The NASA/JPL BlackJack GPS Receiver on CONAE's SAC-C Mission

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GPS BlackJack Receiver on SAC-C

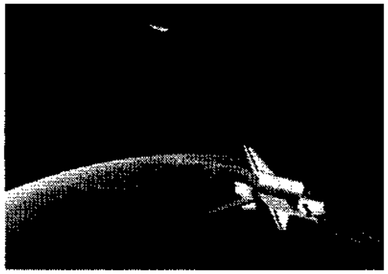
- GPS flight receiver was built and tested by JPL
- Purpose: demonstrate and achieve new capabilities for tracking, navigation, and science remote sensing
  - Navigation/tracking is just one benefit
  - The BlackJack differs from conventional GPS receivers in that it was designed from the start to be multifunctional and software driven, with precision and performance as distinguishing qualities
  - SAC-C has been an extremely valuable platform to mature GPS technologies, related to both precise orbit and remote sensing

BlackJack GPS Receiver on SAC-C: Topics

- Atmospheric and Ionospheric Remote Sensing
- Precision orbit determination
  - Post processed
  - Real time
- Surface Reflections
- Some "firsts"

Current Missions with BlackJack Receivers

• precise orbit

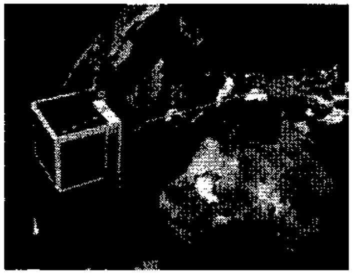


SRTM

(Feb 2000)

JASON-1

(Dec 2001)



FEDSat

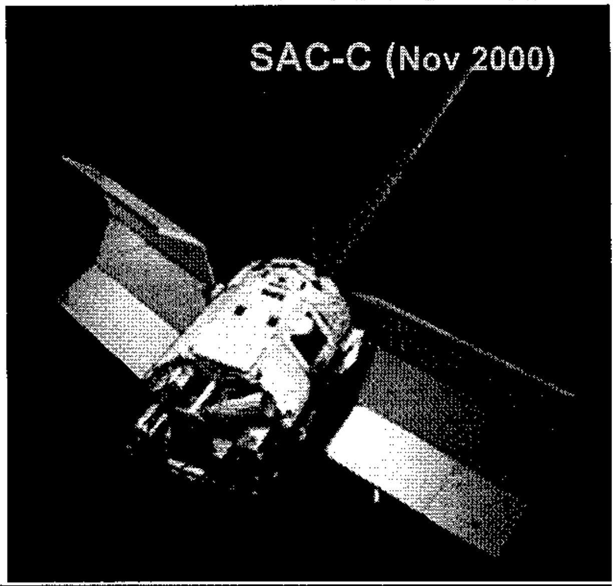
(Dec 2002)

ICESat

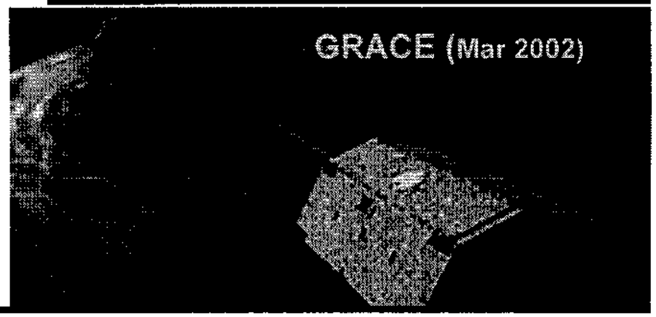
(Jan 2003)

• precise orbit
• atmospheric & ionospheric occultations
• gravity
• surface reflections

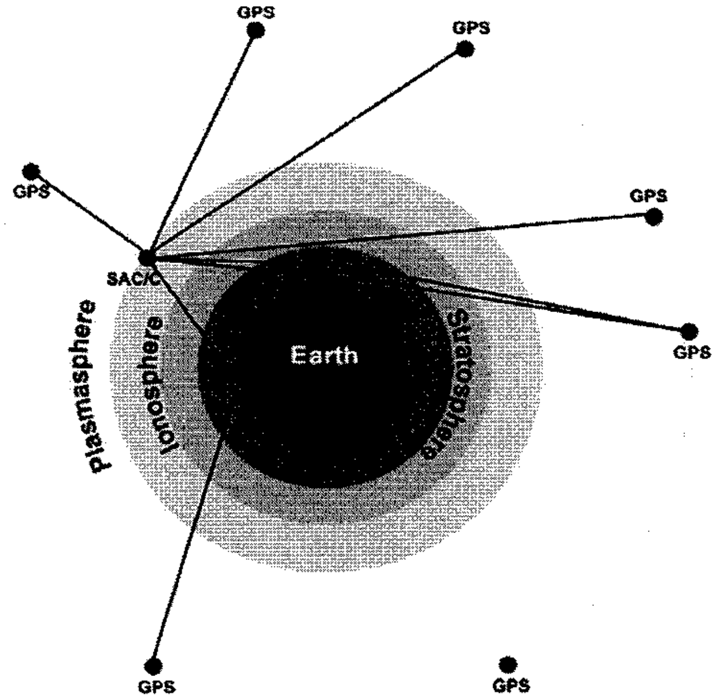
• precise orbit (on-board, real-time)
• atmospheric & ionospheric occultations
• surface reflections



• precise orbit
• gravity
• atmospheric & ionospheric occultations

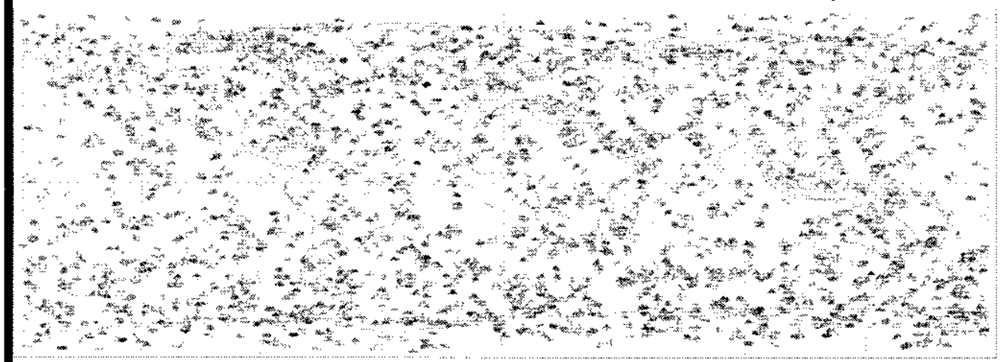


Overview of GPS Remote Sensing Applications on SAC/C

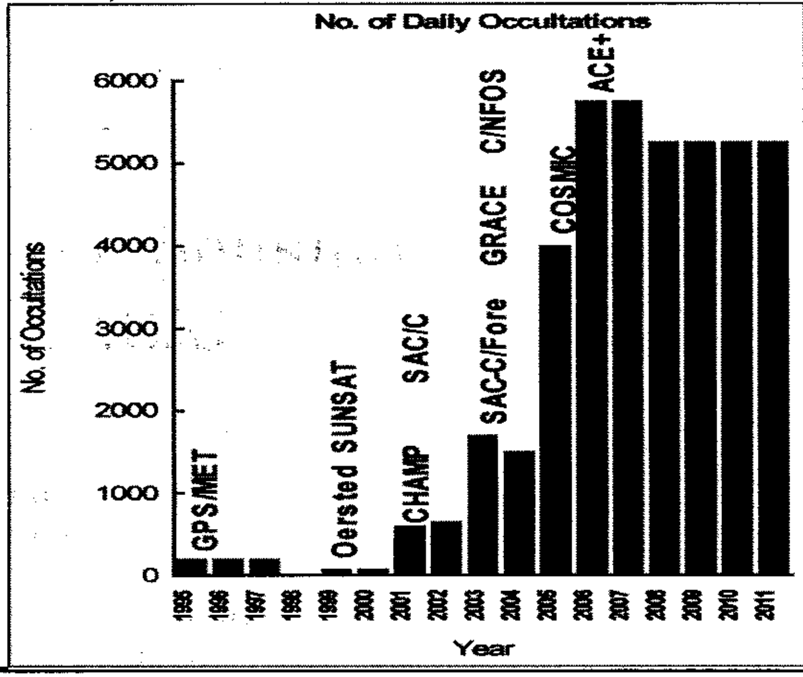


Each occultation provides a high resolution (~100m) profile of atmospheric density, temperature, pressure and geopotential height in the stratosphere and upper troposphere, and temperature or water vapor in the troposphere, electron density and irregularities in the ionosphere. Upward measurements provide 2D tomographic images of electron density in the plasmasphere. Surface reflection data gives ice topography, and possibly ocean height, wind and roughness.

One week coverage from SAC-C and CHAMP (~500 occultations/day)

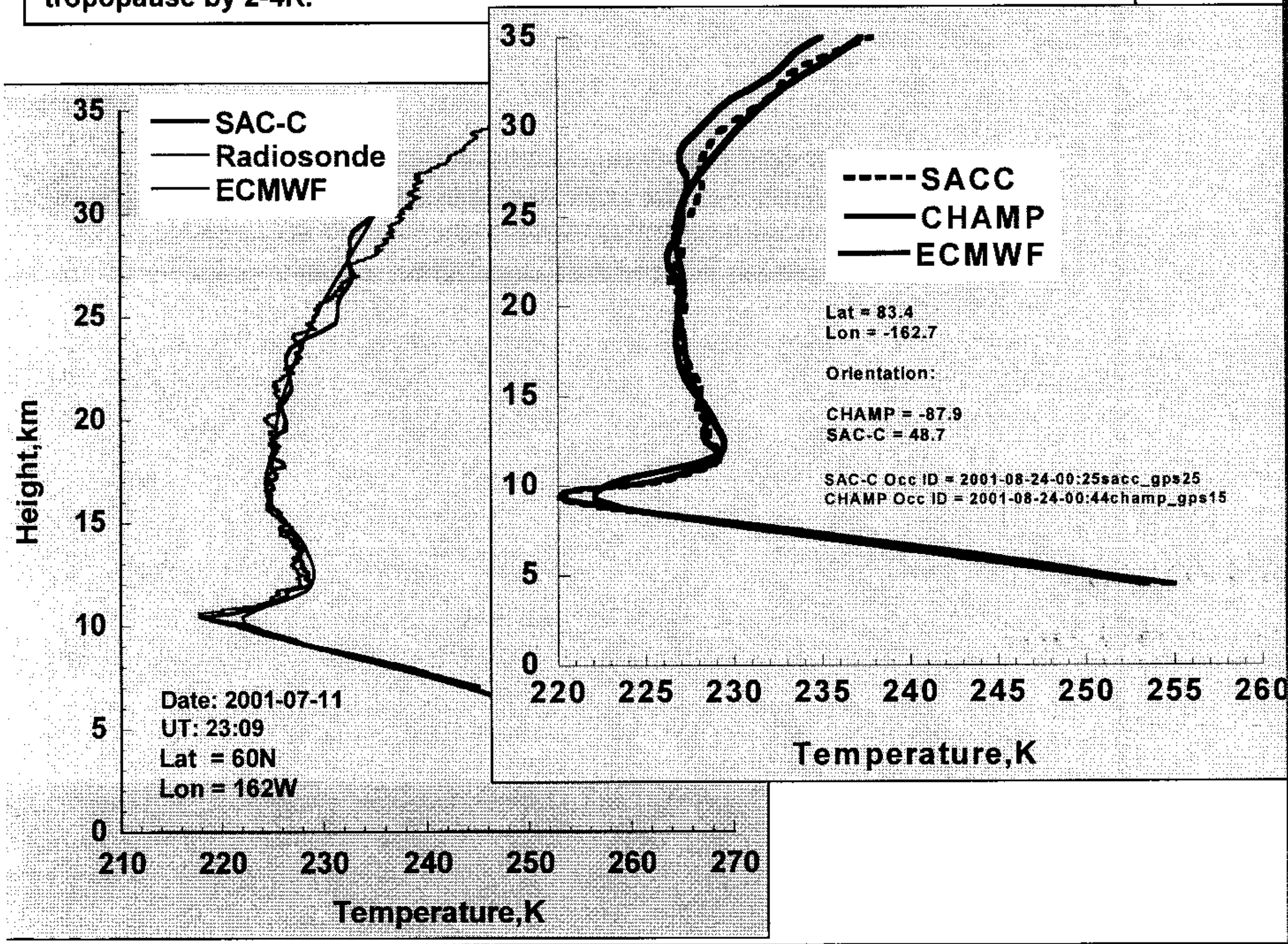


Historic, current and future GPS occultations



Examples OF Temperature Profiles from SAC/C and CHAMP

High correlation between SAC-C and nearby radiosonde (Left) or between SAC-C and CHAMP (right) illustrates the accuracy and high resolution of SAC-C temperatures. The best available weather model (ECMWF) overestimates the tropopause by 2-4K.



Features:

- Relies on precise measurements of time delay between transmitter and receiver
- No long term drift—ideal for global warming detection
- Global coverage
- All-weather remote sensing system
- Measures profiles of refractivity, density, temperature and pressure from surface to 50 km
- Measures water vapor profiles in the troposphere, with accuracy of 0.2 g/kg
- Provides profiles of electron density in the ionosphere with <1 km resolutions
- 0.5K accuracy for individual profiles
- 0.1K accuracy for averaged ensemble
- ~100-m vertical resolution

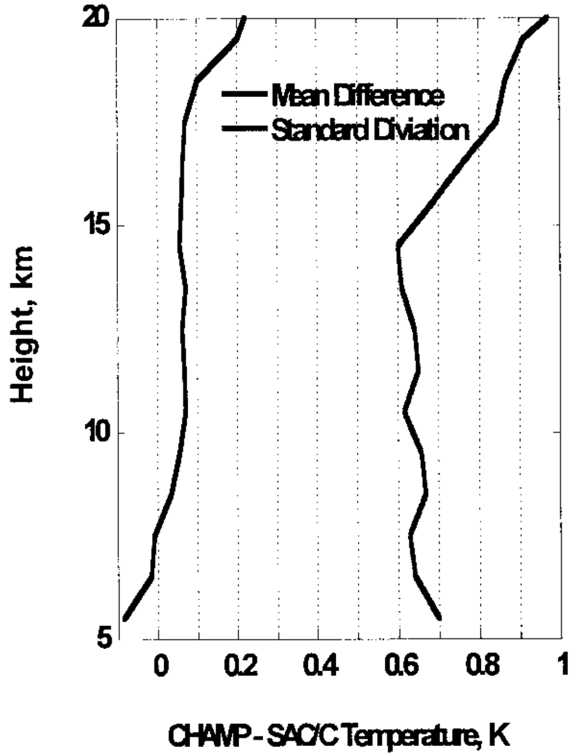
Applications:

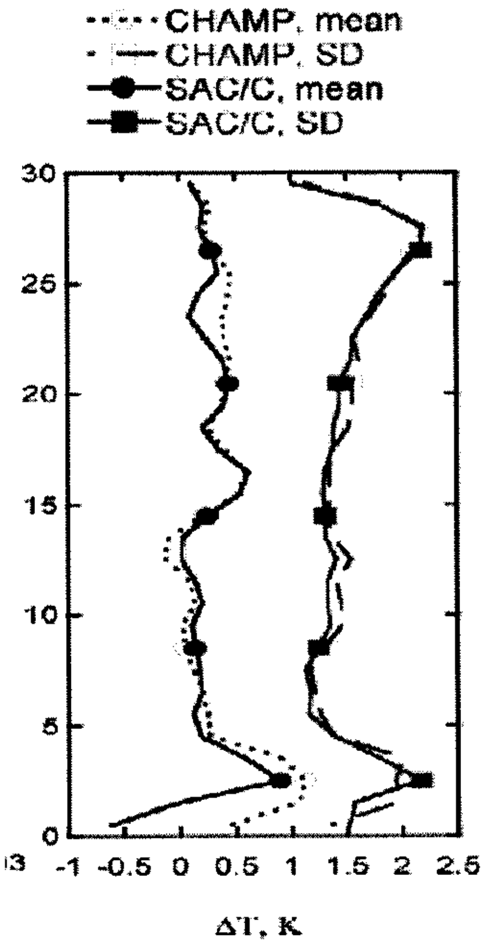
- Climate trend detection
- Assess/calibrate other observations and analyses
- Improve analyses and weather prediction
- Study of atmospheric mass, balanced wind and slab temperatures
- Study of atmospheric moisture
- Study of internal boundaries: Tropopause and Boundary Layer
- Characterize the diurnal cycle
- Characterize the transport of energy by small and large scale waves
- Contribute to knowledge of cloud top & base and conditions of formation, evolution and dissipation
- Reveal features diagnostic of underlying physical processes

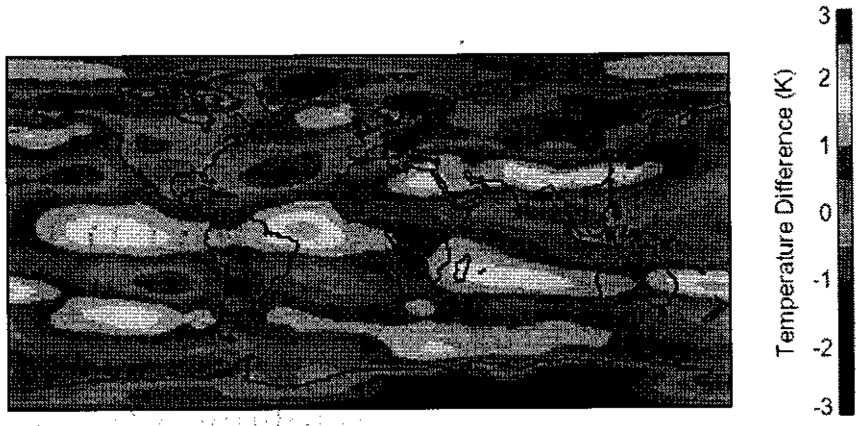
Potential for Climate Trend Detection

Statistics based on ~200 SAC/C and CHAMP occultations that are <1/2hr and <100 km apart show consistent mean T to < 0.1K (below-left). By contrast mean temperature of analysis (NCEP) shows differences of ~0.5K to SAC/C or CHAMP (below-right). After Hajj et al., 2003.

GPS occultations offer independent, very precise measurements for the detection of weak climate trends – 0.1K/decade – as well as a standard against which other instruments can be calibrated.



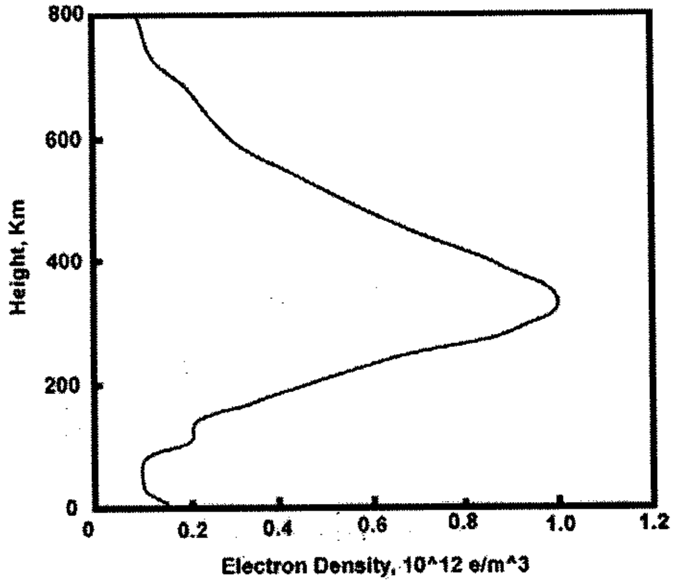




The bias of the 200hPa-300Hpa layer average temperature in ERA-40 weather analysis with respect to GPS occultation from SAC/C and CHAMP averaged over 2002 and 2003. Leroy et al., 2003.

Capabilities:

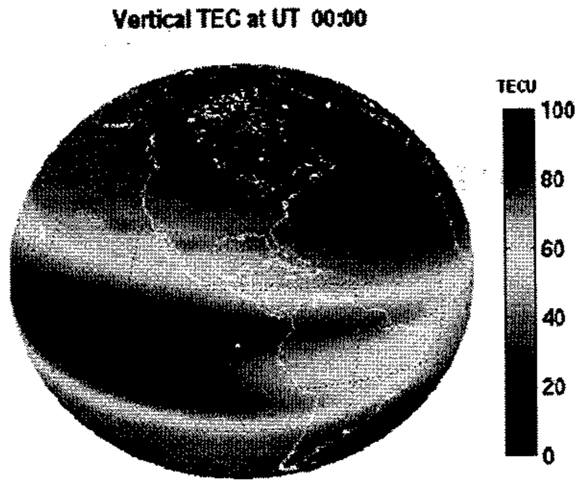
- **Electron density profiles at <1km vertical resolution**
- **Detailed 2D global maps of vertical TEC and ionospheric response to magnetic storms**
- **Global 3D images of electron density as a function of time**
- **Maps of ionospheric scintillations and irregularity statistics**
- **Potentially inferring ionospheric drivers such as electric field, neutral wind, neutral densities and temperatures, solar EUV radiation**



Example of electron density profile obtained with GPS occultations on SAC-C.

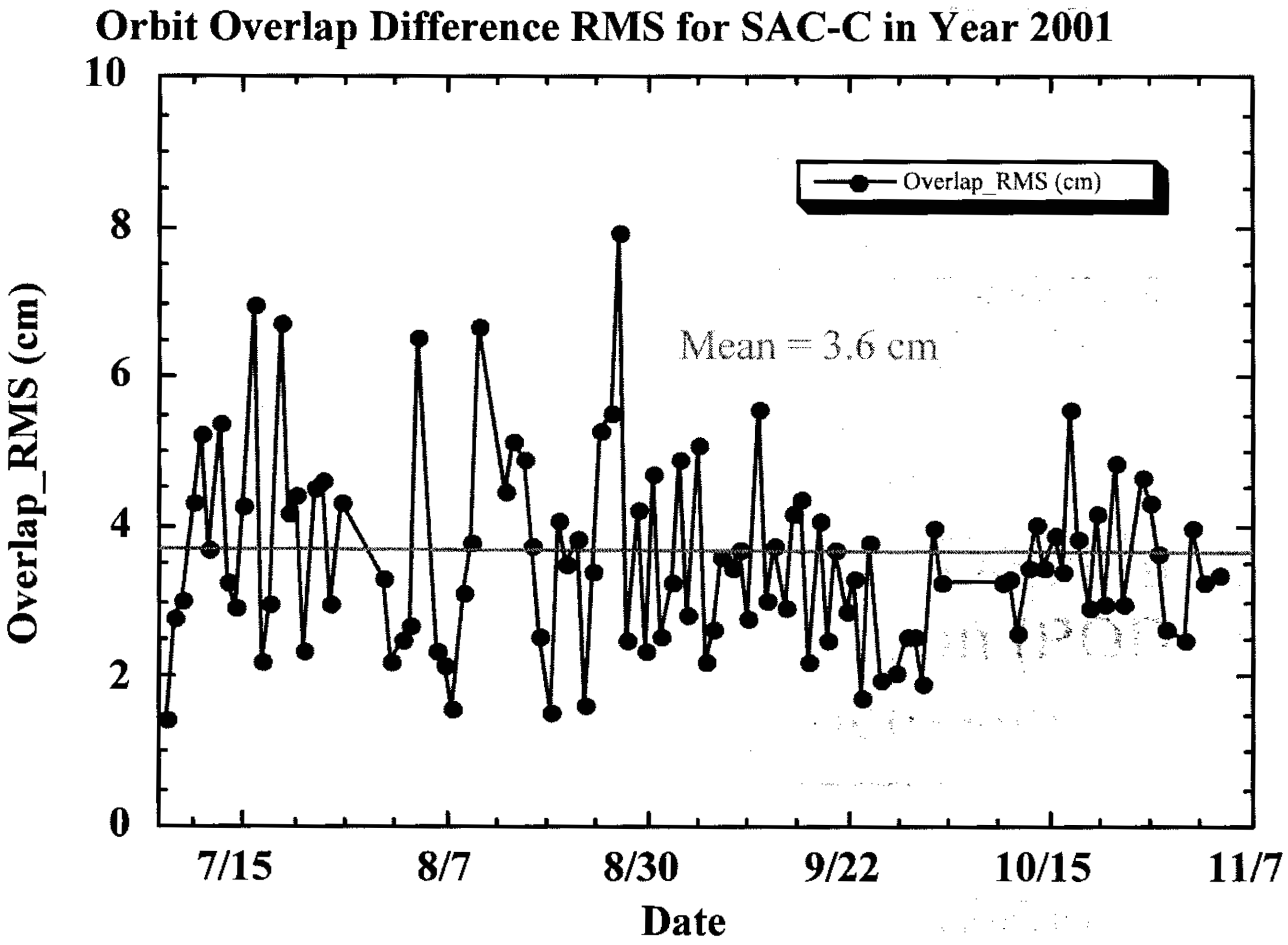
Applications:

- **Improve navigation**
- **Mitigate effects on communications**
- **Improve geo-location**
- **Improve understanding of ionospheric response to storms**
- **Improve understanding of ionosphere-magnetosphere coupling**
- **Improve understanding of ionosphere-lower atmosphere coupling**

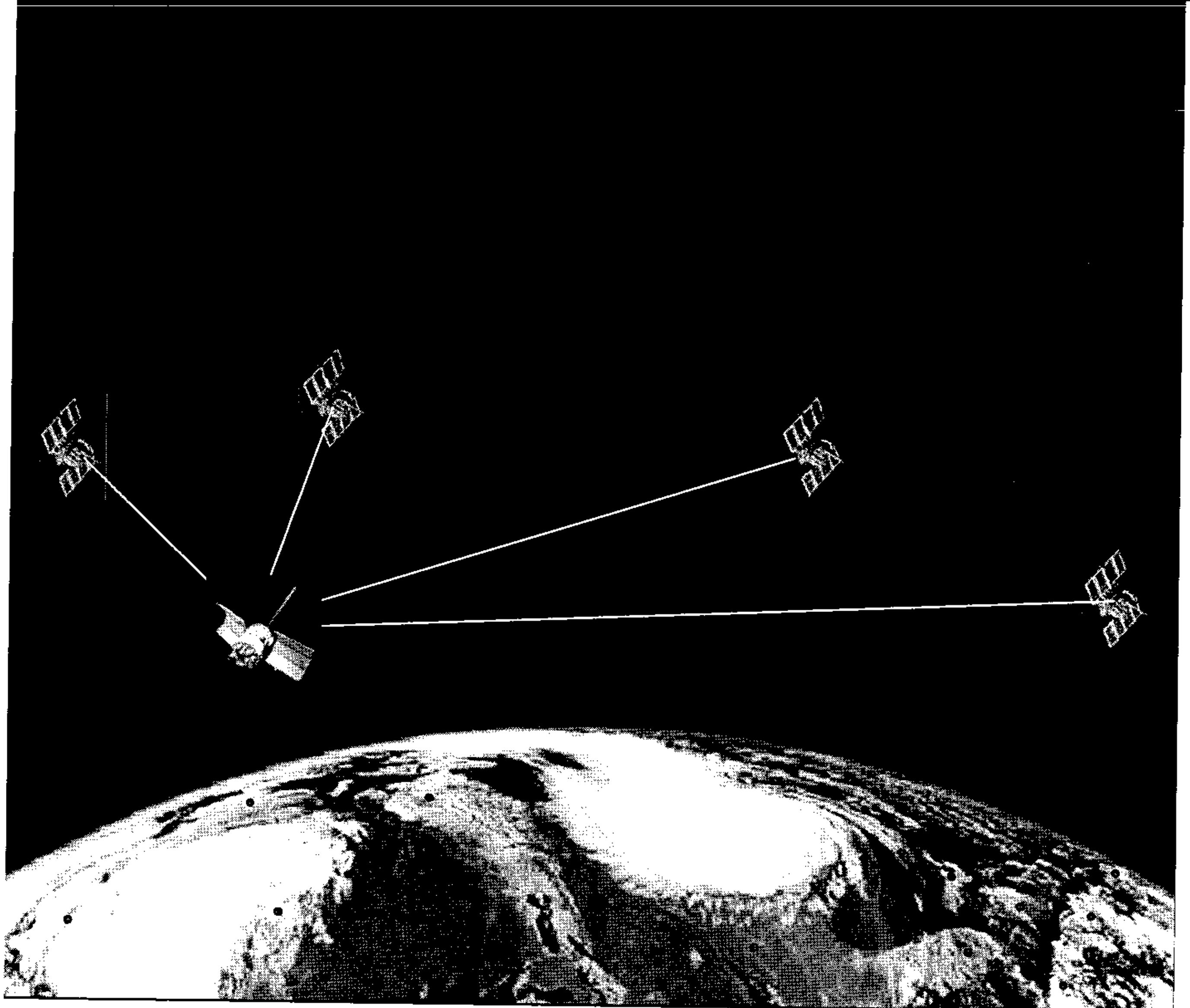


Example of global vertical TEC maps obtained by the Global Assimilative Ionospheric Model (GAIM) by use of SAC-C and CHAMP data.

Precise Orbit Determination (POD) on SAC-C: post processing



Real-time on-board POD: conventional

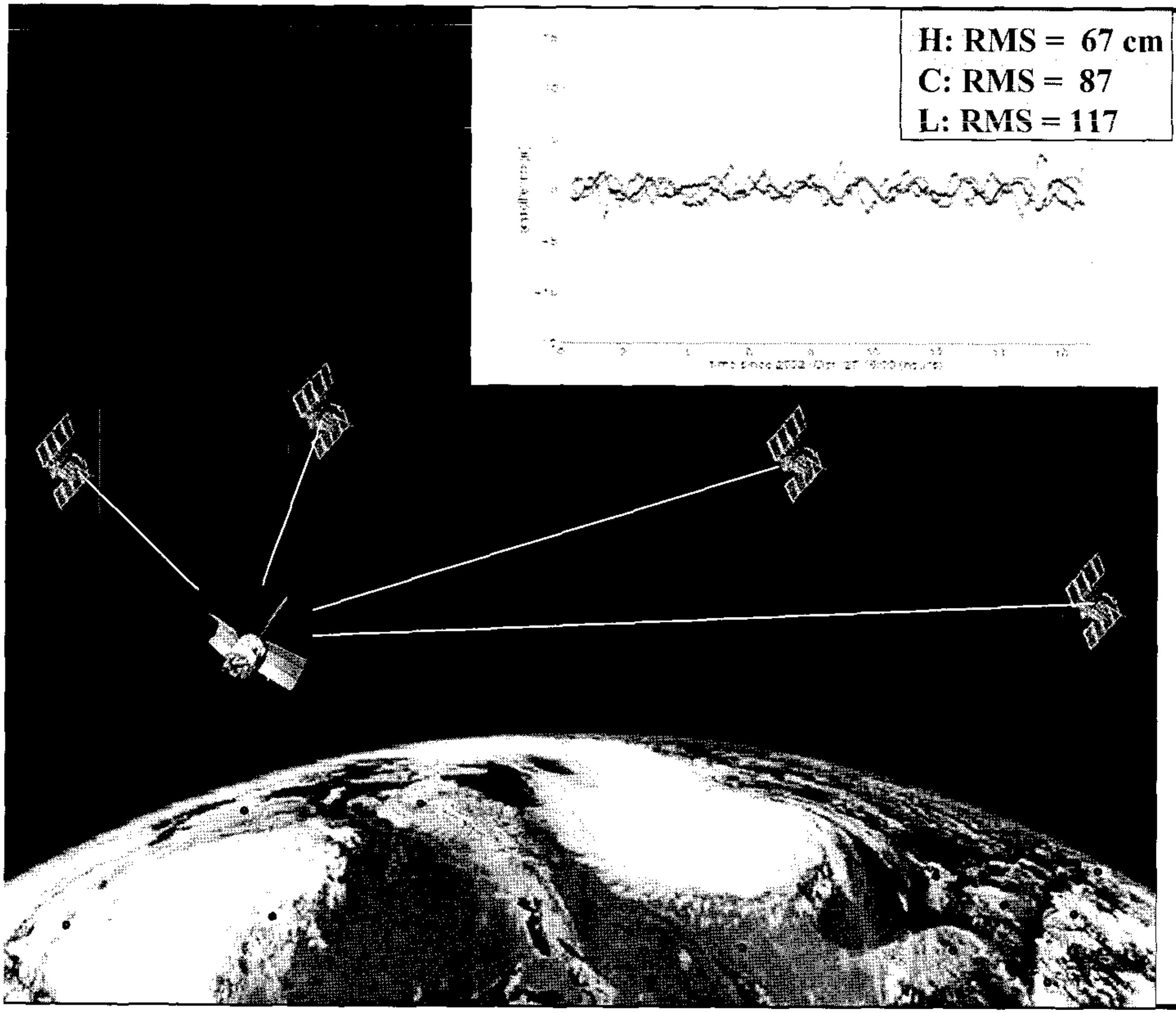


Limits to conventional GPS

- receiver measurements
- modeling of measurements
- GPS satellite orbits and clocks

⇒ several-meter real-time positioning

Real-time on-board POD: what we've done on SAC-C…

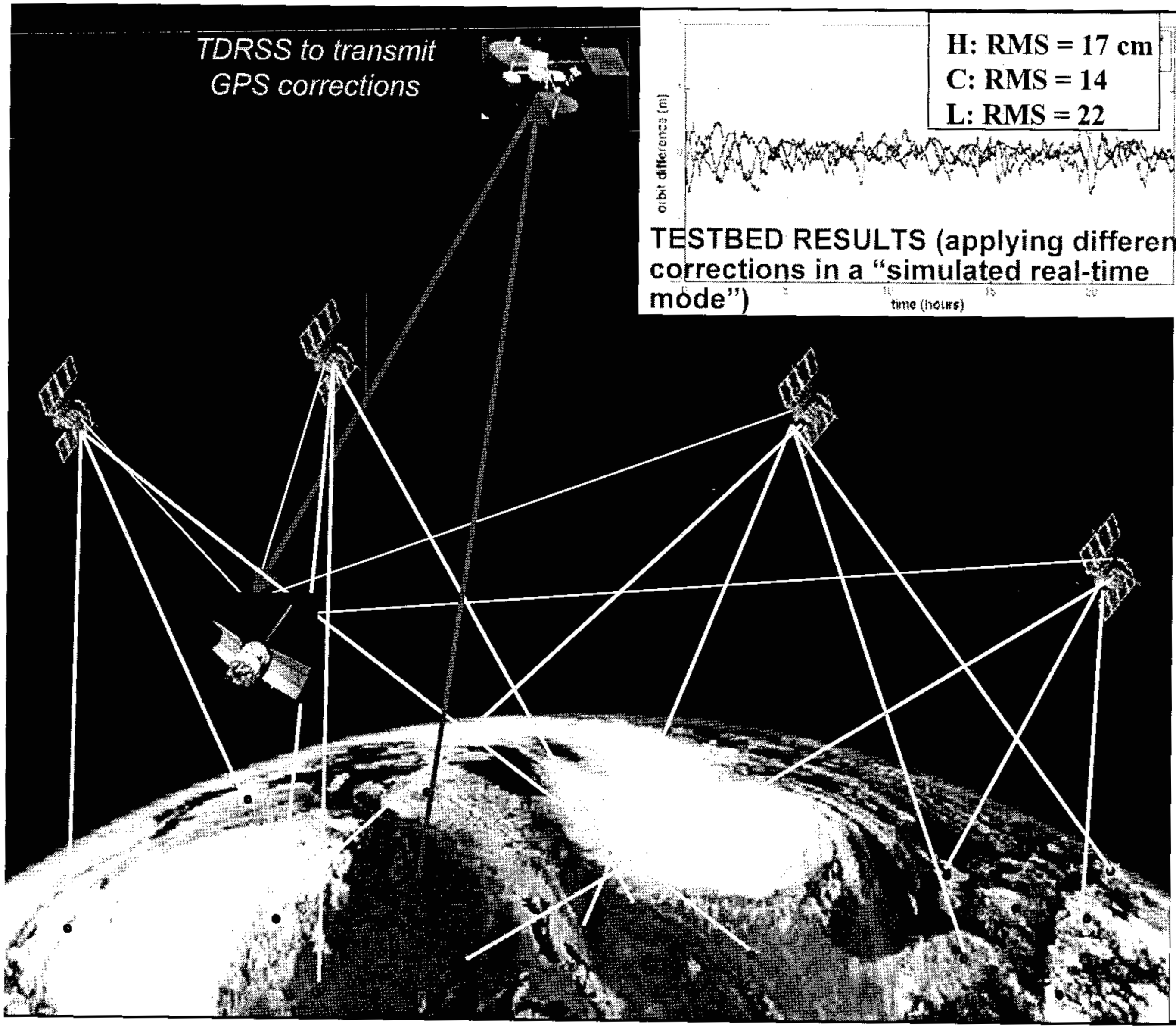


…to overcome limits to conventional GPS

- receiver measurements: **use geodetic quality BlackJack hardware**
- modeling of measurements: **port derivative of award-winning GIPSY software to BlackJack**
- GPS satellite orbits and clocks: *broadcast ephemerides still limiting*

⇒ ~ 1 –meter real-time positioning

Real-time on-board POD: still to be done...

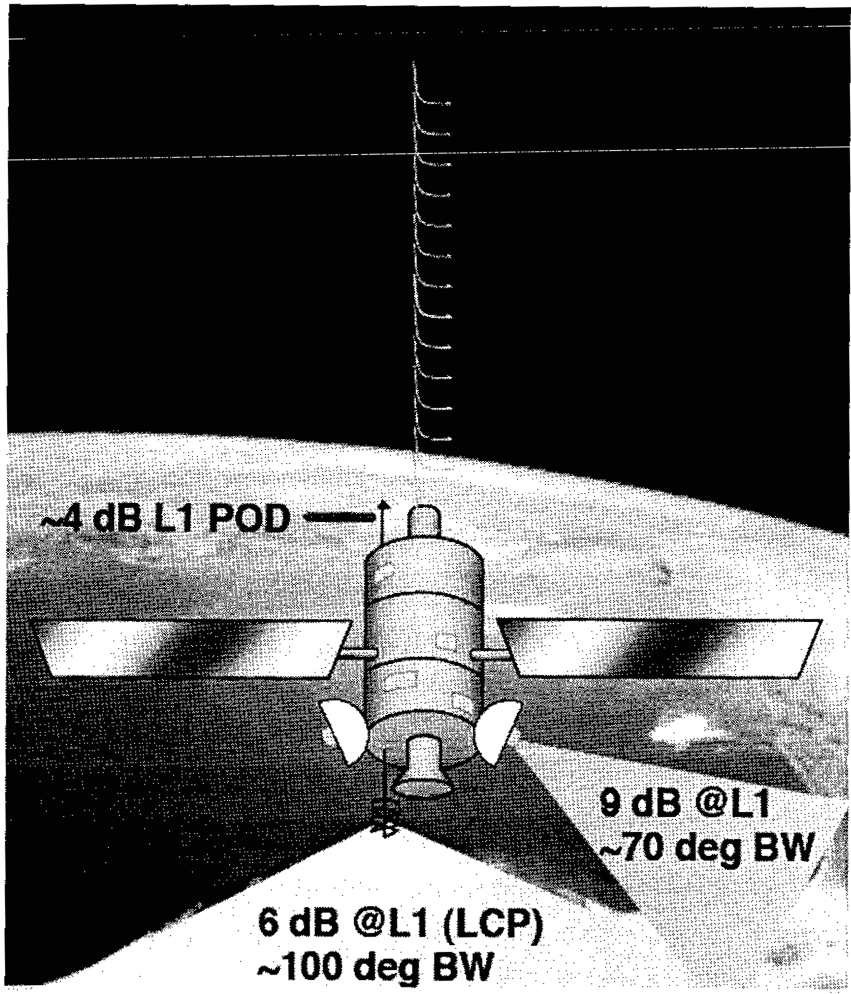


...to overcome limits to conventional GPS

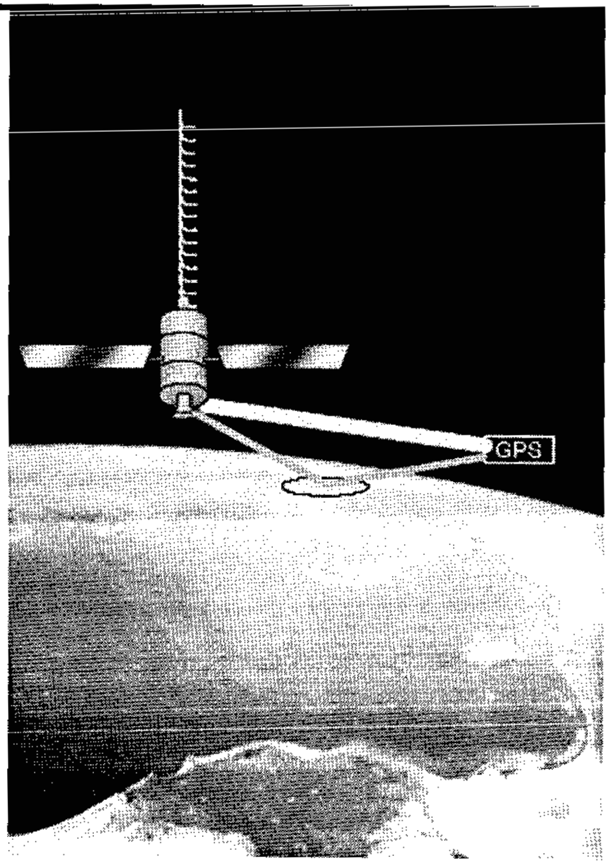
- receiver measurements: **use geodetic quality BlackJack hardware**
- modeling of measurements: **use derivative of award-winning GIPSY**
- GPS satellite orbits and clocks: **NASA's global differential GPS system**

⇒ ~ 20-cm real-time positioning

GPS Surface Reflections on SAC-C



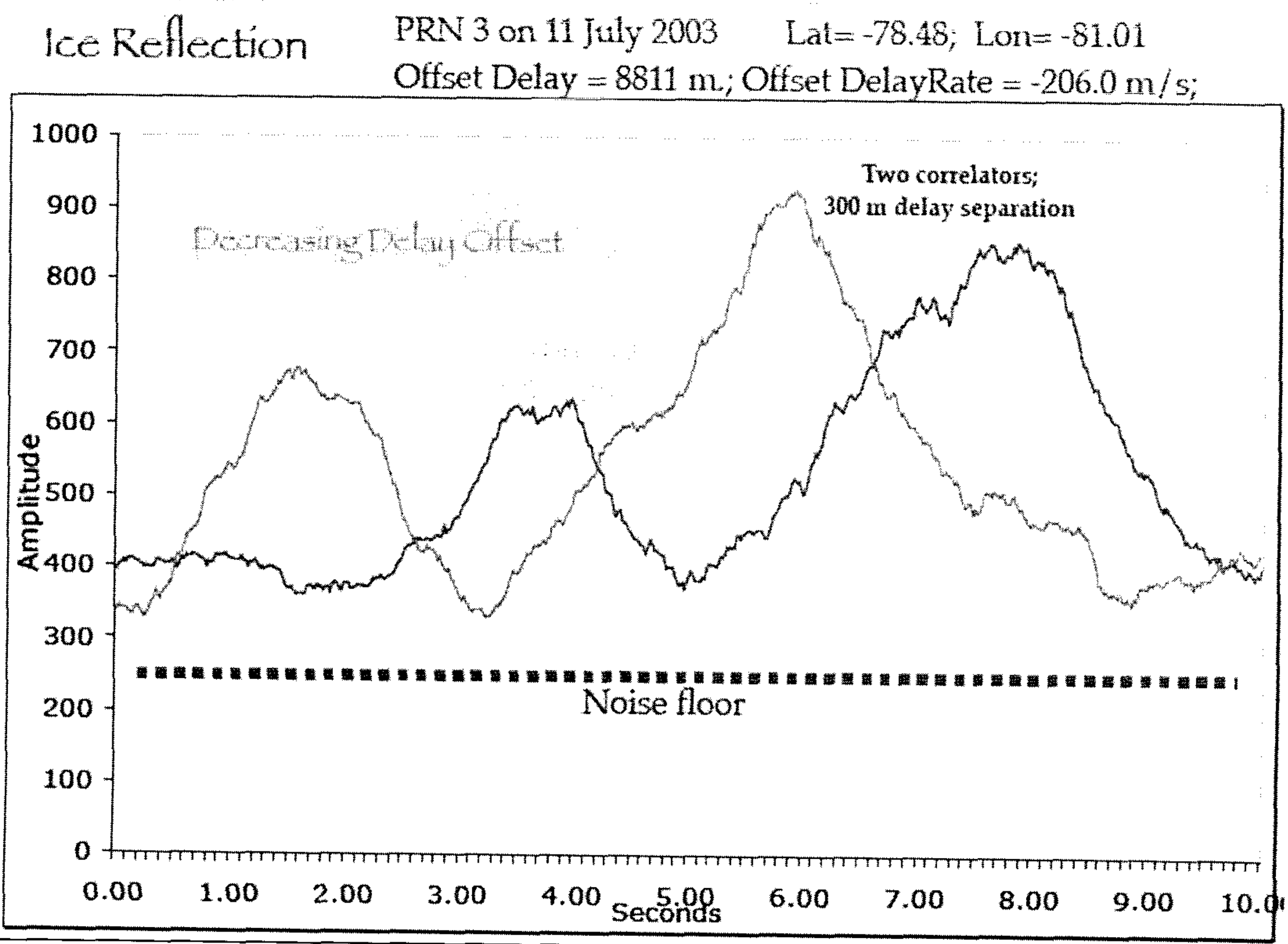
- GPS incident signal – L1-C/A – is tracked through 9-dB occultation antenna
- Nadir (6-db) and occultation antennas simultaneously gather reflection data
- Observations scheduled based on latitude and time of day for reflection angles 5° to 15°



- Delay and Delay-rate models of reflected signal – in terms of offset from incident signal – are re-computed for every 10-s observation period

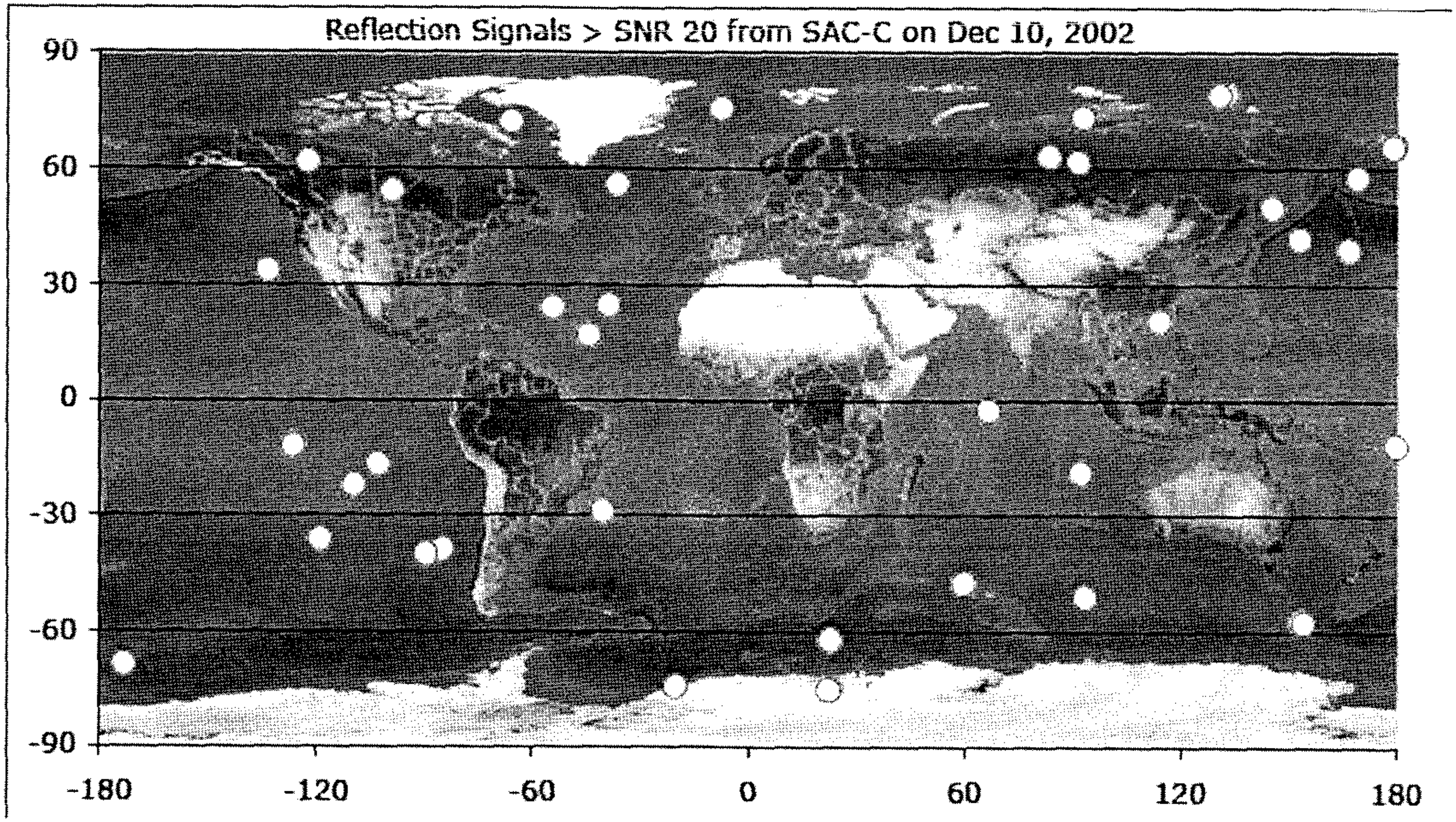
Surface Reflections

- Model of reflected signal is adjusted by 3 m every 20 msec
- Model and measured signals are correlated in two correlators
- Shown is example of detected reflection with high SNR



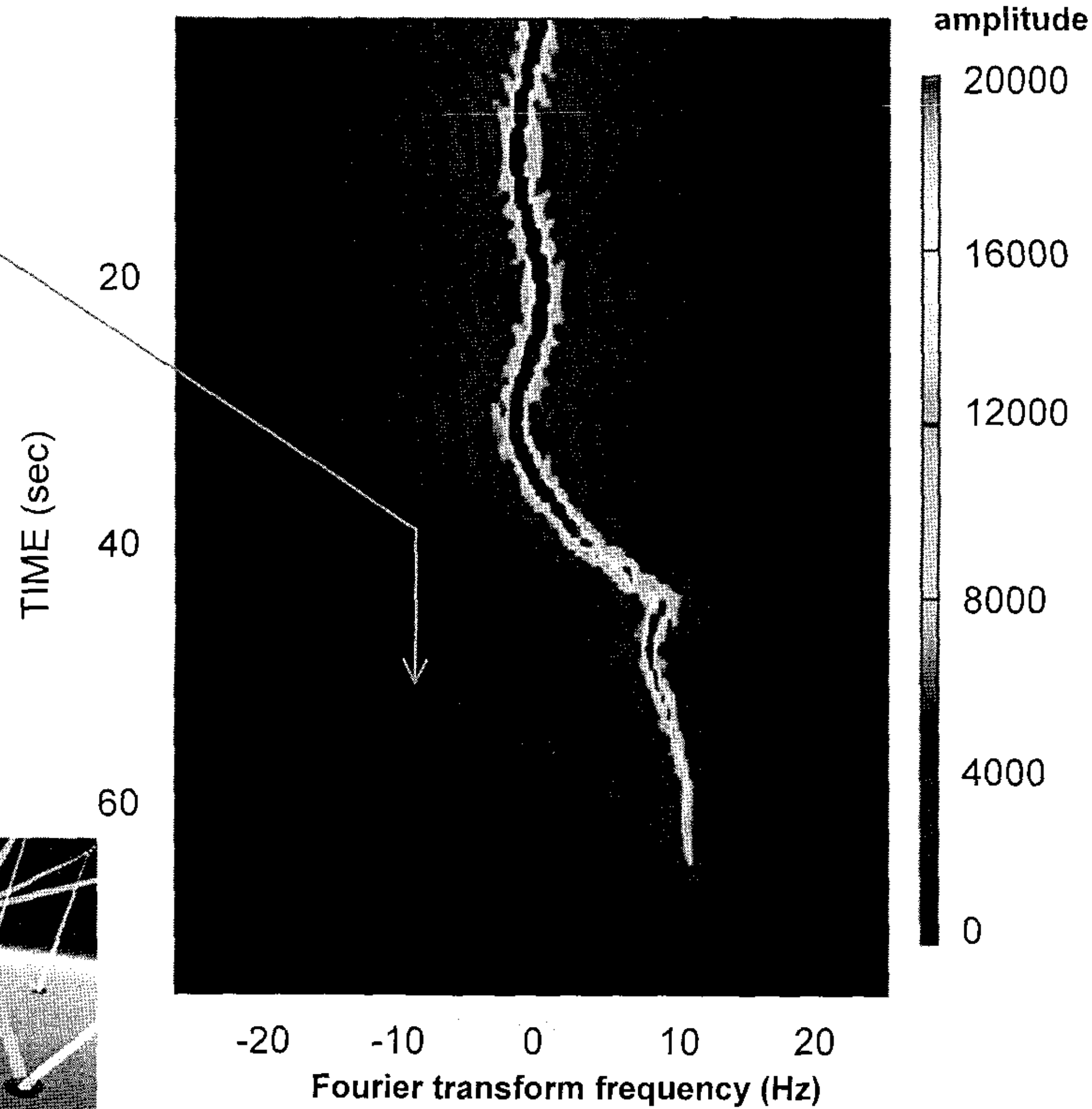
Surface Reflections

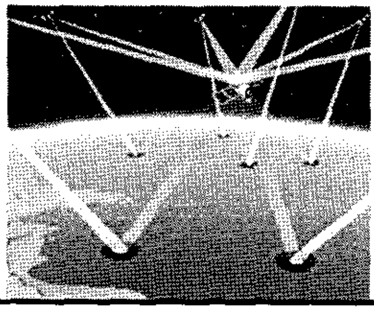
- 24-hr period on December 10, 2002
- Locations of detected reflections with SNR > 20
- Reflections from both oceans and ice



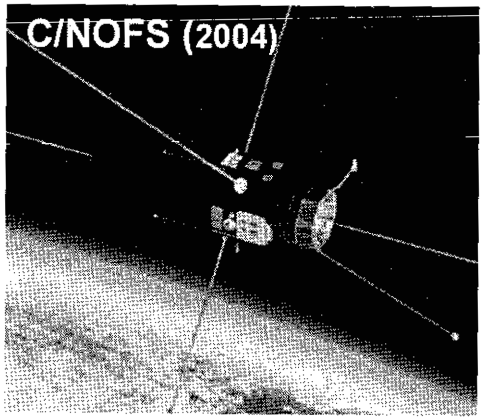
Interferometric phase observation of GPS ice reflection

- GPS reflections have been detected as "horns" extending from surface-grazing occultation signals and analyzed from SAC-C and CHAMP at JPL
- Estel Cardellach (JPL) has for the first time used interferometric techniques to infer simple (decimeter) altimetry measurements
- These data are measuring ice altimetry near the Earth's poles

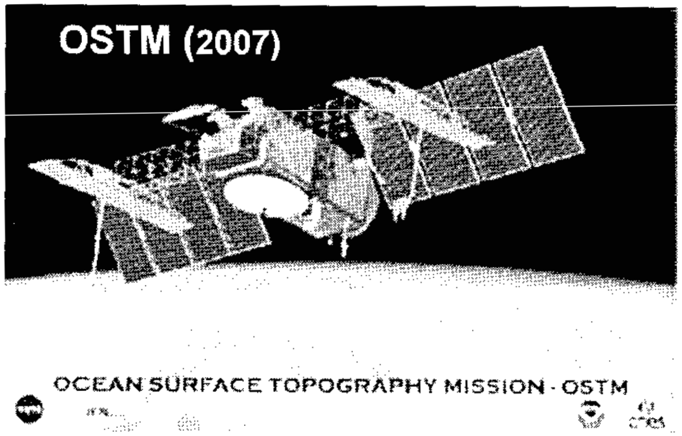




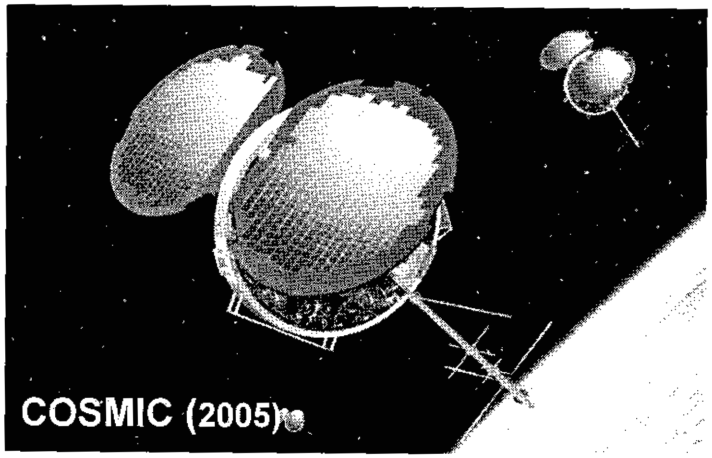
Upcoming Missions with BlackJack Receivers



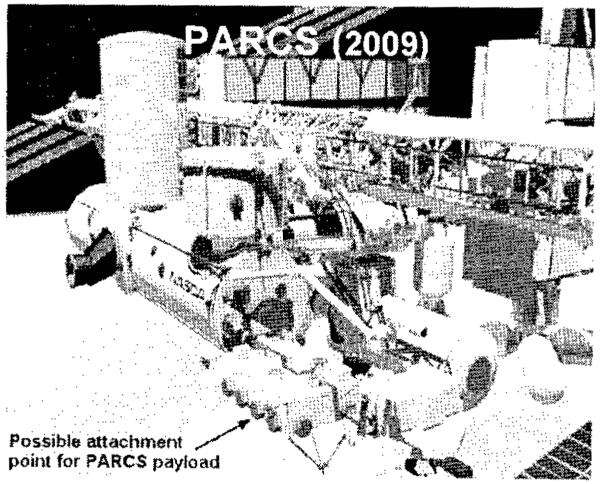
• ionospheric remote sensing



• precise orbit



• precise orbit
• atmospheric remote sensing
• ionospheric remote sensing



• precise orbit and time

GPS Receiver on SAC-C: some "firsts"

- Atmospheric occultations
  - the first "fly-wheeling" software allowed tracking of over 80% of occultations to below 1km altitude
  - the first open-loop software being implemented on SAC/C is anticipated to result in consistent tracking of all occultations to the surface
  - A new capability for rising occultations is presently being tested on SAC-C for the first time ever
- Precise orbit determination
  - 3.6 cm precision & accuracy demonstrated in post processing -- probably a record result for a 705-km altitude spacecraft
  - Precise orbit determination (real-time, onboard): 1-meter accuracy demonstrated. Capability for 20-cm shown through simulations for a future mission scenario
- Although SAC-C was launched several months after CHAMP, many GPS flight software improvements were implemented first on SAC-C and then on CHAMP
- First GPS ocean reflections from a GPS receiver in a low-Earth orbit were detected on CHAMP and SAC-C
- CHAMP and SAC-C were the critical pathfinder missions whose success led to the upcoming COSMIC constellation mission
- *SAC-C has been an extremely valuable platform to mature GPS technologies, related to both precise orbit and remote sensing*