GLOTEC

Global real-time TEC map

Navigation System Reliability Forecast

Contents

- Introduction
- Satellite Navigation Systems
- Goals of GLOTEC
- Details
  - Nowcast Segment
  - Forecast Segment
  - Operative Space Segment
  - Broadcast Infrastructure
- Cost guesstimate, schedule
- Summary

Mission Statement

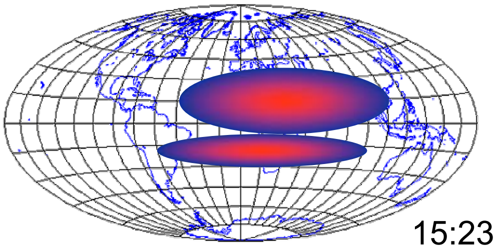
Geomagnetic storms threaten the integrity of satellite navigation (SN) systems. More specifically, the users of single-frequency SN receivers experience loss of accuracy in the calculation of their position. This is due mainly to the existing systems' inability to fully correct for ionospheric delay during severe space weather conditions.

GLOTEC is the solution for these users. Our primary goal is to increase the integrity of satellite navigation systems by

- Providing improved ionospheric delay corrections and
- Providing an early warning system based on reliable forecasts of geomagnetic storm activity

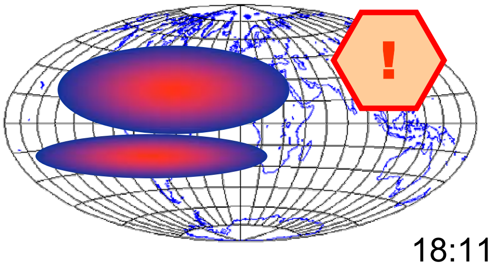
Goals

- Nowcast
  - Total Electron Content (TEC) coverage
  - Error range



15:23 UT

- Forecast
  - expected level of ionospheric disturbances



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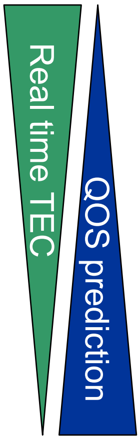
Users

- Primary users:
  - Users of Single Frequency Nav. Receivers
  - Aircraft
  - Communication companies
  - Space Industry
  - Pipeline companies
  - Power companies
- Secondary users
  - Scientists (space weather, geophysics, biology)
  - Amateur radio



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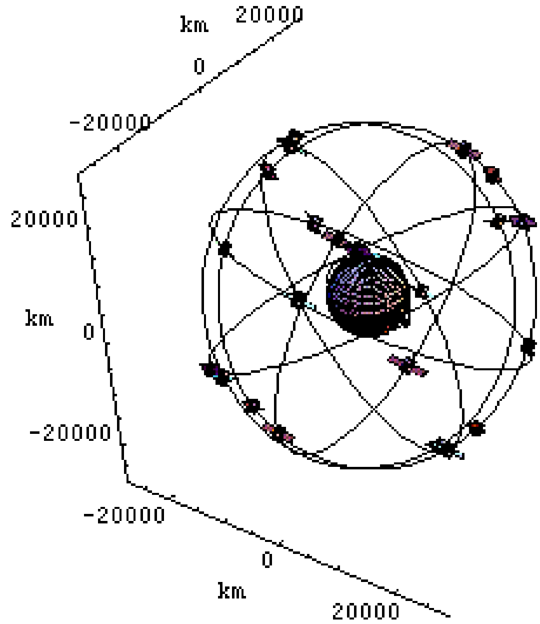
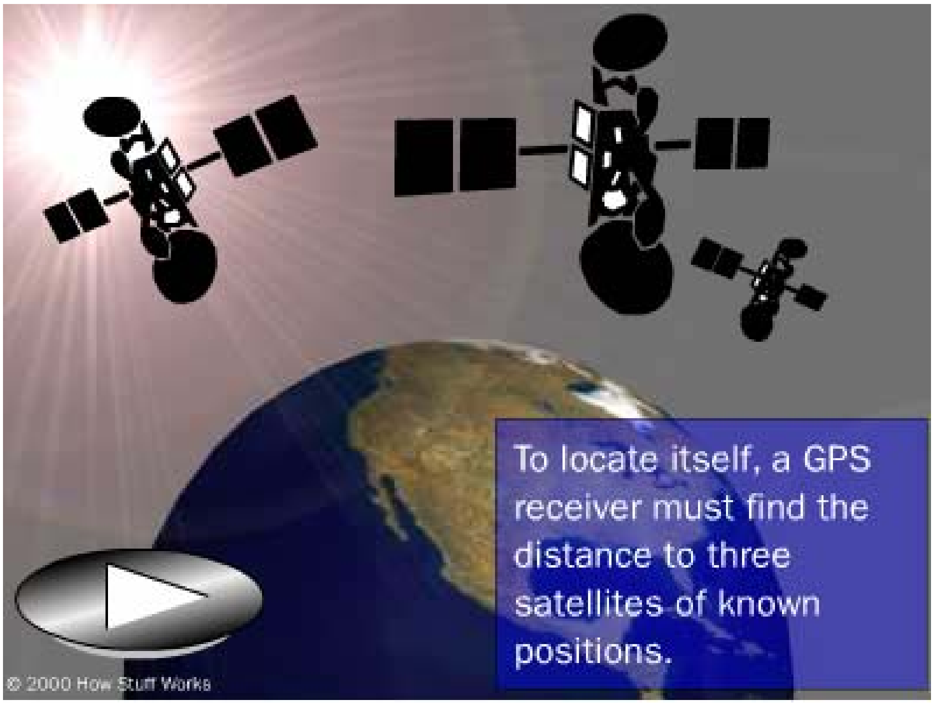
GPS working principle (1)

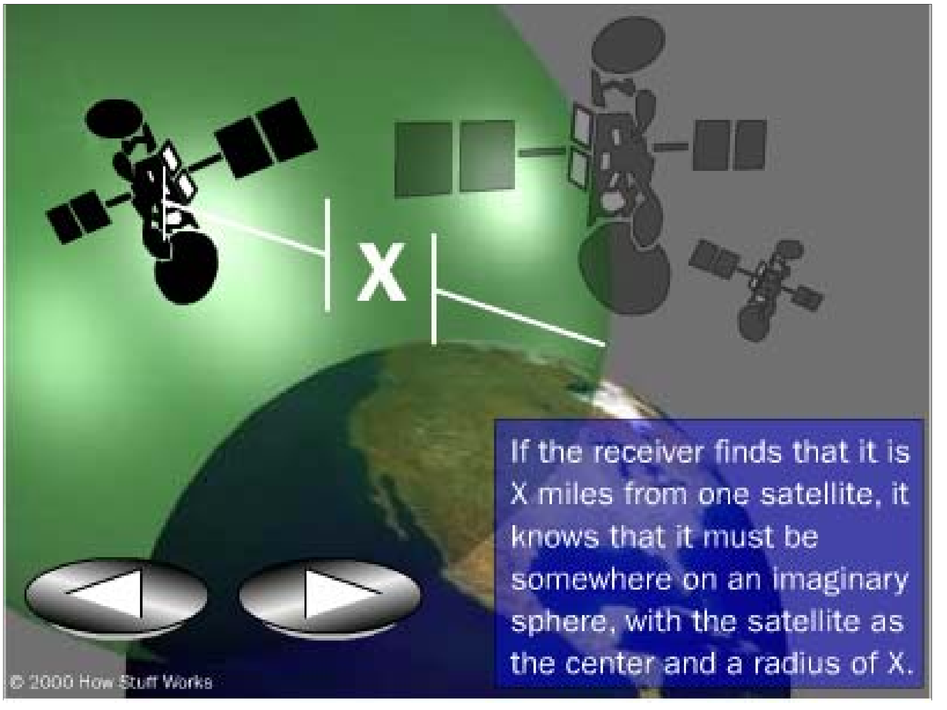
- 24 satellites
- Orbit period 12h
- 6 orbital planes, inclined 55deg
- 5–8 satellites visible at any given time
- Synchroneous clocks on board the satellites



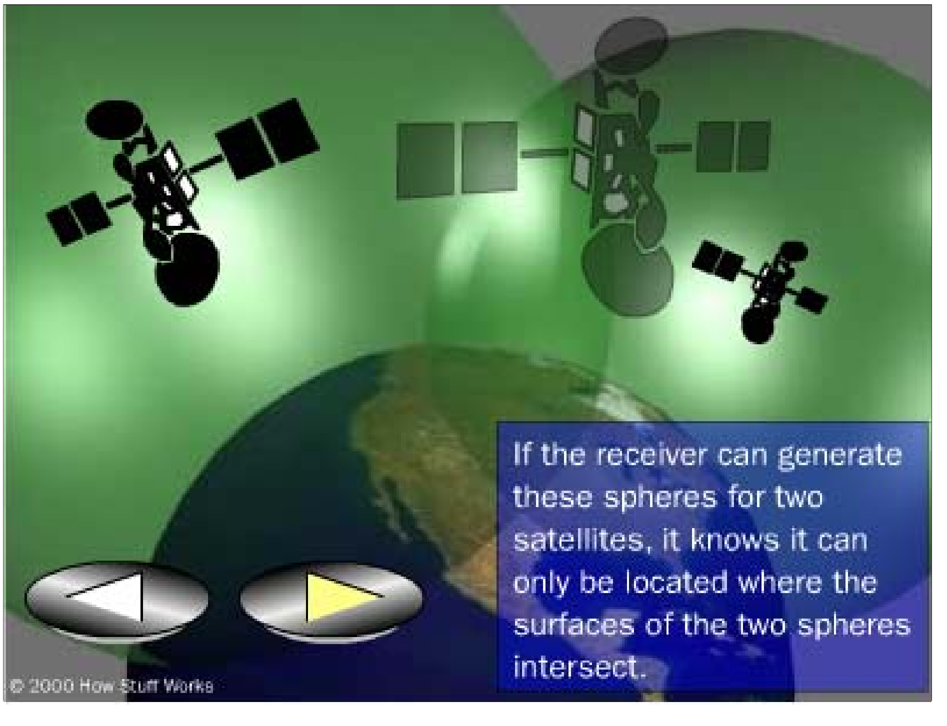
GPS working principle (2)



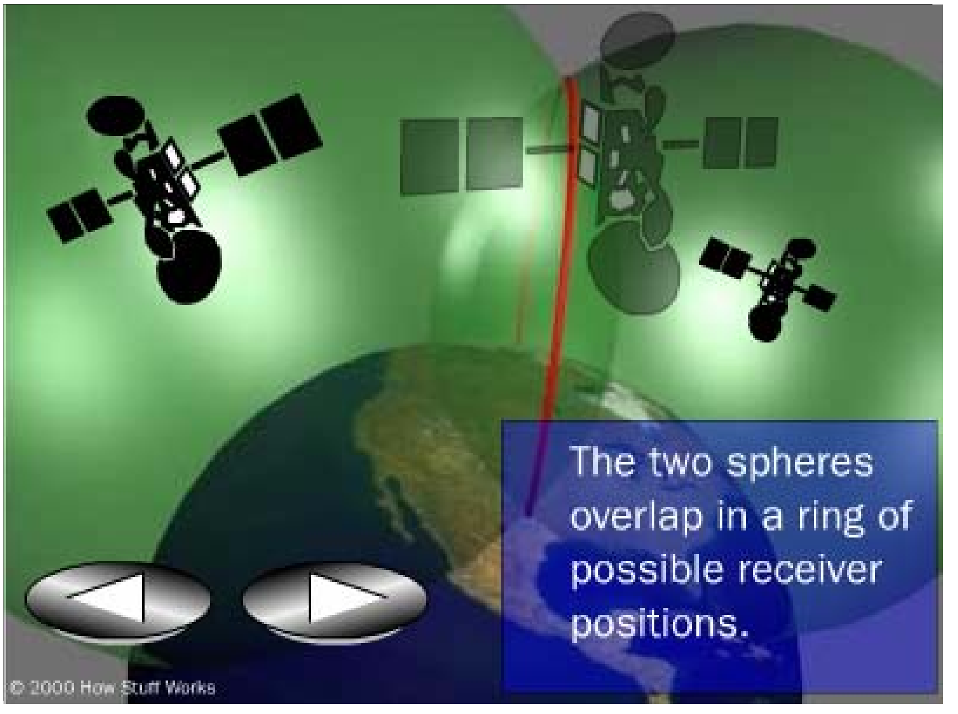
GPS working principle (2)



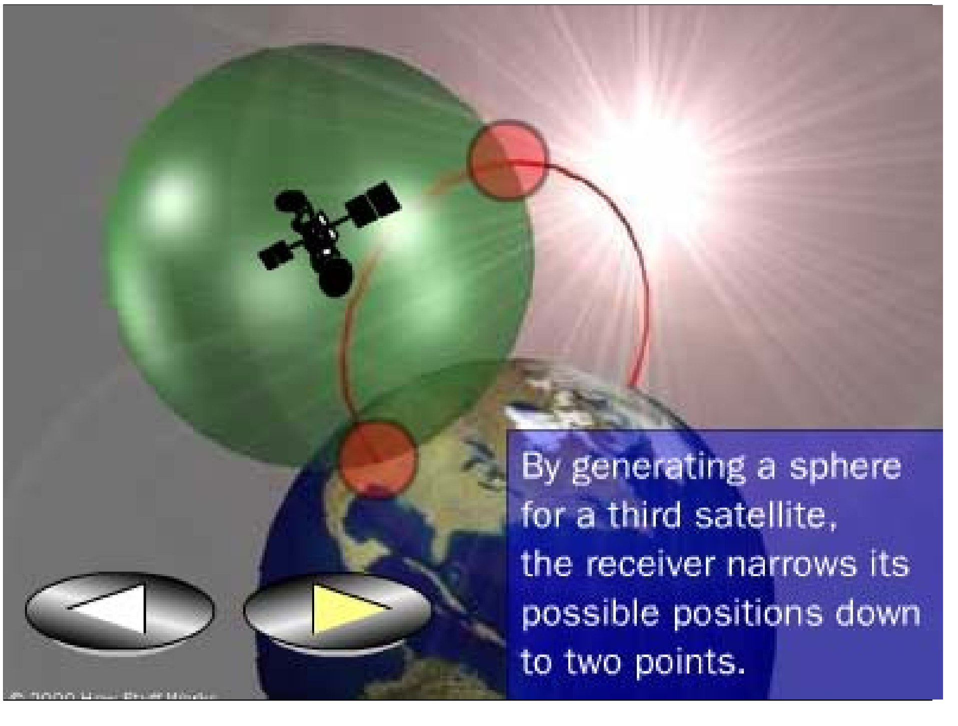
GPS working principle (2)



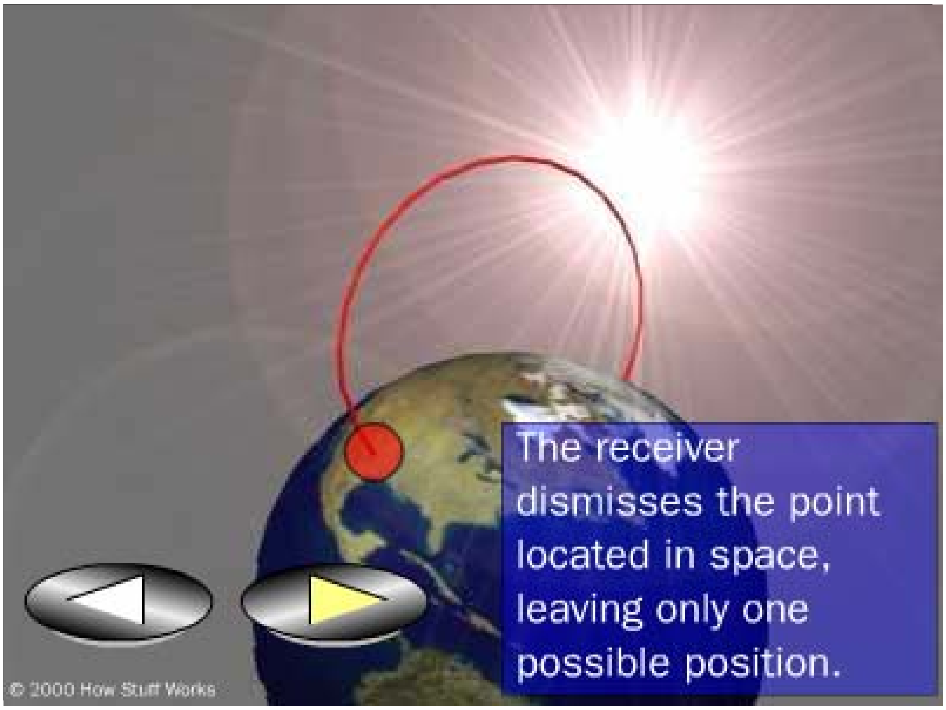
GPS working principle (2)



GPS working principle (2)

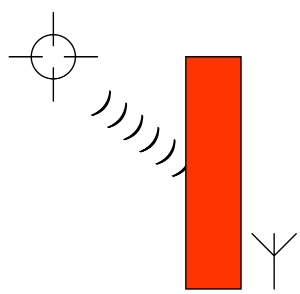


GPS working principle (2)

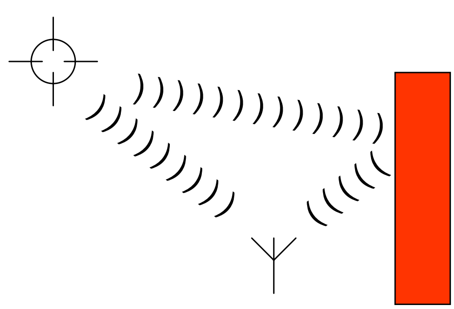


Real World Situation (1)

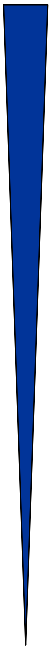
- Geometrical restrictions
  - Blockage



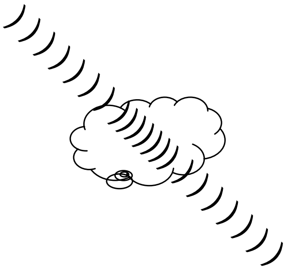
  - Multi-path



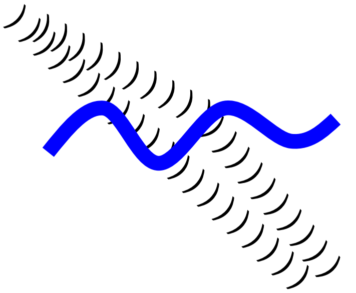
Real World Situation (2)



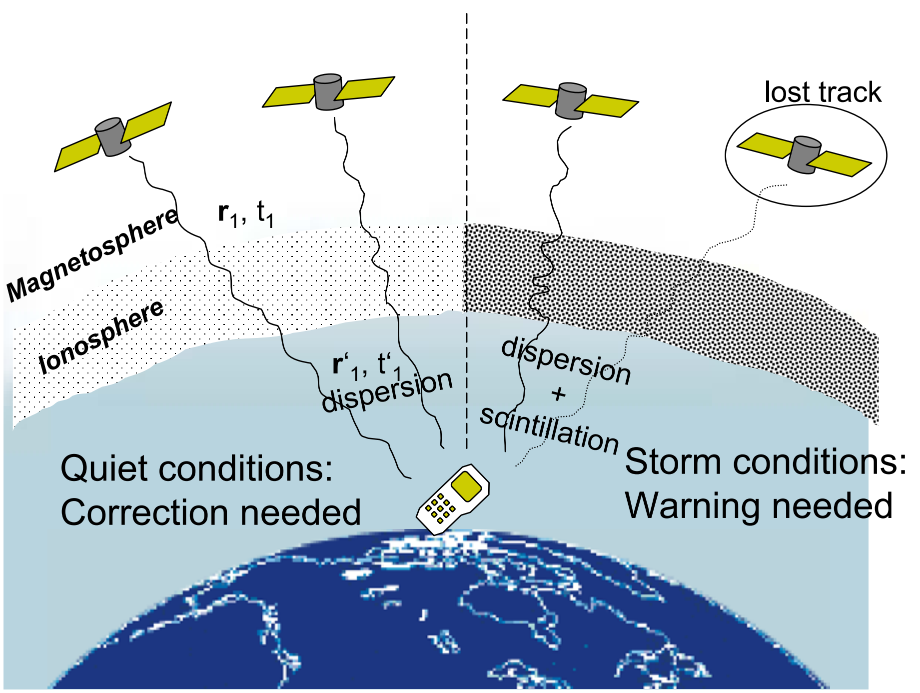
- Atmospheric/Ionospheric
  - Dispersion (60m)



  - Scintillations (0m – inf)



Dispersion / Scintillation



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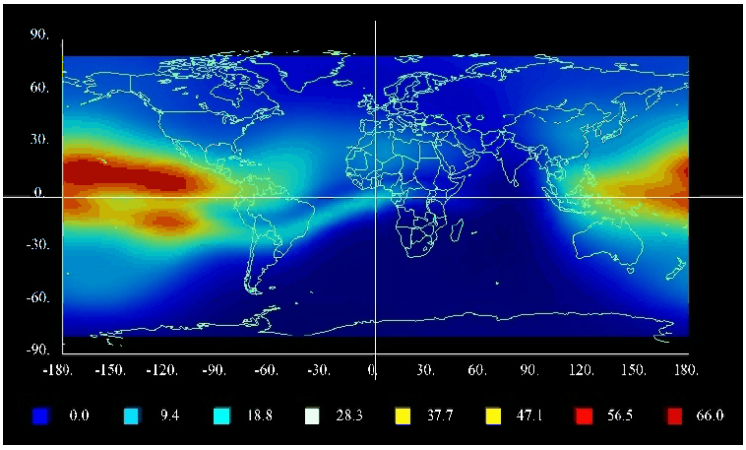
GLOTEC goals (1)

- Nowcast:
  Real-time global TEC map + error range

→ Compensate for time delay

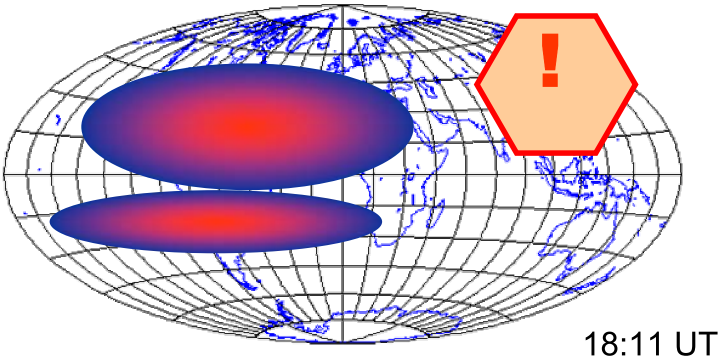


Movie courtesy of B. Arbesser-Rastburg

GLOTEC goals (2)

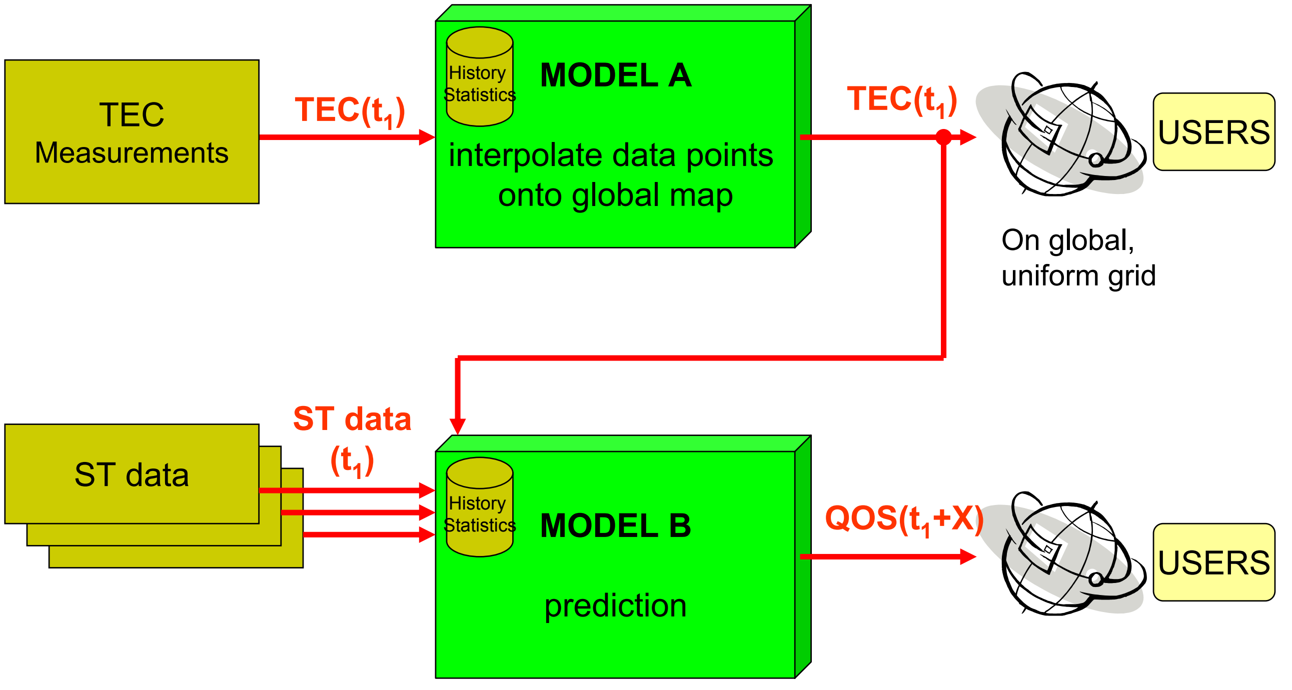
- Forecast based on space weather: expected level of ionospheric disturbances

→ Predicts future Quality of Service (QOS)



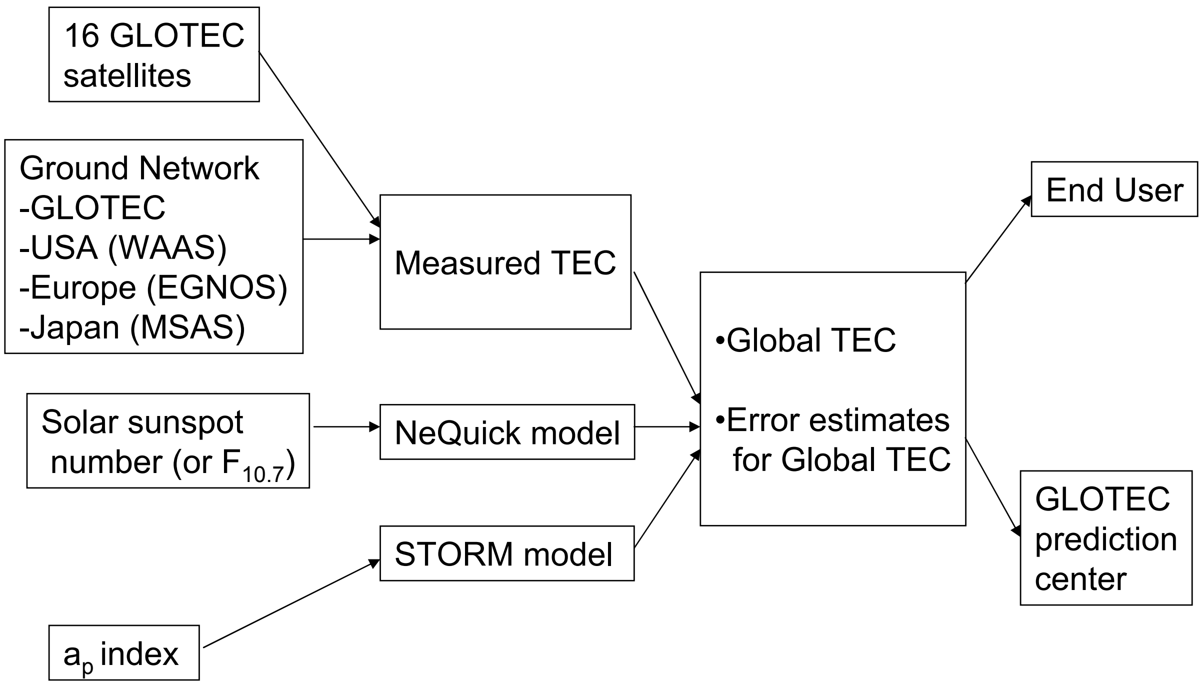
Contents

GLOTEC data flow (overview)



Nowcast Segment

TEC Nowcast



TEC Models

- NeQuick
  - A quiet-time ionospheric model
  - Developed at ICTP Abdus Salam Institute (Italy) and the University of Graz (Austria)
  - Input:
    - Historical database
    - Total sunspot number estimated from $F_{10.7}$
    - Current time

TEC Models

- STORM
  - A simple empirical storm-time ionospheric model
  - Developed at NOAA
  - Input:
    - Previous 30 hours of a_p index
    - Archive of ionosonde measurements from a number of storms
  - Provides good error estimates

Making the global TEC map

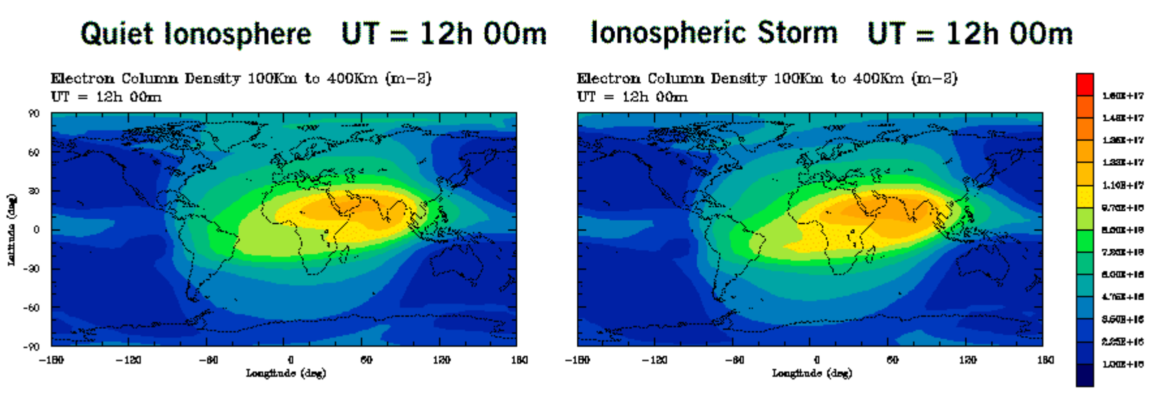
- Map is primarily based on satellite/ground network TEC measurements
- NeQuick or STORM model values are fitted to the true measurement values
- Locations not covered by TEC measurements are given values from the fitted model predictions
- New global TEC maps will be produced continuously

Calculation of TEC error

- Error values will be calculated for all conditions
  The specific error at any point will depend on
  - Density of nearby TEC measurements
  - Time history of TEC measurements
  - Model errors
  - Discrepancy between model values and TEC measurements

- Well known error in TEC will provide the user with good reliability information

Global TEC maps



Forecast Segment

Gero Kleindienst, Sergey Apatenkov, Cathrine Fox, Maule Emilia Huttunen, Stefan Kiehas, Benjamin Luethi, Daniel Martini, Noora Partamies, Fabrice Portier-Fozzani, Aveek Sarkar, Carita Siponen

Outline

- NeQuick TEC model valid during quiet time
- Regional warnings for the storm and substorm periods
- Archive of the global coverage of the TEC measurements for analysis and future prediction

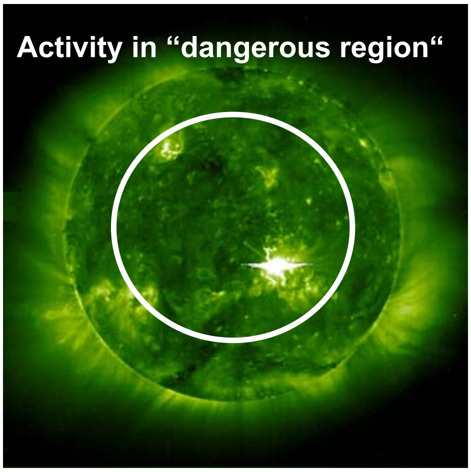
CME Warning System

Halo CME observation
SOHO/LASCO

→

Flare
Level: X-ray flux (GOES-8/GOES-10)
Locations: SOHO/EIT
Disappearing filament
H_α-images (ground solar observatories)

→



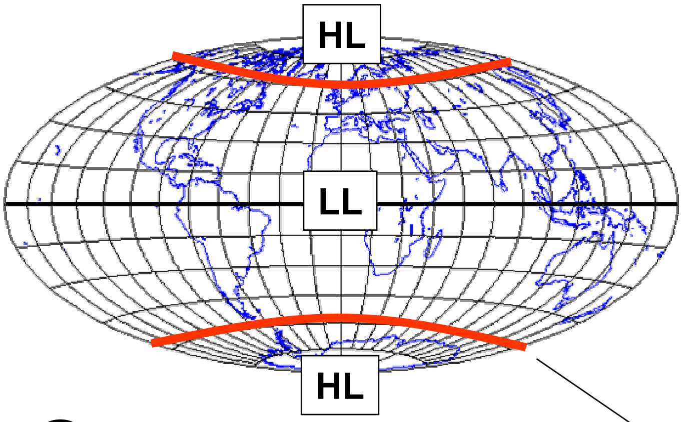
→ **CME WARNING!** →

CME speed and estimate of arrival time to 1 AU
~1.5 – 4 days

Future of CME Warning

- Improved measurements by STEREO (2007)
- Monitoring of type II radio bursts (tracking of CMEs to 1 AU)
- Better observations of CME source region topology and realistic models operating in near-real-time

Warning Regions



HL = high latitude region
LL = low latitude region

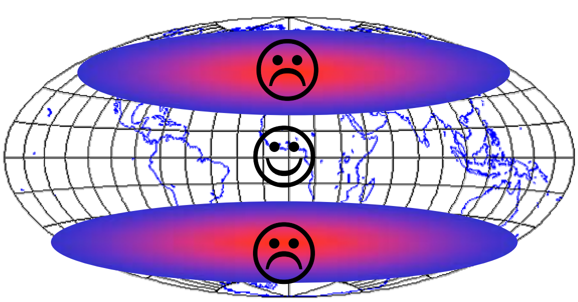
From the auroral oval model by Feldstein [1963]

☺ No Problems

😐 Be careful

☹ I‘m lost

Isolated Substorms



HL : ☹ for 18 – 02 MLT (😐 for ±2 h)

LL : Quiet time model (☺)

L1 (1h ahead)

B, B_x, B_y, B_z, V measured → $\varepsilon > 10^{11}$W and $B_Z < 0$ for at least 20min → Substorm warning to HL region for the next 2h

$$\varepsilon = 10^7 \times BV^2 \sin^4\left(\frac{\theta}{2}\right) l_0^2$$

Storm Warning

From L1 (1h ahead):

$$\frac{dDst}{dt} = \alpha\varepsilon - \frac{Dst}{\tau_R}$$

Burton et al., 1975

Main phase (~6h):

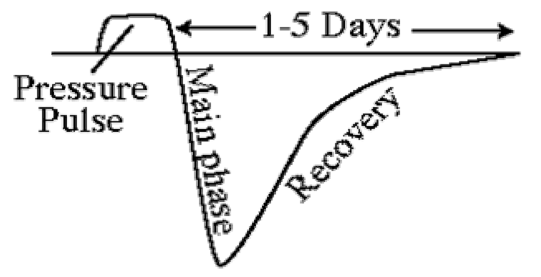
HL: ☹ for 16 – 08 MLT (☺ for ± 2h)

LL: ☺

Severe Storm limit:
Dst < -100nT

→ ☹ everywhere

Dst STORM



Storm limit:
Dst < -50nT

Recovery Phase (~3h):

HL: ☹

LL : ☺

Future

- Auroral precipitation
- Auroral oval location (AE/AL, NOAA, DMSP)
- Neutral wind
- Transportation of the plasma from high to mid latitudes
- Ring current decay
- F region bubbles (quiet time equatorial regions)

Better understanding of the Sun's activity, magnetospheric and ionospheric dynamics and their coupling to the solar wind to get more accurate models and more reliable and longer term predictions

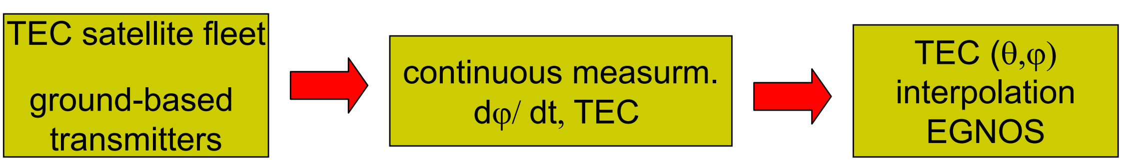
Operative Space Segment

Lisa Blush, Adrian Blagau, Margit Haberreiter, Steffen Heidicke, Tanguy Thibert, Veerle Sterken, Jochen Zönnchen

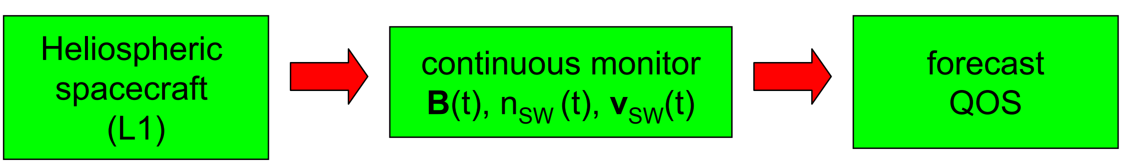
Spacecraft & Satellite Fleet

GLOTEC fleet deployed to measure atmospheric and heliospheric conditions

- To fill spatial gaps in existing sytems:



- To provide **continuous** monitor of heliospheric conditions:



GLOTEC Fleet Overview

- L1 Heliospheric Monitor Spacecraft (forecast)
  - 1 spinning S/C orbiting L1
  - Heritage payload, redundant instrumentation, telemetry
  - 1 minute data integration
  - **Continuous** monitor **B**(t), n_{sw} (t), $\mathbf{v}_{sw}$ (t)

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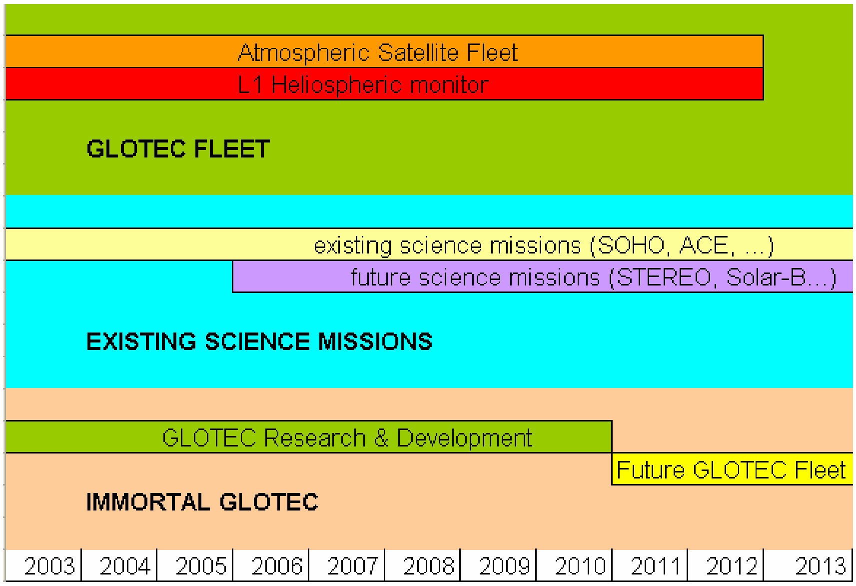
  - Heritage payload, redundant instrumentation, telemetry
  - 1 minute data integration
  - **Continuous** monitor **B**(t), n_{sw} (t), $\mathbf{v}_{sw}$ (t)

- Atmospheric Satellite fleet (nowcast)
  - 16 satellites (+ 2 spares)
  - Extending/updating the ground-based-network
  - Land mass & **ocean** mass coverage
  - 2-D global map of TEC, scintillation data
  - improved spatial resolution (5°) temporal resolution (15-30 min)

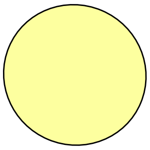
Solar-Terrestrial Technology Vision

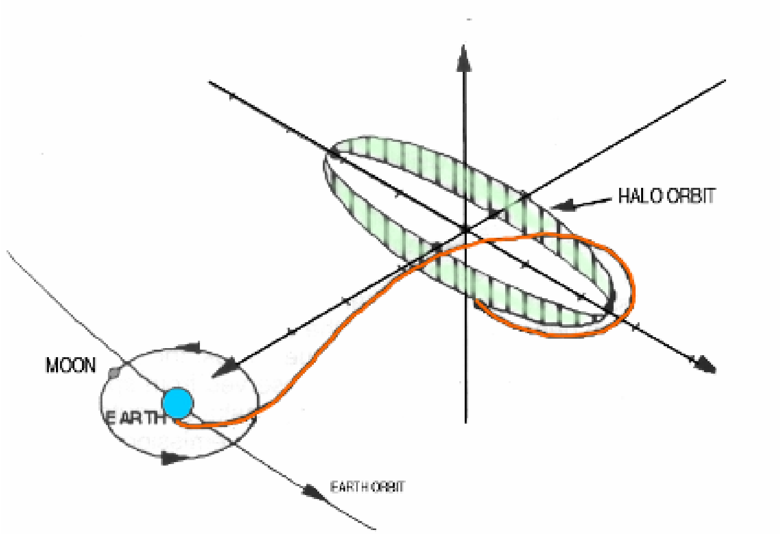
GLOTEC, as a service package, guarantees its long-term commitment to its customers



L1 Spacecraft

The L1 spacecraft monitors
Earth-approaching heliospheric disturbances
(CME with associate B flux rope)

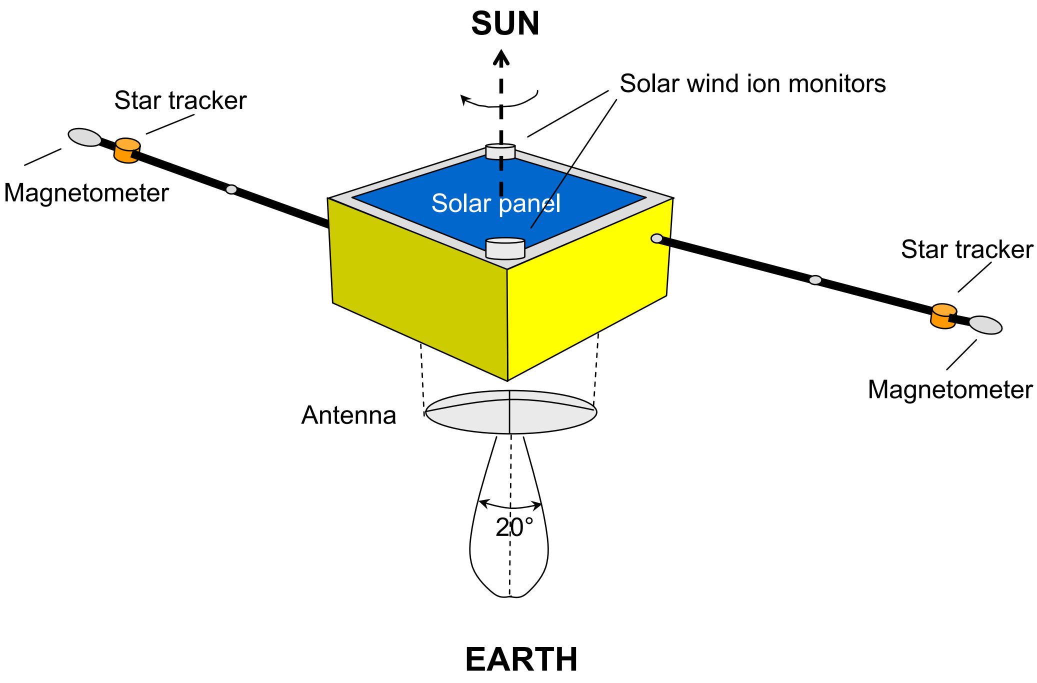




Measure of
B(t), n_{sw} (t), $\mathbf{v}_{sw}$ (t)

- strong CME shock front
- B flux rope

L1 Spacecraft Design



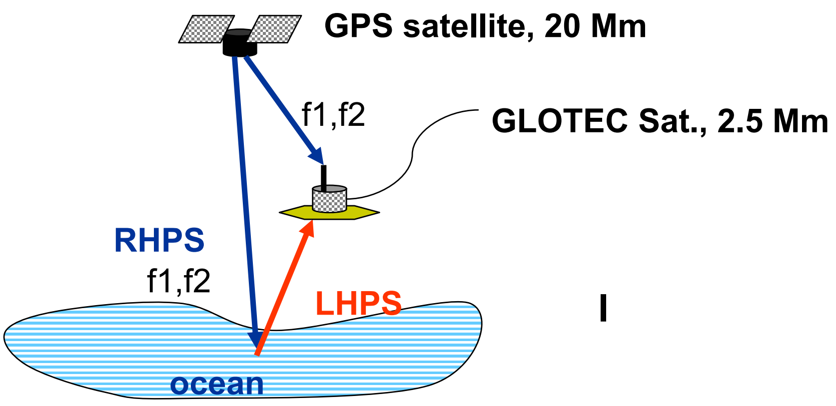
Spacecraft Subsystems

- Launch — 1 S/C deployed 2003 Soyuz-Fregat (37 M$)
- Orbit
  - Halo orbit at Lagrange point L1
  - no launch constraints
- Redundant instrumentation
  - Magnetometer (heritage ACE)
  - SW ion monitor (heritage PM/MTOF/CELIAS/SOHO)
- Attitude and Orbit Control System (AOCS)
  - Sun-Earth spin axis pointing accuracy 1°
  - Sun sensor, gas thrusters, star tracker

Spacecraft Subsystems

- On-board data processing
- Telecommunications
  - 240 bits/sec data downlink
  - Directional antenna (20° aperture)
- Mass — 115 kg
- Radiation environment — Stable thermal environment
- Cost reduction — heritage, operations sharing

Atmospheric Satellite Fleet



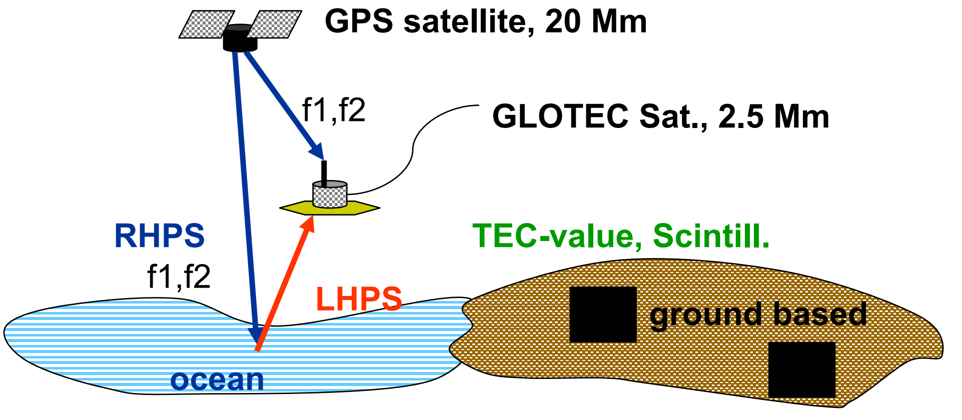
<u>over the ocean:</u>

•Reflected GPS-Signal changes its Polarization to Left-Hand-Side!

•GLOTEC-Sat. receives <u>direct</u> and <u>reflected</u> GPS-Signals in 2 frequencies.

•TEC-Value can be calculated from the differenz in signal-travel-time.

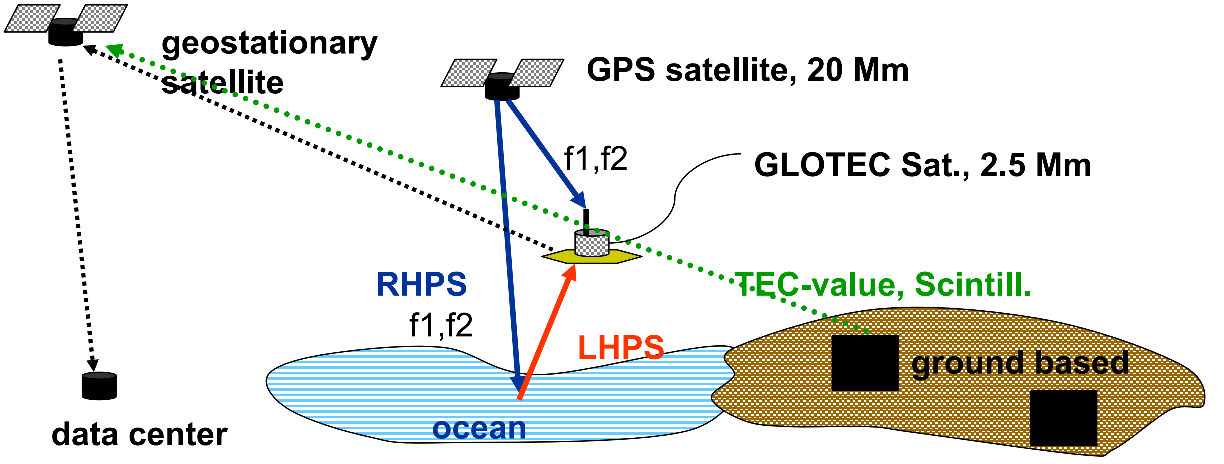
Atmospheric Satellite Fleet



Over ground:

Ground-based-stations receives GPS-Signals on 2 frequencies and calculate TEC in the same way.

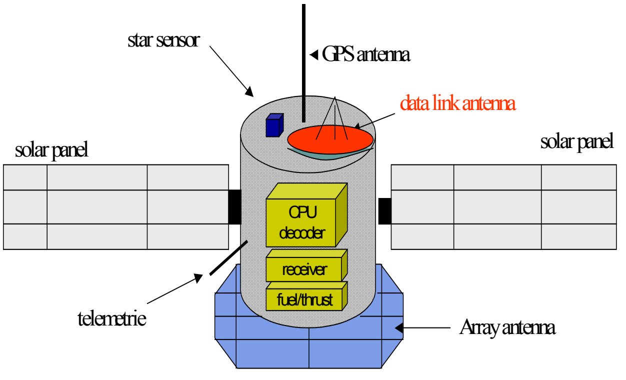
Atmospheric Satellite Fleet



Data-Uplink:

GLOTEC-Sat. And Ground-Stations transmit their TEC-Value to data center via a geostationary satellites.

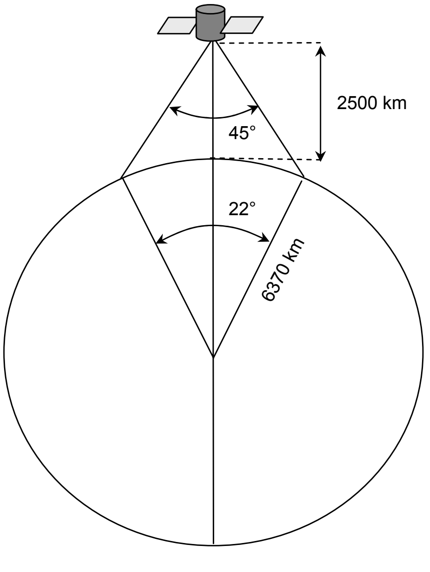
GLOTEC-Satellite Instruments:



Instrumentation:

- 1 omnidirectional GPS-Antenna
- 1 Array-Antenna directed always downward to the earth to receive signals reflected by the ocean (LHSP):
- 1 Communication-Link Antenna
- 1 Telemtrie-Antenna
- 2 Receivers
- Star-Sensor (for attitude-control), Gyroscopic sensors with dumpers
- Thrusters for orbit adjusment and initial positioning
- CPU & Communication Units for Data-Transfer
- power Subsystem (Solarbattery)

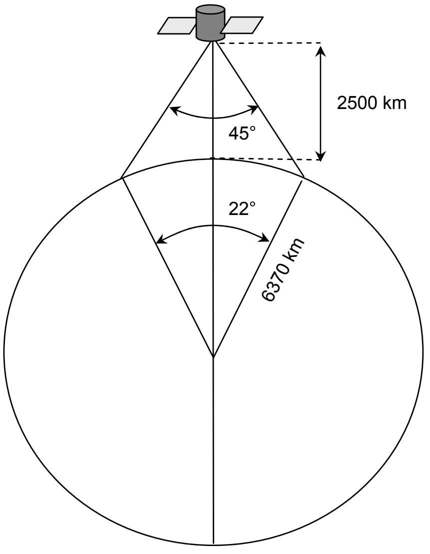
GLOTEC-Sat: Orbitals facts (1)



Orbital Facts:

Altitude :	2.500 km
Period :	about 120 min
Orbit type:	circular, polar orbit
Field of View:	22° on earth for each Sat

GLOTEC-Sat: Orbitals facts (2)



Orbital Facts:

Time-Resolution: 5-30 min

Spatial Resolution: 3-20° (depends on location)

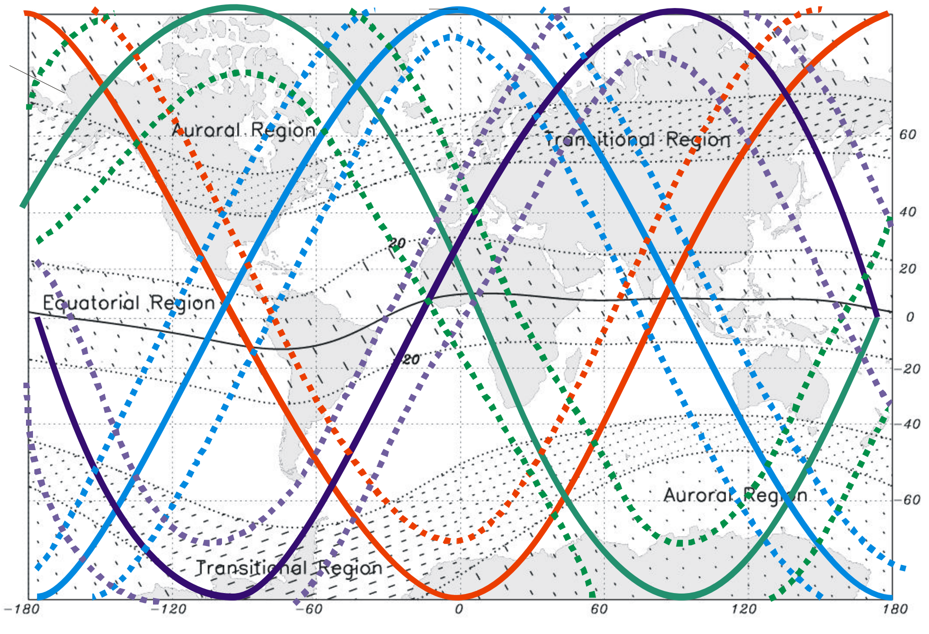
Number of Sat's: 4 equally spaced Sat's per Orbit

Number of orbits: 4 orbits uniformily distributed in longitude

Estimated mass: 40 kg each Sat

(plan: using 2 spares)

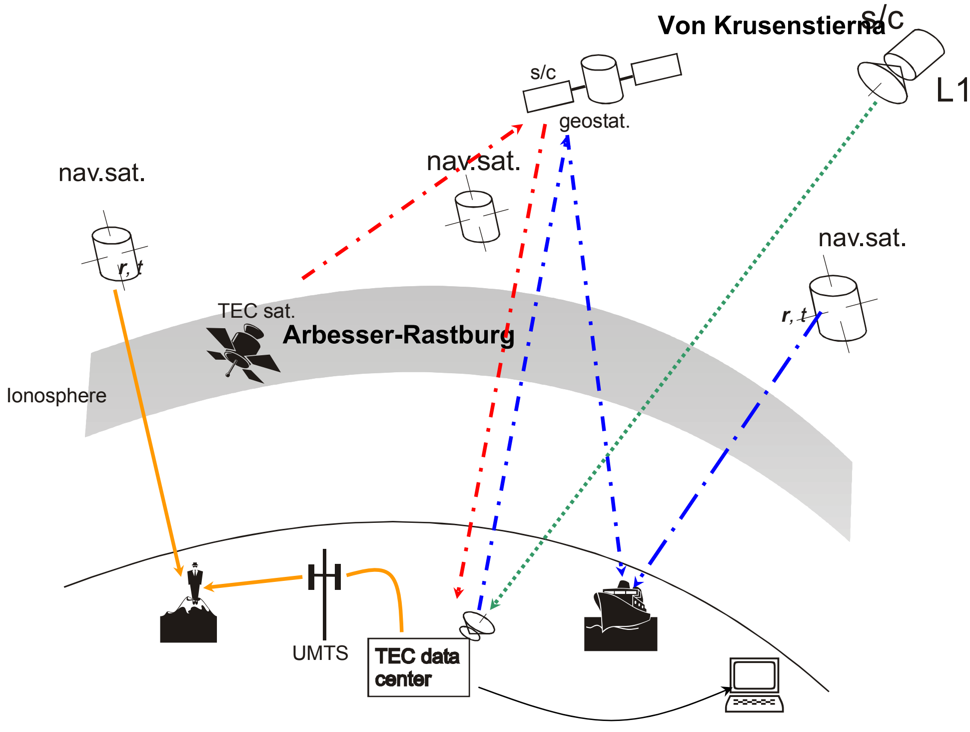
GLOTEC Sat: coverage



Data Center Segment

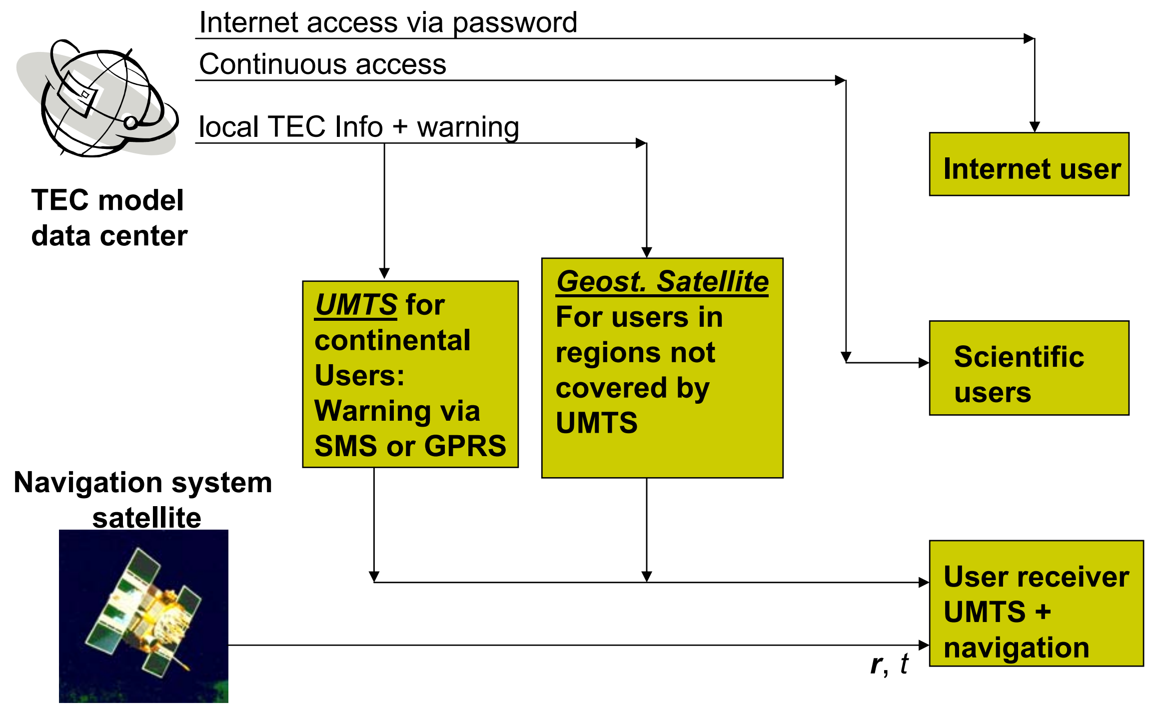
Marie Backrud, Arne Asnes, Martin Grill, Stefan Mühlbachler, Pamela Puhl-Quinn, Britt Rosendahl Hansen, Tero Sahla, Sebastian Schäfer

Information flow model

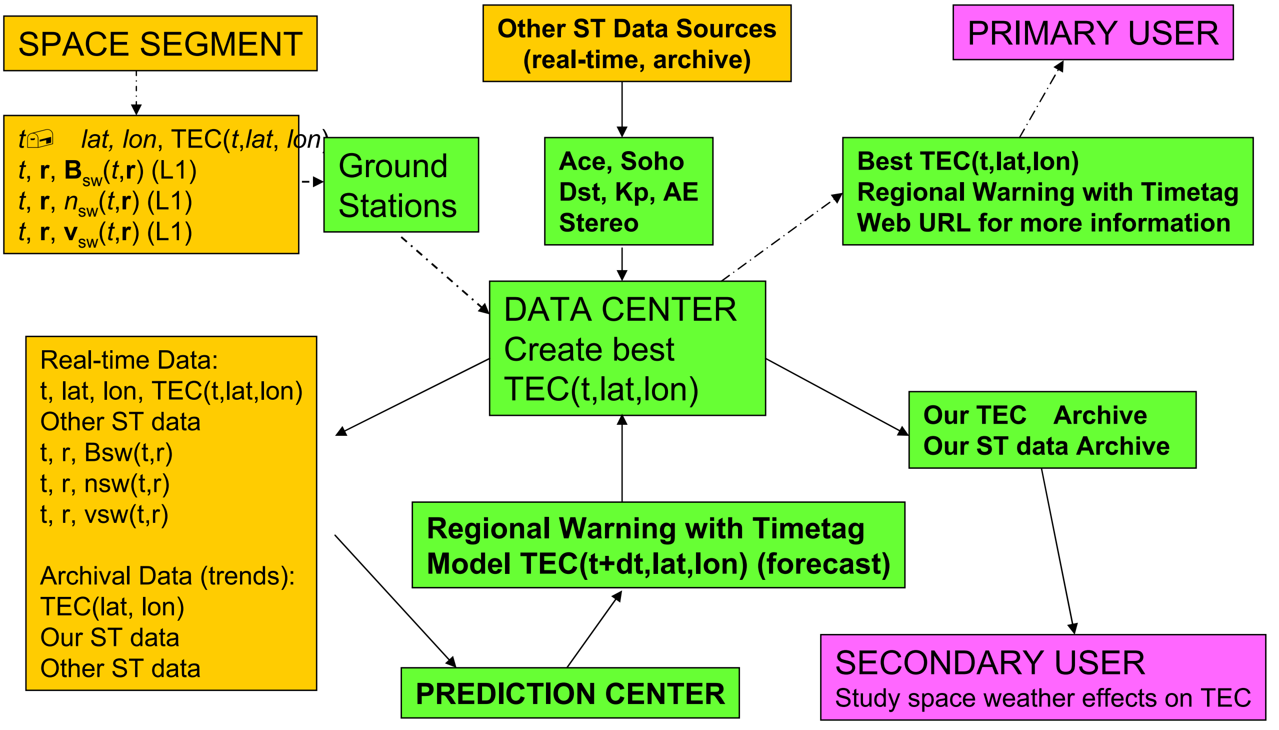


- Paschmann
- Dudok de Wit
- Baumjohann
- Daly
- Koskinen
- Lundstedt
- Friss-Christensen
- Glaßmeier
- Boteler
- Culhane
- Klecker
- Ortner
- Gitsch
- Mauersberg
- Sir Bondi

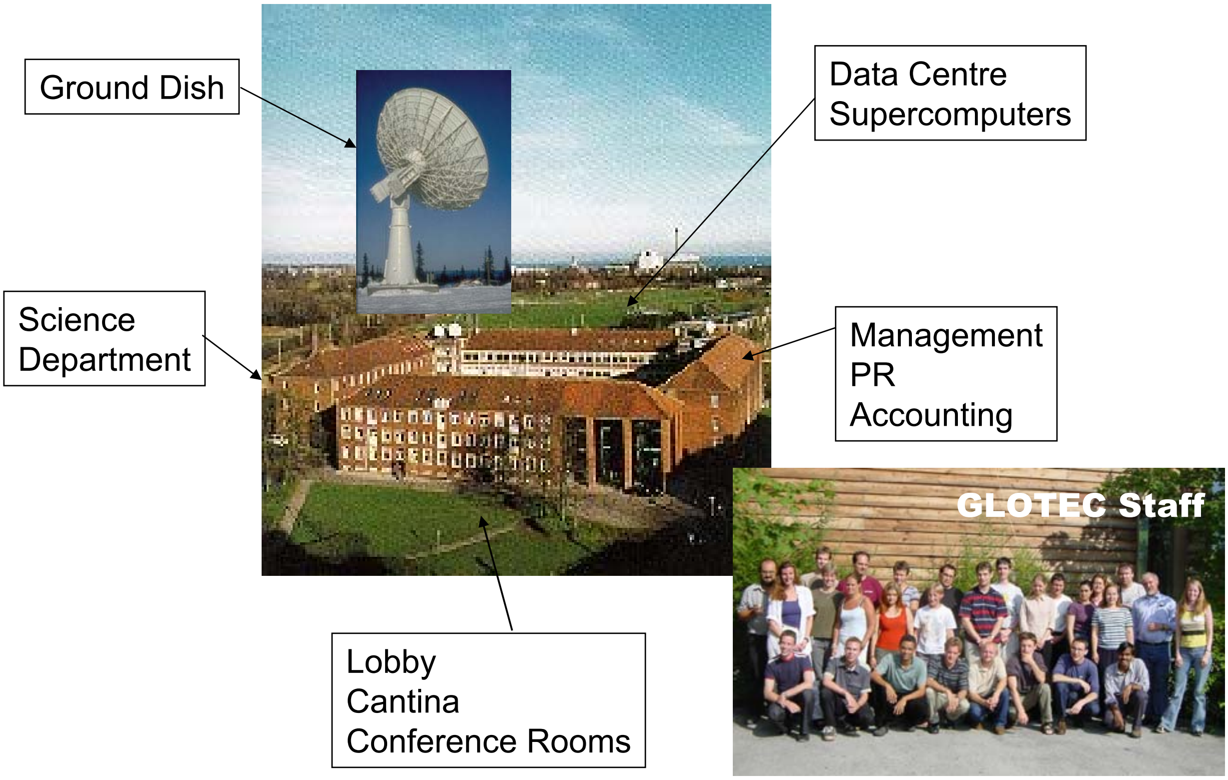
Broadcasting



GLOTEC Data Center Info-Flow



GLOTEC Headquarters



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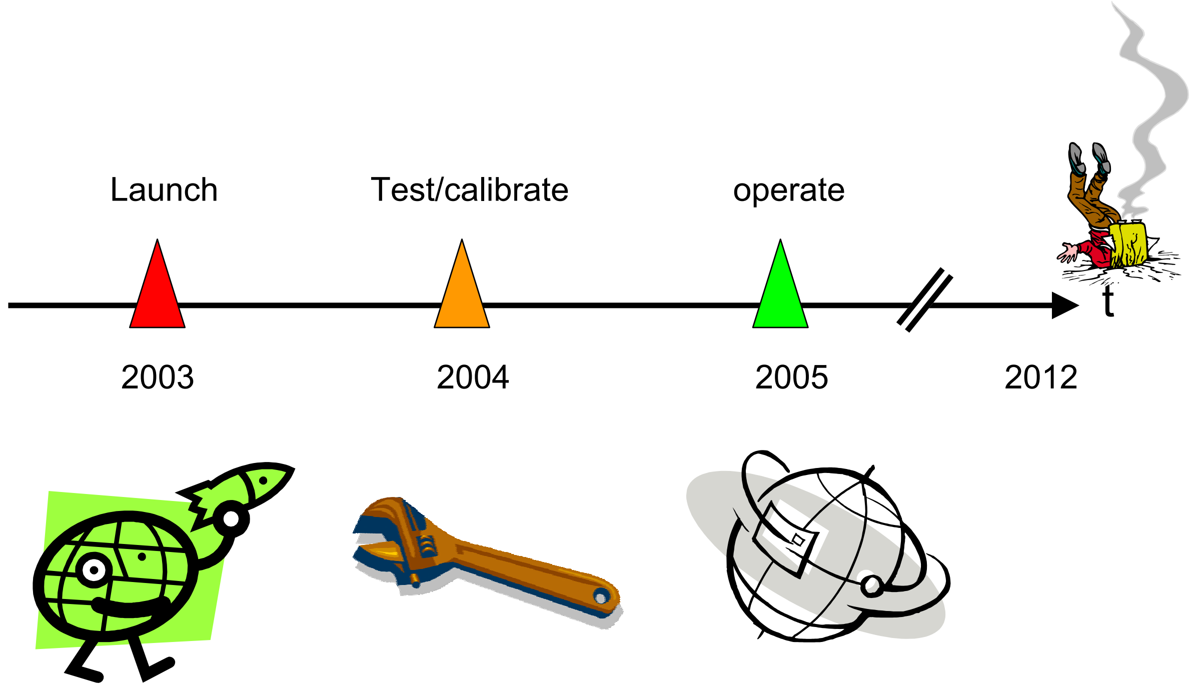
Cost guesstimate

- **L1 spacecraft:** 77 M€
- **TEC measurement system:** 59 M€
  - **18 satellites + ground network**
- **Data- / Prediction Centre:** 8 M€
- **Annual upkeep 6 M€ for 10 yrs** 60 M€

Project total **204 M€**

Timeline



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Summary (1)

- Innovative Achievements
  - Reliable, continuous TEC coverage
  - Highest possible position accuracy for single frequency receivers
  - High quality, continuously self-refining „Quality of Service“ predictions
  - High prediction quality even during severe Space Weather situations

Summary (2)

- Future
  - Advanced prediction models
  - Integration of additional space weather data sources
  - Seamless migration from GPS to GALILEO

Thank you!