

The Evolution of the South-Eastern Baltic Sea Coastline Between 1988 and 2018 by Remote Sensing

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9th International Conference on Geographical Information Systems Theory, Applications and Management Prague (Czech Republic), 25-27 April 2023 Session: Machine Learning for Spatial Data



The Evolution of the South-Eastern Baltic Sea Coastline Between 1988 and 2018 by Remote Sensing

Prof. Dr. Sébastien Gadal, <u>Thomas Gloaguen</u> Aix-Marseille University, CNRS, UMR 7300 ESPACE Kaunas University of Technology









Background	Methods	Results	Discussions
Baltic Sea	Methods Research context • Analysis of coastal of HUANIA	Aynamics between 1988 and 2	2018.
Cape Taran Sambian Kaliningrad RUSS	SIA A World Cover Project, 2021		













Background	Methods	Results	Discussions

Increasing anthropisation of the south-eastern Baltic coastal zone

Background	Methods	Results	Discuss
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Increasing anthropisation of the south-eastern Baltic coastal zone

• Militarisation of the territory during Soviet period: control and limitation of movement and human occupation.



Example of former military infrastructure on the Latvian coast

Results

Discussions

Increasing anthropisation of the south-eastern Baltic coastal zone

- Militarisation of the territory during Soviet period: control and limitation • of movement and human occupation.
- Independence in the 1990s, associated with a rapid transition to a • liberal economic system.



Example of former military infrastructure on the Latvian coast

3

Example of former military infrastructure on the Latvian coast

Development of tourism issues in Palanga (Lithuania)

 Militarisation of the territory during Soviet period: control and limitation of movement and human occupation.

- Independence in the 1990s, associated with a rapid transition to a liberal economic system.
- Economic development combined with land artificialisation: increased human impact on the coast.

Increasing anthropisation of the south-eastern Baltic coastal zone





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Example of former military infrastructure on the Latvian coast

Economic development combined with land artificialisation: •

Natural characteristics and evolution factors of the coastline

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3





Development of tourism issues in Palanga (Lithuania)

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- of movement and human occupation.
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Natural characteristics and evolution factors of the coastline

Transgression and regression of the ancient Littorina Sea onto Pleistocene and Tertiary glacial deposits.



Discussions

Background

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Natural characteristics and evolution factors of the coastline

- Transgression and regression of the ancient Littorina Sea onto Pleistocene and Tertiary glacial deposits.
- Large sand and gravel beaches and dunes predominate on the coast.



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Coastal landscape of wide sandy beaches in Lithuania

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- Large sand and gravel beaches and dunes predominate on the coast.
- Morphodynamics factors: swells, longshore drift, tectonic movements, tidal movements, etc.
- The effects of climate variability will modify the current morphological processes.



Example of former military infrastructure on the Latvian coast



Development of tourism issues in Palanga (Lithuania)



Coastal landscape of wide sandy beaches in Lithuania

Background	Methods	Results	Discussions
Data acquisition			

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Data acquisition			

 Use of Landsat 4-5 TM and Landsat 8 OLI satellite images composed of spectral bands covering visible and infrared with a resolution of 30 m by 30 m + thermal with a resolution of 100 m by 100 m and 120 m by 120 m (resampled to 30 m by 30 m).

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• (1) By photointerpretation.

Spectral bands Blue, SWIR, Near-Infrared

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•	Spatial resolution of 30 m b use a wide range of electro	y 30 m sufficient for long-term cha magnetic measurements.	ange analysis + spectral resolution to	
•	Application of a cloud cover storm swells and ice cover.	threshold (25%) and a time wind	ow (May-June) to limit effects related to	
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Background	Methods	Results	Discussions

• (2) By transformation and enhancement of satellite images.

Background	Methods	Results	Discussions

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Spectral bands Visible, Infrared and Thermal

Results

2 methods of coastline extraction

• (2) By transformation and enhancement of satellite images.





Bac	kground

Results

2 methods of coastline extraction

• (2) By transformation and enhancement of satellite images.




Background	Methods	Results	Discussions
2 methods of coastline ext	raction		



Background	Methods	Results	Discussions



Background	Methods	Results	Discussions



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- Linear Regression Rate: the annual rate of change of the coastline position from a least-squares regression line.



Thieler et al., 2018

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- End Point Rate: ratio of net change to time difference of oldest and most recent measurements. Does not consider intermediate changes.
- Linear Regression Rate: the annual rate of change of the coastline position from a least-squares regression line.
- Weight Linear Regression: same principle but considering margins of error in the calculation.



Thieler et al., 2018

Background	Methods	Results	Discussions













- Between 1988 and 2018, the south-eastern Baltic coast is characterised by overall stability.
- A manual method more sensitive to margins of error.
- 30% of the coastline presents a significantly regular evolution trend in time and space, whatever the extraction method.
 - Non-significant differences between the two coastline extraction methods on both calculations with/without weighting.





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Background	Methods	Results	Discussions
An inter-period evolution we between accretion and ero	vith a regular alternation sion zones disturbed over ti		1988-1999
A trend of coastline retreat o "significant" erosion.	ver time for both methods but no	0 Automatic	0.26 m/yr
			Latvia
		6 B	1999-2009
		2 Automatic 0 -2 -2	-0.19 m/yr
		-4 Russia Lithuania	Latvia
		6	
		4	
		2 0 -2 -4 Russia Lithuania	-0.88 m/yr Latvia
		0 50 100 15	Distance from Cape Taran (km)

Background	Methods	Results	Discussions
An inter-period evolution w between accretion and eros	ith a regular alternation ion zones disturbed over time	6 4 (ree/ju) 2	1988-1999
 A trend of coastline retreat ov "significant" erosion. 	er time for both methods but no	0 under change of change of change of the second se	0.26 m/yr -0.12 m/yr
		-6 Russia I Lithuania	Latvia
			1999-2009
		2 4 4 4 4 4 4 4 4 4 4 4 4 4	-0.19 m/yr
		-6 Russia I Lithuania	Latvia
			2009-2018
		2 0 0 -2 -4 -6 0 50 100 150	-0.88 m/yr -0.71 m/yr Latvia 200 250 300 350 400
			Distance from Cape Taran (km)

Background	Methods	Results	Discussions
An inter-period evolution wi between accretion and eros	th a regular alternation ion zones disturbed over time		1988-1999
 A trend of coastline retreat ov "significant" erosion. 	er time for both methods but no	abury 0 contract of the second	and have been
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			1999-2009
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		-4 Russia Lithuania	Latvia
		-6 6 4 2 2 -4 -4 -4 -4 -4	2009-2018
		-6 Russia Lithuania	
		0 50 100 15	0 200 250 300 350 400 Distance from Cape Taran (km)

Background	Methods	Results	Discussions
An inter-period evolution w between accretion and eros	vith a regular alternation sion zones disturbed over ti	me (resolution of the second s	1988-1999
 A trend of coastline retreat or "significant" erosion. 	ver time for both methods but no	-2 -2 -2 -2 -2 -2 -2 -2 -2 -2 -2 -2 -2 -	and man frank
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Background	Methods	Results	Discussions
An inter-period evolution w between accretion and eros	ith a regular alternation sion zones disturbed over tim		1988-1999
 A trend of coastline retreat ov "significant" erosion. 	ver time for both methods but no	Automatic	and a survey of the
Some alternation of eroding a 1988-1999 for both methods.	and accreting areas for the period	-4 -4 -4 Russia -6 -4 Lithuania	Latvia
 Increasing erosion for the ma variations in Russia and Lithu 	nual method with significant ania.	6 4 (rea/u) object to optimize the second	1999-2009
		(rev(u)) object to be starting of the starting	2009-2018 2009-2018 4 200 200 200 250 300 350 400 Wistance from Cape Taran (km)

Background	Methods	Results	Discussions
An inter-period evolution w between accretion and eros	ith a regular alternation sion zones disturbed over ti	me (res)(r) 2	1988-1999
 A trend of coastline retreat ov "significant" erosion. 	er time for both methods but no	Automatic	
• Some alternation of eroding a 1988-1999 for both methods.	and accreting areas for the period	-6 -6 -6	Latvia
 Increasing erosion for the ma variations in Russia and Lithu 	nual method with significant ania.	6 6 6 6 7 9 9 9 9 9 9 9 9 9 9 9 9 9	1999-2009 1999-2009 Latvia 200 250 300 350
		Ľ	Distance from Cape Taran (km)



Background	Methods	Results	Discussions
An inter-period evolution v between accretion and ero	with a regular alternation sion zones disturbed over time		1988-1999 0.02 m/yr
 A trend of coastline retreat of "significant" erosion. 	over time for both methods but no	abur o crant and a crant a cra	and the second second
 Some alternation of eroding 1988-1999 for both methods 	and accreting areas for the period	-4 -4 Russia Lithuania	Latvia
 Increasing erosion for the m variations in Russia and Lith 	anual method with significant nuania.		1999-2009
 A change in the spatial dyna automatic method. 	amics of coastal evolution for the	LU additional and a second and	
		-6 Russia I Lithuania	Latvia
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Background	Methods	Results	Discussions
An inter-period evolution velocities between accretion and ero	vith a regular alternation sion zones disturbed over time	6 4 (xee()) 2	1988-1999 0.02 m/yr
 A trend of coastline retreat c "significant" erosion. 	ver time for both methods but no		vyr sch har har har har har har har har har ha
 Some alternation of eroding 1988-1999 for both methods 	and accreting areas for the period	-4 -4 -4 -4 -4 -4 -4 -4 -4 -4 -4 -4 -4 -	Latvia
 Increasing erosion for the m variations in Russia and Lith 	anual method with significant uania.		1999-2009
 A change in the spatial dyna automatic method. 	mics of coastal evolution for the	Lithuania -6	Latvia
		6 (res/u) every or every of the second seco	2009-2018 /yr -1.31 m/yr Latvia 50 200 250 300 350 400 Distance from Cape Taran (km)








Background	Methods	Results	Discussions
An inter-period evolution w between accretion and ero	vith a regular alternation sion zones disturbed over times the second state over the second sec	me (reaction of the second sec	1988-1999
A trend of coastline retreat of "significant" erosion.	ver time for both methods but no	o crande o ter and the of crande Automatic	
Some alternation of eroding 1988-1999 for both methods	and accreting areas for the period	-4 -4 Russia I -6	Latvia
Increasing erosion for the ma variations in Russia and Lith	anual method with significant uania.	6 B I 4 I 1	1999-2009
A change in the spatial dyna automatic method.	mics of coastal evolution for the	L - Automatic o o o oparate - 2 - Manual	- And -
Analysis of the spatial acc	uracy of the results	-4 -4	
1988-1999: same evolution t	rends except for the Curonian Spi	t.	
1999-2009: small differences the exception of the Sambiar port region.	between the annual variations wi and Curonian coasts and Pavilos	th sta	2009-2018
2009-2018: significant differe	ences between the two methods.	-2 -2 Manual	man for why why charl
Cyclical dynamics in port are method.	as whatever the period and the	ح -4 -6 -6 0 50 100 150	Latvia 200 250 300 350 400
		-	

Background	Methods	Results	Discussions

Natural and anthropogenic factors explaining the evolution of the coastline

Background	Methods	Results	Discussions
Natural and anthropoger evolution of the coastlin	nic factors explaining the e		

Background	Methods	Results	Discussions
Natural and anthropoger evolution of the coastline	nic factors explaining the		

Intense erosion or changing pre-existing spatial dynamics?

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- Natural processes: sea level rise, increase in "extreme" events, etc.
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A coastline more sensitive to human-induced damage?

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A coastline more sensitive to human-induced damage?

• Disturbance of sedimentary stocks and inputs: weakening of dunes, extraction activities, etc.

Background	Methods	Results	Discussions
Natural and anthropoger evolution of the coastline	ic factors explaining the	a proper	0 <u>4</u> km
 An alternation between er 1999) representative of se drift. 	oding and accreting areas (1988- diment redistribution by longshore		Baltic Sea
Intense erosion or changing p	re-existing spatial dynamics?		
 Natural processes: sea level etc. 	vel rise, increase in "extreme" events,		N ↑
 Extremely limited human i 'natural' dune protection s 	ntervention: beach nourishment, olutions, etc.		0 <u> </u>
A coastline more sensitive to	human-induced damage?		
 Disturbance of sedimental dunes, extraction activities 	ry stocks and inputs: weakening of s, etc.		Baltic Sea
 The case of ports: a disturcauses local erosion of be structures. 	bance of the littoral drift which aches downstream of port		N N
	Hard structures in Klaipeda por	t 1900 1	Coastal annual

Α

в

-2.80 - -1.80 -1.80 - -0.80 -0.80 - 0.80 0.80 - 1.80

_____ 1.80 - 2.80

error

Background	Methods	Results	Discussions

Critical analysis of the methodology

Automatic method

Manual method



Background	Meth	ods	Results	Discussions
	Critic	cal analysis of the m	nethodology	
Time-processing	Automatic method	Manual method	0 50 m	
Accuracy of the shoreline extraction				

Background	Meth	ods	Results	Discussions
	Critic	cal analysis of the m	ethodology	
	Automatic method	Manual method	0 50 m	
Time-processing	+	—		
Accuracy of the shoreline extraction	-	•		
Results	•	0		

N

Background	Meth	ods	Results	Discussions
	Critic			
Time-processing	Automatic method	Manual method	0 50 m	
Accuracy of the shoreline extraction	-	•		
Results	•	-		

• A relationship between spatial resolution and sandy beaches can be questioned ...



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	Criti	cal analysis of the m	nethodology		
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- Integration of other data sources in the analysis ٠ (topographic maps, field measurements, etc.)



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Results

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+

• Use of satellite images with better spatial resolution (at the expense of spectral resolution?)





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- Natural (sea level rise, storms) and anthropogenic (dune degradation, coastal protection strategies, etc.) factors can explain these observed changes.
- The automatic extraction method (MNF transformation and Laplacian filter) showed its advantages in terms of processing time and robustness of the results even if the differences observed between the two methods remain insignificant.



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Thank you for your attention!