# Challenges for Geodetic Observatories – SGF Herstmonceux, UK

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# Global sea level rise determined by altimetry from a series of satellites – **robust reference frame crucial**



# **Motivation and Outline**

- The Global Geodetic Observing System\* vision is to realize a global reference frame at 1mm accuracy

   and 0.1mm/year stability
- Places strong challenges on the global geodetic observatories that will be required to deliver this vision
- New observatories are being designed to meet challenge, e.g., by NASA and collaborators
- Existing observatories will continue to make major contributions provided they meet exacting requirements:

 $\star$  GGOS, the Observing System of the Int. Association of Geodesy, IAG

# The reference frame

- Terrestrial Reference Frame (TRF)
- Crust based, realised through the geodetic coordinates and velocities of a global set of observatories determined by modern geodetic technologies:
  - Satellite laser ranging (SLR)
  - Global Satellite Navigation Systems (GNSS)
  - Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)
  - Very Long Baseline Interferometry (VLBI)

### The International Terrestrial Reference Frame

- Each technique establishes it own reference frame; each technique takes measurements differently – Radio verses optical, satellites verses quasars, looking up verses looking down, active verses passive, etc.
- Co-located systems at the same sites allow us to connect the data and integrate the techniques into a common reference frame for greatest stability and accuracy;
- Proper combination of the data from co-locations sites over the Earth takes advantage of the strengths of each technique and mitigates the weaknesses.
- The best situation is to have SLR, VLBI, GNSS and where possible DORIS together at the same sites (Core Sites). Co-locations with three and two techniques are also very useful.



5LR

VLBI GNSS Solid Earth Observing Systems, University of Liverpool

DORIS

# Technique contributions to ITRF

- **Origin** uniquely realised through the coordinates of a global set of **SLR** stations
  - Coordinates formed through precise orbit determination of LAGEOS and LAGEOS-2
- Scale determined through a combination of the SLR and VLBI-derived scales
- Orientation : using a selection of sites with high geodetic quality (including SGF Herstmonceux)- VLBI, GPS, SLR
- ITRF2008 gives station coordinates and velocities for epoch 2000.0

### The Space Geodesy Facility, Herstmonceux





#### Sited in the grounds of Queen's University, Ontario, Int. Study Centre

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#### Observatory overview

- Operational Satellite Laser Ranger; single shot precision ~5mm at 10Hz or 2kHz
  - Potentially a 24/7 operation, but scheduled at most productive times for single-person out-of-hours tracking
  - Challenging budgetary constraints as well
- Two **GPS/GLONASS** continuous receivers
  - Operational since 1993 and 2003: HERS, HERT
  - HERT streaming in realtime for EUREF and IGS
- UK Ordnance Survey GNSS receiver also hosted on site: HERO
  - One of 12 UK-wide that form backbone of GeoNet reference stations

### Facility overview (2)

- Associated environmental monitoring
  - Automated met data,
  - groundwater level at ~5 min intervals,
  - BGS seismometer as part of their UK broadband network
- Absolute gravimeter FK5; operational from late 2006
  - To provide a standard for UK AG work and investigate local motion/loading
- LiDAR capability
  - Quantify laser backscatter signal for atmosphere studies
  - Recent addition of a Sun photometer
- **H-maser** for accurate time and frequency for GNSS (HERS) and SLR

# Local site stability

- For a multi-technique site, very important to monitor potential **local relative motion** 
  - Clearly, relative motion would compromise the quality of the combination solutions for the TRF
- High-precision inter-technique leveling at 2week intervals for local vertical motion;
  - AG SLR GNSS markers measured by bar-code leveler
- Differential GPS for local horizontal motion;

## Leveling results 2010-2013



# Leveling results 2010-2013

- The only monument that exhibits a significant and systematic height variation is the GNSS tower that holds the HERS antenna
- Temperature measurements and simple models of the braced structure point to seasonal height variations at ~2mm level
- No comparable effects with SLR, HERO, HERT or the AG piers.

# Horizontal stability – 130m across site



- Daily differential GPS solutions for HERS->HERT
- Annual period of amplitude 1mm in baseline
- Possible cause is again the HERS tower
  - But effect also seen in many short baselines-
  - may be constellation related

Wilkinson, Appleby and Sherwood, 2013, Site stability, IAG REFAG Solid Earth Observing Systems, University

# Missing capability – site stability

- A GGOS recommendation:
- In **addition** to the site leveling and horizontal measurement by GNSS:
- Automated, frequent monitoring of intertechnique vectors ('site ties'):
- Use of an automatic 'total station' delivering site tie values at sub-mm accuracy
- Crucial for value of site ties in the ITRF combination process

# SLR - Challenges in *accurately* ranging to the geodetic spheres

- In principle the geodetic SLR technique is straightforward
  - Ultra-short laser pulses and high-speed detectors (for single- or multi-photons)
  - Time-of-flight counters or epoch (event) timers of mm-level precision
  - Compact space segments LAGEOS at 60cm and Etalon at 130cm diameter
    - Ground measurements and station-dependent models for phasecentre (CoM) correction now in use (Appleby and Otsubo, 2014)
- Convolution of these elements' distribution functions gives single-shot precision at ~10mm and 'normal point' precision at 1mm level.
- Ground-target ranging for removal of electronic delays and as a system stability-test

#### Long Term geodetic ranging stability (mm) from QC orbital analysis - Herstmonceux among the best in the Network



# Important also to accommodate systematics during SLR data *analysis*

- For stations including Herstmonceux that observe sufficient passes of LAGEOS *and* LAGEOS-2, it is possible to solve for potential range error simultaneously with reference frame (coordinates, Earth orientation) parameters and orbital state vectors
  - Prevent direct contamination of TRF results (scale)
  - For ITRF2008, scale difference between VLBI and SLR is 1.4 ppb \*
- Solutions carried out on weekly arcs using global ILRS station data and in-house SATAN POD/estimation code
  - Preparation for input to next ITRF ITRF2013
  - Several stations exhibiting >5mm range bias
  - Herstmonceux <2mm</li>
  - For 2002-2013 solutions, scale difference from ITRF2008 is 1.0 ppb
    - EGU2014 presentation (Appleby and Rodriguez)
- \* Altamimi et al, 2011, ITRF2008, J Geod

### **Bias solutions**



### **Bias solutions**

7-day LAGEOS RB solutions for station 8834



#### Gravity lab in SGF basement: FG5 absolute gravimeter operational since 2007





## Absolute gravity time series



# 10-day hourly AG run- residuals imply correction to IERS 2010 Earth tide model at few micro-Gal level



<sup>22</sup> 

# Gravity opportunity

- Much work to be done to understand results on long and short time-scales
  - hydrology-driven long-period signals
  - Evidence too for deficiency in gravity effect of solid Earth tides
- However, good progress has been made on characterising the lab environment
  - Excellent low-noise leading to high-precision gravity values
- High potential as a UK reference lab for episodic gravity surveys in UK and abroad e.g. EPOS volcanology?
  - SGF instrument run weekly for 24 hours
  - Ideal for pre- and post-survey gravity comparisons
  - Also, two NOCL AGs on loan to SGF
  - One operational, one needs some work

# Longer-term development

- In order to contribute even more to international reference frame determination at mm-level;
- Addition of a 12m-class very-long-baselineinterferometry (VLBI) radio dish would:
- Greatly enhance value of site to GGOS aim
  - Linking terrestrial to celestial reference frames
  - Improvement of ITRF scale
- Open up new science for UK geodetic community
- Proposal favourably received by Steering Committee

### Conclusion

- SGF Herstmonceux:
- Excellent SLR and GNSS capability, GGOS compliant, 'next generation' SLR
  - Need better monument for HERS primary GNSS
- Good leveling regime for site stability check
  - Needs automated monitoring of inter-technique vectors
- Opportunity to be significant national resource for gravity work, including survey support
- Addition of VLBI 2010 would establish a GGOS Core Site and secure future for many years