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Dynamical downscaling and data assimilation for a cold-air outbreak in the European Alps during the Year Without a Summer of 1816

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Figures

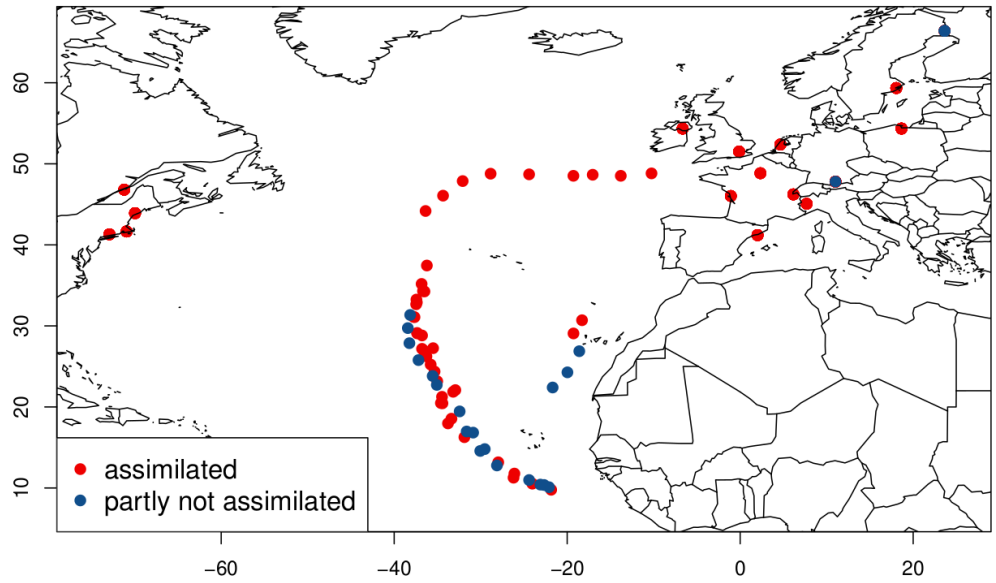

Figure S1: Locations of surface pressure observations (red dots) from ISPDv4.7 that are assimilated into 20CR for the period 5 June 1816 12:00 to 12 June 1816 11:00. Blue dots mark locations with some instances of observations that are not assimilated.

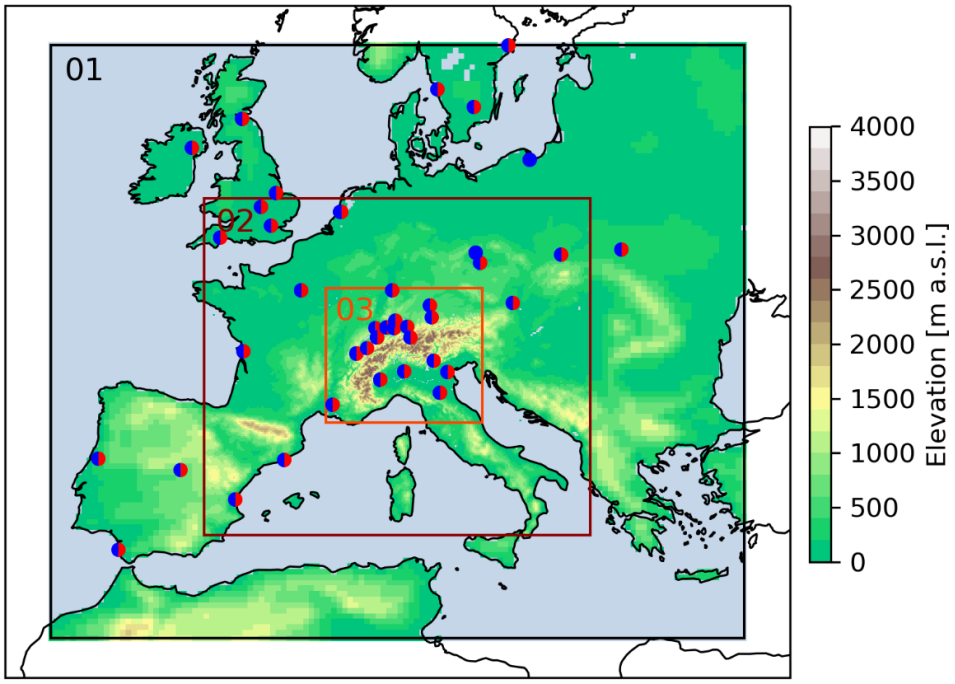

Figure S2: Overview of WRF domains (domain number indicated in top left corner of the respective rectangle). Filled dots indicate station observations of pressure (blue) and temperature (red) used for data assimilation.

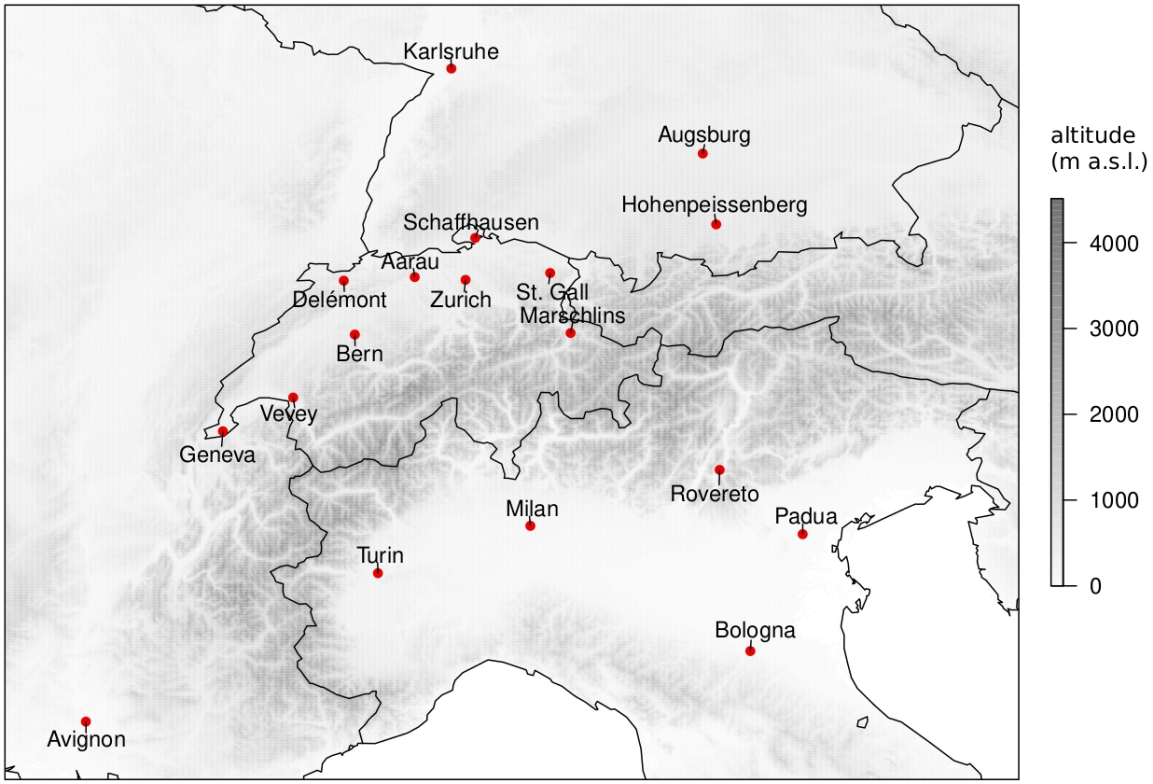

Figure S3: Researched stations (red dots) for the WRF data assimilation experiment and elevation (shade, m a.s.l.). Refer also to Table 1 in the main article.

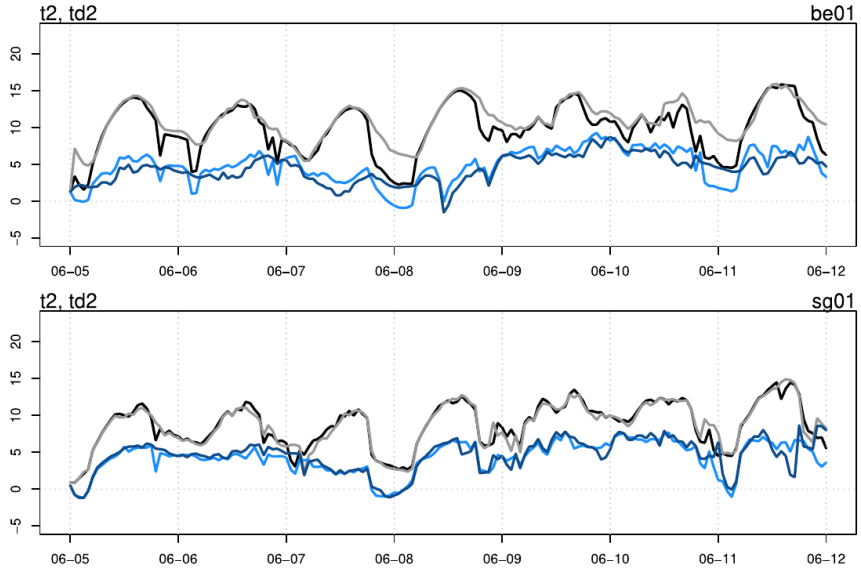

Figure S4: comparison of a WRF NODA simulation based on historical land use categories with WRF NODA simulation based on modern land use categories, for the period between 5 and 11 June 1816 (x-axis). Shown are air temperature (black line for historical, grey line for modern land use; °C 2 m above ground) and dew-point temperature two meters above ground (blue line for historical, dark blue line for modern land use; °C 2 m above ground) for the stations of Bern (top) and St. Gall (bottom).

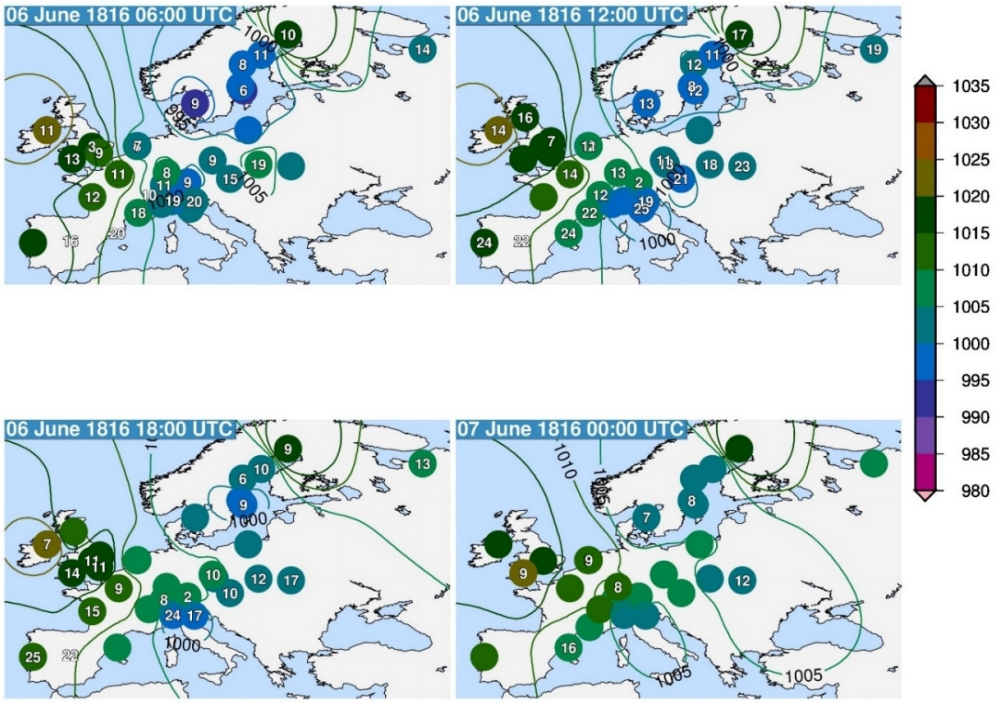

Figure S5: Measurements of surface air temperature (numbers within dots) and pressure (dots, shaded according to indications in hPa, see also color key), and interpolated sea level pressure (lines, same color scale as dots) for Europe and 6 June 1816. Cf. Brugnara et al., (2016).

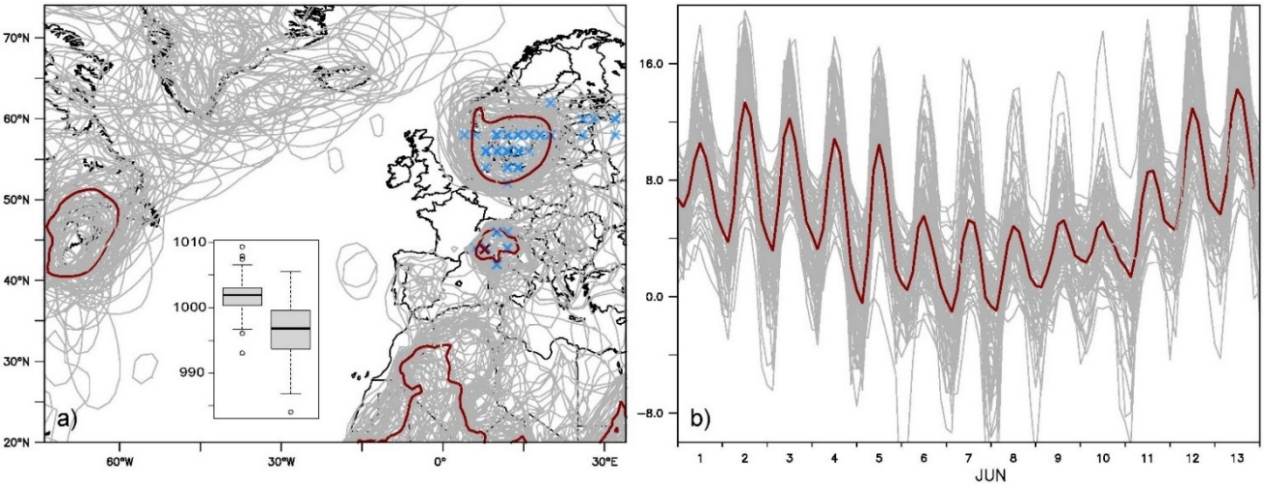

Figure S6: Isobars at 1005-hPa of all 80 ensemble members in 20CR (grey lines) and of the ensemble mean (red lines) for the North Atlantic region on 6 June 1816 18 UTC. Semi-transparent blue crosses mark the location of local minima over Scandinavia and the Alps / Northern Italy; darker color means more pressure minima from the ensemble are located here. The red cross marks the SLP minimum of the ensemble mean over the Alps / Northern Italy. The algorithm did not produce a single minimum for Scandinavia, so not shown. The inset shows the distribution of SLP minima (hPa) in the 80 20CR members over the Alps / Northern Italy (left) and Scandinavia (right). The SLP minimum over the Alps / Northern Italy for the ensemble mean is 1002.09. b) 20CR air temperature at 2 m above ground (°C) at 7.7 E, 47 N from 1 to 13 June 1816. Grey lines mark the 80 ensemble members, the red line the ensemble mean.

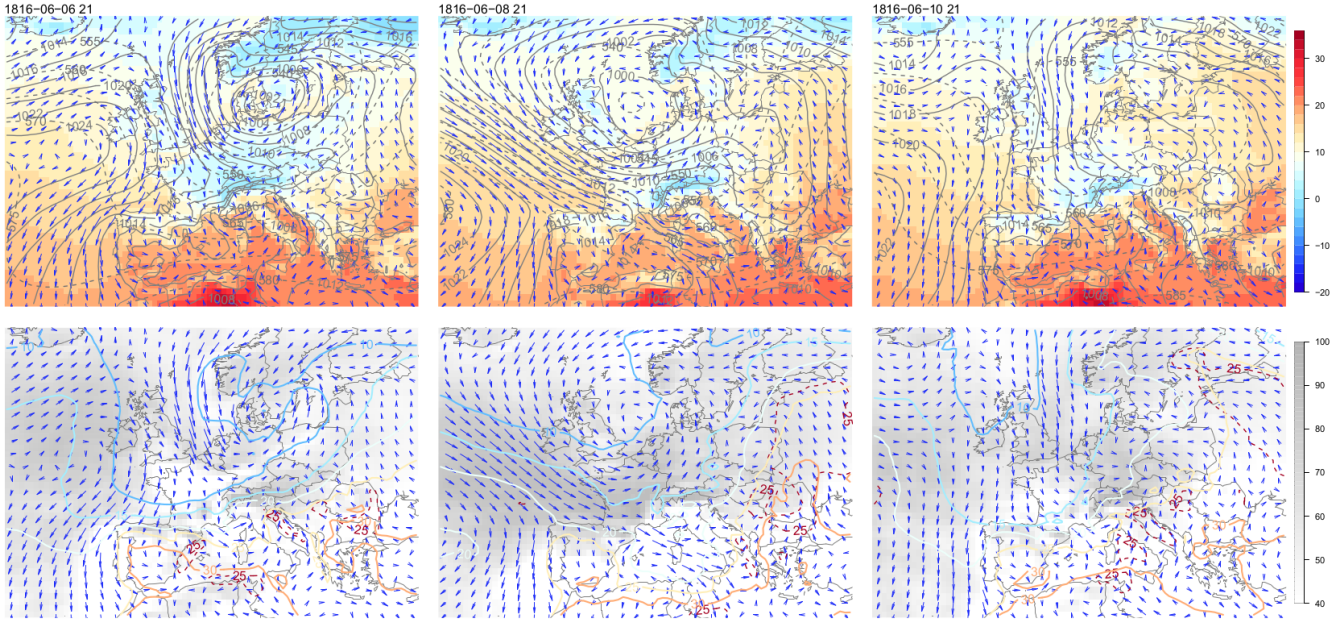

Figure S7: Illustration of (upper panels) 2-meter air temperature (°C; color shade) sea level pressure (hPa; black solid contours), geopotential hight at 500 hPa (m; black dashed contours), and 10-meter wind (qualitative lengths; blue vectors), and of (lower panels) fraction of cloud cover (%; grey shades), 10-meter wind (grey vectors), precipitable water (dark red dashed contour for 25 mm), theta-e at 850 hPa (°C; blue to orange interval contours), and 10-meter wind as in upper panels, for (left panels) 6 June 1816 21:00 LMT, (middle panels) 8 June 1816 21:00 LMT, and (right panels) 10 June 1816 21:00 LMT.

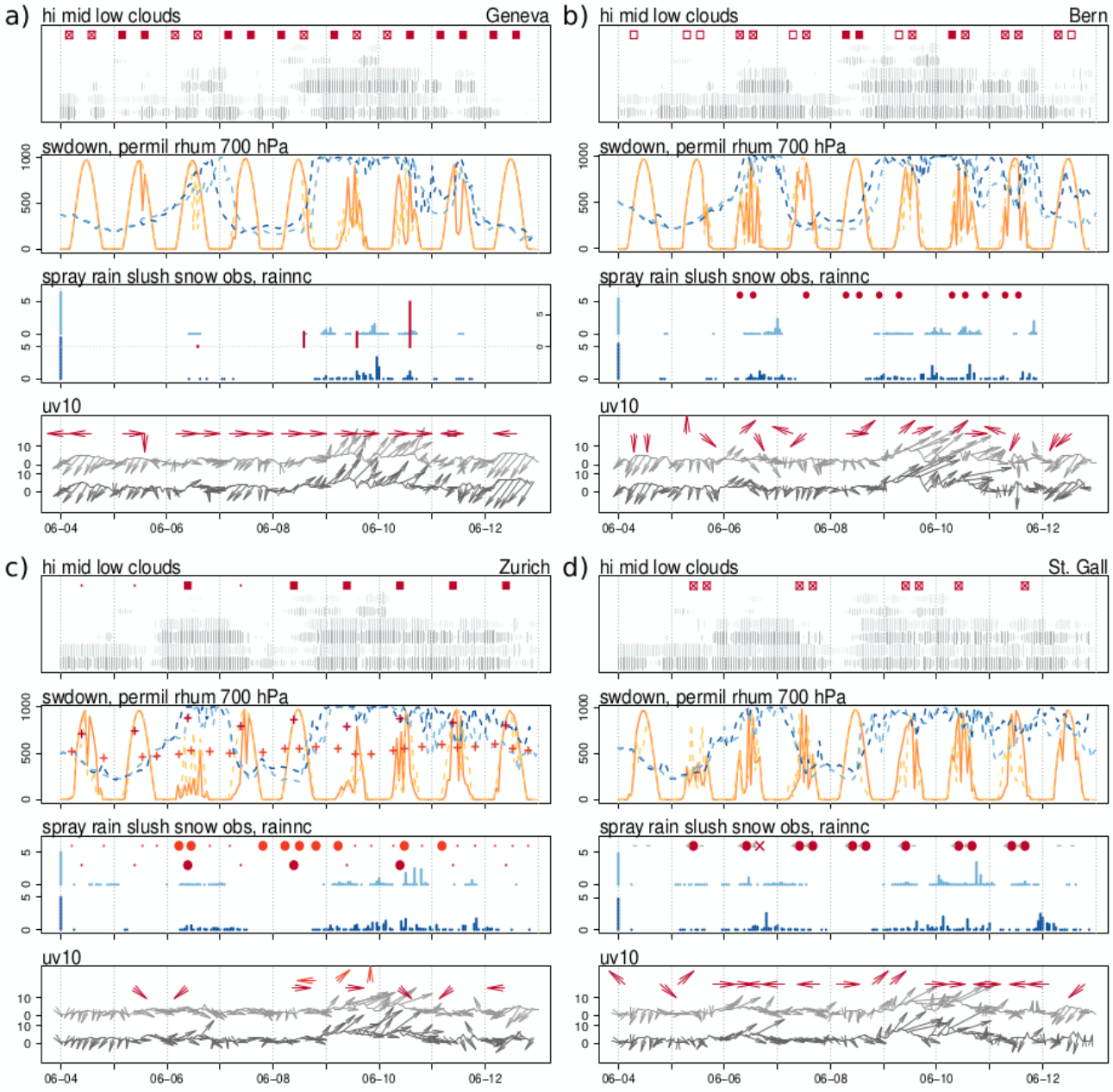

Figure S8: Meteograms of station observations and measurements (red colors) for a) Geneva b) Bern c) Zurich and d) St. Gall with WRF NODA (ligher colors, grey, blue, orange) and DA (darker colors) simulations output for the nearest grid point, for the period between 4 and 12 June 1816 (x-axis). Top panels show observed cloud cover (red squares from 'bright' with no fill to 'mixed' with cross and 'covered' with fill) vs. simulated low, mid- and upper level cloud fraction (larger bars indicate more cloudiness). Second row panels show simulations of downward short wave flux at ground surface (orange lines; W/m2) and relative humidity at 700 hPa (dashed blue line; permil). Red crosses (dark for observer Escher, light for Feer) indicate the relative humidity measurements on the ground for Zurich. Third row panels show thrice-daily observations of precipitation (red dots; red vertical bars for Geneva measurements in mm; darker red dots for Zurich stand for observer Escher, lighter for Feer; red cross for 'rain and snow' added for St. Gall on 6 June 1816) vs. simulated precipitation (blue vertical bars, mm). Bottom panels show

observations of wind direction (red vectors at unit length; north is up) vs. simulated wind direction (grey wind vectors; north is up) and velocity (black line and vector length; m/s at 10 m above ground).

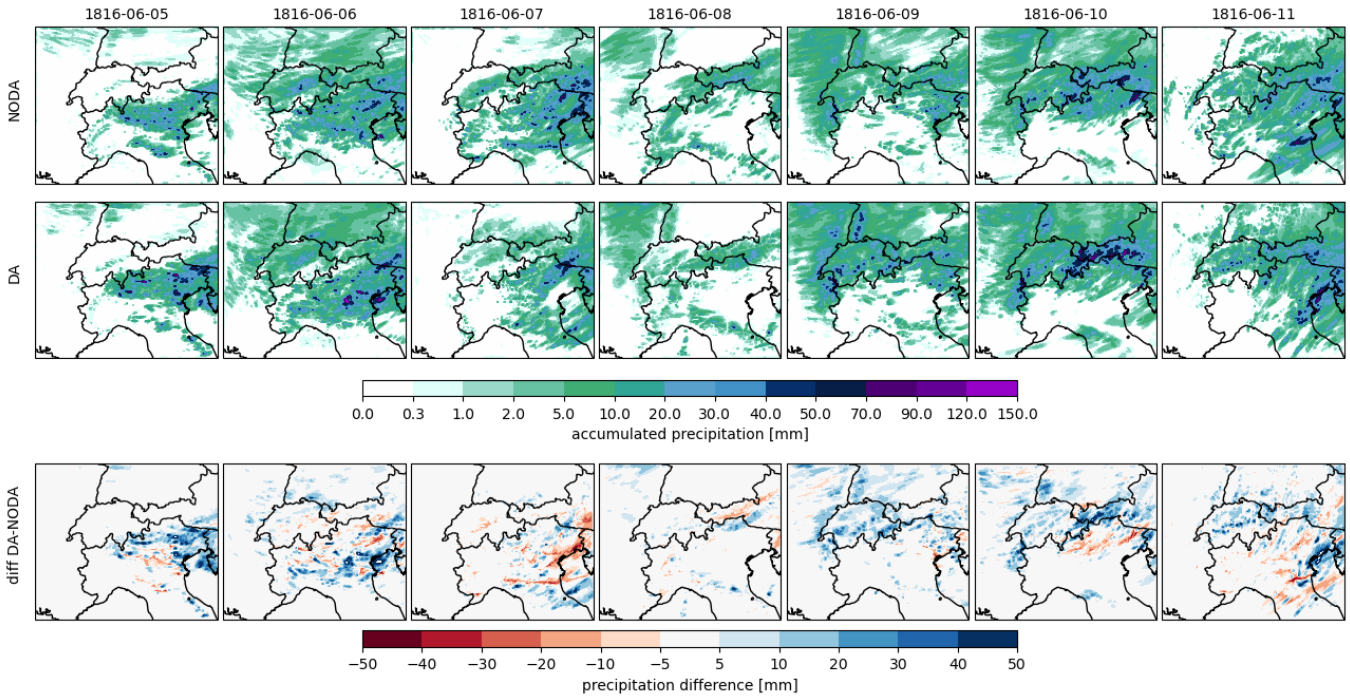

Figure S9: daily accumulated precipitation (00 UTC – 00 UTC of the next day) from June 5 to June 11 1816. Shown are results from NODA (top) and DA (center) simulations, as well as the difference between the two simulations (bottom).