Subsidence mapping in Jakarta - PSI processing of L-band ALOS PALSAR data

Rachel Holley[1], Richard Burren[1], Hasanuddin Z. Abidin[2]

1. Fugro NPA Ltd., Crockham Park, Edenbridge, Kent TN8 6SR, United Kingdom
2. Geodesy Research Division, Faculty of Earth Science and Technology, Institute of Technology Bandung (ITB), Jl. Ganesha 10, Bandung 40132, Indonesia

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Subsidence in Jakarta – historical motion study

- Jakarta Metropolitan Region is known to suffer from subsidence, but most measurements have been point-based (Levelling, GPS) and relatively limited in spatial extent.

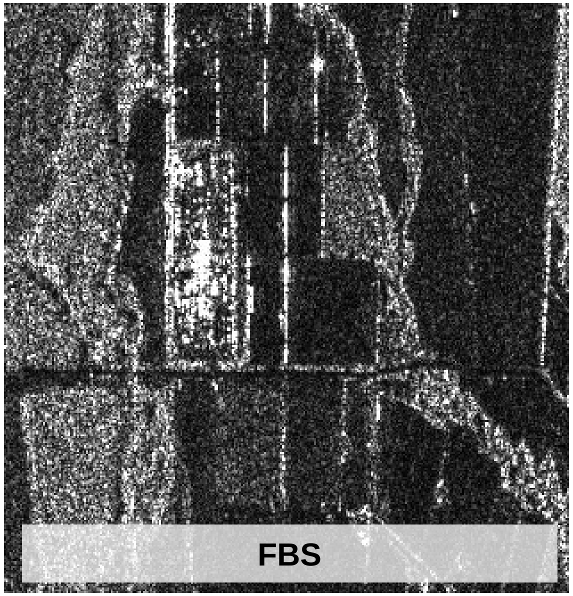
- Requirement for historical PSI motion study to give detailed wide area coverage of the city.

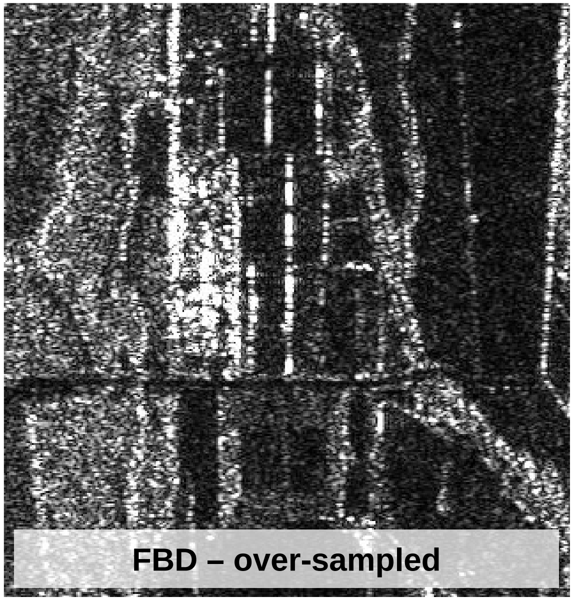
- C-band SAR data archive
  - ERS – max stack size 10 scenes, 1996 to1998
  - Envisat – max stack size 8 scenes, 2007 to 2009
  - Not suitable for C-band PSI – too few scenes
  - A number of individual DifSAR interferograms possible

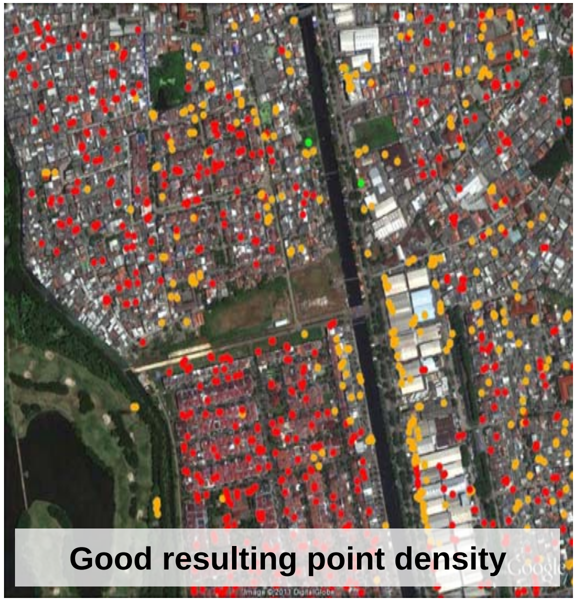
- L-band SAR data archive
  - ALOS PALSAR – stack of 18 scenes, 2007 to 2010
  - Fulfilled PSI processing requirement
  - Mix of FBS and FBD

PALSAR PSI – FBD data

- Archived PALSAR images are a mixture of single-polarisation (FBS) and dual-polarisation (FBD). To get a large PSI stack, need to utilise both.
  - FBD images have half the standard resolution in range – over-sampled by a factor of two before coregistration.
  - Will PS detection still work in over-sampled SLCs? …Yes! …but would under-sampling the FBS be better?
  - Resulting point density very good in urban areas.


FBS

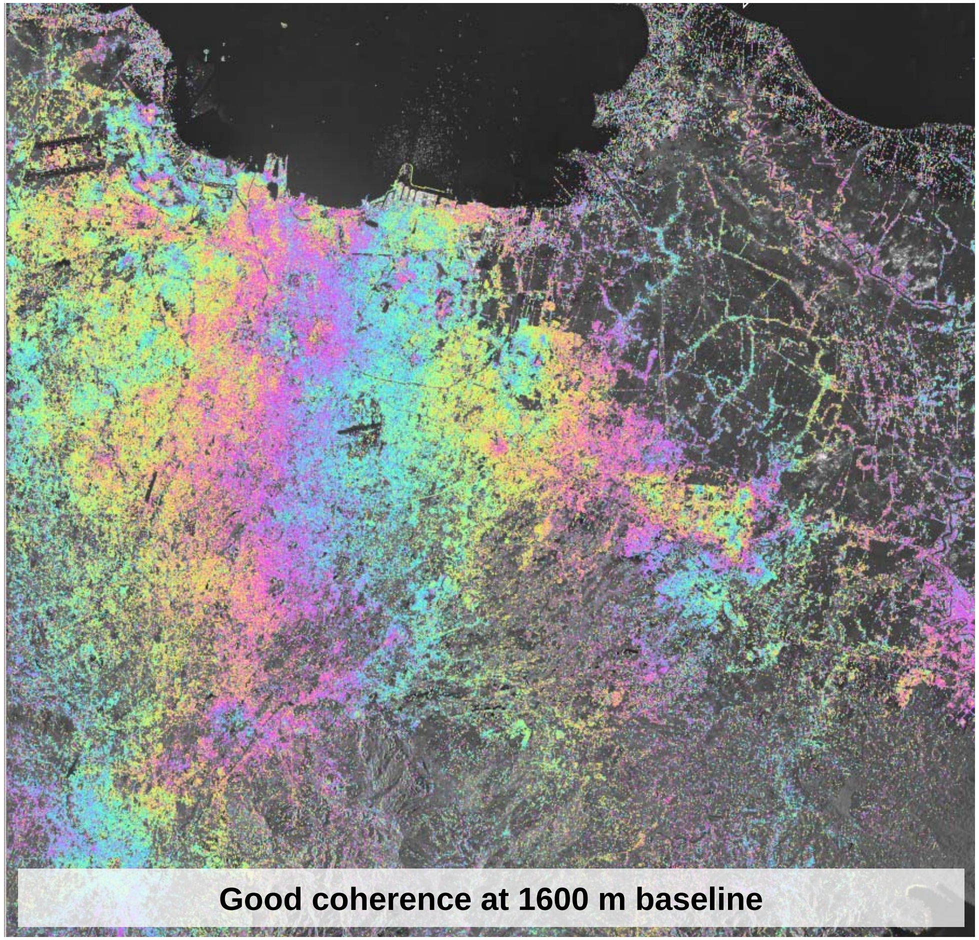

FBD – over-sampled


Good resulting point density

PALSAR PSI – Baselines

- Perpendicular baseline (B_{perp}) and altitude of ambiguity (h_a) characteristics different from C-band PSI
  - Baselines typically much larger than conventional C-band: 1000s of m.
  - Partly compensated by large increase in h_a for a given B_{perp} – predominantly due to larger wavelength, plus larger typical incidence angle.
  - Equivalent h_a equates to ~6 times larger B_{perp} for typical R and θ.

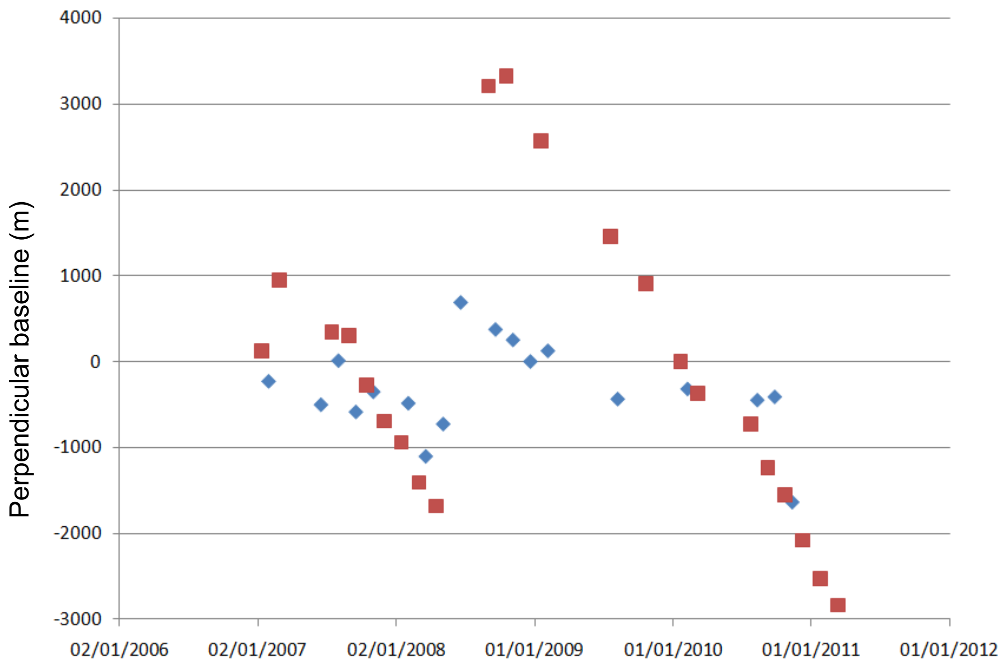
$$h_a = \frac{\lambda R \sin\theta}{2B_{perp}}$$



Good coherence at 1600 m baseline

PALSAR PSI – Baselines

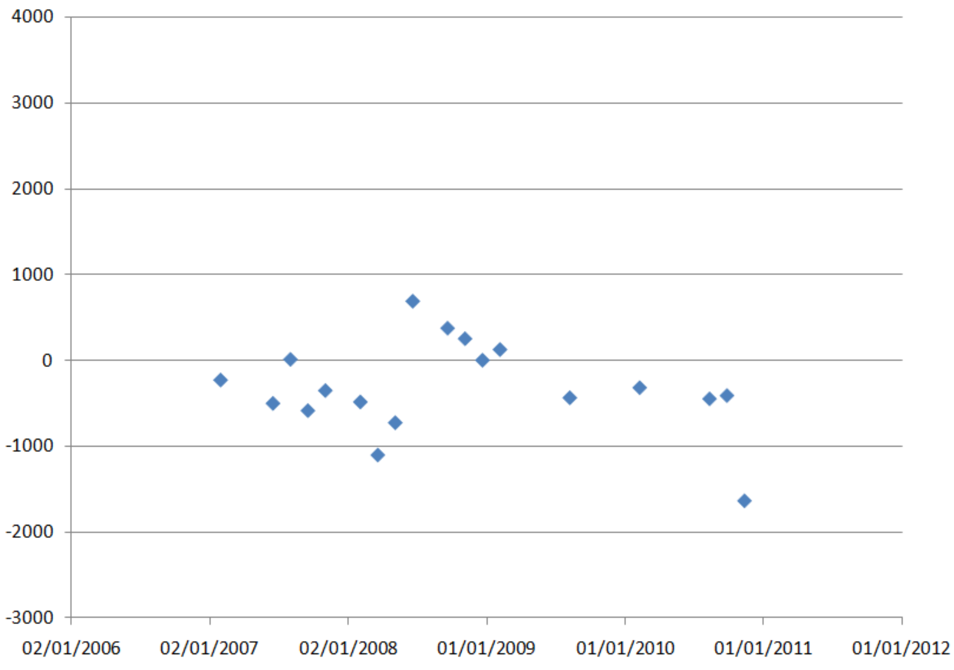
- Perpendicular baseline (B_{perp}) and altitude of ambiguity (h_a) characteristics different from C-band PSI
- Perpendicular baseline distribution correlated in time
  - Steady increase in inclination over time, with one large correction in June 2008
  - PSI (and many network/SBAS-type techniques) assume B_{perp} uncorrelated in time – could introduce a bias.

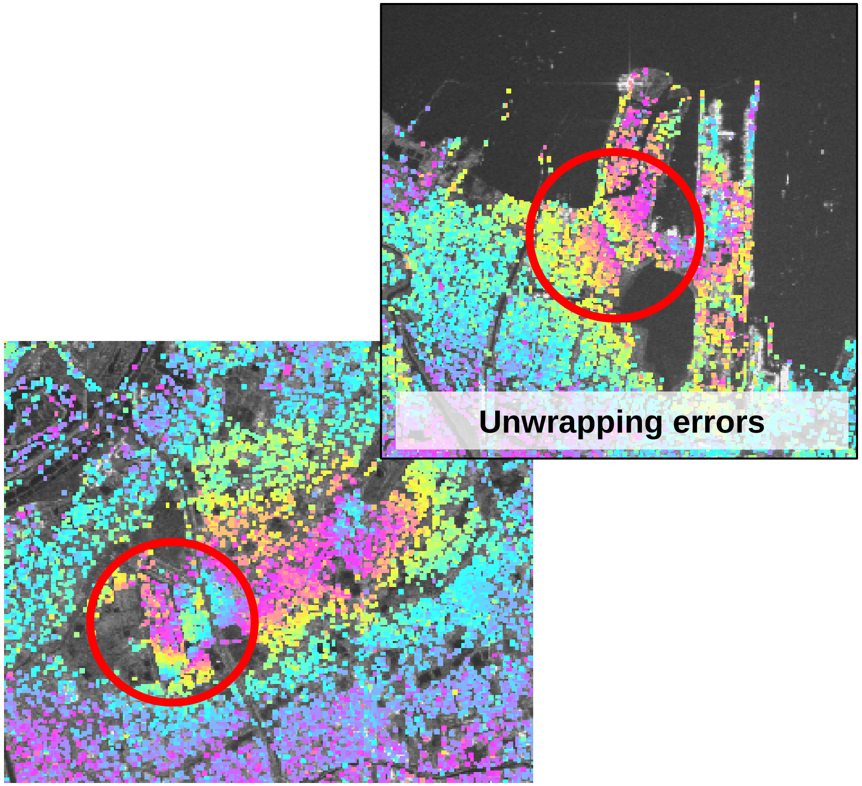


- Jakarta data stack has small baselines and low correlation…
- Problem is markedly worse at Higher latitudes away from the orbital inclination nodes!
- For Jakarta, inverted for an initial height model on short-term multi-master interferograms, after filtering out wide-scale signal

PALSAR PSI – Temporal Characteristics

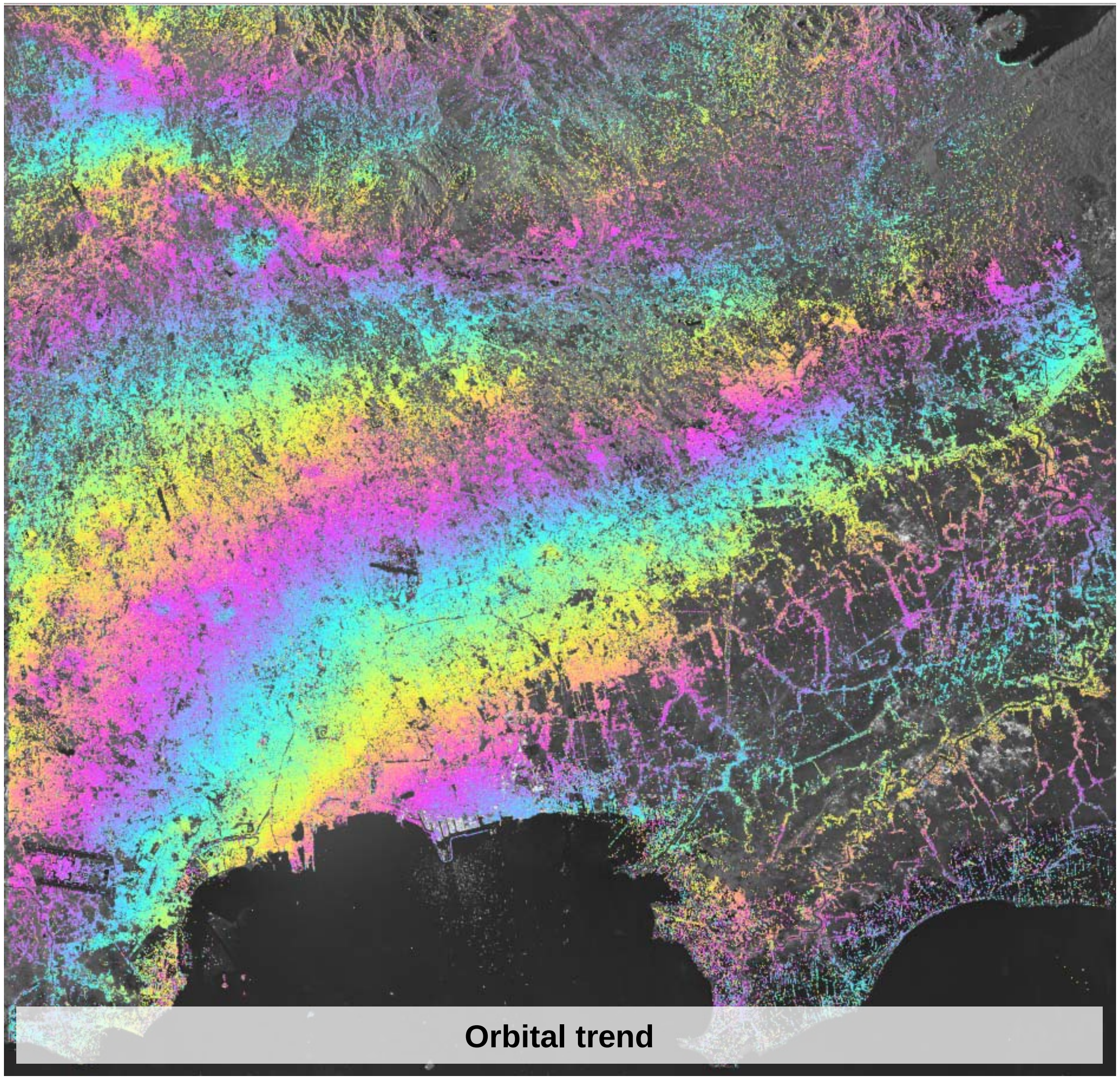
- Temporal distribution of data stack generally good – 18 scenes; some 46-day separations, a few up to 184 days later in time series.
- Long wavelength aids unwrapping across gaps, but some of longest interferograms had unwrapping errors in areas of strong deformation.
- Initial deformation model from shorter interferograms, refined using all data.





PALSAR PSI – Orbital Trends

- Tendency for non-linear orbital trends in ALOS data
- Empirical correction hard due to large areas of strong deformation, residual components hard to eradicate due to relatively small number of images
- Potential for trend in velocity results – empirical correction removed, but could still contain bias if wide-scale deformation gradients are present.



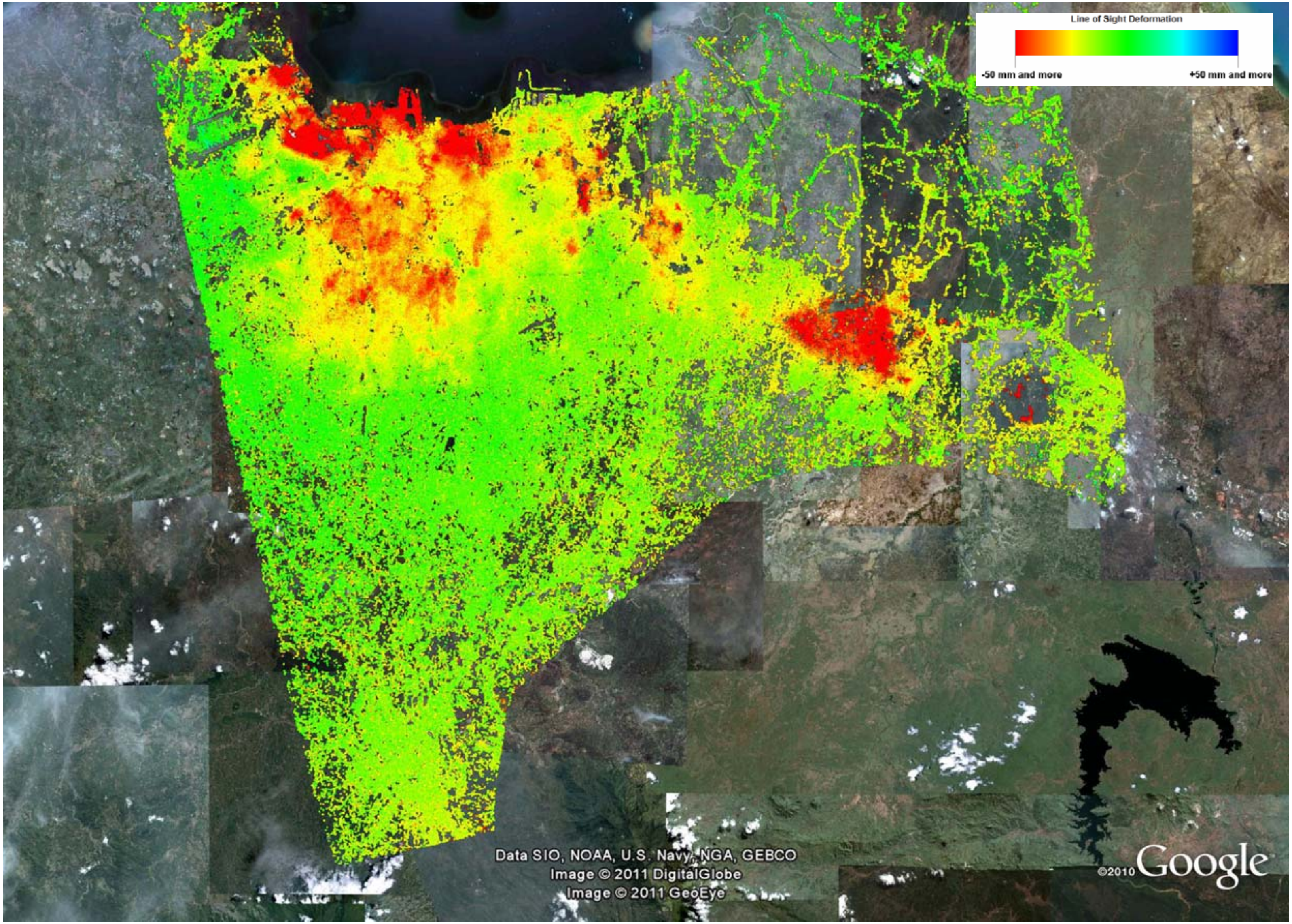
PALSAR PSI – Quality of results

- Relatively high levels of uncorrelated noise remain in result
  - Constraint on maximum motion rate imposed in standard PS processing to remove spurious fits to a deformation model caused by poor quality PS.
  - High motion rates in some areas of Jakarta required a high maximum rate, reducing ability to exclude poor quality PS points without losing genuine deformation signal.
  - Relatively small data stack also increase likelihood of these spurious fits.

- Mountainous areas to the south of Jakarta challenging for PSI
  - These areas far from reference point, so wide-scale orbital and atmospheric variations are largest.
  - Mountains increase topographically-correlated atmospheric errors, and therefore some degree of correlation over time – again small number of scenes reduces ability to remove bias.

- How many scenes should be considered a minimum for PALSAR PSI?
  - 18 scenes used here – adequate in flat areas near reference point, but more would be better…

PSI Results


Line of Sight Deformation
-50 mm and more
+50 mm and more
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2011 DigitalGlobe
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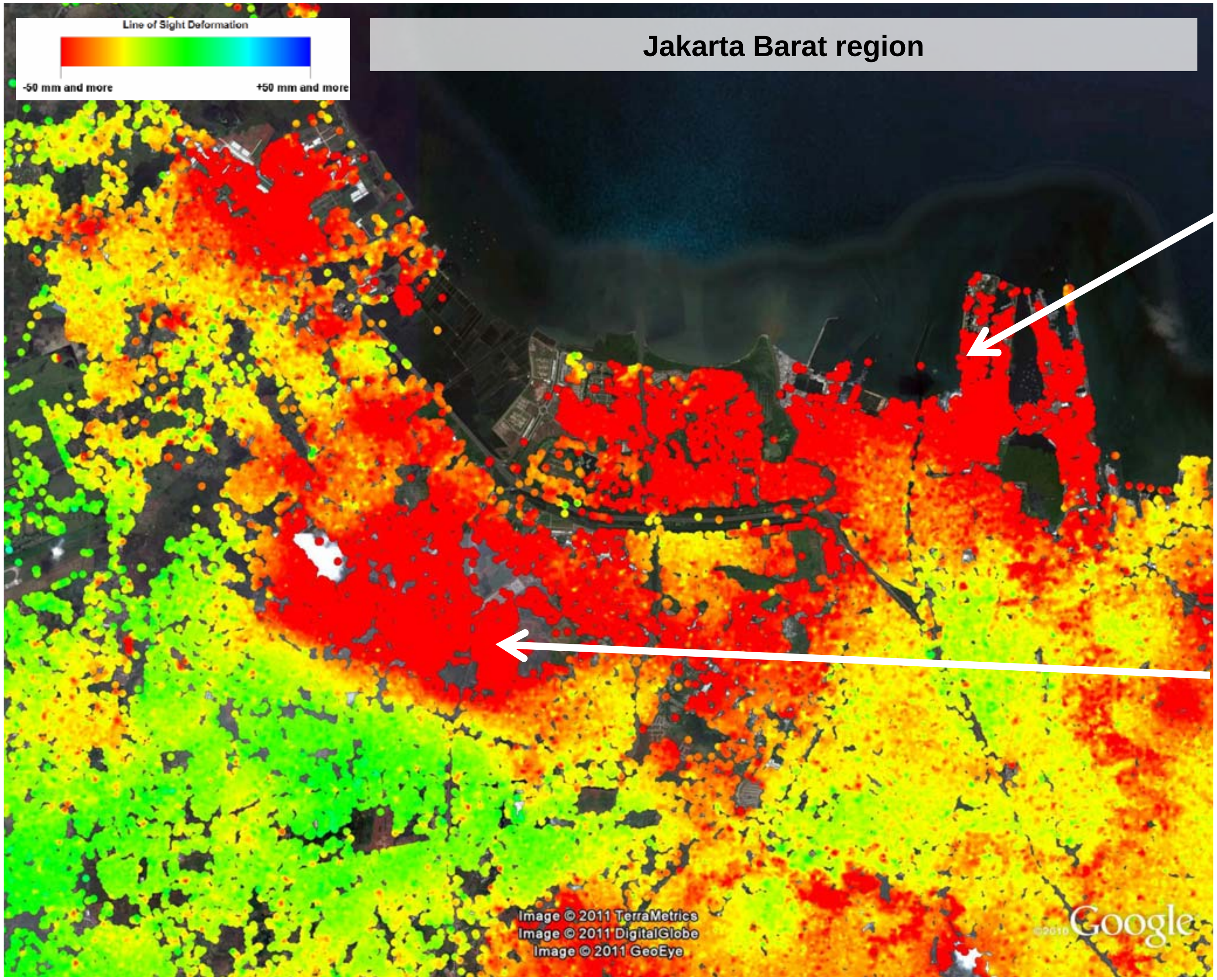
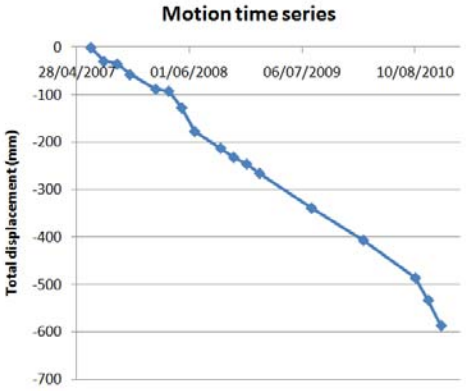
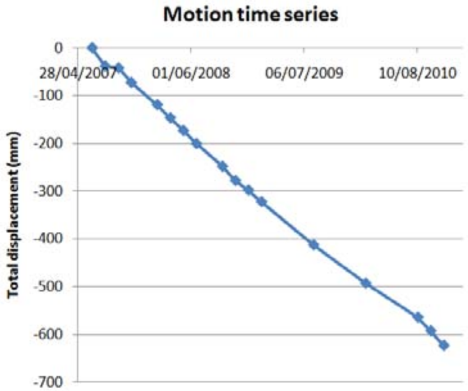
PSI Results

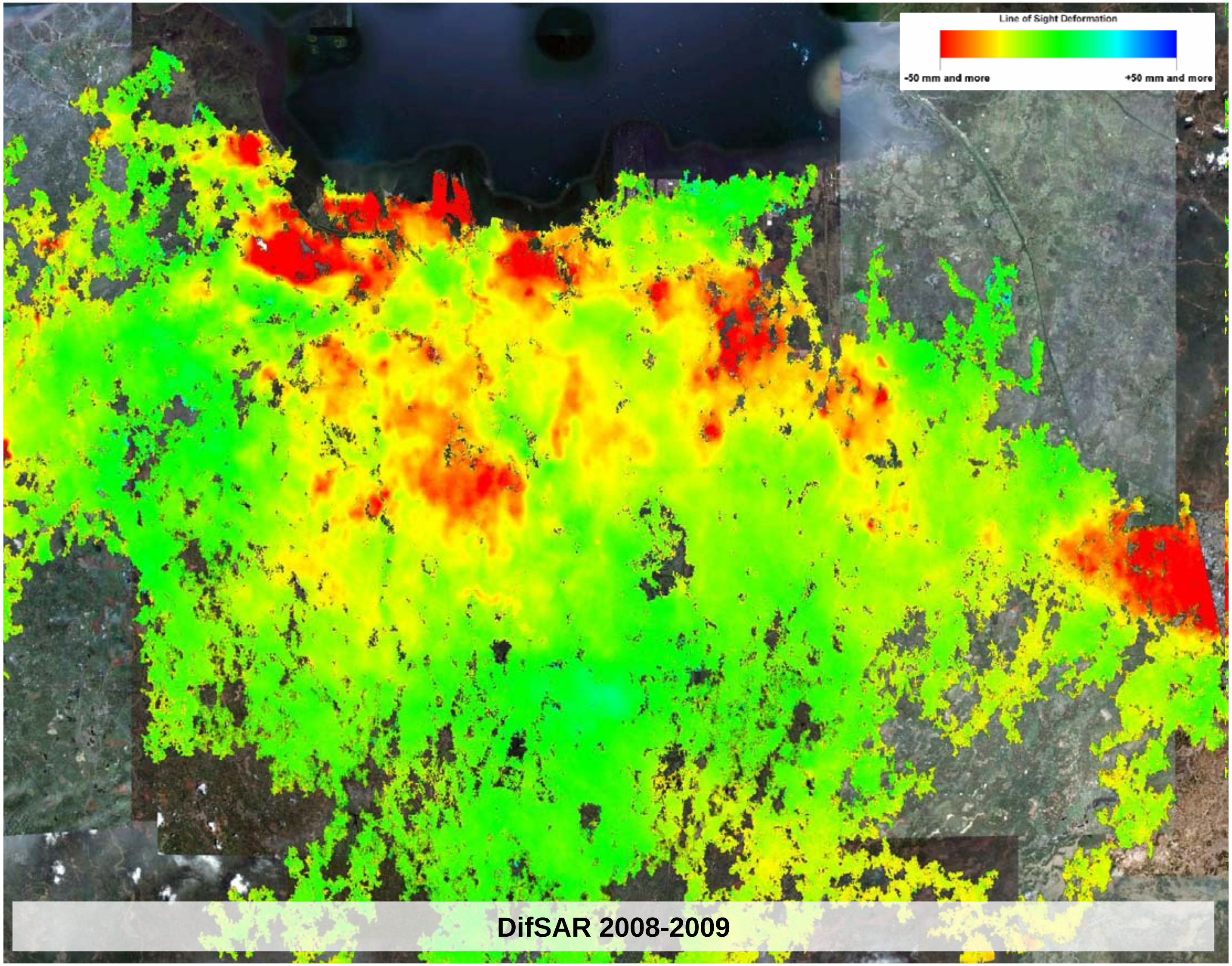




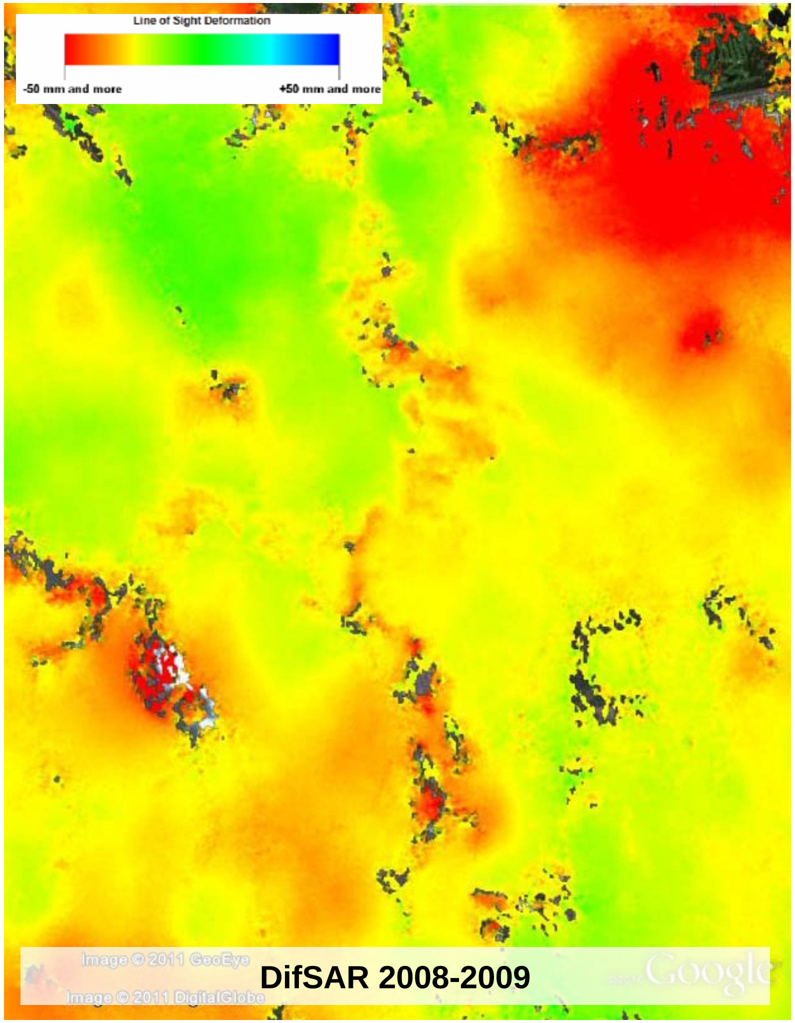


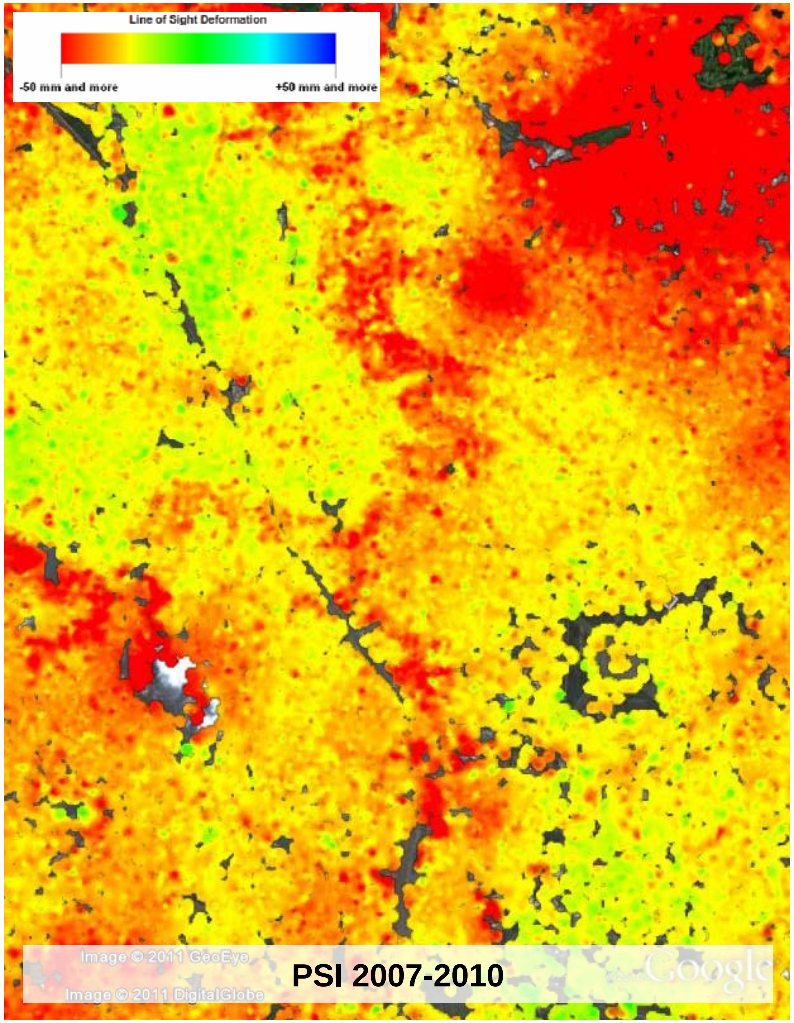
- Rates of up to ~180 mm/yr in some areas

PSI – DifSAR comparison

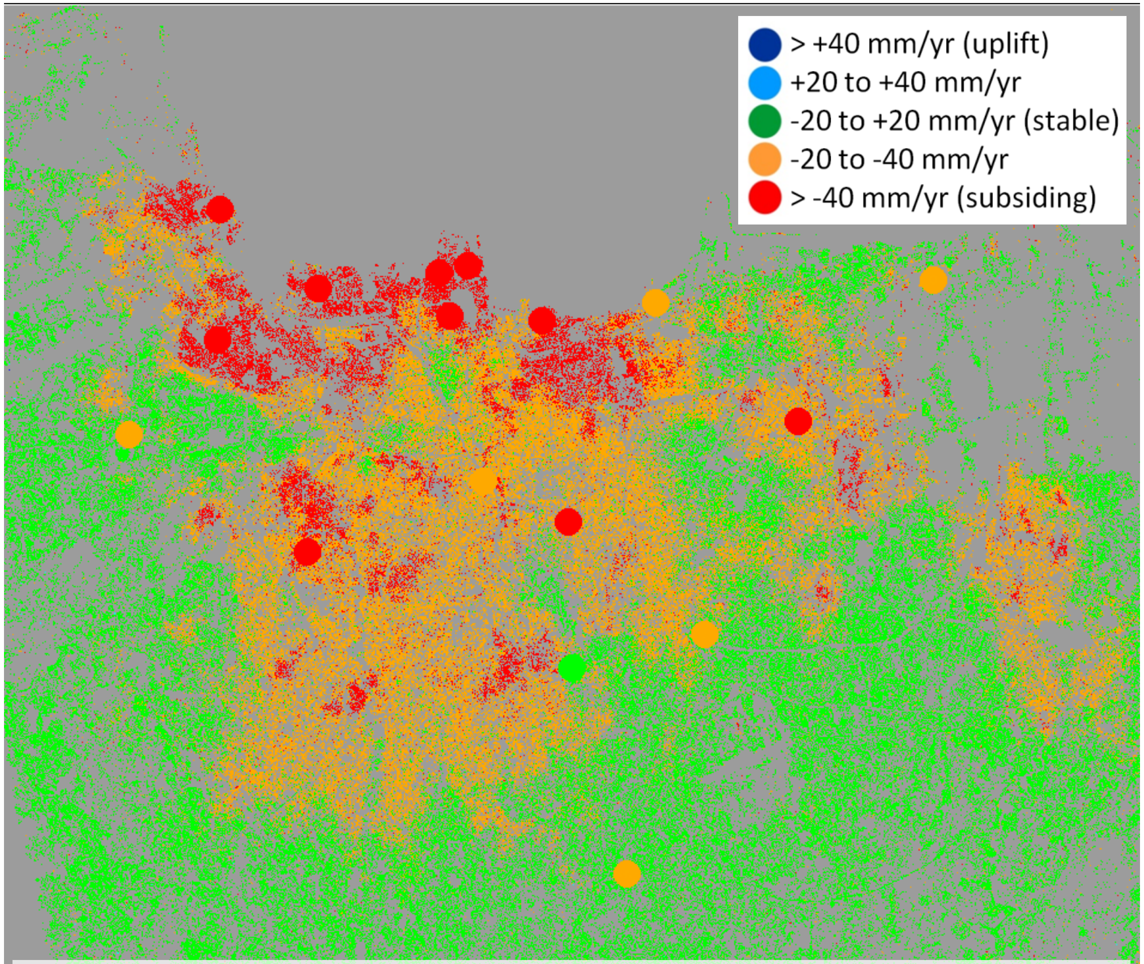


PSI – DifSAR comparison





PSI – GPS comparison



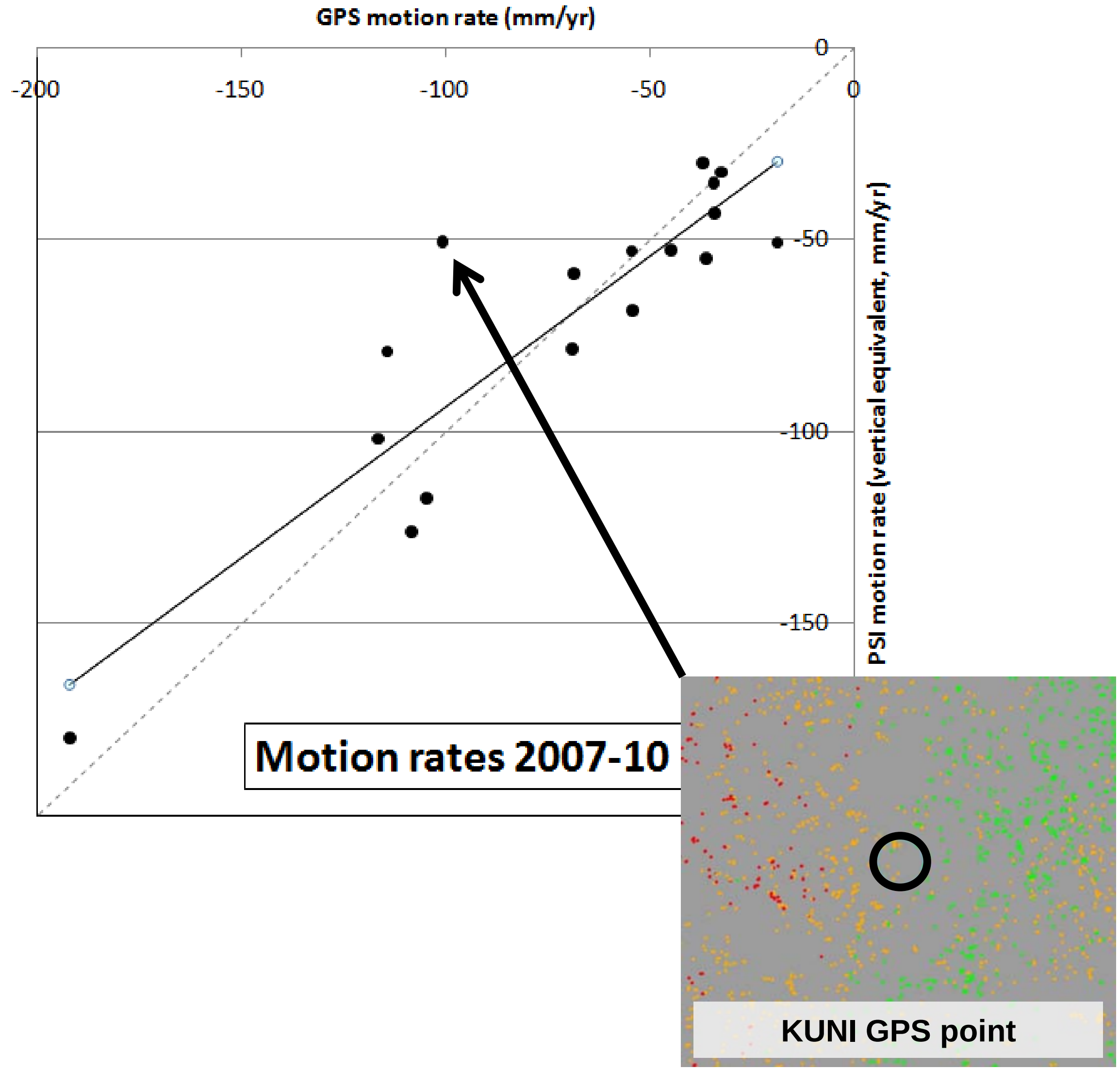
GPS point values (large circles) on PSI average annual velocity field.

- Yearly vertical displacements 2007-2010 available for 17 locations, each epoch errors < 10 mm (courtesy of Institute of Technology Bandung*).
- PSI averaged over 100 m radius to reduce impact of very small-scale deformation variations and noise.
- PSI reference point located 2.7 km from CDTB GPS point – corrected reference point offset of ~23 mm/yr.

***Abidin et al., Hat. Hazards, 2011, DOI 10.1007/s11069-011-9866-9**

PSI – GPS comparison

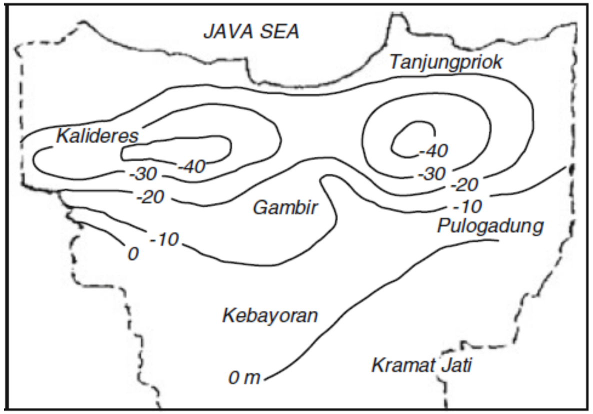
- After subtraction of reference point bias mean of -0.4 mm/yr and standard deviation of 19.7 mm/yr, of same order as accuracy of GPS data.
- Few outliers possibly due to very local variation in deformation, spatial averaging or slight temporal differences.
- Could also compare PSI time series with GPS epochs.
- Use of GPS for trend calibration would require wider distribution of points



Implications for Jakarta

- Four potential causes of subsidence in Jakarta (Abidin et al. 2011*):
  - Groundwater extraction
  - Construction loading
  - Compressible alluvium
  - Tectonic motion
- Huge increase in urban and industrial growth over past few decades
  - Increased demand for water abstraction
  - Exacerbated by urbanisation covering aquifer recharge areas
  - Declining levels of coastal aquifers risks seawater incursion
- Coastal location increases risk of flooding
  - Parts of Jakarta already prone to tidal flooding
  - Increasing land use pressures leading to further development of reclaimed coastal land

Lower Aquifer (140 - 250 m) in 1992




Tidal flooding in coastal Jakarta

***Abidin et al., Hat. Hazards, 2011, DOI 10.1007/s11069-011-9866-9**

Conclusions

- PALSAR PSI possible, though time-correlated baselines an issue with many data stacks. 18 images adequate with moderate baselines in flat areas.
- Large baselines don't prevent coherence, but do make careful height corrections necessary.
- Large deformation signals prevent noise reduction here, but would be interesting to see how much noise can be reduced in slower-deforming areas.
- Initial validation against GPS promising, but would be good to quantify further (including time series data) to get firm estimate of precision.
- Implications of strong subsidence important for future development of Jakarta, including ongoing groundwater abstraction and coastal development.

Thank You