  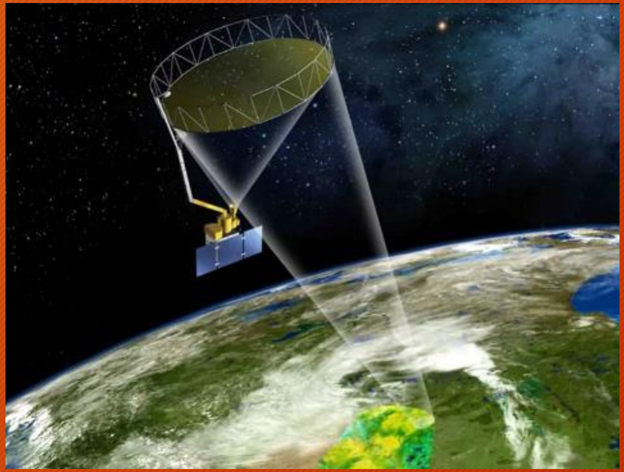 

The Geodesy Crisis Challenge

Everett Hinkley – USFS National Remote Sensing Program Mgr.

PNT Advisory Board
May 2022

   

Disclaimer

Please remember while I am presenting:

1. I am not a working geodesist. I am a remote sensing SME and a cartographer.
2. I am schooled and experienced in mapping, GIS, traditional surveying, GPS surveying, and remote sensing, all of which depend on geodesy.
3. My role here is as a messenger to build awareness of the issue.
4. I did not write, nor co-author the grass roots white paper, but I share the concern.
5. The slides below are derived in part from a PPT by Dr. David Sandwell - a professor of geophysics at the Scripps Institution of Oceanography at the University of California, San Diego, and a member of the National Academy of Sciences.

The Geodesy Crisis Challenge

- What is the crisis? Is it a crisis?
  - Yes, it is a serious challenge with significant immediacy, but we need to be cautious in our terminology.
  - The word “crisis” grabs attention, but this crisis has been in the works for decades due to several converging trends.
- Why should we care?
- What can we do to right the ship?

Grass-roots white paper

January 2022

America's loss of capacity and international competitiveness in geodesy, the economic and military implications, and some modes of corrective action

Michael Bevis
Ohio Eminent Scholar & Prof. of Geodesy
Ohio State University

Chris Jekeli
Professor Emeritus of Geodesy
Ohio State University

C.K. Shum
Professor of Geodesy
Ohio State University

Dave Zilkoski
Former Director of the
National Geodetic Survey

Richard Salman
Former Director, NGA
Office of Geomatics

William Carter
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the National Geodetic Survey

James Davis
Lamont Research Professor
Columbia University-City of New York

Thomas Herring
Professor of Geodesy
MIT

Craig Glennie
Prof. of Geodetic Engineering
University of Houston

David Sandwell
Professor of Geodesy, UCSD
and National Academy of Sciences

Stephen Hilla
Former Chief of Research at
the National Geodetic Survey

Yehuda Bock
Distinguished Research Geodesist
Scripps Institution of Oceanography

Ken Hudnut
Former Geophysicist at the
US Geological Survey

Jeff Freymueller
Professor of Geodesy
Michigan State University

John Factor
Former Geodesist at
NGA Office of Geomatics

"The U.S. is on the verge of being permanently eclipsed in geodesy and in the downstream geospatial technologies. This threatens our national security and poses major risks to an economy that is strongly tied to the geospatial revolution, on Earth and, eventually, in space."

"Averting these dangers at such a late date will require the U.S. to invest in geodetic research and training on an industrial scale."

"The situation in academia is particularly urgent because if corrective action is not taken very soon, the U.S. will no longer have the capacity to take such action at the scale required to avoid permanent disadvantage."

Bevis et al., 2022

Grass-roots white paper

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"China now has more geodesists than the rest of the world combined, and its numerical advantage continues to grow. During this time period, the largest national decline (worldwide) in geodetic research and training capacity has occurred in the U.S."

"Perhaps the most shocking example of the U.S. decline relative to China is that the number of Ph.D. geodesists in the entire DOD, including the National Geospatial-Intelligence Agency (NGA), is now approaching zero."

Bevis et al., 2022

The Geodesy Crisis Challenge

- What is the crisis? Is there a crisis?
- Why should we care?
- What can we do to right the ship?

Don’t we have GPS for Navigation & Positioning?

Things to Consider

Positioning vs. Navigation.

GPS signals received can be processed in a couple of ways: The predicted ephemeris in the broadcast message is a where we *think* the satellite will be. The predicted ephemeris good enough for navigating **but nowhere suitable for accurate positioning**. If one takes received signals from ground control receivers (e.g., CORS), then they can be post-processed to produce very accurate positions.

The **broadcast signals** are WGS84. The **post-processing** gets positions to the current ITRF coordinates.

WGS84 is a space-based reference system. **Unless** one operating in space (and, in the middle of the ocean or in the air counts as "space"), then you probably shouldn't use **WGS84**. **For precise and accurate navigation near or on land, you will want a reference system tied to the earth's crust like ITRF2014 or NAD 83.**

Using a broadcast signal means you are working with a single GNSS signal. There is no redundancy, extra observations, or different radio spectra to give a different solution. That’s both good and bad, and perhaps ugly.

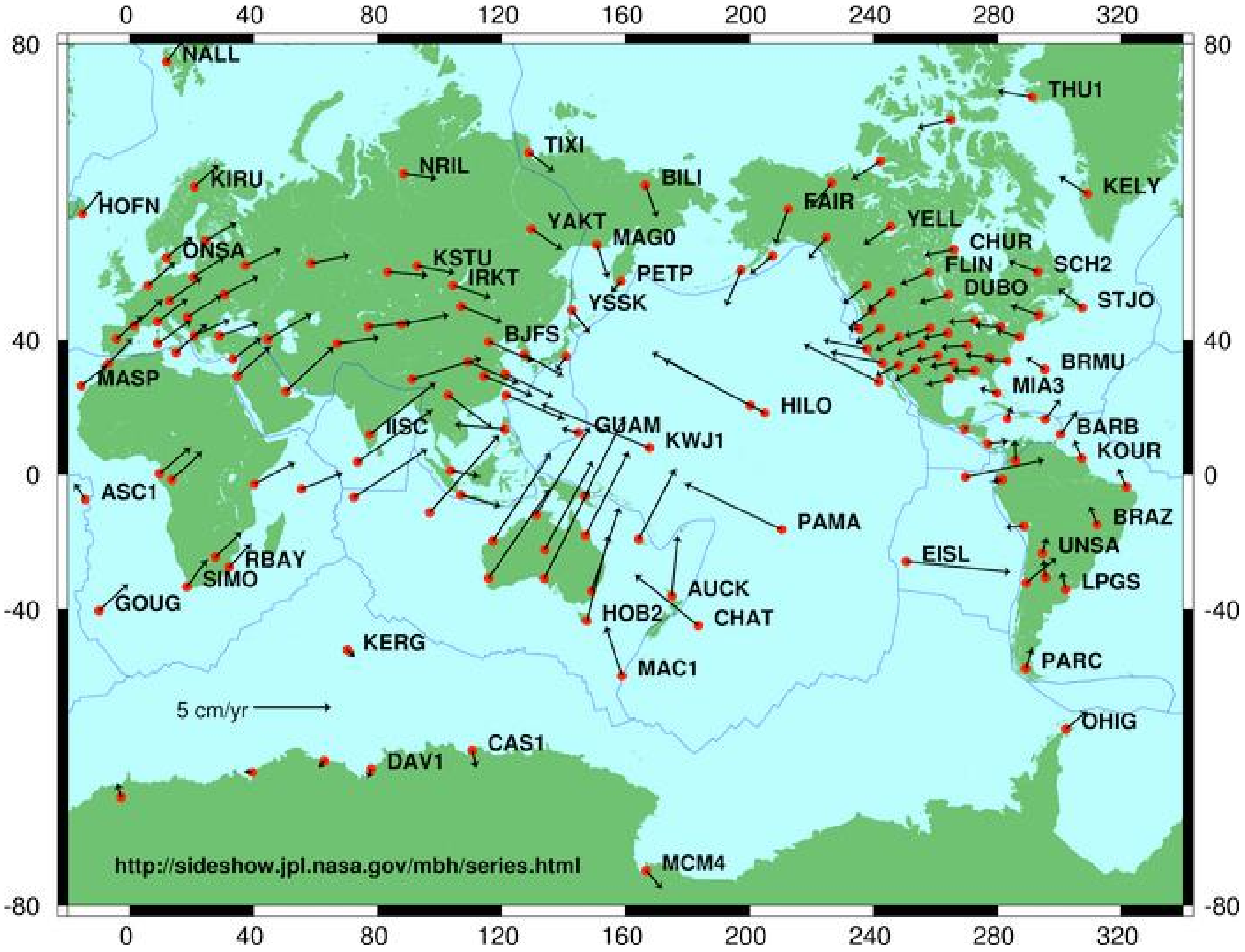
The DoD controls GPS. What about Galileo or GLONASS? How much trust do we have in those signals? More data is usually good, but only if it is trustworthy.

Plate Tectonic Motions

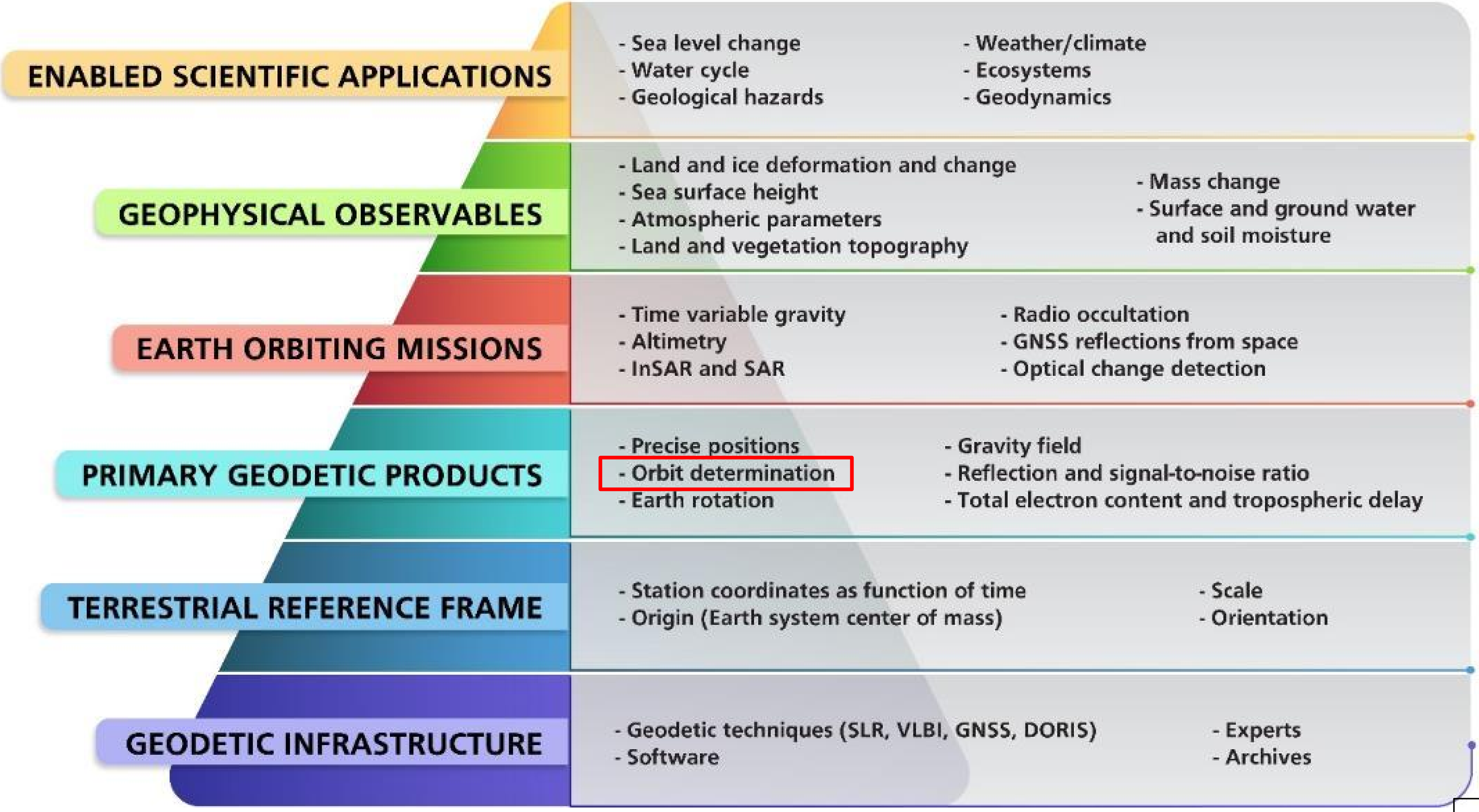
Everything is moving relative to everything else!

These velocity vectors must be understood to keep datums (Lat/Long and elevations) accurate/precise

Locations of any point are time-dependent!



Science Enabled by the Geodetic Infrastructure



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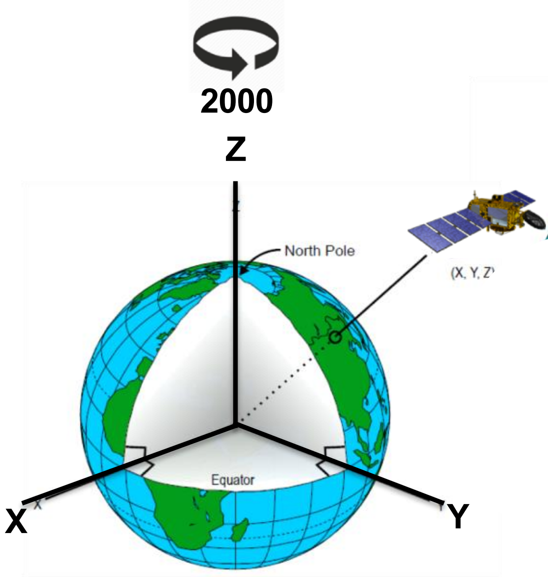
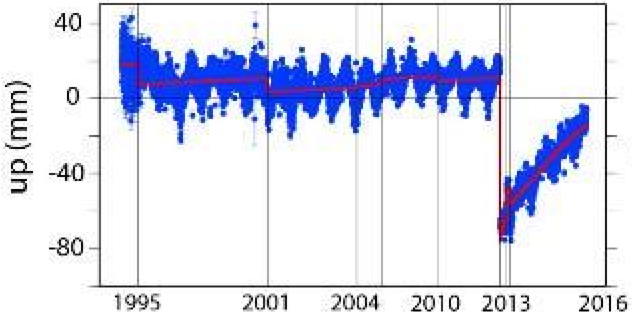
Terrestrial Reference Frame (TRF)



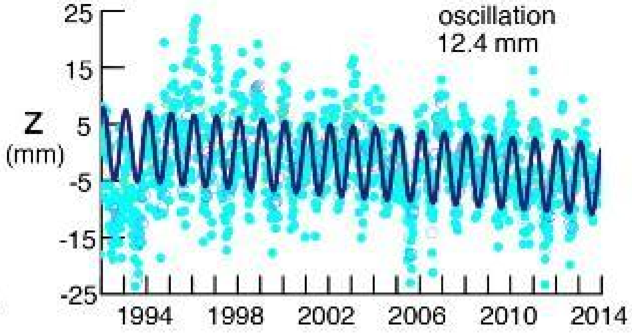
- Origin, orientation, and scale defined by the Geodetic Infrastructure (7-parameters)
- Allows diverse geodetic measurements to be linked over space and time
- Changes over a wide range of time scales as mass is redistributed over Earth's surface

increasing time scale

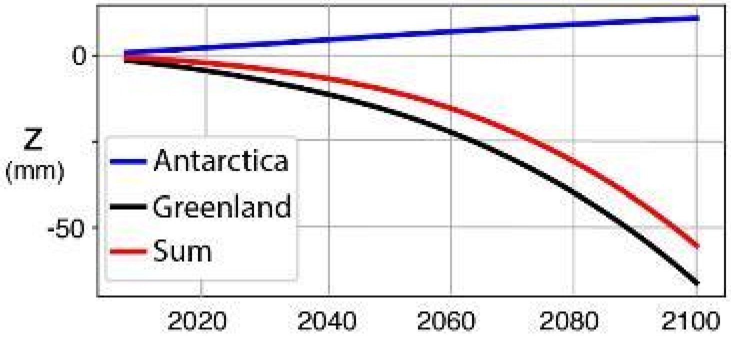
sudden earthquake



annual snow/water



century ice sheet melting



[Altamimi et al., 2016; Argus personal communication; Adhikari et al., 2015]

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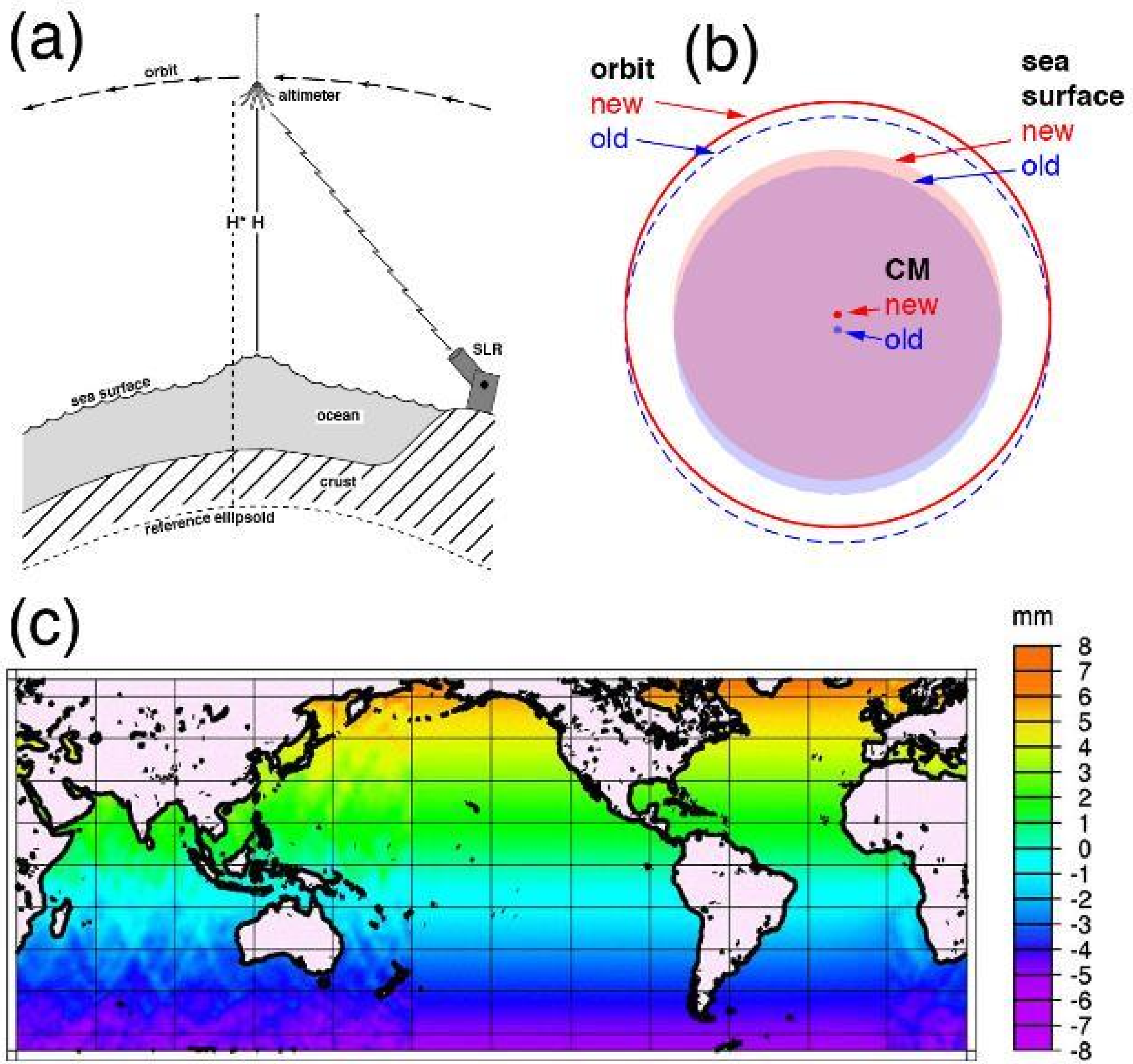
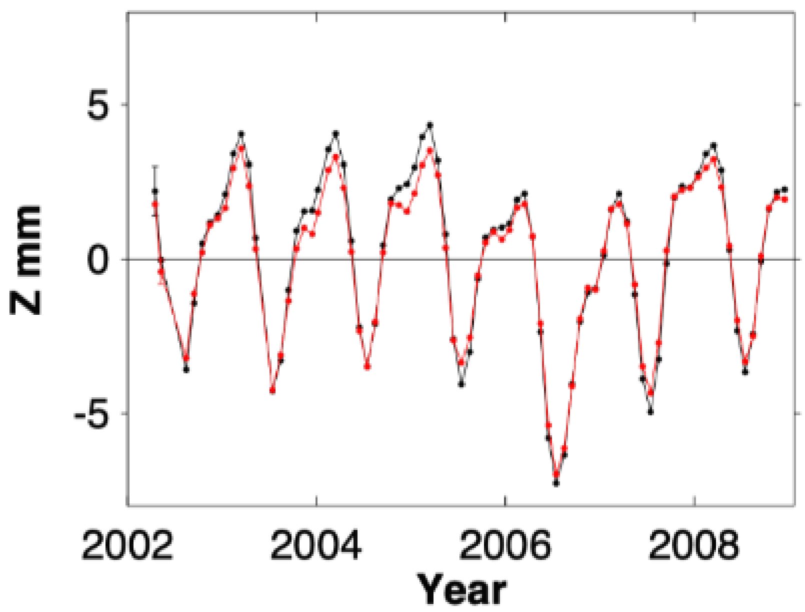
Connection between TRF error and sea level



[Morel and Willis, 2005]



Motion of the CM of the Earth due to seasonal variations in water loading
[Wu et al., AGU 2019]

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Sea-Level Change

Decadal Survey science questions:

C-1. How much will sea level rise, globally and regionally, over the next decade and beyond, and what will be the role of ice sheets and ocean heat storage?

S-3. How will local sea level change along coastlines around the world in the next decade to century?

C-6. Can we significantly improve seasonal to decadal forecasts of societally relevant climate variables?

H-1. How is the water cycle changing? Are changes in evapotranspiration and precipitation accelerating, with greater rates of evapotranspiration and thereby precipitation, and how are these changes expressed in the space-time distribution of rainfall, snowfall, evapotranspiration, and the frequency and magnitude of extremes such as droughts and floods?

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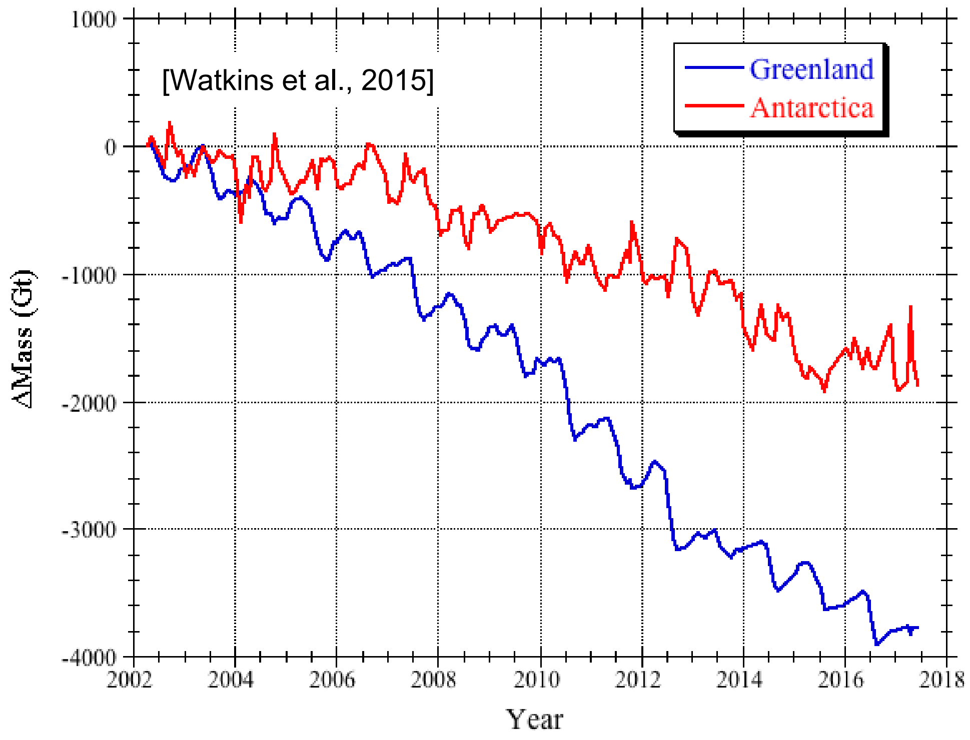
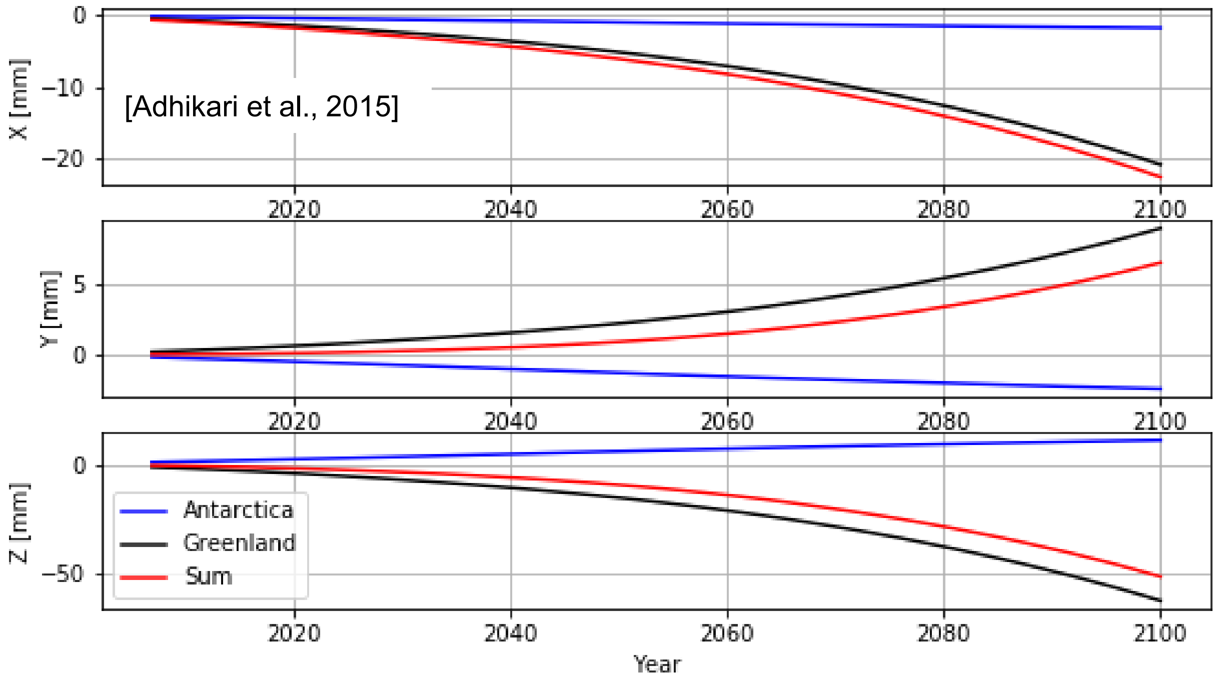
Ice Sheet and Glacier Mass Changes





Ice sheet mass changes require multiple measurements:

- monthly gravity change (e.g., GRACE), GIA correction, ice sheet elevation (e.g., ICESAT-2, CRYOSAT-2), ice stream velocity (i.e., NISAR), visco-elastic rebound (e.g., GNSS)

Mass loss of Greenland and Antarctic ice sheets over the next 100 years will cause large CM motions, so need to maintain absolute accuracy of TRF.

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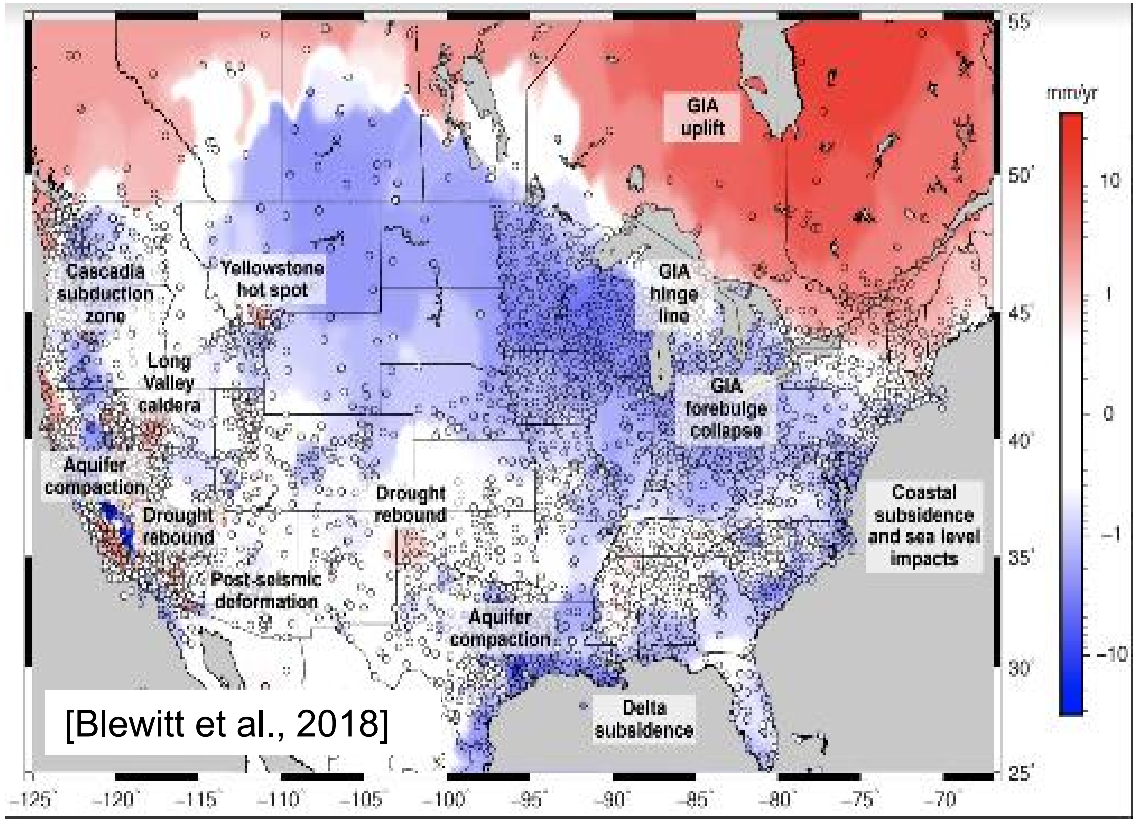
Relative Sea Level and Vertical Land Motion



Relative sea level at coastlines = sea level rise + land subsidence/uplift

Causes of vertical land motion:

- extraction of groundwater or hydrocarbons
- sediment compaction
- glacial rebound
- tectonics

<u>Need</u> long-term stable GNSS sites with 0.5 mm/yr vertical accuracy

NAS 2020

US Workforce - The contrast with China

The Chinese military and defense industries now have access to hundreds of Ph.D. geodesists. In contrast, the number of Ph.D. geodesists in the entire DOD, including the NGA, is now approaching zero. The same is true of the U.S. defense industry.

A competitive advantage in science soon translates into a competitive advantage in technology. For example:

- **China's BeiDou system is at least as good as GPS, and arguably it is significantly better. BeiDou now has more world-wide users than GPS.**
- The geodetic sub-systems that enable China's satellites and space program seem to have reached parity with our own.
- **The near disappearance of American geodesists has led to large numbers of young geospatial engineers who are inadequately trained in the scientific underpinnings of their own discipline*.**

See the white paper for additional examples.

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* In 2019, Trevor Greening, CTO of Towill, Inc., a geospatial engineering company, stated: "we have noted that the rapid development of many new technologies has placed a premium on geodetic science knowledge" but "we see graduates insufficiently skilled to comprehend the basis of the new technology including hardware, software, and procedures".

Bevis et al., 2022

US Workforce - The contrast with China

Academic geodesy programs in the USA are now few, mostly shrinking, and scientifically balkanized*.

The lack of funding for basic research in geodesy has not only lowered the rate of innovation in America's geodetic technologies, it has led to very little graduate training of Americans in geodesy for two decades. America's training capacity in geodesy is now absurdly small compared to that of Germany and China, and it continues its slow collapse.**

If this situation is not reversed very quickly, the US will no longer have the capacity to take corrective action.

---

* In some universities there will be a GNSS geodesy group, in another an InSAR or radar altimetry group, etc. Most isolated groups won't teach geodesy *per se*, but rather their tools applications to other sciences or engineering. OSU seems to be only remaining US geodesy program that researches and teaches courses in every major branch of geodesy.

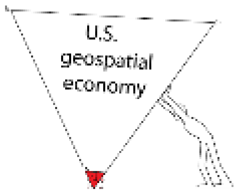
** Juliana Blackwell, the Director of NGS, wrote in 2018
"the reduction in the population of graduate students training in this field is clearly tied to declines in government funding of geodetic research in academia".

Bevis et al., 2022

The Geodesy Crisis Challenge

- What is the crisis? Is there a crisis?
- Why should we care?
- What can we do to right the ship?

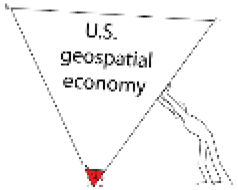
A list of suggestions from the white paper



1. Organize a high-level government review of the geodesy crisis through OST or PCAST, supported by the NAS. Don't delay the following actions until after these reviews are completed.
2. Prevent an imminent loss of academia's capability to train a cadre of new geodesists. Incentivize retiring geodesists.
3. Make the National Geodetic Service (NGS) a line service like the NOS and the NWS.
4. The Office of Geomatics and the Research Directorate at NGA should consider increasing their internal and external funding of geodesy.
5. The military research offices, e.g. AFOSR, ONR, USNO, and DARPA should consider funding geodesy research.
6. The National Science Foundation should develop a funding program in geodesy.
7. The US Geological Survey should support funding to geodesy in areas of interest (e.g. earthquake early warning), and the Dept. of Agriculture and other agencies with geospatial need should do the same.
8. Do everything fast – the U.S. is running out of time for any realistic recovery scenario.

Bevis et al., 2022

Building New Partnerships & Commitments



- NGA is dealing with a lack of geodetic expertise; there are 31 specific products for Precision/Navigation/Targeting and Safety of Navigation missions that have either one or zero staff members with the appropriate expertise.
- New talent **is** coming into the pipeline.
  - NGA is forming an emerging scientist consortium (ESCON) with deep partnerships that exist with Ohio State, UT-Austin and other industry/academic/government partners (including Boeing, USGS, NGS, Oak Ridge National Laboratory and Vricon).
  - A pilot PhD. Geodesy educational program with 3 NGA, 1 NGS employee exists. NGA expects to continue growing this program as there is strong interest. It is possible for federal civil employees beyond NGS to participate.
- NGA's new western headquarters will help bring 350 companies and organizations into a regional GEOINT ecosystem in St. Louis. Moonshot labs, for example, will help enable modernization of geodetic expertise.
- **This is a problem space that will be solved through collaborative effort.**

Building New Partnerships & Commitments

U.S. geospatial economy

Emerging Scientist Program – The Ohio State University

- Pilot program offering distance, virtual learning
- Geodesy, Satellite Geodesy, Photogrammetry, and (*Future*) Space degree and certificate tracks

GEOINT Learning Through Academic Programs (GLAP) Blanket Purchase Agreement

- Partners: Geospatial Intelligence Foundation (USGIF), University of MO – Columbia, and St. Louis University

Education Partnership Agreement (EPA)

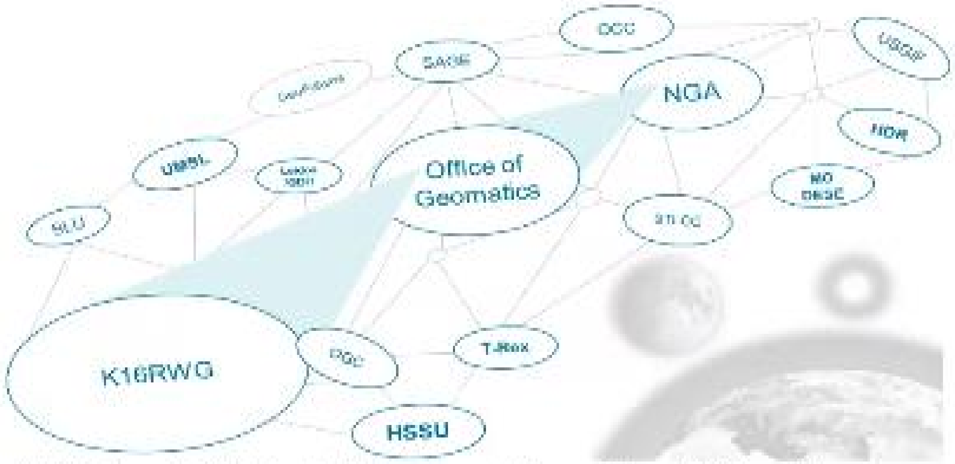
- Harris-Stowe State University (HSSU) / University of Missouri – St. Louis (UMSL)
- Research, Engagement to Student, Better Equipping of K12

St. Louis Area Geospatial Enterprise (SAGE)

- Emerging St. Louis GEOINT Ecosystem
  - Geofutures, TRex, Moonshot Labs
  - Academia, Civic Organizations, State-Local Government

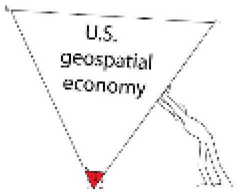
Global Geomagnetic Info (GGI)

- MagQuest Challenge



(U) NGA's Geomatics STEM outreach within the agency, industry, academia, and STL Geospatial ecosystem. (Graphic is U.)

My Perspective



1. **Assuming all the suggestions from the previous slides are acted upon, where are the new crop of geodesists going to come from?**
2. In my mind (and others) the issue runs much deeper than creating opportunities at the top. We need to get children interested in STEM at an early age to prime the pump for needed Earth scientists; geophysicists, mathematicians, electrical engineers, cartographers and people studying and working in the field of geodesy. We need to get kids interested in STEM again and provide growth opportunities for them both in our schools and in careers.
    - Support for our economic “geospatial engine” takes many disciplines working together to build new block satellites, new dynamic datums, new GPS receivers, and so forth.
    - All geospatial disciplines are engaged in geodesy at some level, so pointing the issue solely at geodesy misses the mark a bit.
3. There are career opportunities in the U.S. for geodesy-educated students from other countries, but they are limited by citizenship (ability to work for the federal government).

Questions?

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All Active Sensors Require Precise Orbits

These decadal survey missions would **no longer be useful** if their tracking systems failed.

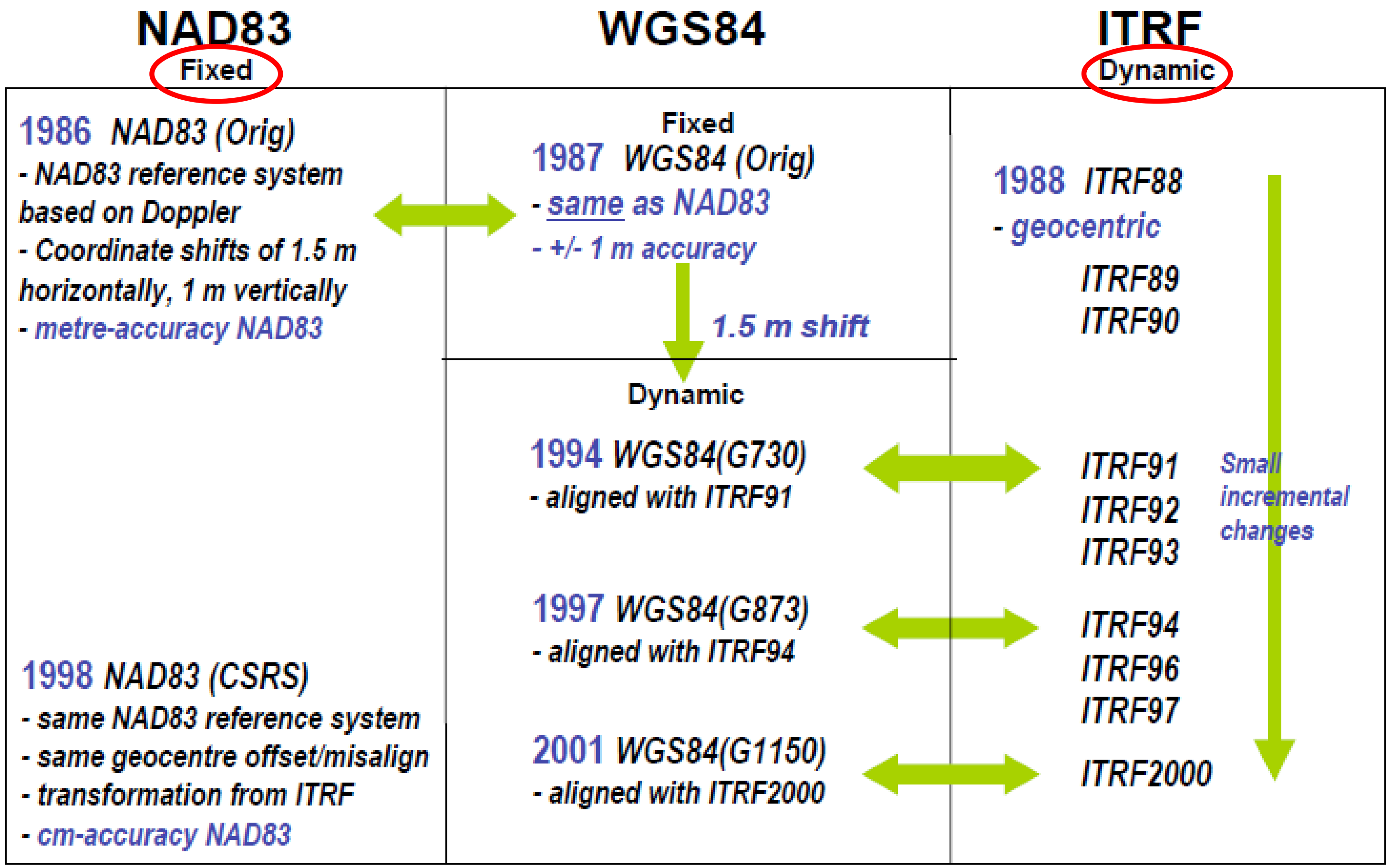
The scientific value of these missions is directly related to the accuracy of their orbits.

SATELLITE	JASON-3	GRACE-FO	ICESAT-2	COSMIC-2	SWOT	NISAR
LAUNCH LIFETIME	2016 5+	2018 5+	2018 3-7	2019 5+	2021 3+	2022 3-10
TRACKING	GNSS, SLR, DORIS	GNSS, SLR	GNSS, SLR	GNSS, SLR, DORIS	GNSS, SLR, DORIS	GNSS, SLR
ACCURACY*	10 mm	< 20 mm	4 mm/yr	20-30 mm	< 30 mm	40–70 mm
PRECISION*	.1 mm/yr	< 2 μm	< 30 mm	< 0.2 mm/s**	2.5 mm	3.5 mm/50km

* Accuracy/precision values are based on actual or projected performance.
**This is really a clock stability requirement. 10^{-12} over 200 seconds.

SLR - Satellite Laser Ranging / DORIS - Doppler Orbitography and Radiopositioning Integrated by Satellite

Datums (likely out of date)



International Terrestrial Reference Frame

Best geocentric system available

- Stable to about a cm
- Maintained by IERS under auspices of IAG
- Primarily for scientific community & national datums

Dynamic system

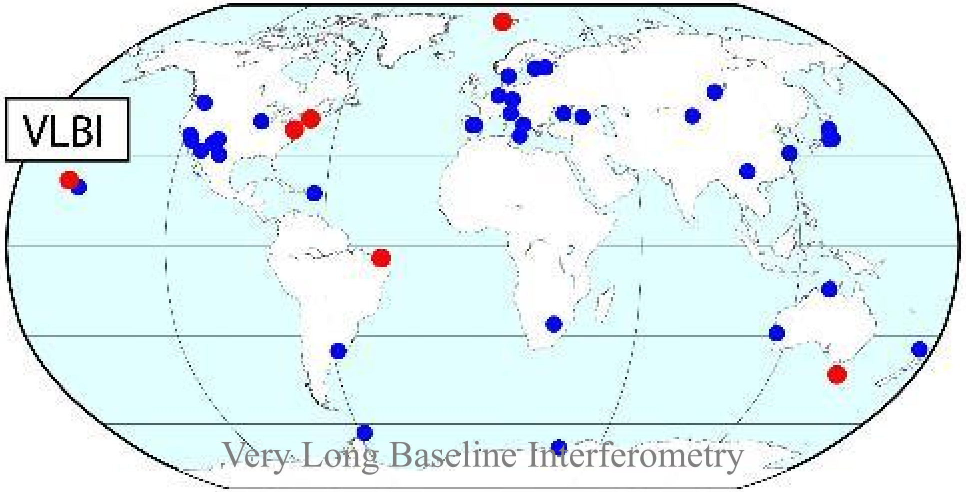
- Coordinates changing due to plate tectonics
- Valid only for a specific date (epoch)
- Velocities provided to update to other epochs

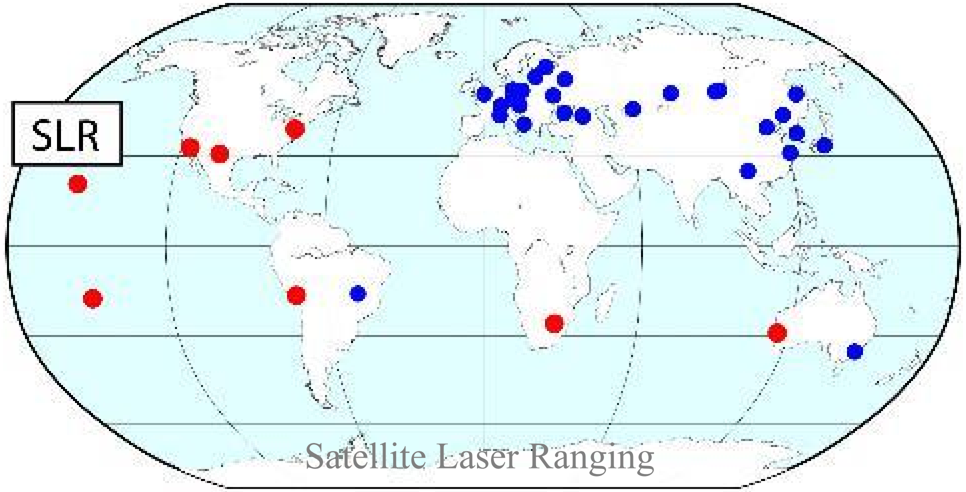
Frequent new realizations

- Due to more data & improved techniques

Current
Geodetic Infrastructure (GI)

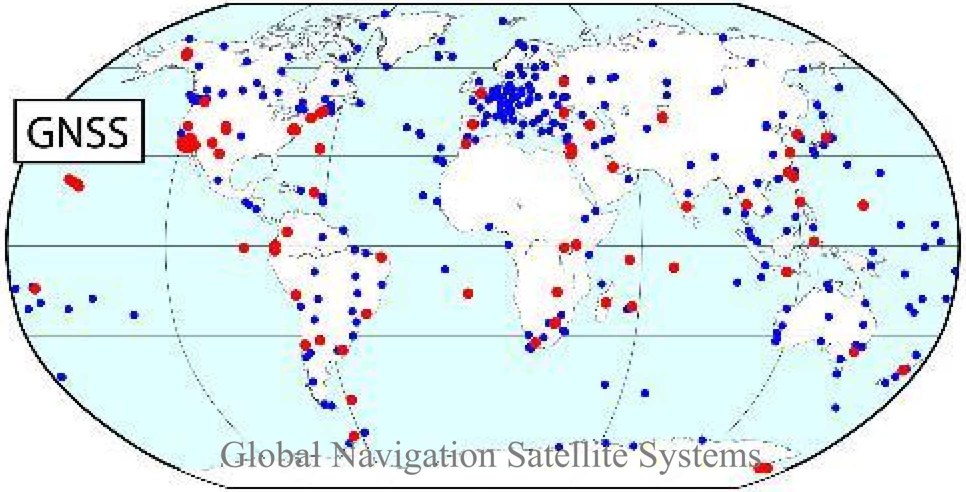
[Frank Lemoine, personal communication;
Carey Noll, personal communication;
https://space-geodesy.nasa.gov]

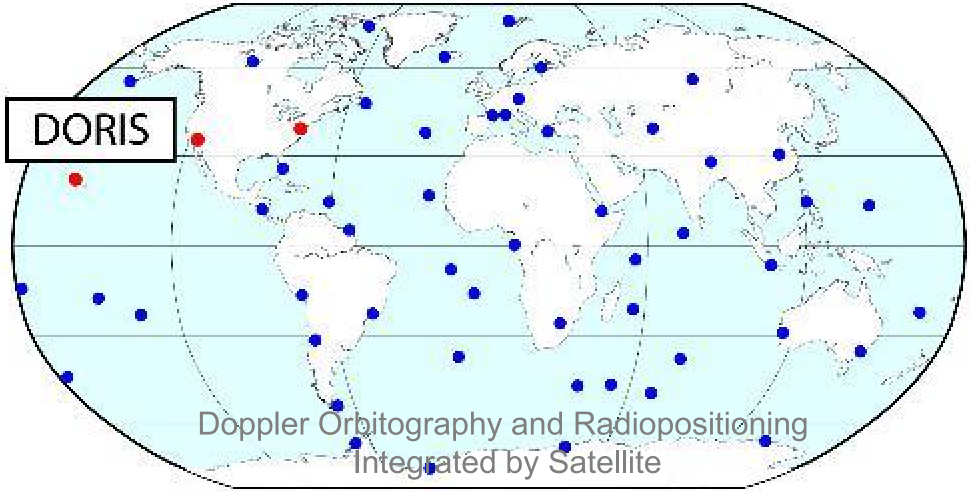




red – NASA, US

blue – International





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Relative Contributions to TRF

[Altamimi, 2016;
Haines et al., 2015,
Argus, personal communication]

technique	VLBI	SLR	GPS
celestial frame (UT1)	**strong**	weak	weak
scale	**strong**	**strong**	medium
geocenter	weak	**strong**	medium
geographic density	weak	weak	**strong**

Need all three systems to define the TRF

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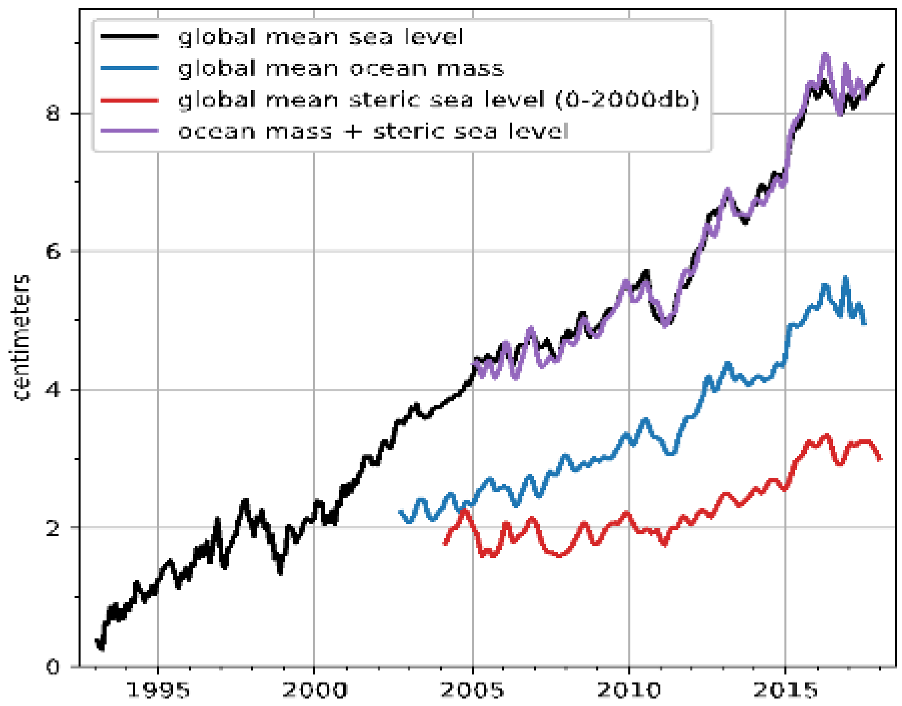
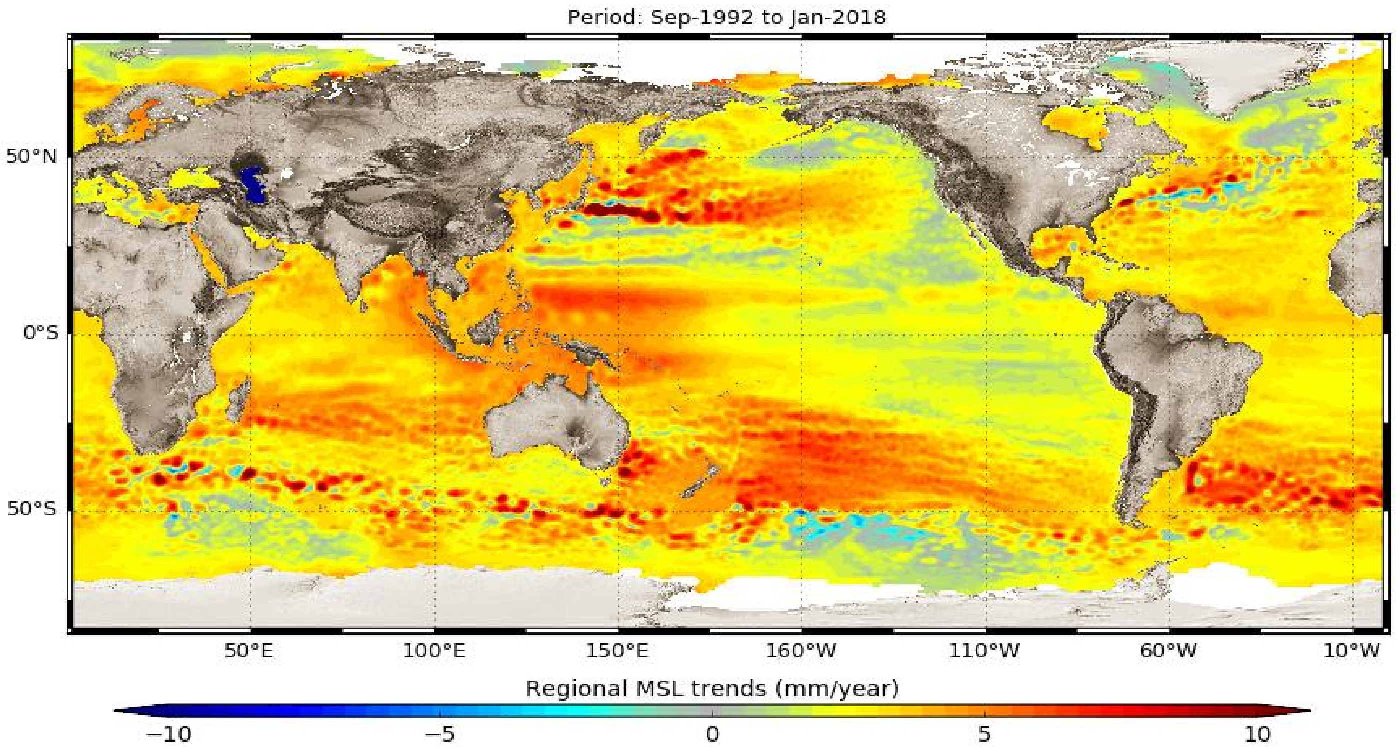
Global and Regional Sea Level Change



[Leuliette and Nerem, 2016]



[Copernicus Marine Environment Monitoring Service]

Absolute sea level measured by temporally overlapping series of satellite altimeters. Tide gauges with GNSS vertical land measurements provide 10-100 year accuracy.

The 2017 Decadal Survey called for determining **global mean sea-level rise to within 0.5 mm/year** over a decade and **regional sea-level change to within 1.5–2.5 mm/year** over a decade.

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Sea-Level Change

MAINTAIN Geodetic Infrastructure

- **Maintain tide gauge record to achieve 0.1 mm/yr averaged over a decade**
- Altimeter orbit determination requirement: 10–20 mm radial position. Ice-sheet flow-rate measurements using InSAR requirement: 3-D better than 0.1 m
- Maintain current accuracy of low degree and order geopotential field
- Maintain and enhance ancillary models and corrections for altimetric satellites

ENHANCE Geodetic Infrastructure

- **Improve TRF accuracy to 1 mm and drift in TRF origin to < 0.1 mm/yr.**
- Improve accuracy of Z-component of the CM. Depends on successful tracking of SLR in southern hemisphere
- Install GNSS stations at tide gauges to achieve absolute vertical land motion requirement of better than 0.5 mm/yr.
- Encourage use of GNSS reflectometry to expand number of worldwide tide gauges defined in the ITRF

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Weather and Climate

MAINTAIN Geodetic Infrastructure

- Maintain robust global distribution of GNSS stations providing free, open, and near-real-time raw observational data
- Support IGS analysis products, including accurate orbits and clocks
- Maintain geodetic expertise for institutional knowledge and availability of trained personnel

ENHANCE Geodetic Infrastructure

- **Upgrade global IGS sites to achieve GPS-like accuracies for other constellations (e.g., Galileo).** Would dramatically increase number of radio occultations for weather and climate applications
- Improve modeling of GNSS observables, including attitude information, satellite metadata and radiation force models.

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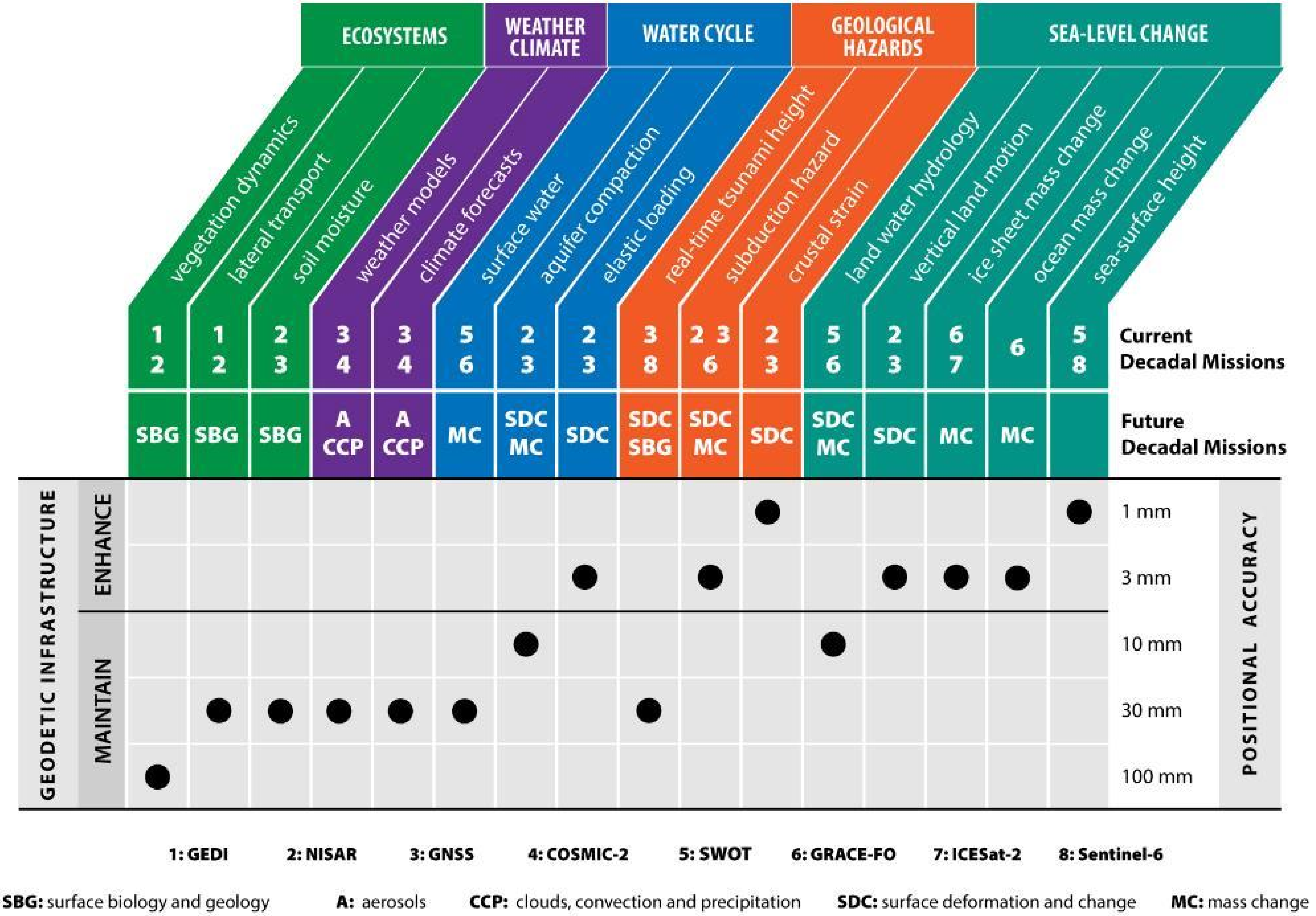
ECOSYSTEMS
WEATHER CLIMATE
WATER CYCLE
GEOLOGICAL HAZARDS
SEA-LEVEL CHANGE
vegetation dynamics
lateral transport
soil moisture
weather models
climate forecasts
surface water
aquifer compaction
elastic loading
real-time tsunami height
subduction hazard
crustal strain
land water hydrology
vertical land motion
ice sheet mass change
ocean mass change
sea-surface height
Current Decadal Missions
Future Decadal Missions
SBG
A CCP
MC
SDC MC
SDC
SDC SBG
GEODETIC INFRASTRUCTURE
ENHANCE
MAINTAIN
1 mm
3 mm
10 mm
30 mm
100 mm
POSITIONAL ACCURACY
1: GEDI
2: NISAR
3: GNSS
4: COSMIC-2
5: SWOT
6: GRACE-FO
7: ICESat-2
8: Sentinel-6
SBG: surface biology and geology
A: aerosols
CCP: clouds, convection and precipitation
SDC: surface deformation and change
MC: mass change

NAS 2020