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GNSS POSITIONING ERROR BUDGET

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PRESENTATION THEMATIC UNITS

- Short introduction
- User equivalent ranging error (UERE)
- GPS ionospheric delay
- Multipart effects
- GPS/GNSS error budget
- Geometric dilution of precision
- Algorithm for positioning point determination
- Total GPS positioning determination error
- Corrections regarding multipath, ionospheric delay...
- Advanced systems (augmentation and assistance)
- Differential GPS
- Satellite based augmentation systems
- EGNOS
- Satellite signal multi-frequency processing
- GNSS

INTRODUCTION

- GNSS position determination is achieved by satellite (radio) signals propagation parameters measurements
- Every measurement is subject to error influences. Moreover, measuring results contain corresponding uncertainity, caused by effects of error causes
- GPS position determination allows for setted characteristics achievement, under the condition of unobstructed sky visibility (95% of time position determination, on 95% of the surface of the Earth, with horizontal error accuracy within 100m, altitude accuracy within 100m, and velocity accuracy within 0.1m/s)
- Error limits are defined by influence parametres

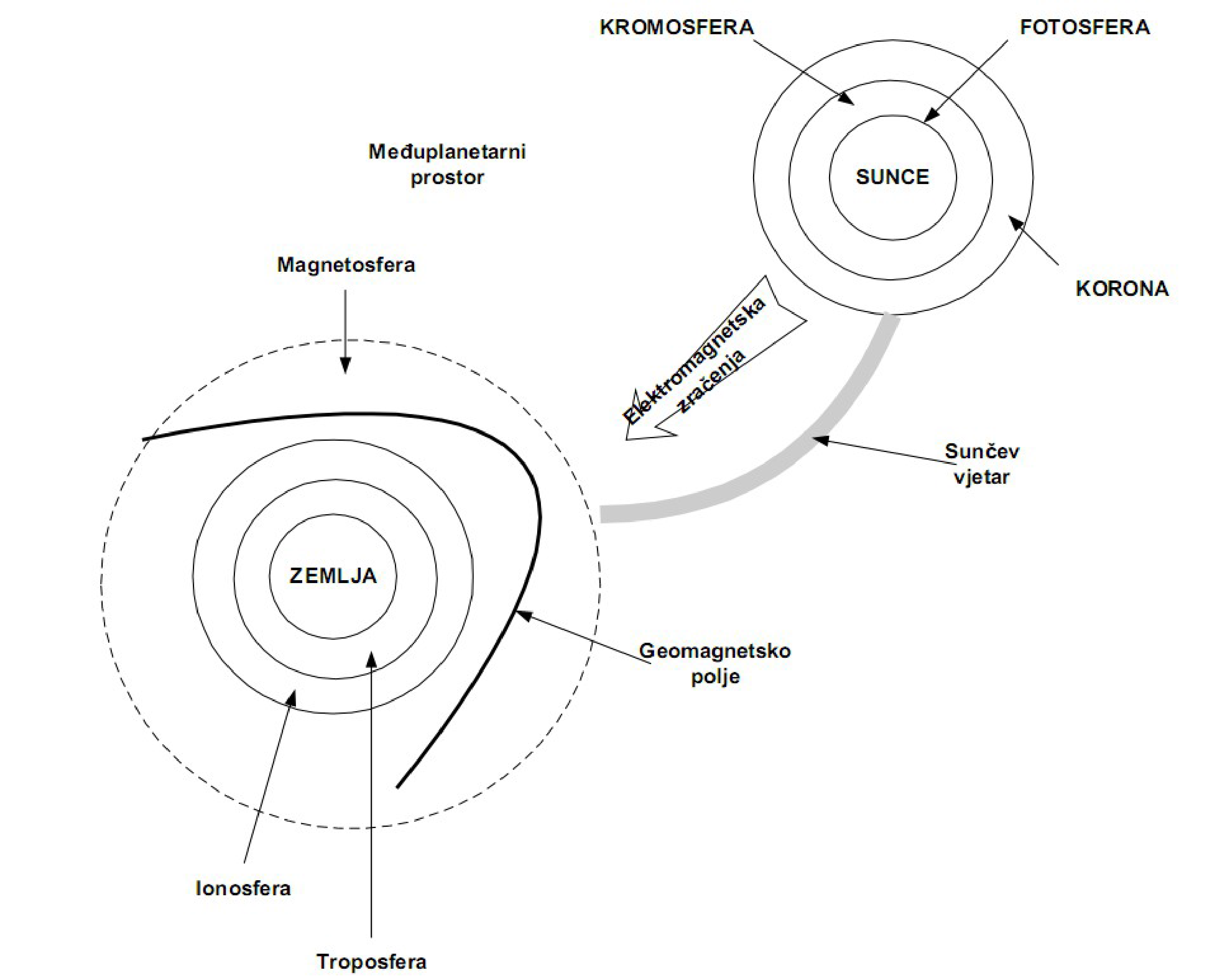
INTRODUCTION

- Total GPS/GNSS positioning error is the result of two independent error causes effect:
  - USER EQUIVALENT RANGING ERROR (UERE) and
  - GEOMETRIC DILUTION OF PRECISION (GDOP)
- UERE appears as result of various influences which affect satellite signal time propagation measurement
- GDOP is a result of current spatial satellite distribution. It is a dimensionless value greater than 1. With appropriate satellite selection, the aim is to reduce the GDOP to a minimum

USER EQUIVALENT RANGING ERROR
- UERE -

- Satellite and Control component errors:
  - Satellite position estimation (ephemeris) error
  - Satellite clock errors
  - Selectieve Availability (terminated)
- User component errors:
  - Multipath effect errors
  - Receiver's noise
- Propagation medium errors:
  - Ionospheric delay errors
  - Tropospheric delay errors

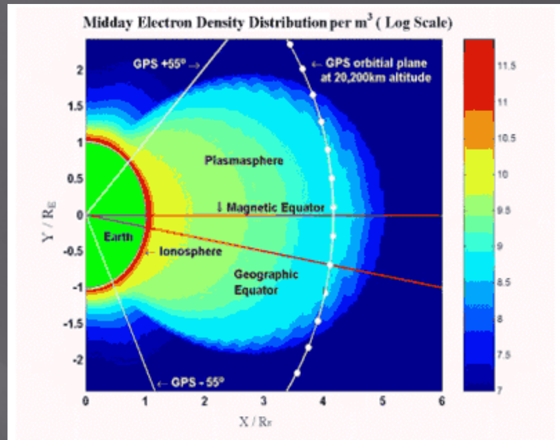
SPACE WEATHER



GPS IONOSPHERIC DELAY

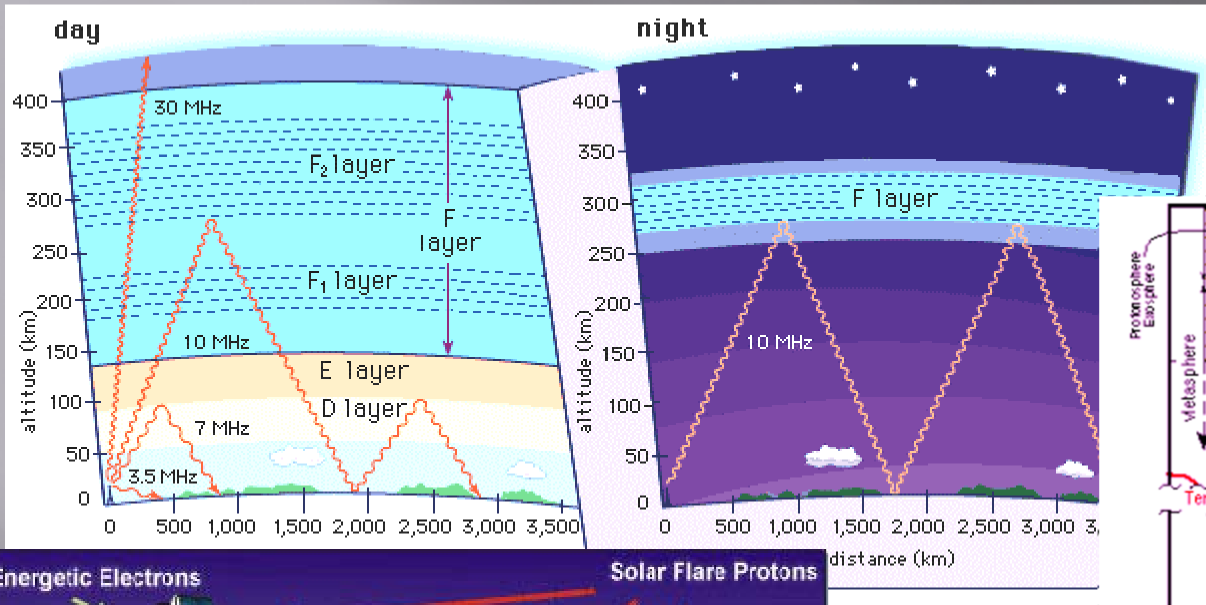
- Occurs due to the satellite signal propagation through ionized inhomogeneous ionospheric layers/regions
- The value of the delay can be achieved as:

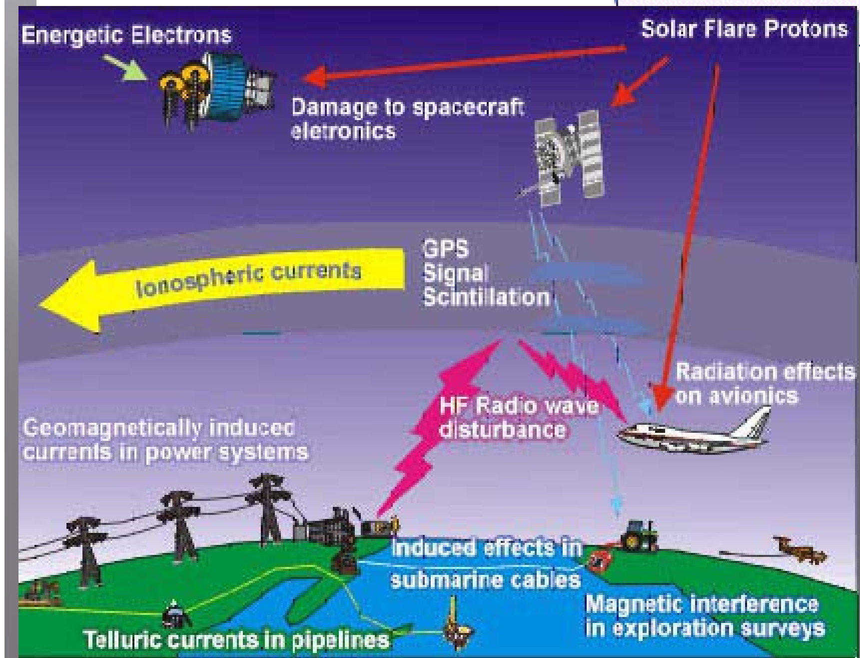
$$\Delta t_{iono} = \frac{40.3}{c \cdot f^2} \cdot \int N(h) \cdot dh$$

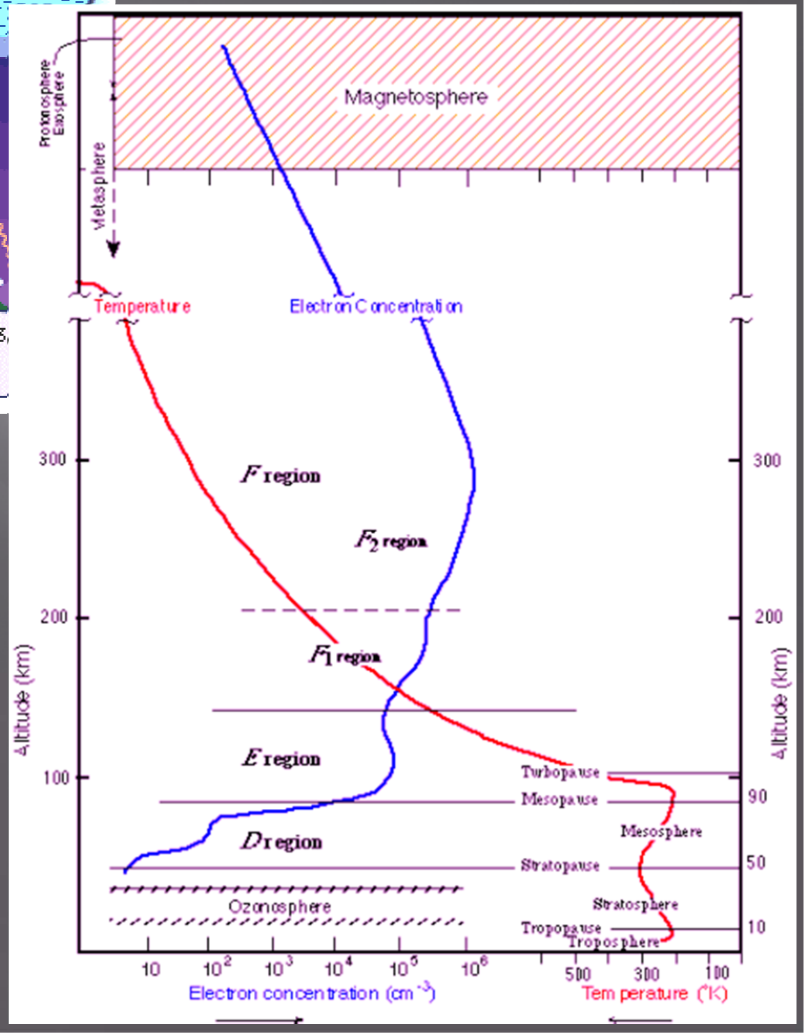


- Vertical ionosphere profile depends on:
  - State of Solar activity and Space weather
  - Global and local ionizing processes
  - Time of the day
  - Season of the year

GPS IONOSPHERIC DELAY

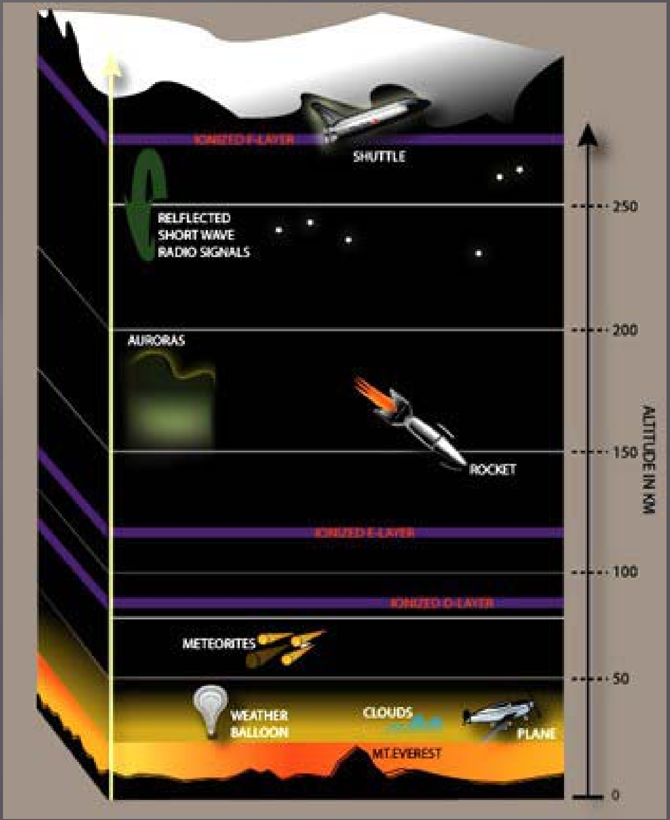




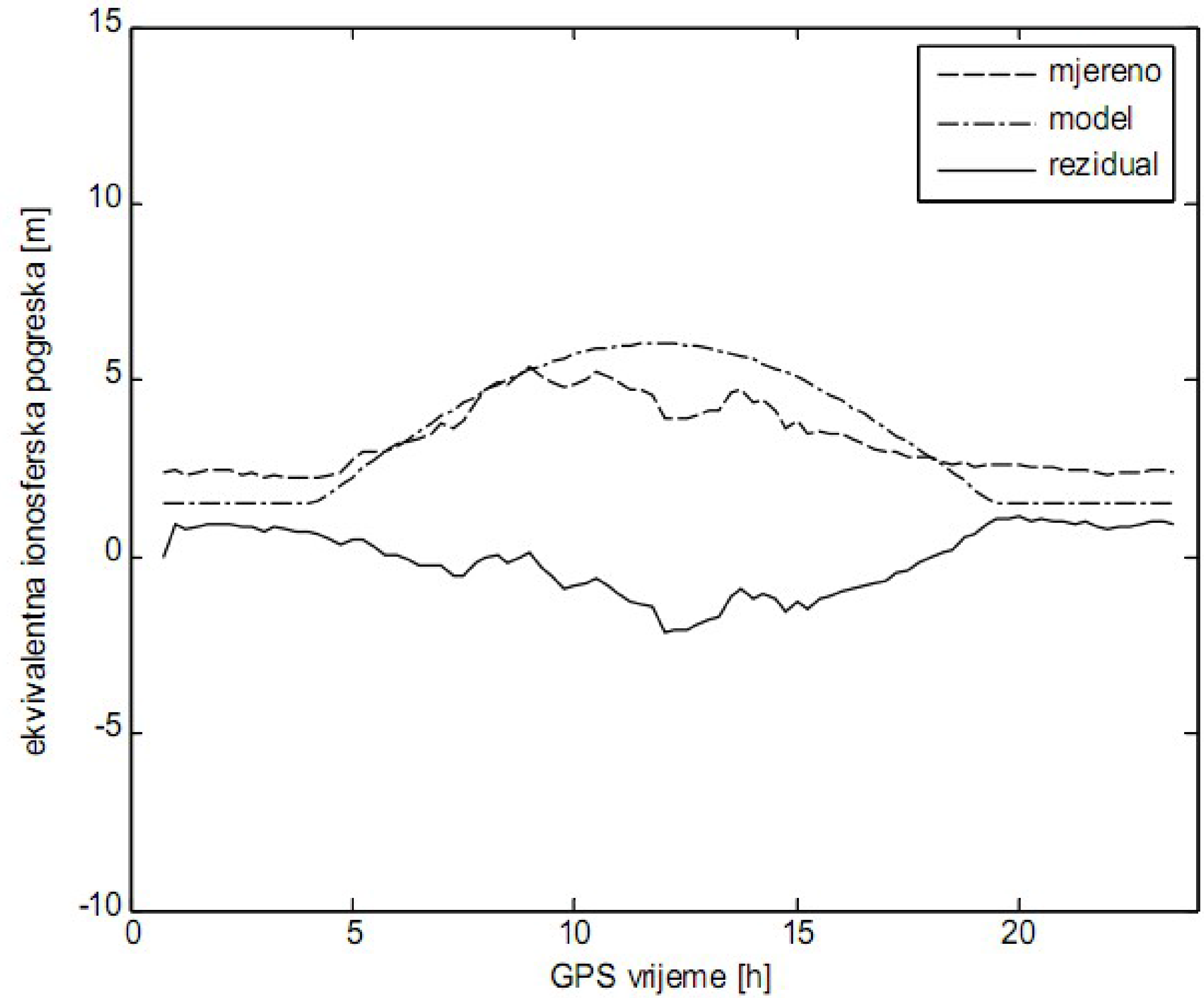


GPS IONOSPHERIC DELAY

- Standard (Klobuchar) Ionospheric Correction Model is included in the GPS position determination service
- It is a global model defined on the GPS ionospheric daily pattern, as well as on averaged values of space weather and ionospheric parameters
- The Klobuchar model is capable to correct up to 70% of actual ionospheric delay, which generally applies for quiet space weather conditions and undisturbed ionosphere

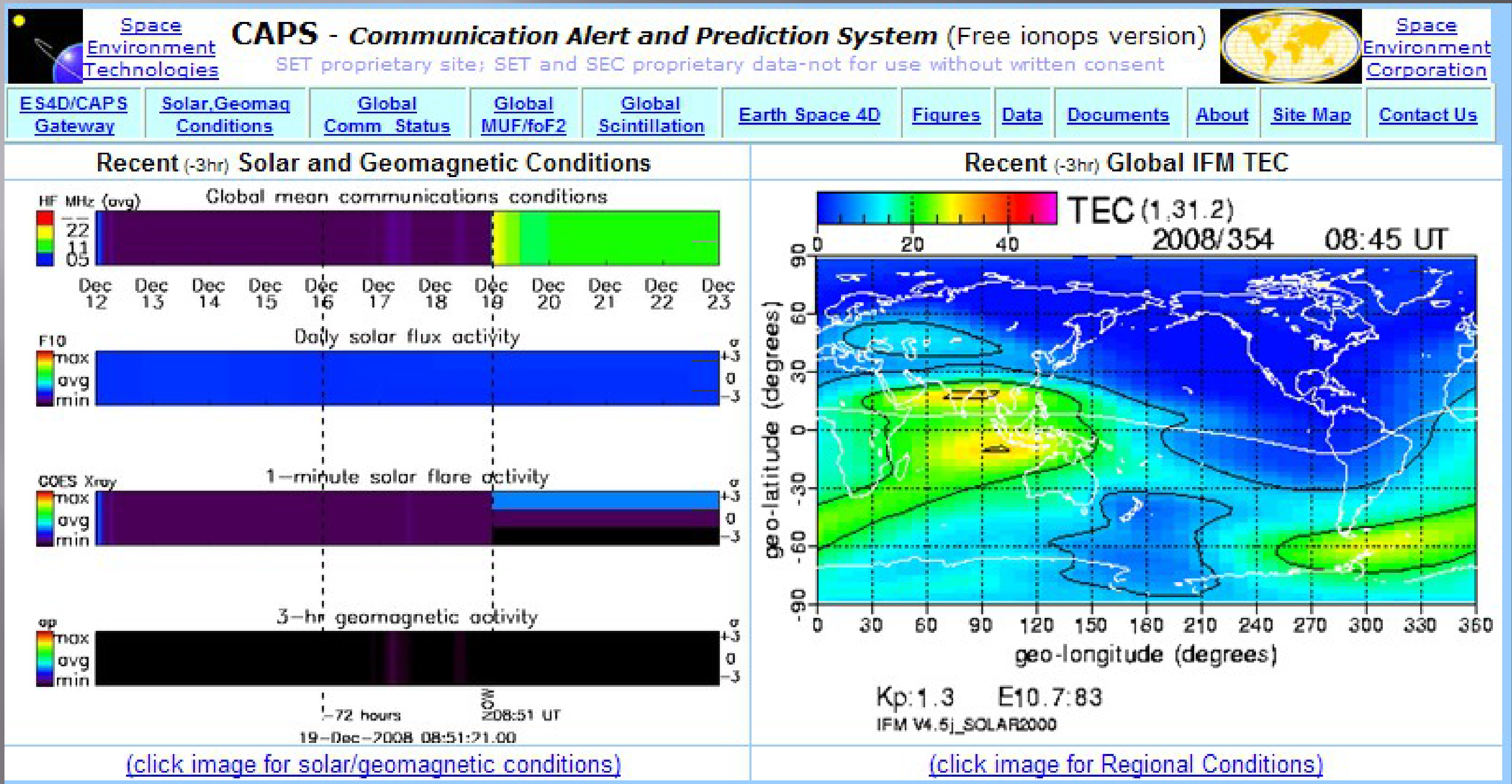


GPS IONOSPHERIC DELAY



GPS IONOSPHERIC DELAY

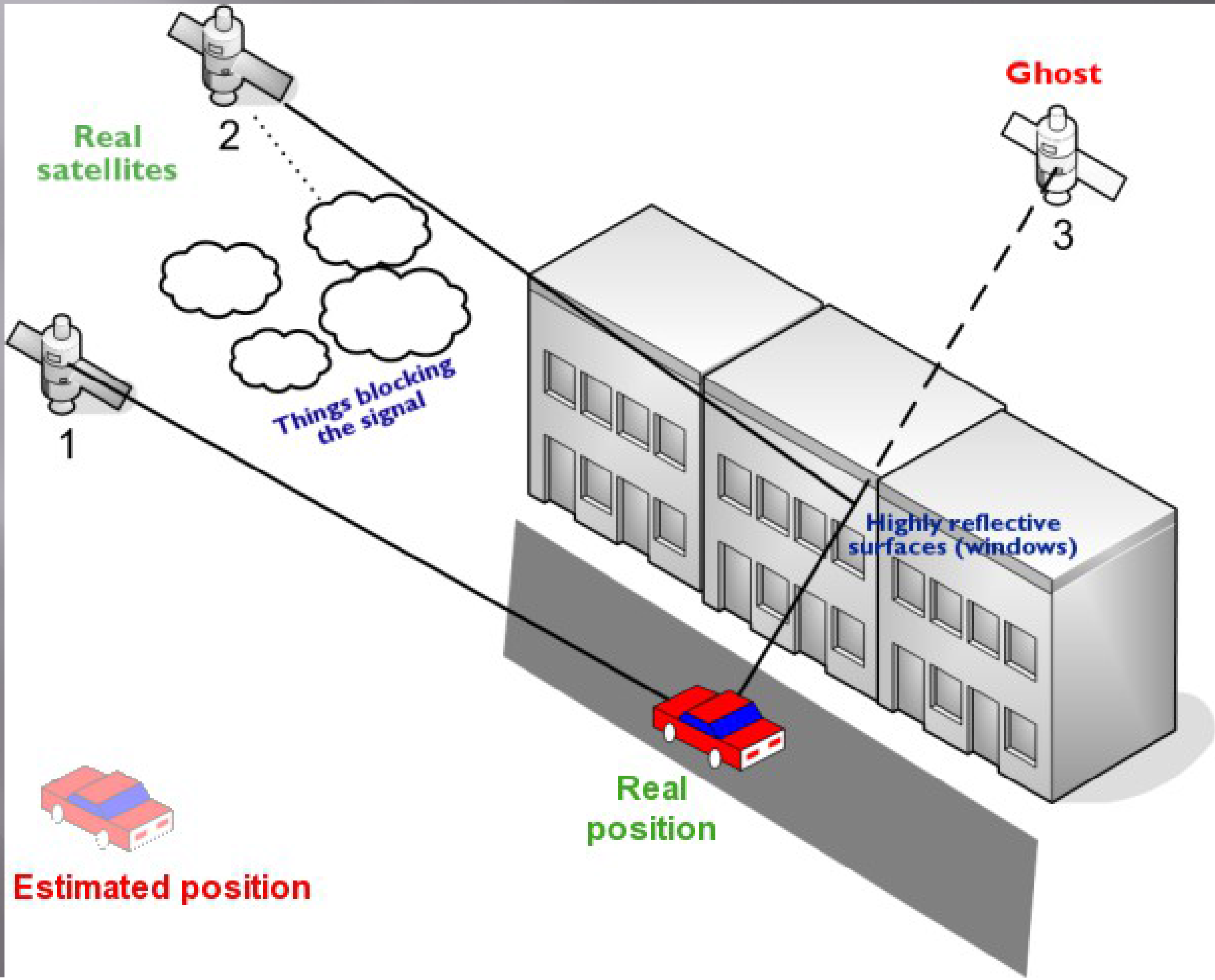
- State of the ionosphere and status of the space weather (http://tinyurl.com/7pul67)



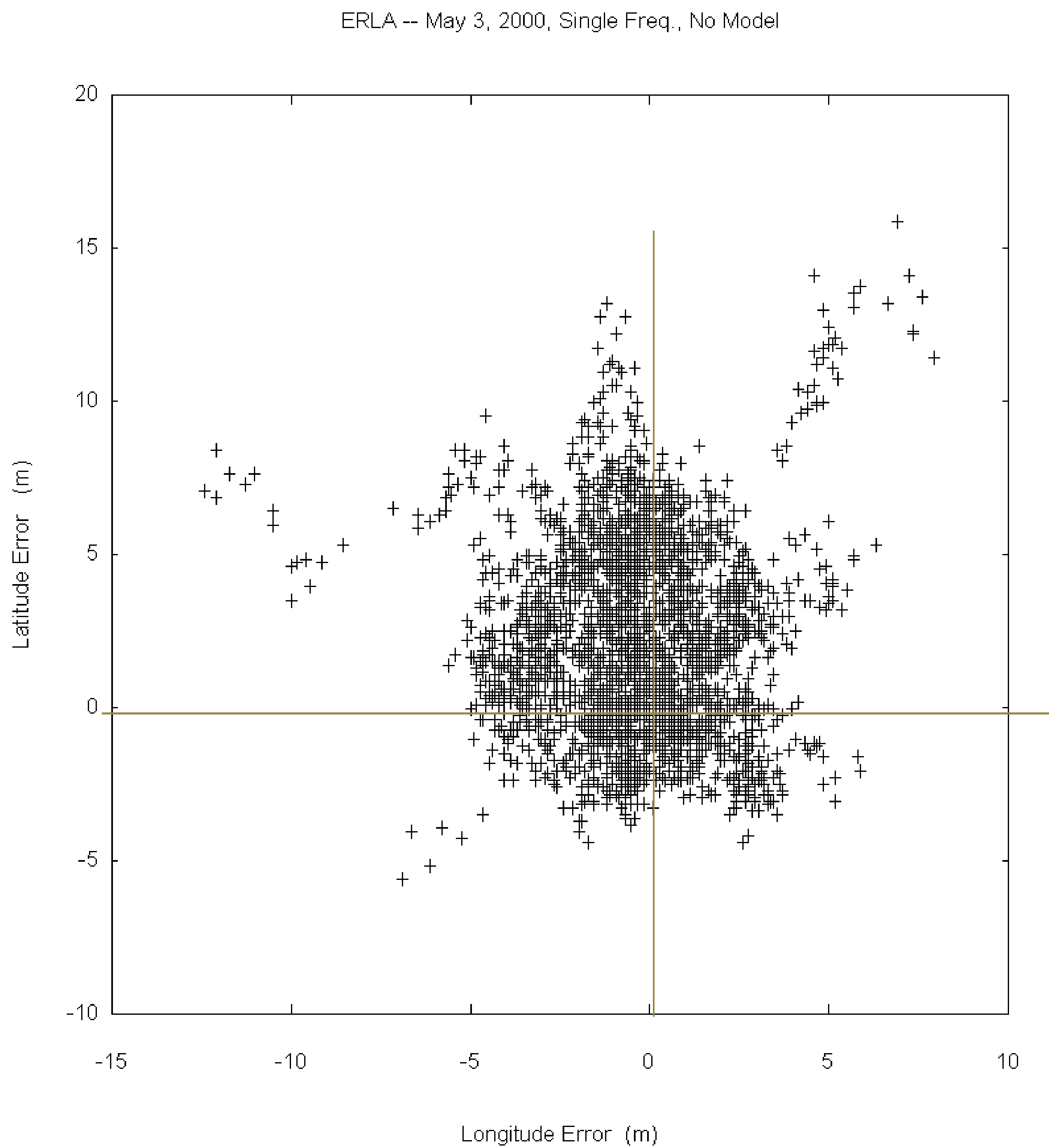
MULTIPATH EFFECTS

- Appears on signal reception location, as a result of original satellite signal local reflections
- The original signal can reflect from various objects and obstacles in the micro-environment of the receiver’s GPS antenna
- Correction of multipath effects is performed (i) using special GPS antennas which are mitigating this effect of degradation (filtering of signals with their angle of elevation smaller than 10^0), and also with (ii) proper selection of the antenna mounting location

MULTIPATH EFFECTS



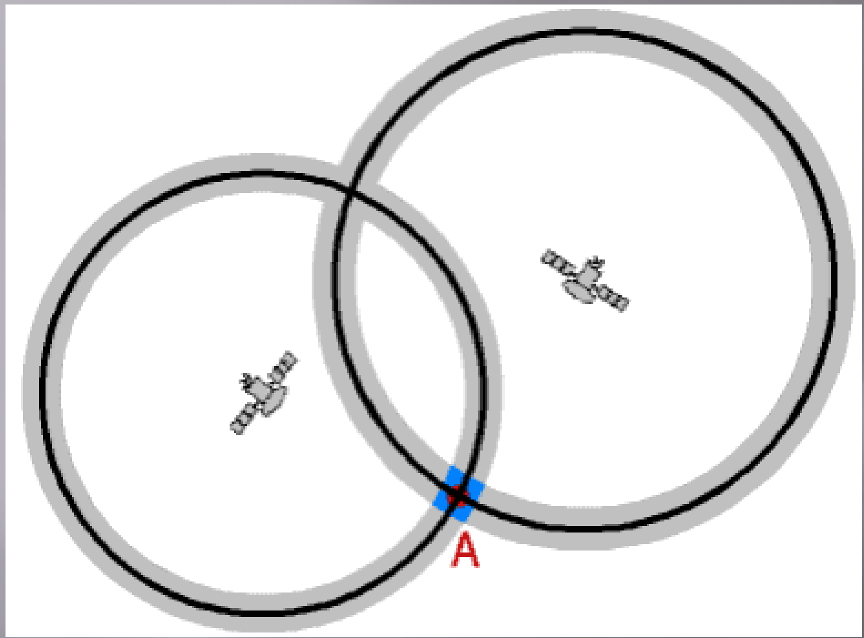
GPS/GNSS ERROR BUDGET

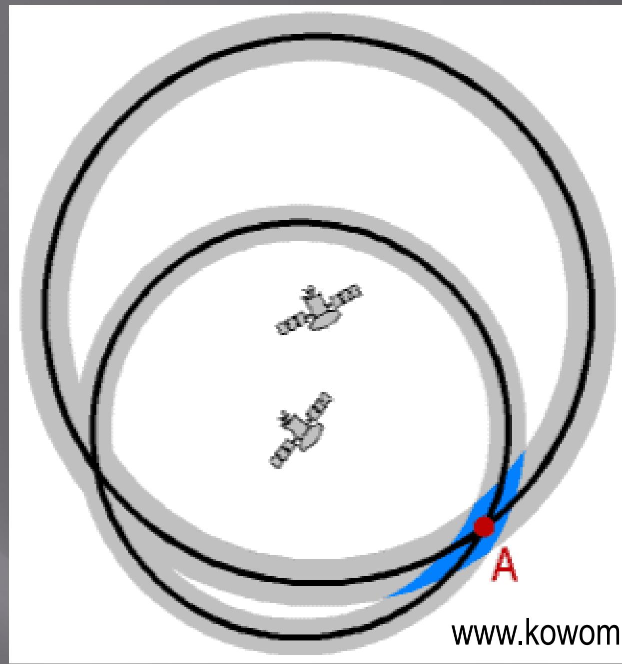


GPS/GNSS ERROR BUDGET

Error source	One-sigma error, m Bias	Random	Total	DGPS
Ephemeris data	2.1	0.0	2.1	0.0
Satellite clock	2.0	0.7	2.1	0.0
Ionosphere	4.0	0.5	4.0	0.4
Troposphere	0.5	0.5	0.7	0.2
Multipath	1.0	1.0	1.4	1.4
Receiver measurement	0.5	0.2	0.5	0.5
User equivalent range error (UERE), rms*	5.1	1.4	5.3	1.6
Filtered UERE, rms	5.1	0.4	5.1	1.5
Vertical one-sigma errors--VDOP= 2.5			**12.8**	**3.9**
Horizontal one-sigma errors--HDOP= 2.0			**10.2**	**3.1**

GEOMETRIC DILUTION OF PRECISION





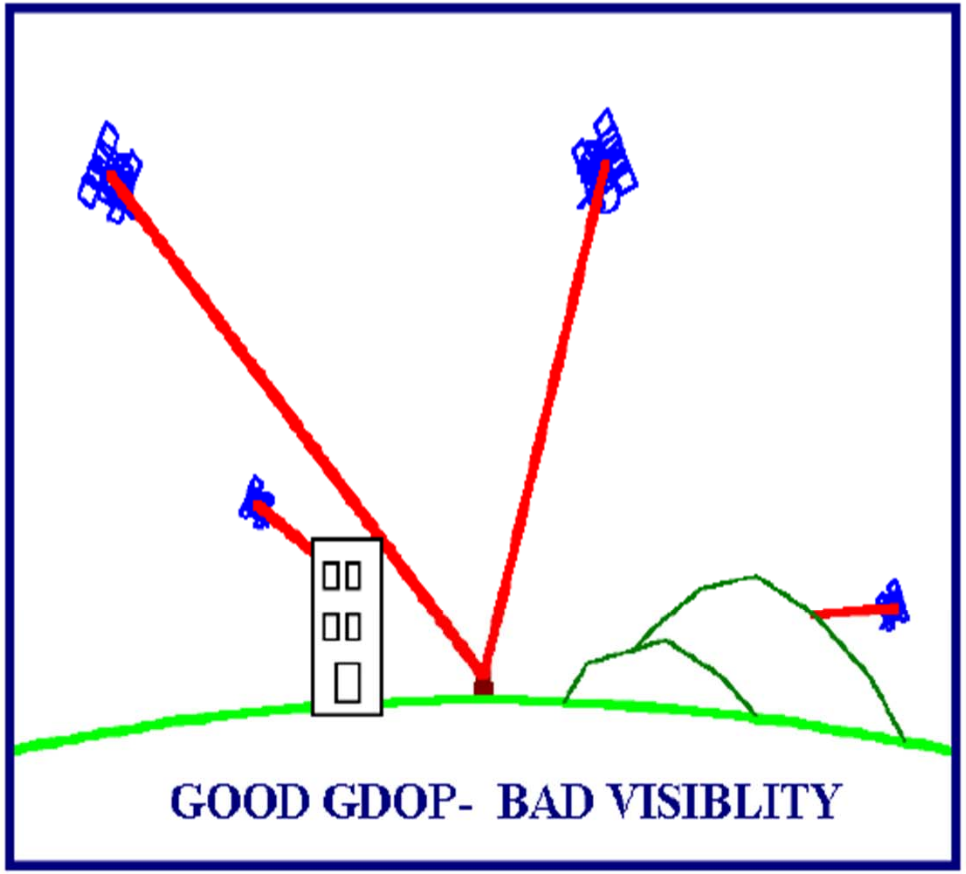
- EDOP – Easting dilution of precision
- NDOP – Northing dilution of precision
- HDOP – Horizontal dilution of precision
- VDOP – Vertical dilution of precision
- PDOP – Positioning dilution of precision
- TDOP – Time dilution of precision
- GDOP – geometric (total) dilution of precision

GEOMETRIC DILUTION OF PRECISION

$$HDOP = \sqrt{(NDOP^2 + EDOP^2)}$$

$$PDOP = \sqrt{(HDOP^2 + VDOP^2)}$$

$$GDOP = \sqrt{(PDOP^2 + TDOP)}$$



ALGORITHM FOR POSITIONING POINT DETERMINATION

$$\delta\rho^{(k)} = \rho^{(k)}_{pravo} - \rho^{(k)}_{est}$$

$$\delta\rho^{(k)} = \frac{\left(x^{(k)} - x_0\right)}{\left(x^{(k)} - x_0\right)} \cdot \delta x + \delta b + \varepsilon_\rho^{(k)} = -I^{(k)} \cdot \delta x + \delta b + \varepsilon_\rho^{(k)}$$

$$I^{(k)} = \frac{1}{\left(x^{(k)} - x_0\right)} \cdot \left[x^{(k)} - x_0, y^{(k)} - y_0, z^{(k)} - z_0\right]^T$$

Za sustav od k jednadžbi:

$$\delta\rho = \begin{bmatrix} \delta\rho^{(1)} \\ \delta\rho^{(2)} \\ \dots \\ \delta\rho^{(k)} \end{bmatrix} = \begin{bmatrix} \left(-I^{(1)}\right)^T & 1 \\ \left(-I^{(2)}\right)^T & 1 \\ \dots & 1 \\ \left(-I^{(k)}\right)^T & 1 \end{bmatrix} \cdot \begin{bmatrix} \delta x \\ \delta b \end{bmatrix} + \varepsilon_\rho$$

$$\delta\rho = G \cdot \begin{bmatrix} \delta x \\ \delta b \end{bmatrix} + \varepsilon_\rho$$

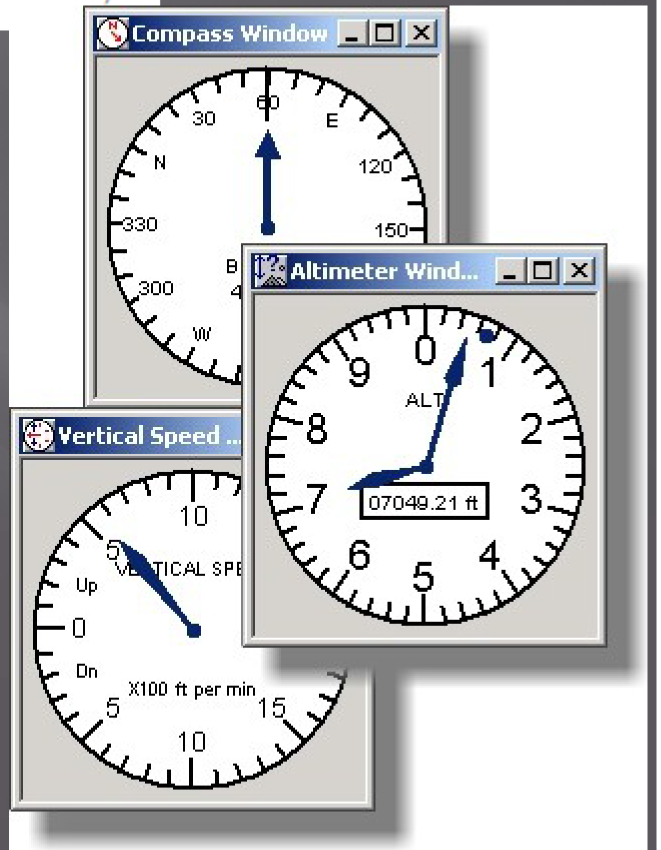
ALGORITHM FOR POSITIONING POINT DETERMINATION

- The G matrix contains several interesting features:

$$I^{(k)} = \left(\cos\left(E^{(k)}\right)\cdot\sin\left(A^{(k)}\right), \cos\left(E^{(k)}\right)\cdot\cos\left(A^{(k)}\right), \sin\left(E^{(k)}\right)\right)^T$$

- Moreover:

$$\left(G^T G\right)^{-1} = \begin{bmatrix} EDOP^2 & & & \\ & NDOP^2 & & \\ & & VDOP^2 & \\ & & & TDOP^2 \end{bmatrix}$$



TOTAL GPS POSITION DETERMINATION ERROR

Horizontal plane determination error:

eHOR = UERE · HDOP

Altitude determination error:

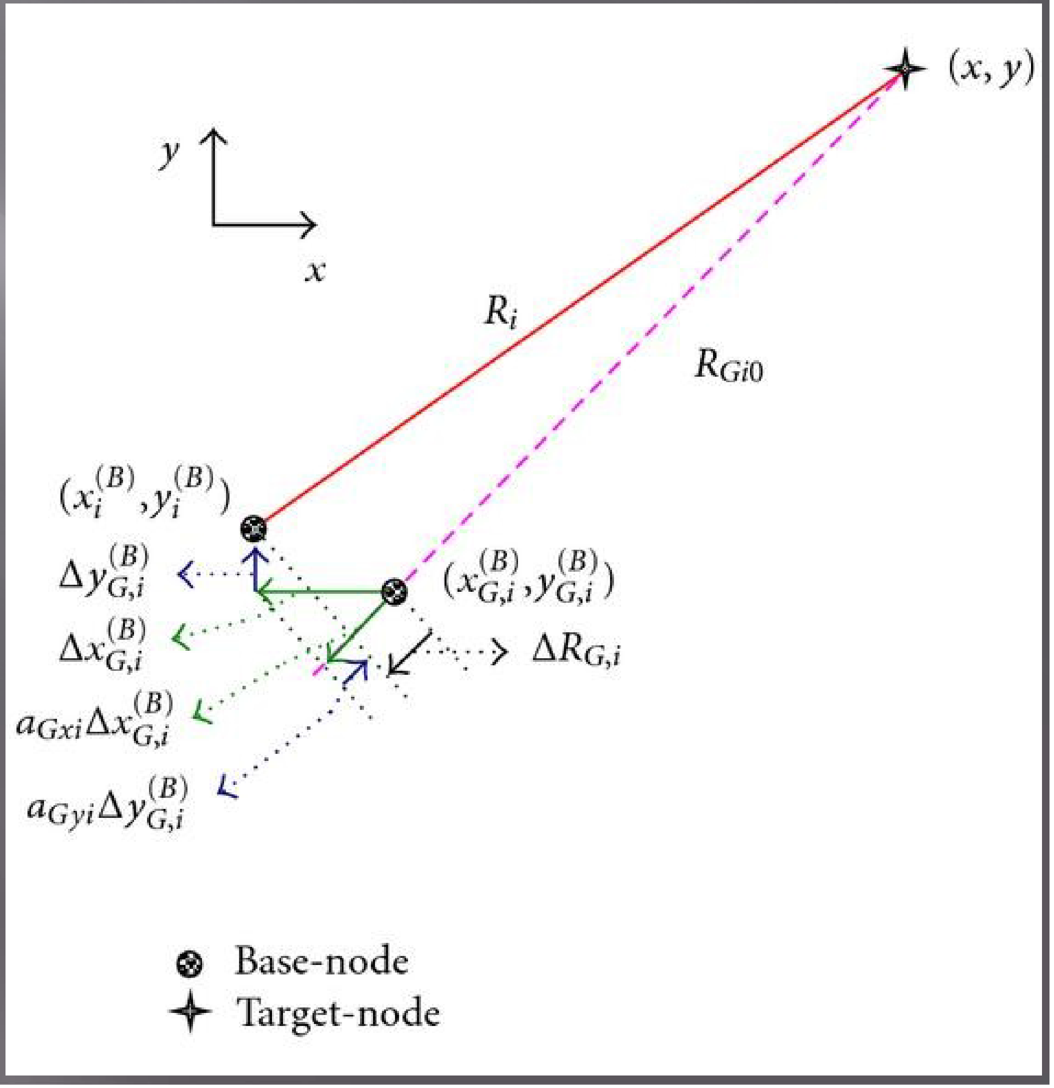
eVER = UERE · VDOP

Time determination error:

eTIME = UERE · TDOP

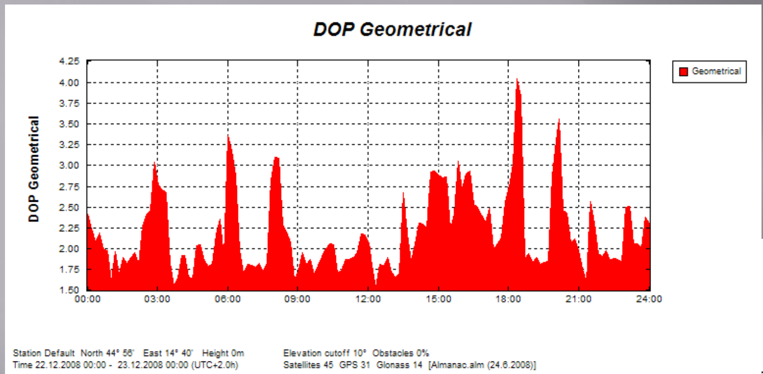
Total positioning determination error (3D):

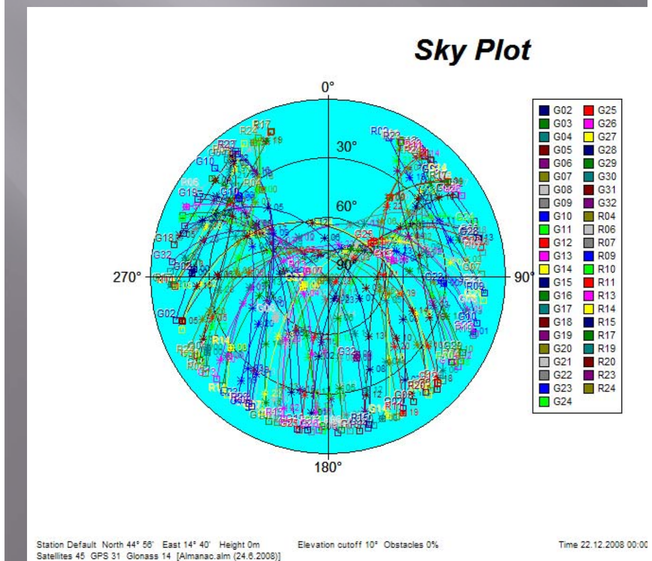
eTOT = UERE · GDOP

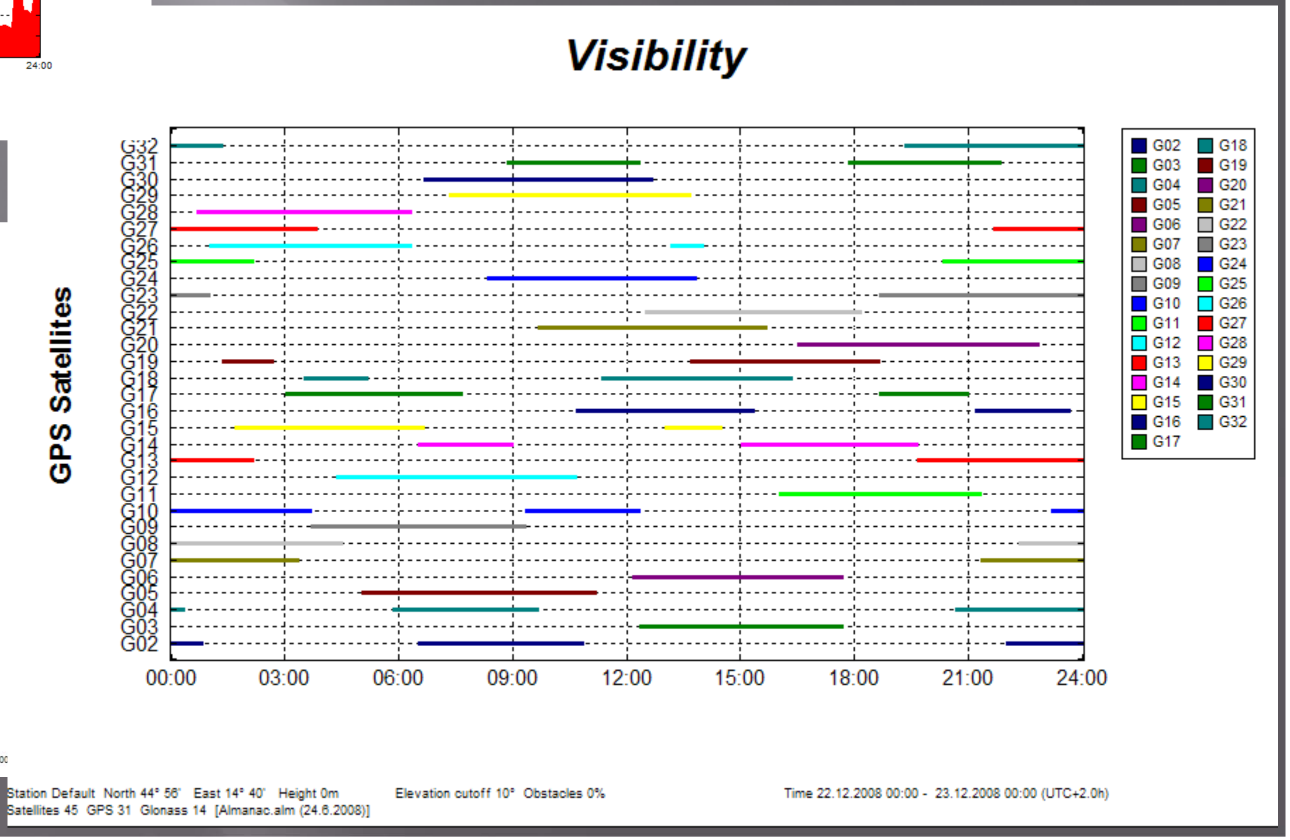


TRANSFERRING KNOWLEDGE AND RAISING AWARENESS

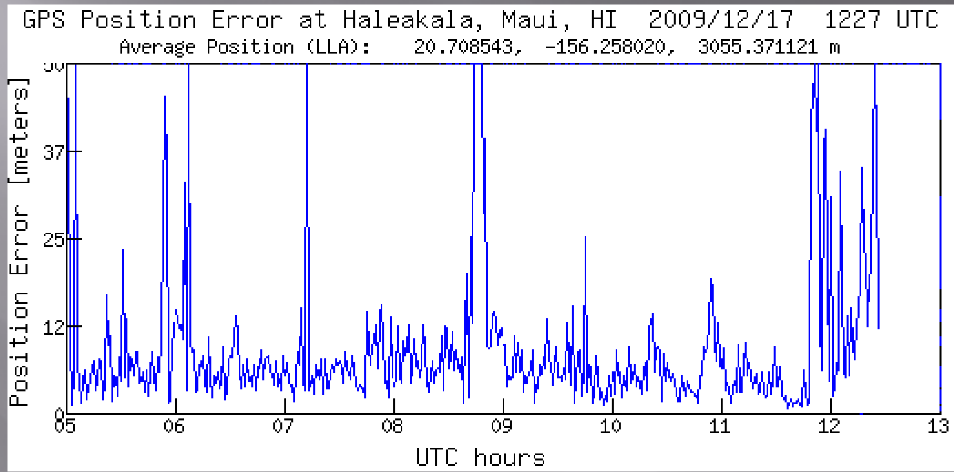
- Software and satellite positions information: http://tinyurl.com/7afhd





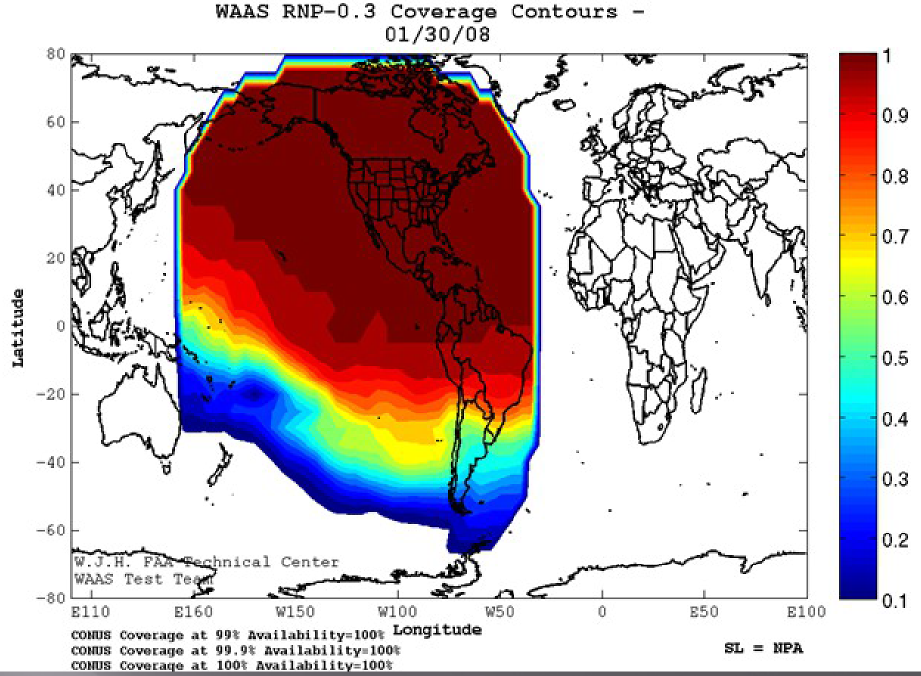


WHAT CAN BE DONE REGARDING GNSS POSITIONING ERRORS



1. Nothing. We can accept them and live with them
2. We can try to correct the effects of impacting quantities applying correction algorithms
3. We can utilize advanced systems for GNSS accuracy and reliability increasement
4. We can conduct systematic navigation with other navigation sensors and systems implementations

CORRECTIONS



- Ionospheric delay corrections
  - Advanced, regional and national correction models
- Multipath effects corrections
  - Correction models (Kalman filter, particle filter, neural networks, …)
- Tropospheric delay corrections
  - For geodetic and other precise measurings
- Post-processing
  - Not appropriate for navigational purposes

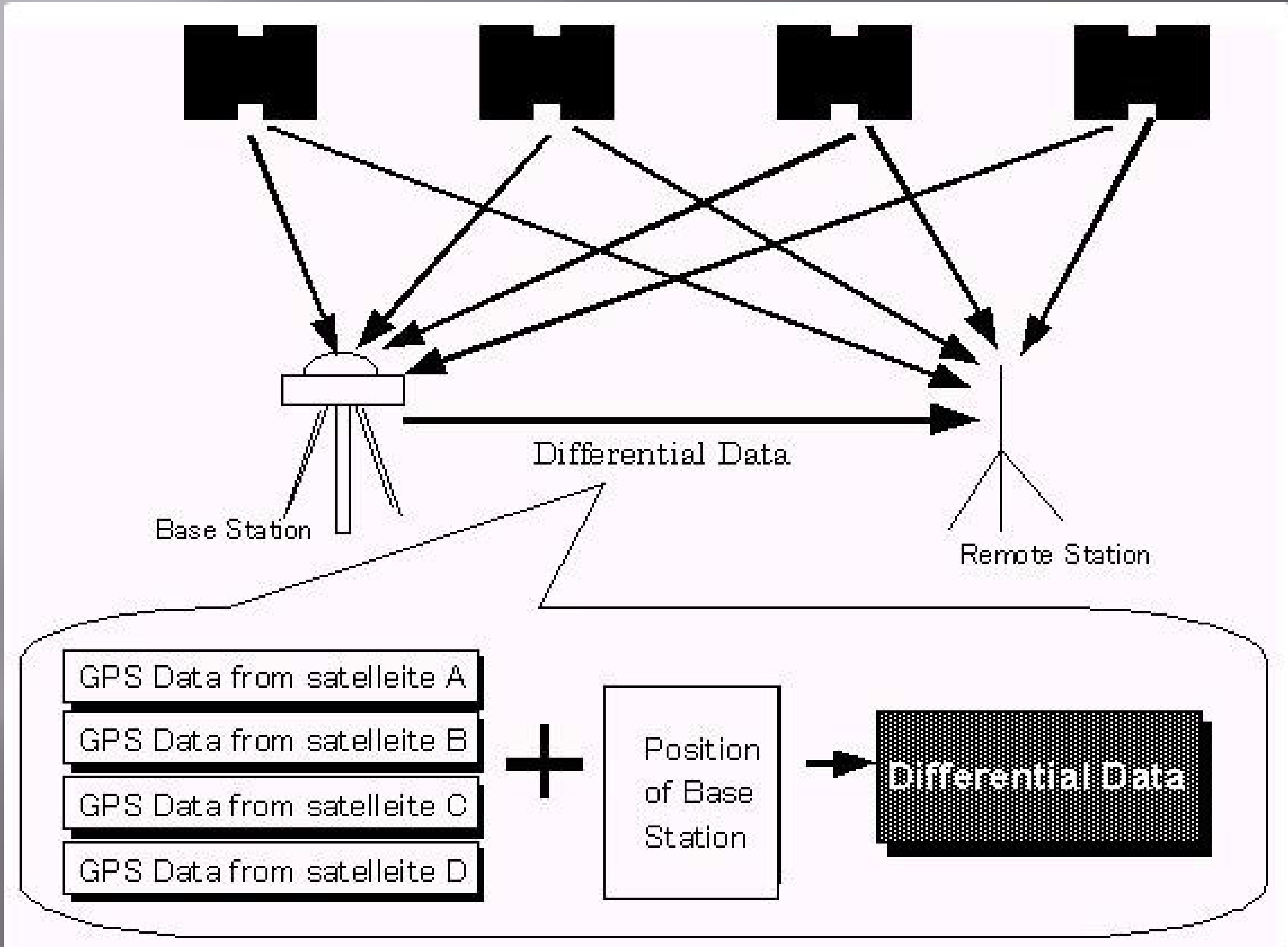
ADVANCED SYSTEMS (AUGMENTATION AND ASSISTANCE)

- Differential GPS
- Satellite-Based Augmentation Systems (SBAS)
- GPS satellite signals multi-frequency processing involvement
- Global Navigation Satellite System (GNSS)

DIFFERENTIAL GPS

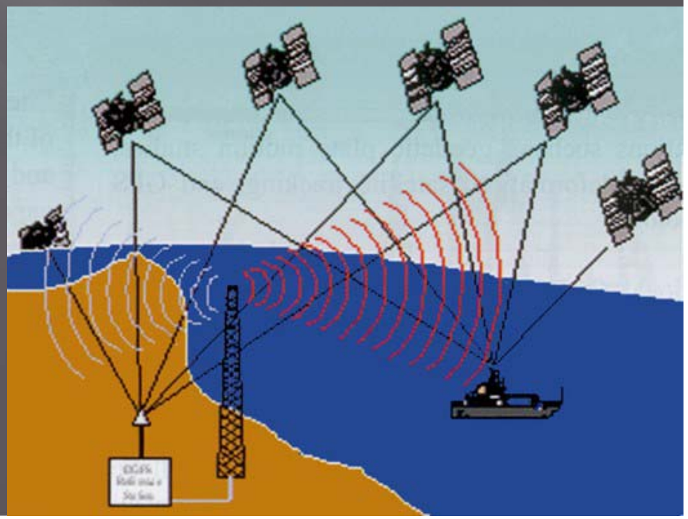
- The principle of DGPS performance is based on the fact that the influence of individual affectations is approximately equal on particular local area around and on the surface of the Earth
- If the delay of particular satellite signals for the area is determined, this information can be used by all GPS users in the local area for pseudorange correction measurements
- Differential GPS station determines delay values of all satellite signals in the visibility area, after what it distributes the same information to users in surrounding area

DIFFERENTIAL GPS



DIFFERENTIAL GPS

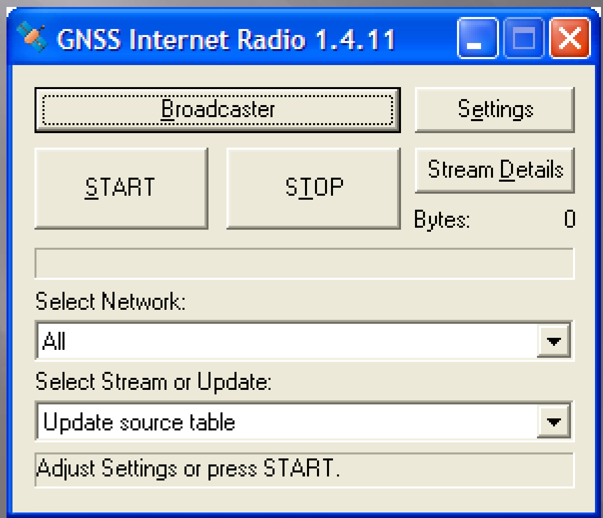
- DGPS is frequently utilized technology, especially in marine navigation
- Using DGPS, the total accuracy of GPS positioning determination can be enhanced to the order of magnitude of 1-5m
- The distribution of differential corrections can be accomplished through:
  - Private radio networks (radiobeacons)
  - Radio Data Systems (RDS)
  - Public communication networks
  - Internet (EUREF-IP project)

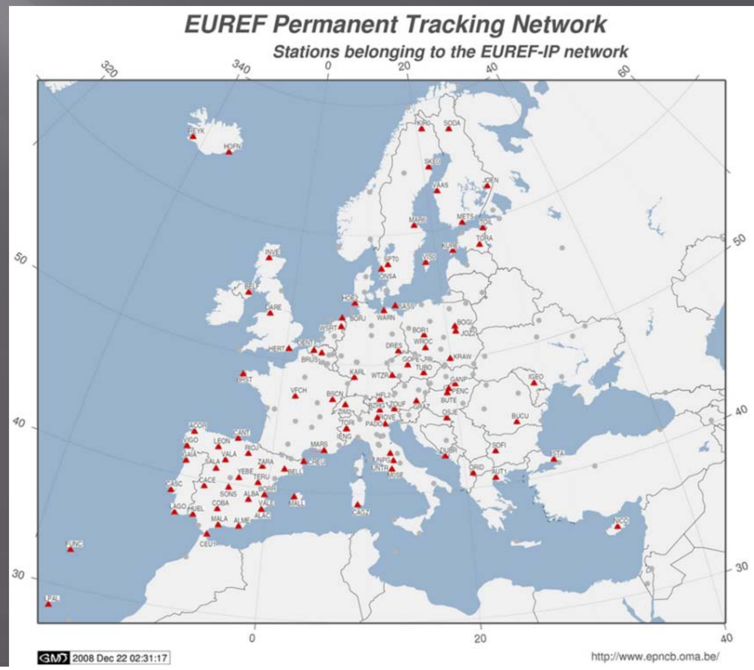


DIFFERENTIAL GPS

- EUREF-IP service: http://tinyurl.com/9of6bv

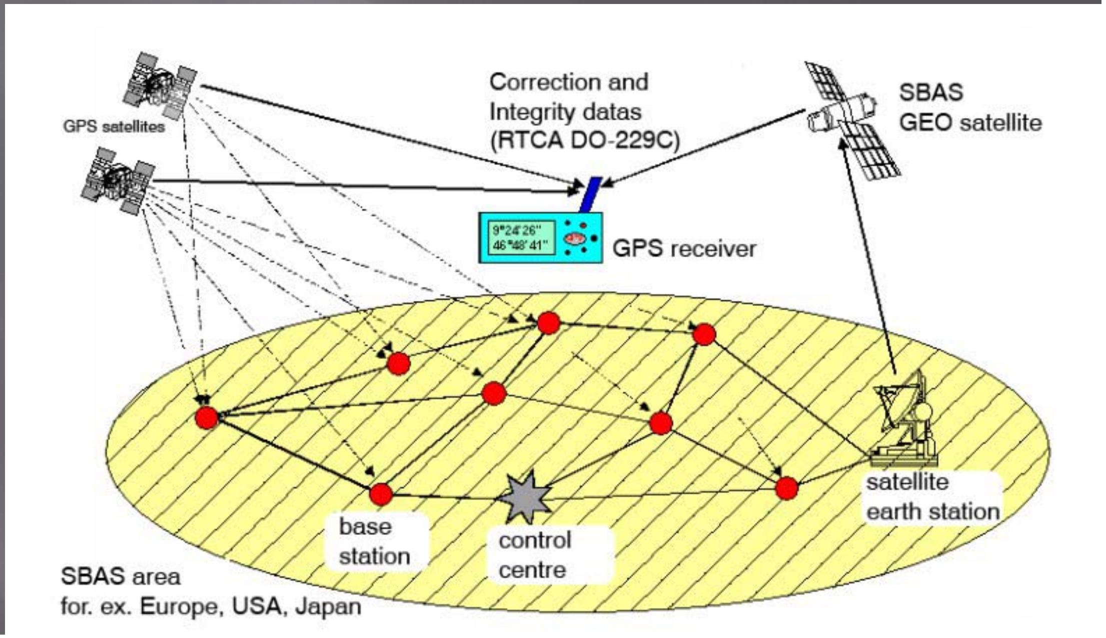
In June 2002 the IAG Reference Frame Sub-Commission for Europe (EUREF) decided to set up and maintain a real-time GNSS infrastructure on the Internet. This real-time GNSS data service named "EUREF-IP Pilot Project" uses a new data dissemination technique called "Networked Transport of RTCM via Internet Protocol" (Ntrip), which has been standardized in September 2004 by the Special Committee 104 of the Radio Technical Commission for Maritime Services(RTCM SC104).





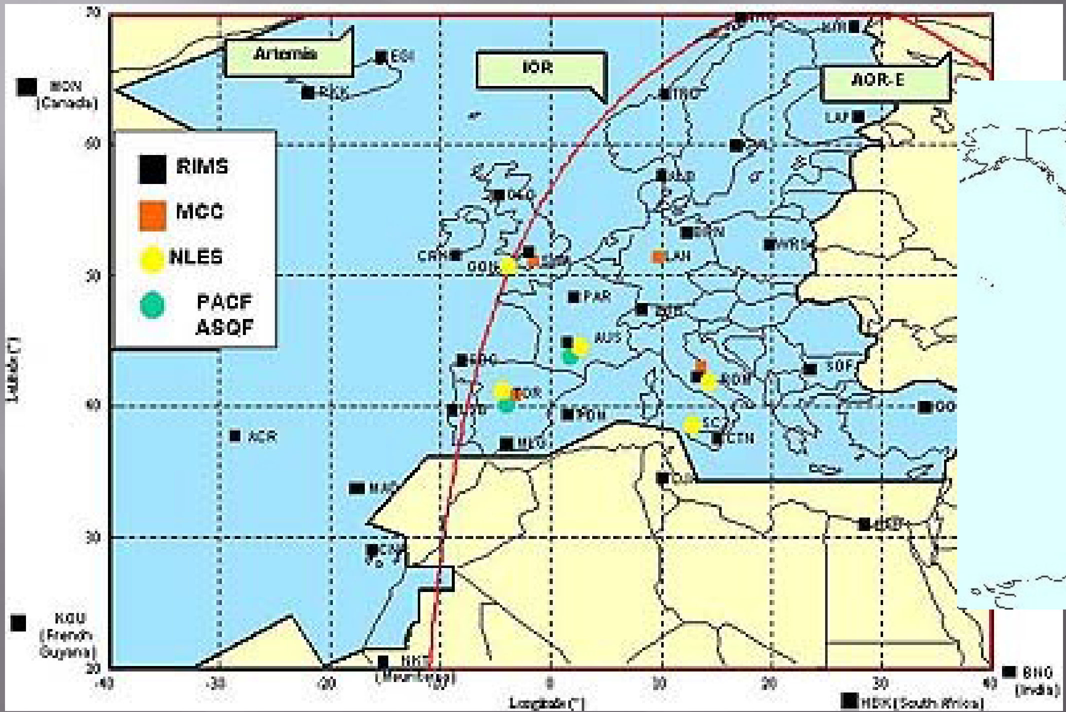
SATELLITE BASED AUGMENTATION SYSTEMS

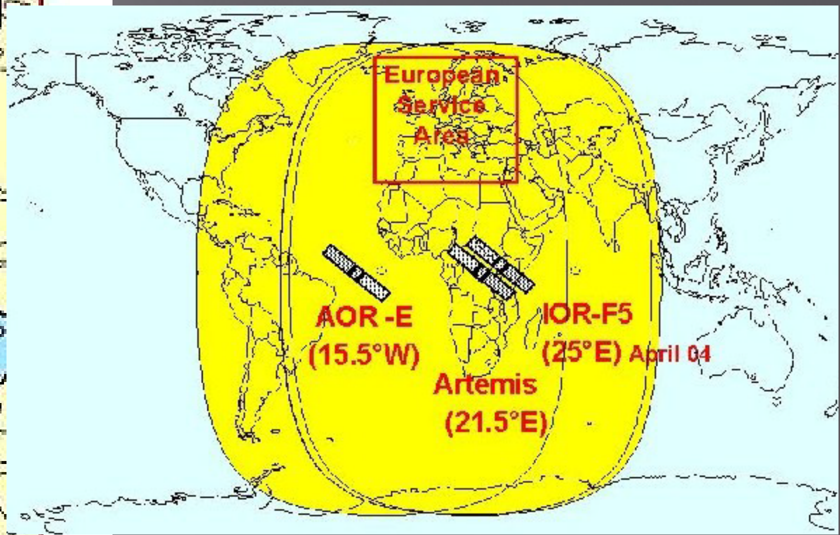
- Parts of the navigational message and/or additional informations (e.g. GPS system 'health') are sent to authorised users through special satellite links
- WAAS - Wide-Area Augmentation System (US)
- MSAS – Multi-functional Satellite Augmentation System (Japan)
- EGNOS – European Geostationary Navigation Overlay Service (Europe)



EUROPEAN GEOSTATIONARY NAVIGATION OVERLAY SERVICE - EGNOS -

- Three geostationary satellites which are sending GPS compatible signals, navigational message and system status





EUROPEAN GEOSTATIONARY NAVIGATION OVERLAY SERVICE - EGNOS -

Error cause and type	**Error without DGPS/SBAS**	**Error with DGPS/SBAS**
Ephemeris data	2.1m	0.1m
Satellite clocks	2.1m	0.1m
Effect of the ionosphere	4.0m	0.2m
Effect of the troposphere	0.7m	0.2m
Multipath reception	1.4m	1.4m
Effect of the receiver	0.5m	0.5m
Total RMS value	5.3m	1.5m
Total RMS value (filtered i.e. slightly averaged)	5.0m	1.3m
Horizontal error (1-Sigma (68%) HDOP=1.3)	6.5m	1.7m
Horizontal error (2-Sigma (95%) HDOP=1.3)	**13.0m**	**3.4m**

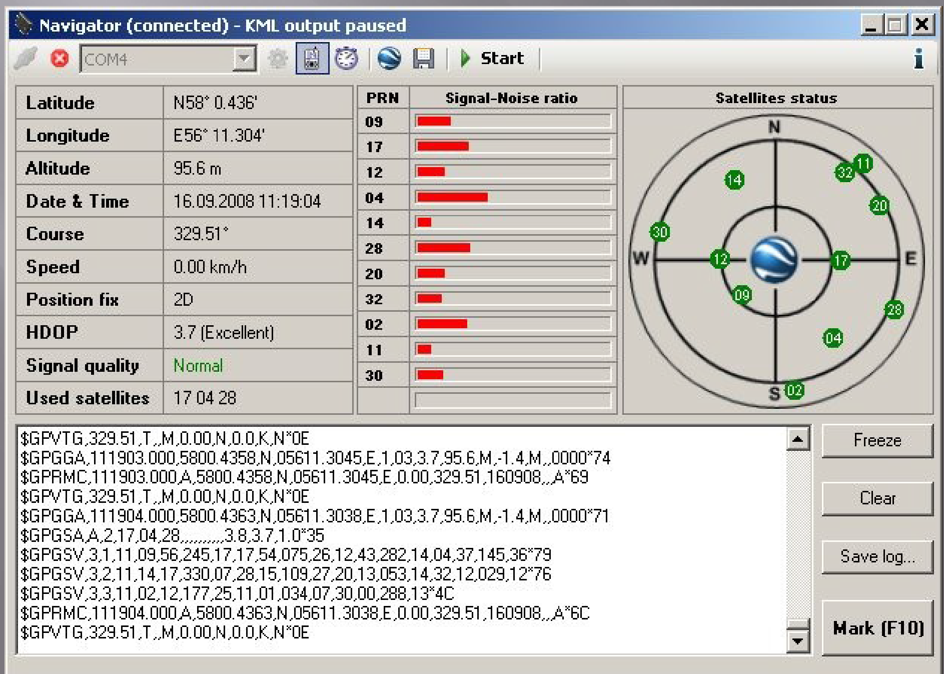
SATELLITE SIGNAL MULTI-FREQUENCY PROCESSING

- Besides the L1 carrier wave frequency, there are been used other available signals (carriers) in the process of positioning determination

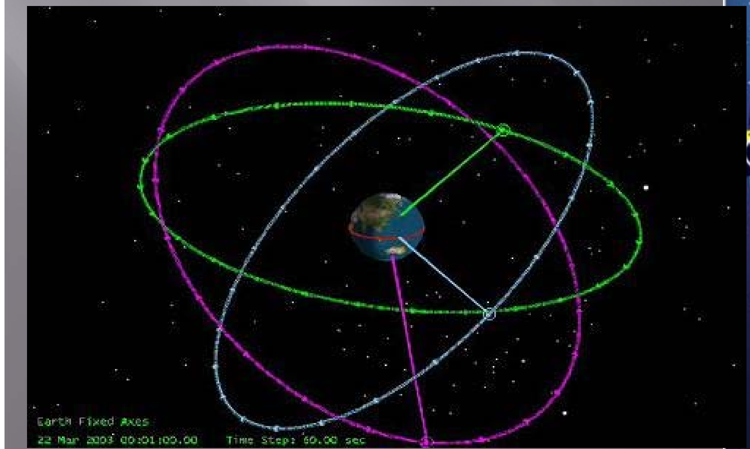
L1	1575.42 MHz
L2	1227.60 MHz
L3	1381.05 MHz
L4	1379.913 MHz
L5	1176.45 MHz

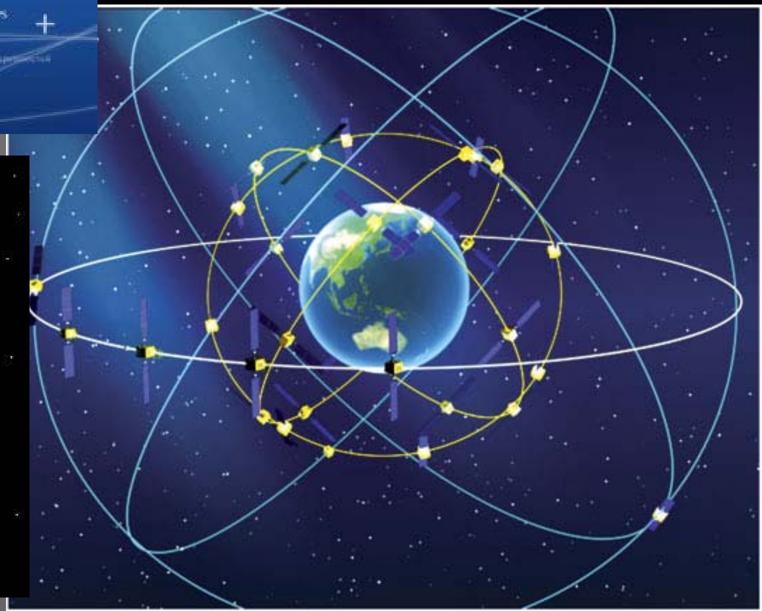
GLOBAL NAVIGATION SATELLITE SYSTEM

- Could be expected that existing and upcoming satellite navigation systems will evolve into a single system – GNSS
- Interoperability as a key feature: individual systems must not interfere with others
- Signal characteristics have to provide the possibility of creation of a single receiver which will be able to use particular signals



GLOBAL NAVIGATION SATELLITE SYSTEM





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