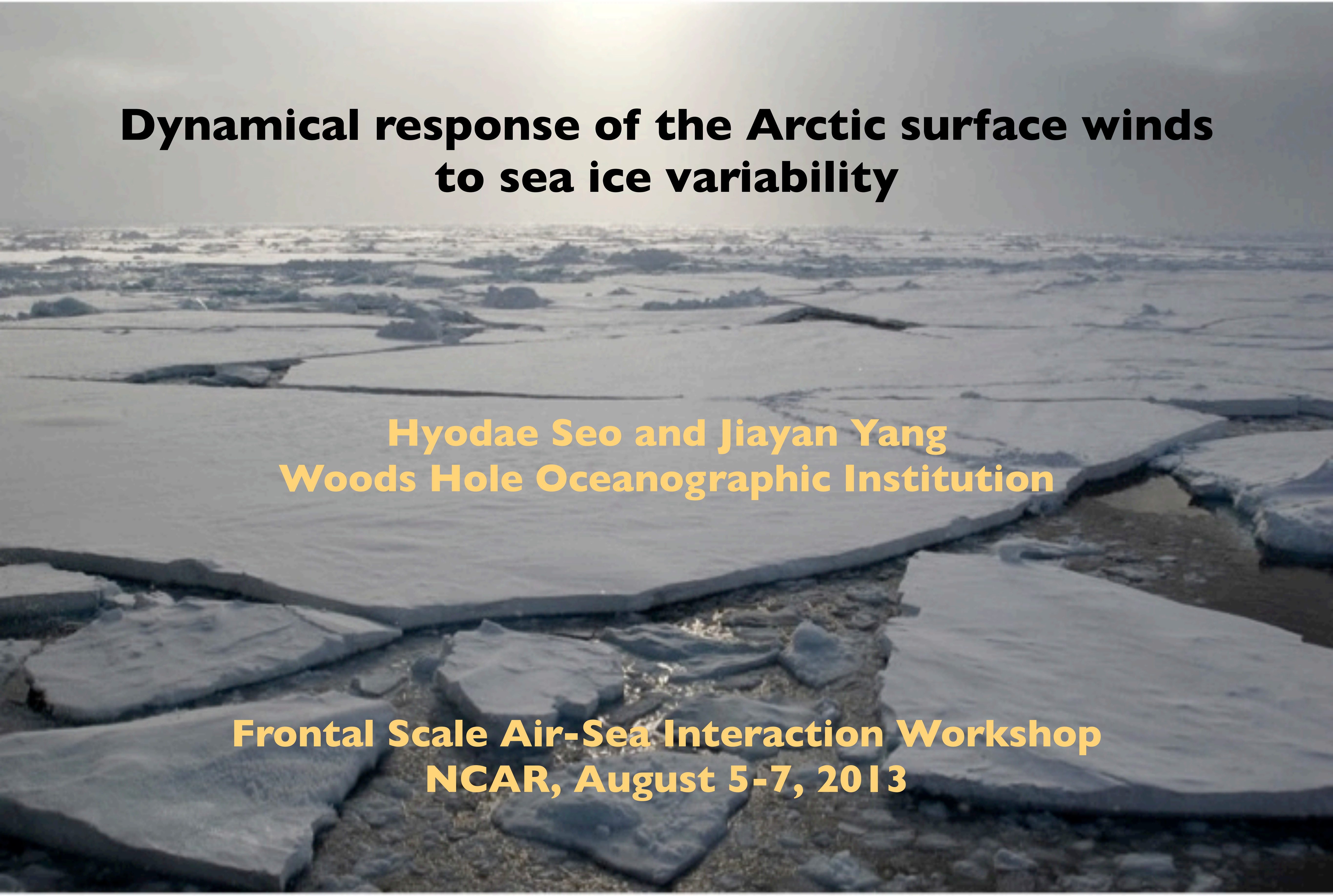

Dynamical response of the Arctic surface winds to sea ice variability

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Atmospheric boundary layer and the Arctic sea ice

- Sea ice variations modulate the structure of the Arctic ABL.
  - Diabatic heating anomalies by motions in sea ice, formation in leads, ponds, and polynyas, and across the ice margins.
  - Aircraft measurements by Overland (1985) showing a factor of 4 increase in wind stress during unstable condition
- Yet another interesting region to study ABL-SST (ice) coupling!

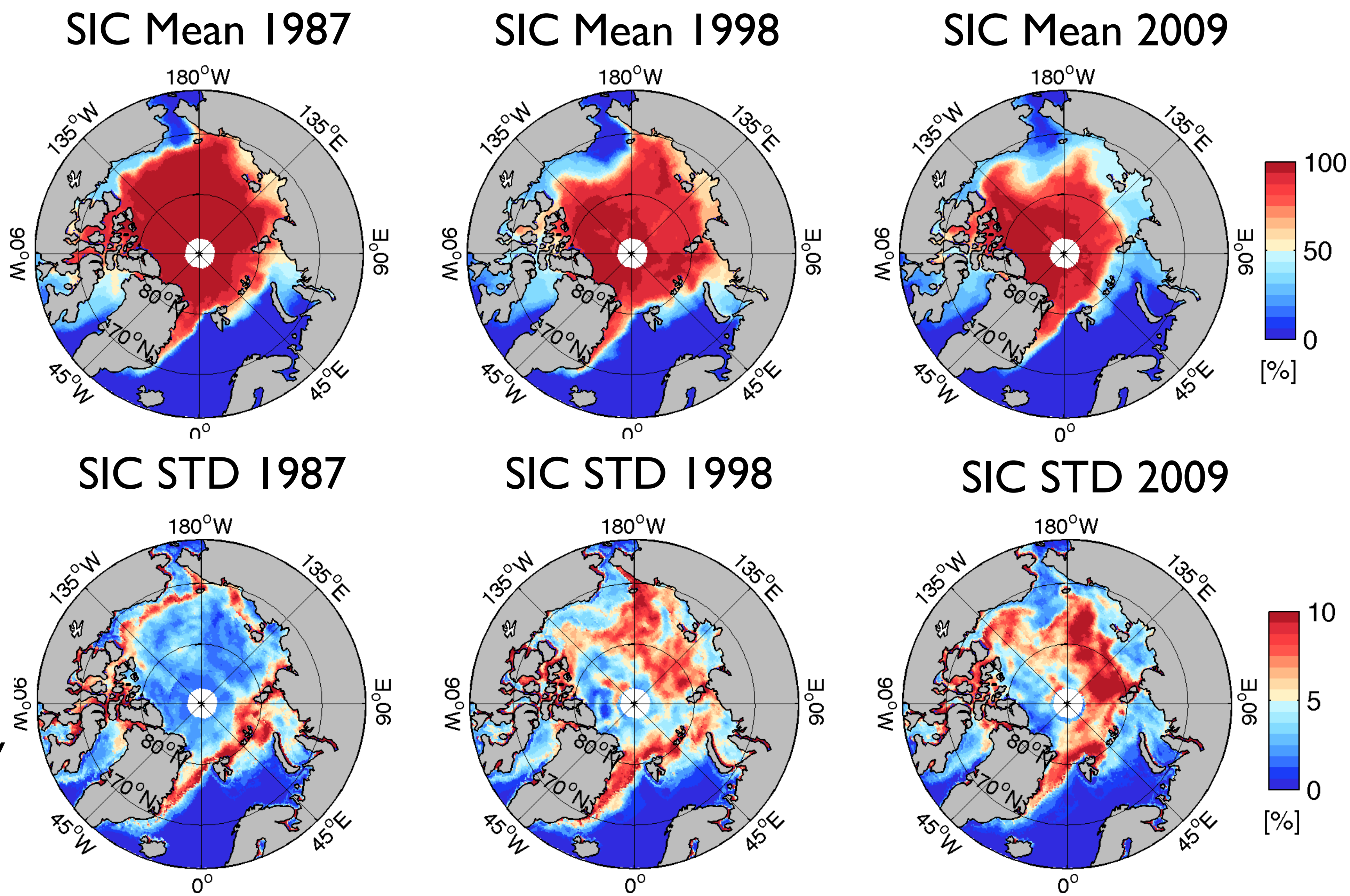
- Sparse observations of surface wind and energy balance over the sea ice.
  - A source of uncertainties in ice-ocean modeling (Hunk and Holland, 2007).
  - Need accurate description of surface winds for a range of ice conditions.

- Sea ice concentration (SIC) from the passive microwave radiometers
  - The most extensively and continuously observed climate variable.
  - Boundary conditions for weather forecast models and ocean models.
  - Different retrieval algorithms lead to diversity in SIC estimates.

Diversity in SIC estimates in autumn (September to November)

MEAN of SIC datasets

STD across SIC datasets ≈ *Uncertainty*



Three SIC datasets used in this study:

1) **NT**: NASA-TEAM algorithm, 25km, Swift and Cavalieri (1985)
2) **BT**: NASA Bootstrap algorithm, 25 km, Comiso (1986)
3) **EU**: EUMET-SAT hybrid algorithm, 12.5 km, Tinboe et al. (2011)

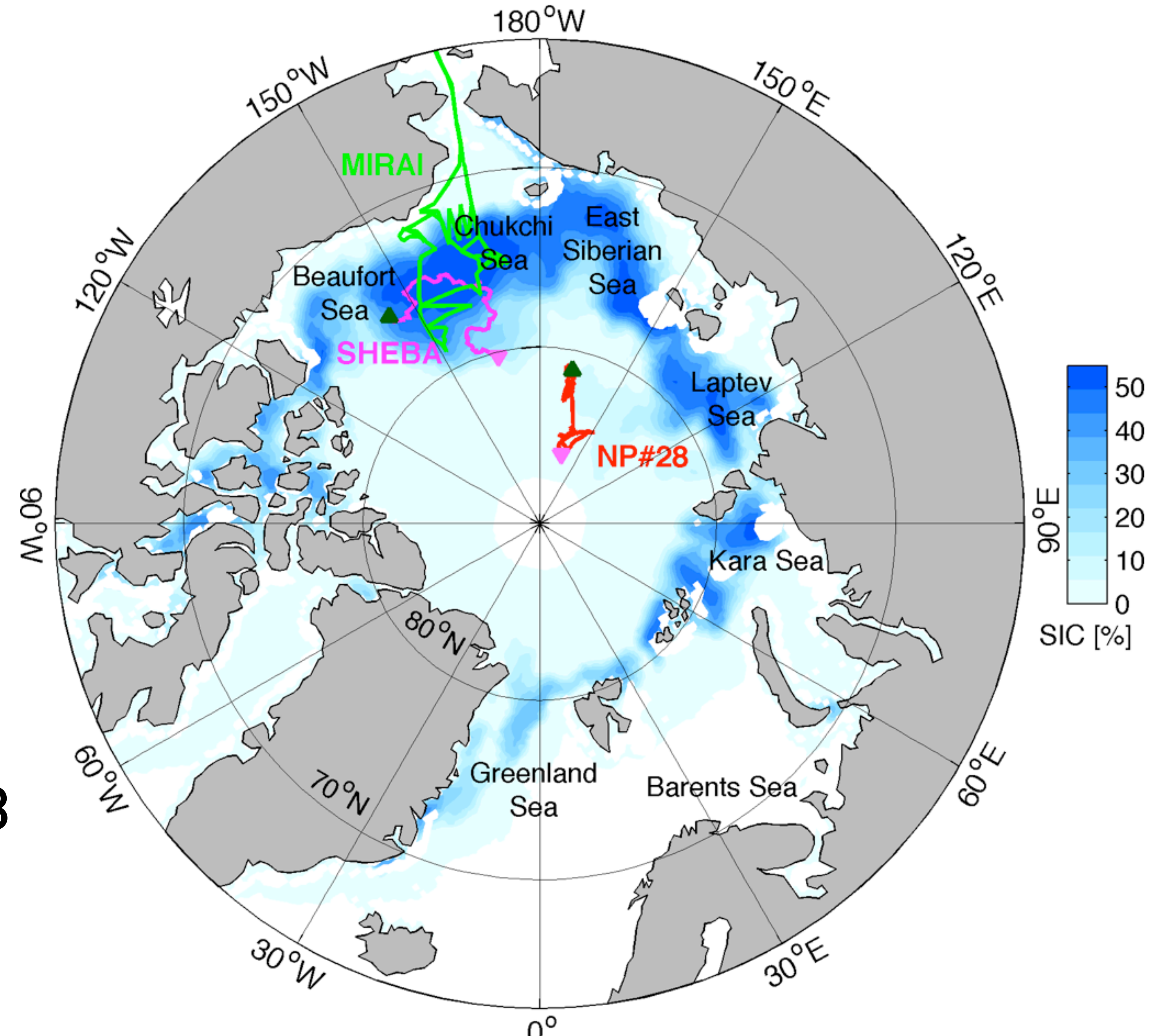
Goals of this study

1. Assess impact of uncertainty in SIC estimates on the model's skill
2. Investigate thermodynamic effect of sea ice on the ABL.
3. Examine response in two surface winds (W10 and Wg)

Polar WRF simulation

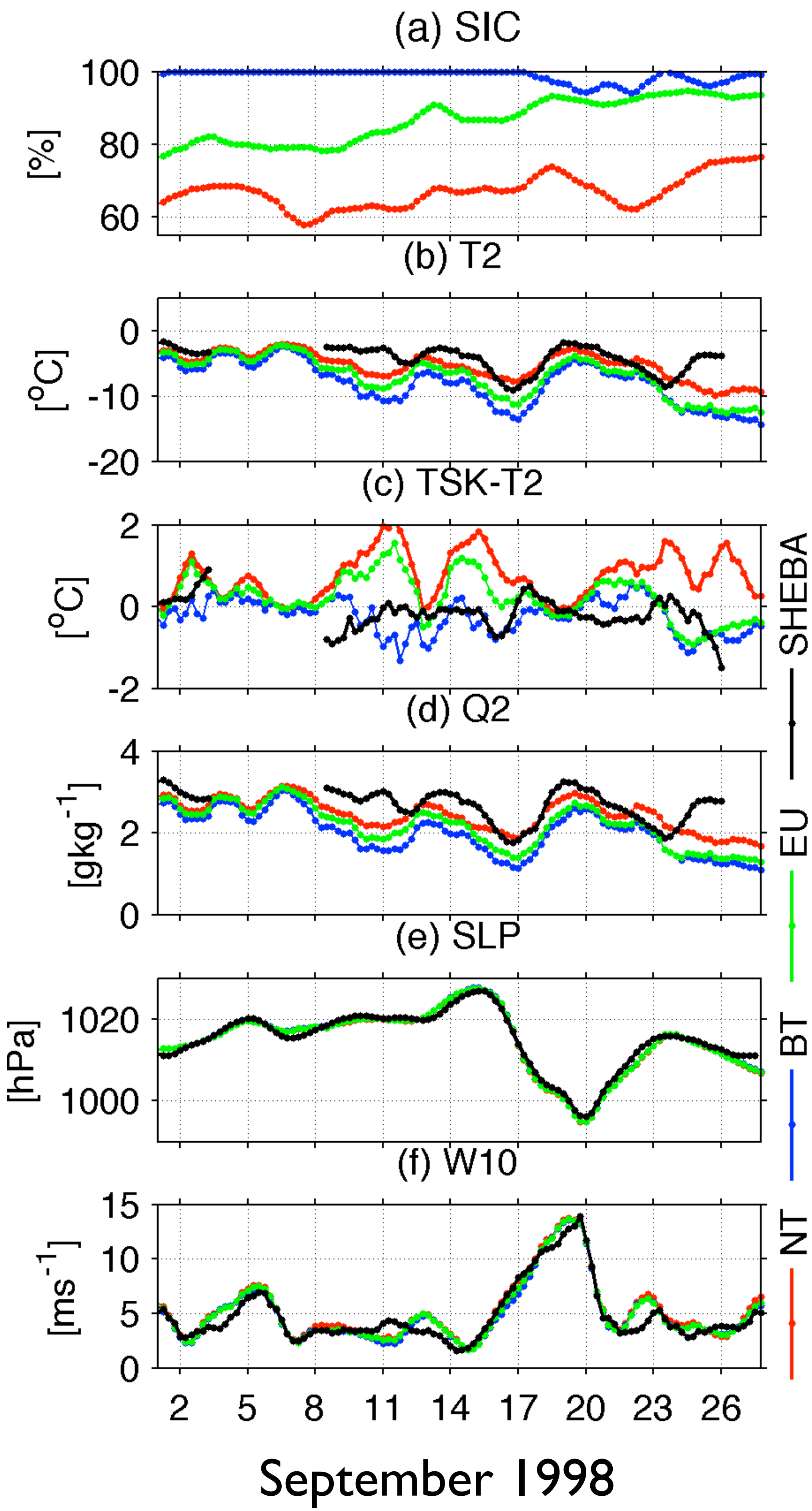
- Polar WRF: Hines and Bromwich (2008)
  - WRF optimized for the polar regions
  - Modified surface layer model for improved surface energy balance
- Experiments
  - Three one-year (Nov-Oct) runs
    - separated by 11 years
    - 1986-1987 : North Pole Station #28
    - ✔ 1997-1998 : SHEBA
    - 2008-2009 : R/V Mirai
  - Each period forced with NT, BT, EU

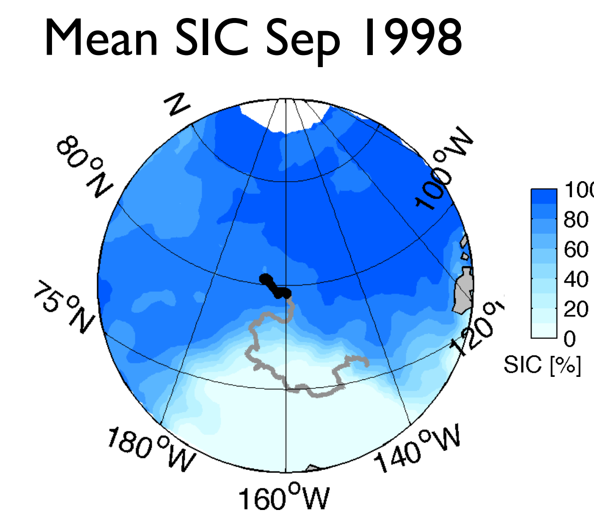
Polar WRF domain, in situ datasets overlaid with STD of SON SIC



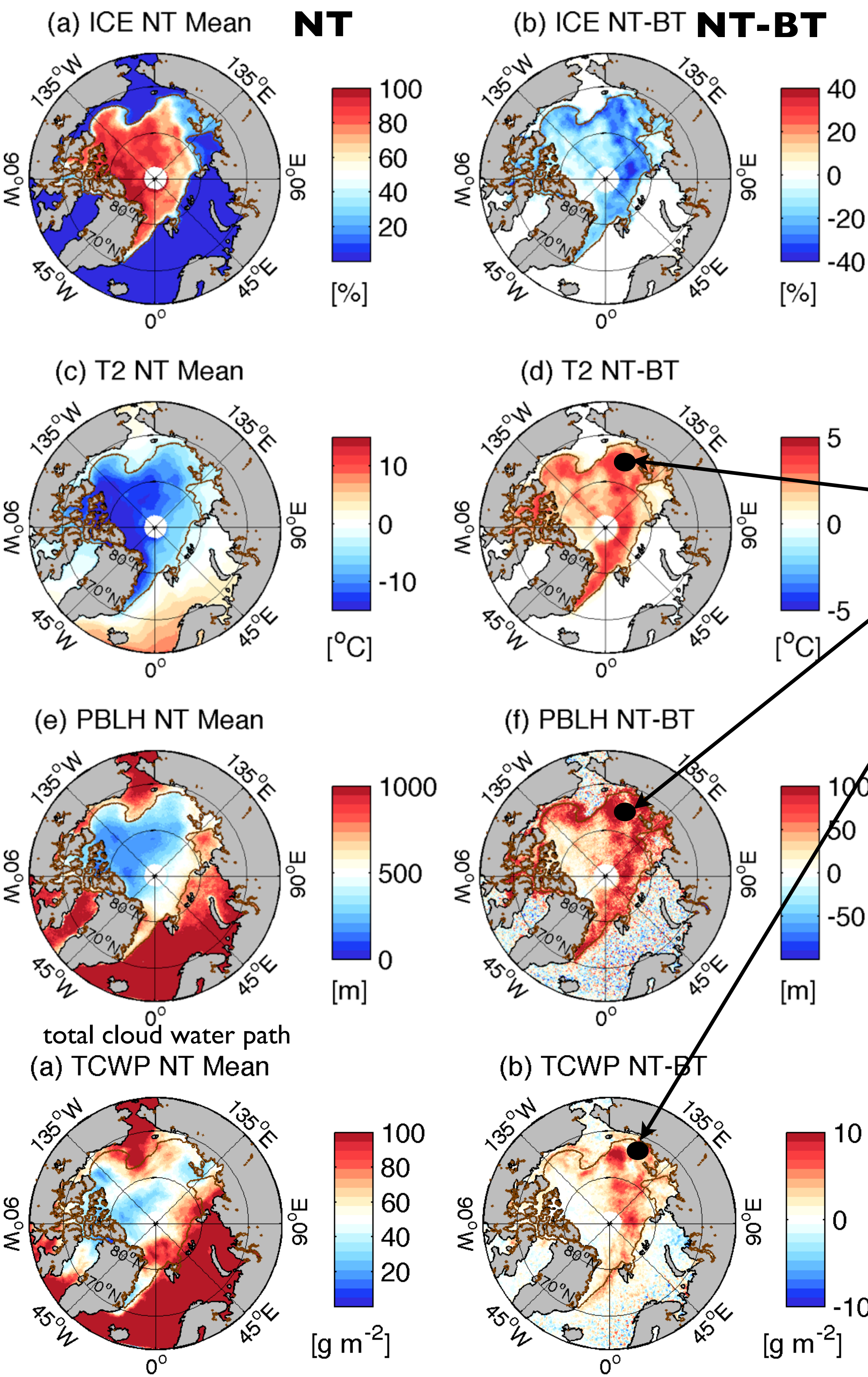
- ABL evolution over different SIC conditions
  - NP#28: Consolidated pack ice
  - ✔ SHEBA: Multi-year thick ice
  - MIRAI : Marginal ice zone

SHEBA Ice Station: Striking sensitivity of ABL over multi-year ice





- SIC: BT>EU>NT
  - 20-40% difference between NT and BT.
- T2, TSK-T2 reflect the SIC evolutions.
  - BT ABL is cold, stable and dry.
  - NT ABL is warm, unstable and humid.
  - EU ABL lies between NT and BT
- Spread in T2: ~5K.
- Conflicting TSK-T2 with different SIC data
- Better T2/Q2 with NT, better TSK-T2 with BT.
- ABL thermodynamic fields show striking sensitivity (spread) to sea ice.
- SLP and W10 sensitivity not as striking.



Pan-Arctic response pattern

Focusing on NT - BT in September 2009

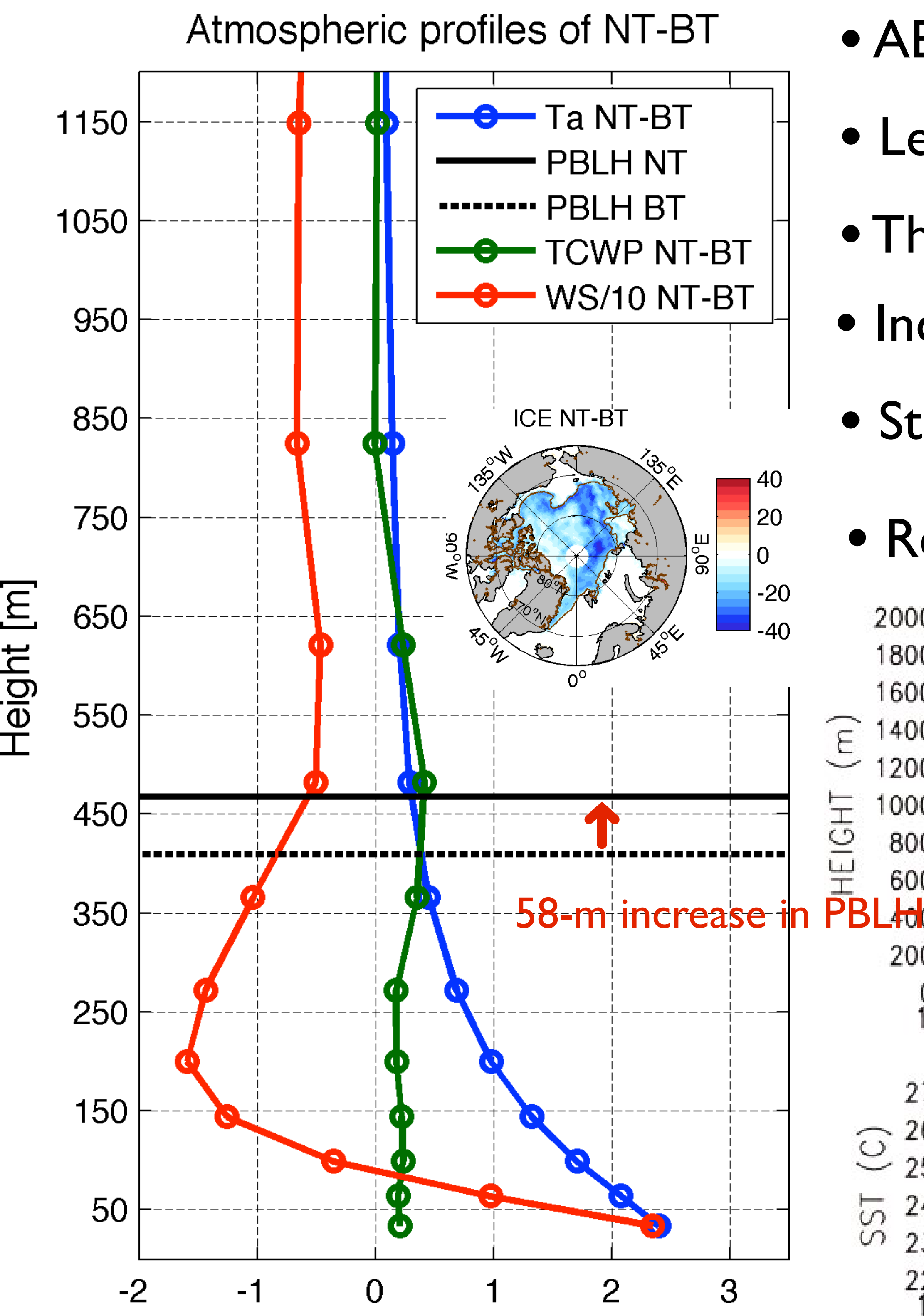
Large change in ABL compared to the mean values

East Siberian Sea	Mean	Difference
T2	-5 °C	+5 °C
PBLH	450 m	100 m
TCWP	60 gm^{-2}	10 gm^{-2}

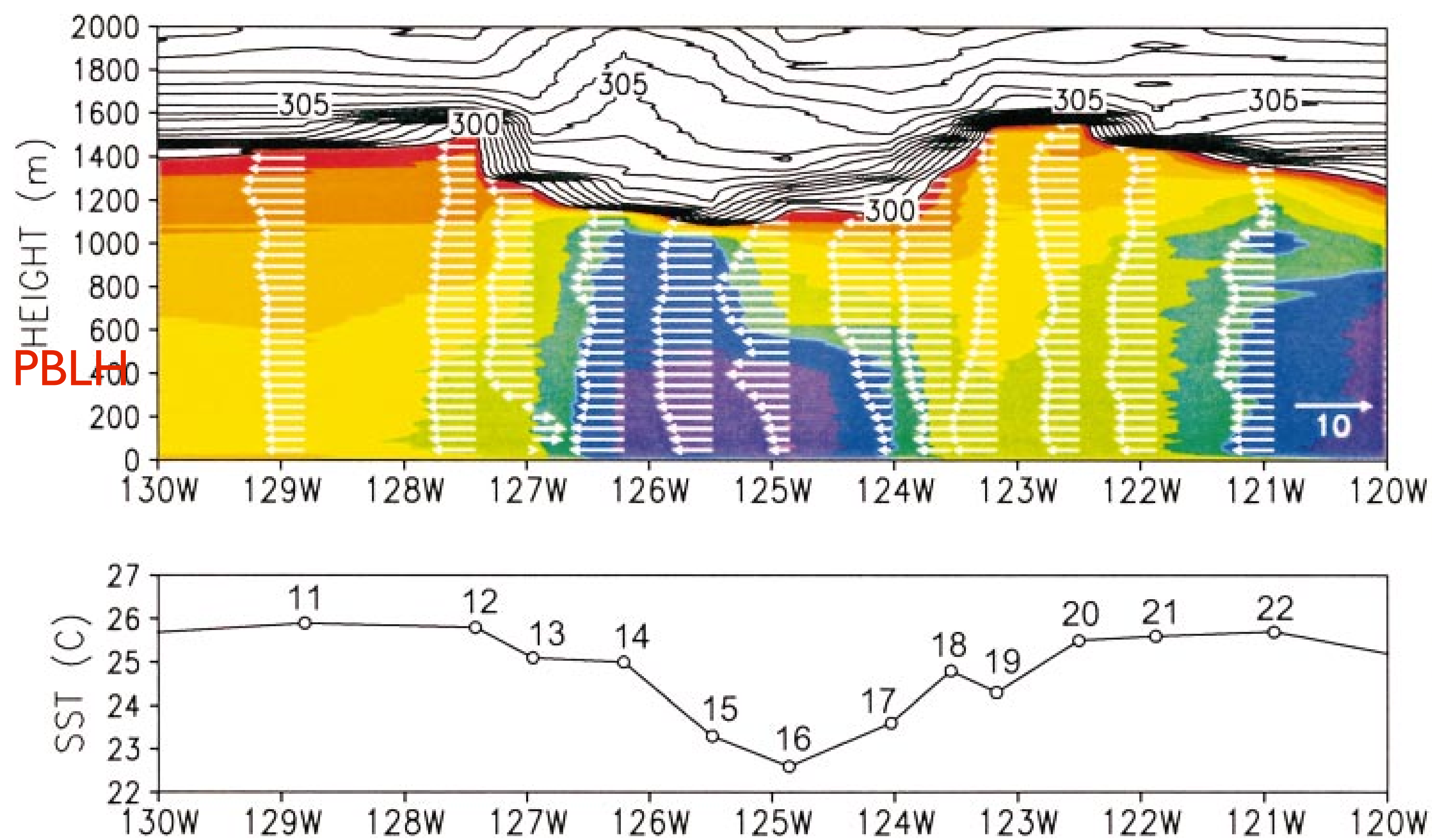
SIC uncertainty is a decisive factor for hindcast skill!

- SIC difference and ABL sensitivity on the comparable basin-scales

Arctic-basin averaged vertical profiles difference (NT-BT)



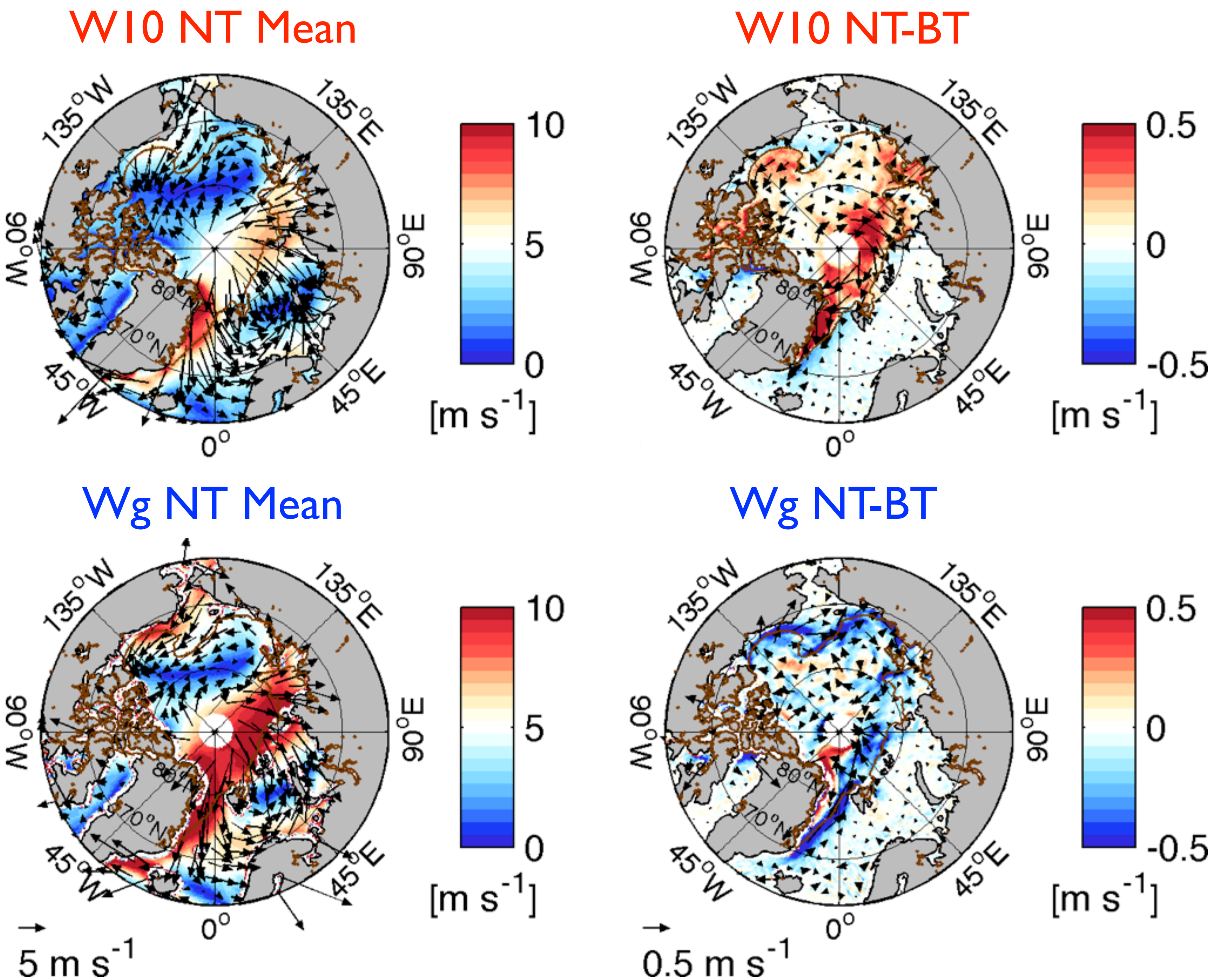
- ABL stability adjustment to SST: Wallace et al., (1989).
- Less SIC ➔ Higher PBL
- The basin-wide increase in air temperatures below PBL.
- Increased cloud water path near the top of PBL.
- Stronger wind below 100 meter but weaker wind aloft
- Reminiscent of what is happening in mid to low latitudes!



Observations of ABL evolution in the eastern tropical Pacific
Hashizume et al. (2002)

Contrasting responses in two near-surface winds: W10 and Wg

NT - BT in September 2009



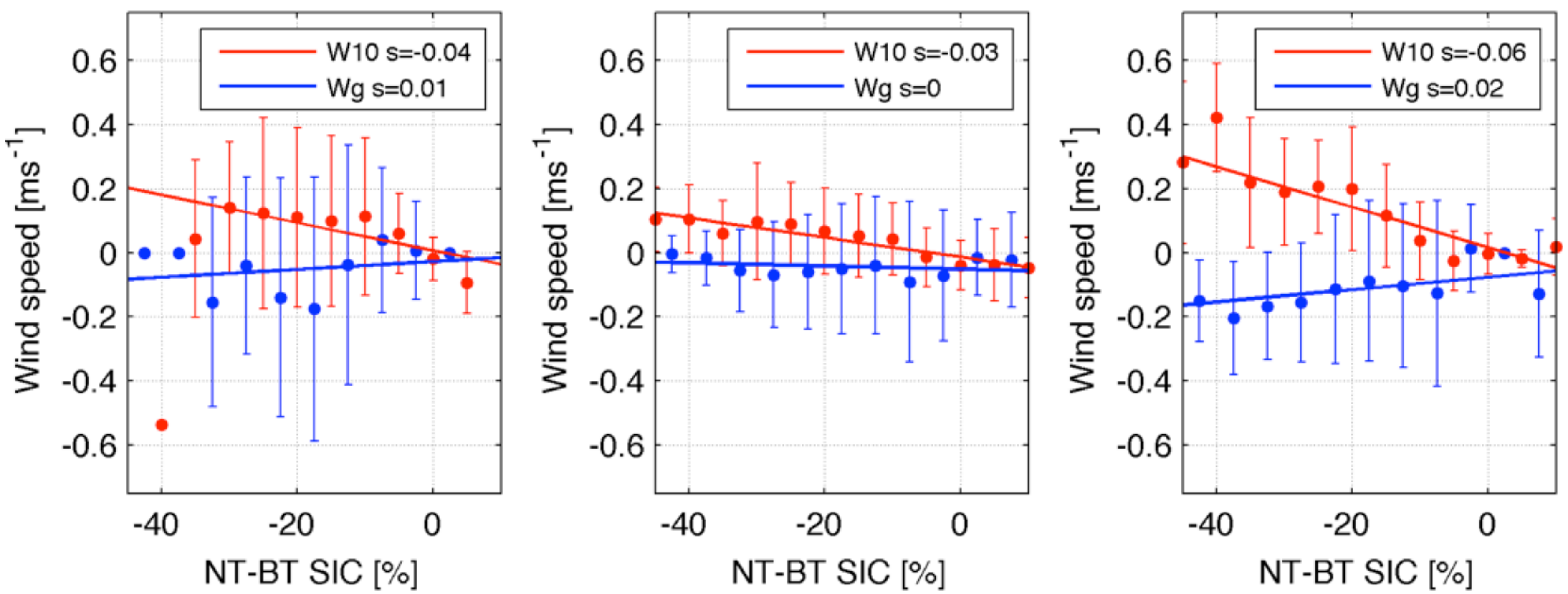
- Stronger W10 with reduced SIC
  - Most dramatic changes in the interior Arctic
  - >10% change of the mean.
- Reduced Wg along the ice margins!
  - Significant changes compared to the mean Wg
  - No significant changes in the interior Arctic.

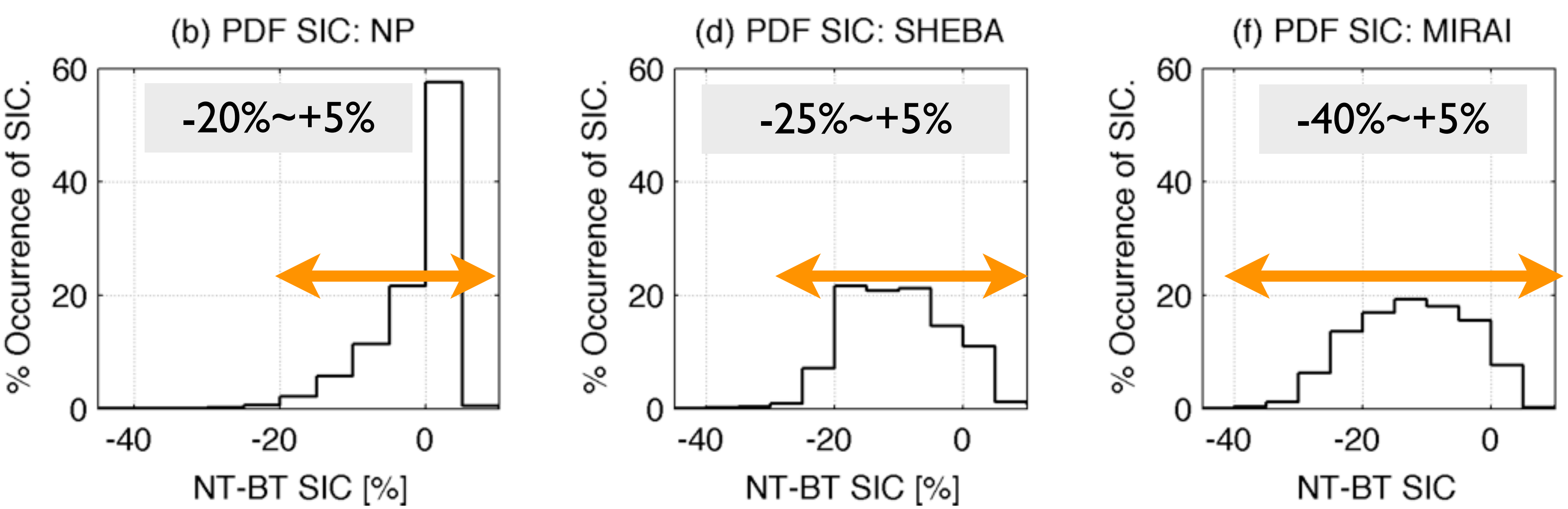
Influence of SIC on W10 and Wg

as measured from the coupling coefficient (as in Chelton et al. 2001)

Binned scatter plots of W10 and Wg against the SIC difference (NT - BT)

Sep 1987 | Sep 1998 | Sep 2009





Increasing uncertainties in September SIC estimates!

- **SIC-W10:**

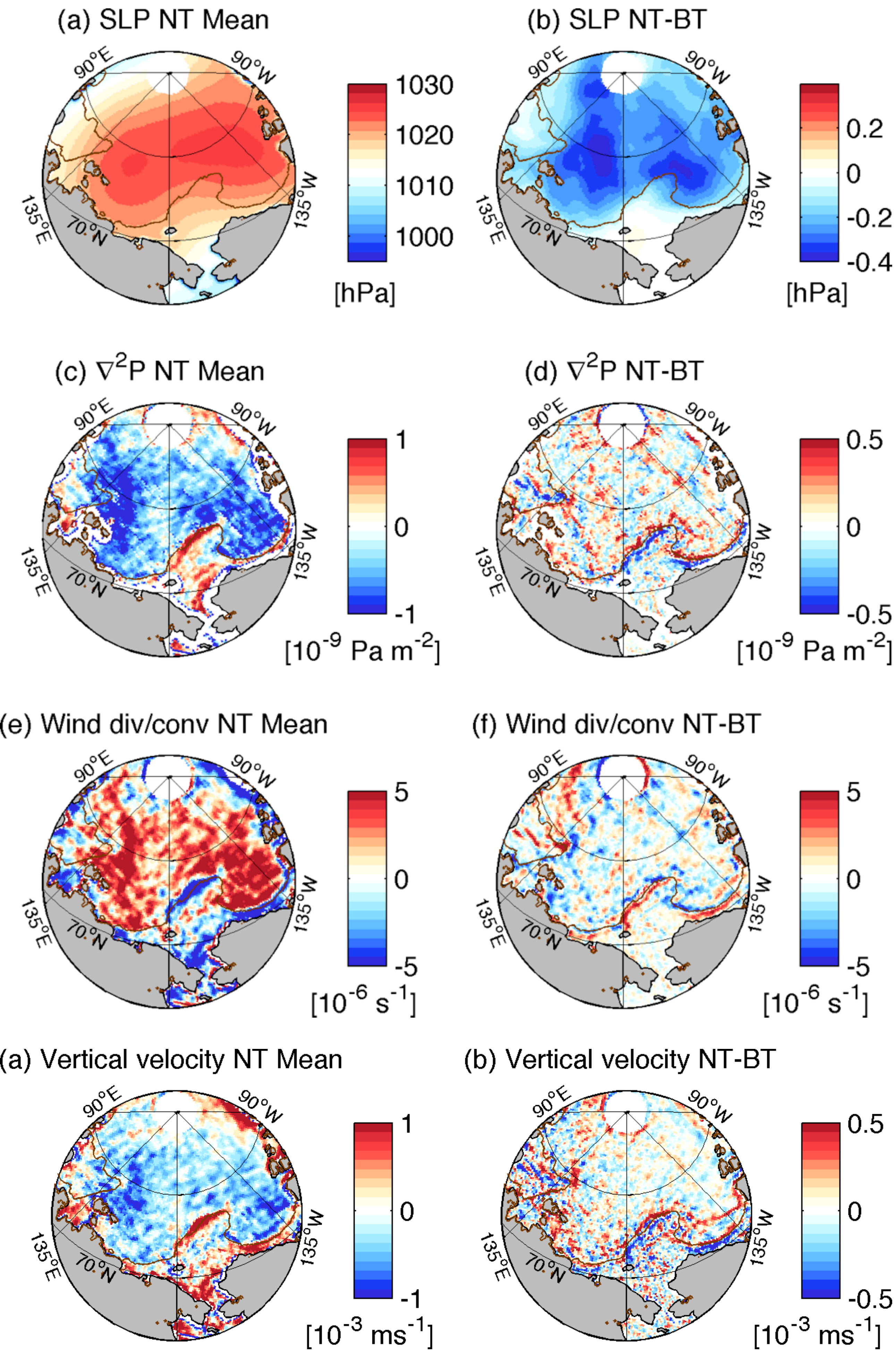
  (1) A Significant negative relationship

  (2) A hint for increasing trend in W10 response

- **SIC-Wg:**

  (1) No significant relationship to SIC, either a weak positive or no correlation.

  (2) No obvious trend in relationship.



Wg response across the ice margins

- A simple marine boundary layer model of *Lindzen and Nigam (1987)*: steady flow, no advection, linear friction,

$$\rho_o\left(\nabla\cdot\vec{u}\right)=-\left(\nabla^2 P\right)\varepsilon/\left(\varepsilon^2+f^2\right)$$

- Div. /Conv. of surface wind is linearly proportional to SIC-induced Laplacian of SLP

$$w(z)=\frac{1}{\rho_o}\left(\frac{\varepsilon z}{\varepsilon^2+f^2}\right)\nabla^2 P$$

- SIC-induced vertical velocity (*w*) is proportional to $\nabla^2 P$.
- ∇^2 would be effective in highlighting small-scale response,

  e.g., along the sea ice margins.

Conclusion (1)

- The satellite-based sea ice datasets feature enhanced uncertainties
  - both in the interior Arctic and the sea ice margins
  - during the onset of freezing (and the day-to-day variations near the ice margins)
  - A hint for increasing trend in SIC uncertainties in autumn.
- These are the factors that lower the skill of Polar WRF.

Conclusion (2)

- Two “familiar” SST-ABL mechanisms also hold for the Arctic with sea ice.
  - Why not!
  - Ice margins and melt ponds represent large spatial variations in TSK
    - ➡ A striking thermodynamic response in ABL on the Arctic basin

- Two ABL response mechanisms appears to act on different spatial scales:

  - Effect #1: Vertical stability mechanism
    - Overland (1985), Wallace et al. (1989)
    - Pronounced on the broad area of the interior Arctic
    - Comparable basin scales in SIC difference and ABL response

  - Effect #2: Pressure-gradient mechanism
    - Lindzen and Nigam (1985), Minobe et al. (2007)
    - Pronounced only across the ice margins.
    - The ∇^2 operator emphasizes the narrowness of the scale.

Implications and future direction

- The ocean-ice modeling community often use the wind stress from

  (1) in situ SLP-based Wg:

  - underestimates the effect of large-scale SIC changes on wind (effect #1).

  (2) coarse resolution atmospheric reanalyses:

  - underestimate the wind variations across the ice margins (effect #2)

Both effects should be taken into account for improved simulation of the ocean circulation and sea ice drift.

- The increasing strength of W10-SIC coupling over time:
  - What is its role in the long-term Arctic climate?

- On going work
  - Long-term WRF simulations to diagnose effect/trend of ABL-SIC coupling
  - Implementing an interactive ice-ocean model to evaluate coupling effect

Thanks!

Seo, H. and J. Yang, Dynamical response of the Arctic atmospheric boundary layer process to uncertainties in sea ice concentration. *JGR-Atmos*., Revised.

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