

COSPAS-SARSAT
MEOSAR Presentation
Yoan GREGOIRE – 14/11/2018



SUMMARY

Introduction to Cospas-Sarsat and current status

- ❖ General introduction and history
- ❖ User, space and ground segment status

MEOSAR Highlights

- ❖ MEOSAR benefits compared with LEOSAR
- ❖ Location processing and moving beacons issue
- ❖ Second generation beacon standard

System evolution: RLS and ELT(DT)

Introduction to Cospas-Sarsat and current status

Introduction to Cospas-Sarsat and current status



Russian COSPAS acronym can be translated in: “Space System for the Search of Vessels in Distress”

Introduction to Cospas-Sarsat and current status

Cospas-Sarsat is an international space system to detect and localize users in distress.

Overall statistics:

- ❖ **12 000** SAR events and **42 000** rescued people since 1982
- ❖ An average of **6 people/day** are rescued since 2010

Introduction to Cospas-Sarsat and current status

Cospas-Sarsat: an international cooperation

- ❖ 4 Parties (founding members)
- ❖ 29 Ground segment providers
- ❖ 9 User States
- ❖ 2 Organisations



Canada



France



Russia



United-States



Introduction to Cospas-Sarsat and current status

Cospas-Sarsat: missions of the system

- ❖ The International Cospas-Sarsat Programme provides **accurate, timely, and reliable distress alert and location data** to help search and rescue authorities assist persons in distress.
- ❖ To achieve this objective, **Cospas-Sarsat Participants implement, maintain, coordinate and operate a satellite and ground system capable of detecting distress alert transmissions from radiobeacons** that comply with Cospas-Sarsat specifications and performance standards, and of determining their position anywhere on the globe. The distress alert and location data is provided by Cospas-Sarsat Participants to the responsible SAR services.
- ❖ **Cospas-Sarsat co-operates with** the International Civil Aviation Organization (**ICAO**), the International Maritime Organization (**IMO**), the International Telecommunication Union (**ITU**) and other international organizations to ensure the compatibility of the Cospas-Sarsat distress alerting services with the needs, the standards and the applicable recommendations of the international community.

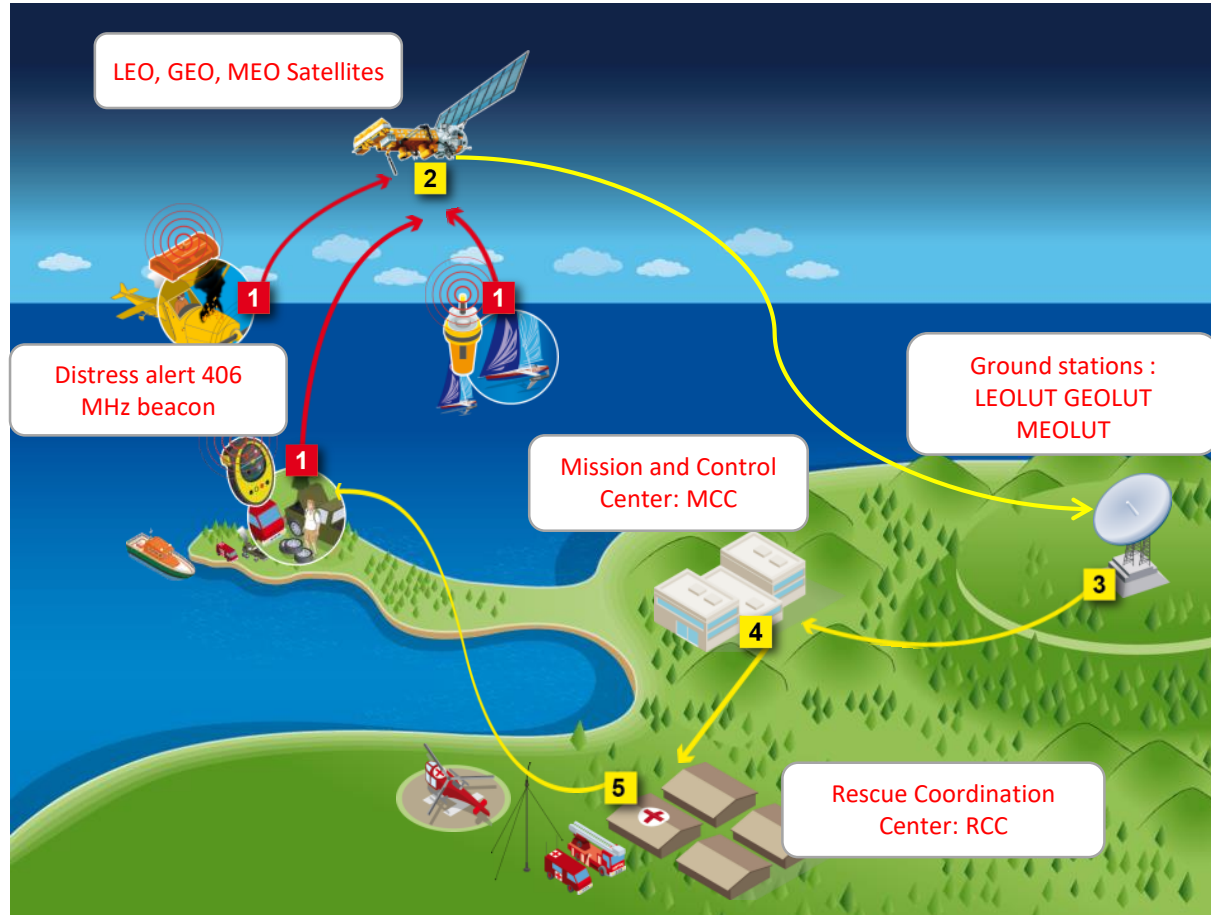
Introduction to Cospas-Sarsat and current status

Cospas-Sarsat: history

- ❖ **1979** : a Memorandum of Understanding covering the system development was signed between the space agencies of four founder states : the former USSR, USA, France and Canada
- ❖ **1982** : first Soviet instrument mounted on Cosmos 1383 satellite and in March 1983 first French and Canadian instrument mounted on the American NOAA-8 satellite
- ❖ **1982** : first rescue in Canada after an aircraft crash
- ❖ **1987**: launch of the first GEOSAR satellite
- ❖ **1988** : the 4 founder states sign an International Cospas-Sarsat Programme Agreement (ICSPA) which ensures service continuity and availability of the system to all States on a non-discriminatory basis
- ❖ **2005** : Cospas-Sarsat Secretariat moves to Montréal, Canada (status as an International Organization)
- ❖ **2010** : 1 million of 406 MHz beacons are deployed
- ❖ **2012** : first GALILEO spacecraft launch with a SAR payload (GSAT0103 and GSAT0104)
- ❖ **2016** : broadcasting of the first MEOSAR operational alerts (Early Operational Capability phase)
- ❖ **2019**: MEOSAR enters Initial Operational Capability ?

Introduction to Cospas-Sarsat and current status

Overview



Introduction to Cospas-Sarsat and current status

Distress beacons

3 types of beacons (currently)

- ❖ ELT for aeronautics
- ❖ EPIRB for maritime
- ❖ PLB for personal use

Yearly Production : around 200,000 beacons

- ❖ 70,000 only in 2005
- ❖ 44% EPIRBs, 15% ELTs, 41% PLBs

Geographical Distribution of manufacturers :

- ❖ Europe: 49 %
- ❖ USA et Canada: 30 %
- ❖ Asia et Australia: 21 %

Population:

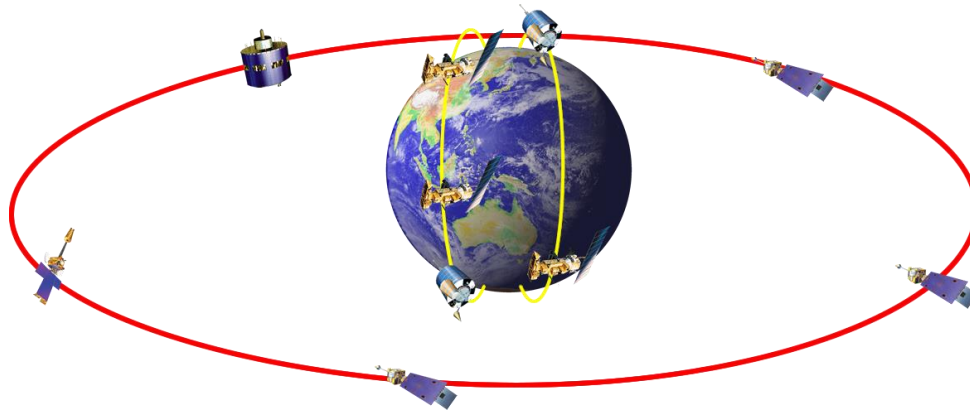
- ❖ End of 2017: 1.6 millions of registered beacons, 2.1 millions estimated population



How Cospas-Sarsat system works

Space segment

- ❖ LEO satellites: Low Earth Orbit (altitude = 800 km typically, polar orbits)
- ❖ GEO satellites: Geostationary Earth Orbit (altitude = 36000 km, equatorial orbits)



- ❖ MEO satellites : Medium Earth Orbit → GNSS satellites at 20000 km typically

Introduction to Cospas-Sarsat and current status

Current status of space segment:

- ❖ 5 operational LEO satellites (NOAA-15, NOAA-18, NOAA-19, MetOp-A, MetOp-B)
 - Equipped with both SARR (SAR Repeater) and SARP (SAR Processor)
 - SARP measures FoA (Frequency of Arrival) upon successive transmitted signals in order to compute the beacon location
- ❖ 6 operational GEO satellites (GOES-13, GOES-15, MSG-1, MSG-2, MSG-3, INSAT-3D)...
- ... and satellites in orbit spare or under testing (GOES-14, MSG-4, GOES-16, GOES-17, Electro-L 2, Louch-5A, Louch-5V, INSAT-3DR, GSAT-17)
- Equipped with SARR repeater only, no independent location possibility

Introduction to Cospas-Sarsat and current status

Current status of MEO space segment:

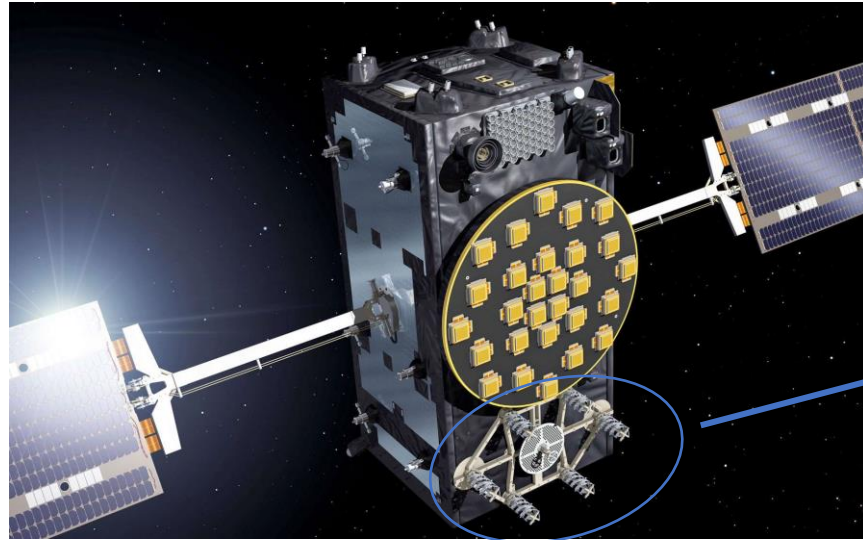
- ❖ 16 Galileo SAR payloads commissioned at FOC level + 4 to be approved soon
 - Equipped with nominal L-band payload (downlink at 1544.1 MHz), SART (SAR Transmitter)

- ❖ 19 GPS/DASS SAR payloads
 - Equipped with non-nominal S-band payloads (downlink at ≈ 2.3 GHz)
 - Initially planned for testing purpose but now used operationally

- ❖ 1 GLONASS SAR payload used for testing purpose

Introduction to Cospas-Sarsat and current status

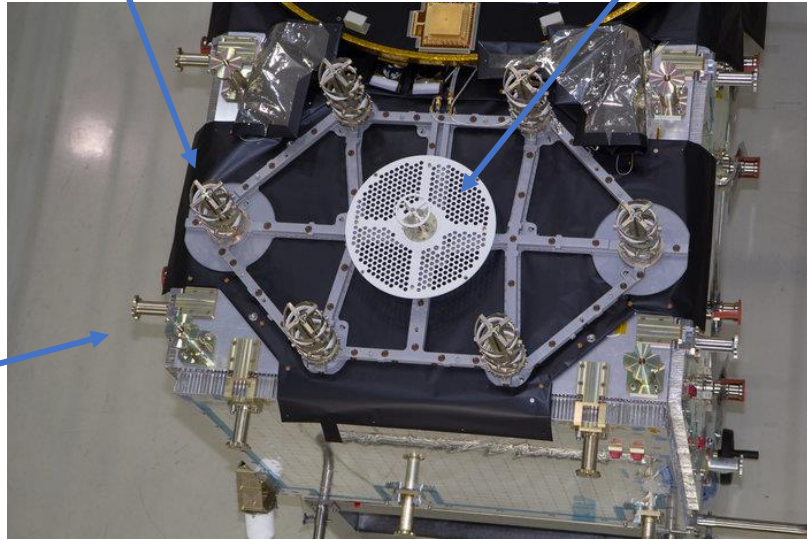
MEOSAR payload example



Galileo FOC (Copyright ESA)

Receiving antennas (406 MHz)

Transmitting antenna (1544.1 MHz)



Galileo FOC SAR antenna (Copyright ESA)

Introduction to Cospas-Sarsat and current status

Ground segment

❖ LUT: Local User Terminal

- LEOLUT: tracks, receives data from LEO satellites (successively), and computes Doppler locations → 56 operational LEOLUTs distributed worldwide
- GEOLUT: tracks and receives data from GEO satellite → 26 operational GEOLUTs distributed worldwide
- MEOLUT: tracks, receives data from MEO satellites (simultaneously), and computes independent location based on TOA/FOA measurements
 - 12 MEOLUT commissioned at EOC level
 - 15 additional MEOLUT planned to be available or commissioned in 2019
 - and more in the coming years...

Introduction to Cospas-Sarsat and current status

MEOLUT Illustration



« Classical » MEOLUT architecture
1 dish antenna tracks 1 MEO satellite



« Innovative » MEOLUT architecture
1 phase array antenna tracks all in view MEO satellites

MEOSAR highlights

MEOSAR highlights

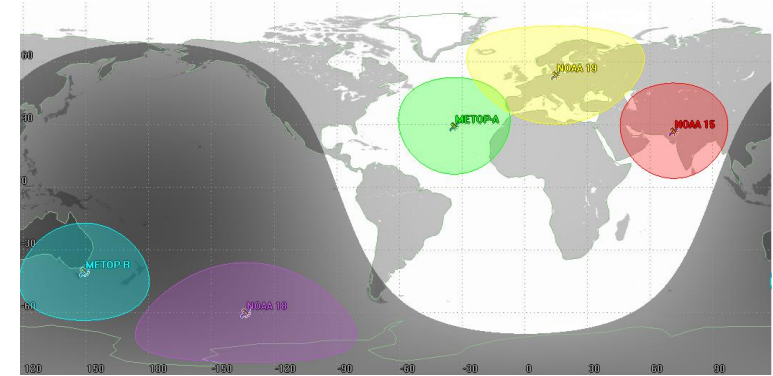
MEOSAR benefits compared to LEOSAR:

- ❖ Instantaneous location capability

- With a sufficient number of MEO satellites and MEOLUTs, a beacon can be located on a single burst

- ❖ Instantaneous global coverage

- With a sufficient number of MEO satellites and MEOLUTs, beacons can be located everywhere on Earth, at every time

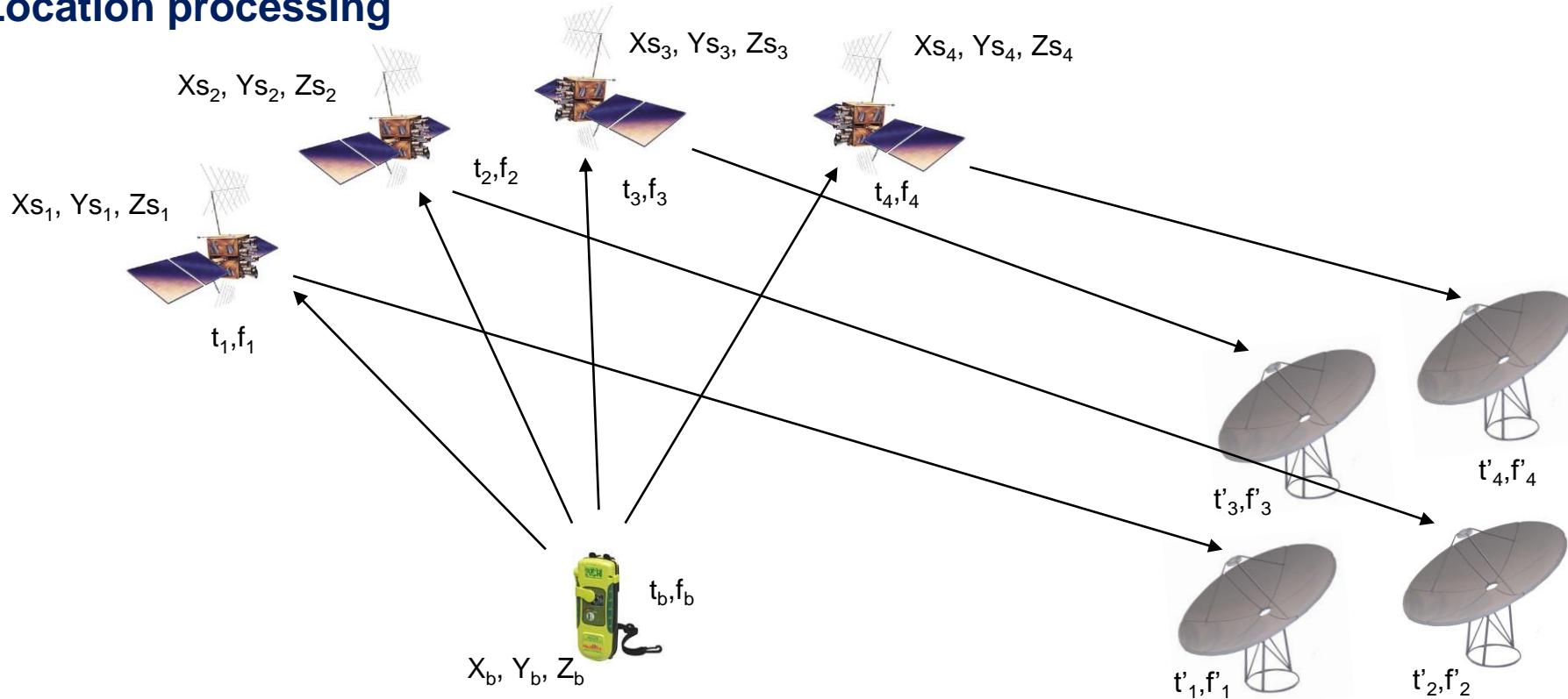


LEOSAR coverage example

In brief: MEOSAR greatly enhances the time to locate a distress (few minutes instead of up to 2 hours with LEOSAR)

MEOSAR highlights

Location processing



MEOSAR highlights

Location processing

❖ MEOSAR localization technique uses:

- Frequency of Arrival (FoA), same as LEOSAR

$$FOA_i = f_t - \frac{f_t}{c} \cdot \left(\vec{V}_s^i - \vec{V}_b \right) \cdot \frac{\left(\vec{X}_s^i - \vec{X}_b \right)}{\left\| \vec{X}_s^i - \vec{X}_b \right\|} \quad (\text{typical measurement noise } \sigma_{FOA} = 0.2 \text{ Hz})$$

- Time of Arrival (ToA) → estimation of ToA is performed at the MEOLUT

$$TOA_i = t_t + \frac{\left\| \vec{X}_s^i - \vec{X}_b \right\|}{c} \quad (\text{typical measurement noise } \sigma_{TOA} = 20 \mu\text{s})$$

t_t : time of beacon burst transmission,

f_t : frequency of beacon burst transmission,

$\vec{X}_s^i = [x_s^i, y_s^i, z_s^i]$: the position vector of the i^{th} satellite,

$\vec{V}_s^i = [vx_s^i, vy_s^i, vz_s^i]$: the velocity vector of the i^{th} satellite,

$\vec{X}_b = [x_b, y_b, z_b]$: the position vector of the beacon,

$\vec{V}_b = [vx_b, vy_b, vz_b]$: the velocity vector of the beacon.

MEOSAR highlights

Location processing

❖ Generally used assumptions

- Use of TDOA/FDOA instead of TOA/FOA as the time/frequency of transmission are not known (this process also simplifies multi-burst processing)
- Beacon is on the ground → 2D location only (latitude, longitude)
- Beacon velocity is small compared to satellite velocity → $V_{b_x}, V_{b_y}, V_{b_z} = 0$? not so easy...

❖ While MEOSAR nominal performance was extensively studied with static beacons, it was quickly realized that moving beacons were located with a significantly degraded performance (even slow moving beacon, such as a beacon bobbing in waves...).

MEOSAR highlights

Location processing

❖ Moving beacon issue: theory

- Location is generally computed with a classic iterative approach:

$$X_b^{n+1} = X_b^n + (H^T \cdot W \cdot H)^{-1} \cdot H^T \cdot W \cdot \Delta Y$$

- With:

X_b^n : the estimated beacon location produced from iteration n,

H: the Jacobian matrix, containing partial derivatives,

W: a weighting matrix (weighting coefficients for TOA and FOA measurements),

ΔY : the difference vector between the TOA/FOA measurements and the TOA/FOA values that would have resulted from the beacon location as evaluated at the last iteration (n).

MEOSAR highlights

Location processing

❖ Moving beacon issue: theory

- If assuming the beacon to be static in the location process, the beacon motion creates a bias that depends on beacon velocity, satellite geometry and relative weights on ToA/FoA measurements:

$$\Rightarrow \Delta x = \frac{f_t}{c} \cdot \sum_{j=1}^N p_{1,j} \cdot (\vec{V}_b \cdot \vec{U}_j)$$

$$\Rightarrow \Delta y = \frac{f_t}{c} \cdot \sum_{j=1}^N p_{2,j} \cdot (\vec{V}_b \cdot \vec{U}_j)$$

$$\Rightarrow \Delta z = \frac{f_t}{c} \cdot \sum_{j=1}^N p_{3,j} \cdot (\vec{V}_b \cdot \vec{U}_j)$$

P : a projection matrix, $P = (H^T \cdot W \cdot H)^{-1} \cdot H^T \cdot W$,

$p_{i,j}$: the value in matrix P in the i^{th} row and j^{th} column,

$\vec{V}_b = [vx_b, vy_b, vz_b]$: the velocity vector of the beacon,

\vec{U}_j : the unit vector pointing from the beacon towards the j^{th} satellite,

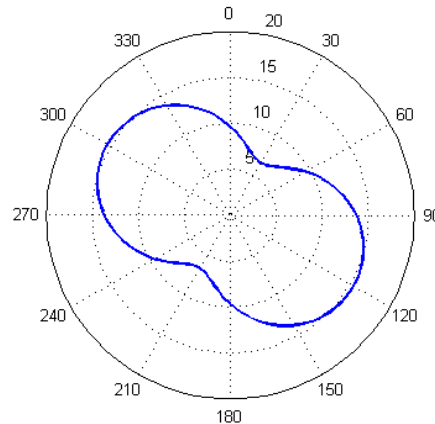
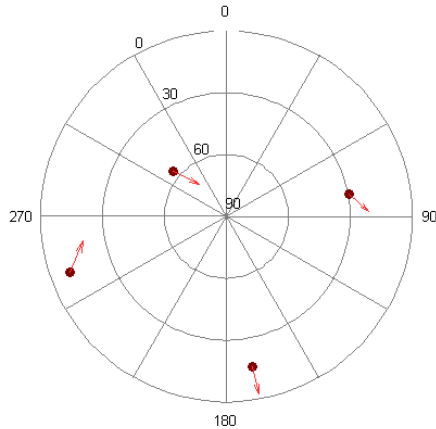
N : the number of satellites.

MEOSAR highlights

Location processing

❖ Moving beacon issue: theoretical example

- Typical location accuracy for static beacons: 5km @ 90% (single burst, using ToA and FoA)
- Effect of a motion of 1 m/s



Minimum bias error resulting from the beacon motion = 6.6 km (for beacon headings towards 30 and 210 deg, at 1m/s)

Maximum bias error resulting from the beacon motion = 15.5 km (for beacons headings towards 120 and 300 deg, at 1m/s)

MEOSAR highlights

Location processing

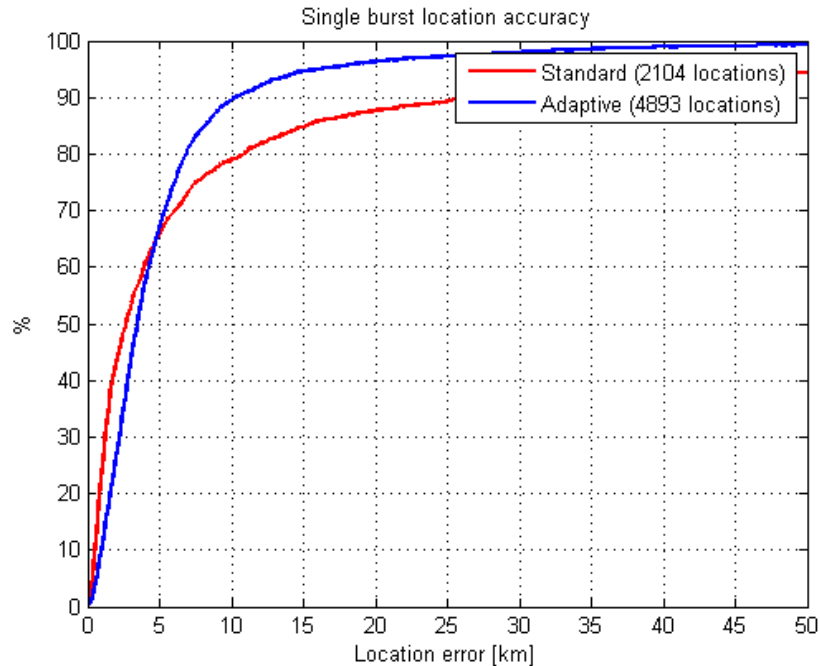
- ❖ Moving beacon issue: solutions
 - It is important to detect if a beacon is moving or not (from velocity estimation from FoA measurement or FoA residuals)
 - If it is detected that the beacon moves with a sufficient speed, 2 possible different strategies:
 - Decrease the weight on FoA measurements (compromise bias vs noise to get the best location accuracy)
 - Use a joint position+speed estimation

- ❖ Location processing has to be adaptive to the beacon speed to get the best location accuracy.

MEOSAR highlights

Location processing

- ❖ Moving beacon issue: improvement due to adaptive algorithm



Results obtained during a test conducted by Norway in March 2016, involving a boat with moving and static phases.

MEOSAR highlights

Location processing

❖ Moving beacon issue: way forward

- Additional work is needed to improve location performance of moving beacons using multi-bursts
 - Trajectory estimation with simple trajectory model ?
 - Kalman filter ?

MEOSAR highlights

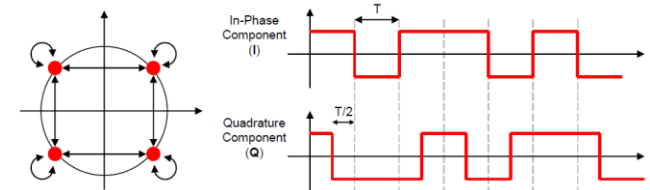
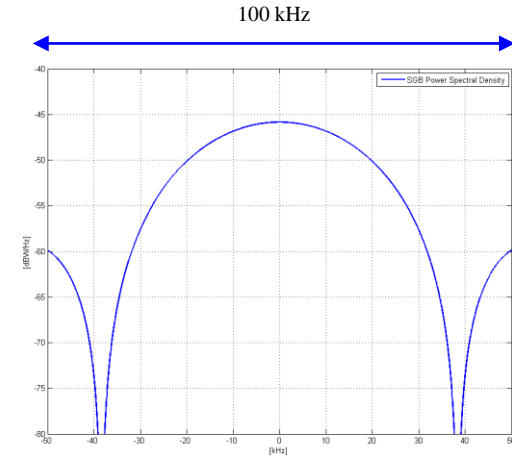
Second Generation Beacon standard

- ❖ In parallel to MEOSAR deployment, a second generation of beacon is being developed
- ❖ Objective: answer to more stringent operational requirements
 - Better detection performance: 99.9% after 30s of activation
 - Better localization performance:
 - 5km, 90% of the time for first burst
 - 5km, 95% of the time after 30s of activation
 - 1km, 95% of the time after 5min of activation
 - 100m, 95% of the time after 30min of activation
 - Increased content of transmitted message

MEOSAR highlights

Second Generation Beacon standard

- ❖ Second Generation Beacons signal characteristics:
 - Waveform: OQPSK with spread spectrum at 38400 chips/s
 - Message: 202 useful bits, 300 bits/s, 1s duration
 - Error correction code: BCH(250,202)
 - Introduction of “Rotating field”: transmission of different information on each burst
 - Cancellation capability



MEOSAR highlights

Second Generation Beacon standard

❖ Performance improvement

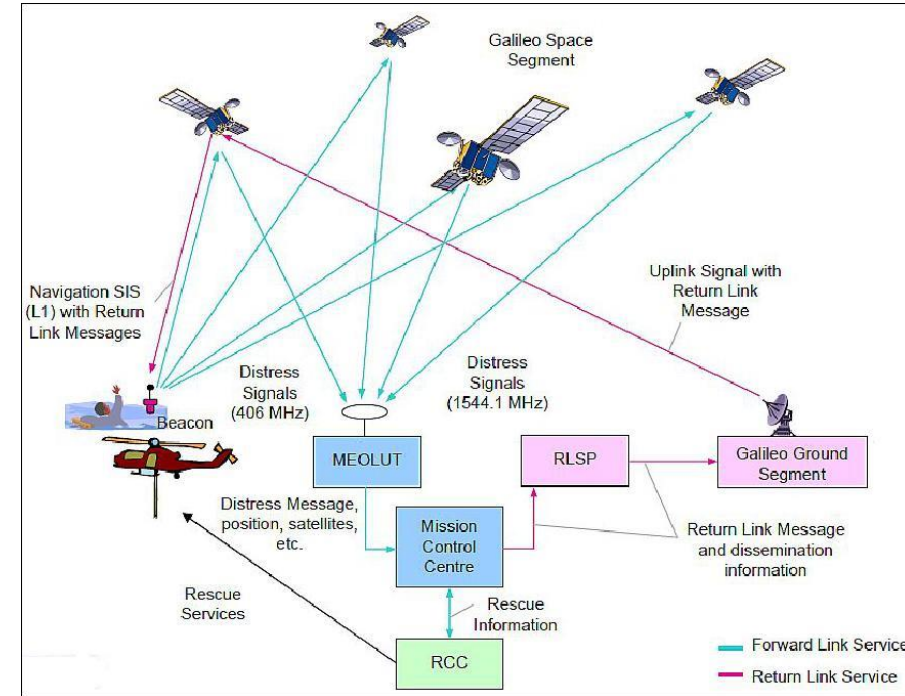
	FGB	SGB
Detection threshold	34.7 dBHz	31.7 dBHz
σ_{FOA}	0.2 Hz	0.15 Hz
σ_{TOA}	20 μs	1 μs
Location performance (static beacon, single burst)	~ 5 km	~ 1 km
Location performance (moving beacon, single burst)	~ 20 km	~ 1km

System evolutions: RLS and ELT(DT)

System evolutions: RLS and ELT(DT)

Return Link Service

- ❖ A Galileo service which allows to send a acknowledgement to user in distress
- ❖ An RLM is sent through the Galileo E1 signal
- ❖ The RLS service should be declared operational in 2019 by EC
- ❖ RLSP (Return Link Service Provider) is operated by CNES



System evolutions: RLS and ELT(DT)

Return Link Service

- ❖ Currently, only the automatic acknowledgement has been agreed but additional uses of RLS are being discussed:
 - Remote activation : a beacon that listen to Galileo signals could be activated from the ground. Useful to track an aircraft that disappears from air traffic control (ex: MH370)
 - Remote command: change beacon transmission characteristics (ex: reduce repetition rate to save battery)
 - Two-way messaging: give more details to SAR forces about the distress situation (ex: number of people involved, type of distress)

System evolutions: RLS and ELT(DT)

Beacons activated in flight: ELT(DT)

- ❖ Following accidents of AF447 and MH370, ICAO has imposed a requirement for new aircrafts being operated after 1st January 2021, to be equipped with a system able to locate the aircraft accident site. The system has to transmit signals from which a location can be retrieved at least once every minute.
- ❖ Cospas-Sarsat answer was the development of the ELT(DT) standard:
 - A beacon activated in flight upon detection of distress situation (total loss of propulsion, unusual attitude, unusual speed, unusual altitude, ground proximity)
 - A GNSS encoded location as primary mean of location
 - Independent location with speed estimation (coarse location accuracy with FGB, enhanced location accuracy with SGB).

Thank you for your attention !
Question ?