Summary: Scientific Achievement, Applications and Future Requirements

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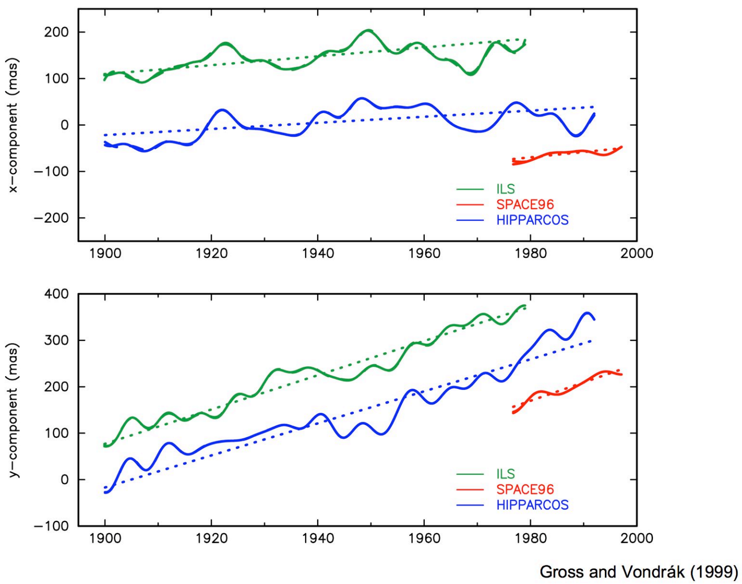
Session Summaries

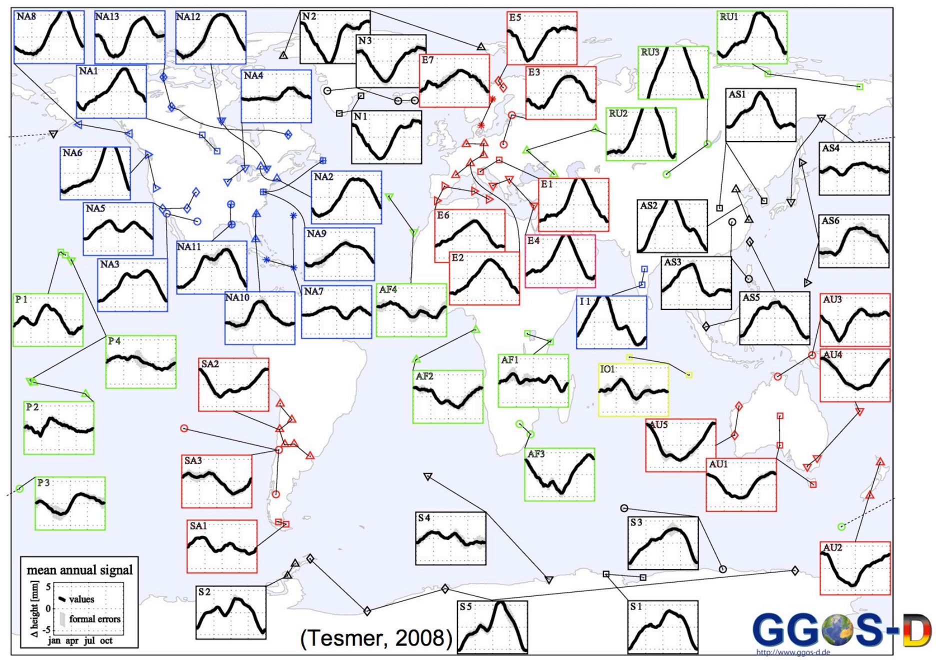
- Terrestrial Reference Frame
  - EOP, geocenter, ITRF, station determination -- 5 papers
- Time Varying Gravity, Gravity Coefficient/Tide Recovery
  - SLR determination, use of new mission capabilities -- 4 papers
  - k2, k3
- SLR Orbit Determination
  - GIOVE-B, LRO, observation corrections, new software -- 4 papers
- Laser Altimetry
  - ICESat, Planetary, Mars Volatile Exchange -- 3 papers
- Lunar Laser Ranging
  - Analysis and constraints on Relativity -- 2 papers
- Frame-dragging effects measured by SLR
  - Lens Thirring, LARES, Gamma -- 3 papers

Reference Frame, Geocenter, Future ITRF

Decadal Polar Motion Variations

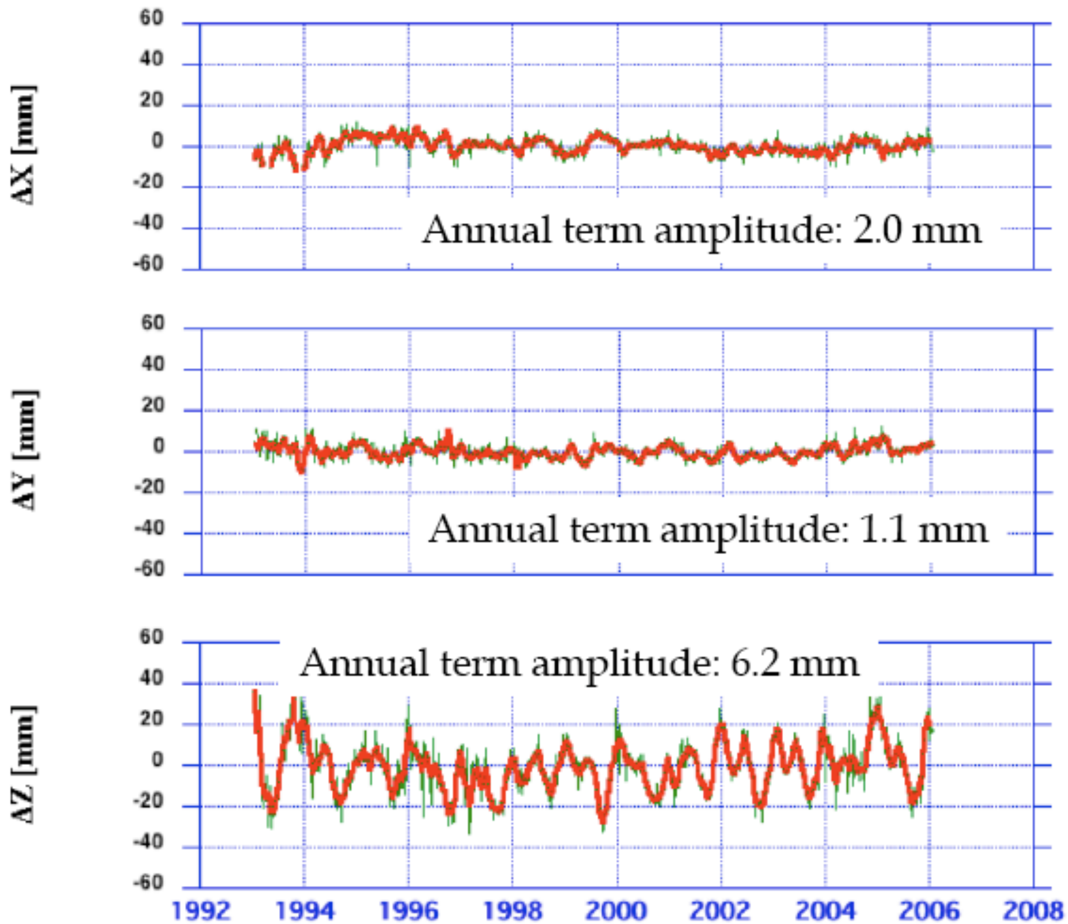


Average Mean Annual Regional Behavior



Status: ITRF approaching few mm level of consistency; scale problems are being resolved, SLR important for long EOP history, and new ITRF2008 upcoming; remaining problems -- geocenter in z direction, and achieving sub-mm goals

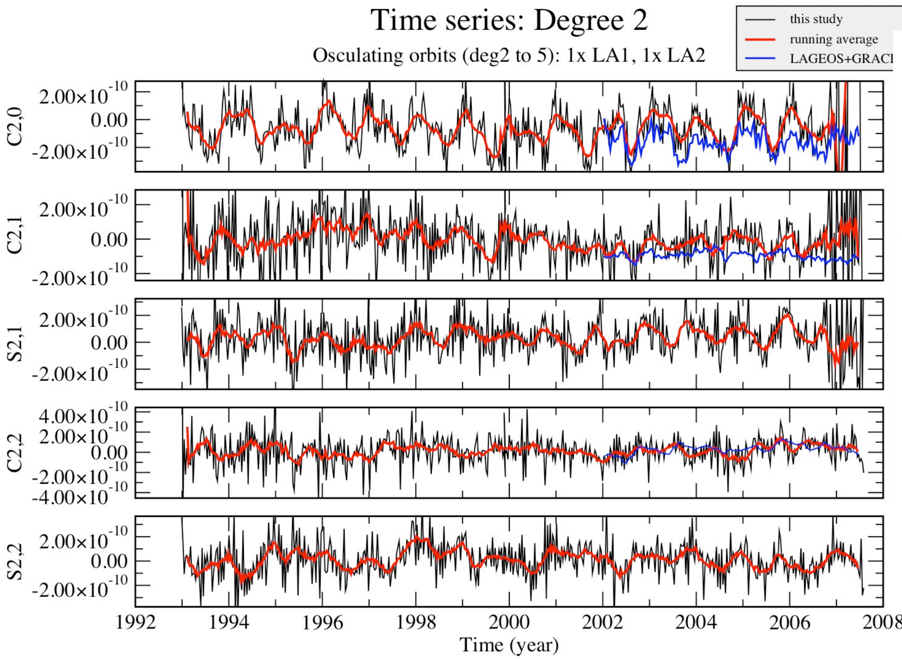
Geocenter from SLR to LAGEOS

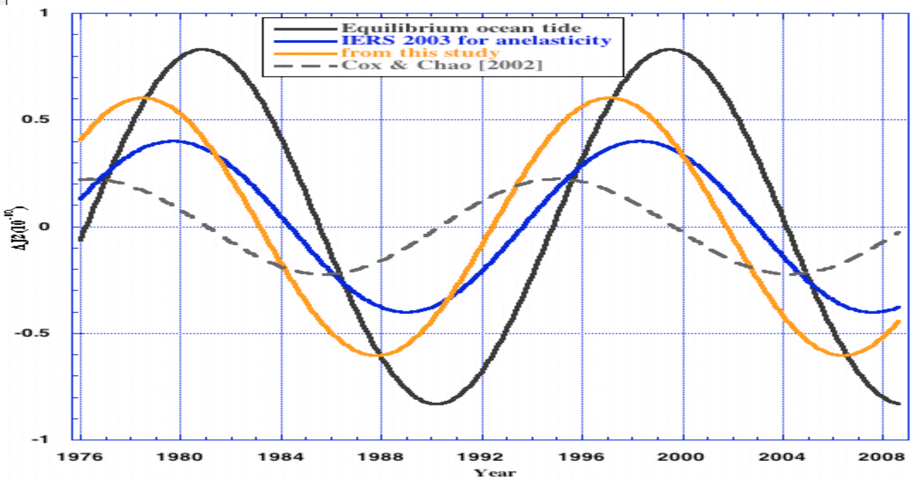


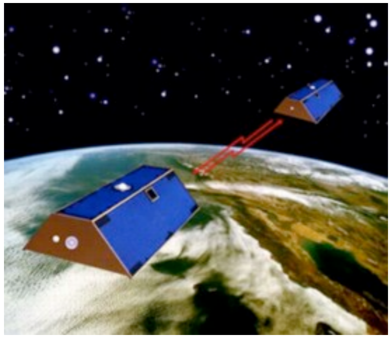
~ 1 inch

Geocenter with respect to ITRF2000 with secular rates removed, raw (green) and 30-day smoothed (red) values [SSC(JCET) 06 L25].

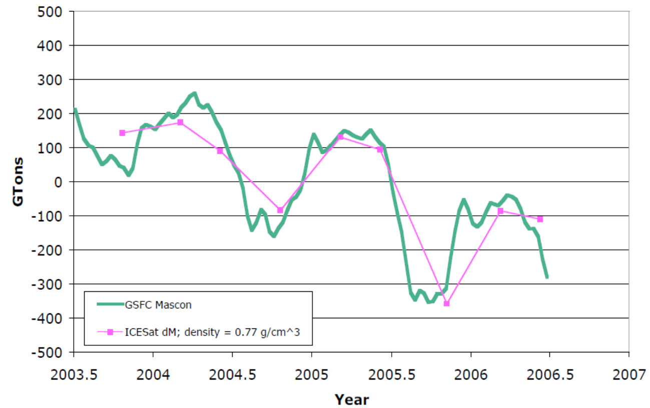
Time Varying Gravity







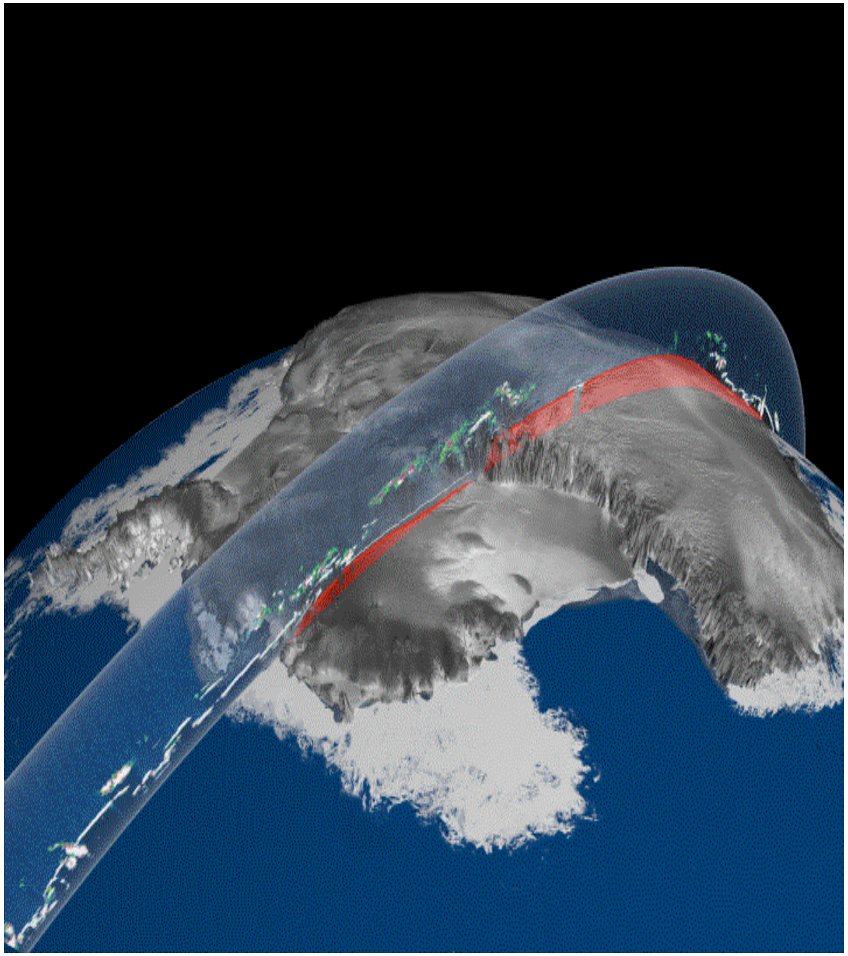
GRACE Mascon Mass Flux vs. ICESat (avg. dens.)



**ICESat dH/dt courtesy Zwally, Li, Yi ...*

Laser Altimetry

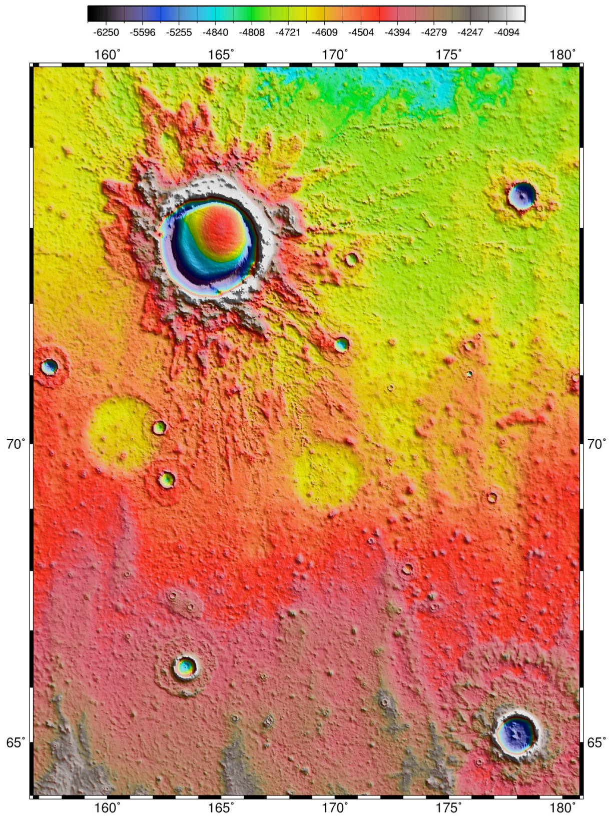
ICESat dh/
dt



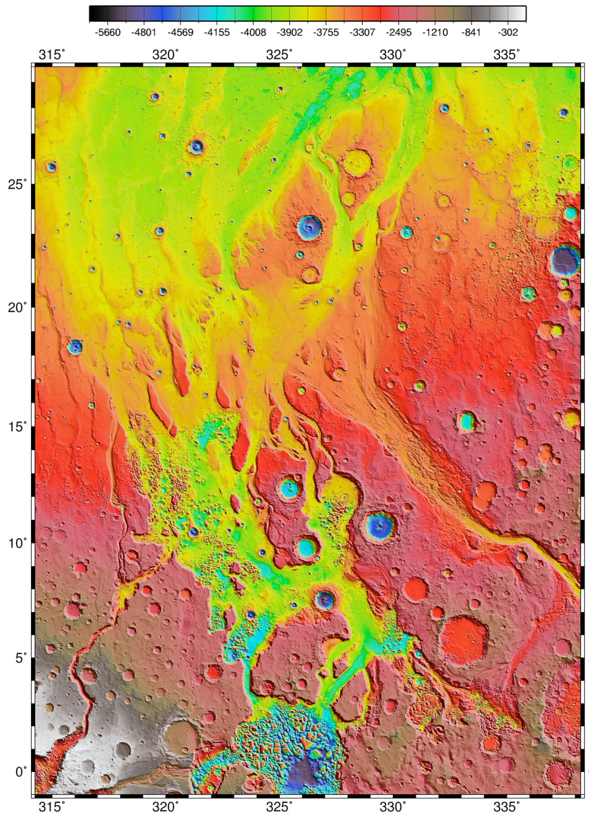
ICESat derived dh/dt shown for 2003-2007
GRACE derived mass change over same period is very similar;
GRACE measures mass change
ICESat measures volume change

Topographic Images from MOLA Altimetry

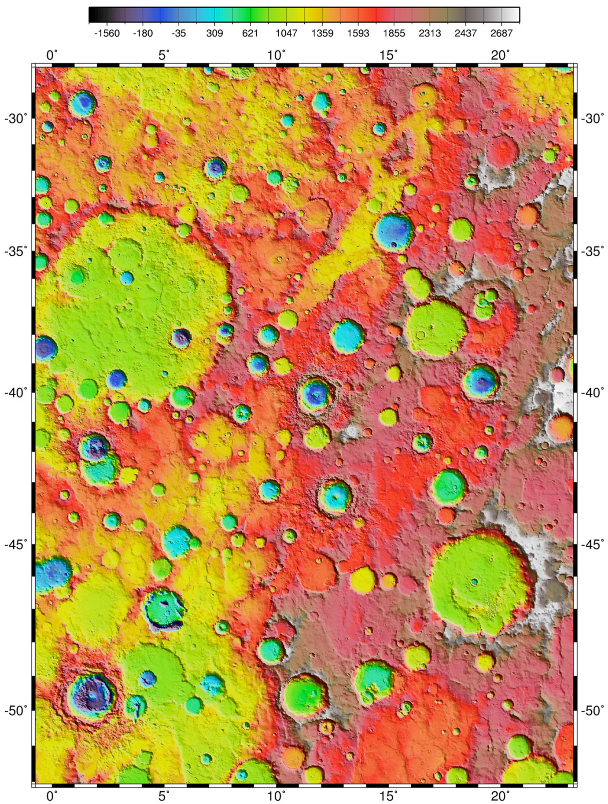
Ice filled crater



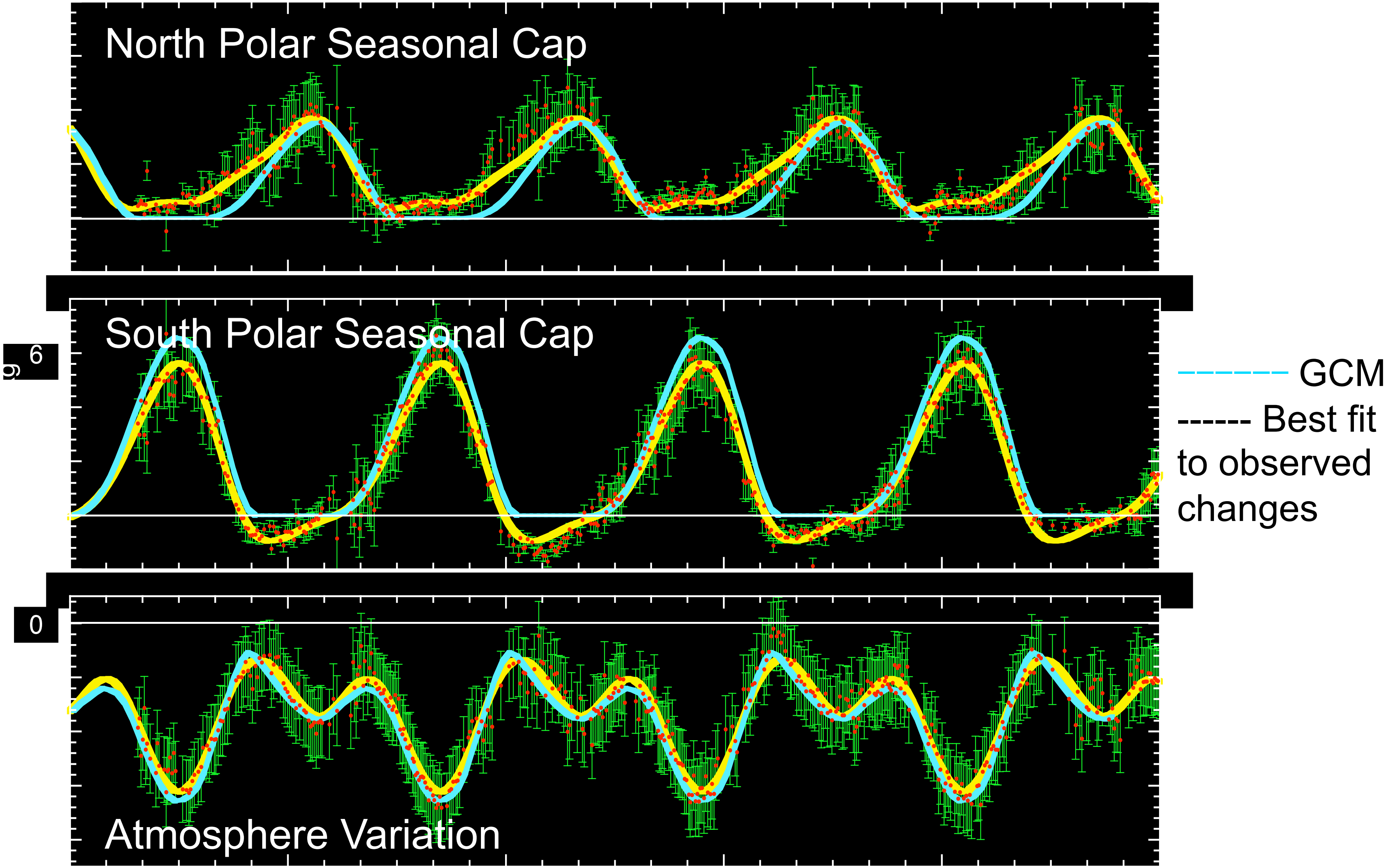
Outflow channels



Cratered highlands

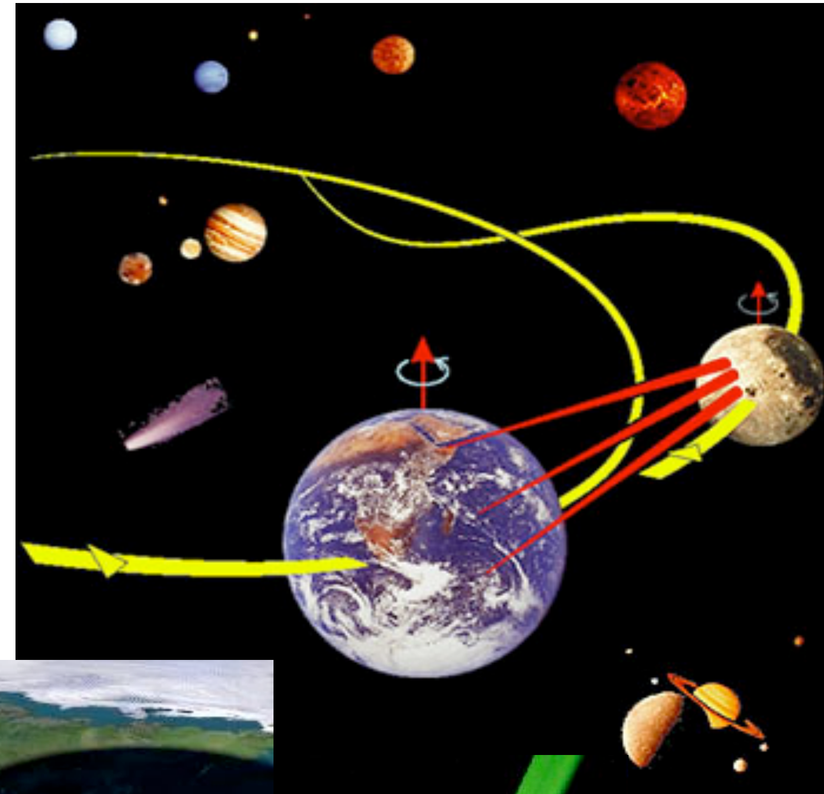


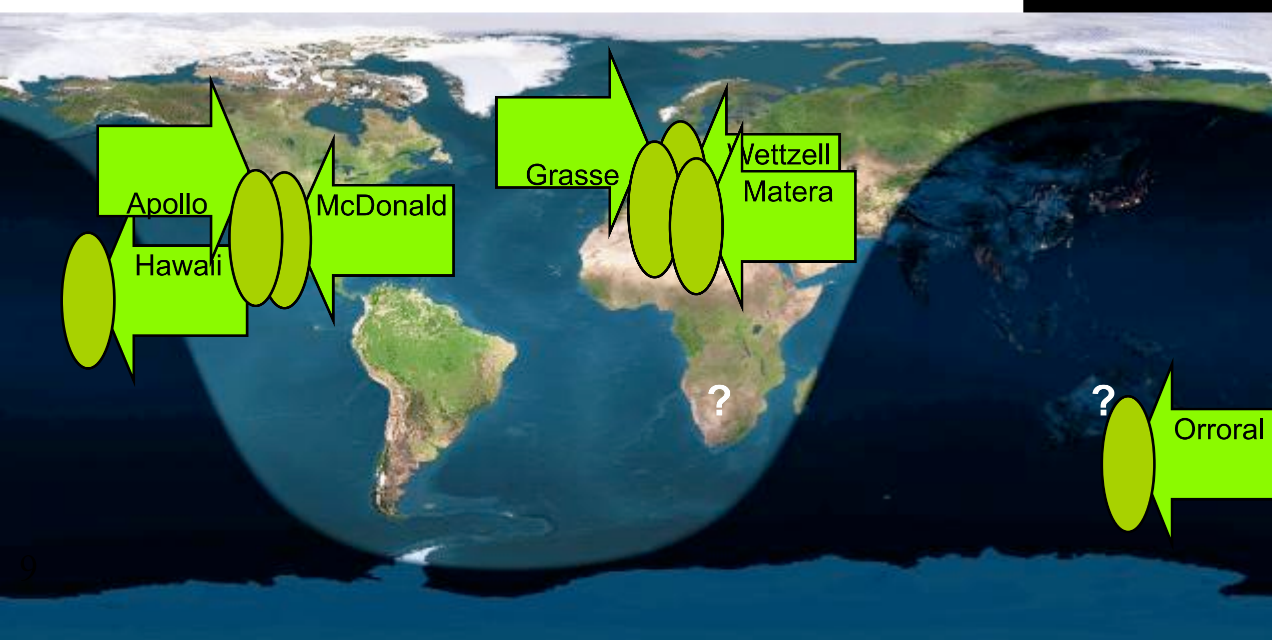
Seasonal Mass Changes over 4 Mars Years



Lunar Laser Ranging (LLR)

38 years of observations
Modelling so far at cm-level
Long-term stability (e.g., orbit)
→ Earth-Moon dynamics
→ Relativity parameters

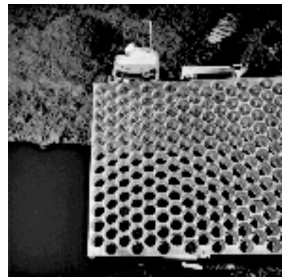




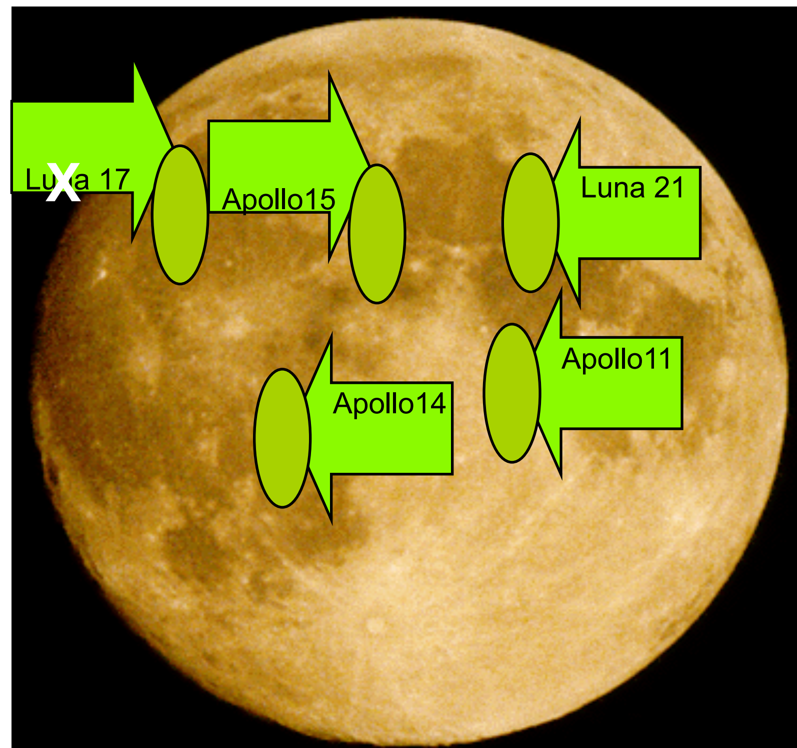
Retro-Reflectors on the Moon

Apollo 11
July 1969

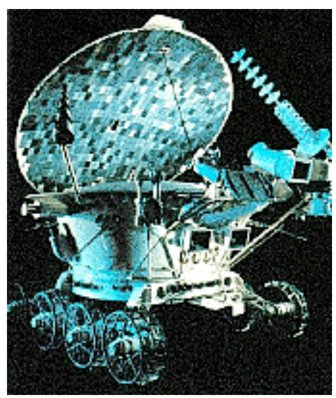
Apollo 14
Jan./Feb.`71



Apollo 15
Jul./Aug.`71



Luna 17
Nov.`70...



Luna 21
Jan.`73...

LT Results for Recent GRACE gravity models

Gravity model	Year	LT signal / GR	C40	C40 Sigma	C60	C60 Sigma
EIGEN-GRACE02S	2004.1	1.25	5.40007101E-07	3.9E-12	-1.49930405E-07	2.0E-12
GGM02S	2004.6	1.01	5.39975648E-07	8.3E-12	-1.49939959E-07	4.5E-12
EIGEN-CG03C	2005.3	1.03	5.39987470E-07	3.8E-12	-1.49955461E-07	1.8E-12
GIF22a	2005.7	0.99	5.39989338E-07	1.5E-13	-1.49953540E-07	1.0E-13
JEM04G	2005.9	0.84	5.39970358E-07	1.2E-13	-1.49967559E-07	9.1E-14
EIGEN-GL04C	2006.3	0.93	5.39973449E-07	4.5E-12	-1.49953685E-07	2.0E-12
JEM01-RL03B	2006.9	1.05	5.39992625E-07	8.5E-14	-1.49956879E-07	6.2E-14
GGM03S	2007.5	0.88	5.39972911E-07	4.6E-12	-1.49959620E-07	1.6E-12
ITG-GRACE03S	2007.8	0.85	5.39965868E-07	3.8E-13	-1.49953913E-07	1.7E-13
EIGEN-GL05C	2008.5	1.04	5.39988199E-07	3.5E-12	-1.49953616E-07	1.4E-12
GGM03S (2003-2007 only)	2007.5	1.03	5.39972911E-07	4.6E-12	-1.49959620E-07	1.6E-12
Mean		0.99	5.39982297E-07		-1.49952464E-07	
StDev		0.12	1.3E-11		1.0E-11	

Our results for the same gravity field (EIGEN-GRACE02S) differ by 26%; suspect mapping of zonals to appropriate epoch, although other modeling differences may also be present

Error estimates assigned to C40 and C60 appear to be generally optimistic; a test of relativity requires robust (conservative) error estimates

Other 'sanity' tests to validate analysis method

GGM02S (model LT)	0.01	(differs by exactly 1.0 as expected)
GGM02S (no GP)	1.58	(Geodesic precession ~57% of LT)
GGM02S (no rates for J3,J4,J6)	1.02	(quadratic from rates is negligible)

SLR Confirms General Relativity

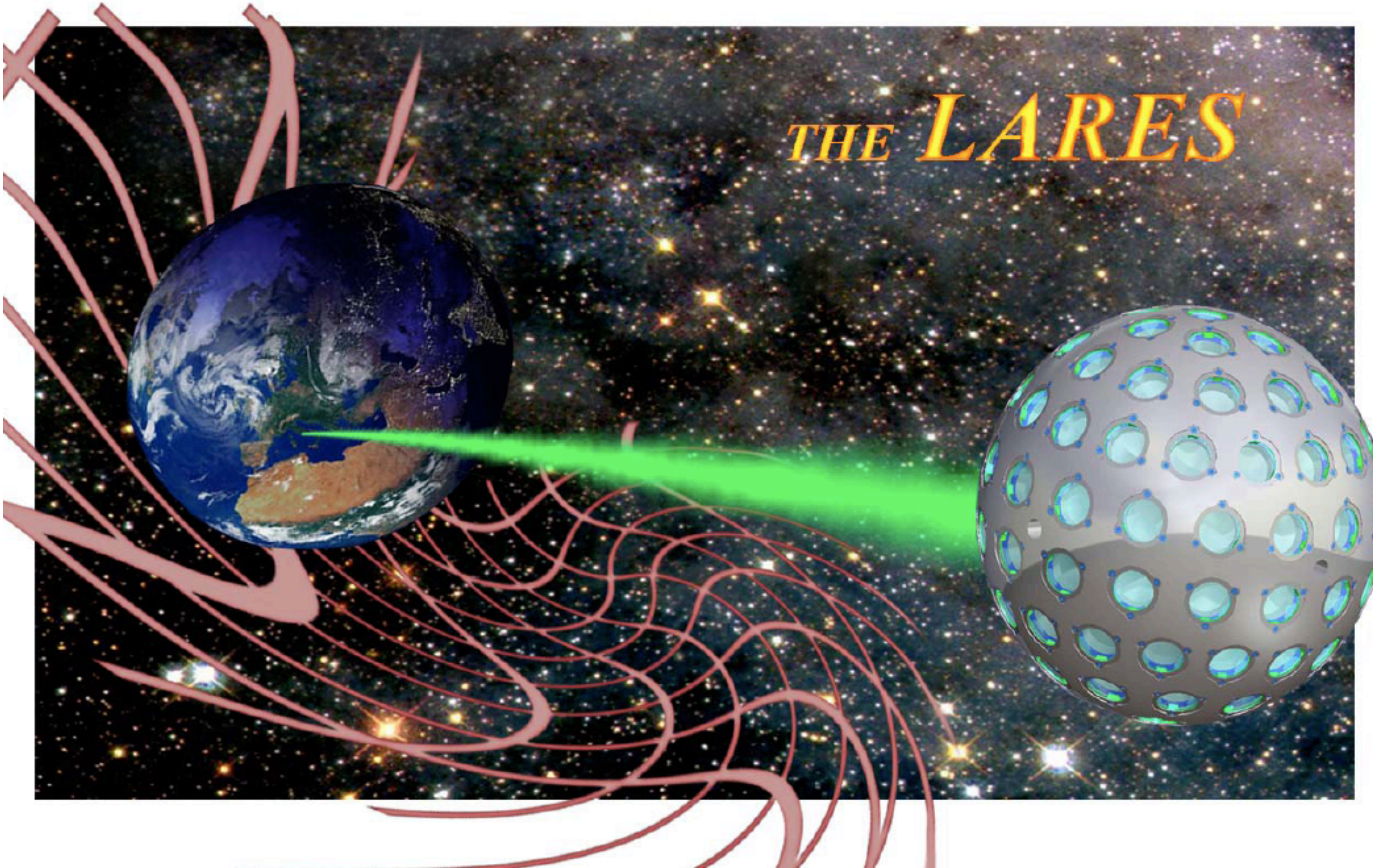
Satellite laser tracking to LAGEOS-1 and -2 appears to confirm General Relativity's prediction of the Lense-Thirring precession at the 8-12% level (1-sigma)

This is possible only with the dramatically improved geopotential models from the GRACE mission

Uncertainties in J4 and J6 (including rates) dominate current error budget, as expected

Improvements in dynamical and measurement models help make it possible to achieve a reliable solution with only a few years of data

More years of GRACE data will provide a more accurate mean field and extend the interval for a Lense-Thirring test that does not require mapping zonals back to an earlier epoch


THE LARES