*EGU22-6354 , AS2.13 Surface Exchange Processes in the Polar Regions: Physics, Chemistry, Isotopes, and Aerosols*

# A bipolar perspective of the boundary layer and associated synoptic influences at Summit Station, Greenland and South Pole Station, Antarctica

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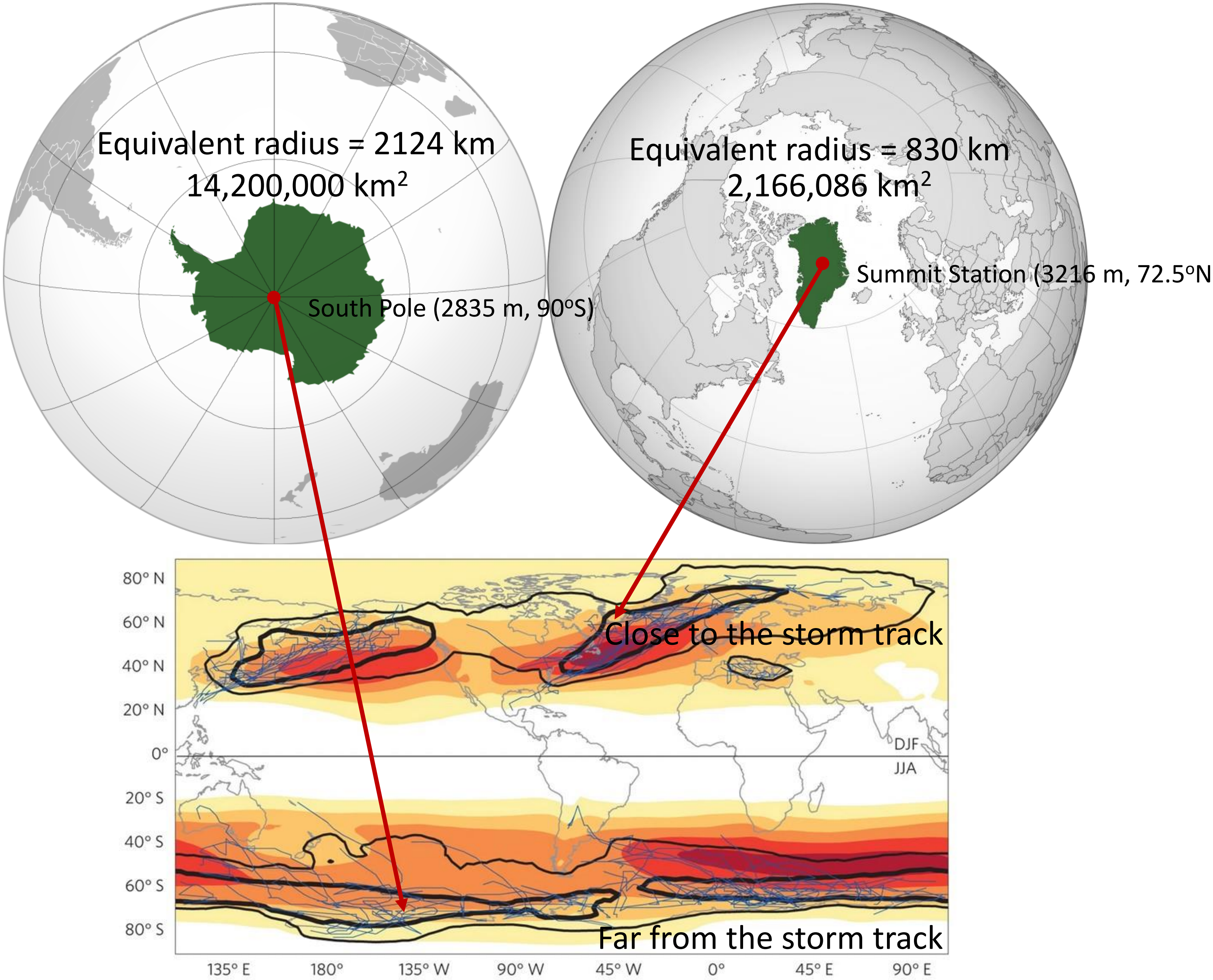
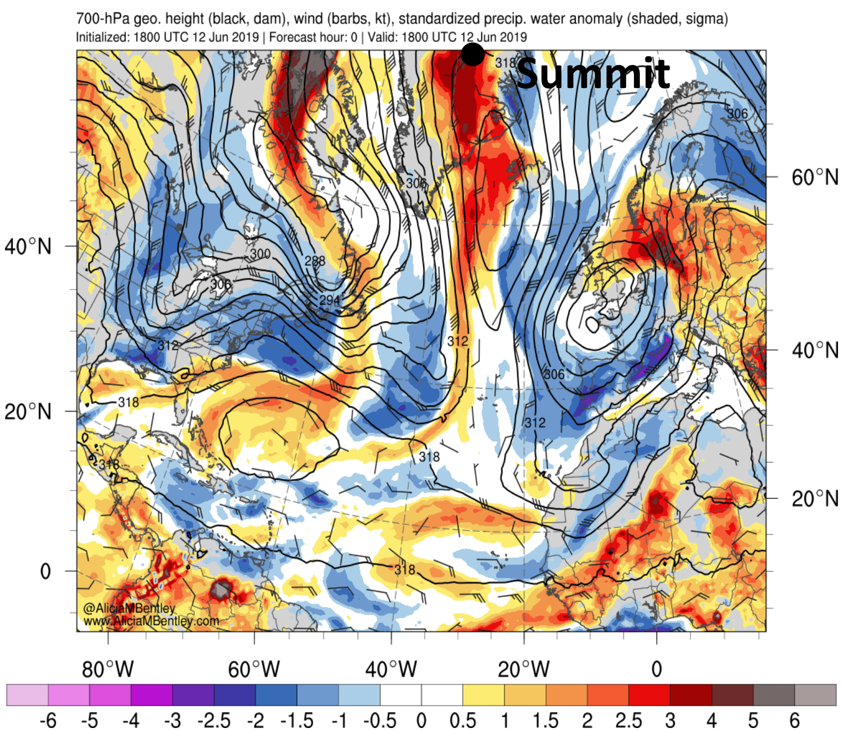
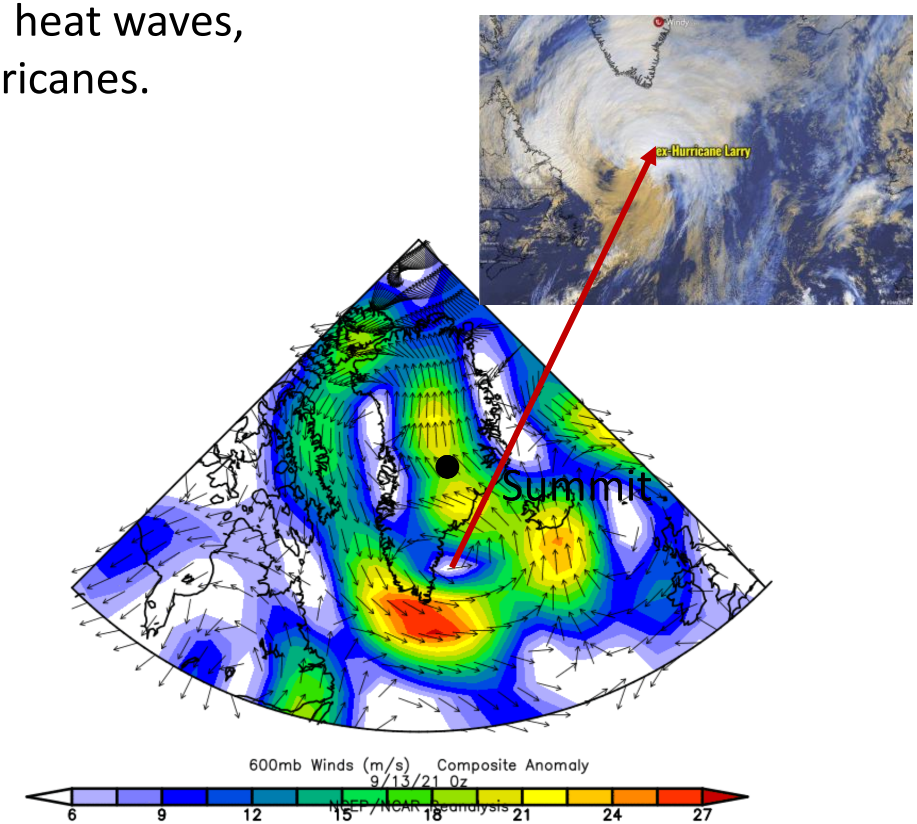


Equivalent radius = 2124 km
14,200,000 km²
South Pole (2835 m, 90°S)
Equivalent radius = 830 km
2,166,086 km²
Summit Station (3216 m, 72.5°N)
Close to the storm track
Far from the storm track
80° N
60° N
40° N
20° N
0°
20° S
40° S
60° S
80° S
DJF
JJA
135° E
180°
135° W
90° W
45° W
0°
45° E
90° E

# Different weather environments: Greenland

Greenland: Directly influenced by the North Atlantic storm track – Extratropical cyclones, continental heat waves, tropical influences including decaying hurricanes.




https://www.severe-weather.eu/winter-weather/atlantic-hurricane-season-2021-larry-winter-storm-forecast-snow-greenland-mk/

Common to both Summit and the South Pole was the use of sodars to probe the normally very stable and shallow boundary layer



FIG. 1. The bistatic minisodar at Summit Station is in the foreground; shown are the two boxes that house the transmitting and receiving antenna systems. The meteorological tower, which held the 3D sonic anemometer that was implemented in this study, can be seen in the distance.

**Evaluation of Boundary Layer Depth Estimates at Summit Station, Greenland**

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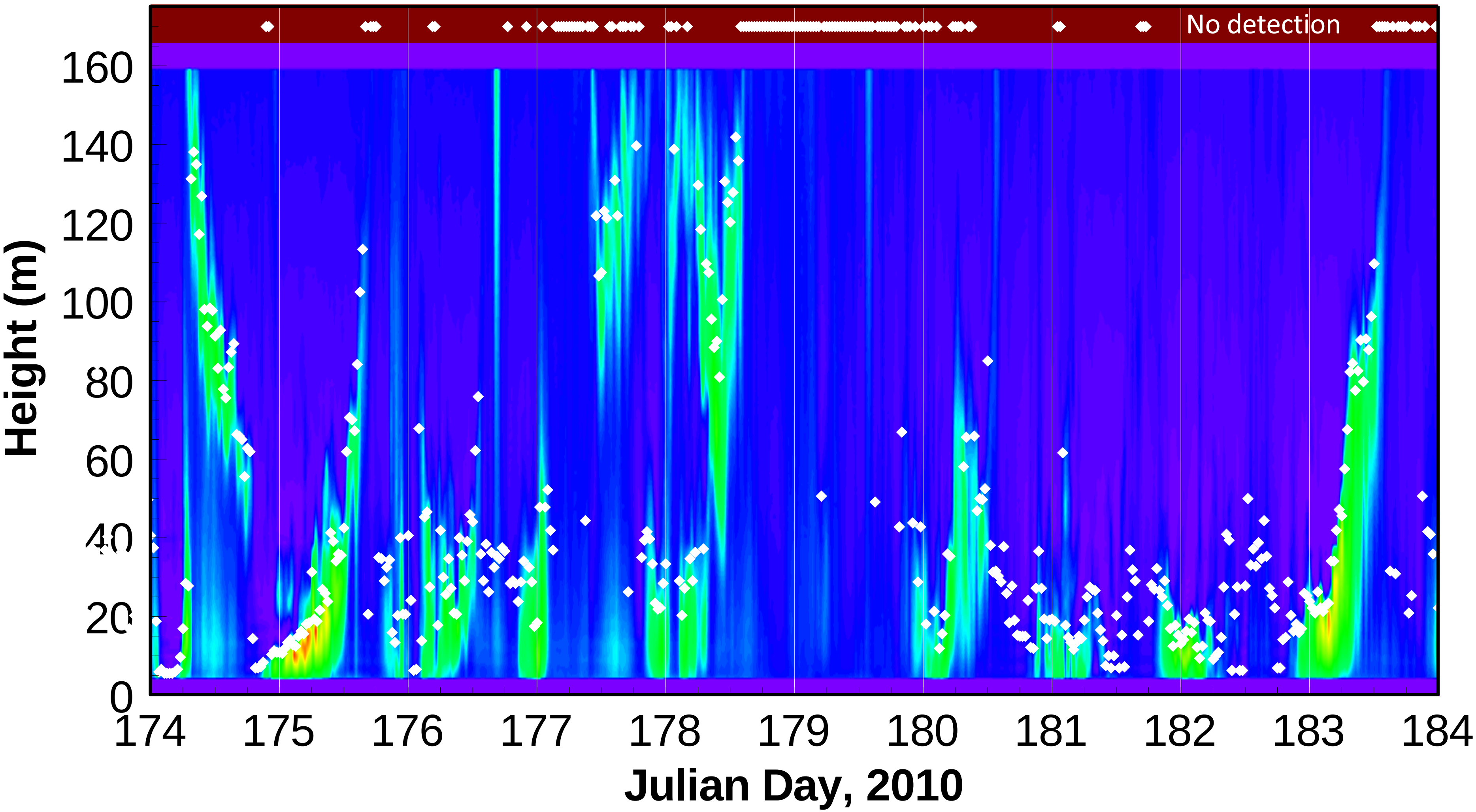
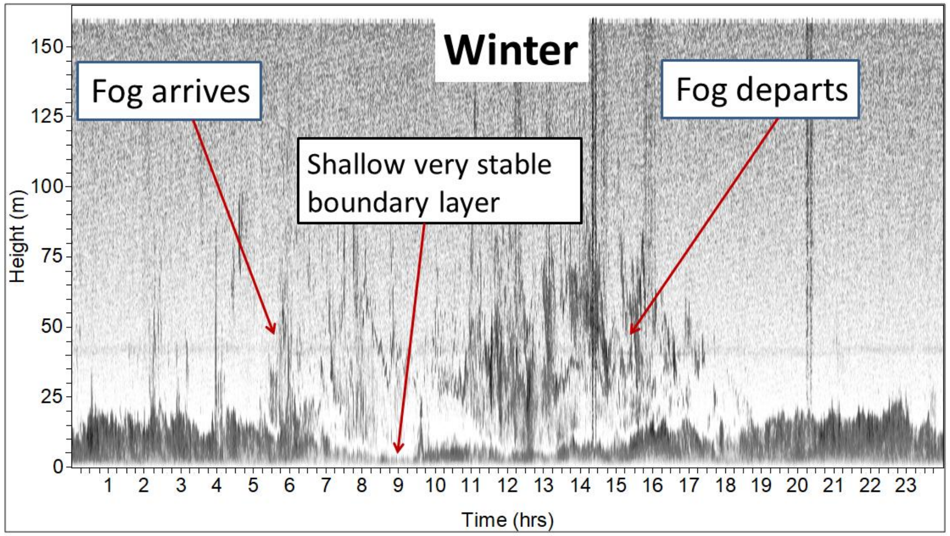
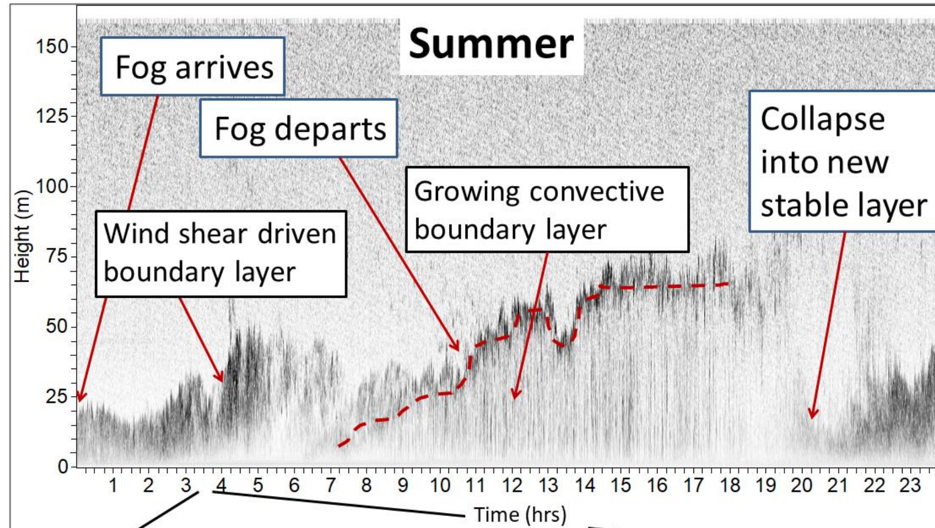
***Greenland: Directly influenced by the North Atlantic storm track:***

Strong diurnal and synoptically driven variability in the summer boundary layer



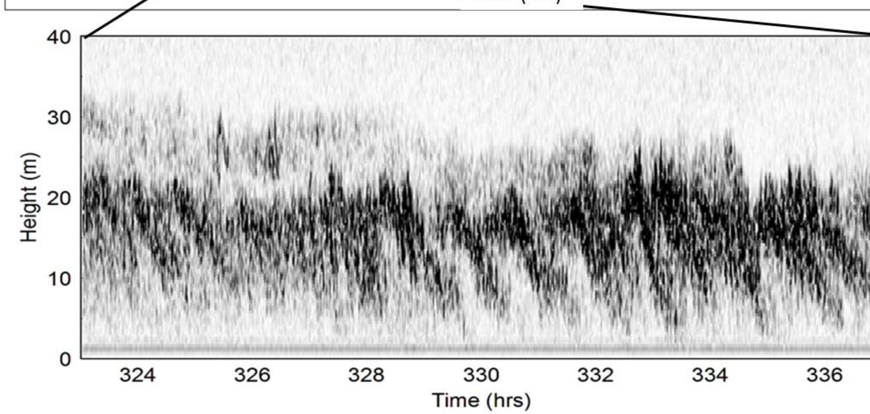
# Boundary Layer Contrasts Winter vs. Summer




**Winter (above, 16 January 2014):** The sodar detects thermal turbulence where mixing occurs within a vertical temperature gradient. With the fog occurrence, the surface stable mixing layer decrease to less than 10m; aloft, additional stable layers extend above 100 m (Neff et al., 2008). Buoyancy waves with periods of a few minutes to 15 min in the upper layer have an observable influence on the surface layer through fluctuations in the horizontal pressure field that produce a moving pattern of convergence/divergence.

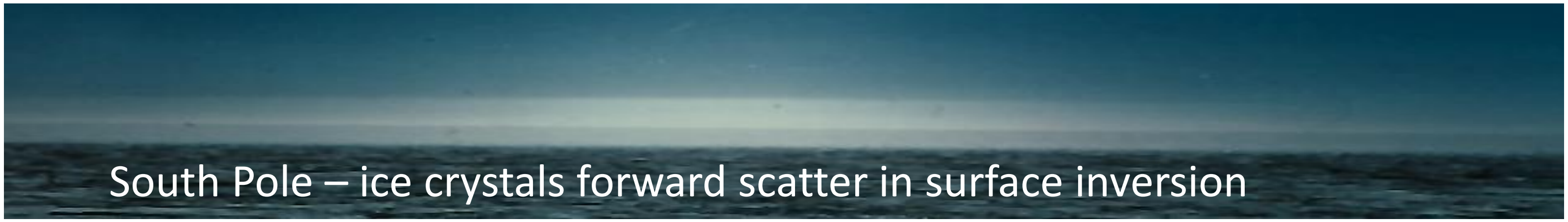
**Summer (above-right, 16 June 16 2013):** The sodar shows a typical summer pattern of a nighttime stable layer before 0700 and after 2000. By 0800 a convective boundary develops, deepening to about 65 m as the solar elevation angle increases. Vertically oriented echoes from about 0900 to 1800 within the boundary layer (below dashed red line) show convective plumes at intervals of order minutes. Past research shows that these echoes typically occur at the boundaries of rising and sinking air.

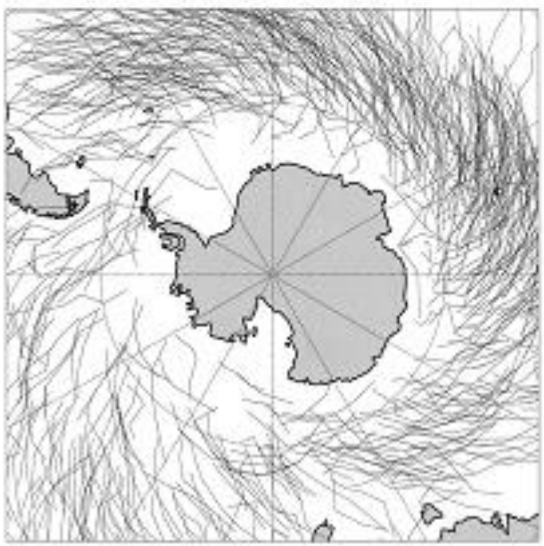



**(above)** Sodar shows Kelvin Helmholtz instabilities in the stable boundary layer from 0323-0337 associated with shear at the top of the fog promoting exchange with the surface.

# Different weather environments: 90ºS

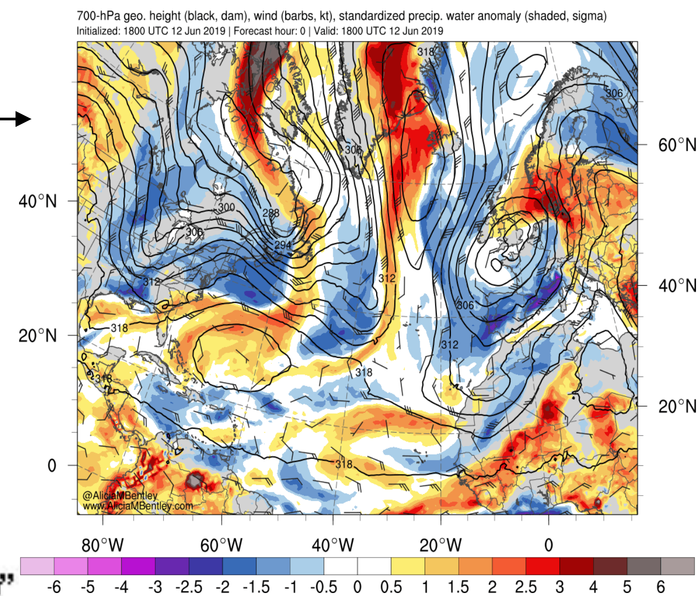
The South Pole: Isolated from the South Pacific storm track:



--from "Synoptic Activity in the Seas around Antarctica"
Simmonds et al., 2002, Mon. Wea. Rev.

Contrast



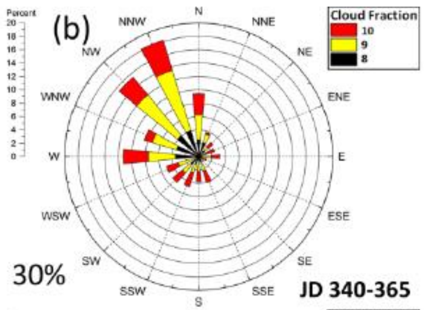
“*Nowhere else on earth are external geophysical-meteorological environments as test-tube-like or clear-cut and well defined as in the Antarctic.”*

--Heinz Lettau, 1968, “Antarctic Atmosphere as a Test Tube for Meteorological Theories”

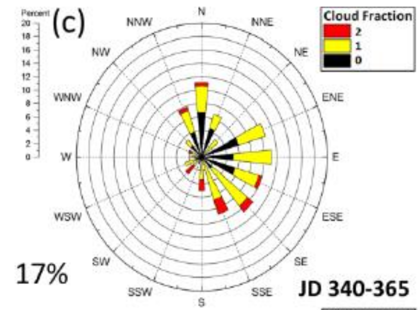
Winds over Antarctica evolve systematically through the seasons given that the diurnal cycle at 90°S is a full twelve months:

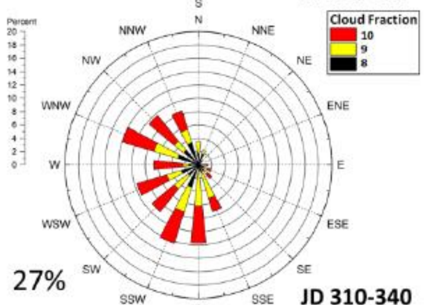
Frequency of winds: High cloud fraction

Frequency of winds: Low cloud fraction

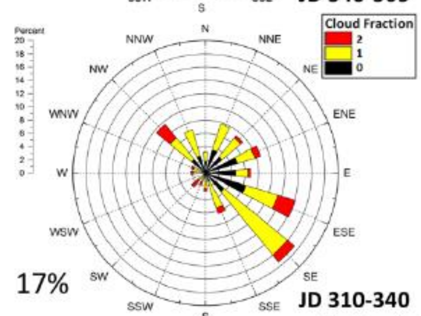


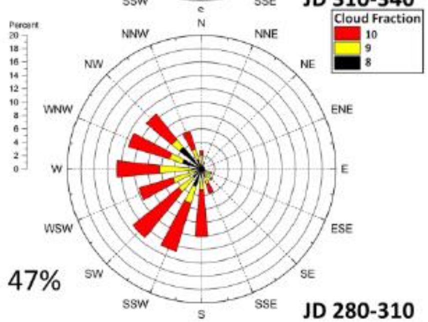

Summer



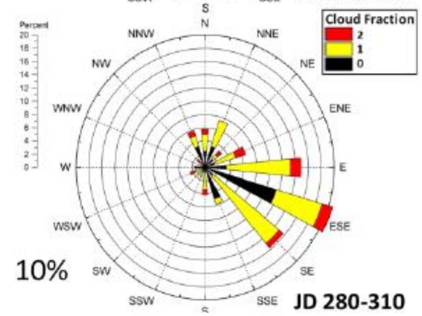




Late Spring




Spring

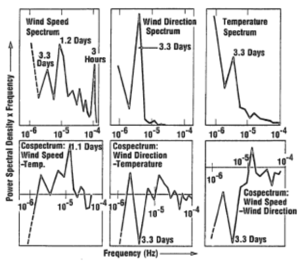



**Cloudy** skies with winds from the SW to NW

**Clear** skies with winds from the SE

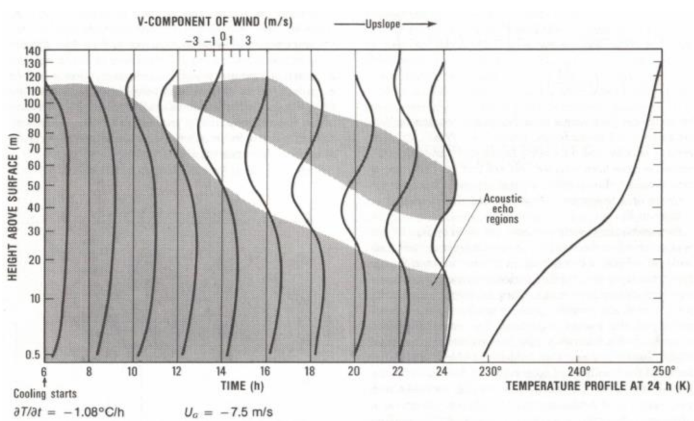
## Results from past research:

- In the absence of a “normal” diurnal cycle, the boundary layer evolves slowly in response to synoptic forcing:




In one winter month, wind and temperature and their sprectra and cospectra reflect a synoptic period of 3.3 days. The negative cospectral peaks reflect the fact that colder, lighter winds with clear skies often prevail from grid east at the Pole with a significant effect on surface chemistry (Neff 1999, Neff et al. 2018).

- The boundary layer also responds slowly to changes in the energy balance at the surface as shown in this higher-order closure 1-D model simulation (Neff 1980, Neff and Coulter, 1986):




In this case, we simulated acoustic echoes to compare with sodar backscatter data that were collection at the South Pole as shown in the next slide where surface cooling led to inertial oscillations of 12-hour period (at 90°S).

Several inertial cycles:



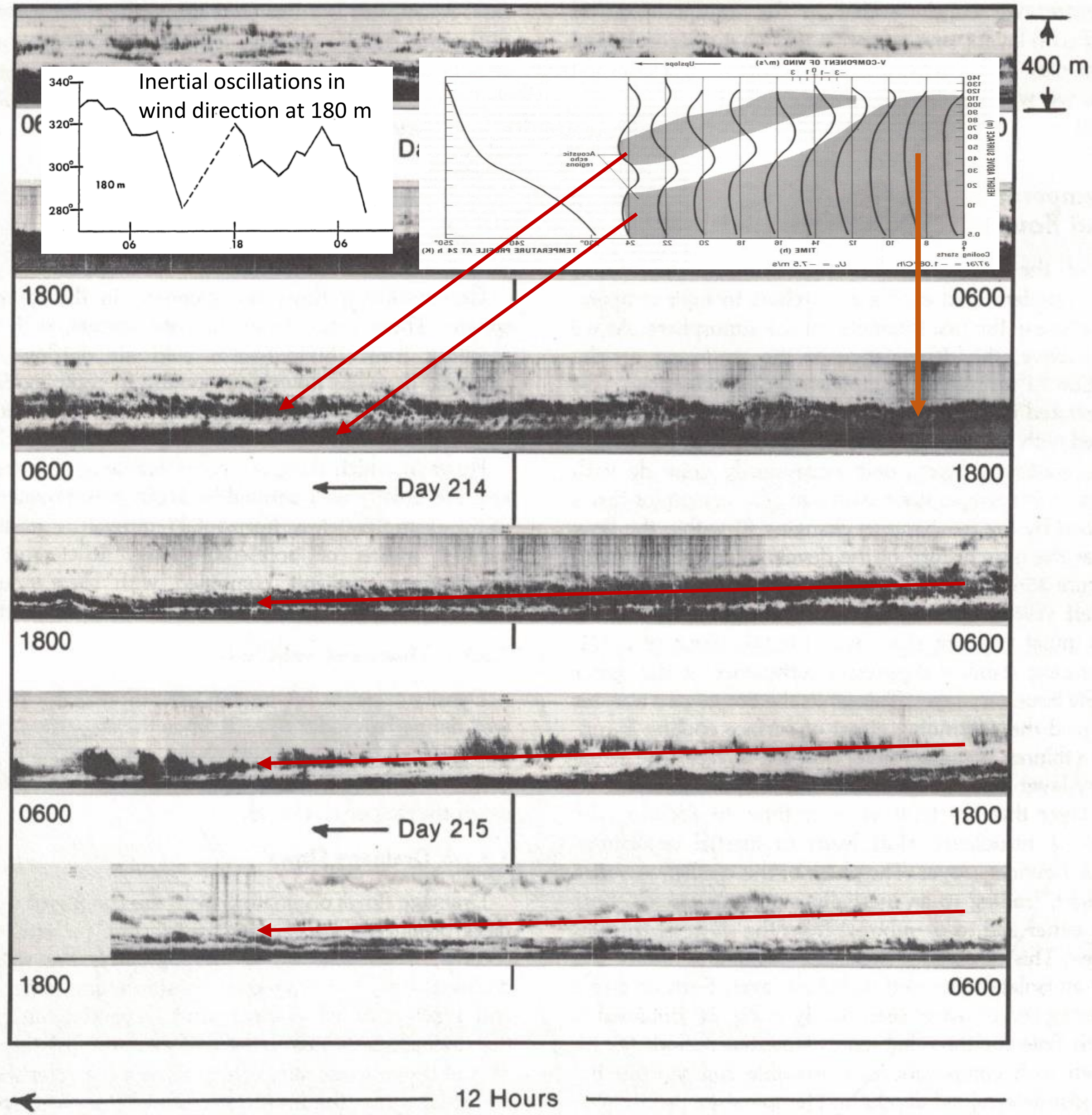



*Fig. 26 Example from the South Pole showing the occurrence of elevated scattering layers reappearing during three successive inertial cycles (of 12 h each). (From Neff, 1980.)*

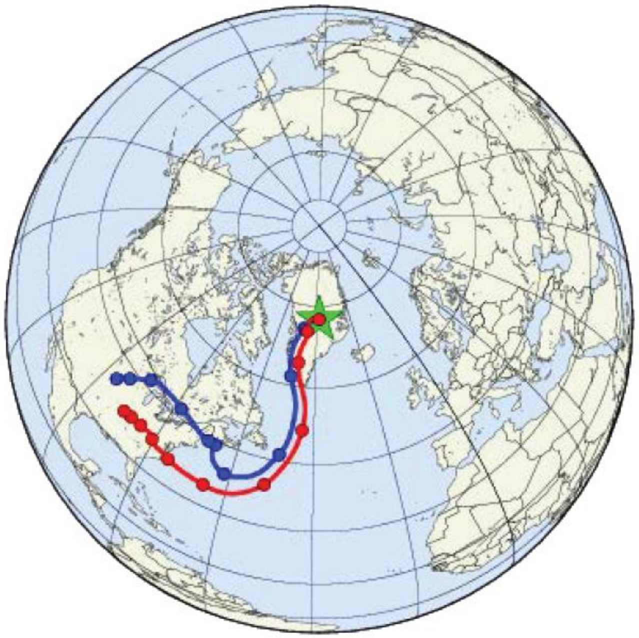
# Conclusions:

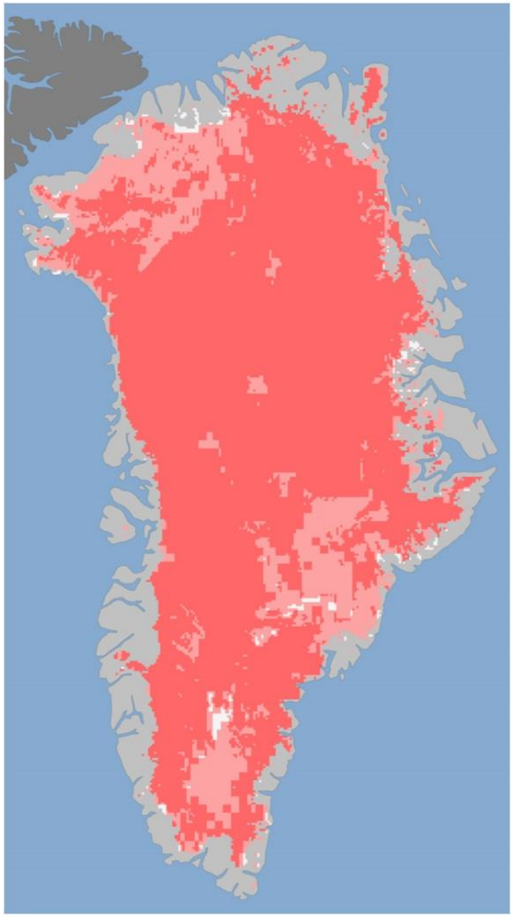
- In the absence of a “normal” diurnal cycle, the boundary layer evolves slowly in response to synoptic forcing at the South Pole.
- The boundary layer at Summit Station has a strong diurnal cycle during the summer but is strongly influenced by synoptic weather systems including hurricanes.
- Boundary layer depth estimates using a simple expression that is strongly dependent on surface stress and weakly on vertical stability works well at both the South Pole and Summit Station despite the higher variability at Summit.
- A decade-long data set is available for Summit Station for ongoing research with high-resolution sodar boundary layer data and supporting turbulence, energy budget, clouds and radiation observations.
- This work supported by ICECAPS (Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit (ICECAPS) project.) Data can be accessed at https://psl.noaa.gov/arctic/observatories/summit/

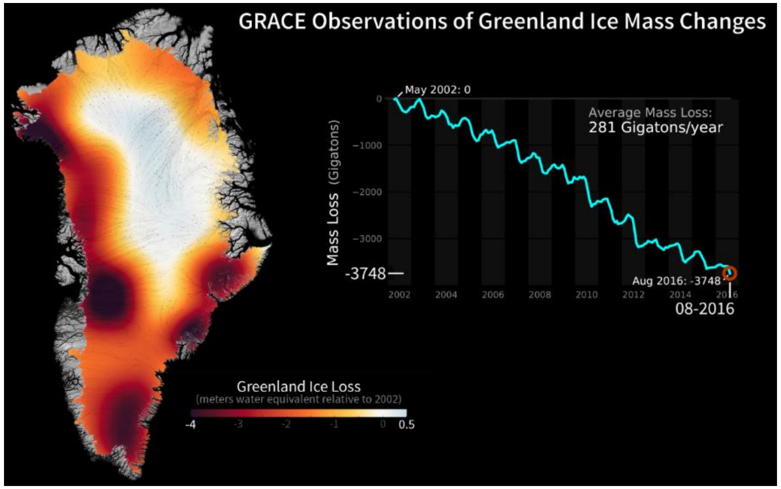
# Supplemental Material

# External Influences on the boundary layer at Summit Station:

Atmospheric Rivers transporting heat and moisture to Greenland: July 11, 2012 melt event








--NASA

--Cyclonic wave breaking (Liu and Barnes, 2015)

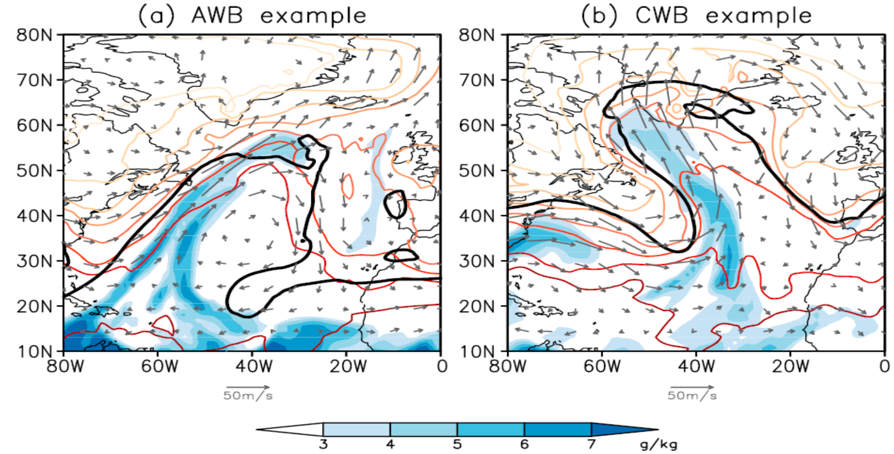
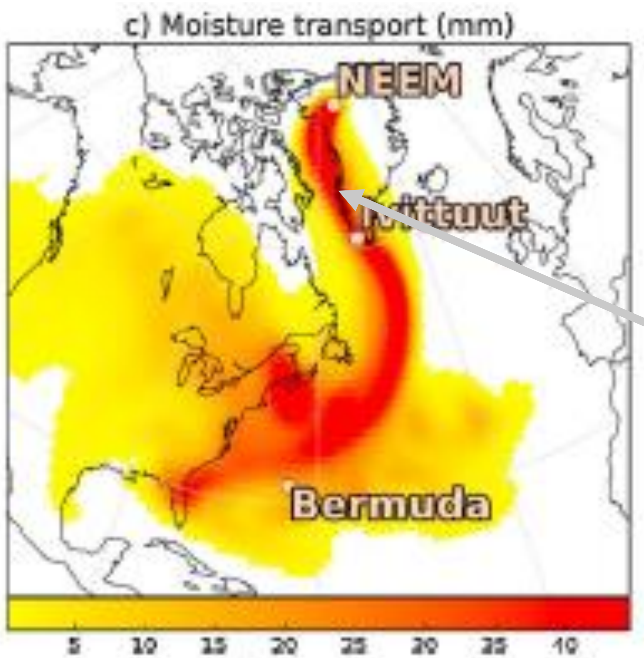


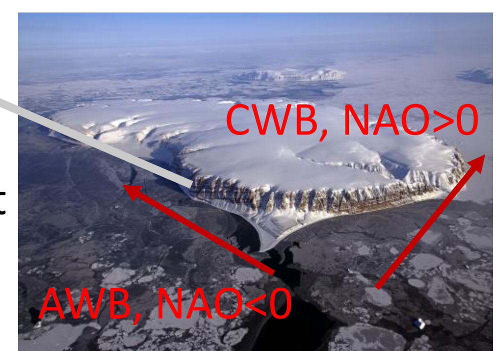

**Figure 5.** Mixing ratio of water vapor (shading), potential temperature (colored contours), and horizontal wind (arrows) on 700 hPa for (a) an anticyclonic wave breaking on 8 January 2006 and (b) a cyclonic wave breaking on 22 January 2007. The potential temperature contour interval is 5 K. The thick solid black line is the potential temperature contour on the 2 PVU surface that is used to identify Rossby wave breaking events.




--Bonne et al. 2015

"In the positive (negative) phase of the NAO, AWB transports more (less) moisture through the Norwegian Sea and CWB transports less (more) along the west coast of Greenland."

Note transport along the topography of the ice sheet



**We took advantage of the topographic barrier effect of Greenland for these CWB-type events:**

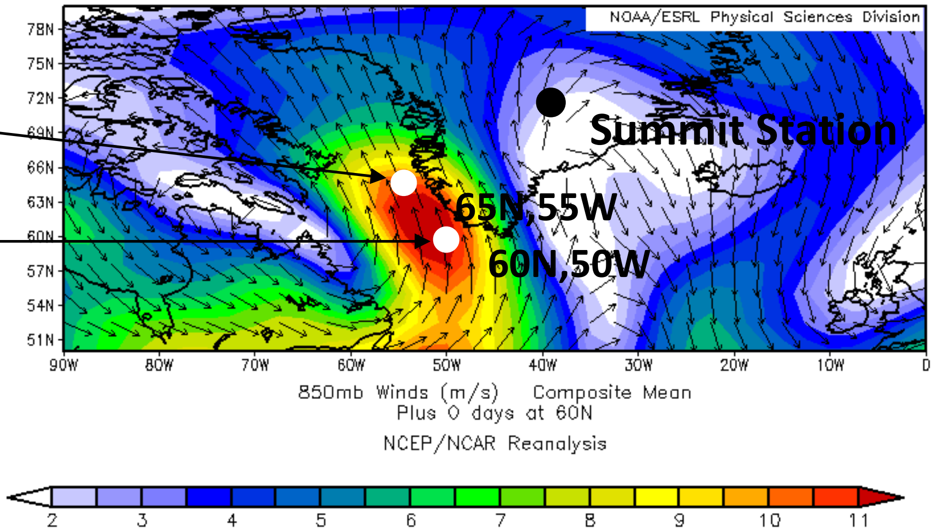
***We*** **created composite fields after setting criteria for northward transport (120º to 220º) transport at 850 hPa as follows with** *IWV> 20 kg/m², WS>10m/s* **:**

Criteria set at two locations:

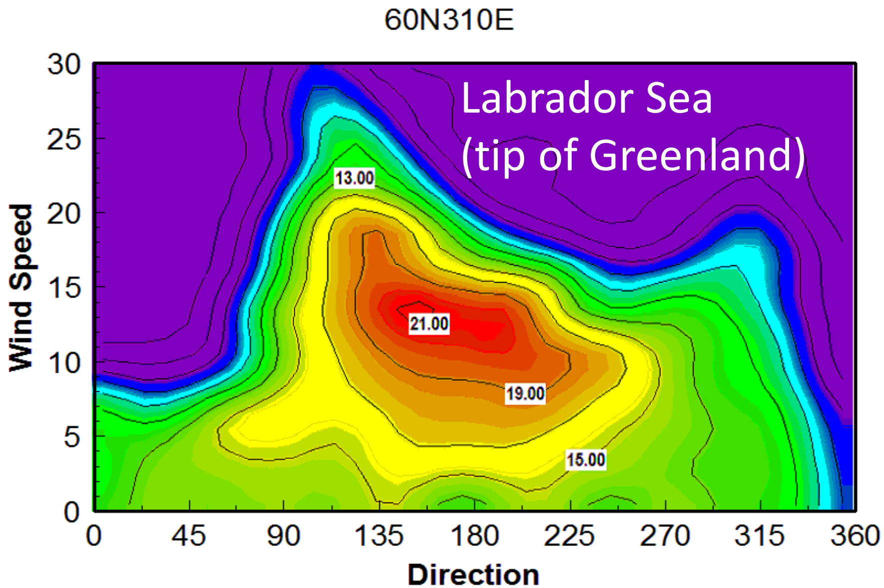
*65ºN,55ºW*

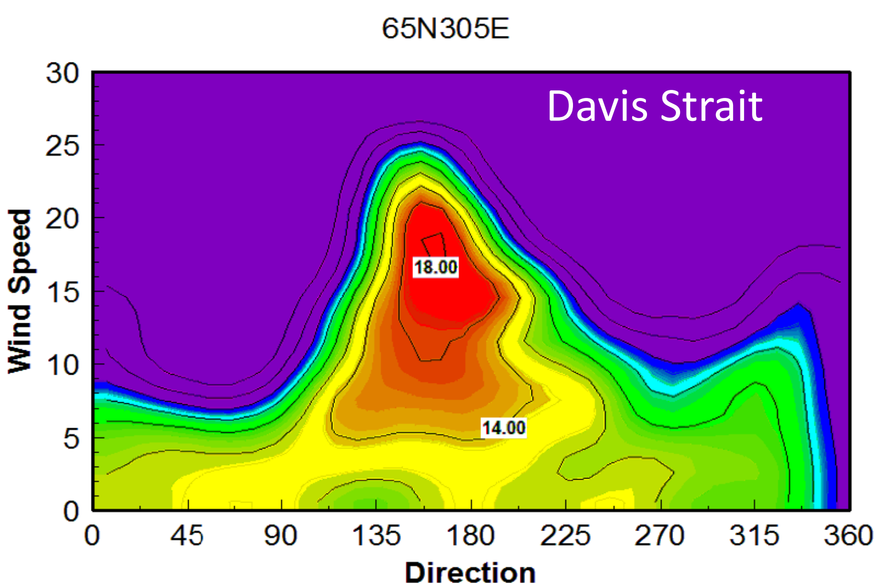
*60ºN,50ºW*

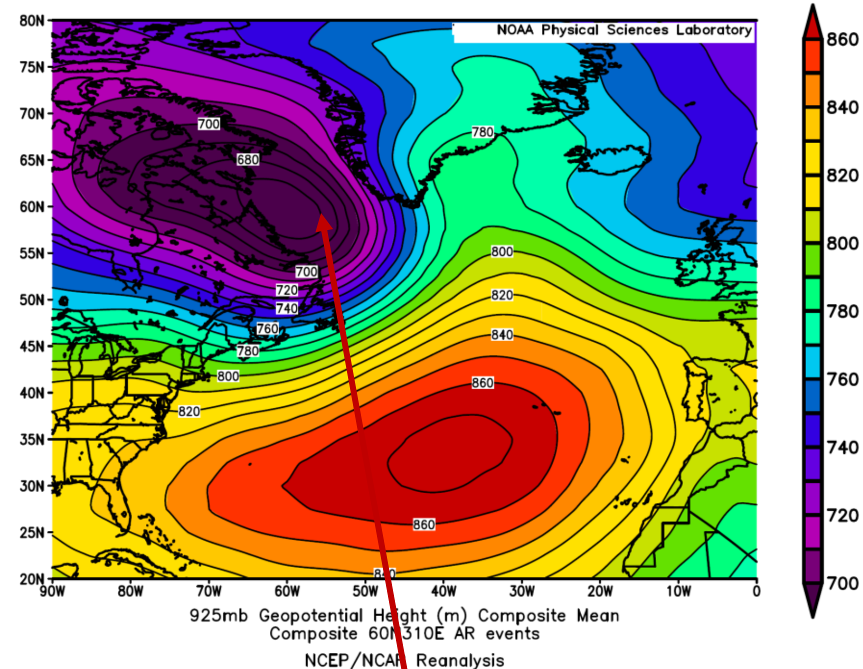
Composite: Vector winds (850 hPa)



# Total column water vapor (kg/m², ERA5) as function of wind speed and direction (2000-2021, JJAS)



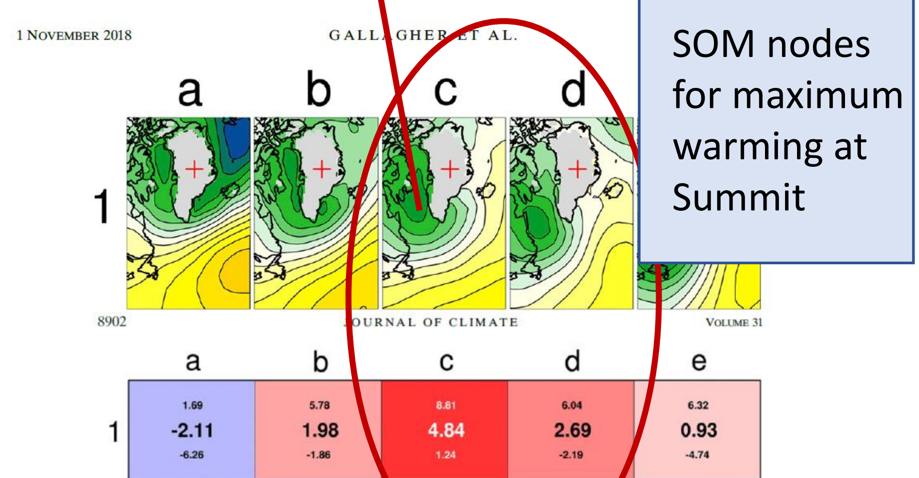
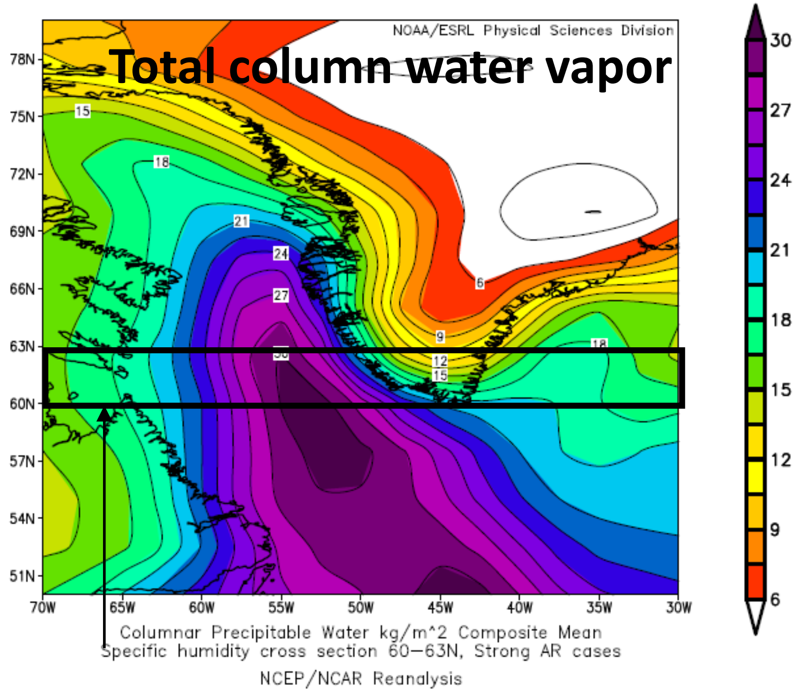
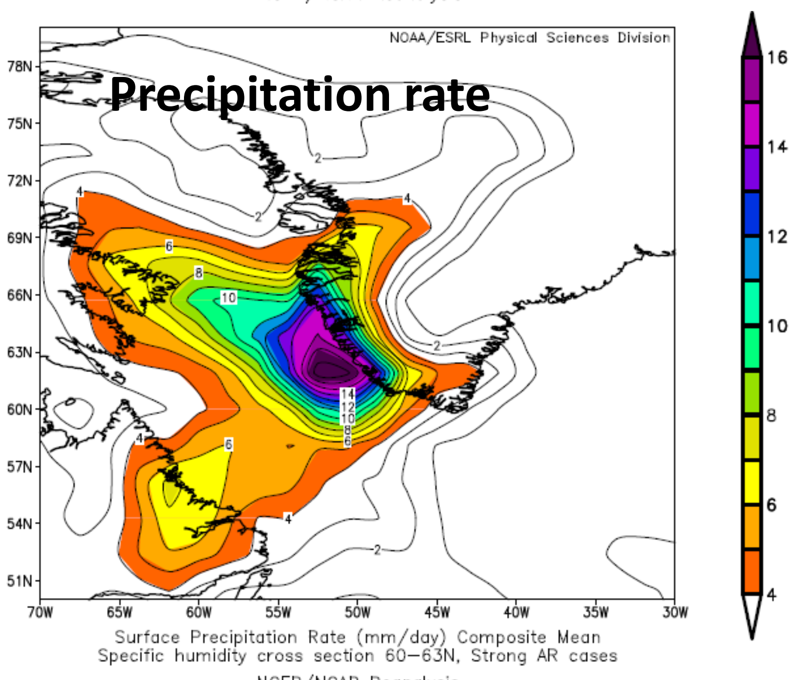



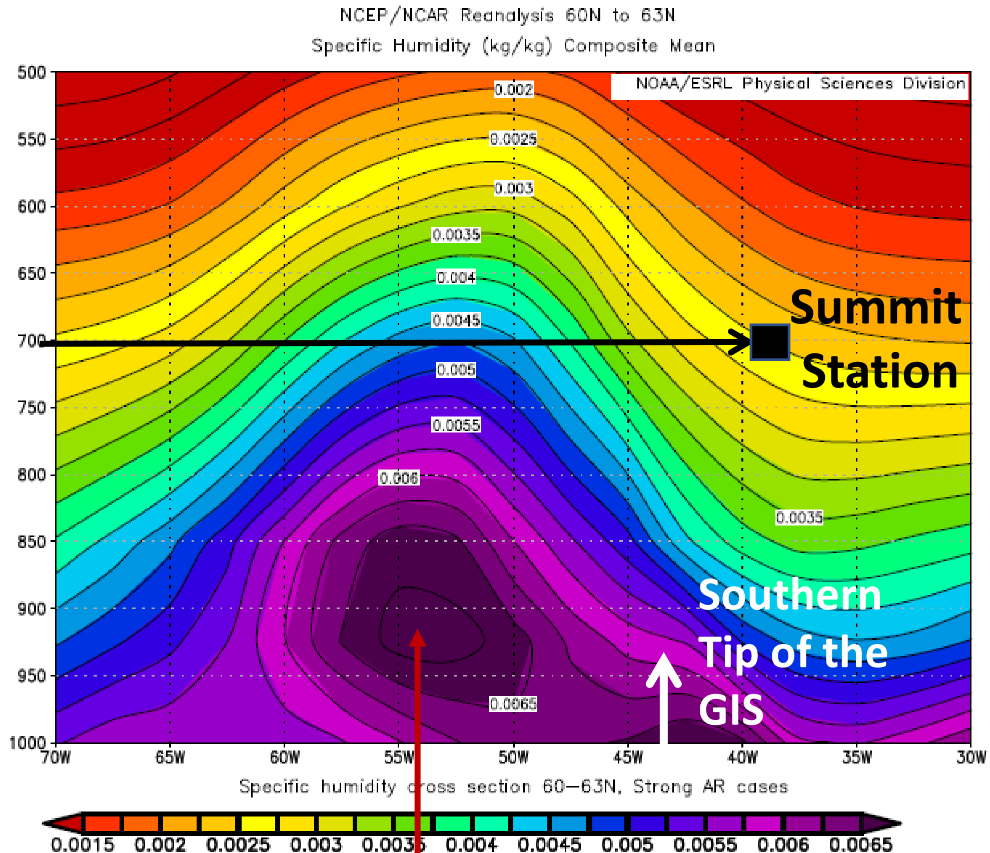

FIG. 4. Node-averaged Summit Station 2-m anomalous temperature (8C).

Gallagher, M. R., Shupe, M. D., & Miller, N. B. (2018). Impact of Atmospheric Circulation on Temperature, Clouds, and Radiation at Summit Station, Greenland, with Self-Organizing Maps, *Journal of Climate*, *31*(21), 8895-8915.




## Vertical cross-section specific humidity

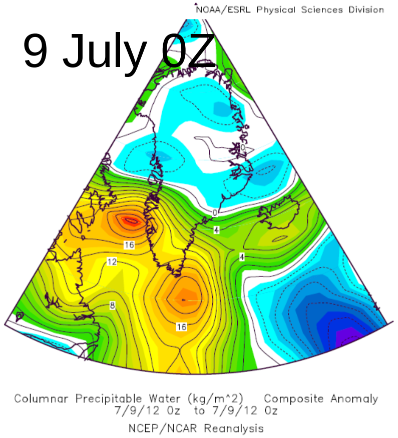


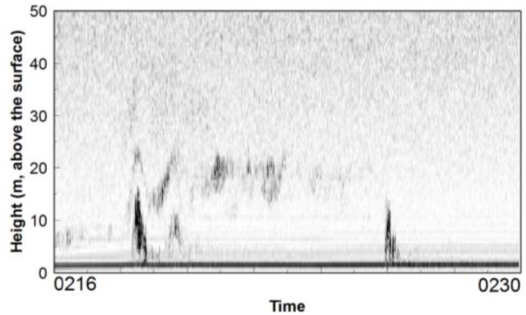

***Along-GIS-barrier transport of moisture***

# Boundary layer evolution during the 2012 melt event

IWV Anomalies

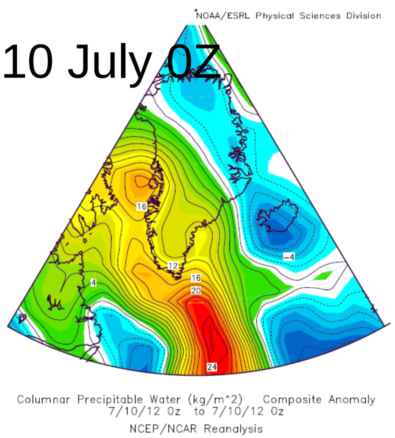
9 July 0Z

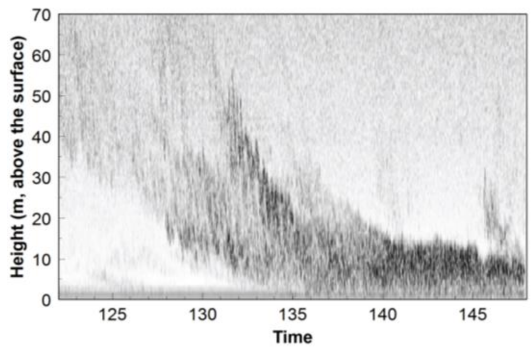



Case A: Sodar image during extreme stability case (~12$^{o}$C/8m). Note the intermittent nature of turbulence near the surface and the absence of any echoes at times suggesting nearly laminar flow.

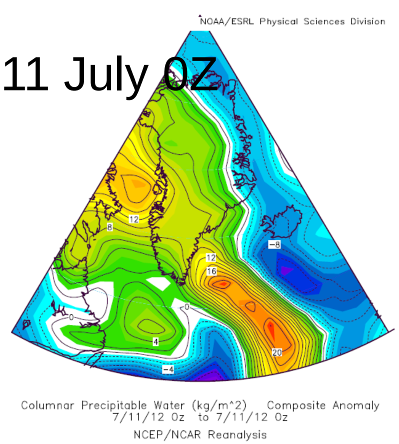
10 July 0Z

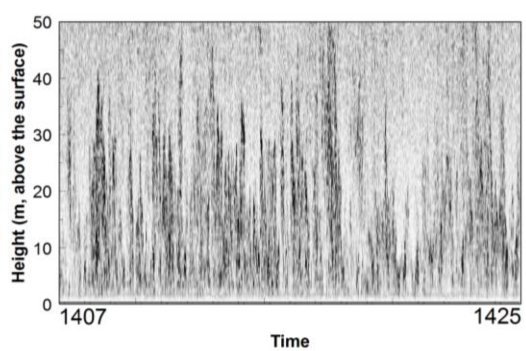



Case B: Early morning on the 11$^{th}$ prior to the melt episode during a period of weak stability (~2$^{o}$-3$^{o}$C/8m).
Despite the appearance of increased mixing the temperature difference between 2- and 10-m stays virtually constant.

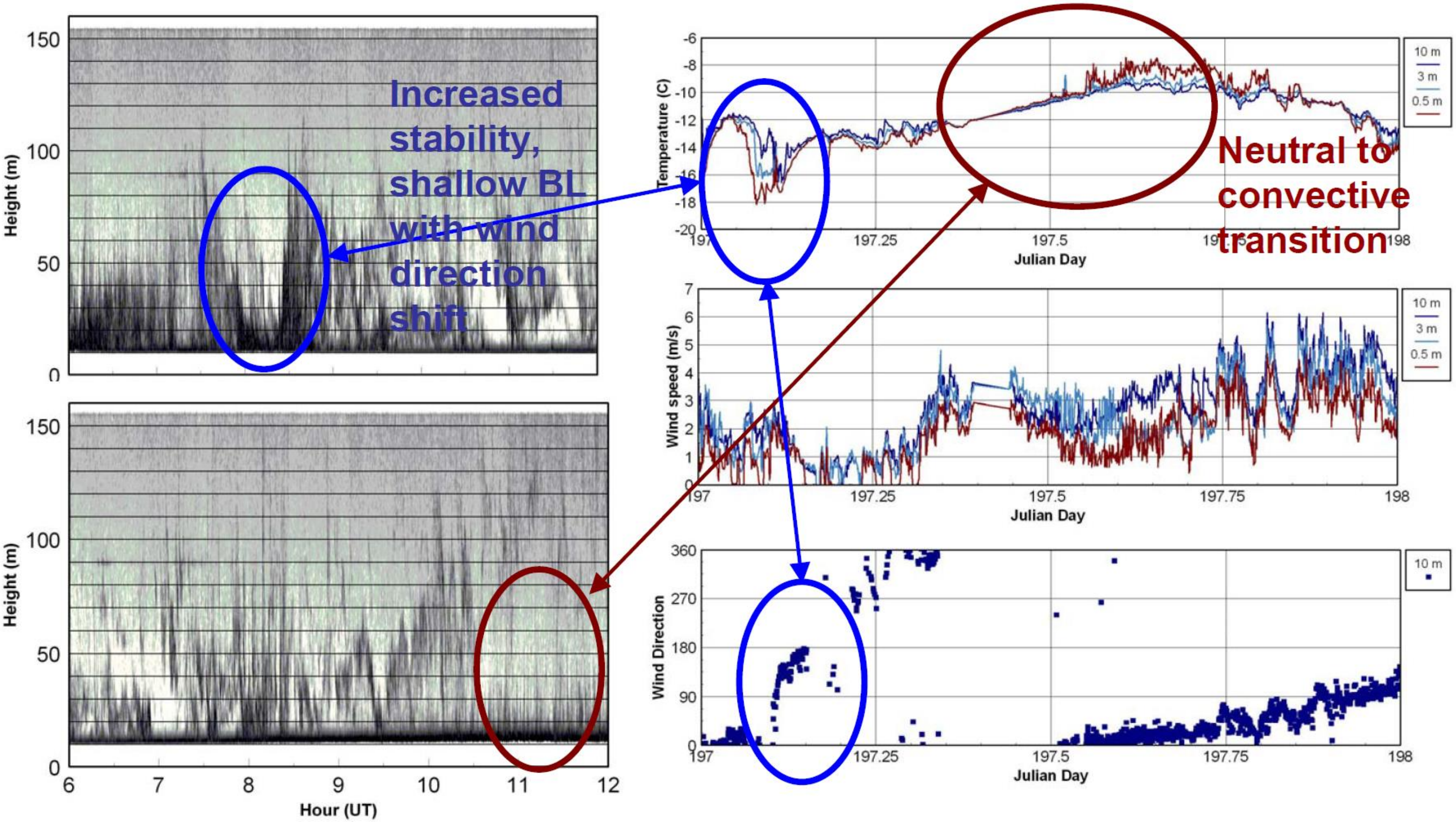
11 July 0Z




Case C: Afternoon on the 11$^{th}$ during the melt episode when the temperature difference is superadiabatic. Vertically oriented structures are individual thermal plumes.

# Comparing sodar records with time series for a short tower measurement of Temp, WS, & WD



# Testing the extensibility of a boundary layer result from Antarctic (slowly evolving) to Greenland (strong diurnal and synoptic weather variability):

**Evaluation of Boundary Layer Depth Estimates at Summit Station, Greenland**

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L. KRAMER
*Department of Geological and Mining Engineering and Sciences, Michigan Technological University, Houghton, Michigan*

to approach an equilibrium depth. The first of these equations for the BLD (also called $H$) is an expression that was originally devised by Pollard et al. (1973) for an oceanic mixing layer, driven primarily by surface stress and assuming equilibrium at inertial time scales:

$$H = 1.2u_*(fN_b)^{-1/2}. \qquad (1)$$

In this equation, $u_*$ is the friction velocity [defined as $(-\overline{u'w'})^{1/2}$, where $u$ and $w$ are the horizontal and vertical wind components, respectively], $f$ is the Coriolis parameter, and $N_b$ is the Brunt–Väisälä frequency given by

$$N_b = \sqrt{\frac{g}{T}\frac{\partial\theta}{\partial z}}. \qquad (2)$$

Here, $g$ is the gravitational acceleration, $T$ is the absolute temperature recorded by the sonic anemometer, and $\partial\theta/\partial z$ is the potential temperature gradient with height. Neff (1980) found that this diagnostic model gave a good estimation of BLD during weak-to-moderate

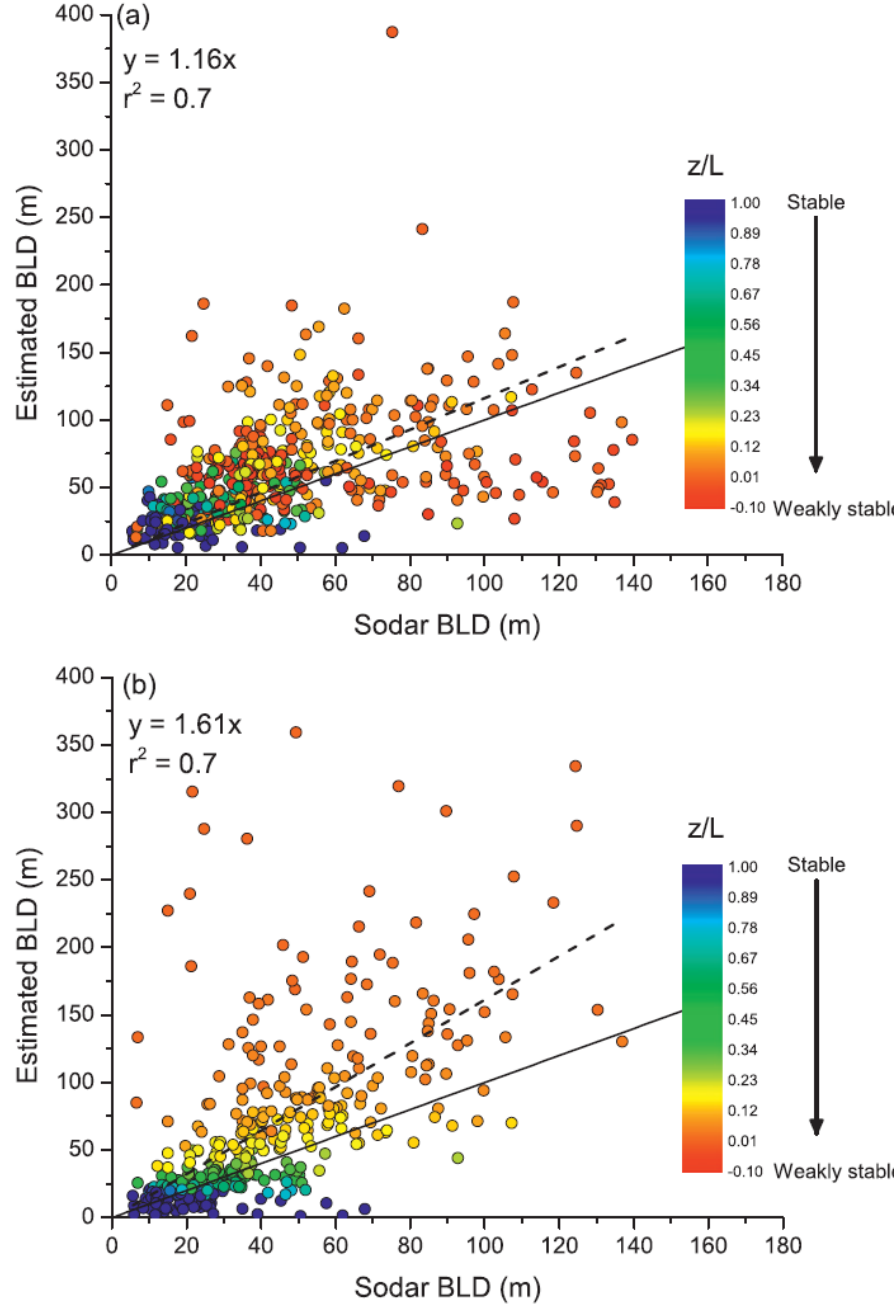
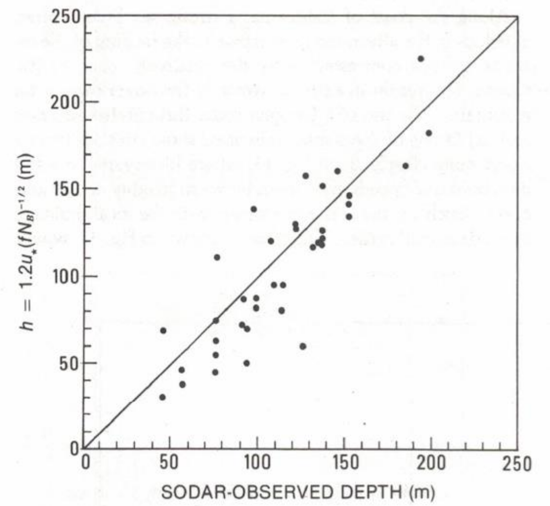



FIG. 5. Regression analysis of BLD estimates using (a) Eq. (1) derived from Pollard et al. (1973) and (b) Eq. (3) derived from (Zilitinkevich and Baklanov 2002) for June 2010. Only stable to weakly stable conditions were considered. The solid black line is the 1:1 line, and the dashed line is the linear regression fit to the data. Colors correspond to the value of the stability parameter.

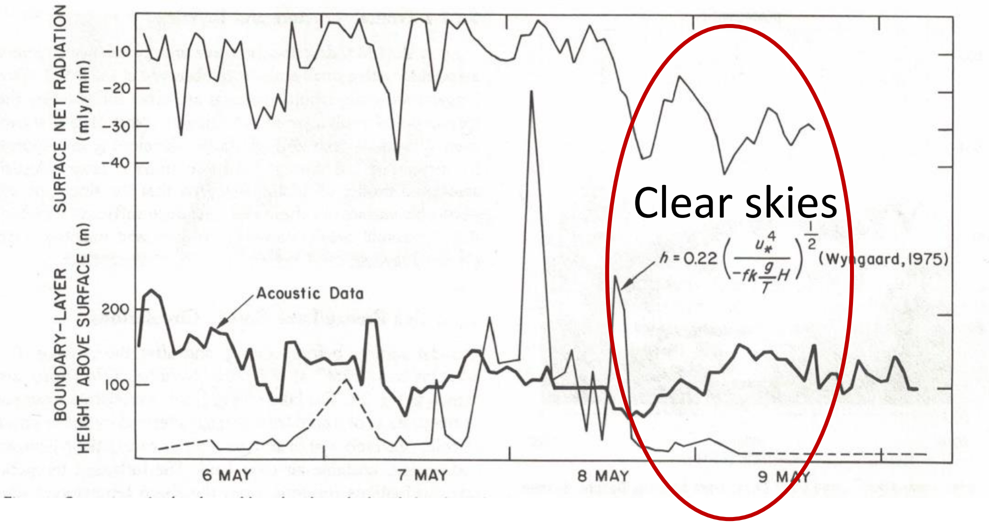
Why the Pollard et al. 1973 seemed attractive for estimating the boundary layer depth at the South Pole:

- External synoptic forcing was generally weak and slowly evolving from a dynamical perspective.
- However, other expressions that depend on surface radiative forcing expressions are subject to more variability in external forcing and the slow adjustment in the boundary layer (e.g. Van Dam et al. 2013).

Sodar-derived BL depth compared with Pollard et al. 1973 estimate:




Below: Sodar-derived boundary layer depth with surface heat flux (H) and net radiation. Result: The Boundary layer does not adjust rapidly to changes in surface heat flux (due to rapid changes in cloud cover aloft.)



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Neff, W. D. (1999). "Decadal time scale trends and variability in the tropospheric circulation over the South Pole." Journal of Geophysical Research: Atmospheres **104**(D22): 27217-27251.

Shupe, M. D., D. D. Turner, V. P. Walden, R. Bennartz, M. P. Cadeddu, B. B. Castellani, C. J. Cox, D. R. Hudak, M. S. Kulie, N. B. Miller, R. R. Neely and W. D. Neff (2013). "High and Dry: New Observations of Tropospheric and Cloud Properties above the Greenland Ice Sheet." Bulletin of the American Meteorological Society.

Van Dam, B., D. Helmig, W. Neff and L. Kramer (2013). "Evaluation of Boundary Layer Depth Estimates at Summit Station, Greenland." Journal of Applied Meteorology and Climatology **52**(10): 2356-2362.