Improving NWP models with observations from the Iceland Greenland Seas Project

Ian Renfrew, Andy Elvidge,

and many others…

University of East Anglia

iceland-greenland seas project

An overview of the Iceland Greenland Seas Project
(I) surface drag over sea ice
(II) sea ice distribution

The Iceland – Greenland seas Project

A coordinated atmosphere-ocean research project, centered on a rare wintertime field campaign to the Iceland and Greenland Seas, seeks to determine the location and causes of dense water formation by cold-air outbreaks

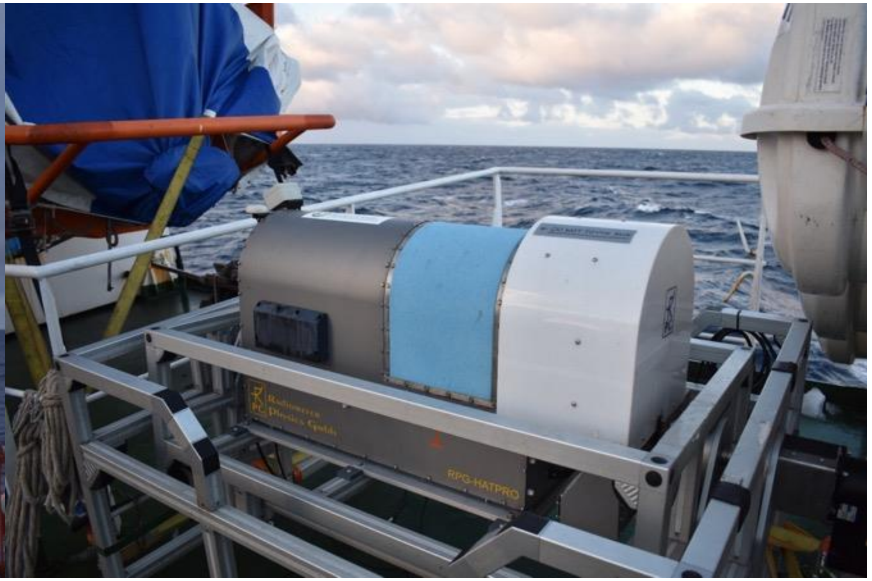
See: Renfrew, Pickart, et al. (2019, BAMS)

R/V *Alliance* winter cruise

- 43 days from Reykjavik, Iceland
- February and March 2018

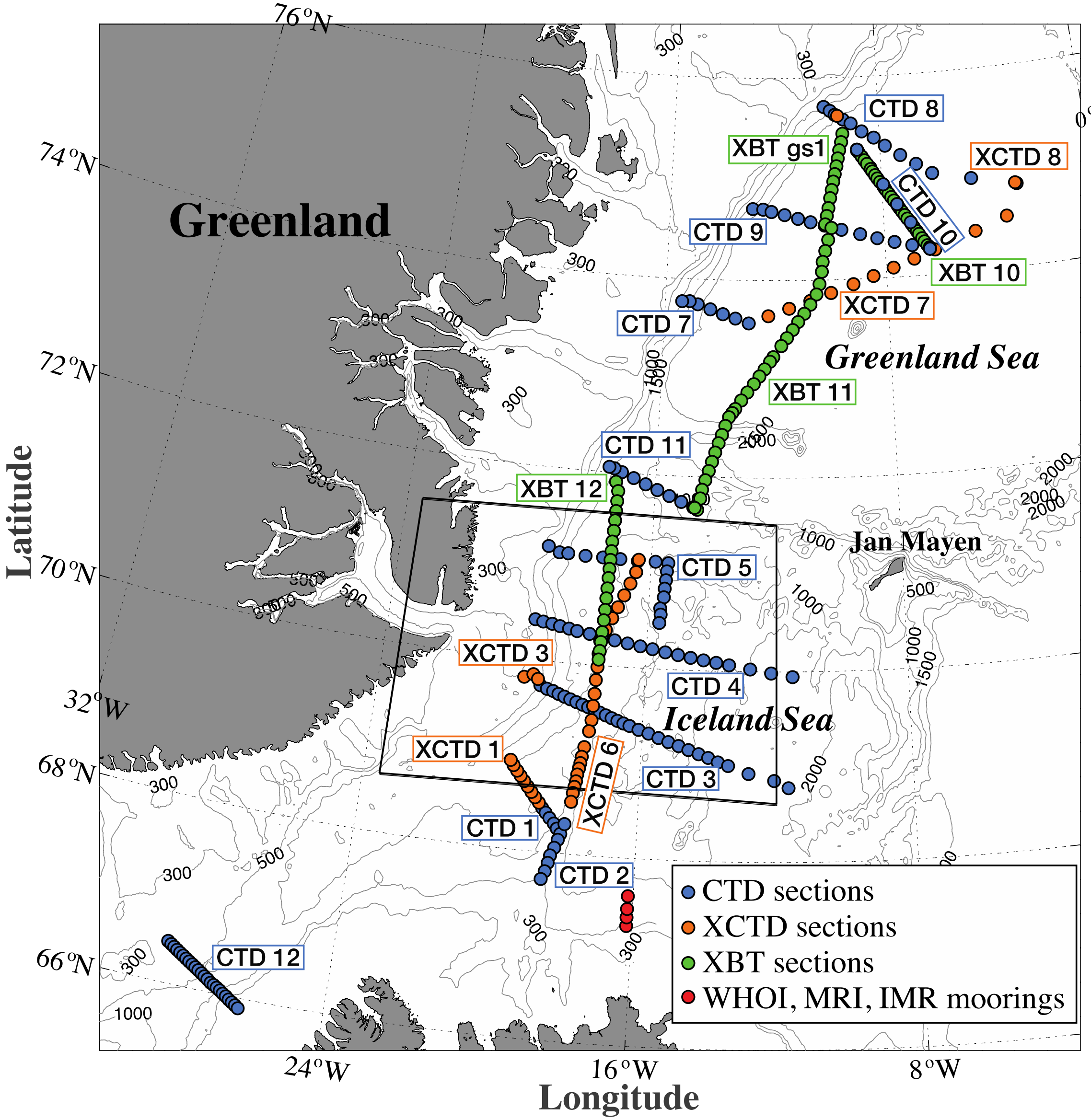
Meteorological instrumentation:

- Basic meteorology
- Radiosondes (100): Daily to 3-hourly
- HatPro radiometer: BL T profiles
- Windcube lidar: BL wind profiles
- Micro rain radar
- Water vapour isotopes (leg II)



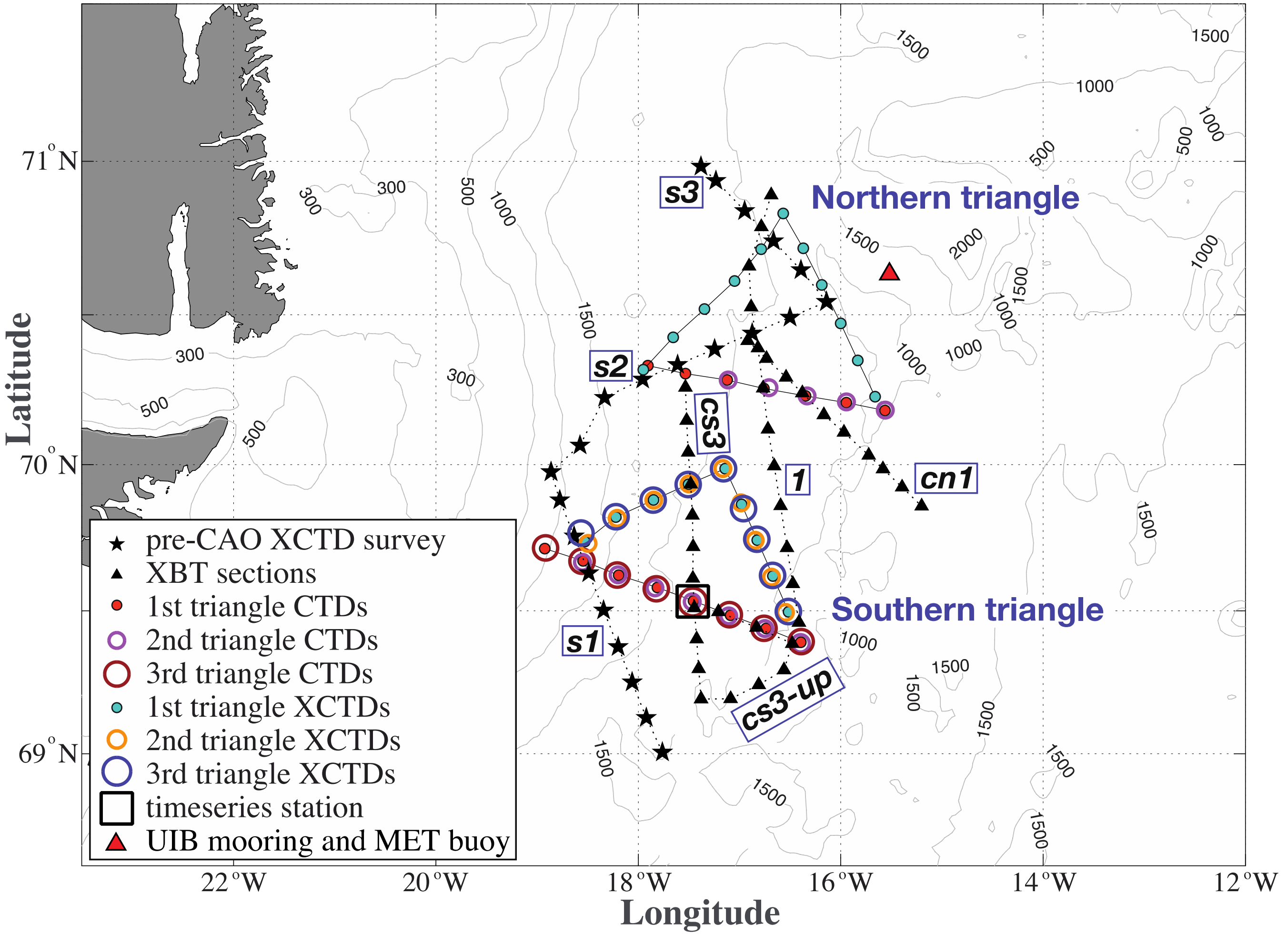
R/V *Alliance* winter cruise

Sections and surveys



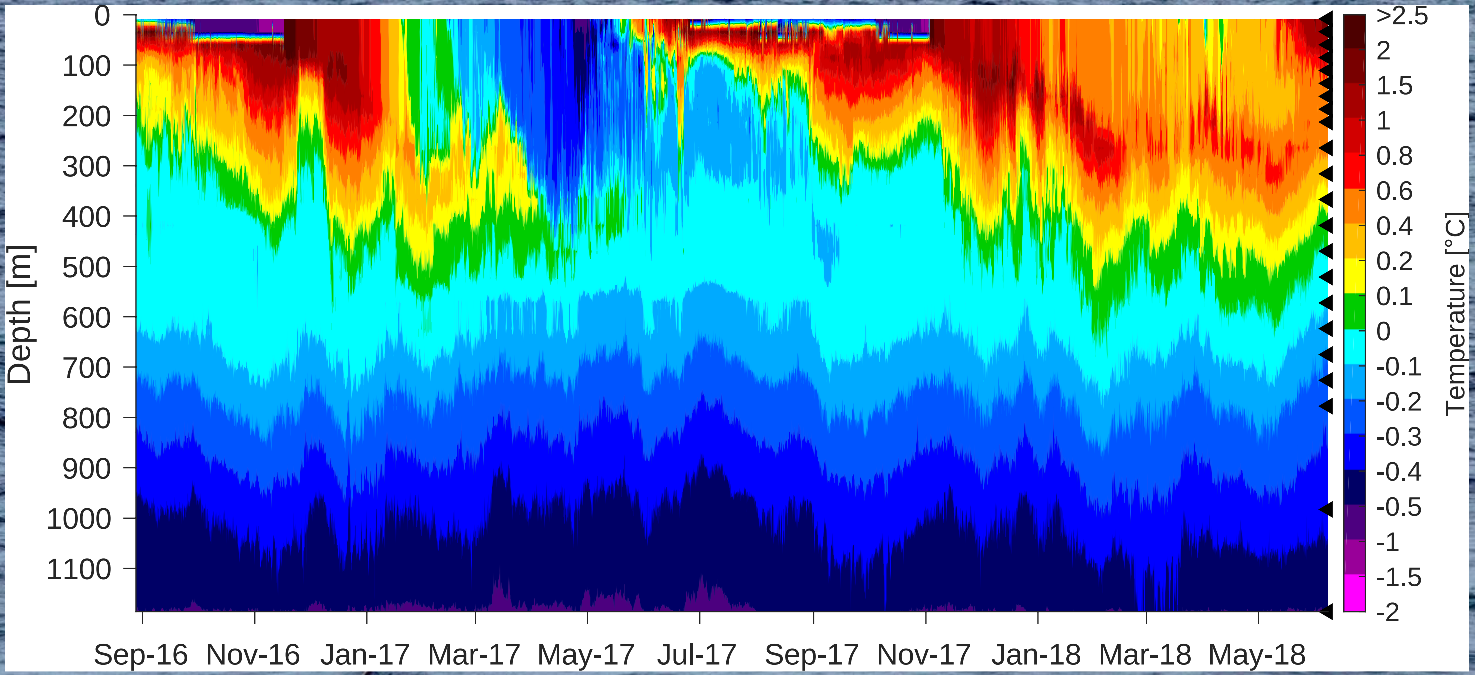
Oceanography instrumentation:

- CTDs, XCTDs & XBTs (total of 453 profiles)
- ADCP & underway CTD
- Argo and RAFOS floats
- Water sampling: salinity, O_2, CFC-12, & SF-6



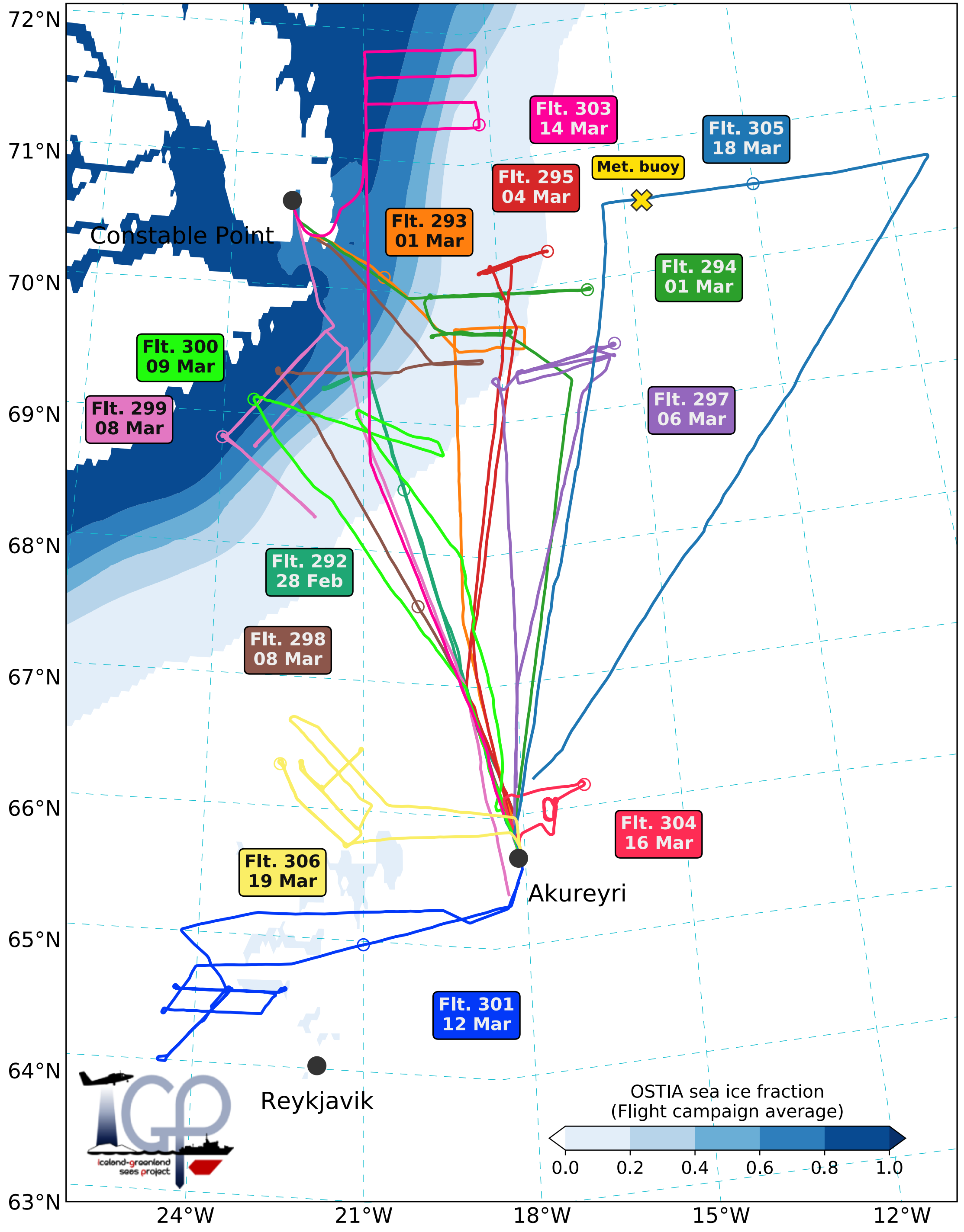
Long-term observations

- Oceanographic mooring (2 years)
- Meteorological buoy (5 months)
- Sea gliders



Aircraft Campaign

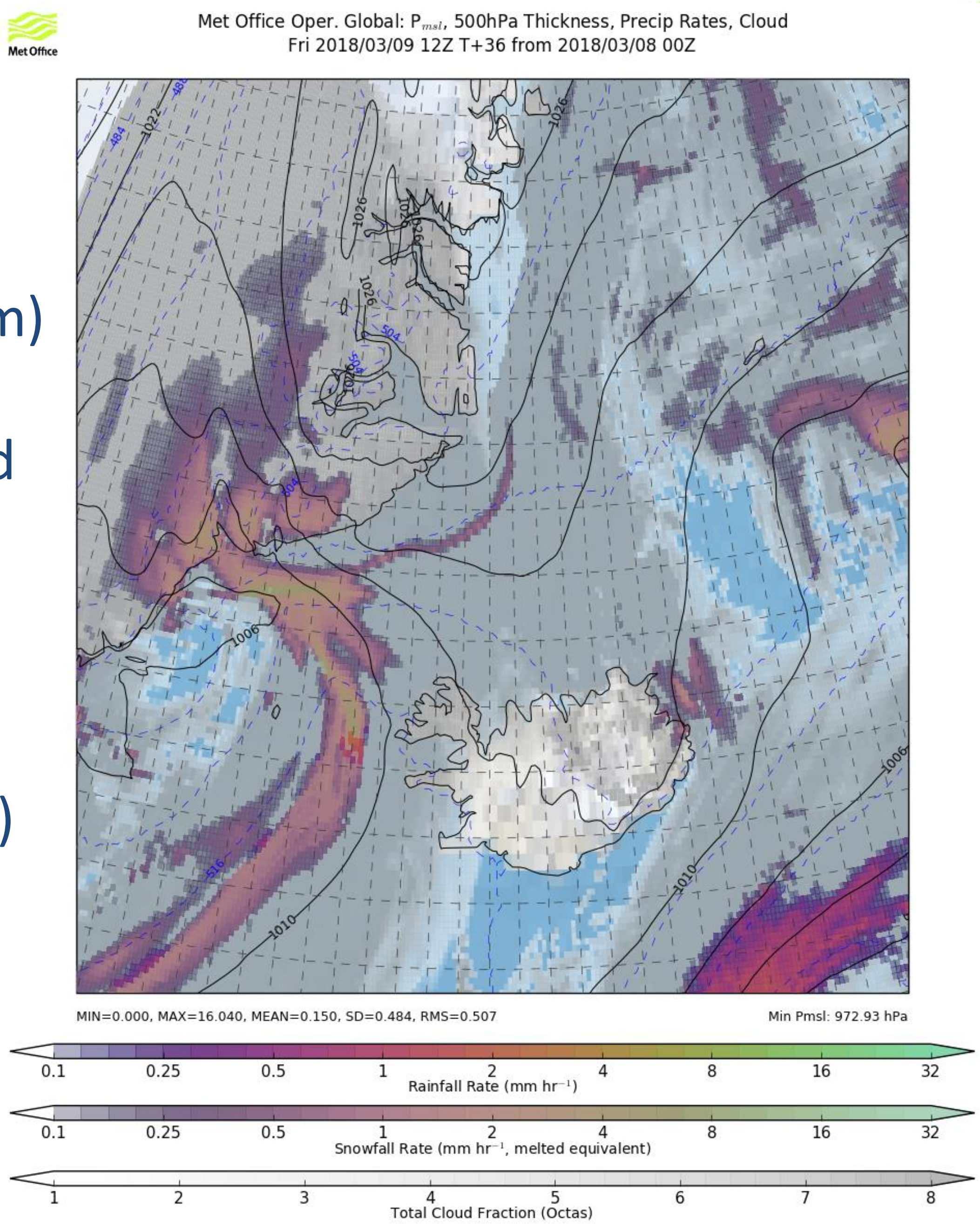
- **BAS Twin Otter**
- 14 science flights
  - 11 Cold Air Outbreaks
    - 7 over/adjacent sea ice
  - 2 orographic flows
- 70 h flying
  - 500 mins at 20-40 m.

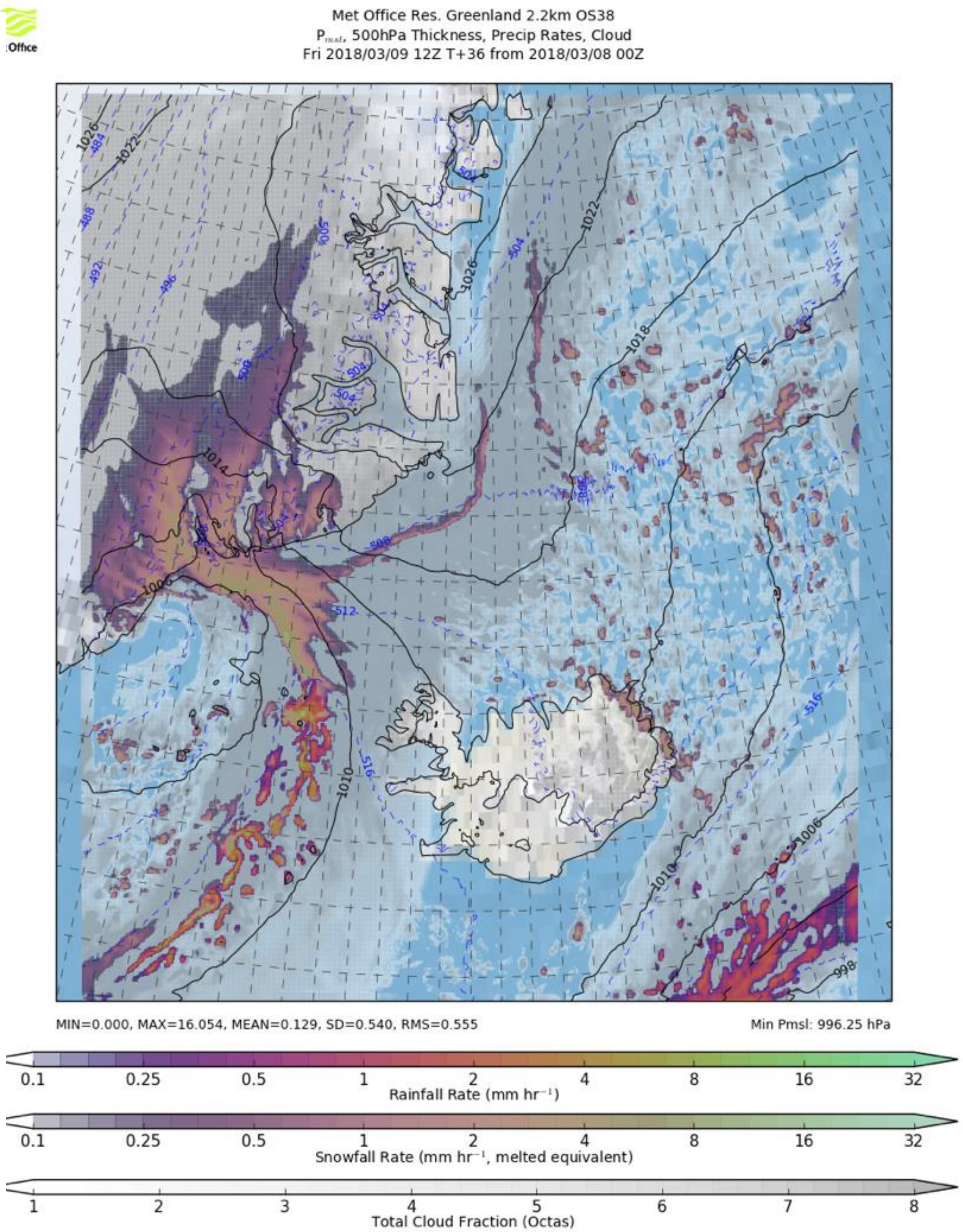


Forecasting tools

Met Office

- Global operational forecast (10 km)
- Global coupled forecast
- Convection-permitting forecast (2 km)





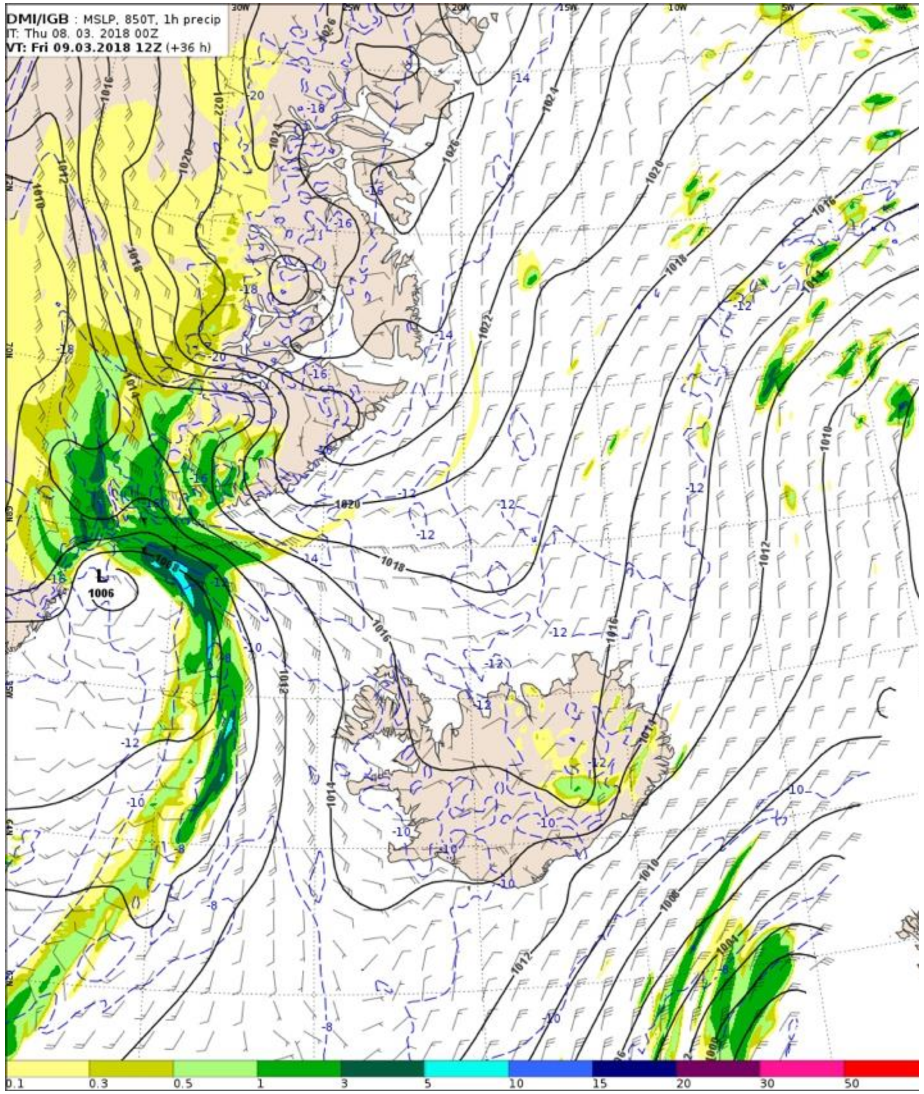
Forecasting tools

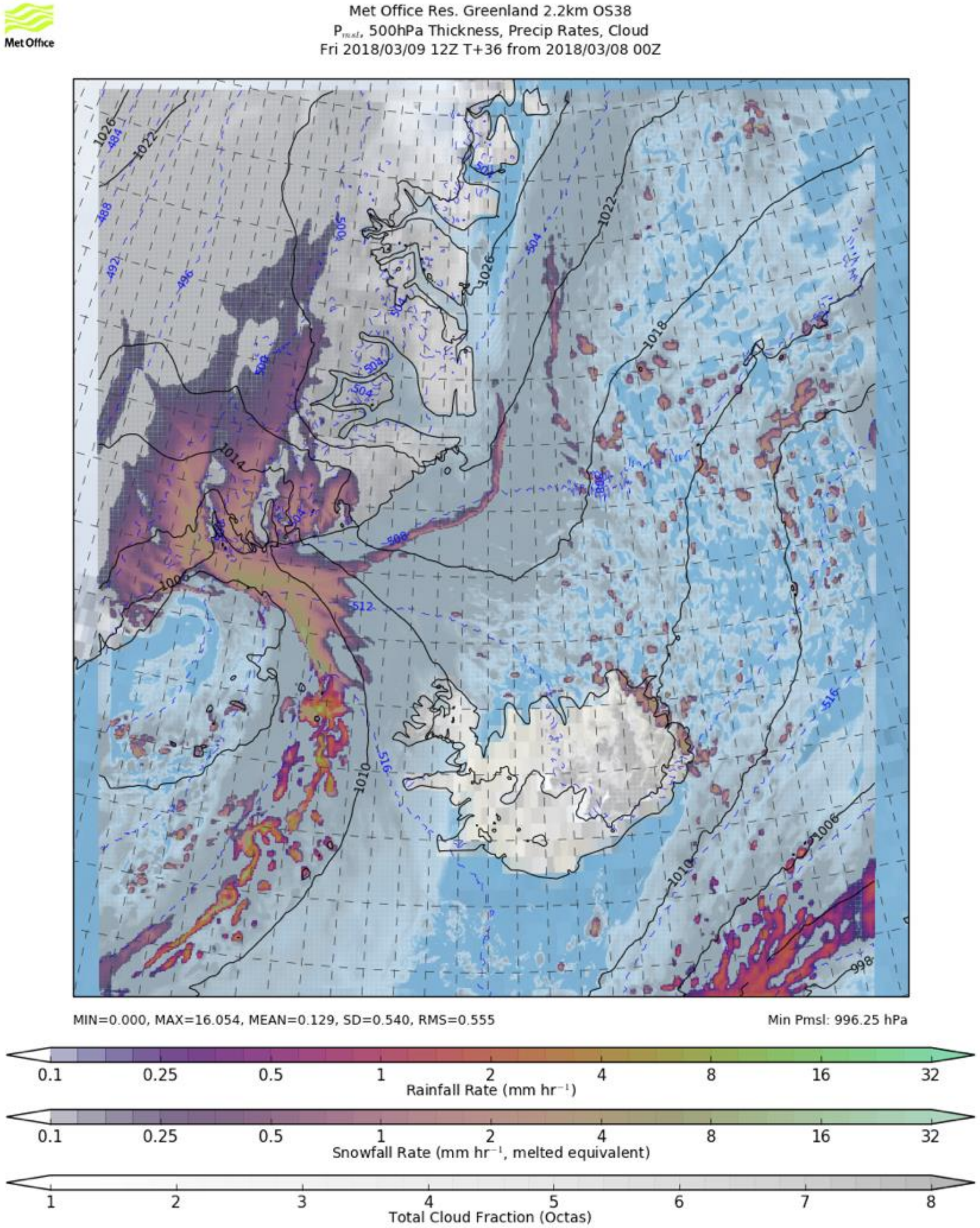
Met Office

- Global operational forecast (10 km)
- Global coupled forecast
- Convection-permitting forecast (2 km)

DMI/IMO

- Limited domain (2.5 km)

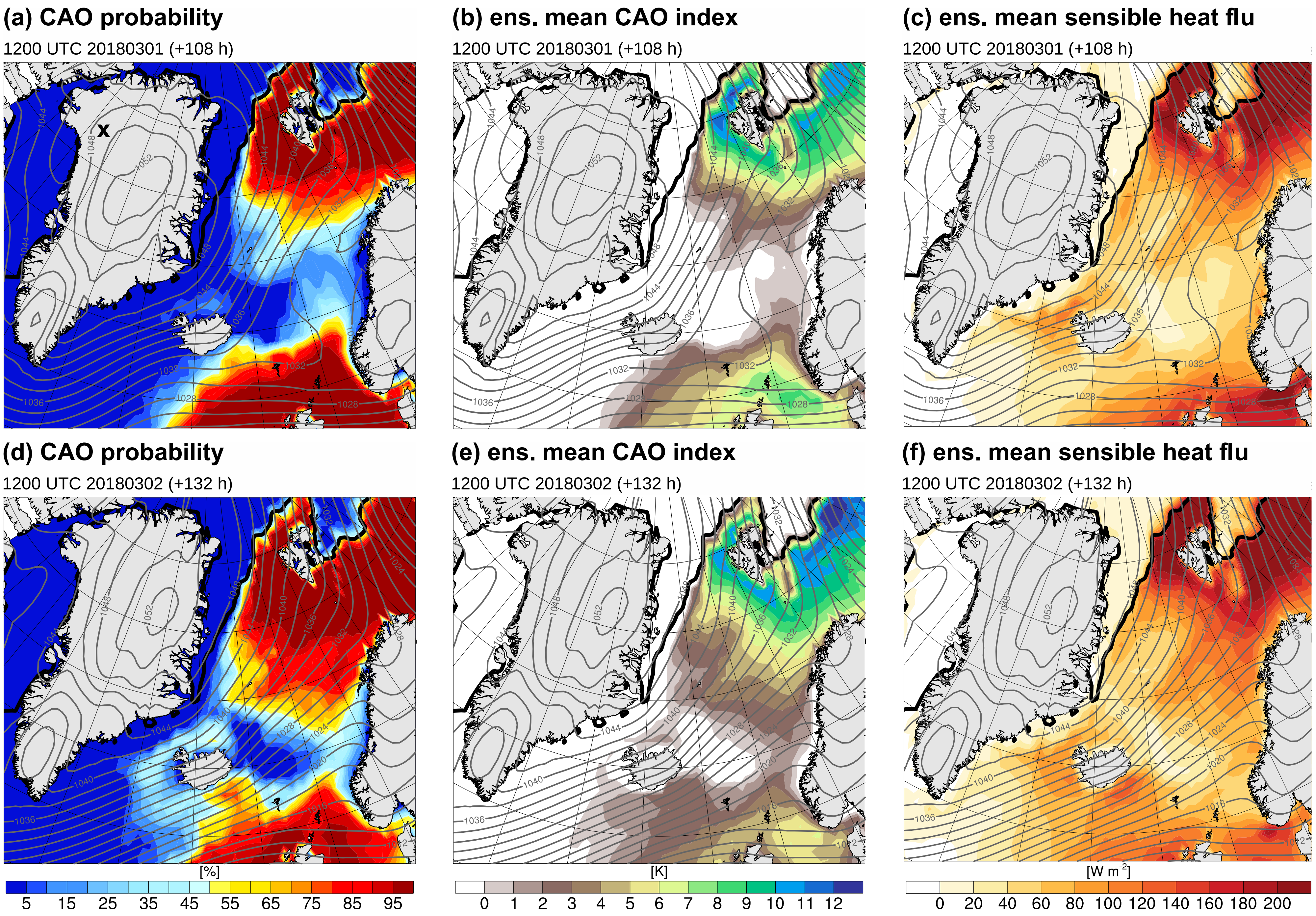




Forecasting tools

Ensemble Prediction System diagnostics based on ECMWF EPS

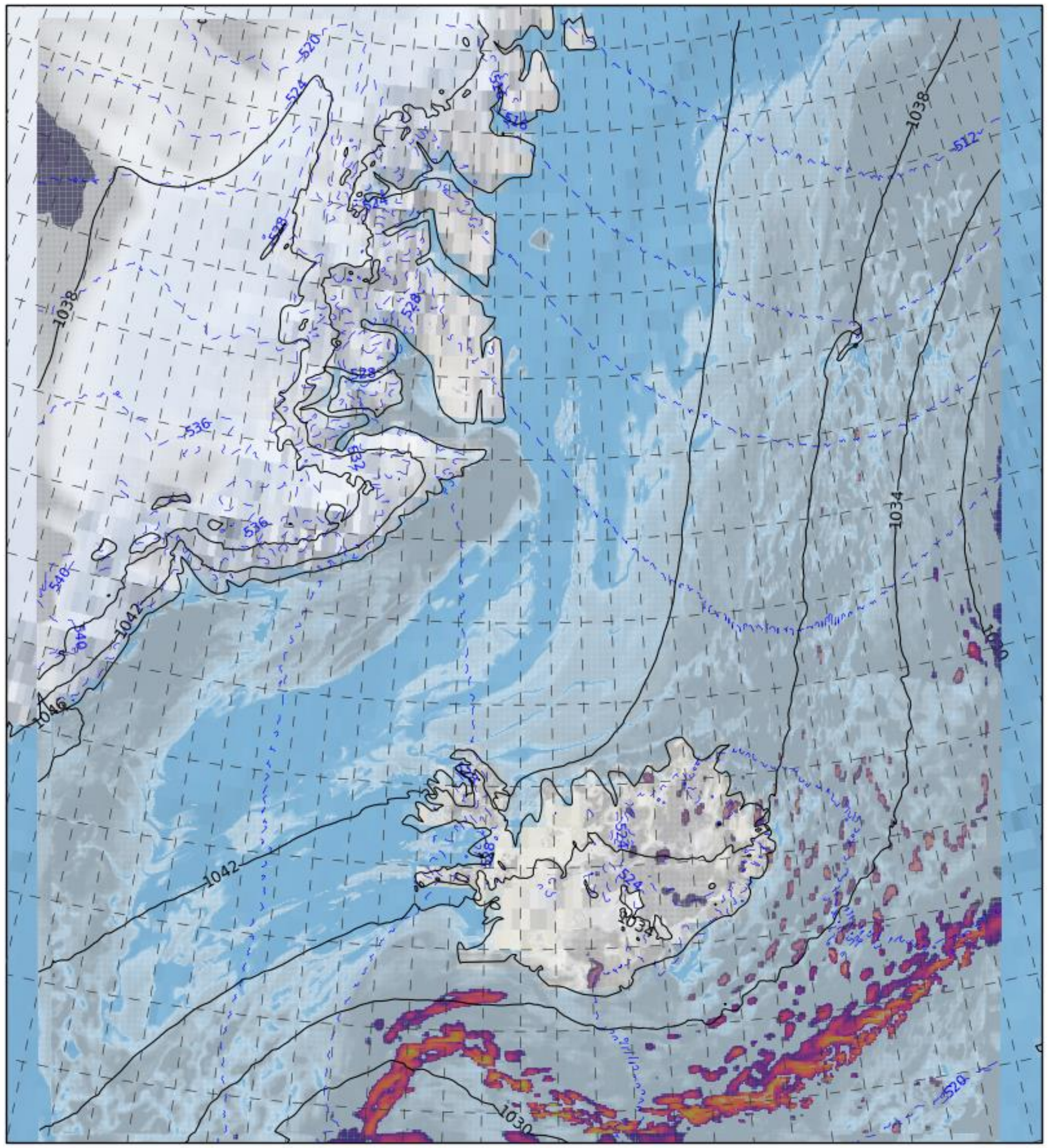
- CAO probability of occurrence
- CAO index:
  $\boldsymbol{\theta}_{SST} - \boldsymbol{\theta}_{850}$
- Surface sensible heat flux
- Plots: Lukas Papritz (ETH)



Case study: Development of a Cold Air Outbreak

- 28 February to 2 March 2018
- A cold-air outbreak develops
- Captured via
  - co-ordinated sampling of atmosphere and ocean
  - several research flights
  - 3 hourly radiosondes from the R/V Alliance
  - Repeated CTD/XCTD surveys

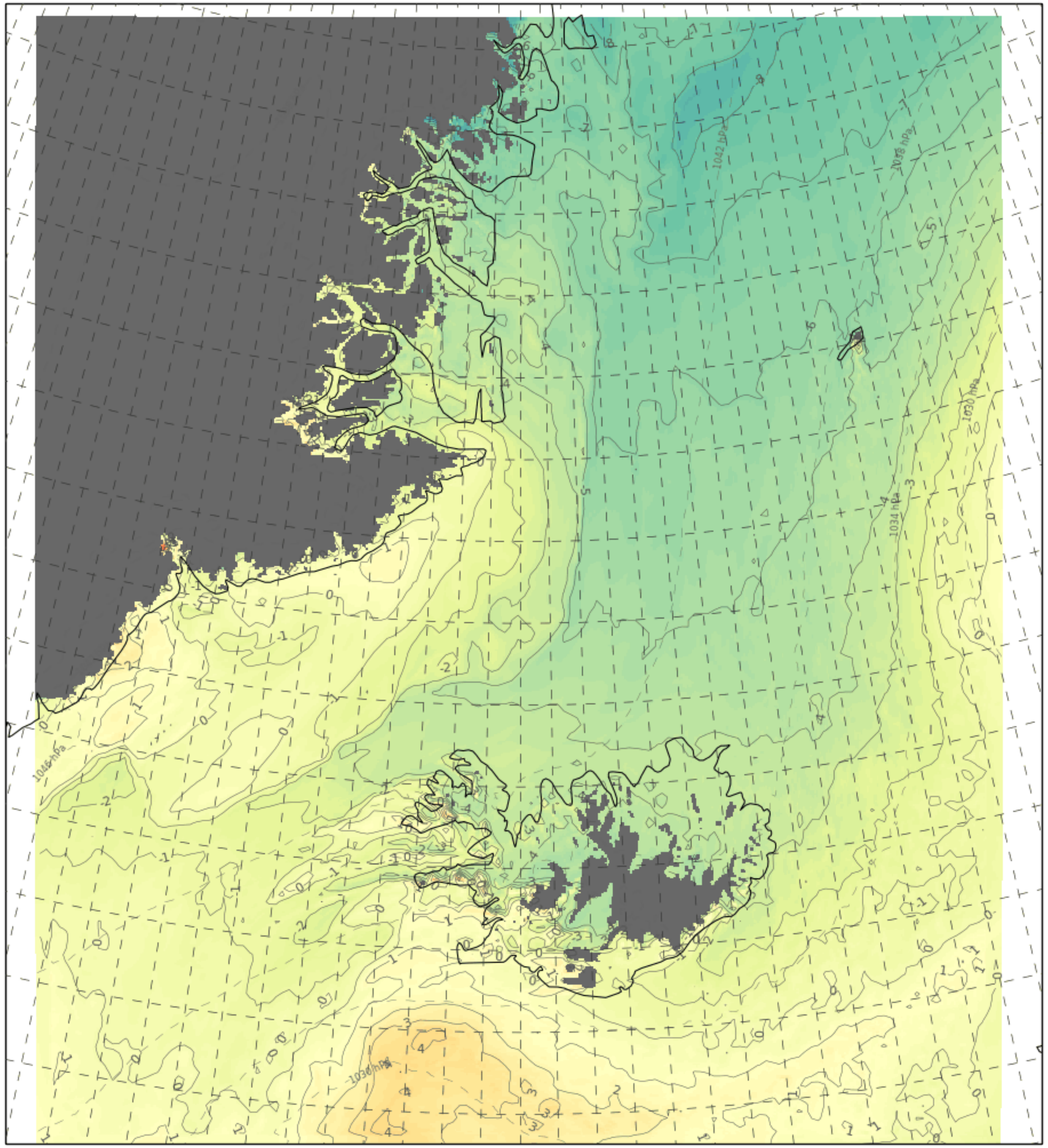
Met Office Res. Greenland 2.2km OS38
P_{msl}, 500hPa Thickness, Precip Rates, Cloud
Thu 2018/03/01 12Z T+36 from 2018/02/28 00Z



MIN=0.000, MAX=9.366, MEAN=0.031, SD=0.245, RMS=0.247 Min Pmsl: 1025.89 hPa

0.1 0.25 0.5 1 2 4 8 16 32
Rainfall Rate (mm hr^{-1})

Met Office Res. Greenland 2.2km OS38
Potential Temperature (°C) at 950 hPa
Thu 2018/03/01 12Z T+36 from 2018/02/28 00Z

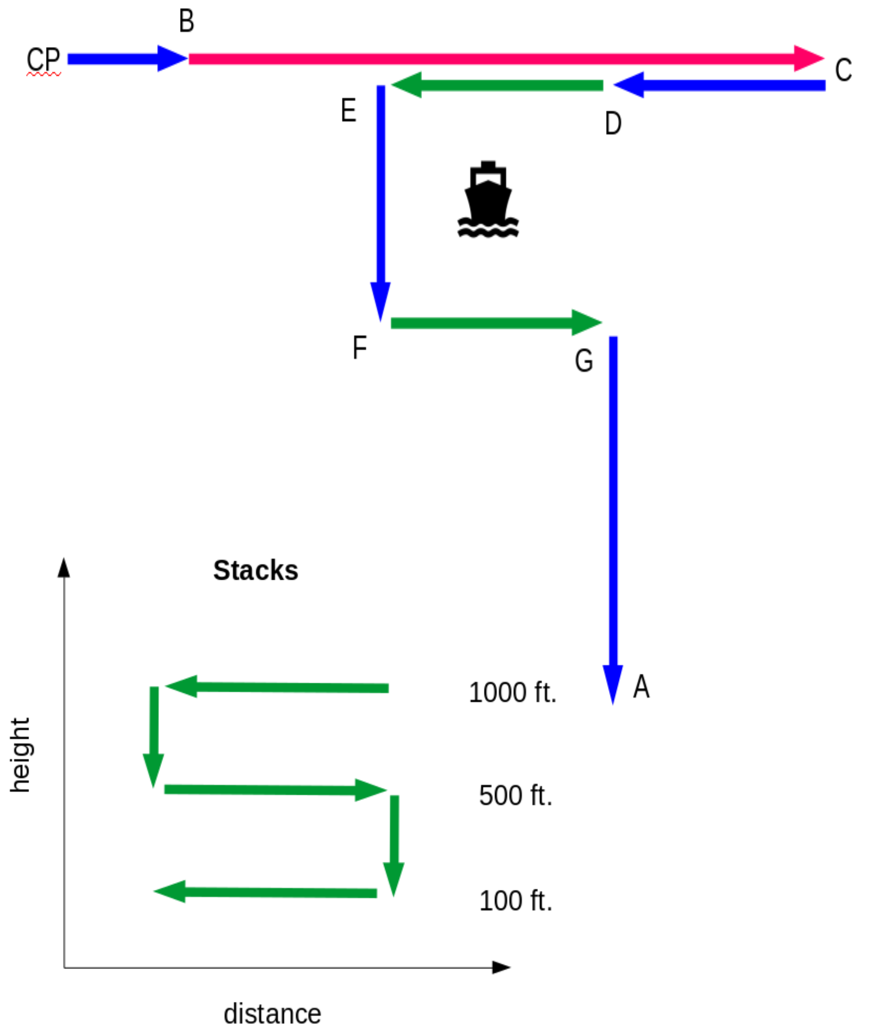


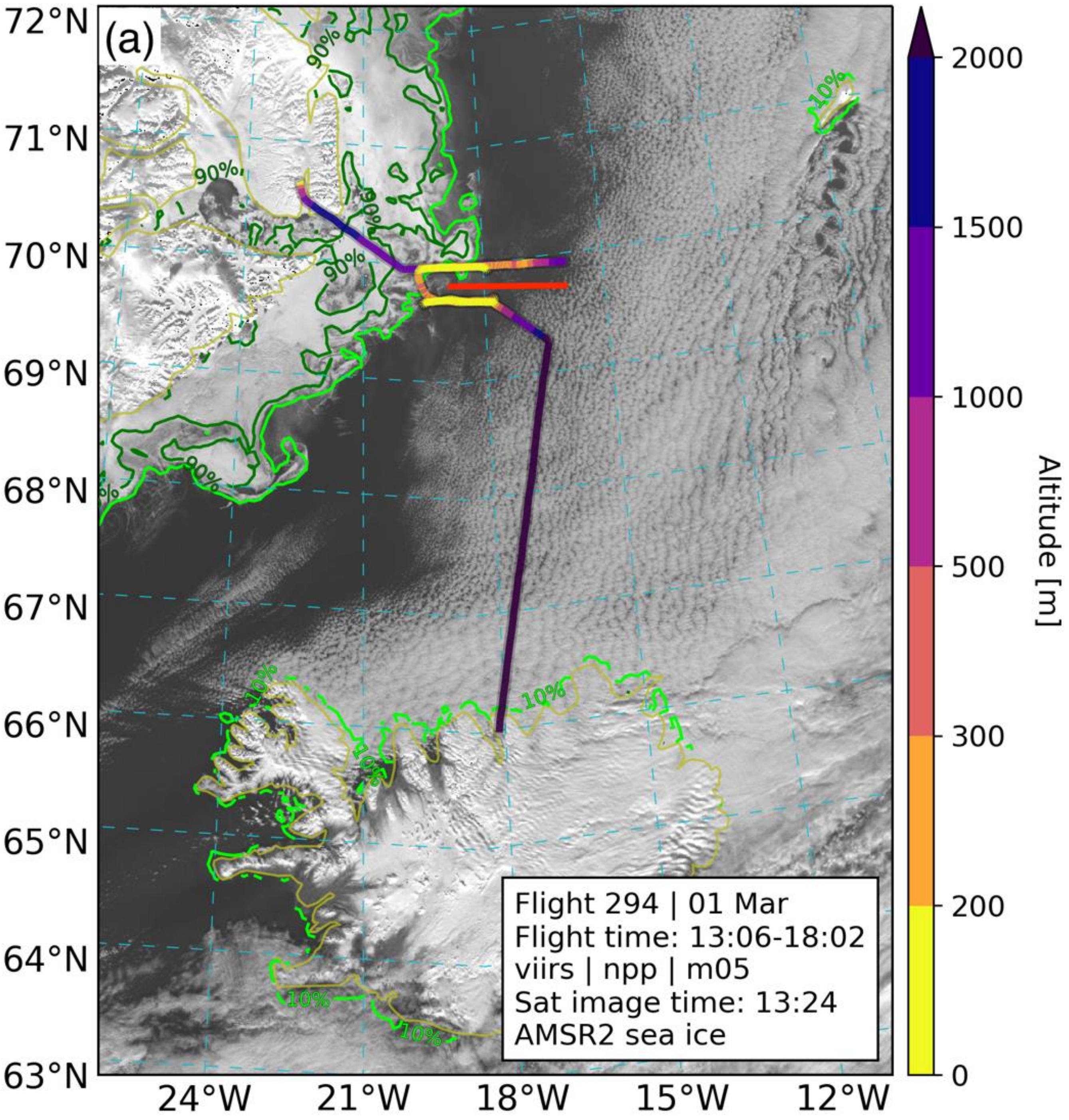
MIN=-12.357, MAX=9.460, MEAN=-2.603, SD=2.864, RMS=3.870

-14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16
Temperature (°C)

1 March 2018
Flight 294

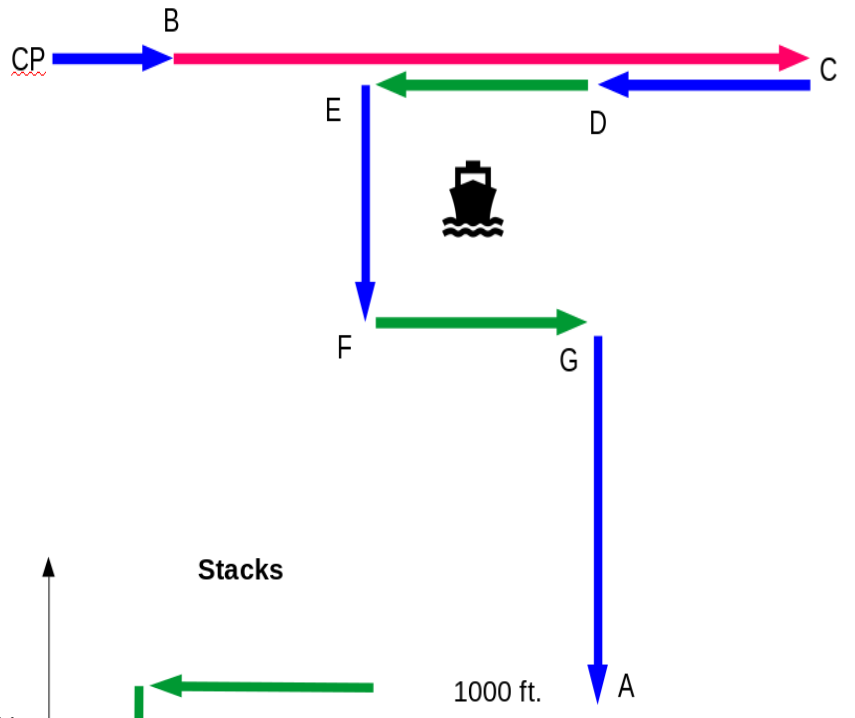
- Map CAO airmass upstream & downstream of ship

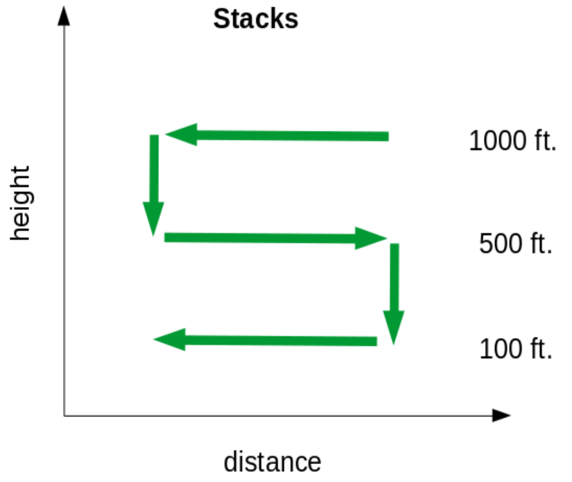


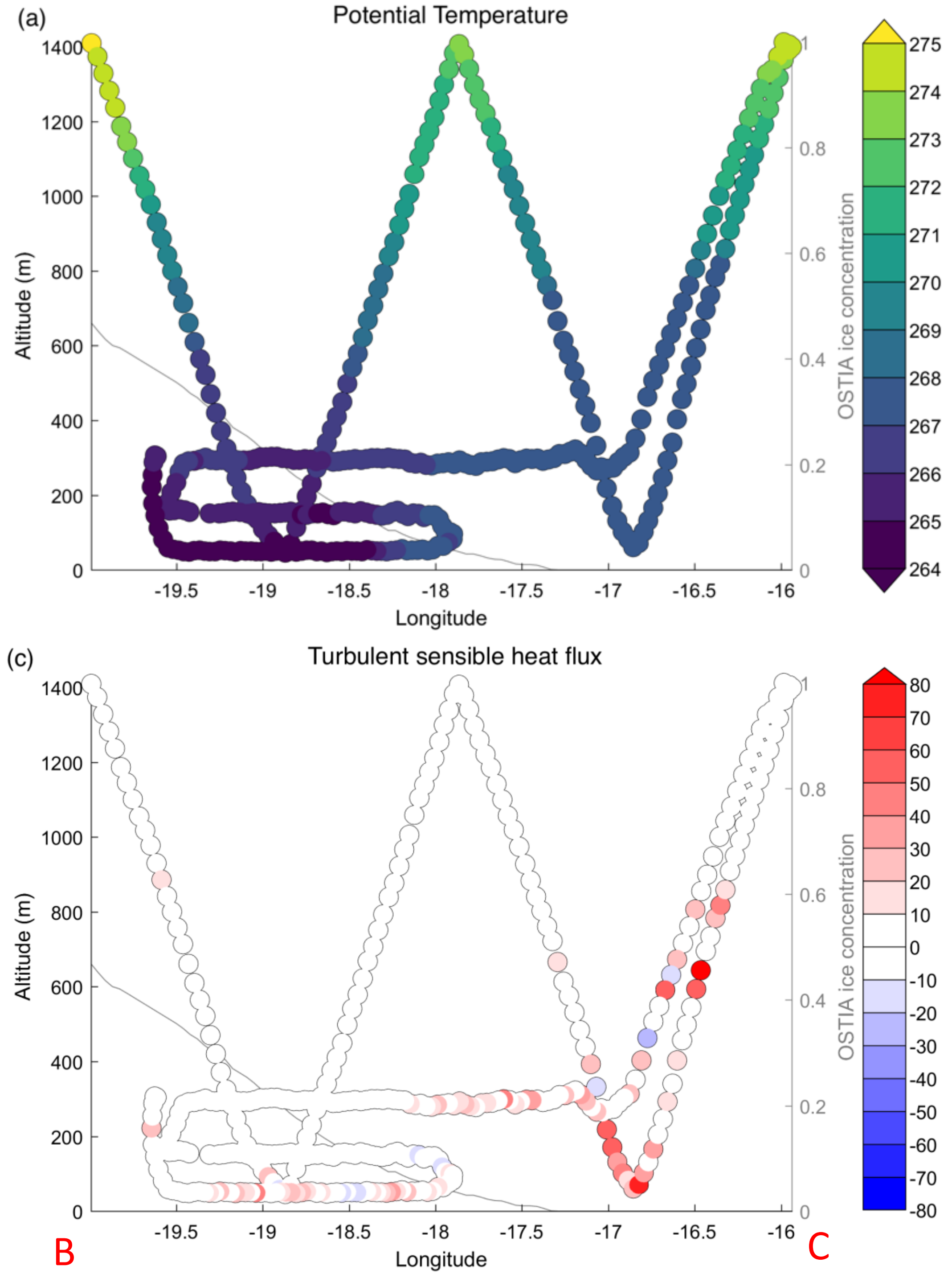


1 March 2018
Flight 294

- Map CAO airmass upstream & downstream of ship

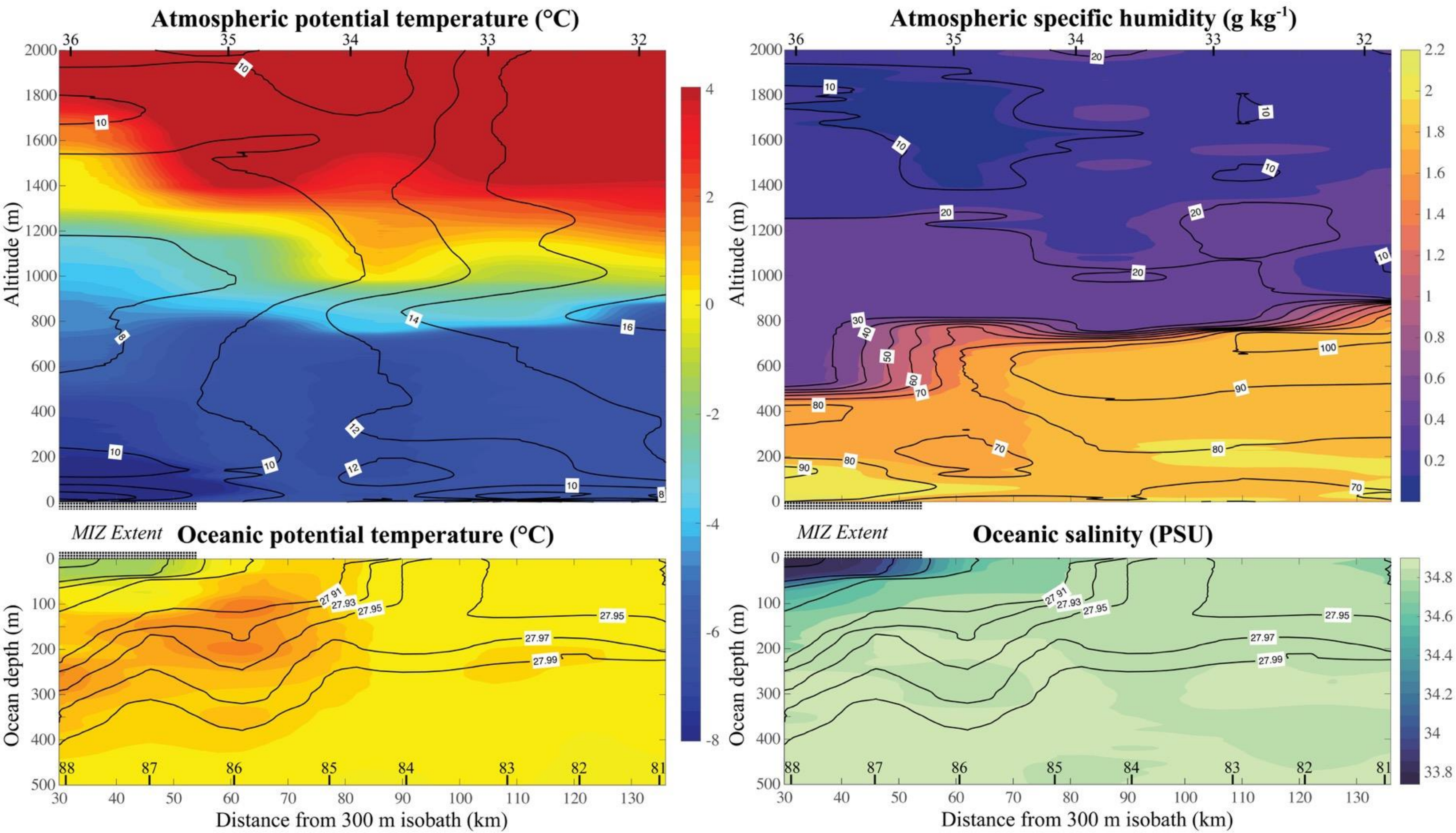






Potential temperature

Sensible heat flux



Atmospheric potential temperature (°C)
Atmospheric specific humidity (g kg-1)
Altitude (m)
MIZ Extent
Oceanic potential temperature (°C)
Oceanic salinity (PSU)
Ocean depth (m)
Distance from 300 m isobath (km)

An overview of the Iceland Greenland Seas Project
(I) surface drag over sea ice
(II) sea ice distribution

Representing surface drag over sea ice

Parameterize 10-metre neutral drag coefficient, C_{dn10}, and account for surface type (skin drag) and surface roughness (form drag).

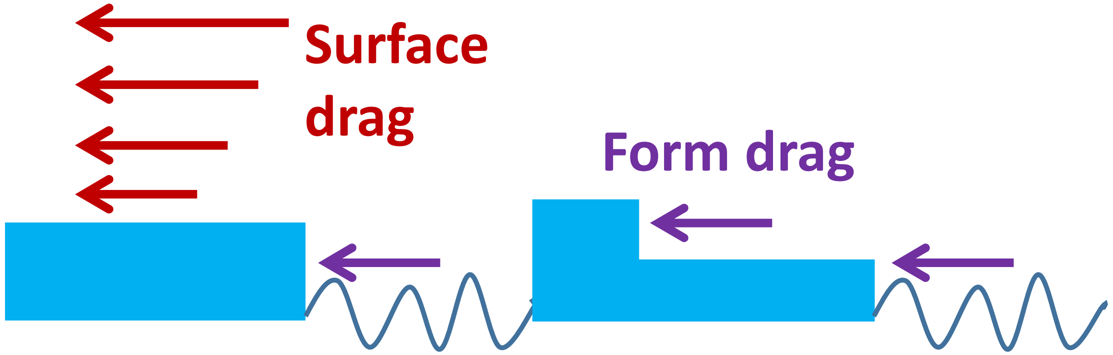
$$C_{dn10} = (1-A)C_{dw} + A\,C_{di} + C_{df}$$

↓ Skin drag over water

↓ Skin drag over ice

C_{df} can be parameterized as a function of Ice fraction

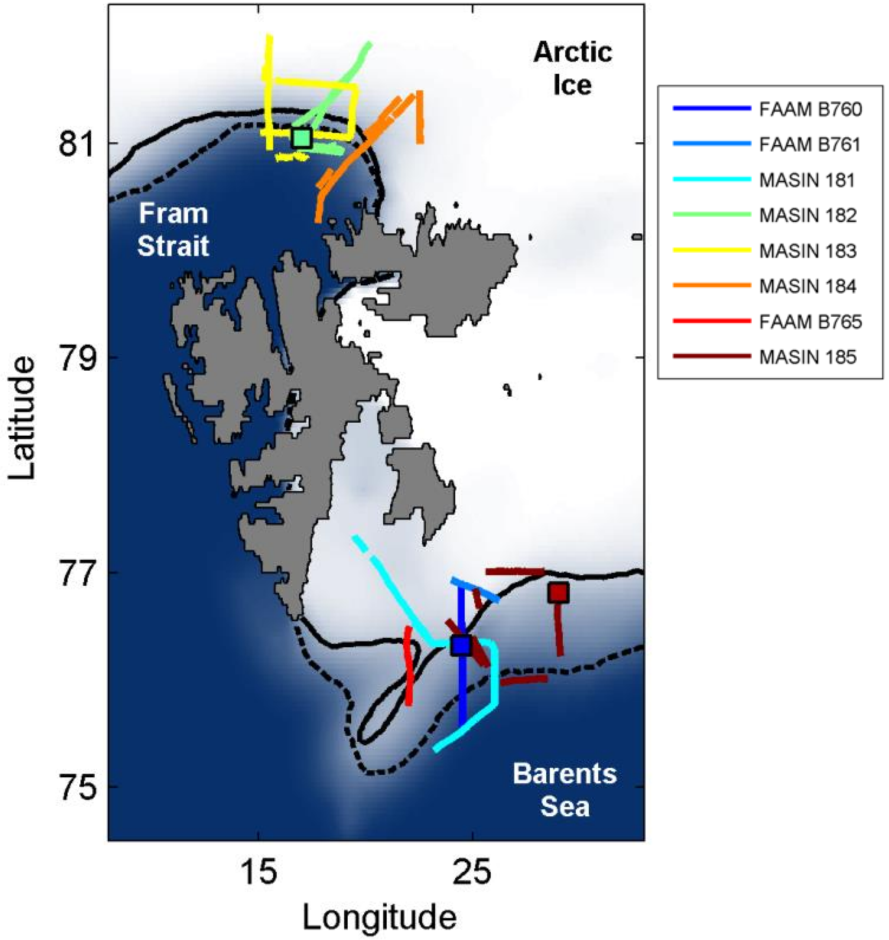
(The simplest conceptual model)



Lüpkes, et al. (2012), J. Geophys. Res., doi:10.1029/2012JD017630.

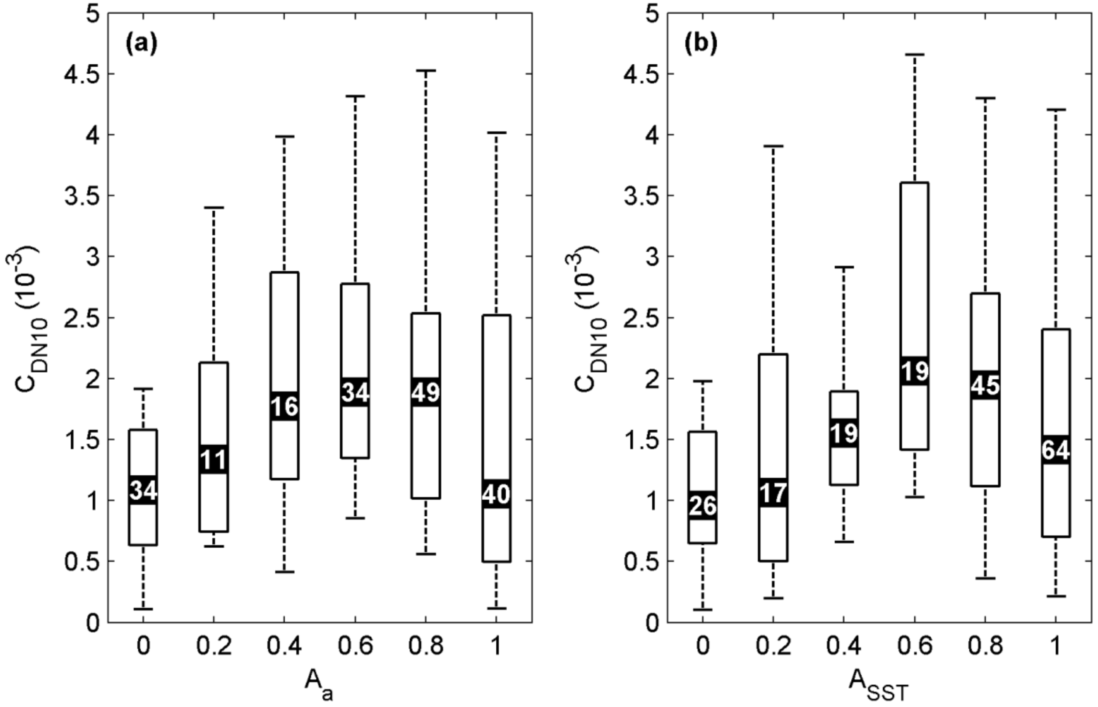
Representing surface exchange over sea ice

ACCACIA Field campaign – March and April 2013



Elvidge, Renfrew, Weiss, Brooks, Lachlan-Cope and King 2016: Observations of surface momentum exchange over the marginal-ice-zone and recommendations for its parameterization, *Atmospheric Chemistry and Physics,* **16**, 1545-1563.

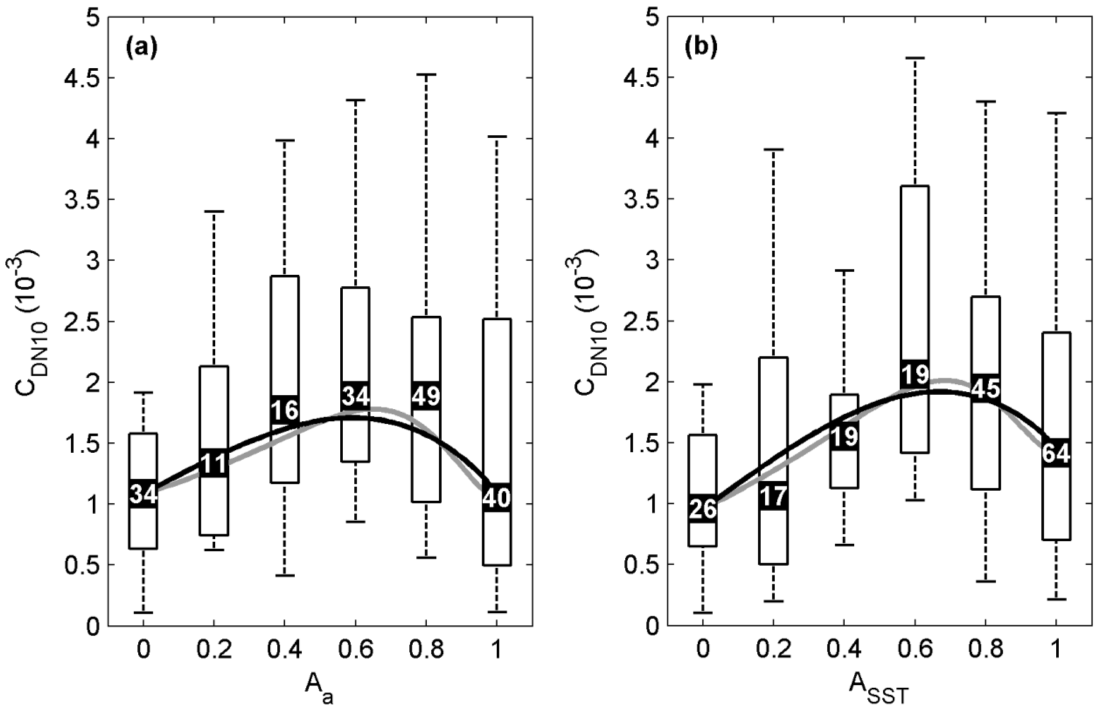
Drag Coefficient versus Ice Concentration



- 195 data points
- Doubles previously available data

Elvidge, Renfrew, Weiss, Brooks, Lachlan-Cope and King 2016: Observations of surface momentum exchange over the marginal-ice-zone and recommendations for its parameterization, *Atmospheric Chemistry and Physics,* **16**, 1545-1563.

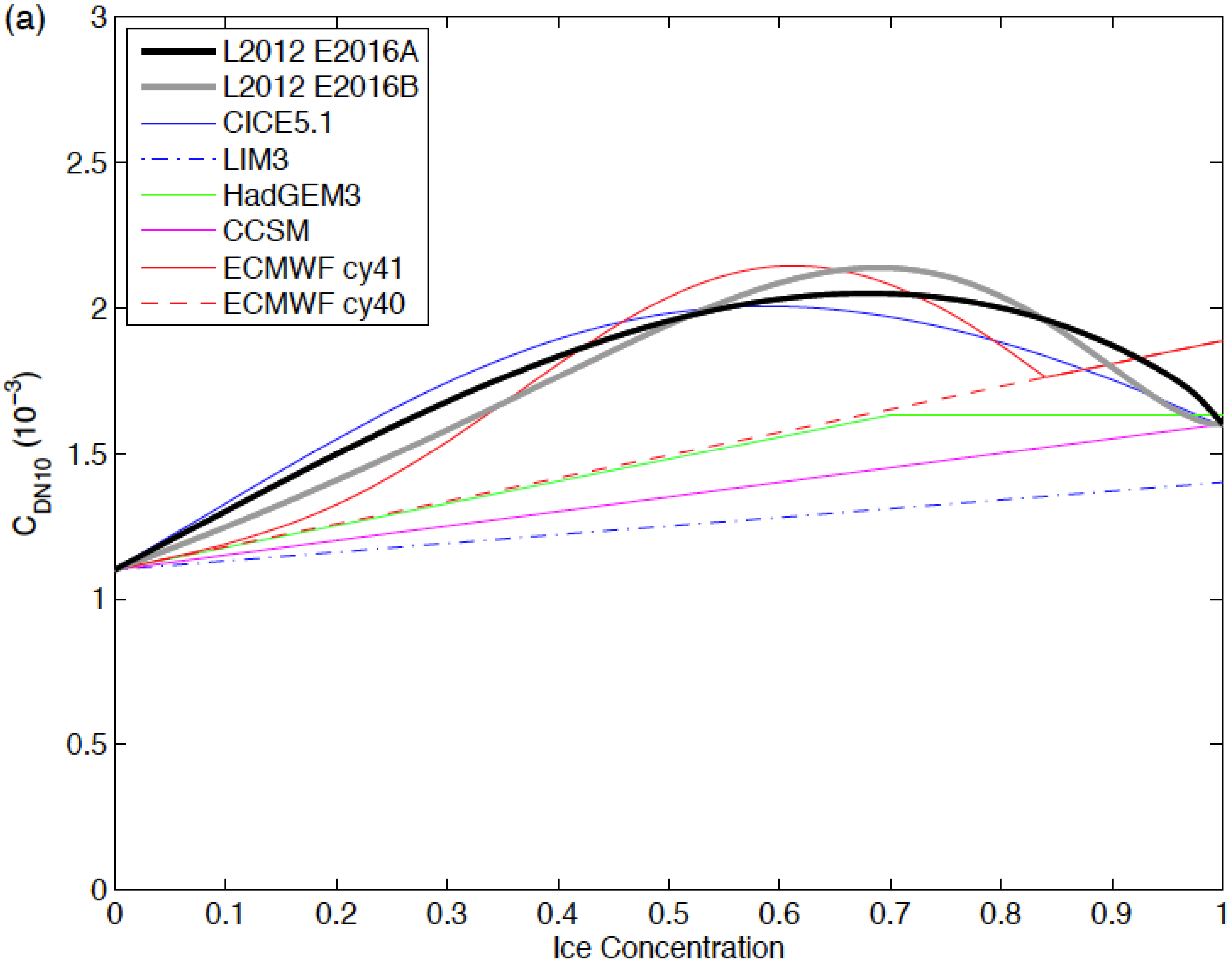
Drag Coefficient versus Ice Concentration: All flights (195 data points)



c_e = effective resistance coefficient
β = sea-ice morphology exponent (describing the dependence of D_i (floe length) on A)

	c_e	s	D_{min}	D_{max}	h_{min}	h_{max}	β
L2012	0.3	0.5	8 m	300 m	0.286 m	0.534 m	1
E16A	0.17	"	"	"	"	"	"
E16B	0.1	"	"	"	"	"	0.2

Model parameterizations



IFS change was 2015

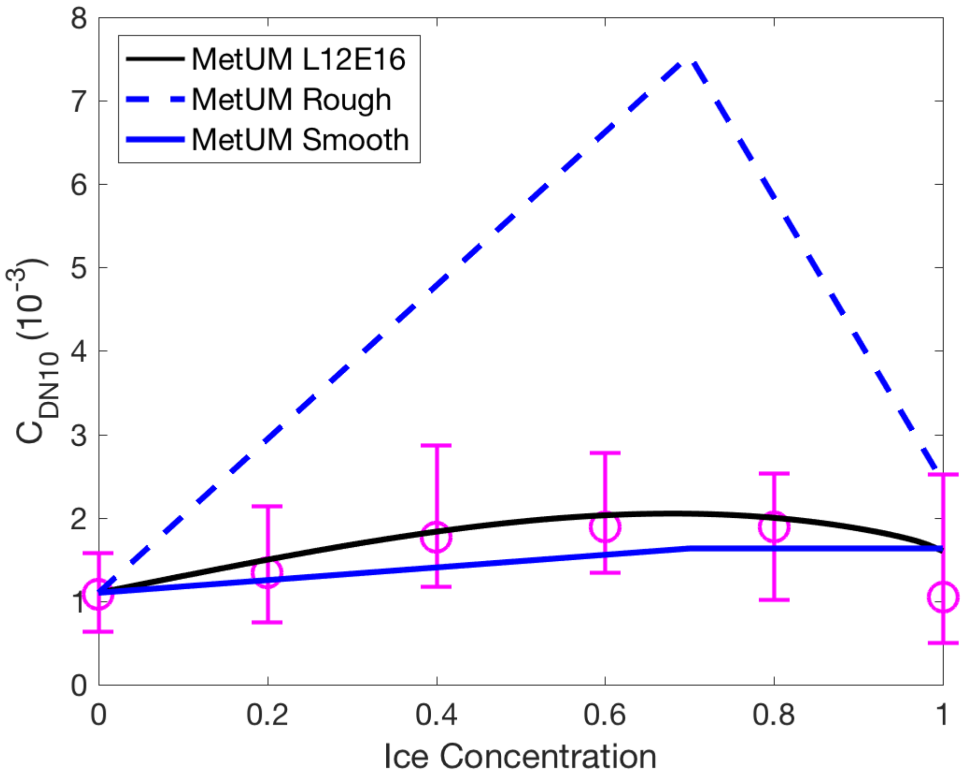
Impacts of MIZ drag on the atmosphere

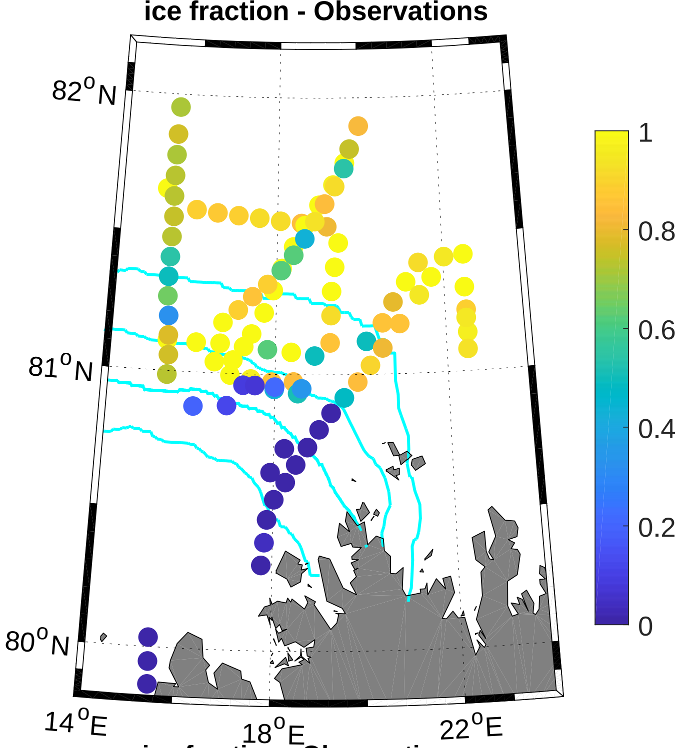
MetUM MIZ Drag Experiments:

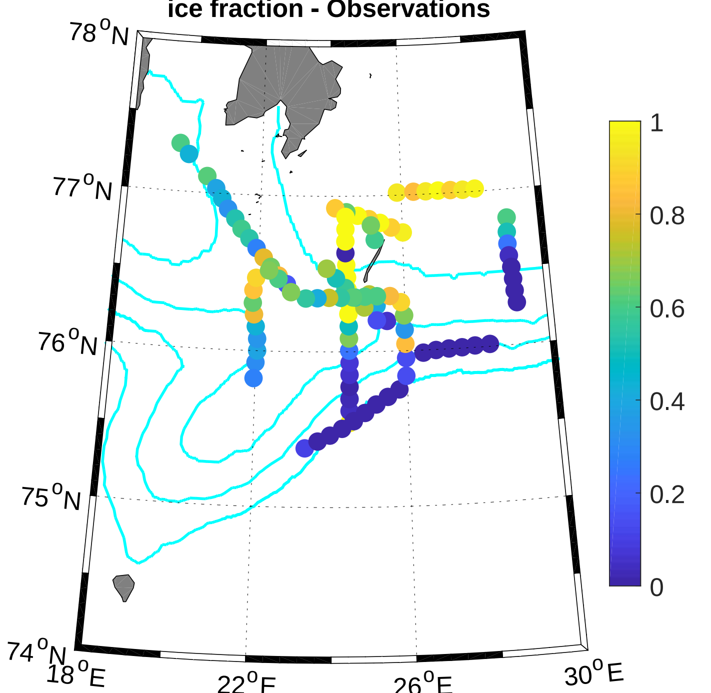
Rough: a large z_0 (Operational till Sep 2018)

L12E16 (New scheme; GL8)

Smooth: a small z_0 (HadGEM3)







Renfrew, I. A., A. D. Elvidge, J. Edwards 2019: *QJRMS,* **145,** 1165-1179. doi:10.1002/qj.3486

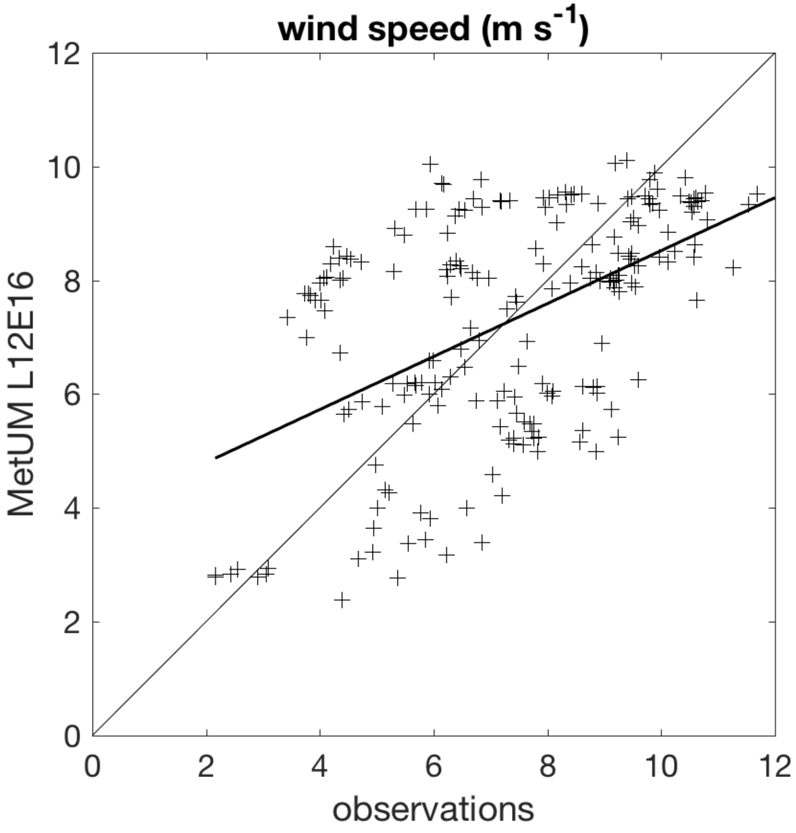
Impacts of MIZ drag on the atmosphere: Wind speed

MetUM MIZ Drag Experiments:

Rough: a large z_0 (Operational till Sep 2018)

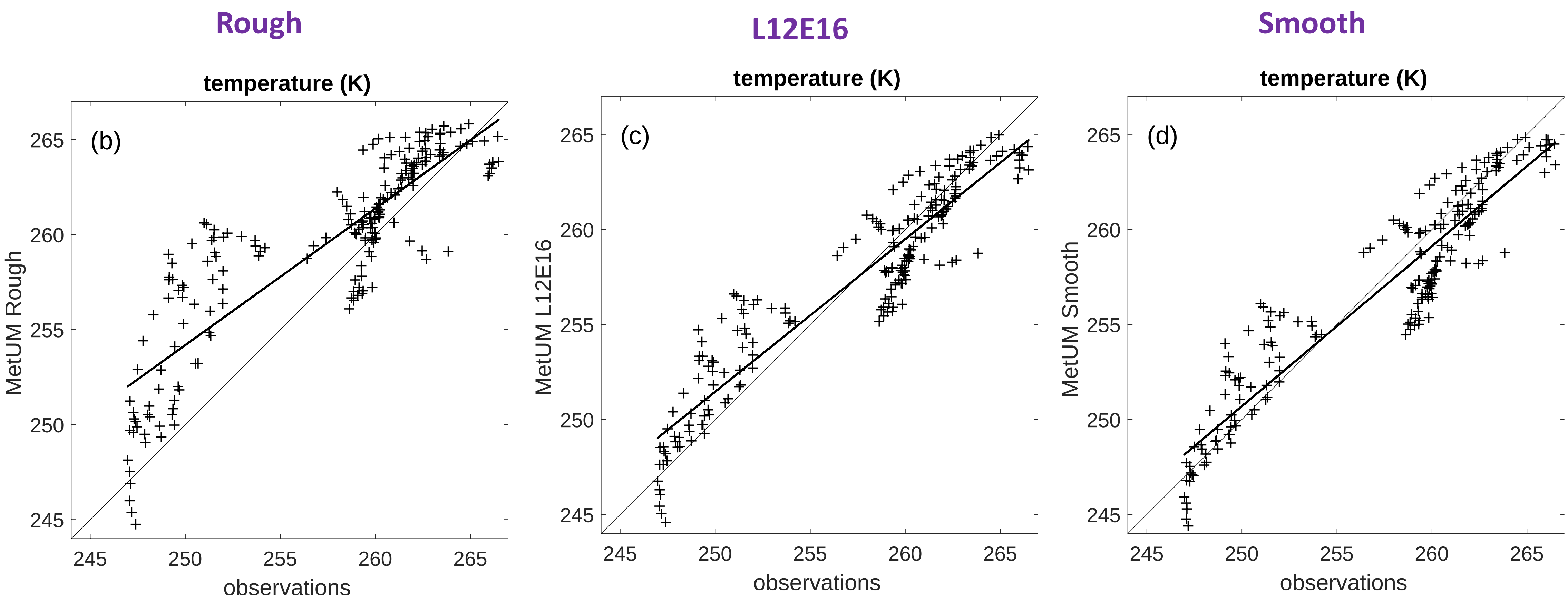
L12E16 (New scheme; GL8)

Smooth: a small z_0 (HadGEM3)



	Correlation Coefficient			Bias			RMS Error		
Experi-ment	Rough	L12E16	Smooth	Rough	L12E16	Smooth	Rough	L12E16	Smooth
U	0.51	**0.53**	0.52	-0.51	**-0.06**	0.28	2.14	**2.09**	2.14

Impacts of MIZ drag on the atmosphere: Temperature



	Correlation Coefficient			Bias			RMS Error		
Experi-ment	Rough	L12E16	Smooth	Rough	L12E16	Smooth	Rough	L12E16	Smooth
T	0.86	**0.93**	**0.93**	2.12	**0.02**	-0.46	3.62	**2.13**	2.16

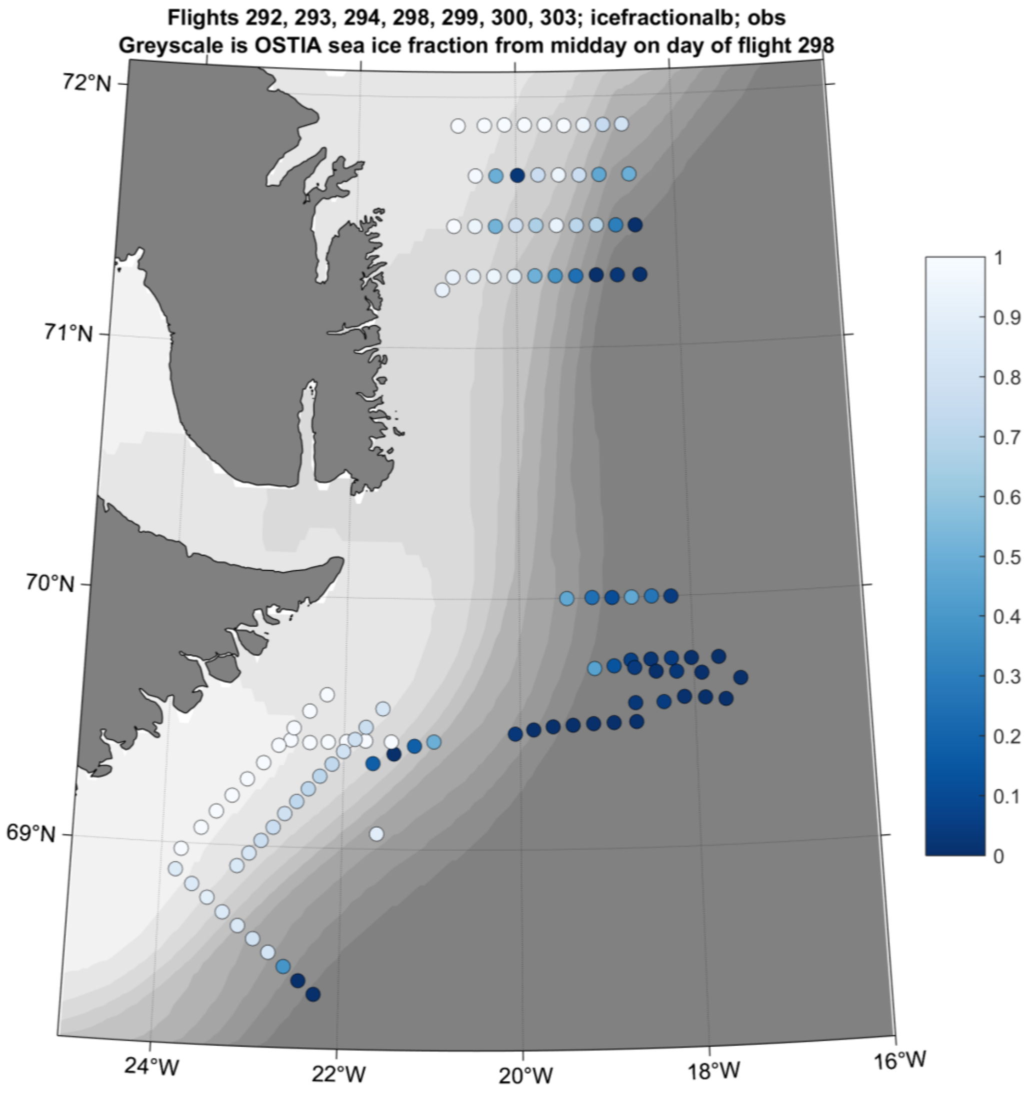
Conclusions of MIZ drag studies

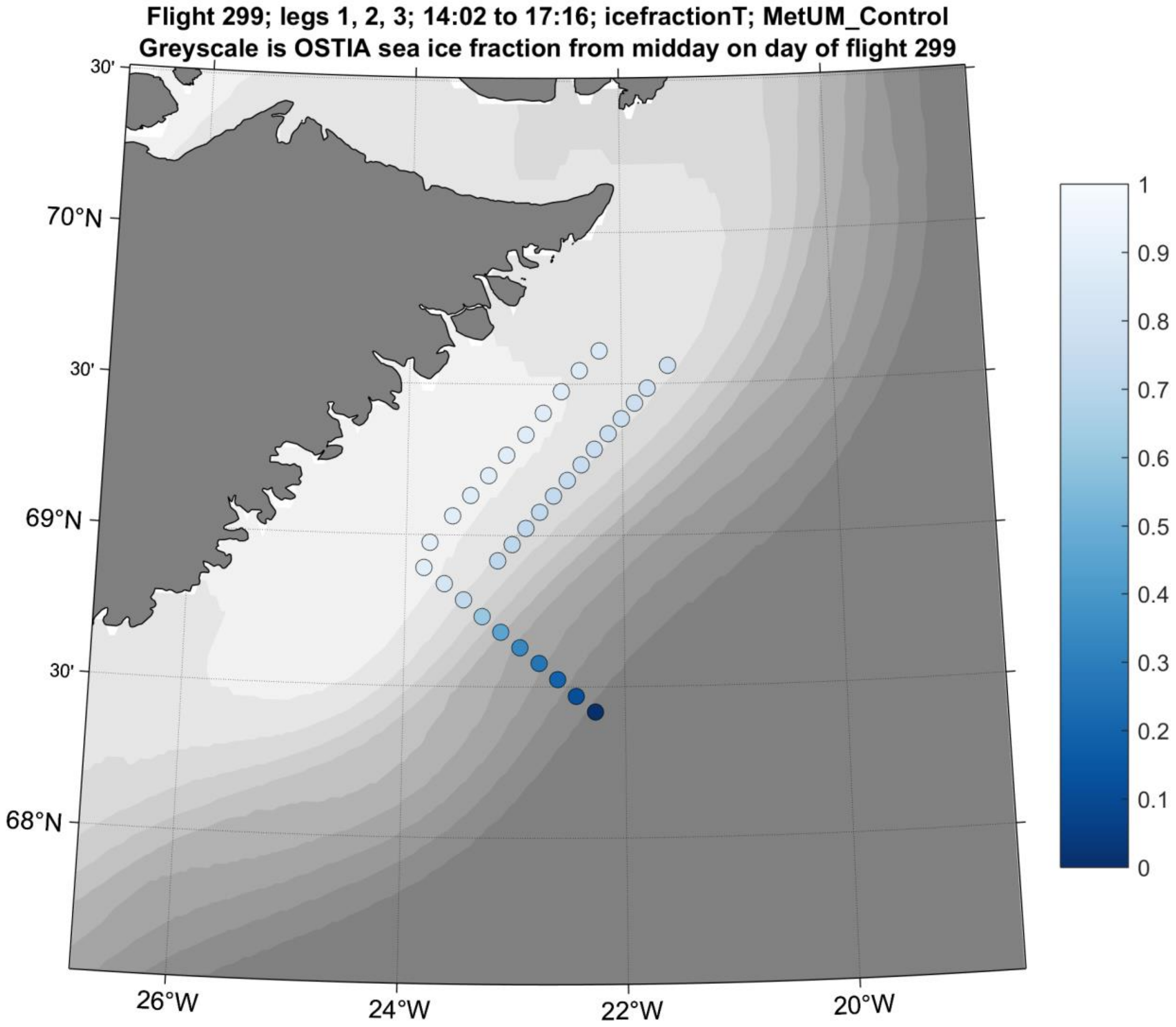
- A new sea-ice drag parameterization has a significant impact on the atmospheric boundary layer, changing the:
  - surface momentum flux by 0.1-0.2 N m^{-2} *(comparable to the mean)*
  - and low-level temperatures by 2-3 K near the MIZ
- Comparing against aircraft observations over and downwind of the MIZ the new ‘L12E16’ drag scheme has the lowest bias and lowest root-mean-square errors
- In global simulations the atmospheric response is relatively widespread – impacting most of the Arctic and Antarctic sea-ice areas
- L12E16 became operational at the Met Office in September 2018 and in next configuration of climate model (GA8)

Renfrew, I. A., A. D. Elvidge, J. Edwards 2019: *QJRMS*, **145,** 1165-1179. doi:10.1002/qj.3486

Impact of sea-ice representation: distribution

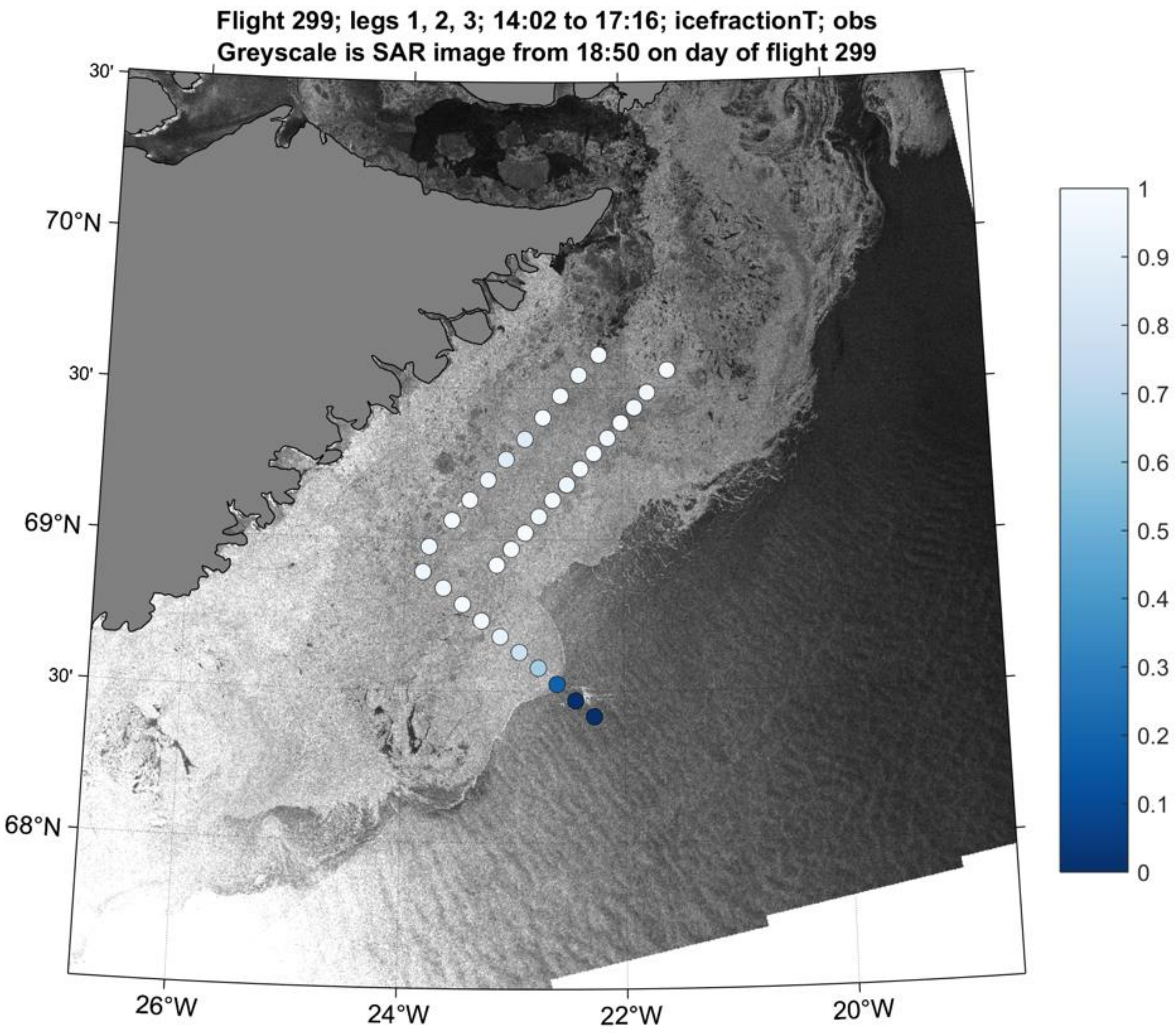
- Most forecasting systems use very smooth sea-ice analyses, e.g. OSTIA
  - Dramatic impacts locally
  - Impacts downstream?
  - Impacts on atmospheric forecasts?
- 7 flights from IGP

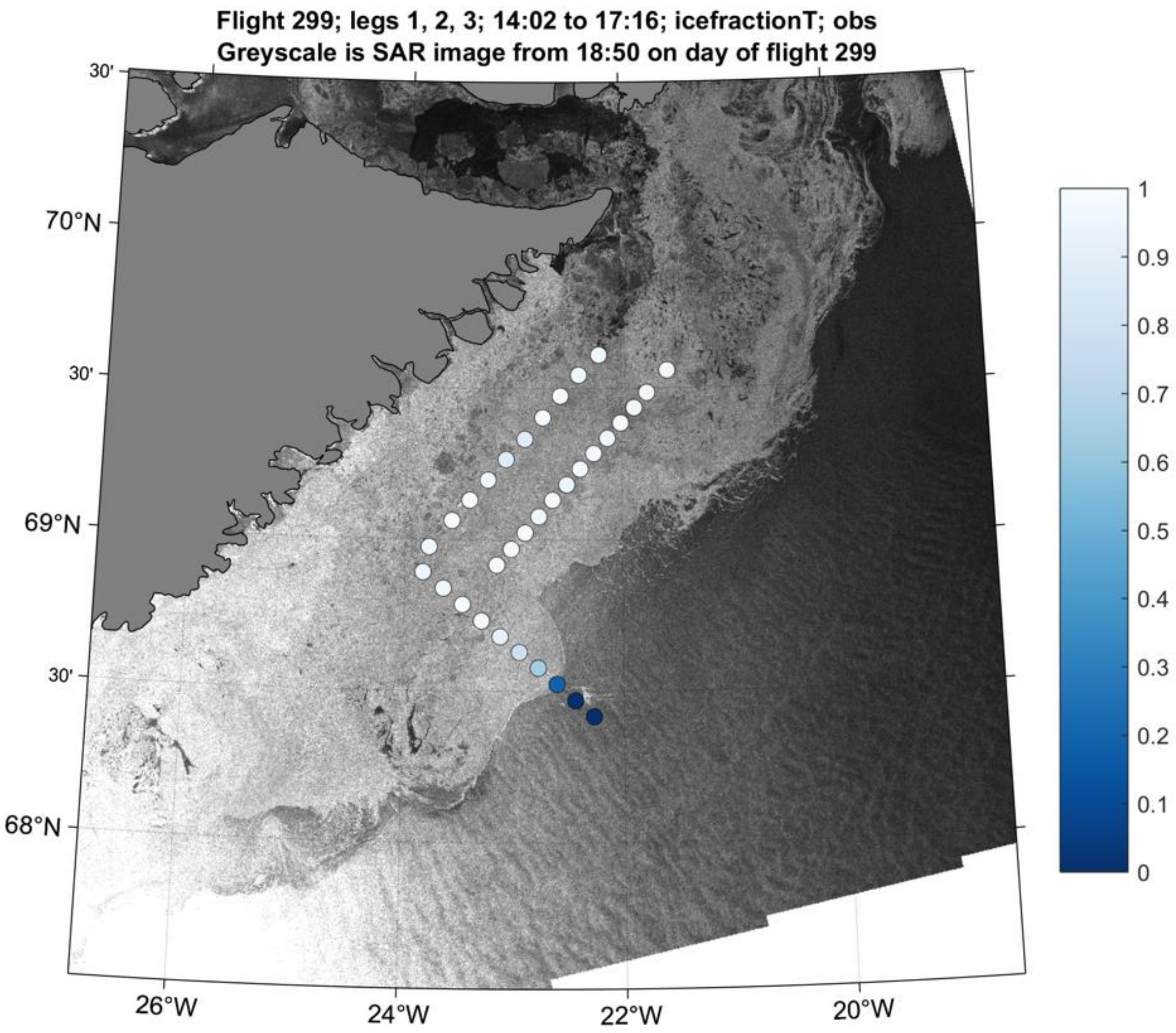




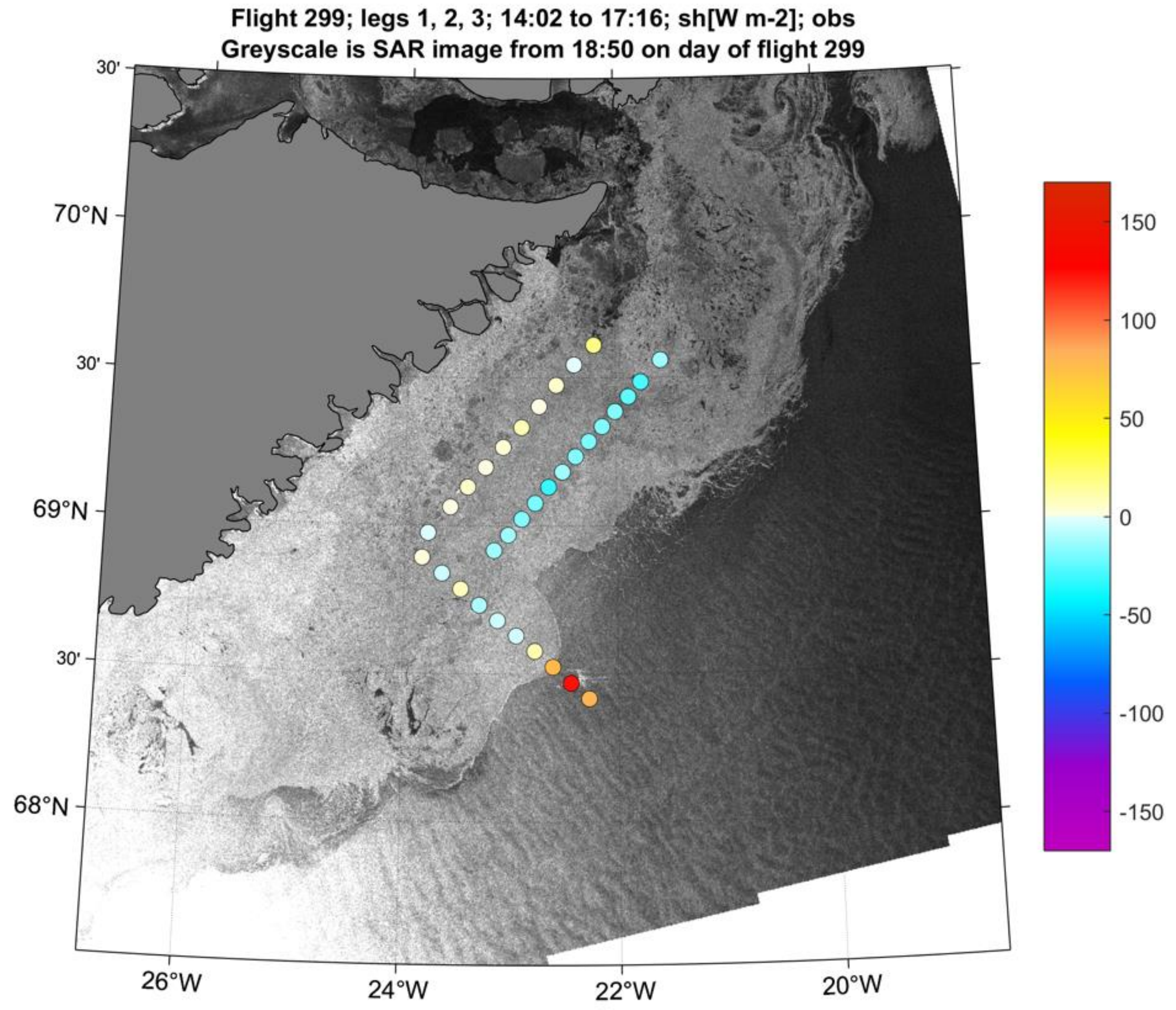
- IGP Case Study
  - OSTIA sea-ice
  - MetUM ice fraction
  - Distribution smoothed

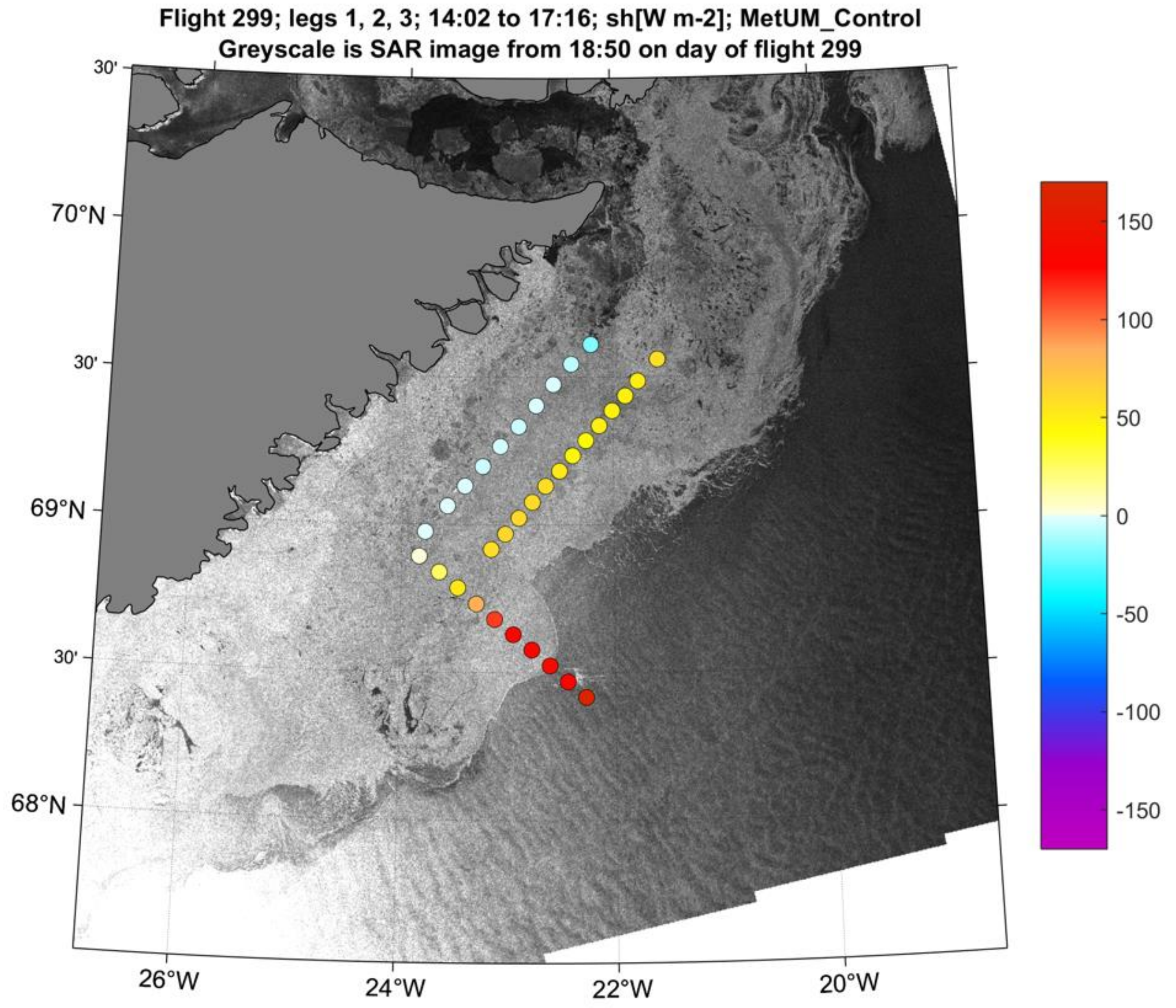
- IGP Case Study
  - – SAR image
  - – aircraft ice fraction
  - – sharp gradients

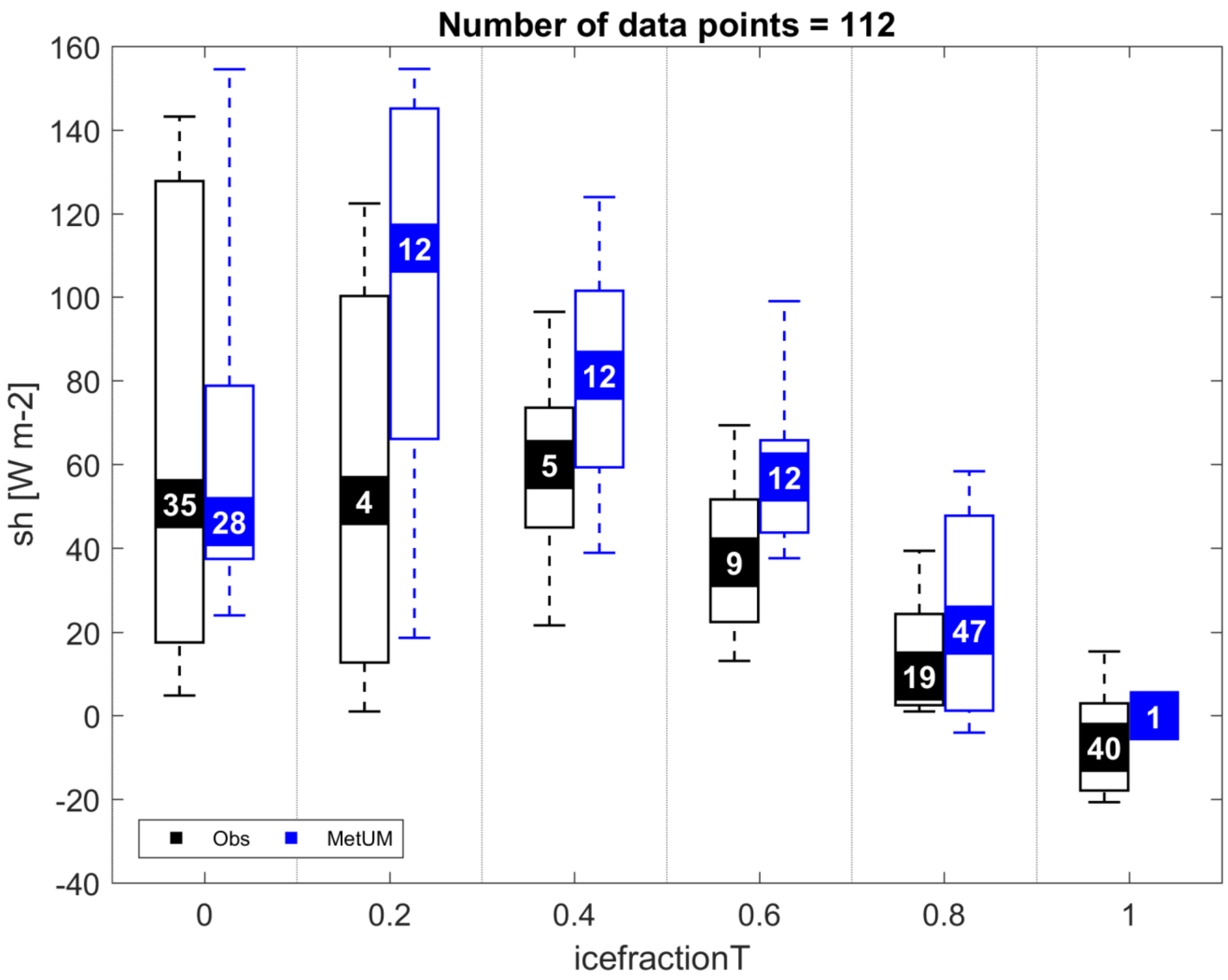




- IGP Case Study
  - – SAR image
  - – aircraft ice fraction
  - – sharp gradients


Flight 299; legs 1, 2, 3; 14:02 to 17:16; sh[W m-2]; obs
Greyscale is SAR image from 18:50 on day of flight 299
30'
70°N
30'
69°N
30'
68°N
26°W
24°W
22°W
20°W
150
100
50
0
-50
-100
-150

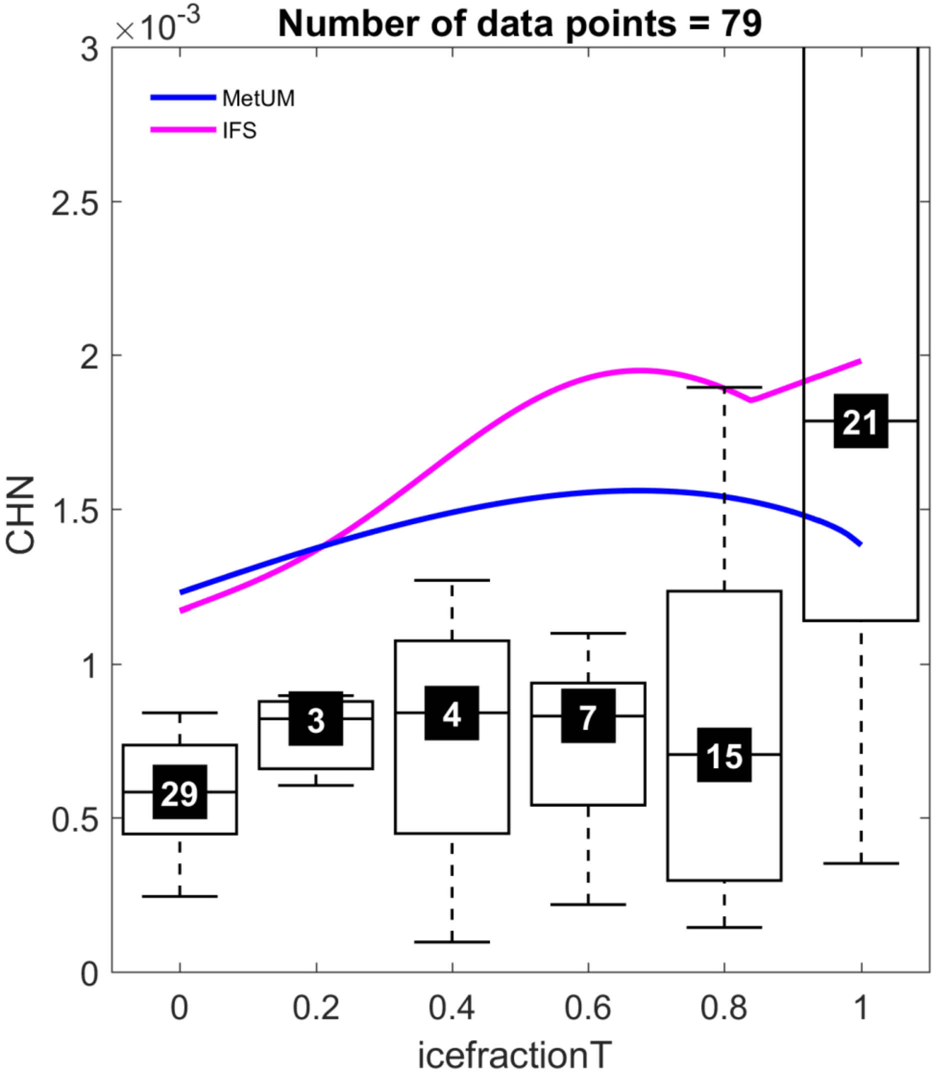

Flight 299; legs 1, 2, 3; 14:02 to 17:16; sh[W m-2]; MetUM_Control
Greyscale is SAR image from 18:50 on day of flight 299
30'
70°N
30'
69°N
30'
68°N
26°W
24°W
22°W
20°W
150
100
50
0
-50
-100
-150

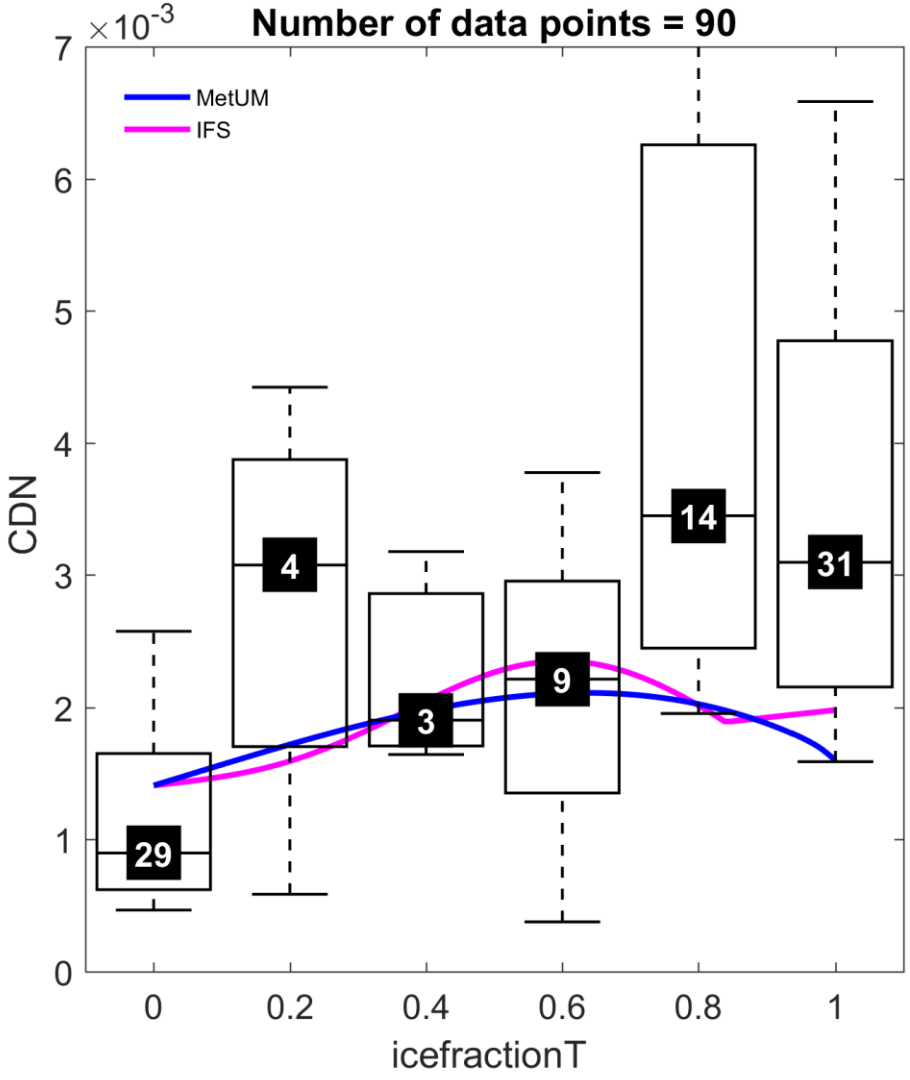


Over sea-ice and marginal-ice-zone:

- MetUM systematically over-estimates sensible heat flux
- Similar for latent heat flux

Preliminary results!





Preliminary results!

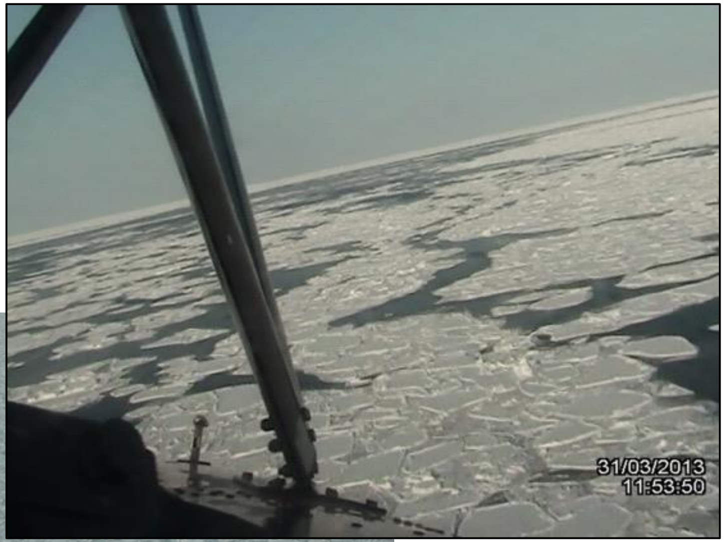
- Exchange coefficients for heat (and moisture) are too large over MIZ
- Ok for drag over MIZ
- BUT only one value is used for 100% sea-ice

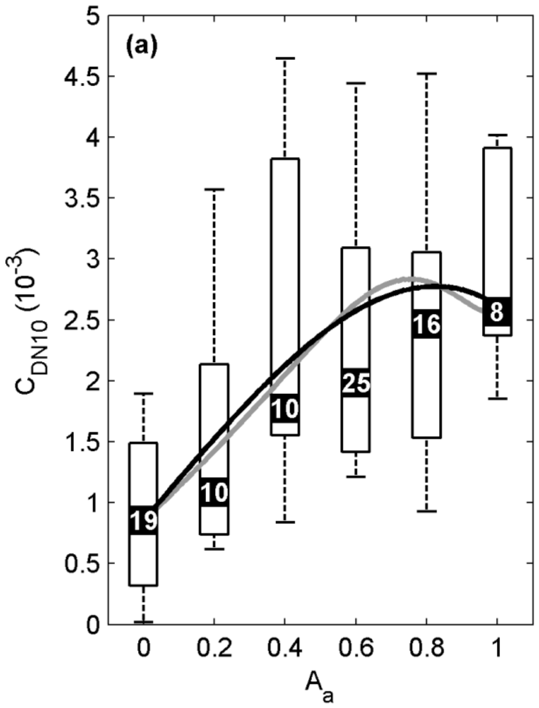
IGP Analysis

- Characterising Cold Air Outbreaks
- Turbulent flux evaluation (in vicinity of MIZ)
- Evaluation of meteorological analyses
  - Model deficiencies on a thematic basis
- Leeside fluxes, wakes & gravity waves
- Coupled atmosphere-ocean investigations
- Regional climate & ocean modelling

Variability within the dataset: Barents Sea

- 99 data points
- small, deformed, pancake ice with raised edges.





Variability within the dataset: Fram Strait

- 101 data points
- homogenous, non-deformed ice