Applications of satellite radar imagery for hazard monitoring: insights from Australia

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Supplementary Information

This supplementary information contains three tables. Table S1 lists resources for non-specialist Synthetic Aperture Radar (SAR) data users. Table S2 details the SAR satellites described in the manuscript. Table S3 details the SAR datasets and processing parameters used to produce the example case studies in this study.

Table S1

Key resources for non-SAR users. Links are accessed on 26 Nov 2020.

Data access	
• Comprehensive details of SAR data access can be found in The SAR Handbook, chapter 2 [1] • Data acquired from all Sentinel satellites for the South-East Asia and South Pacific region can also be access via the Regional Copernicus Data Hub Forum https://copernicus.nci.org.au/sara.client/#/home	
Processing/analysis software	
• Commercial processing/analysis tools that were used in this study (not an exhaustive list): o GAMMA – GAMMA Remote Sensing https://www.gamma-rs.ch/software o SARScape – ENVI https://www.l3harrisgeospatial.com/Software-Technology/ENVI-SARscape • Comprehensive details of open-access processing tools can be found in The SAR Handbook, chapter 2 [1] • Open-access processing/analysis tools that were used in this study (not an exhaustive list): o SNAP - European Space Agency http:// step.esa.int/main/download/ o ISCE (InSAR Specific Computing Environment) – JPL/Caltech/Stanford https://winsar.unavco. org/isce.html o StaMPS (STAnford Method of Persistent Scatterers) – Stanford/University of Leeds https://homepages.see.leeds.ac.uk/~earahoo/stamps/	
Other publications and training resources used by the authors	
The SAR Handbook, SERVIR	https://gis1.servirglobal.net/TrainingMaterials/SAR/SARHB_FullRes.pdf [1]
Echos in Space, ESA EO College	https://eo-college.org/courses/echoes-in-space/
NASA Earth Data	https://earthdata.nasa.gov/learn/backgrounders/what-is-sar (Includes access to one-page summary of SAR data pre-processing steps)

Table S2

Details of the SAR satellite missions used in this study. This table is adapted from Flores-Anderson et al. (2019), which also includes other past, present and future missions.

Satellite	Agency	Lifetime	Wavelength	Revisit time	Resolution	Polarisation	Data policy	Link
Past missions								
ERS-1/2	European Space Agency	1991-2001	C-band λ = 5.6 cm	35 days	26 x 6-30 m	VV	Restrained	https://earth.esa.int/eogateway/instruments/ami-sar?text=ers-1
ENVISAT ASAR	European Space Agency	2002-2012	C-band λ = 5.6 cm	35 days	28 x 28 m	HH, VV, VV/HH, HH/HV, VV/VH	Restrained	https://earth.esa.int/eogateway/missions/envisat?text=envisat
ALOS PALSAR *Fine beam single (FBS) and fine beam dual (FBD) only	Japan Aerospace eXploration Agency (JAXA)	2006-2011	L-band λ = 22.9 cm	46 days	FBS: 10x10 m FBD: 20x10 m	FBS: HH, VV FBD: HH/HV, HH/VH	Free and open	https://www.eorc.jaxa.jp/ALOS/en/about/palsar.htm
Radarsat-2 *Multi-Look Fine only	MacDonald, Dettwiler and Associates Ltd. (MDA)	1995-2013	C-band λ = 5.6 cm	24 days	3.1 x 4.6 m	HH, VV, HV, VH,	Commercial	https://mdacorporation.com/geospatial/international/satellites/RADARSAT-2/
Active missions								
TerraSAR-X *Stripmap only	German Aerospace Center (DLR)	2007-	X-band λ = 3.5 cm	11 days	3 x 3 m	HH, VV, HH/VV, HH/HV, VV/VH	Commercial or restrained scientific	https://www.dlr.de/content/en/articles/missions-projects/terrasar-x/terrasar-x-earth-observation-satellite.html
ALOS-2 PALSAR-2 *Stripmap only	Japan Aerospace eXploration	2014-	L-band λ = 22.9 cm	14 days	3-10 m	HH, VV, HV, VH, HH/HV, VV/VH, HH/HV/VH/VV	Commercial or restrained scientific	https://www.eorc.jaxa.jp/ALOS-2/en/about/palsar2.htm

	Agency (JAXA)							
Sentinel-1 (two satellites Sentinel-1A and -1B) * Interferometric Wideswath only	European Space Agency	2014-	C-band $\lambda = 5.6$ cm	12 days (6 days for full constellation)	Interferometric Wide Swath (IW): 5x20 m	HH, VV, HH/HV, VV/VH	Free and open	https://sentinel.esa.int/web/sentinel/missions/sentinel-1
NovaSAR-1	Surrey Satellite Technology Ltd. (SSTL)	2018-	S-band $\lambda = 9.4$ cm	~16 days (drifting orbit)	6-50 m (mode dependent)	HH, VV, HH/VV, HH/HV, VV/VH, HH/VV/HV Mode dependent	Mission partners manage distribution of their capacity share in different ways	https://www.sstl.co.uk/space-portfolio/launched-missions/2010-2020/novasar-1-launched-2018
ICEYE	ICEYE	2018 - Date of first satellite launch - additional satellites are to be added to the constellation	X-band $\lambda = 3.5$ cm	12-36 hrs (at time of writing)	0.25-3 m (mode dependent)	VV	Commercial	https://www.iceye.com/
Future missions								
NISAR	National Aeronautics and Space Administration -Indian Space Research Organisation (NASA-ISRO)	2021-	L-band $\lambda = 24$ cm	12 days	3-20 m (mode dependent)	HH, VV, VH, HV, HH/HV, VV/VH, HH/VV, HH/HV/VH/VV	Free and open	https://nisar.jpl.nasa.gov/

ROSE-L	European Space Agency	2028-	L-band $\lambda = 22$ cm	Up to 3 days				https://esamultimedia.esa.int/docs/EarthObservation/Copernicus_L-band_SAR_mission_ROSE-L_MRD_v2.0_issued.pdf

Table S3

Table of SAR datasets and processing parameters used to produce the example case studies in this study.

Fig	Case study	Dataset	Processing parameters/method/software	Data source	Author
3	Location: Wildman area, Northern Territory Application: flood monitoring in coastal floodplains	Satellite: Sentinel-1 IW SLC Number of images: 49 Start date: 20160805 End date: 20180409	Conversion to Sigma-nought radar backscatter coefficients, Time-series coregistration (spatial resampling over one primary image). Range/Azimuth Looks 8/2; SARScape	Sentinels Australasia Regional Access hub – link in Table S1	Castellazzi P.
4	Location: Perth, Western Australia Application: groundwater extraction and managed aquifer recharge	Satellite: ENVISAT Number of images: 11 Start date: 20080605 End date: 20090511	InSAR velocity maps and cumulative displacement profile produced using StaMPS [2]	ESA	Parker A.
		Satellite: TerraSAR-X Stripmap Number of images: 43 Start date: 20170105 End date: 20180526		DLR under science project LAN1499	
5	Location: Torrington, New South Wales Application: Burned area mapping	Satellite: Sentinel-1 Number of images: 3 Start date: 20191025 End date:20191130	Conversion to sigma-nought radar backscatter coefficients and RGB image produced using the European Space Agency SNAP Sentinel-1 toolbox. Complementary Sentinel-2 natural colour images (RGB bands 4-3-2) were also produced using the European Space Agency SNAP toolbox	Sentinels Australasia Regional Access hub – link in Table S1	Parker A.
6	Location: Tahmoor, New South Wales	Satellite: RADARSAT-2	InSAR analysis using GAMMA software [3] to generate interferograms; cumulative LOS	MDA/Maxar	Fuhrmann T.

	Application: Underground mining	Number of images: 55 / 61 (asc/desc) Start date: 20150715 / 20150703 (asc/desc) End date: 20190531 / 20190706 (asc/desc)	displacements from phase observations in consecutive interferograms; temporal and spatial interpolation of ascending and descending LOS displacements to calculate East-West and Up-Down displacements using methodology of [4].		
7	Location: Latrobe Valley, Victoria Application: Aboveground mining	Satellite: ALOS PALSAR Number of images: 19 Start date: 20070915 End date: 20110208	InSAR analysis using GAMMA software [3] to generate interferograms; InSAR time series processing using StaMPS software [2].	JAXA	Fuhrmann T.
8	Location: Cadia gold mine, New South Wales Application: Aboveground mining infrastructure	Satellite: Sentinel-1 Number of images: 68 Start date: 20151202 End date: 20180225	InSAR analysis using GAMMA software [3] to generate interferograms; InSAR time series processing using StaMPS software [2].	Sentinels Australasia Regional Access hub – link in Table S1	Fuhrmann T.
9	Location: Petermann Ranges, Northern Territory Application: Seismic hazard	Satellite: ALOS-2 Number of images: 2 Start date: 20151215 End date:20160614	InSAR processing using GAMMA software [3] to generate flattened geocoded interferogram from each satellite dataset.	JAXA under "Research Announcement 4" project 1133	Garthwaite M.
		Satellite: Sentinel-1 Number of images: 2 Start date: 20151017 End date: 20160601		Sentinels Australasia Regional Access hub – link in Table S1	
10	Location: Wildman area, Northern Territory, Northern Territory Application: Mapping and monitoring geomorphic features	Satellite: Sentinel-1 IW SLC Number of images: 30 Start date: 20170108 End date:20181222	SAR intensity: Conversion to Sigma-nought radar backscatter coefficients, time-series coregistration (spatial resampling over one primary image). Range/Azimuth looks 5/1. ENVI/SARSCAPE 5.5 InSAR: ISBAS [5] 128 interferograms (mean of 8.53 per image); Range/Azimuth Looks 5/1; Coherence Threshold of 0.2 for 70% of images and 70% of interferograms; Goldstein adaptive filtering; MCF unwrapping; ENVI/SARSCAPE 5.5.	Sentinels Australasia Regional Access hub – link in Table S1	Castellazzi P.

11	Location: 75km North-West of Alice Springs, Northern Territory Application: Tracing sediment transport in the Australian Outback	Satellite: Sentinel-1 IW SLC Number of images: 57 Start date: 20170504 End date: 20190317	InSAR: SBAS [5] 250 interferograms (mean of 8.77 per image); Range/Azimuth Looks 24/6; Coherence Threshold of 0.25 for 75% of images and 75% of interferograms; Final temp. coherence threshold of 0.3; Goldstein adaptive filtering; MCF unwrapping; ENVI/SARSCAPE 5.5	Sentinels Australasia Regional Access hub – link in Table S1	Castellazzi P.

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