Technical University of Denmark

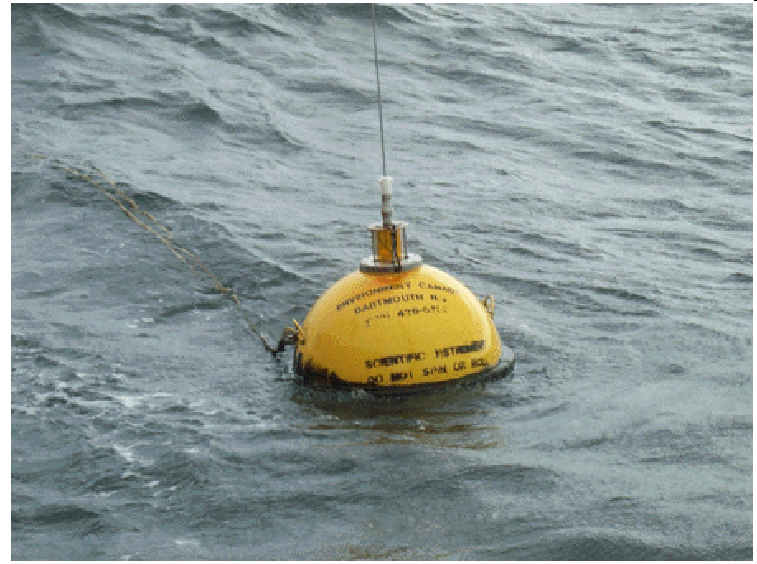
Sea state estimation from an advancing ship - The wave buoy analogy

Presentation at Skibsteknisk Selskab

Nielsen, Ulrik Dam; Andersen, Ingrid Marie Vincent

Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record



Sea State Estimation from an Advancing Ship – The wave buoy analogy

Ulrik Dam Nielsen and Ingrid Marie Vincent Andersen

Technical University of Denmark

Presentation at Skibsteknisk Selskab

March 5th , 2012, Ingeniørhuset Kalvebod Brygge

Content

- Introduction - Field of interest (guidance and decision support systems)
- Means to obtain sea state parameters
- The wave buoy analogy – Wave estimation using measured ship responses
- Results – Numerical simulations and full-scale data
- Summary/conclusions

Introduction

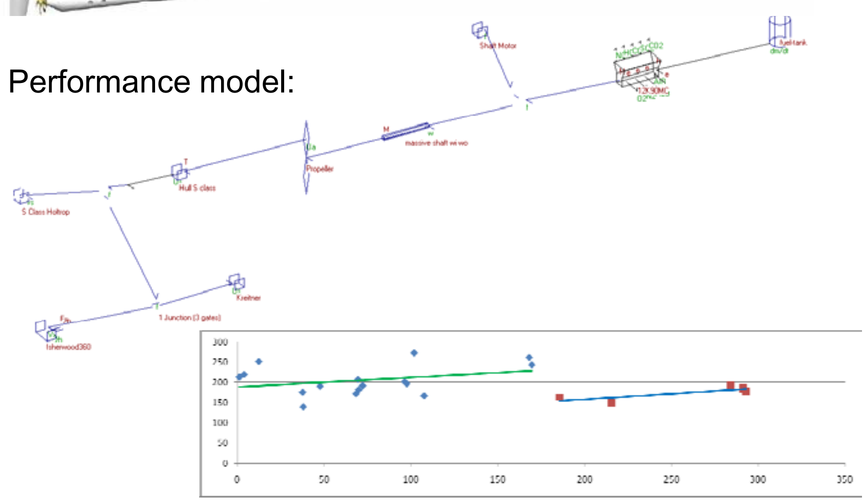
Estimates of the on-site wave spectrum are essential for safe and efficient ship operations at sea:

- Operational guidance and decision support systems
  (e.g. risk of parametric roll and large wave-induced accelerations; evaluation of fatigue damage accumulation, etc.)

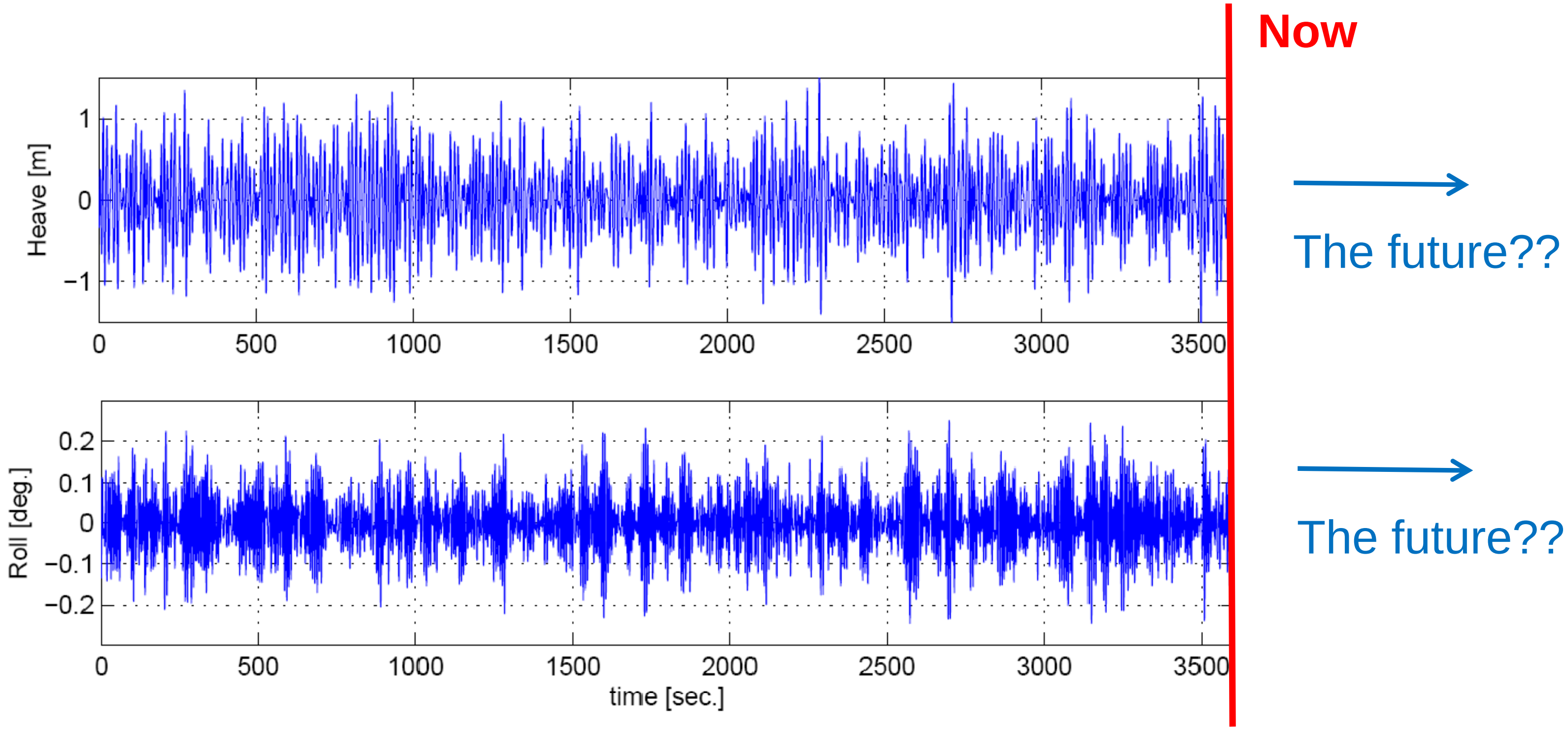
- Vessel performance and monitoring

- **Basically, we would like to look into the future.**

Performance model:



How to look into the future?



- For a ship advancing with **constant speed** and at a **constant wave heading**, future (risk) events can be derived on the basis of trend analysis (i.e. statistics) of the past recorded signals. (Assuming a stationary sea!)

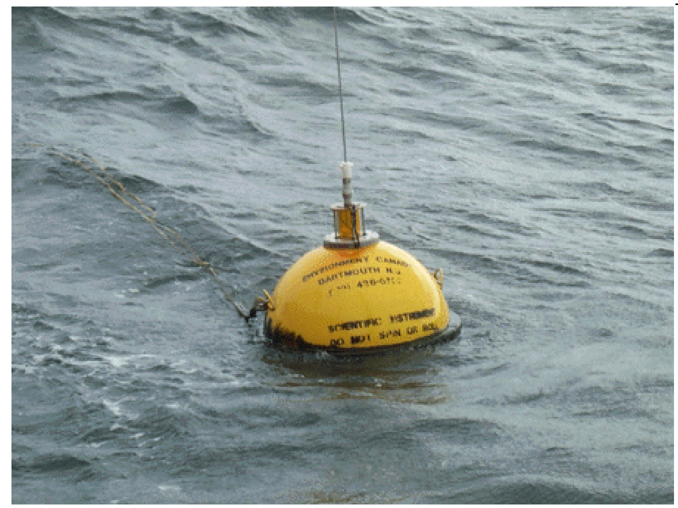
- However, to include the effect of changing operational parameters (speed, course, etc.), information about the on-site sea state is required!

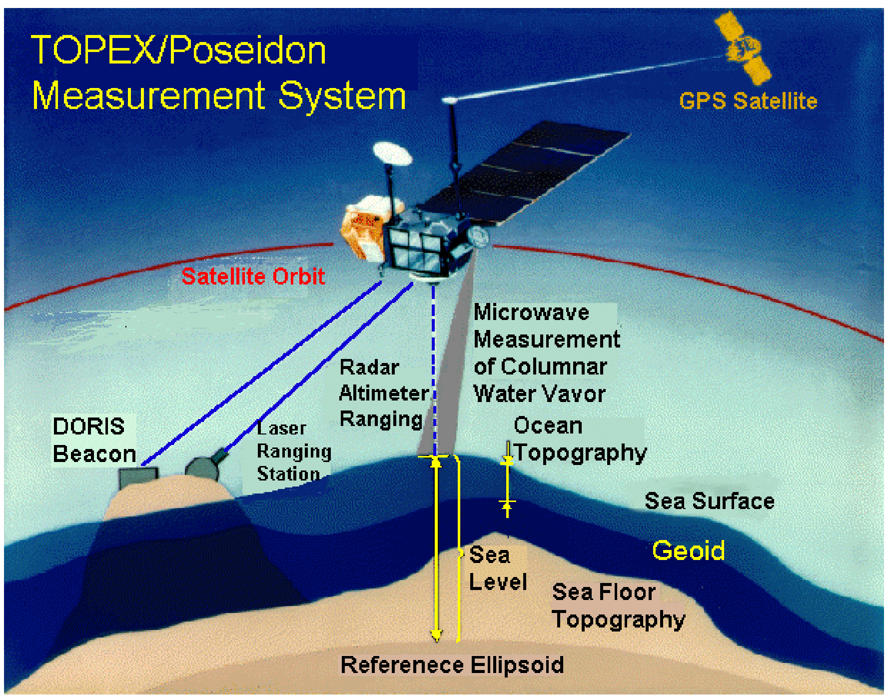
- Means to estimate sea states: wave rider buoys, wave radars, satellite measurements, **wave buoy analogy**.

Means and problems for wave estimation

- **For decision support systems the sea state parameters are needed on a continuous basis (i.e. on a 10-20 minutes basis) and at the exact position of the moving vessel.**

  - Due to their fixed position, the information from **wave rider buoys** is difficult to use (in particular on open ocean where the information is scarce).

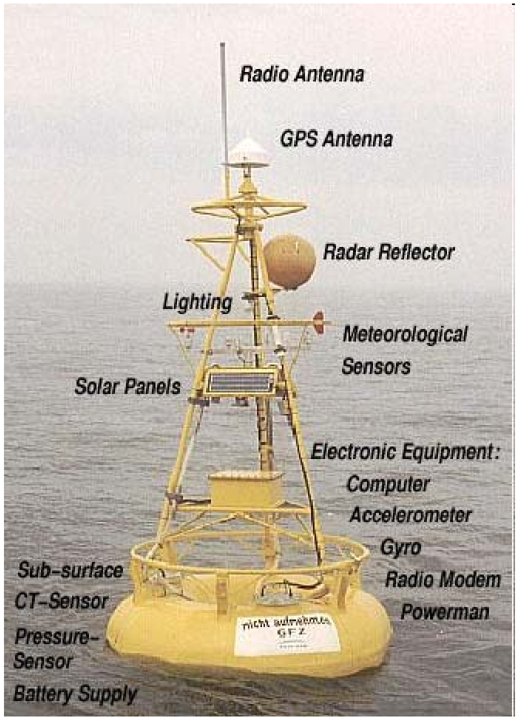




  - **Satellite measurements** offer a paramount tool for the statistical description and treatment of ocean waves and sea states. However, presently satellite measurements cannot be used in the context of DSS. (Further developments are needed.)

Means and problems for wave... contd.

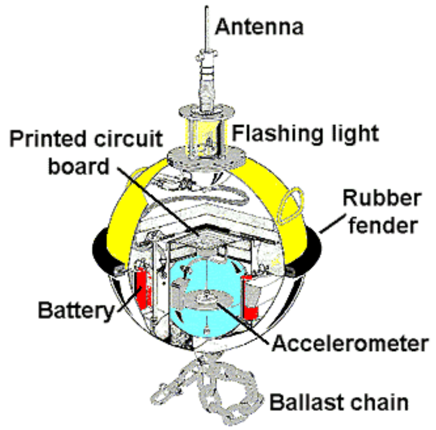
- **Wave radar systems** work on a continuous basis and at the exact position of the vessel. Several studies report good and reliable estimation of sea states, but reports on the opposite also exist. Systems are somewhat expensive and require careful calibration.

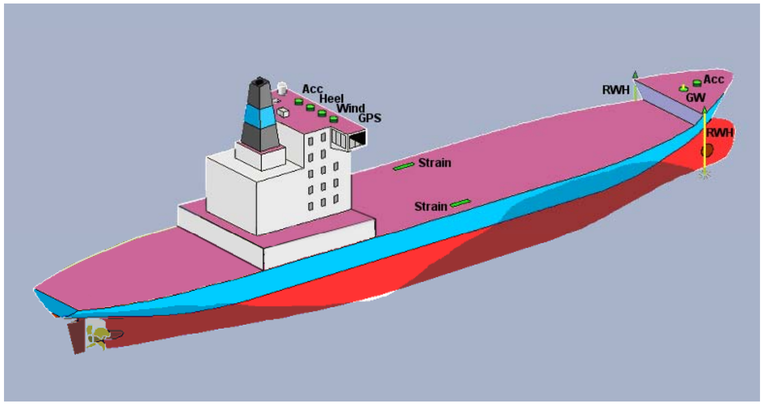


- ***What about a ship; is it not similar to a wave buoy???***

Content

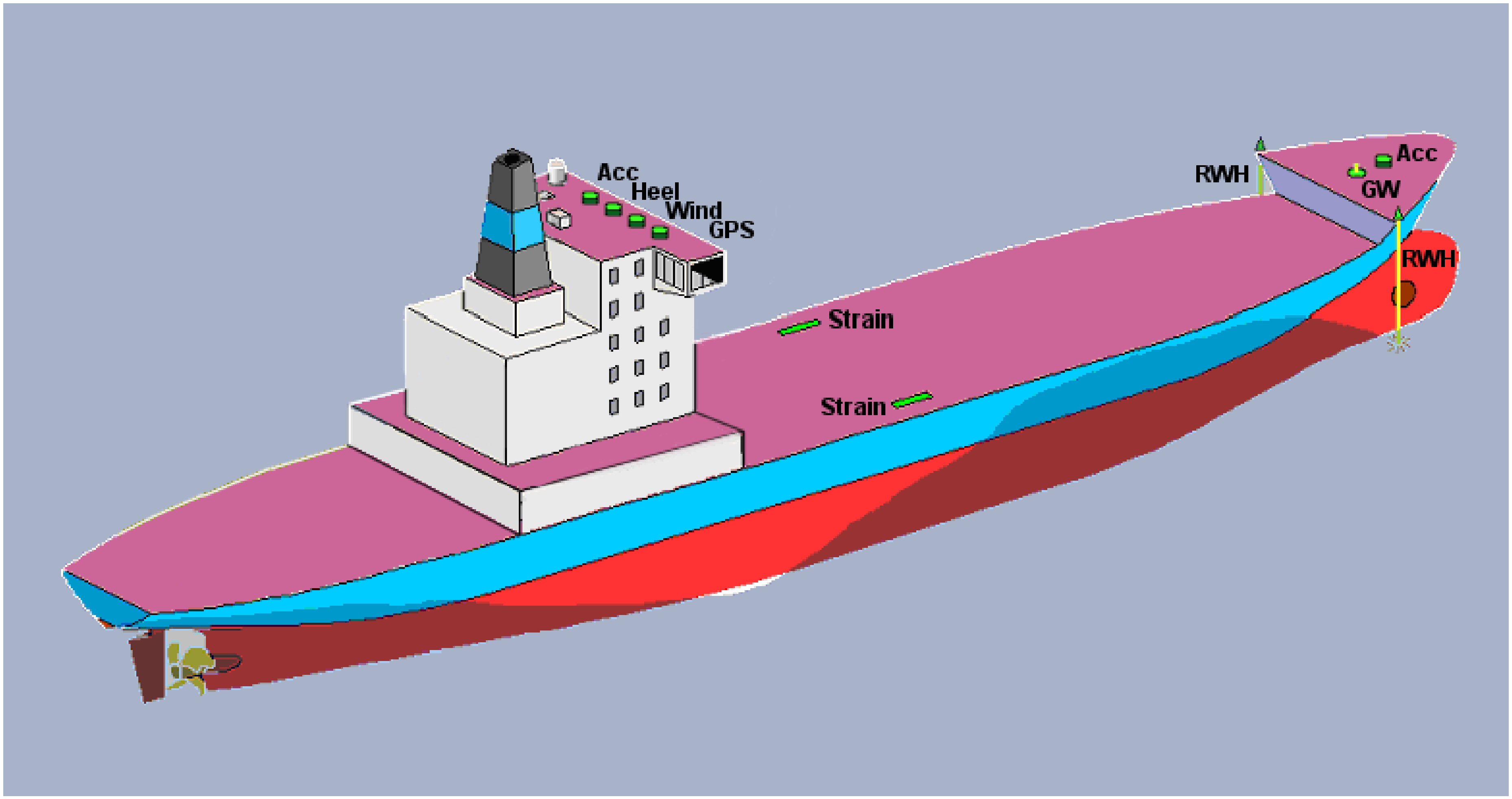
- Introduction - Field of interest (guidance and decision support systems)
- Means to obtain sea state parameters
- **The wave buoy analogy – Wave estimation using measured ship responses**
- Results – Numerical simulations and full-scale data
- Summary/conclusions



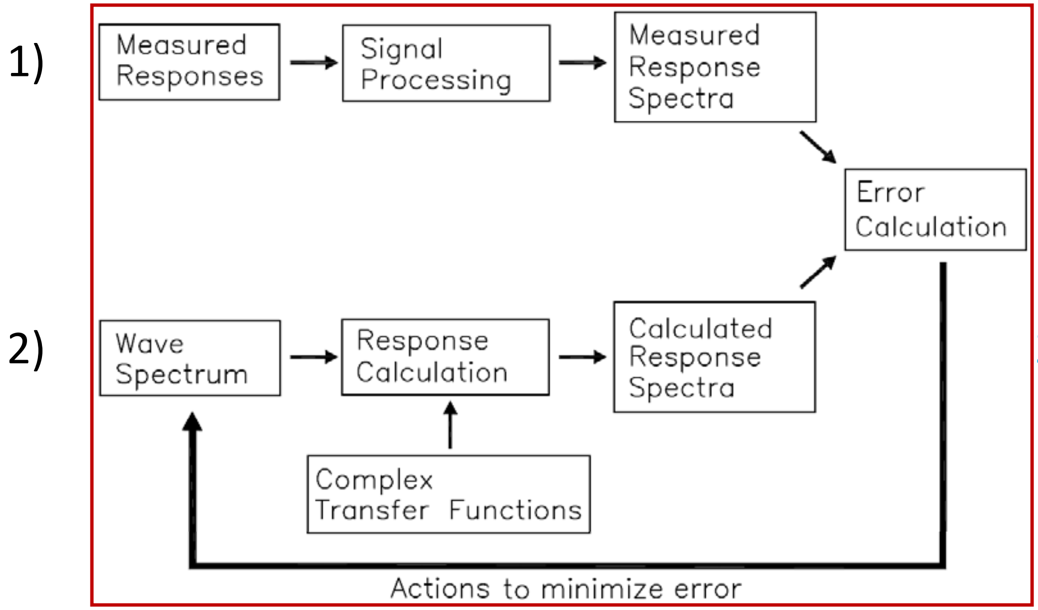


Wave buoy analogy

Estimation of wave spectra based on measured ship responses
(measurements by a number of sensors)



The principle of the wave buoy analogy



1) Measurements: from measured ship responses, response spectra are *measured*.

2) Calculations: by combination of a wave spectrum and linear transfer functions of the responses, response spectra are *calculated*.

- **Assumptions**: stationary ship responses, linear relationship between wave excitations and ship responses (linear transfer functions)

- Representations by parametric and non-parametric modelling. Studies by e.g. Tannuri et al. (2003), Aschehoug (2003), Waals et al. (2002), Iseki and Terada (2002), Nielsen (2006, 2008).

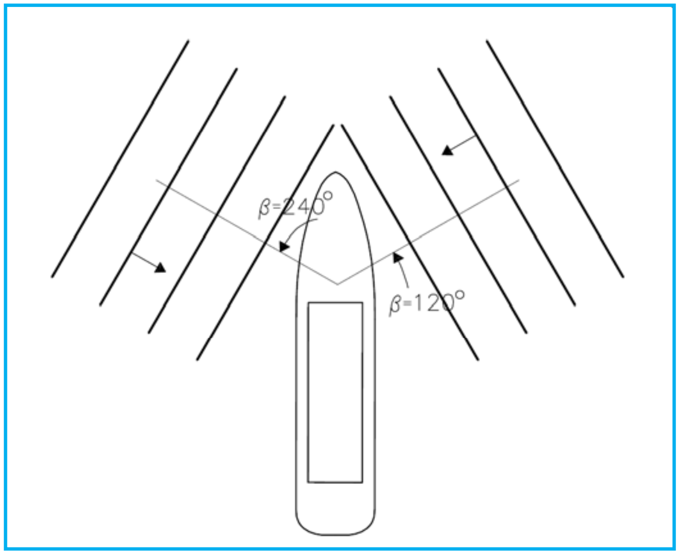
Which type of responses should be considered?

- Global ship responses, including the complex-valued transfer function. (acceleration(s), roll, wave induced VBM amidships, ...)

- A set of three responses is simultaneously considered. This has shown to be the best compromise.

- At least one response must exhibit port/star-board asymmetry in its corresponding transfer function (e.g. sway and roll).

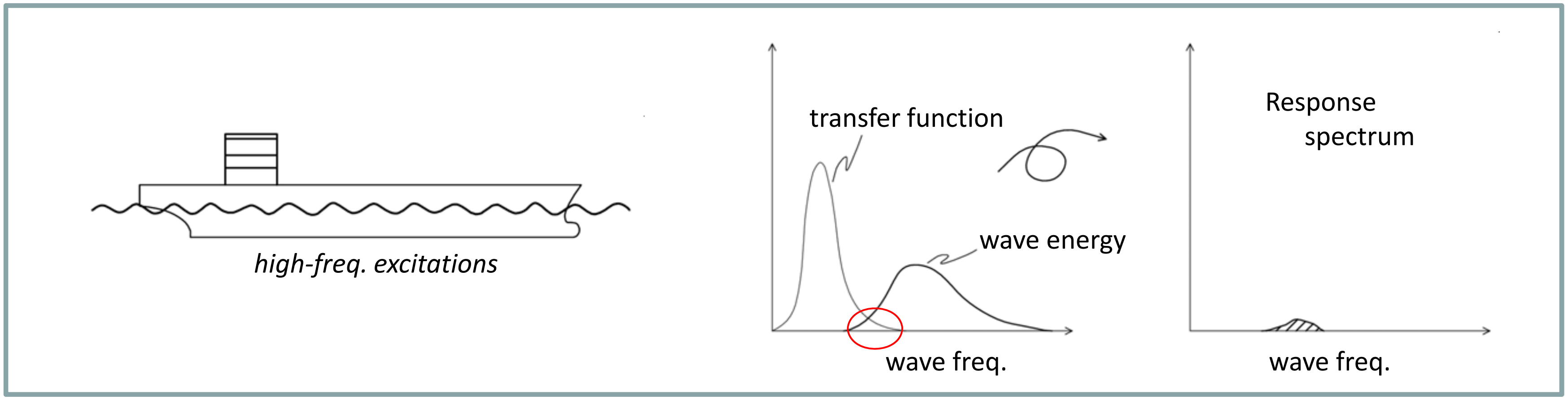
- Responses of different sensitivity in the frequency range.



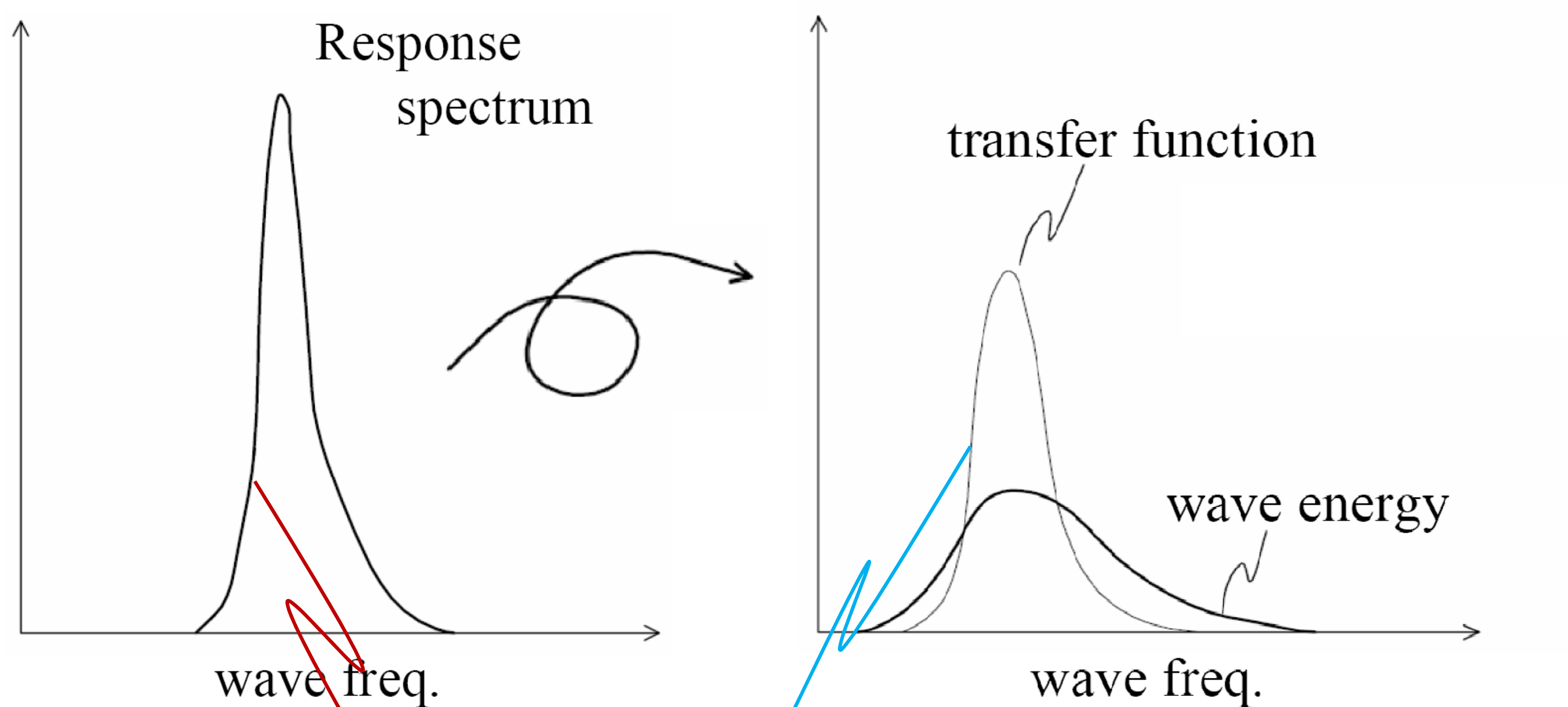
Important issues to keep in mind...

- For severe sea states (non-linearity between excitations and responses), estimations are likely to be less reliable.

- Frequency insensitivity (the ship needs to respond to the waves). Consider responses with different frequency sensitivity.



Governing equation(s)

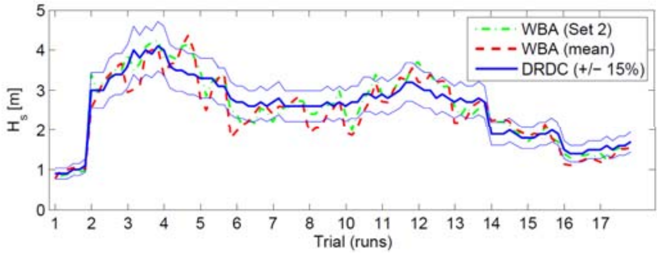


$$S_{ij}(\omega_e) = \int_{-\pi}^{\pi} \Phi_i(\omega_e, \beta)\, \overline{\Phi_j(\omega_e, \beta)}\, E(\omega_e, \beta)\, d\beta$$

Measured Calculated Unknown

Content

- Introduction - Field of interest (guidance and decision support systems)
- Means to obtain sea state parameters
- The wave buoy analogy – Wave estimation using measured ship responses
- **Results – Numerical simulations and full-scale data**
- Summary/conclusions



Results - Overview

1) A study based on only **numerical simulations**.
- LNG carrier
- responses: {heave, pitch, roll}

(Nielsen, 2008a, 2010)

2) Analysis of **full-scale motion measurements**
- container ship
- eight data sets, A, B, ..., H. Duration of 15 minutes.
- responses: {heave, pitch, roll}
- measurements recorded during operation.
- comparison with wave radar (WAVEX)

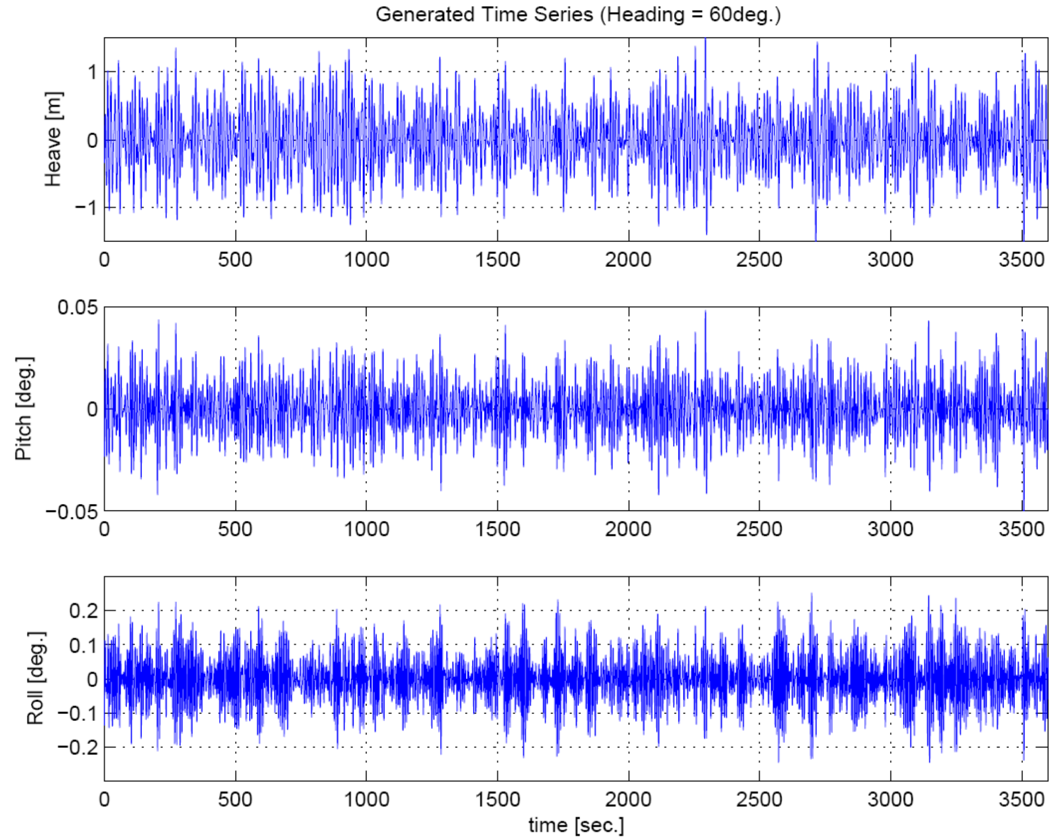
(Nielsen, 2006, 2008b)

3) Analysis of **full-scale motion measurements from sea strial**
- research vessel (DRDC Atlantic)
- comparisons with buoy data

(Nielsen, 2011, 2012)

Numerical simulations of time series (1)

- Time series data where the underlying wave parameters are precisely known.
- LNG carrier. RAOs calculated by 3D panel code (Wasim)



$$R(t) = \sum_{n=1}^{N} \sum_{m=1}^{M} [u_{mn} c_{mn}(t) + \bar{u}_{mn} \bar{c}_{mn}(t)]$$

$$c_{mn}(t) = \sigma_{mn} |\Phi_R(\omega_n, \beta_m)| \cos(\omega_{e,n} t + \epsilon_{mn})$$

$$\bar{c}_{mn}(t) = -\sigma_{mn} |\Phi_R(\omega_n, \beta_m)| \sin(\omega_{e,n} t + \epsilon_{mn})$$

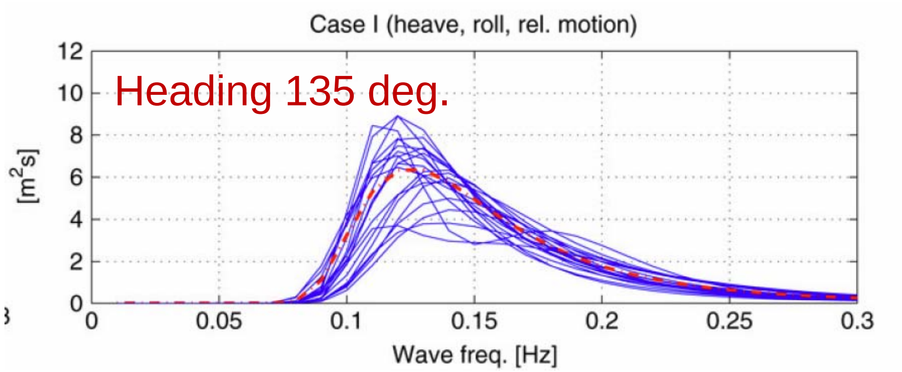
$$\omega_e = \omega - \omega^2 A \quad , \quad A = \frac{V}{g} \cos\beta$$

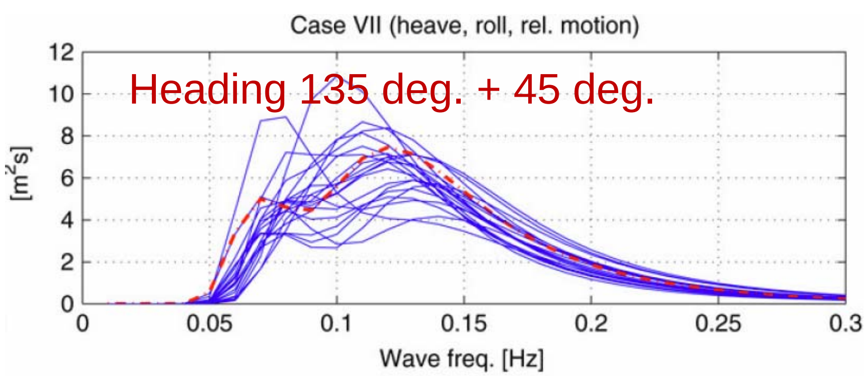
$$\sigma_{mn}^2 = E(\omega_n, \beta_m) \Delta\omega_n \Delta\beta_m$$

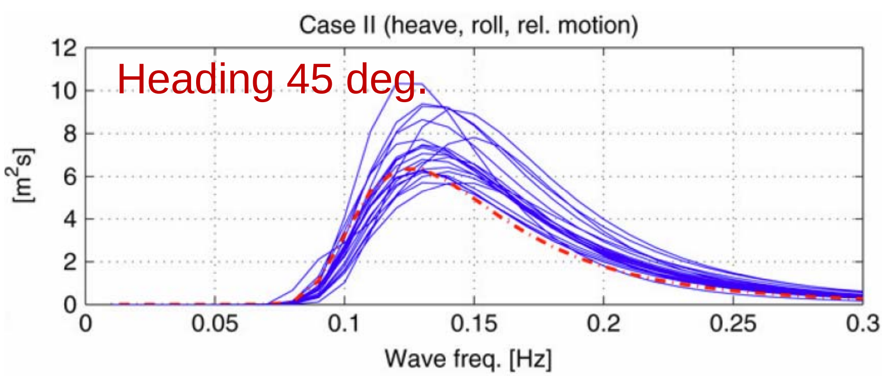
Numerical simulations of time series (2)

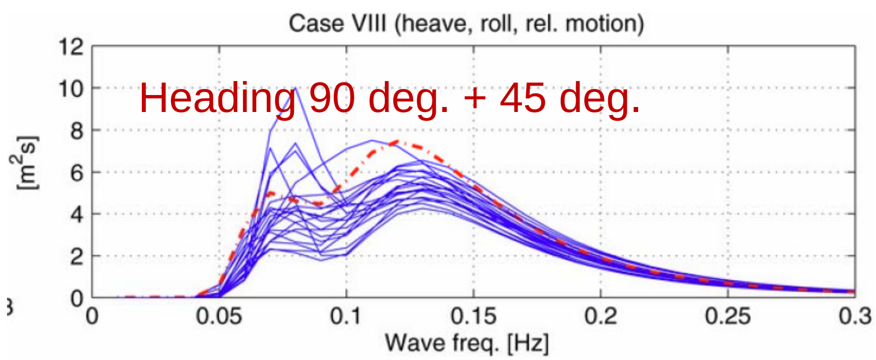
Uni-modal sea states

Mixed sea (wind + swell)

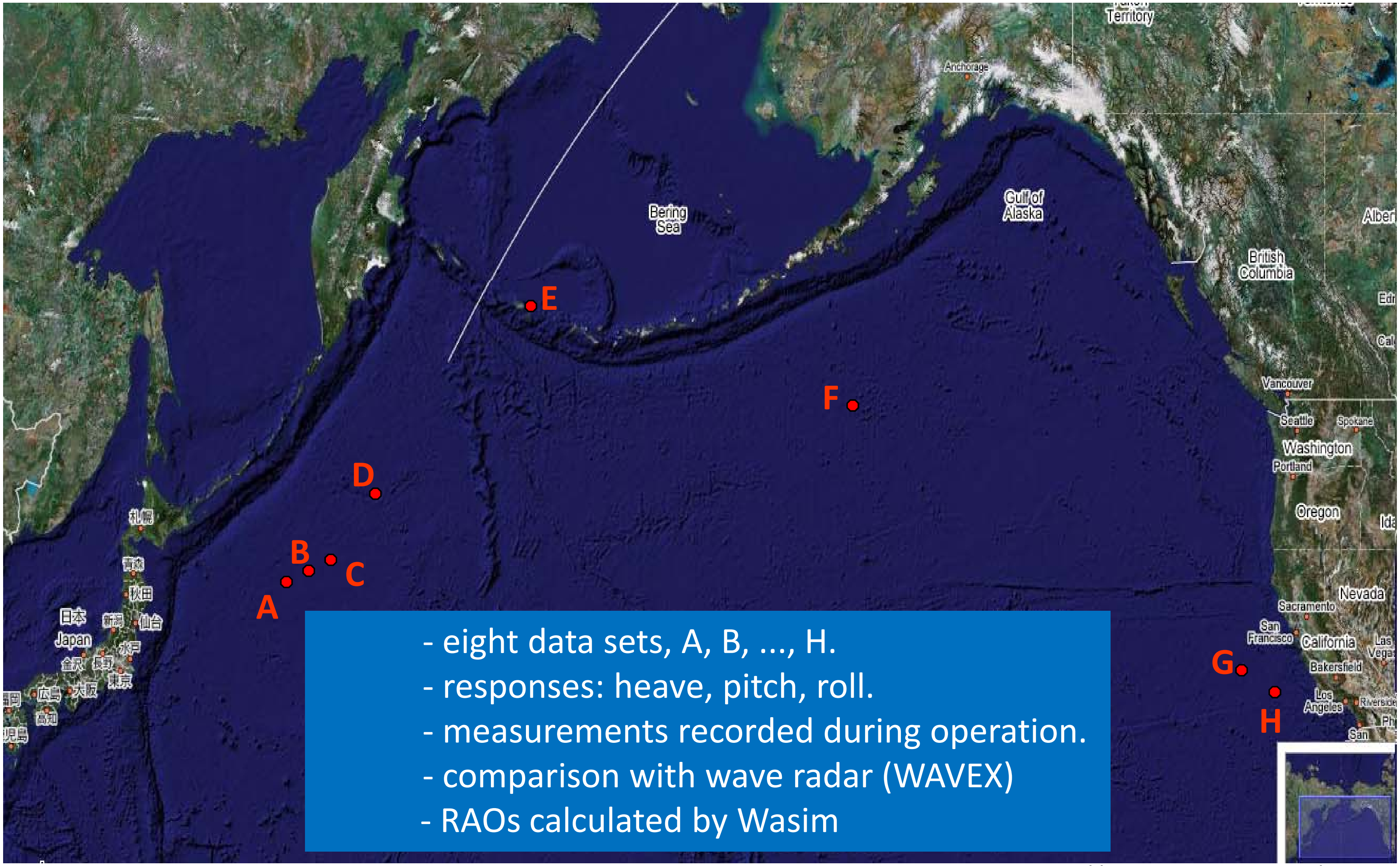








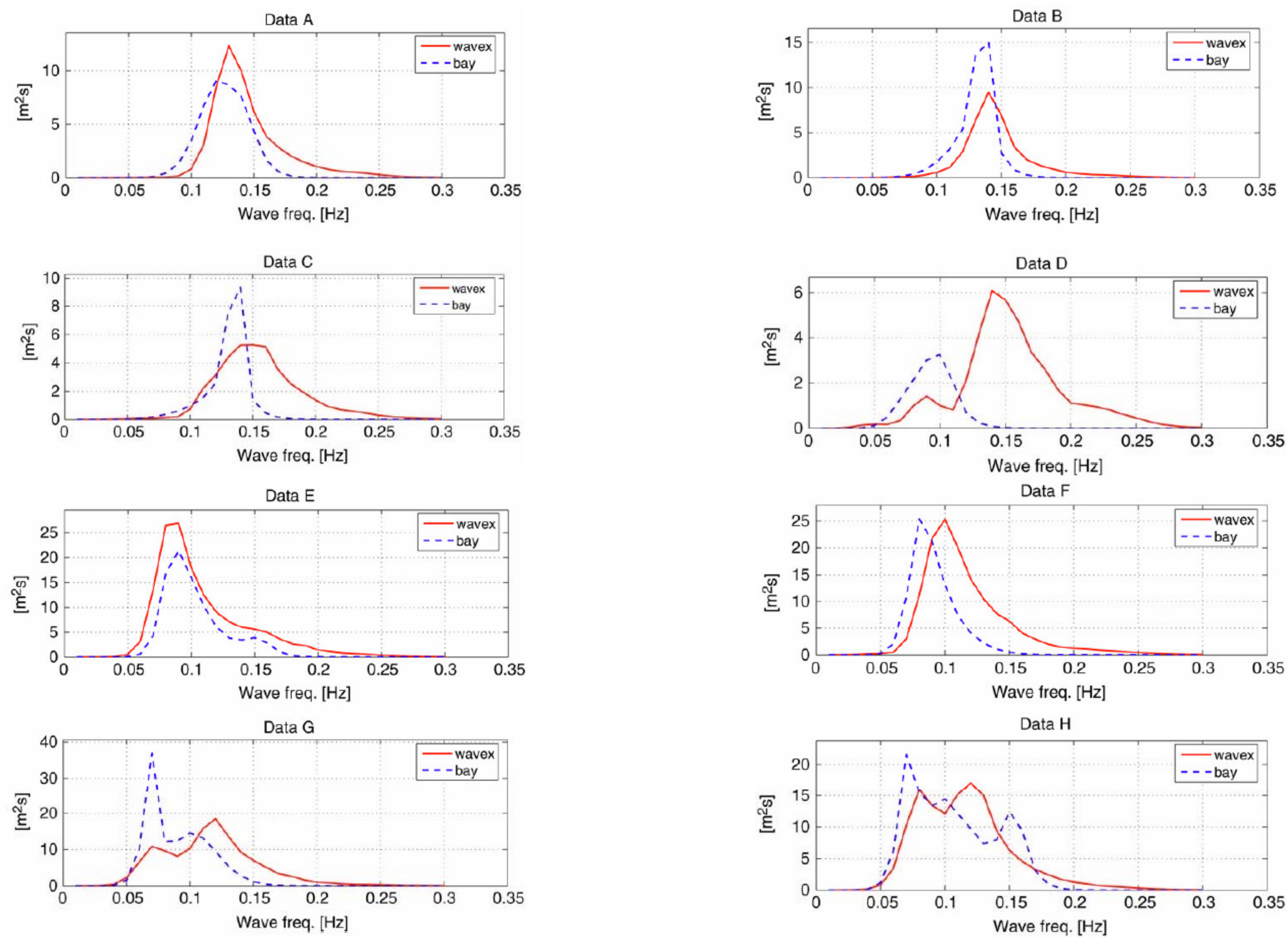
Full-scale measurements from container ship (1)



- eight data sets, A, B, ..., H.
- responses: heave, pitch, roll.
- measurements recorded during operation.
- comparison with wave radar (WAVEX)
- RAOs calculated by Wasim

http://maps.google.com/maps

Full-scale measurements from container ship (2)



Full-scale measurements from sea trial (1)

Fig. 2: The Canadian Navy research ship CFAV Quest.
(L = 71.6 m, B = 12.8 m, T = 4.8 m, C_b = 0.51)

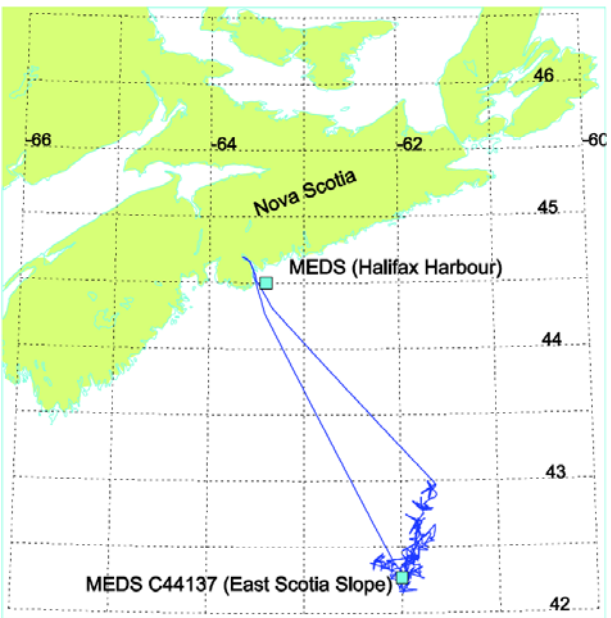


Fig. 3: Voyage map of sea trials.

- Responses: roll rate, roll angle, pitch rate, pitch angle, horizontal acc. and vertical acc. (all recorded at bridge).
- Ship motions calculated by DRDC (SHIPMO7) using 2D strip theory
- Sea state monitored continuously by three wave rider buoys (MEDS C44137 and two drifting Triaxys buoys)
- 16 sets of trials, all with identical "relative" run patterns

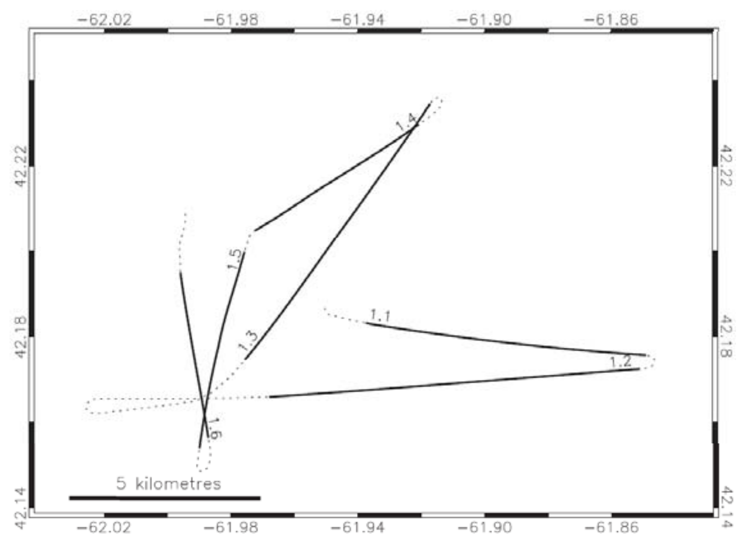
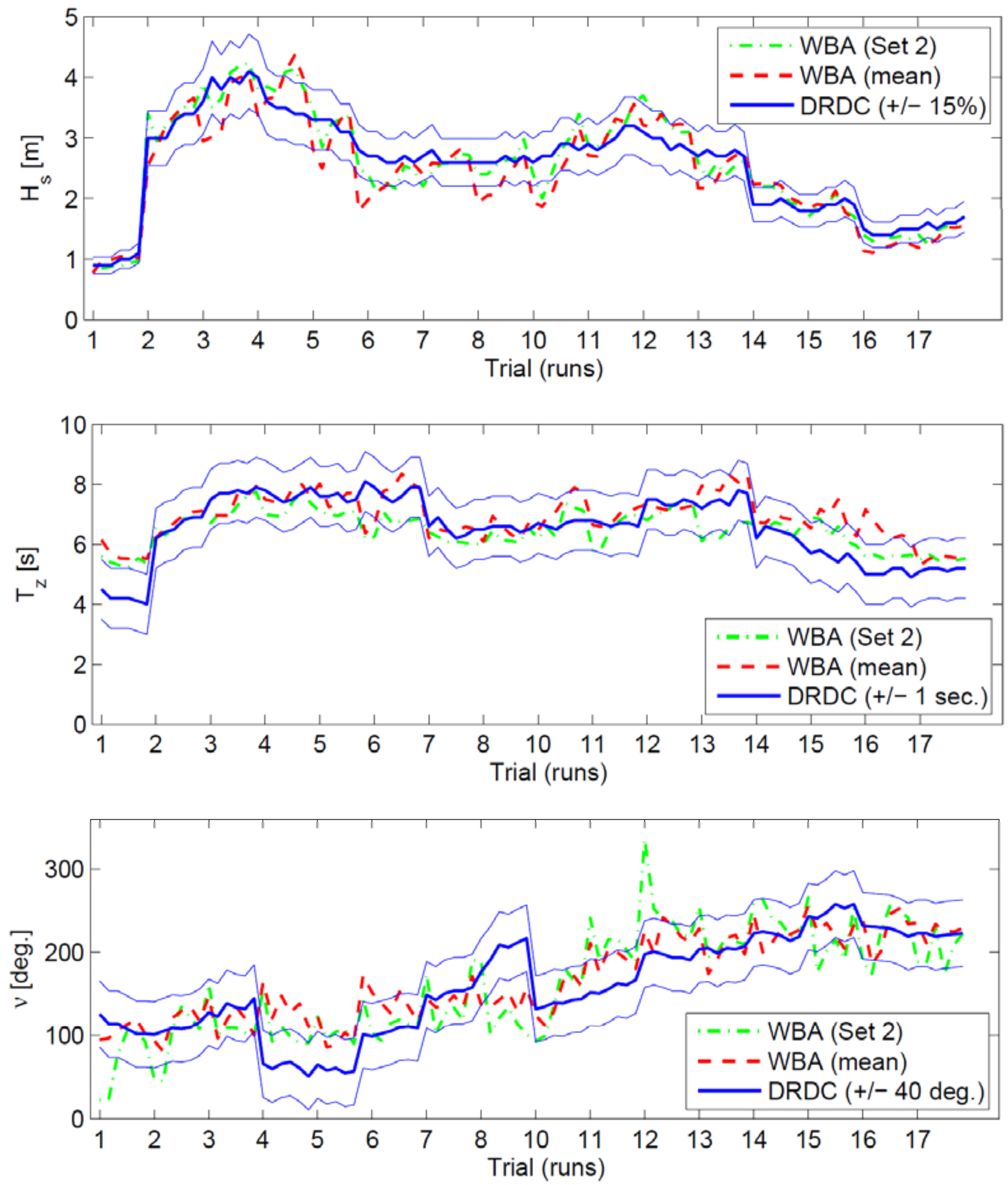


Fig. 4: Run pattern of trial no. 1.

Full-scale measurements from sea trial (2)



WBA: Results by wave buoy analogy.

DRDC: Results obtained as the weighted average value of three floating wave rider buoys.

Content

- Introduction - Field of interest (guidance and decision support systems)
- Means to obtain sea state parameters
- The wave buoy analogy – Wave estimation using measured ship responses
- Results – Numerical simulations and full-scale data
- **Summary/conclusions**

Concluding remarks

- Several means and methods (e.g. wave ride buoys, satellite meas., wave radars) exist to estimate wave parameters.
- In DSS, wave parameters are needed continuously and at actual position of the vessel. (Exclusion of some means...)
- By use of the wave buoy analogy the ship is itself considered as a wave buoy and, hence, wave estimations can be based on measured ship responses.
- Comparisons based on numerical simulations show good agreement.
- Comparisons based on full-scale data show reasonable agreement with estimates from wave radar and wave rider buoy measurements.
- The phenomenon of filtering will affect the wave estimations.
- Which combination of responses is – under given conditions – the best? And, can this combination be chosen automatically? What about uncer- tainties in RAOs and sea state estimation? Ungoing work as a Ph.D. project (IMVA).


Thank you – Questions?
APL
MAERSK
CAI