Spatial variability of rape yields reduction due to the winter warming and frost events – case study Poland

Dariusz Ziolkowski[1] and Alicja Malinska[1]

*Institute of Geodesy and Cartography, Department of Remote Sensing, Warsaw, Poland;
dariusz.ziolkowski@igik.edu.pl, alicja.malinska@igik.edu.pl*

Abstract. The aim of the study is to analyse spatial variability of wintering conditions of rape on the territory of Poland. The wintering conditions were determined using models of yield forecasts based on Vegetation Condition Index (VCI) developed at the Institute of Geodesy and Cartography. The models of yield forecasts, which were done at the end of the eleventh decade of the year, were used. 10-day's composites of NOAA AVHRR images recorded daily from 1997 to 2012 were the input data for the calculation of indicators. The spatial and temporal variability of wintering conditions of rape in NUTS4 regions were determined using three indicators which take into account frequency and value of yield reduction. Moreover, comprehensive index was also created. The most unfavorable winter conditions for rape occur in western Poland in PL43 and PL41 NUTS2 regions, which are characterized by potentially highest yields. The most favorable wintering conditions occur in south-eastern Poland in PL32 NUTS2 region. Frequent heavy frosts following winter warming events causing loss of snow cover are the reason of unfavorable wintering conditions of rape in western Poland. This fluctuation of weather conditions is associated with the location of this area in the impact zone of the continental and oceanic influence. By contrast, in eastern Poland predominates continental climate. This results in lower temperatures and the presence of stable snow cover which protects crops from stress during the whole winter season. These results correlate well with the indicator developed by the Central Statistical Office for NUTS2 regions on the basis of field interview.

Keywords: NOAA AVHRR, vegetation condition indices, wintering of crops, yield forecasts.

1. Introduction

Crop plants are exposed during the growing season to many stresses associated with climatic conditions that can contribute to a significant reduction in yield, e.g. droughts or prolonged rainfalls. Winter crops are especially vulnerable to heavy frosts significantly dangerous for the areas not covered by snow. The territory of Poland is relatively often exposed to this type of natural disasters due to its location in the impact zone of the continental and oceanic influence what is reflected in changes of snow cover associated with fluctuations of winter weather conditions. The fluctuations cause high spatial and temporal variability of wintering conditions for crops. Particularly unfavorable conditions, can lead to the deterioration of majority of the winter crops. Such event took place, in February 2012 in western NUTS 2 areas of Poland.

The wintering conditions of crops can be studied from two different perspectives: analyzing the stress factors for plants during the winter period (mainly the occurrence of freezing temperatures in the absence of snow cover) or assessing the effects of these factors by examining the crop conditions at the beginning of the growing season. In the case of Poland it would be very difficult to perform first research approach using remote sensing techniques due to the very frequent occurrence of cloud cover during the winter season. Therefore it was decided to test the latter approach. The aim of the study is to analyse spatial variability of wintering conditions of rape on the territory of Poland using models of rape yield forecasts which were done in the early growth stage of crops.

2. Methods

All indicators of wintering of crops and models of yield forecasts used in the studies are based on information derived from daily database of NOAA AVHRR images recorded from 1997 to 2012 year. The spatial resolution of the data is 1 km2. Due to the relatively high frequency of cloud cover in Poland all analyses were carried out using 10-day's composites. These data were the input for the calculation of the vegetation condition indices (VCI and TCI), which are used in models of crop yields forecasts developed at the Institute of Geodesy and Cartography [1, 2].

The research was carried out only in agricultural areas. Non-agricultural areas were excluded from the analysis using the mask developed at the Institute of Geodesy and Cartography [3]. After the calculation of vegetation condition indices the information derived from 1 km2 pixels were averaged within NUTS4 regions. Further analysis (yield forecasts, statistical analysis) was carried out on the values averaged within these administrative units.

Assessment of wintering conditions of crops was carried out on the basis of NOAA AVHRR images registered from the beginning of the growing season till the end of the 11 dekade of the year. This is usually the second or third decade after the start of the growing season. The results obtained on the basis of the data registered till the end of the earliest dekades were unreliable because of the relatively small coverage of the surface by crops that were in the initial stage of growth. The reflection from the ground and, consequently, values of the vegetation indices were strongly modified by soil moisture conditions. It was considered that the studies carried out on the basis of the data recorded in the later periods of the year could also be unreliable. In this case, the results could be strongly influenced by the crop growth conditions after the start of the vegetation period. It was decided that the forecast of rape yields reduction prepared at the end of the eleventh dekade of the year will be considered as an indicator of the wintering conditions of rape in a given year and NUTS4 region.

The reference point for the assessment of the wintering conditions of rape in each year were the maximum values of rape yield forecast obtained at the end of the eleventh decade of the year for the given NUTS 4 region during the study period (1997-2012). Due to the variable climatic conditions in Poland in particular winters it was assumed, that in each region of Poland during the study period there was at least one year with very favorable wintering conditions, which resulted in very high yields. According to the available data, such very good conditions occurred in Poland and throughout whole Europe in the years 2004 and 2009. Therefore, the reference of all analyses to the maximum values of the forecast from the study period is well justified. The correctness of this approach confirms the distribution of values of index of wintering rape provided by the Central Statistical Office of Poland [4, 5, 6, 7, 8, 9, 10, 11, 12]. The maximum values of this index from the period 2003 - 2012 in particular NUTS2 regions of Poland are very close to each other (Fig. 1). The analyses were not referenced to the spatial variability of absolute values of yields of rape on the territory of Poland since these depend on many different factors not related directly to the wintering conditions of crops, such as soil type, length of the growing season and weather conditions during the later periods of the growing season.
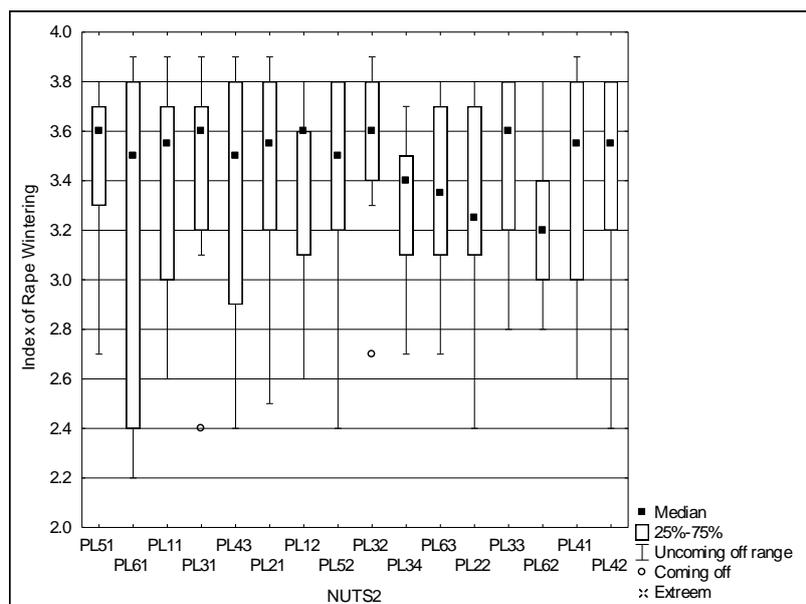
Figure 1. Index of wintering of rape in the period 2003 – 2012 for NUTS2 regions by Central Statistical Office of Poland. The indicator can take values from 0 to 5. The value of 5 means very good wintering conditions for rape.

The forecast of yield reduction of rape for each year of the period 1997 – 2012 and for each NUTS4 region was calculated using the formula:

$$R_N\ (\%) = ((Yields_{max} - Yields_N\ ) / Yields_{max}\ )* 100$$

where:

R_N = reduction of yields of rape in the year N as a percentage

$Yields_{max}$ = maximum value of the forecast of yields of rape after the eleventh decade of the year from the period 1997 – 2012 for given NUTS4 region.

$Yields_N$ = forecast of yields of rape after the eleventh decade of the year in the year N for given NUTS 4 region.

In order to present spatial and temporal variability of the distribution of wintering of rape in Poland in the period 1997 - 2012 three indices were calculated:

1 The median of forecast of yield reduction of rape - it is the middle value of the forecasts of yield reduction in the period 1997 - 2012 for the given NUTS4 region.

2 Number of years in the period 1997 - 2012, for which the county forecast of yield reduction due to the poor wintering conditions for given NUTS4 region was greater than 10% (The average of the median of the forecast of yield reduction for the whole country for the year from 1997 to 2012 – see index 1).

3 The averaged value of the forecast of yield reduction for given NUTS4 region counted only for years for which reduction of yields exceeded the threshold of 10%. This index inform not only about the frequency of high reduction of yields, but also on the amount of such reduction.

The use of these three indicators allows to evaluate both the frequency of unfavorable winter conditions in particular areas of Poland and to assess how much they affected the condition of vegetation after the start of the growing season.

Three indices presented above contain complementary information on the wintering conditions of rape. This was the reason to create a comprehensive index by weighting the information from the first three indicators.

The individual indicators are assigned the following weights:

627

1 Median Index: 0.3
2 Number of years with unfavorable conditions: 0.25
3 Average yields reduction for years with unfavorable conditions: 0.45

The comprehensive index can take values from 0 (very good conditions) to 10 (extremely unfavorable conditions). The range of indicator values has been divided into 10 equal classes.

3. Results

The results of the spatial variability of wintering conditions of rape obtained on the base of the individual indices are presented on figures 2, 3 and 4. The median of rape yield reduction forecast on the Polish territory equals to 10% (Fig.2). According to this index the worse conditions than median for the whole Poland are located throughout the western part of the country and on the border of PL12 and PL62 NUTS2 regions in the eastern part of Poland. This index takes strongly the highest values (the most unfavorable conditions) in PL 43 and PL41 NUTS2 region in the western part of Poland. In some NUTS4 units of this region the median of yield reduction of rape reaches the values up to 20%. In the eastern part of Poland, where there are conditions more unfavorable than the median for the whole country, this index reaches values much lower than in the western part. The wintering conditions more favorable than the median for the whole country are located mostly in the eastern part of Poland in the areas of greater influence of continental climate. Definitely the best wintering conditions are located in the PL32 NUTS2 region. In some NUTS 4 regions of this area the median of yield reduction of rape in last 15 years ranges from 0% to 2.5%.
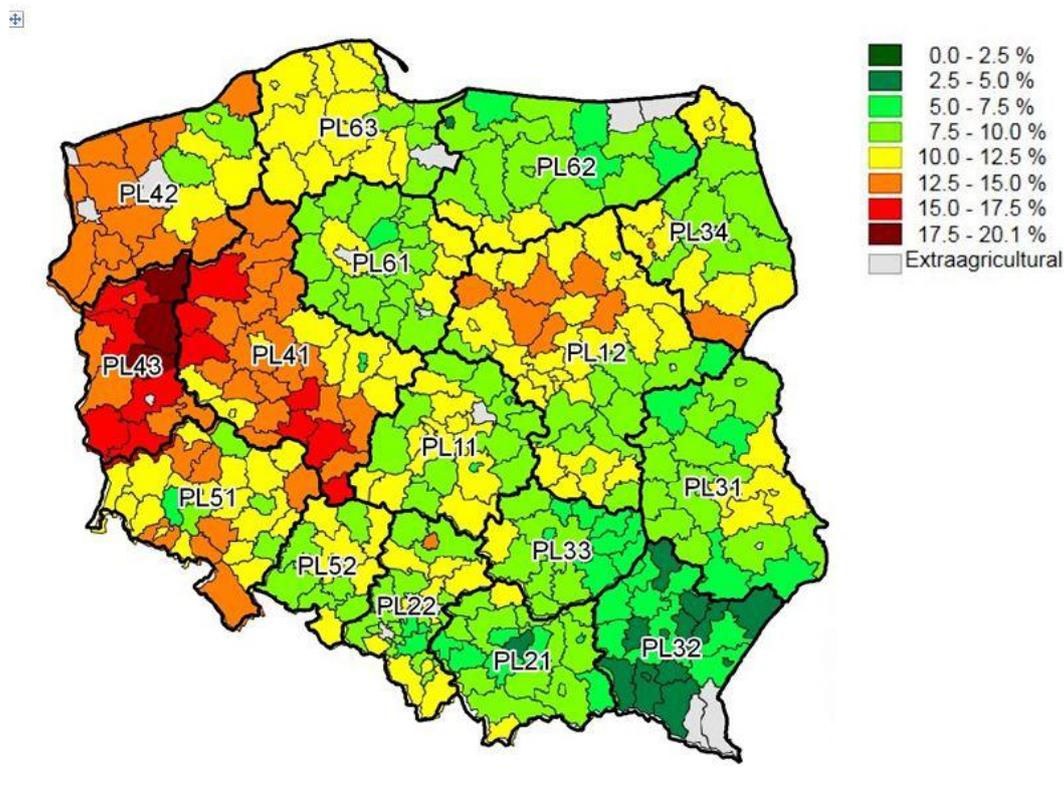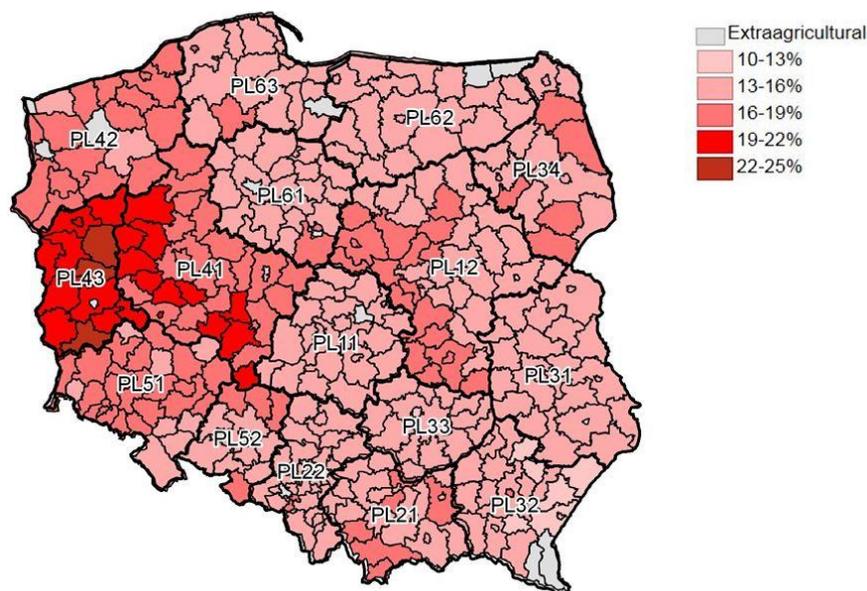

Figure 2. Median of the forecast of yield reduction of rape. The median value of the forecast of yield reduction due to the unfavorable wintering conditions from the period 1997 – 2012 expressed as a percentage. The range of values was divided into eight equal intervals. NUTS regions in yellow, red and brown represents the areas in which the median of forecast of yield reduction was higher than the average for the whole country. Green color represents the areas with wintering conditions more favorable than the average for the whole country.

Very similar pattern of wintering conditions of rape is obtained on the basis of the second indicator. Figure 3 presents the number of years for which the forecast of yields reduction of rape due to the unfavorable wintering conditions was greater than 10%. Also in this case the worst wintering conditions were obtained for the western part of the country (particularly in the north-west) and on the border between PL12 and PL62 NUTS2 regions in the east. In many NUTS4 regions during last 15 years forecasts of yield reduction greater than 10% occurred from 10 to 12 times which is up to 80% of the analyzed years. Comparing the results to the previous index it can be seen a lower variation in the areas with unfavorable wintering conditions. According to this indicator the unfavorable wintering conditions in the western part of the country (PL41, PL42 and PL43 NUTS2 regions) do not differ a lot from the unfavorable wintering conditions in units on the border between PL12 and PL62 NUTS2 regions in the east. Also variation within the area on the west is much smaller than in the case of the first index. Similar to the median index the most favorable wintering conditions characterize the areas in the south east of the country (PL32 NUTS2 region), where in some NUTS4 units the reductions of yields greater than 10% took place only one or two times in the whole analyzed period.
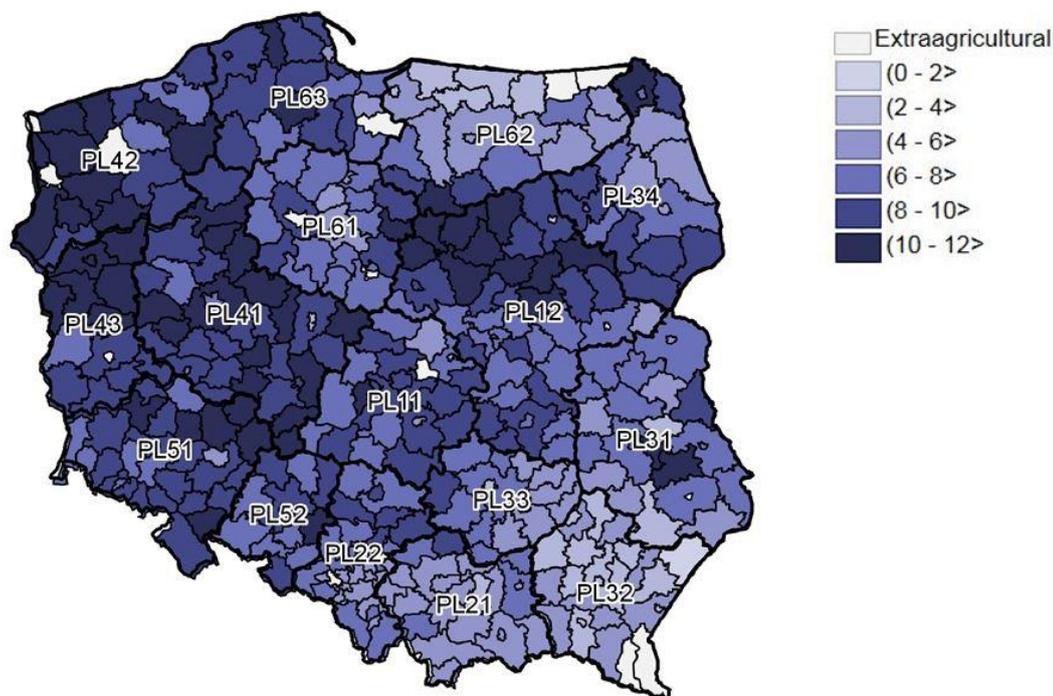

Figure 3. Number of years in the period 1997 - 2012, for which the county forecast of yield reduction due to the poor wintering conditions for given NUTS 4 region was greater than 10% (The average of the median of the forecast of yield reduction for the whole country).

A slightly different pattern can be seen using the third indicator - the average of the yields reduction forecast counted only for years for which the reduction has exceeded the threshold of 10% (Fig.4). Definitely the highest values of this index (the most unfavorable wintering conditions) are reached in the western part of the country, especially in the PL43 region (averaged value of forecasts of yield reduction of bad years ranges from 19% to 25%). This means that if stressful conditions occur in this region during the winter season, they often take the extreme values contributing to a very high yield reduction of yields caused by freezing. The pattern of this index also explains the differences in the spatial distribution of values of the first and second index. Crop plants are exposed during the winter season to stresses in many regions of Poland but in majority of the areas the wintering conditions are not as extremely unfavorable as in the PL43 region.

Figure 4. The averaged value of the forecast of yield reduction for given NUTS 4 region counted only for years for which reduction of yields has exceeded the threshold of 10%.

The results obtained using comprehensive index (weighted average of the first three indices) is presented in figure 5. It can take values from 0 (very good conditions) to 10 (extremely unfavorable conditions). The range of values of the indicator has been divided into 10 equal classes. Definitely the most unfavorable wintering conditions of rape during the period 1997 - 2012 took place in three NUTS4 units of PL43 region (values of the index: 7.57, 7.3, and 7.04). In the whole country very unfavorable wintering conditions of rape were in fourteen NUTS4 units. Thirteen of them are located in PL43 and PL41 NUTS2 regions. The best wintering conditions characterize areas located in south-eastern and north-eastern part of the country. In many cases the comprehensive index does not exceeds the rate of two (very good wintering conditions for rape).
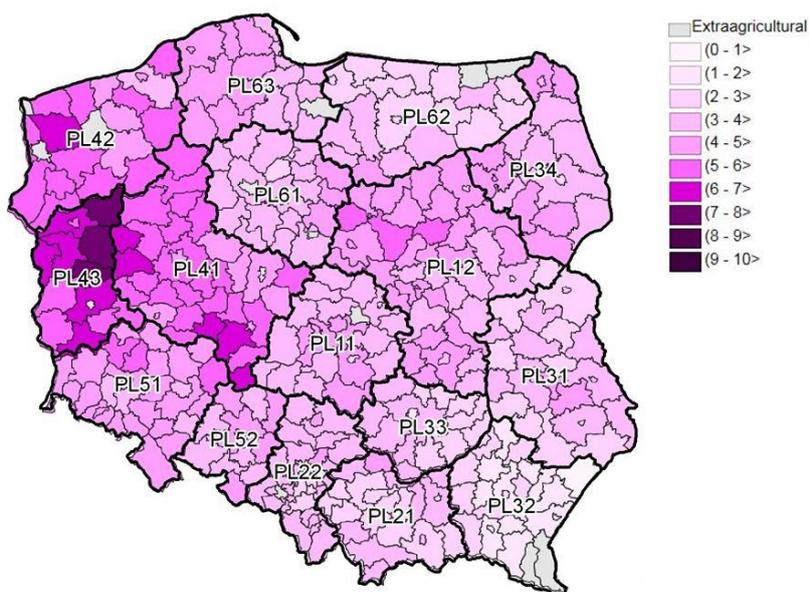

Figure 5. The comprehensive index of wintering conditions of rape in NUTS4 regions by Institute of Geodesy and Cartography.

630

The spatial distribution of wintering conditions of rape obtained using VCI index developed by IGiK based on the data registered till the end of the eleventh decade of the year were compared with wintering index of rape provided for NUTS2 regions by the Central Statistical Office of Poland. The latter one is obtained on the base of field works performed in the first half of May. As this index has been published only since 2003, the comparison of the results could be held only for 10 years. Despite such a short period of time relatively high correlation can be observed for the most NUTS2 regions of Poland between both indices. No statistically significant correlation between the indices was observed only for PL63 NUTS2 region.

As the methodology of calculating a wintering rape index by the CSO is unknown, therefore, it is difficult to identify the reasons of the lack of the correlation between both indices in PL63 region.

The differences may result from the fact that the input data for these indices are collected in different time (in the case of CSO index at first half of the May and in case of IGiK index at the 11th decade of the year – 20th April). This means that CSO index can be affected by an error associated with the crop growth conditions after the start of the growing season. Relatively high frequency of cloud cover in early spring at the beginning of the growing season can be another source of errors. As a result, the vegetation indices derived from NOAA AVHRR data and counted by IGiK are sometimes not collected from the whole agriculture area in given NUTS regions but only from the part of it (usually the other in subsequent years). These reasons can affect the correlation between indices also in other NUTS regions.

The results obtained from satellite data and models provided by IGiK indicate that the most unfavorable conditions for wintering of rape on Polish territory are located in the western provinces, where there might be potentially the highest yields. Figure 6 presents the yields of rape in the period from 1997 to 2012 in NUTS2 regions of Poland on the basis of data provided by CSO. These data show very good agreement with the yield forecast provided by IGiK at the end of June each year (mean error less than 10%). It is clearly seen that the PL43 and PL41 NUTS2 regions are characterized by potentially the highest yields but also by the greatest variability in the individual years. Factors which are characterized by high variability in individual years, what is typical for weather conditions, are responsible for this variability.
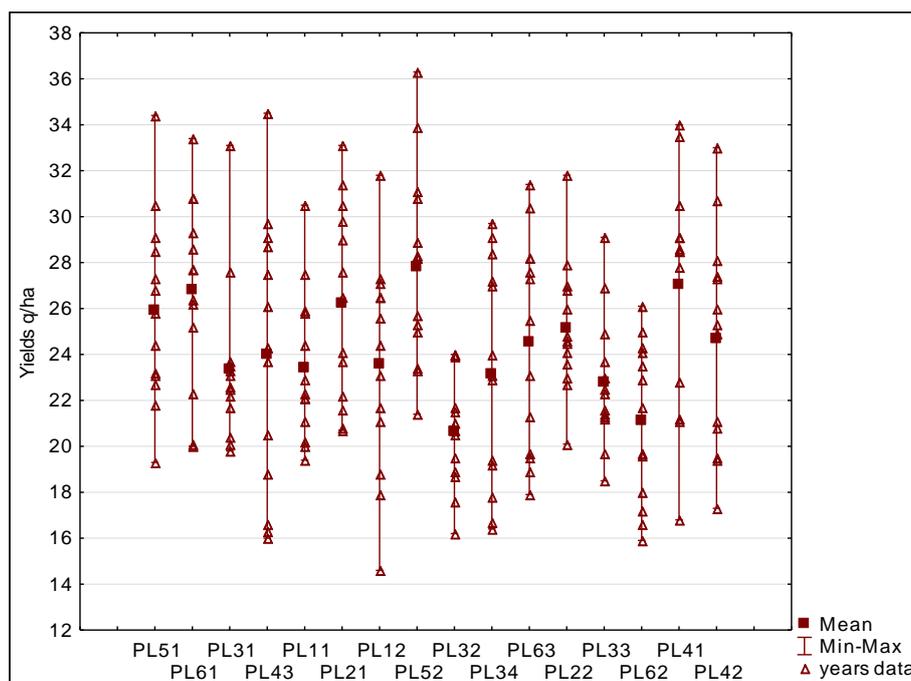

Figure 6. Yields of rape in years 1997-2012 on the basis of data provided by the Central Statistical Office of Poland.

631

Yields of rape are also well correlated with Wintering Index of Rape provided by CSO (Table 2) and by IGiK. It indicates that wintering conditions of rape are responsible for the large part of this variation.

Table 1. The Correlation between Wintering Index of Rape and Yields of rape provided by Central Statistical Office of Poland for the period 2003 – 2012.

Statistical significane (p-value) < 0.05	
NUTS2 codes	**11 dekade**
PL11	0.7308
PL12	0.3704
PL21	0.6537
PL22	0.6230
PL31	0.1015
PL32	0.4026
PL33	0.7515
PL34	0.6281
PL41	0.8597
PL42	0.9395
PL43	0.8627
PL51	0.7169
PL52	0.6823
PL61	0.8573
PL62	0.7615
PL63	0.6422

This is confirmed by forecasts of yield of rape provided by IGiK every ten days starting from the beginning of the growing season (Fig. 7). It is clearly seen that the poor conditions of the crops at the beginning of the growing season due to the unfavorable winter conditions result in most cases in lower yields in a given year.
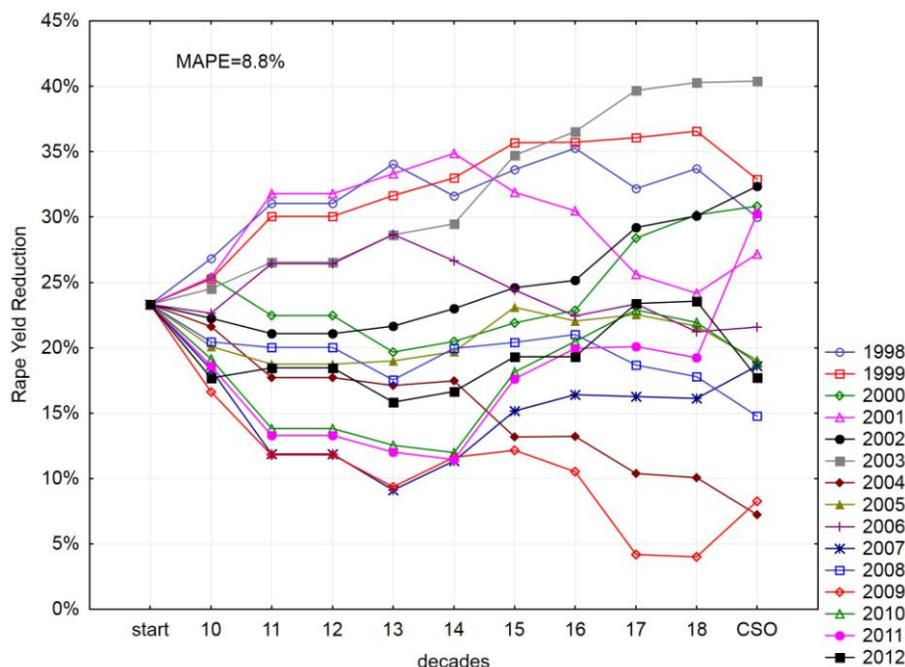

Figure 7. Forecasts of yields reduction of rape in the period 1997 – 2012 prepared using models provided by IGiK. The forecasts start from the 10th decade of the year. The last value on the x-axis presents the yields in a given year by the Central Statistical Office.

According to the data of CSO, the lowest absolute values of yields in Poland are produced in PL32 NUTS2 region (Fig. 6). However, also a relatively small variation of yields is observed in this region in particular years. One can therefore conclude that low values of yields result rather from permanent factors like poor soils and short growing season characterizing this region than from wintering conditions. This interpretation is confirmed by wintering indices of rape provided by CSO (Fig. 1) and by IGiK (Fig. 5) which shows very favorable wintering conditions in this region.

The spatial distribution of wintering conditions can be largely explained by the location of Poland in the impact zone of the continental and oceanic influence resulting in high variability of weather conditions during the winter. This implies varied exposure of winter crops in different parts of the country to stressful conditions during the winter. Heavy frost following winter warming events causing loss of snow cover is the most powerful factor. It causes the greatest losses in winter crops.

The western part of the country is more influenced by the oceanic climate resulting in milder winters. It is therefore often prone to winter warming and complete loss of snow cover. The subsequent heavy frosts resulting from the inflow of cold continental air masses are responsible for the frequent freezing of crops resulting in very high reduction of yields. The eastern part of the country is characterized by lower temperatures in winter however in most cases the presence of a stable snow cover throughout the whole winter makes the crops much less likely to be exposed to stressors.

An example of this situation is presented in Figure 8a.
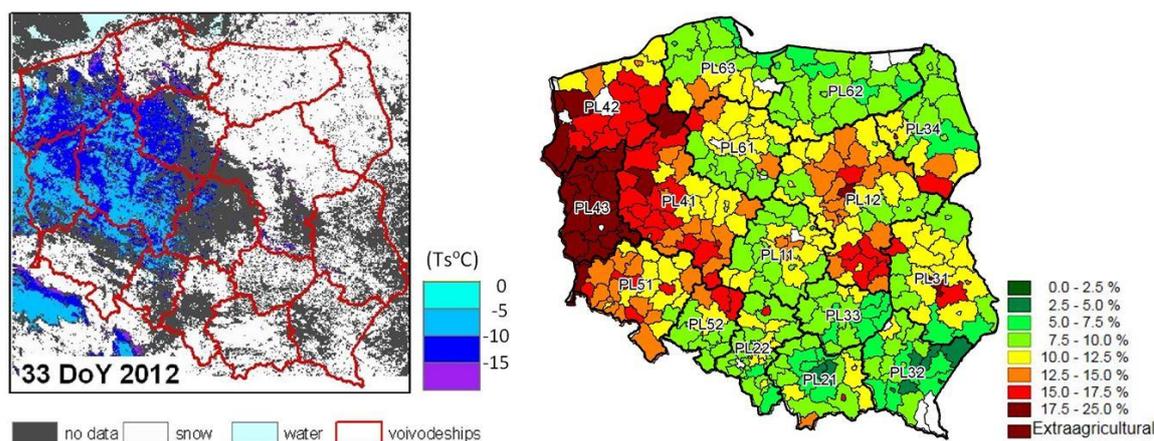
Figure 8. (a) The extend of snow cover in Poland on 02-02-2012. The surface radiation temperature derived from NOAA AVHRR images is presented in areas not covered by snow. The grey mask is overlaid on areas with cloud cover. (b) Forecast of yields reduction of rape in year 2012 by IGiK prepared at the end of the 11thh decade of the year.

This figure presents the extent of snow cover in Poland on 02-02-2012 and distribution of the surface radiation temperature on the areas not covered by snow. This data are compared with the forecast of yields reduction of rape in 2012 prepared by IGiK at the end of the 11th decade of the year (Fig. 8b). It is clearly seen that the areas with the greatest reduction of yields in the western part of the country coincide well with areas characterized by freezing temperatures and lack of snow cover.

The analyses presented above clearly indicate that it is a major stress factor for crops during the winter season and the spatial distribution of wintering conditions of rape in Poland provided by IGiK is very reliable.

4. Conclusions

This article presents the results of the research on the spatial diversity of wintering conditions of rape on the territory of Poland based on the forecasts of yield reduction of rape made in the early stages of the growing season. The results indicate that the most unfavorable wintering conditions are in western part of the country, in particular in the PL43 and PL41 NUTS2 region, which are characterized by the potentially highest yields. This is due to the location of this area in the impact zone of the continental and oceanic influence what is reflected in high variability of winter weather conditions. Frequent winter warming causing loss of snow cover (oceanic influence) and following heavy frosts (continental influence) expose the winter crops to heavy stressors and result in their freezing. The most favorable wintering conditions are in south-eastern Poland, located within the area of predominant continental influence. This result in lower temperatures and the presence of stable snow cover which protects crops from stresses during the whole winter season. The results obtained using models provided by IGiK which work on the basis of NOAA AVHRR 10-day's composites correlate well with the wintering indicator of rape provided by the Central Statistical Office of Poland and calculated on the basis of field survey. IGiK indicators developed from satellite data are obtained at the earlier stage of the growing season and in more spatial detail (NUTS4 units) than those of the Central Statistical Office of Poland (NUTS2 regions).

References

[1] Dabrowska-Zielinska, K., Kogan, F., Ciolkosz, A., Gruszczynska, M. & Kowalik, W., 2002. *Modeling of crop growth conditions and crop yield in Poland using AVHRR based indices.* International Journal of Remote Sensing (Elsevier), Vol. 23, No 6, pp. 1109-1123

[2] Dabrowska-Zielinska, K., Ciolkosz, A., Malinska, A., Bojanowski, J., Kowalik, W., Budzynska, M. & Bartold, M., 2010. *Estimates of Yield Reduction Caused by Drought.* Remote Sensing for Science, Education, and Natural and Cultural Heritage, Rainer Reuter (Editor), EARSeL Symposium, Paris, France, 31 May-3 June 2010.

[3] Turlej, K., Bojanowski, J. & Bartold, M., *Analiza udzialu klas rolniczych uzyskanych z bazy Corine Land Cover w siatce kilometrowej zdjec NOAA-AVHRR dostosowanego do wskaznikow roslinnych.*, Archiwum Fotogrametrii, Kartografii i Teledetekcji, In press

[4] Central Statistical Office of Poland, Department of Agriculture. Wiosenna ocena upraw rolnych i ogrodniczych w 2012 r. http://www.stat.gov.pl/cps/rde/xbcr/gus/RL_wiosenna_ocena_stanu_upraw_2012.pdf

[5] Central Statistical Office of Poland, Department of Agriculture. Wiosenna ocena upraw rolnych i ogrodniczych w 2011 r. http://www.stat.gov.pl/cps/rde/xbcr/gus/RL_wiosenna_ocena_stanu_upraw_2011.pdf

[6] Central Statistical Office of Poland, Department of Agriculture. Wiosenna ocena upraw rolnych i ogrodniczych w 2010 r. http://www.stat.gov.pl/cps/rde/xbcr/gus/RL_wiosenna_ocena_stanu_upraw_2010.pdf

[7] Central Statistical Office of Poland, Department of Agriculture. Wiosenna ocena upraw rolnych i ogrodniczych w 2009 r. http://www.stat.gov.pl/cps/rde/xbcr/gus/RL_wiosenna_ocena_stanu_upraw_2009.pdf

[8] Central Statistical Office of Poland, Department of Agriculture. Wiosenna ocena upraw rolnych i ogrodniczych w 2008 r. http://www.stat.gov.pl/cps/rde/xbcr/gus/wiosenna_ocena_stanu_upraw_2008_bez_podpisow.pdf

[9] Central Statistical Office of Poland, Department of Agriculture. Wiosenna ocena upraw rolnych i ogrodniczych w 2006 r. http://www.stat.gov.pl/cps/rde/xbcr/gus/wiosenna_ocena_stan_upraw_rol_i_ogro_2006.zip

[10] Central Statistical Office of Poland, Department of Agriculture. Wiosenna ocena upraw rolnych i ogrodniczych w 2005 r. http://www.stat.gov.pl/cps/rde/xbcr/gus/wiosenna_ocena_stan_upraw_rol_i_ogro_2005.zip

[11] Central Statistical Office of Poland, Department of Agriculture. Wiosenna ocena upraw rolnych i ogrodniczych w 2004 r. http://www.stat.gov.pl/cps/rde/xbcr/gus/wiosenna_ocena_stan_upraw_rol_i_ogro_2004.zip

[12] Central Statistical Office of Poland, Department of Agriculture. Wiosenna ocena upraw rolnych i ogrodniczych w 2003 r. http://www.stat.gov.pl/cps/rde/xbcr/gus/wiosenna_ocena_stan_upraw_rol_i_ogro_2003.zip