COSMO simulations of air-sea-ocean interaction processes and impacts on polynya formation and sea ice production

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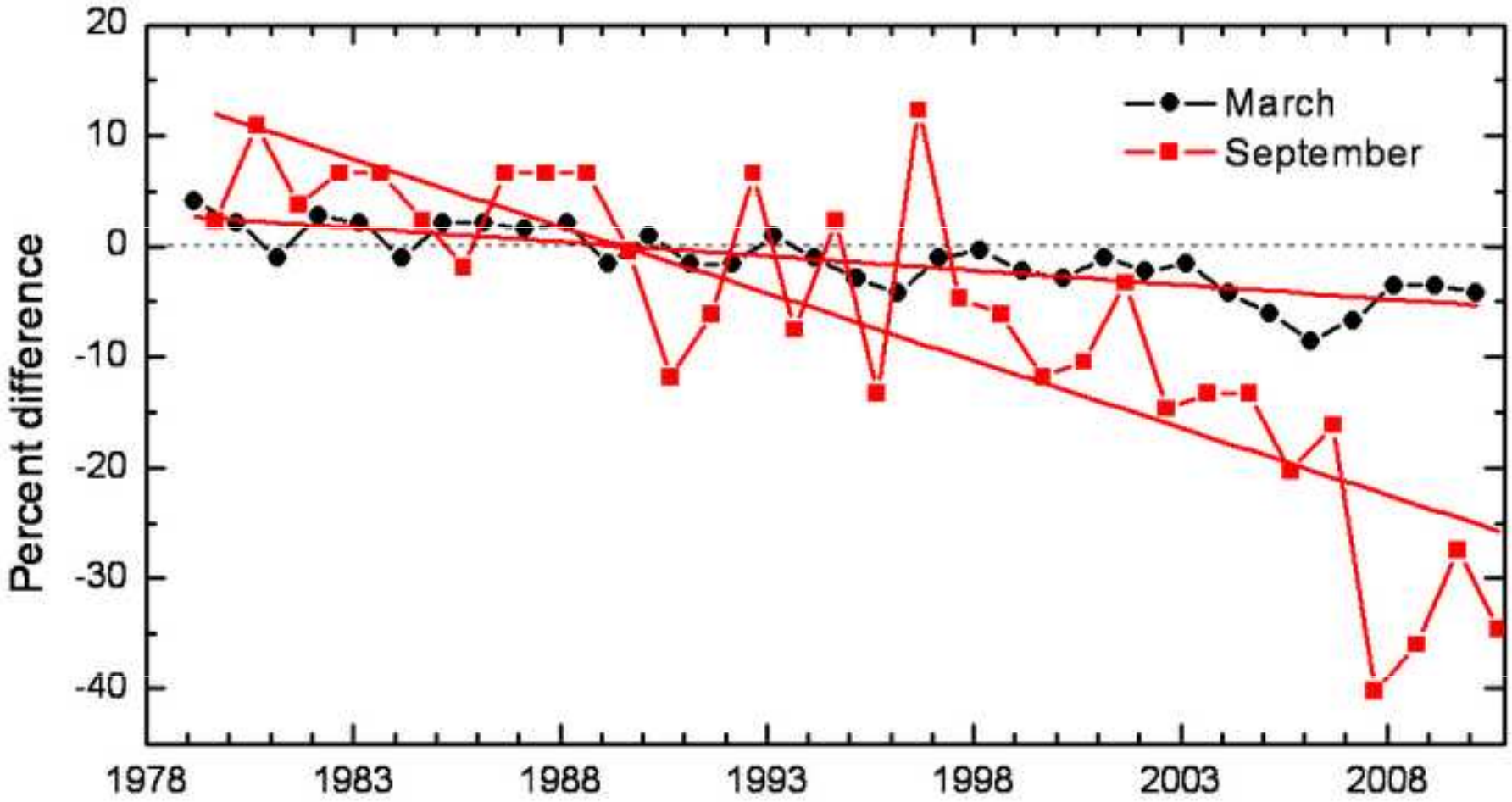
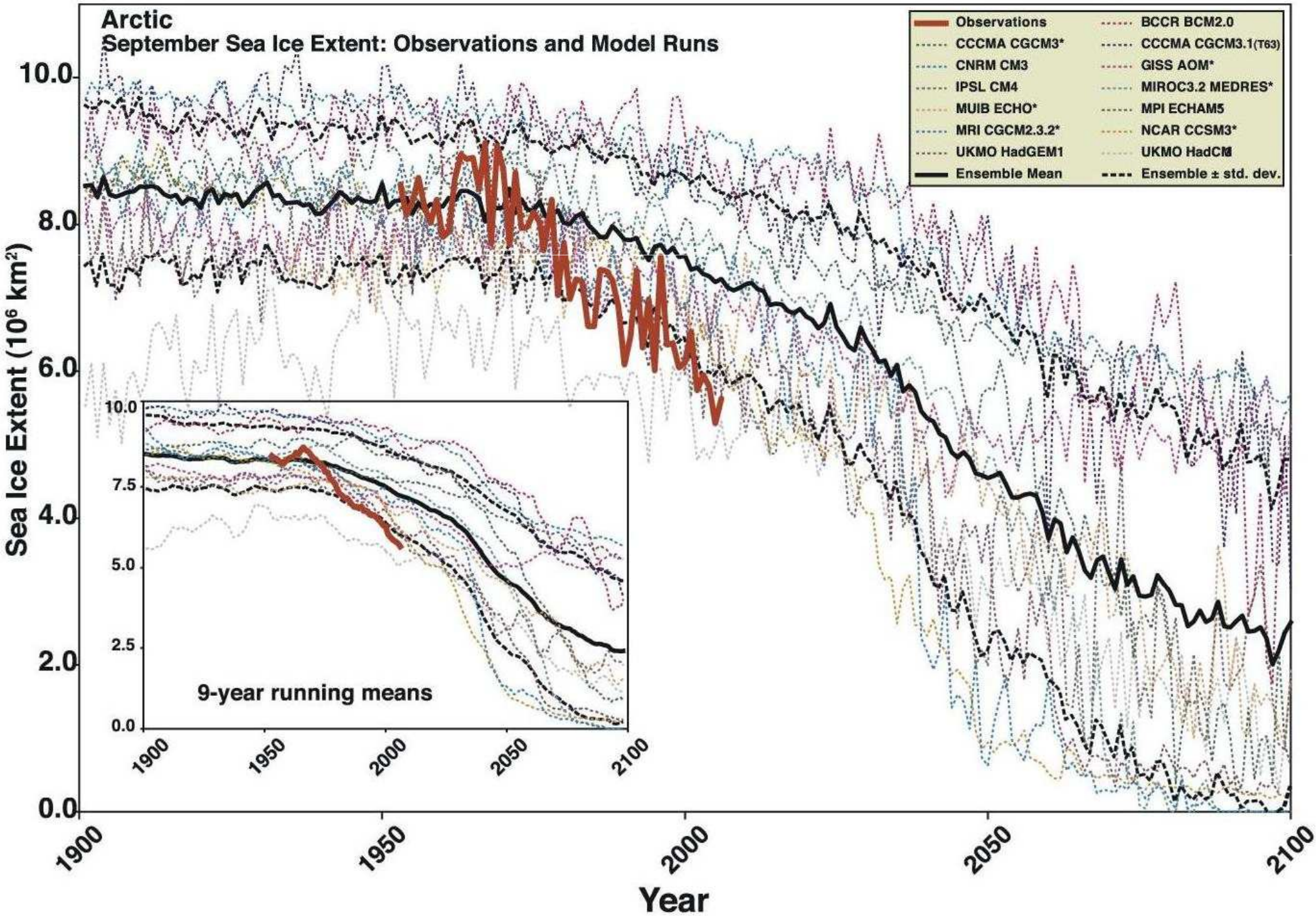
Sea ice extent: observations



Time series of the percent difference in ice extent in March (ice extent maximum) and September (ice extent minimum) relative to the mean values for the period 1979–2000 (rate of decrease: March –2.7% and September–11.6% per decade). (NSIDC 2010)

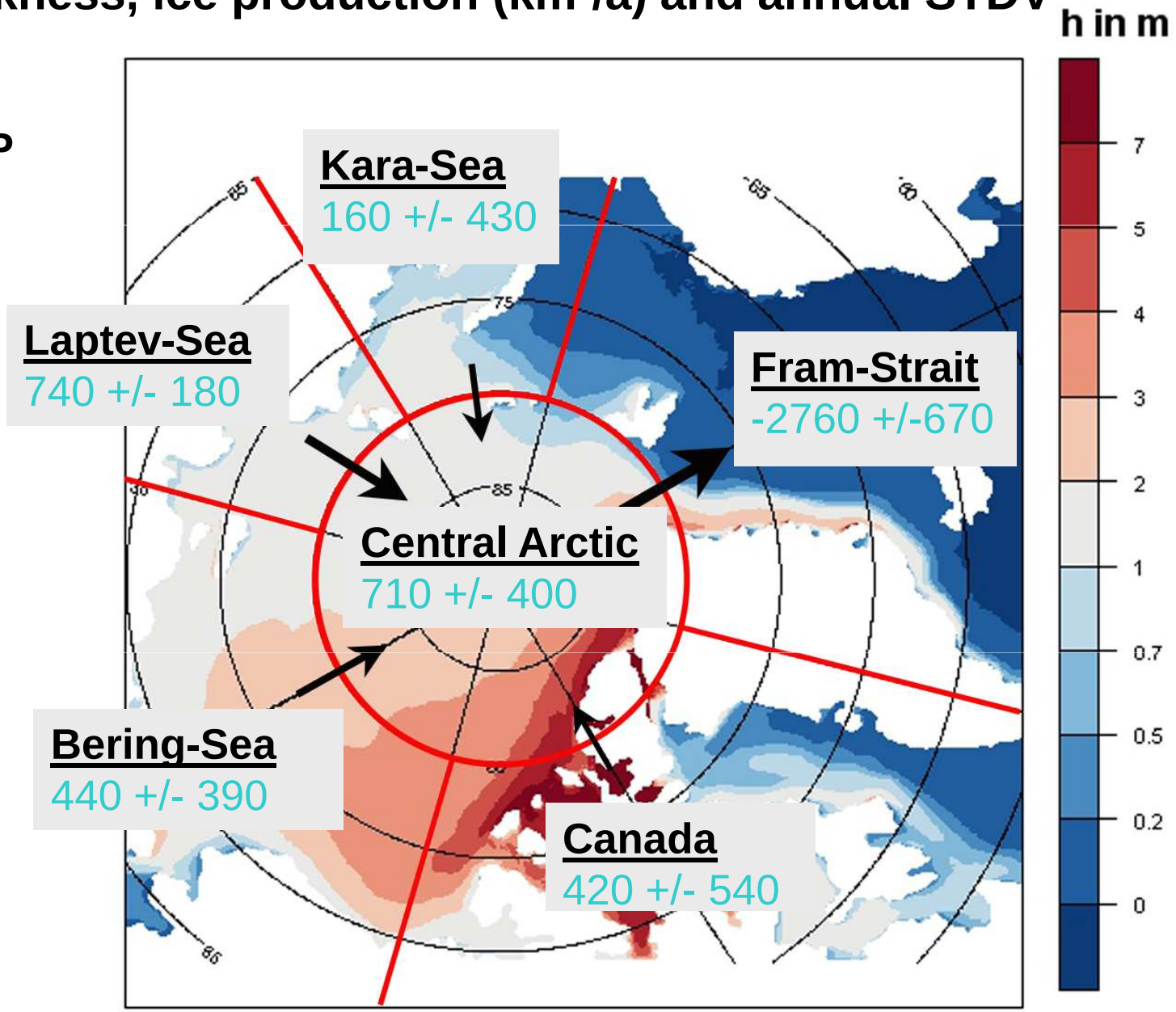
Arctic A1B scenario, 13 AR4 climate models (Stroeve et al., 2007)



Estimation of sea ice production in the Laptev Sea with a regional ocean/sea ice model

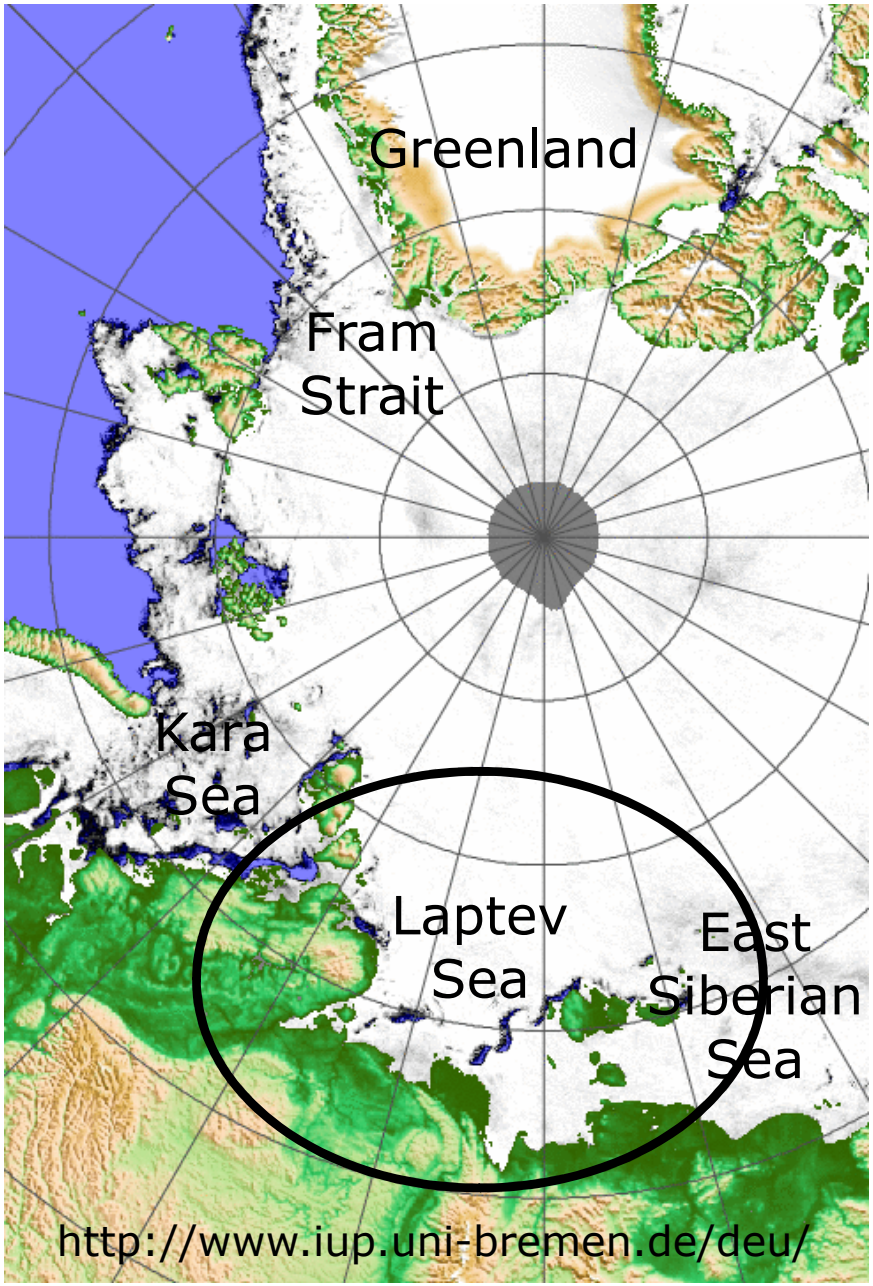
Mean ice thickness, ice production (km^3/a) and annual STDV

NAOSIM-9km, driven by NCEP reanalyses 1990-2008

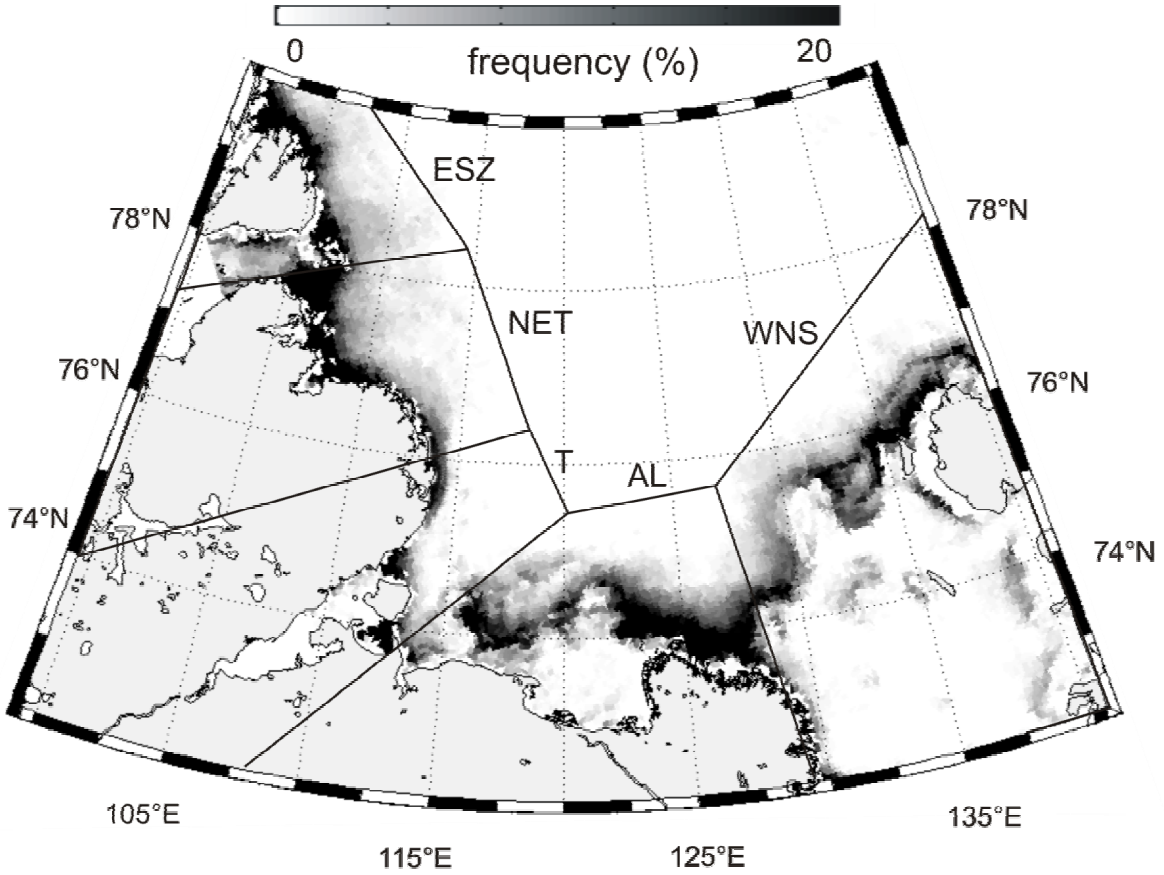


Kohnemann (2010)

Region of interest



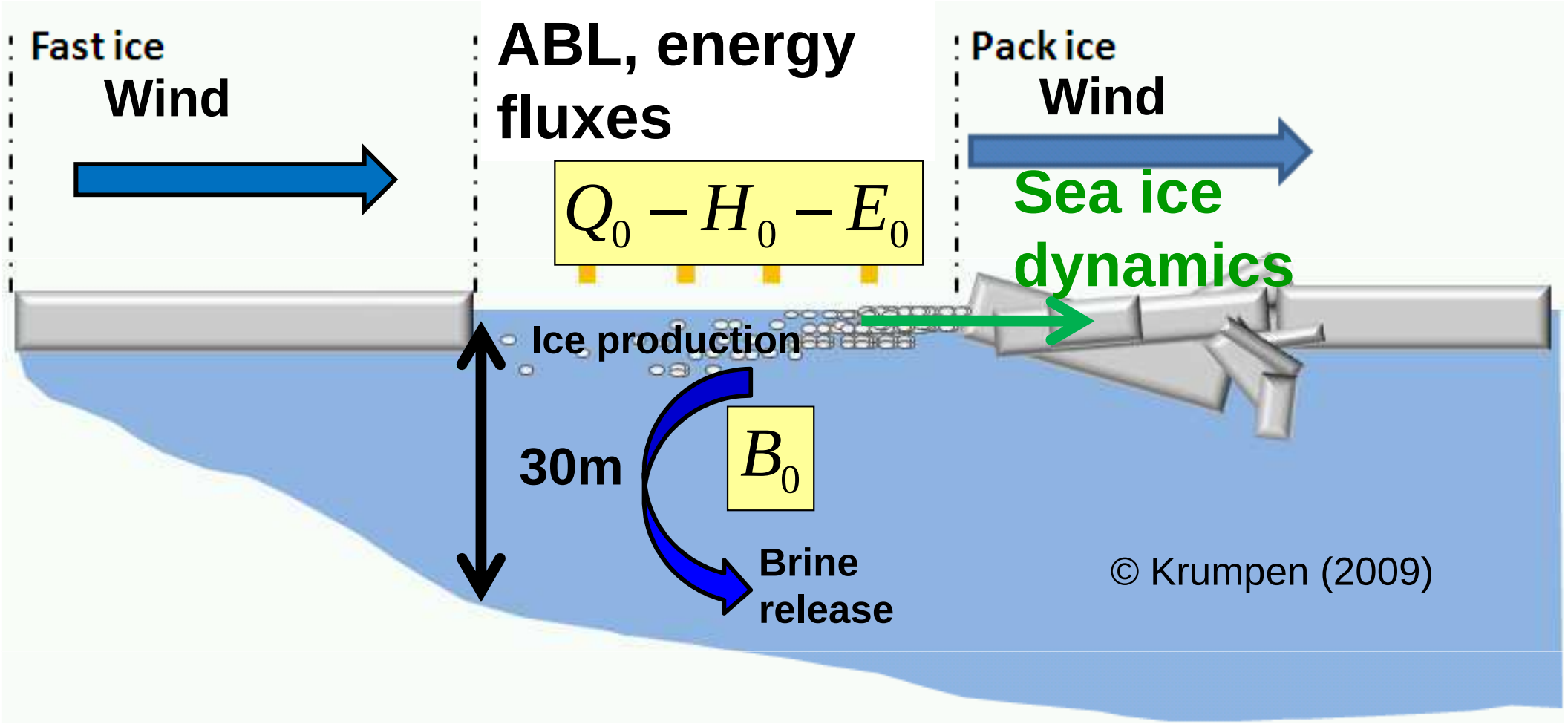
Polynya frequency



PSSM (AMSR-E) Nov-Apr 2002-2008

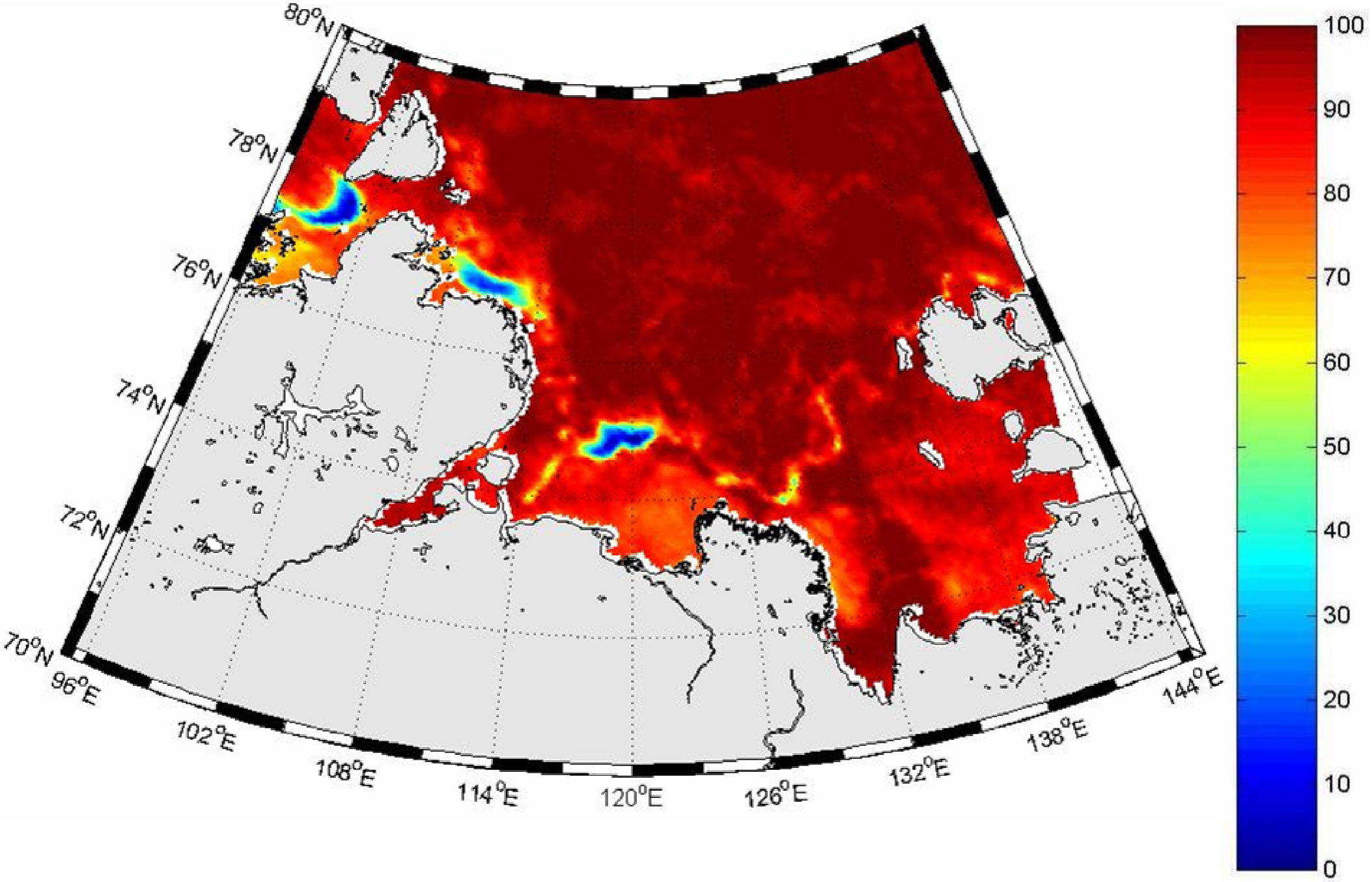
Willmes et al. (2011)

Polynya processes

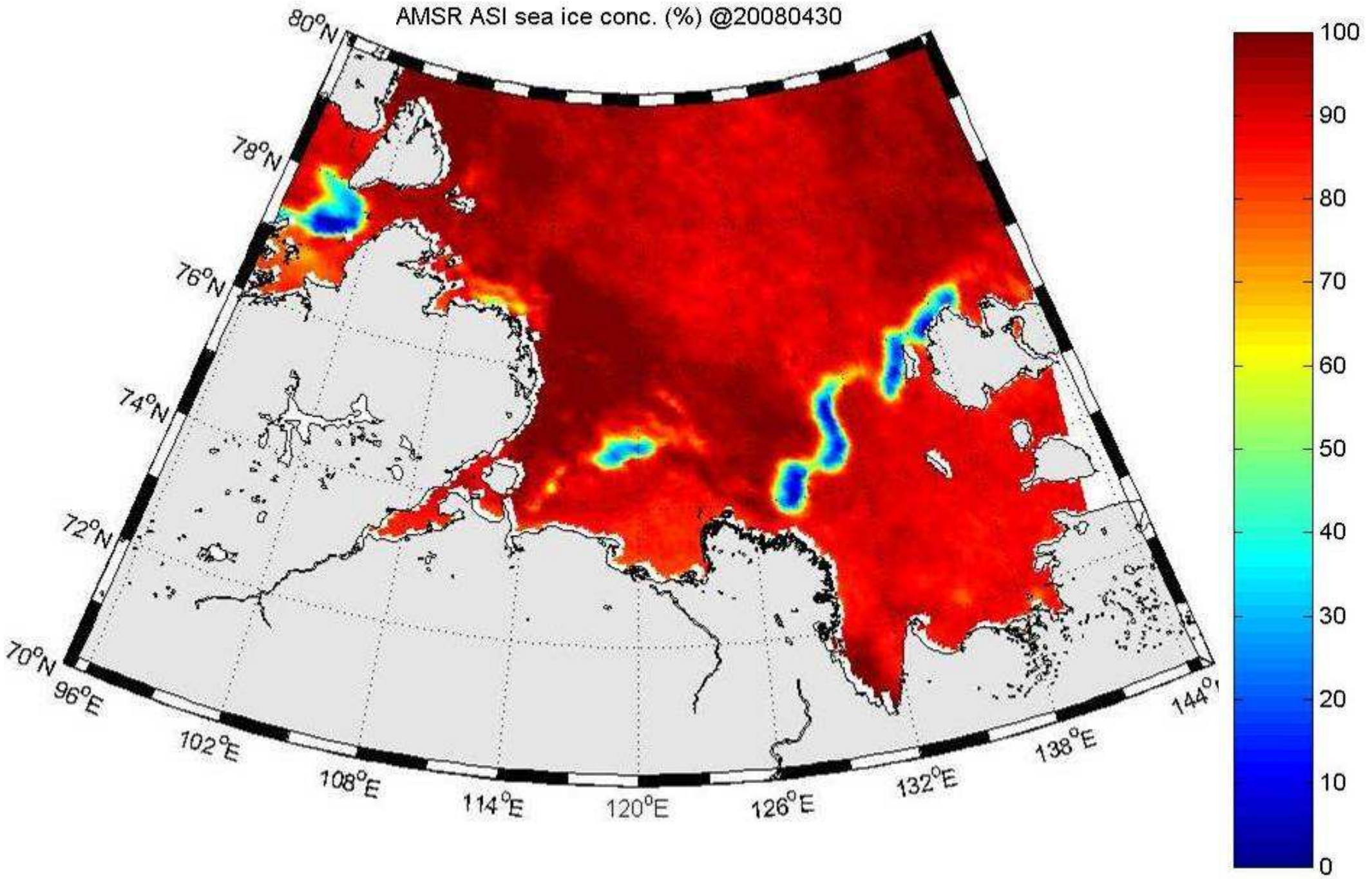


Q_0: net radiation
H_0: sensible heat flux
E_0: latent heat flux
B_0: soil heat flux (ice production)

Sea ice coverage 28 April 2008



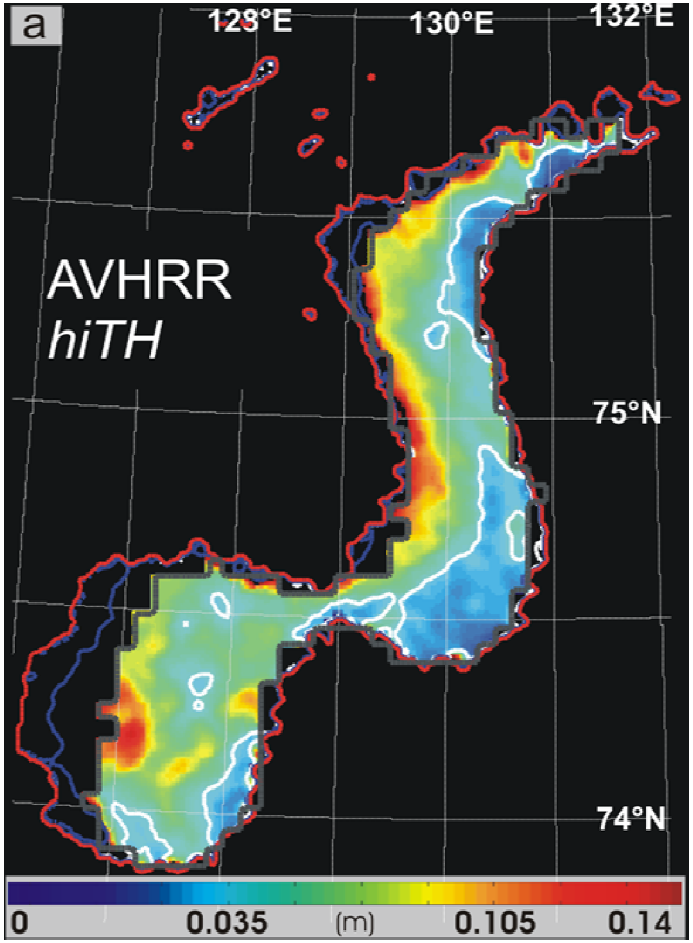
Sea ice coverage 30 April 2008



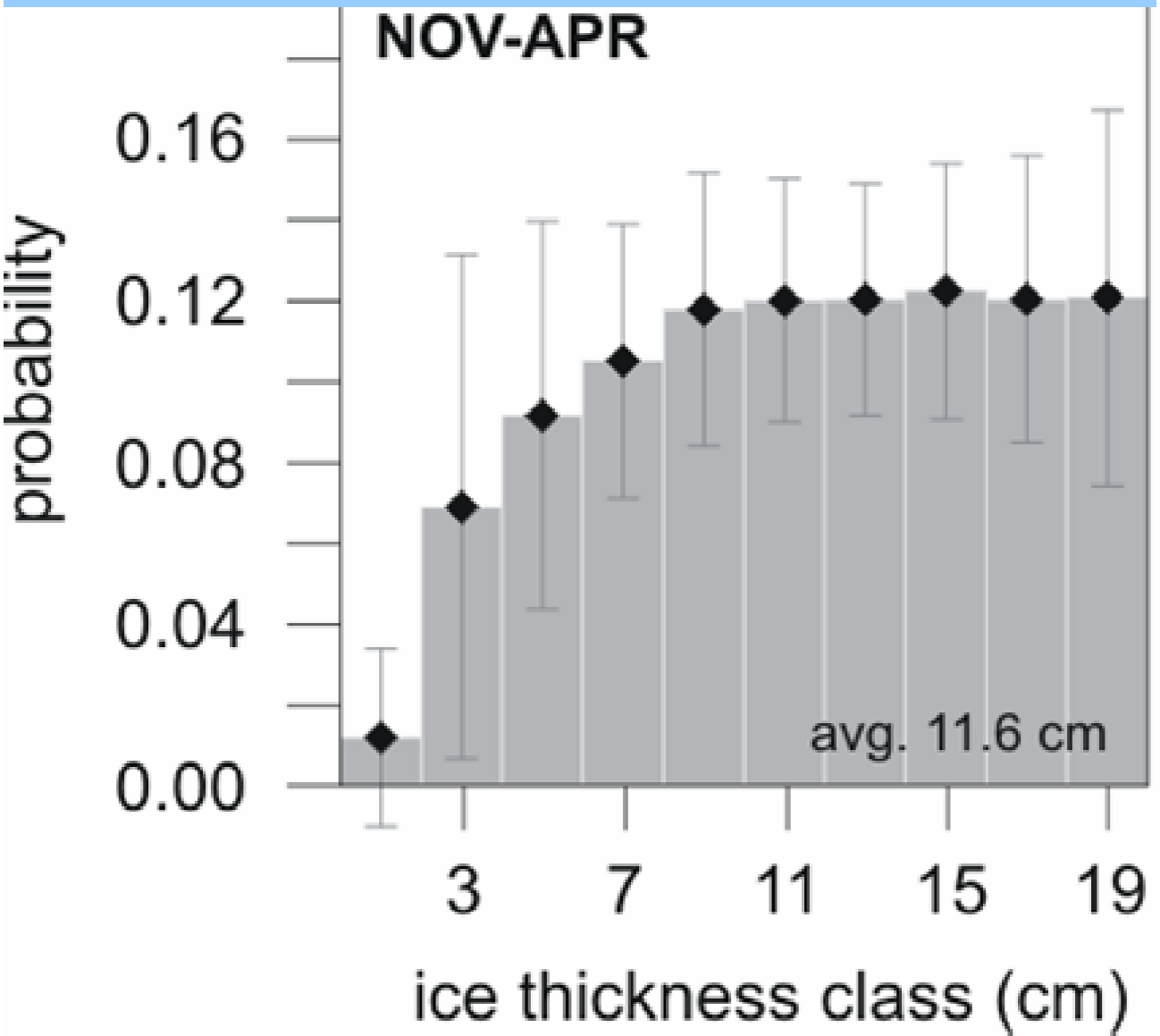
Remote sensing: sea ice

Thin ice statistics: MODIS, 59 Laptev polynya cases

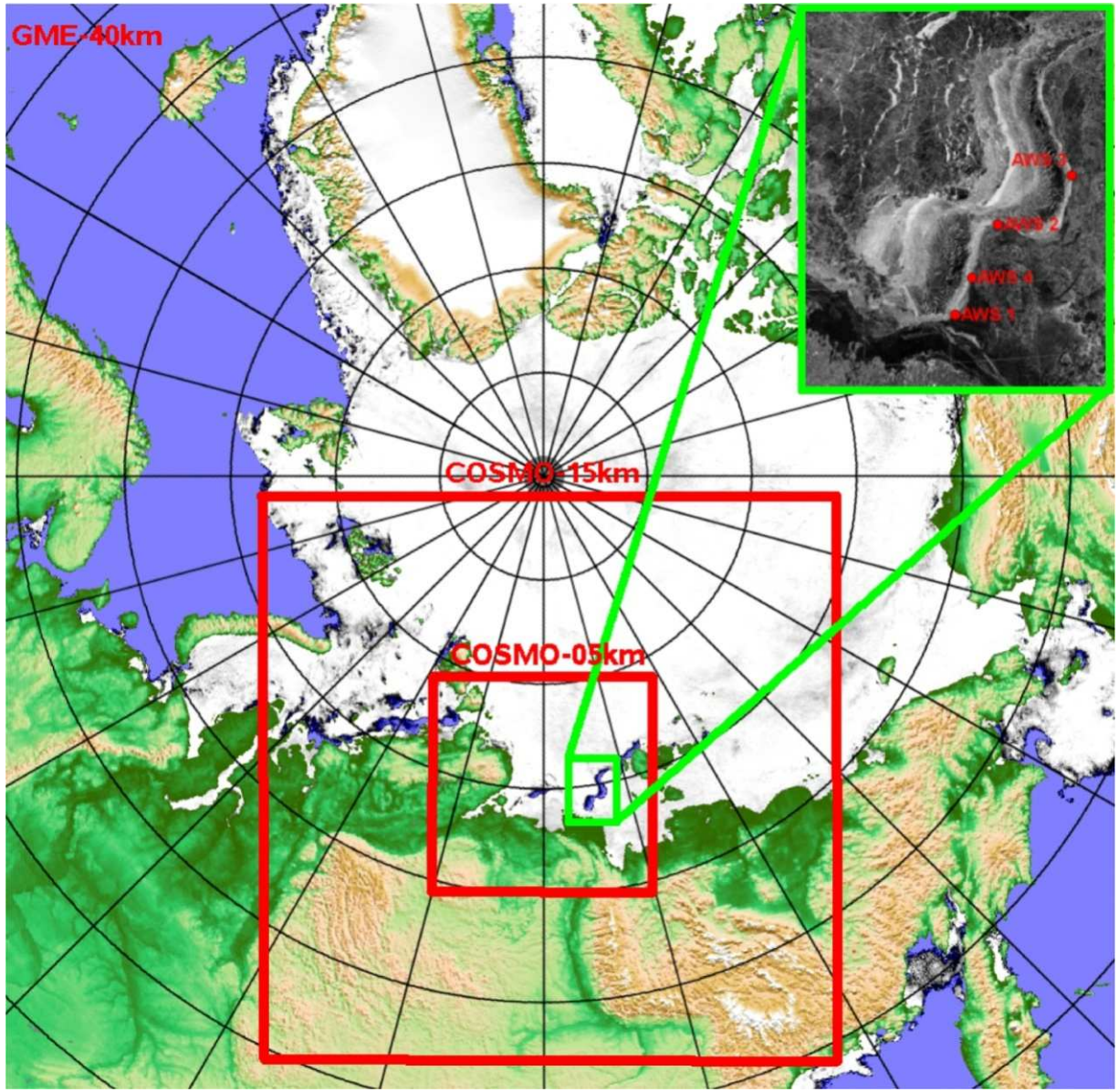
thin-ice thickness
AVHRR (hiTH)



hiTH contour lines 0.05m (white), 0.2m (blue), 0.5m (red)



Atmospheric modelling: COSMO



Model domains
COSMO-15km: 3000km
COSMO-5km: 1000km

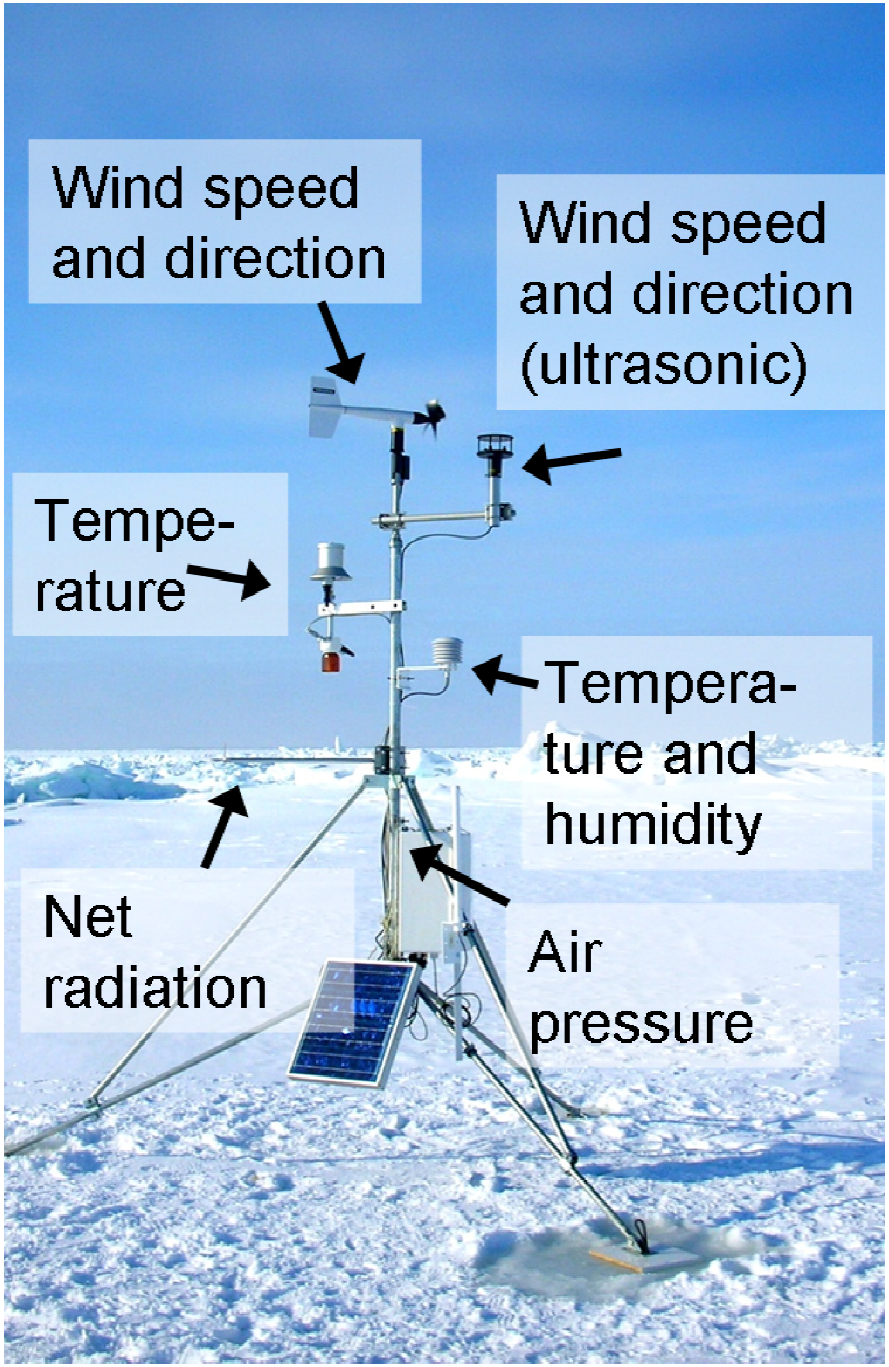
Forcing
GME
ERA-Interim

Forecast mode
+30h, 6h spin-up

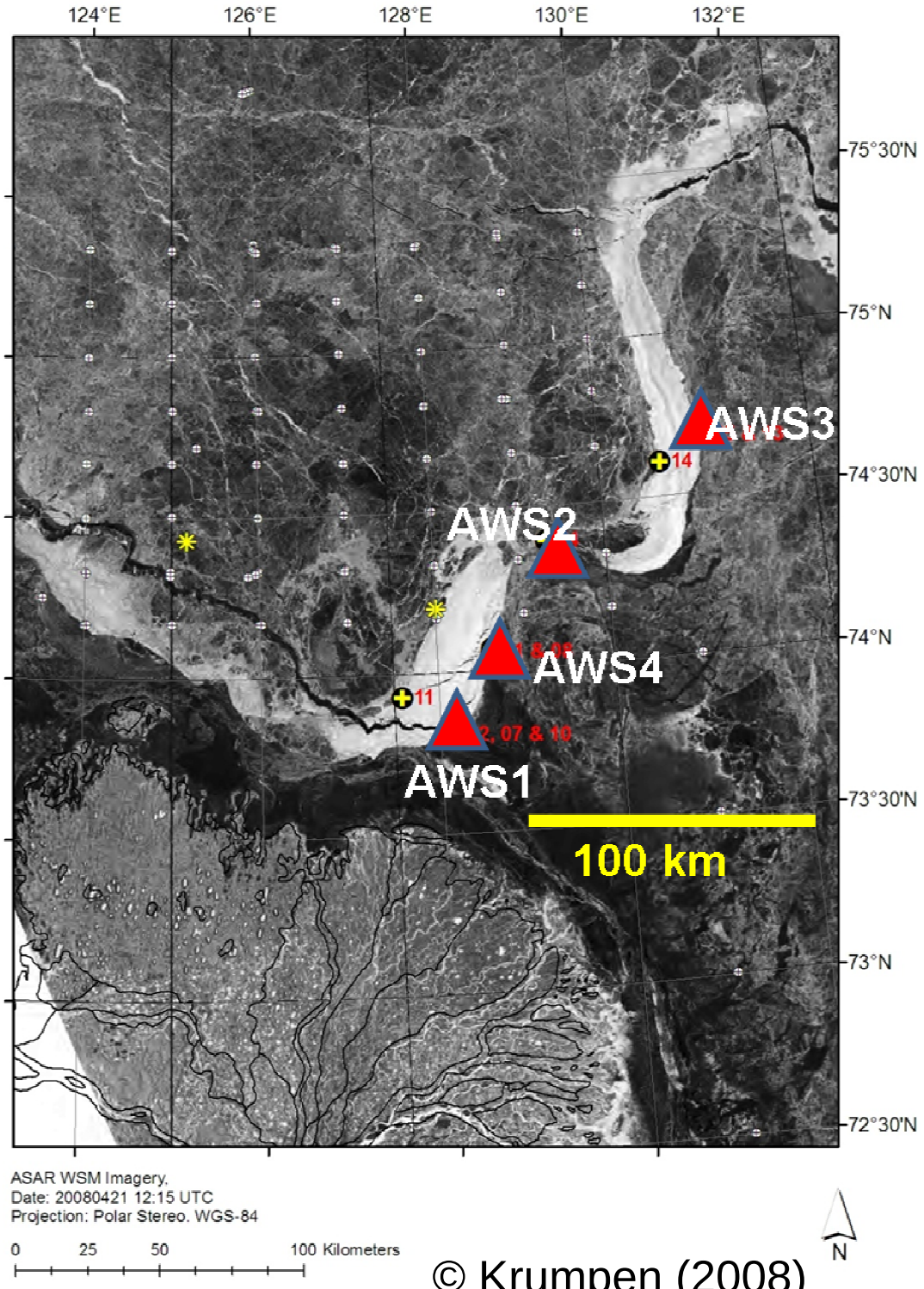
Schröder et al. (2011)

→ thermodynamic two-layer sea-ice model
→ dynamic-thermodynamic sea-ice-ocean model FESOM (AWI)

AWS measurements

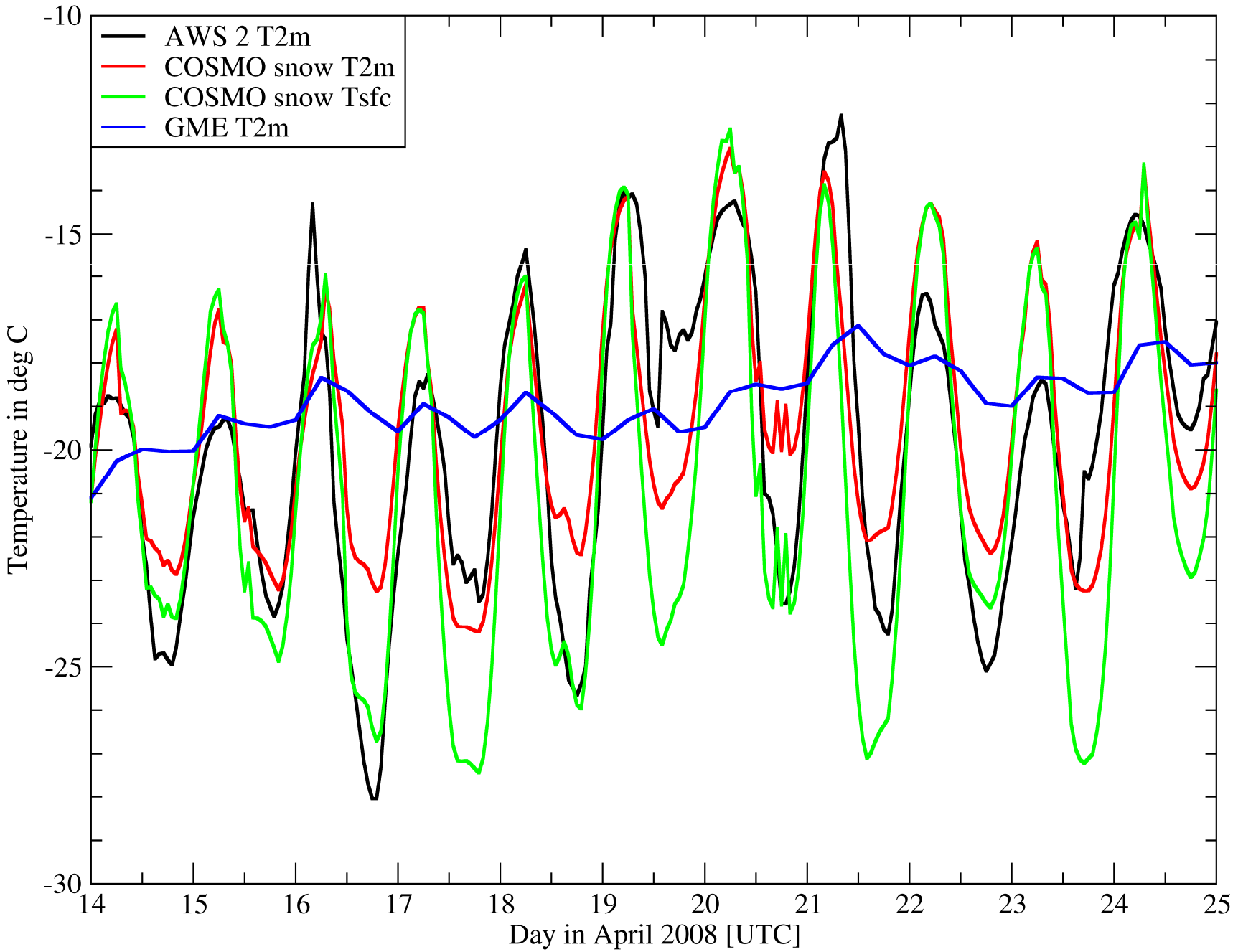


© Helbig (2008)



© Krumpen (2008)

Verification using AWS: temperature



Ice production in polynyas

$$Q_0 - H_0 - E_0 = B_0$$

potential ice production:

$$\frac{\partial h_i}{\partial t} = \frac{B_0}{\rho_i L_i}$$

ice production and thin ice thickness from MODIS satellite data: energy balance method

T_0 satellite measurements: longwave emission, q_0

Atmospheric forcing data (NCEP, COSMO,…)

Parameterizations: turbulent fluxes from bulk ansatz, incoming longwave radiation

$$B_0 = \rho_i c_{pi} k_i \left.\frac{\partial T_i}{\partial z}\right|_0 = \rho_i c_{pi} k_i \frac{T_0 - T_{bot}}{h_i}$$

Thin ice thickness (<20cm) from satellite data

$$h_i = \rho_i c_{pi} k_i \frac{T_0 - T_{bot}}{Q_0 - H_0 - E_0}$$

Ice production in polynyas

$$Q_0 - H_0 - E_0 = B_0$$

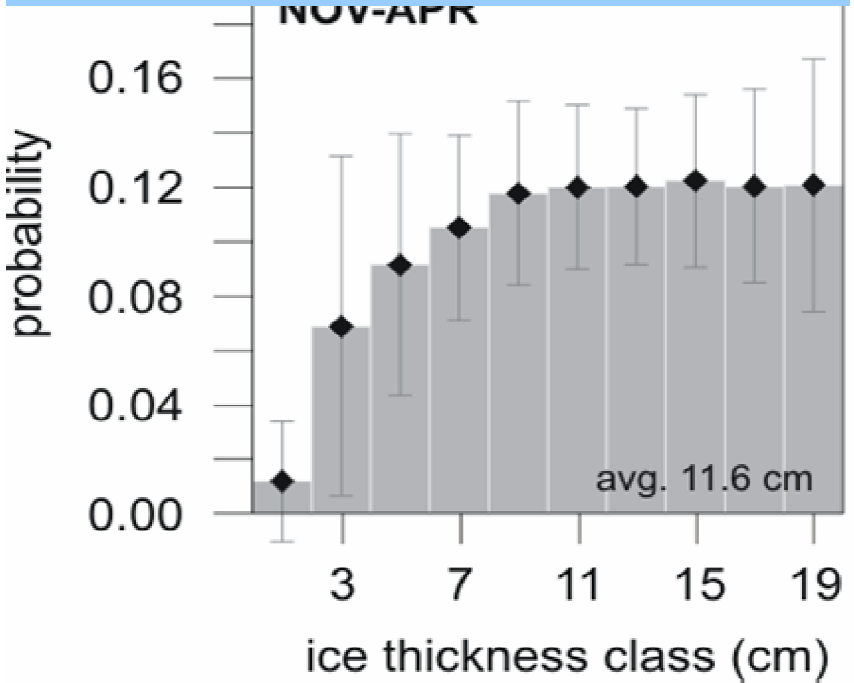
potential ice production:

$$\frac{\partial h_i}{\partial t} = \frac{B_0}{\rho_i L_i}$$

ice production from microwave (AMSR, SSM/I) satellite data

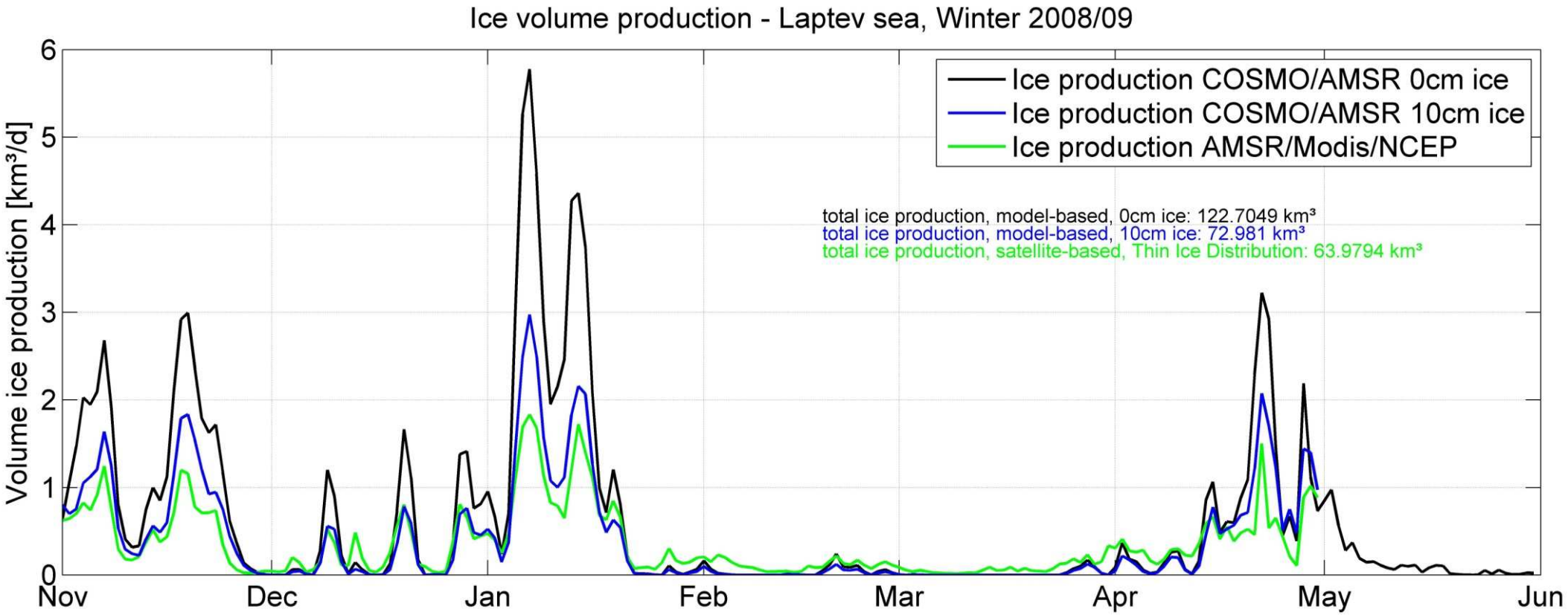
prescribed thin ice thickness distribution (climatology from MODIS, open water)

Thin ice statistics: MODIS, 59 Laptev polynya cases



Ice production in Laptev polynyas

COSMO-5km runs winter 2008/09



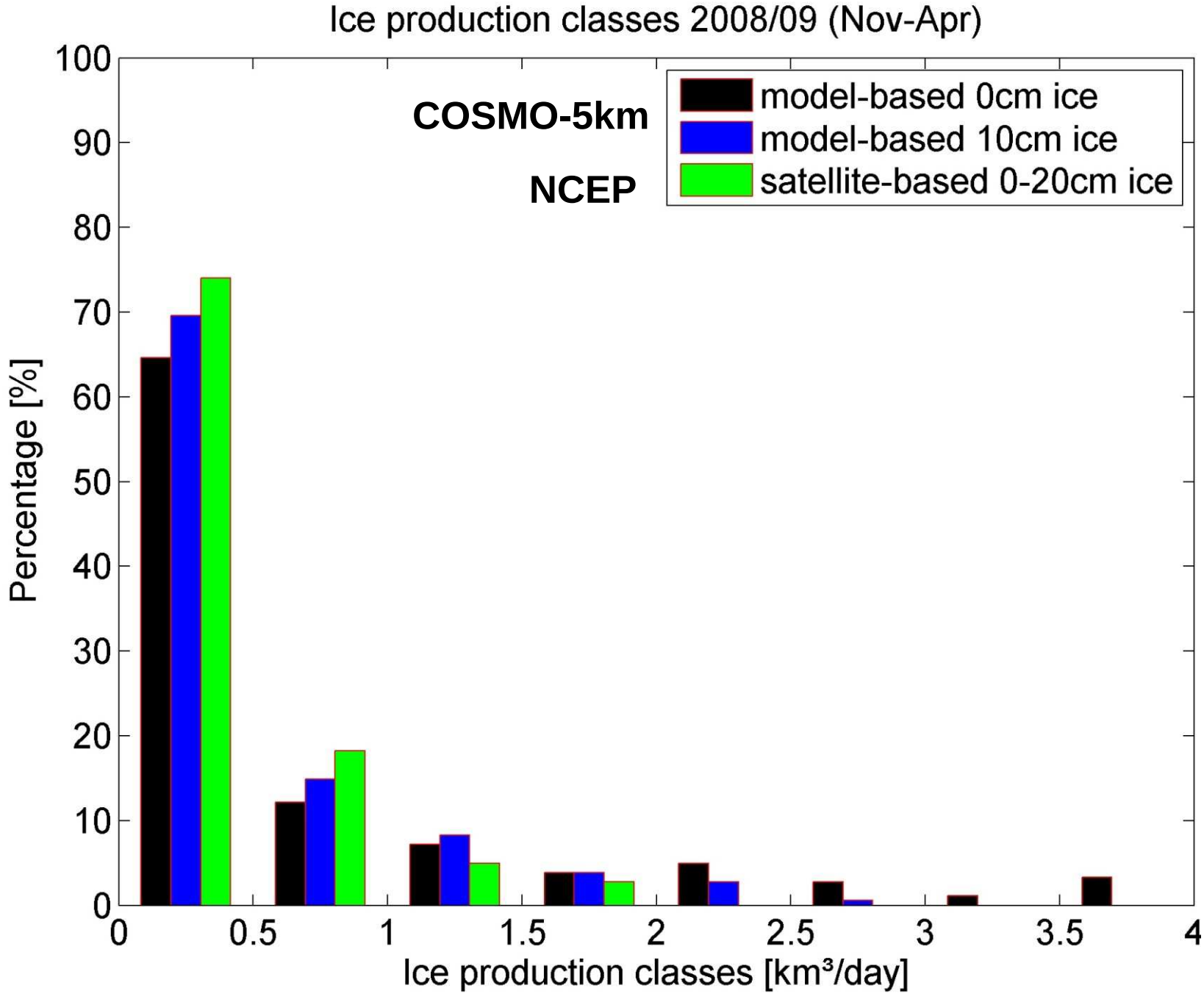
COSMO

Ice-free polynyas: 123 km³

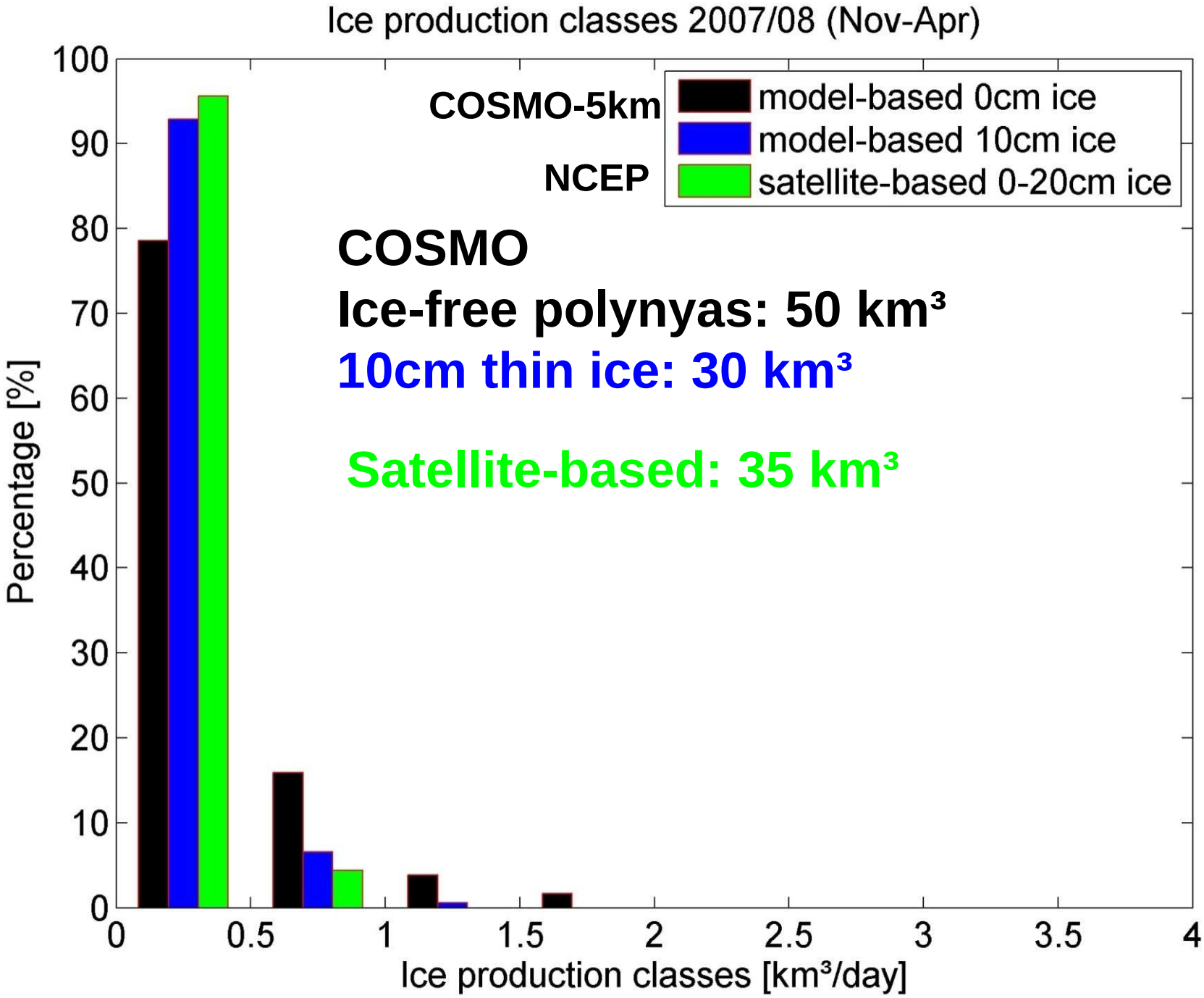
10cm thin ice: 73 km³

Satellite-based: 64 km³

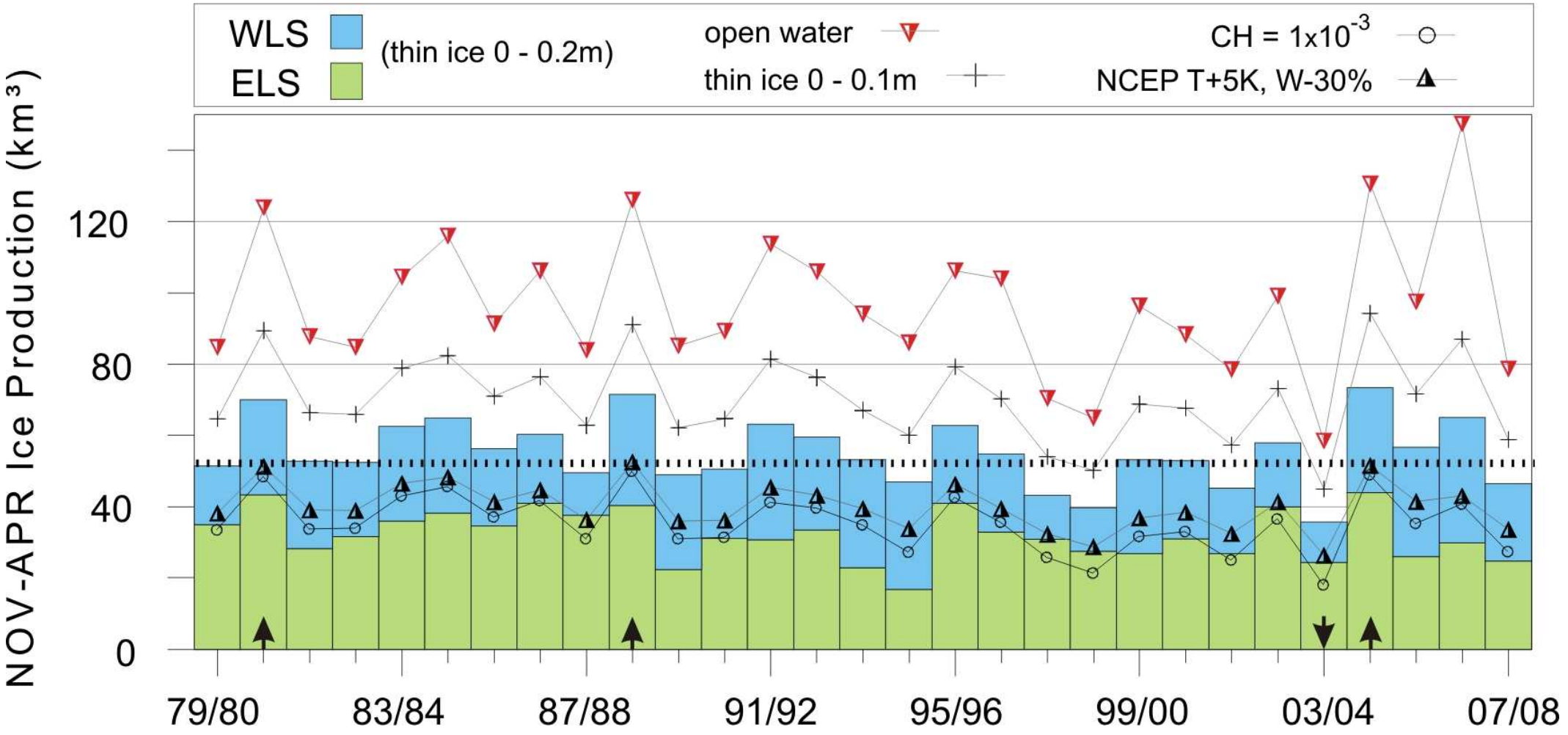
Ice production in Laptev polynyas



Ice production in Laptev polynyas



Ice production: satellite-based



Willmes et al. 2011

Black arrows: significant deviation from the long-term average

Ocean-ice modelling: FESOM

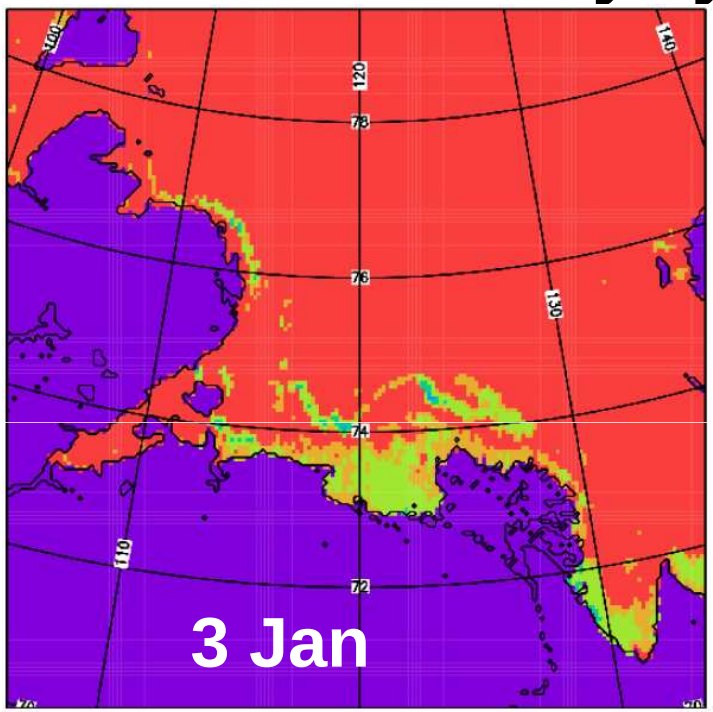
sea-ice-ocean model FESOM (AWI, Timmermann et al. 2009):

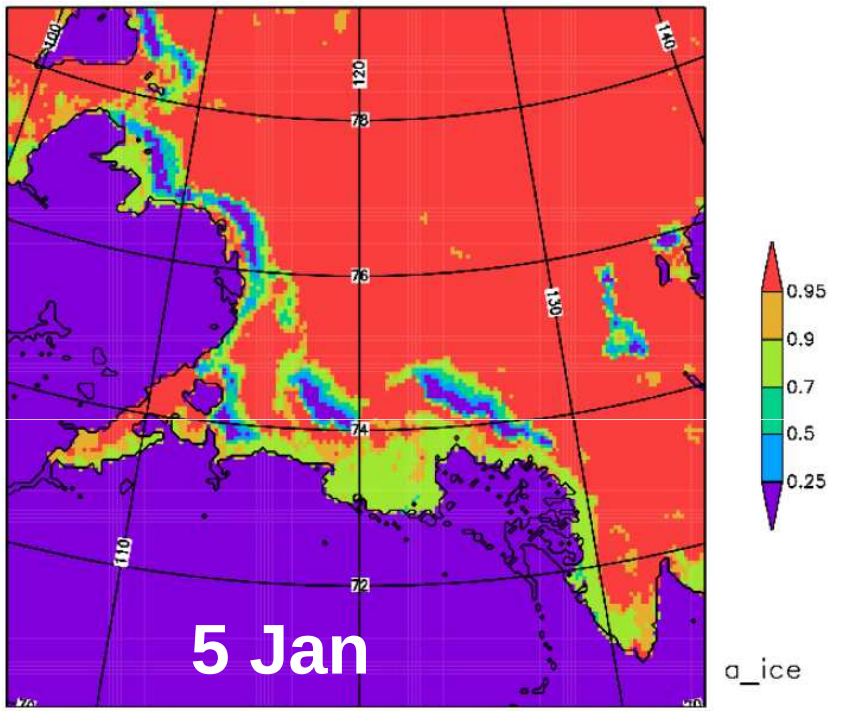
- hydrostatic primitive-equation ocean model, dynamic-thermodynamic sea ice model
- finite element model, grid points identical to COSMO grid points (5km)

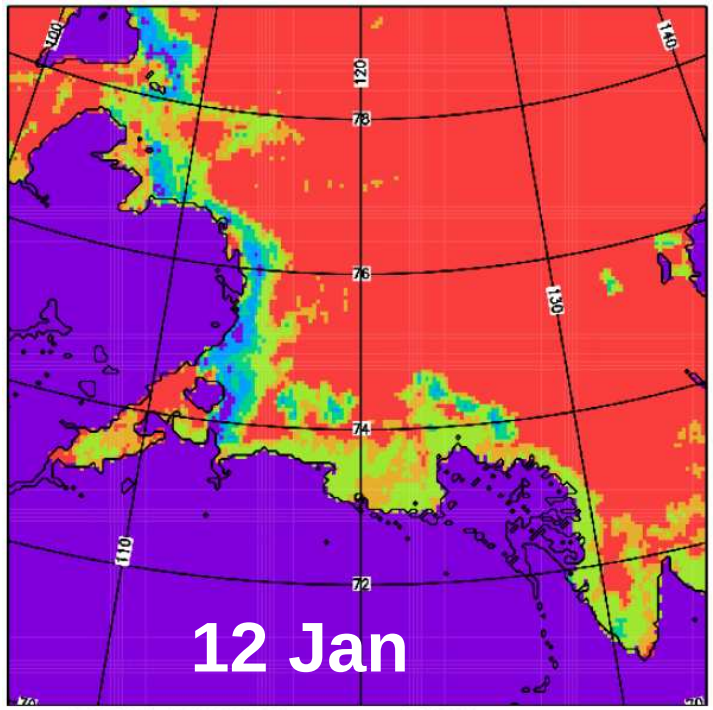
- 30 day runs with 5 days spin-up
- atmospheric forcing from COSMO
- intermittent assimilation of MODIS thin ice thickness

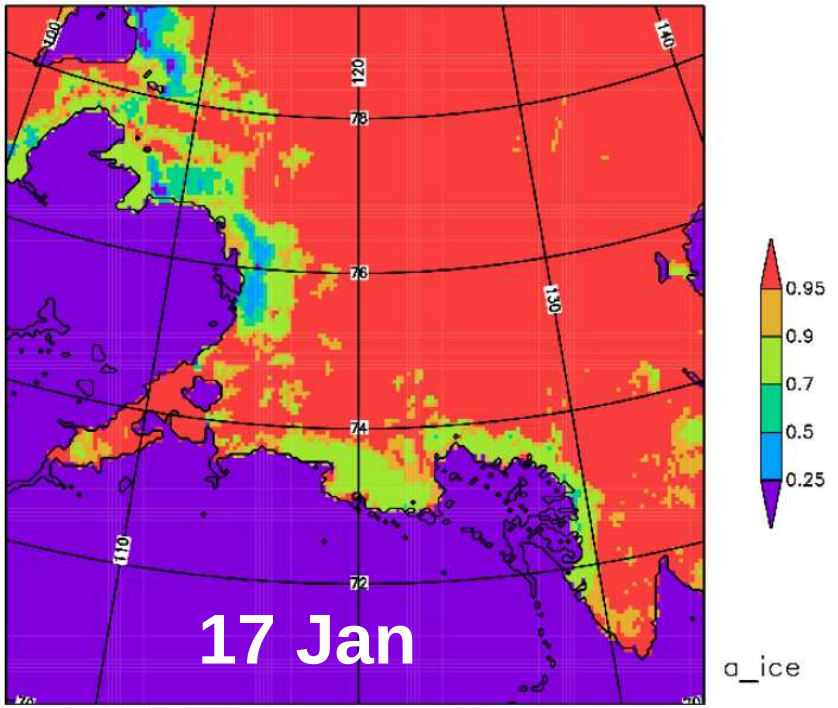
Polynya event Jan. 2009

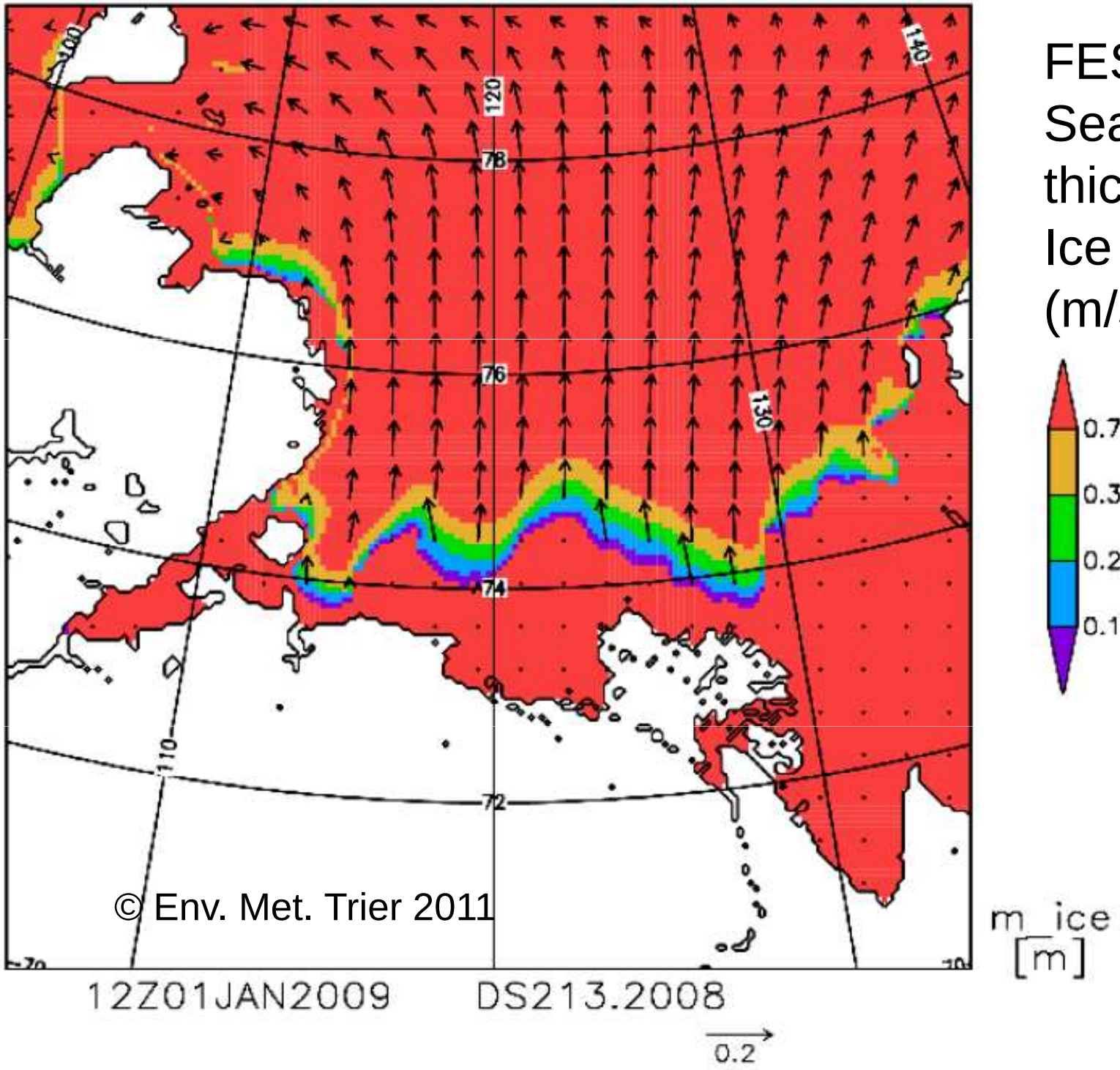
Observations
AMSR
Sea ice conc.



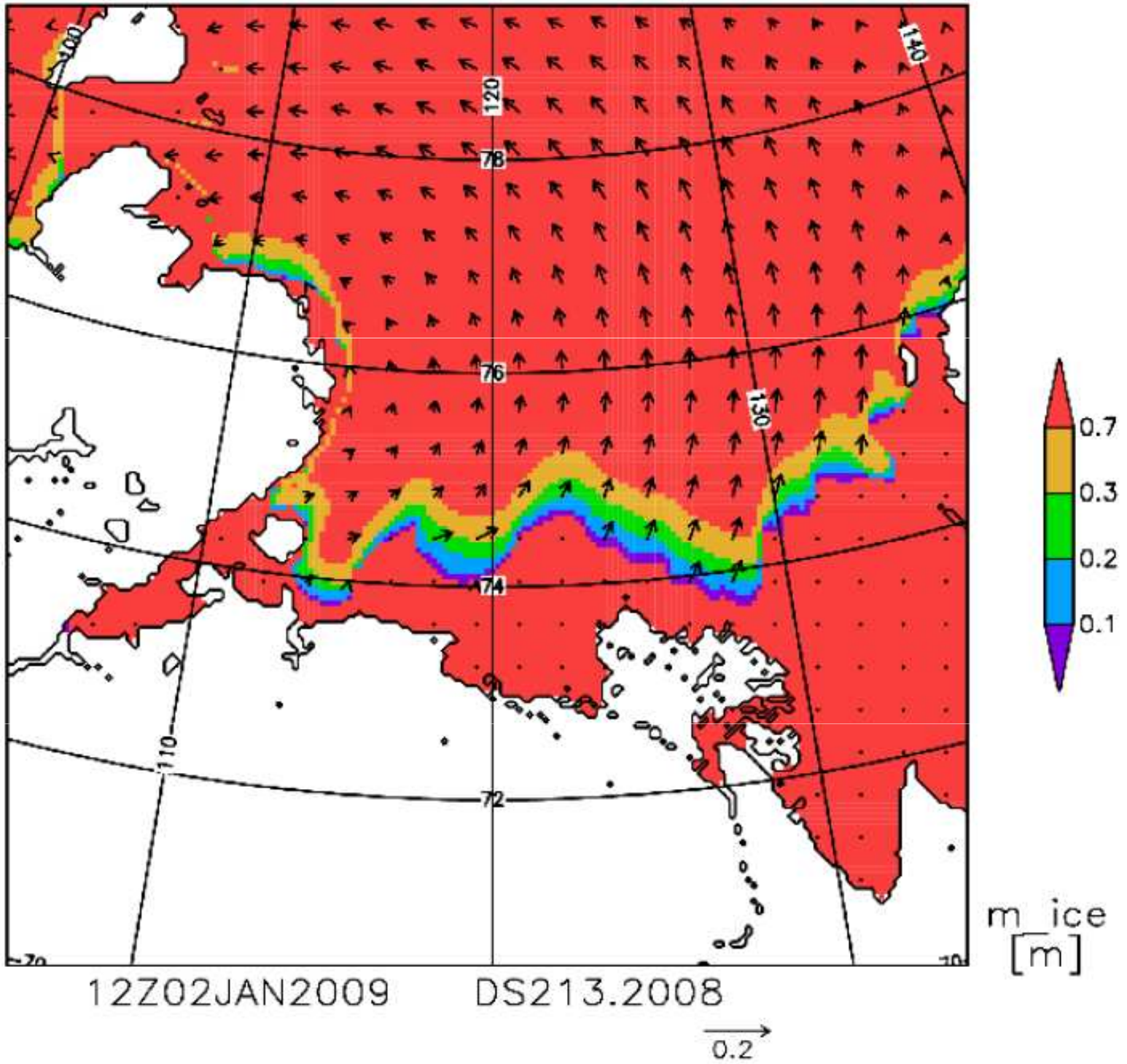








FESOM
Sea ice thickness
Ice vectors (m/s)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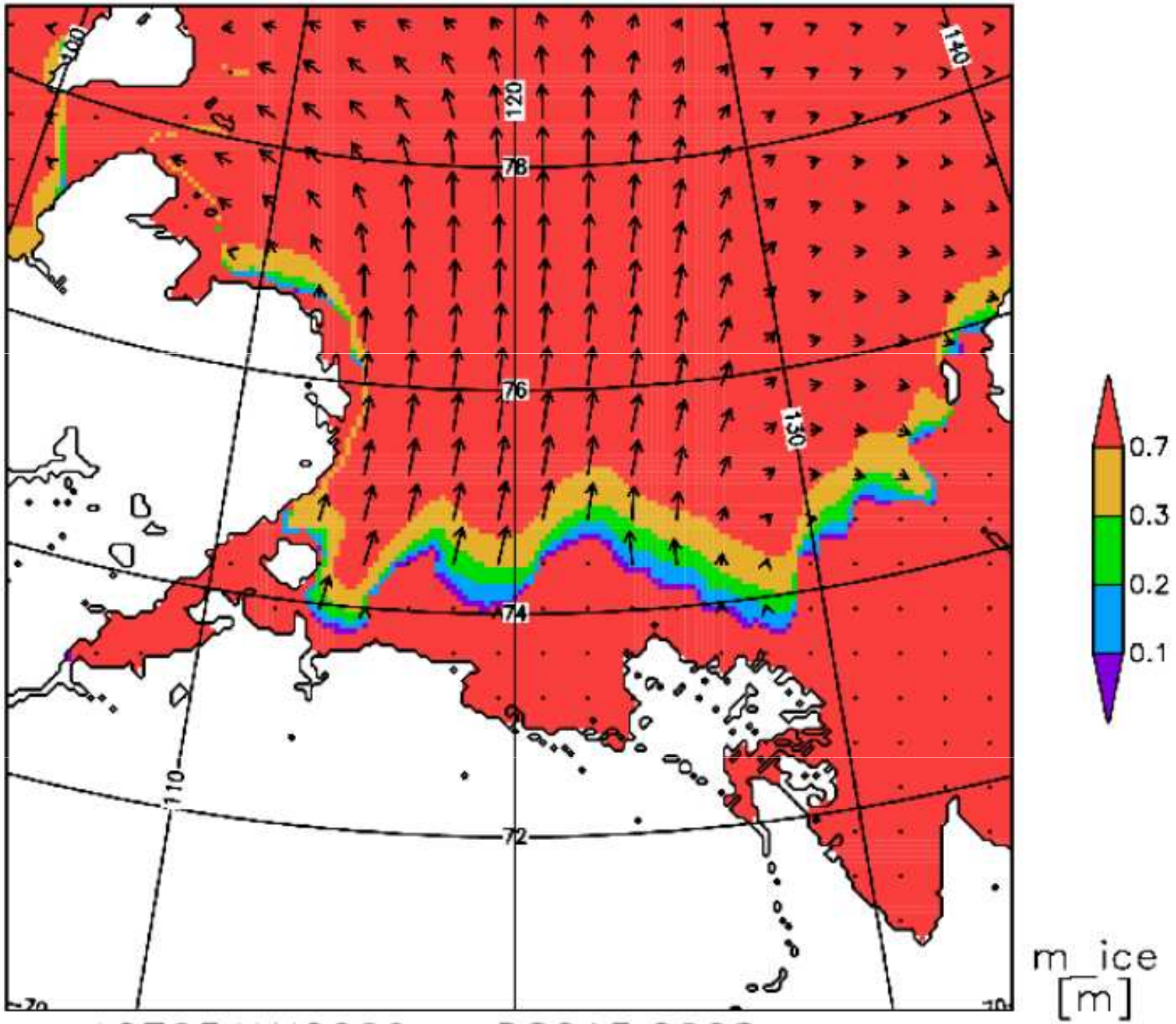
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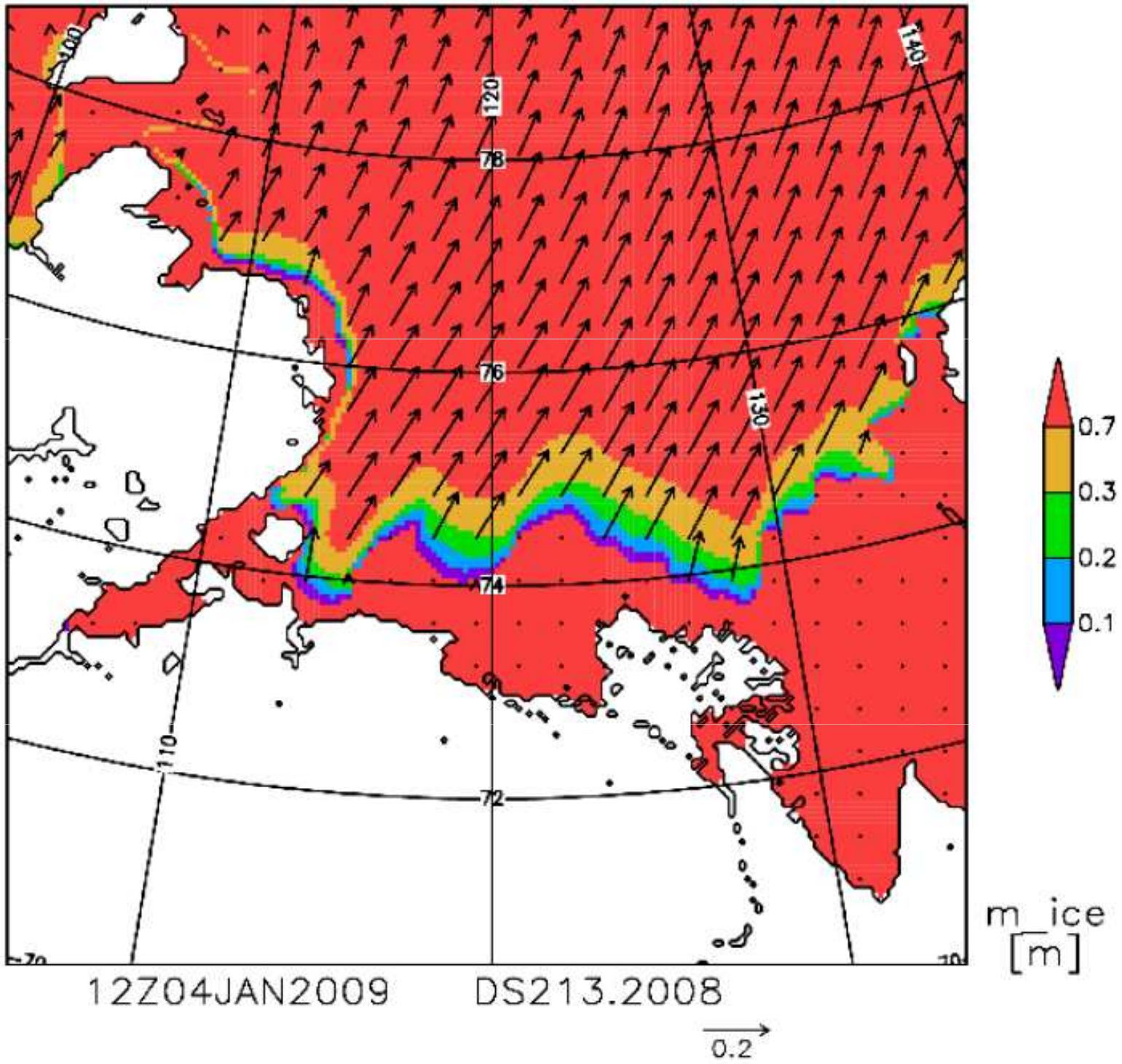
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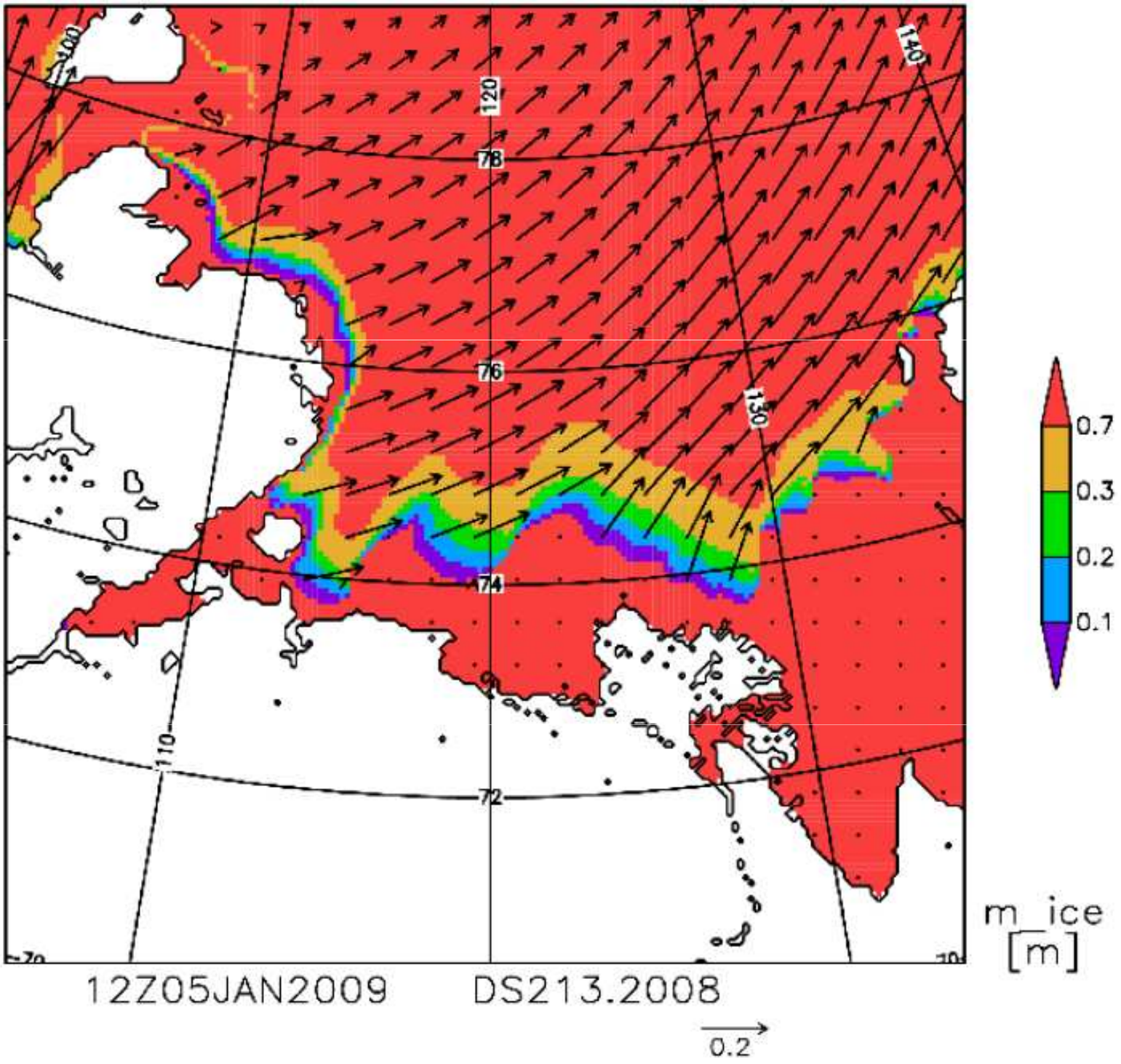
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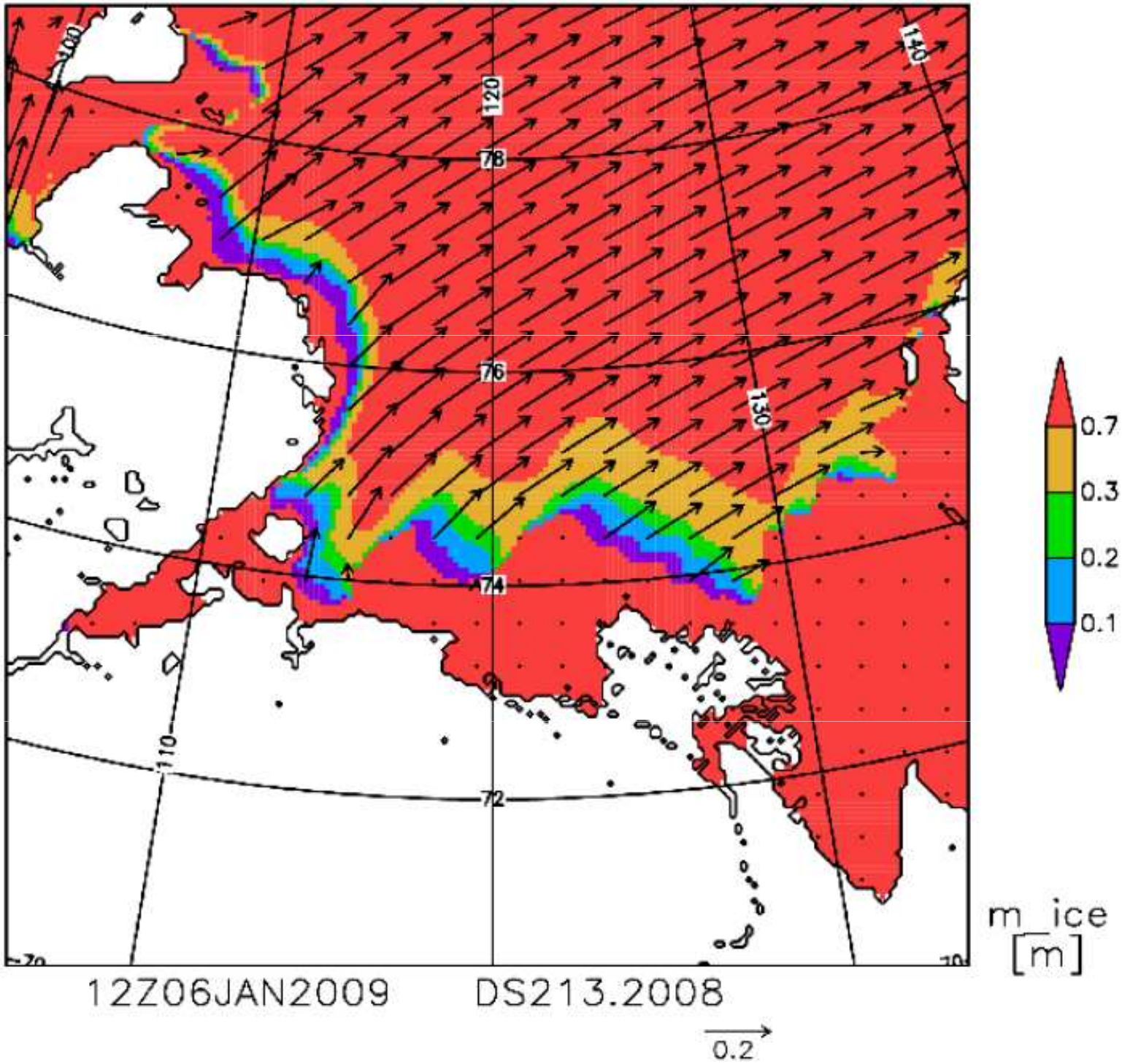
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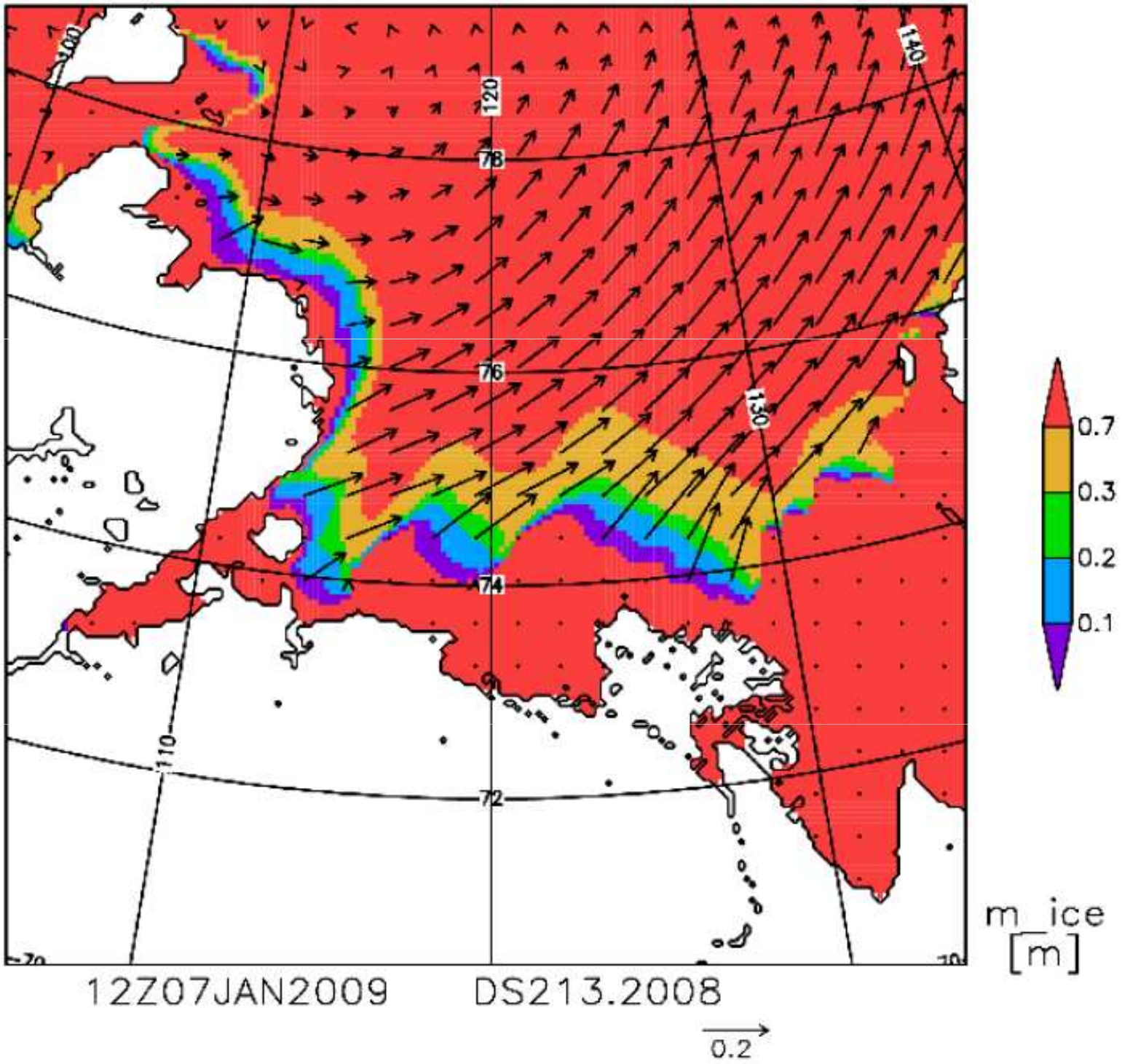
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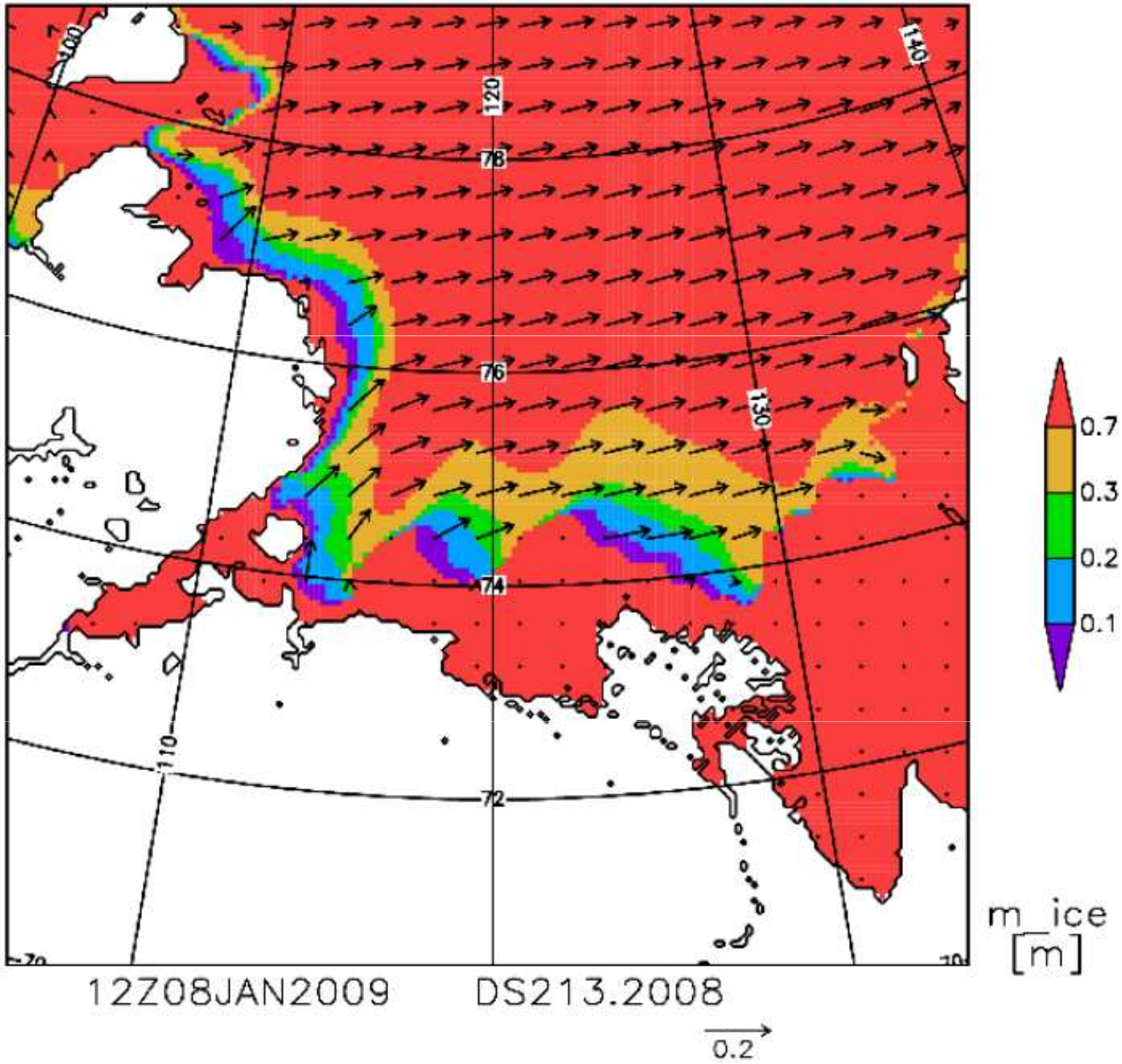
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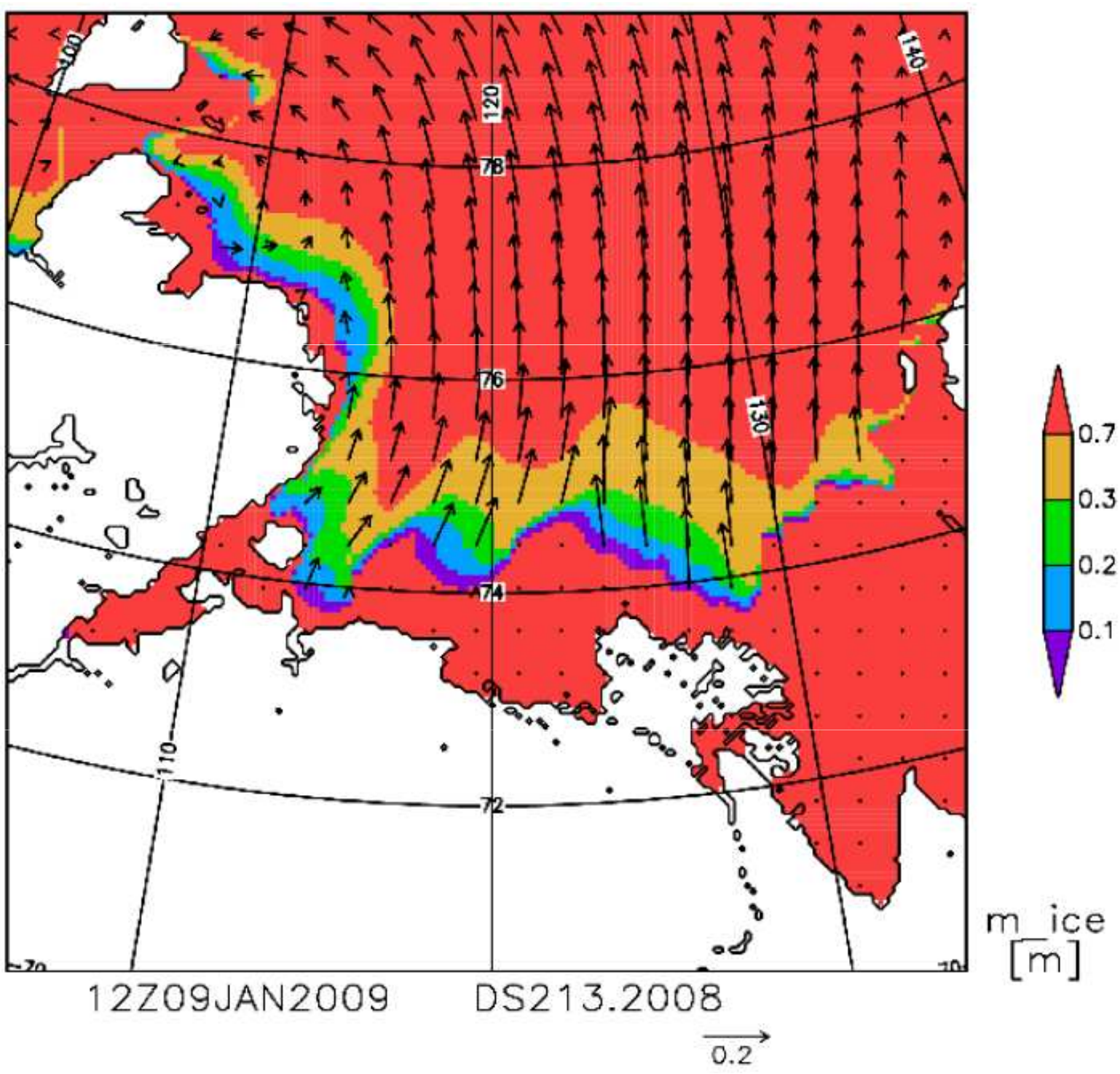
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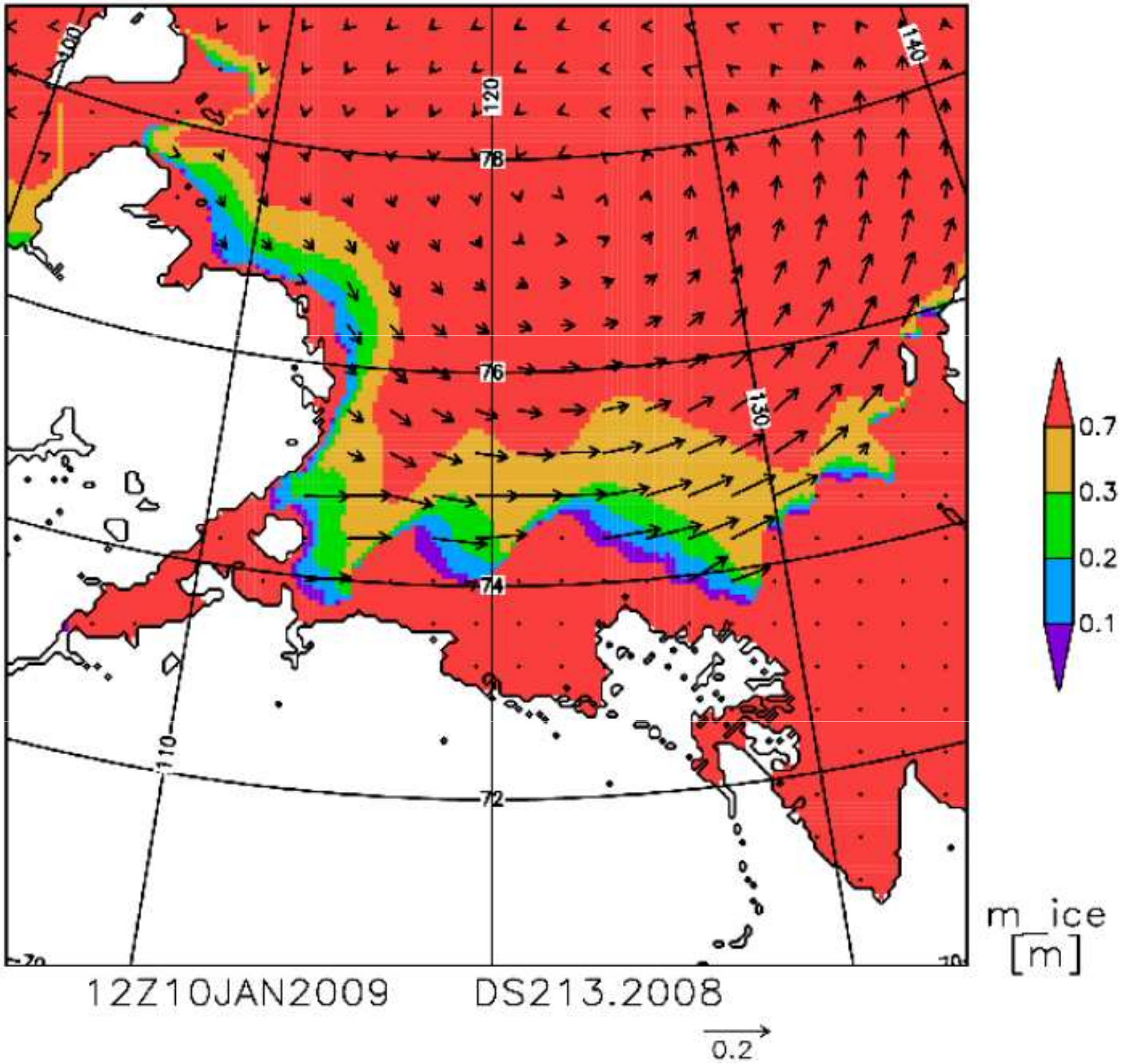
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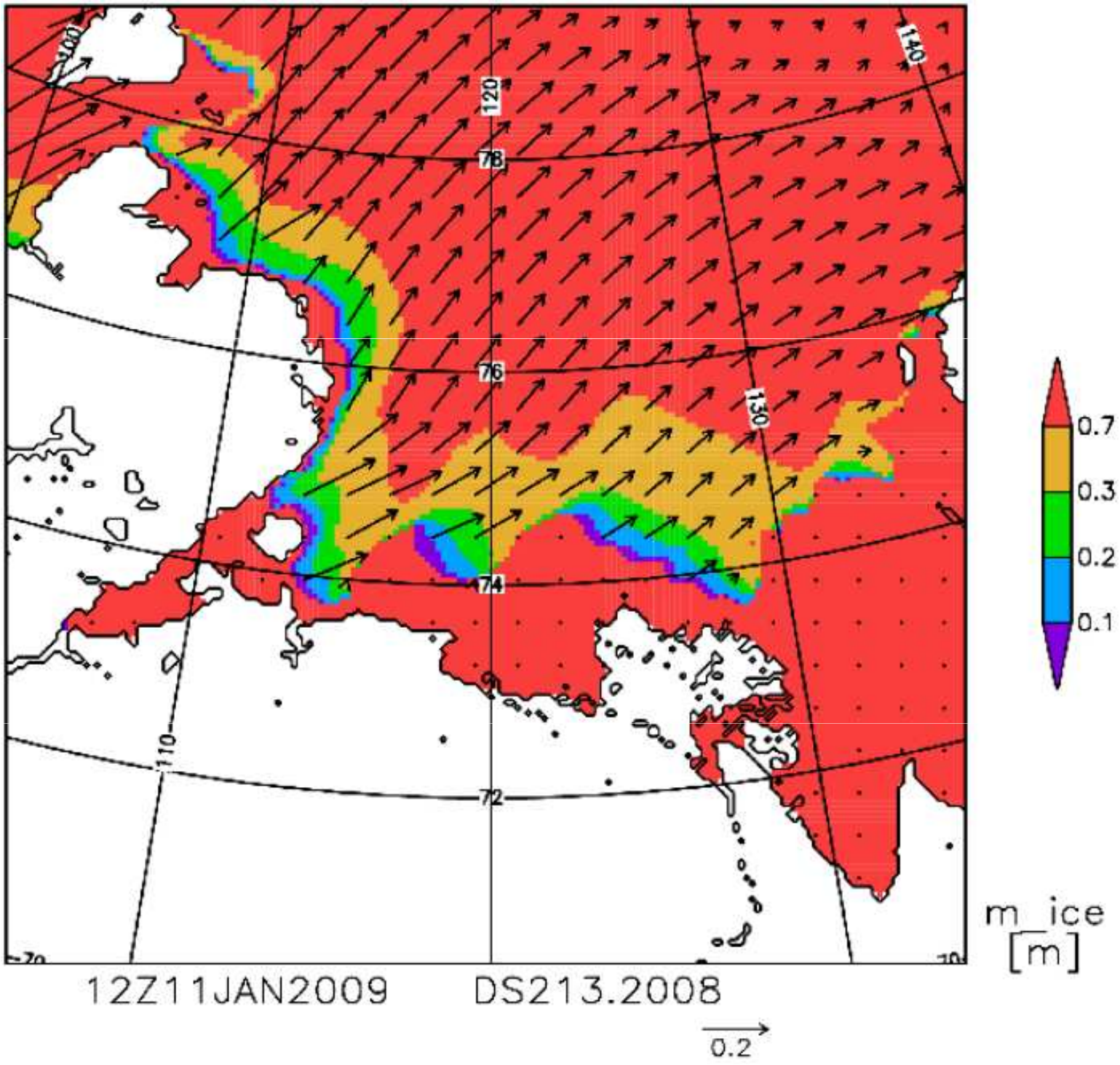
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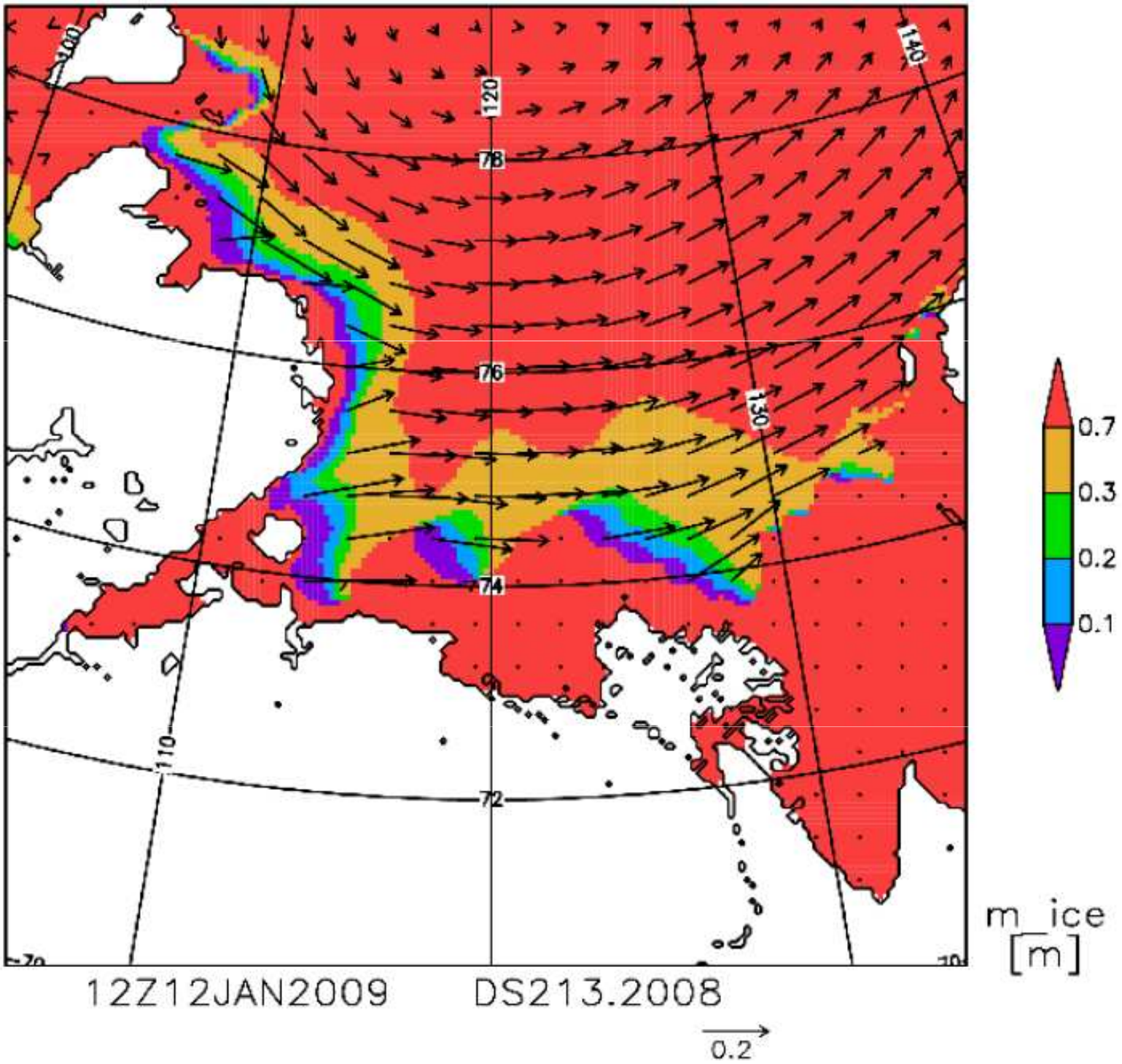
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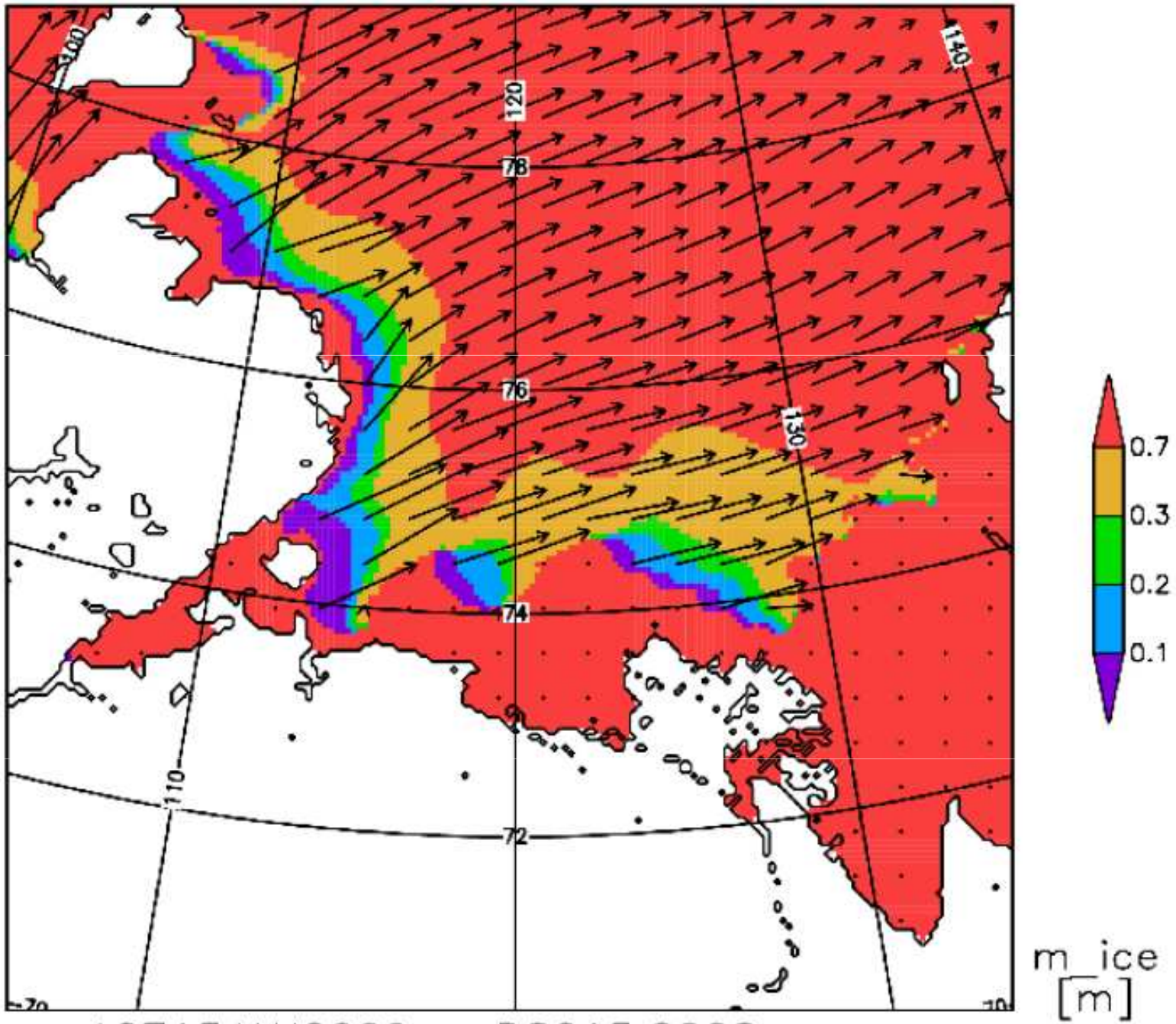
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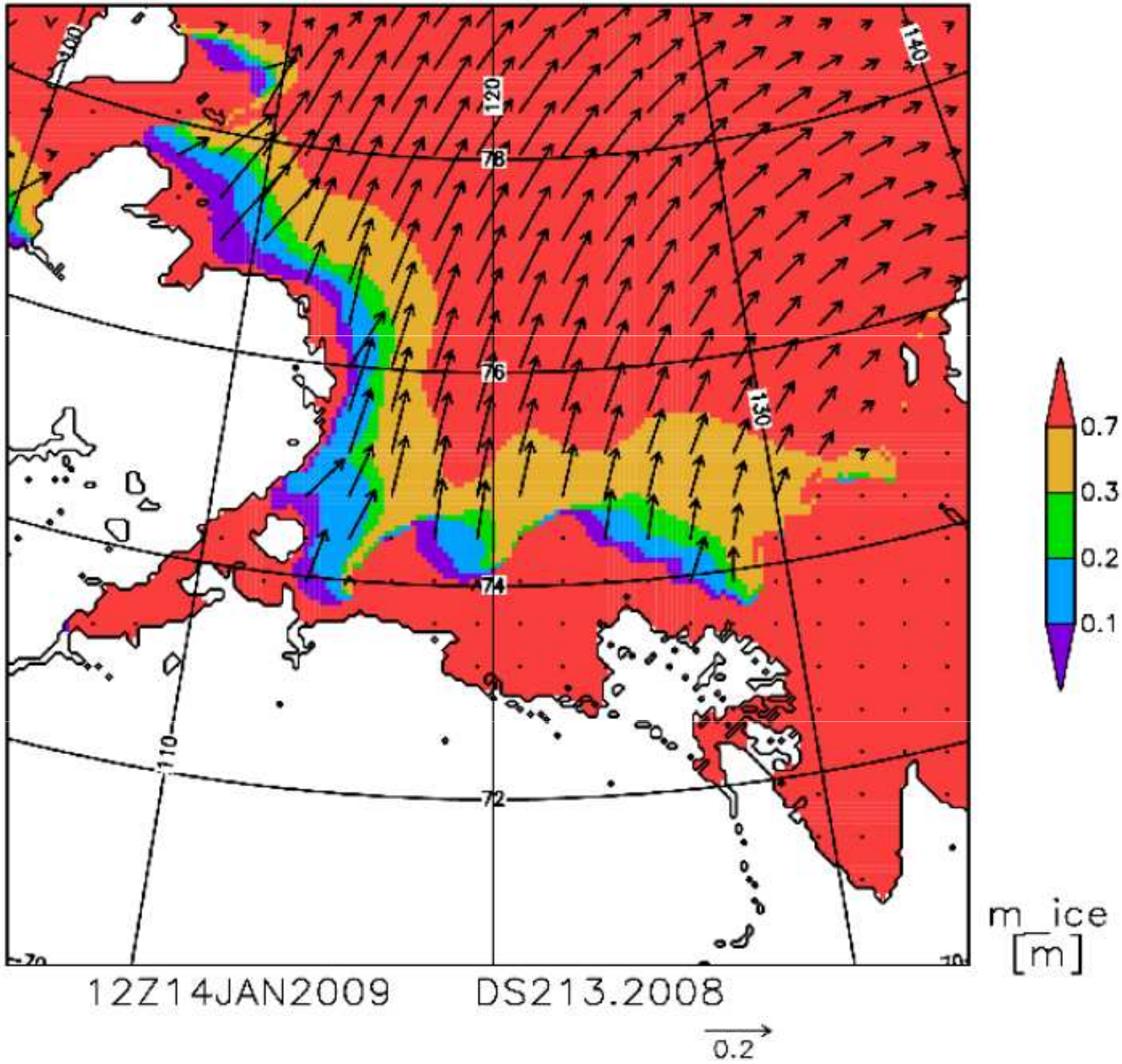
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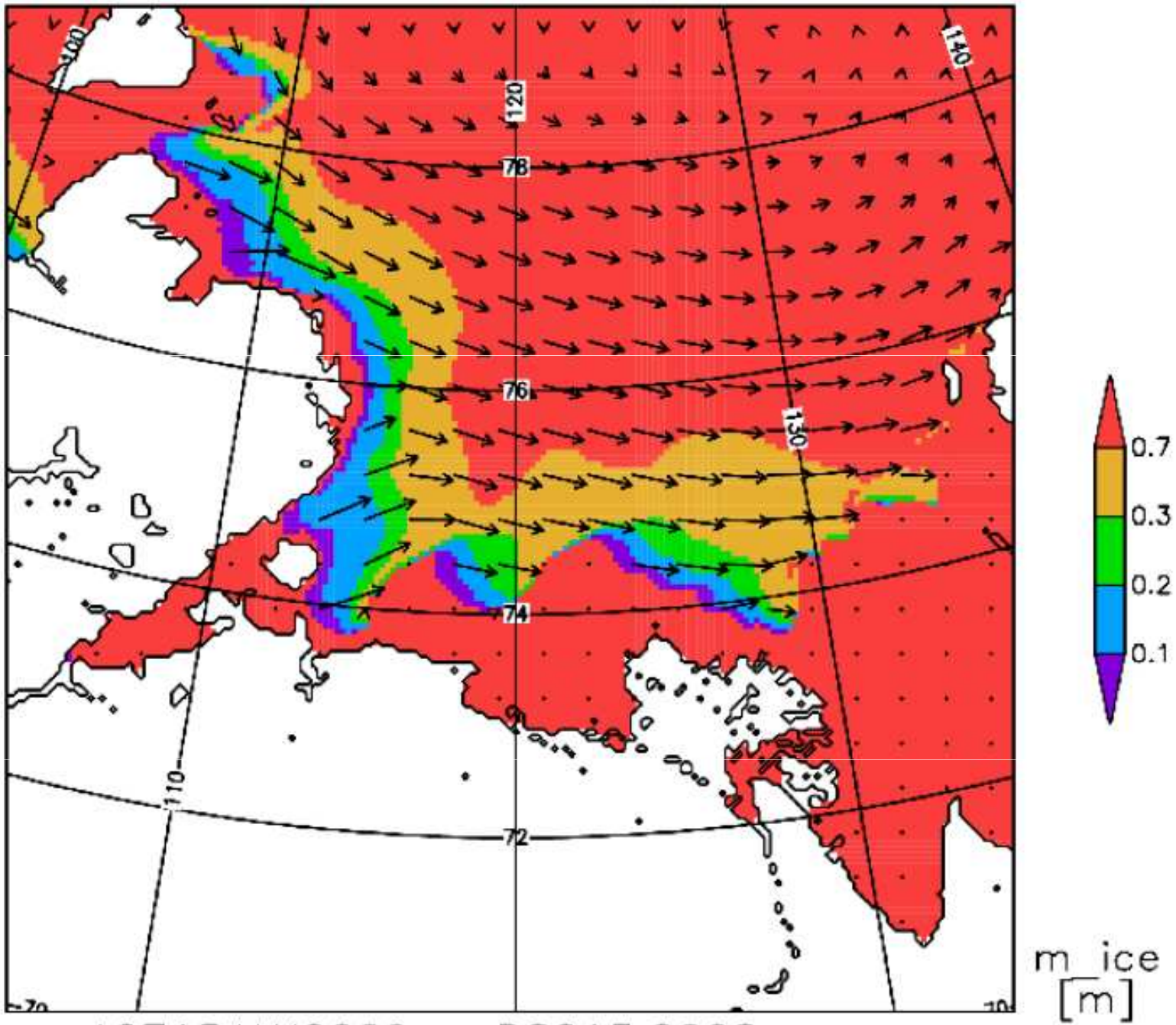
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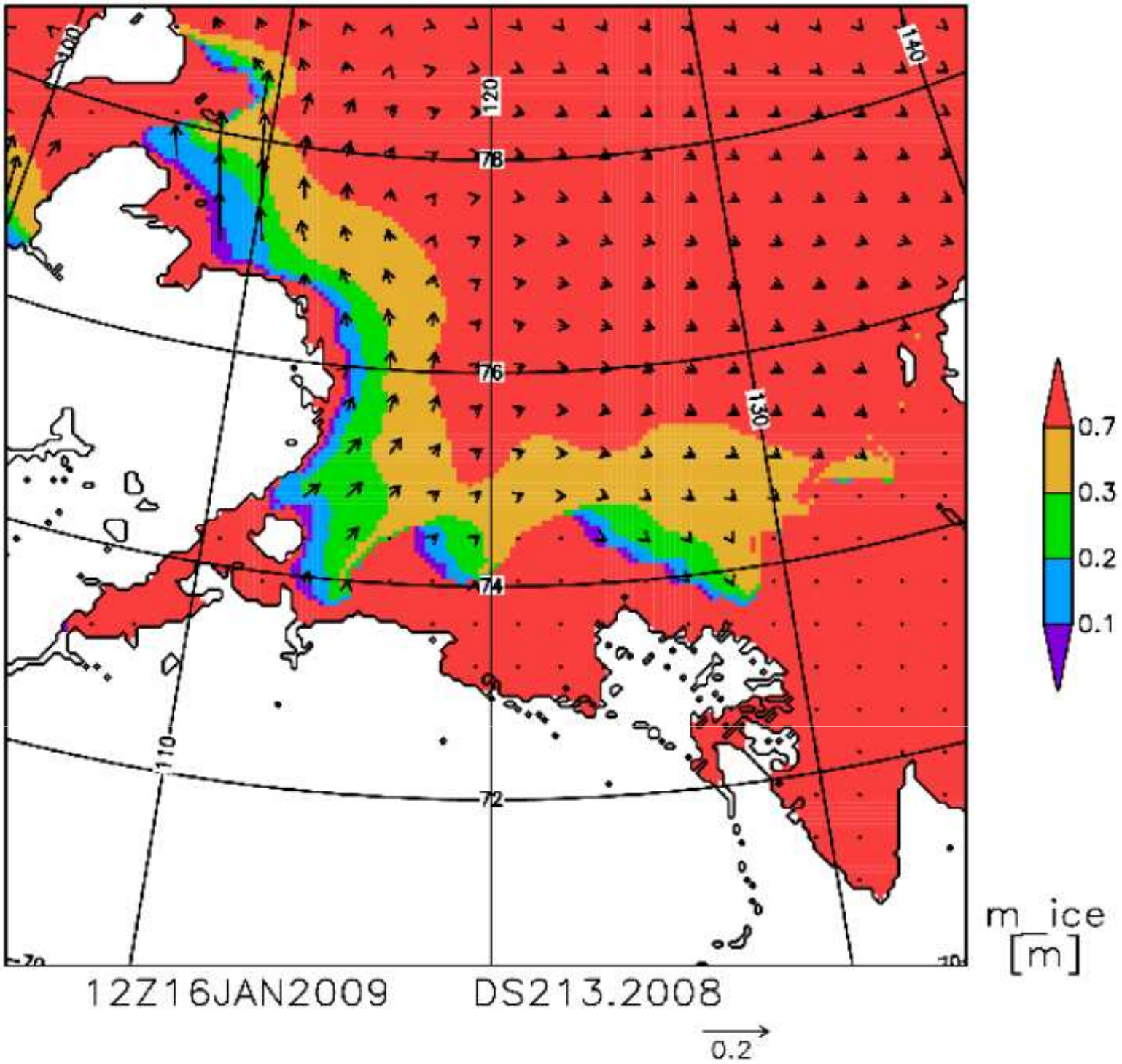
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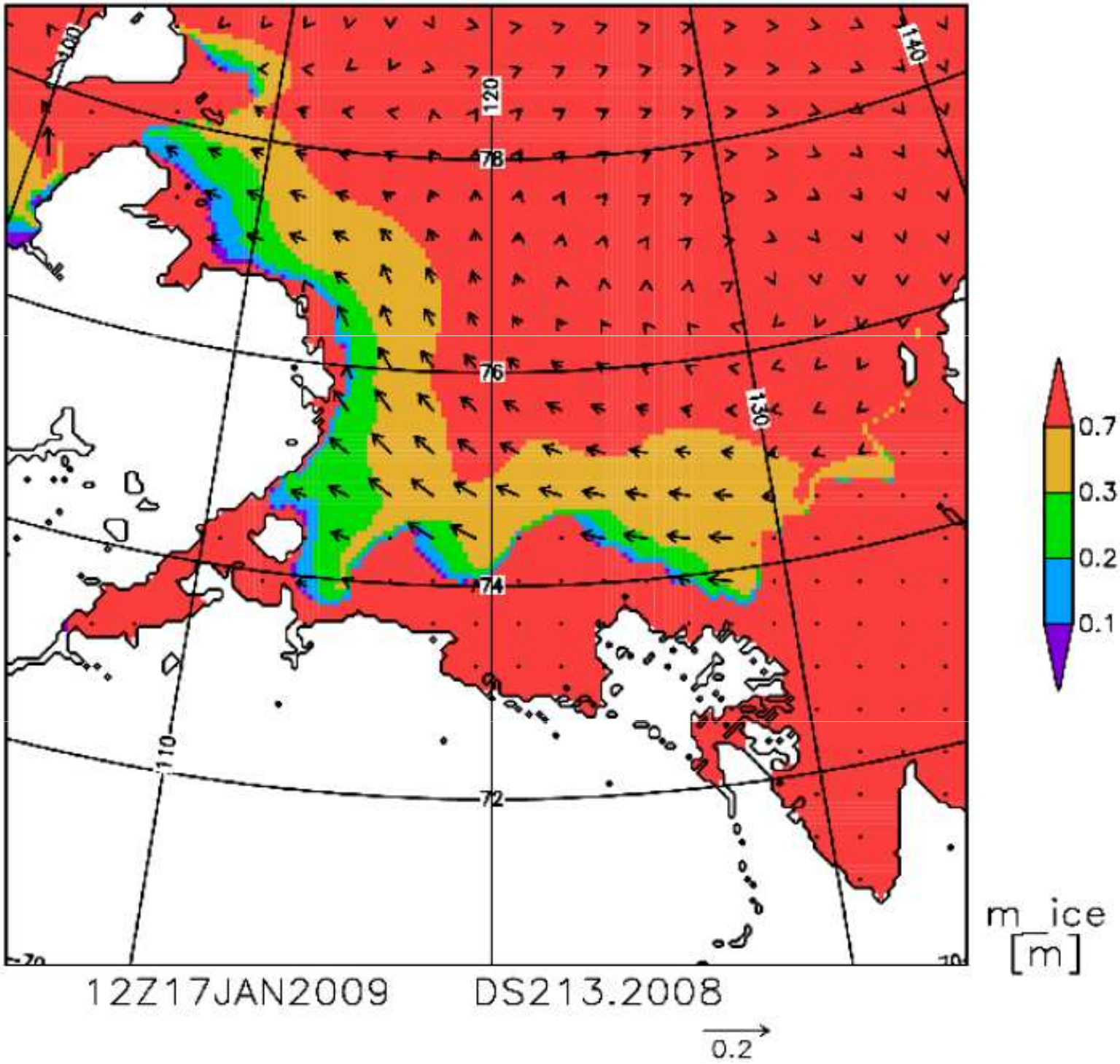
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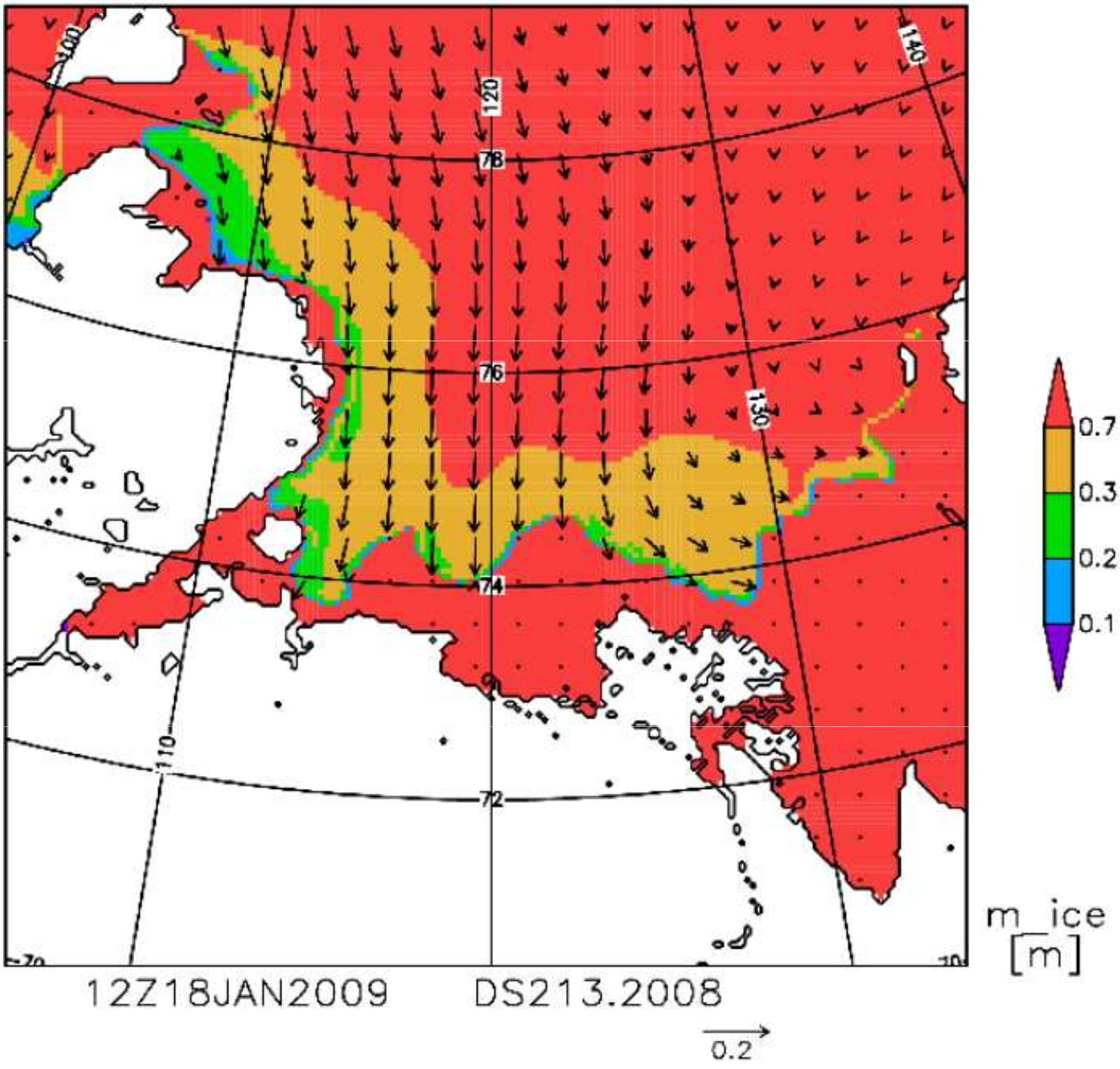
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Net annual ice volume production

Laptev Sea:

NAOSIM, Kohnemann (2010): 780 km^3

Dmitrenko et al. (2009): 1000 ±500 km^3 (1960–1990)

→ 25-30% of annual ice export trough Fram Strait (3000 km^3)

Laptev polynyas:

Dethleff et al. (1998): 258 km^3 (only 1990/91)

satellite-based study Willmes et al. (2011): 55 ±15 km^3

COSMO study: Ice-free 50/123 km^3, 10cm thin ice 30/73 km^3 for 2008/2009

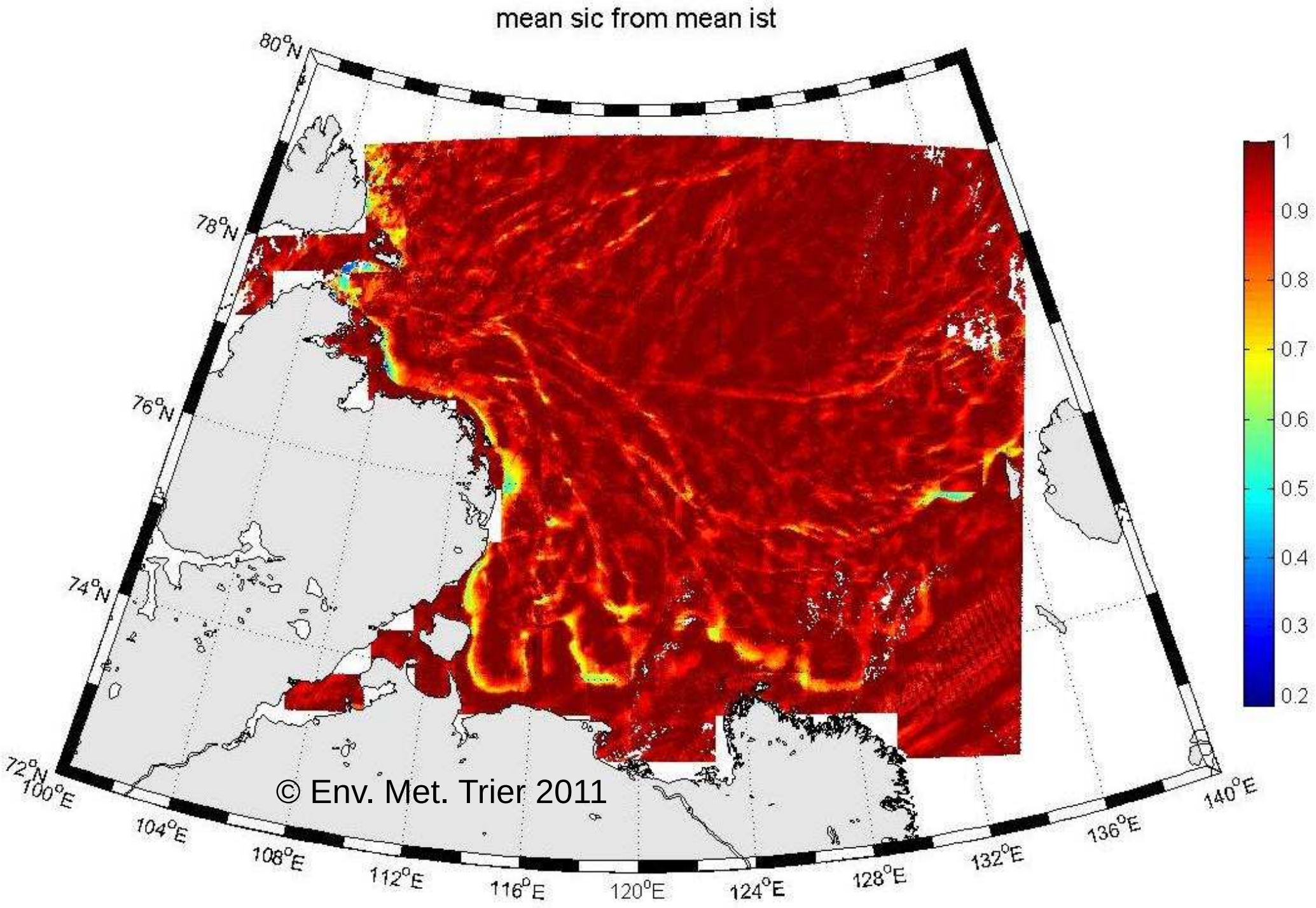
Annual ice area production Laptev Sea

Alexandrov et al. (2000): 480,000 km^2 (1987–1995)

Accumulated daily polynya area per winter

Willmes et al. (2011): 1,100,000 km^2 (1979–2008)

MODIS sea ice concentration 17 March 2011



Conclusions

- polynyas are an important ice factory for the Arctic/Antarctic

- polynya formation is wind-driven and occurs during the whole winter season

- strong surface energy fluxes have a strong impact on the ABL

- high-resolution simulations are needed

-COSMO-FESOM simulations can represent the polynya formation processes realistically

-previous studies seem to overestimate the ice production by the polynyas

In-situ observations at the Laptev polynya