Remote Sensing of Illegal Black Sand Mining in the Philippines

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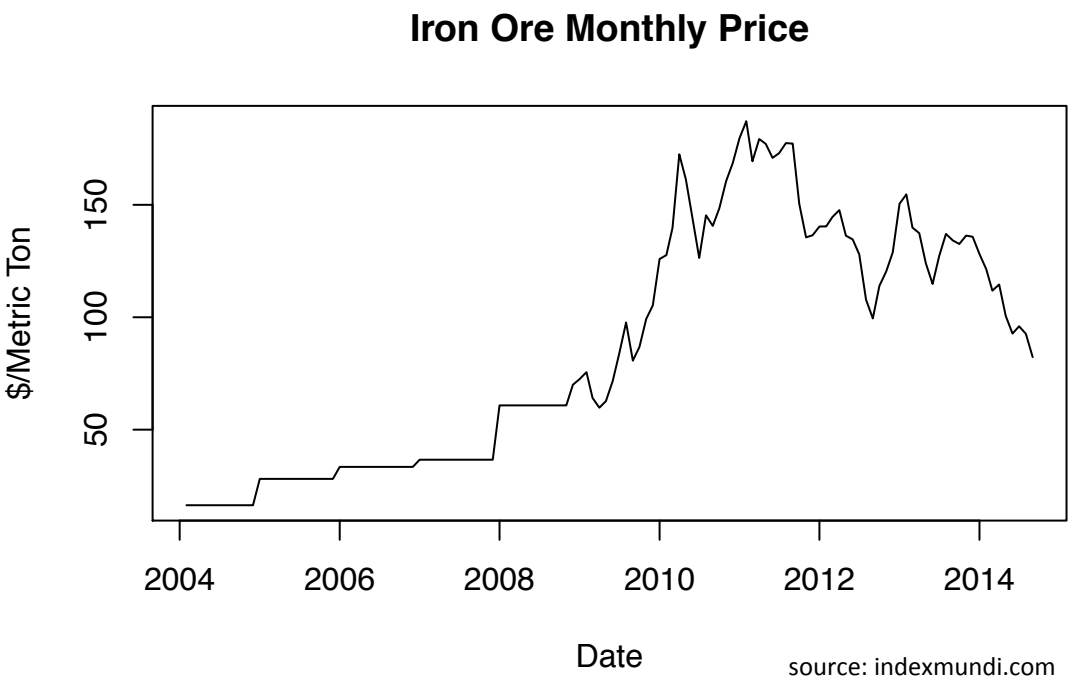
CEGA Behavioral Sensing Challenge 2014

What is black sand?

- Black sand, or magnetite, is a type of iron ore.
- Often used in steel production.
- High demand in rapidly developing countries, such as China.
- Naturally occurs in riverbeds and on beaches in the Philippines.



source: indexmundi.com

Black Sand Mining

Black sand extraction:

- Offshore – ships that siphon sand from ocean floor.
- Onshore – "quarrying," or digging up sand and loading onto trucks.
- River – "dredging," siphon sand from river bed.
- Sand is processed on ships or at processing plants on land.

Black Sand Mining

Effect on local livelihoods:

- Erosion; communities on the coast.
- Disturbs local marine ecosystem; threat to fisheries.
- Allows saltwater to penetrate water table; freshwater less suitable for drinking and agriculture.

Black Sand Mining

Increased vulnerability to natural disasters:

- Land subsidence and erosion → flooding
- Climate change → more extreme weather

Black Sand Mining

Illegality:

- Philippine Mining Act 1995: illegal to mine within 200 m of coastline.
- Since 2006, illegal black sand mining has been on the rise in Luzon.
- Local politicians receive bribes from foreign mining firms.
- Incumbent politicians then use these rents to bribe citizens for votes.

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Information based on interviews conducted in each province, September 2014

Province	***Number of Bgy with mining*** Before 2007	2007-2010	2010-2013	2013-present
Cagayan	1	1	27	18
Ilocos Norte	1	1	0	0
Ilocos Sur	6	17	13	4
La Union				
Pangasinan				
Zambales				1-2*

Project Aims

Explore potential for using remote sensing to measure the scope of illegal black sand mining and its environmental impacts in the Philippines.

1/ Use Landsat/Google Earth optical images to identify mining sites.
2/ Use ALOS InSAR to identify land subsidence.
3/ Combining subsidence rate and elevation, evaluate the time to permanent flooding.
4/ Verify sites and mining methodologies, and collect local election results.

Data and Method

Optical (Visible/IR) satellite imagery

-> "reflectivity map": how well different colors of light are reflected: depends on the property of the surface (wavelength absorbed)

Data: Landsat (30 – 60 m) & freely available (Google Earth)

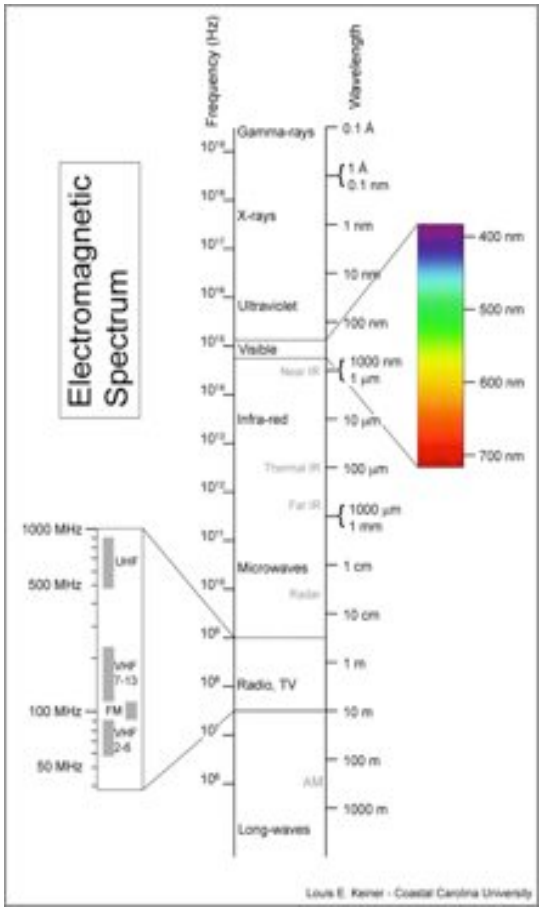
RADAR (microwave) satellite imagery

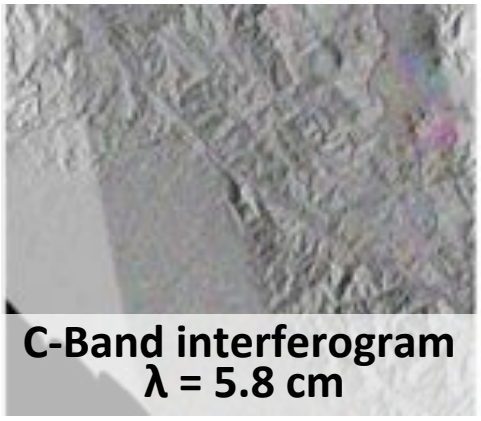
-> how well radio waves reflect and scatter, determine the range.
Advantages: day & night, not affected by clouds, penetrates trees

InSAR

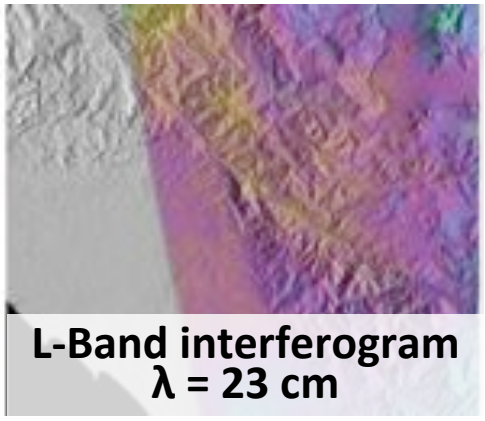
Measure the phase difference of two radar images of the same area acquired at different times

Data: ALOS 2007-2011 globally observing satellite & L-Band: signal unaffected by vegetation

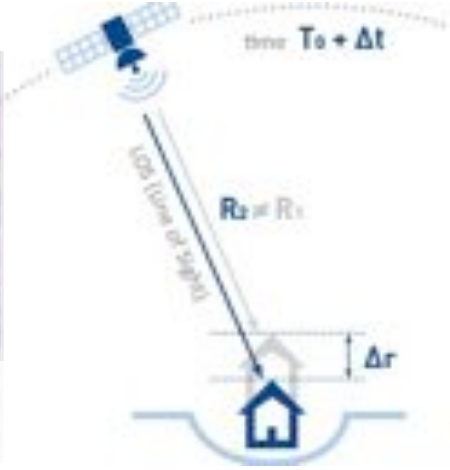


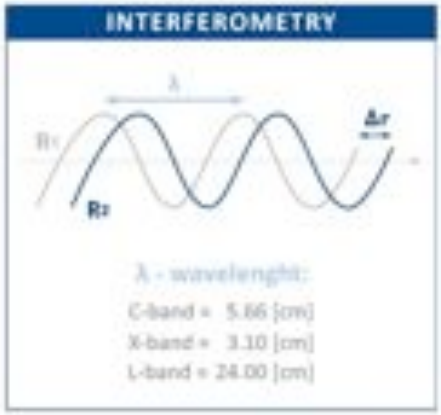


C-Band interferogram
λ = 5.8 cm



L-Band interferogram
λ = 23 cm



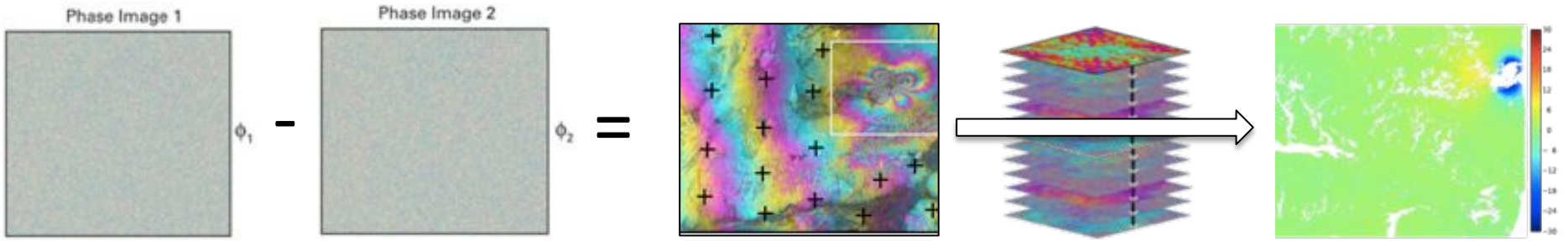


Data and Method

InSAR Time Series

- Inversion of many interferograms to extract the displacement through time

-> Averaged velocity maps, remove atmospheric noise, identify small amplitude deformation



Mean velocity map

Why InSAR time series for detection of mining related subsidence?

-Remote sensing: no ground access

-High precision and high spatial coverage:
InSAR can resolve deformation at the size of a pixel (10 m) but also covers hundred of km^2

-Can resolve deformation as small as 1 cm/yr

How to separate mining from natural subsidence in InSAR TS?

-Each process causing subsidence result in deformation with characteristic rates & extent (natural: large scale & slow/ mining: local & fast)

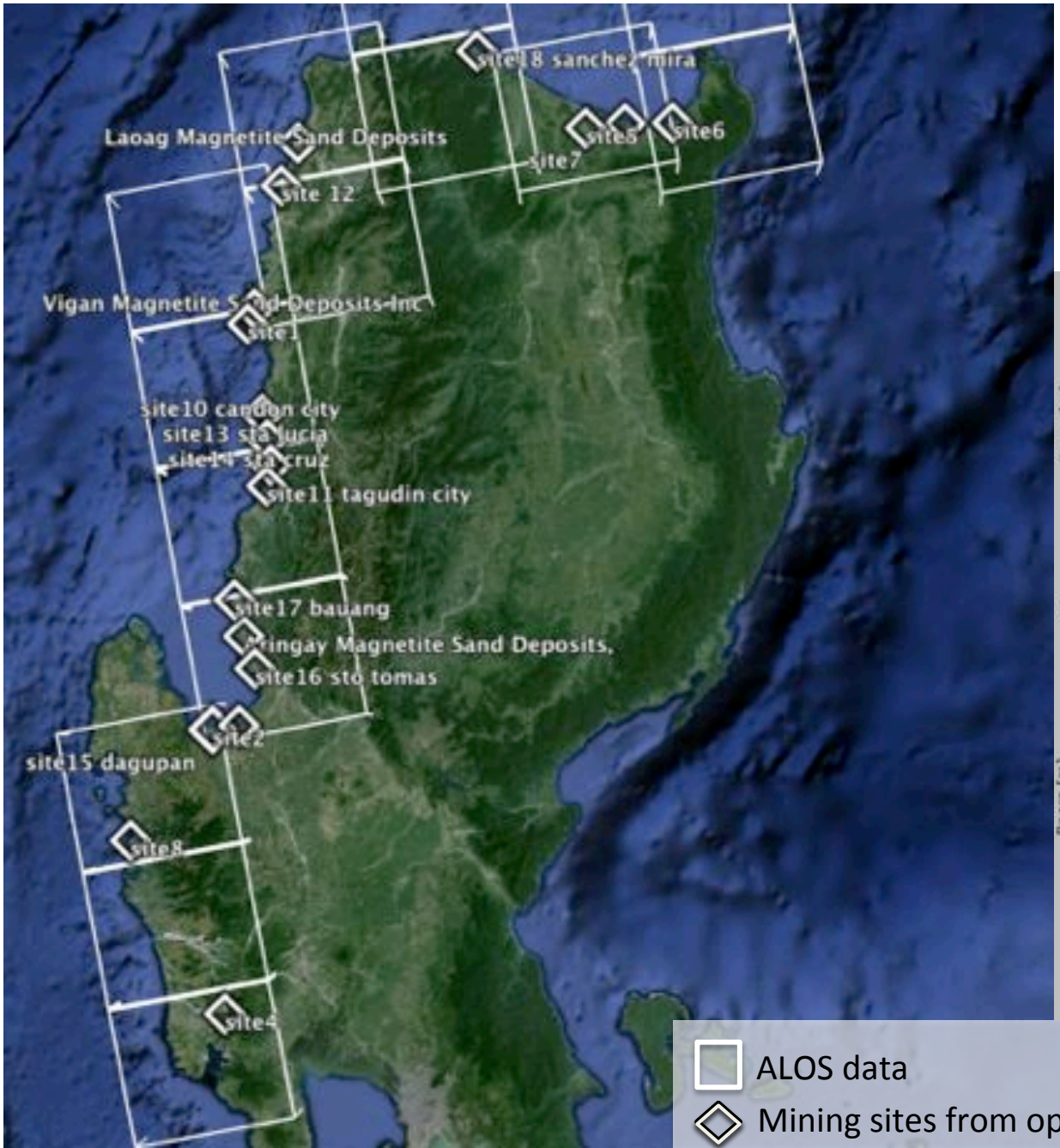
Subsidence process		Rates	Spatial pattern	Surface geology	Land use
Natural	Holocene sed. compaction	<1 cm/yr	Large	Compressible deposits	All types
Anthropogenic	Fluid withdrawal	Up to tens of cm/yr	Large to patchy	Compressible deposits	Indust., mixed, and agricult. (water, gas, oil extraction)
	Solid withdrawal	Up to tens of cm/yr	Local to patchy	All deposits	Industrial (mining)
	Surface water drainage	<5 cm/yr	Large to local	Compressible deposits	Indust., mixed, and agricult. (harvest or recently developed areas)
Mixed	Sediment loading (settlement)	<5 cm/yr	Large (sed. load) Patchy (buildings)	Compressible deposits	Industrial and mixed (recent massive buildings)

1/ Identification of mining sites with satellite optical images

→ Identification of 19 illegal black sand mining sites.

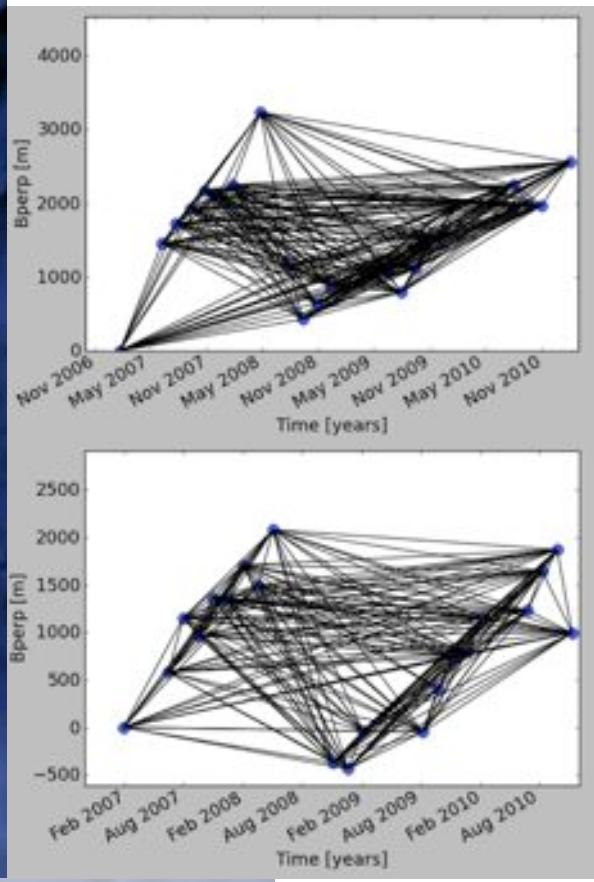
1/ Identification of mining sites with satellite optical images

2/ InSAR for land subsidence identification



-> Processing of 14 ALOS frames with each 9-25 acquisitions

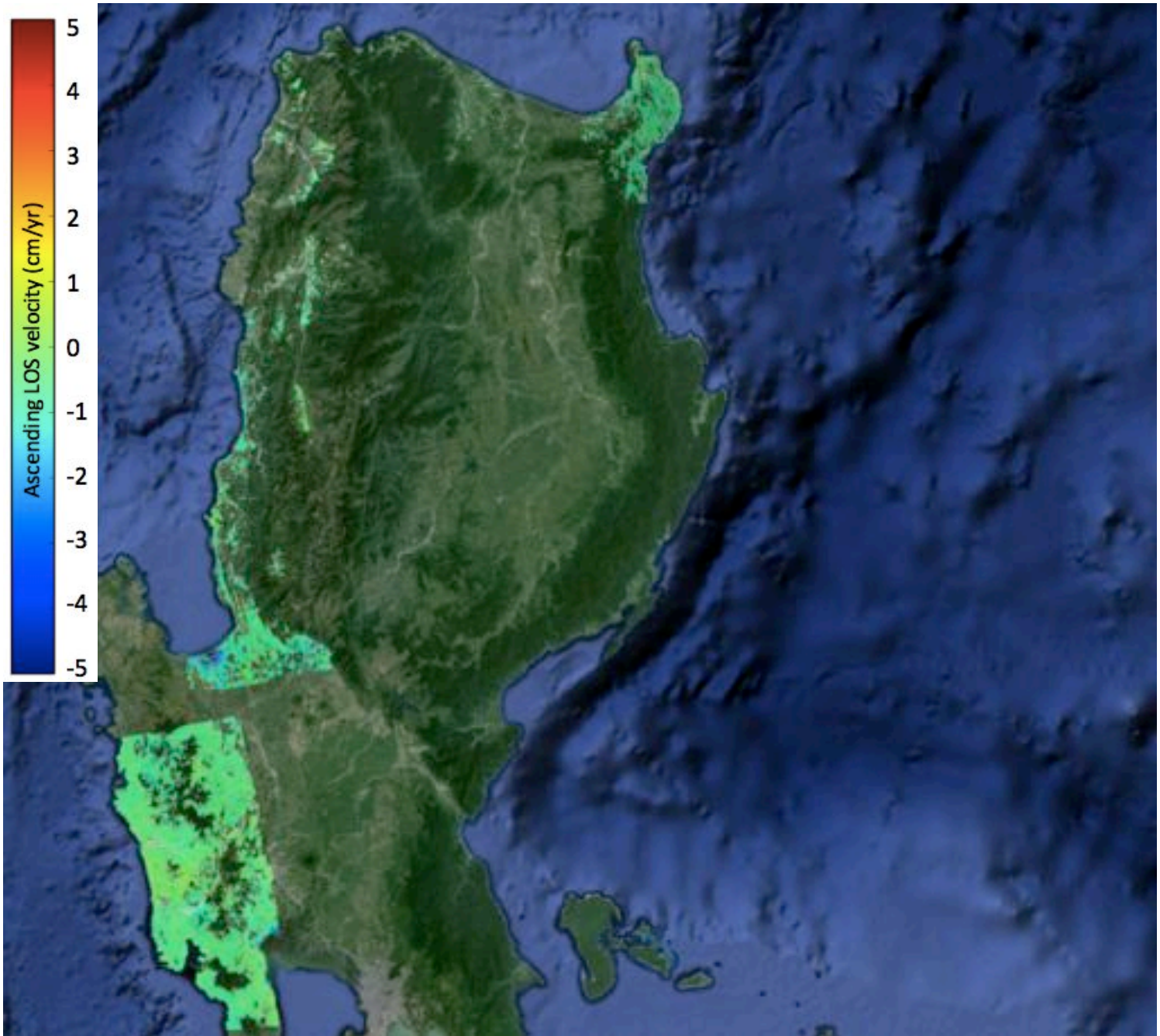
→ 40 to 250 interferograms per track



ALOS data

Mining sites from optical images

2/ InSAR for land subsidence identification



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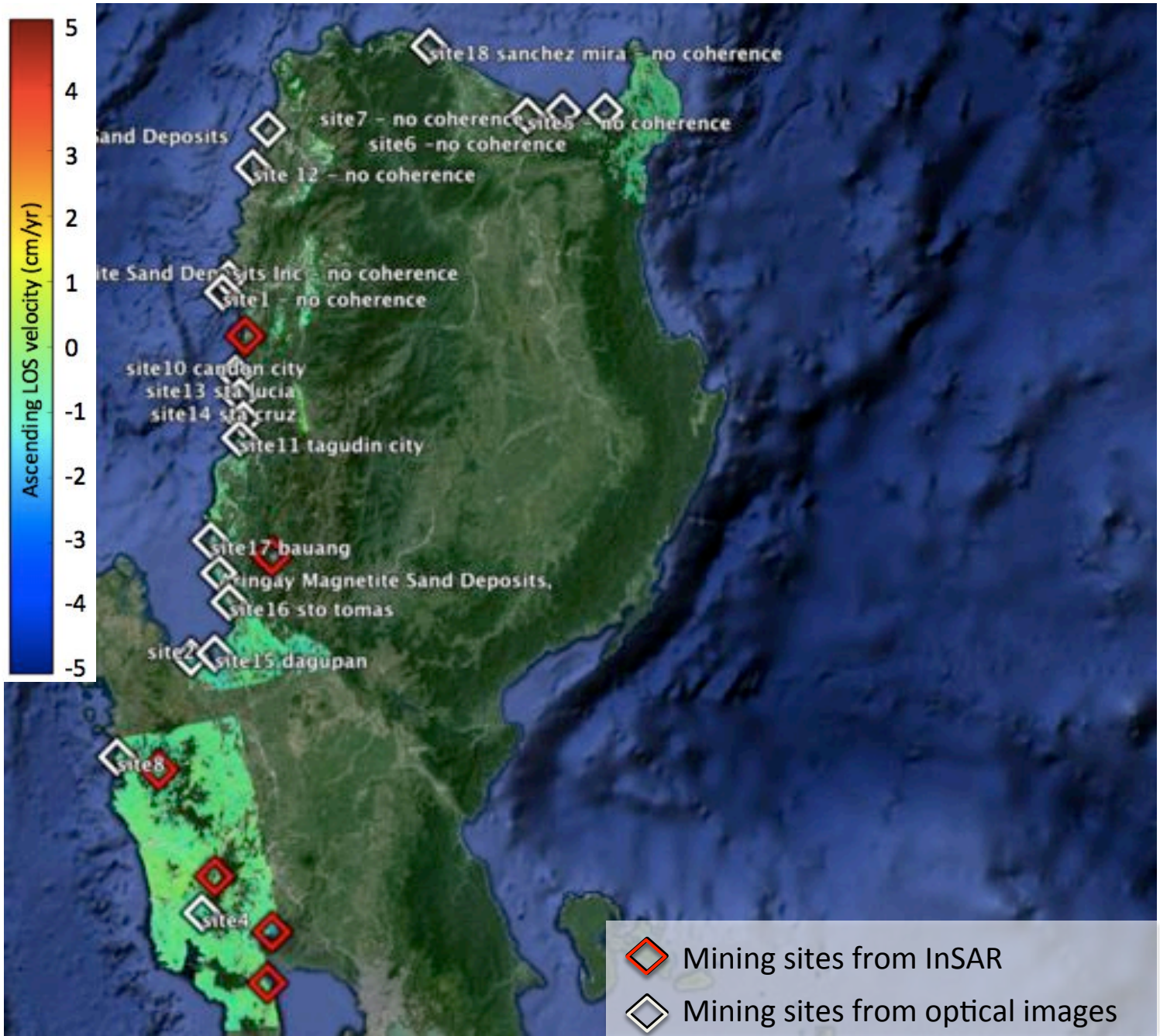

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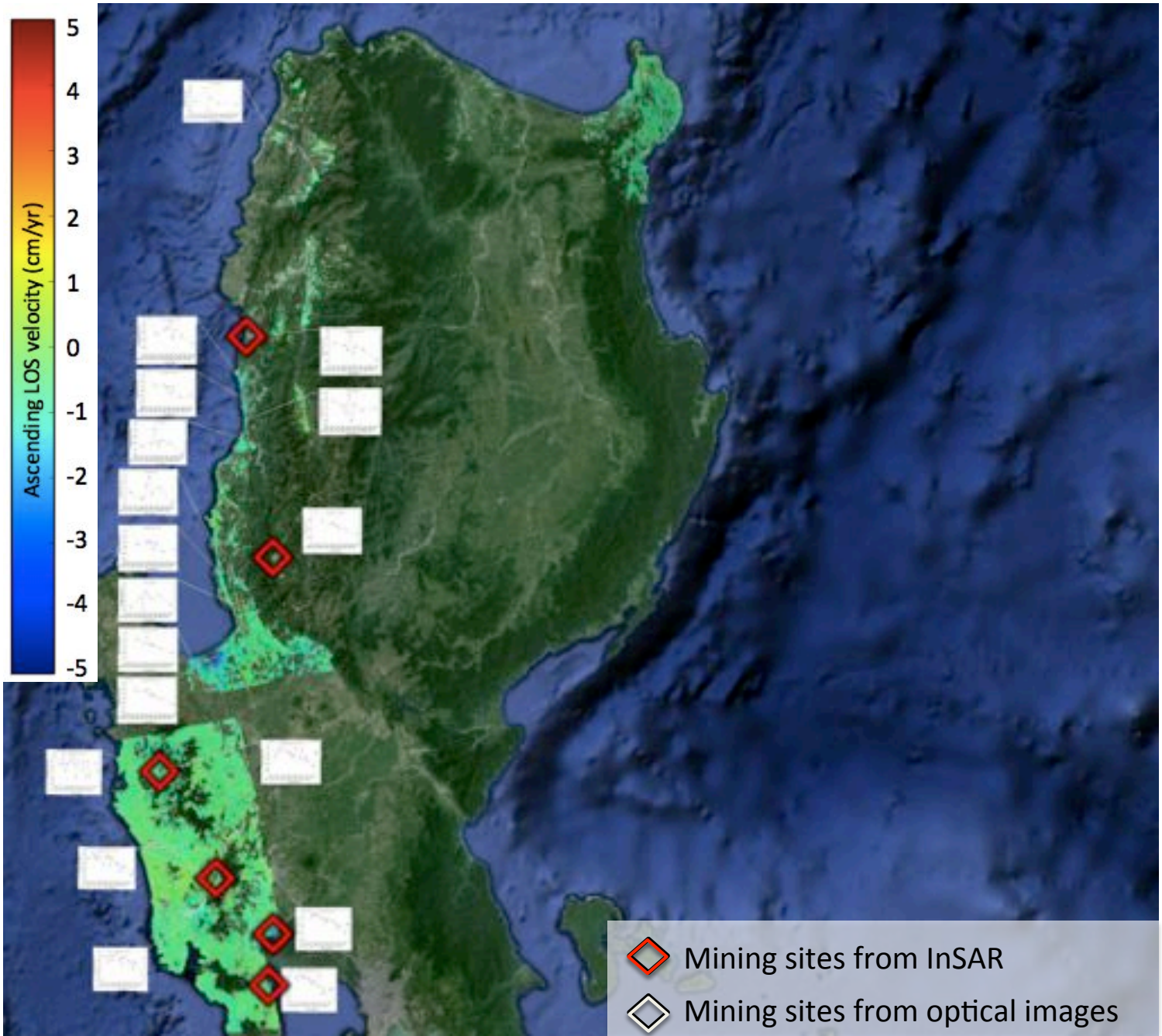

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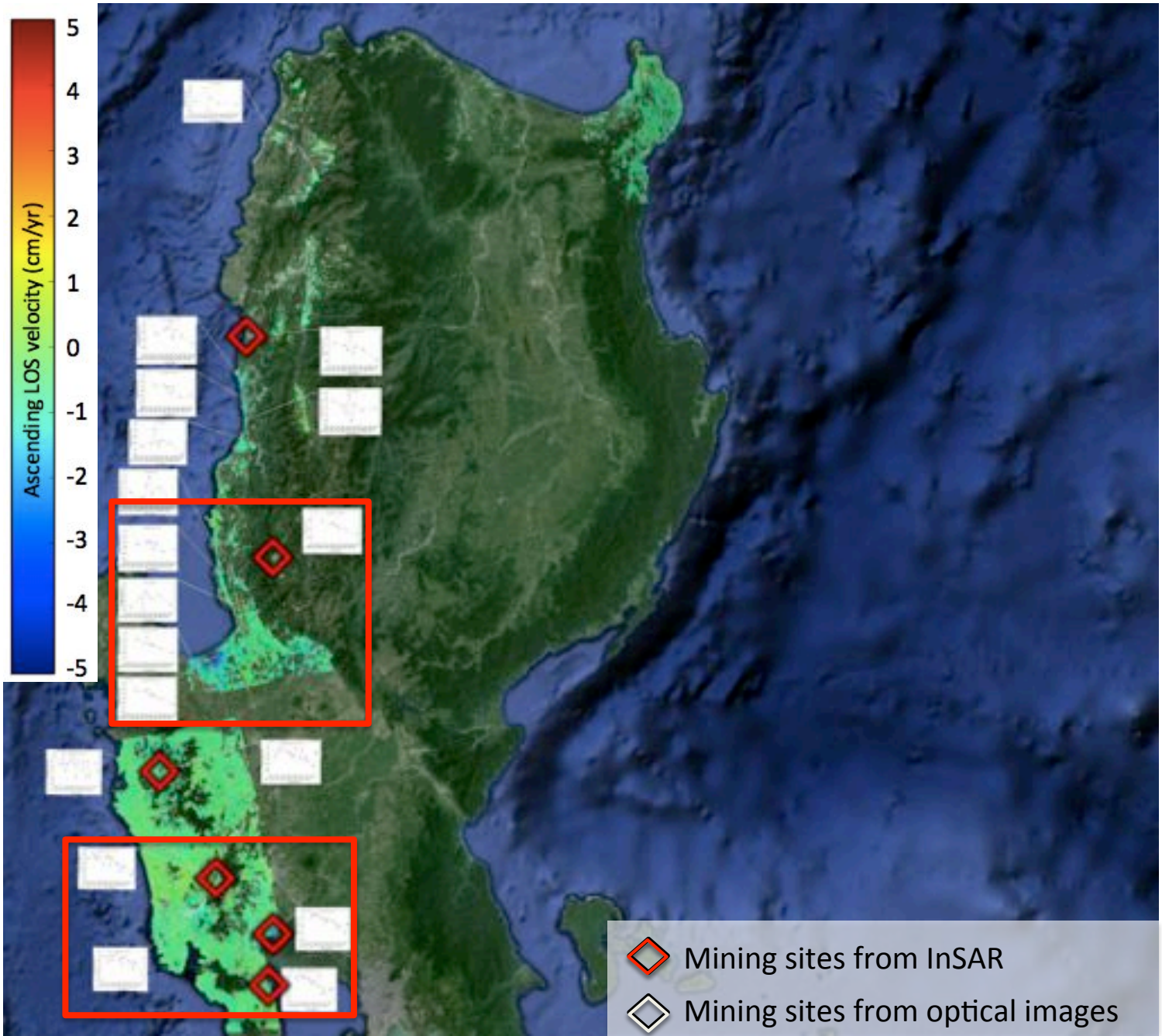
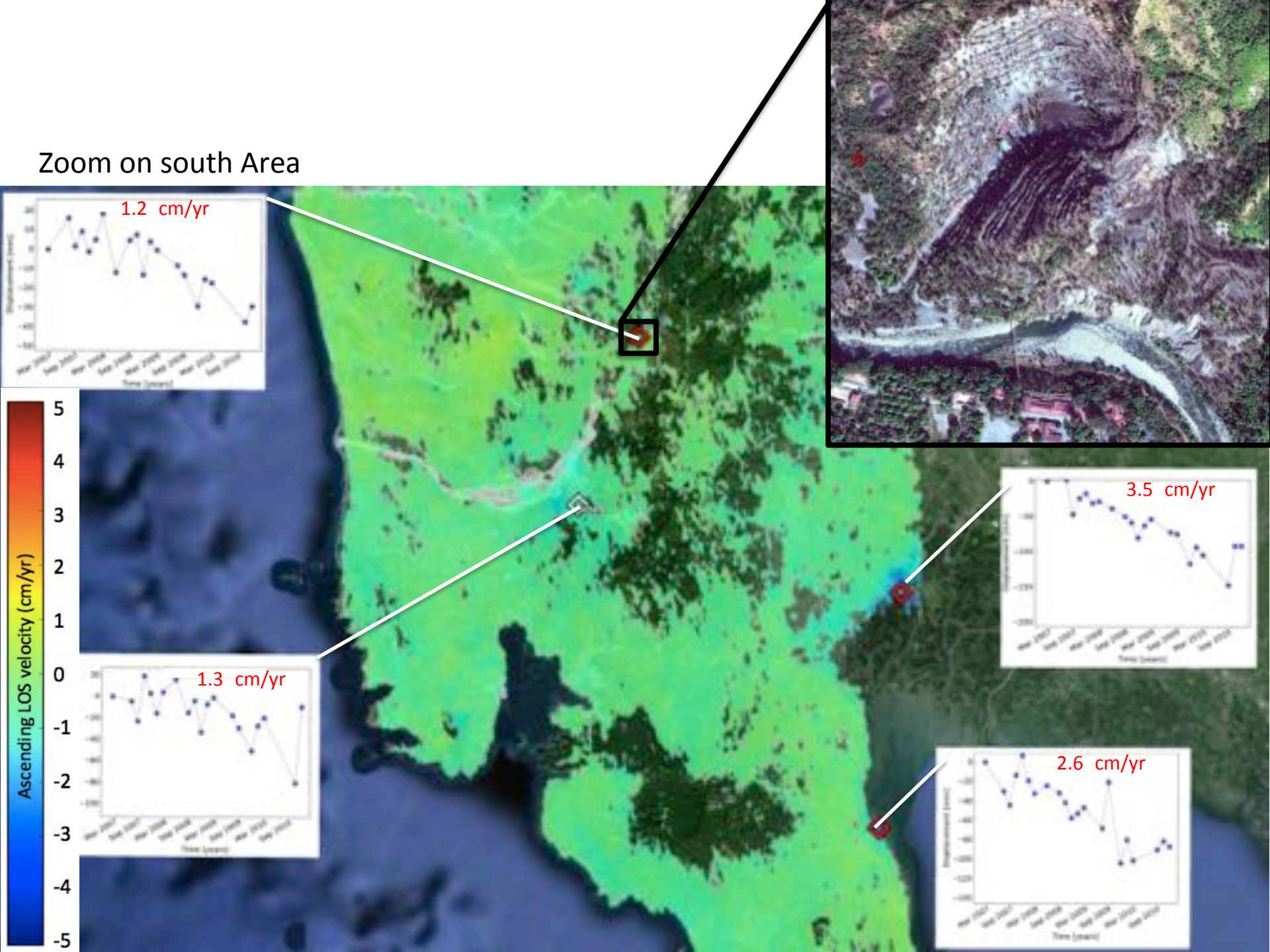
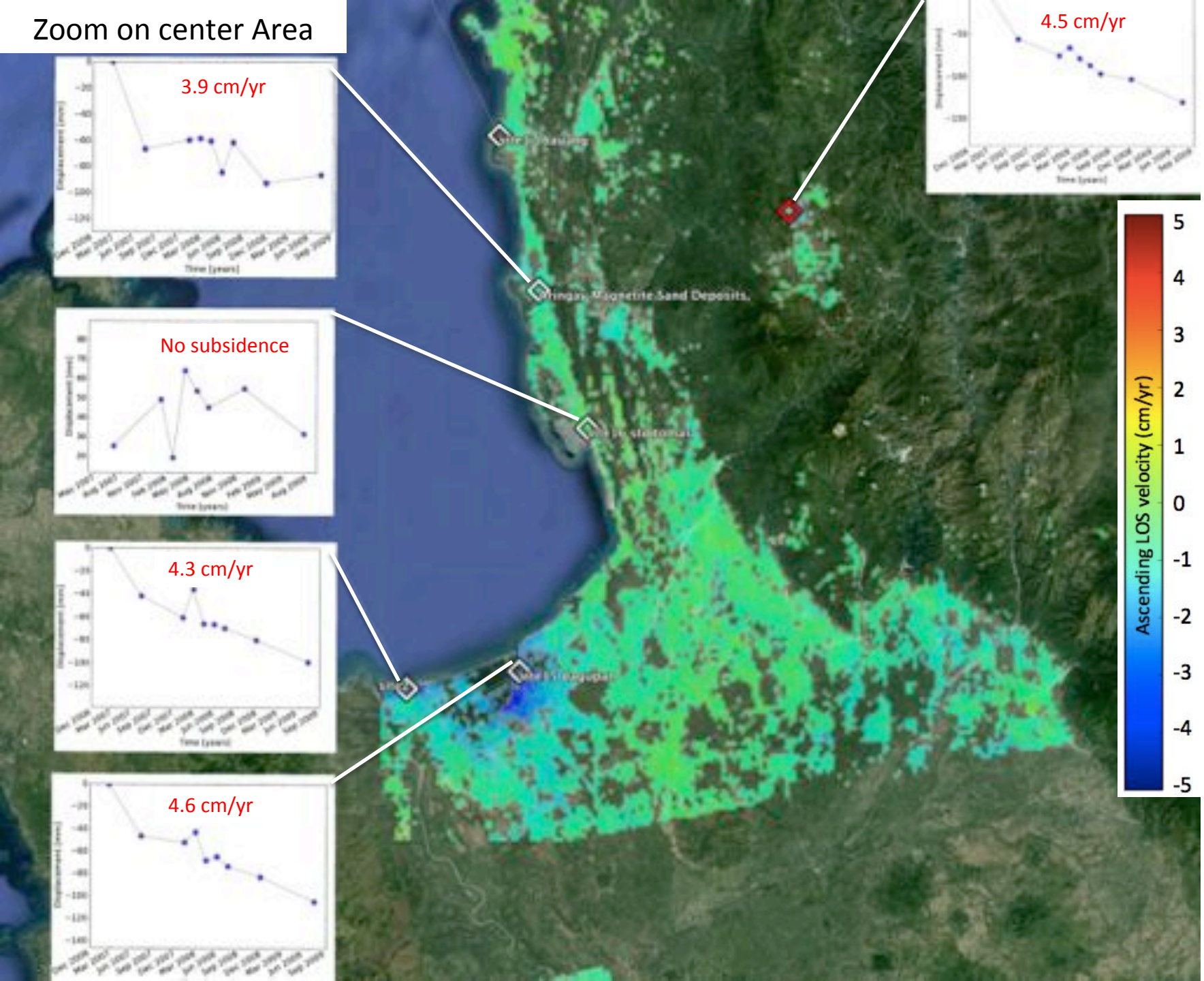


Zoom on south Area




Zoom on center Area
3.9 cm/yr
4.5 cm/yr
No subsidence
4.3 cm/yr
4.6 cm/yr
Ascending LOS velocity (cm/yr)
5
4
3
2
1
0
-1
-2
-3
-4
-5

Summary

- Optical images enable identification of some illegal mining sites.

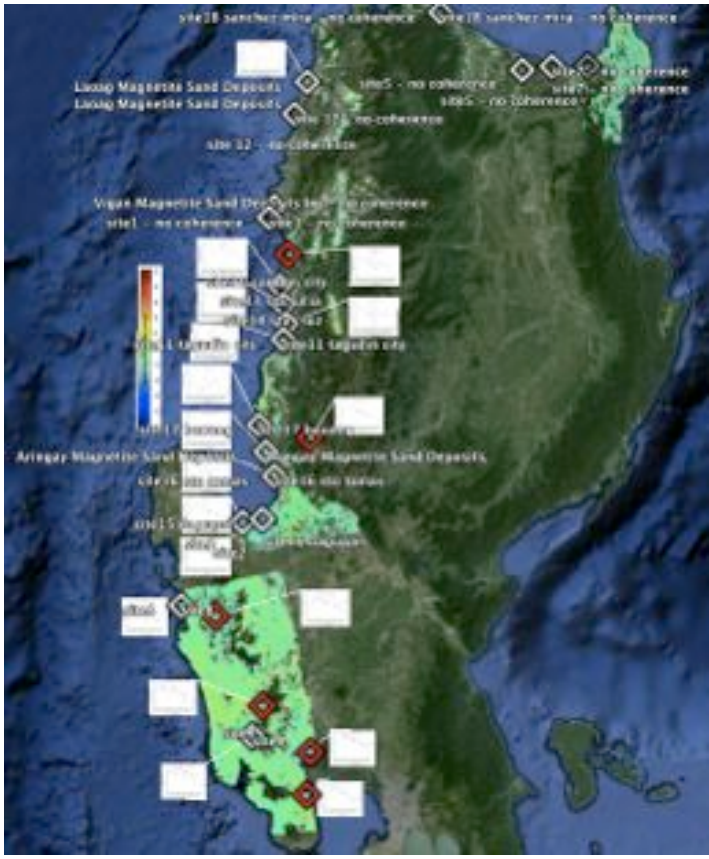
- 7 mining sites have no coherence in InSAR images – biggest limitation of InSAR
(too much change in properties – too recent development? too much subsidence?)

- 5 sites show no subsidence: subsidence likely depends on the amount of mining/pumping and timing.

- **13 sites show subsidence**
  - 6 not originally identified with optical images
  → InSAR can further help identify areas of high risk

  - Pattern ~ 100 time larger than mining site
  (mining 0.05 km^2 / subsidence 5-10 km^2)

  - Subsidence up to 7 cm/yr in coastal area
  → Increases the threat of flooding



Site	Subsidence (cm/yr)	Adding sea level rise (1.3 cm/yr - NOAA)	Elevation above sea level (m)	Time before land is below sea level (yrs)
Candon 10	3.6	4.9	2-4	41-82
Sta Lucia 13	5.2	6.5	2-4	31-62
Aringay	4.7	6.0	4-6	67-100
Dagupan 15	5.5	6.8	2-4	29-59
Lingayen 2	5.2	6.5	2-4	31-62
Candelaria 8	2.2	3.5	2-4	57-114

Next Steps

- Incorporating election and census data.
- Further evaluation of land use and water extraction near high subsidence sites.
- DigitalGlobe imagery grant – two high-resolution images of one site.
- Partnership with Big Pixel Initiative, Calit2 @ UCSD + DigitalGlobe, to explore magnetite ID and/or land use classification in high-resolution satellite data.
- Field experiment in 2015 to test effect of monitors equipped with smart phones and apps to report illegal mining in real time.
- ALOS-2 launched summer 2014.

Acknowledgements

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