PERFORMANCE OF GNSS-BASED PRECISE POSITIONING TECHNIQUE FOR THE SAFETY OF MARITIME TRANSPORT

(GNSS Evolution for Maritime Transport)

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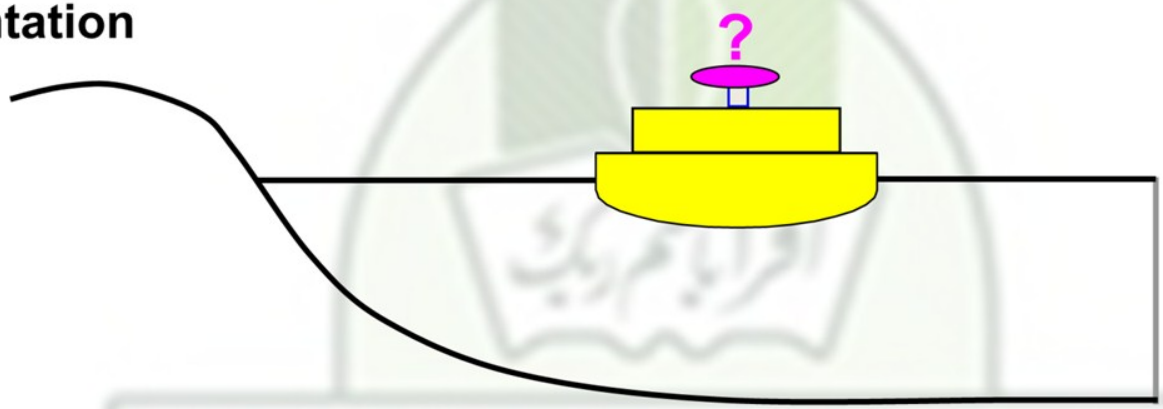
OUTLINE

- Introduction
- Maritime Navigation
- Evolution of Positioning and Navigation Systems
- GNSS Positioning
- GNSS Positioning for Maritime Navigation (DGNSS and PPP Case Studies)
- Conclusion

INTRODUCTION

- **Pilots need accurate position to satisfy the International Maritime Organization (IMO) standards for the safety of maritime navigation and transport**
- **An accurate positioning technique is required to meet the IMO standards**
- **Evolution of current positioning techniques are discussed in this presentation**



For Safety of life in maritime transport, we should answer the following questions:

- Where am I? Ship position: latitude and longitude or Northing and Easting)?
- Am I safe to navigate? Integrity concept!
- How accurate is my position? Accuracy concept!

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MARITIME NAVIGATION

CONSEQUENCE OF INCORRECT NAVIGATION SOLUTION

Ocean: two vessel collision

Inland waterways: vessel collides land

MARITIME NAVIGATION
IMO ACCURACY AND INTEGRITY REQUIREMENTS

- **Marine navigation usually consists of three major phases identified as Ocean/Coastal/Port approach/Inland waterway, in port navigation and automatic docking.**

Table 1: IMO minimum maritime user requirements accuracy and integrity of GNSS based positioning [1]

Navigation phase	Horizontal absolute accuracy (m)	Integrity			Availability (per 30 days)
		Alert limit (m)	Time to alarm (s)	Integrity risk (per 3 hours)	
Ocean/Coastal/Port approach/Inland waterway	**10**	**25**	**10**	**10^{-5}**	**99.8%**
In port navigation	**1**	**2.5**	**10**	**10^{-5}**	**99.8%**
Automatic docking	**0.1**	**0.25**	**10**	**10^{-5}**	**99.8%**

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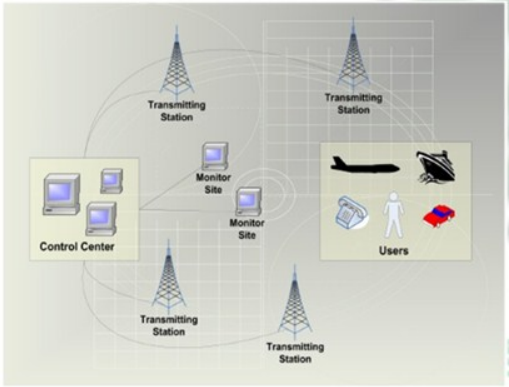
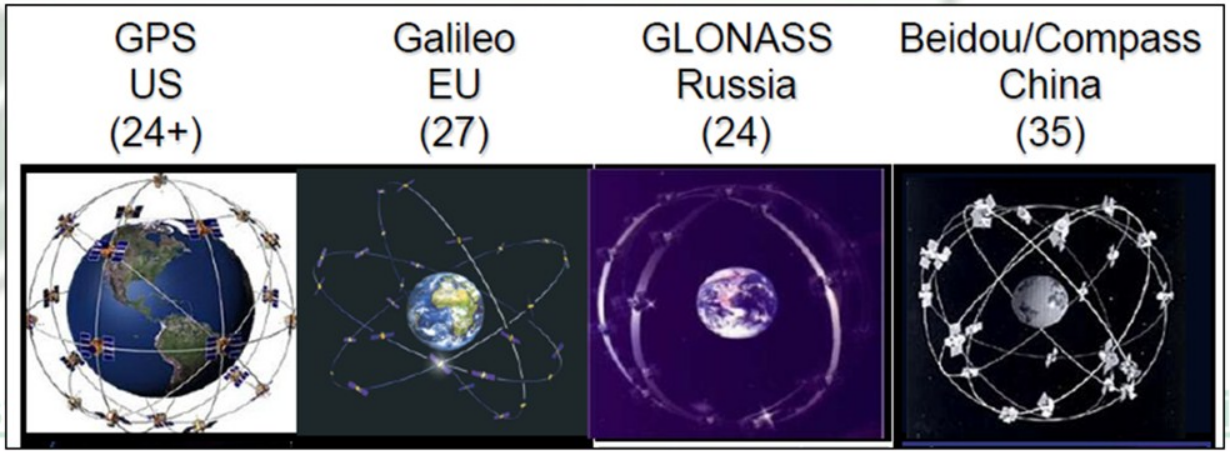
EVOLUTION OF POSITIONING AND NAVIGATION SYSTEMS

- Celestial Navigation
- Optical Positioning
- Radar Positioning (Microwave-based system)
- Long Range Navigation (LORAN) Positioning (Radio wave based system)
- Satellite Positioning (GPS, GLONASS, Galileo,BeiDou, SBAS, GNAS)
- Integrated Positioning system (GNSS and Inertial Navigation System)





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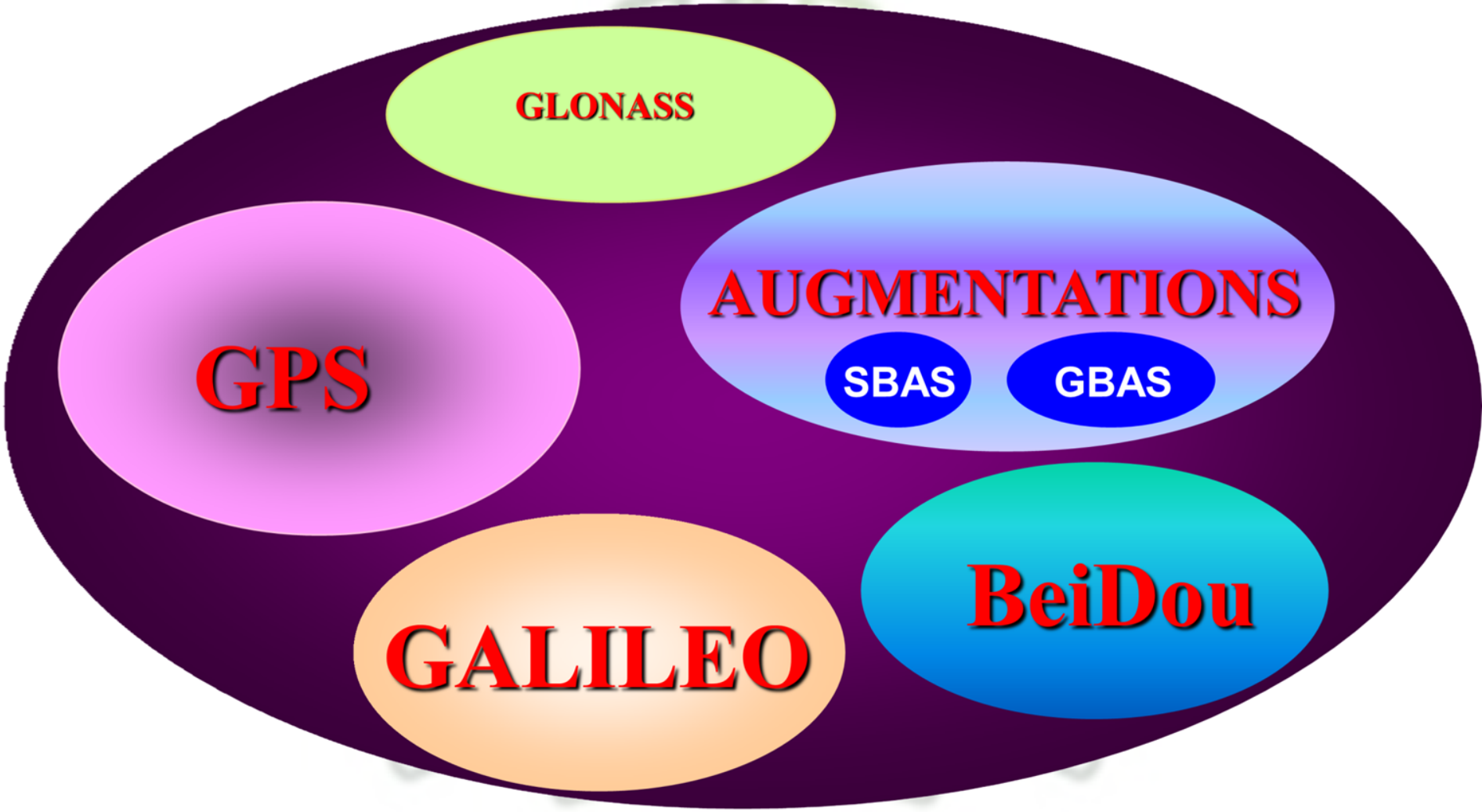
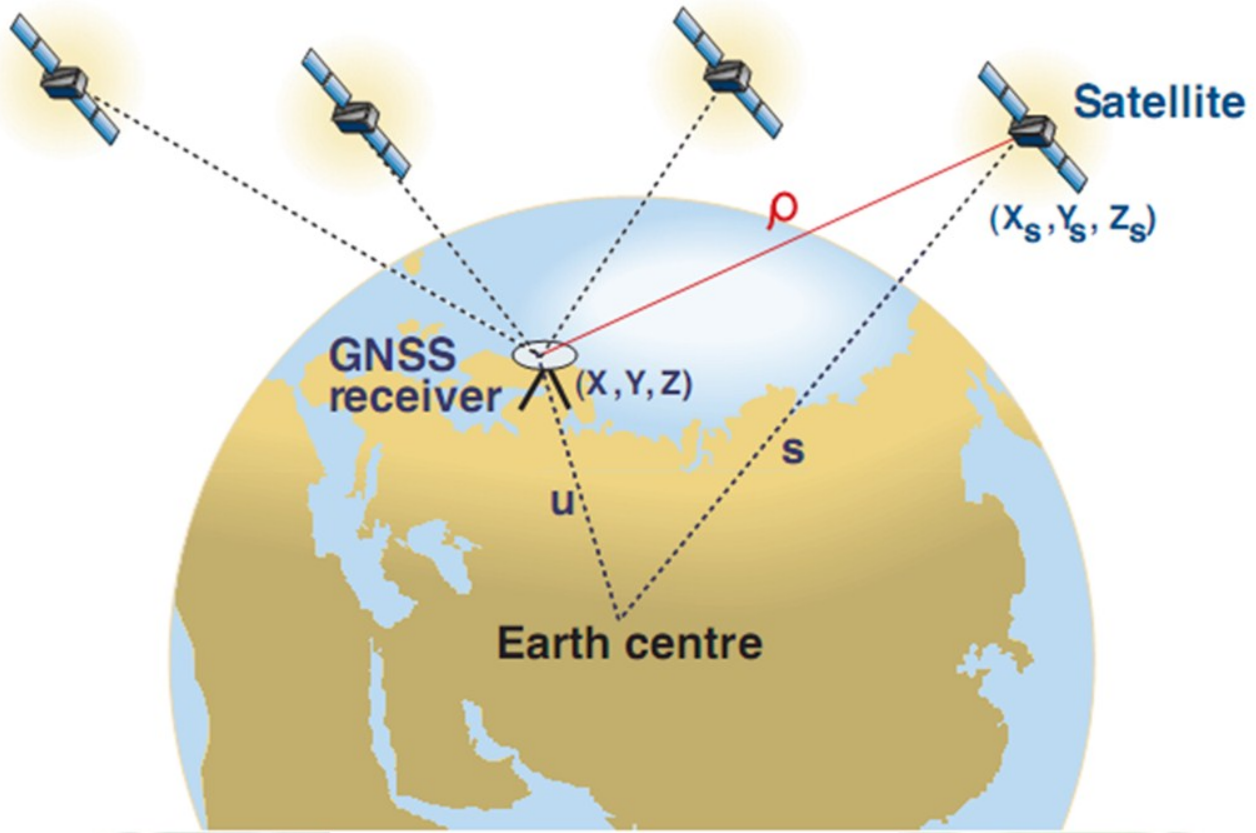
GNSS POSITIONING
GNSS CONCEPT



GNSS POSITIONING

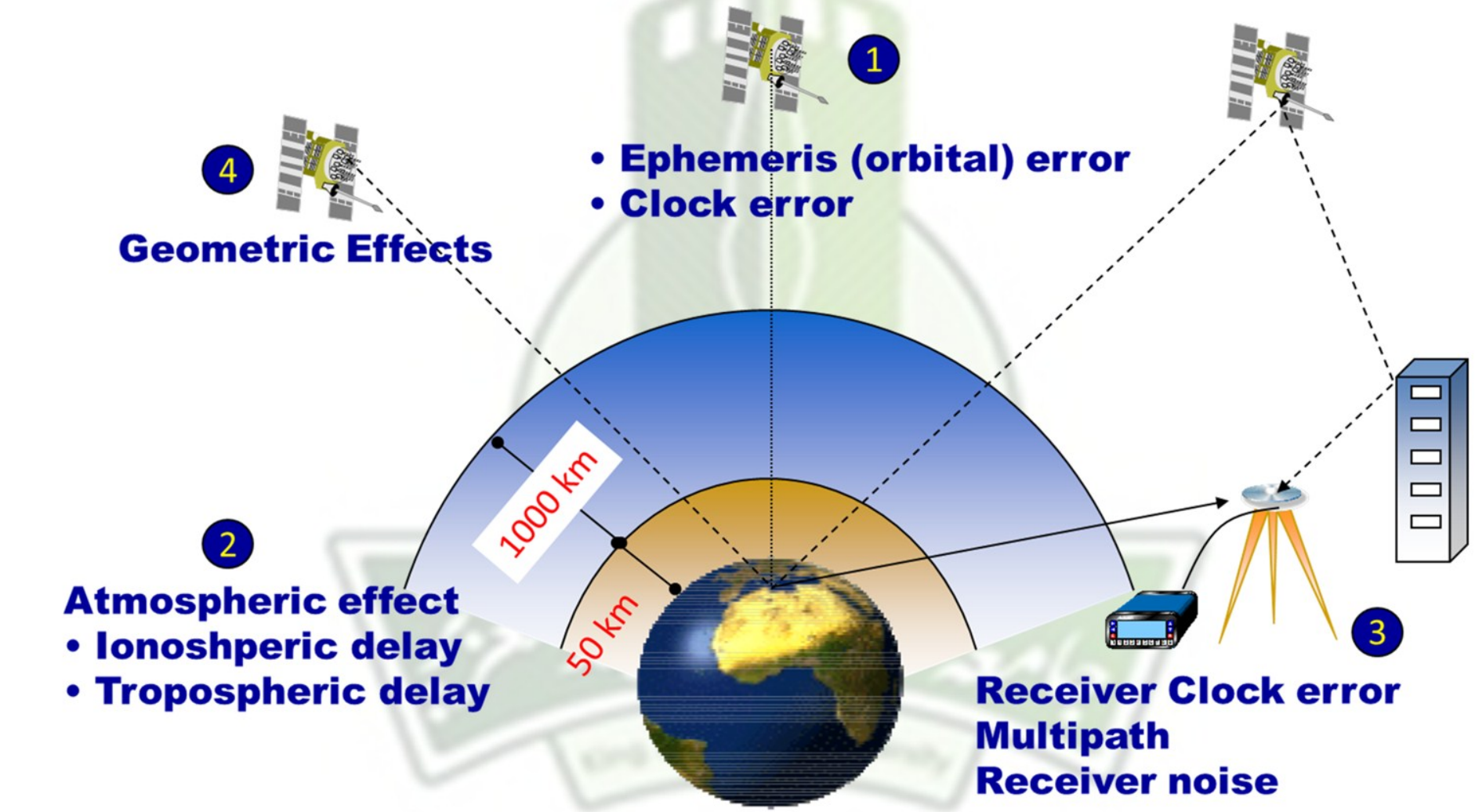
GNSS POSITIONING CONCEPT



Longitude: 9°24'23,43"
Latitude: 46°48'37,20"
Altitude: 709,1m
Time: 12h33'07"

GNSS POSITIONING

GNSS SYSTEMS ERRORS



GNSS POSITIONING

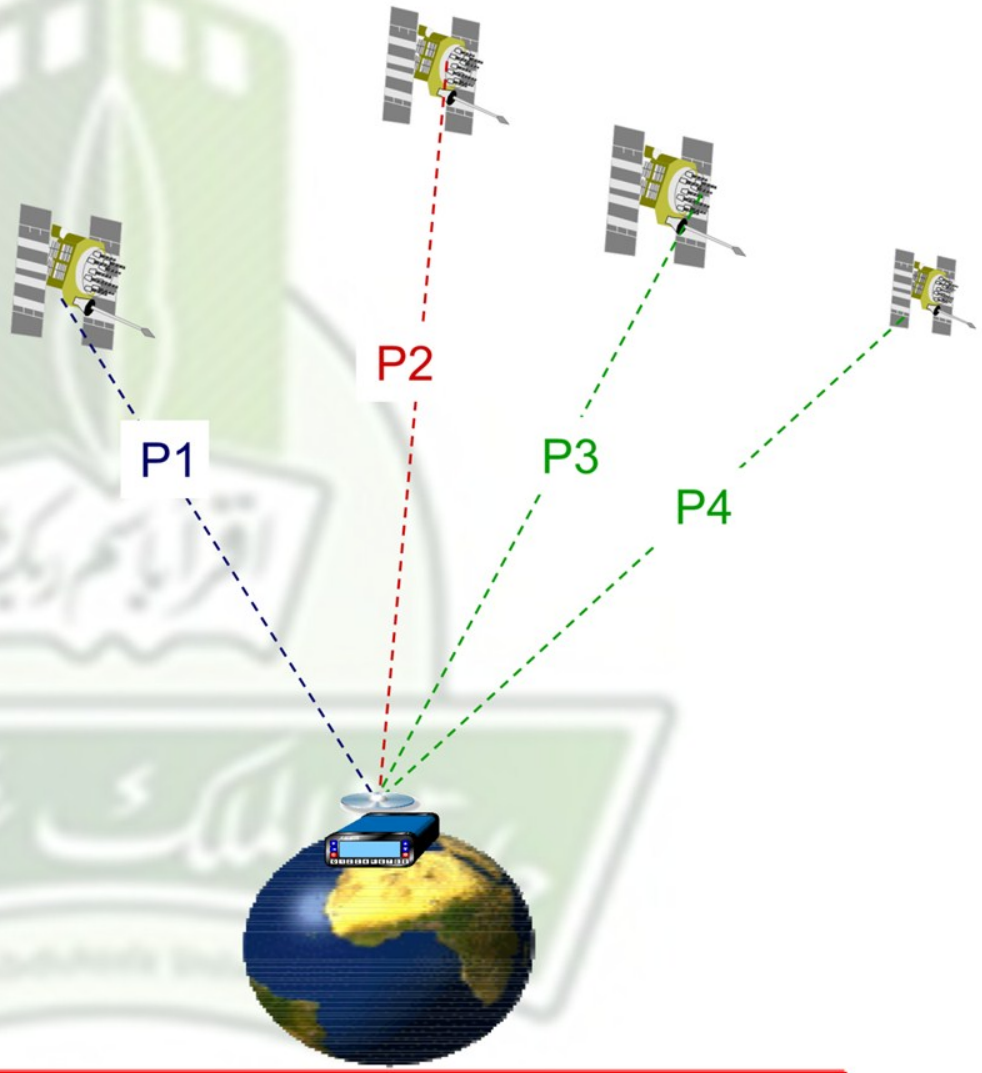
GNSS SINGLE (STANDARD) POINT POSITIONING (SPP)

Known

x_i, y_i, z_i
of at least 4 satellites

Observables:
Codes
P_1, P_2, P_3, P_4

Unknowns:
X, Y, Z of the receiver
+ clock error



Accuracy: ~10 to 15 m (one sigma)

GNSS POSITIONING

GNSS PRECISE POINT POSITIONING (PPP)

MAJOR ERRORS ARE CANCELED OR MODELED

Known

x_i, y_i, z_i
of at least 4 satellites

Observables:
Ionosphere-Free for codes and phases
P_{IF1} , P_{IF2} , P_{IF3} , P_{IF4}
Φ_{IF1} , Φ_{IF2} , Φ_{IF3} , Φ_{IF4}

Unknowns:
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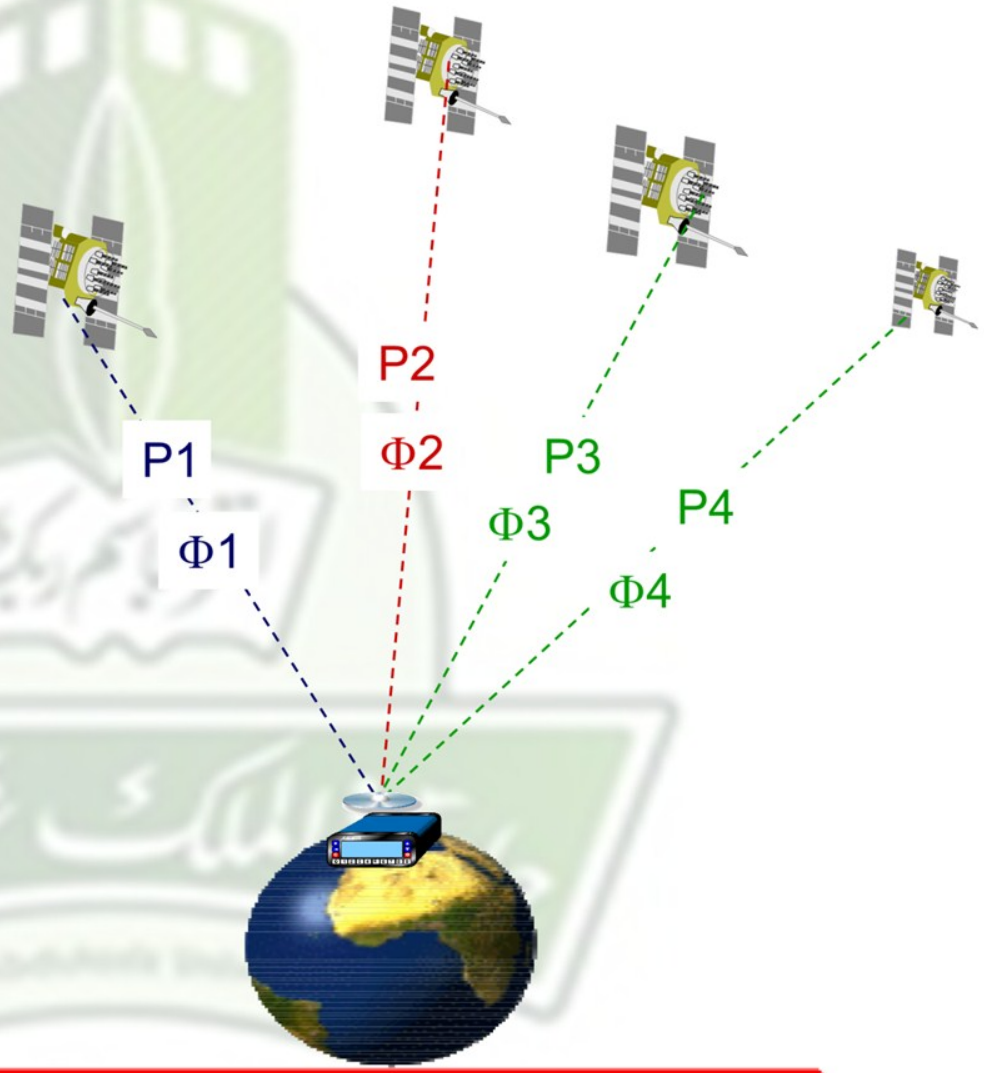


Accuracy: ~ centimeter to decimeter level (one sigma)

GNSS POSITIONING

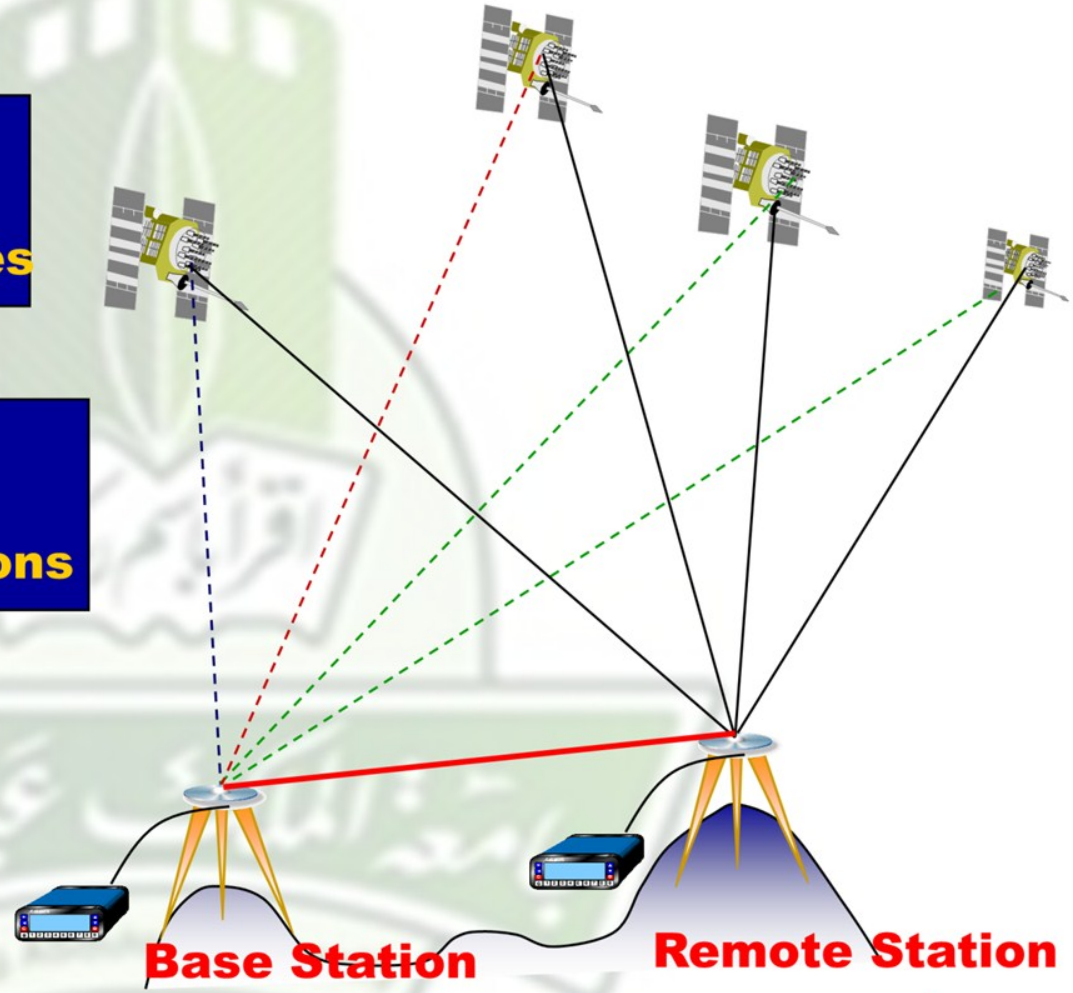
DIFFERENTIAL GNSS POSITIONING DGNSS

MAJOR ERRORS ARE REDUCED USING CODE CORRECTIONS FROM BASES

Known: X_S Y_S Z_S
of at least 4 satellites
+ Base Stations Coordinates

Measurements: Ranges
R_1 , R_2 , R_3 , R_4
from base and Remote Stations

Unknowns:
X, Y, Z of the receiver



Positioning Accuracy: few meters (one sigma)

GNSS POSITIONING

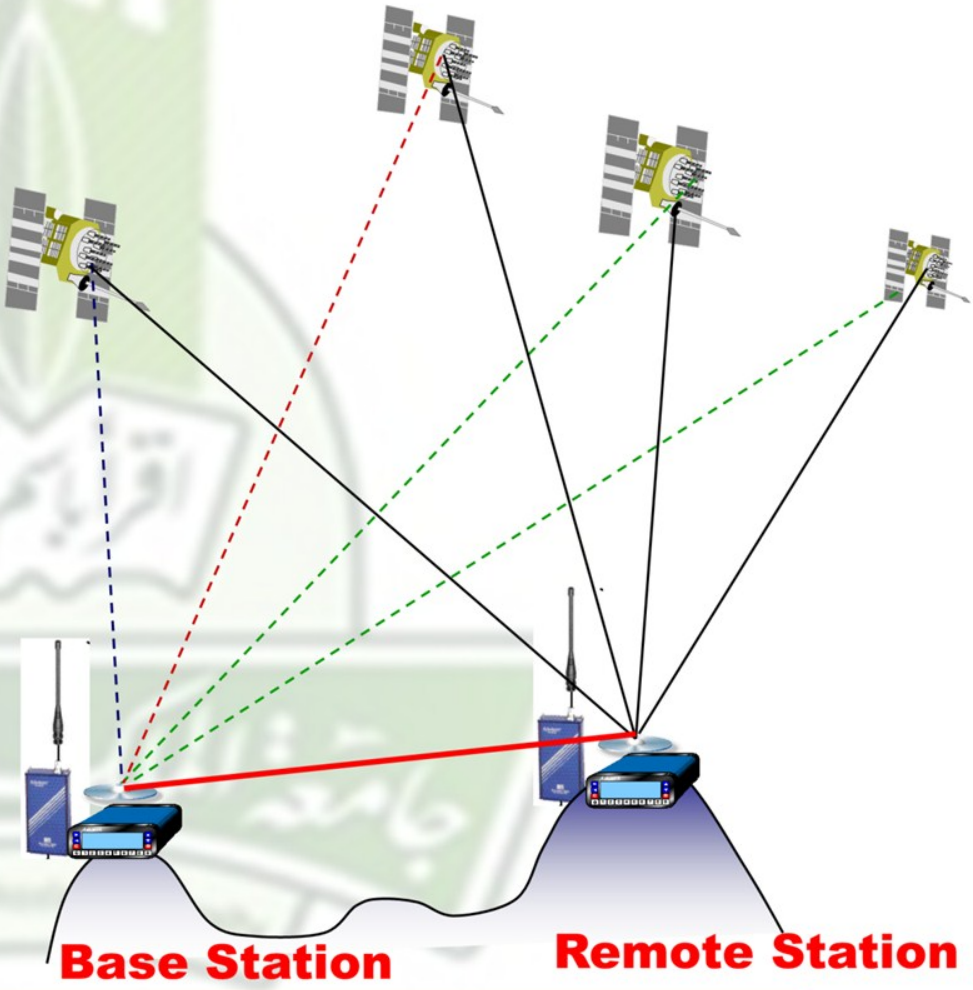
REAL-TIME KINEMATIC (RTK) GNSS POSITIONING

MOST OF THE ERRORS ARE REDUCED OR CANCELED

Known: x_i, y_i, z_i
of at least 4 satellites
+ Base Station Coordinates

Observables:
double differences
between base and remote
Stations for codes
$\nabla\Delta\Phi_{12}$, $\nabla\Delta\Phi_{13}$, $\nabla\Delta\Phi_{14}$

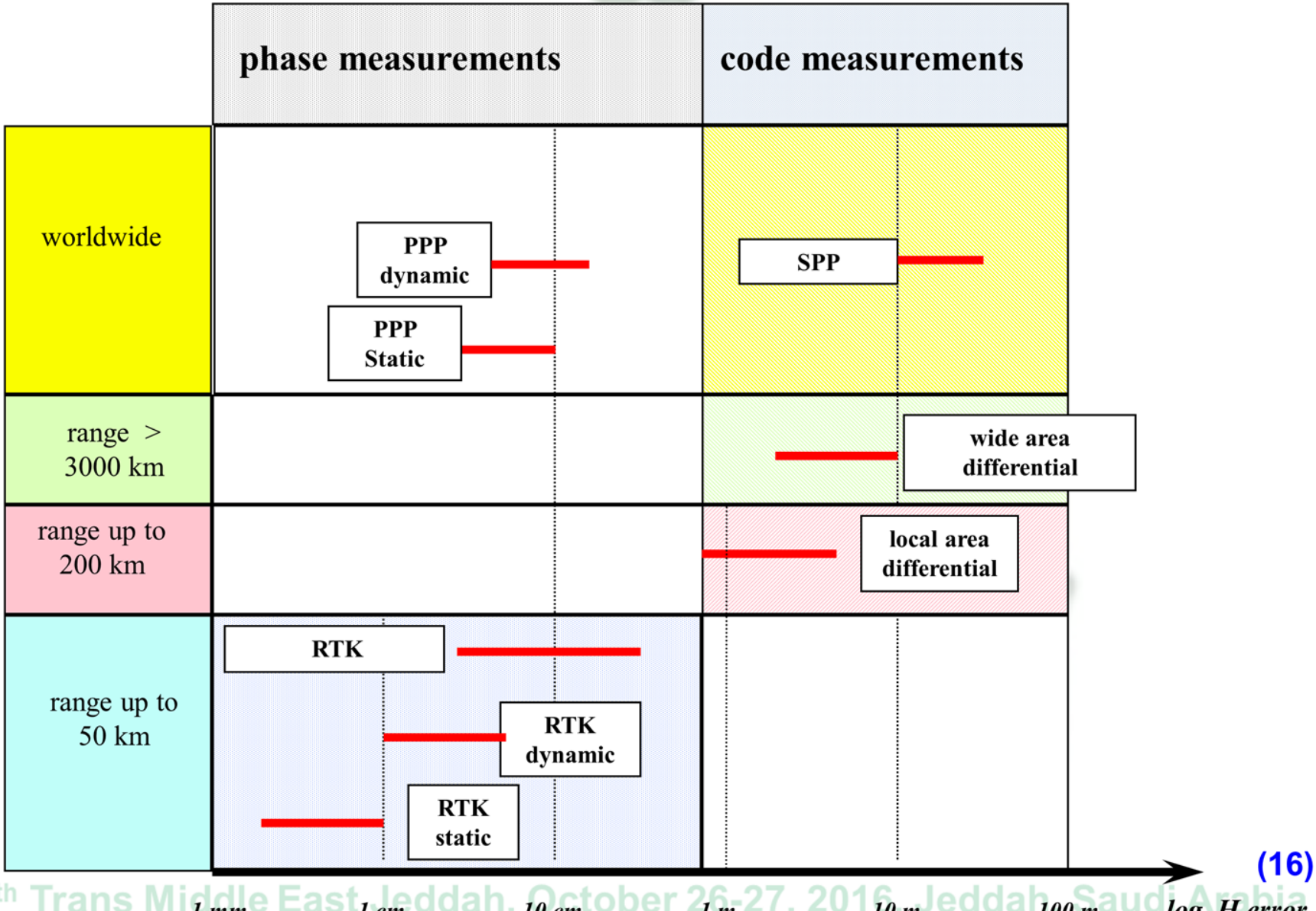
Unknowns:
Estimate baseline dx, dy, dz
and then X, Y, Z of the receiver



Positioning Accuracy: sub centimeters (one sigma)

GNSS POSITIONING

GNSS POSITIONING TECHNIQUES



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GNSS POSITIONING FOR MARITIME NAVIGATION

SHIPBORNE GNSS EMBEDDED SYSTEM

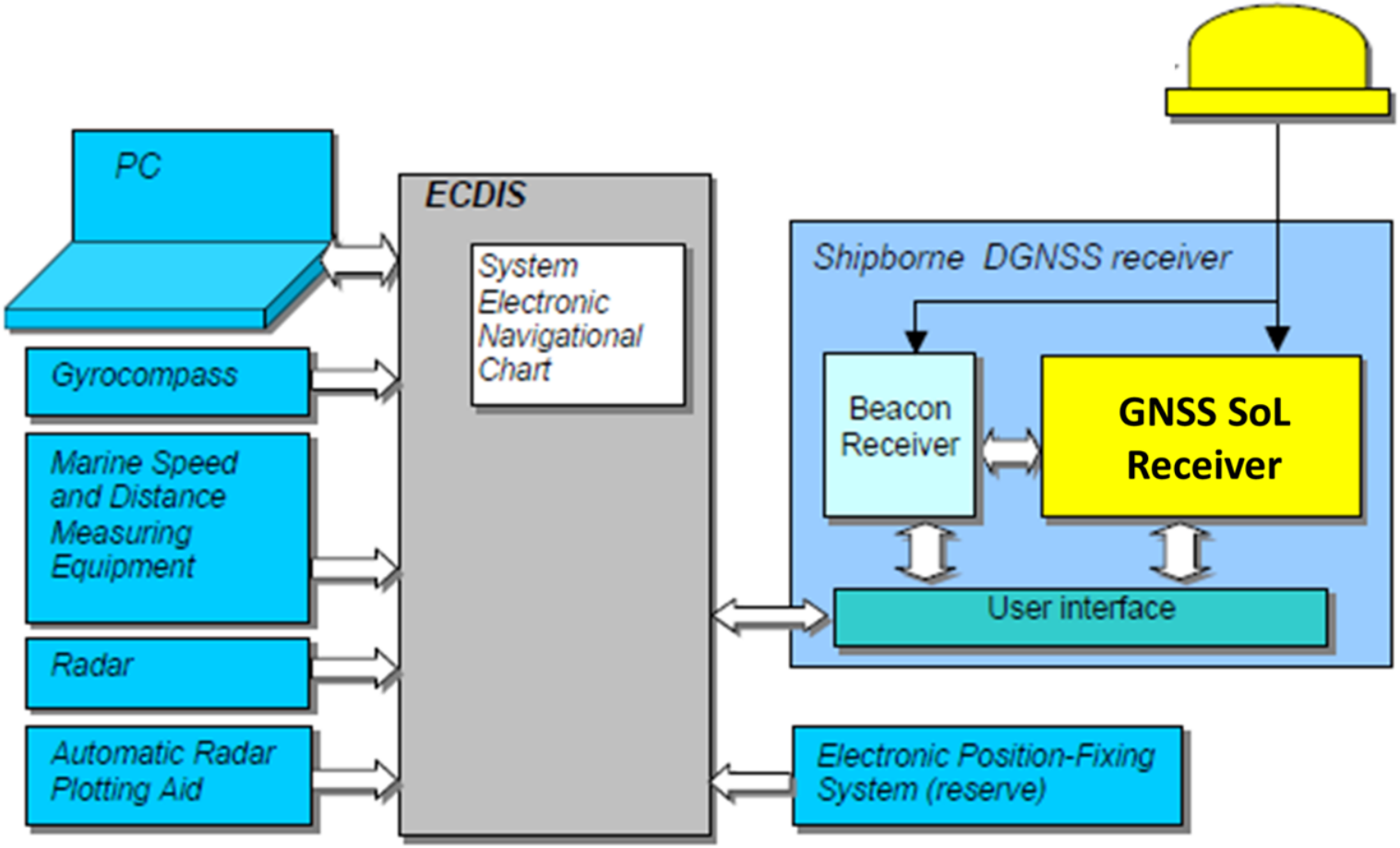
The following maritime equipment require an embedded GNSS positioning capability:

- **AIS – Automatic Identification System;**
- **ECDIS – Electronic Chart Display and Information System;**
- **GMDSS – Global maritime distress and safety system;**
- **VDR – Voyager Data Recorder;**
- **JNSB - Joint Navigation System For a Ship Bridge;**
- **EPIRB - Float-Free Satellite Emergency Position-Indicating Radio Beacon;**
- **SSAS - Ship Security Alert System.**

GNSS POSITIONING FOR MARITIME NAVIGATION

SHIPBORNE GNSS EMBEDDED SYSTEM

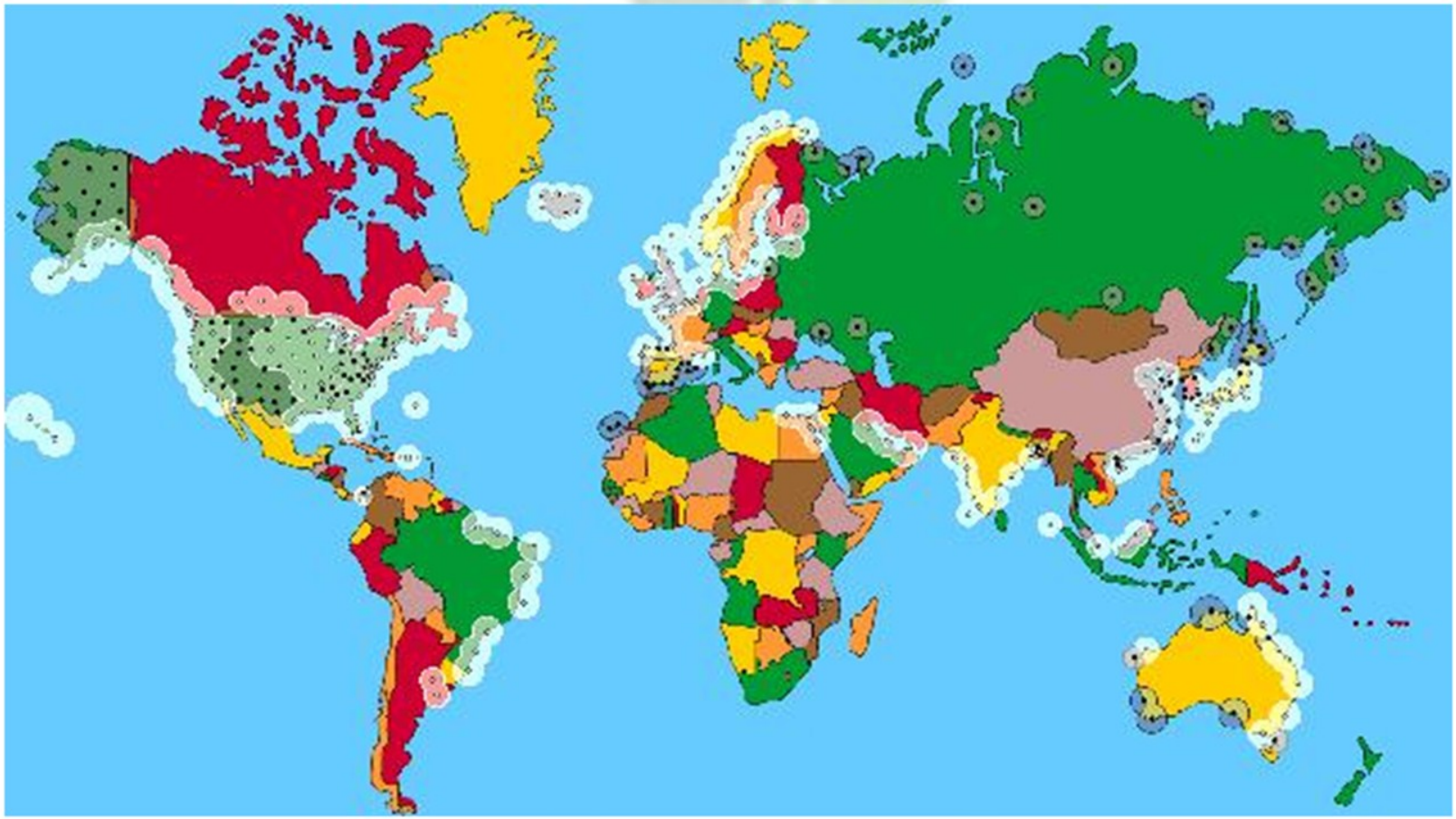
ECDIS example: The accuracy requirements are specified at the level of the requirement for position-fixing for navigation and maneuver according to IMO standards.



GNSS POSITIONING FOR MARITIME NAVIGATION

DGNSS RADIO-BEACONS: LOCAL AREA AUGMENTATION DGPS (LADGPS)

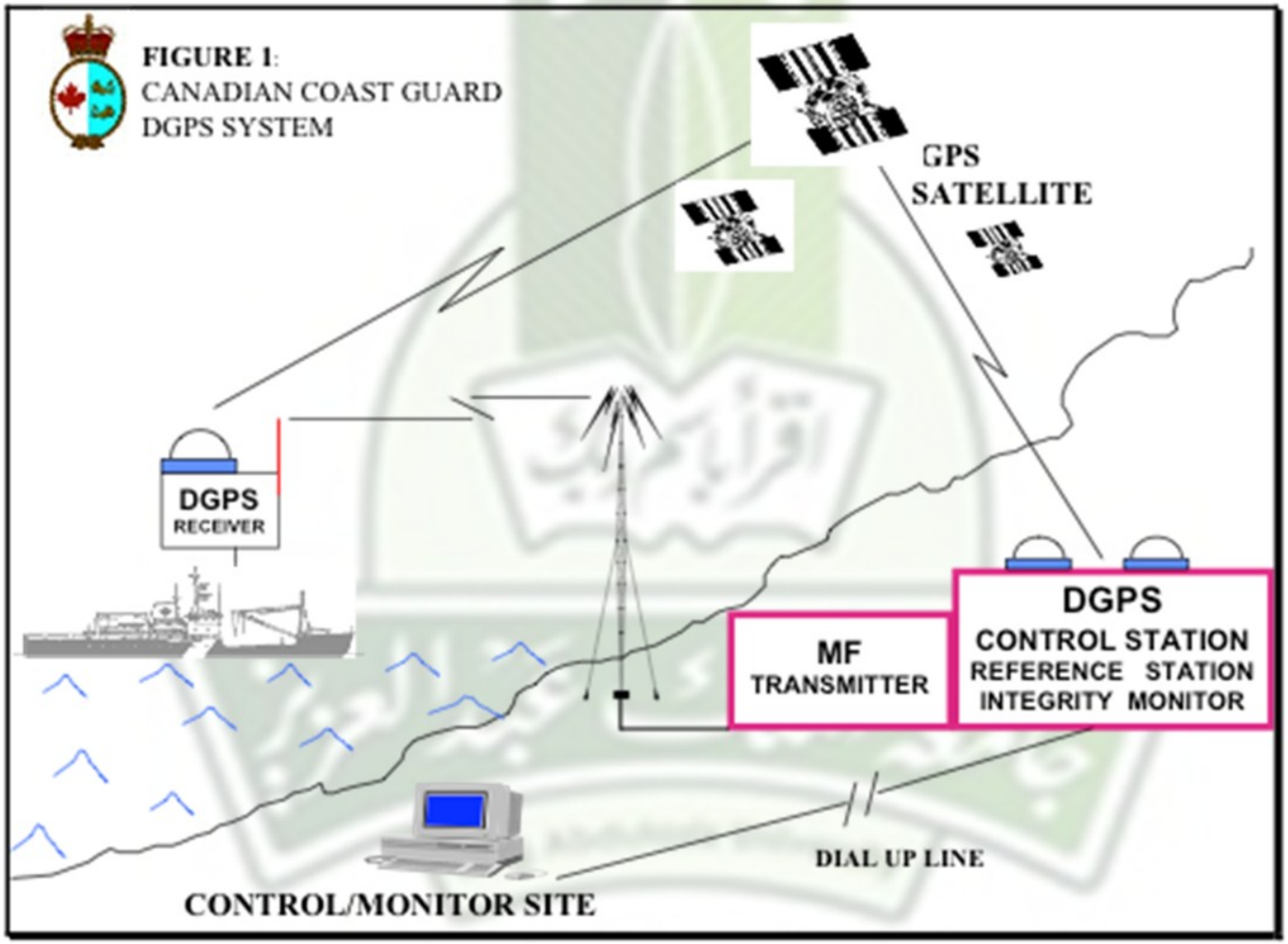
- **DGNSS Radio-beacons coverage (200 -300 km range):**



GNSS POSITIONING FOR MARITIME NAVIGATION

DGNSS RADIO-BEACONS: LOCAL AREA AUGMENTATION DGPS (LADGPS)

Few meters accuracy

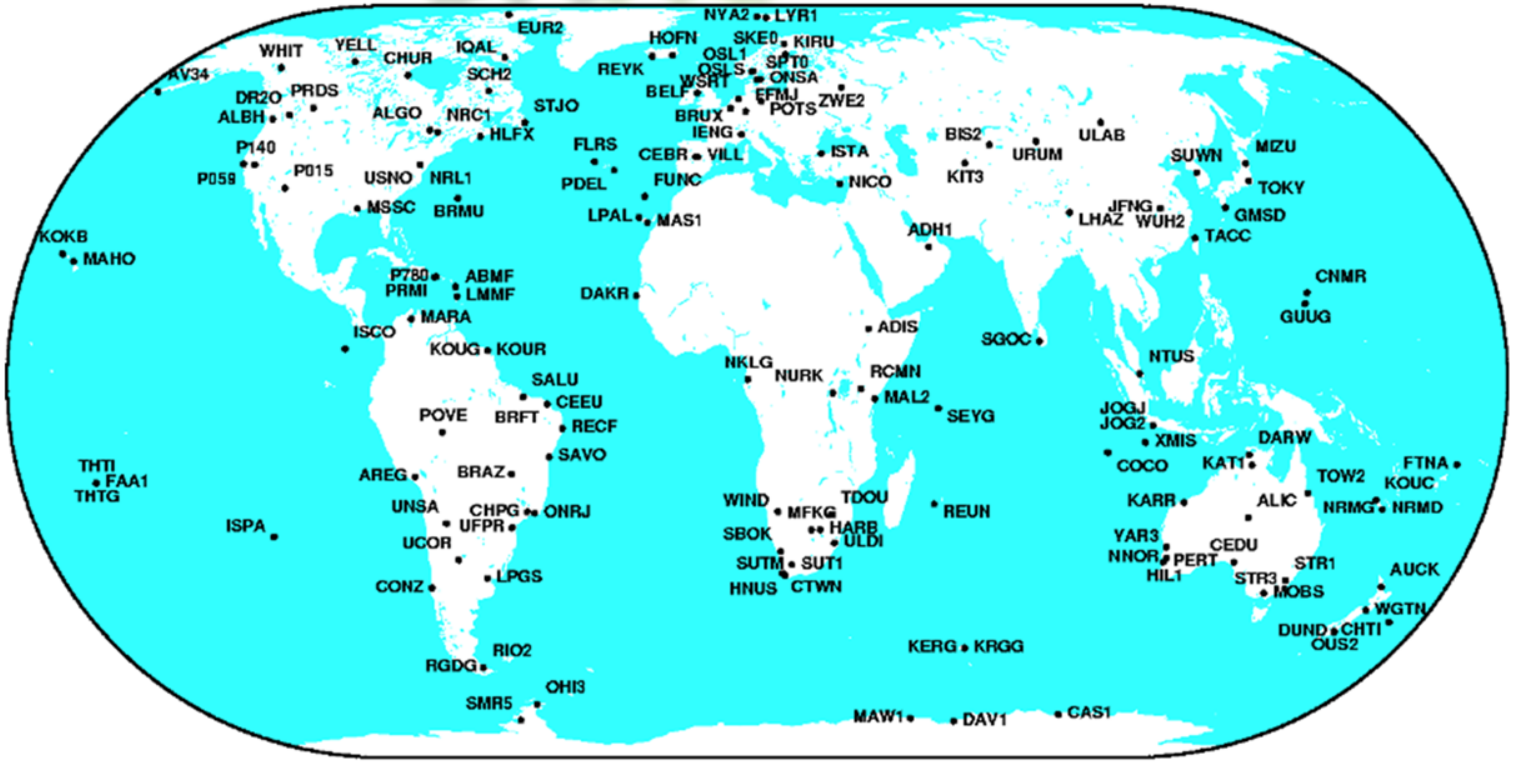


(Courtesy, Canadian Coast Guard)

GNSS POSITIONING FOR MARITIME NAVIGATION

PRECISE POINT POSITIONING (PPP) USING IGS-RTS SERVICE

A PROMISING WORLDWIDE SATELLITE POSITIONING SOLUTION



The real time IGS network

Product	Parameter	Accuracy	Latency
Real-Time Service (RTS) (estimated)	orbit	5 cm	25 s
	clock	0.5 ns	

GNSS POSITIONING FOR MARITIME NAVIGATION

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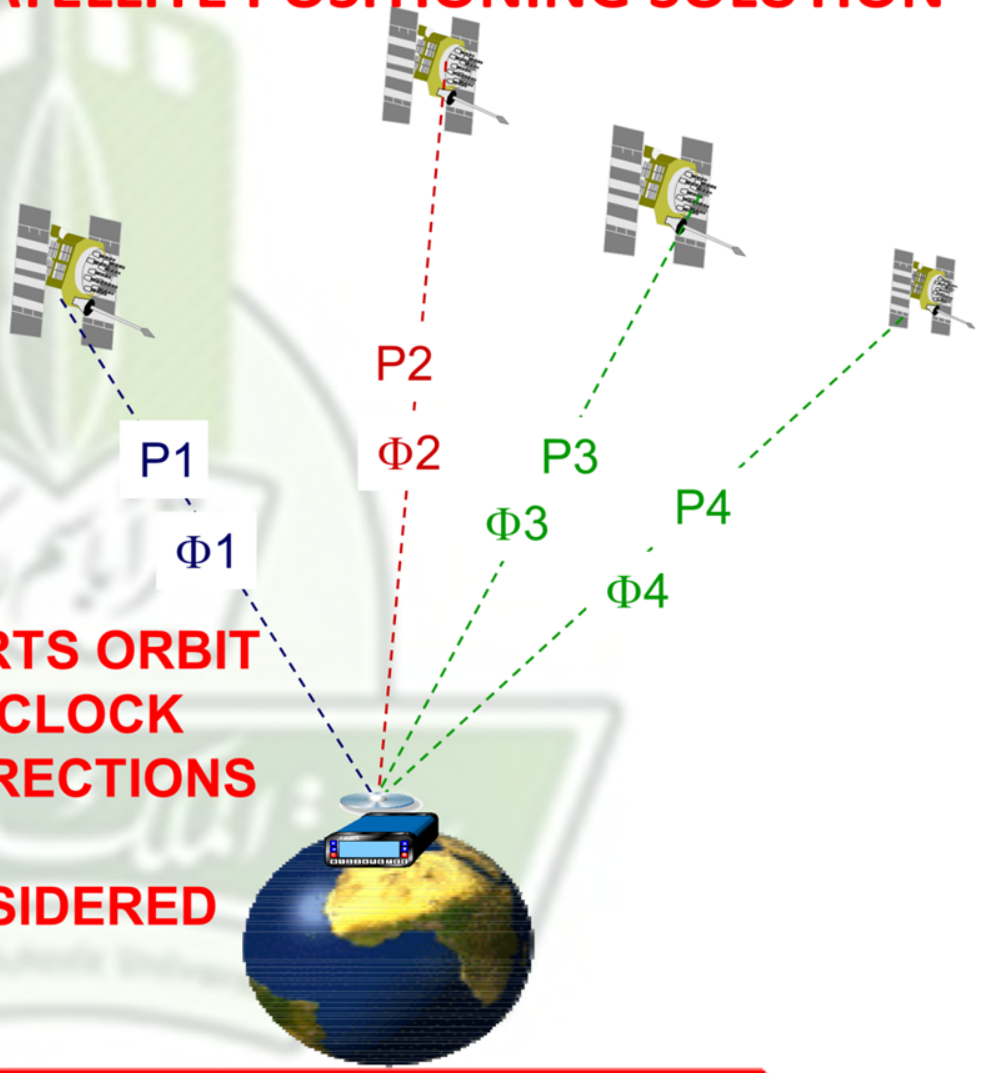
X, Y, Z of the receiver + clock error

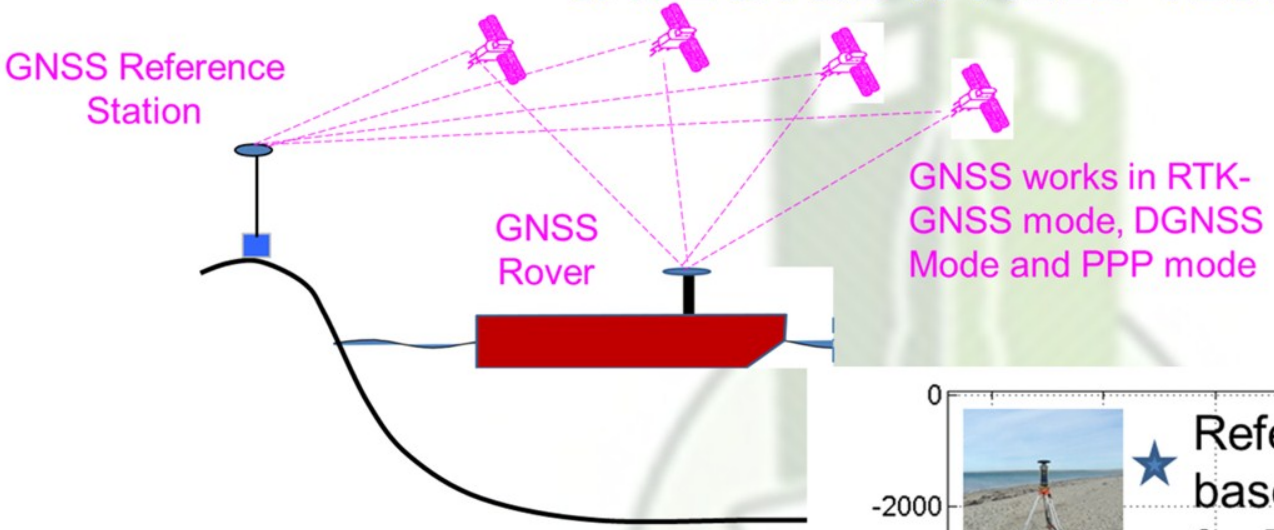


IGS-RTS ORBIT AND CLOCK CORRECTIONS ARE CONSIDERED

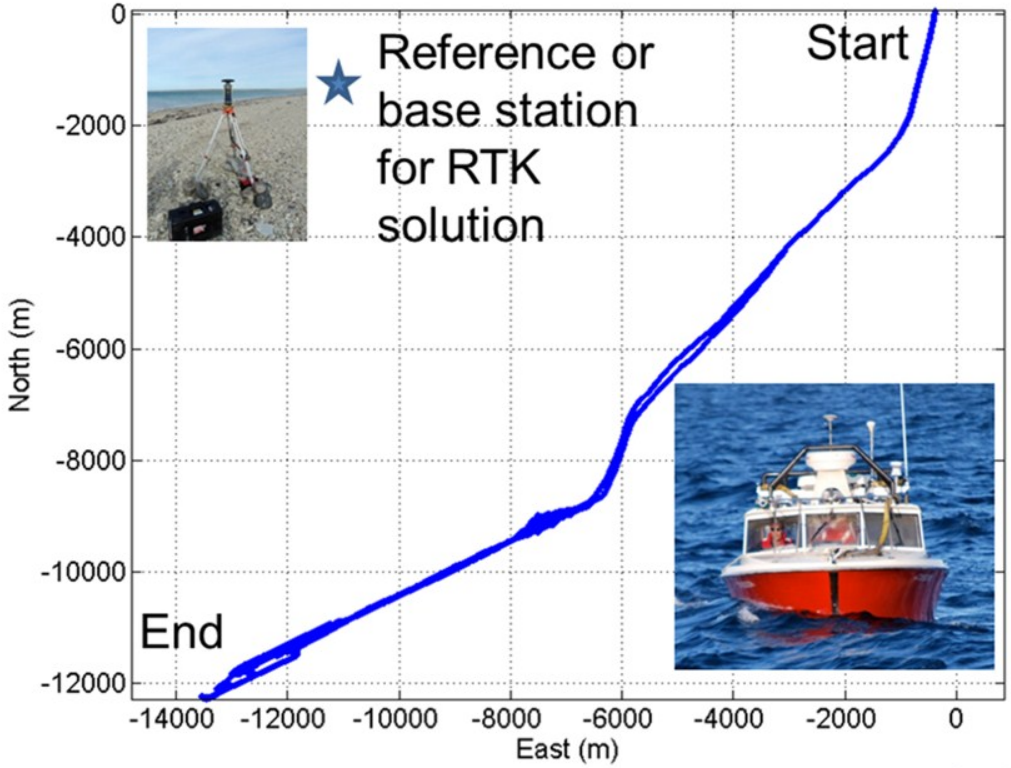
Accuracy: ~ centimeter to decimeter level (one sigma)

GNSS POSITIONING FOR MARITIME NAVIGATION

CASE STUDY: FIELD TEST



BD960 GNSS Receiver (tracked signals)
• GPS L1 / L2
• GLONASS L1 / L2
• WAAS



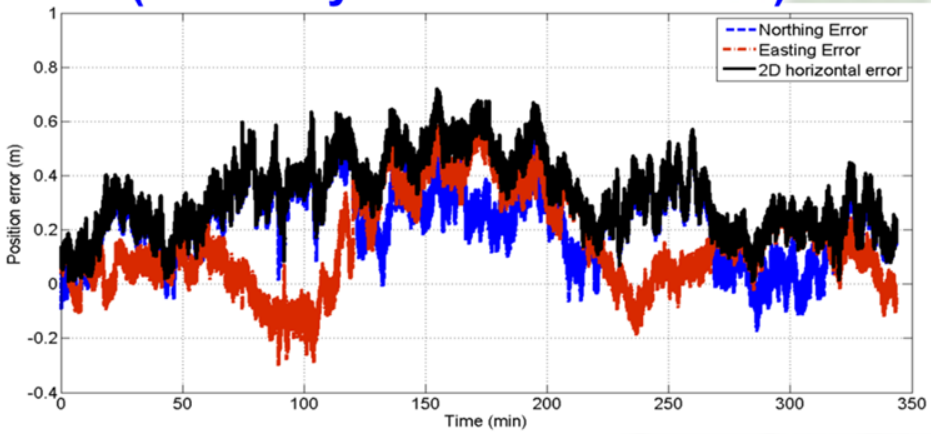
Error Estimation:

- Error of PPP = PPP-RTK
- Error of DGNSS = DGNSS-RTK

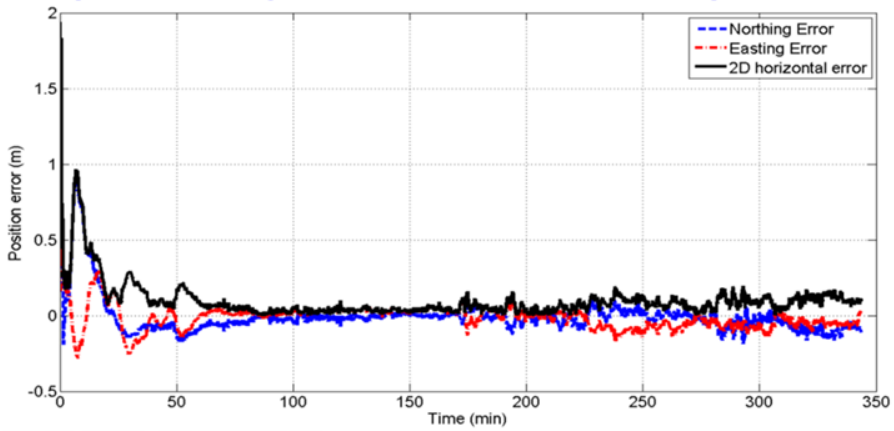
GNSS POSITIONING FOR MARITIME NAVIGATION

CASE STUDY: ACCURACY OF DGNSS AND PPP-GNSS WITH IGS-RTS SERVICE SOLUTIONS

DGNSS-based solution errors (accuracy = 0.9 m at 95% CL)



PPP-based GNSS solution errors (accuracy = 0.2 m at 95% CL)



Navigation phase	Does DGNSS-based solution meets IMO requirements?		Does IGS-RTS PPP-based solution meets IMO requirements?	
	Horizontal accuracy	Integrity	Horizontal accuracy	Integrity
Ocean / Coastal / Port approach / Inland waterway (IMO accuracy = 10 m)	Yes	Yes	Yes	Yes Immediately
In port navigation (IMO accuracy = 1 m)	Yes	Yes	Yes	Yes after 2 minutes
Automatic docking (IMO accuracy = 0.1 m)	No	No	No	Yes after 40 minutes

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CONCLUSION

- GNSS positioning using DGNSS and PPP solutions were shown in this presentation.
- The accuracy and performance of DGNSS and PPP solutions were investigated whether they fulfill IMO standards.
- The DGNSS-based and PPP-based solutions fulfil the IMO accuracy of for Ocean/Coastal/Port approach/Inland waterway and in port navigation applications with accuracy requirement ranges from 10m to 1m but cannot fulfil the automatic docking application with an accuracy requirement of 0.10m.
- The advantage of IGS-RTS PPP-based GNSS solution over the DGNSS solution is that the PPP-based solution is a worldwide solution but the DGNSS solution is limited to the regional area with DGNSS corrections.

Thank you!