Providing a Stable Reference Frame for Observing the Effect of Global Climate Change on Sea Level

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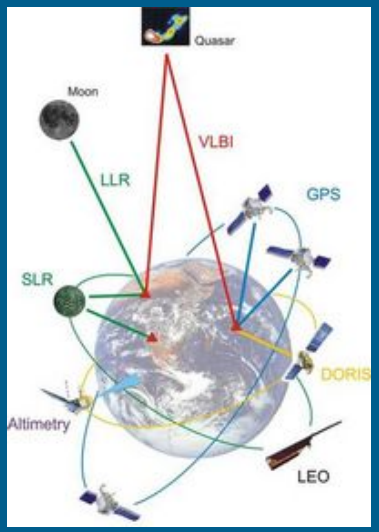

with thanks to co-authors of WCRP workshop

"Understanding Sea-Level Rise and Variability"

J. Davis, R. Gross, C. Kuo,
F. Lemoine, R.Neilan, H.-P. Plag,
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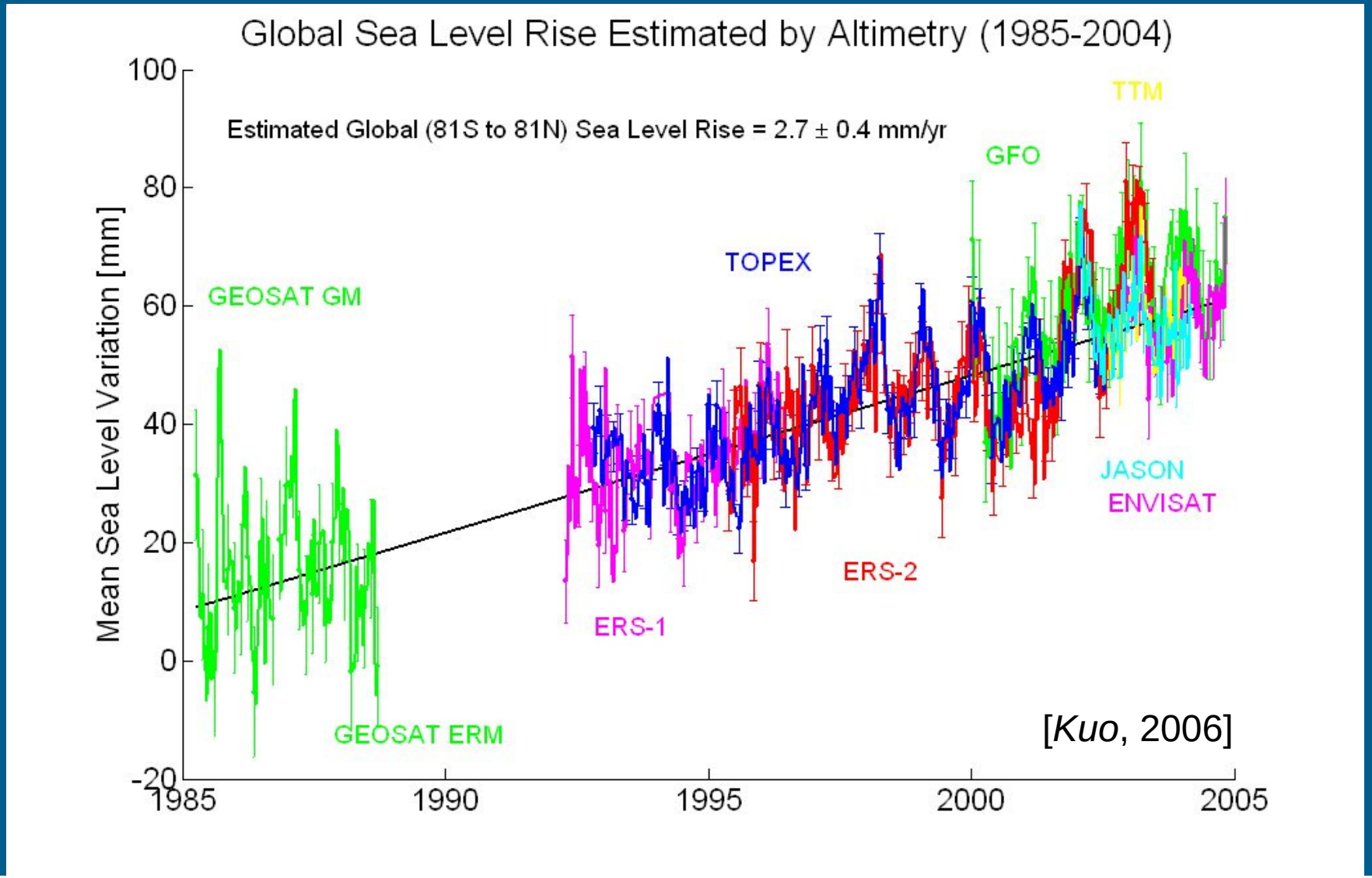
Overview

- Relevance of reference frames to sea level change
- Defining a reference system and reference frame
- Geodetic techniques for realizing the International Terrestrial Reference Frame (ITRF)
- Errors related to reference systems and their effects
- Challenges and future requirements
- Recommendations

Relevance of Reference Frames to Sea Level Change



Relevance of Reference Frames to Sea Level Change

- **Terrestrial Reference Frames**
  - **One of the biggest sources of error in quantifying long-term variation in sea level**
  - **2 mm/yr origin error (Earth center of mass)**
    - ⇨ **0.4 mm/yr in global sea level from satellite altimetry**
  - **0.1 ppb/yr (10^{-10}/yr) scale error**
    - ⇨ **0.6 mm/yr global sea level rate**
- **Frame-related errors are <u>comparable</u> in magnitude to individual physical contributions**
  - **Glaciers, Greenland, Antarctic, thermal expansion, ...**

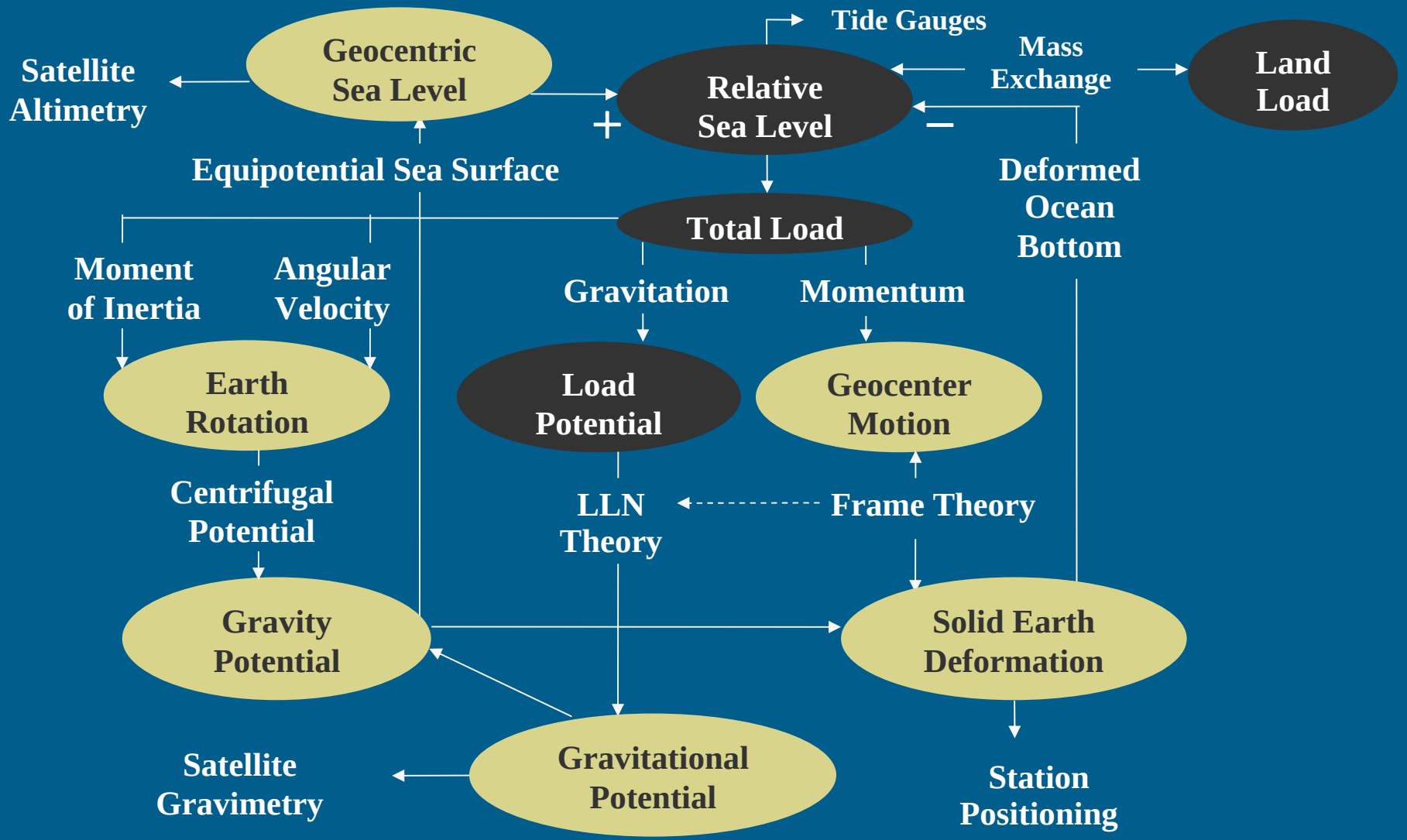
Relevance of Reference Frames to Sea Level Change

- **Need to tie sets of observations in a consistent model**
- **(1) Sea level from satellite altimetry**
  - **Sea surface in the frame of the satellite orbits**
  - **Reference system needed for consistency over decades**
  - **TRS origin = Earth center of mass ⇨ "Geocentric sea level"**
    - **not directly related to impacts**
    - **not directly related to ocean volume**
- **(2) Relative Sea Level = Sea Surface – Ocean Bottom**
  - **RSL directly relates to coastal impacts and to ocean volume**
  - **RSL can be related to observations that are tied within a TRS**

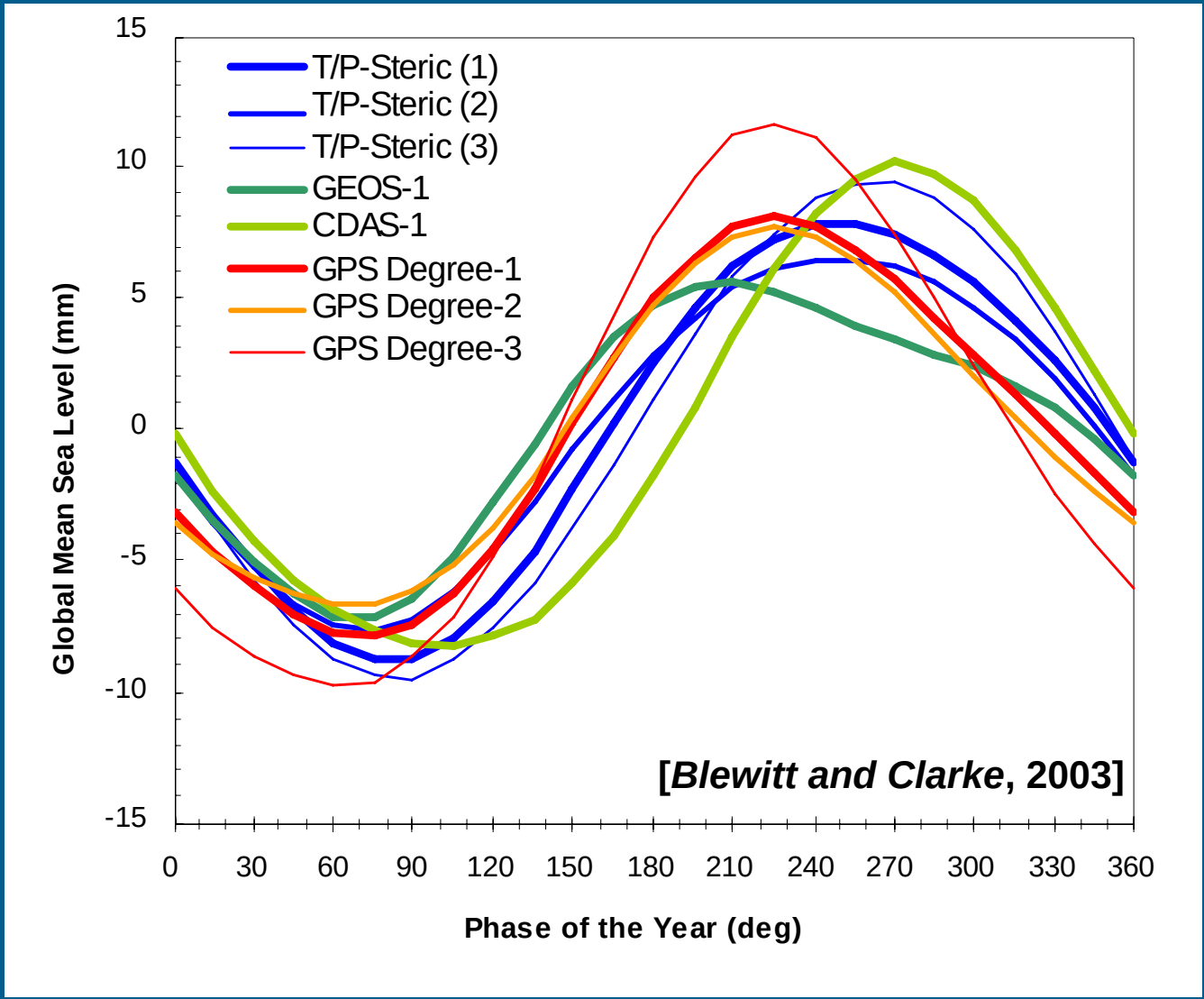
Static sea surface (t)	**⇦ Earth's gravitational shape (t)**
Ocean bottom (t)	**⇦ Earth's geometrical shape (t)**

    - **surface loading theory, sea-level equation, mass conservation**

A Geodesist's View of Sea Level



Example: Seasonal Variation in Global Sea Level from Earth's Shape



Defining a Reference System and Reference Frames

- **Three conceptual levels [*Kovalevsky et al*., 1989]:**
  - **Ideal Terrestrial Reference System (TRS) is a mathematical, theoretical system**
  - **The Conventional TRS is the sum of all conventions (models, constants,...) that are necessary to realize the TRS**
  - **A Conventional TRF, which uses above to realize the TRS.**
- **In effect:**
  - **The TRS is an ideal, conventional model**
  - **The TRF is a list of station coordinates and velocities based on space geodetic observations**
  - **The "meaning" of coordinates and velocities should only be taken within the context of the conventional TRS**

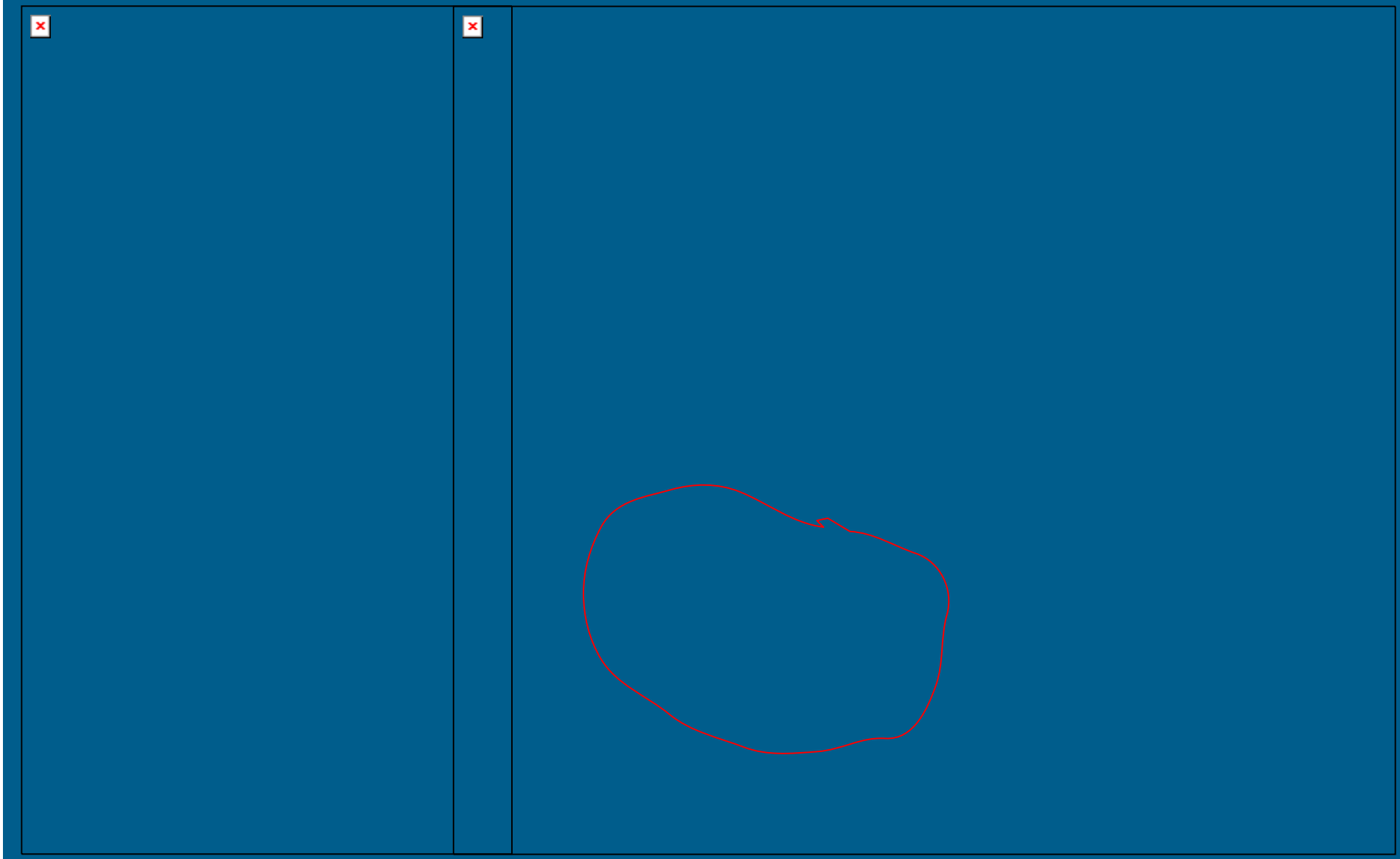
Geodetic Techniques for Realizing ITRF

- **Mix of techniques is necessary to realize a frame that is stable in origin, scale, and with sufficient coverage**
  - **VLBI**
  - **SLR**
  - **GNSS (GPS,....)**
  - **DORIS**
- **Also important to understand biases and so improve the frame**
- **Requires links between techniques**

Technique Signal Source Obs. Type	VLBI Microwave Quasars Time difference	SLR Optical Satellite Two-way absolute range	GPS Microwave Satellites Range change
Celestial Frame UT1	**Yes**	No	No
Polar Motion	**Yes**	**Yes**	**Yes**
Scale	**Yes**	**Yes**	Yes
Geocenter	No	**Yes**	Yes
Geographic Density	No	No	**Yes**
Real-time	Yes	Yes	**Yes**
Decadal Stability	**Yes**	**Yes**	Yes

From Ries et al., 2005, presented at NASA Sea Level Workshop

Errors Related to Reference Frames



Errors Related to Reference Systems and their Effects (1)

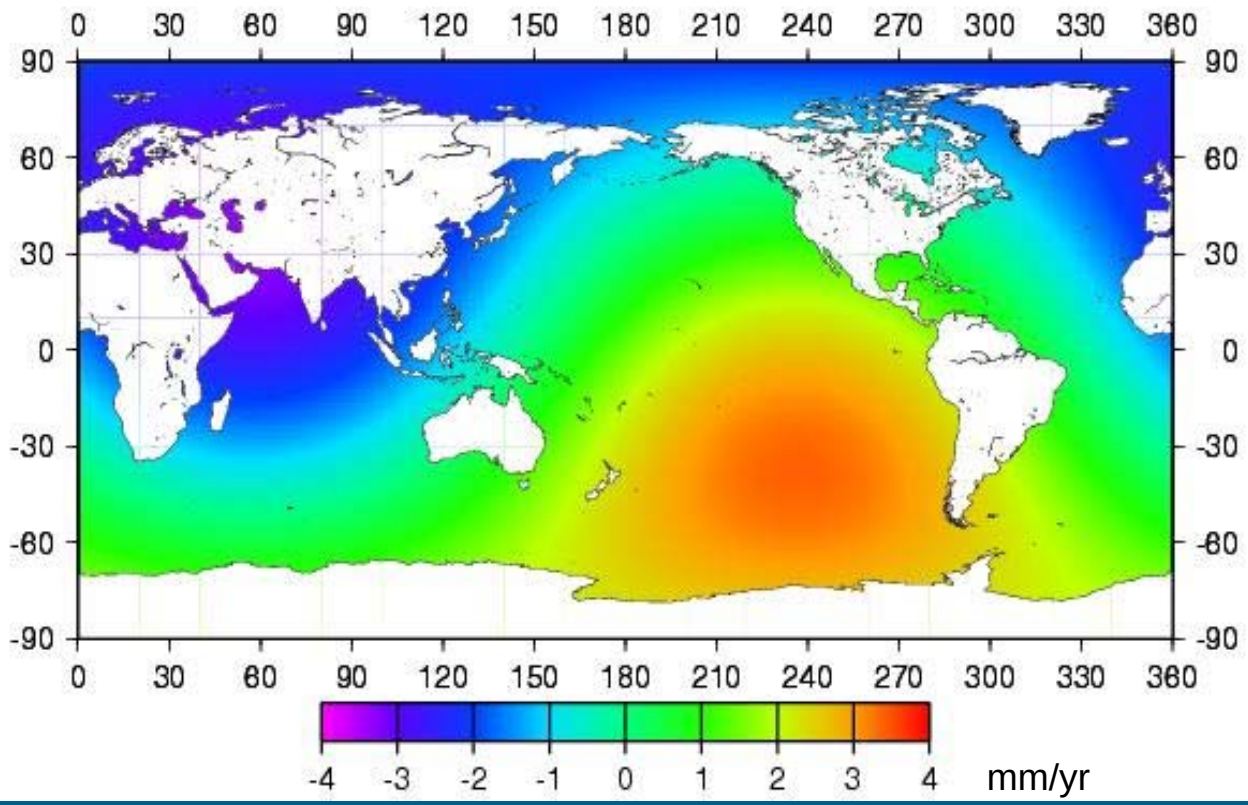
- **Hierarchy of Errors**
  - **Model error in the reference system conventions**
    - **Station motion model, gravity field, etc.**
  - **External error in alignment of the reference frame**
    - **Origin, scale and orientation, and their stability in time**
  - **Internal error in coordinates of stations within the frame**
    - **Stations used for relative positioning of user's station**
- **All above is in addition to user's observational errors**

Errors Related to Reference Systems and their Effects (2)

- **Errors in TRS conventions map into**
  - **Errors in station positions and satellite orbits**
  - **Errors in sea surface, gravity, Earth surface geometry**
- **Errors in origin and scale map into**
  - **Errors in geocentric sea level**
- **Errors in TRF station coordinates map into**
  - **Errors in motion of tide gauges**
  - **Errors in altimeter bias calibration**
- **As conventions and frames are updated, so do the <u>entire</u> position time series, hence interpretation**
  - **Unlike tide gauge data, cannot simply “archive” positions**

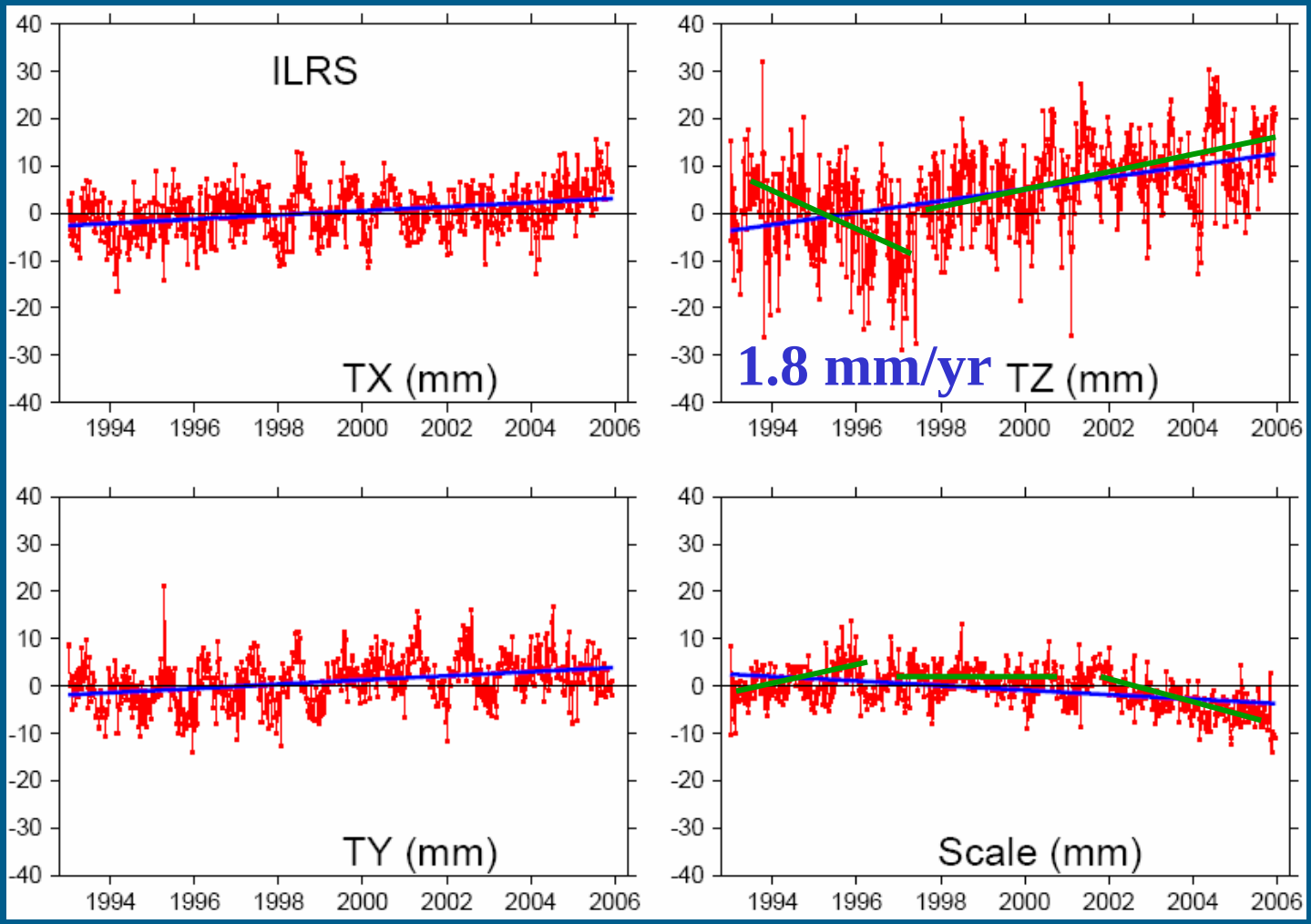
Example: Effect of Origin Translation

[*Plag*, 2006, *Kierulf and Plag* 2006]



- **(IGS – ITRF2000) origin rate:** **v = (–1.5, –2.2, –2.1) mm/yr**
  - **Effect on T/P sea level trend = $-0.09389v_x - 0.04847v_y - 0.11536v_z$**
  - **local = 3 mm/yr; global mean = 0.4 mm/yr, T/P mean = 0.5 mm/yr**

SLR Origin & Scale Variation (wrt ITRF2000)



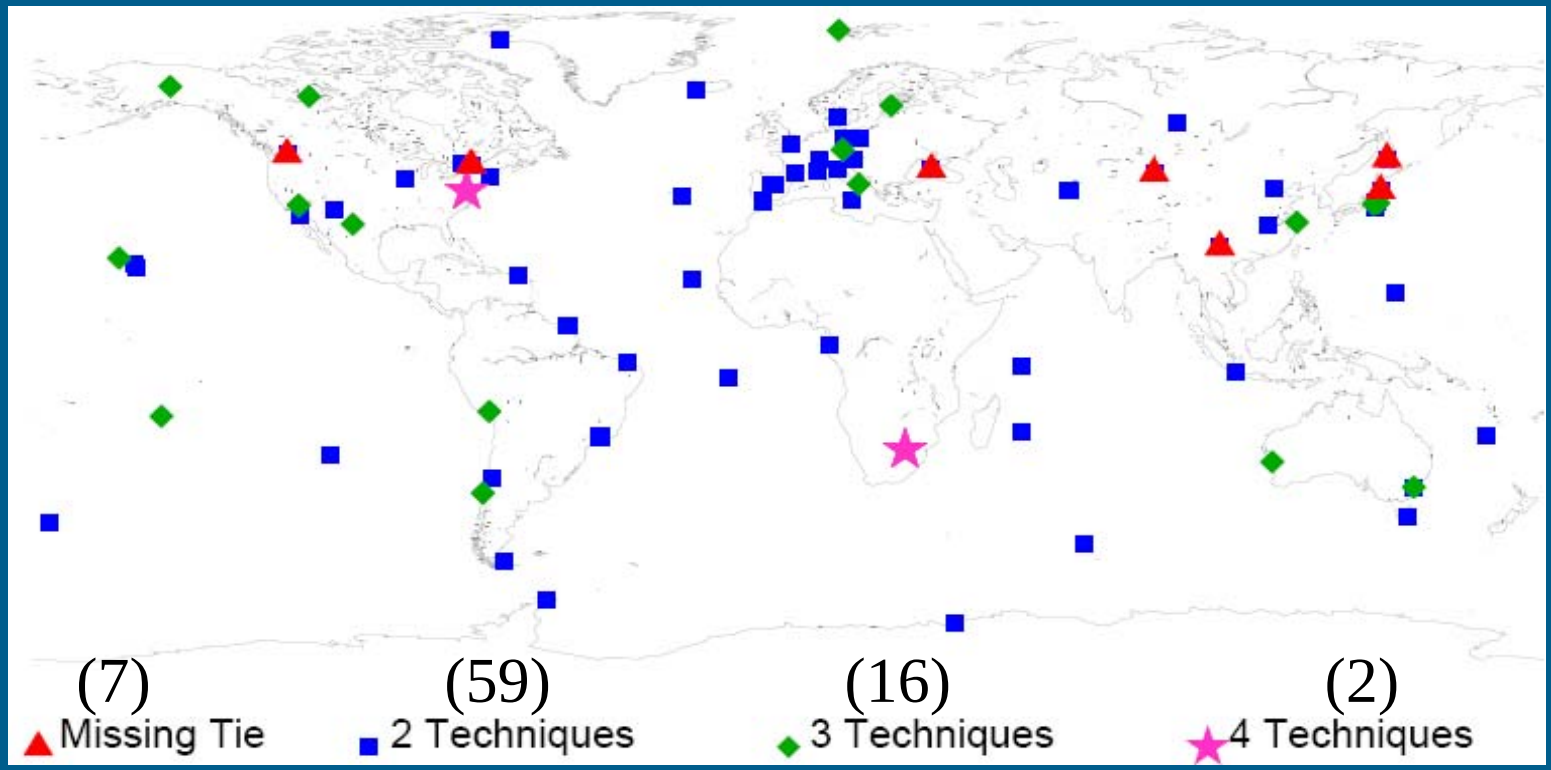
Impact of the Z-translation drift between ITRF2005 & ITRF2000: 1.8 mm/yr

- **Vertical velocity change by** ***1.8 sin(φ) mm/yr***
  - **Zero at the equator and +1.8, -1.8 mm/yr at north and south poles, respectively (PGR/GIA?)**
- **North velocity change by** ***1.8 cos(φ) mm/yr***
  - ***1.8 mm/yr at the equator and zero at north and south poles, respectively***

Challenges and Future Requirements

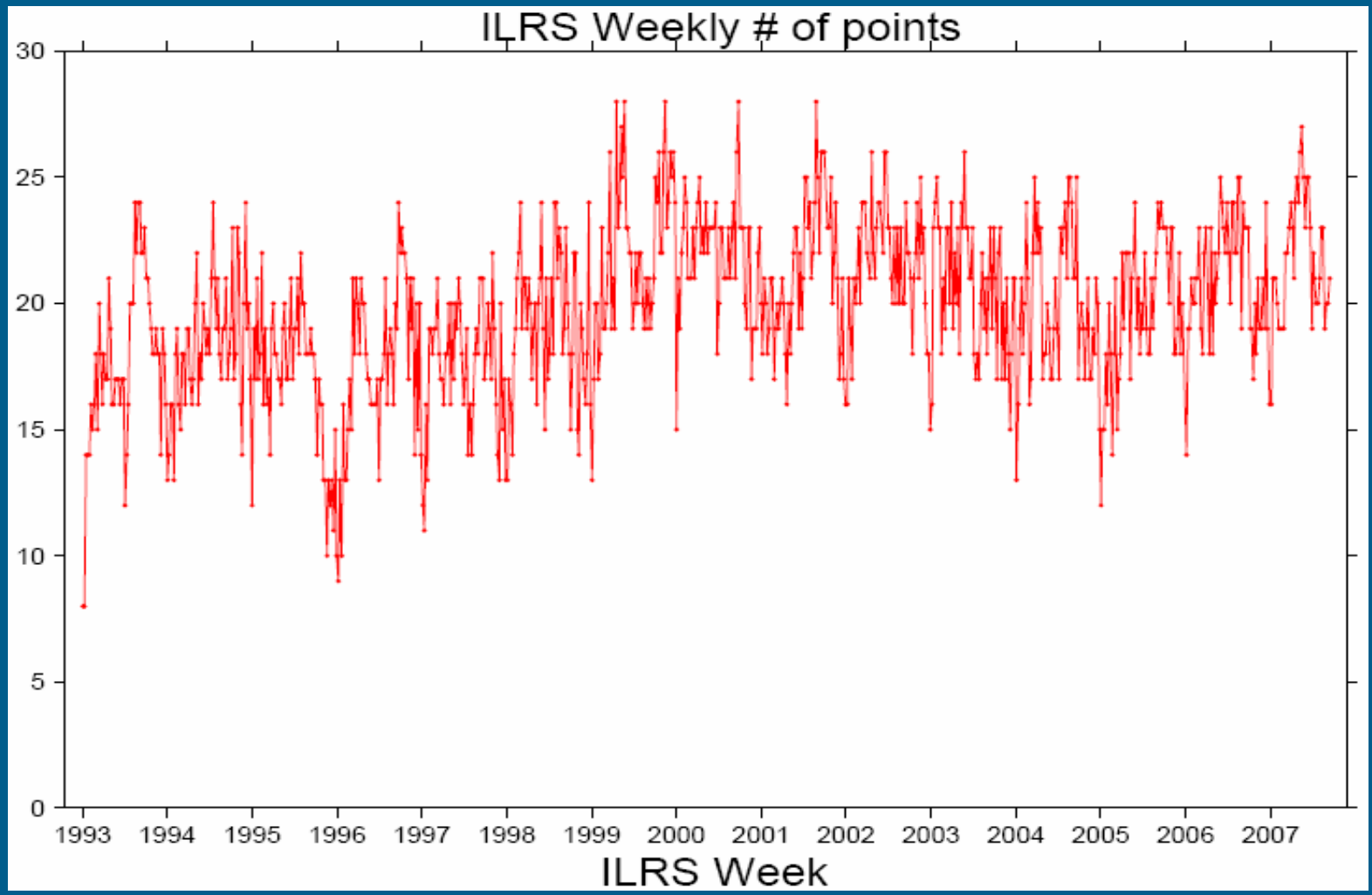
- **ITRF needs to be made more robust and stable**
  - **Current accuracy: 1–2 mm/yr origin, 0.1 ppb/yr scale**
  - **Target accuracy: 0.1 mm/yr origin, 0.01 ppb/yr scale**
- **Global sea level monitoring critically depends on:**
  - **GNSS to locate satellites and Earth's surface (tide gauges)**
  - **SLR to realize the origin as the Earth center of mass**
  - **VLBI and SLR to realize a stable scale**
  - **Control of biases in geodetic systems**
- **Threats?**

Threats: ITRF on “shaky ground”:
current collocations

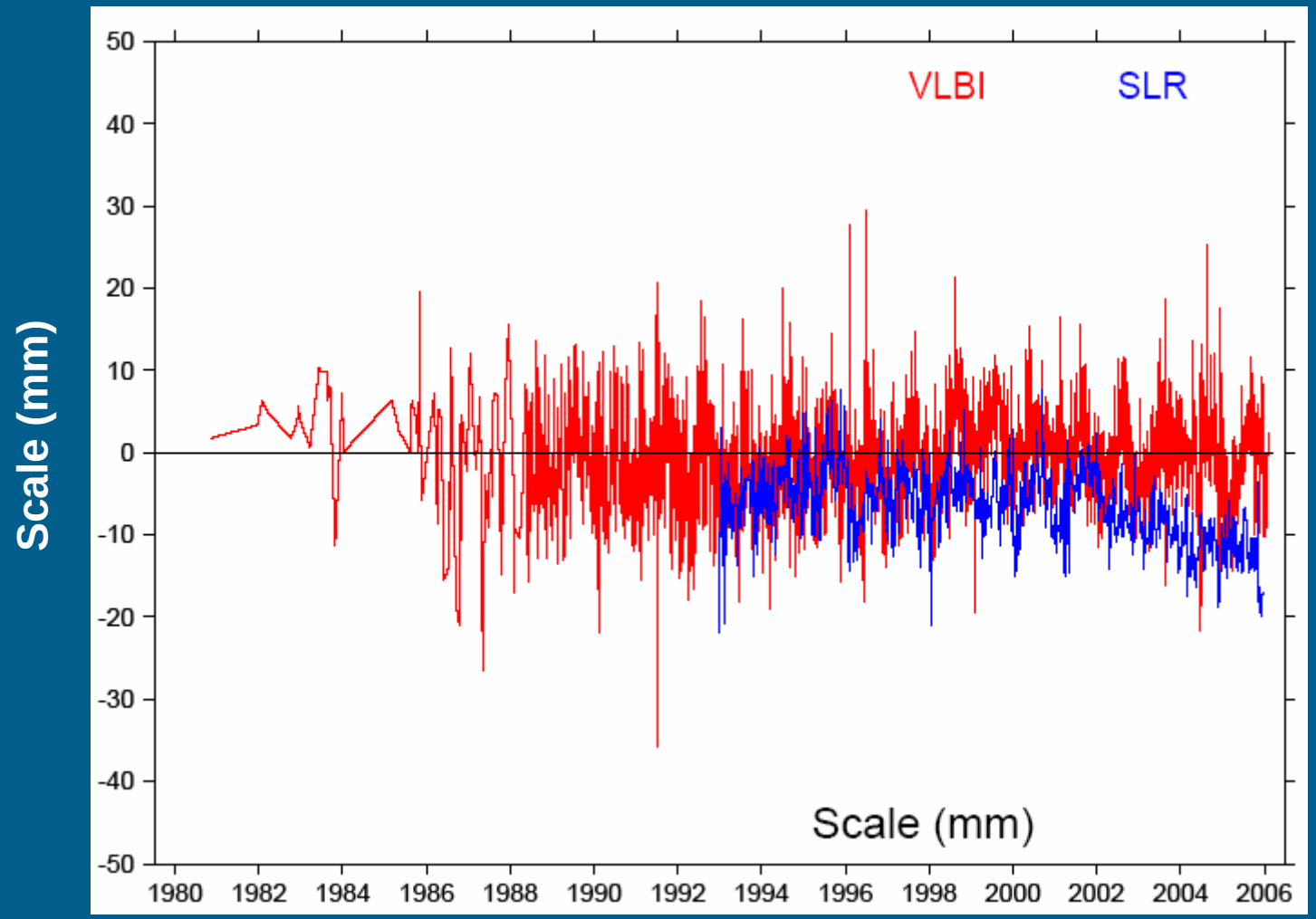


- Ties between SLR-VLBI-GNSS are weakening in time
- Uneven station distribution leads to biases
- No long-term systematic commitment to support ITRF

ILRS Network

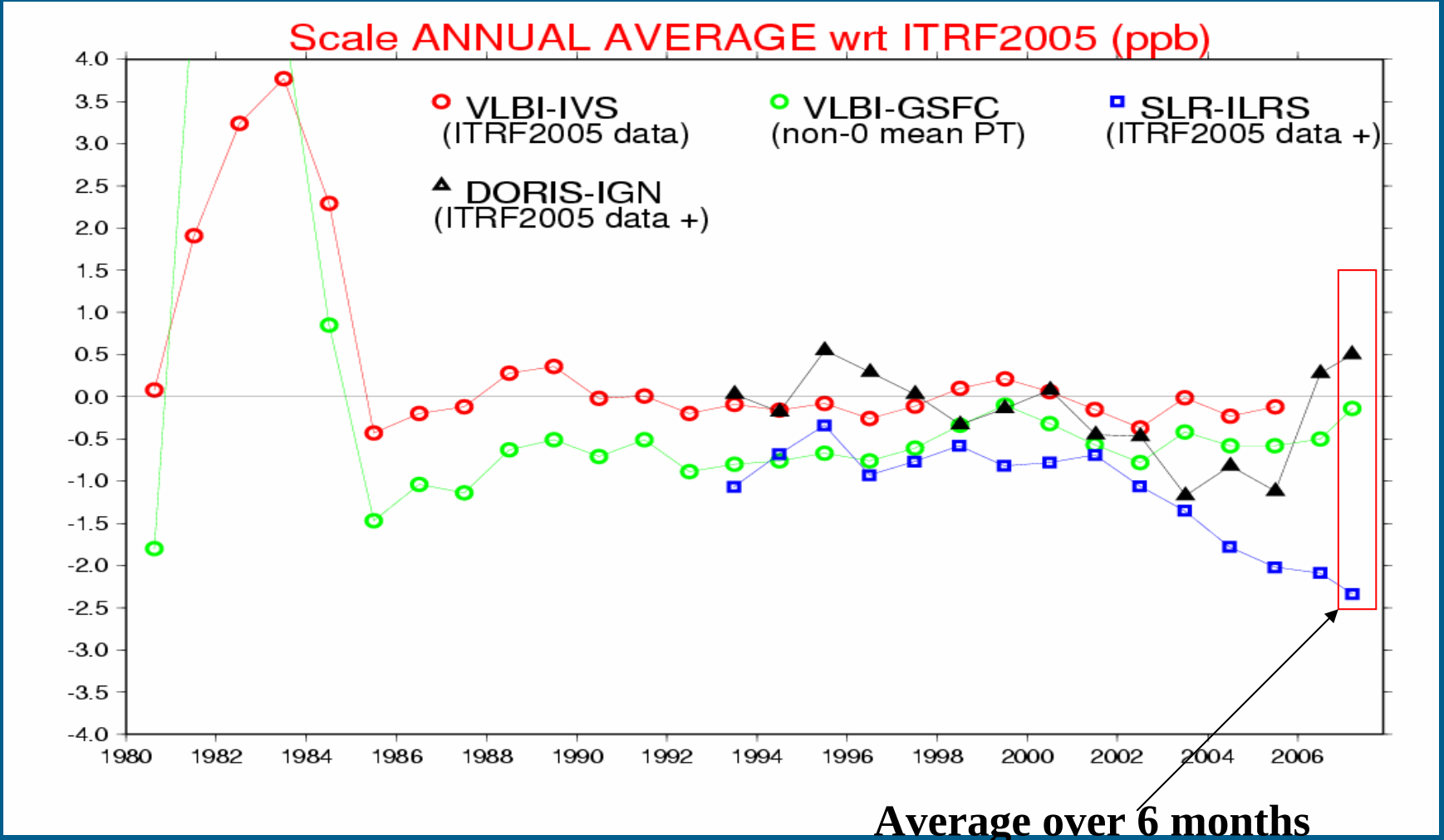


Threats: VLBI vs SLR Scale wrt ITRF2005



Post ITRF2005 Analysis

Scale Annual Average



Recommendations

- **Strengthen ITRF: Make more robust and stable**
  - **Research to realize 0.1 mm/yr origin and 0.01 ppb/yr stability**
  - **Strengthen geodetic infrastructure to realize the same**
  - **Improve network design (distribution and collocation)**
  - **Support GGOS as the paradigm for geodetic integration**
- **Continue overlapping altimetric missions indefinitely**
  - **Monitoring of biases to ensure long-term consistency**
- **Establish long-term commitment to ITRF**
  - **Reference frames need international recognition as being fundamental to many aspects of Earth observations, including sea level monitoring**