

SUPPLEMENTARY MATERIAL

Table S1. Main characteristics of the SAR Envisat Dataset processing and surface velocity maps.

SBAS ENVISAT			
SAR ADQUISITION			
Band/Polarisation	C/VV		
Wavelength (cm)	5.6		
Incidence angle	23		
Revisiting period (days)	35		
Orbital track/Frame	152/58	101/152	
Acquisition geometry	Ascending	Descending	
Pixel size (m) radar geometry	4x20		
SAR PROCESSING			
Number of SAR images	25	29	
Temporal span	June 2004/September 2010	March 2003/September 2010	
Number of interferograms	63	85	
Bounding box (Lat, Long, proj.WGS84)	41.99, -1.36 / 41.279, -0.007	41.99, -1.17 / 41.51, -0.29	
Reference point coord (Lat, Long; proj.WGS84)	41.65, -0.87		
Processing mode	Multi-Temporal DInSAR Analysis		
Max Perpendicular Baseline (m)	400		
Max Temporal Baseline (days)	1500		
Ground Pixel Dimension (m)	80, 80		
Max Allowed Delta-Doppler (Hz)	1000		
Max Allowed Doppler Centroid (Hz)	2000		
GoldsteinWeight	0.5		
Coherence threshold	0.7		
APS Smoothing TimeWindow (days)	200		

Table S2. Main characteristics of the SAR SBAS Sentinel Dataset processing and surface velocity maps.

SBAS SERVICE- SENTINEL				
DDSS_ID	LOS_DISPLACEMENT_TIMESERIES			
Product_ID	DTSLOS_jgiturbe_20141105_20210126_8F3K	DTSLOS_jgiturbe_20160609_20210126_9Q45	DTSLOS_jgiturbe_20190612_20210219_CZIJ	DTSLOS_jgiturbe_20190612_20210219_CZIJ
Product_format	ASCII			
Product_size	1323062937	1041037638	3265478652	3588016971
Preview_url	/Pompu/Track_103/DTSLOS_jgiturbe_20141105_20210126_8F3K/DTSLOS_jgiturbe_20141105_20210126_8F3K.png	/Pompu/Track_8/DTSLOS_jgiturbe_20160609_20210126_9Q45/DTSLOS_jgiturbe_20160609_20210126_9Q45.png	/Pompu/Track_30/DTSLOS_jgiturbe_20190625_20210226_OY0I/DTSLOS_jgiturbe_20190625_20210226_OY0I.png	/Pompu/Track_8/DTSLOS_jgiturbe_20190612_20210219_CZIJ/DTSLOS_jgiturbe_20190612_20210219_CZIJ.png
Legend_url	/Pompu/Track_103/DTSLOS_jgiturbe_20141105_20210126_8F3K/DTSLOS_jgiturbe_20141105_20210126_8F3K.legend.png	/Pompu/Track_8/DTSLOS_jgiturbe_20160609_20210126_9Q45/DTSLOS_jgiturbe_20160609_20210126_9Q45.legend.png	/Pompu/Track_30/DTSLOS_jgiturbe_20190625_20210226_OY0I/DTSLOS_jgiturbe_20190625_20210226_OY0I.legend.png	/Pompu/Track_8/DTSLOS_jgiturbe_20190612_20210219_CZIJ/DTSLOS_jgiturbe_20190612_20210219_CZIJ.legend.png
Product_url	/Pompu/Track_103/DTSLOS_jgiturbe_20141105_20210126_8F3K/DTSLOS_jgiturbe_20141105_20210126_8F3K.zip	/Pompu/Track_8/DTSLOS_jgiturbe_20160609_20210126_9Q45/DTSLOS_jgiturbe_20160609_20210126_9Q45.zip	/Pompu/Track_30/DTSLOS_jgiturbe_20190625_20210226_OY0I/DTSLOS_jgiturbe_20190625_20210226_OY0I.zip	/Pompu/Track_8/DTSLOS_jgiturbe_20190612_20210219_CZIJ/DTSLOS_jgiturbe_20190612_20210219_CZIJ.zip
Bounding_box	41.103333 -3.4877778 / 42.299444 -0.34055556	41.098889 -2.4308333 / 42.339722 0.75083333	41.554167 -1.5291667 / 42.585556 1.6136111	41.098611 -2.4302778 / 42.670278 0.80277778
Bounding_box_wkt	POLYGON((-3.4877778 41.103333,-0.34055556 41.103333,-0.34055556 42.299444,-3.4877778 42.299444,-3.4877778 41.103333))	POLYGON((-2.4308333 41.098889,0.75083333 41.098889,0.75083333 42.339722,-2.4308333 42.339722,-2.4308333 41.098889))	POLYGON((-1.5291667 41.554167,1.6136111 41.554167,1.6136111 42.585556,-1.5291667 42.585556,-1.5291667 41.554167))	POLYGON((-2.4302778 41.098611,0.80277778 41.098611,0.80277778 42.670278,-2.4302778 42.670278,-2.4302778 41.098611))
License	https://creativecommons.org/licenses/by/4.0			
Software_version	CNR-IREA P-SBAS 28			
Applied_algorithm_description	Parallel SBAS Interferometry Chain			
Main_reference	10.1109/ISTARS.2014.2322671, 10.1109/TGRS.2019.2904912			
Date_of_measurement_start	2014-11-05T18:02:47.371816Z	2016-06-09T06:09:07.161949Z	2019-06-13T17:54:32.301760Z	2019-06-12T06:08:38.021799Z
Date_of_measurement_end	2021-01-26T18:02:38.685732Z	2021-01-26T06:09:34.680956Z	2021-02-20T17:54:39.993884Z	2021-02-19T06:09:33.863176Z
Date	2014-11-05T18:02:47.371816Z/2021-01-26T18:02:38.685732Z	2016-06-09T06:09:07.161949Z/2021-01-26T06:09:34.680956Z	2019-06-25T17:54:32.301760Z/2021-02-26T17:54:39.993884Z	2019-06-12T06:08:38.021799Z/2021-02-19T06:09:33.863176Z
Date_of_production	2021-02-12T01:56:09Z	2021-02-04T20:30:32Z	2021-05-24T18:42:46Z	2021-03-03T09:24:19Z
Service_used_for_generation	EPOSAR			
Geographic_CS_type_code	EPSG_4326			
Used_DEM	SRTM_1arcsec			
Super_master_SAR_image_ID	S1B_IW_SLC__1SDV_20180130T180219_20180130T180246_009404_010E50_FA99.SAFE	S1A_IW_SLC__1SDV_20180927T060924_20180927T060951_023880_029B31_03D3.SAFE	S1B_IW_SLC__1SDV_20200514T175436_20200514T175504_021581_028F88_C06C.SAFE	S1A_IW_SLC__1SDV_20200507T060929_20200507T060956_032455_03C224_6D40.SAFE
Spatial_resolution	90, 90			
Sensor	S1			
Mode	IW			
Antenna_side	Right			
Relative_orbit_number	103	8	30	8
Orbit_direction	ASCENDING	DESCENDING	ASCENDING	DESCENDING
Wavelength	0.05546576			
Value_unit	N/A, deg, deg, m, cm/yr, N/A, N/A, N/A, N/A, cm			
Number_of_looks_azimuth	5			
Number_of_looks_range	20			

Applied_filter	Goldstein_0.50			
Number_of_SAR Images	74	51	100	
Reference_date	2014-11-05T18:02:47Z	2016-06-09T06:09:07Z	2019-06-25T17:54:32Z	2019-06-12T06:08:38Z
Reference_point	43.283572 / -0.75918026	40.634330 / -1.7713063	41.803843 / -0.35949912	41.707304 / -1.5339751
Applied_corrections	No_Corrections			

Table S3. Main characteristics of the SAR FASTVEL Sentinel Dataset processing and surface velocity maps.

FASTVEL SERVICE_SENTINEL				
Job name	FASTVEL ZAR Jul2019- Mar2021 SmallAOI	FASTVEL Alcala Jul2019- Mar2021 SmallAOI	FASTVEL UteboAlago n Jul2019- Mar2021 SmallAOI	FASTVEL Zuera Jul2019- Mar2021 SmallAOI
ID	f584d832- 15d3-4d84- 89f6- 3b767514239 6	f18692ba- 564f- 4097- 865c- 69107815 1dfa	5bbfc07b- b84d-4135- ae25- 8e322a86a8 18	6e21a7d7- b99f-43a8- afcc- 43ee05eb3b 1a
SAR ACQUISITION				
Sensor	S1			
Mode	IW			
Product Type	SLC			
Orbit_direction	DESCENDING			
Track	8			
Date_of_measurement_start	2019-07-12T06:09:53.97			
Date_of_measurement_end	2021-03-21T06:09:13.556			
Geographic_CS_type_code	EPSG_4326			
SAR PROCESSING				
Spatial_resolution	40, 40			
Number_of_SAR Images	100			
Processing mode	MTA			
Area of interest	- 0.979,41.625, -0.86,41.692	- 1.251,41.7 59,- 1.109,41.8 34	- 1.133,41.65 4,- 0.935,41.78 2	- 0.829,41.87 1,- 0.713,41.92 7
Reference_point_lat	41.653	41.786	41.681	41.888
Ref_point_lon	-0.877	-1.219	-1.072	-0.763
Maximum Temporal Baseline [days]	365			
Maximum Perpendicular Baseline [m]	400			
Maximum Doppler Difference [Hz]	1000			
Maximum Doppler Centroid [Hz]	2000			
Goldstein phase filter exponential factor	0.5			
Phase Unwrapping	False			
Coherence Threshold	0.5			
APS Correlation Distance [m]	3000			

Table S4. Chemical composition, total dissolved solids (TDS), alkalinity (Alk) and saturation indexes (si) performed with the PHREEQC software and the Pitzer database for the Zuera sinkholes water samples.

Western sinkhole sample 1	T ^a	pH	TDS (mg/l)	ppm HCO ₃ ⁻	ppm Cl ⁻	ppm SO ₄ ²⁻	ppm Ca	ppm Mg	ppm Na	ppm K
	13.5	7.8	92296	183.88	52600	3294	1649	131	34400	38
			Alk	Ionic balance	Ionic Strength	si_Calcite	si_Dolomite	si_Gypsum	si_Halite	si_CO ₂ (g)
			0.0030855	1.12	1.69313	1.0021	1.2273	-0.2406	-1.567	-2.8596
Western sinkhole sample 2	T ^a	pH	TDS (mg/l)	ppm HCO ₃ ⁻	ppm Cl ⁻	ppm SO ₄ ²⁻	ppm Ca	ppm Mg	ppm Na	ppm K
	13	8.06	94716	136.04	53900	3680	1813	142	35000	45
			Alk	Ionic balance	Ionic Strength	si_Calcite	si_Dolomite	si_Gypsum	si_Halite	si_CO ₂ (g)
			0.0022837	0.82	1.74325	1.1462	1.5107	-0.1618	-1.5476	-3.273
Eastern Sinkhole	T ^a	pH	TDS (mg/l)	ppm HCO ₃ ⁻	ppm Cl ⁻	ppm SO ₄ ²⁻	ppm Ca	ppm Mg	ppm Na	ppm K
	11	7.7	1974	455.95	153	837.5	247.6	139	127.4	13.95
			Alk	Ionic balance	Ionic Strength	si_Calcite	si_Dolomite	si_Gypsum	si_Halite	si_CO ₂ (g)
			0.0074873	0.74	0.0501455	0.7699	1.5583	-0.4941	-6.3203	-2.1828

Table S5. Average vertical rates derived from the InSAR and DoD maps along the A23 Highway in Zuera Sinkhole site.

INSAR (SBAS SENTINEL)		
Vertical motion rate	Area (m²)	Subsidence (cm/yr)
3.71	8046.81	29853.67
2.41	830.996	2002.7
2.36	122.475	289.04
Total	9000.281	32145.41
Average Subsidence (cm/yr · m²)		3.57

DIFFERENTIAL LiDAR DEMS (2010-2016)		
Number of points	Area (m²)	Subsidence (cm/yr)
9003	9000.281	-64781.86
Average Subsidence (cm/yr · m²)		-7.19

Figure S1. Vertical deformation rate of the InSAR data obtained from the 2019-2021 sentinel-1 images and the SBAS Sentinel approach.

Figure 1 shows the vertical deformation map for the SBAS Sentinel approach in the Zuera sinkhole site derived from the Sentinel-1 data. The maximum deformation rates range between -1 and -2 cm/yr for the western sinkhole and -3 and -4 cm/year for the eastern sinkhole with maximum negative values on the southern edge of the lake and along the A22 Highway and N330 Road. This is consistent with the severe damage recorded in these infrastructures and the surface deformation features recognized in the field (Desir et al., 2018). The InSAR and differential LiDAR deformation pattern is similar for the western sinkhole although the vertical deformation rates obtained by the SBAS Sentinel approach are around 2 times lower.

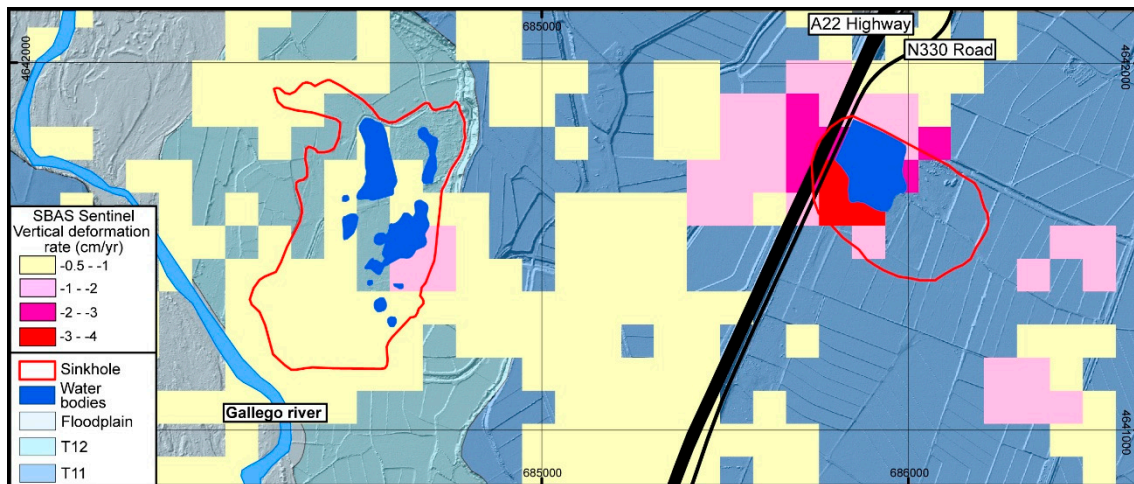


Figure S2. LOS velocity and vertical deformation rates of the detailed area around Zaragoza city from the 2003-2010 Envisat SAR images and the SBAS Envisat approach.

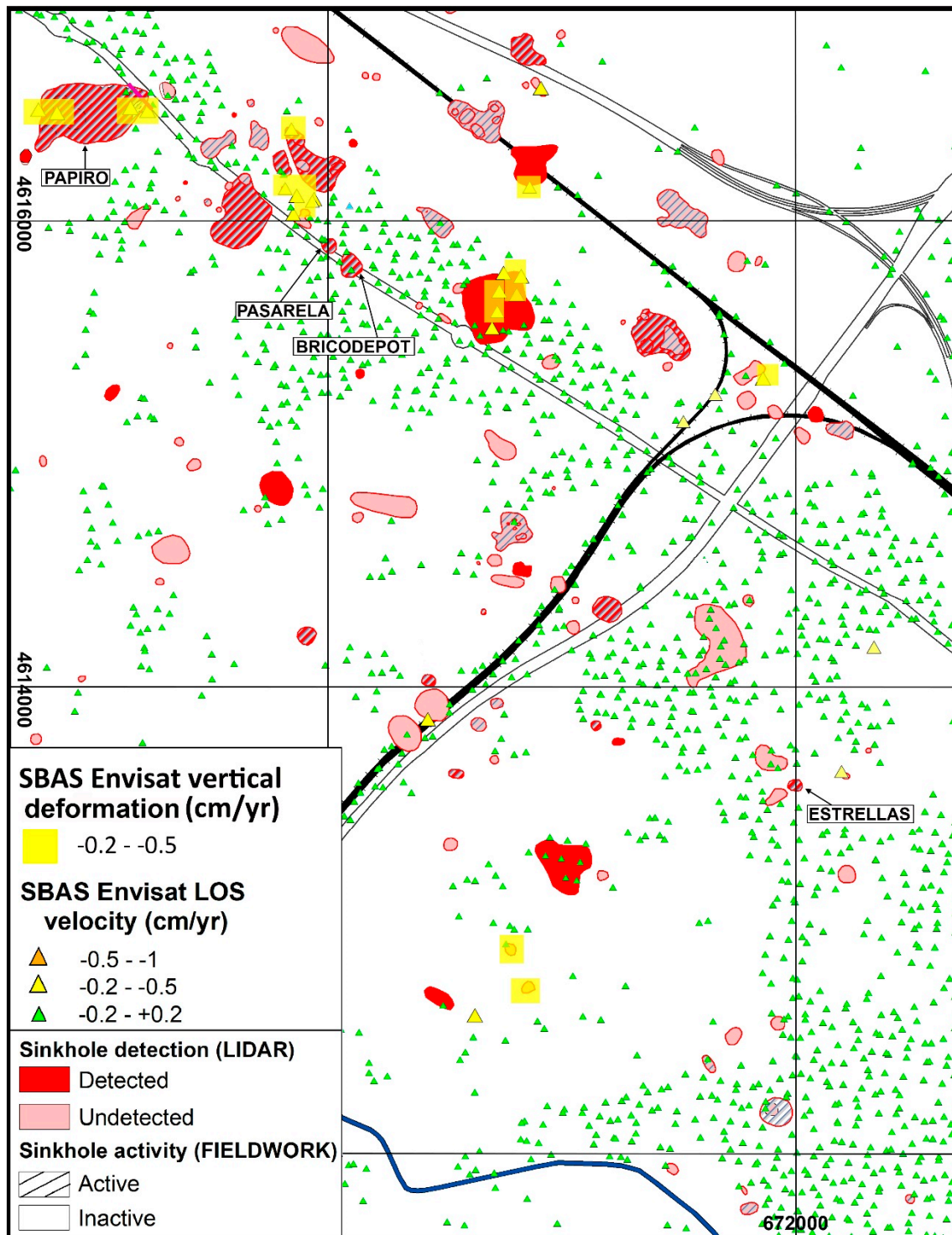


Figure S3. LOS vertical deformation map of the detailed area around Zaragoza city from the 2019-2021 Sentinel-1 SAR images and the FASTVEL Sentinel approach.

