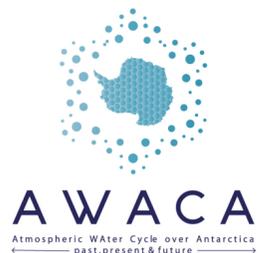


Stratified atmospheric flow at the Antarctic surface: need for sub-grid parameterizations in climate models

Cécile Agosta & Cécile Davrinche & Anaïs Orsi & AWACA (atmospheric) modelling team:
Etienne Vignon, Christophe Genthon, Jean-Baptiste Madeleine, Valentin Wiener, Thomas
Dubos, Patryk Kiepas, Yann Meurdesoif, Sébastien Fromang



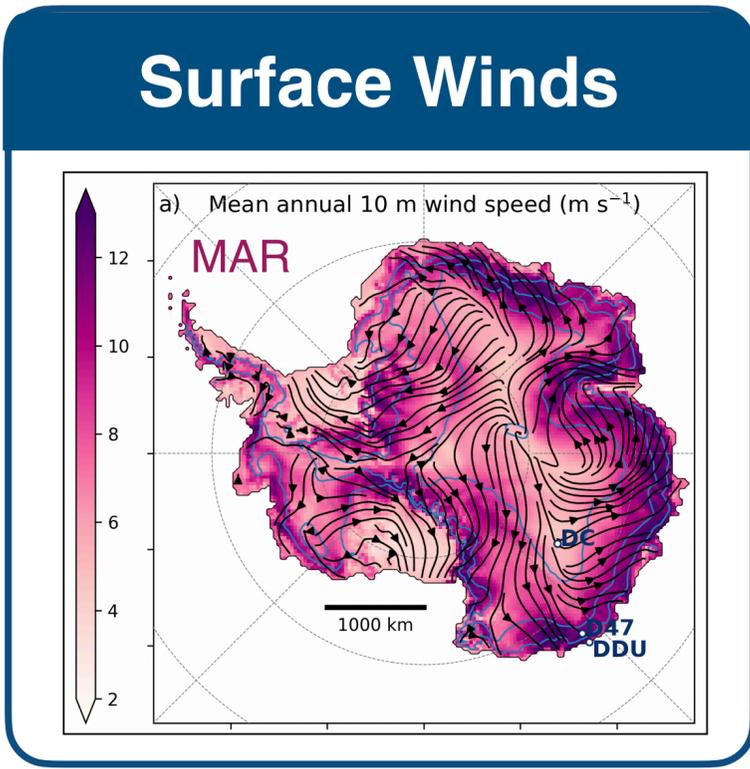
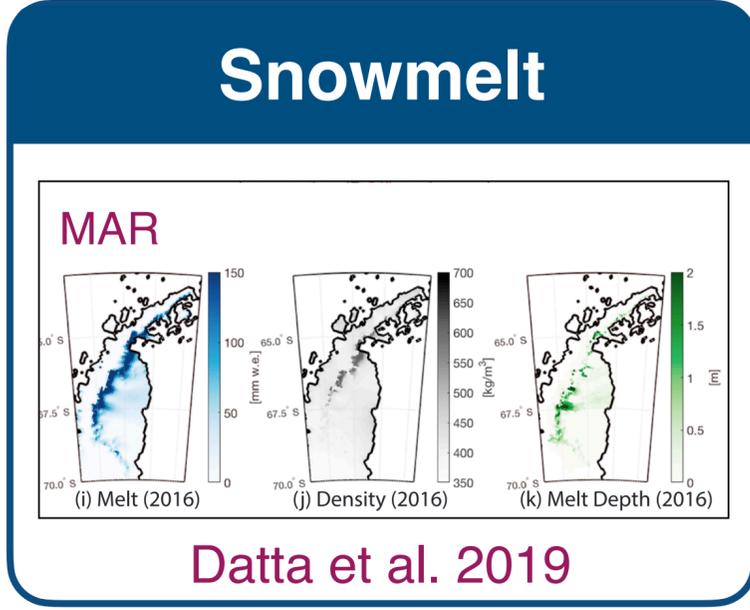
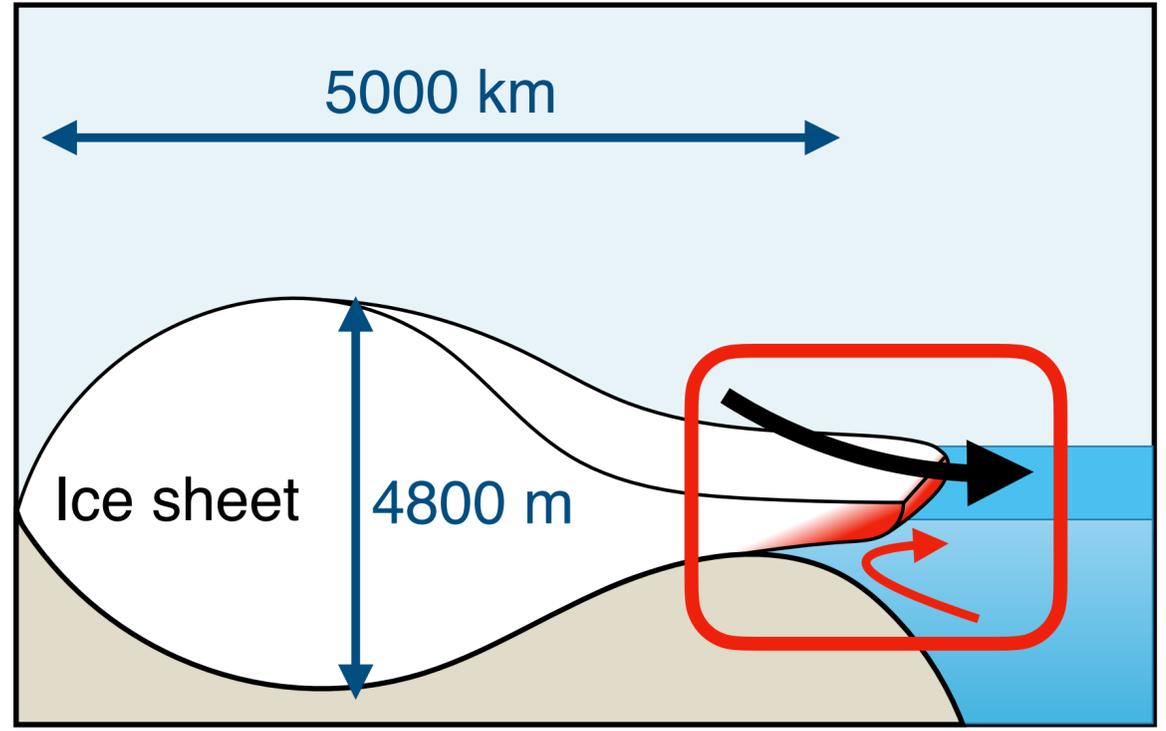
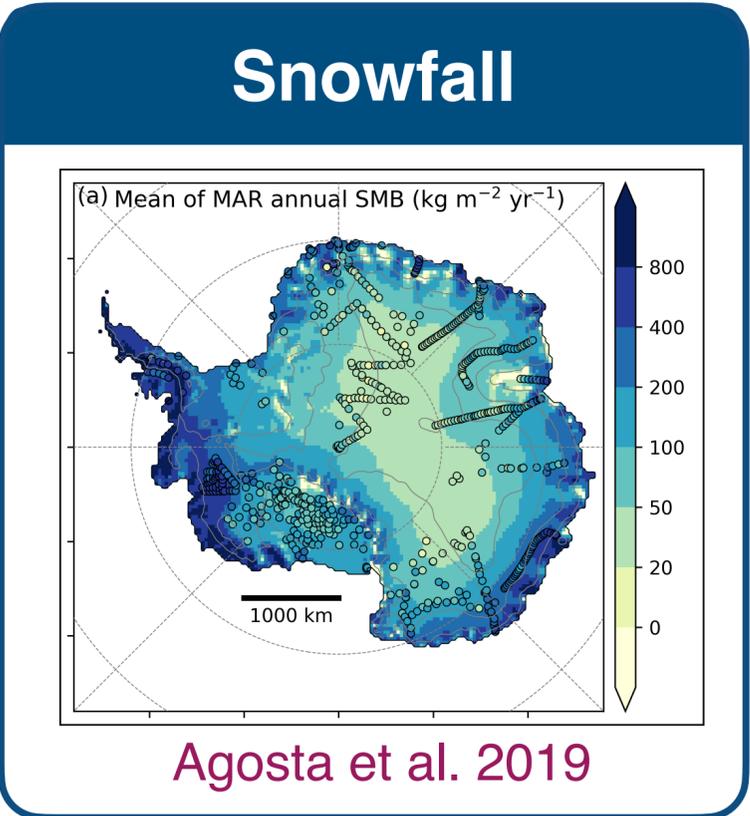
Journées du GDR MathGeoPhy
Octobre 2022



This presentation is part of the AWACA project that has received funding from the European Research Council (ERC Synergy) under the European Union's Horizon 2020 Research and Innovation Programme (Grant agreement No 951596)

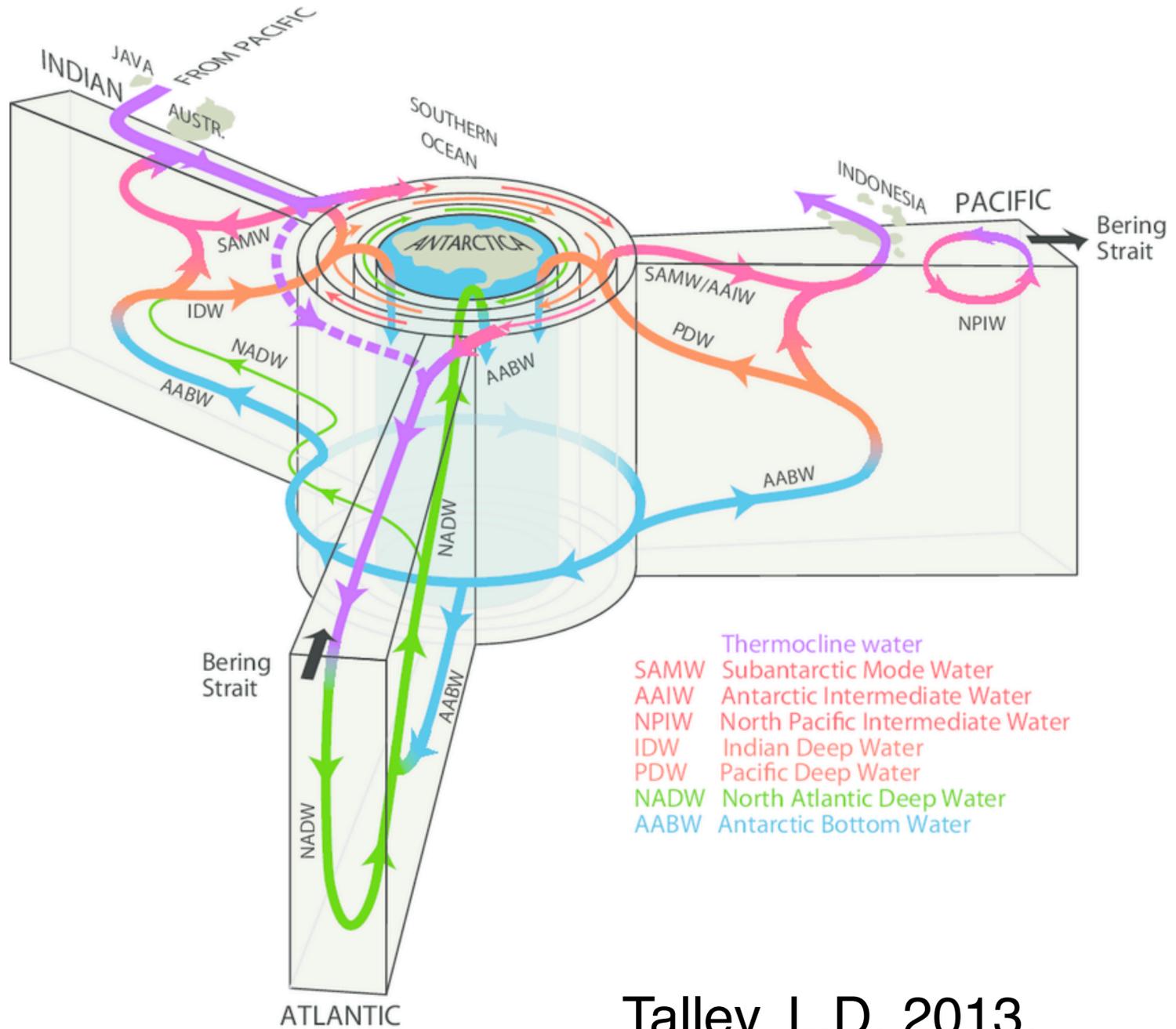
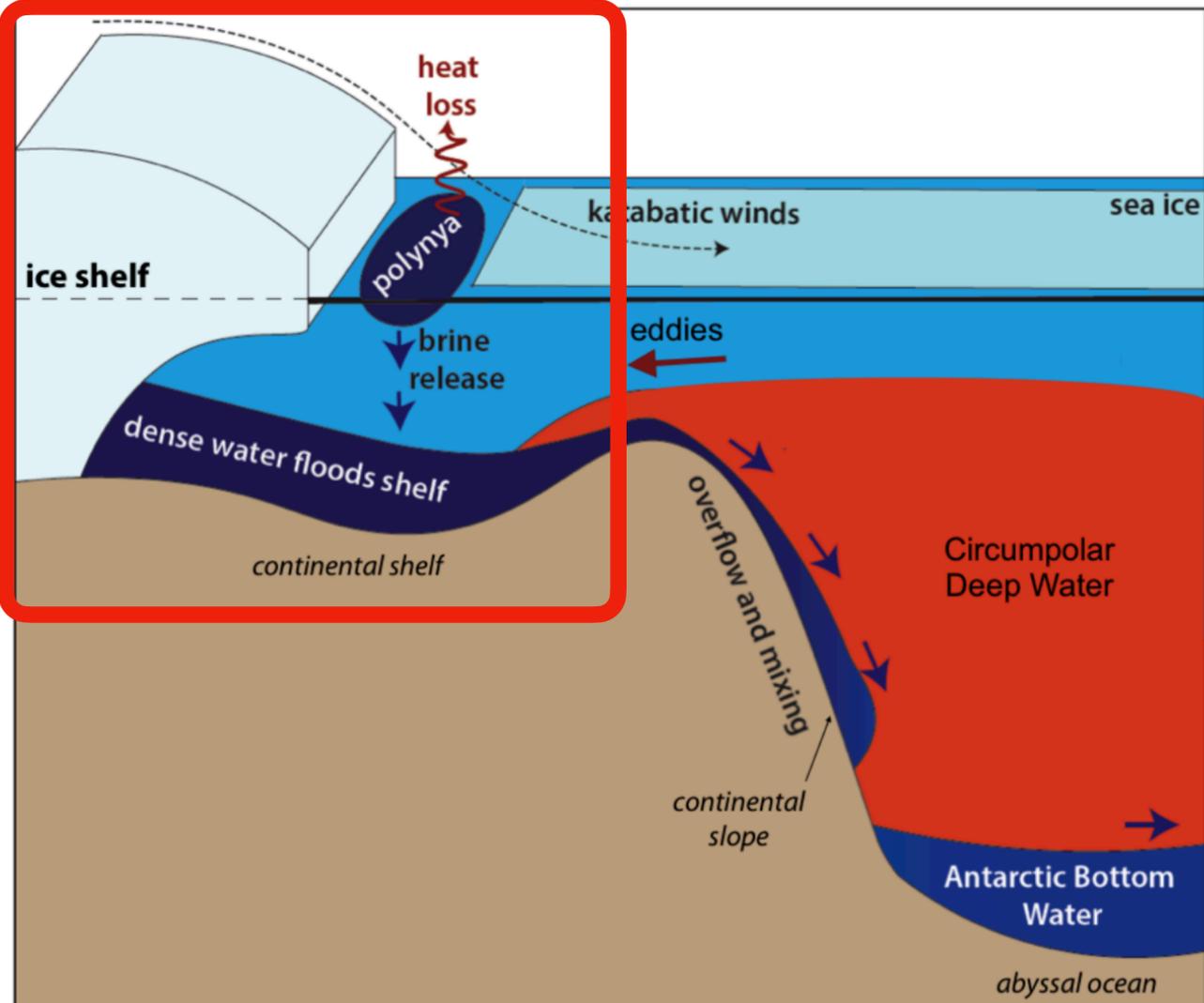
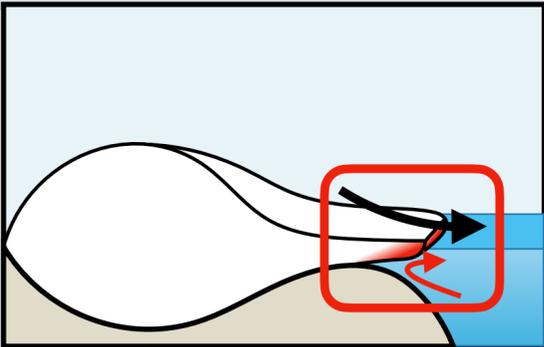
Coupling atmosphere, ocean and ice-sheet in Antarctica

Atmospheric forcings of the Antarctic ice sheet



➔ Ocean currents

Importance of surface winds for ocean circulation

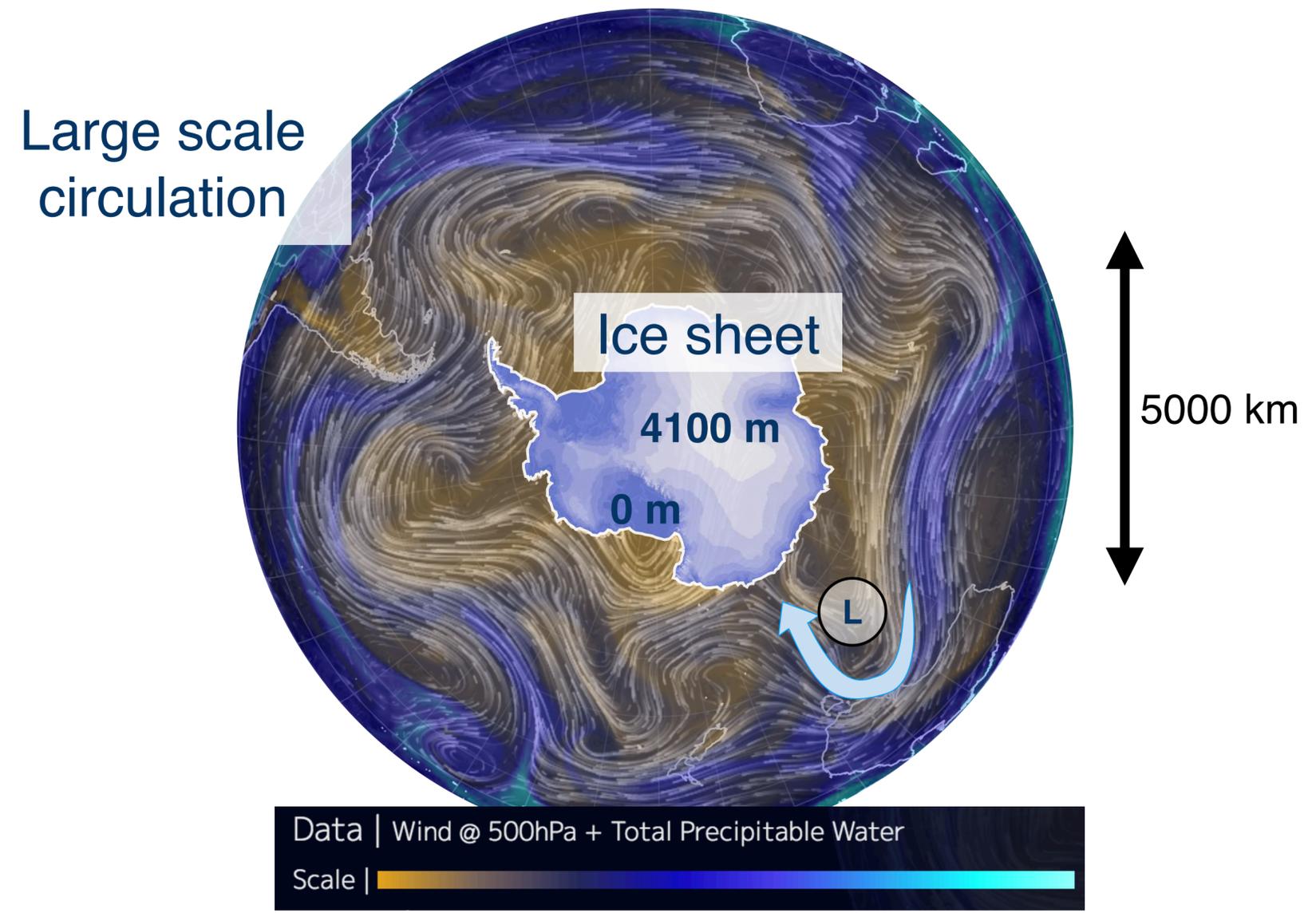


R. Moorman (2019) Silvano et al. (2018)

Talley, L.D. 2013.

General atmospheric circulation over Antarctica

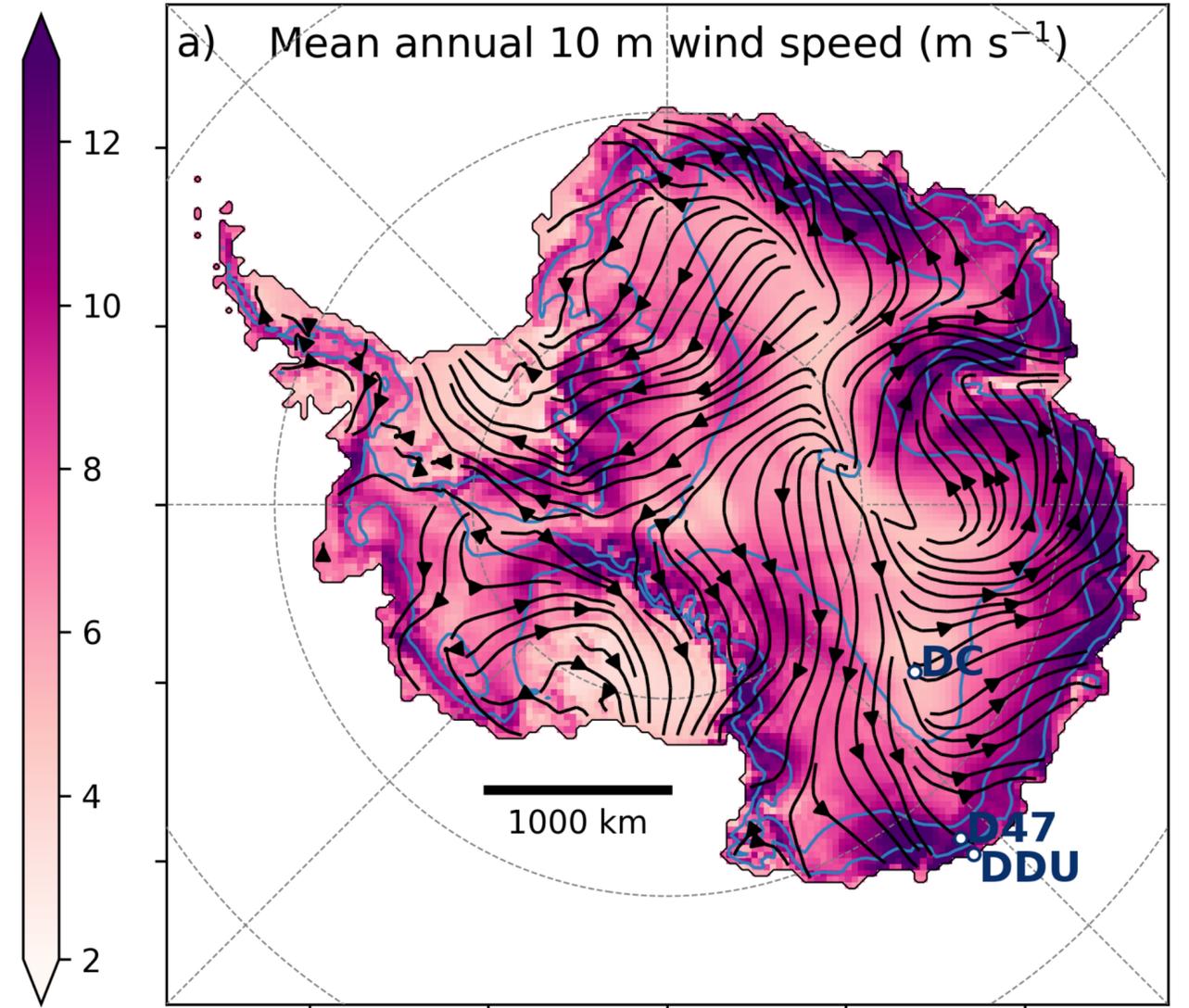
In the free atmosphere
500 hPa ~5500 m above sea level



<https://earth.nullschool.net/#current/wind/surface/level/orthographic=-352.23,-79.97,299>

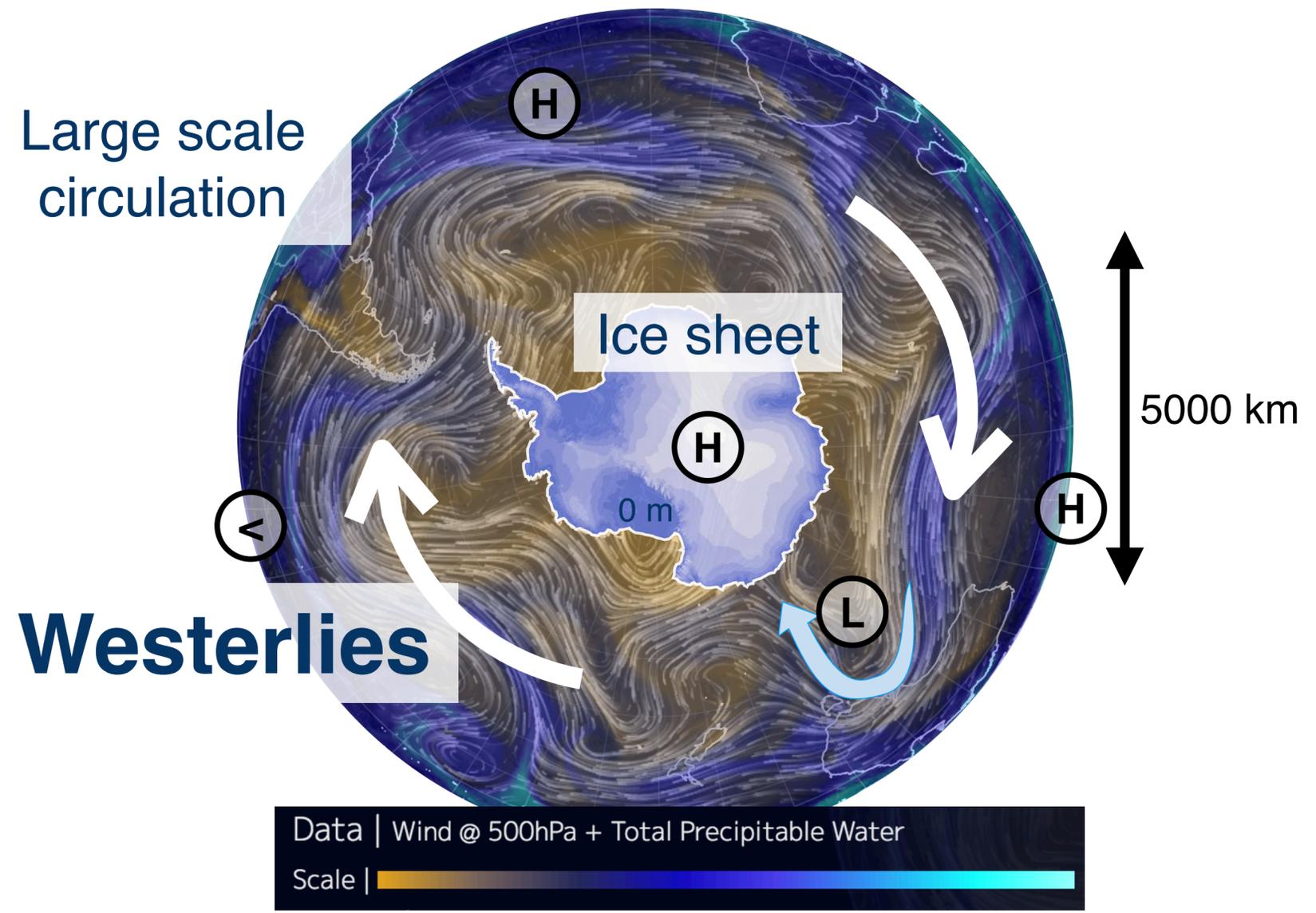
At the surface

1979-2017, atmospheric model simulation (MAR)



General circulation over Antarctica

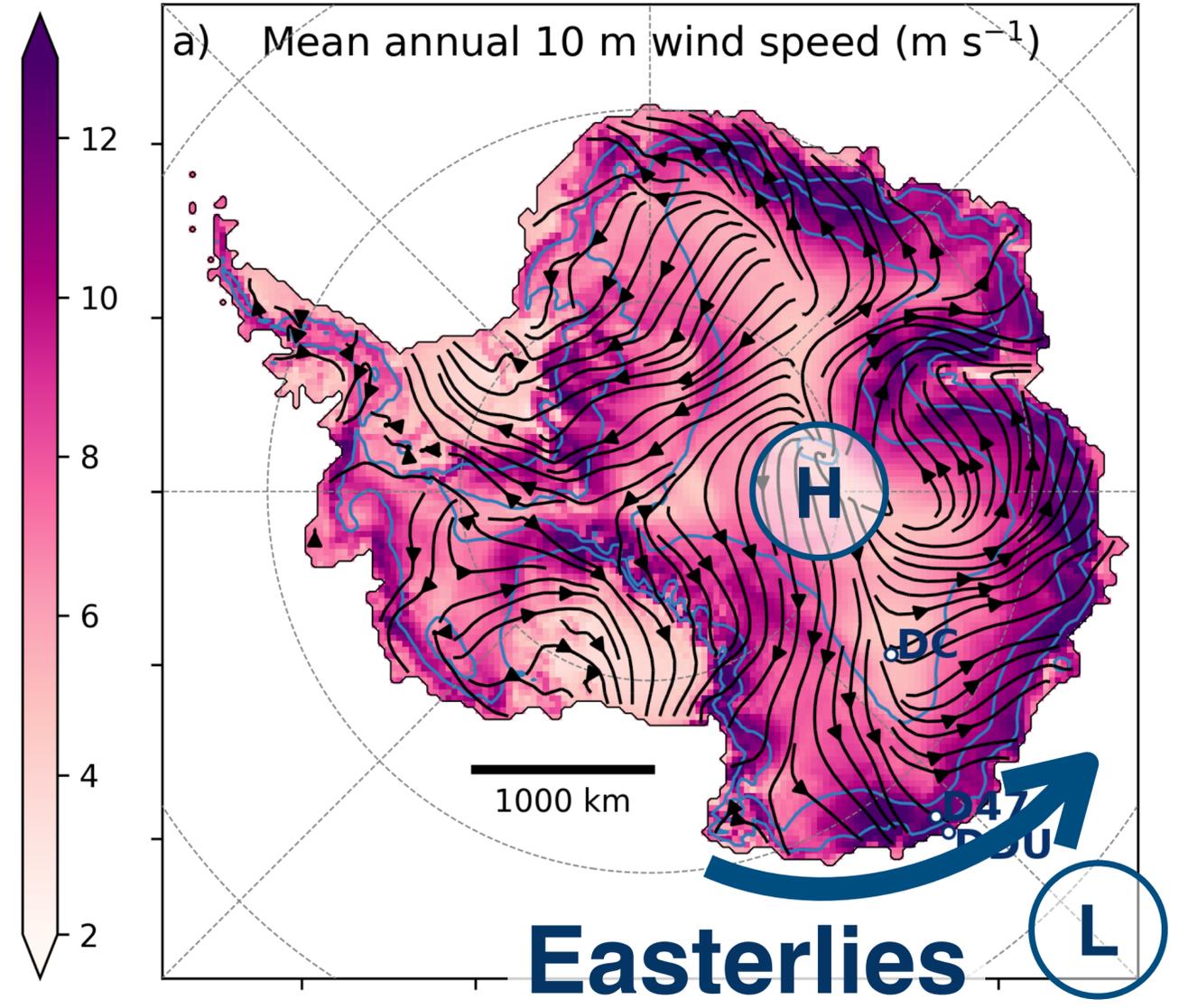
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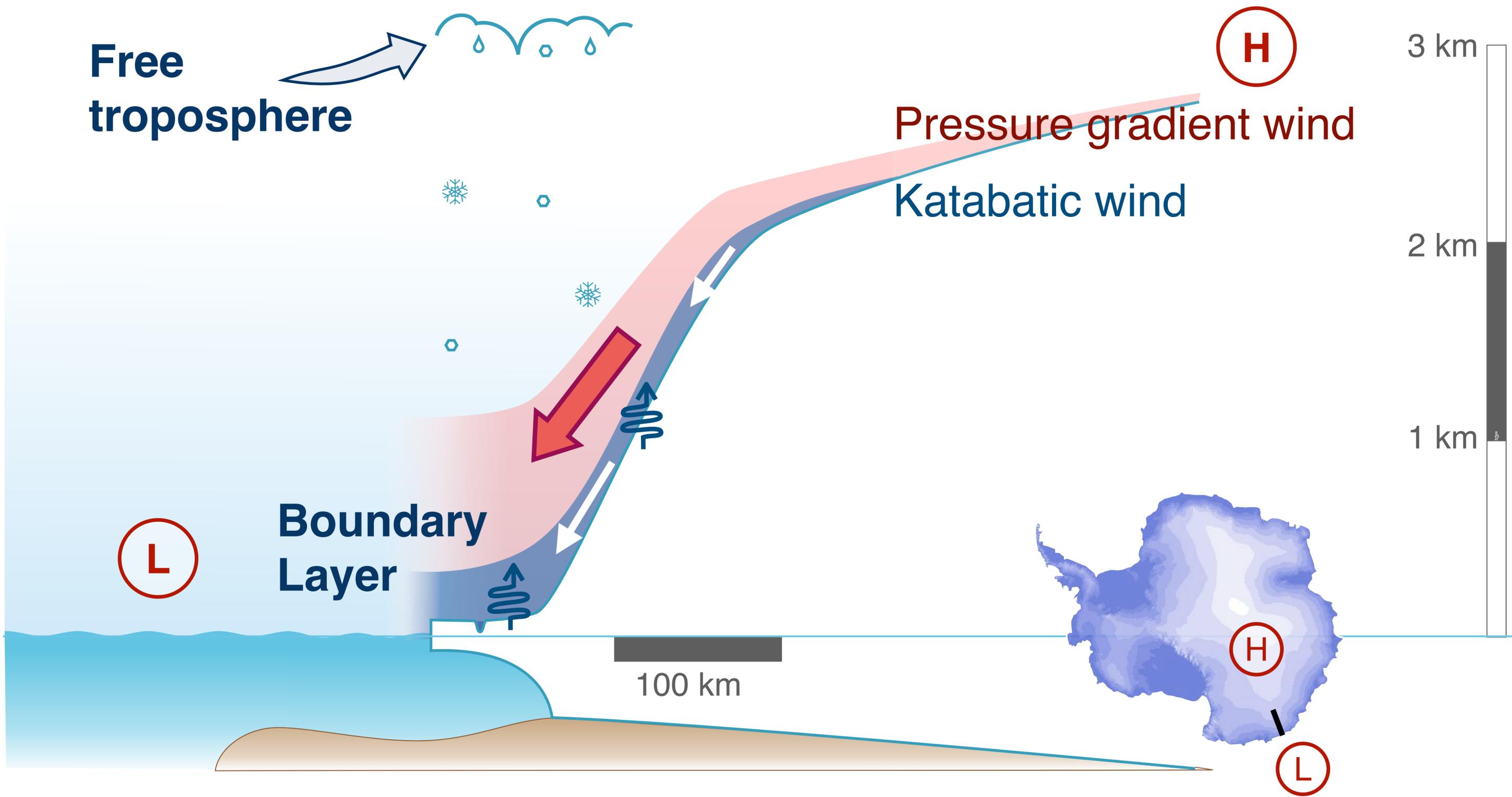
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At the surface

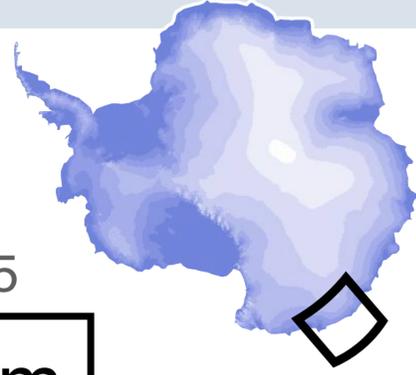
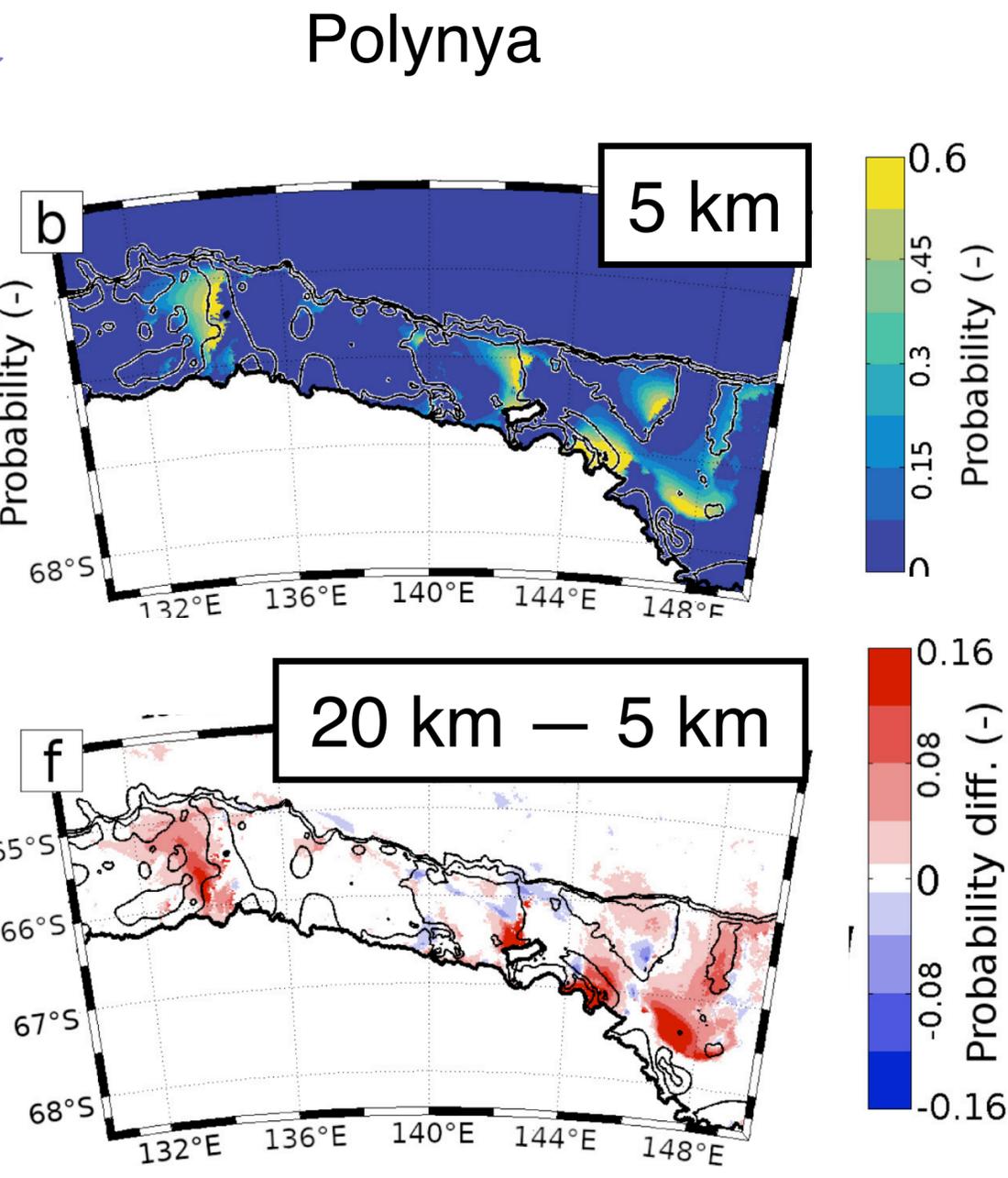
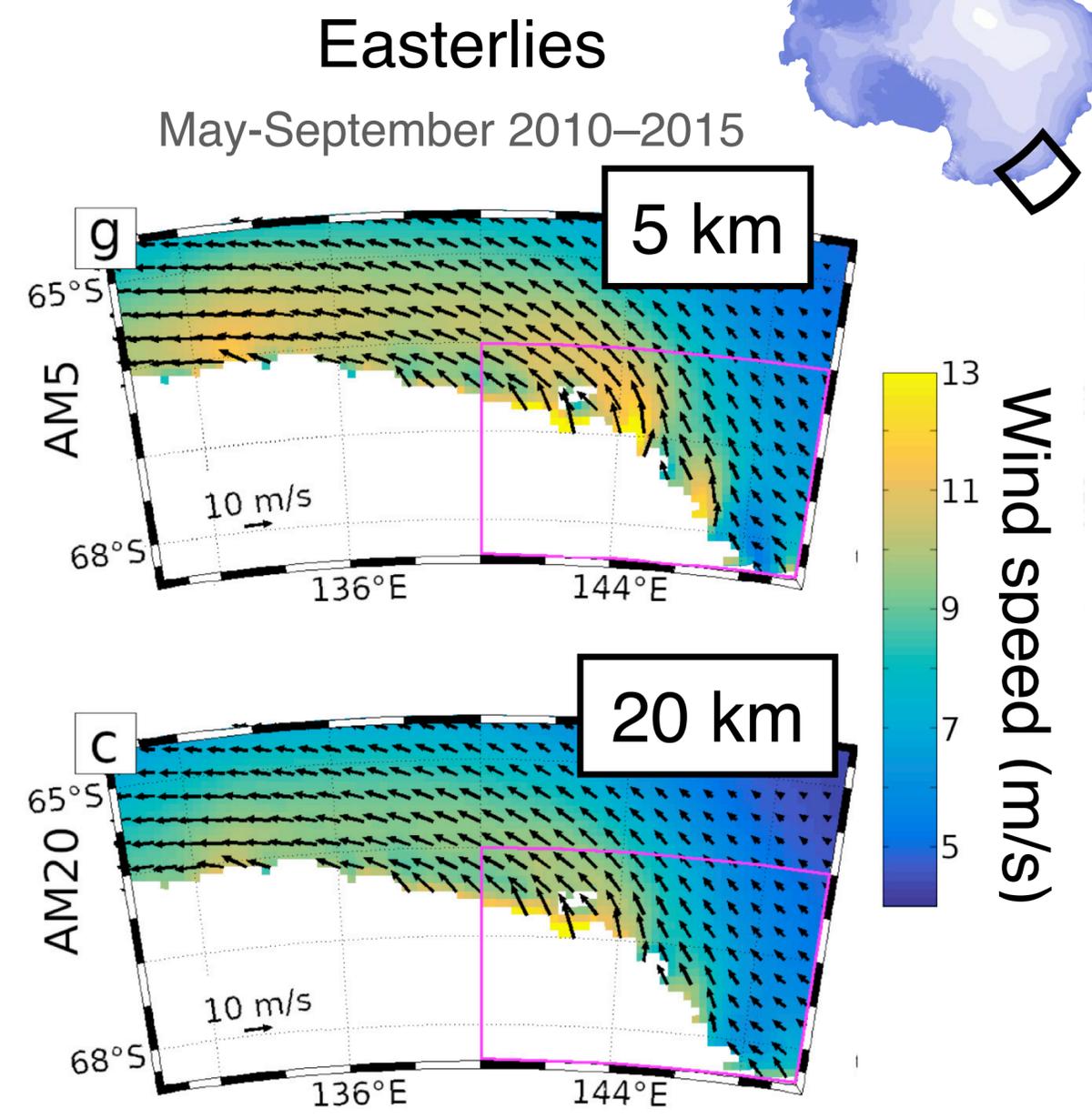
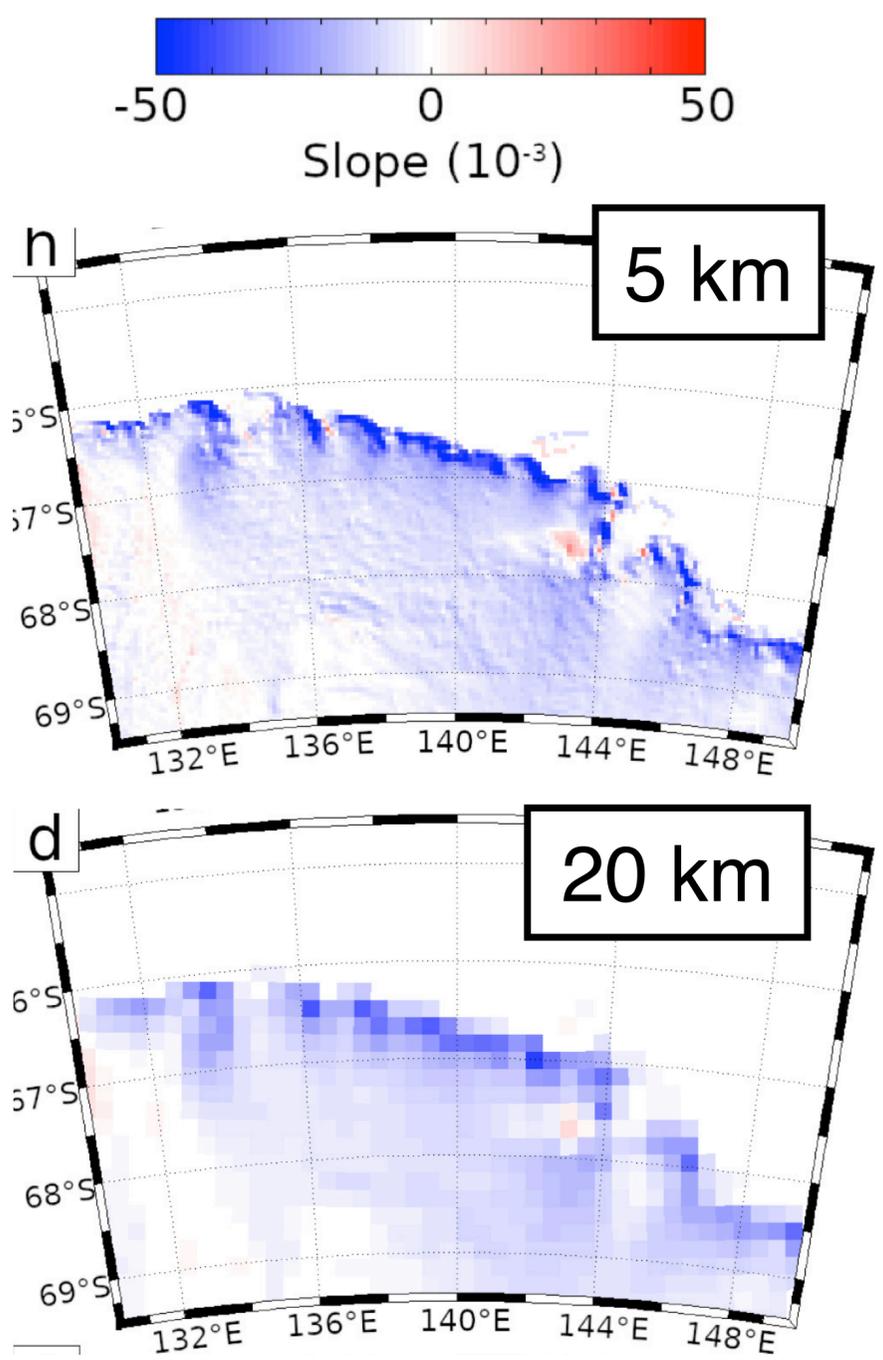
1979-2017, atmospheric model simulation (MAR)



Free troposphere vs. Surface layers



Effect of the atmosphere model resolution on polynya formation



Regional atmospheric model MAR
Hydrostatic

Huot et al. (2021)

Modelling the winds in atmospheric climate models

Regional atmospheric model MAR :

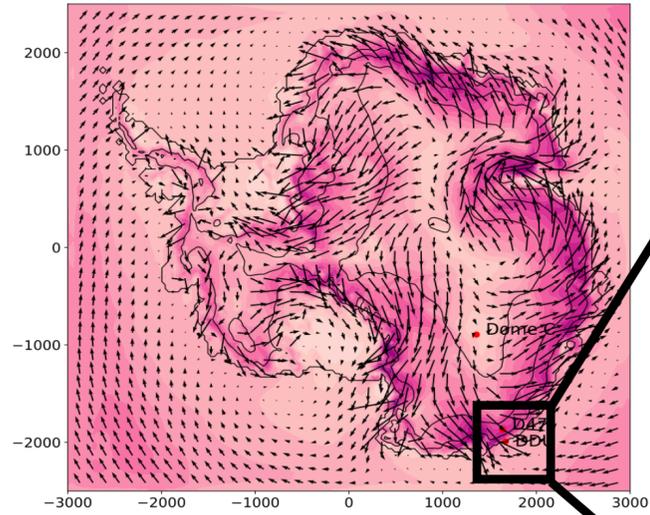
- 35 km horizontal grid for climate simulations (40-100 years)
- Hydrostatic
- Snowpack and air-snow interactions

MAR-35km

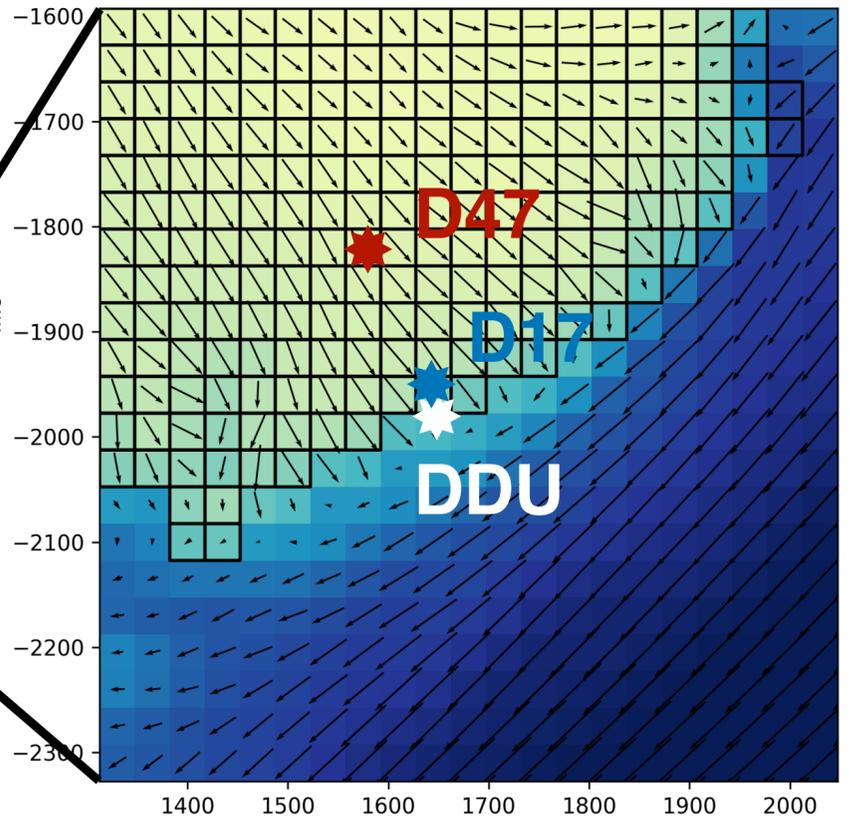
Zoom over Adélie Land

Specific humidity 29/12/2016 18:00 (kg kg^{-1})

Mean July 1979-2020 surface layer wind-speed, MAR



Mean July 1979-2020

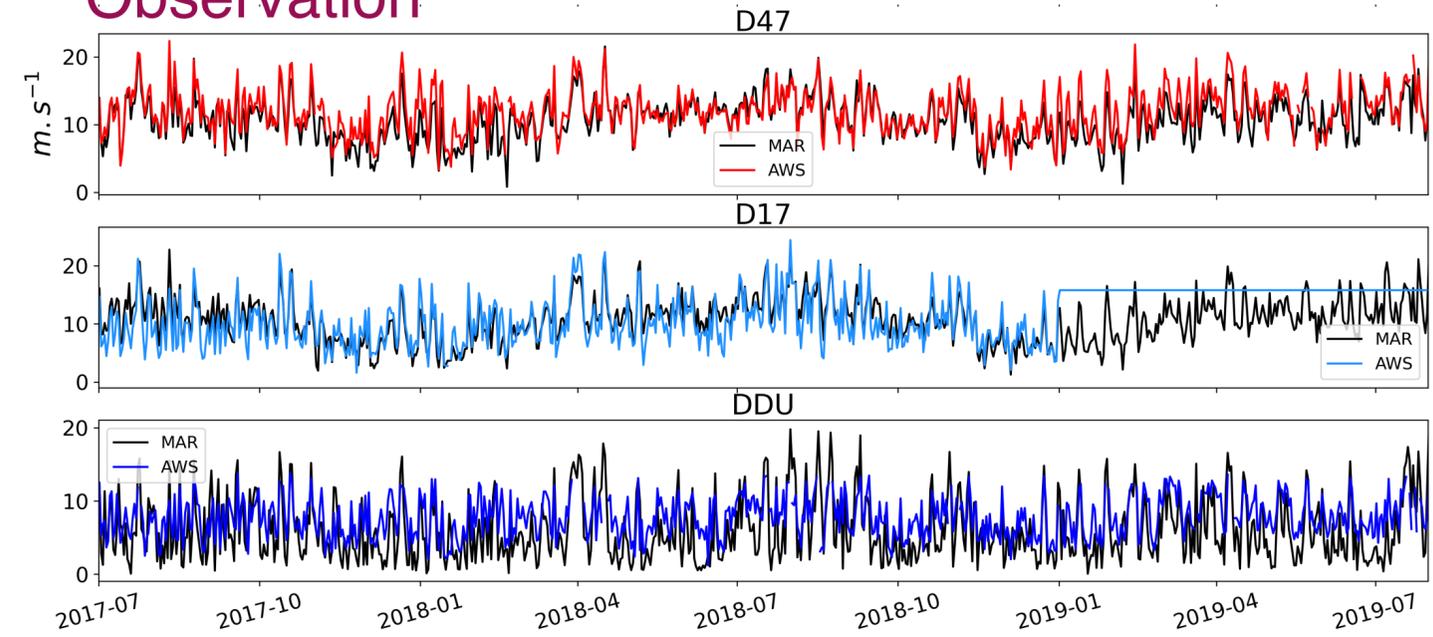


Bréant et al 2019

Evaluation for surface winds Daily, 07/2017-07/2019

MAR

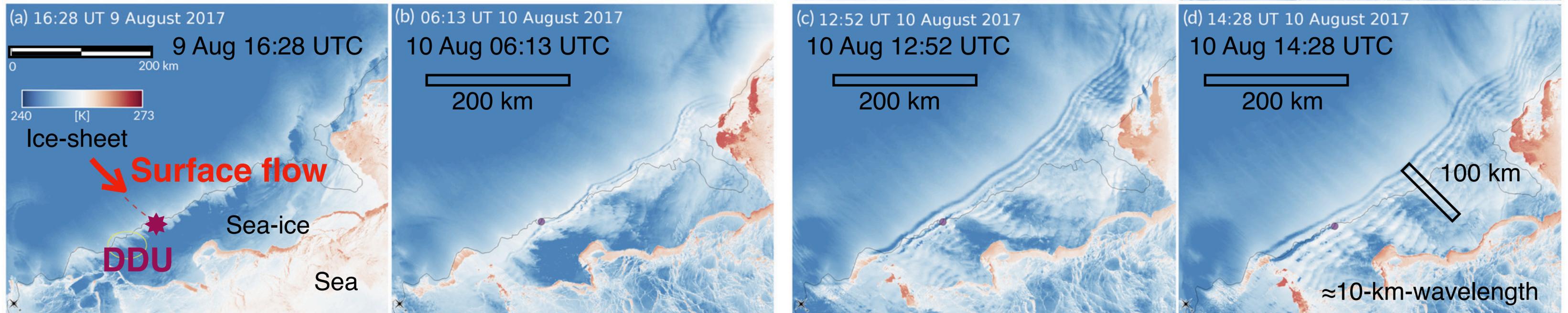
Observation



Cécile Davrinche (PhD student)

Trapped gravity waves at the ice-sheet-ocean interface (Vignon et al. 2020)

Vignon et al. 2020 : Journal of the Atmospheric Sciences 77, 4; [10.1175/JAS-D-19-0264.1](https://doi.org/10.1175/JAS-D-19-0264.1)

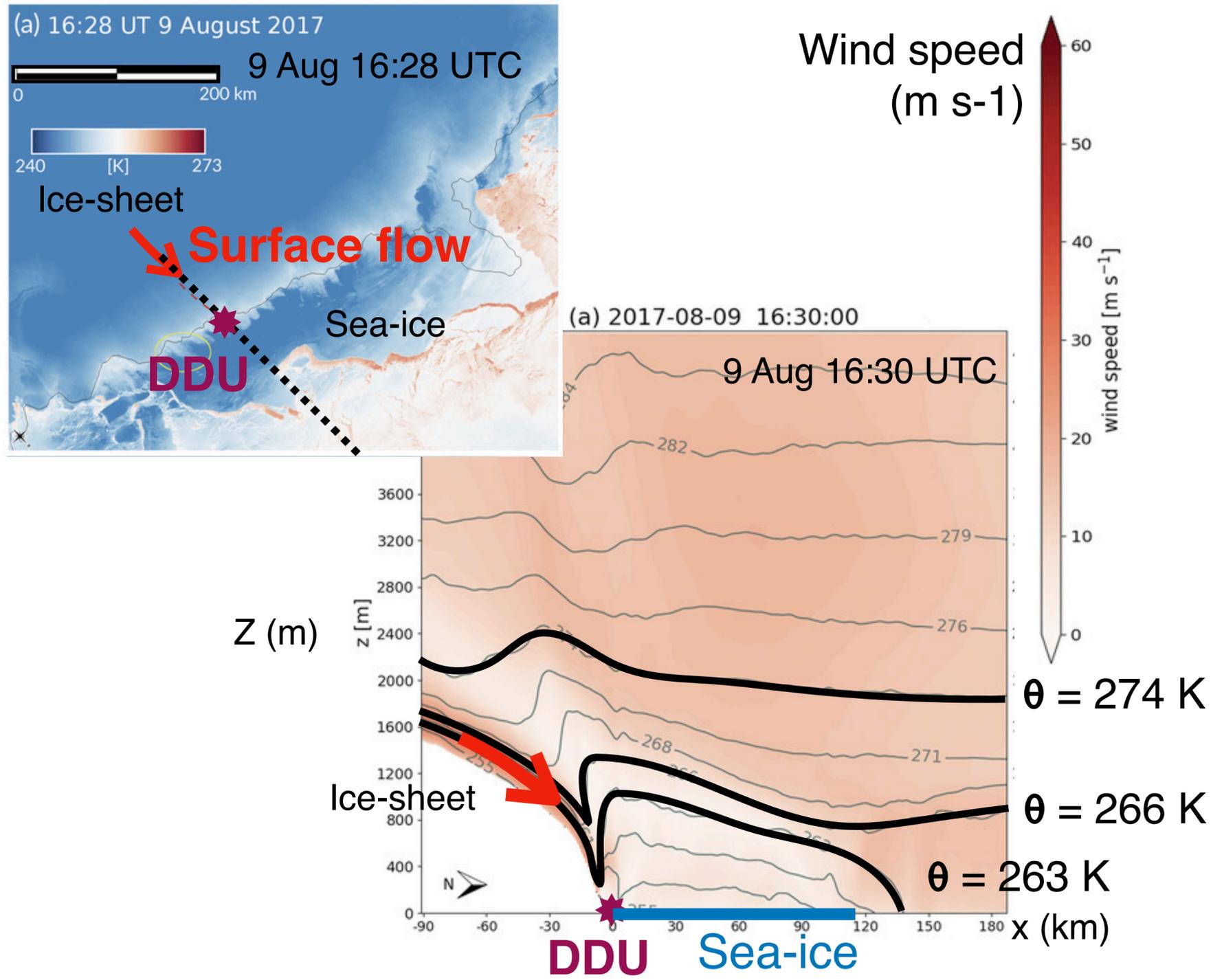


Satellite Radiometer : Brightness temperature at 11.4 μm
 \approx physical temperature of the topmost ice crystals

Brightness temperature images at 11.4 μm (thermal infrared band) from the Visible Infrared Imaging Radiometer Suite (VIIRS; band I5 in the Sensor Data Record product; [Cao et al. 2013](#))

Trapped gravity waves at the ice-sheet-ocean interface (Vignon et al. 2020)

Vignon et al. 2020 : Journal of the Atmospheric Sciences 77, 4; [10.1175/JAS-D-19-0264.1](https://doi.org/10.1175/JAS-D-19-0264.1)



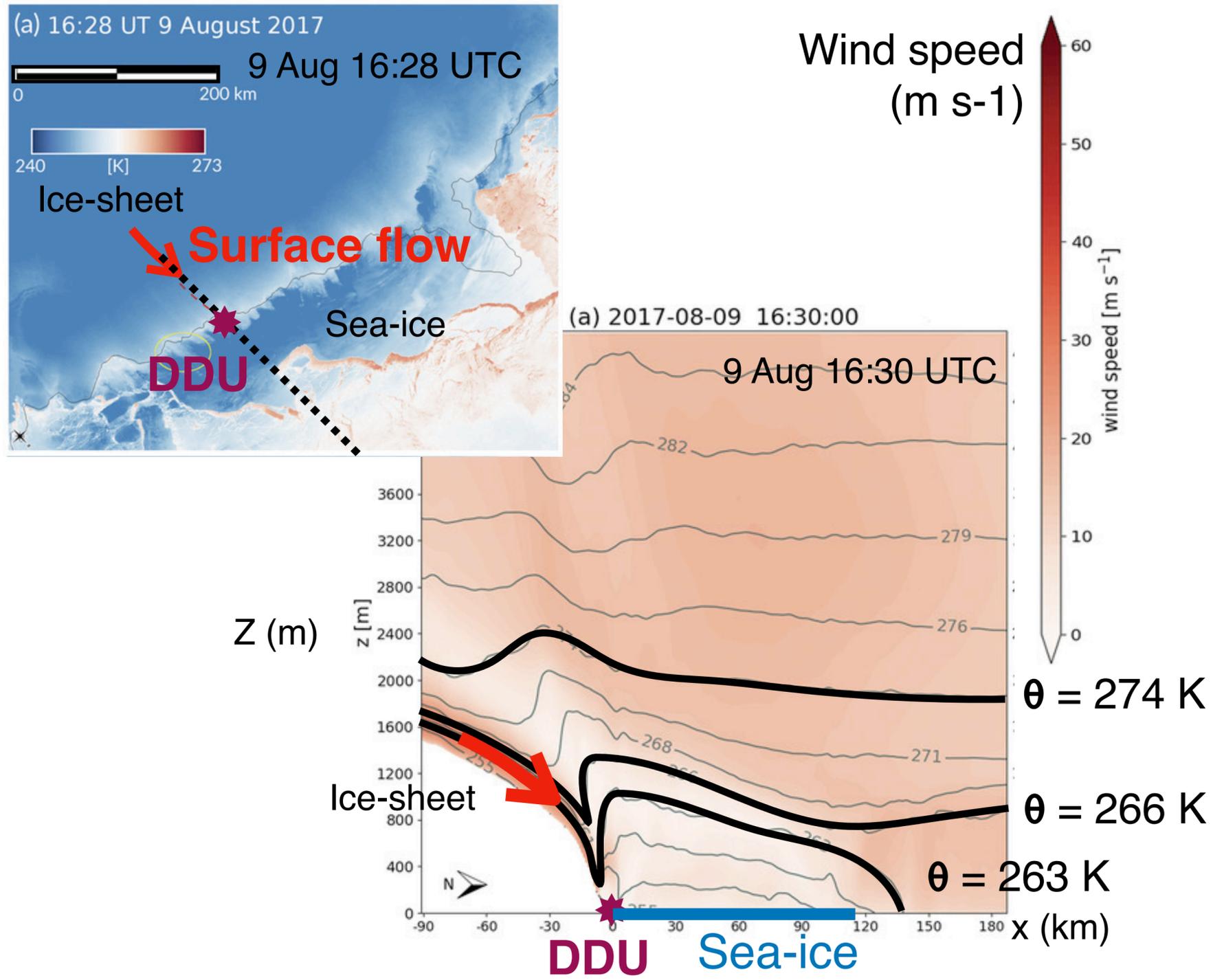
Satellite Radiometer

Regional atmospheric model WRF

- 1 km horizontal grid
- Non-Hydrostatic (Navier-Stokes)
- Sub-grid parameterizations:
 - Turbulent bulk closure
 - Clouds
 - Radiative transfers

Trapped gravity waves at the ice-sheet-ocean interface (Vignon et al. 2020)

Vignon et al. 2020 : Journal of the Atmospheric Sciences 77, 4; [10.1175/JAS-D-19-0264.1](https://doi.org/10.1175/JAS-D-19-0264.1)



1. Strong surface flow

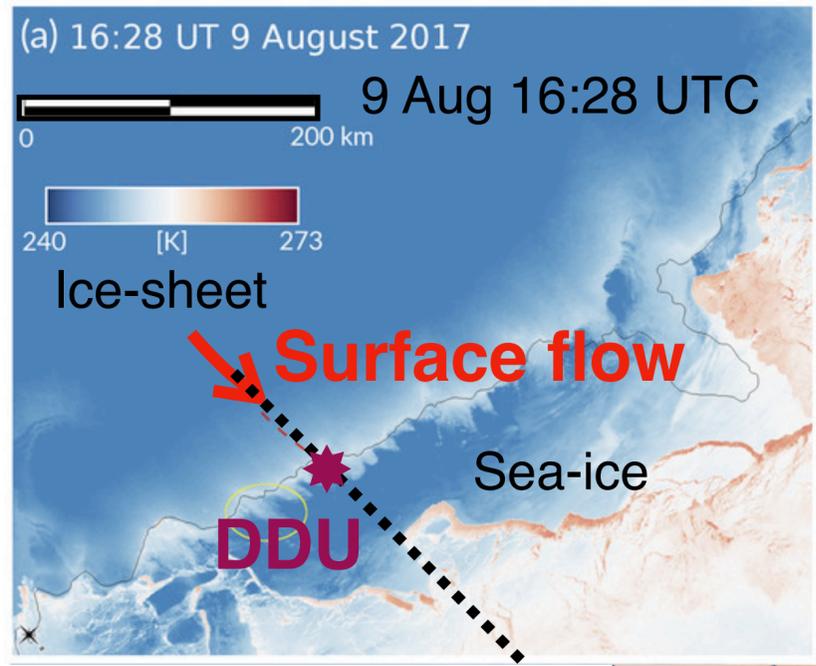
Air from inland piles-up over the stable boundary layer overlying the sea ice

⇒ **Over sea-ice : Cold air pool & Decrease in wind speed**

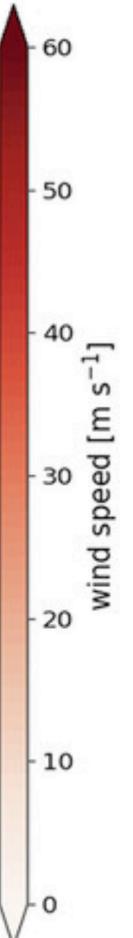
Initiation of the katabatic jump

Trapped gravity waves at the ice-sheet-ocean interface (Vignon et al. 2020)

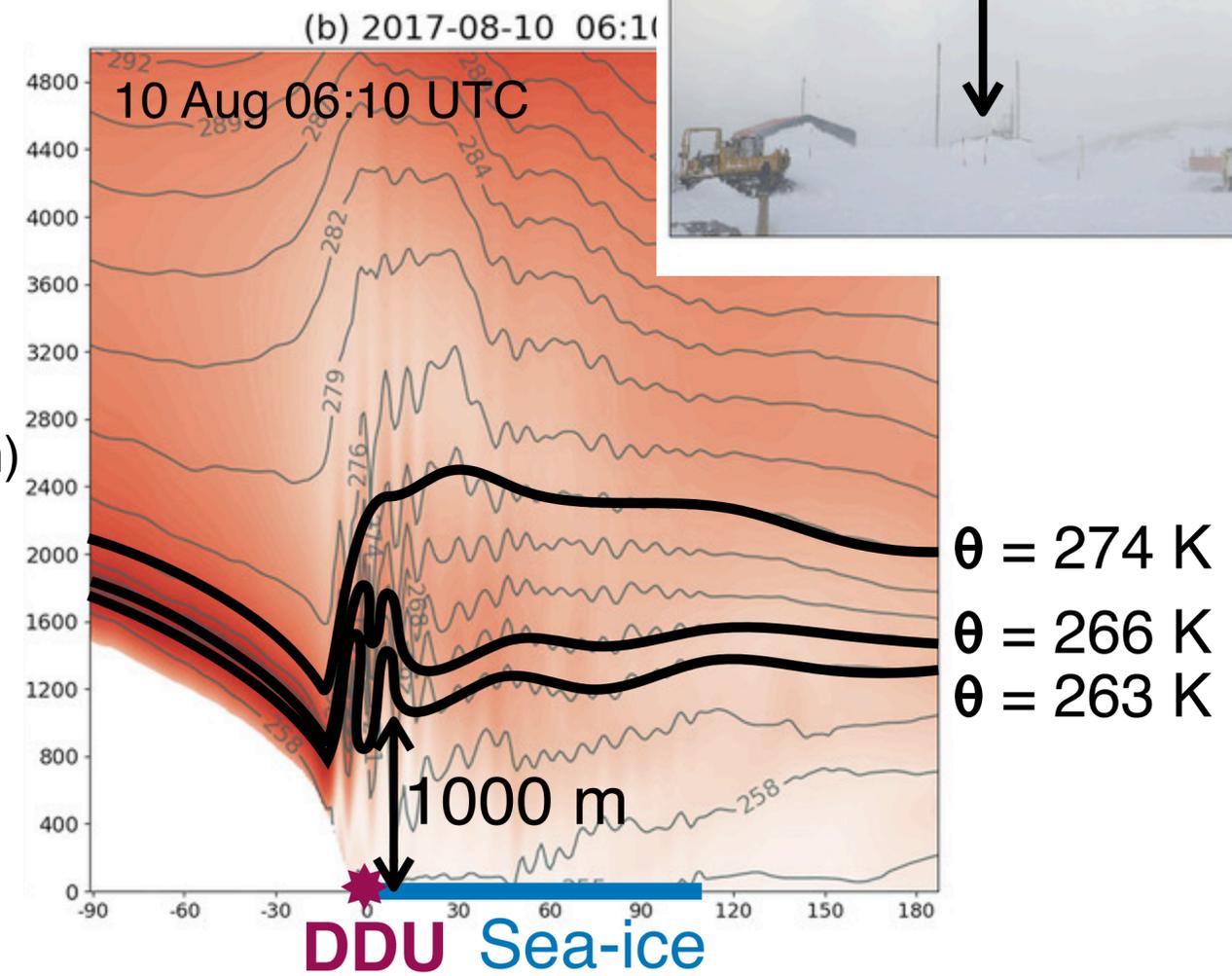
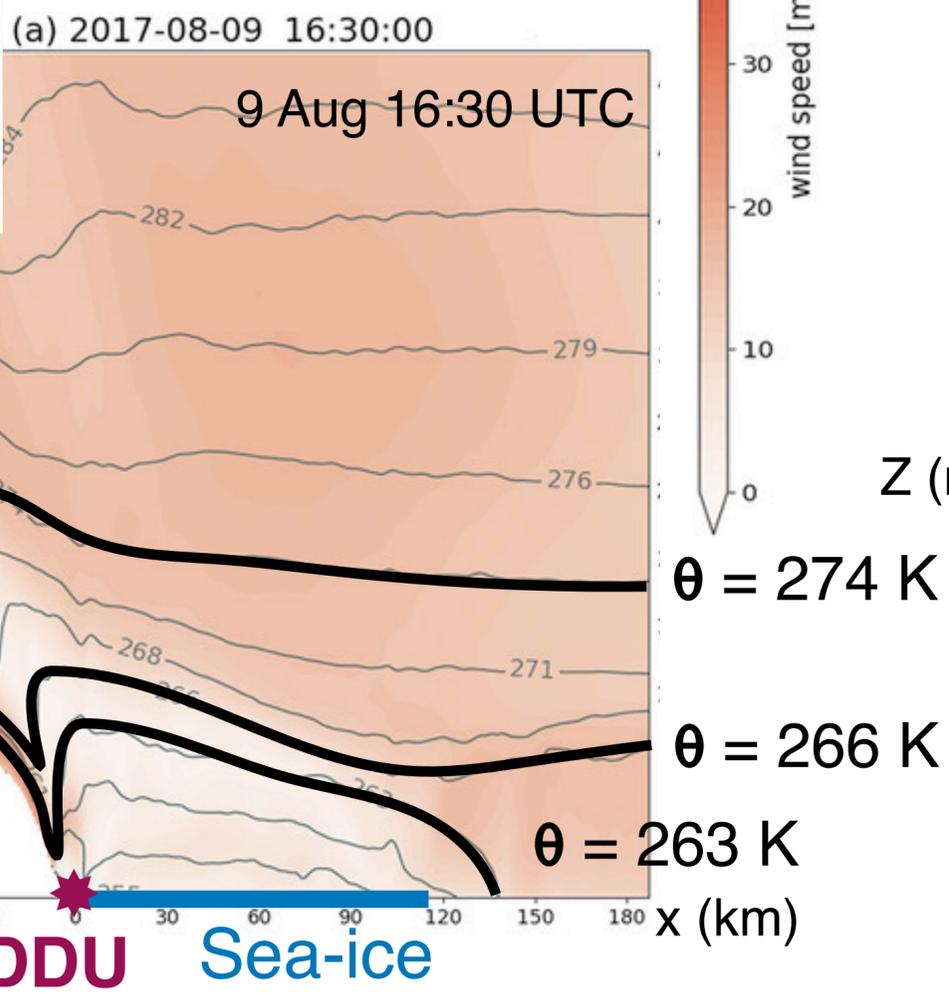
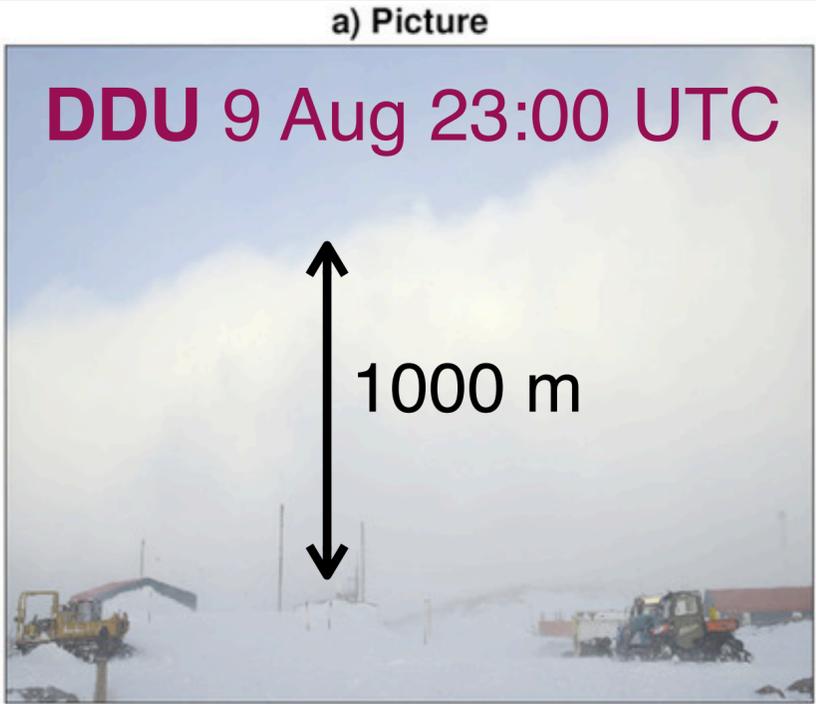
Vignon et al. 2020 : Journal of the Atmospheric Sciences 77, 4; [10.1175/JAS-D-19-0264.1](https://doi.org/10.1175/JAS-D-19-0264.1)



Wind speed
 (m s⁻¹)



2. Katabatic Jump



Trapped gravity waves at the ice-sheet-ocean interface (Vignon et al. 2020)

Vignon et al. 2020 : Journal of the Atmospheric Sciences 77, 4; [10.1175/JAS-D-19-0264.1](https://doi.org/10.1175/JAS-D-19-0264.1)

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Air from inland piles-up over the stable boundary layer overlying the sea ice

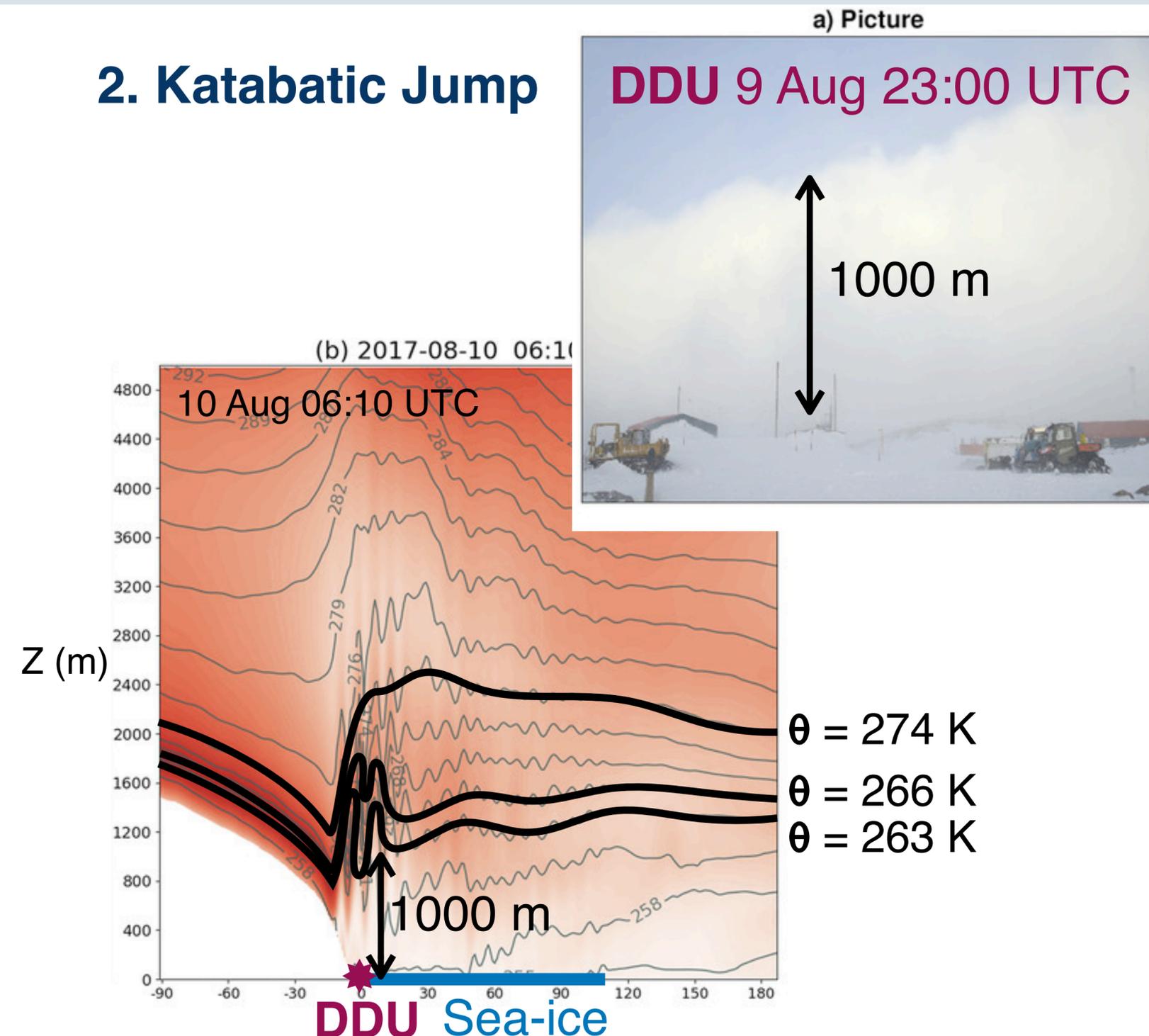
⇒ **Over sea-ice : Cold air pool & Decrease in wind speed**

Initiation of the katabatic jump

2. Katabatic Jump

- Froude number upstream: 3.5 ($Ri = 0.08$)
- Froude number downstream: 0.3 ($Ri = 11.1$)
- « **Rotor** » **mixing** : ~1000 m depth

2. Katabatic Jump



Trapped gravity waves at the ice-sheet-ocean interface (Vignon et al. 2020)

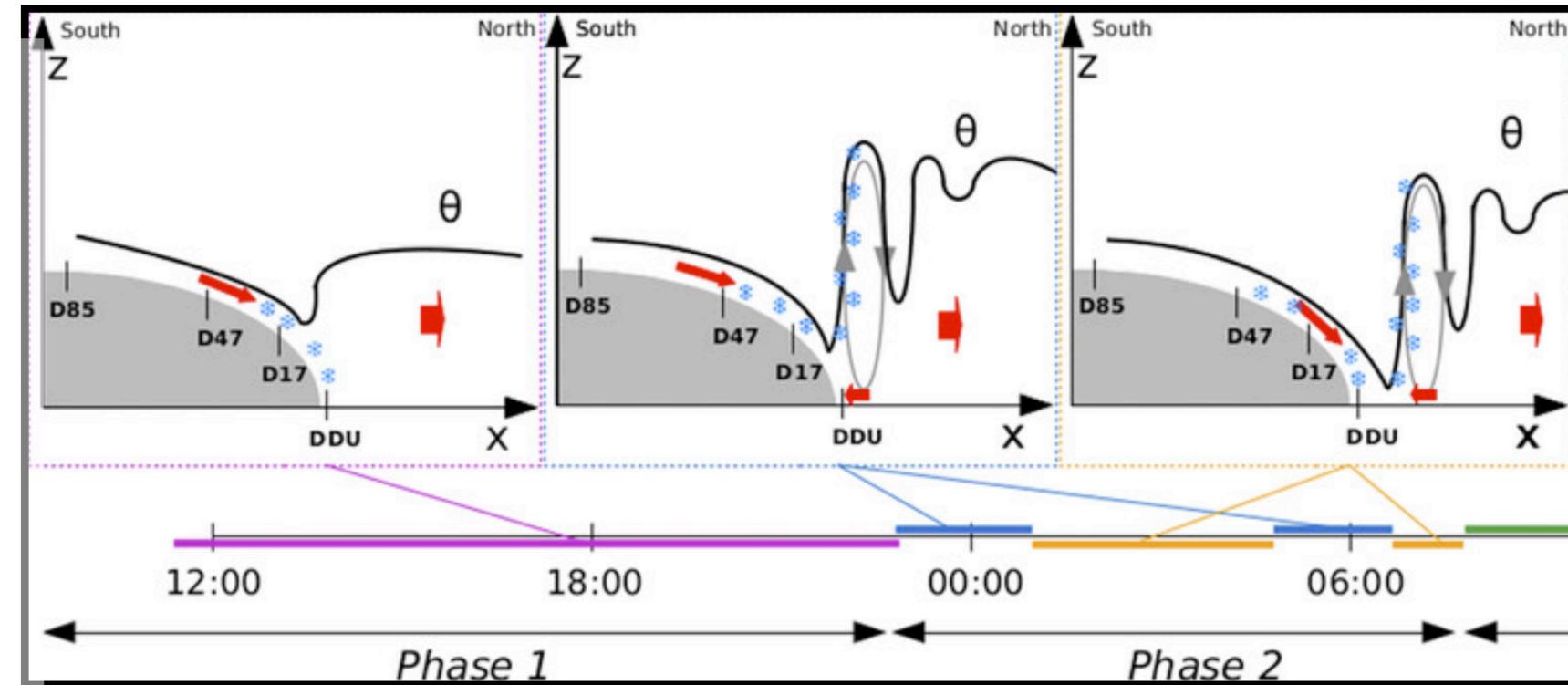
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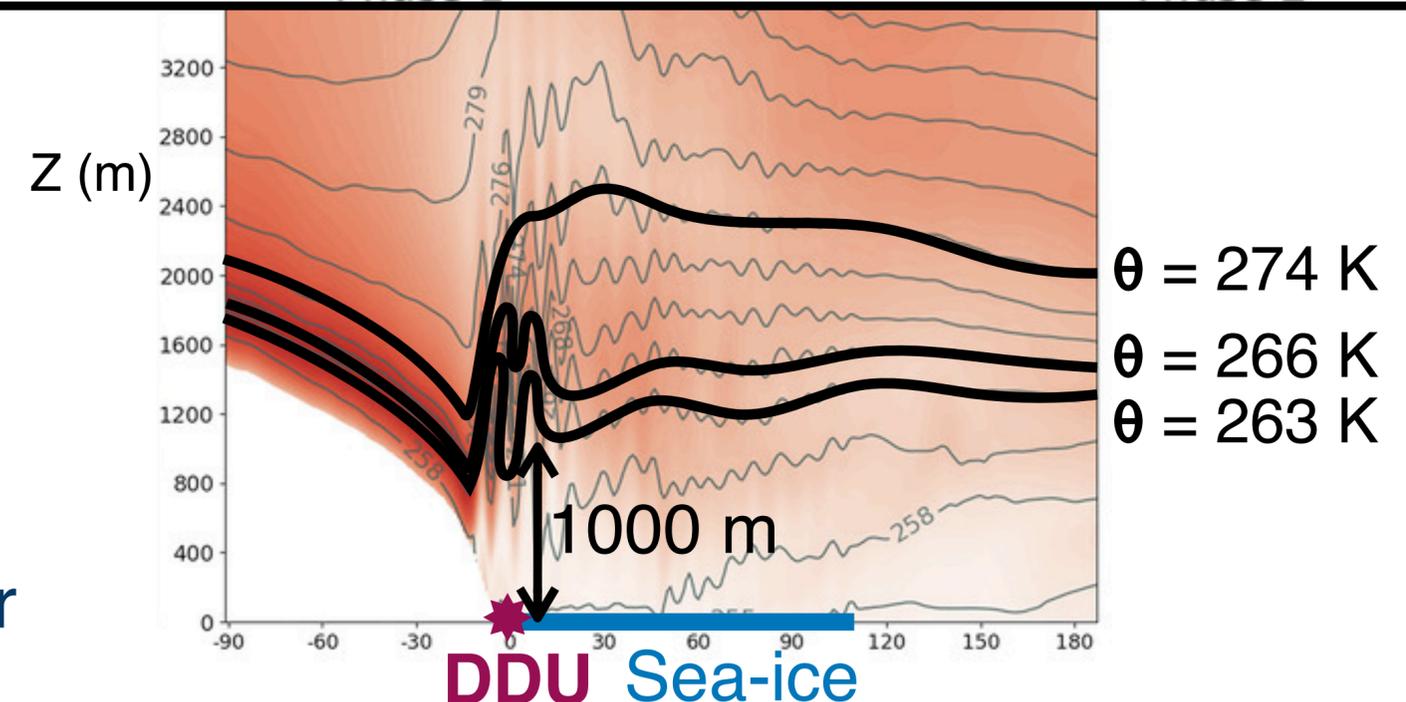
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Initiation of the katabatic jump



2. Katabatic Jump

- Froude number upstream: 3.5 ($Ri = 0.08$)
 - Froude number downstream: 0.3 ($Ri = 11.1$)
 - « **Rotor** » mixing : ~1000 m depth
- ⇒ Strong mixing of katabatic flow and upper air

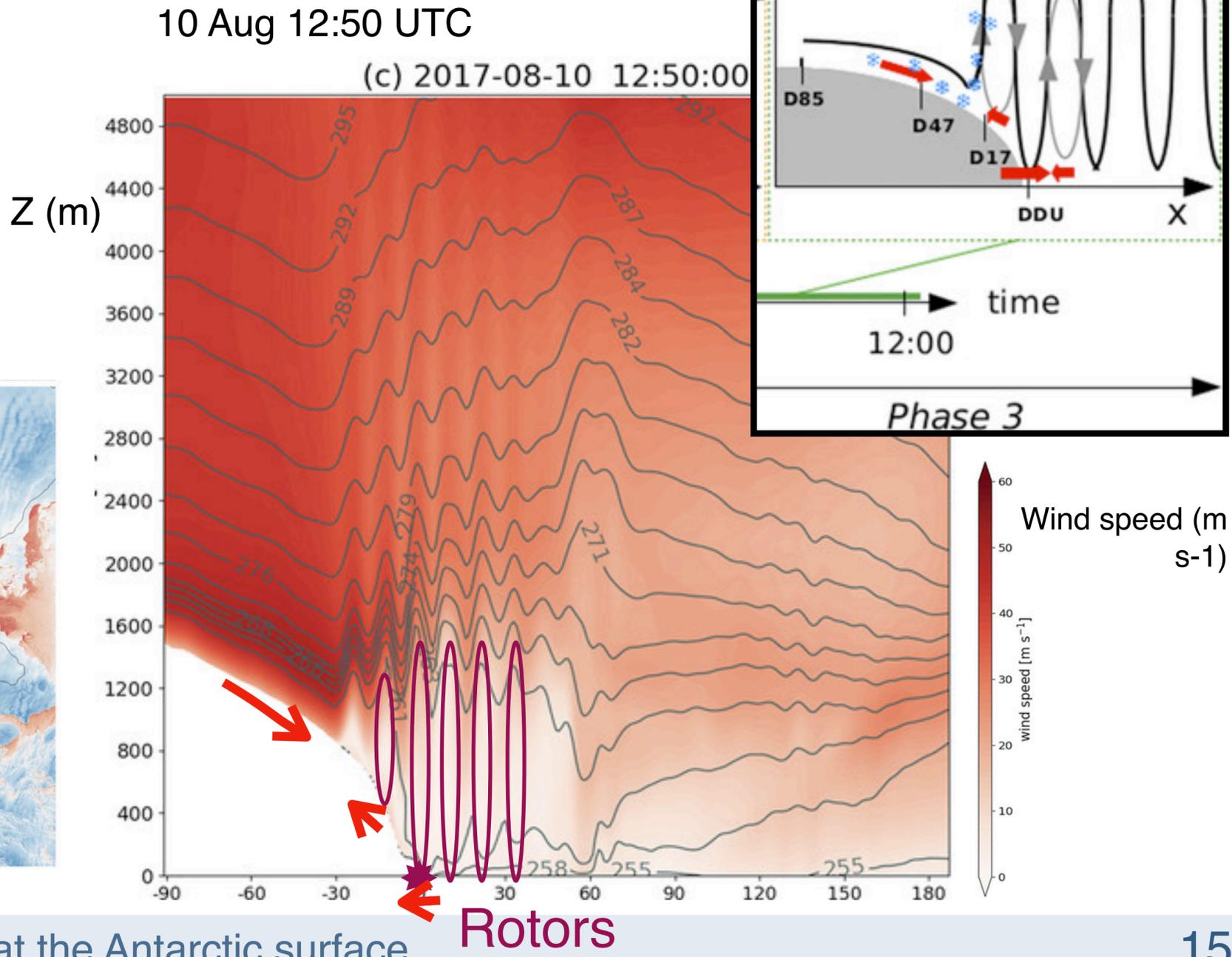
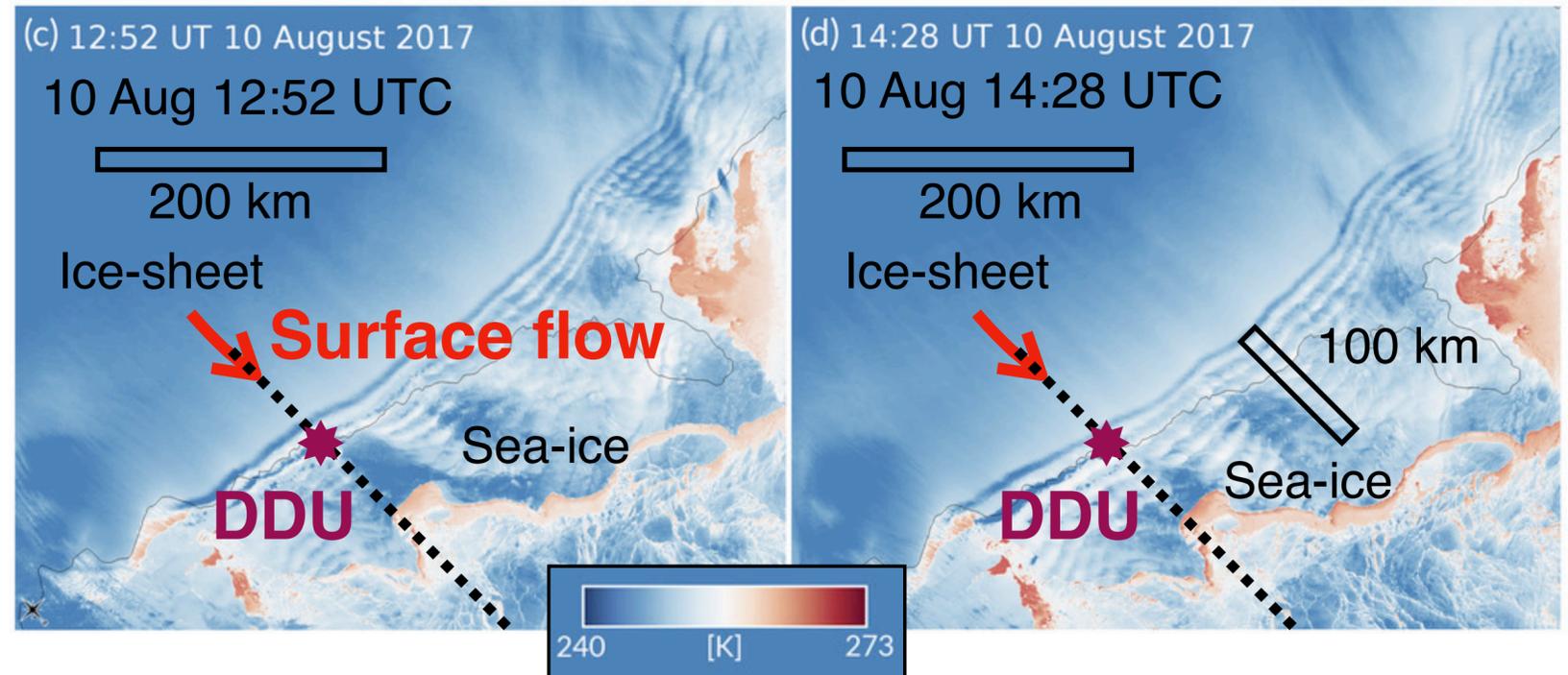


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3. Gravity wave trapping : Rotors

- **Downdraft:**
 - Adiabatic warming
 - Strong surface wind (vertical transport)
- **Wave crest:**
 - Decrease in wind speed
 - Flow reversal underneath first wave crest

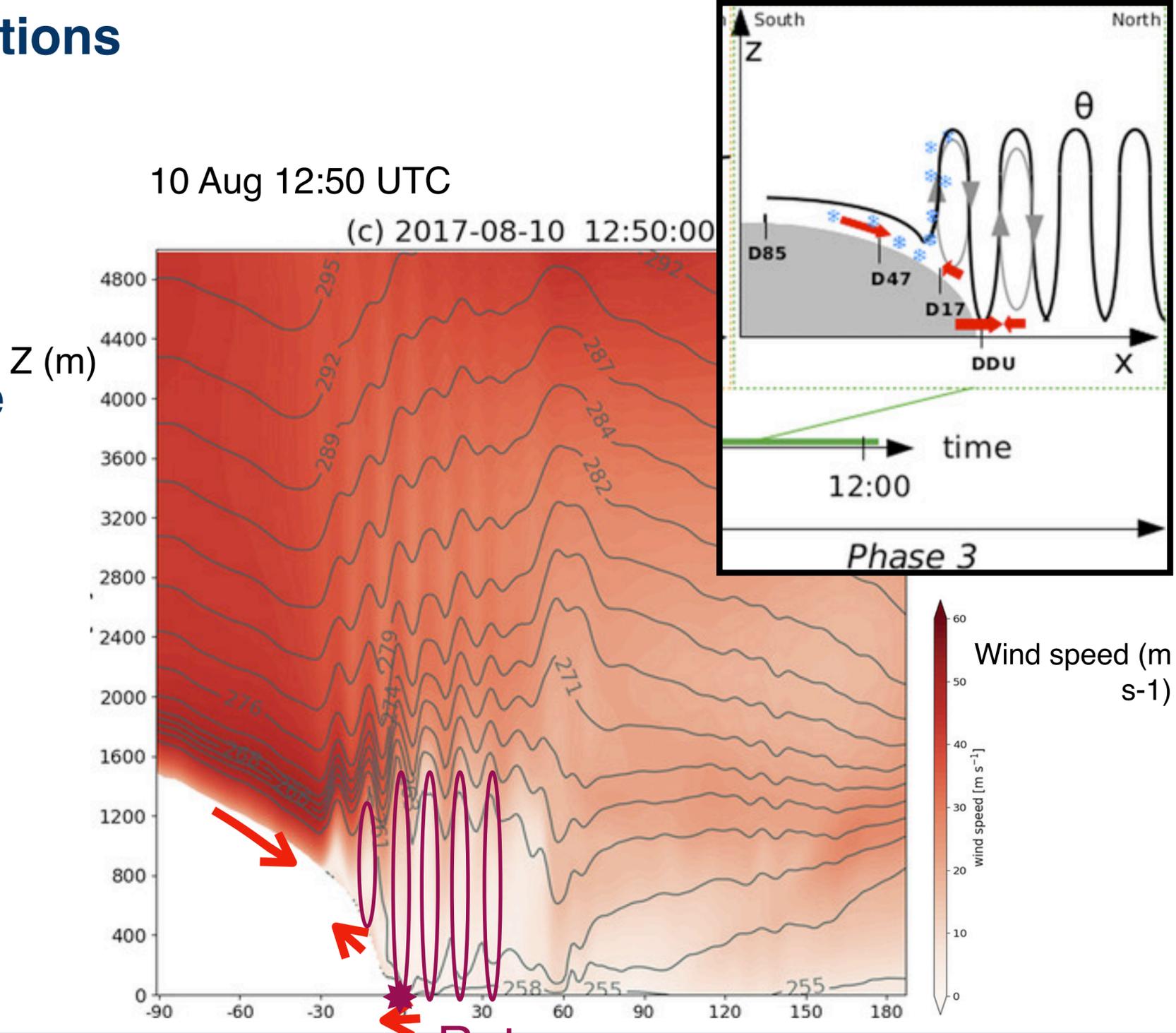
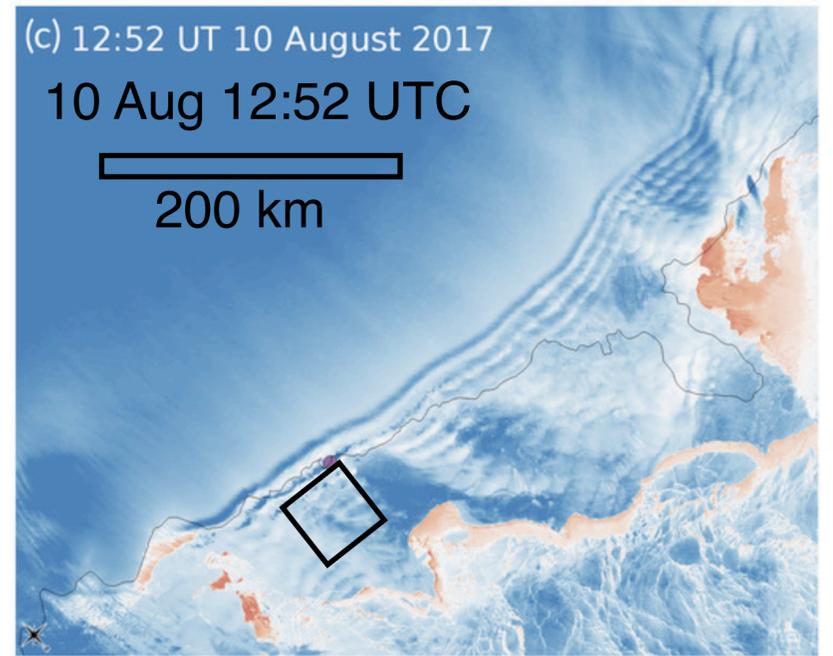


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3. Gravity wave trapping : background conditions

- Scorer parameter $S = (N^2/U^2) - (1/U)(d^2U/dz^2)$ decreases with increasing altitude
 - ⇒ wave evanescent above a turning point
 - ⇒ horizontal propagation
- Surface background flow dynamically unstable ($Ri < 0.25$) favored by katabatic jump



Trapped gravity waves at the ice-sheet-ocean interface (Vignon et al. 2020)

Vignon et al. 2020 : Journal of the Atmospheric Sciences 77, 4; [10.1175/JAS-D-19-0264.1](https://doi.org/10.1175/JAS-D-19-0264.1)

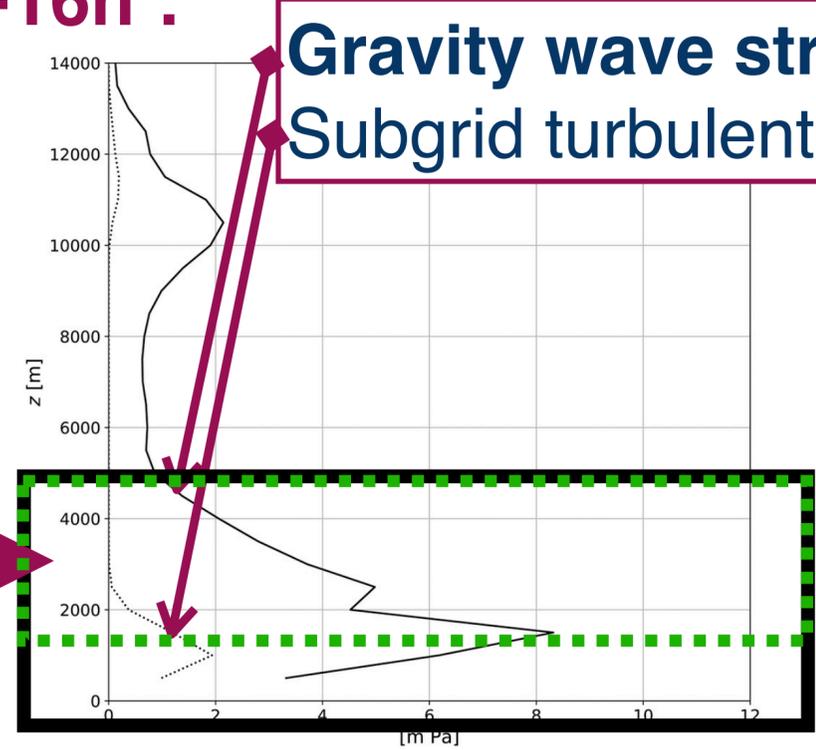
3. Gravity wave trapping : surface drag

Decay of trapped gravity waves by boundary layer dissipation

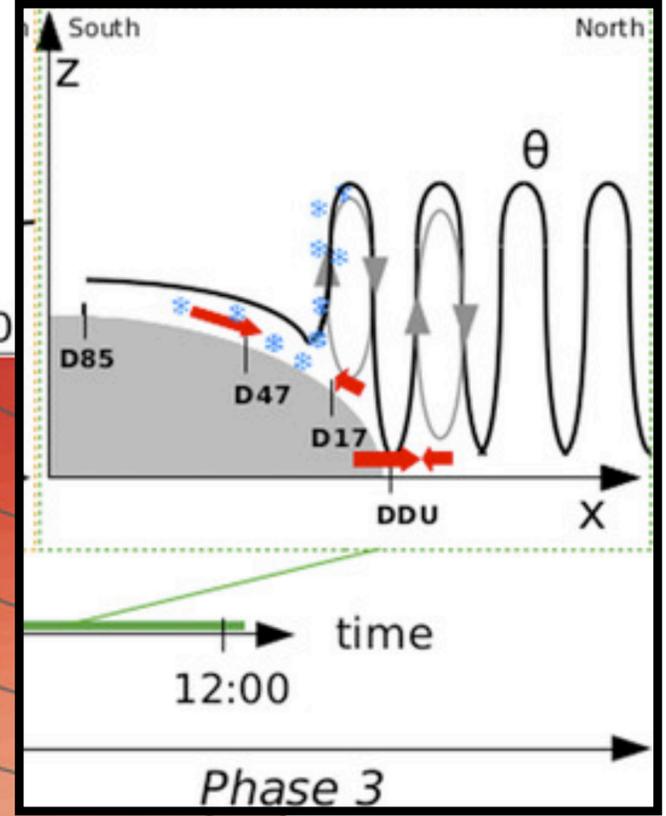
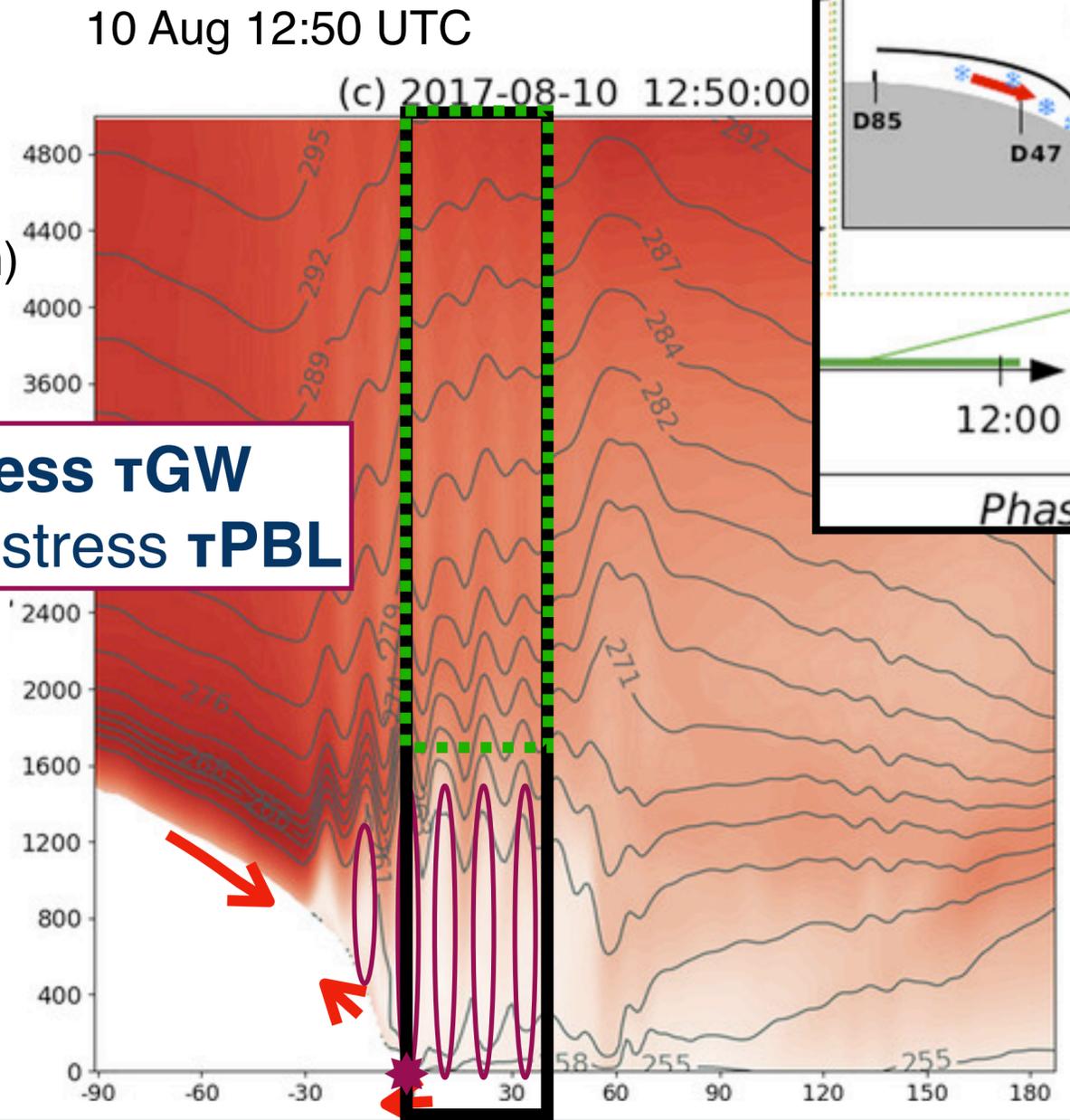
⇒ drag at low levels

⇒ substantial slow down the katabatic outflow

40 km x 40 km box, 10h-16h :



Gravity wave stress τ_{GW}
Subgrid turbulent stress τ_{PBL}



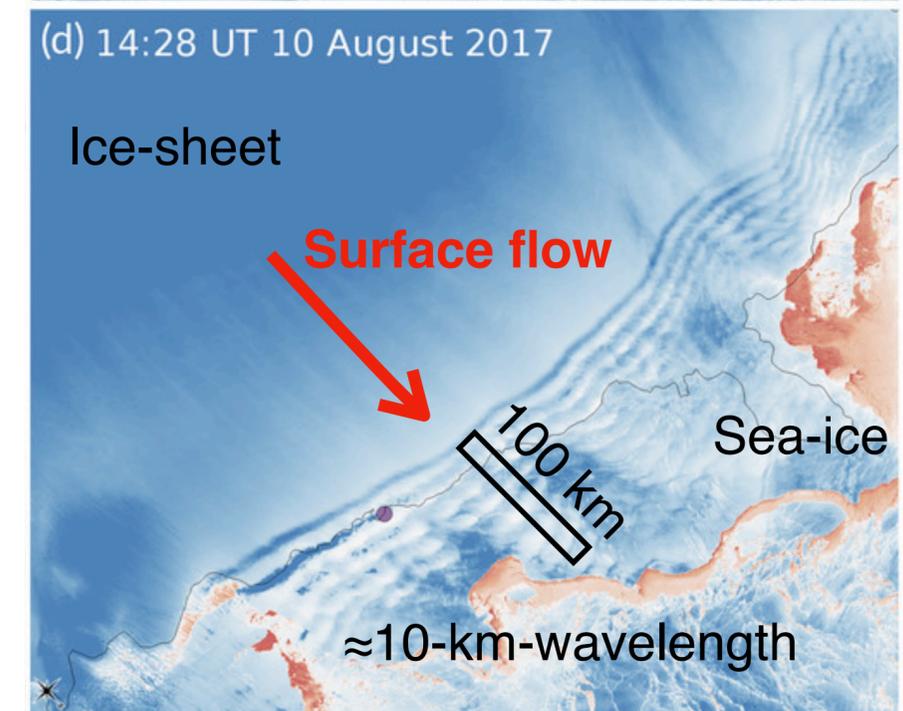
Rotors

Trapped gravity waves at the ice-sheet-ocean interface (Vignon et al. 2020)

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Background conditions for surface trapped gravity waves:

- Cold-air pool located near the foot of the slope (sea-ice cover)
- Synoptic conditions promoting supercritical downslope winds:
 - Transit of a synoptic weather system off the coast
 - And/or High pressure system over the plateau
- Abrupt change in the topography (concavity of the terrain)
 - ⇒ Sudden change in the pressure-gradient force near the foot of the slope



Conditions met over large parts of the Antarctic coast in winter (sea-ice cover).

« Best » resolution in climate models: ~30 km

⇒ **Need of parameterization for surface ocean forcing**

Recent work on mountain wave drag: e.g. Soufflet et al. 2022 ([10.1175/JAS-D-21-0263.1](https://doi.org/10.1175/JAS-D-21-0263.1))

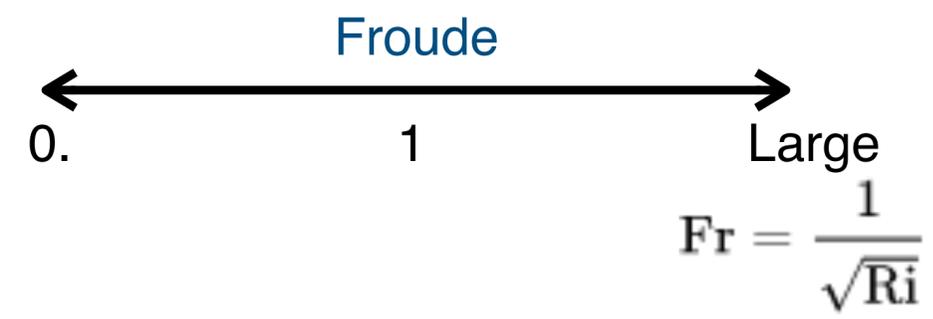
Lott et al. 2021 ([10.1175/JAS-D-20-0144.1](https://doi.org/10.1175/JAS-D-20-0144.1))

Thank you for your attention



Froude & Richardson cheat sheet

Subcritical Laminaire **Supercritical Turbulent**



$$Ri = \frac{\text{buoyancy term}}{\text{flow shear term}} = \frac{g}{\rho} \frac{\partial \rho / \partial z}{(\partial u / \partial z)^2} \quad Ri = \frac{N^2}{\left(\frac{du}{dz}\right)^2}$$

