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Contradistinction of Arctic and Antarctic Sea Ice Change

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Science Issue

A key issue in climate change science is the <u>Polar Sea Ice Paradox</u>: Why Arctic sea ice has been reducing and Antarctic sea ice has been stable or even slightly increasing?

Objective

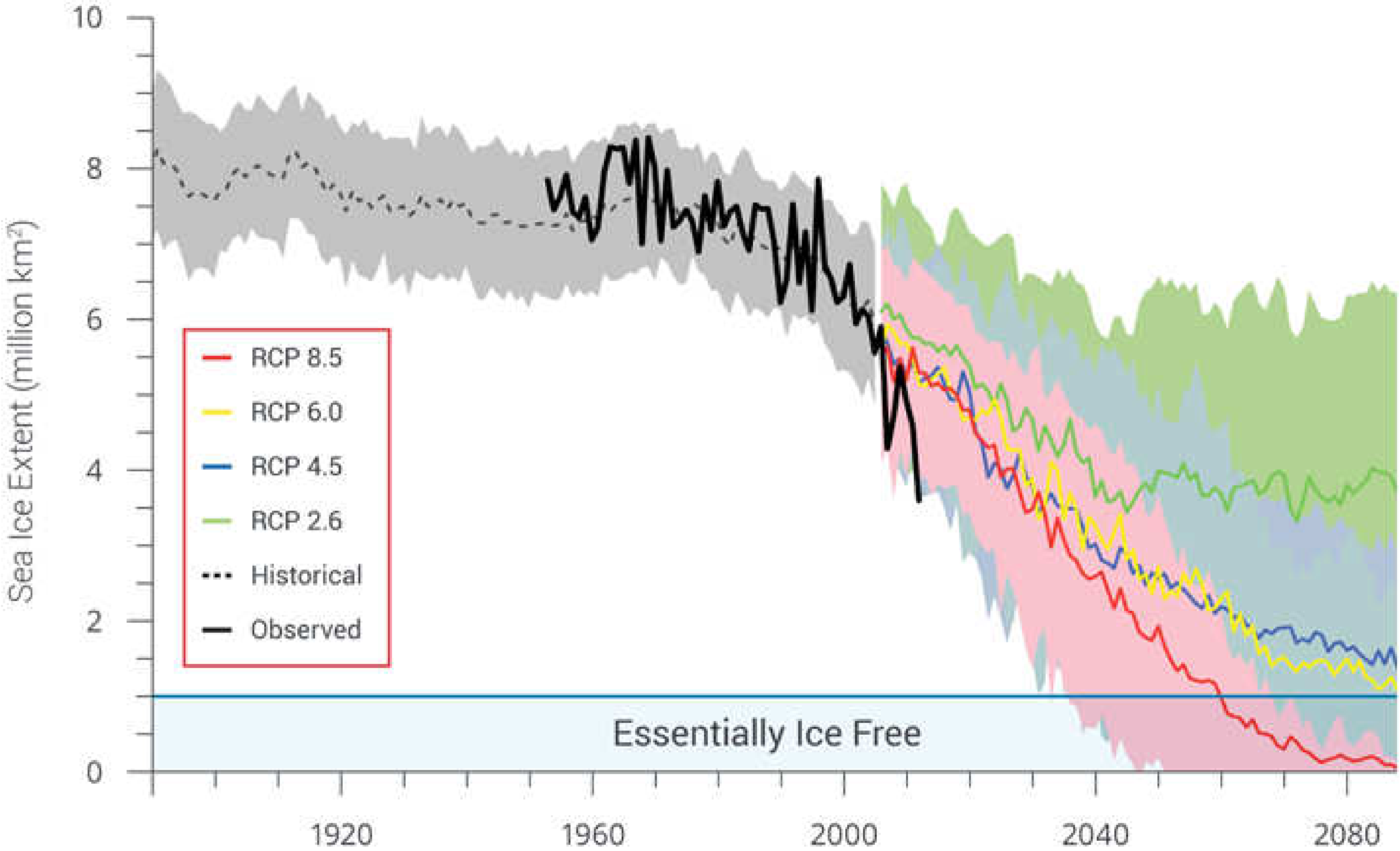
To examine the differences between Arctic and Antarctic sea ice characteristics and how they have changed under different geophysical and climatic conditions in polar regions to explain the Sea Ice Paradox.

Arctic Sea Ice

Rapid Reduction of Sea Ice Extent

National Climate Assessment Report, 2014

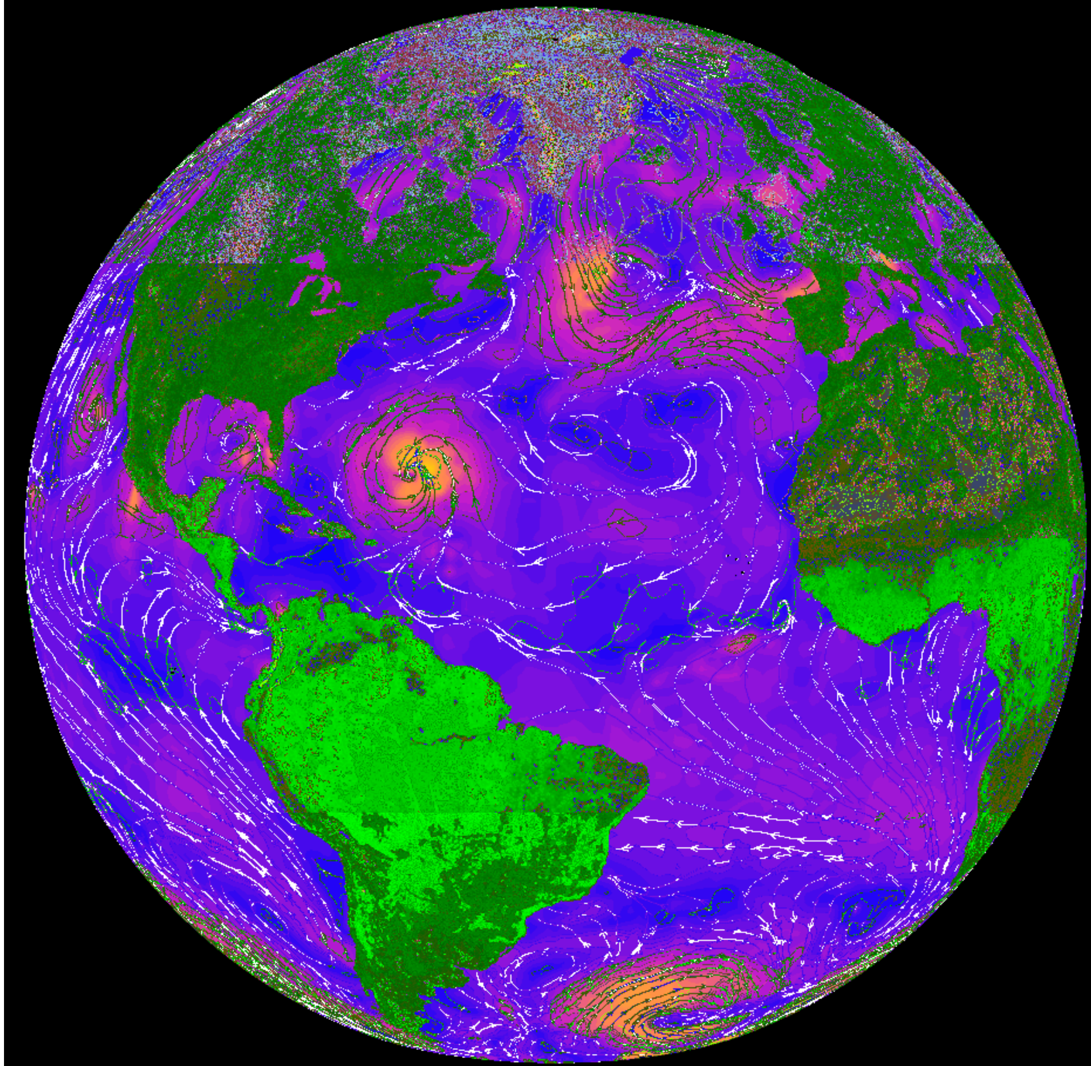
http://nca2014.globalchange.gov/report/our-changing-climate/melting-ice



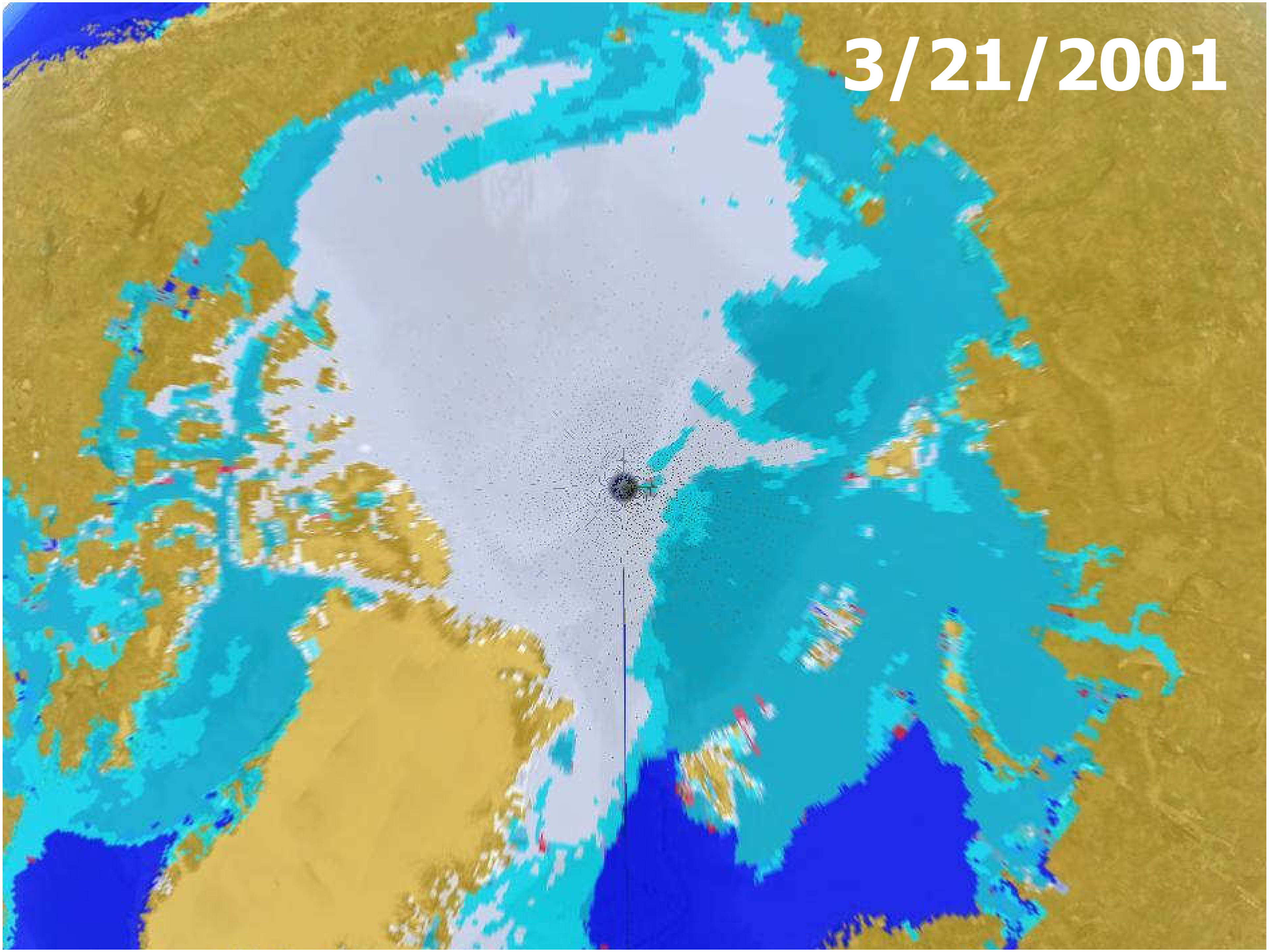
Two Major Ice Classes

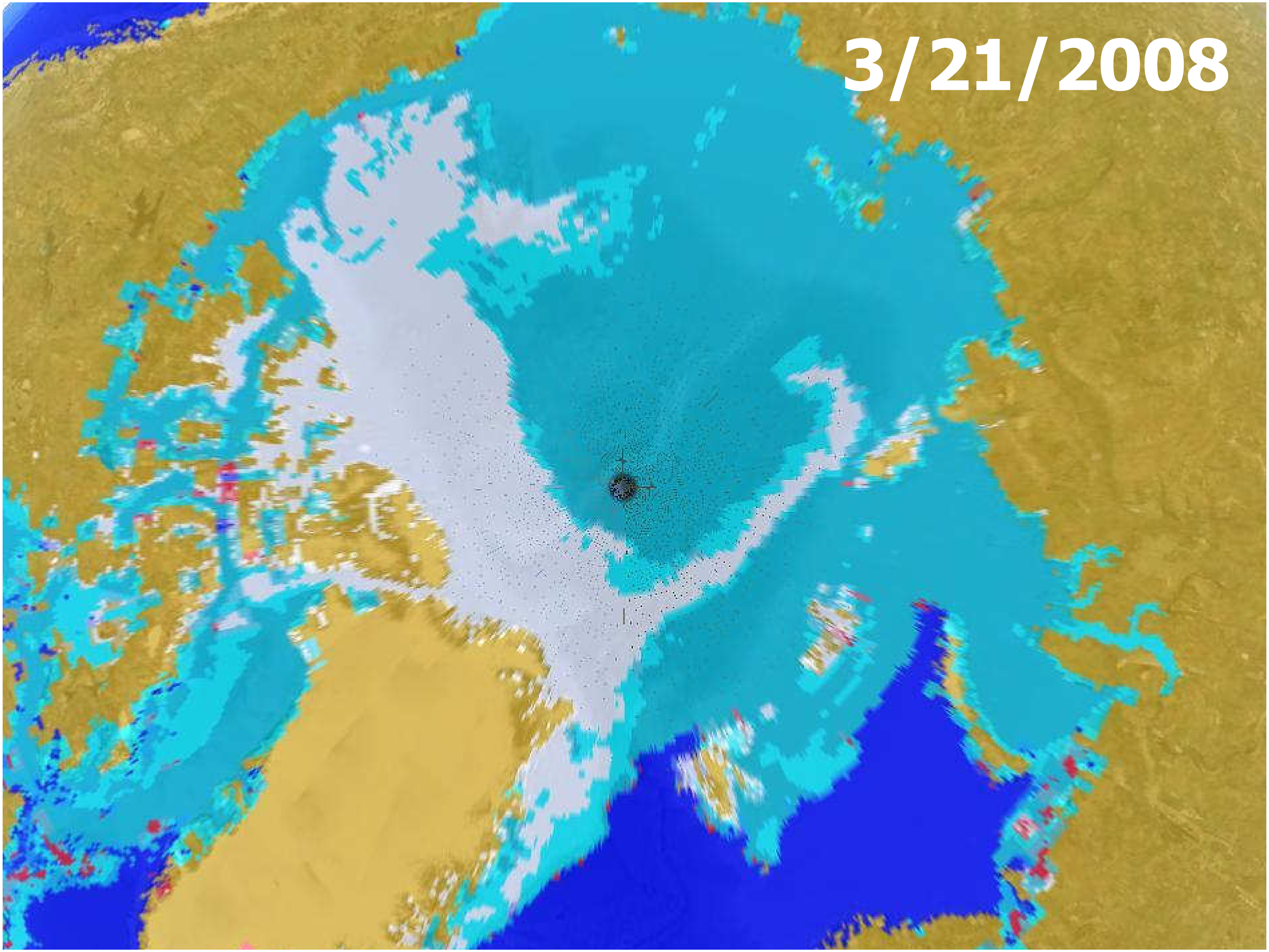
- Perennial sea ice: Surviving at least a summer melt, multi-year age, thick ice, important to ice mass and ice pack stability
- Seasonal sea ice: Thinner ice, forming and melting away seasonally
- Marginal Ice Zone near edge

Satellite Scatterometers

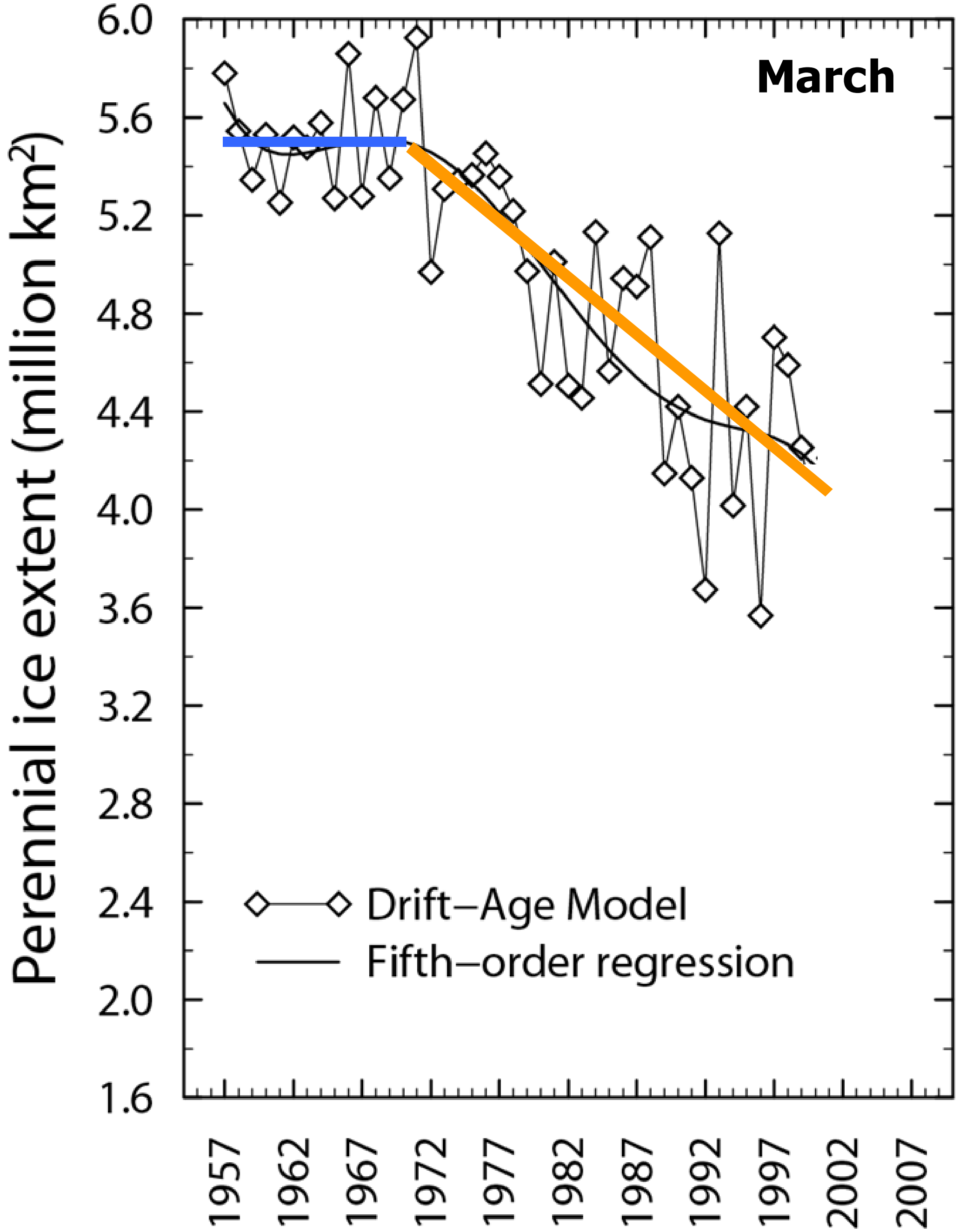


- Covering 90% of the world in a day
- Coarse resolution of 25 km
- NASA QuikSCAT 1999-2009
- ISRO Oceansat-2 1999-2014
- ISRO SCATSAT-1 2016-2021


3/21/2001


3/21/2008

Perennial Sea Ice Change 1957-1999



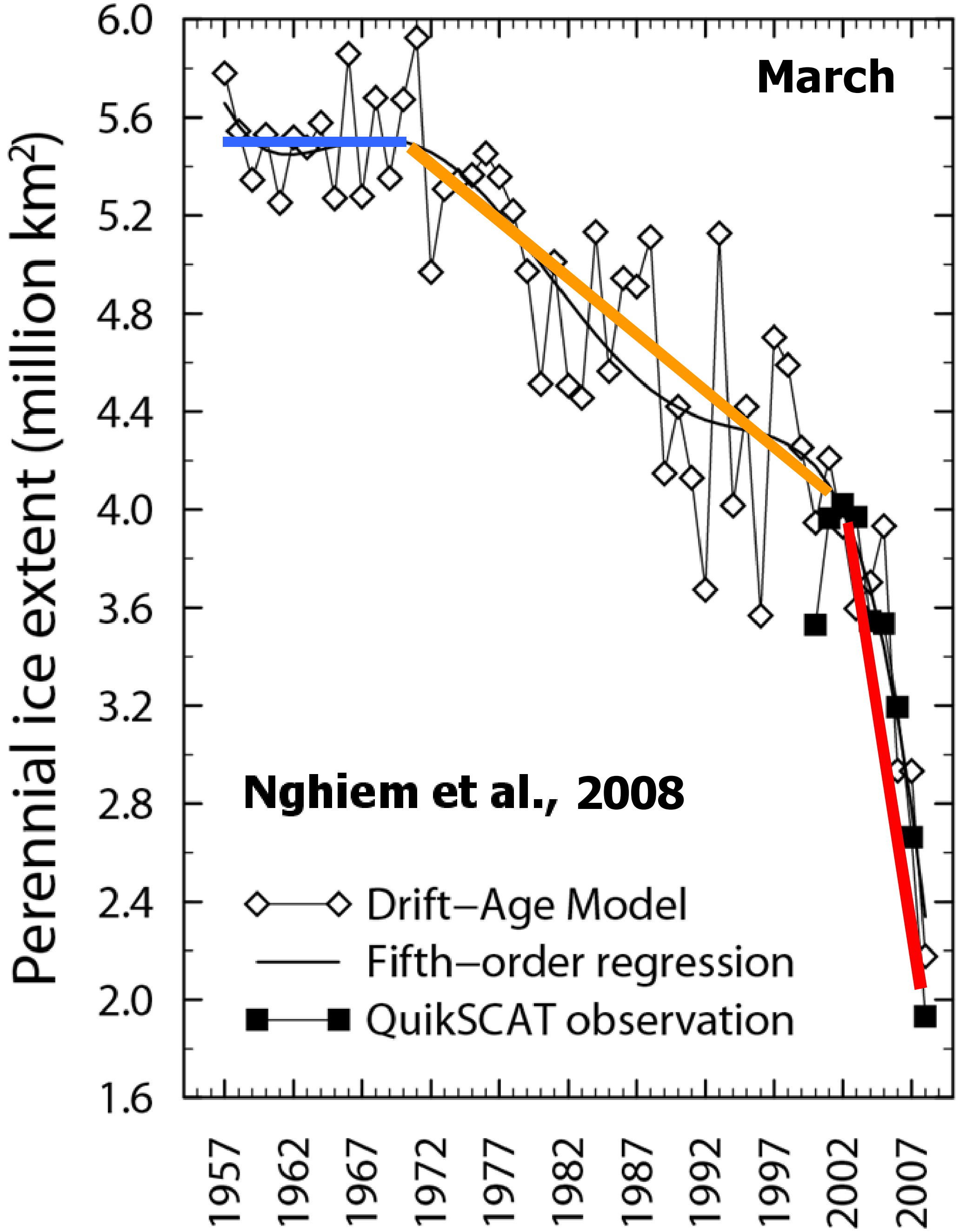
Before 1970:

No discernable trend in March perennial ice extent.

1970-1999:

Decrease of 0.5×10^6 km^2 per decade in March perennial ice extent as estimated from the Drift-Age model.

Perennial Sea Ice Change 1957-2008



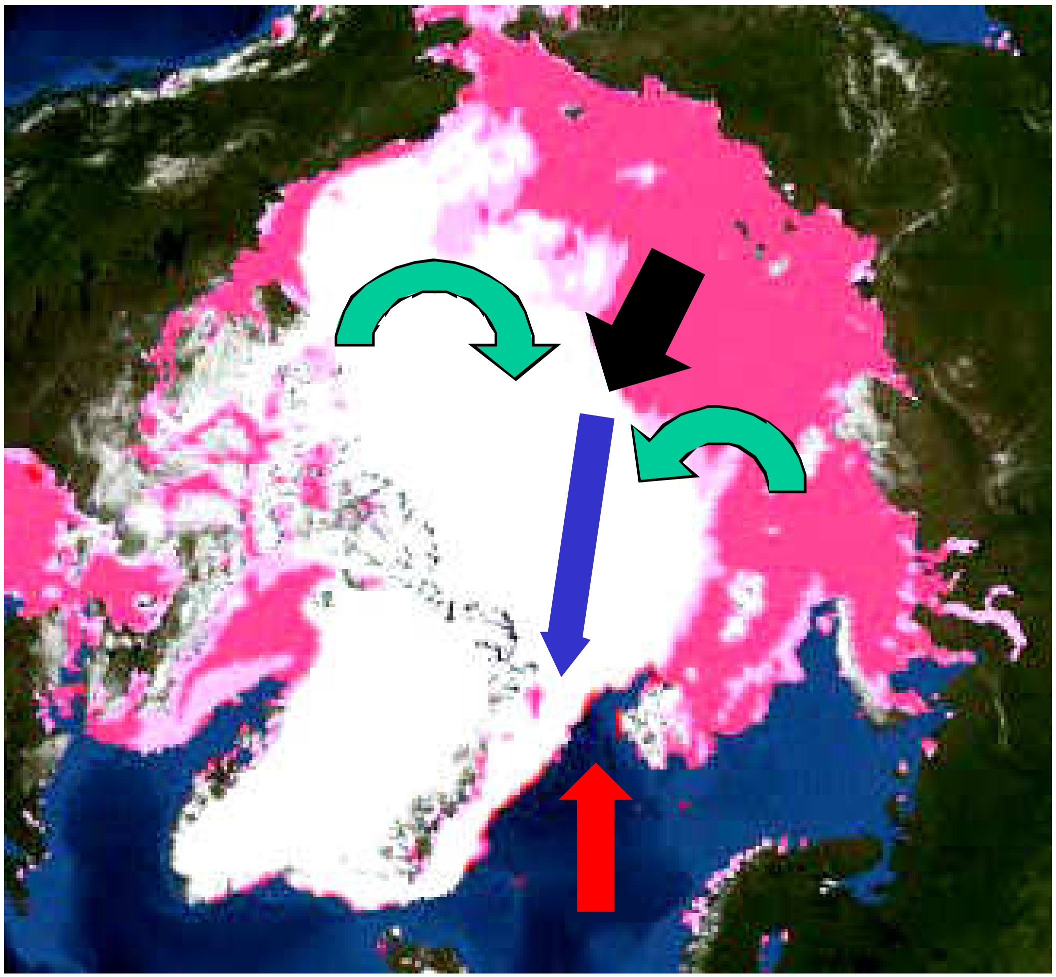
2000-2008:

Decrease of 1.5×10^6 km^2 per decade in March perennial ice extent as measured from <u>QuikSCAT data</u> and estimated from the Drift-Age model.

<u>TRIPLE THE LOSS RATE</u> in the previous three decades

‘The Polar Express’

Ice loss mechanism in any season (not just summer)



Ice compression from East to West Arctic

Ice compression into Transpolar Drift (TD)

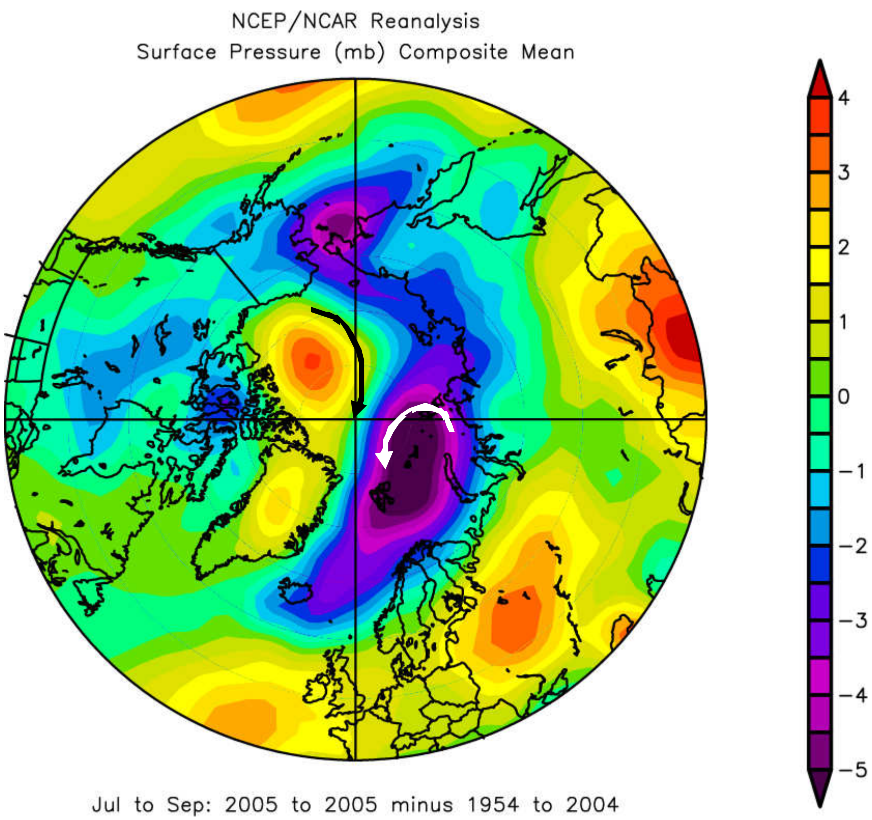
Acceleration of TD[1] carrying ice out of Arctic via Fram Strait

Warm Atlantic water effectively melted ice in Greenland Sea

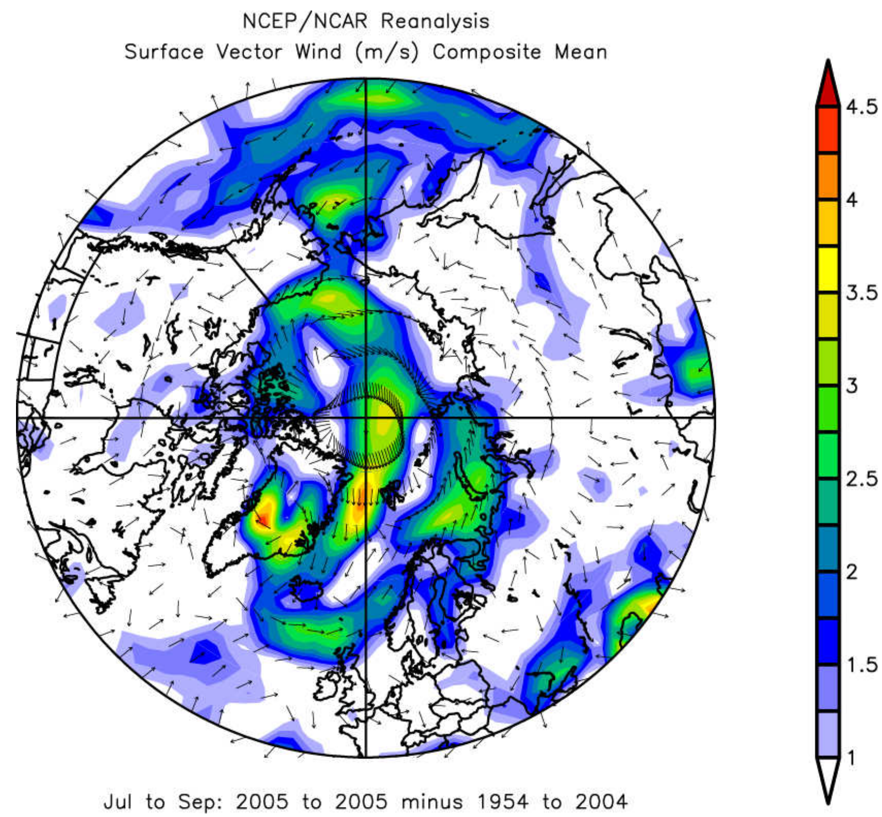
Nghiem et al. GRL, 2007

The Polar Express in 2005

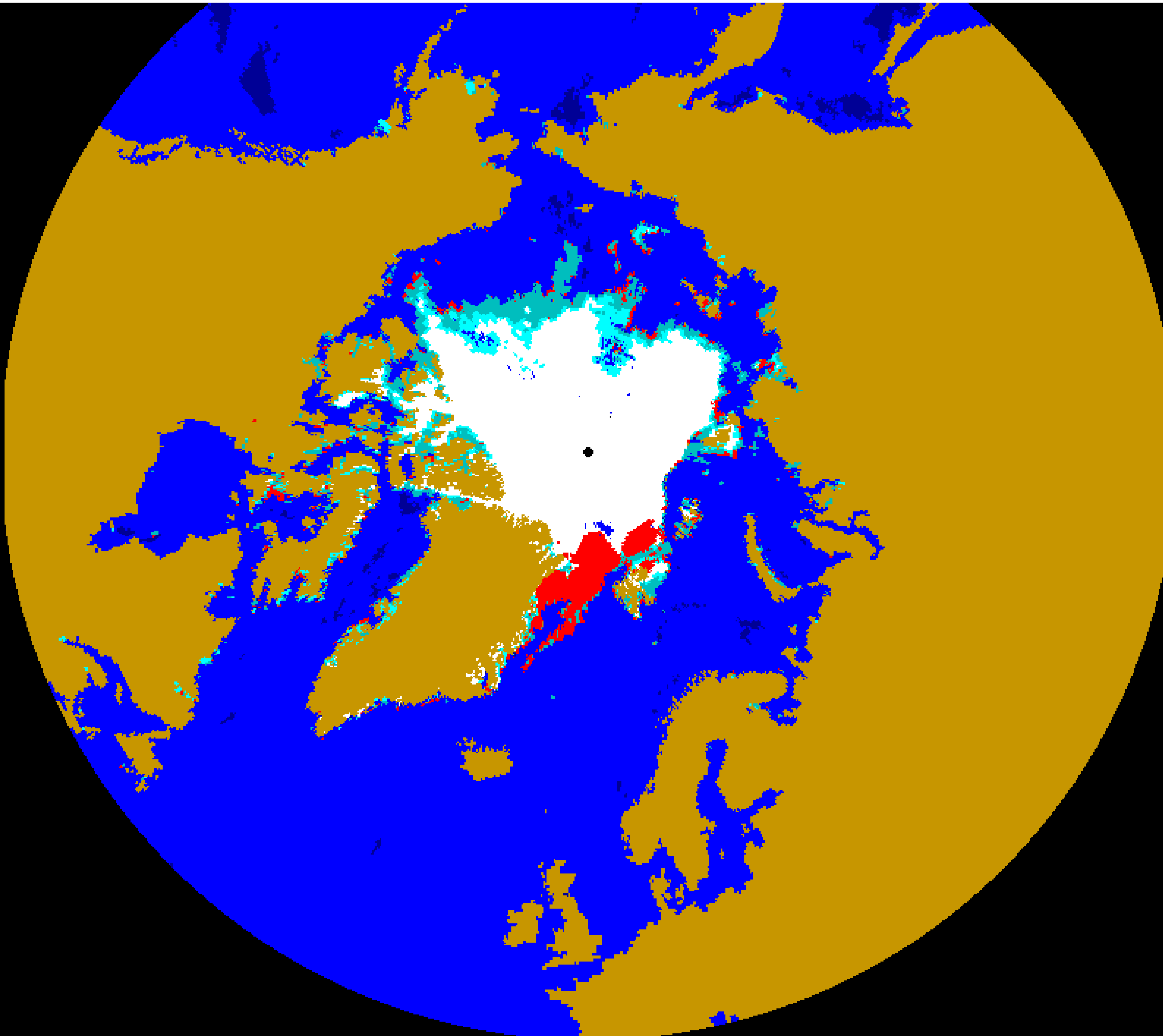
Barents-Sea low and Canadian-Basin high anomalies set up anomalous winds over Fram Basin and Greenland Sea



Dipole anomaly



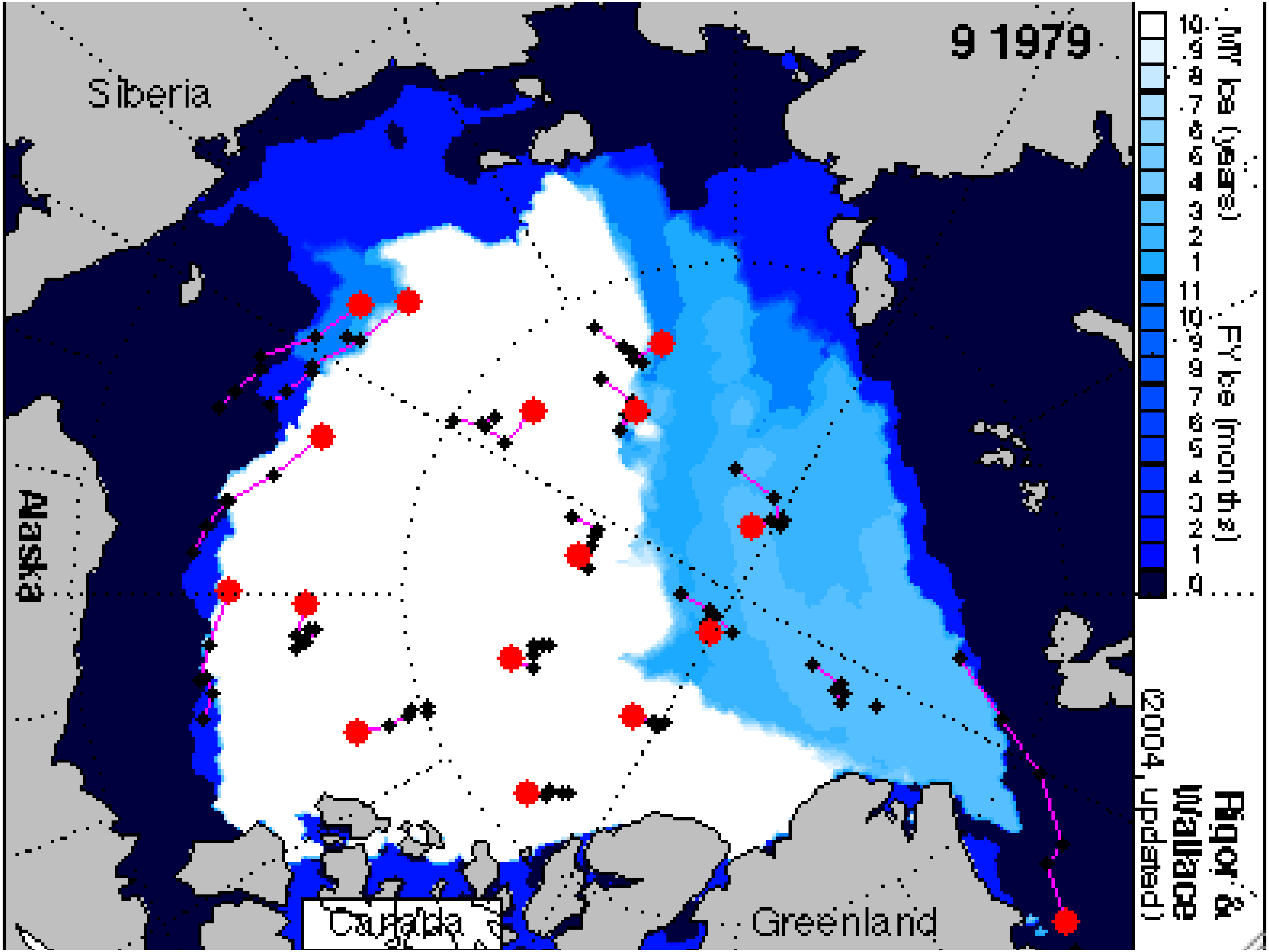
Animation of sea ice 20 frames per second



2008-09-12

SEA ICE CLASSES

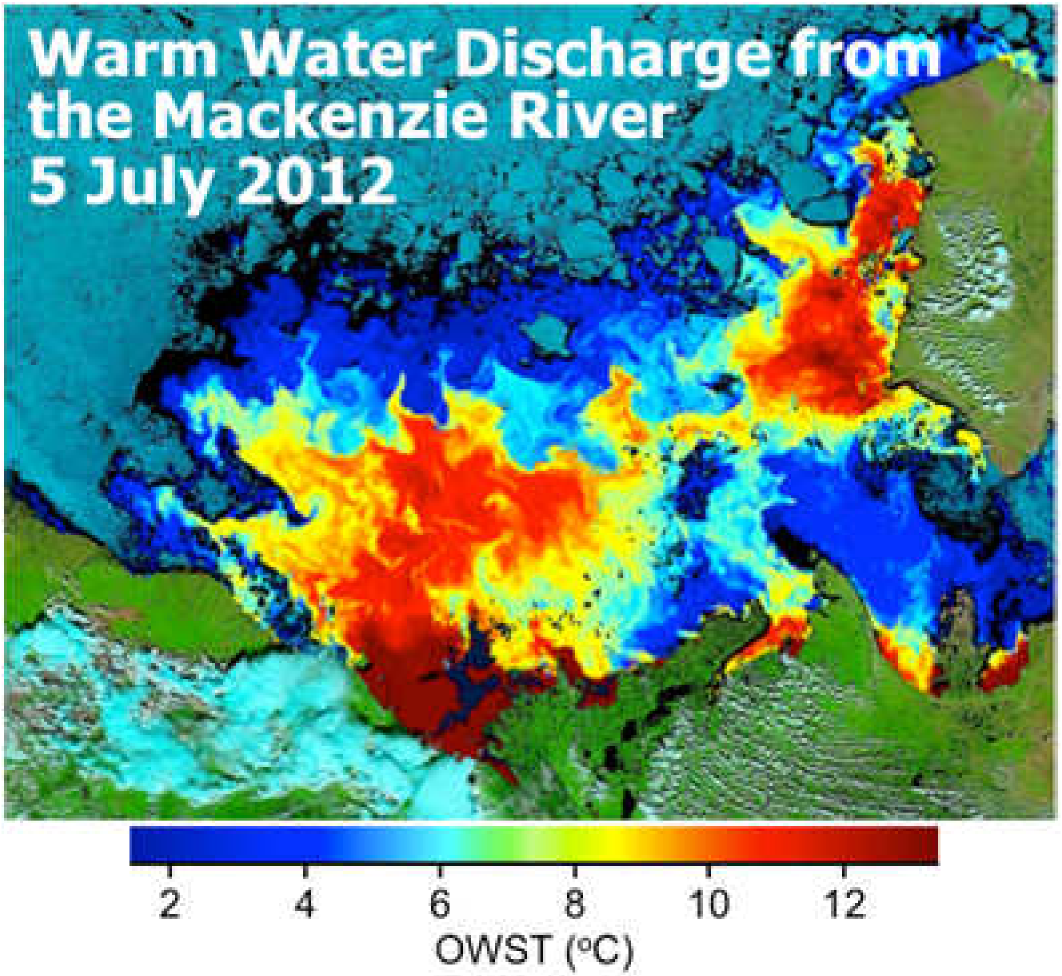
- Seasonal
- Mixed ice
- Perennial
- Melt



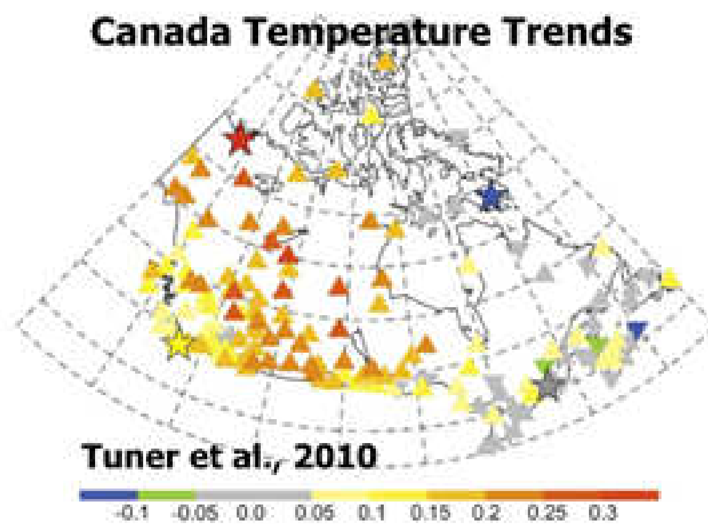
9 1979
Siberia
Alaska
Canada
Greenland
MY Ice (years)
10
9
8
7
6
5
4
3
2
1
11
10
9
8
7
6
5
4
3
2
1
0
FY Ice (months)
Rigor & Wallace (2004, updated)

Arctic River Discharge

Effective pathway linked to warming continents



Nghiem et al., Geophys. Res. Lett., 2014
Nghiem et al., Bionature, 2013



Landfast sea ice hinders river discharge

Memory in landfast sea ice

Lead in 2013 and landfast ice edge in 2012 conform to 25-m isobath

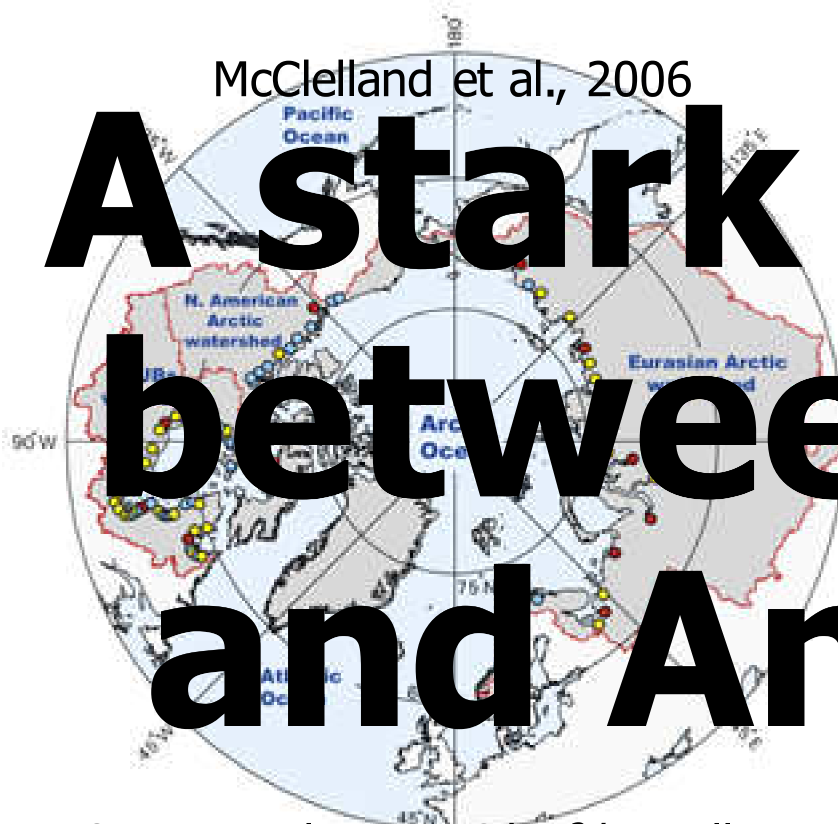
6/14/2012 vs 5/17/2013

Heat Source from Rivers

- **Arctic sea ice: Warm river water discharge**
- **Antarctic sea ice: Frozen continent**

McClelland et al., 2006

A stark contrast between Arctic and Antarctic!



72 rivers: Blue = <6 km^3/y; Yellow = 6 to <60 km^3/y; Red = 60 to 600 km^3/y.

1.0×10^{19} J/yr/1^{o}C above 0^{o}C
2.5 gigaton of TNT/yr/1^{o}C

No such rivers!

Antarctic Sea Ice

Issues to be addressed for Antarctic sea ice

1. Mechanisms for sea ice production
2. What protects the sea ice cover
3. What factors sustain Antarctic ice
4. What causes regional variability
5. Consistency among factors above
6. Same physics but opposite effects in Arctic versus Antarctic sea ice

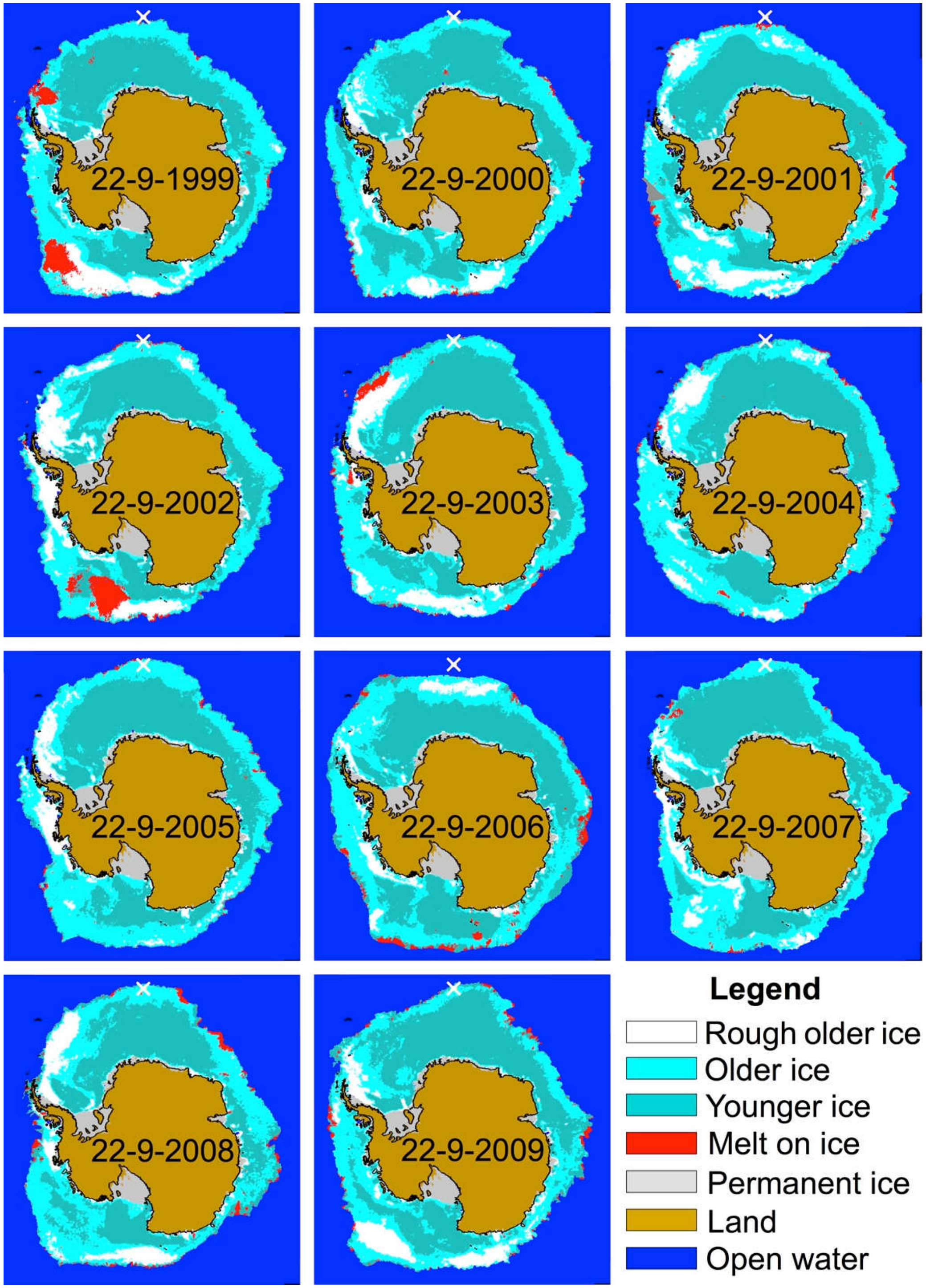
Antarctic Sea Ice Production

- **Ozone change increasing sea ice** (Marshall, 2003; Gillett & Thompson, 2003; Son et al. 2010) but not effective (Sigmond & Fyfe, 2010)
- **Lower salinity/density in the near-surface layer weaken mixing** (Manabe et al., 1991)
- **Enhancement of thermohalocline stratific-ation** (Zhang, 2007); **Meltwater from ice shelves in cool layer** (Bintanja et al., 2013)
- **Wind intensifications for more ridging and thus thickening sea ice** (Zhang, 2013)

Synoptic Sea Ice Classes

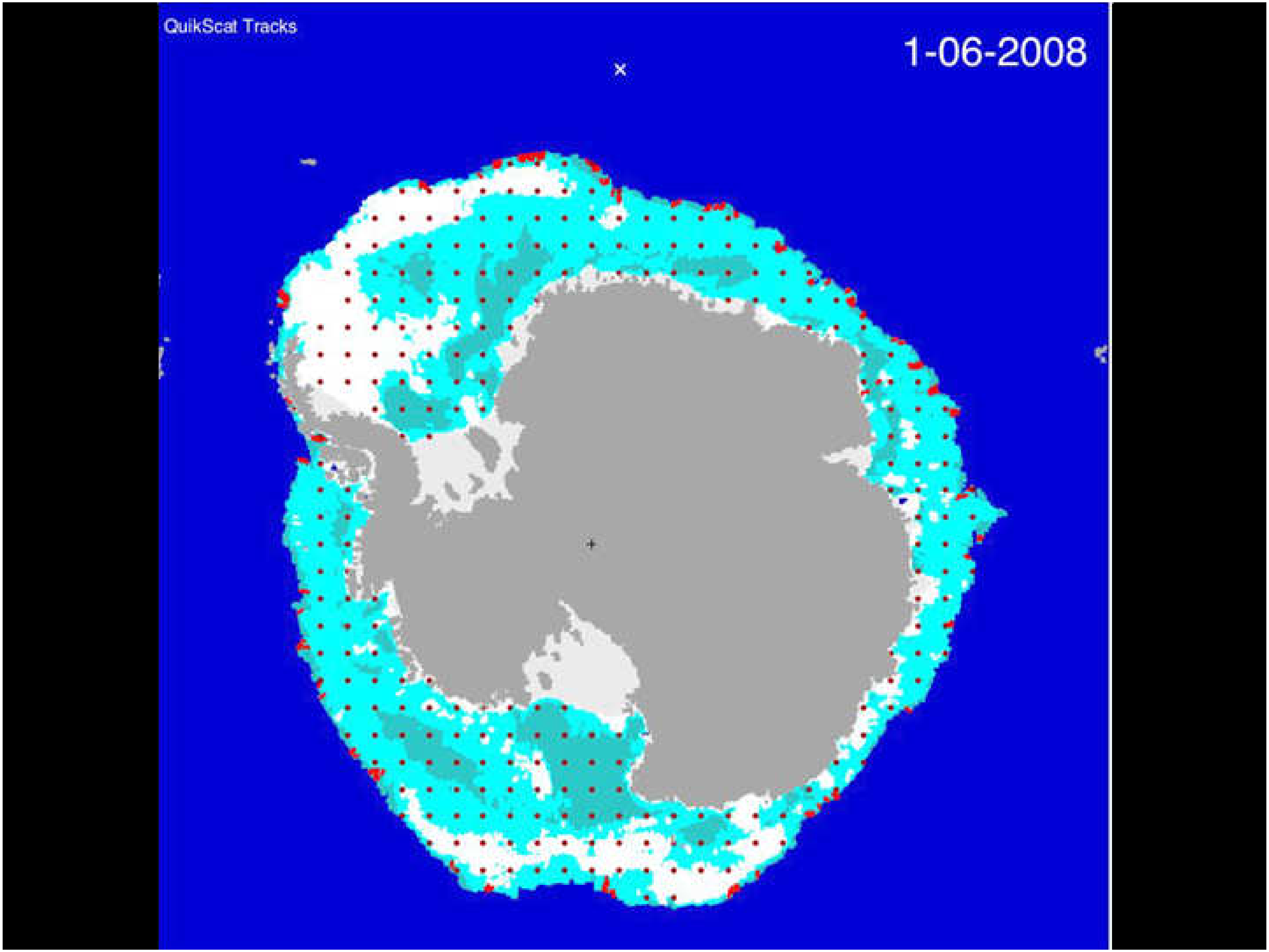
- Statistical analysis shows a Gaussian distribution of Antarctic sea ice backscatter signatures in contrast to the bimodal distribution for Arctic sea ice.
- Using the Gaussian mean and STD, we define 'YI Class' for younger ice, 'OI Class' for older ice, and 'RI Class' for rough older ice with highest backscatter.
- Use >10 years of backscatter data (1999-2009) to map synoptic sea ice classes over the Antarctic sea ice cover.


OI Class - Older, rougher, thicker
Photo courtesy of Michael J. Lewis, SIMBA Field Campaign, October 2007

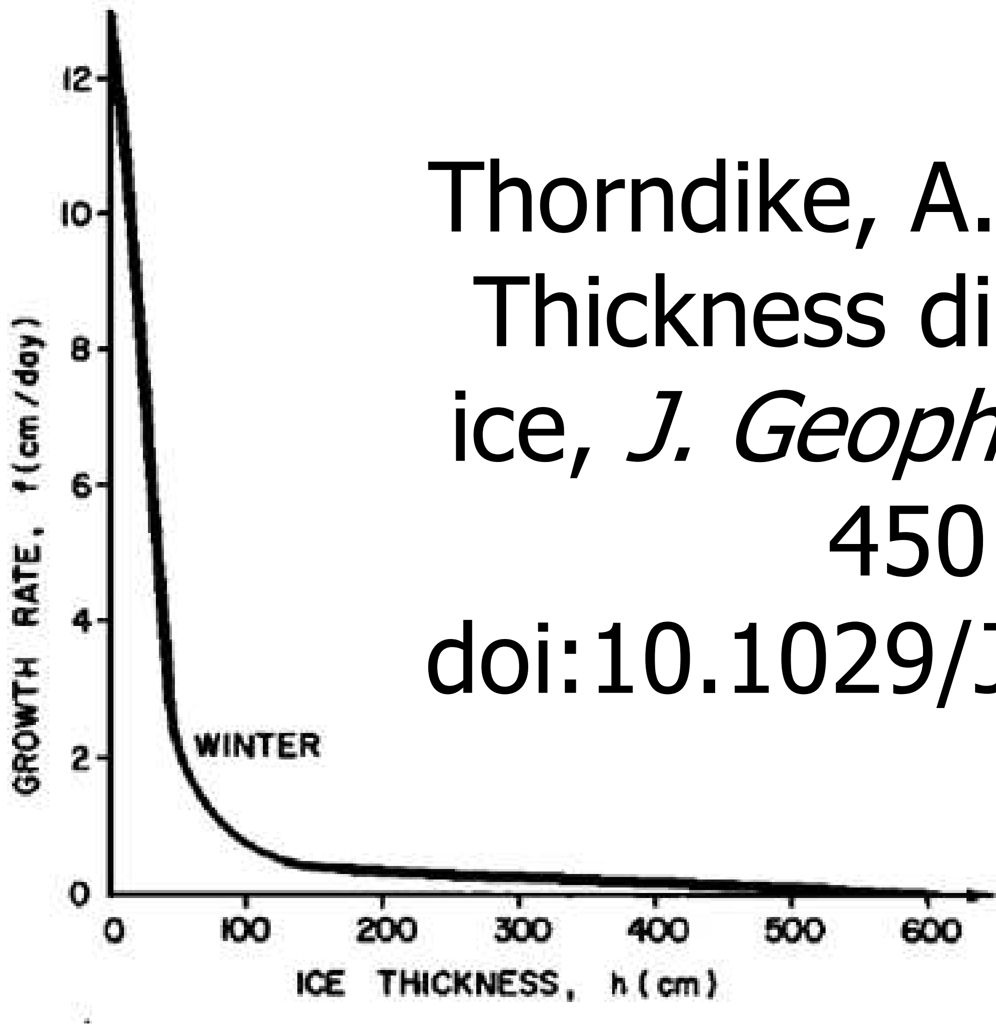


Decadal maps of synoptic sea ice classes

Antarctic FIZ surrounded & encapsulated the Antarctic sea ice cover vs Arctic MIZ

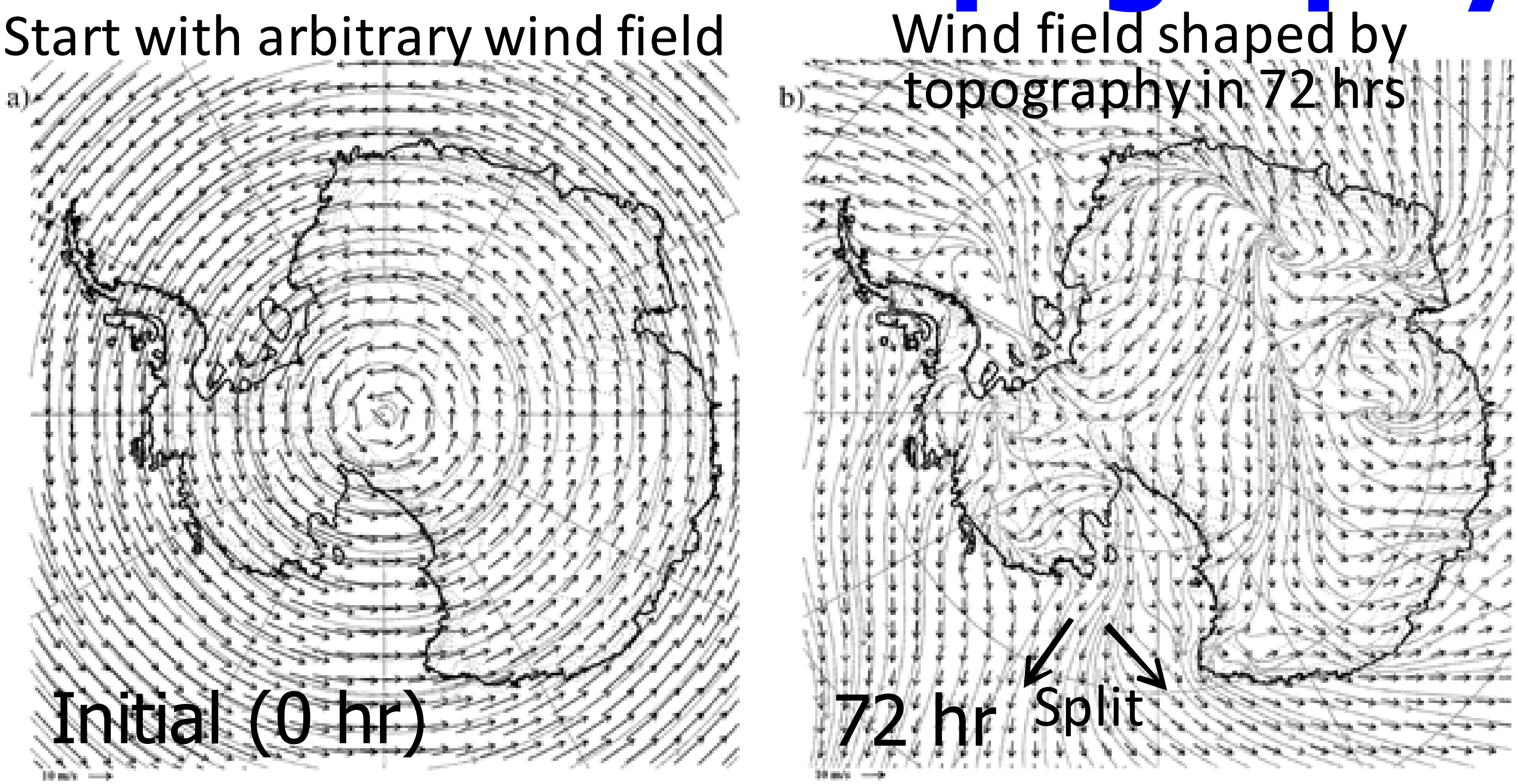

QuikScat Tracks
1-06-2008

Effective Growth of Sea Ice in the Regions of Younger Sea Ice (YI) Class



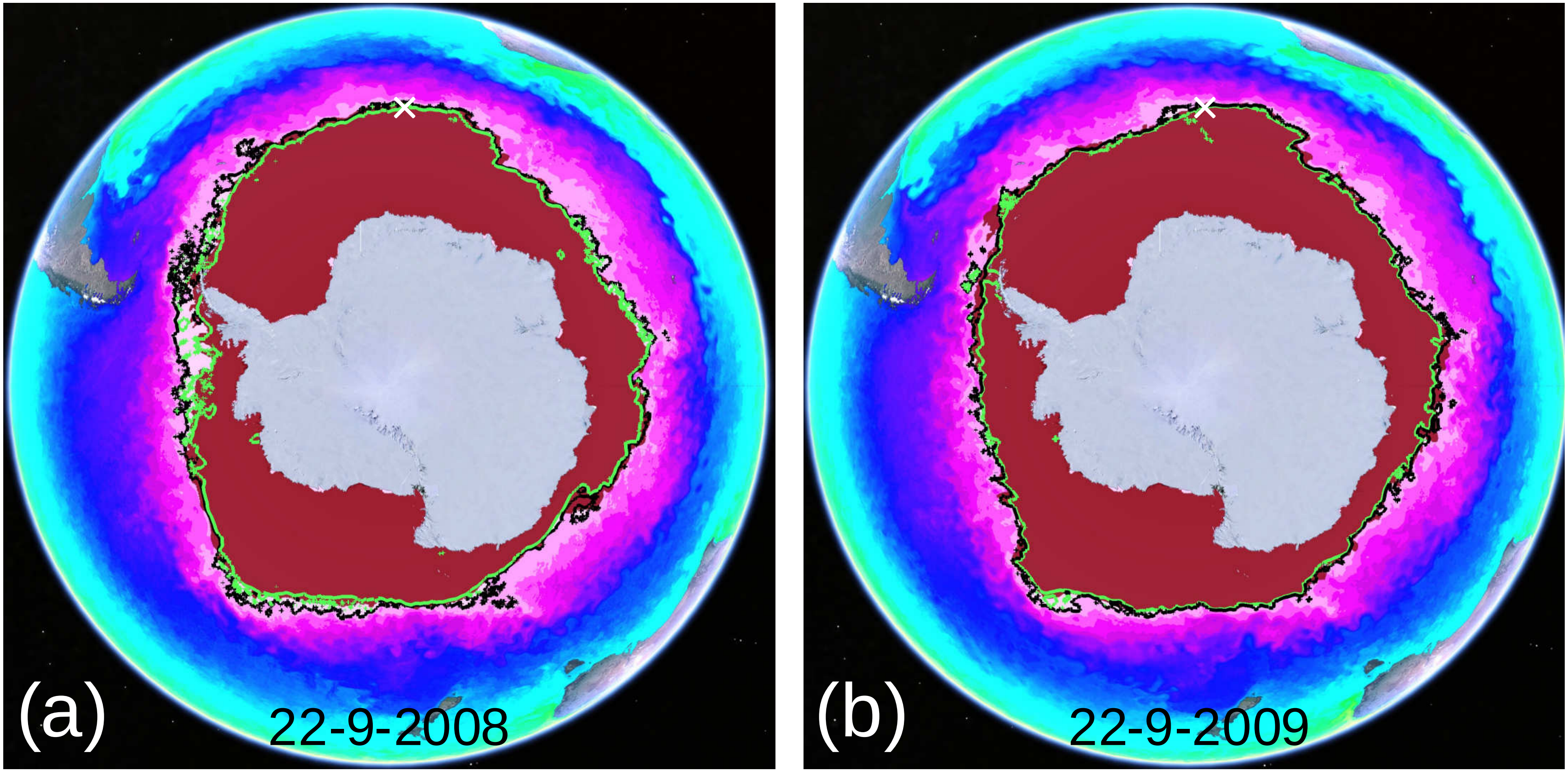
Thorndike, A. S., et al. (1975), Thickness distribution of sea ice, *J. Geophys. Res.*, *80*(33), 4501-4513, doi:10.1029/JC080i033p04501

Wind Pattern Shaped by Continental Topography

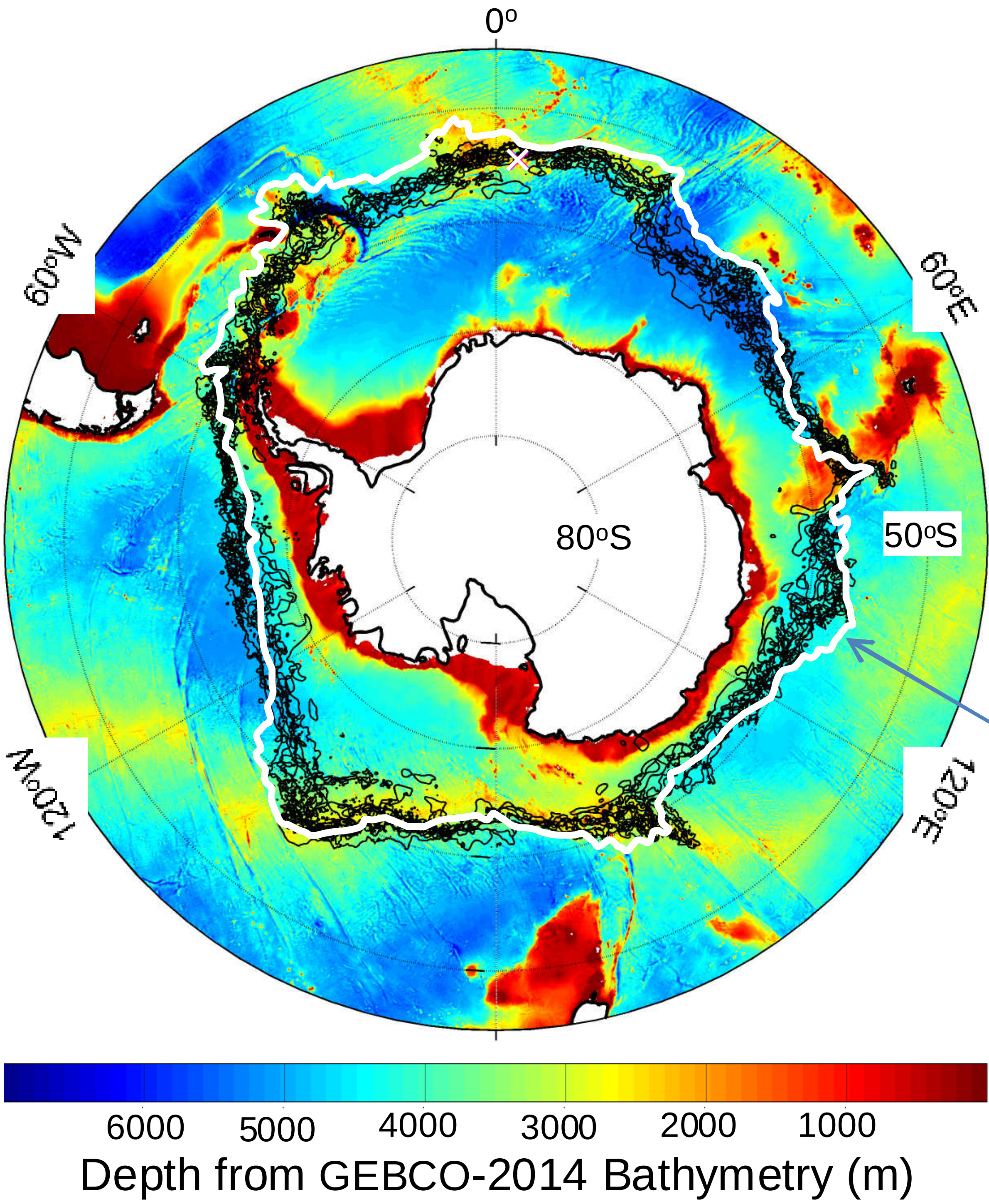


Parish, T. R., and J. J. Cassano, J. J. (2003). Diagnosis of the Katabatic Wind Influence on the Wintertime Antarctic Surface Wind Field from Numerical Simulations. *Monthly Weather Rev.*, *131*, 1128-1139.

Sea Ice and Sea Surface Temperature (MUR Product)

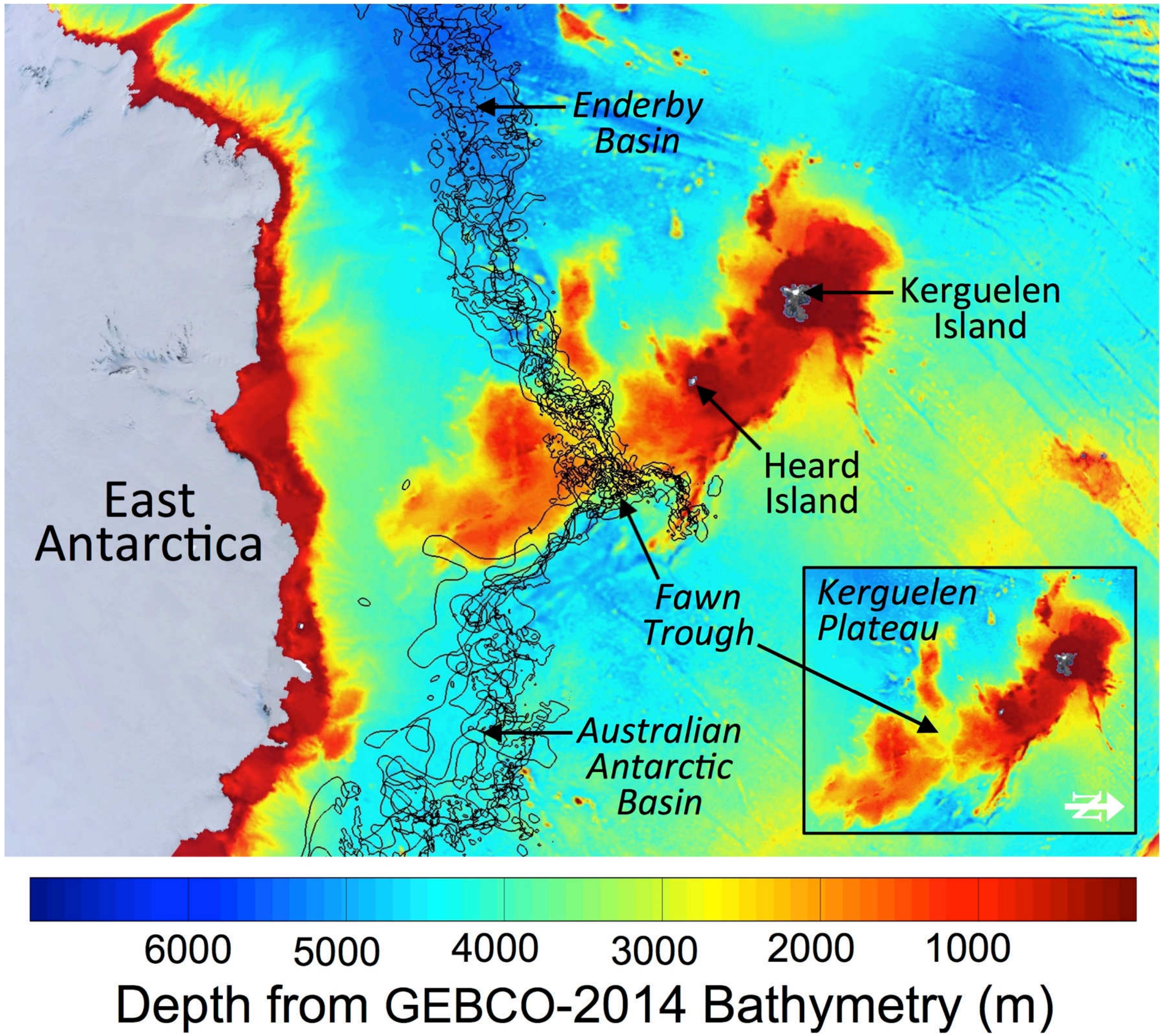


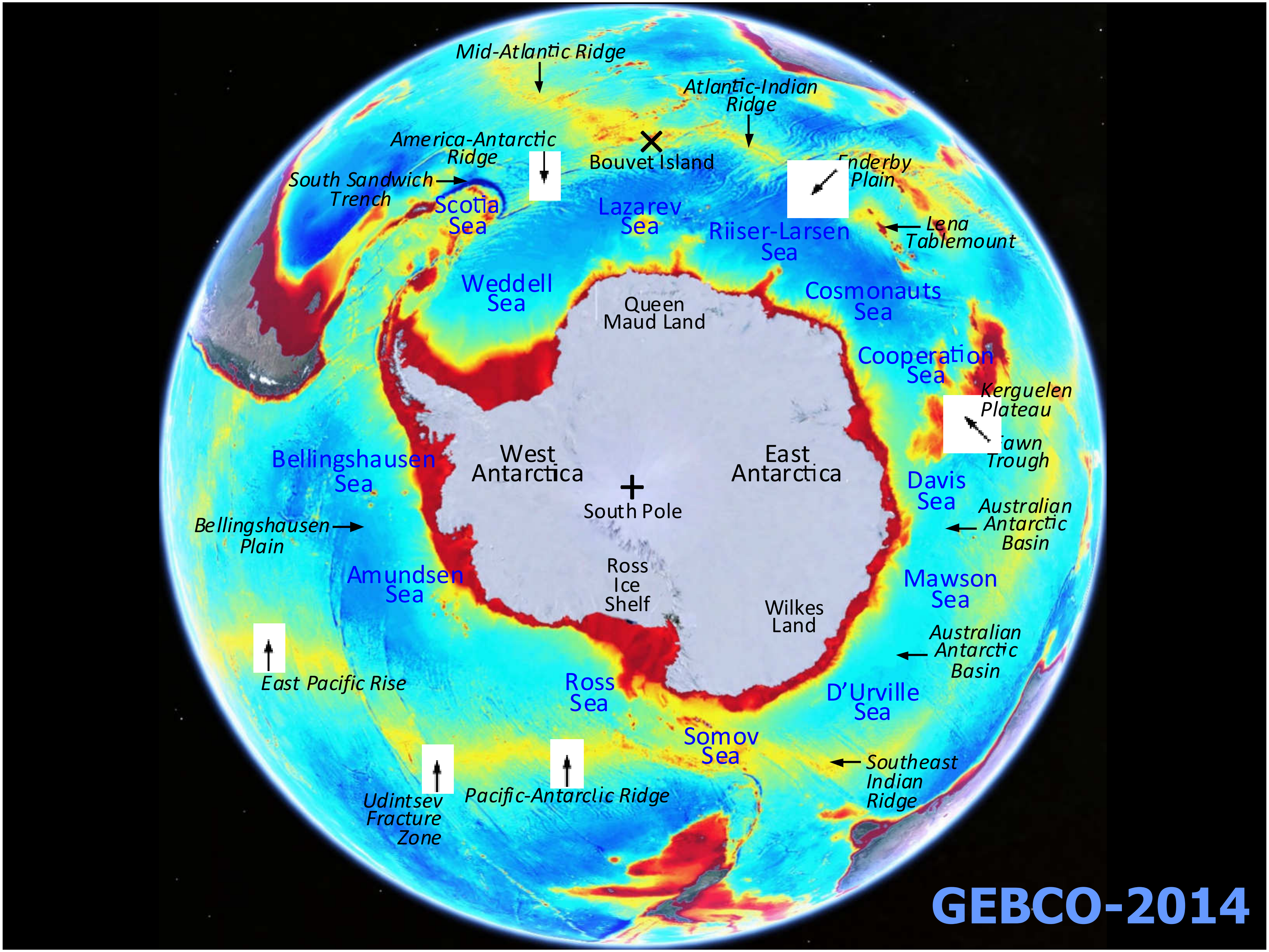
SST Isobaths (1999-2009) and GEBCO-2014 Bathymetry



Southern Antarctic Circumpolar Current (ACC) front (sACCf) delineated by Kim and Orsi (2014)

SST over Kerguelen Plateau




Mid-Atlantic Ridge
Atlantic-Indian Ridge
America-Antarctic Ridge
Bouvet Island
nderby Plain
South Sandwich Trench
Scotia Sea
Lazarev Sea
Riiser-Larsen Sea
Lena Tablemount
Weddell Sea
Cosmonauts Sea
Queen Maud Land
Cooperation Sea
Kerguelen Plateau
awn Trough
Bellingshausen Sea
West Antarctica
East Antarctica
South Pole
Davis Sea
Australian Antarctic Basin
Bellingshausen Plain
Amundsen Sea
Ross Ice Shelf
Mawson Sea
Wilkes Land
Australian Antarctic Basin
East Pacific Rise
Ross Sea
D'Urville Sea
Somov Sea
Southeast Indian Ridge
Udintsev Fracture Zone
Pacific-Antarctic Ridge
GEBCO-2014

Same Physics but Opposite Effects

- **Sea Ice Properties**: Antarctic circumpolar FIZ with older rougher and thicker sea ice vs Arctic MIZ with younger and thinner sea ice.
- **Atmospheric Forcing**: Antarctic winds create ice factories, ridging/recirculating ice vs Arctic winds causing ice loss by exporting sea ice.
- **Oceanic Forcing**: Antarctic bathymetry cons-trains the location of the sACCf and sea ice vs Arctic bathymetry responsible for mechanisms that aggravate sea ice loss (e.g., release of warm waters from the Mackenzie River).

Conclusions

- "Great Shield" zone of Antarctic Sea Ice: with OI and RI, encapsulating and protecting internal YI sea ice, bounded by the sACC front. FIZ recirculation by the persistent westerlies.
- Wind consistently opening internal sea ice for effective ice growth (ice factories in YI areas).
- Geological factors, topography for winds and bathymetry for waters, persistently maintain the stability of Antarctic sea ice.
- Antarctic sea ice behavior is consistent with Antarctic geophysics and thus not a paradox.

Contact

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