SBAS Worldwide implementation status

Benoit Roturier

France – NSP ICAO Chair

NAM CAR SAM region PBN & GNSS workshop

Lima, Peru, 15 to 17 August 2016

1st part - SBAS systems in operation

WAAS (not presented here - see FAA presentation) – North AM

EGNOS - Europe

MSAS - Japan

GAGAN - India

EGNOS infrastructure owned by the European Commission

2x MCC

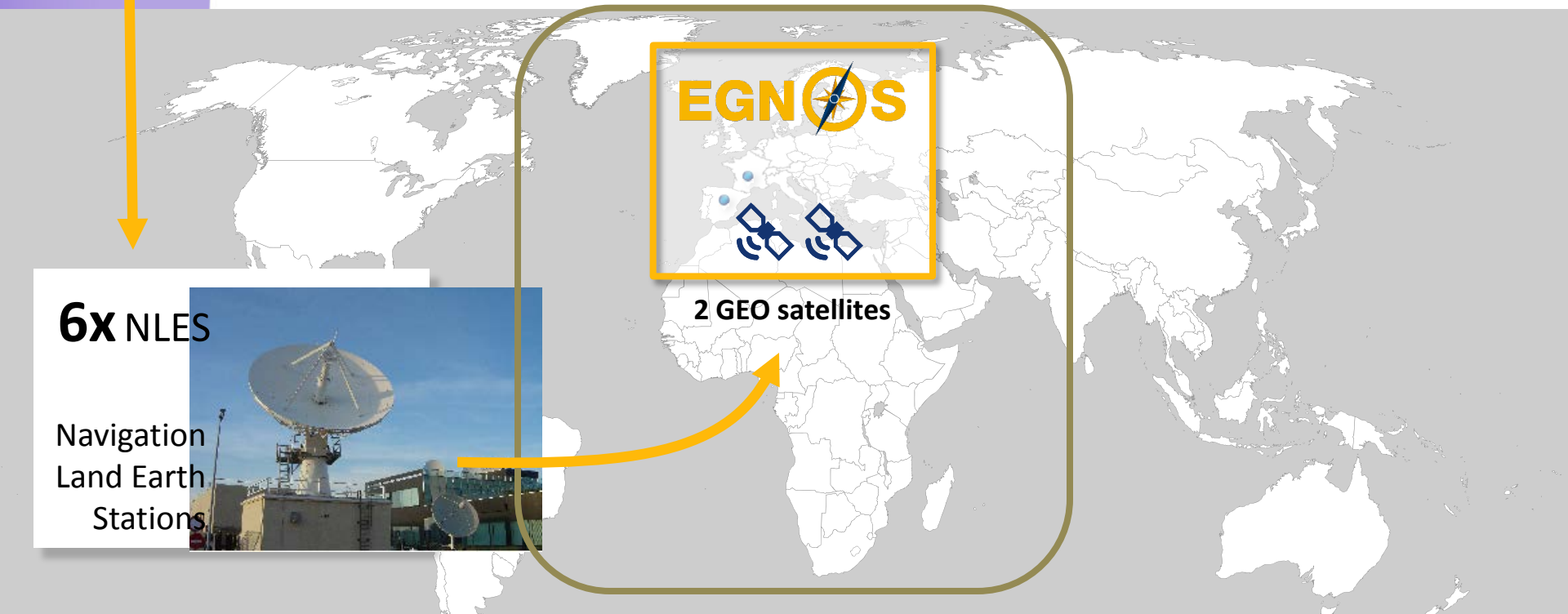
Mission Control Centers

5x CPF

39x RIMS

Ranging & Integrity Monitoring Stations

GPS signal



6x NLES

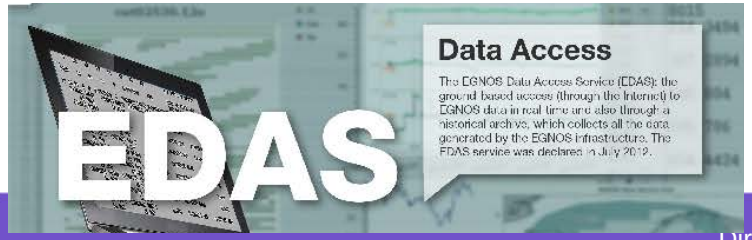
Navigation Land Earth Stations

EGNOS services

since **2009**

since **2011**

since **2012**



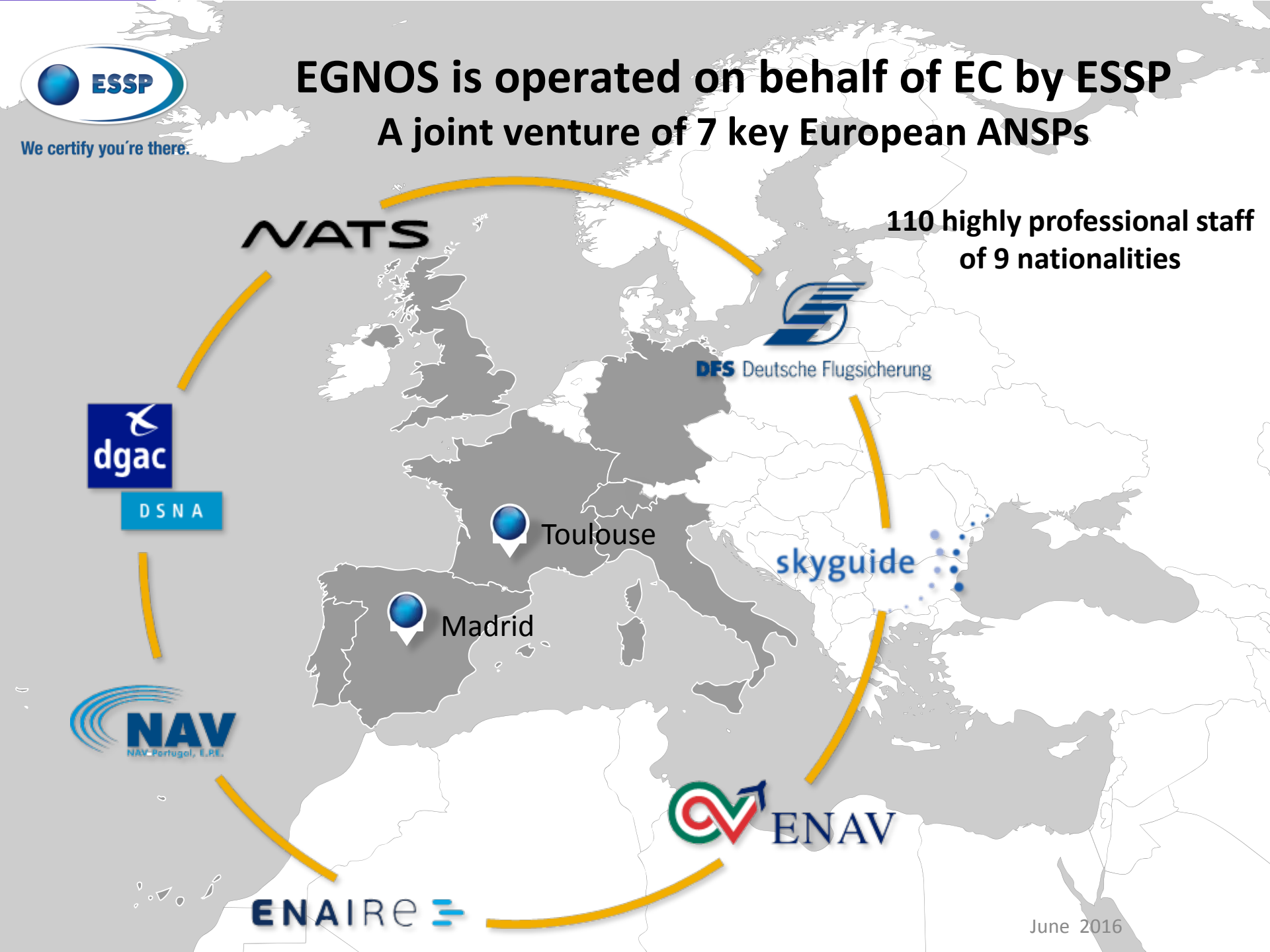
EGNOS is operated on behalf of EC by ESSP

A joint venture of 7 key European ANSPs

ESSP

We certify you're there.

110 highly professional staff of 9 nationalities



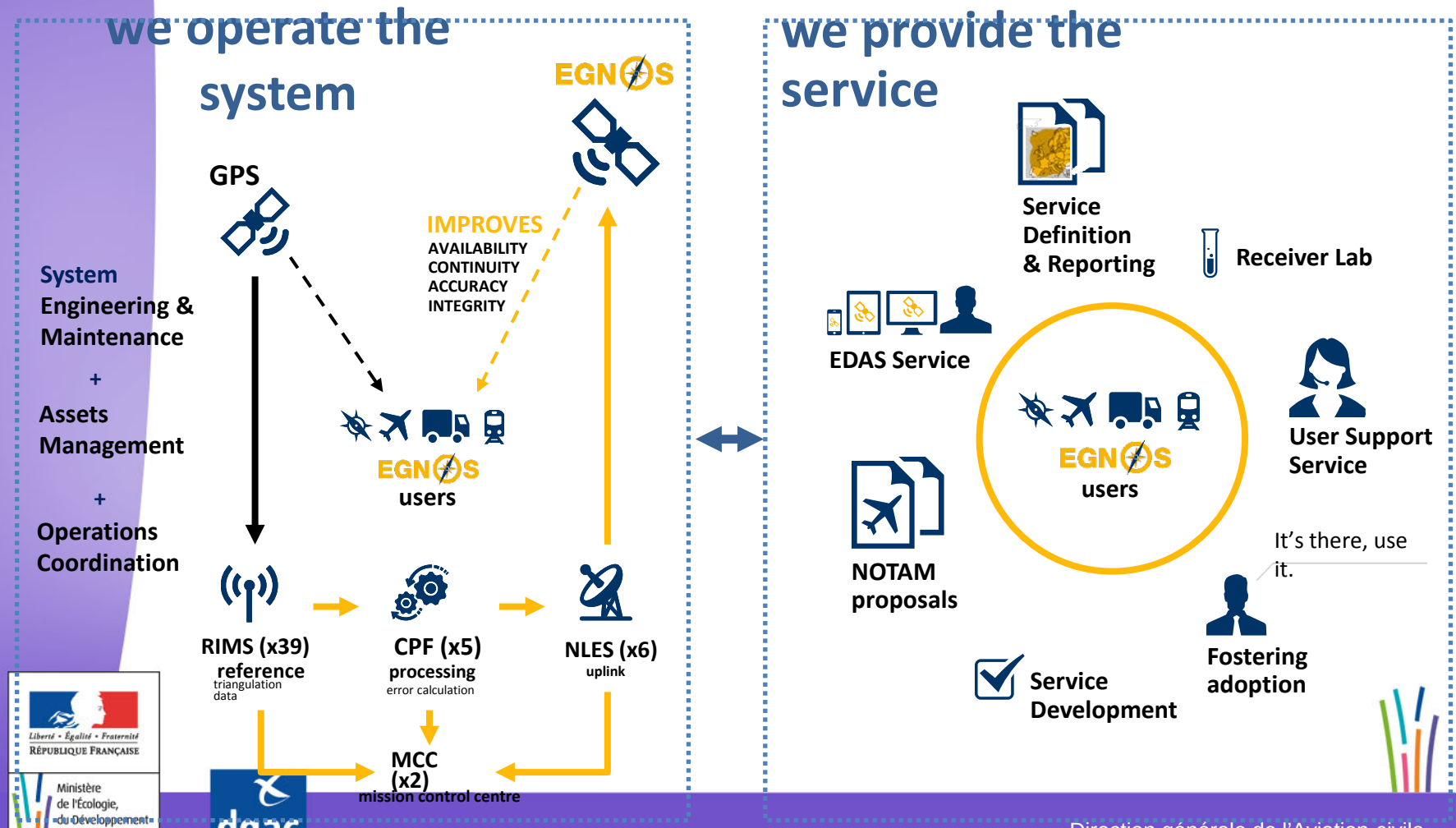
EGNOS service provision by ESSP

Toulouse

System Operations Unit & Compliance Management Unit

Madrid

Service Provision Unit



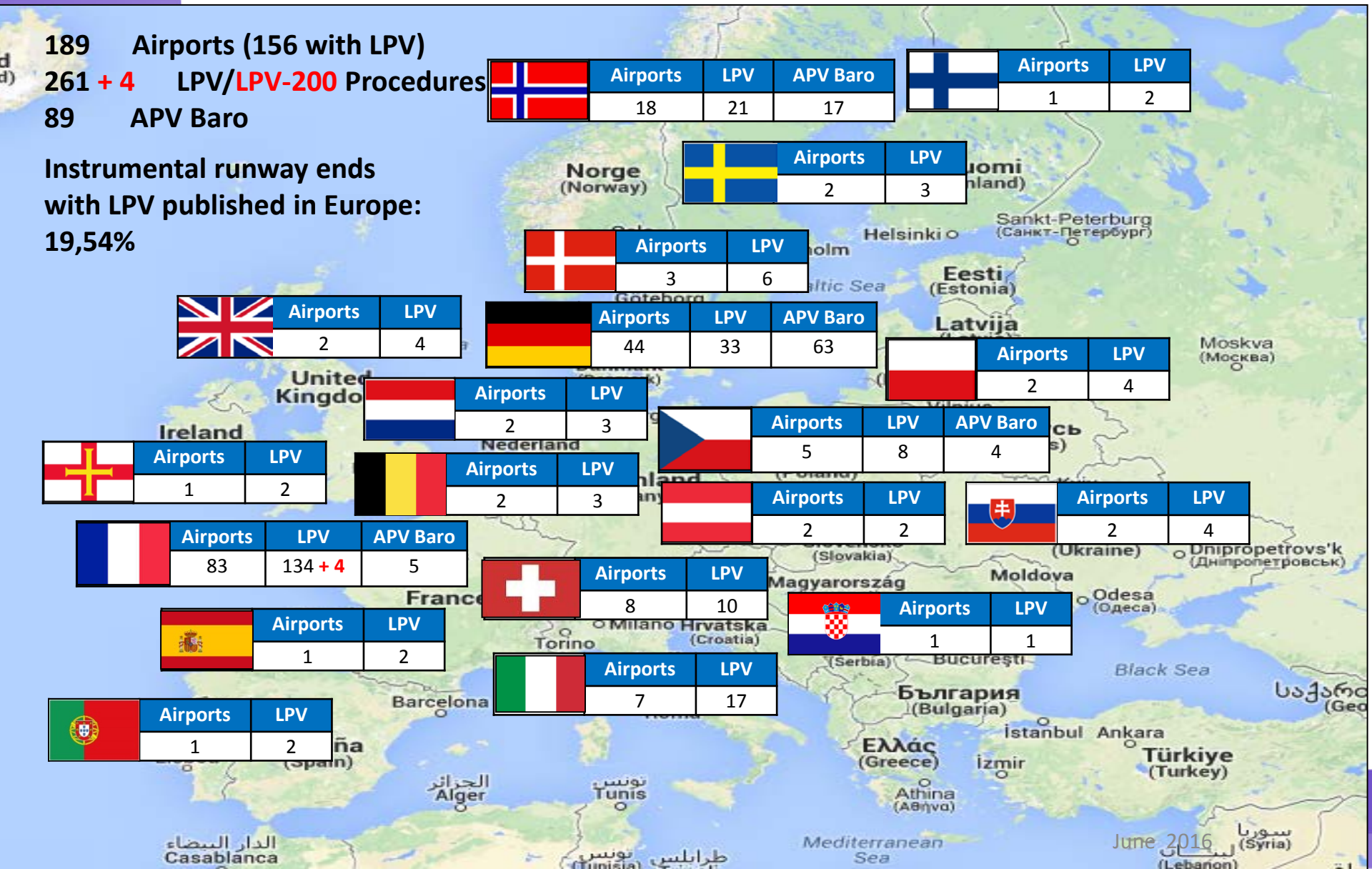
EGNOS LPV 200

- New **LPV 200**_EGNOS Service Level available since Sept 2015, **free of charge as all other EGNOS aviation services**
- Supporting Category I (**200' DH)** PBN approaches
- Allows "***Cat1 anytime, everywhere***" concept in conjunction with existing/reduced ILS networks
- First LPV 200 approach procedures flown in Paris CdG on May 3rd by an Airbus A350, a Falcon 2000X and an ATR42

LPV Procedure development is now accelerating in Europe

189 Airports (156 with LPV)
261 + 4 LPV/LPV-200 Procedures
89 APV Baro

Instrumental runway ends with LPV published in Europe: 19,54%



Airports	LPV	APV Baro
18	21	17

Airports	LPV
1	2

Airports	LPV
2	3

Airports	LPV
3	6

Airports	LPV
2	4

Airports	LPV	APV Baro
44	33	63

Airports	LPV
2	4

Airports	LPV
2	3

Airports	LPV	APV Baro
5	8	4

Airports	LPV
1	2

Airports	LPV
2	3

Airports	LPV
2	2

Airports	LPV
2	4

Airports	LPV	APV Baro
83	134 + 4	5

Airports	LPV
8	10

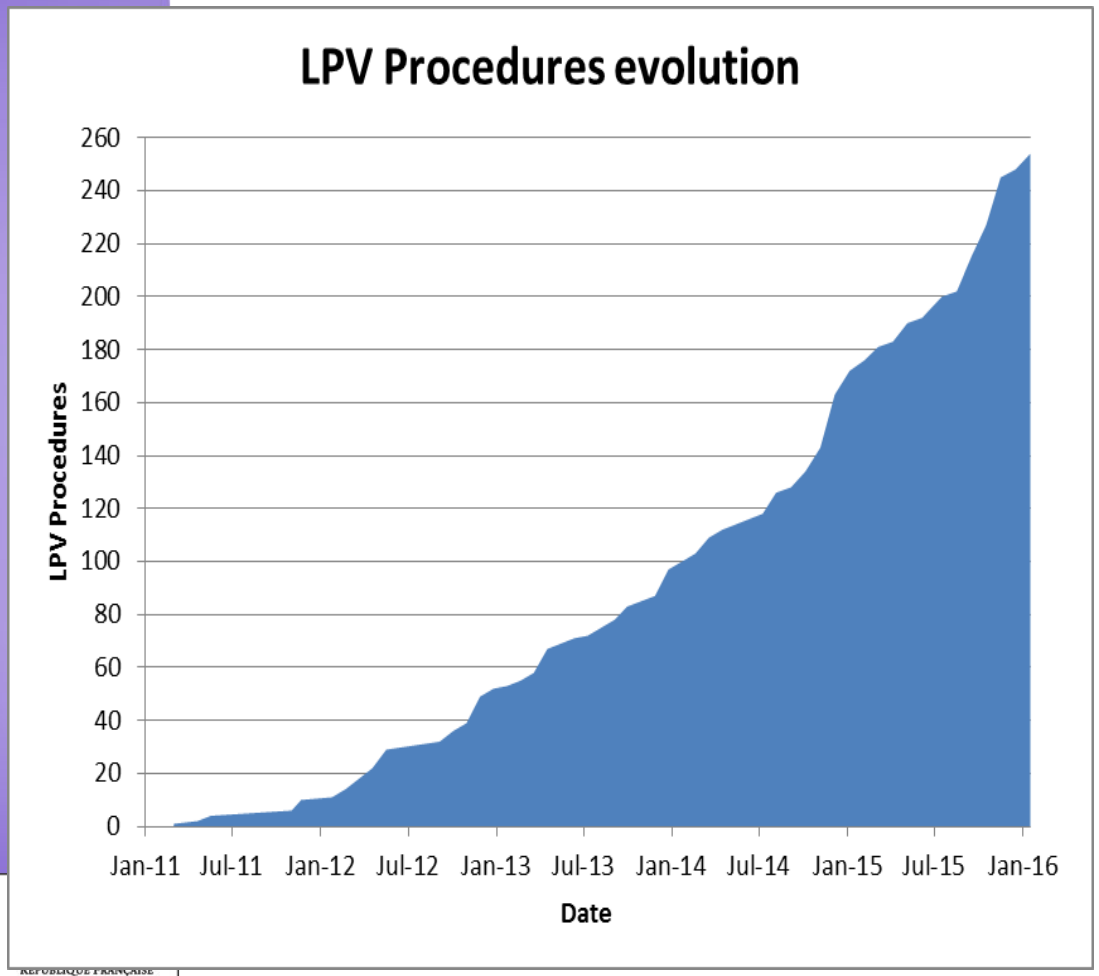
Airports	LPV
1	1

Airports	LPV
1	2

Airports	LPV
7	17

Airports	LPV
1	2

LPV Procedure development is now accelerating in Europe



Plans by 2018

> 440 LPV procedures

Check link: http://egnos-user-support.essp-sas.eu/new_egnos_ops/?q=content/lpv-procedures-map

WHO is using EGNOS?

SBAS ready Business Aviation aircrafts

BOMBARDIER

Challenger 300/350, Learjet 70/75/60XR

Cessna

Citation Mustang, M2, CJ2+, CJ3+, CJ4, XLS+, Latitude, Sovereign+, X+ and Longitude

EMBRAER Executive Jets

Legacy 500/600/650 & Phenoms SB for E-170/175/190/195

Gulfstream™ A GENERAL DYNAMICS COMPANY

G650 and G280, SB G150/G550/G450/G350

Hawker Beechcraft

King Air, Baron, Bonanza , Hawker 400XPR/800XPR

DASSAULT AVIATION

SB Falcon 900LX/5X/ 7X/2000LXS/2000S;

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Ministère de l'Écologie du Développement durable et de l'Énergie

dgac

DSNA

Who is using EGNOS?

SBAS ready Commercial Aviation aircrafts

ATR

ATR42-600, 72-600

ATR 42-200/300/400/500
ATR 72-100/200

AIRBUS

Airbus A350 and Beluga
A320 under investigation

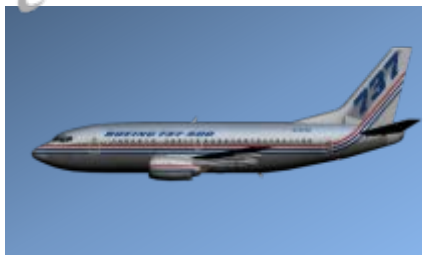
BOMBARDIER

Bombardier CRJ 700/900/1000,
CS100/300, Dash 8 Q400

CRJ100/1000
Dash8-100/200/300/400

- **BAE** Avro RJ / 146 / J41
- **SAAB** 340/2000
- **Britten Norman** BN-2A

BOEING



737-300/400/500

Fokker

Fokker 50

Retrofitting: STCs

PBN FOR APPROACHES
TARGETS FOR FRANCE

Modernizing/rationalizing French landing system infrastructure,

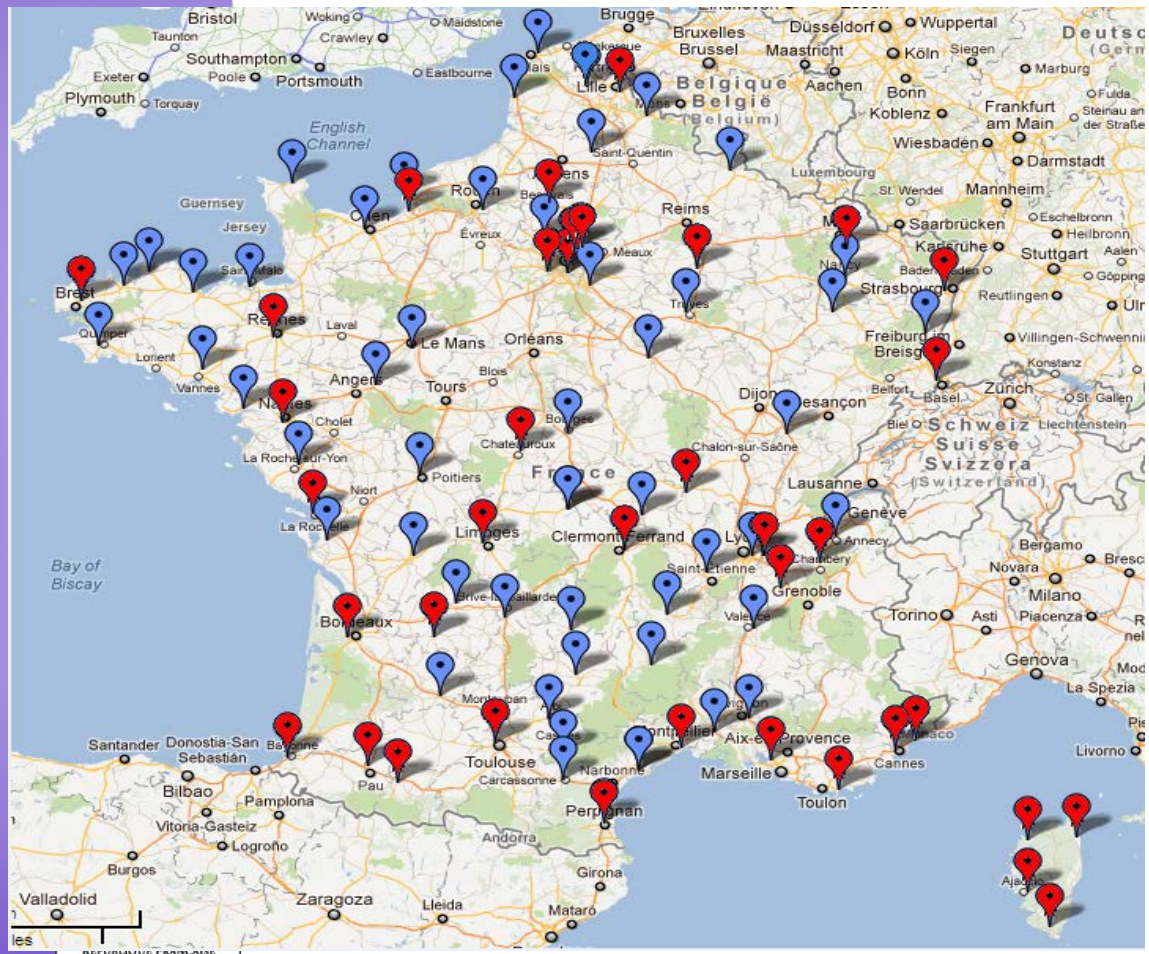
- improve safety, airport accessibility
- reduce ANSP's costs (technology transition)

- **PBN target for primary runways:**
  - Good quality backup to ILS (outages, maintenance, renewal ,etc…)

- **PBN target for secondary runways:**
  - More direct paths, increased safety (vertical guidance in final), increased airport accessibility vs. conventional navaids

- **PBN target for about 50 small/medium airports:**
  - Cut landing infrastructure costs (ILS Cat I) by transitioning to PBN
  - **EGNOS now supports CAT I performance** (LPV 250 ft today, LPV 200 ft by Q4 2015)
    - **First LPV 200 published at Paris CDG March 2016**

PBN with SBAS supports France ILS CAT I rationalisation plan



2016: ILS reduced network

2016: Airports where the existing ILS Cat I is proposed to be replaced by a PBN approach with LPV

About 5 M€ yearly savings Contributes to the French Landing Tax reduction program:

2018 : 225,50 €
2017 : 224,45 €
2016 : 227,1 €
2015 : 228,62 €
2014 : 233,23 €

FRANCE PBN APPROACHES OPERATIONAL LESSONS LEARNED

- **PBN EGNOS LPV** are high performance approaches, and highly appreciated by equipped users, even wrt ILS Cat I
- **PBN LNAV and LNAV/VNAV** also appreciated, in particular wrt VOR/NDB/Circling type approaches, by equipped users
  - **But have a lower level of performance wrt PBN LPV, in particular:**
  - **Higher approach minima** due to less performing lateral and vertical guidance
  - **Issue of « RAIM unavailablities »** when RNP APCH is the prefered approach
    - daily LNAV and LNAV/VNAV un-availabilities may exist depending upon the avionics,
    - it is not possible to make ATC aware of on-board LNAV and LNAV/VNAV unavailability
  - **Lower safety level:**
    - lack of vertical guidance for PBN LNAV,
    - QNH mis-setting events from the ground or airborne side have been reported for PBN LNAV/VNAV

Current MSAS Configuration

1 SAT 2PRNs

6 GMSs

2 MCSs

GPS Constellation

MTSAT-2

Dual PRN Operation

User

PRN129

PRN137

GMS &MCS Kobe

GMS Sapporo

GMS Fukuoka

GMS & MCS Hitachiota

GMS Tokyo

GMS Naha

MCS Hitachi-Ota with GMS

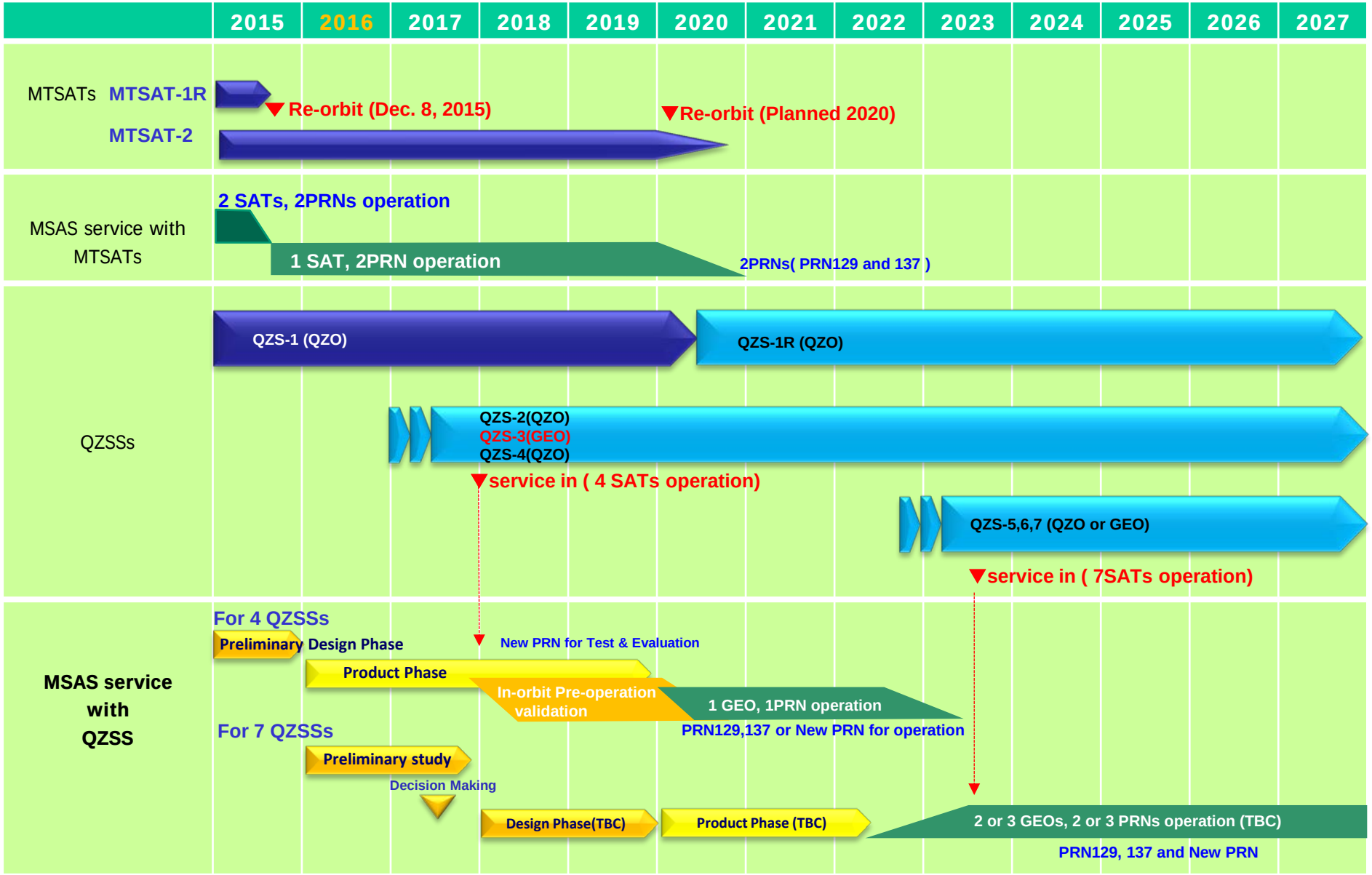
MCS Kobe with GMS

MCS: Master Control Station
GMS: Ground Monitor Station

- Service for air navigation
  - GPS Augmentation Information for RNAV, from En-route through NPA (RNP 0.3)
    - Within Fukuoka FIR
    - horizontal guidance only due to ionosphere

Future Plan

Near-term schedule



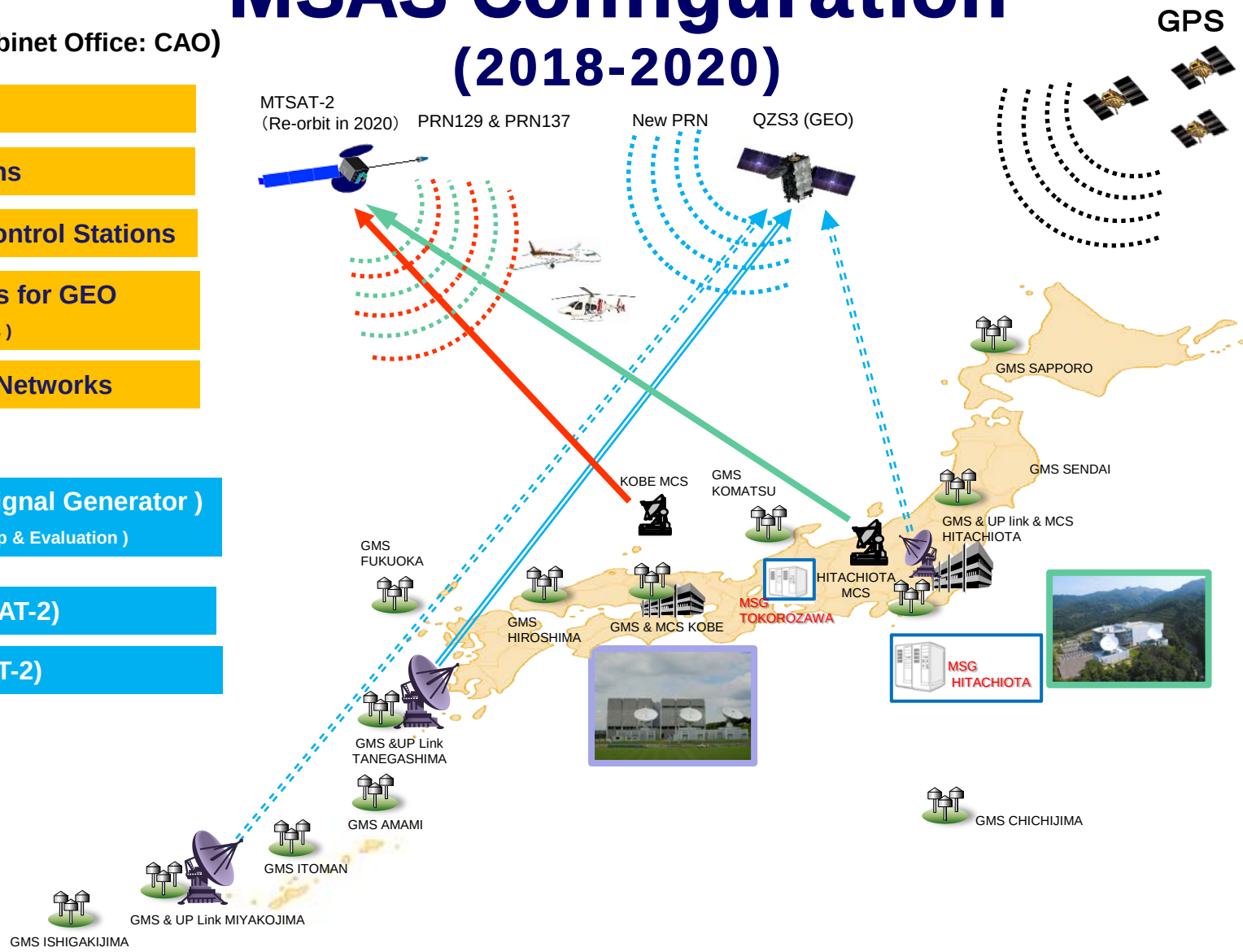
MSAS Configuration (2018-2020)

QZSS Facility (Cabinet Office: CAO)

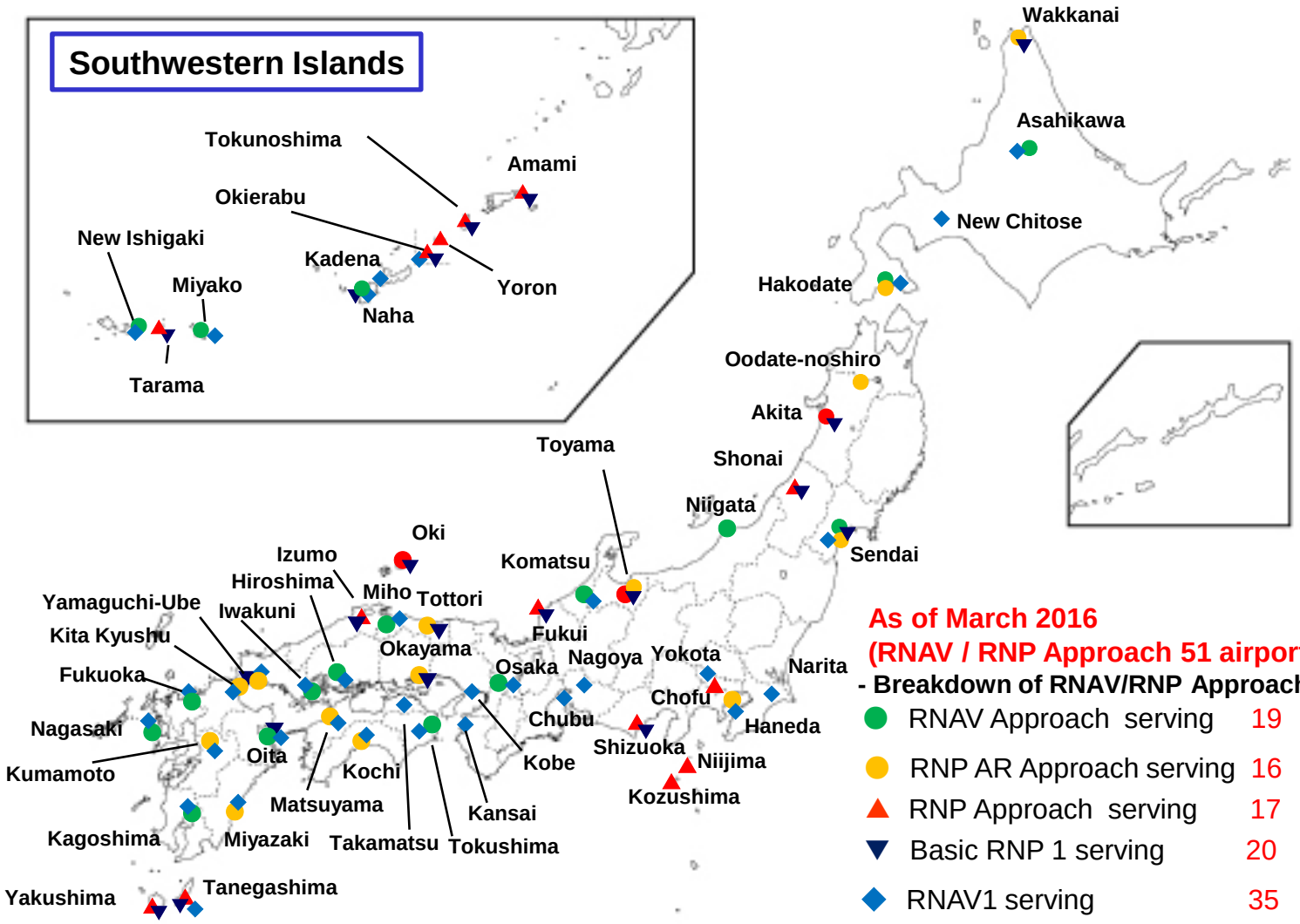
- 1 SAT (1PRN)
- 13 Monitor Stations
- 2 QZSS Master Control Stations
- 3 Up Link stations for GEO
  (1operation , 2Backups)
- 2 Commnication Networks

JCAB Facility

- 2 MSGs(MSAS Signal Generator)
  (1 Operation, 1 Backup & Evaluation)
- 2 MCSs (for MTSAT-2)
- 1 SAT (for MTSAT-2)



GNSS & PBN



As of March 2016
(RNAV / RNP Approach 51 airports)

- Breakdown of RNAV/RNP Approach -

RNAV Approach serving	19	airports
RNP AR Approach serving	16	airports
RNP Approach serving	17	airports
Basic RNP 1 serving	20	airports
RNAV1 serving	35	airports

Japanese aircraft with SBAS capability

- Mitsubishi Regional Jet (MRJ) 70-90 seat
  - ✓ Now, Flight test and evaluation
  - – First delivery of MRJ is planed in 2017.
- Rockwell Collins Pro Line Fusion has a LPV capability
- Purchase Agreement with:

  ANA 25 aircraft, Trans States Holdings 100 aircraft,
  SkyWest 200 aircraft,
  Eastern Air Lines Group 40 aircraft,
  Air Mandalay Limited 10 aircraft,
  And JAL 32 aircraft,
  Aerolease Aviation LLC 20 aircraft,
  Rockton AB 20 aircraft,

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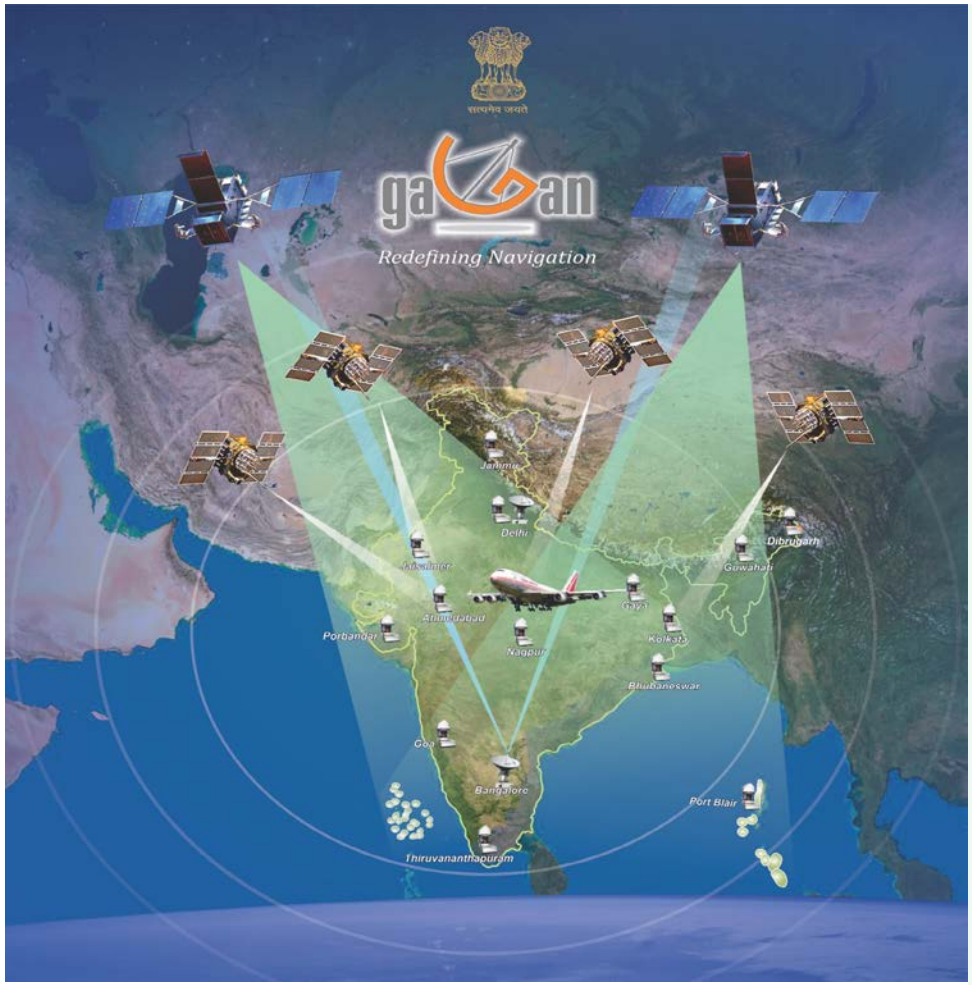
AIRPORTS AUTHORITY OF INDIA



GAGAN

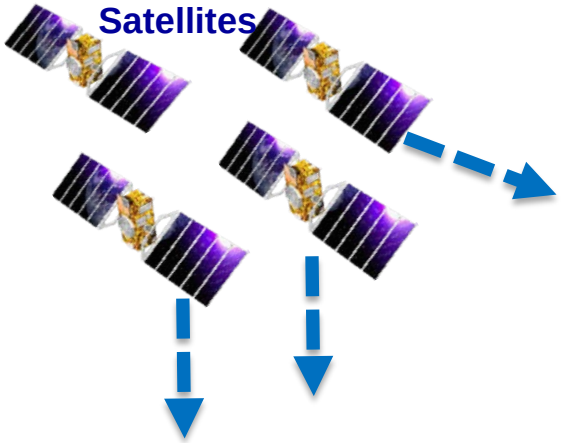
- India's FIRST satellite navigation system developed jointly by AAI & ISRO
- 4th SBAS in the World
- 3rd to achieve Approach with Vertical Guidance Certification
- 1st system developed in Equatorial Region making India the leader in Asia Pacific Region

PROVIDES

APV 1 & RNP 0.1 SERVICE IN INDIAN FIR

GAGAN ARCHITECTURE

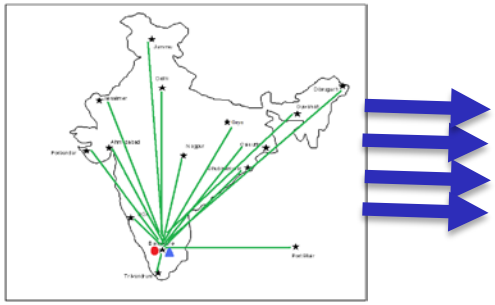
GPS Satellites



GSAT-8 (PRN-127)

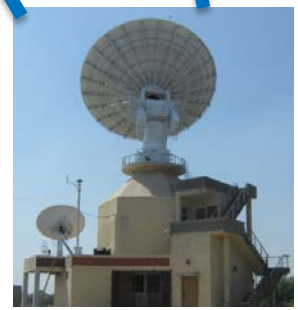
GSAT-10 (PRN-128)

Both Geostationary satellites (GSAT-8 & GSAT-10) send correction messages to Users



15 Ground Reference Stations located at various airports collect data from GPS and forward to Indian Master Control Centres

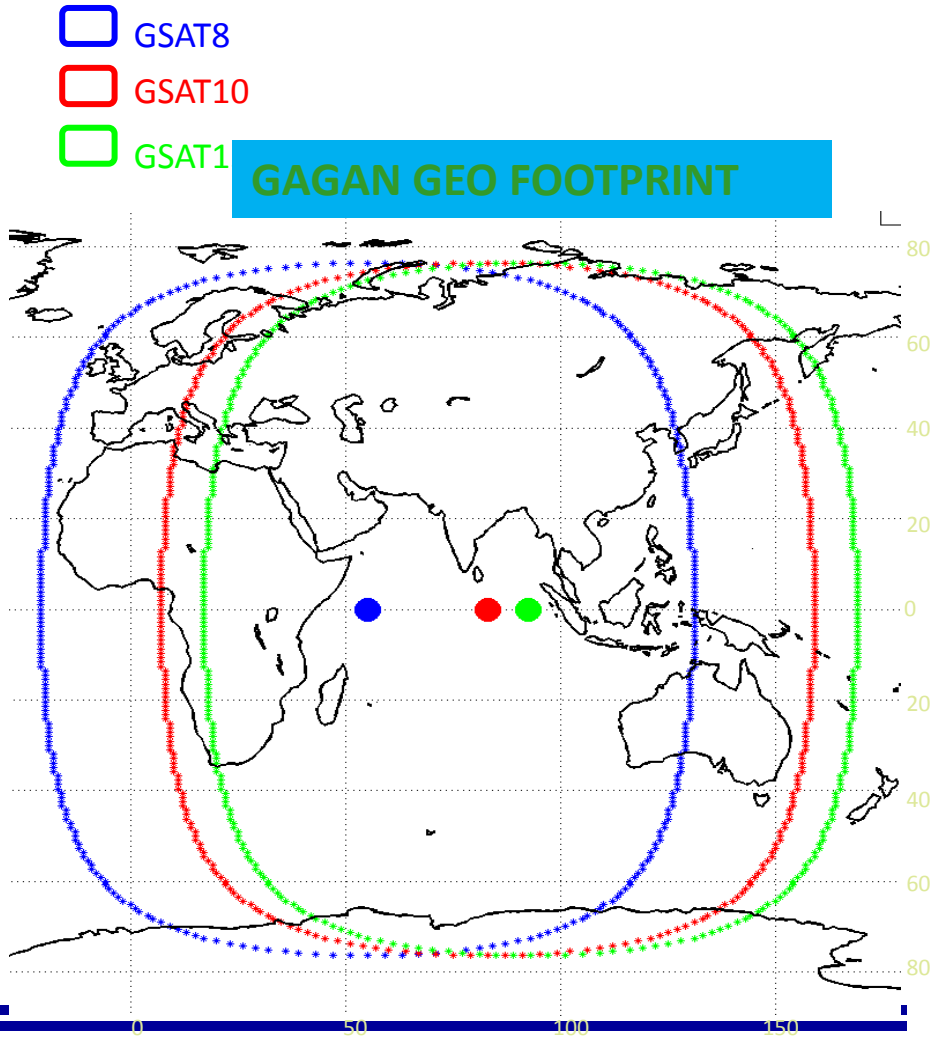
2 Indian Master Control Centres receiving data from reference stations and provide Ionospheric, Clock and Ephemeris corrections and send it to Uplink stations



3 Indian Land Uplink Stations uplink correction messages to 2 Geostationary satellites (GSAT-8 & GSAT-10)

GAGAN features

- GAGAN is the first system in the world to have implemented in the equatorial ionospheric region. GAGAN ionospheric algorithm known as Multi-Layer Data Fusion (MLDF 1.4) was developed by ISRO.
- GAGAN is interoperable with other SBAS systems like WAAS, EGNOS
- Draft Civil Aviation Policy 2015 prescribes *"New aircraft being registered in India from 1st April 2017 will mandatorily have to be GAGAN enabled"*



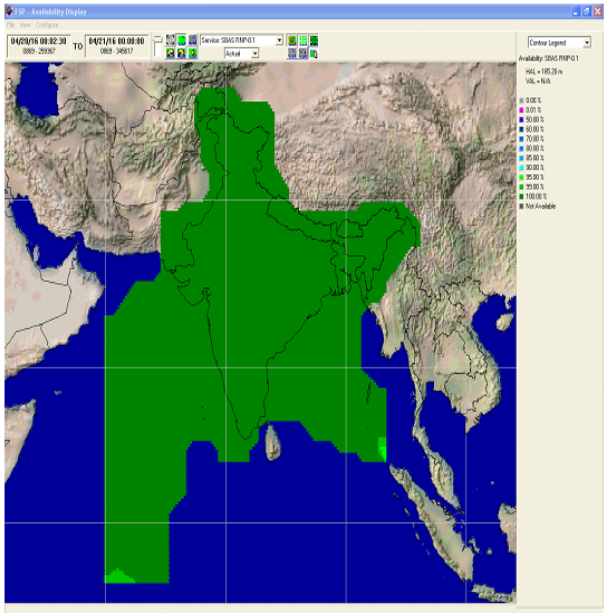
GAGAN RNP 0.1 & APV 1 Performance as of 21.04.2016

RNP 0.1 21.04.2016

PRN-127

GAGAN Service RNP 0.1
Availability Coverage % at

100%	99.14
99%	100.00
95%	100.00

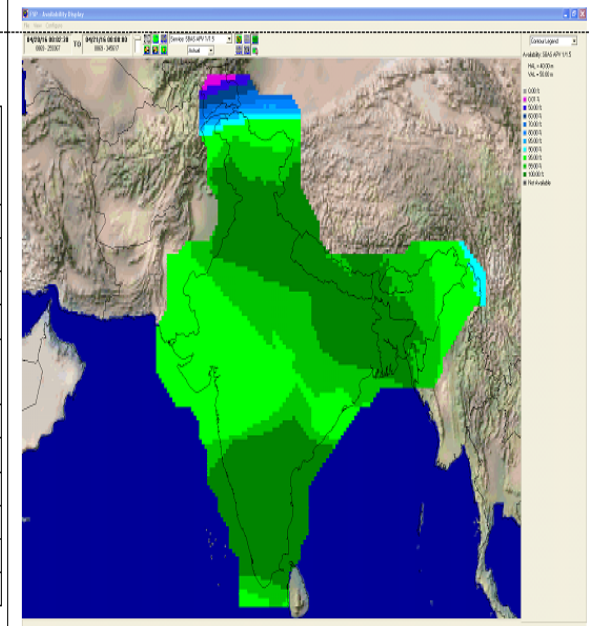


APV1 21.04.2016

PRN-127

GAGAN Service APV 1

Contour – % of time	Availability - % of Indian Land mass
Values generated by System	
100%	43.04
99%	67.35
95%	99.18
Values generated by AAI developed tool	
90%	99.77
85%	99.96
80%	100.00
70%	100.00
60%	100.00
50%	100.00



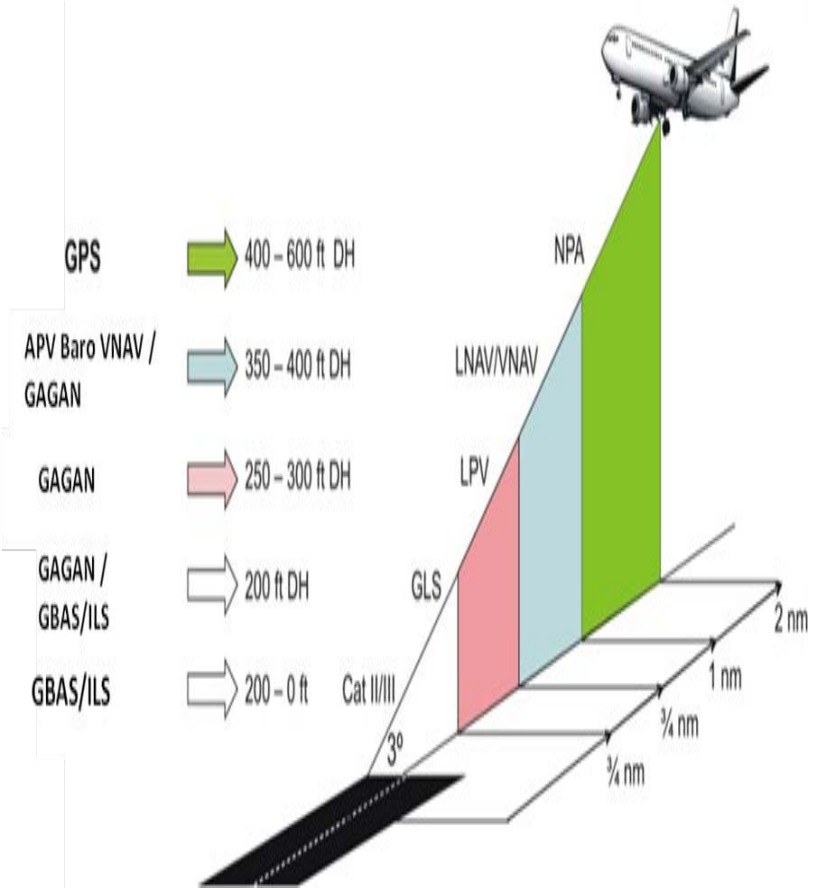
GAGAN Implementation Plans - AAI

- **For Runways equipped with ILS:**
  Alternative to ILS, when ILS becomes unserviceable or under maintenance.

- **At runways not equipped with ILS** or at terrain constrained airports where ILS installation is not practicable, GAGAN approaches will provide the requisite vertical guidance.

- **At small airports** where only few aircraft movement exist.

- **At new airports** where traffic density is expected to be **less than 10 movements/day**.



2nd part - SBAS systems in development

SDCM - Russia

SBAS ASECNA - Africa

KASS – South Korea

BDSBAS - China

Systems Under Development
SDCM & SBAS-ASECNA

- **System of Differential Correction and Monitoring (SDCM) - Russia**
  - In development with plans for horizontal and vertical guidance
  - L1 SBAS coverage over Russian territory by 2016
  - L1/L5 SBAS service and L1/L3 GLONASS precise point positioning service in 2018
  - SDCM certification for APV-1/2

- **SBAS-ASECNA** - ASECNA is 18 Member States (Africa & Indian Ocean)
  - In development with plans for supporting en-route, terminal and approach operations in the ASECNA area of responsibility
  - APV services provision objectives:
    - Early LPV/LP (L1) services by 2019/20
    - Full LPV/LP (DFMC) services by 2023 onwards
  - See backup slides for more details

SBAS Under Development
BDSBAS & KASS

- **BDSBAS - China**
  - In development with plans for supporting en-route, terminal and approach operations
  - Plan to launch first SBAS GEO in 2018
  - Preliminary single-frequency and dual-frequency service augmenting BeiDou in 2020 with potential to augment additional constellations
  - See backup slides for more details

- **KASS - Korea**
  - In development with plans for supporting en-route, terminal and approach operations in Korea
  - Program kick-off in October 2014
  - Expect to award implementation contract in 2016
    - Preliminary operation / open service 2019 - 2022
    - Full APV services by 2022 onwards
  - See backup slides for more details

Potential future systems

- EGNOS in Africa Programme - Africa & Indian Ocean region
  - Initiative for SBAS/EGNOS development and services provision in Africa, beyond ASECNA area of responsibility
  - Coordinated and supported by the pan-African instrument “EGNOS-Africa Joint Programme Office” through Africa-EU Strategic Partnership
- South- America ?

Modular approach foreseen

3rd part – Longer term SBAS evolutions

Dual Frequency Multi Constellation
ADS B mandates

SBAS Evolution
Dual Frequency

- GNSS Dual Frequency Operations
  - Increases SBAS availability and performance by direct avionics correction of ionospheric signal delay
    - Specifically during ionospheric storms and in equatorial regions
  - Improves robustness against unintentional interference

- SBAS Service Provider Objectives
  - Avionics manufacturers support multi-constellation/multi-frequency avionics as flight-certified navigation solutions
  - Provide continued support to legacy L1-only users
  - Provide an improved level of service for SBAS operations (lower DH)
  - Support cooperative development of future SBAS standards consistent with ICAO Block upgrades

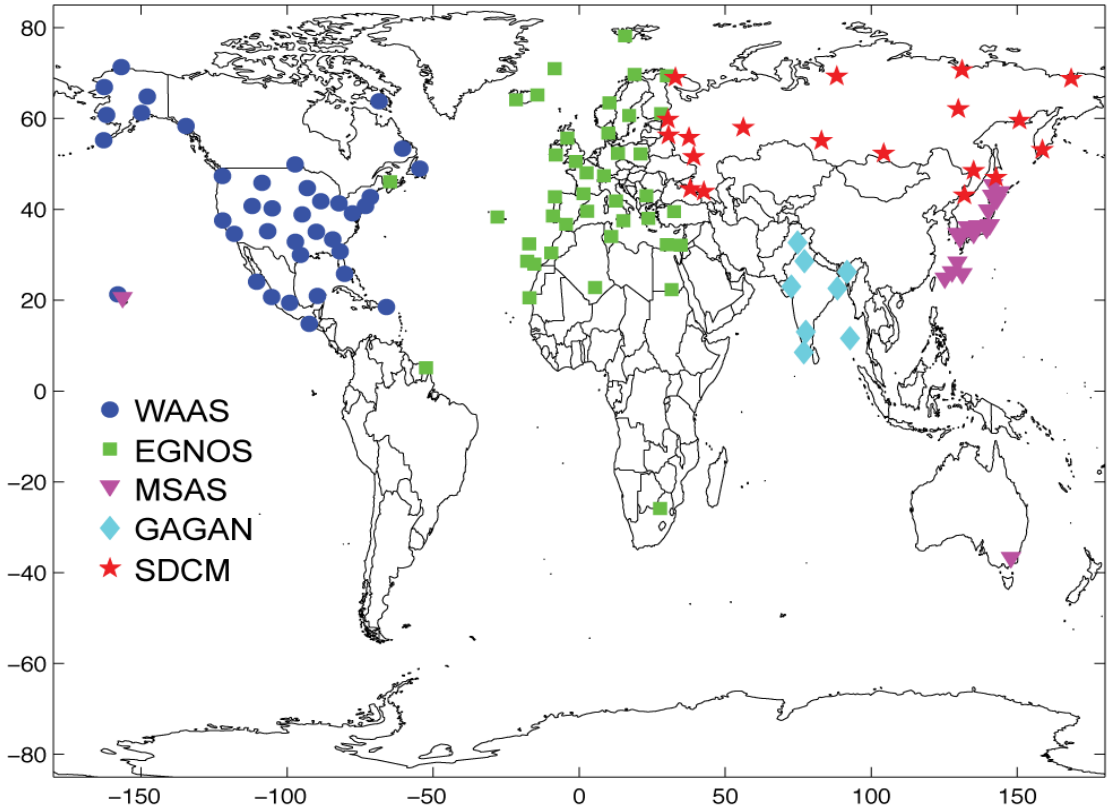
SBAS Evolution
Multiple Constellation

- GNSS Multiple-Constellation Operations
  - Develop standards to enable augmentation of multiple constellations by SBAS
    - DFMC SBAS Definition Document captures concept and system / subsystem requirement
      - Enables SBAS to augment up to four constellations
      - Concept only requires SBAS to augment a single constellation
    - DFMC SBAS Interface Control Document defines proposed DMFC interface messages
      - Supports augmentation of 4 constellations concurrently

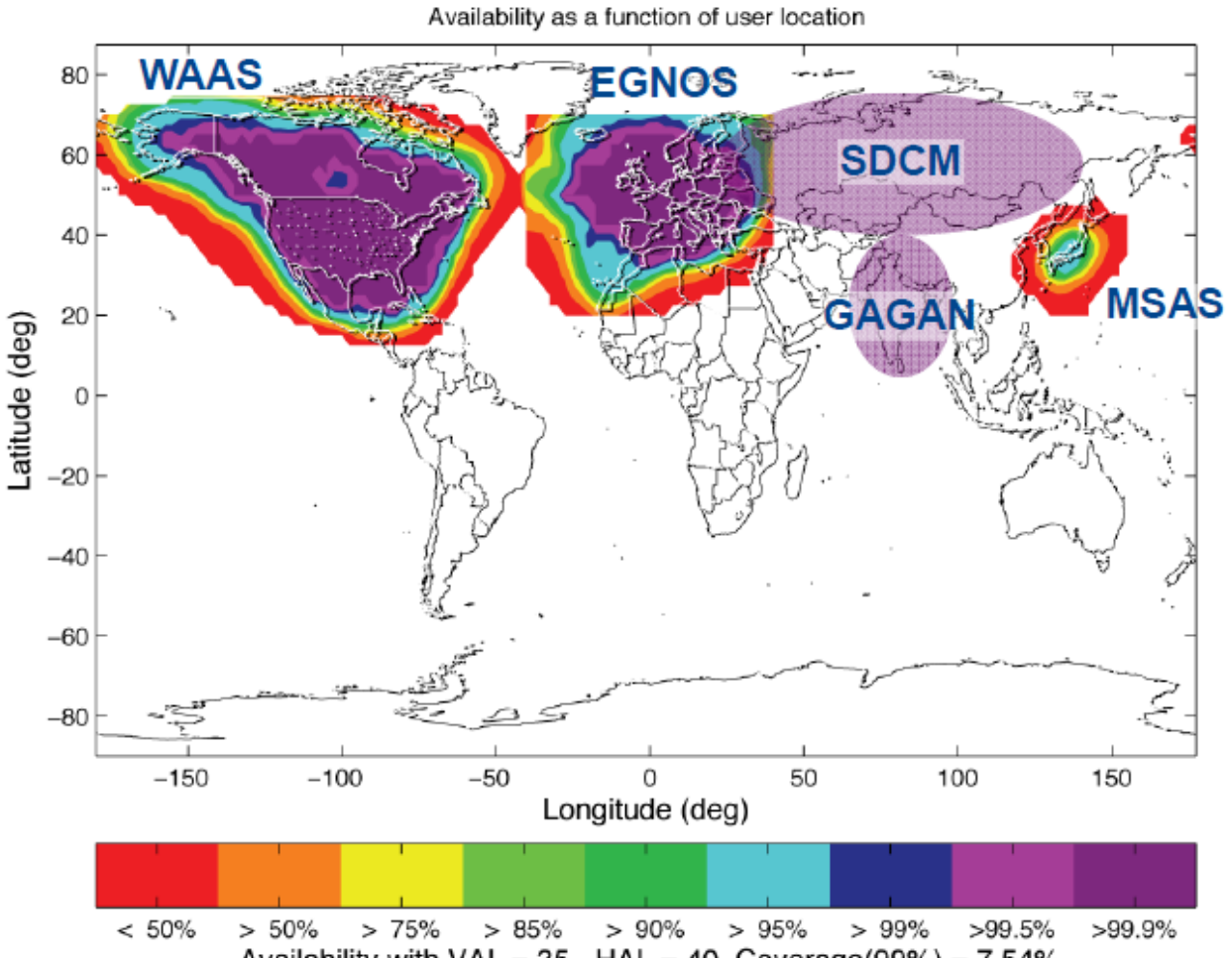
SBAS Evolution
DMFC SBAS User Equipment

- Development of DFMC SBAS MOPS
  - Targeted for development in EUROCAE and RTCA
    - Targeting 2018/2019 for draft 2021/2022 for final
  - Planned to develop a joint MOPS
  - Modifications to include new signals and constellations will require additional information
    - Requires inclusion of GNSS constellations in ICAO Annex 10, and Concept of Operation developement
      - GPS L5, GLONASS CDMA, Galileo, Beidou
      - Actions allocated to NSP
    - Requires constellation provider performance commitment

CURRENT SBAS GROUND NETWORKS

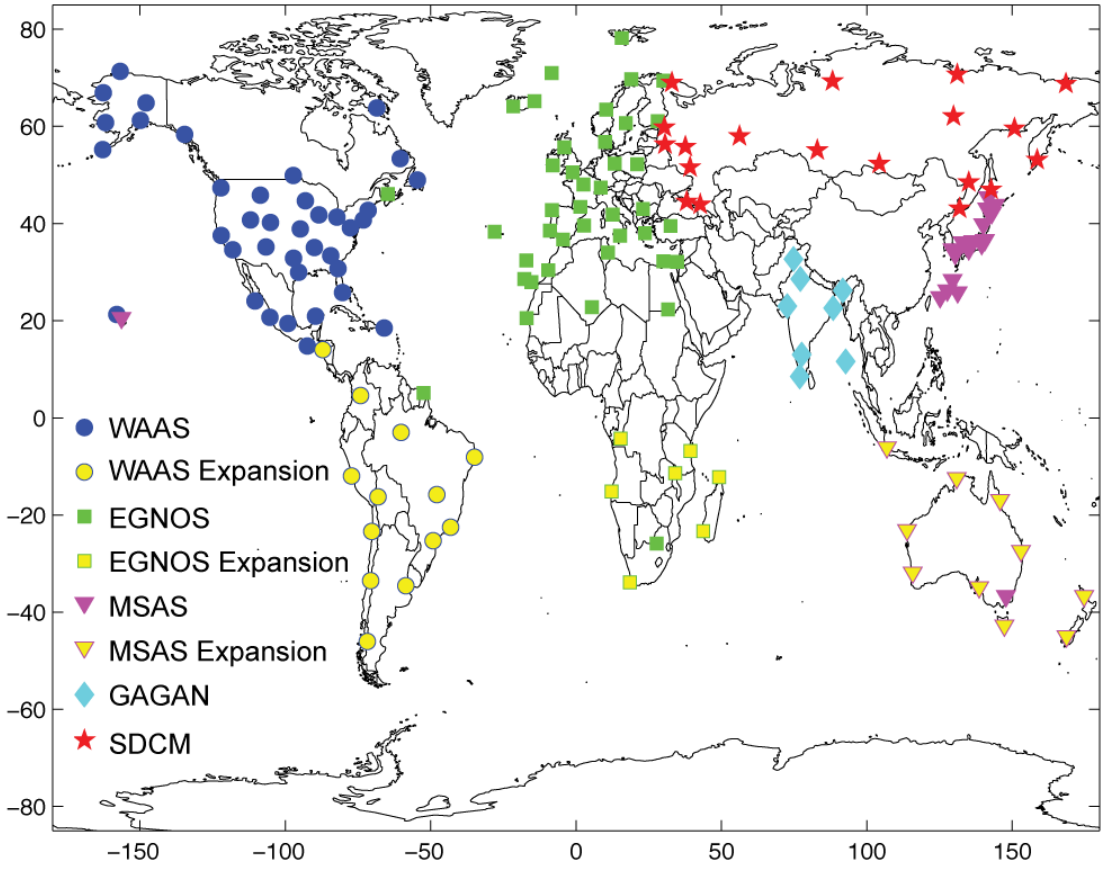


CURRENT SBAS COVERAGE AREAS

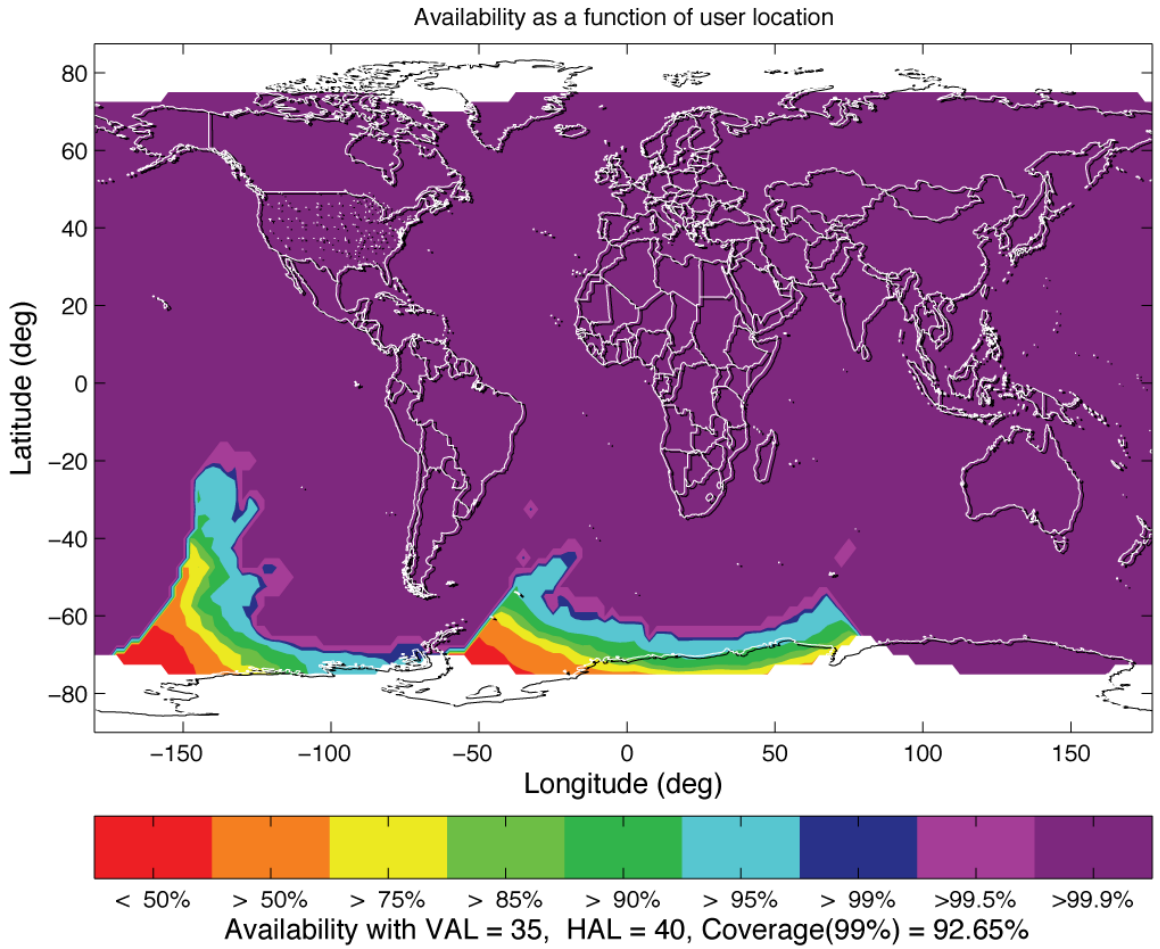


SBAS: Satellite Based Augmentation System VAL: Vertical Alert Limit HAL: Horizontal Alert Limit

EXPANDED SBAS GROUND NETWORKS



POTENTIAL SBAS COVERAGE AREA WITH DFMC AND EXPANDED GROUND NETWORKS



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Ministère de l'Écologie, du Développement durable et de l'Énergie

DSNA

SBAS IS RECOMMENDED BY AIRCRAFT MANUFACTURERS TO SUPPORT THE US FAA ADS-B MANDATE

	Surveillance (> 99,9 % Availability)		Navigation (> 99,0 % Availability)		Positioning sensor
	Accuracy (95%)	Containment (10-7)	Accuracy (95%)	Containment (10-7)	Dual Freq SBAS / Single Freq SBAS / GPS
Oceanic and Remote areas	NACp 5	NIC 4	10 Nm **RNAV 10**	20 Nm	
	NACp 5	NIC 4	4 Nm **RNP 4**	8 Nm	
En-Route	NACp 7/8**	NIC 6/7**	5 Nm **RNAV 5**	10 Nm	
	NACp 7/8**	NIC 6/7**	1 Nm **RNP 1**	2 Nm	
Terminal	NACp 7/8**	NIC 5/7**	1 Nm **RNAV 1 RNP 1**	2 Nm	
Approach and Landing	NACp 7/8**	NIC 5/7**	0,3 Nm * **LNAV**	0,6 Nm*	
	NACp 7/8**	NIC 6/7**	0,1-0,3 * Nm **RNP AR**	0,1-0,3* Nm	
	NACp 7/8**	NIC 5/7**	16 m/ 4m **LPV 250**	40 m/50 m	
	NACp 7/8**	NIC 5/7**	16 m/4 m **LPV 200**	40 m/35 m	
	TBD	TBD	TBD **Cat I/II Autoland**	TBD	

* Requires GPS INS integration (e.g. Airbus GPIRS)

** Might be supported by GPS INS integration (e.g. Airbus GPIRS).Under Airbus study

Thank you for your attention !

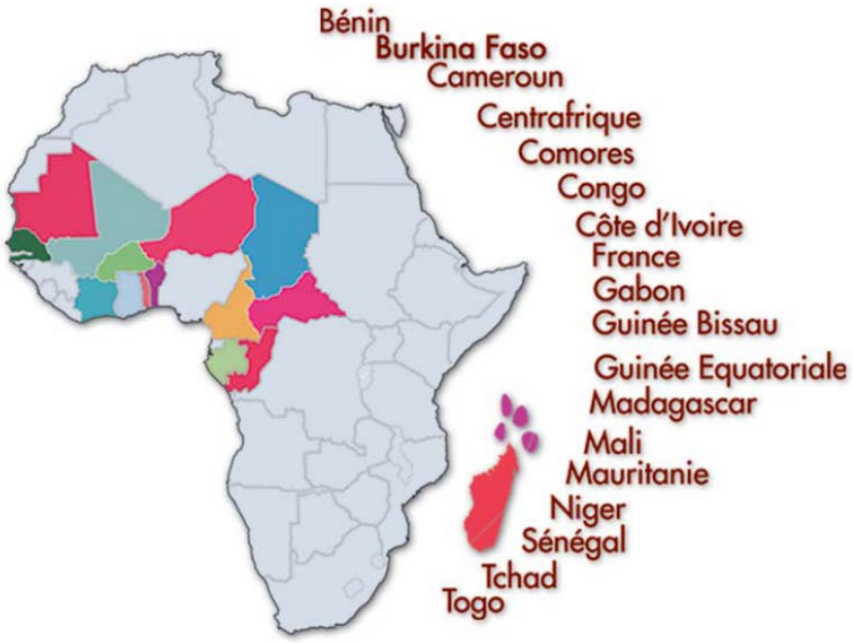
Any question?

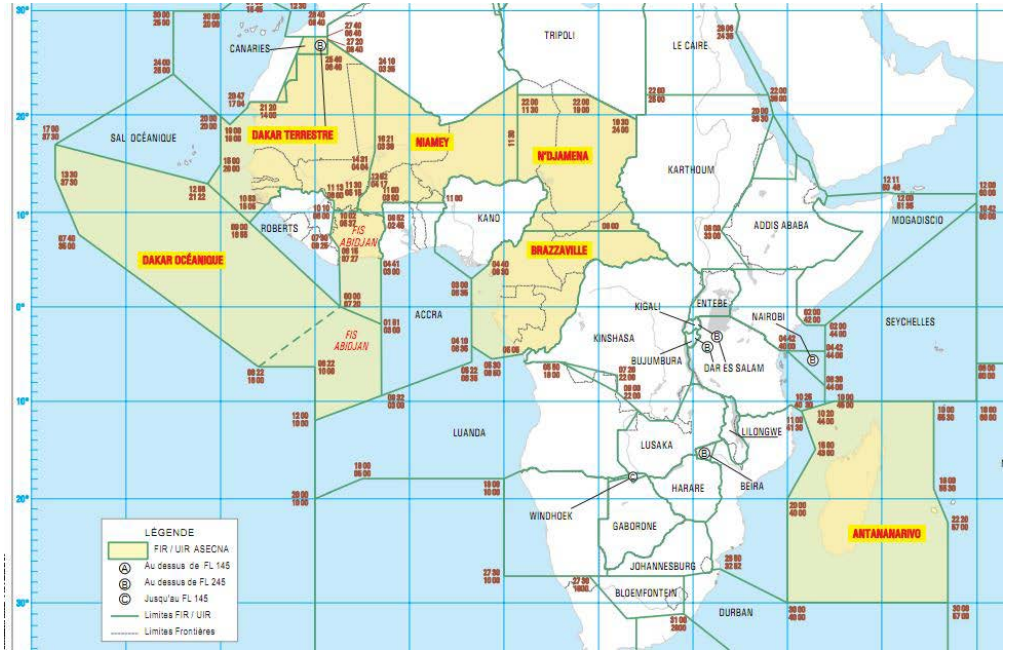
Backup Slides

ASECNA at a glance

Agency for Air Navigation
Safety in Africa
and Madagascar

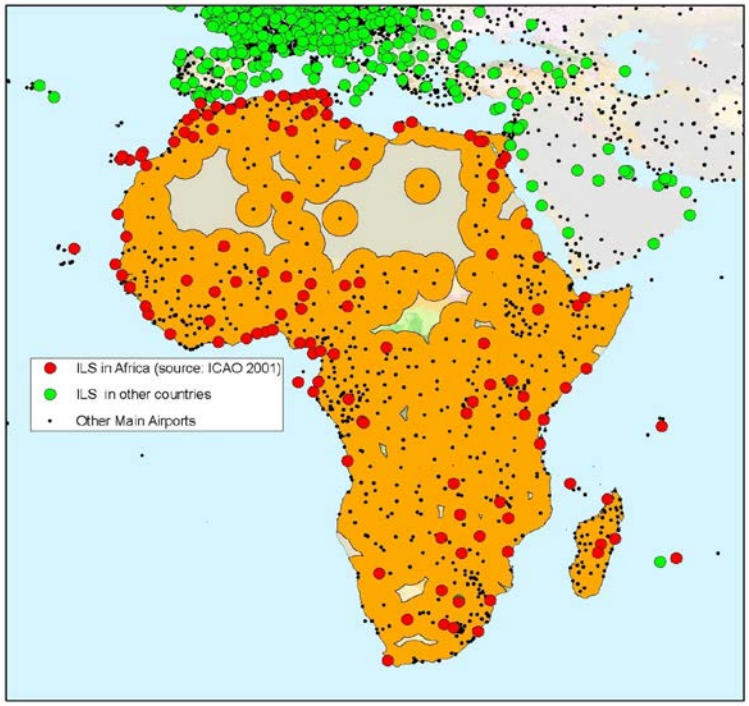
Benin, Burkina Faso, Cameroun, Centrafrique, Congo, Côte d'Ivoire, France, Gabon, Guinée Bissau, Guinée Equatoriale, Madagascar, Mali, Mauritanie, Niger, Sénégal, Tchad, Togo, Union des Comores





Cooperative management of a Single Sky of 16,1 millions km^2
(1,5 * Europe)

Operational needs



Safety lessons learned

37% of Africa is 250 km from ILS equipped airport (14% of runways ends):

- main international airports
- only one runway end

87% of Africa is 250 km from a main or regional airport

IATA forecasting 2013-17 CAGR : 5,3%

Need for RNP APCH APV :

ASECNA strategic directions

LNAV/VNAV (Baro) (short-term)

LPV/LP (SBAS) (medium-term)

Objectives

- **Directions:**
  - Ownership of the infrastructure
  - Control and provision of Signal in Space (SiS)
  - Autonomous provision of services to end users

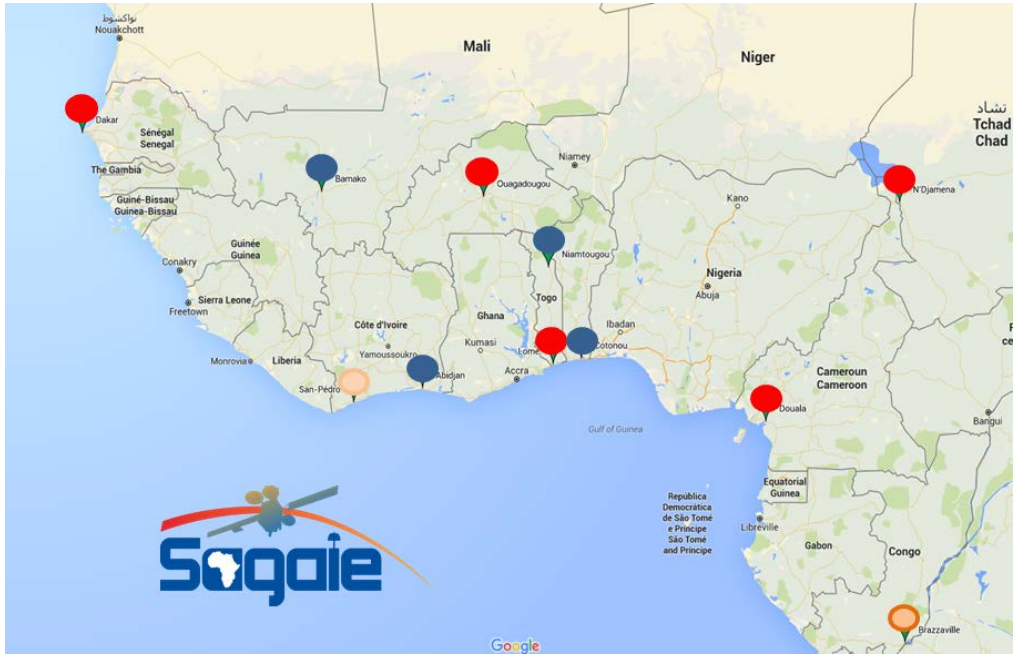
- **Objectives:**
  - **Step 1:** Provision of **Early SBAS-ASECNA (**EGNOS-based) **services** (LPV/LP, L1) by **2019/20**
  - **Step 2:** Provision of **Full SBAS-ASECNA** (EGNOS-based) **services** (LPV/LP, L1/L5) by **2023 onwards**

Towards early services

- **Ionosphere characterisation: SAGAIE (2013-on-going)**
  - Deployment & exploitation of a network of GNSS stations in ASECNA
  - Collection of real GPS/GAL/GLO/GEO raw data for ionospheric studies, to improve knowledge on ionosphere in ASECNA area in order to optimise EGNOS model for SBAS-ASECNA system

Joint initiative:

complemented by

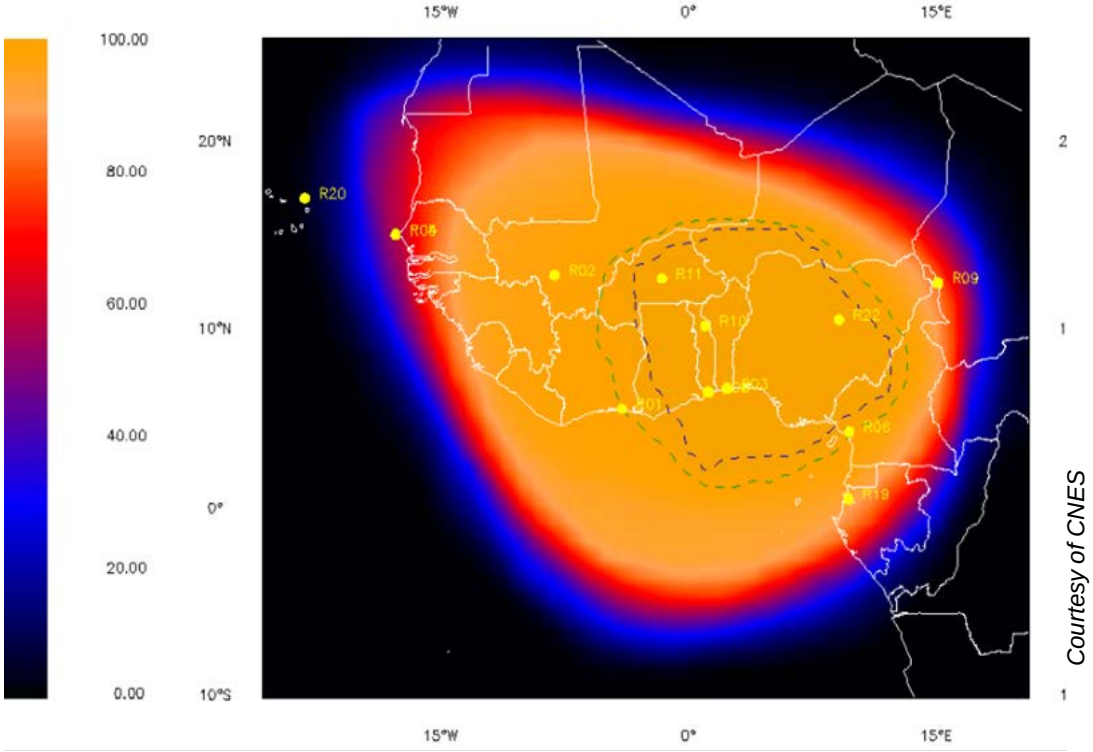


Towards early services

APV-1 availability

11/10/2015 (24h)

(high iono activity)



- High ionosphere activity in equatorial area is no longer an unsolvable issue for SBAS L1 performance !

Cooperation and external relations

International agreement
(under negotiation)

Technical Officer *(under discussion)*
(System Development)
& Cooperation (MONITOR, EGEP…)

Cooperation
(services provision)

SBAS-ASECNA Programme

Cooperation (missions)

Cooperation
(SAGAIE, MONITOR…)

SBAS IWG

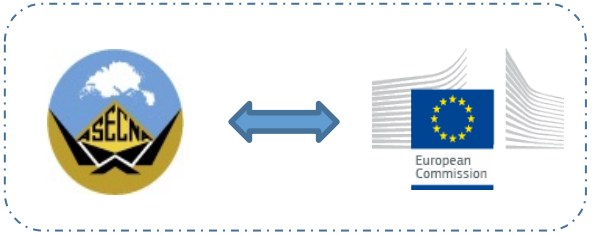
Synergies

…

EGNOS Africa-JPO

Africa-EU Partnership

ASECNA-EU international agreement



- To lay down the terms and conditions for the provision of SBAS services in ASECNA based on EGNOS
- As per Regulation (EU) 1285/2013 on the implementation & exploitation of European Satellite Navigation Systems and the resolution n°2011 CA 120-18 of ASECNA Member States
- Opening of negotiations authorised by the Council of EU (Competitiveness Council, 25-26 September 2014)
- Negotiations launched on March 2015 in Dakar, very satisfactory progress, main phase completed on April 2016 in Dakar
- Draft of agreement under review within EU institutional system

EGNOS-Africa Joint Programme Office

Pan-African entity to coordinate and support harmonised SBAS/EGNOS development and services provision in Africa

- Implementing measure of the Africa-EU Strategic Partnership
- Pan-Africa team of experts based in Dakar, Senegal

- Phase 2016-17 (funded by Panafrican programme): to accelerate the adoption of SBAS/EGNOS in Africa
- Regional modular approach foreseen

BDSBAS Status Updates

Jun Shen, Xiaochun Lu

China Satellite Navigation Office (CSNO)

May 16, 2016

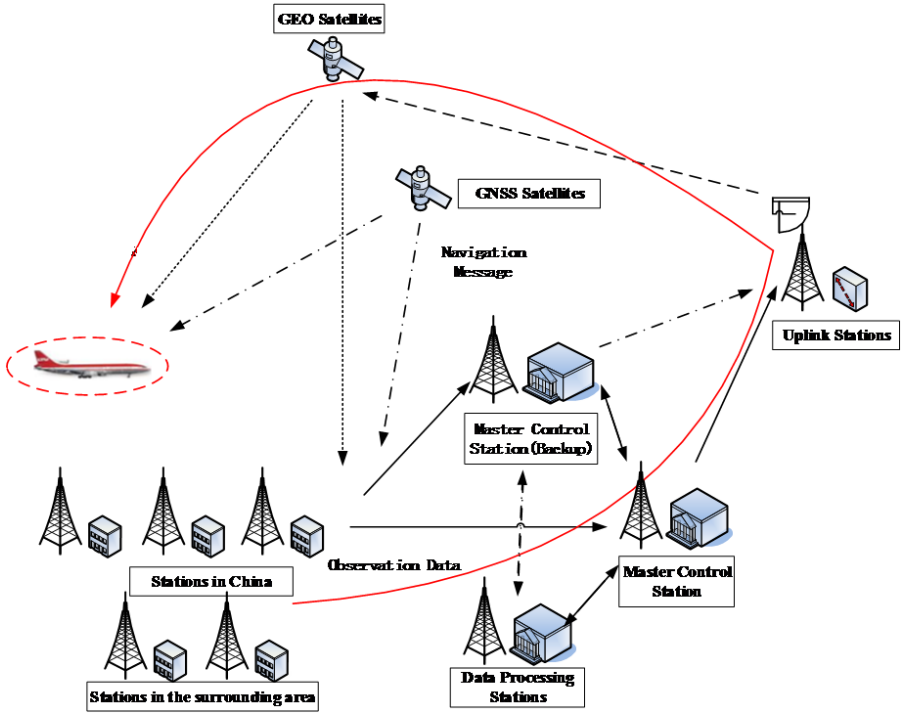
Changsha , China

System Components

BeiDou Satellite-based Augmentation System (BDSBAS)

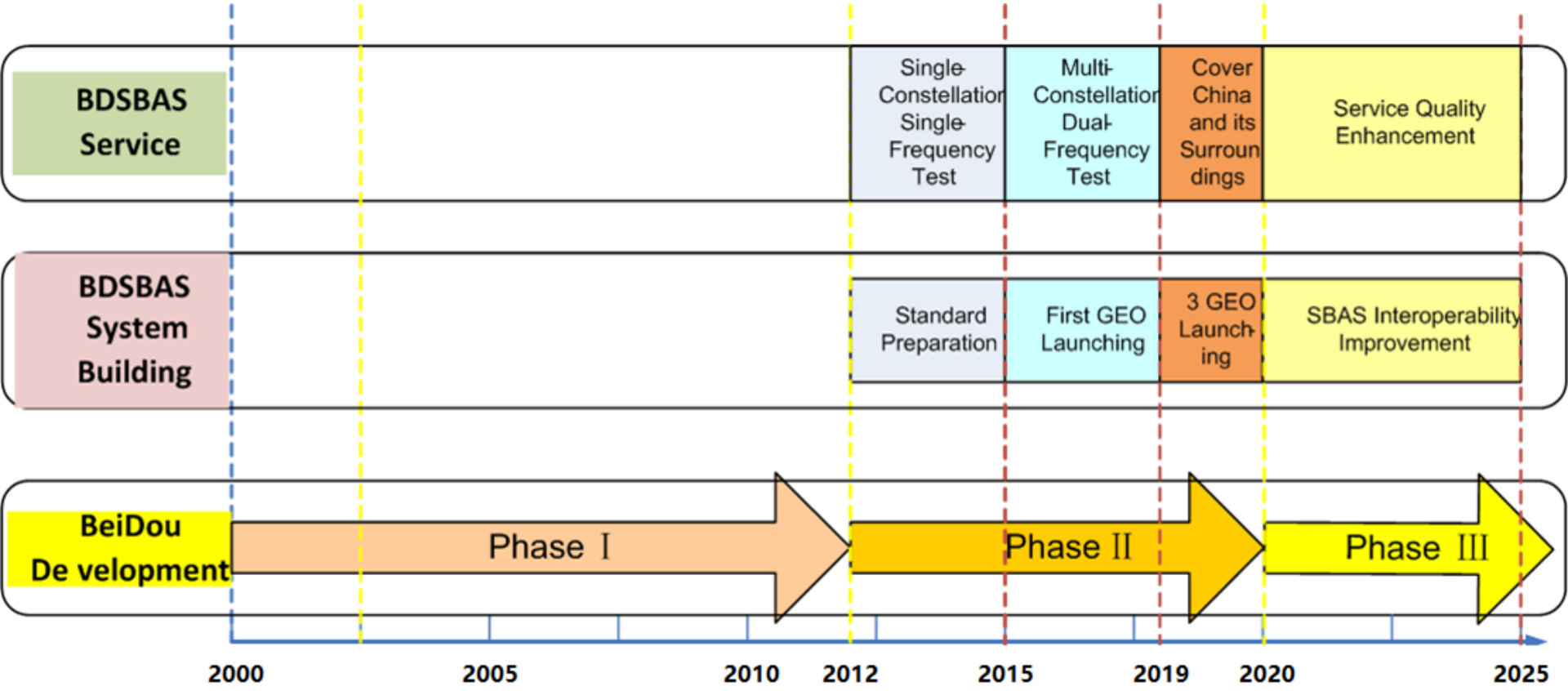
Service	Signal	Interface
SF/ DF	B1-C(1575)	SFMC SBAS ICD
	$B2_a$(1176)	DFMC SBAS ICD

- **Space**
  - 3 GEO
- **Ground**
  - Master control station,
  - Data processing system,
  - Uplink stations,
  - Monitoring stations
- **User**
  - Augmentation user



Development Plan

- **Development Schedule**



Korea SBAS Program

May 16, 2016

Eunsung Lee

SBAS Program Office
Korea Aerospace Research Institute

KARI Korea Aerospace Research Institute

The Name of Korean SBAS

KASS
Korea Augmentation Satellite System

KASS :

Abbreviation of

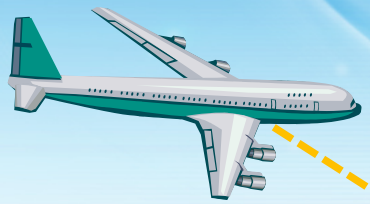
"Korea Augmentation Satellite System"

KARI Korea Aerospace Research Institute

History of KASS Program

2013.08	Government decided to launch the Korean SBAS (K-SBAS) Program
2013.12	Preliminary Study on K-SBAS (2013.12 ~ 2014.06) - 2014.06 : The result of study was reported to Korean Government - 2014.09 : RFP for selecting K-SBAS Program Manager was announced
2014.10	KARI was awarded as K-SBAS Program Office (Program Manager: Dr. Nam Gi-Wook)
2014.12	K-SBAS Program was officially kicked off.
2015.05 & 07	Mission Requirements Review & System Requirements Review.
2015.09	Tender Notice for Contractor.
2015.10 ~ Now	Negotiation with Candidates

Performance Goal of KASS Program



- **1st Project : KASS development for APV-I SoL service**

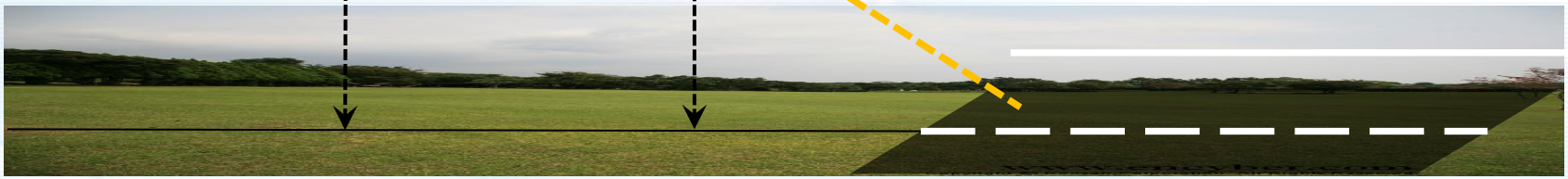
APV-I

- Provide APV-I SoL Service in the Korean Peninsula area
- Meet ICAO Standard (Annex 10)

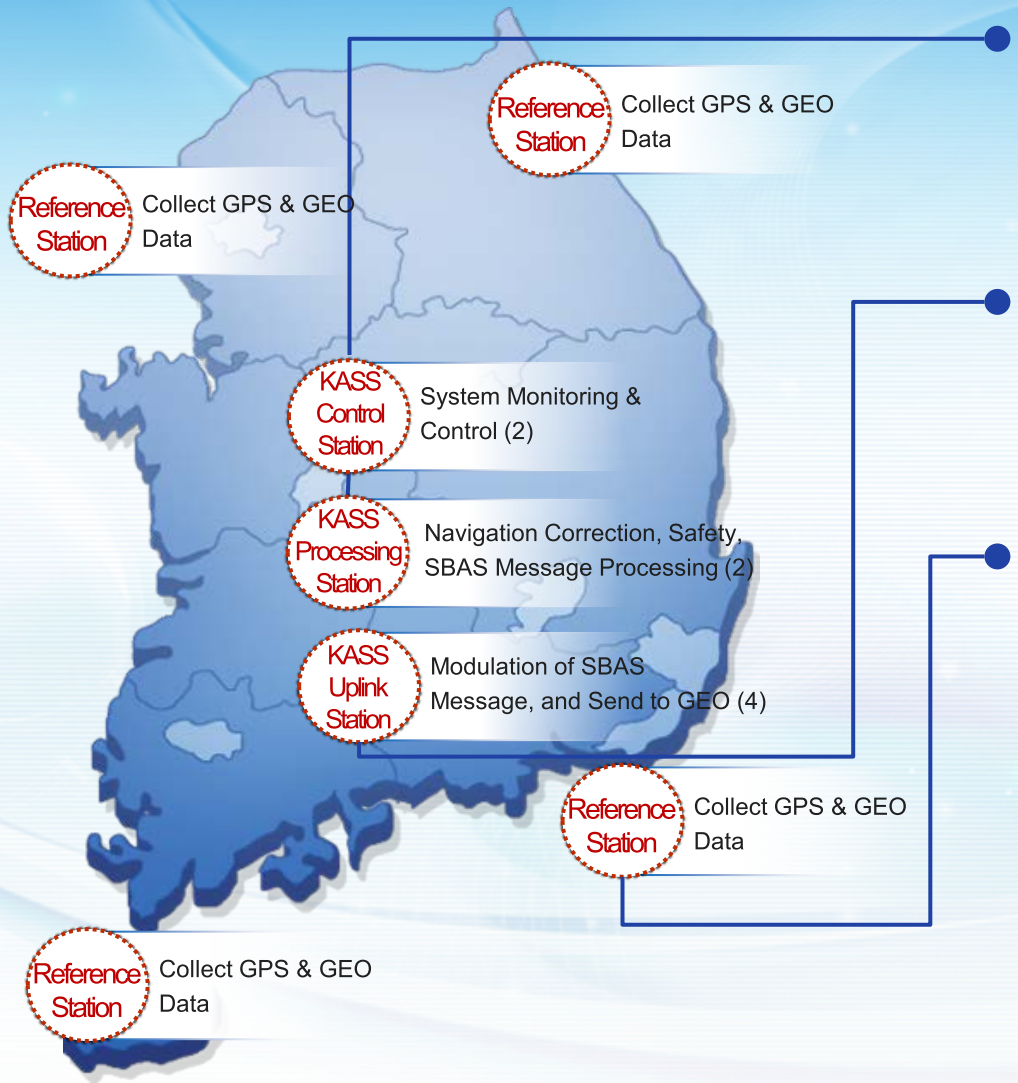
- **2nd Project : R&D for CAT-I Technology**

CAT-I

- Research CAT-I Technology
- Multi Frequency and Multi Constellation



KASS APV-I System Architecture



KASS Control Station

KASS Processing Station

KASS Uplink Station

KASS Reference Station

KASS Reference Station

GEO Satellite
SBAS Message Broadcasting (2)

GEO Satellite

Roadmap of KASS Development