Subsidence in the Mekong Delta

Quantifying groundwater extraction-induced subsidence in the Mekong delta, Vietnam
3D process-based numerical modeling

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Deltares Enabling Delta Life

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Introduction

Many major river deltas in the world are subsiding and consequently become increasingly vulnerable to flooding and storm surges, salinization and permanent inundation. For the Mekong Delta, annual subsidence rates up to several centimetres have been reported. Excessive groundwater extraction is suggested as main driver. As groundwater levels drop, subsidence is induced through aquifer compaction.

Over the past 25 years, groundwater exploitation has increased dramatically, transforming the delta from an almost undisturbed hydrogeological state to a situation with increasing aquifer depletion. Yet, the exact contribution of groundwater exploitation to subsidence has remained unknown. In this study we deployed a delta-wide modelling approach, comprising a 3D hydro-geological model with an integrated subsidence module.

Approach: 3D hydro-geological model with an integrated subsidence module

- **Subsurface model based on hydrogeological cross-sections and borehole logs (Fig. 1).**
- **Transient groundwater flow model (1991-2015) simulating groundwater extraction at monthly increments (Fig. 2&3).**
- **Recharge: measured time series of precipitation and evaporation.**
- **PEST model calibration using measured piezometric levels at 101 locations and 10 pilot points.**
- **Deltares Open-source modelling software: iMOD (Modflow-based).**

3D subsurface model

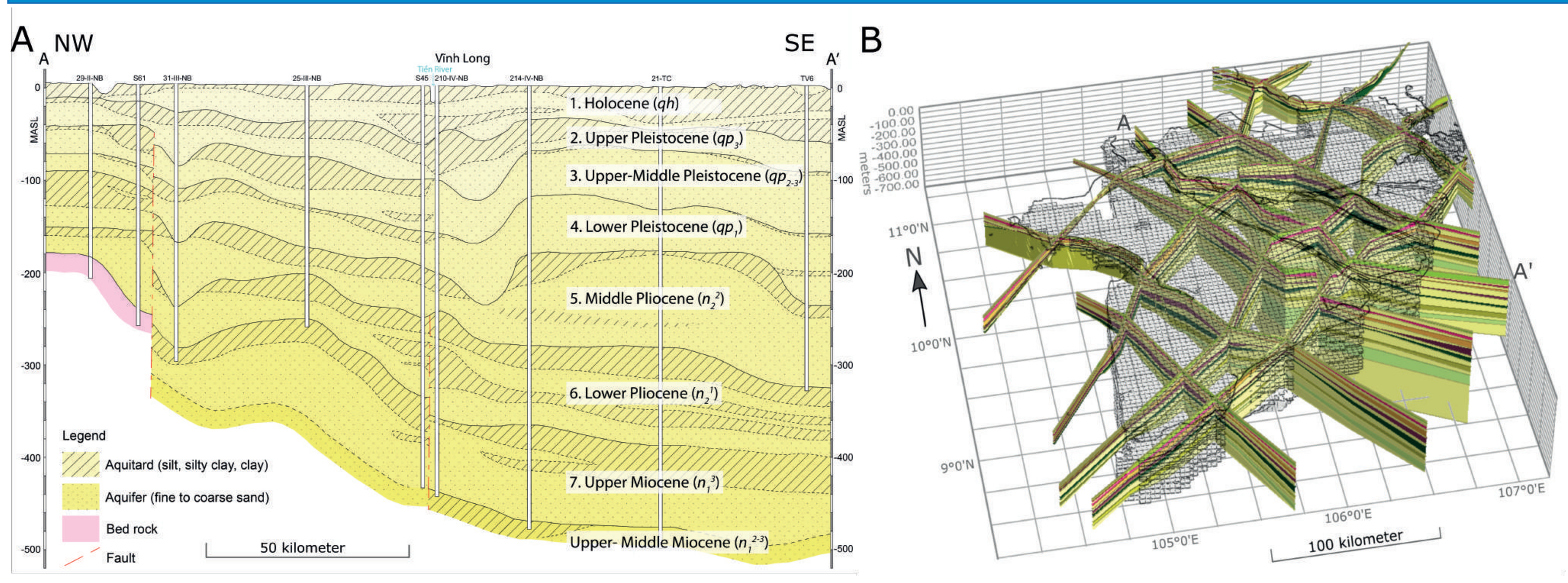


Figure 1. A) Hydrogeological cross-section with the interpretation of the deltas subsurface aquifer-system identifying the main units. Each unit consists of a permeable bottom layer (aquifer) and an occasionally discontinuous, confining top layer (aquitard). B) Ten hydrogeological cross-sections distinguishing aquifers and aquitards used to create the 3D subsurface model of the Mekong delta.

Groundwater extraction

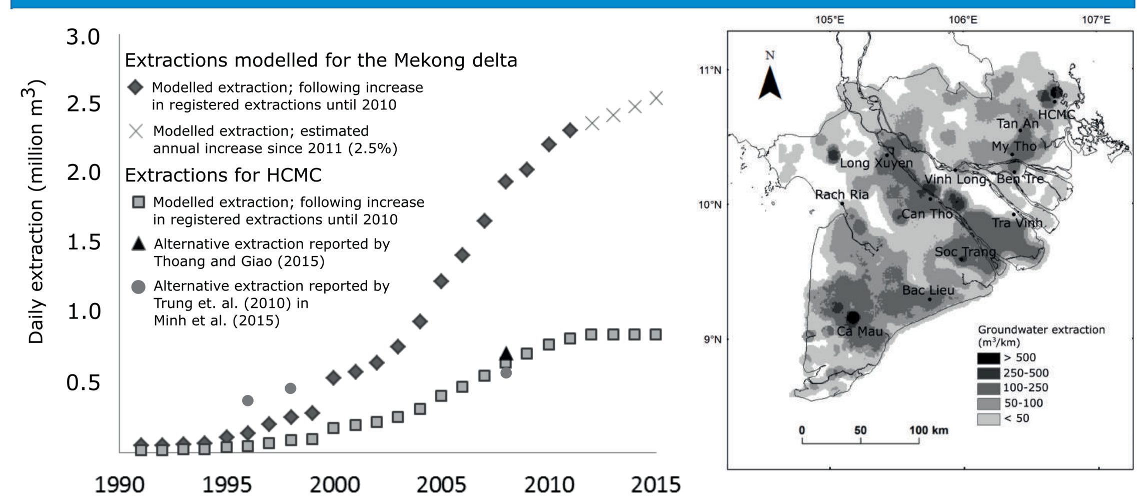


Figure 2. Annual modelled groundwater extraction and modelled extraction volume adopting a 5 km radius around a single well for 2015.

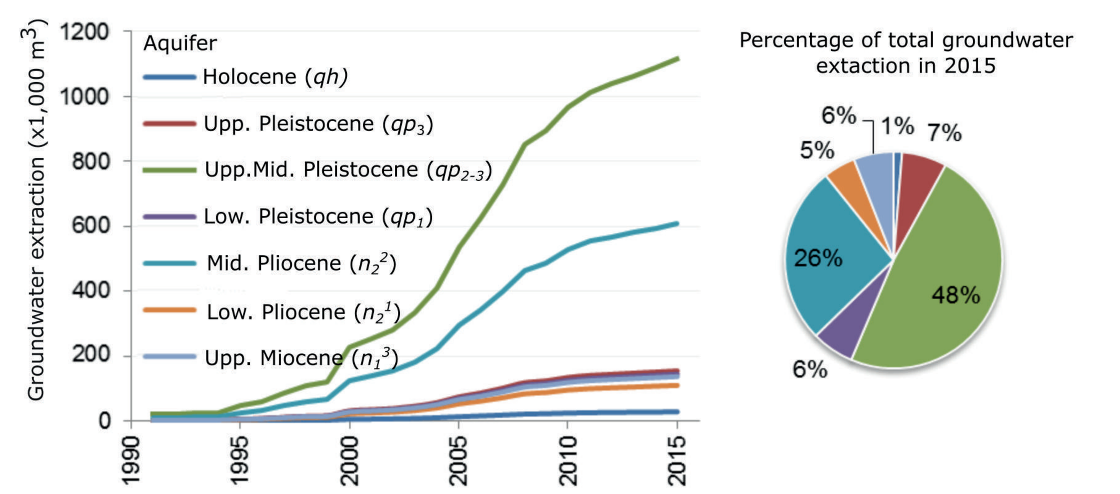


Figure 3. Extracted volume for each aquifer in the Mekong delta.

Hydrogeological model calibration

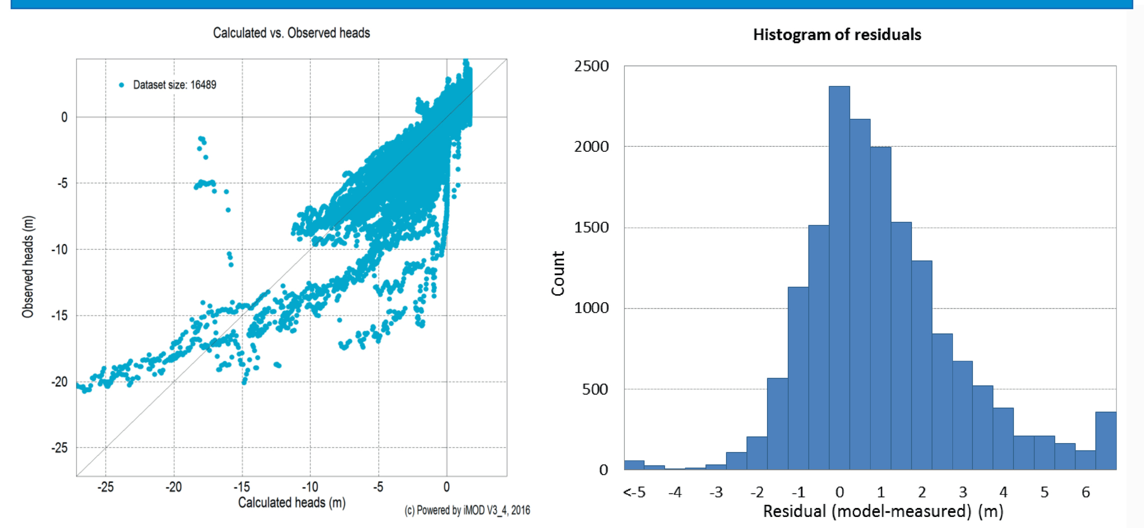


Figure 4. Left: monthly measured versus modelled hydraulic heads (r^2 = 0.73; median cross-correlation (r) = 0.94). Right: >75% of modelled head residuals within 2 meters of observed heads.

Subsidence calculation

1D consolidation through aquifer-system compaction following the hydraulic head decline (i.e. decreasing pressure) was calculated with SUB-CR, an elasto-visco-plastic module in iMOD, using the abc model based on the isotach concept including creep.

Results

Aquifer drawdown after 25 years

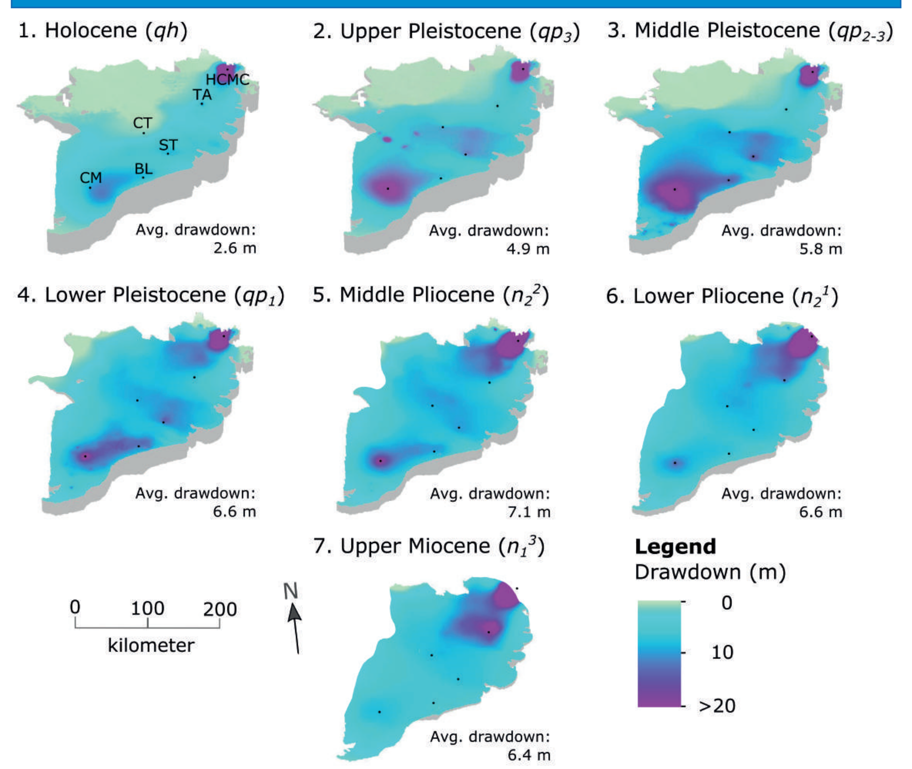
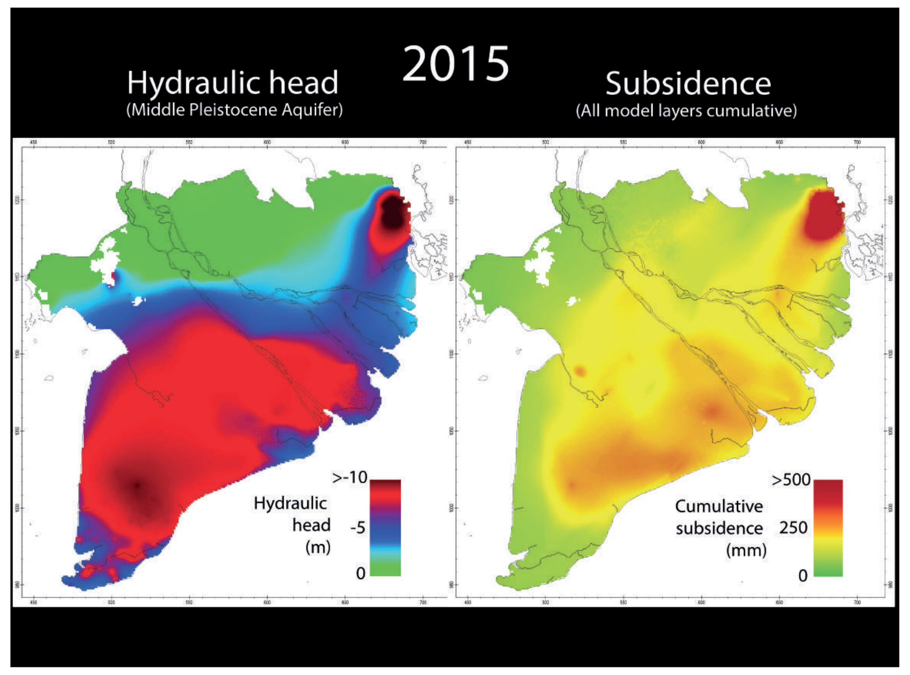


Figure 5. Modelled aquifer drawdown at the start of 2016 after 25 years of simulated groundwater extraction.

Impact of 25 years groundwater extraction



Groundwater extraction-induced subsidence

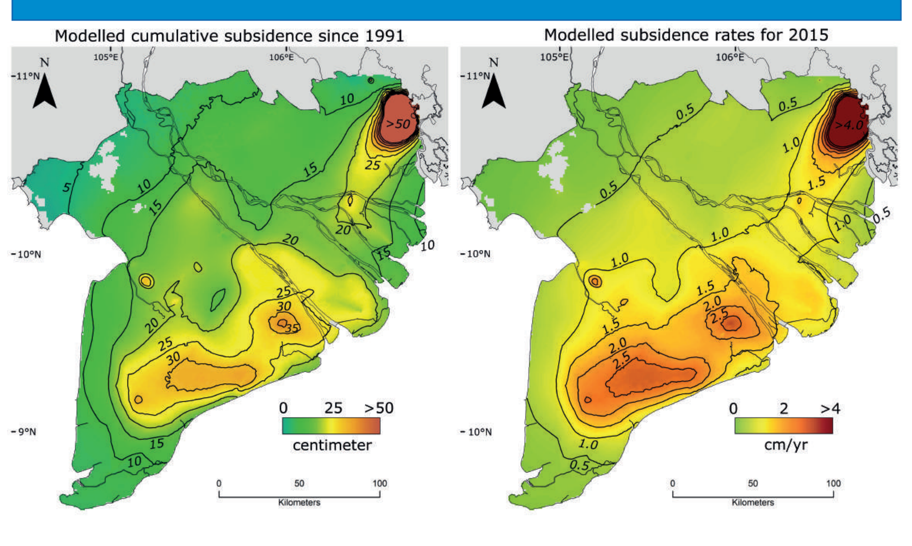
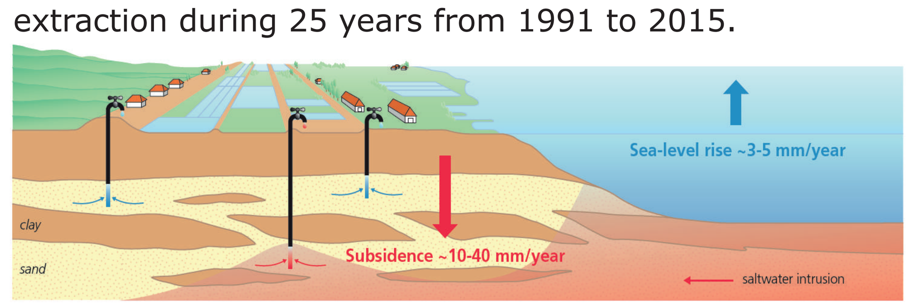


Figure 6. A) Modelled subsidence following groundwater extraction during 25 years from 1991 to 2015.



InSAR-measurements compared to modelled subsidence

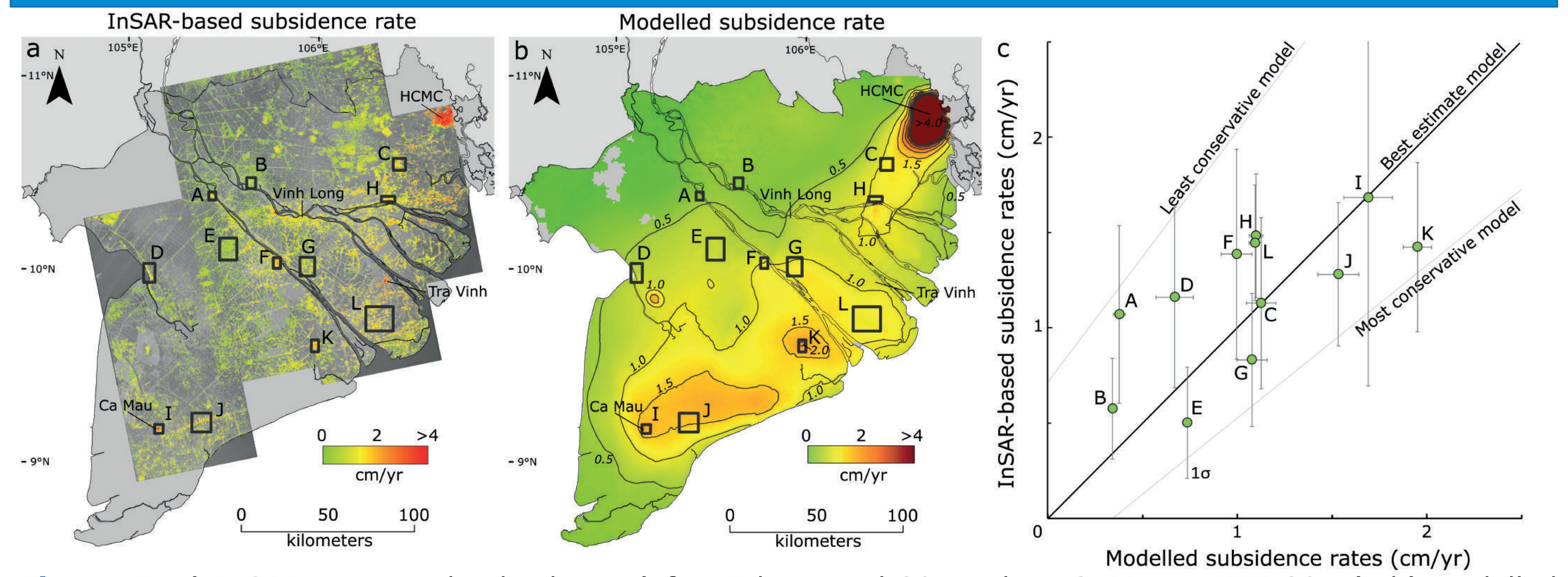


Figure 7. a) InSAR-measured subsidence (after Erban et al 2014, data © JAXA, METI 2011). b) Modelled subsidence of the best estimate model. c) Fit between modelled subsidence rates and InSAR measurements. Rates in annual averages between 2006-2010.

Impact of 25 years groundwater extraction

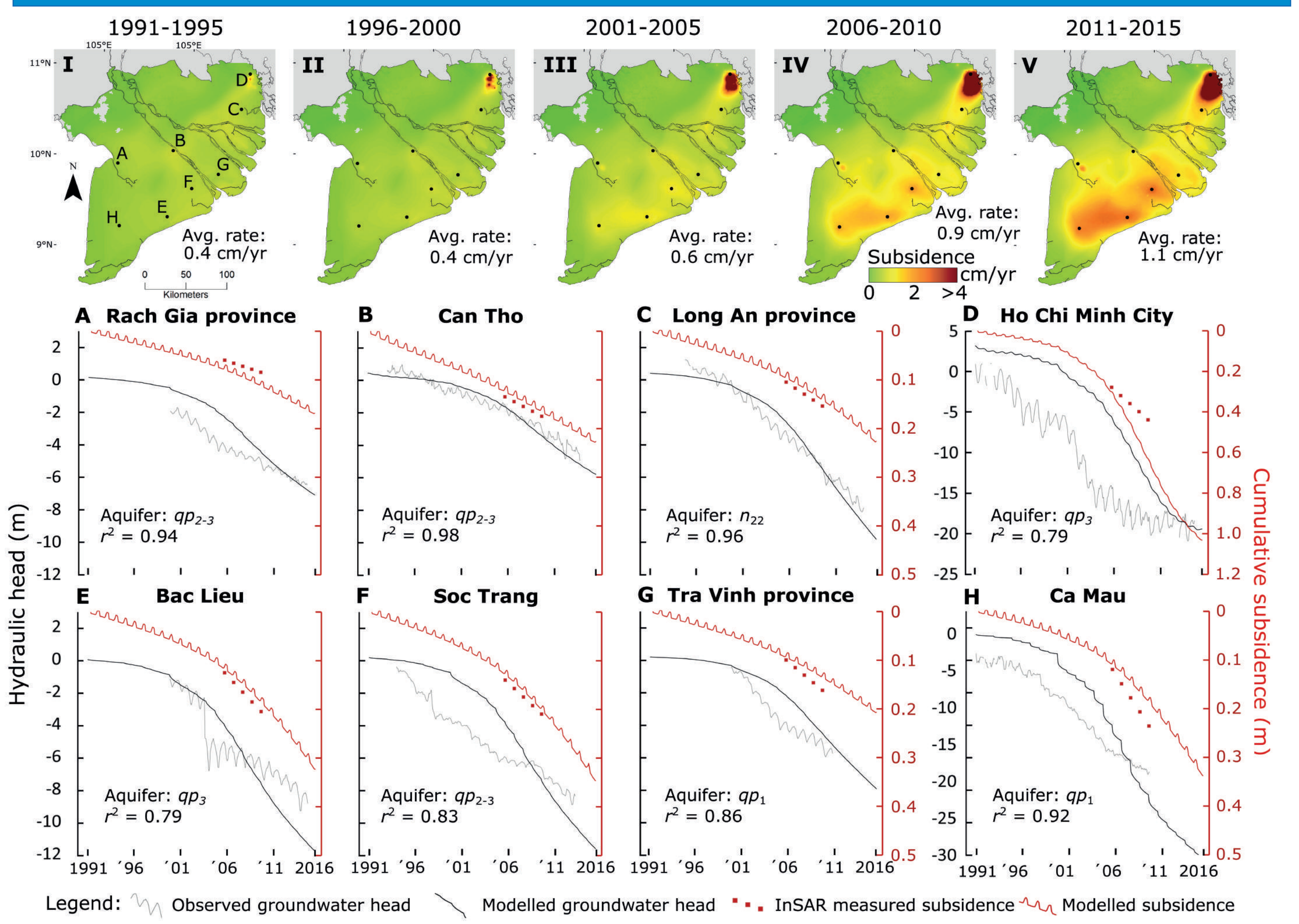


Figure 8. I-V) Annual groundwater extraction-induced subsidence rates for each five year period. A-H) Modelled and measured hydraulic head time series at monitoring well locations. Cumulative calculated subsidence in red. Red dots represent InSAR-measured subsidence.

Conclusions

- **The hydrogeological situation has changes drastically during the past 25 years; from almost undisturbed to the current state with increased aquifer depletion**
- **Groundwater extraction-induced subsidence started ~2 decades ago, with highest subsidence rates modeled at present**
- **Groundwater extraction is a dominant subsidence driver, but does not explain all InSAR-measured subsidence, leaving room for other subsidence drivers**

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References: Erban L. E., Gorelick S. M. and Zebker H. A. 2014. Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Vietnam. Environ. Res. Lett. 9

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