The existential crisis of the Mekong delta: Impact of accelerating land subsidence

Results of the Rise and Fall research program (2014-2019): *Towards strategies for the subsiding Mekong Delta facing increasing salt water intrusion*. *Urbanizing deltas of the World (UDW NWO-WOTRO)*

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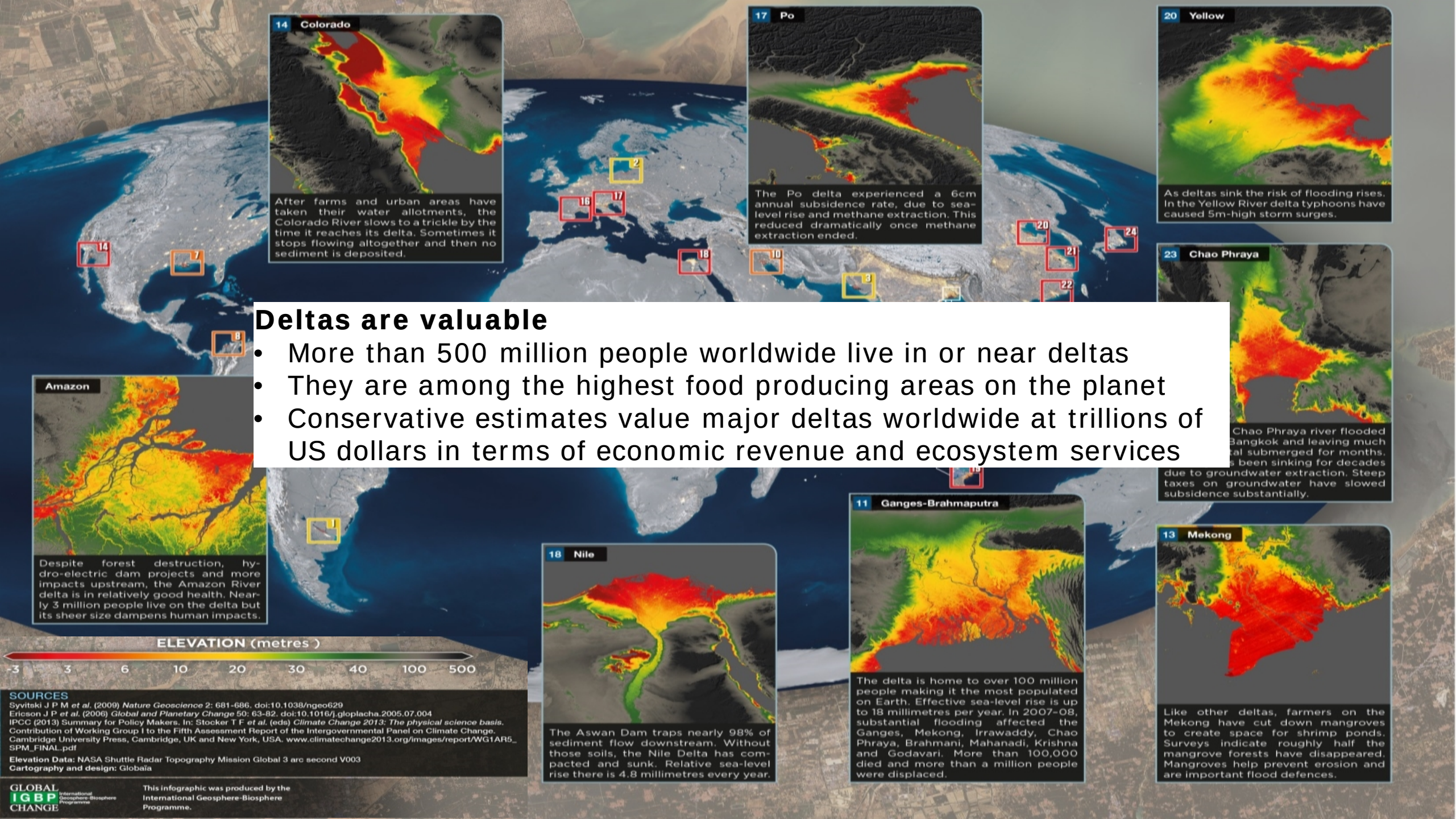

Deltas are valuable

- More than 500 million people worldwide live in or near deltas
- They are among the highest food producing areas on the planet
- Conservative estimates value major deltas worldwide at trillions of US dollars in terms of economic revenue and ecosystem services

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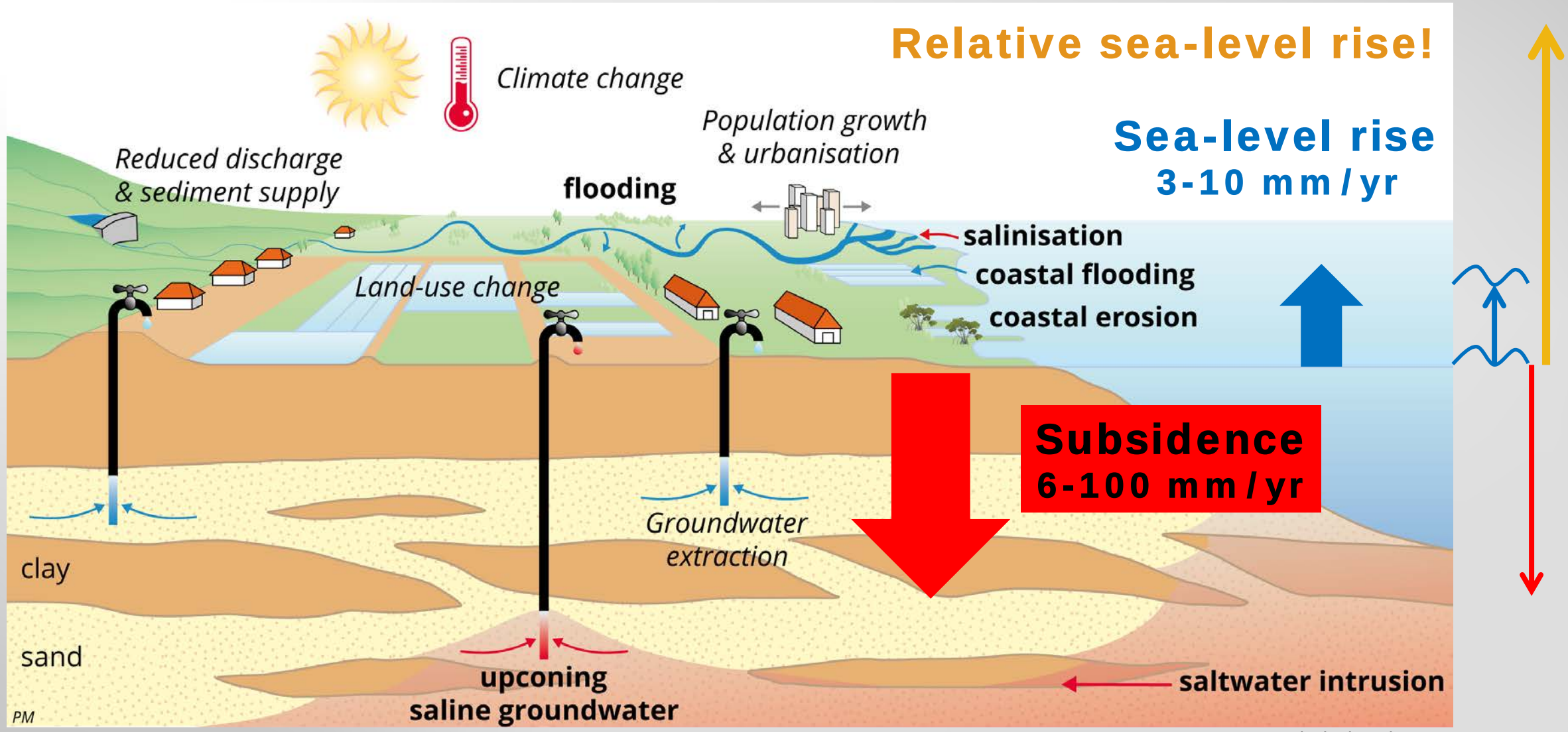
Changes in delta systems around the world



Minderhoud, 2019

Subsidence >> Climate-change driven SLR

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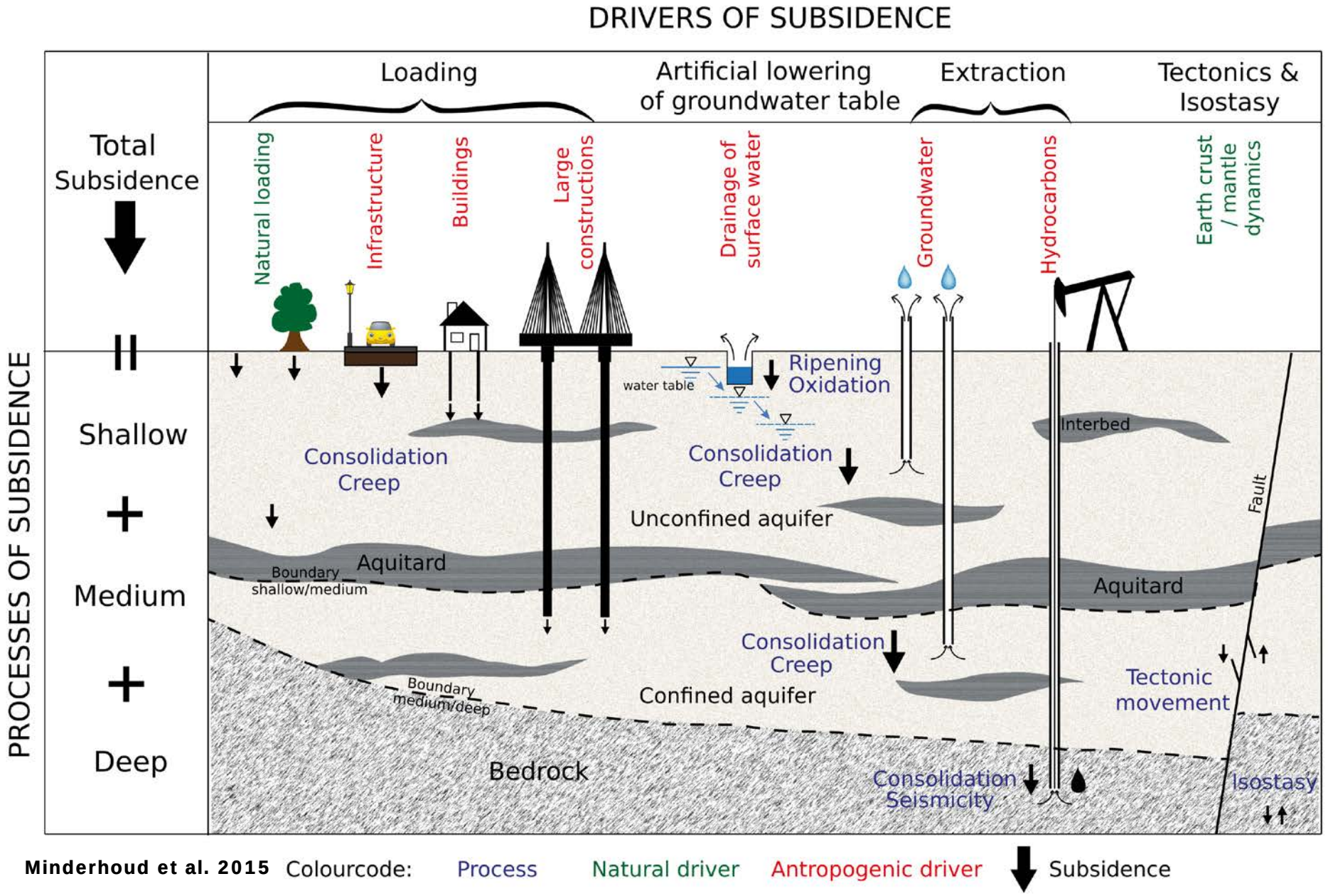
Causes of subsidence in deltas

Land subsidence is natural process in deltas.

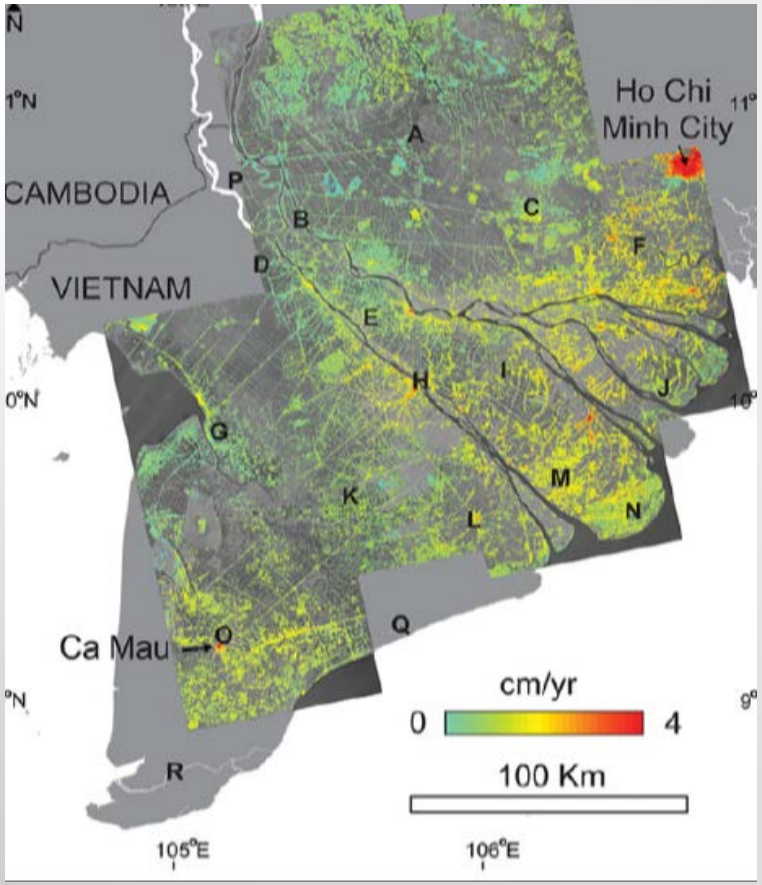
Land subsidence can be **accelerated** by human activities that increase physical loading or change the hydrogeological situation

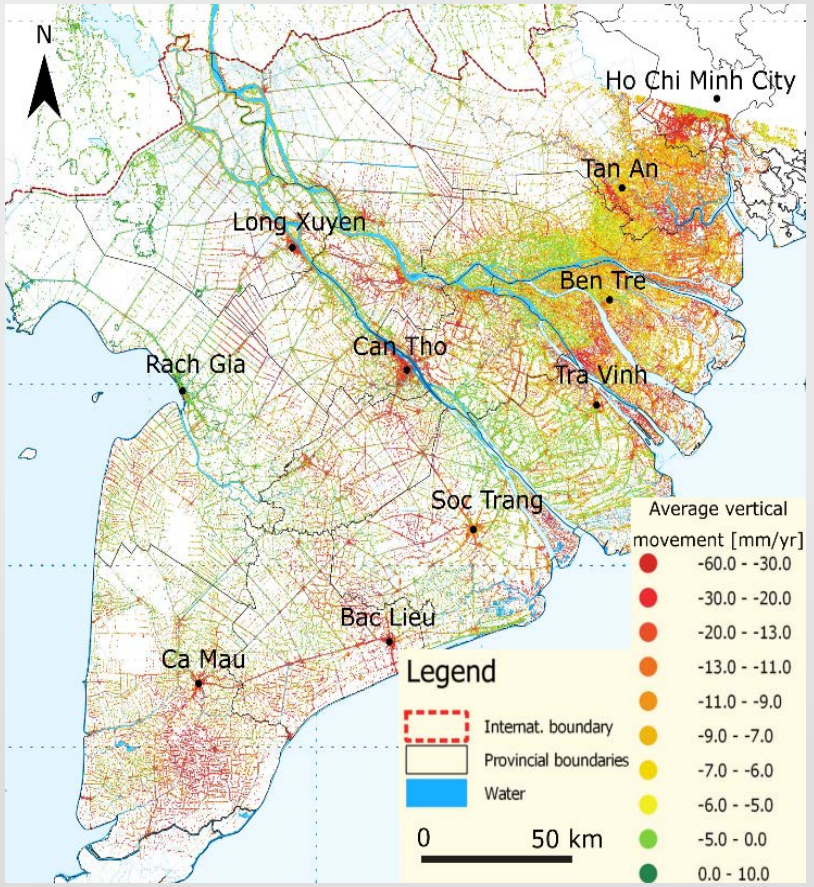
Total subsidence is the cumulative effect of all processes.



The Mekong delta is sinking at accelerating speed

Estimated InSAR-derived subsidence rates (cm/yr)





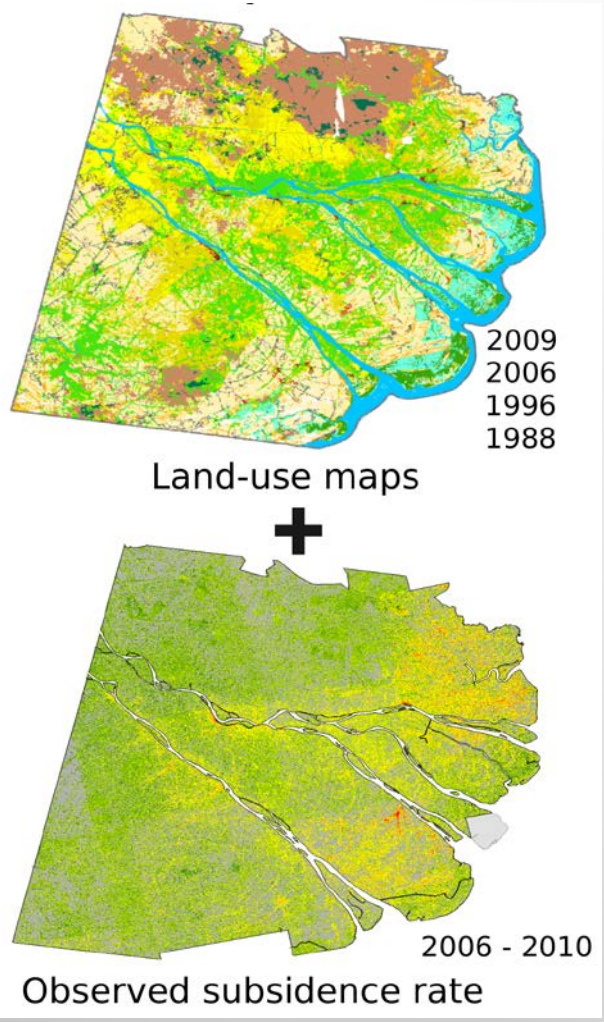
2006-2010:
Up to 2-3 cm/yr

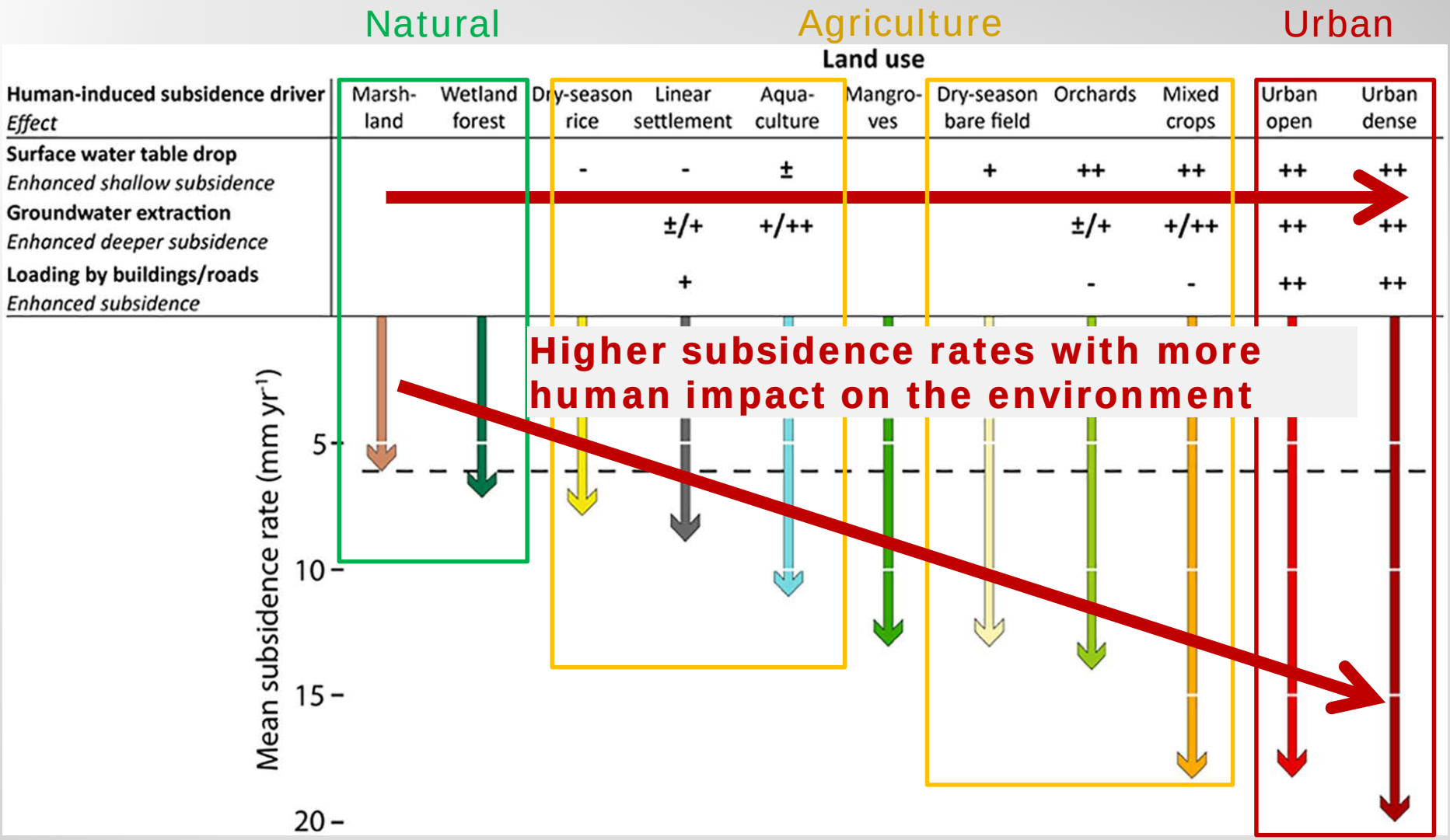
Erban et al., 2014. Environ. Res. Lett.

2014-2019:
Up to 5-6 cm/yr

EU Copernicus EMSN062
Minderhoud et al., 2020 (IAHS)

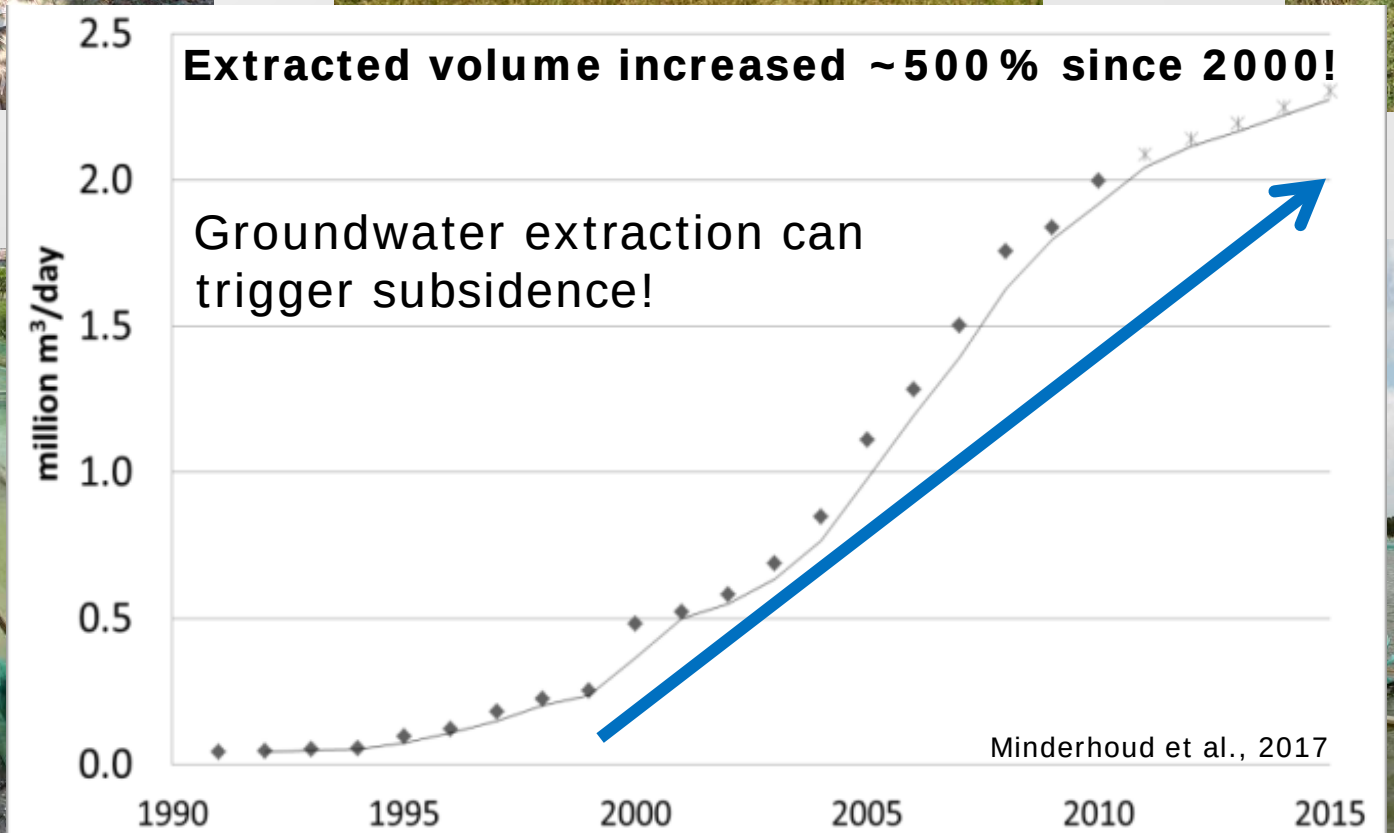
The relation between land use and subsidence - Evidence of human impact





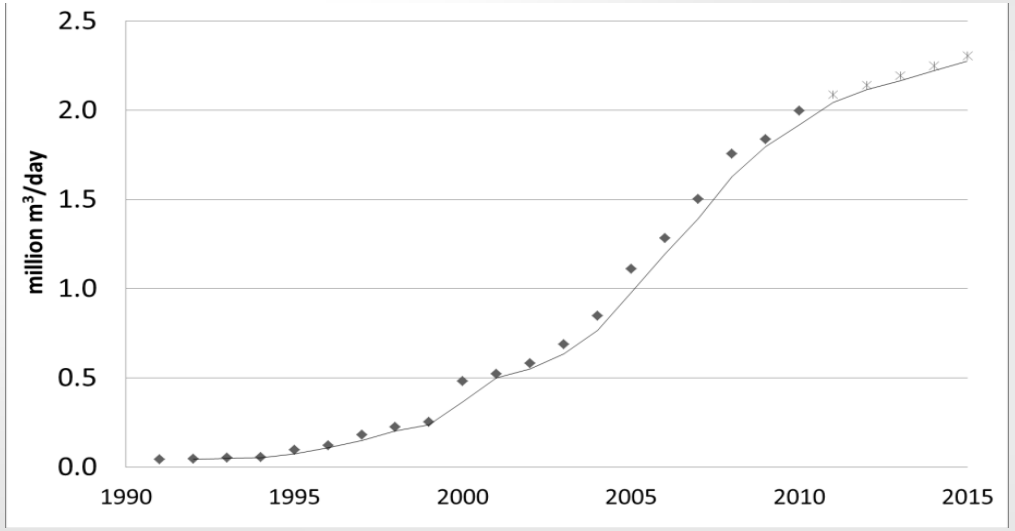
Minderhoud et al., 2018. *Science of the Total Environment*

Mekong delta and groundwater extraction

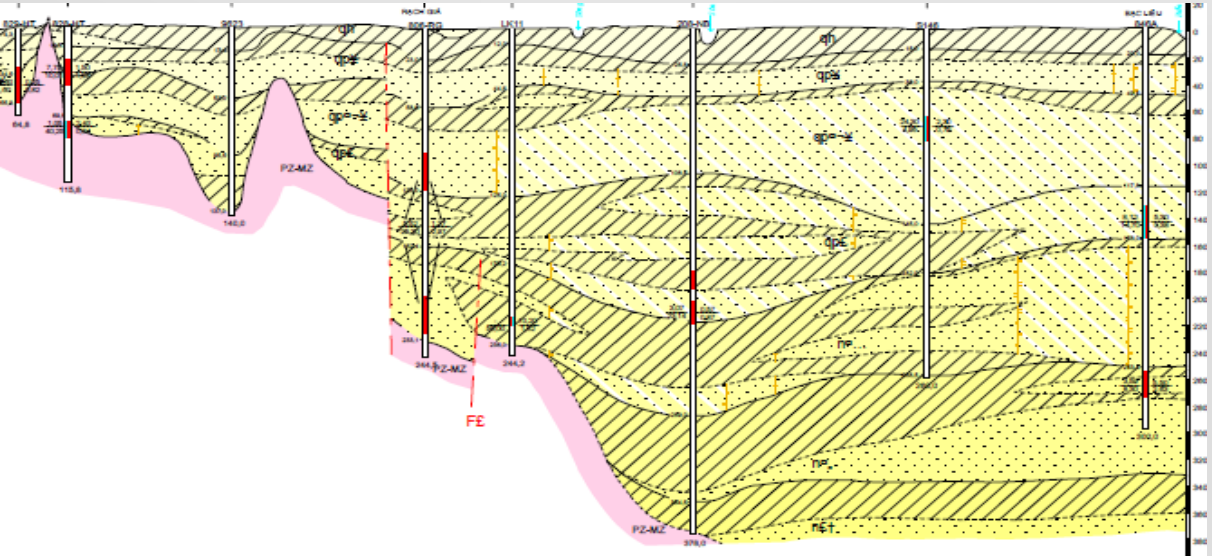


Groundwater extraction and observed hydraulic heads

Groundwater extraction in the Mekong delta

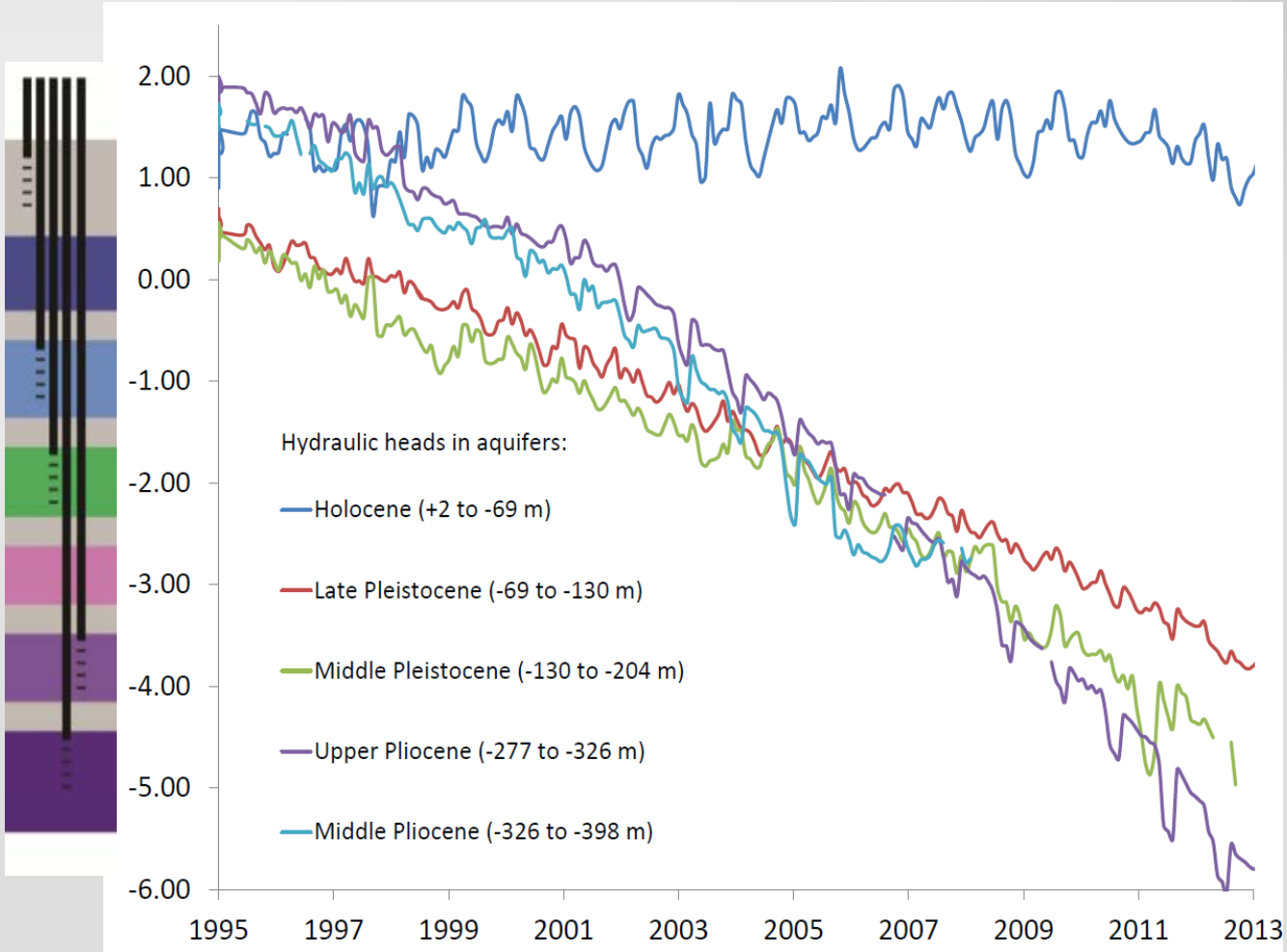


Multi-aquifer system of the Mekong delta

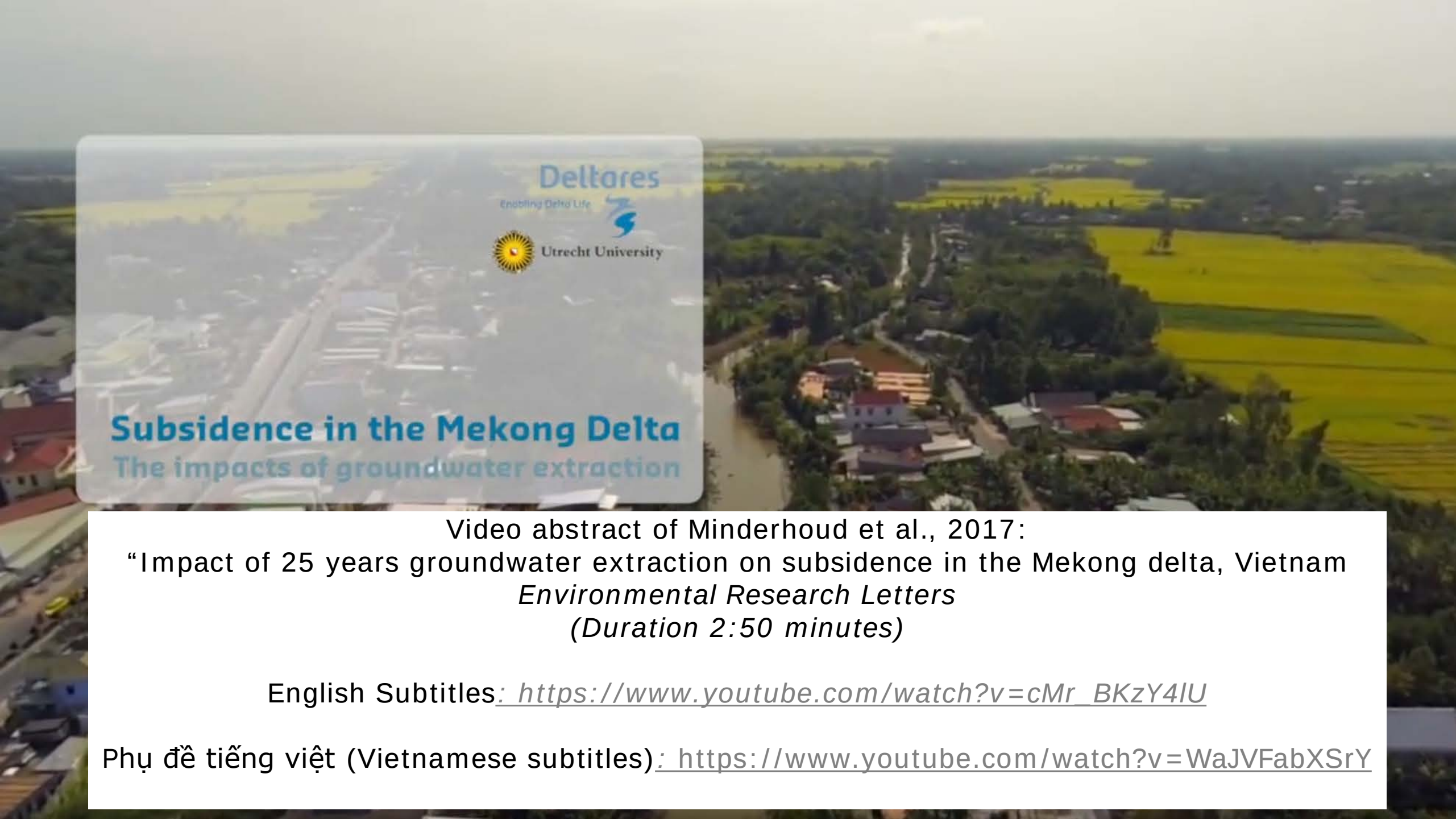


Monitoring wells near Can Tho

Representable for the situation in the Mekong delta



Minderhoud et al., 2017



Video abstract of Minderhoud et al., 2017:
"Impact of 25 years groundwater extraction on subsidence in the Mekong delta, Vietnam
Environmental Research Letters
(Duration 2:50 minutes)

English Subtitles*: https://www.youtube.com/watch?v=cMr_BKzY4lU*

Phụ đề tiếng việt (Vietnamese subtitles)*:* https://www.youtube.com/watch?v=WaJVFabXSrY

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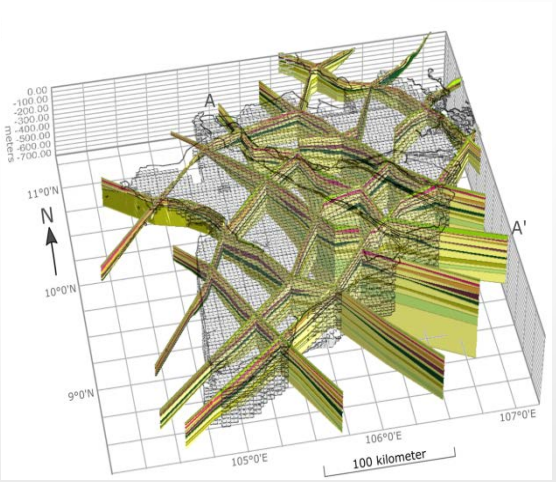
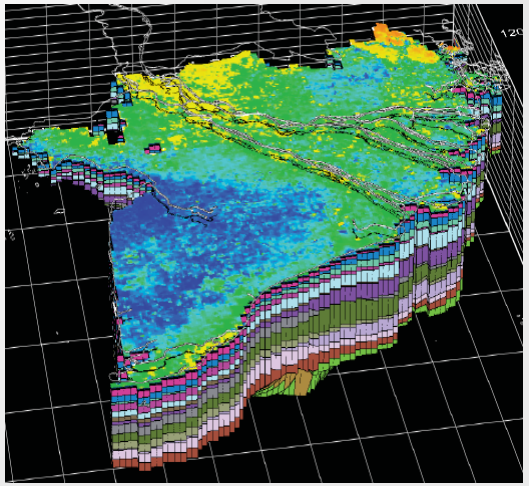
3D hydrogeological model with subsidence module

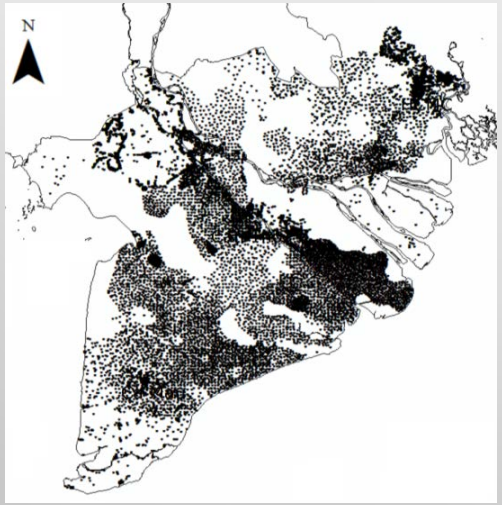
Input data



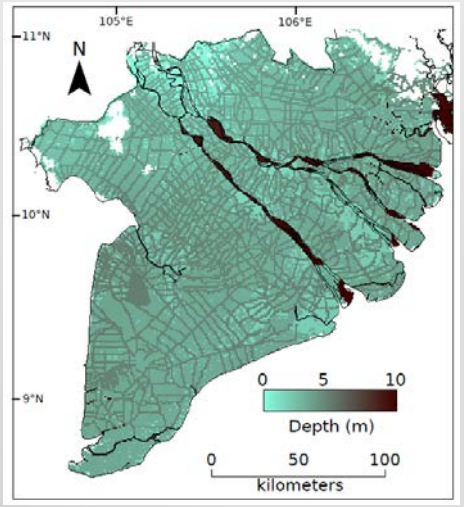
Geological borelogs and cross-sections



3D subsurface

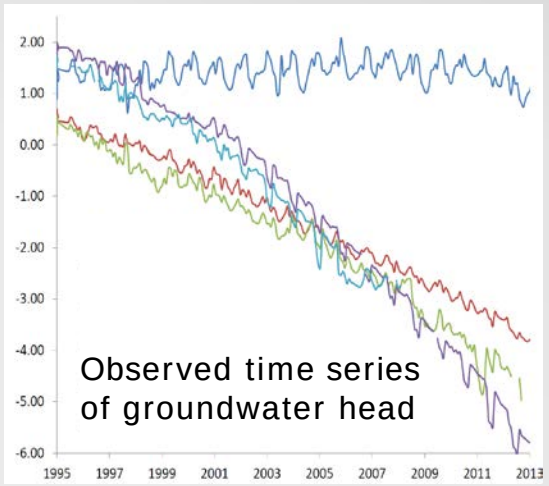


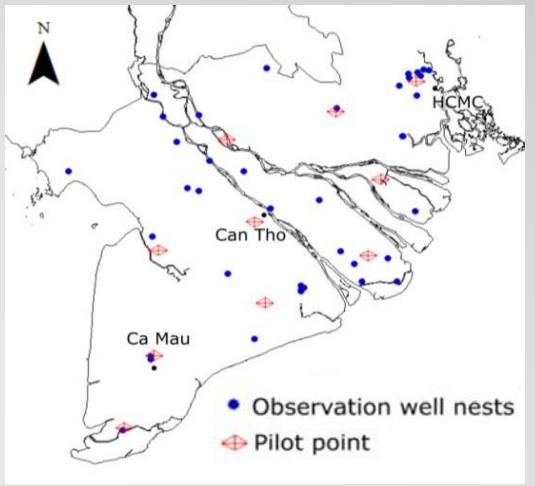
Location, depth & rate of groundwater extractions



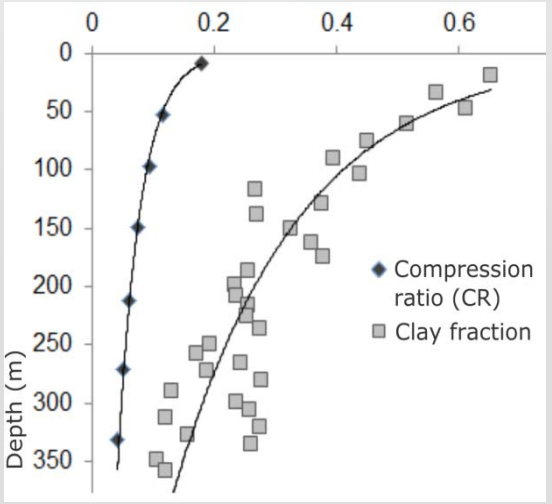
Surface water system

Hydrogeological calibration

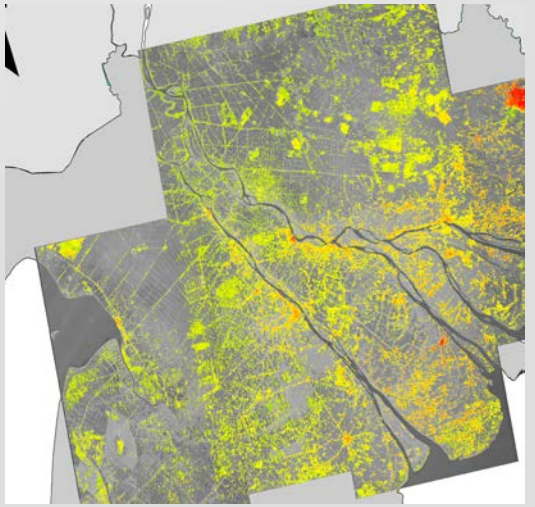




Subsidence module



Geotechnical parameters based on field data

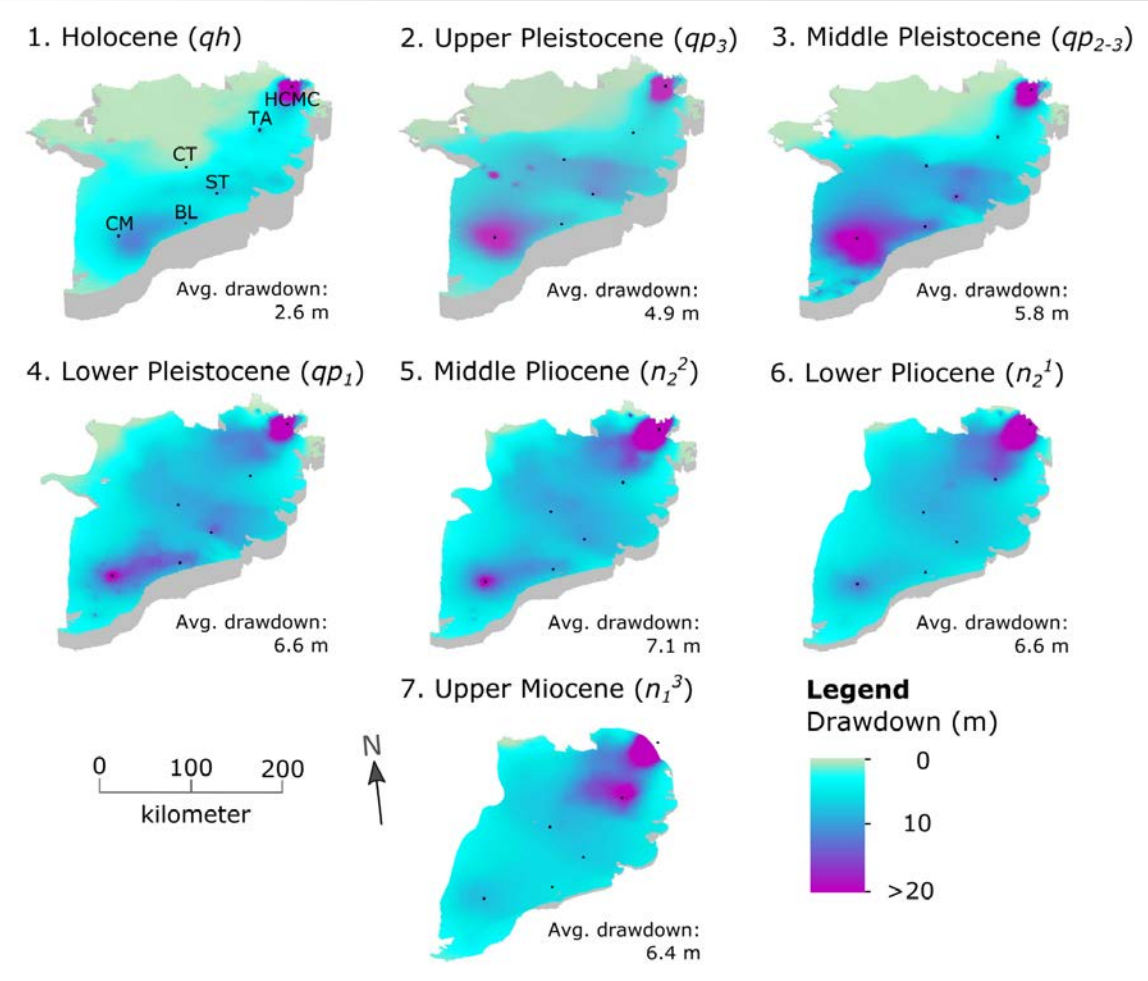


Validation: InSAR-derived subsidence (Erban et al., 2014)

Minderhoud et al., 2017 - Environmental Research Letters

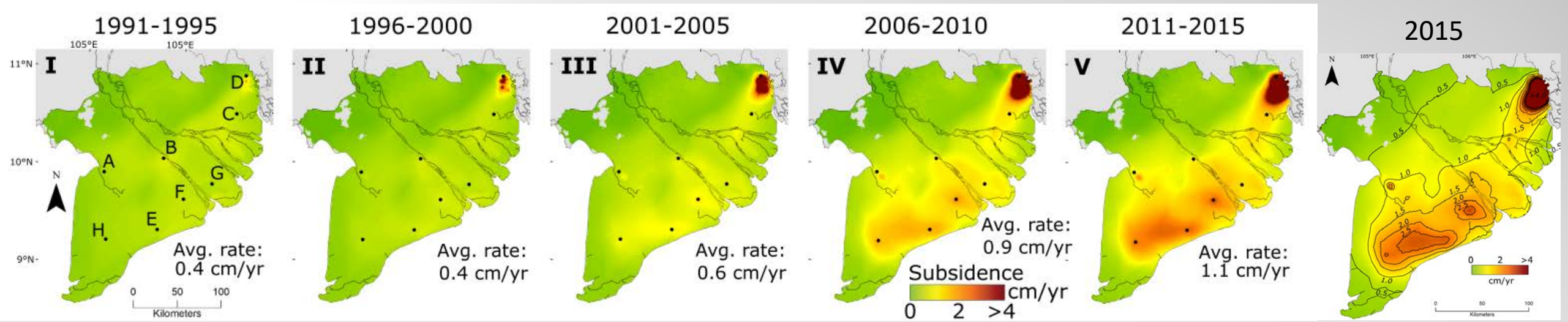
25 years of simulated groundwater extraction

Hydraulic head in the aquifers

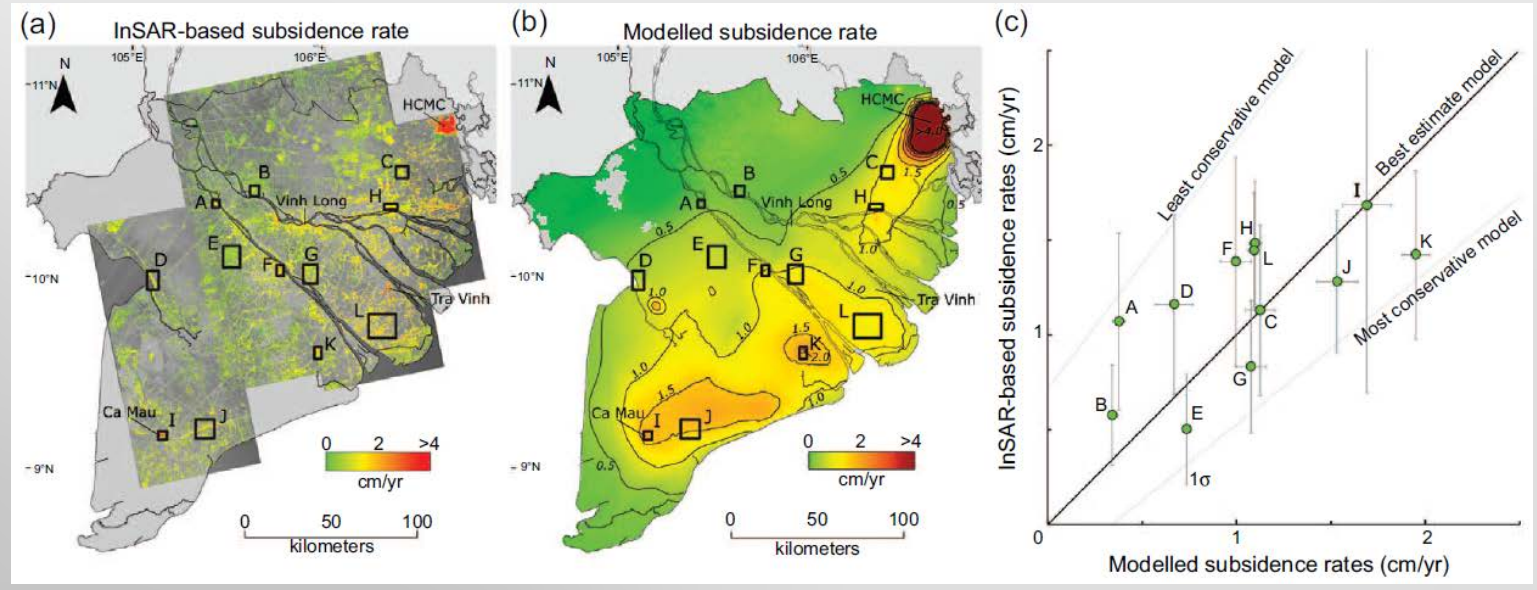


Groundwater extraction is much larger than groundwater recharge → overexploitation

Extraction-induced subsidence is accelerating!



Groundwater extraction-driven subsidence exceeds absolute sea-level rise by a magnitude!



Most/least conservative model: **60%/160%** of the best estimate model rates

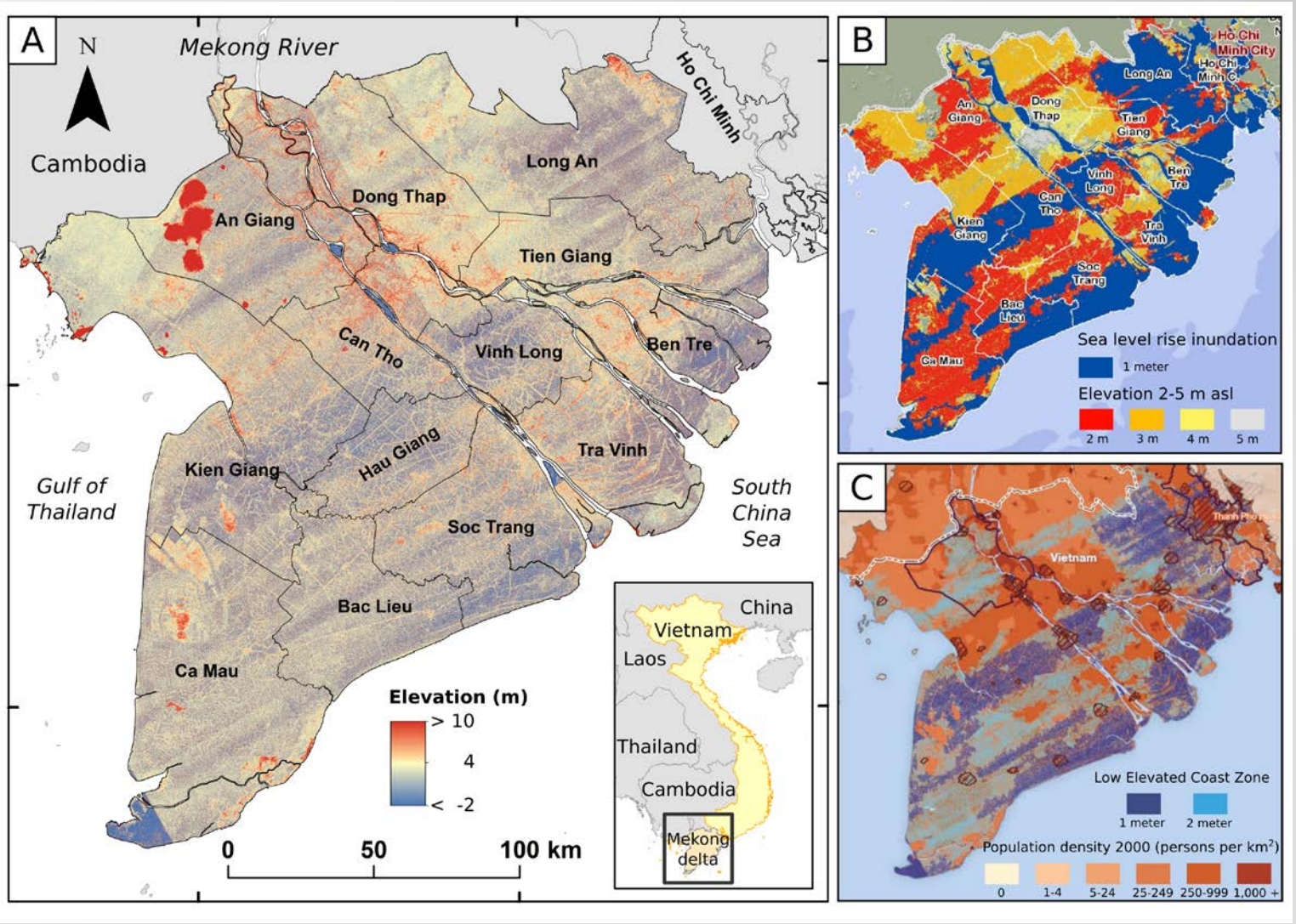
Sources of uncertainties in modeling results:

- Hydrogeology and geotechnical parameters
- Extraction data
- Geological schematization
- Layer discretization

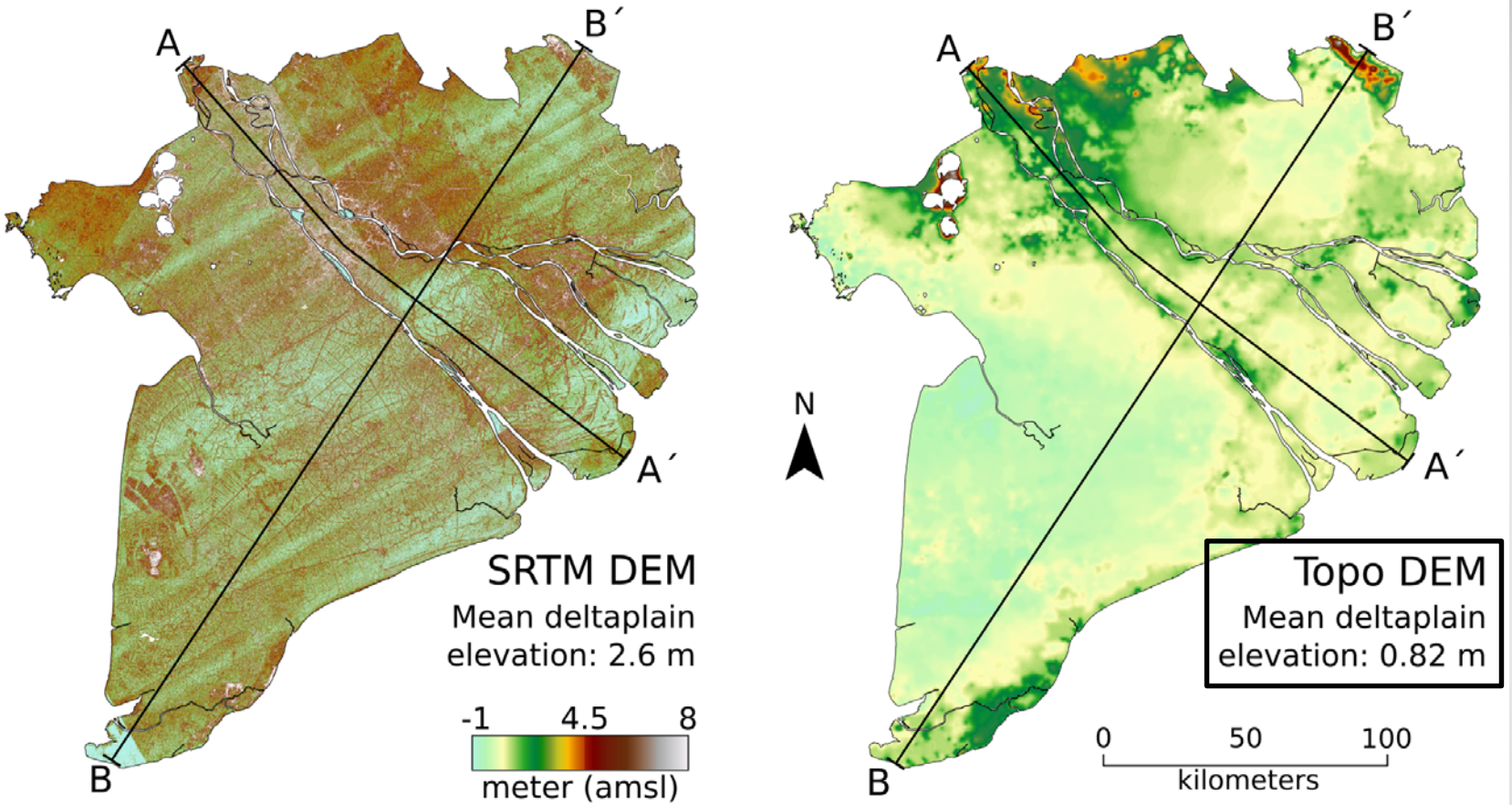
Rates may vary for each location, but the accelerating trend is clear!

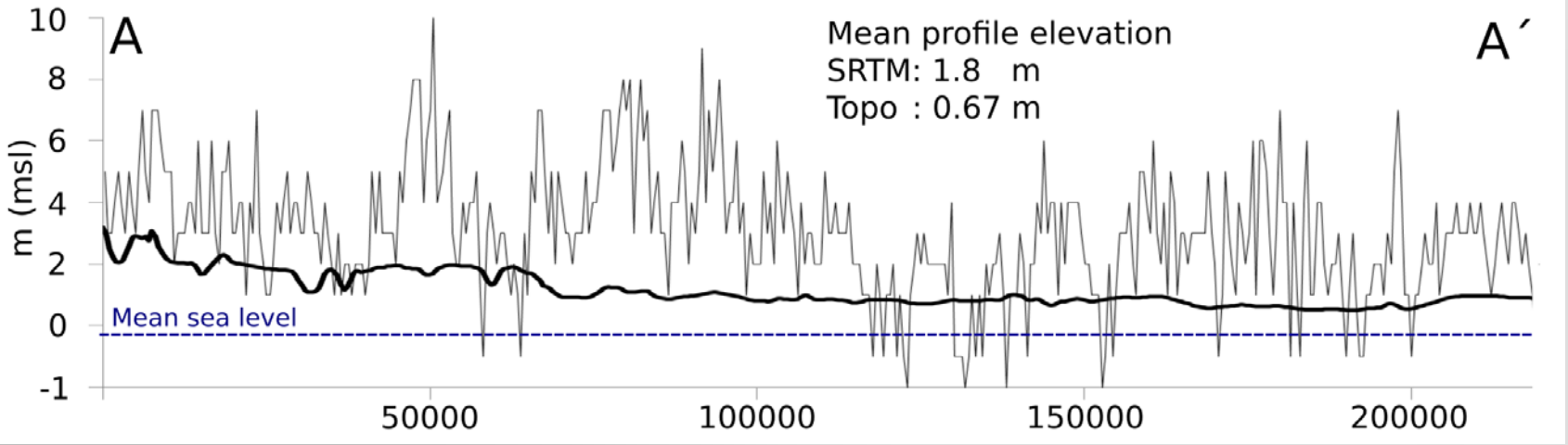
Minderhoud et al., 2017 - Environmental Research Letters

Impact of subsidence is relative: elevation is key!



A) SRTM Digital Elevation Model of the Mekong delta.
B&C) Two examples out of many previous sea-level rise impact assessments using SRTM elevation data and erroneously assuming zero elevation (EGM96 datum) as local sea-level.





Mekong delta much lower than internationally thought!

Reasons:

1) SRTM DEM absolute vertical accuracy for Eurasia: 6.2 meter.

2) SRTM referenced to global GEOID (EGM96) which turns out to have an unexpectedly large vertical offset with local tidal (*Hon Dau*) datum: ~1.5 meter!

Implications:

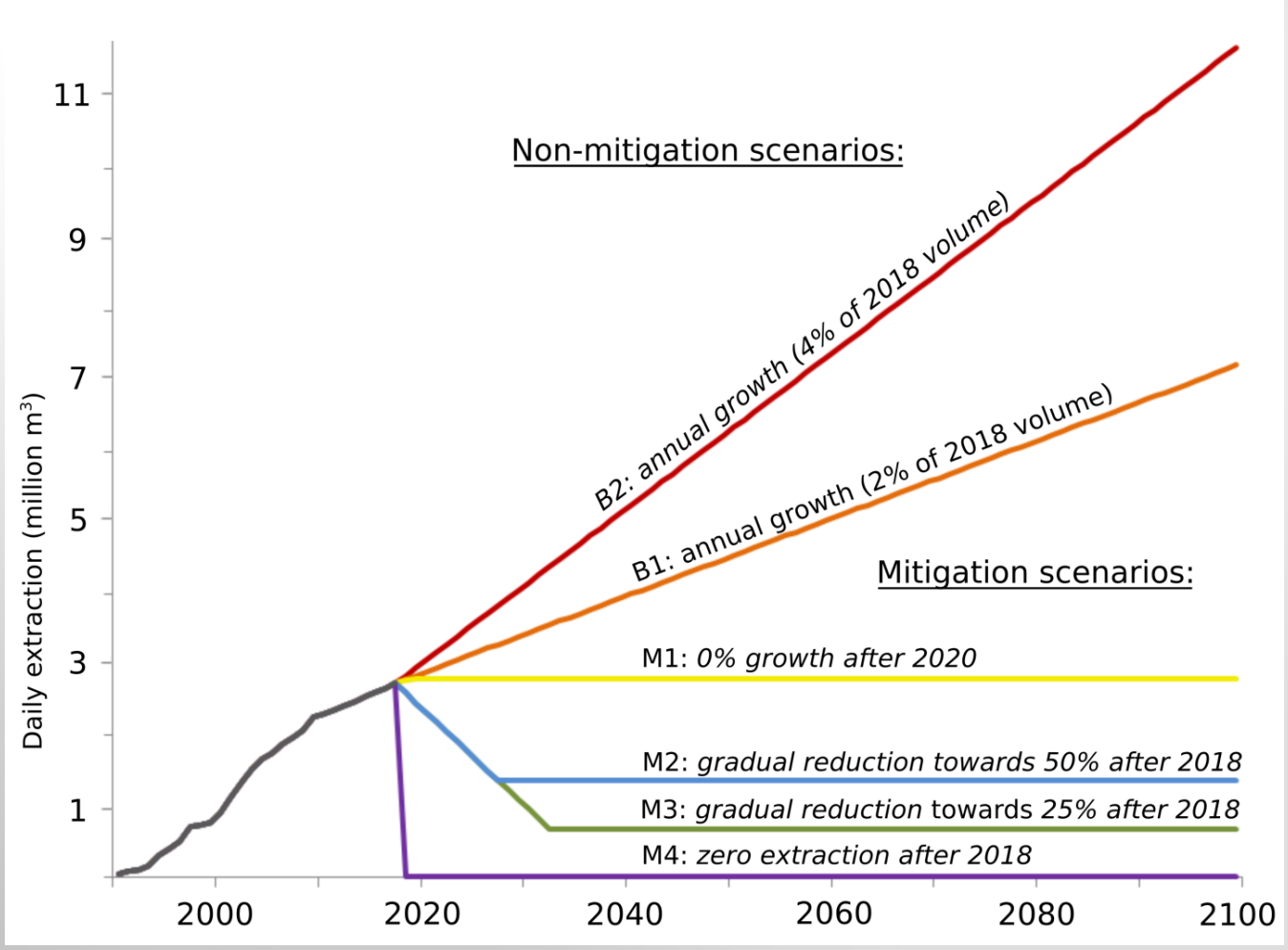
- Mekong delta is much lower elevated than international research studies assumed, so much more *vulnerably* to relative sea-level rise than previously thought

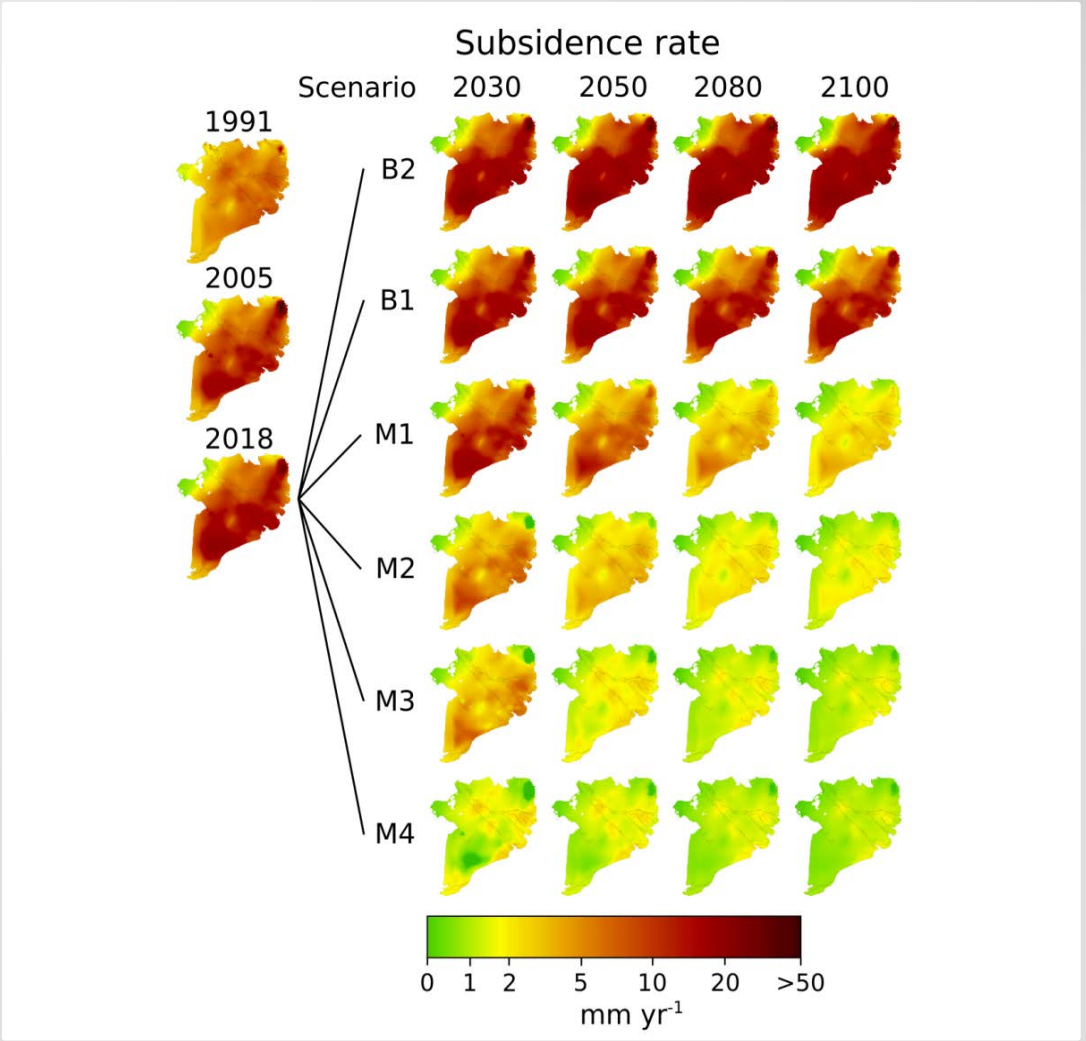
- Other deltas and coastal regions in the world potentially face similar underestimations!

Minderhoud et al., 2019 *Nature Communications*

The future of the Mekong delta: use pathways!

Modeling scenarios with different groundwater extraction pathways



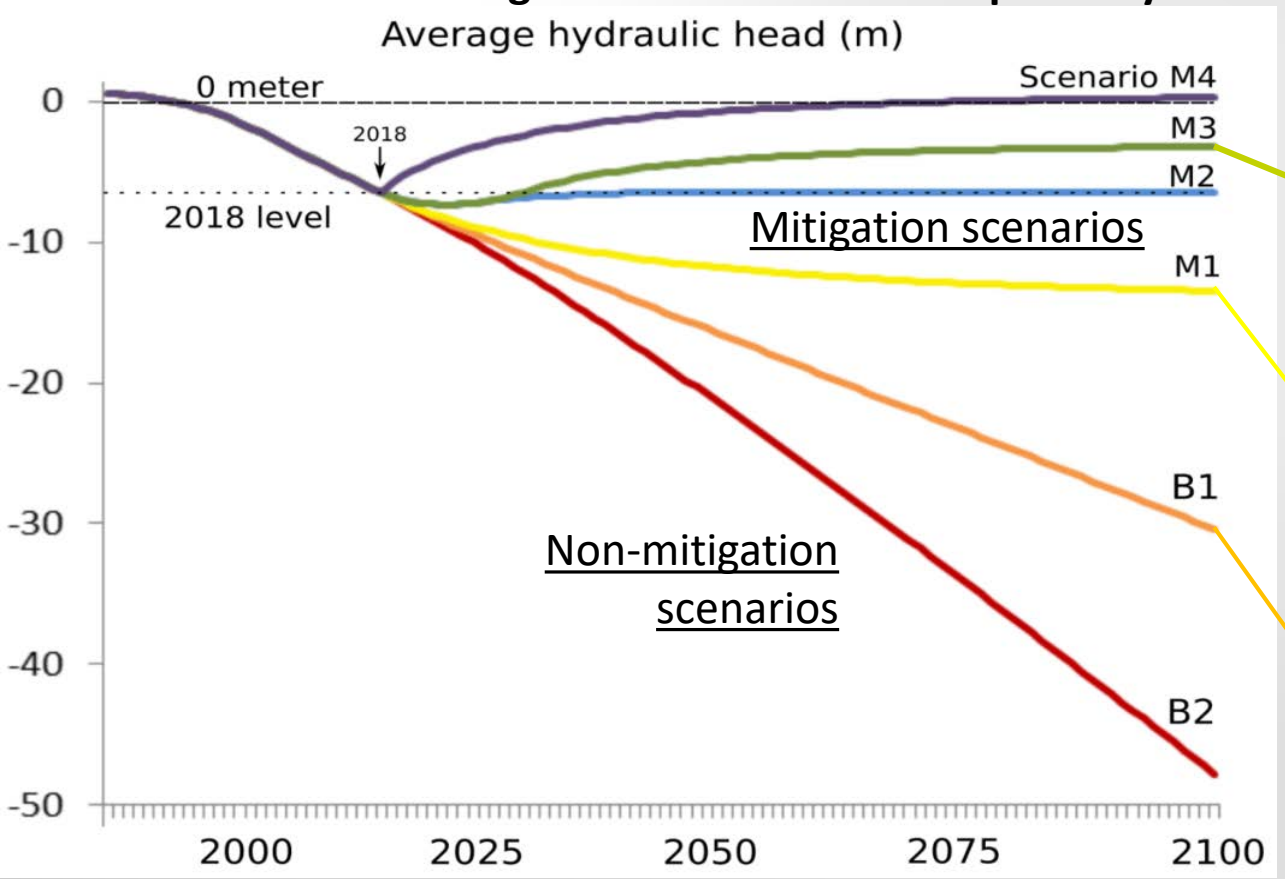


Minderhoud et al., 2020 Environmental Research Communications

The future of the Mekong delta: use pathways!

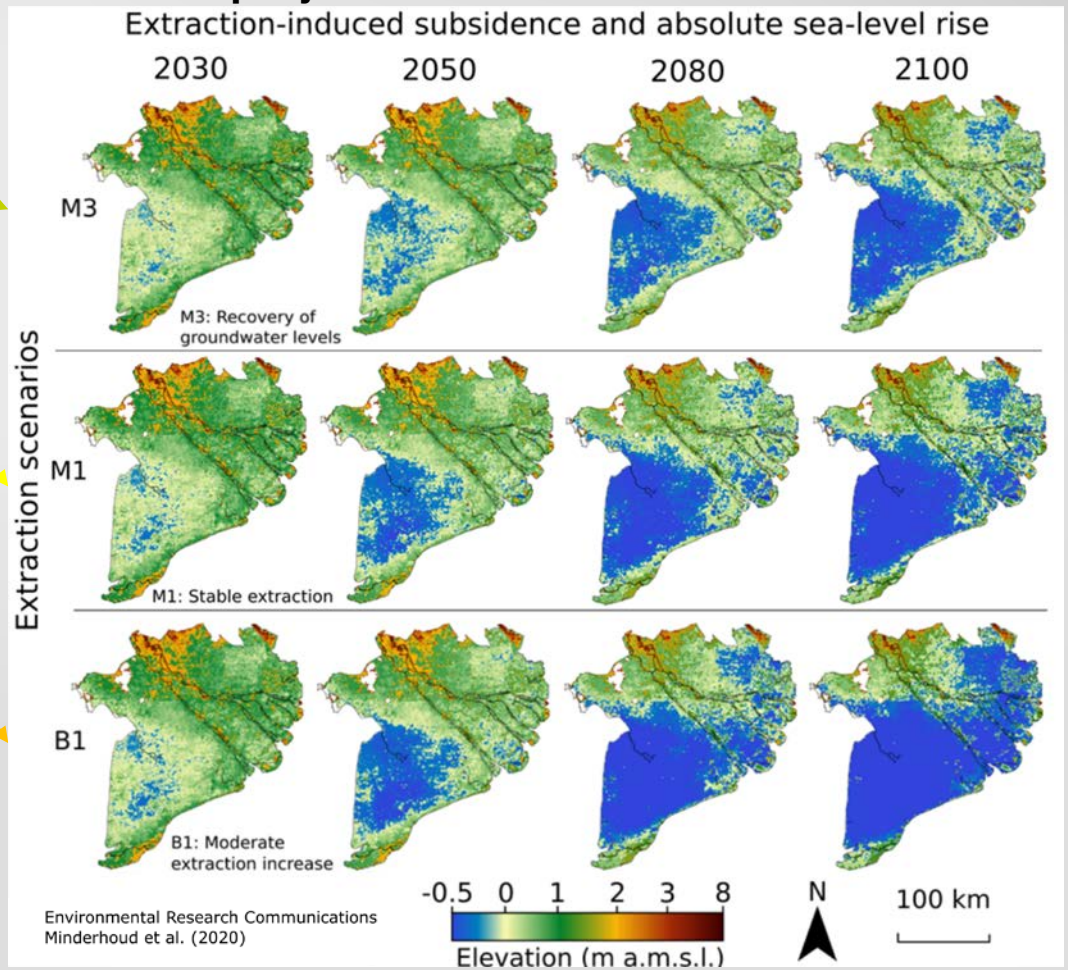
The decisions of today will determine the status of the delta tomorrow

Scenarios of future groundwater extraction pathways



- Without mitigation, **extraction-induced subsidence alone** may **sink** large parts of the delta by the end of the century
- **Groundwater** in the delta is **not** a **free** resource – it is **paid** for **by elevation. Elevation**, and thus **time**, **is running out!**

Future projected elevation of the delta



- *Elevation projections assume SLR according to RCP 4.5 projections.*
- *Elevation gain through sediment accumulation is assumed to counterbalance natural compaction*

Minderhoud et al., 2020 Environmental Research Communications

How to deal with subsidence in Vietnam

<u>Measure</u> in-situ land subsidence

- Install a subsidence observation network to monitor in-situ land subsidence

There are two strategies to deal with subsidence:

<u>Mitigate / Reduce</u> groundwater-extraction induced subsidence:

- Strongly reduce groundwater extraction – increase surface water use
- Short term, temporal solution: Change to 'smarter' extraction / artificial recharge (local solution)

<u>Adapt</u> to unavoidable subsidence caused by high natural compaction:

- Allow natural sedimentation as much as possible to elevate the land
- Build constructions with deep foundations

Protecting the entire Mekong delta with dyke systems will be impossible → Difficult policy decisions to prioritise what areas to protect with dykes and polders (irreversable situation).

<u>The hardest part is still to come</u>

Towards solutions

Adequate and inclusive (ground)water management is key!

- Create **awareness** of human-driven impacts on the environment – most of the impact comes from internal rather than external factors
- Use thorough understanding of the interconnected natural system to design **mitigation** (i.e. *reduce extraction of water and sand*) and **adaptation strategies** (i.e. *prepare for consequences of relative sea-level rise and erosion*)
- Adaptive pathways – inclusive water (and sediment) management

<u>Strategies for Vietnam:</u>

- Reduction extraction of water and sand
- Find alternative water sources – surface water
- Water saving practices and smart agriculture (water efficient crops, drip irrigation, salt resistant crops).
- Smart fresh water management – save excess fresh water during wet season for dry season – subsurface storage → grow fresh water lens)

Solutions are all possible with enough and thorough system knowledge -

→ No **'one solutions fits all**' – System understanding required!

References

Erban, L.E., Gorelick, S.M., Zebker, H.A., 2014. Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Vietnam. Environ. Res. Lett. 9. doi:10.1088/1748-9326/9/8/084010

Minderhoud, P. S. J, Middelkoop, H., Erkens, G., Stouthamer, E., 2020: Groundwater extraction may drown mega-delta: projections of extraction-induced subsidence and elevation of the Mekong delta for the 21th century, Environmental Research Communications, https://doi.org/10.1088/2515-7620/ab5e21

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