Ciro Snowstorm mostly strengthened by Human-driven Climate Change

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Press Summary (First published 2023/12/05)

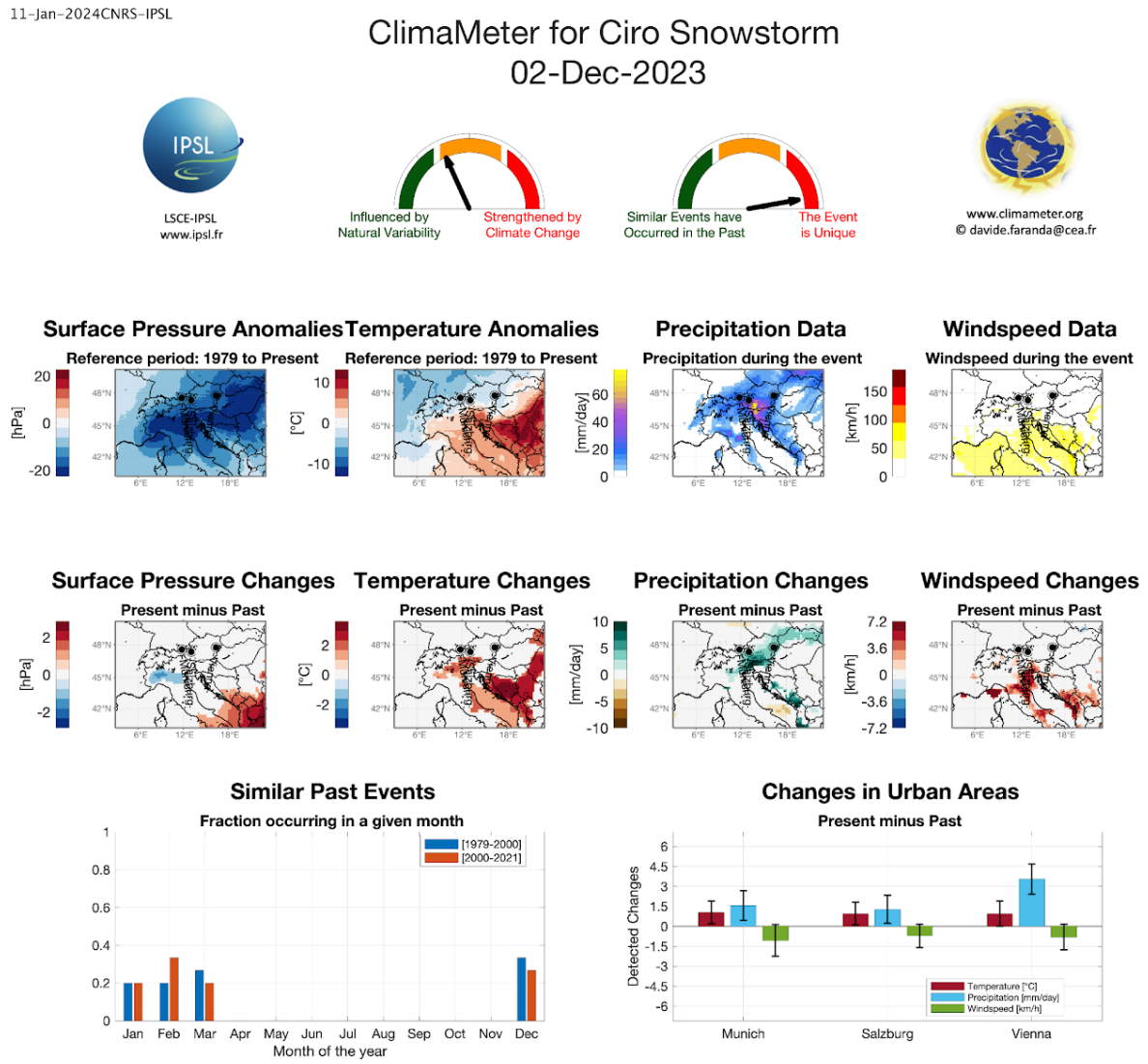
- Low pressure systems similar to that producing the December 2023 Ciro Snowstorm are locally 0-5 °C warmer and 2-10mm/day (i.e., 2-15 cm snow, that is 10-30%) snowier in the present than they have been in the past.
- The December 2023 Ciro snowstorm was a largely unique event.
- Natural climate variability likely played a role in driving the pressure pattern linked to Ciro snowstorm, but human-driven climate change have also contributed by increasing the temperature from negative values in the past, to values close to 0°C and enhancing the freezing rain and the snowfall associated with the storm.

Event Description

On December 2, 2023, Central Europe experienced an unprecedented snowstorm named Ciro by the Italian Aeronautica Militare meteorological Service. The storm produced extreme weather broadly across Central Europe with a severe cold frontadvancing from the North, bringing polar temperatures to the Baltic countries and the Scandinavian Peninsula. The intense cold has enveloped the British Isles, Northern France, Germany, Belgium, the Netherlands, and much of Poland and the Czech Republic. Temperatures have dropped to 0°C in Paris, -2°C in London and Brussels, and -5°C in Berlin. Amsterdam is experiencing -4°C, and Munich has been hit by heavy snowfall.

Bavaria was indeed the most affected region by Ciro, with the highest snowfall of about 50 cm, the most substantial in the past 20 years. This followed advisories from the German Weather Service on December 1, 2023, predicting heavy snowfall in southern

Bavaria and Baden-Wurttemberg. Although the forecast anticipated snowfall between 10 to 40 cm (4 to 16 inches), the actual accumulation exceeded these projections.



Munich's airport experienced a complete grounding of all flights (approximately 760 flight cancellations) on Saturday following a winter storm that blanketed southern Germany, Austria, Switzerland, and the Czech Republic with snow, causing widespread travel disruptions throughout the region. Initially, the airport announced a temporary halt to air traffic until noon on Saturday, which was later extended to a cancellation of flights until 6 a.m. on Sunday. Other regional airports, including Zurich, also reported delays and cancellations due to adverse weather conditions. Germany's national railway announced a suspension of trains to and from Munich's central station, advising

passengers to either delay or reroute their journeys. Reports from the news agency revealed that some passengers in Munich and nearby Ulm spent Friday night on trains due to the suspension. Public transportation in Munich faced extensive disruptions, with buses and trams not operating as of Saturday afternoon, according to the local transit authority. Some subway and regional train lines were also affected by the severe weather. The heavy snowfall resulted in downed trees, leaving many thousands without power across Bavaria, as reported by utility company Bayernwerk. Numerous activities across the city, including the Bayern Munich soccer game against Union Berlin, were canceled due to the adverse weather conditions.

Beyond transportation issues, police in lower Bavaria responded to 350 incidents related to snow and ice, resulting in minor to moderate injuries. Avalanche concerns prompted officials in Austria and Switzerland to raise warnings to the second-highest level in affected regions. The Austrian railway company OeBB reported closures of various stretches of its routes due to the storm. In the Czech Republic, major highways and roads were blocked, leading to delays and cancellations in trains and public transportation, with over 15,000 households without power.

The *Surface Pressure Anomalies* reveal a weather pattern characterized by a low-pressure systems over Northern Italy, Croatia, and Czech Republic. This atmospheric setup led to a significant influx of cold air toward the Central and Eastern Europe. *Temperature Anomalies* indicate that most of the area located southernely to the Alps experienced near-surface temperatures close to freezing point of the ice (0 °C), leading to snowfall events on ground. *Precipitation Data* show that the Southern Germany, Croatia, and Austria received large amounts of precipitation, mostly in the form of snow. The storm also caused strong winds over Italy as shown in *Windspeed Data.*

Climate and Data Background for the Analysis

The IPCC AR6 WG1 (IPCC AR6 WGI FR - Page 1839) report discusses the significant impact of climate change on the frequency and intensity of cold outbreaks in Europe. According to the IPCC, there is a long-term decreasing frequency of winter cold spells in Europe, and this trend is projected to continue in the future with a high level of confidence. The probability of occurrence of cold spells is expected to decrease and virtually disappear by the end of the century. The frequency of frost days is also very likely to decrease for all scenarios and all time horizons, which will have consequences for agriculture and forests. Additionally, there is a large observed decreasing trend for winter heating energy demand in Europe, which is very likely to continue through the 21st century. The decreases in heating demand are projected to be in the range of 20-30% for Northern Europe, about 20% for central Europe, and 35% for southern Europe by mid-century under the highest greenhouse gases emissions scenarios.

Our analysis approach rests on looking for weather situations similar to those of the event of interest having been observed in the past. For the December 2023 Ciro Snowstorm, we have low confidence in the robustness of our approach given the available climate data, as the event is largely unique in the data record.

ClimaMeter Analysis

We analyze here (see Methodology for more details) how events similar to the low-pressure systems leading to the December 2023 Ciro snowstorm have changed in the present (2000–2021) compared to what they would have looked like if they had occurred in the past (1979–2000) in the region [3°E 23°E 40°N 50°N]. The *Surface Pressure Changes* show that low-pressure systems have not significantly changed their intensity compared to the past, except in some limited areas (Po Valley). *Temperature Changes* show that similar events produce milder conditions (0-5 °C) in the present than in the past over the Adriatic Sea. Examining *Precipitation Changes* reveals that

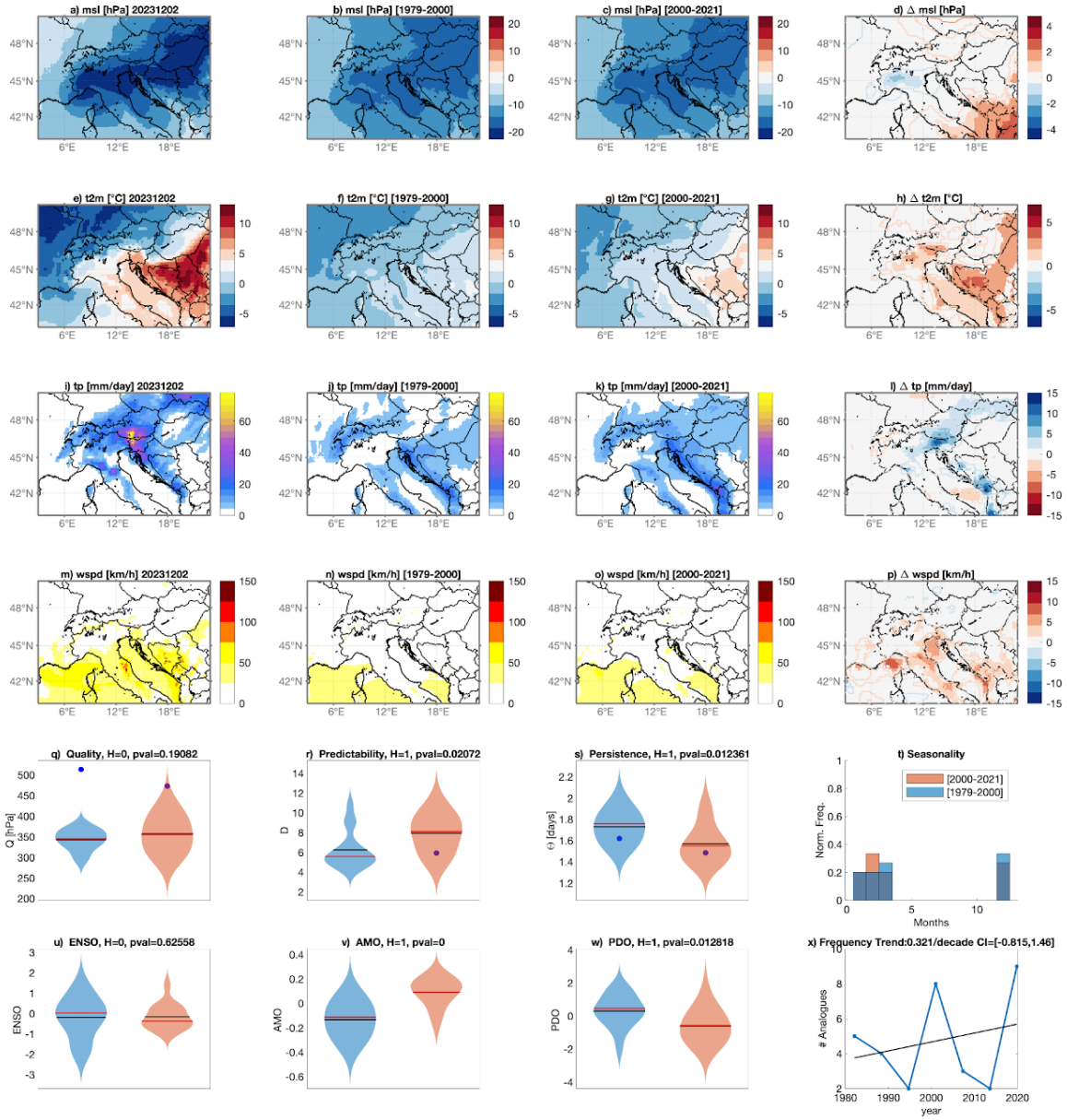
present events exhibit a significant uptick in snowfall, ranging from 2 to 10 mm/day (equivalent to 2-15 cm of snow). This indicates a substantial increase, amounting to 10-30% more snow than experienced in the past. *Windspeed Changes* show that present events lead to generally windier conditions (0-7 km/h) over the Adriatic Sea. We also find that Similar Past Events have about the seasonal occurrence of events has not changed compared to the past. Considering the affected urban areas of Munich, Salzburg, and Vienna, our analysis finds that they are (0-0.5°C) warmer in the present than in the past during similar events. All urban areas also tend to receive more snow or freezing rain in the present than in the past (1-3 mm/day, equivalent to 1-5 cm more snow or freezing rain than in the past) during winterstorm similar to Ciro. Finally, we find that sources of natural climate variability, notably the Atlantic Multidecadal Oscillation and the Pacific Decadal Oscillation, may have influenced the event. This suggests that the changes we see in the event compared to the past may be due to human-driven climate change, with a contribution from natural variability.

Conclusion

Based on the above, we conclude that low pressure patterns similar to that causing the December 2023 Ciro snowstorm are locally 0-5 °C warmer and 2-10mm/day (i.e., 2-15 cm snow, that is 10-30%) snowier in the present than they have been in the past. We interpret the December 2023 Ciro Snowstorm as a largely unique event for which natural climate variability played a role.

Additional Information : Complete Output of the Analysis

- NB1: The following output is specifically intended for researchers and contain details that are fully understandable only by reading the methodology described in Faranda, D., Bourdin, S., Ginesta, M., Krouma, M., Noyelle, R., Pons, F., Yiou, P., and Messori, G.: A climate-change attribution retrospective of some impactful weather extremes of 2021, Weather Clim. Dynam., 3, 1311–1340, https://doi.org/10.5194/wcd-3-1311-2022, 2022.
- NB2: Colorscales may vary from the ClimaMeter figure presented above.



The figure shows the average of surface pressure anomaly (msl) (a), average 2-meter temperatures anomalies (t2m) (e), cumulated total precipitation (tp) (i), and average wind-speed (wspd) in the

period of the event. Average of the surface pressure analogs found in the counterfactual [1979-2000] (b) and factual periods [2001-2022] (c), along with corresponding 2-meter temperatures (f, g), cumulated precipitation (j, k), and wind speed (n, o). Changes between present and past analogues are presented for surface pressure Δslp (d), 2 meter temperatures Δt2m (h), total precipitation Δtp (i), and windspeed Δwspd (p): color-filled areas indicate significant anomalies with respect to the bootstrap procedure. Violin plots for past (blue) and present (orange) periods for Quality Q analogs (q), Predictability Index D (r), Persistence Index Θ (s), and distribution of analogs in each month (t). Violin plots for past (blue) and present (orange) periods for ENSO (u), AMO (v) and PDO (w). Number of the Analogues occurring in each subperiod (blue) and linear trend (black). Values for the peak day of the extreme event are marked by a blue dot. Horizontal bars in panels (q,r,s,u,v,w) correspond to the mean (black) and median (red) of the distributions.