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**THE SPECIFICITY OF PRECIPITATION
AND THEIR MEASUREMENTS IN THE COASTAL ZONE**

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Abstract

The article analyses the weather and climate specificity of coastal zones and their influence on precipitation amounts and frequency. Coastal zones show some phenomena affecting rainfall, which is not observed anywhere else. It is mainly due to thermal contrast between land and sea and is connected with the Land-Sea Breeze System. Unfortunately, due to many difficulties with measurements in the coastal zone over the marine area, variability of the precipitation in a narrow zone of sea-land has not been thoroughly investigated. However, in this paper several methods to measure precipitation above the sea were presented.

Key words: precipitation, coastal zone, LSBS, coastal front, measurement

INTRODUCTION

Sea and land surfaces, which are the substrate and forming Atmospheric Boundary Layer (ABL) in the coastal zone differentiates among others the values of roughness and temperature. Both of them influence on the thermal stratification, the wind profile and the local atmospheric circulation and cause the development of a range of atmospheric phenomena, typical for coastal areas, such as breeze (the Land-Sea Breeze System LSBS), the breeze and coastal fronts (Malda et al. 2007, Coastal Meteorology... 1992, Simpson 1994) or zones of convergence and divergence of airflows (Baker et al. 2001, Ewert 1984, Rogers 1995). These phenomena and gradients of many meteorological factors affecting modifies values in precipitation (Attema and Lenderink 2011, Malda et al. 2007, Rogers 1995, Coastal Meteorology... 1992, Wielbińska 1962), deciding on the diversity of their total sums and intensity compared to the inland precipitation.

Analysis of the causes of variability of precipitation in the coastal zone is so important that the coast is focused to a large extent both the economy and tourism. Better understanding of coastal meteorology is of benefit to the society, since it affects commerce, industry, transportation, health, safety, national defense and recreation (Rogers 1995).

Problems of measurement of precipitation in the coastline zone

Ground-based measurement of precipitation in coastal zones is very difficult. While there is a relatively extensive network of measurement points on land, sea surface is almost devoid of them. Observations of precipitation are made there primarily through the use of remote sensing methods- from ground-based radar and satellites. However, these methods are not without shortcomings hindering the process of knowing weather processes taking place along the seashore.

Weather radar measurement has several advantages – spatial and temporal continuity of observation, the possibility of real-time observation of large areas and possibilities of automatic obtaining, processing, storage, distribution and precipitation data visualization with attachment to the map of the area (Moszkowicz and Tuszyńska 2006). Doppler radars not only detect the intensity and location of precipitation at several levels, but also measure its speed and detection of movement within the area swept, whether it is moving towards the site or away from it (Weather radar 2011). However, the primary disadvantage radar observations is the indirect measurement. A radar measurement will never be precise, because the relationship of radar reflectivity and precipitation intensity is not functional but statistical. In addition, the sources of radar measurement errors are: variability of phase states and drops' size distribution, the occurrence of the melting layer, the presence of interference echoes, changing the reflectivity profile with altitude and modification of precipitation on the run to the ground, signal measurement error, random error signal and wave suppression in a precipitation. Comparison of the intensity of precipitation measured by the radar and the pluviometer showed with the probability of 75% that the radar measured intensity of precipitation is in the range from 0.5 to 2 times of the precipitation intensity measured of the pluviometer (Moszkowicz and Tuszyńska 2006).

The disadvantage of microwave-bases satellite precipitation products are the coarse resolution and it is not possible to accurately determine the precipitation totals. The data obtained from AMSU (Advanced Microwave Sounding Unit) onboard NOAA-15 provides categorical precipitation estimates. Precipitation is divided into follow categories: precipitation-free, risk of precipitation, precipitation between 0.5 and 5 mm/h and higher. Algorithm for scattering-based precipitation identification were employed for land and sea areas. Algorithm used for coastal areas is an average of both, weighted by the fraction of land in the footprint. In the case of the coast, values are averaged according to the percentage of the area within the coverage area on the image (Bumke and Rubel 2005).

An important system of estimating the precipitation totals over maritime area is HOAPS (Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data). The HOAPS – 3 collected data from over the entire surface of the global ocean free of ice since 1987. (Andersson et al. 2010). Comparison of data from the database

HOAPS and data obtained from measurements on ships also showed very large differences in the order of even several hundred millimeters per year. Satellite data acquisition system has greatly hindered the registration of low rainfall. Moreover, the HOAPS system ignores areas with less than 50 km from the coastline (Bumke et al. 2012).

Some surface rainfall data in global scale are provided by A-Train system. It is a constellation included five satellites: Aura, CloudSat, CALIPSO, Aqua (American NASA missions) and PARASOL (French Centre National d'Etudes Spatiales CNES mission). They utilized radar and lidar sensors to obtain, for example, profiles of precipitation, as important components of the atmospheric branch of the global water cycle, and to probing the internal structure of cloud and aerosol layers (L'Ecuyer and Jiang 2010). In February, 2013 to this system Japanese SHIZUKU AMSR2 (Advanced Microwave Scanning Radiometer 2) was attached. It is a satellite aboard the GCOM-W (Global Change Observing Mission-Water) to monitor the land, ocean and atmosphere globally. It was launched by the JAXA (Japan Aerospace Exploration Agency) in May 2012 (www.jaxa.jp/projects). However, it is difficult to detect the phenomena in a narrow strip of a coastal zone because of data resolution. Spatial resolution of satellite product provided by SHIZUKU AMSR2 is 15 km (www.jaxa.jp/press). The horizontal resolution of the most precise satellite science operation mode CloudSat (which study clouds in detail) is 1.4 km (Earth Science... 2006).

Measurements on the Baltic Sea were made by appropriate meteorological radars (Koistinen and Michelson 2002, Walther and Bennartz 2006) or measuring instruments located on merchant shipping measuring in-situ on a few selected routes (Bumke et al. 2012, Clemens and Bumke 2001, 2002). These measurements, due to the much stronger winds than in the land area causing the incidence of rain water on a horizontal surface at an acute angle, were made using by suitably modified rain gauges (Bumke and Seltman 2012, Clemens and Bumke 2001, Hasse et al. 1998).

Description of precipitation over the Baltic Sea was also carried out by using a system Mesoscale Analysis MESAN created both by the data from meteorological stations located in the area of land around the Baltic Sea, as well as radar data and a mathematical model of regional weather forecasting High Resolution Limited Area Model HIRLAM (Rutgersson et al. 2001).

Phenomena occurring on the seashore influencing on the precipitation

Within Atmospheric Boundary Layer (ABL) in the sea and the land contact zone, specific thermal conditioning is produced, which affect to different rainfall regimes in different seasons at the same directions of inflow of air masses. On the Polish coast of the Baltic Sea has been found that the air advection from the sea in the late spring and summer is the influx of a cold sea air over the warmed land surface, causing destabilization of the balance of convection in the atmosphere and the development of ascending currents. It is a cause of the formation of convective clouds such as cumulus and cumulonimbus. These clouds are the source (especially Cb) of isolated showers, storms, violent and very intense precipitation. Air advection from the same direction in the late autumn and winter is the influx of a warm air from the sea,

which cools slower than the land and stabilizing the balance and inhibiting vertical movement. It promotes the development of layer clouds stratocumulus (as well as fog and cloudless weather) generating continuous precipitation, long-term, covering a large area, low and moderately intense one (Świątek 2009, Wielbińska 1962).

The study of differences between precipitation in the coastal area less than 50 km from sea and the inland area further away conducted in the Netherlands (Attema and Lenderink 2011) revealed that in spring coastal precipitation is approximately 0.2 mm day^{-1} (10% of the mean amount) less than inland, and in autumn approximately 0.3 mm day^{-1} (10-15%) more. In October precipitation amount are even 30-40% higher close to the coast than inland. For winter and summer observed coastal effects were small. These effects authors connected with the temperature (and humidity) contrast between sea and land. In autumn, warm and wet air above the sea leads to convective showers, some of which rain out over the coastal region. This results in an increased amount of precipitation for coastal areas. The effect is opposite in spring. Cold and moist air which originates from the sea becomes unstable over the warmer land. Showers develop and rain out some distance from the sea (Attema and Lenderink 2011).

In the coastal zone there are a lot of interesting climate phenomena, which is not observed anywhere else. The thermal contrast between the land and sea creates the land-sea breeze system (LSBS), breeze fronts and coastal atmospheric fronts. The convergence of marine and land air over the coastline can result in strong convection and heavy precipitation (Rogers 1995). It was found that approximately 40% of Florida's precipitation totals and probably more in many other coastal regions are associated with storms caused by a sea breeze (Coastal Meteorology... 1992). The sea breeze brings air, which is cooler and more humid than the air found over the land. This cool air plows underneath the warmer air over the land and forms a localized cold front known as a "sea breeze front". The sea breeze front gradually advances inland during the day and is associated with the development of sea breeze cumulus clouds (Greenland 2005). A longer-lived cousin of the land and sea breeze front, called a "coastal front", can form and remain quasi-stationary, parallel to the coast, for several days. When the sea (or great lakes) is much colder than the land, a cold front moving parallel to the coast undergoes local intensification and advances rapidly along the coast while being inhibited farther inland (Coastal Meteorology... 1992). Frictional convergence is the key process that enhances the coastal front intensity. A thermal difference between land and sea equal zero still yields the development of the coastal front. A lower sea surface temperature generates a reversed coastal front (Malda et al. 2007). The formation of fronts in the coastal zone results the formation of precipitation clouds and consequently rainfall (Hsu 1988, Malda et al. 2007).

Research on the eastern coast of the Mediterranean Sea (Heiblum et al. 2011) have shown also special privilege of the sea coast in terms of the formation of precipitation due to the convergence of a moist air. Radar measurements showed in directly rapid decrease in precipitation as it moves away from the coast to inland.

The distribution of initial soil moisture influences the timing and location of precipitation. The heaviest precipitation preferentially occurs over wet soil. Nonlinear interaction between coastal curvature and initial soil moisture produces extremely

heavy precipitation near regions of wet soil. The combination of coastline curvature and early-morning land breezes causes in some regions of world a significant change in the location of heavy precipitation because of localized convergence along sea-breeze front (Baker et al. 2001). Convergence zones are especially common at headlands and peninsulas, both areas of strongly convex coastlines (Simpson 1994). The inland penetration of the sea-breeze front produces effects similar to the passage of a cold front, with convective storms. The most intense convergence developed at approximately 30 km inland, with showers. In Aquitaine (France) a precipitation maximum is located around 20-40 km inland (Planchon and Cautenet 1997). Similar relationships have been demonstrated for the Polish Baltic coast (Ewert 1984).

Some influence on the formation of precipitation in the coastal zone shall also the phenomenon of upwelling. In Peru and northern Chile upwelling of cold-water gives rise to fog that is often the only source of precipitation in this dry climate (Greenland 2005).

The rising of sea surface temperature could have impact on coastal and inland precipitation, and therefore change the precipitation distribution, especially in the coastal area. Water temperature of the surface layers of the southern Baltic Sea during 1998-2010 shows a positive trend of $0.16^{\circ}\text{C year}^{-1}$ (Rak and Wiczorek 2012) so the climate changes on the Polish coast of the Baltic Sea are very probable. The sea surface temperature is largely dependent on the atmospheric conditions, such as the atmospheric flow (Attema and Lenderink 2011)

Phenomena affecting precipitation occurring in the Polish coastal zone of the Baltic Sea

The effects of climatic differences in the coastal zone, related to the interaction of the sea, reach quite far inland: the breeze from the Baltic Sea accompanied by the winds from the direction of the western sector may reach up to tens of kilometers from the seashore (Michalczewski 1965). The belt of increased rainfall (especially in the autumn) caused by the coastal convergence extends along a substantial part of the coast and is located on the edge of the Pomeranian Lake District (Ewert 1984). In Poland (especially in the central coast) the convergence of shoreline occurs during a WSW direction wind, while the divergence during a ENE direction wind. These phenomena affect the pluvial conditions in the coastal area – the convergence of air masses contributing to the increase of precipitation totals, and the divergence reduces it.

Polish coast are also characterized by specific seasonal variability of precipitation totals. In the spring, the cooling effect of the Baltic causes the delay of the annual cycle of precipitation on the coast, as well as the entire Pomerania. In the autumn, precipitation totals on rainfall stations located on the Polish coast are higher, and most of all more frequent, than the spring ones. Domination in terms of precipitation totals the autumn over the spring is connected with the influence of the Baltic Sea on the increase of precipitation totals during the period when the sea is warmer than the land and the air above it. It causing unstable stratification of air masses (moist, unstable equilibrium) and therefore favors the occurrence of rainfall especially in the narrow coastal belt (Ewert 1984). The influence of the Baltic Sea is also reflected in a shift of the maximum concentration of precipitation to the autumn (Świątek 2009).

Less known are phenomena in Atmospheric Boundary Layer above the sea surface. Some studies (Rubel and Hantel 2001) suggest that the precipitation over the basin of the Baltic Sea are rather smaller than over the land. In some seasons, however, when the sea is relatively warm, precipitation over the sea is larger. Periodicity and the strength of the thermal effects of land and sea on the parameters of ABL is subject to distortions by frequent changes of macroscale circulation systems. The specificity of the Polish coast is a particularly important role of lows and accompanying them fronts in shaping pluvial conditions. This involves very frequent shifting lows over the Baltic Sea. According to Walther and Bennartz (2006) analyzing radar data on the Baltic Sea about two thirds of the total precipitation fell in association with frontal systems.

SUMMARY AND CONCLUSION

Specificity of the Atmospheric Boundary Layer is due to the topographical diversity and differentiation of physical characteristics of the land and the sea (such as heat capacity, thermal conductivity, etc.) manifested in thermal gradients and a very great diversity in terms of the roughness of the substrate. These conditions are the cause of a particular, local air circulation dependent on the characteristics of the surface over which air mass moves. Within the ABL in the coastal zone there are also formed clouds (eg. cumulus, stratocumulus), whose genesis is related to phenomena such as sea breeze (the land-sea-breeze system) and the coastal front. All of this is the cause of the formation of specific pluvial conditions on the seacoast. The impact of the sea on the rainfall in the coastal zone is manifested inter alia in the shaping of the annual cycle of precipitation, contributing to the increase in precipitation in autumn and the decrease it in the spring. Unfortunately, due to the almost absence of measurement network in the coastal zone over the marine area, variability of the precipitation in a narrow zone of sea-land has not been thoroughly investigated. Measurements conducted remotely (radars and satellites) does not guarantee a sufficiently accurate measurements.

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SPECYFIKA OPADÓW I ICH POMIARÓW W STREFIE BRZEGOWEJ

Streszczenie

W pracy przeanalizowano specyfikę pogody i klimatu strefy brzegowej ze szczególnym uwzględnieniem sumy i częstości opadów atmosferycznych. W strefie brzegu morskiego występują pewne zjawiska wpływające na wielkość opadów, które nie są obserwowane nigdzie indziej. Zjawiska te spowodowane są głównie kontrastem termicznym między lądem a morzem i wiążą się z występowaniem bryzy morskiej i lądowej. Niestety, ze względu na znaczące trudności dotyczące pomiarów w strefie przybrzeżnej w jej morskiej części, zmienność opadów wąskiej strefy brzegowej nie została dokładnie zbadana. Dokonuje się jednakże pomiarów nad akwenem morskim, w niniejszym artykule przedstawiono kilka ich sposobów.