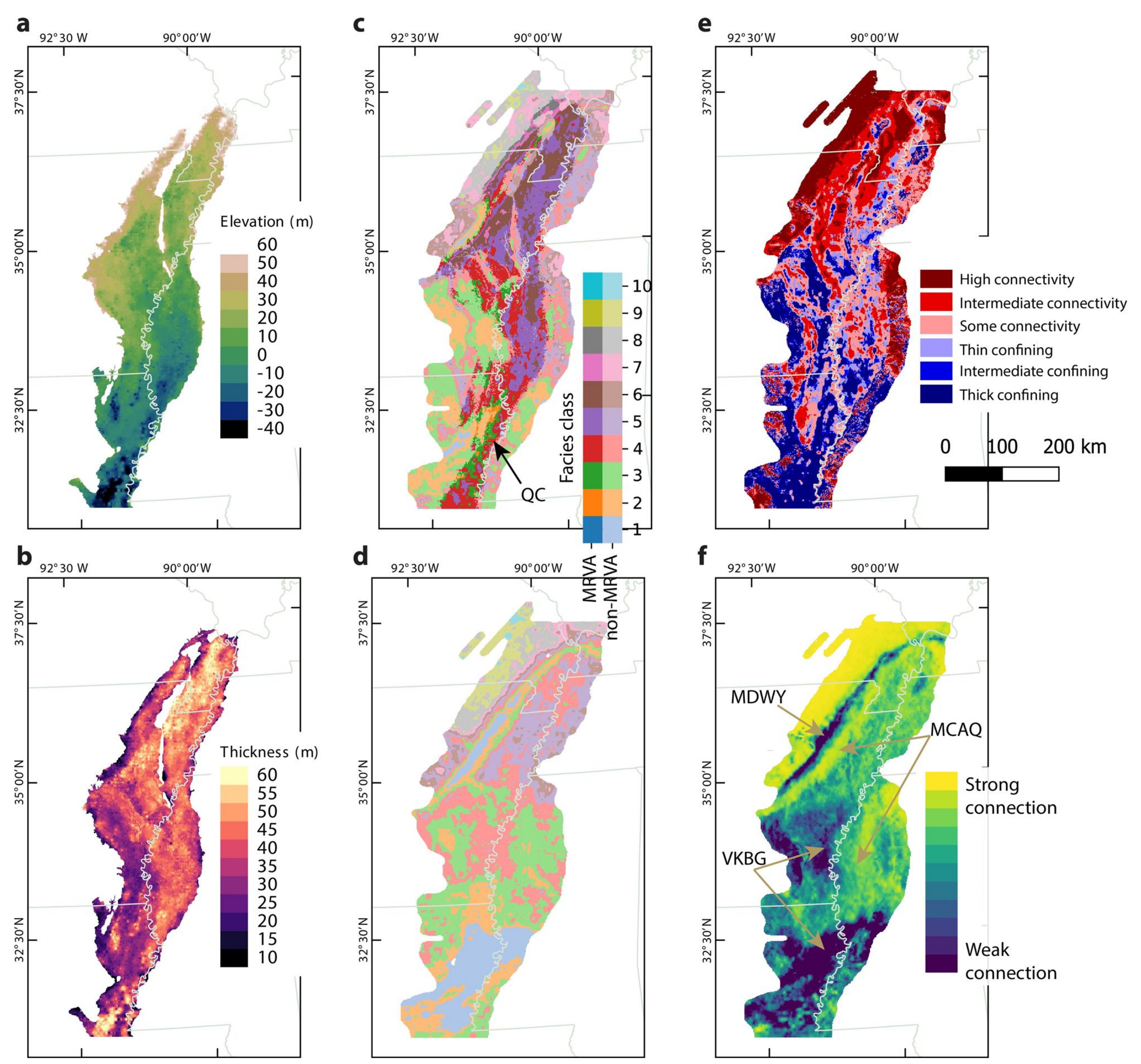


Extracting information from images.

Automated in Python using Tesseract and OpenAI API

PyMuPDF → Tesseract OCR → OpenAI

Input image



Output text (Tesseract)

Text editor - 21

```
35°00 N

32°30 N

92°30 W 90°00'W 92°30'W 90° 00'W 92°30'W 90° 00'W

37°30 N
37°30'N
37°30'N

35°00 N
35°00'N
35°00'N

HB High connectivity

|| Intermediate connectivity
|| Some connectivity

I) thin confining

|| Intermediate confining

|| Thick confining

32°30 N
32°30'N
32°30'N

00 200 km
```

Extracted data (OpenAI)

User: "If there are coordinates in the text, extract them as minimum and maximum coordinate pairs:

System: "Example output: X: 100, 100. Y: 100, 100"

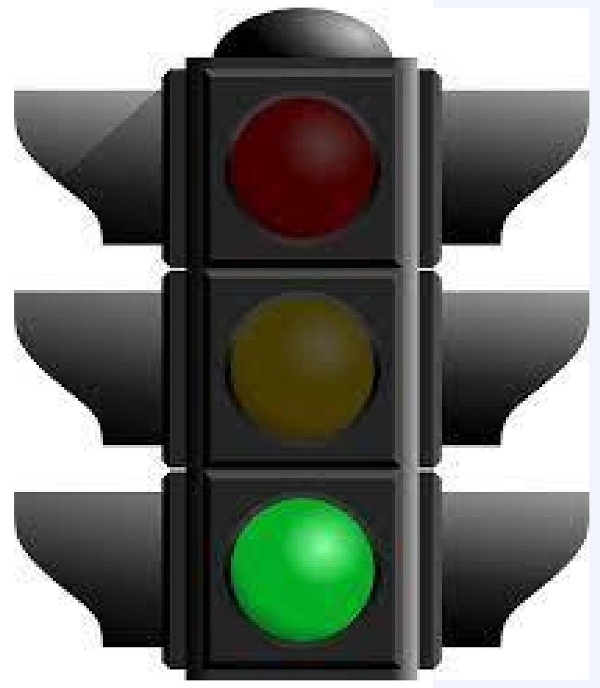
Text editor - 21

```
Minimum coordinate pair: 32°30'N, 90°00'W
Maximum coordinate pair: 37°30'N, 92°30'W

Image: 2021_Airborne geophysical surveys of the lower Mississi_6.png
```

Data mining hydrogeology

New: multi-modal GPT-4 to process multiple types of input data, including text, images, associating and combining visual and textual information!



Extracting information text.

Automated in Python using OpenAI API

PyMuPDF → OpenAI

Input text

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ELSEVIER

Joint estimation of groundwater salinity and hydrogeological parameters using variable-density groundwater flow, salt transport modelling and airborne electromagnetic surveys

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[a] Utrecht University, Department of Physical Geography, Utrecht, the Netherlands

Extracted data (OpenAI)

User: "Extract model parameters from the text in tabular format:"

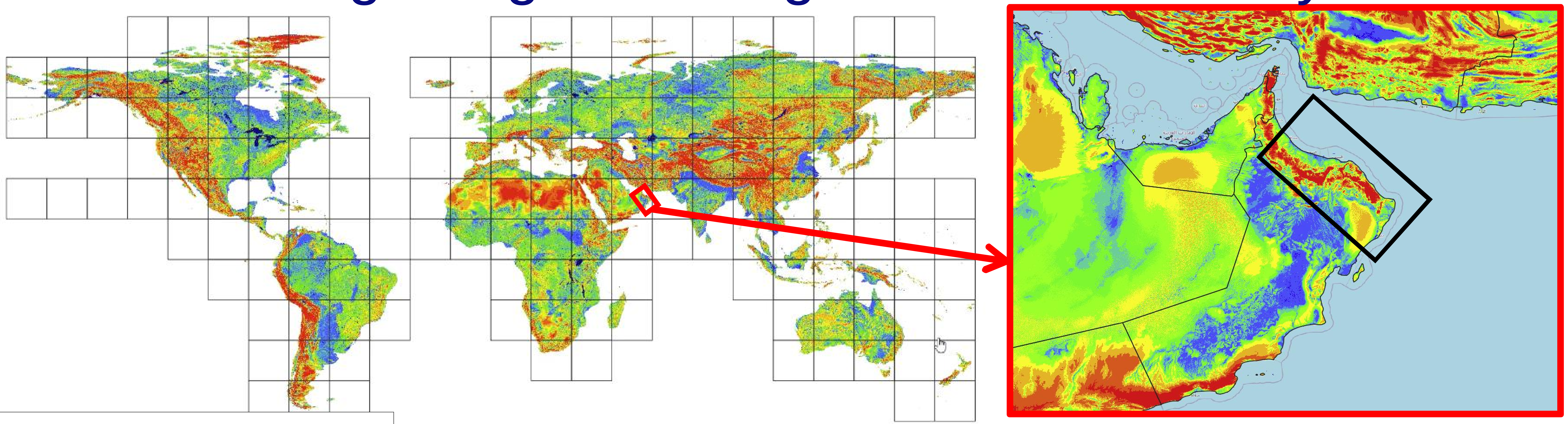
System: "Example: X,Y,Z,1,2,3"

```
Initial Estimate | Actual Value | Predicted Value (difference actual)
--- | --- | --- | ---
Kh Aquifer (m/day) | 1 | 10 | 10.63291 (0.63291)
Kv Aquifer (m/day) | 0.3 | 3 | 3.312433 (0.312433)
Kh Aquitard (m/day) | 0.001 | 0.01 | 0.011838 (0.001838)
Kv Aquitard (m/day) | 0.0005 | 0.005 | 0.005831 (0.000831)
Porosity | 0.1 | 0.35 | 0.386181 (0.036181)
```

```
Kh Aquifer | Horizontal hydraulic conductivity of the aquifer | 10 (m/day)
Kh Aquitard | Horizontal hydraulic conductivity of the aquitard | 0.01 (m/day)
Kh/Kv | Anisotropy | 3.3 (aquifer) 2 (aquitard)
Porosity | Porosity | 35 (%)
Recharge winter | Recharge in winter, higher values denote ASR areas | 0.003 m/day (ASR areas), 0.0015 m/day (other areas)
Recharge summer | Recharge in summer, negative value denotes evaporation | -0.0005 m/day
Well Extraction winter | Groundwater extraction in winter | 0 m3/day per model cell
Well Extraction summer | Groundwater extraction in summer | -0.625 m3/day per model
```

Test 1 Making a regional 3D groundwater salinity model

- Oman case
- 223*274*12 cells of 1*1km^{2};
- Simulating groundwater salinity paleo-reconstruction (120**k**yrs) and 300 yrs into the future including extractions (using PCR-GLOBWB).
- Computation time: < 1day, parallel on only 24 cores; using supercomputer Snellius, but even on a laptop it is doable

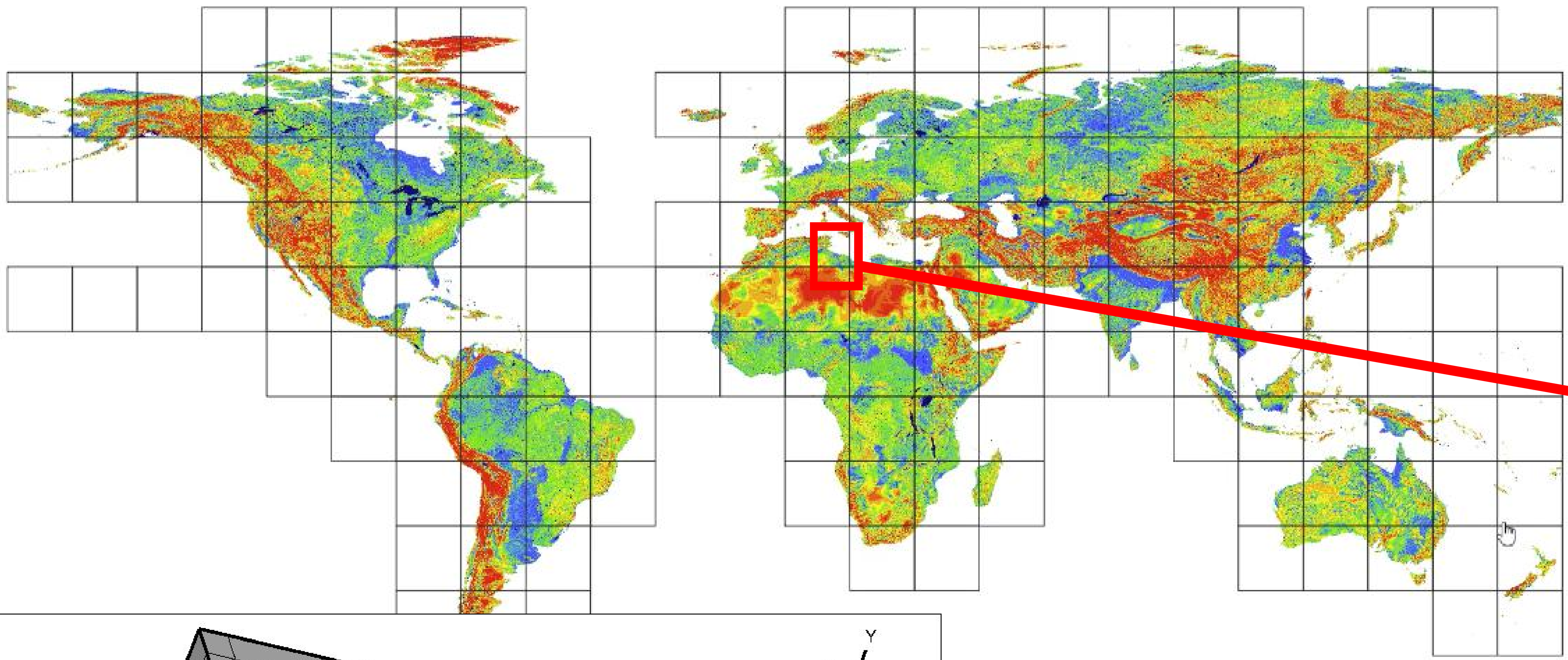


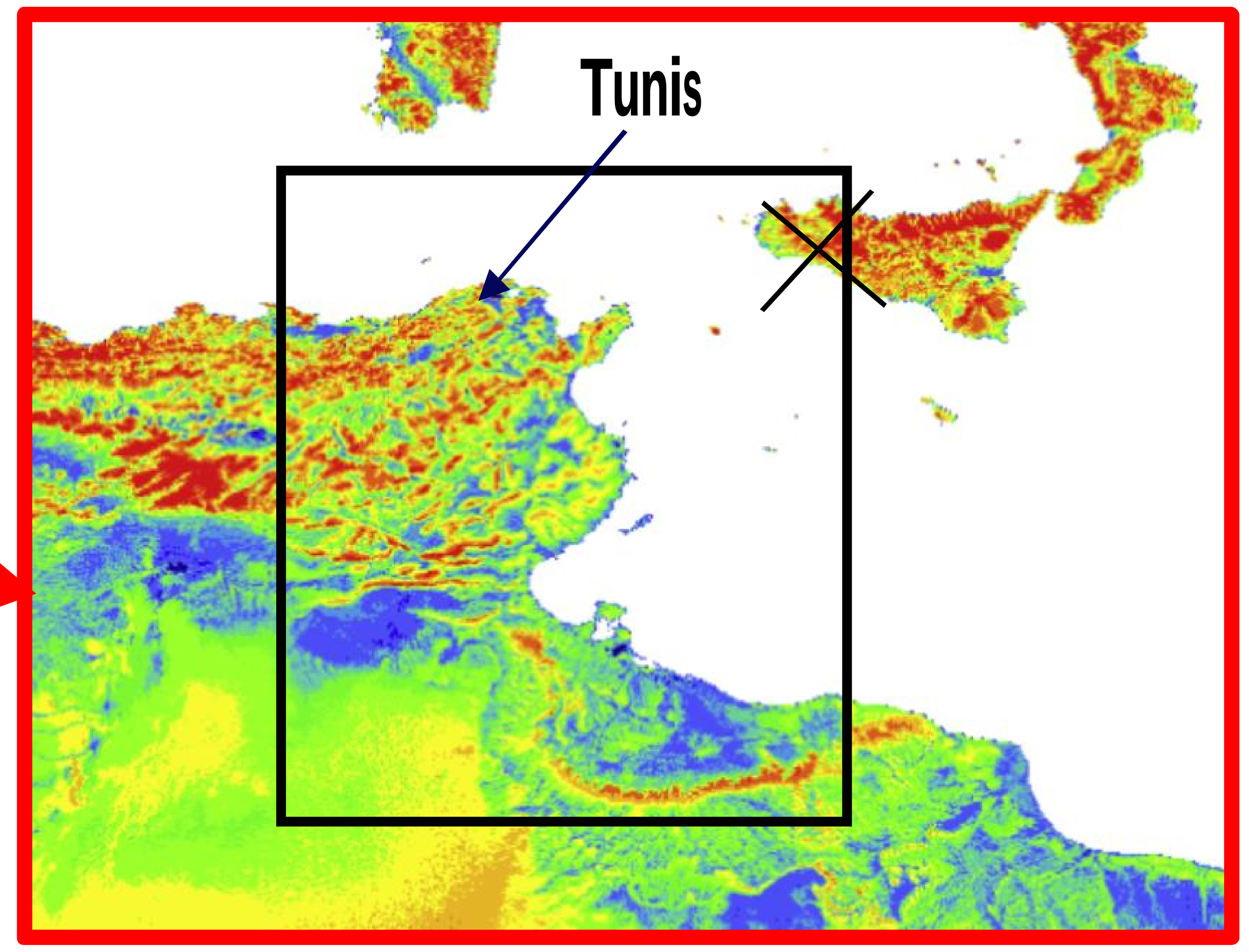
Deltares

Utrecht University

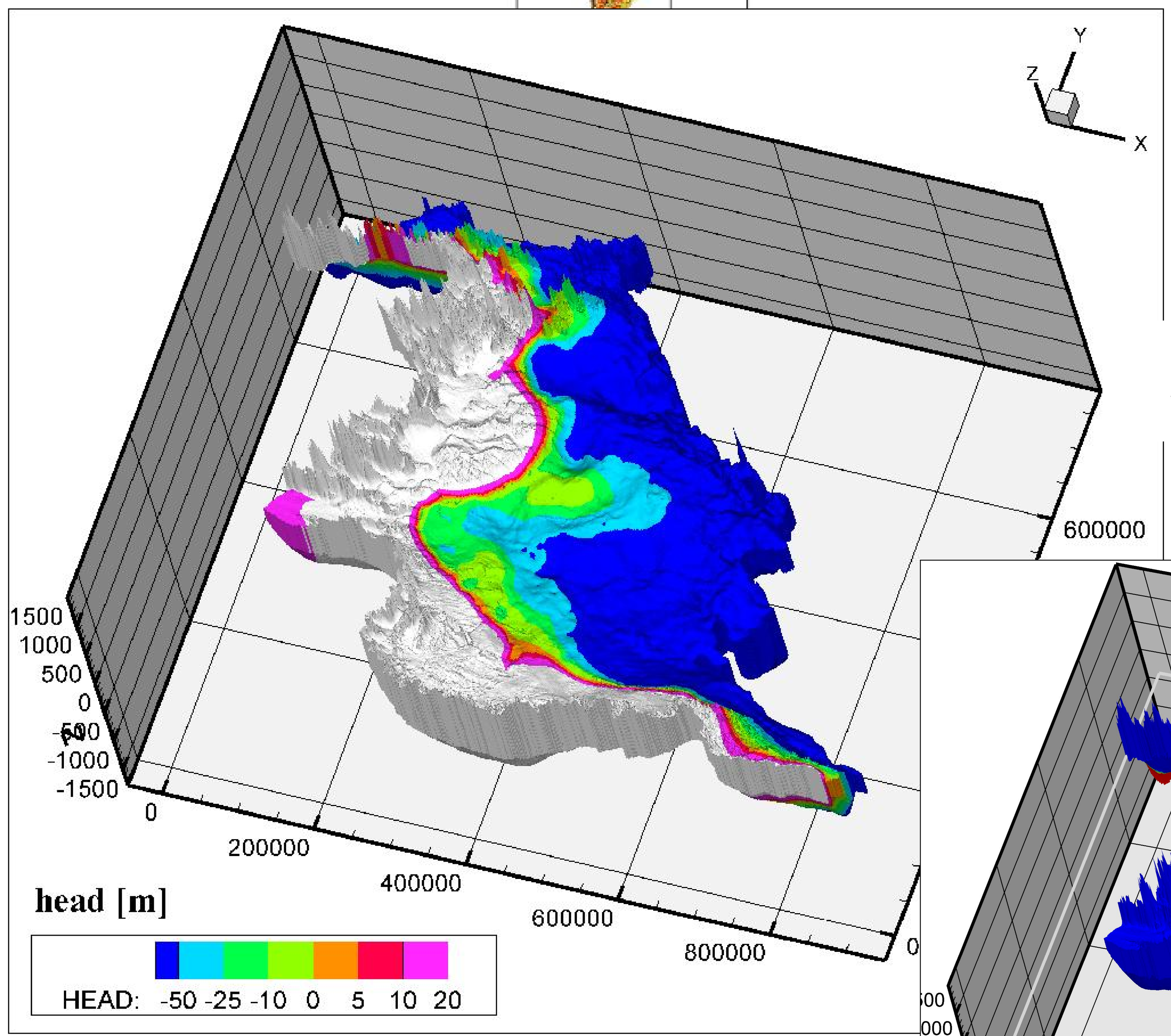
Test 2 Making a regional 3D groundwater salinity model

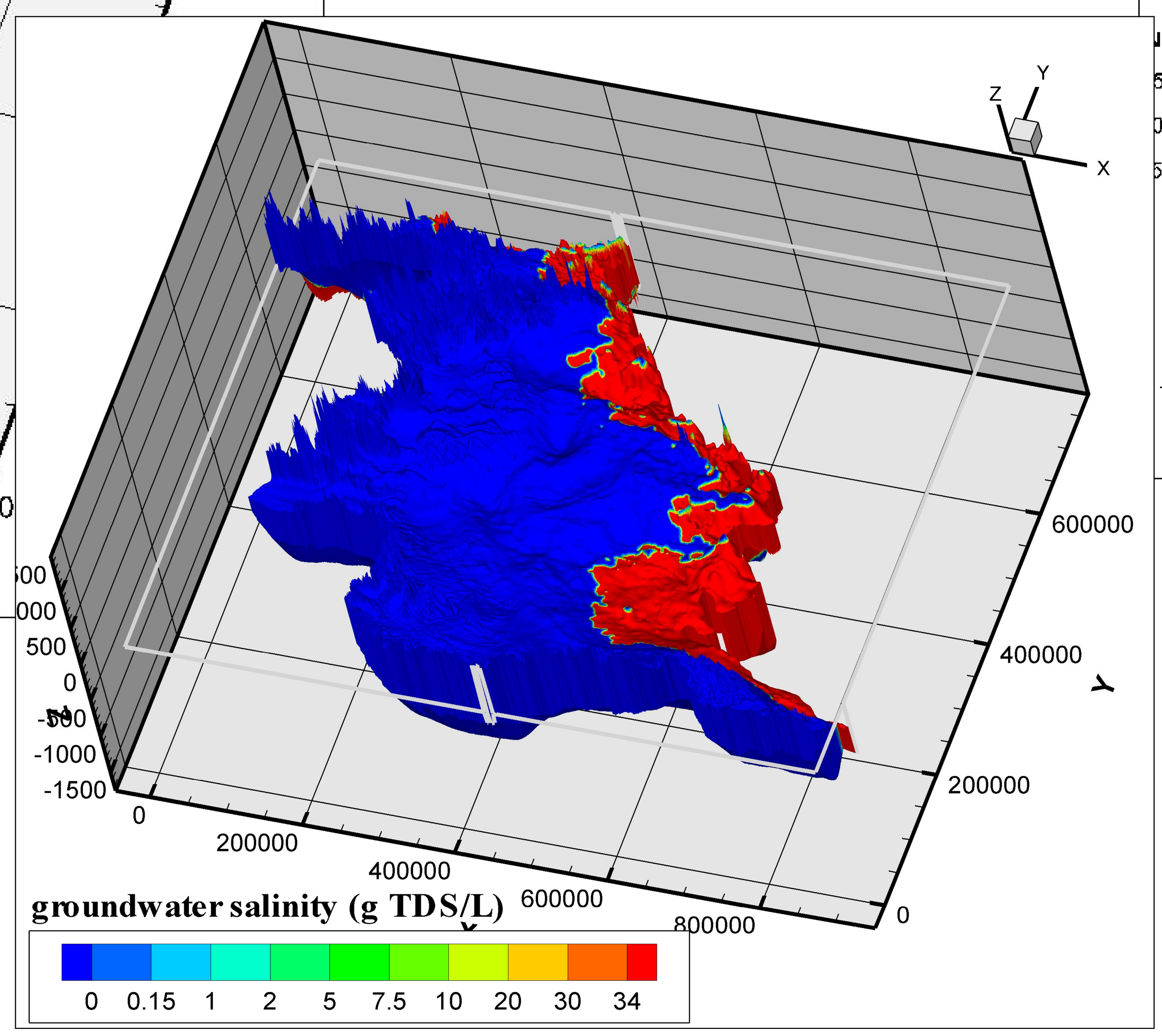
- **Tunesia-Lybia** case
- 907*747*12 cells of 1*1km^2
- Simulating groundwater salinity paleo-reconstruction. For now 30-20**k**yrs BP.
- Testing parallel on 62-128 cores; using supercomputer Snellius

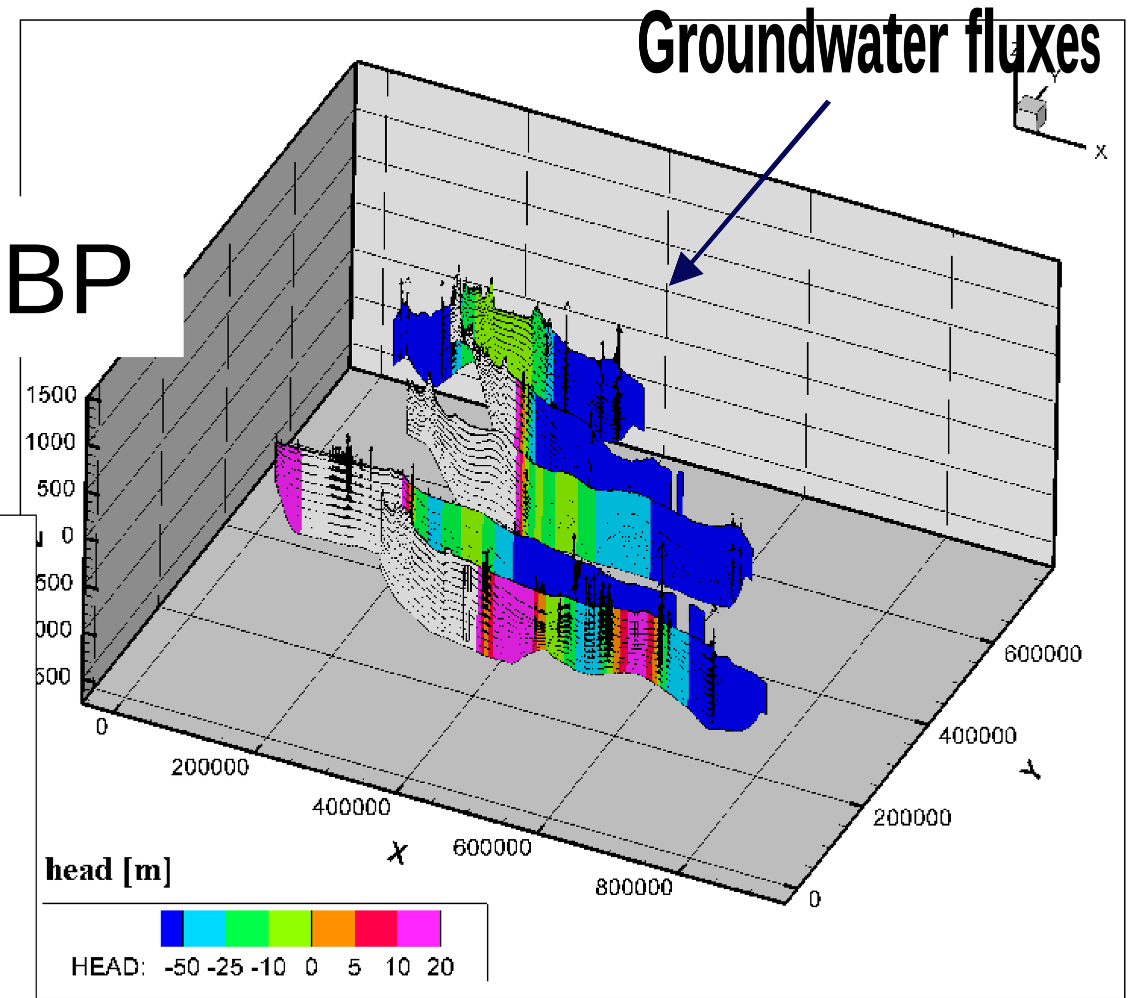




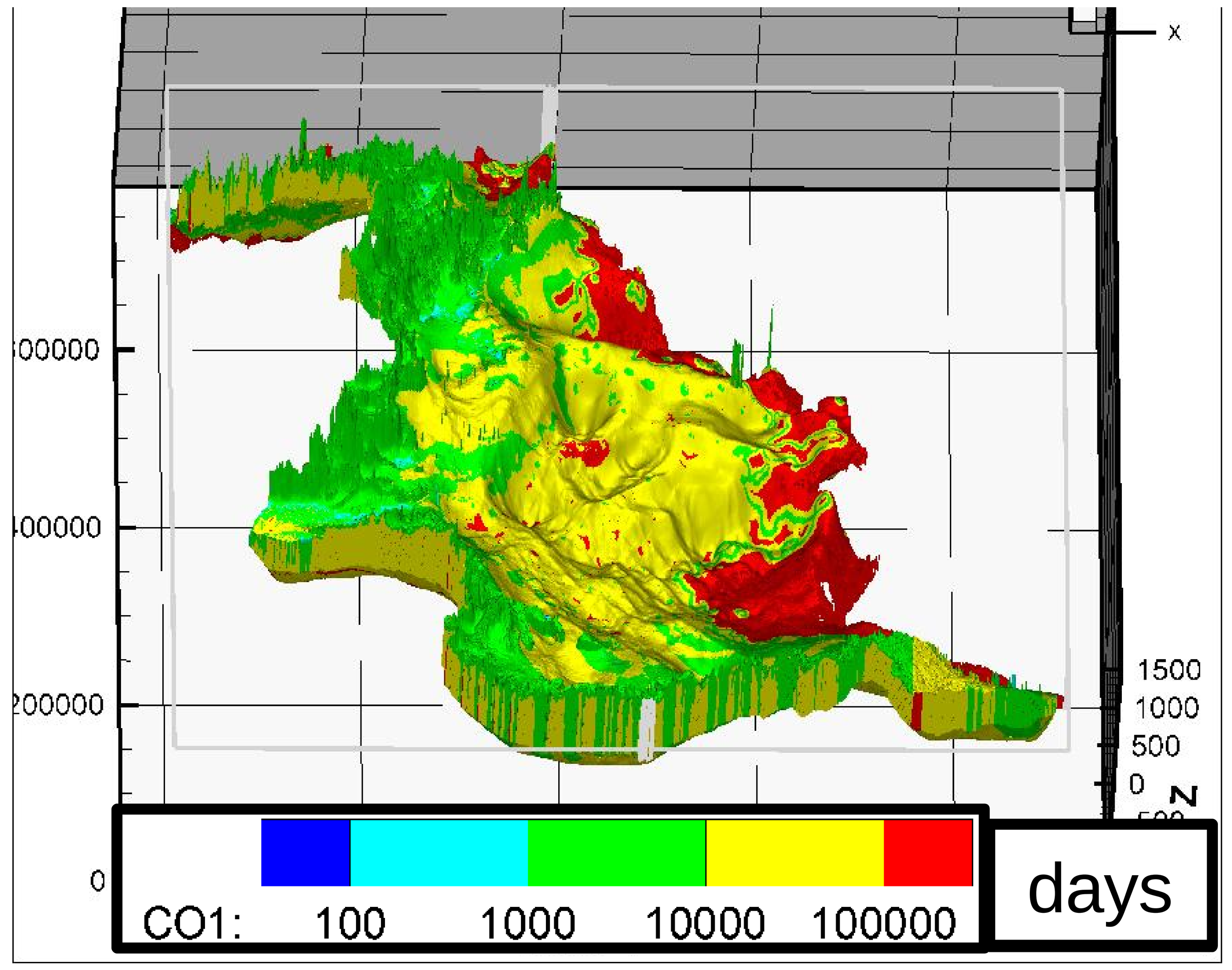
Situation 30000 yr BP







Automated STEPSIZE analysis!



- Advection,

$$\Delta t \leq \frac{R}{|v_x|/\Delta x + |v_y|/\Delta y + |v_z|/\Delta z}$$

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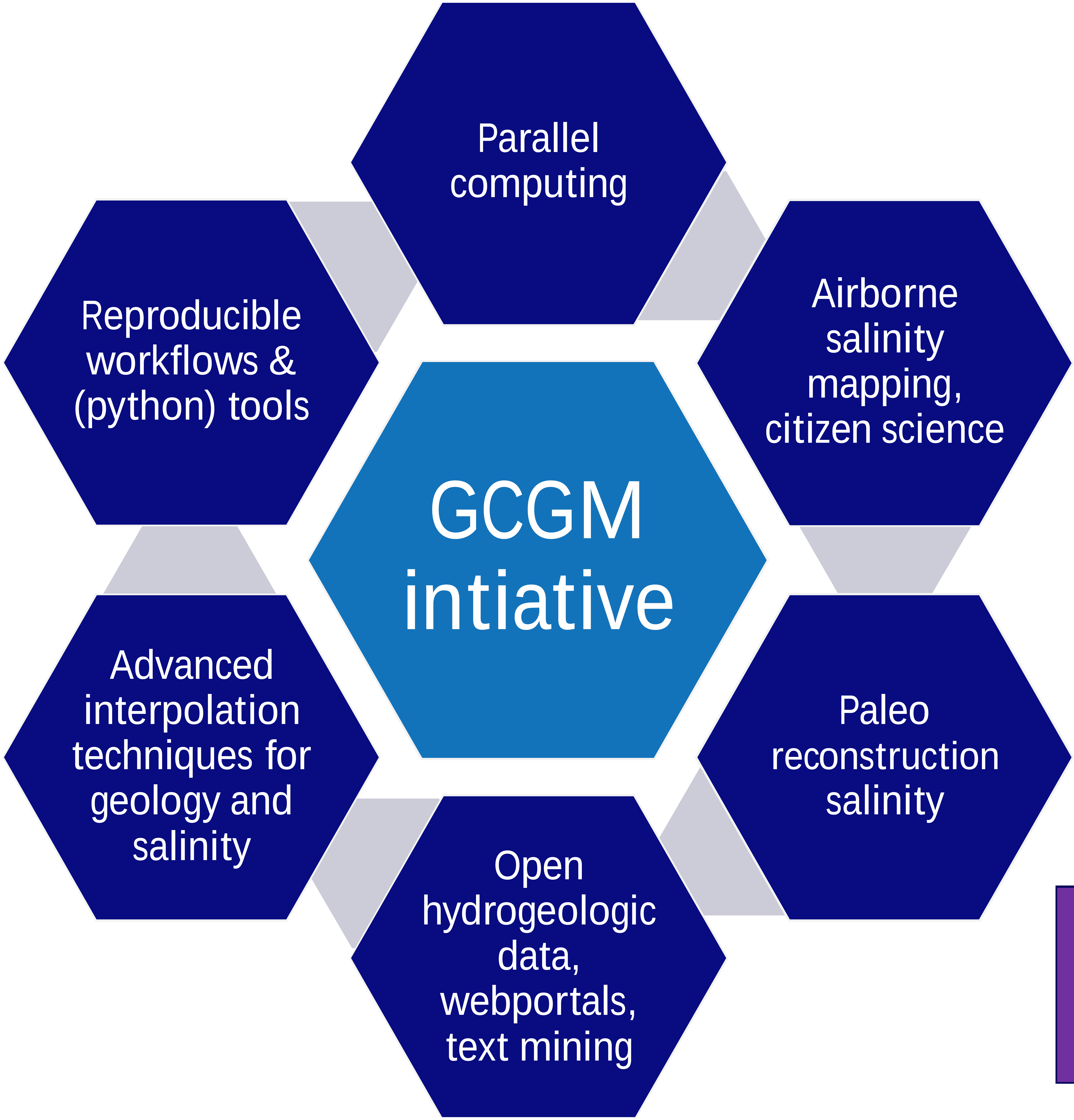
New developments global coastal groundwater salinity modelling



groundwater community initiatives, *making the invisible visible*

Thank for you attention

Questions?

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pdf on wiki freshsalt.deltares.nl

EGU23-7607 **HS8.2.6**	A study on the suitability and quantitative potential of aquifer storage and recovery and brackish water extraction in Dutch coastal areas.	**Ilja America - van den Heuvel et al**
EGU23-15557 **HS8.2.6**	Monitoring & simulation groundwater salinity due to extractions in a coastal aquifer	**Thijs Hendrikx et al**
EGU23-17249 **HS8.2.6**	Effects surface water boundary condition scaling on modelled groundwater salinity and salt fluxes	**Ignacio Farias et al**
EGU23-2859 **HS8.2.6**	Assessing impact of climate change and anthropogenic factors on future salinization; a case in Northwestern Germany)	**Stephan L. Seibert et al**
EGU23-1844 Henry Darcy Medal Lecture	**Global Water Resources and the Limits to Groundwater Use**	**Marc Bierkens**

And PICO Zamrskly et al.: **EGU23-11444** HS8.2.6

More information:

Parallel SEAWAT, imod-python and 3D viewer:

- https://oss.deltares.nl/web/imod/about-imod5
    - Verkaik, J. et al., 2021. Distributed memory parallel computing of three-dimensional variable-density groundwater flow and salt transport. Adv. Water Resour. 154, 103976. https://doi.org/10.1016/j.advwatres.2021.103976
    - https://deltares.github.io/iMOD-Documentation/python_index.html iMOD Python
    - https://deltares.github.io/iMOD-Documentation/viewer_index.html iMOD Viewer

Reproducibility and transparency, Gitlab

- https://gitlab.com/deltares/imod/nhi-fresh-salt
- Delsman, J.R. et al 2023. Reproducible construction of a high-resolution national variable-density groundwater salinity model for the Netherlands. Environ. Model. Softw. 105683. https://doi.org/10.1016/j.envsoft.2023.105683

- 3D Paleo-reconstruction groundwater salinity and iMOD-WQ
    - Seibert, S.L. et al., 2023. Paleo-hydrogeological modeling to understand present-day groundwater salinities in a low-lying coastal groundwater system (Northwestern Germany). Water Resour. Res. https://doi.org/https://doi.org/10.1029/2022WR033151
    - Van Engelen, J., Verkaik, J., King, J., Nofal, E.R., Bierkens, M.F.P., Oude Essink, G.H.P., 2019. A three-dimensional palaeohydrogeological reconstruction of the groundwater salinity distribution in the Nile Delta Aquifer. Hydrol. Earth Syst. Sci. 23, 5175–5198. https://doi.org/10.5194/hess-2019-151

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Orange issues

- Calibration, validation, verification.
- Tekst mining: IPR of articles.
- Interferences with local hydrogeological communities, some same regional scale.