ICAO GNSS RFI Mitigation Plan

and associated Eurocontrol Efforts

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Overview

Note: Work supported by SESAR WP 15.1.6 Spectrum, 15.1.7 CNS & 15.3.4 GNSS plus NM

- High Level ICAO Provisions
- GNSS RFI Mitigation Plan Overview
  - Principles
  - Regional and Global Support to States
- Summary of Supporting Developments Plans
  - Short, Medium & Long Term Detection Capabilities
    - “Closed Loop GNSS Service Provision”
  - Intervention Capabilities to Locate and Stop RFI Events

State Responsibilities: ICAO ANC/12

Recommendation 6/8 – Planning for mitigation of global navigation satellite system vulnerabilities

That States:

a) assess the likelihood and effects of global navigation satellite system vulnerabilities in their airspace and apply, as necessary, recognized and available mitigation methods;

b) provide effective spectrum management and protection of global navigation satellite system (GNSS) frequencies to reduce the likelihood of unintentional interference or degradation of GNSS performance;

c) report to ICAO cases of harmful interference to global navigation satellite system that may have an impact on international civil aviation operations;

d) develop and enforce a strong regulatory framework governing the use of global navigation satellite system repeaters, pseudolites, spoofers and jammers;

e) allow for realization of the full advantages of on-board mitigation techniques, particularly inertial navigation systems; and

f) where it is determined that terrestrial aids are needed as part of a mitigation strategy, give priority to retention of distance measuring equipment (DME) in support of inertial navigation system (INS)/DME or DME/DME area navigation, and of instrument landing system at selected runways.

ANSP Responsibilities: ICAO GNSS Manual (Doc 9849)

- 5.1.5 State regulators and **ANS providers can take the measures described in this chapter** to reduce the likelihood that GNSS service will be lost.
- 7.11.3.1 **ANS providers must be prepared to act when anomaly reports** from aircraft or ground-based units suggest signal interference. If an analysis concludes that interference is present, ANS providers must identify the area affected and issue an appropriate NOTAM.
- 7.12.5 **National and international coordination of actions to prevent and mitigate GNSS interference is essential**.
- 7.13.1.1 As described in Chapter 5, States can **take measures to reduce the likelihood of service outages** due to unintentional and intentional signal interference. **ANS providers must still, however, complete a risk assessment** by determining the residual likelihood of service outages and the impact of an outage on aircraft operations in specific airspace.
- Appendix B, Roles of ANS Providers and Regulators: **ANSP to establish appropriate strategies to mitigate GNSS outages**, Regulator to validate the safety aspects of the mitigation strategies.

Introduction to RFI Mitigation Plan

- GNSS RFI Mitigation Plan History & Context
  - Initiated by Spring 2013 Workshop at Eurocontrol Navigation Steering Group Meeting
  - Guidance developed through ICAO Navigation Systems Panel
    - In response to ICAO 12th Air Navigation Conference Job Card
  - Proposed for inclusion in GNSS Manual, ICAO DOC 9849
    - June 2016 Change Package (already used by EUR FMG)
  - Under final review by ICAO NSP Spectrum WG Correspondence Group

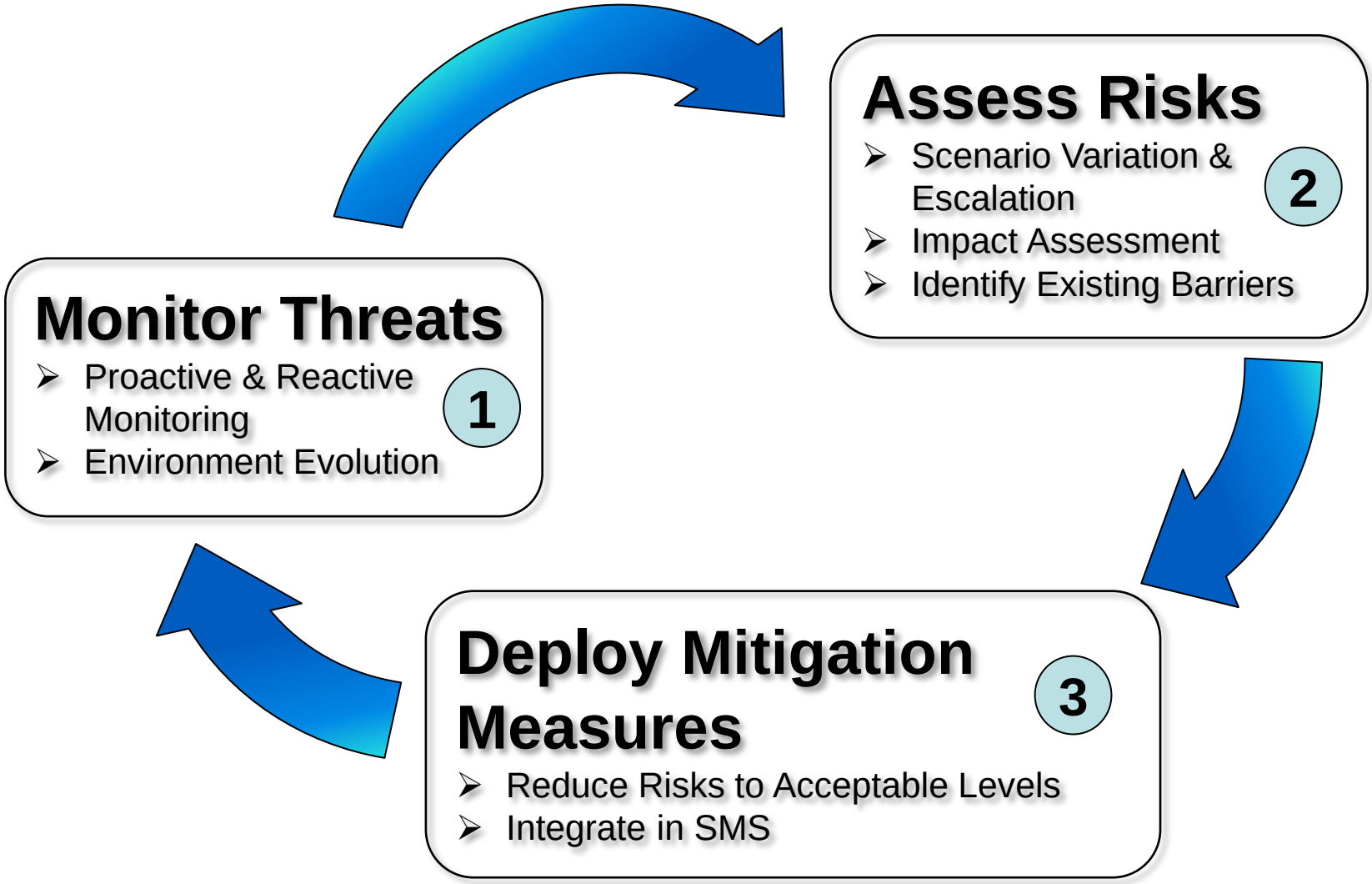
- Scope
  - Limited to threats requiring radio frequency propagation
  - Not dealing with corruption of position once it has left receiver

Moving from Vulnerability to Mitigation

- Objective of RFI Mitigation Plan
  - **Define set of activities for States to ensure that risks to aviation from GNSS RFI are sufficiently mitigated**
  - Checklists of set of activities to be considered
  - Much is already in place, State to decide depending on local environment
  - *Not intended to impose a significant workload or investment*
  - To enable reliance on GNSS and associated aviation benefits

- Focused on States
  - Spectrum a sovereign responsibility
  - Regulation and enforcement part of national oversight
  - Framework to encourage coordination and exchange of best practices
  - Supported by regional and global mechanisms due to system nature

Mitigation Plan Framework



Threat Types

- Unintentional
  - TV Broadcast Harmonics, Equipment Failure
- Intentional, not directed at aviation
  - Avoiding charges or tracking
- Intentional, directed at aviation
  - Ranges from nuisance to military threat
- Special Types
  - Military Testing
  - Spoofing

- Classification drives mitigation strategies

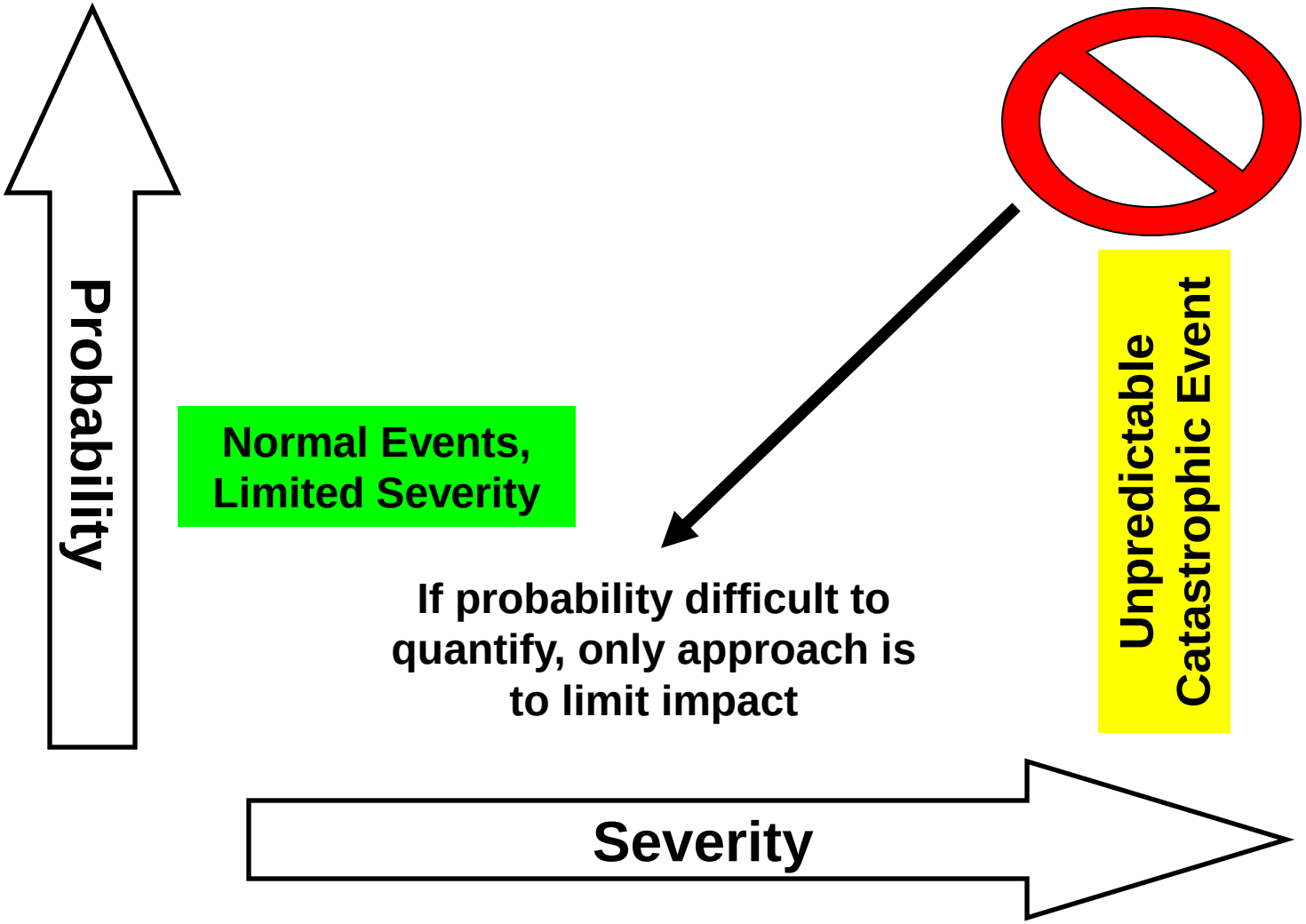
SPOOFING?

We don't need to do anything, it all works, business as usual

- Aircraft Integration provides significant mitigation but situation is evolving
- Duty to close any open doors that can reasonably be closed

The world will come to an end if we ever rely on GNSS!

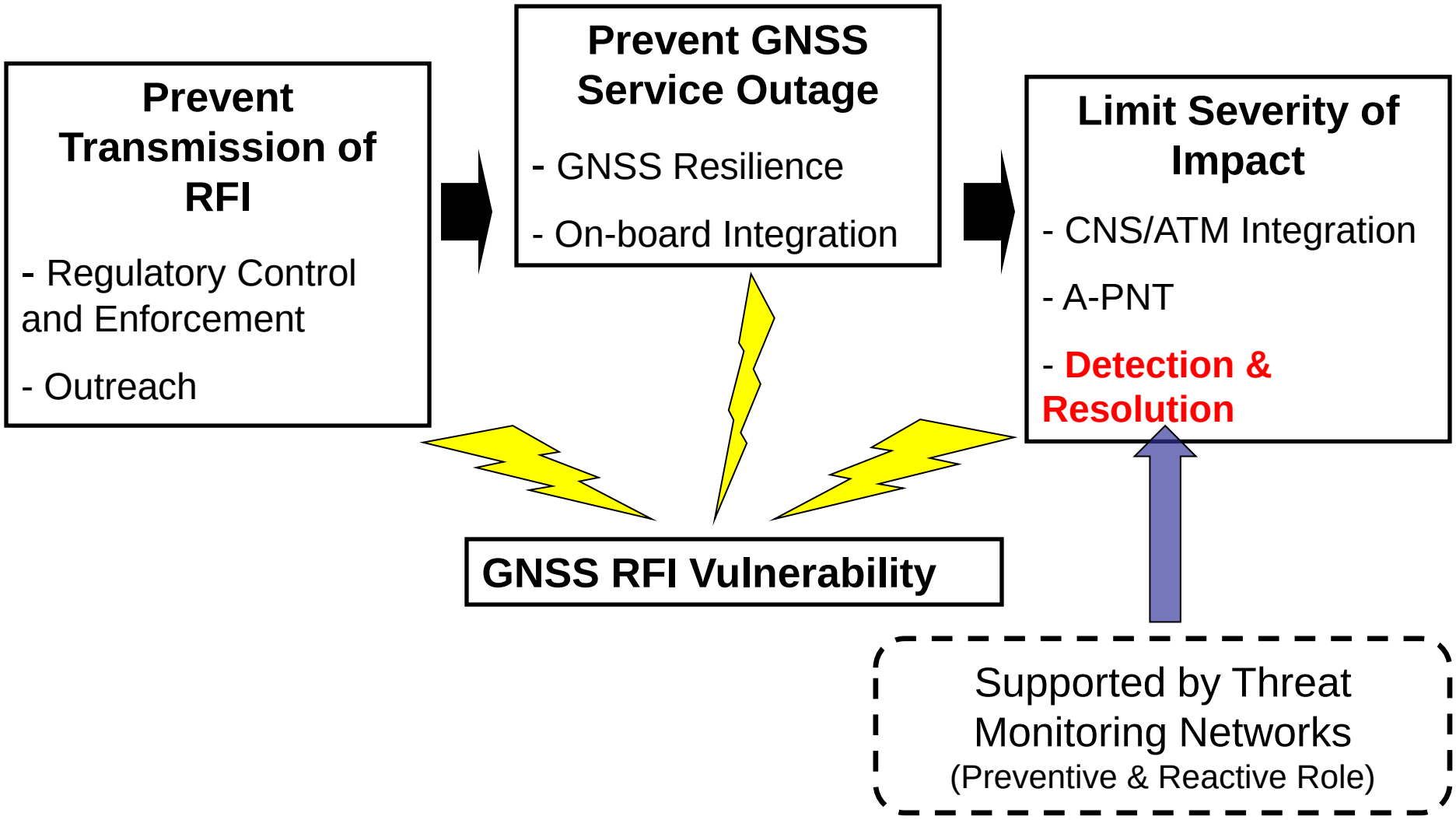
Risk Trade Space



Operational Risk Context

- "Loss of Nav" is an event that each aircrew needs to be prepared for at any time
  - Safety Procedures are in place
- Potential of Wide Area GNSS Outage: ATM Context
  - Especially in busy airspace, significant workload risk if many aircraft ask controller for navigation assistance
  - Very busy airspaces tend to be mainly vectored already but move to PBN should reduce this
  - NAV has multiple roles including pilot SA to manage flight
- Reversion Scenarios for PBN
  - Majority of Air Transport Users has DME/DME and INS
  - "Budapest Real Time Simulation"
  - VOR/DME does not provide suitable RNAV capability
  - PBN implementation planning
  - ICAO Annex 10 NAVAIDS Strategy

Implementing Mitigation Barriers



Generic RFI Mitigation: 4 Steps

*Note: applies to **all** RFI types & scenarios!*

1. **Detection** of RFI
   - Ground monitoring networks (aviation & non-aviation)
   - Pilot reports: difficulty in cause-effect recognition & subsequent processing
     - Automated in-flight detection would be better?
   - Flight Inspection: continuous or on occasion (non-uniform capabilities!)
   - Determination of affected area and impact critical to launch response
2. **Localization** of Source: ranges from simple to extremely difficult
   - In cooperation with telecom regulator / affected non-aviation parties
   - Identification of operator
3. **Termination** of RFI:
   - Need clear legal basis and resources for enforcement action
   - Cross border issues can be lengthy to resolve
4. Application of **Consequences**: fine, publicity - future deterrent
   - Update of RFI Mitigation planning as needed

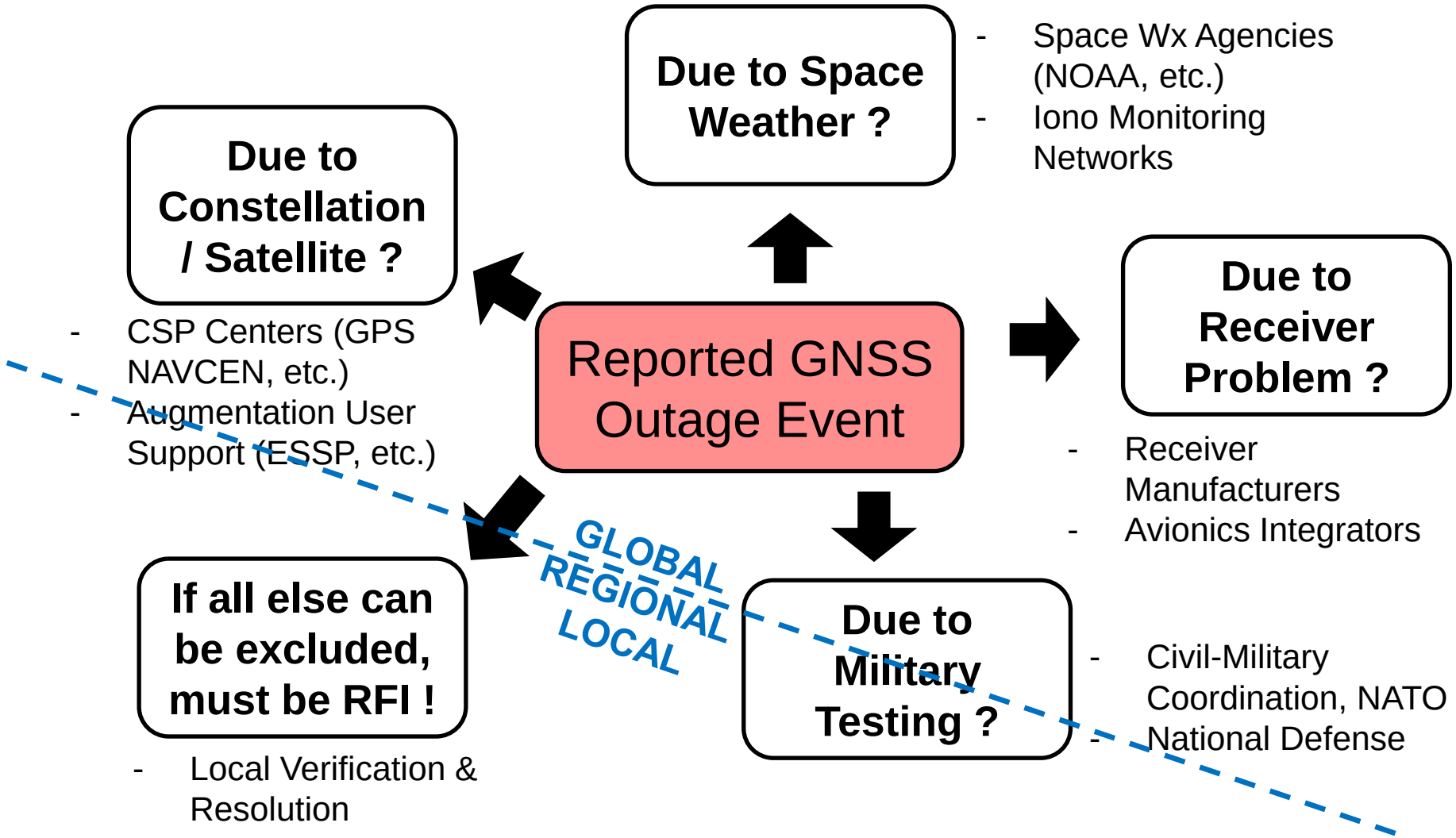
Key Starting Challenges

- Observability of RFI Events
  - Lack of reports does not mean that RFI cases don’t exist
  - Existing Spectrum Groups receive few reports
  - NOTAM search produced few results
    - Standardized terminology developped
  - Need to know what happens at aircraft!

- Confirmation of RFI Event
  - Difficult to conclude that GNSS outage is result of RFI
  - All other causes of outages are not local ANSP issue

- Both Challenges require State-external support

Identification of Probable Cause Through Elimination



GPS OUT Reporting Streams Today

GNSS Multi-Modal

Aviation one User among many

Aviation Specific

GNSS Out One Issue among many

First Step: Align Aviation Coordination

GPS NAVCEN

IATA

Second Step: Interfaces with GNSS System Providers

AO

- Airline OPS Center
- FOQA Monitoring?
- PIREP: Local AIS

ESSP

Eurocontrol Network Manager

Local ANSP ?

- AIS to Technical Services
- Technical Services activate subsequent process?

No aggregate vision of events ➔ Incomplete threat picture

Resolution depends on awareness of many individuals

Meeting “Stated ATCO Requirement”

- Budapest GPS Outage Simulations:
  - “Tell me when event starts, when it ends, and how many sectors are affected”
  - No simple technical solutions exist today
  - Allows contingency planning through planner ATCO

- **Best to monitor at the impact source: aircraft receiver**
  - Currently, only pilot can observe receiver outage
  - Subsequent reporting requires support at regional and global level to determine probable cause (only RFI is local problem)
  - Provides essential risk assessment link on operational impact

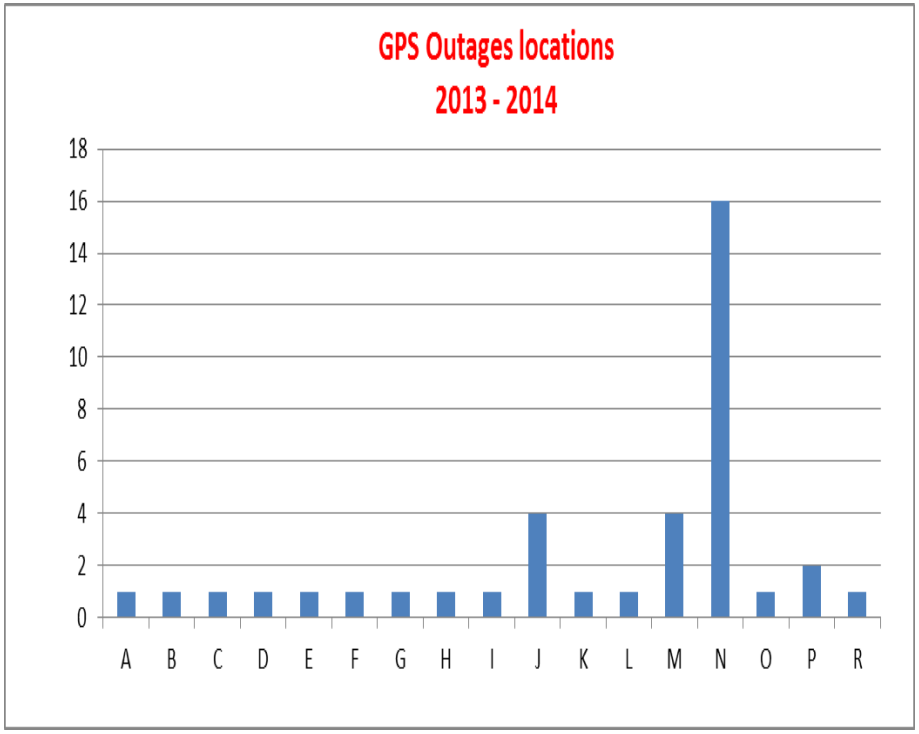
Implemented: GNSS in EVAIR

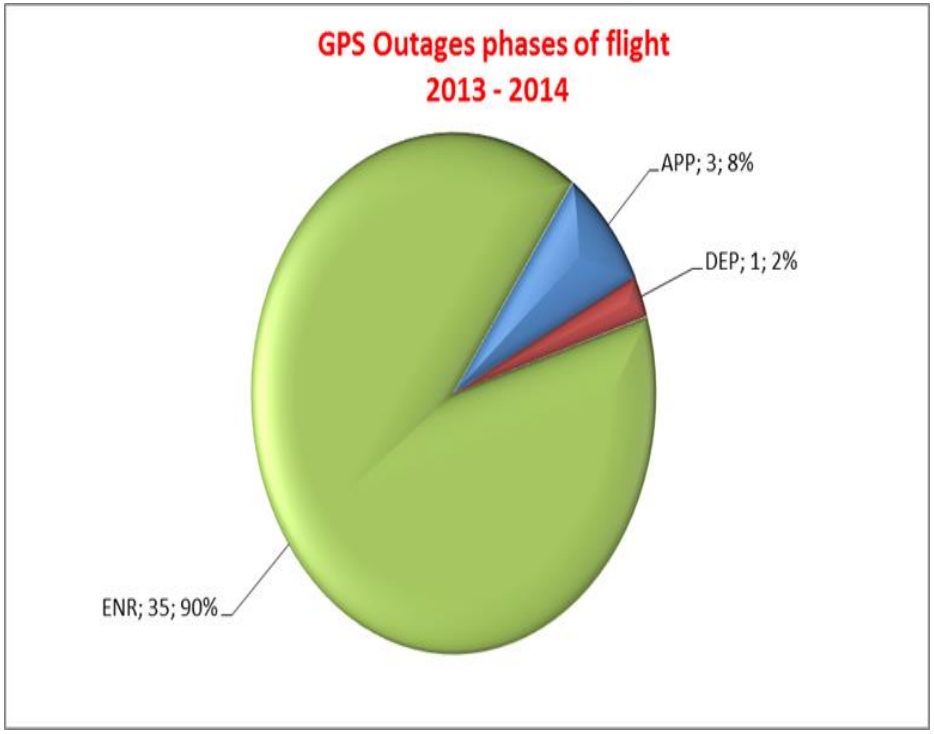
- EVAIR = Eurocontrol Voluntary ATM Incident Reporting
  - Established Safety Process (Confidentiality, Anonymity)
  - 250 Participating Aircraft Operators
  - Coverage: Europe, Middle East, Northern Africa
  - Close cooperation with IATA
  - Part of Network Manager Functions
- Info Bulletin / Request sent beginning 2015
  - Initial wave of reports received covering 2013/2014
  - Additional reports coming in every few weeks
  - GNSS Outage one issue among many
  - Simple to set up because it is an existing process / framework
  - Working on further awareness materials

GPS Issues: EVAIR Findings

(Status May 2015)

- **First reports received in 2013**
- **No of reports in the DB - 42**
- **No of AOs (Aircraft Operator) reporting GPS outages so far - 11**
- **No of locations identified – 17**
- **En-route flight phase most affected**

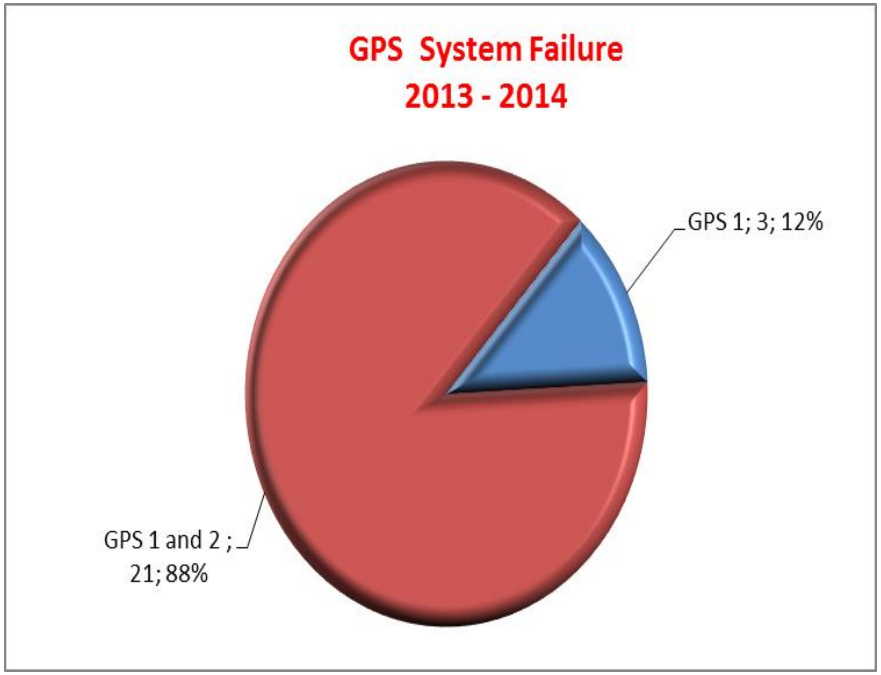


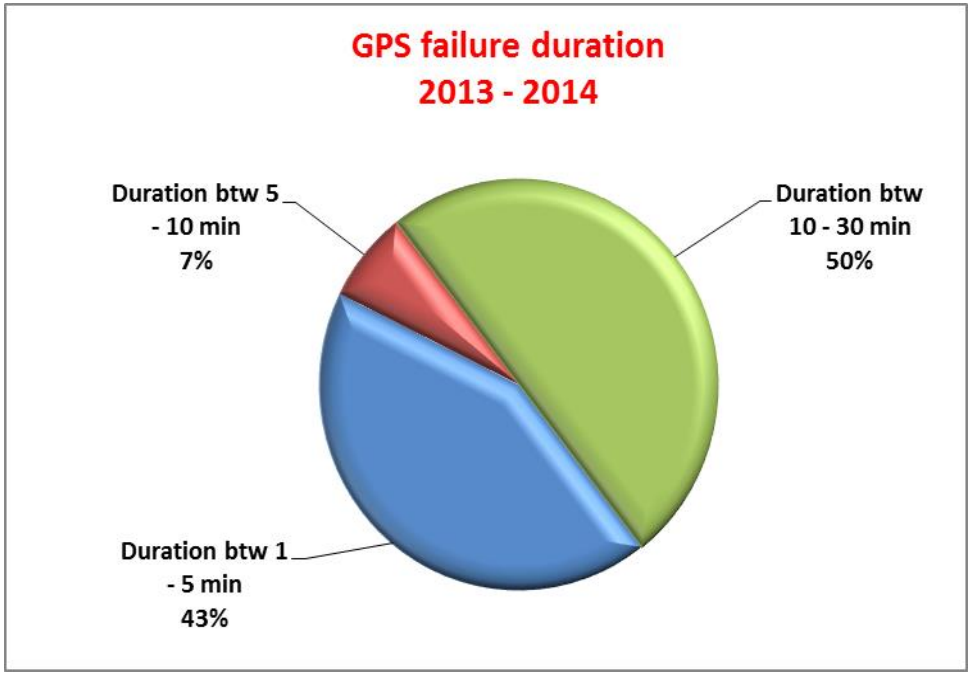


GPS Issues: EVAIR Findings

Type of reported GPS issues 2013 – 2014

- Loss of GPS Signal
- GPS Outage
- GPS Jamming
- Total Loss of GPS
- GPS 1 and 2 Lost
- GPS 1 Lost





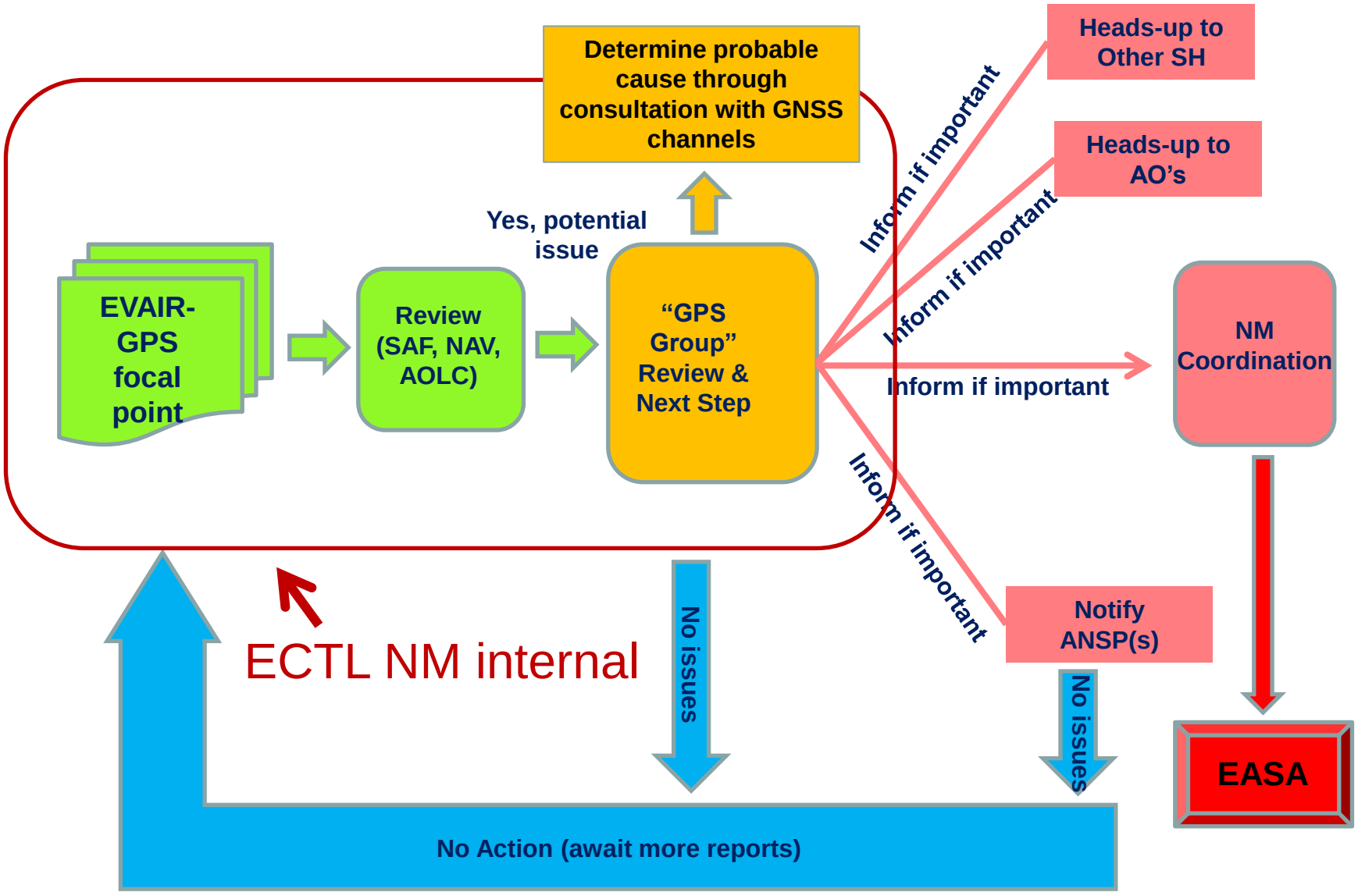
GNSS in EVAIR: Threat Monitoring

- Return to normal operations & impact on both receivers on few aircraft point to RFI with high probability
  - **Proves that RFI Outages are REAL but also limited in operational impact currently**

- Time-limited, single events do not warrant action
  - **Supports strategic objective of threat monitoring**
  - Enables setting boundaries on event probability and severity
  - Provides detection if environment changes

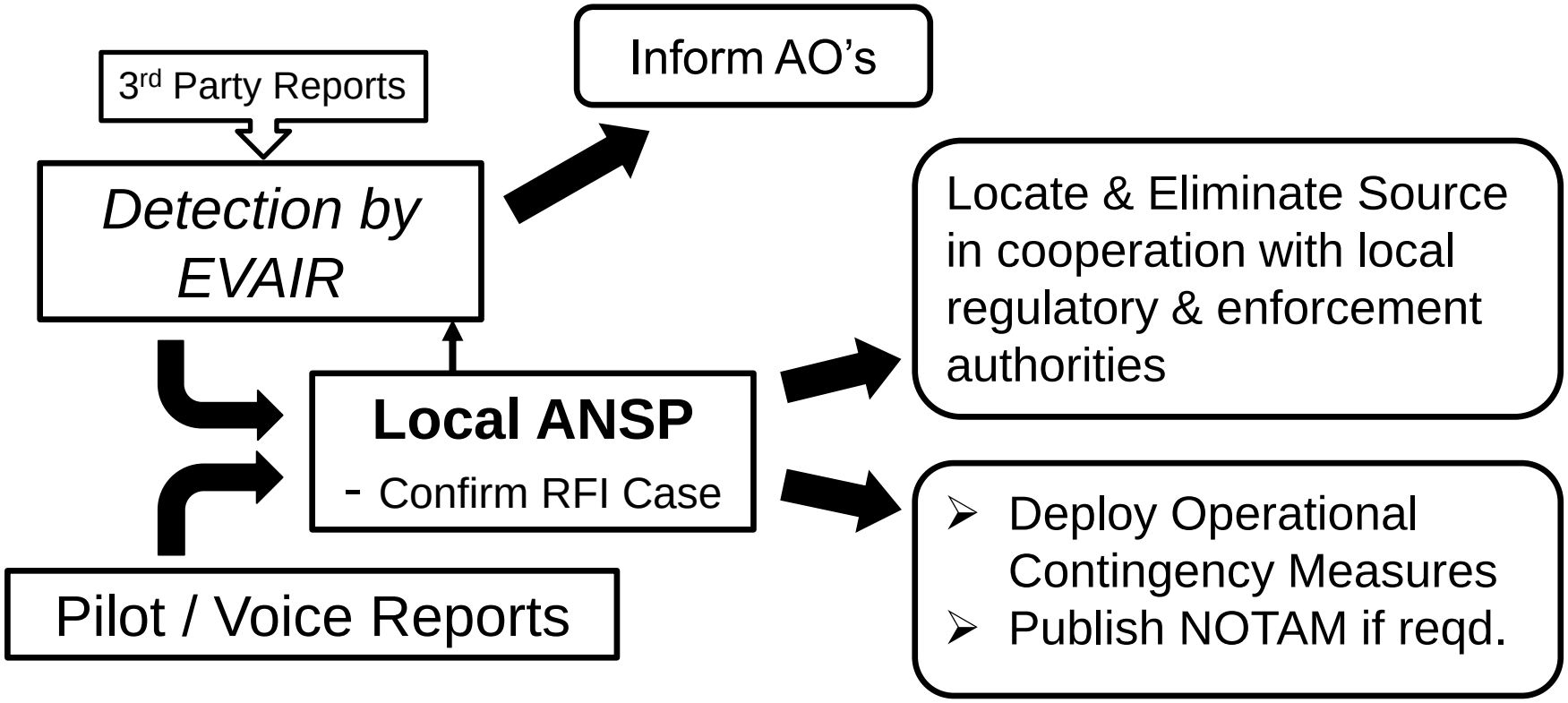
- Maintain central repository and statistics of GNSS Outage events
  - Consultation of GNSS service and space weather monitoring reports provide further refinement
  - May also benefit from data from local ground receivers
  - Clarify interfaces for aviation-relevant reporting

EVAIR GPS Issues Information Flow



EVAIR: Trigger for Detection & Mitigation

- Significant accumulation of events in specific area leads to detection and triggers mitigation action
- Ensuring timely resolution reduces vulnerability / exposure



Interfaces with GNSS System Operators (GSO)

- Currently, mainly GPS NAVCEN and ESSP
  - Multi-constellation: GLONASS, Galileo, Beidou Service Centers
  - Regional SBAS User Support Centers (GBAS with local ANSP)

- **Case 1: Strategic Long Term Threat Monitoring**
  - Info from GSO to Aviation: Ensure comprehensive view of all aviation-relevant cases

- **Case 2: Tactical Mitigation: Actual Significant Outage Event**
  - Request from Aviation to GSO: Support in identifying probable cause
  - Benefit from established links (receiver issues, ionosphere, RFI testing)

Medium Term Improvements

- Not really Pilot's job to determine cause of GPS outage or to report signal in space issues
  - In the age of SWIM, should be automated
  - RFI detection standard feature in many commercial receivers

- CNS Idea: Reporting through ADS-B Figure of Merit
  - Part of ongoing investigations
  - Feasibility demonstration: Australia
  - Demonstrated benefit of air-ground cooperative approach
  - Need to test and build experience in how to integrate information
- Some guessing remains with respect to probable cause
  - Especially for wide-area outage where resolution should be fast
  - Serendipitous capability, but not ideal

ADS-B PIC Use for GNSS Monitoring

- ADS-B:
  - Different versions of the ADS-B Out MOPS in use
    - Different ways to encode integrity
  - Not all aircraft are “proper” ADS-B Out:
    - Version 0 implemented on voluntary basis (along with Mode S mandates, ADS-B only certified on a non-interference basis)
    - Later AMC 20-24 certification only applies to subset of fleet
    - Not necessarily using GNSS as position source
    - Some known avionics issues with version 0

- GNSS:
  - Different levels of performance
    - Limited information about the position source (SA On/Off, SBAS etc.)

ADS-B based GNSS Monitoring: Issues

- Difficult Capability to Test without significant RFI Event
  - Study tried to correlate ADS-B Position Integrity Category with events:
  - Known RFI Events
  - Predicted RAIM Outages
  - Iono Events
  - None of the investigated events produced reliable correlation
- But learned about use of ADS-B data
  - Careful filtering of reliable data – establish white list?
  - On-board issues usually result in a certain NUCp/NIC behaviour
    - not so common – can be filtered out
  - Most of the fleet has stable quality indicators
  - SPI IR implementation of ADS-B Out version 2 (ED-102A / DO-260B) expected to further improve the picture
- **Still think that method has promise at least for “massive” RFI events**

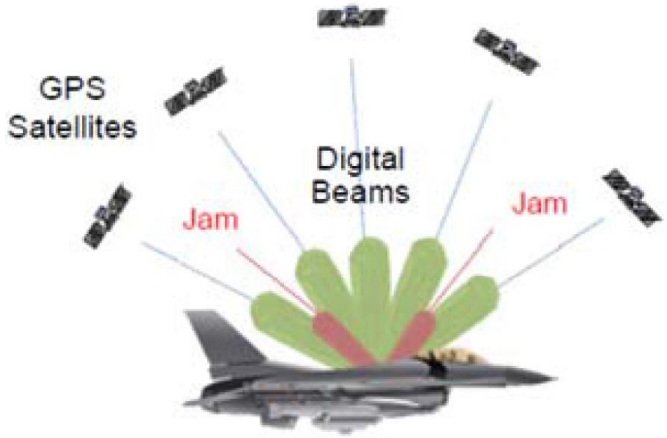
Long Term RFI Mitigation Improvements

- A lot can be done with current capabilities at reasonable cost
  - EVAIR is available now
    - *Mostly a matter of setting up interfaces and data integration*
  - ADS-B FOM Monitoring excellent example of CNS synergy use without introducing additional complexity
    - Still want to reduce guesswork in future equipment
- Next Generation MC GNSS Avionics
  - ICAO NSP requested implementation of reasonable mitigation capabilities from RTCA / EUROCAE
    - Must be careful to not impact continuity of service
  - Detection capability seen as a feasible minimum
    - Permit aircraft to switch to “A-PNT capability”
  - Information must reach ANSP
    - Quick Access Recorder, Flight Operations Quality Monitoring
    - Future: SUR Downlink Aircraft Parameters (DAP) ??

RFI Localization Developments

- Controlled Radiation Pattern Antennas CRPA
  - Multi-element GNSS antenna used in defence applications
  - Not an option for airliners, but maybe flight inspection aircraft?
  - Cooperative project with FAA and DSNA

- Project Goals
  - Develop and Demonstrate Concept & Feasibility
  - Increase localization antenna sensitivity
  - Maintain own-ship position during RFI



- Process
  - Directly obtain pointing to RFI source with reduced search time
  - Allow efficient deployment of ground capabilities
  - Reduce vulnerability by dramatically reducing intervention time

Summary

ICAO GNSS RFI Mitigation Plan

- Mature and available to States
- Hope to learn from feedback from local implementation

Regional and Global Support Process being put in place

- EVAIR Data and Network Manager Process
- Continuing work on appropriate airborne monitoring capabilities
- Continuing work on increased intervention capabilities
- ATCO training can mitigate until next generation capabilities in place

A lot can be done with relatively simple means

- So far, GNSS RFI threats have not lead to significant risks to aviation operations
- Continued cooperation and development of RFI vulnerability mitigation capabilities can ensure that this remains the case
- To enable full exploitation of Operational PBN Benefits

Back-Up

- Sydney Case to confirm utility of ADS-B monitoring to narrow search area

- Position Integrity Category Table

Sydney Case: ADS-B Lessons Learned

- ADS-B reports key to identifying probable source location: Aerospace Industrial Park
  - “Search” proved sufficient to terminate 3h event
- Most Ground Monitor Stations didn’t see RFI
  - Some outages on WAM network, but difficult to locate
  - Need to evaluate line of sight

- Lessons Learned
  - Aircraft with INS didn’t lose NAV
  - Contingency procedures worked
  - Some aircraft GPS receivers didn’t recover (even on turnaround!)
  - Air Services Australia recommends recording of GPS status on QAR
  - Ground and aircraft based localization must work in complement
  - Implementation simplest if within existing processes & infrastructure

Position Integrity Category

- Ground system notation (Asterix) for integrity containment bound encoding

PIC	Integrity Containment Bound	NUCp ED102/DO260	NIC (+ suppl.) DO260A	NIC (+ suppl.'s) ED102A/DO260B		
				NIC	A/B	A/C
15	not defined					
14	< 0.004 NM	9	11	11	-	-
13	< 0.013 NM	8	10	10	-	-
12	< 0.04 NM		9	9	-	-
11	< 0.1 NM	7	8	8	-	-
10	< 0.2 NM	6	7	7	-	-
9	< 0.3 NM	-	-	6	0/1	1/0
8	< 0.5 NM	5	6 (+ 0)	6	0/0	-
7	< 0.6 NM	-	6 (+ 1)	6	1/1	0/1
6	< 1.0 NM	4	5	5	-	-
5	< 2.0 NM	3	4	4	-	-
4	< 4.0 NM	-	3	3	-	-
3	< 8.0 NM	-	2	2	-	-
2	< 10.0 NM	2	-	-	-	-
1	< 20.0 NM	1	1	1	-	-
0	No integrity (or > 20.0 NM)	0	0	0	-	-