2018 Baarda Lecture

Geodesy and Society: Applications in Natural Hazards, Climate Change, and Autonomous Vehicles Research

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Baarda, W. (1968) A testing procedure for use in geodetic networks.

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“What is the purpose…of geodetic networks in society? How should the requirements… be quantified?”

What can Geodesy do in a period of rapid human-induced climate change?

> Measure rates of processes
> Improve understanding => improve mitigation strategies
> Help the public to visualize the problem

The Netherlands is not the only country that has to worry about sea level rise and flooding

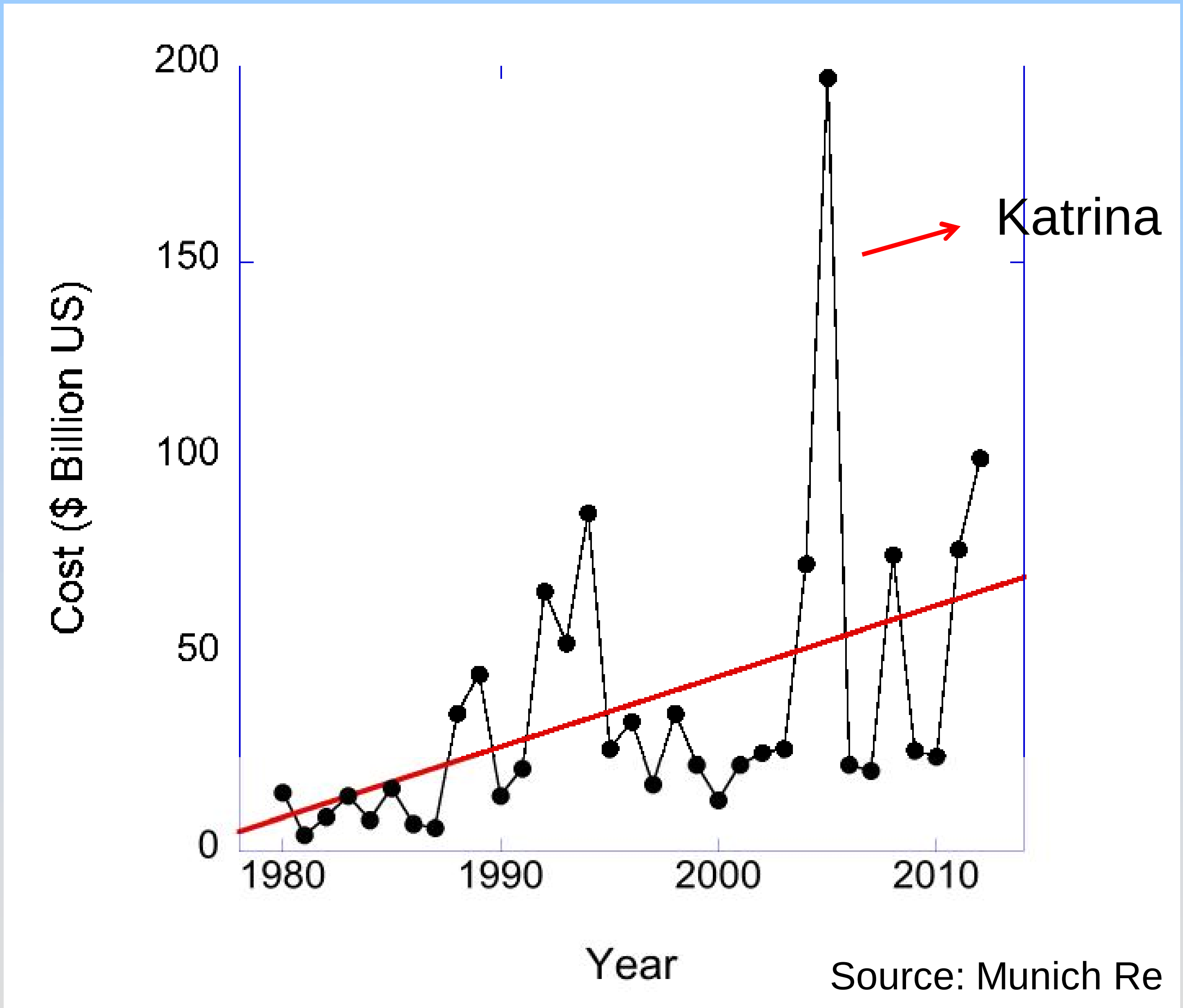
Hurricane Sandy (2012, ~$50 B in losses)

Hurricane Katrina (2005, ~$200 B in losses)

Harvey & Irma (2017, ~$75 B in losses,

Natural Disasters, Cost vs Time

US only, insured + uninsured

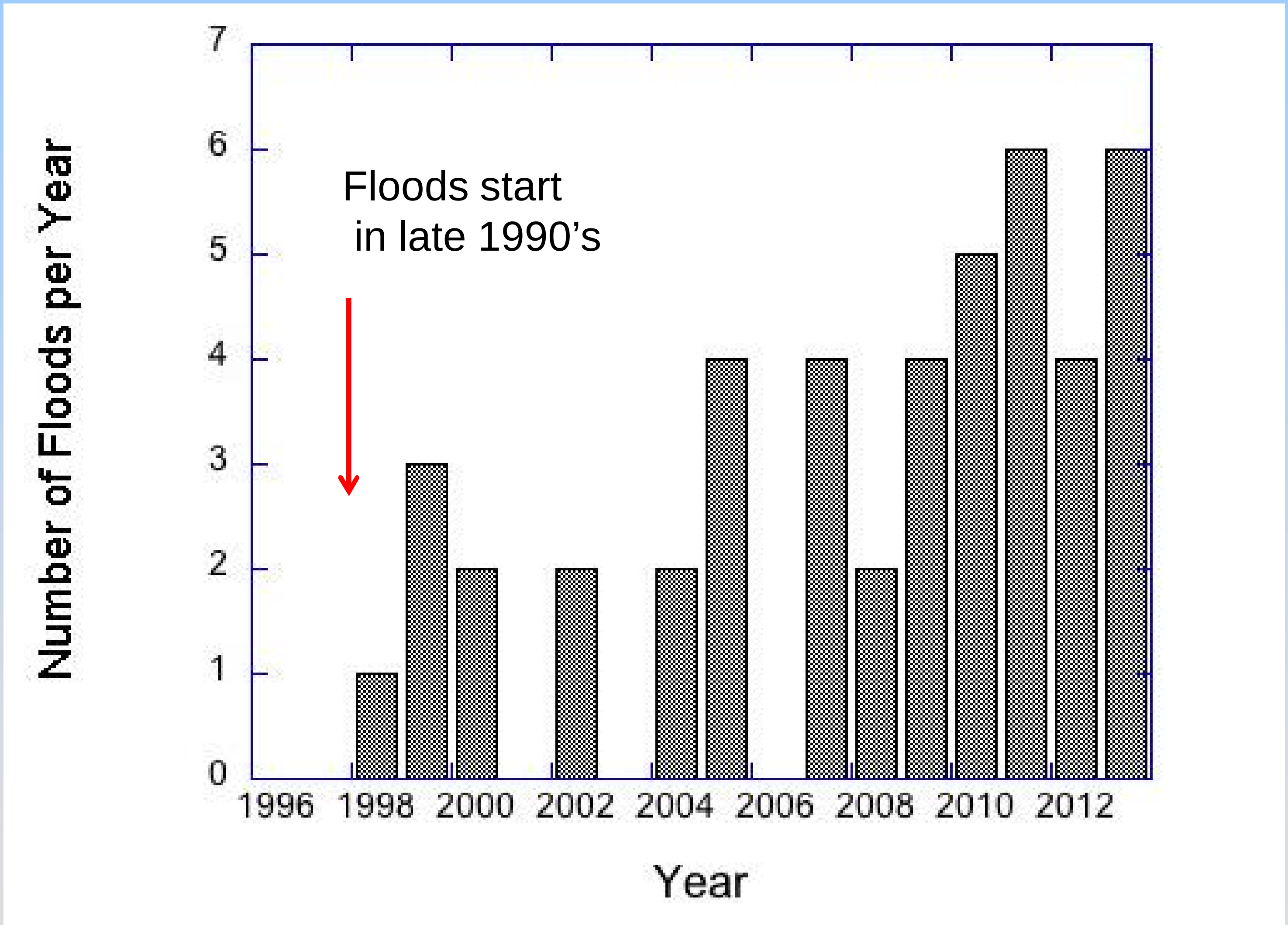


"Sunny-day" or "nuisance" flooding in Miami Beach

Not considered a disaster, but has costs, and shows future flood potential from SLR

Because of its low elevation, Florida is "ground zero" for problems related to sea level rise

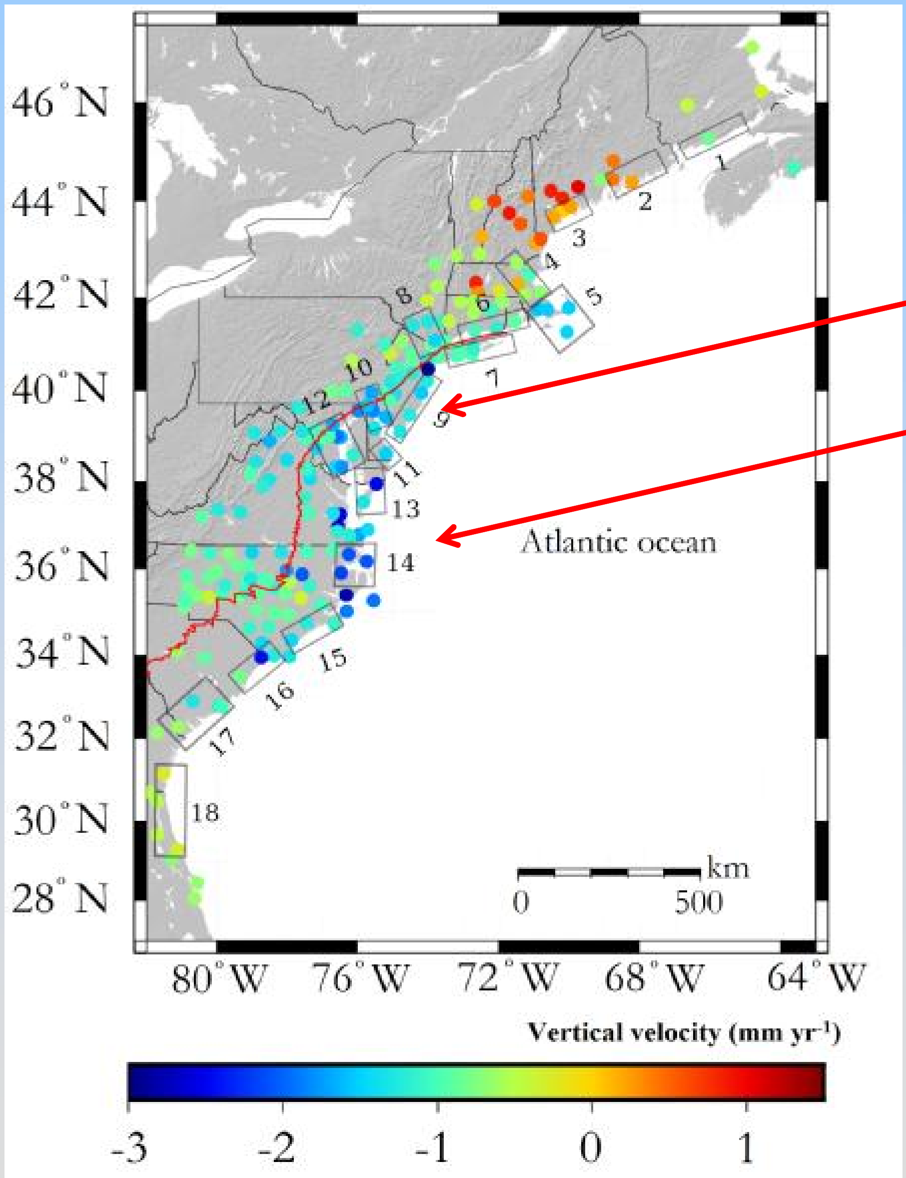
*Local Rate of SLR >> global rate after 1998
*Why?



Nuisance flooding

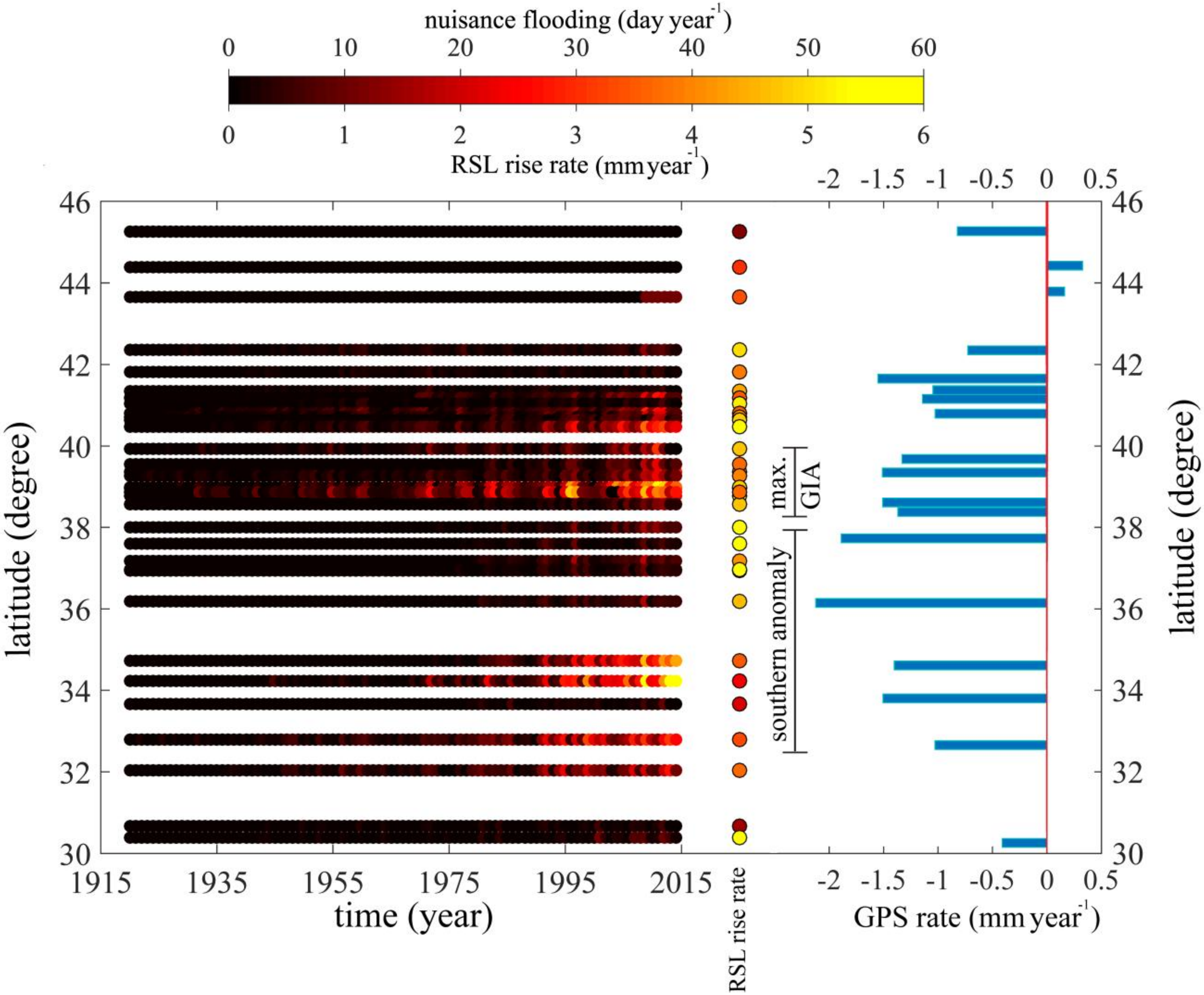
- Part of the US eastern seaboard is subsiding, exacerbating flood hazard from Sea Level Rise
- Due to both human and natural causes
  - Glacial Isostatic Adjustment (GIA)
  - Ground water extraction
  - Both measurable with geodesy
  - "Canary in the coal mine"

GPS Measurement of Coastal Subsidence



Collapse of peripheral bulge

Groundwater Extraction



nuisance flooding (day year^{-1})
0 10 20 30 40 50 60
0 1 2 3 4 5 6
RSL rise rate (mm year^{-1})
latitude (degree)
46 44 42 40 38 36 34 32 30
1915 1935 1955 1975 1995 2015
time (year)
RSL rise rate
max. GIA
southern anomaly
-2 -1.5 -1 -0.5 0 0.5
GPS rate (mm year^{-1})
latitude (degree)

Natural versus Human Caused Hazards

- Traditionally considered separately

- Hurricane/typhoon and associated flood hazards are usually the largest natural hazard “killers”

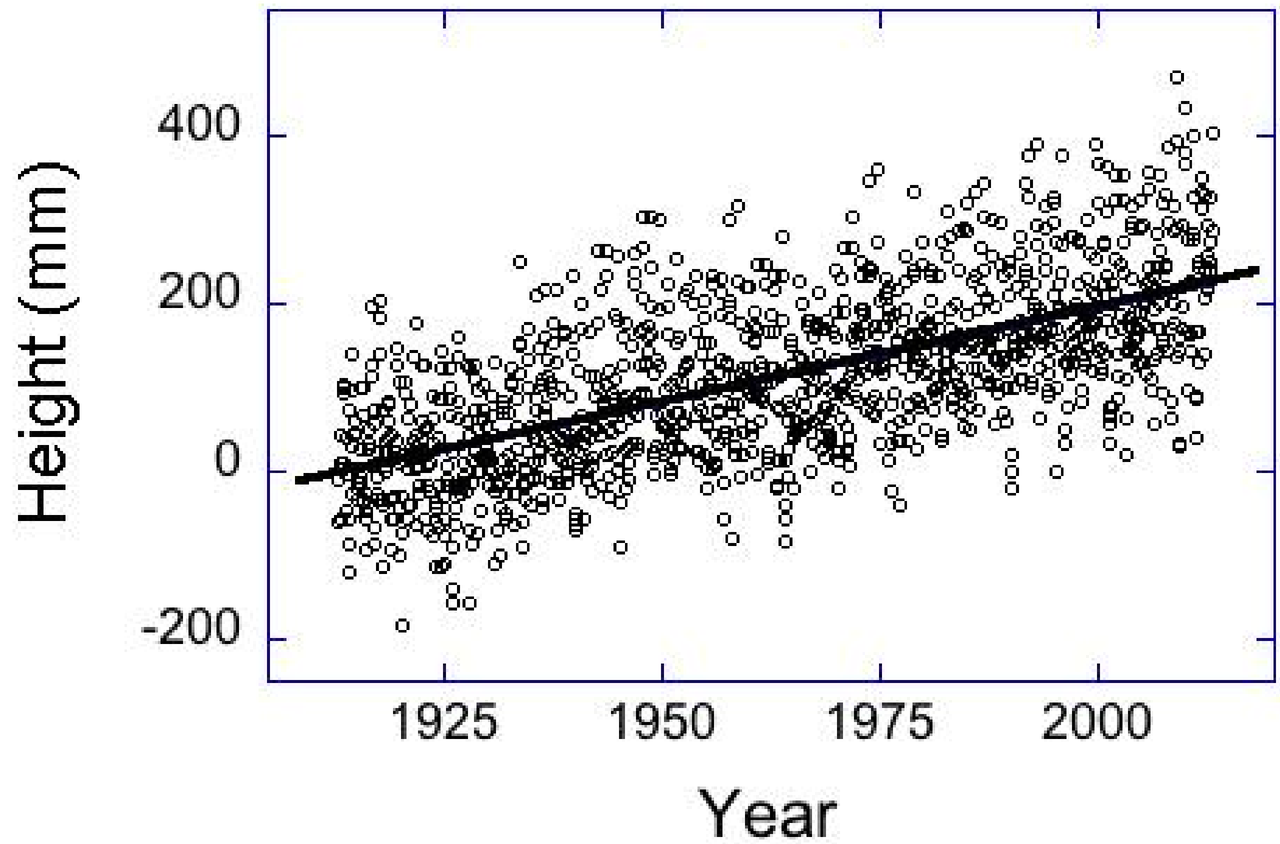
- They are increasing in severity due to human-caused global warming

- Geodesy has an important role to play, by illustrating processes, and educating and increasing awareness among public and policy makers

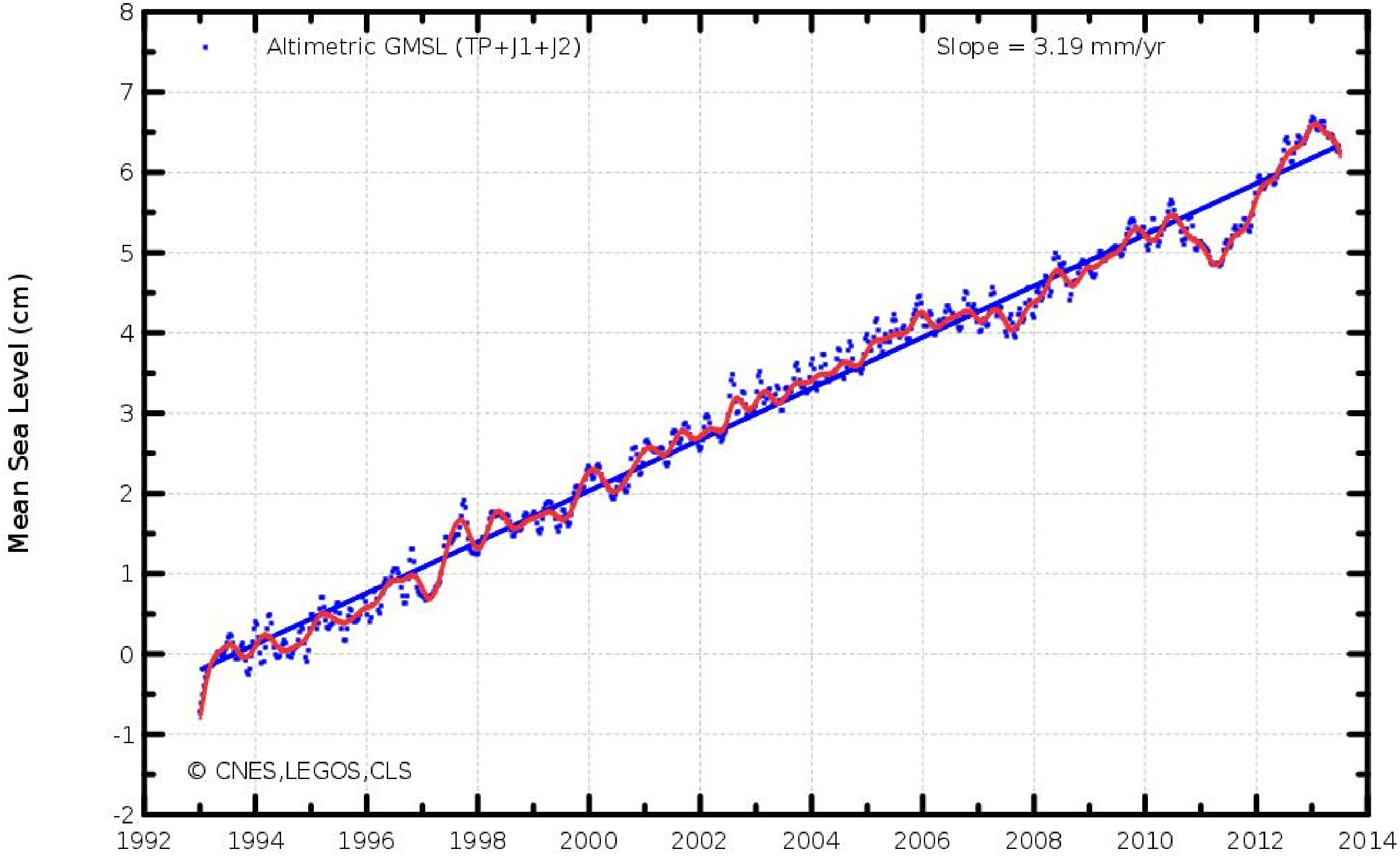
Tide Gauge: Sea Level at Key West, Florida:

20th Century rise = 2 mm/yr

Similar to global rate



Global Sea Level Rise Measured by Satellite Altimetry since 1993 = 3.2 mm/yr
(its accelerating!)



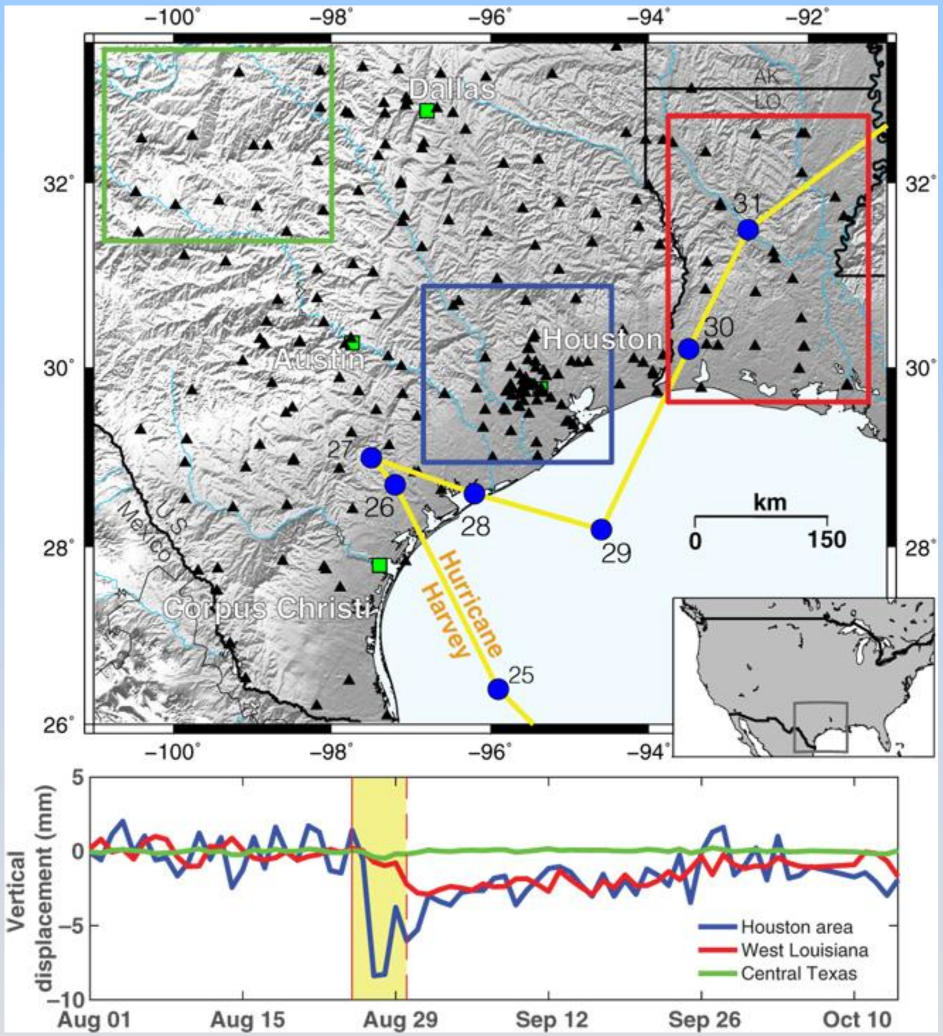
Future flooding: global warming vs other human causes

- **Increased high rainfall events from warmer atmosphere ****
- **Increased ocean mass from melting of Greenland and other glaciers ****
- **Increased ocean volume from thermal expansion****
- **Increase intensity of hurricanes from warmer ocean water**

** Measurement role for geodesy

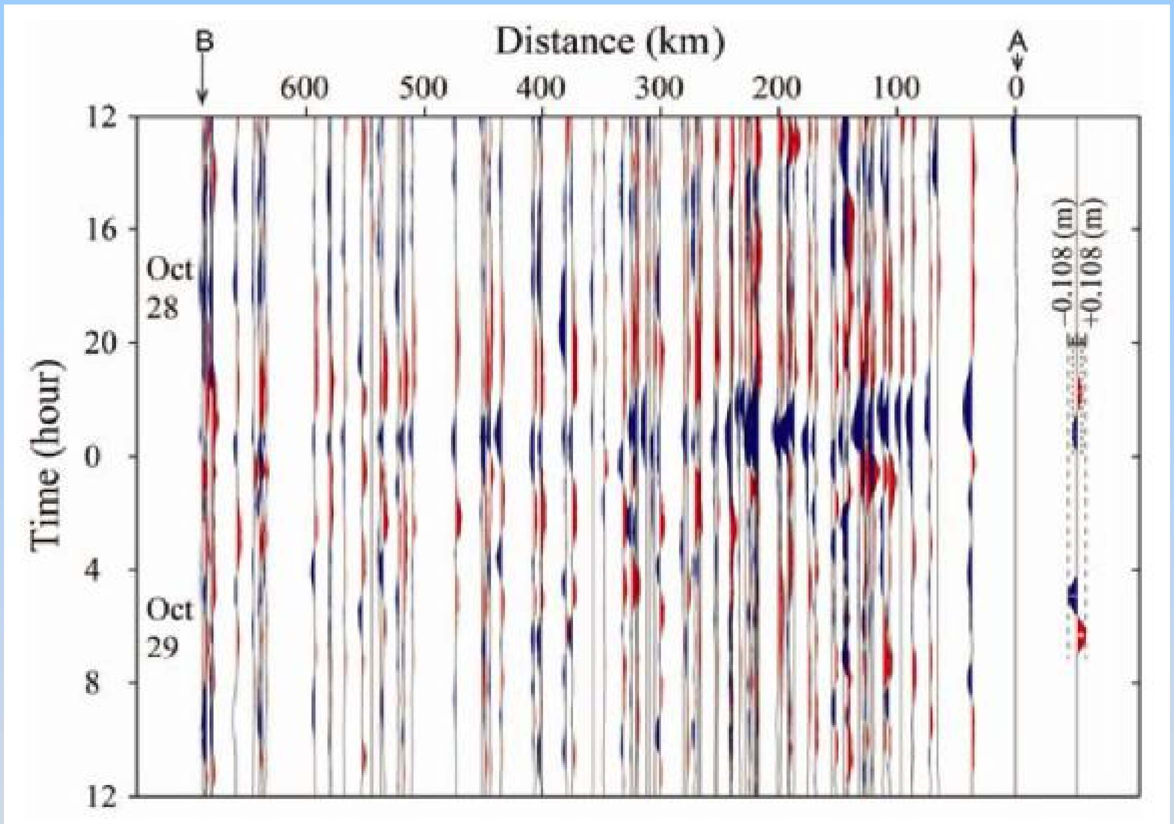
- **Building styles, zoning:**
  - **"hardscape" increases flooding from high rainfall events**
  - **Increased coastal development, loss of natural protection (dunes, mangroves)**

GPS motions during Hurricane Harvey



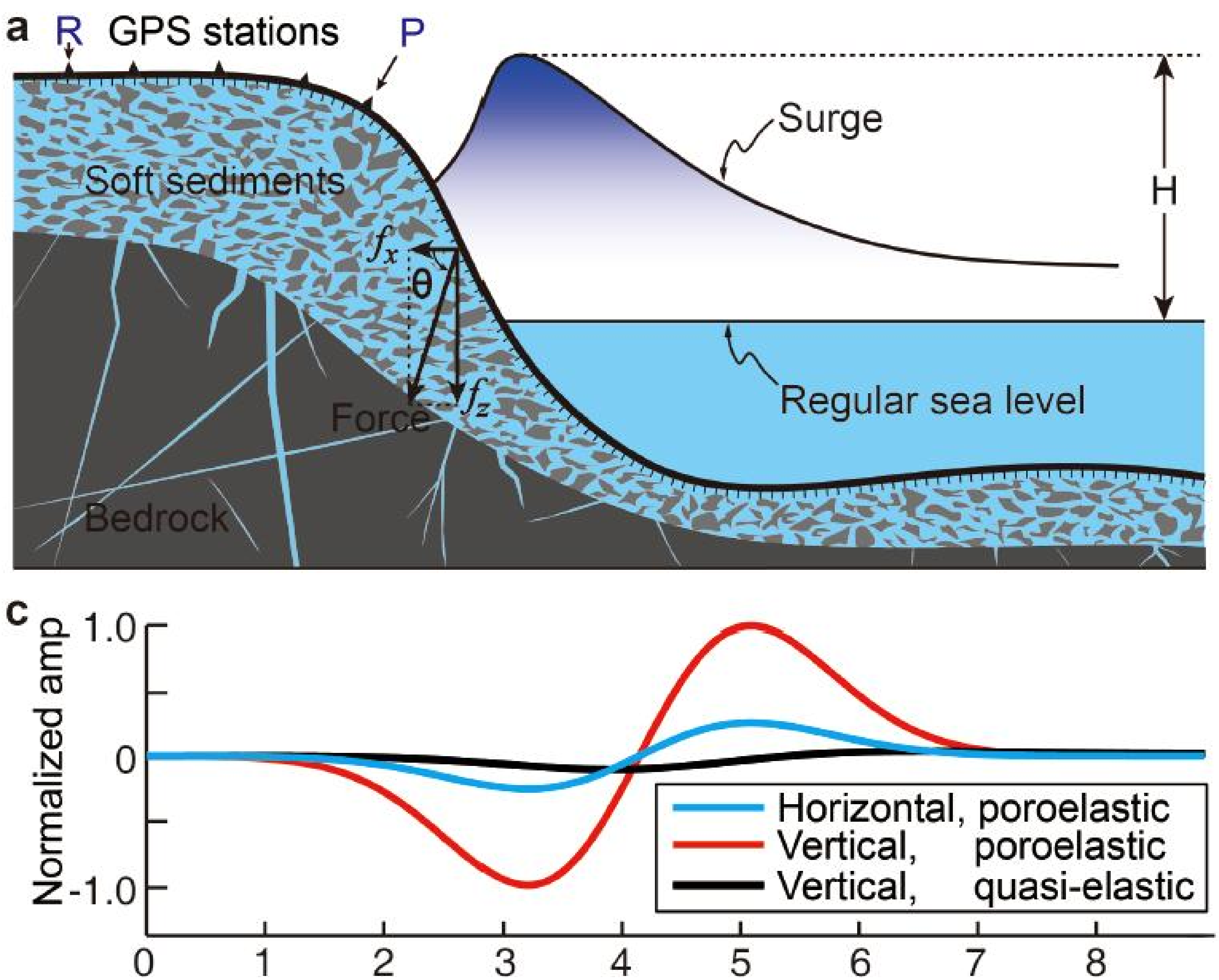
Milliner et al. Sci Adv 2018

Crustal loading from storm surge (Hurricane Sandy)



- High amplitude, long period, slow wave (“Biot wave”) recorded by GPS during peak storm surge of Hurricane Sandy
- Poroelastic theory predicts loading from storm generates high amplitude (0.1 m), long-period (4 hours) slow wave (65 + 15 m/s) that attenuates inland
- Holt et al, In revision

Amplitude Model



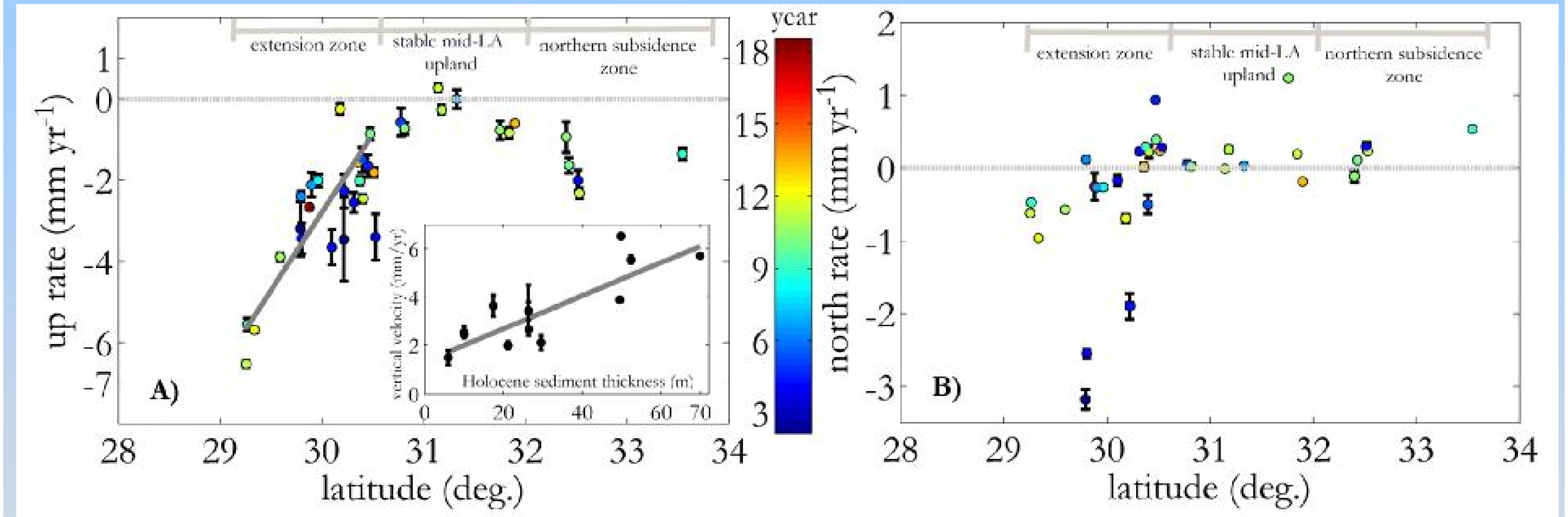
- **Biot Wave – the movie**

New Orleans and Hurricane Katrina example

New Orleans is uniquely vulnerable to flooding because it is built on a subsiding delta

Yet it holds important lessons for other coastal cities around the world

- GPS shows Mississippi Delta is subsiding and moving south
- Most of this motion is natural



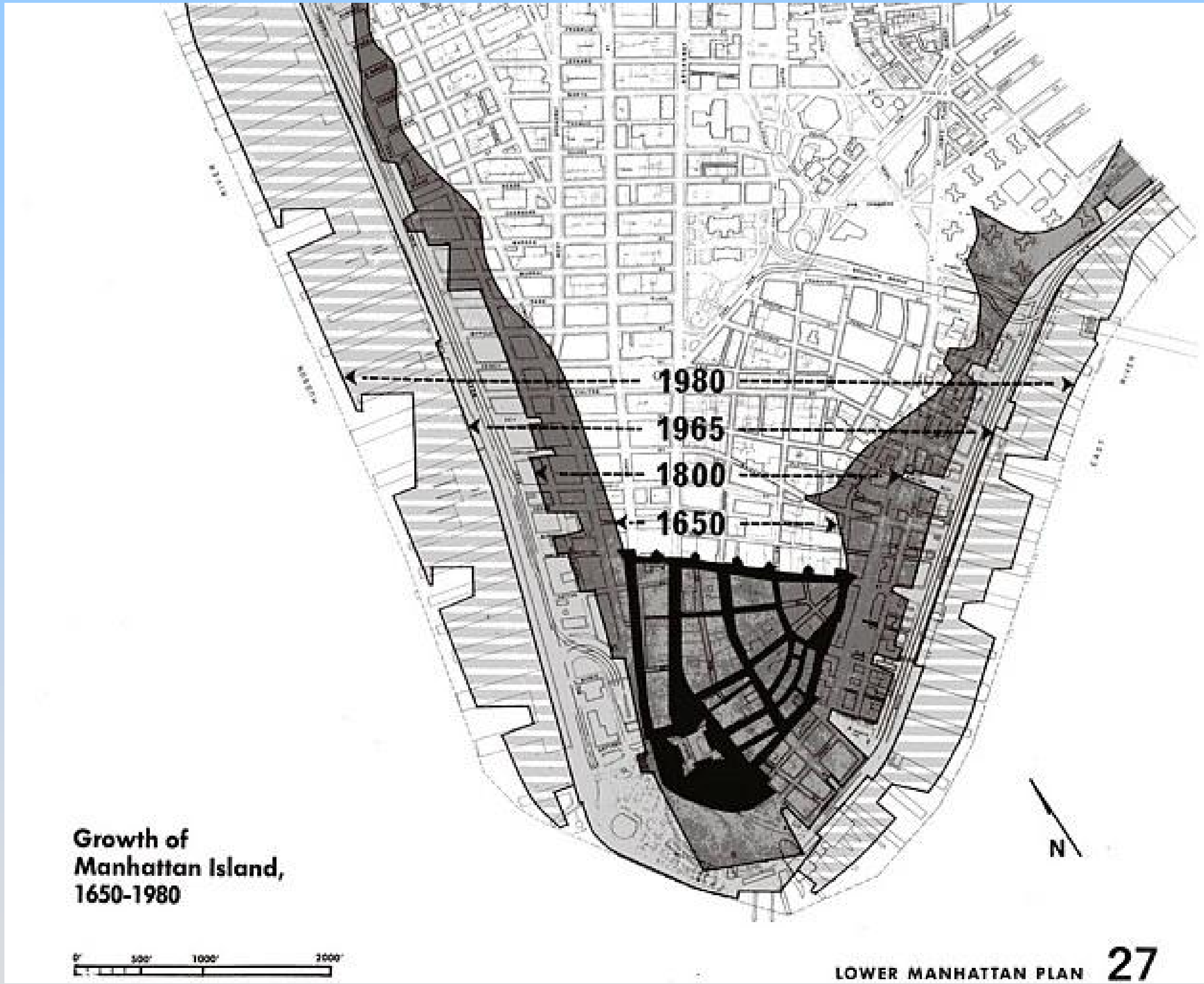
Delta

Delta

Local subsidence can also play a role

- **“Reclaimed” land (=sinking land) example in New Amsterdam (New York City)**

Flooding in Manhattan during Hurricane Sandy

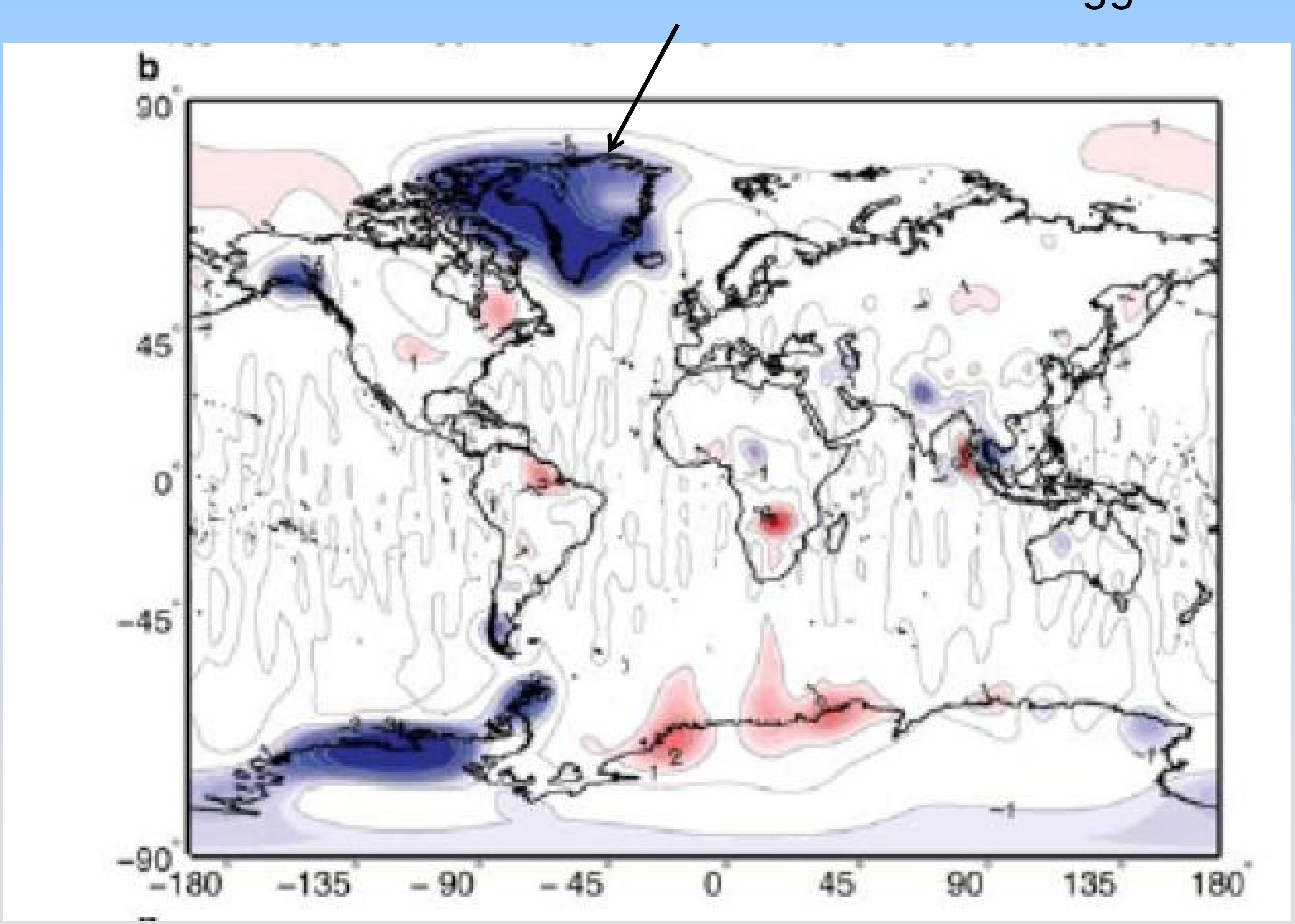

1980
1965
1800
1650
N
Growth of
Manhattan Island,
1650-1980

The Importance of Greenland

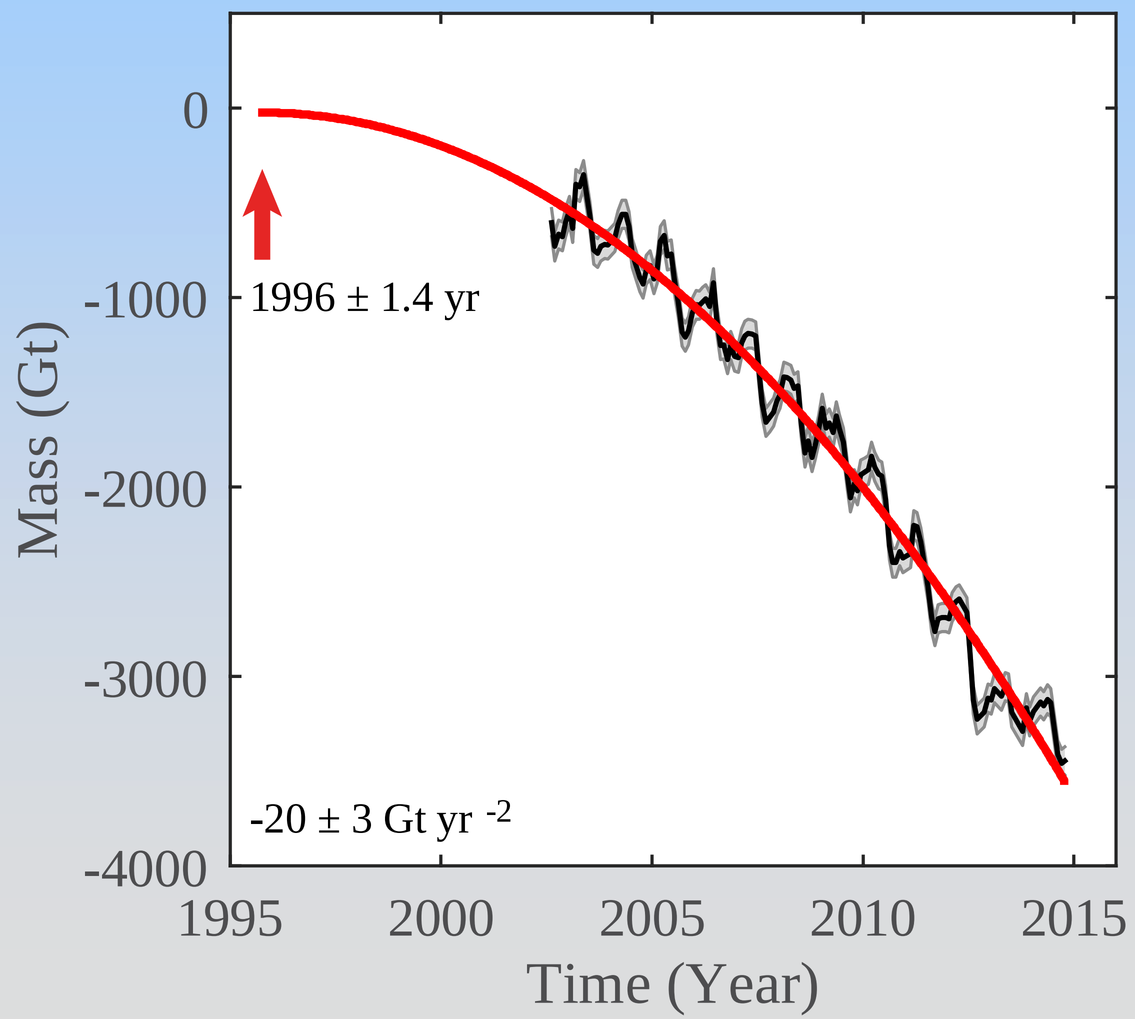
- **What happens in Greenland does not stay in Greenland**
- **Impacts both sea level and ocean circulation**
- **Provides “teachable moments” for mid- and low latitude citizens**
- **GRACE (regional) and TRI (local) examples**

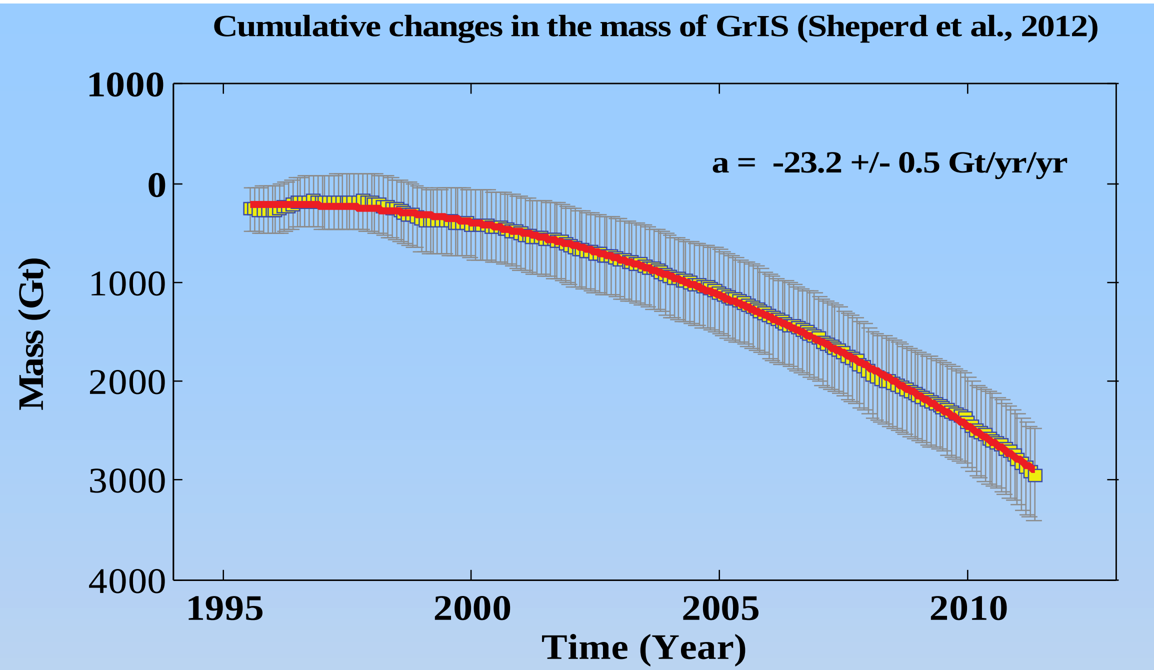
GRACE Results, 2002-2011

Greenland: world’s biggest “loser”

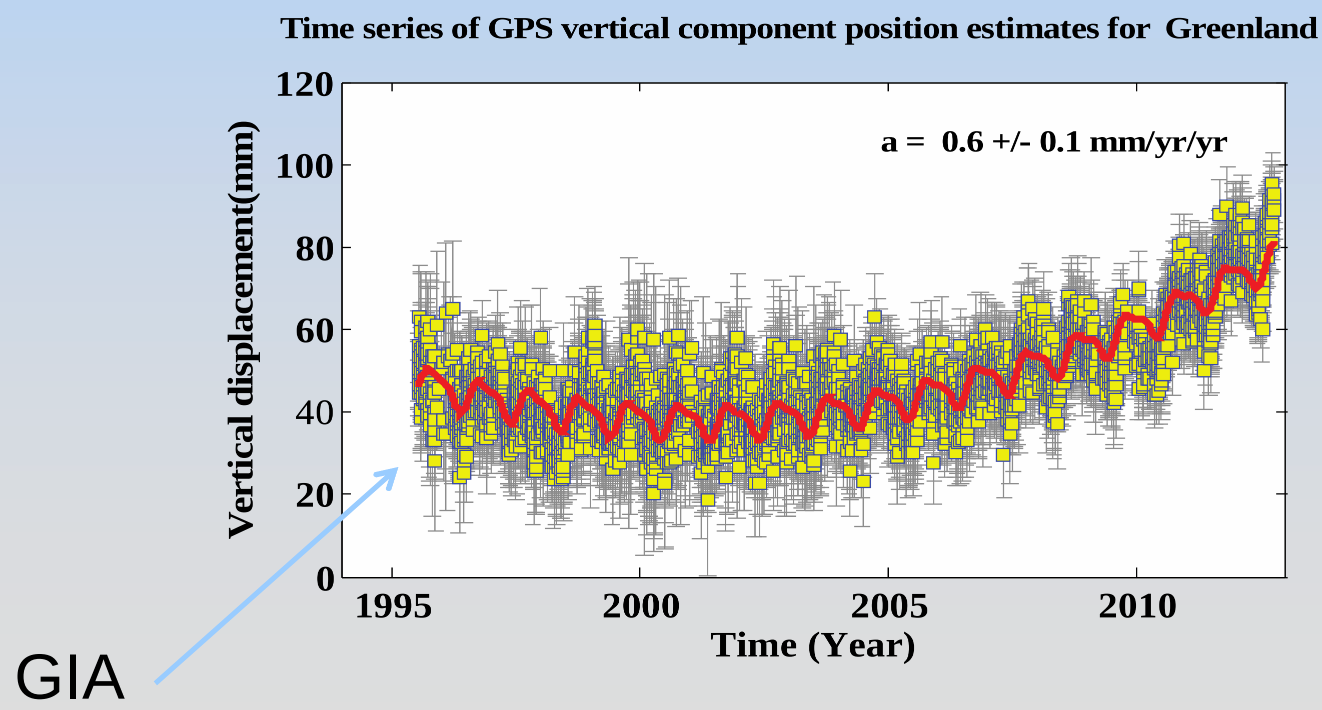


*Average loss for Greenland ~250 GT/yr (1 GT= 1 km^3)
*Curvature shows acceleration (2015 loss ~ 400 GT/yr)
*Fit to data (assuming constant acceleration) constrains timing of recent acceleration – began in mid-1990's





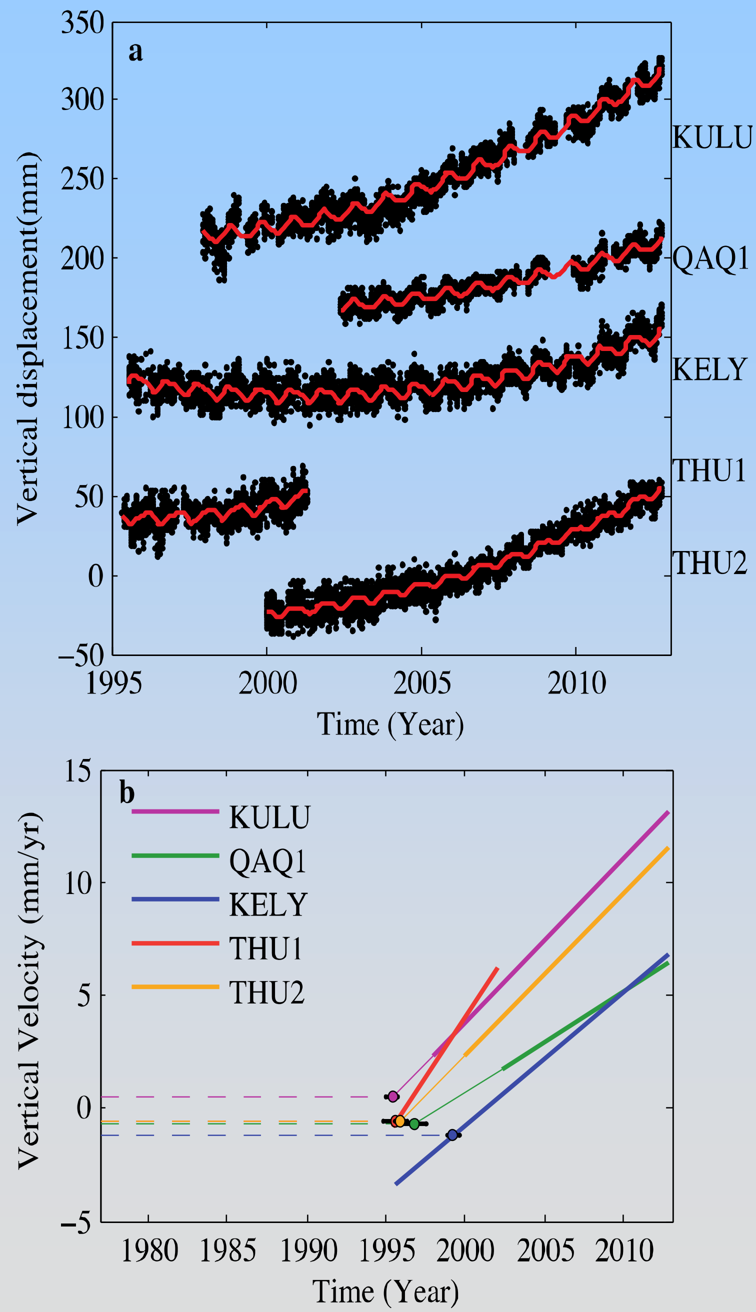
GPS and other data consistent with mid-90's start to accelerated mass loss



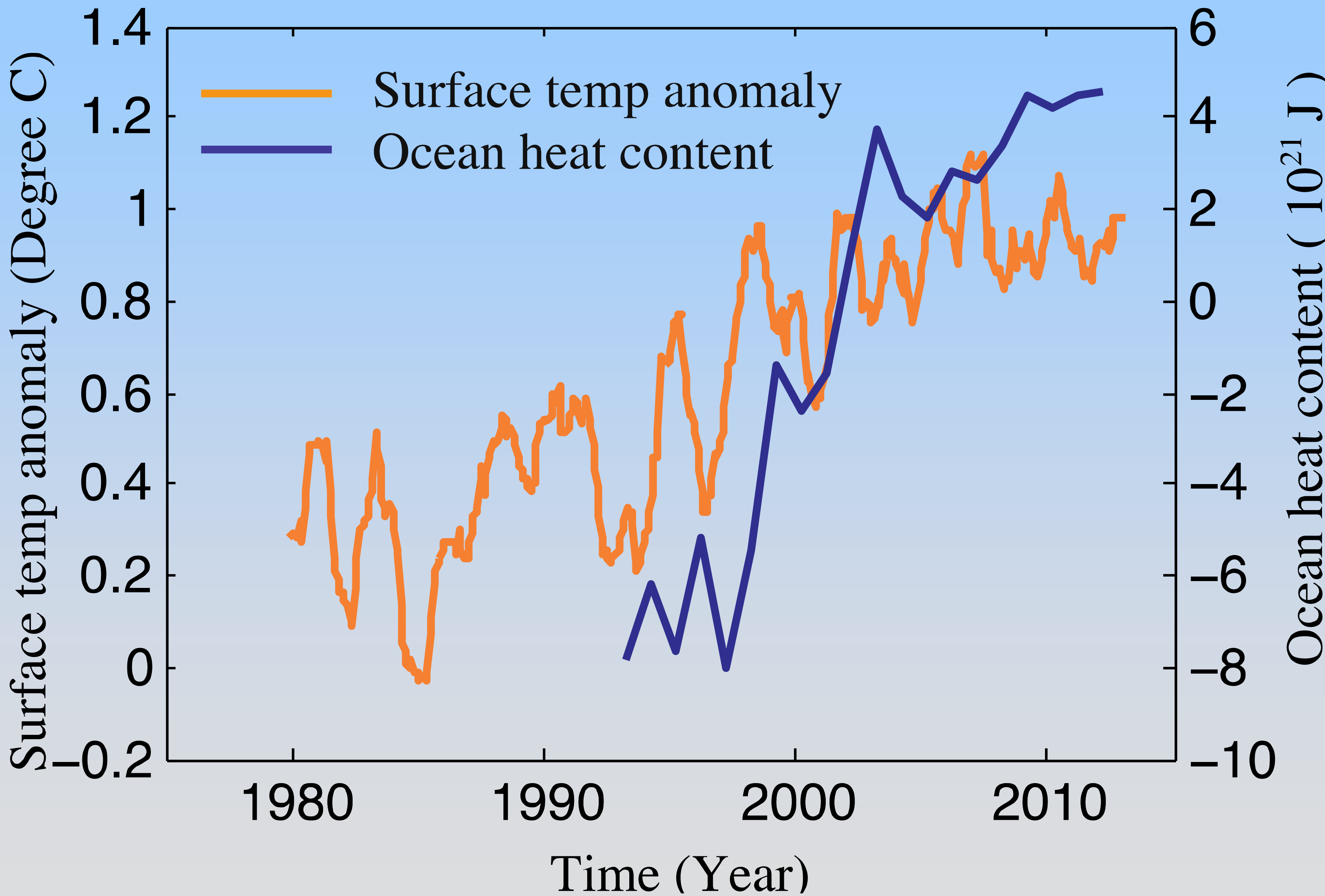
Model (red curve):
Initial Velocity
Constant acceleration
Annual & semi-annual terms

Timing of accelerated uplift estimated by intersection of GPS with GIA model:
mid-late 1990's,
a time when other changes were happening in North Atlantic

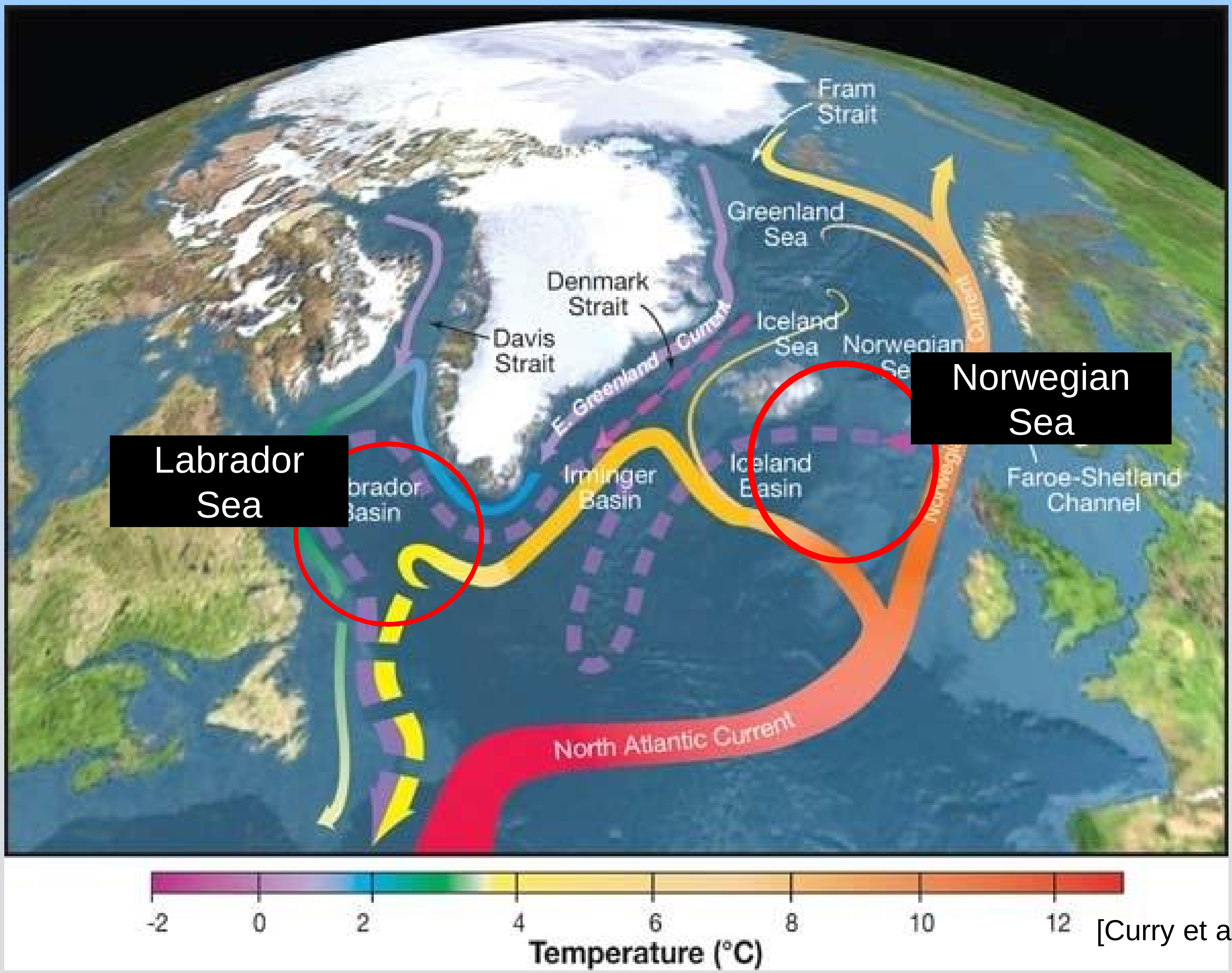
Initial Velocity from GIA model →



North Atlantic Surface Temperature vs Global Ocean Heat



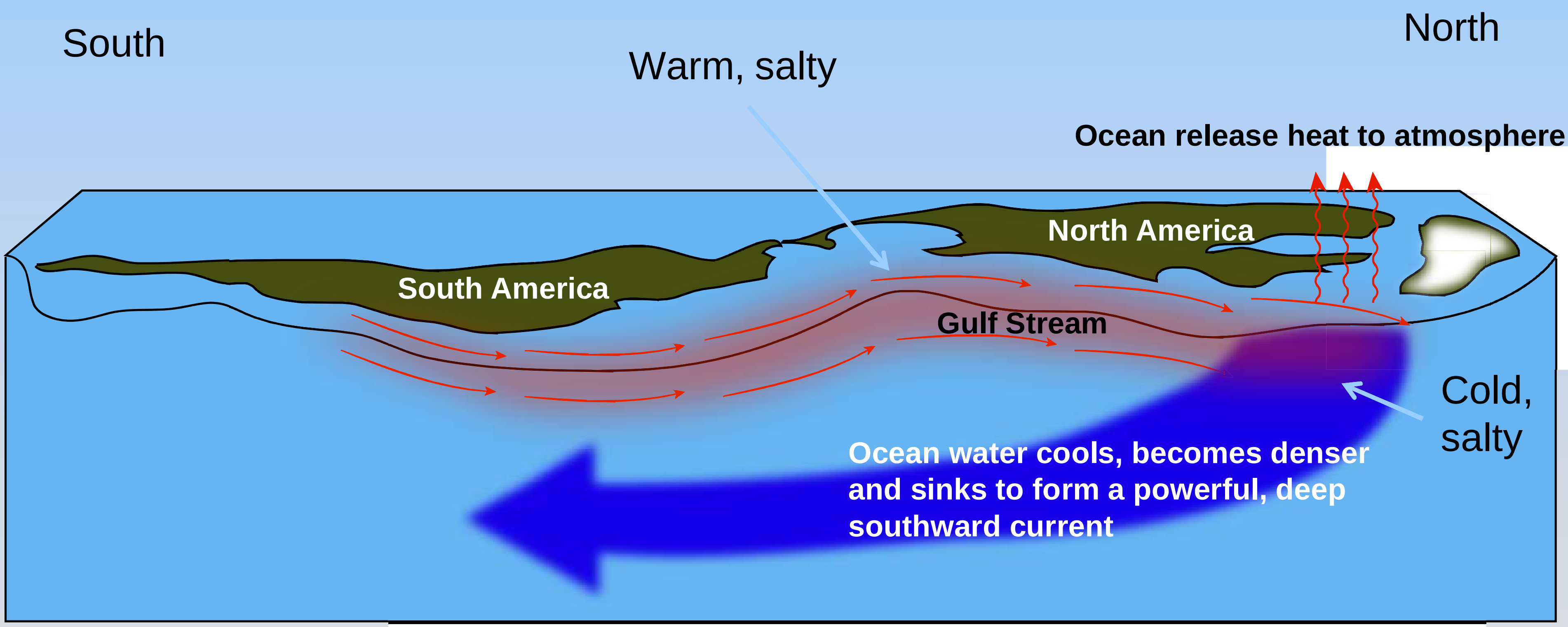
Atlantic Meridional Overturning Circulation (AMOC)
(Gulf Stream's Third Dimension)



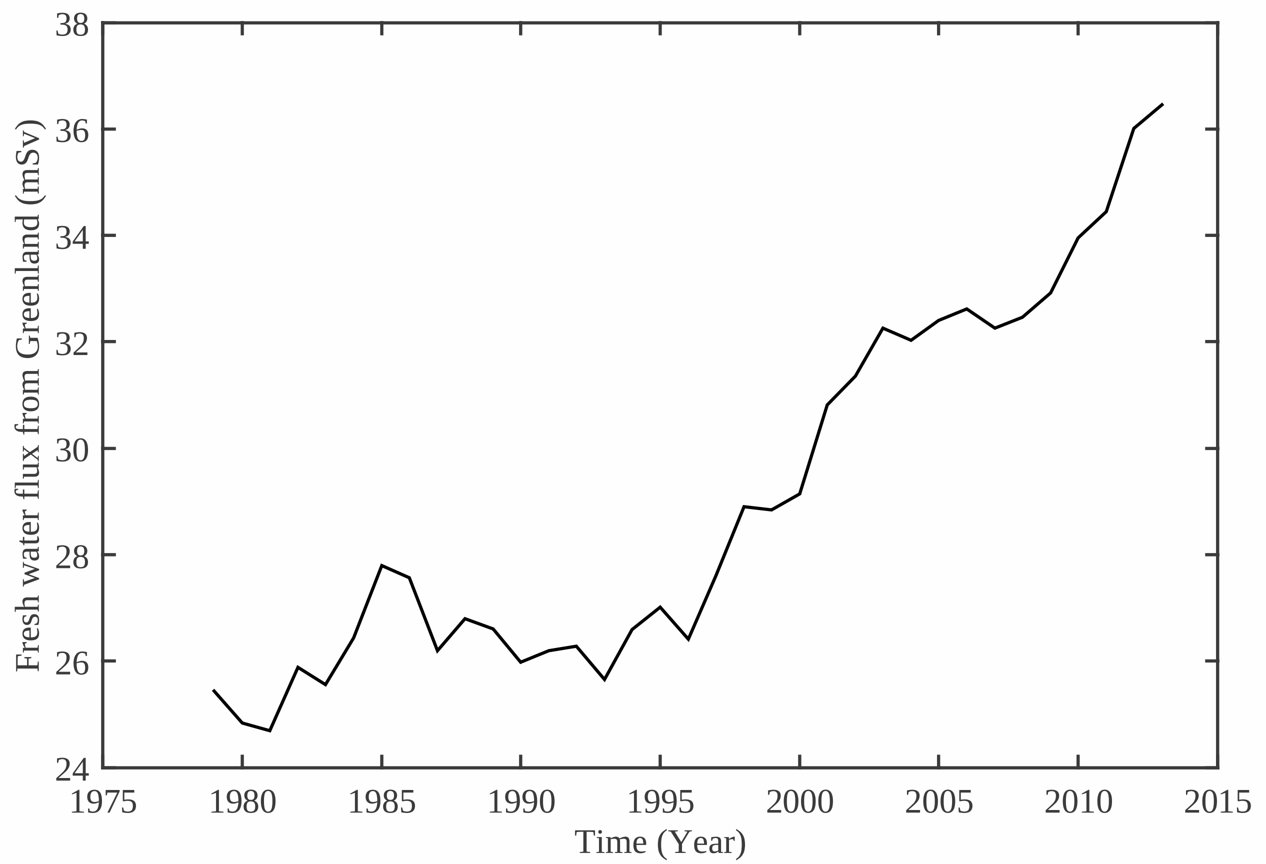
[Curry et al., 2005]

AMOC is 3-D, thermo-haline circulation, driven by density changes, sensitive to salinity and temperature

- could be disrupted by rapid Greenland melting
- could affect Gulf Stream (GS)

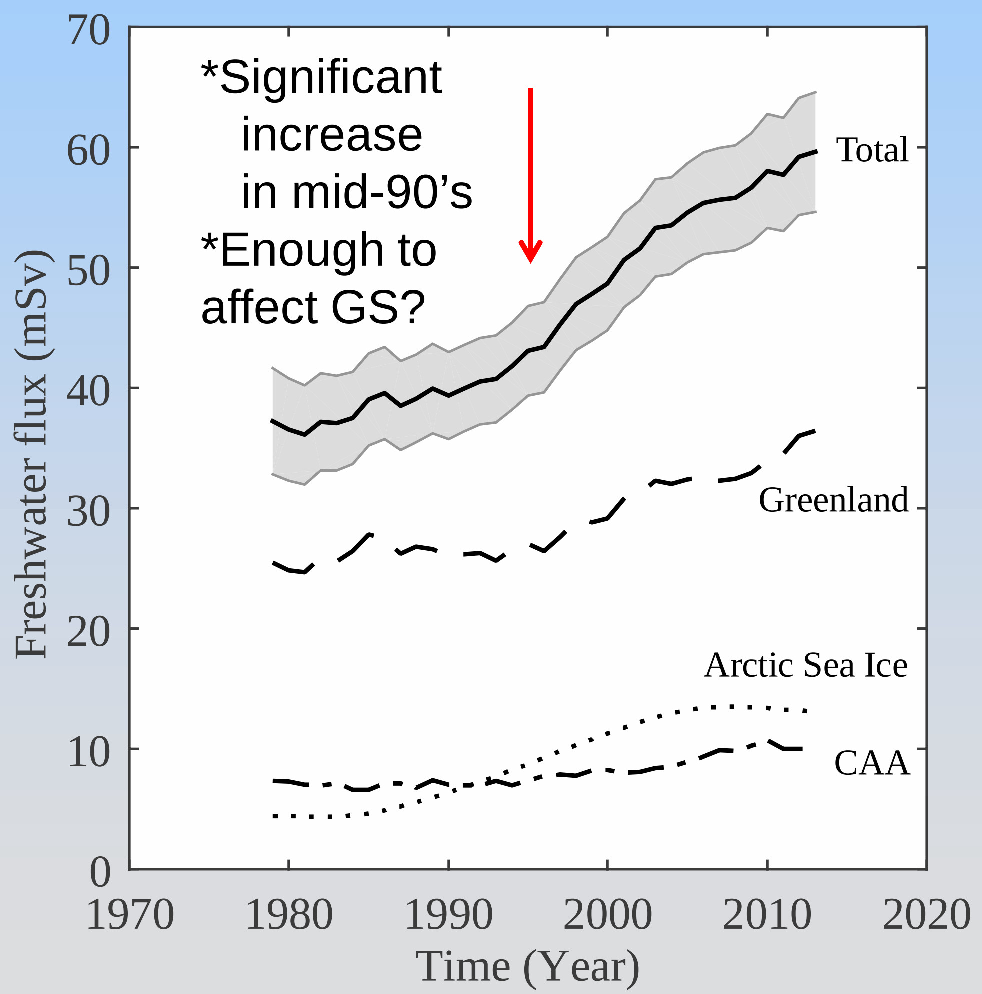


Freshwater flux from Greenland ice sheet, derived from GRACE and RACMO



Total freshwater flux from Greenland + CAA + Arctic sea ice

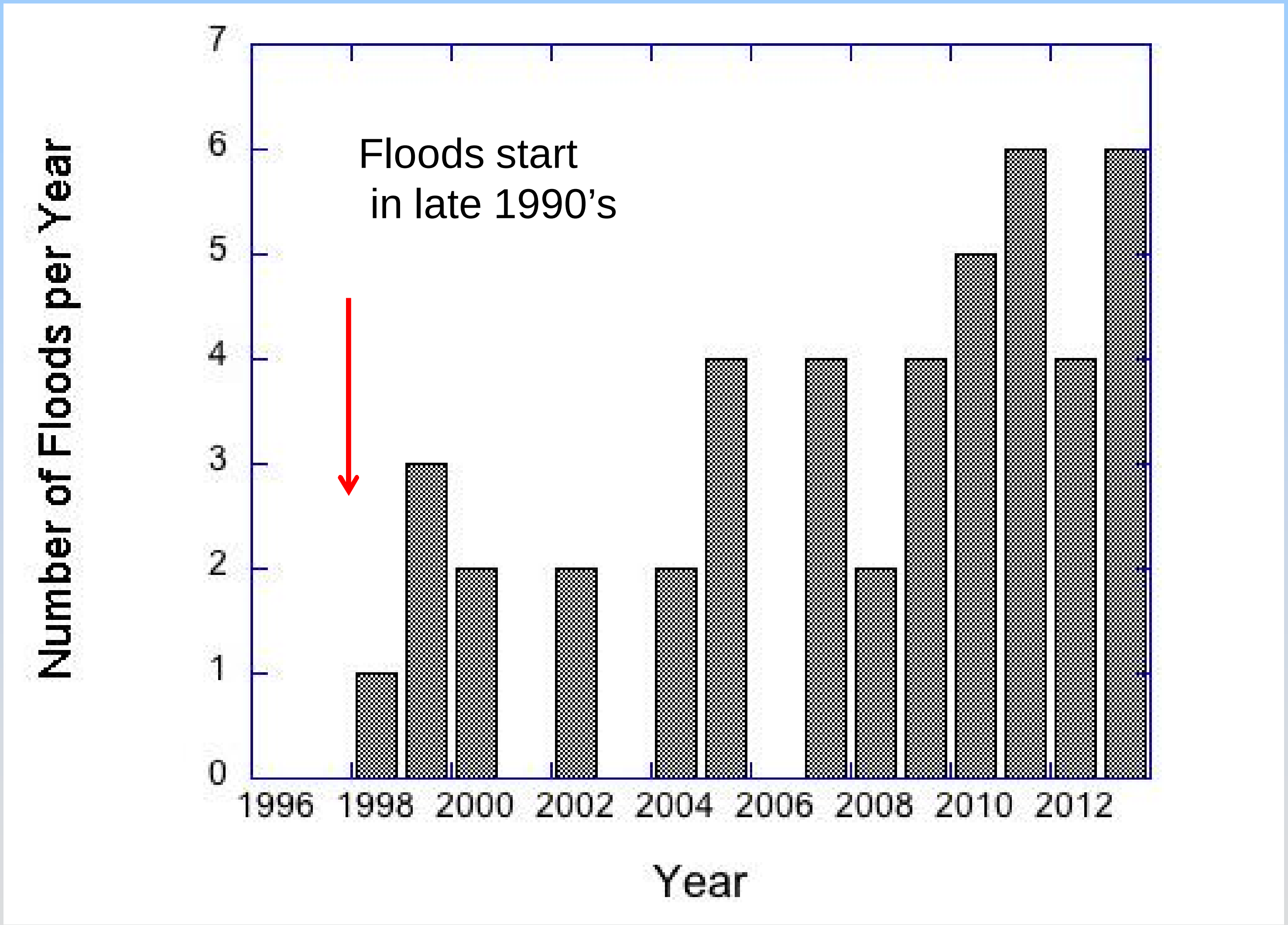
Yang et al (2016) Nature Comm



Miami Nuisance Flood Events vs Time

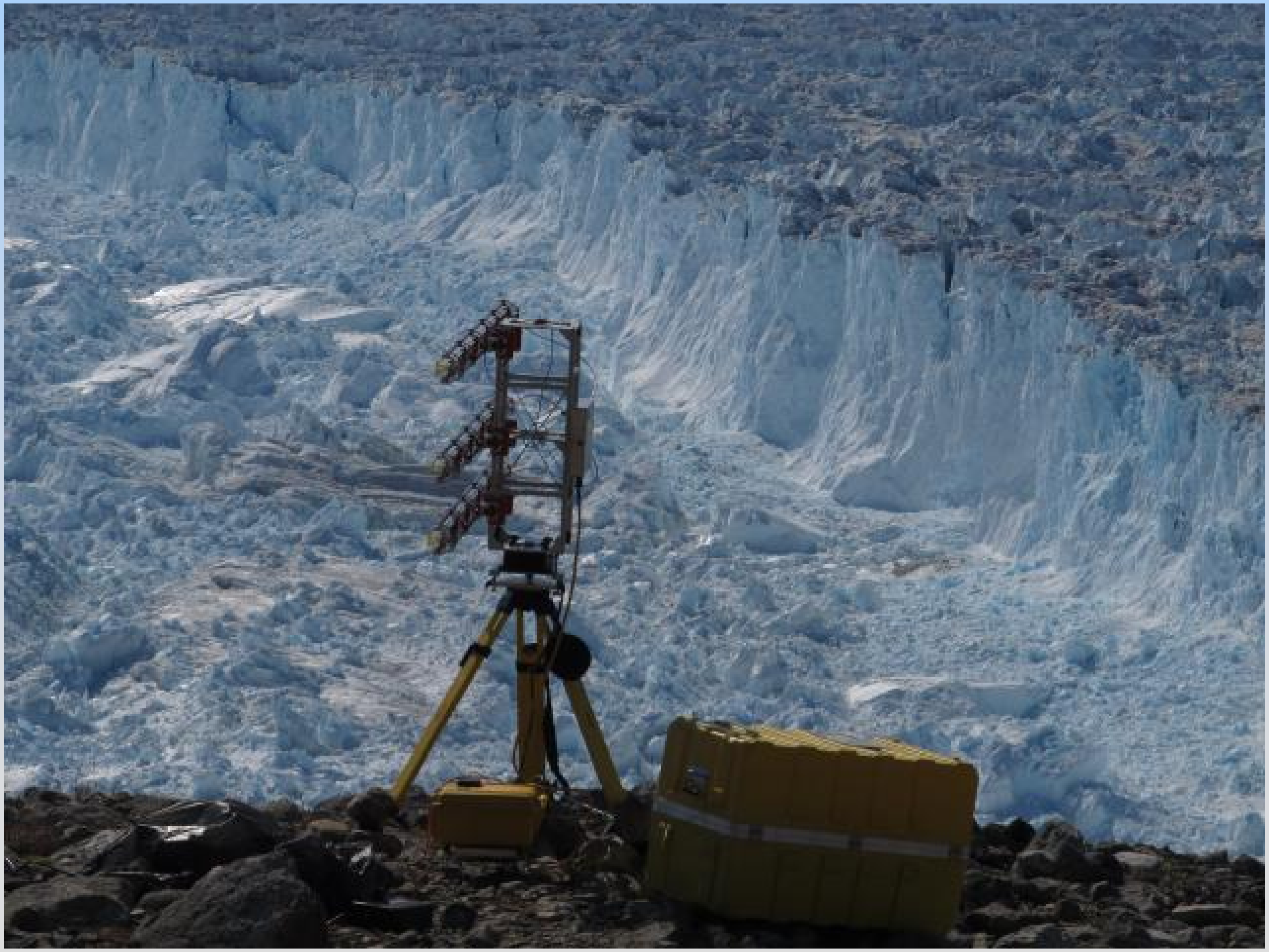
*Local Rate of SLR >> global rate after 1998

*Due to change in Gulf Stream or tidal amplitude?



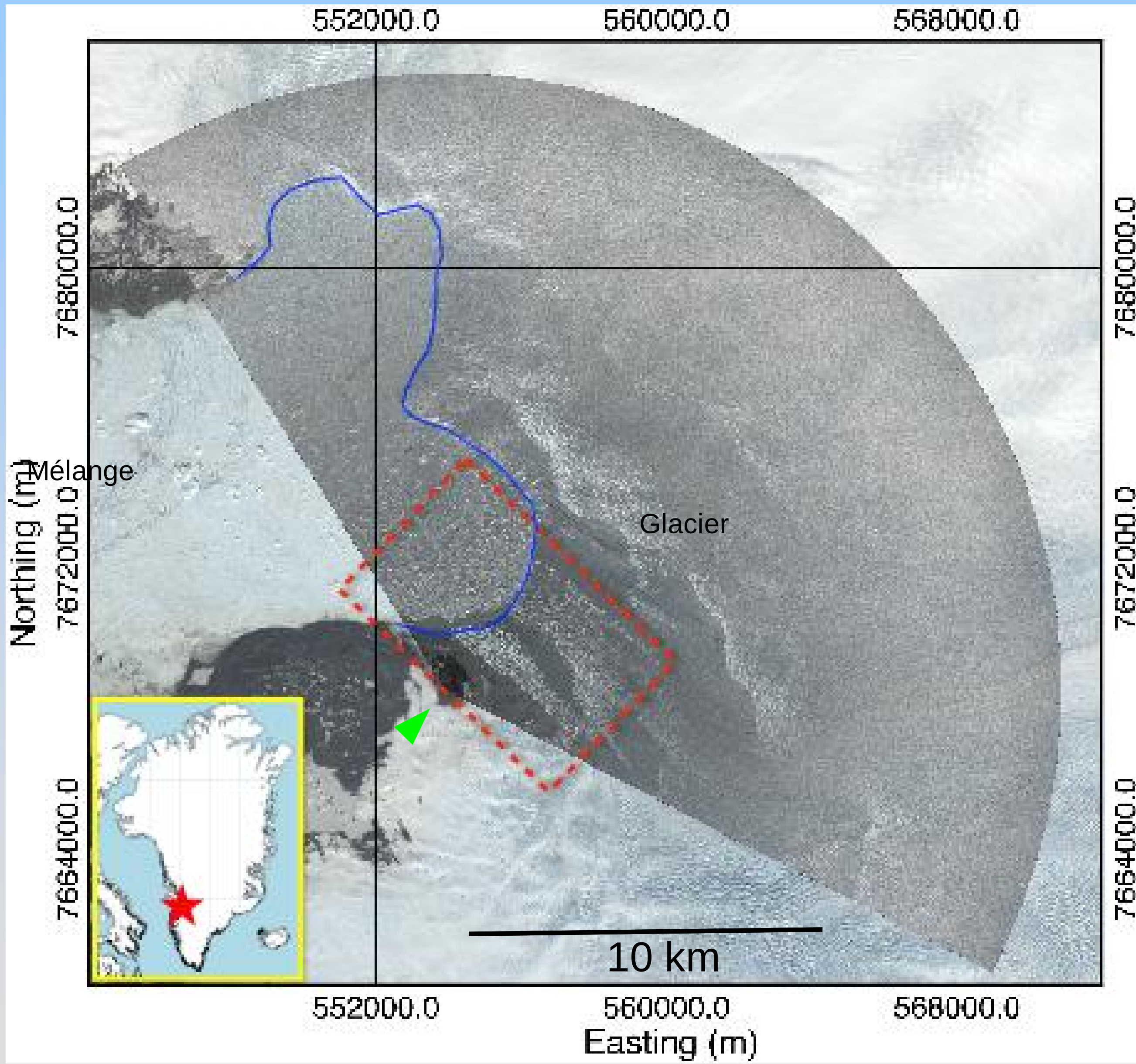
TRI and Iceberg Calving

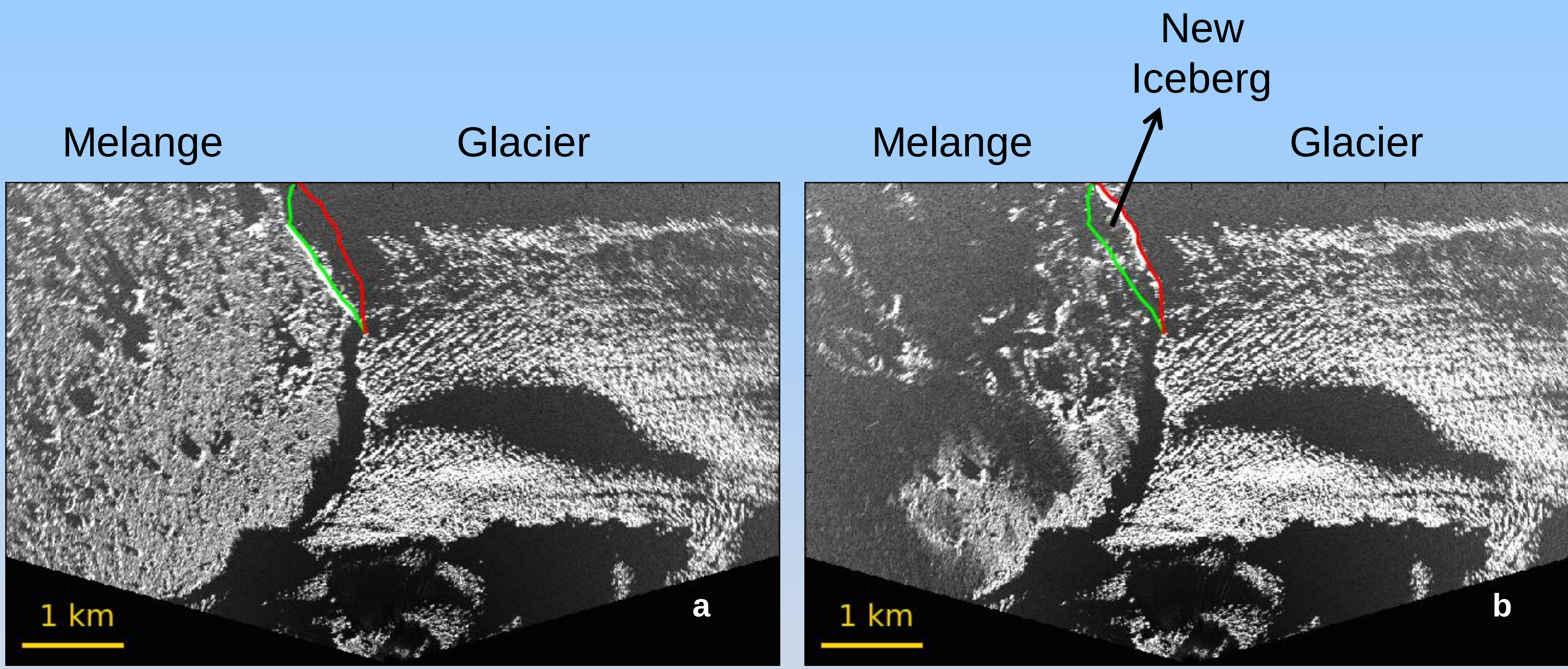
- **Iceberg calving is a critical ice mass loss mechanism for Greenland outlet glaciers, but controlling factors are poorly understood**
- **Terrestrial Radar Interferometry (TRI) produces frequent (2-3 minute) images of glacier velocity and DEMs, useful for studying calving**



Radome – reduces wind jitter

TRI Coverage - Jakobshavn

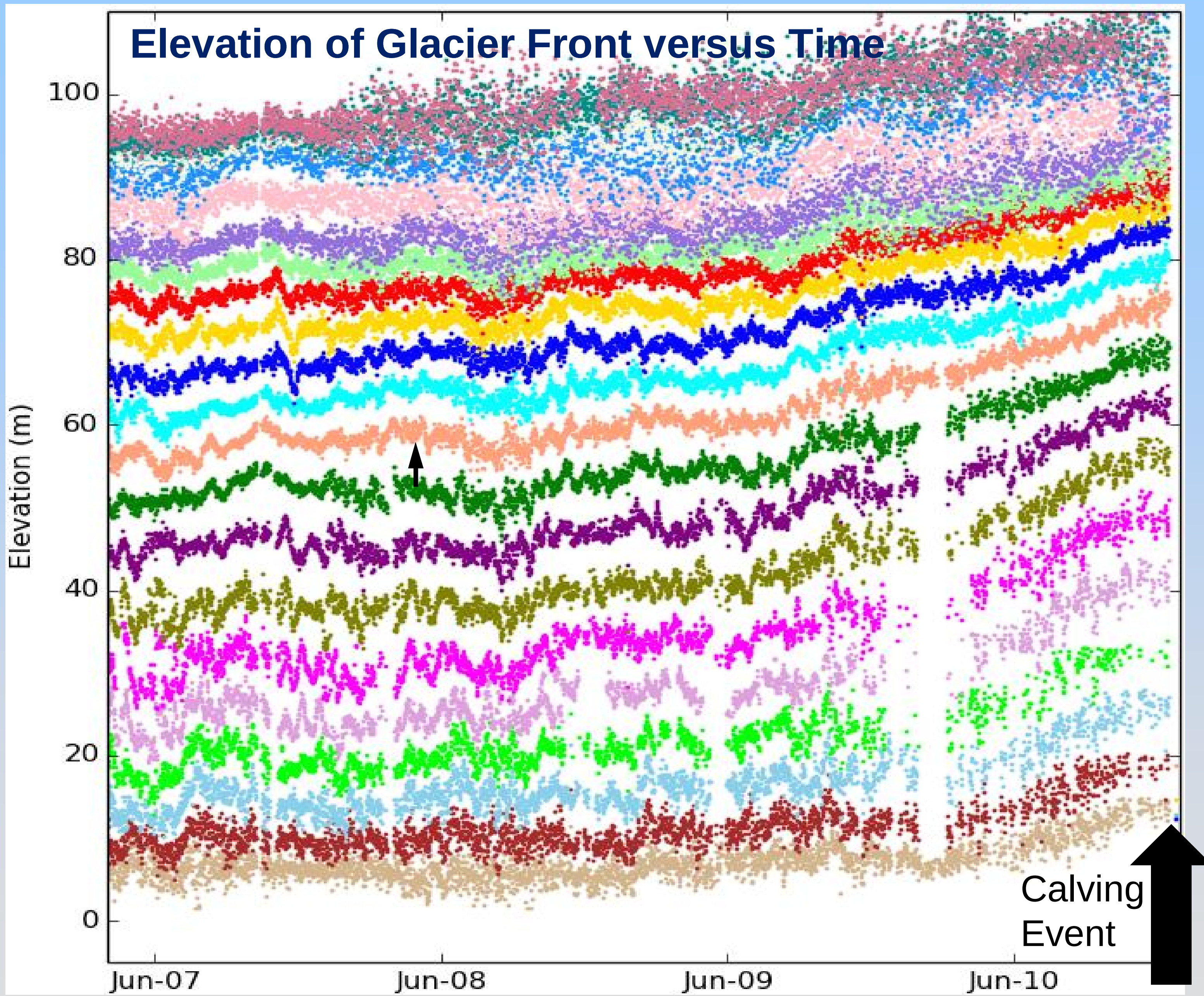




June 10

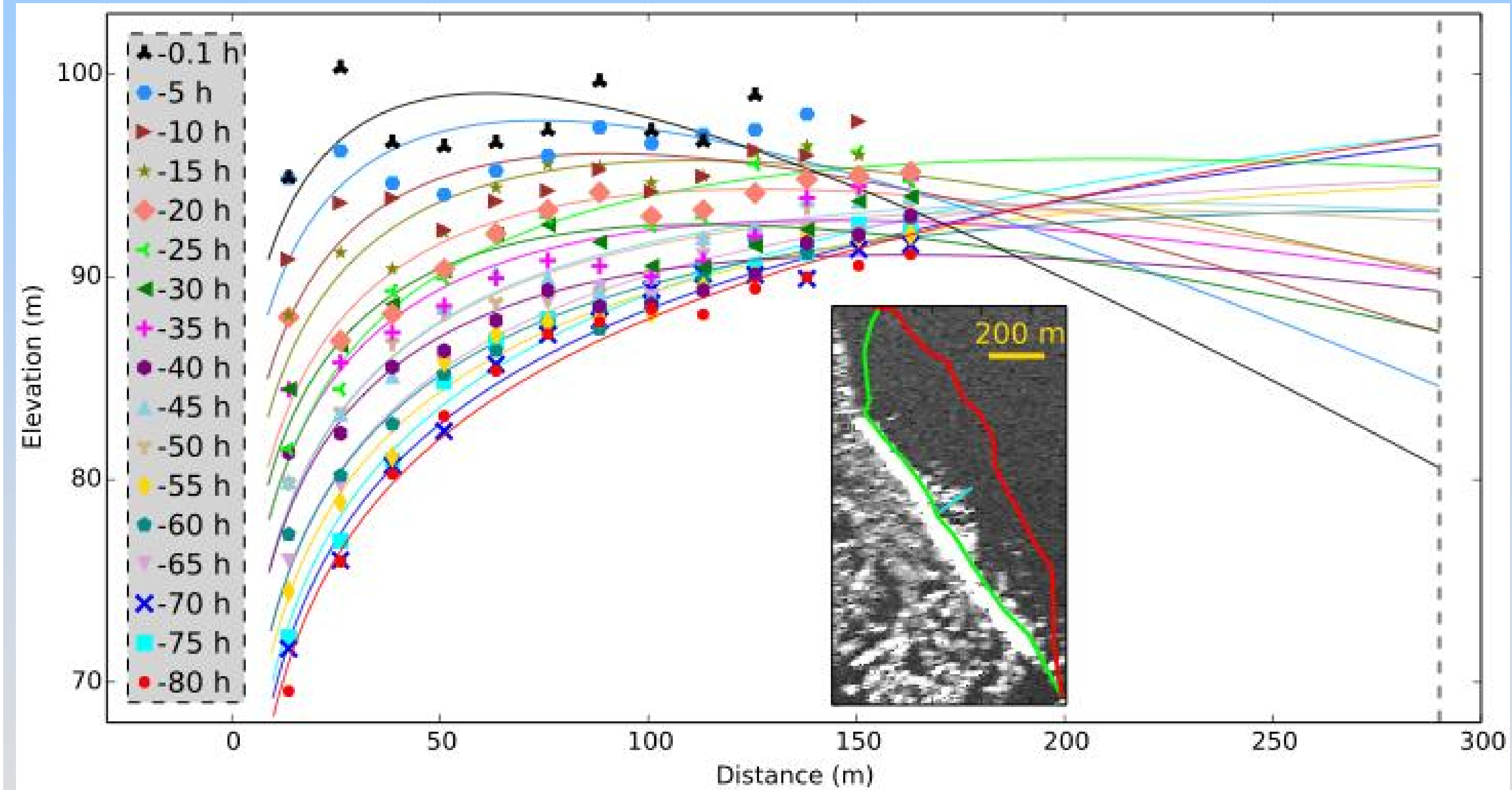
June 10
(26 minutes later)

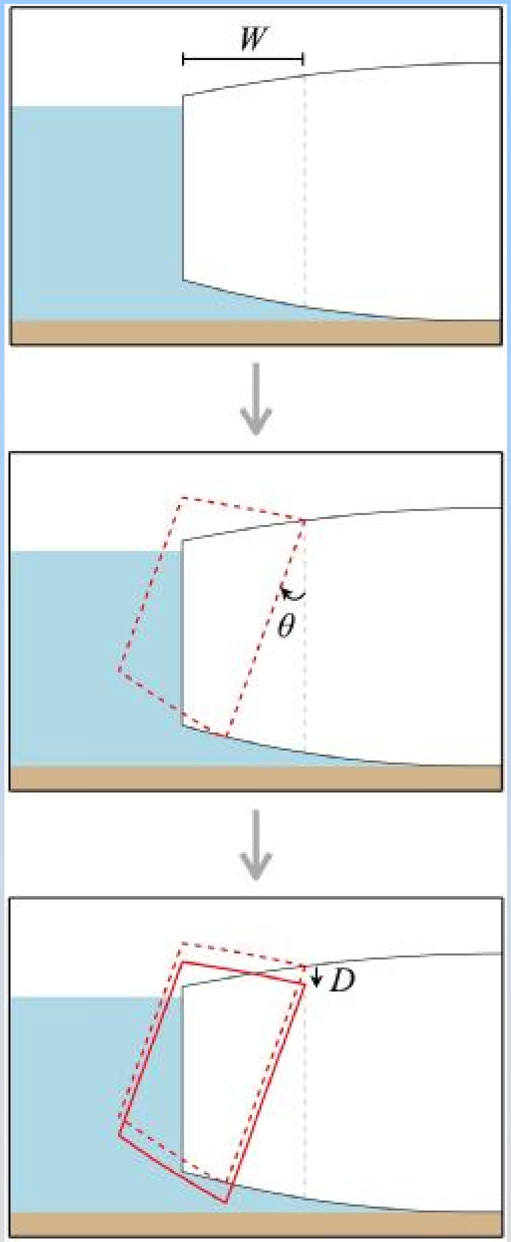
c



Elevation of Glacier Front versus Time
Elevation (m)
100
80
60
40
20
0
Jun-07
Jun-08
Jun-09
Jun-10
Calving Event

Elevation Profile, Perpendicular to Calving Front, Changes with Time





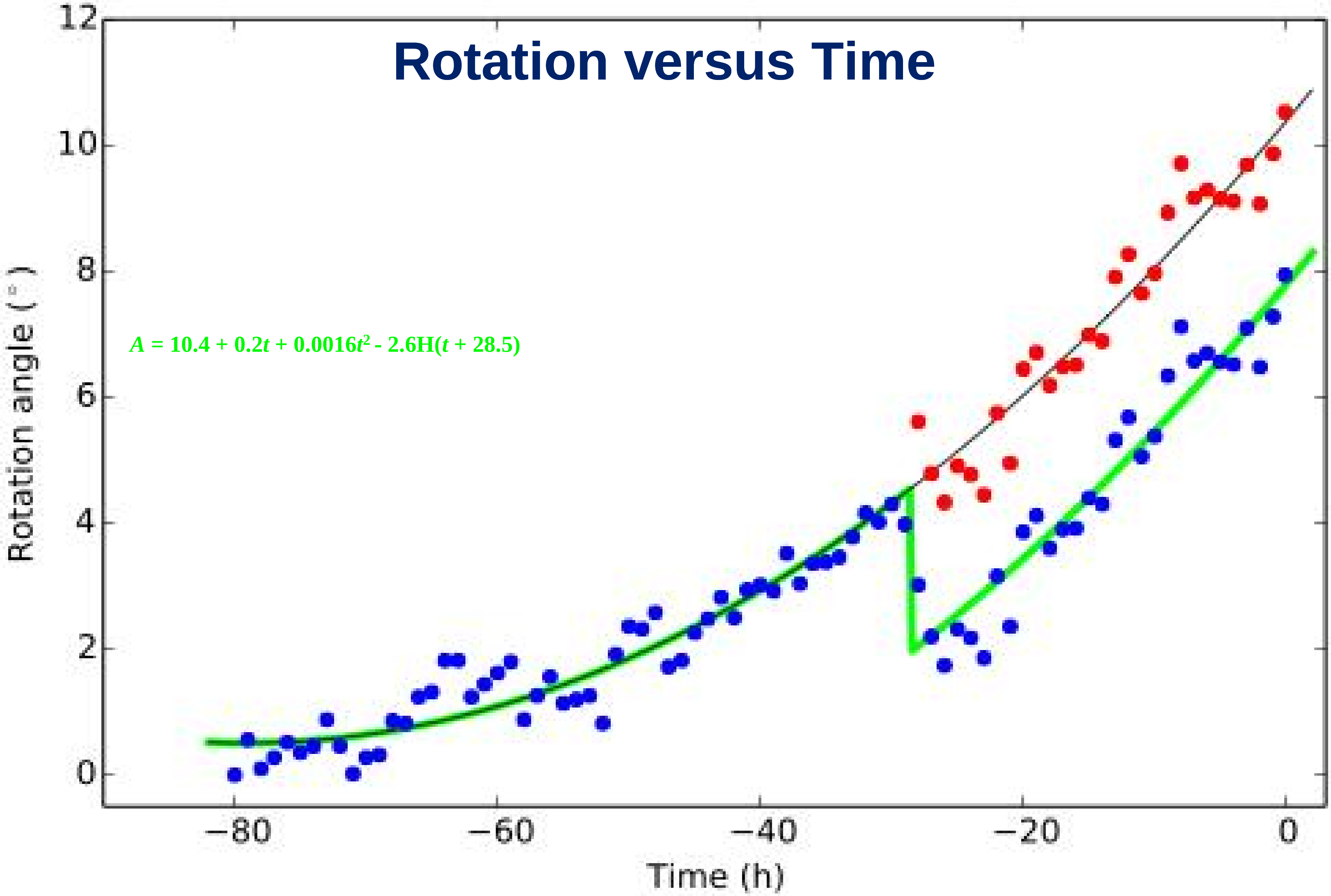
Simple Block Rotation Model (3 Parameters)

W = Block Width (fixed)

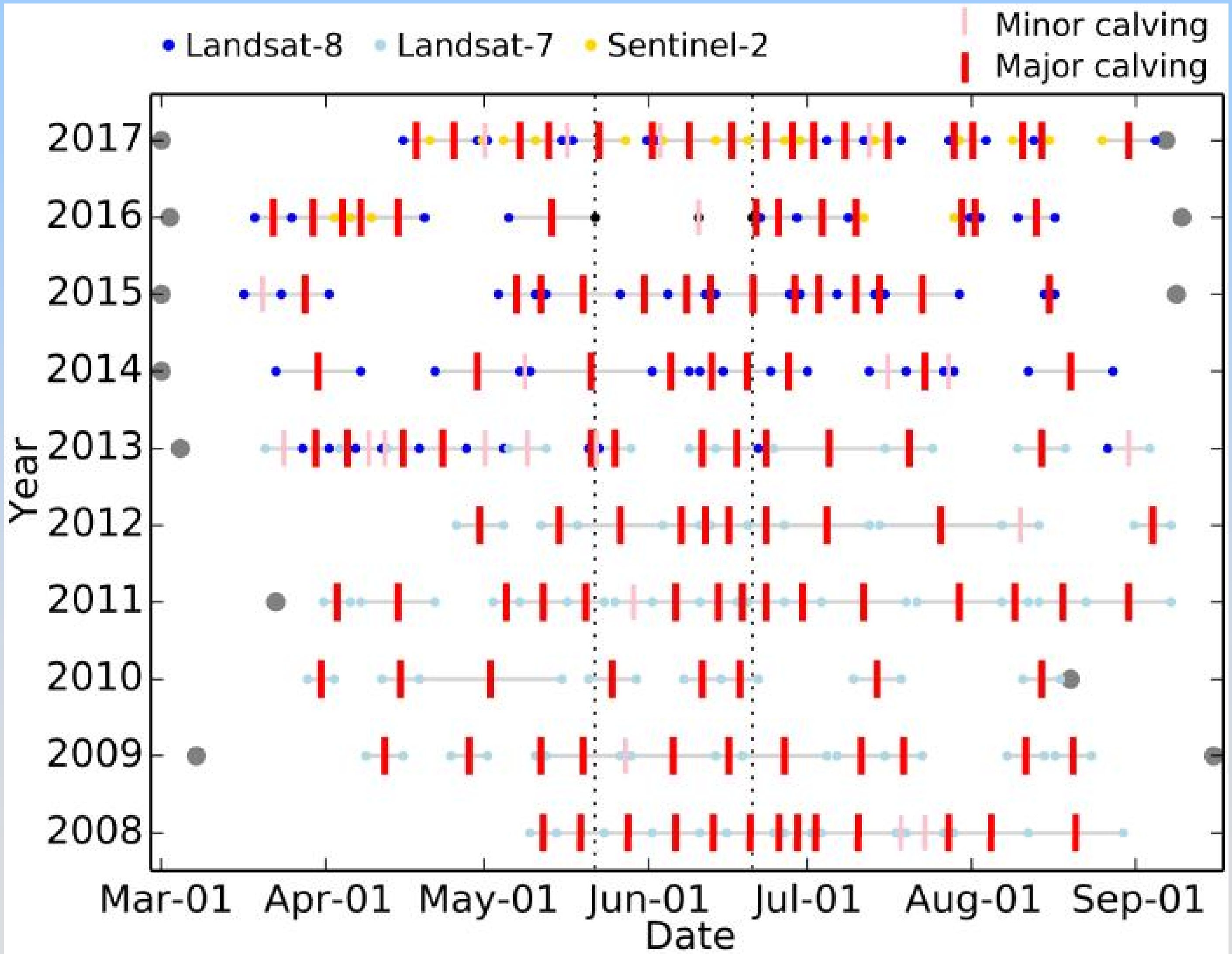
θ = Rotation Angle
(increases with time)

D = Block Subsidence
(increases with time)

Rotation versus Time

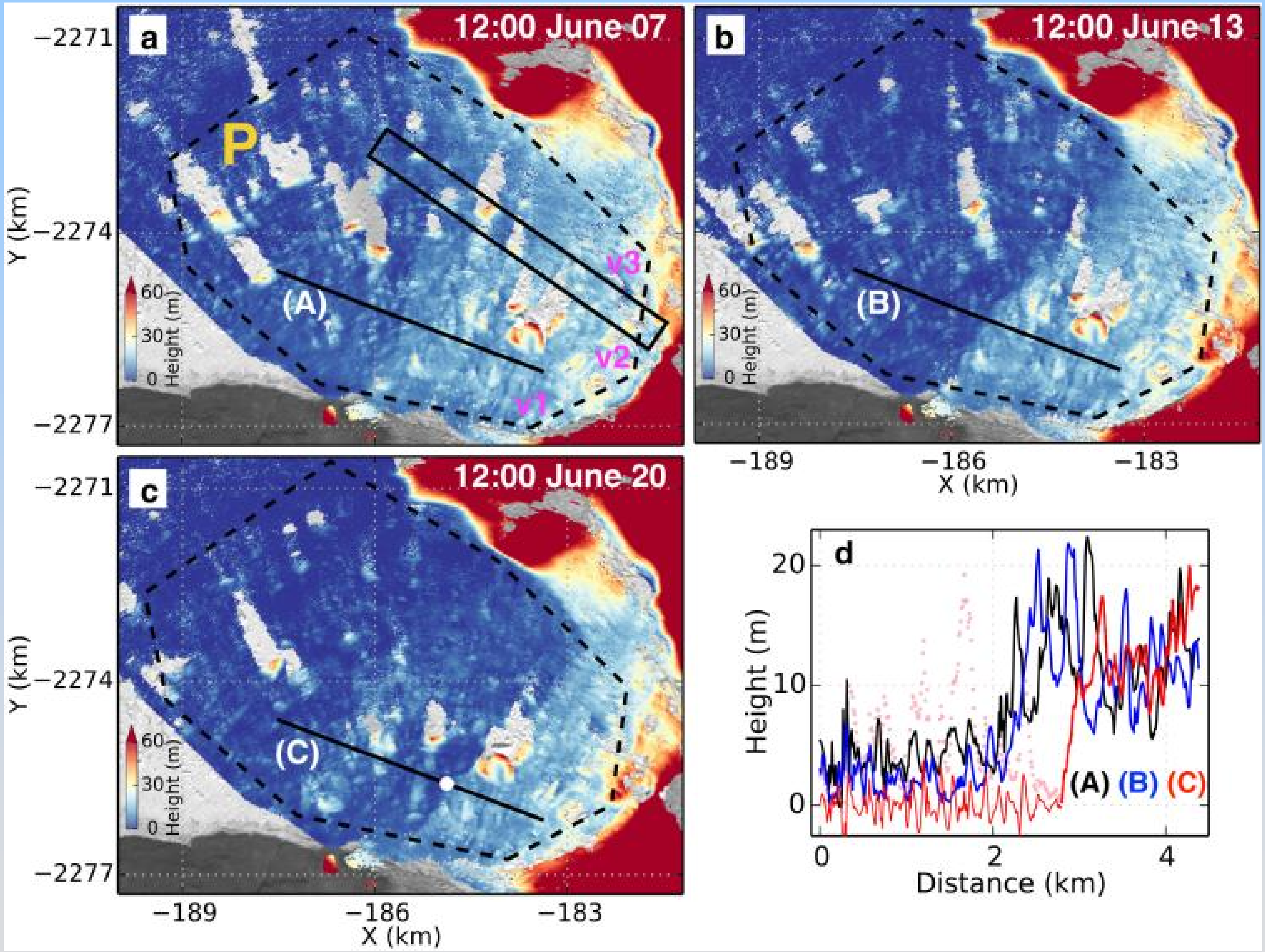


Melange buttresing: can tightly packed melange can reduce iceberg calving via backstress?

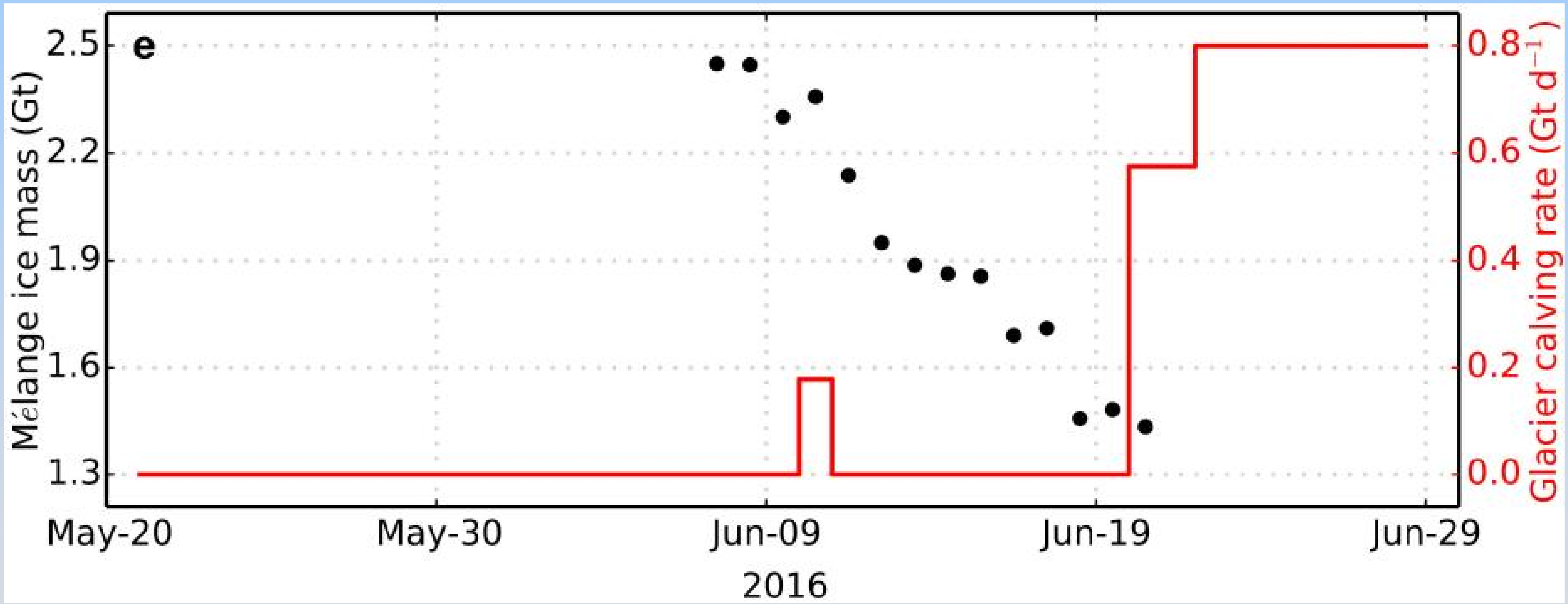


- **TRI at Jako – the movie**

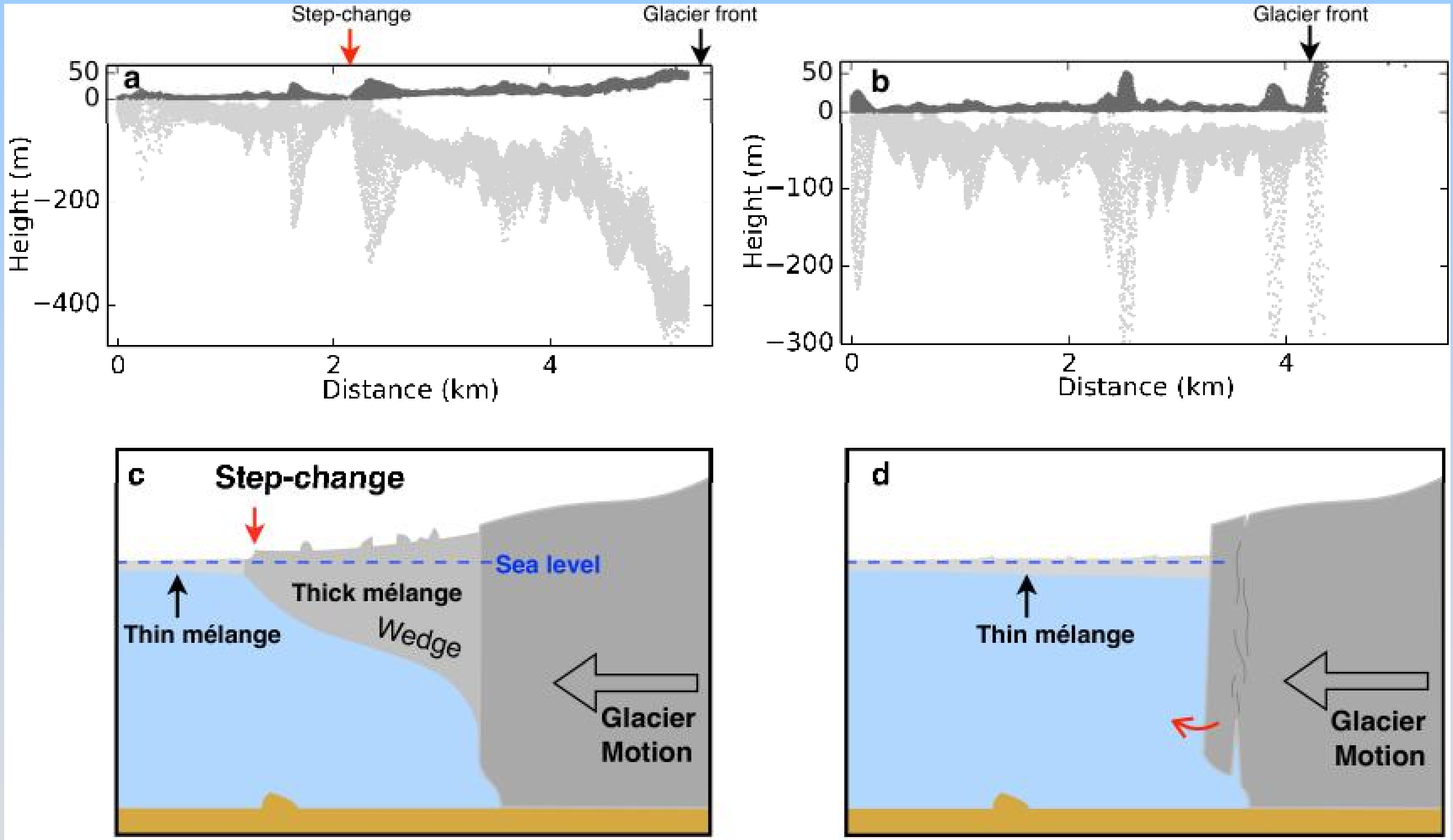
Time-Varying DEMs



Calving rate increases when melange mass in front of glacier drops below critical value



Model: thick melange wedge in front of glacier may reduce growth of basal crevasses



The Future

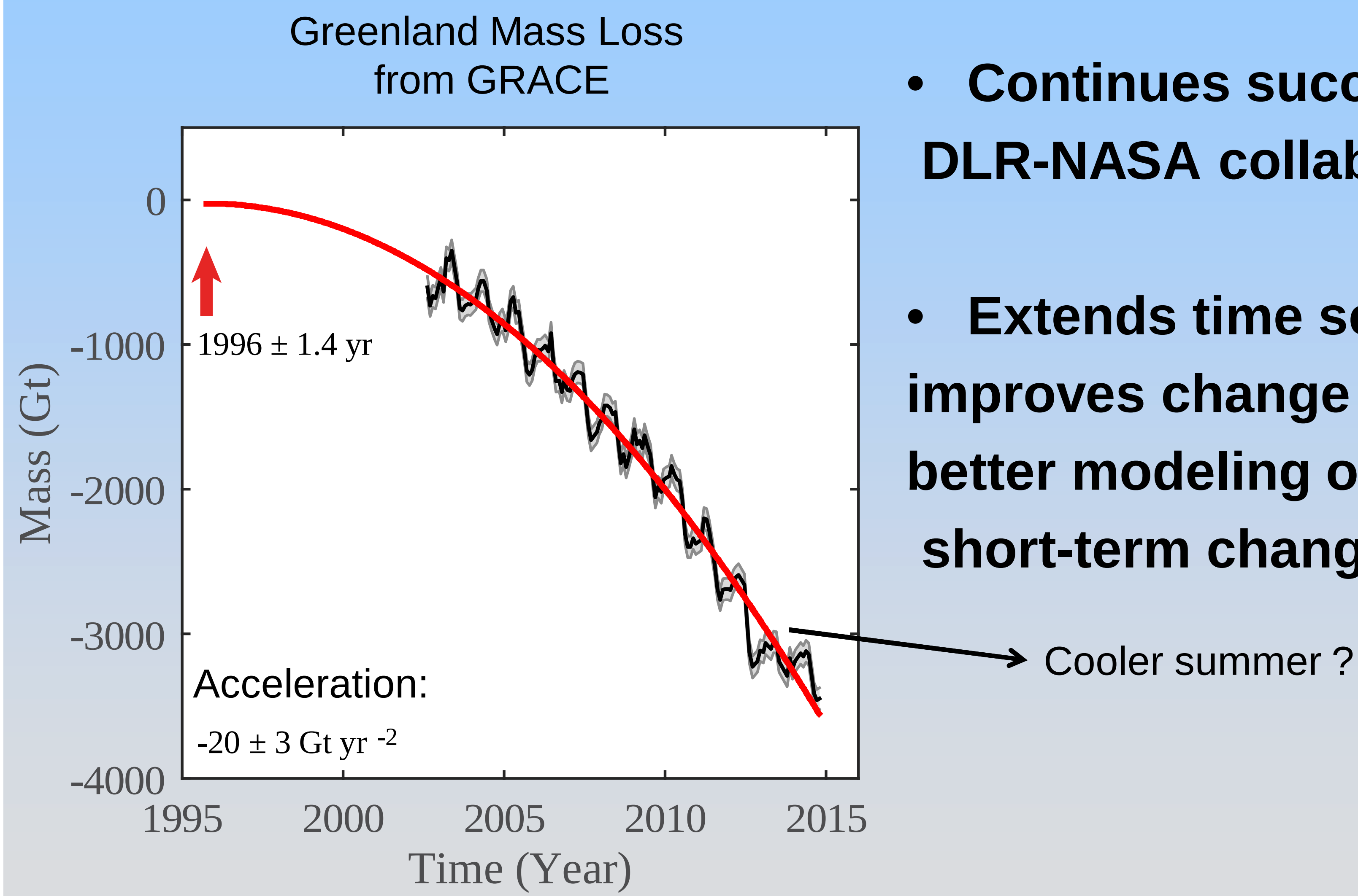
Sentinel

Sentinel

- **Sentinel's free and open data policy is leading to a large increase in the number of users, including young people who have never worked with SAR data**

- **Combined with the increasing availability of easy-to-use, open source software, this will lead to an explosion of new applications**

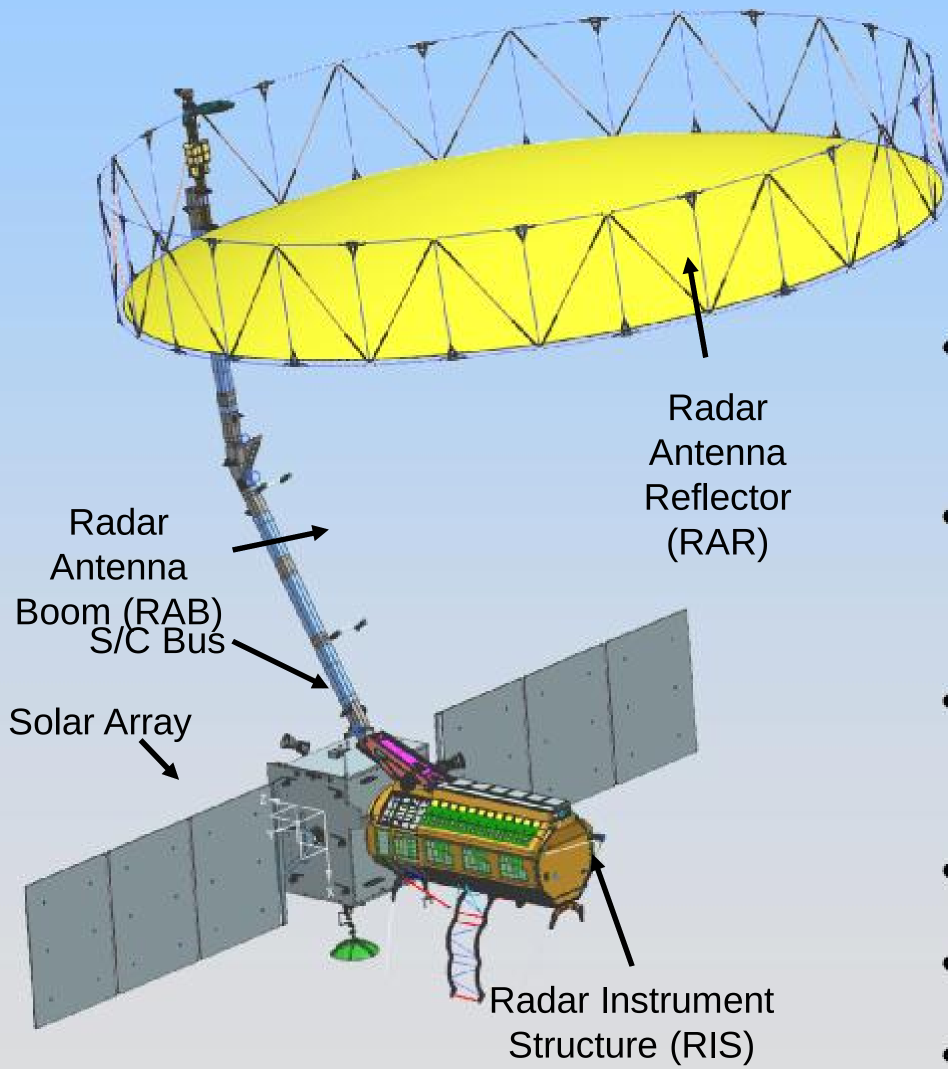
GRACE Follow On (GRACE FO)



- **Continues successful DLR-NASA collaboration**

- **Extends time series, improves change detection, better modeling of short-term changes**

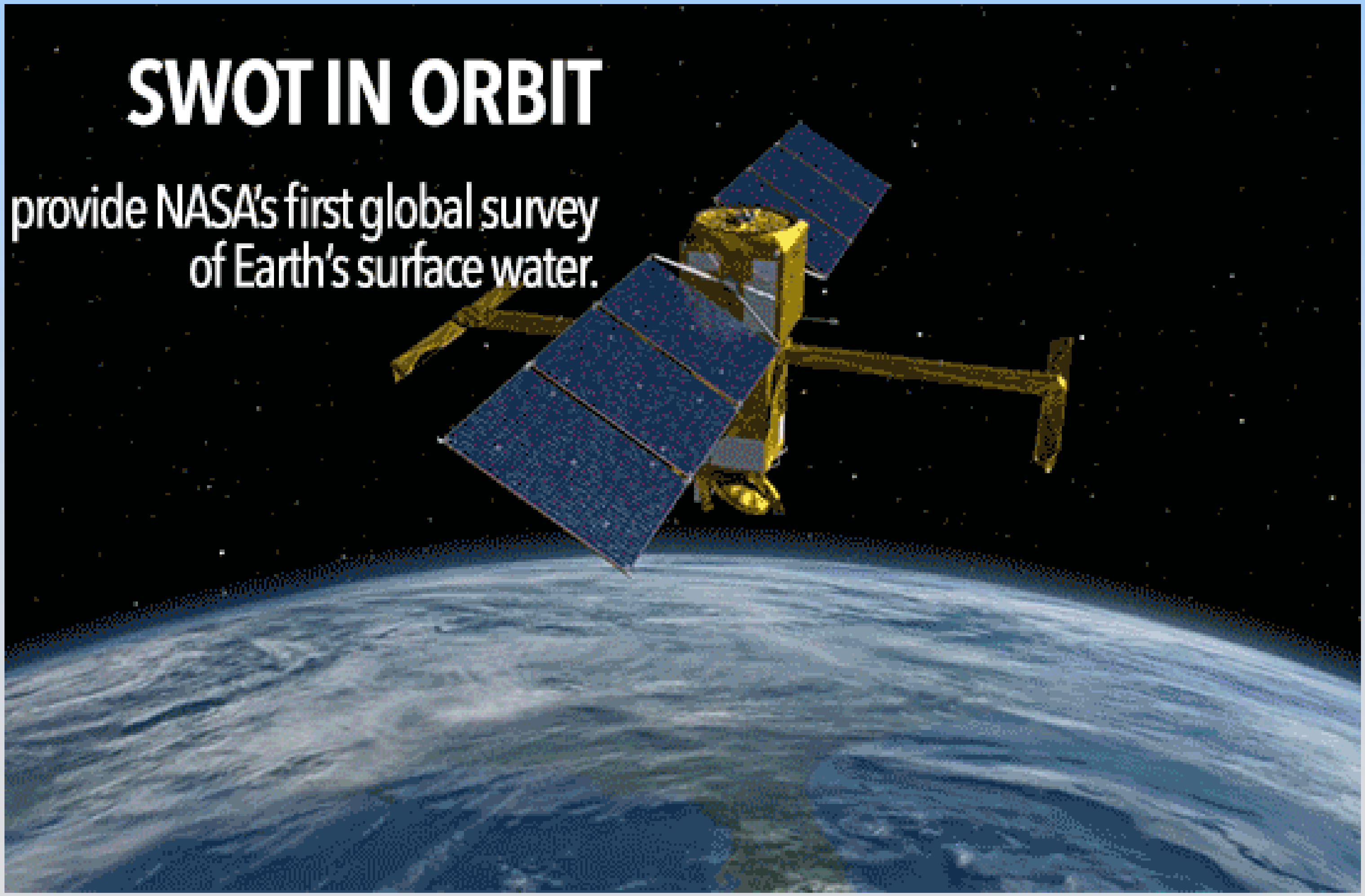
NISAR (NASA-India SAR)



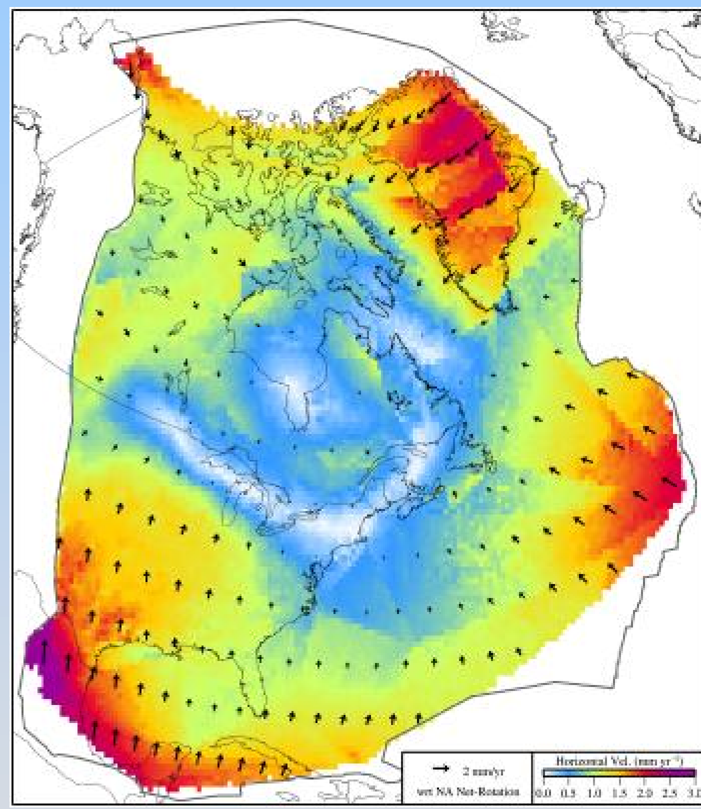
- **Quad-pol, dual frequency (L, S)**
- **240 km swath width (Sweep-SAR)**
- **Global coverage, 12 day repeat**
- **35 Tb/day**
- **Launch 2022**
- **Open data policy**

SWOT: Surface Water and Ocean Topography

* CNES-NASA Collaboration, 2022 launch
* Ocean Altimetry plus large lakes and rivers-hydrology and coastal flooding applications



Assimilation of high precision GNSS data into realistic Earth rheology models



Robust Estimation of 3-D Intraplate Deformation of the North American Plate From GPS, JGR: 123, 4388-4412

Local Geodesy

- **Reduced size of electronic components and falling costs lead to new instrumentation**
- **Terrestrial radar interferometry (TRI), LIDAR, GPS-GNSS, low cost drones and improved communication systems promote new applications**

Structure From Motion (SfM)

- Creates high resolution DEMs from photographs
- Augments and in some cases will replace airborne LIDAR

SfM video

- https://www.youtube.com/watch?v=Wu_SdeAGzBk

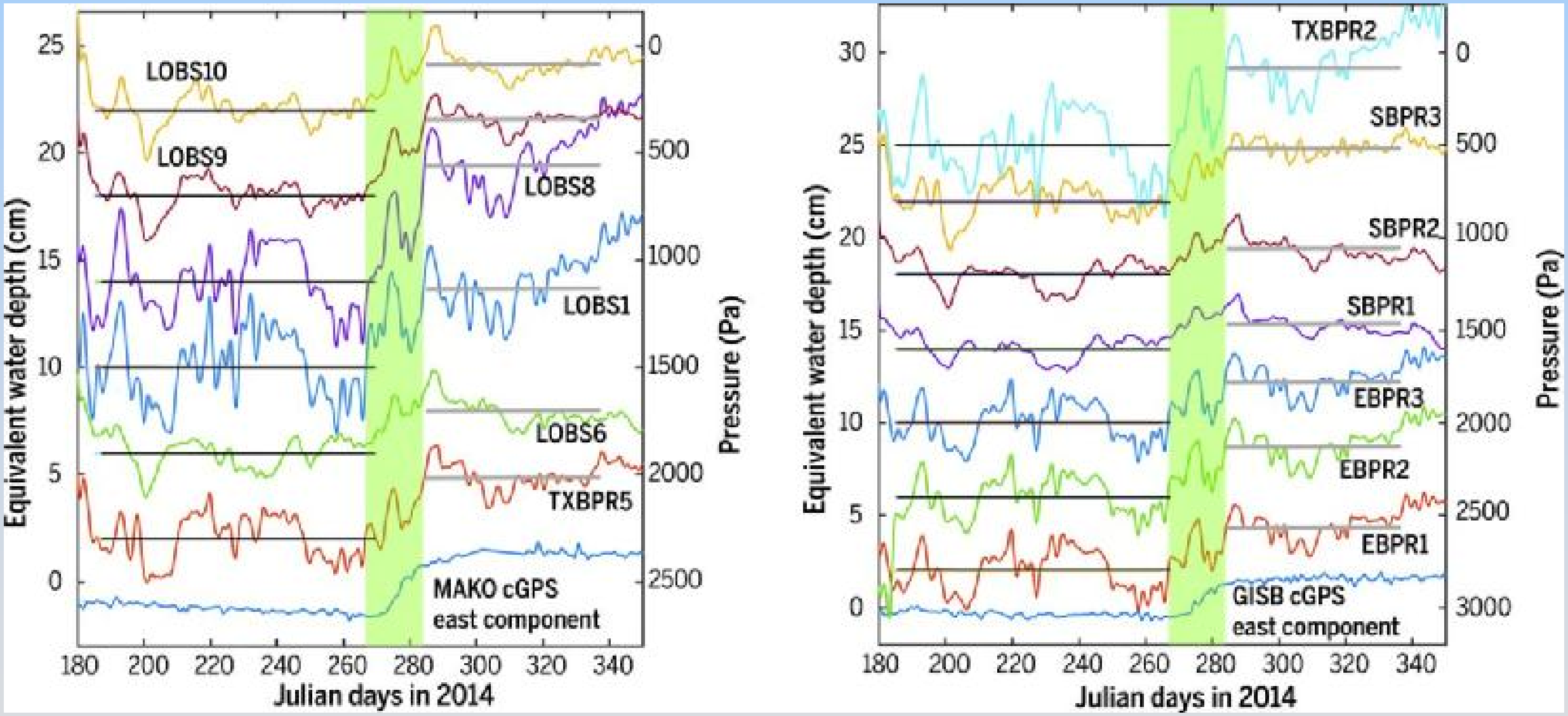
Sea Floor Geodesy – the next frontier

- **Critical for hazard assessment – will improve forecasting of subduction zone earthquakes and tsunamis**

Sea Floor Geodesy – Shallow Water

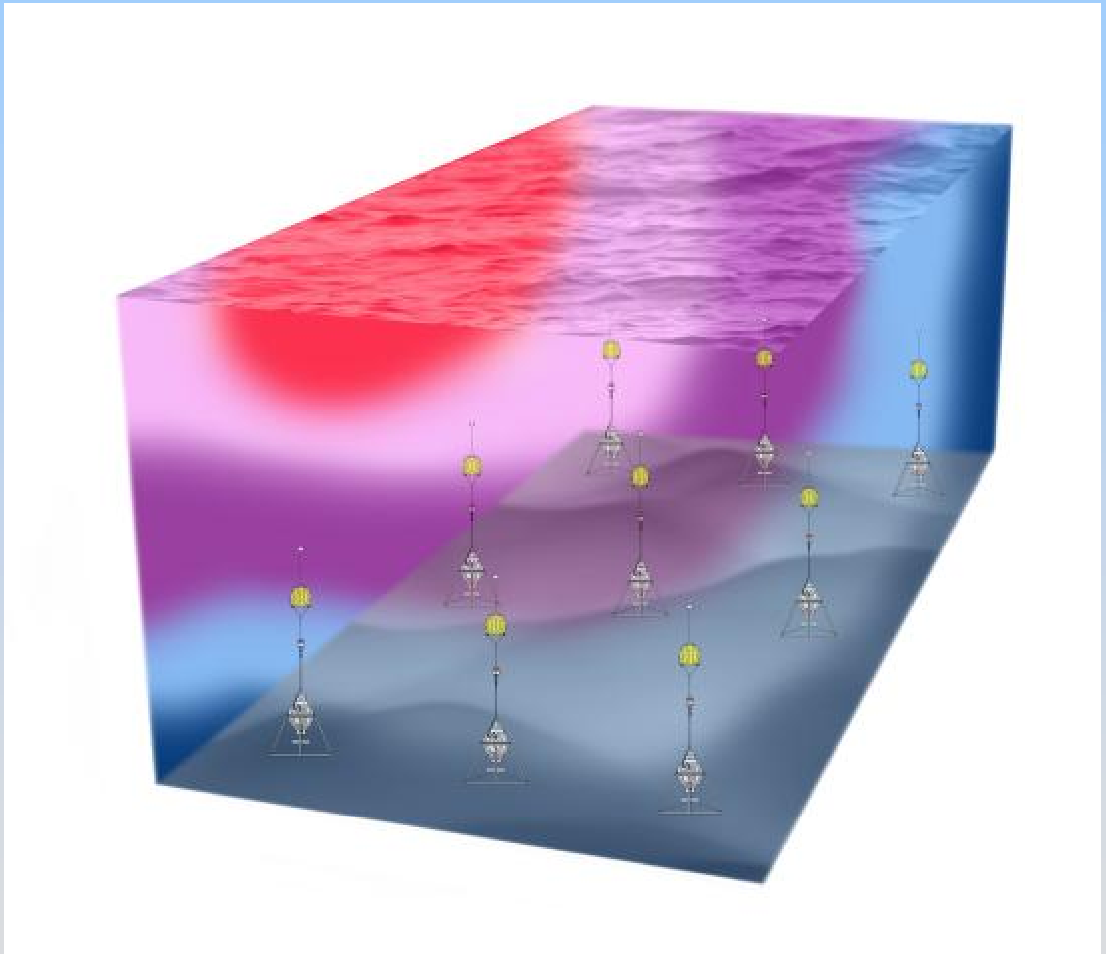
Sea Floor Geodesy in Deep water: More Challenging

- **Sea floor pressure gauges – some events are near the noise limit of this technique, due to oceanographic noise**
- **We need to calibrate ocean contribution to pressure change**



Wallace et al., Science 2016

Calibrating the Ocean Contribution to Sea Floor Pressure Change with Inverted Echo Sounders



Speed of sound in water is sensitive to temperature and salinity, both of which affect ocean density

Autonomous (driverless) cars

- **New demand for high resolution DEMs, up-datable "cityscapes" and real-time navigation (geodetic tools)**
- **Promotes concept of "sharable" personal transportation**

Autonomous, Low Cost Air Taxis

- **Continued development of**
  - **Autonomous vehicles**
  - **Electric, programmable drones**
  - **Acceptance of sharable personal vehicles**

- **Combined with increasing traffic congestion in large cities…**
- **Will lead to development of economical air taxis**
- **This will increase demand for high resolution 4-D DEMs (updatable DEMs) for urban landscape, and advanced tracking & navigation systems**

How Far in the Future?

How Far in the Future?

- **VIDEO of DRONE Air Taxi**
- **https://www.youtube.com/watch?v=IYfzK6uYI14#action=share**
- **https://futurism.com/videos/ehang-air-taxi-passengers**
- **https://www.youtube.com/watch?v=alKb0p3KN8E**

What is Required?

1. Better, cheaper urban DEMs (including buildings)
2. Real time navigation
3. Obstacle detection (radar, LIDAR)
4. Integration of 1, 2 and 3 using AI for safe, autonomous operation

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=> job opportunities for next generation geodesists!

Dank u!