Lake-effect precipitation at Lake Constance, Austria: Climatology and forecasting

L. Lehner[1]*, L. Umek[1], A. Gohm[1], S. Drechsel[2]

[1]University of Innsbruck (Austria), [2]Central Institution for Meteorology and Geodynamics (ZAMG, Austria)

*Lukas.Lehner@student.uibk.ac.at

Introduction

In the past, heavy precipitation events occurred at the **southeastern shore of Lake Constance** that have not been predicted by numerical weather prediction models and weather forecasters. Especially on winter days when distinct convection is rare, **unexpected** heavy snowfall of 20 to 50 cm in a few hours can lead to traffic chaos and infrastructural damage. Hence the interest in the formation and the forecast of this local phenomenon is high.

The **stationarity and often banded structure of precipitation** are evocative of lake-effect events that are known from the Great Lakes and the Great Salt Lake in North America. Lake Constance (see Fig. 1) - at the tripoint of Austria, Germany and Switzerland - is 60 km long, 10 km wide and located at 394 m MSL.

Lake-effect precipitation may develop when **relatively cold air** flows over a **warm water body** which destabilizes the air mass due to sensible and latent heat fluxes. The uptake of heat and moisture leads to cloud formation and precipitation on the leeward coast (see Fig. 2). Various factors may affect this formation:

- Synoptic forcing: advection of cyclonic vorticity → quasi-geostrophic lifting
- Water temperature as an indicator of the stored **thermal energy**
- Greatest possible **fetch**: the distance that an air mass travels over a body of water
- Unstable **stratification** to allow vertical displacement
- **Uplifting mechanisms**: converging onshore breezes, the convergence due to different surface roughness or of mesoscale origin and orographic lifting at the Pfänder mountain

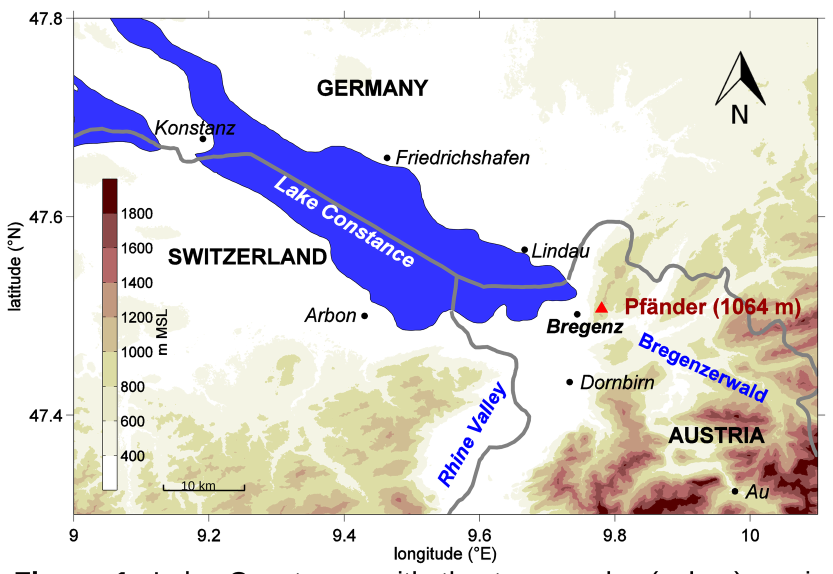

Figure 1: Lake Constance with the topography (colors), main cities and geographical regions. The gray lines mark the political borders and the red triangle shows the Pfänder mountain.

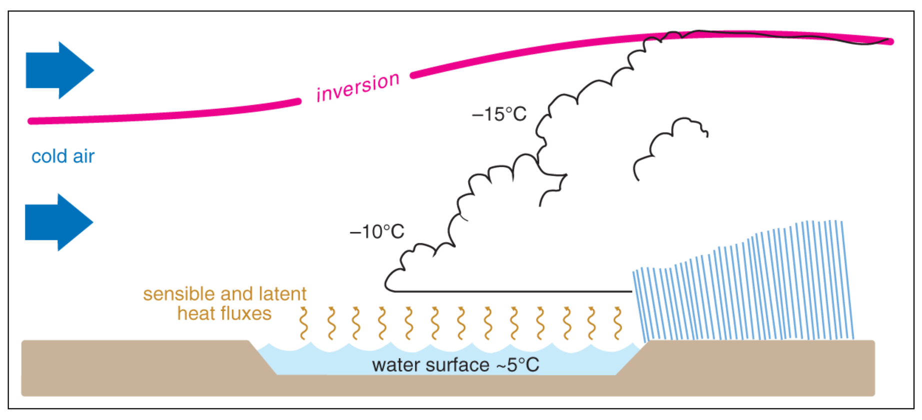

Figure 2: Schematic illustrating the modification of the cold air mass that leads to the development of lake-effect convection. (from Markowski and Richardson 2010)

Characteristic RADAR images

The RADAR images of four out of 30 known lake-effect cases are shown in Figure 3. These chosen events show **precipitation bands over the lake and downstream** in the extension of the major axis. The bands of high reflectivity in Figures 3b and 3d are located more in the east due to stronger westerly winds at the western coast. The formation of lake-effect precipitation **strongly depends on the wind direction** in the boundary layer. The maximal fetch occurs for wind directions between 290 ° and 310 ° where the city of Bregenz and the Bregenzerwald (see Fig. 1) are mainly affected by the enhanced precipitation.

Climatology

In this **first study of the lake-effect precipitation at Lake Constance**, an inventory of events has been created which provides the basis for further research. In a first step, weather station data were analysed to identify possible cases. Subsequently, these cases were double-checked with RADAR reflectivity images.

- From 2001 to 2013, **30 events** with lake-effect precipitation have been identified (all seasons considered)
- **5 events per year** were found in the last five years (better RADAR resolution)
- **Highest relative frequency in November and December** when the lake is still warm and the number of cold air outbreaks are increasing → 63 % in autumn and winter, 37 % in spring and summer
- Stationary precipitation bands can occur at any time of day but are **often observed during night and in the morning**.
- **Absolute unstable stratification** in most of the events with a vertical temperature decrease of up to 19 K within a layer of 1100 m (see Fig. 4)
- The difference between the water (-50 cm) and the 2-m air temperature is typically between 4 and 10 K with 40 % between 8 and 10 K.
- No correlations have been found between the temperature difference (T_{lake}-$T_{850\ hPa}$) and the lifetime of precipitation bands or the precipitation sum.
- **Lake-effect events typically occur after the passage of a cold front**, when temperatures in the lower troposphere decrease.
- The precipitation sums during lake-effect cases are highly variable. They reach 10 to 60 mm water equivalent in winter. The **record 24 hour fresh snow amount** was **55 cm** measured in Bregenz (427 m MSL) on 08 Feb 2013. In summer, lake-effect precipitation sums are between 30 and 100 mm.

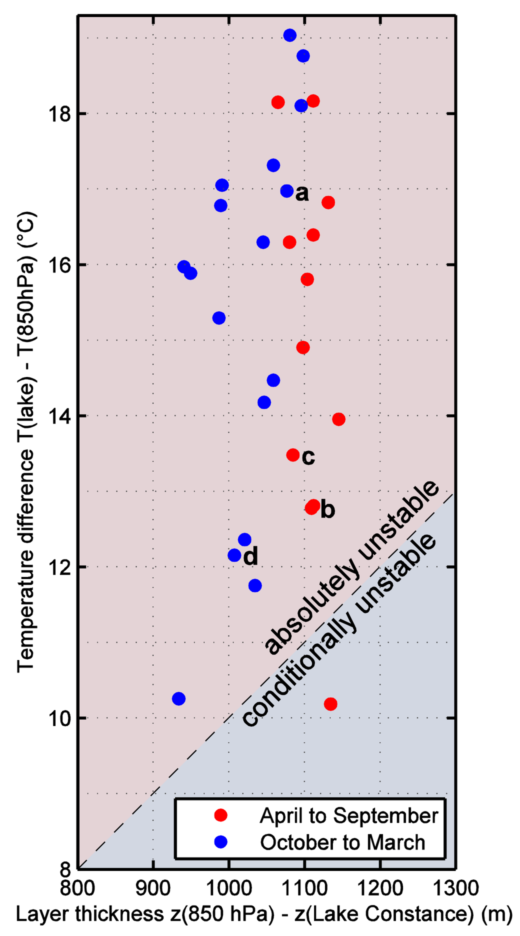

Figure 4: The temperature difference between the water surface (-50 cm) and the 850 hPa level in relation to the layer thickness is shown for all known lake-effect events identified between 2001 and 2013. The letters (a) to (d) represent the RADAR images in Figure 3.

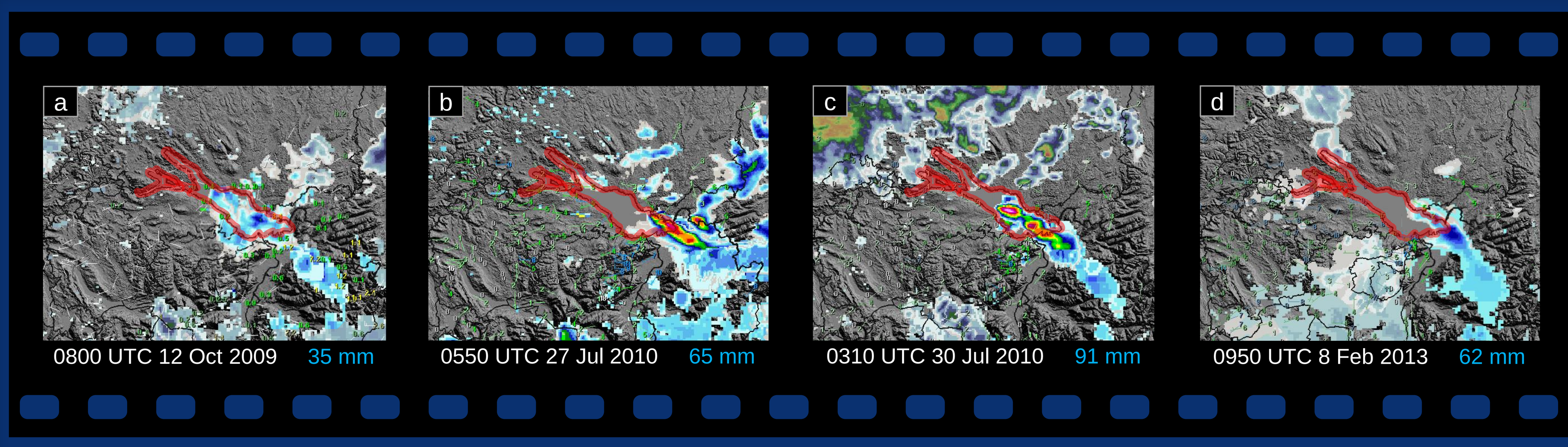

Figure 3: RADAR composite images combined with in situ measurements are shown for four lake-effect cases. Below the images, the maximum amount of precipitation (water equivalent) in the period of the events measured by automatic rain gauges is denoted.

Lake-effect forecasting

The prediction of lake-effect events is difficult, the exact location and strength of precipitation is hard to forecast. Case studies have shown that the **AROME high-resolution model** of the ZAMG can provide important information on the occurrence of lake-effect precipitation. **A convergence line or even a precipitation band** is often **well represented** but not always at correct locations as shown in Figure 5.

The **results and experiences** collected during this investigation have been **summarized in a decision tree** (see Fig. 6). He is intended for weather forecasters who do not have a lot of experience in forecasting lake-effect events.

The first element asks the user a **general question** concerning the overall stability in the boundary layer. Up to the third item, the questions should be answered easily. After the affirmation of these elements, a **short mental arithmetic** follows. A high-resolution model should help answering the last question to **finally get a decision**.

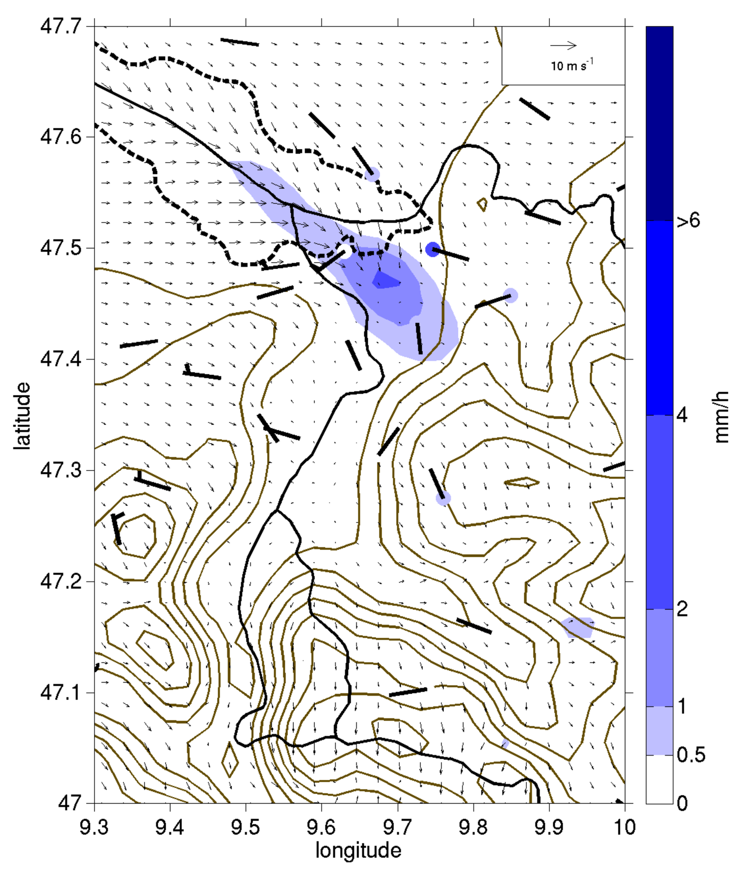

Figure 5: Operational AROME forecast of the ZAMG valid for 00 UTC 17 Jan 2013 together with surface observations: Forecast of hourly precipitation amounts from 8 to 9 UTC (shading) and measured hourly amounts (dots). Predicted 10-m wind field at 9 UTC is shown as vector field and the measured values as wind barbs. The model topography is shown by brown contour lines with a 200-m interval.

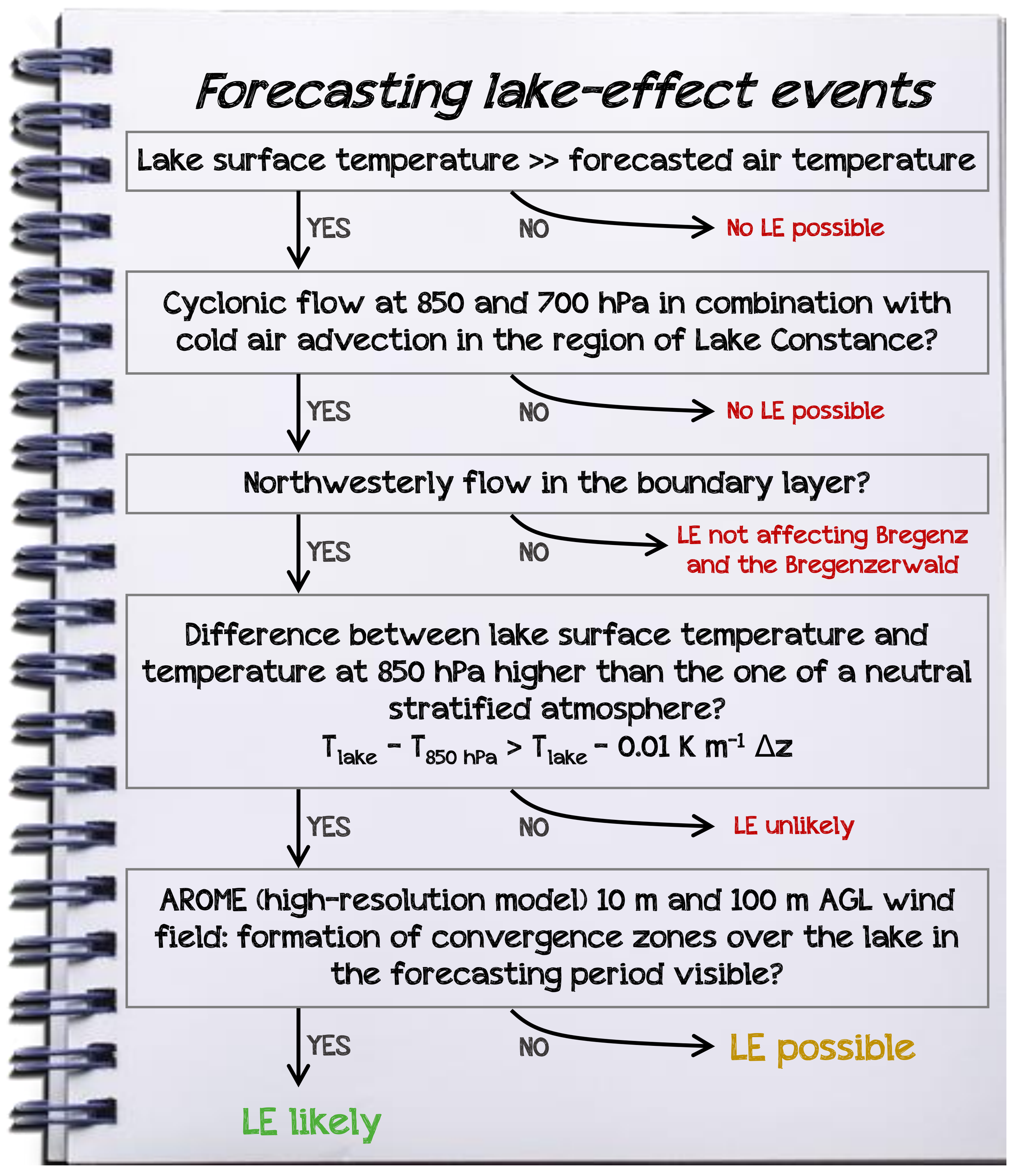

Figure 6: Decision tree to support the forecast of lake-effect (LE) events at the downstream shore of Lake Constance.

The decision tree in Figure 6 has been used by the first author since the end of 2014. The false alarm rate is high but the event observed on 26 Dec 2014 **was predicted.** The resulting snow cover of half a meter surprised the author anyway.

Conclusion

- The stationary and often banded structure of precipitation downstream of Lake Constance can be explained by the lake-effect
- They are a complex result of lake-effect convection and orographic precipitation
- Strongest precipitation occurs in the city of Bregenz and the adjacent Bregenzerwald
- These events occur **most often from July to February** after the passage of a **cold front** with a **northwesterly upstream flow**.
- **Five events per year** were identified from 2009 to 2013
- A **decision tree supports** the prediction of such events but does not give any hints on the strength and precise location.
- High-resolution models are able to indicate lake-effect precipitation but they should be used with caution.

Figure 7: An isolated snow shower on Lake Constance the day after a strong lake-effect event (see Fig. 3d), photographer: Cyrill Schlauri

Acknowledgements

The ZAMG is acknowledged for supporting the work and providing data. Ralf Grabher (Hydrographic Service Vorarlberg) is acknowledged for providing precipitation and lake surface temperatures. MeteoGroup Switzerland AG is acknowledged for RADAR composite images and the access to their measurement network. MeteoSwiss is acknowledged for providing data of automatic weather stations.

Reference

Markowski, P. and Y. Richardson, 2010: *Mesoscale meteorology in midlatitudes*. Wiley-Blackwell, 430 pp.