The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2333-5

Workshop on Science Applications of GNSS in Developing Countries (11-27 April), followed by the: Seminar on Development and Use of the Ionospheric NeQuick Model (30 April-1 May)

11 April - 1 May, 2012

Introduction to Satellite Navigation

DOHERTY Patricia

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CHESTNUT HILL MA 02467-3862
Massachusetts
U.S.A.

GPS Block 11F Satellite

Introduction to Satellite Navigation using GNSS

Patricia H. Doherty

Boston College

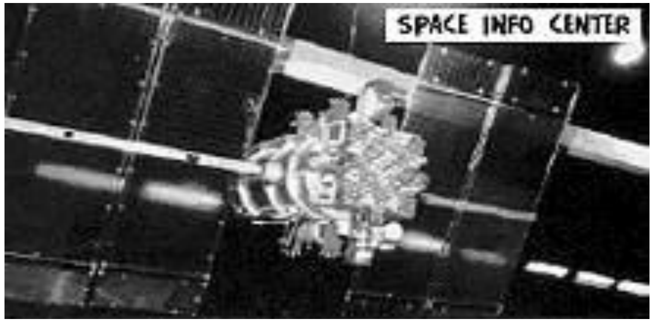
Workshop on Science Applications of GNSS in Developing Countries
11 April 2012 ----- ICTP, Trieste, Italy

Outline

- Basics of Satellite Navigation
  - GNSS Systems
  - GPS System, Measurements, Performance
- Augmentation Systems
  - Differential GPS (DGPS)
  - Space Based Augmentation Systems (SBAS)
  - Ground Based Augmentation Systems (GBAS)
- Practical Applications
- Scientific Exploration
  - Ionospheric Studies
  - Space Weather
- Summary

GNSS Systems
Compatible and Interoperable


Galileo (EU)



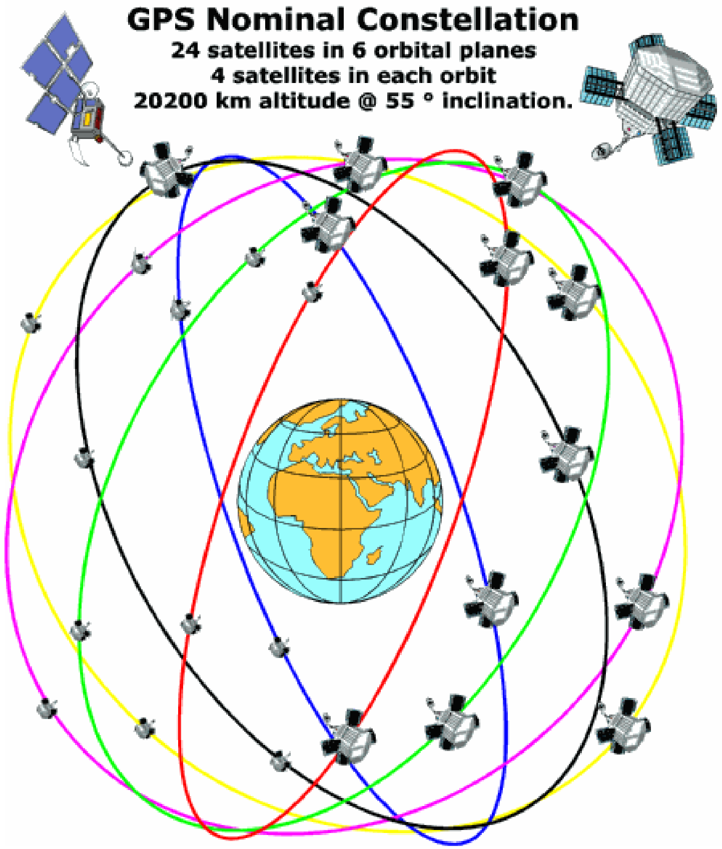
GLONASS


Beidou/COMPASS (China)


Global Positioning System (GPS)

The Global Positioning System (GPS)

- **Worldwide Radio-Navigation System**
  - Developed and maintained by U.S. DoD
  - Original intended use was military
  - Early-on civilian use was enabled
- **Provide 3D Positioning, Velocity and Time**
  - 24hrs/day,7 days/wk, everywhere!
- **GPS Consists of Three Segments**
  - Space Segment
  - Control Segment
  - User Segment
- **Based on Satellite Ranging**
  - Users determine position by measuring the distance from a group of satellites in space



GPS Space Segment

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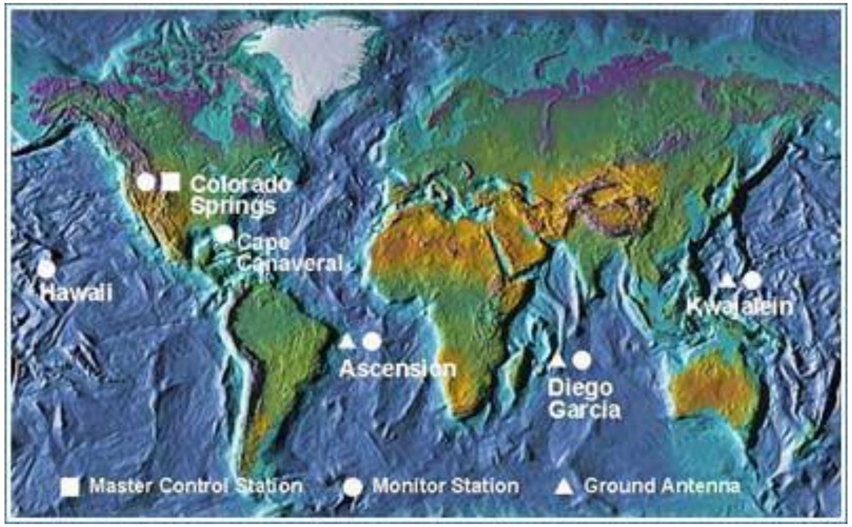
User Segment:
You and 200 Million other people



GPS Control Segment

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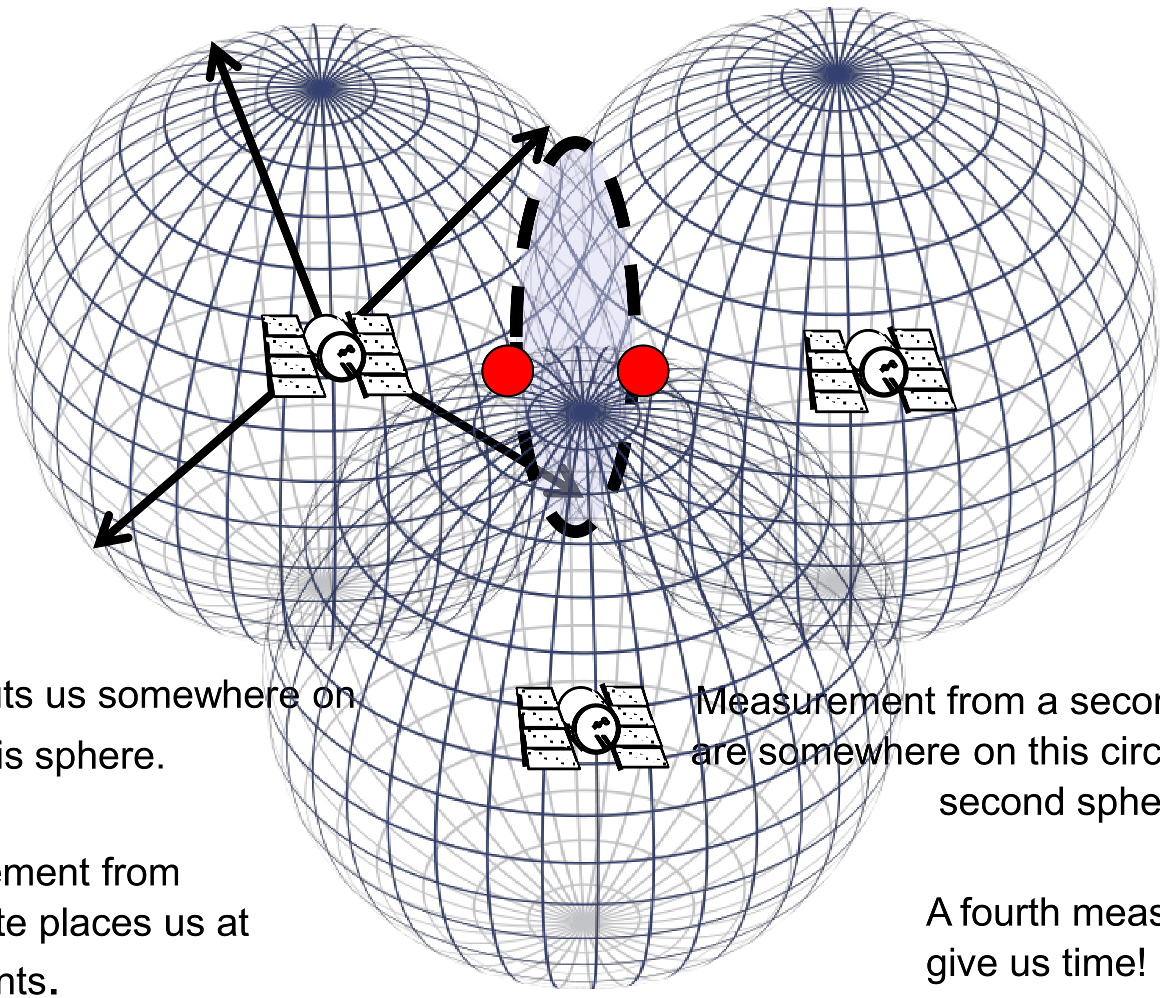
6 Monitor Stations
1 Master Control Station
3 Ground Antennas

How does it work?
Trilateration by Satellite



First measurement puts us somewhere on this sphere.

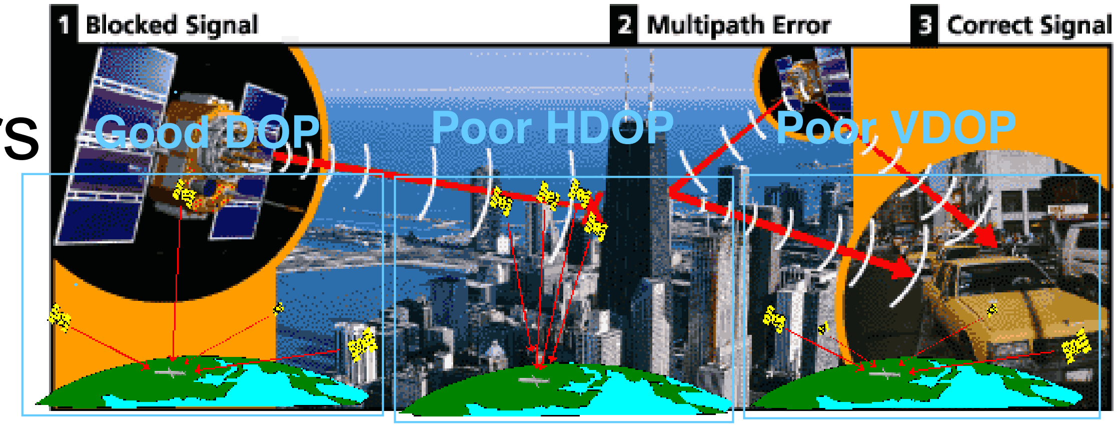
Measurement from a second satellite shows we are somewhere on this circle where the first and second spheres interrsect

Third measurement from another satellite places us at one of two points.

A fourth measurement will give us time!

Sources of GPS Errors

- Receiver clock errors
- Signal multipath
- Orbital errors
- Number of satellites visible
- Satellite geometry
- Tropospheric and Ionospheric delays



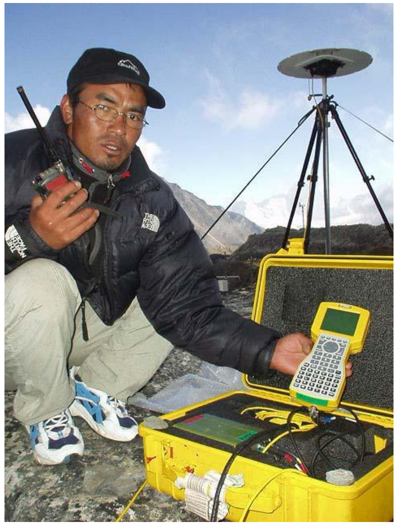
(www.garmin.com)

Typical Standard Positioning Service (SPS) GPS position accuracy:

~10-15 meters (mostly due to the ionosphere)

Two Levels of GPS Service

- **Precise Positioning Service (PPS)**
  - Authorized users ONLY
  - U. S. and Allied military
  - Requires cryptographic equipment, specially equipped receivers
  - Accurate to 21 meters 95% of time
- **Standard Positioning Service (SPS)**
  - Available to all users
  - Accuracy degraded by Selective Availability until May 2000
    - Horizontal accuracies ~100 m
  - Current accuracy similar to PPS (≤15m)
    - Less for Augmented GPS: DGPS,SBAS,GBAS



GPS Augmentations

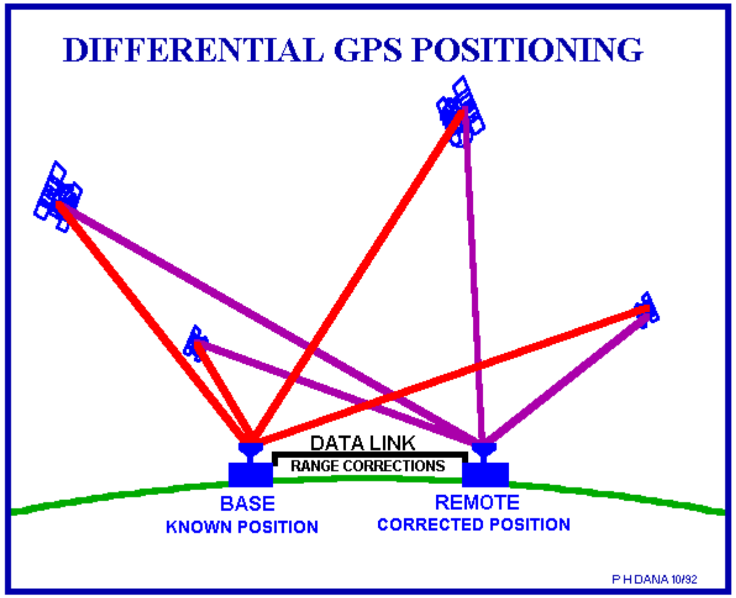
- **Why augment?**
  - **For better accuracy: Mitigate measurement errors**
  - **For robustness: Mitigate effects of**
    - RFI (intentional or not)
    - Signal attenuation due to blockage (foliage, building, or temporary loss of signal
- **How augment?**
  - **Transmit corrections for errors that are correlated spatially and temporally**
    - Differential GPS
    - Wide Area Differential GPS
      - Space Based Augmentation Systems (SBAS)
    - Local Area Augmentation Systems (GBAS)
  - **Assist GPS receiver with complementary technologies (e.g. intertial), signals of opportunity (eLoran), or offloading some functions (to a cell tower in E911)**

Based on P. Misra, 2009

Differential GPS (DGPS)

- Uses 2 receivers
  - Reference receiver
  - Remote/roving receiver

- Reference receiver calculates the errors in the received GPS signals
- Transmits corrections to rover receiver
  - via radio link or mobile phone
- Public and private reference beacon stations are available
  - US Nationwide NDGPS
  - US Maritime MDGPS
  - 40 other countries have similar systems



DGPS Accuracy: ~1–3 m
Degrades with distance

Real Time Kinematic

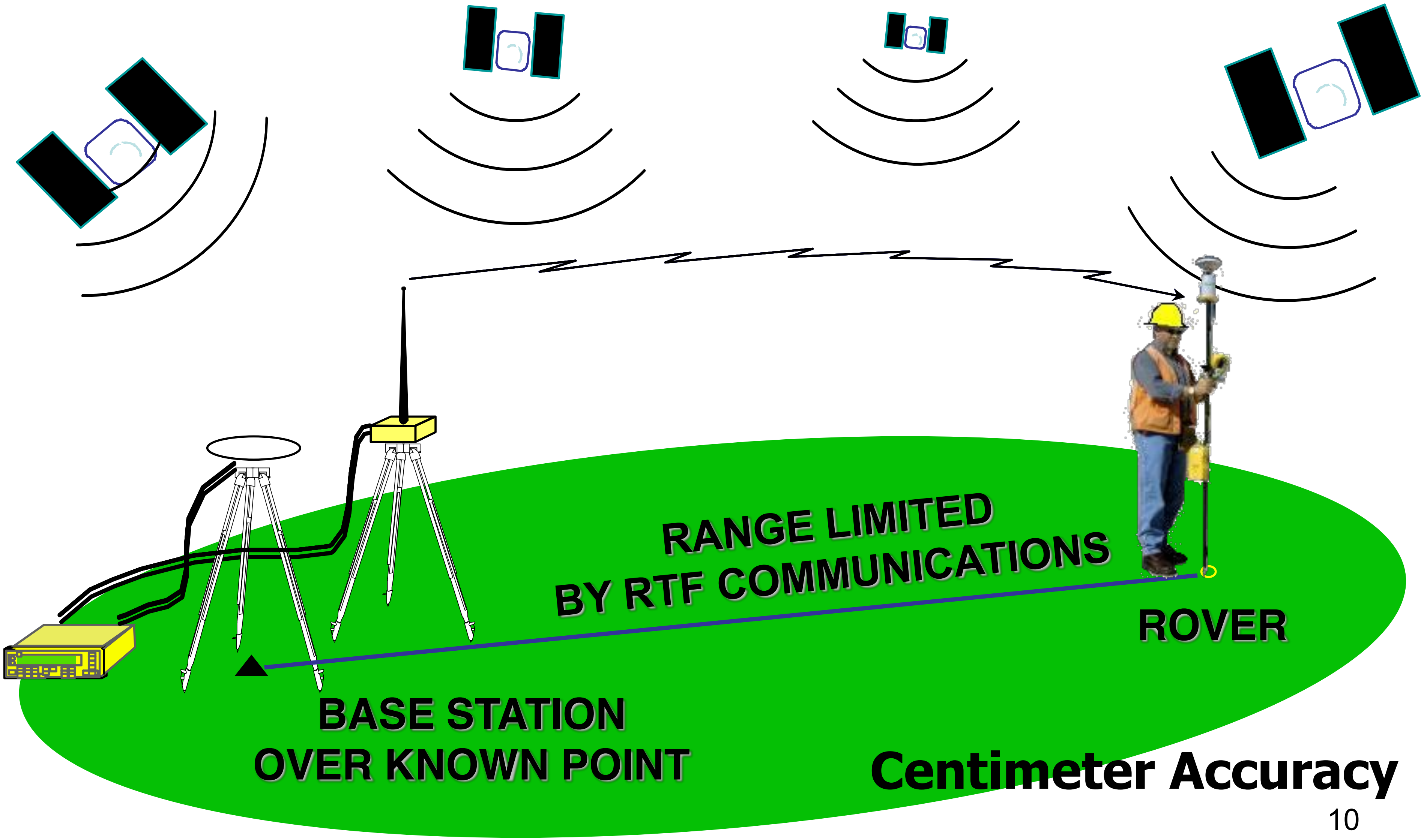
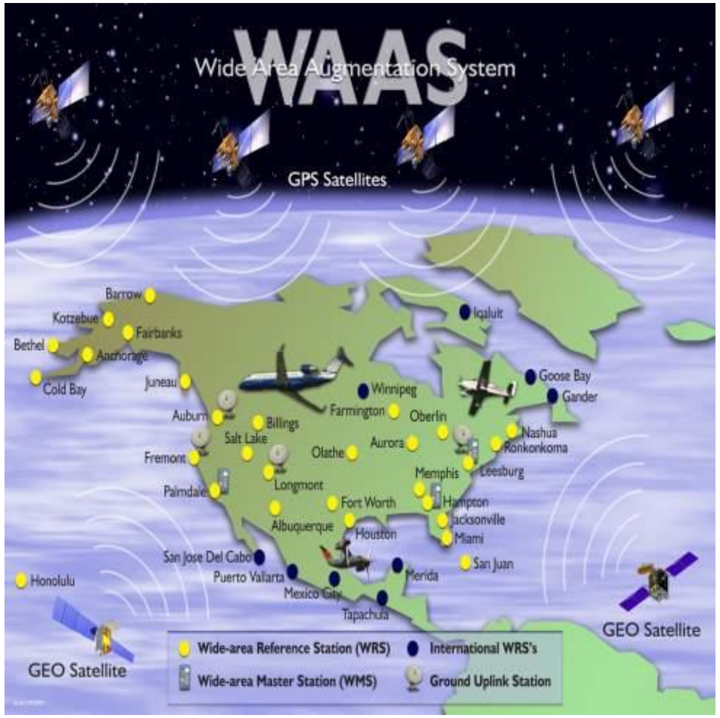


Figure from Dorota Brzezinska

Satellite Based Augmentation Systems (SBAS)

Designed to improve GPS accuracy, availability and integrity for civil aviation.



Current Infrastructure:

•38 Reference Stations

•3 Master Stations

•4 Uplink stations

•2 Communications Satellites

WAAS message provides:

•corrections for satellite orbits, time and the ionosphere

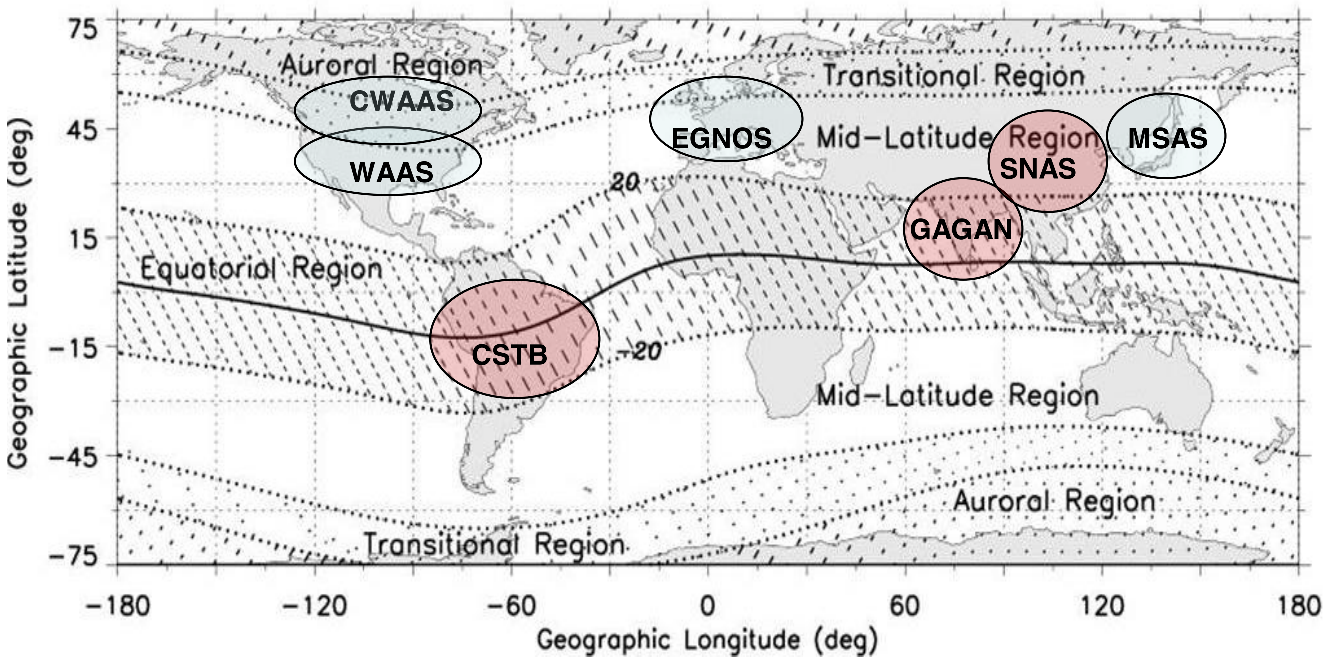
•estimates of the uncertainty of those corrections

- **Future primary means of civil air navigation**
- **For all aircraft in all phases of flight**
  - **Non-Precision Approach (NPA) – en-route**
  - **Vertically Guided Approach (LPV) – runway**
- **First of many worldwide systems – EGNOS, MSAS, GAGAN**

WAAS Accuracy: ~1–3 m

Satellite Based Augmentation Systems (SBAS)

(ICAO is committed to transition to satellite navigation)



WAAS operational in 2003

EGNOS – The European Satellite Augmentation System – 2009

MSAS – The Asia Pacific Satellite Augmentation System – 2007

CSTB – South American Satellite Augmentation System - TBD

GAGAN – Indian Satellite Augmentation System – TBD

SNAS – Chinese Satellite Navigatior Augmentation System - TBD

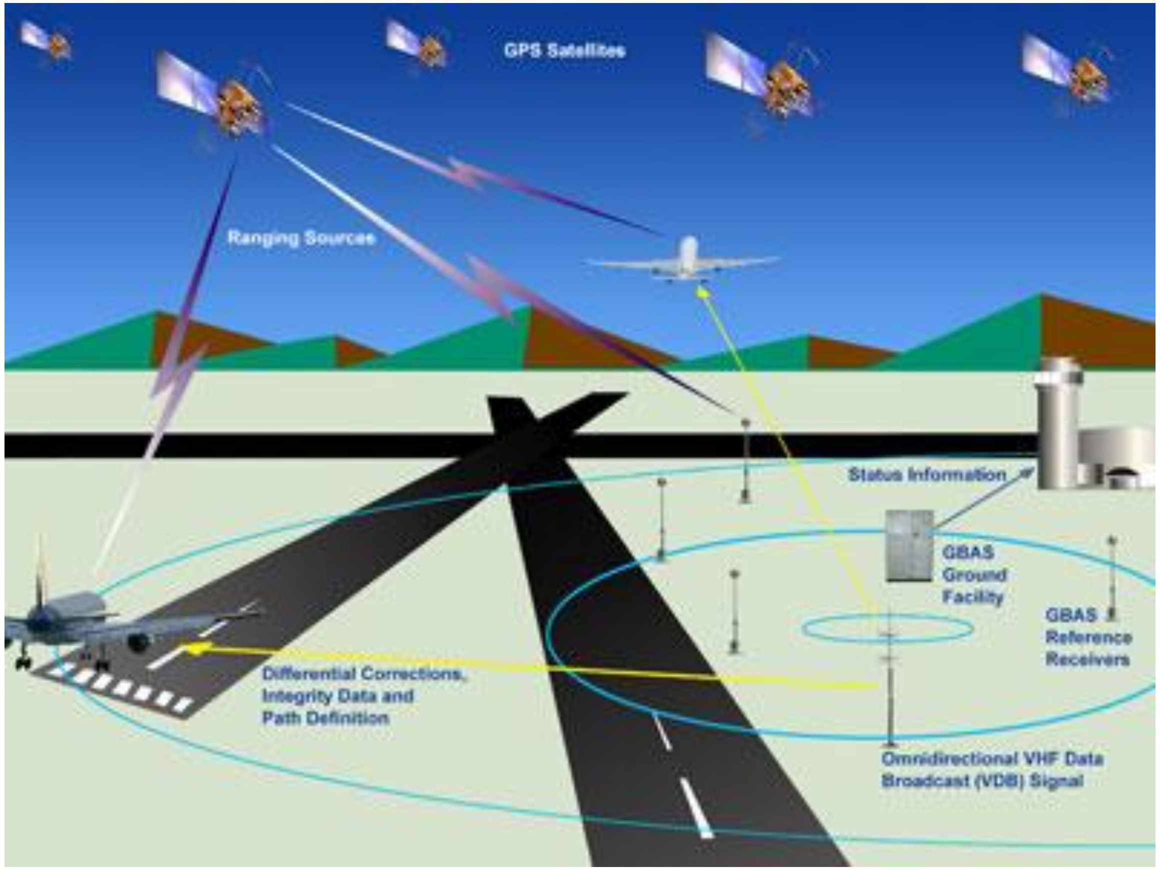
Systems in equatorial regions will face more challenging ionospheric dynamics.

Ground Based Augmentation System (GBAS)

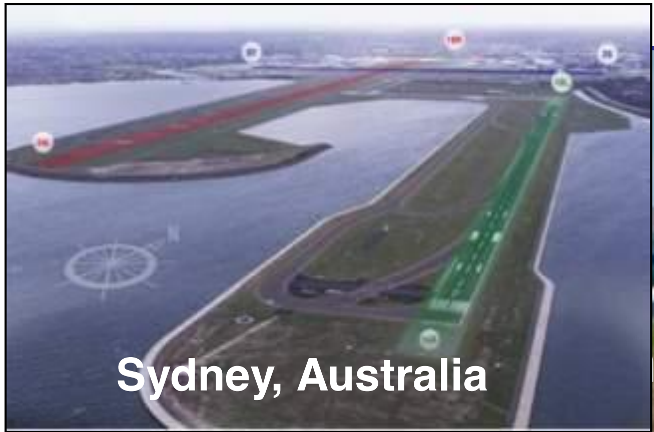
- Provides local airport coverage: ~20-30 mile radius
- 4 Receivers; 1 VHF radio data link from a ground-based transmitter
- Precision Approach for CAT- I, II, III
- Procedures for Arrival and Departure
- Multiple runway coverage at an airport terminal area
- Demonstrated accuracy is < 1 meter

LAAS

Local Area Augmentation System



LAAS/GBAS International Efforts



Typical GPS Ranging Errors

Error Source	SPS GPS	Differential GPS	RTK
User Range Errors			
System Errors Ephemeris Data Satellite Clocks	0.4 -0.5 m 1-1.2m	Removed Removed	Removed Removed
Atmospheric Errors Ionosphere Troposphere	**0.5 – 5m** 0.2 -0.7m	**0.2 – 2.0m** Removed	**0.0005 - .01m** Removed
Total Typical URE Errors	***1.7 – 7.0m***	***0.2 – 2.0m***	***0.0005-0.01m***
User Equipment Errors			
Receiver	0.1 – 3m	0.1 – 3m	Almost All Removed
Multipath	0-10m	0-10m	Greatly Reduced

Applications

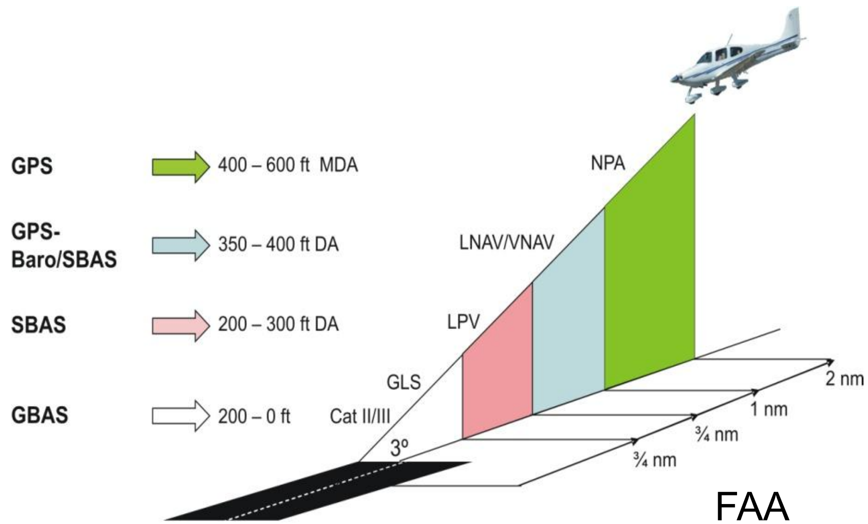
Annual Commerce in GPS Products and Services > $10billion

>200 Million Users

Precision Approach & Landing (SBAS&GBAS)

Improves the accuracy, integrity and availability of GNSS

- **Efficiency**
  - More direct en-route paths
  - Greater runway availability
  - Precision Approach for all users
- **Cost**
  - Low cost avionics
  - Reduction of ground based navigation aides
- **Safety**
  - Vertical Guidance for all phases of flight
    - takeoff, en-route to precision approach
  - Available at all runway poor visibility
  - Situational Awareness



FAA

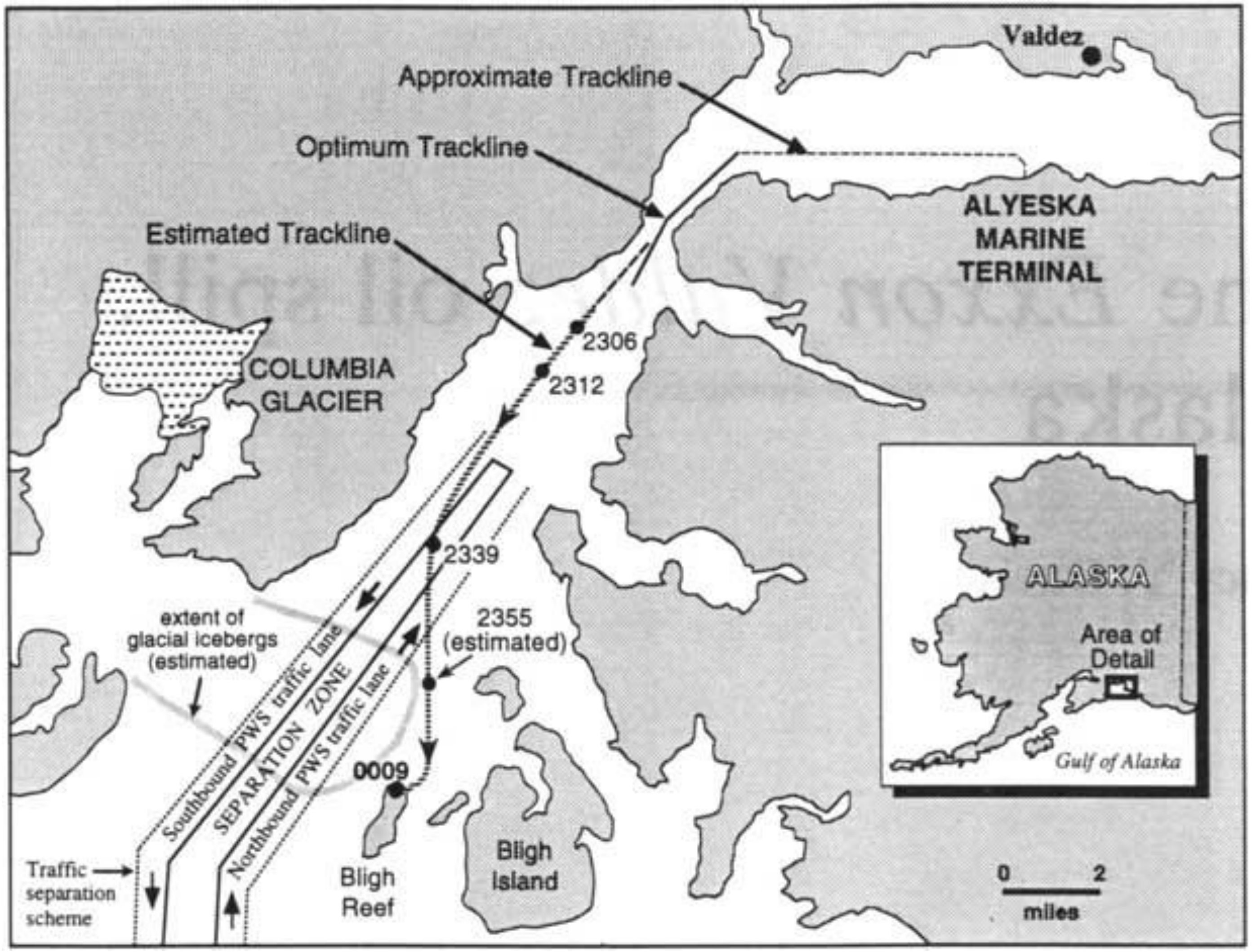
GARMIN Aircraft Receiver

Detroit, Mich., 3 Dec. 1990

Northwest Airlines DC-9

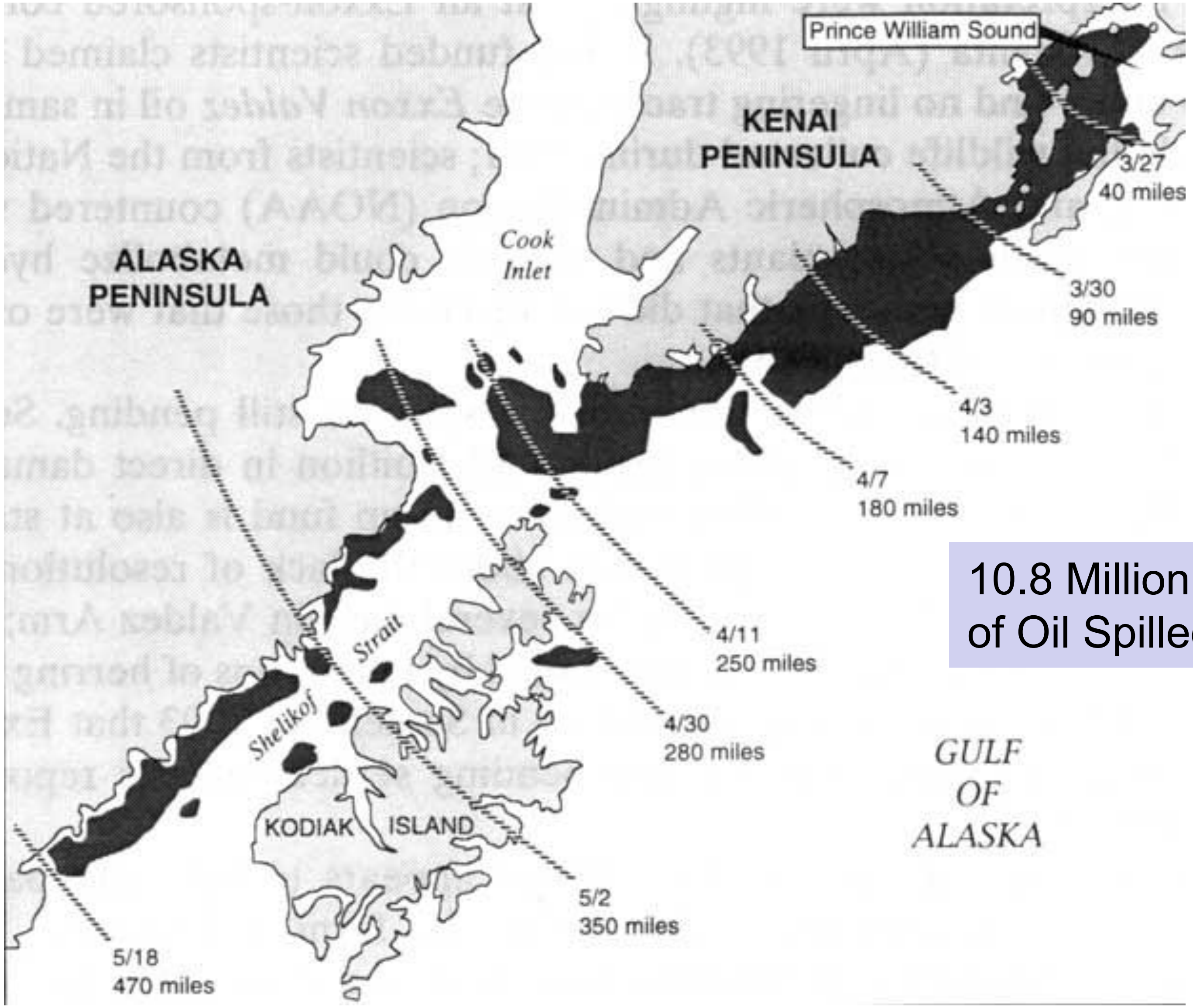
DC9, lost in fog, blunders onto an active runway and is struck by departing 727. 8 dead, 22 injured

Exxon Valdez, March 24, 1989
Ran Aground on Bligh's Reef



2008, Institute of Navigation, Per Enge

Exxon Valdez (continued)



10.8 Million Gallons of Oil Spilled

2008, Institute of Navigation, Per Enge

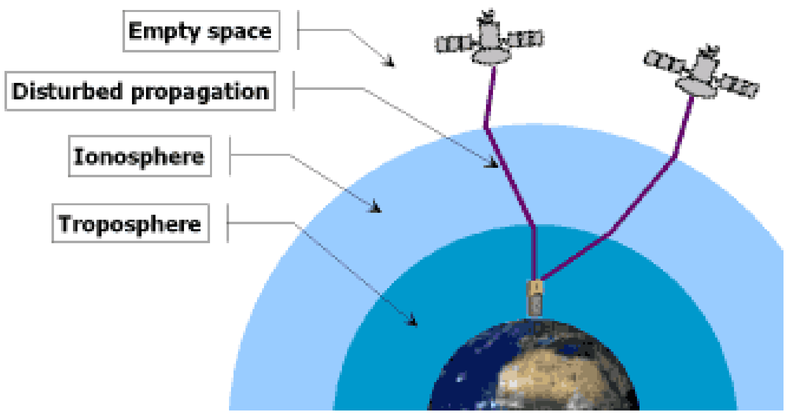
Smart Phones

- Smart Phones (cell phone + PDA)
  - GPS used for emergency calls
  - Emergency location
  - Applications include:
  - Basic maps
  - Turn by turn directions
  - $200 – $400

- Cell Phones with GPS embedded
  - Mostly for E911 calls only

Scientific Exploration with GNSS

- Seismic monitoring & prediction
- Volcano monitoring
- Climate change
- Gravity fields
- Atmospheric science
  - ground water vapor
  - the ionosphere
  - space weather



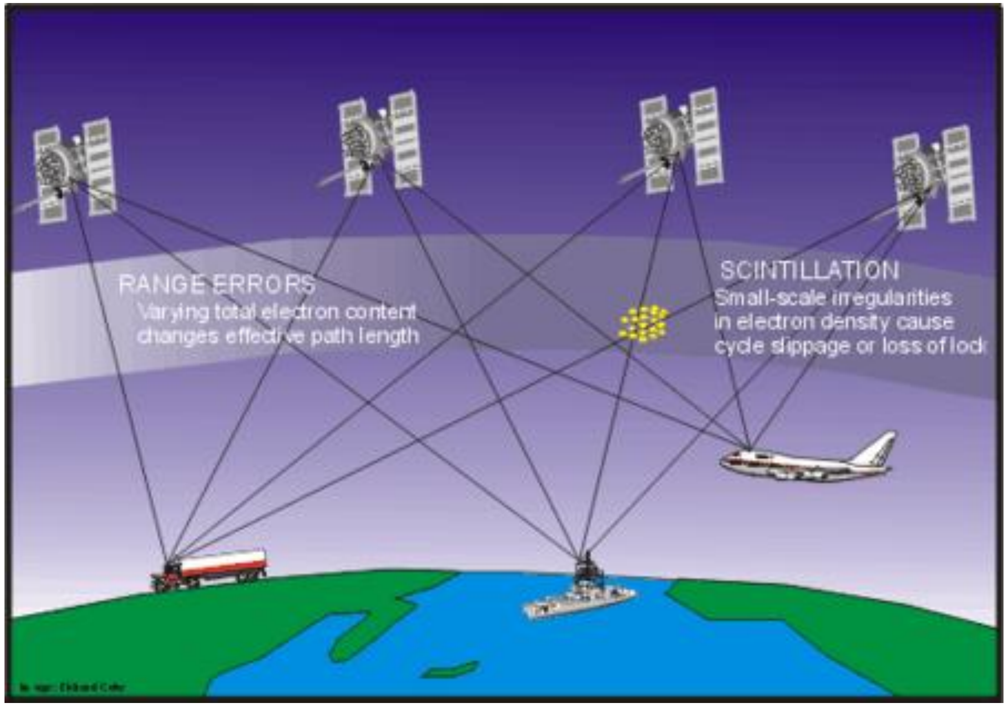
Ionospheric Effects on GPS

•**TEC**

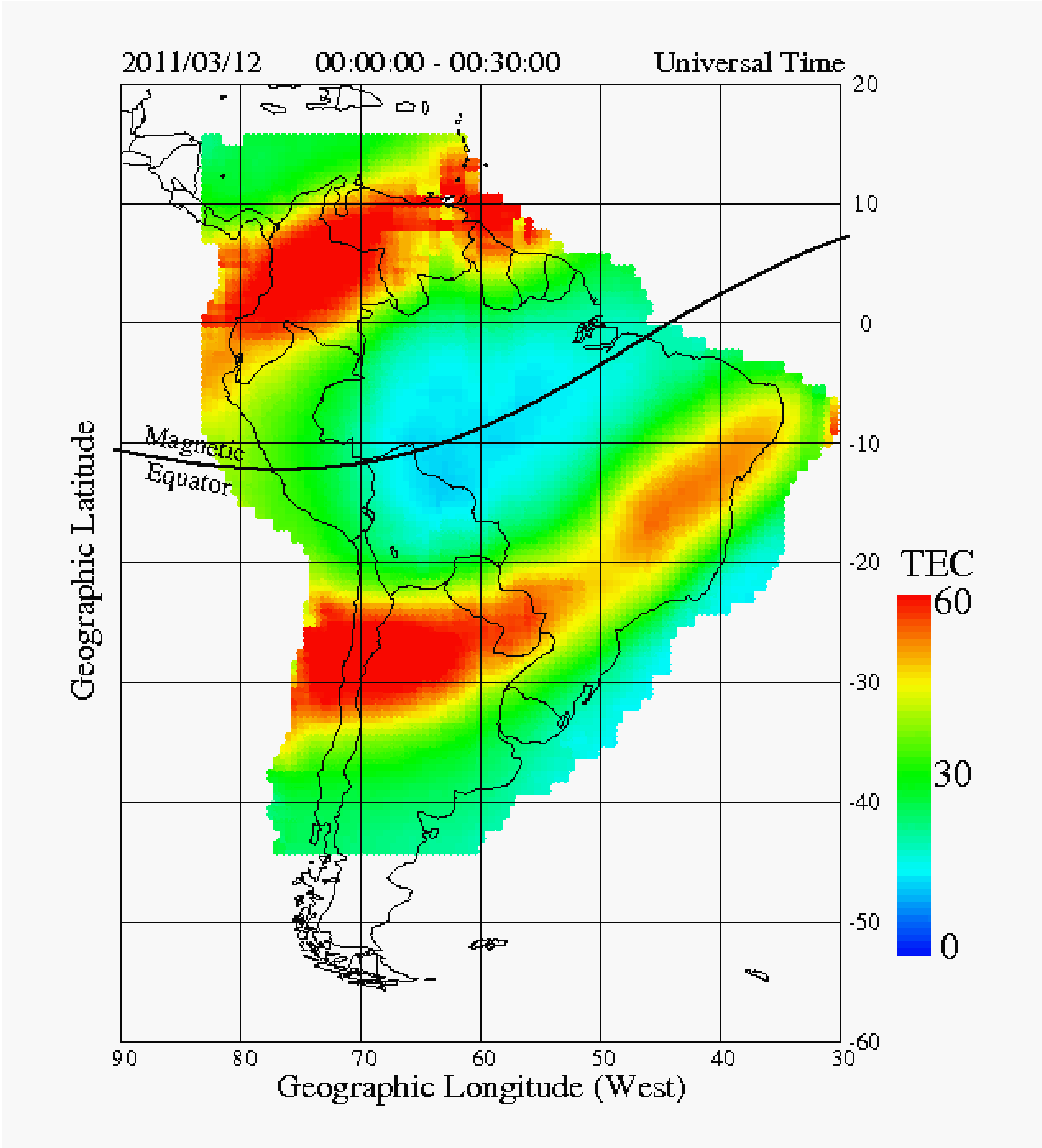
- •Induces Range Errors
- •Highly variable with location, time, season, magnetic and solar activity

•**Scintillation**

- • Induces rapid changes in amplitude and phase of incoming signal
- •Can induce cycle slips and loss of lock that degrade performance



The LISN Network using >75 GPS Receivers



GNSS for Scientific Research in Africa

Africa has a most challenging ionosphere :

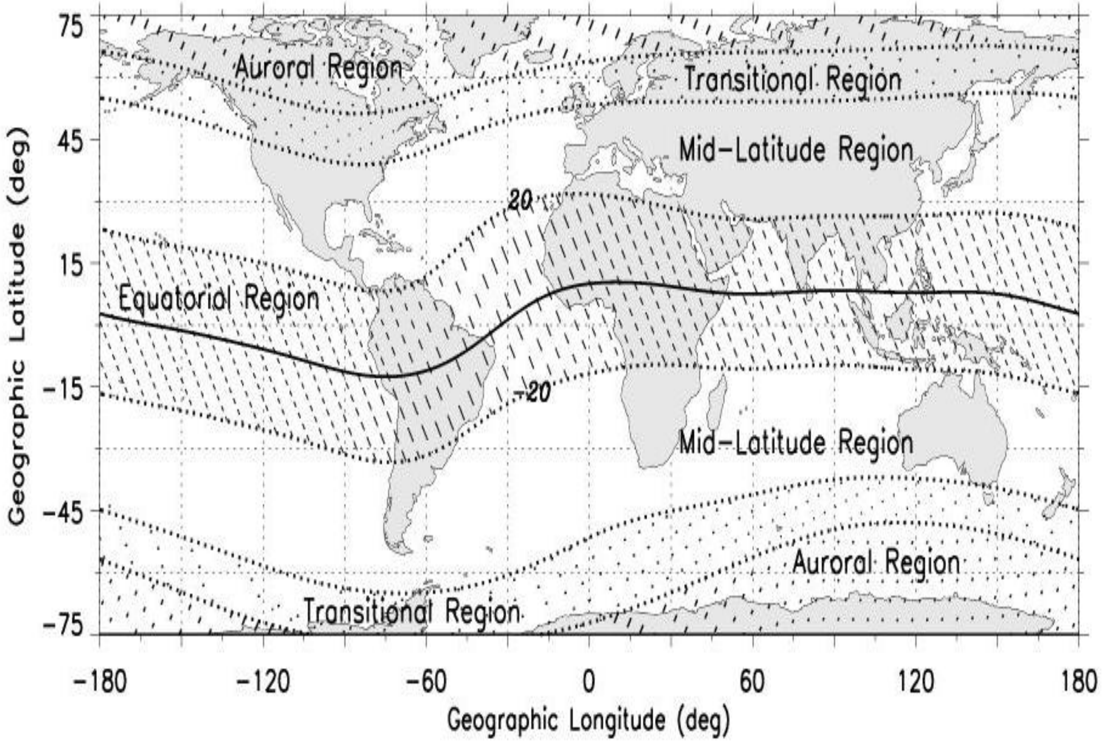
Strong latitudinal gradients

Within northern and southern anomaly peaks

Covers a wide longitudinal region

Depletions and scintillation are potentially the worst conditions worldwide

The Worldwide Ionosphere

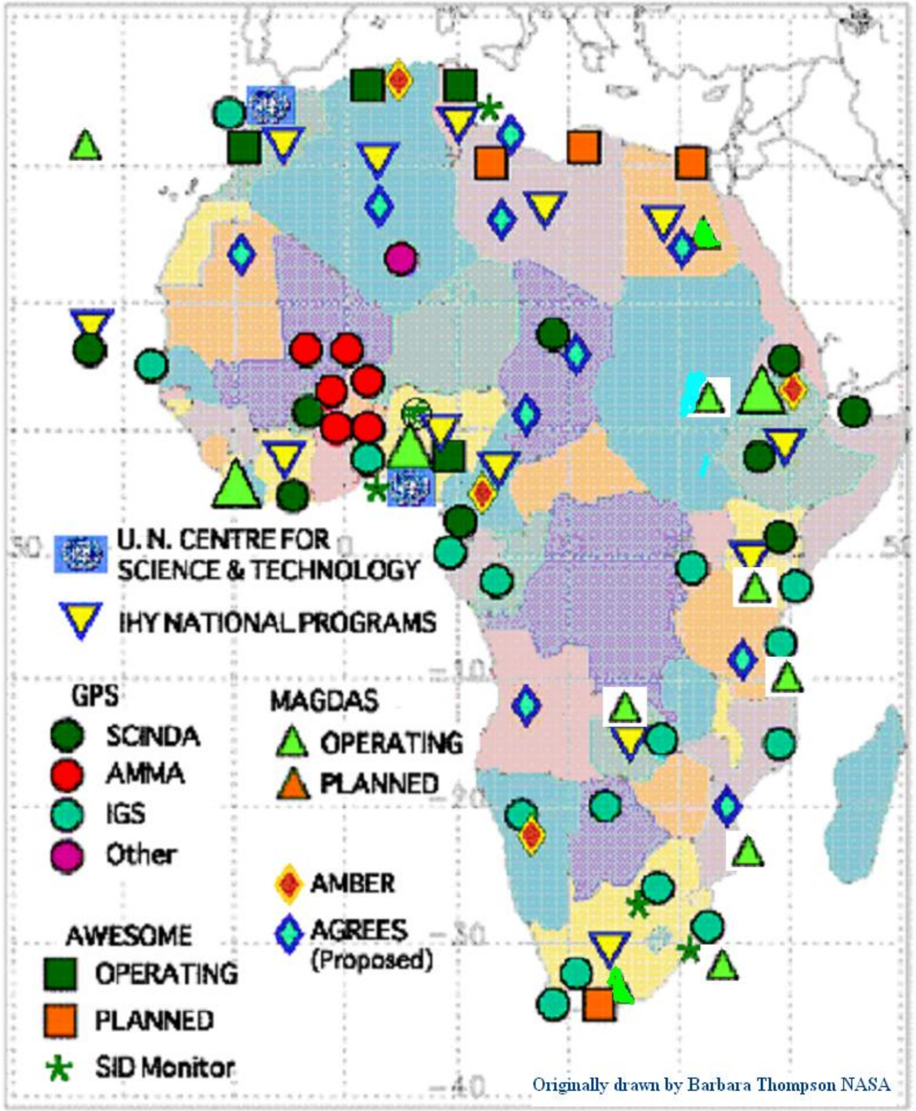


Ionospheric Monitors in Africa

- 13 units of MAGDAS
- 7 units of GPS including SCINDA,
- 4 units of AWESOME
- 20 units of SID monitors

data obtained from these facilities are being used to improve our understanding of space weather as it affects the performance of GNSS

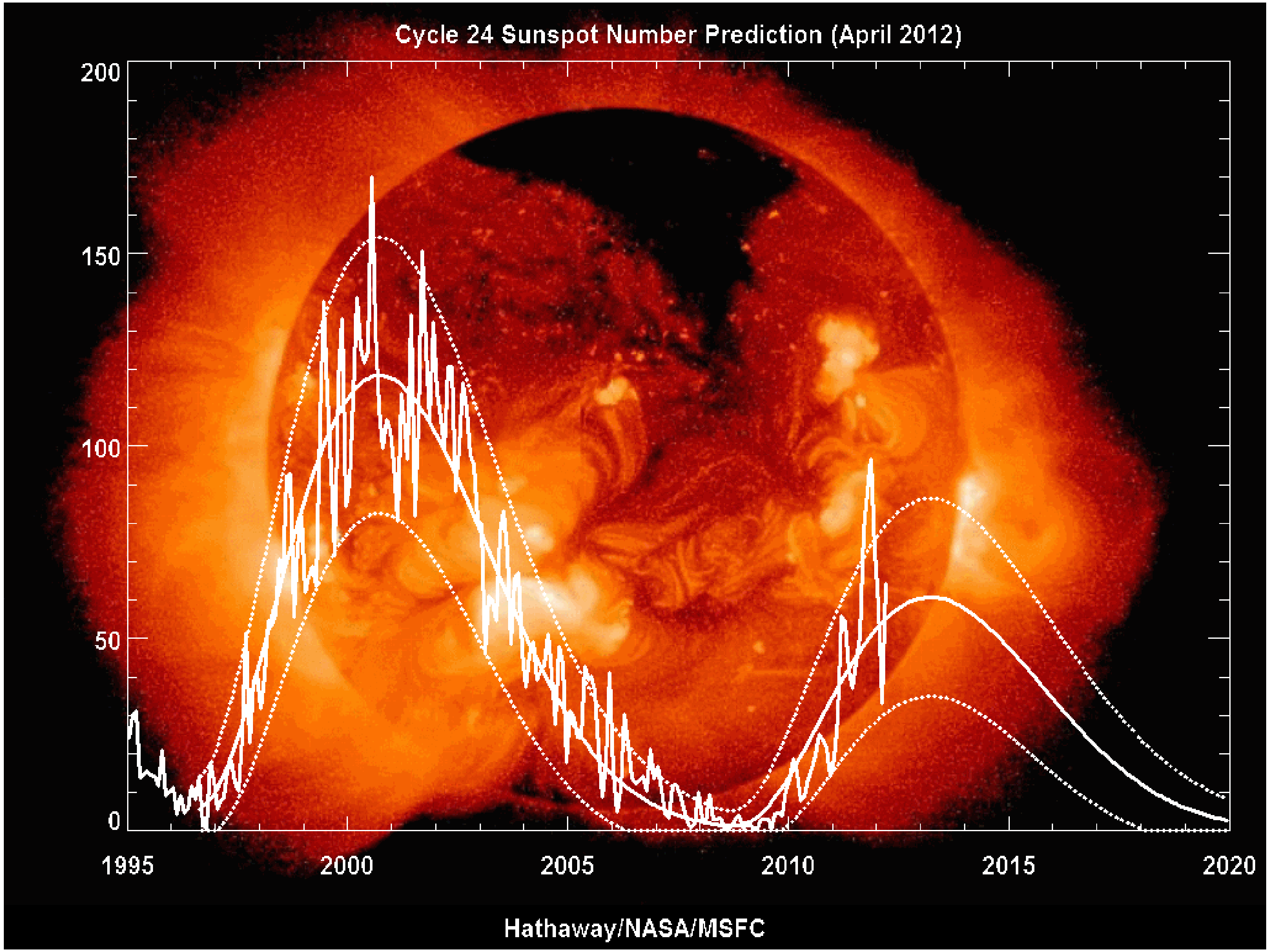
Additional monitors:
3 units GPS from BC –
More planned under ICTP/BC partnership
Ionosondes planned



Based on presentation by Dr. Rabiu Babatunde

Solar Cycle Dependence

all effects intensify with increasing solar activity



Simple Summary

GNSS is an enabling technology that can make major contributions to economic growth and societal betterment. It is also a key to scientific exploration.