Remote sources of water vapor forming precipitation on the Norwegian west coast at 60°N – a tale of hurricanes and an atmospheric river

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Precipitation trends in Norway

Precipitation amounts have increased in most areas of Norway during the period 1895-2004 [Hanssen-Bauer, 2005] and in southwestern Norway.

The precipitation trends are strongest in fall. Along with the monthly mean precipitation, heavy precipitation events have also become more frequent. Climate model predictions suggest that precipitation in Norway will increase further, particularly in the western parts of the country [Hanssen-Bauer et al., 2003].

Motivation

We want to identify the evaporative source regions of the water falling as precipitation in Norway and, in particular, understand how trends in precipitation there are related to trends in the evaporative strengths in the source regions, which are possibly related to changes in the sea surface temperatures. As a first step, we have identified the moisture source regions for an extreme precipitation event [Stohl et al., 2007].

Method

We use a Lagrangian particle dispersion model based on ECMWF analyses and an algorithm to identify moisture changes along particle trajectories and translate them into moisture gains (evaporation) and losses (precipitation) in the air mass [Stohl and James, 2004, 2005]. A large number of particles was initialized in the area with strong precipitation, precipitating particles were identified, and tracked backward for 12 days, thus establishing the history and regions of moisture uptake.

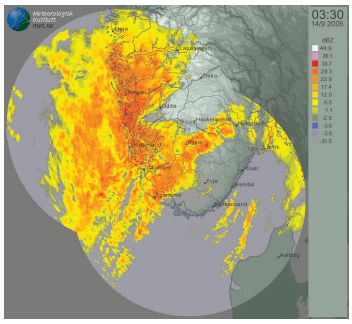

Figure 1: Precipitation radar image showing strong topographically enhanced precipitation in western Norway.

Case study

During the night from 13 to 14 September 2005, the storm "Kristin" hit the Norwegian west coast and caused extreme precipitation, flooding and landslides. The weather station Bergen-Florida (5.3°E, 60.4°N) measured 156.5 mm precipitation within 24 hours. Another station, Opstveit (6.0°E, 59.9°N), recorded a daily precipitation amount of 179.5 mm, the largest daily value ever measured in entire Norway in a September (*Fig. 1*). The extreme event was related to the northward transport of warm moist tropical air associated with two hurricanes, Maria and Nate (*Fig. 2*). Just before the event, extremely moist air stretched from the Caribbean all the way to Norway (*Fig. 3*). The associated horizontal water vapor fluxes were typical of an atmospheric river. However, without actually diagnosing the moisture budget it was not clear whether the moisture was continuously fed into the storm system from close-by regions or was indeed transported across long distances. The moisture tracking algorithm indeed identified long-range transport of moisture as the main reason for the precipitation event (*Fig. 4*). The water source regions included the subtropics and even the tropics.

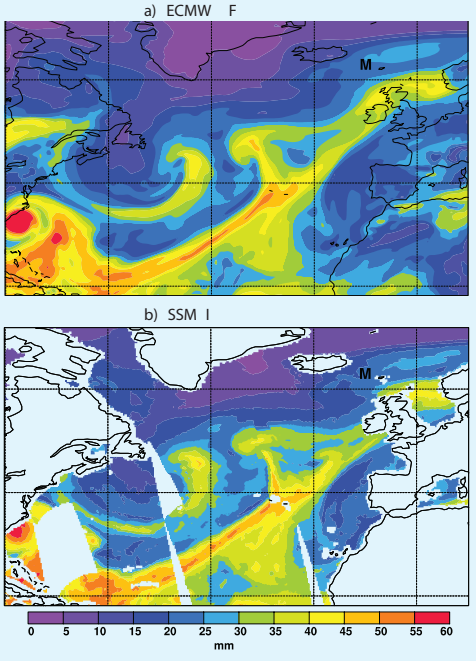

Figure 3: Maps of the vertically integrated water vapor from (a) the ECMWF analysis on 13 September 2005 at 18 UTC and (b) the SSM/I measurements made during the afternoon overpasses on 13 September 2005.

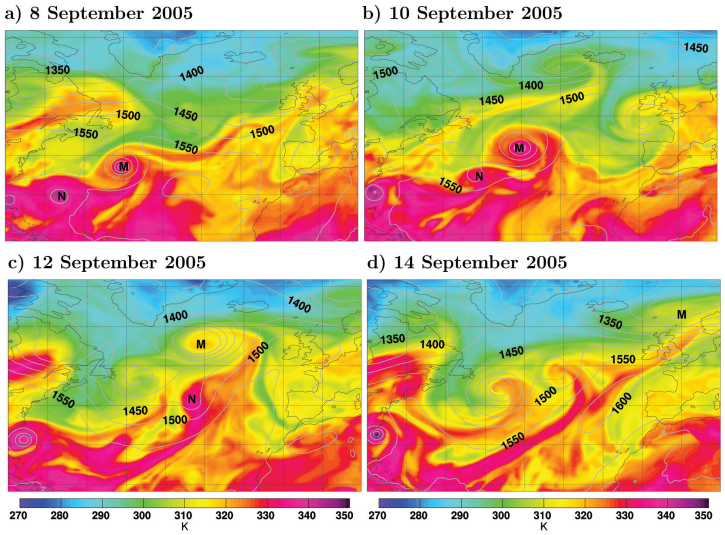

Figure 2: Equivalent potential temperature (in K, color shading) and geopotential height (in m, isolines) at 850 hPa on (a) 8, (b) 10, (c) 12, and (d) 14 September 2005, all at 0 UTC. The positions of (former) tropical cyclones Maria and Nate are marked with the letters "M" and "N", respectively.

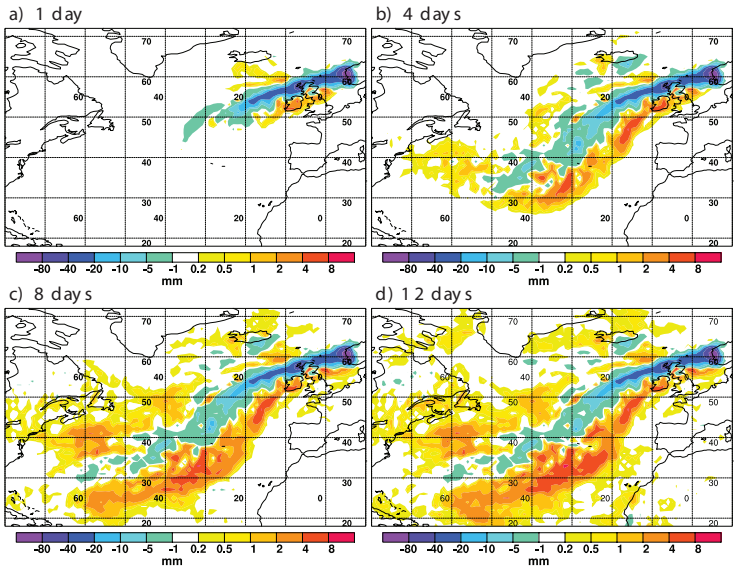

Figure 4: Moisture source regions for the precipitation falling around the city of Bergen as identified with the Lagrangian method. Warm colors indicate net uptake of moisture, cool colors net loss of moisture. Moisture was collected over large parts of the North Atlantic Ocean, especially in the subtropics. But some of the moisture even originated in the tropics, indicating a transport across more than 40° of latitude.

Potential implications

The event in southwestern Norway occurred at a time of the year when strong upward trends in both mean precipitation and the frequency of extreme precipitation events have occurred already and are predicted for the future. Our study shows that hurricanes undergoing extratropical transition can unfold devastating precipitation over Norway. If the frequency of hurricanes increases in the future, more extreme precipitation events might thus be expected in western Norway, thus contributing to the increase of precipitation in fall.

References

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