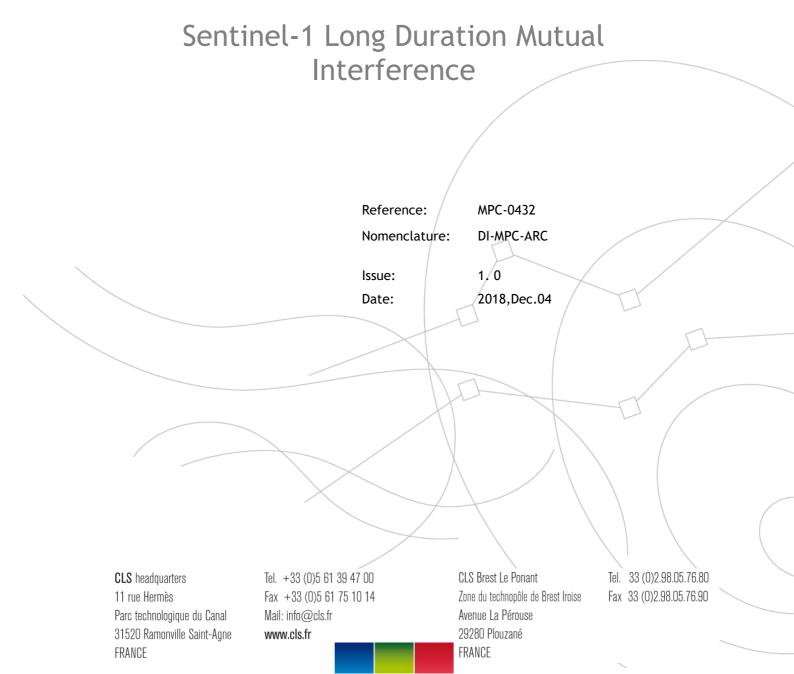


MPC-S1



Chronology Issues:

Issue:	Date:	Reason for change:	Author
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Index Sheet:

Context:	Report on long duration interference identified in Sentinel1-A & B imagery
Keywords:	S-1A, S-1B, Interference
Hyperlink:	N/A

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Applicable documents

AD 1 None.

Reference documents

RD-1 Rommen, B. et al., 'Joint Investigations on Radarsat-2/Sentinel-1A Mutual RFI', Proceedings of the CEOS SAR Workshop, October 27-29, 2015, ESTEC, Noordwijk, The Netherlands.

RD-2 Heavens-Above website (http://www.heavens-above.com).



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1. Purpose and scope

This technical note describes the long duration mutual interference that has occurred between Sentinel-1 and the Canadian Radarsat-2 satellite, the Chinese GAOFEN 3 satellite and an unknown satellite which operate at the same frequency as Sentinel-1.

All the examples of this type of interference, which can be seen in imagery lasting for several minutes, are shown in this report - the majority being with Sentinel-1A.

Notice than a former technical note called "Sentinel-1 / Radarsat-2 Mutual Interference", MPC-0353 was originally published by S-1 MPC. The current report extent it with other sources of mutual interferences. The document MPC-0353 is thus now obsolete.

2. Sentinel-1 and Radarsat-2

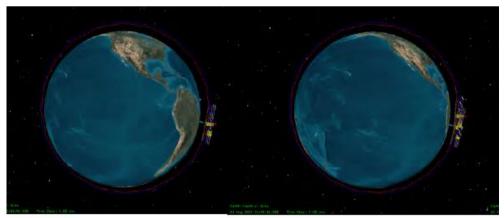
2.1. Orbit Configurations

Table 1 gives some of the orbit characteristics of Sentinel1-A & B (S1-A, S1-B) and the Canadian Radarsat-2 (RS-2) satellites. The most important common characteristics between S1 and RS-2 in relation to mutual interference are (i) both operate using the same central frequency of 5.405 GHz, (ii) both have an almost identical ascending mode crossing time, the mean local solar time (MLST), of 18:00 hrs and (iii) both can image to the right. The consequence of the S1 and RS-2 orbits is that RS-2 pass above S1 after 50 orbits for S1 and 49 orbits for RS-2 as illustrated in **Figure 2** (from **RD-1**). This time period corresponds to 3.5 days and so RS-2 will pass directly above S1 and if both SARs are acquiring data, there is a possibility of mutual interference. **Figure 2** shows an example of simultaneous imaging from S1-A and RS-2.

	Sentinel-1	Radarsat-2
Orbit Type	Sun-Synchronous	Sun-Synchronous
Repeat Cycle (days)	12	24
Repeat Cycle (orbits)	175	343
Altitude	~693 km	~789 km
Orbital Period	5924.57 s	6045.48 s
Orbital Inclination	98.18°	98.58°
MLST	~18:00 hrs	~18:00 hrs

Table 1: Sentinel-1 and Radarsat-2 Orbit Characteristics

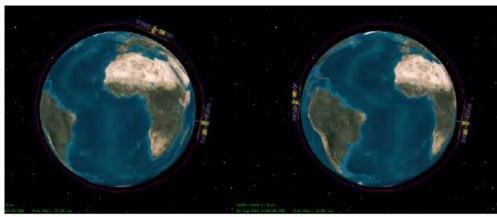
As the time period between possible mutual interference is every 3.5 days (i.e. less than the repeat period), this leads to longitude of the interference being at a different longitude although the pattern of longitudes does repeat every 84 days. The latitude of the possible mutual interference slowly changes due to the slight drift in the MLST of both S1 and RS-2. **Figure 3** shows the location of the possible mutual interference for S1-A in September 2014 and September 2015 (from **RD-1**). A clear shift in latitude from the southern to northern hemispheres can be seen.



Crossing position

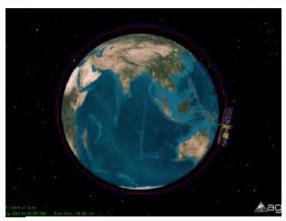
After one RS2 orbit





After 10 RS2 orbits

After 25 RS2 orbits



After 50 RS2 orbits

Figure 1: Relative Position of S1 and RS-2 (RD-1).

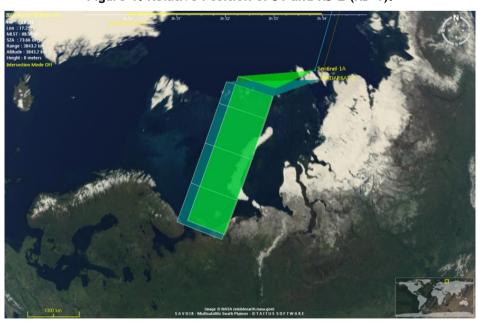


Figure 2: Example simultaneous SAR imaging for S1 and RS-2.



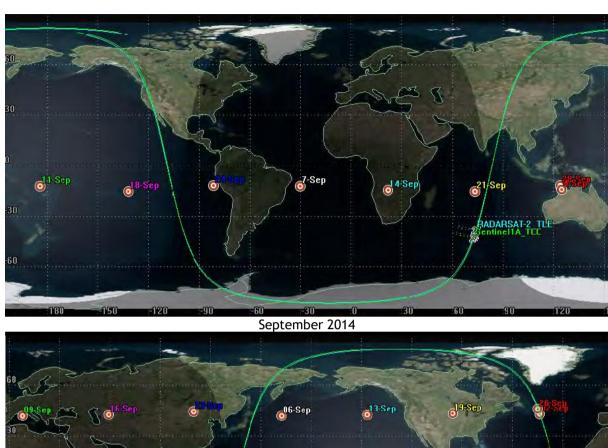


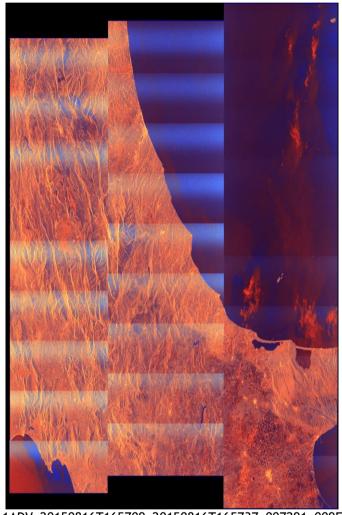
Figure 3: S1-A RS-2 Crossing Locations (RD-1).

Note that the S1 SAR is used to its maximum capability per orbit to enable extensive coverage of the Earth's surface to be obtained (see https://sentinel.esa.int/web/sentinel/missions/sentinel-1/observation-scenario). A different approach is used for RS-2 where most of the data acquisition is primarily based on user requests. The consequence of these different approaches is that mutual interference many not occur at all possible opportunities since both SARs, especially RS-2, may not be operating at the same time.



2.2. Examples of \$1/R\$2 Mutual Interference

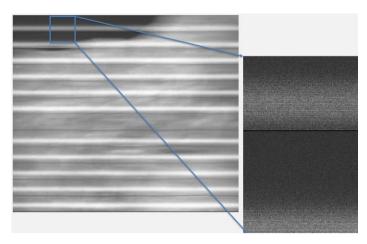
The first occurrence of S1-A/RS-2 interference identified at the MPC Coordination Centre is shown in **Figure 4** for a single IW VH/VV SLC product from central Italy in August 2015 (near range is to the left). The interference is more obvious in VH polarisation than in the VV polarisation (due presumably to the lower scene radar cross-section in VH). Adjacent products also show similar interference as shown in **Figure 5** (right) giving an azimuth extend of the interference of several hundred km. The identification that the feature seen in **Figure 4** and **Figure 5** (right) is indeed interference is confirmed by examining the L0 (raw) data. **Figure 5** (left) shows the L0 intensity for each of the IW sub-swaths for the scene shown in **Figure 4** - for IW1 and IW2 it is clear that the L0 intensity is dominated by many range lines with high intensity, each of which is indicative of interference. For IW3, the interference is less obvious but can be seen when examining the range lines in detail (as indicated by the arrows).



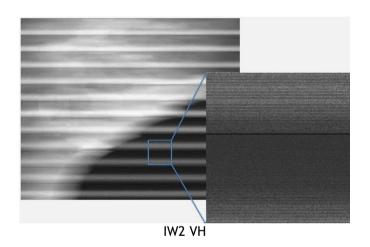
\$1A_IW_SLC__1ADV_20150816T165709_20150816T165737_007291_009FF3_BEAC.\$AFE

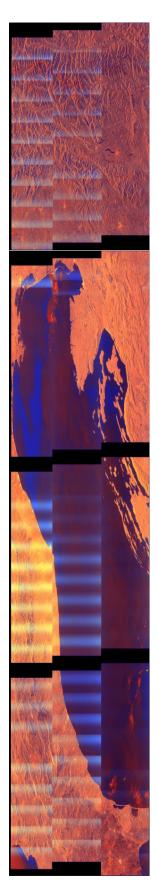
Figure 4: S1-A RS-2 Mutual Interference over Italy (16th August 2015)





IW1 VH







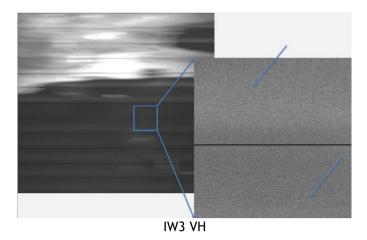




Figure 5: S1-A RS-2 Mutual Interference over Italy (16th August 2015): L0 intensity (left) and full interference extent (right)

The RS-2 ScanSAR wide VV polarisation image acquired at the same time as the above S1-A image is shown in **Figure 6** and **Figure 7**. The interference from S1-A is less obvious than in S1-A imagery but is nevertheless visible (range position indicated by arrows).

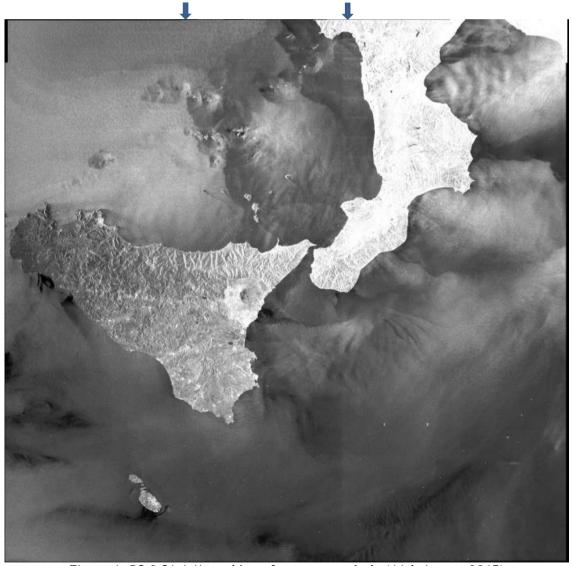


Figure 6: RS-2 S1-A Mutual Interference over Italy (16th August 2015)



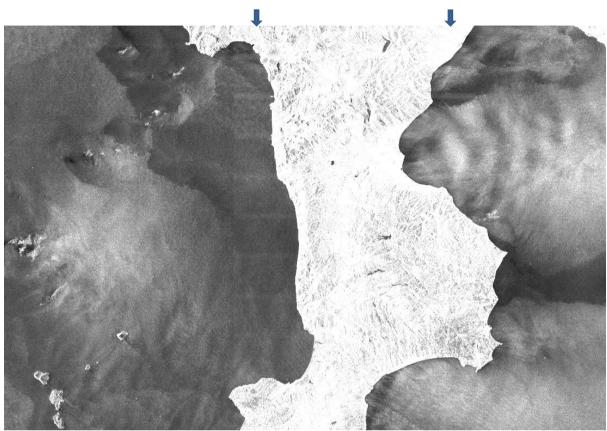
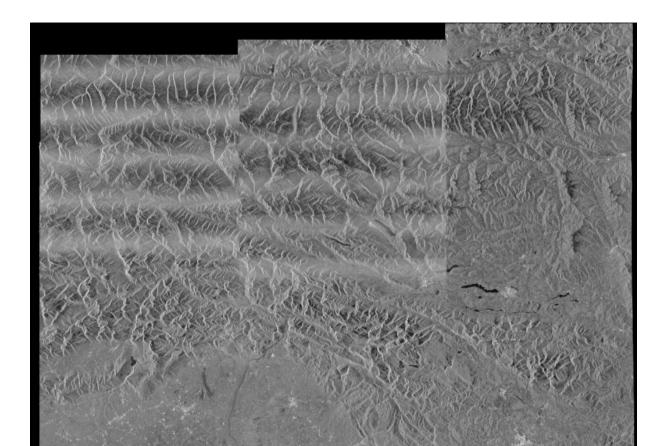


Figure 7: Detail of RS-2 S1-A Mutual Interference over Italy (16th August 2015)

Another example from 3rd October 2015 is shown in **Figure 8**. These images were acquired 48 days after those shown above (i.e. 2 RS-2 cycles and 4 S1-A cycles later). As discussed in Section 2 the slight change in ascending node crossing times for both S1-A and RS-2 between 16th August and 3rd October leads to a slight difference in the geographical latitude of the interference.



S1-A



Figure 8: S1-A RS-2 Mutual Interference from 3rd October 2015 over northern Italy/Switzerland

A more recent example of S1-A mutual interference is shown in **Figure 9** over Kazakhstan/China on 5th February at 00:13 to 00:14 UT. This also shows the track of S1-A and RS-2 as viewed from the town of Altay, China which is located within the interference (tracks obtained from **RD-2**) - the position of the two tracks are very similar as is the time indicating the source of the interference is indeed RS-2.

The final example is the only mutual interference with S1-B identified at the MPC Coordination Centre - see Figure 10.



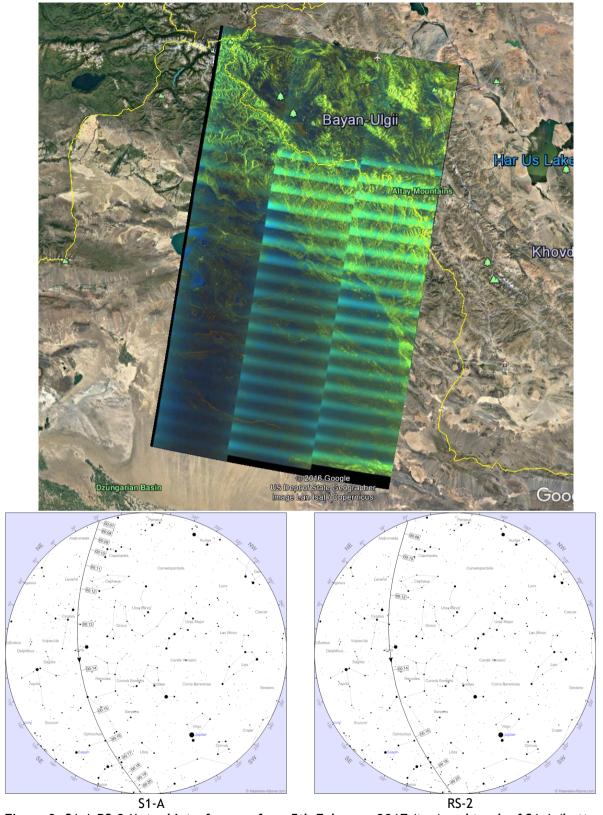
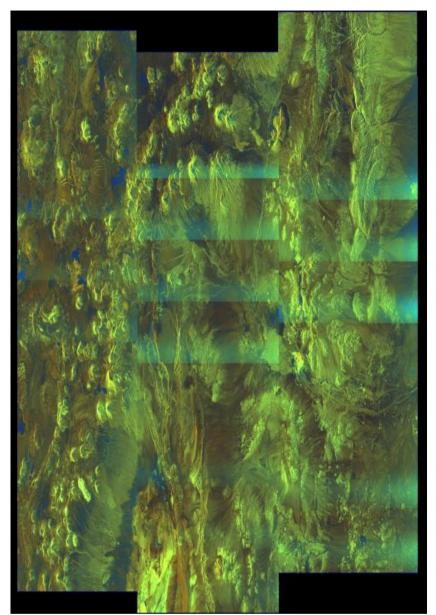


Figure 9: S1-A RS-2 Mutual Interference from 5th February 2017 (top) and track of S1-A (bottom left) and RS-2 (bottom right) as viewed from Altay, China.





S1B_IW_SLC__1ADV_20170503T100010_20170503T100036_005432_00985E_FAE9.SAFE Figure 10: S1-B RS-2 Mutual Interference from 3rd May 2017

Table 2 and **Table 3** give the full list of mutual S1 and RS-2 interferences identified at the MPC Coordination Centre. The following is noted:

- All the S1-A cases are in the northern hemisphere whereas the only S1-B case is in the southern hemisphere.
- The first S1-A case occurred over 12 months after S1-A launch. The first cases were from ascending passes, whereas the more recent cases are from descending passes.
- The latitude of the S1-A cases were increasing up to late 2016 whereas since then the latitude has been decreasing.
- There is a wide spread of longitudes for which S1-A cases have occurred.

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Satellite	Orbit	Relative Orbit	Acquisition Date	Start Time (UT)	End Time (UT)	Approx. Latitude	Approx. Location
S1-A	7291	44	16th August 2015	16:55	16:58	43° N	Italy
S1-A	7641	44	9th September 2015	16:57	16:58	46° N	Italy/Austria
S1-A	7991	44	3rd October 2015	16:58	16:58	48° N	Italy/Austria
S1-A	8341	44	27th October 2015	16:56	17:00	51° N	Germany
S1-A	8691	44	20th November 2015	16:59	17:00	52° N	Germany
S1-A	9091	94	18th December 2015	03:19	03:20	60° N	Alaska
S1-A	9391	44	7th January 2016	16:56	17:04	62° N	Sweden
S1-A	9741	44	31st January 2016	16:58	17:04	62° N	Sweden
S1-A	10091	44	24th February 2016	17:03	17:04	63° N	Norway
S1-A	12441	119*	3rd August 2016	20:40	20:41	73° N	NE Russia
S1-A	12741	69*	24th August 2016	10:24	10:24	70° N	Greenland
S1-A	13091	69*	17th September 2016	10:22	10:24	74° N	Greenland
S1-A	13223	35*	27th September 2016	04:10	04:11	53° N	Belarus/Russia
S1-A	13441	69*	11th October 2016	10:22	10:26	74° N	Greenland
S1-A	14691	94*	5th January 2017	03:38	03:39	50° N	Ukraine/Russia
S1-A	15141	19*	5th February 2017	00:13	00:14	47° N	Kazakhstan/China
S1-A	15291	169*	15th February 2017	07:05	07:05	48° N	North Atlantic
S1-A	15491	19*	1st March 2017	00:14	00:16	40° N	China
S1-A	15741	94*	18th March 2017	03:42	03:43	34° N	Cyprus
S1-A	15792	144*	21st March 2017	13:59	14:00	36° N	US West Coast
S1-A	15841	19*	25th March 2017	00:15	00:17	36° N	North China
S1-A	15941	119	31st March 2017	20:51	20:52	36° N	Japan
S1-A	16191	19*	18th April 2017	00:17	00:18	30° N	China
S1-A	16541	19*	12th May 2017	00:19	00:20	25° N	North India
S1-A	16891	19*	5th June 2017	00:21	00:22	20° N	India

Table 2: List of S1-A Data with S1/RS2 Mutual Interference

^{*} Descending Pass

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Satellite	Orbit	Relative Orbit	Acquisition Date	Start Time (UT)	End Time (UT)	Approx. Latitude	Approx. Location
S1-B	5432	156*	3rd May 2017	10:00	10:01	20° S	Bolivia

Table 3: List of S1-B Data with S1/RS2 Mutual Interference

^{*} Descending Pass

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3. Sentinel-1 and Gaofen-3

One example of mutual interference has been identified between Sentinel1-A and the Chinese GAOFEN 3 (NORAD ID 41727) C-Band SAR satellite. **Table 4** gives the orbital characteristics of S1 and GAOFEN 3. As for Radarsat-2, GAOFEN is in a higher orbit than S1 and in a dusk-dawn orbit.

	Sentinel-1	GAOFEN 3	
Orbit Type	Sun-Synchronous	Sun-Synchronous	
Repeat Cycle (days)	12	29	
Repeat Cycle (orbits)	175	419*	
Altitude	~693 km	~751 km	
Orbital Period	5924.57 s	5980 s*	
Orbital Inclination	98.18°	98.42°	
MLST	~18:00 hrs	~18:00 hrs	

Table 4: Sentinel-1 and GAOFEN 3 Orbit Characteristics *deduced values

The long duration interference occurred over China between 11:14 and 11:20 UT on 10th October 2018 as can be seen in Figure 11 with in more detail shown in Figure 12 (including the location of the town of Liangshan, China). Figure 13 shows the track of S1-A and GAOFEN 3 as viewed from Liangshan which is located within the interference - the position of the two satellite tracks in the night sky as viewed from Liangshan are very similar as is the time indicating the source of the interference is indeed GAOFEN 3.

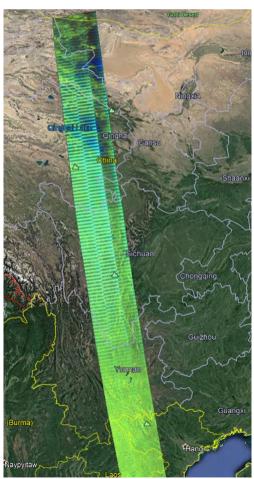


Figure 11: S1-A GAOFEN 3 Mutual Interference from 10th October 2018

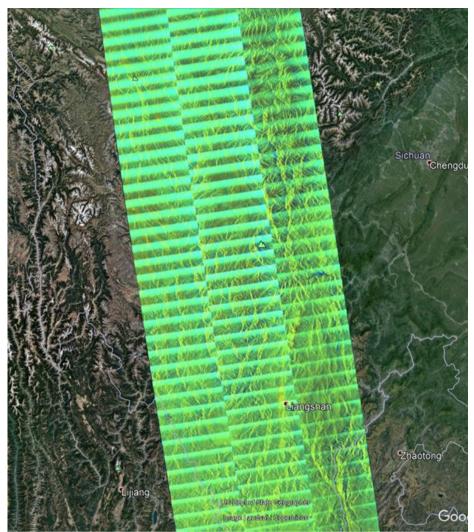


Figure 12: Detail of S1-A GAOFEN 3 Mutual Interference from 10th October 2018

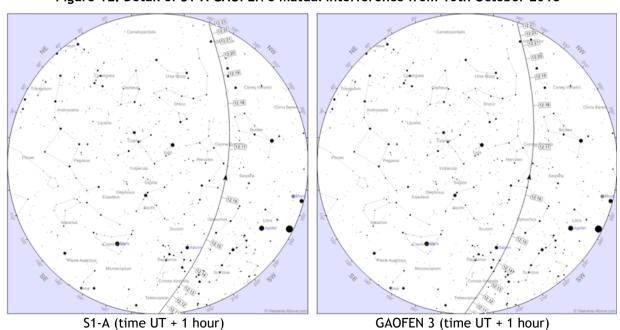


Figure 13: The track of S1-A (left) and RS-2 (right) as viewed from Liangshan, China.



4. Sentinel-1 and Unknown Satellite

Further examples of long duration interference have been identified in S1-A imagery, but the source of the interference has yet to be identified. Given the duration of the interference, it is assumed that the source is another satellite C-Band SAR. Six occurrences have been found, five around the Gulf of Mexico/Florida/Cuba/Caribbean and one over Hawaii. All occurred at approximately the same latitude of 25°N.

Table 5 gives the list of S1-A mutual with an unknown satellite while **Figure 14** to **Figure 22** shows interference itself. The timing between the various occurrences is quite irregular. Note that the appearance of the interference is very similar in all six examples and quite different from that caused by Radarsat-2 and Gaofen-3.

Satellite	Orbit	Acquisition Date	Date Take	Start Time (UT)	End Time (UT)	Approx. Location
S1-A	14295	8th December 2016	17230 & 17231	23:27	23:30	Florida, USA
S1-A	17401	9th July 2017	01D117	23:03	23:05	Caribbean
S1-A	17423	11th July 2017	01D1C6	11:52	11:54	Mexico
S1-A	19056	31st October 2017	0203AE	11:18	11:23	Mexico/Cuba
S1-A	19129	5th November 2017	0205E3 & 0205E4	11:27	11:31	Mexico/Cuba
S1-A	22355	14th June 2018	026B9E	16:31	16:33	Hawaii

Table 5: Sentinel-1 and Unknown Satellite Mutual Interference Occurrences

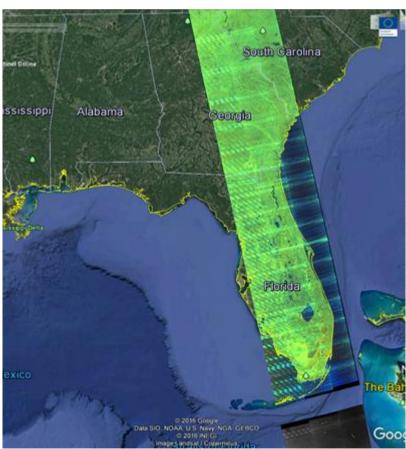


Figure 14: S1-A Mutual Interference from 8th December 2016

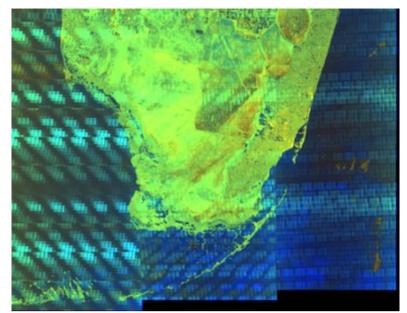


Figure 15: Detail of S1-A Mutual Interference from 8th December 2016

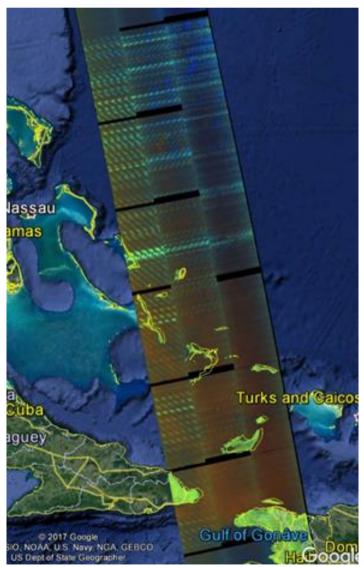


Figure 16: S1-A Mutual Interference from 9th July 2017

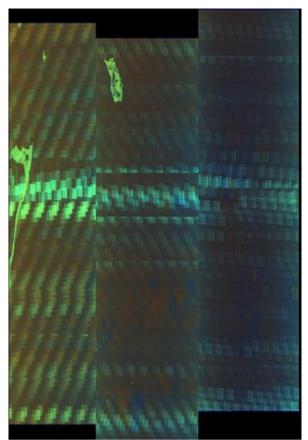


Figure 17: Detail of S1-A Mutual Interference from 9th July 2017

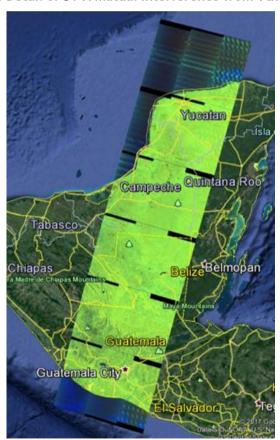


Figure 18: S1-A Mutual Interference from 11th July 2017



Figure 19: Detail of S1-A Mutual Interference from 11th July 2017



Figure 20: S1-A Mutual Interference from 31st October 2017



Figure 21: S1-A Mutual Interference from 5th November 2017

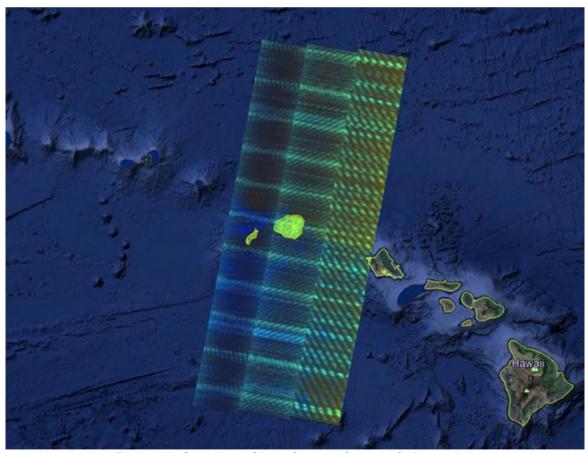


Figure 22: S1-A Mutual Interference from 14th June 2018

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5. Conclusions

This report has described long duration mutual interference between Sentinel-1 and the Canadian Radarsat-2 satellite, the Chinese GAOFEN 3 satellite and an unknown satellite. Many S1-A and RS-2 interference examples are shown in imagery from both satellites.

A full list of all known RS-2 interference in S1-A image has been provided (*). All known examples of interference with GAOFEN-3 and an unknown satellite are shown (*).

(*) At the publication date of this report.

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Appendix A - List of acronyms

MLST	Mean Local Solar Time
MPC	Mission Performance Centre
RFI	Radio Frequency Interference
RS2	Radarsat-2
S1	Sentinel-1