Safeguard CO2 Storage Site with Radar Satellite Remote Sensing

应用雷达卫星遥感监测二氧化碳封存区的安全

Never Stand Still

School of Civil & Environmental Engineering

Dr. Linlin GE（葛林林）

A/Professor

Remote Sensing and Earth Observation

新南威尔士大学土木与环境工程学院

澳大利亚　　悉尼

Email: l.ge@unsw.edu.au

Web: www.gmat.unsw.edu.au/LinlinGe

Outline 提纲

- Introduction – radar satellite remote sensing
  雷达卫星遥感简介
- InSAR R&D
  雷达干涉技术的研发
- Radar satellite remote sensing of In Salah CCS site
  应用雷达卫星监测阿尔及利亚英萨拉的商业化天然气田和碳捕获与封存场
- Radar satellite remote sensing of Otway CCS site
  应用雷达卫星监测澳大利亚的奥特威CO2封存试验场
- Concluding remarks
  结 语

Radar satellite remote sensing 雷达卫星遥感

- Radar satellite

  雷达卫星
- SAR – Synthetic Aperture Radar

  合成孔径雷达
- InSAR – Interferometric SAR

  干涉合成孔径雷达技术
- DInSAR – Differential InSAR

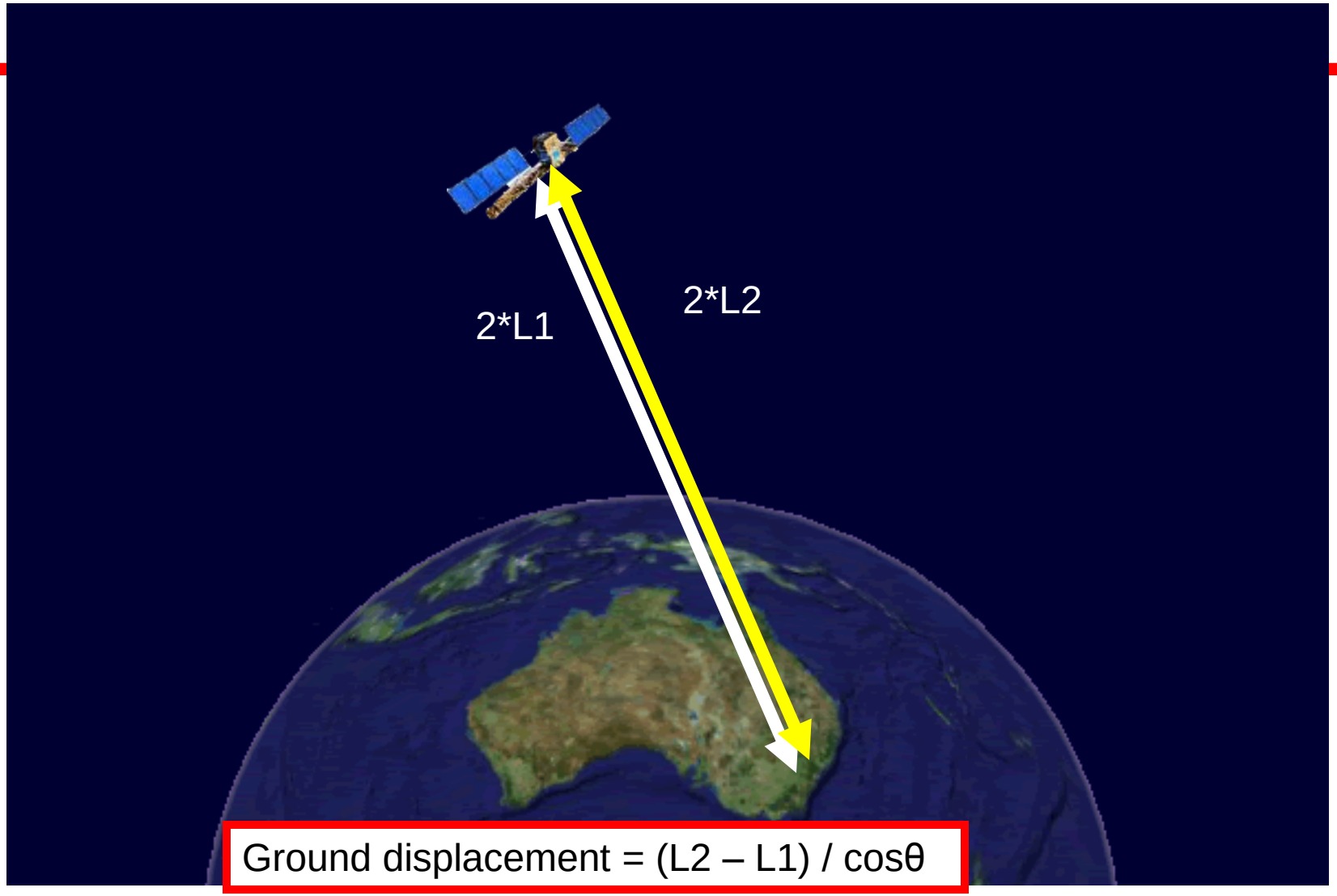
  差分干涉合成孔径雷达技术
- PSI – Persistent SAR Interferometry

  永久反射体雷达干涉技术

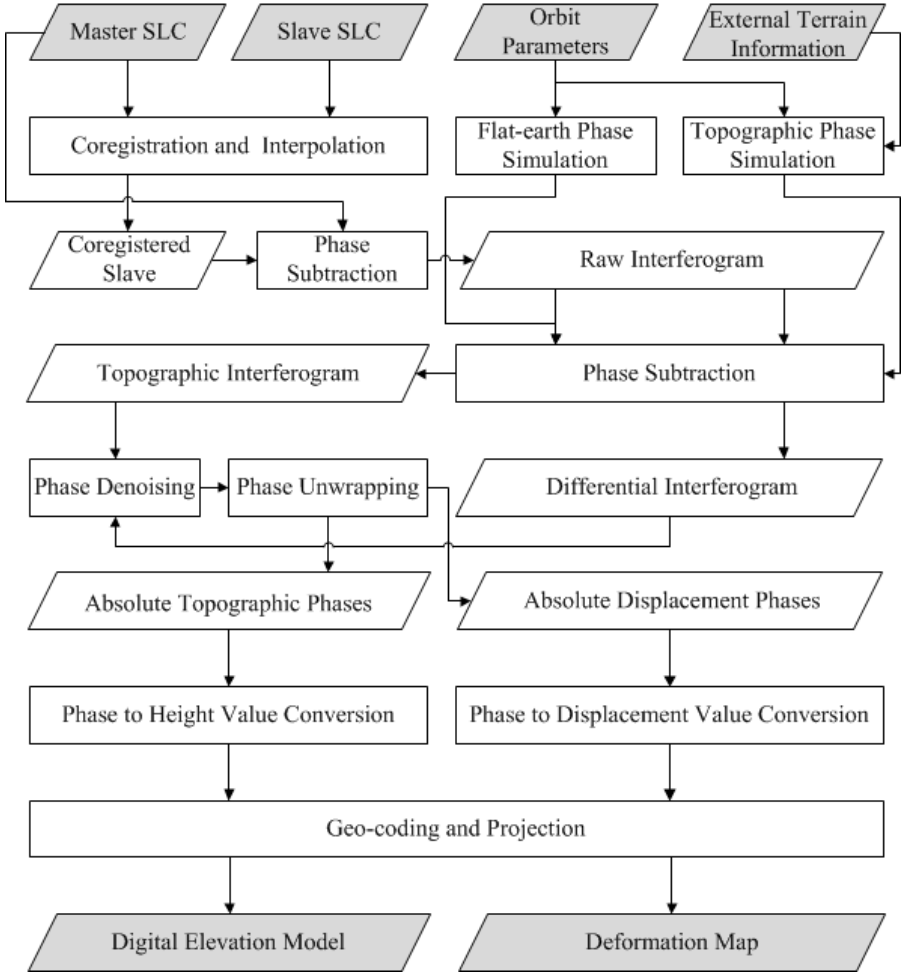
Radar satellite remote sensing

卫星雷达遥感

Differential Interferometric Synthetic Aperture Radar (DInSAR)
差分干涉合成孔径雷达技术



SAR Interferometry (InSAR and DInSAR)
雷达干涉及差分雷达干涉技术



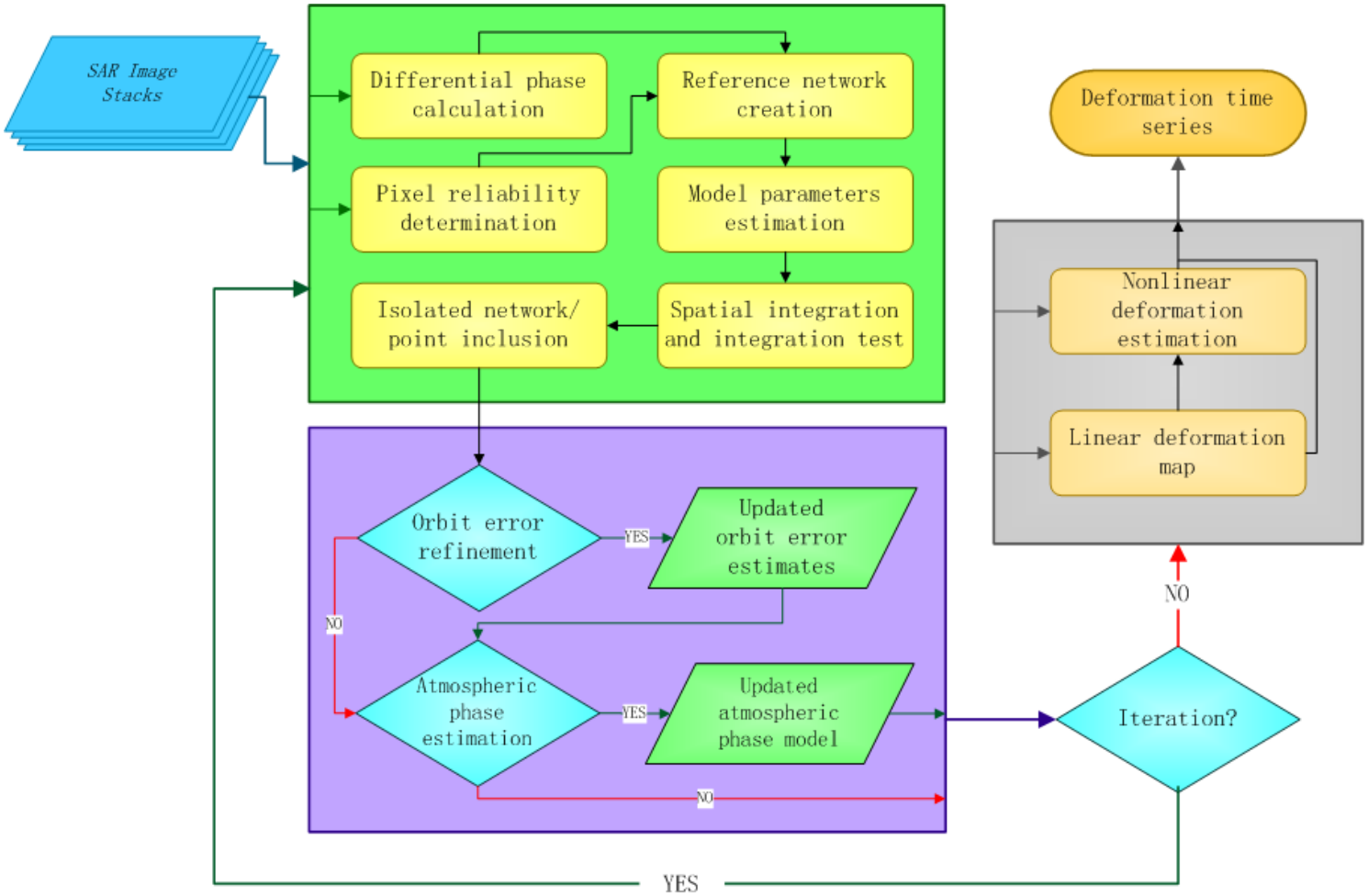
Persistent Scatterers 雷 达 永 久 反 射 体

Natural

Man-made

Fabricated

Key processing steps of PSI technique
永久反射体雷达干涉技术



InSAR R&D – feasibility studies　雷 达 干 涉 可 行 性 研 究

- Mine subsidence monitoring

  矿**区沉降**监测

- High-speed railway track stability

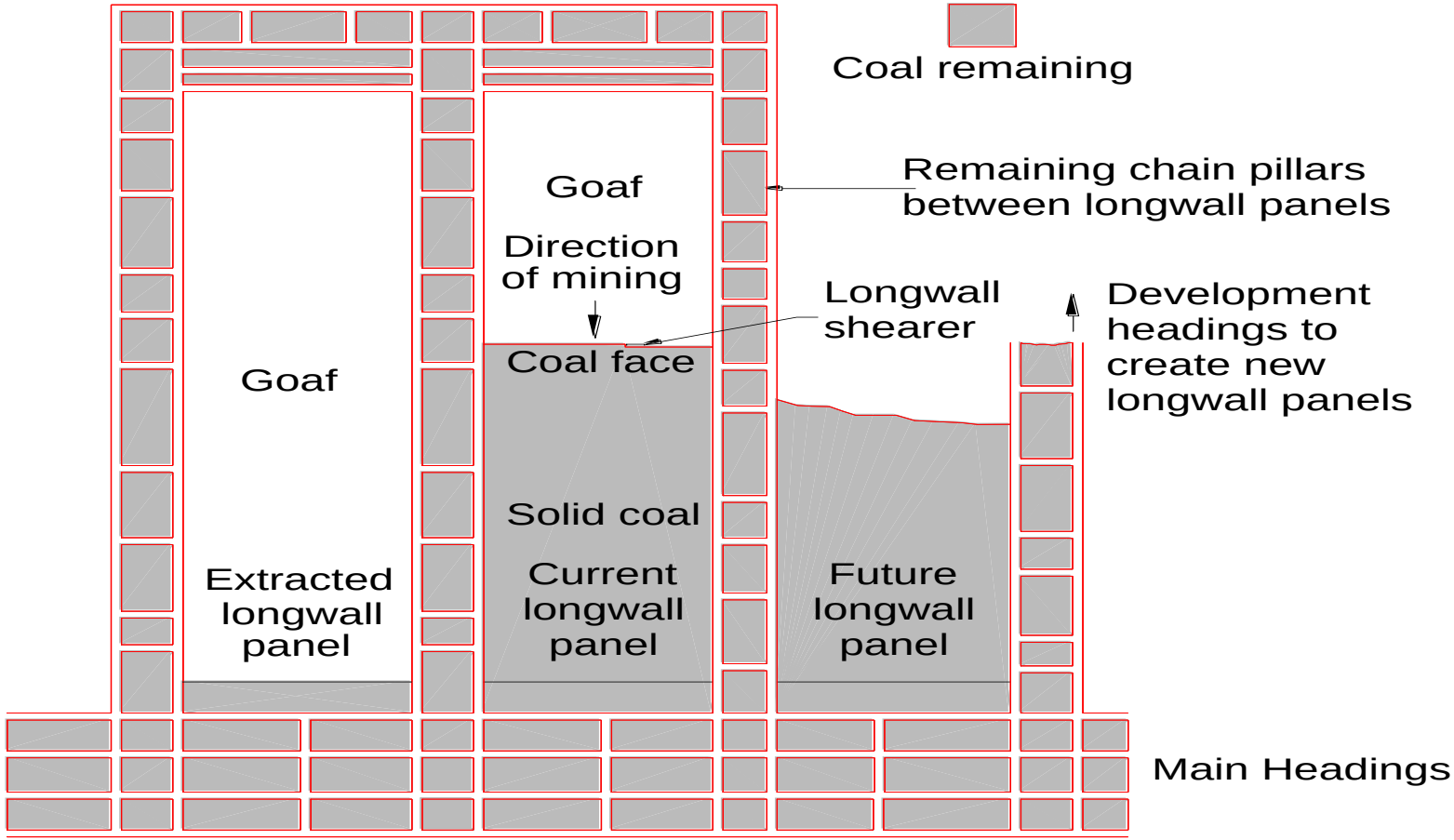
  高铁稳**定性**监测

- 2008 Sichuan Earthquake

  2008年汶川特大地震近实时监测

Typical Plan View of Longwall Panels

长壁采煤



Mining Subsidence 采矿沉降

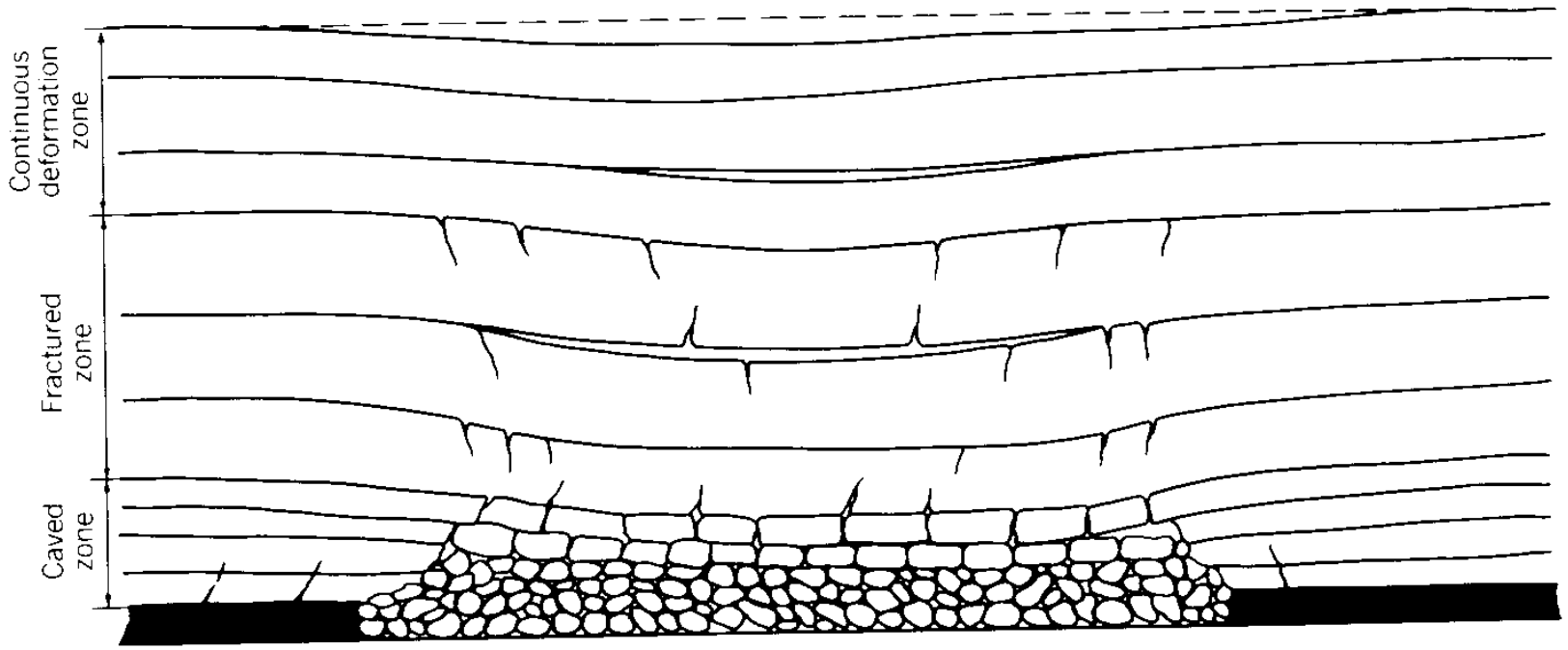
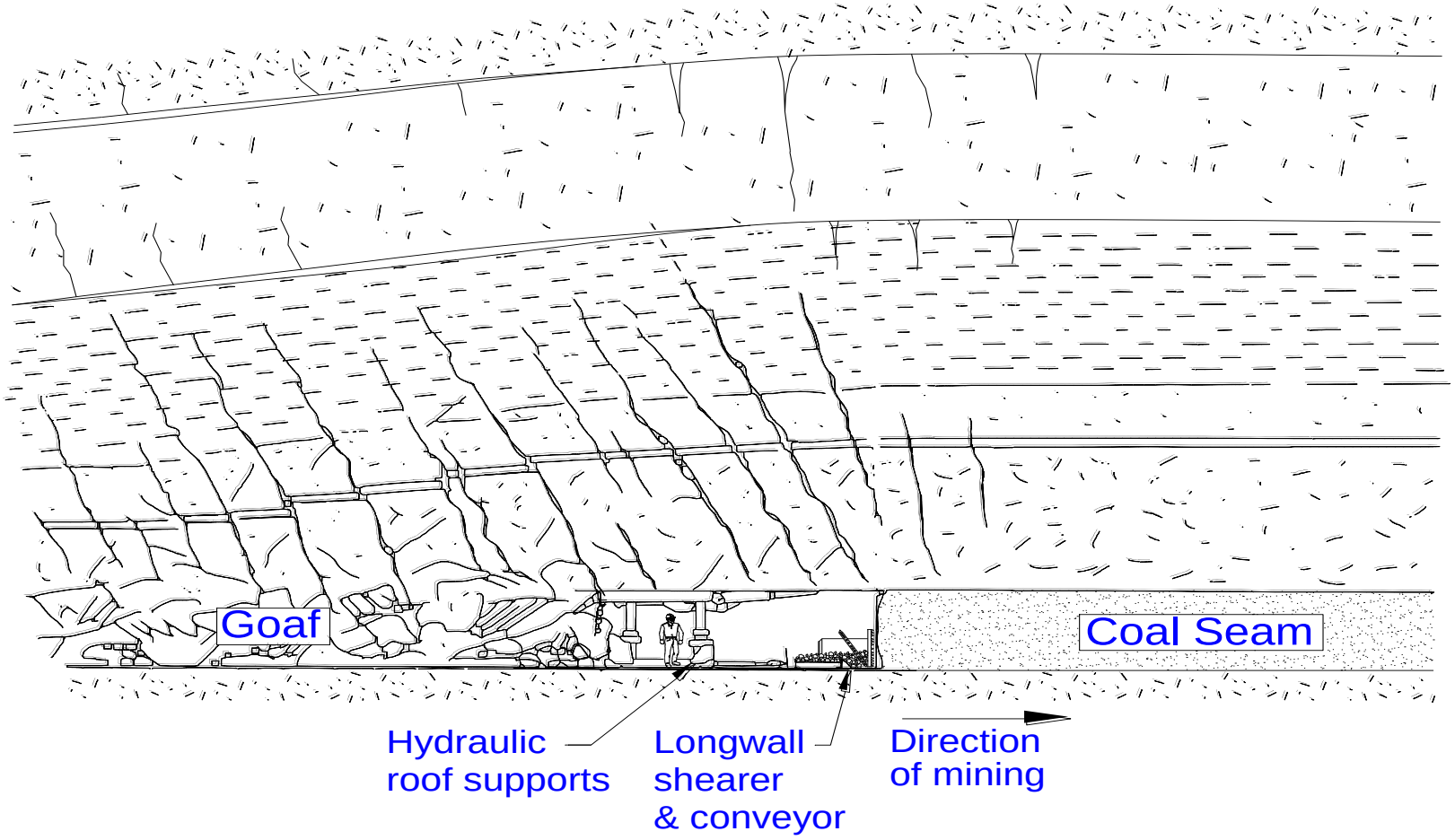
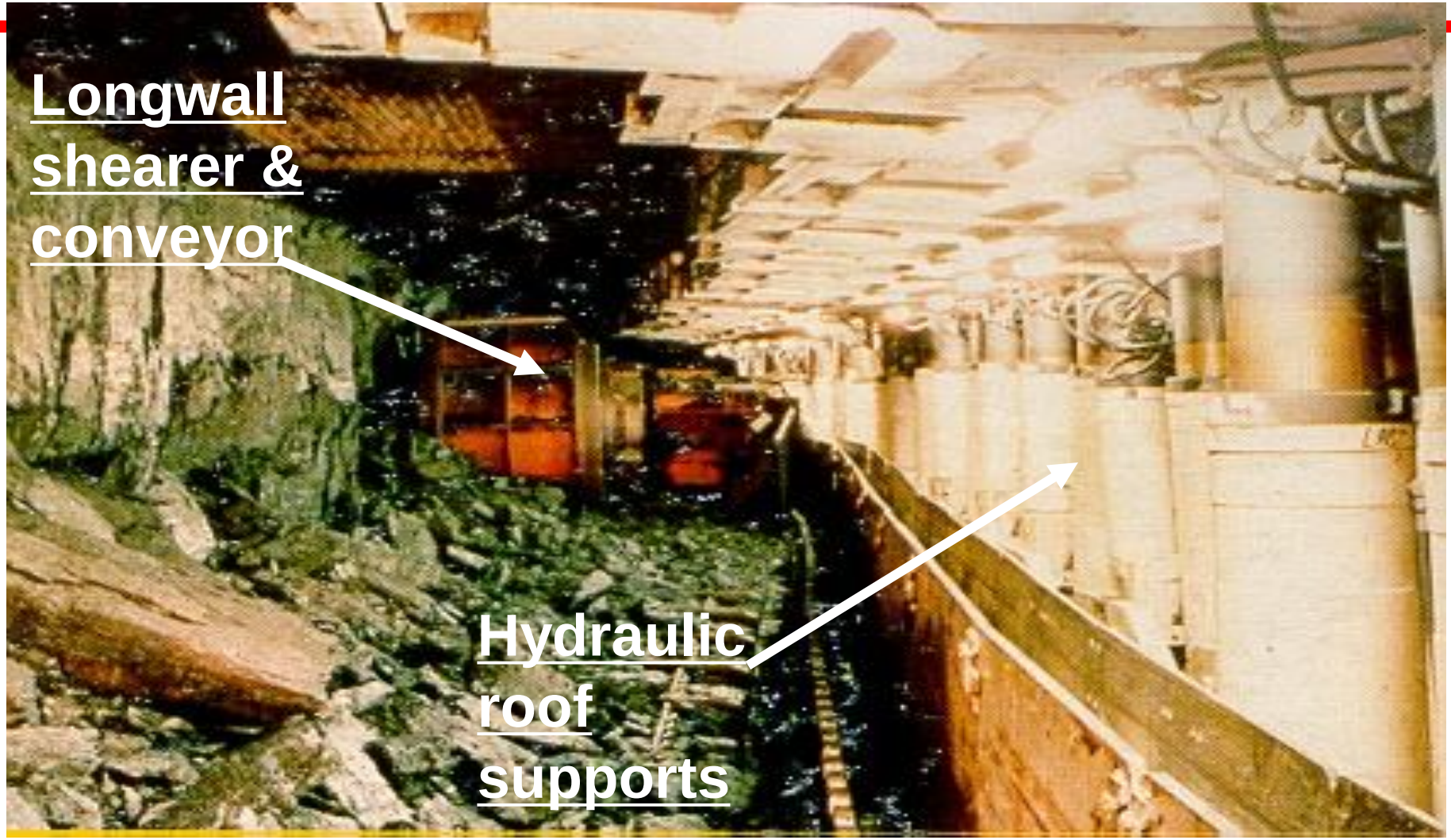


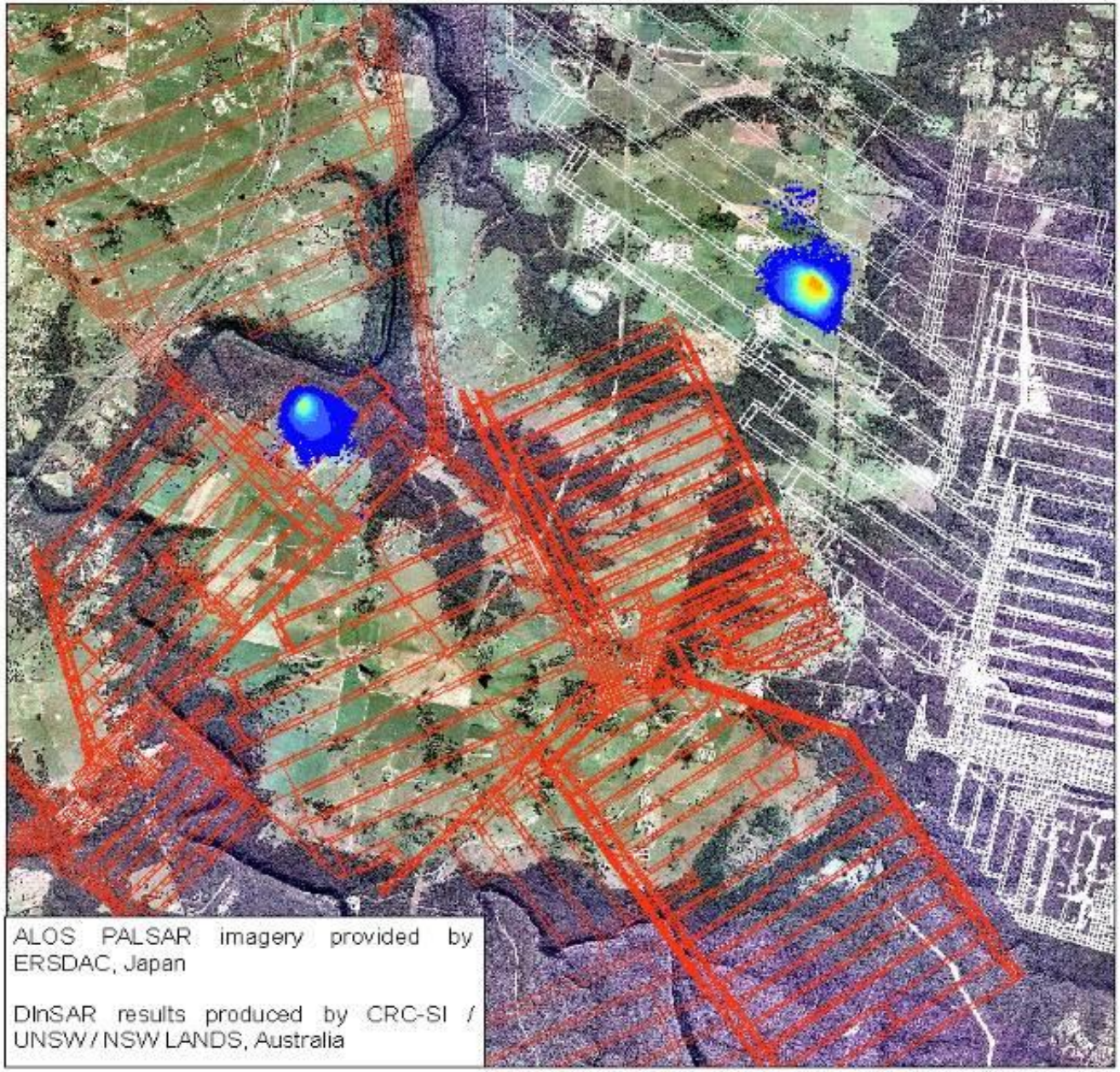
Fig. 8.4.1 Three zones in overburden due to longwall mining (Peng and Chiang, 1984).

Cross Section of a Typical Longwall Face 長壁剖面



Longwall Face 采煤工作面





Period:

06/02/2008 ~ 23/03/2008

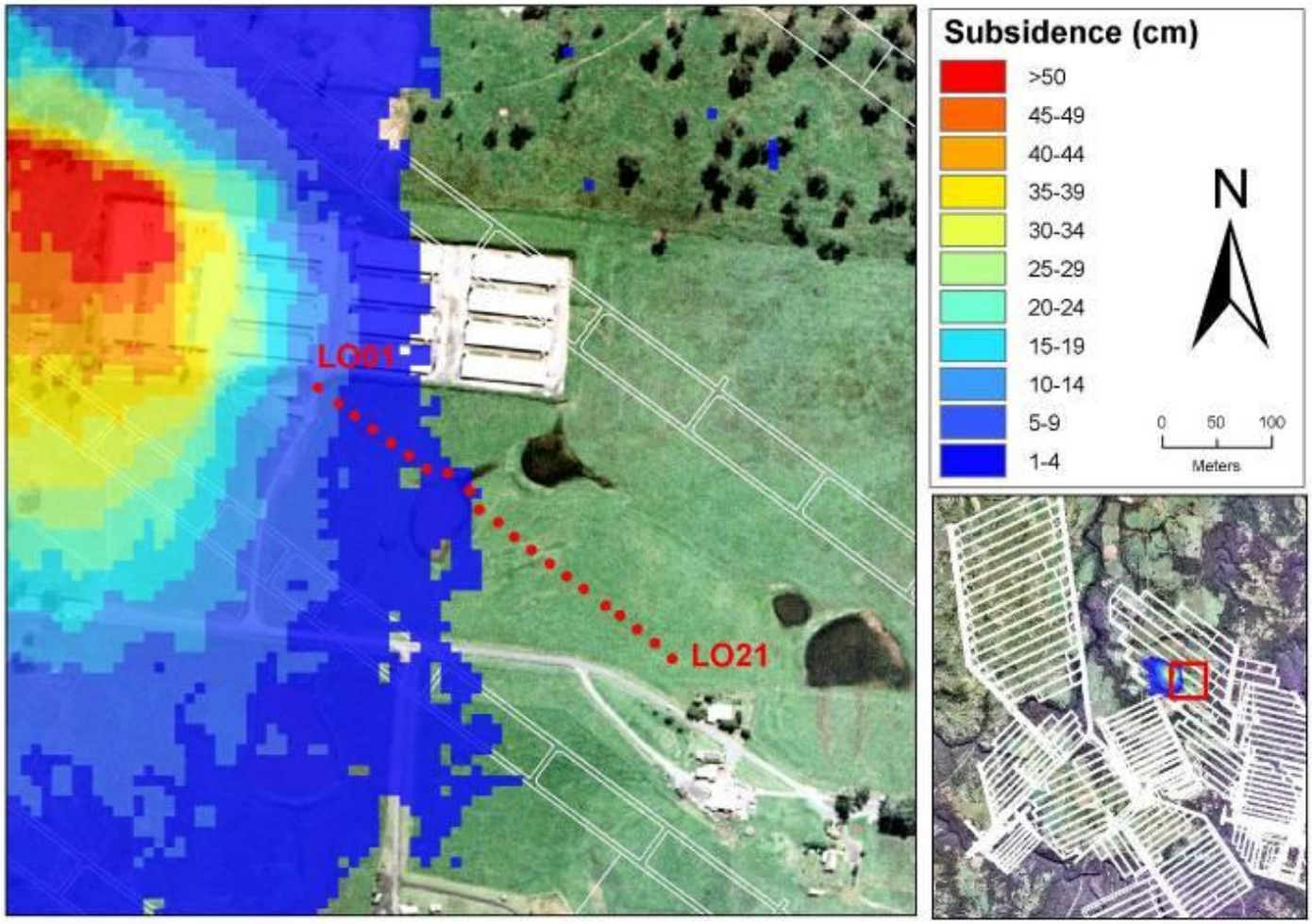
Perpendicular baseline:

-127m

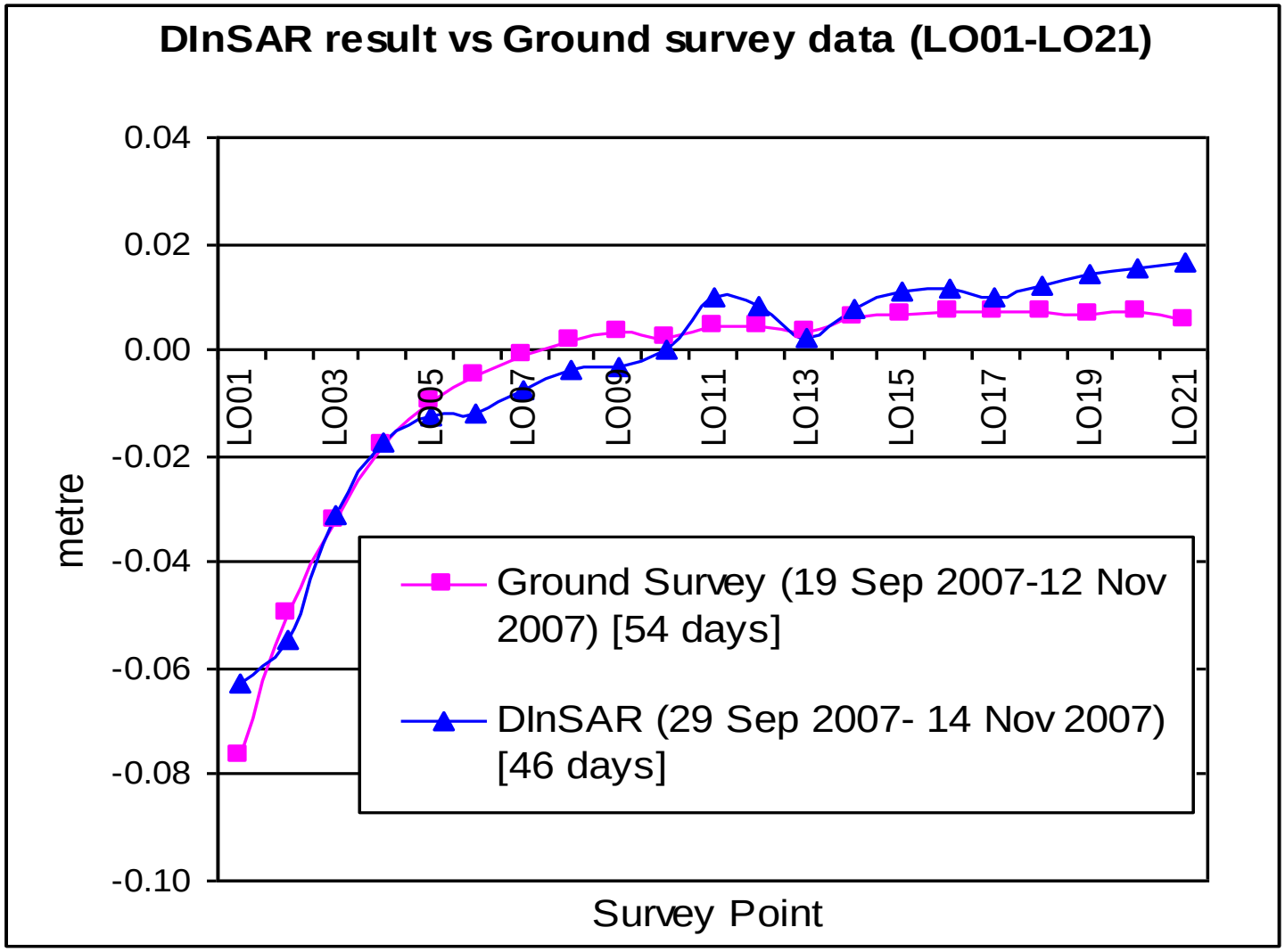
Temporal baseline:

46days

Validation – Westcliff 遥感与地面测量比对



Validation - Westcliff



ALOS image dates

- 29 Sept 2007
- 14 Nov 2007

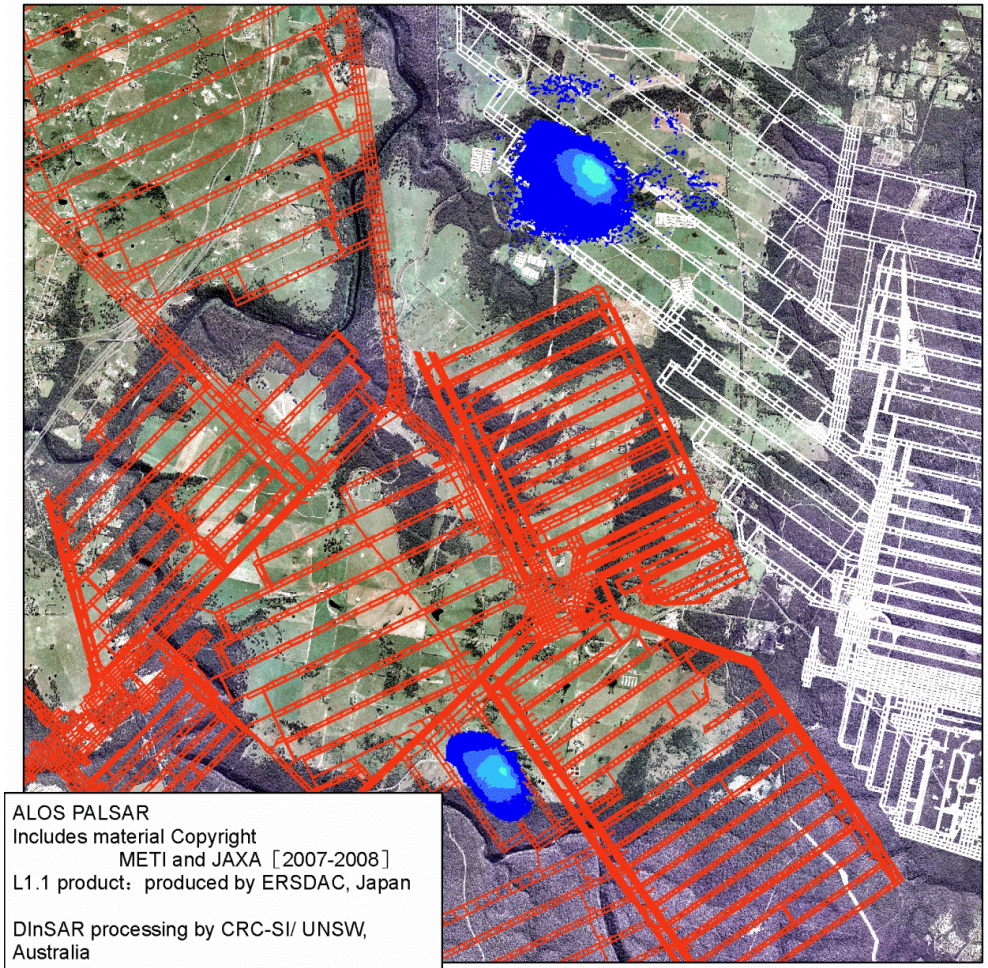
Ground survey dates

- 19 Sept 2007
- 12 Nov 2007

RMSE = 6 mm

比测精度

ERSDAC - Japanese satellite operator
日本卫星运作单位



Subsidence (cm)

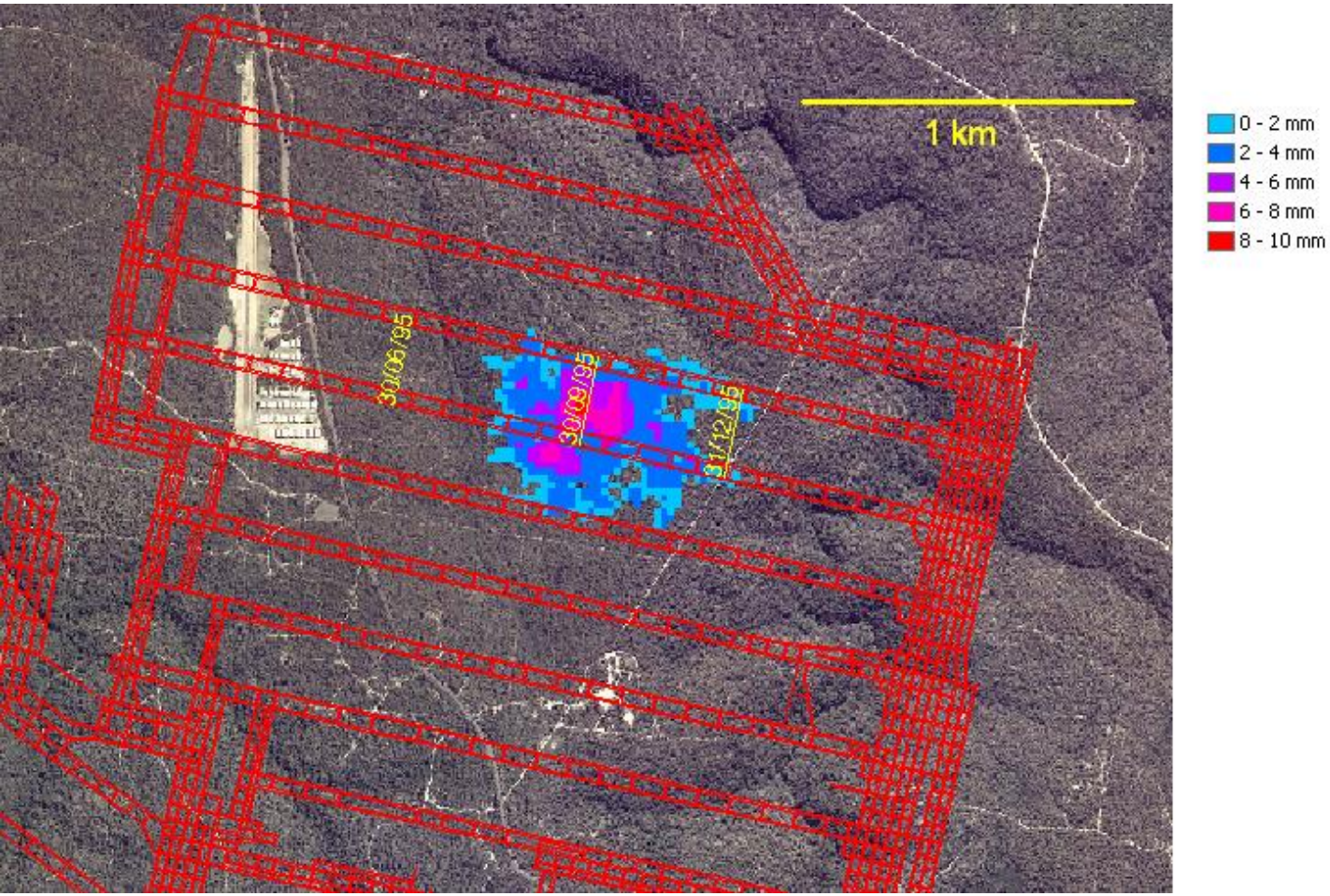
- >80
- 70-80
- 60-70
- 50-60
- 40-50
- 30-40
- 20-30
- 10-20
- 0-10

N

0 500 1,000
Meters

29/06/2007		
	14/08/2007	46 days
	29/09/2007	92 days
	14/11/2007	138 days
	30/12/2007	184 days
	14/02/2008	230 days
	31/03/2008	276 days

Ground movement in 24 hours – ERS tandem DInSAR
欧洲空间局ERS串飞卫星监测地表24小时内沉降



- Master: 29 October 1995, ERS-1; Slave: 30 October 1995, ERS-2;
- Remarkable result of subsidence in 24 hours;
- DLR
- IAEA
- A constellation of InSAR satellites

Stability of high-speed railway tracks 高铁稳定性监测

Subsidence in Yuyao - 11 November 2005 余姚铁路沉降

- Rail transport between Shanghai and Ningbo was adversely affected after more than 100 meters of railway track suddenly subsided

BTR - “zero tolerance” on subsidence 京津高铁沉降容限

- <3mm at the railway bases
- < 2cm over 20m length
- For the bridge, the allowance of the maximum subsidence is 2cm, and the deformation between neighbouring piers must be less than 0.5mm

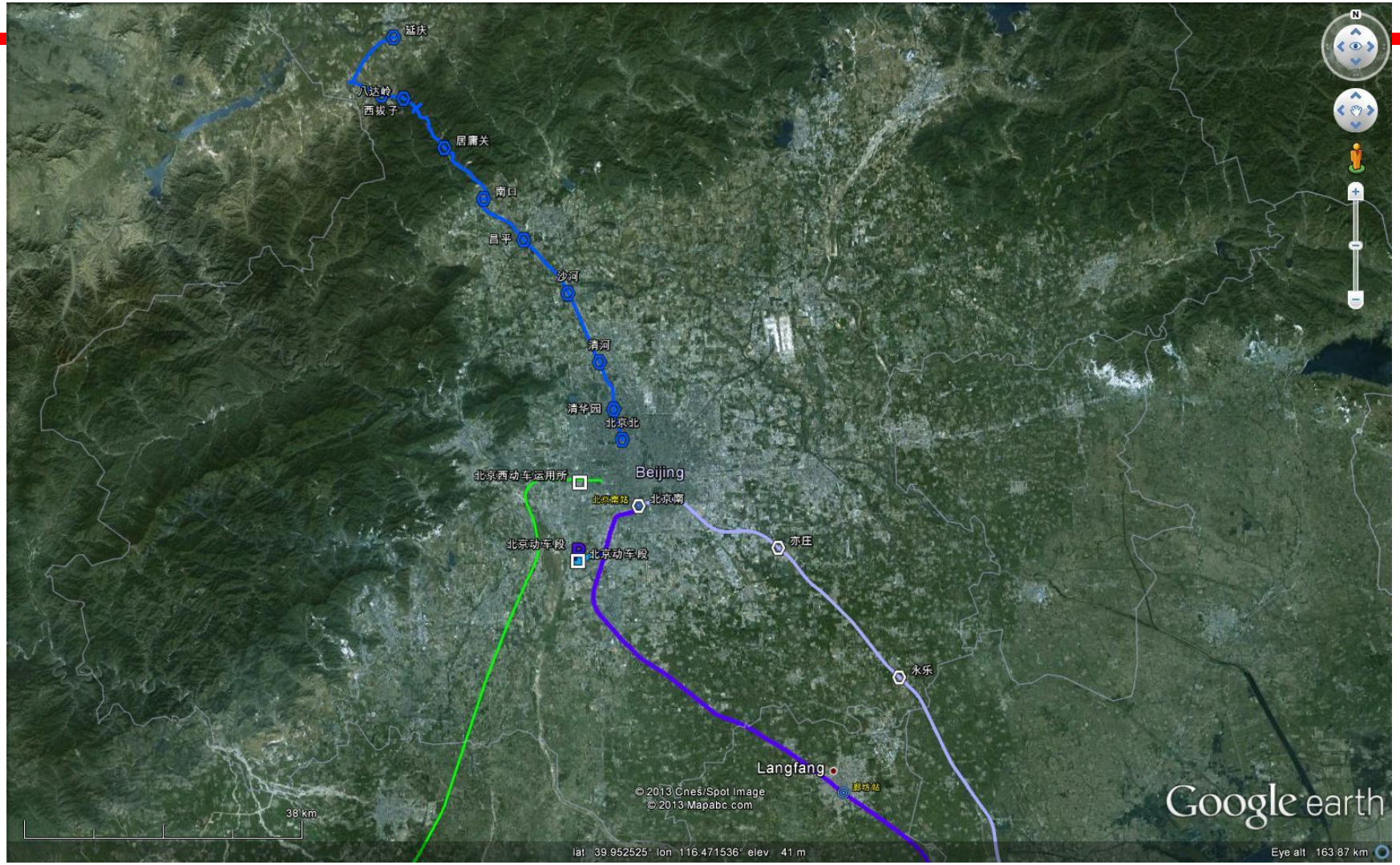
Elevated bridge based design

- Extensive use of railway viaducts
- Over a total length of 113 km of the railway, about 100.17km are elevated on viaducts
- 90% of the whole railway travelling at the high speed in the corridor in the air

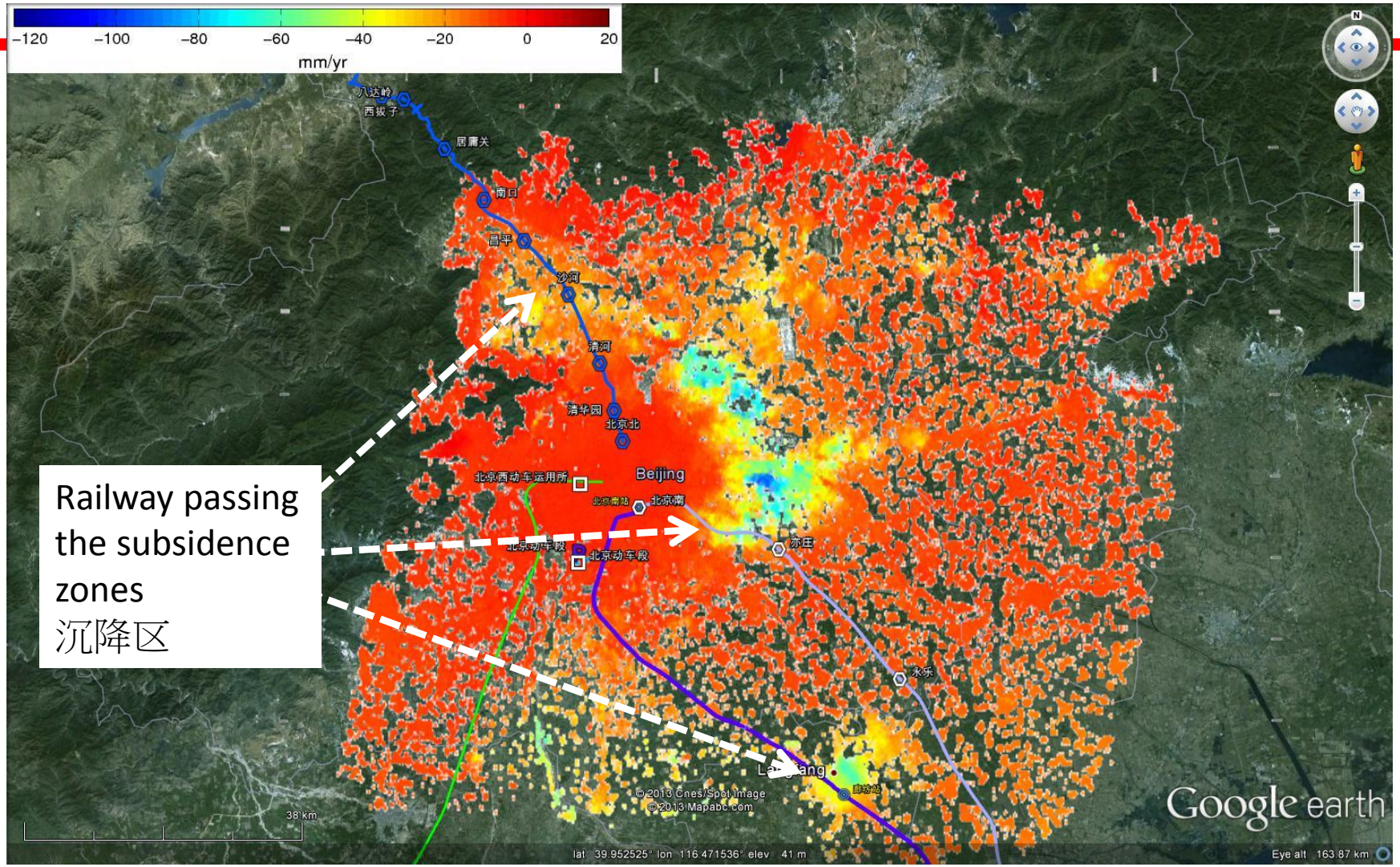
Railway Viaduct

铁路高架桥

Monitoring highway and high speed railway in Beijing
北京主要铁路线



Monitoring highway and high speed railway in Beijing

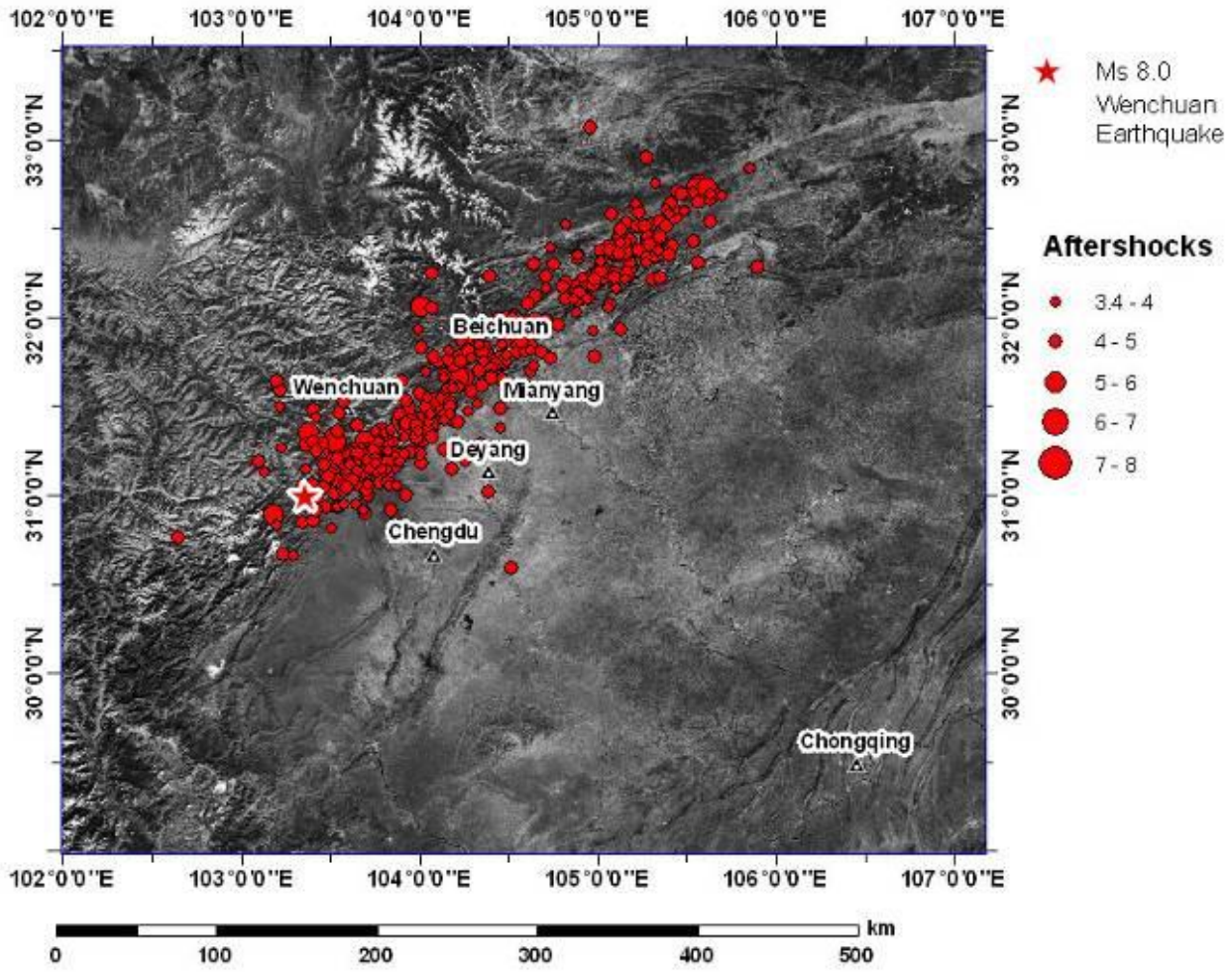


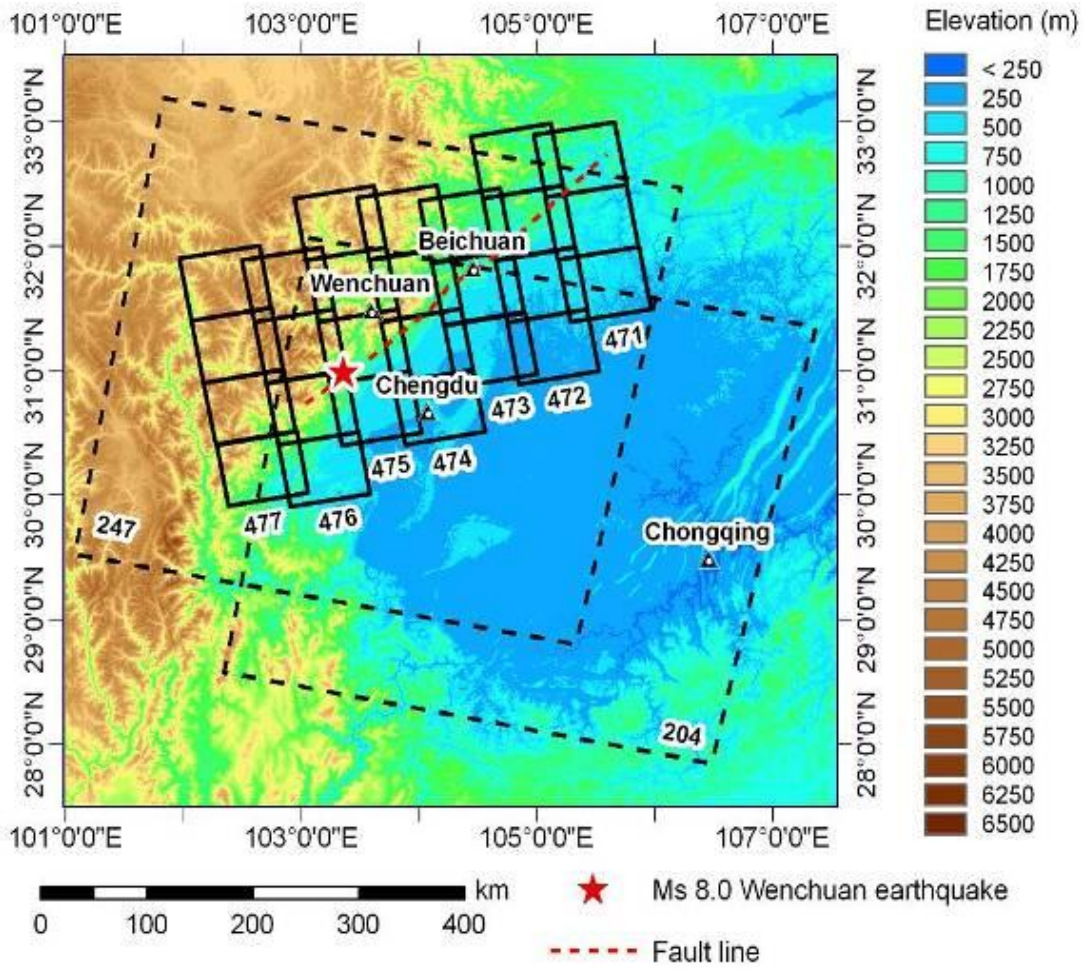
Near real-time mapping of the 2008 Sichuan Earthquake
2008年汶川特大地震近实时监测

- 12 May 2008 14:28:01.42 CST
- Ms 8.0
- More than 80,000 people killed
- "Experts Estimate Over $75 Billion Economic Loss"

2008 Sichuan Earthquake, China 汶川地震

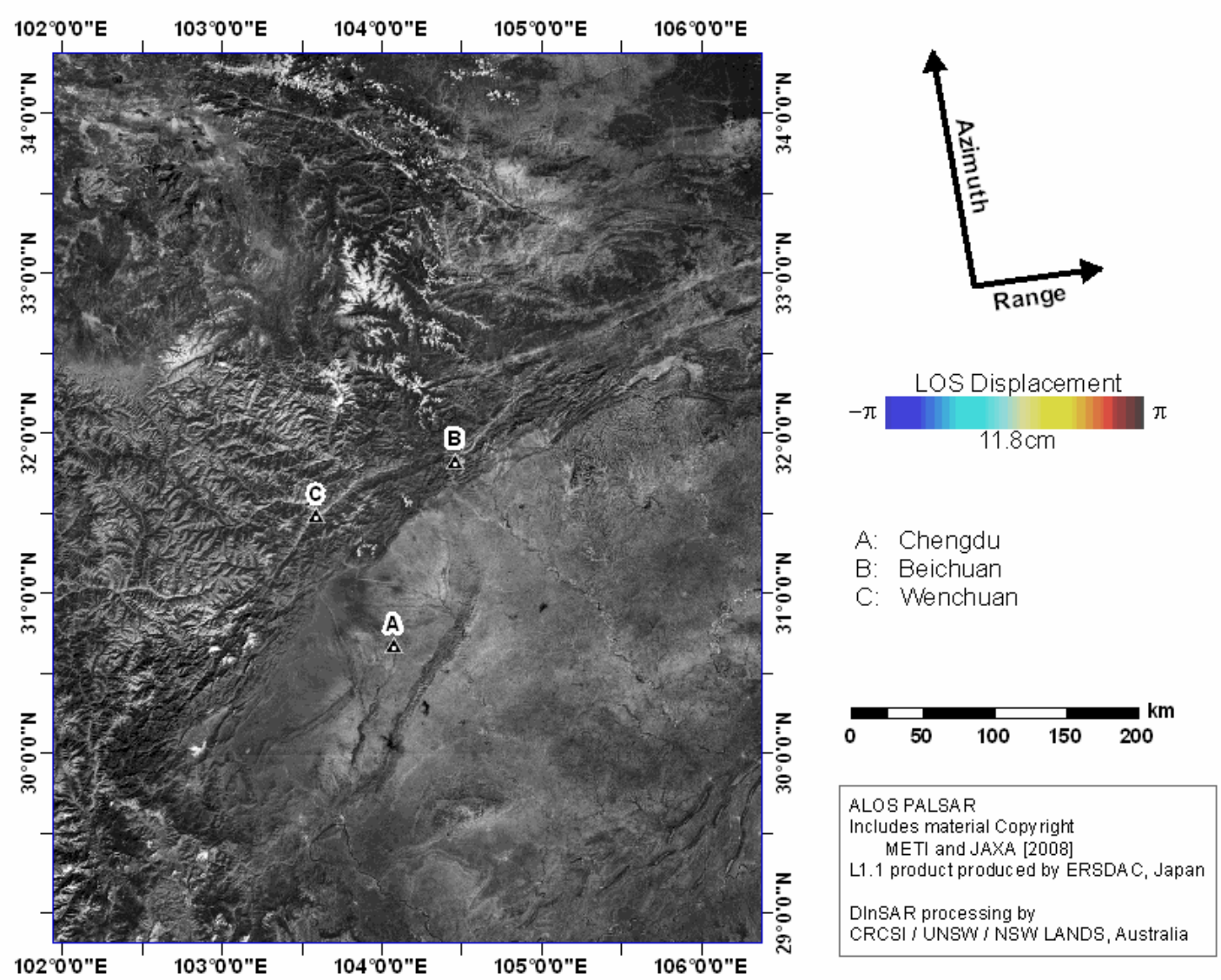
> 600 Aftershocks!　　600多次余震





Mapping the 12 May 2008 Sichuan Earthquake with InSAR

调用欧空局、日本两颗卫星

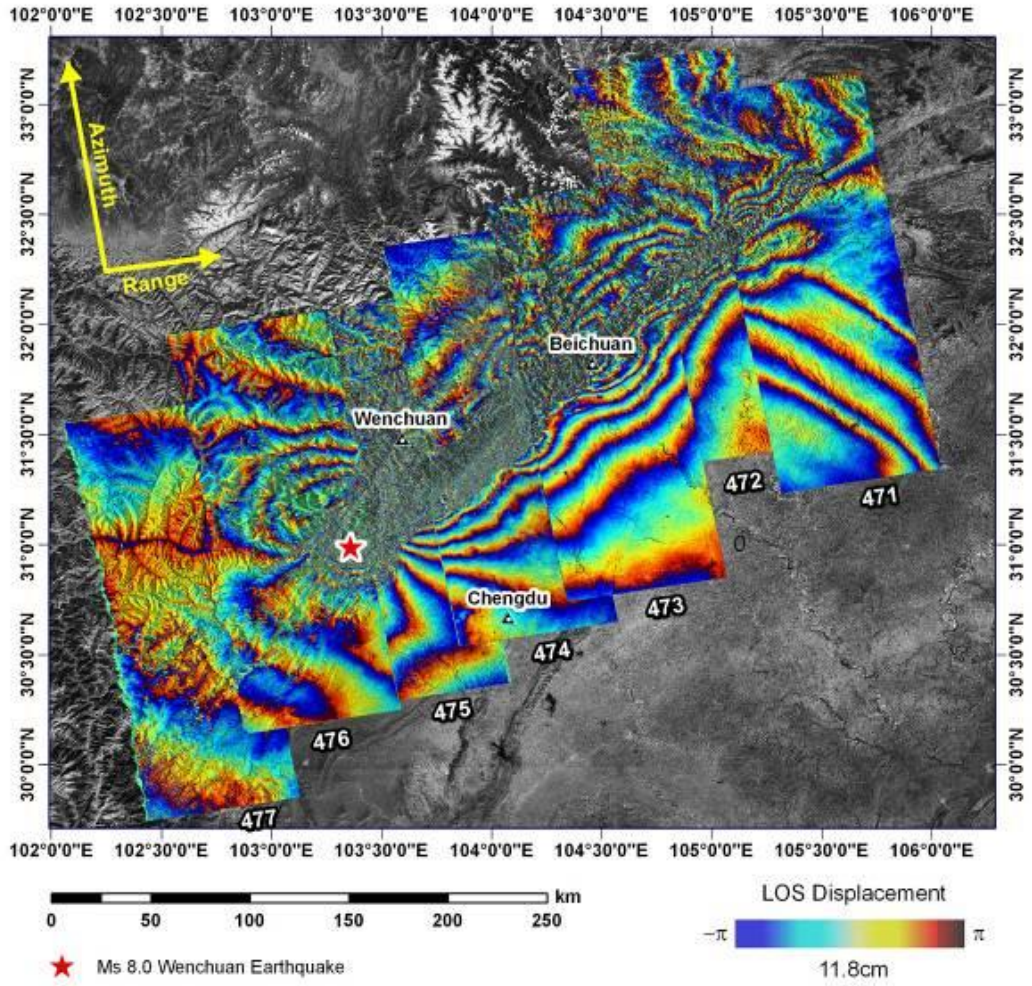


Post-seismic acquisitions:

473: 19 May 2008 476: 24 May 2008 471: 31 May 2008 474: 5 June 2008

477: 10 June 2008 472: 17 June 2008 475: 22 June 2008

Took > 1 month!



ALOS/PALSAR DInSAR results

* delivered and applied in near real-time (CEA, NDRCC)
被中国地震局、民政部使用

* made news around the world
引起全球媒体关注

Integrated radar and optical satellite remote sensing for safeguarding carbon capture and storage

基于雷达及光学卫星遥感集成的二氧化碳捕集与封存安全监测

Project Leader: Linlin Ge (葛林林)

- Australian participants 澳大利亚参加单位
  - UNSW - University of New South Wales, Sydney, Australia (新南威尔士大学)
  - CO2CRC - Cooperative Research Centre for Greenhouse Gas Technologies (国家温室气体技术合作研究中心)
- Chinese participants 中国参加单位
  - NRC - National Research Centre, State Administration of Work Safety (国家安全生产监督总局研究中心)
  - IRSM - Institute of Rock and Soil Mechanics, Chinese Academy of Sciences (中国科学院岩土力学研究所)
  - Shenhua - Shenhua Group Corporation & Shenhua Energy Company Limited (神华集团有限责任公司 暨 中国神华能源股份有限公司)
  - CRESDA - Centre for Resources Satellite Data and Application (中国资源卫星中心)

- Satellite technologies
  - Optical – vegetation stress
  - Radar – ground deformation
- 所用卫星技术
  - 光学 – 植被变异监测
  - 雷达 – 地表形变监测

- Carbon capture and storage (CCS) site selection
- CO2 migration monitoring and modelling
- Long-term impact monitoring
- 二氧化碳捕集与封存选址
- CO2 迁移监测与模拟
- 长期稳定性监测

- Study sites
  - Otway, Iona, …
  - Ordos, Liulin, …
- 监测试验场
  - 奥特威、艾奥纳
  - 鄂尔多斯、柳林

Satellite Radar Remote Sensing
雷达卫星遥感

Key techniques developed
关键技术研发 – UNSW-GEOS

- DInSAR - differential interferometric synthetic aperture radar
- PSI - persistent scatterer interferometry
- APSI – advanced PSI

- 差分合成孔径雷达干涉技术
- 永久散射体雷达干涉技术
- 高级永久散射体雷达干涉技术

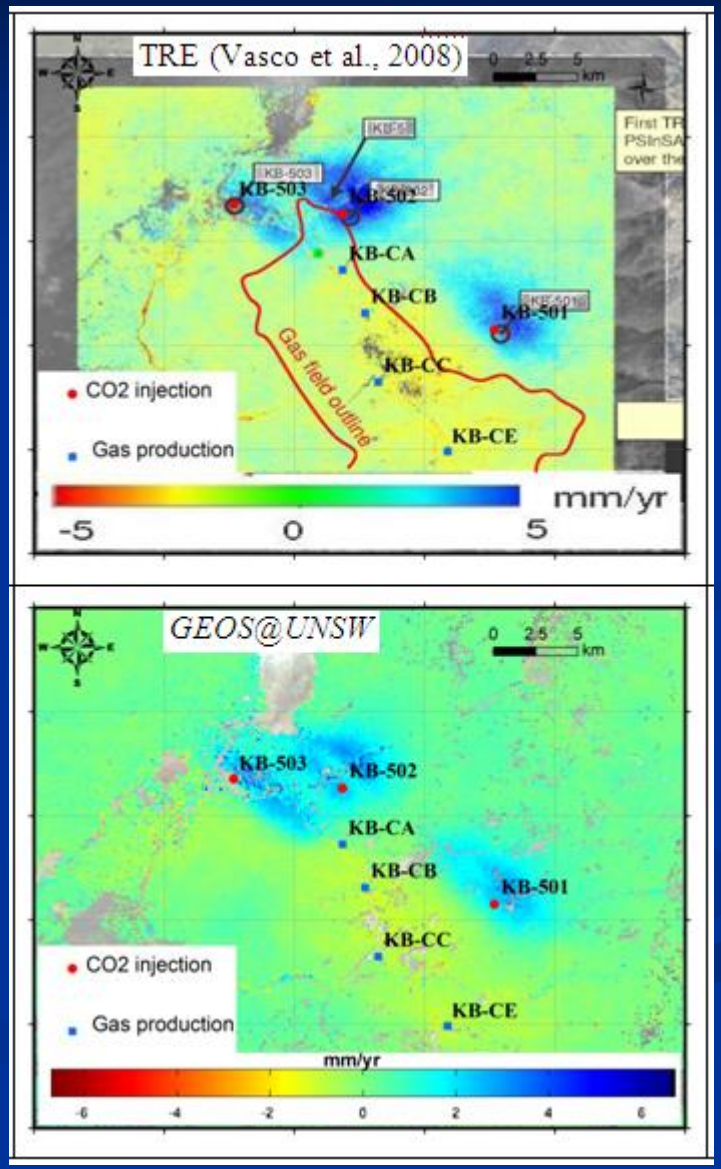
Selected results
代表性结果

Satellite Radar Remote Sensing
雷达卫星遥感

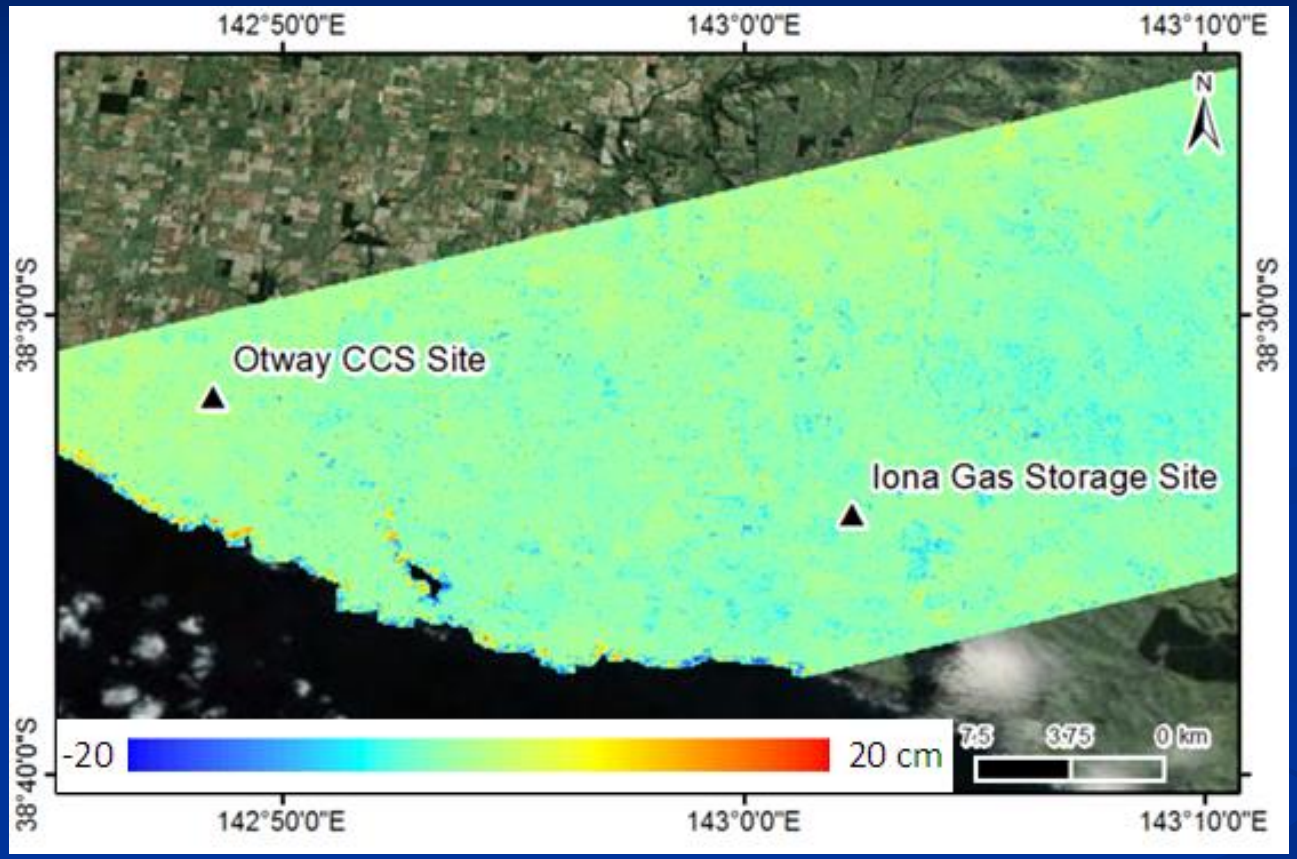
In Salah CCS and Gas Field
PSI: UNSW vs TRE

阿尔及利亚英萨拉的
商业化天然气田
和碳捕获与封存场

UNSW与国际同行结果对比



Satellite Radar Remote Sensing
雷达卫星遥感



DInSAR: Otway & Iona, Australia

澳大利亚的奥特威碳捕获与封存场

艾奥纳的天然气贮存场

Concluding remarks 结语

- Potential CO2 leakage has to be carefully monitored

  我们应该密切监测封存区潜在的CO2泄漏
- Radar satellite remote sensing can be used as a highly sensitive, cost-effective, and long-term monitoring technique to complement ground-based and aerial surveys at CCS sites

  雷达卫星遥感可以作为一个高度敏感、具有成本效益的长期监测技术，与地面和航空CCS监测互补
- DInSAR with ERS Tandem achieved 2mm resolution at a test site

  DInSAR技术结合ERS卫星串飞数据在某试验场达到了2毫米分辨率
- PSI with multi-year radar satellite data has successfully measured uplift and subsidence at the In Salah CCS site

  PSI技术结合多年雷达卫星数据已成功在阿尔及利亚英萨拉的商业化天然气田和碳捕获与封存场测量到由于二氧化碳注入所致隆起和天然气开采引起的沉降
- PSI with multi-year radar satellite data has been successfully applied to the Otway CCS site but did not detect ground heave due to CO2 injection

  PSI技术结合多年雷达卫星数据已成功地应用于奥特威CO2封存区，但没有检测到由于二氧化碳注入所致地面隆起
- Diverse applications: urban subsidence (groundwater extraction and tunnelling), mine subsidence, earthquake and landslide monitoring, etc

  极为广泛的应用：城市沉降（地下水开采和隧道工程），矿区沉降，地震、山体滑坡监测等

Acknowledgement 致 谢

- DRET / JCG
- 澳大利亚资源、能源及旅游部 -中澳清洁煤协调小组

- Australian Research Council
- 澳大利亚研究基金会会

- Cooperative Research Centre program
- 澳大利亚合作研究中心计划

- Geoscience Australia
- 澳大利亚地球科学组织

References

- **Ge, L.,** H-C Chang and C Rizos, 2007. Mine Subsidence Monitoring Using Multi-source Satellite SAR Images, *Photogrammetric Engineering and Remote Sensing* (PE & RS), 73(3), 259-266.

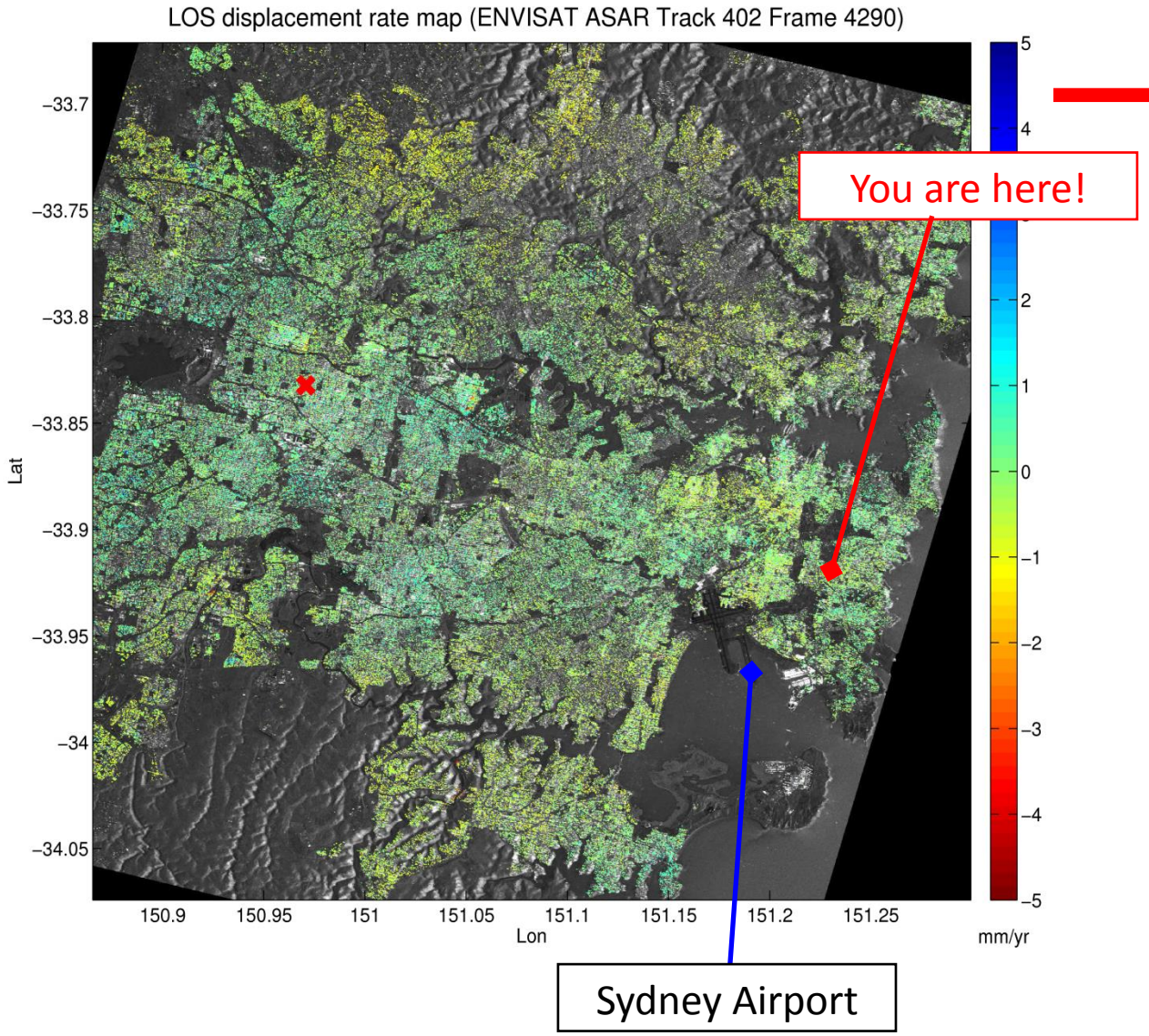
- **Ge, L.,** X. Li, C. Rizos, and M. Omura, 2004. GPS and GIS Assisted Radar Interferometry. *Photogrammetric Engineering and Remote Sensing (PE & RS)*, Vol. 70, No. 10, 1173-1178.

- Zhang, K., **Ge, L.,** Li, X. and Ng, A. H.-M., 2013. Monitoring ground surface deformation over the North China Plain using coherent ALOS PALSAR differential interferograms, *Journal of Geodesy*, 87(3), 253-265. DOI:10.1007/s00190-012-0595-y.

- Ng, A.H.M., **L. Ge,** X. Li, H. Z. Abidin, H. Andreas, K. Zhang, 2012. Mapping Land Subsidence in the Jakarta city, Indonesia using Persistent Scatterer Interferometry (PSI) Technique with ALOS PALSAR, *International Journal of Applied Earth Observation and Geoinformation,* 18, 232 - 242. doi:10.1016/j.jag.2012.01.018.

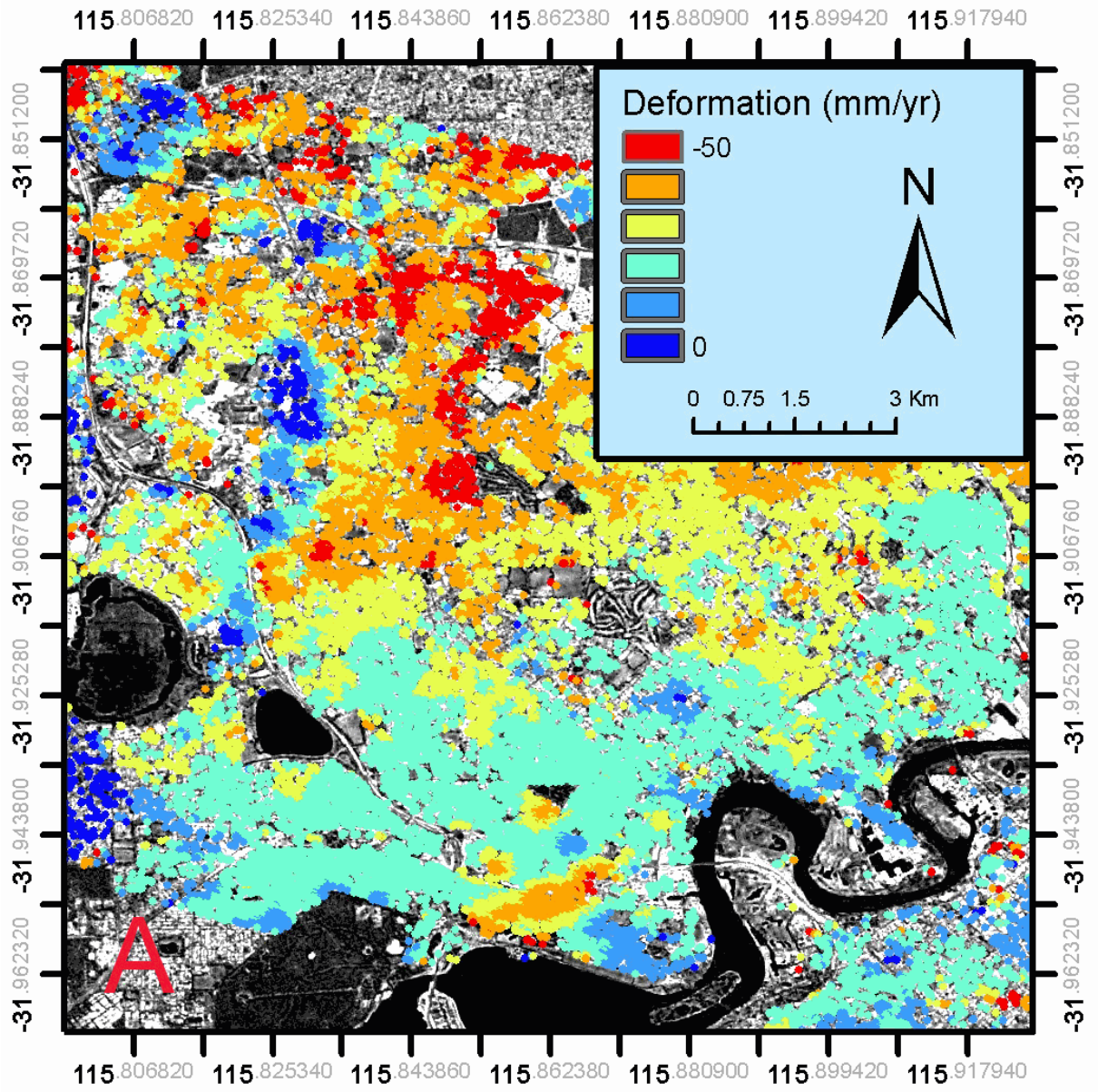
- Ng, A.H.M., **L. Ge,** X. Li, K. Zhang, 2012. Monitoring ground deformation in Beijing, China with Persistent Scatterer SAR Interferometry, *Journal of Geodesy,* 86(6): 375 - 392*,* DOI 10.1007/soo190-011-0525-4.

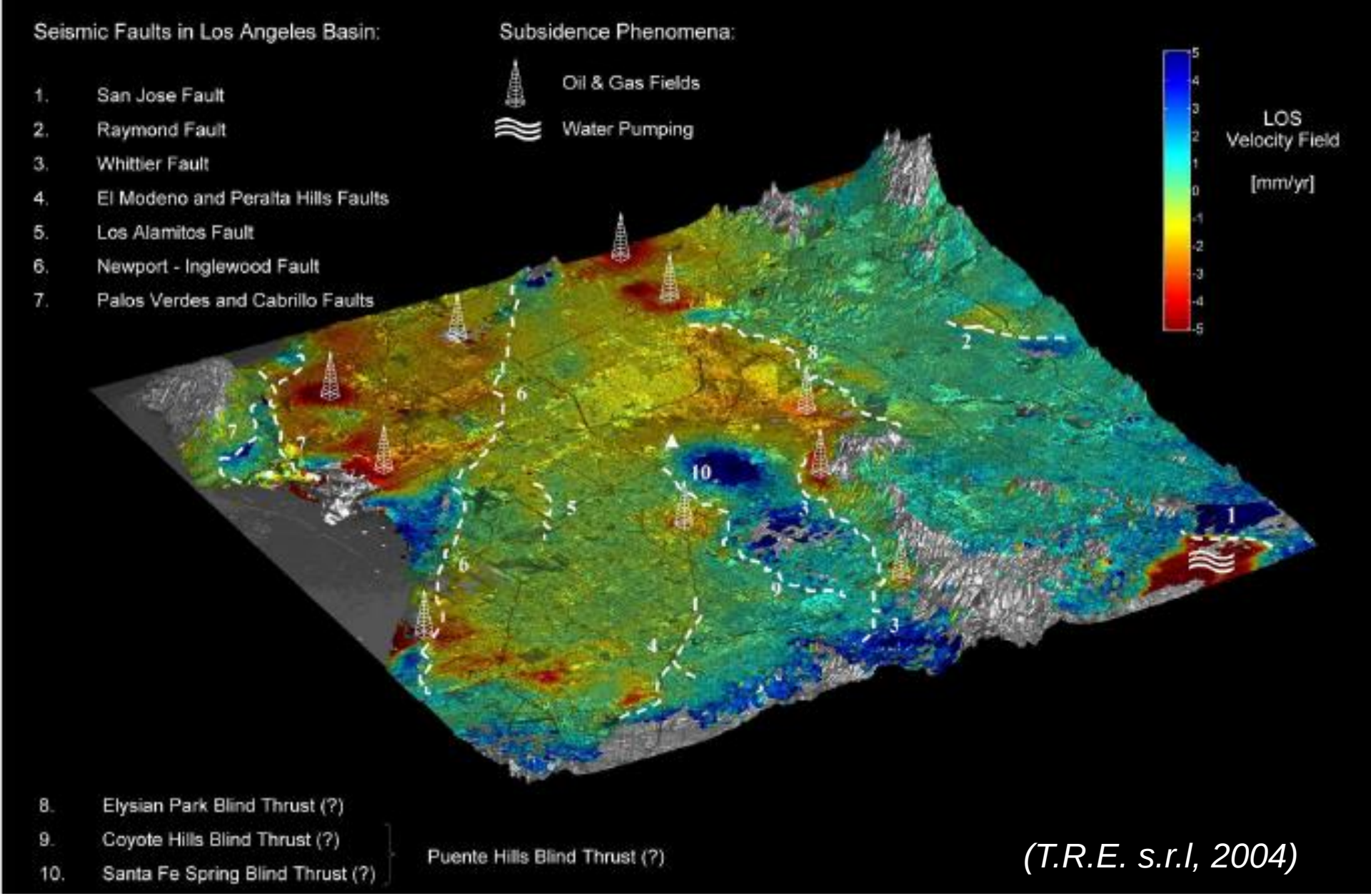
Sydney


LOS displacement rate map (ENVISAT ASAR Track 402 Frame 4290)
Lat
Lon
mm/yr
−33.7
−33.75
−33.8
−33.85
−33.9
−33.95
−34
−34.05
150.9
150.95
151
151.05
151.1
151.15
151.2
151.25
5
4
2
1
0
−1
−2
−3
−4
−5
You are here!
Sydney Airport

A = Perth Deformation Map

B = Change in mean groundwater levels in Perth (A. Smith et al., 2005 CSIRO)




Seismic Faults in Los Angeles Basin:
1. San Jose Fault
2. Raymond Fault
3. Whittier Fault
4. El Modeno and Peralta Hills Faults
5. Los Alamitos Fault
6. Newport - Inglewood Fault
7. Palos Verdes and Cabrillo Faults
Subsidence Phenomena:
Oil & Gas Fields
Water Pumping
LOS Velocity Field
[mm/yr]
8. Elysian Park Blind Thrust (?)
9. Coyote Hills Blind Thrust (?)
10. Santa Fe Spring Blind Thrust (?)
Puente Hills Blind Thrust (?)
(T.R.E. s.r.l, 2004)