Remote sensing of rivers and lake water heights (part I)

face 2 face workshop Soil Moisture and Inland Water Monitoring with Satellite Radar

Dar es Salaam, Tanzania, 19th October 2023

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esa

UNIVERSITY OF TWENTE.

ITC

→ THE EUROPEAN SPACE AGENCY

Intensification of the water cycle

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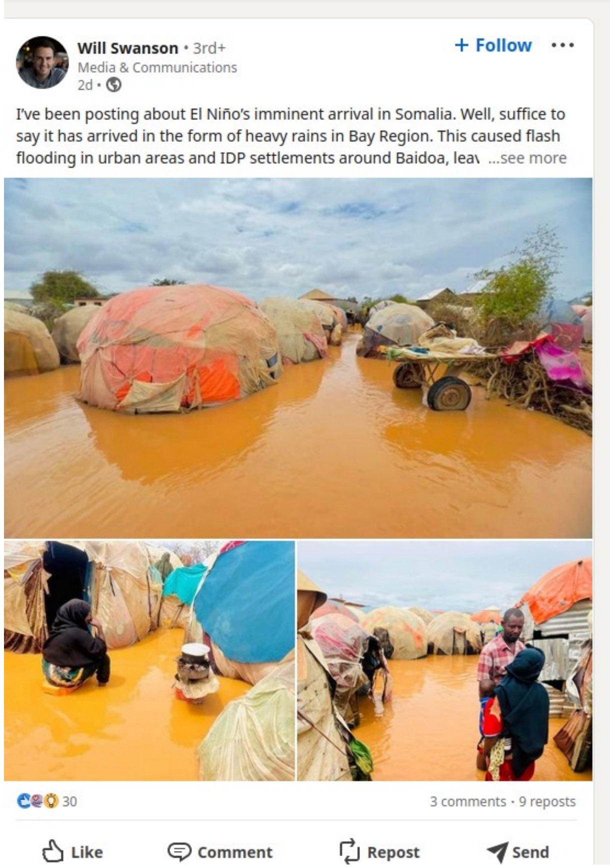
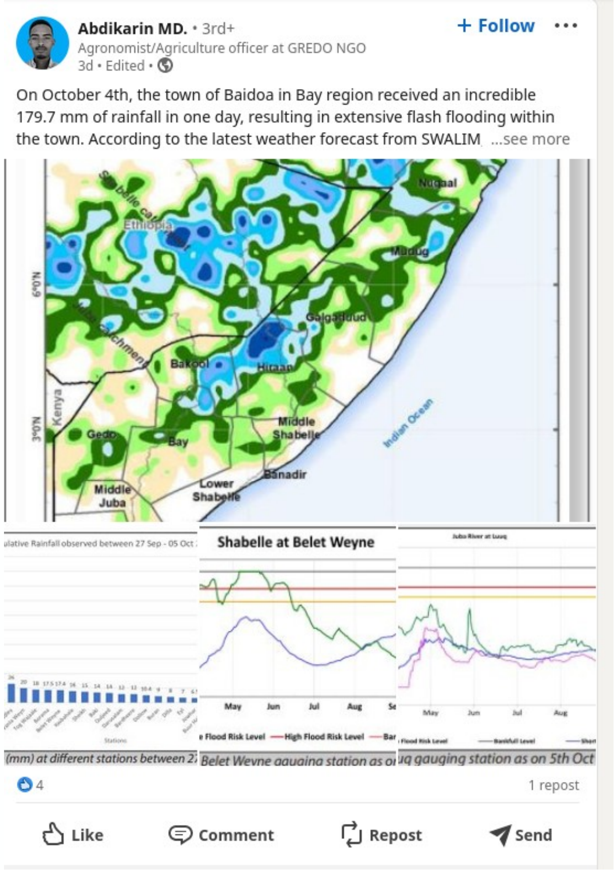
Flash floods October 2023

- After a multiyear drought in the Horn of Africa
- 180 mm of rain in one day…





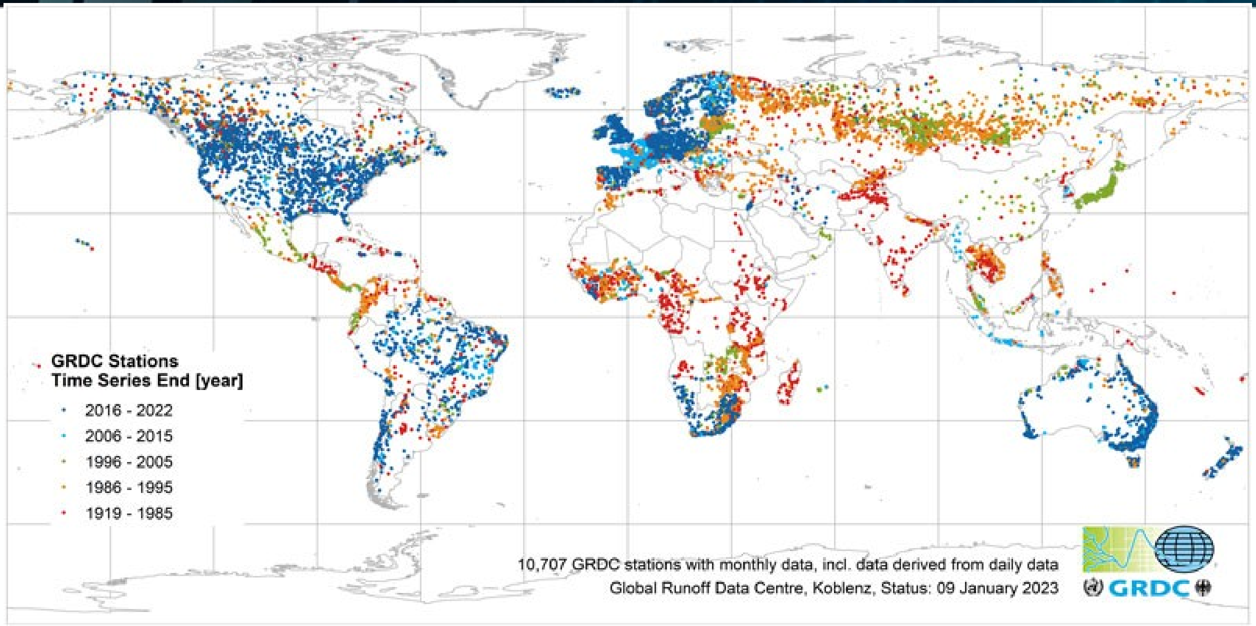
Today (& tomorrow)

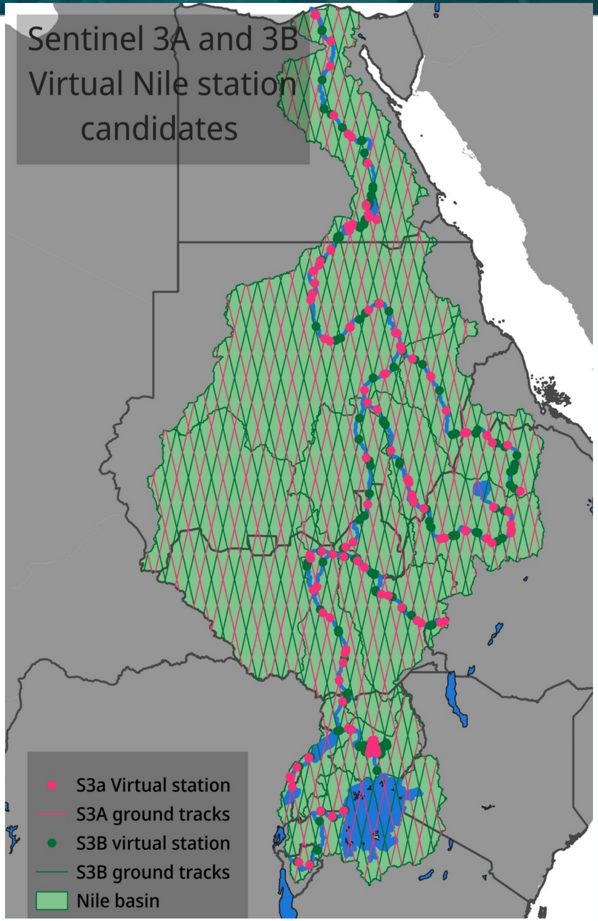
- Motivation of measuring lake and river heights from space
- Principles of radar altimetry
  - “conventional” radar altimetry (pulse limited)
  - “modern” radar altimetry (beam limited)
  - Geophysical corrections

Surface water heights

- Water height potentially provides information on water cycle parameters:
  - River discharge
  - Lake capacity and extent
- In situ measurements (not always possible/available)
  - Point measurements
  - High temporal resolution (min →)
- Satellite platforms: lidar (e.g. icesat), radar altimetry (covered in this module)
  - Comprehensive (near global) spatial coverage
  - Low temporal resolution (10 days →)

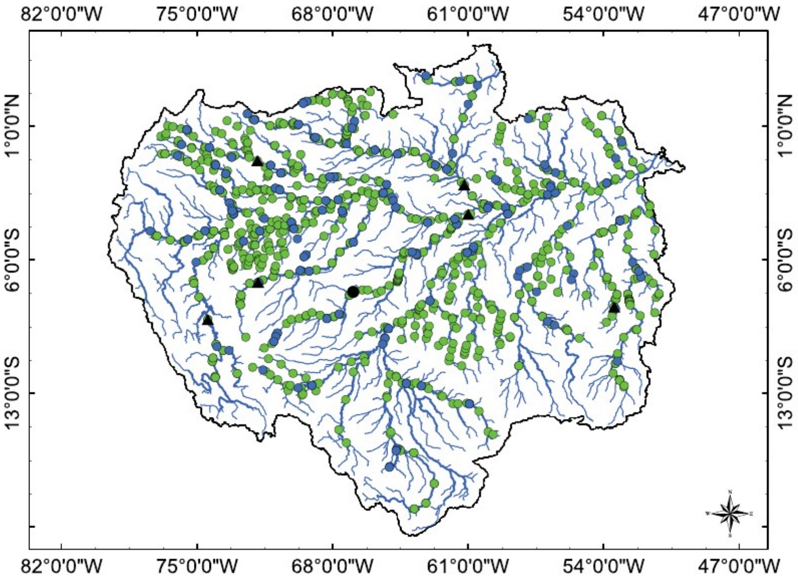
Remote sensing of rivers





It’s becoming increasingly difficult to obtain recent in situ discharge data in many rivers of the world

River discharge from radar altimetry



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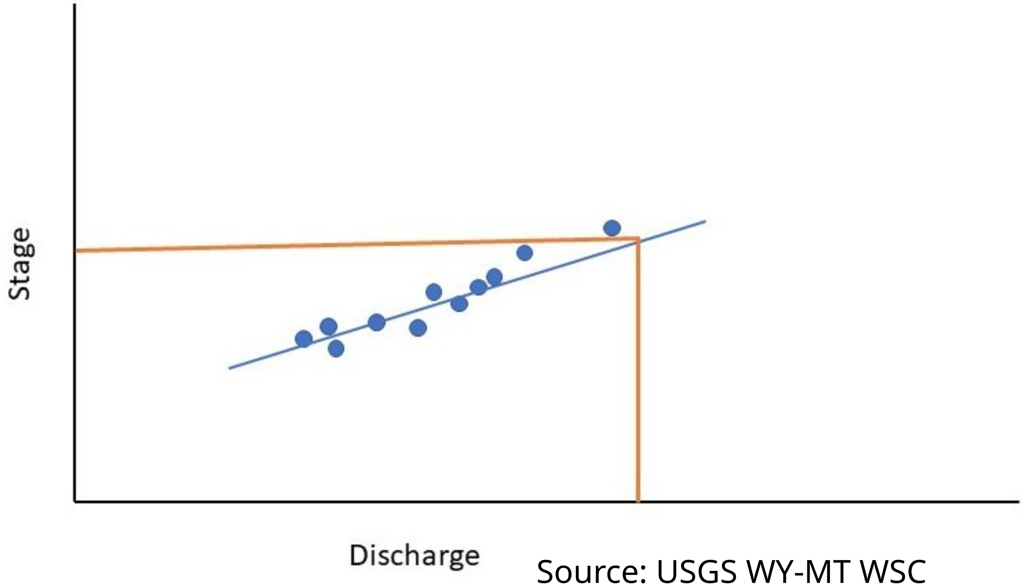
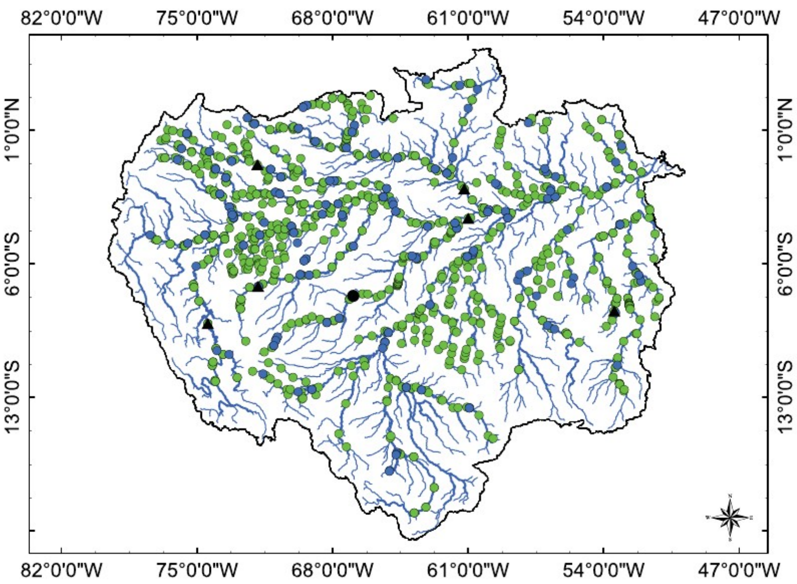
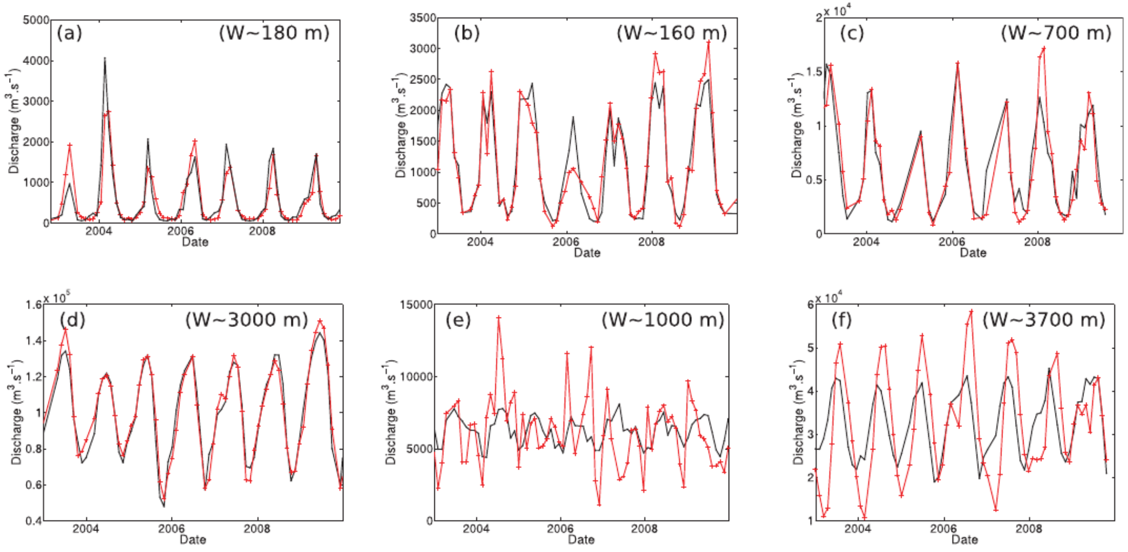


Source: USGS WY-MT WSC

Paris et al. 2016, Stage-discharge rating curves based on satellite altimetry and modeled discharge in the Amazon basin

River discharge from radar altimetry

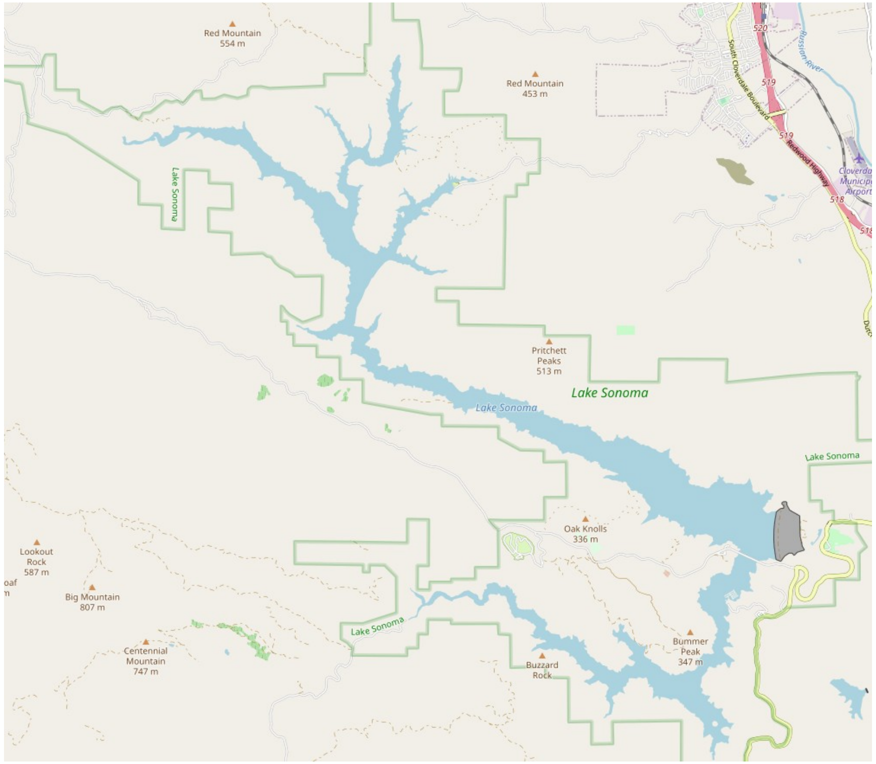




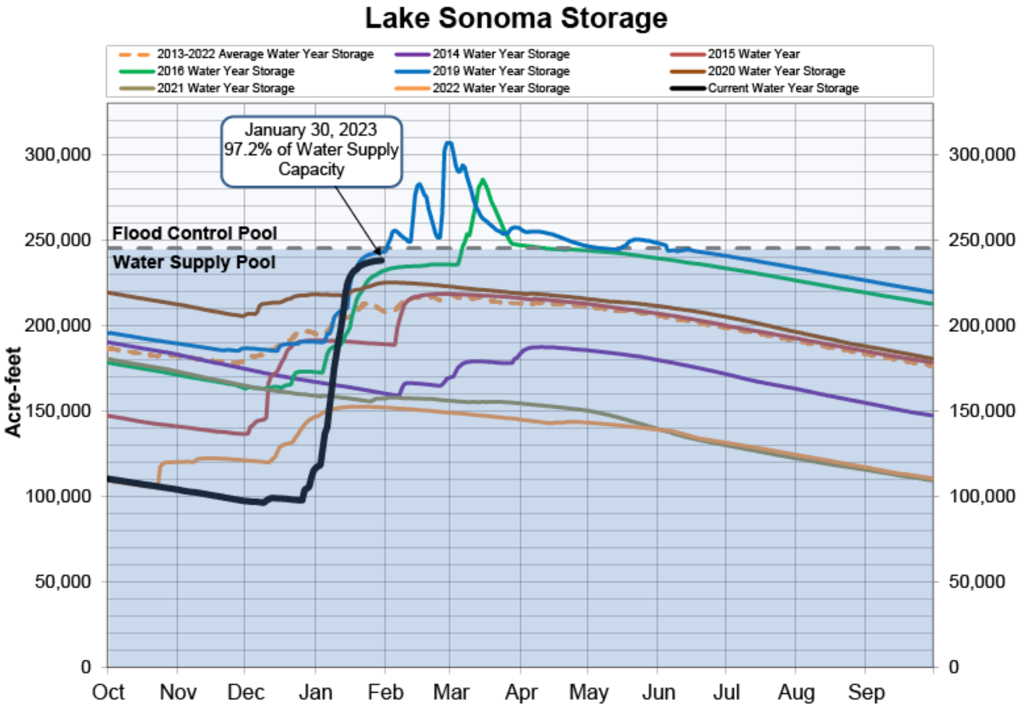
Red: from gauges, black: from altimetry

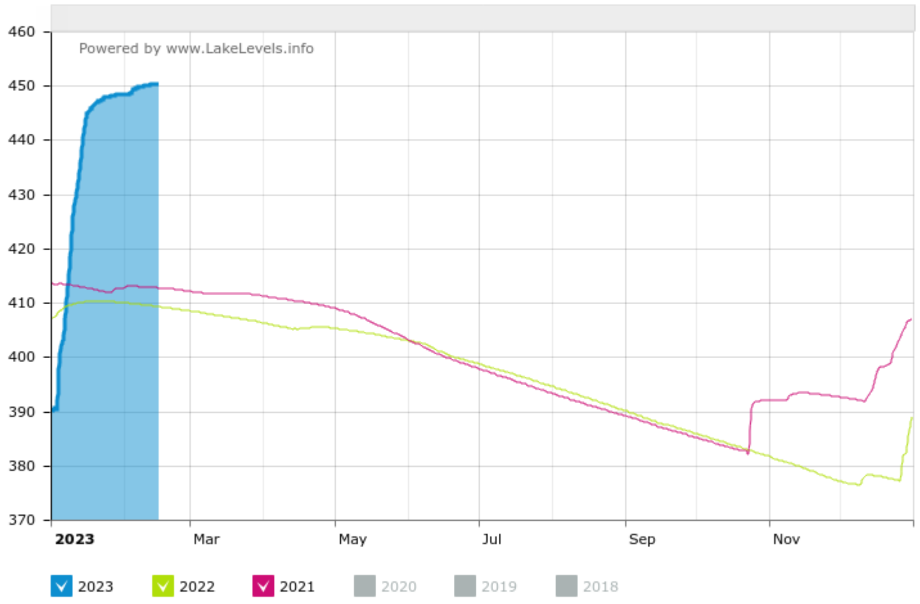
Paris et al. 2016, Stage-discharge rating curves based on satellite altimetry and modeled discharge in the Amazon basin

Water management with Lake elevation-area-volume



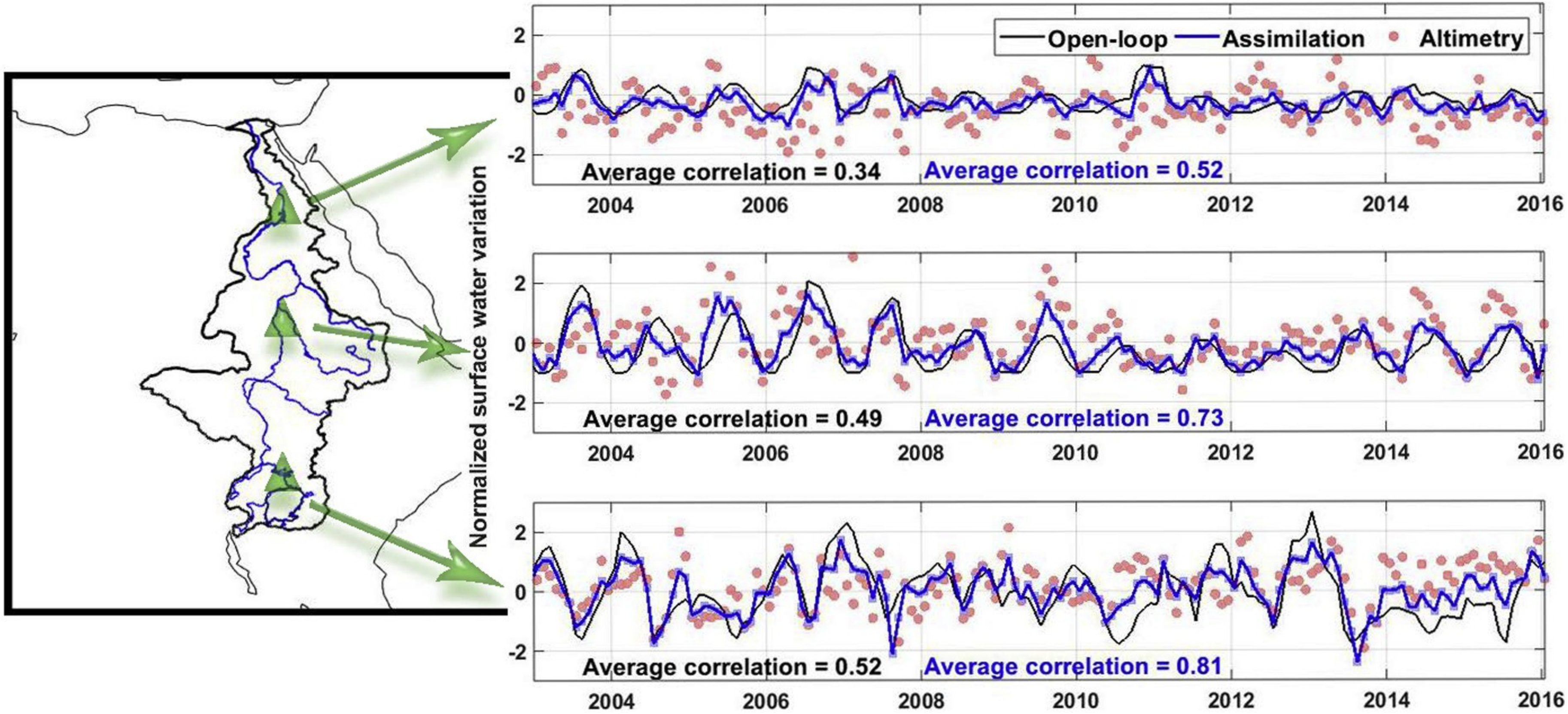
Water management with Lake elevation-area-volume





https://www.sonomawater.org/current-water-supply-levels

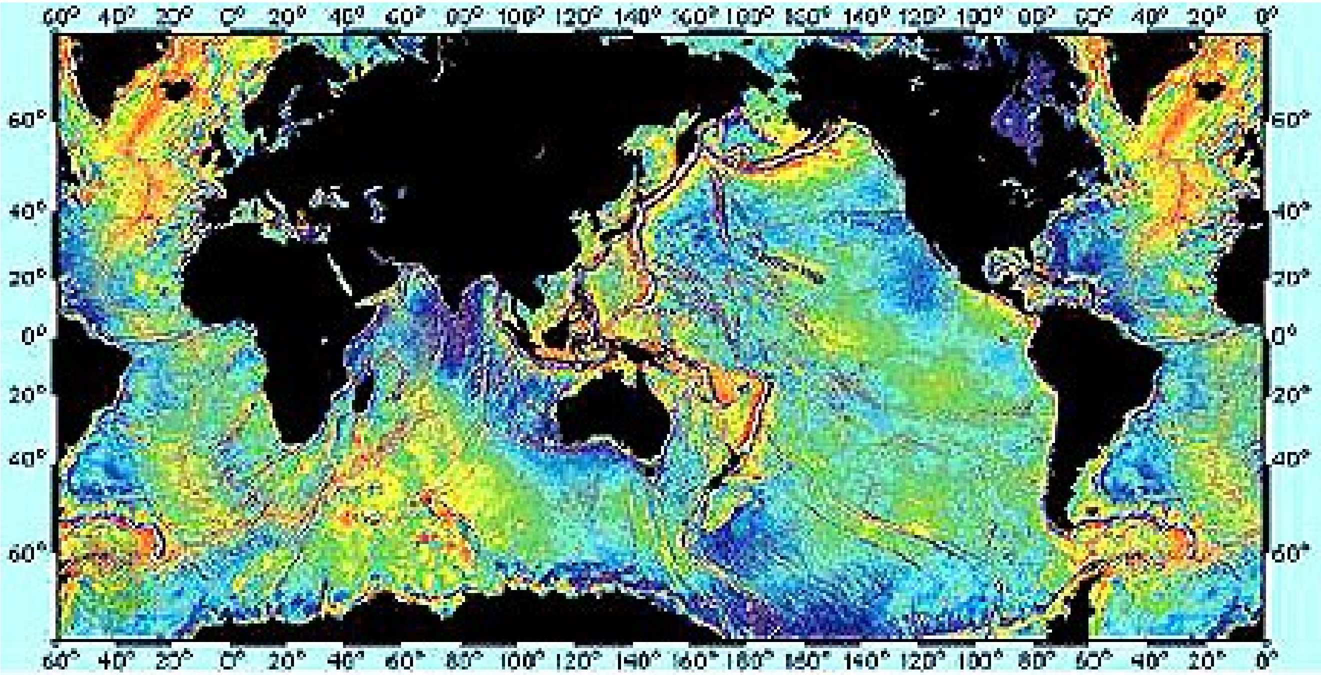
Potential for data assimilation



Khaki et al 2020, data assimilation of radar altimetry in the W3A hydrological model

A first look at the ocean with seasat (1978)

- What is shown here?



A first look at the ocean with seasat (1978)

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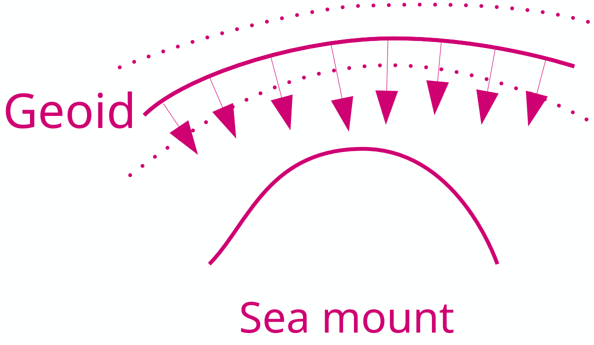
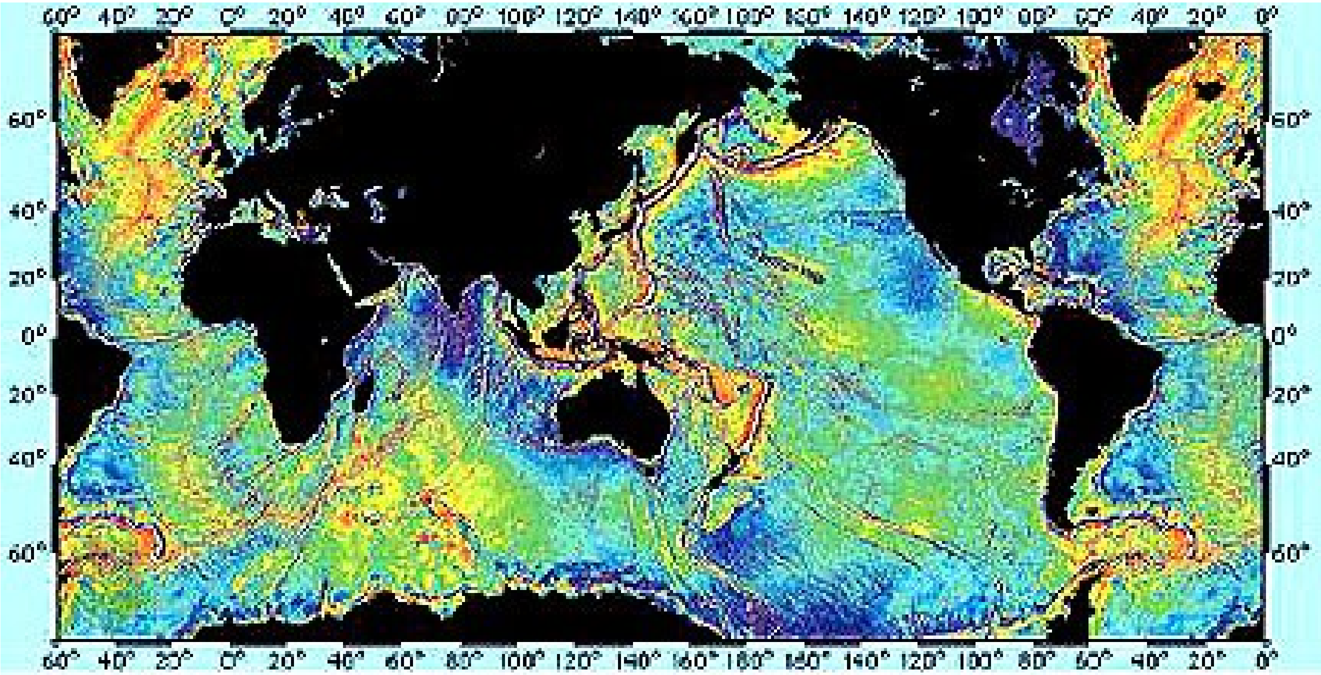




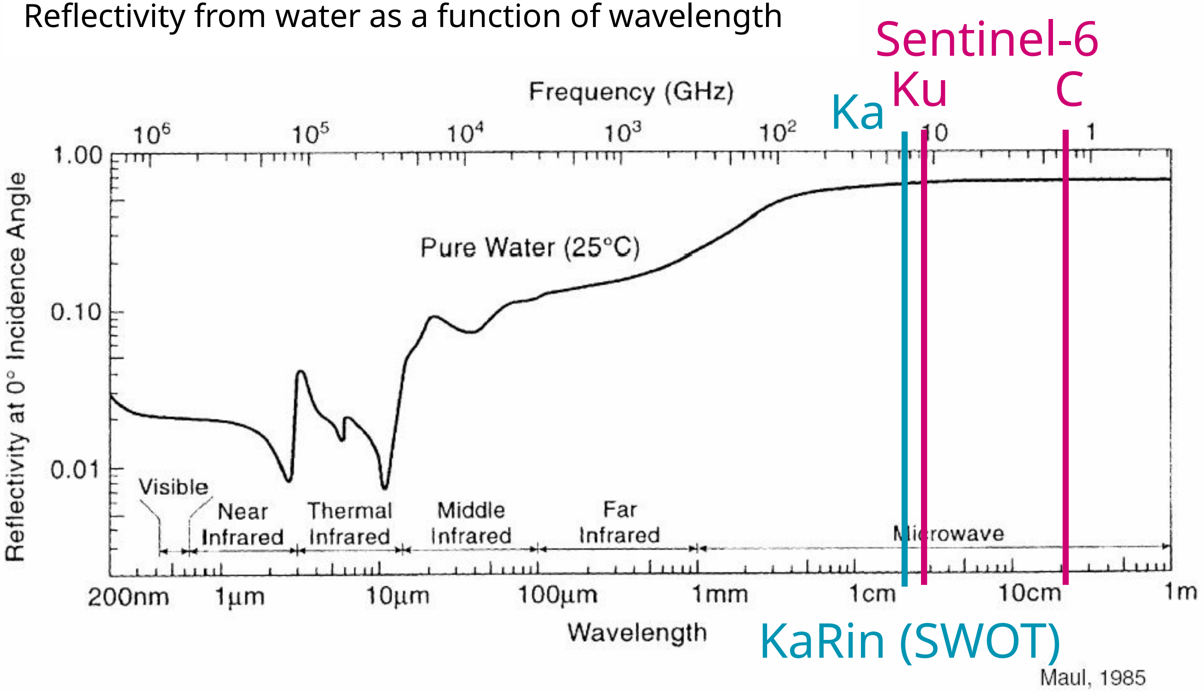
Seasat (1978) marine geoid. credit JPL

Why radar (microwaves)?

- In nadir direction: microwaves reflect well on water

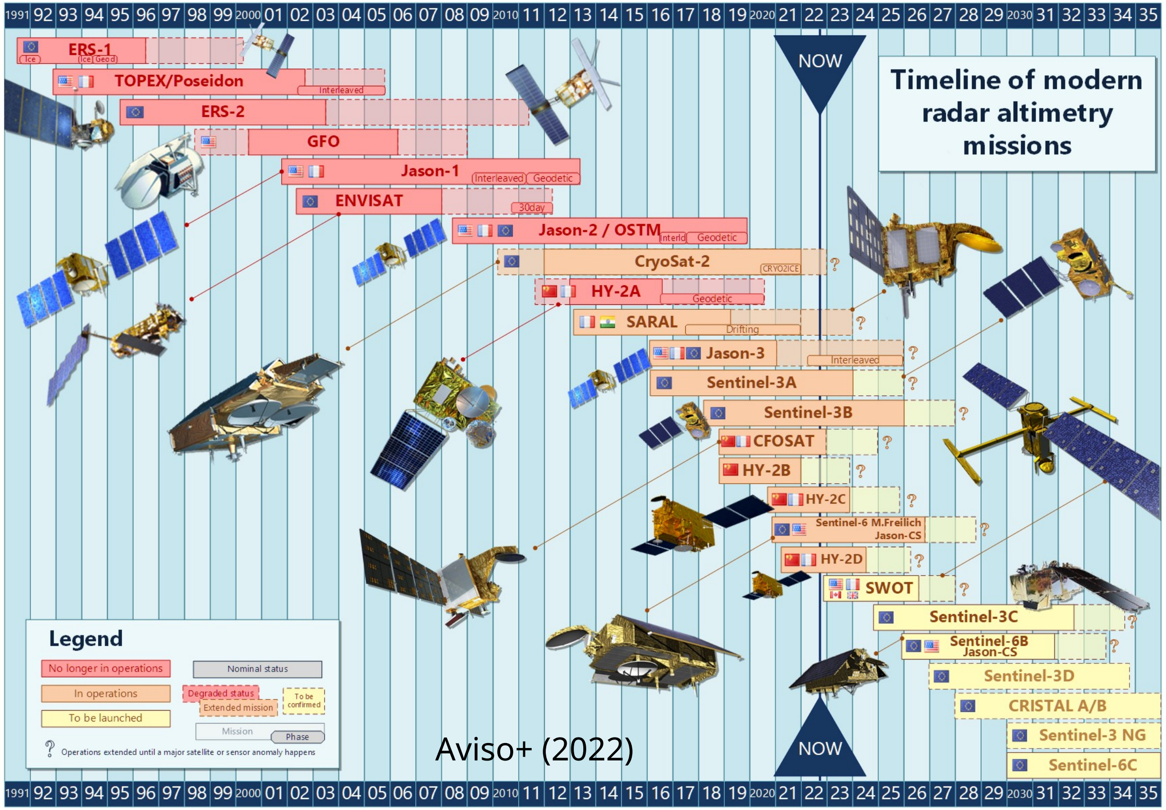
- Bands used in radar altimetry
  - S Band 1.55 – 4.20 GHz
  - C 4.20 - 5.75 GHz
  - X 5.75 – 10.9 GHz
  - Ku Band 10.9 - 22.0 GHz
  - Ka Band 35 GHz

Reflectivity from water as a function of wavelength

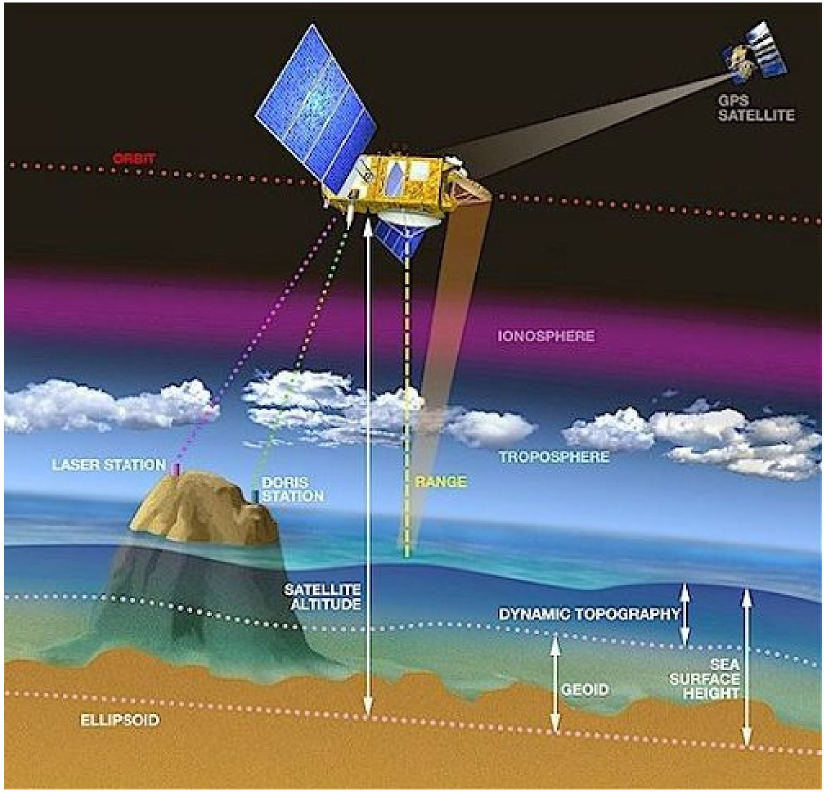


Radar altimetry since the 1990's

- Mainly ocean focused (geoid, bathymetry, sea surface variations, sea level)
- International efforts

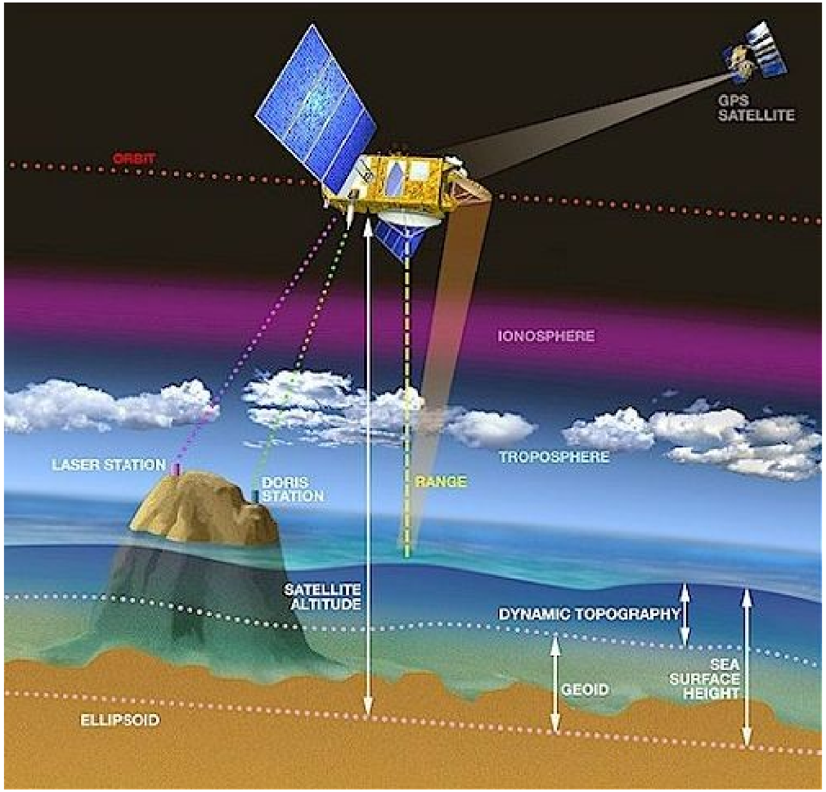


What would an altimeter system need to function?



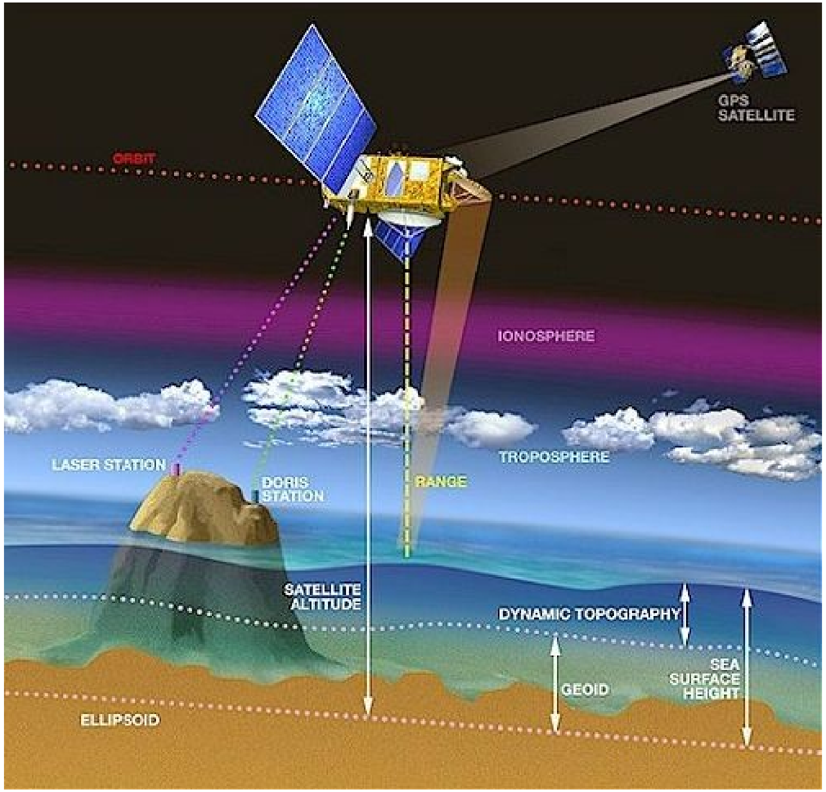
What would an altimeter system need to function?

- Orbit (altitude above ellipsoid)



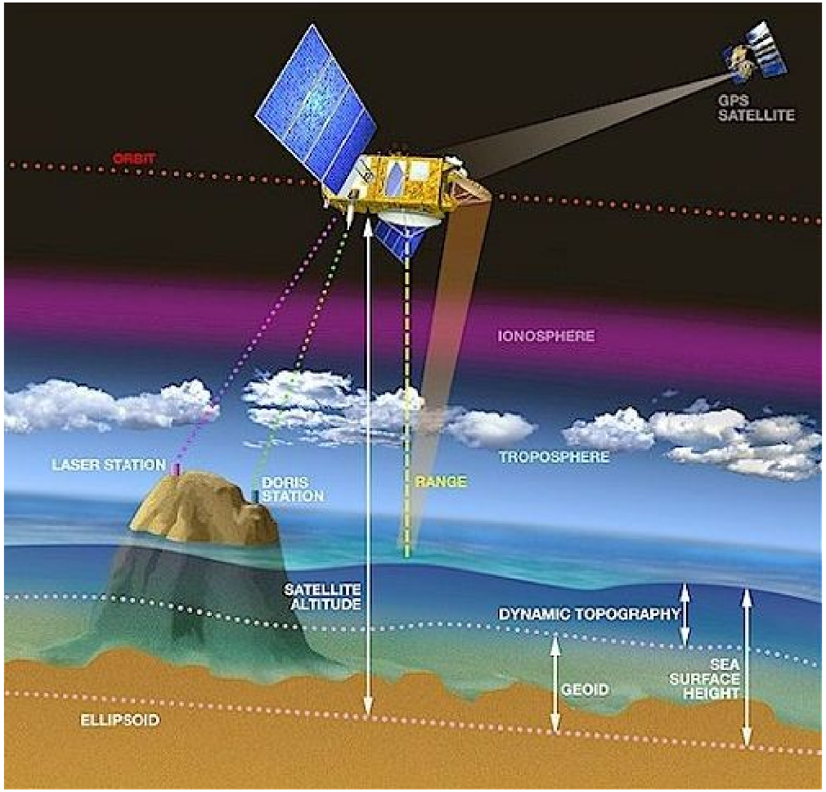
What would an altimeter system need to function?

- Orbit (altitude above ellipsoid)
- Range



What would an altimeter system need to function?

- Orbit (altitude above ellipsoid)
- Range
- (Geophysical) corrections (ionosphere,atmosphere, sea state bias, tides, …)

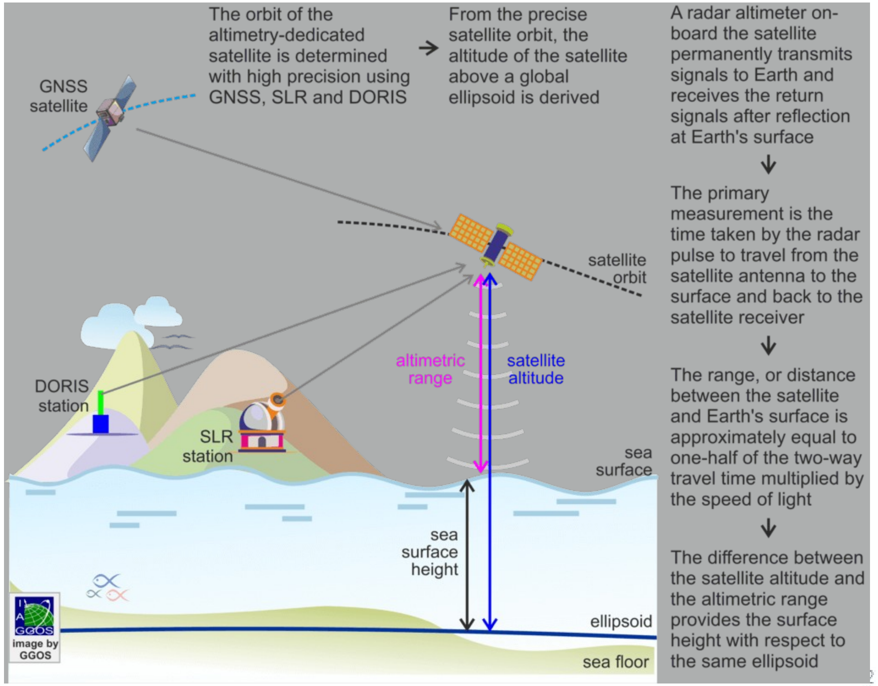


Sea (water) surface height

$$h_{water} = h_{sat} - r_{alt} \left(+ \sum h_{corr} \right)$$

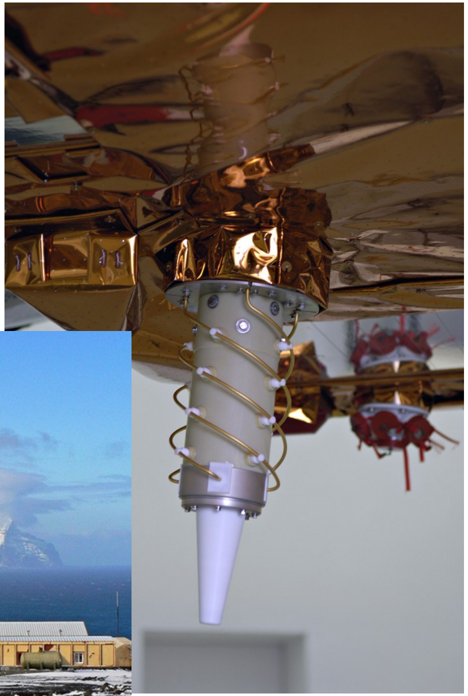
$$\sum h_{corr} = -\delta h_{dry} - \delta h_{wet} - \delta h_{iono} - \delta h_{ssb} - \delta h_{tides} - \delta h_{dac}$$

- Altimetry provides heights relative to an ellipsoid
- Various corrections need to be applied (discussed in the second part)



Precise Orbit Determination

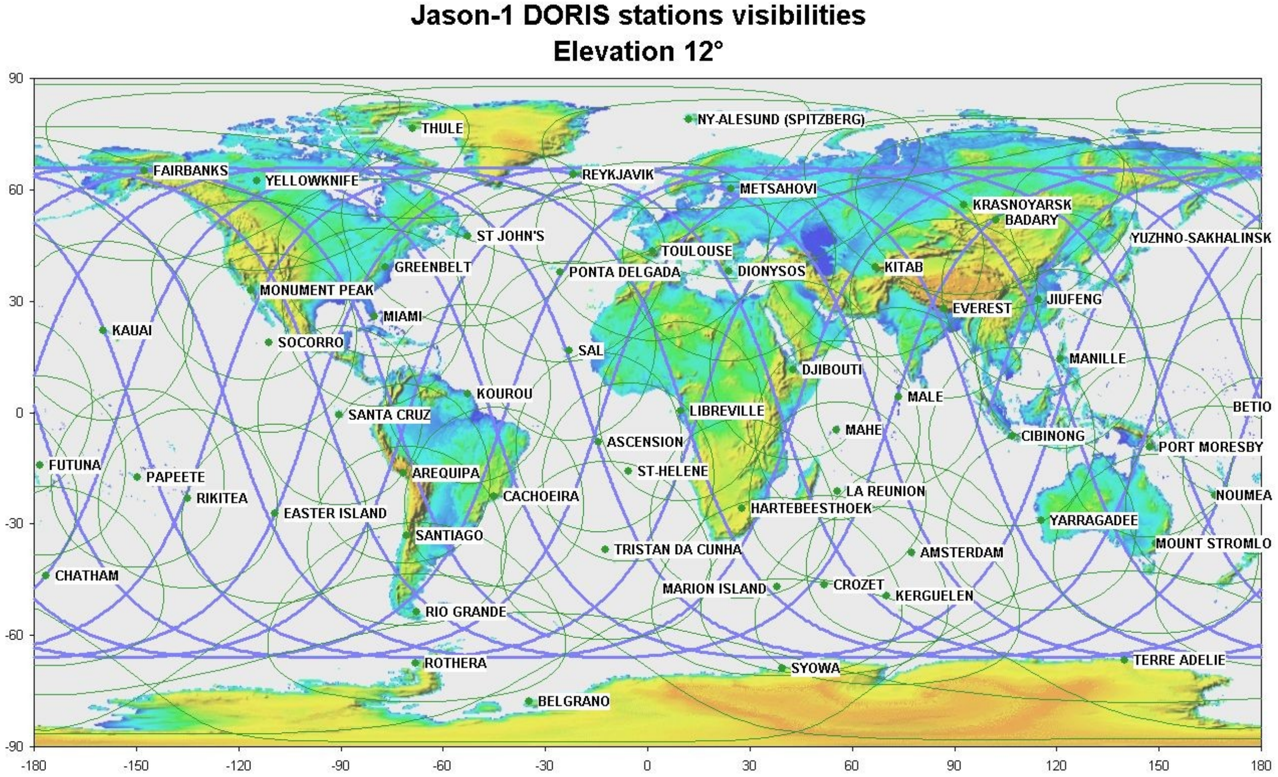
- Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS)
- Dual freq system with ground beacons
- Observes line-of-sight range changes
- Orbit + gravity field determination possible when collecting many beacon signals



DORIS station on the remote Crozet Island (credit: IGN France)

Precise Orbit Determination

- DORIS: radial orbit errors ~2cm
- Orbit errors can correlate along track



TOPEX (NASA)-like orbit

- **Inclination:** 66º
- **Height above equator:** ~1350 km
- **Repeat cycle: optimal (day) for oceanography :10,** for Geodetic phase ~300
- Quick revisit times
- No high latitude data

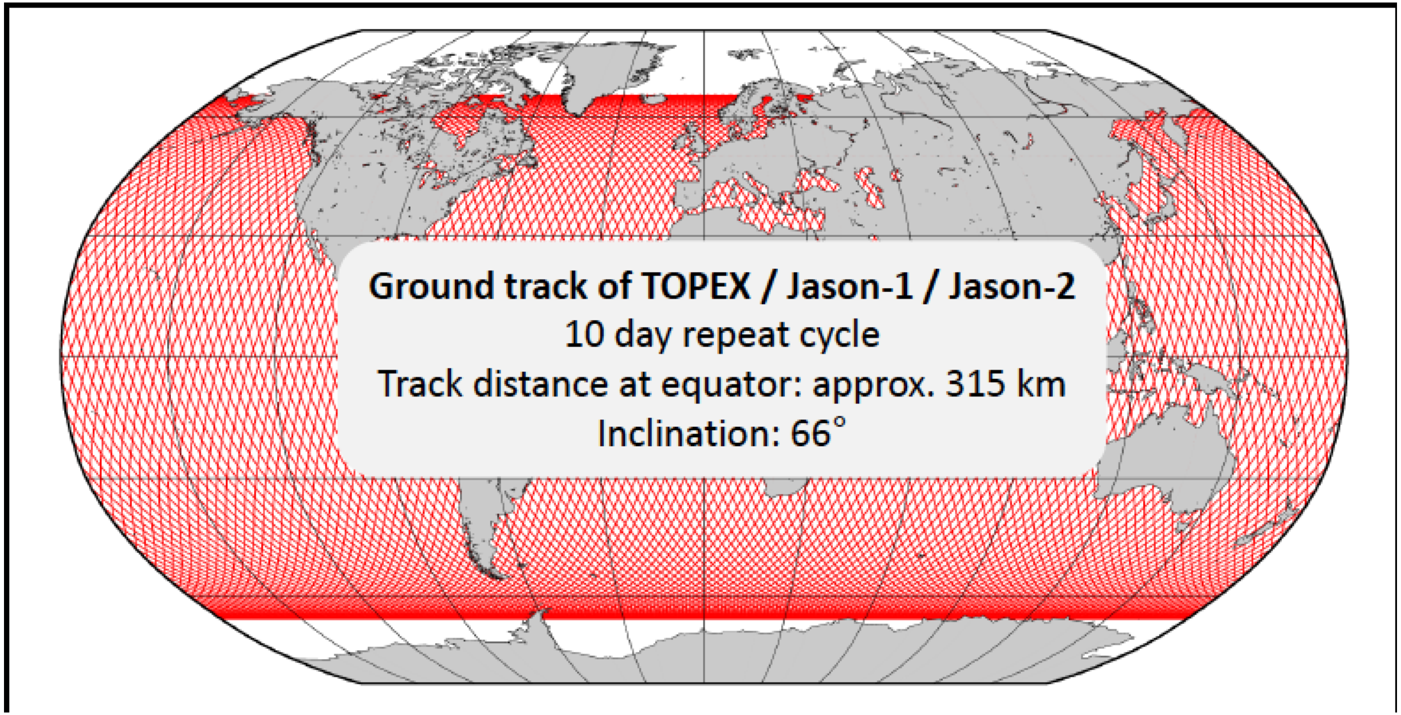


Image courtesy: L. Fenoglio

Envisat (ESA)-like orbit

- Inclination: 98º (ESA)
- Height above equator :~800 km
- Repeat cycle:
  optimal (day) for oceanography : ~35 days
- Higher latitudes visited
- Longer revisit times

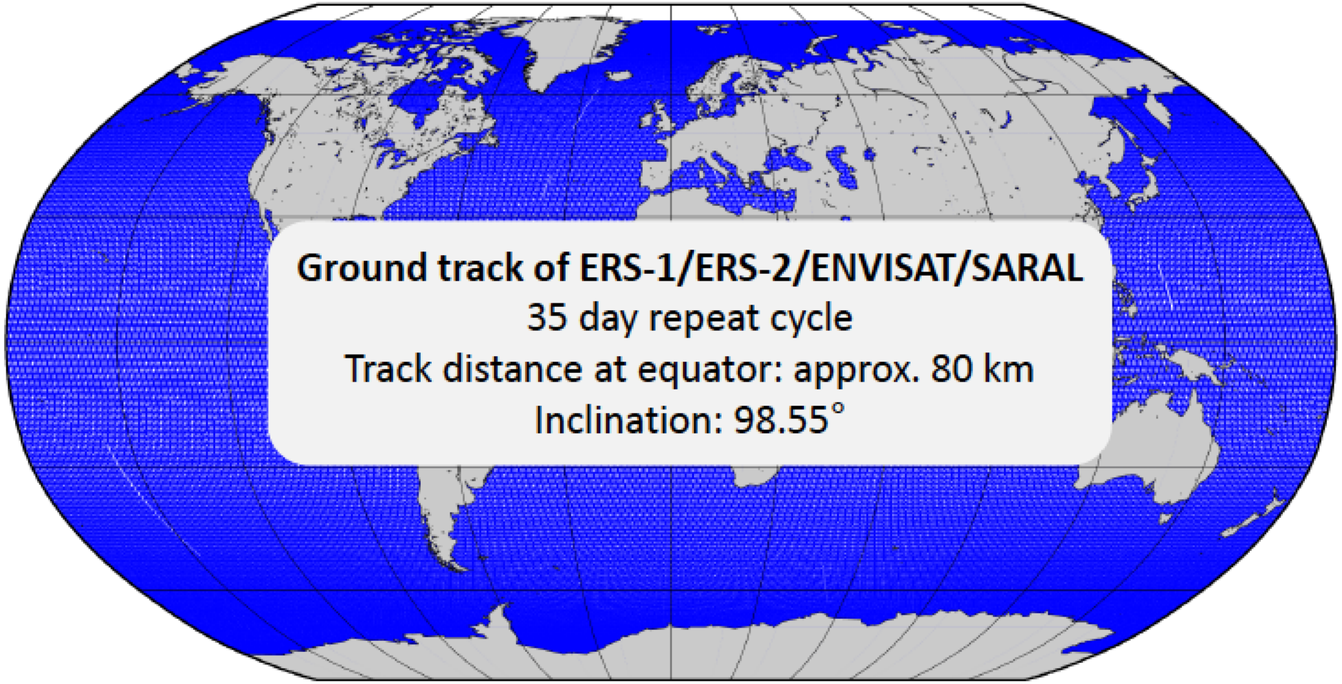
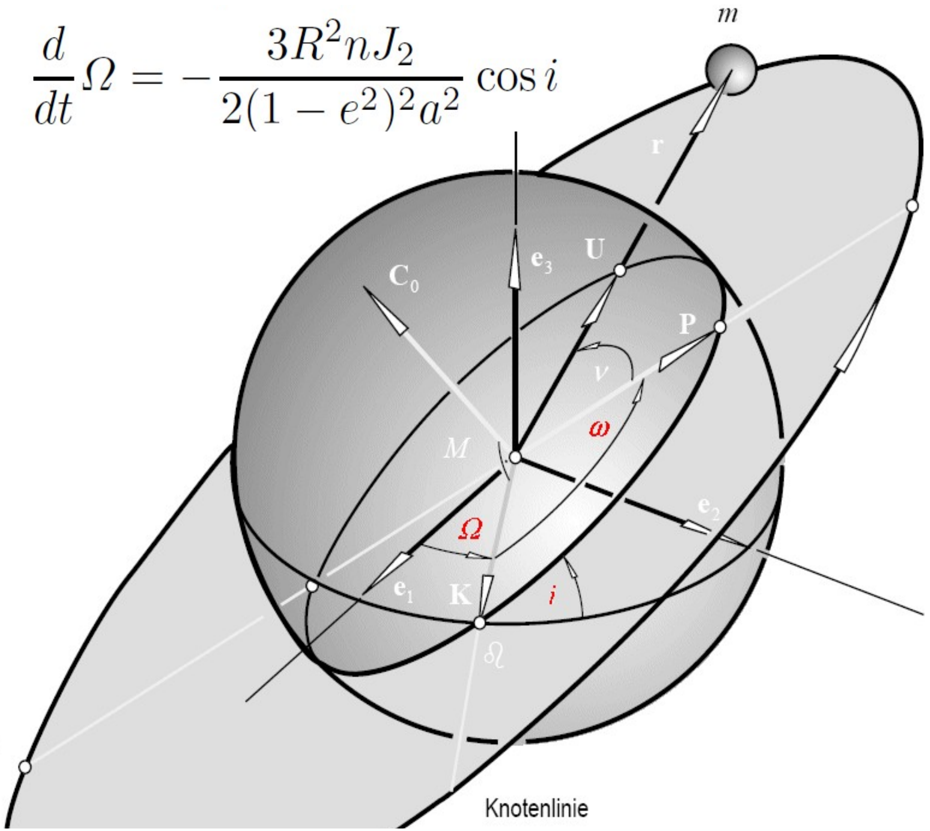


Image courtesy: L. Fenoglio

Orbit design

- Trade off between revisit time and coverage
- Inclination and height can be tuned to design repeat-orbits
  - Ellipsoidal flattening of the Earth allows tuning the rotation of the orbital plane
- For rivers and lakes:
  - Better to have high temporal or high spatial resolution?

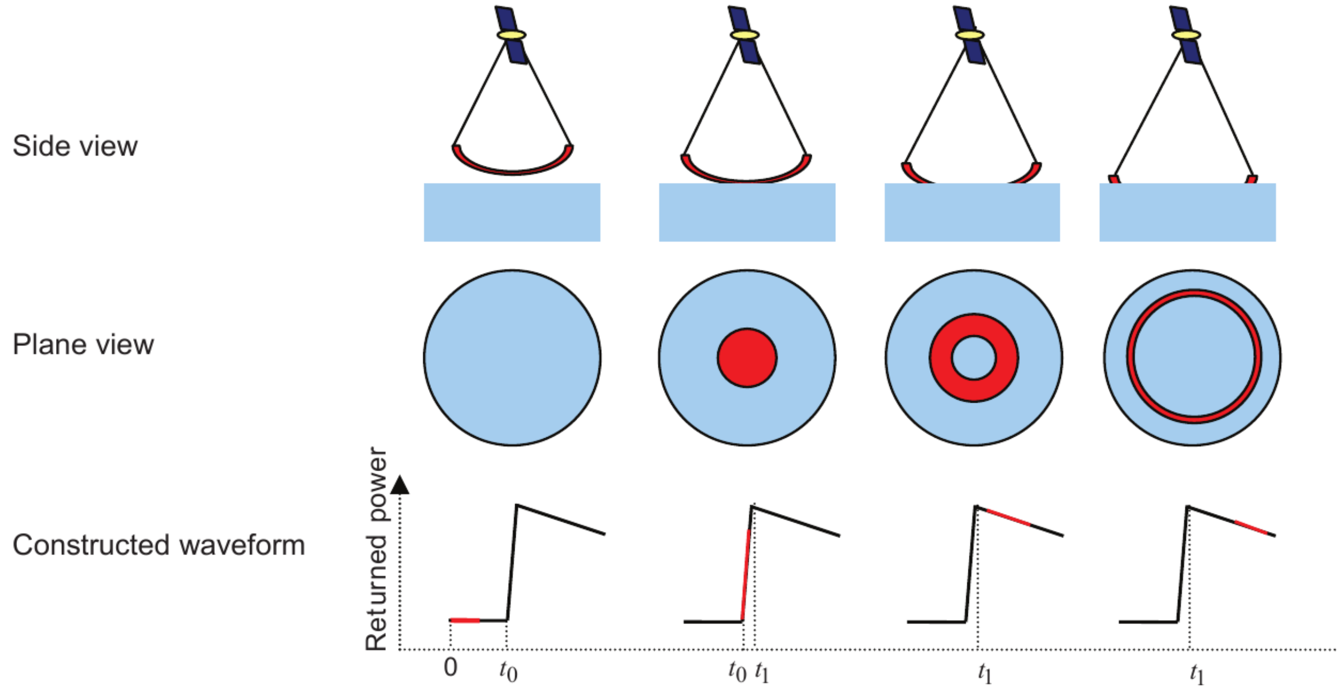
$$\frac{d}{dt}\Omega = -\frac{3R^2 n J_2}{2(1-e^2)^2 a^2}\cos i$$



Pulse limited (conventional) altimetry

- Active radar pulse is transmitted
- Antenna senses arrival of echos (h=Tc/2)
- How short would a pulse need to be for 5cm resolution?

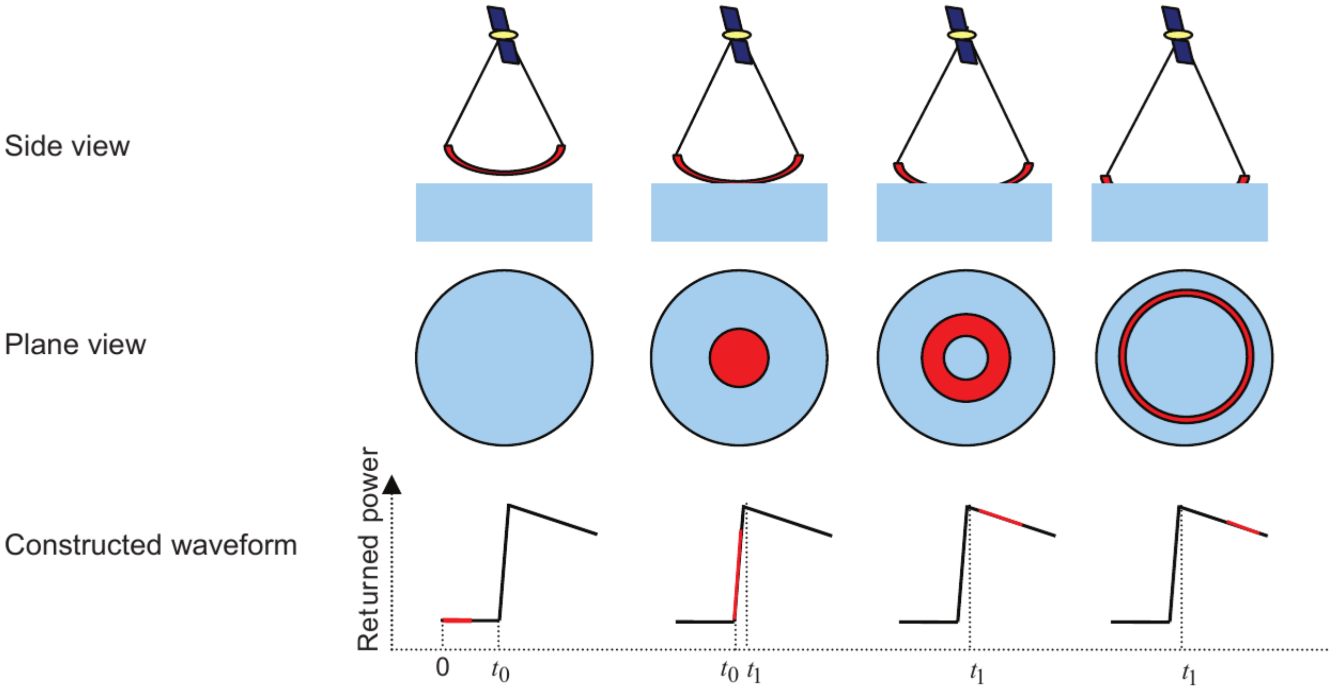
Source: M. Tourian 2009



Pulse limited (conventional) altimetry

- Active radar pulse is transmitted
- Antenna senses arriva of echos (h=Tc/2)
- How short would a pulse need to be for 5cm resolution?
- ~0.3 nanoseconds: But this is not technically possible..

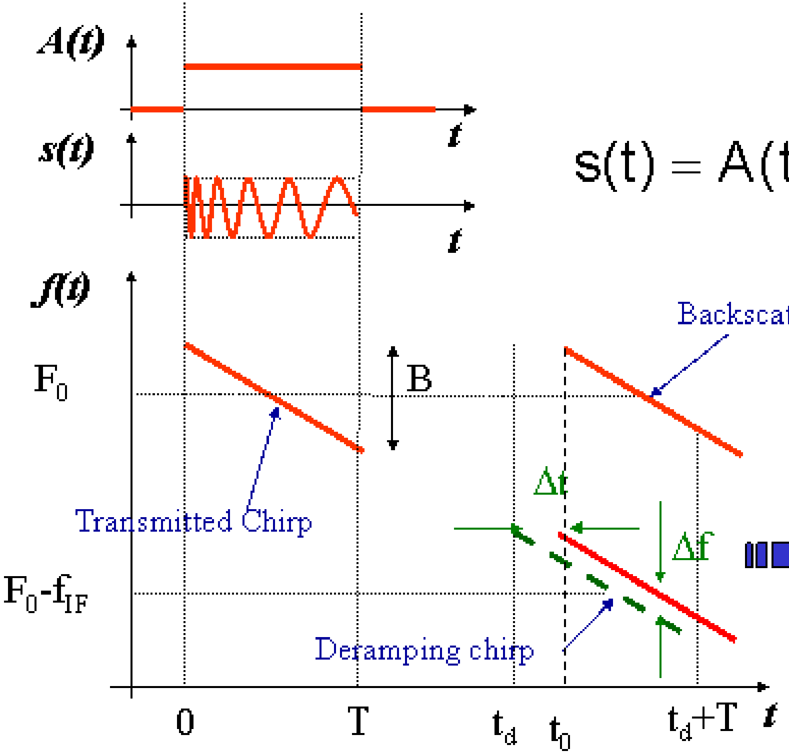
Source: M. Tourian 2009



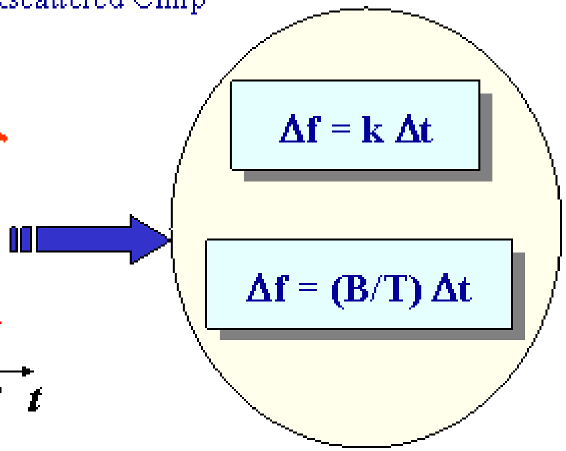
Solution: Use chirps (woop woop!)

- A chirp is transmitted
- On board instrument generates a delayed "deramping" chirp to compare received chirps with
- The mixed signal has a constant frequency which is a measure of the time delay
- (see also supplied notebook)

Source: http://www.altimetry.info

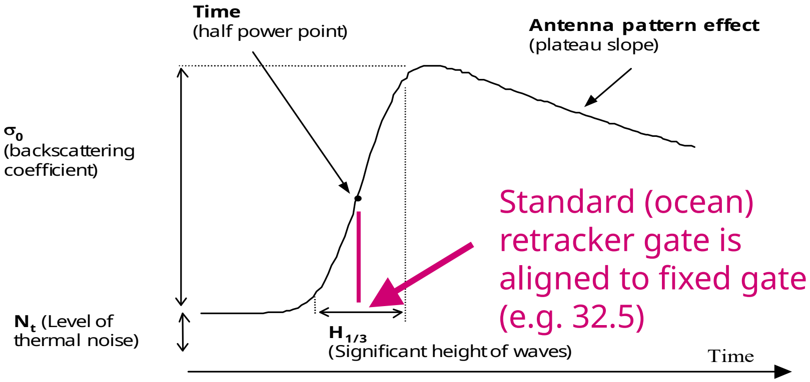


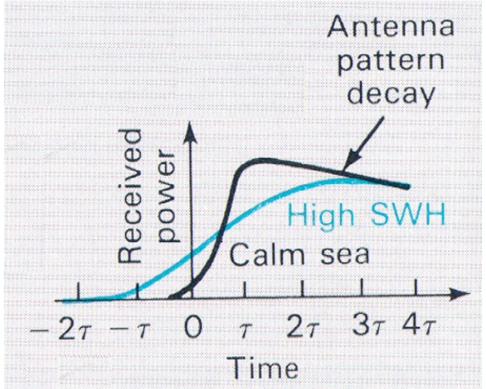
$$s(t) = A(t).e^{-\pi ikt^2}$$

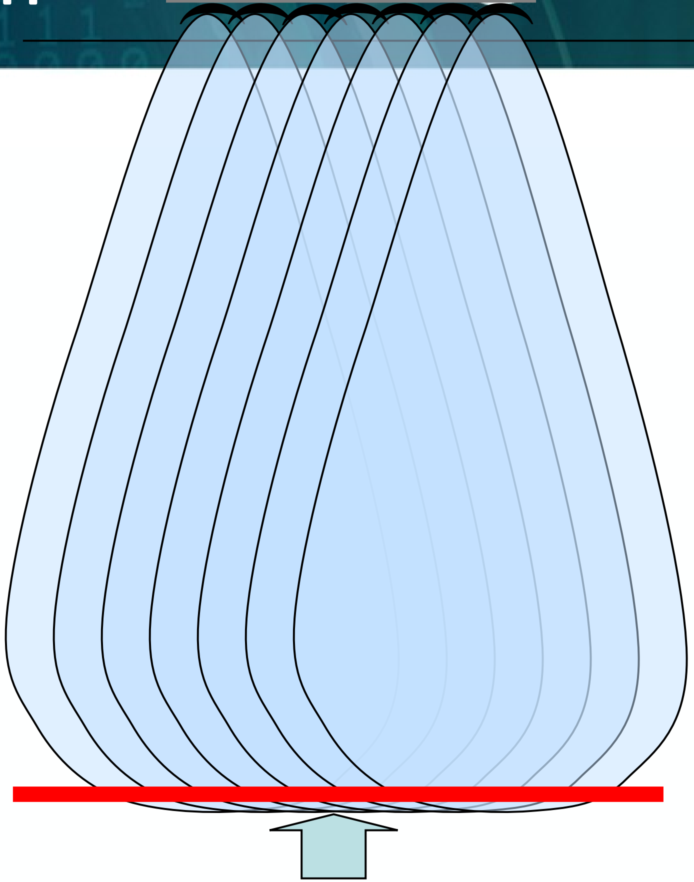


Building a waveform

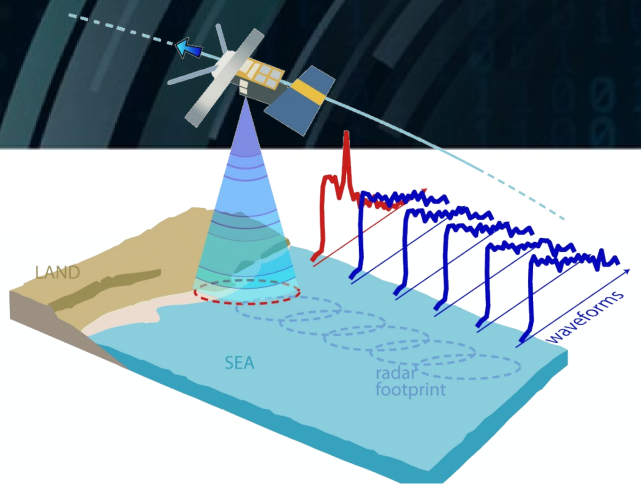
- Pulse repetition frequency ~ 2 kHz
  - Collect over an integration time (20Hz)
- X-axis: Chirps are deramped and binned according to their delta t (range gates)
- Y-axis: Average the received pulses (power) in 20 Hz blocks (y-axis)
- **Pulse-limited**: Chirp bandwidth (B) determines range resolution:
  - Dr =c/(2B). So B=320Mhz resolves to 0.468m (3 nanosec) range resolution
  - When a waveform has 128 gates, how large is the “range window”?
- Over the ocean: the waveform can be modelled with an analytical ‘Brown model´

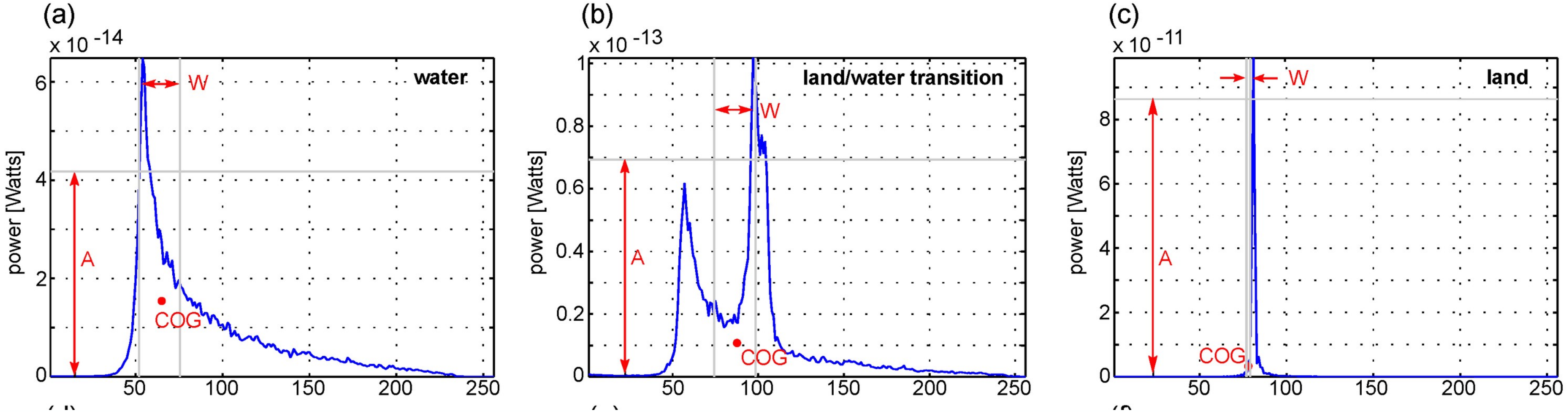






Naughty (inland) waveforms





Retracking: (reprocessing waveforms)

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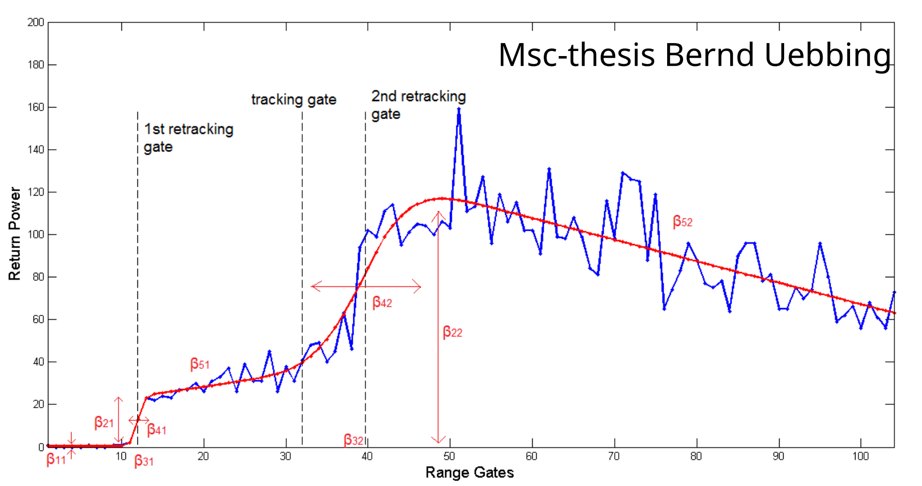
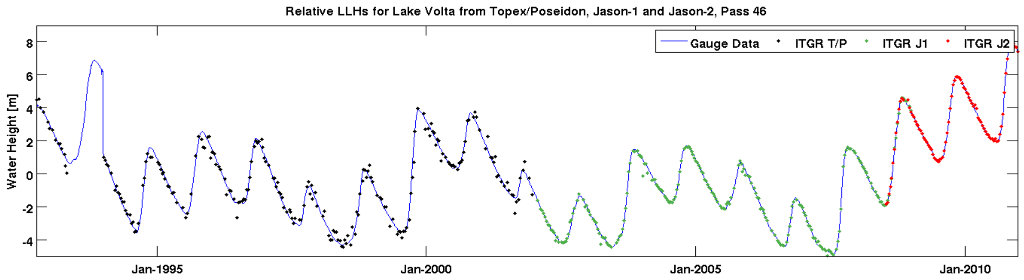
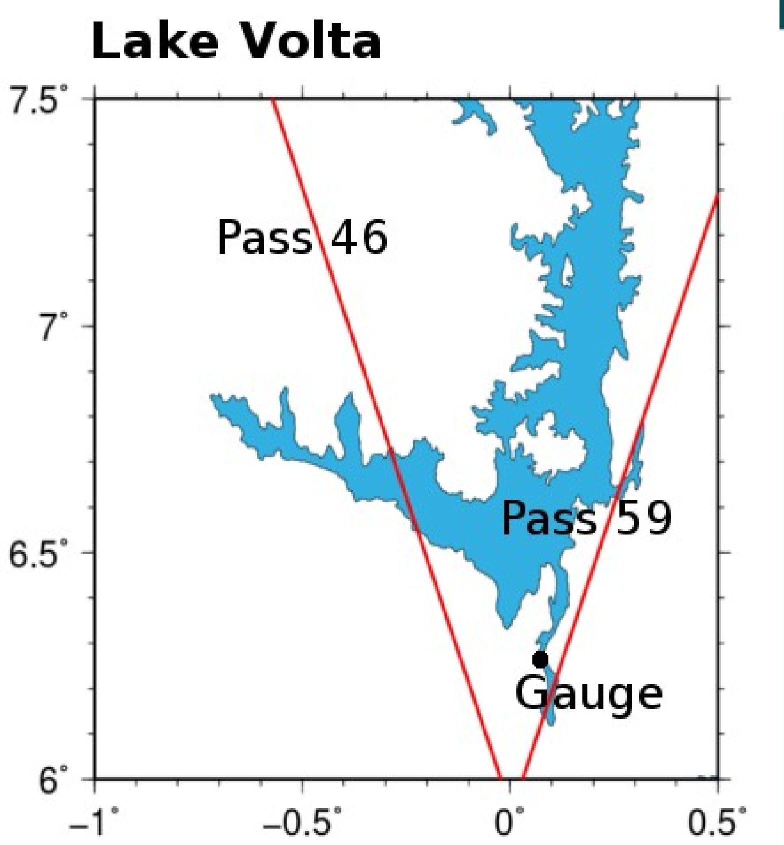
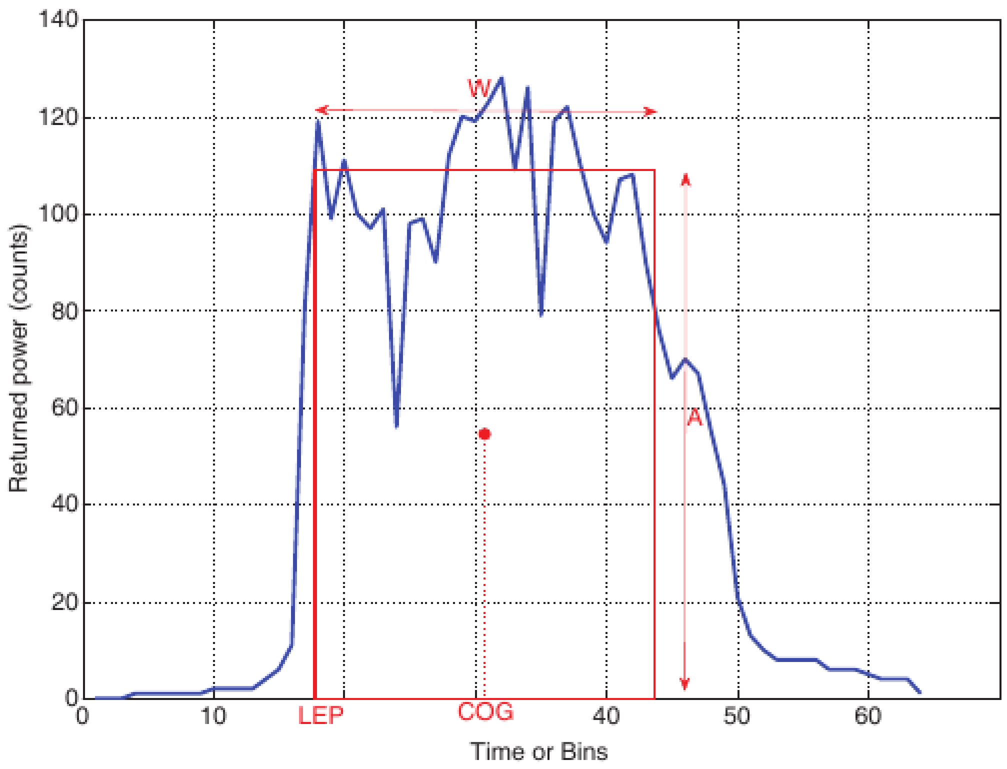






Exercise: OCOG retracker

- Offset Center of Gravity retracker (OCOG), Wingham et al 1986
- Originates from ice altimetry
- Idea:
  - compute an equivalent rectangle (WxA) and center of gravity (COG) of that rectangle.
  - Use leading edge position (LEP) as the range gate representative of the reflecting surface



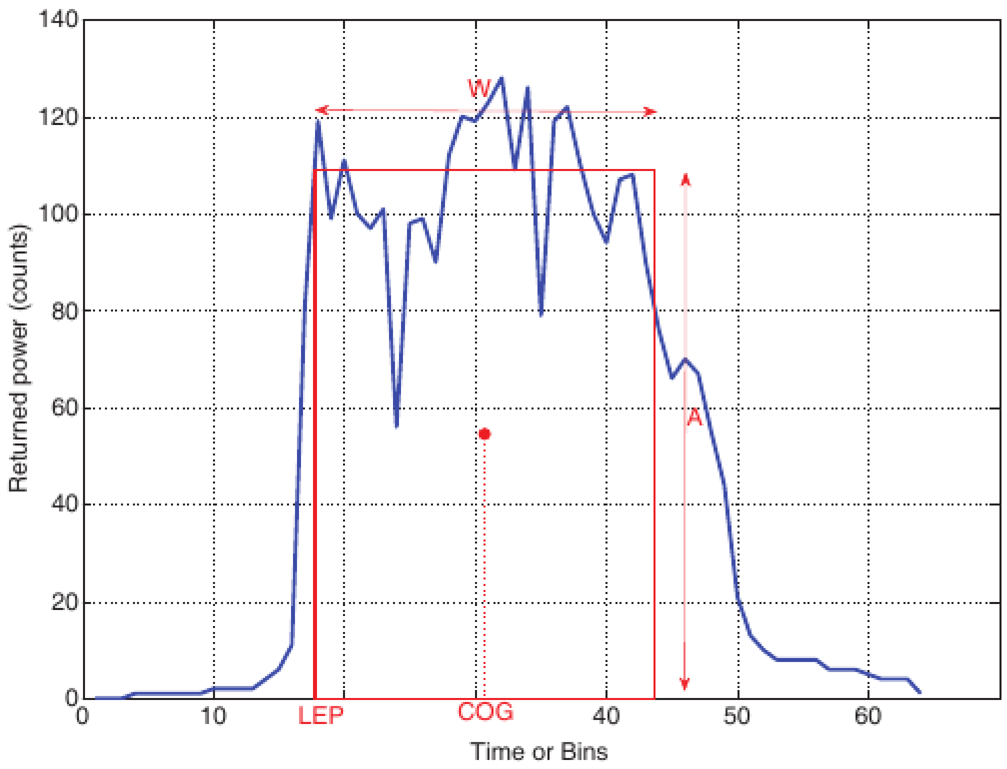
Exercise: OCOG retracker

$$W = \left(\sum_{i=1+n_1}^{N-n_2} P_i^2(t)\right)^2 \Bigg/ \sum_{i=1+n_1}^{N-n_2} P_i^4(t)$$

$$A = \sqrt{\sum_{i=1+n_1}^{N-n_2} P_i^4(t) \Bigg/ \sum_{i=1+n_1}^{N-n_2} P_i^2(t)}$$

$$COG = \sum_{i=1+n_1}^{N-n_2} iP_i^2(t) \Bigg/ \sum_{i=1+n_1}^{N-n_2} P_i^2(t)$$

$$LEP = COG - \frac{W}{2}$$



Your take home points?

Your take home points?

- (remote) observation of river and lake heights: provide information for water resources (management)
- Radar altimetry requires knowledge of the orbit, range, and corrections
- The radar altimeter sends out chirps at the pulse repetition rate (e.g. 20 Khz)
- In pulse limited altimetry the chirp bandwidth limits the (vertical) resolution.
- Waveforms are build by ‘counting’ reflected chirps and assigning them to range gates
- Waveforms over the ocean and land have different shapes