Dynamics of the near-surface wind response to Arctic sea ice

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1. Summary

Goal: Understand two dynamically distinctive processes, acting on different spatial scales, determining surface wind variations over the Arctic sea ice.

Method: Use a skillful Polar WRF model applied to the Pan-Arctic domain forced with three different satellite sea ice concentration (SIC) datasets.

Implication: An accurate representation of these two effects of sea ice on the surface winds is needed to reduce uncertainties in surface forcing for ice-ocean models.

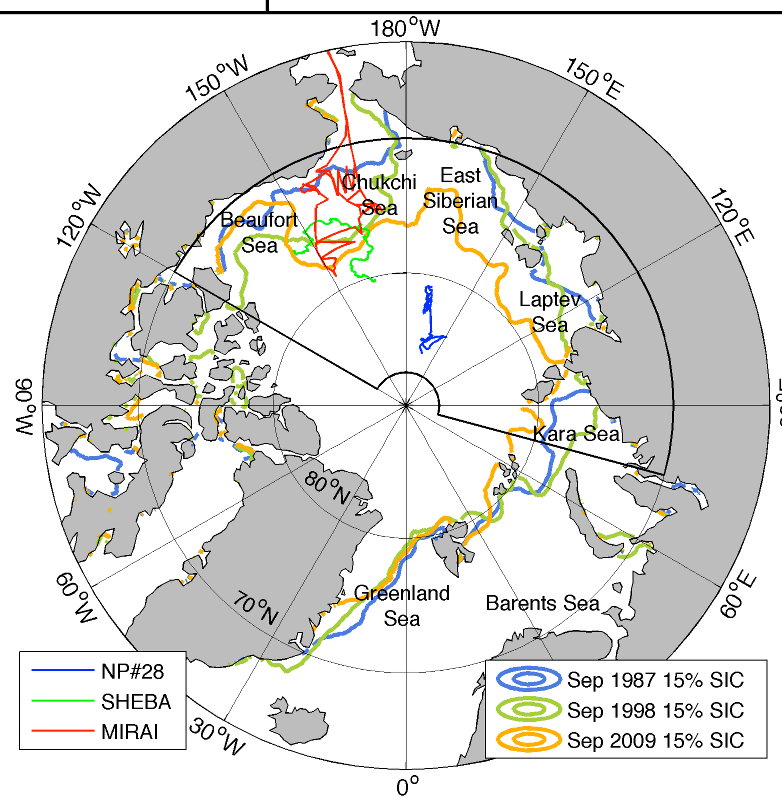
two SST-wind mechanisms	vertical mixing	pressure adjustment
proposed by	Overland et al. (1985), Wallace et al. (1989)	Lindzen and Nigam (1985)
key process	modulation of ABL stability and vertical mixing of momentum	SLP anomalies leading to conv./div. of surface winds
phase relationship	in-phase $\nabla \cdot u \propto \nabla_d T$	90° out-of-phase $\nabla \cdot u \propto -\nabla^2 P$
spatial scale	scales of wind and ice comparable, across the broad Arctic basin	wind response scale much smaller, near the ice margins

2. Model, experiment, and data

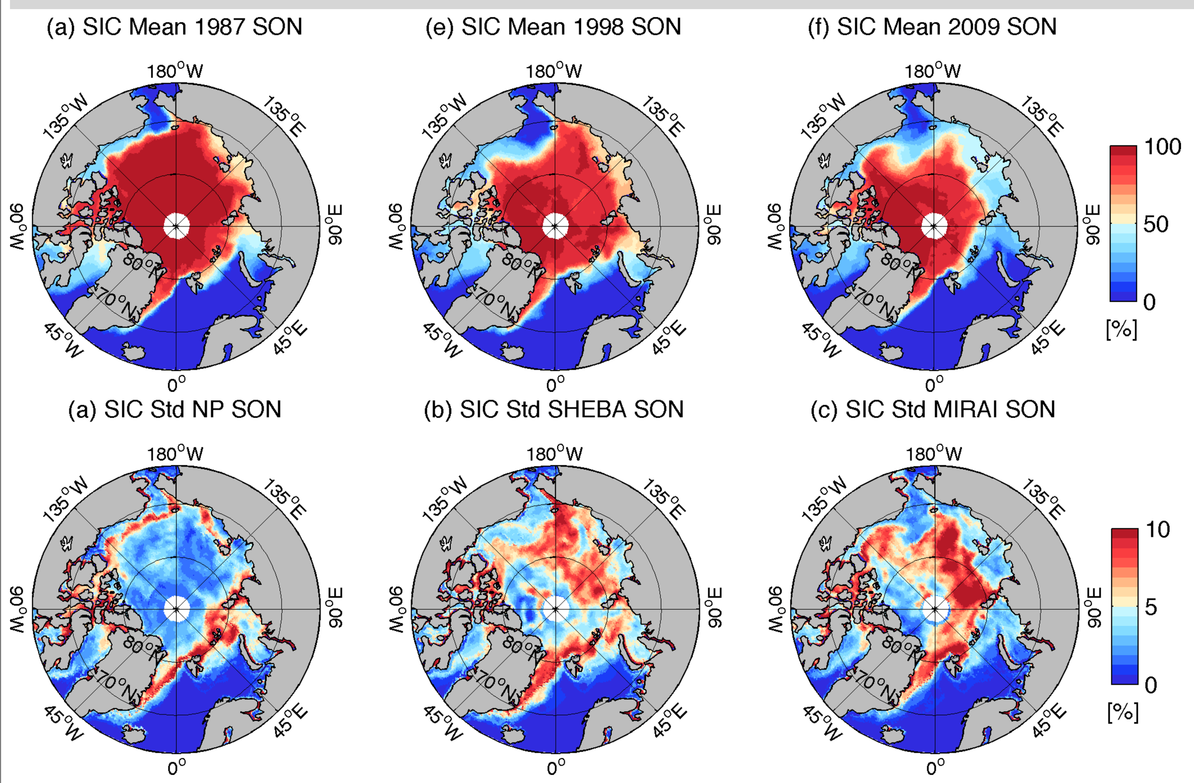
- Model: Polar WRF model (Hines and Bromwich, 2008), 25 km resolution
- Experiment: A series of 1-year integration forced with three SICs
- Sea Ice Concentration (SIC) Datasets
1) NT: NASA Team, daily 25 km (Cavalieri et al. 1996)
2) BT: Bootstrap, daily 25 km (Comiso 2000)
3) EU: EUMETSAT hybrid, daily 12.5 km (Tonboe et al. 2011)

- ABL measurements in the Arctic in September
1) Consolidated pack ice : NP drifting ice station #28, Sep 1987
2) Multi-year thick ice: Ice Station SHEBA, Sep 1998
3) Marginal ice zones: R/V Mirai, Sep 2009

Polar WRF domain, SIC and in situ data

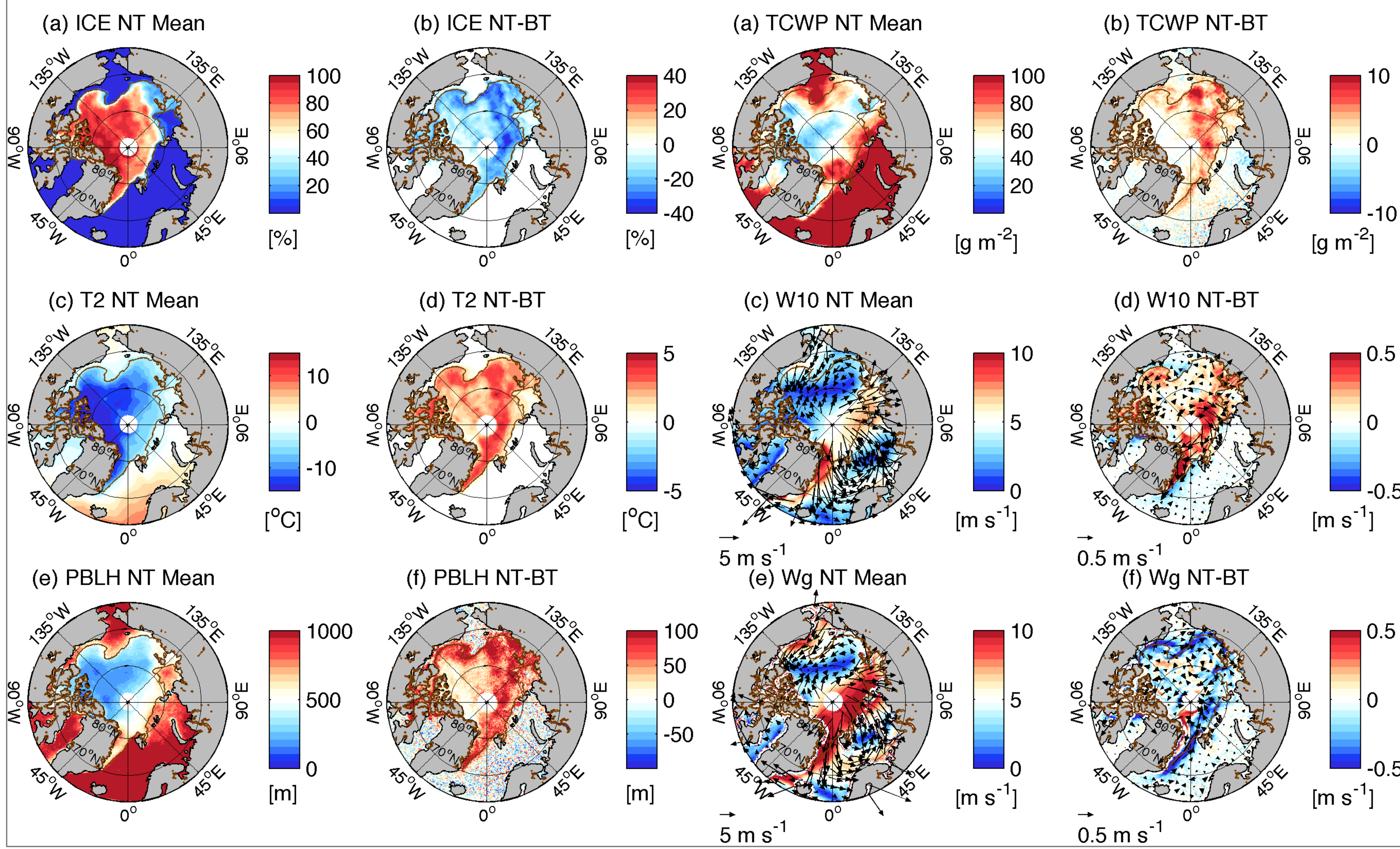


3. Uncertainties in sea ice concentration estimates in autumn



- The autumn SIC uncertainty showing a striking uncertainty pattern in the marginal ice zones and the interior Arctic.
- Uncertainty (STD of the across-data SIC) reaching 10%, representing a significant fraction of across-data mean SIC.
- Increasing trend in SIC uncertainties

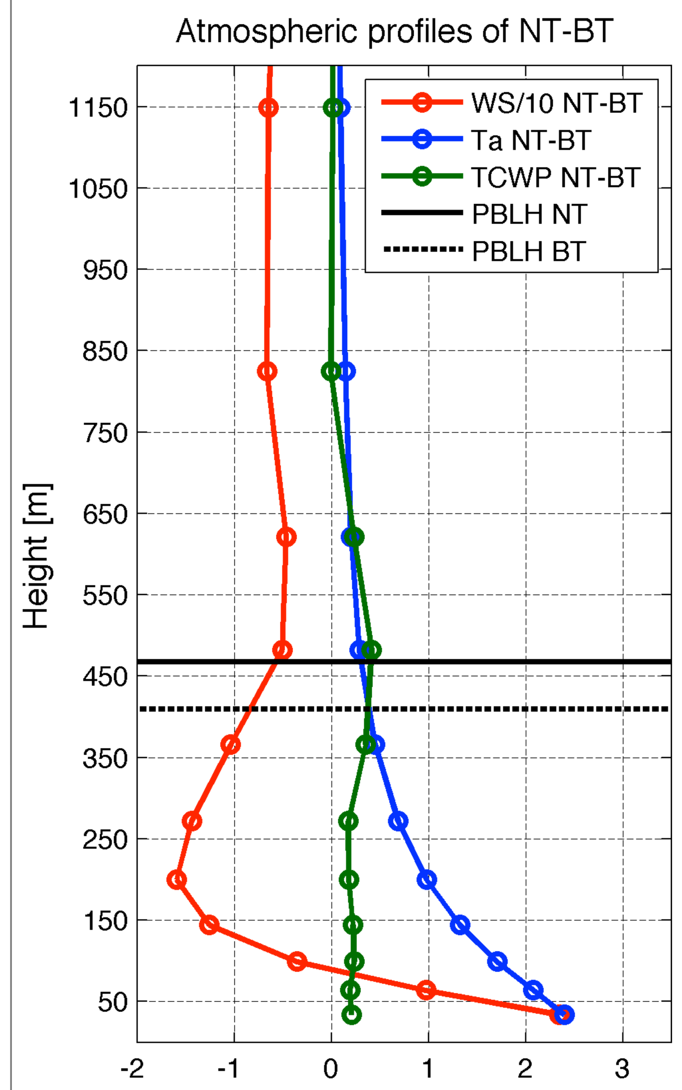
4. Pan-arctic response of the Arctic atmospheric boundary layer to SIC difference: NT-BT



- Substantial basin-wide SIC difference: 20-40%.
- Lower SIC in NT produces higher T2, higher PBL, increased cloud water path, and W10, an indication of an unstable ABL leading to increased W10.
- Comparable spatial distribution and extent of the ABL response to those of SIC difference, as expected from Chelton et al. (2001)

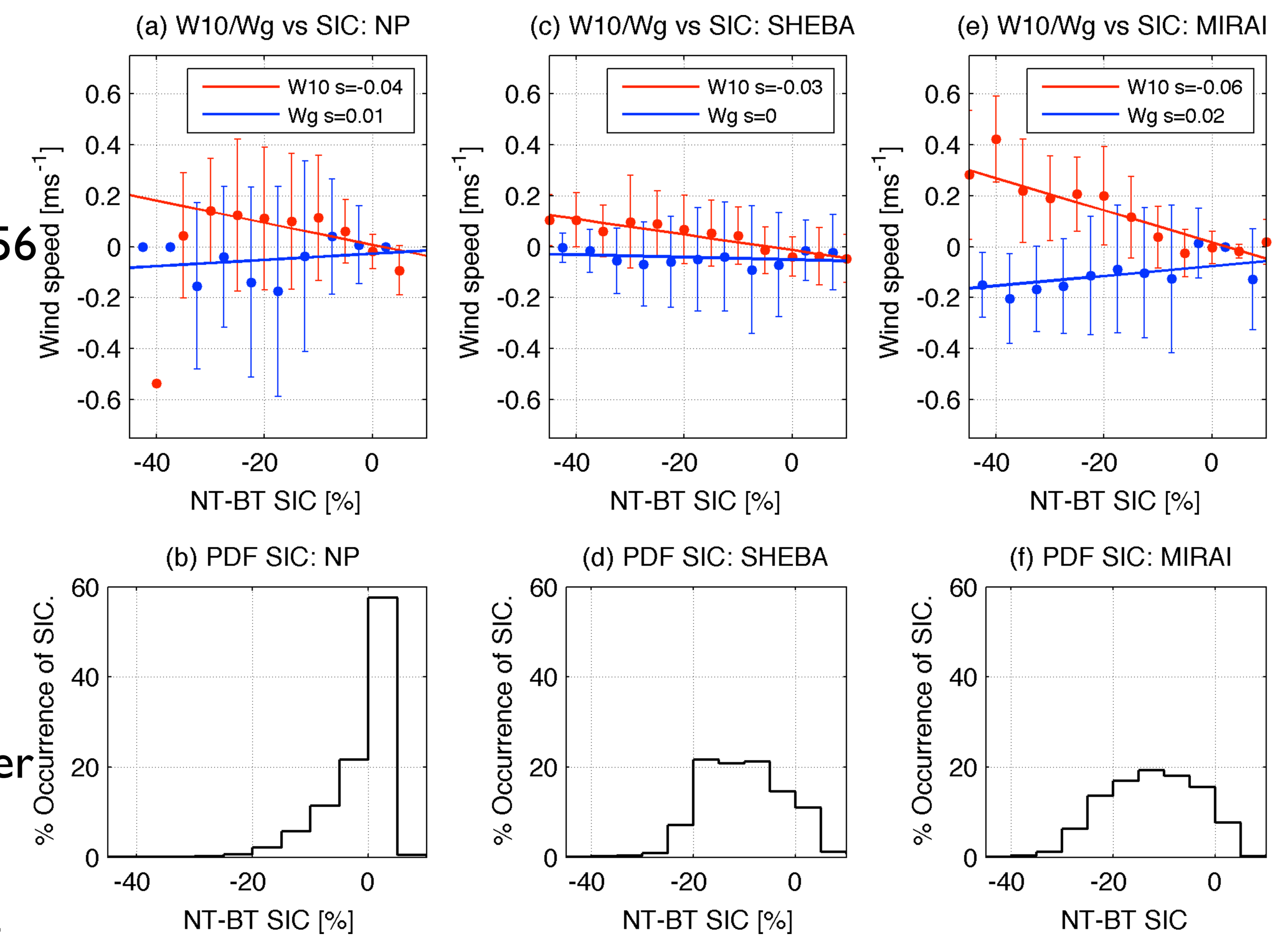
$$\nabla \cdot u \propto \nabla_d T$$

5. Modulation of static stability of the Arctic ABL



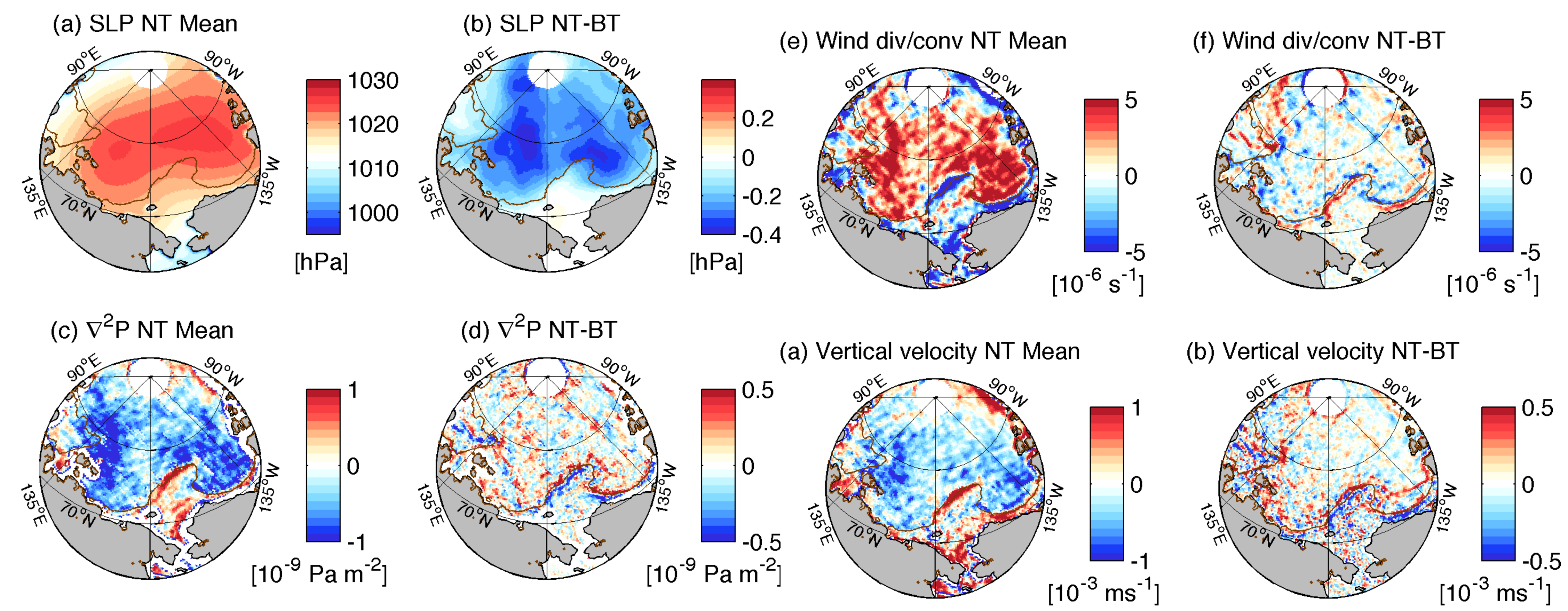
- Destabilized PBL in NT produces positive Ta anomaly. PBLH is elevated by 56 m, where the increase in cloud water path is most pronounced.
- Increased wind speed in the surface layer at the expense of decrease aloft, indicating downward momentum transport.

unit of ms^{-1} per 10% difference in SIC



- Increase in SIC uncertainty in time.
- Increased positive linear response of W10 to SIC uncertainty
- Either insignificant or negative linear response in Wg.

6. Modulation of surface pressure



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

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

- $\nabla \cdot u$ is negatively proportional to $\nabla^2 P$ (e.g., Minobe et al. 2008).

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

- Ice-induced vertical velocity (w) within the ABL is proportional to $\nabla^2 P$.
- Correspondence of $\nabla \cdot u$ to $\nabla^2 P$ introduces a quadrature relationship.
- ∇^2 is highly effective in highlighting small-scale response (e.g., sea ice margins).

7. Implication and Future Work

1. Due to the scarcity of surface-wind measurements over sea ice, the Arctic Ocean modeling community has often relied upon the SLP-based Wg to estimate the surface stress and to drive the ocean-ice models. Our result suggests that the SLP-based Wg may not fully represent the effect of sea ice variations (reduction).

2. Small-scale variation in Wg across the sea ice margins would be underestimated in the atmospheric reanalysis datasets due to their coarse resolution in the high latitudes, a potentially important source of uncertainty in wind forcing for the ocean-ice models.

3. A more accurate representation of the surface wind variability reflecting both of these two dynamical effects is needed to improve the predictive skills in models of ocean circulation and sea ice variability.

4. Long-term Polar WRF simulations, with an interactive ice-ocean model, are needed to diagnose effect and long-term trend of ABL-SIC coupling and to evaluate the coupled feedback to atmosphere, ocean and ice.

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