Numerical tools and methods for design of offshore wind turbines in complex sea ice environments

Dr. ing. Åse Ervik, ase.ervik@multiconsult.no
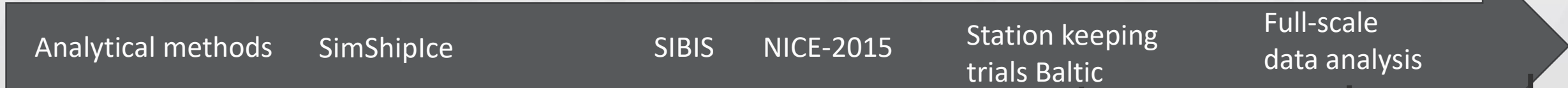
Multiconsult

Development of ice engineering at Multiconsult

Intact ice cover (Shtokman, Arctic concept studies)
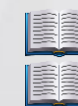
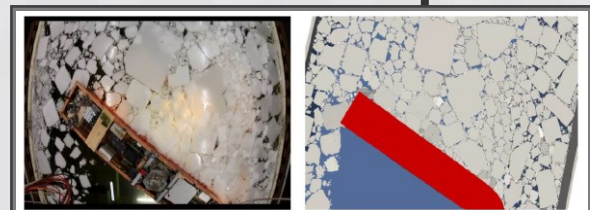**Broken ice cover** (Johan Castberg, Bay du Nord, Wisting)

Analytical methods   SimShipIce   SIBIS   NICE-2015   Station keeping trials Baltic   Full-scale data analysis

2008

📖 ISO 19906 (2010)

2014

2019

📖 ISO 19906 (2019)
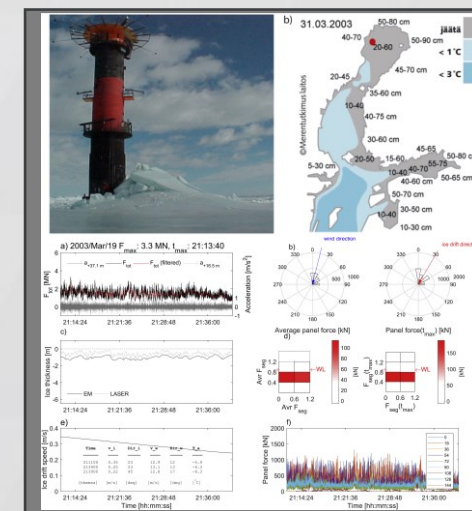📖 Ervik et al. (2019)

Measurements   Simulations
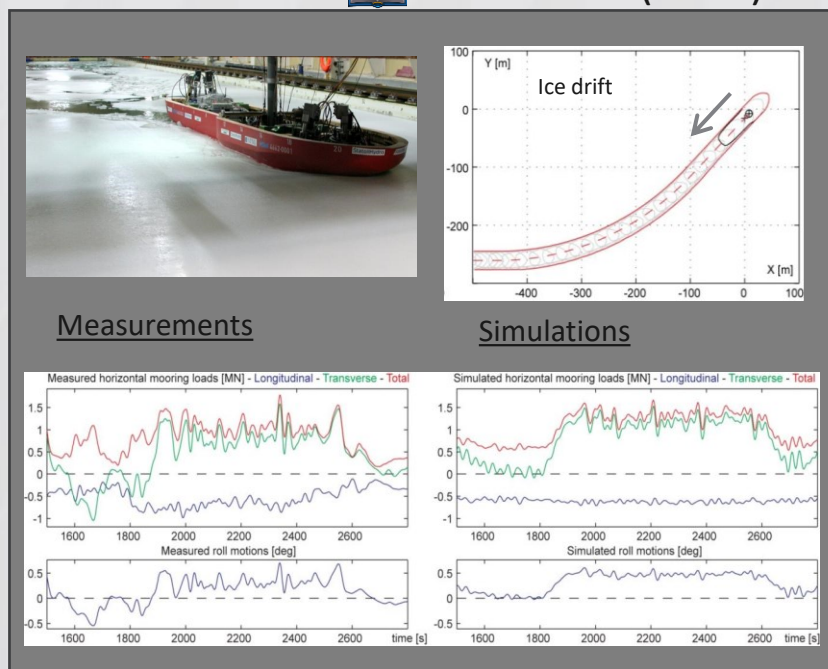
2015

Field work (Norwegian polar institute)

2017

SKT2017 (Equinor)

Now

Sea ice – a complex environment

A sea ice enviroment includes non-linearities on multiple scales

- Ice concentration and floe size
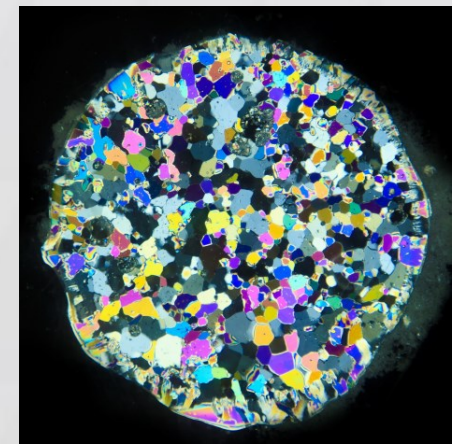- Ice thickness and ridges
- Ice strength and drift

~2 km

~ 100 m

~10 m

~ 10 cm

Sea ice action, international standards

- Sea ice can cause failure/impediment operability of offshore structures

Engelbrektson (1987)

Croasdale et al. (2006)

- Experience gained over time in offshore Oil and Gas industry

- Offshore wind standards (IEC CEV 61400-3-1) partly based on O&G standards (ISO 19906).

IEC CEV 61400-3-1
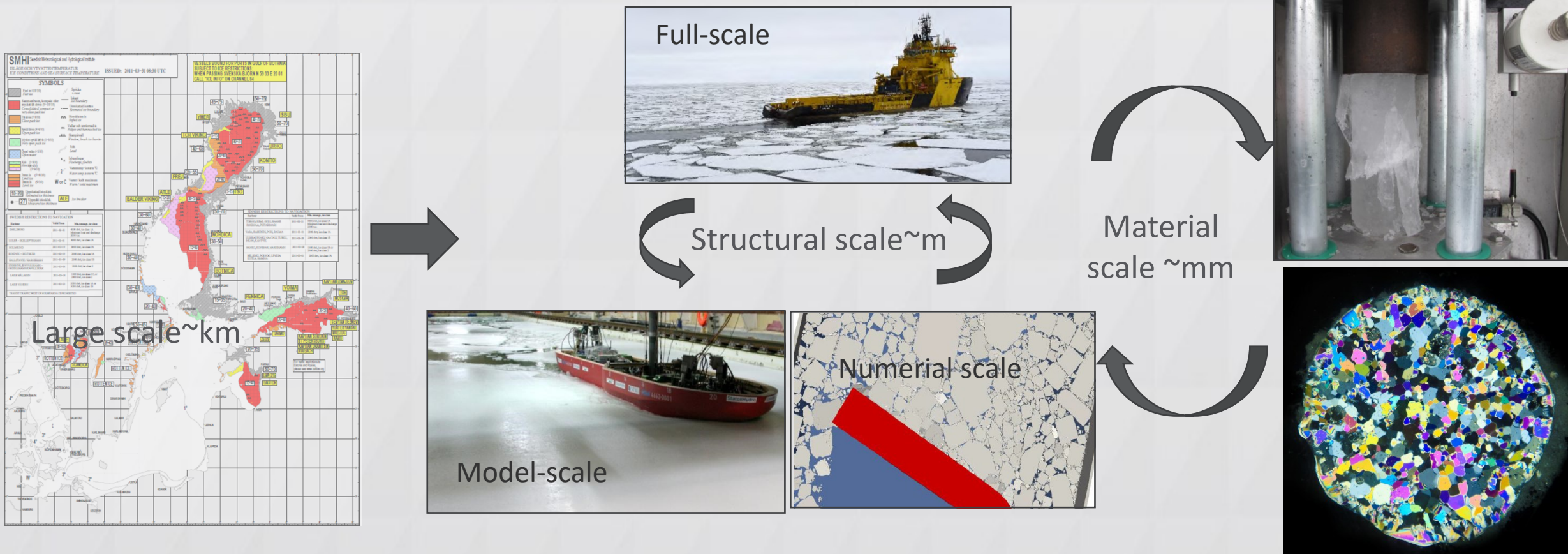Design requirements for fixed offshore wind turbines

ISO 19906
Petroleum and natural gas industries — Arctic offshore structures

Sea ice design – on multiple scales

Full-scale
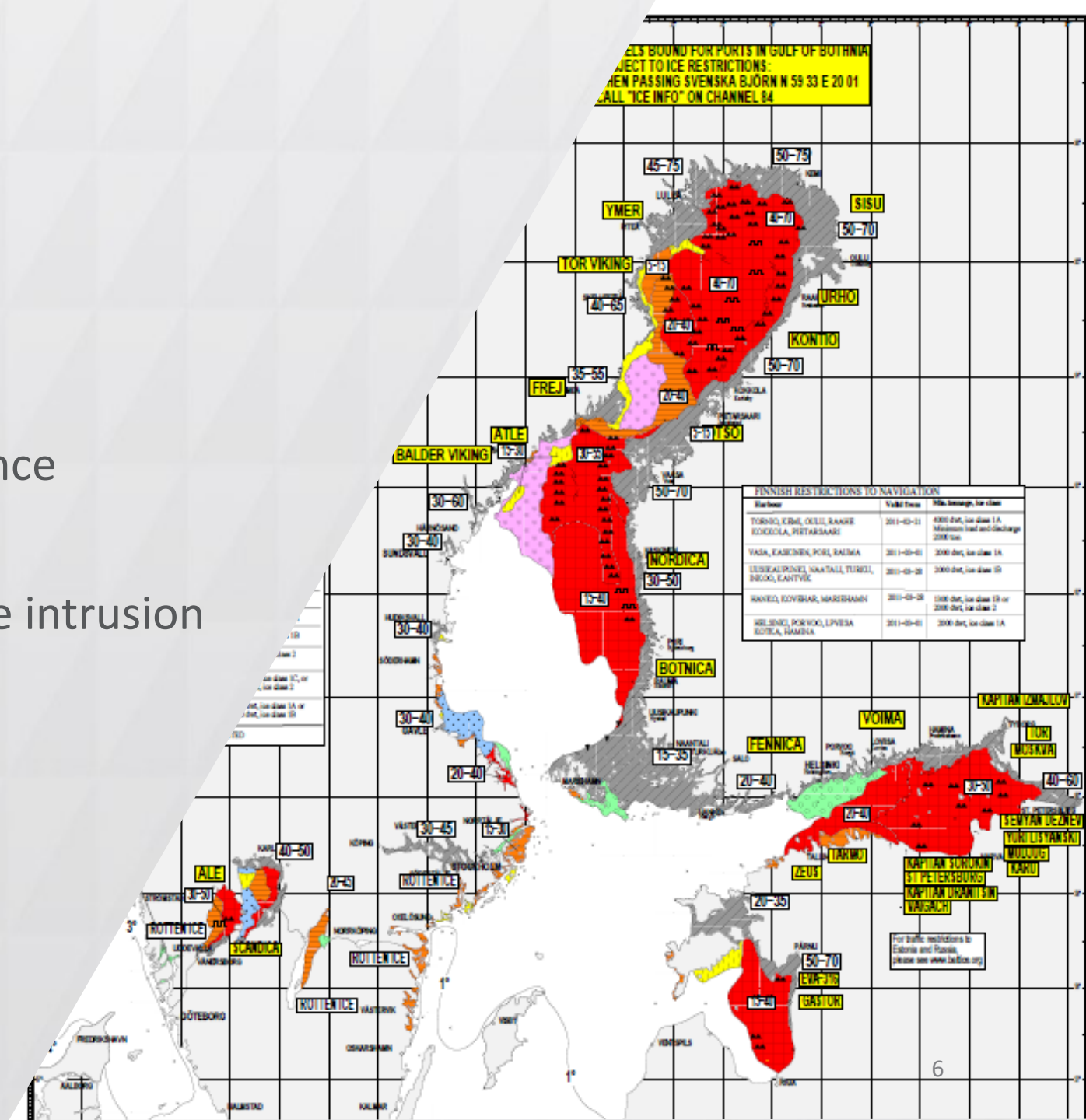
Structural scale~m

Material scale ~mm

Large scale~km

Model-scale

Numerial scale

Sea ice in the Baltic Sea

- Seasonal and spatial variations

- Gulf of Bothnia → seasonal occurence

- Southern Baltic → rare events of ice intrusion

Sea ice in the Baltic Sea

2 km

Ice concentration and ice failure mode

High ice concentration → ice crushing

- High loads

- Large displacements and accelerations
  - Ice velocity dependency
  - Higher pressures for narrow structures opposed to wide structures

Ice concentration and ice failure mode

Low ice concentration →limited crushing

- Lower forces and reponses opposed to crushing in intact ice
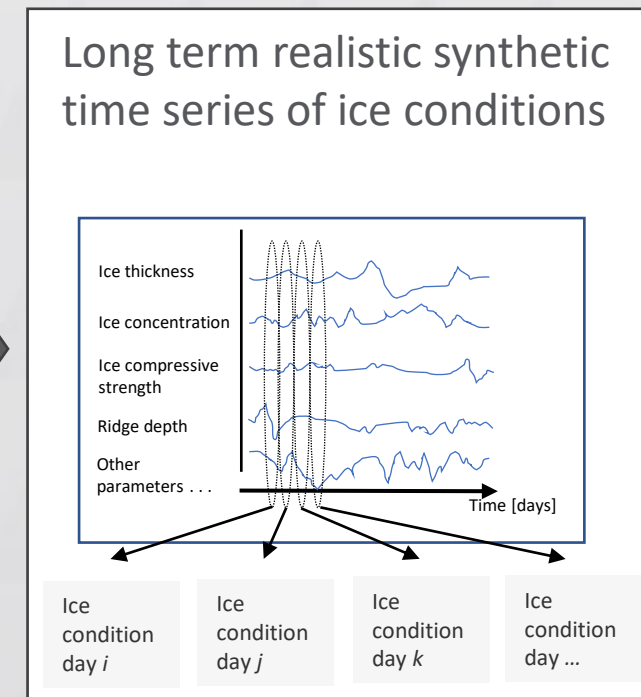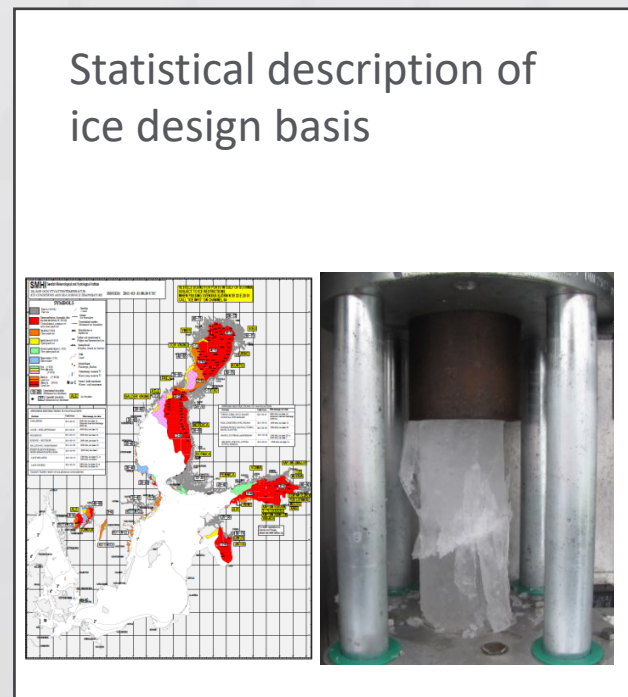- Typical for southern Baltic Sea

Rubble accumulation

- Transport and accumulation of ice rubble

- Multi-legged structures and ice rubble entrapment

- Ice ride up and pile up

Croasdale et al. (2006)

Long time series of ice events - SATSS

- A collection of scripts and methods have been developed to generate realistic long term time series of ice conditions

Statistical description of ice design basis

SATSS Synthetic Arctic Time Series System

Long term realistic synthetic time series of ice conditions

Ice thickness
Ice concentration
Ice compressive strength
Ridge depth
Other parameters . . .

Time [days]

Ice condition day *i*

Ice condition day *j*

Ice condition day *k*

Ice condition day ...

SIBIS Software – overview

- Equinor software, developed by Equinor – Multiconsult – D-ICE Engineering
- Realistic simulation of drifting sea ice action on offshore structures

Ice tank walls (when simulating model tests)

Floating ice pieces

Moored / DP / fixed structure

Ice-ice interactions

Ice-wall interactions

Ice-structure interactions (including ice failure)
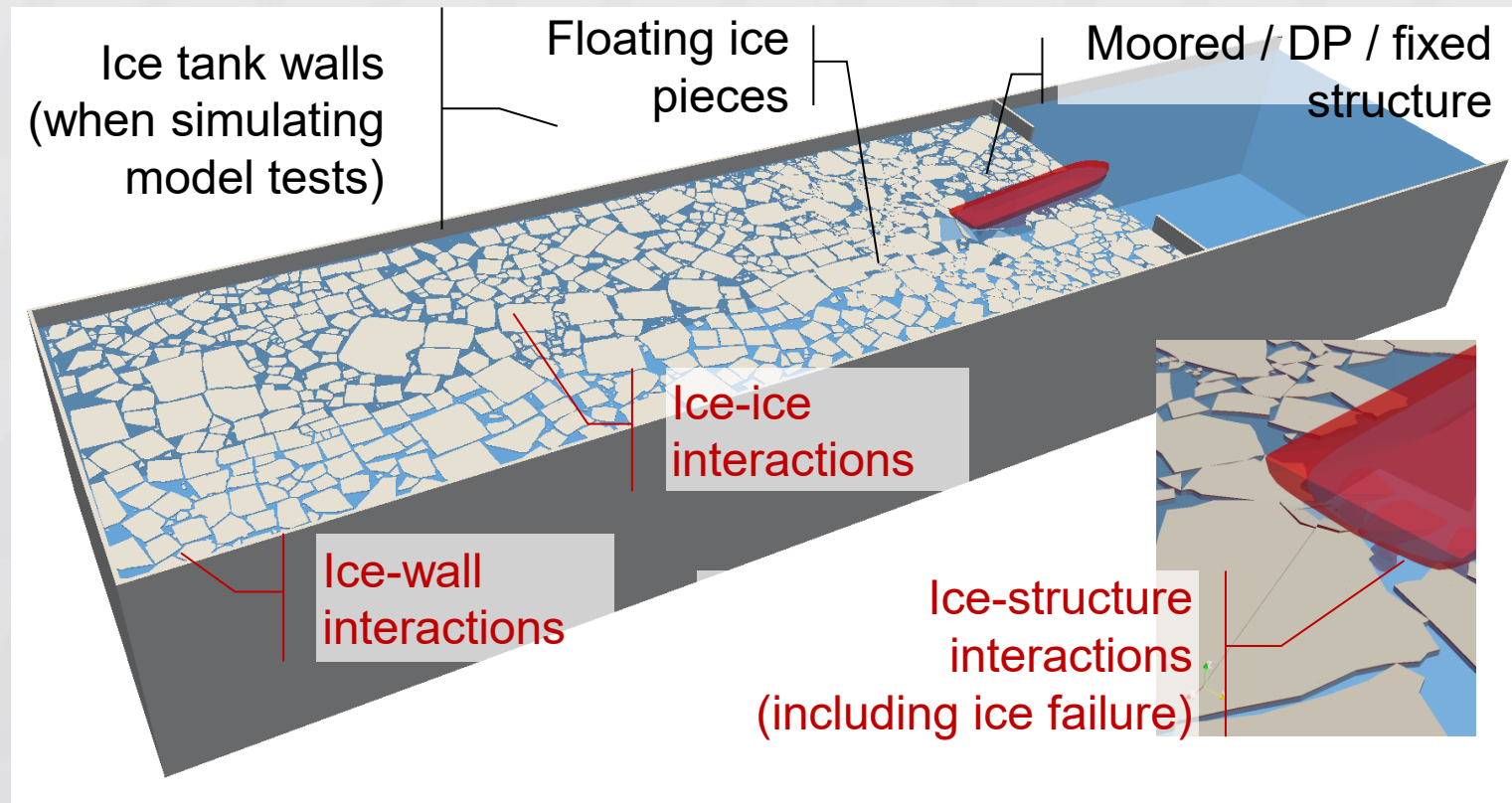
SIBIS Software – properties and components

- CAD-file, structure and ice properties import

- Possibility for multiple fixed or floating structures

- Simulation of marine operations – multiple structures and dynamic positioning
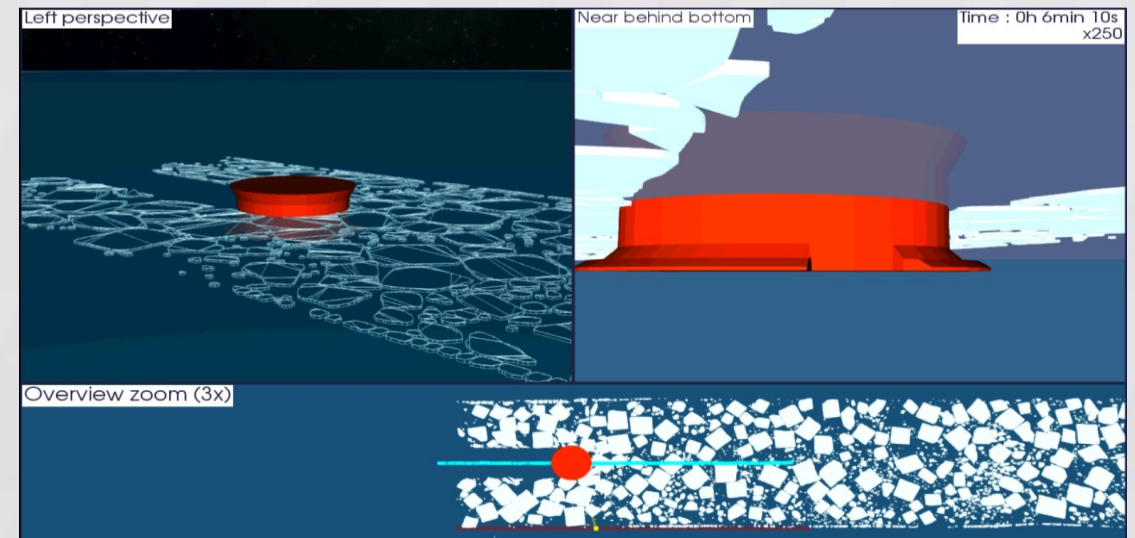
SIBIS Software – ice mechanics

- Ice bending and crushing failure

- Ice crushing model based on full-scale data and ISO19906

- Geometrical ice splitting

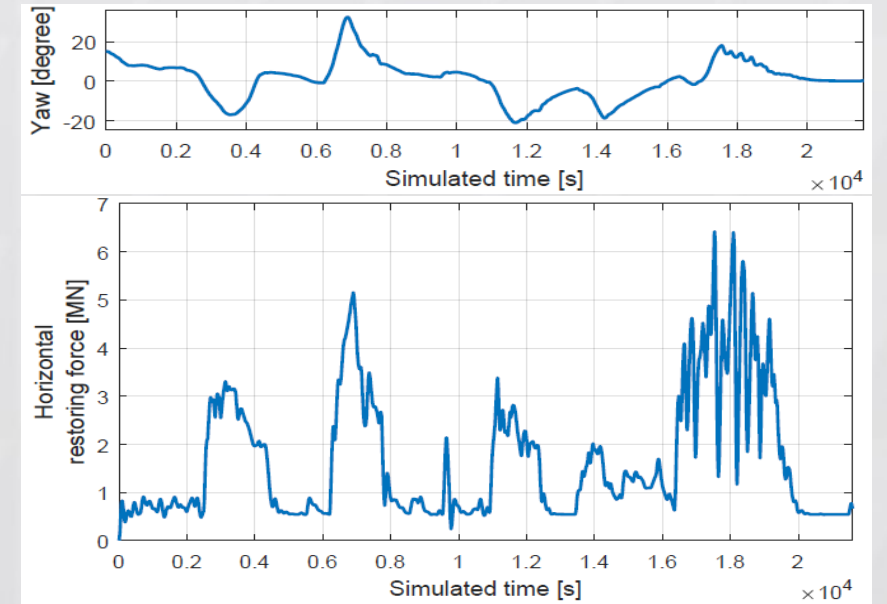- Rubble transport and accumulation on structure

Full scale data

Force distribution

Force stochasticity

Probabilistic model
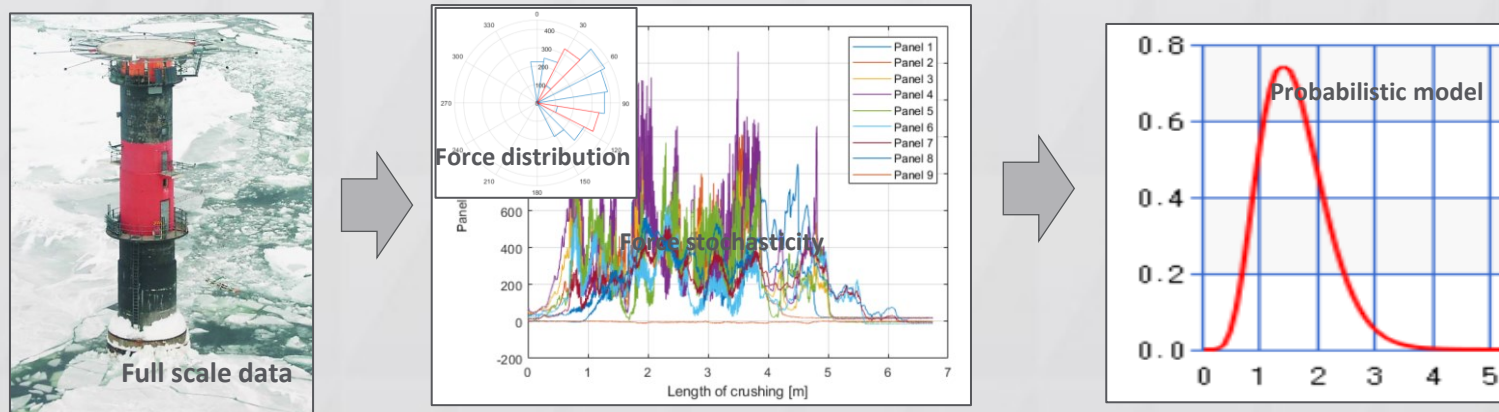
SIBIS Software – output

Time series
- Offsets, restoring forces, contact forces, solver convergence

Videos
- Next slides

SIBIS Software – output

Videos
- Multiple view angles
- Display of synchronized time series
- Ice floes, ridges and structure geometries
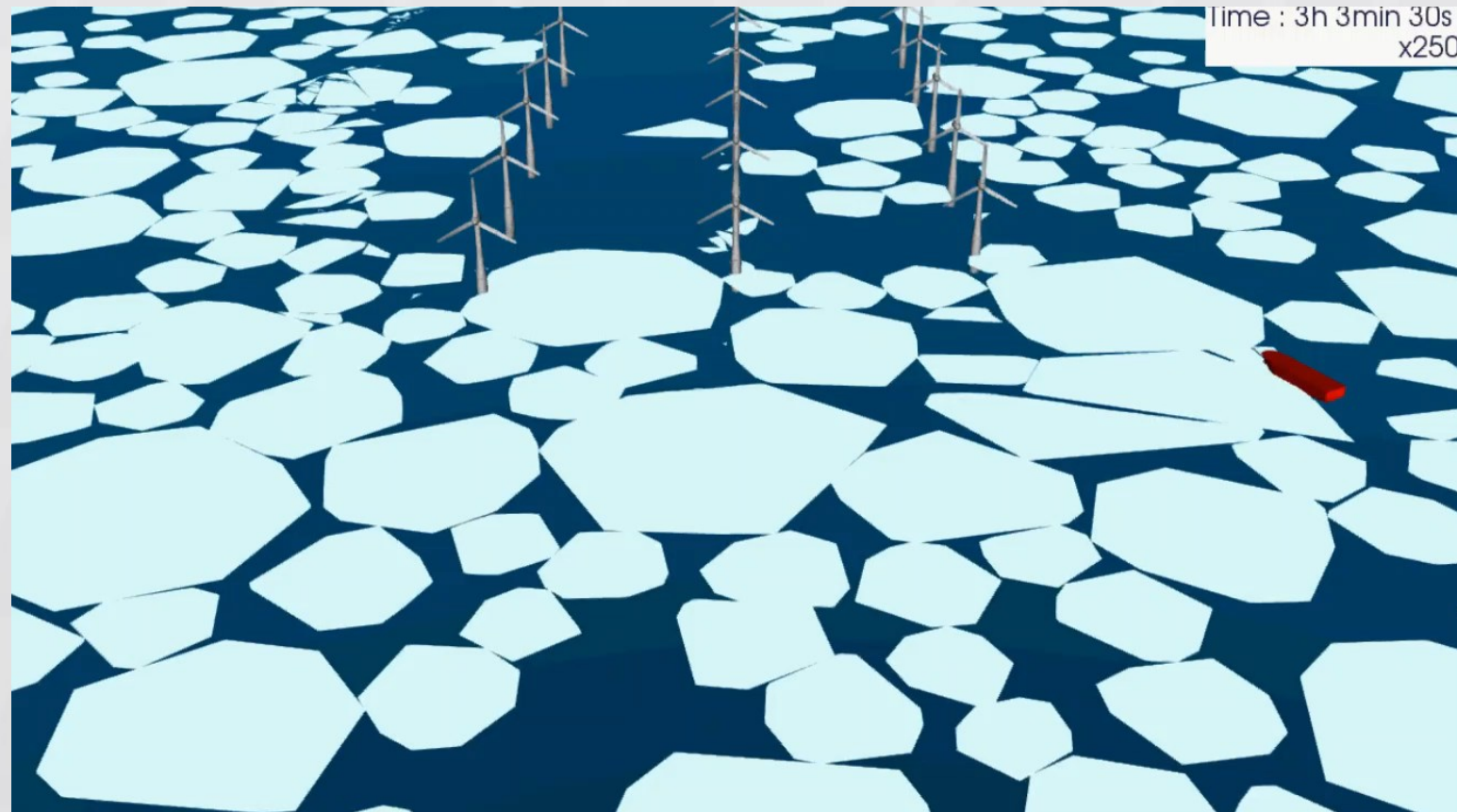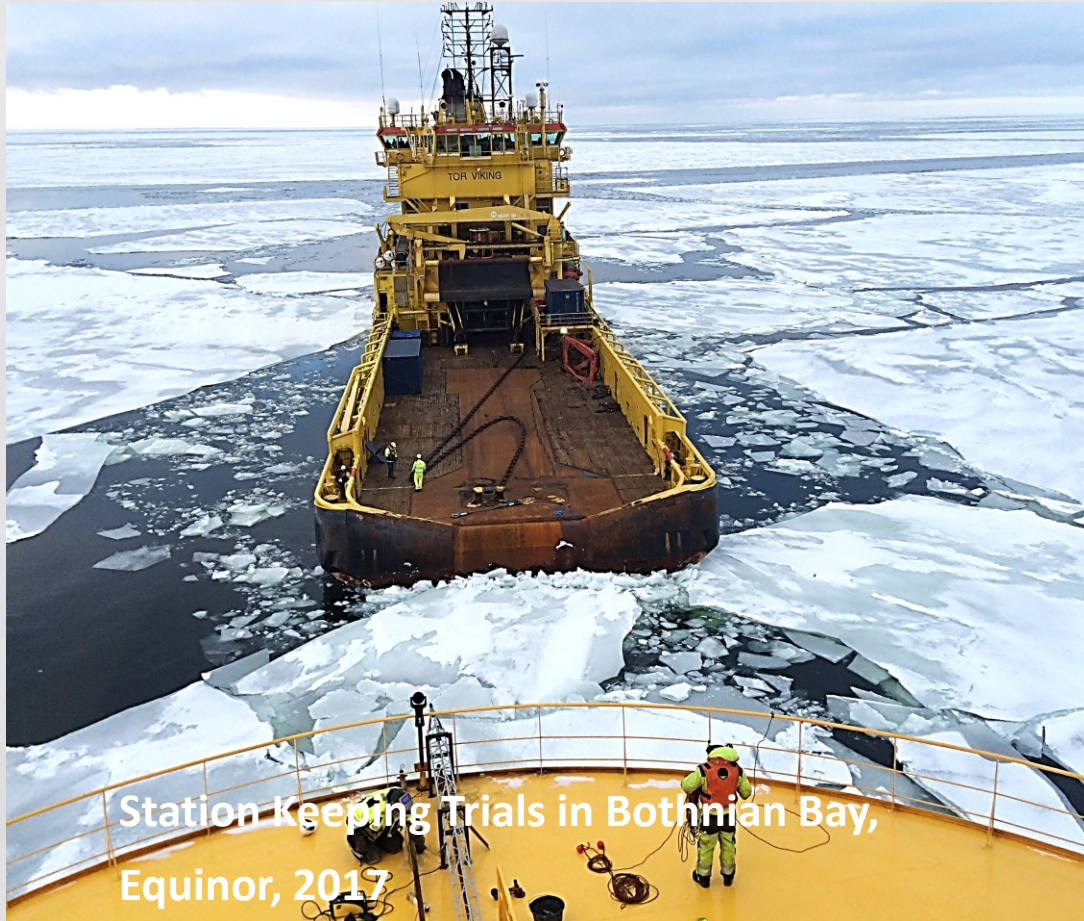- Display of contact forces, ice failure mode, contact width, etc.

SIBIS Software – output

Videos
- Multiple view angles
- Display of synchronized time series
- Ice floes, ridges and structure geometries
- Display of contact forces, ice failure mode, contact width, etc.

SIBIS Software – reference projects

Station Keeping Trials in Bothnian Bay, Equinor, 2017
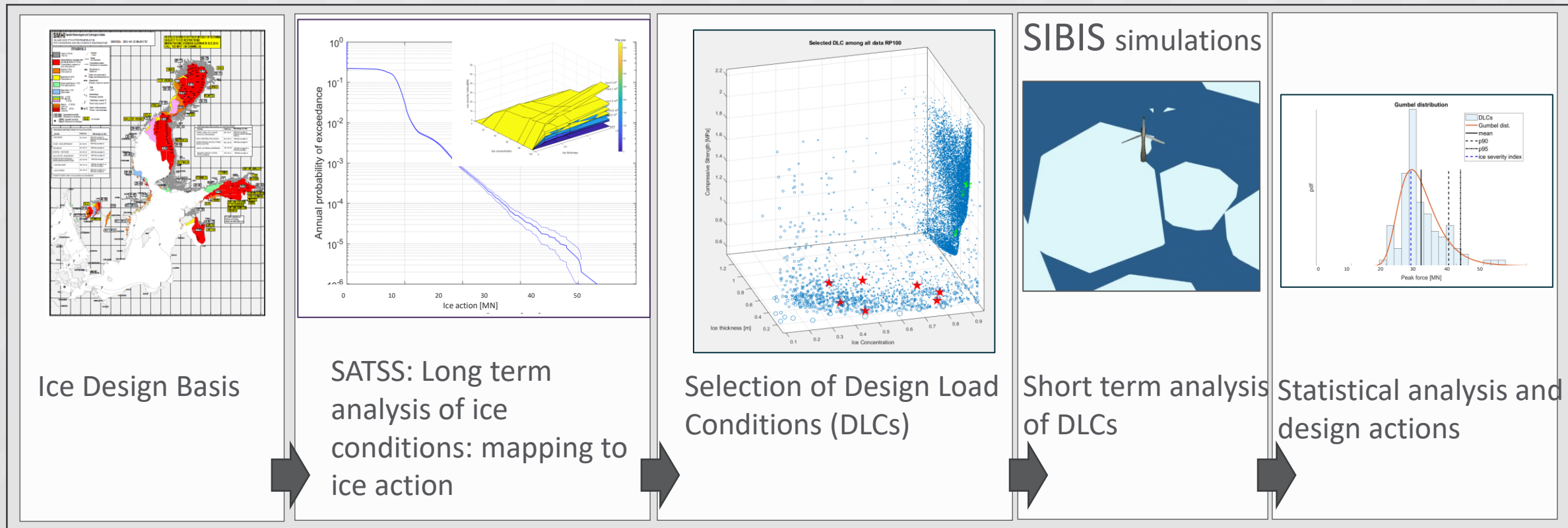
- 2017 Station keeping trials in northern Baltic - Equinor
- 2017-2019 Bay Du Nord – Equinor
- 2019-2019 Wisting – OMV
- 2019 -2022 Wisting – Equinor
- 2021 Drillships concept study - Client
- 2022 Bay Du Nord – Equinor

Sea ice design methodology – summary

Ice Design Basis

SATSS: Long term analysis of ice conditions: mapping to ice action

Selection of Design Load Conditions (DLCs)

SIBIS simulations

Short term analysis of DLCs

Statistical analysis and design actions

Sea ice design methodology – summary

Ice Design Basis

SATSS: Long term analysis of ice conditions: mapping to ice action

Selection of Design Load Conditions (DLCs)

SIBIS simulations

Short term analysis of DLCs

Statistical analysis and design actions