Towards the GEOSAT Follow-On Precise Orbit Determination Goals of High Accuracy and Near-Real-Time Processing

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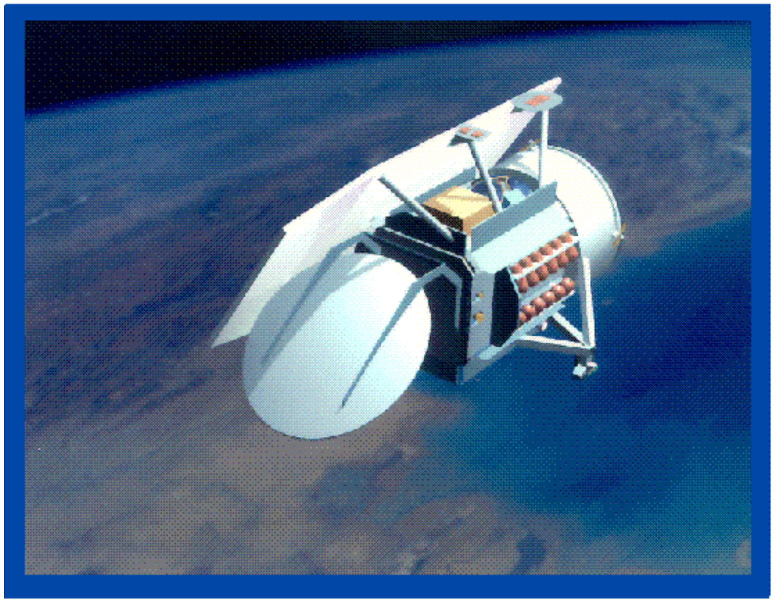

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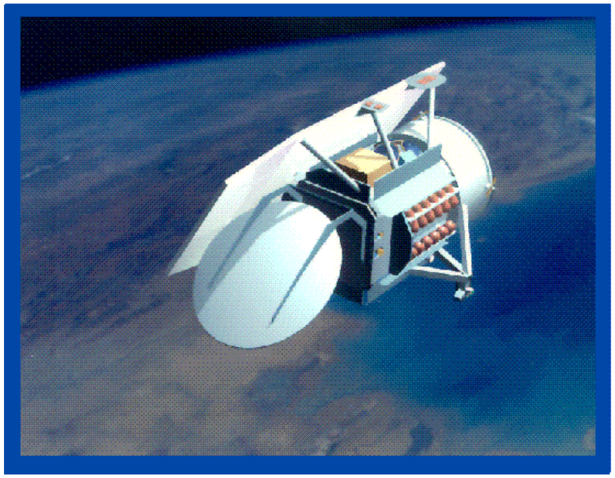

Outline

I. Introduction
II. Data
III. Description of GFO POD System
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V. Macromodel
VI. Medium precision orbit (MOE) results
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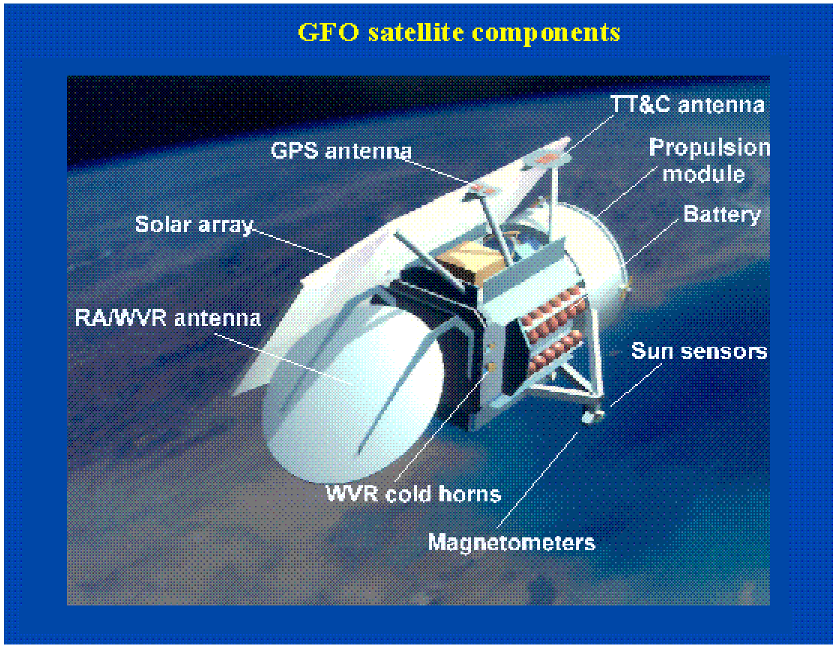
VIII. Summary



NAVSOC: Operates s/c.
NASA: Coordinates SLR tracking with ILRS. Computes daily medium precision and precise orbits.
NOAA: Distributes altimeter data (IGDR and GDR)

GEOSAT-FOLLOW-ON (GFO-1)

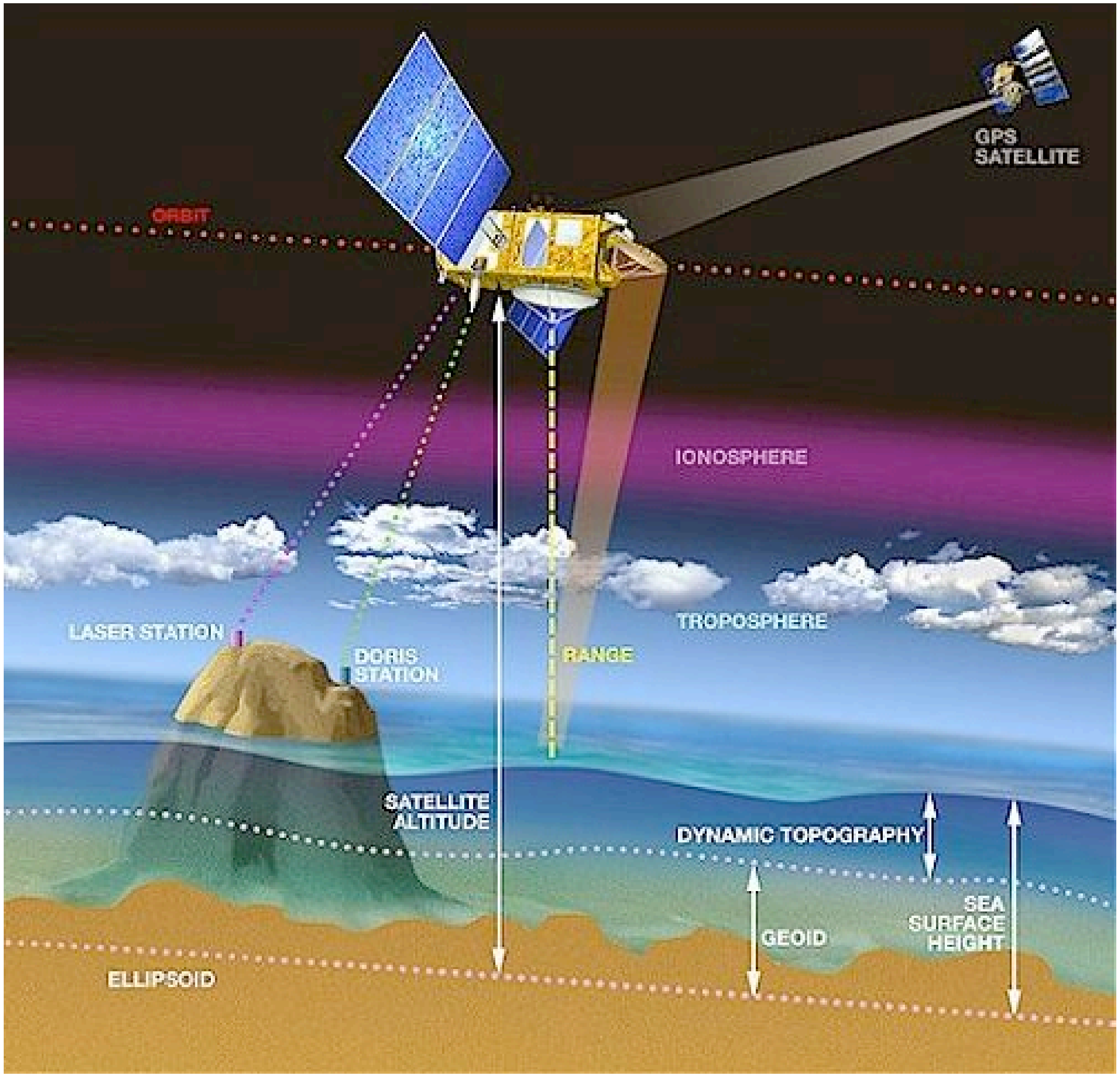
Manufactured by: Ball Aerospace for the US Navy.
Launched: February 10, 1998.
Declared Operational: Nov. 29, 2000.
Orbit:

Altitude:	784 km
Eccentricity:	0.0008
Inclination:	108.04°
Arg. of perigee:	90.5° (frozen orbit)

Repeat Period: 244 revs in 17 days.

Payload:
- Radar Altimeter
- Water Vapour Radiometer
- SLR Retroreflector
- Doppler Beacon
- GPS antenna (not operational)

Altimeter Measurement Schematic



GFO Orbit Determination Challenge

=>> Altimeter range measurement accuracy depends on orbit quality.

=>> In light of the failure of GPS on GFO, can the other GFO tracking systems (SLR, Doppler, Altimeter) deliver sufficient data to meet POD requirements, especially since GFO altitude (784 km) is more challenging than Topex/Poseidon altitude (1336 km)?

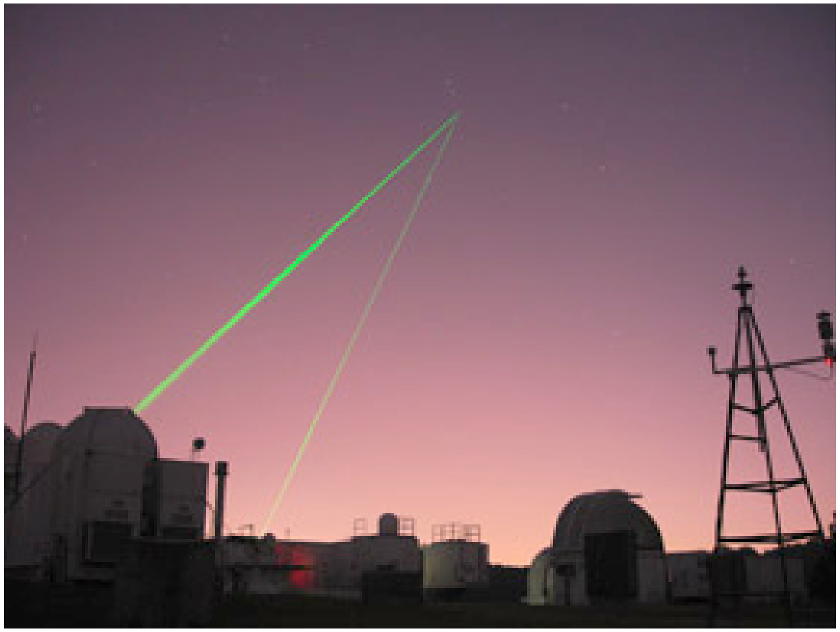
=>> Can SLR+Doppler data be used to compute operational orbits (latency of < 24 hrs)?

=>> How do we measure orbit accuracy?

Satellite Laser Ranging

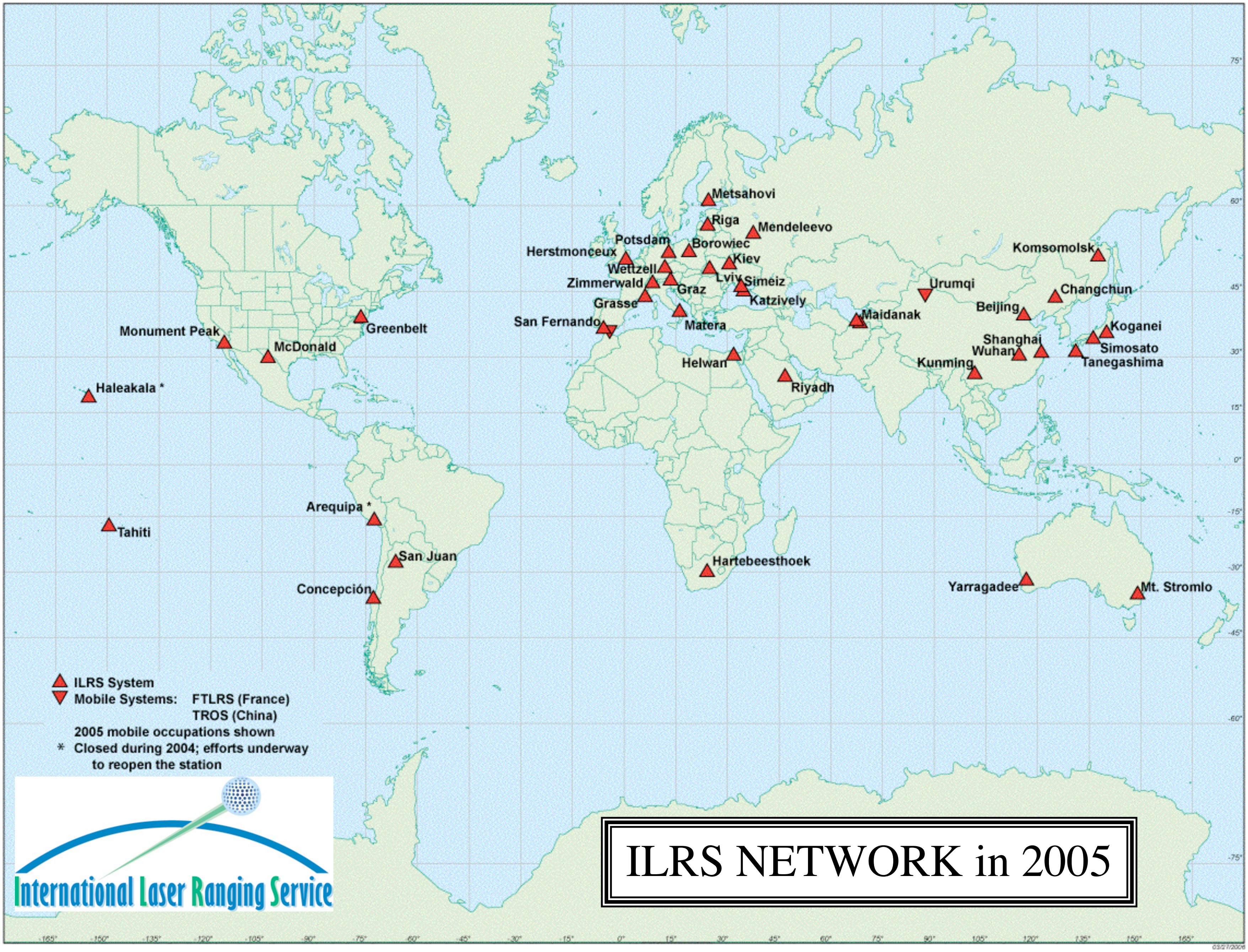
Up to 40 stations worldwide operate under the aegis of the International Laser Ranging Service (ILRS)
URL: http://ilrs.gsfc.nasa.gov/

The best stations deliver ranging accuracy of a few mm.



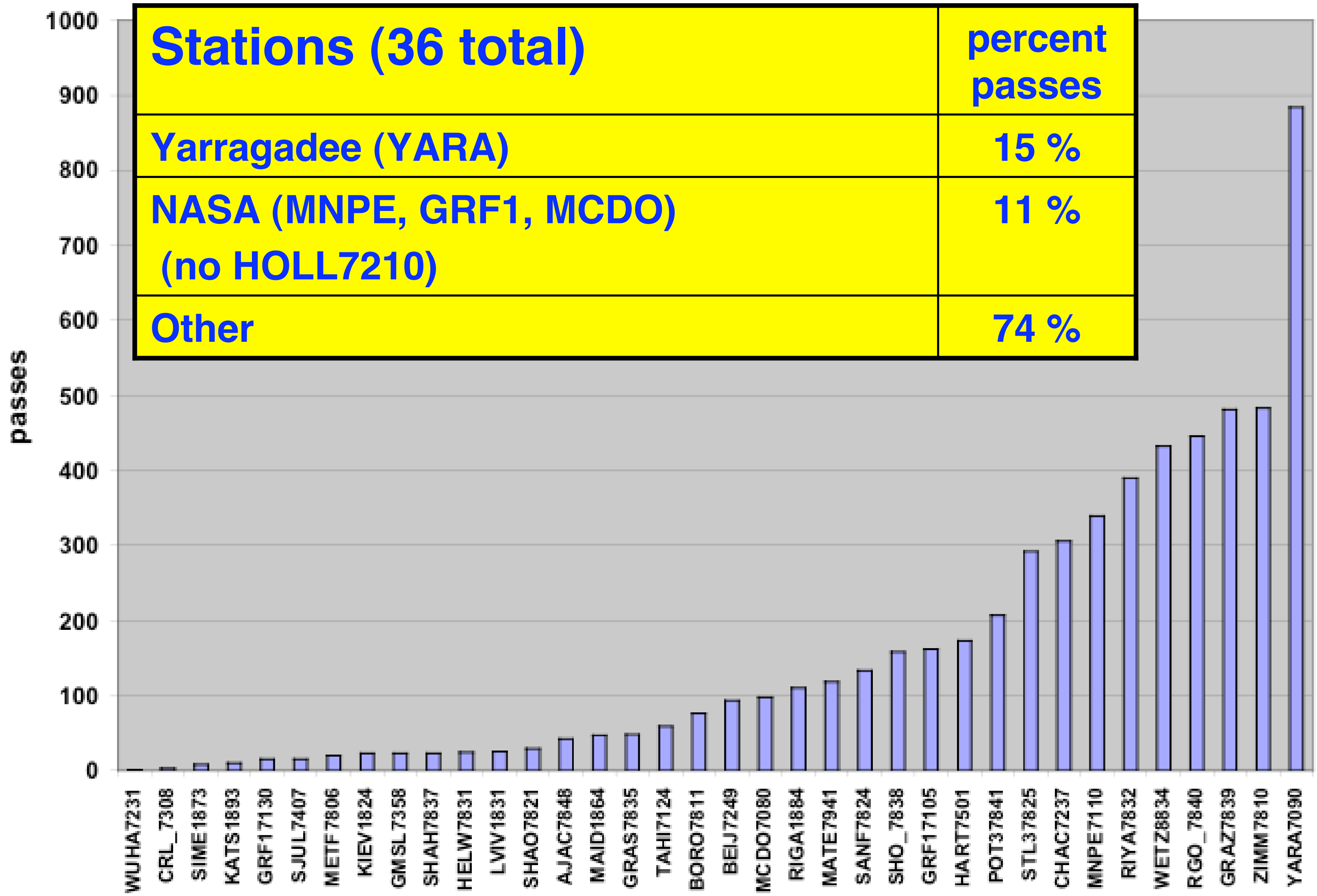
Greenbelt, Maryland, USA

Mt. Stromlo, Canberra, Australia

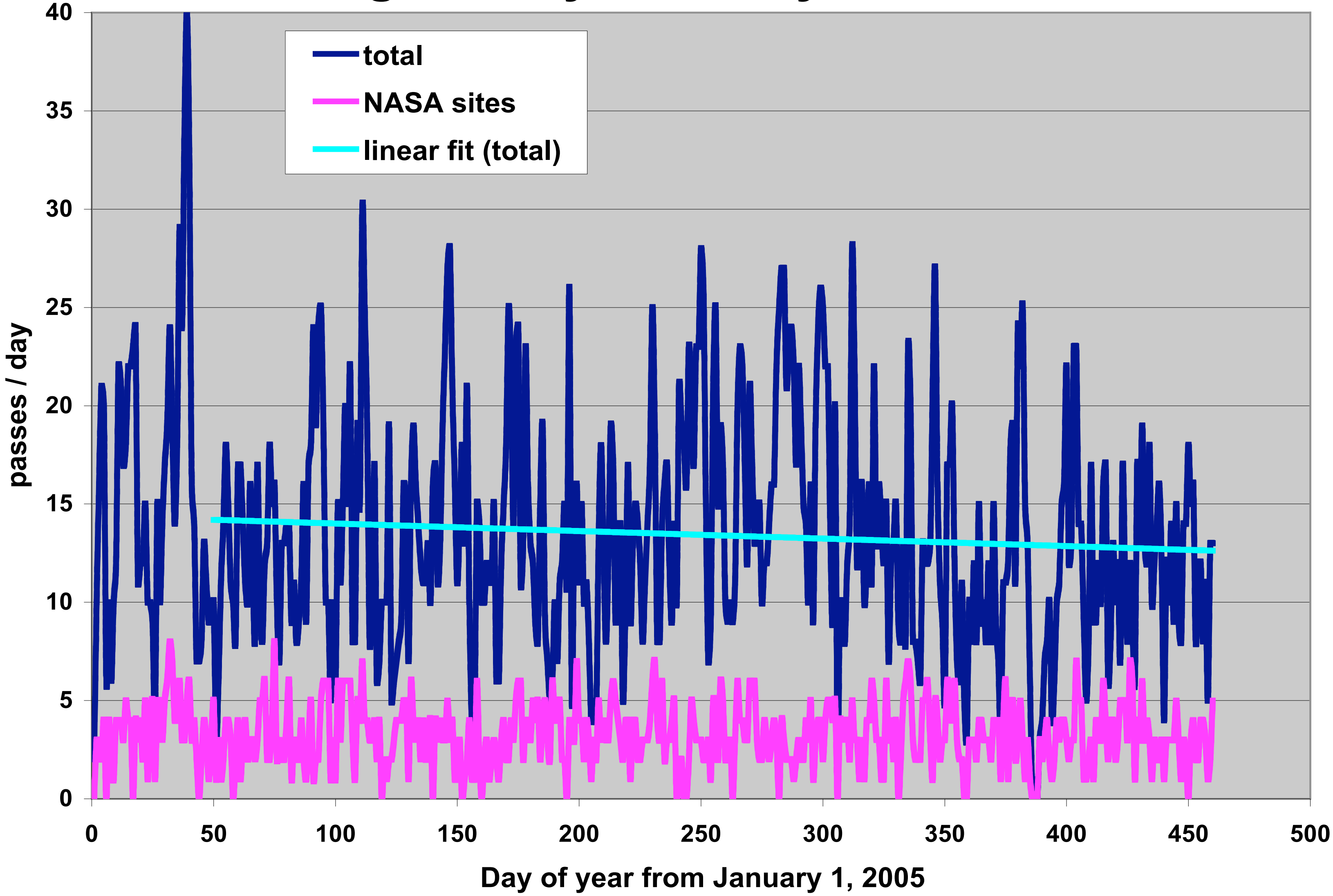

ILRS NETWORK in 2005
Metsahovi
Riga
Mendeleevo
Potsdam
Borowiec
Herstmonceux
Kiev
Wettzell
Lviv
Simeiz
Zimmerwald
Graz
Katzively
Grasse
Matera
San Fernando
Helwan
Riyadh
Maidanak
Urumqi
Komsomolsk
Changchun
Beijing
Koganei
Shanghai
Wuhan
Simosato
Tanegashima
Kunming
Monument Peak
McDonald
Greenbelt
Haleakala *
Tahiti
Arequipa *
San Juan
Concepción
Hartebeesthoek
Yarragadee
Mt. Stromlo
ILRS System
Mobile Systems: FTLRS (France)
TROS (China)
2005 mobile occupations shown
* Closed during 2004; efforts underway to reopen the station
International Laser Ranging Service

Number of SLR Passes for GFO, January 2005 to March 2006

Stations (36 total)	percent passes
Yarragadee (YARA)	15 %
NASA (MNPE, GRF1, MCDO) (no HOLL7210)	11 %
Other	74 %



SLR Tracking History: January 2005 - March 2006



Doppler and Altimeter Data

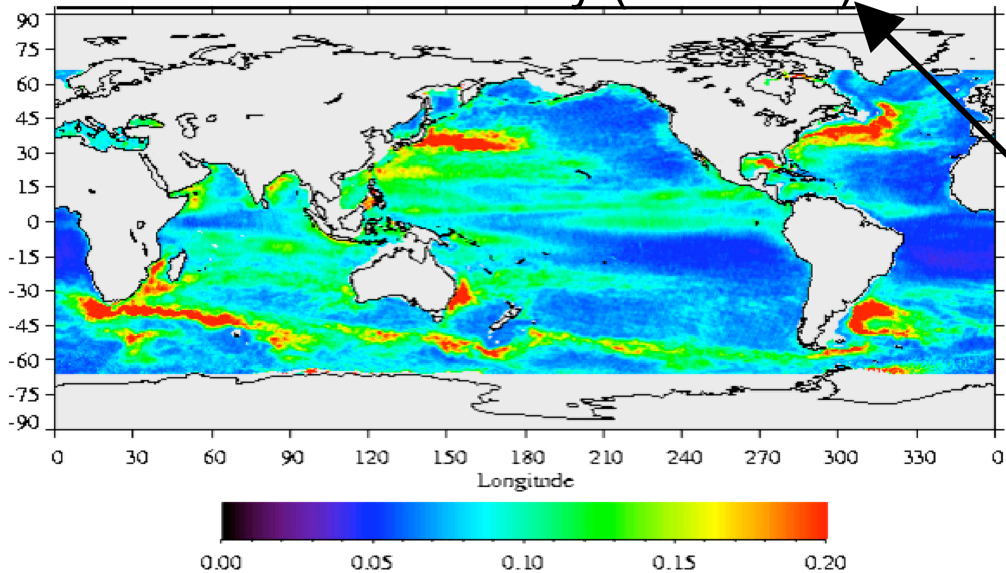
Doppler Data: Three stations: Guam, Point Mugu, California; Maine. Dual-frequency 150/400 Mhz. Noise 1.5 - 2.0 cm/s.
Altimeter Data: Use data from NOAA IGDR (Intermediate Geophysical Data Record). Form altimeter crossovers.

Altimeter Range Modelling for the GFO IGDR

Ocean Tide	GOT00.2 (Topex derived tide model)
Earth Tide	Cartwright & Eden (updated)
Dry Troposphere	NCEP
Wet Troposphere	GFO WVR or NCEP
Ionosphere	IRI95
Inverse barometer	f (dry troposphere)
EM bias	3.8% SWH

GFO Altimeter Crossover Modelling

Sea Surface Variability (TP+ERS)



Editing Criteria

Bathymetry:

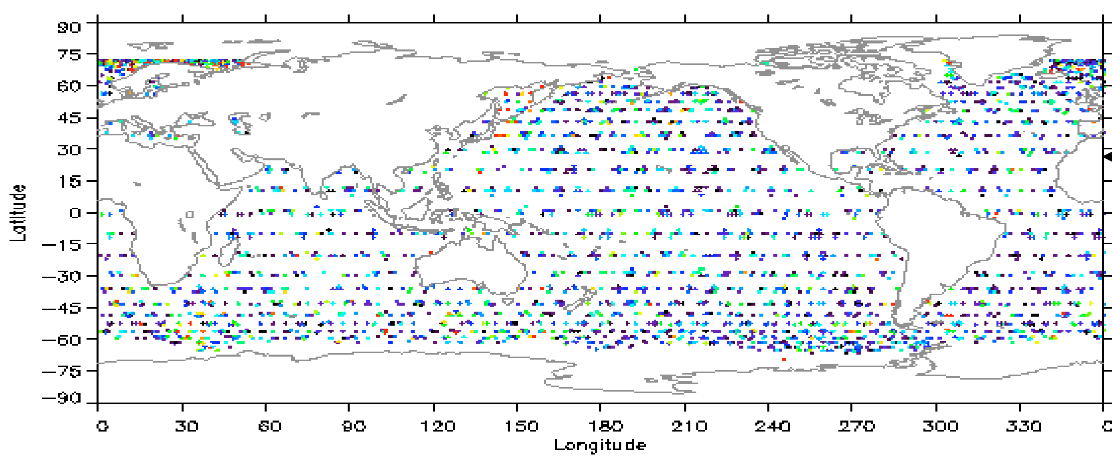
(Reject depth < 500 m)

Sea surface variability:

(Reject > 20 cm)

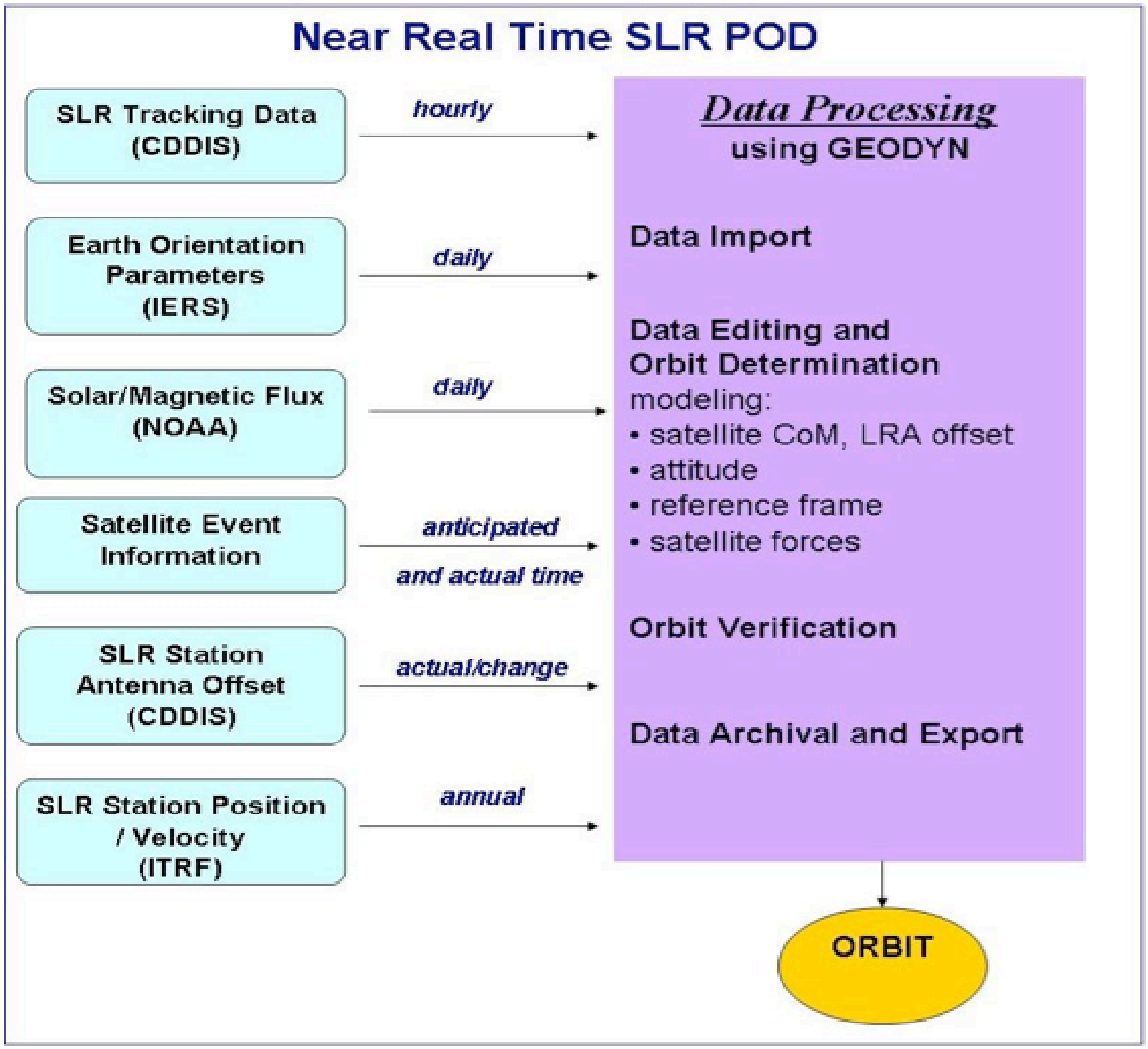
Max Residual:

(Reject > 20 cm)



Example of Crossover Data Distribution

GFO Precision Orbit Determination System



Typical Processing Scenario

=>Import SLR Data and Doppler data by early afternoon
(local time, or 17:00-18:00 UT).
(SLR data delivered hourly to ILRS data centers)
=>Import IGDR altimetry data from NOAA
(Lag of 48 hrs in data delivery).
⇒Import updated Earth orientation parameter info (IERS) and solar flux/geomagnetic index info (NOAA/NGDC)
⇒Process data with GEODYN Orbit Processor and Geodetic Parameter Estimation Program. Medium precision orbits (MOE's) have five day sliding window.
⇒By COB, or 21:00 to 23:00 UT, deliver MOE orbit to users at NOAA and the US Navy.
=>Send new ephemeris predict based on daily MOE orbit to SLR stations.
⇒Precise orbits have a latency of ~3 weeks.
(6-day arcs with 1-day overlaps).
=> Maneuvers introduce complications!!

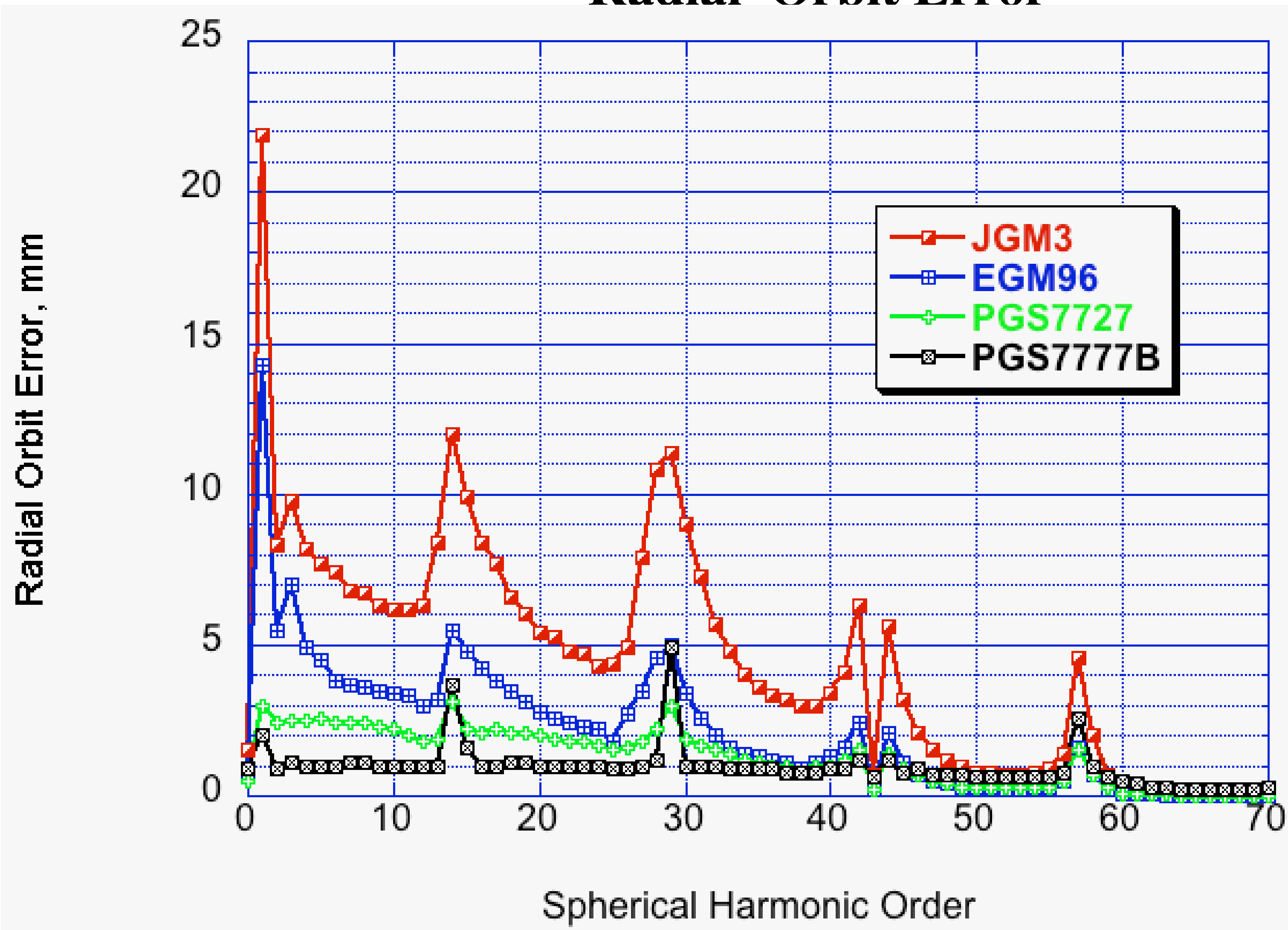
GFO Processing Standards

POE Generation	1st: PGS7727 (2001)	2nd: PGS7777b (2004)	New: GGM02C (2006)
Gravity	PGS7727 (70x70)	PGS7777b (110x110)	GGM02C (120x120)
Time-variable Gravity	C20dot, C21dot S21dot	Same +zonal annuals	20x20 annuals from GRACE
Ocean Tides	Ray99 + pgs7727 resonant	Ray99 + pgs7777b resonant	GOT00.2 (20x20)
Solid Earth tides	k_2, k_3, + FCN	Same	IERS2003
Albedo/IR	Knocke/Ries, 1988	Same	Same
Drag	MSIS86	Same	Same
Parameterization	C_d/ 8hrs, opr along+cross/day	Same	Same
SLR coordinates	ITRF2000	ITRF2000	ITRF2000
Doppler coordinates	Tuned with CSR95L02	Same	Same
LRA offset	Estimated with CSR95L02	Same	Same

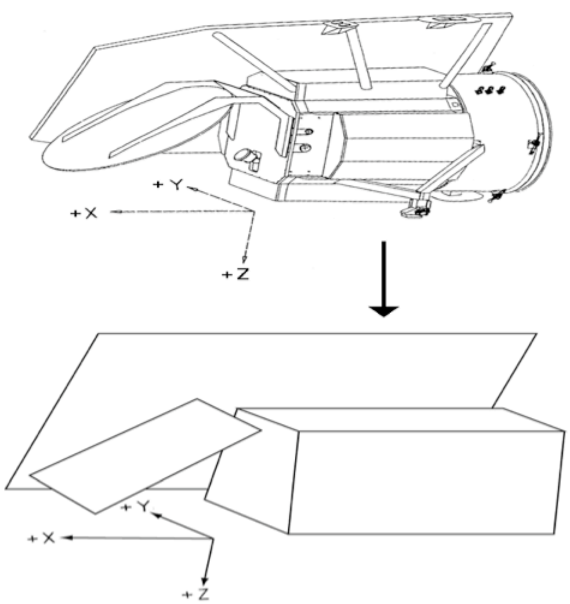
GEOSAT Gravity Model Error

Gravity model	projected radial orbit error (mm)
JGM-3 (1995) Update to JGM-2 with TOPEX/GPS, Stella and other satellite data	49.8
EGM96 (1996) Model with new-satellite tracking data, altimetry, and surface gravity	26.2
PGS7727 (2001) computed from post-EGM96 pgs7609g using GFO SLR, Doppler, GFO and TOPEX-GFO altimeter crossover data	13.2
PGS7777b (2003) computed from pgs7727 using 87 days of Champ data and tracking data from GFO (SLR/Crossovers), TOPEX (SLR/DORIS), Jason (GPS), Envisat (SLR/DORIS), and other SLR data	10.0
GGM02C (2004) GRACE-based combination model	4.0 (Ries 2006)

GEOSAT Gravity Model
Radial Orbit Error



GFO Macromodel
(Nonconservative Force Modelling)



Acceleration due to radiation pressure on a flat plate:

$$\Gamma = -\frac{\Phi A \cos\theta}{Mc}\left[2(\delta/3+\rho\cos\theta)\mathbf{n}+(1-\rho)\mathbf{s}\right]$$

where

Γ = acceleration (m/s^2)

Φ = radiation flux from source

A = surface area of flat plate (m^2) *

θ = incidence angle (surface normal to source)

M = satellite mass (m)

c = speed of light (m/s)

δ = diffuse reflectivity *

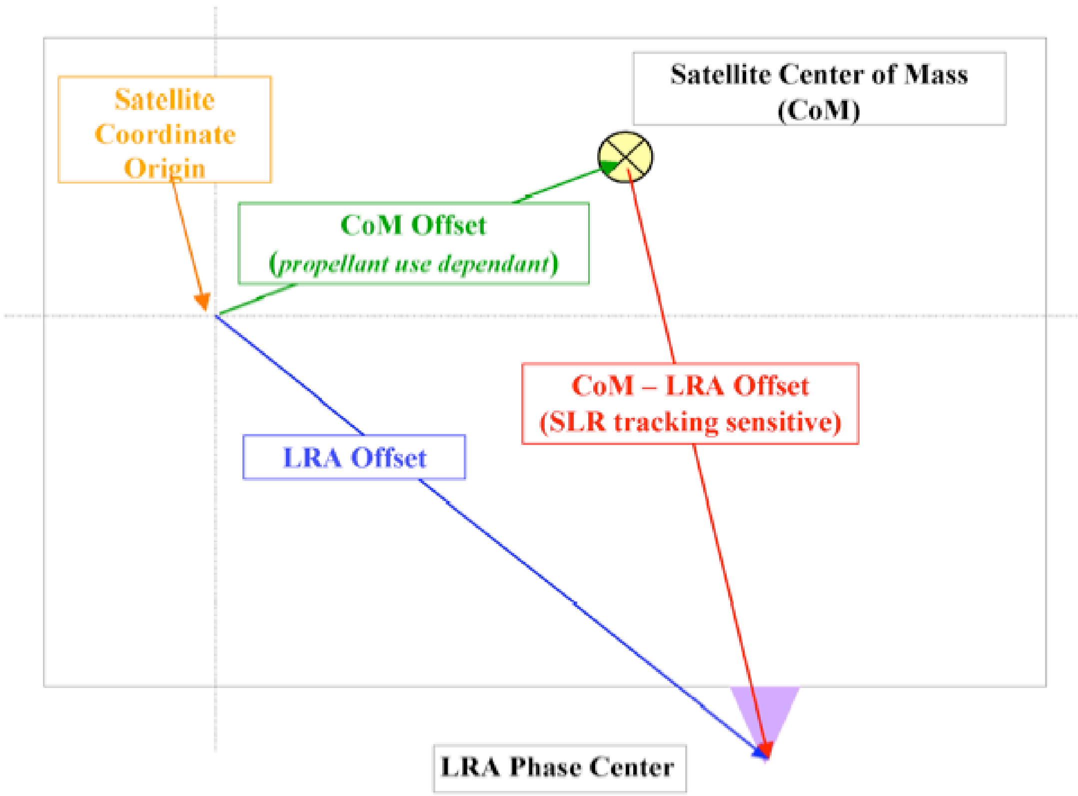
ρ = specular reflectivity *

n = surface normal unit vector

s = source incidence unit vector

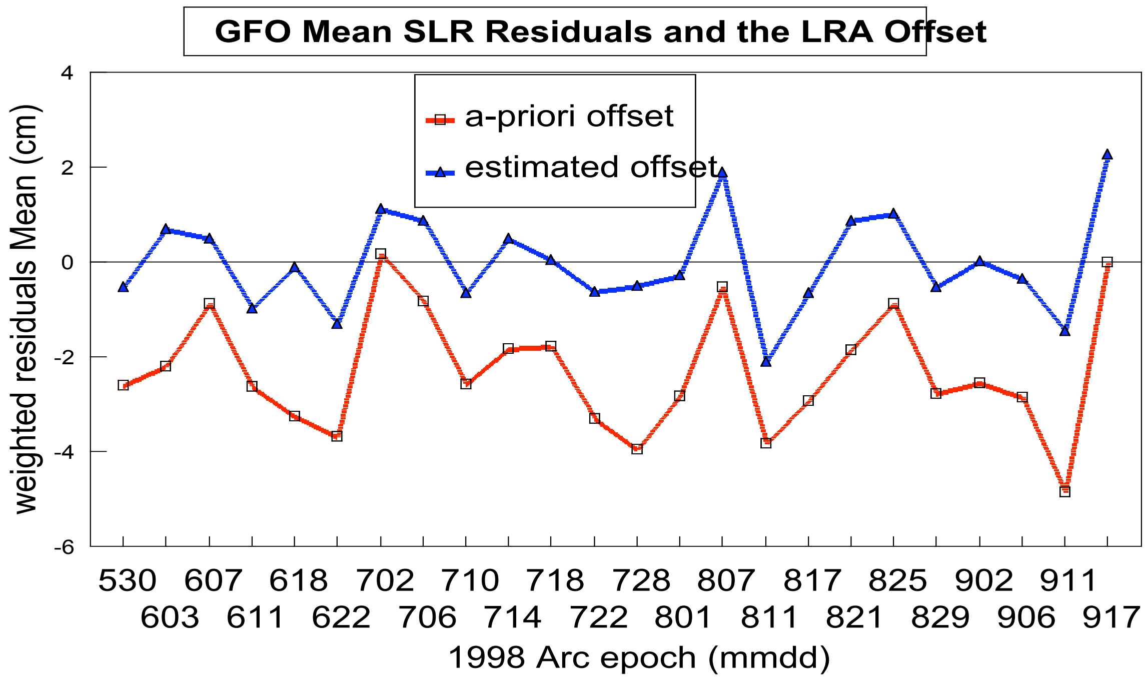
*** are the adjustable macro model parameters**

GFO LRA Offset Modelling

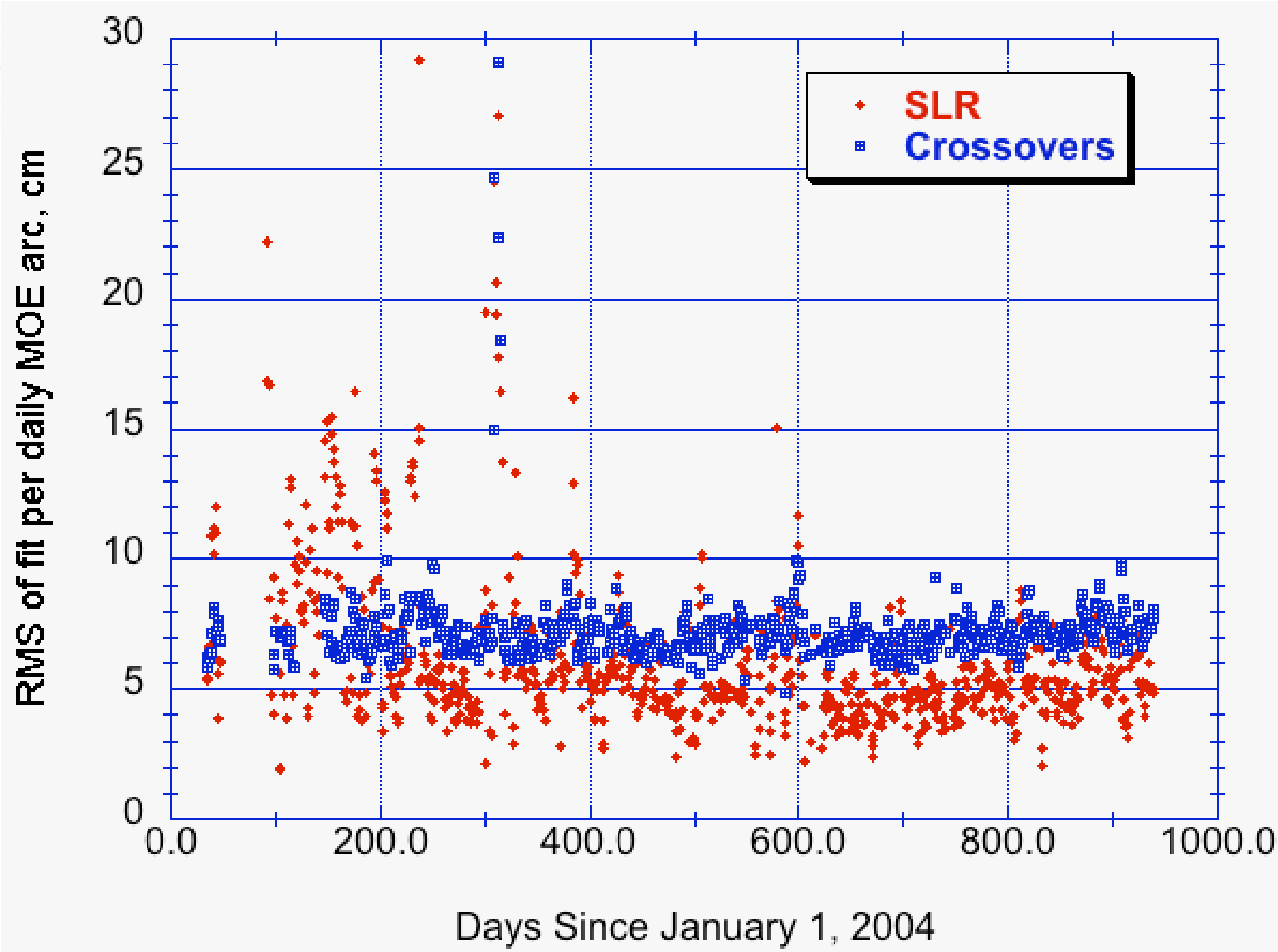


Estimate GFO LRA Offset using June '98 SLR Data

Description	Spacecraft body-fixed coordinates (cm)			SLR residuals (cm)	
	X	Y	Z	Mean	RMS
A priori CoM	89.7	0.8	-6.6		
A priori LRA offset	114.2	77.2	42.7	2.5	10.7
Estimated LRA offset	107.9	76.1	53.3	-0.1	10.0



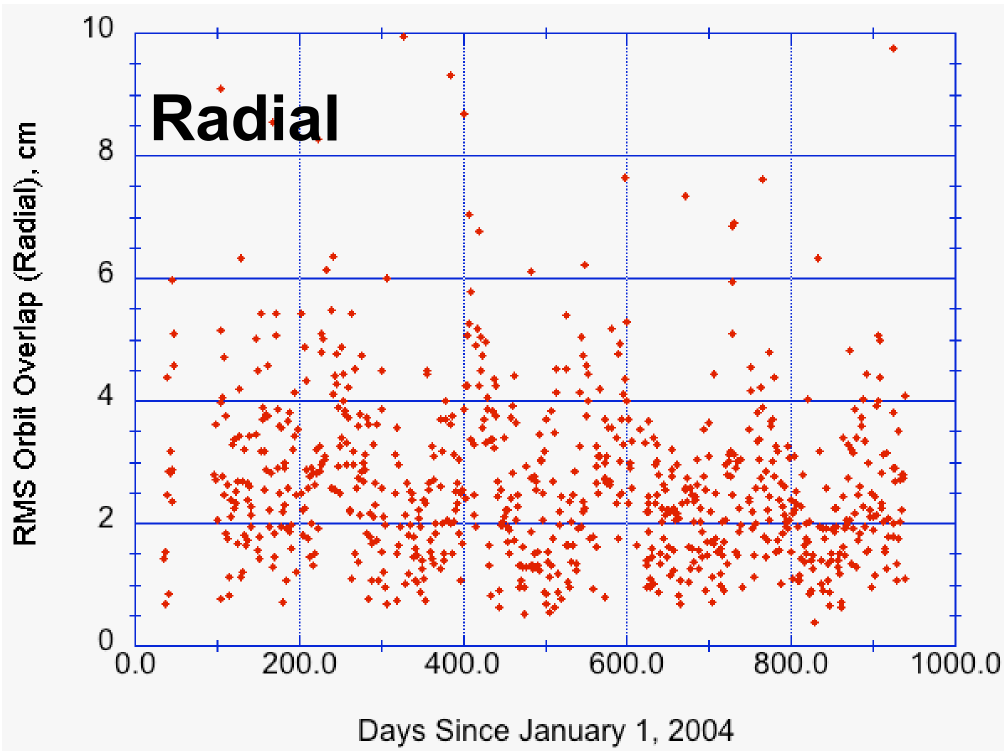
GFO MOE RMS of Fit



SLR avg. RMS = 6.1 cm
Crossover avg. RMS = 7.3 cm

Due to latency issues, MOE arcs, have altimeter crossovers for first three days of each arc only.

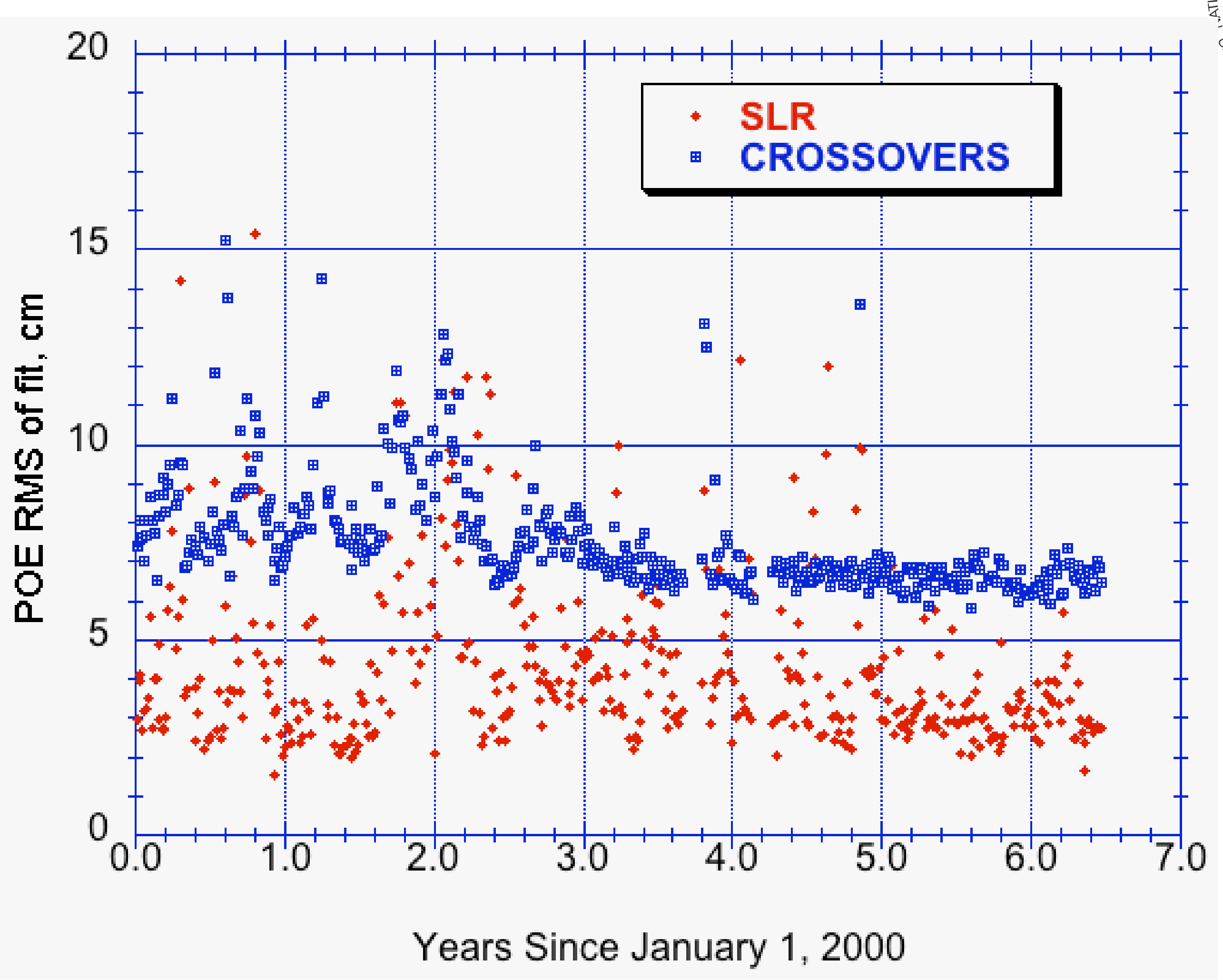
GFO MOE Orbit Overlaps



MOE Orbit Statistics (cm) (Avg. RMS Overlaps)	
Radial	**5.11**
Cross-track	**11.89**
Along-track	**23.82**

(Only show statistics since we started routinely including crossovers in MOE orbits in February 2004)

GFO POE RMS of Fit

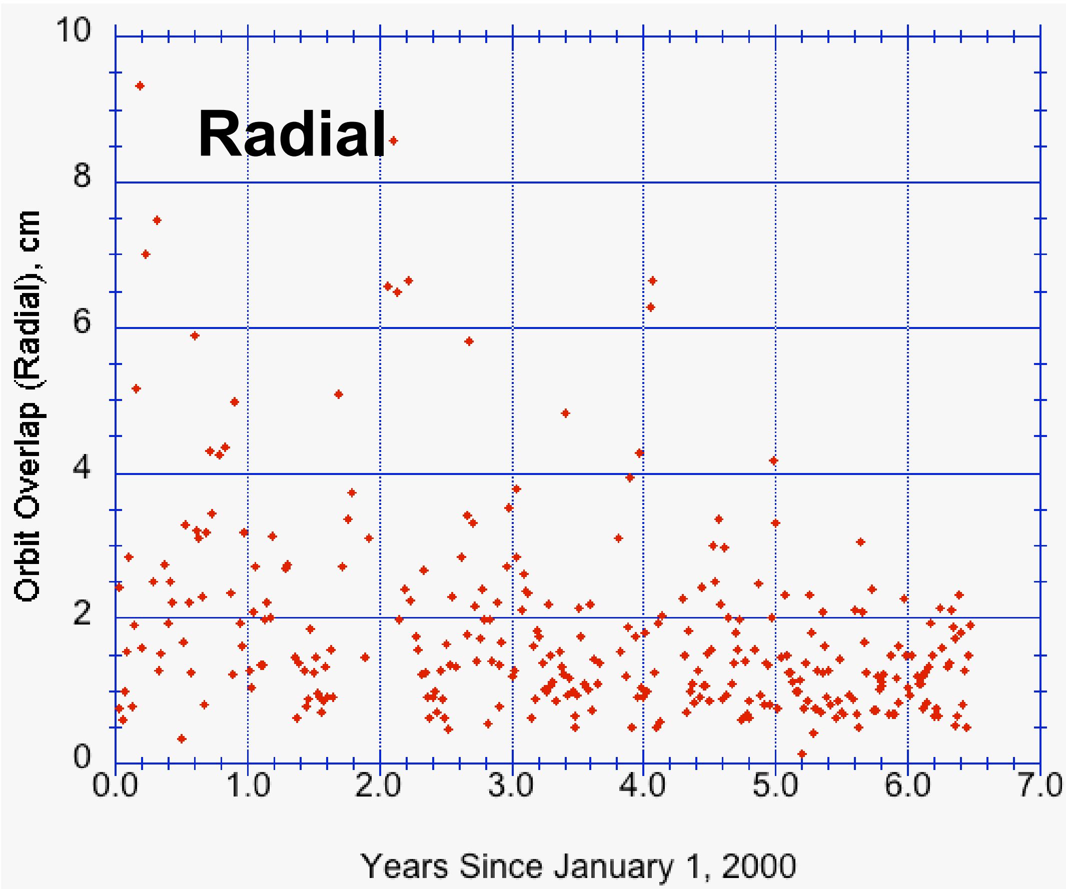


SLR avg. RMS = 4.37 cm
Crossover avg. RMS = 7.51 cm

GFO POE RMS of Fit Summary

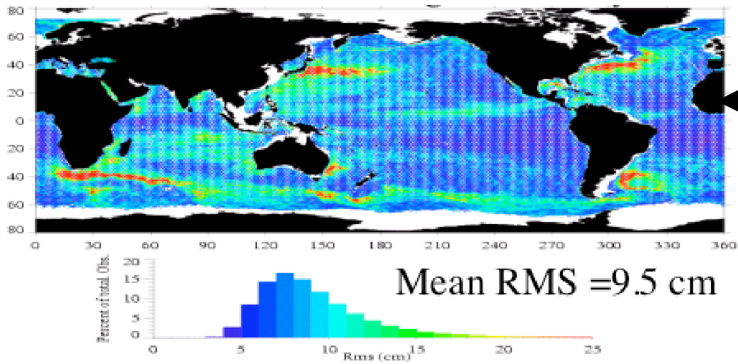
Year	No. of Arcs	SLR (cm)	Crossovers (cm)	Doppler (cm/s)
2000	67	4.68	8.41	1.74
2001	60	4.70	8.64	1.93
2002	66	5.39	8.12	2.10
2003	63	4.45	7.12	1.93
2004	62	4.49	6.80	1.75
2005	71	3.26	6.57	1.90
2006	34	3.18	6.58	1.54
ALL	**423**	**4.37**	**7.51**	**1.89**

GFO POE Orbit Overlaps

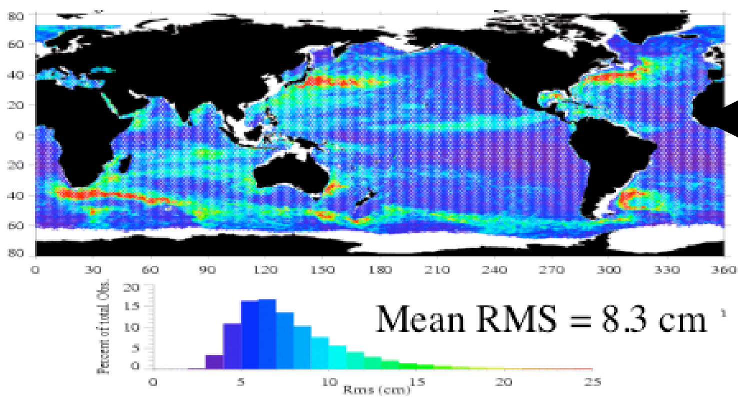


POE Orbit Statistics (cm) (Avg. RMS Overlaps)	
Radial	1.84
Cross-track	11.56
Along-track	13.50

GFO Orbit Error Assessment from analysis of mean of the GFO sea surface variability



Before Empirical Correction



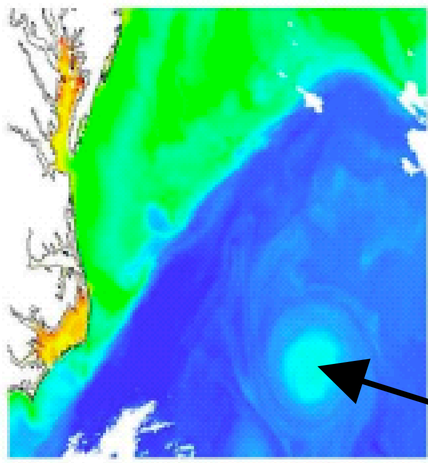
After Empirical Correction with Topex/POSEIDON

Orbit Error (relative to Topex) from RSS difference = 4.62 cm.
Including Topex error (2.5 cm) => GFO orbit error = 5.25 cm.
This assessment done with PGS7727 orbits early in mission.

Applications: Mapping of Ocean eddies

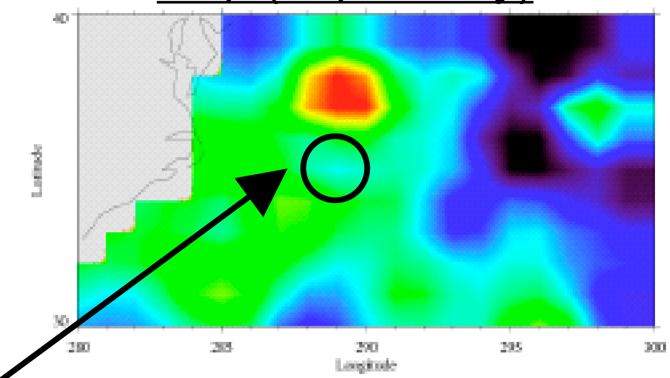
(Courtesy Anthony Liu & Brian Beckley, NASA GSFC)

Chlorophyll-a concentration from SeaWifs: May 8, 2000

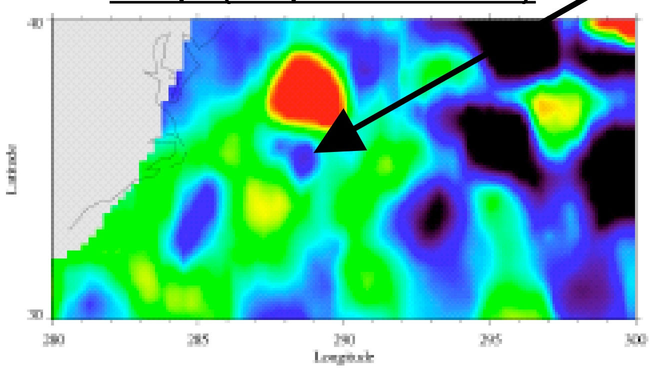


Eddy

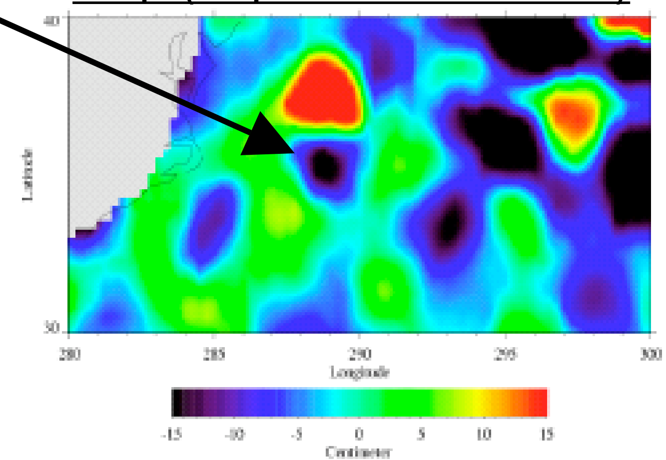
Sea Surface Height anomaly map (Topex-only)



Sea Surface Height anomaly map (Topex+ERS2)

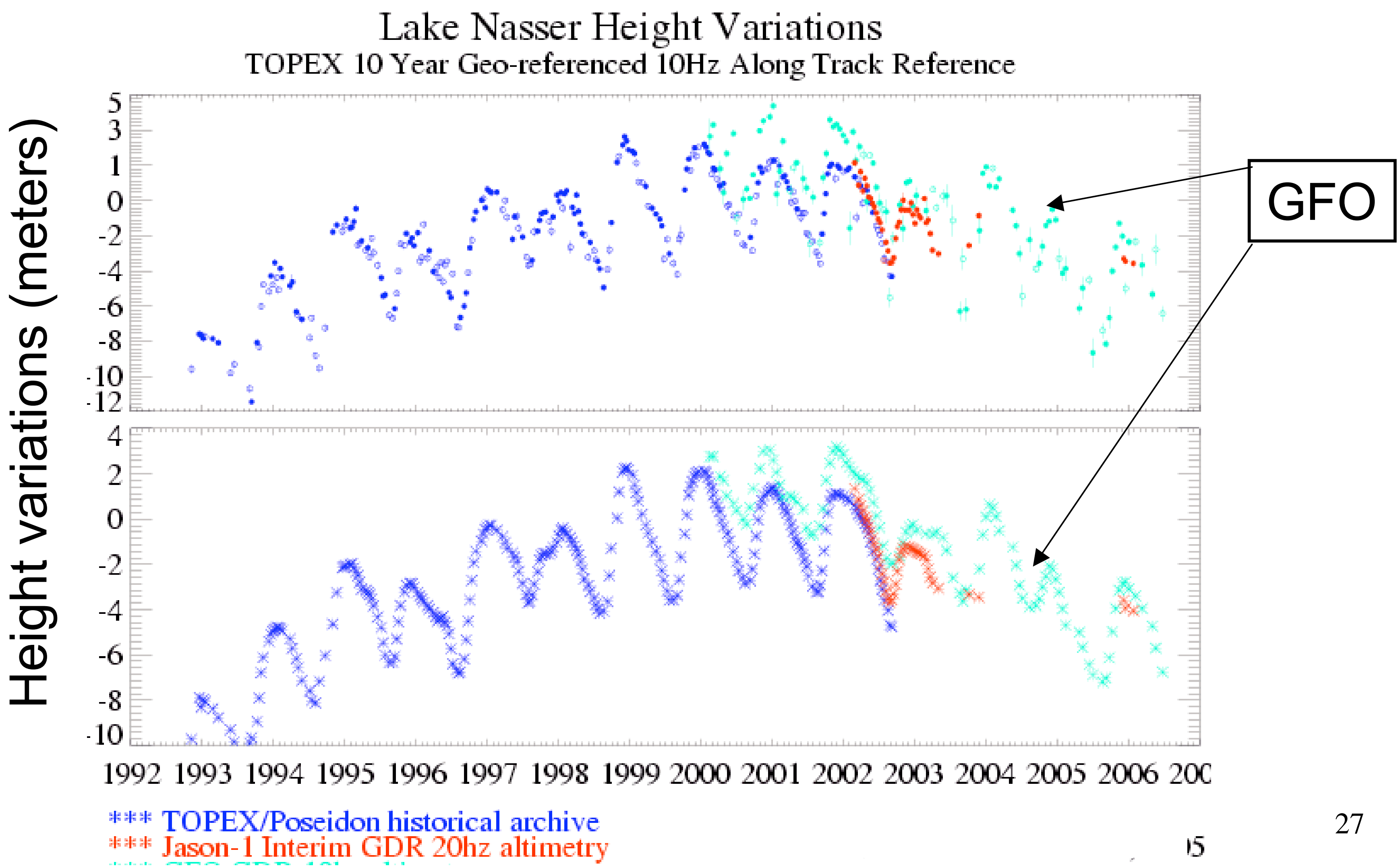


Sea Surface Height anomaly map (Topex+ERS2+GFO)



Applications: Lake level monitoring

(Courtesy Charon Birkett & Brian Beckley,
UMD & NASA GSFC;
Lake level monitoring funded by the USDA)



Summary

• The GFO mission was rescued by the laser retroreflector and the demonstration of near-real-time POD using SLR, Doppler, and altimeter crossover data.
• MOE (medium precision) orbits are exported daily, with a probable radial accuracy of 15 to 20 cm.
• POE (precise) orbits are exported with a ~3-week latency with a radial accuracy of about 5 cm.
• GFO altimeter data have many scientific applications, especially in combination with data from other missions such as Jason-1, Envisat, ERS: mapping of eddies; near-real-time monitoring for hurricane forecasts; inland lake monitoring; detection (*ex post facto*) of the Indian Ocean tsunami.
• Further orbit modelling improvements are planned using GRACE gravity models, better CG modelling, improved drag and radiation pressure modelling.

GFO orbit and altimetry data availability

Orbits [1]

MOE

1-day latency
anonymous ftp
dirac.gsfc.nasa.gov
cd pub/earth/gfo/moe

POE

3-week latency
anonymous ftp
dirac.gsfc.nasa.gov
cd pub/earth/gfo/poe

Altimeter Data [2]

IGDR

2-day latency
authorized ftp (NOAA)

GDR

4-week latency
authorized ftp,
and CDs (NOAA)

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