marine.copernicus.eu

Arctic sea ice (and icebergs) in a changing climate

L. Bertino, Nansen Center
with contributions from colleagues P. Rampal, J. Xie …

Assignment

- How has our understanding of changes and model projections evolved since 2008?
- What is current best practise, including the most appropriate models, downscaling approaches and analysis techniques?
- Is current practice at a state where it can be relied upon for long-term business decisions?
- What are the recognised gaps and uncertainties in current practise
- and what needs to be done to close these gaps and address the uncertainties?

State of knowledge as of 2008

2007 was the "then-record" sea ice minimum
- Anxiety about abrupt sea ice loss.
- Many lower records since then. Many more to come…

Loss of multi-year ice
- Still valid

Sea ice drift acceleration was yet unknown
- Rampal et al. 2009.

Sea ice thickness only observed twice a year by ICESat
- SMOS, CryoSAT2, Sentinel3, soon ICESat2. But ONLY IN WINTER.
- Knowledge of ice volume still uncertain

Storminess and waves expected to increase
- Still valid, higher and longer waves but less steep.

Ocean warmth intrusion in the Arctic
- "Atlantification" of the Arctic, Polyakov et al. 2011, but no warm water intrusions since then.
- Positive feedback in Barents Sea du the loss of ice (Lind et al. 2018)

More icebergs
- Still unsure

Acidification
- Still valid

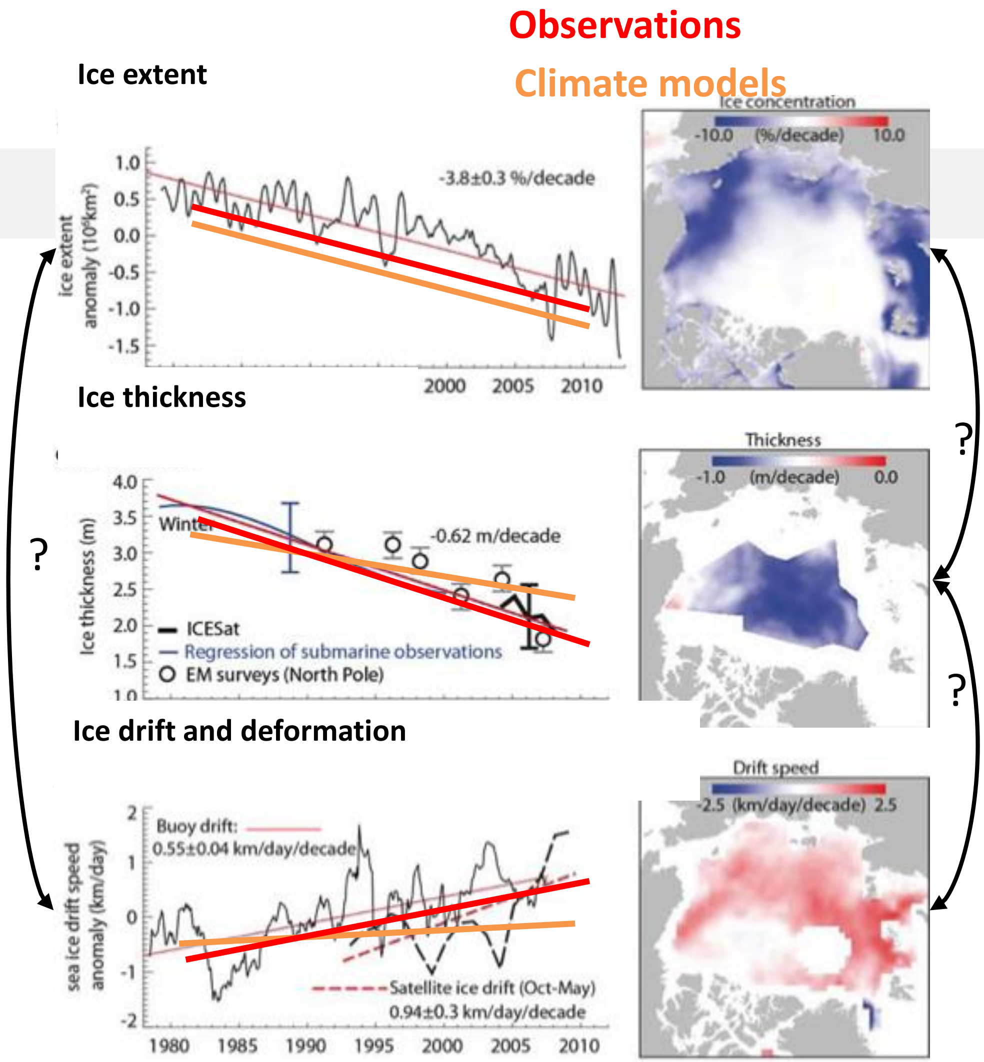
Resilience of the ecosystem (lack thereof)?
- Still debated

Known trends in the Arctic sea ice

Smaller

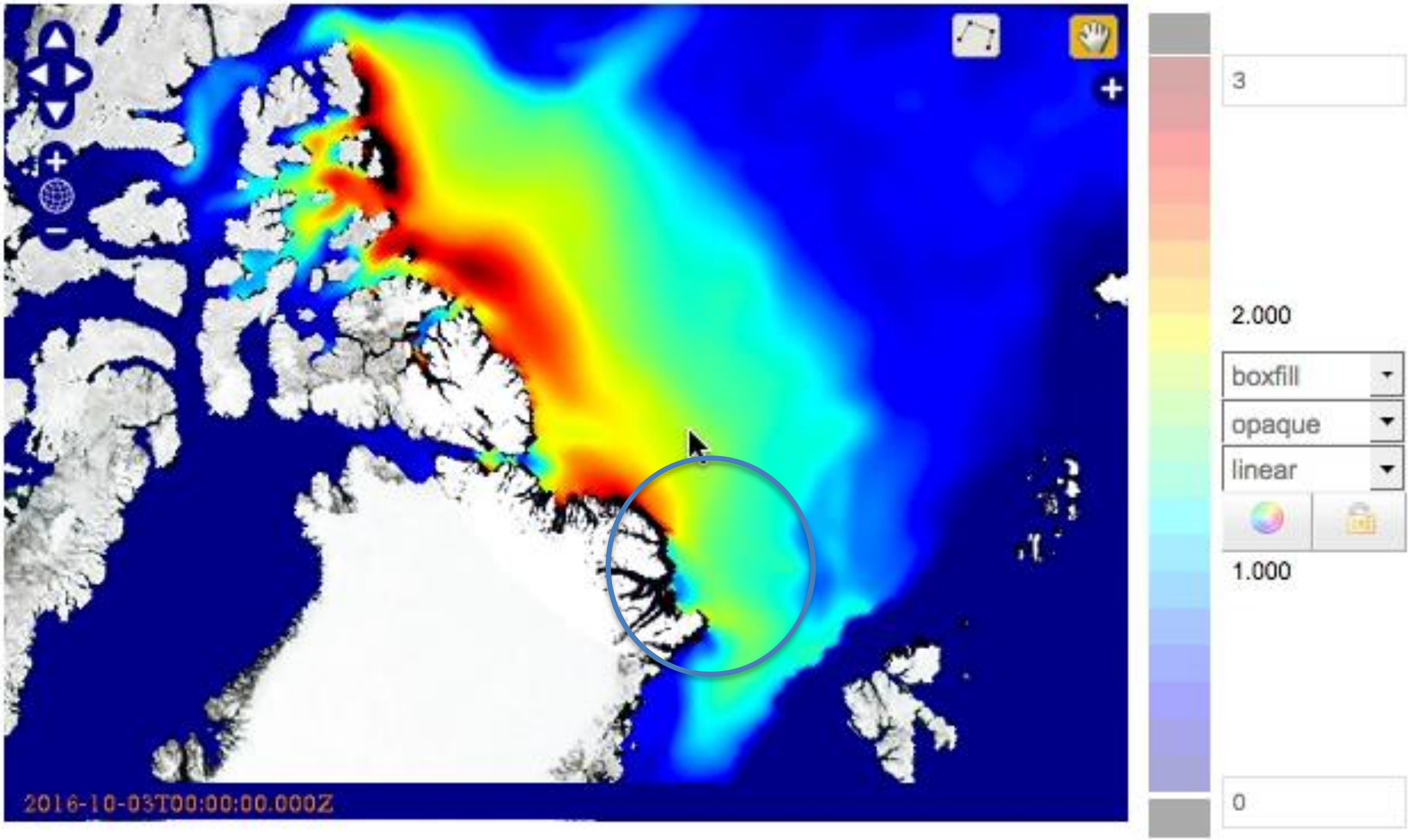
Thinner

Faster



From IPCC report, 2013

Present situation 2016 - 2018



From http://marine.copenicus.eu
Note the polynyas in Feb 2018 and Aug. 2018

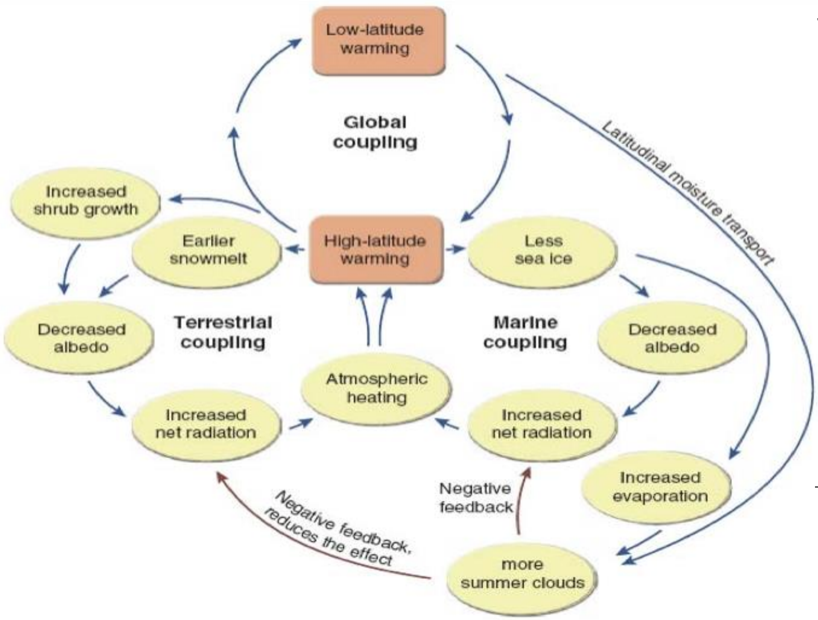
Arctic amplification

As of 2008

Albedo feedback (positive)

Cloud feedback (negative)

Chapin III et al. 2005



As of 2018

Temperature feedbacks

Albedo feedbacks (ice + snow)

Pithan & Mauritsen (Nat. 2014),

Based on models only, but

- mis-represented feedbacks (known unknowns)
- unexpected feedbacks… (unknown unknowns)

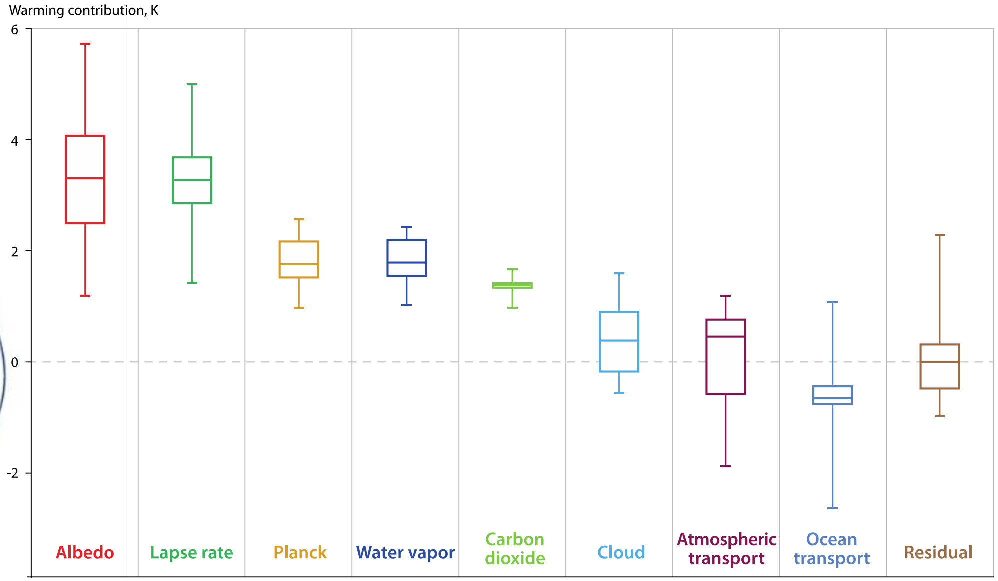
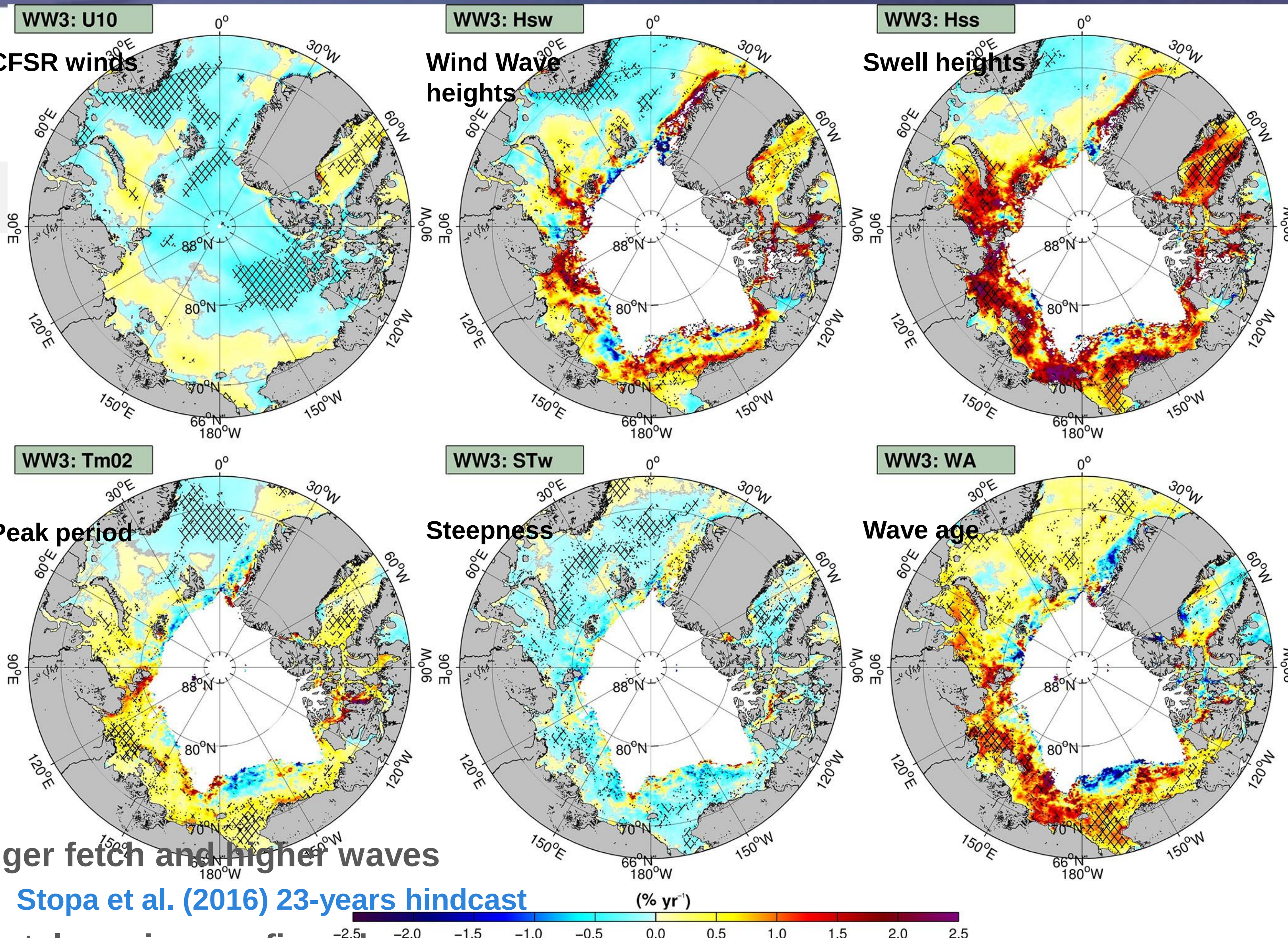


Figure 2.10 Contributions of various feedbacks to total Arctic warming in CMIP5 global climate models (Pithan and Mauritsen, 2014).

Changing wave climate in the Arctic



Longer fetch and higher waves

Stopa et al. (2016) 23-years hindcast

Coastal erosion confirmed

Enhanced mixing in the Arctic Ocean

Rippeth et al. 2015:

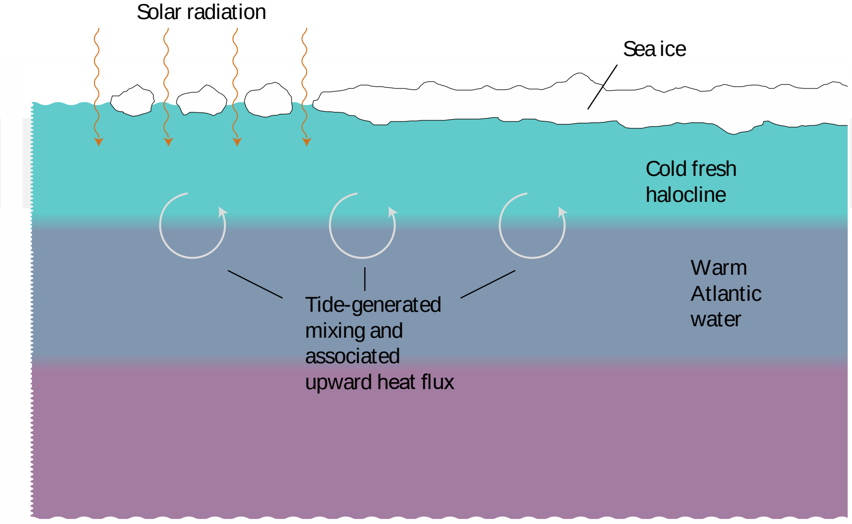
- Upward mixing of heat independent of sea ice
- Associated with tidal mixing

Lind et al. Nature 2018

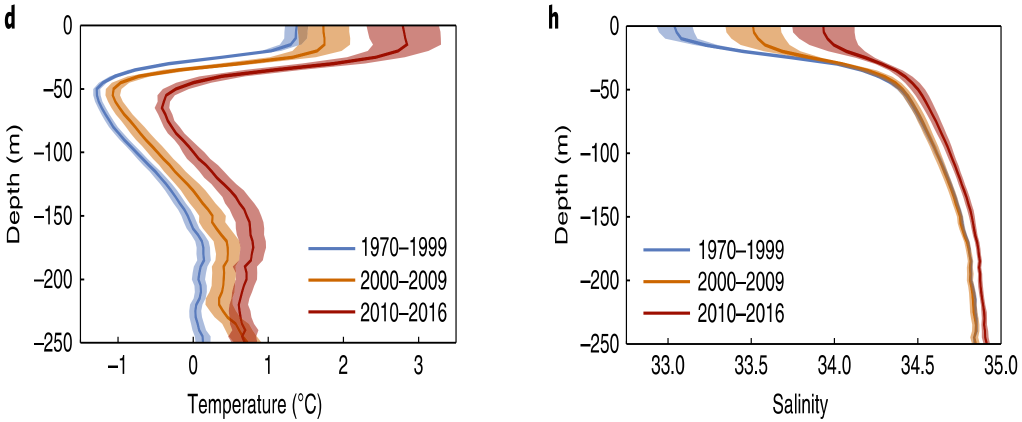
- Less sea ice transport to the Barents Sea
- Loss of salinity-driven stratification

Polyakov (in prep)

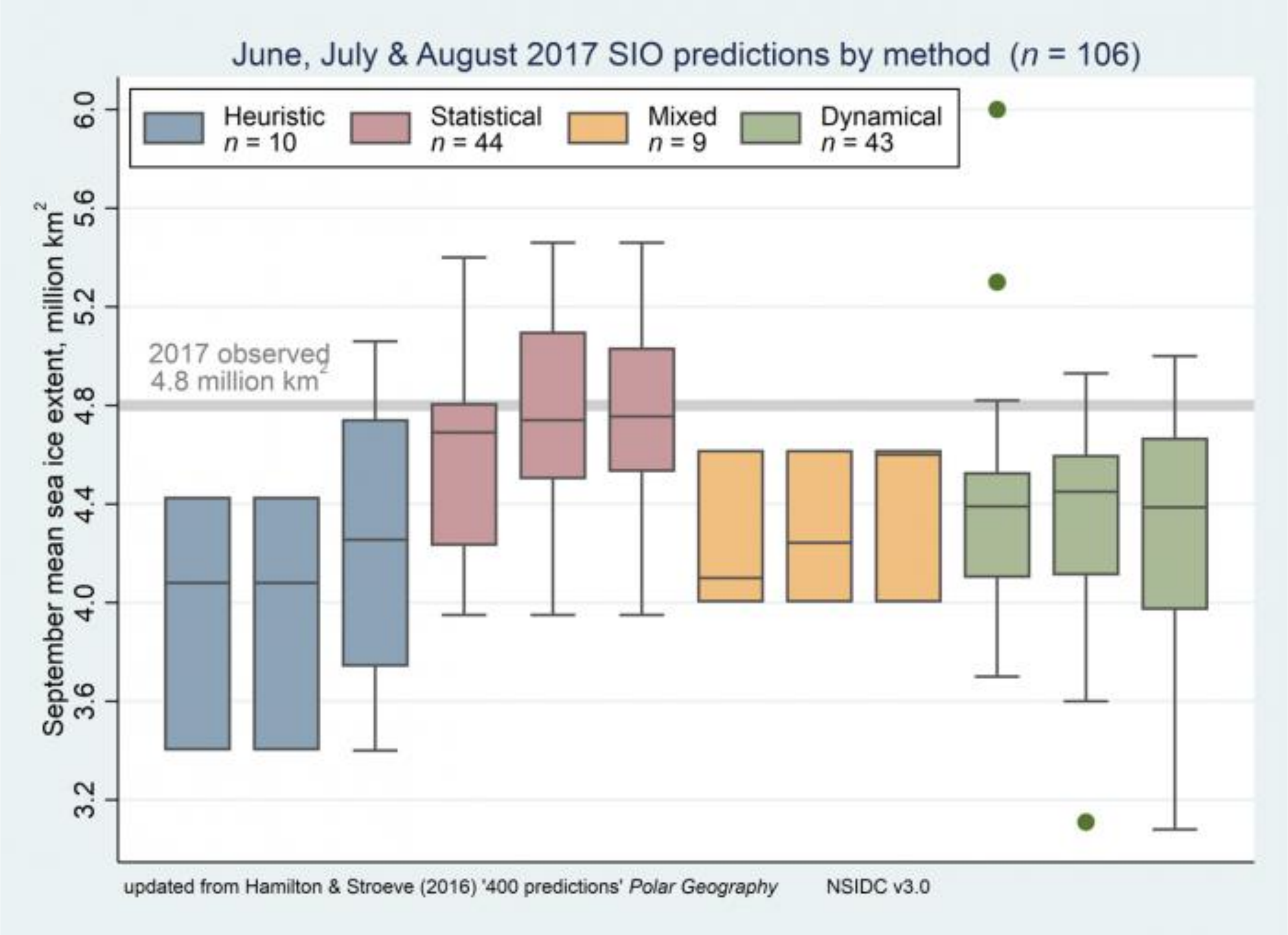
- Loss of double-diffusion in Laptev Sea mooring



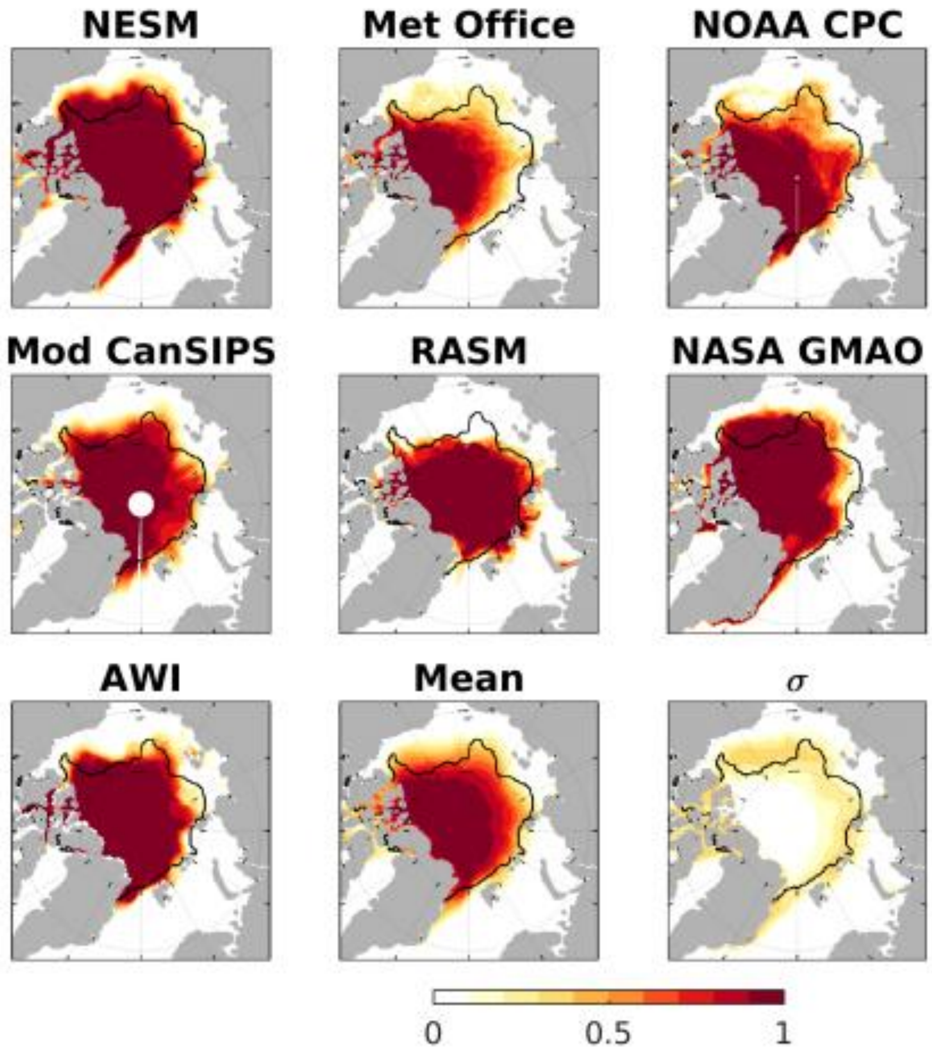
Lique Nat Geo 2015



Sea ice outlooks (not yet updated 2018)

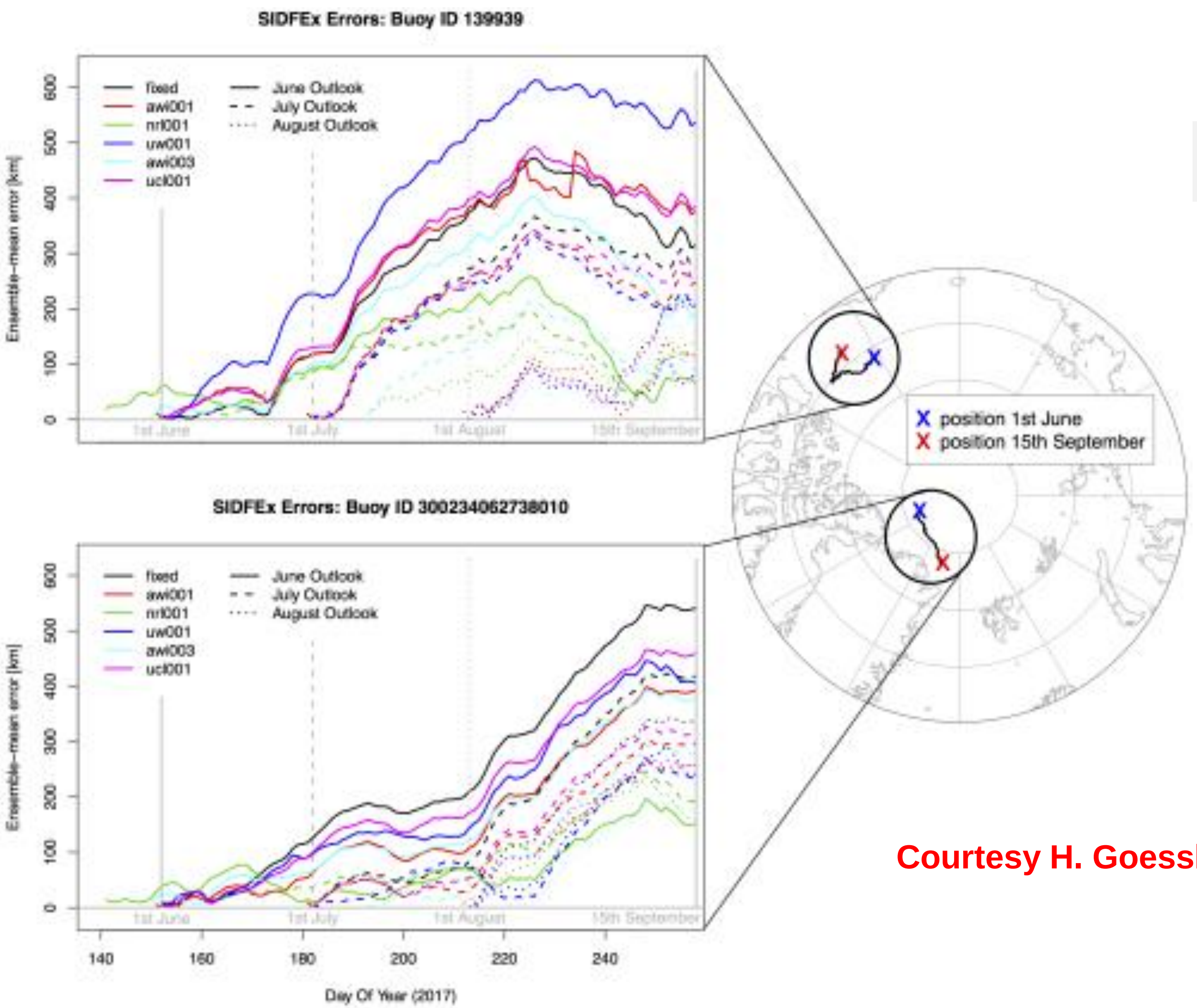


Sea ice outlooks



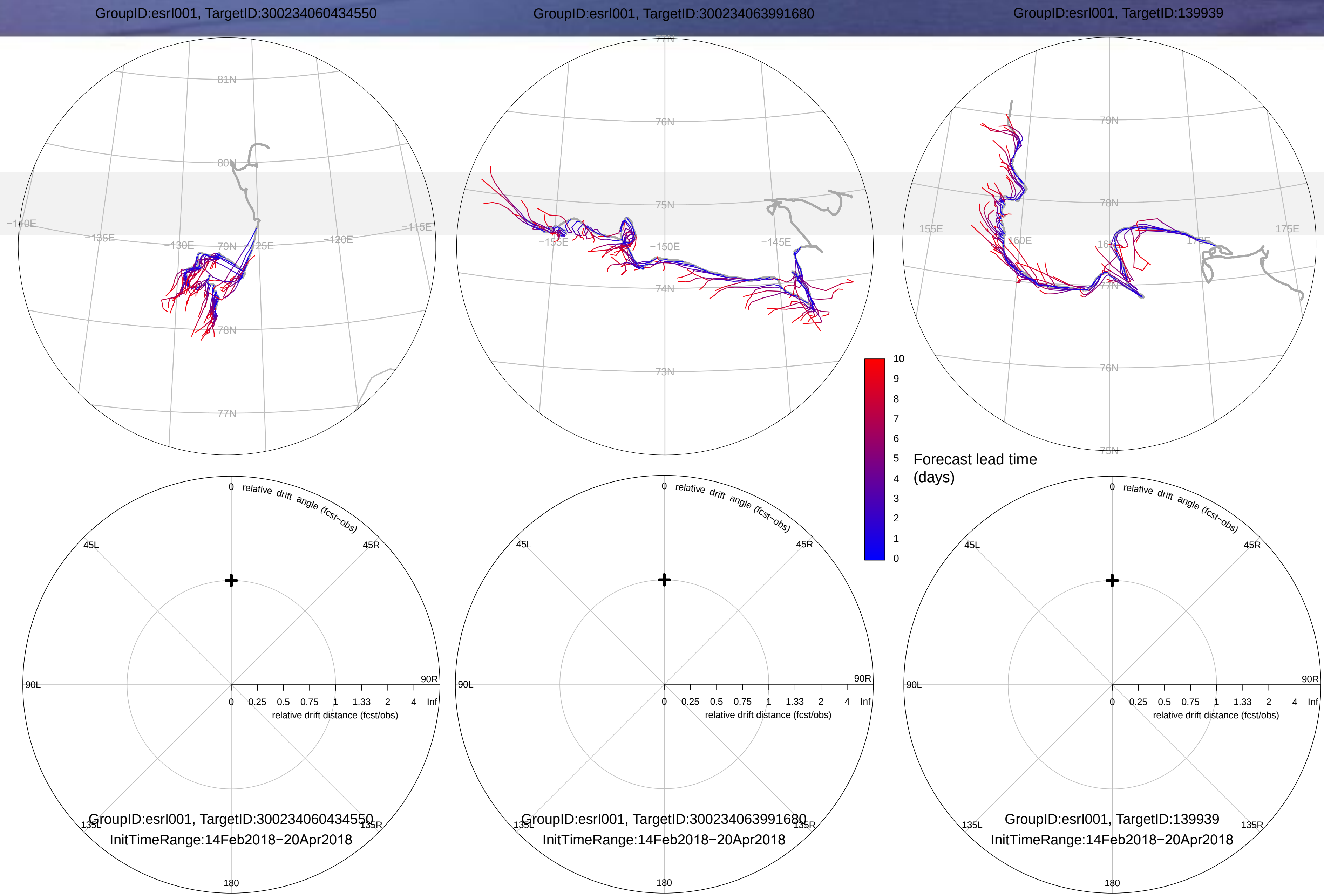
From SIPN website June forecasts for September 2017

Sea ice Drift experiment: SIDFEx

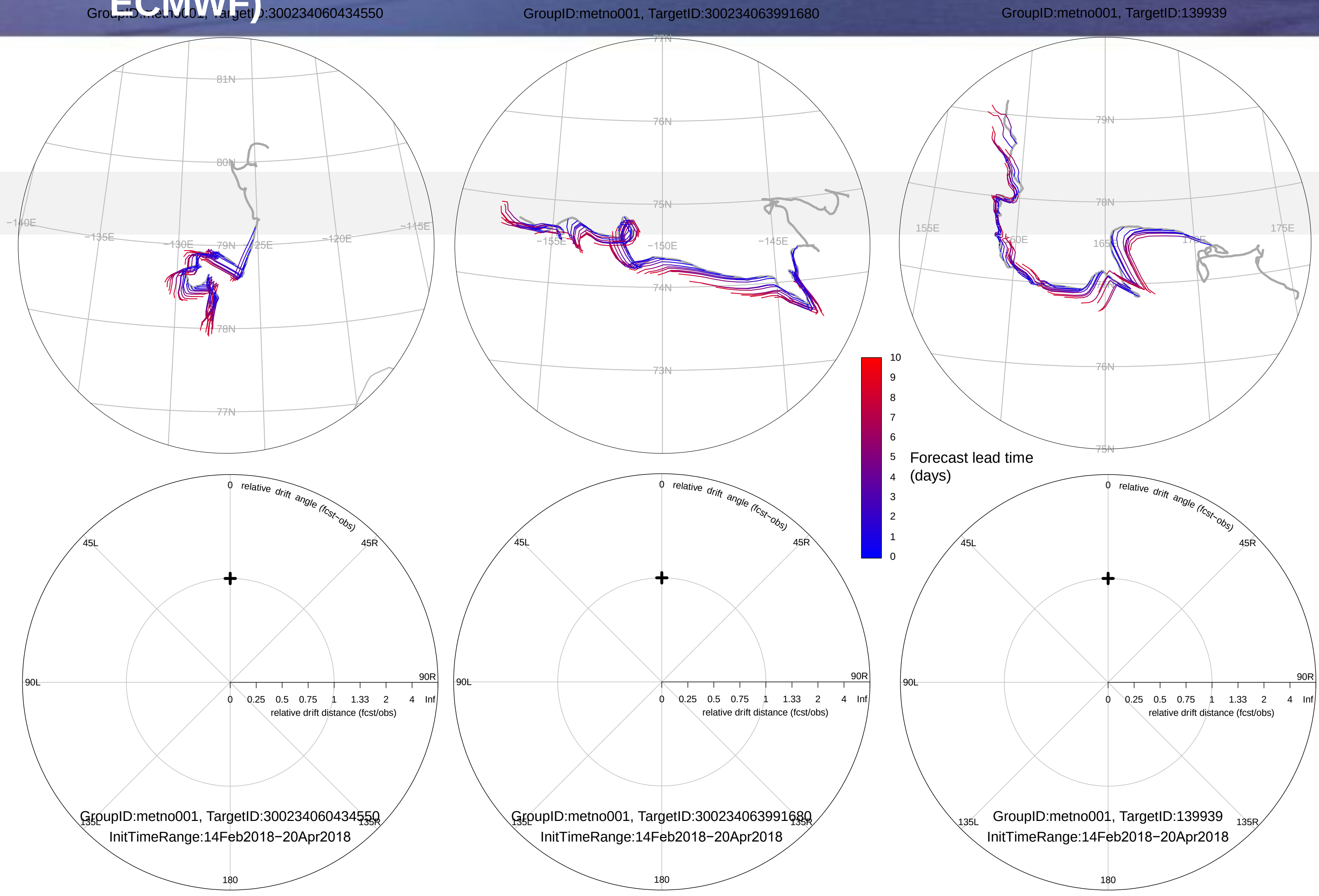


Courtesy H. Goessling, AWI

SIDFEx Short-term forecasts: ESRL (coupled ensemble)



SIDFEx Short-term forecasts: TOPAZ (uncoupled, forced by ECMWF)



Climate models exhibit common biases

Sea ice thickness in CORE II simulations and ICESat observations

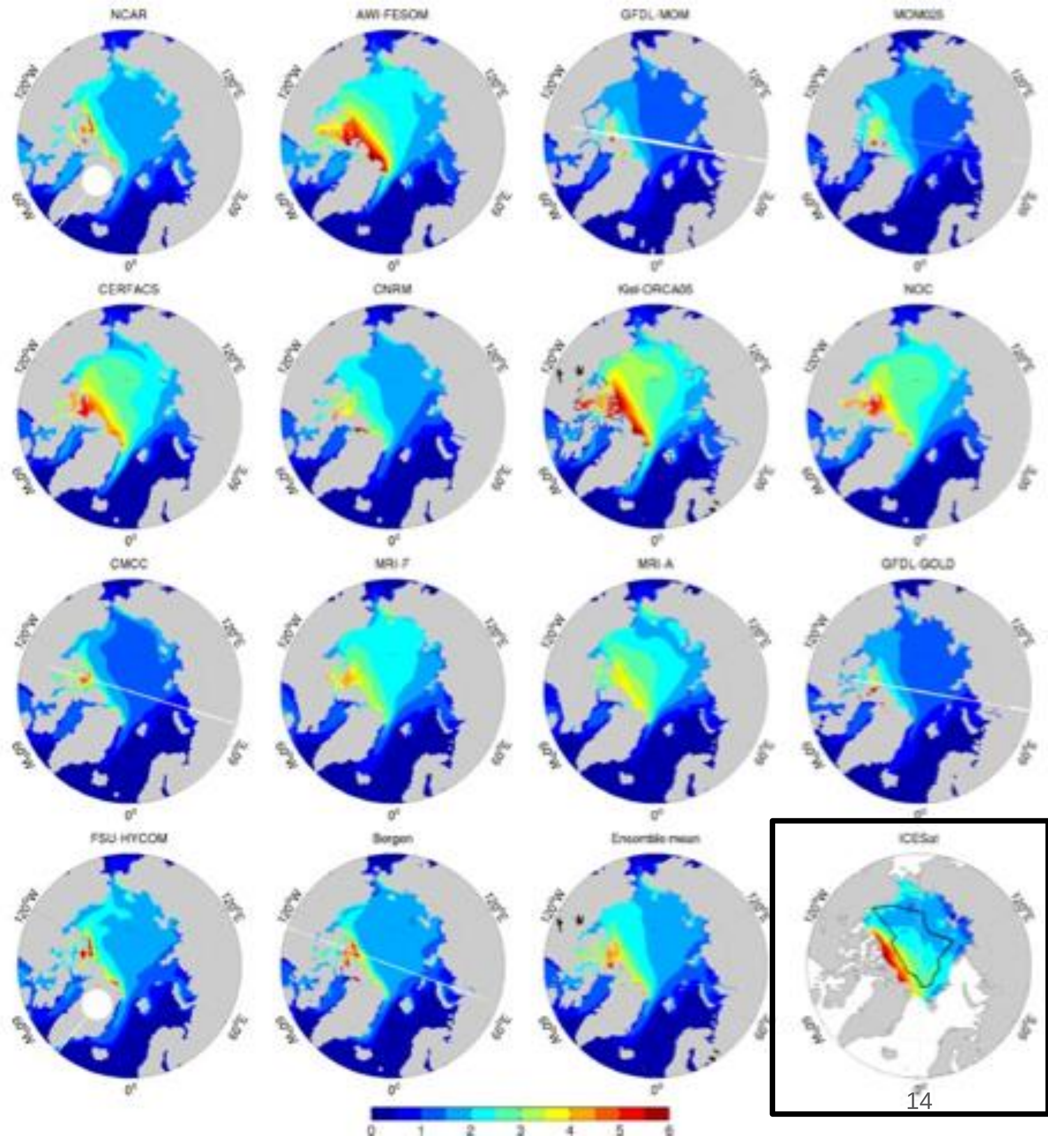
Too much in Beaufort Sea

Too little on European side

Wang et al. (2016)

Causes?

- **Sea ice drift**
- **Melt ponds in Beaufort Sea**



Long term business decisions?
Example: Shipping in Marginal Seas

Single variable analysis (sea ice):

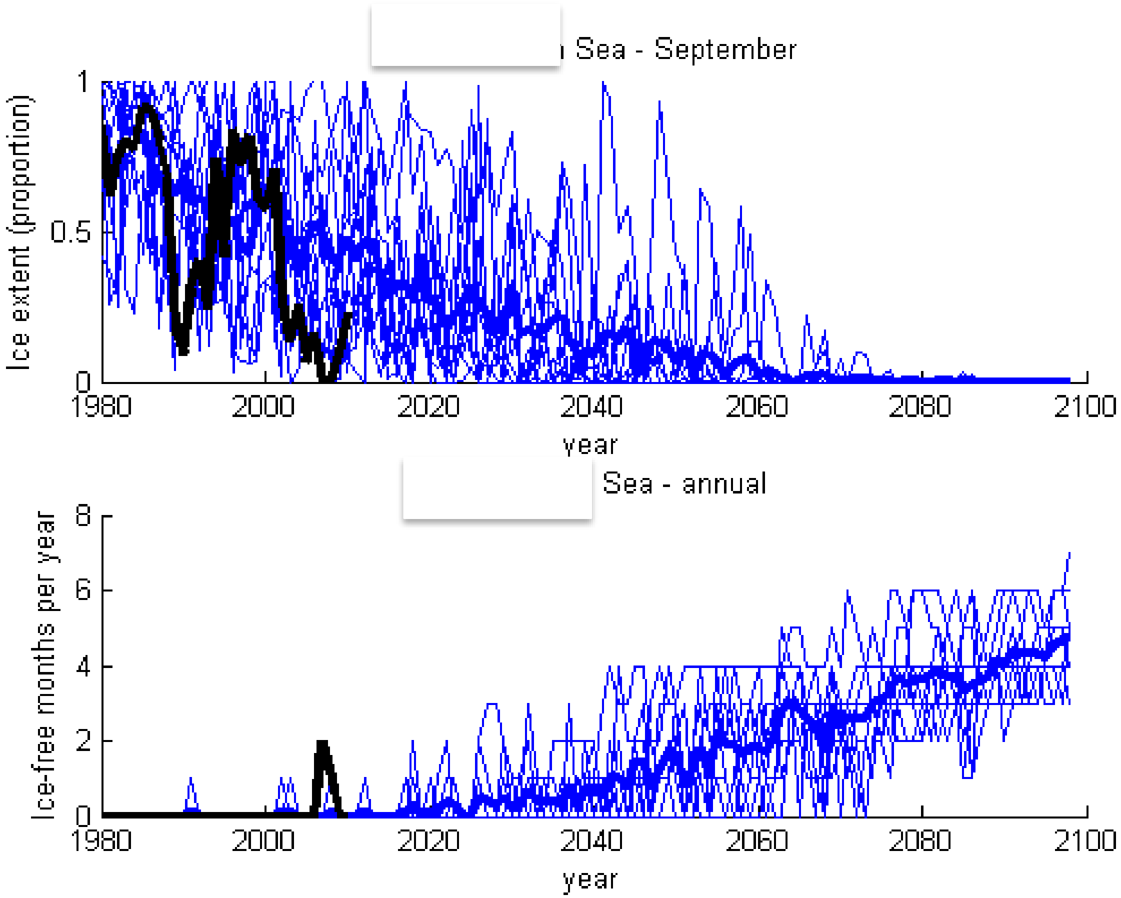
- Several climate projections fit reasonably well
- Seems like we can make a decision, but …

September ice extent

Blue: Selected CMIP5 proj.

Black: reanalysis

Number of ice-free months per year



Graphics by courtesy of Shell

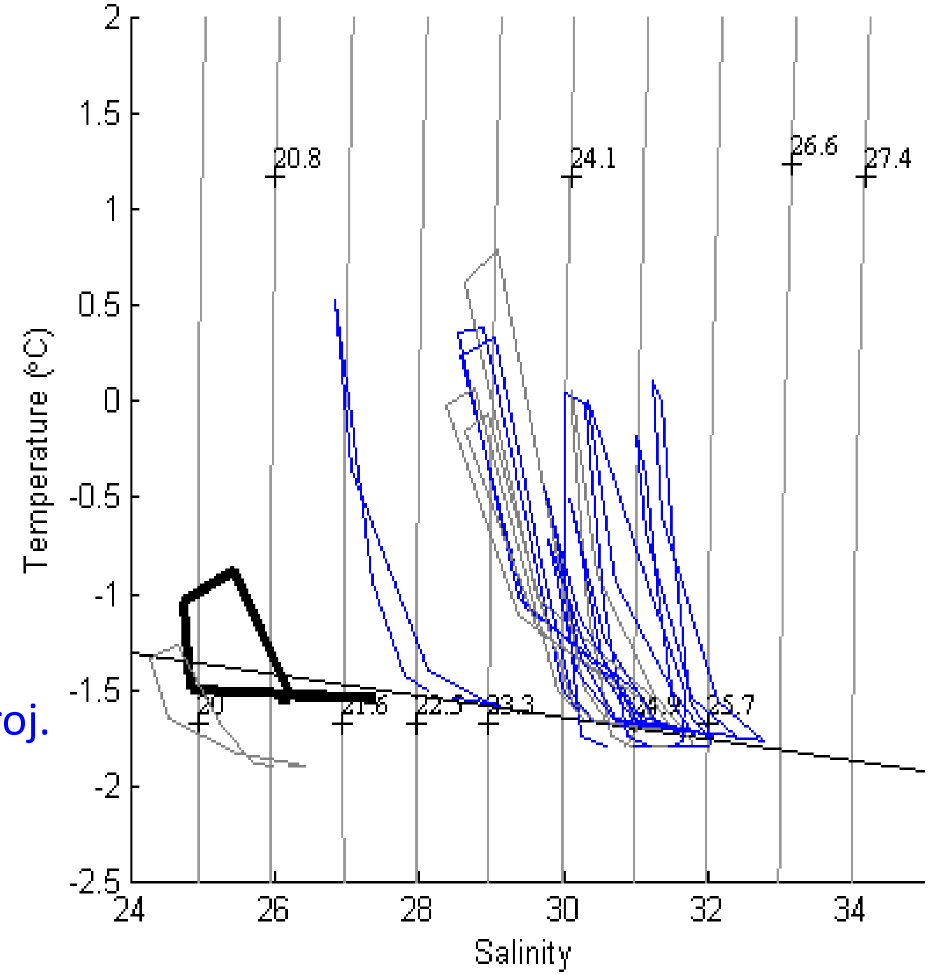
Example: Shipping in Marginal Seas? (continued)

Comparison to ocean temperature & salinity:

- Cold halocline missing from all projections
- None of the members satisfies <u>both</u> ocean and sea ice conditions
- Ice is right for the wrong reason
- … No answer to the question

Needs a complete baseline data

- Improved ocean models



Blue: Selected CMIP5 proj.

Black: climatology

Shortcomings in atmospheric models

- Biases in heat fluxes (order of +/- 40 W/m^2)
  - Cloud cover / cloud types / fog
  - Shallow stable boundary layer
  - Heat fluxes through sea ice leads
- Biases in wind speeds
  - Surface roughness
  - Shallow stable boundary layer
- Biases in precipitations
  - Clouds
  - Uncertainty about 100%
  - Snow depth important for sea ice freeboard
- Ocean and sea ice model need to compensate for those biases
  - Some issues alleviated in coupled models
  - Some problems enhanced by couplers
- Most relevant parameterisations date back to SHEBA (90's)
- Expect newer observations from YOPP, MOSAiC targeted observations / cruises

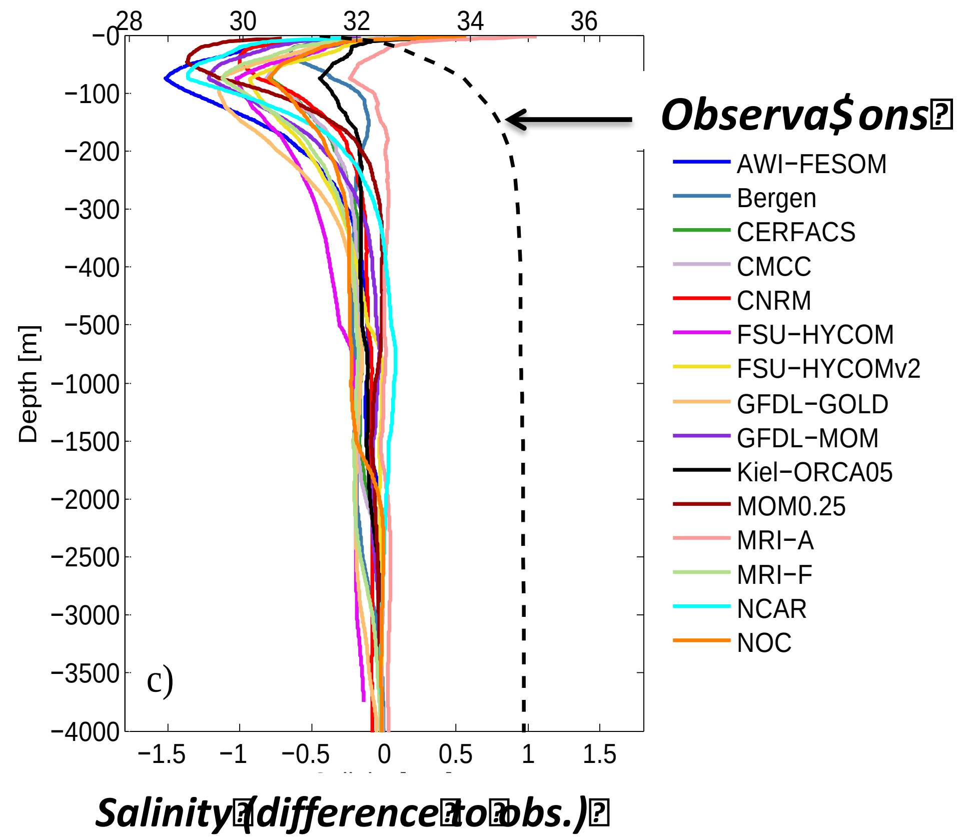
Shortcomings of ocean models

Salinity-driven mixing

All models have trouble maintaining the Atlantic Water layer in the Arctic

The simulation of the Cold Halocline Layer is also a common problem.

Ilicak et al. (2016)



Present trends in ocean modelling

Vertical coordinates

- Generalized: HYCOM, MOM6, MPAS
- Z-levels: MITgcm, NEMO
- Terrain following: ROMS
- Each has advantages and shortcoming

Unstructured grid models

FESOM, FELIM, MPAS…

Numerical schemes:

Lemarié (OM 2015) supports coupled space-time numerical schemes (as in MITgcm)

Trends: modelling of ecosystem, pollutants, plastics

More tracers

Mixing schemes

- KPP (advanced): HYCOM, MITgcm, ROMS
- K-Eps (simpler): NEMO
- GLS (advanced): NEMO (tested in Arctic?)

Trends: more mixing to come

- Bigger waves
- Inertial waves transmission through more compliant ice (Gimbert et al. 2012)

Present trends in sea ice modelling

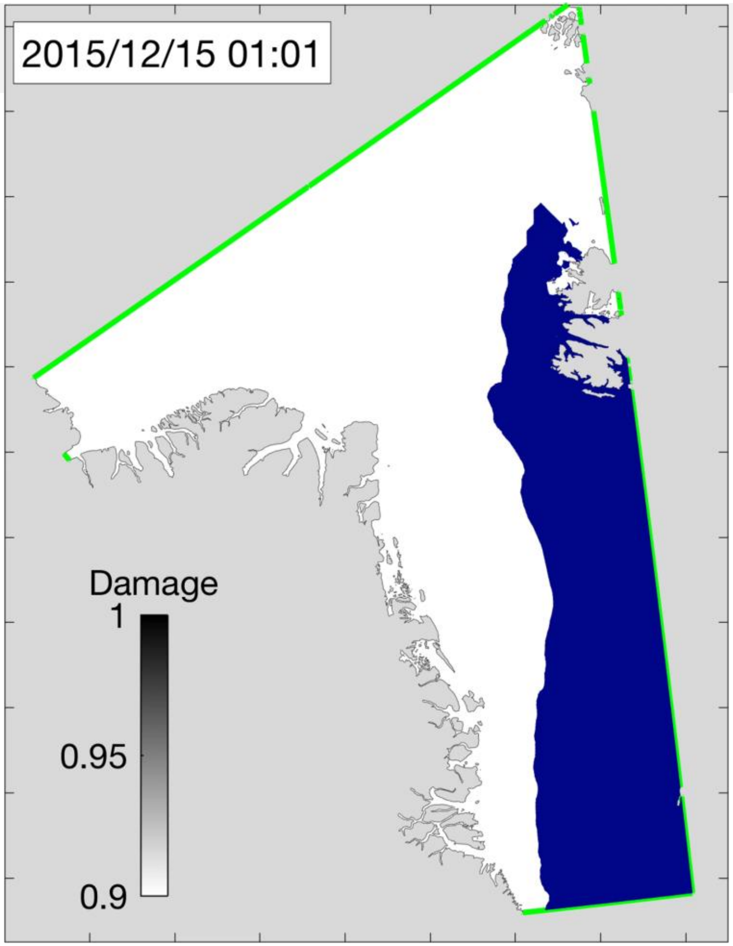
Sea ice models

CICE and LIM (soon SI³) community models

- Most popular rheologies are EVP and VP
- Use the same grid as the ocean model
- Focus on ice thermodynamics (ice thickness distribution, ice salinity, melt ponds)
- Resolve deformations at 10 times the grid cell

neXtSIM

- Use the Maxwell-Elastic-Brittle rheology
- Lagrangian mesh with remeshing
- Simpler thermodynamics
- Resolve deformations at the grid cell.
- May not need very complex thermodynamics.
- Akin to Sulsky's MPM method.
- More challenging coupling



Present trends in wave modelling

Waves in ice

Attenuation of waves in ice

- Combination of scattering and drag
- Implemented in Wavewatch3 (Ardhuin) and WAM (Bidlot)

Breaking of ice by flexural wave action

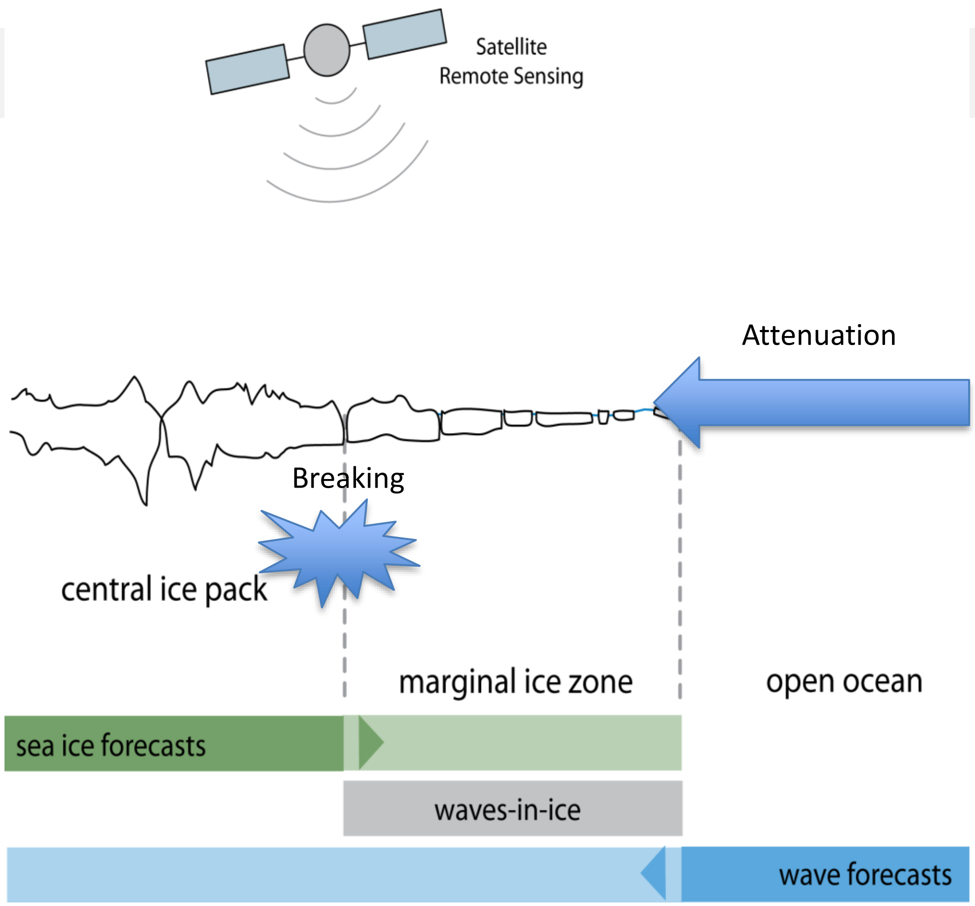
- Implemented in CICE by LANL (Bitz & Kohout), NERSC (Williams) and NOC (Hosekova).
- Implemented in neXtSIM (Williams)

Requires coupling of waves and sea ice models

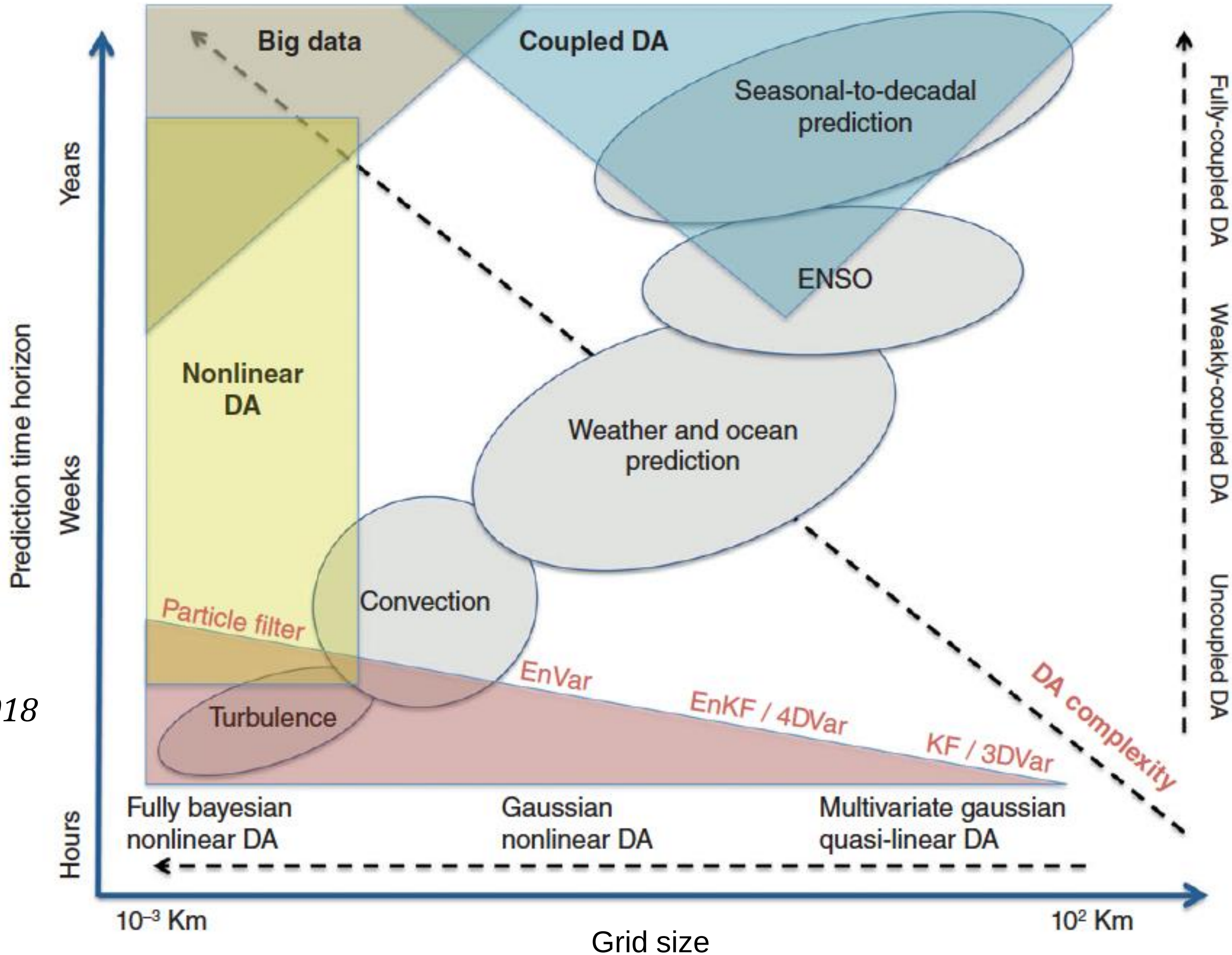
Not yet included in climate projections

Limitations:

- Too few observations of breaking events
- Wave scattering difficult to model



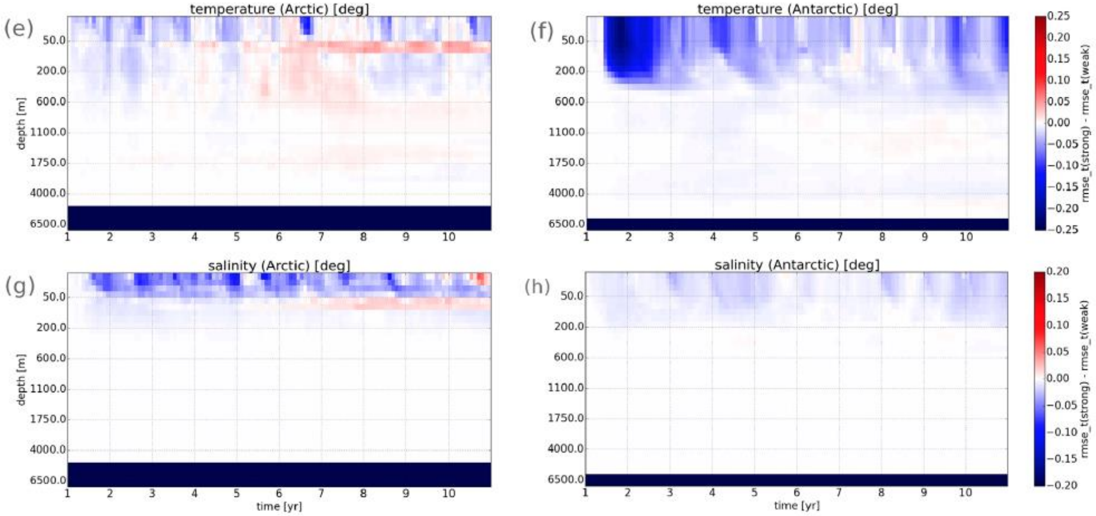
Present trends in data assimilation



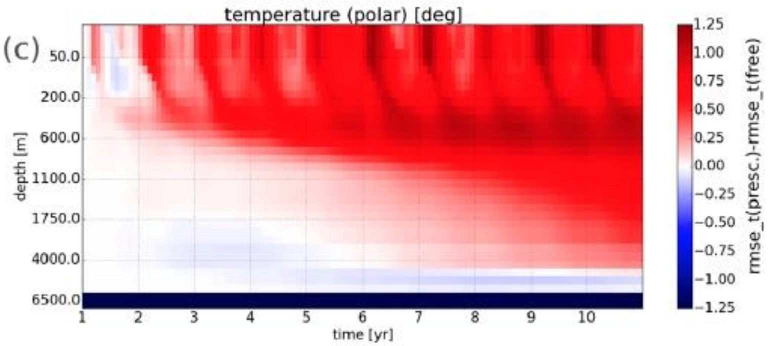
Carrassi et al., 2018

Assimilation in Coupled Earth System models

- Example among others:
- NorESM: Earth System Model
- CICE4: multi-category
- EnKF
- Assimilation of ice concentrations
- Comparison of weakly vs. strongly coupled assimilation
- And vs. simple prescribed ice-ocean covariance



Blue: Strong > weak assimilation



Red: Prescribed worse than free run

Strong coupled DA > weakly coupled >> prescribed

Present fashions: machine learning / AI

Machine Learning

Should apply to forecasting in principle.

Relies on many analogues for training

Favoured by stationarity

Not ideal for changing situations (Arctic …)

Table 10. Features of various Artificial Intelligence (AI) applications.

Type of Application	Rules are known and do not change	The environment is known and stable	Predictions can influence the future	Extent of Uncertainty (or amount of noise)	Examples
Games	Yes	Yes	No	None	Chess, GO
Image and speech recognition	Yes	Yes	No	Minimal (can be minimized by big data)	Face Recognition, Siri, Cortana, Google AI
Predictions based on the Law of large numbers	Yes	Yes	Minimally	Measurable (Normally distributed)	Forecasting the sales of beer, coffee, soft drinks, weather etc.
Autonomous Functions	Yes	Yes	No	Can be assessed and minimized	Self-Driving Vehicles
Strategy, Competition, Investments	No	No	Yes, often to a great extent	Cannot be measured (fat tails)	Decisions, Anticipations, Forecasts
Combinations of the above	It may be the ultimate challenge moving towards GAI (General AI) but also increasing the level of complexity and sophistication of algorithms				Eventually it can cover everything

https://doi.org/10.1371/journal.pone.0194889.t010

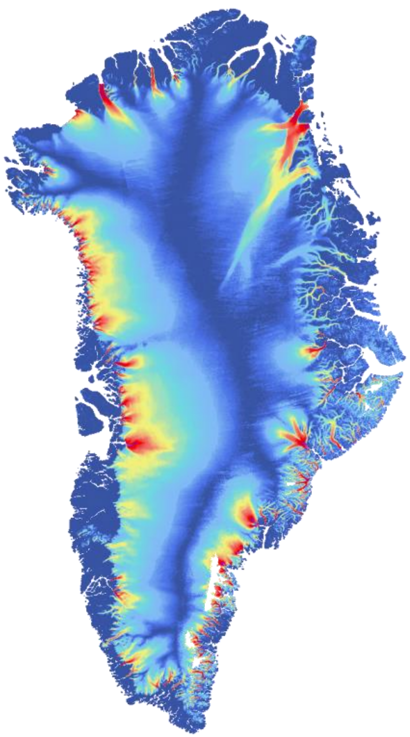
Makridakis et al. PLOS ONE 2018

About icebergs

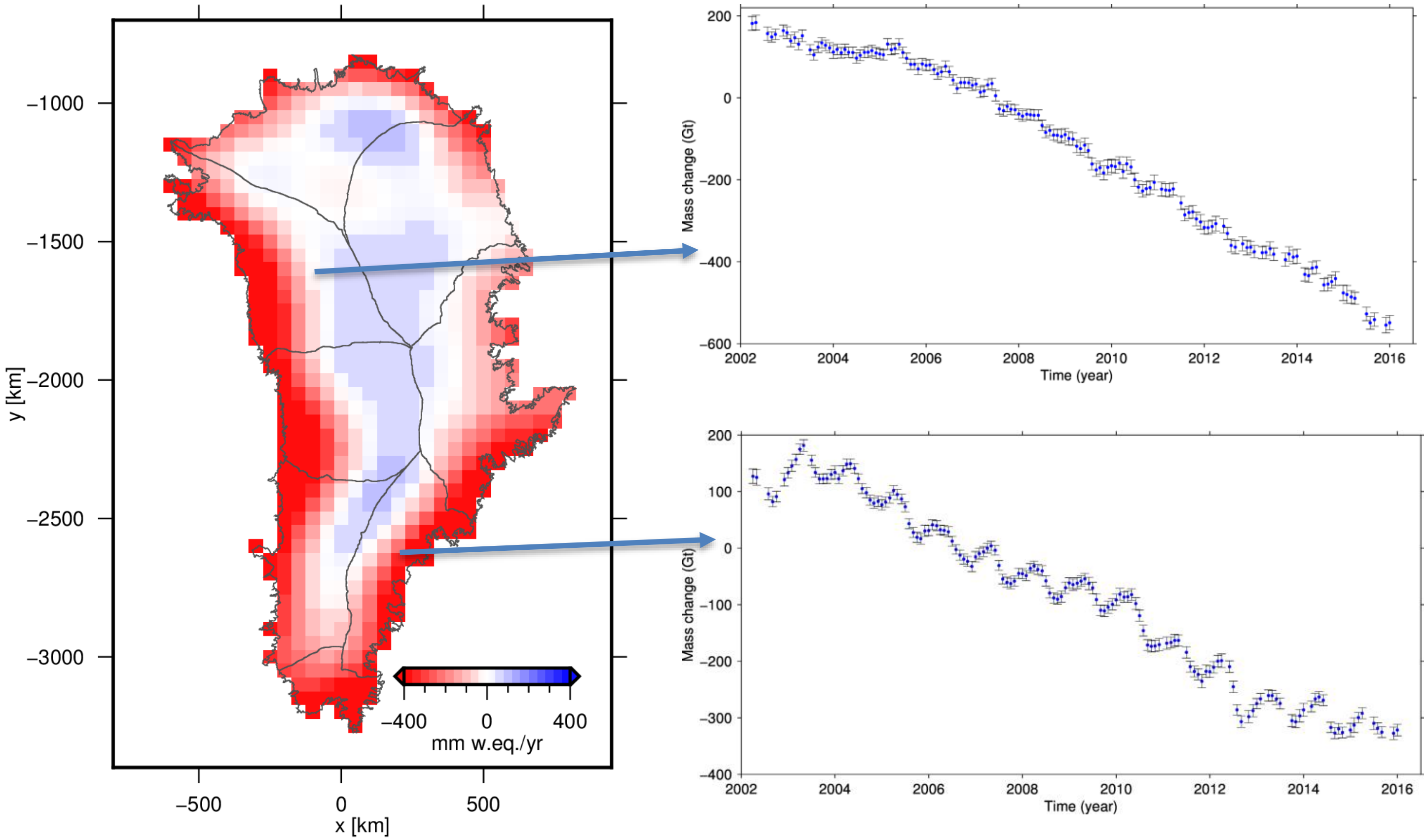
Calving from Greenland: ~375 Gt of ice per year.

Twice as fast in 2011-2014 as over 2003-2008 (AMAP, SWIPA 2017)

Most icebergs remain trapped in Greenland fjords

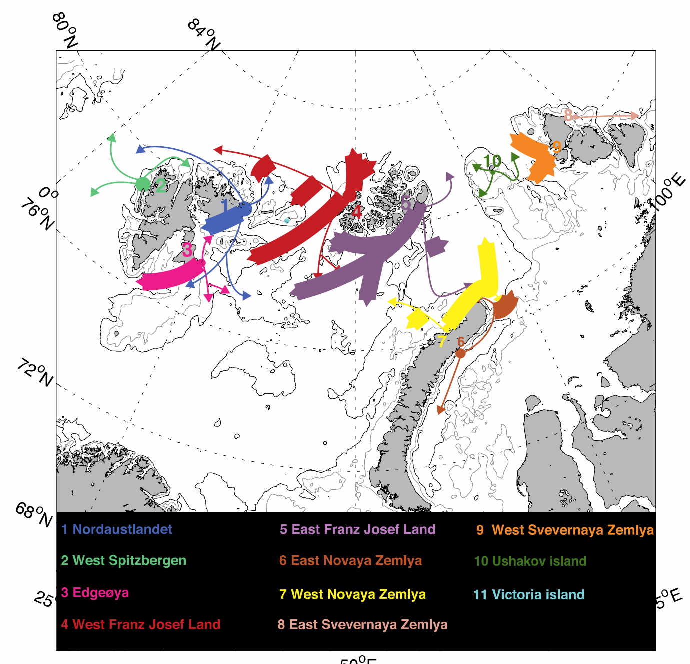


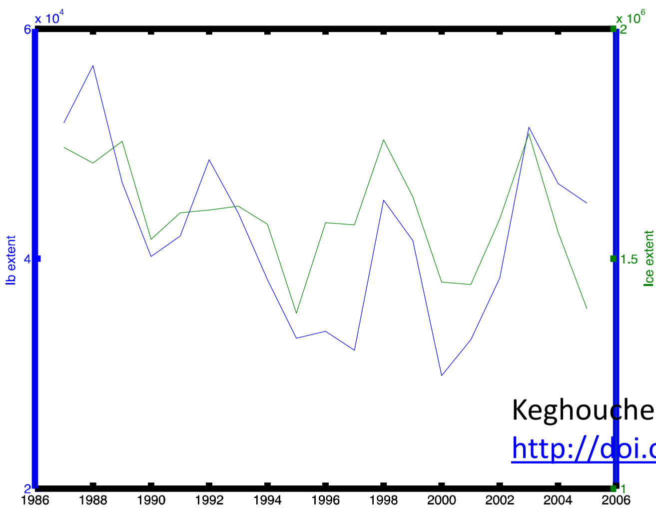
Ice velocities Dec 2017 – Feb 2018

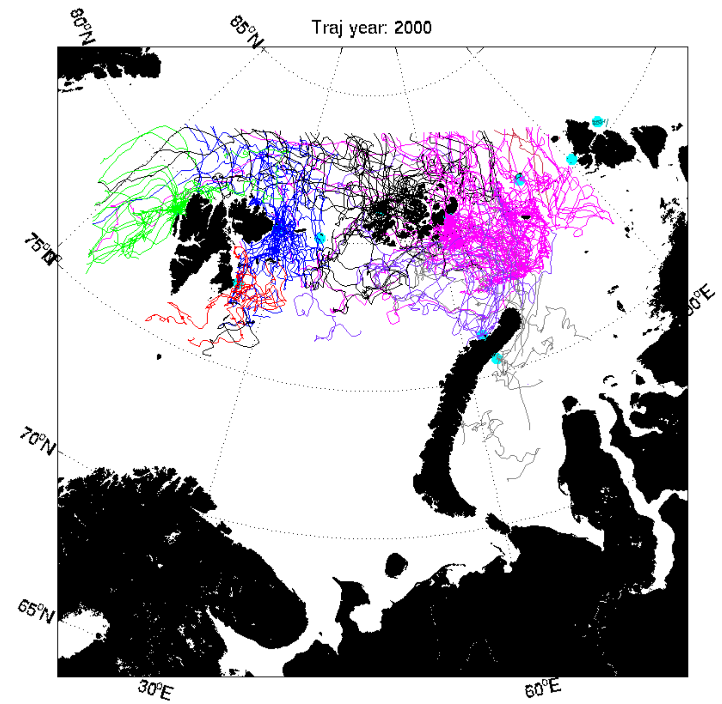


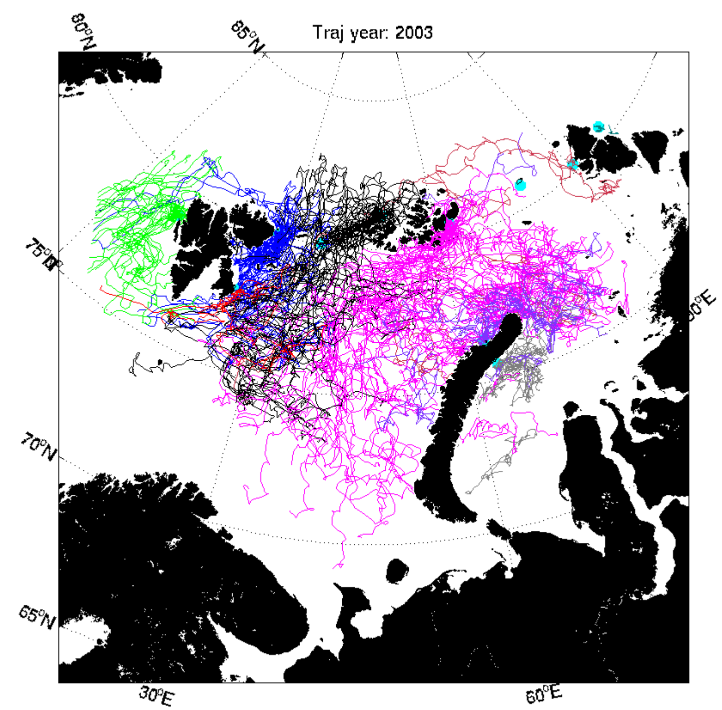
Gravimetric Mass loss 2002 – 2016

About icebergs in the Barents Sea



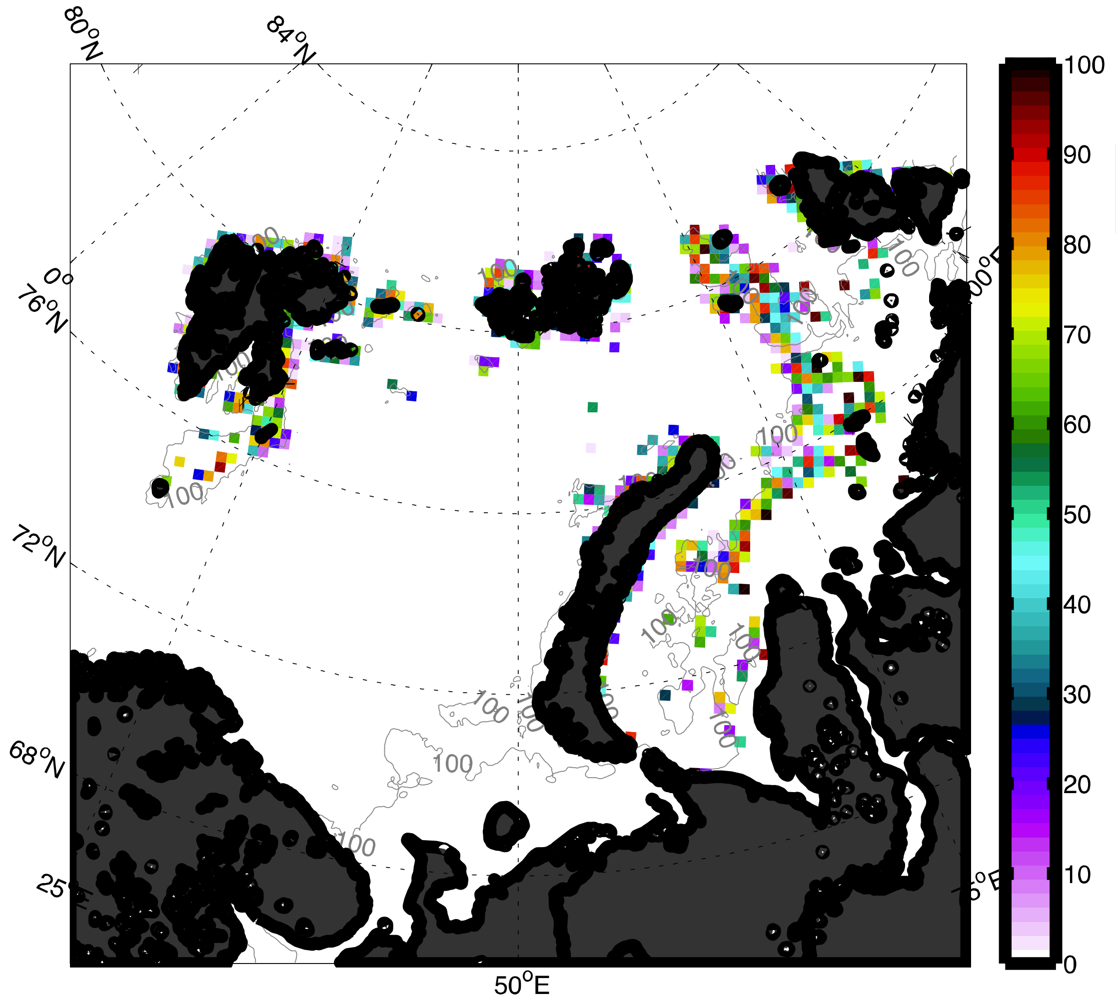






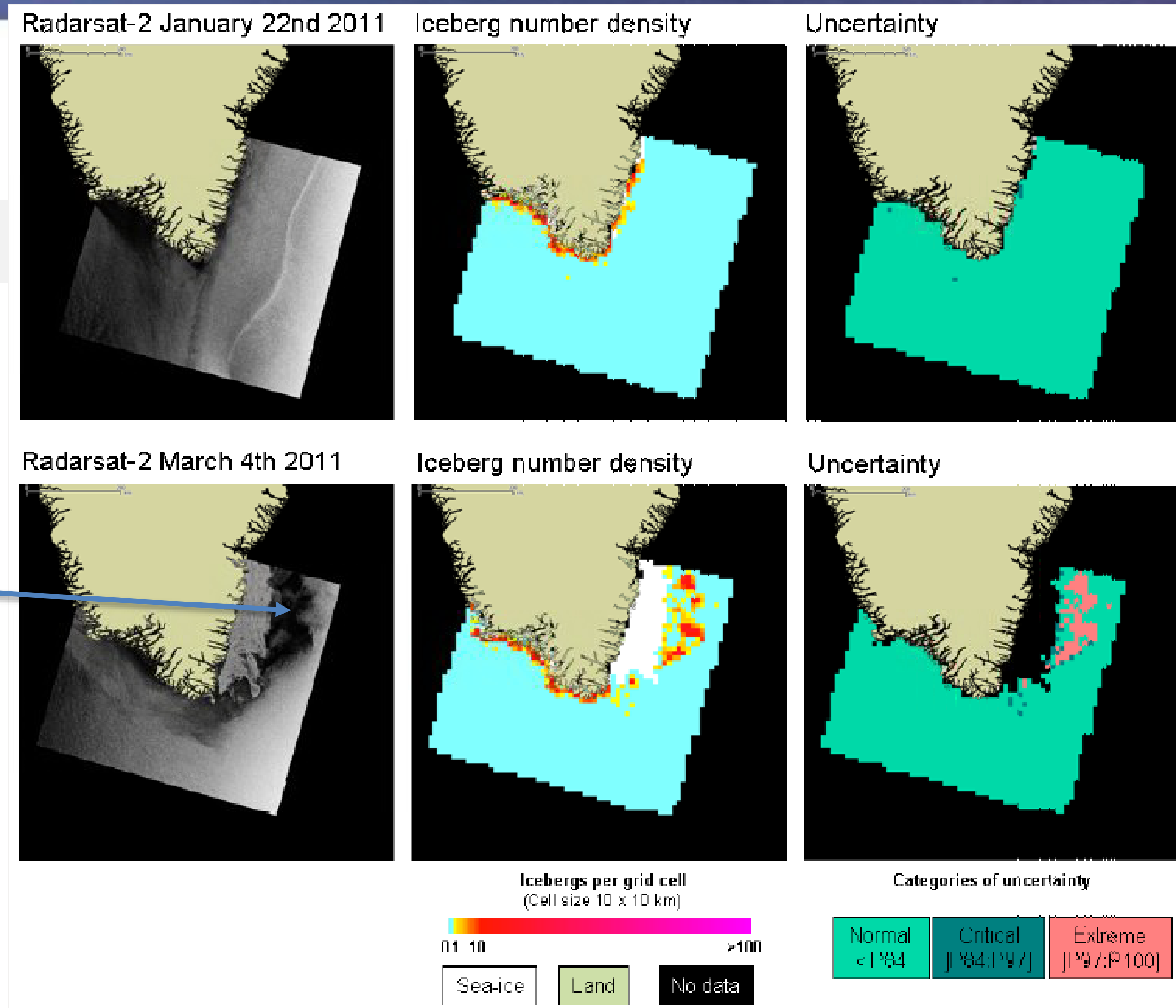
Keghouche, I., Counillon, F., & Bertino, L. (2010). http://doi.org/10.1029/2010JC006165

Grounding of icebergs



Probability of encountering at least one grounded iceberg in a 25x25 km square
Based on a 10-years simulation (Keghouche et al. 2010)

Satellite observations of icebergs



Low backscatter
= low image dynamics
= large errors

Automated CMEMS SAR-based iceberg concentration products from DMI (Whole Arctic)

http://marine.copernicus.eu SEAICE_ARC_SEAICE_L4_NRT_OBSERVATIONS_011_007

Present trends in iceberg modeling

Main unknowns:

- Iceberg calving rates
- Size distribution of icebergs

Drift simulation

- Winds
- Currents
- Sea ice drift
- Waves

Trends:

less sea ice, more spreading of icebergs.

Also faster melting of icebergs

Remote sensing of icebergs

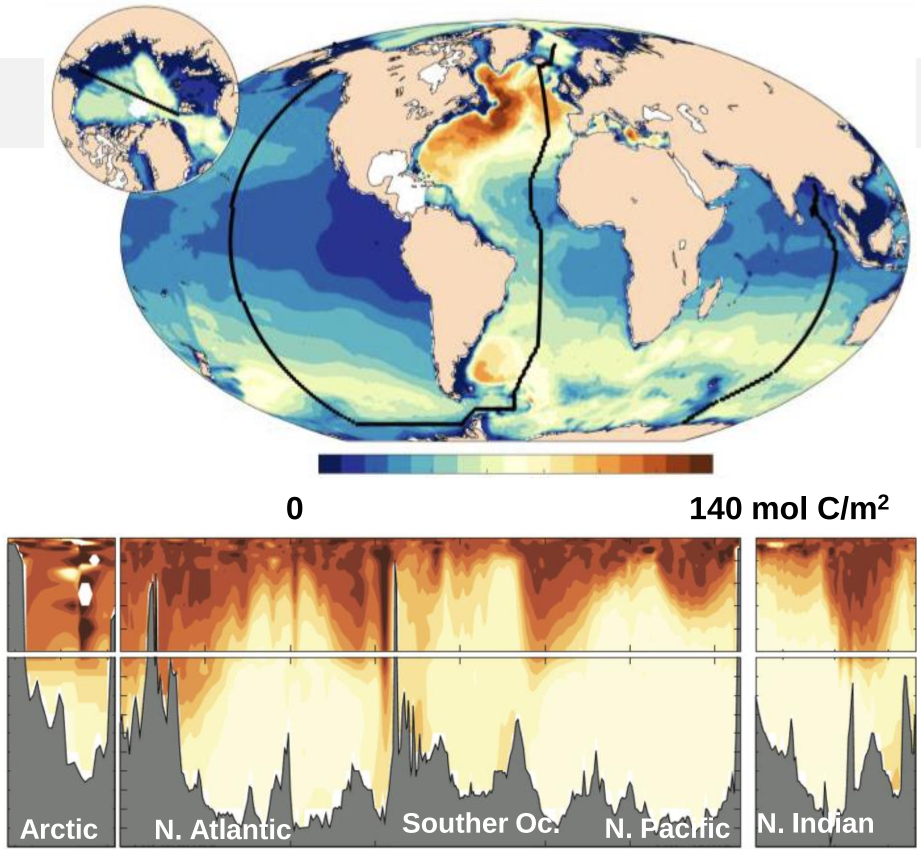
New techniques, new satellites

More or fewer icebergs?

More	Fewer
Warmer ice sheets / glaciers	Warmer water
Less sea ice	Less sea ice
Warmer ocean water	More waves
More calving	More efficient melting / erosion
More icebergs on the loose	… on shorter trajectories

Ocean acidification

Anthropogenic Carbon



GLODAP2
Lauvset et al. 2016

If CO_2 emission continue to increase

- **Within the 21st Century**
- **Unsaturated conditions for aragonite (carbonate mineral) in Arctic / S. Ocean**
- **Aragonite is part of shells and reef structures**
- **Detrimental effects for pteropods and cold water corals**

Ocean acidification acts in combination with other stressors of marine ecosystems.

May not affect fish directly, but through their food supply and habitat.

Not clear how a whole ecosystem will respond.

Olsen et al.

UN Foresight Brief, July 2018

Marine Ecosystem: Fish migrations

Fish migration

- Recent warming in the Barents Sea has led to a change in spatial distribution of fish communities
- with boreal communities expanding northwards
- at a pace reflecting the local climate velocities

Fossheim et al. (Nature Climate Change 2015).

Change of fish communities confirmed by birds diet (black-legged kittiwakes).

Vihtakari et al. (Scientific Reports 2018)

Fish migration limited to the North by deep waters

Primary Production

- Declines in sea ice cover in the Arctic Ocean can fundamentally alter marine ecosystems.
- Annual net primary production (NPP) in the Arctic Ocean rose 30% between 1998 and 2012.
- Increased NPP was associated with reduced sea ice extent and longer growing season.
- Increased nutrient fluxes may also play an important role.

Arrigo and van Dijken (Prog. Ocean. 2015)

Bathymetric maps

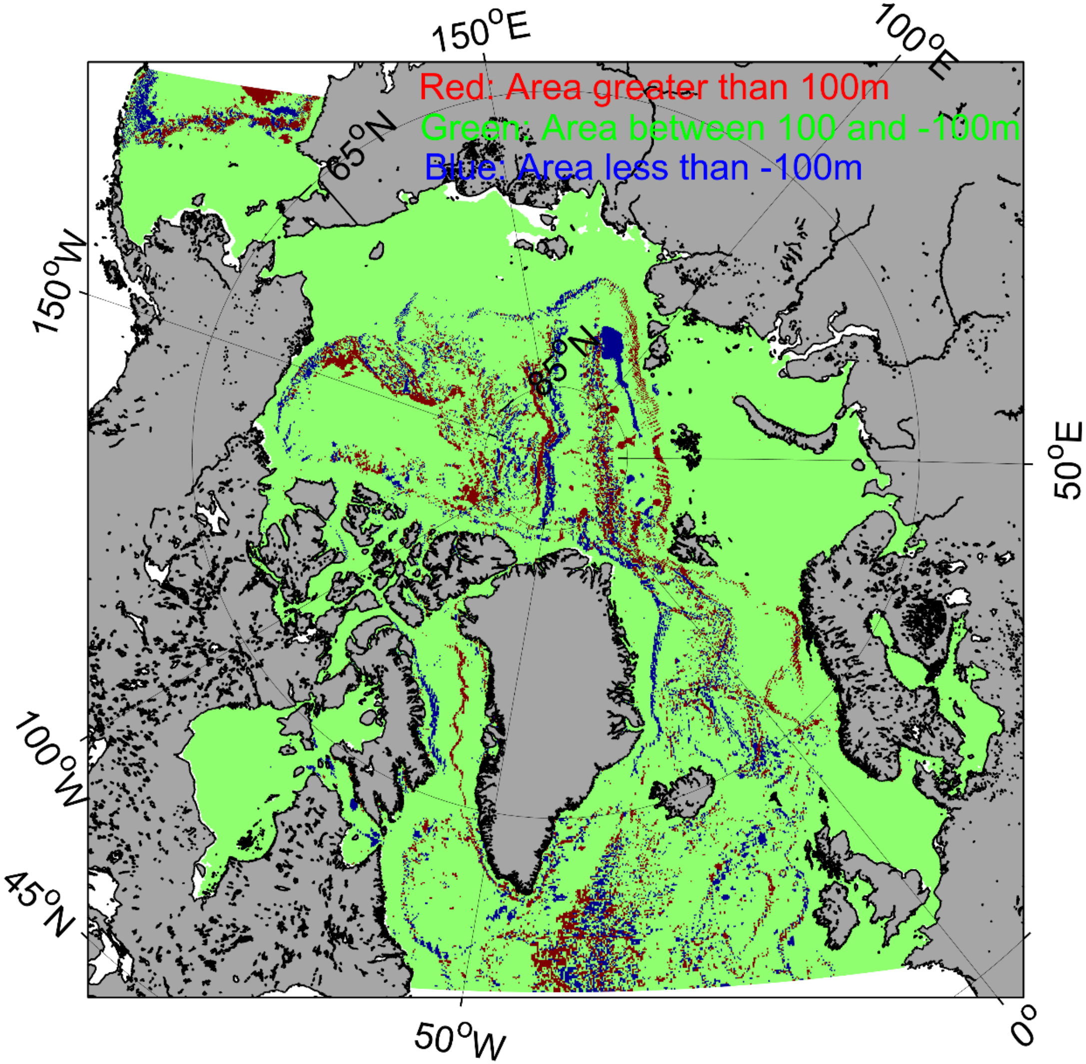
Differences between 2 bathymetric datasets

At the same resolution

Both recent versions

ETOPO minus GEBCO

- ocean basins at resolution <10km
- Less than 10% of ocean bottom surveyed.



Gaps and uncertainties in current practice

Basic knowledge

- Clouds
- Sea ice
- Greenland ice sheet
- Ocean mixing
- Ocean Biology
- Topography

Sometimes the understanding is there, but not the quantitative knowledge

Other uncertainties

- Funding for HPC power
- Funding for modelling initiatives (many are US-based)
- Continuity of space programmes
- Sustainability of in situ measurement programmes

What can YOU do?

Support (real) model biodiversity

- Regional modeling studies / hindcasts
- Ensure models deliver what they promise
- Support development of coupled

Support young researchers

Wake up your data!

- EMODNET
- https://emodnet-ingestion.eu/
- And/or CMEMS
- servicedesk.cmems@mercator-ocean.eu

Assignment

- How has our understanding of changes and model projections evolved since 2008?
  - Understanding was pretty good (man-made global warming)
  - Arctic amplification more complex than thought 10 years ago, not a solved question.
  - Model projections have improved slightly (sea ice area decline)
  - Model projections are increasingly using advanced + coupled data assimilation
- What is current best practise, including the most appropriate models, downscaling approaches and analysis techniques?
  - Real model biodiversity (less inbreeding, new ideas)
  - Better model design
- Is current practice at a state where it can be relied upon for long-term business decisions?
  - Yeah, go for renewable energies
  - High stakes / high uncertainty
- What are the recognised gaps and uncertainties in current practise
  - Clouds, biogeochemistry, sea ice, ocean mixing, Greenland ice sheet and other glacial melt
  - Sustainability of observing systems (satellite and in situ).
  - Future supercomputers will not support the needs of models and data assimilation
- and what needs to be done to close these gaps and address the uncertainties?
  - Heavy measurement campaigns, shared data.
  - Support investments in space programs, model developments, HPC infrastructure
  - Step-change in model developments,
  - Support indigenous people in keeping traditional knowledge


Thank you!