TACSAT-2
Target Indicator Experiment (TIE)
AIS Payload Overview

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Purpose

- **Brief overview of the Naval Research Laboratory (NRL) Target Indicator Experiment (TIE) Automated Identification System (AIS) payload**
  - **TACSAT-2, the host spacecraft**
  - **Top level architecture**
  - **AIS receiver attributes**
  - **Phased array antenna attributes**
- **Top Level Data Flow**
- **Brief mention of regulatory and authorities which provided non-technical challenges**
- **Some snapshots of TIE data collections**
- **Way forward**

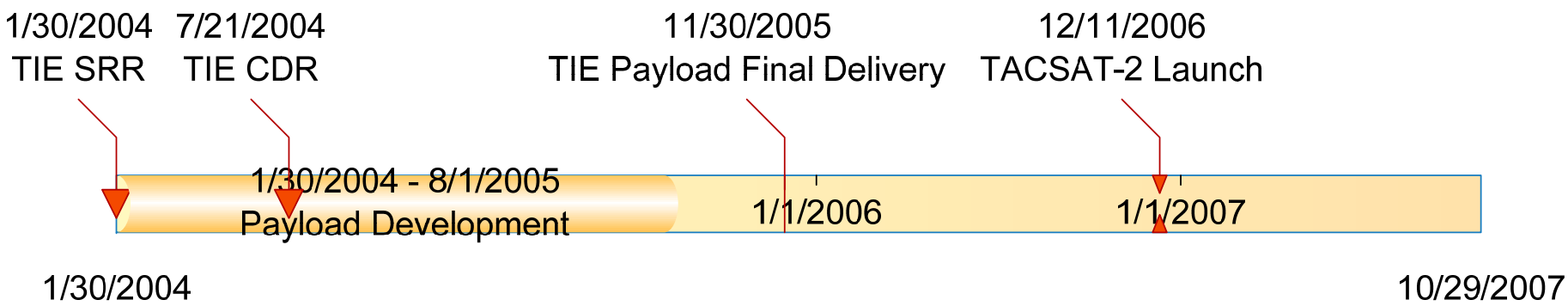
Genesis of AIS on TACSAT for Experimentation

Objectives

From Original Space Test Program (STP) objectives

2) Experiment w/ Space Collection of AIS From Ships for Port Safety & Homeland Defense

- **At the time the TIE development opportunity presented itself, the TIE team had just concluded TACSAT-1 development**
- **Team was looking to take the next logical step in reducing size, weight and power while adding new functionality**
- **Adding AIS capability to original payload foundation met internal goals for working with software defined radios and demonstrated a measure of effectiveness to emerging requirements (i.e. receiving AIS messages**



AIS Receiver Development

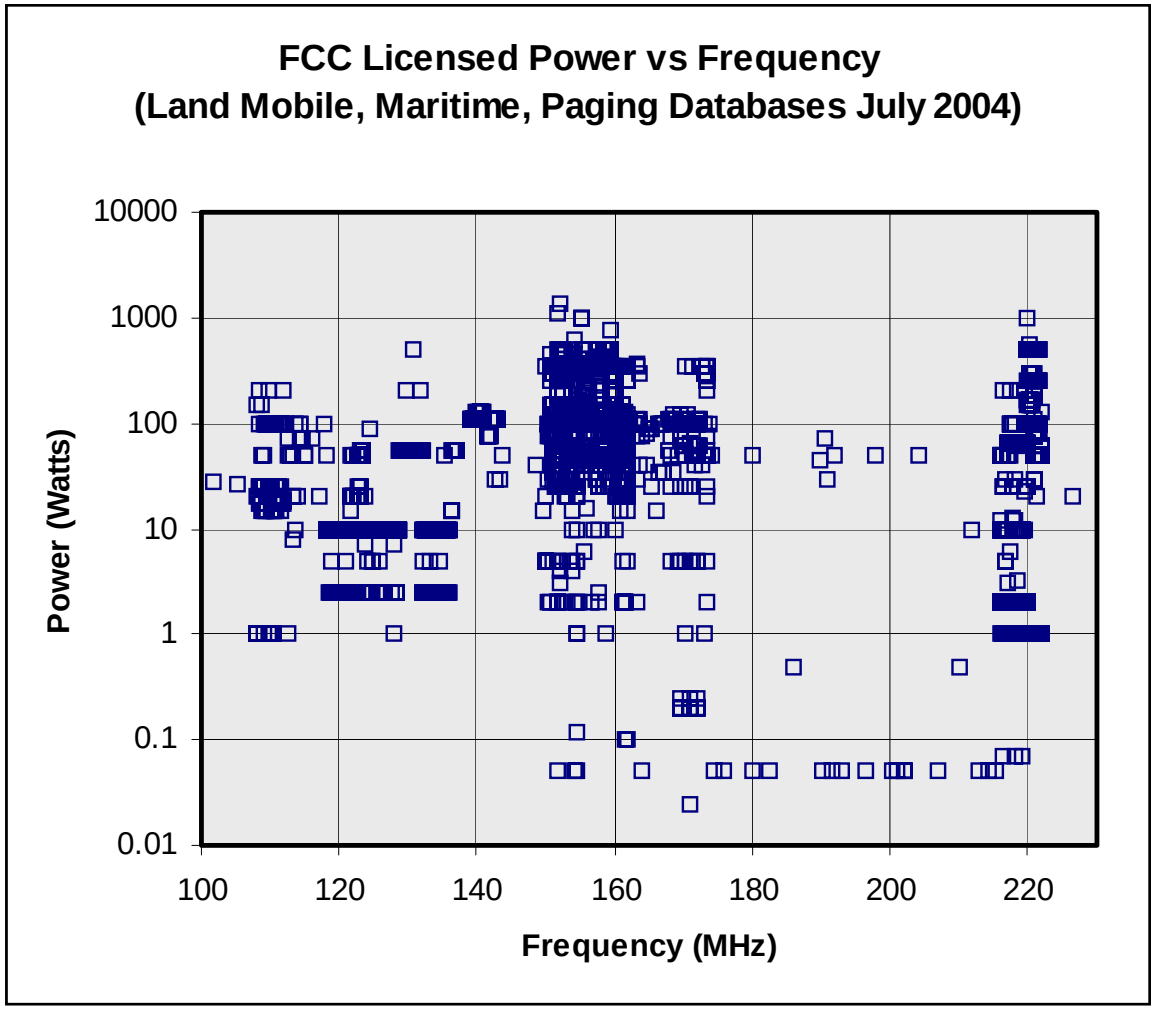
- **Receiver itself funded through Office of Naval Research (ONR) and the Copperfield-2 foundation primary through Navy N6 TENCAP funds**

- **Government, Industry, FFRDC Joint Effort**
  - **Aeronix, Inc developed the processor card which was “reprogrammed” to demodulate the AIS waveform**
  - **Aerospace Corp (Dr. Jeff Stocker, Dr. James Hicks) team developed AIS receiver FPGA and processor algorithms and code**
  - **NRL team developed AIS receiver antennas, beam former, and RF Front End Unit, and provided final integration of components together**
  - **Environmental testing performed by NRL team for the space platform, as well as for airborne and ground testing**

- **Extensive (hundreds of flight hours) aircraft testing on various platforms in dense maritime environments**
  - **Southern CA**
  - **Mid-Atlantic East Coast (NY, NJ, Philadelphia)**

- **Receiver designed from the ground up to be built with government-owned intellectual property and without any classified algorithms or proprietary software**

AIS Receiver Design and Dynamic Range



- **A challenge of the TIE AIS receiver design was to allow it to be useful in a very high dynamic range environments – identical hardware to be used onboard *both* aircraft and spacecraft**
- **Maximum signal level**
  - **-147 dBm range for a 400 km spacecraft**
  - **-50 dBm or higher for a terrestrial AIS receiver at very close range to the transmitter**
- **100+ dB dynamic range is challenging to meet!**

Design Trades

- **Budgetary limitations but more importantly schedule drove severe design trades which limit performance but enabled meeting other programmatic requirements**

- **TIE implemented a simple RF Front End with a wide-bandwidth pre-selection filter**
  - **Custom designed filter would have provided better selectivity but was not obtainable in the schedule**
- **Adaptation of TACSAT-1 Copperfield-2 board set limited some receiver performance with some impact on sensitivity and digital filter performance**
- **A simple demodulator single-bit differential GMSK modulator was designed and utilized**

- **While a phased-array antenna approach was utilized and implemented, it was a basic design vice a fully-steerable electronic array**

TIE AIS Receiver General Attributes

- Designed to provide a platform for AIS signal collection, demodulation, and experimentation
- Software defined radio architecture
  - Digital filtering and cross-correlation functions happen within a field programmable gate array (FPGA) device
  - Demodulation of Gaussian minimum-shift keying (GMSK) waveform occurs within a general purpose processor
  - Output of the AIS receiver is “industry standard” NMEA-0183 message format within a container message format
- Store and forward architecture allows for autonomous data collection and archiving
- Ground processing architecture allows for receipt and processing of the spacecraft data to expose the original NMEA-0183 message format

Areas of AIS Receiver Experimentation

- **The payload was specifically designed to be a platform for *experimenting* with the AIS signal**

- **Co-channel and/or adjacent channel interference investigations**
  - **Software-defined nature of the demodulator allows uploading new algorithms**
  - **Extensive on-board telemetry monitors every step in the demodulation process**
  - **Phased array antenna provides directivity**

- **Optimal antenna design experimentation**
  - **Omni-directional (coverage versus directivity)**
  - **Phased array for nulling high power emitters**
  - **Array orientation (wider coverage versus repeat)**

- **On-board processing and databasing**
  - **Reducing data rate requirements by filtering-onboard**

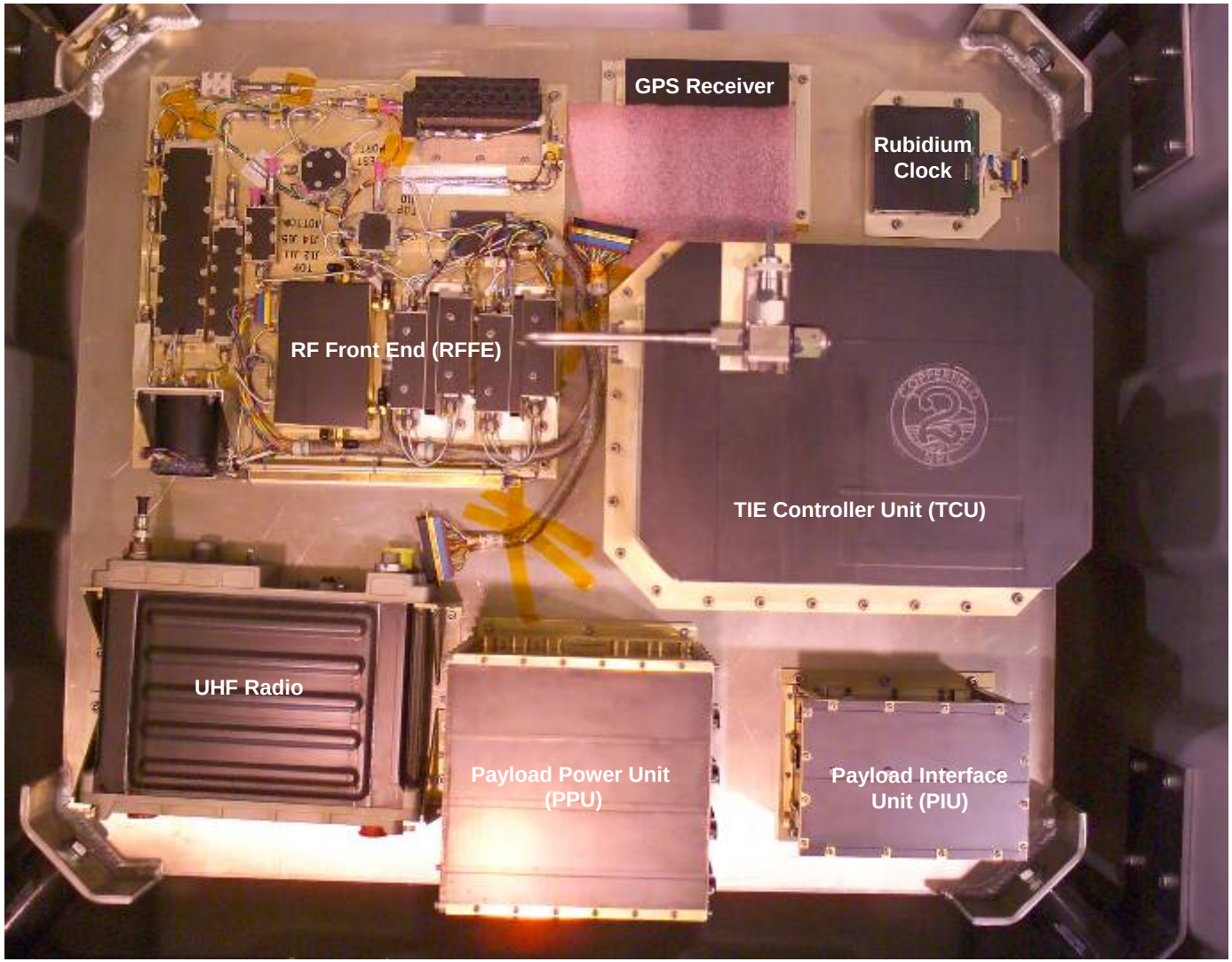
Phased Array Investigations

- During the initial design, we considered likely problems with co-channel interference from terrestrial sources and maritime sources
  - Self Organizing Time Domain Multiple Access (SOTDMA) networks see limited numbers of nodes around them versus a space node which sees far more
  - Terrestrial sources such as NOAA weather radio and other in-channel sources which are legally licensed but high-powered
- Limited front end filtering
  - Acquisition cost and schedule for a custom-designed filter were a driver
  - Practical challenges when a 4 kHz Doppler-induced error can be expected on the signal as it is received while maintaining narrow-band performance
- Given the “wing”-span of the solar arrays on the host spacecraft, a VHF phased array seemed like a workable area to experiment
  - 10 dB of gain and directivity
  - Reduce the effective instantaneous field of view
  - Spacecraft motion would compensate for limited instaneous view by providing robust coverage

TIE AIS Receiver Software Message Filter Capabilities

- Two-Channel Receiver
- Live Data Streaming
  - AIS1 and AIS2 Channel Messages Streamed Live in Default Mode
  - All AIS Messages Archived Into Internal Database (Reset at Each Power Cycling)
  - Parametric Data Augments Each Message
    - Time-of-Intercept
    - Additional message characterization
  - Distance from Receiver Platform to Vessel-reported Position can be Calculated
- Live and Archived Data Filtering
  - AIS Messages can be Filtered by one or more of:
    - Message Type (Type 1, 2, or 3 Position Reports; Type 5 Ship Static and Voyage-related Data)
    - MMSI or IMO (regular expression)
    - Navigation Status (regular expression)
    - Cargo Type (regular expression)
    - Latitude and Longitude (Min/Max)
    - Speed-Over-Ground (Min/Max)
    - Time-of-Intercept (Min/Max)

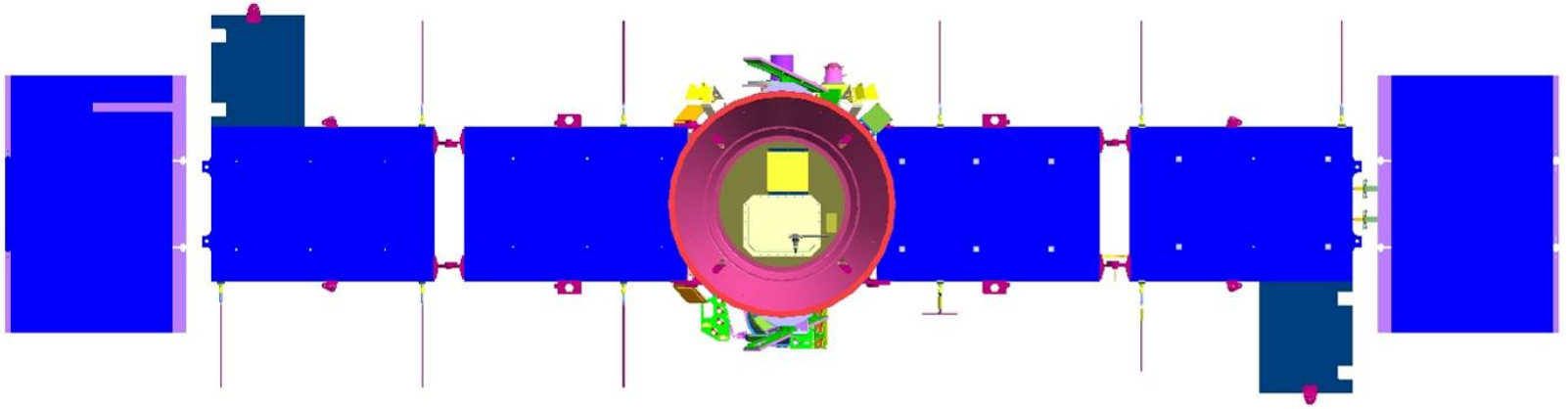
TIE Equipment Suite: Pre-Ship

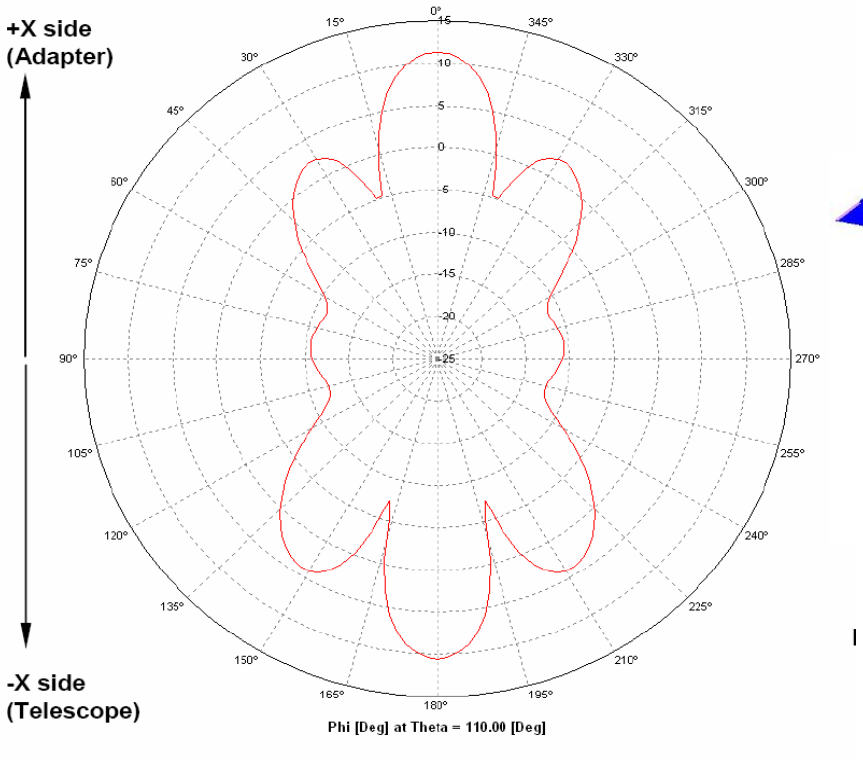


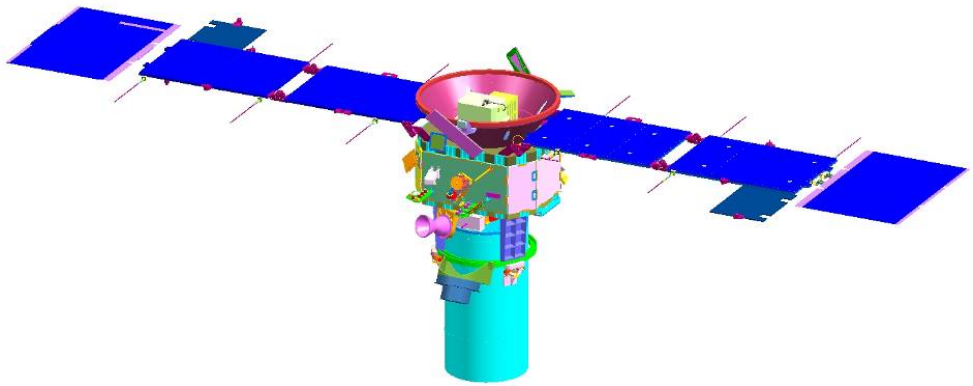
TACSAT-2 General Attributes

- Launched December 16th, 2006 on a Minotaur-I launch vehicle from Wallops Space Flight Facility, VA
- 420 kilometer Low Earth Orbit (LEO) satellite at about 40 degrees inclination
- About ten other experiments onboard the spacecraft with competing demands for power, pointing and downlink bandwidth

TACSAT-2 Spacecraft

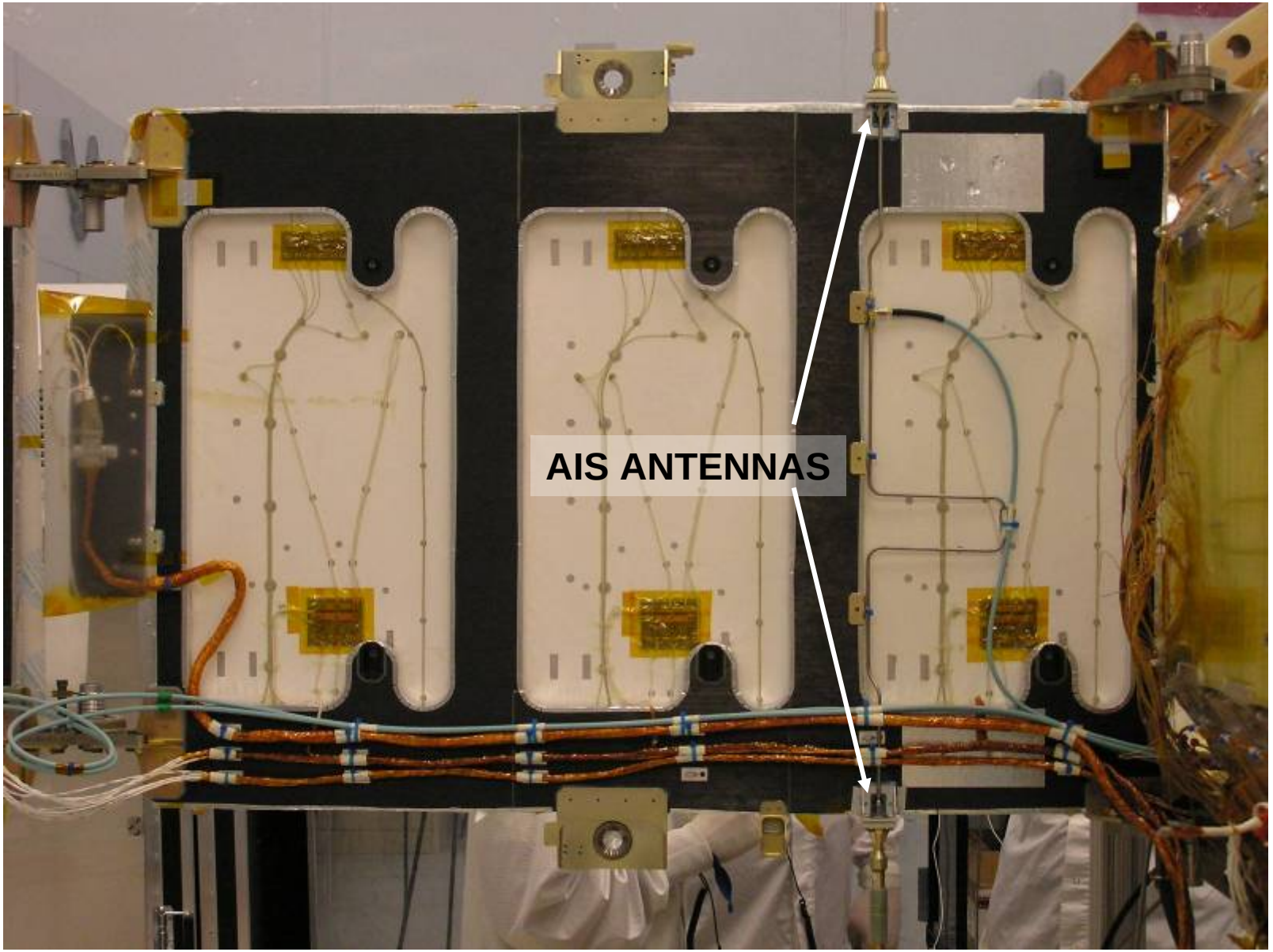




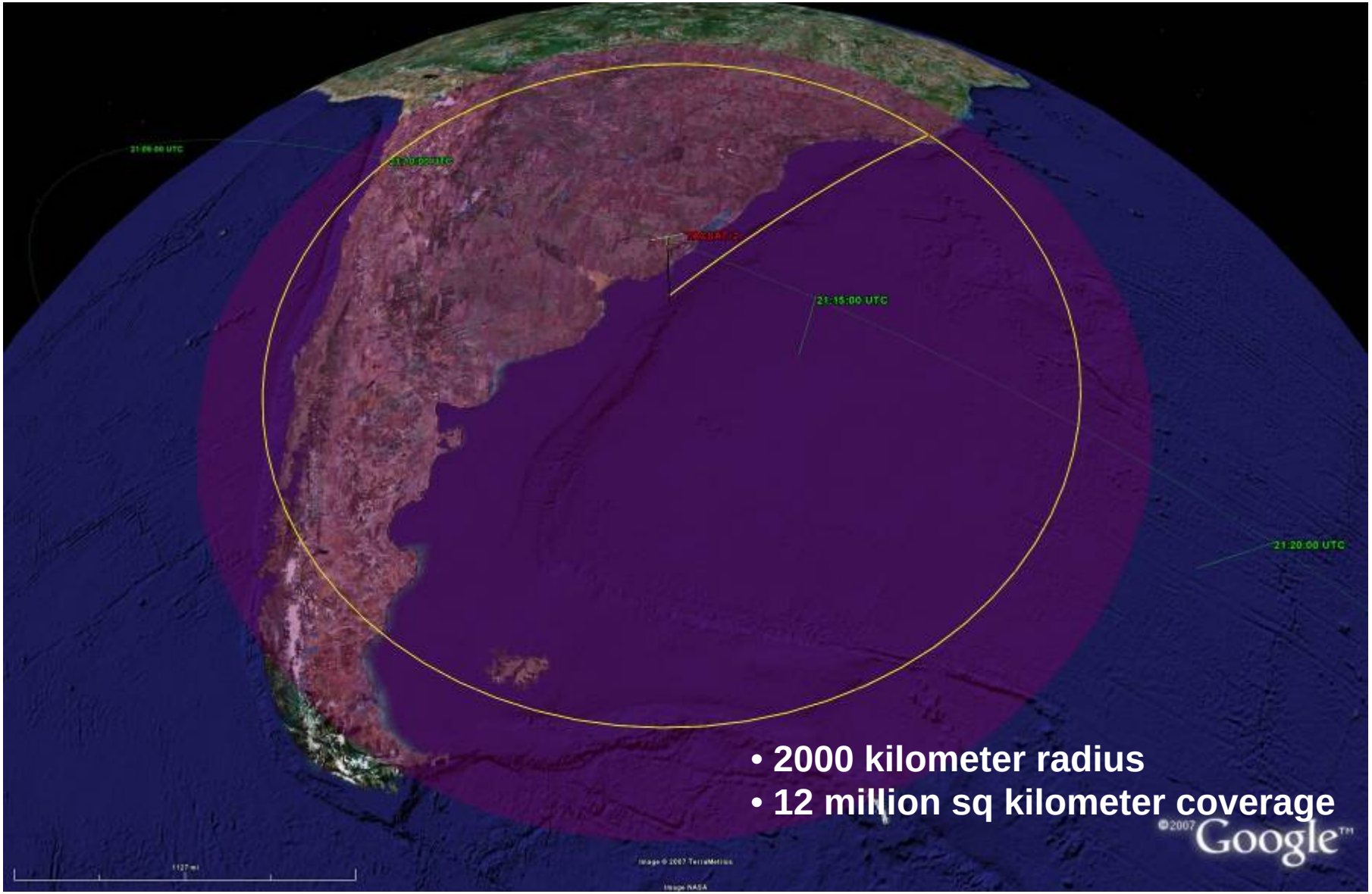


Antenna Installation on TS-2 Spacecraft

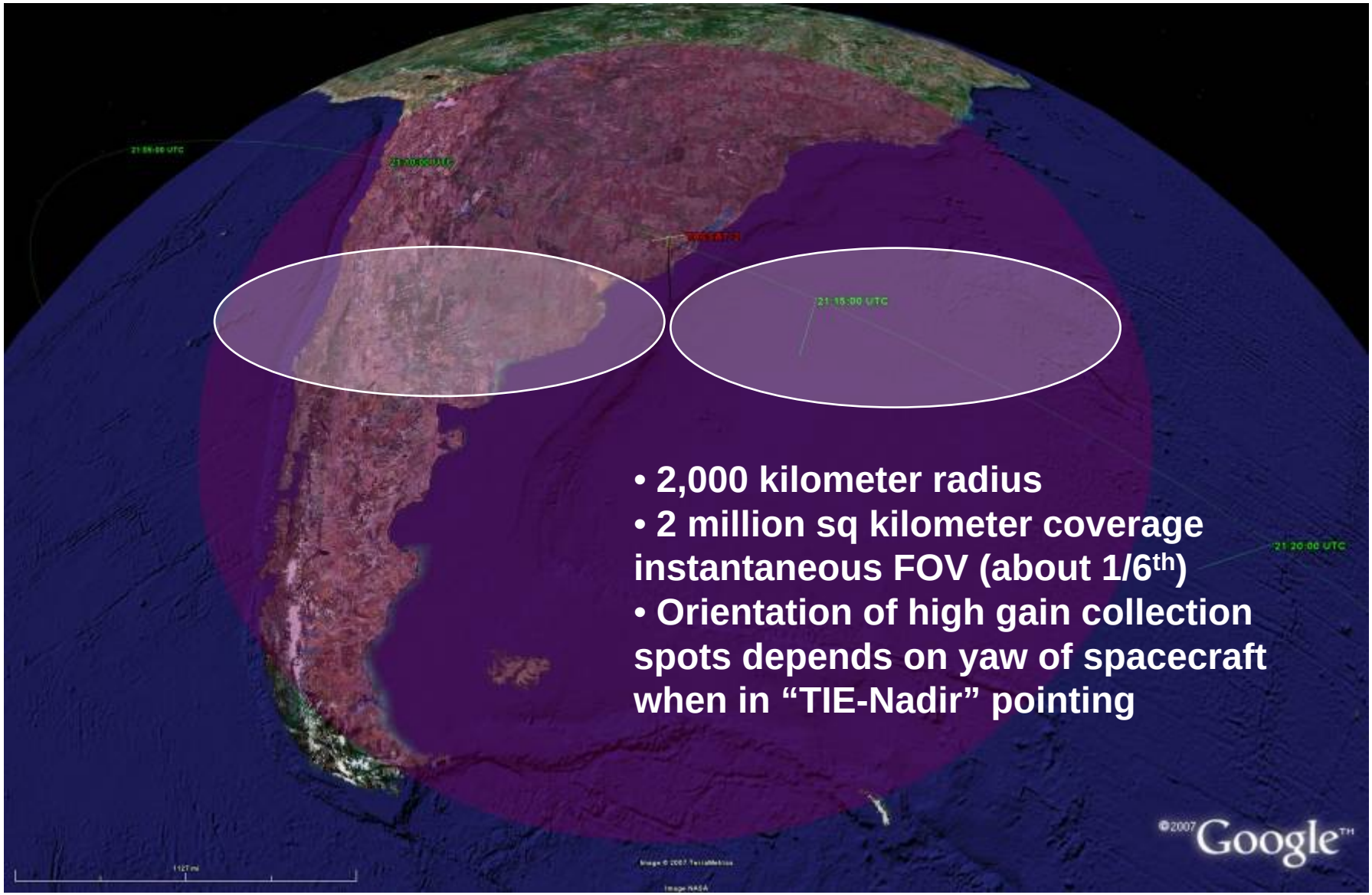
Close-Up of TIE AIS Antennas Installed on Solar Array Panels



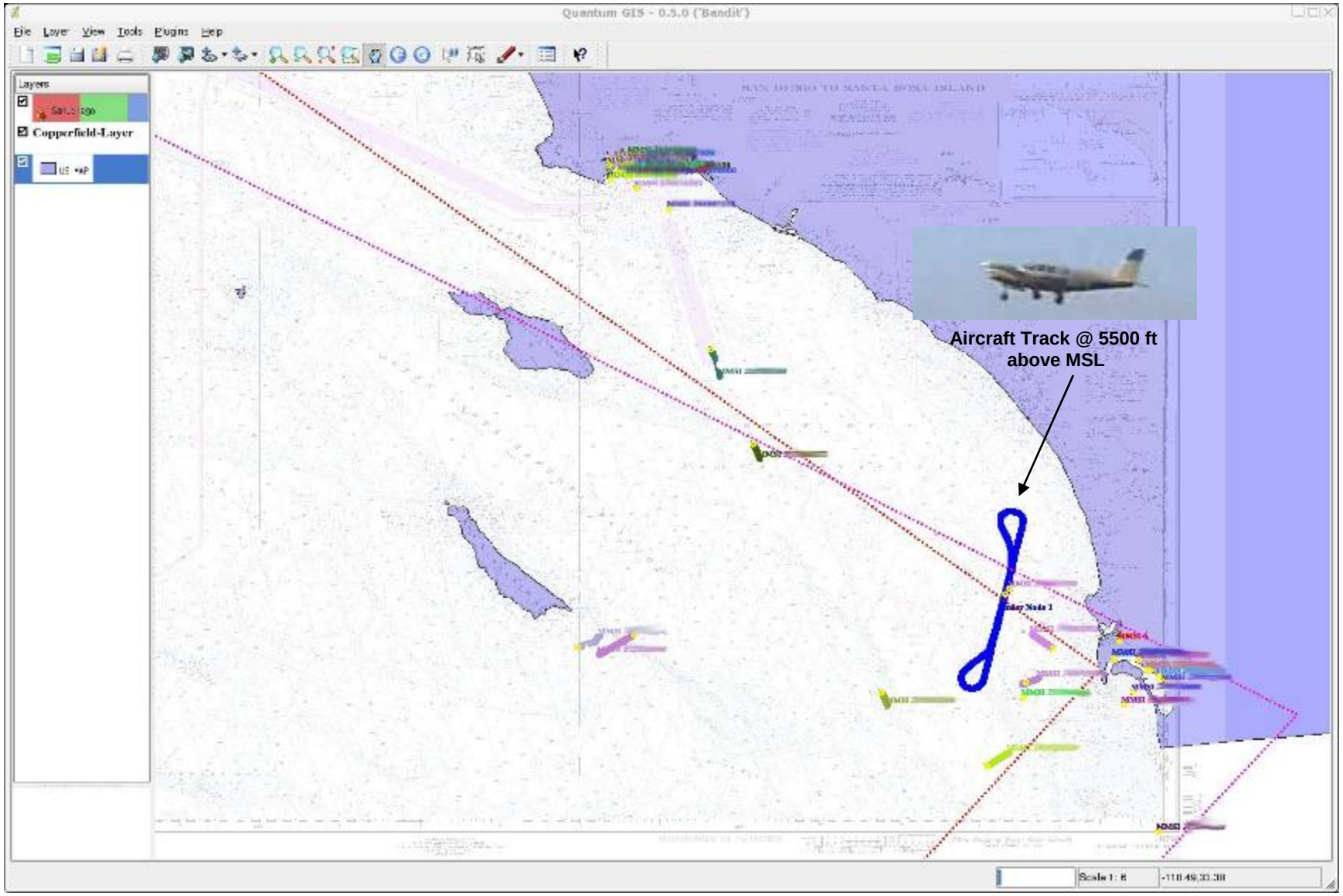
Earth Coverage of TACSAT-2



Earth Coverage of TACSAT-2 with Phased Array Antenna Pattern



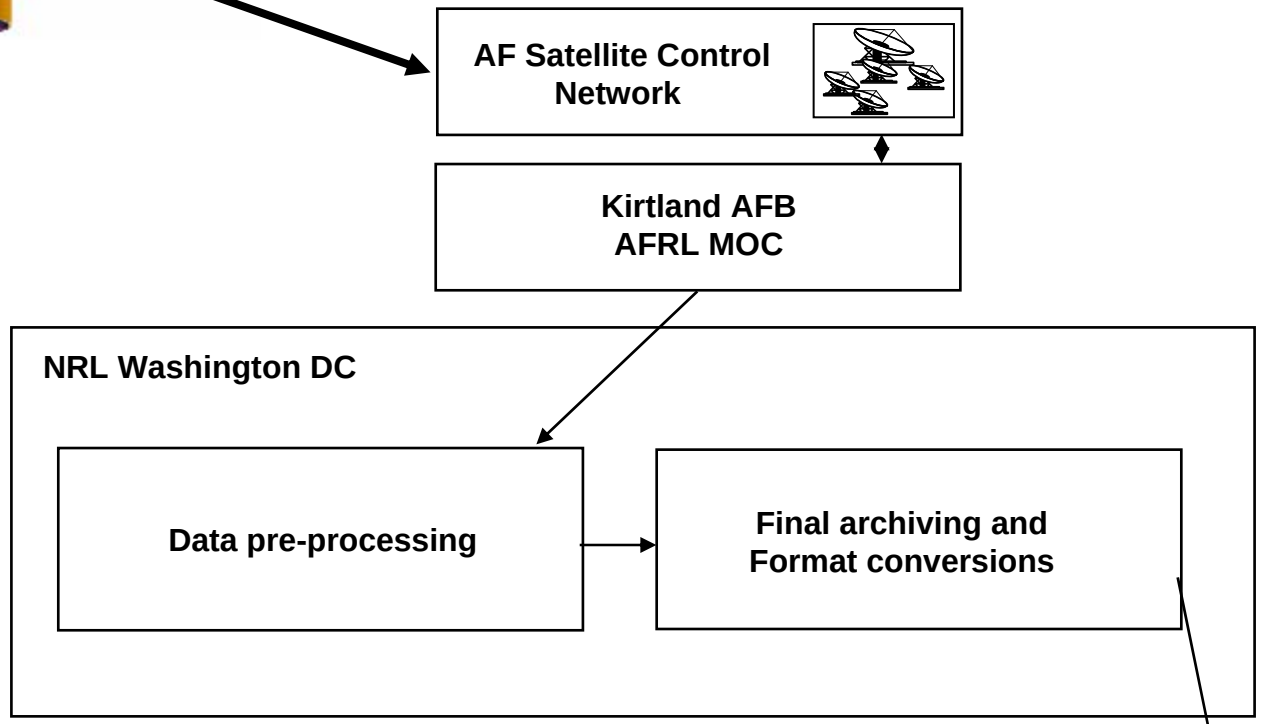
Airborne AIS Testing



TIE Authorities and Legal Issues

- While launched in mid-December, 2006, the spacecraft had challenges that prevented its use to experimenters until mid-January 2007
- Legal concerns were raised by the intelligence community (IC) in late January 2007 that had to be addressed before major experimentation could begin
- April 2007, permission was given to start operating TIE in a limited fashion restricting the use of its data for test and checkout purposes
- Finally, in September 2007, agreements and authorities allow TIE data to be used by limited US Government (USG) entities starting with the US Navy and US Coast Guard for the purposes of Homeland Defense and Maritime Domain Awareness applications
- October 2007 -- Data-sharing plans are under review and will allow use of TIE data first with DoD and USCG entities, possibly others later

Top Level Data Flow

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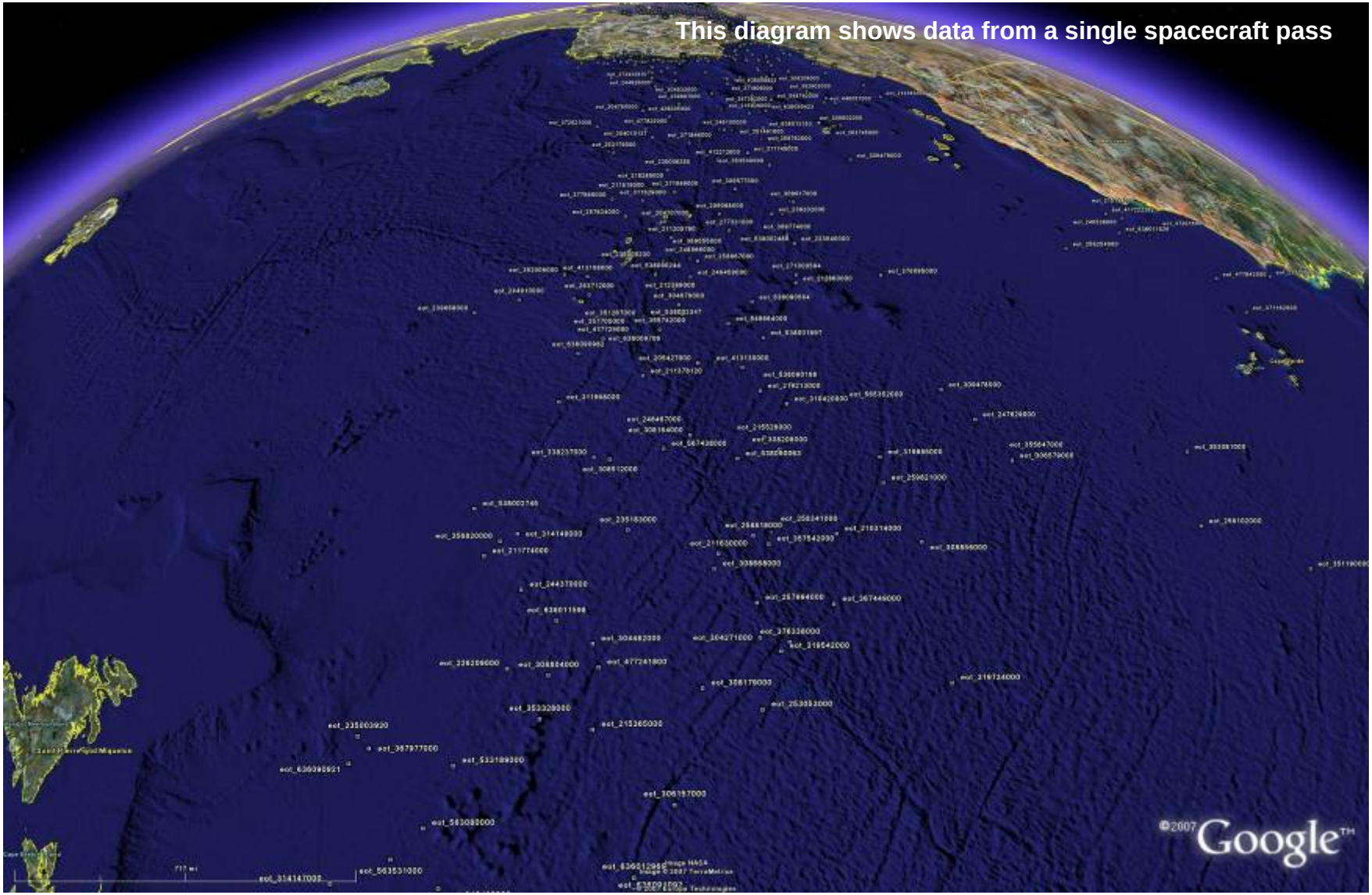
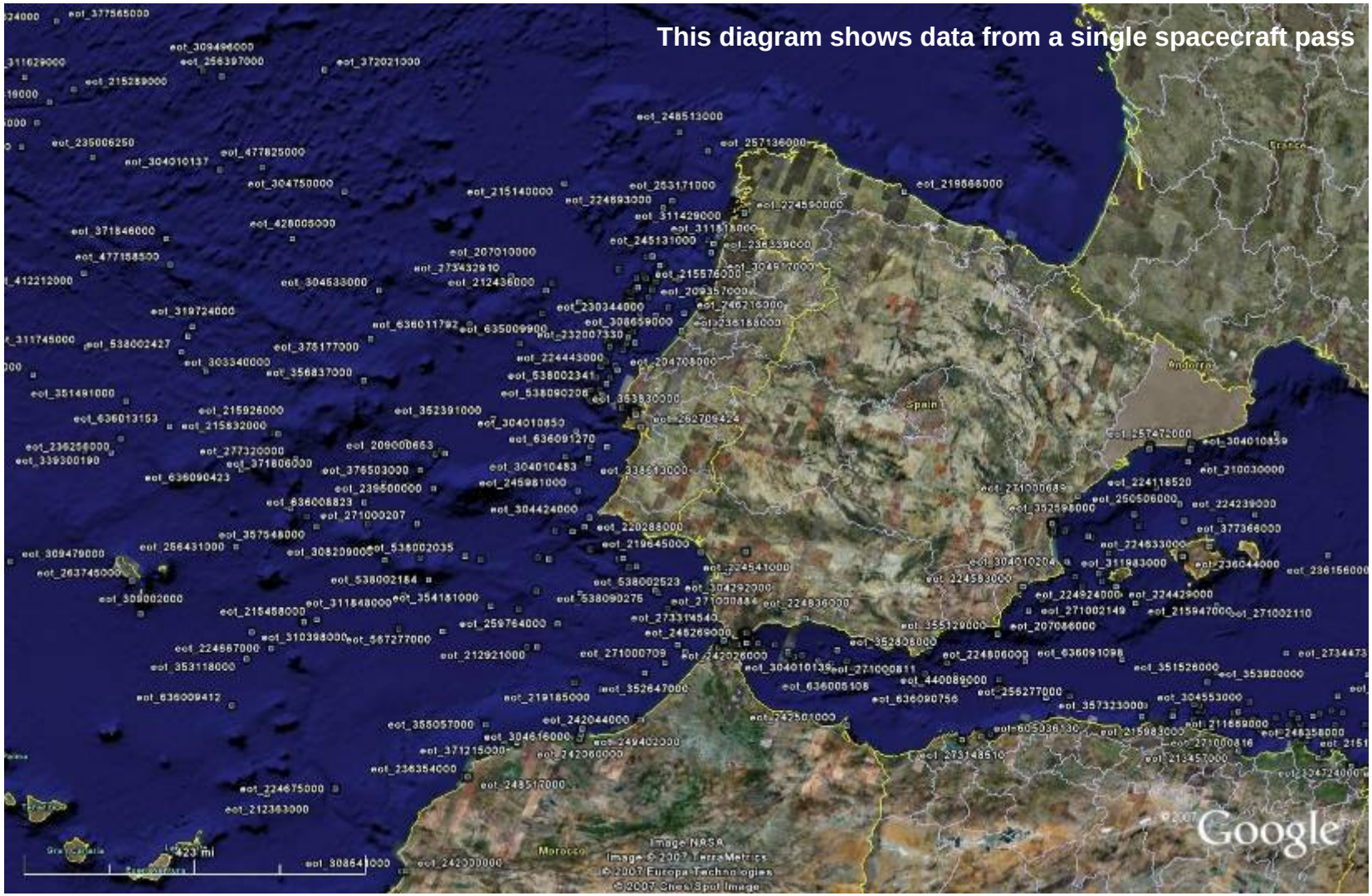
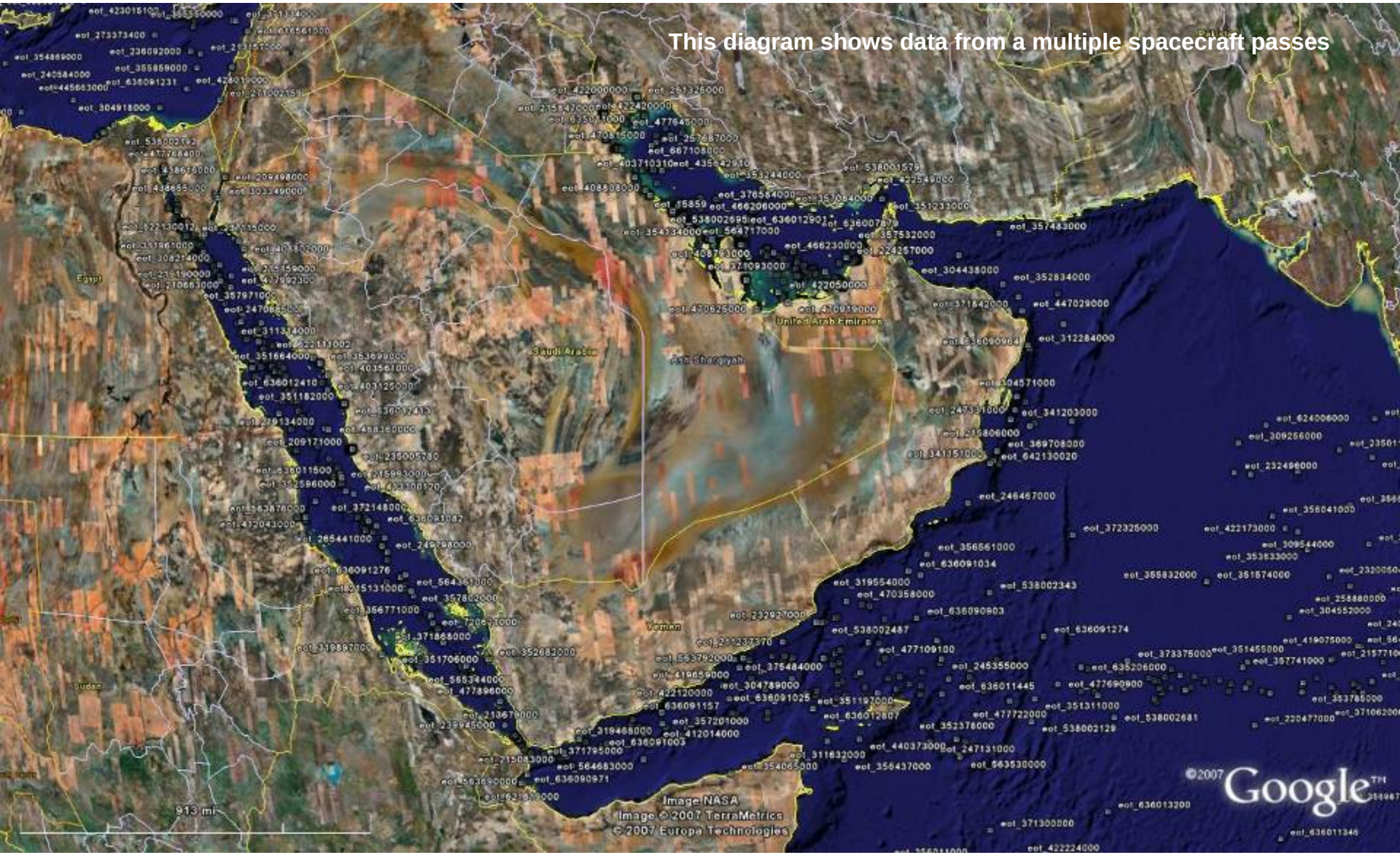
View over the Mid-Atlantic



Spain, Portugal, Gibraltar



Mid-East


This diagram shows data from a multiple spacecraft passes
Egypt
Saudi Arabia
United Arab Emirates
Yemen
Sudan
913 mi
Image NASA
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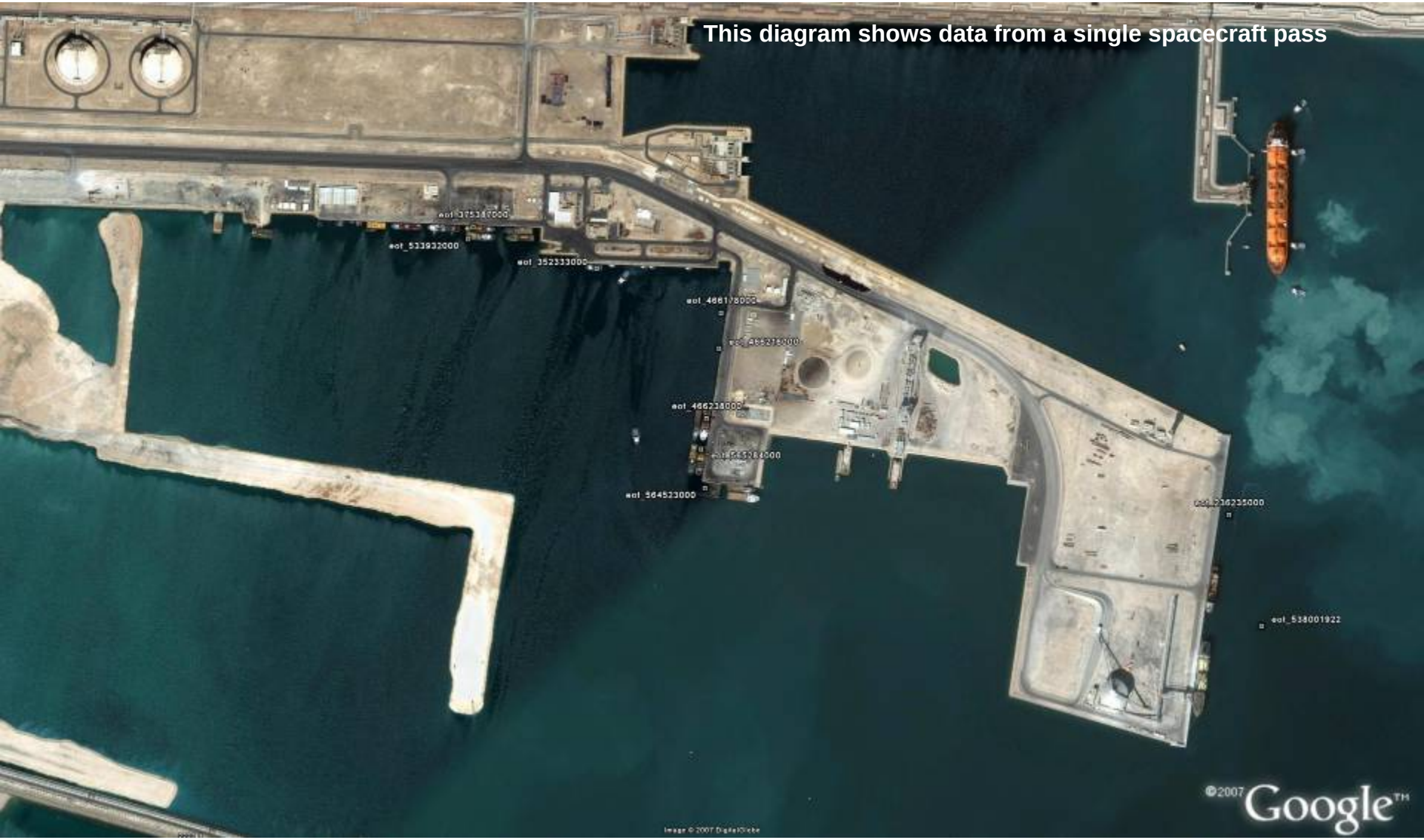
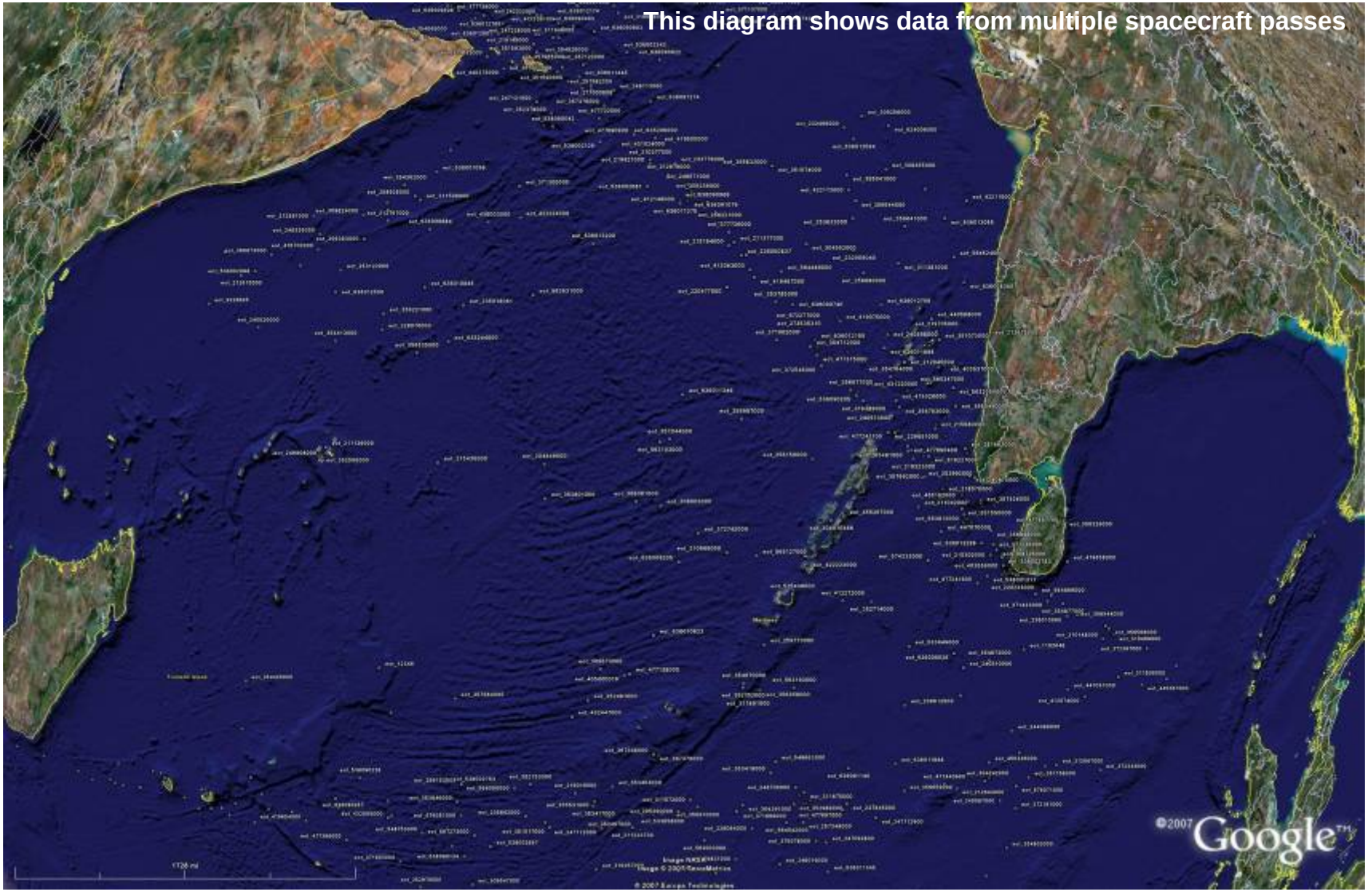
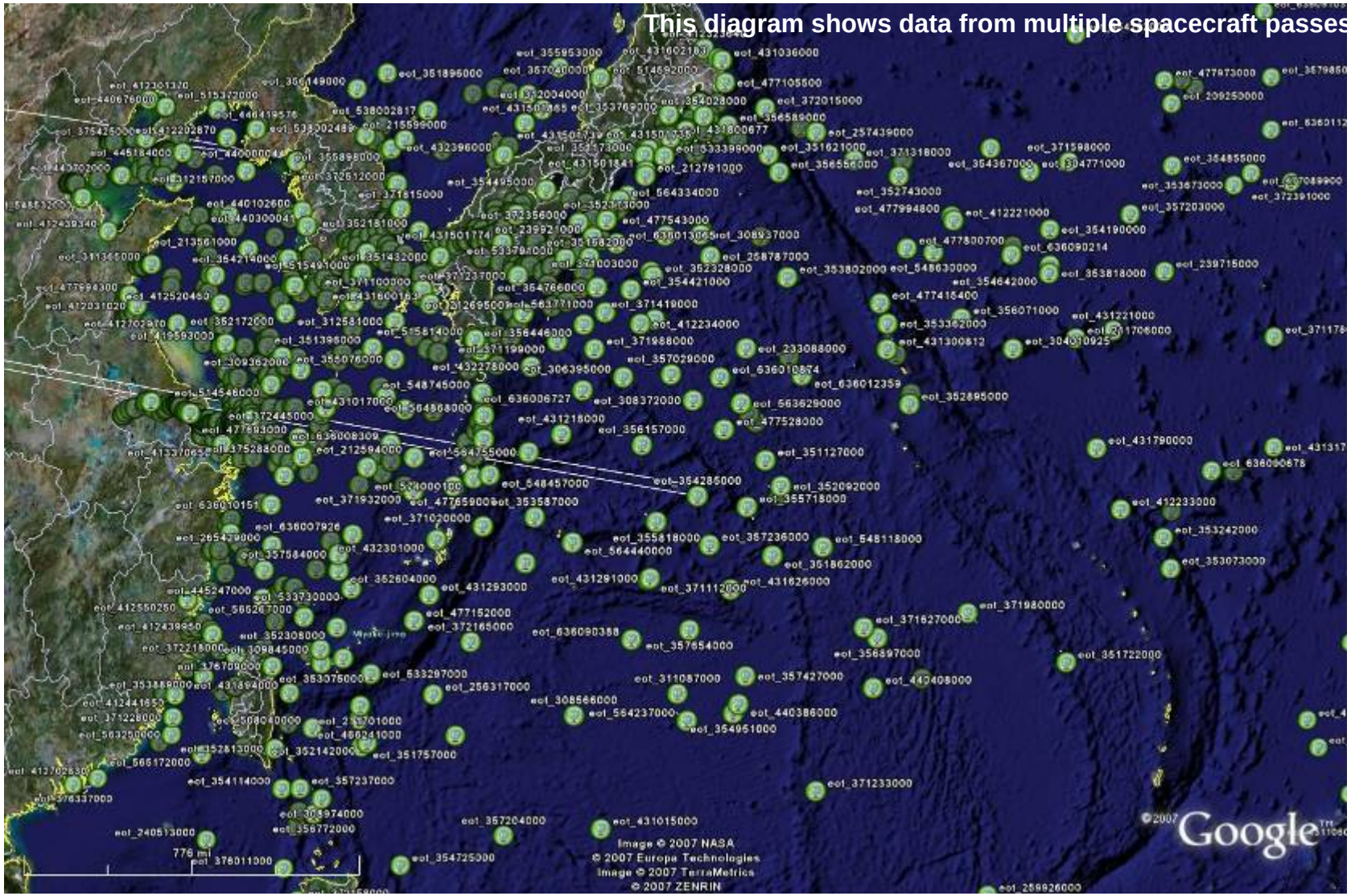
Oil Terminal



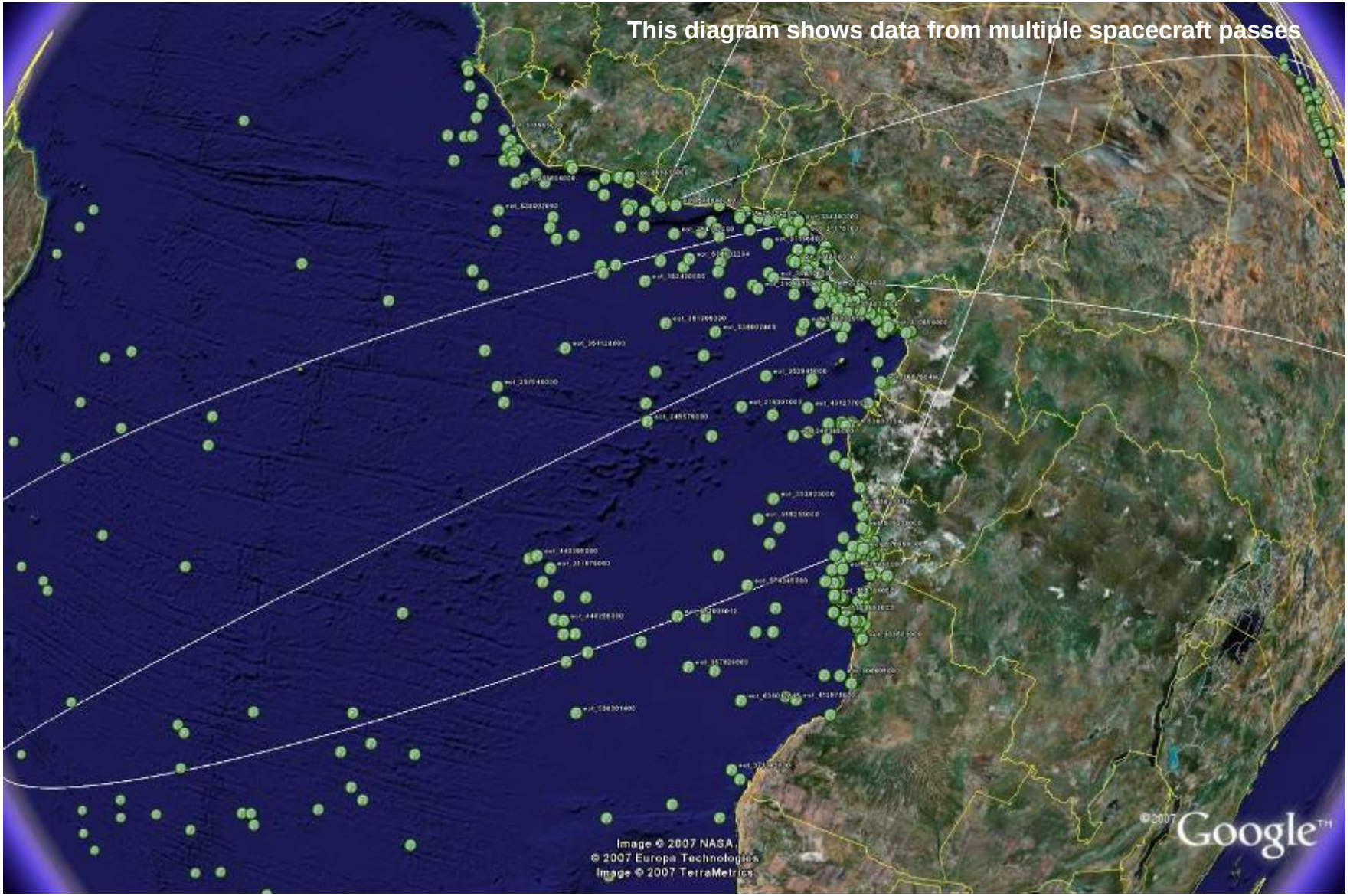
Indian Ocean



South China Sea/Sea of Japan



Africa


This diagram shows data from multiple spacecraft passes
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Way Ahead

- TACSAT-2 entered “extended operations” 1 October 2007 with primary goals to continue AIS testing
- Experimentation continues
  - Antenna array orientation testing
  - “6-parameter” testing
  - Calibration and received signal level testing
- Fate of TACSAT-2 after December 31, 2007 not yet known, possibility for extended operations
- Continued efforts to clear the path for data sharing at USG level first, but also considering other partners
- AIS receiver development and experimentation will continue on at NRL through TACSAT-2, and other current and on the horizon efforts