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Hydrology and Earth System Sciences
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Discussions

# *Interactive comment on* "Estimating the water needed to end or ameliorate the drought in the Carpathian region" *by* T. Antofie et al.

**T. Antofie et al.**

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We would like to thank the Reviewer for the positive comments and suggestions to improve the manuscript. The specific comments are addressed in detail below. Please note that the Reviewers' comments are shown in bold text and authors' replies are in plain or italic text.

**Main comments:**

1. **The authors come to the conclusion that the most likely end of a drought is during the wet season, and vice versa. This reasoning is not correct. Obviously, a wet climatological period will on average end a dry period, but that is not how the end of a dry period is usually defined. A drought is defined as the anomaly**



**of a time period (month, several months, season) against its own climatology. For longer periods of accumulation, a wet season will obviously dominate the drought signal, therefore a wet anomaly in the normally wet season leads to a recovery regardless of the precipitation of the dry season. This is trivial, and hardly something to discuss. The most trivial example is the dry season being interrupted by the monsoon/rain season. The real problems starts when there is a dry anomaly in the wet season. The recovery of droughts should rather be studied with regards to the inter-annual variation of the precipitation and what governs this. Obviously, even a wet anomaly in the dry season could compensate for this. Therefore, my suggestion in the review process: Can the recoveries be related to large-scale patterns, or are they random variations? If the answer to the former is yes, then can they be predicted?**

Recommendations considered in text.

We agree with the reviewer in that fact that obviously a wet period will end a dry period. Also we agree with the definition of droughts regarding to abnormally dry periods compared with its own climatology. The reviewer also pointed out the extreme case of a monsoon dominated area. We agree with the fact that the main climatological results are in line with greater scale atmospheric features and obviously related with precipitation patterns. The intention of the methodology is to assess the potential of recovery for single events. As shown in Figure 5, the drought events are centred in different seasons but the potential recovery should be benchmarked with the climatological values. As this drought recoveries are associated with different circulation patterns (that are outside the scope of this paper) this can be predicted with the same skill of the state of art seasonal forecast systems for the region. Moreover, even if the information related to the water needed to recover is not a forecast, it can be used to re-define irrigation schemes even with the only knowledge of the climatology. A brief description of the main circulation patterns are depicted below:

For both, the required precipitation and the probabilities of recovery from drought, a spatial pattern linked with the atmospheric circulation responsible for the climate variability in the Carpathian region can be noticed. The southern and southwestern Carpathians and the western Carpathians act like a barrier for the main sources of moisture (Mediterranean and North Atlantic air masses; Busuioc and von Storch, 1996, Busuioc, 2001). The intra-annual variability of these systems are causing firstly high precipitation amounts and a pronounced annual precipitation cycle, as it is the case of North Atlantic circulation in the western, northern and northwestern part of the Carpathian region. Secondly, highly variable precipitation intensity and a relatively constant distributed precipitation regime through the year (by creating a second precipitation peak in autumn), as it is the case of Mediterranean cyclones in the southwestern and southern part of the Carpathian region.

The cyclonic presence and trajectories have been the subject of extensive climatological research (e.g. W. van Bebber, 1891; Radinovic, 1987; Katsoulis, 1980; Flocas, 1988; Maheras, 2001). Often these studies establish a connection between the advance of the cyclones from the Mediterranean area and intense precipitation events. High amounts of precipitation with genesis in the Mediterranean space (Gulf of Genoa) are produced on the cyclonal trajectory V (from the Tyrrhenian Sea to Ukraine). Most important for the Carpathian region are the trajectory Vc, that crosses from west to east, the south of Carpathian region, in spring and very rarely in summer and trajectory Vb, important for the western part of the Carpathian region, passing over the Pannonian Plain, towards Poland. For both trajectories, the cyclones circulate especially in autumn, winter and spring with the largest probability of occurrence in April and a secondary maximum in early autumn. The cyclone circulation diminishes and migrates southwards in December-January, due to the intensification of the Azores and Siberian anticyclones (Maheras, 2001). Even if the annual cycles of the moisture supply and demand follow a continental pattern (imposed by the North Atlantic circulation) with a maximum of supply and demand at the beginning of the summer (May/June/July) and end of summer (July/August) respectively a minimum in the winter months (December/January/February) the months with the higher probability of substantial excess of



precipitation from the normal (April/May in spring and October/November in autumn) will be related with the cyclonic presence from the Mediterranean area.

Flocas, A. A.,: Frontal depressions over the Mediterranean Sea and central southern Europe. MeÌĄditerraneÌĄe 4: 43 – 52, 1998.

Katsoulis, B. D., Makrogiannis, T. D, Goutsidou, Y. A.,: Monthly anticyclonicity in southern Europe and the Mediterranean region. Theoretical and Applied Climatology 59: 51 – 59, 1998.

Maheras, P., Flocas, H. A., Patrikas, I., and Anagnostopoulou, C.,: A 40 year objective analysis of surface cyclones in the Mediteranean region: Spatial and temporal distribution, Int. J. Climatol., 21, 359–367, 2001.

van Bebber, W.,: Die Zugstrassen der barometrischen Minima, Meteorol. Z., 8, 361–366, 1891.

Radinovic, D.,: Mediterranean Cyclones and their Influence on the Weather and Climate. Programme on Short and Medium Range Weather Prediction Research (PSMP), W.M.O Sofia 24, 1987.

2. **The authors do not mention the motivation of the study until the end of the results section, where the winter wheat is mentioned. Please start off the paper with this information. Furthermore, there is little information on when is the sensitive period for these crops. I would assume that most important would be to have enough water during the initial growing period, but it is important to have a wet winter, or it is enough with spring rains? My point is that the authors should concentrate on the most important and sensitive season and accumulation time. This would also make the analysis easier.**

Recommendations considered in the text. Sensitive periods for the crops provided:

*As shown, in Carpathian region, the water deficit occurs throughout the whole year. As the agriculture is an important economic sector in the Carpathian region the drought* *impact could be essential. Most crops may experience water stress (deficit) at various stages in their growth cycle. The sequences of vegetative growth with their key physiological phases (i.e. crop phenology) and their sensitivity to water deficit can be used to highlight the importance of seasonal analysis of drought occurrence. Winter crops (i.e. winter wheat) are planted in Carpathian region in September through October and harvested July through August of the next year, while the spring crops (i.e. maize, spring wheat, sunflower, potatoes) are planted April through May and harvested August through September or even October (potatoes) of the same year (KEO; UNEP/DEWA 2007). Early drought in the growing season - the end of autumn in October and November for winter crops and the end of spring in late April and May for spring crops - are affecting wheat germination and crop establishment (Bouaziz and Hicks, 1990). The water stress during the vegetative stages – the months of April and May for winter crops and late May and June for spring crops – may affect the leaf index development (Rickman et al., 1983). Soil water deficit increased towards harvesting – early summer for winter crops and late July or beginning of autumn in August for spring crops - is likely to produce a severe reduction in grain growth and quality which eventually cause reduction in final yields. Nevertheless it has been noted that water deficit in the maturity (anthesis) and harvesting period accelerates development (Simane et al., 1993) and significantly contribute to grain yield (Palta et al., 1994).*

Bouaziz, A., Hicks, D.R.,: Consumption of wheat seed reserves during and during and early growth as affected by soil water potential. Plant Soil, 128: 161-165, 1990.

Palta, J.A., Kobata, T., Turner, N.C., Fillery, I.R.,: Remobilization of carbon and nitrogen in wheat as influenced by post-anthesis water deficits. Crop Sci., 34: 118-124, 1994.

Rickman, R.W., Klepper, B.L., Peterson, C.M.,: Time distribution for describing appearance of specific culms of winter wheat. Agron. J., 75: 551-556, 1983.

Simane, B., Peacock, J.M., Struik, P.C.,: Differences in development and growth rate among drought-resistant and susceptible cultivars of durum wheat (Triticum turgidum



L. var. durum). Plant Soil, 157: 155-166, 1993.

3. **Why was the Palmer drought index used? It is not very commonly used outside the US and it has clear disadvantages? SPI is the index recommended by WMO, and it should at least be used as a comparison index. If you want to include soil moisture also standardized soil moisture index could be used.**

Motivation for using Sc-PDSI provided in text. More detailed motivation presented below.

Palmer Drought Severity Index (PDSI) was developed (Palmer, 1965) with the intention of measuring the departure of soil moisture from the normal conditions, using a hydrological accounting system. Other drought indices (Standardized Precipitation-Evapotranspiration Index - SPEI, Standardized Precipitation Index - SPI, Reconnaissance Drought Indicator - RDI, and Palfai Drought Index - PADI) are based on past statistics of certain climate variables and often include precipitation alone (Dai, 2011). For example SPI is an exclusively precipitation-based drought indicator which assumes that droughts are directly controlled by the temporal variability of the precipitations. Recent studies have sustained the importance of the effect of other variables, such temperature, on drought conditions. These studies (Williams et al., 2011; Martínez-Villalta et al., 2008; McGuire et al., 2010; Linares et al., 2011) have shown that temperature rise affects the severity of the droughts and mainly the drought stress induced by heat waves on net primary production and tree mortality. As examples, the heat waves in Europe in 2003 and 2010 are mentioned due to their extreme role on drought severity which increased evapotranspiration and aggravated the drought severity (Rebetez et al., 2006). As result major decreasing in net primary production (Ciais et al., 2005) and high forest mortality under precipitation shortages (Adams et al., 2009) occurred. This illustrates at the end, how drought stress – through increased evapotranspiration - is determined, to a large degree, by the availability of soil moisture. The standardized precipitation evapotranspiration index (SPEI) developed by Vicente-Serano et al. (2010), considers also the temperature (in the computation of potential evapotranspiration - PE) however it is the actual evapotranspiration that affects the soil moisture availability and thus the drought conditions (Dai, 2011). Therefore, the use of drought indices which is based on a physical soil water balance model, such PDSI or modified versions as Sc-PDSI (used in this paper), is required in order to calculate current soil moisture conditions. In addition, Dai et. al, (2004) shows that PDSI is significantly correlated with measured soil moisture especially in warm season. Moreover, PDSI model, takes the precedent conditions into account in contrast with other drought indices that are based purely on past statistics (Dai. 2011). It uses previous and current moisture supply (precipitation) and demand (potential evapotranspiration) into a hydrological accounting system. The PDSI or modified versions of PDSI have been used to quantify drought as a recurrent extreme climate event both at continental (Europe, North America) and global level (Dai, 1998; 2004; 2011; Wells et al., 2004; van der Schrier et al., 2006; 2007). By changing the standardization used by Palmer, (1965), which was based on data from US, Wells et al., (2004) proposed the Sc-PDSI – drought indicator used in our article - and it was recognized as an improvement of the original PDSI (Dai, 2010). Moreover, the statistical based drought indices, such SPI and SPEI are normalized measures with respect to location and period, which makes the frequency of their severity classes climatologically consistent for any site (Heinrich, G., 2012). Practically they were not designed to identify regions that are more 'drought-prone' than others (Hayes et al., 1999). Therefore, Sc-PDSI has been used as it allows for comparison of drought frequency within different severity classes on different locations and it is suitable to account the drought under global warming conditions. Various aspects (CAFEC precipitation - precipitation needed to maintain a normal soil moisture level, a climate characteristic coefficient and the moisture anomaly index) of the Palmer Drought Model, on which the Sc-PDSI is based on, are directly used in the calculation procedures of the precipitation required to end or ameliorate the drought, which not only confers homogeneity but also offers means of validation of the results obtained.

Adams, H.D., Maite, G. C., Greg, A. B. G., Juan, C. V., David, D. B., Chris, B. Z., Peter, A. T., Travis, E. H.,: Temperature sensitivity of drought-induced tree mortality



portends increased regional die-off under global-change-type drought. Proceedings of the National Academy of Sciences of the United States of America 106: 7063-7066, 2009.

Ciais, Ph., Reichstein, M., Viovy, N., Granier, A., Ogée, J., Allard, V., Aubinet, M., Buchmann, N., Bernhofer, C., Carrara, A., Chevallier, F., De Noblet, N., Friend, A.D., Friedlingstein, P., Grünwald, T., Heinesch, B., Keronen, P., Knohl, A., Krinner, G., Loustau, D., Manca, G., Matteucci, G., Miglietta, F., Ourcival, J.M., Papale, D., Pilegaard, K., Rambal, S., Seufert, G., Soussana, J.F., Sanz, M.J., Schulze, E.D., Vesala, T., Valentini, R.,: Europe-wide reduction in primary productivity caused by the heat and drought in 2003. Nature 437, 529-533, 2005.

Heinrich, G., Gobiet, A.,: The future of dry and wet spells in Europe: a comprehensive study based on the ENSEMBLES regional climate models. Int. J. Climatol., 32: 1951–1970. doi: 10.1002/joc.2421, 2012. Linares, J.C., Camarero, J.J.,: From pattern to process: linking intrinsic water-use efficiency to drought-induced forest decline. Global Change Biology 18: 1000-1015, 2011. Martínez-Villalta, J., López, B.C., Adell, N., Badiella, L., Ninyerola M.,: Twentieth century increase of Scots pine radial growth in NE Spain shows strong climate interactions. Global Change Biology 14: 2868–2881, 2008. McGuire, A.D., Ruess, R. W., Lloyd, A., Yarie, J., Clein, J.C., Juday, G. P.,: Vulnerability of white spruce tree growth in interior Alaska in response to climate variability: dendro-chronological, demographic, and experimental perspectives. Canadian Journal of Forest Research, 40: 1197-1209, 2010. Rebetez, M., Dupont, O., Giroud, M.,: Heat and drought 2003 in Europe: A climate synthesis. Annals of Forest Science 63: 569-577, 2006. Vicente-Serrano S.M., Beguería, S., López-Moreno, J. I.,: A Multi-scalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index – SPEI. Journal of Climate 23: 1696-1718, 2010. Williams A.P., Xu, Ch., McDowell, N.G.,: Who is the new sheriff in town regulating boreal forest growth?. Environmental Research letters 6: doi: 10.1088/1748-9326/6/4/041004, 2011.

4. **Figure 3 and 4 nicely shows what I think is an inherent problem in the Palmer index. From this it is obvious that the number of severe and extreme droughts are grossly overexaggerated. I cannot from this draw any conclusions on the reason behind this, but it might be a problem in the calibration of PDSI or the fact that it is a cold region, or that two short time periods are evaluated. Using the numbers from table 1 you can see that the categories slightly wet to extremely wet comprise 25% of the cases, whereas slightly dry to extremely dry 41%. There is a dry bias in the current setup of PDSI which will also bias your results.**

We would like to bring some arguments to support that the current severity frequencies of Sc-PDSI datasets presented in our work might have a common characteristic encountered also in other studies:

Recent studies have shown that the temperature rise, noticed mainly in the last decades had an important impact on drought magnitude producing an increase in the severity, areal extend and duration of drought events. Analyzing the impact of the temperature rise on drought, these studies - Brázdil et al., 2008 (for Czech Republic), Brunet M., et al., 2007 (for Spain), Szinell et al. (1998) (for Carpathian Basin), Briffa et al., 2009 (for Europe in summer) and Vicente-Serrano et al., 2010 (for a few locations around the world), Vicente-Serrano et al. 2014 (for Southern Europe), M. Sousa et al. 2011 (for Mediterranean, Iberian and Balkan area), van der Schrier et al. 2007 (for the Alpine region) - showed that, the extreme temperature, in particular, caused an increased evapotranspiration and aggravated the drought severity. This increasing in severity of drought caused an extension of the areas with drought conditions by the upscalling of the frequency of normal or mild spells towards a more severe class. As an example Schrier et al. 2007 concludes that in Alpine regions by 'temperature-related' effect only since 1992 an increasing of the areal extent of moderate (or worse) droughts is noticed. When backed up by anomalously low precipitation, as it happened in 2003, an increase in the percentage area with moderate (or worse) drought of 31.2% occurs, increasing the frequency of droughts with higher severity for these areas. Moreover



8.4% of the total area of the Alpine region examined experienced extremely dry conditions, of which 7.1% can be explained by high temperatures alone. Briffa et al., 2009, when analyzing the areal extend of summer droughts at European level concludes that, mostly in the last decades of the 20th , the dry areal extend is increasing, the dry summer are more frequent than the wet and this results are particularly strong in central Europe . Also in Central Europe, in Hungary, Szinell et al. (1998) using PDSI and two statistical tests showed that frequencies of moderate and severe drought events became greater in the 20th century, when analyzing data for the period 1881 – 1995.

In the Carpathian region the frequency of extremely dry spells is 4.0%, severely dry is 7.6%, moderately dry 12.5% and slightly dry is 16.7% of the entire dataset. It is the moderately and slightly dry spells that presents values that could be considered over exaggerated compared with slightly (11.6%) or moderate (7.4%) wet spell frequencies, not the extreme. For the Carpathian region van der Schrier et al., 2007 found between 2.5% and 5% frequency of the extreme dry spell and less than 2.5% for the extreme wet spells, values comparable with what we found. No data is presented for the frequency of other severity classes. It remains for a future analysis of the data to fully prove the origins of this frequency distribution per classes if not accepting the drought severity aggravation due to 'temperature-related' effect.

Brázdil R., M. Trnka, P. Dobrovolny, K. Chromá, P. Hlavinka, Z. Zalud (2008). Variability of droughts in the Czech Republic, 1881-2006. Theoretical and Applied Climatology 97:297-315, doi;10.1007/s00704-008-0065-x.

Briffa K. R., Van der Schrier G., P. D. Jones (2009). Wet and dry summers in Europe since 1750: evidence of increasing drought. International Journal of Climatology. 29:1894-1905, doi:10.1002/joc.1836.

Brunet M., P.D. Jones, J. Sigró, O. Saladié, E. Aguilar, A. Moberg, P.M. Della-Marta, D. Lister, A.Walther and D. López (2007), Temporal and spatial temperature variability and change over Spain during 1850-2005. Journal of Geophysical Research-Atmospheres

112:D12117, doi:10.1029/2006JD008249

van der Schrier, G., Efthymiadis, D., Briffa, K.R., Jones, P.D.,: European alpine moisture variability 1800–2003. Int. J. Climatol. 27, 415–427

Szinell Cs., Bussay A., Szentimrey T., 1998, Drought Tendencies in Hungary, Int. J. Climatol., 18, 1479−1491.

Vicente-Serrano, S.M.; López-Moreno, J.I.; Beguería, S.; Lorenzo-Lacruz, J.; Sanchez-Lorenzo, A.; García-Ruiz, J.; Azorin-Molina, C.; Morán-Tejeda, E.; Revuelto, J.; Trigo, R.; Coelho, F. and Espejo, F., : Evidence of increasing drought severity caused by temperature rise in southern Europe. Environmental Research Letters, 9, 044001, doi:10.1088/1748-9326/9/4/044001, 2014.

5. **How exactly do the authors define a drought? In the Appendix you mention that extreme "wet/dry spells" should be at least 3 months? But in the results you talk of extreme droughts occurring 5-45 days per year? I assume you mean the daily index temporarily goes below extreme values, but that is a short dry spell, not a drought.**

Correction made in the text. The drought is considered in this paper as Dry/wet spell. A monthly value, which represents a negative/positive departure from the normal of the soil moisture. In the Appendix the authors' intention was to refer to extremely dry/wet periods (no smaller than 3 consecutive months and with highest/lowest intensity of Zi) of various lengths which are used in the computation of the duration factors. Practically the Zi values accumulated over these periods of different lengths of time was regressed against its duration (months) aiming at representing the most extreme dry/wet periods of various lengths.

**Minor comments:**

1. **You used the term "ameliorate" in the title, and that is correct English. However, even though I consider myself to be able to read English at a professional**



**level I had to look up the word to be certain what it meant. I would seriously consider to replace it with something more common.**

Correction made in the title.

2. **P1496, L14. You state here that PDSI can be used as meteorological, hydrological and agricultural drought index, but also indexes like SPI and SPEI can be used the same way, it is more a matter of the time scale.**

Corrections made in the text. The authors mend to underline the use of a physical model based on a rather complex soil water budget system that can account for a meteorological, hydrological and agricultural drought index.

The time period from the arrival of water inputs to availability of a given usable resource differs considerably. Thus, the time scale over which water deficits accumulate becomes important and functionally separates different types of drought (hydrological, meteorological, and agricultural) McKee et al. (1993). Nevertheless, the relationship between accumulation period and impact depends on a wide range of physical parameters (geology, soil properties, hydro-meteorological characteristics, vegetation) not only on its time scale of accumulation. SPI for example, allows for estimating different potential impacts (immediate, medium, long impacts) of a meteorological drought, through its different rain fall accumulation periods. Sims et al. (2002) indicated that SPI, even if it appears to be suited for estimating soil moisture deficit, it gives errors in indicating drought conditions when it is calculated at short time scales or for precipitation regimes when zero precipitation value is climatologically expected. From the acceptance of agricultural drought the soil moisture is a key variable for the evaluation of this type of drought. On the other side PDSI has been criticized because of its inability to indicate drought conditions for time scales shorter than 12 months (Vicente-Serrano. et al., 2010). However the Z index (Soil moisture anomaly index) from the Palmer Drought Model it is known for its high sensibility to changes in soil moisture (Karl, 1986).

Sims, A.P.; Niyogi, D.; Raman, S. Adopting drought indices for estimating soil moisture: A North Carolina case study. Geophysical Research Letters, v.29, p.24.1-24.4, 2002.

3. **P1496, L22-25. Sentence is not easy to understand, please rephrase.**

Corrections made in the text:

*Based on these considerations and using the assumptions of the Palmer Drought Model (PDM), the precipitation needed to end or ameliorate a drought (in 1,3 or 6 months period) for different levels of severity (moderate when Sc-PDSI ≤ -2, severe when Sc-PDSI ≤ -3, extreme when Sc-PDSI ≤ -4) and their climatological probability have been computed.*

4. **Figure 1. Please improve the figure with country names, colorbar for elevations, and put it into a European context.**

Figure improved.

5. **Figure 8 is too small and cannot be interpreted.**

All the figures have been provided to the publisher with the requested resolution (300dpi)

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 11, 1493, 2014.



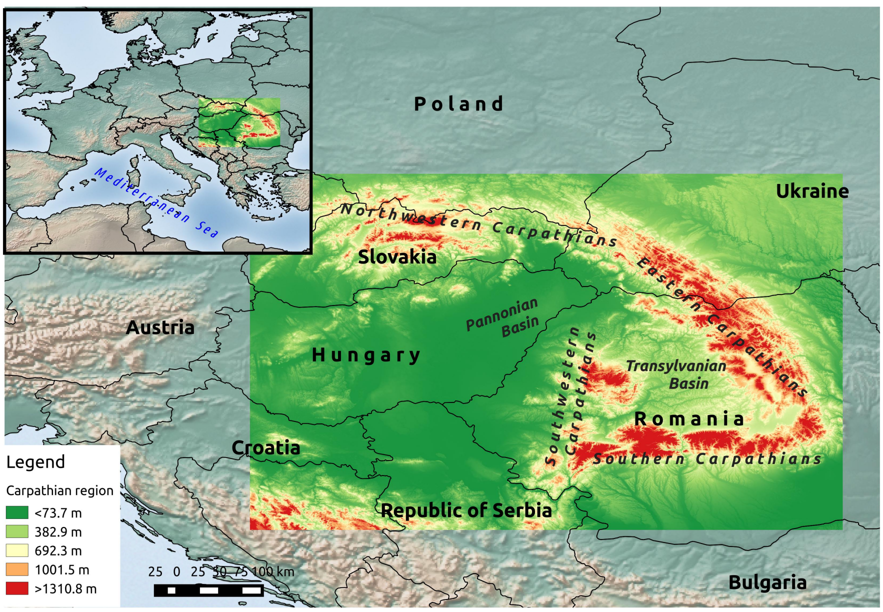


**Fig. 1.**