Hails in Ny Alesund, Svalbard atmospheric vertical structure and dependence on circulation

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Hails in Ny Alesund, Svalbard- atmospheric vertical structure and dependence on circulation

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Abstract

Hail observed at Ny Alesund, Svalbard in Arctic during December - February 2018-19 is examined along with the atmospheric circulation patterns. When hail was noticed, surface warming and southwesterly – westerly winds were noticed. Atmospheric circulation pattern was characterised by high pressure anomaly over northwestern Europe or in the North Atlantic and represented the first and third EOF of SLP anomalies north of 40N. EOF-2, even though, characterised by a high pressure anomaly over northern Europe (EOF-2) did not result in intense precipitation. Cloud as well as liquid water were higher/lower during EOF-1 and 3 / EOF-2 active phases. This is because winds travel over ocean collect more moisture as well as transport nucleating particles to Svalbard when EOF-1 and EOF-3 were active. At the same time, the West Spitzbergen current (WSC) induce a strong east west sea surface temperature (SST) gradient in the ocean west of Svalbard. A corresponding gradient in the atmospheric temperature is also maintained by the WSC in the west to east direction in the lower atmosphere. Moisture laden westerlies cross the SST gradient inducing strong frontal activity in the lower atmosphere resulting intense precipitation and hail. Human activities in Arctic as elsewhere is bound to increase. Hence, there is a need to study the intense precipitation in Arctic as well as its reasons as it can impact the Arctic environment and human activity. This calls for more continuous observations to clearly identify mechanisms and frequency of intense precipitation in the Arctic.

Introduction

In a warming climate climate hazards are expected to increase in intensity and frequency (AghaKouchak et al. 2020). Knowledge on increased precipitation and intensity are important in climate hazard mitigation. One of the important factors which lead to uncertainty in future trends in precipitation is the dynamics of intense events. The fraction of intense precipitation will increase due to rise in global temperatures (Bennett and Walsh 2015). Every 1°C rise in temperature the water holding capacity of atmosphere increase by 7% (U.S. Global Change Research Program 2009). Since the Arctic is warming at twice the global rate, extreme weather events are expected to impact the Arctic more. Global climate models (GCM) simulation for the Arctic suggests positive trends for precipitation, river runoff and evapotranspiration in the future (Rawlins et al. 2010). Under a pseudo global warming scenario intense precipitation increase due to enhanced saturation vapour pressure and follows the Clasius-Clapeoyrn relationship (Poujol et al. 2020). Synoptic circulation systems also impact the intense precipitation events. It is shown that convective precipitation is more sensitive to temperature change than stratiform precipitation (Berg et al. 2013). Lot of places over northern Eurasia has recorded increase in convective precipitation (Ye et al. 2017; Chernokulsky et al. 2019). In a changing climate, atmospheric circulation features are expected to change. One of the most conspicuous changes in the Arctic is the reduction in sea-ice area related to regional and global scale atmospheric circulation changes (Trapp and Hoogewind 2018). Even remote climate variability is also attributed to the large scale atmospheric circulation changes in high latitudes (Piper et al. 2019; Nuncio et al. 2020). An analysis of three decade long information, warm air advection intensified by North Atlantic Oscillation results in thunderstorm activity in Svalbard (Czernecki et al. 2015). Thus, large scale circulation governed by both remote and local drivers together with the thermodynamic response, intense precipitation events in the Arctic will be tough to predict.

One aftermath of intense precipitation events is the formation of Hails. Hail particles form when strong vertical motion in thunderstorms facilitate the accretion of super cooled liquid water. Large hails can inflict severe damage to property, while small hails can damage agriculture (Púčik et al. 2019). Hailstorm variability and climate change is a nascent field, not many studies are devoted to this. In the northern Europe, climate change is expected to increase hailstorms mainly due to the increase in low level humidity (Rädler et al. 2019). Tropical processes like ENSO is attributed with hail in United states (Allen et al. 2015). There are studies that link severe storms with NAO in Europe (eg. Miglietta et al. 2017). However, in Arctic such studies are limited. Severe convective storms (SCS) are the precursors for hails. Across the united states, increase in Convective Available Potential Energy (CAPE) is related to increase in severe thunderstorms (Chen et al. 2020). High instability and CAPE were attributed to a recent Canadian thunderstorm (Brown et al. 2020). The study also noted that the increase in CAPE is due to increase in low level humidity. However, occurrence of SCS is quite low in the Arctic. In the present study, we investigate occurrence of hail during 2018-19 December January February(DJF) in Ny Alesund, Arctic. The purpose of the study is to investigate occurrences of hail with atmospheric circulation patterns and examine atmospheric vertical characteristics during hail events.

Data and Methods

As a part of Indian Arctic program, an OTT parsivel is installed in Ny Alesund (Figure.1). It can detect eight types of precipitation types. It has less maintenance, and its installation and operation are easy. The OTT PARSIVEL^2 measures the amount of precipitation by measuring the particle size using a horizontal laser beam. To determine the particle speed, the duration of the signal is measured as soon as a precipitation particle enters the laser beam and ends when it has completely left the beam. The OTT Parsivel^2 detects Drizzle, Drizzle with rain,

Rain, Rain/drizzle with snow, Snow, Snow grain, Soft hail, Hail. The atmospheric vertical structure and clouds are obtained from a Radiometrics Radiometer. This is a passive remote sensing instrument that provides profiles of atmospheric temperature and humidity by measuring atmospheric brightness temperature in the frequencies between 51 – 59 and 22 - 30 Ghz respectively. Totals Total Index is also computed using RAOB software from Radiometrics and use the expressionT_{850} + Td_{850} – 2 x T_{500} where T and Td are temperature and dew point at 850 and 500 hPa levels. An index value of 45-55 suggests moderate severe weather while values greater than 55 indicate strong chances of severe weather.

ERA5 hourly reanalysis was utilised to study the large scale atmospheric circulation patterns. Wind patterns at Ny Alesund is investigated using met observations carried out by Alfred Wegner Institute (Maturilli, 2019).

Results and Discussion

Precipitation intensity During DJF 2018-19

During DJF 2018-19 maximum intensity in precipitation was noticed during December and February (Figure. S1). An intense spell was noticed during second and third week of December. The precipitation intensified by 10th December gradually reduced after a fortnight. A second enhancement was noticed by last week of December. January had relatively less precipitation, During February another intense spell started peaking by the third week. It is these intense spells during December and February that we subject our analysis for Hail. Among these precipitation events, hail was noticed on five occasions (Figure.2). On 13th December 04-07 UTC, 15th December 17-19 UTC, 18th December 18 – 22 UTC and 21 February During these days maximum intensity of precipitation was a result of Hail, except the spell on 18th December 09-14 UTC.

Vertical Temperature Structure

During the intense precipitating events when hails formed, the vertical structure of the atmosphere was characterised by strong warming, mostly in the lower layers (Figure.3). Totals totals index computed indicate values ranging between 45-55 indicating moderate severe weather in Ny Alesund. In all the cases maximum warming occurred at the ground level. Winds and temperature have a strong relationship in Ny Alesund. During 13 December, however, wind direction fluctuated between easterlies to north westerlies (Figure. 4), Temperature at lowest level was maximum when the wind direction was southwesterly between 3-5 UTC, during this time totals total index showed high values indicating severe weather in Ny Alesund. The temperature declined further when the wind direction became north westerlies rest of the day. During 15^{th} December wind was predominantly easterlies, however the air temperature was above zero in the lowest levels until 18 UTC when the wind direction turned north westerly. If we compare both the days, on 13^{th} south westerlies warmed up the atmosphere on two occasions, while no warming noticed on 15^{th} December, the lower atmosphere did not show any co variability with wind direction until 18 UTC. When the hail was observed wind was westerlies during 15-18 UTC. On 18^{th} December however, easterlies were characterised by a continuous increase in temperature, nonetheless during late evening wind turned southerlies, maximum temperature and hail was noticed during this time. A similar relationship was noticed on 21th February also. Therefore, in all the cases hail was noticed when the wind direction was around 250 Degrees accompanied with an increase in atmospheric temperature. High values of totals total, an indication of severe weather, was noted during all the hail events. However, one exception was on the morning of 15 December. Even though, there was an indication of severe weather, hail was noted only when the wind turned south westerly. Hail production require formation of hydrometeors like cloud droplets or ice particles (Allen etal., 2019). Smaller water droplets freeze at a lower temperature of about -40°C called homogenous freezing. However, in the presence of nucleating particles like dusts, particles of biological origin or ashes trigger ice formation at much higher temperature. For example, volcanic ash is an active ice nucleating particle at below -10°C whereas biological species can be active above -5°C (Lamba and Verlinde, 2011). In Ny Alesund, Svalbard, local origin particles mainly constitute CCN during summer, while in autumn and winter, particles of remote origin dominate CCN composition (Jung etal., 2018).

Vertical structure of temperature during this formation of hails suggest that -10°C isotherm was approximately at 2km height whereas -5°C isotherm was below 1 km. Therefore, strong precipitation and hail formation could be with in these altitude levels.

Cloud vertical structure and liquid water content in the atmosphere

Clouds obtained from microwave radiometer showed cloud extended from 500 to 5000 m when the hail occurred (Figure. 2). The radiometer also showed high liquid water content during the days when hail occurred. Therefore, when hail was observed southwesterly winds as well as high clouds, liquid water and conditions for severe weather was noticed and is linked with the large scale circulation patterns (Figure. 4). These patterns were characterised the first three EOF modes of SLP during the study period. EOF-1 was characterised by a low pressure anomaly over north Atlantic and a high pressure anomaly near the Barents and the Kara seas. The second and third patterns were characterised by high pressure anomalies over northern Europe. There is a subtle difference between the second and the third pattern, the high pressure anomaly over the northern Europe in the second pattern was displaced to the west in the third EOF pattern. The hail events were noticed either when EOF-3 was in its positive phase or EOF-1 was in the negative phase. It is interesting to note that EOF-2 did not result in any enhanced precipitation. The formation of clouds during positive phase of EOF-2 was low and was characterised with low liquid water content (Figure. S2e). During the peak phase of EOF-2, on 3rd February, winds were mostly easterly to south easterly and cloud formed in the morning, however clouds and liquid water reduced subsequently. The remote source of CCN in winter is mainly associated with Arctic Haze (Jung etal., 2018). The dominant circulation patterns characterized by southerlies transport these particles to Ny Alesund.

SST variability impact cloud formation. Coupled modelling studies suggests relatively warmer ocean initiate shallow convection and low level cloud formation in the north sea (Fallman etal., 2017). West of the Svalbard west Spitzbergen(WSC) current make the ocean warmer and develops a west-east SST gradient(Figure S3). As the wind move over the warm WSC, shallow convection may be initiated followed by low level cloud formation. The necessary CCN required for this process might be supplied by the winds from the low latitudes. The SST gradient maintain a strong atmospheric temperature gradient in the west to east direction(Figure S4). Reanalysis suggest this gradient is strong in the lower 2 km of the atmosphere. Therefore, the frontal activity, in the lower atmospheric layer could be more intense when the winds are westerly. All these suggest to the role of WSC in the atmospheric dynamics in the central Arctic. These aspects however require coupled modelling efforts and will be attempted in the future.

Conclusions

Occurrences of hail during the DJF 2018-19 was studied. Hails were formed when strong precipitation occurred. During this time the atmospheric vertical structure was charcaterised with high liquid water content with in a temperature range of -5 to -20°C. It has been found that hails occurred when there was southwesterly to westerly winds. These winds were a part of largescale pressure systems in the northern Europe and the north Atlantic. These pressure systems formed the first three leading modes of the SLP north of 40N. However, it is noted that, EOF-2 which was shifted to the eastwards than EOF-3 did not resulted in strong precipitation. The reason for this could be that, as the pressure anomaly is shifted to the east, winds travel less over the oceans resulting in less moisture transport to the Svalbard, however as the winds southwesterly- westerly winds gather more moisture as well as nucleating particles along its way resulting enhancing the precipitation. Cloud formation as well as liquid water was higher/lower during EOF-1 and 3 / EOF-2 active phases. The atmospheric circulation is suggestive of the role of marine nucleating particles in strong precipitation. During EOF-2 low liquid water was noticed, thereby depriving the chances for condensation and precipitation. The role of WSC in the atmospheric dynamics is also discussed. The warm WSC could potentially impact the atmospheric dynamics by means of the SST gradient, which could lead to shallow convection or intense frontal activity. These aspects will be studied using coupled modelling efforts in the future.

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References

AghaKouchak A, Chiang F, Huning LS, Love CA, Mallakpour I, Mazdiyasni O, Moftakhari H, Papalexiou SM, Ragno E, Sadegh M (2020) Climate Extremes and Compound Hazards in a Warming World. Annu Rev Earth Planet Sci 48(1):519–548. https://doi.org/10.1146/annurev-earth-071719-055228

Allen JT, Tippett MK, Sobel AH (2015) Influence of the El Niño/Southern Oscillation on tornado and hail frequency in the United States. Nat Geosci 8:6

Allen JT, Giammanco IM, Kumjian MR, Punge HJ, Zhang Q, Groenemeijer P, Kunz M, Ortega K (2019) Understanding Hail in the earth system. Reviews of Geophysics 10.1029/2019RG000665.

Bennett KE, Walsh JE (2015) Spatial and temporal changes in indices of extreme precipitation and temperature for Alaska: CHANGES IN INDICES OF EXTREME PRECIPITATION AND TEMPERATURE FOR ALASKA. Int J Climatol 35(7):1434–1452. https://doi.org/10.1002/joc.4067

Berg P, Moseley C, Haerter JO (2013) Strong increase in convective precipitation in response to higher temperatures. Nat Geosci 6(3):181–185. https://doi.org/10.1038/ngeo1731

Brown DM, Kochtubajda B, Said RK (2020) A Severe Thunderstorm Outbreak North of 70°N Over the Canadian Arctic Islands with Unusual Lightning Characteristics. Atmosphere-Ocean 58(4):231–242. https://doi.org/10.1080/07055900.2020.1792405

Chen J, Dai A, Zhang Y, Rasmussen KL (2020) Changes in Convective Available Potential Energy and Convective Inhibition under Global Warming. J Clim 33(6):2025–2050. https://doi.org/10.1175/JCLI-D-19-0461.1

Chernokulsky A, Kozlov F, Zolina O, Bulygina O, Mokhov II, Semenov VA (2019) Observed changes in convective and stratiform precipitation in Northern Eurasia over the last five decades. Environ Res Lett 14(4):045001. https://doi.org/10.1088/1748-9326/aafb82

Czernecki B, Taszarek M, Kolendowicz L, Szyga-Pluta K (2015) Atmospheric conditions of thunderstorms in the European part of the Arctic derived from sounding and reanalysis data. Atmospheric Res 154:60–72. https://doi.org/10.1016/j.atmosres.2014.11.001

Jung CH, Yoon JY, Kang HJ, Gim Y, Lee B Y, Strom J, Krejci R, Tunved P (2018), The seasonal characteristics of cloud condensation nuclei in the Arctic lower troposphere, Tellus B: Chemical and Physical meteorology, 70:1, 1-13, DOI:10.1080/16000889.2018.1513291

Lamb D, Verlinde J (2011) Physics and Chemistry of Clouds, Cambridge, UK, Cambridge university Press.

Miglietta MM, Mazon J, Motola V, Pasini A (2017) Effect of a positive Sea Surface Temperature anomaly on a Mediterranean tornadic supercell. Sci Rep 7(1):12828. https://doi.org/10.1038/s41598-017-13170-0

Nuncio M, Chatterjee S, Satheesan K, Chenoli SN, M.P. S (2020) Temperature and precipitation during winter in NyÅlesund, Svalbard and possible tropical linkages. Tellus Dyn Meteorol Oceanogr 72(1):1–15. https://doi.org/10.1080/16000870.2020.1746604

Piper DA, Kunz M, Allen JT, Mohr S (2019) Investigation of the temporal variability of thunderstorms in central and western Europe and the relation to large-scale flow and teleconnection patterns. Q J R Meteorol Soc 145(725):3644–3666. https://doi.org/10.1002/qj.3647

Poujol B, Prein AF, Newman AJ (2020) Kilometer-scale modeling projects a tripling of Alaskan convective storms in future climate. Clim Dyn 55(11–12):3543–3564. https://doi.org/10.1007/s00382-020-05466-1

Púčik T, Castellano C, Groenemeijer P, Kühne T, Rädler AT, Antonescu B, Faust E (2019) Large Hail Incidence and Its Economic and Societal Impacts across Europe. Mon Weather Rev 147(11):3901–3916. https://doi.org/10.1175/MWR-D-19-0204.1

Rädler AT, Groenemeijer PH, Faust E, Sausen R, Púčik T (2019) Frequency of severe thunderstorms across Europe expected to increase in the 21st century due to rising instability. Npj Clim Atmospheric Sci 2(1):30. https://doi.org/10.1038/s41612-019-0083-7

Rawlins MA, Steele M, Holland MM, Adam JC, Cherry JE, Francis JA, Groisman PY, Hinzman LD, Huntington TG, Kane DL, Kimball JS, Kwok R, Lammers RB, Lee CM, Lettenmaier DP, McDonald KC, Podest E, Pundsack JW, Rudels B, Serreze MC, Shiklomanov A, Skagseth Ø, Troy TJ, Vörösmarty CJ, Wensnahan M, Wood EF, Woodgate R, Yang D, Zhang K, Zhang T (2010) Analysis of the Arctic System for Freshwater Cycle Intensification: Observations and Expectations. J Clim 23(21):5715–5737. https://doi.org/10.1175/2010JCLI3421.1

Trapp RJ, Hoogewind KA (2018) Exploring a possible connection between U.S. tornado activity and Arctic sea ice. Npj Clim Atmospheric Sci 1(1):14. https://doi.org/10.1038/s41612-018-0025-9

United States: a state of knowledge report. Cambridge University Press, Cambridge [England] ; New York

Ye H, Fetzer EJ, Wong S, Lambrigtsen BH (2017) Rapid decadal convective precipitation increase over Eurasia during the last three decades of the 20th century. Sci Adv 3(1):e1600944. https://doi.org/10.1126/sciadv.1600944

Statements and Declarations

The work was conducted under the Indian Arctic Research Program, Ministry of Earth Sciences, India. The authors declare that they have no financial or competing interests.

Ethical statement

No animal or human trial were conducted for this study.

Figure Captions

Figure.1 Location map depicting the measurement location in Svalbard.

Figure. 2. Precipitation during the time period when hail was recorded in OTT Parsivel at Ny Alesund Svalbard. Yellow dots indicate total precipitation intensity, and the red dots indicate hail.

Figure.3 Vertical temperature structure and totals totals index when hail was recorded in Ny Alesund.(a)13-Dec-2018 (b) 15-Dec-2018 (c) 18-Dec-2018 and (d) 21-Feb-2019 Distinct warming can be noticed in the lower layers of atmosphere can be noticed during the time of hail(please refer Figure.2). The black line depicts the totals totals index. When hail was noticed totals total index was also high indicating severe weather. Right y axis scales for totals total index.

Figure.4 Wind and temperature at 10m obtained from automated weather station operated by Alfred Wegner Institute in Ny Alesund,Svalbard. Hail was noticed when the wind turned southwesterly – westerly.

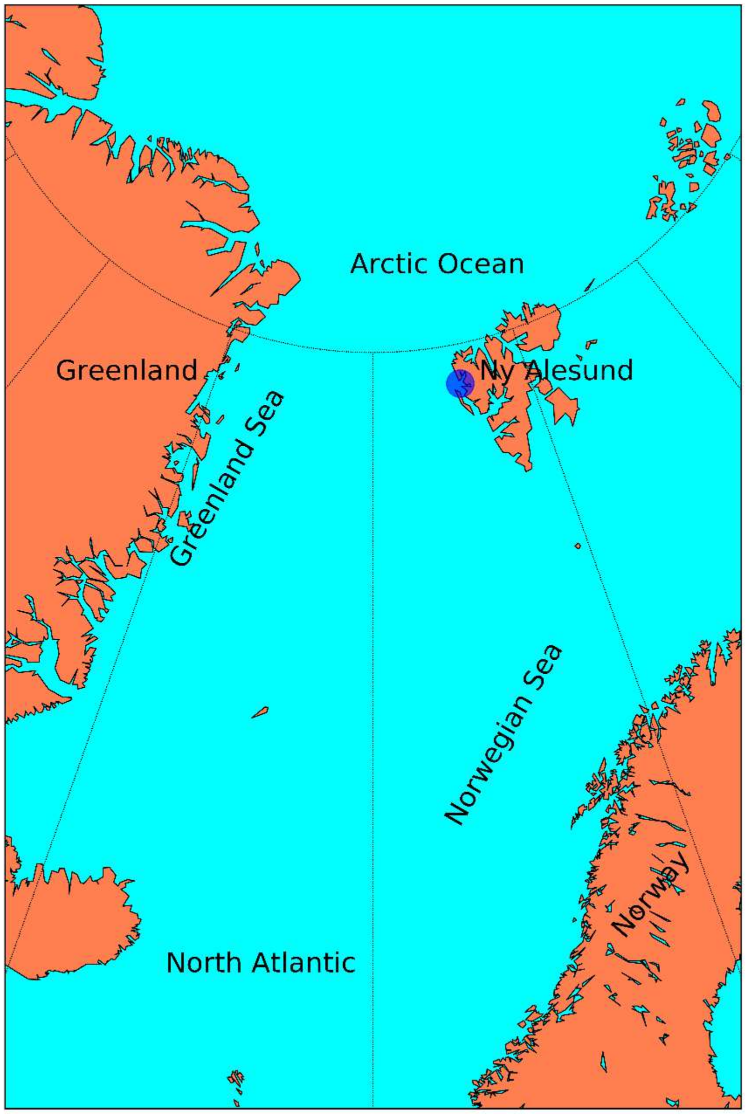
Figure.5. First six leading modes for the EOF of SLP anomalies during December – February 2018-19(a-c) and their temporal variability(d-e). Hail was recorded when EOF-1/2 was in negative/positive phase.

Figure. S1. Average daily intensity of precipitation obtained from OTT parsivel located in Ny Alesund Svalbard. Precipitaiton was intense during December 2018 and in February 2019. There were the two time periods when hail was recorded in Ny Alesund.

Figure.S2. Clouds and liquid water obtained from radiometer in Ny Alesund during strong precipitation and hail (a) 13-Dec-2018 (b) 15-Dec-2018 (c) 18-dec-2018 (d) 21-Feb-2019. (e) depicts clouds and liquid water when the EOF-2 was active during 3-Feb-2019.

Figure.S3. Sea surface temperature during Deccember 2019 near Svalbard. The brown colourrepresents warm SST of the West Spitzbergen current. The current maintain a east-west temperature gradient conducive for cloud formation as the westerly wind blows over.

Figure. S4. Air temperature gradient during December 2018 (a) The meridional temperature gradient along the longitude of Ny Alesund (11°E)(b) latitudinal temperature gradient along 79°E. Gradients are strong in the east – west direction(b). There are two distinct gradient in (b), the first one is a positive gradient just west of 0 longitude this is induced by the boundary between coastal Icelandic current and the west Spitzbergen Current(WSC). Another one is between 10 and 15°E longitude. This represents the gradient formed by the cooler land temperature and warm WSC west of it.



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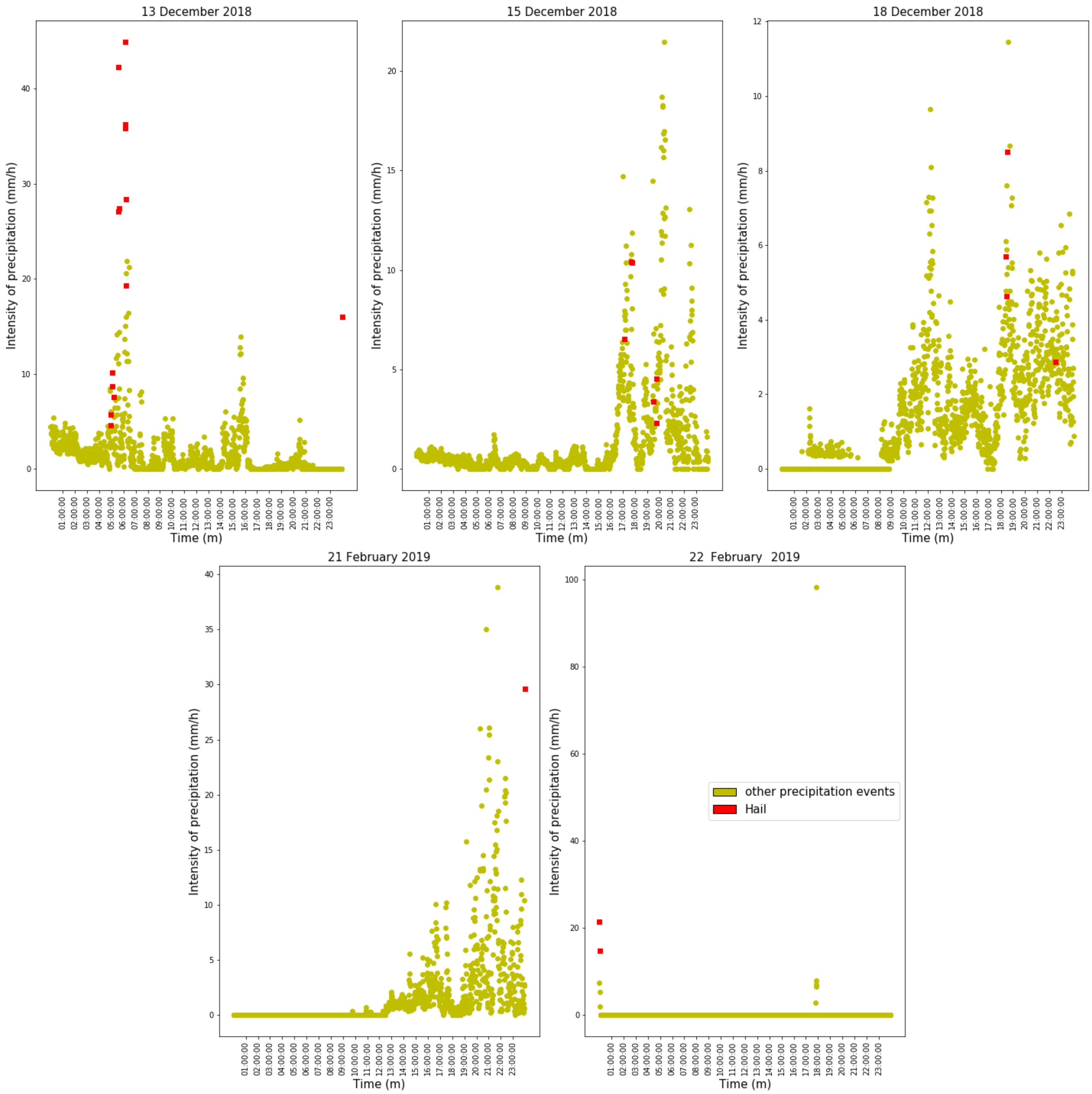

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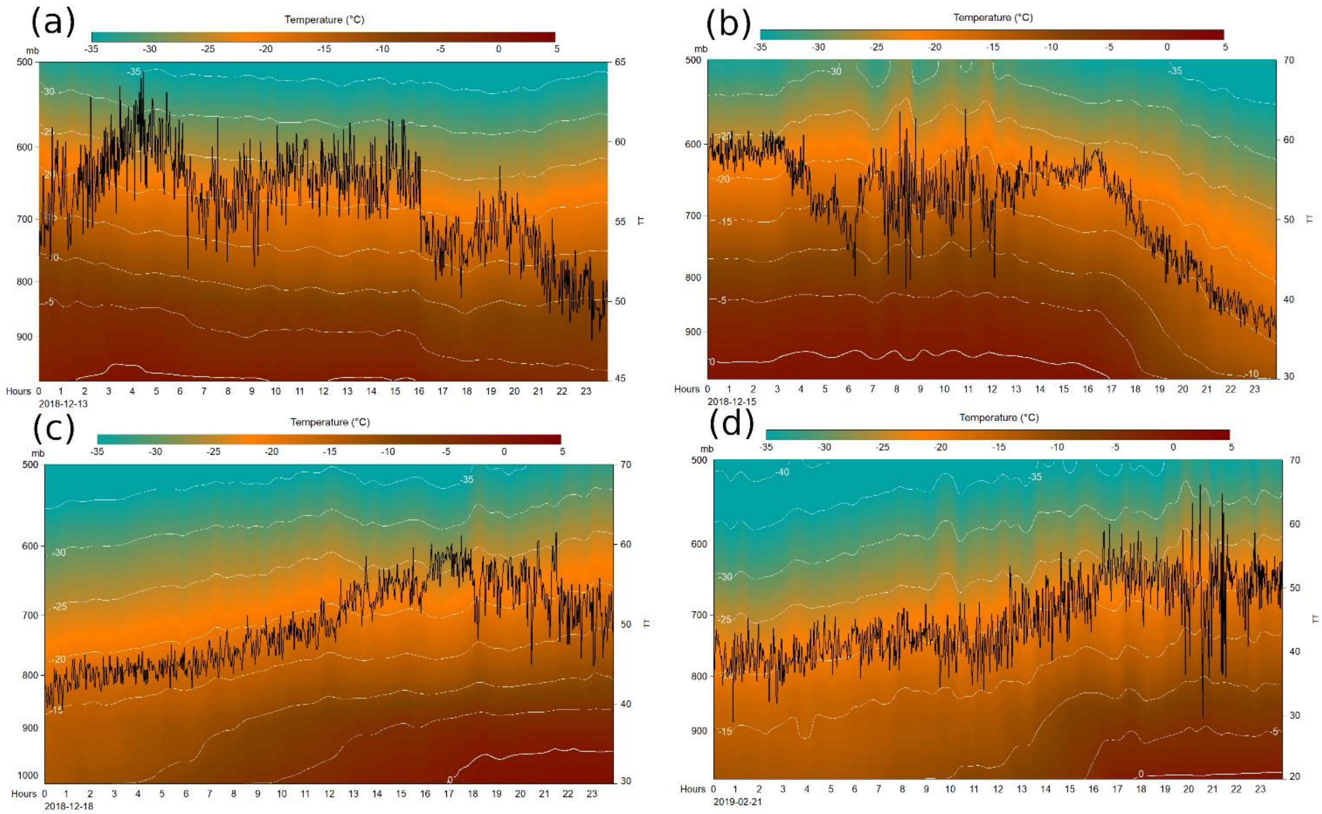

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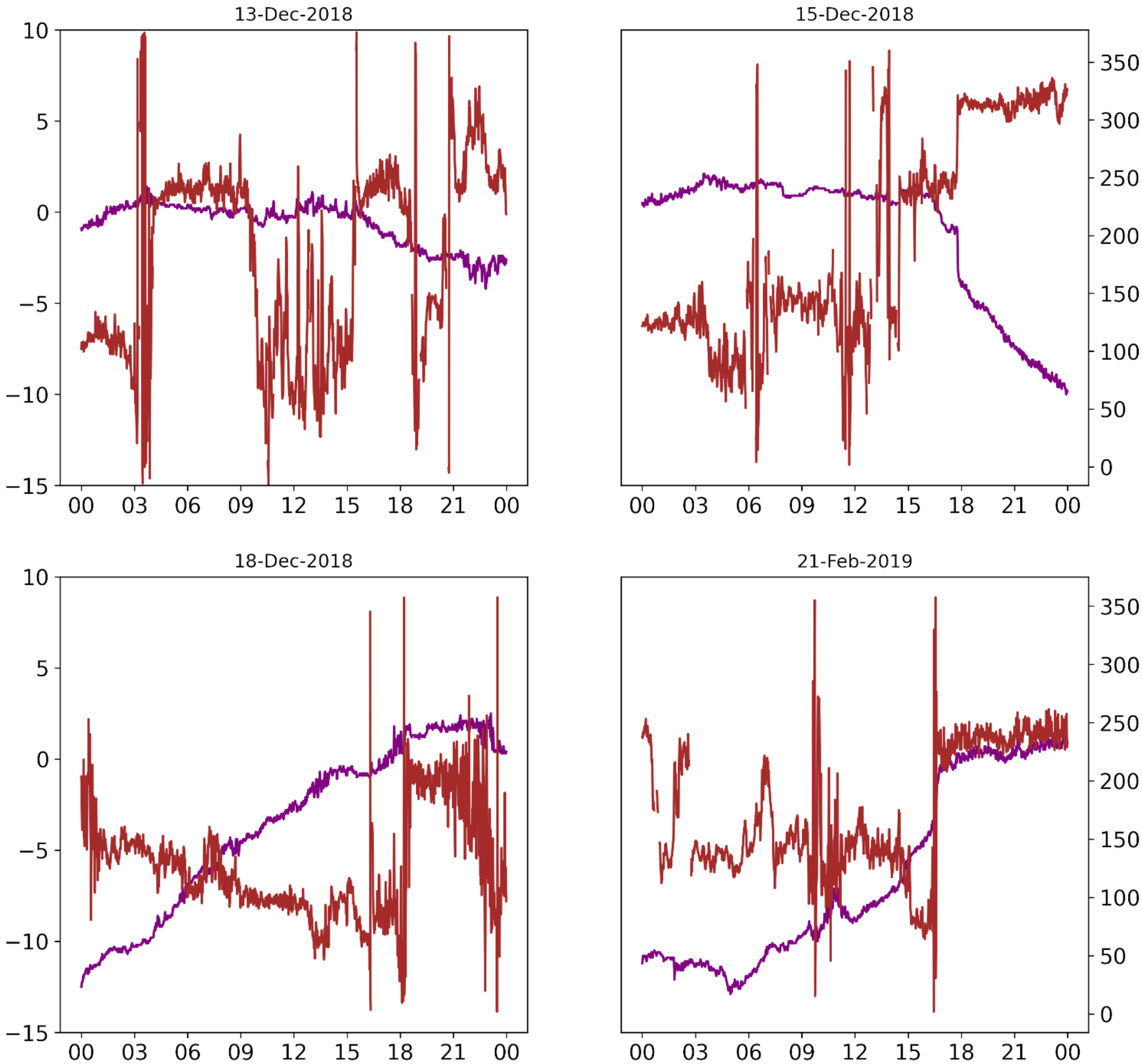

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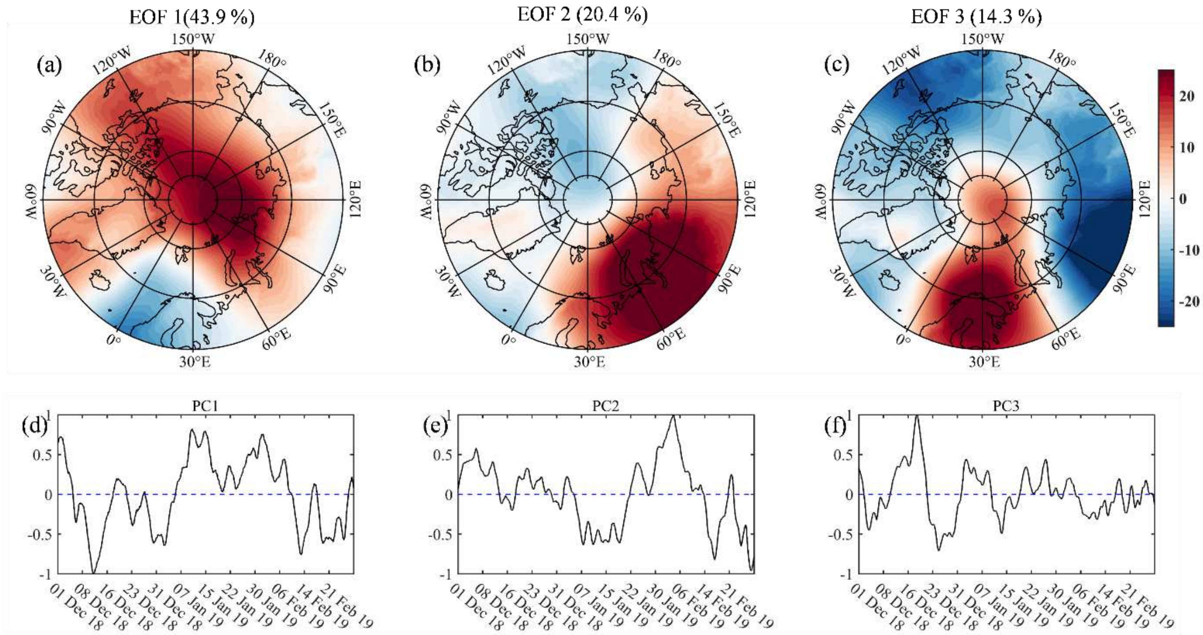

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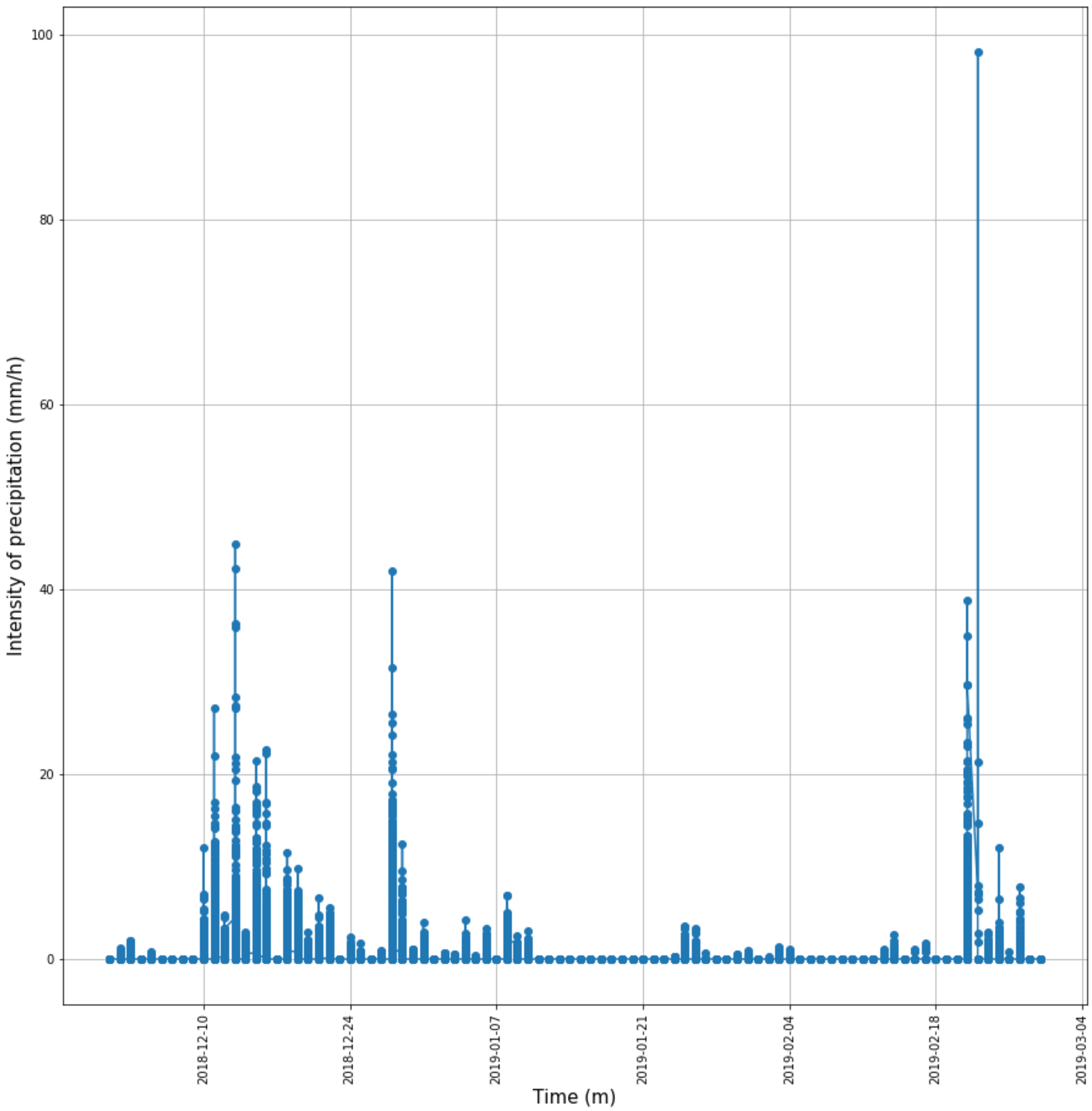

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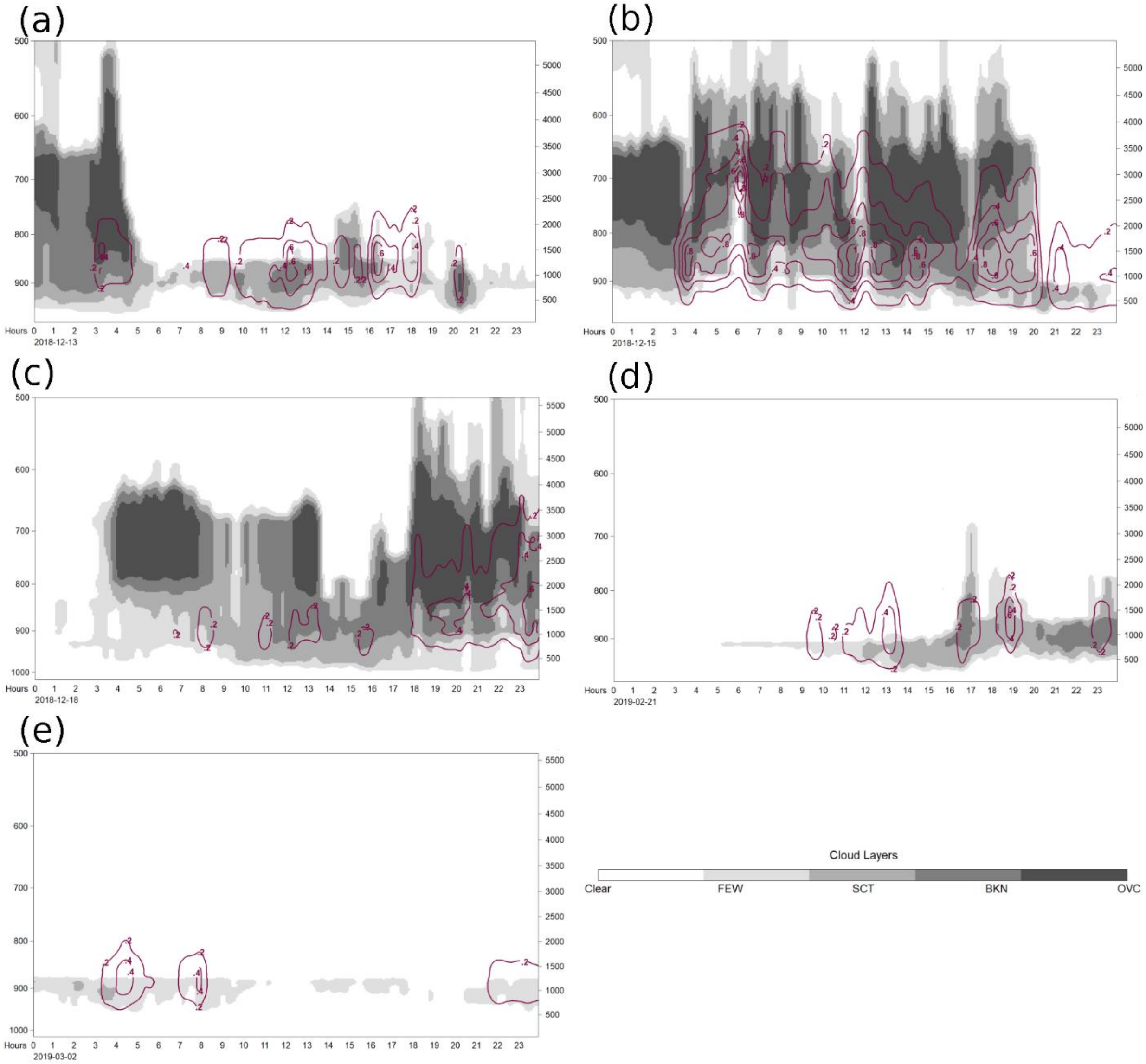

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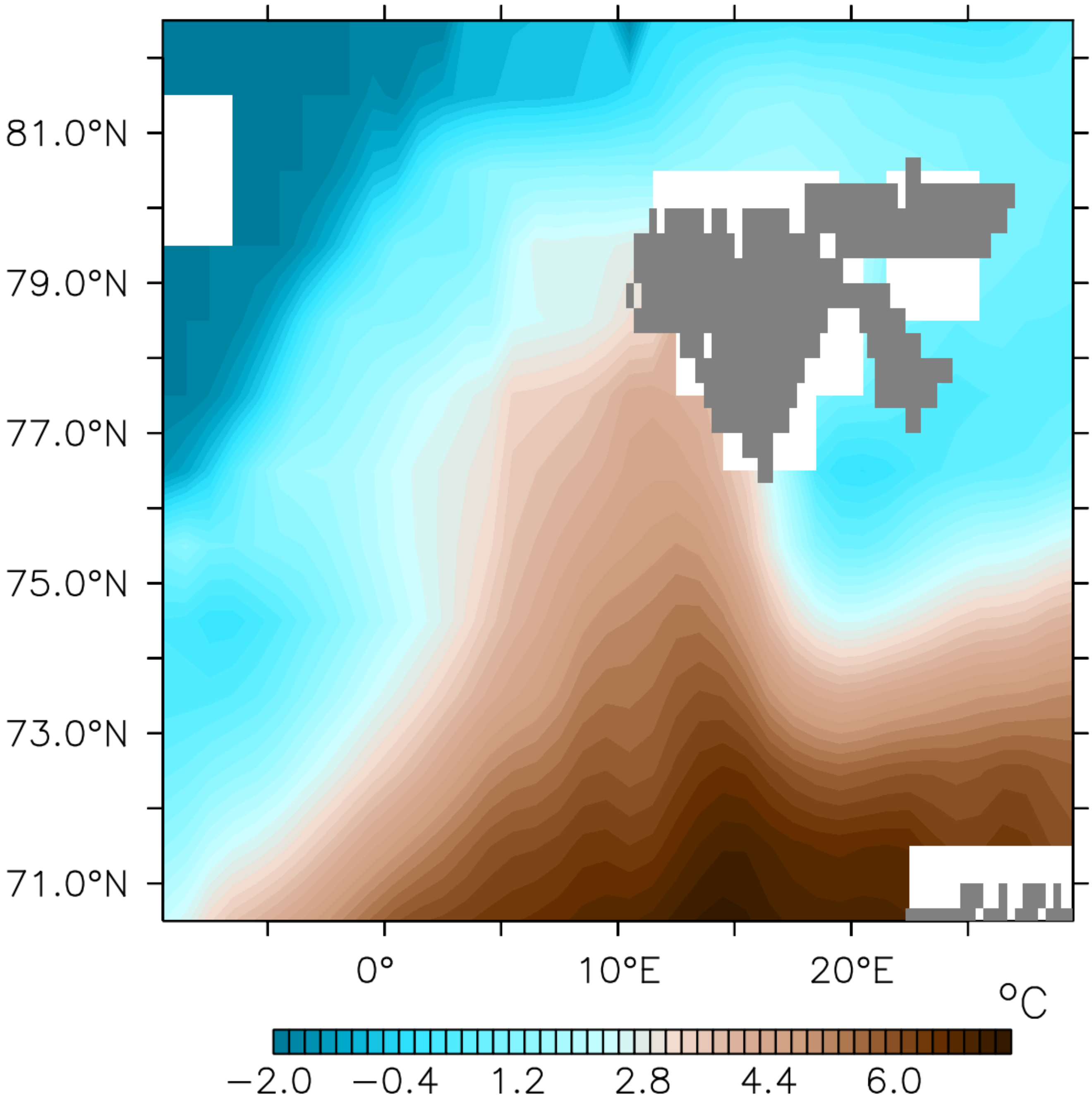

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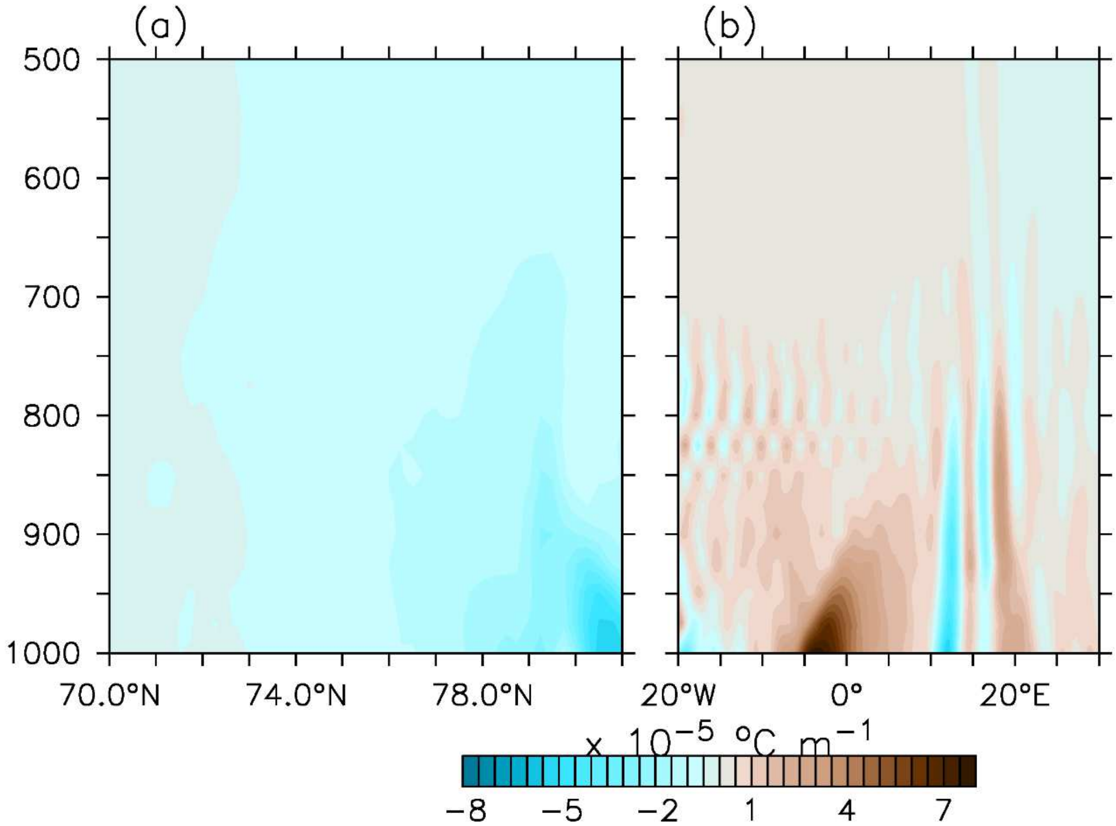

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