Unraveling the relation between land use and subsidence
A case study from the Mekong delta, Vietnam

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Introduction

The Vietnamese Mekong delta is subsiding due to a combination of natural and human-induced causes. Over the past several decades, large-scale anthropogenic land-use changes have taken place as a result of increased agricultural production, population growth and urbanization in the delta. Land-use changes can alter the hydrological system or increase loading of the delta surface, amplifying natural subsidence processes or creating new anthropogenic subsidence. We quantified subsidence rates for the various land-use classes and past land-use changes and evaluated the relationship strength between current land use, land-use history and subsidence by predicting subsidence rates during the measurement period solely based on land-use history.

Data and approach

We created a new consistent time series of land-use maps by classifying Landsat Thematic Mapper (TM) 5 images using object-based image analysis. The land-use maps were used to create the land-use history for the period 1988-2006. Combined with InSAR-based subsidence rate, the subsidence rate for each individual land use and land-use change trajectory was quantified. To assess the strength of the relationship between land use, land-use change and subsidence, we evaluated the ability to predict subsidence rates based solely on land-use history.

InSAR-based subsidence rate

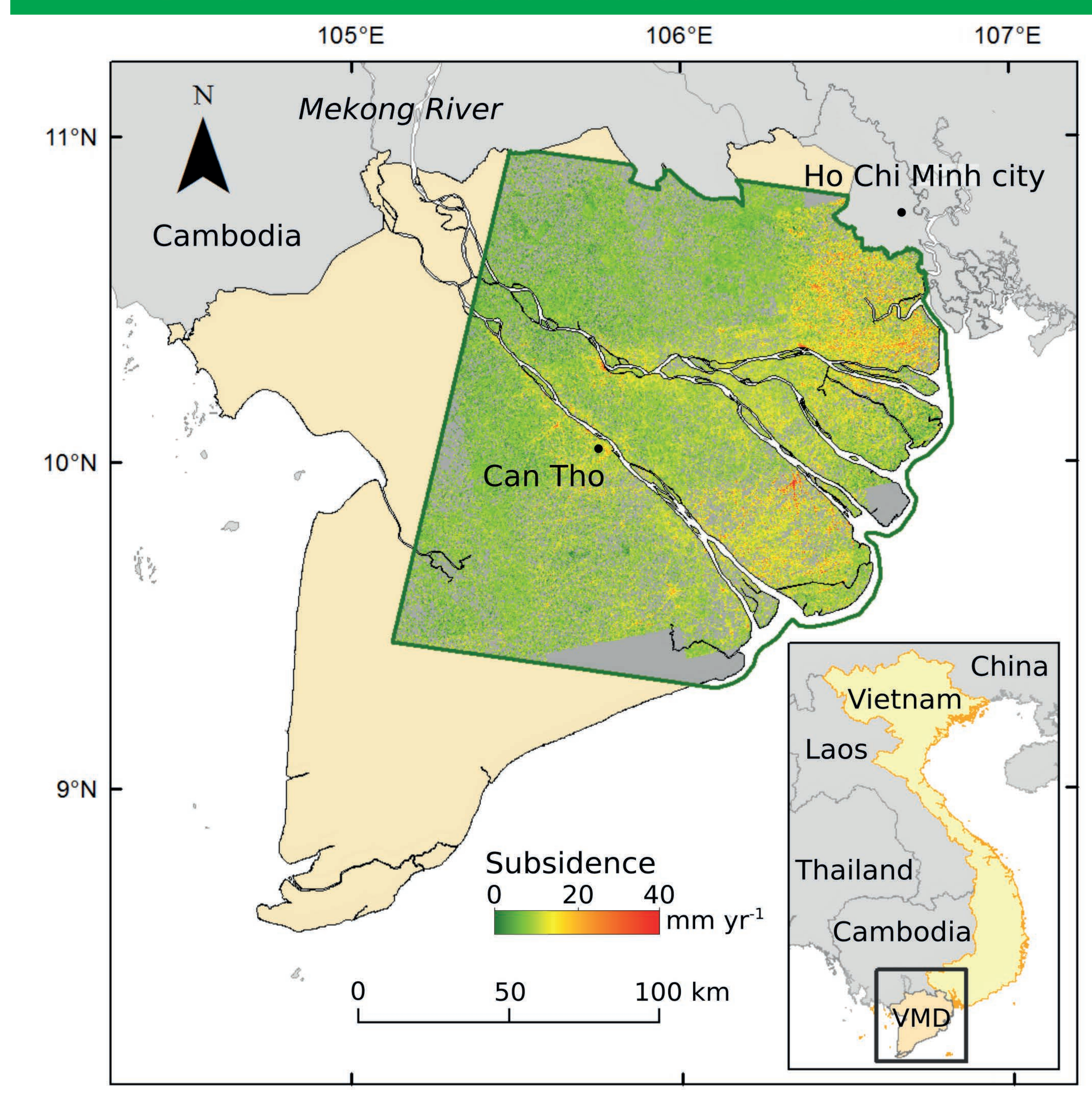

Figure 1. Study area with InSAR-derived subsidence rates (2006-2010 by Erban et al., 2014) in the Vietnamese Mekong delta (VMD) in Southeast Asia.

Land-use maps

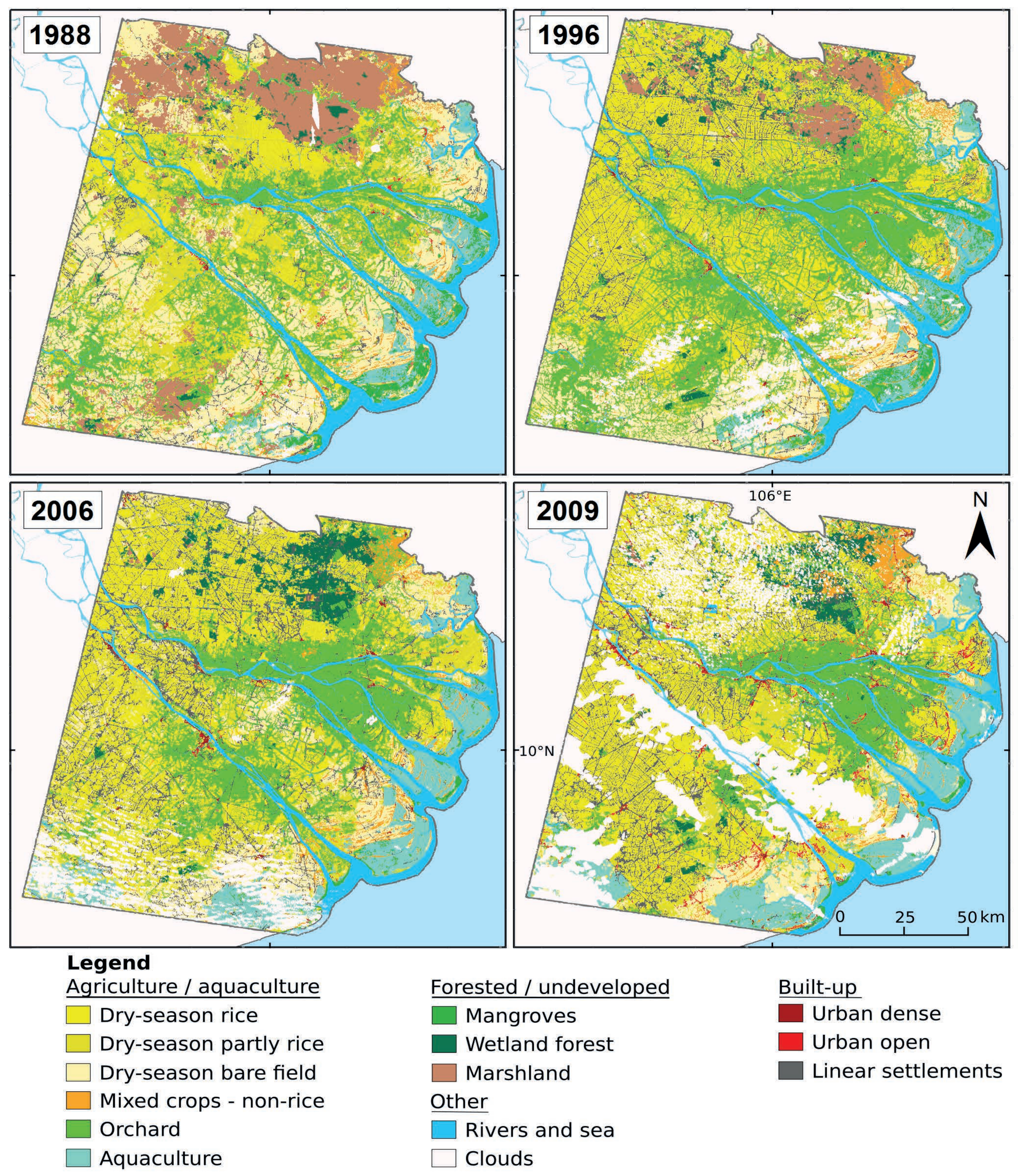

Figure 2. Land-use maps of the northeastern part of the Vietnamese Mekong delta derived from Landsat 5 TM imagery of 1988, 1996, 2006 and 2009.

Land-use change

Main land-use classes	Land-use maps 1988	1996	2006
Undeveloped	18	9	5
Rice	54	50	54
Other agriculture	21	32	23
Aquaculture	4	4	8
Urban	3	5	10

Table 1. Area in percentages of the main land-use classes in the land-use ,maps of 1988, 1996 and 2006. Colour from small (green) to large (red).

Subsidence rate per land-use type

Human-induced subsidence driver / *Effect*	Marsh-land	Wetland forest	Dry-season rice	Linear settlement	Aqua-culture	Mangro-ves	Dry-season bare field	Orchards	Mixed crops	Urban open	Urban dense
Surface water table drop *Enhanced shallow subsidence*			-	-	±		+	++	++	++	++
Groundwater extraction *Enhanced deeper subsidence*				±/+	+/++			±/+	+/++	++	++
Loading by buildings/roads *Enhanced subsidence*				+				-	-	++	++

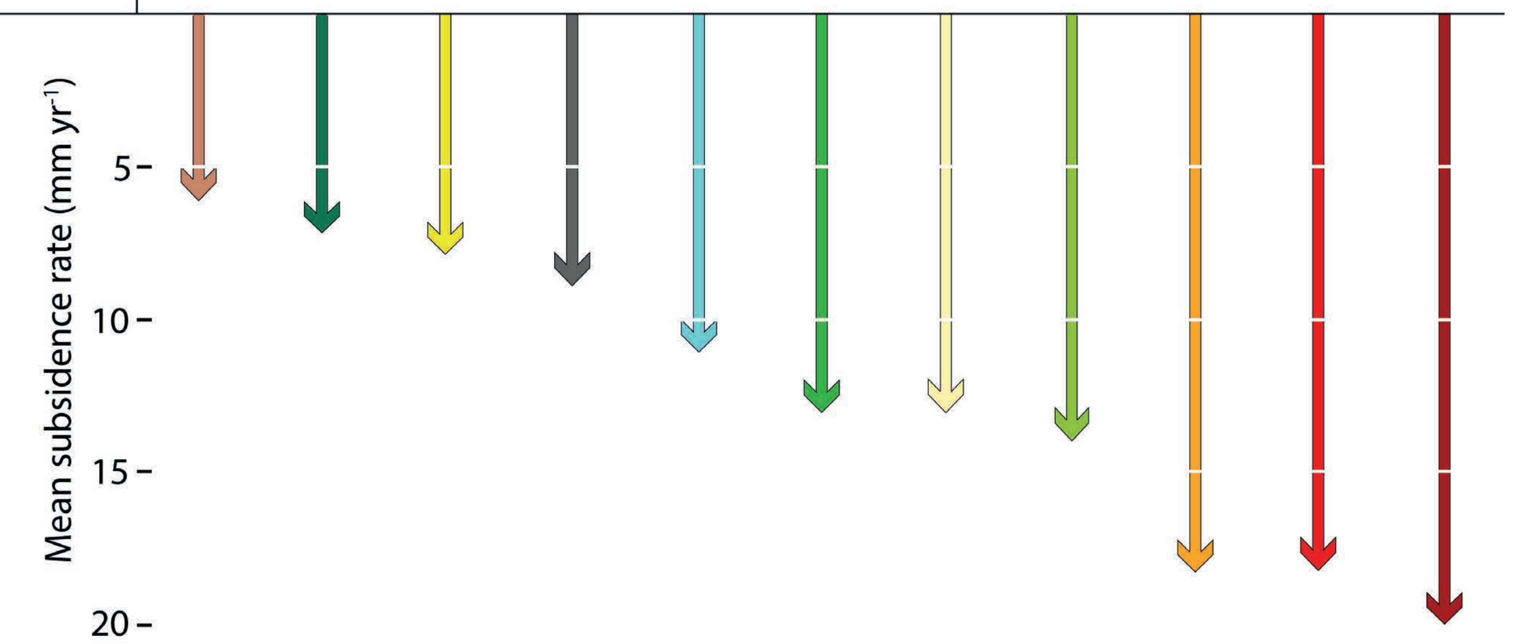

Figure 3. Estimated impact of subsidence drivers, and mean InSAR-based subsidence rate per land-use type (similar land-use class from 1988-2006). The estimated impact of each subsidence driver is ranked: minimal (-), low (±), moderate (+) and high (++).

The effect of land-use change on subsidence rate

Land use change: *Development*	Original land use *Land use 1*	Land use after change *Land use 2*	Subsidence rate (mm yr^{-1}): *Unchanged LU 1*	*Transition from LU 1 to LU 2* 1996-2006	1988-1996	*Unchanged LU 2*
Cultivating undeveloped land	Marshland	Dry-season rice	6	8	8	8
	Marshland	Linear settlement	6	8	8	9
	Marshland	Dry-season bare	6	9	10	13
	Marshland	Orchard	6	9	11	14
	Mangroves	Aquaculture	13	11	11	11
Changing agriculture	Dry-season bare	Dry-season rice	13	10	8	8
	Dry-season rice	Orchard	8	10	12	14
Urbanization	Dry-season rice	Urban dense	8	9	27	20
	Dry-season bare	Urban dense	13	16	23	20
	Orchard	Urban dense	14	16	20	20

Figure 4. Impact of past land-use (LU) changes on the subsidence rates in the Mekong delta. The mean subsidence rates (in mm yr^{-1}) for areas in which LU 1 and LU 2 was unchanged during the period 1988-2006 and for areas that experienced a transition from LU 1 to LU 2 between 1996-2006 and 1988-1996, respectively <10 and 10-18 years before the measurement period (2006-2010).

Conclusions

- Land use and land-use history have an indirect causal relationship with subsidence rates in the Mekong delta
- Different land-use classes are experiencing different rates of subsidence
- Highest subsidence rates were found for land-use classes in which the natural environmental conditions were most altered by human activities

Subsidence prediction

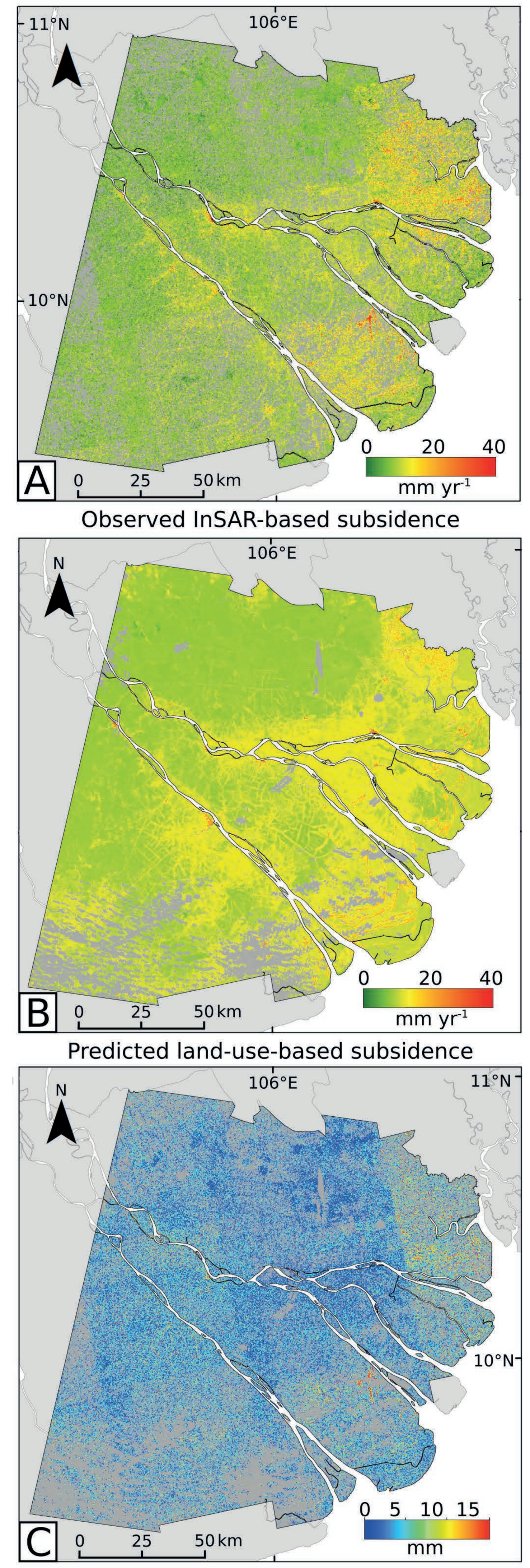

Figure 5. The predicted subsidence over the period 2006-2010 (B) is based on land-use history. 66% to 92% of the predictions fall the error range of the observed InSAR-based subsidence values (5 to 10 mm).

Acknowledgements
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References
Erban, L. E., Gorelick, S. M., & Zebker, H. A. (2014). Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Vietnam. Environmental Research Letters, 9(8), 1–6.

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