Föhn events at Cole Peninsula (Antarctica) in in-situ measurements and model simulations

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Background: Why Föhn, why here?

Location: Where are we?

Data and methods: What data is used?

Data and methods: How is Föhn identified?

Results: Föhn vs no Föhn

Results: Observations vs Model

Results: The Role of Clouds

Thank you and credentials!

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Background:

Föhn:

The Antarctic Peninsula is one of the fastest warming regions in the world.

There are regional and seasonal differences, with winter winter warming strongest on the western side, and strong warming in summer and autumn on eastern side.

A mechanism to explain these seasonal and regional differences are Föhn winds.

A positive trend in the Southern Annular Mode (SAM) supports this. A stronger SAM index leads to stronger circumpolar westerly winds. Instead of being blocked by the mountain range, these stronger winds are more likely to overcome the barrier. This in turn leads to Föhn effect on the lee side of the Antarctic Peninsula.

Larsen Ice Shelves:

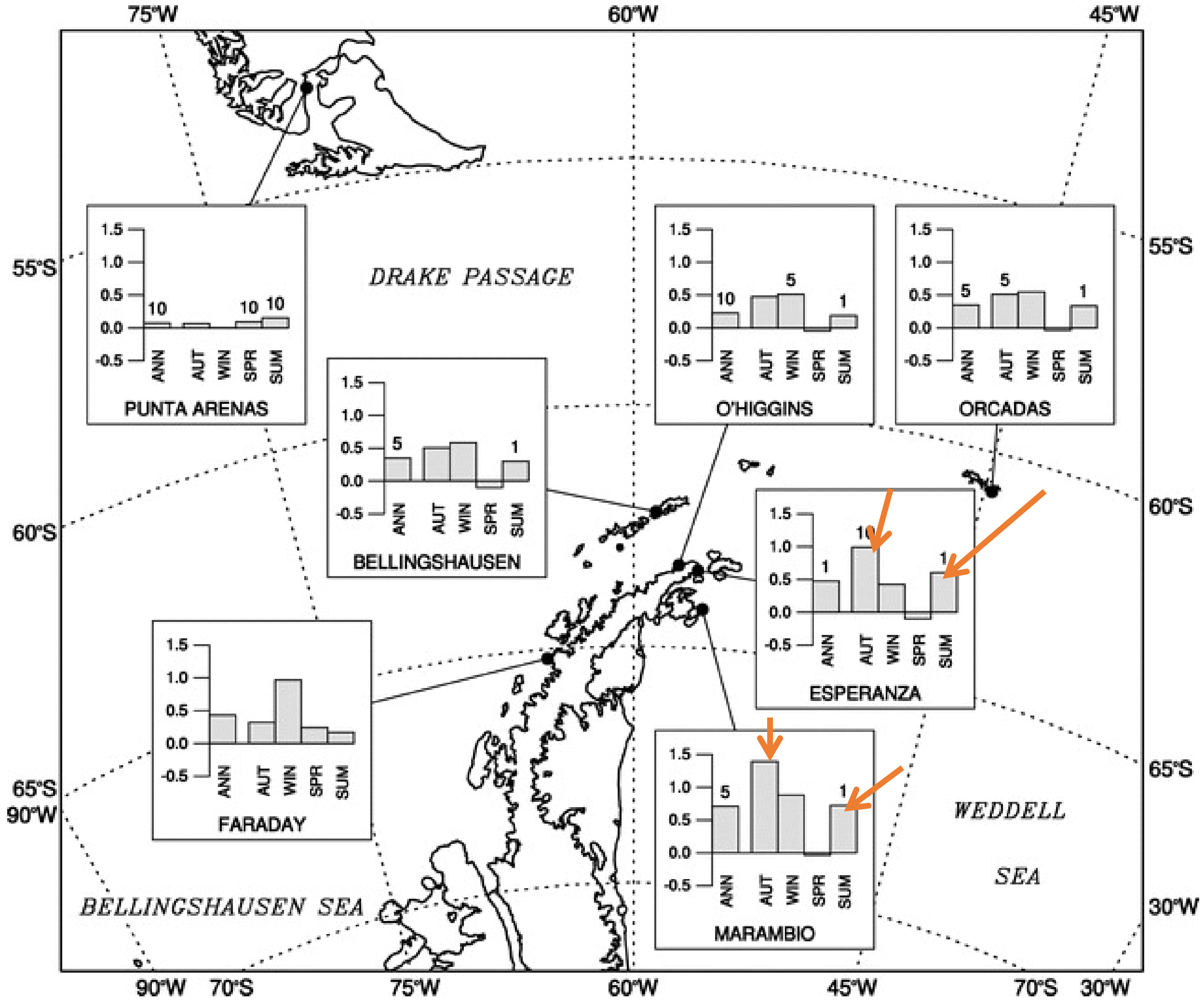
The dominant feature on the leeside of the Antarctic Peninsula is the Larsen Ice Shelf.

Its northern parts Larsen A and Larsen B have collapsed in 1998 and 2002 respectively.

Warm, dry Föhn winds are thought to have provided the atmospheric conditions that have led to the collapse through hydro-fracturing (Scambos et al., 2004).

Föhn winds are a major influence on the stability of the remaining Larsen C ice shelf.

- ❄ Antarctic Peninsula has warmed more rapidly than global average
- ❄ regional and seasonal differences
- ❄ winter warming strongest on the western side
- ❄ strong warming in summer and autumn on eastern side



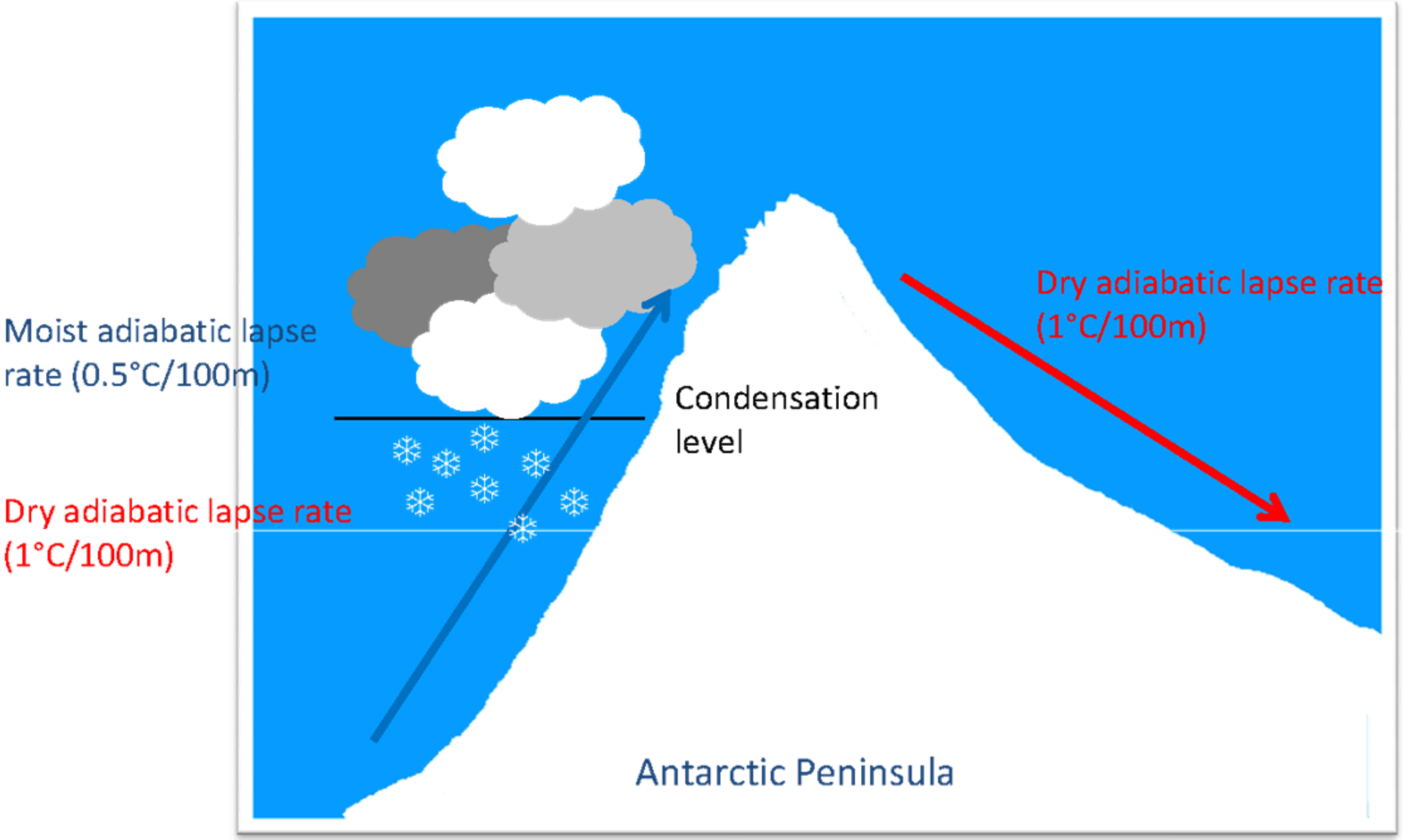
Marshall et al (2006), Journal of Climate

Three Föhn mechanisms:

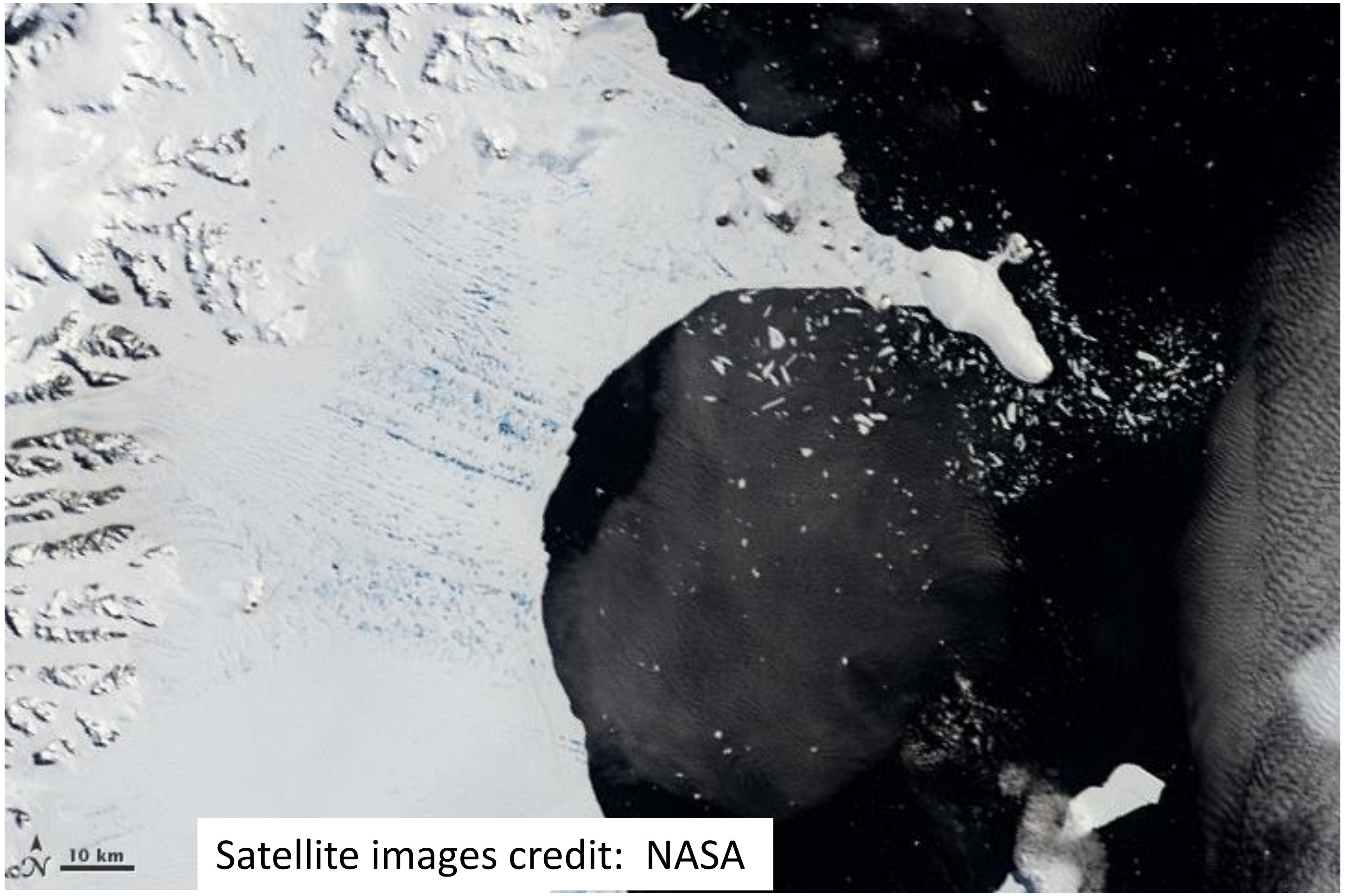
- ❄ Latent cooling and precipitation
- ❄ Isentropic drawdown
- ❄ Mechanical mixing

(Elvidge and Renfrew, 2016)

Föhn effect via latent cooling and precipitation



Animation of the collapse of Larsen B Ice Shelf collapse over the period from Jan 31st to April 13th 2002

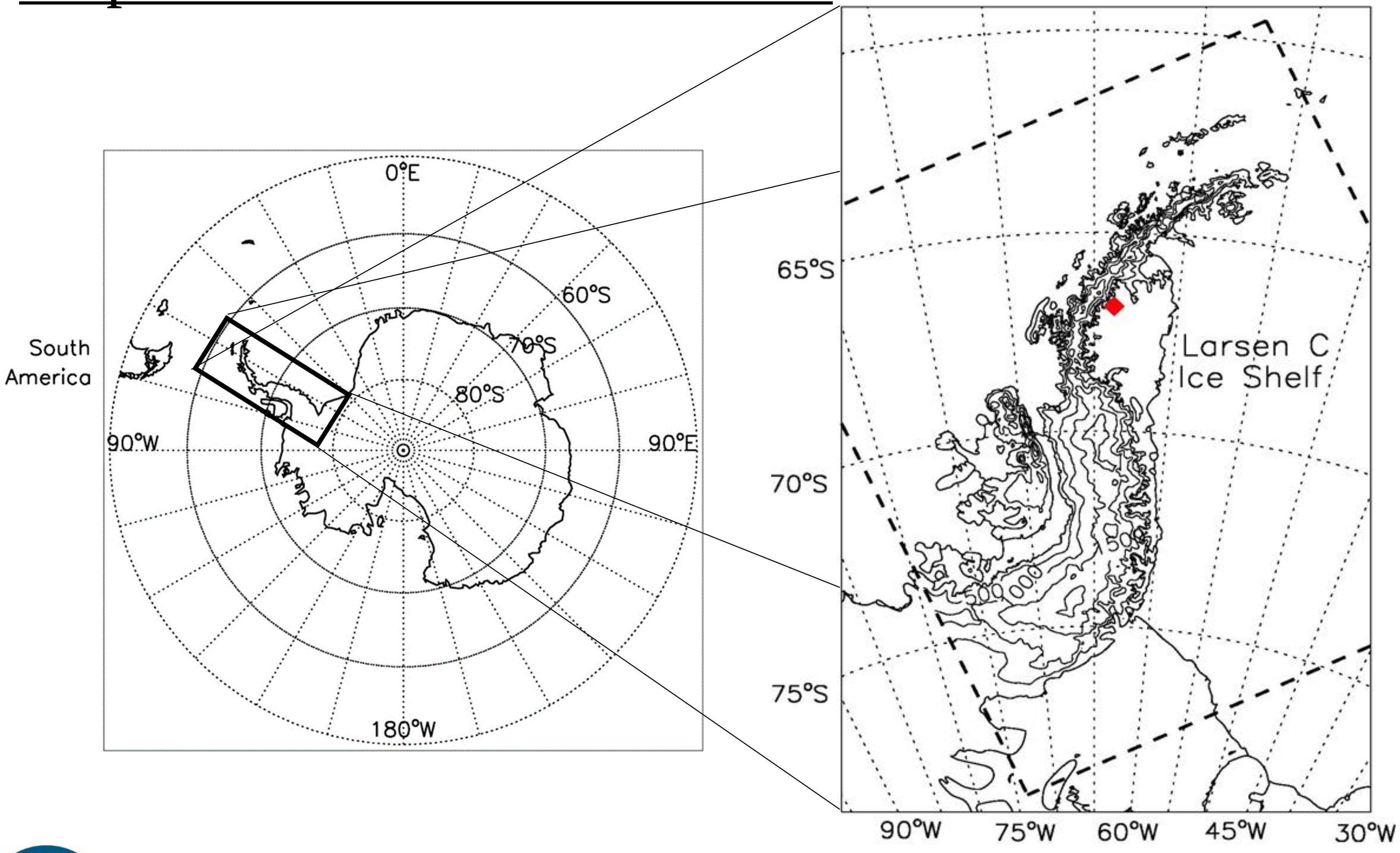


Satellite images credit: NASA

It is widely accepted that hydrofracturing, the widening of crevasses due to the excess hydrostatic pressure exerted by meltwater which accumulates inside them, is the mechanism behind the break-up of the Larsen A and Larsen B ice shelves (e.g. Scambos et al, 2004).

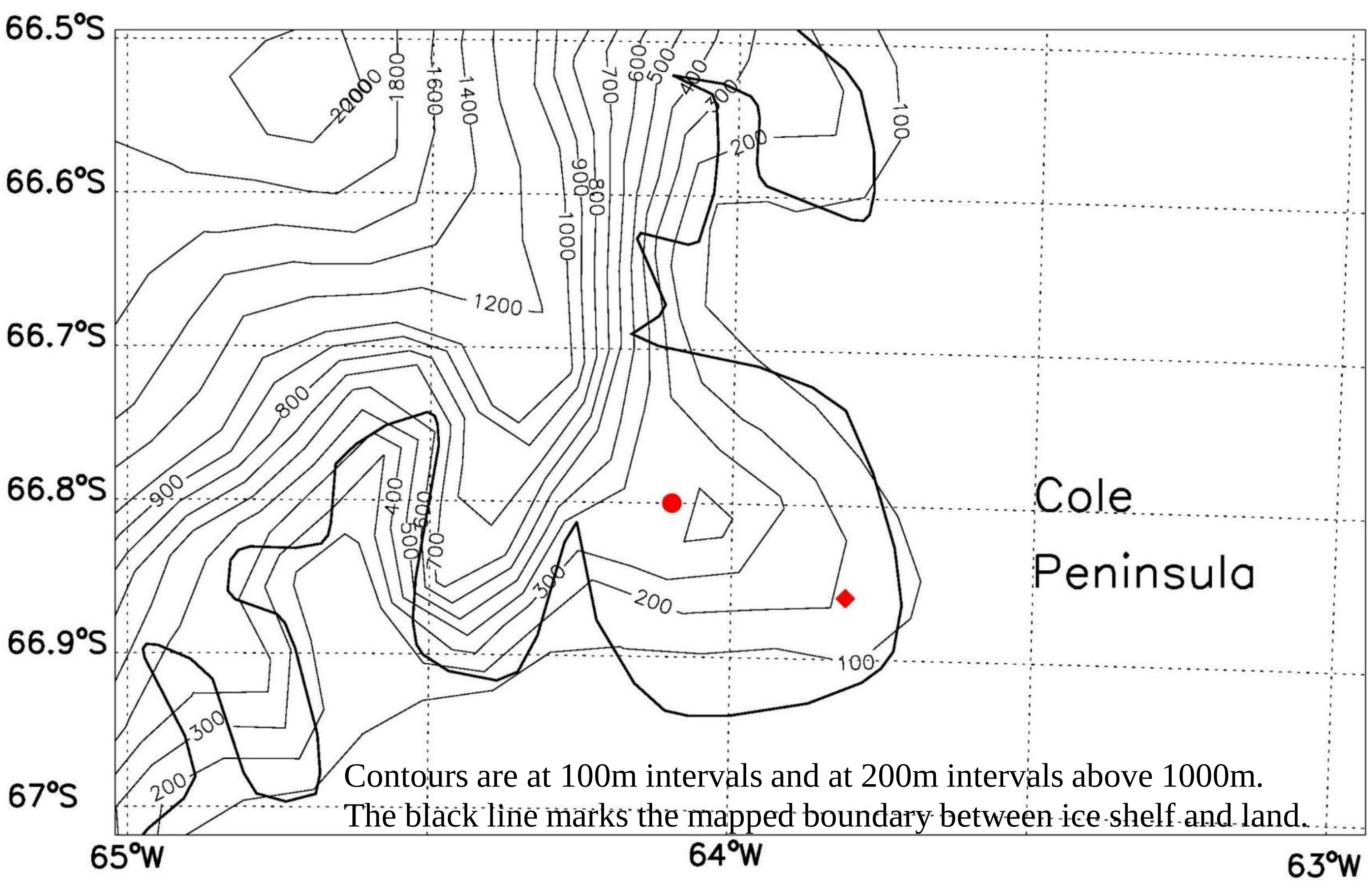
Location

Map of the Antarctic Peninsula



Dashed lines mark the model domain of the Antarctic Mesoscale Prediction System.

The red diamond marks the location of Cole Peninsula AWS.



Contours are at 100m intervals and at 200m intervals above 1000m.
The black line marks the mapped boundary between ice shelf and land.

● location used for comparison
◆ AWS location in model

The model orography in the area of Cole Peninsula differs from reality.

The diamond marks the GPS location of the AWS projected onto model orography. The circle marks the location chosen for the comparison between measurements and model output, as it more closely resembles the AWS location in reality (424m asl).

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Data sets

Observations

- Automatic Weather Station at Cole Peninsula
- Temperature & Relative Humidity
- Wind speed and direction
- Air pressure
- Solar powered with battery back up
- Data transmission via Iridium short burst messages
- 10 min measurements collated to six hour mean values

Data available at: https://catalogue.ceda.ac.uk/
(search for “AWS”, “Antarctic Peninsula”

Model data

- Antarctic Mesoscale Prediction System AMPS
- Weather, Research and Forecasting model WRF
- 5km resolution
- 44 model levels
- output of initialisations at 00UTC and 12UTC combined to 6 hourly artificial time series.

Data available: www.earthsystemgrid.org

Automatic Weather Station at Cole Peninsula

Operational from Jan 21st 2011 – Jan 4th 2012

Location: 66°51'48''S, 63°48'39''W
424m above sea level

Photo credit: Andy Elvidge

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Automatic Weather Station at Cole Peninsula

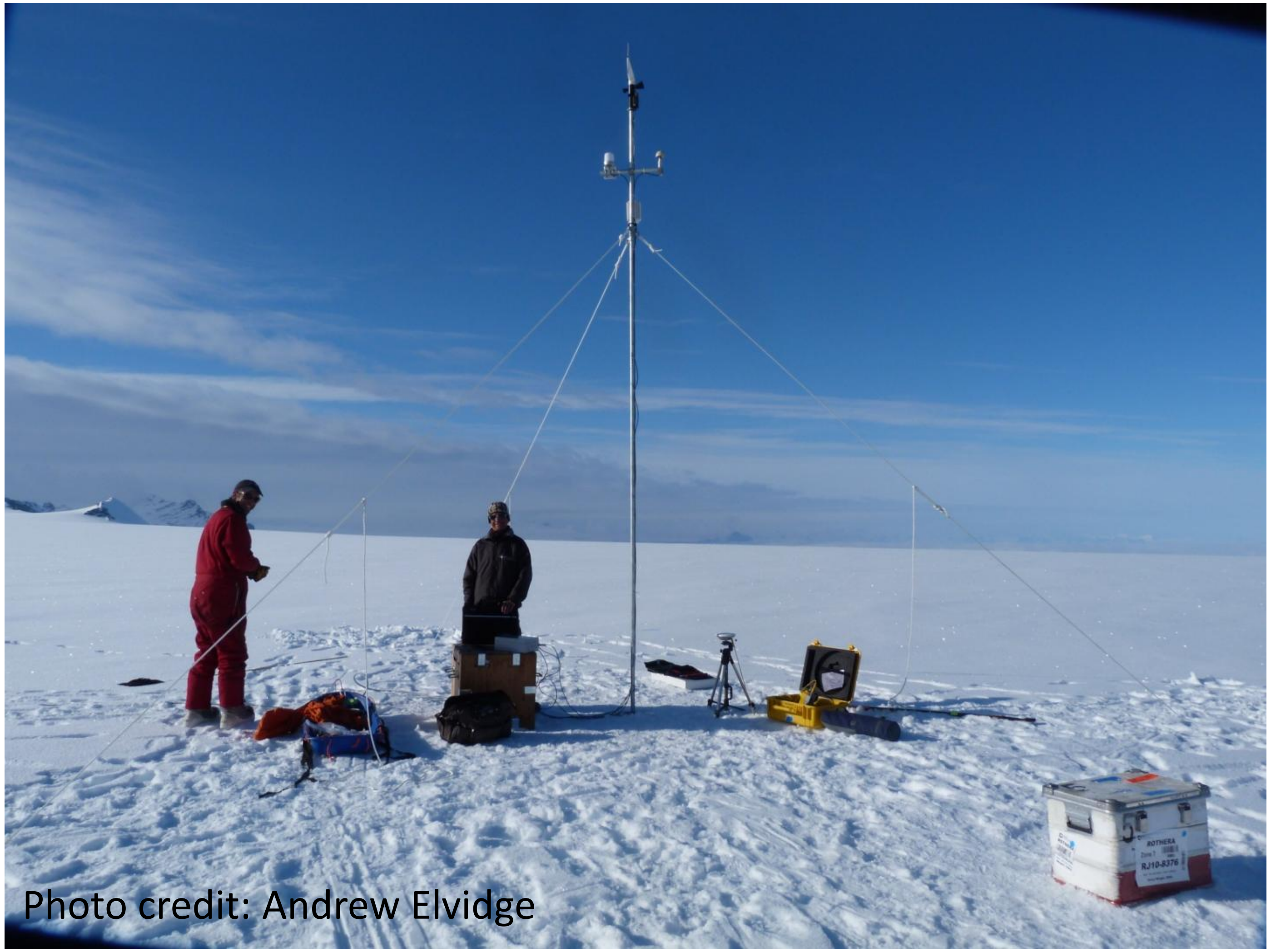
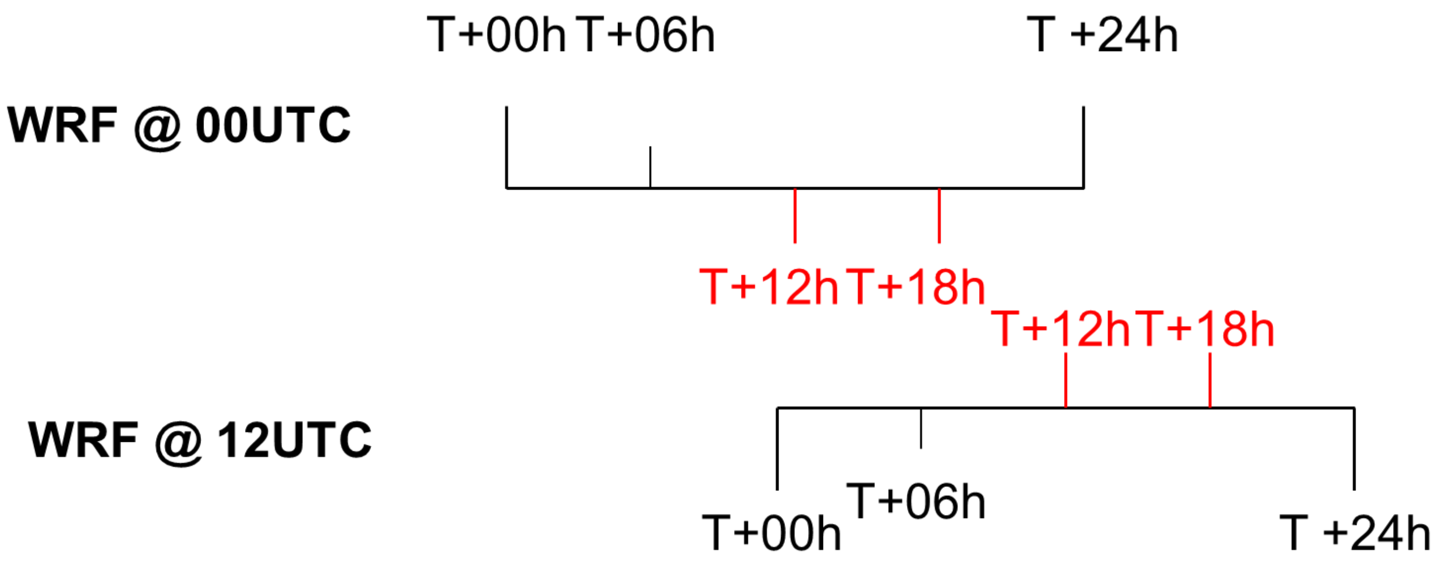


Photo credit: Andrew Elvidge

- RM Young prop vane (4m above surface)
- GPS and Iridium antenna at 3.5m
- Humicap HMP45D at 3m
- Pressure sensor buried with logger box at the foot of the AWS.

Schematic of how the two daily initialisations of the model runs were combined into a 6 hourly time series. E.g. Seefeldt and Cassano (2008) have shown that up to 12 hours are needed for the model to adjust to topography.



How do we identify Föhn cases?

In the observations:

We use thresholds empirically obtained from measurements during an intensive aircraft field campaign.

either RH < 65%
or RH < 70% and 3K temperature increase or decrease over 12 hours.

For the comparison only data points are considered that are identified as Föhn in observations and simulations.

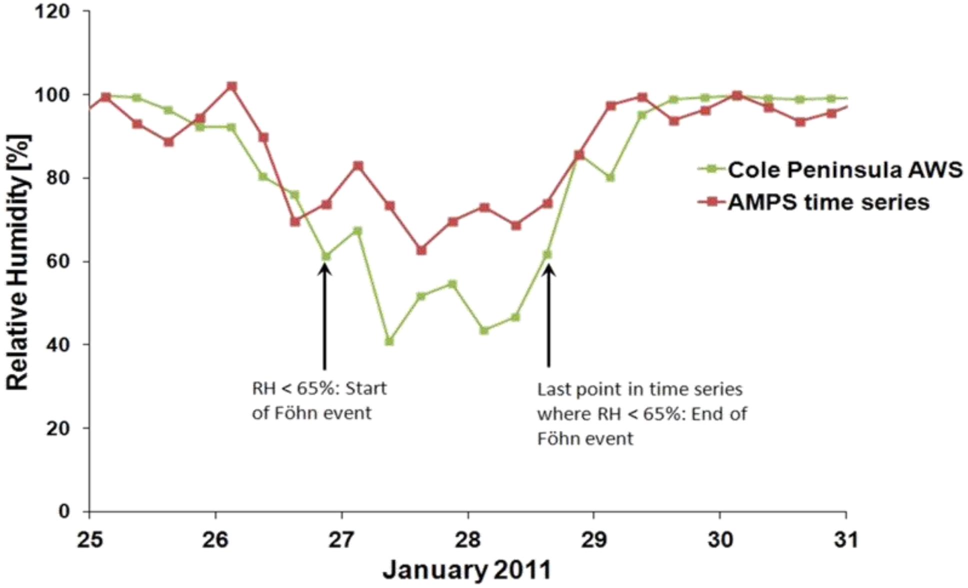
In the model simulations:

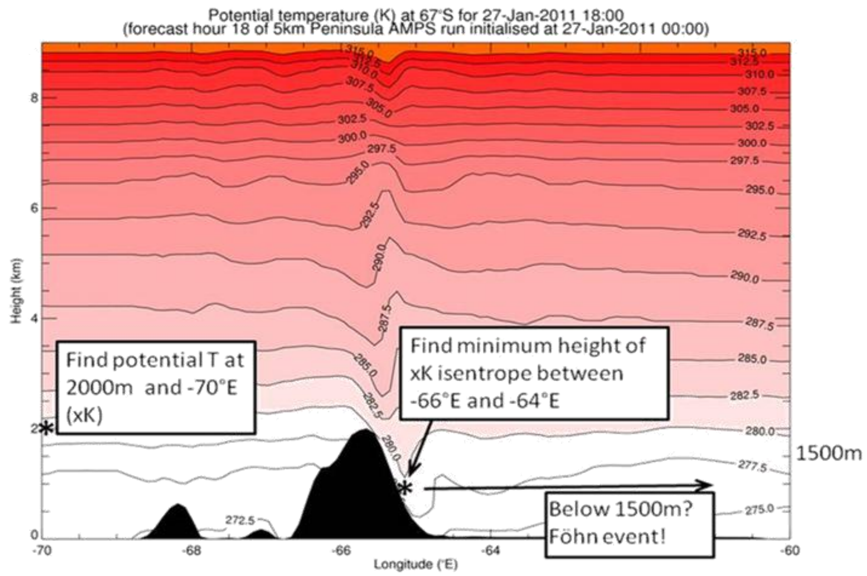
We extract the potential temperature at 70°W and 66.8°S (to match the latitude of the AWS) at 2000m height.

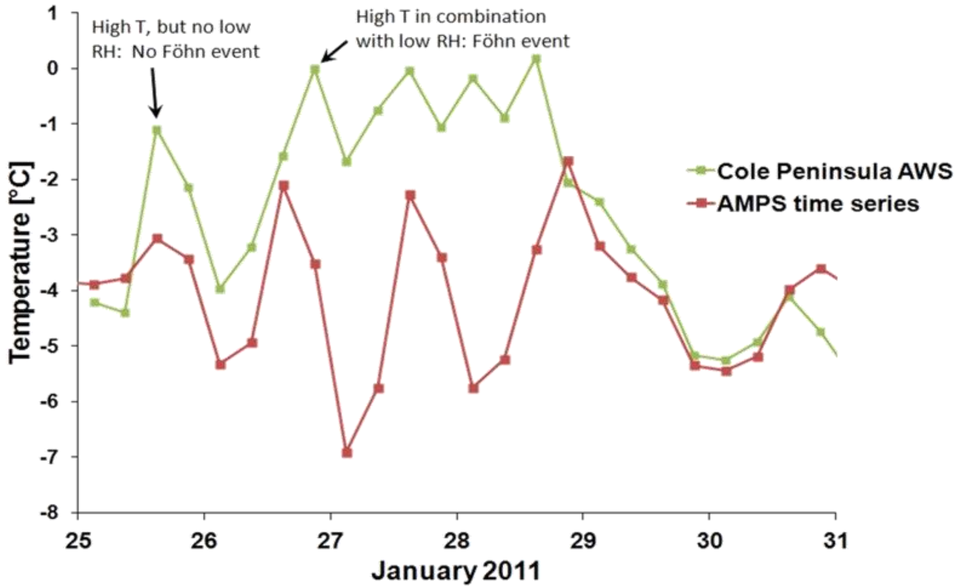
The point at 70°W is about one Rossby radius upwind of the AP, and therefore can be considered representative of the undisturbed upwind flow under westerly conditions.

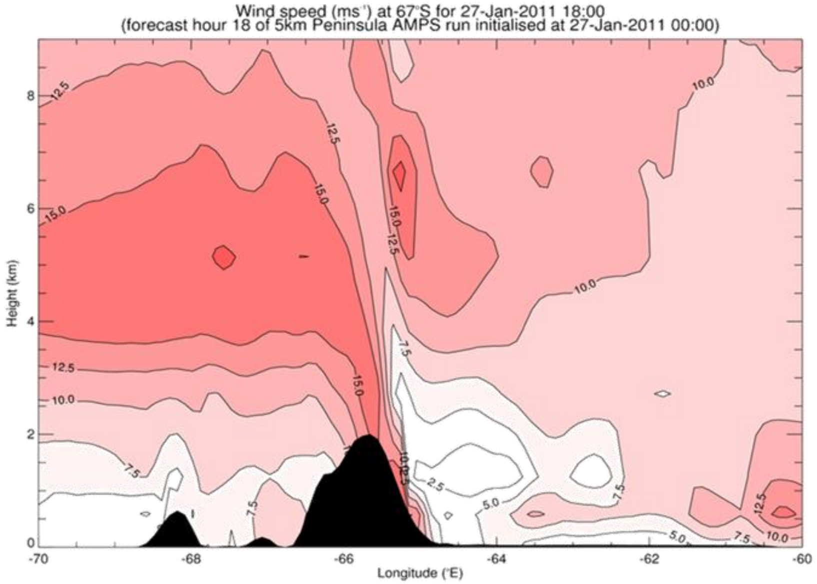
Then the minimum height of this potential temperature value on the lee side of the mountains along 66.8°S was determined in the section between 64°W and 66°W.

If this minimum height was lower than 1500m (signifying a drawdown of at least 500m), this data point was classified as Föhn.


Relative Humidity [%]
January 2011
Cole Peninsula AWS
AMPS time series
RH < 65%: Start of Föhn event
Last point in time series where RH < 65%: End of Föhn event


Potential temperature (K) at 67°S for 27-Jan-2011 18:00
(forecast hour 18 of 5km Peninsula AMPS run initialised at 27-Jan-2011 00:00)
Height (km)
Longitude (°E)
Find potential T at 2000m and -70°E (xK)
Find minimum height of xK isentrope between -66°E and -64°E
1500m
Below 1500m? Föhn event!


Temperature [°C]
January 2011
High T, but no low RH: No Föhn event
High T in combination with low RH: Föhn event
Cole Peninsula AWS
AMPS time series

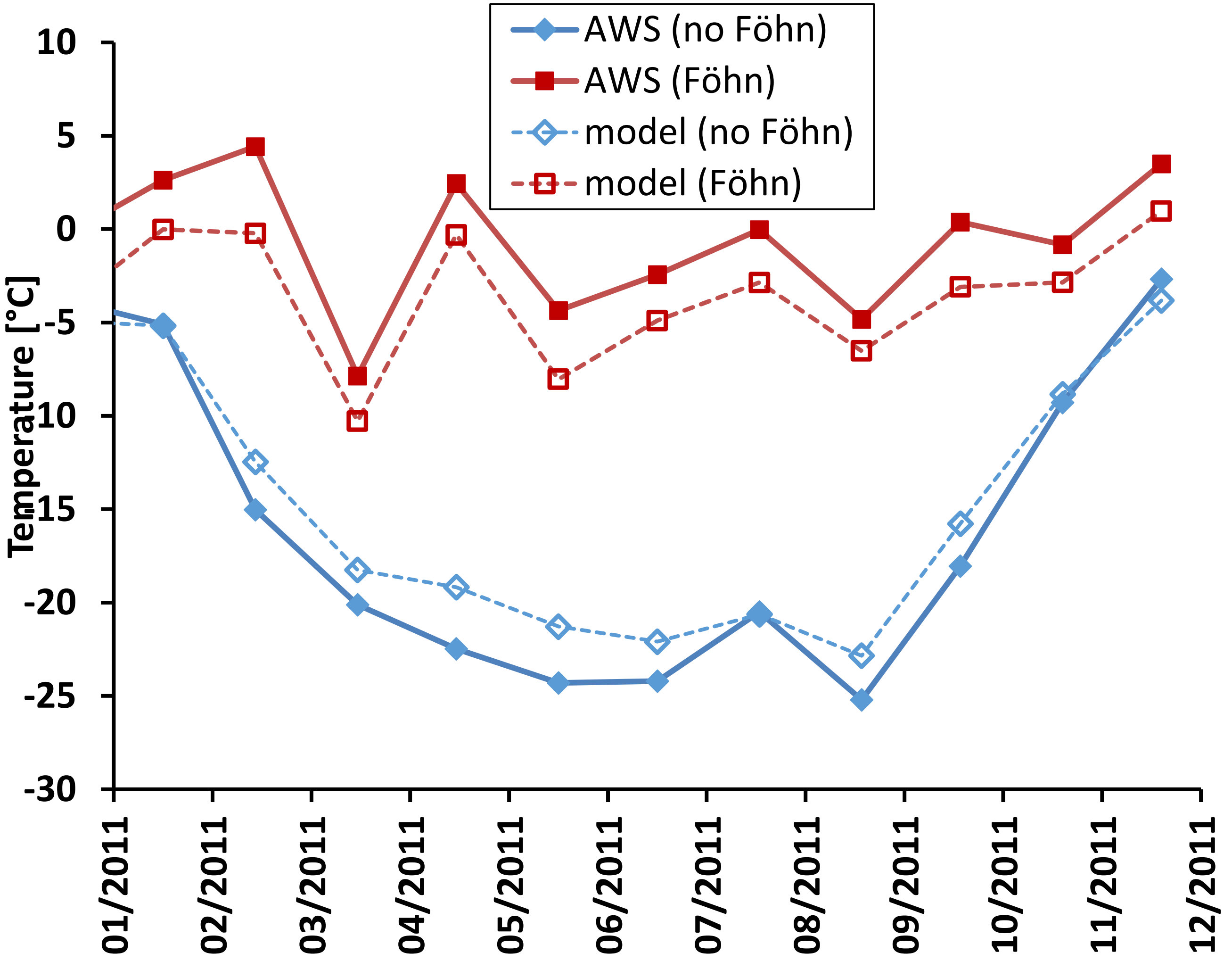

Wind speed (ms⁻¹) at 67°S for 27-Jan-2011 18:00
(forecast hour 18 of 5km Peninsula AMPS run initialised at 27-Jan-2011 00:00)
Height (km)
Longitude (°E)

Observations vs simulations

- ❄ AMPS overestimates the near surface Temperature
- ❄ AMPS underestimates near surface Relative Humidity
- ❄ Wind speed and direction do not agree that well. In such complex terrain this is not unexpected.
- ❄ **Generally the model does a good job simulating meteorological conditions at Cole Peninsula**

n = 1352	T [° C]	p [hPa]	RH [%]	u [m/s]	v [m/s]	ff [m/s]
AWS	-12.3 ±10.3	942.7 ±11.9	84 ±23	1.5 ±4.2	-1.8 ±1.7	3.9 ±3.3
AMPS	-11.8 ±8.6	942.5 ±12.2	81 ±19	3.8 ±4.5	1.2 ±4.9	6.6 ±4.7
Mean bias	0.5	-0.2	-2	2.3	3.0	2.7
Correlation	0.93	0.99	0.76	0.28	-0.07	0.49
RMSE	3.88	1.59	15.6	5.68	6.07	5.05

Temperature



- generally model and observations agree well
- for „no Föhn“ data points the model **over**estimates temperature
- for „Föhn“ data points the model **under**estimates the temperature

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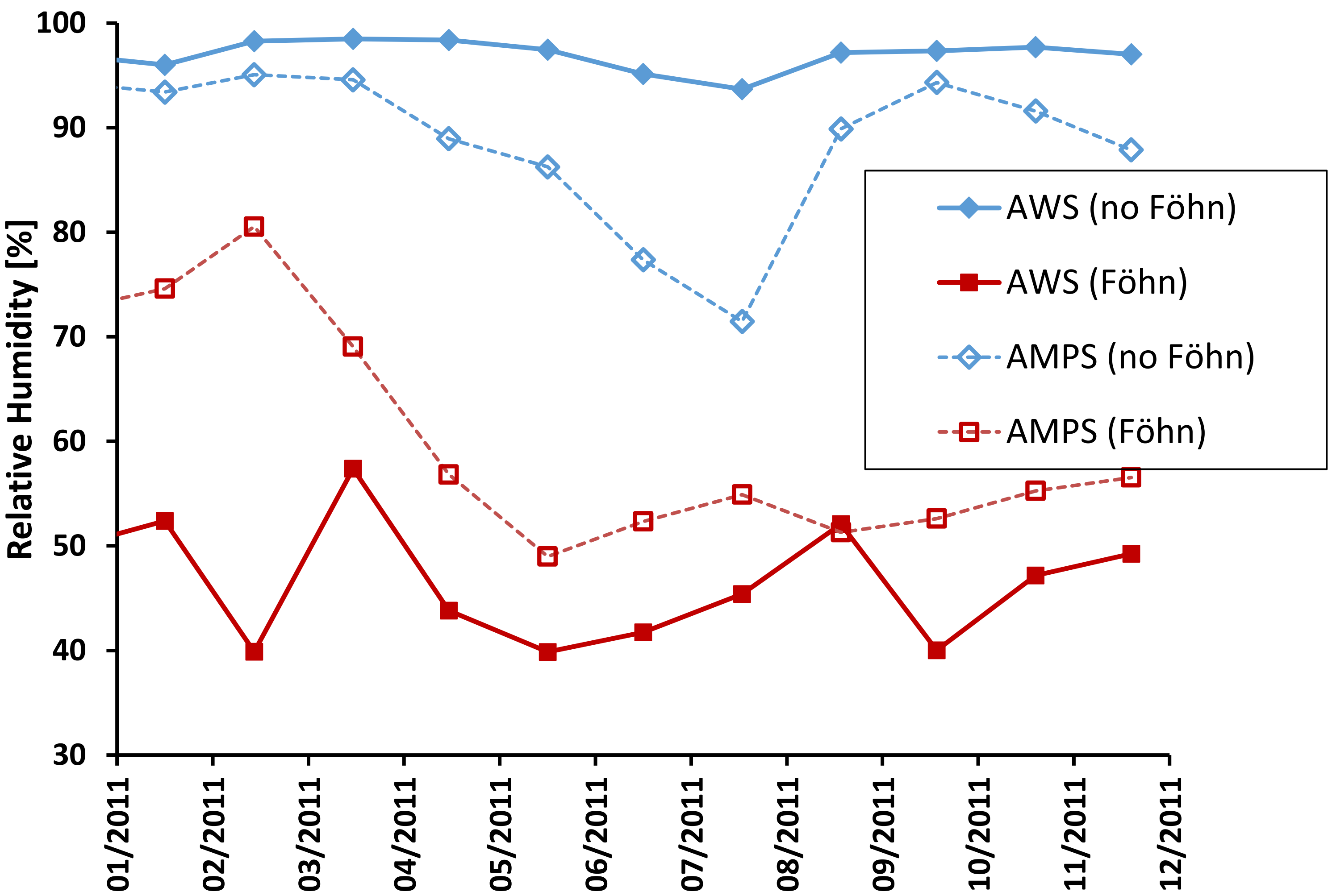
Relative humidity



- generally good agreement, less so in winter
- for „no Föhn“ data points the model **under**estimates RH
- for „Föhn“ data points the model **over**estimates RH

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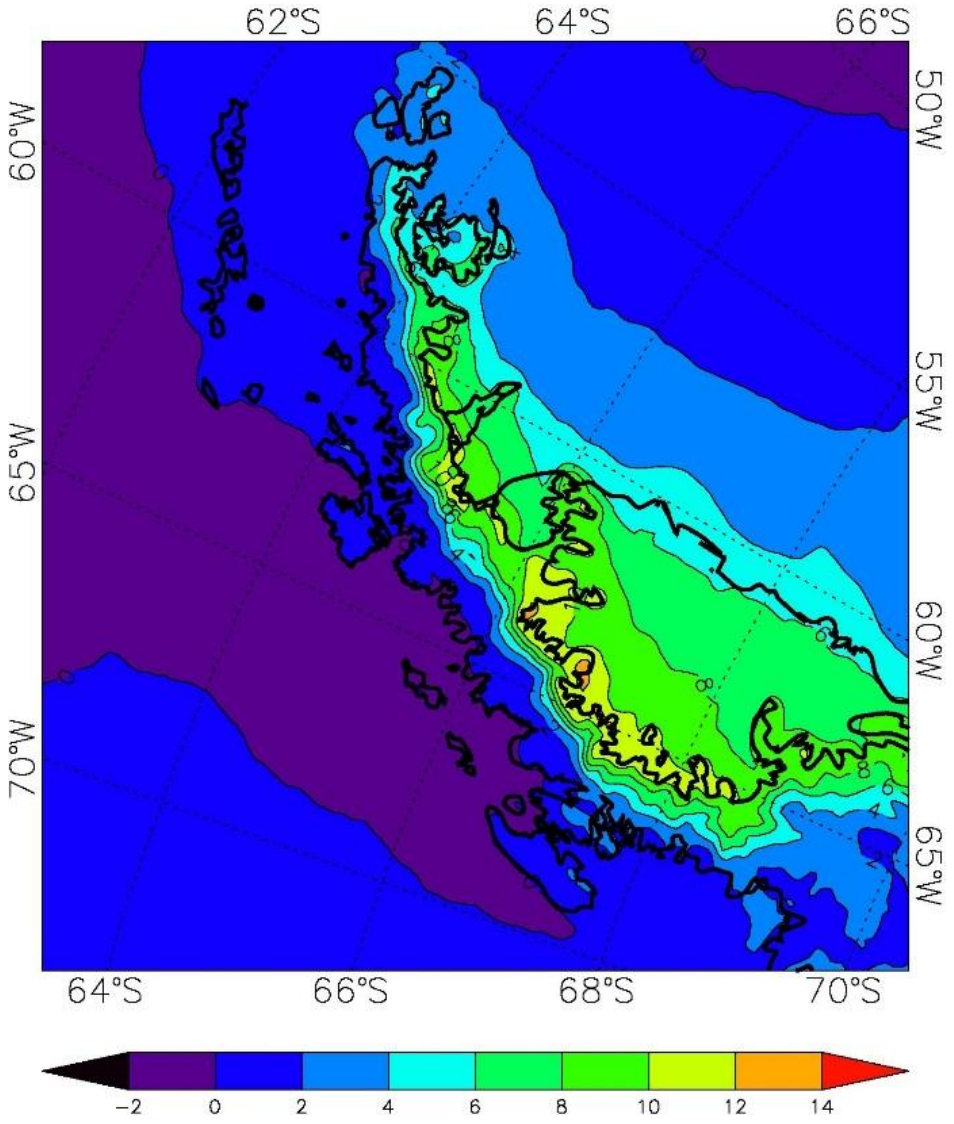
Föhn vs no Föhn

Föhn versus no Föhn

- Significantly higher T during Föhn than no Föhn in both data sets
- Significantly lower RH during Föhn than no Föhn in both data sets
- AMPS underestimates T during Föhn
- AMPS overestimates RH during Föhn

	T [° C]	p [hPa]	RH [%]	a [g/m^3]	u [m/s]	v [m/s]	ff [m/s]
no Föhn (AWS):	-16.9± 8.8	942.9±11.8	97 ± 5	2.9±0.8	2.3 ± 4.0	-1.7 ± 1.5	3.8 ± 3.4
Föhn (AWS)	-0.4 ± 4.9	943.4 ±11.4	46 ± 13	2.2±0.6	-0.9 ± 2.6	-2.2 ± 2.6	3.4 ± 2.7
Difference (AWS)	16.5K	0.5	-51	-0.7	-3.2	-0.5	-0.4
no Föhn (AMPS):	-15.3 ±7.9	942.6 ±12.0	91 ± 13	1.5±1.0	2.7 ± 2.7	3.0 ± 3.7	5.4 ± 3.0
Föhn (AMPS):	-3.2 ± 4.6	942.7 ±11.8	60 ± 13	2.3±0.9	7.6 ± 7.2	-4.4 ± 4.5	10.4 ± 7.4
Difference (AMPS)	12.1K	0.1	-31	0.8	4.9	-7.4	5.0



Difference in modelled 1.5 m temperature (K) between composites for Föhn and no Föhn conditions.

Up to 12K difference in surface near air temperature are shown in model output between Föhn and no Föhn conditions.

The largest difference occurs at the foot of the Antarctic Peninsula mountains.

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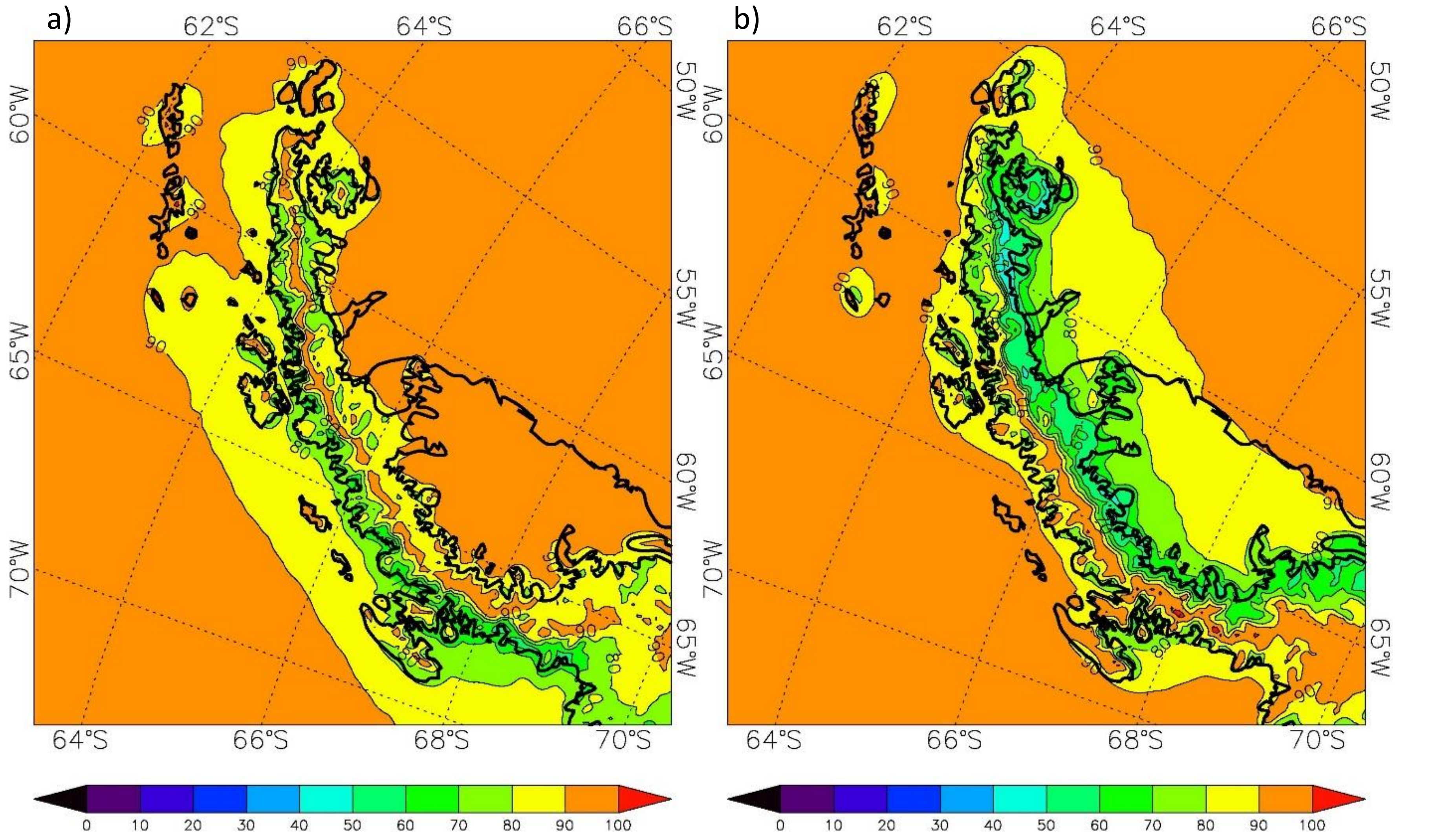
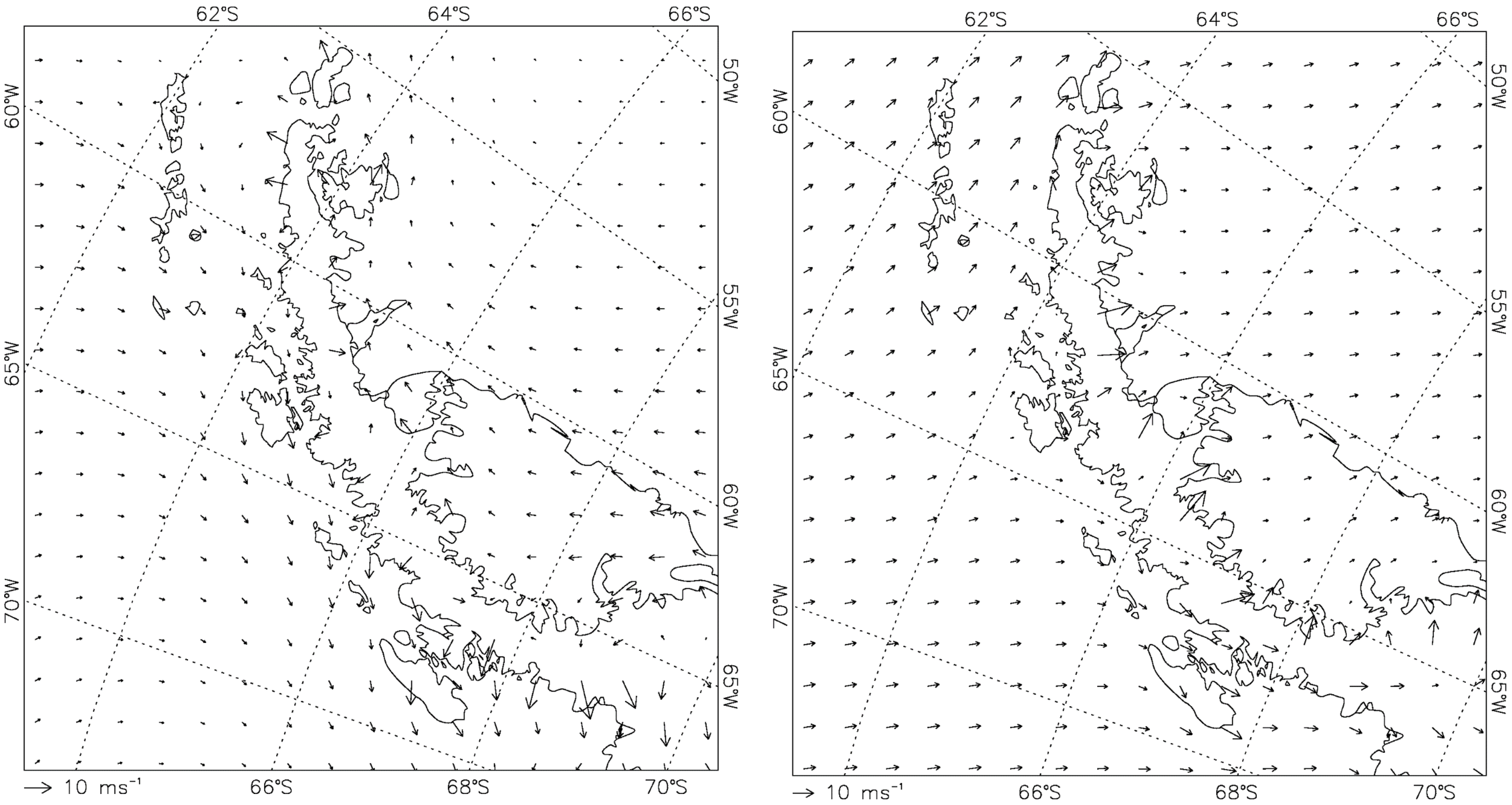


Composite plots of relative humidity with respect to ice for non-Föhn (a) and Föhn (b) conditions based on AMPS data (lowest model level, ~16m).

Simulated RH shows a stark contrast between Föhn and no Föhn conditions.

Largest differences are found in the direct lee of the spine of the Antarctic Peninsula mountains.



Composite plots of the wind speed and direction at 10m height for non-Föhn (left) and Föhn (right) conditions during 2011, based on AMPS data.

The blocking effect of the mountain range during normal conditions is clearly visible (left).

Strong cross barrier winds from NW to W dominate during Föhn conditions (right).

Clouds

The Role of Clouds

Surface energy balance comparison by King et al. (2015) indicate WRF simulates

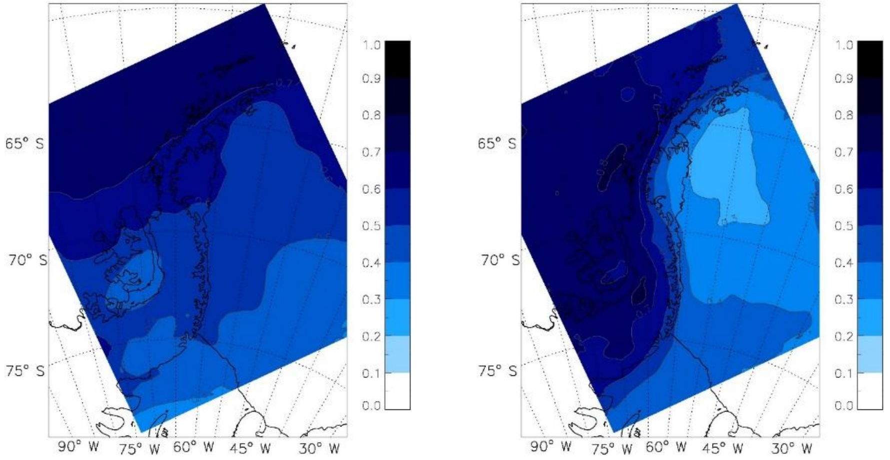
- low level clouds that are optically too thin.

Experiments by C. Listowski show that independent of cloud scheme, the model

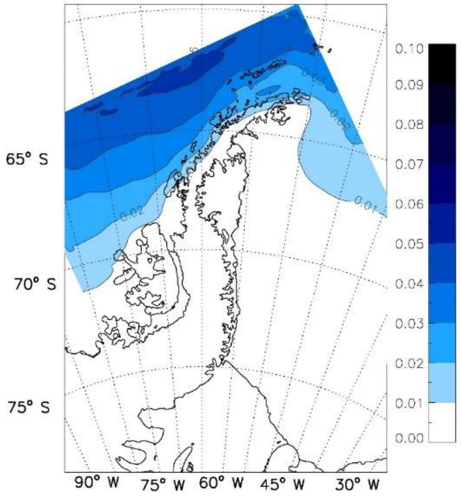
- underestimates the fraction of low level cloud, on the windward side. Hence the
- cloud clearing effect of Föhn is likely smaller, and thus
- the effect on T and RH is also reduced.

Possible reason is the absence of any liquid water in clouds in the area in the simulations.

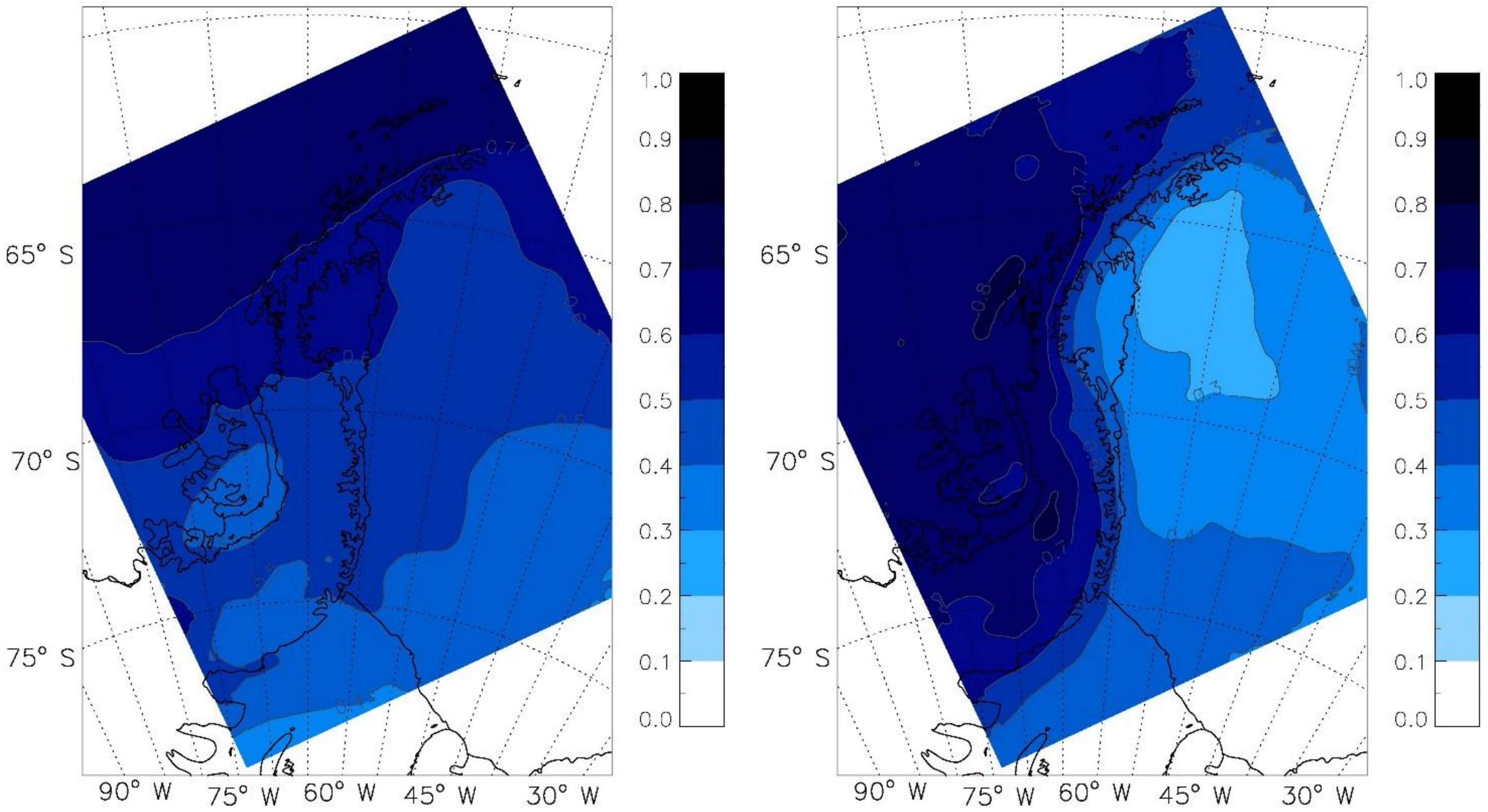
Studies by Grosvenor et al. (2012) and Lachlan-Cope et al. (2016) have shown that, in reality, a significant amount of liquid water is present in clouds on both sides of the Antarctic Peninsula.



No Föhn Cloud fraction Föhn



Liquid cloud water (all data points)



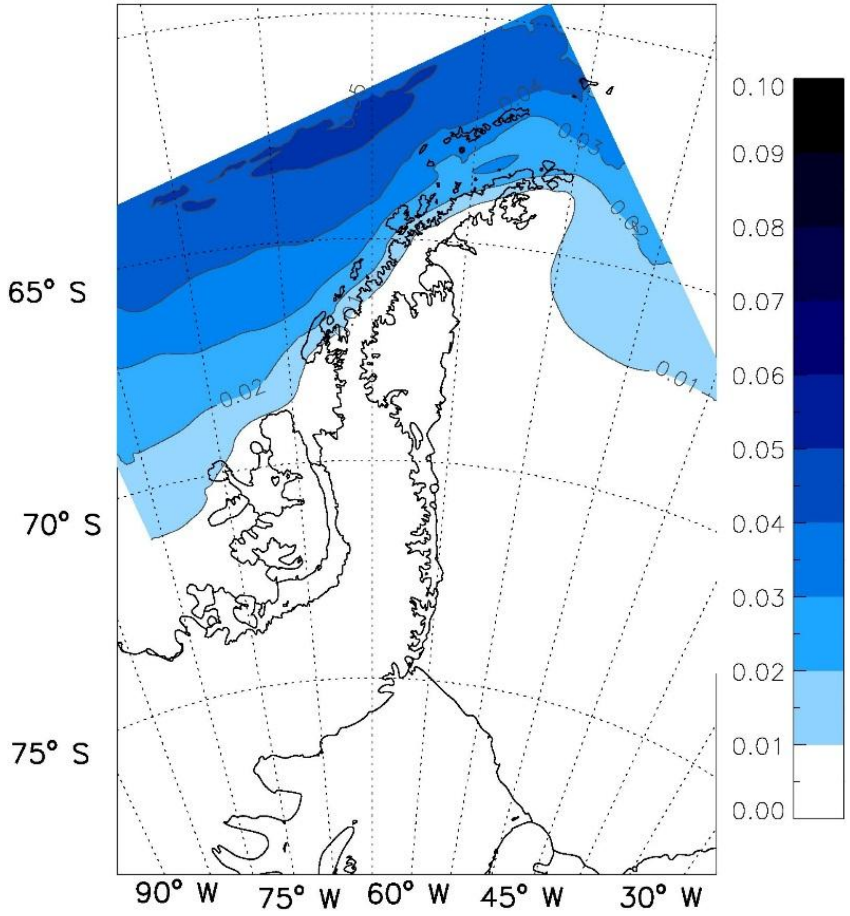
This comparison of simulated cloud fraction between no Föhn and Föhn shows that the model generally reproduces a cloud clearing effect through Föhn in the lee of the mountain range.

Composite plots of cloud fraction for non-Föhn (left) and Föhn (right) in AMPS in 2011.

The model though does not simulate any liquid cloud or rain water south west of a line from 70°S and 75°W to 65°S and ~62°W.

According to the model all clouds over our study area are ice clouds, which are optically thinner than liquid water or mixed-phase clouds with the same water content.

Studies by Grosvenor et al. (2012) and Lachlan-Cope et al. (2016) have shown that, in reality, a significant amount of liquid water is present in clouds on both sides of the Antarctic Peninsula.



Many thanks for your interest!

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