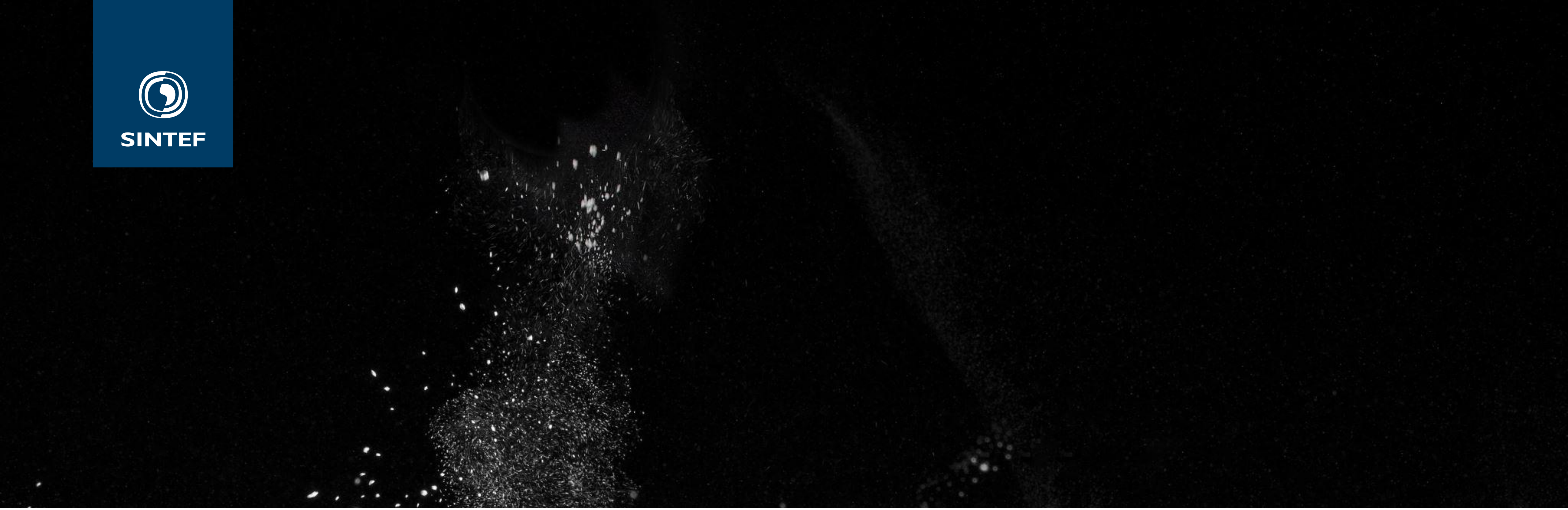

Simuleringer av produsertvannplume på Ekofisk og sammenligning med måledata

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Overview

- We have simulated a tracer added to the produced water plume at Ekofisk using the DREAM model
- Model predictions were made ahead of time and used in planning of field measurement, based on historical data and models
- Model results been compared with *in situ* fluorescence and PAH measurements (from NGI, see Espen's presentation)
- Numerical models are a simplification of reality, containing what we think are *key processes.*
  - But does it provide results that compare reasonably with measurements?

Overview

- The DREAM model
- Model input data and measurements
- The discharge
- Simulations and comparison with measured data

The DREAM model

Developed for O&G industry

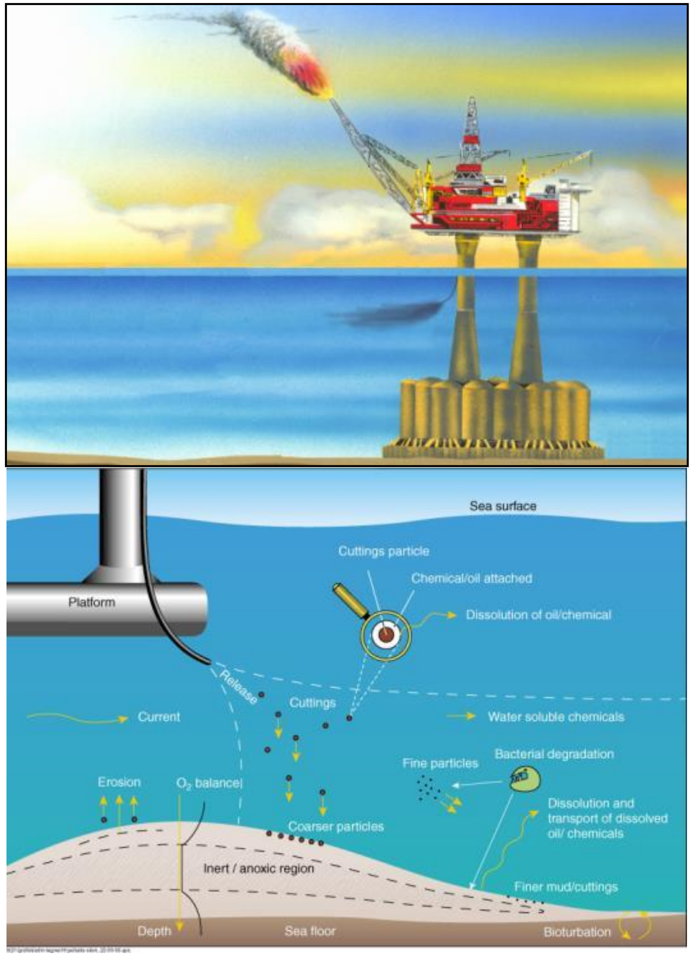
- Produced water discharges
- Drilling discharges

Three-dimensional Lagrangian transport model

- Multi-site, multi-component releases
- Chemical and biological fate processes
- Predict concentrations, sedimentation in space and time

Optional submodels:

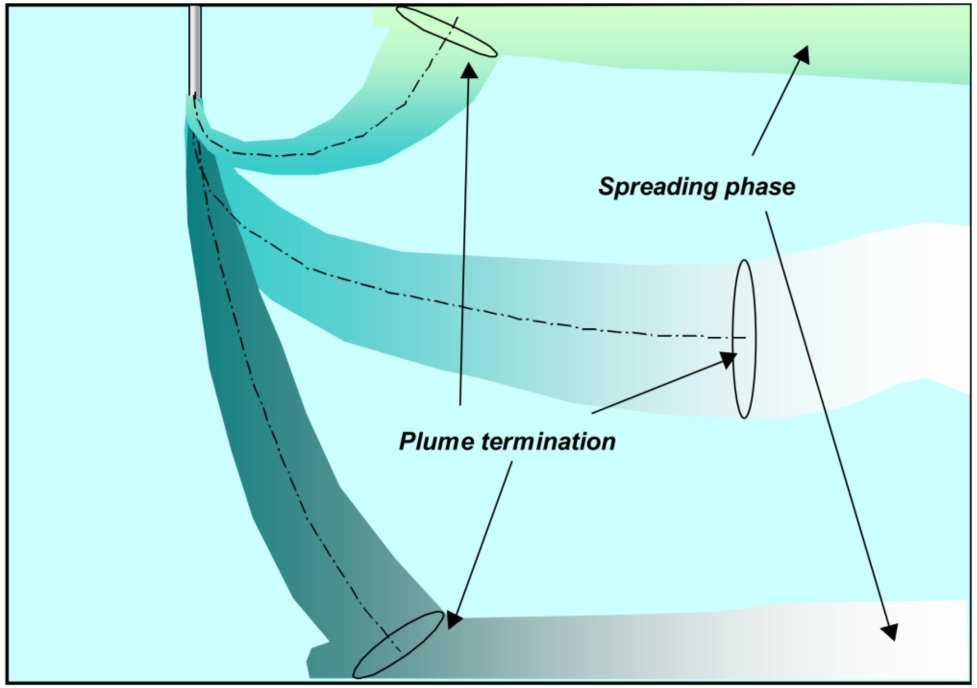
- Sediment re-suspension
- Benthic fate model
- Near-field integral plume model



www.sintef.no/DREAM

The near-field plume model

- Predicts plume trajectory based on relative bulk buoyancy and initial momentum (jet)
- Entrainment of surrounding water dilutes the plume and reduces relative buoyancy
- Large particulates or gas bubbles may escape from the main plume
- Plume termination at surface, sea bed or trapping
- Particulates and chemicals are then released to the free water masses and transported

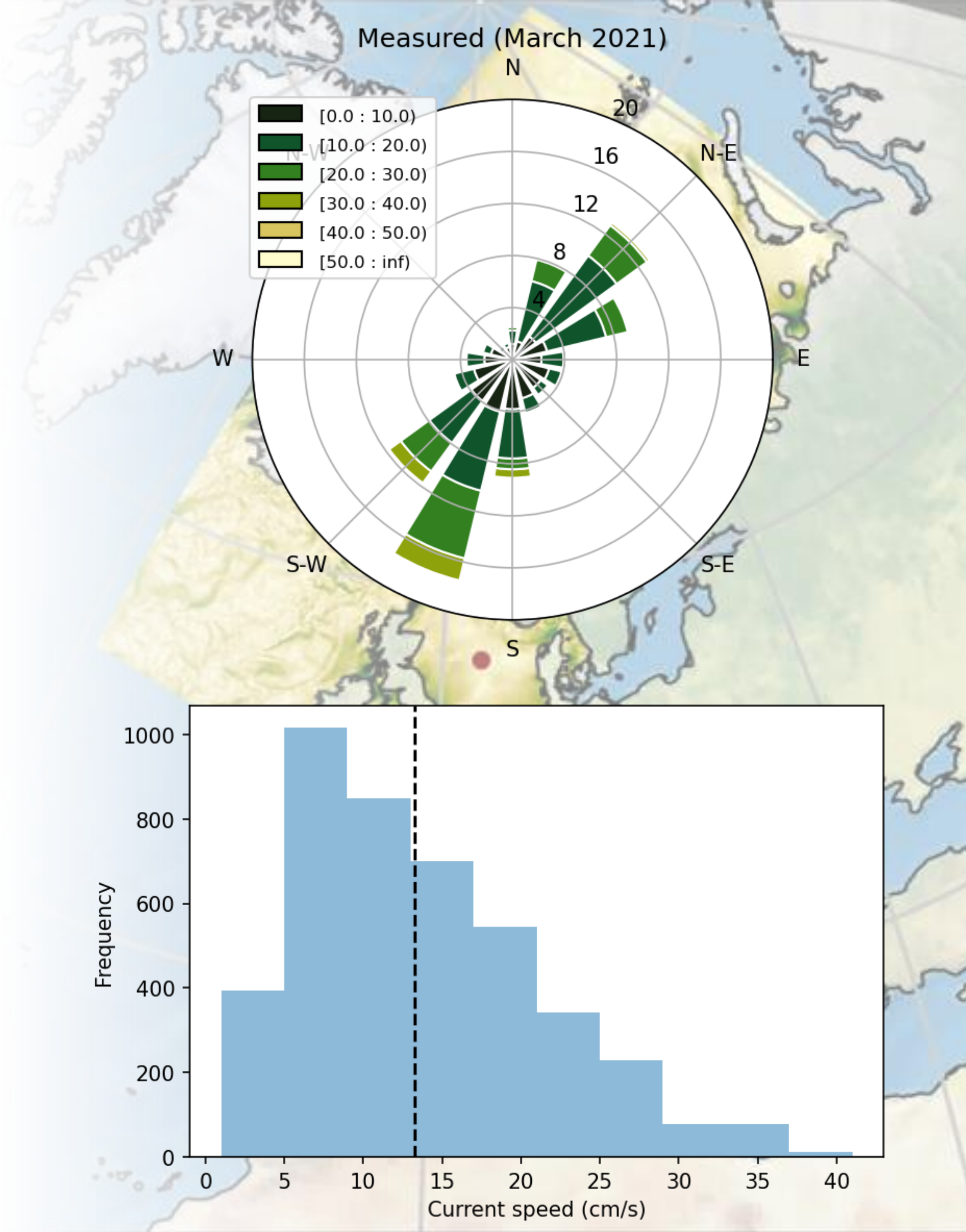


Ocean currents

- Key controlling factor in transport of pollutants
- Important input variable (forcing) driving advective transport in the model
- Data sources:
  - Nordic4 4 km model, operational, from MET Norway
  - Current point meter at Ekofisk (multi-year time series, ConocoPhilips and MET Norway)
  - 2x ADCP data from sampling period (NIVA)

Ocean currents

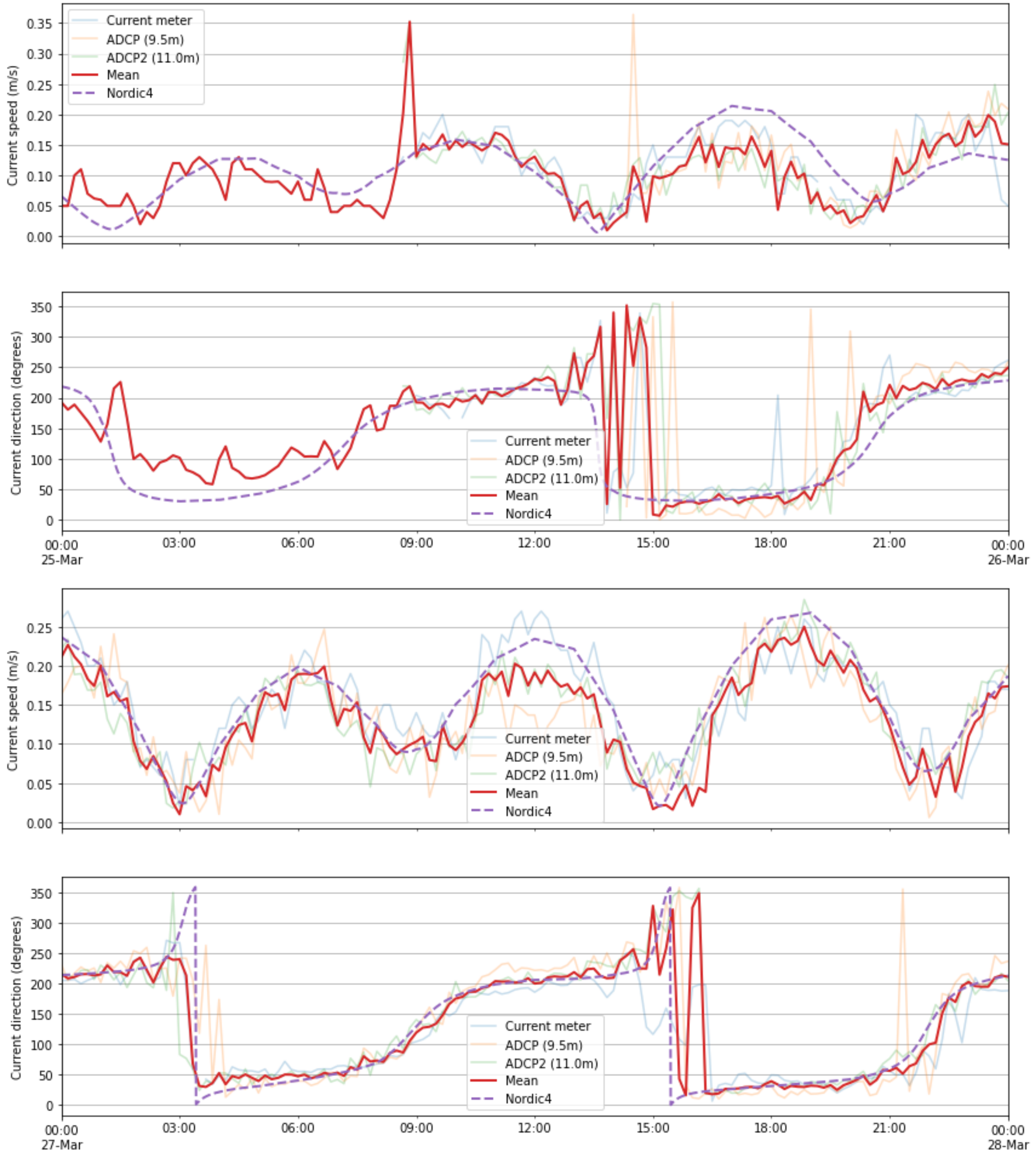
- Tidal-dominated currents at Ekofisk
- Predominantly north-east / south-west
- Speeds for March 2021 typically in range 5 - 23 cm/s
  - Mean: 13 cm/s



Ocean currents

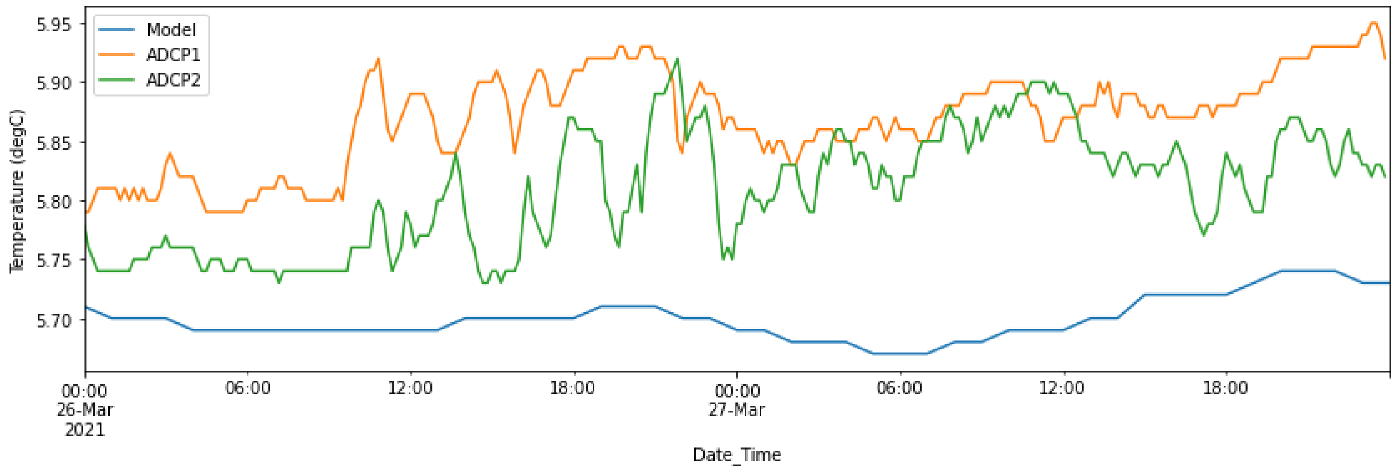
SINTEF

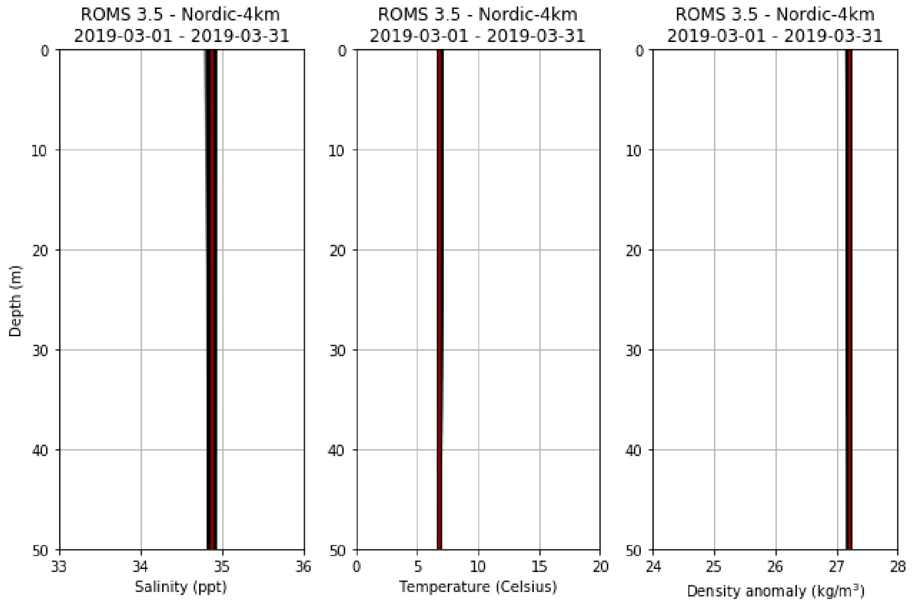
- MET Nordic4 model and Ekofisk point current meter in good agreement for 25-27 March 2021
- Also good agreement with ADCP data in period
- Mean of 2x ADCP and current meter used as model input



Ocean temperature and salinity

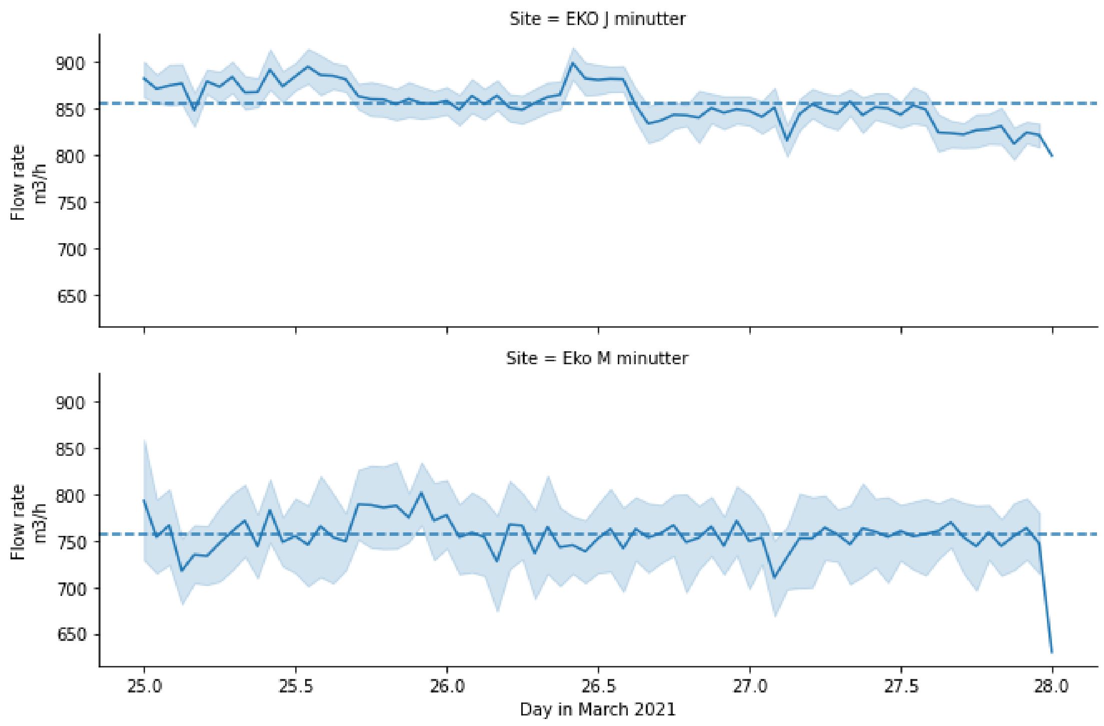
- Nordic4 model predictions quite close to measured temperature (NIVA data) for 2021
  - Around 5.8 ℃
- Generally little stratification in March/April
- Important for near-field plume behavior





PW discharge and tracer

- Ekofisk has two discharge points, tracer added to EKOM
  - EKOM has five outlets at depths between 20 – 30 m
  - EKOJ single outlet at 48 m
- Variable flow rate; period mean rate was 855 m^3/h (EKOM)
- Temperature: 70 degC (but variable)
- Salinity: 45 g/L (but variable)

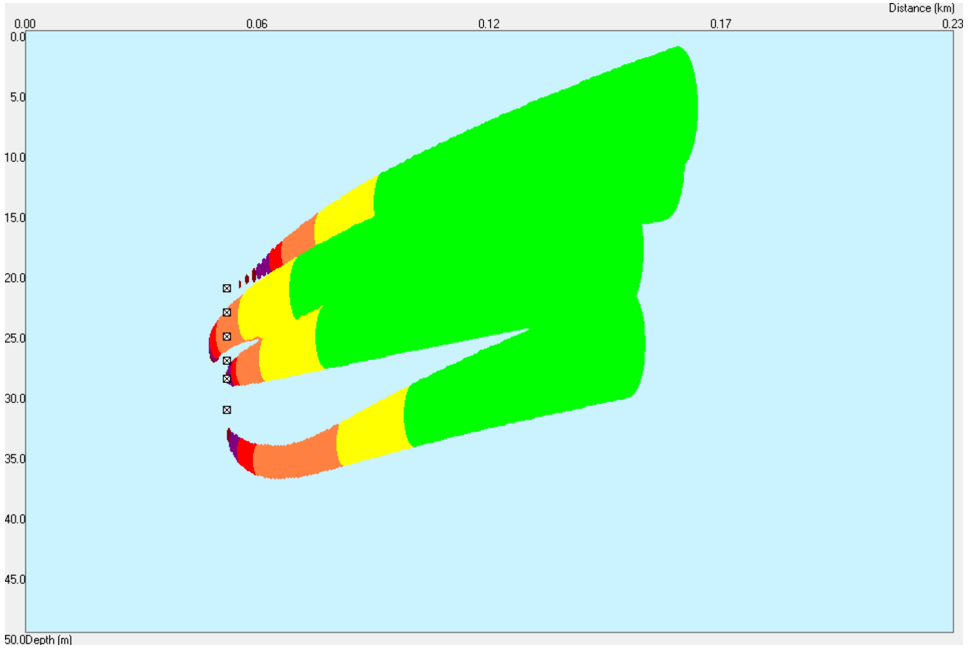


Fluorometer and IMIRO data

- First time sufficiently sensitive PAH sensor/fluorometer and accurate 3D positioning has been available for the WCM
- Using scaled concentration
  - IMIRO PAH calibrated to actual discharged PW
  - Fluorometer values dividied by calculated tracer concentration in discharge
- Data from NGI (Espen's presentation)
- Tracer visible on surface
  - Indicates plumes terminates near the surface in some cases (e.g. low current speeds)

Plume trajectories - EKOM

- A buoyant plume is generated at each of the 5 outlets
- Initial water is warm (70 degC) with high salinity (45 g/L)
- Plume ***expands*** due to entrainment of ambient water
- Trajectory determined by buoyancy and ambient currents
- Plume is trapped when density approaches ambient (else surfaces)

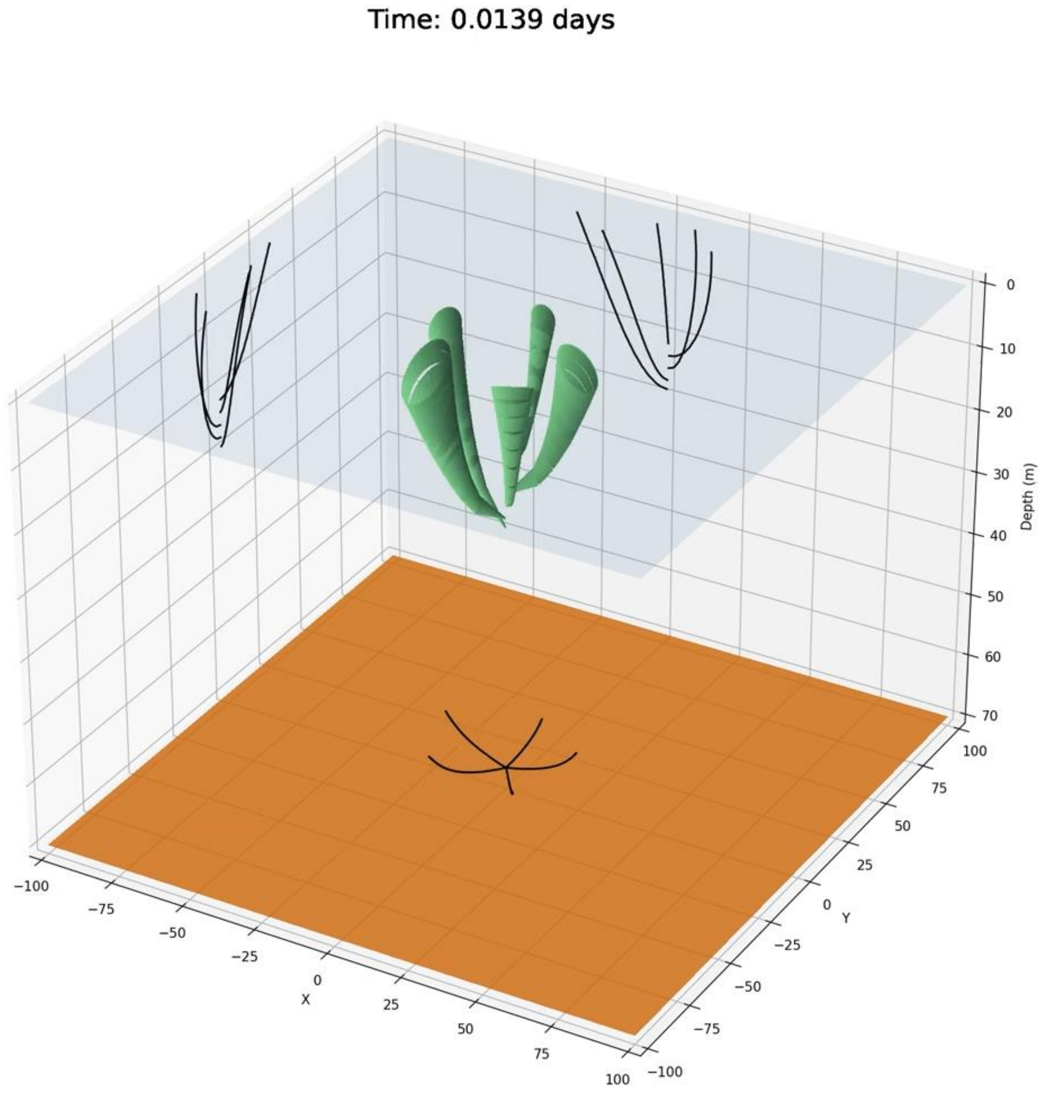


Simulation of plume trajectories

- Currents stretch and bend the plumes, strong tidal effect

- Forced entrainment from stronger currents can cause deeper trapping

- Plumes also termine near/at surface in some situations (weaker currents) – also observed (tracer patches)

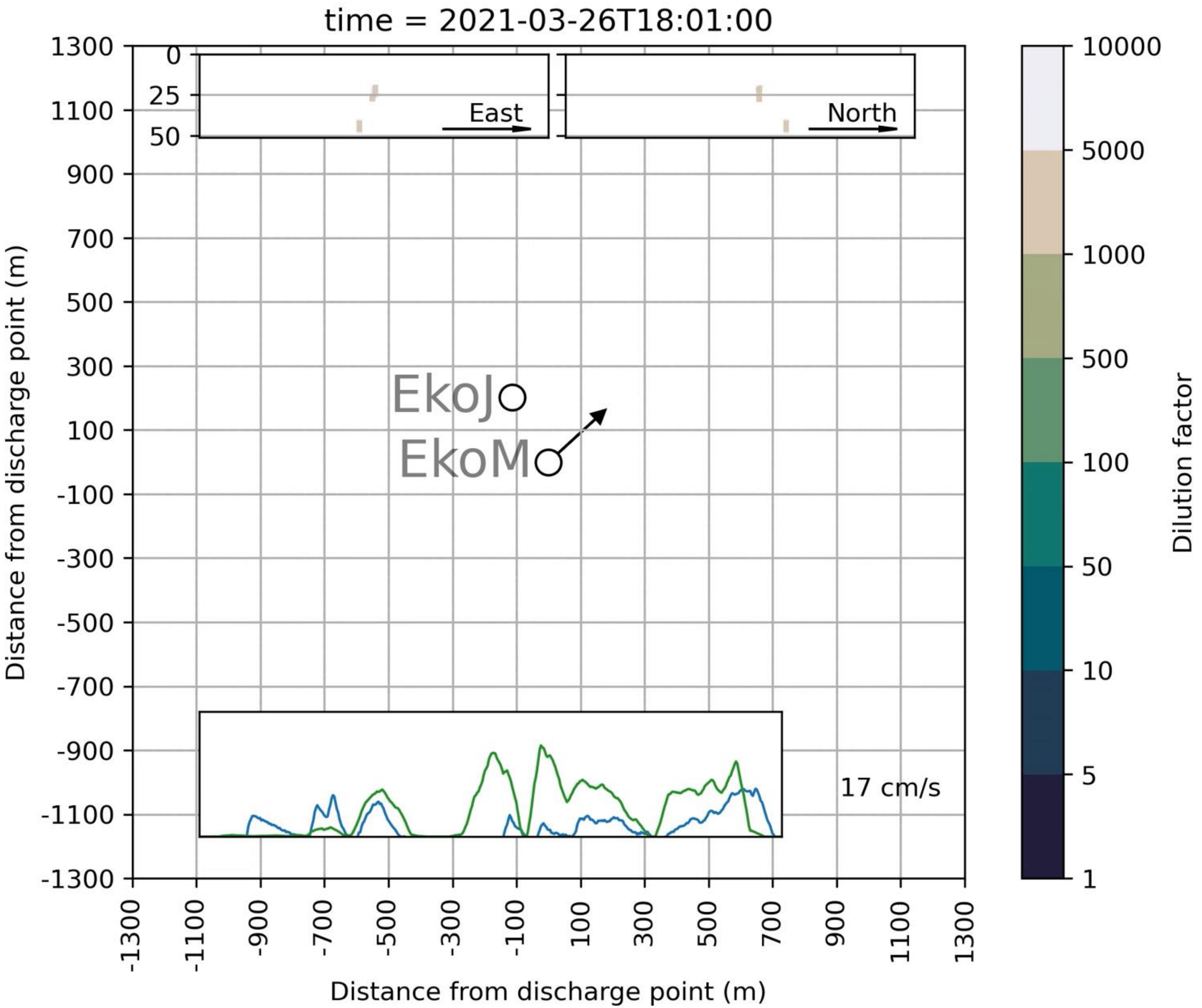


Period B – 27 March – IMIRO

Discharge from both EKOJ/EKOM

IMIRO PAH measurements

Plumes from EKOJ and EKOM sometimes merge

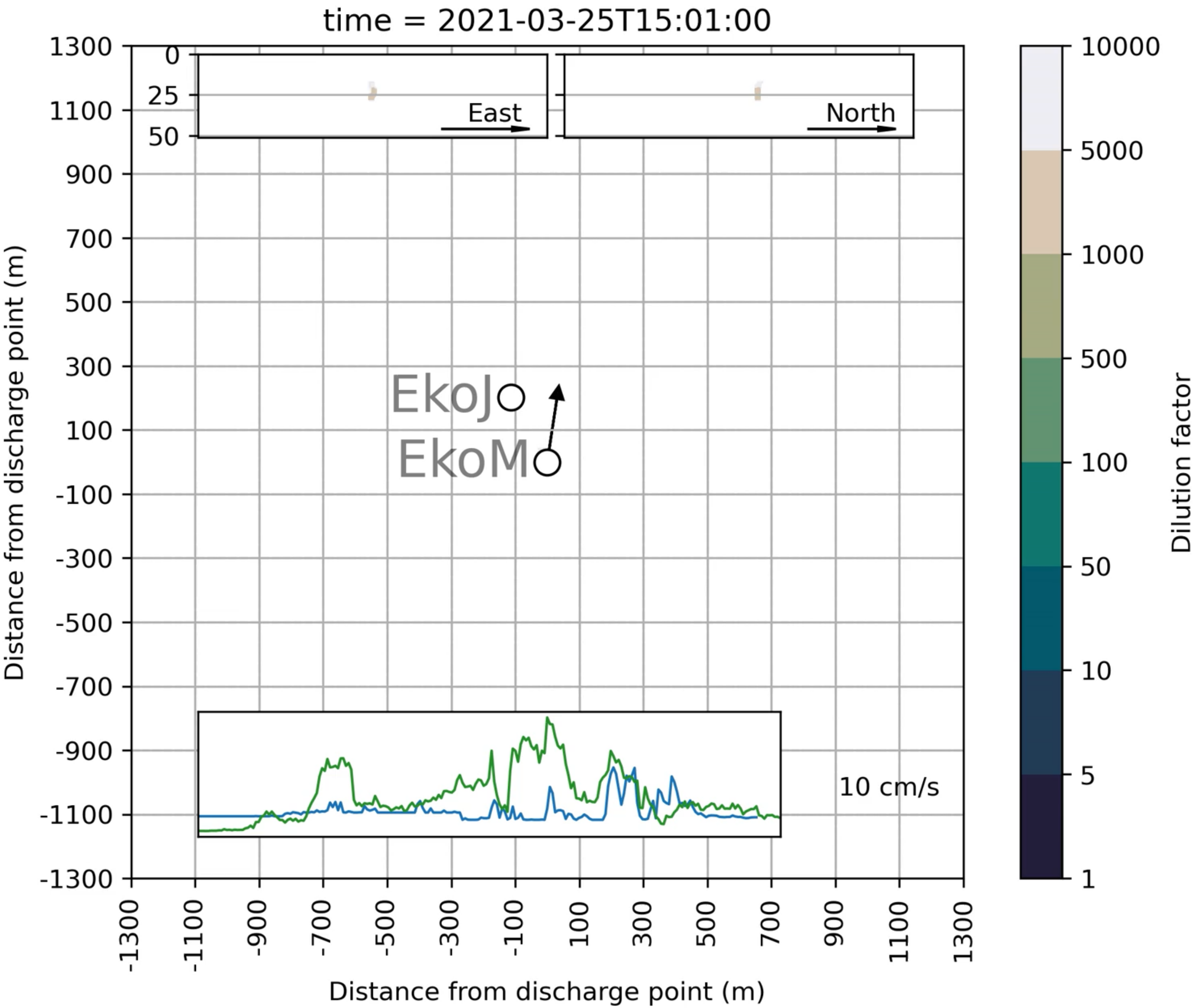


Period A – 25 March – tracer

Tracer added 15:30 – 18:30

Spotter on M indicated incorrect vessel position rel. to plume surface signature (other vessel blocked)

Later corrections to positions showed plume signal (measured and model)



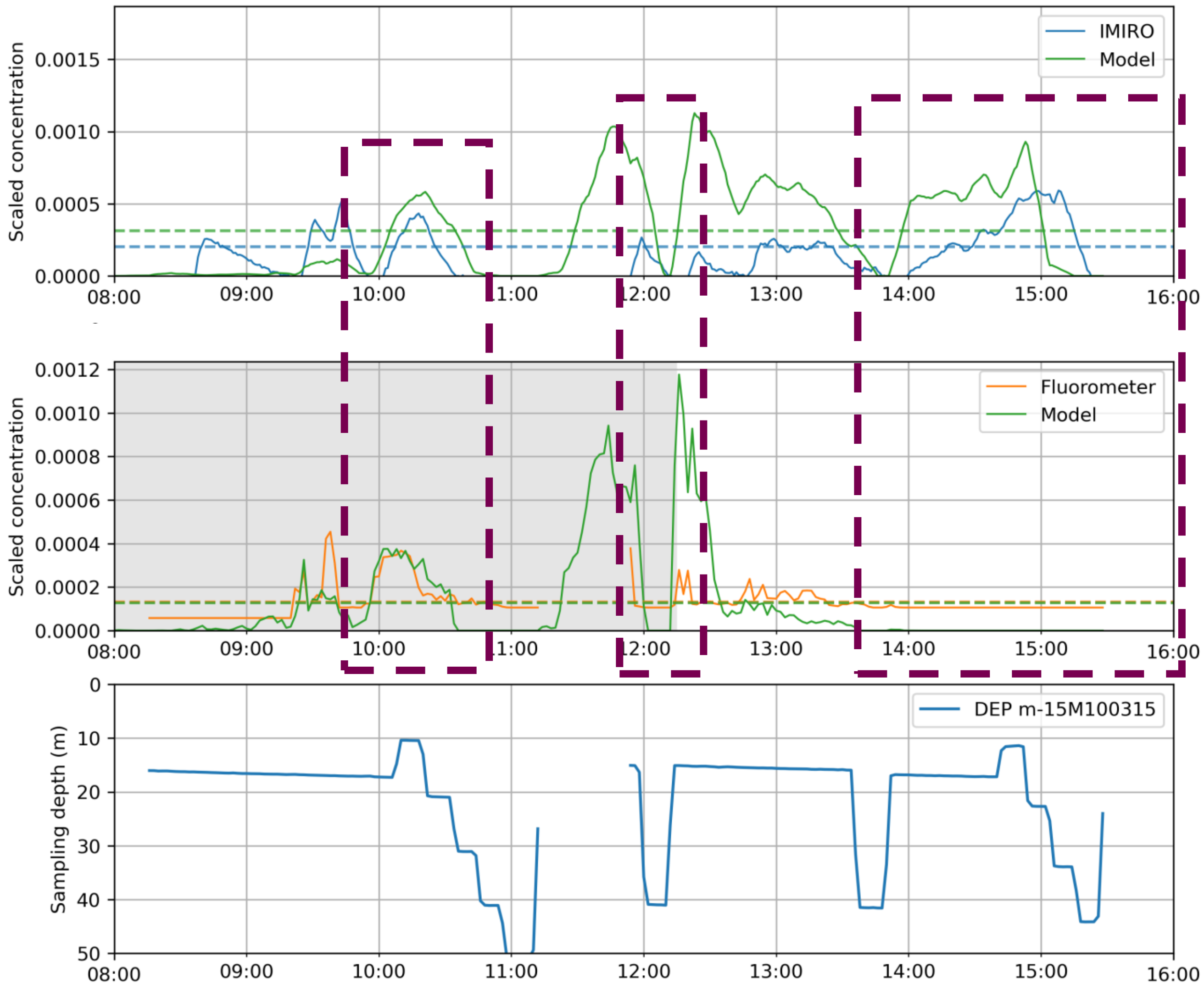
Period B – 27 March

Tracer discharge window (gray)

Scaled concentrations (Measured / Discharged)

Good agreement between model and fluorometer/IMIRO around 10:00

IMIRO sensor and model both show plume signal after tracer signal drops to near zero



Some assumptions and uncertanties

- Variability in discharge rate, salinity, temperature not accounted for in model setup (used constant/mean values)

- Spatial high-resolution currents not available (point/profile or 4 km model)
  - Small-scale mixing parametrization is assumed (not known)

- Model resolution vs. sensor resolution
  - Grid cell (20 x 20 x 2 m), sensor is point-like

- Actual tracer concentration in discharge was calculated, not measured

Summary and conclusion

- “All models are wrong – but some are useful” (G. Box)
- A transport and near-field numerical model can make useful predictions for planning and interpreting *in situ* measurements of PW discharges
- Model results in fair agreement with measured values, some interesting correlations

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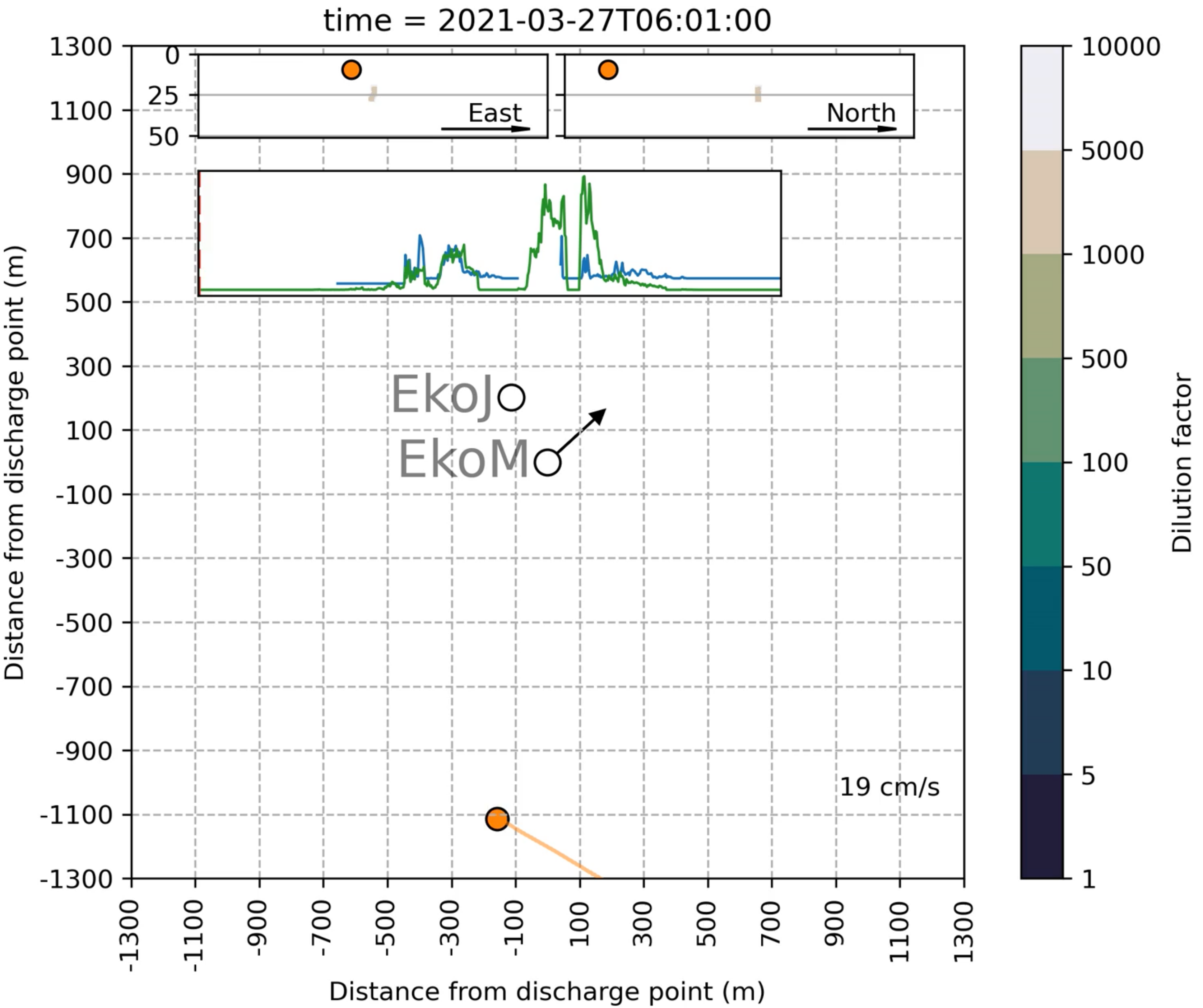
Period B – 27 March – tracer

Tracer added 06:30 – 12:00

Vertical profile around 12 show clear signal drop at depth



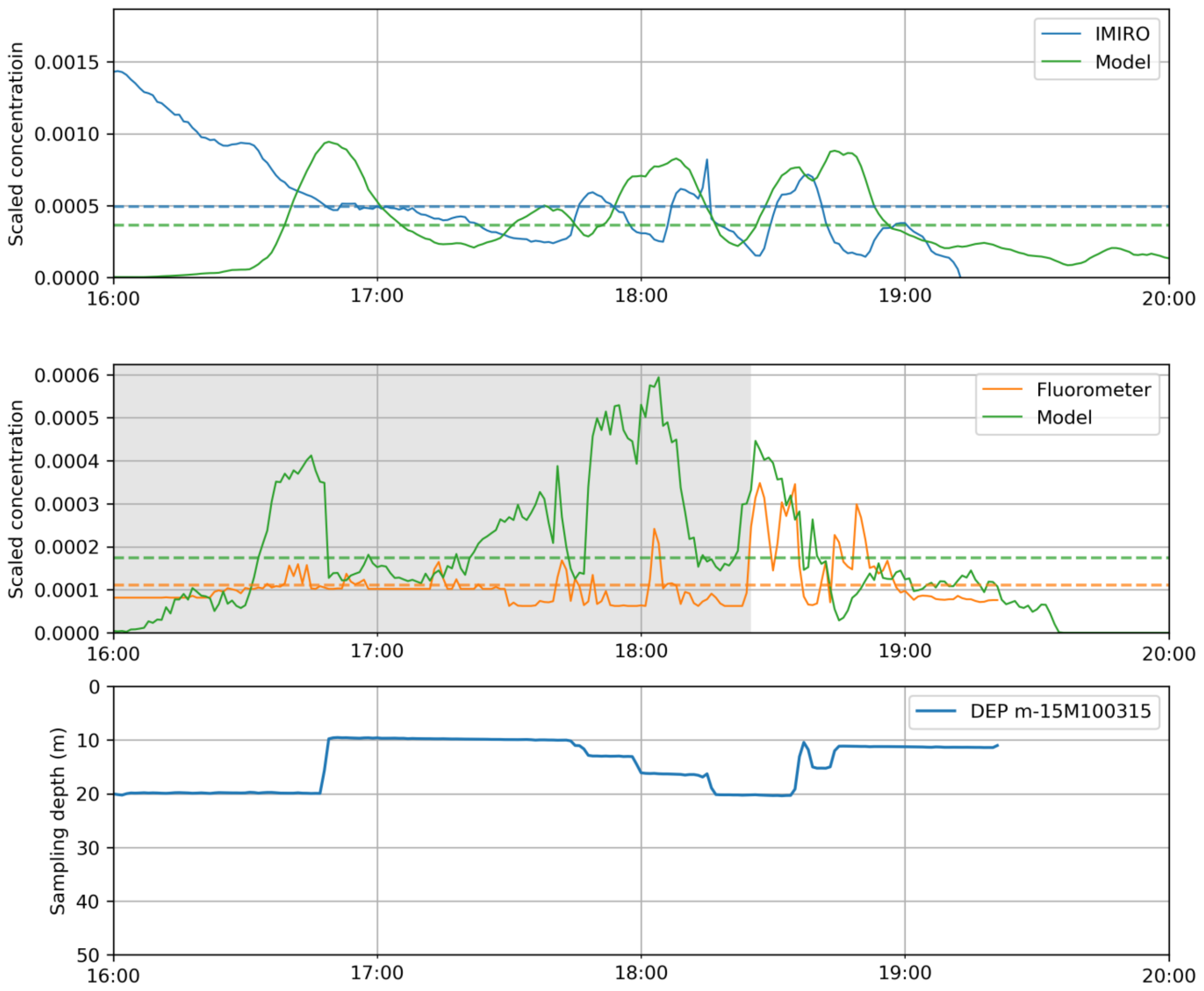
Period A – 25 March

Tracer discharge window (gray)

Scaled concentrations
(Measured / Discharged)

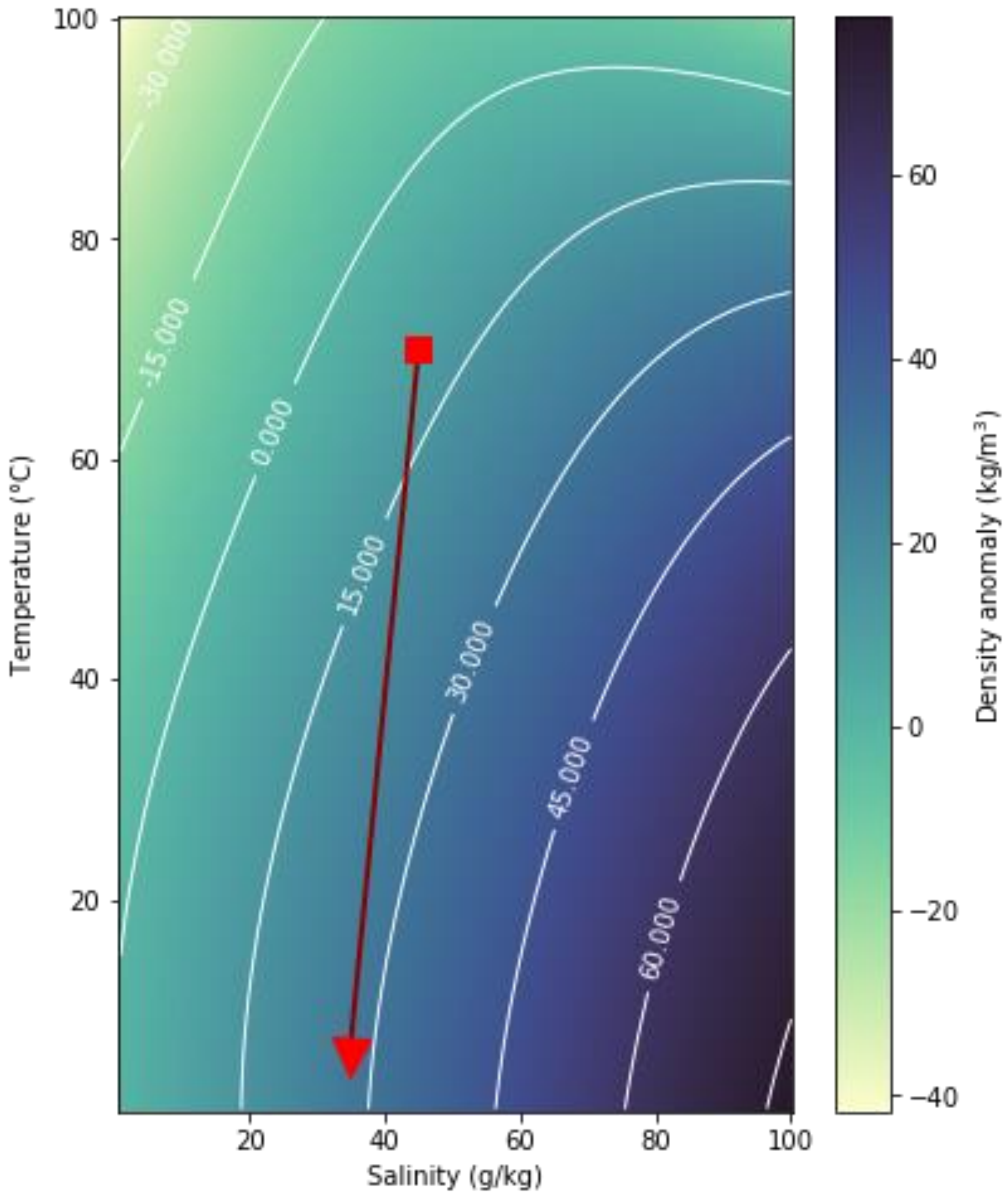
Better model-measurement agreement towards end of period

Tracer scaled concentrations generally a bit higher in the model



Water density

- Initial plume is warm and salt, with slightly lower density than the ambient sea water
- Entrainment causes cooling and (salt) dilution



Model setup

- Time step: 1 minute
- Grid resolution 20 m x 20 m x 2 m
- Particles: 80 000 (200 per time step)
- Horizontal diffusivity: 1 m^2/s
- Dynamic currents and wind input