Predictive Modelling of Land Subsidence and its Impacts in The Netherlands

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Research problem & goal

- The economic and environmental costs associated with the land subsidence[8,14] and GHG emissions in the Netherlands[13] were recently recognized. Although costs are recognized, there is no comprehensive land subsidence adaptation/mitigation strategy in place.
- Research problem: Land subsidence and peat oxidation causes irreperable damage to the Dutch landscape, causing societal and economic harm. Without proper management, the negative impacts of land subsidence will further increase and the quality of life in the soft soil areas will decrease
- Research question: Can we evaluate the impact of specific mitigation and adaptation strategies against land subsidence in the Netherlands using 3D predictive modeling over a 100-year timeframe?
- Research goal: Assess the long-term impact of innovative mitigation and adaptation strategies on land subsidence and peat oxidation in the Netherlands through 3D predictive modeling. By the end of this study, we aim to provide valuable insights and recommendations for sustainable land management practices and policies that can help mitigate the adverse effects of subsidence in this vulnerable area.

Land subsidence: A complex problem

- Land subsidence is a natural process in deltas that can be overprinted and accelerated by anthropogenic activities (Figure 1). In addition to consolidation and creep, clays and organic rich peats tend to undergo additional processes such as shrinkage/swelling and oxidation based on clay-water interaction or peat-air interaction, respectively.
- Anthropogenically enhanced subsidence originates from human activities that increase the physical loading or change the local or regional hydrogeological state. Modification of the surface (land use/ land cover), the shallow water table (polders, drainage) and/or the subsurface (exploitation of natural resources: groundwater, salt, gas, hydrocarbons) determines the degree of anthropological subsidence.

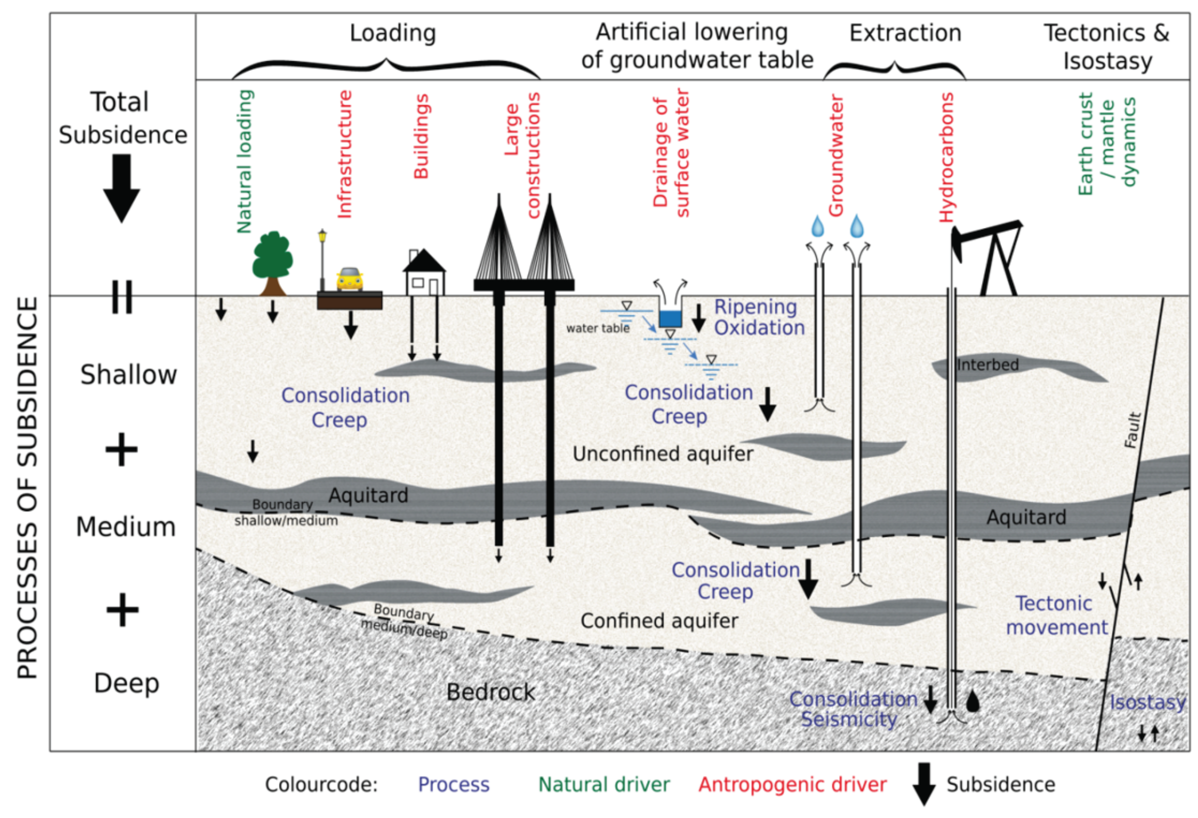


Figure 1: Subsidence processes and their drivers at shallow, medium, and deep horizons. (Minderhoud et al., 2015)

Can we predict the future subsidence?

Lets consider an example, several factors contribute to the global sea level rise e.g. melting of Antarctic and Greenland ice sheets, Mountain glaciers; thermal expansion of water due to warmer climate, contribution of land water.

IPCC[6] in their first asssesment report[7] in1990, with the understanding of the contributing factors to the sea level rise, predicted the sea level rise rates quite well as shown in figure 2. The predicted rates of sea level rise and the amount of sea level rise are both within the uncertainty ranges, and close to their best estimate.

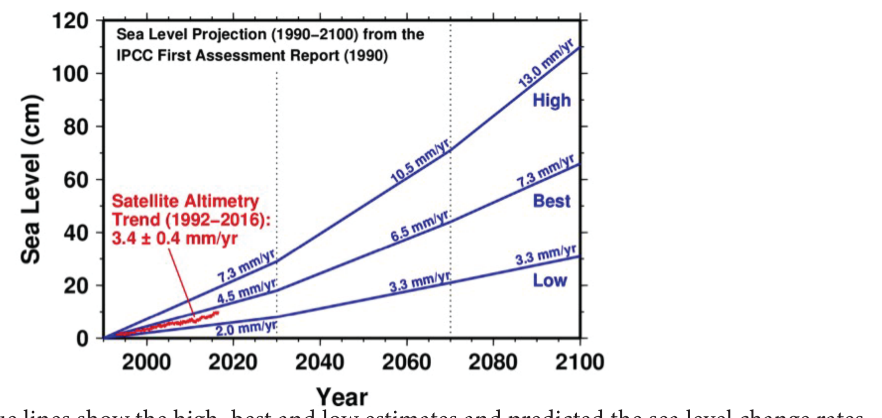


Figure 2: Blue lines show the high, best and low estimates and predicted the sea level change rates from the IPCC's first assessment report (1990), the red line shows the recorded sea level time series from the University of Colorado, which is based on satellite altimetry observations from 1992-2016. (Conrad, 2017)

A similar understanding of the contributing factors to land subsidence in the Netherlands can allow us to predict within an acceptable uncertainty range!

How do we put together data and process information to model and predict land subsidence in the Netherlands?

NWA-LOSS Program

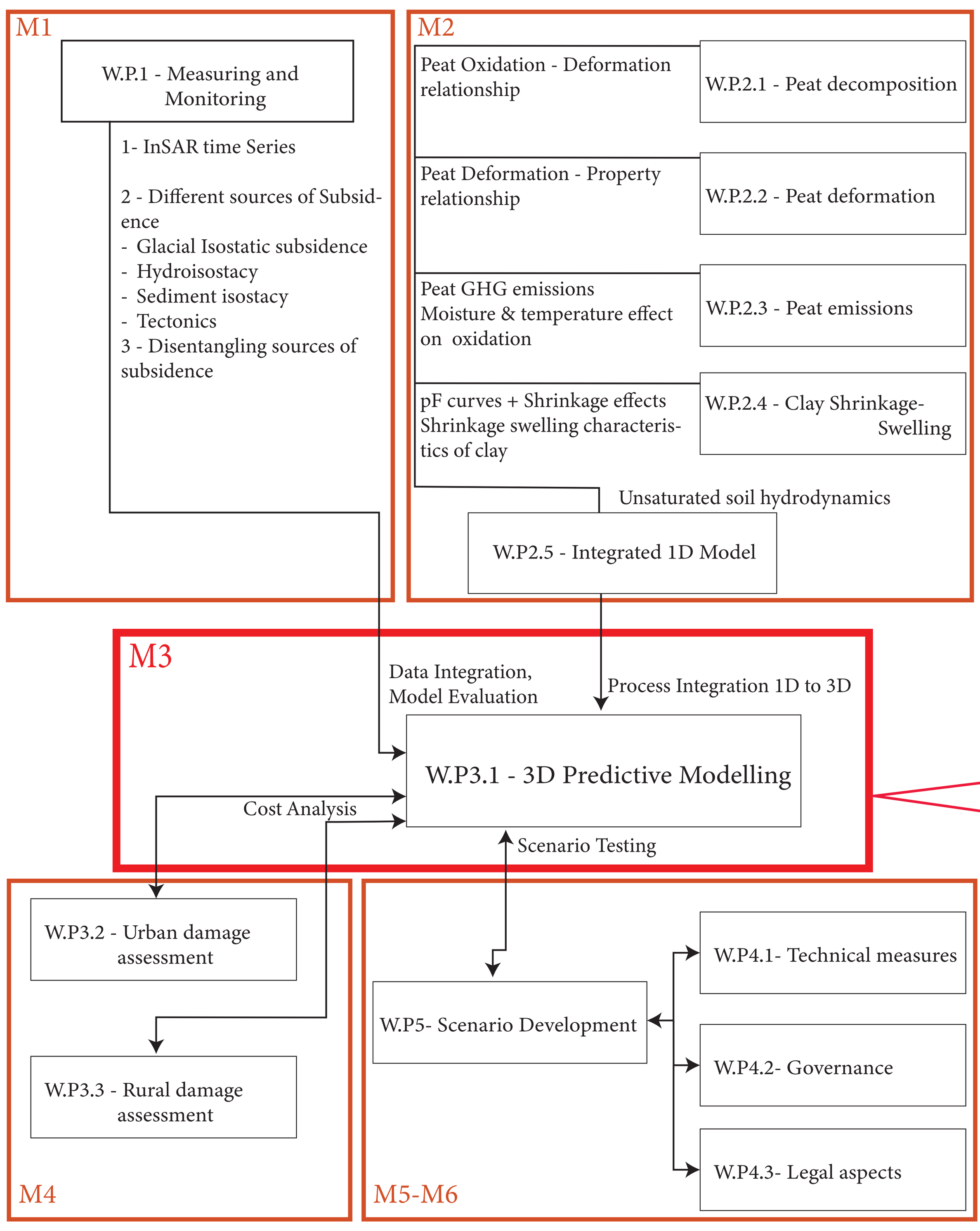


Figure 3: The NWA-LOSS program shown in a diagram. Arrows indicate the flow of data between work packages. Orange and red boxes indicate the link between the 6M approach (Erkens and Stouthamer, 2020) and NWA-LOSS work packages. Between M3 and M4, M3 and M5-M6, an information feedback loop exists.

Integrated Spatial Data/Modelling Framework (The Work Package 3.1 - M3)

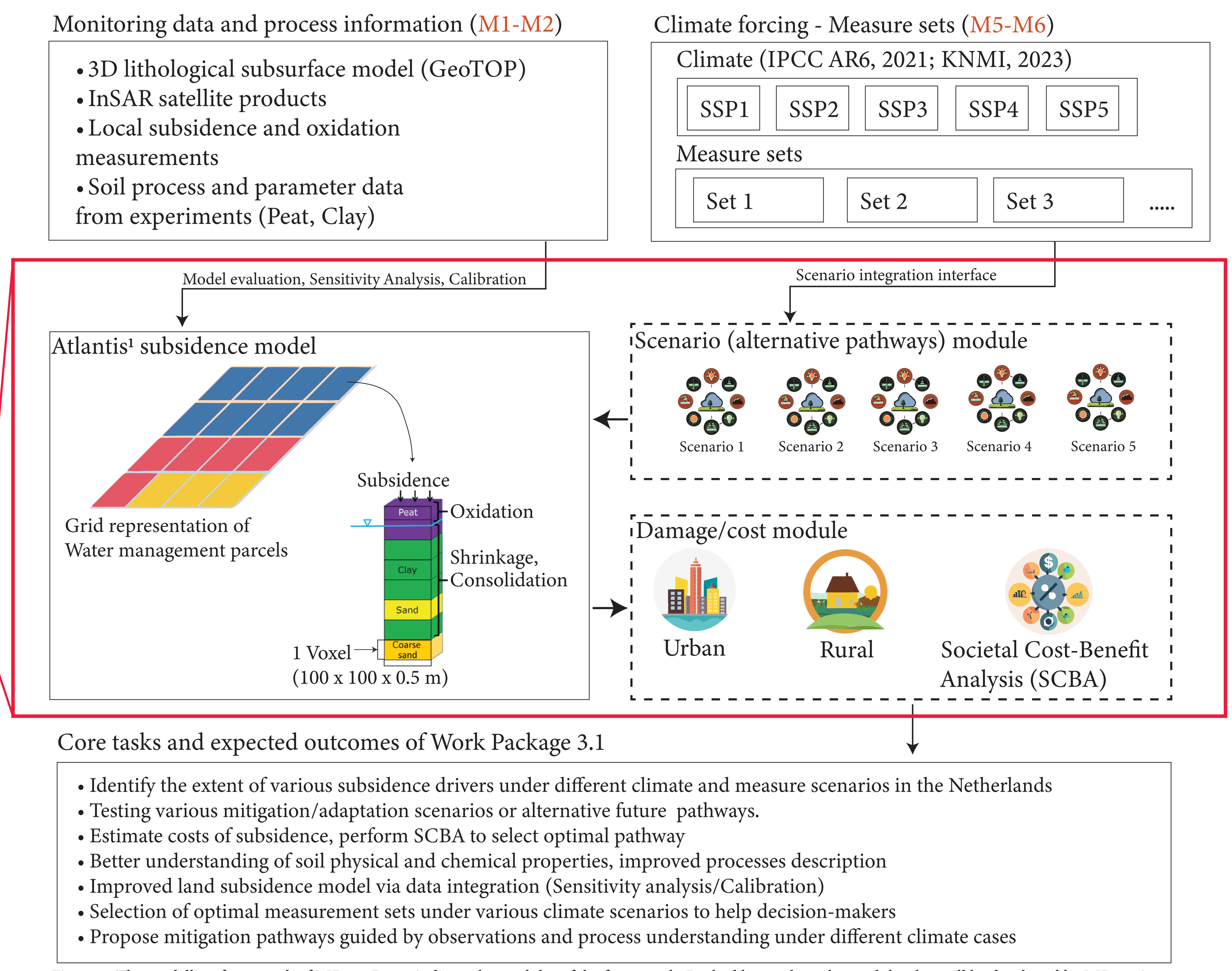
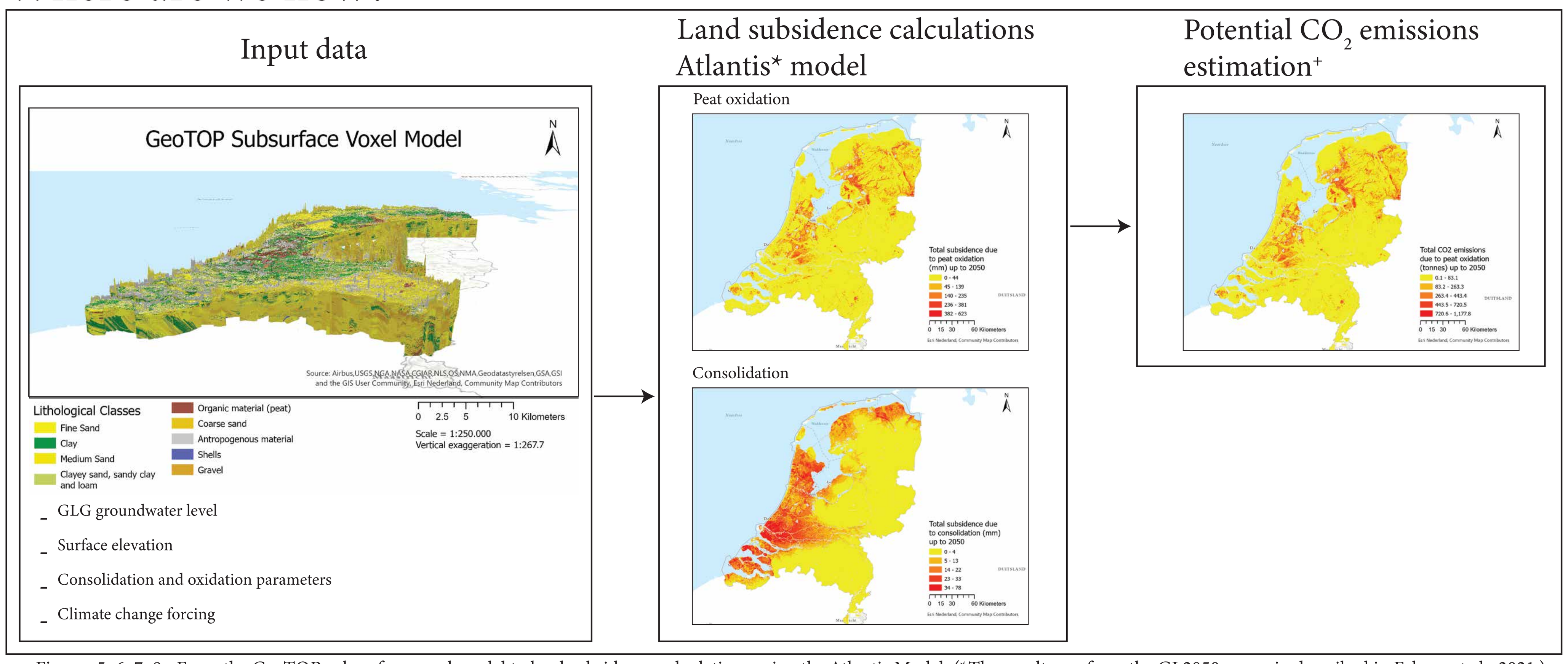


Figure 4: The modelling framework of W.P.3.1, Boxes indicate the modules of the framework. Dashed boxes show the modules that will be developed by W.P.3.1, including the model integrations. Arrows show the flow of the data in the modelling framework. The Atlantis model will be futher improved by sensitivity analysis-calibration work that will be carried out by W.P.3.1.

Where are we now?



Figures 5, 6, 7, 8: From the GeoTOP subsurface voxel model to land subsidence calculations using the Atlantis Model. (*The results are from the GL2050 scenario described in Erkens et al., 2021.) CO_2 emissions linked to the peat oxidation are now also calculated! (+CO2 emissions are calculated following Erkens et al., 2016 in the ArcGIS Pro environment)

What is coming in the near future?

- New processes: Clay shrinkage
- Model calibration by integrating observations into the model
  - Extensometer, satellite data
- New optimization scenarios to be tested
  - Minimum subsidence
  - Minimum emissions
  - Minimum damages
  - Governance driven land management
- Land subsidence related damage estimations, including rural, urban and GHG emissions related damages:

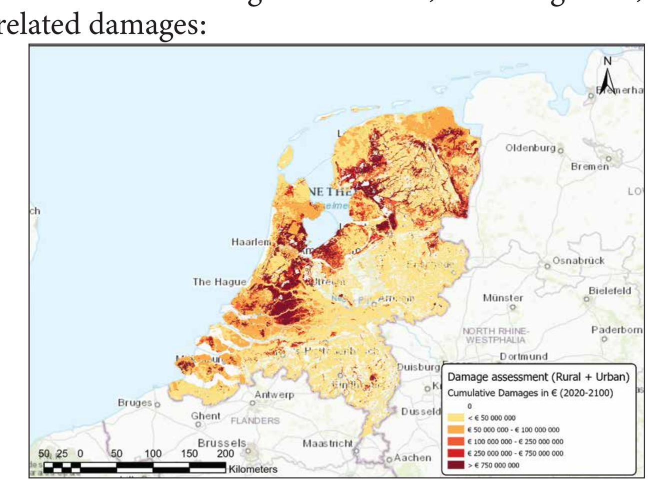


Figure 9: An example of the cumulative damage assessment in the period 2020-2100 (in EUR). The damage values are for demonstration purposes only, potential damages are not yet calculated.

References

1. Bootsma, H., Kooi, H., & Erkens, G. (2020). Atlantis, a tool for producing national predictive land subsidence maps of the Netherlands. Proceedings of the International Association of Hydrological Sciences, 382, 415-420.
2. Conrad, C. (2017), How good were the old forecasts of sea level rise. EGU Blogs. https://blogs.egu.eu/divisions/gd/2017/09/13/modern-day-sea-level-rise/ (Last accessed on 19-03-2024)
3. Erkens, G., & Stouthamer, E. (2020). The 6M approach to land subsidence. Proceedings of the International Association of Hydrological Sciences, 382, 733-740.
4. Erkens, G., H. Kooi, and R. Melman. "Actualisatie bodemdalingsvoorspellingskaarten." Deltares, Utrecht, Nederland (2021).
5. Erkens, G., Van der Meulen, M. J., & Middelkoop, H. (2016). Double trouble: subsidence and CO2 respiration due to 1,000 years of Dutch coastal peatlands cultivation. Hydrogeology Journal, 24(3), 551.
6. IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647.
7. IPCC, 1990: Climate Change, The IPCC Scientific Assessment. WMO/UNEP. Houghton, J.T. , Jenkins, G.J. , and Epthraums, J. J. (Eds.). Cambridge University Press (UK), pp355.
8. KNMI, 2023: KNMI'23 klimaatscenario's voor Nederland, KNMI, De Bilt, KNMI-Publicatie 23-03.
9. Kok, S., & Angelova, L. (2020). Impact droogte op funderingen (Technical 11205062–002; p. 35). Deltares.
10. Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., ... & Zhou, B. (2021). Climate change 2021: the physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change, 2.
11. 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 21st century. Environmental Research Communications, 2(1), 011005.
12. Minderhoud, P. S. J., Erkens, G., Pham, V. H., Vuong, B. T., & Stouthamer, E. (2015). Assessing the potential of the multi-aquifer subsurface of the Mekong Delta (Vietnam) for land subsidence due to groundwater extraction. Proceedings of the International Association of Hydrological Sciences, 372(372), 73-76.
13. Schouten, C. (2020, July 13). Letter to Parliament by the Dutch Minister of Agriculture on the Reduction of Greenhouse Gas Emissions From Peatlands (in Dutch). https://www.rijksoverheid.nl/documenten/publicaties/2020/07/13/verplicht-format-bijlage-onderbouwing-en-evaluatie-veenplan-1e-fase.
14. Van den Born, G. J., Kragt, F., Henkens, D., Rijken, B., Van Bemmel, B., Van der Sluis, S., ... & ten Brinke, W. B. M. (2016). Dalende bodems, stijgende kosten: mogelijke maatregelen tegen veenbodemdaling in het landelijk en stedelijk gebied: beleidsstudie.

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