LGM Overview and MEOSAR EOC

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Introduction

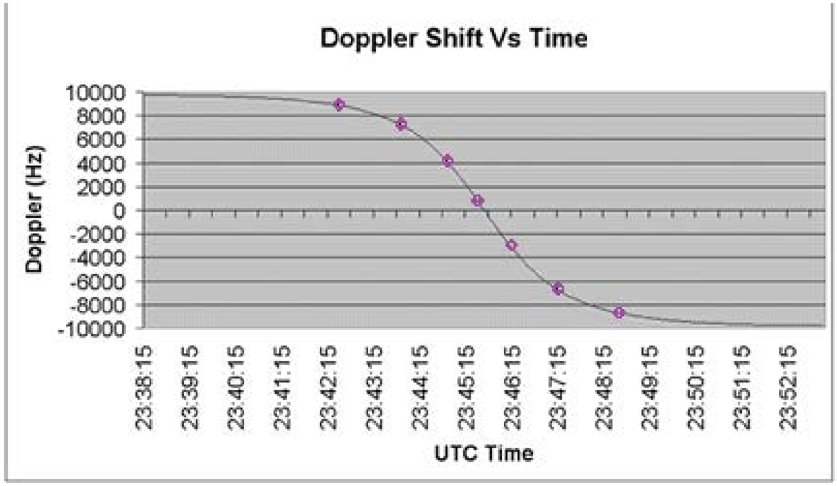
- On 13 December 2016 the Cospas-Sarsat system entered the Early Operational Capability (EOC) for the MEOSAR System

- This means that the USMCC now processes and provides alert data for three types of satellite systems, Low-Earth Orbiting (LEO), Geostationary Orbit (GEO) and Medium-Earth Orbiting and is hence a LEOSAR/GEOSAR/MEOSAR, or LGM MCC

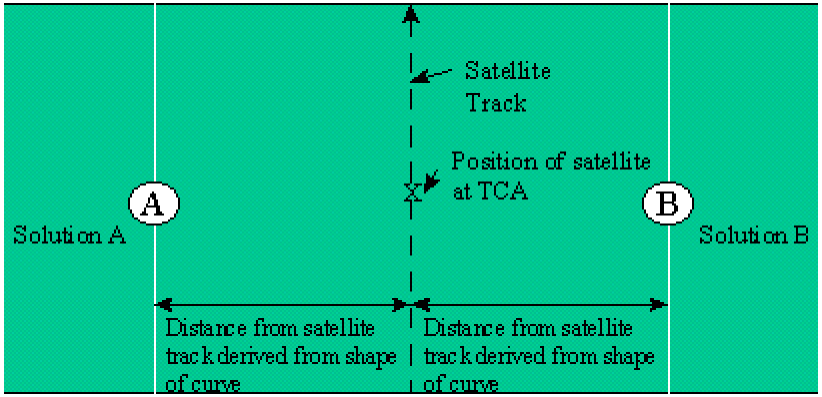
- A quick review is provided on how these different systems function, along with some of their individual advantages and disadvantages, followed by additional detail on MEOSAR

- Then we consider how the introduction of MEOSAR alert data, and the associated move to EOC and its underlying requirements, enhance and affect the end product provided to RCCs

406 MHZ DISTRESS BEACONS AND LEO PROCESSING

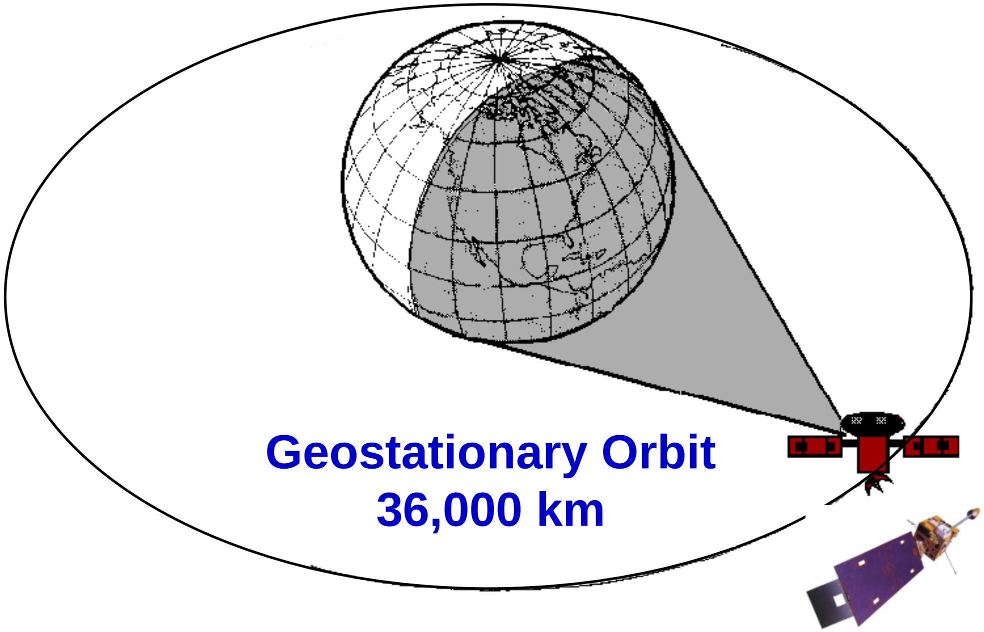


- Transmit signals: ½ second bursts, one burst every 50 seconds
- Each burst contains 120 bits of digital information
- The job of a LEOLUT is to get the burst(s) relayed via satellite, and as possible, "independently" compute a location



PRESENT GEOSAR SYSTEM

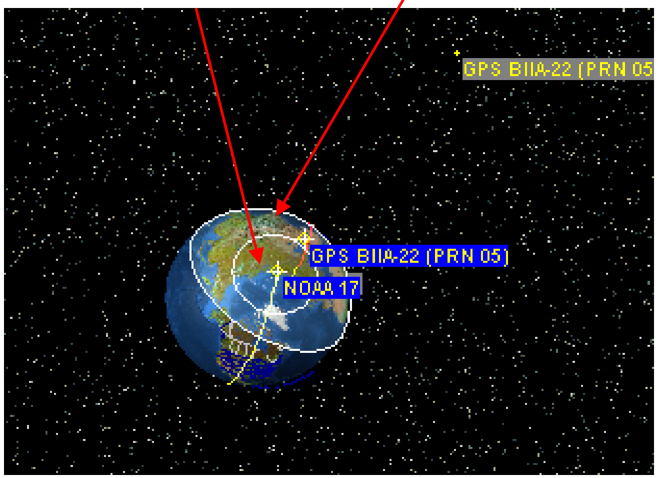
- 36,000 km high: Geostationary satellites relay transmissions from beacons
- GEOLUTs only "detect" alerts and repeat the digital message
- Large, fixed coverage areas (none near poles)
- With no relative motion between beacon and satellite there is no Doppler effect on signal to use for determining location
- Location is available only if beacon has a GNSS receiver chip (or a similar external device) and the location is encoded in the beacon message



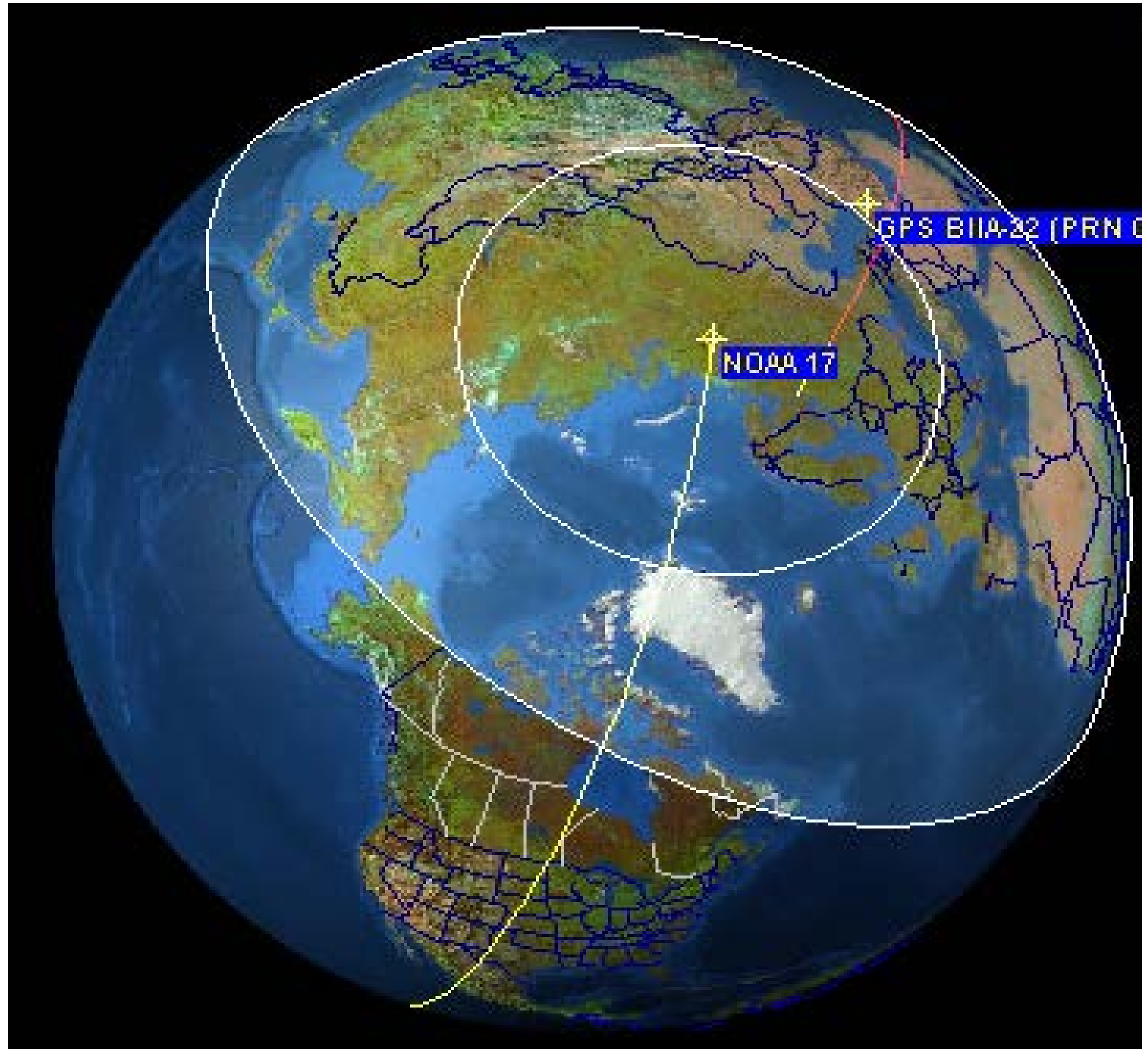
MEOSAR: AN IMPROVED SYSTEM CONCEPT

MEO sat at 20,000 km

LEO sat at 800-900 km



- MEO larger footprint than LEO
- Combines the best attributes of LEO and GEO
- Continuous global coverage (including poles)



LEOSAR vs. GEOSAR vs. MEOSAR

- LEOSAR
  - Small footprint
  - Limited satellites, hence wait times can be significant
  - On-board storage, global coverage is achieved
  - Independent locations via Doppler processing (need 3 or more bursts)

- GEOSAR
  - Large footprint
  - No coverage at the poles
  - Repeater only, geostationary, hence more susceptible to blockages
  - No independent location capability

- MEOSAR
  - Large footprint
  - Coverage at the poles
  - Repeater only, moving, slow orbit (longer sustained coverage)
  - Requires mutual visibility to 3 or more satellites for independent location
  - An independent location can be achieved on a single burst

MEOSAR – INDEPENDENT LOCATION

- Similar to standard GPS receivers, MEOLUTs use multiple satellites to compute the location of a 406 MHz beacon (this location is "independent" of the encoded location produced by the beacon and provided within the beacon message)

- The actual methodology used by MEOLUTs is more complicated (typically a version of linear regression), but it stems from standard triangulation techniques, with 3 unique satellites providing a "2D" location (latitude and longitude), and 4+ providing a "3D" location (includes altitude)

- Rather than just using differences in the time the signal takes to be relayed to the ground (like GPS receivers), MEOLUTs use differences in frequency as well

- The measurements refer to the relayed satellite signal as received at the MEOLUT, and are named Time of Arrival (TOA) and Frequency of Arrival (FOA), and the independent location captures both as Difference of Arrival (DOA)

- A major advantage of MEOSAR is that DOA locations can be generated from a <u>single burst</u> from a 406 MHz distress beacon, noting that a MEOLUT will also combine data from multiple bursts, which improves accuracy

MEOSAR – INDEPENDENT LOCATION (cont.)

- The MEOLUT location accuracy requirements for EOC are:
  - Single burst: 70% within 5 km; and 90% within 10 km
  - Multiple burst: 95% < 5 km and 98% < 10 km, within 20 minutes

- And, location accuracy requirements in the future are:
  - Single burst: 90% within 5 km (no 10 km criteria)
  - Multiple burst: 95% < 5 km and 98% < 10 km, within 10 minutes

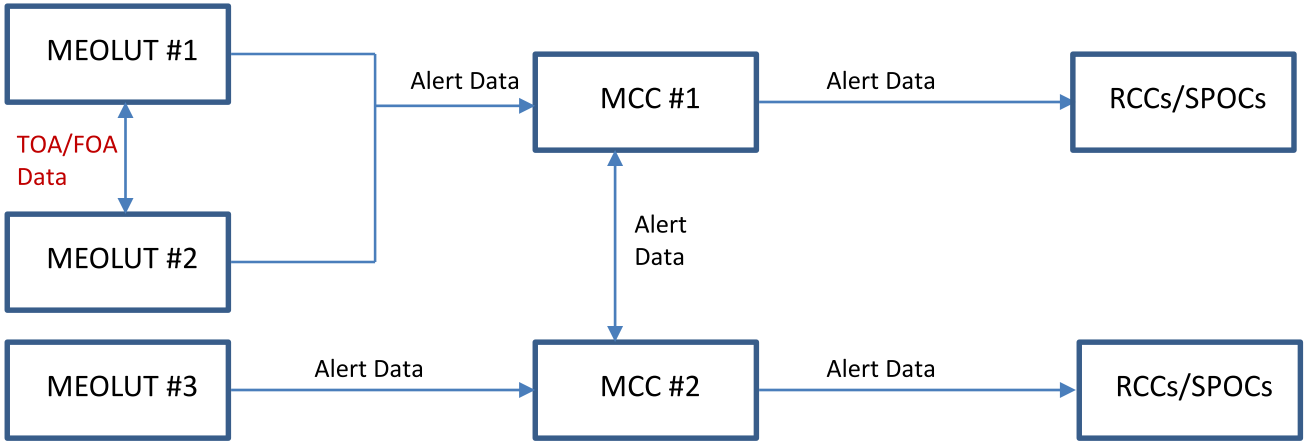
- Each MEOLUT independent location is provided to the MCC with an expected horizontal error (EHE), which not only helps predict a potential search radius, but more importantly provides a measure of quality for comparing locations and sending additional data when indicated

- For the expected horizontal error, a given DOA position is expected to within that radius with probability of 95% (+- 2%)

- Note: the EHE is not currently provided to US Coast Guard RCCs due to a lack of reliability in this data for slowly moving beacons

MEOLUT NETWORKING

- MEOLUT Networking refers to the exchange of TOA/FOA data “directly” between MEOLUTs
- The purpose of this data exchange is to enhance the performance of the MEOSAR system, providing more TOA/FOA data to a MEOLUT, which improves location accuracy
- This data exchange of “raw” data, is NOT to be confused with the sending of alert data (processed data) that occurs between C/S MCCs using the Nodal “network”
- The standard configuration for the USA ground segment employs MEOLUT Networking between the Hawaii and Florida MEOLUTs, and will include foreign MEOLUTs in the future



LEOSAR/GEOSAR/MEOSAR (LGM) MCC

- The LGM MCC processes and provides outputs to the RCCS for the three LGM data types per national agreements and the rules of the Cospas-Sarsat Data Distribution Plan (DDP), providing initial alert, updated or conflicting information, and as inherent for all MCCs, suppressing redundant data

- With respect to MEOSAR data:
  - When the MEOLUT first computes an independent location (i.e., on a single burst) it will immediately send that location to the MCC
  - Thereafter independent MEOSAR locations will generally include multiple bursts, and will be forwarded to the MCC at a minimum of 5 minutes intervals, and more often if better quality is indicated or new information is available (e.g., encoded location first available or changed)
  - The MCC in turn will forward MEOSAR data to RCCs, SPOCs and other MCCs per rules pertaining to redundancy etc., sending messages more often when new information is indicated, but at a minimum at 5 minute intervals before the position confirmation, and at 15 minute intervals after position confirmation for updated MEOSAR position and 10 minute intervals for position conflicts

LGM MCC (cont.)

- With respect to LEOSAR/GEOSAR data:
  - Before position confirmation, non-redundant LEOSAR and GEOSAR data will be provided by the LGM MCC to RCCs as it becomes available
  - After position confirmation these data types as they become available are forwarded to RCCs using data distribution rules similar to those previously used by the LEO/GEO (L/G) only MCC (per separate presentations on National and International Data Distribution)

- In the big picture, an LGM MCC functions very similar to previous MCCs; as while MEOSAR is a significant technical advance, it essentially just adds a new data type to the processing stream

- Likewise, there is a new data content, and some new associated message types on outputs to RCCs, but overall the formats are very similar and the critical information of locations, as well as supporting information like beacon decode and registration data all remains the same

LGM MCC (cont.)

- Key impacts resulting from the inclusion of MEOSAR alert data are:
  - Independent locations will often be available earlier, often on the very first burst
  - Detect only data will sometimes arrive earlier as well
  - MEOSAR data can now confirm a LEOSAR position, or visa versa
  - In general there is more data overall, especially after position confirmation but before that point also
  - Due to continuous monitoring, there is an increase as well in detect only activations (inappropriate testing etc.); and with many more antennas and sometimes high noise levels in signals there is also a higher potential for system generated anomalies (more on this in a moment)

- Further differences MEOSAR alert data introduces relative to LEOSAR:
  - No inherent ambiguity of its own to resolve
  - MEOSAR to MEOSAR Position confirmation is handled differently (requires a unique set of satellites or significant time separation from one solution relative to another)
  - Extra matching MEOSAR position data sent every 5 minutes (as available) until position is confirmed

EOC Experience – Slow Moving Beacons

- Extensive testing, and more notably real world data received and collected by the USCG, has indicated that location accuracy from MEOSAR data is often degraded (sometimes significantly) when the beacon is in motion

- Slow moving beacons (e.g., < 5 knots) are generally drifting or even bobbing at sea (which happens quite often), but could also apply to a hiker walking with a PLB and other conditions as well

- Why does this occur for MEOSAR and not for LEOSAR?
  - The relative motion of a beacon with respect to an orbiting satellite will always introduce a small Doppler shift in the measured frequency of the distress beacon signal (in addition to the shift due to satellite motion itself)
  - Both LEOLUTs and MEOLUTs use measured frequency in location processing, but a LEO satellite moves much faster, so the additional frequency shift caused by a slow moving beacon is comparatively small
  - MEOSAR processing, which can produce a location on a single burst (minimum of 3 required for LEO), is inherently much more sensitive to frequency measurements

EOC Experience – Slow Moving Beacons (cont.)

- The issue with slow moving beacons pertains exclusively to First Generation Beacons (FGB) for which a MEOLUT relies heavily on frequency (FOA) measurements
- In the future, second generation beacon (SGB) location processing will not suffer from this impact as time measurements (TOA) are all that is needed for highly accurate locations (SGB testing begins later this year)
- Ideally, accuracy for slow moving FGB beacons will be the same as for static ones (< 5 km with 95% probability
- FGB specifications are under consideration that may allow for some degradation (e.g., possibly < 10 km with 95% probability)
- Current FGB accuracy is notably lower, but significantly better MEOLUT algorithms are under development which involve computations that directly estimate velocity as well as location
- All performance specifications for moving beacons are expected to be finalized at the JC-32 meeting in October 2018

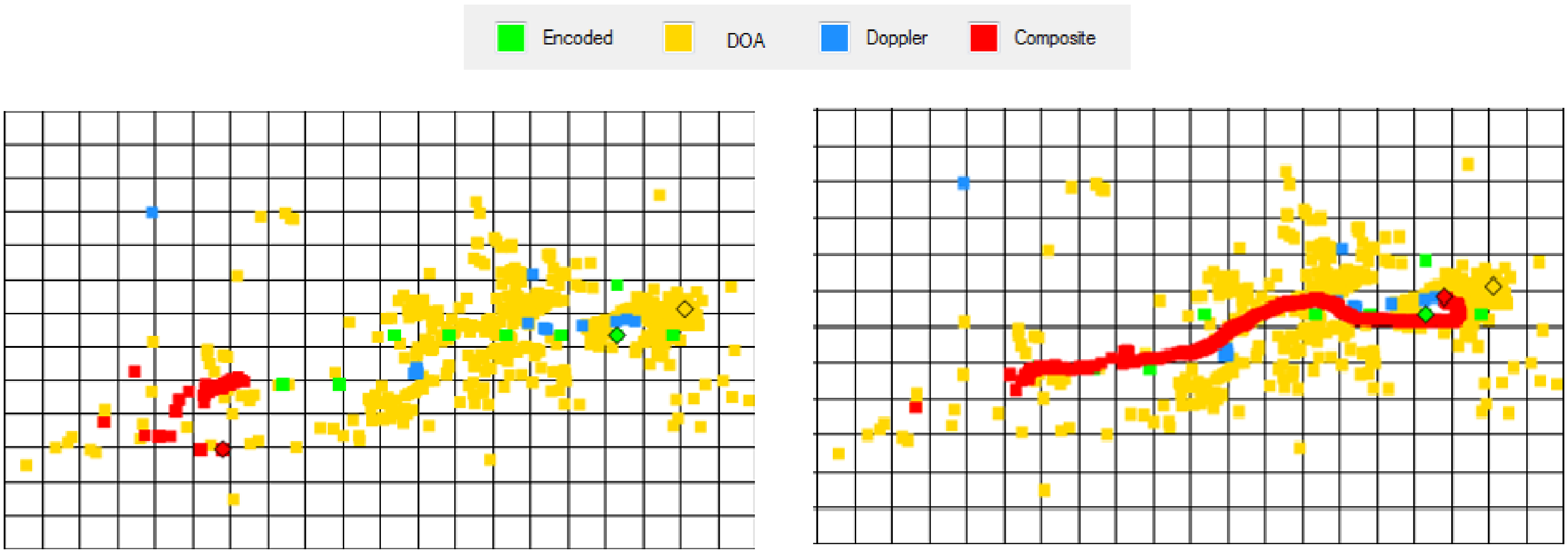
EOC Experience – Slow Moving Beacons (cont.)

- While there is clearly an impact on SAR personnel from the poor locations themselves, this situation was being further exacerbated by default MCC processing which simply was not designed to handle this large volume of widely scattered location data

- As a result, RCCs were receiving numerous position conflict messages, in some cases essentially nothing else, as the composite location would quickly become "stuck" wherever several locations happen to match, and then rarely or never moving from a given area

- In response, algorithms were implemented at the USMCC in February and March of 2017 to significantly improve this situation:
  - The composite (confirmed) location now better follows the track of a moving beacon
  - Which in turn significantly reduces the number of position conflict messages

EOC Experience – Slow Moving Beacons (cont.)



Before USMCC Software Updated | **After USMCC Improvements Implemented**

- In the above example, the original processing generated several composite positions (red squares), but they clearly never moved much beyond the area where the beacon was first located
- With the improved software, there is a several minute delay, but after that the composite position "catches up" and from then onward is able to closely track the path the beacon actually traveled

EOC Experience – Suspect Alerts

- "Suspect Alerts" pertain to data sent to an RCC that the MCC has reason to believe may not be from an actual 406 MHz distress beacon, no corroborating information is available, and hence it could be a "system generated anomaly"
- The LUT conversion of analog signals (RF) downlinked from satellites to digital (bits) inherently includes some noise which increases uncertainty when translating energy levels to 1's and 0's
- There is always a chance that a resulting bit sequence will "look like" the bits from an actual beacon, but is really either a corrupted beacon message, or more often random data, resulting in a SGA
- Regardless, the origin of a Suspect Alert begins when this bit sequence passes all error correction (BCH) and validation processing and enters further MCC processing as a valid 406 MHz distress beacon message
- Lower orbits and better link budgets make SGAs rare for LEOSAR, and while a much higher orbit and lower signal strength result in more for GEOSAR, MEOSAR is significantly more susceptible to this behavior than the other two systems

EOC Experience – Suspect Alerts (cont.)

- The key reasons for the susceptibility of MEOSAR are:
  - Multiple Antennas: each antenna has its own downlink stream and hence the opportunities for an SGA to occur is multiplied by the number of antennas, currently 12 in the US (rising to 21) versus only 1 for a LEOLUT or GEOLUT
  - The link budget is good, but still the orbit is fairly high and the potential for noise is hence increased (relative to LEOSAR)
  - The repeater on the experimental GPS (DASS) satellites was not designed for SAR, and includes out of band signals (200 kHz bandwidth vs. 100 kHz)*

- The concern with the increased likelihood of SGAs was identified during MEOSAR D&E testing and measures where taken to reduce this impact prior to the start of EOC

- While the work of reducing these occurrences at the MEOLUT continues, the key response was for MCCs to indicate when an alert is "Suspect" in the message sent to an RCC

*Currently these satellites represent about 2/3 of the those available, but in the future this will be overcome by satellites with dedicated SAR repeaters

EOC Experience – Suspect Alerts (cont.)

- The essential property of a Suspect Alert is that there is no corroborating information available, which for MEOSAR means that a single beacon message was produced from data received at a single MEOLUT antenna

- As such there is no independent location available, but an encoded position could be present along with other decoded information

- Rules are in place to limit what is sent to RCCs, and appropriate procedures for handling Suspect Alerts are defined by the USCG and USAF, noting the following:
  - Suspect alerts are valid beacon IDs (all validation checks have been passed)
  - Suspect alerts have led to SARSAT rescues
  - Subsequent alerts (or registration data) can corroborate a suspect alert

- The message formats, data distribution rules and procedures, as well as real world experiences are addressed in other presentations

EOC and Beyond

- EOC provides a transition period for Cospas-Sarsat participants to efficiently manage the introduction of the significant technical advancement of the MEOSAR System

- Specifically, this transition period allow for:
  - Operational use of MEOSAR data with some requirements relaxed (most notably MEOLUT location accuracy) as the technology improves
  - An opportunity to learn from experience, and potentially adapt, ensuring the best data distribution procedures in future implementations (e.g., improving location accuracy for slow moving beacons and reducing suspect alerts)

- When Cospas-Sarsat enters the Initial Operational Capability (IOC) for MEOSAR (targeted for October 2019):
  - Standard MEOSAR location accuracy requirements will be met
  - Lessons learned should have solidified data distribution procedures

- Once global MEOSAR coverage is achieved, Cospas-Sarsat will reach Full Operational Capability (FOC) for the MEOSAR system