Air-Ice-Ocean Interactions at MOSAiC: A Storm Case Study (Jan 29 - Feb 4, 2020)

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Introduction

Objective: Examine and understand atmospheric structure and processes producing changes in near-surface winds, and the resulting air-ice-ocean responses to wind changes

- wind changes typically observed near **atmospheric fronts** associated with Arctic cyclones.
- preliminary response results not only involve **ice deformation**, but also changes in **internal ice stress, upper-ocean currents**

Key Premise: Atmospheric winds are primary forcing that moves and deforms sea ice, and influences upper-ocean currents. Results suggest modification to this statement.

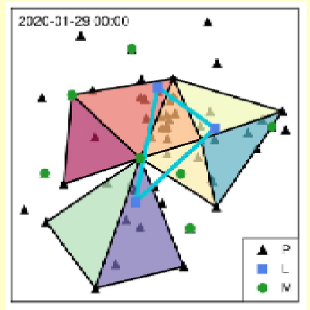
Changes in ice velocity — *Internal stress tensor* — *atmospheric stress* — *ocean stress* — *Coriolis forcing* — *large-scale ocean slope*

$$m\,\partial \mathbf{u}/\partial t \;=\; \nabla \bullet \sigma \;+\; \tau_a \;+\; \tau_w \;-\; [\mathbf{k} \times (m\, f_C\, \mathbf{u})] \;-\; m\, g\, \nabla H_0$$

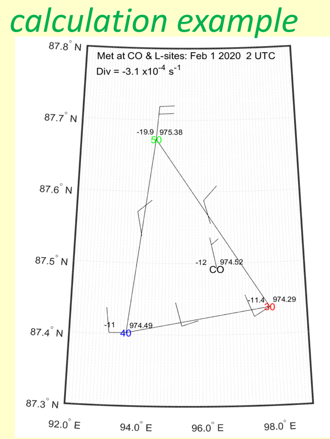
Method: Use air, ice, ocean observations from MOSAiC with NOAA CAFS coupled model

Impacts of ice deformation

Ice deformation triads



Atmospheric divergence calculation example

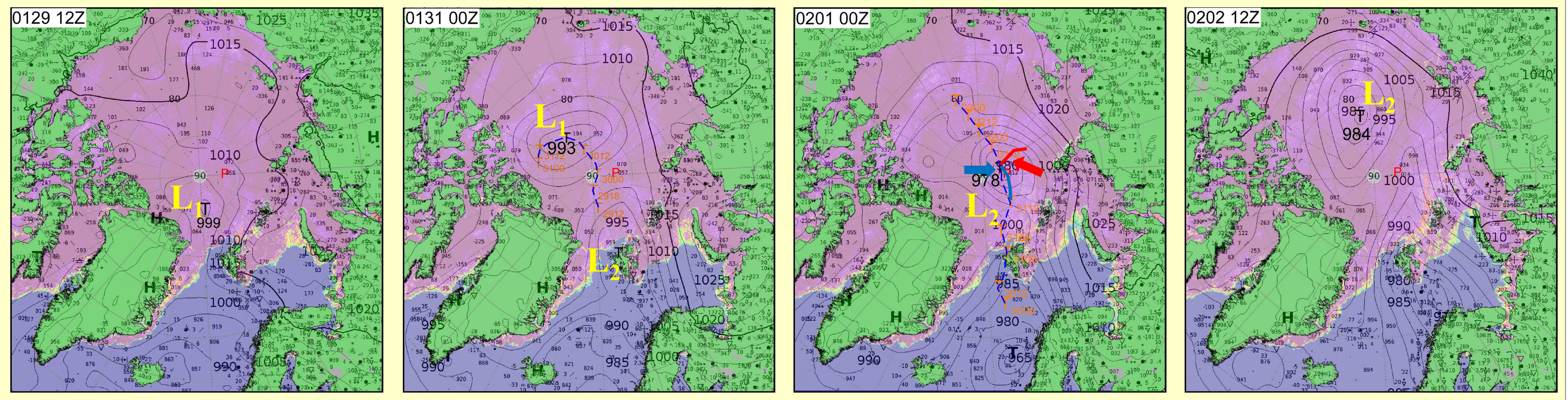


ADCP measurements of ocean currents

Ice and near-surface atmospheric divergence/ deformation calculated using GPS buoys (e.g., triads) and L-site Atmos Surface Flux Systems (ASFS) in distributed network (DN)
ice: mid-Oct 2019 – July 2020; atmos: Oct 10, 2019 – Feb 4, 2020

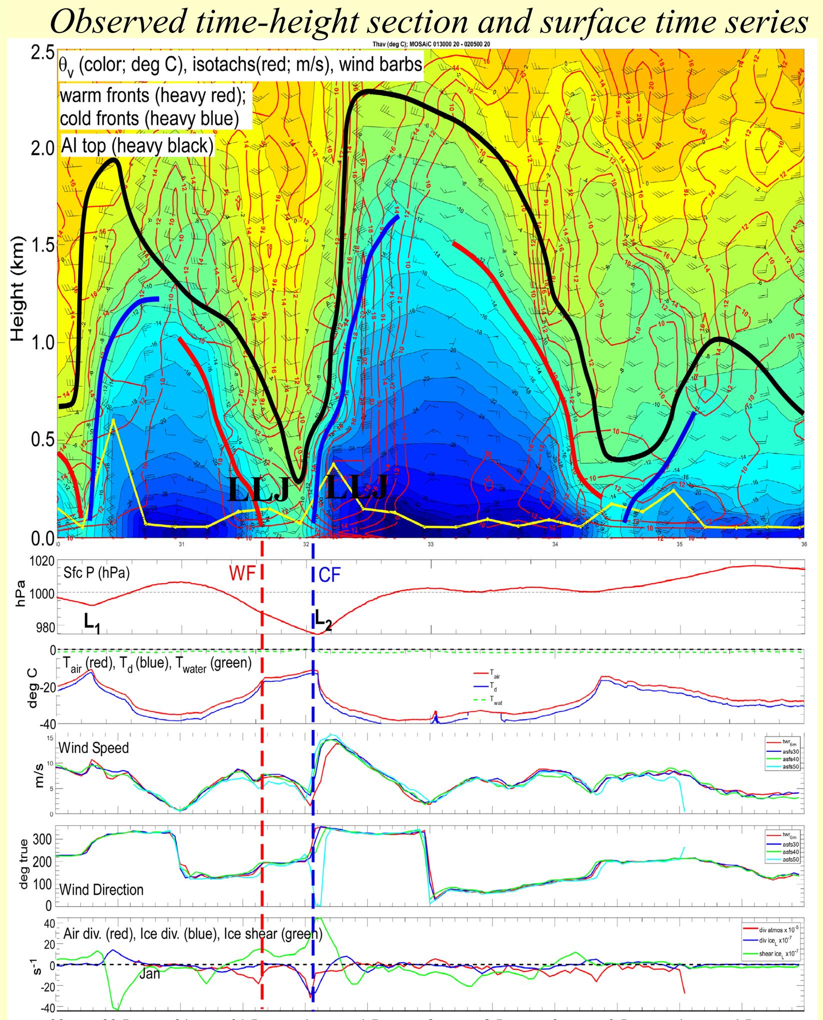
Key Synoptic & Mesoscale Atmospheric Structures

Jan 29 - Feb 4, 2020: Two lows emanating from Svalbard; At Polarstern (red P), L_2 produced rapid wind speed/direction changes & significant ice dynamics (DWD MSLP analysis; AMSR2 ice conc)

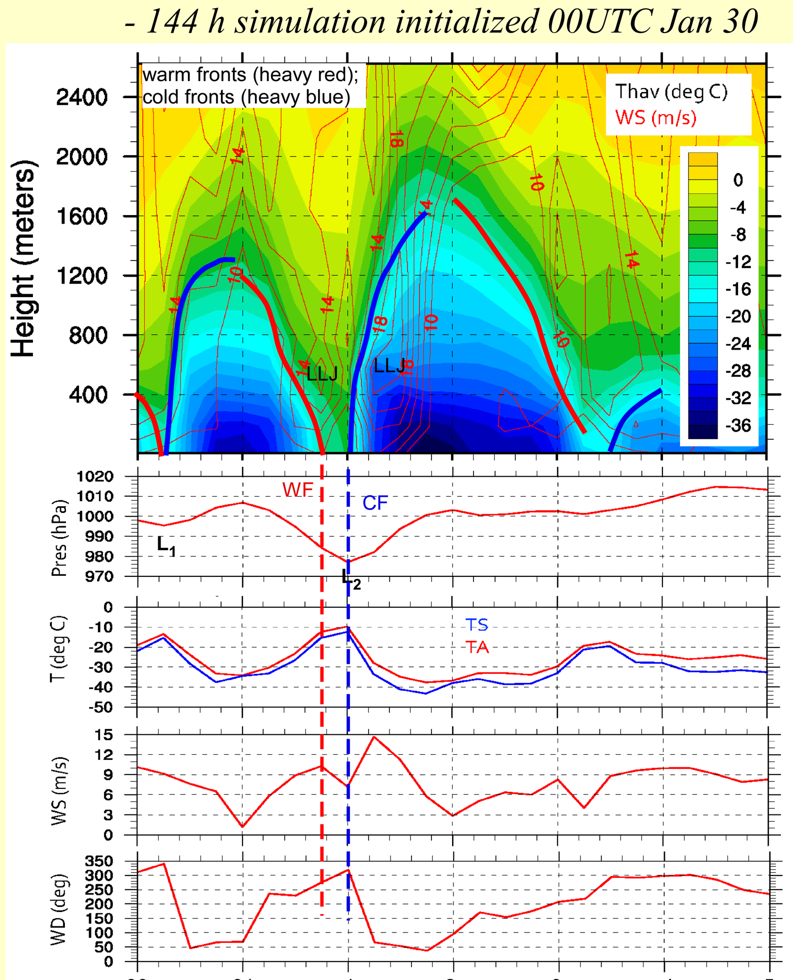


Second low had quasi-axisymmetric low-level jet (LLJ), appearing as south-southwest LLJ of ~15 m/s in warm sector near 1540 UTC Jan 31 and northerly LLJ of ~21 m/s just behind cold front near 05 UTC Feb 1. Axisymmetric LLJ produced large, surface wind speed and directional changes between 23 UTC Jan 31 and 04 UTC Feb 1. Reproduced well by CAFS model.

Observed time-height section and surface time series

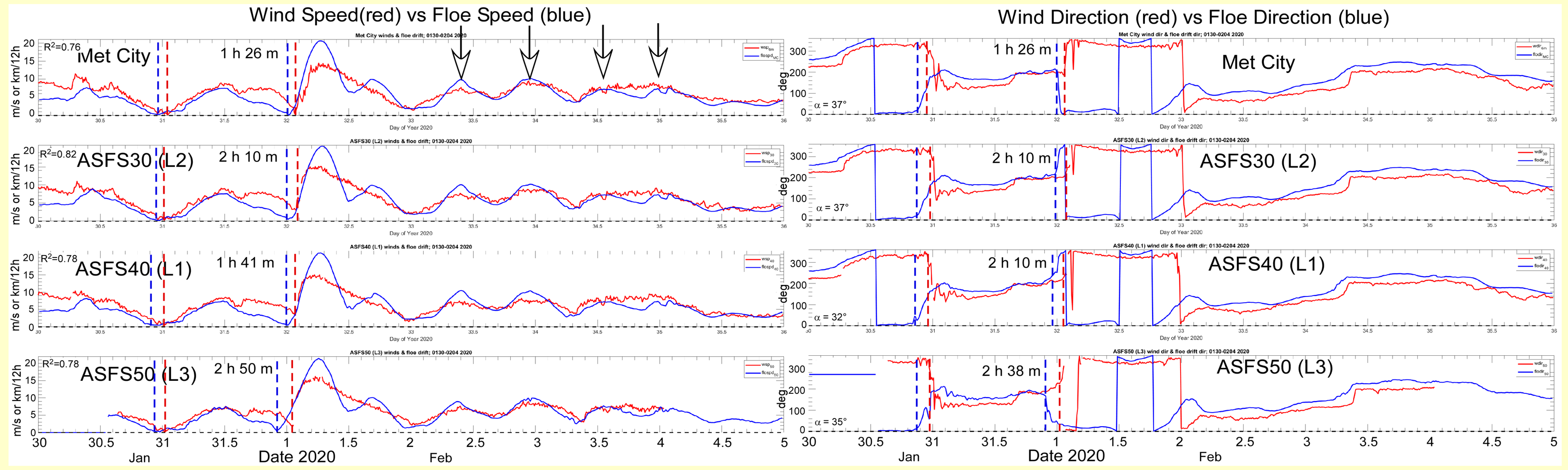


Coupled air-ice-ocean model output (CAFS) - 144 h simulation initialized 00UTC Jan 30

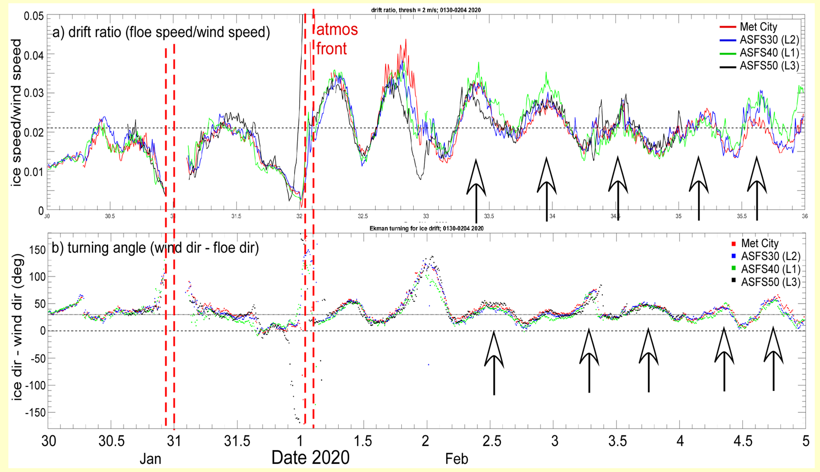


Atmospheric Forcing of Ice Motions

- wind speed – floe speed correlation ~ 0.8; turning angle ~32-37 deg, but with cyclic variations



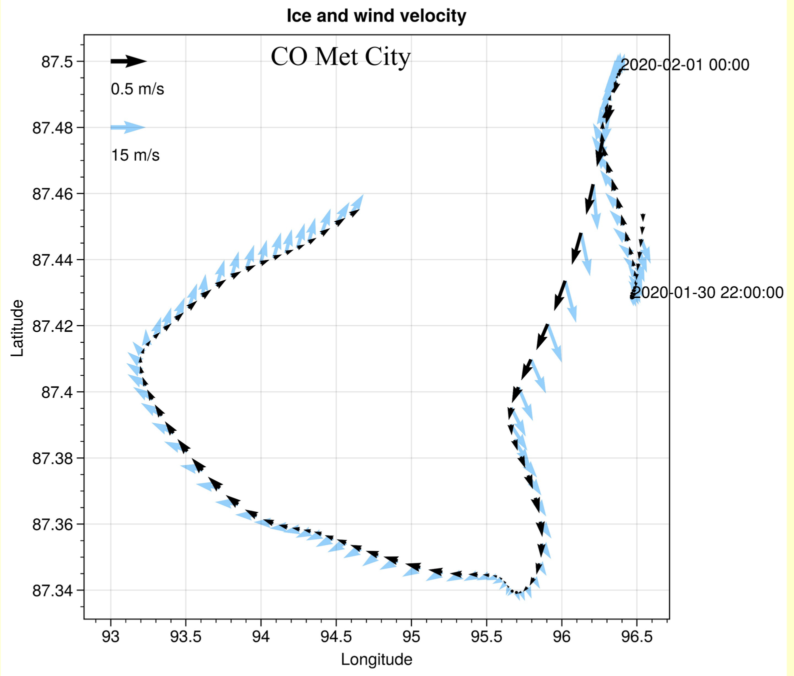
- speed/direction transition near 00Z Feb 1 occurs 1.5 - 3 h earlier for ice floe motion than for wind
  implies forcing of local ice motion by wind conditions on other side of front & local ice acceleration through internal stress term
- post-frontal inertial oscillations (arrows) occur primarily in ice motion

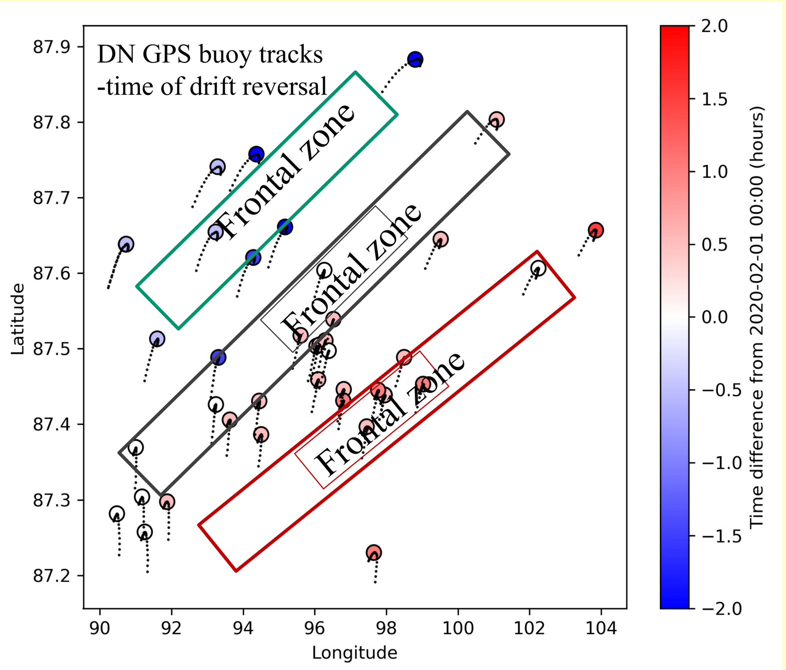


Mean drift ratios (~0.021) **& Ekman turning angles** (~32-37 deg) consistent with previous studies
- drift ratios and turning angles vary significantly with time, with large impacts by wind transitions at atmospheric frontal passages and inertial oscillations of ice

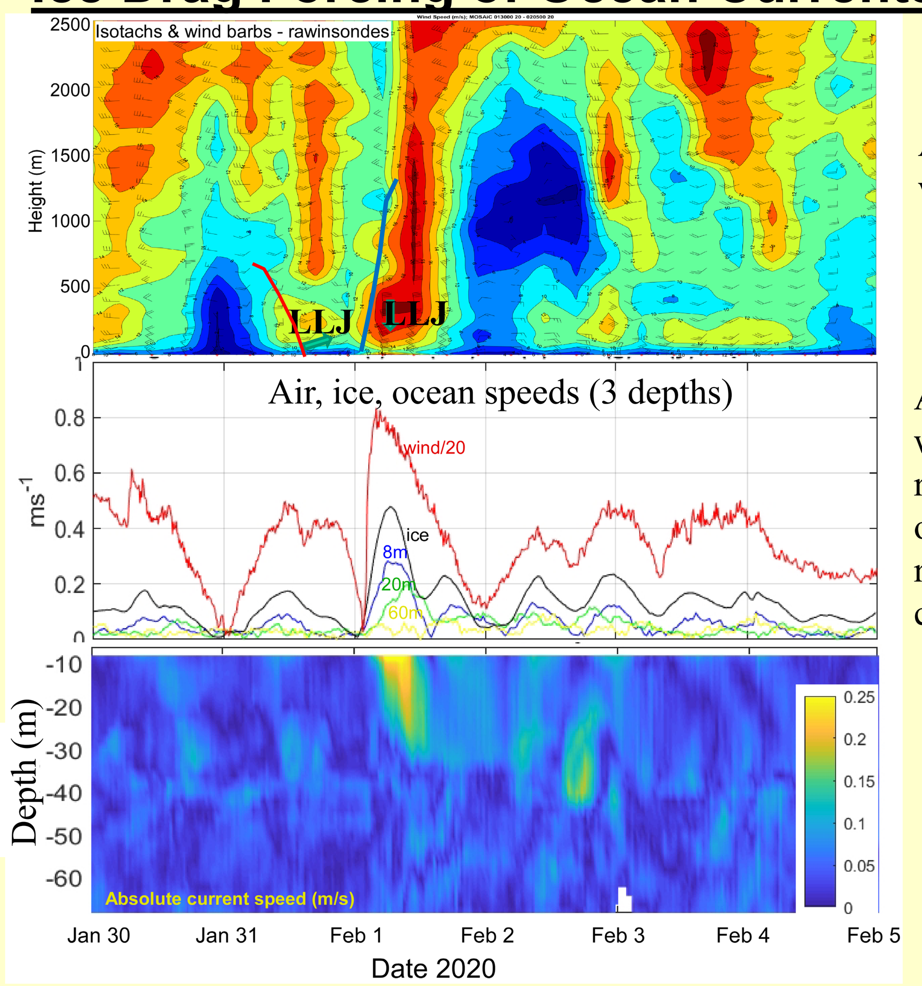
DN buoy tracks (dots) and track cusp times (Jan 31 18Z – Feb 1 6Z; ½-hour intervals)
- track cusps mark times of floe direction change
- cusp timing progresses from NW to SE across DN in ~2-3 hours, with transition centered on 00Z Feb 1 in center of DN (at CO) 2 h BEFORE CO wind shift
- ice analysis also implies atmospheric forcing of ice north of front propagates ahead of atmospheric front

CO Met City positions, wind vectors (blue) & ice motion vectors (black) (00Z Jan 30 – 00Z Feb 4 2020)
- ice track changes abruptly with wind changes
- ice track reverses near 00Z Feb 1, forming track cusp





Ice Drag Forcing of Ocean Currents



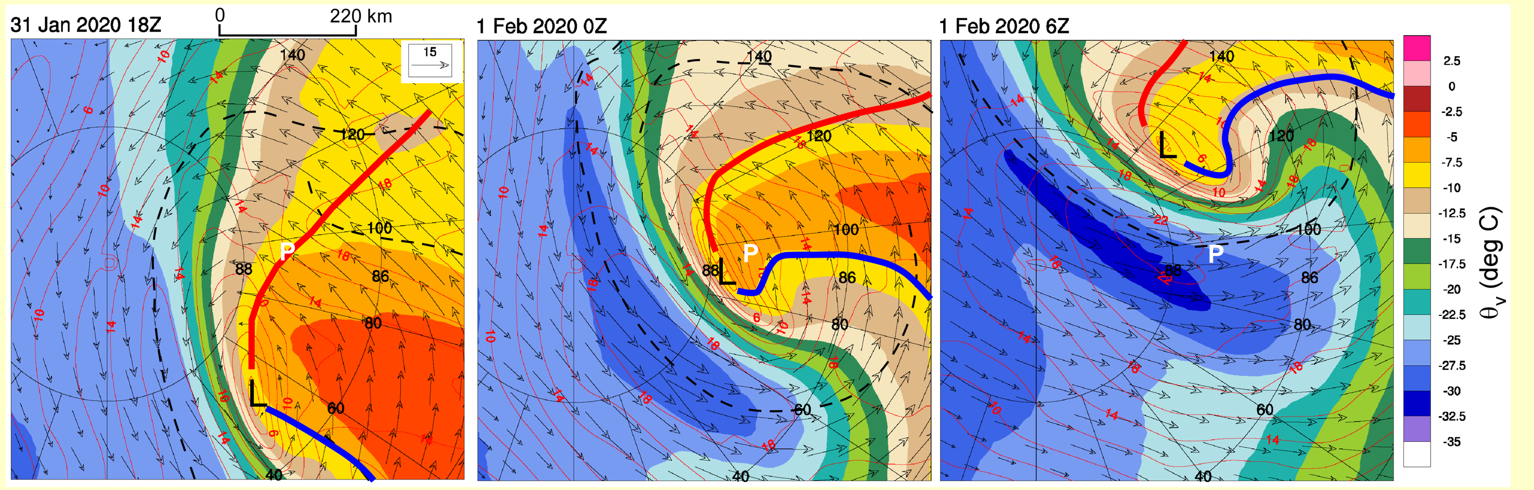
Atmospheric winds

Atmospheric frontal transitions associated wind speed and direction changes are rapidly transmitted to the ice and into the ocean mixed layer – post-frontal inertial ringing of ice and ocean mixed layer currents

Ocean current speed

Process Diagnostics and Validation Using CAFS

CAFS Output: *Virtual potential temperature (color) and isotachs (red isopleths) at 925 hPa for 3 times. Core of LLJ (black dashed), circulation center (L), Polarstern (P), and warm/cold fronts are marked.*



- quasi-axisymmetric LLJ
- PS passed through warm sector, encountering LLJ near warm front and behind cold front
- model atmospheric structure very similar to observations; primarily small timing differences

CAFS Output: *10-m winds & atmos divergence (top), ice motion & ice divergence (middle) and mixed-layer currents & divergence (bottom). Surface low (L), cold front (blue), warm front (red), and Polarstern (circle). are marked.*

Winds: classical circulation around low; transitions at fronts

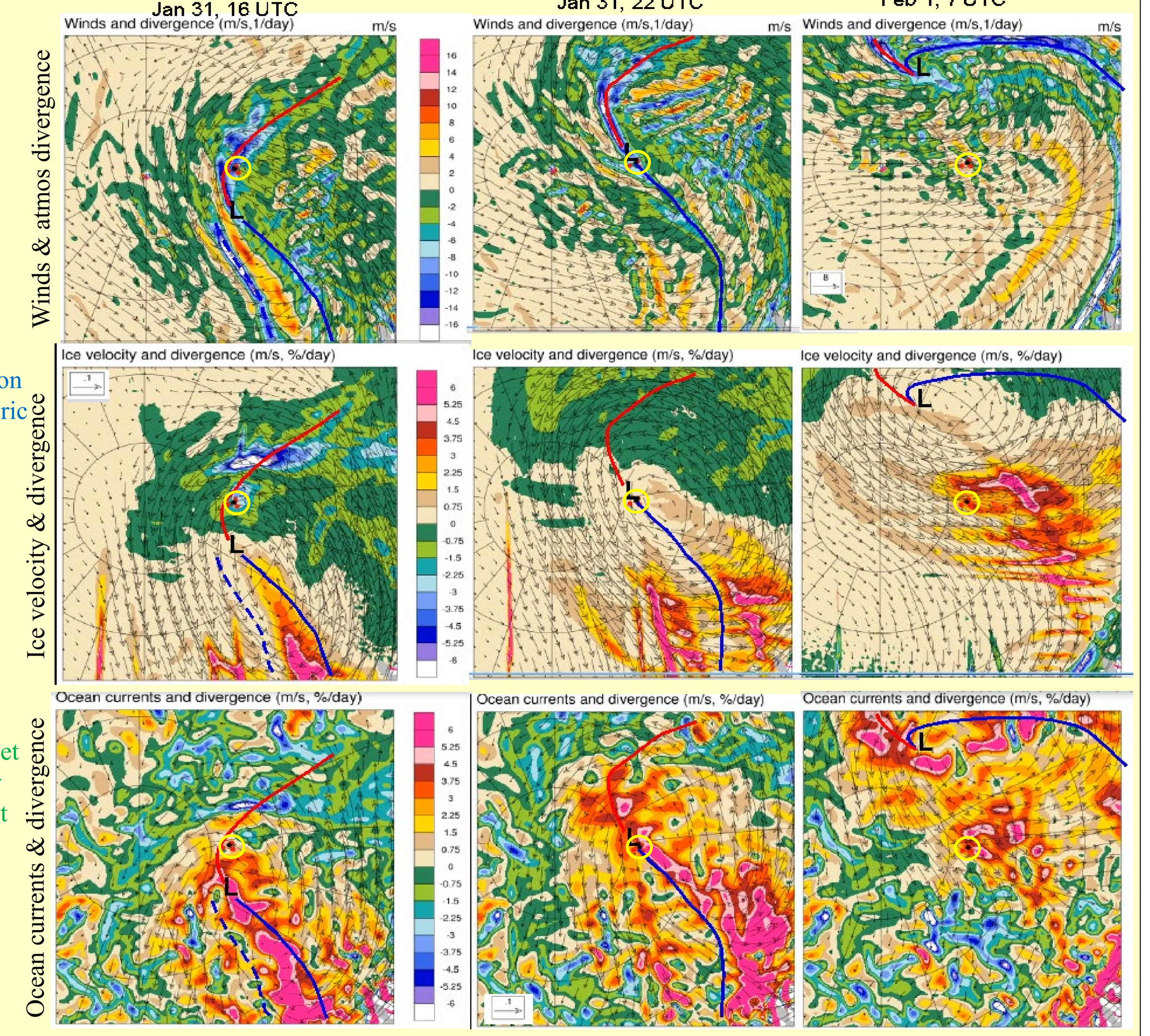
Divergence: convergence at fronts; divergence behind cold front

Ice velocity: circulation center trails atmospheric low; to right of winds

Divergence: convergence near warm front & in warm sector; divergence near cold front and behind it

Ocean currents: circulation center offset from atmospheric low and elongated; to right of ice motion

Divergence: upper-ocean divergence dominant during cyclone passage; implies upwelling(?)



- coherent air-ice-ocean motions and divergence during cyclone passage
- primarily atmospheric convergence; ice divergence (convergence) near warm (cold front); primarily upper ocean divergence (implies upwelling)

Conclusions

a) Variations in near-surface wind speed and direction at MOSAiC are controlled by synoptic and mesoscale atmospheric dynamics associated with Arctic cyclones, frequently producing features important for air-ice-ocean interactions, such as low-level jets and large direction changes at fronts.

b) Case studies from MOSAiC show that variations in wind speed and direction, generally linked to low-level jets and fronts, produce or enhance ice deformation events and internal ice stress and waves;
- consequently, these ice events are also then linked to the specific regions of Arctic cyclones where the atmospheric features occur
- however, local ice dynamics events may not be directly forced by local atmospheric forcing, as atmospheric forcing at a distance may propagate through the ice as internal stress. This case study shows atmosphere-ice timing offsets of ~2 h because of this effect.

c) Coupled modeling of Feb 1, 2020, cyclone case suggests systematic, coherent relationships between motions in atmosphere, ice, and upper-ocean during passage of an Arctic cyclone. These relationships are being verified using the MOSAiC observations, but suggest that the passage of atmospheric Arctic cyclones may have direct and predictable impacts on motions in the ice and upper ocean. Their generality also needs to be assessed


Photo: B. Blomquist