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Enabling Delta Life

Ice modelling in Delft3D, with application to the North Sea and to lakes

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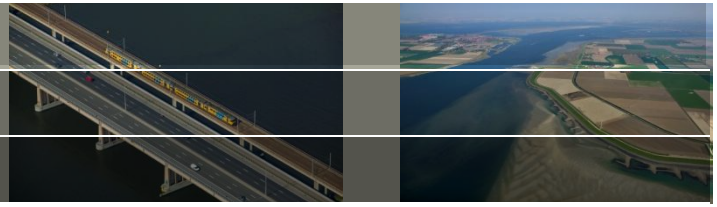
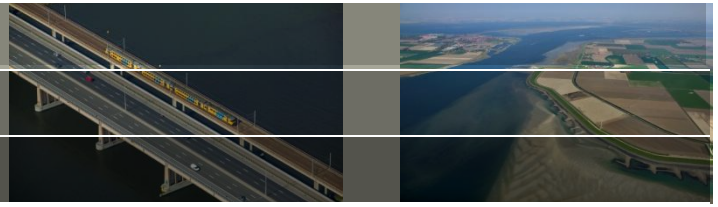
19 mei 2014

Outline



1) Why ice?
2) Conceptual description of Delft3D-FLOW ice model
3) Numerical implementation
4) Ice modelling results (100-year simulation, Lake IJssel, Lake Spirit in USA, North Sea)
5) Conclusions, future work

Why ice?



Offshore wind farms

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Why ice?

Ice dams in rivers

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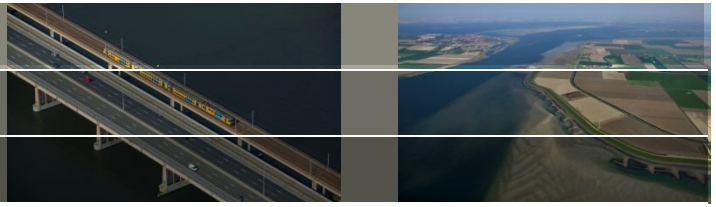
Why ice?



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Why ice?

Oil/gas exploration

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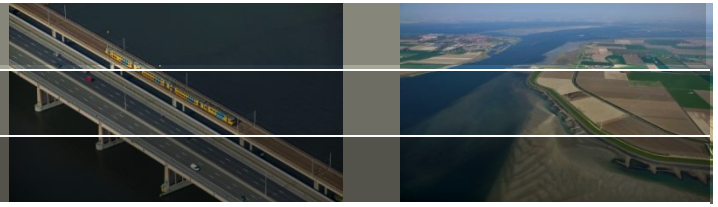
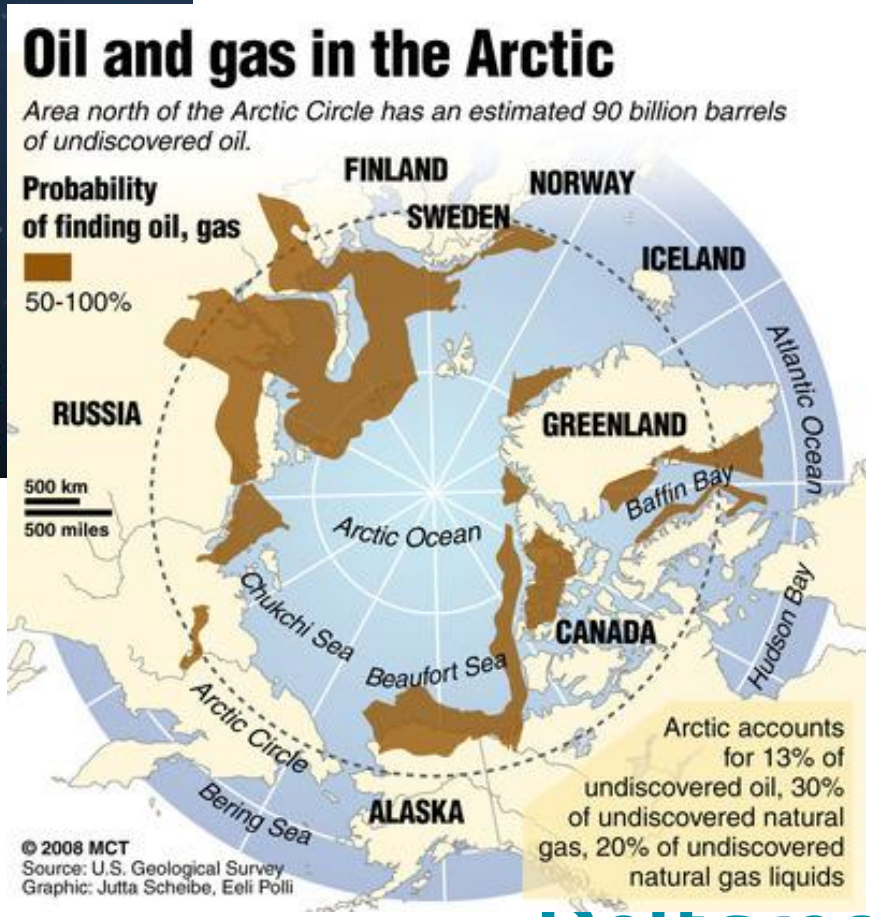
Why ice?





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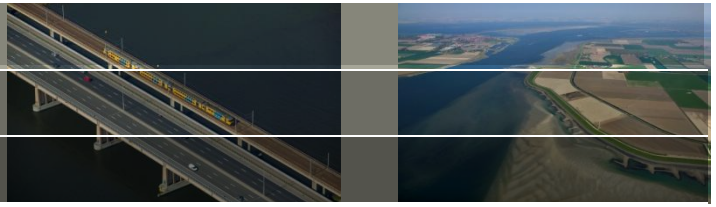
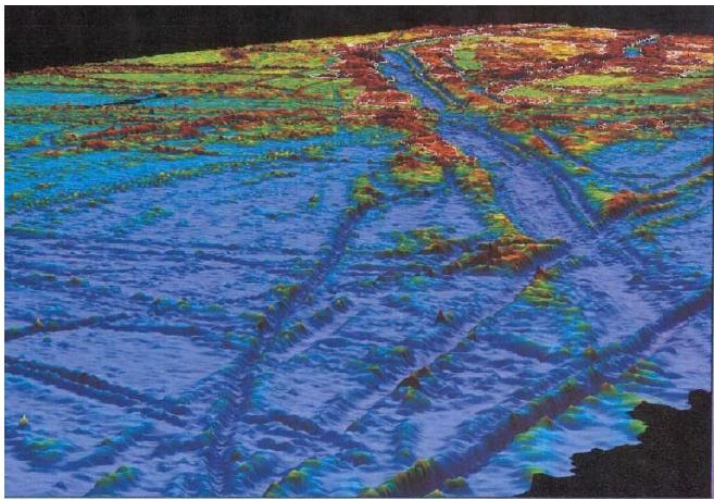
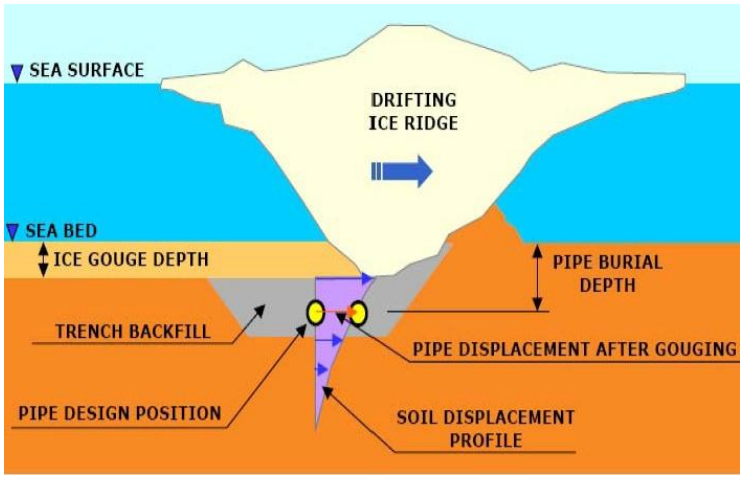
Why ice?







Ice gouging

(source: SINTEF)

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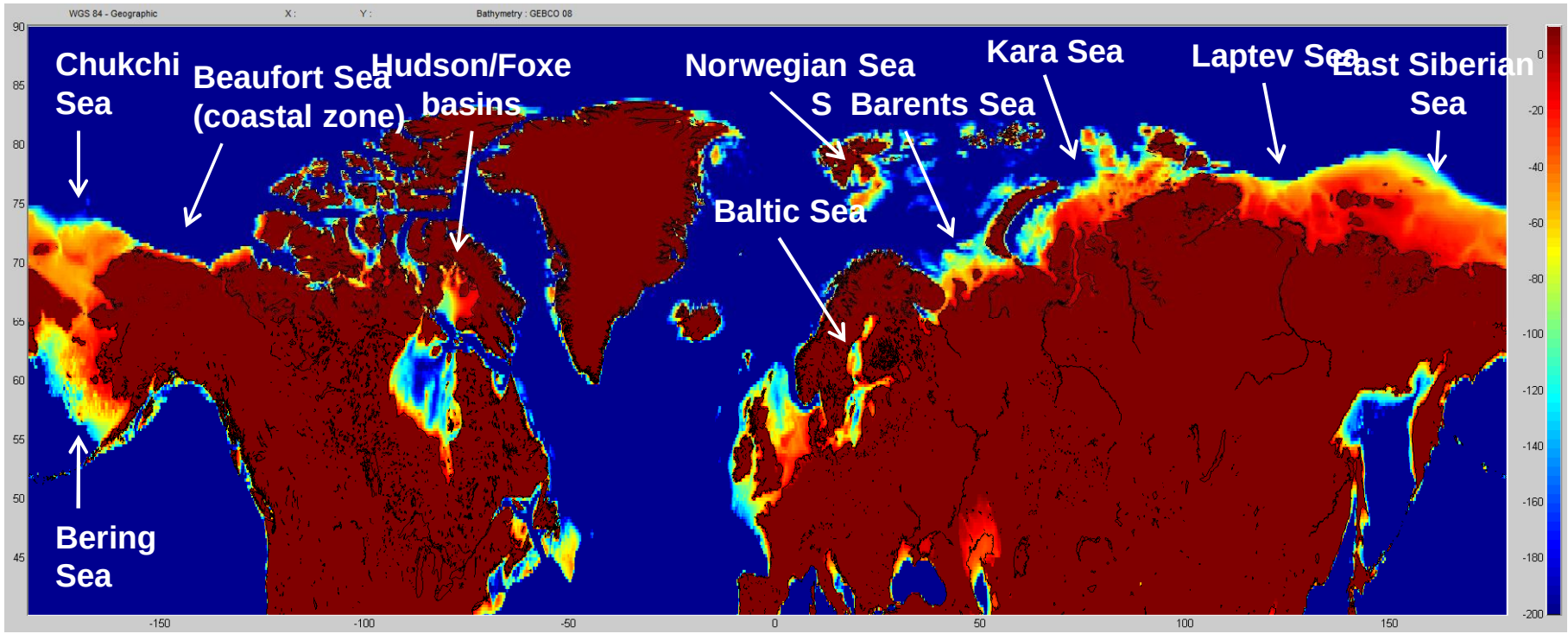
Why ice?

Dutch national winter hype

23 of the 32 speed skating medals in Socchi!

Shallow seas (< 100m), how relevant?



- Develop integrated modelling framework <u>including ice</u> for the purpose of planning and design of coastal structures in shallow-water (sub-)arctic regions

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Conceptual description

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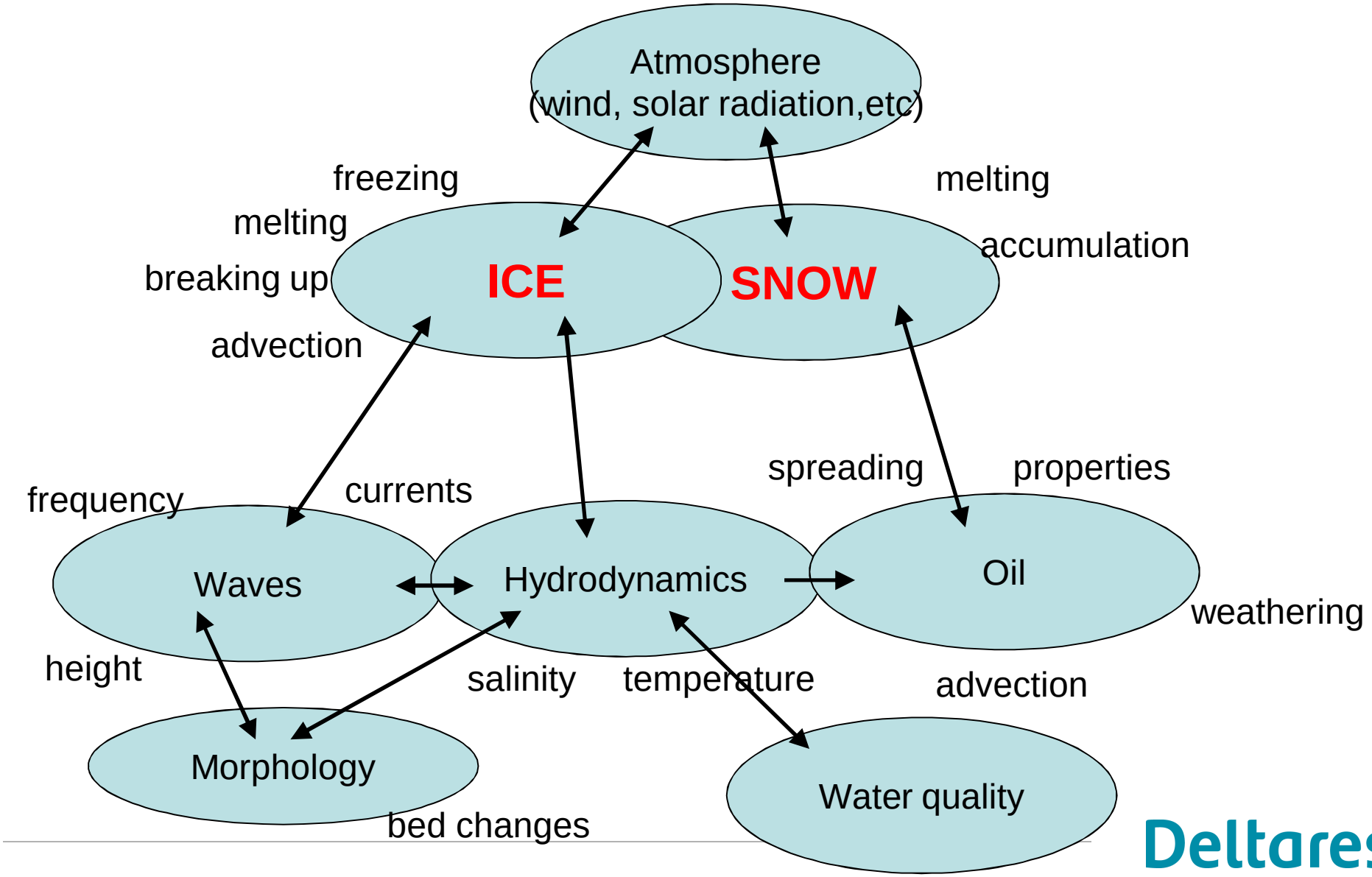
Ice module integrated in Delft3D



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Dynamic-thermodynamic ice model

$$\frac{\partial u_{ice}}{\partial t} + u_{ice}\frac{\partial u_{ice}}{\partial x} + v_{ice}\frac{\partial u_{ice}}{\partial y} - fv_{ice} = F_{u\_ice} - g\frac{\partial \zeta}{\partial x}$$

$$\frac{\partial v_{ice}}{\partial t} + u_{ice}\frac{\partial v_{ice}}{\partial x} + v_{ice}\frac{\partial v_{ice}}{\partial y} + fu_{ice} = F_{v\_ice} - g\frac{\partial \zeta}{\partial y}$$

$$\frac{\partial A}{\partial t} + \frac{\partial (u_{ice}A)}{\partial x} + \frac{\partial (v_{ice}A)}{\partial y} = W_{wat\_ice} \qquad with \quad 0 \le A \le 1$$

$$\frac{\partial AH_{ice}}{\partial t} + \frac{\partial (u_{ice}AH_{ice})}{\partial x} + \frac{\partial (v_{ice}AH_{ice})}{\partial y} = W_{wat\_ice} + Q_{air\_ice}$$

Ice drift velocity (u_{ice}, V_{ice}),

Ice concentration A, ice thickness H_{ice}

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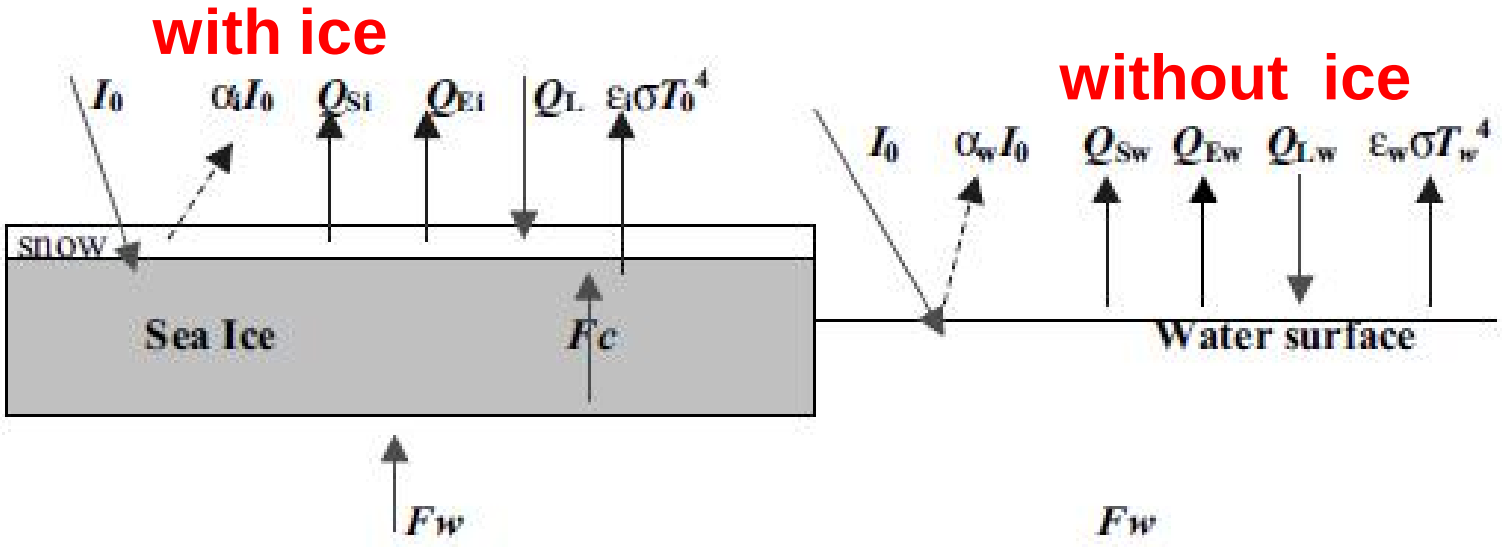
Ice modelling in Delft3D-FLOW

- **Extension of temperature module of Delft3D-FLOW**

- no additional input required, because already available:
  *) wind speed
  *) relative humidity, air temperature and cloudiness
  *) snow fall (precipitation with negative air temperature)
  *) removal of snow (evaporation with negative air temperature)



Numerical description

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Thermodynamic ice model in Delft3D-FLOW

Two options:

- KNMI_empirical_ice_model

  open source; 0-dimensional

  (lake of 2 m deep)

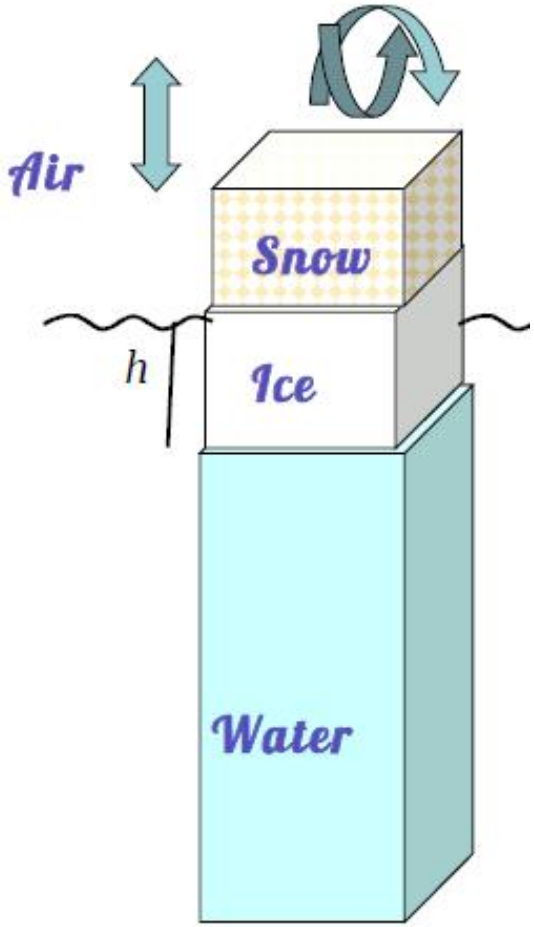
  1-way coupling ice-water

- Deltares_ice_flux_model

  based on approach from Semtner (1976)

  ≈ ice-model of SLIM, ROMS, POM, CICE, THREETOX and many others

  2-way coupling ice-water



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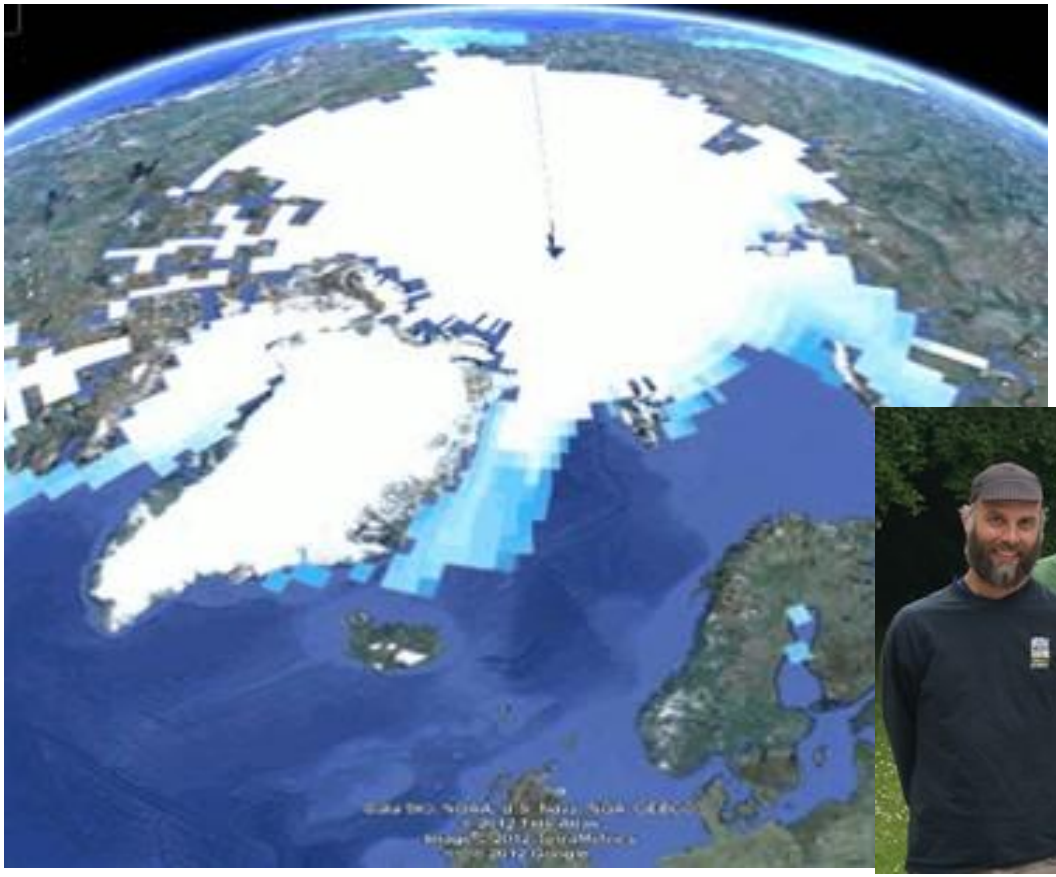
Numerical implementation ice module

Combination of:

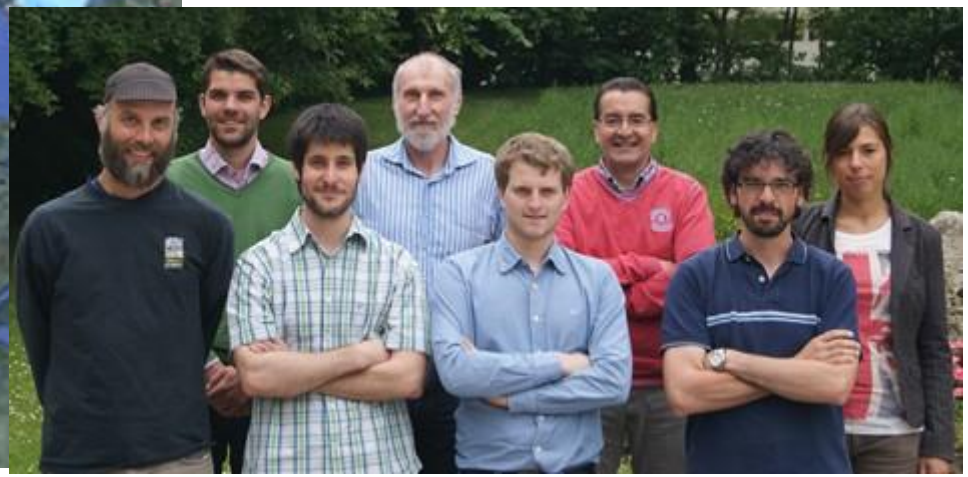
- thermodynamic model based on a single ice layer concept with snow on top (Semtner, 1976)
- dynamic model based on the elastic-viscous-plastic (EVP) sea-ice rheology (Hunke and Dukowicz, 1997) and Second-generation Louvain-la-Neuve Ice-ocean Model code (LIM3)

Dynamic ice model

- Starting point open source LIM3 code, rewritten to the Delft3D-FLOW datastructure
- LIM3 = most advanced Louvain-la-Neuve Sea Ice



www.climate.be/slim



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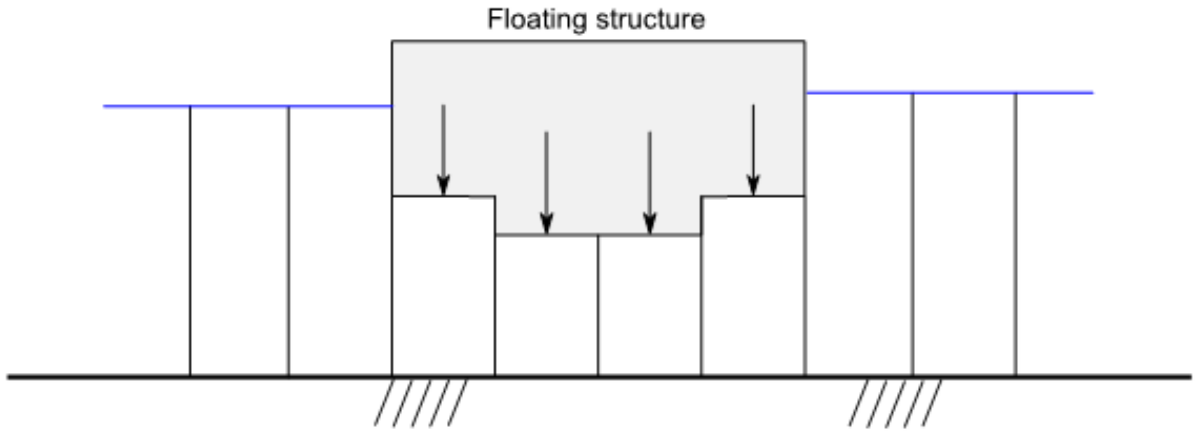
Numerical implementation in Delft3D-FLOW



Cross-sectional view floating structure

- Ice ≈ floating structure (rigid lid approach)
- Including drying and flooding
- Threshold depth for ice
- Alternating Direction Explicit time integration, with same time step as hydrodynamic model

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Iterative process for surface ice temperature

$$Q_{tot} = Q_{sn} + Q_{an} - Q_{br} - Q_{ev} - Q_{co}$$

$$Q^{*}_{tot} - Q_{br} = k_{ice}\left(T_{ice} - T_{freeze}\right) / H_{ice}$$

Linearization of net atmospheric radiation

$$Q^{*}_{tot} - \alpha\, T^{4}_{ice} = k_{ice}\left(T_{ice} - T_{freeze}\right) / H_{ice}$$

$$Q^{*}_{tot} - \alpha\, T^{4}_{k\text{-}1} - 4\alpha\, T^{3}_{k\text{-}1}\,\Delta_k = k_{ice}\left(T_{k\text{-}1} + \Delta_k - T_{freeze}\right) / H_{ice}$$

$$with\ \ \Delta_k = T_k - T_{k\text{-}1}$$

Fast convergence; N =2 (or 3)

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Model results

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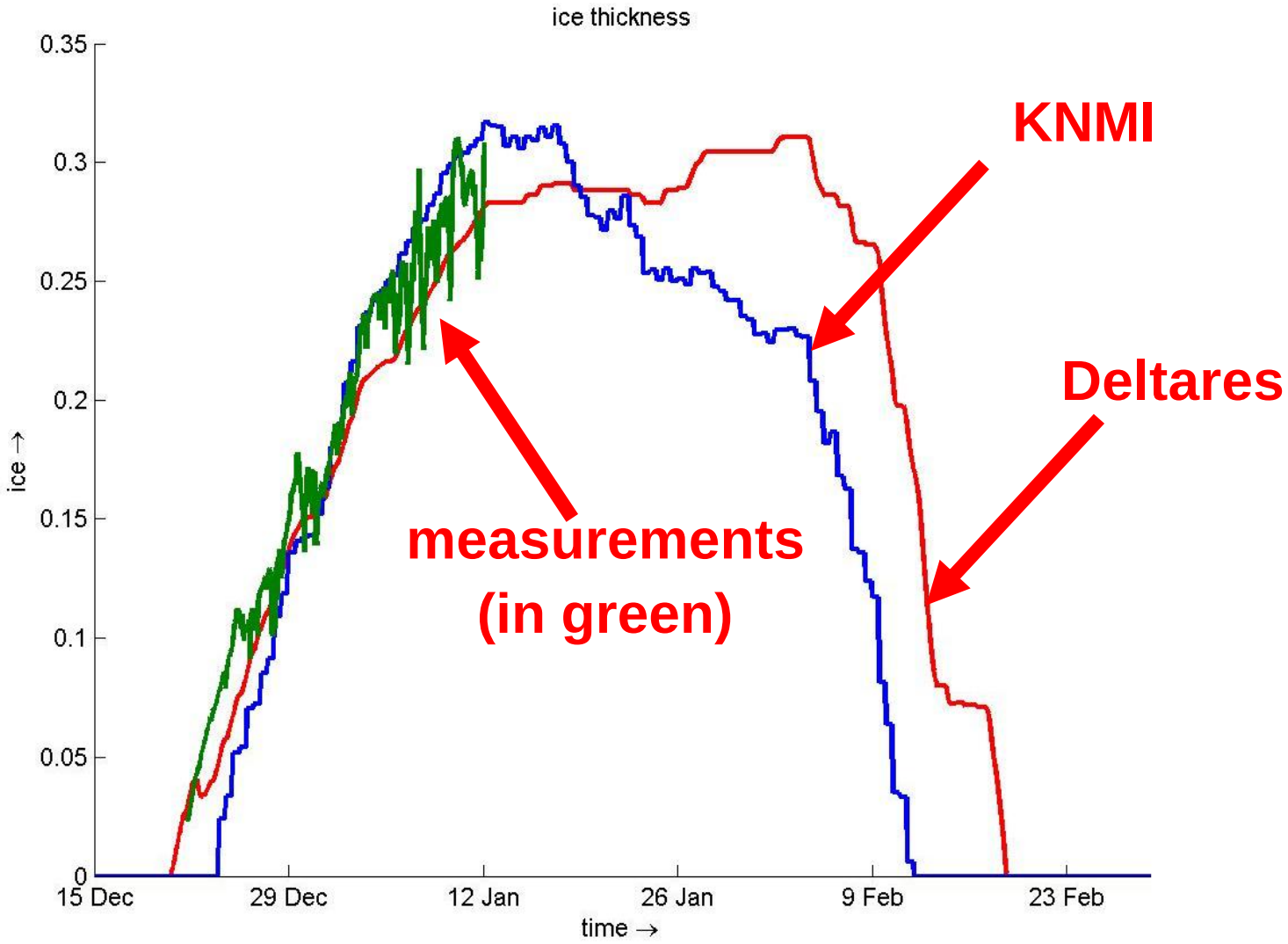
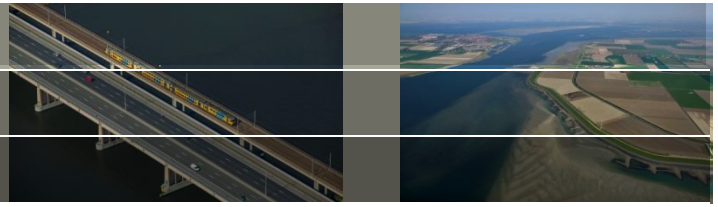
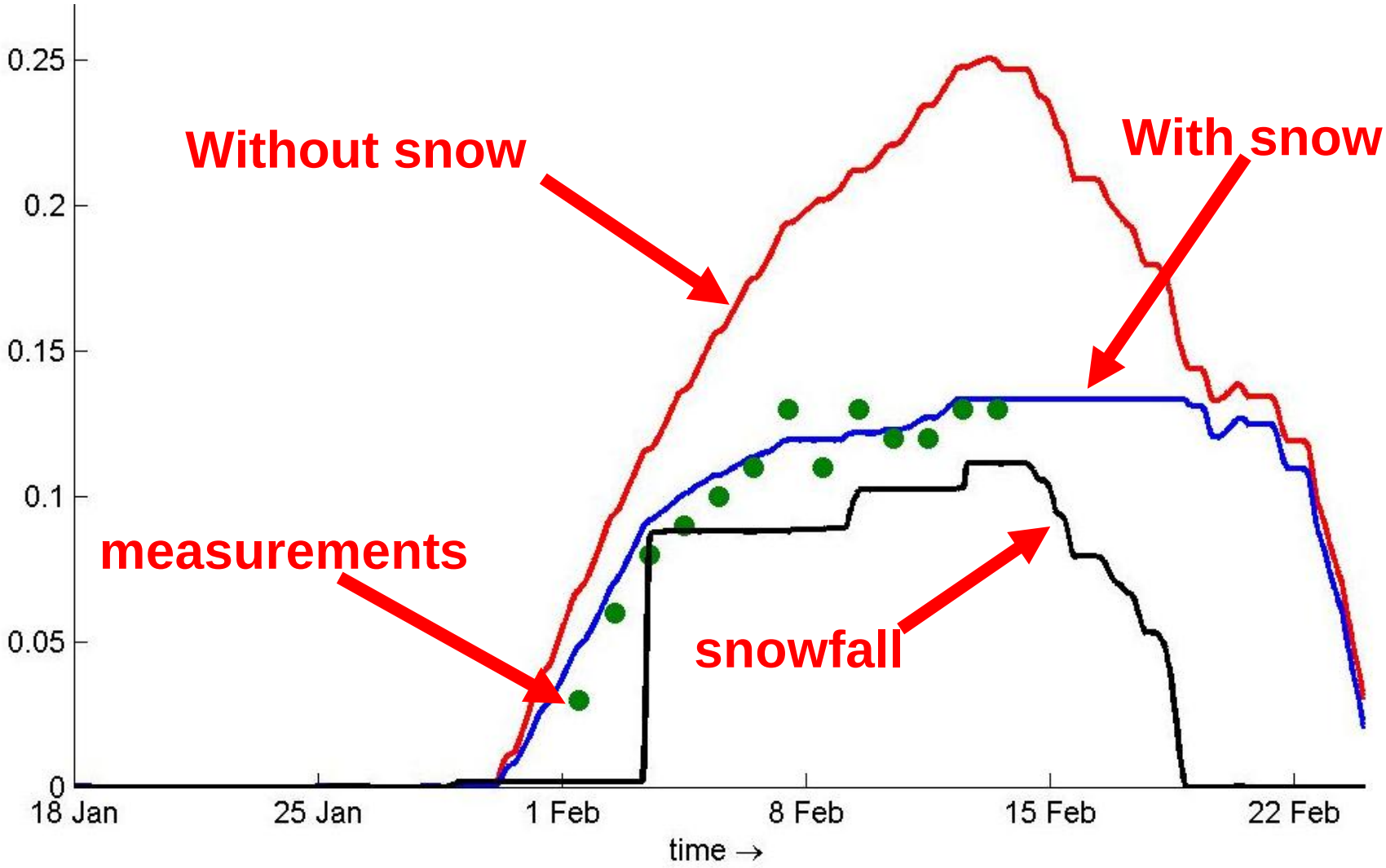
Ice growth/melt winter 1996/1997



Ice growth/melt winter 2012





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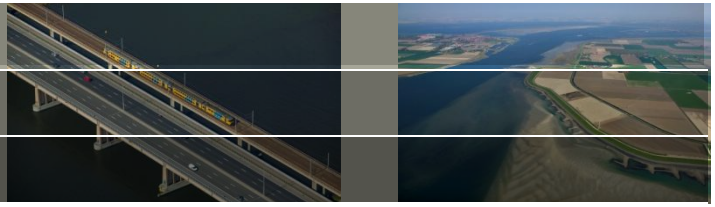
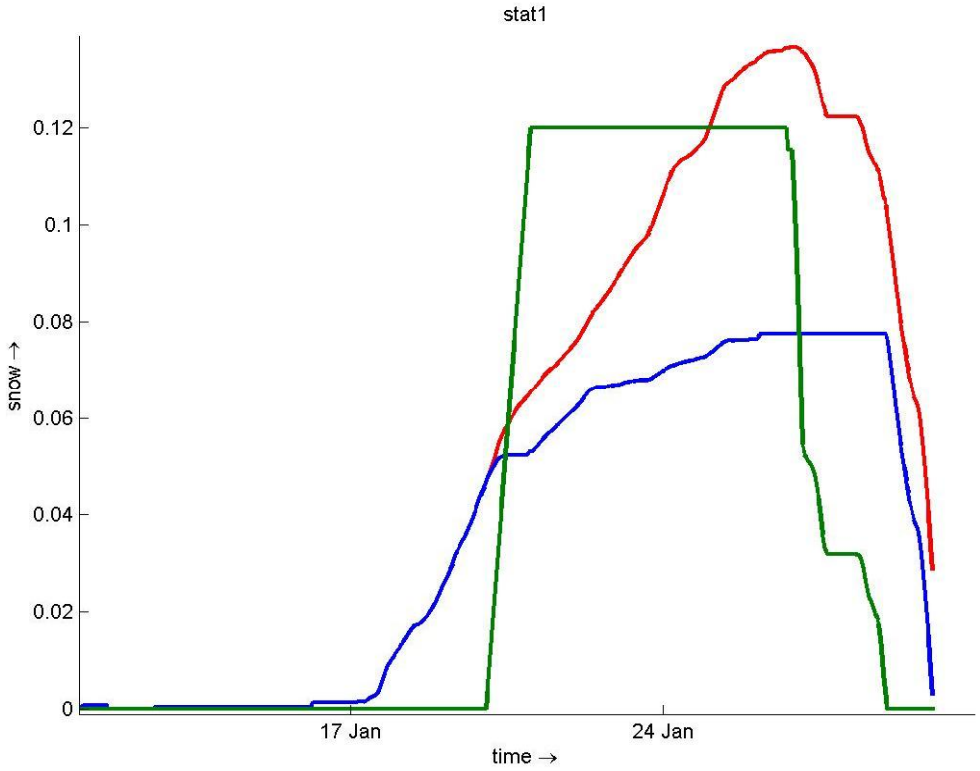
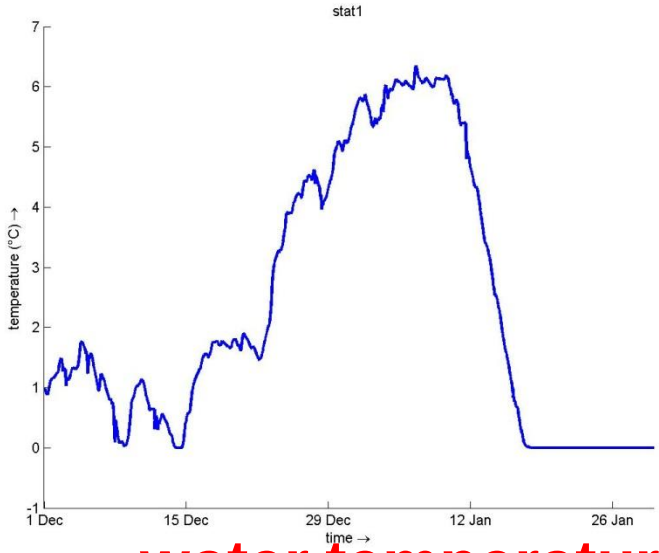
Ice growth/melt winter 2013







water temperature

Red=without snow; blue=with snow; green=snowfall

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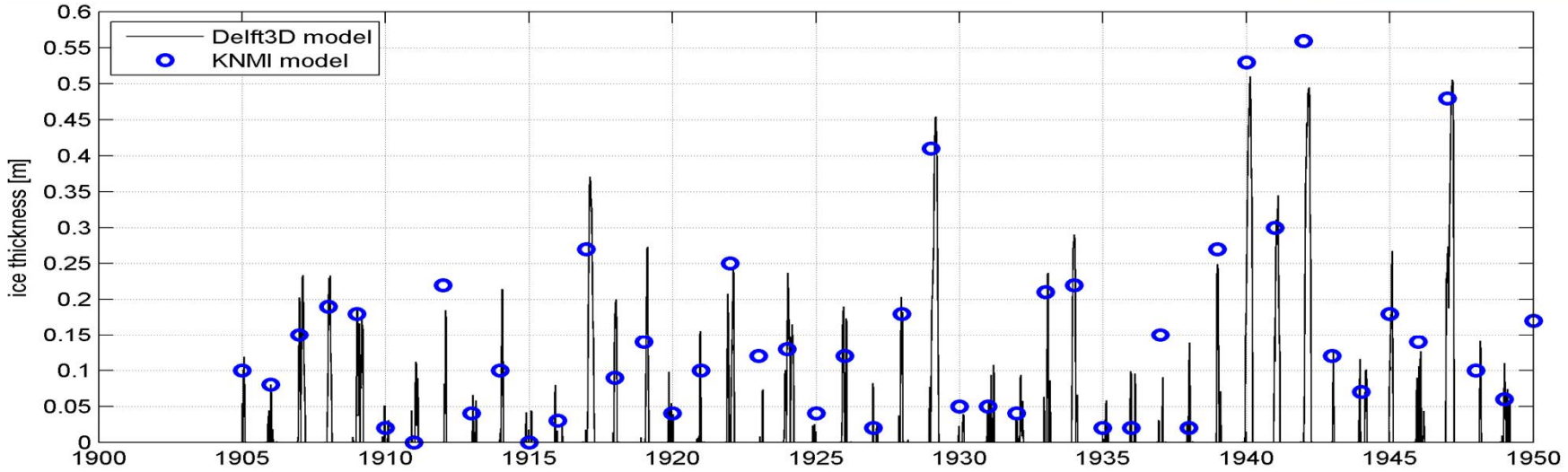
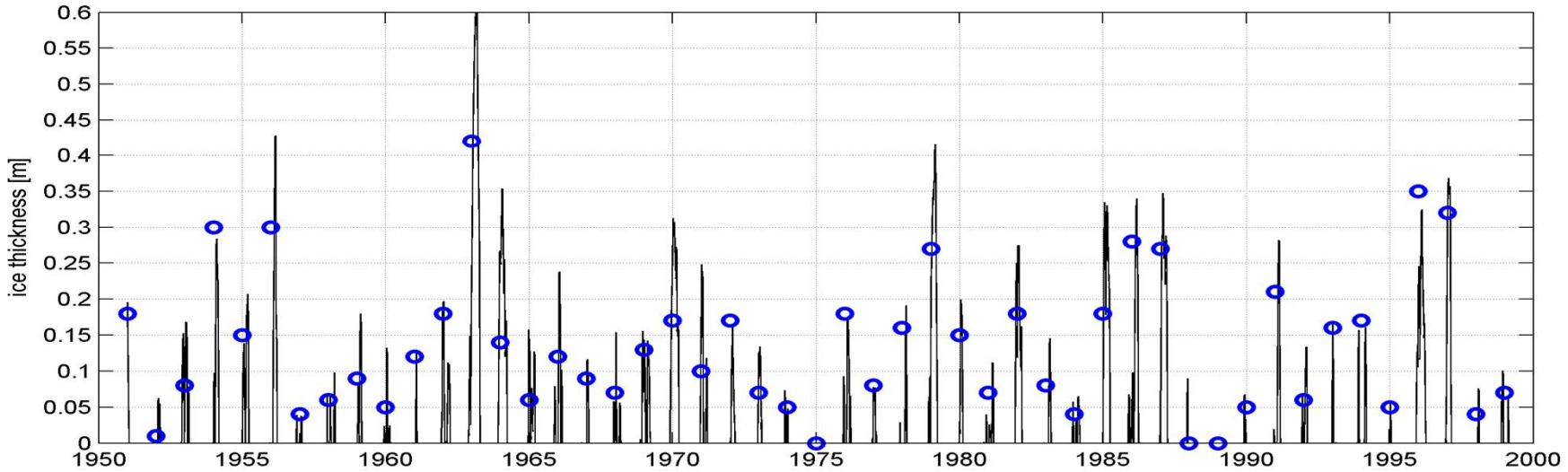
100-year simulation for a shallow lake





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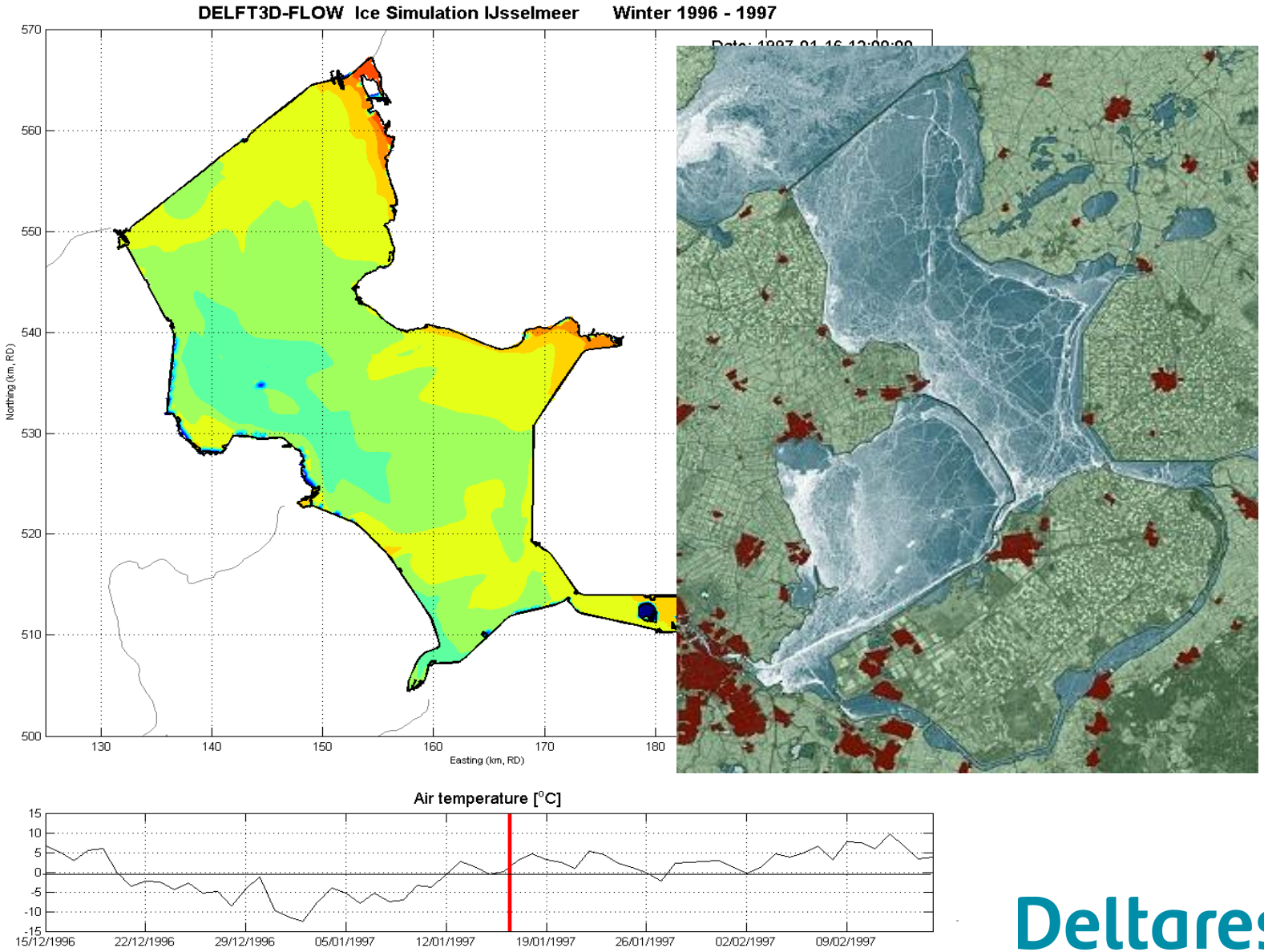
Ice thickness at Lake IJssel at 16 January 1997



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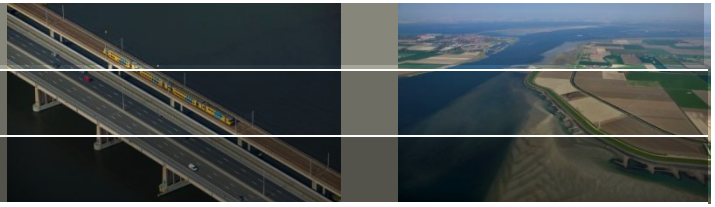
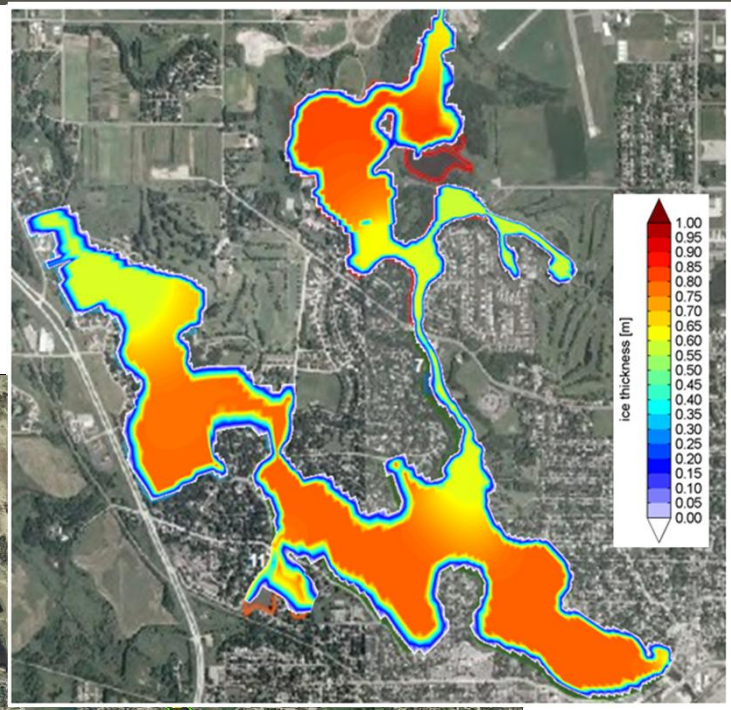
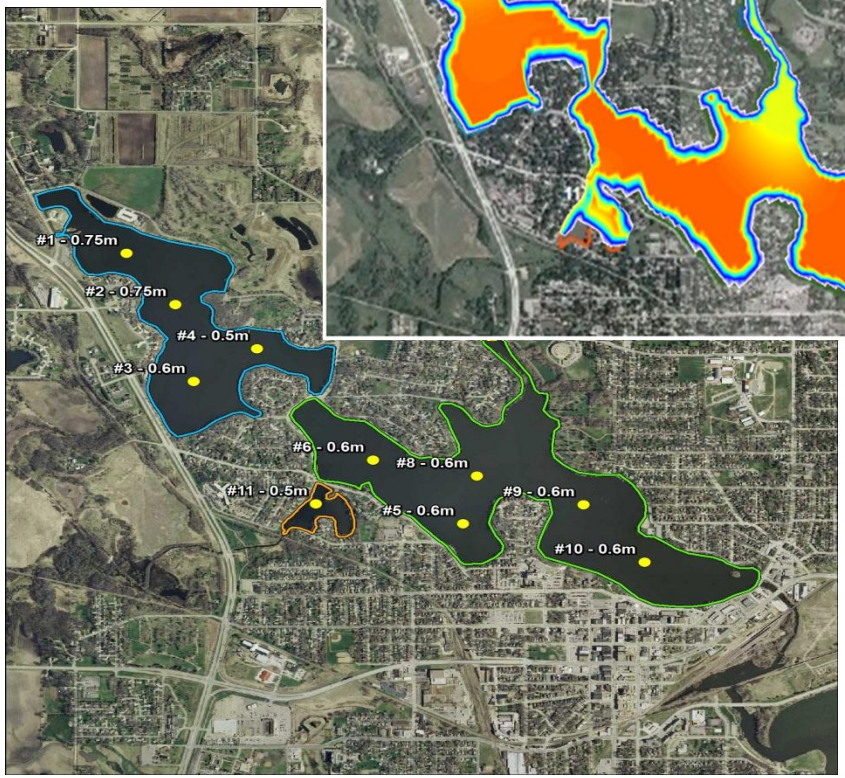
Fountain Lake, USA

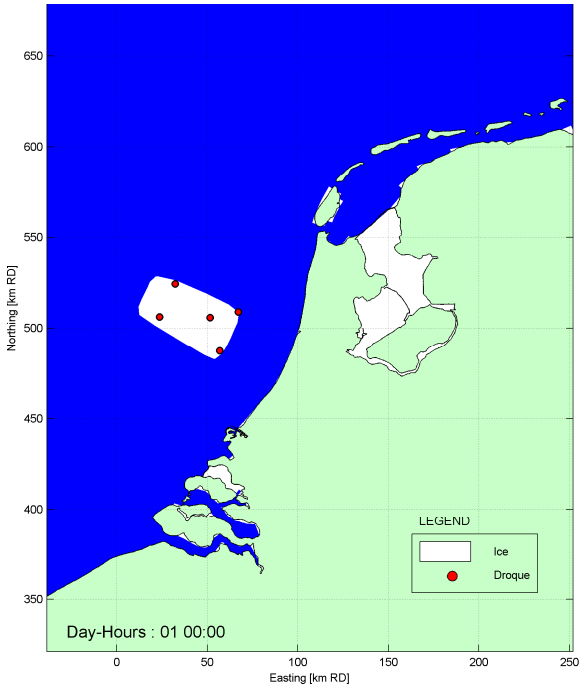


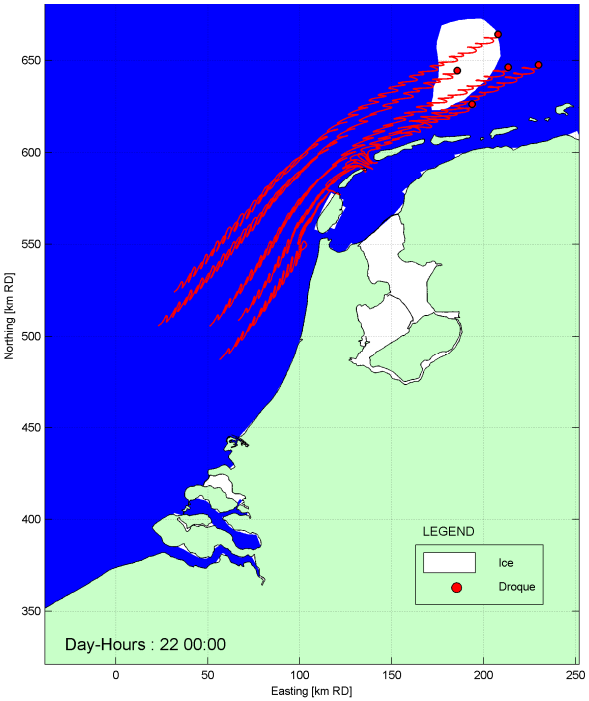


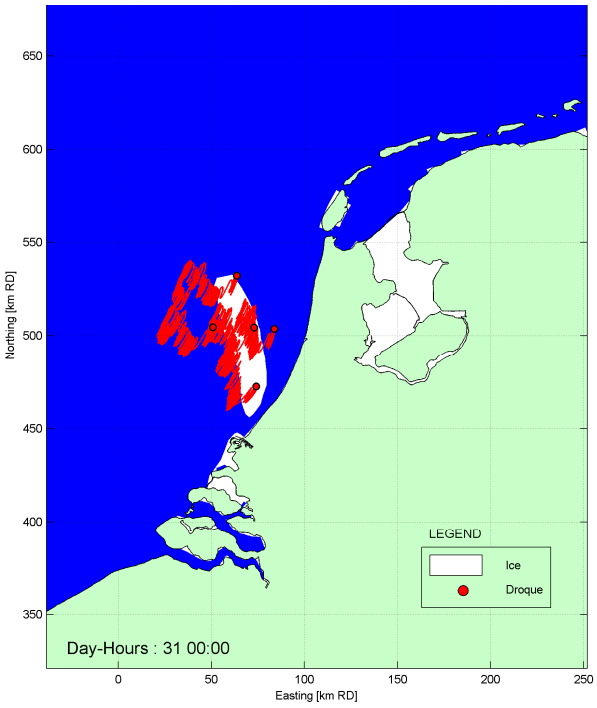


Location	Measured	Computed
1	0.75	0.60
2	0.75	0.65
3	0.60	0.70
4	0.50	0.75
5	0.60	0.75
6	0.60	0.75
7	0.50	0.55
8	0.60	0.75
9	0.60	0.75
10	0.60	0.75

North Sea testcase for dynamic ice model







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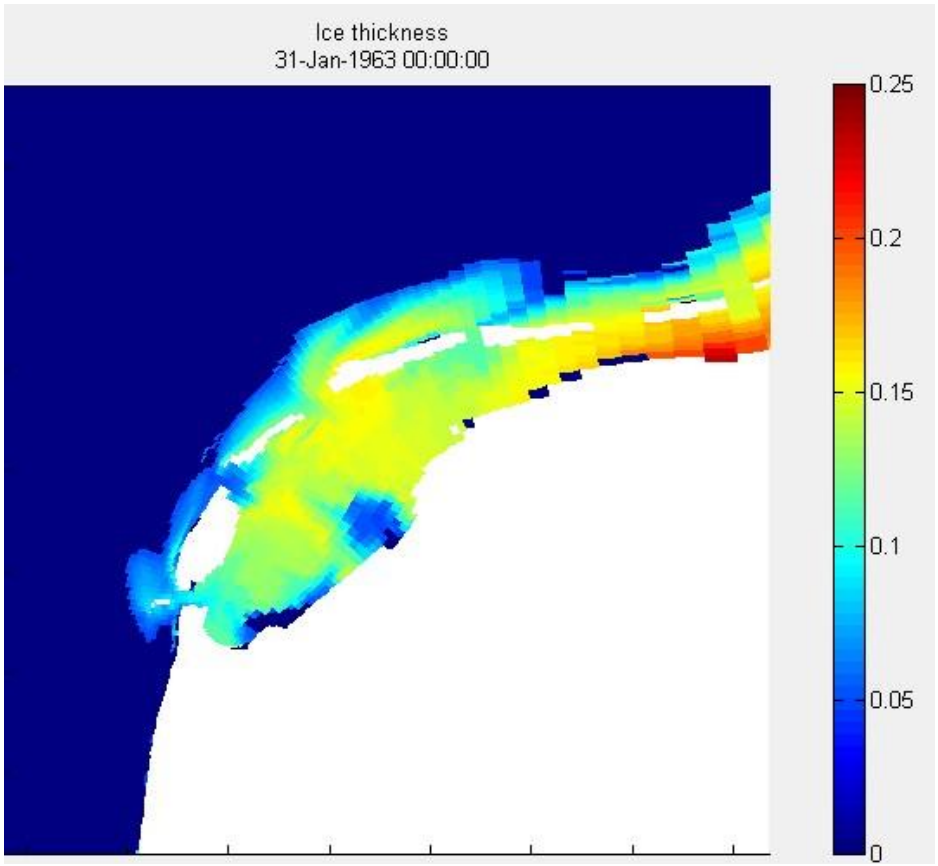
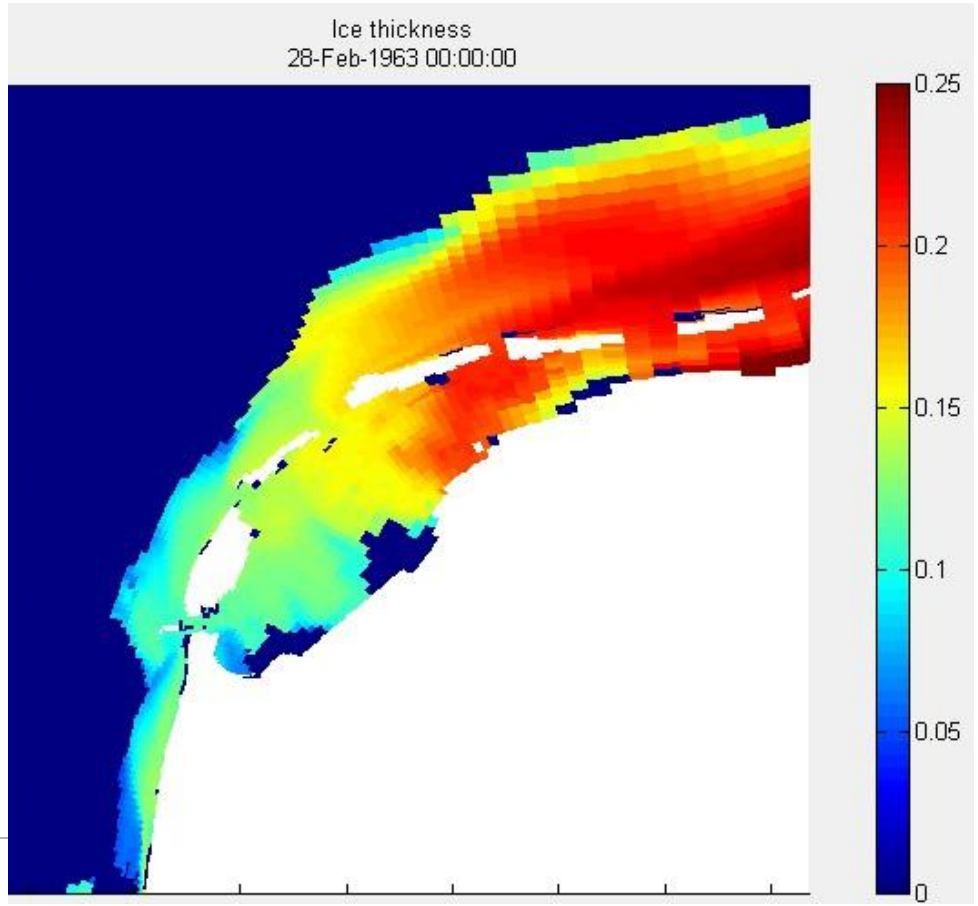
3D North Sea model for winter 1962/1963





Conclusions

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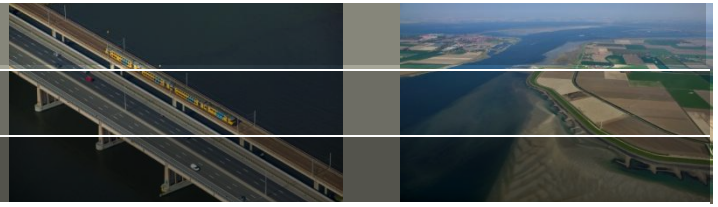
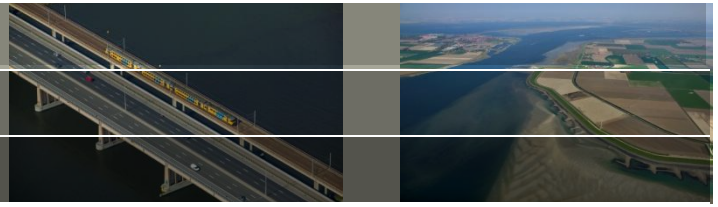
Conclusions



- First version of sea-ice module in Delft3D now available
- In Delft3D-FLOW open source branch
- Suitable for lakes and shallow seas
- Not suitable for Arctic regions

Thanks to the Université Catholique de Louvain (UCL) for open source LIM3 sea-ice model!

Future initiatives



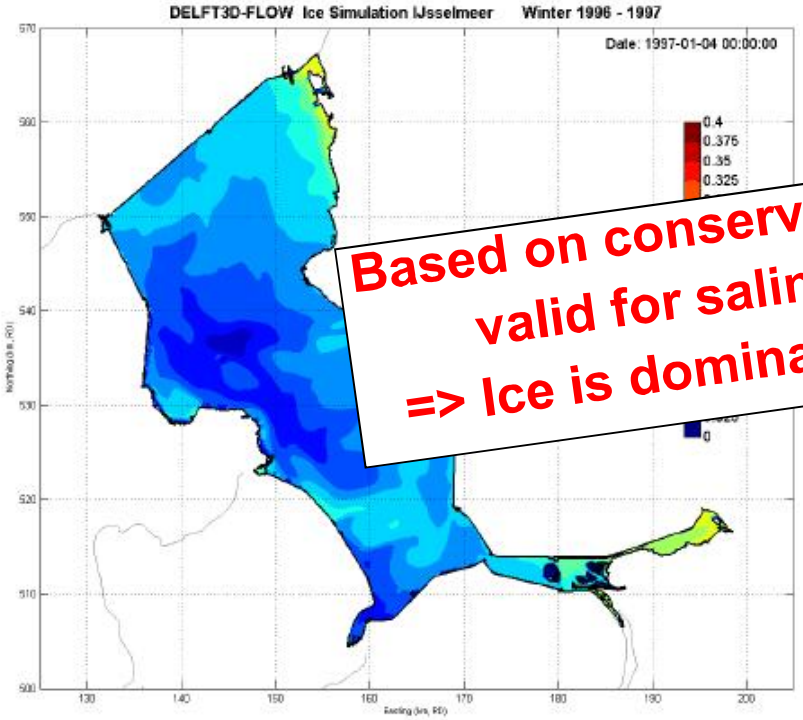
- Developments preferably via Delft3D open source

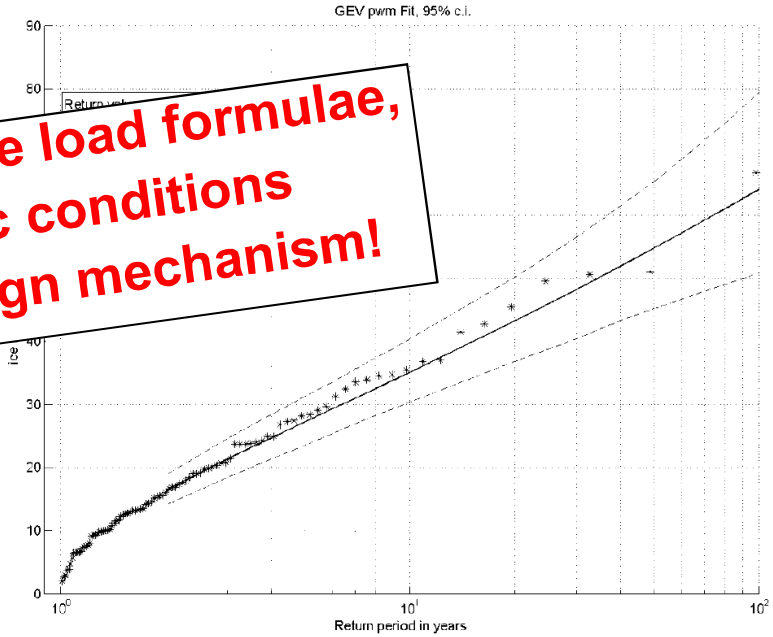
- More testing and validation needed!
- Consider other ice and snow formulations
- Looking for interested participating institutes
- More applications in lakes, rivers (near thermal outfalls) or estuaries
- Testing of dynamic coupling with wave model
- Development of dynamic coupling with local scale ice-structure model

Ice study IJsselmeer

As input for design of NOP Wind Farm:

- Ice statistics (based on 100 year ice-growth simulation)
- Ice properties and ice load mechanisms





Based on conservative ice load formulae, valid for saline/arctic conditions
=> Ice is dominant design mechanism!

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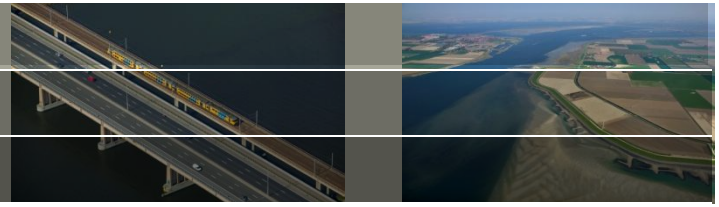
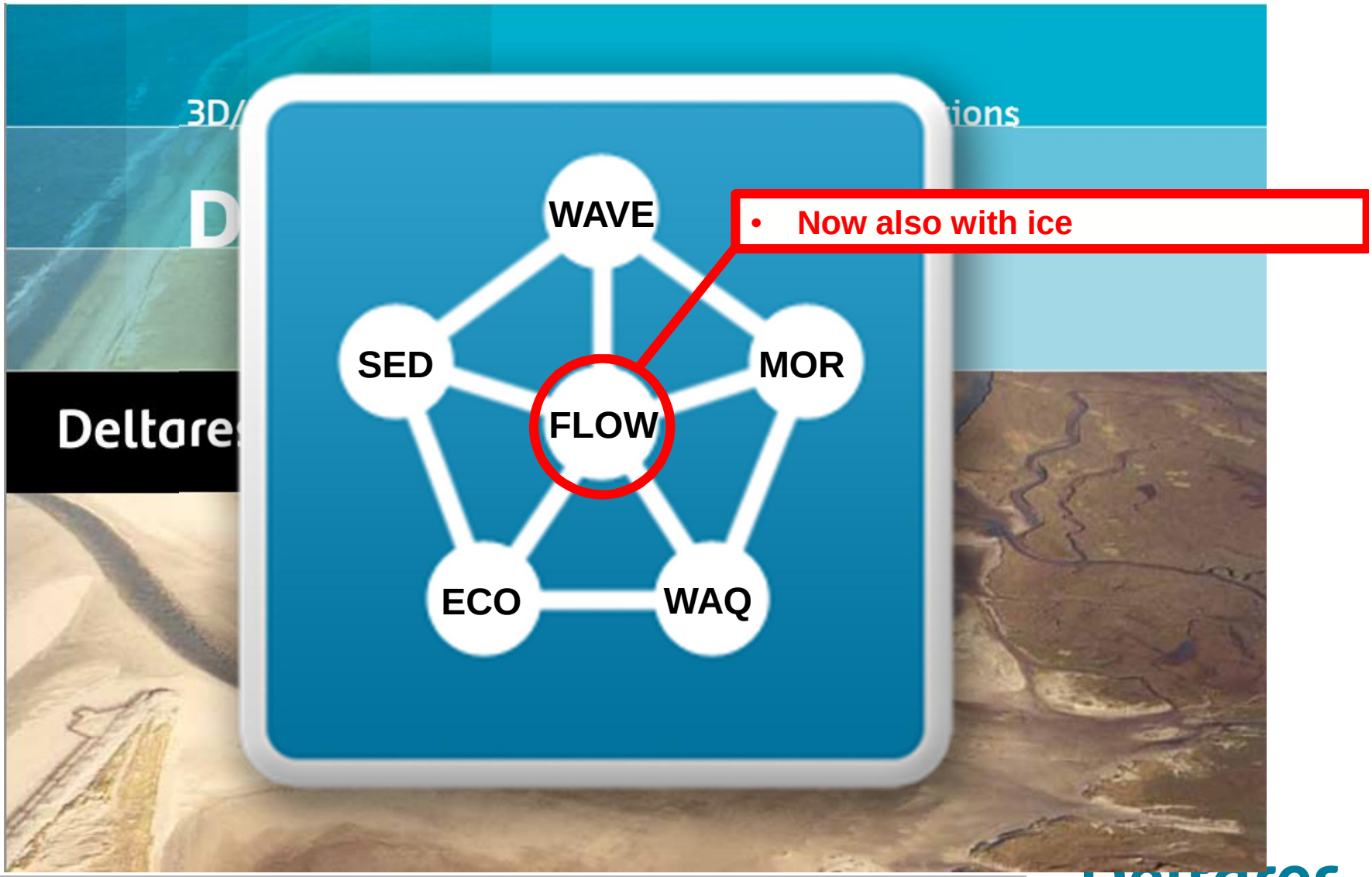
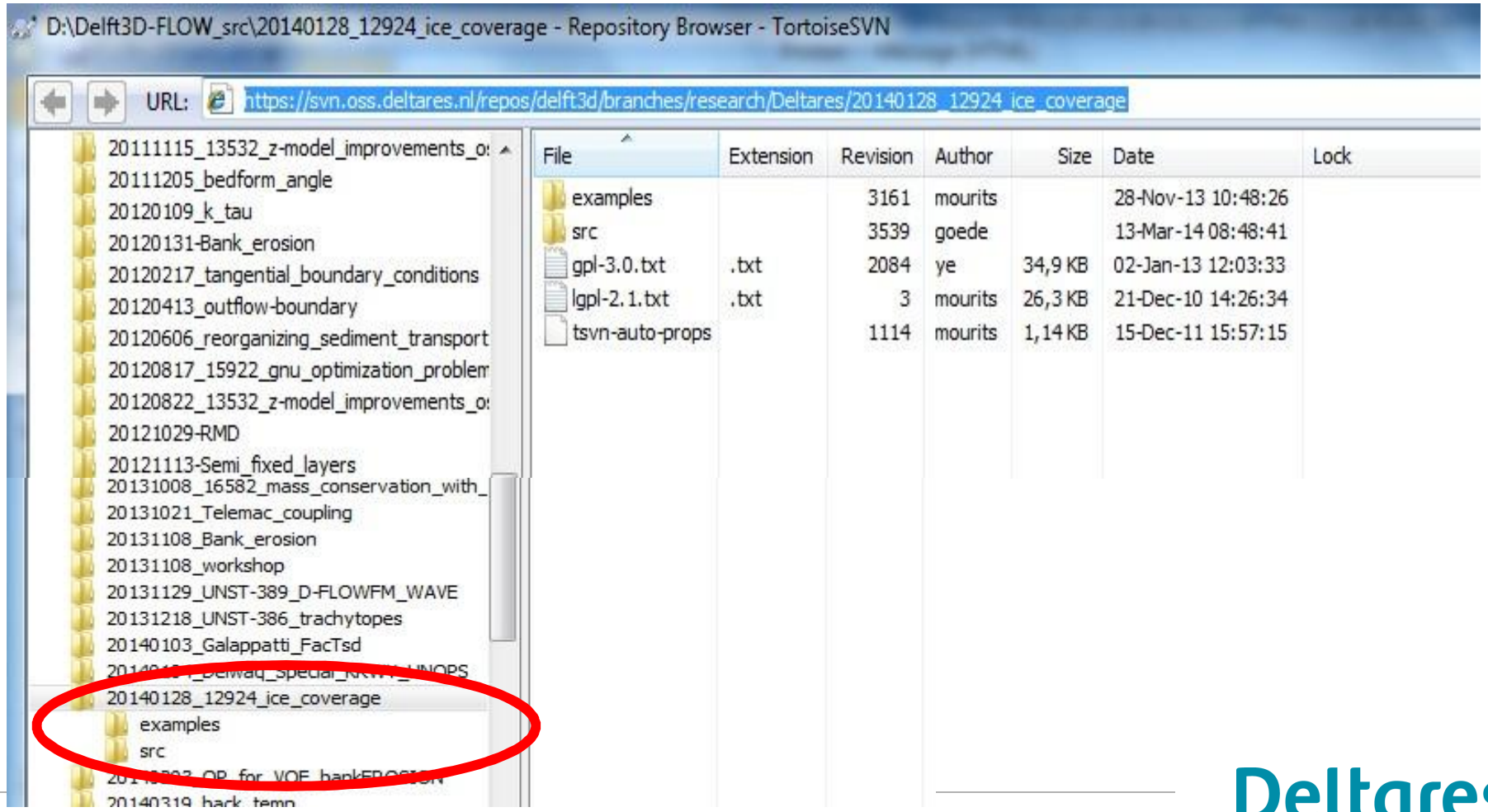
System overview of Delft3D





Delft3D ice module branch (open source)

- https://svn.oss.deltares.nl/repos/delft3d/branches/research/Deltares/20140128_12924_ice_coverage



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Delft3D ice module (open source)

http://oss.deltares.nl/web/delft3d/developments

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Developments Delft3D software

Ice modelling with Delft3D

With the changing climate and the consequential increase of human activities in Arctic, sub-Arctic and mid-latitude regions, there is an increasing demand for accurate ice modelling capabilities. Accurate predictions of ice thicknesses, ice loads, ice flows or other ice characteristics are crucial for:

- planning of safe operations in Arctic and sub-Arctic regions
- design of breakwaters, sluices, artificial islands, offshore wind farms, subsea pipelines, platforms, etc. in ice-covered waters
- preparing the Dutch for their national winter-hype: skating on lakes and canals!

Recently, the Delft3D-FLOW temperature module has been extended with an ice module to allow for the prediction of growth and melt of ice on the basis of time-varying meteorological input (air temperature, relative humidity and wind). The animation on the right shows the results of an ice simulation in the Dutch IJssel Lake for the relatively severe winter of 1996-1997, using meteorological input from the Royal Dutch Meteorological Institute (KNMI).

We envisage that the ice module will be incorporated in the open source version of Delft3D-FLOW, which is presently not yet the case. Main focus will be on the growth/melt and transport of ice in lakes, rivers, estuaries and coastal seas. By linking an ice module with other Delft3D modules, it will also be possible to study aspects like seabed scour, erosion of permafrost coasts, oil spills or water quality in temporarily or partly ice-covered waters.

In order to make these developments possible, the *Deltares Ice-Team* invites Delft3D Community Members to contribute to the joint development of an ice module in Delft3D-FLOW, or to couple an existing ice module with Delft3D-FLOW. If you are interested to participate, please send an email to Erik de Goede (erik.degoede@deltares.nl) or Reimer de Graaff (reimer.degraaff@deltares.nl).