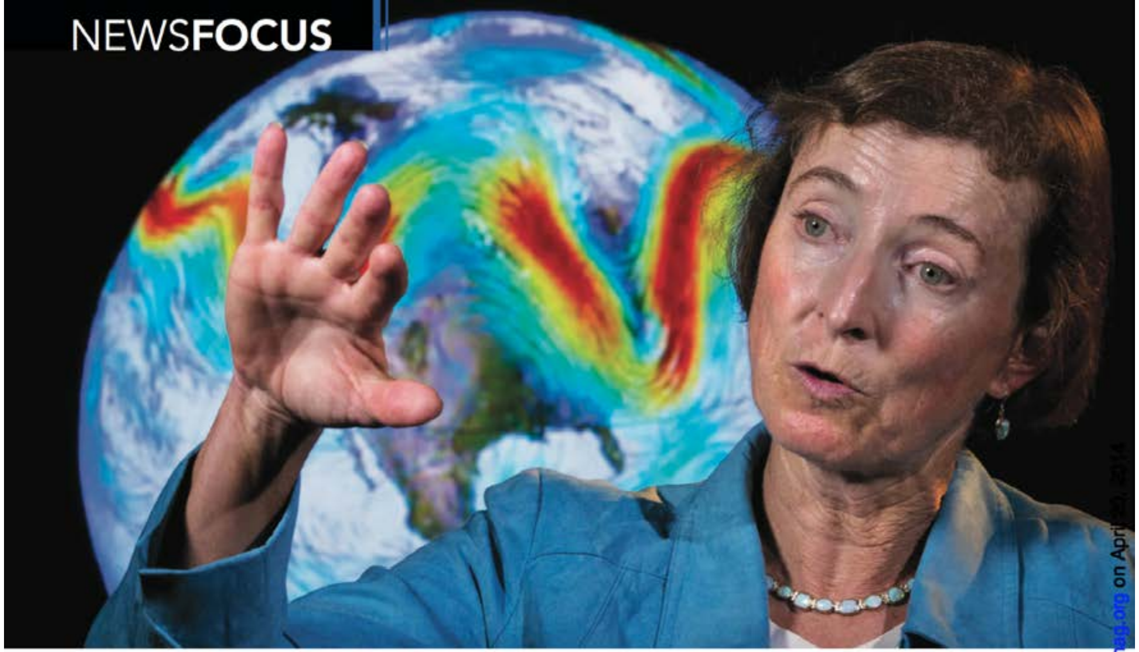
KOPRI’s Modelling Activities & Future Contribution to PAG

Baek-Min Kim
Korea Polar Research Institute

Atmospheric modelling activities



CREDIT: JACQUELYN MARTIN/AP PHOTO

Into the Maelstrom

Jennifer Francis has made waves linking the melting Arctic to extreme weather around the world. But a storm of criticism has forced the climate scientist to defend her hypothesis

When 40 climate experts huddled in a small conference room near Washington, D.C., last September, all eyes were on an atmospheric scientist named Jennifer Francis. Three years ago, Francis proposed that the warming Arctic is changing weather patterns in temperate latitudes by altering the behavior of the northern polar jet stream, the high, fast-moving river of air that snakes around the top of the world. The idea neatly linked climate change to weather, and it has resonated with the press, the public, and powerful policymakers. But that day, Francis knew that many of her colleagues—including some in that room—were deeply skeptical of the idea, and irritated by its high profile.

Sometimes, Francis is anxious before high-pressure talks and wakes before dawn. Not this time, even though the National Academy of Sciences had assembled the group essentially to scrutinize her hypothesis. "I wasn't nervous," she recently recalled. "I was prepared for the pushback."

It came fast and hard. Just one slide into her talk, before she could show a single data point, a colleague named Martin Hoerling raised a challenge. "I'll answer that with my next figure," Francis calmly responded, her bright blue eyes wide open. Two minutes later, Hoerling interrupted again, calling a figure "arbitrary." Francis, unruffled, parried—only to have Hoerling jab again.

Francis presented the evidence for her hypothesis as an orderly chain of events. "I challenged every link in the chain," recalls Hoerling, an atmospheric dynamicist at the National Oceanic and Atmospheric Administration's (NOAA's) Earth System Research Laboratory in Boulder, Colorado. Eventually, the workshop's organizer had to intervene. No more questions "so the dissertation defense can go on," nervously joked David Robinson, a climatologist at Rutgers University in New Brunswick, New Jersey, where Francis also works.

Later, some attendees praised Francis's performance. "The way [Hoerling] aggressively interrupted was unusual," says Arctic scientist Walt Meier of NASA's Goddard Space Flight Center in Greenbelt, Maryland. "But she handled it very well, with grace."

Hoerling's assessment? "She was unpersuasive," he says. "The hypothesis is pretty much dead in the water."

A stiff headwind

Francis's hypothesis has divided colleagues ever since she first proposed it in 2011, and the divisions have only deepened as Francis became a go-to climate scientist for reporters, a marquee speaker at major conferences, and an informal consultant to John Holdren, President Barack Obama's science adviser. "It's become a shooting match over her work," says atmospheric dynamicist Walter Robinson of North Carolina State University in Raleigh. "Which side are you on?"

More than scientific bragging rights are at stake. If a warming Arctic is already affecting weather in the midlatitudes, then climate change "no longer becomes something that's remote, affecting polar bears," Meier says. Instead, it's a day-to-day reality affecting billions of people—and a challenge to policymakers responsible for assessing and reducing the risks.

Published by AAAS

ARTICLE

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Weakening of the stratospheric polar vortex by Arctic sea-ice loss

Baek-Min Kim[1], Seok-Woo Son[2], Seung-Ki Min[3], Jee-Hoon Jeong[4], Seong-Joong Kim[1], Xiangdong Zhang[5], Taehyoun Shim[4] & Jin-Ho Yoon[6]

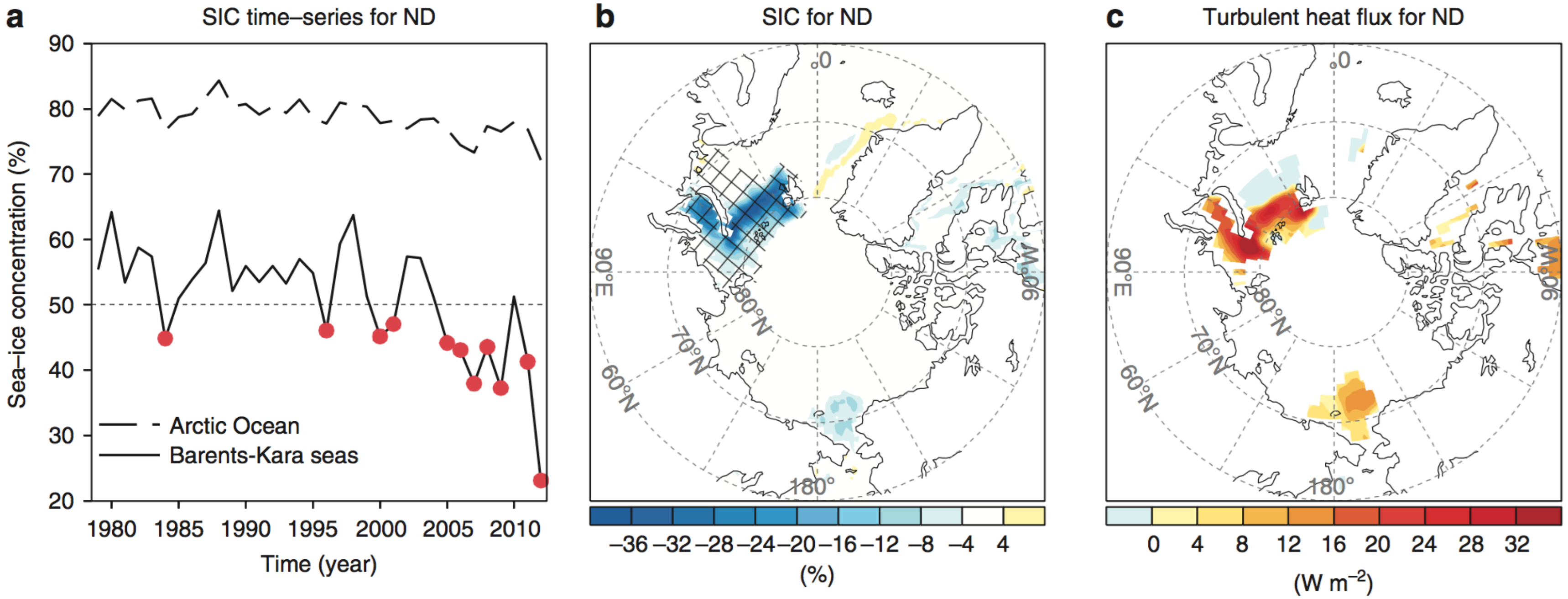
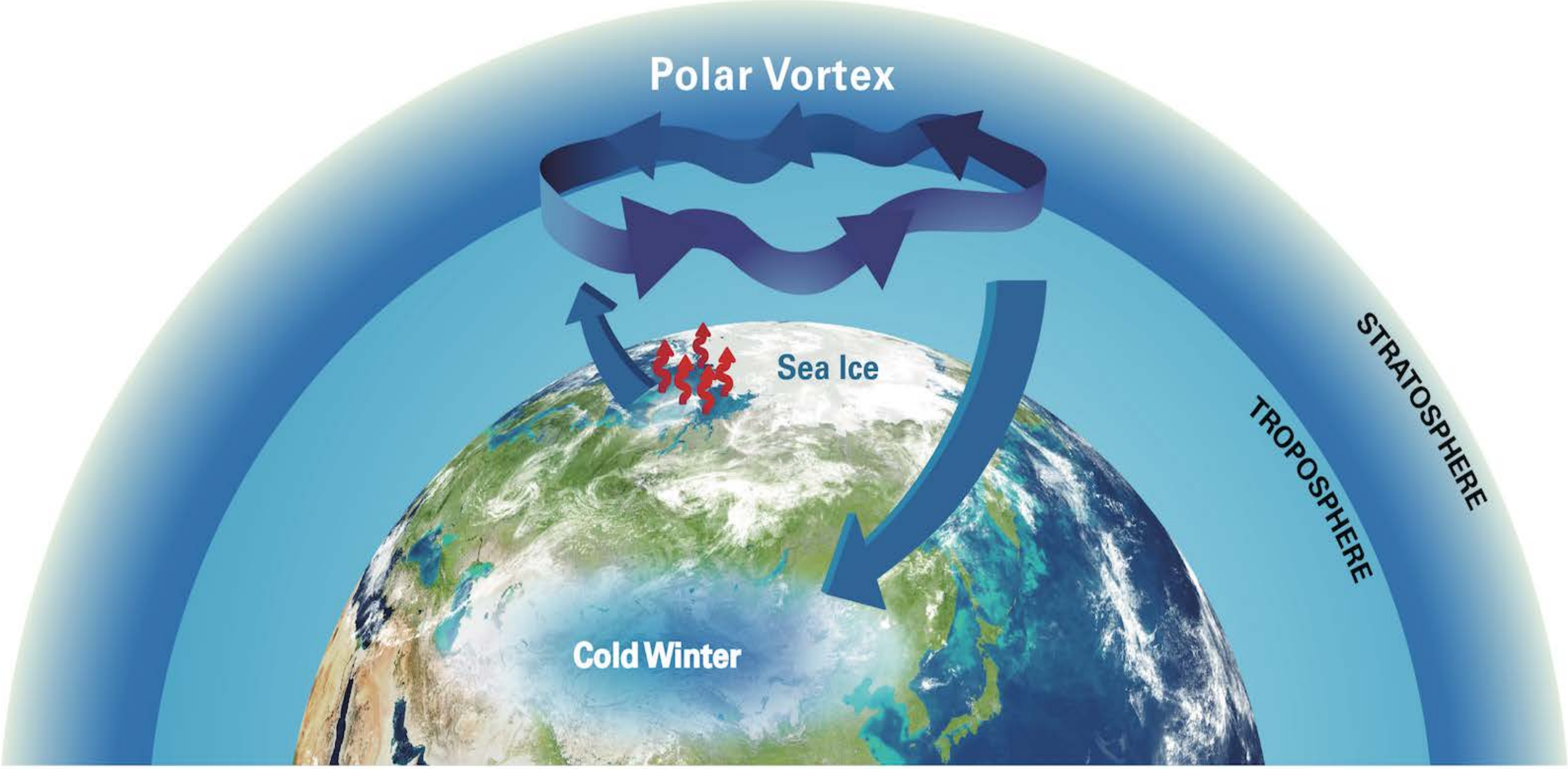


Figure 1 | SIC variability over the B-K seas during the early winter season. (**a**) An area-averaged time-series of SIC for the entire area of the Arctic Ocean (dashed) and B-K seas (solid) during the early winter for the period 1979–2012. The area of the B-K seas is indicated by hatched region in **b**. Years during which the area-averaged SIC $<50\%$ over the B-K seas are indicated by red dots (11 sample years). The composite mean anomaly of (**b**) SIC (%) and



Kim et al. (2014)

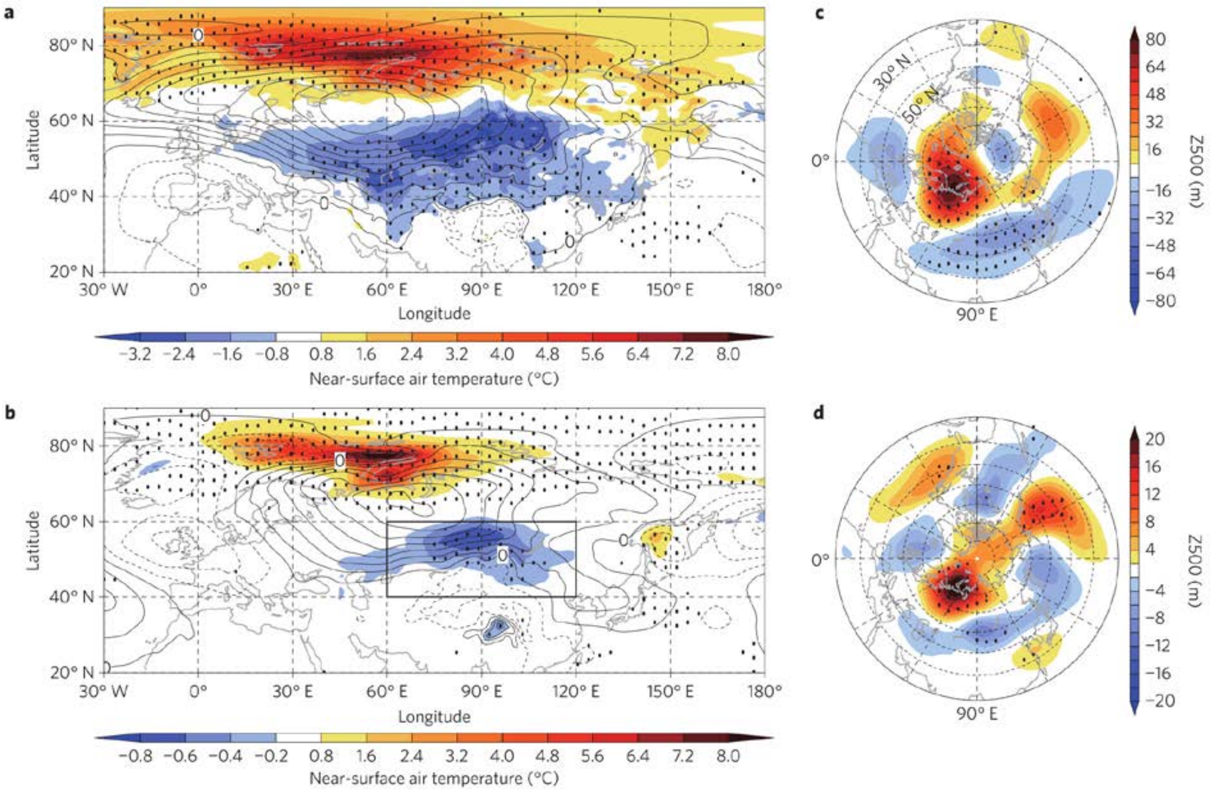
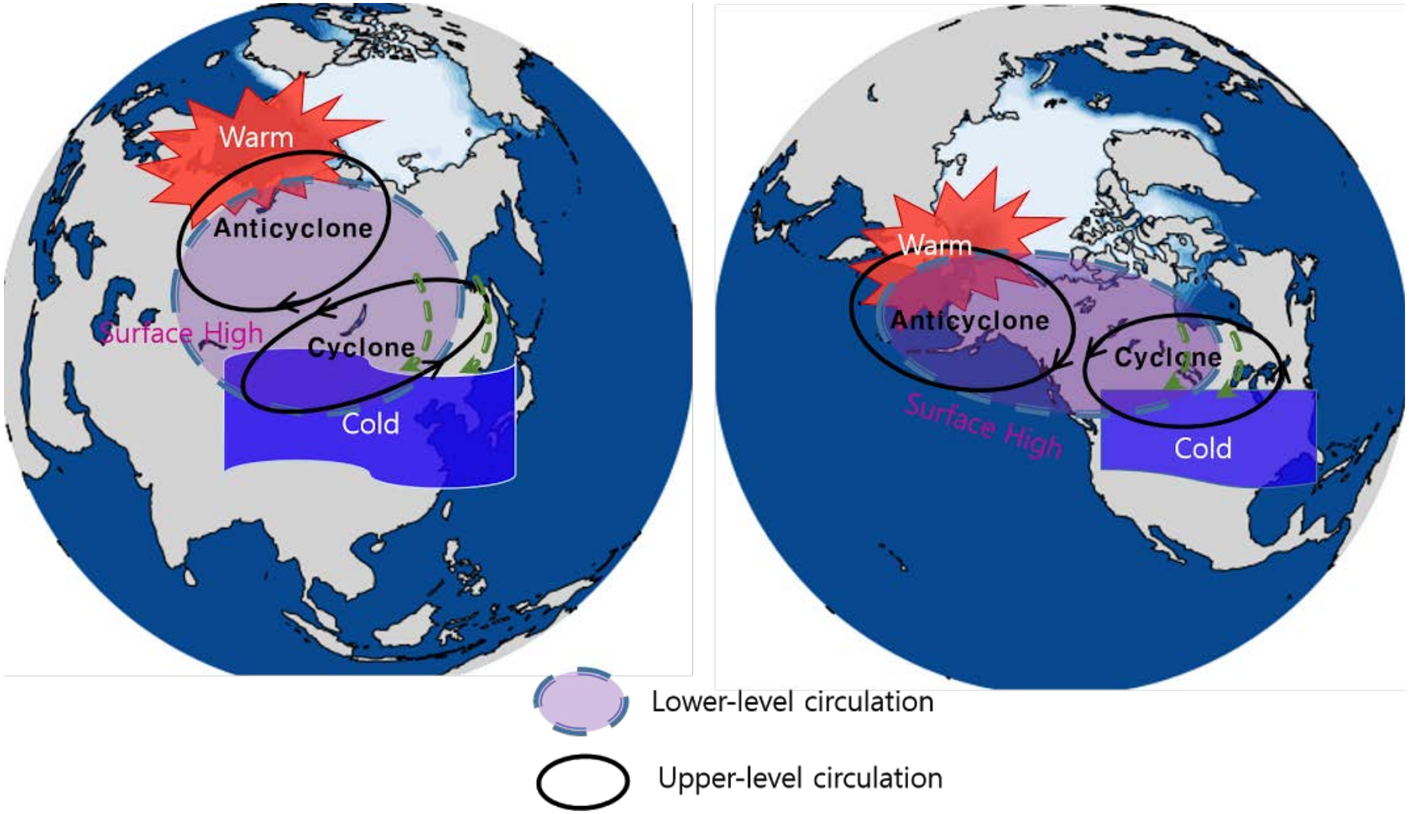


Figure 1 | Observed and simulated change in winter SAT and atmospheric circulation associated with sea-ice retreat in the Barents–Kara region. **a**,**b**, Differences of composite fields between the low- and high-ice years (that is, the former minus the latter) for SAT (colour) and SLP (contours) in DJF, taken from ERA-Interim (**a**) and the 100-member ensembles of the LICE and HICE experiments (**b**). Contour interval is 0.8 hPa in **a** and 0.2 hPa in **b**, with negative contours dashed. Stippling indicates regions of significant difference exceeding 95% statistical confidence. **c**,**d**, Differences of composite fields between the low- and high-ice years (that is, the former minus the latter) for Z500 in DJF, taken from ERA-Interim (**c**) and the 100-member ensembles of the LICE and HICE experiments (**d**). Stippling indicates regions of significant difference exceeding 95% statistical confidence.

Mori et al. (2014)

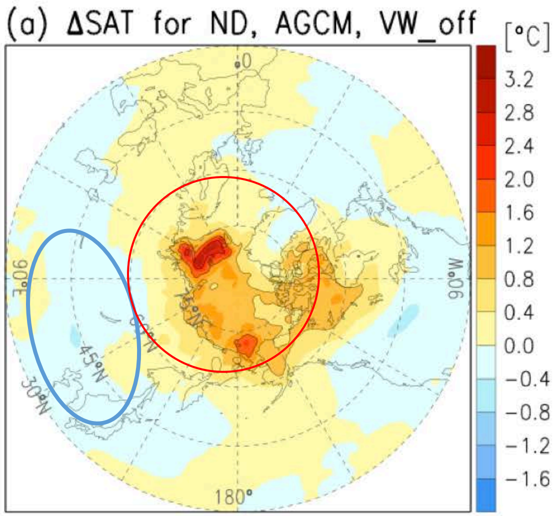


Kug et al. (2015)

Cloud is a key to understanding the Arctic Mid-latitude teleconnection

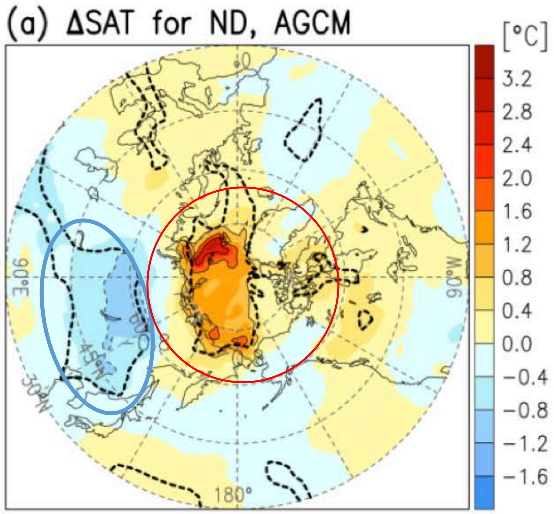
<Cloud fraction (ordinary method)>

$$f = \left[\frac{(\mathrm{RH} - \mathrm{RH}_{\mathrm{MIN}})}{(1 - \mathrm{RH}_{\mathrm{MIN}})}\right]^2$$



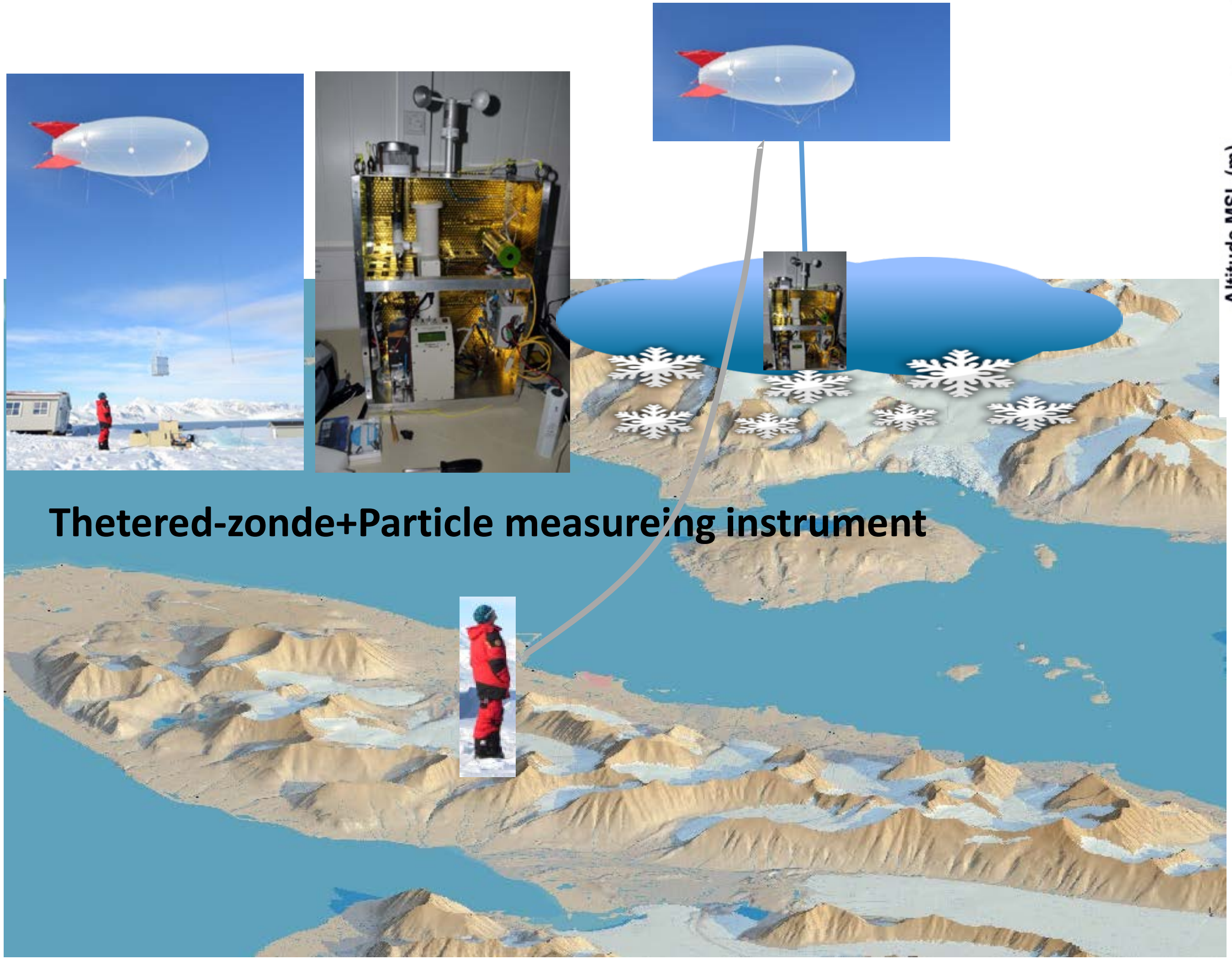
<Cloud fraction (modified)>

$$f = f \times \left[\max(0.15, \min)\left(1.0, \frac{q}{0.003}\right)\right]$$

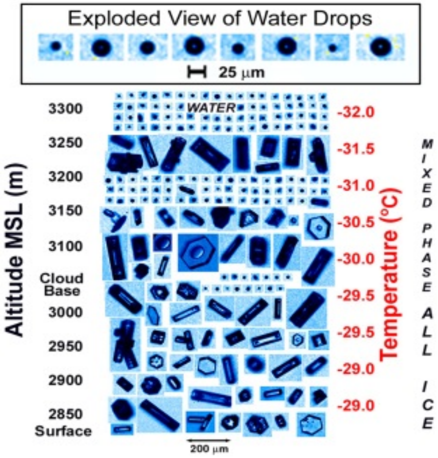


Kim et al. (2014)

Cloud microphysical processes

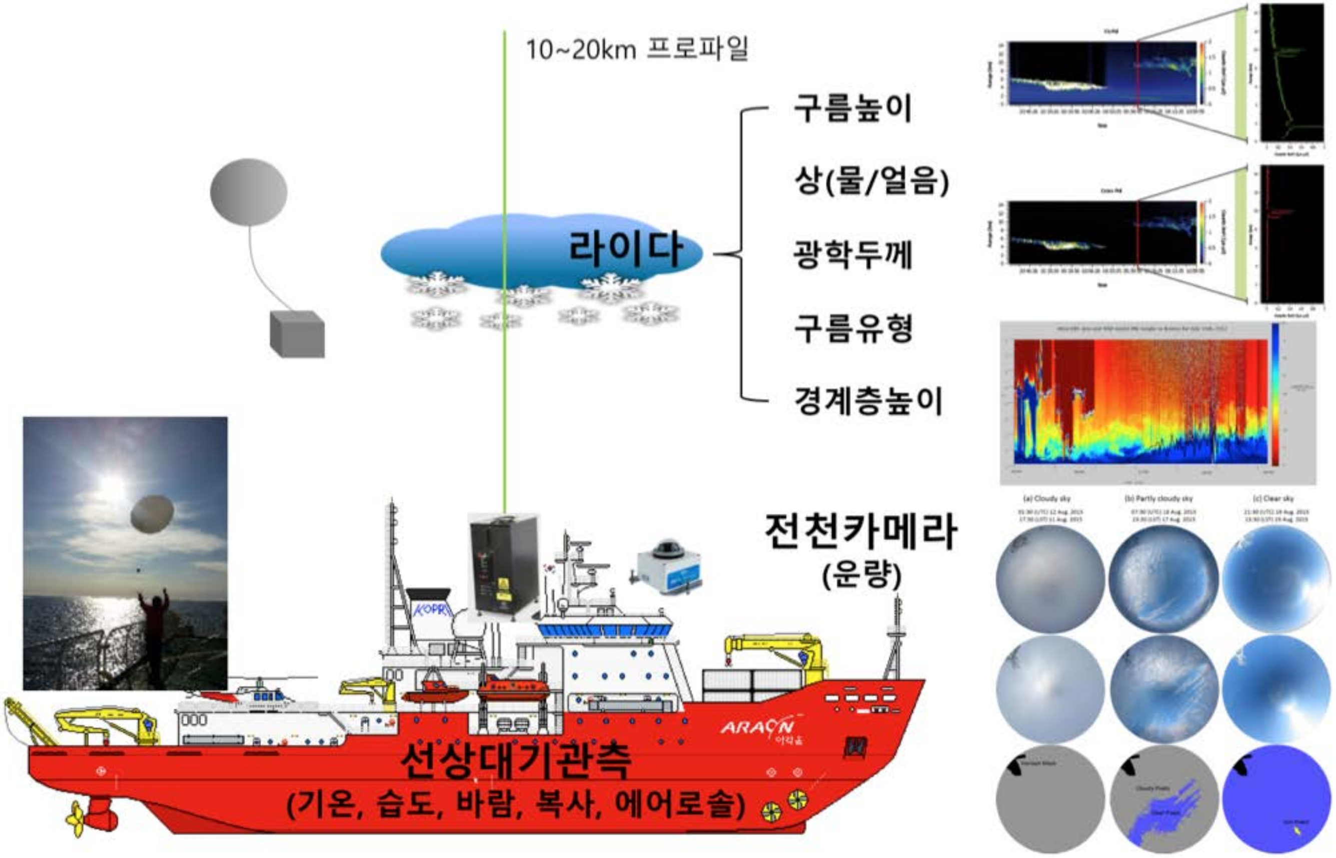


Thetered-zonde+Particle measureing instrument



Direct observation of cloud inside

Araon-based cloud observations



10~20km 프로파일

라이다

구름높이

상(물/얼음)

광학두께

구름유형

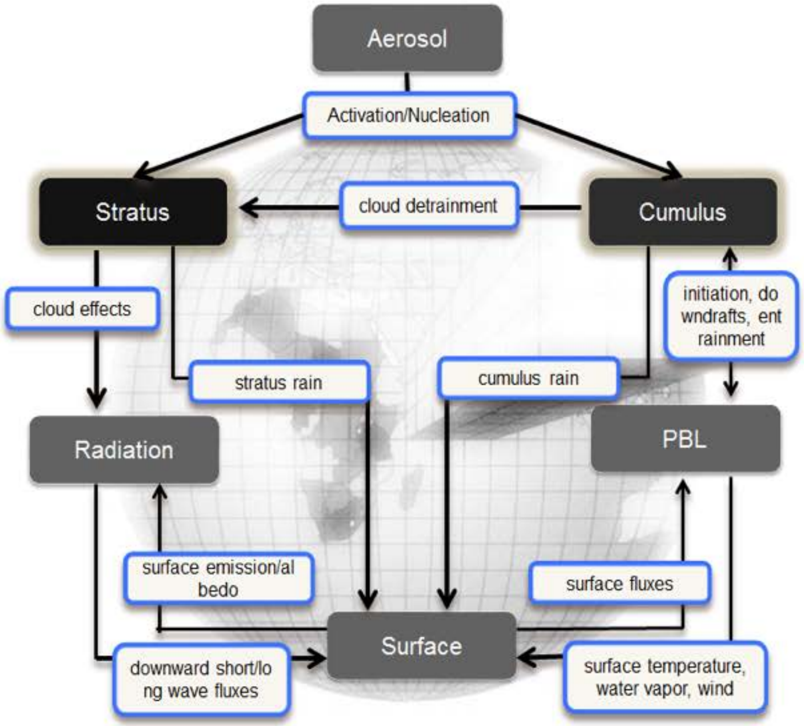
경계층높이

전천카메라
(운량)

선상대기관측
(기온, 습도, 바람, 복사, 에어로솔)

'극지예측의 해(YOPP)'대비 북극해 대기관측망 강화*

***태평양북극그룹(PAG)활동에 기여**



Aerosol

Activation/Nucleation

Stratus

cloud detrainment

Cumulus

cloud effects

initiation, downdrafts, entrainment

stratus rain

cumulus rain

Radiation

PBL

surface emission/albedo

surface fluxes

Surface

downward short/long wave fluxes

surface temperature, water vapor, wind

- Develop physical packages for Arctic clouds & PBL based on Arctic observations (DASAN, ARAON, PAG, MOSAiC)

- Construct regional & global modelling system equipped with newly developed physics

Ocean-sea ice modelling activities & plan

Model


Community Earth System Model
v1.2
Atmosphere Models
Land Models
Sea Ice Models
Coupler
CESM Coupler (CPL7)
Ocean Models
Land Ice Models
River Models

CESM description

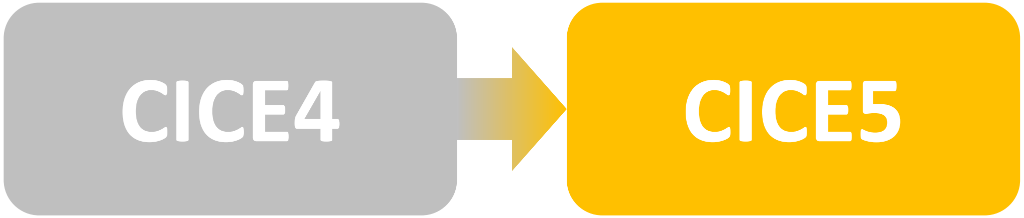
Model	CCSM3 (2004)	CCSM3.5 (2007)	CCSM4 (Apr 2010)	CESM1 (Jun 2010)
Atmosphere	**CAM3 (L26)**	**CAM3.5 (L26)**	**CAM4 (L26)**	**CAM5 (L30)**
Boundary Layer Turbulence	Holtslag-Boville (93) Dry Turbulence	Holtslag-Boville (93) Dry Turbulence	Holtslag-Boville (93) Dry Turbulence	Bretherton-Park (09) UW Moist Turbulence
Shallow Convection	Hack (94)	Hack (94)	Hack (94)	Park-Bretherton (09) UW Shallow Convection
Deep Convection	Zhang-McFarlane (95)	Zhang-McFarlane (95)	Zhang-McFarlane (95) Neale et al. (08) Richter-Rasch (08)	Zhang-McFarlane (95) Neale et al. (08) Richter-Rasch (08)
Cloud Macrophysics	Zhang et al. (03)	Zhang et al. (03)	Zhang et al. (03)	Park-Bretherton-Rasch (10) UW Cloud Macrophysics
Stratiform Microphysics	Rasch-Kristjansson (98) Single Moment	Rasch-Kristjansson (98) Single Moment	Rasch-Kristjansson (98) Single Moment	Morrison and Gettelman (08) Double Moment
Radiation/Optics	CAMRT (01)	CAMRT (01)	CAMRT (01)	RRTMG Lacono et al. (08)/ Mitchell (08)
Aerosols	Bulk Aerosol Model	Bulk Aerosol Model	Bulk Aerosol Model	Modal Aerosol Model Liu et al. (10)
Dynamics	Spectral	Finite Volume	Finite Volume	Finite Volume
Chemistry	-	-	-	CAM-CHEM
Ocean	**POP2 (L40)**	**POP2.1 (L60)**	**POP2.2**	**POP2.2**
Land	**CLM3**	**CLM3.5**	**CML4 – CN**	**CLM4 – CN**
Sea Ice	**CSIM4**	**CSIM4**	**CICE4**	**CICE4**

Improvement of physical processes

Interactive chemistry model

Carbon-Nitrogen cycle model

Parameterization impact study



What's new in CICE5?

physics

- A method for **prognosing sea ice salinity**, including improved snow-ice formation
- Two new explicit **melt pond parameterizations** (topo and level-ice)
- Sea ice biogeochemistry
- Elastic-Anisotropic-Plastic rheology
- Improved parameterization of form drag
- The "revised EVP" under-damping approach
- Gracefully handles the case when an internal layer melts completely

infrastructure

- Ice and snow enthalpy defined as tracers
- ...

efficiency

- ...

miscellaneous

- ...

http://oceans11.lanl.gov/trac/CICE/wiki/UpdatesSeptember2013

Thermodynamics in CICE5

- zero-layer thermodynamics
- Bitz and Lipscomb model (fixed salinity profile)
- mushy formulation (salinity evolves)

Parameterization impact study

Sea ice thermodyamics

Bitz and Lipscomb model (fixed salinity profile)

Multi-year ice salinity constant over time

(Maykut 1992)

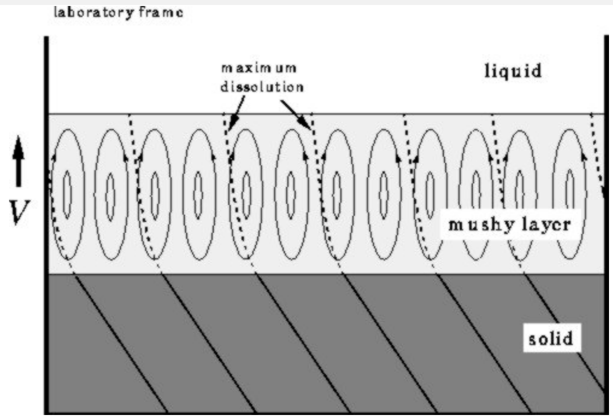
$$S_{ik} = \frac{1}{2} S_{\max}[1 - \cos(\pi z^{(\frac{a}{z+b})})]$$

$$c_i(T,S) = c_0 + \frac{L_0 \mu S}{T^2}$$

$$K_0 = 2.03 \text{ W/m/deg} \qquad K_i(T,S) = K_0 + \frac{\beta S}{T}$$

$$\rho_i c_i \frac{\partial T_i}{\partial t} = \frac{\partial}{\partial z}\left(K_i \frac{\partial T_i}{\partial z}\right) - \frac{\partial}{\partial z}[I_{pen}(z)]$$

Mushy (Feltham et al. 2006) formulation (salinity evolves)



$$C_{bulk}(z,t) = \phi C_i + (1-\phi)C.$$

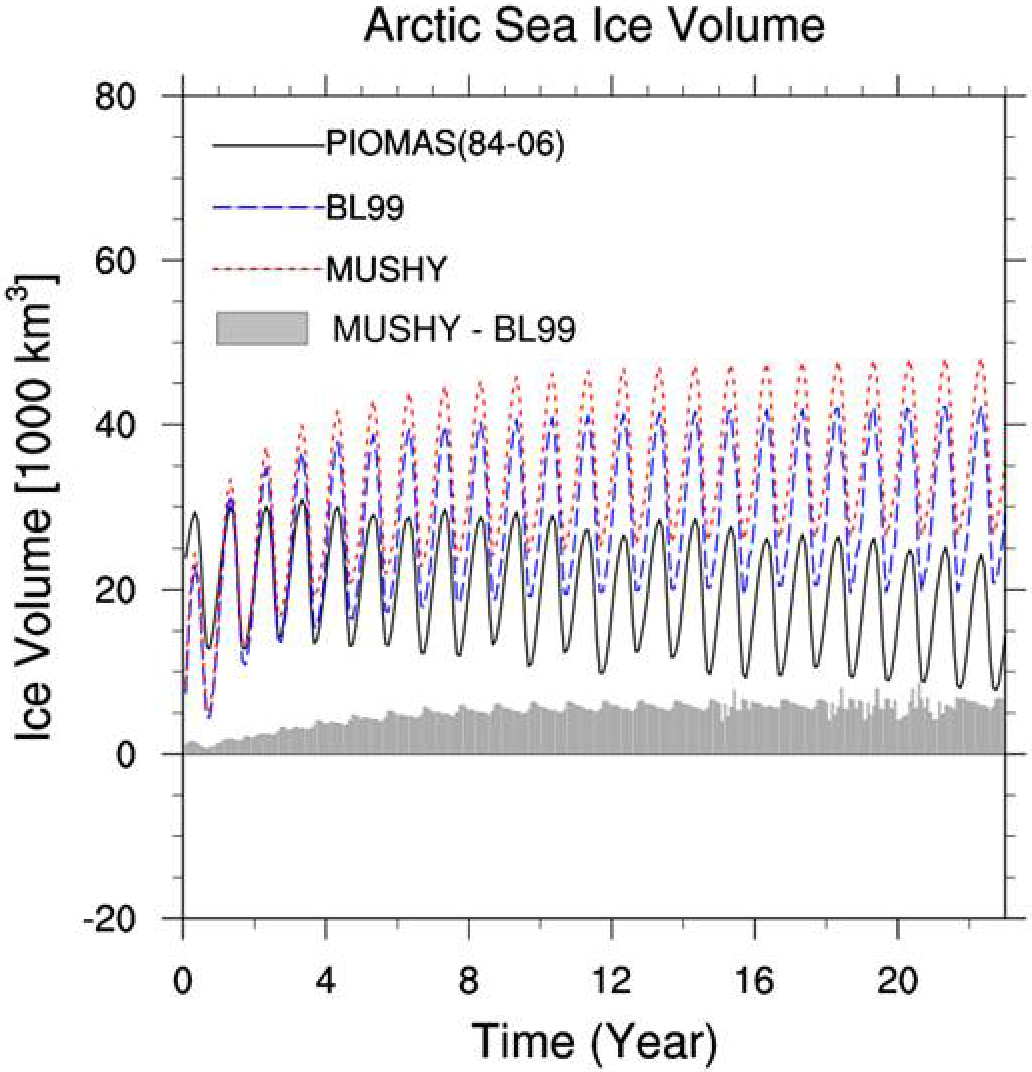
$$\frac{\partial C_{bulk}}{\partial t} \approx \frac{1}{\Gamma}(\mathbf{u} \cdot \nabla T). \qquad T_L(C) = T_L(0) - \Gamma C.$$

$$c_{\text{eff}} \equiv \mathcal{L}\frac{T_L(C_i) - T_L(C_{bulk})}{(T_L(C_i) - T)^2} + \frac{T_L(C_i) - T_L(C_{bulk})}{(T_L(C_i) - T)}(c_b - c_i) + c_i$$

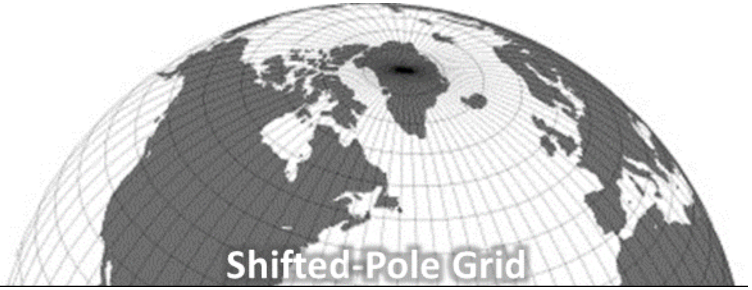
$$k_{\text{eff}} \equiv k_i - \frac{T_L(C_i) - T_L(C_{bulk})}{(T_L(C_i) - T)}(k_i - k_b)$$

$$\left\{c_m + \mathcal{L}\frac{T_L(C_i) - T_L(C_{bulk})}{(T_L(C_i) - T)^2}\right\}\frac{\partial T}{\partial t} + \left\{c_b + \frac{\mathcal{L}}{T_L(C_i) - T}\right\}\mathbf{u} \cdot \nabla T = \nabla \cdot (k_m \nabla T) + A_R.$$

Stand-alone (sea ice model only) simulation



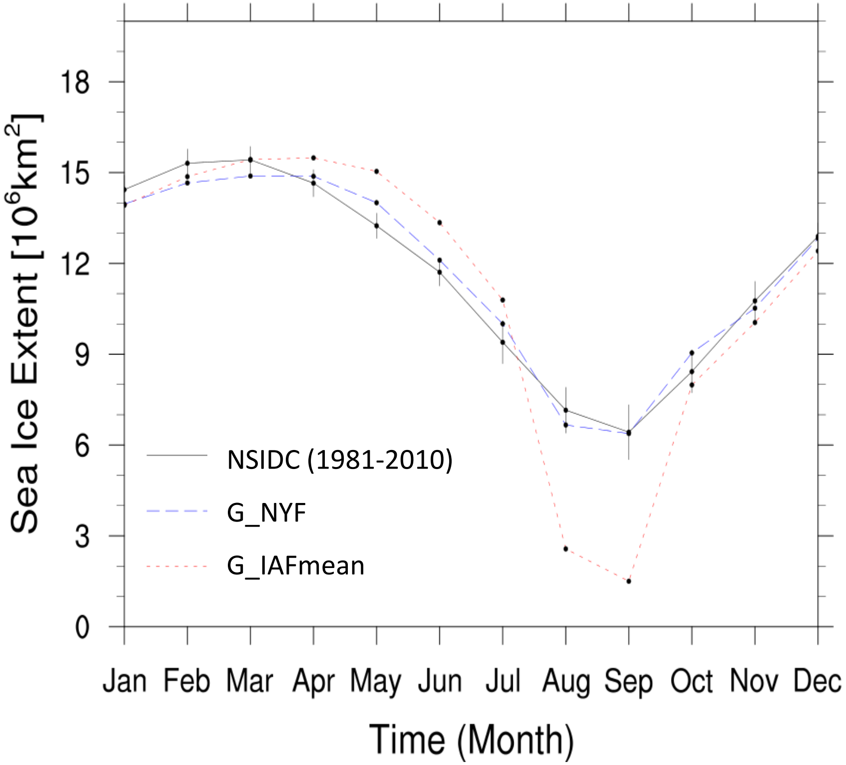
CESMv1.2.1 G-Compset
100 year spinup



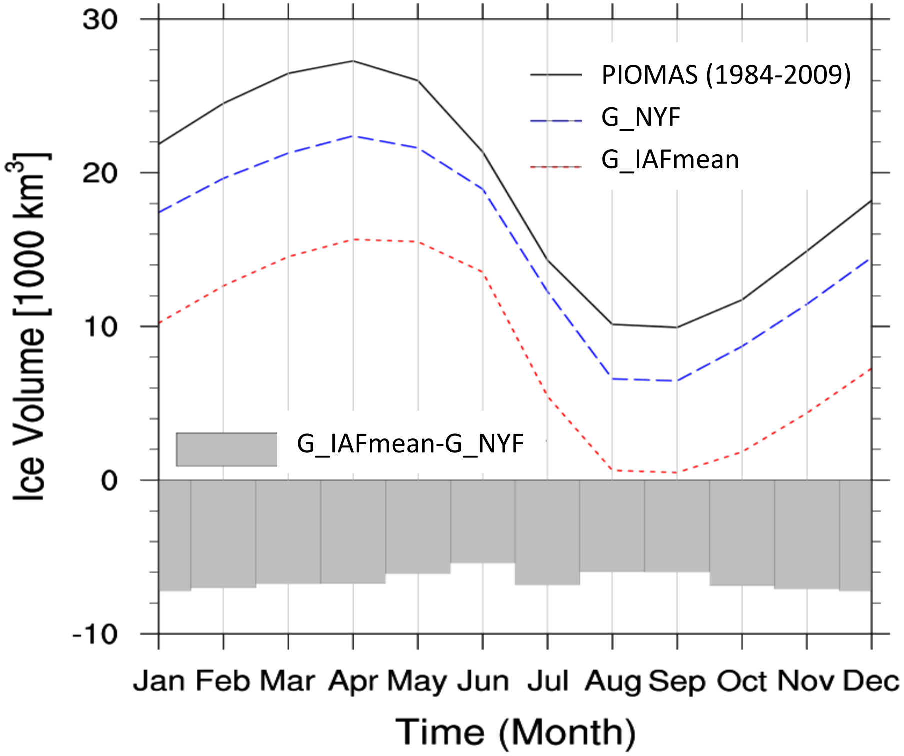
Model		Community Earth System Model (CESM) version 1.2.1	
Organization		NCAR	
Components set		G_NORMAL_YEAR	
		Parallel Ocean Program version 2 (POP2)	Community Ice CodE version 4 (CICE4)
Resolution	Horizontal	gx1v6 (~1°x1°)	
		shifted-pole grid	
	Vertical	60 layer	-
Forcing	IC	Levitus – PHC2 (Polar science center Hydrographic Climatology)	
		Levitus98 (Levitus et al., 1998) + Steele et al. (2001)	
		Monthly sea temperature, salinity and zero velocity	
	BC	Control **(G_NYF)**	COREv2, Normal Year Forcing
		EXP **(G_IAFmean)**	climatological mean of interannually varying COREv2 forcing (1984-2009)

Monthly variations of Arctic sea ice

Arctic Sea ice extent

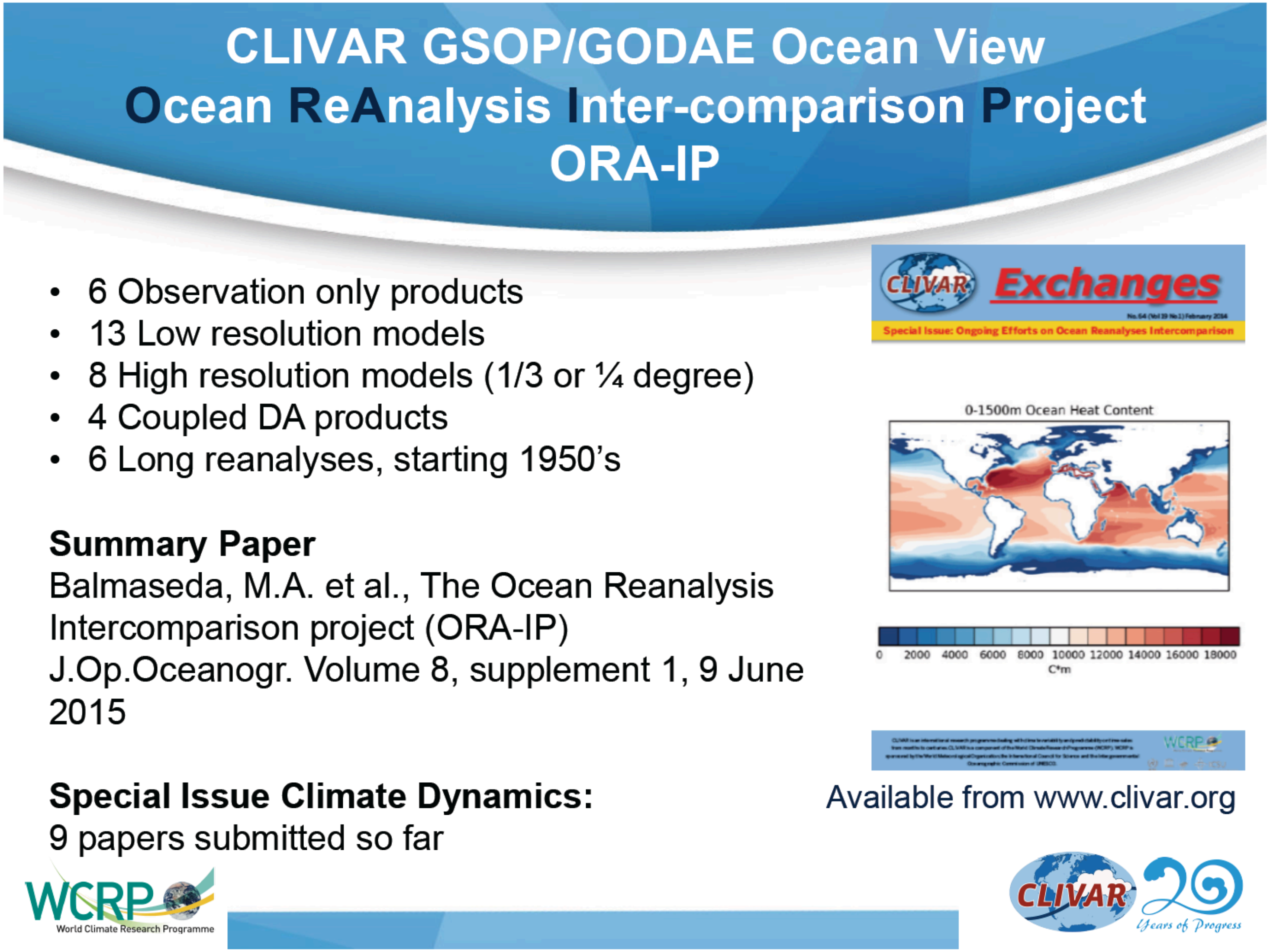


Arctic Sea ice volume



Data assimilation

Ocean Reanalysis Inter-comparison Project (ORA-IP)



CLIVAR GSOP/GODAE Ocean View
Ocean ReAnalysis Inter-comparison Project
ORA-IP

- 6 Observation only products
- 13 Low resolution models
- 8 High resolution models (1/3 or ¼ degree)
- 4 Coupled DA products
- 6 Long reanalyses, starting 1950's

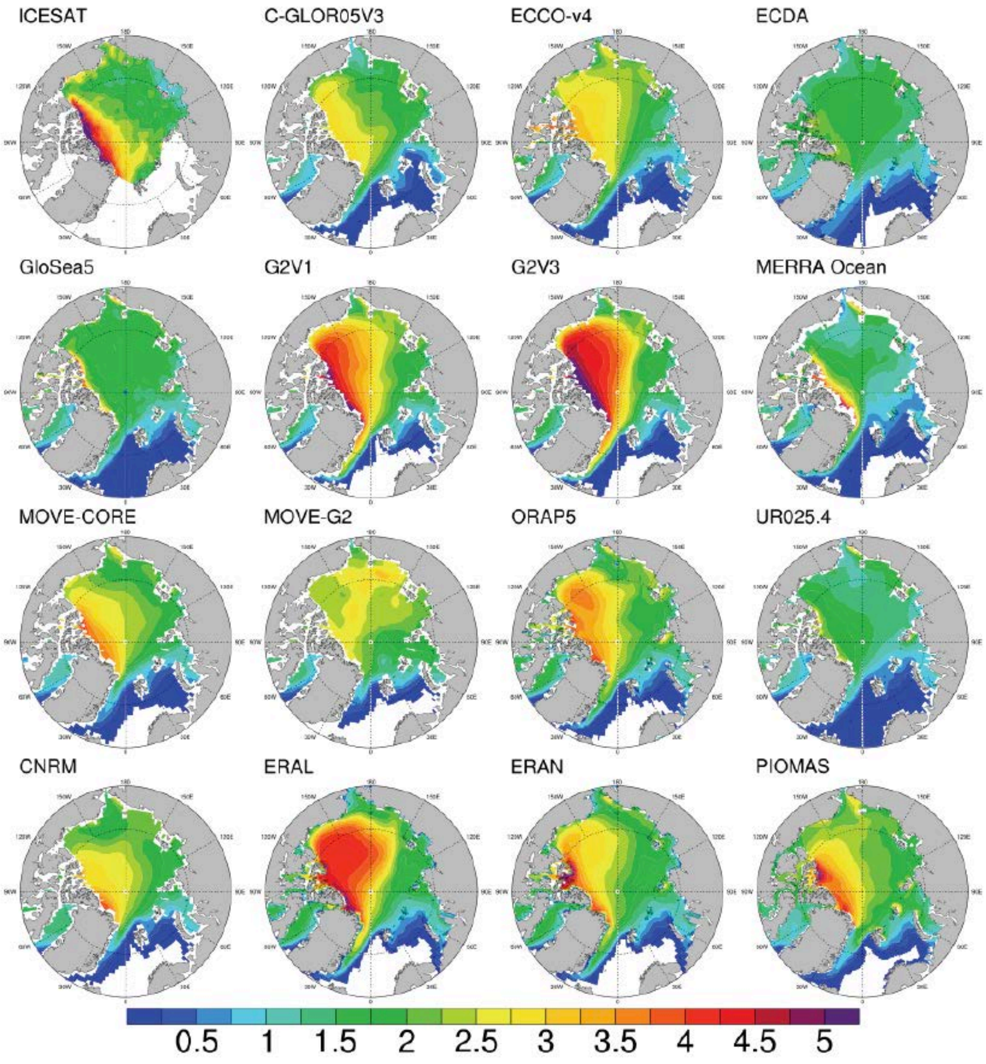
Summary Paper
Balmaseda, M.A. et al., The Ocean Reanalysis Intercomparison project (ORA-IP)
J.Op.Oceanogr. Volume 8, supplement 1, 9 June 2015

Special Issue Climate Dynamics:
9 papers submitted so far

CLIVAR Exchanges
No. 64 (Vol 19 No.1) February 2014
Special Issue: Ongoing Efforts on Ocean Reanalyses Intercomparison

Available from www.clivar.org

Sea-ice thickness at Mar2007



(Chevallier et al., Clim Dyn., 2015)

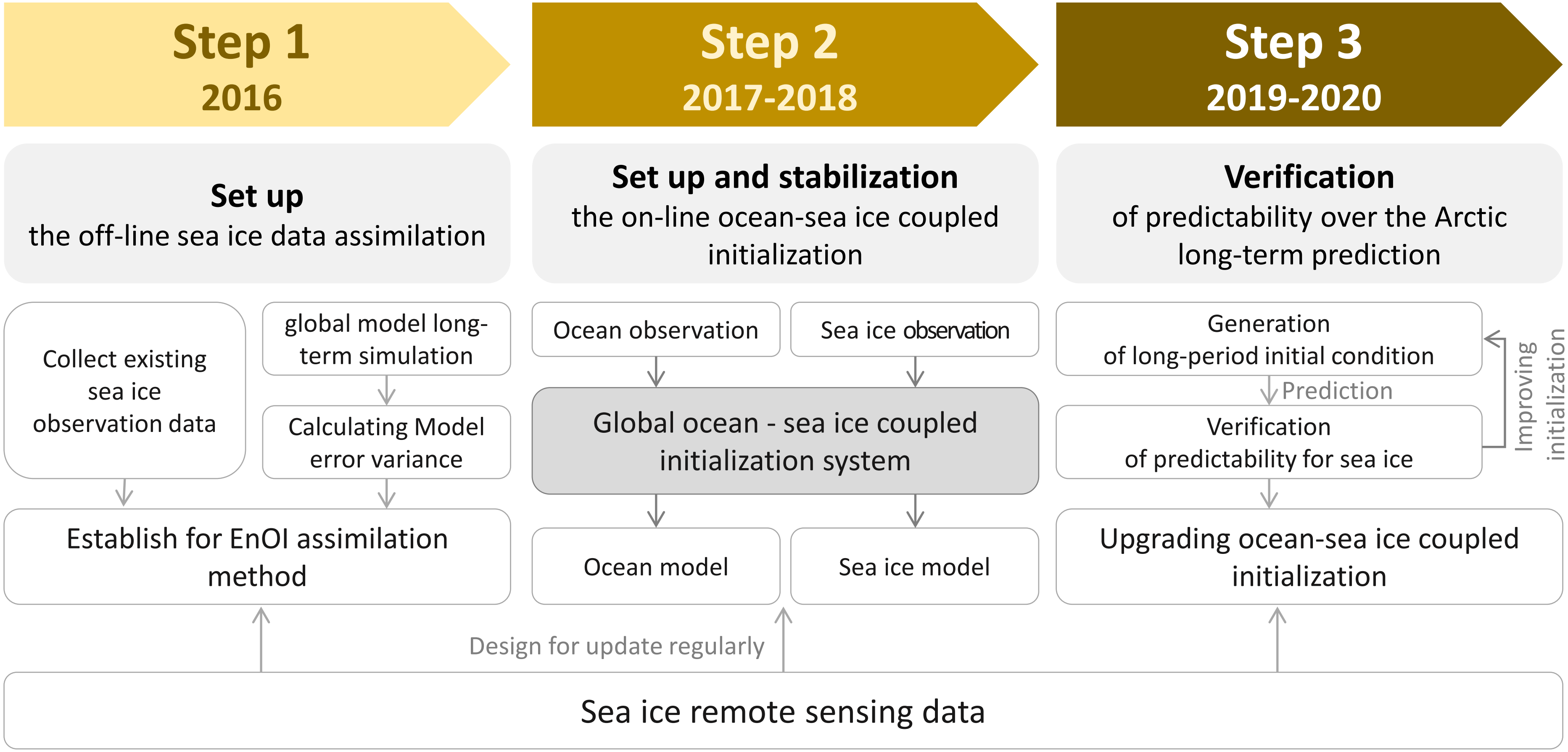
Large discrepancies among reanalyses

→ Research and development of assimilation method for sea ice is necessary

[ORA-IP models]

Product	Institution	Product	Institution
CFSR	NCEP	**ECCO-v4**	NASA/JPL
GODAS	NCEP	**GECCO2**	Hamburg University
Glosea5	UK MetOffice	**MOVE-C**	MRI/JMA
ORAS4	ECMWF	**MOVE-G2**	MRI/JMA
PEODAS	BMRC	**MOVE-CORE**	MRI/JMA
GLORYS	Mercator	**K7-ODA**	JAMSTEC
C-GLORS	CMCC	**K7-CDA**	JAMSTEC
UR025.4	Reading University	**SLCCI**	ESA
GEOS5	NASA/GMAO	**ARMOR3D**	CLS (T/S/SLA)
ECDA	GFDL	**NODC**	NOAA (T only)
SODA	University Meryland	**EN3**	MetOffice (T only)
ECCO-NRT	NASA/JPL	**LEGOS**	LEGOS (SLA only)

Roadmap for development of KOPRI Arctic Sea Ice Initialization



Step 1
2016

Set up
the off-line sea ice data assimilation

Collect existing sea ice observation data

global model long-term simulation

Calculating Model error variance

Establish for EnOI assimilation method

Step 2
2017-2018

Set up and stabilization
the on-line ocean-sea ice coupled initialization

Ocean observation

Sea ice observation

Global ocean - sea ice coupled initialization system

Ocean model

Sea ice model

Step 3
2019-2020

Verification
of predictability over the Arctic long-term prediction

Generation of long-period initial condition

Prediction

Verification of predictability for sea ice

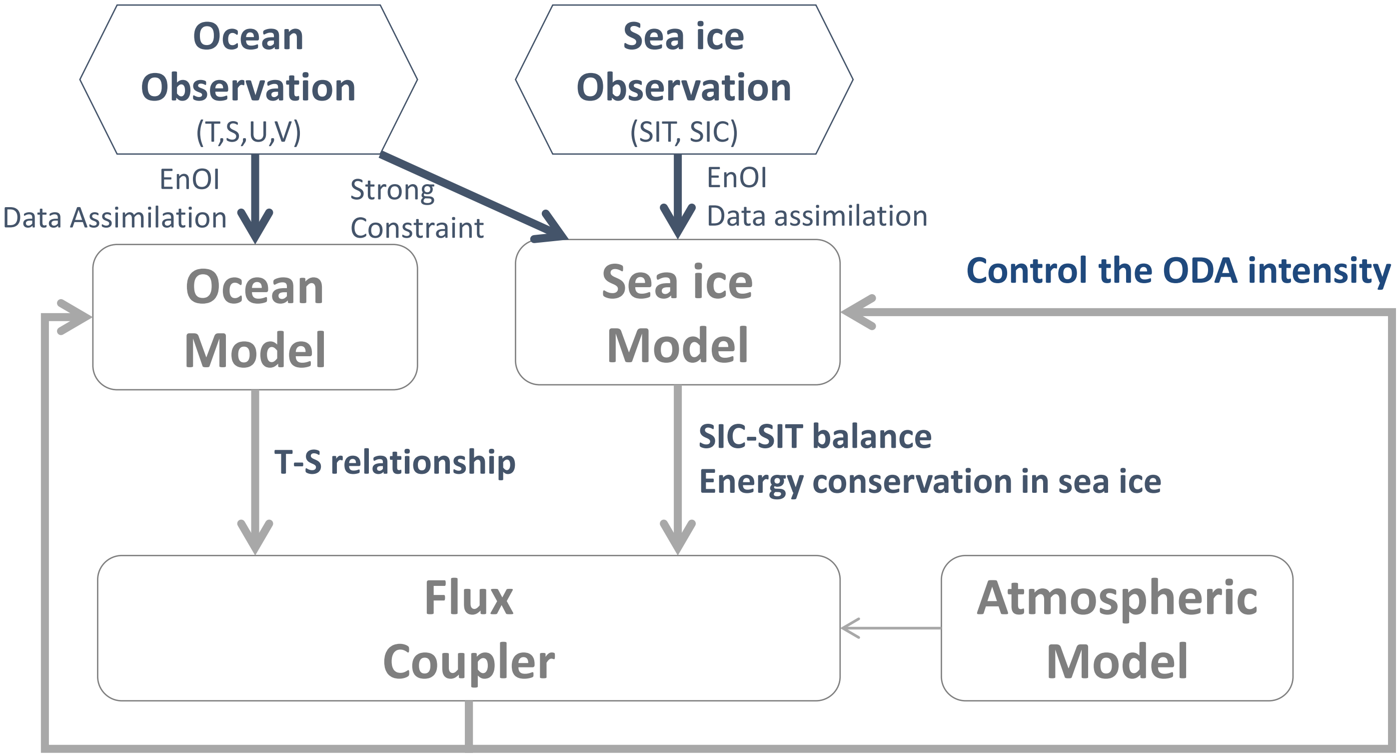
Improving initialization

Upgrading ocean-sea ice coupled initialization

Design for update regularly

Sea ice remote sensing data

Outline of KOPRI Sea ice–Ocean coupled Initialization system



Ocean Observation (T,S,U,V)

Sea ice Observation (SIT, SIC)

EnOI Data Assimilation

Strong Constraint

EnOI Data assimilation

Ocean Model

Sea ice Model

Control the ODA intensity

T-S relationship

SIC-SIT balance
Energy conservation in sea ice

Flux Coupler

Atmospheric Model

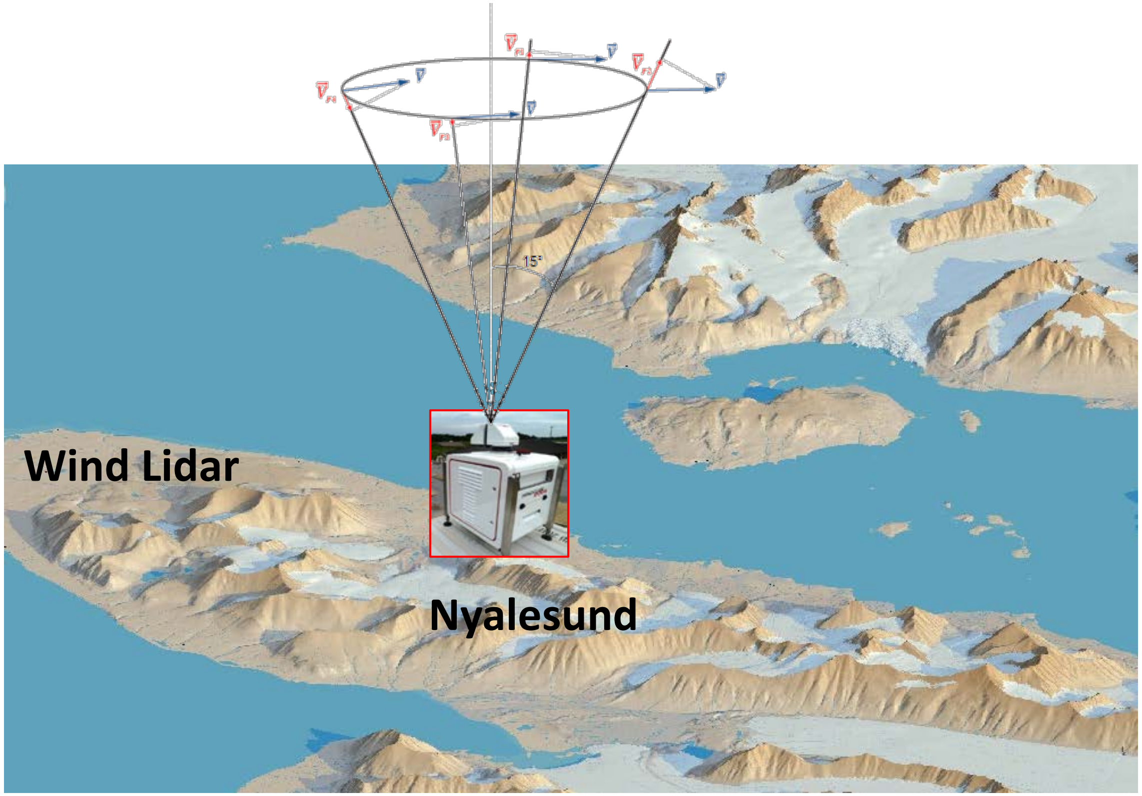
* S-SIC balance

(ex. T<Tf~F(S), SIC zero)

(ex. Ice formation, S >upper bounce)

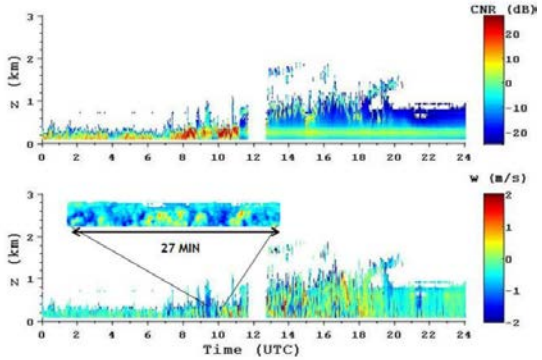
* T-SIC balance

(ex. Ffrzmlt<0, SIC zero)

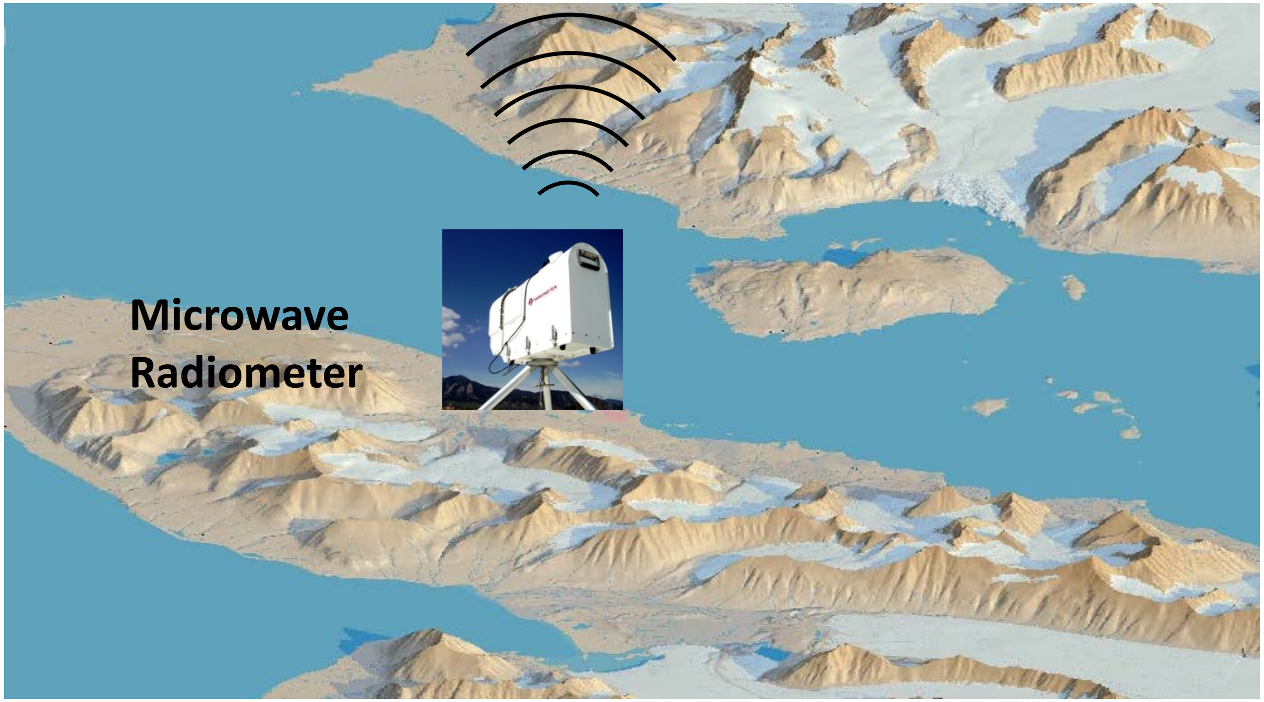


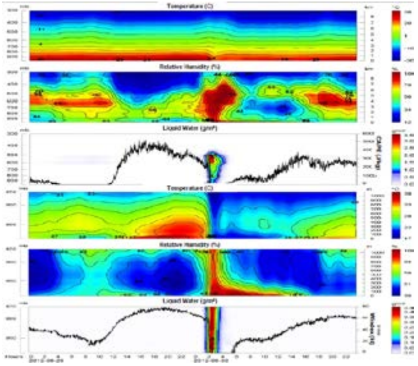
Wind Lidar

Nyalesund

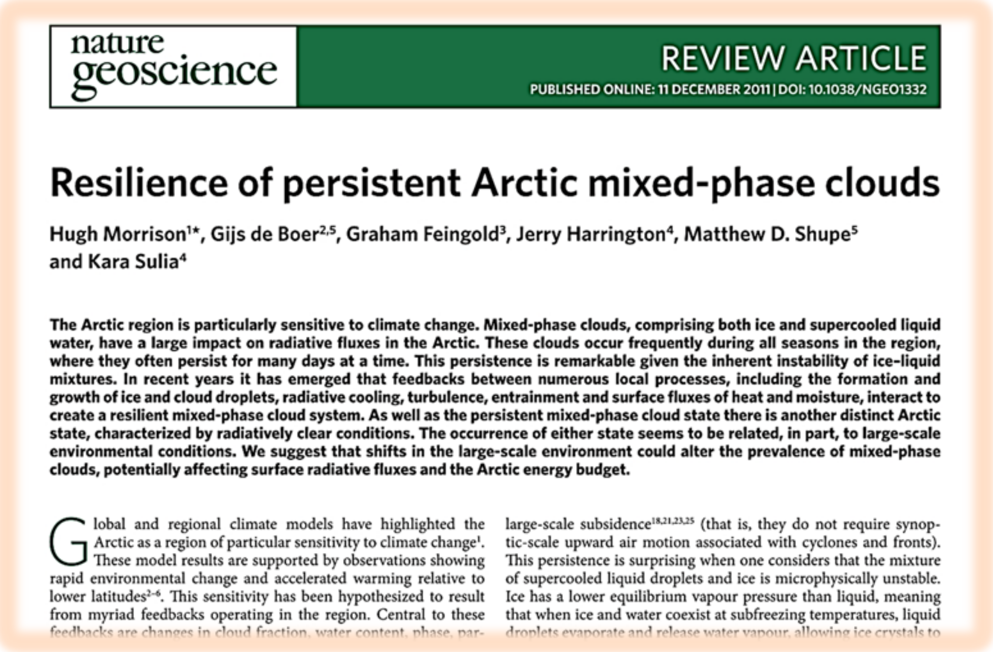


Wind profile


Microwave
Radiometer


Temperature (C)
Relative Humidity (%)
Liquid Water (g/m³)
Temperature (C)
Relative Humidity (%)
Liquid Water (g/m³)

T, Q profile



nature geoscience

REVIEW ARTICLE

Resilience of persistent Arctic mixed-phase clouds

Hugh Morrison[1*], Gijs de Boer[2,5], Graham Feingold[3], Jerry Harrington[4], Matthew D. Shupe[5]
and Kara Sulia[4]

The Arctic region is particularly sensitive to climate change. Mixed-phase clouds, comprising both ice and supercooled liquid water, have a large impact on radiative fluxes in the Arctic. These clouds occur frequently during all seasons in the region, where they often persist for many days at a time. This persistence is remarkable given the inherent instability of ice–liquid mixtures. In recent years it has emerged that feedbacks between numerous local processes, including the formation and growth of ice and cloud droplets, radiative cooling, turbulence, entrainment and surface fluxes of heat and moisture, interact to create a resilient mixed-phase cloud system. As well as the persistent mixed-phase cloud state there is another distinct Arctic state, characterized by radiatively clear conditions. The occurrence of either state seems to be related, in part, to large-scale environmental conditions. We suggest that shifts in the large-scale environment could alter the prevalence of mixed-phase clouds, potentially affecting surface radiative fluxes and the Arctic energy budget.

Global and regional climate models have highlighted the Arctic as a region of particular sensitivity to climate change[1]. These model results are supported by observations showing rapid environmental change and accelerated warming relative to lower latitudes[2–6]. This sensitivity has been hypothesized to result from myriad feedbacks operating in the region. Central to these feedbacks are changes in cloud fraction, water content, phase, par-

large-scale subsidence[18,21,23,25] (that is, they do not require synoptic-scale upward air motion associated with cyclones and fronts). This persistence is surprising when one considers that the mixture of supercooled liquid droplets and ice is microphysically unstable. Ice has a lower equilibrium vapour pressure than liquid, meaning that when ice and water coexist at subfreezing temperatures, liquid droplets evaporate and release water vapour, allowing ice crystals to