HASARDS – Final Presentation

HAPS-Augmented Search-And-Rescue Demonstration System

8/03/2023 – AO-10320 – Multi-layer PNT for Search and Rescue

Summary

1. **Project Overview**
   - Reminders on C/S
   - Methodology
   - Use Cases

2. **HAPS technologies and potential enhancements**
   - HAPS Technologies
   - Operational Limits (LoS coverage)

3. **Promoted Solutions**
   - Solution Blocks
   - System model
   - ConOps

4. **Validation Phase**
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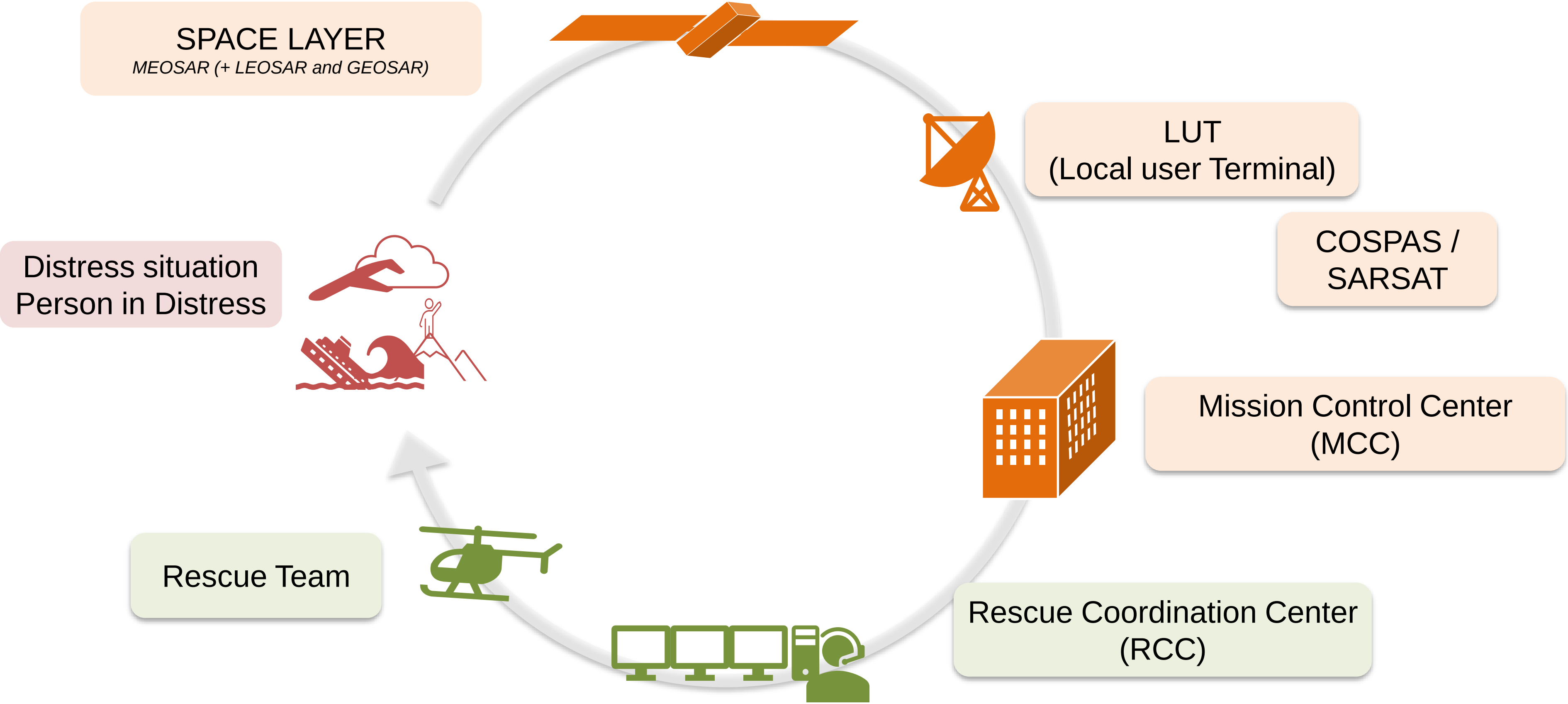
   - Flight test campaign
   - Simulation campaign
   - Validation results

5. **Proposed HAPS Concept & Tech development**
   - Concept Presentation
   - Product Development Plan

6. **Conclusion and Way forward**

Project Overview

COSPAS SARSAT AND SAR

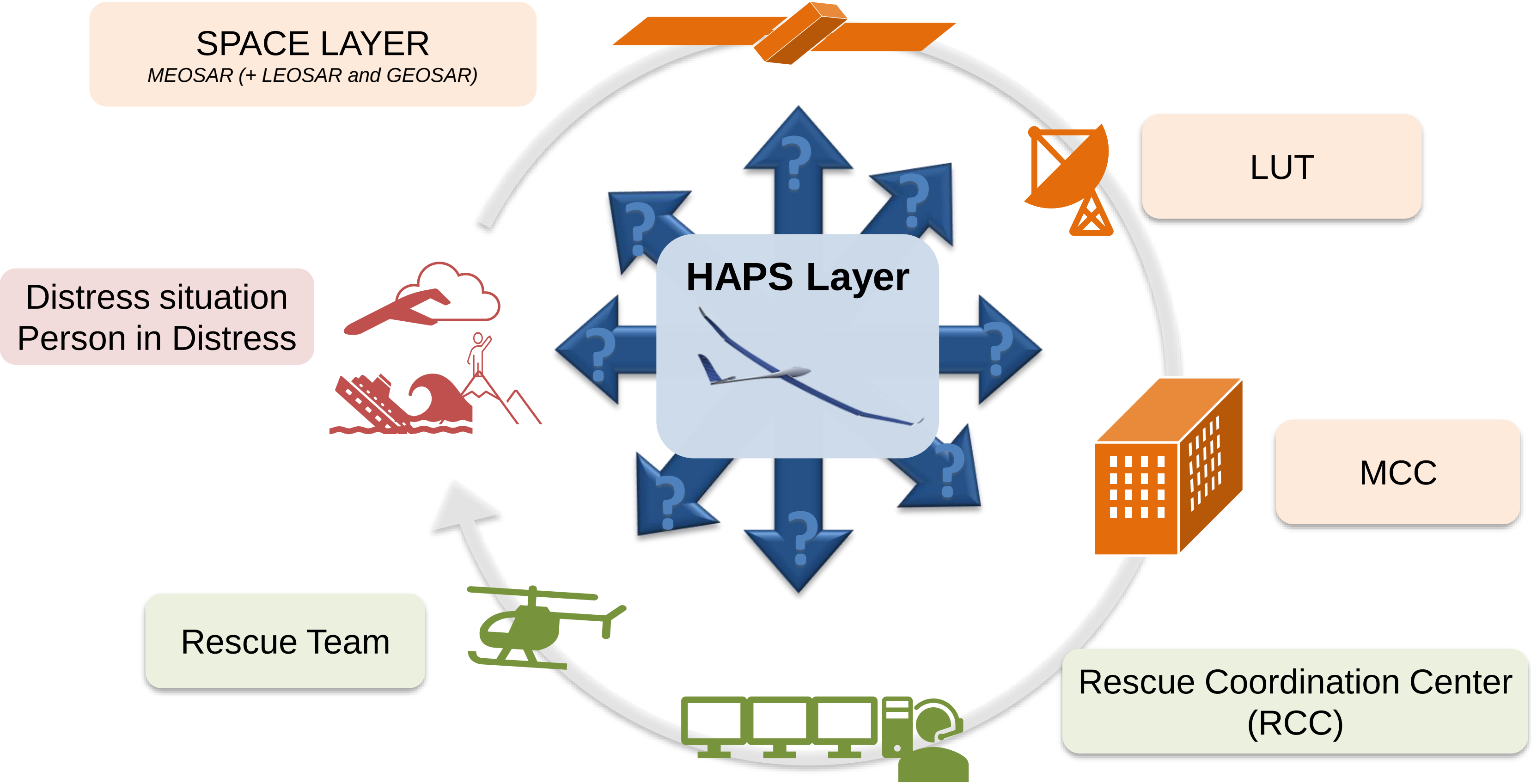


HAPS POTENTIAL AND HASARDS

High Altitude Pseudo Satellites (HAPS)

- ✓ Long endurance operations
- ✓ Good service availability,
- ✓ Smaller area than MEOSAR
- ✓ Operates at lower altitude,
- ✓ better signal to noise ratio
- ✓ robust to downgraded conditions.
- ✓ communication and imagery payload
- ✓ **Could help SAR operations?**

HASARDS:
HAPS IN THE SAR - C/S CONTEXT



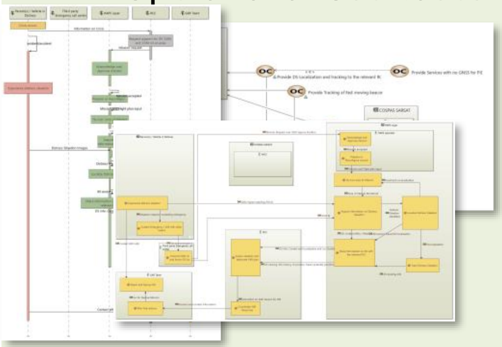
STRATOS SOLUTION HASARDS PROJECT OVERVIEW

HASARDS PROJECT OVERVIEW

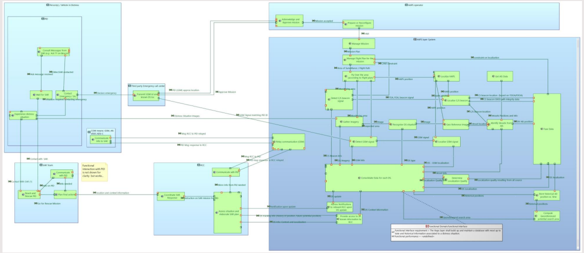
METHODOLOGY

Operational Use cases	System analysis		Validation
User requirements	Function requirements	Functional performance requirements	Validation objectives and Acceptance criteria

Operational Use cases

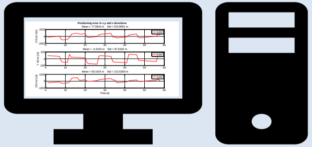


Functions, interfaces, system allocation



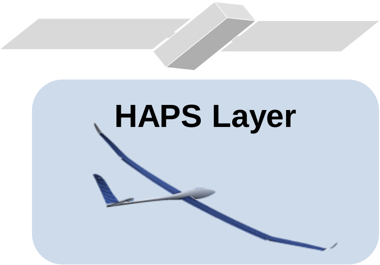
Flight tests

Simulation



Capella – Modelling and document generation

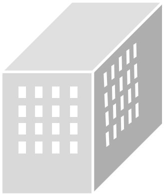
Operational Use cases



"Localization":
UC1 (trajectory tracking),
UC2 (weak signal), and UC4 (No GNSS)
AUC1 (localization through cellular signal)

COSPAS
SARSAT
Network

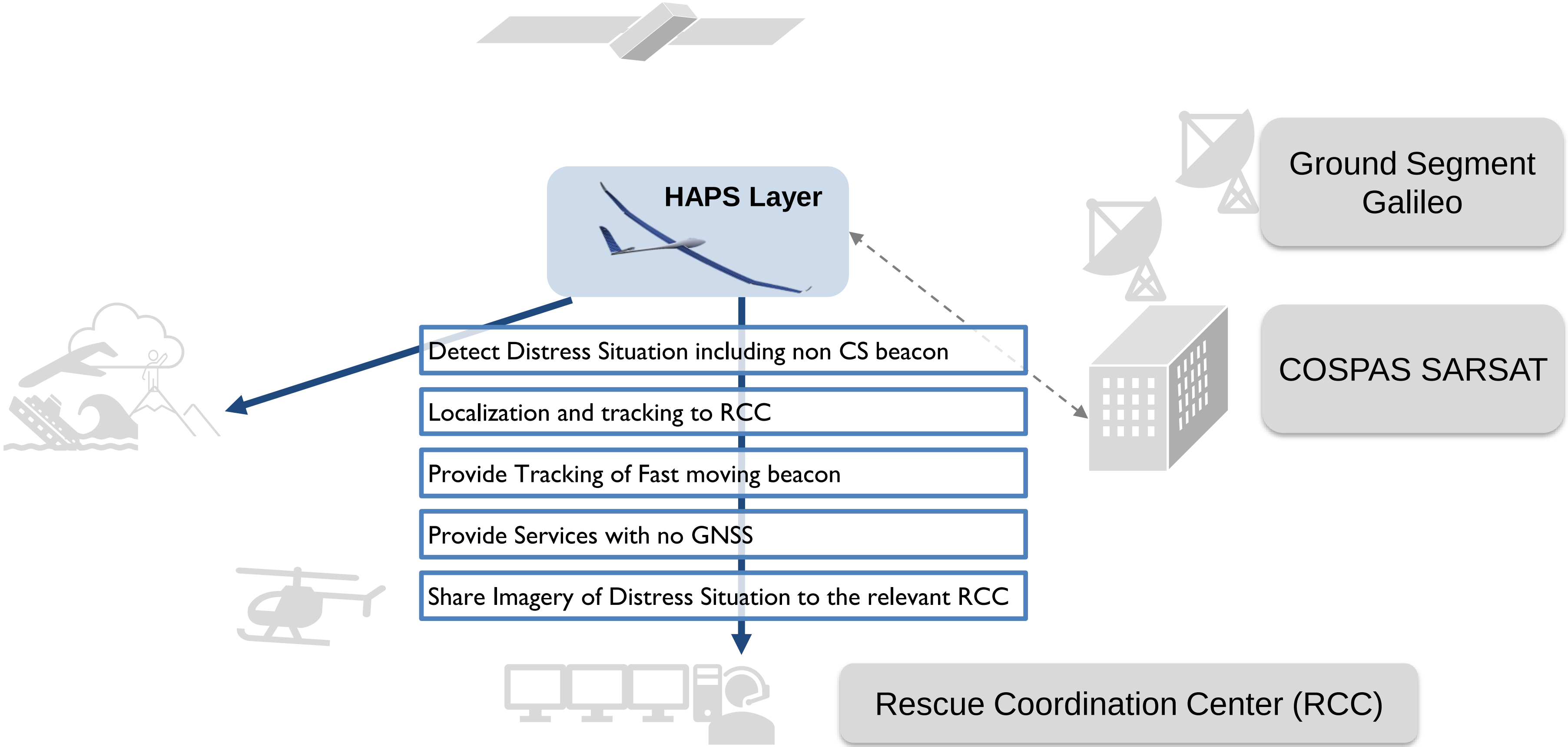
"Communication":
UC5 (Distress positioning sharing), and
AUC2 (direct communication)
AUC3: Automatic Acknowledgment message



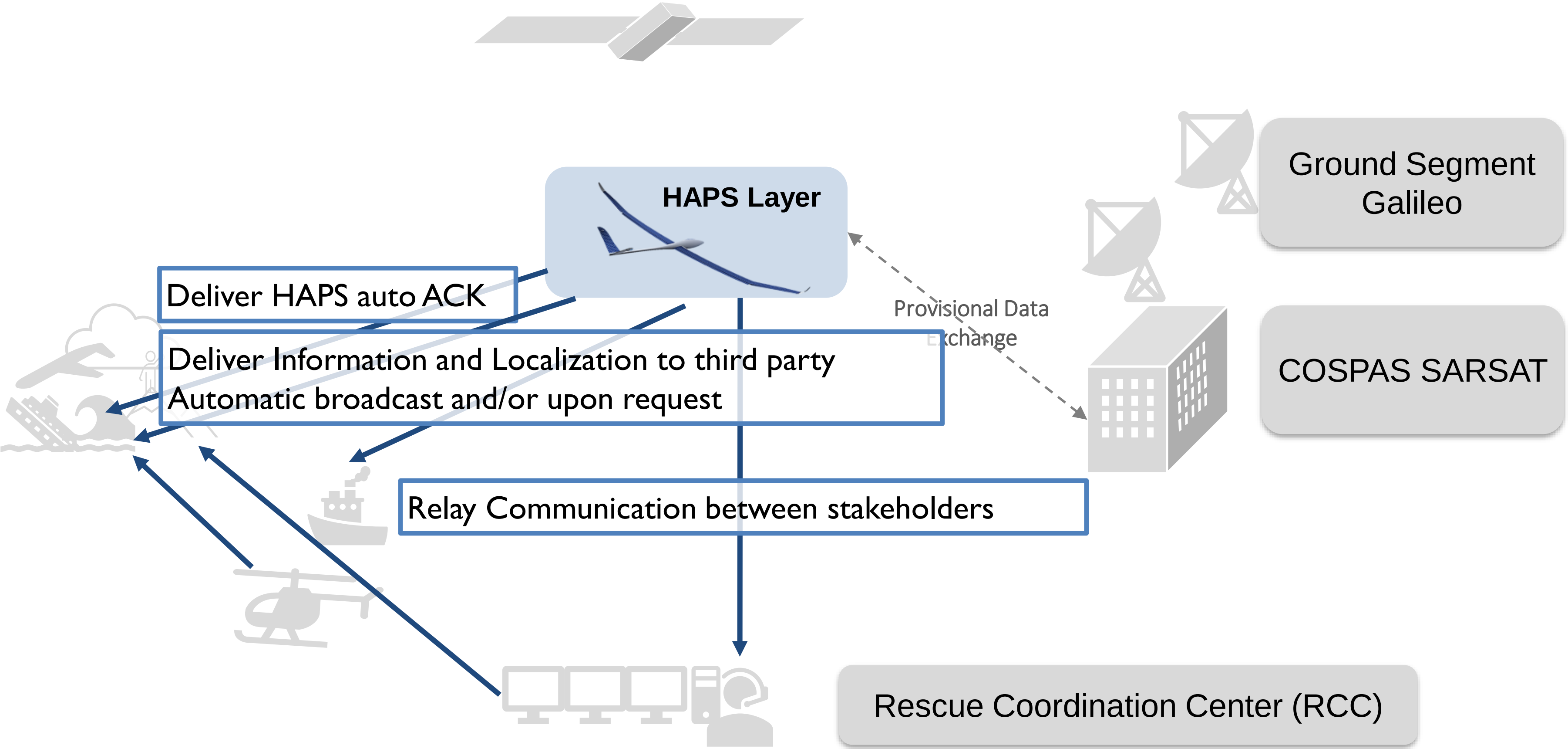
"**Imagery**":
UC3 (Humanitarian crisis)

Rescue Coordination Center (RCC)

Operational objectives



OPERATIONAL OBJECTIVES



HAPS Technologies and potential enhancements

HAPS Classification

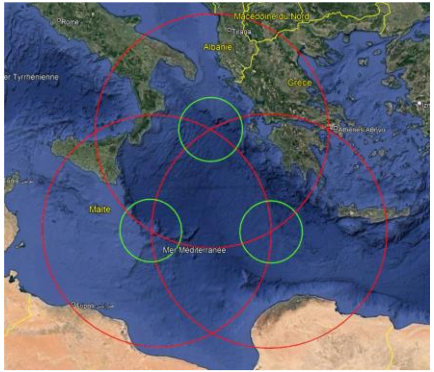
	Balloons	Airships	Light Aircraft
Payload mass	Very light	Medium-Heavy	Light
Available power	Very low	Medium-High	Low
Deployment speed	Very slow	Intermediate	Fast
Flight speed	Very slow	Slow	Intermediate
Mission control	N/A (passive)	Slow retasking	Fast retasking
Endurance	Few years	Few years	Few months
Operational costs	Intermediate	Expensive	Expensive
Mission profile	Global telecom network	Telecom relays Earth observation with heavy payload	Local PNT support Earth observation with light payload

COVERAGE VS CONOPS

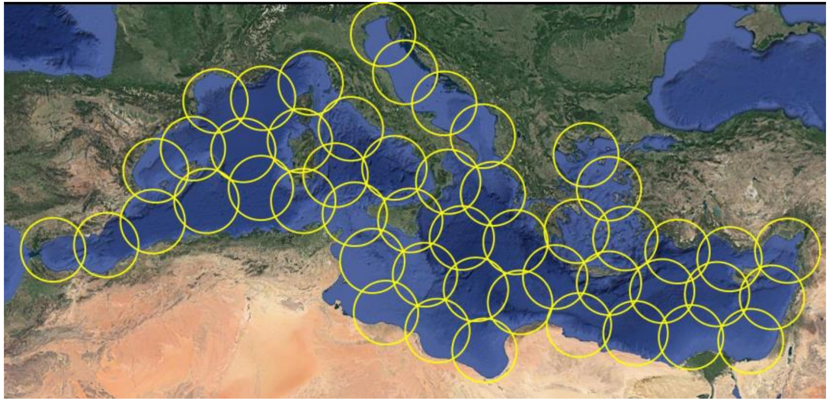
Coverage is a central element for Conops definition. Main parameters:

- HAPS altitude
- Minimal incidence
- Payload capabilities

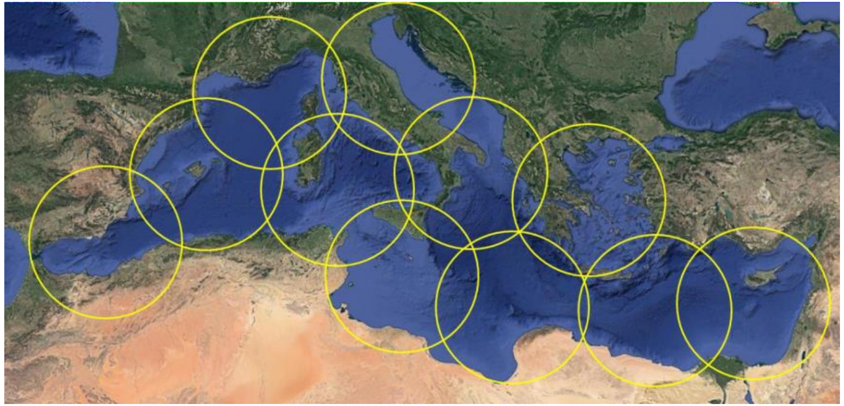
Possibility to have "dual coverage" when exploiting different payloads (e.g. top-right image).



Dual coverage: 100km / 400km

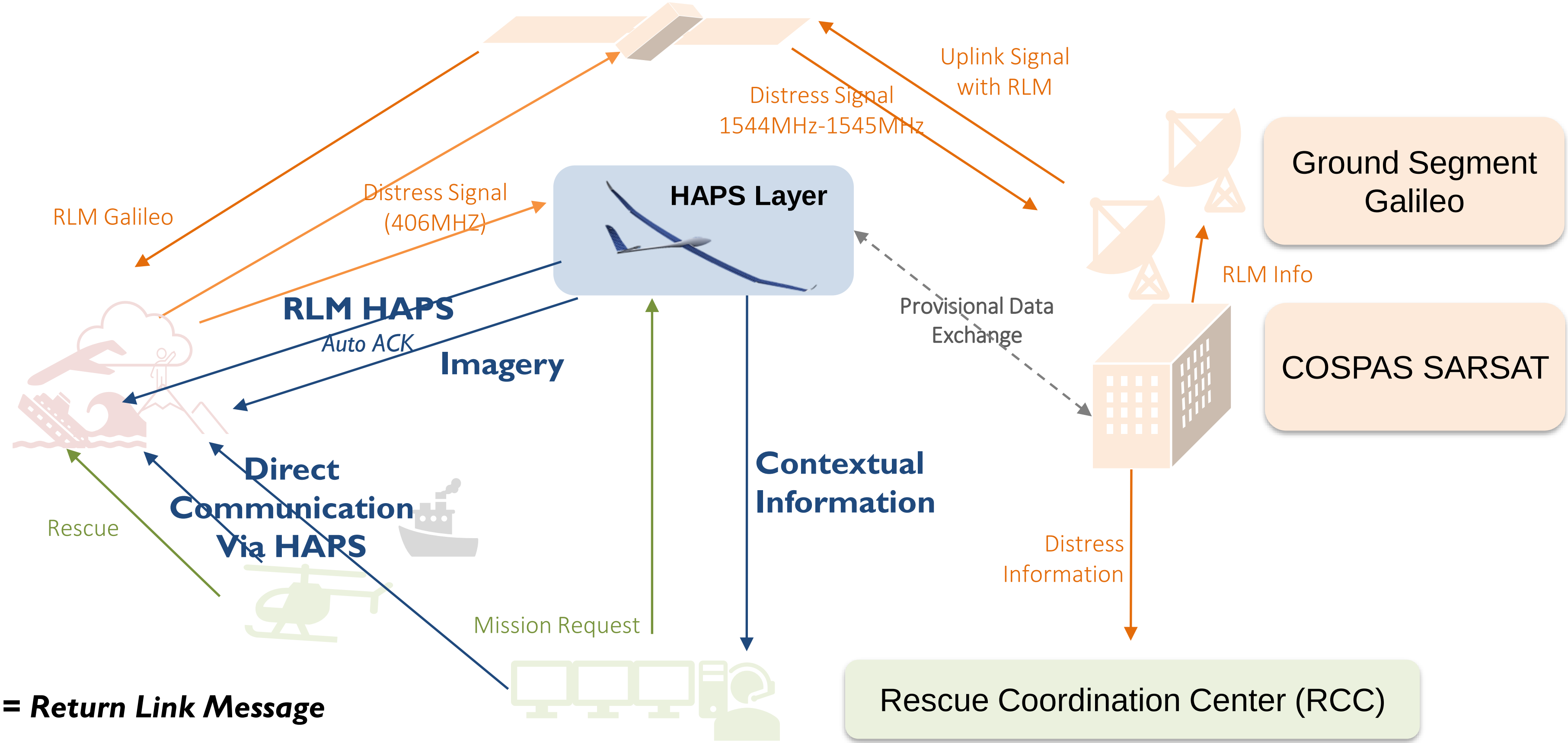


Range: 160km / Nb HAPS: 49



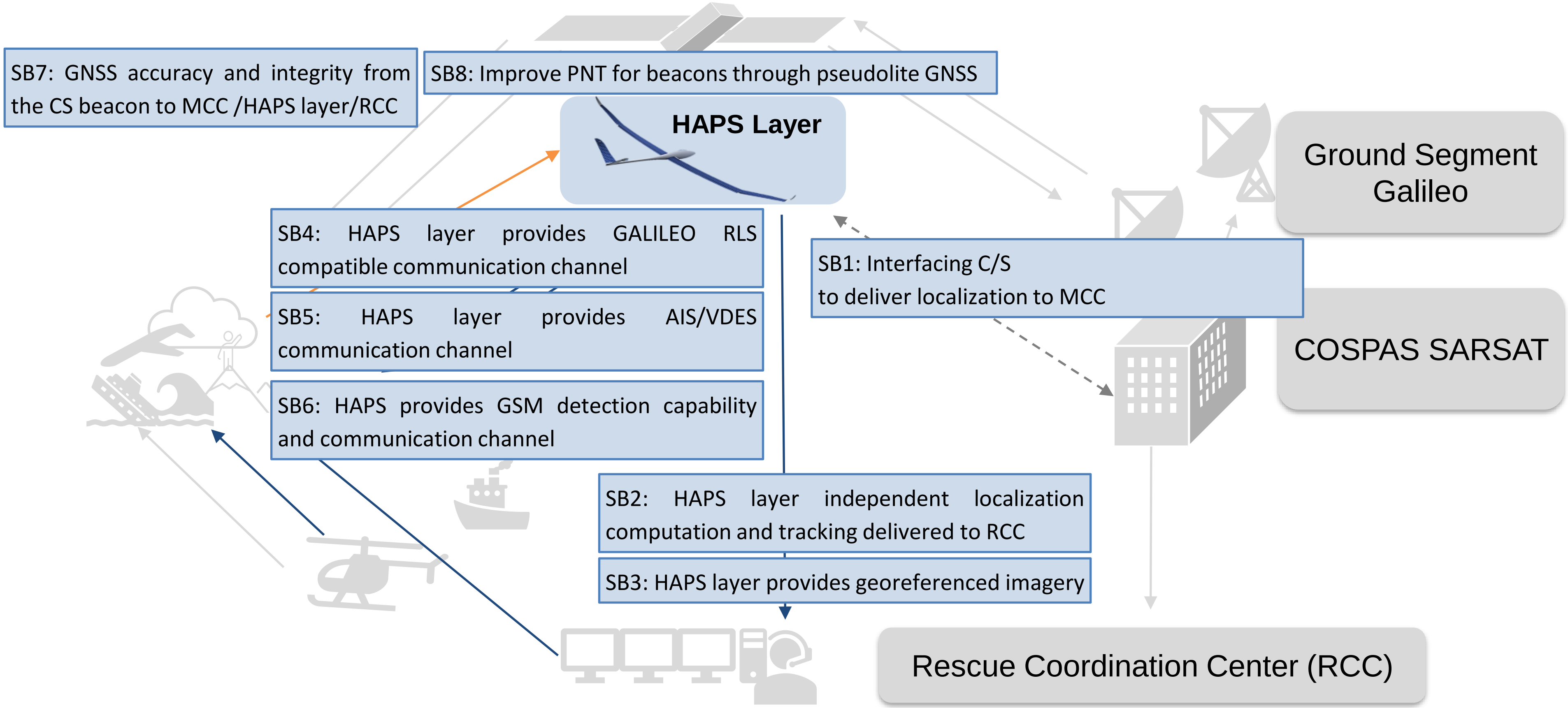
Range: 350km / Nb HAPS: 11

HASARDS PRINCIPLE'S DIAGRAM



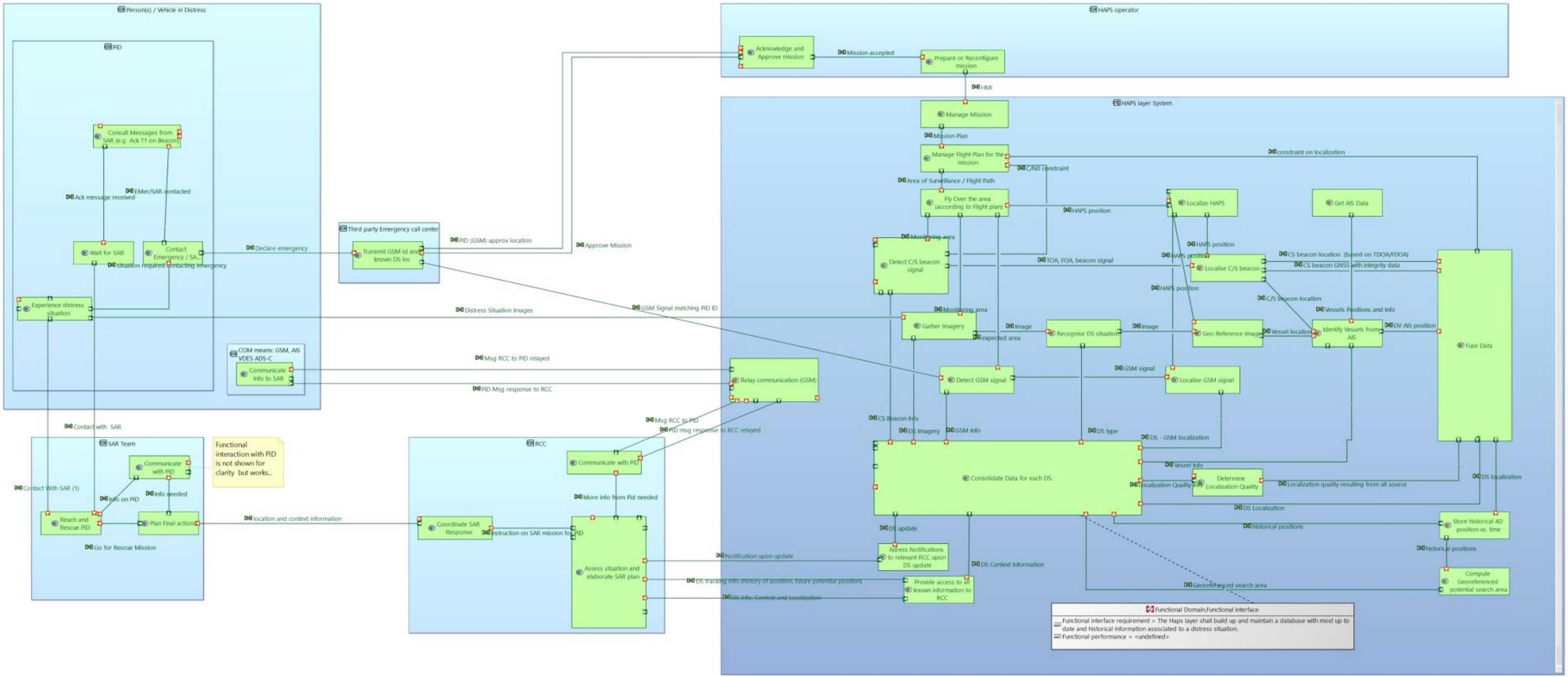
RLM = Return Link Message

HAPS-BASED ENHANCEMENT CANDIDATES TO COSPAS-SARSAT SERVICES

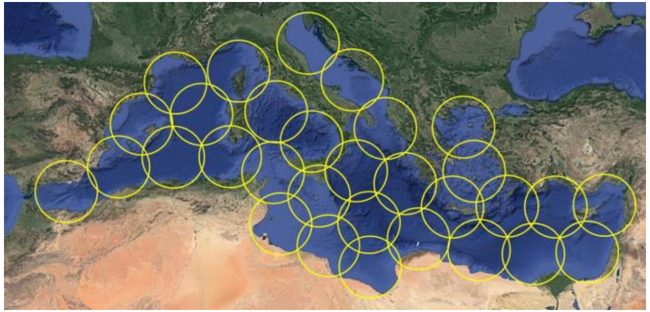


PROMOTED SOLUTION

SYSTEM ARCHITECTURE



Preliminary Service Provision & Concept of Operation



- Estimation of area coverage based on measurements
- Limitation on altitude: >30km is unlikely, whatever the HAPS architecture (fixed-wing/airship/balloon)
- Limited advantage to have HAPS-based localization => 1-HAPS coverage is sufficient

Mediterranean Sea coverage

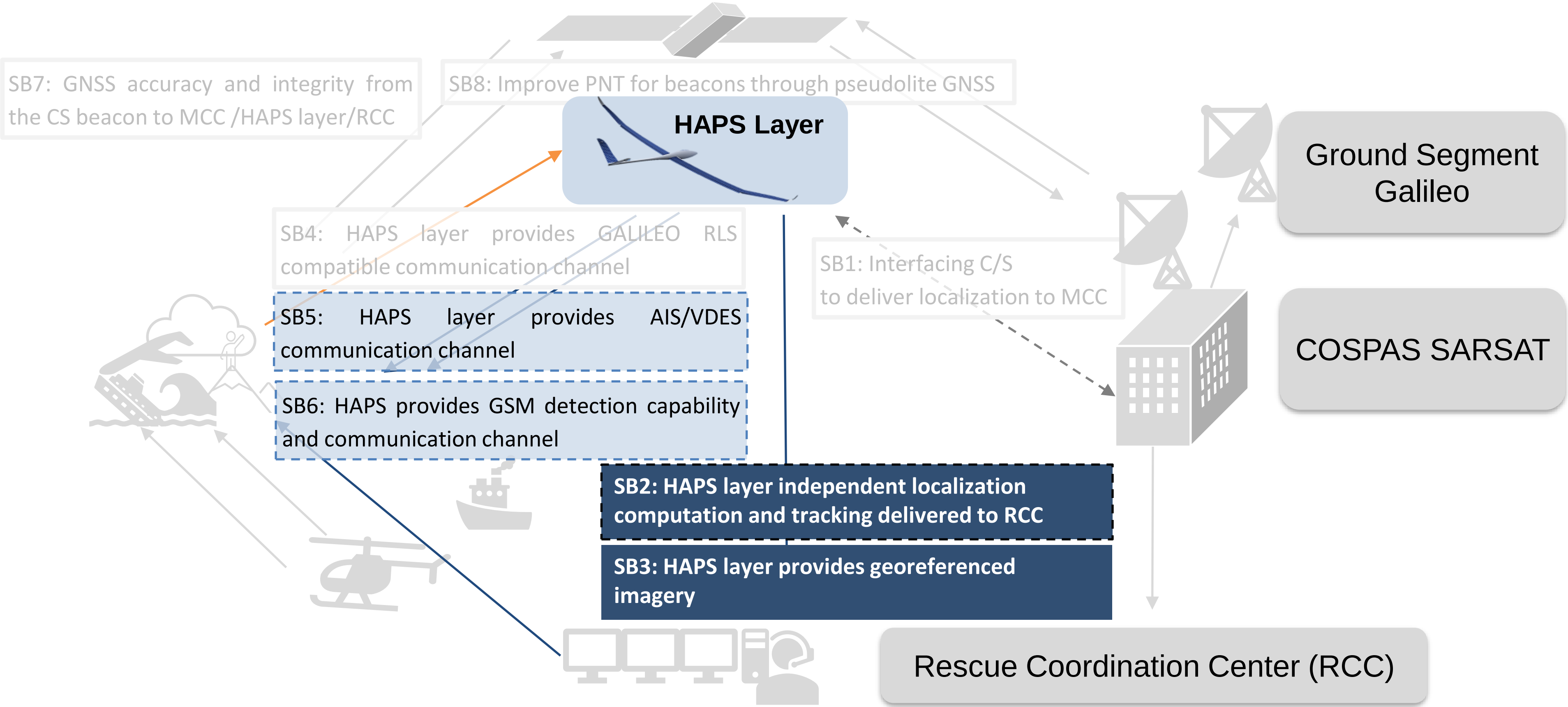
h [km]	Range [km]	1-HAPS coverage [km²]	Nb of HAPs
16	160	80 016	49
18	177	98 423	41 (*)
20	194	118 379	34
25	235	173 655	23 (*)
30	274	235 908	17
35(**)	311	303 858	13 (*)
40(**)	347	377 652	11

(5°incidence ranges)

Solution Block Mission Concepts:

1. C/S interfacing => Fewer HAPS is better => Higher is better
2. Independent beacon signal detection = 3 HAPS => Higher is better
3. Trajectory tracking => 3-4 HAPS => Higher is better
4. Image resolution => Lower is better
5. Imagery = ~100km range max => Speed is better
6. AIS => Greater range is better => Higher is better
7. GSM => 150 km range max => Not need for highest operational ceiling
8. PNT pseudolite => Fewer HAPS is better => Higher is better

HAPS-BASED ENHANCEMENT CANDIDATES TO COSPAS-SARSAT SERVICES



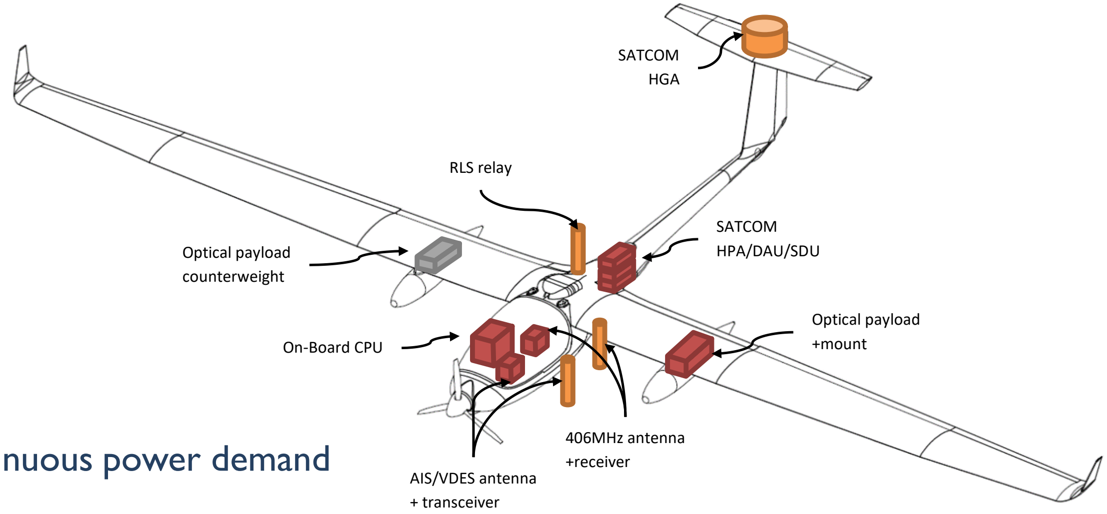
HAPS Concept Preliminary Design

Imagery key figures:

1. Optical range (aperture ~200mm):
   - Detection up to ~100km (e.g., detection of stranded boat)
   - Recognition up to 50km (capacity to classify an object)
2. Synthetic Aperture Radar: similar resolution performances, with the advantage of all-weather application, but at the expense of limited range (up to 60km) and higher mass and power consumption.

The baseline design proposal includes the following equipment:

- 406MHz receiver
- AIS/VDES antenna + transceiver
- RLS Galileo relay
- Optical payload + mount
- On-board CPU
- SATCOM



The total payload mass is 26.5kg, for a total continuous power demand of 360 W.

Validation Phase

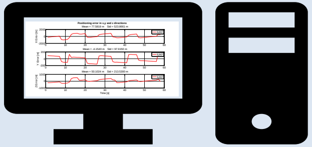
Validation Objectives

Operational Use cases	System analysis		Validation
User requirements	Function requirements	Functional performance requirements	Validation objectives and Acceptance criteria

- What are the **localization & tracking performance** of 4 HAPS considering
  - the troposphere,
  - dynamic aspects: beacon trajectory, HAPS flight plan, beacon burst emission at a representative repetition.
- What are the **localization performance benefits** brought by **beacon GNSS position** information?
- What are the **benefits** brought by **georeferencing**? (HAPS imagery payload)

Flight tests

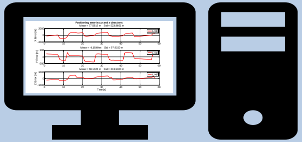
Simulation



STRATOS SOLUTION — REAL FLIGHTS & SIMULATION OBJECTIVES

Flight tests

Simulation



Real flight

Real beacon and
radio transmission

Simple cases / Trajectories

1HAPS/ 1 Distress vehicle
Single speed (fixed /moving vehicles)
Low altitude

Beacon simulator

Simulated Trajectory

Troposphere model

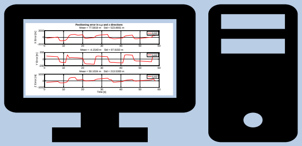
More operational use cases

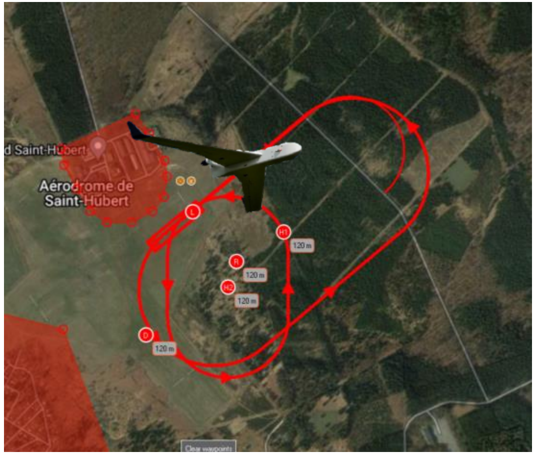
4 HAPS / 1 distress Vehicle
Multiple speed difference
Consideration of beacon GNSS
Consideration of geolocation perf

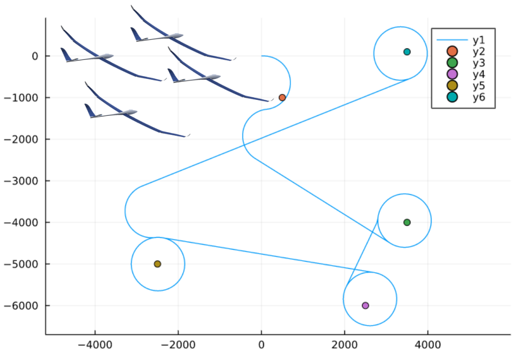
VALIDATION - TRAJECTORIES

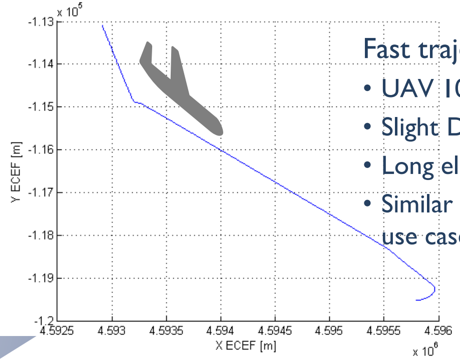
Flight tests

Simulation









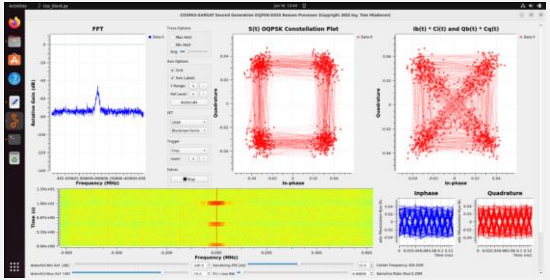
Fast trajectory Distress

- UAV 100km/h wind speed
- Slight Descent(-300m loss)
- Long elongation (~7 km over 5min)
- Similar to ICAO GADSS tracking use case.

VALIDATION – REAL FLIGHT / SIMULATION

Flight tests

Signal Quality assessment



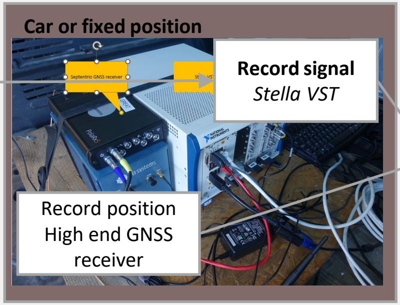
CS-SGB-Processor tool - Output:

- Spectrum,
- OQPSK constellation plot
- eye diagram,
- time domain signal.

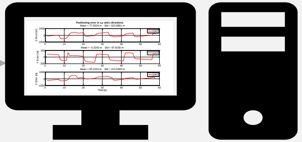
Objective1
Validate simulator 2nd Generation beacon generator

Record Data (I/Q) for later simulation

Recorded trajectory : to be reinjected in the simulator



Manipulate Data Manipulation and preparation



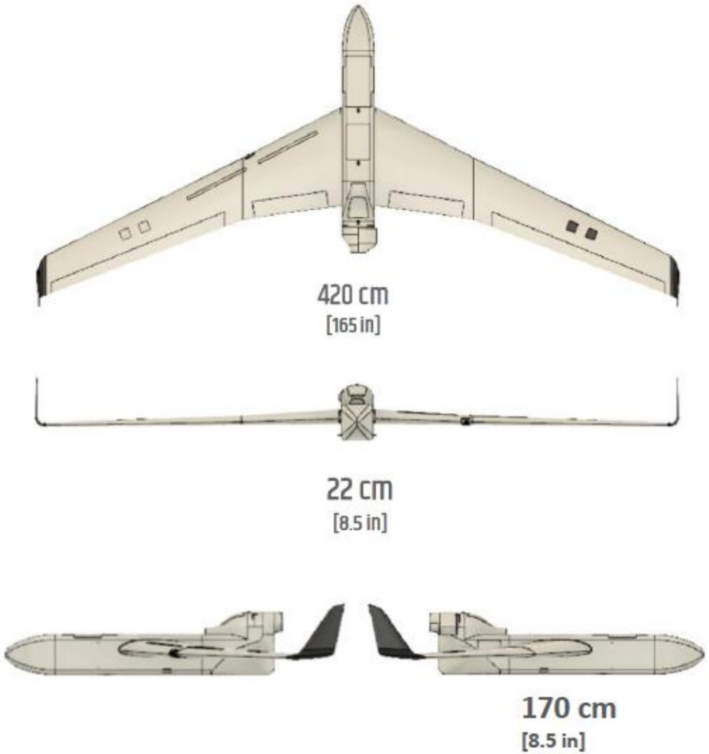
Objective2
take opportunity to characterize simulator performance against real signals)

SGB INTEGRATION IN UAV

Second Generation Beacon (SGB)

- Modulation : OQPSK-CDMA (2nd Generation)
- Protocol : User Protocol
- Weight : 968 grs
- Dimensions : 184 x 115 x 650 (without antenna)
- Li-Ion battery (endurance 2H with repetition time of 90s @ 37dBm)

BOREAL UAS



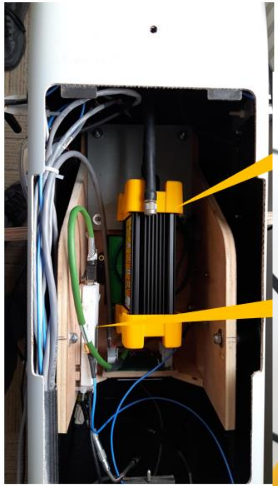
25 Kg
MTOW

8 h
Maximum Endurance

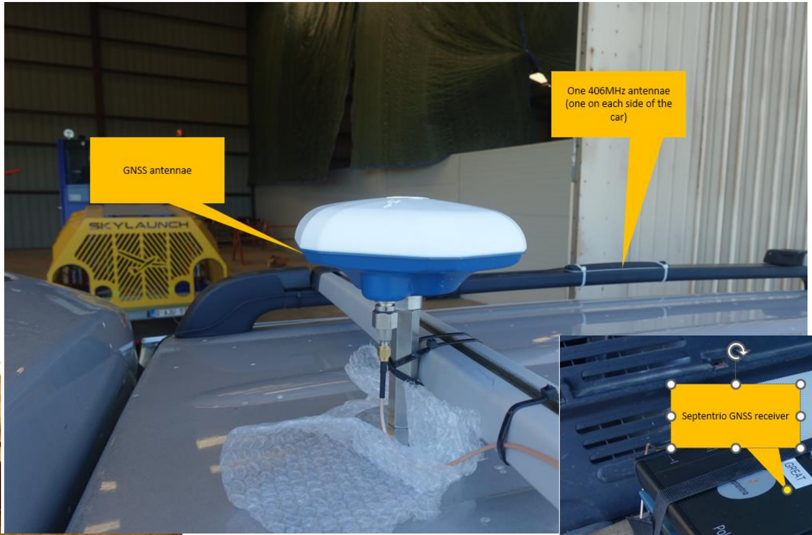
800 Km
Range

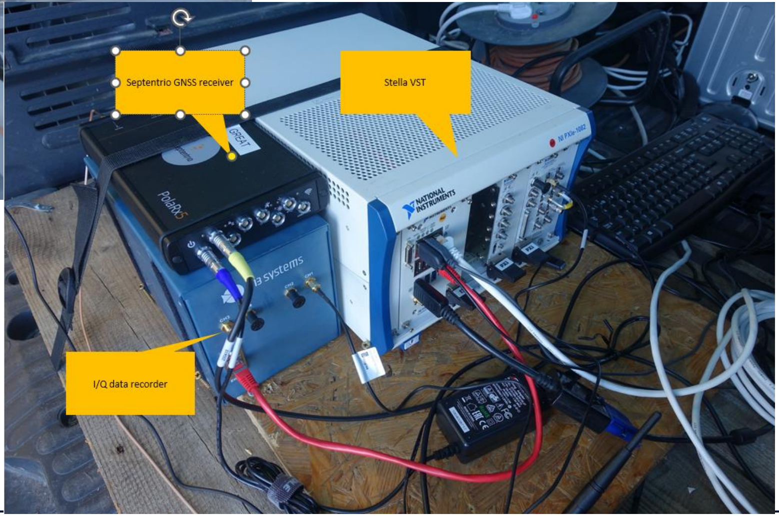
7 Kg
Maximum Payload's weight

SGB ON BOREAL AS PAYLOAD

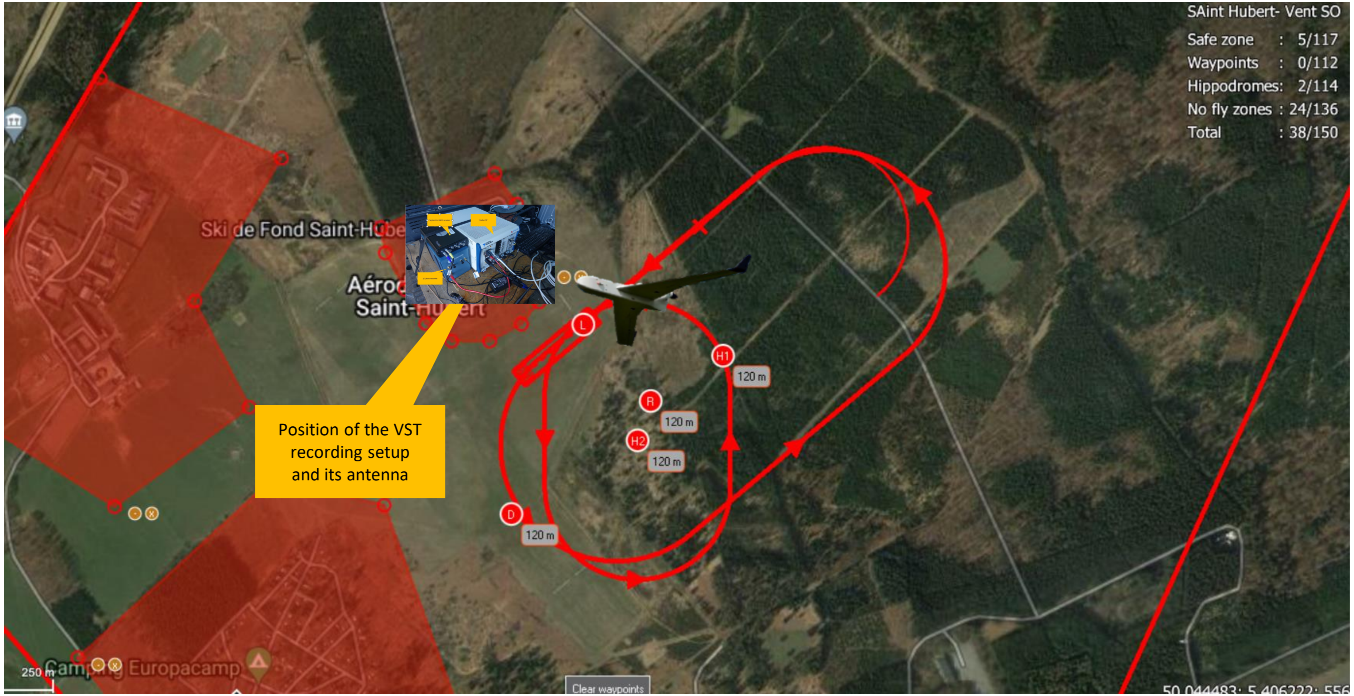


Recording setup on the car





FLIGHT AT SAINT HUBERT – FLIGHT PATH

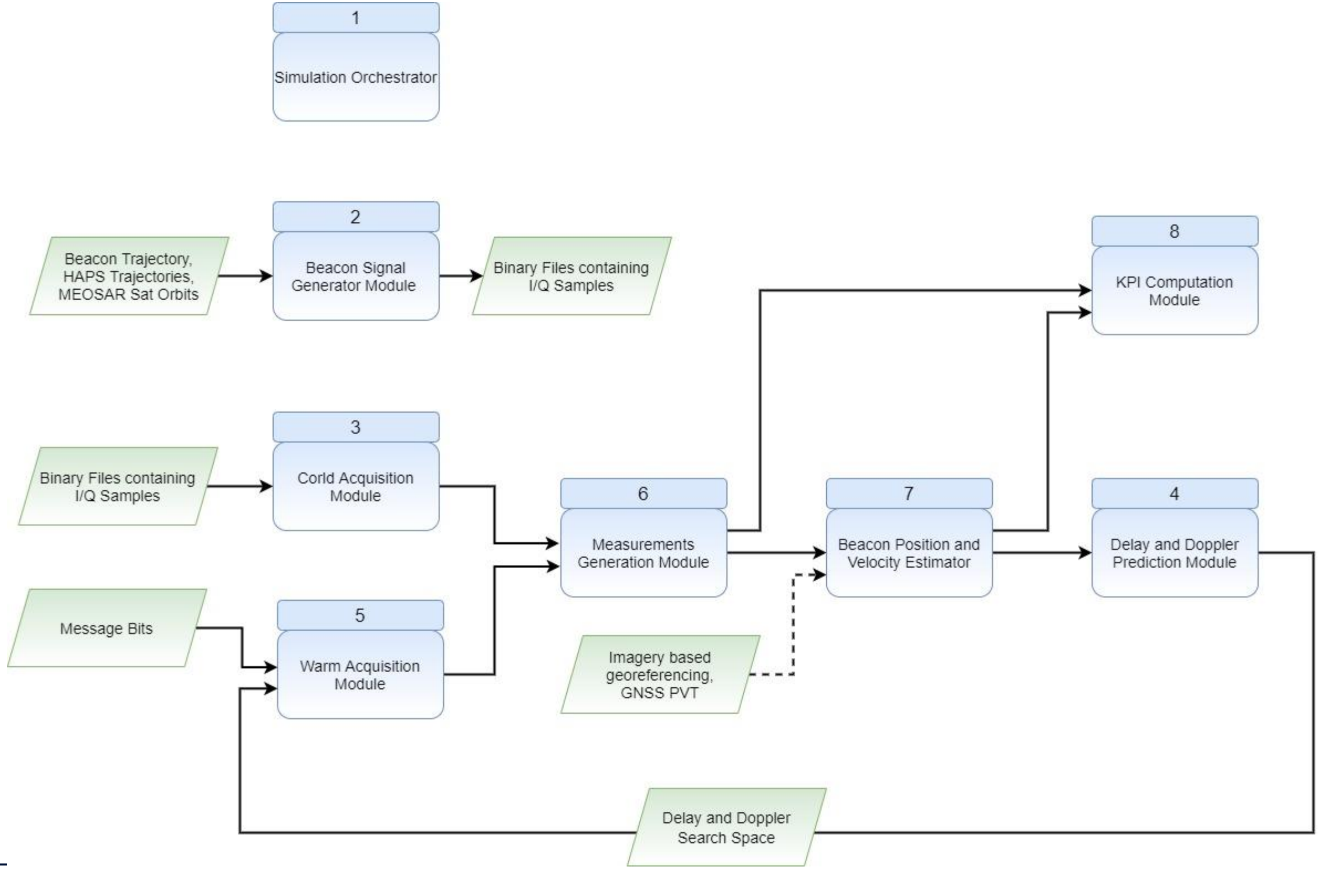


Flight planning

FLIGHT AT SAINT-HUBERT

SIMULATION RESULTS

SIMULATOR DESCRIPTION



COMPARISON WITH C/S T.019

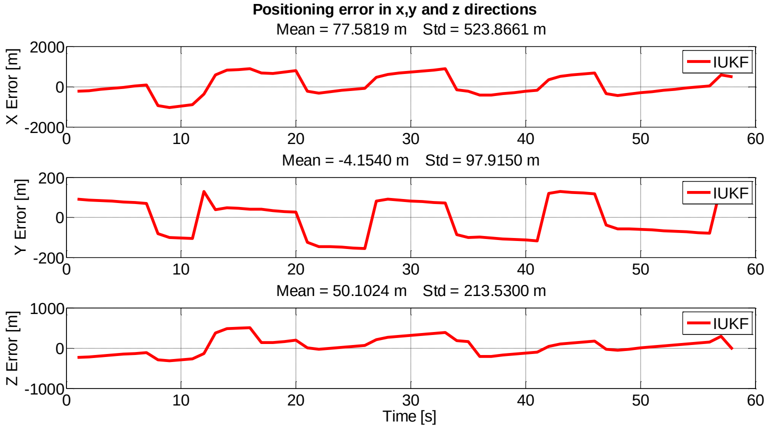
Comparison with C/S MEOLUT PERFORMANCE SPECIFICATION AND DESIGN GUIDELINES

Speed	C/S T.019 for SGB 5min *An independent location provided within 5 minutes from the first beacon message transmission shall meet the following accuracy requirement:*
nearly-static [0 ; 0.5] m/s	M/N shall be greater than or equal to 0.97 where: M = number of locations within 1 km N = number of locations.
Medium speed [5; 10] m/s	M/N shall be greater than or equal to 0.97 where: M = number of locations within 1 km N = number of locations.
Fast >10 m/s.	M/N shall be greater than or equal to 0.97 where: M = number of locations within TBD km N = number of locations.

Simulation Execution - Solution scenarios: 4 HAPS & Slow moving beacon (initialization with position sent by the Beacon)

Percent_500m_X = 60.3448
Percent_500m_Y = 100
Percent_500m_Z = 98.2759

Percent_1km_X = 98.2759
Percent_1km_Y = 100
Percent_1km_Z = 100



Georeferencing – Statistical Analysis on Accuracy Performance

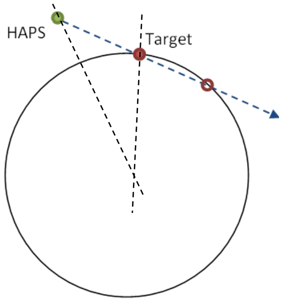
Principle

Direct GeoReferencing (DGR) is the estimation of a target's location, based on the camera's characteristics and orientation, and an assumed terrain's digital elevation model.

Driving factors

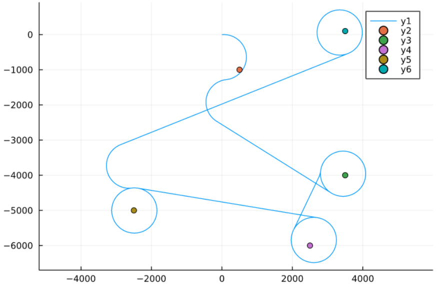
DRG performances are based on:

- Typical IMU angle performances (~0.01° RMS)
- Flight characteristics (altitude, range)
- 2nd order perturbations (gimbal, boresight, optical distortion, etc.)



Applications

Various scenarios were runs to account for multiple flight configurations (height, distance, payload)



Results

At 110km (max. optical range), the localisation error (RMS) from DGR is estimated to be ~800m in "depth" and ~110m in "transverse" directions.

The target is assumed to be on the ground / sea, or with very low height

Preliminary Service Provision & Concept of Operation

High-Level Operation of Proposed Prototype

Selected functionalities:

- Provide near real-time imagery
- Provide direct-georeferencing capability
- Provide a new communication channel
- Provide additional RLM (“ACK-2”) to PiD
- Provide capability to raise alert in covered region (“EMG-1”)

There are two significant advantages with this configuration:

1. This provides the most obvious and promising enhancement to SAR – imagery & direct georeferencing
2. Costs can be share with other EU institutions such as ESMA (European Maritime Safety Agency), for maritime surveillance (illegal fishing, border control, smuggler detection, illegal degassing boats, etc.) would be readily available and operational.

The main assumption of HAPS fleet operation:

- Imagery Coverage : 1 HAPS (due to user needs w.r.t. proposed enhancements)
- Max detection range : 110km (optical limits)
- Flyover period : 0h (meaning permanent coverage)
- HAPS availability : 90% (due to scheduled maintenance, repair, or upgrade)
- Mission location : All EU basins (49 HAPS for Mediterranean Sea)

Alternate solution: 30km-height balloon for trajectory tracking (on mainland)

Validation Results - Conclusion

- Dynamic simulation results confirm that HAPS layer can locate Distress situation with an error (standard deviation) of less than **500m average** with 4 HAPS based operations.
- With static cases, the mean absolute positioning error is less than **170 m and the standard deviation less than 1.1 km**.
- For **tracking of fast object**, the mean absolute positioning error is less than 40 m and the standard deviation less than 1.8 km, which would comply with GADSS ICAO Conops requirements of having an estimation of the aircraft crash **within a 6NM radius.**
- In all cases the **initialisation with GNSS** would help localization algorithm to converge faster and provide more accurate result (and the calculated position accuracy improves compared to static without considering the position) (mean absolute value **below 80 m and standard deviation below 550 m**)
- The **georeferencing** is proving to be very effective: **error of the same order of magnitude as the TOA/FOA algorithm** and provides **more accurate results when the HAPS is Around 110km** from the beacon or less, in case of static distress vehicle at least.
- Georeferencing performance degrade rapidly with Distress vehicle's height.

PROPOSED HAPS CONCEPT & TECH DEVELOPMENT

Preliminary Service Provision & Concept of Operation

Operational Cost

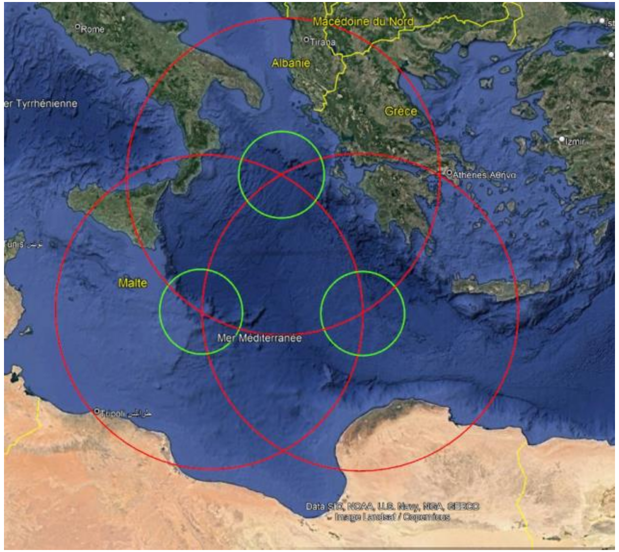
Based on previous Earth Observation project, HAPS operational cost is estimated to be ~100€/h

As a work basis for this study, 49 HAPS for *full* Mediterranean Sea coverage with imagery => 42M€ / year

Quite expensive for S&R application alone, *but* plausible if **shared cost** with other end-users (for Border Control, Law Enforcement, ISR, etc.)

Hence, the following (adapted) CONOPS is proposed:

- Under coverage for imagery compensated by roaming, with "just enough" triangulation (3-4 HAPS) ~30M€/y (compromise on localisation performances)

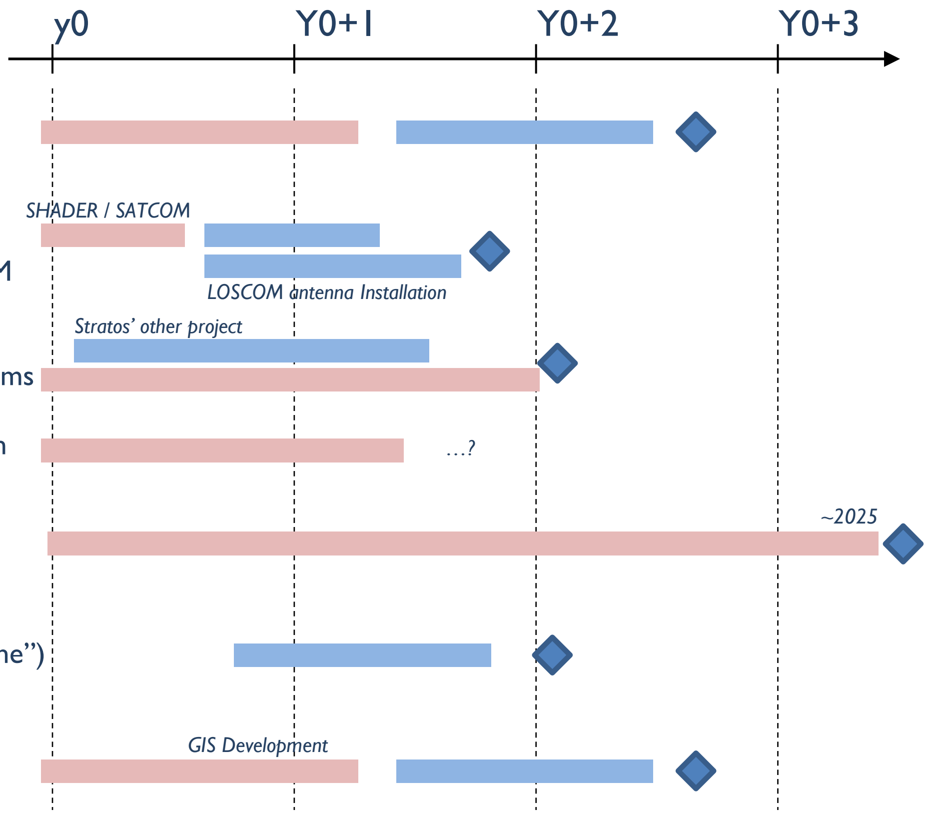


Green : imagery coverage

Red : 406Mhz signal coverage

TECHNOLOGY DEVELOPMENT PLAN

	Key points
Specific Payload Development	Integration to *shave* weight Adaptation to temperature
Telecommunications	BLOSCOM limitation SATCOM (& cost) vs fixed LOSCOM
On-Board Processing & Data fusion	Server integration Compression & multiplexing algorithms
Operational Procedure	Dependent of evolution of regulation
Batteries & Solar panels	Waiting for batteries > 500 Wh/kg 2025 ?
Multi-sensor payloads	Integration of multi-sensor ("all-in-one") TRL > 6
Ground Applications	XXXX



For a **demonstration flight** (= intermediate milestone), estimated integration cost using Stratos's HAPS prototype: 650k€ (focus put on test preparation, integration, and execution)

No dates were provided in [3]. These are for illustration purpose.

Conclusion & Way forward

CONCLUSIONS

The analysis results highlights the following

- HAPS layer should feature a weak coupling with C/S.
- The HAPS layer targets mainly RCC and may interface the C/S only for providing the beacon signal to C/S.
- Another name needed for ACK type, to differentiate HAPS localization from C/S localization.
- Transmit RLM on C/S compatible beacon through Galileo RLS, is technically feasible
  - Though, deployment feasibility has not been studied (using pseudolite or sending same type of signal on E1).
  - Other Service than Galileo could be used to deliver RLMs (e.g. using AIS/VDES, 5g).

Conclusion from the validation phase

- Georeferencing localisation error is of the same order of magnitude as TOA/FOA based localisation for static distress vehicle use case on flat ground or floating on the sea.
- In some configurations, georeferencing, is more accurate.
- TOA/FOA is useful to track aerial Distress vehicle (fast and with potentially high changing altitude - ICAO GADSS use case.

Towards a most Cost effective solution

- For TOA/FOA based localization determination, HASARDS showed that a minimum of 3 HAPS is required (4 optimal), which multiplies the operational cost.
- Georeferencing would need only 1 HAPS where TOA/FOA requires 4 HAPS.
- Alternate viable solution, for maritime use case (slow moving distress vehicle on the sea (no altitude) would be:
  - a coverage of the area based on one HAPS, equipped with C/S and AIS alert only to detect the emergency alert, and relying mainly on georeferencing for localisation.
  - Other communication module such as
    - SB5 AIS/VDES communication channel
    - And/or SB6 HAPS layer provides GSM detection capability and communication channel

Way Forward

Direct continuation of the study

Continuation on the localization/tracking performance based on more intricated data fusion module using

- Georeferencing
- GNSS position from Beacon
- C/S detection
- TOA/FOA performance

The objectives would be

- deepen the understanding of data complementarity: which data source for which use case: for maritime slow use case, do we TOA FOA or could we rely solely on georeferencing? Re-assess the need of number of HAPS in that case if only C/S signal detection is needed for localization, with less need for TOA/FOA.
- Definition and design of data fusion
- V&V activities

Complementary study

- C/S interface and modification impact: start with easiest stage: provide data for a HAPS layer?
- VDES coupling and interface especially to use VDES as support of a RLS in complement of Galileo

Way Forward – Projects concept proposals

"Data fusion": Operational integration and quality data and service to SAR

- Purpose:
  - Mature ConOps
  - Improve understanding of data complementarity
- Objectives:
  - Develop Better data fusion module
    - Georeferencing
    - GNSS position from Beacon
    - C/S detection
    - TOA/FOA performance
  - Develop service delivery to SAR

"Operational Flight Demonstration": Single HAPS operations

- Purpose:
  - Reach TRL 5/6 on general performances
- Description:
  - Stratos's HAPS prototype (in flight campaign phase) to perform typical ISR missions over the North Sea.
  - Focused on implementation of most promising technologies identified during HASARDS.
- Objectives:
  1. to assess KPIs of a representative system in operational conditions regarding localization & delay;
  2. to consolidate the operational plan;
  3. to provide a budget estimation for future operations.
- Cost and duration is estimated at 650k€ and 18 months (tbc at consolidated at consortium level)