Polar storms and polar jets: Mesoscale weather systems in the Arctic & Antarctic

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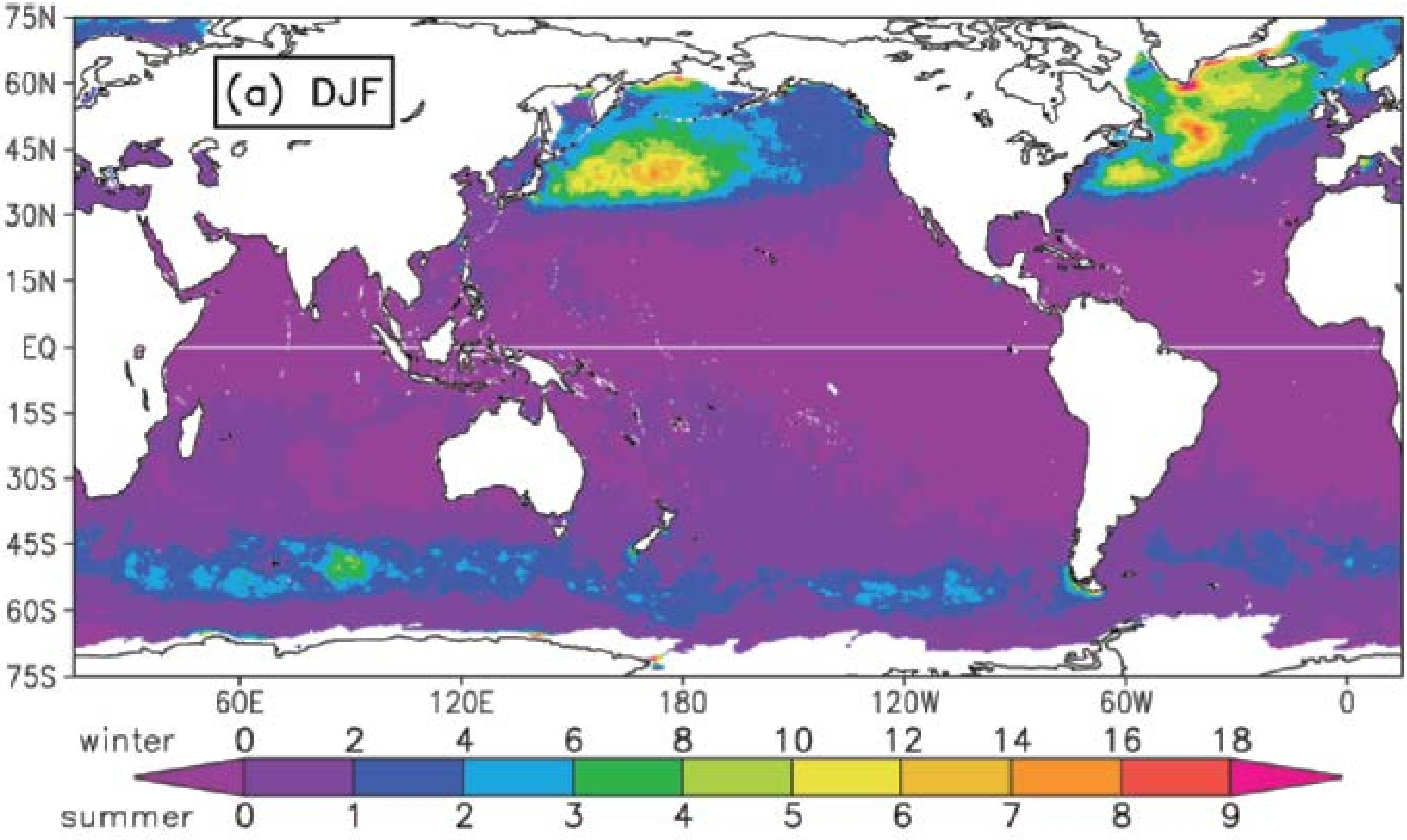
ECMWF-WWRP/Thorpex Polar Prediction Workshop – 24-27 June 2013

Outline

University of East Anglia

- Introduction: global wind climatologies
- Mesoscale jets in the polar regions
  - Tip jets
  - Barrier winds
  - Katabatic winds
  - Gap flows
  - Polar foehn jets
- Polar mesoscale cyclones

A global climatology of oceanic high wind speed events (> 20 m/s)



From: Sampe and Xie 2008 (BAMS): Mapping high sea winds from space – a global climatology

Table 1. Top 10 lists for frequent high winds, for (a) the annual mean, (b) DJF, and (c) JJA seasons. Red and blue colors indicate high-wind spots due to SST frontal and orographic effects, respectively. Shading indicates regions close to sea ice edges where valid wind data are relatively few.

(a) Annual

	Frequency (%)	Position	Name
1	16.4	59°N, 43°W	Cape Farewell, Greenland
2	11.6	65°S, 52°E	Enderby land, Antarctica
3	11.5	65°N, 36°W	East coast of Greenland
4	10.3	68°N, 22°W	Denmark Strait
5	10.0	55°S, 3°E	Bouvet Island, South Atlantic
6	7.9	47°S, 86°E	South Indian Ocean
7	7.6	45°S, 76°E	Northeast of Kerguelen Island, south Indian Ocean
8	7.5	56°S, 68°W	Cape Horn
9	6.9	51°N, 44°W	North Atlantic
10	5.9	43°S, 64°E	Northwest of Kerguelen Island, south Indian Ocean

Top 4 stormiest places in world ocean have orographic influence
All around 60-70 degrees N/S

From: Sampe and Xie 2008 (BAMS): Mapping high sea winds from space – a global climatology

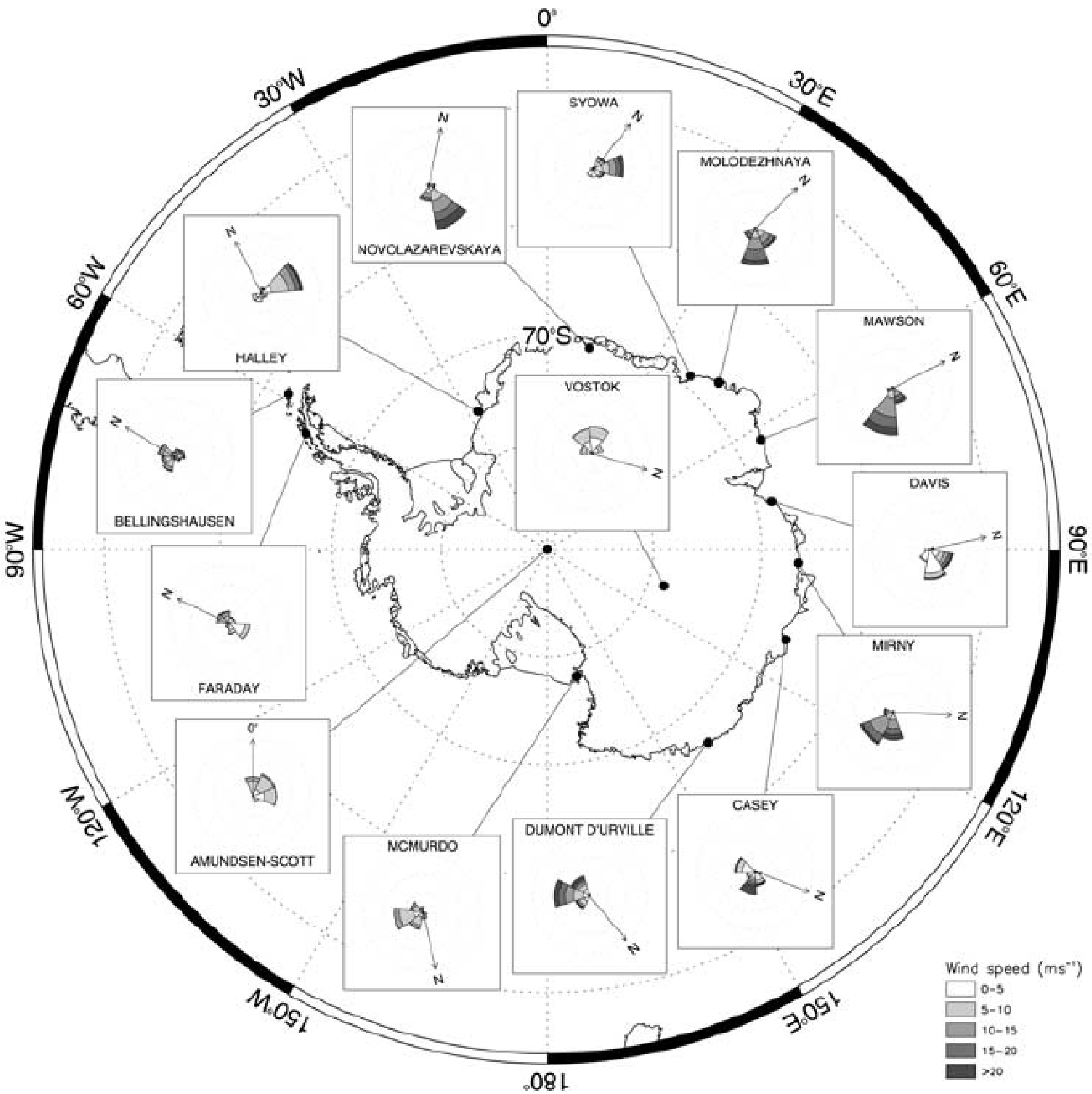
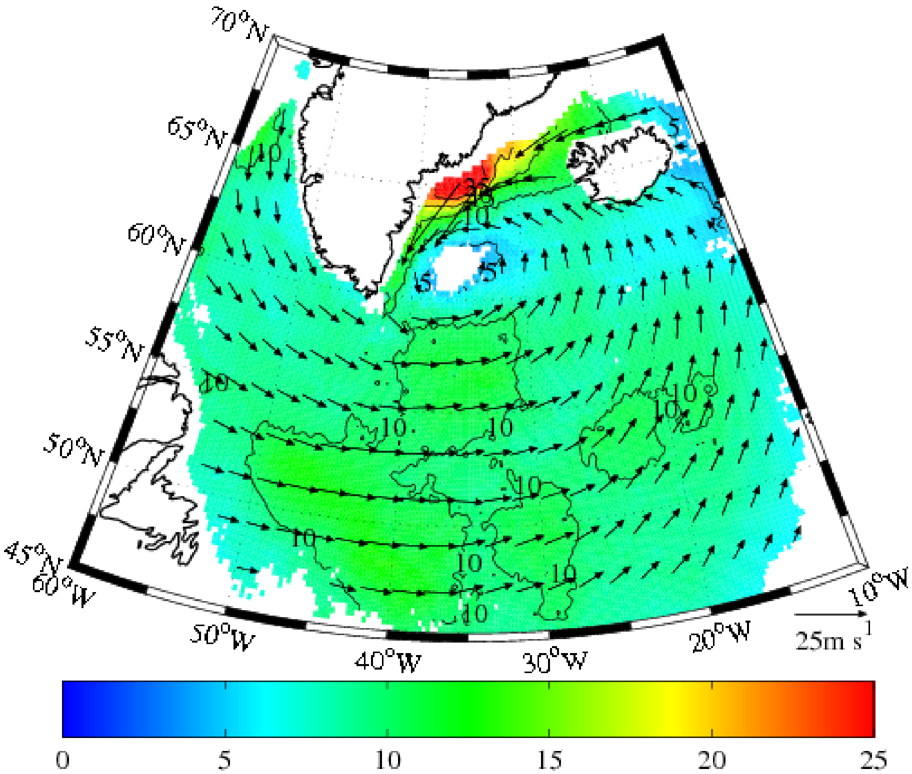


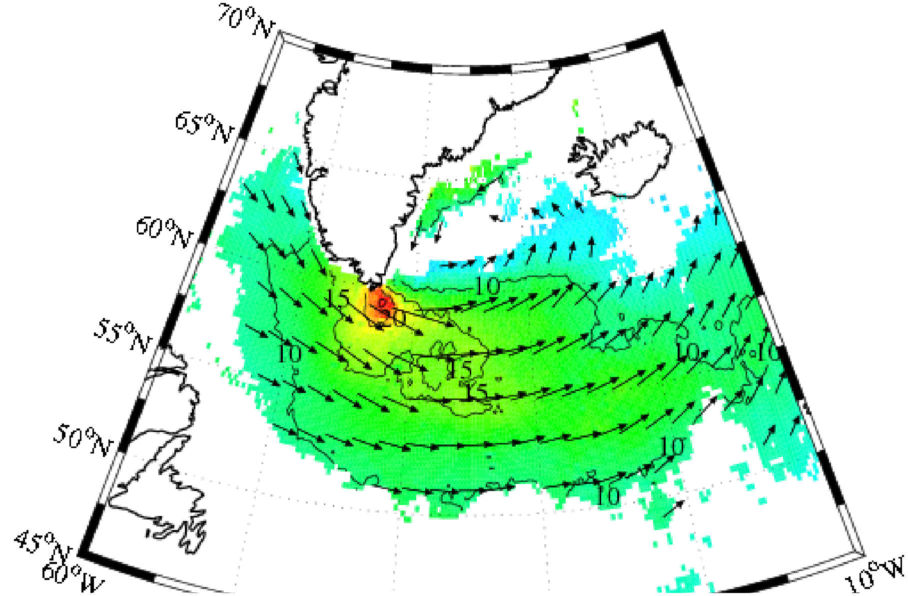
Figure 3a. Winter wind roses for the stations referred to in this study. Each wind rose is oriented so that north (0° for Amundsen-Scott) is aligned with the north (0°) direction at the relevant station (shown as a black dot). The dashed concentric rings on the wind roses show observation frequencies with a 25% interval.

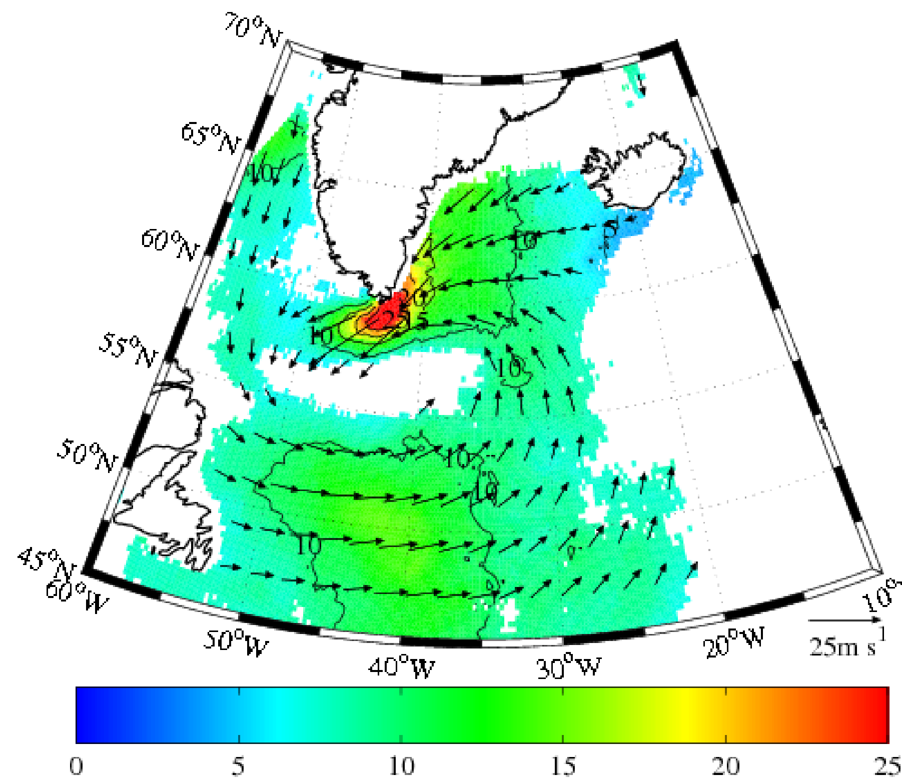
QuikSCAT climatology

- Tip Jets
- Barrier Winds



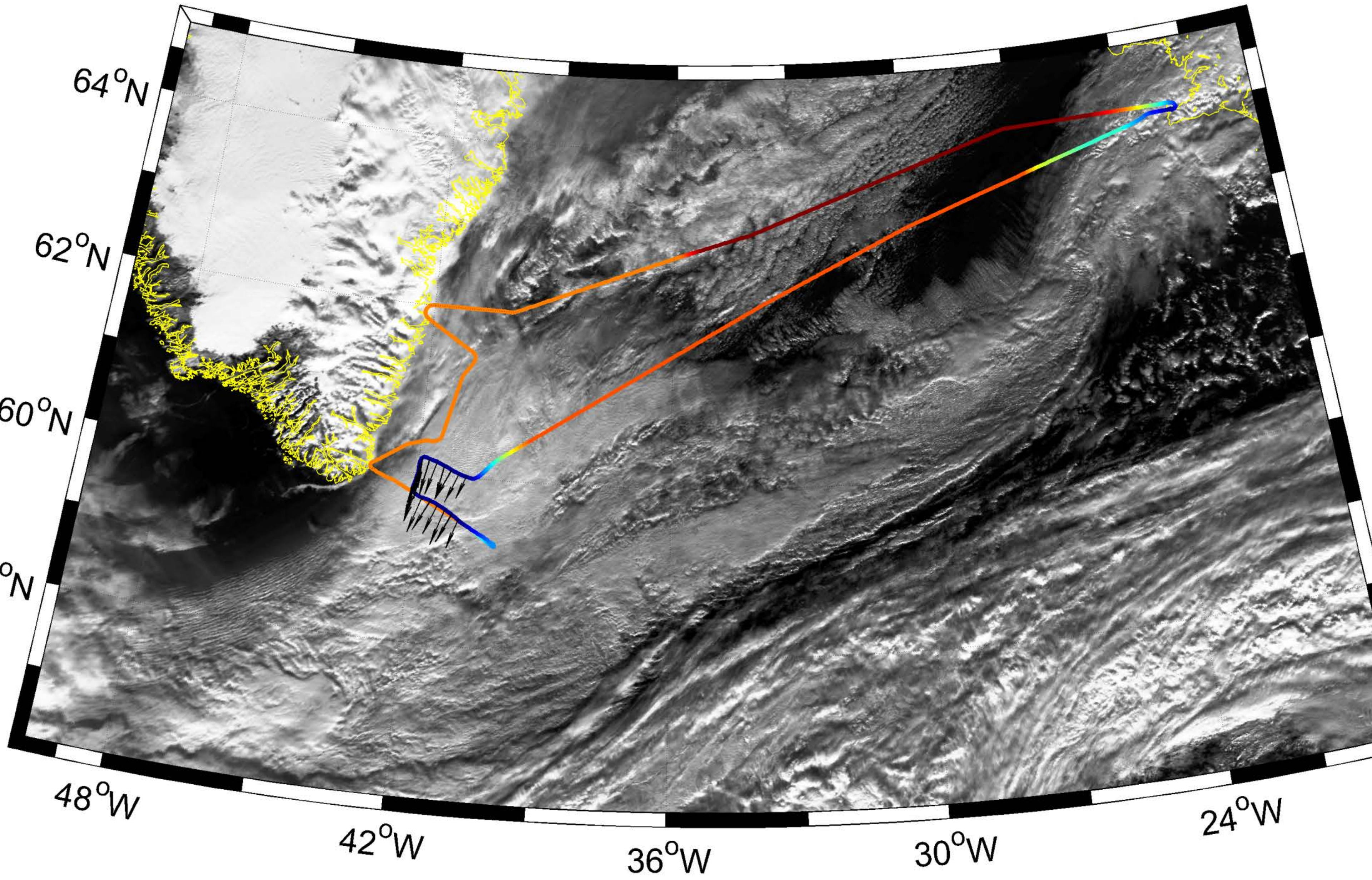
Moore and Renfrew 2005, J. Climate



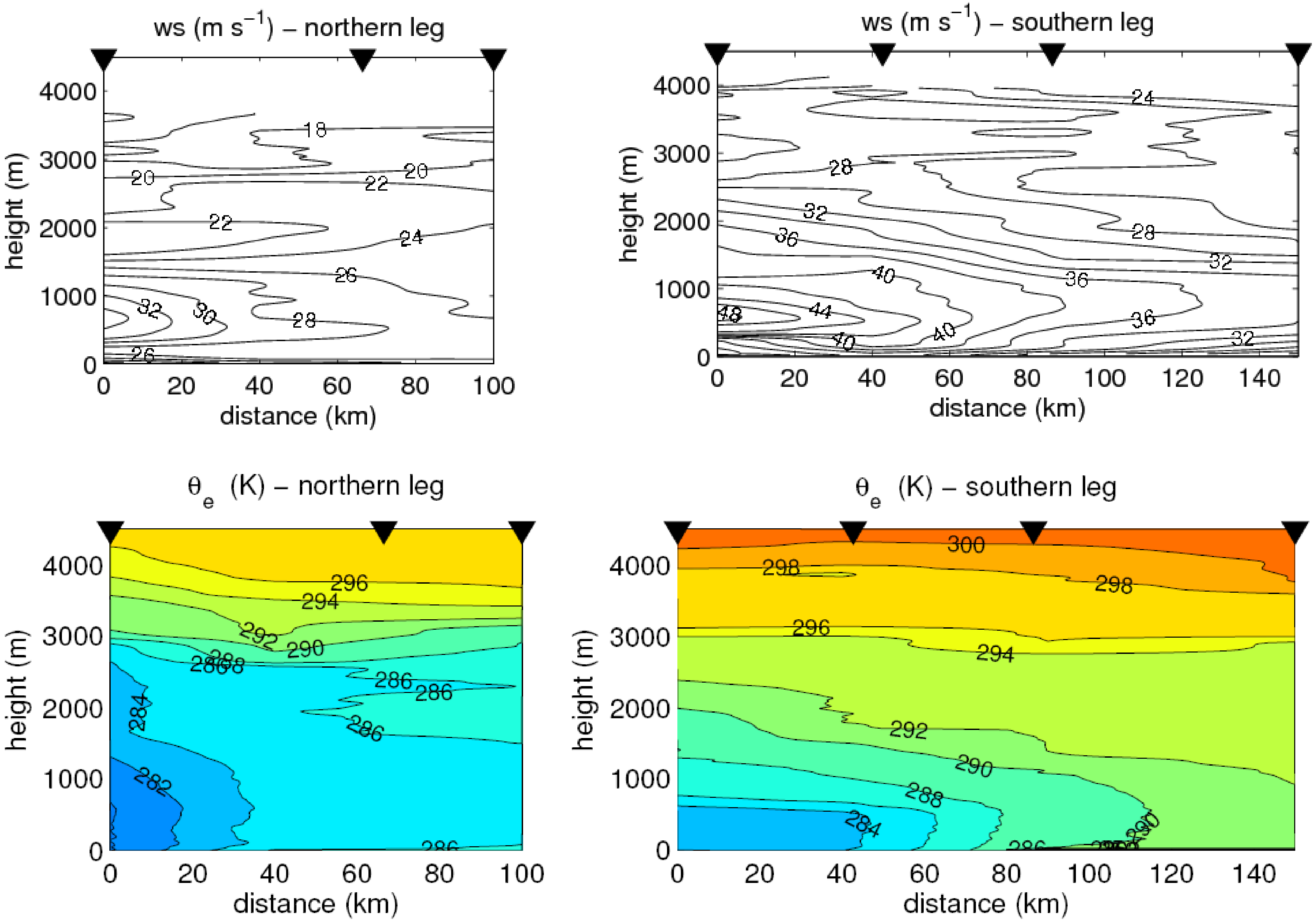


- Field programme: 17 Feb – 12 March 2007
- Detachment: Keflavik, Iceland
- 62 flight hours + 9 hours (EUFAR)

Greenland Flow Distortion experiment



From: Renfrew et al. 2008, Bulletin Amer Met Soc



From: Renfrew, Outten & Moore, 2009

Numerical Simulation:

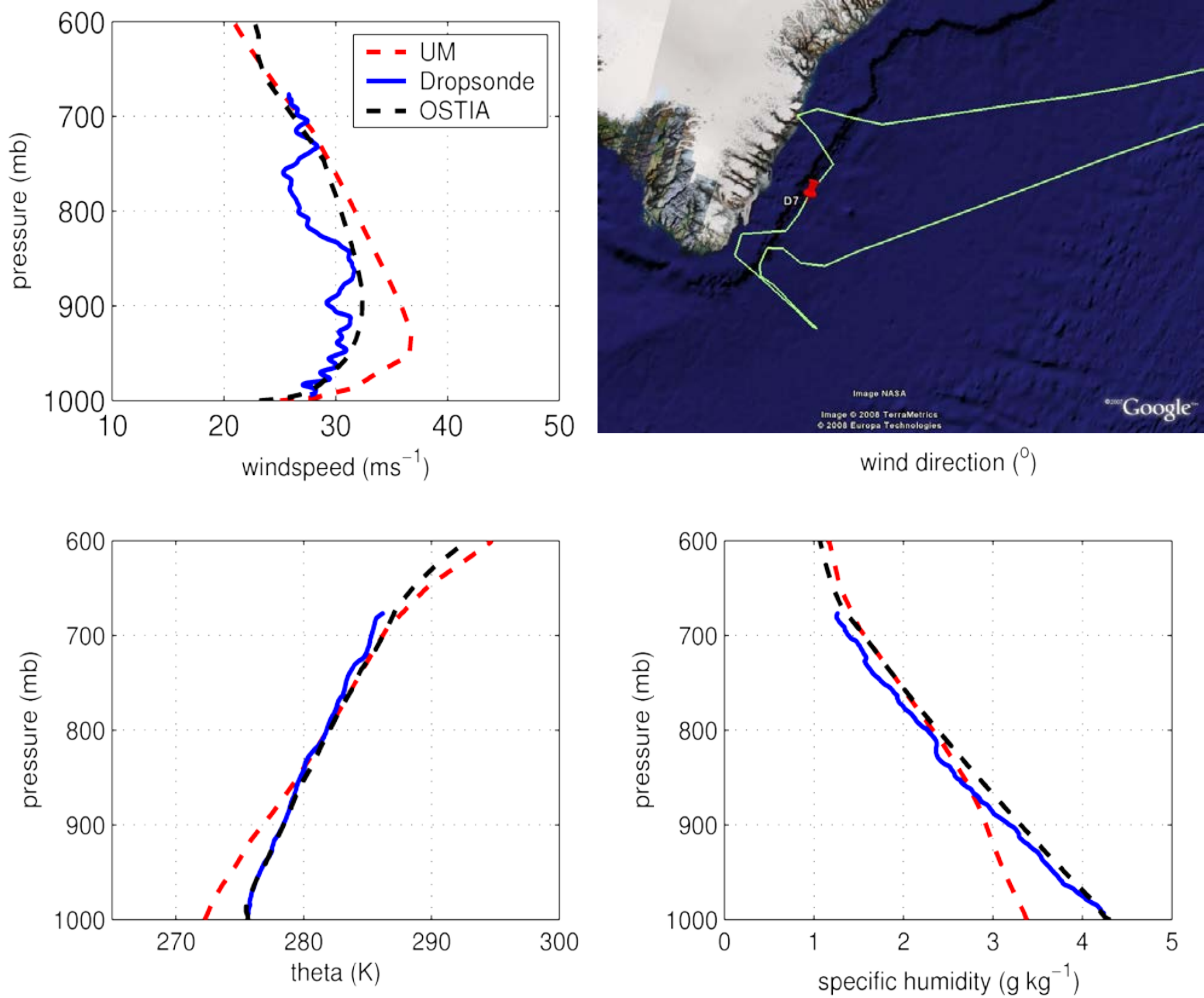
- Met Office UM 6.1
- 12 km grid & 76 levels
- Initialised from Met Office global analyses

Configuration changes:

- z_0 over marginal ice zone changed 100mm → 0.5mm
- z_0 over sea ice changed 3mm → 0.5mm
- OSTIA high resolution SST & sea-ice field

Reasonably accurate simulation:

- 1-2 K and 2-3 m s^{-1} in ABL



Renfrew, Outten and Moore, 2009: I Aircraft observations
Outten, Renfrew and Petersen, 2009: II Simulations and Dynamics
+ Erratum…

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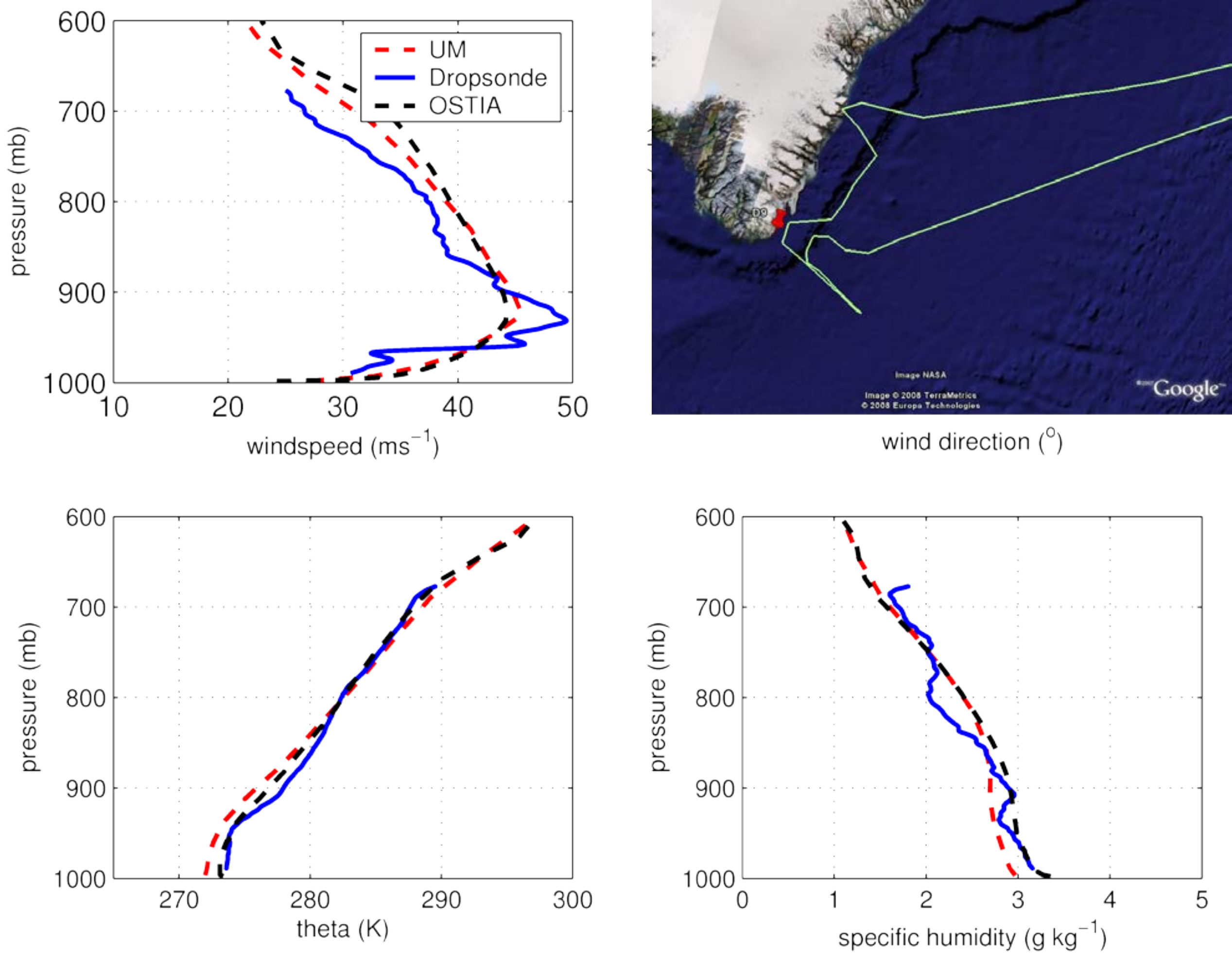

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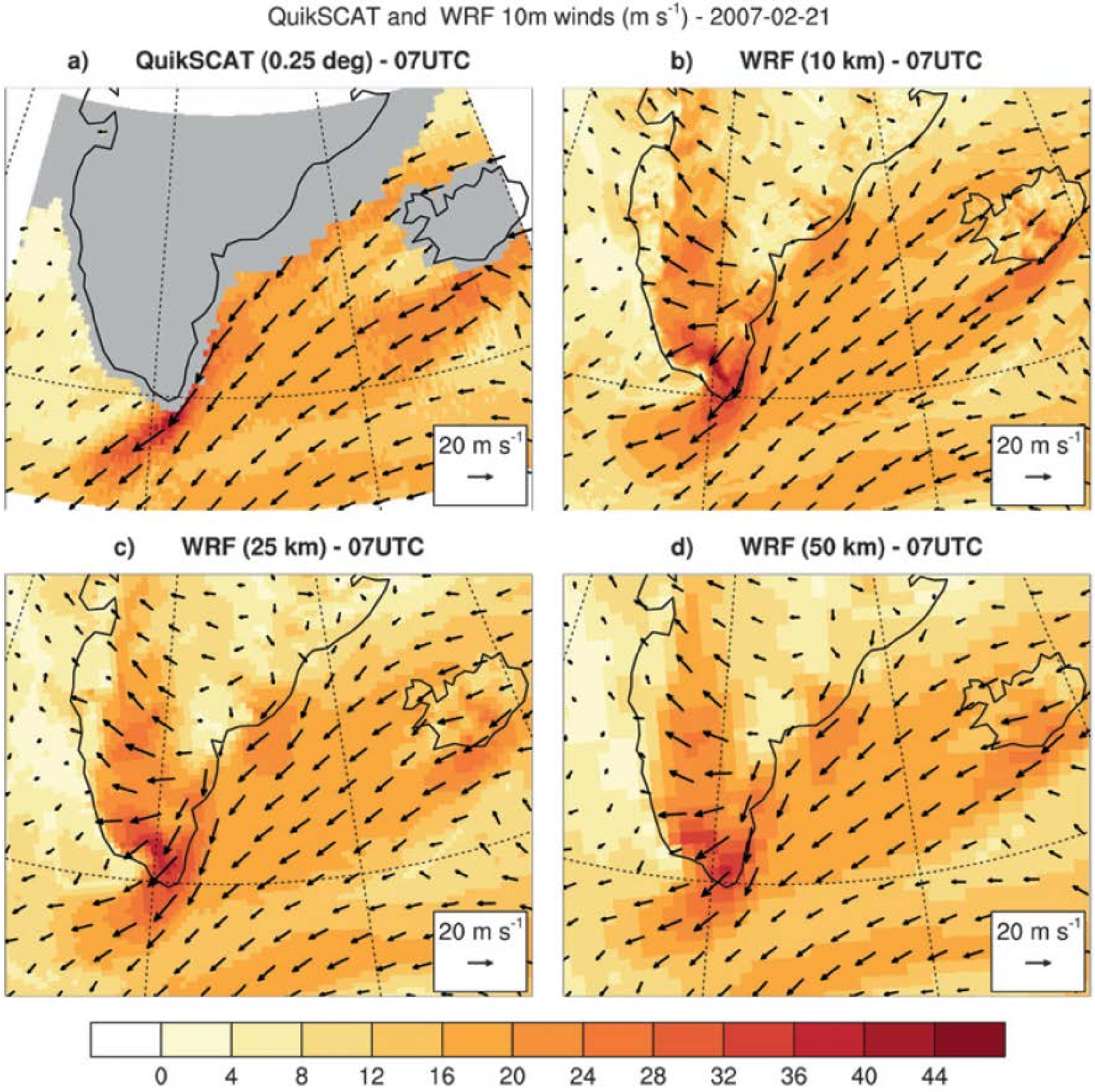
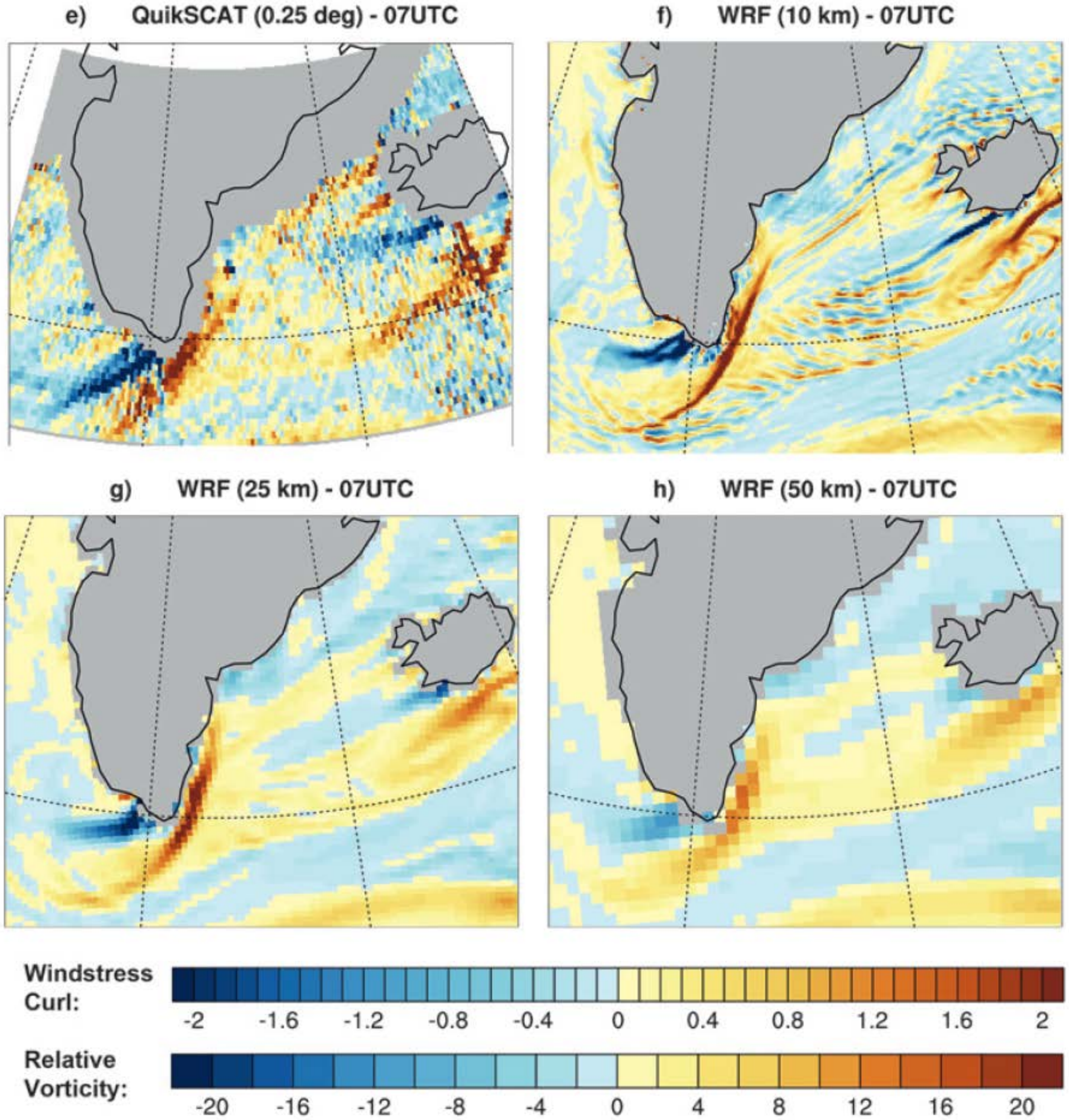
Renfrew, Outten and Moore, 2009: I Aircraft observations
Outten, Renfrew and Petersen, 2009: II Simulations and Dynamics
+ Erratum…

What model resolution is required?



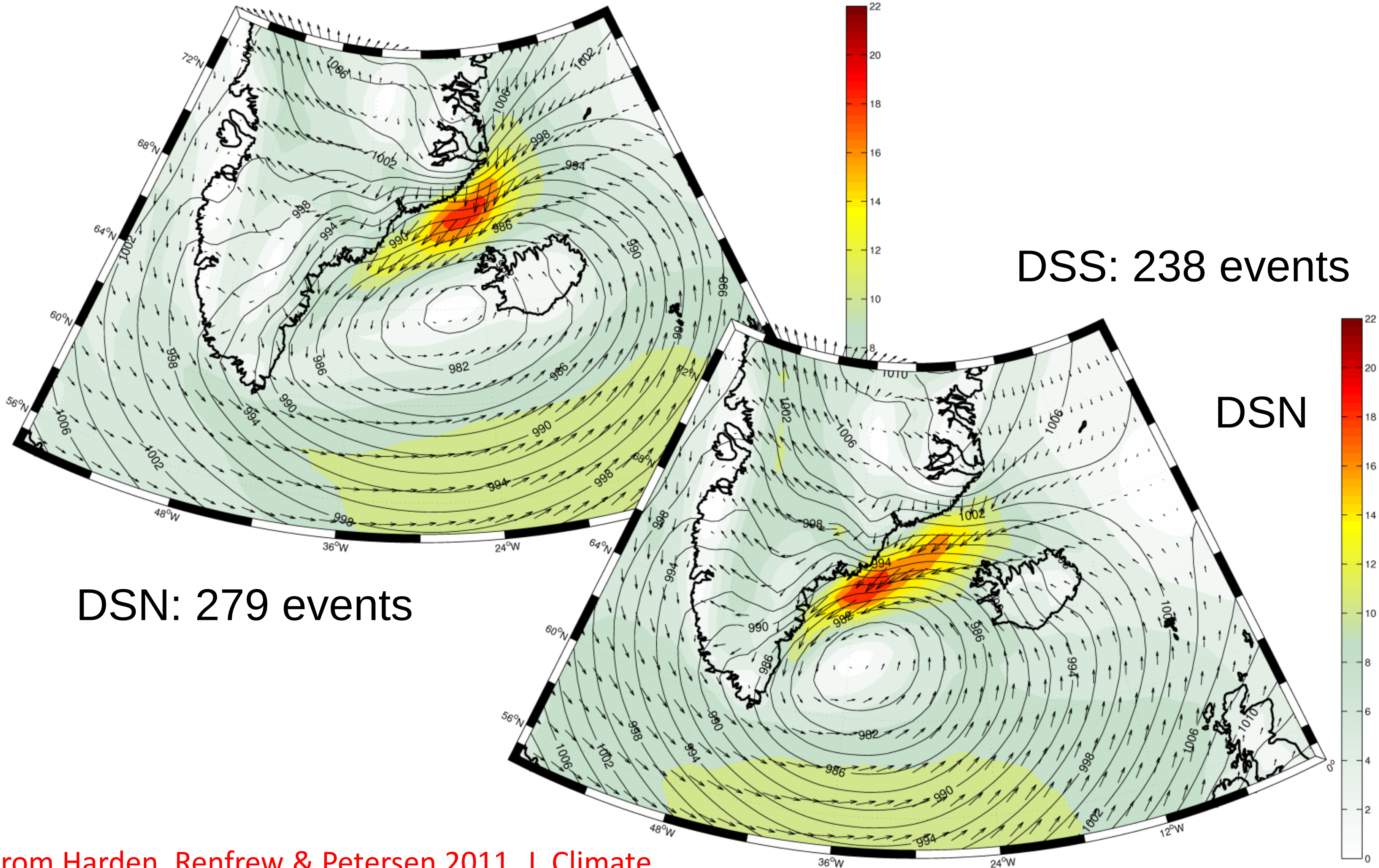
All 40L

From: DuVivier and Cassano, 2013, Mon Wea Rev, "Evaluation of WRF Model Resolution on Simulated Mesoscale Winds and Surface Fluxes near Greenland"



From: DuVivier and Cassano, 2013, Mon Wea Rev, “Evaluation of WRF Model Resolution on Simulated Mesoscale Winds and Surface Fluxes near Greenland”

ERAI BW climatology: Synoptic control



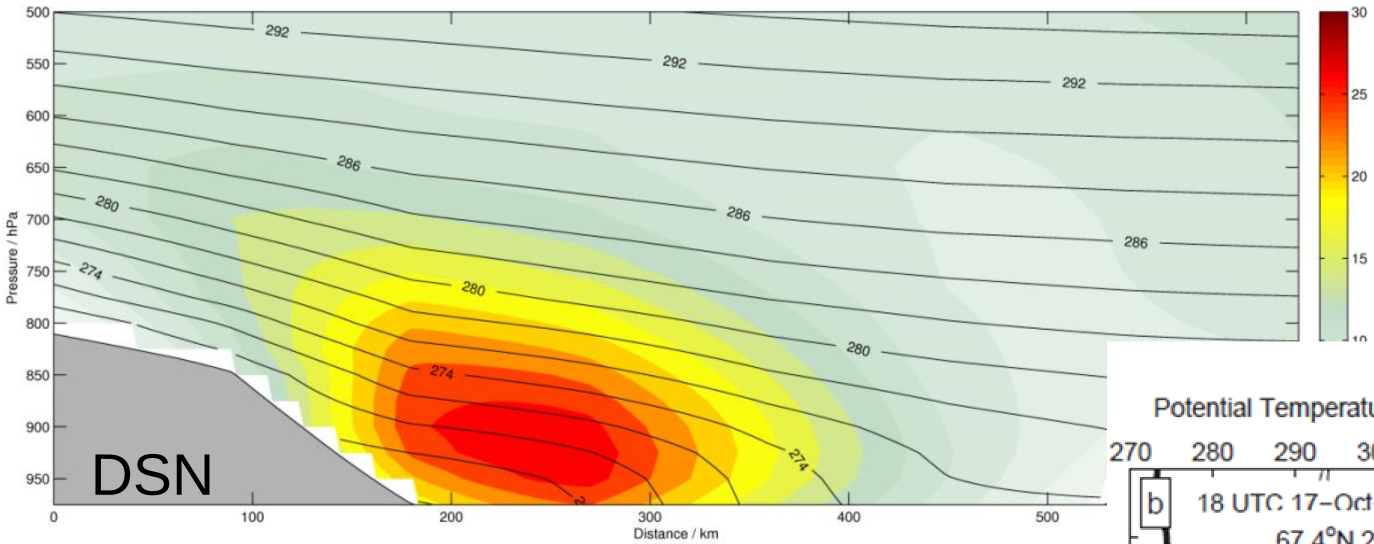
DSS: 238 events

DSN

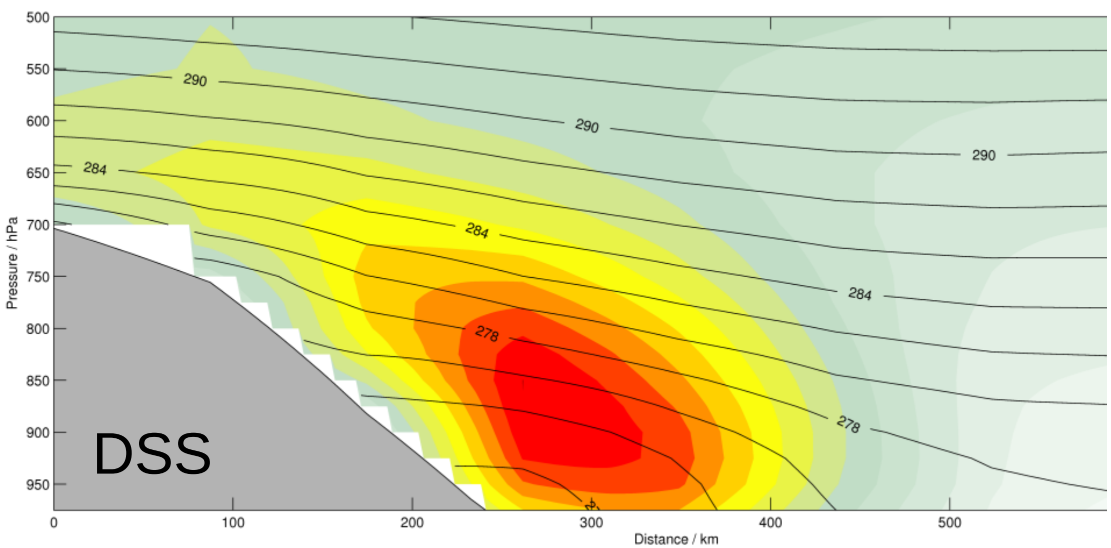
DSN: 279 events

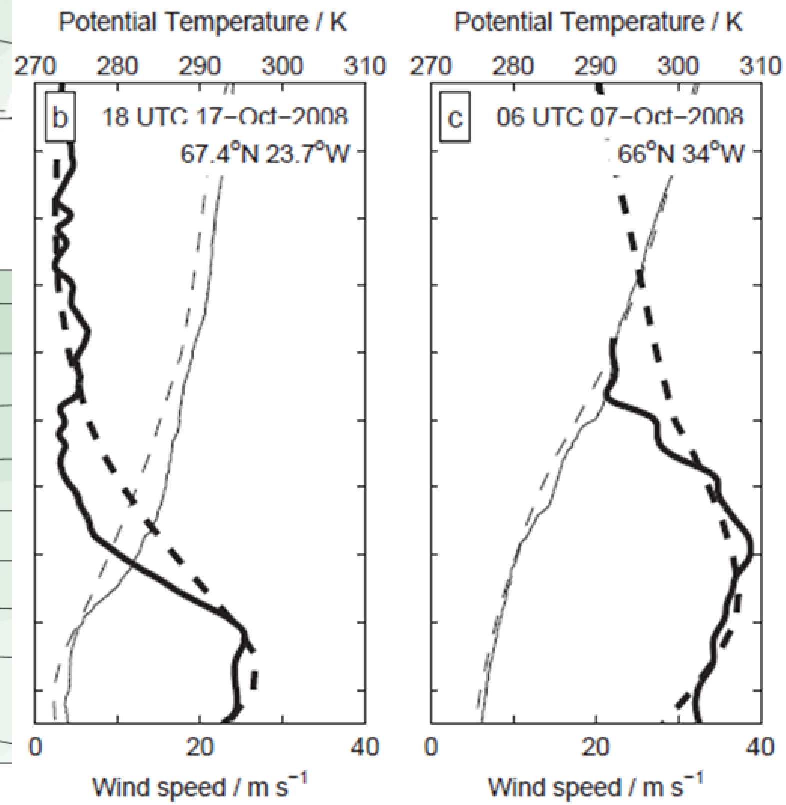
From Harden, Renfrew & Petersen 2011, J. Climate

ERAI Barrier Wind cross sections

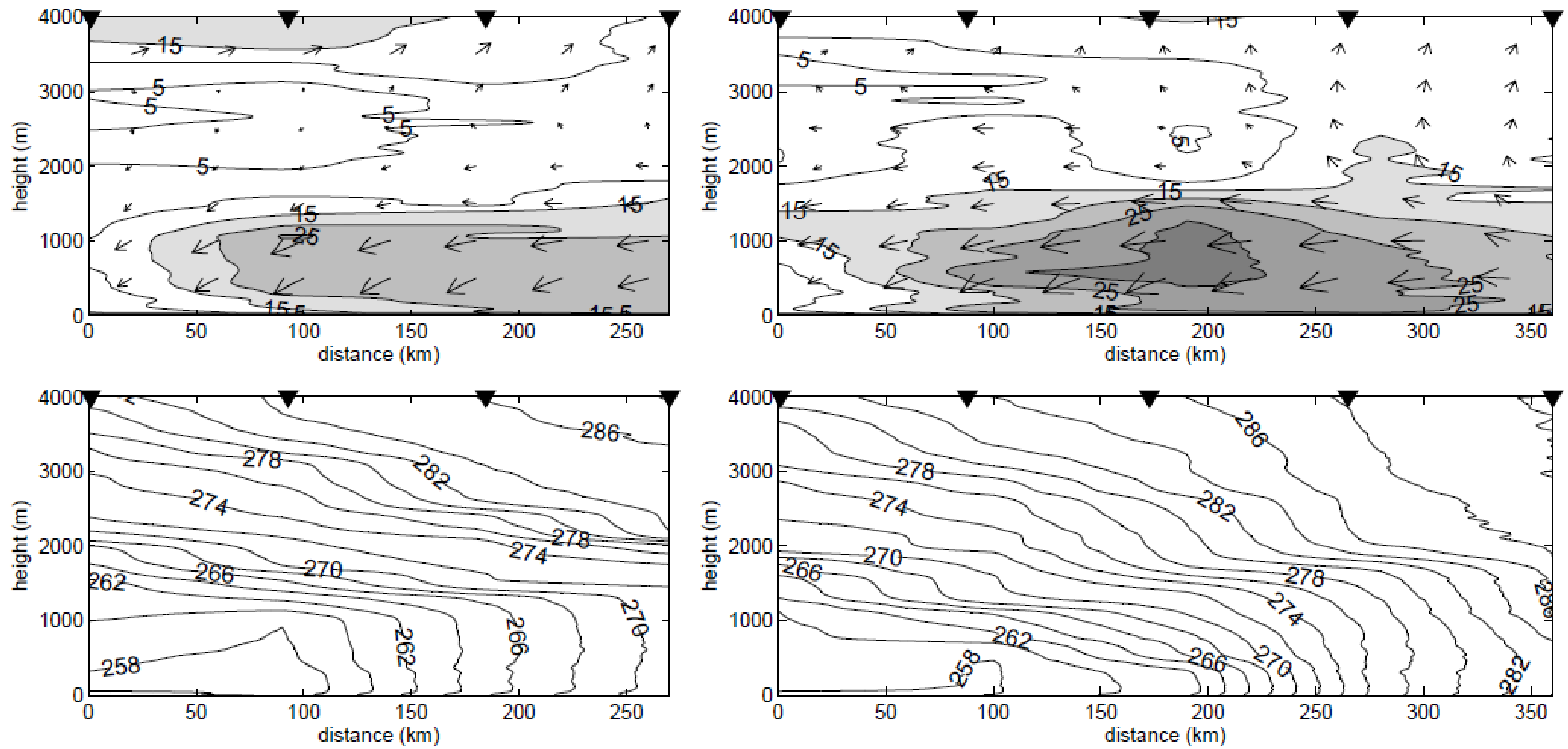


ERAI - dashed
Wind speed (thick)
Potential temperature (thin)





Barrier Flows: 2 March



DS North Cross-section

DS South Cross-section

Barrier Flows: 2 March
Representation at 12 km grid, 76L is reasonable

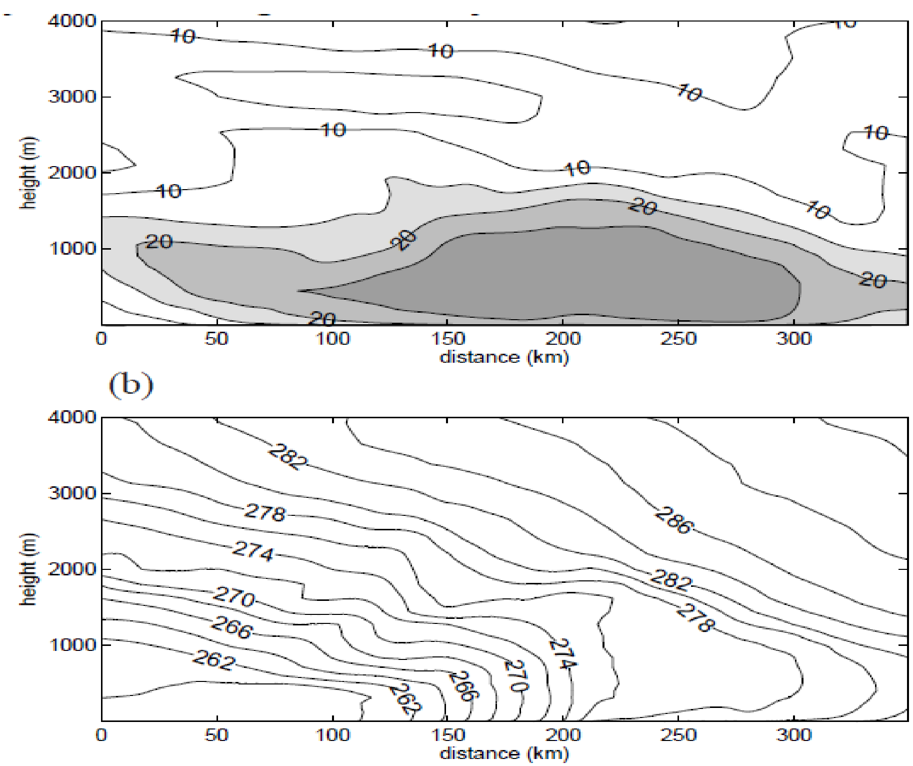
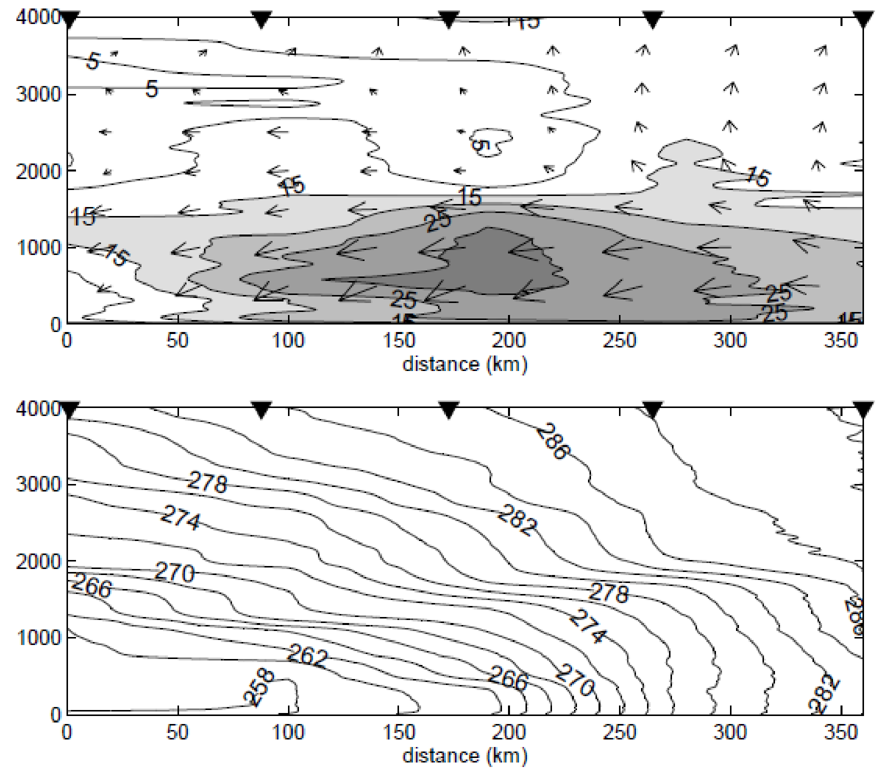
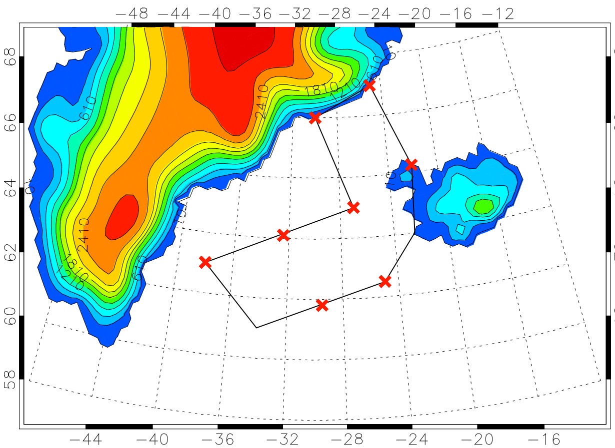


Figure 9. Simulated barrier flow at 12 UTC 2 March (T+36h) in the DSS cross section, see Figure 6(c) for location. (a) Wind speed ($m\,s^{-1}$), contour interval 5 $m\,s^{-1}$ with wind speed exceeding 15 $m\,s^{-1}$ shaded. (b) Equivalent potential temperature (K), contour interval 2 K.

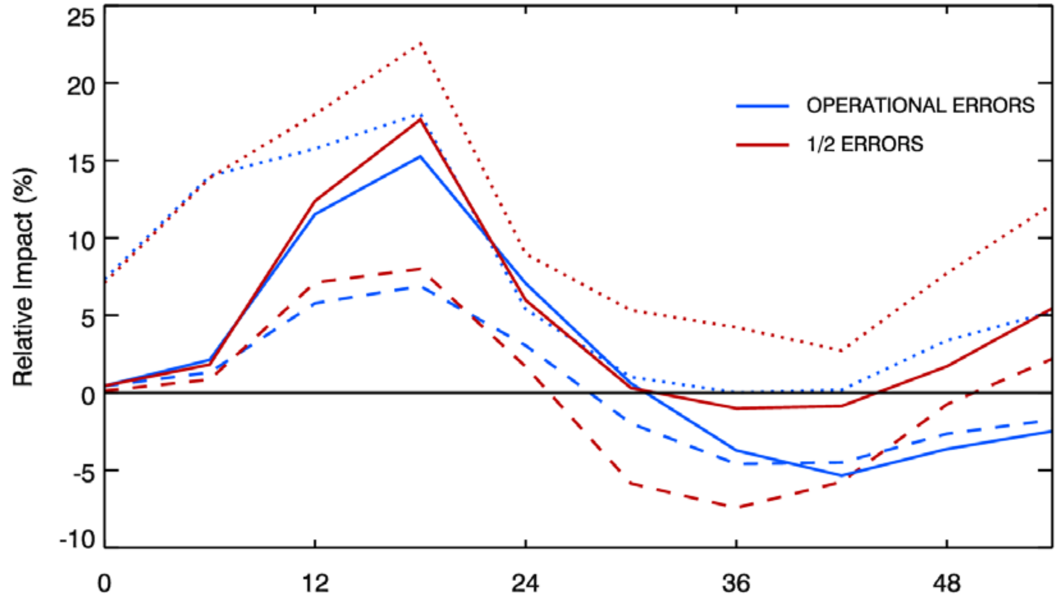


DS South Cross-section

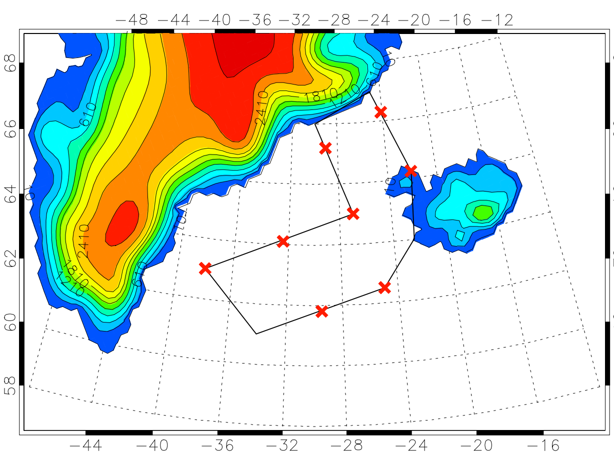
Impact of dropsonde data on Greenland coast



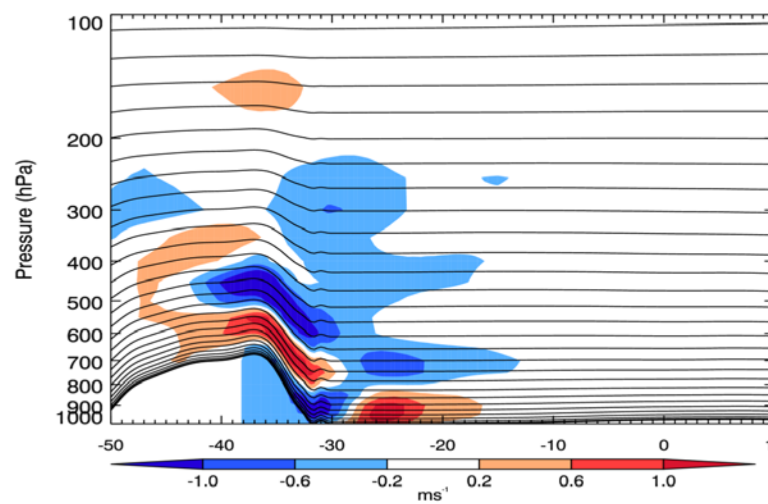
ORIGINAL DATASET
(targeted sondes)



Dashed line = targeted
solid line = all sondes
dotted line = MODIFIED

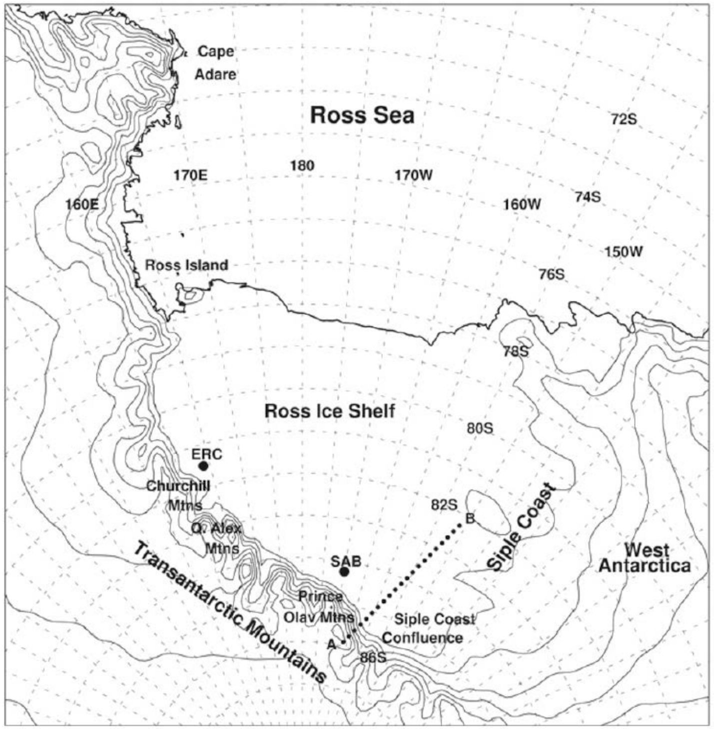


MODIFIED DATASET
Replaced sondes on coast)



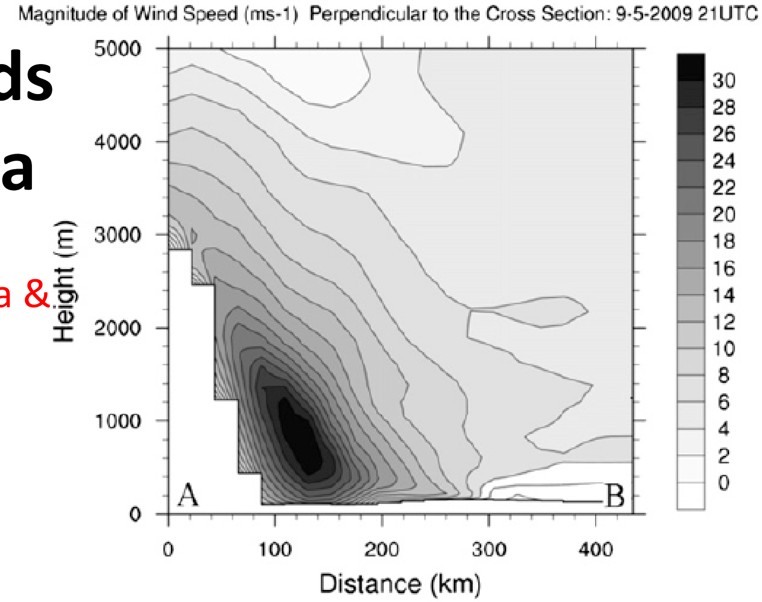
See Irvine et al 2011, Mon Wea Rev

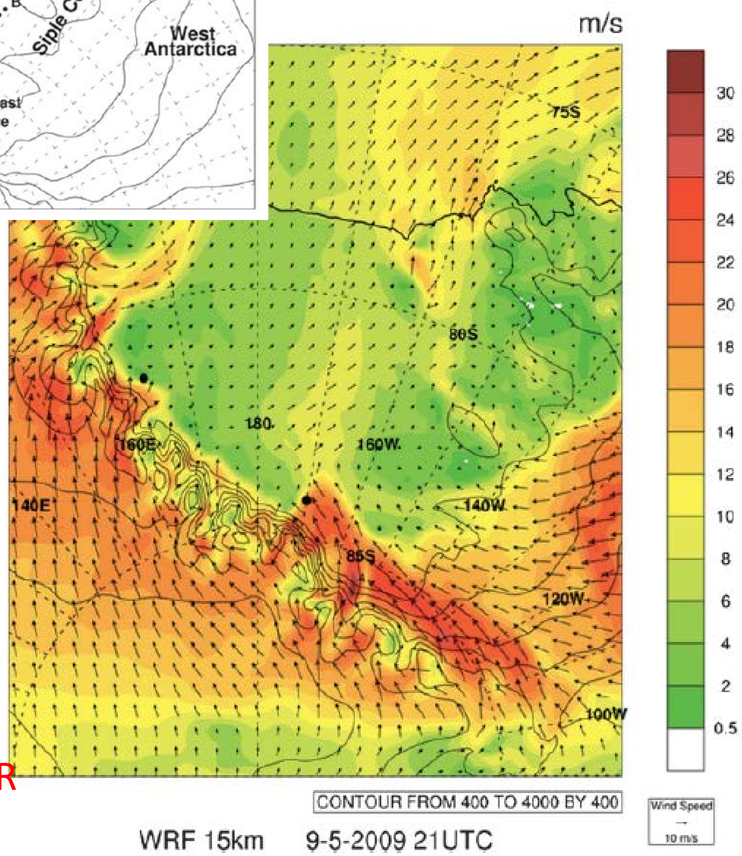
NIGRO ET AL.

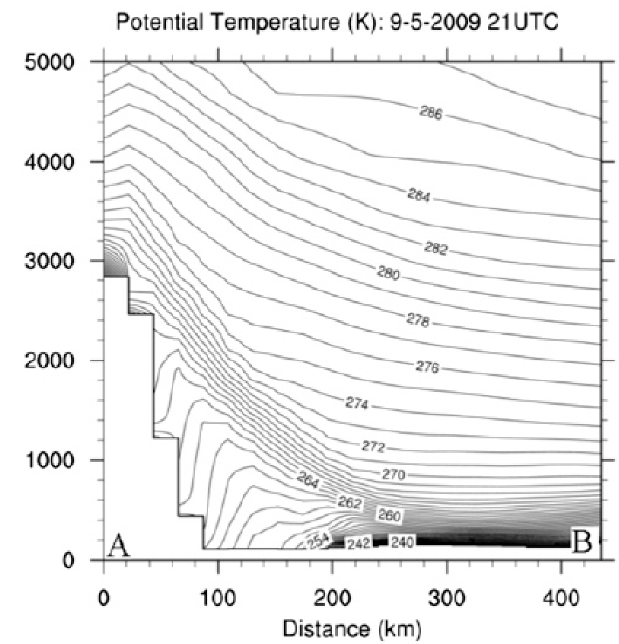


Barrier Winds in Antarctica

Nigro, Cassano, Lazzara & Keller, Mon Wea Rev, 2012

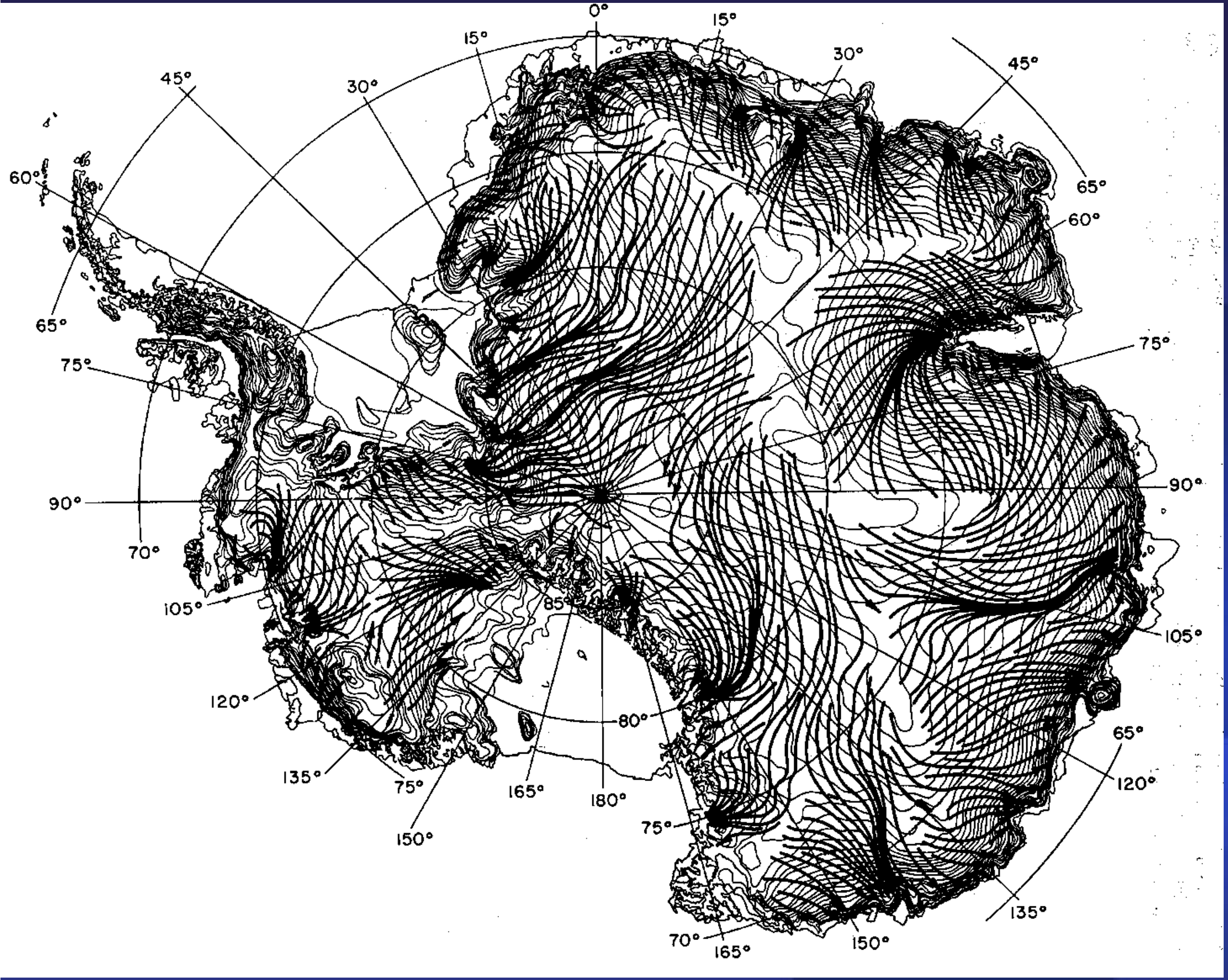






See also
Schwerdtfeger 1975, MWR
Parish 1983, JGR

Katabatic flows: Background



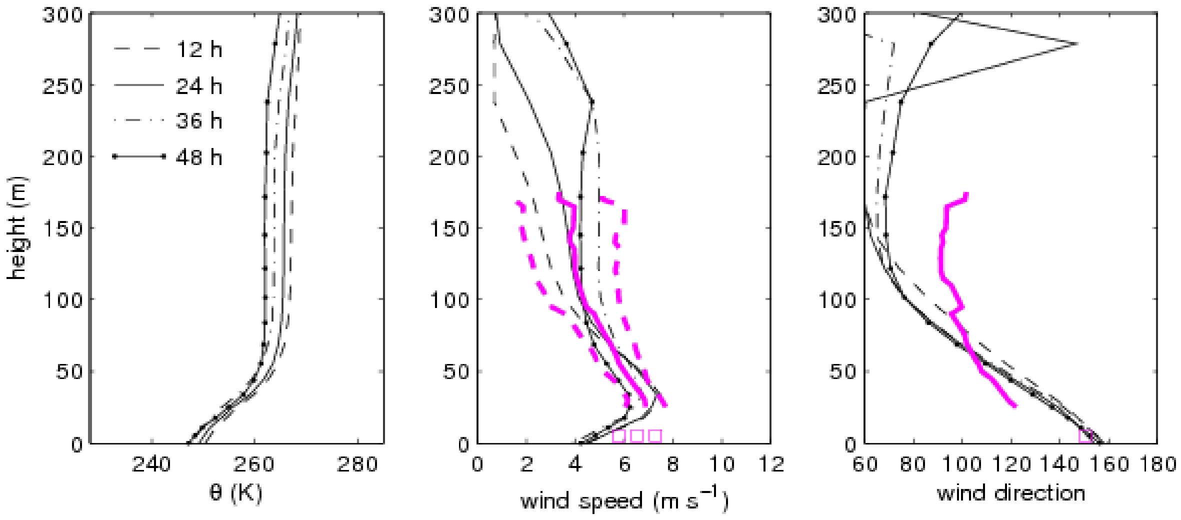
From Parish and Bromwich 1987, Nature

Locally driven “pure” katabatic flow

Essentially

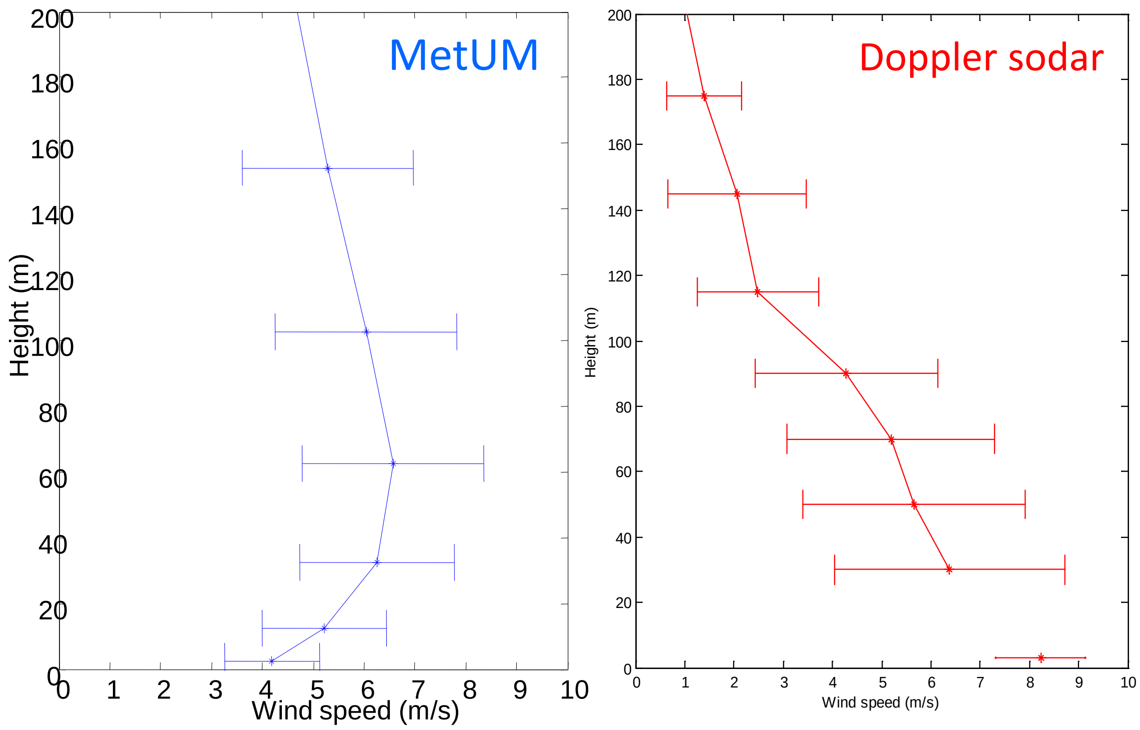
$F_b = (\Delta\theta/\theta_0).g.\alpha$,
where α = slope

RAMS idealised simulations



- Validation from observed katabatic flows.
- Conditionally sampled 6 < Umax < 8 m s^{-1} and 20 < zmax < 60 m

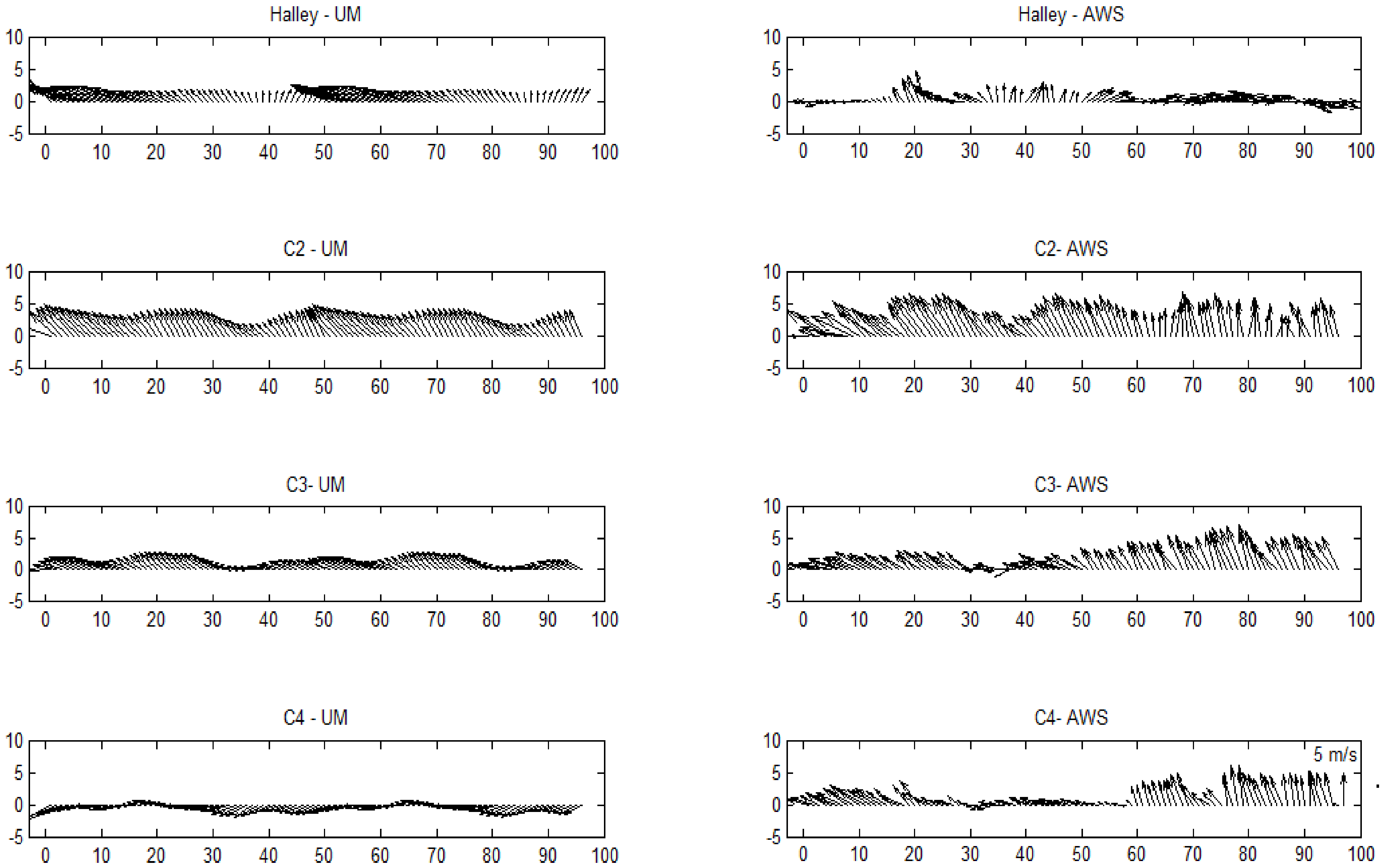
From Renfrew and Anderson (2006), Q. J. Royal Met. Soc.



Nightime comparison from summer-time case study – February 2002

MetUM at 4 km and 70L

Summer case: wind



Barrier Flows, Tip Jets & Katabatic flows

- Synoptic situation and orography controls the jets location, timing and magnitude
  - As predictable as synoptic-scale flow
  - e.g. Barrier effect doubles peak wind speeds
- Resolution: ~10 km and 40-76 L seems necessary
  - MetUM simulations good (12 km & 76 L; 4 km for Katabatic)
  - WRF simulations good at 10 km, but 25 & 50 km grid size don't capture gradients
  - ERAI representation (80 km) ok for climatology, but similar concerns about diffuse gradients
- Parameterizations
  - Sea-ice & SST fields and surface exchange vital
  - What can be done to capture sharp vertical gradients?
  - Poor representation of katabatic flows in vertical (SBL parameterization problems?)

Quarterly Journal of the Royal Meteorological Society Q. J. R. Meteorol. Soc. 137: 1731–1738, October 2011 A

RMetS
Royal Meteorological Society

Observation and modelling of gap flow and wake formation on Svalbard

Idar Barstad* and Muralidhar Adakudlu

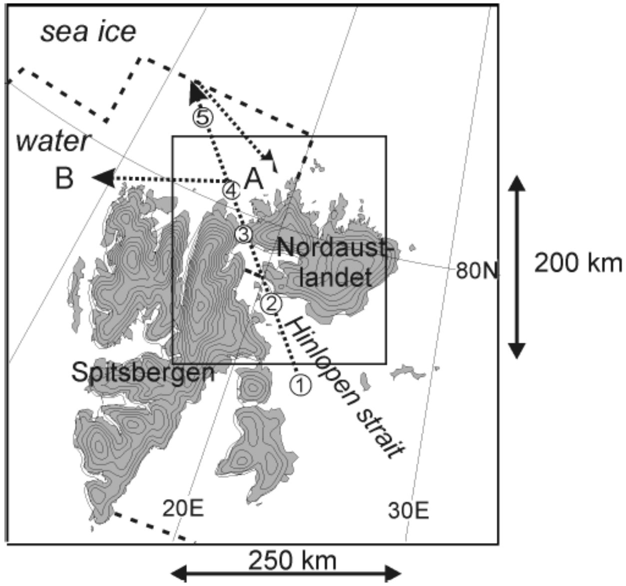


Figure 2. The area for the 3 km domain and the nested 1 km domain, showing geographical names. The terrain contours every 100 m are shown for the 3 km grid. The sea-ice edge for the CTL run is indicated as a dashed line. Dotted arrows indicate the flight track (northward flying direction) through the strait with labels showing the numbered dropsondes (also plotted on Figure 3). The cross-section in the lee (A–B) is shown in Figure 4.

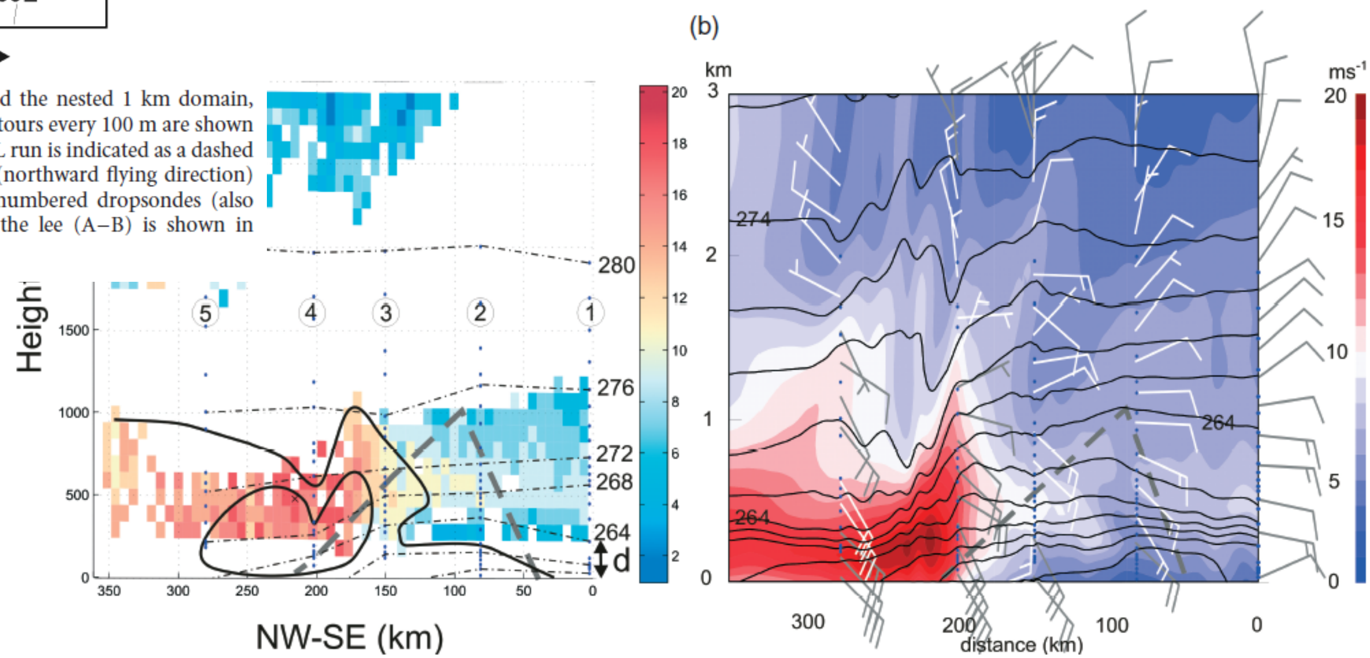
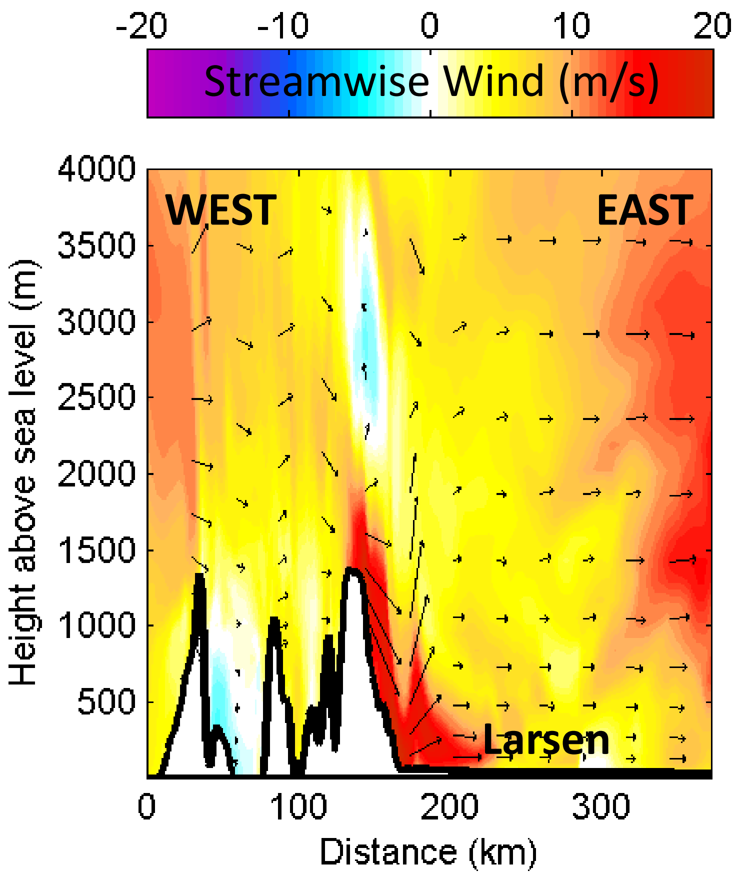


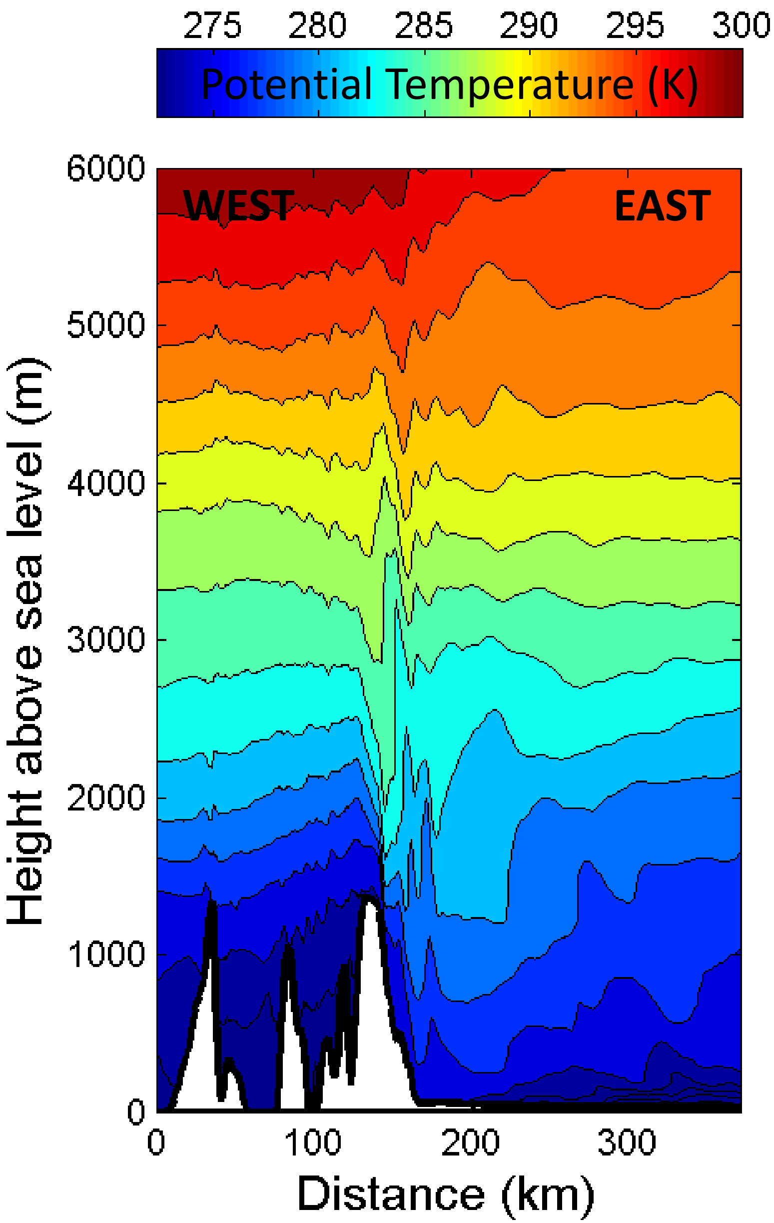
Figure 3. (a) Observations from the flight leg conducted between 1400 and 1430 UTC displayed in a vertical cross-section through the gap as shown in Figure 1. Wind speed from the wind lidar scan is shown in colour. Solid black curves are hand-drawn isotachs based on dropsonde information (found in (b)), with the outer isotach 10 m s^{-1} and the inner 15 m s^{-1}. The dots show potential temperature every whole degree, with the uppermost dot at 280 K, and broken contours at 4 K intervals. The large-scale terrain in the vicinity is indicated by a heavy, broken line. 'd' indicates a surface inversion of 9 K (250 m)$^{-1}$. (b) The model simulation of the same cross-section (wind speed in colour and theta as solid lines at 2 K intervals) with dropsonde information overlaid. Dots are as in (a). A long tick on the wind barb indicates 10 kt.

Foehn flows over Antarctic Peninsula

Wave breaking
Downslope windstorm
Hydraulic jump



Vertical winds exaggerated (x25)

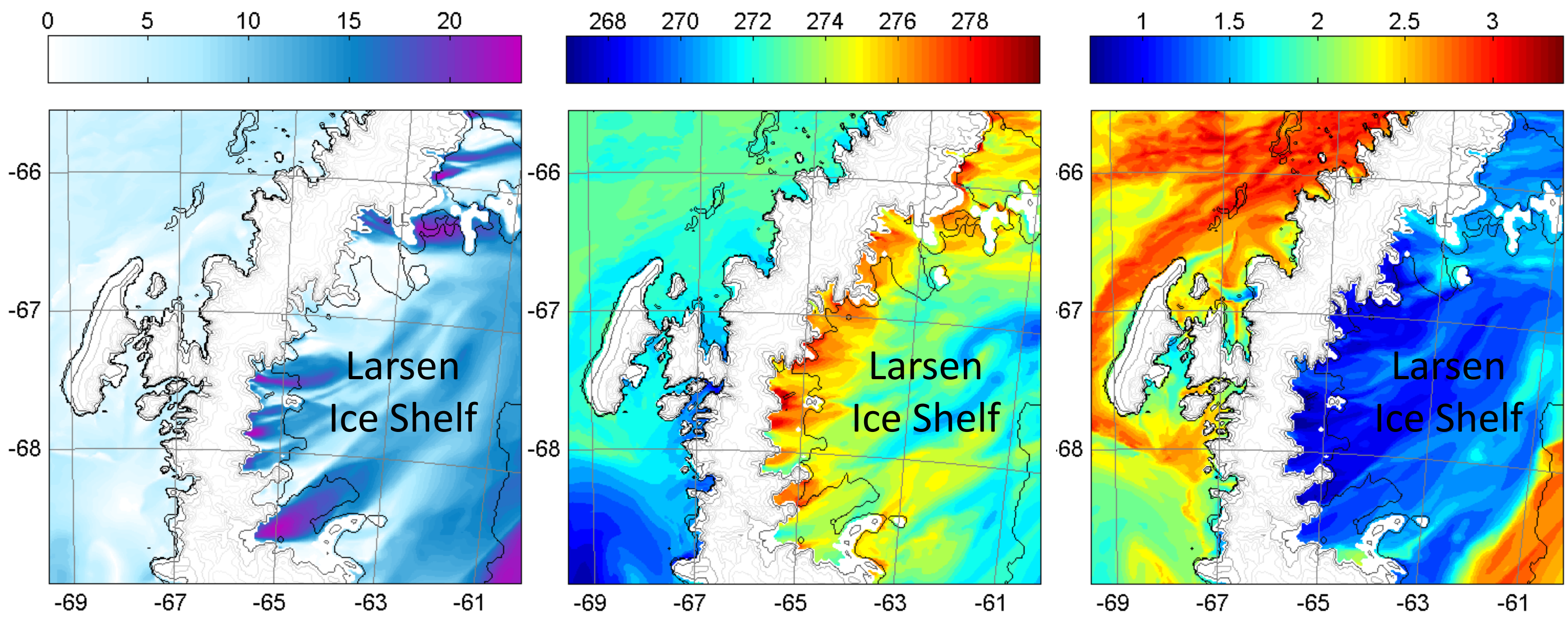


Polar Foehn Jets

Met UM 1.5km simulation – 5 Feb 2011

Plot height = 150 m

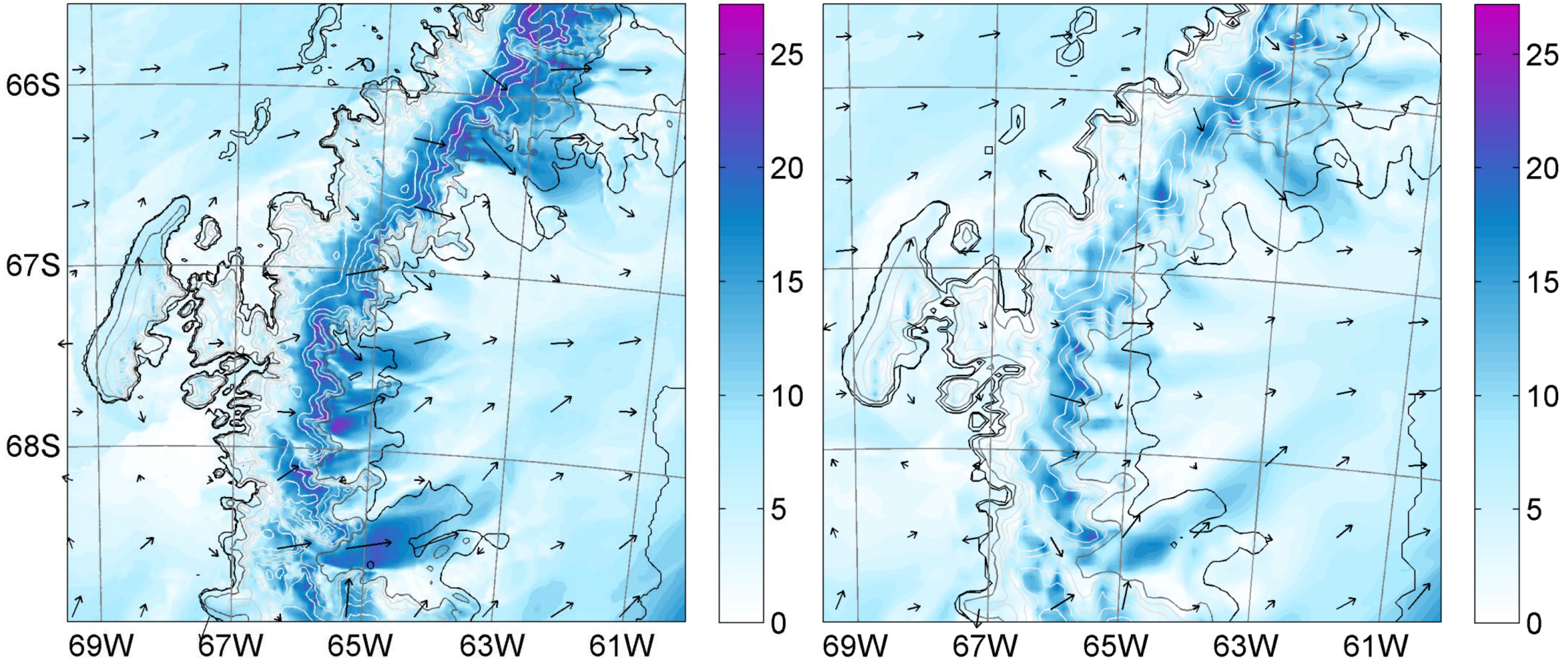
Wind speed (m s^{-1}) | Potential temperature (K) | Specific humidity (g kg^{-1})



University of East Anglia

Andy Elvidge, Ian Renfrew (UEA)

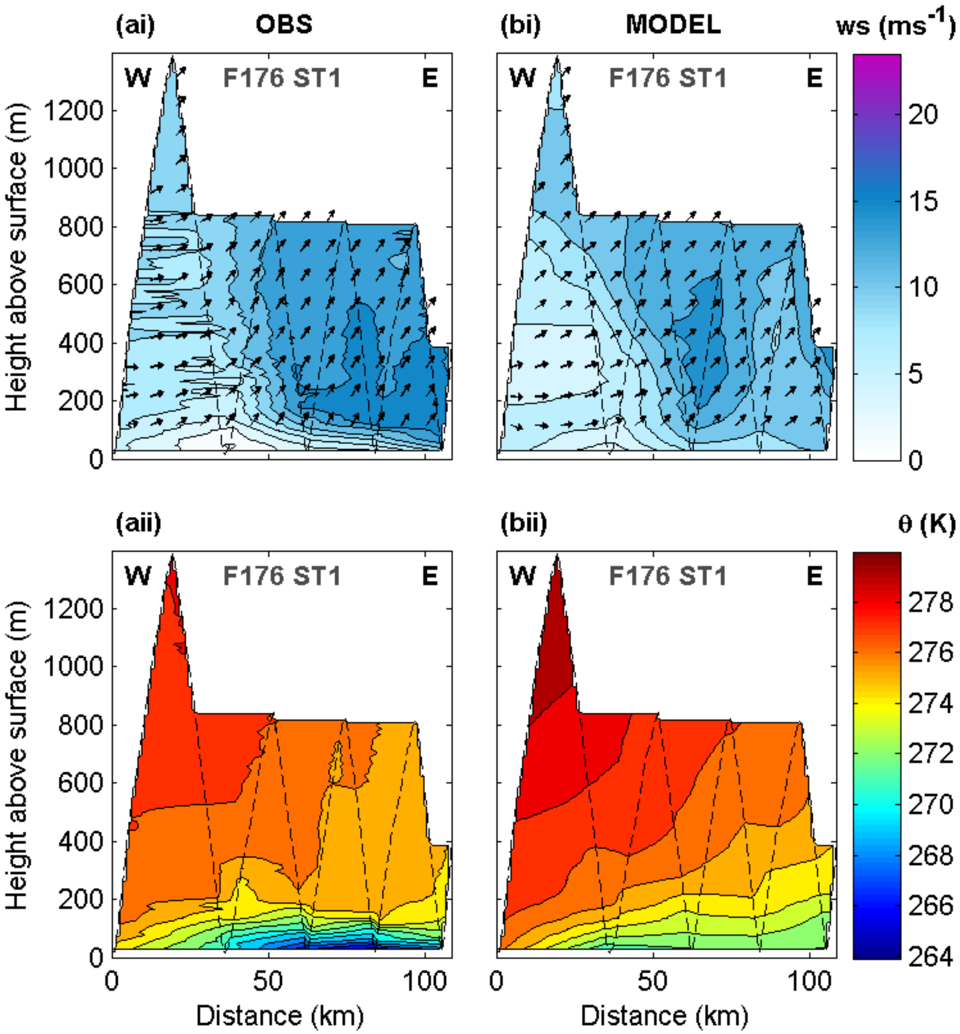
MetUM 1.5 km versus 4 km – 5 Feb 2011



- 1.5 km grid size (76L) is required to simulate these polar foehn jets (gap flows).
- In addition surface exchange and BL parameterization is vital.

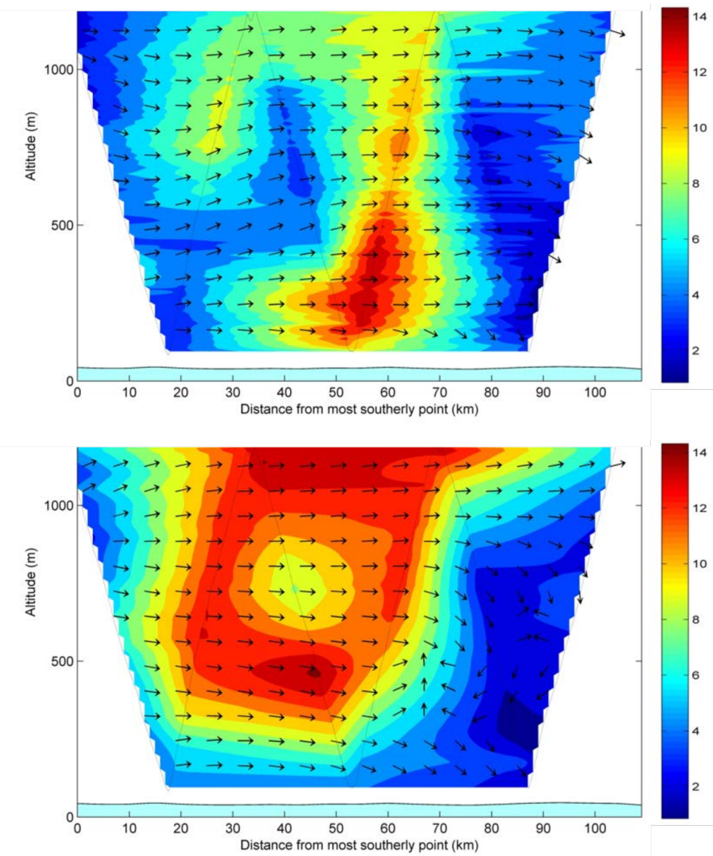
Observations versus model

- **Left: along jet** - shows warm föhn air reaching ice shelf with cold boundary layer to the east
- **Below: across jet wind speed** - shows model captures jet magnitude and approximate structure



OBS

MODEL



Met Office UM simulations at 1.5 km are able to capture most aspects of observed jet structure

Andy Elvidge, Ian Renfrew (UEA)

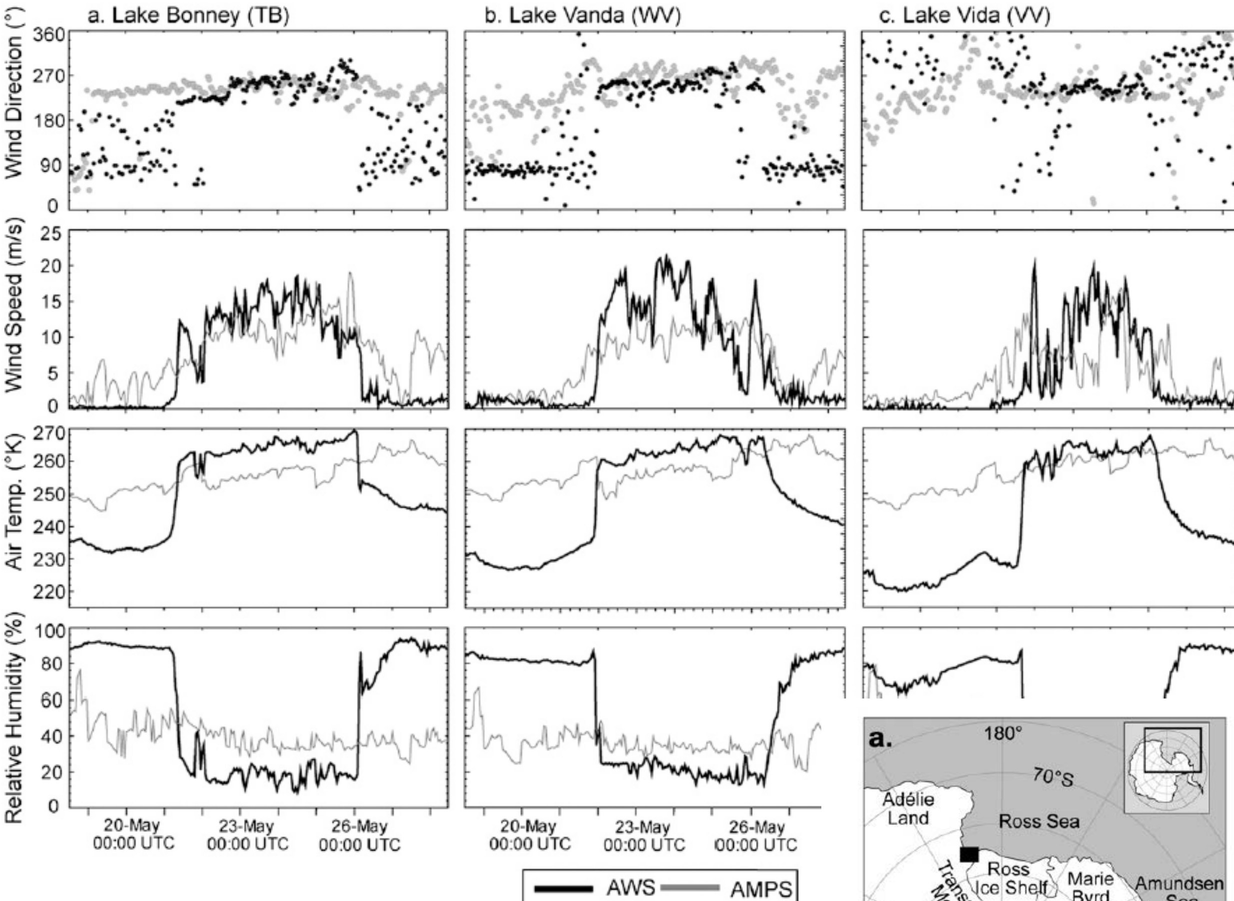


FIG. 4. Foehn meteorological observations and AMPS model output 19–28 May 2007
Valley), (b) WV (Wright Valley), and (c) VV (Victoria Valley). AWS data were resampl
match AMPS output.

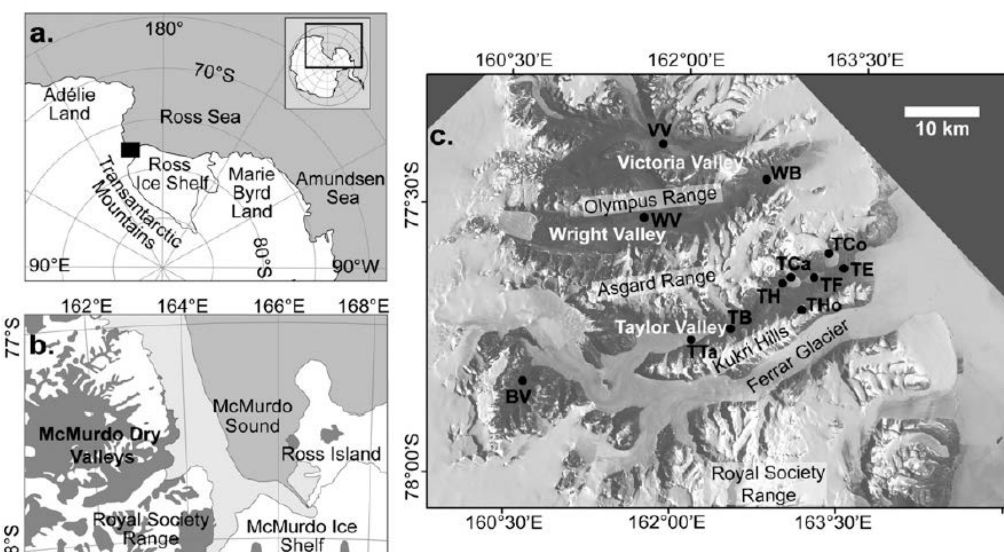
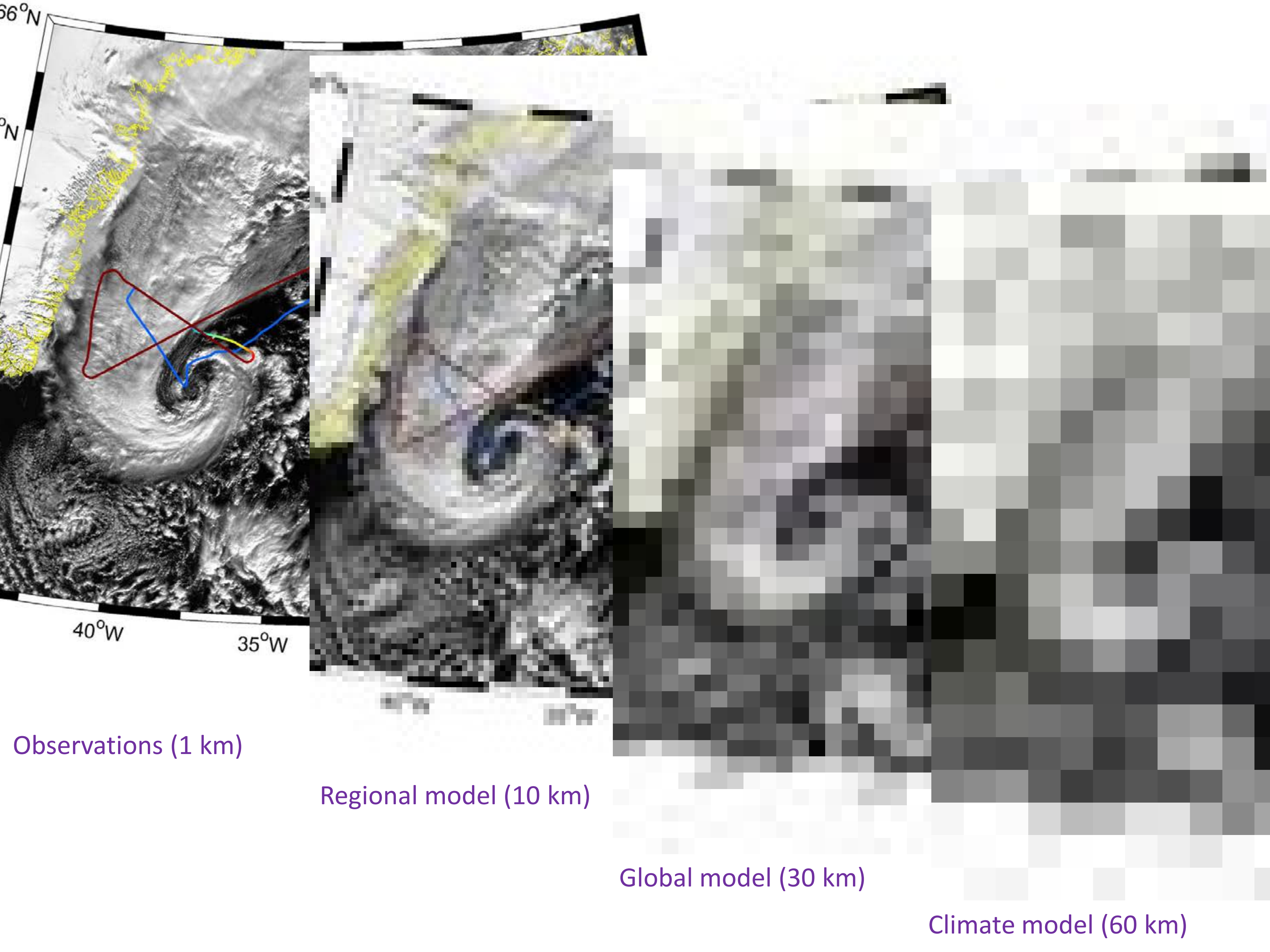


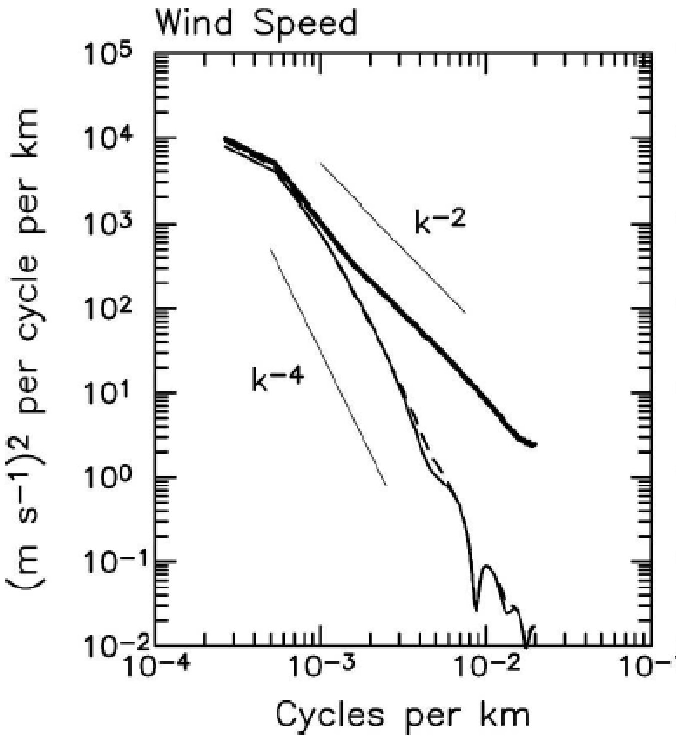
FIG. 1. (a) Map of the Ross Sea region of Antarctica. (b) Inset of black box in (a) showing the MDVs region. (c) The MDVs AWS network: VV, WV, Lake Brownworth (WB), BV, TTa, TB, TH, THo, TCa, TF, TCo, and TE. Landsat Enhanced Thematic Mapper (ETM+) image captured 21 Nov 2001.

Gap Flows, Polar foehn jets,

- Jets location and scale set by orography
- Synoptic situation controls the jets timing and magnitude
  - As predictable as synoptic-scale flow?
- Resolution: ~1 km and 76 L seems necessary
  - MetUM simulations good (at 1.5km & 76 L)
  - WRF simulations good at 1 km
- Parameterizations
  - Surface exchange vital
  - ABL parameterizations vital, e.g. SBL and BL transitions


66°N
°N
40°W
35°W
Observations (1 km)
Regional model (10 km)
Global model (30 km)
Climate model (60 km)

What can atmospheric models resolve?



Along-track 10m wind speed spectra from QuikSCAT, ECMWF (dashed) and NCEP (thin) for the North Pacific in 2004. From Chelton et al. MWR, 2006

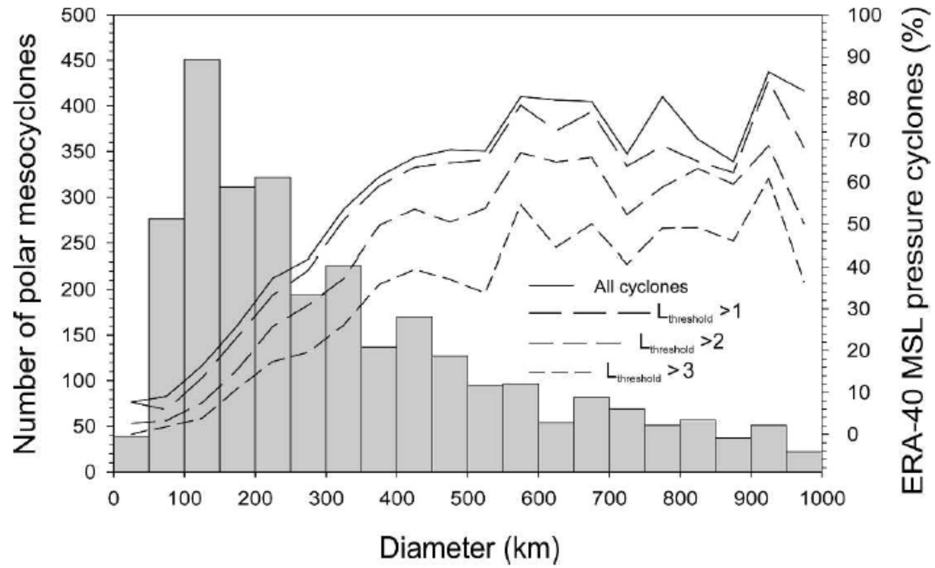


FIG. 7. Number of satellite-observed cloud vortices detected over the 2-yr climatology per 50-km size category (shaded bars). Overlaid are the percentages of cloud vortices in each size group with a cyclonic circulation in the MSL pressure reanalysis for all cyclones and those when $L_{\text{threshold}}$ is set at 1, 2, and 3 hPa $(\text{deg})^{-2}$.

From Condron et al. 2006, Mon Wea Rev

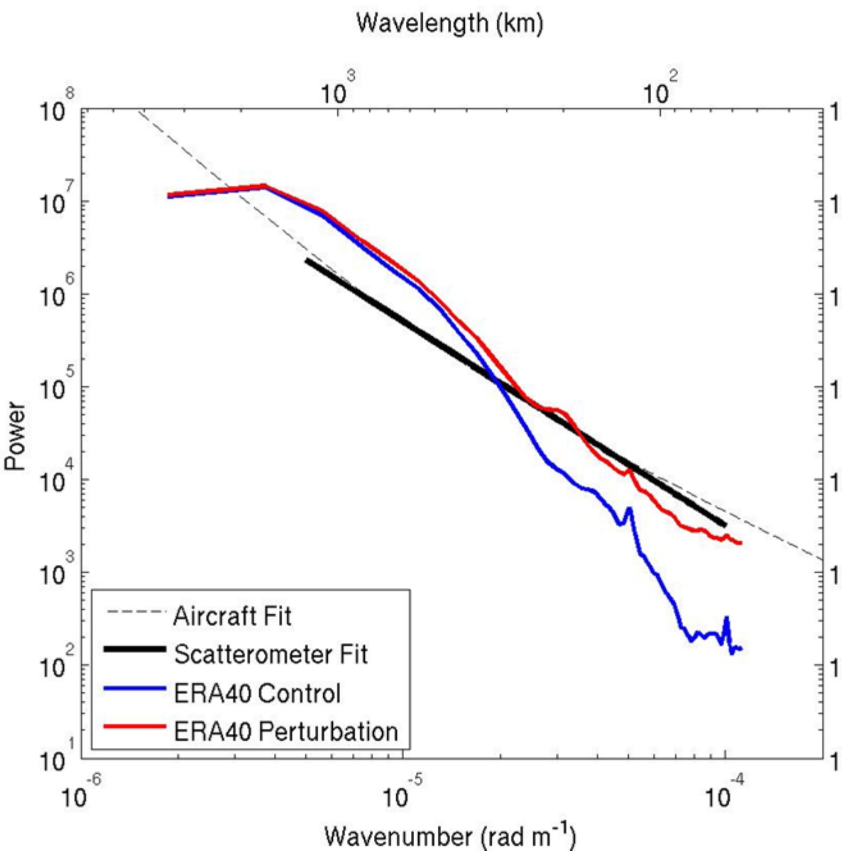
- Meteorological analyses (and climate models) have large amount of power "missing" in the atmospheric mesoscale
- Does this matter for ocean circulation?

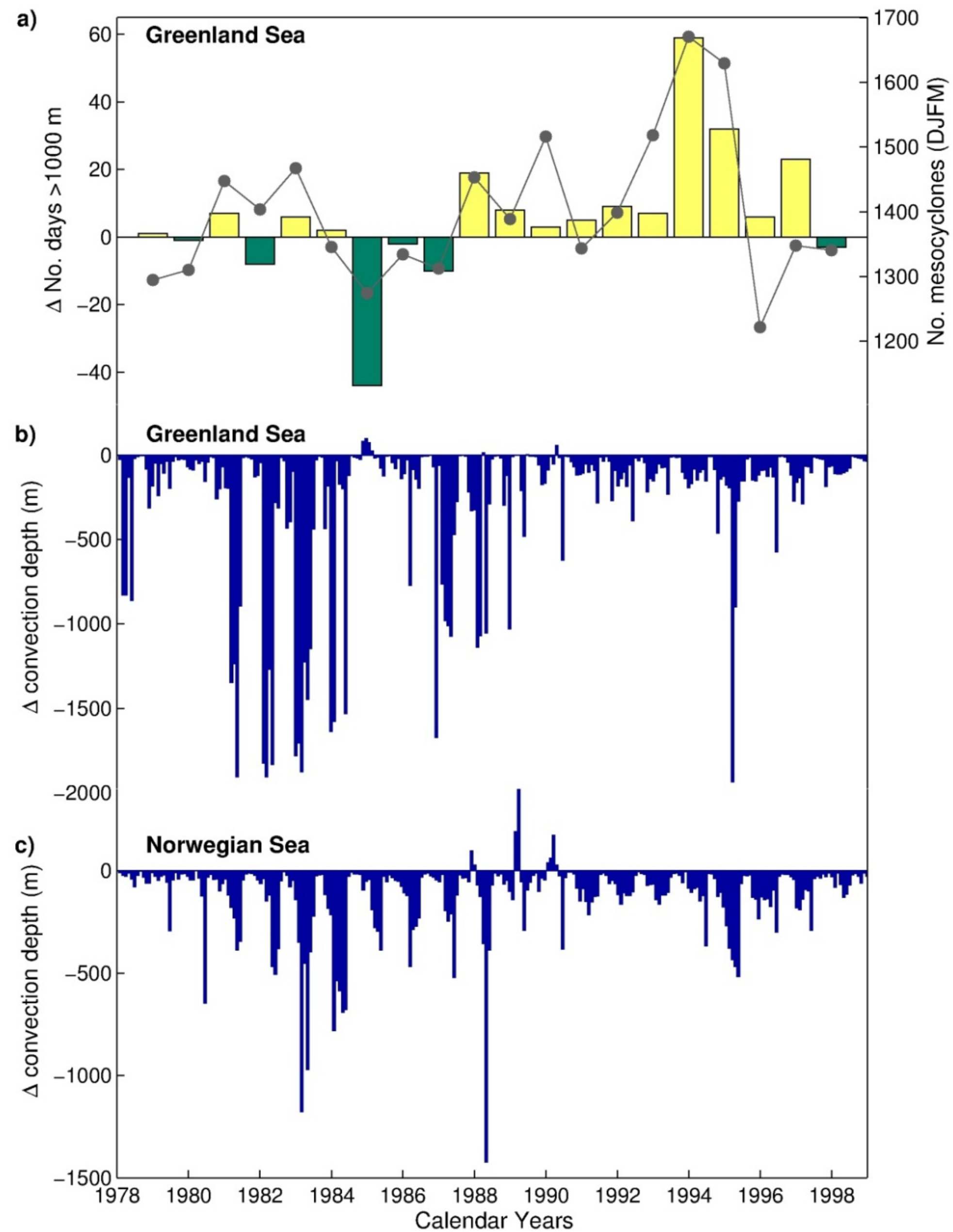
LETTERS
PUBLISHED ONLINE: 16 DECEMBER 2012 | DOI: 10.1038/NGEO1661
nature geoscience

The impact of polar mesoscale storms on northeast Atlantic Ocean circulation

Alan Condron[1] and Ian A. Renfrew[2]*

Impact on deep convection in the Greenland Sea





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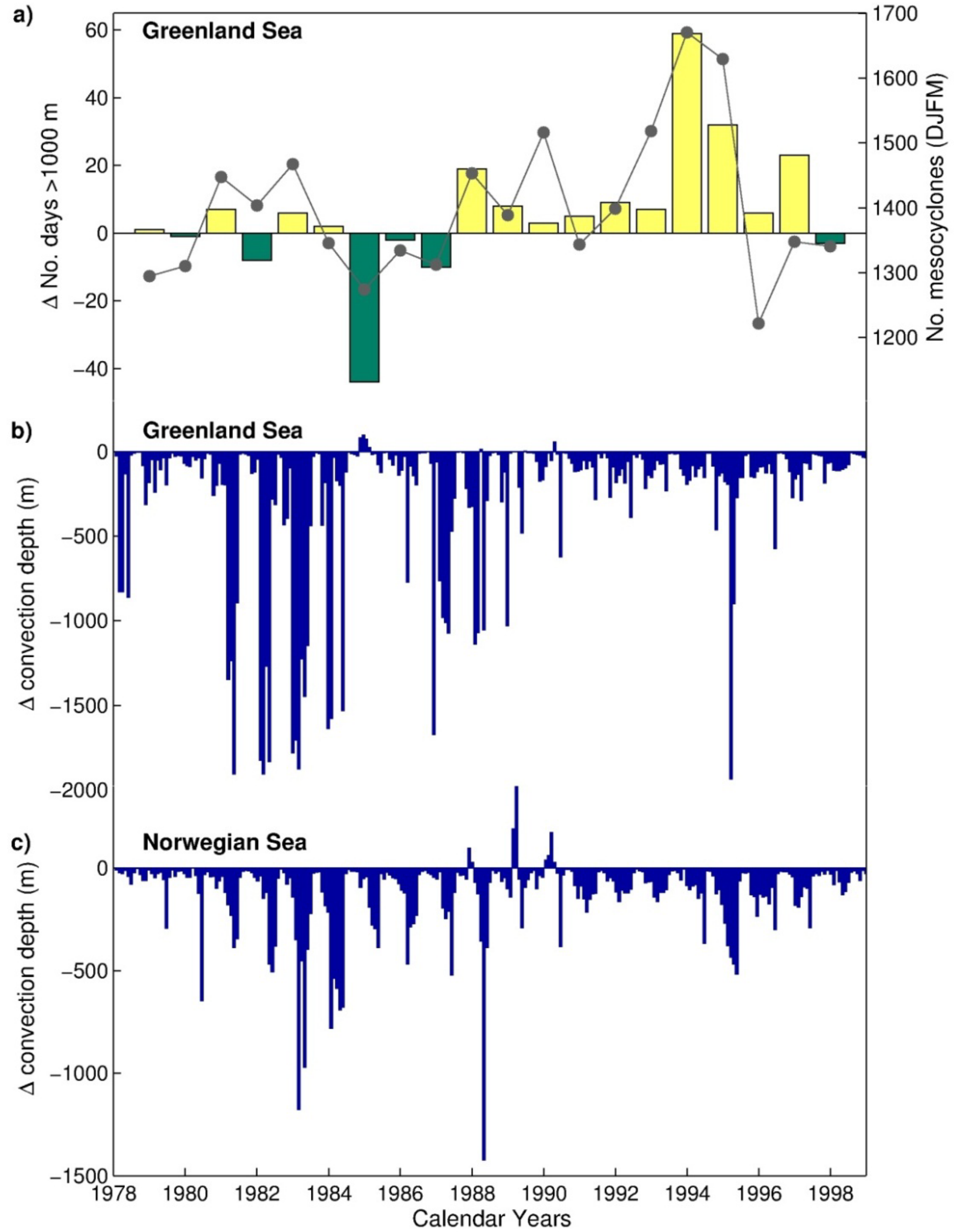
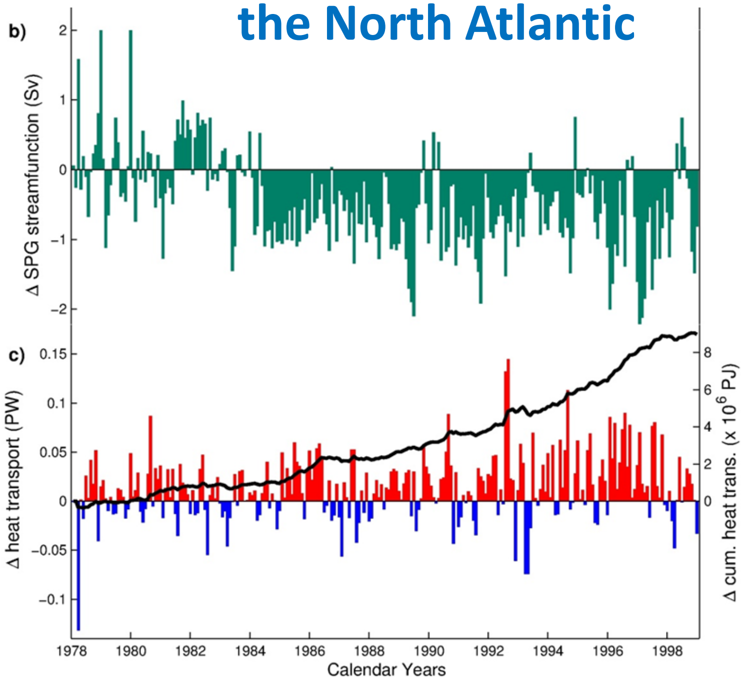
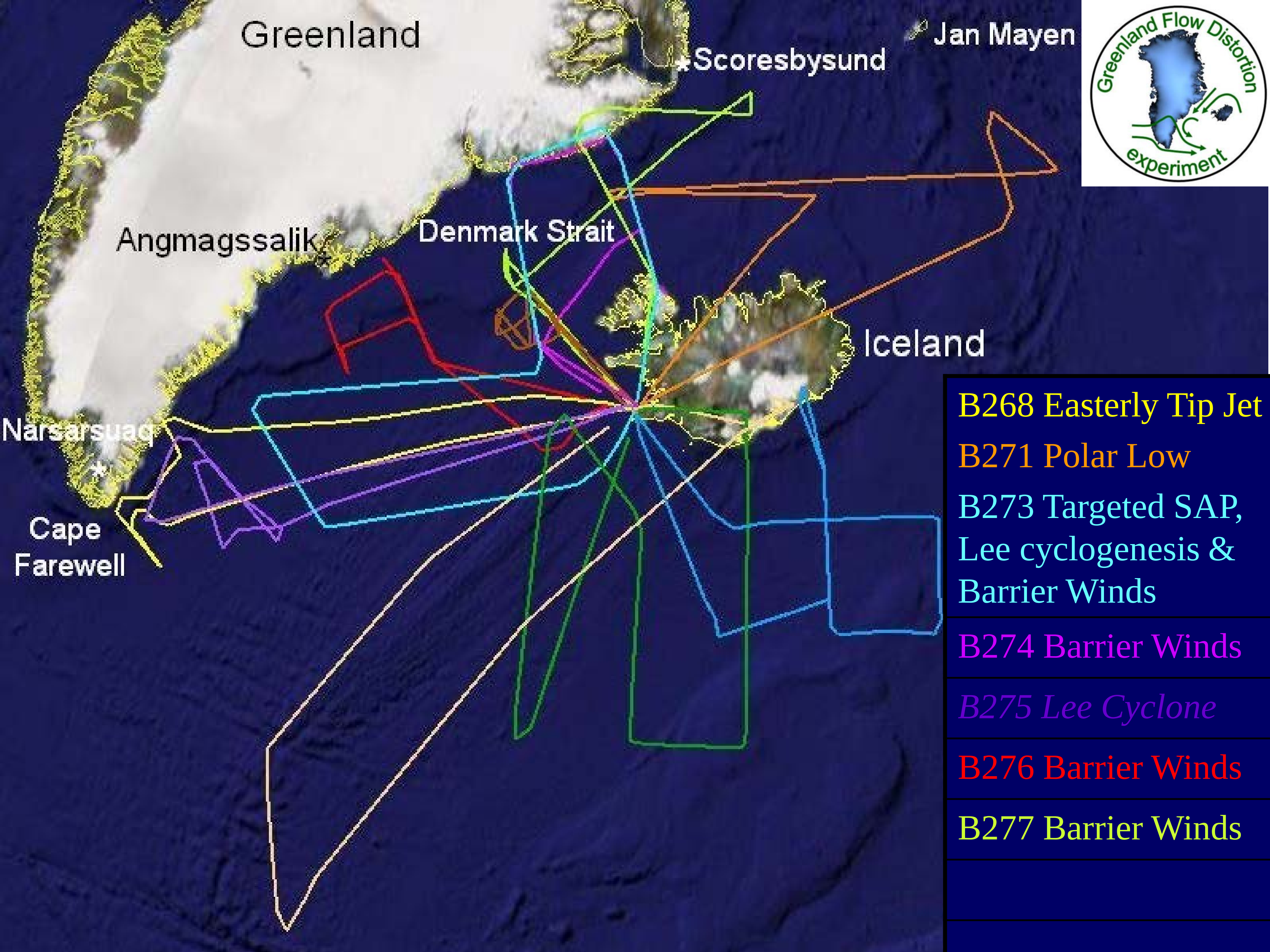


Impact on subpolar gyre of the North Atlantic



Conclusions

- Appropriate model resolution is vital to resolve jets
  - ~10 km for larger-scale orographic jets
  - ~1 km for complex orography
- Appropriate parameterization schemes vital for accurate representation
  - SBL, surface exchange, etc
- Predictability seemingly controlled by synoptic-scales


Greenland
Jan Mayen
Scoresbysund
Angmagssalik
Denmark Strait
Iceland
Narsarsuaq
Cape
Farewell
Greenland Flow Distortion experiment
B268 Easterly Tip Jet
B271 Polar Low
B273 Targeted SAP, Lee cyclogenesis & Barrier Winds
B274 Barrier Winds
B275 Lee Cyclone
B276 Barrier Winds
B277 Barrier Winds

Barrier Flows: Temperature inversions

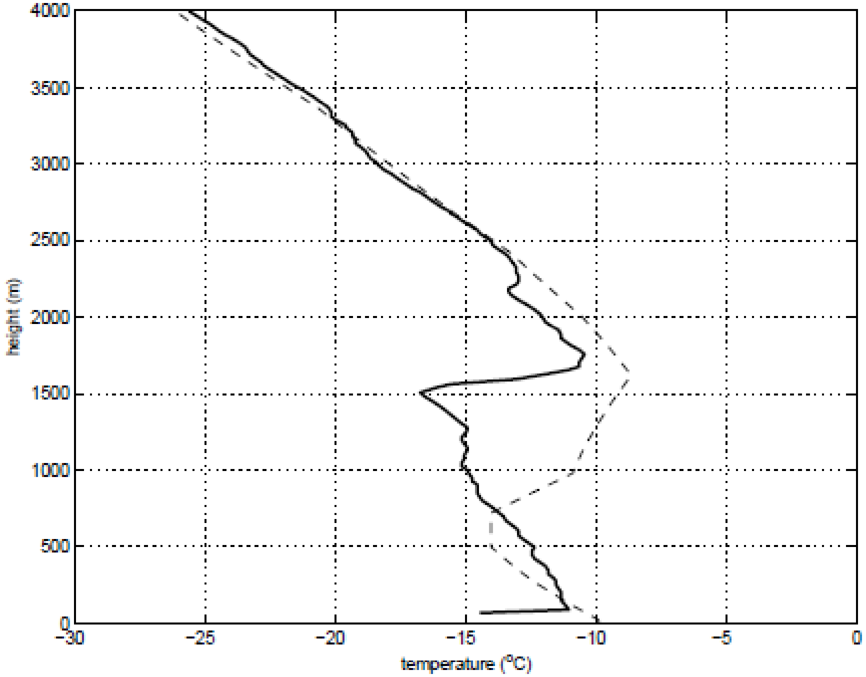
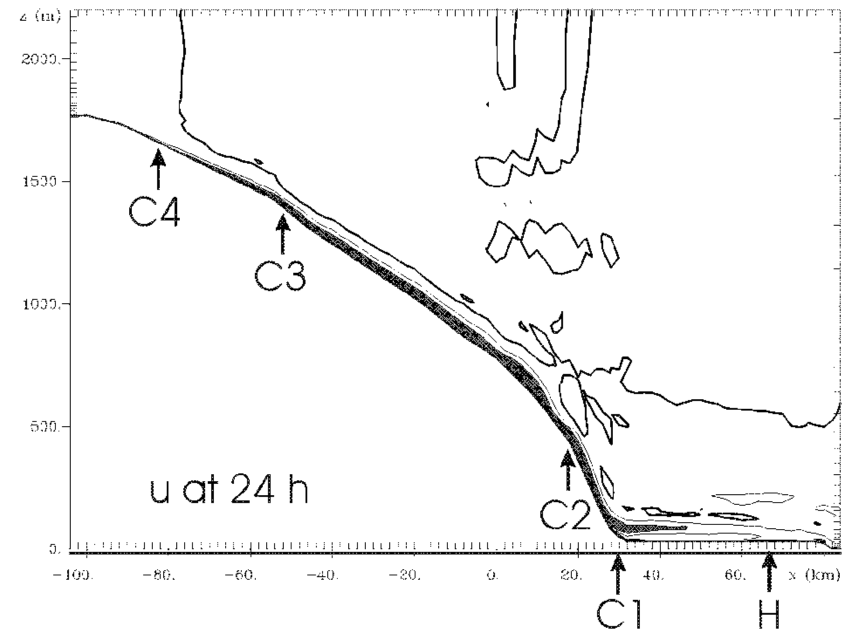
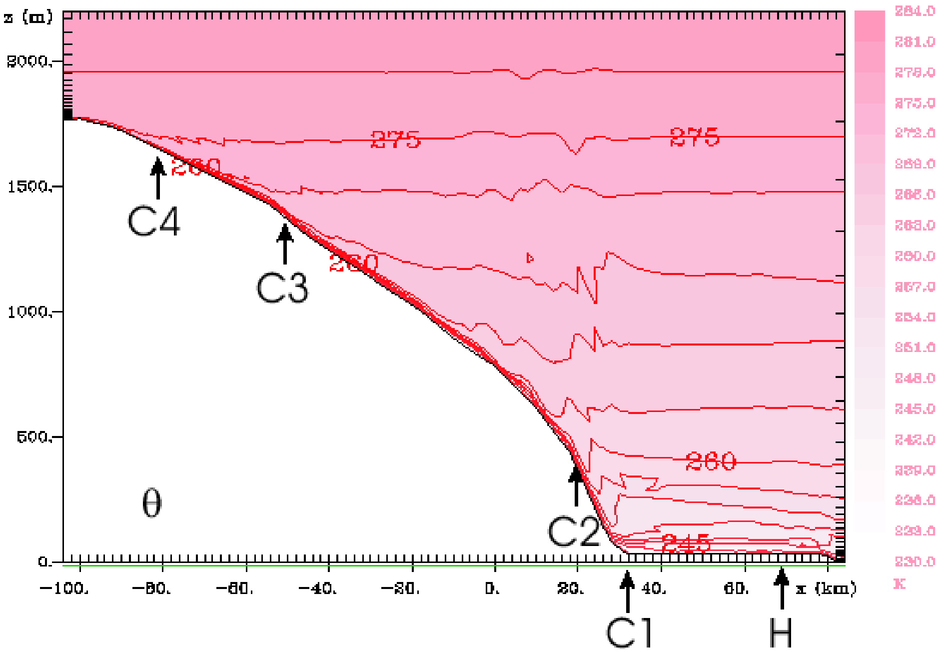


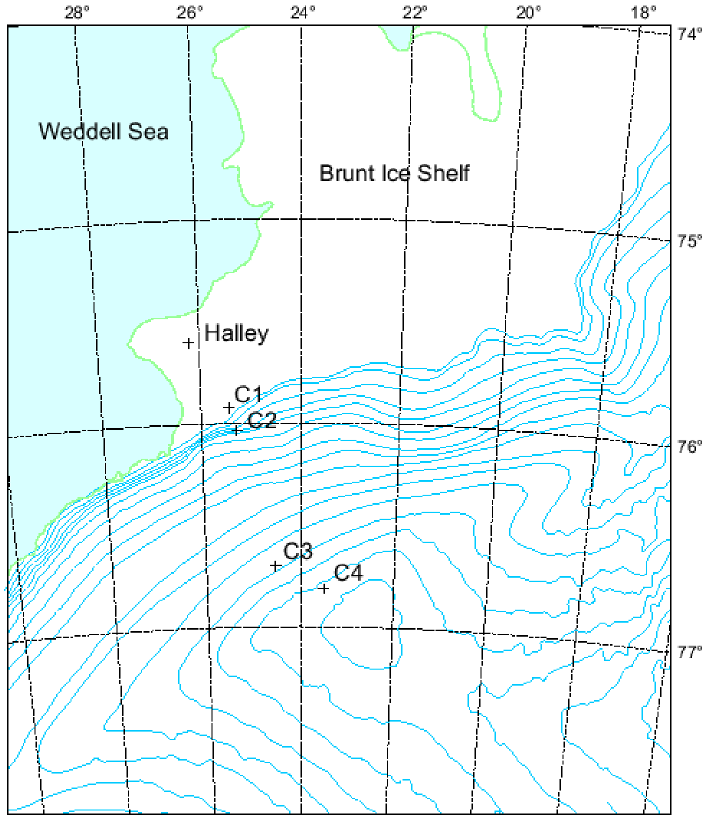
Figure 13. Temperature (°C) profiles at 00 UTC 5 March 2007 in Ittoqqoroormiit (Scoresbysund, 70°29′′N, 21°57′′E). The radiosonde ascent is shown with a solid, bold line and the analysis with a dashed line.

See Petersen, Renfrew and Moore, QJRMS, 2009

Numerical Simulations: RAMS at 3 km resolution



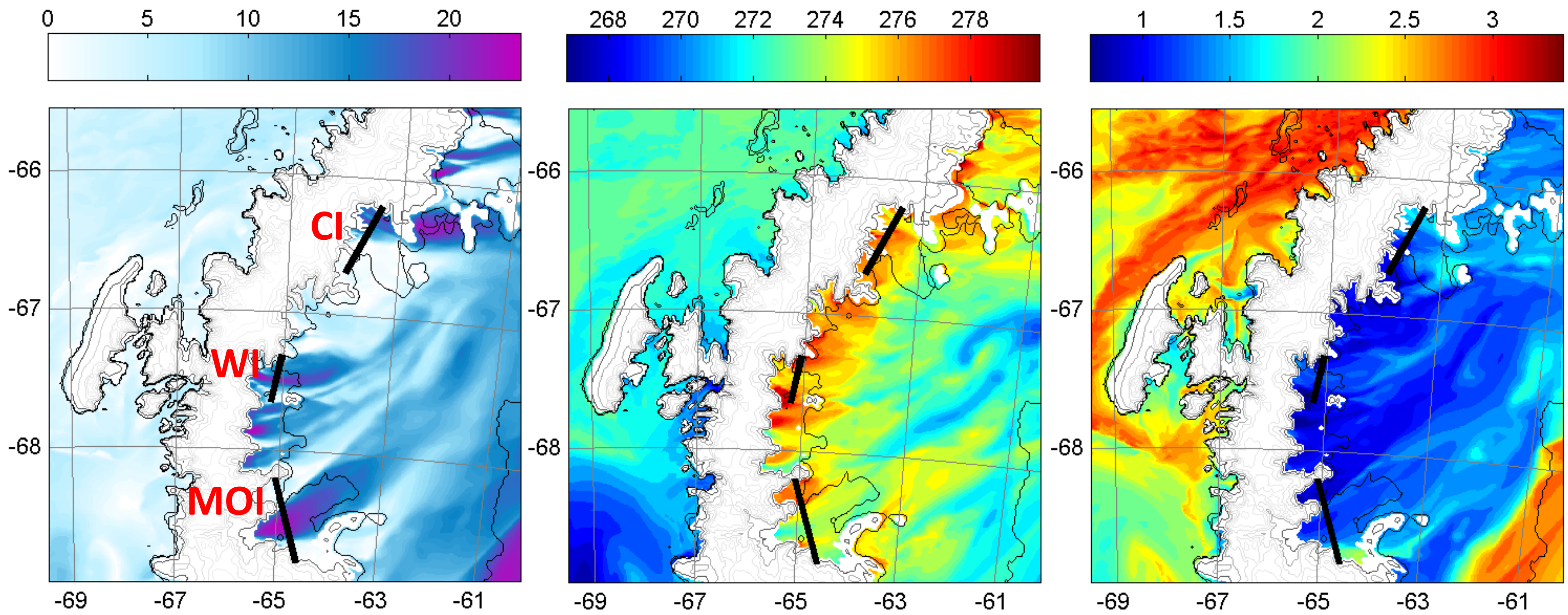




Met UM 1.5km simulation – 5 Feb 2011

Plot height = 150 m

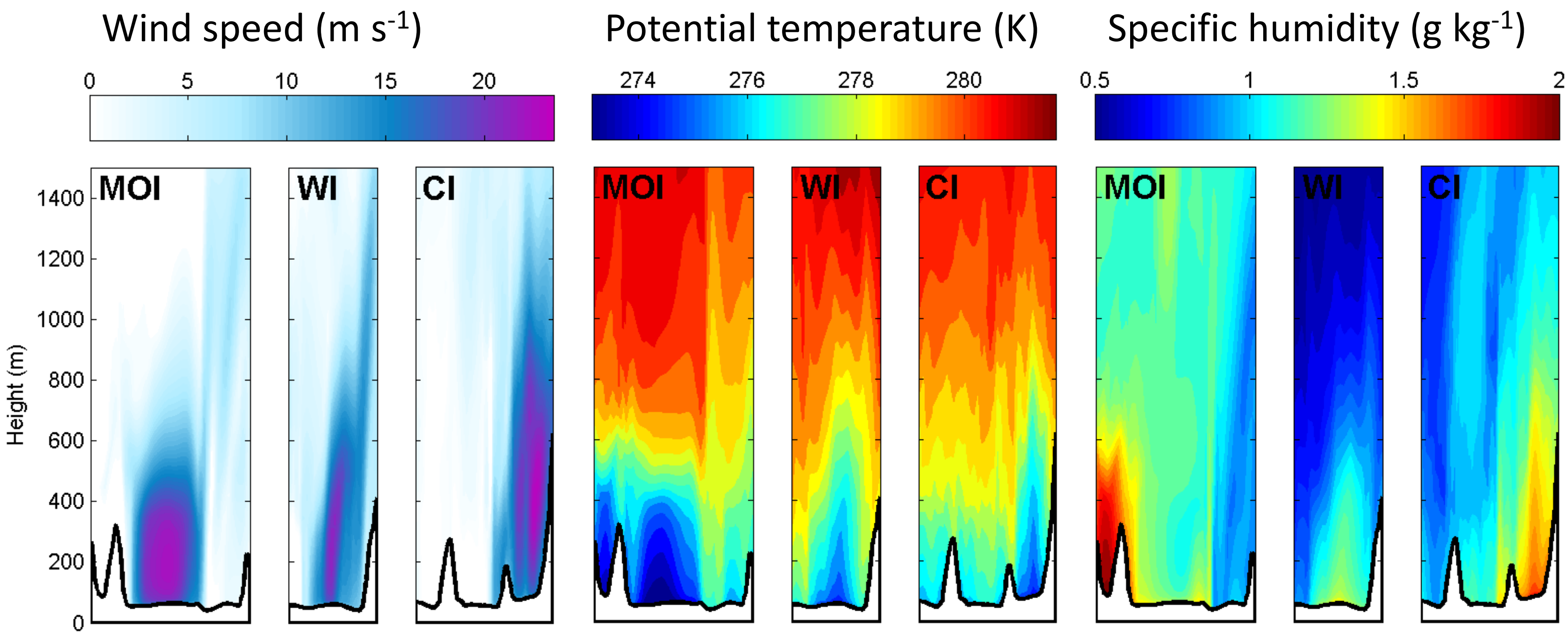
Wind speed (m s^{-1}) Potential temperature (K) Specific humidity (g kg^{-1})



MOI = Mobil Oil Inlet
WI = Whirlwind Inlet
CI = Cabinet Inlet

Andy Elvidge, Ian Renfrew (UEA)

UM 1.5km simulation



MOI = Mobil Oil Inlet
WI = Whirlwind Inlet
CI = Cabinet Inlet

Andy Elvidge, Ian Renfrew (UEA)

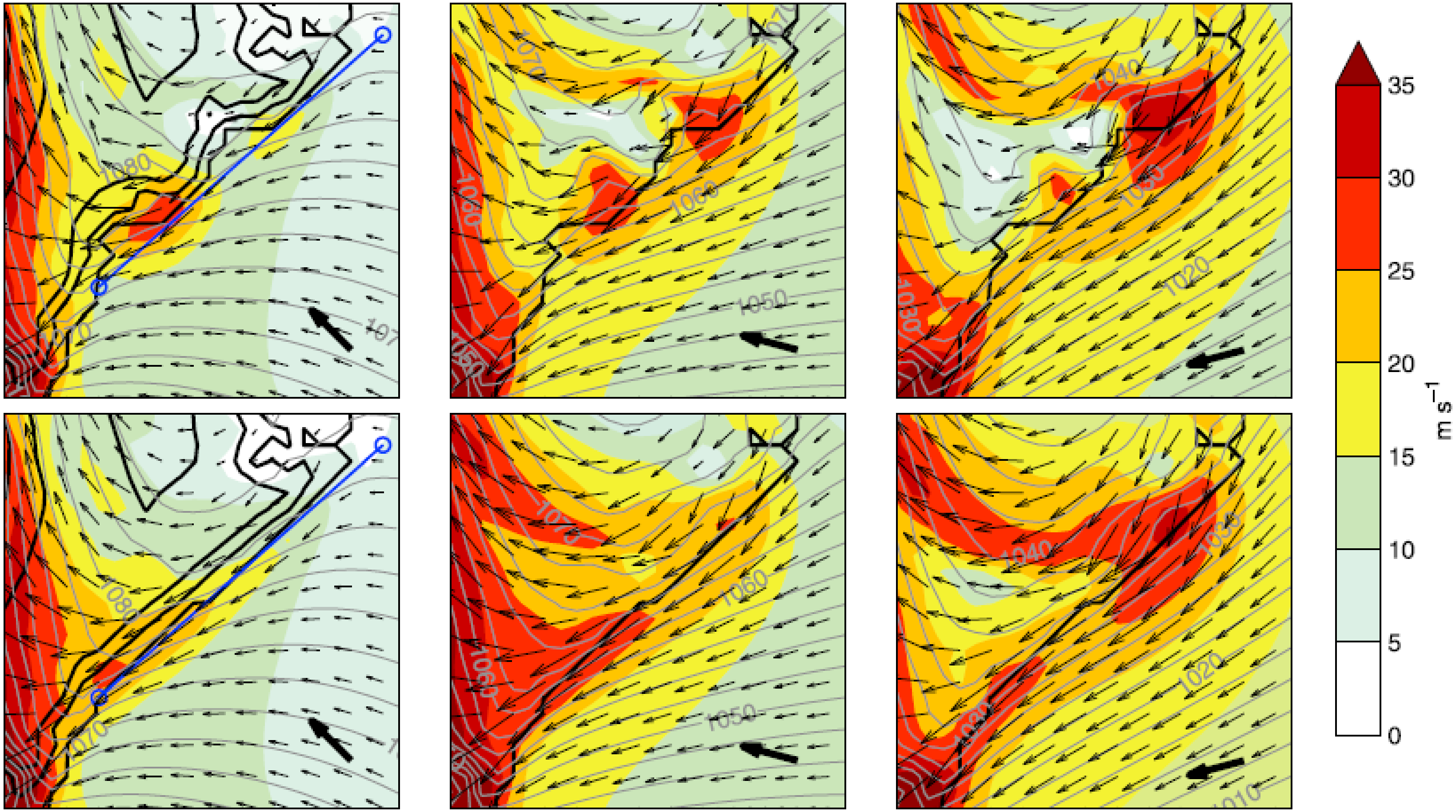


Figure 2. Lowest model level wind speed (colors) and mean sea level pressure (gray contours) for experiments with a Brunt-Väisälä frequency of 0.01 s^{-1} with (top) realistic and (bottom) modified orography. The inflow angles are shown with solid arrows (bottom right) and are (from left to right) 135°, 105° and 75°. The lowest level wind vectors are shown every second grid point. Coastline shown in solid black and orography contours are shown every 1000 m for left hand panels. The blue cross section lines are for Figure 3.