Ship-based Oceanwide Observation of Sea Surface Heights in Consideration of Hydrodynamic Corrections

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MOTIVATION

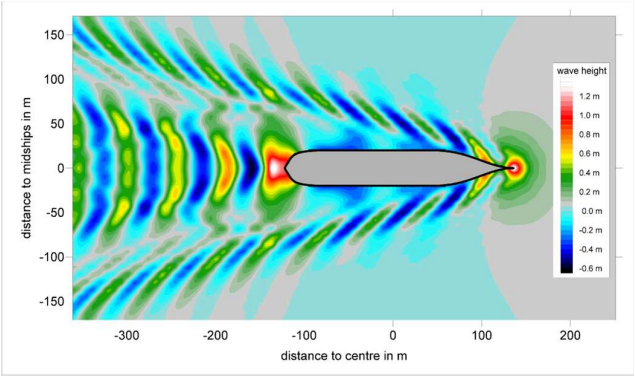
JADE HOCHSCHULE
Wilhelmshaven Oldenburg Elsfleth

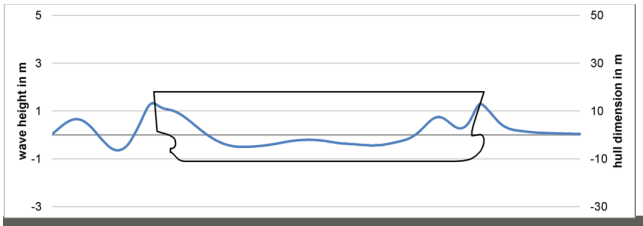
- Sea Surface Heights (SSH) observed
  - locally: tide gauge
    - → only at coasts
    - → data valid only at observation site
    - → spatial interpolation: hypothetical behaviour must be assumed
  - globally: satellite altimetry
    - → many systematic effects, calibration required
    - → still problematic close to coast
    - → spatial and temporal resolution restricted
  - GNSS aboard ships?

MOTIVATION

- Ship-based SSH observation using GNSS
  - seems to be easy: applied by many groups for different purposes
  - BUT: hydrodynamic behaviour
    - → completely neglected
    - → not considered
    - → wrongly considered
    - → considered approximately

wave system of a moving ship extends over a large area



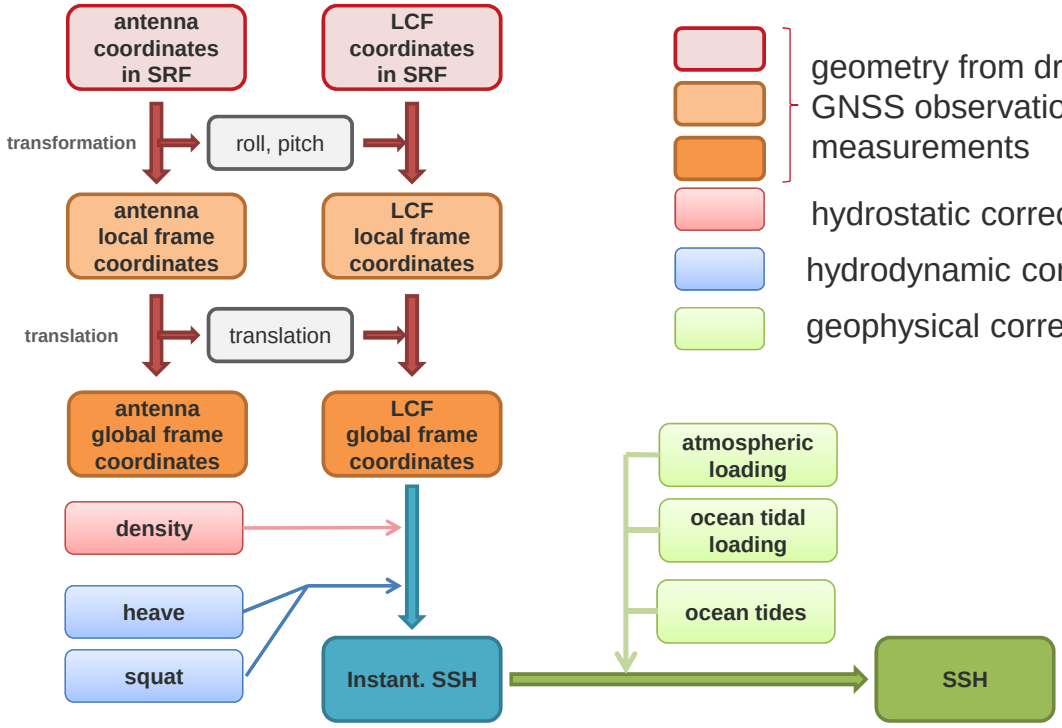


ship squat:
a moving ship will experience a change of sinkage and trim

PROCEDURE

- SSH from observed GNSS antenna heights at ships
  - Assumptions
    - → three GNSS receivers aboard the ship
    - → coordinates in a global reference frame from PPP or differential solution for at least one GNSS receiver available
    - → 3D coordinate differences between antennas from a “moving baseline” differential solution in a local frame
    - → precise position changes in time from epoch-to-epoch double difference GNSS solution for every single antenna
    - → antenna coordinates in ship reference frame (SRF) known from static measurements
    - → Longitudinal Centre of Floatation (LCF) as height reference point, SRF coordinates from e.g. ship’s loading computer

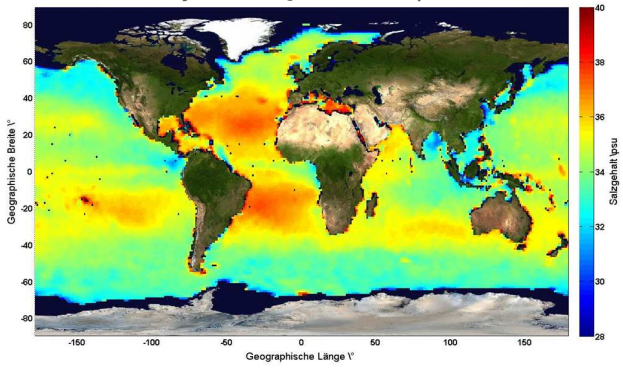
PROCEDURE

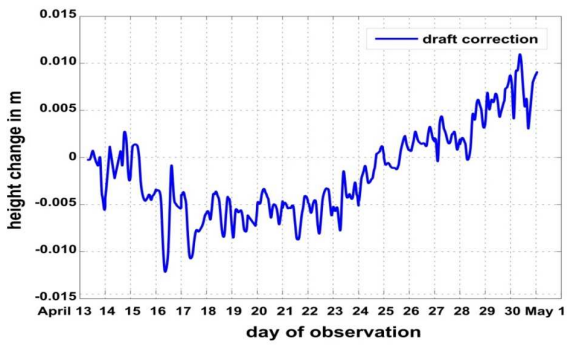


CORRECTIONS

- **density:**
  - draft computed with assumed salinity and temperature
  - differs from actual salinity (e.g. from AQUARIUS satellite)
  - draft correction from ship's particulars or volume of hull model

salinity from AQUARIUS April 2012





CORRECTIONS

- density:
  - draft computed with estimated salinity and temperature
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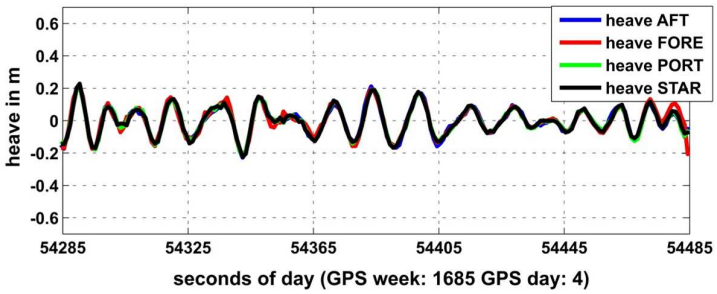
- **heave:**
  - epoch-to-epoch double difference GNSS solutions
  - corrected for roll and pitch changes
  - accumulated and high-pass filtered



heave at LCF: mean of heave at GNSS antennas

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- heave:
  - epoch-to-epoch double difference GNSS solutions
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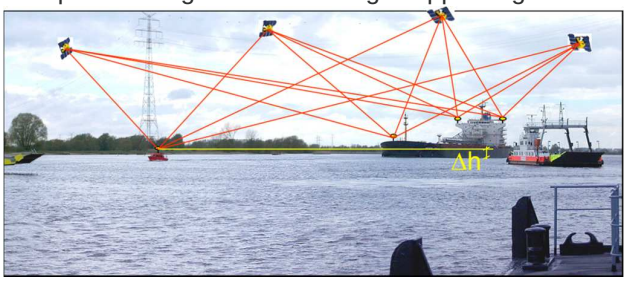
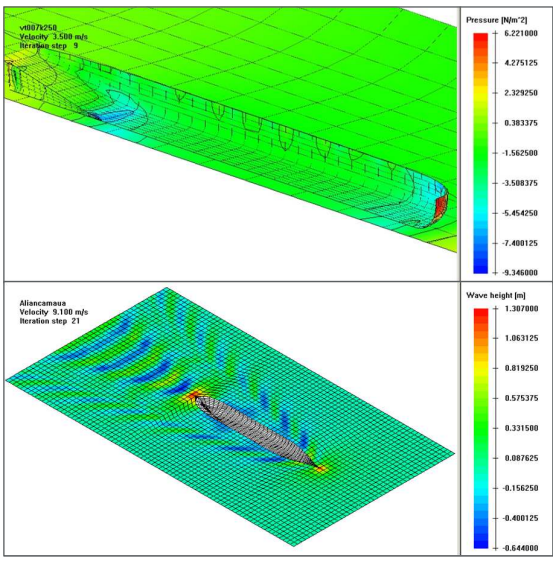
  - accumulated and high-pass filtered
- **squat:**
  - Computational Fluid Dynamics (CFD) simulations
  - full scale calibration experiment
  - speed through water from e.g. Doppler log





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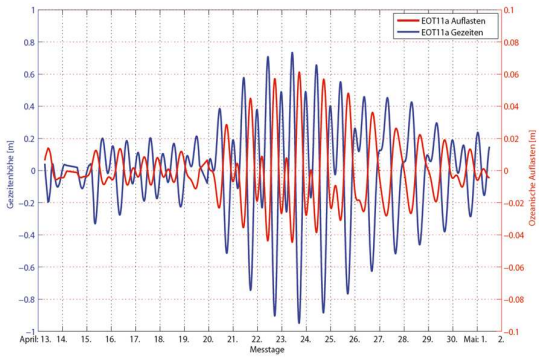
- squat:
  - CFD simulations
  - full scale calibration experiment
  - speed through water from e.g. Doppler log
- **ocean tide / ocean tidal loading:**
  - tidal models FES2004, DTU10, EOT11a etc.
  - SPOTL software (Agnew)



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- ocean tide / ocean tidal loading:
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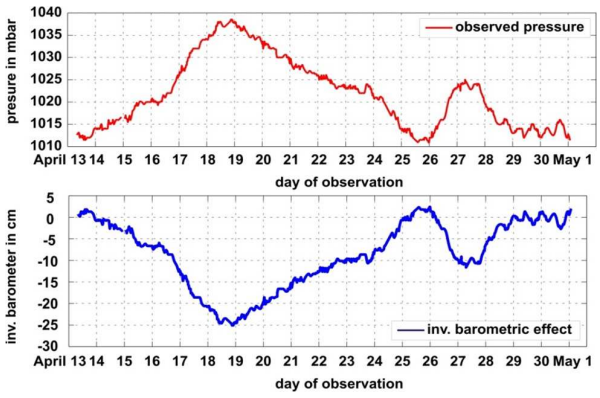
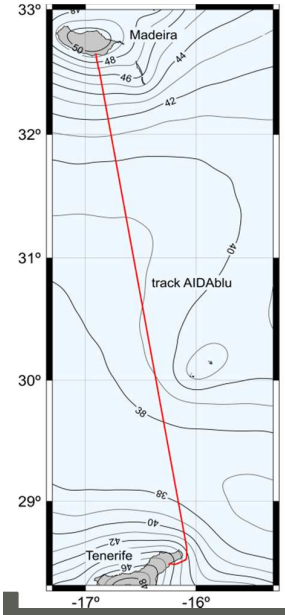
  - SPOTL software (Agnew)
- **atmospheric loading:**
  - atmospheric pressure from ship's barometer
  - calculation of Inverse Barometer IB



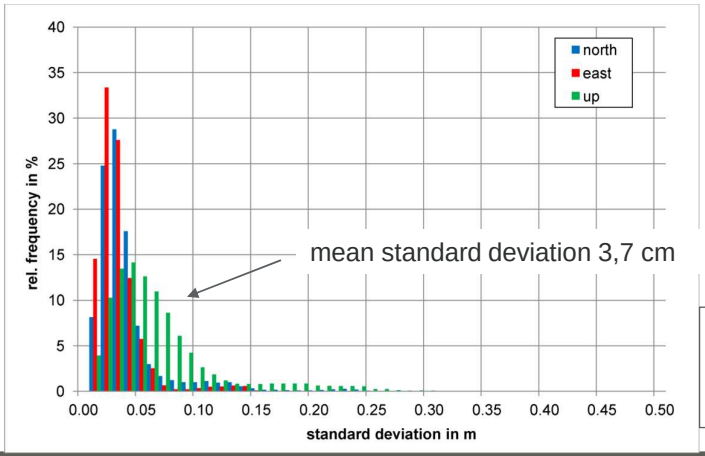
EXPERIMENT: ATLANTIC OCEAN

- cruise vessel *AIDAblu* between Tenerife and Madeira, March 2011
- escort craft for calibration experiment: *Oceanodromo*
- main purposes: → test of SHIPS calibration method in open ocean
  → quality estimation of resulting instantaneous SSH using PPP



EXPERIMENT: ATLANTIC OCEAN

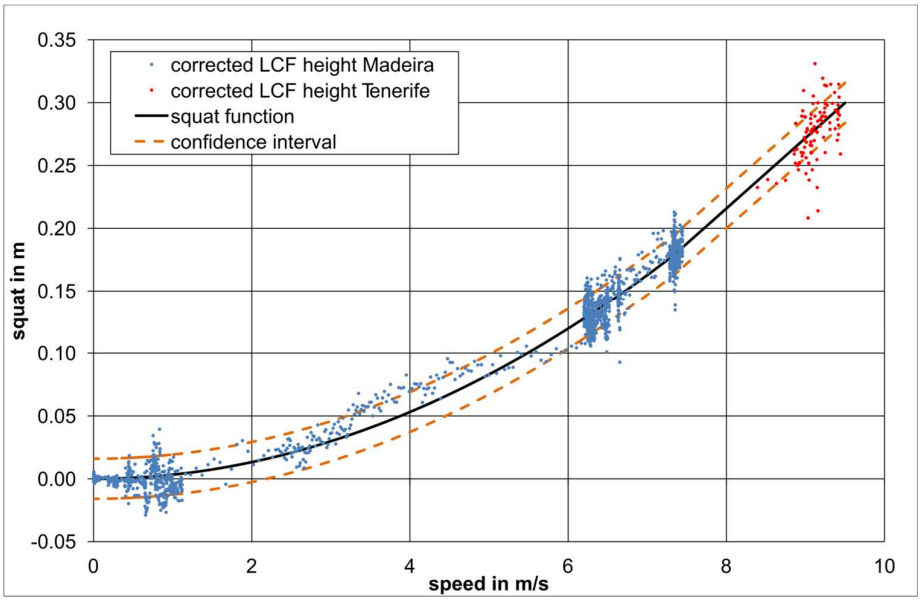
- GNSS processing
  - comparison of coordinate differences between antennas
    → from “moving baseline” solution (own software)
    → from PPP solution (Bernese 5.0)
  - detect and eliminate gross errors
    → eliminate epochs showing larger discrepancies



histogram of standard deviation from translational transformation of “moving baseline” solution to PPP solution

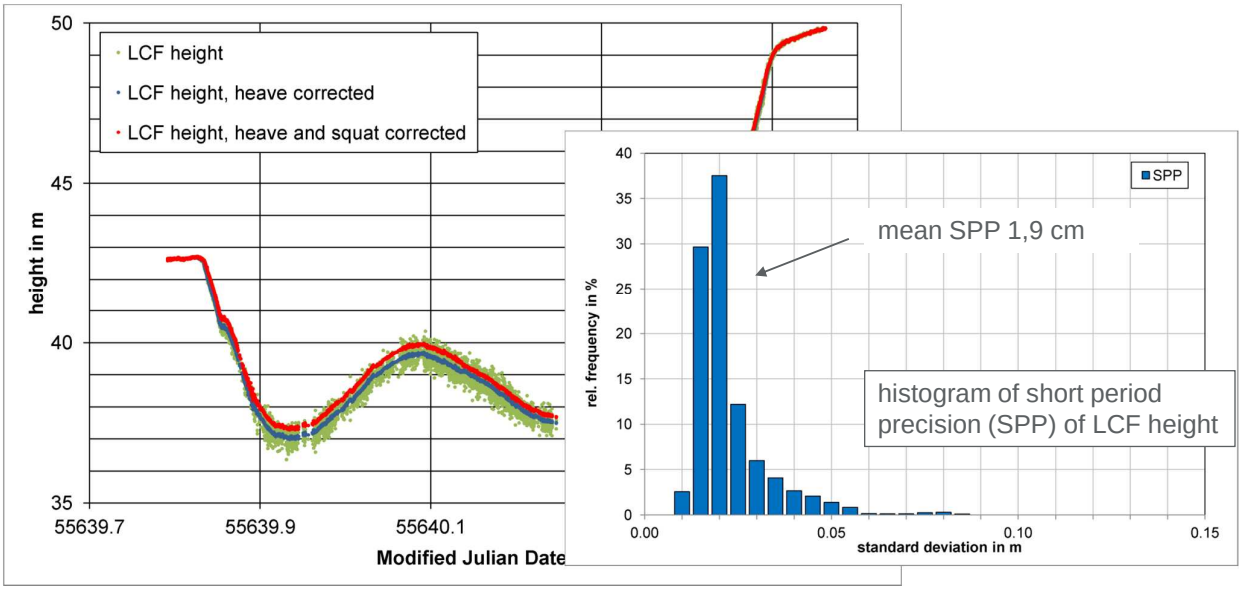
EXPERIMENT: ATLANTIC OCEAN

- squat correction
  - Tenerife: GNSS and tide gauge data
  - Madeira: GNSS data of cruise vessel and escort craft



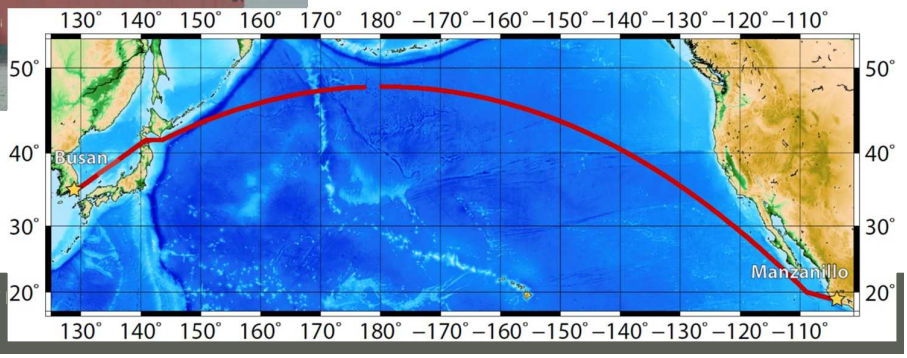
EXPERIMENT: ATLANTIC OCEAN

- instantaneous SSH
  - short period precision (SPP): standard deviation of the mean value of the derived SSH over an interval with a length of 500 m



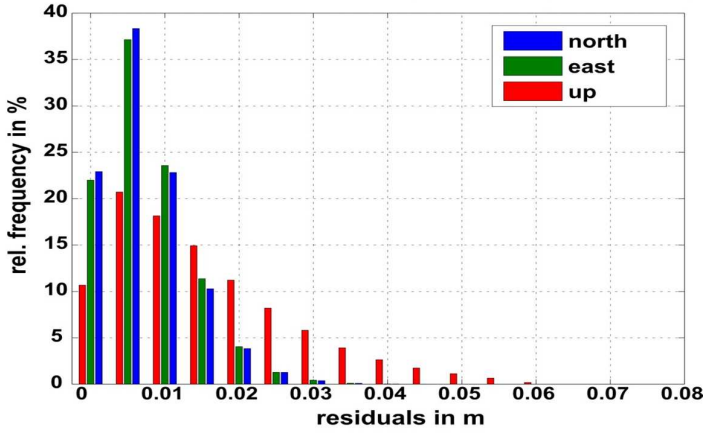
EXPERIMENT: PACIFIC OCEAN

- container vessel *Monte Verde* between Korea and Mexico, April/May 2012
- main purposes: → test over large distance, long period under practical and routine conditions
  → comparison to altimeter data



EXPERIMENT: PACIFIC OCEAN

- GNSS processing
  - comparison of coordinate differences between the two dual-freq.-antennas
    → from “moving baseline” solution (own software)
    → from PPP solution (NRCan online service)
  - detect and eliminate gross errors
    → eliminate epochs showing larger discrepancies

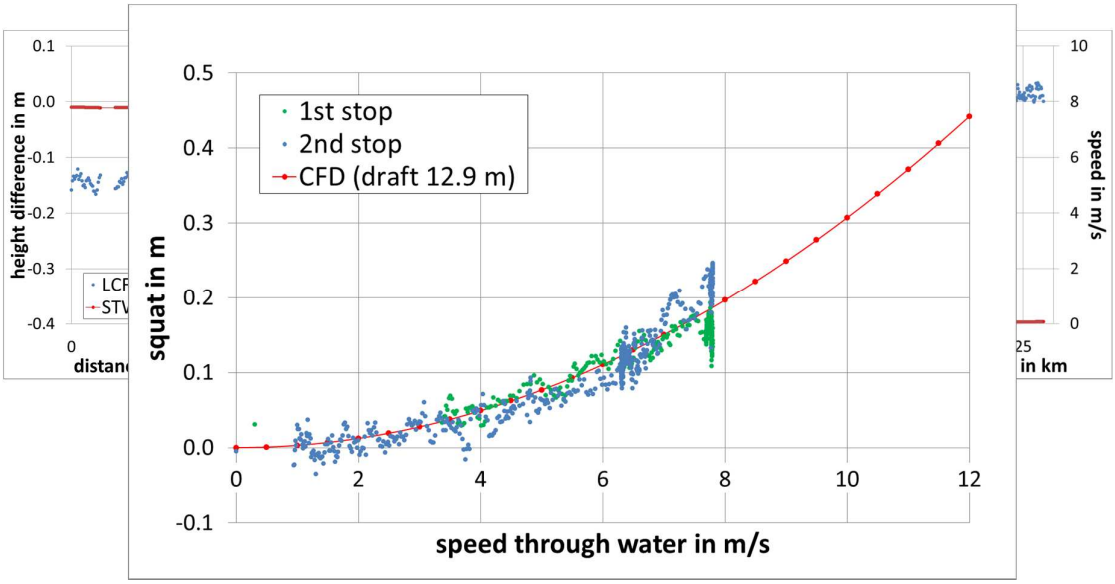


mean standard deviation 1,7 cm

histogram of standard deviation from translational transformation of “moving baseline” solution to PPP solution

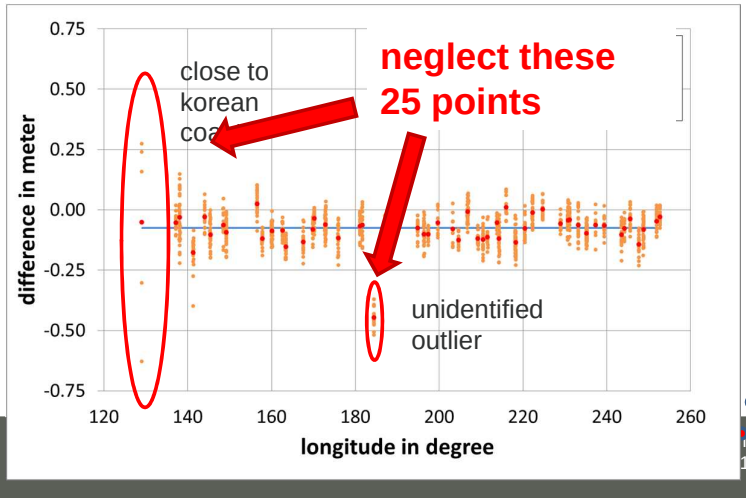
EXPERIMENT: PACIFIC OCEAN

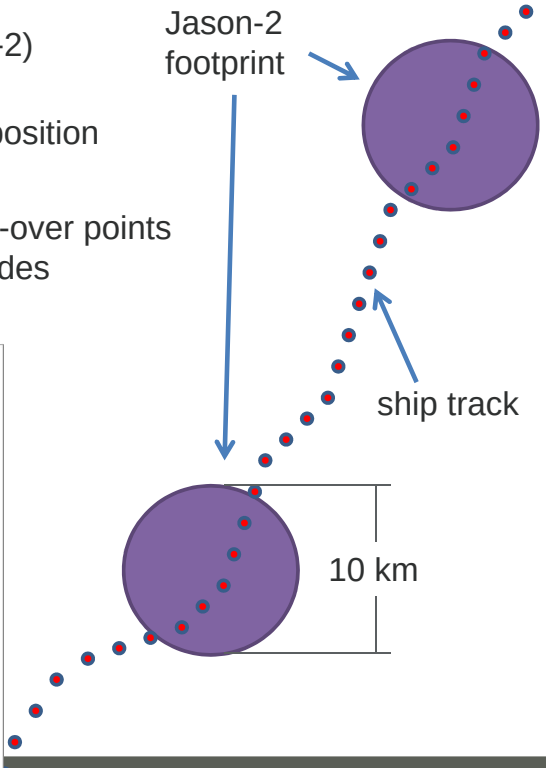
- squat correction
  - hull model available: CFD simulation for unrestricted water
  - two stop maneuvers for engine maintenance



EXPERIMENT: PACIFIC OCEAN

- comparison with SSH from altimetry (Jason-2)
  - cross-over points: all footprints within a distance of less than 5 km from ship's position
  - in total 1342 cross-over points
  - regular pattern of Jason-2 tracks: cross-over points form groups at almost the same longitudes





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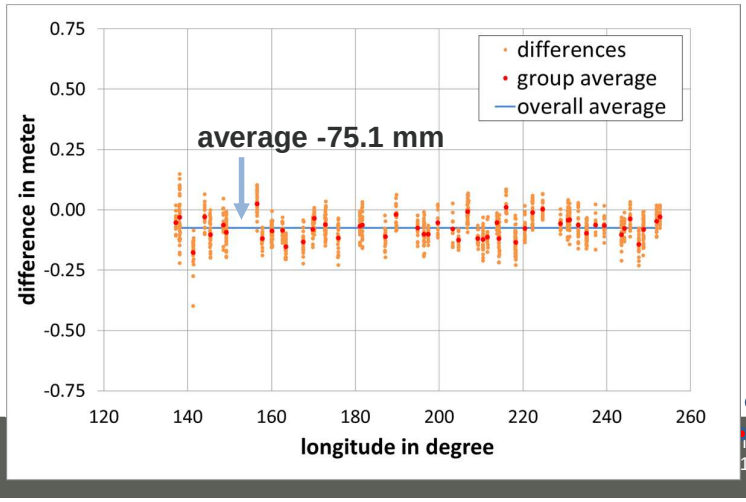
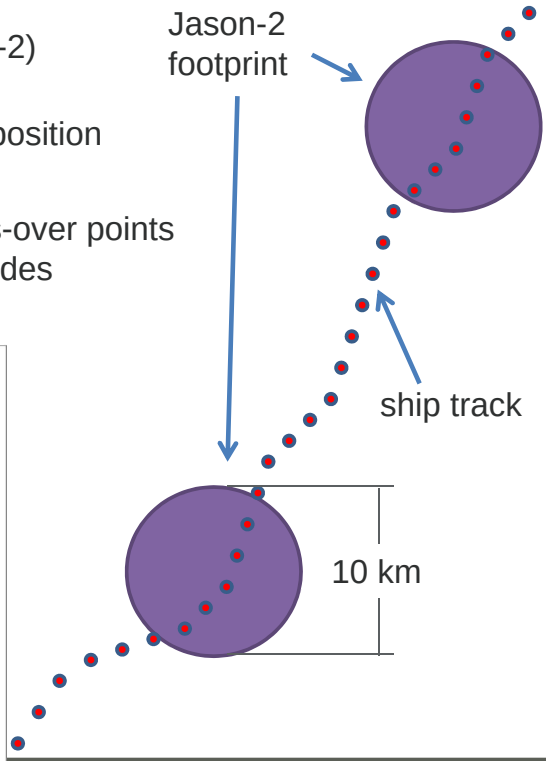




CONCLUSION

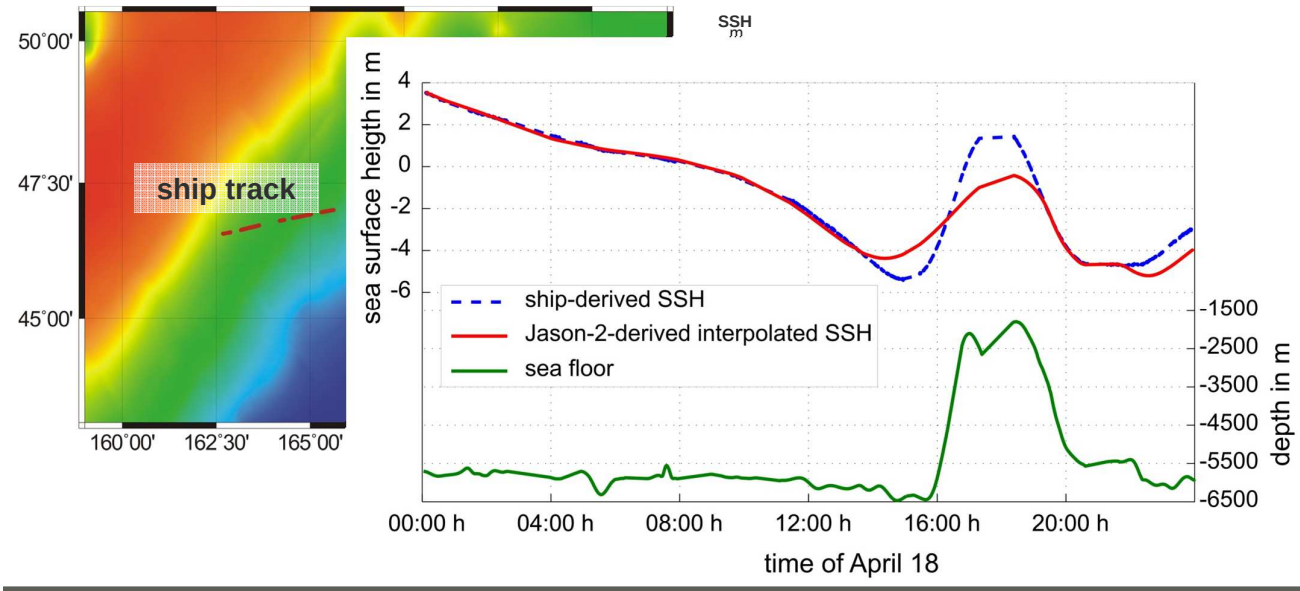
- measurements can be done on almost any kind of ship
- use of merchant vessels would open up a new, continuous data source
- determination of antenna heights from GNSS limits the precision
- ship-based SSH determination is consistent with satellite altimetry results
- allows cross-wise validation over large areas
- ship-based observations could be a significant complement to remote sensing methods

Thank you for your attention

ADDITIONAL SLIDES

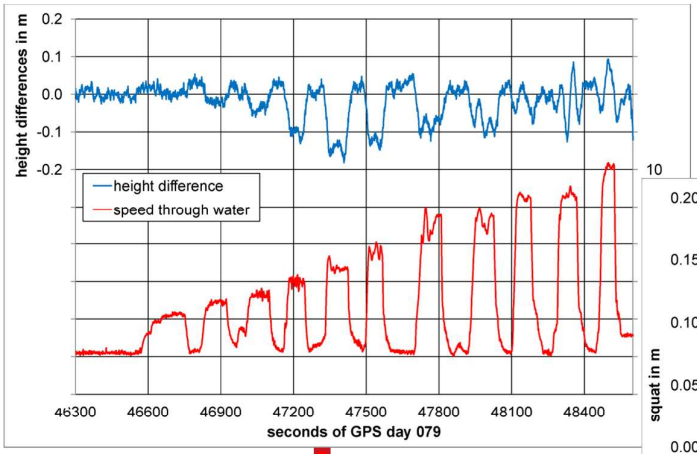
EXPERIMENT: PACIFIC OCEAN

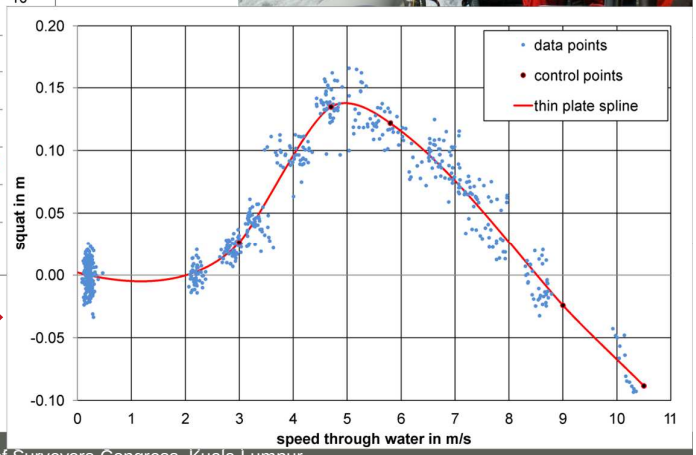
- comparison with SSH from altimetry (Jason-2)
  - spatial resolution: interpolated SSH from Jason-2 at the Hawaii-Emperor seamount chain



CALIBRATION ESCORT CRAFT

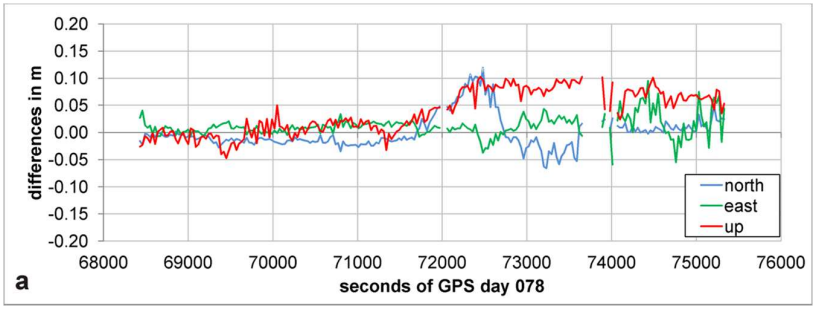
- inverted SHIPS method at the berth:
  - LCF as height reference
  - escort craft operated at various speeds





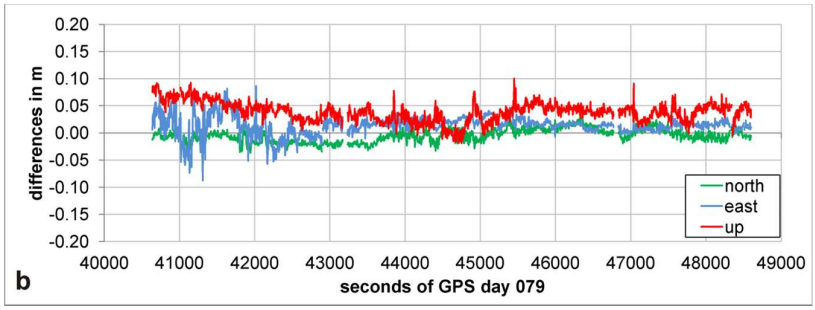
COMPARISON PPP

- PPP solution and differential kinematic solution, reference stations in Tenerife and Madeira



departure Tenerife

arrival Madeira



ANTENNA POSITIONS IN SRF

- GNSS measurements at berth
- additionally: tide gauge readings, draft readings, LCF position in SRF