Evolution of the Global Space Geodesy Network

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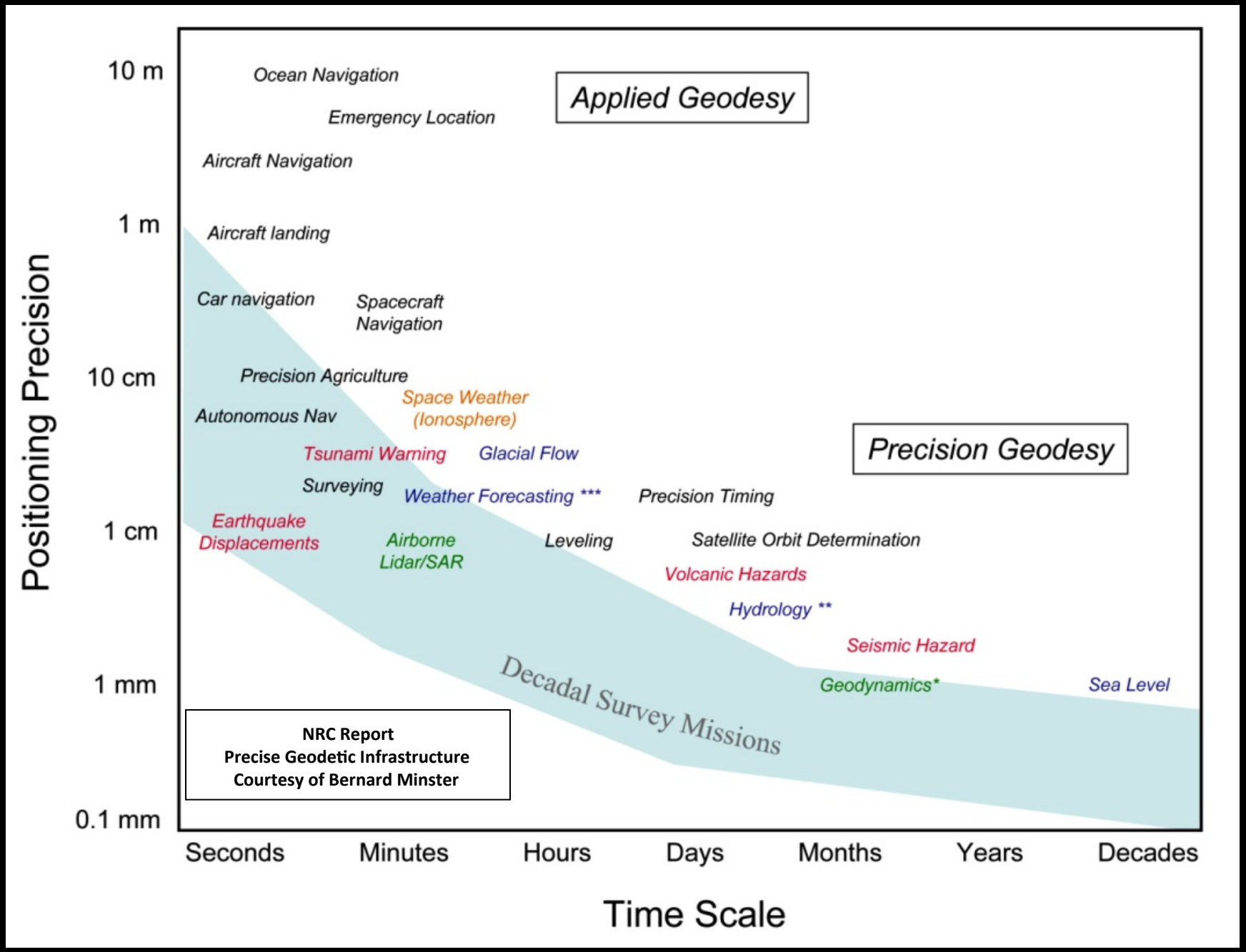
EGU General Assembly 2013
April 10, 2013



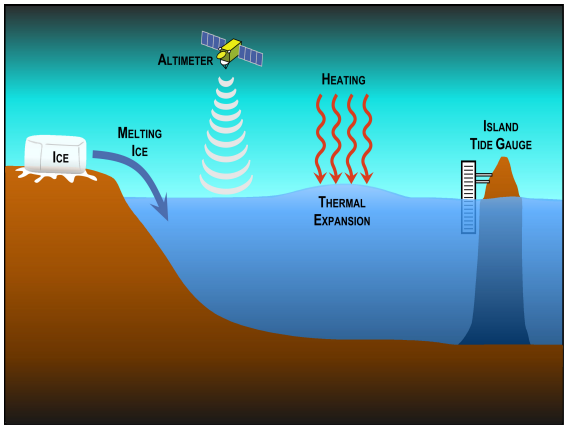
Courtesy of Bernard Minster
http://dels.nas.edu/Report/Precise-Geodetic-Infrastructure-National-Requirements/12954

Global Geodetic Observing System Reference Frame Requirement

- Most stringent requirement comes from sea level studies:
  - "accuracy of 1 mm, and stability at 0.1 mm/yr"
  - This is a factor 10-20 beyond current capability
- Accessibility: 24 hours/day; worldwide
- Space Segment: LAGEOS, GNSS, DORIS Satellites
- Ground Segment: Global distributed network of "modern", co-located SLR, VLBI, GNSS, DORIS stations
- Co-locate with and support other measurement techniques including gravity, tide gauges, etc.
- Simulation studies to date indicate:
  - ~30 globally distributed, well positioned, co-location stations will be required to define and maintain the reference frame;
  - ~16 of these co-location stations must track GNSS satellites with SLR to calibrate the GNSS orbits which are used to distribute the reference frame.

The Geodetic Reference Frame

(International Terrestrial Reference Frame)



<u>Basis for measuring change over space, time and evolving technology</u>

<u>Requirement</u> (Source GGOS 2020):

<1 mm reference frame accuracy

< 0.1 mm/yr stability

- Measurement of sea level is the primary driver
- Improvement over current ITRF performance by a factor of 10-20.

<u>Means of providing the reference frame</u>:

- Global Network of co-located VLBI/SLR/GNSS/DORIS CORE SITES define the reference frame
- Dense network of GNSS ground stations distributes the reference frame globally to the users

Users anywhere on the Earth can position their measurements in the reference frame

GGOS Site Requirements Document

(http://cddis.gsfc.nasa.gov/docs/GGOS_SiteReqDoc.pdf)

- Introduction and Justification
  - What is a Fundamental Station?
  - Why do we need the Reference Frame?
  - Why do we need a global network?
  - What is the current situation?
  - What do we need?
- Site Conditions
  - Global consideration for the location
  - Geology
  - Site area
  - Weather and sky conditions
  - Radio frequency and optical Interference
  - Horizon conditions
  - Air traffic and aircraft Protection
  - Communications
  - Land ownership
  - Local ground geodetic networks
  - Site Accessibility
  - Local infrastructure and accommodations
  - Electric power
  - Site security and safety
  - Local commitment

Global Geodetic Observing System (GGOS)

Site Requirements for GGOS Core Sites
(Revision 1a)

July 18, 2012

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Techniques are all Making Progress

- Satellite Laser Ranging
  - Several systems working in the Khz regime
  - Increased data yield and daylight ranging on the GNSS satellites
  - Steady progress on the new SLR prototype at GSFC
  - Progress on the GPS-3 arrays
- VLBI
  - Prototype VLBI 2010 in testing at GSFC
  - New Systems Fielded in Tasmania, Katherine, Yarragadee Station, etc
  - Wettzell twin telescopes are being constructed
- GNSS
  - Multiple constellations
  - Additional frequencies
  - New ground stations
- DORIS
  - Nearly complete network already
  - Additional satellites
  - New beacons

Realty

- If we do achieve the full complement of core sites in the right places, it will take a long time
- Aside from core sites we will always need co-location sites(2 techniques or more) to help link the techniques and enhance global coverage
- We will have a mix of new technology and legacy sites for a long time (maybe forever)
- Out data products will depend on this sites and technology mix indefinitely

Model to Project the Capability of the Network

- Based on the results form the GGOS CfP
- Based on what people tell us
- Based on performance that we see from the data
- We project this forward 5 and 1o years hence.
- Use Simulation techniques to see what we can expect in the future
- Test some of the sensitivities (tie vector, atmosphere, etc.)

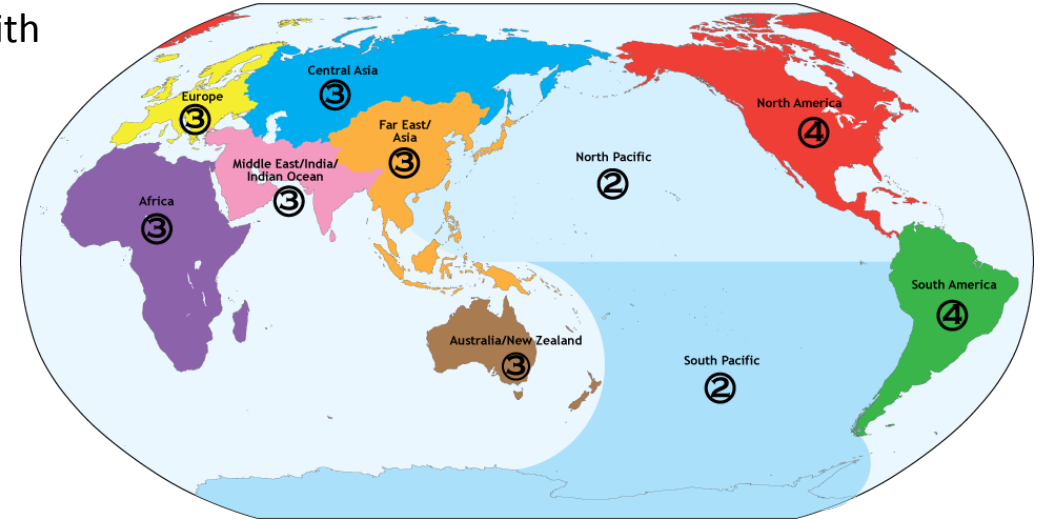
Sample Page from the Site Model

Region/Class	Sites	Current Config. G	V	S	D	Gr	5 Year Projected Configuration G	V	S	D	Gr	10 Year Projected Configuration G	V	S	D	Gr	Partner/ Agency	Other Equipment	Ground Stability	Ease of Business	SLR Production	SLR Eq. Rating	SLR Cloud Cover	SLR Site Tie Closure (mm)	VLBI Days/Year	VLBI Data Rate	VLBI RFI Conditions	VLBI Site Tie Closure (mm)	Sponsor Commitment	Equipment Provider	Issues/Comments
North America																																
VLBI	Brewster	L	L				L	L				L	L				NRAO		3				3		6	1	1	3			VLBA
VLBI	Hancock		L					L					L				NRAO						2		6	1	1				VLBA
VLBI	Kitt Peak		L					L					L				NRAO						3		6	1	1				VLBA
VLBI	Los Alamos		L					L					L				NRAO						3		6	1	1				VLBA
VLBI	Mauna Kea	L	L				L	L				L	L				NRAO		2				3		6	2	1				VLBA
VLBI	North Liberty	L	L				L	L				L	L				NRAO		3				2		6	1	1	7			VLBA
VLBI	Pie Town	L	L				L	L				L	L				NRAO		1				2		6	2	1	4			VLBA
VLBI	St. Croix	L	L				L	L				L	L				NRAO						2	3	6	1	1	3			VLBA
Europe																																
Core	Wettzell, Germany	N	L	L		AS	N	N	N		AS	N	N	N			BKG		3	3	3	2	2	9	133	3	1	4,10	3		Historic Site
VLBI	Grasse, France	L		L			N		L		AS	N		L			GRGS		3	3	3	2	2	2,7					3		Historic Site
VLBI	Effelsberg, Germany		L					L					L				MPIR						1		2	3	1				
Core	Matera, Italy	N	L	L			N	L	L		A	N	N	N		A	ASI		3	3	3	2	2	6	52	0	0	10	3		Historic Site
Core Plan	Yebes, Spain	L	L			AS	N	N			AS	N	N	N		AS	IGN		2				2		35	3	1	7	3		
VLBI	Madrid, Spain	L	L				N	L				N	L				NASA						2		8			9			
VLBI Plan	Canary Islands						N	N				N	N				IGN						2				1		S		very cloudy Nov - June, other time can be very clear...depending on exact location
VLBI Plan	Azores						N	N				N	N				DRCTC		3				3				1		S		Mostly cloudy at the Terciera Island location. Need better location identifiaction
SLR (Core Plan)	Herstmonceux, GB	N		L		A	N		N		A	N	N	N		A	NERC		3	3	3	3	2	4					3		Historic Site
SLR	Graz, Austria	N		N			N		N			N		N			OEAW		3	3	3	3	2	6					3		Historic Site
SLR	Zimmerwald, Switzerl	N		N			N		N			N		N			AIUB		3	3	3	3	3	2,6					3		Historic Site
SLR	Potsdam, Germany	L		L			N		L			N		L			GFZ		3	3	2	2	2	7,22					3		Historic Site
SLR	San Fernando, Spain	L		L			N		L			N		L			ROA		3	3	2	2	3	21					3		Historic Site
SLR	Borowiec, Poland	L		L			N		L			N		L			SRC/PAS		3	3			2	3					2		Historic Site
VLBI (Core Plan)	Metsahovi, Finland	L	L			AS	N	N	N		AS	N	N	N		AS	FGI		3	3			2	12,62	10	3	1		3		
VLBI (Core Plan)	Ny Alesund, Norway	N	L				N		N			N	N	N			NMA		3	3			2		133	1	1		3		
VLBI	Medicina, Italy	L	L			S	N	L			S	N	N				IRA		2	3			2		24	3	0	4	3		
VLBI	Noto, Italy	L	L				N	L				N	N				IRA		3				2		12	3		7	2		
VLBI	Onsala, Sweden	L	L			AS	N	N			SA	N	N			AS	OSO		3	3			2		40	3	1	12	3		Historic Site
SLR VLBI	Simeiz, Ukraine	L	L	L			N	L	L			N	L	L			CRAO		3	3	2	1	2		12	1	1	8	3		
Middle East																																
SLR (Core Plan)	Riyadh, Saudi Arabia	L		L			N		N			N		N			KACST		3	1	1	1	3						2		

Simulation Studies to Scope the Network

(impact on the Reference Frame)
(Erricos Pavlis)

- Simulations completed
  - ~30 globally distributed, well positioned, co-location Core Sites with modern technology and proper conditions;
  - 16 of these Core Sites must track GNSS satellites with SLR to calibrate the GNSS orbits;
- Simulations underway
  - Sensitivity to intersystem vector accuracy
  - Phased deployment; evolution of the products
  - Impact of errors and outages;
  - Additional space objects
  - Tracking scenarios



Current Network of Co-Located Sites

New Core Sites in Russia

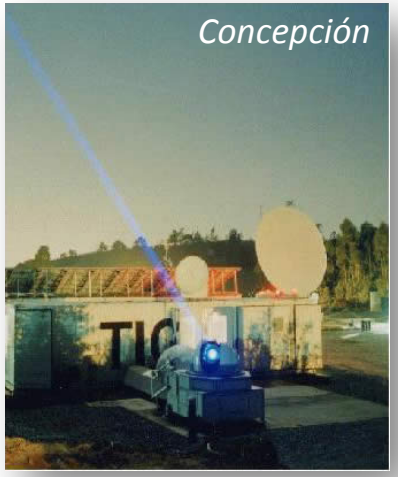
- Institute of Applied Astronomy (IAA) RAS
- SLR+VLB+GNSS; +DORIS (Badary only)
- VLBI operations since 2003
- SLR operations since 2012
- Legacy site with upgrades (300 Hz laser systems)

Core Sites in China

- Shanghai Astronomical Observatory (SHAO):
  - Shanghai: SLR+VLBI+GNSS
    - 10kHz SLR system planned
  - Changchun: SLR+GNSS
    - VLBI 2010 planned in 5-6 years
  - Beijing: SLR+VLBI+GNSS
  - Wuhan: SLR+GNSS+DORIS
  - Kunming: SLR+VLBI+GNSS
  - Urumqi:
    - SLR planned in few years
- In 2020, China will have five co-location sites equipped with SLR, VLBI, and GNSS: Shanghai, Changchun, Beijing, Urumqi, Kunming.

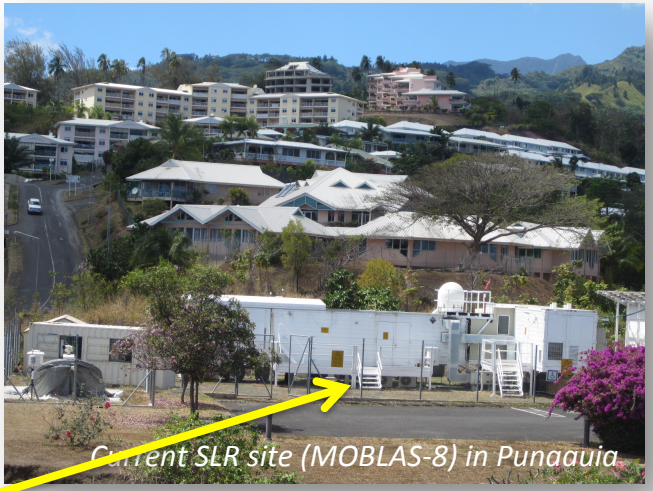
Core Site Locations Under Consideration
Colombia and Brazil

- Discussions underway with:
  - Colombia: Instituto Geográfico Agustín Codazzi (IGAC)
  - Brazil: National Institute For Space Research (INPE)
- Plan for TIGO move from Concepción to La Plata
- San Juan:
  - SHAO planning 40m VLBI2010 system completion in 2015



Core Site Locations Under Consideration
French Polynesia

- Cooperation between NASA, CNES, and UFP
- SLR:
  - MOBLAS-8 operational since 1997
  - Co-located GNSS and DORIS
- VLBI:
  - Discussions underway

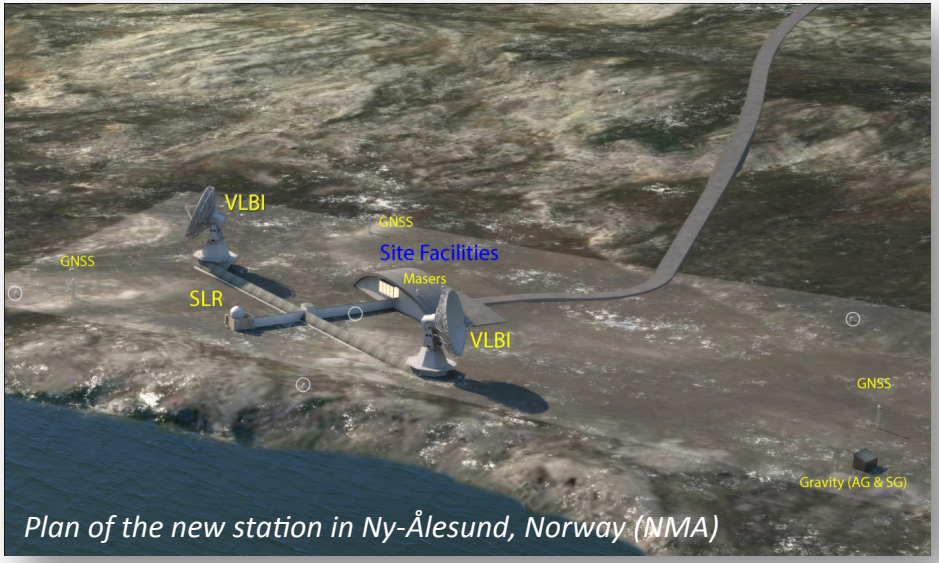


Future Core Site Location
Sejong, Korea

- National Geographic Information Institute (NGII)
  - VLBI
    - Operational March 2012
  - GNSS
    - Operational since 1999
  - Gravimeter
- Korea Astronomy & Space Science Institute (KASI)
  - SLR
    - kHz station in testing at KASI HQ
    - Relocation and operations planned for mid-2013
  - DORIS
    - Planned future installation

Future Core Site Location
Ny Ålesund, Norway

- Norwegian Mapping Authority (NMA)
- Ny Ålesund Geodetic Observatory
- New VLBI telescopes are planned
  - Operational in 2018
  - Removal of existing antenna in 2022
- SLR included in 2020



Plan of the new station in Ny-Ålesund, Norway (NMA)

Future Core Site Location
Metsähovi, Finland

- Finnish Geodetic Institute
- SLR:
  - Operational 1980-2005
  - New telescope ordered
  - Installation/operations 2013-2015
- VLBI:
  - Operational since 1989
  - VLBI2010 compatible telescope 2014-2016
- GNSS:
  - Operational since 1992
- DORIS:
  - Operational since 1990
- Superconducting gravimeter:
  - Operational since 1994
  - New instrument installation planned for mid-2013
  - Absolute gravimeter also installed
- Other scientific instrumentation
  - Seismometer
  - Precise leveling test field
  - Part of Finnish permanent GNSS reference network

Future Core Site Location
Yebes, Spain

- National Geographical Institute (IGN) and Direccao de Servicos de Cartografia e Informacao Geografica (DSCIG)
- Yebes (IGN)
  - VLBI, GNSS, and gravimeter site
  - VLBI upgrade (S/X/Ka band receiver) planned (2012?)
  - SLR installation planned (2016-17)
- Azores:
  - VLBI planned at Flores (2014), DSCIG
  - VLBI planned Santa Maria (2013), IGN and DSCIG
- Canary Islands:
  - VLBI planned at Tenerife (2013

Core Site Locations Under Consideration
Malindi, Kenya

- Discussions initiated with the Italian Space Agency (ASI) for a partnership site
- Existing GNSS operated by ESA