Chapter 7:

Precipitation over the BALTEX area

by

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7.1. Motivation

Although precipitation is one of the main components of the hydrological cycle, it is still a scientific problem to derive high quality precipitation fields.

Even today there is a lack of accurate precipitation measurements (Bumke and Clemens, 2001), since conventional rain gauges show a number of systematic errors caused by flow distortion, wetting and evaporation losses (Sevruk, 1982, or Førland, 1996). Flow distortion is also mainly responsible for the deficiency in number of reliable precipitation measurements over the sea (e.g. Reed, 1977). Therefore, methods have been developed to derive precipitation rates over sea from visual observations of the present weather (e.g. Tucker, 1961, or Lindau, 2002).

Another problem with respect to analyse fields is the high variability of precipitation in space and time. This was investigated by Rubel (1996) in general and by Clemens and Bumke (2002) for the Baltic Sea area. Consequently dense observation networks are needed to get accurately interpolated precipitation fields. Unfortunately due to financial reasons the precipitation network will deteriorate in future, thus, alternative methods have to be developed to fill in the gaps, mostly based on remote sensing techniques like weather radars or micro wave meteorology. However, these techniques as well as numerical model output used for weather prediction or climate modelling, necessitates the validation by in-situ measurements to allow well-founded statements about their quality.

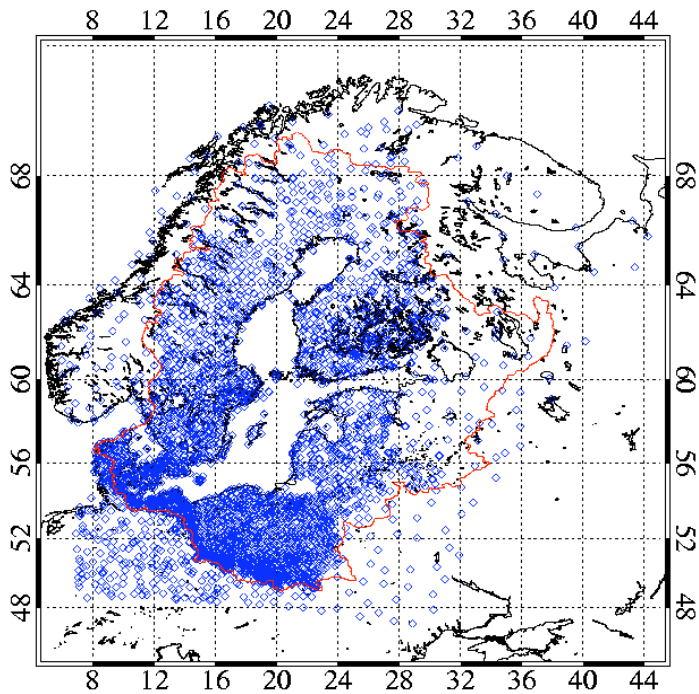

Figure 7.1: Spatial distribution of the synoptic precipitation data.

7.2. Collection and on-event bias correction of existing precipitation measurements

In the frame of BALTEX most of the available precipitation measurements and other meteorological data in the BALTEX catchment area were collected at the BALTEX Meteorological Data Center (BMDC), located at the German Weather Service (Lehmann et al., 2000). The total number of precipitation gauges with daily observations is about 4000 (Fig.1). Rubel and Hantel (1999) corrected these daily observations for systematic measurement errors caused by aerodynamic effects as well as wetting and evaporation losses. The meteorological information needed for the correction procedure is mostly unknown at the location of the precipitation gauges. Therefore, meteorological information was taken from the closest synoptic stations. In the Baltic Sea drainage basin most rain gauges are in the local vicinity of a synoptic station, not more than 45 km away; the mean distance to the closest synoptic station is 30 km. Allerup et al. (2000) applied a similar correction method to the Danish precipitation database to investigate the influence of off-site weather information. They concluded that wind speed can be extrapolated from remote sites not farther away than approximately 50 km, while information on rain intensity and temperature can be safely extrapolated across longer distances.

The annual averaged precipitation deficit of the raw rain gauge observations is about 13% (Rubel and Hantel, 2001). The bias-corrected precipitation measurements can serve as ground truth for precipitation over land (Rubel, 1998) and are invaluable for example in the design of new algorithms for remote sensing techniques.

7.3. Introduction of new instruments to measure precipitation

Simultaneously the development of several new kinds of instruments to measure precipitation have started. Two instruments were constructed to measure precipitation especially under high wind speeds as they occur usually on moving platforms like ships or in mountainous areas. These are a new kind of a ship rain gauge (Hasse et al. 1998) and an optical disdrometer (Großklaus et al., 1998), which gives drop size distributions, too. Predominantly for the use on land a vertical looking micro rain radar (Peters et al., 1998) and a new mini sodar were developed.

Within the Pilot study of Evaporation and Precipitation (PEP, Smedman et al., 2002) in BALTEX and APOLAS (Accurate areal Precipitation measurements Over Land And Sea) in DEKLIM (Deutsches KLIMaforschungsprogramm) the ship rain gauges have been used routinely on several merchant ships to measure precipitation along their sea routes from Germany/Denmark to Finland/Poland/Russia. These measurements produce a new set of in-situ precipitation data over the Baltic Sea (Fig. 2), an area not covered by the existing synoptic precipitation gauge network (Fig. 1). The micro rain radar was used at several sites, for example in Zingst, Germany, and on the small islands Christiansø, Denmark, and Östergarnsholm, Sweden (Fig. 2). Within the frame of the DEKLIM program all these instruments are mounted at Westermarkelsdorf and most of them in Zingst, both Germany, to allow extensive comparisons with conventional gauges and other instruments like the Joss Waldvogel disdrometer to test their suitability for routine observations of precipitation (Fig. 2).

As mentioned above it is also possible to derive precipitation rates over sea from visual weather observations, where the present weather code is taken as an indicator for the precipitation rate. This method has their own problems (Dorman and Bourke, 1978), but it is the only possibility to investigate precipitation from observations over the recent decades. For the Baltic Sea area Lindau (2002) improved and used this method to estimate precipitation from the Comprehensive Ocean and Atmosphere Data Set (COADS).

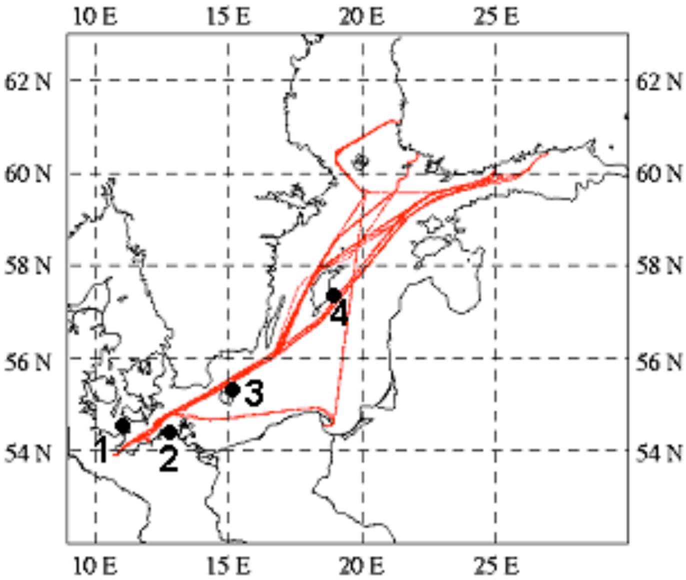

Figure 7.2: The red lines give the spatial distribution of the rain fall measurements by the observing ship rain gauges during autumn 1998. The symbols mark those locations (1 = Westermarkelsdorf, 2 = Zingst, 3 = Christiansø, 4 = Östergarnsholm), where additional precipitation measurements have been performed during PEP and APOLAS.

7.4. Interpolation of precipitation measurements

To get precipitation fields from in-situ measurements three different methods have been developed within BALTEX. One is the MESAN (MESoscale ANalysis) of the Swedish Meteorological and Hydrological Institute (SMHI) which analyses precipitation fields on the base of synoptic observations, distributed via the Global Telecommunication System (GTS), and, at a lower degree, from the BALTRAD radar estimates (Michelson et al., 2000b). For that purpose spatial structure functions of each synoptic station in terms of correlation functions have been estimated which serve as weighting functions in the analysis scheme. Radar estimates of precipitation were checked for their reliability and merged with synoptic observations to get realistic precipitation fields. The precipitation measurements were not corrected for systematic errors like wind distortion, wetting and evaporation losses. Due to missing in-situ measurements of precipitation over sea it is to expect that the uncertainties of MESAN are increasing over the Baltic Sea area.

Another interpolation scheme uses all available precipitation measurements in the BALTEX area. To get unbiased estimates Rubel and Hantel (1999) used those measurements, which were corrected for systematic errors. Interpolation was done by applying a statistical method, the block kriging, on the data. Resulting errors over land are small, but over the Baltic Sea they may reach about 40% (Fig. 3).

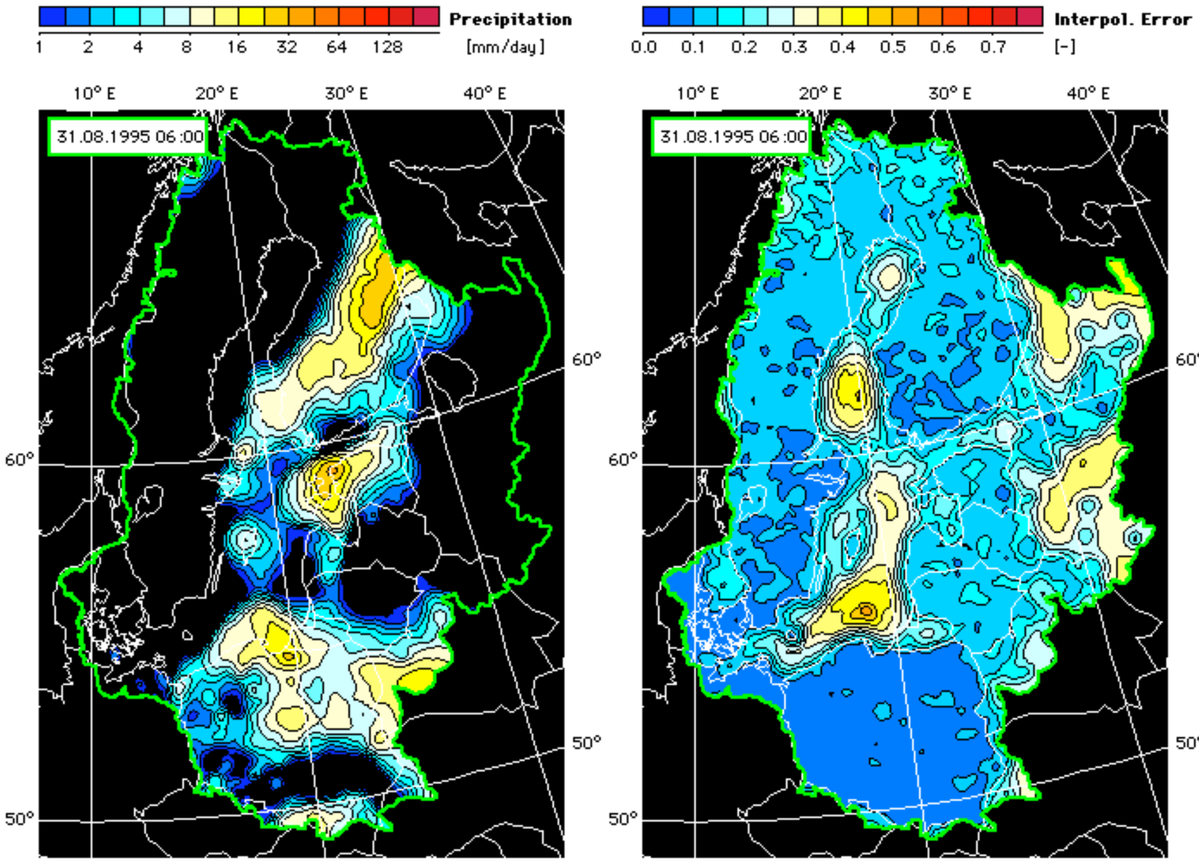

Figure 7.3: Objectively analysed precipitation field and the normalised interpolation error (Rubel, 1998)

Recent data sets collected in the framework of the ELDAS project comprise more than 21,000 gauges over Europe (Rubel, 2004). Improvements concerning the precipitation analysis in the Baltic Sea drainage basin result from additional Norwegian precipitation gauges collected during ELDAS (Rubel et al, 2004a).

A third method makes use of ship rain gauge measurements on merchant ships to estimate precipitation over the Baltic Sea, only. This interpolation scheme (Clemens, 2002) bases also on the Kriging method and allows to estimate seasonal precipitation fields along the main ships' routes with an accuracy of about 15% (Fig. 4).

No efforts were made so far to combine in-situ measurements over land and sea to estimate precipitation fields. Depending on the chosen interpolation system this will necessitate the investigation of spatial structure functions of precipitation fields in coastal areas.

7.5. Remote sensing techniques

A different approach to estimate precipitation fields over land and sea is to use remote sensing techniques. The most prominent example is the composition of BALTRAD, which is a network of Swedish, Finnish, Norwegian, Danish, German, and Polish weather radars combined with some synoptic stations mainly in Poland and over the Baltic states by the SMHI (Michelson et al., 2000a). BALTRAD gives a good insight in the actual precipitation patterns (Fig. 5) due to their excellent spatial and temporal resolution. But it fails on longer time scales (Strümpel, 2001). One reason is that the derivations of these fields demand the use to full distance range of a radar, also outside the doppler radius, which causes consequently a number of problems due to a possible occurrence of artefacts. Other problems may arise from refraction in the marine atmosphere, typically following from stable atmospheric conditions as they are frequent in spring.

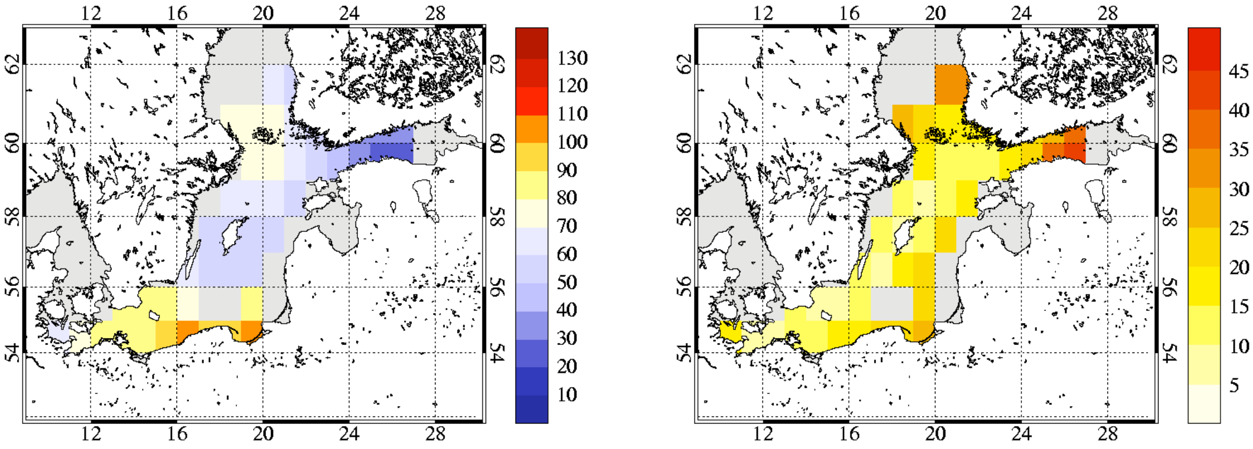

Figure 7.4: Spatial distribution of precipitation estimates (in mm/month, left) and of relative error estimates (in %, right) for autumn 1998 resulting from the kriging method (Clemens, 2003).

Vertical-looking micro-rain-radars (MRR) can also be used to estimate precipitation. The measured vertical profile of rain rate and drop size distribution allows to link the weather radar measurements aloft with surface precipitation measurements. Figure 6 shows a first attempt of simultaneous measurements of radar reflectivity obtained at Zingst with a MRR-2 and the Rostock weather radar. The MRR-2 data have been converted into equivalent Rayleigh reflectivity on the basis of retrieved drop size distributions.

A new 3-hourly precipitation data set has been presented by Rubel et al. (2004a, b). 3-hourly precipitation fields have been estimated by disaggregating daily gauge analyses with radar data from quality controlled BALTRAD (Michelson, 2003; Michelson, 2004) and CERAD (Brugger, 2004) data, respectively. This dataset is available for the period Oct. 1999 to Dec. 2000 and has been designed for both, NWP data assimilation and model verification studies.

Another remote sensing method, developed for nowcasting applications has been presented by Bennartz et al. (2002). Based on data obtained from the Advanced Microwave Sounding Unit (AMSU) onboard NOAA-15, this satellite product provides categorical precipitation estimates. Precipitation is divided into the 4 categories: precipitation-free, risk of precipitation, precipitation between 0.5 and 5 mm/h, and precipitation higher than 5 mm/h. Algorithm for the scattering-based precipitation identification were employed for land and sea areas. Algorithm used for coastal areas is a average of both, weighted by the fraction of land in the footprint..

Global monthly precipitation fields with a spatial resolution are available from the GPCP project (Huffman et al., 1997; see also Rubel and Hantel, 2004). These fields are based on various satellite products merged with the precipitation database of the GPCC. These dataset has been designed for use in climatological studies. It covers the period 1979-2002. A daily precipitation product estimated from multiple satellites is also available from the GPCP project (Huffman et al., 2001). These daily satellite estimates cover the period 1997-2002.

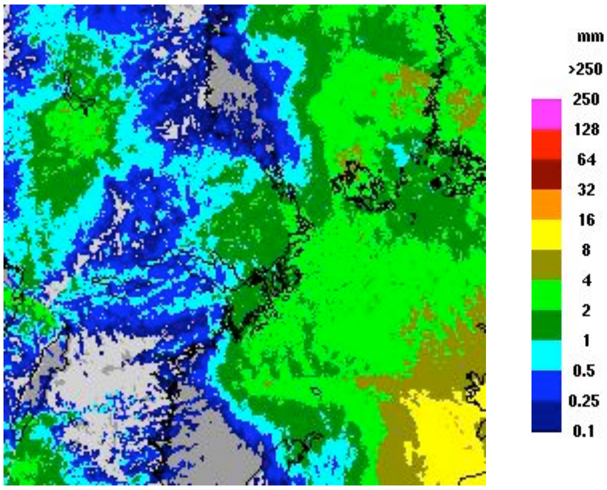

Figure 7.5: 12-hour accumulated precipitation from gauge adjusted radar for an area covering eastern Sweden, south western Finland, and part of the Baltic Proper. February 7, 2000, 18 UTC (Smedman et al., 2002).

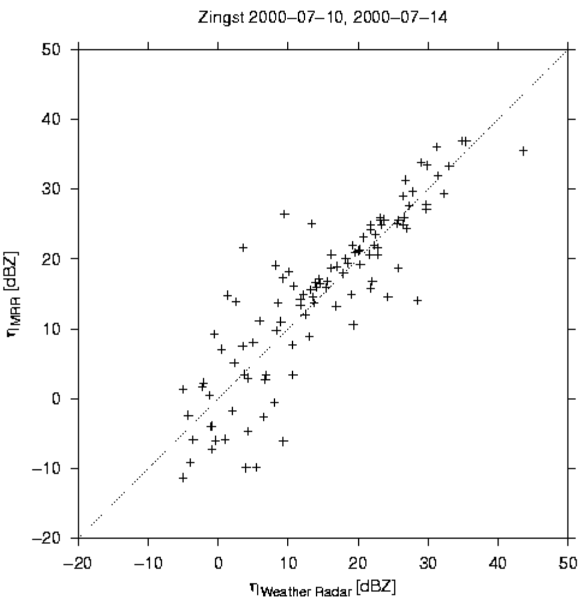

Figure 7.6: Radar reflectivity, MRR" versus Rostock weather radar (Peters, pers. communication).

7.6. Numerical models

A prerequisite for a lot of applications is that data are continuously available on regularly distributed grid points. Due to a lack of other data this can be achieved by the use of numerical models to compute precipitation rates. Precipitation is part of the forecast, thus, numerical models of weather prediction ought to be used for that purpose. Such models differ considerably in the spatial resolution, for the BALTEX area it typically ranges from about 1° for the SMHI to 0.1° latitude/longitude for the HIRLAM model (Rutgersson et al., 2001). These models are suitable to give precipitation estimates over the Baltic Sea for recent years, e.g. for September 1998 until 1999 (Fig. 7). Annual precipitation ranges for this 12 month period between 620 and 800 mm/y, depending on the chosen model. As an 18 years average for the period 1971 until 1988 Rutgersson et al. (2002) give 585 mm/y, which is close to the value of 50 mm/month estimated from COADS (Lindau, 2002). Alternatively products like the NCEP/NCAR reanalysis project have to be used. These allow an insight in precipitation for the last 50 years.

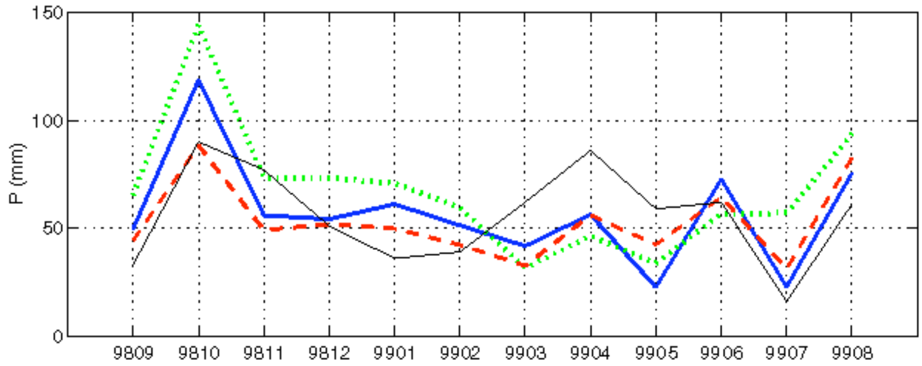

Figure 7.7: Monthly averages of precipitation (in mm/month) for the Baltic Proper using different methods. Thick full line is the REMO-DWD model, dotted line is the HIRLAM (Swedish version) model, dashed line is the PROBE-Baltic model and thin solid line is the 'ships model'. The time period is September 1998 to August 1999 (Smedman et al., 2002).

For investigation of climate change climate models like the REgional MOdel REMO were developed. During BALTEX the progress in the model development was tremendous especially on the field of air sea interaction. Therefore, atmospheric models were coupled with models of the Baltic Sea (Omstedt et al., 1997, and Hagedorn et al., 2000) to get better estimates of air sea fluxes like evaporation. But with regard to precipitation all models are hampered by the fact that they were often validated over land, only. Due to missing in-situ data no direct comparisons over sea were performed. Now available precipitation fields over the sea from in-situ measurements on merchant ships have been used for first comparisons to numerical model output (Rutgersson et al., 2001). That study clearly depicts the must of an improvement of precipitation predictions in numerical models.

7.7. Snow

Still a problem is the measurement of snow, since conventional gauges fail in measuring snow (Sevruk, 1982). Also remote sensing techniques like radar are hampered by differences in physical properties of snow and rain.

7.8. Conclusions

Precipitation over the Baltic Sea is still not exactly known. The uncertainties are of the same order as uncertainties in evaporation (Smedman et al., 2001, Hennemuth et al., 2003). Thus, it is still an open question whether precipitation exceeds evaporation or vice versa.

7.9. References

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