



EAS
ENVI ANALYTICS SYMPOSIUM

Commercial SAR Change Detection

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NATIONAL GEOSPATIAL **NGA** INTELLIGENCE AGENCY

Topic Outline

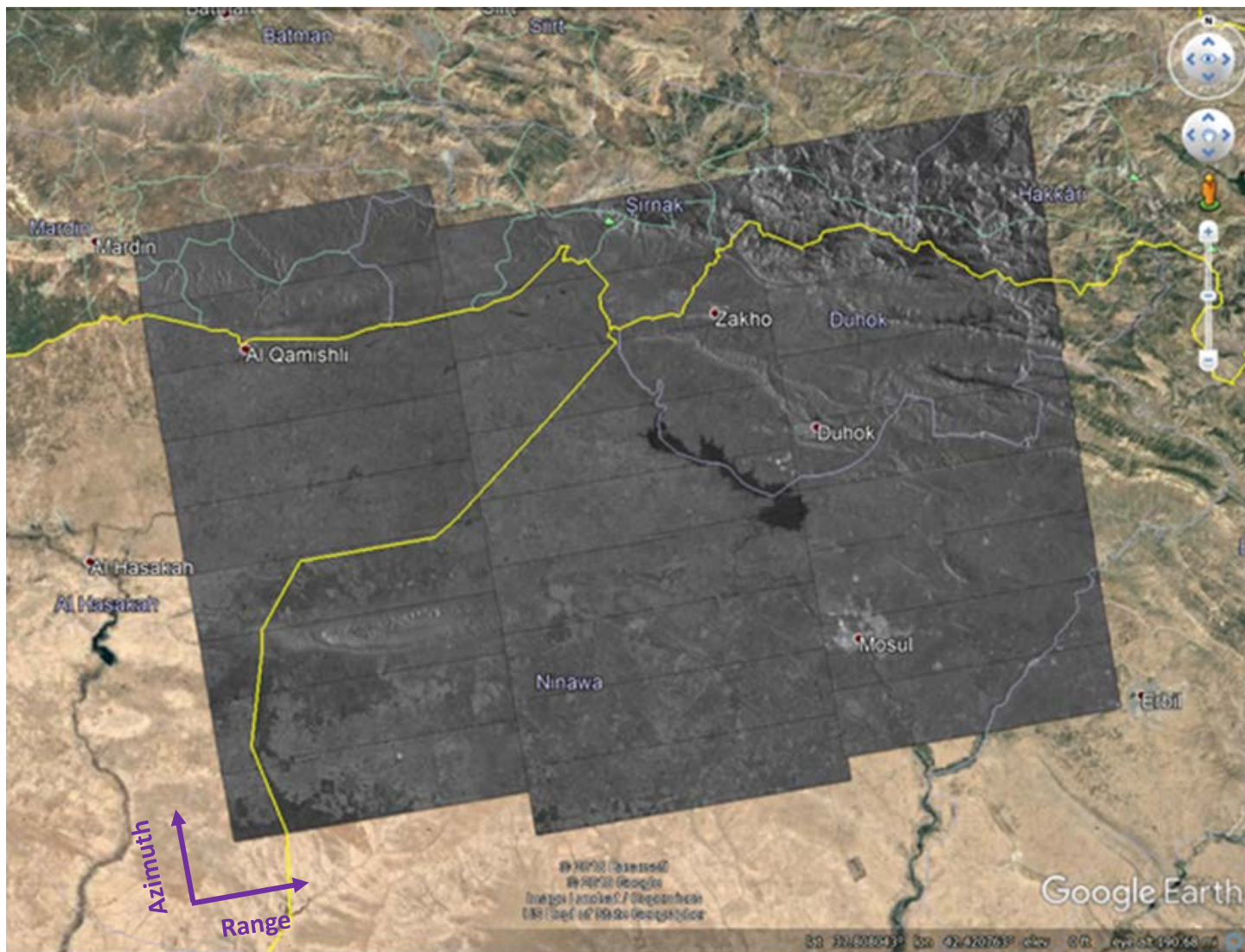
- NGA COMSAR Objectives
- Program Objectives
- Highlights - Current Phase
- Example Results
- Potential Future Efforts

NGA COMSAR Objectives

- Use commercial overhead SAR capability to augment GEOINT analysis
 - ▶ Apply large area, exquisite revisit collection systems for activity analysis and cueing
 - ▶ Use these as complementary assets to other, heavily-tasked systems
 - ▶ Utilize in areas that are not routinely collected by other systems
 - ▶ Unclassified data and products offer distribution flexibility and speed
- Demonstrate value of discoverable change information
 - ▶ Automatically perform change detection on periodically collected revisit data
 - ▶ Extract change detections and attributes from the pixel data
 - ▶ Package change information into textual format for querying and analysis purposes

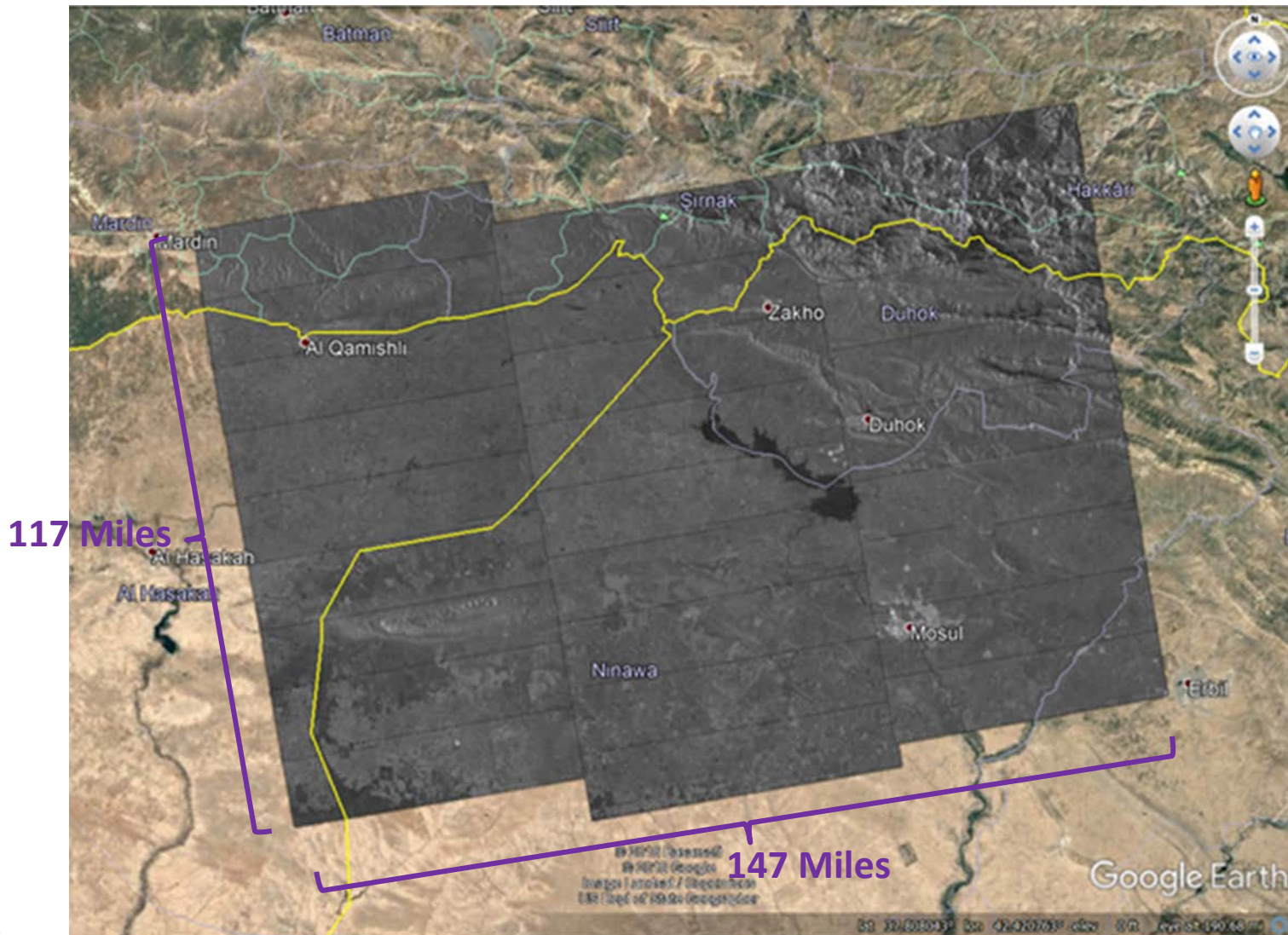
Develop and demonstrate concept to automatically generate queryable change objects from large area overhead SAR imagery

Sentinel-1 Interferometric Wide Swath (IW) mode provides the pixel data



- 12 day revisit (one sat), 6 day revisit (across two sats)
- Near exact imaging geometries between collected pairs
- Each image consists of:
 - ▶ 3 Subswaths along Range
 - ▶ Each subswath sliced into 9 sections (bursts) along Azimuth
- Nominal Resolution:
 $R_g = 3 \text{ m}$, $A_z = 22 \text{ m}$

Challenge: Finding a needle in a stack of needles



- Single Image Interpretation
 - ▶ 17K square miles
 - ▶ 33M pixels to review
 - ▶ Delivered in 27 sections
- Search for Change in Pair
 - ▶ 34K square miles
 - ▶ 66M pixels to review
 - ▶ 54 sections
- Perform Change Analytics
 - ▶ Massively complicated



Program Objectives

- Demonstrate automated change detection, information extraction, and change analytics in support of NGA COMSAR Objectives
- Perform on Sentinel-1 imagery within NGA's Scale environment
- Extend and enhance ACD (Amplitude Change Detection) algorithm
- Derive new attributes to be packaged with the change detections within a GeoJSON structure; derive structured observations from the pixel data
- Support, enable, and demonstrate change analytics and visualization using the automatically generated GeoJSONs

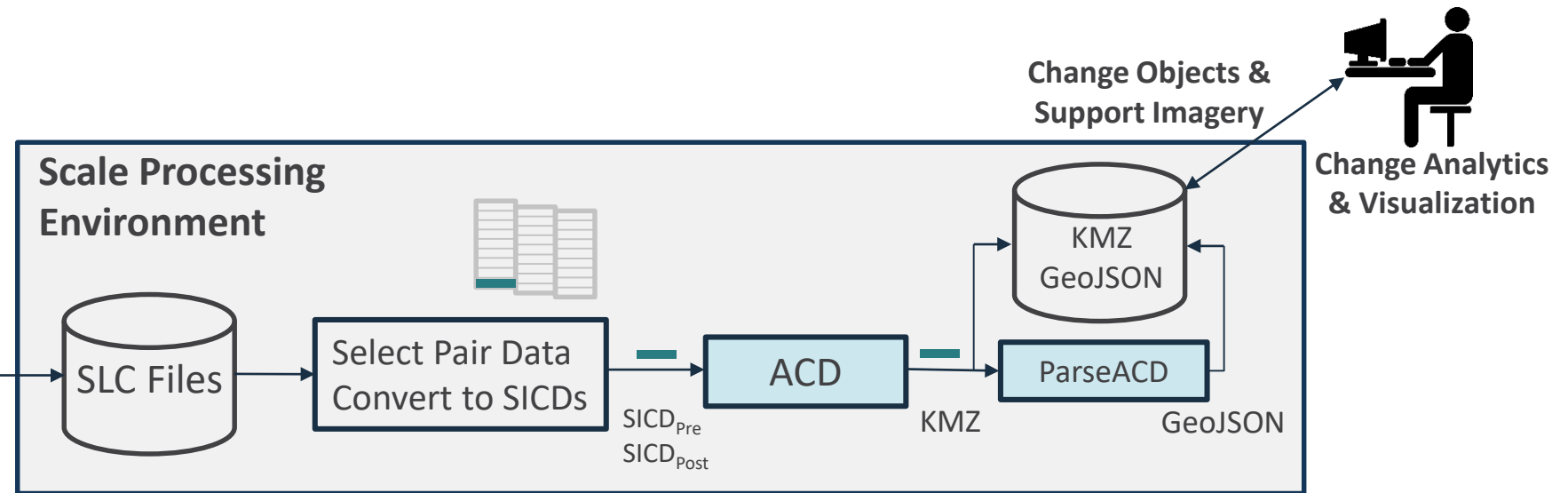
Demonstrate utility of deriving queryable change objects from pixel data

Program Highlights – Current Phase

- Added new ACD detection mode; **RCS-Based Detection**
 - ▶ Application of Sentinel-1 radiometric calibration parameters
 - ▶ Adaptive thresholding algorithm
- Added new **RCS-Based Attributes** to the GeoJSON format
- Ready to provide Google Earth **super-overlays in KMZs**, if desired



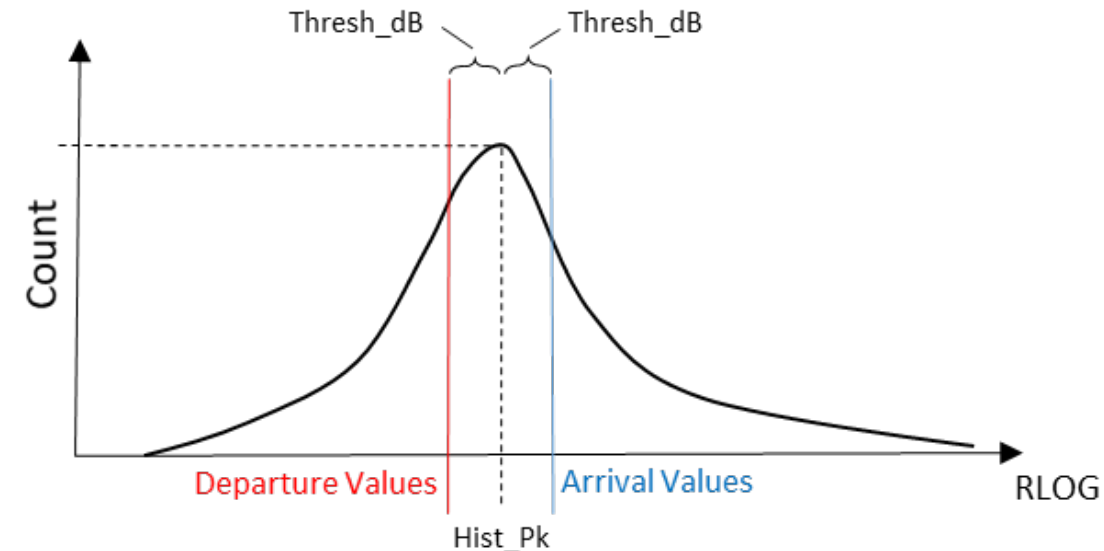
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Near Term Emphasis: ACD Enhancements & New Attributes

Legacy ACD Detection Mode: RLOG

- Based on the ratio of pixel intensities between the Pre- and Post- images
 - ▶ Creates a *log power ratio* image $RLOG = 10\text{Log}(\text{Post}/\text{Pre})$
 - ▶ Detection thresholds are referenced to full scene statistics
- Limitations
 - ▶ Local threshold decision is referenced to Hist_Pk (measured over entirety of both images)
 - ▶ Detection response is sensitive to low return pixels
 - ▶ No physical relation between RLOG measure and Thresh_dB



Better suited for detecting larger area, natural change events

New Detection Mode: RCS-Based Detection

- Use radiometric calibration parameters to scale thresholding in terms of RCS levels (square meters)
 - ▶ Removes antenna pattern, slant range, incidence angle variation
 - ▶ Results in a RADAR physical quantity – RCS (Square meters)
 - Relates pixel intensity to RCS at target peak
 - Relates expected clutter power to reflectivity
- Advantages
 - ▶ Establishes thresholds in terms of target peak RCS
 - ▶ Perform independent thresholding on each image
 - ▶ Enables more precise measurements of change area
 - ▶ Supports measurement of RCS-based attributes

Radiometric calibration

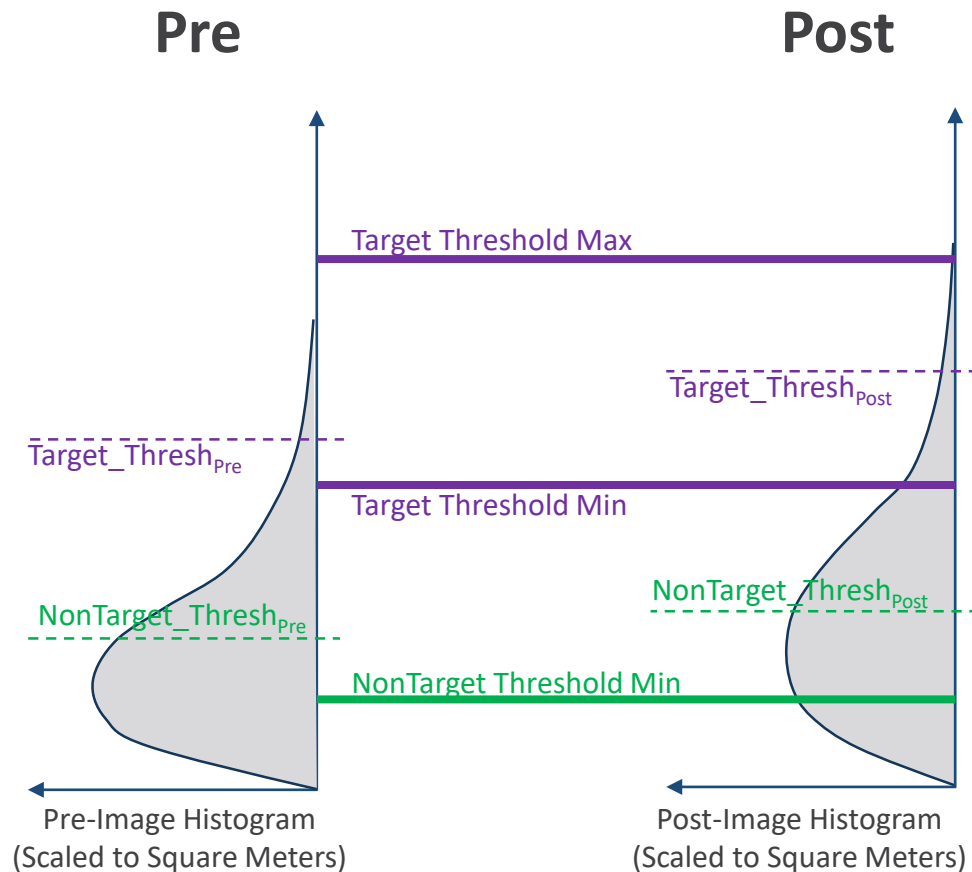
Table 2.2 Typical RCS values for some common targets*

Target	RCS on linear scale	RCS on log scale
Bird	0.001 m ²	−30 dB m ²
Cruise missile	0.01 m ²	−20 dB m ²
Person		
Small boat	1 m ²	0 dB m ²
Small aircraft		
Cabin cruiser	10 m ²	10 dB m ²
Fighter–bomber aircraft		
Road traffic	100 m ²	20 dB m ²
Large aircraft		
Tankers	1000 m ²	30 dB m ²
Large passenger ships		

* Introduction to RADAR Systems; M.I. Skolnik, 1981

Designed for detecting changes associated with man-made targets

RCS-Based Detection Description – Adaptive Threshold Determination



Computes thresholds adaptively per image

- Target_Thresh_{Pre} and Target_Thresh_{Post}
- NonTarget_Thresh_{Pre} and NonTarget_Thresh_{Post}

Max and Min limits are checked and adopted if exceeded

- Target Threshold Max & Min (Square Meters)
- NonTarget Threshold Min (Square Meters)

Resulting thresholds are translated to intensity levels for the detection process

- Target_Thresh_{Pre}' and Target_Thresh_{Post}'
- NonTarget_Thresh_{Pre}' and NonTarget_Thresh_{Post}'

RCS-Based Detection Description – Thresholding Concept

For the next pixel, perform the following tests:

If $\text{Pix}_{\text{pre}} > \text{Target_Thresh}_{\text{pre}}'$ AND $\text{Pix}_{\text{post}} < \text{NonTarget_Thresh}_{\text{post}}'$
Then **DEPARTURE CHANGE**
Compute RCS_{pre} and $\text{Clutter}_{\text{post}}$
Move to next pixel location and start at top

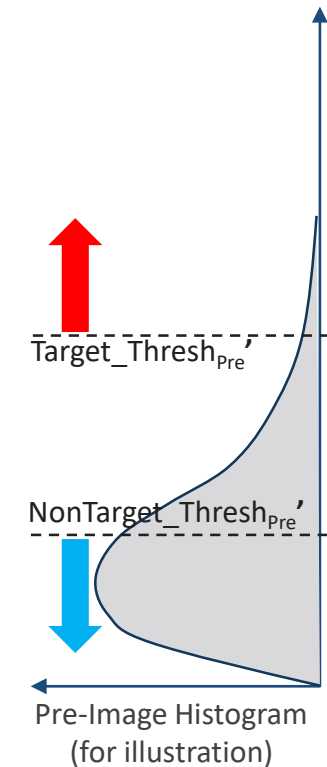
Otherwise

If $\text{Pix}_{\text{post}} > \text{Target_Thresh}_{\text{post}}'$ AND $\text{Pix}_{\text{pre}} < \text{NonTarget_Thresh}_{\text{pre}}'$
Then **ARRIVAL CHANGE**
Compute RCS_{post} and $\text{Clutter}_{\text{pre}}$
Move to next pixel location and start at top

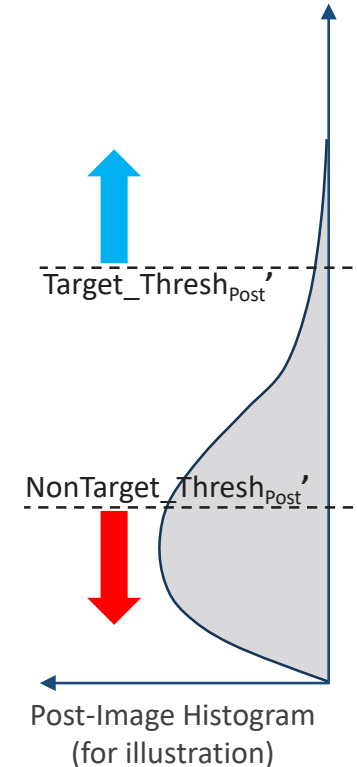
Otherwise

NO DETECT; Move to next pixel location and start at top

Pre



Post



Recorded Information for each change detection

MetaData	Units	Description
Image IDs		Image ID from each SICD
Incidence Angles	degrees	Grazing and Azimuth Angle
Attributes	Units	Description
Detect Strength	dB	Max RLOG value from change detection pixels (+Arrival, -Departure)
Change Area	meter ²	Area span of change detection
Pixel Count		Number of pixels comprising the change
Centroid	degrees	Latitude and Longitude (unweighted and weighted)
Length	meter	Length along major and minor axes
Eccentricity		Ellipse fitting metric
Orientation	degrees	Angular measure from north
Perimeter	meter	Length around the change area
Compactness		Metric relating ratio of perimeter to area
Target Return	meter ² (dB)*	Minimum, maximum, mean, and total target return
Background Return	meter ² (dB)*	Minimum, maximum, and mean background return

New
Addition

* Units are dB if derived with RLOG detection mode

Examples

IRAN: 19Oct-12Nov 2014

Zoom-in

Google Earth

Image © 2019 Maxar Technologies
Image © 2019 DigitalGlobe
Image © 2019 GeoEye

IRAN: EO Image (zoom-in)



Google Earth

Image © 2019 CNES / Airbus
Image © 2019 Maxar Technologies

IRAN: Pre-Image



Google Earth

IRAN: Post-Image



Image © 2019 CNES / Airbus
Image © 2019 Maxar Technologies

Google Earth

IRAN: RLOG Detection

Arrival #12, Arrival #21, Arrival #139, Arrival #362, Arrival #158, Arrival #67, Arrival #278, Arrival #157, Arrival #316, Arrival #303, Departure #4, Arrival #84, Arrival #161, Arrival #65, Arrival #285, Arrival #263, Arrival #274, Arrival #78, Arrival #125, Arrival #73, Arrival #284, Arrival #69, Arrival #349, Arrival #193, Arrival #269, Arrival #231, Arrival #216, Arrival #181, Arrival #141, Arrival #292, Arrival #279, Arrival #44, Arrival #312, Arrival #321, Departure #61, Arrival #108, Arrival #164, Arrival #344, Arrival #113, Arrival #302, Arrival #250, Arrival #353, Arrival #241, Departure #55, Departure #63, Arrival #155, Departure #58, Arrival #358, Arrival #313, Arrival #163, Arrival #99, Departure #48, Arrival #283, Arrival #361, Arrival #115, Arrival #40, Arrival #317, Arrival #213, Arrival #286, Arrival #206, Arrival #335, Arrival #369, Arrival #311, Arrival #190, Arrival #68, Arrival #373, Arrival #96, Arrival #81, Arrival #134, Arrival #368, Arrival #201, Arrival #147, Arrival #242, Arrival #308, Arrival #306, Arrival #258, Arrival #64, Arrival #66, Arrival #207, Arrival #211, Arrival #70, Arrival #148, Arrival #370, Arrival #348, Arrival #212, Arrival #111, Arrival #118, Arrival #305, Arrival #243, Arrival #254, Arrival #53, Arrival #25, Arrival #117, Arrival #110, Arrival #109, Arrival #108, Arrival #107, Arrival #106, Arrival #105, Arrival #104, Arrival #103, Arrival #102, Arrival #101, Arrival #100, Arrival #99, Arrival #98, Arrival #97, Arrival #96, Arrival #95, Arrival #94, Arrival #93, Arrival #92, Arrival #91, Arrival #90, Arrival #89, Arrival #88, Arrival #87, Arrival #86, Arrival #85, Arrival #84, Arrival #83, Arrival #82, Arrival #81, Arrival #80, Arrival #79, Arrival #78, Arrival #77, Arrival #76, Arrival #75, Arrival #74, Arrival #73, Arrival #72, Arrival #71, Arrival #70, Arrival #69, Arrival #68, Arrival #67, Arrival #66, Arrival #65, Arrival #64, Arrival #63, Arrival #62, Arrival #61, Arrival #60, Arrival #59, Arrival #58, Arrival #57, Arrival #56, Arrival #55, Arrival #54, Arrival #53, Arrival #52, Arrival #51, Arrival #50, Arrival #49, Arrival #48, Arrival #47, Arrival #46, Arrival #45, Arrival #44, Arrival #43, Arrival #42, Arrival #41, Arrival #40, Arrival #39, Arrival #38, Arrival #37, Arrival #36, Arrival #35, Arrival #34, Arrival #33, Arrival #32, Arrival #31, Arrival #30, Arrival #29, Arrival #28, Arrival #27, Arrival #26, Arrival #25, Arrival #24, Arrival #23, Arrival #22, Arrival #21, Arrival #20, Arrival #19, Arrival #18, Arrival #17, Arrival #16, Arrival #15, Arrival #14, Arrival #13, Arrival #12, Arrival #11, Arrival #10, Arrival #9, Arrival #8, Arrival #7, Arrival #6, Arrival #5, Arrival #4, Arrival #3, Arrival #2, Arrival #1.

Google Earth

Image © 2019 CNES / Airbus
Image © 2019 Maxar Technologies

IRAN: RLOG Detection

Arrival #12, Arrival #21, Arrival #139, Arrival #362, Arrival #158, Arrival #67, Arrival #278, Arrival #157, Arrival #316, Arrival #303, Departure #4, Arrival #84, Arrival #161, Arrival #65, Arrival #285, Arrival #263, Arrival #274, Arrival #78, Arrival #125, Arrival #73, Arrival #284, Arrival #69, Arrival #349, Arrival #193, Arrival #269, Arrival #231, Arrival #216, Arrival #181, Arrival #141, Arrival #292, Arrival #279, Arrival #44, Arrival #312, Arrival #321, Departure #61, Arrival #108, Arrival #164, Arrival #344, Arrival #113, Arrival #302, Arrival #250, Arrival #353, Arrival #241, Departure #55, Departure #63, Arrival #155, Departure #58, Arrival #358, Arrival #313, Arrival #163, Arrival #99, Departure #48, Arrival #283, Arrival #361, Arrival #115, Arrival #40, Arrival #317, Arrival #213, Arrival #286, Arrival #206, Arrival #335, Arrival #369, Arrival #311, Arrival #190, Arrival #68, Arrival #373, Arrival #96, Arrival #81, Arrival #134, Arrival #368, Arrival #201, Arrival #147, Arrival #242, Arrival #308, Arrival #306, Arrival #258, Arrival #64, Arrival #66, Arrival #207, Arrival #211, Arrival #70, Arrival #148, Arrival #370, Arrival #348, Arrival #212, Arrival #305, Arrival #243, Arrival #254, Arrival #53, Arrival #111, Arrival #118, Arrival #117, Arrival #117, Arrival #25

Image © 2019 CNES / Airbus
Image © 2019 Maxar Technologies

Google Earth

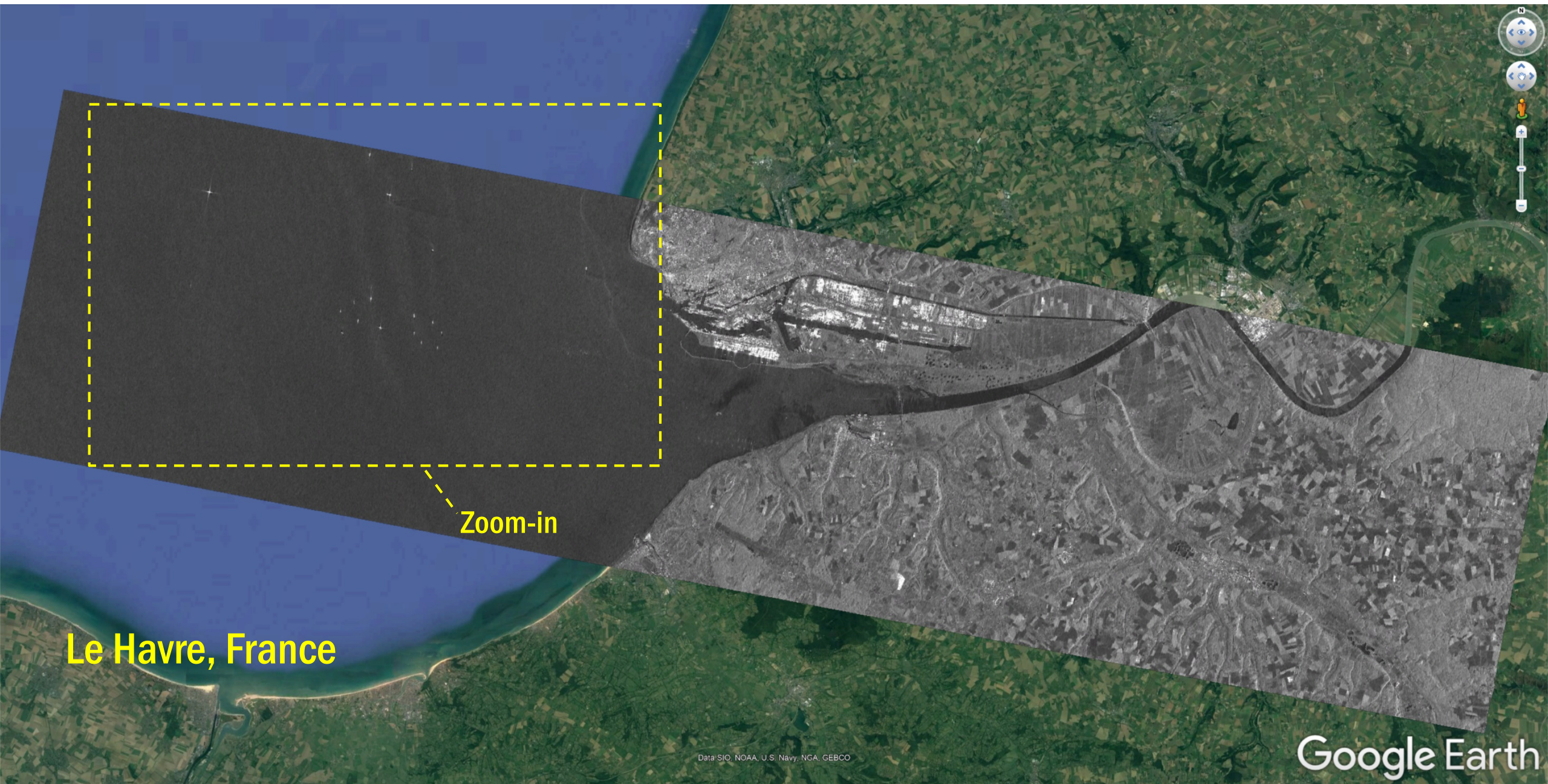
18

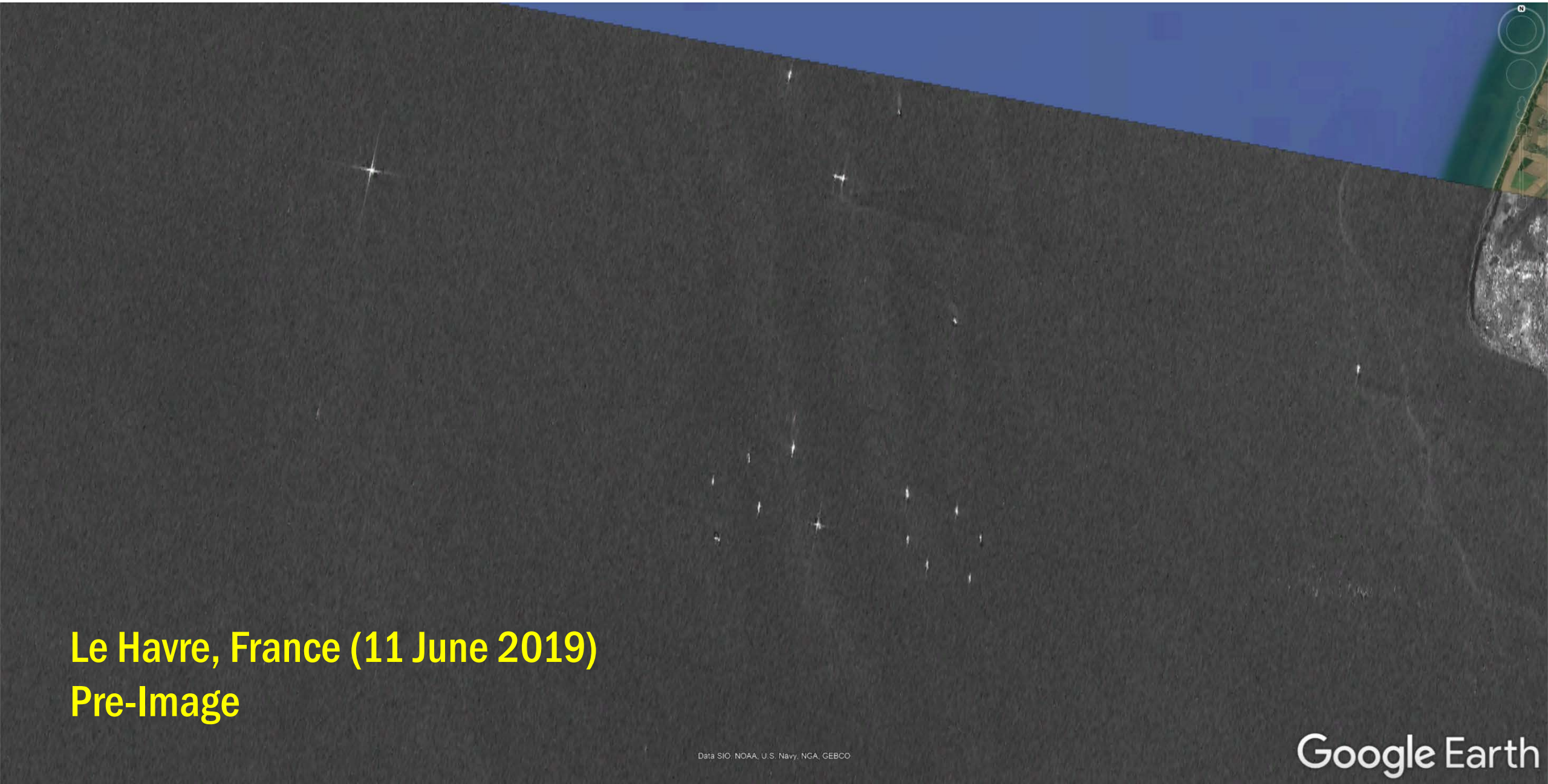
Approved for Public Release, 19-886

[illegible]

IRAN: RCS-Based Detection



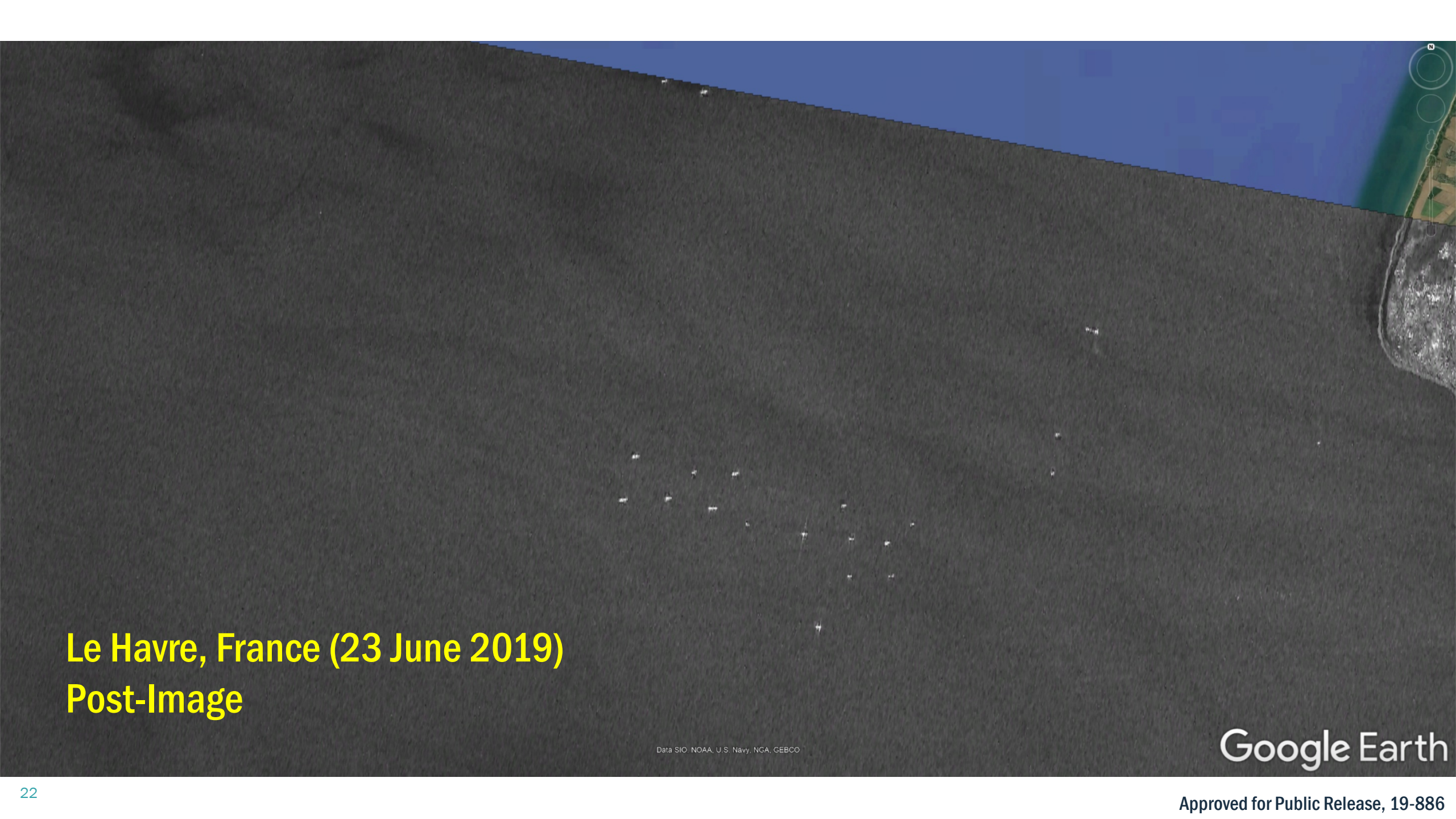




Le Havre, France (11 June 2019)
Pre-Image

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

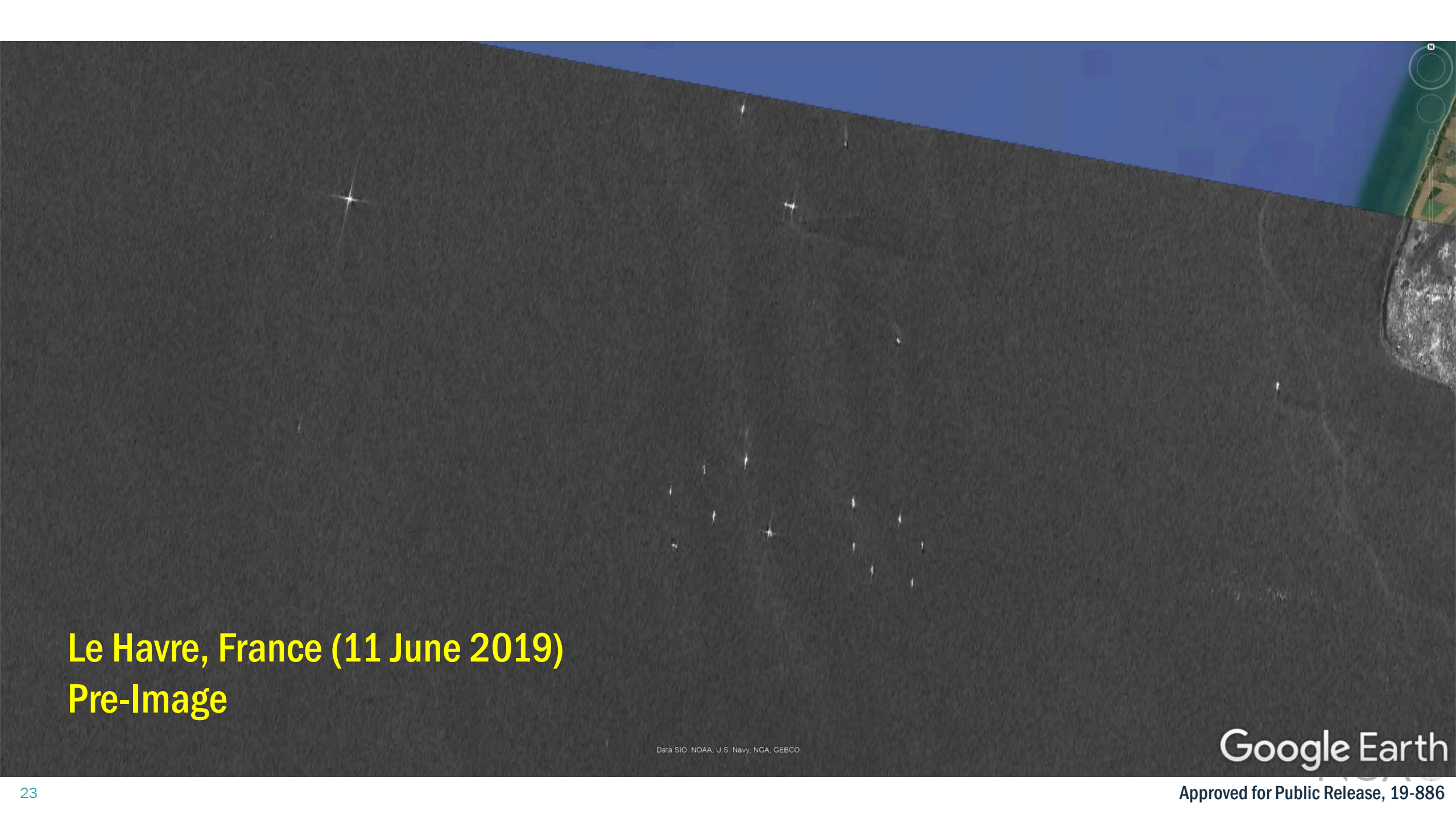
Google Earth

A satellite image of the ocean surface, showing a large, dark, irregularly shaped oil spill. The spill is located in the upper right portion of the image, extending from the top edge towards the center. The surrounding water is a lighter, textured blue-grey. In the bottom right corner, a small portion of a coastline is visible, showing some land features and a small body of water. The overall image is a high-resolution satellite capture.

Le Havre, France (23 June 2019) Post-Image

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Google Earth

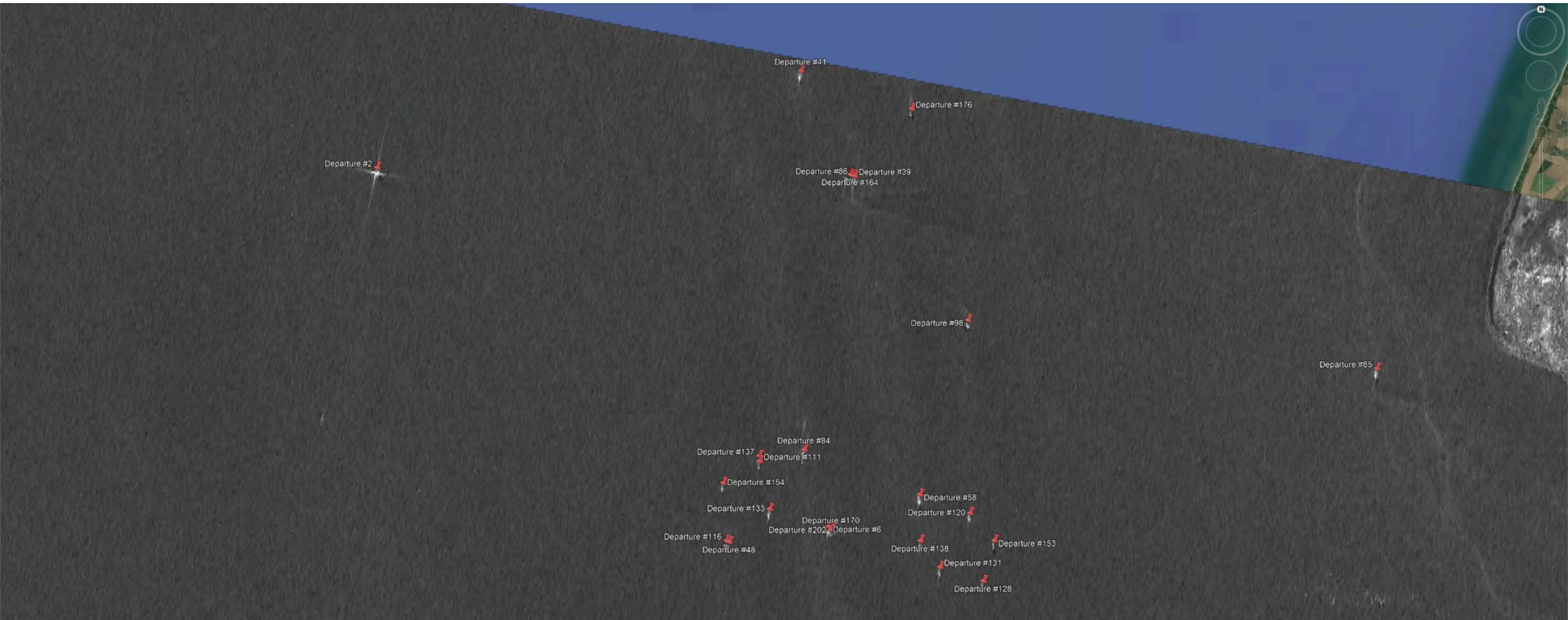


Le Havre, France (11 June 2019)
Pre-Image

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Google Earth

Approved for Public Release, 19-886



Le Havre, France (11 June 2019) Pre-Image + Departures

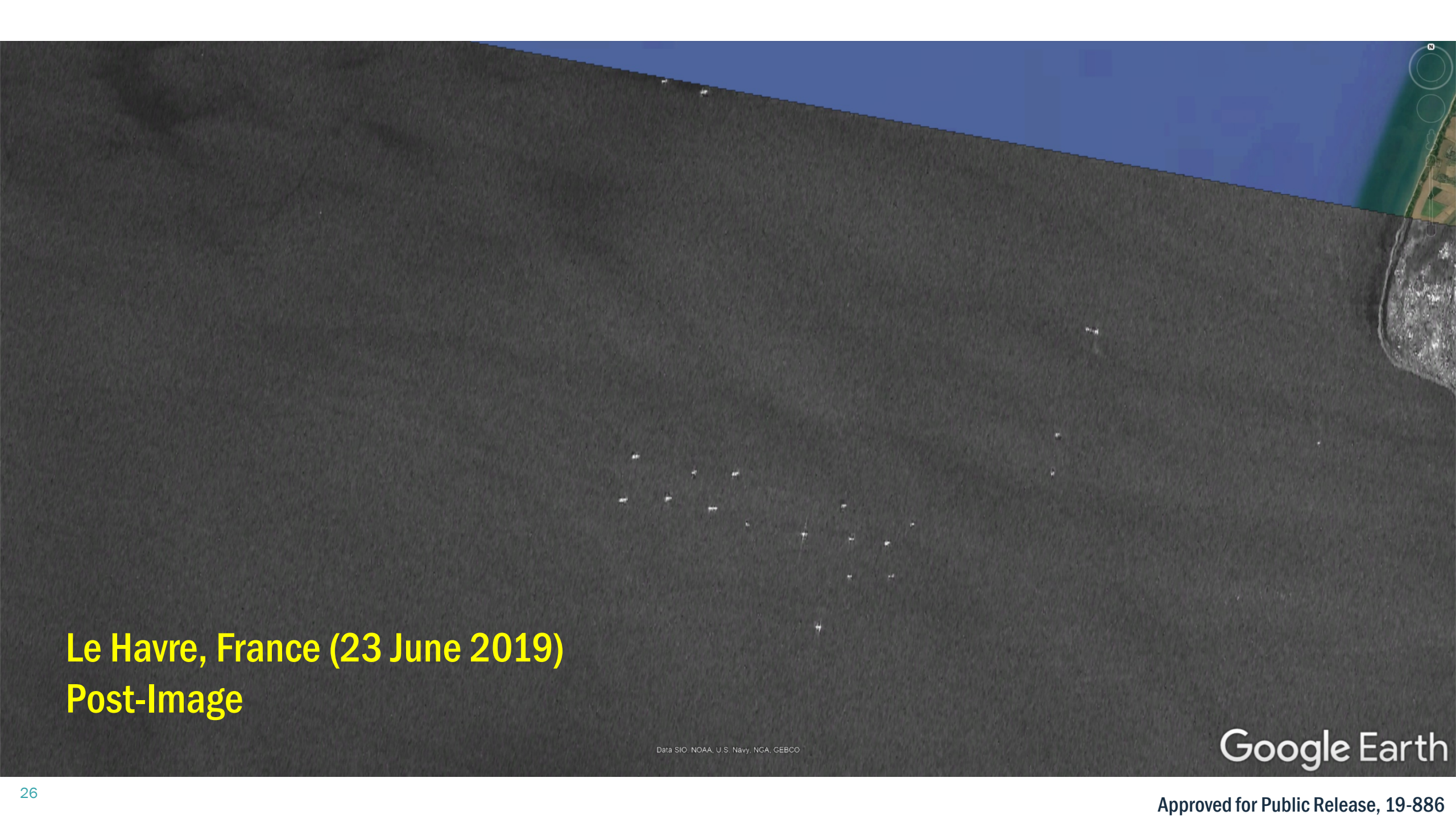
Departure #2	
IIDs	11Jun19S1A204345_17_IW1_04_VV_SICD - 23Jun19S1A205685_17_IW1_04_VV_SICD
Lat	49.538825 deg
Lon	-0.256976 deg
Detect Strength	-52.8 dB
Change Area	11895.05 m²
Pixel Count	196
IID 1	GrazeAng = 56.311104 ; AzimAng = 100.925190
IID 2	GrazeAng = 56.314271 ; AzimAng = 100.924165
Centroid	lat = 49.538702 ; lon = -0.256915
Major Axis Length	306.55 m
Minor Axis Length	144.77 m
Eccentricity	0.8815
Orientation	82.6713
Perimeter	1274.14 m
Weighted Centroid	lat = 49.538699 ; lon = -0.256944
Compactness	0.7179
Target Mean Return	12489.34
Target Minimum Return	0.00
Target Maximum Return	364015.64
Target Total Return	2447909.77
Background Mean Return	1.19
Background Minimum Return	0.00
Background Maximum Return	6.78
Processing Type (Return Units: Rlog (dB) or RCS (sqm))	RCS

Le Havre, France (11 June 2019)

Pre-Image + Departures

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Google Earth

A satellite image from Google Earth showing a large, dark, irregular oil spill on the ocean surface. The spill is located in the northern part of the Atlantic Ocean, near the coast of France. The spill is composed of many small, dark patches that are spread out over a large area. The surrounding ocean is a lighter blue color. In the top right corner, there is a small inset map showing the location of the spill relative to the coast of France. The text "Le Havre, France (23 June 2019)" and "Post-Image" is overlaid on the bottom left of the image.

Le Havre, France (23 June 2019)

Post-Image

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Google Earth



Google Earth

Le Havre, France (23 June 2019)

Post-Image + Arrivals



Arrival #168	
IIDs	11Jun19S1A204345_17_IW1_04_VV_SICD - 23Jun19S1A205685_17_IW1_04_VV_SICD
Lat	49.489667 deg
Lon	0.045972 deg
Detect Strength	22.7 dB
Change Area	485.51 m²
Pixel Count	8
IID 1	GrazeAng = 56.311104 ; AzimAng = 100.925190
IID 2	GrazeAng = 56.314271 ; AzimAng = 100.924165
Centroid	lat = 49.489544 ; lon = 0.046032
Major Axis Length	50.91 m
Minor Axis Length	25.30 m
Eccentricity	0.8678
Orientation	98.5514
Perimeter	106.12 m
Weighted Centroid	lat = 49.489550 ; lon = 0.046050
Compactness	1.4649
Target Mean Return	169.68
Target Minimum Return	62.58
Target Maximum Return	367.88
Target Total Return	1357.48
Background Mean Return	1.73
Background Minimum Return	0.03
Background Maximum Return	3.31
Processing Type (Return Units): Rlog (dB) or RCS (sqm)	RCS

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Google Earth

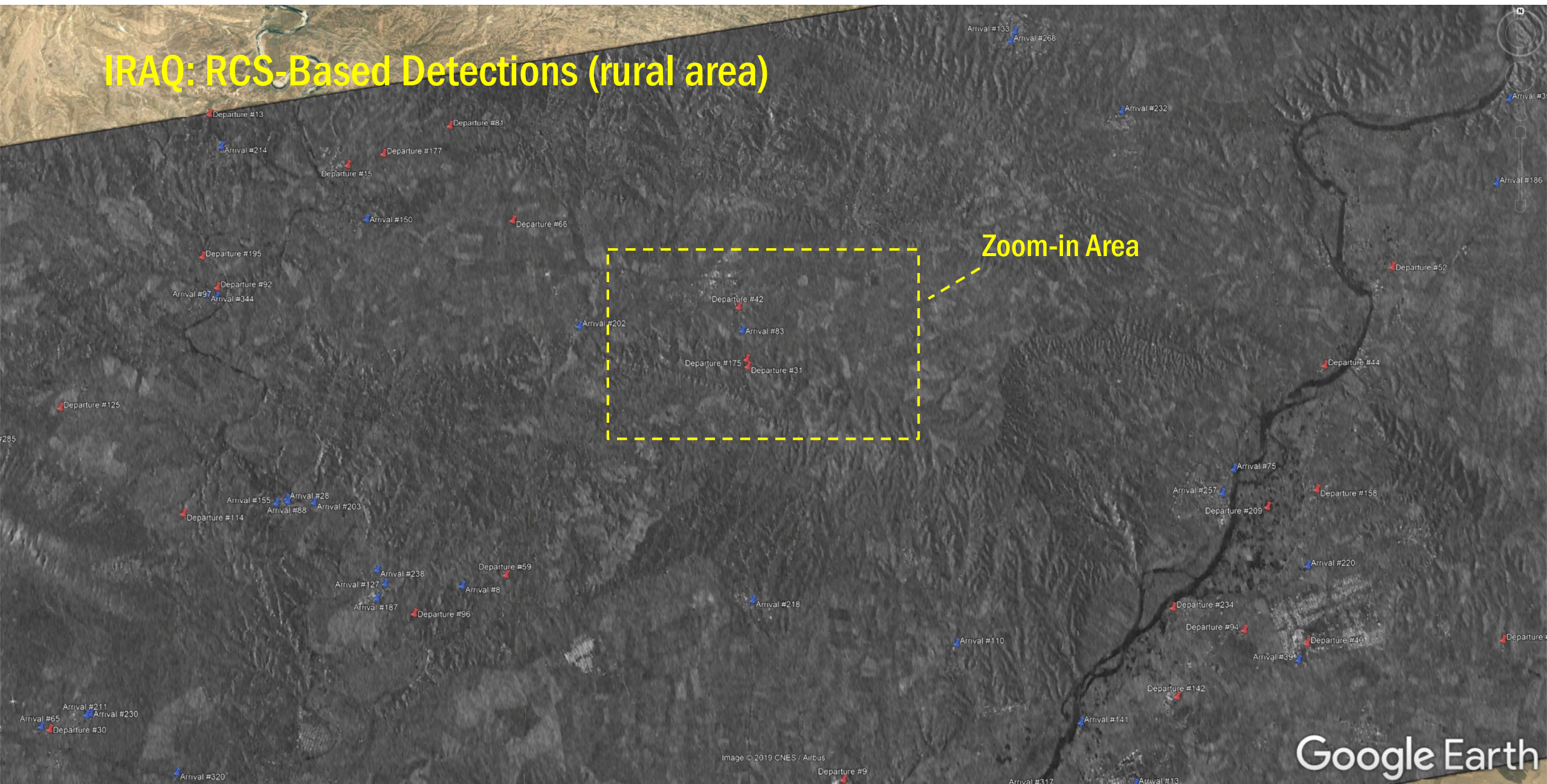
IRAQ: Mosul Region (3 Feb – 15 Feb 2019)

Rural Area

Google Earth

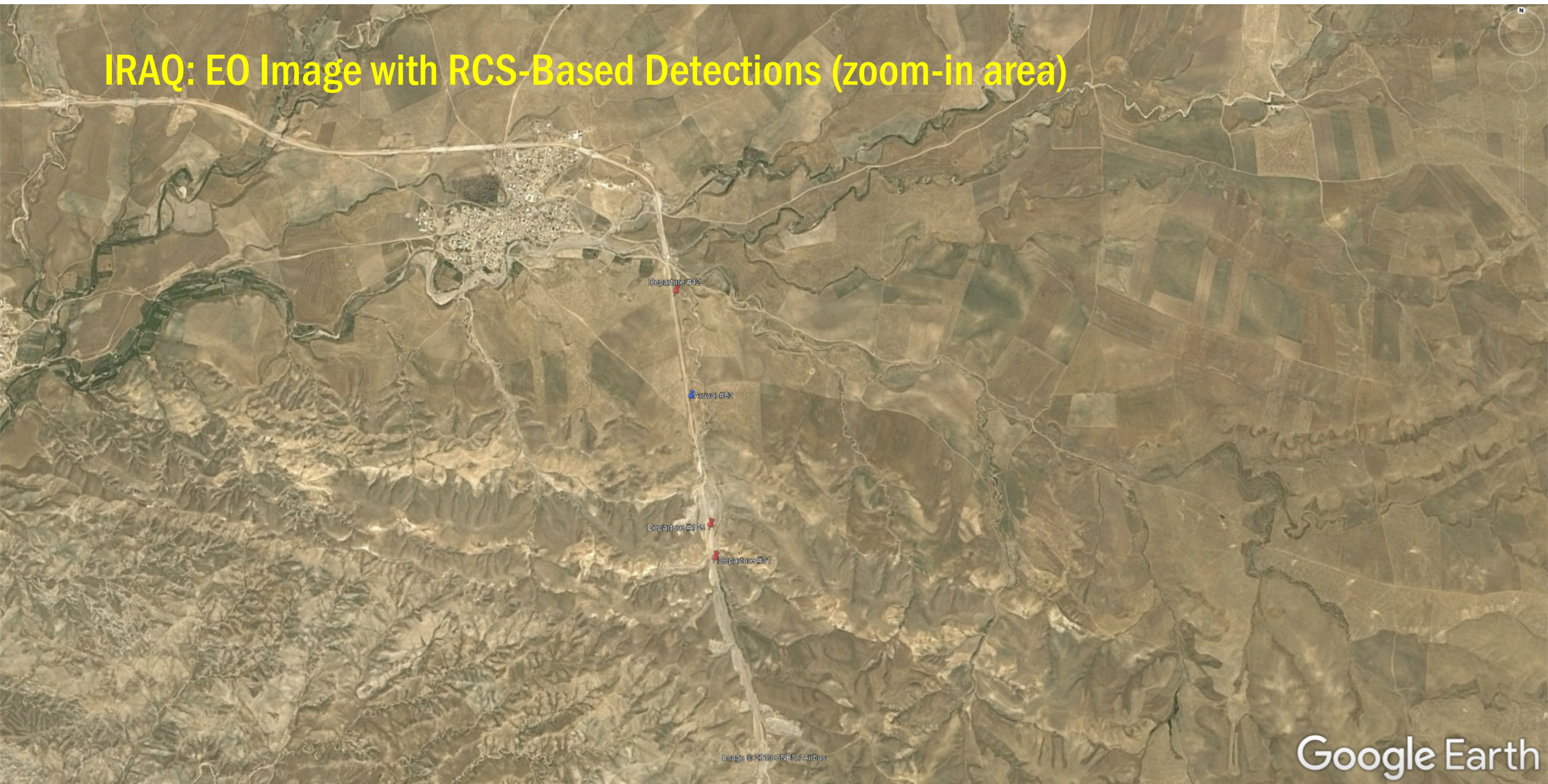
Image © 2019 CNES / Airbus
Image © 2019 DigitalGlobe

IRAQ: RCS-Based Detections (rural area)



Google Earth

IRAQ: EO Image with RCS-Based Detections (zoom-in area)



Google Earth

IRAQ: Mosul Region

Urban

Google Earth

Image © 2019 CNES / Airbus
Image © 2019 DigitalGlobe

IRAQ: RCS-Based Detections (urban)

Google Earth

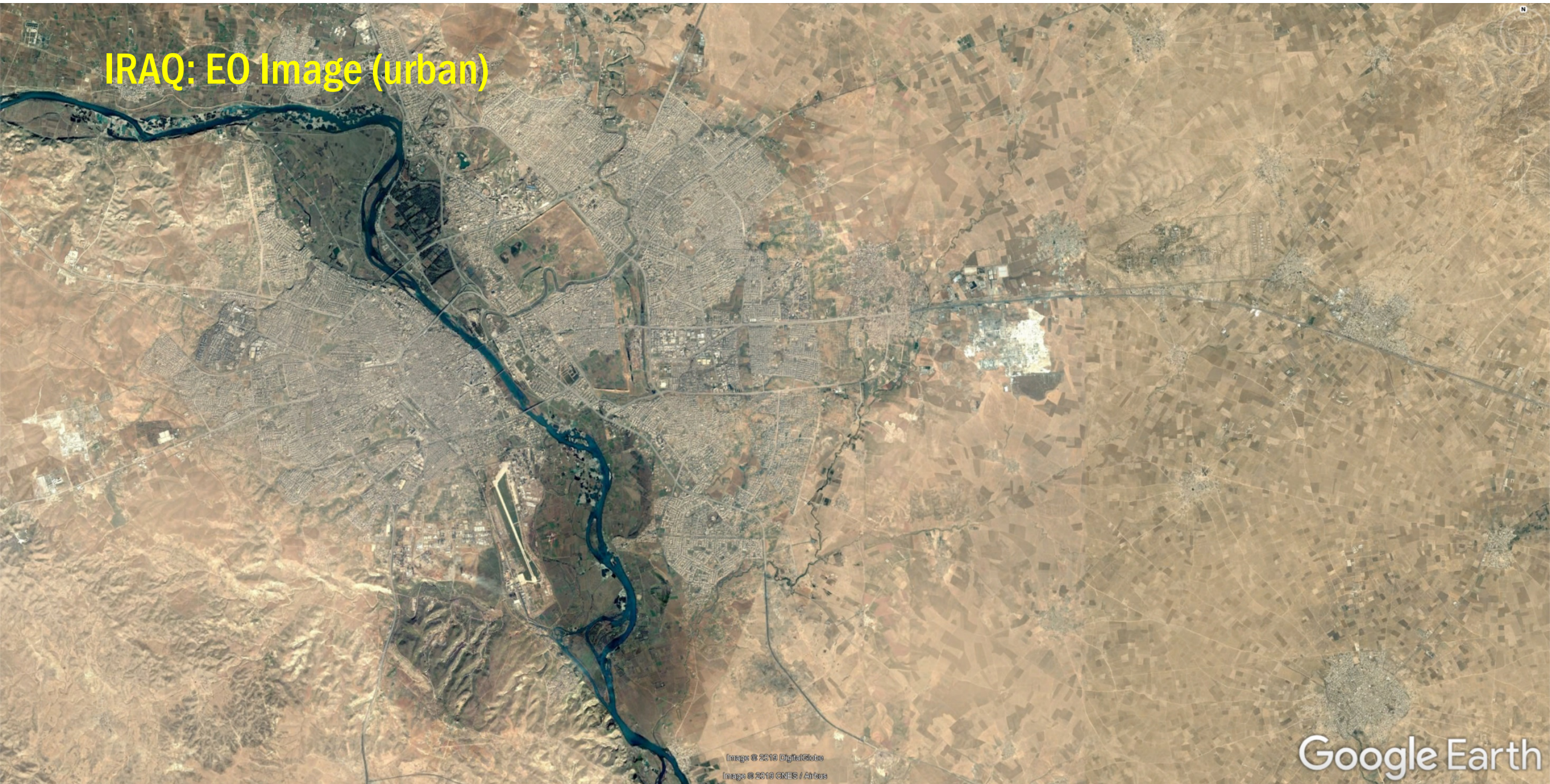
Image © 2019 DigitalGlobe
Image © 2019 CNES / Airbus

IRAQ: RCS-Based Detections (urban)

Google Earth

Image © 2019 DigitalGlobe
Image © 2019 CNES / Airbus

IRAQ: EO Image (urban)



Google Earth

Image © 2018 DigitalGlobe
Image © 2019 CNES / Airbus

IRAQ: EO Image with Urban Context Layer – Preliminary Example

Good Earth imagery overlay highlights the pixels automatically determined to be from urban areas. This type of information can be associated per detection as a context attribute for downstream analytics and visualization purposes.

Google Earth

Potential Future Efforts

- Add scene context attributes with detections to support filtering during analytics or visualization
 - ▶ Urban area
 - ▶ Terrain slope
 - ▶ Water body
- Investigate using both RCS-Based and RLOG techniques for complementary attributes
- Use-case development
- Change analytics demonstrations

Focused on Improvements that Align with NGA Objectives

