2. WEATHER CONDITIONS (DWD)

Robert Hausen[1], Christian Rohleder[1] [1]DE.DWD

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A stable high pressure system with a maximum surface pressure partly above 1020 hPa near the North Pole was weather-determining in the week of the exchange (28th of February - 05th of March). In fact, it was the coldest period of the entire MOSAiC expedition lasting until the mid of March with only short interruptions. The temperatures exceeded values of -40 degrees centigrade in 2 meters height (record in Met-City with -42.3 degrees on the 4th of March). The absolute minimum of the sensors on the bridge (at 29m height) was recorded on the 10th of March with -39.5 degrees centigrade. Due to a very strong inversion (temperature increase with height) close to the surface, the temperatures in the crow's nest (29m) reached values of around 5 Kelvin higher than in 2 meters. The cold was threatening cargo and scientific operations and it was challenging for people. Despite almost calm conditions the wind chill was between -50 and -60 degrees (minimum -61.2 degrees) causing frost nibs and bites within only a few minutes on unprotected areas of skin. Additionally, the Pistenbullies and Skidoos were not working properly anymore, the oil got solid and stuck. Helicopters were not able to fly at temperatures below -35 degrees. Besides, crane operations were stopped below -30 degrees, because the guarantee was not valid under those conditions.
After the 7th of March the weather pattern changed. Low pressure systems gained the upper hand and a dominant track of the cyclones from Svalbard further to the East was predicted by the models, initially. The consequence for our weather would have been a basically undisturbed cold backside. With the event approaching, forecast models tended to continuously move the track further westwards, finally rotating very close to our actual position (88 N 30 E). The outcome was the advection of milder maritime air masses leading to clouds formation, winds and "warmer" temperatures above -30 degrees. In terms of flight operations it was very challenging as remnants of a former occlusion dissolved over the forecast area with rapidly changing weather conditions. Sometimes it took only a few minutes between broken Stratocumulus with bases of 1000 FT above the ground with light snowfall and visibilities around 3 km on the one hand and scattered Stratocumulus in 4000 FT with very good visibility and contrast on the other hand.
In the mid of the month a well-defined storm established and covered almost the whole Arctic. Although our location was very close to the strongest temperature gradients (air mass boundary), winds from north to northwest indicated more or less the side to the rear flank of the storm. But the multiple back band occlusion suppressed the "typical" backside weather. Instead we had to deal with low clouds, light snowfall and poor visibilities. Fortunately, our position was close enough to the center of the storm in order to avoid the heaviest winds. In the end the maximum averaged wind speeds were limited to 6 Bft combined with heavy drifting snow.
As the low slowly moved towards the South via Nowaja Semlja, we experienced the strongest gradients on its northern flank on the 15th of March. In this context, longer lasting stormy winds with speeds of 14 to 18 m/s (Bft 7 to 8) and gusts around 20 m/s (Bft 9) from northeast were the consequence. At the same time our drift to the south accelerated and we reached drifting velocities of up to 0.8 knots.

When the storm weakened in the beginning of the following week, we still experience partly whiteout conditions due to light snowfall despite decreasing wind speeds down to 22 knots.

With the dying storm also the pressure on the ice was released and a huge lead with open waters formed directly in front of Met-City towards easterly direction. Therefore, several gear and scientific equipment had to be rescued by helicopter as it was not possible anymore to reach the area on foot or skidoo.
After a short period of calm and good weather conditions with northerly flow, the next storm approached on the 19th of March. It developed in the entrance of the Bering Street and moved southwards. The values of the maximum wind speeds of this and the former storms were surprisingly constant with 7 to 8 Bft from northwest to west.
After the passage of the storm towards Franz-Josef-Land weak high pressure influence followed from 21st of March until 24th of March. At some point weak disturbances passed through, but we experienced good visibilities and no significant cloud formation which was favorable for intensive flight operations.
On the 25th of March the next storm formation occurred, this time coming from the south of Spitsbergen. These two types of the storm tracks describe here were the most common. Either a storm over the Atlantic Ocean took a swing via Svalbard or Franz-Josef-Land into our direction or it turned southwards from the Bering Street and passed over northern parts of Canada. No matter the track, it always caused a widespread storm field, horizontally extending over several hundreds of kilometers, which was very impressive. Thus it took a while until the winds died down and the blowing snow deposited again. Therefore it was important to take also the winds in the closer surrounding into consideration to forecast the development of the (flight-) visibility properly. The storm of the 25th of March was special and nasty in the sense that it regenerated consecutively due to numerous short wave troughs passing the main trough. Its influence on our weather ended in the course of the 29th of March.
The following event of temporary high pressure influence was not less impressive. The fog channel of our satellite recording device on board displayed a translucent, large extended (bright blue) area coming in from the northwest. A perpendicular view from the surface upwards corroborated a clear blue sky. However, it turned out that the sky was covered by a thin layer of low stratus between 150 and 200 FT above the ground. As the visibility above and below that layer was very good and flight operation were only planned very close to the vessel, there was no real danger (hardly any potential for icing). From the helicopters' perspective the Polarstern was not visible anymore above the cloud layer when choosing a flat-angular view.
But it took only a little while, before the next storm affected us as the month changed from March to April. Strong to stormy northerly winds pushed us further to the south and we crossed the latitude of 85 N. Within two weeks (25th of March until 06th of April) we even drifted more than 100 nautical miles, but the time with stormy wind speeds of 8 Bft was rather short in this time period. Nonetheless, we experienced more or less steady speeds of 6-7 Bft, which were sufficient to produce a lot of blowing snow with reduced visibilities around 1 km. As this event was not exceeding critical thresholds scientific activities on the floe remained basically unaffected – in contrast to the flight activities that all had to be postponed.

Afterwards, relatively high pressure with only weak disturbances (shallow troughs, benches of lower clouds in a parallel flow on the 9th and 10th of April, small upper level low on the 11th of April) caused prevailingly good weather conditions with weak to moderate winds (mainly from northwest), mostly good visibilities and noncritical ceilings above 1000 FT AGL. Easter passed by – similar as in Germany – friendly in terms of the weather, even though comparably cold with temperatures between -25 and -30 degrees. In that period, the ice situation consolidated and we did not experience new big cracks or leads.
New tension on the ice was expected on Easter Monday, the 13th of April, as a new storm approached from the east Greenland Sea towards Spitsbergen. We observed winds from southerly direction and from the ice edge (between Franz-Josef-Land/Spitzbergen and close to their west at about 80 N latitude / distance to Polarstern at this time almost 300 nm) that swept 6 meter high waves northwards. Confronted by this scenario becoming more realistic, the captain decided, that the Pistenbully had to be taken on board due to the threat of new cracks. As a consequence of that, the helideck was blocked and flight operations were temporarily interrupted, but weather conditions were not forecasted to be favorable anyway.

In the end strong southeasterly winds with means of 6 Bft led to a significant temperature increase up to -1.5 degrees on the 16th of April and the scientists in Ocean City reported suddenly rising water temperatures above -1.0 degrees. As the winds died down again old and partly new leads opened up. But it turned out that this was only the start of a new and even more impressive warming event from the south. While the surface-based air masses during the last event had their origin in the Barents Sea, that area was covered by a high pressure system this time on the 19th of April. On the other side, a complex low over the Atlantic Ocean was forcing a strong southerly flow even over the Greenland plateau. This process initiated the development of a low on the lee side north of Station North moving slowly further north towards the North Pole. Besides, a waving cold front formed parallel to the shore of east Greenland. Thus, the southerly winds were not only intensified, but also the passage of the cold front was delayed. In this context temperatures in 850 hPa (approx. in 1000 meters height) rose to values around zero degrees and due to a well-mixed boundary layer also the temperatures near the surface reached slightly positive values of +0.2 degrees for the first time of our leg (19th of April). Wet snow fell out occasionally of multilayered clouds with very low bases of only a few hundred feet. In the section of the warm air mass itself the precipitation process vanished and partly dense patches of fog passed through. In the evening hours of the 19th of April even some light drizzle was observed. It constituted the preliminary climax of the thaw.
On Monday, the 20th of April the next cold front passed us leading to a temperature drop to below -10 degrees. The associated snowfall became drier again. As the pressure rose steadily with 3 to 4 hPa per 3 hours at the same time, the northwesterly winds increased again. The deterministic models struggled with the formation of numerous new frontal waves, which were caused by a complex pattern of the geopotential in 500 hPa due to several interacting lows. Originally, it was anticipated that one core passed eastwards very quickly leading to a rapid improvement of the general weather condition in the course of that day. But model solutions varied a lot from run to run (consistency) and also among the different models. Once one run shifted the termination of the storm event to 6 hours later, another model denied that and vice versa. Finally, a strong tendency to a delay of the improvement of at least one day manifested not before two days before the event started. So, the storm with average wind speeds of high 8 Bft's and gusts up to 100 km/h (Bft 10) was weakening not before Tuesday evening, the 21st of April. That was of major importance as two MedEvac flights with TwinOtters from Station North were on the agenda in order to fly out 7 people.

Luckily, Wednesday the 22nd of April brought bright sunshine and the blowing snow ended as the winds decreased below 25 knots. After a final, successful inspection and flagging of the runway (about 400 m prepared by leg 2 people were still intact) flight operations worked safely in CAVOK conditions.
Afterwards, predominant high pressure influence favored by negative vorticity advection in upper tropospheric levels became dominant. As a consequence we experienced quite sunny and cold conditions with temperatures between -15 and -20 degrees until the 27th of April. This has been the part of leg 3 with the most stable and good conditions (view also statistics of landing conditions).
The weather situation with a southerly flow on the edge of a high pressure system east of us appeared once again on the 28th of April. Hence, the formation of another low close to the northern tip of Greenland started again. It was slowly moving to the North Pole until the end of the month. On its southern flank the progression of the cold front to the east was delayed due to several frontal waves. That is why a significant improvement of the weather did not take place before the beginning of May. There were not high wind speeds associated to that system (in maximum 6 Bft), but with the warm advection from the Atlantic Ocean we were faced nearly without exception with very high water contents in the clouds in lower levels as temperatures reached around -5 degrees. This fact resulted in very poor horizon and contrast conditions as soon as the sky was completely overcast. Compared to clouds with higher percentages of ice concentrations a translucent sun was not ensured anymore. In that context, we temporarily observed light drizzle. Additionally, it was the first time during our expedition that convective shapes in patches of broken Stratocumulus occurred after passage of the cold front – also successfully identified in satellite images. The boundary layer was well-mixed and gusts

exceeded more than 2 Bft on top of the average wind speeds, meaning that numerous gusts with 7 Bft occurred. Conditions (vertical profiles of temperature and humidity) resembled typical central Europe situations.
The first week of May provided no spectacular weather. The final warming of the lower stratosphere happened and the polar vortex disappeared. Usually, this event is correlated with the troposphere in such that severe storms become more unlikely. This is what we observed as we experienced shortly afterwards only weak pressure differences, basically embedded in a high pressure regime over Siberia. Mainly good flight conditions were only interrupted by critical patches of low stratus with bases between 300 and 500 FT above ground level and isolated patches of mist or fog. In the end it turned out another time, that one has to expect a few snowflakes out of nearly each compact low cloud patch whereas diamond dust is more common to fall out of medium level clouds and/or in environments with temperatures below -15 degrees.
As the end of our leg came closer, between 5 and 16 May, we picked up and rescued big amounts of the gear and technical equipment from the floe. About three weeks of interruptions were planned and some autonomously measuring instruments were left on the floe for Polarstern to take care of with the crew from leg 4 after the exchange near Spitsbergen. Helicopters were used again in order to evacuate the heavy huts and to do the final scientific flights. As usual, exactly during that busy time the weather conditions have been very challenging. At first, an almost stationary, intense low near Spitsbergen caused strong winds of 6 to 7 Bft from northeast and multilayered clouds with longer lasting snowfalls. Especially as the wind speeds exceeded the threshold of 25 knots drifting snow became blowing snow and in combination with snowfall at the same time we experienced whiteout conditions again.

During the weekend of the 9th/10th of May a shallow and weak ridge moved along from the north. For the further logistical planning this scenario played an important role, because the conditions were anticipated to be favorable enough for flight operations in the surrounding, and an immediate deterioration was expected afterwards related to a new low approaching from the New Siberian Island. Paradoxically the conditions in the high pressure regime have been rather poor with overcast Stratocumlus in 1000 to 2000 FT AGL and missing horizon/contrast. As the low approached on Sunday compensatory descending led to some gaps in the clouds. Although cloud type and ceiling remained more or less steady, the broken layer did not blog sunlight at all anymore and as a consequence horizon and contrast improved to a moderate, partly even good state. This facilitated many flight operations that day with logistical maneuver towards Met-City (tidy up the floe) as well as last science activities (e.g. laser scan and first operation of the helipod).
On Wednesday, the 13th of May, only a few days before the scheduled departure, a powerful storm hit us. The minimum pressure exceeded 965 hPa over Spitsbergen. In terms of extreme weather events during MOSAIC it was the dramatic end of the extended leg 3 beating all previous records. Compared to leg 1 with a maximum wind speed (average of 10 minutes) of 22.9 m/s (Bft 9) recorded on the 16th of November 2019, and leg 2 with 21.4 m/s (Bft 9) on the 1st of February, we easily exceeded those values with 25.1 m/s (weak Bft 10) in the morning hours on the 13th of May. At the same time, persistent easterly winds moved mild and maritime air masses towards the floe and cleared the entire cold pool over the central Arctic as well. In fact, this was the beginning of the summer season with temperatures between 0 and -4 degrees. Due to a positive radiation balance the lower troposphere was from now on also not able to produce even locally lower temperatures below -10 degrees anymore. Increasingly, break up of the ice – at the end also in the rather stable logistic area - led to an enhanced risk of fog. Due to safety reasons, it was decided to pick up most of the scientific gear after the storm.
On our journey to Svalbard an extended zone of high pressure caused only weak winds and enhanced risk of fog and low stratus. The temperatures remained in a range of about -5 degrees. Coming closer to the end of May a well-defined low pressure complex established from Iceland towards the Frame Street. Located in front of that system moderate winds from southeast came up and moved continuously mild air masses with origin west of the Hebrides

toward us. Thus, the temperatures rose to positive values with maximums around 2.5 degrees. The observed precipitation phase turned from solid into liquid more and more often. Melt ponds formed and the snow layer became heavier, but also thinner. It was essential to provide information concerning the ice situation based on satellite images in the visible channel with emphasized contrasts during that period of time. Unfortunately, cloudy conditions inhibited an undisturbed view to the surface for details very often.
In the evening hours of Tuesday, the 2nd of June, we reached the ice edge and the day after we entered the Isfjord in order to fulfill the exchange with leg 4 waiting on the research vessels "Sonne" and "Maria S. Merian". The weather-determining low close to the east of Svalbard caused northerly winds around 6 Bft, temperatures around the freezing point and occasional snow showers.

Finally, we would like to thank explicitly the Heli service, the nautical officers and the cruise leader as well as the team leaders for a successful co-operation based on trust and respect despite all the unexpected circumstances. That is nothing to take for granted and was highly appreciated.

Day	February	March	April	Mai
	DBLK	DBLK	DBLK	DBLK
1		M	p	m
2		G	p	g
3		m	m	m
4		G	m	m
5		G	m	m
6		p	m	m
7		p	g	p
8		P	m	p
9		M	m	m
10		P	g	m
11		m	m	m
12		p	m	m
13		n	m	p
14		m	m	m
15		p	p	g
16		p	p	m
17		g	g	m
18		m	m	
19		n	p	
20		m	n	
21		m	p	
22		m	g	
23		g	g	
24	p	m	g	
25	p	p	g	
26	m	m	g	
27	m	p	m	
28	G	p	p	
29	G	m	m	
30	x	m	m	
31	x	p	x	
good	2	5	8	2
marginal	2	13	14	12
poor/nil	2	13	8	3

Tab. 1: *Daily subjective assessment regarding landing conditions at DBLK MOSAiC-floe during leg 3, capital letter in case of temperatures below -35°C*