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PannEx (the Pannonian Basin Experiment) is a Regional Hydroclimate Project (RHP) of the Global Energy and Water Exchanges project (GEWEX) Hydroclimatology Panel (GHP) which aims to achieve a better understanding of the Earth system components and their interactions in the Pannonian Basin. The international efforts in PannEx provide scientific support and involve the international research community in an integrated approach towards identifying and increasing adaptation capacity in the face of climate change in the Pannonian Basin.

The WCRP Core Project on Global Energy and Water Exchanges (GEWEX) is an integrated program of research, observations, and science activities that focuses on the atmospheric, terrestrial, radiative, hydrological, coupled processes, and interactions that determine the global and regional hydrological cycle, radiation and energy transitions and their involvement in global changes.

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Contents

1. Introduction

1.1. An integrated study of physical processes at the local, regional and global scales

The World Climate Research Programme (WCRP) aims to determine the predictability of climate and the effect of the human activities through the improvement of the understanding of the climate system. Its core project GEWEX (Global Energy and Water EXchanges) aims to observe, understand and model the hydrological cycle and energy fluxes in the Earth's atmosphere and at and below the surface. It proceeds by means of an integrated program of research, observations and science activities that focuses on the atmospheric, terrestrial, radiative, hydrological, coupled processes and interactions that determine the global and regional hydrological cycle, radiation and energy transitions, and their involvement in climate change.

The GEWEX Hydroclimatology Panel (GHP) oversees all GEWEX hydroclimatology projects. It coordinates the plans and the focus of scientific issues related to the development and implementation of the Regional Hydroclimate Projects (RHPs) and has oversight over all GEWEX regional hydroclimate and GHP crosscutting projects. A principal task of GHP is to guide these projects in the goal of achieving demonstrable skill in predicting changes in water resources and soil moisture as an integral part of the climate and weather system at sub-seasonal and longer time scales.

1.2. The Pannonian (Central Danubian) Basin: an ideal natural laboratory

The Danube Basin occupies an area located between the proposed RHP, Baltic Earth, and the active RHP, HyMeX, and several European countries that are a part of this basin (Figure 1). The basin can be divided roughly into three parts: the upper Danube (from its origin until Vienna), the Pannonian Basin (until the narrow gorges between Serbia and Romania), and the lower Danube (until the Black Sea). The almost closed geophysical structure of the Pannonian Basin makes it a very good natural laboratory for the study of the water and energy cycles, enabling focus on particular physical processes of interest.

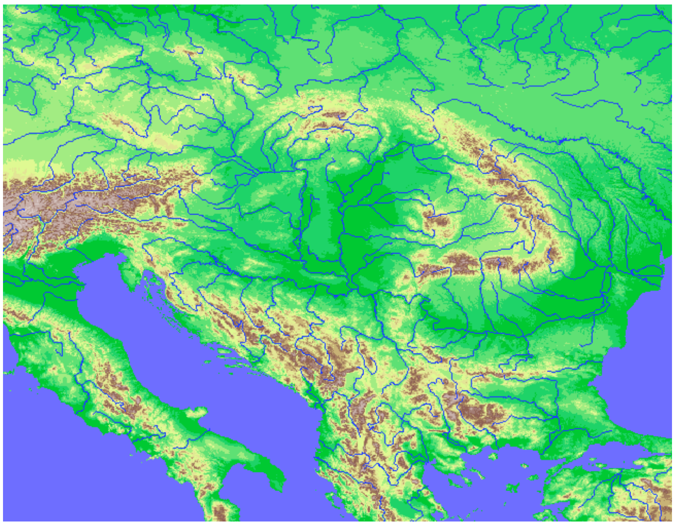

Figure 1: Southeastern Europe with major orographic and river systems.

A workshop organized by GHP, the Meteorological and Hydrological Service of Croatia (DHMZ) and the University of Osijek at Osijek (Croatia) was held on November 2015. Interested parties were invited to explore the possibility of establishing an RHP centered upon the Pannonian Basin, with a possible extension in a second phase to the entire Danube Basin.

1.3. A first glance to the potentialities of the basin and of previous and ongoing research

Fifty-six scientists from the Pannonian Basin region attended the Osijek workshop, which consisted of 23 keynote talks on pre-selected subjects, 24 poster presentations on related research in the region, and a general discussion guided by the GHP co-chair to identify the main scientific subjects and related societal issues for the Pannonian Basin.

Atmospheric circulations, climatological characterization and modeling, air quality issues, hydrological monitoring and modeling, and agricultural practices were first discussed, followed by a review of the status of the observational networks and available research infrastructure. The consensus of those at the workshop was that the community had the necessary size, scientific expertise and interest to undertake a supranational action at the basin scale, the Pannonian Basin Experiment (*PannEx*).

1.4. The need for a White Book

The attendees decided to select five main issues ("the flagship questions"; FQ) and three transversal subjects ("the crosscuts"; CC) combining the current scientific challenges with the related societal needs.

The five flagship questions (FQ) address the impact of global changes on, respectively, agriculture, air quality, sustainable development, water management and, finally, the education related to these issues. Three crosscutting actions are devoted to: (1) data and knowledge rescue, (2) process modeling, and (3) developing and validating modeling tools. An International Planning Committee (IPC), composed of seven members, was selected to further develop these areas, with each flagship question and crosscutting action being a chapter of a White Book written by a pool of authors and coordinated by a member of the IPC.

1.5. Development of the White Book

Seventy participants, including representatives from WMO and WCRP, gathered at the Hungarian Meteorological Service headquarters at Budapest (Hungary) in June 2016, where scientific talks and a poster session were followed by discussions sessions on how to proceed with the White Book. The status of each chapter was presented to the attendees and discussion was made on the contents, structure and strategies (Figure 2).

The summer of 2016 saw intensive work at the home institutions with each of the writing teams completing their text so that a first draft could be presented during the GHP meeting held in Gif sur Ivette (France) early October 2016. In that meeting interaction with the GHP Panel Members and with Chairs of the other GHP actions (RHPs, Crosscutting actions and Global Data Centers) provided additional comments to complete the PannEx White Book. The document was further refined during the third PannEx workshop at Cluj-Napoca (Romania) in March 2017 and its contents received additional contributions from the community during an executive meeting of the International Planning Committee (IPC) at Belgrade (Serbia) in September 2017.

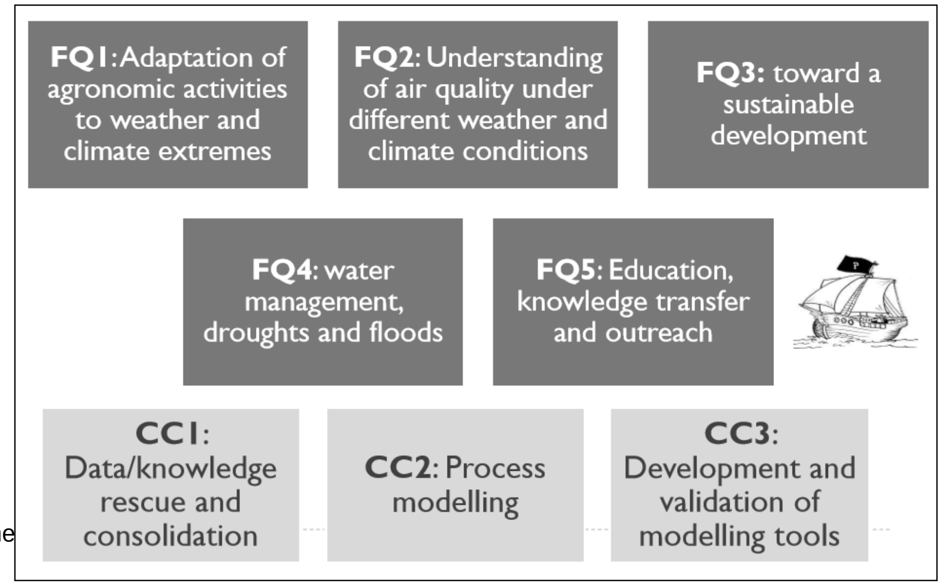

Figure 2: The PannEx Flagship science Questions and Cross Cut subjects. Results of 2nd PannEx workshop in Budapest, June 2016.

1.6. Towards a Science Plan and a Complete Project Plan

To become a full-working RHP, PannEx must outline its foreseen actions through a detailed Science Plan and provide an Implementation Plan, which in addition to a description of how the science is being executed has to include a description of (1) the coordination mechanism, (2) a calendar, (3) a data management strategy and (4) an estimation of the human resources to be involved. Guidelines for the science and implementation plans were discussed in the third PannEx workshop at Cluj-Napoca in Spring 2017 and the contents of this White Book have been a very useful guideline to define the first iteration of the Science and Implementation Plan during the meeting of the IPC at Belgrade.

2. FQ1: Adaptation of agronomic activities to weather and climate extremes

Coordinator: Danijel Jug
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Key topics:

- Weather scale predictions of yields and plant phenology
- Response to climate change (farming practices, crop types and varieties, pests and diseases, CO_2 fertilization effect, quality of yield)
- Water management and irrigation
- Land and soil use changes
- Evolution and full implementation of European policies
- Biomass production management

2.1. Background

Climate change strongly impacts the Pannonian Basin (Mezősi et al., 2014) and it is one of the main factors affecting the entire agroecosystem, it is also recognized as an element that will have a significant influence on the form, the scale, and the spatial and temporal impact on agricultural productivity (Fuhrer, 2003). This takes place in different ways and leads to a shift in productivity and stability of agricultural production systems. The agricultural sector and in particular agricultural production is the most vulnerable to climate change and biodiversity due to direct dependence on the weather conditions (Feehan et al., 2009; Kumar and Gautam, 2014). Climate change affects agriculture directly – plant level, and indirectly – system level (Fuhrer, 2003). Direct impact at the plant level includes:

- effects of increasing CO_2 at crop productivity and resource use efficiencies (Ainsworth and Long, 2005),
- effects of temperature, precipitation, radiation and humidity at crop development and growth (Olesen and Bindi, 2002) and,
- damages caused by extreme events like heat waves, floods, hail and droughts (Cherenkova et al., 2015a).

Indirect impact at system level means:

- changing suitability of different crops such as northward expansion of warm-season crops (Fronzek and Carter, 2007),
- changes in crop nutrition and occurrence of weeds, pests and diseases (Rosenzweig et al., 2000) and,
- environmental pollution or degradation of the main resources (Olesen et al., 2011),
- changes in livestock production (Nardone et al., 2006).

Related to aforementioned, the biological component of soil is mostly present in 0-30 cm of soil layer and amongst others (e.g., vegetation, soil type, management practices) is strongly affected by climate change, especially extremes (DEFRA, 2005). Therefore, these changes affect all components of society (through urban-rural links including transport, economic, cultural etc.) and the dynamic of socio-economic relations (OECD, 2003).

The Pannonian Basin and its surrounding region are facing changing climatic conditions and consequences already present. Recent climate changes show a rise of the temperature and more inconsistently in precipitation patterns in Pannonian Basin (Čačić, 2014; Várallyay, 2010). As a result, there is more and more uncertainty in crop production, both summer and winter crops, with worsened prospects in near and mid-future (IPCC, 2007a). There is certainty of more frequent spring and summer droughts, more problems with water availability, both by precipitations and rivers, and higher risks of wild fires (IPCC, 2007b).

2.2. *Knowledge, gaps and relevance*

According Eitzinger et al. (2009), within regional differences agriculture is affected by ongoing climate change in the Pannonian region increasingly, for example, by:

- increase in extreme weather events such as drought, dry winds, wet spells, intensive precipitation, frosts, heat and cold waves,
- increase in soil salinization,
- decrease of crop growth and development because of higher air temperatures,
- increasing spatial and interannual yield variability due to extreme weather (mainly summer droughts and heat waves),
- annual rainfed summer crops with high water demand such as sugar beet are already disappearing in some regions by climatic reasons (where irrigation systems or water is not available or economic),
- potential of increasing soil erosion in vineyards and crop farming in hilly terrain due to regional increasing trend of heavy and winter precipitation,
- change of pest and disease occurrence; pests are generally considered by farmers as the second important danger beside of drought (especially several thermophile insects are affected),
- shortening of the cropping cycle, effecting fieldwork timing.

Another recognized problem is the continuing decline of organic matter in soils under agricultural production due to poor land management practices (burning/incineration and the removal of crop residues, overgrazing, inappropriate tillage – mainly deep moldboard plowing), (Liu et al., 2006). In addition, a large part of the crop residues is used for production of biofuels and other biomass energy, which is a good precondition to loose large amounts of organic matter in soil (Mann et al., 2002). Increased risk of runoff/erosion and flooding of agricultural land that can occur due to extreme fluctuations of the annual distribution of the total precipitation in the Pannonian Basin, and the content of organic matter in soil have significant positive influence in the mitigation of aforementioned effects (Trenberth, 2011; Birkás et al., 2015; Gregory et al., 2015).

Regarding winter crops (major being winter wheat), optimum period of seeding regarding air and soil temperature appears later than earlier, winter temperatures are higher, there is often no snow cover, spring growth starts earlier and there is higher chance for earlier maturity, but also for heat waves, which can severely damage crops in early maturity growth stages. Regarding summer crops (such as maize), seeding conditions starts earlier, problems with deficiency of summer precipitation and inadequate weather conditions for pollination are more frequent, but autumn frosts are delayed further toward winter (Branković et al., 2013). Increasing spring temperatures contribute to an earlier start of the vegetation period; however, increasing climate variability poses a risk for more frequent late spring frosts, which might interfere with the sensitive stages of crops and fruits including grapes (such as the springs of 2016 and 2017 in several central European countries, Ceglar et al., 2016; European Commision (EC), 2017).

Orchards and vineyards are an important part of many cultures and economies requiring considerable management. The lifetime periods for these species are at least 20-40 years, but can live up to 100 years. As a subject of scientific research, the longevity of apple orchards contrasts with annual crops, or even shorter-lived crops such as grapes, which are often studied for climate change effects. Critical decisions must be made by orchard and vineyard managers as they choose varieties, which they believe, will prosper in the current and future environments. Global climate change studies can benefit from the large number of observations made by both orchard and vineyard managers. Flowering and fruit development of these species are triggered by degree-days with different varieties having different trigger values. Their sensitivity to seasonal variations provides the scientific community with additional ways to monitor local environmental disturbances. Recent research has correlated climate change with fluctuations in flowering times for some cultivars. As climate change modifies the local environments, there are some varieties that will be poorly adapted to the new temperatures and to likely changes in rainfall. At the same time, new environments are going to allow other varieties to prosper. The result will be a shift in the ability of specific locations, most likely in extreme growing environments, to support specific varieties.

Negative impacts of recent climate trends on overall biodiversity have been more common than positive (Porter et al., 2014). Although it is anticipated that the climate change negatively affects almost all aspects of the world’s agriculture, it is interesting that insect pests predominantly show contrary results and are less sensitive to direct climate effects with more negative impacts than previously thought. Namely, they are more adaptive to climate change and more dangerous. The vast majority of species influenced by climate change are insects, and their impact on Earth is huge. Because of the short life cycles, high mobility, high reproductive rates, and physiological sensitivity to temperature, insects will respond more quickly to climate changes than long-lived organisms such as higher plants and vertebrates (Ladányi and Horváth, 2010). They have responded to warming temperatures in all predicted ways, from changes in insect phenology and distribution to alterations on insect behavior and physiology: development, reproduction and survival rate (Parmesan, 2007).

Plant species have a range of soil moistures conditions that are suitable for their survival and growth, and agriculture of any type is strongly influenced by the availability of water (Olesen and Bindi, 2002). Changes in water availability can have an influence on biological properties of weeds (germination, plant size and seed production). Drought causes a different response in crops but makes them less competitive with weeds (Patterson, 1995). Moreover, a decrease in annual precipitation could lead to distribution of weeds from the dryer regions. On the other side, wetter and milder winters are likely to provide the survival of some winter annual weeds (Hanzlik and Gerowitt 2012). Elevated atmospheric CO_2 can lead to imbalance in weed/crop competitive interactions, especially in species differing in energy capture mode (C3 and C4 photosynthetic pathways). Since the land use management is affected by climate change this has an indirect influence on weeds as well. Adopting cropping systems and management measures to new climate conditions (different crops, crop rotations, sowing dates, conservation tillage methods, etc.) has an indirect influence on the weed occurrence (Gunton et al., 2011). With the introduction of new crops and changing the crop rotations the occurrence of new weed species is to be expected. The conservation crop production systems, including conservation and reduced tillage methods have great capacity of adapting to climate change and to mitigate their negative impacts. However, this type of plant production can cause new weed species to occur and requires new strategies in plant protection management.

Changes in weather and climate conditions as well as microclimate in the stable (predominantly occurrence of heat stress) can have a major negative impact on livestock production, animal health and animal welfare. Climate change will have far-reaching consequences for dairy and meat production. Specific impacts of climate change on livestock production are in the main of:

decline in livestock productivity, decline in forage resources, problem of access to water, restricted livestock mobility, conflict over natural resource use, fluctuations in livestock market prices, animal diseases (emerging and re-emerging), species and breed of livestock that can be kept (potentially shift in livestock species). The impact of climate change can heighten the vulnerability of livestock systems and exacerbate existing stresses upon them, such as drought. Ensuring good animal welfare will be paramount to addressing these challenges; breeds suited to the local environment are often more robust and resilient than industrially farmed breeds (Pilling and Hoffmann, 2011).

The climate is an important factor determining the biodiversity of any biogeographic region. Climate and weather changes could have a strong influence on different levels of biodiversity, from organism to biome scales. To survive, individuals, populations or species must create effective adaptation strategies, otherwise known as adaptive responses to climate change: ability to disperse to areas with suitable habitat or move to new micro locations, ability to change its phenology and diurnal rhythms and ability to change its physiology to cope with new climatic and environmental conditions (Bellard et al., 2012).

The impact of climate change on all human activity has long been inevitable question for professional and political bodies when comes to making decisions on the future spatial development. Potential solutions have two sides: adaptation and mitigation. Mitigation aims to prevent or reduce the effects, while aims to adjust to the current situation, that we cannot influence/change. The extremely large spatial potential and rich biological and landscape diversity of Pannonian Basin, must be protected against inappropriate interventions, which inevitably reduce the value of space and the quality of life and causing permanent damage to the environment and nature.

It is extremely difficult to thoroughly assess the impact of climate change on agricultural production, consumption, prices and trade. Similarly, it is difficult to estimate the cost of all needed measures for adaptation to climate change without a detailed analysis of agricultural demand and supply possibilities as a model of projections which is associated with biophysical crop production model. An important component of the impact of climate change on rural area is on food safety and well being of the population in rural areas. The impact of climate change on agriculture and rural areas is reflected in the biological effects on crop yields including prices, production and consumption.

Analysis of long-term trends between 2000 and 2050 years for the most important agricultural crops (e.g. wheat, corn and soybeans) is expected to decrease surface area due to population growth, income and demands for bioenergy and expected growth in the price. Analyses indicate that agriculture and the well being of the rural population will have further negative impact on climate change. Yields of most important crops will decrease and negatively affect production with the prices increasing of the same culture and meat.
Mitigation of negative demographic processes in rural areas, as consequence of climate change impacts, emphasizes the importance of improving urban-rural links. Better inter-connections include many aspects (e.g. transport, economy, culture) and dynamic socio-economic changes and new development trends, with the primary goal, strengthening of the capacity to adapt to climate change. These changes will affect all components of society.

2.3. Potential activities

Because climate change is recognized as a huge global issue with serious environmental, social, economic and political consequences for humanity, one of the biggest challenges is how to find proper measures for adaptation and mitigation of the negative effects of climate change. One of the major problems in our understanding of the climate change effects, on local or regional scale, is our inability to precisely predict the time, place and level of its negative or positive impact on agriculture production as a whole, as well as consequences for the individual plants (Howden et al., 2007).

Climate change impacts on agricultural production are strongly depending on the socio-economic development (knowledge, tradition, mechanization, technology, science implementation etc.) and agro-ecological conditions (climate, soil, water, crop, biology, etc.), (Eitzinger et al., 2009; Jug, 2013) such as:

- small scale of irrigated area (of total arable land),
- large fragmentation of agricultural land – small size farms (property - estate),
- undefined inheritance of farmland (leads to further fragmentation),
- a large proportion of the agricultural population in total of active population,
- aging of the agricultural households,
- the low level or inadequate applied knowledge of farmers (education),
- traditional approach to crop production (especially in rural region),
- low level of science implementation,
- low and inadequate investment.

Due to climate changes, it is necessary to conduct certain activities to adapt to new conditions in all sectors of the economy at the local and regional level in order to protect themselves from negative influences and/or take advantage of new opportunities that may arise due to new climate conditions. Having all that in mind, it is hard to bring only one cropping strategy, but scientists, policy makers and crop producers should embrace several. All activities should support the concept of self-sufficiency and production of sufficient quantities of healthy and quality food while preserving the environment and biodiversity with rational use of natural resources.

On the other hand, parallel to the climate change impacts, there is need for the monitoring and seasonal forecasting of crop yields. This task can be approached using satellite information and seasonal climate forecasts. Vegetation products of satellite remote sensing allow to monitor the vegetation conditions depending on the weather, as well as development of simple and effective crop yields models, which consider the weather conditions at the beginning of the growing season (Semenova, 2015).

As a result of social and political changes in the past 20 years, agriculture in Eastern Europe (including the Pannonian Basin) is still transitioning toward a market economy. Therefore, the potential adaptation measures of the respective agroecosystems are influenced by site-specific production and socio-economic conditions (Eitzinger et al., 2009). The Pannonian Basin is recognized as a region with potentially rich plant production and a very heterogeneous area with divergent agro-ecological conditions influenced at yield levels from year-to-year in wide scale (Jug et al., 2010). This variation primarily depends on climate aberrations but also because of many other problems, which each separately and/or all together lead to reduction of production and low productivity, high production costs and loss of biodiversity.

Therefore, one of the biggest challenges for plant breeders nowadays is how to create new varieties and hybrids that will ensure stable and high yields with good quality in different environmental conditions and how to preserve and use autochthonous genetic resources that are closely linked with adaptability to abiotic stresses (Dwivedi et al., 2016).

Many techniques and technologies are offered as an adequate solution for adaptation and mitigation to climate change, but only some of these are really functional. Conservation agriculture (CA) is one of the possible ways to combat primarily negative influence of climatic changes. This technology is not a novelty in the Pannonian Basin, but it´s applications are usually because of economic reasons (cheaper production) or as an alternative system (Jug, 2013). CA includes three main bases for successful agriculture production in relation to agro-ecological conditions, namely: minimal set of soil tillage treatments (minimal soil disturbance), permanent soil cover (with crop or crop residue) and diversification in crop production, predominantly crop rotation (Kassam et al., 2015). The applications of these principles will positively affect many other key elements of crop production (plant nutrition, soil materials, irrigation, plant breeding, crop protection, environmental considerations, etc.). Since the soil is still the basic media for crop production, soil tillage can play a major role in soil vulnerability to climatic change. Soil tillage affects many soil quality aspects: erosion (by water and wind), biogenity (organisms), organic matter, water content (storage, infiltration), compaction (anthropogenic or natural causes), nutrient status, pest and diseases (potential risk), weed infestation, in words physical, chemical and biological aspects. As soil tillage is closer to CA principles, we can expect less damages and potential problems and risks. At this moment, the application of CA in the Pannonian Basin is still very heterogeneous and persists on different levels and with different success in each country of the region (Jug et al., 2010). Since climatic changes do not follow national borders and since agriculture is extremely vulnerable to them, a common action to find adequate and effective measures to face climatic changes is an imperative.

The need to research climate change effects on weed populations and weed/crop interaction will increase in the future since weed management is a significant ecological, financial, logistical and research challenge. It is important to identify which weed species are problematic in the Pannonian Basin and develop appropriate weed management strategies as a priority. Climate change will promote the further spread and invasive potential of weeds but the exact outcome cannot be predicted in any generalized way. Reducing the impact of weeds and preventing occurrence of new invasive weed species is the key of maintaining balance in agroecosystem with giving native species the best option to deal with negative impacts of climate change.

Climate change directly impacts interactions between crops and plant pathogens and can induce severe epidemics. Many reviews of the literature on plant diseases and climate change include effects of climate change on plant pathosystems and predicting scenarios for target pathogens and various plant disease control methods. Physiologically stressed plants (e.g., field crops, orchards, vineyards) are more susceptible to some diseases. A change in temperature could directly affect the spread of infectious diseases, survival of pathogens between vegetation, increased aggressiveness, the development of different dormant forms and geographical distribution of pathogens. Understanding all the factors that trigger the development of plant disease epidemics is extremely important to create and implement effective strategies for disease management. Since disease management strategies depend upon climate conditions, the use of mitigation strategies is needed.

Given the examples of interactions between disease and climate change, suggest the necessity of permanent monitoring of diseases (existing and emerging pathogens), inoculum monitoring (especially for soil-borne diseases), fast diagnostics, develop of warning systems for forecasting disease epidemics, breeding programs for diseases resistance and tolerance to environmental stress, use of ecofriendly methods in disease management because changes in temperature and precipitation can alter fungicide residue dynamics in the foliage.

Scientists predict additional generations of important pest insects in temperate climate zones as a result of the combined effects of climate (higher temperatures, reduced precipitation, humidity) and other components like soil moisture, atmospheric CO_2 and tropospheric ozone (O_3), probably requiring more insecticide applications to maintain populations below economic damage thresholds. Is it possible to isolate the effects of climate change on pest insects and diseases from the many other global changes? Although precise impacts are difficult to predict, it seems possible to project future condition or occurrence of such pests and diseases. Species with high genetic variation and rapid life cycles may be most likely to respond to climate change, so we need to follow trends in climate and track their effects on pest life cycle. Climate change has changed our decision-making processes which need to rely on the basics of integrated pest management program (IPM) such as long-term monitoring insect and disease impact, examination of the influence of climatic variables, pest forecasting, identification of potential invasive species, economically and environmentally control measures.

Plant breeding plays an important and irreplaceable role in mitigating the effects of climate changes and is one of the key scientific disciplines for coping with the new climatic challenges. Other important activities in agriculture that are related to better adjustment to the newly created climate change are in domain of:

- encouragement of biodiversity (the cultivation and use of national and local varieties/hybrids that possess strong phenotypic and genotypic plasticity and ability to adapt to various ecoregions, careful introduction of new species with inherited resilience to climate stresses),
- changes of the established agricultural practices and management methods (extension of the genetic basis of crops, change of sowing and planting time, the use of cover crops, green manure, precise fertilization, increasing the proportion of legumes in crop rotation, the construction of facilities for the collection and storage of the water, the need to develop new technology, sustainable land management, the usage of organic farming, which contributes to reduction of fossil fuel use, reduce greenhouse gas emissions, reduce the risk of soil erosion and increment of soil fertility in a natural way (Iglesias et al., 2007; Supit et al., 2012),
- continuous implementation of field testing (of the most important agronomic traits of crops, such as yield and quality), in a series of comparative experiments on a number of locations along with the continuous monitoring of climatic conditions is an essential activity of future programs.
- continuous efforts to improve crop models and their application in agricultural systems, the main aim being to increase preparedness and adaptation of agricultural production to expected climate change. Crop models can be used to aid plant breeding by simulating the effects of changes in the morphological and physiological characteristics of crops which aid in identification of ideotypes for different environments (Kropff et al., 1995). Probabilistic assessment needs to be assessed in order to provide end users also with the estimate of uncertainty,
- benefit from continuous efforts from seasonal climate forecasting improvements to provide farmers and other decision makers with timely information for rapid decision-making during the growing season (e.g. Ceglar et al., 2017, 2018; Turco et al., 2017).

2.4. Expected outcomes

We can conclude that there is no simple solution to successfully tackle the problems of climate change. For successful approaches to adaptation and mitigation processes we need to create an adequate and useful information system (mainly about usually applied technology in crop production and agro-ecological conditions), which will be used as a starting point in processes of creating strategy and decision-making. The adaptation and mitigation of climatic change needs to be based on long-term research and in relation with stronger regional cooperation, with professional competence to reach satisfying results in relation to agro-ecological conditions-crop production-environment.

Some of the positive effects and outcomes successfully derived from implemented know-how technics and technology include:

- upgraded and improved understanding of the plant-soil-environment relation processes in light of adaptation and mitigation of climate changes,
- improved, "updated" or new rules in crop/plant production taking into account *specificum* of each agro-ecological region/conditions,
- recognize the positive role livestock and animal welfare can have in achieving sustainable agriculture and incorporate specific and regionally-sensitive policies and measures to ensure that global food production is both humane and sustainable,
- building the scientific case for the better treatment of animals,
- collecting and monitoring relevant data with the methods agreed among the countries of the Pannonian region, as a base for open-approach of collected data sets,
- stronger interconnections of different science and research institutions/centers at national and especially at international levels, as a base for further actions,
- stronger connections and bonding of science/scientists (knowledge, relevance, achievement) and farmers (implementation of…),
- defined some stable networks and infrastructures for education processes according to relevance and specific problems/issues at national and international levels.
- early warning system using real-time and forecast weather (long range and seasonal-to-decadal) to provide farmers with relevant advice for short and long term adaptations.

3. FQ2: Understanding air quality under different weather and climate conditions

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Key topics*:*

- Urban-scale processes
- Scale-dependent meteorological and transport processes, air quality-planning
- Surface and boundary layer processes
- Interactions with agricultural practices (soil, water and air)
- How does a warmer climate effect air quality and human health

3.1. Background

Air quality is highly dependent upon weather and is therefore sensitive to climate change. The weather and climate of the Pannonian Basin develops under three major effects (oceanic, continental and Mediterranean), depending on the air masses drifted over the region (*Micu et al.*, 2015). The Pannonian Basin is one of the world's largest enclosed basins with special meteorological, hydrological and air pollution situations. One merely has to consider the winter cold air pool that affects the pollutant enrichment in the basin. The increasing frequency of heat waves also has significant environmental impacts (*Szépszó*, 2008), which particularly affect the people living in large cities (*Páldy et al.*, 2005; *Baccini et al.*, 2011), but affect agricultural production, too (*Gaál et al.*, 2014). In overall air pollution processes such as emission, transport, dilution, chemical transformation and eventual deposition of air pollutants are influenced by the meteorological variables of radiation, temperature, humidity, wind speed and direction, mixing height, etc. (*Kinney*, 2008). In terms of climate change the significant temperature increase of the basin might considerably exceed the global warming rate (see for example: *Molnár* and *Mika*, 1997, *Bartholy et al.*, 2008). Wetter winters and more frequent droughts during the other seasons are expected (*Bartholy et al*., 2009; *Cindrić et al.*, 2016). The general spatial pattern of the aridity remains steady along 1961-2050, but important qualitative shifts towards more aridity will occur over the Pannonian Basin (*Cheval et al.,* 2017). This climate penalty means that stronger emission controls will be needed to meet a given air quality standards. In order to develop optimal control strategies for key pollutants like ozone (O_3), reactive nitrogen compounds (Nr) and fine particles assessment of the potential future climate conditions and their influence on the attainment of air quality objectives is highly required. For example *Juda-Rezler, et al.*, (2012) show an increase of mean O_3 in summer and a decrease in annual mean of PM_{10}. In addition, other air contaminants of relevance to human health, including smoke, airborne pollens and other particle matters (PM) influenced by climate change (*Kinney*, 2008) should be analyzed. Furthermore, in the last decades experimental works in the framework of projects like ABRACOS (*Gash* and *Nobre*, 1997), Harvard forest experiment (*Moore et al.*, 1996), BOREAS (*Sellers et al.*, 1995), FLUXNET (*Luyssaert et al.*, 2009; *Haszpra*, 2011), FP5 CarboEurope IP (*Dolman et al.*, 2006), FP6 NitroEurope IP (*Sutton et al.*, 2011) shed light on the physical, chemical and biological processes governing and determining plant canopy considered as a complex and active biophysical system. This system is not just an interface between atmosphere and soil surface but it plays dynamical role in changing atmospheric flows, energy and water balance, gas exchange and particle deposition in the surface atmospheric layer.

The research of air pollution focusing on the Pannonian Basin is important for many reasons; large emission sources located in the area, high PM levels, limited regional studies and the presence of specific atmospheric conditions e.g., long lasting high atmospheric pressure systems contributing to the regional air pollution episodes during the colder period of the year. In summer, the same weather type is often connected with the extreme pollen concentrations and maintains the atmospheric transport and dispersal of bio-aerosols (*Prtenjak et al.*, 2012). The chemical properties of air pollutants together with the physical processes of the planetary boundary layer (PBL) including surface-biosphere-atmosphere interactions and cloud microphysics need to be known in order to parametrize and determine the behavior of the pollutants in the atmosphere (*Jeričević et al.,* 2010; *Szintai et al.,* 2015; *Gašparac et al.*, 2016), and consequently, to manage the negative effects of air pollution on human health and the environment.

Dealing with the possible impacts of 21st century warming in the Pannonian Basin we are likely to get more extreme climate with the issues of the future state of the air environment and the health risks (*UNEP*, 2007; *Werners et al.,* 2014). Our changing climate influencing significantly the air quality raises common problems in fields of urban environment, agriculture, and hydrological cycle, which require regional answers.

3.2. Knowledge, gaps and relevance

Because of the typical continental mid-latitude position of the Pannonian Basin, significant seasonal dependency of air pollution on the relevant atmospheric circulation pattern appears. Synoptic situations can be organized in a few tens of weather types and can be applied, extended and clustered for the entire Pannonian surrounding (e.g., *Zaninović et al.,* 2008; *Philipp et al.,* 2010). However we have situations for examples of the weather with fog or/and low cloudiness in the basin and sunny in the sporadic highlands and the basin's surrounding mountains. Nevertheless, winters in the area may also be characterized by rapid cold air outbreaks from N and NE, inducing strong winds. Essentially, most of the impinging flows are somewhat modified by the mountains that surround the basin from all directions. During persistent deep cyclones and intensive meridional moist flow, flooding events may occur in the basin.

However, temporarily alterations of large scale flows may allow also various secondary circulations to take place, i.e., mesoscale and local flows such as drainage flows, thermal lows, mesoscale convective systems, squall lines and low level jet in nighttime, etc. These flow types regularly depend on the underlying surface properties (orography, moisture, etc.) and air masses in play. Other flow structures could also occur over the basin. For example, summertime blocking situations often causing heat waves and droughts *(Semenova, 2013; Cherenkova et al., 2015b, Sfîcă et al., 2017, Herbel et al., 2017)*, while certain weak pressure gradient conditions may promote significant trans-boundary transport and dispersion of air-pollution including airborne pollen, especially ragweed (e.g., *Prtenjak et al.,* 2012; *Makra et al.,* 2016). Hence, it is straightforward to conclude that various mesoscale and microscale meteorological processes take place in various chains of events over the Pannonian Basin. However, many of them are not well documented scientifically, not to mention the processes' interactions and effects toward and within other disciplines (hydrology, soil sciences, agriculture, etc.).

Biosphere-atmosphere feedbacks are important in understanding weather and climate causes and consequences and in their proper treatment in numerical weather prediction (NWP) models with different temporal and spatial scales. It is not just a scientific curiosity, which governs researchers of turbulent transfer above and within plant canopies.

For numerous physiological, ecological, hydrological and agricultural applications, proper treatment of canopy micrometeorology is of utmost importance. As *Kaimal* and *Finnigan* (1994) pointed out, "The understanding of turbulent transfer within foliage canopies provides the intellectual underpinning for the physical aspects of agricultural meteorology."
Enhanced level of knowledge in this complex field can be achieved only by full implementation of "Experiment-Theory-Practice" framework based on regional (Pannonian region) integrative functions. In that framework, present micrometeorological measurements, data analysis and application should be joined in order to: (i) fill data gaps and optimize future experimental activities; (ii) introduce new modules and parameterization procedures in NWP models in order to optimize its application for ecological urban environmental and agricultural purposes; (iii) increase visibility of research and findings by involving young people and iv) provide NWP products' application for agricultural production. These are the requirements we now address.

We also know that climate change is likely to increase the vulnerability of ecosystems towards air pollutant exposure or atmospheric deposition on a European scale, including the Pannonian region (*Sutton et al.,* 2011; *Moring* and *Horváth,* 2014). Such effects may occur as a consequence of combined perturbation, as well as through specific interactions, such as between droughts, O_3, N and aerosol exposure. Impacts of air pollution on European ecosystems occur over a range of spatial scales from the global (ozone background), through regional (O_3 and N deposition) to local scale (N deposition and $PM_{2.5}$, NH_3 exposure). In a changing climate, the spatial patterns of impacts are likely to change as a result of changing emissions, land use and atmospheric processes. In terms of climate models, all that is highly dependent on the treatment of the PBL processes (e.g., *Güttler et al*., 2014).

Chemical composition of the lower atmosphere is strongly influenced by the surface processes. The concentrations and turbulent fluxes of the atmospheric trace substances (gases, aerosol particles) are the results of (i) emission, (ii) turbulent transfer, (iii) dry and wet deposition and (iv) chemical transformations. All of these processes are depending on the canopy homogeneity and horizontal isotropy, as well as the morphological, aerodynamic and thermal characteristics.
On the other hand, the chemical composition of the air surrounding the crop can affect the physiological processes of the plant, like photosynthesis, intensifying or reducing its rate.

The air quality is largely influenced also by the (not always well-known) effects of anthropogenic activities having impact on the greenhouse gas concentration distributions and fluxes of different reduced and oxidized compounds through affecting the (a) atmospheric chemical processes, as well as (b) the metabolic processes of the animals, (c) plants and (d) a large variety of microorganisms.

Agricultural areas cover twice as much land as forestry and more than ten times as much as urban areas in Europe (*Walls,* 2006). Consequently, balancing food production with environmental protection and predicting the impacts of climate change on both food production and environment safety in agro-ecosystems becomes a major question. Agricultural activities may modify the natural cycles (both directly and indirectly), such as increasing carbon dioxide (CO_2) emissions to the atmosphere by increasing plant decomposition rate and burning plant biomass.
Nitrogen fertilizer production and application contributes to nitrous oxide (N_2O) – GHG – emissions with environmental impacts. Effects of the secondary air pollutants (ozone, nucleation, etc.) and pollen transport are also important problems in different scales.

The interactions of (i) climate change, (ii) change in nitrogen deposition, (iii) increasing atmospheric CO_2 concentration, (iv) changing aerosol burdens and (v) changing ozone background and peak levels make projections of pollution impacts on terrestrial ecosystems challenging.

This is especially so, since the ecosystems give different physical and biogeochemical responses to these effects on different spatial and temporal scales in either positive or negative ways (e.g., on ecosystem productivity, water use efficiency, carbon storage or biodiversity). Furthermore, changing biogenic emissions in response to air pollution and/or climate change can affect air pollution and climate change in turn, in a complex system that contains multiple, interacting feedbacks (based on *Sutton et al.,* 2011 and results of FP7–ECLAIRE program *Sutton et al.,* 2015).

Several important urban agglomerations from the Pannonian region alter the background climate generating adverse consequences on the air quality. The urban heat island (UHI) generated by large cities like Bucharest, Cluj-Napoca, Novi Sad, Szeged (*Cheval and Dumitrescu 2015*; *Göndöcs et al 2017*; *Herbel et al*., 2016, 2017; *Unger et al*., 2011) or its impact on human health (*Stanojević et al. 2014)* have been studied. However, research linking the UHI to air quality is still needed in order to provide coherent tools for urban development in the area.

In order to introduce future climate projections into impact studies, first we need to evaluate the ability and accuracy of the models regarding not only the basic climatic parameters (temperature and precipitation) but also the other components of the energy budget and hydrological cycle. For example, despite the large climate modeling communities, studies addressing validation of solar surface radiation (SSR) in global and regional models using different parametrizations and different spatial scales are still scarce in number. However significant differences in the representation of solar radiation in global and regional climate models have been detected (*Bartók et al.,* 2010; *Jerez et al.,* 2015a,b). The main subjects of the planned collective work and scientific cooperation focusing on the Pannonian Basin, are:

- spatial and temporal structure of the atmospheric processes in the Pannonian region (meso- and microscale),
- air pollution transport and dispersion (natural and anthropogenic sources and sinks, emission clusters, transmission, dry and wet deposition, etc.),
- hierarchy of applied models (SVAT, PBL, NWP, RCM),
- harmonization of workflow of modeling (measuring, initialization, developing of numerical models, validation, interpretation, probability forecast, etc.),
- parameterization schemes (SVAT, turbulence, cloud and precipitation formation, radiation transfer, chemical transformation, nucleation, etc.),
- surface-atmosphere and hydrosphere-atmosphere interactions (turbulent exchange processes) development of the hydrological model interface and the meteorological pre-processors,
- urban climate monitoring, assessment and predictions within the climate change context.
- In the environmental impact studies these subjects are connected by the following viewpoints:
- requirement for description of cross-border pollutant transport processes,
- need of measuring systems with the same quality,
- configuration of unified and checked environmental database, (Why would the condition of air environment be different on the two sides of a border?),
- solving the common regional problems (urbanization, health effects of air pollution, trace material load of different ecosystems, for example reactive nitrogen, ozone, PM, SO2),
- requirement to quantify the tendency of the effects of climate change on the environment.

The countries of the Pannonian Basin are embedded in international cooperative programs that continuously develop meteorological (e.g.,ECMWF, the 25 years old ALADIN consortium), air environmental (COST, ES 0602; ES 1006, EMEP, etc.) and regional climate modeling activities (e.g., CORDEX), update their measuring systems (WMO GOS, WMO GAW, EMEP) and construct their air environmental and emission database (EMEP, IPCC GHG Inventories). There are also institutional bases of regional cooperation in Central and Eastern Europe, for example the RC-LACE in Prague, the SEECOP Consortium in Beograd, and the NEESPI Focus Research Centre for Non-boreal Eastern Europe in Sopron, Hungary.

There are potential financial backgrounds for solving regional problems in cooperative ways: Carpathian Convention, Interreg, Danube Transnational Programme, The International Visegrad Fund and The NATO Science for Peace and Security Programme. These funds ensure the background of the common actions.
Thanks to the well-developed international cooperation and the application of national and WMO standards unified regional databases such as CARPATCLIM (*Spinoni et al.,* 2015b; *Lakatoks et al.,* 2016) have been created. Similar to that is the harmonization and quality checking of databases coming from air pollution networks (gases, aerosol particles, pollen, dry and wet deposition precipitation chemistry) that would be necessary in the region and could serve the regional requirements beyond the EMEP database. The measurement and the harmonization of the parameterization schemes to determine the components of radiation and surface energy budget components still remains an important question. To quantify the evaporation above different surfaces and to compare regional measurements and modeling methodologies is also essential (*Szilagyi,* 2015).

Trace gases (reactive nitrogen compounds, ozone, CO_2, etc.) and aerosol concentration and flux measurements were done previously and still are done at the present embedded in international cooperation actions (FLUXNET, FP4 – ECLAIRE, FP5 – CarboEurope IP, FP6 – NitroEurope IP, FP7 – ECLAIRE). Based on these the data validation of ecological models could be elaborated. Furthermore, the pollution load that reaches the surface, the biosphere and water bodies could be more precisely determined thus standard emission methods could be developed at regional scale.

The chemical properties of air pollutants together with the physical properties of the PBL need to be known in order to parametrize and determine their behavior in the atmosphere. Consequently, the successful management of the effects of air pollution on human health and the environment can be elaborated.

In general, air pollutants are categorized as primary air pollutants (i.e., pollutants directly emitted to the atmosphere) or secondary air pollutants, which are formed in the atmosphere from the so-called precursor gases (e.g., secondary PM, O_3 and secondary NO_2). Air pollutants can also be classified as natural and anthropogenic as a function of the origin of their emissions or the origin of the precursors. Particulate matter (PM) is both directly emitted to the atmosphere (primary PM) and formed in the atmosphere (secondary PM). Black carbon (BC) is one of the most important constituents of fine PM and has a warming effect (Gelencsér, 2005). Contribution of PM emissions and their origins can be relevant at different spatial scales ranging from local to regional and long-range, transboundary transport scales and should be analyzed accordingly (e.g., *Querol et al.*, 2004; *Juda-Rezler et al.*, 2011).

The precursor gases such as NH_3, SO_2 and NO_x react in the atmosphere to form ammonium, sulphate and nitrate compounds. These compounds form new particles in the air or condense onto pre-existing ones and form so-called secondary inorganic aerosols.
Nucleation events (new particle formation) often develop within the Pannonian Basin (*Némét and Salma*, 2014; *Salma et al.,* 2016). Understanding the nucleation processes is one of the key questions in the fields of air quality and climate systems (cloud formation, etc.). Connection among the cloud physics processes, aerosol types and concentrations is also a fundamental question (*Muhlbauer et al.*, 2012; *Lábó* and *Geresdi*, 2016; *Sarkadi et al.*, 2016).

Patterns of pollution may occur not only in highly concentrated sites such as densely populated urban areas, but also in regions with lower concentrations of population widely dispersed over the area including agricultural regions, forests and surface waters. Trace gases and aerosol particles can be transported far away from their sources before being deposited on the surface (*Bozó*, 2005). Due to the deep economic changes in the Pannonian Basin during the past three decades, its energy and industry sectors were reorganized, which resulted in a significant decrease of pollutant emission. Out-of-date industrial technologies are being replaced by less energy consuming and more environmentally friendly ones. Thermal power plants have been equipped with efficient sulphur and dust filters. Leaded gasoline has been phased out of use. The rates of changes in pollutant emission, however, were different in the countries of the region. As a result of these changes, now the region is coping with less serious atmospheric environmental problems than 25–35 years ago. However change in atmospheric aerosol content has impact on the radiation balance of the atmosphere, the last few decades are characterized by "solar brightening" (*Wild, 2009*). Furthermore a recent study shows that the increase of solar surface radiation also explains the detected trends in maize yields in agriculture (*Tollenaar et al, 2017*).

The main task for the near future is to develop coupled meteorological-climatological and air pollution models (*Kukkonen et al.*, 2012; *Žabkar et al.*, 2015). This is the so-called chemical weather/climate modeling at basin and urban scales (*Miranda et al.,* 2015; *Kovács et al.,* 2016, *Lázár and Weidinger* 2017). Besides the one-way coupling of these, two-way models will appear in the near future (*Kong et al.*, 2015). The new variables (trace gases, aerosol particles, airborne pollen) and interactions (radiation, cloud formation, turbulence, etc.) cause further uncertainties in the chemical weather models. In addition, the parameterization-specific optimization procedures for the region have high priority, which requires an excellent measuring background. It contributes to the harmonization of models used in the Pannonian Basin (*Ivančan-Picek et al.*, 2011; *Syrakov et al.*, 2015; *Žabkar et al.*, 2015). In respect of integrated modeling of present and future air quality under a changing climate, there is a need for greater use of model ensembles and also to capture the full range of uncertainties in future impacts (see also *Kinney*, 2008).

3.3. Potential activities

Measurement network: Air quality stations measure the concentration of CO, O_3, SO_2, NO_x, PM_{10} and meteorological variables, such as wind speed and direction, air temperature, relative humidity. The national air quality monitoring network provides current and historical air quality data nationwide. Measurements are needed for the source identification analyses using different techniques [e.g., bivariate polar plots (*Jeričević et al.*, 2016)]. The database is based on data measurements that could be used to validate regional climate/air chemistry models and surface energy budget calculations.

Measuring potential in the field of micrometeorology (soil and surface energy budget, evaporation above different kinds of vegetation and water surfaces), *remote sensing technics* in PBL, nucleation, etc. for better understanding the climate system and working out region-specific parameterizations are also important topics.

One of the main objectives of the present proposal is to *improve the simulation of PBL in the NWP models*. This is envisaged during the completion of the following tasks:

- extensive validation of the applied NWP models in the planetary boundary layer (PBL) using measurements campaigns,
- installation of a single column version of the PBL models (AROME, WRF, etc.),
- research in connection with the grey zone of turbulence at very high model resolutions.

Scale dependent modeling: To address environmental concerns there is a need for data and processed information. In the context of the Copernicus programme (*copernicus.eu*), the MACC-III project had the overall functional objective of delivering reliable operational products and information services that support research, European environmental policy and the on-going development of user specific downstream services. It is prepared for the transition to long-term sustainable operation as the fully-fledged Copernicus Atmosphere Monitoring Service (*CAMS; atmosphere.copernicus.eu/*) from the second half of 2015 onwards. In order to create comprehensive assessments of climate change impacts the analysis of consistency regarding projections among different climate models employing different parametrizations and different spatial scales is highly relevant. Quantifying the discrepancies in different climate models indicates the degree of robustness of the projected changes and gives a reference for the uncertainty transferred to impact studies.

The mathematical modeling of air pollution processes is usually based on a system of nonlinear partial differential equations called transport-chemistry system. The numerical integration of this system is a rather difficult computational task, especially in large-scale and global models, where the number of grid-points can range from few thousands to a few hundred thousand, and the number of chemical species is typically between 20 and 200. Total air pollution is the sum of locally (from a given scale) and non-locally produced pollution, which is advected in from the outside. It is the so-called background air pollution from natural and anthropogenic sources. Each scale (from continental to local) is originating from larger scales. By using this scheme, contributions from global, continental, regional and urban background pollution could be easily analyzed for any geographic location (*Szepesi et al.*, 1995). Of course only the locally produced pollution can be locally regulated. One of the most effective methodologies for the regularization is the bubble theory where the sum of the source intensity on the given scale (so called bubble) is limited (see more detail for example in *Hussen*, 2005).

Chemical weather forecast: The coupled meteorological and chemical transport models have two basic types: (i) the off-line (separately, without feedback), which appear in the daily forecast routine of each country of the Carpathian Basin and (ii) the on-line (at the same time, with feedbacks) integrated models. The off-line models are the present, while the on-line models might be one of the dominant developments in the near future. The on-line coupled chemical transport model system can forecast dispersion and air pollution fields at the same time. The meteorological data should be available in every time step. In this case they advert the effects between the meteorological processes and the chemical substances. The results may have multiple applications: we can obtain a physically, chemically and biologically related weather forecast. The difficulties of the on-line models are the bigger complexity, more input parameters and the lesser-known interaction-systems. On the other hand, this is the important research goal of the near future, which results will also appear in the regional, nested climate models for the Pannonian Basin. The countries of the region have international cooperation, the computing background is well developed, and the earlier experiences of the cooperation in COST are available too (*chemicalweather.eu*, *Baklanov et al.*, 2014).

Agricultural, ecological and water quality modeling: the outputs of weather and/or climate models and the measurements could be used as input for coupled agricultural, ecological and water quality models. Applications of the ecological models are (i) the comparison of model calculations with regional meteorological, air quality and environmental databases, and (ii) the review of operative models and investigation of their applicability in the Pannonian Basin. The main goals are:

- assessment of current and available data sets in order to improve knowledge about the biosphere- atmosphere interaction and its impact on air quality under different weather and climate conditions;

- testing new modeling approaches and their effects in SVAT models of numerical weather prediction (NWP) to improve the modeling of physical processes, particularly those crucial for parameterization of vegetation as a source and sink of air pollution;
- cooperation and synergies with other expert teams especially the FQ1 planning group in PannEx. Improved parameterization of physical and chemical processes in presence of vegetation is important in the perspective of agricultural production too. Since biosphere-atmosphere interaction is one of the main issues affecting the quality of long-term weather forecast, improvements in this direction could enhance the quality of NWPs and their efficacy in agricultural application in different time scales.

The effects of precipitation and humidity are important modeling questions; hence the specificity of our region is the *drought susceptibility*. The results of the coupled environmental models depend on the quality of the NWP databases and the optimal settings of parameterizations (*Grosz et al.*,2015).
There are attached models used in the Pannonian Basin, such as the widely used plant growth and crop forecasting models (*Lalić et al.,* 2014). The methods of the comparison regarding assistant models are presented in the Agricultural Model Intercomparison and Improvement Project (AgMIP, *Rosenzweig et al.*, 2013). Besides that, the main goals of the bio-geochemical models are to simulate the exchange of ecosystems carbon (C), nitrogen (N) and C- and N-containing trace gases. We can simulate the exchange processes among soil, atmosphere and biosphere with these models, and introduce correction factors based on measurements and observations. In our region the DNDC and the Biom-BGC model (*Machon et al.,* 2015; *Sándor et al.,* 2015) are used successfully.

Coupled meteorological-hydrological models: Investigation of interaction between atmosphere and lakes/water surfaces can be carried out on the basis of calculation of the turbulent fluxes (momentum, sensible and latent heat) and eddy diffusivity coefficients for momentum, heat, and concentration using grid point model (e.g., FLake, see in *Vörös et al.,* 2010), a two-way exchange model of trace materials and the 2D and 3D hydrological models (e.g., FVCOM) for producing wave-forecasts. Recently, the nitrogen budget of Lake Balaton was modeled (*Kugler et al.*, 2014). The energy balance and sediment processes of Lake Balaton and Lake Fertő have been also estimated (*Krámer et al.*, 2012; *Kiss* and *Józsa*, 2015). In this area the information exchanged between the countries of the region, and the development and comparisons of the applied lake and flood models is of common interest.

Urban studies: Detailed and harmonized surveys of emissions from different source categories is essential for urban air quality studies and modeling. Representativeness of locations of urban climate and air quality measuring sites is the key issue related to setting up common methodology in measurements over the Pannonian Basin and making comparison studies among cities (*Unger et al.,* 2011). Models used for urban studies calculate and predict local climate elements, urban air quality, heat island intensity and human comfort parameters, as well as the impact of extreme temperature events on health. Because countries in the Pannonian region use several types of urban scale models, the exchange of experiences among partners is needed before undertaking joint actions and strategies for the mitigation harmful effects caused by urbanization. In addition, the statistical assessment of meteorological conditions of pollution can be effective, including the synoptic pattern method for automatic (probabilistic) detection of possibilities for pollution. (e.g., *Ivus et al*., 2012).

3.4. Expected outcomes

There are long-term calibrated data sets available from standard meteorological and air pollution measurement networks (EMEP, WMO GOS). However, it may be more efficient to develop special, dedicated measurements that are important for running, testing and developing SVAT (soil moisture, radiation, energy budget) profiles, air pollution models (nucleation processes, aerosol and trace gases fluxes), NWP models, remote sensing technics for the PBL and EUMETSAT products (e.g., Climate Monitoring, Ozone & Atmospheric Chemistry Monitoring), especially for the Pannonian Basin. That would also provide possibilities to get new scientific answers for the following questions:

How does a warmer climate affect air quality and human health?

- Air pollutant and pollens transported over country borders requires close international collaboration and common activity to mitigate their harmful health effects.
- Investigation of the spatial representativeness of monitoring sites and the Intercomparison of trace gas measurements are also recommended.
- Satellite imagery produced by EUMETSAT for Pannonian Basin could be useful to amend surface based measurements and for monitoring the general condition and the moistening of the land surface, soil and vegetation.
- Mapping of air pollutant concentrations and depositions over countries' borders is also essential.

What kind of interactions do the soil, water and air have with agricultural practices?

- Investigation of exchange and interaction between the spheres of the Earth, like atmosphere, biosphere, hydrosphere and soil system can be utilized in agriculture.
- Ecosystem modeling of eutrophication and long-lived toxic elements (Pb, Cd etc.) is also important.

Physics and chemistry of the surface and of the PBL; improving forecasts.

- Measuring and modelling the (bidirectional) fluxes of the reactive nitrogen, carbon dioxide, ozone and aerosol particles over different surface and vegetation types are essential for the parametrization of physical processes and budget calculations.
- Improved measurement and modeling techniques and methodologies. Biosphere-atmosphere interaction is one of the main issues affecting quality of long-term weather forecast. Improved modeling techniques can improve quality of NWP and its efficacy in agricultural application at different time scales. Urban effects are also important.

Refinement of emission inventories.

- Updated emission databases calculated by harmonized methods considering uncertainties of different emissions projections

Perception of populations, urbanization.

- Sharing best practice how to mitigate harmful effect of climate change in urban environment.

There are already many well-developed European cooperation programs, however it is important to harmonize the regional scale country-specific measurements and modeling activities in order to get better results. In the fields of air quality and climate change, many international programs encourage cooperation among countries and regions that aim to improve the environment, to find innovative solutions for competitiveness and attractiveness in this part of Europe. The results from the planned activities continue to demonstrate that an integrated approach addressing the scientific questions is necessary in order to develop an integrated policy perspective. This integration would allow the selection of win-win scenarios or shows prioritization needs, which could lead to more effective policies (see also *Amann et al.,* 2015; *Sutton et al.,* 2015).

4. FQ3: Toward a sustainable development

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Key topics:

- Preserving ecological services
- Hydropower potential evolution
- Wind and solar energy potential
- Biomass production and conflict with agronomic needs
- Building the infrastructure for forecasting and coordination of the energy production
- Evolution of the energy needs (cooling and heating) in a warmer climate

4.1. Introduction/Background

Energy is an essential factor for sustainable development. Energy systems are the engines of economic and social development and they influence all aspects of human welfare. Emissions from the energy sector account for the largest share of GHGs. The UN Secretary-General has called upon governments, businesses, and other sectors to double the share of renewable energy (www.se4all.org/decade_about) by 2030.

At the United Nations Sustainable Development Summit on 25 September 2015, world leaders adopted the 2030 Agenda for Sustainable Development, which includes 17 Sustainable Development Goals (SDGs) with 169 associated targets. WMO stated that the National Meteorological and Hydrological Services and the broader WMO community, including WCRP could contribute to the SDGs at the national and international levels (WMO, 2016a). WMO also gave several examples on how the organizations can contribute to 11 of the 17 SDGs. Some of these show how weather forecasts can help to protect energy infrastructure from hydrometeorological hazards and promote partnerships and projects for supporting energy-management decisions with weather and climate information.

WMO also prioritizes the energy sector in their contemporary leading programs. WMO established the Global Framework of Climate Services (GFCS) to develop user-tailored weather-water-climate services for different economic sectors (WMO, 2011). Energy is one of the most important elements in the Programs. GFCS can help improve efficiency and reduce risk associated with hydro-meteorological hazards affecting energy systems (Troccoli, 2015). The GFCS Energy Exemplar (WMO, 2016b) focus on the energy sector includes renewable energy resources and was developed in close cooperation with the energy industry. Documents have been sent to NHMSs all over the world to explain how improved how climate services benefit the energy sector. Documents summarized the wide number of other organizations around the world assisting the energy sector with climate related information. In 2011, the International Renewable Energy Agency (IRENA) and the World Meteorological Organization (WMO) signed a Memorandum of Understanding to jointly implement activities related to the assessment of renewable energy potentials. WMO also takes an active part in the Green Climate Fund that was established in 2016 by United Nations Framework Convention on Climate Change (UNFCCC), which aims to mobilize investments in low-emission and climate-resilient developments, with the energy sector being one of the most prominent investment pillars.

By taking into account weather and climate information, energy systems can therefore considerably improve their resilience to weather extremes, climate variability and change, as well as their full chain of operations during their entire life cycle.
This improves the efficiency of the system and reduces costs of renewable energy integration, and thus reduces the GHG emissions and contributes to the mitigation of the climate change.

Within the environmental issues vital for the EU and future member states, the energy challenge has become a top priority for policy makers. The insecurity of traditional energy supplies and climate change threats make the uptake of renewable energy and more efficient use of energy one of the main objectives of the EU sustainable development strategy. Therefore, the Directives of the European Parliament promote binding targets of 20% renewable energy share in electricity consumption, 20% reduction of greenhouse gasses and 20% improvement in energy efficiency by 2020 (Directive 2009/28/EC). Furthermore, the 2030 Energy Strategy specifies more ambitious goals that include a 40% cut in greenhouse gas emissions compared to 1990 levels, that there is at least a 27% share of renewable energy consumption and at least 27% energy savings compared with the business-as-usual scenario (directive in preparation). Meteorology and climate are increasingly important to reaching the above goals and targets, because energy generation and demand are markedly affected by meteorological conditions. To achieve these ambitious goals the fast diffusion of renewable based energy generation technologies is needed. This is especially true for the countries of the Pannonian and Danube basins. The countries of the Pannonian Basin have diverse power generation systems and plans for future development. The national energy strategies in the countries of the region are still mainly based on fossil and nuclear resources. In the near future their energy mix must include renewables. There are several barriers against the use of renewable based energy technologies (Deutsch and Pintér, 2015). The countries in the Pannonian region have to enforce their cooperation in R&D in order to overcome these difficulties. It would be worthwhile to join our efforts and find a way to fund participation in developing the GFCS and Copernicus Energy Services on a regional level.

COPERNICUS is the European system for monitoring the Earth. Copernicus Climate Service (C3S) has become a major contributor from the European Union to the GFCS and its Climate Monitoring Architecture. C3S is headed by ECMWF and began its activity in November 2015. C3S will combine observations of the climate system with the latest science to develop authoritative, quality-assured information about the past, current and future states of the climate in Europe and worldwide. C3S contains three subprojects dedicated to the energy sector: CLIM4ENERGY, ECEM and WISC (EC, 2016a).

4.2. Preserving ecological services

The Pannonian Basin is recognized by the European Environmental Agency (EEA) as one of eleven biogeographical regions in Europe[1]. A wide range of endemic species and communities live exclusively in this biogeographic region that hosts three biomes: the temperate forest, the forest steppe and the steppe biome. The biomes make this region a particularly useful natural laboratory for assessing climate change impacts, since a small change in climate can manifest itself as a change in biome identity (e.g., from forest to forest steppe), which is readily detectable (Mihailović et al. 2015; Szelepcsényi et al. 2018). While being a peculiar biogeographic region, the favorable abiotic conditions (good soils, moderate climate) make the area highly suitable for agriculture, resulting in considerable pressure on natural vegetation.

The impact has been profound since the Middle Ages, leading to almost complete disappearance of forest communities from lowland areas. Goals for stable agricultural yields have also presented demands in water management, which lead to the regulation and

1 http://www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-in-europe-1

restriction of river courses, including the intentional or unintentional drainage of wetlands and gallery forests.

The high level of habitat transformation makes the natural communities vulnerable to climate change, since the compensation mechanisms such as adaptation by migration or the buffering effects of surrounding vegetation is not always available. The vulnerability of natural habitats, however, is a problem for society as well. A wide range of ecosystem services is provided by intact natural communities, (e.g. hosting pollinators that visit nearby agricultural fields, thus increasing the yields; preventing erosion, cooling the temperature during a heat wave). Many of the ecosystem services are directly linked to the hydrological cycle (e.g. retains excess water from extreme precipitation events as well as the presence of intact vegetation along rivers greatly mitigates the floods, the same vegetation also filters water for drinking water wells and for recreation). For example, the Kis-Balaton wetland filters the polluted water of the Zala River before reaching Lake Balaton or the Koviljsko-Petrovaradinski rit wetland, which buffers the Danube river water levels near Novi Sad and potentially prevents more frequent floodings of agricultural and residential areas. Vegetation intactness is the key to many ecological functions delivered by animals in the landscape, since habitat availability determines the presence of animals and intact ecological processes as well. Therefore, we place special emphasis on habitat suitability, vulnerability and restorability.

Recent research efforts have provided a way for better understanding of potential consequences of environmental changes. The approaches based on grouping species according to their similarities in responses to abiotic factors and/or in their impacts on ecosystem processes seem to be highly promising in tackling this type of ecological questions at the scale of ecosystems, landscapes or biomes (Suding et al., 2008). This could also serve as good basis towards developing a set of bio-indicators. Certain plant traits have strong predictive powers to ecosystem responses to environmental change, and, at the same time, can have strong impacts on ecosystem processes (Lavorel and Garnier, 2002). More importantly, the approach provides a way to assess the capacity of ecosystems to respond to future disturbances and to avoid the shift towards undesirable states (Chapin et al. 2010), therefore, better informing future strategies aiming to strengthen this capacity.

The Pannonian Basin extends to the area of several countries also joined by the river Danube and Tisza. There are areas dissected by borders, which are part of one ecosystem complex (the Mura-Drava-Danube area and the southern part of the Great Hungarian Plains), where it is impossible to improve ecological sustainability without the collaboration of all affected parties. These transborder regions will receive special focus in our research. We plan to synchronize our efforts to understand and mitigate the threats of climate change in ecological sustainability, which directly leads to agricultural and social sustainability. We are aware that ecological sustainability is in many ways in conflict with human activities whether they take the form of urbanization, energy production (even if it appears sustainable from the energetic point of view, e.g. biofuels), agriculture or intensive silviculture. Therefore we aim at identifying these conflicts and evaluate potential risks and benefits of decisions. We specifically aim at:

- exploring the degree of threat climate change presents for natural and semi-natural habitats in the Pannonian Basin
- identifying the key stands of currently existing habitats that are particularly important
- providing mitigation options by restoring habitats with special emphasis on water-related issues

Protecting ecosystem services and biodiversity in a sustainable way is a core task of society as a whole and requires among others, considering global change in decision-making. For example, the sturgeon, a flagship species of the Danube once providing livelihood for many communities along the Danube River, but now faces extinction due to overexploitation and habitat loss (disruption of migration routes, pollution, hydro-morphological changes). Restoring the sturgeon fishery in the Middle and Lower Danube could be an important ecological as well as an economic goal. Another example is related to wetland restoration in the Mura-Drava-Danube area (WWF, 2011; Csagoly et al., 2016).

4.2.1. Outcomes/Proposed activities

- Provide essential information on weather and climate, air quality, hydrological and soil conditions that are needed to understand different processes relevant to ecological services and biodiversity in the region. (Database compilation).
- Develop a common set of indicators that can be relevant for ecological services and biodiversity monitoring over the whole region as a unique biogeographical area. A common set could help in developing a better understanding of the processes and changes in the Pannonian Basin as a biogeographical region and could help countries in the region to easier exchange relevant information and experience (many habitats, such as Mura-Danube-Drava area, are situated over territories of several countries in region).
- Evaluate the potential the database prepared in the previous step.
- Conduct a comprehensive analysis of the potential impacts of climate change on natural habitats in the Pannonian region and other anthropogenic stressors (especially ground water changes) for sustainable functioning of ecological services.
- Explore possibilities for the development of different nature-based mitigation strategies, which can help to improve eco-services and reduce future risks related to climate change.
- Identify areas vulnerable to climate change and human water use.
- Identify restoration priorities with maintenance of water cycling as a target.
- Understand the impact of past climate change and agriculture practices on hydrological cycle (especially related to soil moisture dynamics) water quality. A better understanding of this impact can help in developing better strategies for potential restoration or preservation of current habitats and biodiversity.
- Understand the current state and future perspectives of forest ecosystems and their socioeconomic relevance through the prism of climate change.

4.3. Hydropower potential evolution

Hydroelectric generation is not new to the Pannonian Basin. Primarily due to the efforts of Nikola Tesla the hydropower plant HE Jaruga near Šibenik in Croatia became operational two days after the Niagara hydropower plant and thus became the second alternating current electric generating hydropower plant in operation worldwide. Since that time the countries in the Pannonian Basin have relied heavily on hydropower (e.g., in Croatia it contributes to around 50% of the installed energy capacity). Hydropower's key advantage is the absence of fuel costs, which has helped continuous development in the past, meaning that many of the obvious plant locations have been exploited. The major rivers in the basin are the Danube, Tisza, Sava and Drava.Table 1 lists some of the biggest hydropower plants (HPPs) on these four rivers in terms of installed capacity.

Table 1. Major hydropower plants on the Danube, Tisza, Sava and Drava Rivers

River	Country	Hydropower plant (HPP)	Installed capacity (MW)
Danube	Romania	Portile de Fier I	1166
Danube	Romania	Portile de Fier II	314

Danube	Serbia	Djerdap I	1058
Danube	Serbia	Djerdap II	270
Danube	Slovakia	Gabčíkovo	720
Sava	Slovenia	Mavcice, Vrhovo, Medvode, Moste, Bostanj	152
Drava	Croatia	Varaždin, Čakovec, Dubrava	251
Drava	Slovenia	Zlatolicje, Formin, Ozbalt, Vuhred, Mariborski, Otok, Fala, Vuzenica, Dravograd	581
Tisza	Hungary	Kisköre, Tiszalök	39

There are many smaller HPP on major rivers tributaries that are located mostly in the surrounding mountains (ICPDR, 2013a). According to CEE Hydropower outlook there are many more potential areas for power plants on rivers in this region. Already planned is a new HPP or HPP that will be upgraded (KPMG, 2010).

Relevant information about the potential impacts of future climate change on river runoff and consequently on power production requires long-term planning and the estimation of potential risks due to changes in annual mean runoff or changes of the annual redistribution. Countries along the Danube River have recognized the fact that new hydropower development is one option for reducing greenhouse gas emissions, but at the same time causes negative impacts on the riverine ecology, imposing the requirement of a sustainable, balanced and integrated approach.

Information about the potential impacts of climate change is also important to prepare efficient adaptation strategies and reduced future risks. Some already published studies pointed to the direction of the future change (Stagl and Hattermann, 2015; Papadimitriou et al., 2016; de Roo et al., 2016) of general trend towards a decrease in summer runoff for the whole Danube basin, and additionally, in autumn runoff for the middle and lower Danube basin, aggravating the existing low flow periods. For the winter and early spring seasons, mainly January-March, an increase in river runoff is projected. The impacts of changes in the hydrological cycle on hydropower production have been studied to a limited degree. There are just a few estimates about the impacts related to changing run-off to hydropower production in the region. One example is the WATCAP project (SC, 2015).

4.3.1. Outcomes/Proposed Activities

- Develop comprehensive and detail analyses of changes in different elements within the hydrological cycle in regions relevant to hydropower production, based on a wide spectrum of information from observed conditions in the past to future changes using climate change scenarios available through open databases (CMIP, CORDEX, MedCORDEX and regional projects).
- Assess future changes in hydropower potential, based on the changes within hydrological cycles, for already exiting HPPs.
- Assess future hydropower potential, based on the changes within hydrological cycles, for HPP that are planed according to national plans and national energy development strategies.
- Estimate negative impacts on the riverine ecology and general impact on environment, especially under the potentially changed future climate condition (low flow, shortage in summer precipitation, etc.).
- Assessment of impacts from the increase of water temperatures on power plant cooling processes and the potential reduction of efficiency for thermal power plants (nuclear and fossil).

4.4. Wind and solar energy potential

The increased importance of renewable energy can be explained by the crucial necessity of reducing greenhouse gases (GHGs) to avoid irreversible damages from global warming. Also, renewable energy supplies are necessary for diversifying and improving the security of the energy supply and substituting finite and depletive fossil resources. The European Union has the objective of cutting emissions by 80% below the level of 1990 emissions by 2050. Renewable energy, such as low carbon energy will play a key role in reaching that target. The EU Renewable Energy Directive commits EU Member States to setting by 2020, binding individual targets of 20% energy from renewable sources in its gross final consumption, and 27% share according to the 2030 Energy Strategy, taking into account their respective potential for generating renewable energy.

On 23-24 October 2014 the European Council decided on a new set of targets for 2030 by adopting the “2030 Climate and Energy Policy Framework.” This framework includes binding targets for (i) domestically reducing greenhouse gas emissions by 40% by 2030 and for (ii) increasing the share of renewables to 27%. Countries are free to choose a specific mix of renewable energy sources. In most countries in the Pannonian region hydropower currently represents the most important component of total renewable energy production. According to an ICPDR report (ICPDR, 2013b) hydropower will remain a relatively significant contributor of renewable energy for the modernization and refurbishment as well as the development of new hydropower plants. However the share of hydropower to total renewable electricity production will not increase in the surveyed Danube countries. Other renewable energy sources, such as wind and solar are developing more dynamically than hydropower. European environmental agency report (EC, 2016b) found than wind and solar PV energy are two of the progressive renewable energy technologies that are experiencing strong growth worldwide as a result of cost reductions achieved through innovation, technological learning and economies of scale. The current wind power capacity installed in Europe is almost 130 GW, covering around 10% of the electricity needs, and could exceed 400 GW by 2050. Realistic global wind and solar electricity potentials together are ranging between 730 and 3700 EJ per year, which is far above the world's gross energy consumption of 76 EJ per year in 2013. The long-term contribution of wind and solar power to the world's energy needs could be vast, outstripping our energy needs.

Such a high expectation of future developments calls for comprehensive analysis of current and future potentials for worldwide power production from wind and solar includes the Pannonian Basin. Furthermore, it is important to notice that wind energy is sensitive to changes in climate.

The near-surface wind resources are affected by changes in large-to-local scale circulation, as well as by changes in land cover or aerosol concentration levels. Changes in extreme events such as storms, floods or icing can also lead to increased/decreased damages on wind turbines and alter their efficiency (Tobin et al, 2016). It is also important to define which types of potentials (Šliavac, 2015) (namely theoretical, geographical, technical, economical or market potential) that are considered.

Some pioneer works (Horvath et al., 2011; Hueging et al., 2013; Jerez et al., 2015a,b) for the Europe and Pannonian Basin can be used as a starting point to more comprehensive analysis. Solar energy is the most abundant energy resource. Even if only 0.1% of this energy could be converted at an efficiency of 10%, it would be four times larger than the total world’s electricity generating capacity of about 5 000 GW. The average annual global solar irradiation on the optimal plane in Europe changes between 600 and 2000 kWh/m2. The Pannonian Basin belongs to Danube region, which is favorable for solar energy generation with global solar irradiation ranging from 1100 to 1800 kWh/m2. Studies on solar Resources in the Danube region concluded that for general assessment of theoretical, geographical and technical potentials, the most obvious choice is the PVGIS. The power sector experienced its largest annual increase in capacity ever, with significant growth in all regions (REN21, 2016).

4.4.1. Outcomes/Proposed activities

- Develop a comprehensive and detailed analysis of available wind power potential in the region, based on a wide spectrum of information from observed conditions in the past (in situ observations, satellite data, gridded climatology, reanalysis, RCM hindcasts) to the possible future changes using climate change scenarios (RCP2.6, RCP4.5 and RCP8.5) available through the open databases (CMIP, EURO-CORDEX, MedCORDEX, regional projects as well as regional mesoscale reanalysis).
- Develop comprehensive and detailed analysis of available solar potential for power production in the region, based on a wide spectrum of information from observed conditions in the past (in situ observations, gridded climatology, reanalysis, RCM hindcasts) to the possible future changes using climate change scenarios available through the open databases (CMIP, EURO-CORDEX, MedCORDEX, regional projects as well as regional mesoscale reanalysis).
- Accurate meteorological data is needed for, the design, implementation and operational phases of solar power plants. There are many freely available radiation data sets. WMO coordinated high quality surface measured global radiation data sets (BSRN, WRDC, GEBA) contain only a few stations in the Pannonian Basin. In the absence of long-term surface data, solar resources can be estimated via satellites. EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF) provides long-term data and products dedicated to solar energy applications. Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI) can be obtained from geostationary satellites. Numerous services use also PV-GIS data for further applications, including the SMA iPhone App and EVALO for house renovation (Trentmann et al., 2013). Validation of CM SAF data for Pannonian Basin is a gap. CM SAF can provide an opportunity to prepare radiation Atlas and long term statistics for the project area.
- Several other meteorological variables are needed for estimation of PVs and include temperature, wind, humidity and pressure. These data are necessary not only for impact assessments in the preliminary phase but during operations and maintenance. Collection of resources including existing global and regional resources (e.g., IRENA and ESMAP) would be necessary for our region. Estimate possible future risks related to the adverse weather and climate events (e.g., super-cell storms, hail, strong winter winds, floods, icing, heat waves and high temperatures) especially for the already existing wind and solar farms, and locations that are currently seen as attractive, or locations that are part of national plans and energy development strategies.
- Estimate potential negative impacts on the environment, especially in the case of not well-planed development (to avoid negative outcomes). Even solar power plants have some negative impacts on the environment. They may cause adverse local ecological problems, such as habitat loss, decrease of biodiversity and alteration of local climate. The manufacturing of PV panels requires rare and toxic materials. Moreover, if the panels are not properly recycled and the supporting structures removed, the land may suffer further. This is a new research area. Study to identify suitable (e.g. degraded areas, rooftops) in examined region which are likely to suffer the least adverse ecological impacts from PV farm installation would be useful for all participating countries.
- Estimate air-pollution reduction achieved after fossil thermal power plants are closed (PM, SOx, etc.). Reduced emissions of pollutants, besides the positive impact on human health, also have an impact on radiation budget.
- High resolution Wind atlas (assess possibility to harmonize atlases that already exist on national level).

- Develop comprehensive high-resolution wind and solar atlases based on mesoscale reanalysis and dynamical downscaling for future climate change projections. Analyze complementarity of the wind and solar energy resources in the basin.

4.5. Building the infrastructure for forecasting and coordination of energy production

All renewable energy power production (except geothermal) depends on weather and climate condition. Especially, wind and solar production is highly dependent from hour-to-hour and day-to-day weather variability. This variability of wind and solar power introduces unique challenges to those who must maintain the constant balance between energy supply and demand required for a stable electric power grid. For the stabilizing the system, which is now transitioning from old to smart, the base-load generation has to be developed otherwise the reliability of the power system can't be ensured, moreover no more renewables can be integrated into the system otherwise (Katon, 2015).

National weather services have already started to develop dedicated forecast systems for power production from renewable sources (Table 2). Accurate and timely forecasts can be crucial to avoiding the generation of excessive energy, timely act on energy markets, better organization of power distribution within the power grid (Koračin, 2014; Lazić, 2010; 2014).

Table 2. List of some dedicated forecast systems for power production from renewable sources.

Country	Web page
Germany	http://www.dwd.de/EN/research/weatherforecasting/num_modeling/07_weather_forecasts_renewable_energy/weather_forecasts_renewable_energy_node.html
US	www.esrl.noaa.gov/gsd/renewable/
Croatia	http://klima.hr/razno.php?id=projekti&param=will4wind http://www.will4wind.hr/

For solar and wind power production the biggest benefits are from short to medium range forecasts. On the other side, hydro and biomass can probably have some benefits from sub-seasonal to seasonal forecast (Dubus, 2012; 2013). In both cases the ensemble approach (single and multi-model) appears to be more than is necessary.

4.5.1. Outcomes/Proposed activities

Operation of solar facilities strongly relies on weather forecasts at time scales from 30 minutes to several hours. Application of NWP models is necessary beyond several hours to cover these demands. Development of different statistical methods and software for very short time scales (below 30 minutes) and for longer term (beyond monthly) are also missing. Common R&D is necessary on these fields. It is a key task because the solar power forecasting is the main factor of the integration of solar power into the grid.

There are proposals for observational network upgrades and optimization, especially because of possible improvements in assimilation cycles for short range forecast for wind and solar radiation. Although satellite data are easily available for solar assessments, accurate surface measurements of incoming solar irradiance are still the most important information for all phases of solar investments. Traditional surface measurement of global and especially direct radiation is necessary in order to evaluate the long-term mean and variances.

- Create a joint (meta) database of near-real time observations in the Pannonian Basin.
- Conduct experiments with very high-resolution (close to 1 km and higher) non-hydrostatic models over microgrid, distribution, and dense wind farms facilities areas.
- Develop inter-institutional multi-model ensemble prediction products especially developed for renewable power sectors needs (exchange or collection of certain output fields, relevant for topic).
- Develop seamless prediction forecast products from days to seasons that are relevant to hydro-power production and agricultural activities related to the biomass production.
- Design specific experiments/case studies related to the improvement of different physical parameterization (e.g., wind profiles and surface turbulence for wind, radiation for solar, surface hydrology for hydro) relevant for solar/wind/hydro power production.
- Develop meteorological mesoscale numerical weather prediction models with hydrological and oceanographic models coupled.
- Unify meteorological mesoscale numerical weather prediction models and energy production and energy efficiency models.
- Adapt weather predictions for assessment of dynamical line rating of transmission lines.

4.6. Evolution of the energy needs (cooling and heating) in a warmer climate

Temperature is probably the major driver of energy demand in Europe, affecting summer cooling and winter heating. The ClimateCost project found that while cooling is predominantly powered by electricity, heating uses a wider mix of energy sources (Mima et al, 2011). According to the results of this project, future cooling demand is expected to increase in Europe by about 3% per year during this century, following the BAU scenario. The study has also assessed the decrease in heating demand (a benefit) from same climate change scenario. The reduction in heating demand is approximately 10% (by 2050) and 20% (by 2100) in comparison to the baseline heating demand.
Negative trends in heating demand can already be observed. For the period of 1980-2009 the number of heating degree days (HDD) decreased by 13% on average for all of Europe, yet with substantial interannual variation. In the Pannonian Basin this trend was between -10 and -20%. Summer cooling could be a challenge for the Pannonian Basin in the future, since results from climate change scenarios show that the region is expected to have the highest increase incombined hot summer days (T2mMAX > 35 °C) and tropical nights (T2mMIN > 20 °C) for June-August season2.

2 http://www.eea.europa.eu/data-and-maps/figures/projected-average-number-of-summer-1

Trends in seasonal as well as in monthly heating degree-days (HDD) and cooling degree-days (CDD) were determined for five locations in Croatia for the period 1901-2008 (Cvitan and Sokol Jurković, 2016). It is confirmed that the applied monthly scale for analyses is suitable for assessing heating and cooling practices.

Conversely it is interesting that in recent years, renewable heating and cooling continue to be the dominant renewable energy services (RES) market sector in Europe, representing over half of all gross final consumption of renewables in 18 Member States. Solid biomass-based technologies are still predominant in this sector, but the fastest compound annual growth rates since 2005 were recorded by biogas, heat pumps and solar thermal technologies (EEA, 2013).

The global trend of rising energy prices puts buildings into focus, as these technical systems are responsible for 40% of energy consumed by mankind. Predictive control techniques are the optimal way to gather the whole building dynamic model with available information on meteorological conditions and forecasts into an algorithm of energy-efficient building control. Therefore, predictive control of energy management in buildings can considerably reduce the energy demand in a changing weather and climate conditions.

4.6.1. Outcomes/Proposed activities

- Assessment of current trends in heating/cooling demand, and their relation to observed trends in temperature and other relevant parameters.
- Assessment of cooling demands during extremely high temperatures and prolonged heat waves in the past (e.g., heatwave during July 2007) in residential and service sectors, with an estimate of possible excessive pressure on energy production system.
- Assessment of changes in heating/cooling demand in the future following different climate change scenarios, together with demands on energy production or redistribution of energy production during the year, and it's relation to the RE perspectives.
- Weather predictions for predictive control of energy management in buildings.
- Estimate of excessive cooling demands during extreme heat waves in the warmer climate.
- To develop/suggest new heating/cooling metric more appropriate for the Pannonian Basin.
- Periodical (annual, every two and five years) evaluation of the energy needs for the PannEx region.
- Modeling the energy need, together with methodology development, for PannEx region both for near future and long term.

5. FQ4: Water management, droughts and floods

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Key topics:

- Evolution of precipitation and temperature (weather) extremes and risk assessment
- Understanding the water cycle of the Pannonian Basin (hydrological perspective)
- Hydrometeorological forecasting and early warning systems
- Anthropogenic influence (e.g., dams, reservoirs) on the hydrological cycle
- Regulation of the Danube and its tributaries: management of floodplains
- Aquifers: sustainability and current usages.

5.1. Background

Water is a key environmental element characterizing the Pannonian Basin. It is a limiting factor for agriculture, its extremes determine the main natural disasters, the shift of the xeric (south) border of plant species effect the area of different species detecting the climate change impacts. The PannEx region has a specific geographical feature determining spatial-dependent meteorological and climatological attributes because the surrounding area is not very high, but are curved mountains. The neighboring large water bodies and the Eurasian continent can cause very high spatial and temporal variability of precipitation.

5.2. Evolution of precipitation and temperature (weather) extremes and risk assessment

Many affecting factors, like influences of the Mediterranean Sea, Atlantic Ocean and the large Eurasian continent make the climate variable in the region, causing large spatial and temporal distribution of precipitation. The increasing occurrence of short-term intensive precipitation leads to the growth of extreme events severity and frequency such as droughts and flash floods. Climate change is evident through the variation of the frequency of the revealing weather patterns in the region. The European cyclonic tracks frequently shift further north causing dry conditions in Central Europe and in the Mediterranean region. The high amplitude of NAO leads to development of weather patterns that cause large precipitation anomalies in the Pannonian Basin.

In the recent years the frequency and intensity of extreme events related with precipitation have increased in many regions of Europe (*Seneviratne et al.,* 2012). In other regions, including the Pannonian Basin, the observed trends are not significant and often show inconsistent behavior (*Klein Tank and Können*, 2003; *Gajić-Čapka et al*., 2015, *Croitoru et al*., 2016b).

Several types of extreme indices are defined for describing extreme precipitation events based on precipitation summaries, which are exceeding specific (fix and percentile based) thresholds (Zhang et al., 2011). The CARPATCLIM data set currently represents the most harmonized and comprehensive gridded data set of several climate variables and derived extreme indices, based on in situ observations in the Carpathian Region (http://www.carpatclim-eu.org/). The warm extremes and related heat waves have become more frequent, longer, more severe and intense in the entire Carpathian Region, in particular, in the summer in the Hungarian Plain and in Romania (*Spinoni et al*., 2013, 2015a; *Lakatos et al*., 2016, *Croitoru et al.*, 2016a, *Piticar et al*., 2018).

In order to be well prepared for the future climate conditions it is essential to estimate the changes in precipitation events, such as the reduced precipitation and the heavy rainfall. The future projections are analyzed in several international projects (e.g., PRUDENCE, CECILIA, ENSEMBLES). More frequent extreme events are likely to occur in the near future in Central Europe (Kyselý et al., 2011).

One of the major natural hazards for society is flooding. More intense precipitation can cause severe flood events in Central Europe. The flood risk has increased in the recent decades in the region due to more extreme precipitation events. Ensemble modeling projects results using the intermediate A1B scenario show remarkable increasing trends of precipitation extremes projected for Central/Eastern Europe by 2071-2100 relative to the 1961-1990-reference period (Bartholy et al., 2015). These changes may result in more frequent and more severe flooding, therefore, it is highly recommended that appropriate flood protection and management strategies be developed.

5.2.1. Knowledge gaps and relevance

- Publications related to climate extremes usually focus on trend estimation of extreme indices. Extreme precipitation and temperature indices are derived mainly from the daily precipitation summary, however there is a demand for sub-daily scale examinations due to the lack of the reliable and representative data for understanding the nature and drivers of global and regional precipitation extremes and changes on different time scales that are relevant to society.
- Understanding the evolution of weather extremes related to precipitation requires an integrated observation and modeling approach, using observations on the sub-daily time scale.
- Surveys and the development of definitions and methodologies for calculating extreme weather and climate events, such as heat waves and cold waves, should reflect on the final application of such extremes (e.g., for climate change detection and attribution studies; sector specific applications such as agricultural, hydrological, or risk management; or for weather and climate monitoring purposes and early warning systems and climate watches, climate outlooks). Identification of more complex extreme indices that consider duration, intensity and persistence of the extremes events is needed; establishing regional thresholds for the indices recommended by WMO and implemented in ClimPACT2 software (*Alexander et al.*, 2013). Additionally, the definition of new indices that take into account not only the duration and intensity of extreme events, but also their scaled severity could support the studying of the regional extremes in the Pannonian Basin. The identification of regional extremes that influence wider region, even the whole territory of the Danube catchment could support the risk assessments.

5.2.2. Proposed activities

- Explore the sub-daily rainfall records available in the Pannonian Basin and quality control and homogenization of the observation data.
- Define new extreme precipitation indices for sub-daily time scale for different applications.
- Apply a more complex approach in analysis of extremes at particular spatial and time scales (e.g., yearly, season, monthly, daily or sub-daily) and spatial scales (e.g., location or a region).
- Develop methods to identify regional extreme events in the Pannonian Basin and the wider region, (in the Danube catchment for instance when the data availability makes that possible).

5.2.3. Expected outcomes

- Available sub-daily measurements can support an integrated observation-modeling approach to provide better (micro, mezo and climate) model results for the region and contribute to understanding and predicting weather and climate extremes'.
- Better understanding of the behavior of regional extremes.

5.3. Water cycle - hydrological perspective

5.3.1. Background

The water cycle or the hydrological cycle describes the continuous movement of water on, above and below the surface of the Earth, and is fueled by solar radiation energy. During the water cycle the form and the aggregate state of water is changing. The water cycle links the atmosphere and Earth's surface waters.

The main elements of the water cycle are precipitation (*P*), infiltration into the soil (*Rs*), surface and subsurface water storage (*S*), the surface, subsurface and channel runoff (*Rss*), and evapotranspiration (*ET*). The water cycle is also seen as partitioning between its elements. For a given section of the atmosphere-land surface system and during a given *i* (time period) the entering, leaving and storing water amount are balanced and can be described by the water balance equation

$$P,i = Rs,i + Rss,i + ETa,i \pm \Delta S,i,$$

where ΔS is the change in storage. Here, we neglect the changes of the water in the soil. A drying tendency, in the simplified water balance equation can be described as

$$P = ET + R,$$

where *P, ET* and *R* are the mean annual precipitation, evapotranspiration and (channel) runoff.

The water cycle and water balance of catchments are mostly dependent upon the climate (precipitation, radiative budget, temperature), land surface (topography, exposure, vegetation canopy) and soil conditions. The water balance is a useful tool for managing water supply and water shortages. Understanding the water cycle and water balance is important to maintaining and preserving the ecosystems, ecology, economy and different sectors of social-economical area.

Scientific and methodological foundations in calculating the maximum flow characteristics in most countries are based on a synthesis of experimental observations using theoretical models that are based on the geometric schematization hydrographs of floods.

In Gopchenko et al. (2015) the variant of calculation scheme, realizing two principal operators of model drainage formation is proposed. It is obvious that two operators must describe the process of formation of channel runoff: “precipitations – slope influx” and “slope influx – channel runoff”. This is the theoretical and methodical base of problem solving (for example, forecasting hydrographs of the channel runoff due atmospheric precipitation). However in practice of hydrological calculations, on solving of a whole series of problems, the great interest is given not to the whole hydrograph of channel runoff, but to its maximum ordinate, moreover, to infrequent exceedance probability. Model that is offered enables to enter «climatic amendments» directly to maximal snow supply and runoff forming precipitations during spring floods, and also to the coefficients of flow (Gopchenko et al. 2015). To justify the calculation methods used database of maximum rain flood runoff on 93 hydrological stations and posts of the State Hydrometeorological network within the territory of the Ukrainian Carpathians.

All components of the calculating scheme had determined using statistical analysis and spatial generalization, accuracy of methods is at the level of accuracy of the initial information, and the method itself is recommended for practical use for any rivers in Pannonian Basin.

In Romania the hydrological stations recalculate (reconstitute) the original/natural runoff values every year for the previous year, it is important to do this at the Pannonian Basin spatial scale, because it would give a starting point regarding the natural water resource changes and variations. The anthropogenic impact varies from year to year and the natural runoff (naturalized flows) would give a more real insight regarding the variation of runoff resources.

5.3.2. Knowledge gaps and relevance

Water balance models had been studied since the 1940s. Some monthly water balance models have been developed for several conditions and purposes.
In the Pannonian Basin water balance models (normally based on monthly data), have been evaluated since the1990s for various catchments areas in order to examine the expected impact of climate change, and also to detect past changes in the water cycle. The studies used different water balance models,

- e.g. for Slovakian and some Romanian catchments mainly the WatBal model,
- for some Austrian catchments the SWAT model,
- for the Croatian catchments the simplified Palmer model was used. The models are usually spatially lumped models.

The difference between these models appears mostly in the method of calculation of evaporation. The evaporation cannot be measured on the catchment level and its calculation makes evaporation the most uncertain element of water balance models. The calculation of catchments evaporation often uses the Turc method, requiring only precipitation and temperature data and information about the vegetation canopy within the catchments. In Hungary there are some studies for development and practical use of the CREMAP model recommended by Morton on the basis of the Bouchet complementary principle. For selected catchments of the Hungarian part of the Tisza-basin the actual monthly values of precipitation, evaporation, runoff and monthly change in water storage were calculated for every year over 30-year periods. The monthly water balances calculated for years make it possible to study more exactly the features of spatial and temporal variability, and also temporal changes to the water balance structure. For the catchments area of the Zala River feeding the Lake Balaton, the annual water balances were calculated in order to detect and explain the deterioration of the water balance condition of the lake.

In addition to water balance models, process-oriented physically based hydrological modeling may provide essential information on the small catchments scale (i.e., 5000-20000 km^2). For this purpose, fine resolution meteorological input drives the hydrological models with at least daily temporal resolution resulting in detailed information of the discharge values, and thus water levels of rivers.

All models mentioned above (WatBal, SWAT and Palmer) used in the region to represent water cycle and predict water balance at different time scales have limitations that might seriously reduce the accuracy of their simulations. Their major disadvantage is the fact that the lateral (surface) dynamics is missing or too simplified and usually not tightly linked with the infiltration process.

Within SEEVCCC (http://www.seevccc.rs/ SEECOP and http://seecop.meteo.co.me/ consortia) a new generation of hydrology modeling concepts were applied that promise more accurate treatment of the hydrologic processes in general. SEEVCCC develops an Earth system model

in which environmental components (atmosphere, hydrology, aerosol and ocean) are integrated through different feedback mechanisms. For the atmosphere-hydrology component, the Hydrology Prognostic system (HYPROM) (Nickovic et al, 2010) is used. This is a new generation of hydrology models designed to predict/simulate hydrology processes at different scales ranging from flash floods to flows of large and slow river basins. Unlike most of the other models of that kind, HYPROM does not use any significant approximation (e.g., the Manning kinematic condition).
It also includes a river routing as a collector for the extra surface water. Such approach allows appropriate representation of different hydrology scales ranging from flash floods to flows of large and slow river basins.
The model uses high-resolution real topography, river routing data, and land cover data to represent surface influences. It has been also used in a regional IPCC-type assessment of the water potential in the Balkan region (Djurdjevic *et al, 2010*). Most recently, HYPROM has been integrated with the NCEP/NMMB non-hydrostatic atmospheric model in a two-way coupled manner (Vujadinović Mandić, 2015), including important feedback processes between the atmosphere and hydrology.

A review of water balance studies confirms that there is no uniform method in the modeling of water balance to study the water cycle. This makes comparisons between models/methods difficult and no generalization can be made except for water balance for limited catchments within the Pannonian Basin (Pandžić et al., 2006; Szilagyi and Jozsa, 2008: Wriedt and Bouraoui, 2009: Stagl and Hattermann, 2015: Hercegh et al., 2016, Nistor et al., 2017). Therefore, there is a need to carry out water balance modeling for a large number of representative catchment areas using a uniform method. The generalization of catchments modeling, would make possible a more reliable regional comparison of the water cycle and its elements within the Pannonian Basin. It is appropriate also to carry out the research work to detect the statistically significant change in the monthly water cycle to research the natural and anthropogenic cause of changes. The use of spatially distributed and fully dynamic 2D hydrology models that are integrated with atmospheric models is more preferable. Particularly important is the use of a uniform method for calculation of catchments evaporation or at least models could be compared and harmonized.

5.3.3. Proposed activities

- Review past water balance modeling, namely the presentation, comparison and evaluation of methods.
- Choose a common method proposed for the calculation of catchment scale evaporation and explore available atmospheric models in the region that are appropriate for performing this task
- Identify hydrological models applied in the region as candidates for studying the water cycle in the catchments within the Pannonian Basin and test these models for selected representative catchments.
- Select a common model to carry out the calculation of monthly water balances for periods longer than one year.
- Prepare a database that is suitable for researching the features of temporal and spatial variation and the variability of the water cycle and its elements. As a first step, the CARPATCLIM database could be used for this purpose.
- Adapt fine resolution, process-oriented, physically-based hydrological models to different catchments that have special characteristics within the Pannonian Basin.
  For the calibration, various hydrology-related variables are needed (e.g. exact topography and land use types, different soil layers). For instance, interception is assessed by using NDVI derived from satellite measurements.

5.3.4. Expected outcomes

- Monthly, seasonal, annual, and multi-annual catchment water balance management elements (such as water retention, drought management, runoff control) could be projected more reliably with integrated atmosphere-hydrology (hydrometeorological) fully dynamically-based modeling systems, and can be linked more accurately to natural and/or anthropogenic changes in the water cycle. (Currently, without monthly forecasts all of this information is not easily available).
- The catchments water balances can be a useful tool for testing the reliability of regional climate models.
- In addition to the monthly scale, a shorter temporal resolution may provide useful information on faster discharge processes, day-to-day river water level changes on target catchments, and thus key input for local adaptation strategies.

5.4. Hydrometeorological forecasting and early warning systems

Climate change is the most significant environmental problem existing today. Therefore, we have to adapt to it, and the early warning system (EWS) is one of the mostly used adaptation activities. EWSs have four main parts: risk assessment, monitoring, forecast and dissemination of results and responses. Dissemination of results means stakeholder-dialogue science-policy-interface (SPI).

In the case of water related disasters, GEWEX research covers a large part of the EWS, therefore, GEWEX could serve as input for drought and flood EWS. However, different disasters require different spatial and temporal scales. Droughts have effects on the largest scale comparable with the Basin spatially, and weekly or longer temporally. River floods can have the same scale as a drought or smaller, and flash floods are of smaller temporal and spatial scales.

Many investigations deal with risk assessments. Following the European Union Water Framework Directive (EU WFD) and the Communication of the EU Expert Group on Water Scarcity and Drought, drought strategies were developed in the countries and flood directives were launched on European and national levels. These documents contain risk assessments for most river floods. Research is planned and is ongoing for drought risk assessments.

Strong national features can be detected for at least two basic systems from the three (risk assessment, monitoring and forecast). Therefore, harmonization activities are needed at basin wide development, with different scale catchment water balance estimations. This activity has to be established upon previous work that was been done by various countries to provide usable information for transnational and comparable information for national catchments.

The development of integrated monitoring and early warning systems covering more sectors – agriculture, hydrology, eventually also energetics would be the more complex approach.

5.5. Droughts

The most relevant topic related to droughts is "the evolution of precipitation and temperature (weather) extremes and risk assessment", and closely connected is "Hydrometeorological forecasting and early warning systems." Both contribute to the knowledge of drought as a natural phenomenon. The contribution below is targeting these two topics. What is missing is a topic covering drought impacts. The closest is "Agronomic and environmental practices: water quality and usage" – however it deals with water quality and not with management of water shortage as a result of drought.

5.5.1. Background

Drought is by definition is a natural, weather related extreme event. In Europe, it causes the third (after floods and storms) highest economic losses (WMO 2014) and is one of the biggest natural threats to socio-economic development. Due to climate change more droughts could be expected and in recent years (2012 and 2015) extreme droughts affected large parts of Europe (e.g., Zahradníček et al., 2015; Cindrić et al., 2016; Ionita et al., 2017). Although it is the general opinion that determination of occurrence and severity of drought is straightforward, sound scientific definition has proven to be quite complicated.

In the past there were many projects dealing with the determination of the optimum set of drought indices – globally and specifically for regions in eastern and southeastern Europe. It is important to emphasize that drought can be meteorological, agricultural and hydrological and more precise usage of the definition is necessary depending on the process considered.

5.5.2. Knowledge gaps and relevance

Drought monitoring and forecasting remains on the agenda – if not purely due to academic challenge, also due to constant requirements from the users. For this reason, despite doubts on practical and even theoretical possibilities, long term drought forecasting remains one of the important tasks and a challenge. However, if it is a requirement that drought-monitoring systems be more connected to drought impacts, then more emphasis should be placed on remote sensing. Drought monitoring systems that are based on classical meteorological data are appropriate for preparation of reports on large scale, needed by governments, national media, etc. However there is demand to prepare more detailed information on drought impacts, which in combination with auxiliary data, such as soil characteristics, crop types and phenology should be based on available high resolution remote sensing data. Satellite monitoring of droughts is very selective (Semenova, 2014), and there is a need to establish the criteria of drought intensity for different areas by studying the relationships between vegetation indices, for example, with meteorological drought indices using the long archives of the satellite observations (e.g., NOAA archives).

5.5.3. Proposed activities

Proposed activities are dependent to a large degree on available funding sources. It is important that networks, created during past projects (e.g., IDMP CEE, CARPATCLIM and DMCSEE) remain active and be capable of proactive initiatives in reacting to opportunities, such as open calls for project proposals.

Project proposals should contain work packages that tackle open questions, such as: how well are current weather forecast systems, operated by global meteorological centers, as well as by regional providers, done in predicting recent droughts over various timescales? Has the situation improved with regard to past years? What are weather forecasting and climate change networks existing in our region that could support the contribution to prediction of drought conditions and drought causes. Among such networks are the SEEVCCC and the SEECOP Consortium.

Apart from NWP output, are there any post-processing/downscaling/other methods and techniques for forecasting droughts? What is the value of state-of-art forecasts specifically in our region and how can they be implemented by end users?
Are there additional possibilities to better connect drought impacts and drought indicators? Can recently available remote sensing data help in this respect? Can it be used – despite short time series – in risk assessment studies?
Is there potential (in our region) for remote sensing data to improve drought forecasting? Is there any other method (such as measurements and modeling of soil moisture) that has potential to improve drought forecasts?
More questions (specially connected to management practices) remain to be addressed by institutions, assembled in project consortia. Of course priorities should be determined through consultations with end users.

5.5.4. Expected outcomes

Recent projects finished with final report and possibly also web page and collection of available data. It is important that any possible new achievement is maintained and updated after termination of the project. This becomes increasingly more challenging as less and fewer resources are available for regular tasks and institutions are more dependent on project income. Nevertheless, it is expected that improved hydrometeorological forecasts, improved monitoring products with increased resolution and also improved risk assessments will be available and regularly updated.

5.6. Water management strategy: flood protection and water shortage management

5.6.1. Background

One important task in the development of a water management strategy is how to manage the extreme hydrological events, particularly the floods and droughts. To control the flood events and to solve the water scarcity problems a various form of measure was developed in the past, the most important and frequently used measures shown in the Table separately the proactive and the reactive ones, also separately the structural and non-structural tools.

Table 3: The measures most frequently used regarding to manage the extreme hydrological events

	Proactive Measures		**Reactive Measures**
	Structural Measures	*Non-structural Measures*	
Management of Water Shortage	Reservoirs, inlets of abstracted subsurface water into the rivers, water transfers between catchments	Water demand management, water legislation, water pricing	Temporary restriction of water use, temporary water supply, wildlife rescue
Management of Floods	Levees, reservoirs, emergency reservoirs	Limiting development in flood-prone areas, preparedness, early warning	Flood protection, temporary evacuation

The basic question is will the effectiveness of the measures used in the past for extreme hydrological events be sufficient in the future. More likely, it will be necessary to review and revise the strategy of water management and its tasks related to climate change.

New strategies should pay more attention to proactive (preventive) measures both in the flood protection and the water shortage management, to risk management, and also to the integrated water resources management (IWRM) of water related problems.

5.6.2. Knowledge gaps and relevance

The decision processes used for flood protection and water shortage management in the past are generally unknown. It is obvious that the natural conditions related to floods and drought vary for regions and catchments. Also, the history of the land use and land use change in areas prone by floods or/and water shortage and the technical options to manage extreme hydrological events are unknown. There is no clear knowledge of which measures used today will ensure the best practices in future, especially taking into consideration some new factors, such as climate change, the need of sustainable development, and the need of integrated water management. The better understanding of decision-making process made in the past in flood protection and water shortage management is a very important task.

5.6.3. Proposed activities

- Identify and evaluate measures used for management of water shortage and flood problems in the past for various regions and watersheds
-
- Conduct and evaluate a cost-benefit analysis of the measures used in flood and water shortage management
- Identify and rank the best practices.

5.6.4. Expected outcomes

- A better understanding of decision-making processes in the formulation of past strategies in the water related problems would help the development of new water management strategies,
- A compilation of best practices available in management of extreme hydrological events

5.7. Anthropogenic influence (dams, reservoirs) on the hydrological cycle

5.7.1. Background

The hydrological cycle is highly dependent on climatic factors, such as precipitation and its seasonal distribution, intensive rainfall events, temperature, evapotranspiration. Nevertheless, hydrological regimes can be modified by different anthropogenic activities towards water bodies directly (river training, flood control, flow regulation, water abstractions and inlets) or indirectly to catchments (urbanization, land use changes, deforestation). Anthropogenic activities can significantly influence hydrological regimes, may cause the rise in water temperature (reservoirs, inlet of used water), the change of ice regime (river training, rise of salinity), the rise of low flow (inlet of extracted subsurface water into the river, regulation of stream-flow by reservoirs), and the rise of floods (land use change, decrease the channel capacity of floodplains). In Hungary the flood protection carried out in the 19th Century by the building of dams along the great rivers can be considered as the greatest anthropogenic intervention in the flow regime of rivers.

5.7.2. Knowledge gaps and relevance

To detect changes in the hydrological cycle or hydrological regime in the past and to predict the expected changes in the future, hydrological system-wide modeling is the best tool. Although hydrological system-wide modeling nowadays is increasingly used, the testing of change in the past usually is limited to a few selected hydrological characteristics. To detect changes in

hydrological characteristics, methods of mathematical statistics (frequency analysis, trends, stationarity) are mostly used. There is not a uniform method in testing and that makes it difficult to compare results of investigations between the different water catchments. Moreover the results of tests strongly depend on the quality of hydrological records of observation, especially on the technology of observation, and the change in measurements technology. Preliminary checking the quality of the hydrological records before the testing of change usually has not happened. The carefully applied methods of mathematical statistics should be appropriate to detect and prove changes in the past, but should not to be suitable without further investigation to find and justify the root causes of the changes. Finding and proving the root causes appears to be an easy task because the possible causes are usually known. Nevertheless, only limited such studies are available and there is not any generalization of the research results of such studies, which would not be allowed to make any clear conclusions. There is not an appropriate method to separate the anthropogenic and climatic effects in the hydrological characteristics, which make it difficult to detect and to prove the impact of climate change in the past, to support the climate change itself in the past and to project the climate change in the future. There are many good literature examples for the study of anthropogenic and climatic effects, for example the article by Hall et al. (2014) is a useful example of studying change in flood regime of Pannonian Basin.
In addition, over the flood regime the water abstraction from surface and subsurface water bodies impacts the water cycle. When we speak about the increase of air temperature and evapotranspiration, we will increase the demands on irrigation. Therefore, there are questions should be answered:

- how will increasing demands on irrigation affect water regime/water storage?
- Will we have enough water available for agriculture in all seasons? Especially, when we speak about the increasing frequency of heavy rainfalls, but no increase in monthly precipitation totals in spring and summer months. It means higher percentage of precipitation fallen in short time, which are connected with higher direct runoff shortly after heavy rainfall event.

5.7.3. Proposed activities

- The recognition and identification of the anthropogenic activities in the past for water bodies directly or indirectly linked to catchments are particularly important in studying the effect of deforestation in catchments runoff, and the effect of dams (reservoirs) built in the river on the floods of the tributaries.
- The choice of uniform methods of mathematical statistics for further use in the detection of change in the selected hydrological characteristics, the testing the preferred method for selected catchments
- Developing methods to separate the anthropogenic and non-anthropogenic effects, including the climatic effects in the changing hydrological regime. Assessing the possibilities of the use of hydrological system-wide modeling for detection of change in hydrological regime. The extension of study results in non-studied catchments and rivers inside of the Pannonian Basin
- The evaluation of the effects of change in hydrological cycle and hydrological regime, particularly on the existing ecosystems.

5.7.4. Expected outcomes

Learning from the past regarding anthropogenic effects on hydrological regimes would be useful in projecting water management measures in the future that promote sustainable development.

5.7.5. Knowledge gaps for further elaborations

- Harmonization of precipitation measurements (has been done for weather radar but not for in situ)
- Combination of remote sensing data with in situ (connection to H SAF?)
- Risk assessment of extreme precipitation – too many or not enough (CARPATCLIM is the last solution, better the use of measured data, but managed by common methods, therefore E-OBS isn't good either)
- Transnational water quality information transfer
- Transnational catchment based water balance calculations

5.7.6. Potential activities

- mezo-, local-, microscale hydrological modeling
- extreme value statistics
- calibration of model results based on in-situ (reference) and satellite data
- predictability, appropriate skill of the forecast
- water quality modeling (may be backcast?)
- catchment based water balances

5.7.7. Expected outcomes

- Early warning systems on quality, drought, flood
- Catchment based water balance monitoring

5.8. Possibilities and perspectives in flood forecasting

5.8.1. Large-scale floods

5.8.1.1. Background

Floods belong to the most serious weather-related hazards in central Europe. There are several types of floods, which character and predictability can be very different, depending on the scale of the weather event. The first category is floods induced by large-scale circulation, cyclones or low-pressure troughs of synoptic dimensions (i.e., several thousands of kilometers in diameter). These usually develop as a consequence of atmospheric wave-instabilities (barotropic or baroclinic), which grow in time and change the character of the flow from zonal to strongly meridional (Grams et al., 2014). In response, intense, persistent vertical motions (but of velocity usually not exceeding 1 m/s) can develop on relatively large areas, leading to large amounts of precipitation (up to several hundred millimeters during 3-7 days). Such situations are also characterized by significant anomalies in the field of temperature and of some conservative parameters as potential vorticity, which could be eventually isolated from their sources (in case of the so-called cut-off lows). These anomalies can persist for several days. Because of the dimension of the precipitation bands, even catchments of large rivers (Danube, Tisza, Morava, Drava) become quickly saturated and the flood can develop within a few days. Floodwaves can then propagate far downstream to areas, which were not affected by the precipitation. The intensity of the rain bands is further enhanced by orographic effects or by smaller-scale instabilities.

5.8.1.2. Knowledge gaps and relevance

In central Europe, floods of this type have occurred several times in the past decades (e.g., in 1997, 2002, 2010 and 2013) on the rivers Danube, Elbe, Vltava, Morava, etc., causing severe damage and casualties (Rudolf and Rapp, 2003; Ulbrich et al., 2003a,b; Kašpar et al., 2013, 2014; Daňhelka et al., 2014). The high precipitation occurring in such large-scale floods can be predicted by operational numerical weather prediction (NWP) models in short- or medium range (several days ahead), even using hydrostatic approximation and parameterization of some physical processes (e.g., convection). Nevertheless, there is still some uncertainty in the position, track or depth of the predicted cyclones, which is related to initial or boundary conditions. Hence, forecasters do not rely on single (deterministic) forecasts of the events but use the outputs of ensemble runs (consisting of 50 or more members) and probabilistic parameters (e.g., showing probability of exceeding certain critical amounts of precipitation in the area of interest) (Bonta et al., 2015; Mátrai and Ihász, 2015). The experiences with floods listed above also showed that the horizontal resolution of the model and representation of the orography was very important in their prediction (highest precipitation usually occurs in mountainous areas). Besides global models (ECMWF, DWD Global model, ARPEGE) with horizontal resolution of about 10 km, limited area models (ALADIN, AROME, LM) of higher (2-8 km) resolution have been used for this purpose.

Special cases include ice jam floods during cold winters, when the surface of even large rivers can freeze and the accumulated ice can block the water flow, causing water levels to rise. This effect can be accompanied and enhanced by melting snow or precipitation. In the past, serious floods of these types occurred on The Danube River and still represent a hydrological problem, despite river regulation. Ice jam floods occurred on the Tisza River and several smaller rivers in Slovakia in January and February 2017.

Forecasting of ice jam floods requires accurate information on temperature, snow- and ice cover and thorough descriptions of related physical processes (e.g., melting, evaporation). Thus, forecasts of these events can be more difficult and more uncertain compared to floods caused simply by high precipitation. Besides river flooding, frequent occurrence of high precipitation on large areas can cause inland floods and long lasting flooding of fields, resulting in significant losses in agriculture. These phenomena appeared several times in Hungary during 2010, 2011 and 2016.

5.8.1.3. Potential activities

The precipitation outputs of NWP models can be coupled with hydrological rainfall-runoff models (Nester et al., 2016). The accuracy of the latter ones strongly depends on the geographical and hydrological information (e.g. description and state of the river watercourse, Mandlburger et al., 2009). The trends in the occurrence of large-scale floods in Europe have been thoroughly studied (Blöschl et al., 2013; Glaser et al., 2010). The assessment of their frequency and possible links with global climate change could be obtained explicitly from the precipitation outputs of climate models, although, horizontal resolution can be a limiting factor. Furthermore, floods are consequences of rare, extreme weather events growing from relatively small instabilities and their forecast requires accurate description of initial conditions. Hence, it is possible that their frequency and related precipitation amounts can be underestimated in some contemporary climate models. Another approach is to study and diagnose extreme weather conditions (e.g., anomalies in the fields of temperature, pressure or vorticity), which may be responsible for the development of flooding. There were attempts to identify flood signatures with use of indices (Müller and Kašpar, 2014, Müller et al., 2015). The deficiency of the methods is that there can be large uncertainty in the position and amount of high precipitation related to such signatures, hence the outputs are rather qualitative. Nevertheless, these methods can help to understand the reasons for the trends in large-scale flood occurrence.

5.8.1.4. Expected outcomes

For improved operational forecasting of large-scale floods, higher-precision NWP forecasts of precipitation distribution are needed. Besides, more realistic simulation of snow-cover, advanced assimilation of snow observations and better parameterization of precipitation type are important. Progress can be expected due to increasing resolution of global models and their EPS versions within the next 5-10 years. In the second step, a network could be established in cooperation with hydrology, and the NWP outputs might be linked with state-of-the-art rainfall-runoff models. In climatological modeling, both frequency of high precipitation and frequency of typical flood situations might be evaluated.

5.8.2. Flash floods

5.8.2.1. Background

Flash floods are a consequence of very heavy rainfall and the rapid rise of water level, usually within several hours (Doswell, 1997). In contrast to large-scale floods, flash floods are related to mesoscale (several tens or hundreds of kilometers in diameter) weather events, due mainly to the presence of moist deep convection (Doswell, 1996). Convection generates vertical motions, which average velocity is well above 1 m/s, and the peak values reach several tens of meters per second in the strongest updrafts of the thunderstorm clouds. In case, there is sufficient moisture at low levels and the convective rain bands are quasi-stationary, very high precipitation rates (50-100 mm/h) can occur. Though, the high precipitation is rather confined to small area (sometimes only tens or hundreds of kilometers squared), the sudden increased mass of water cannot be drained off by the usual watercourses of small rivers and creeks. Very hilly and mountainous areas are susceptible to flash floods. The geological composition of the terrain (e.g., presence of flysch) and orography (slopes, narrow valleys) can also increase the probability of flash flood occurrence. Flooding is also likely to occur in urban areas, because of drainage problems (Simon, 2011).
In these cases, the intensity of the rainfall can be more important than the overall amount of precipitation, which is not always extreme (e.g., sometimes only 20-30 mm).
Maddox et al. (1979) has recognized several weather situations, which are typical for flash flood occurrence. Presence of high pre-frontal instability, streamwise moist conveyor belts in the forward flank of deep upper-level troughs can be favorable for the development of mesoscale convective systems, persisting for several hours and even up-to one day in the most extreme cases. Some fraction of flash flood producing storms develop in the vicinity of stationary fronts or can be triggered by outflows on the flank of surface, mesoscale anticyclones. Generally, it is important that the relative motion of the storm, as observed by radar or satellite, is slow and there is a constant source of buoyancy and moisture in its environment. Many times, a line of convergence (confluence of the wind) can be detected at low levels of the atmosphere. This can ensure continuous regeneration of the convective cells, which lifetime is short in usual conditions (within one hour).

In the Carpathian region, there have been many notable flash-flooding incidents.. Probably the most disastrous was the flood in Jarovnice (eastern Slovakia) on 20 July 1998, causing 55 casualties (Majtán et al., 1999). The culmination discharge on the Malá Svinka River has been estimated to have risen to 230 m^3/s, which would correspond to 200-1000 year frequency of occurrence (Majerčáková et al., 2004). Significant flash flooding events also occurred in Slovakia in 2011 on the Gidra River catchment and in 2014 in Vrátna Valley (Pekárová et al., 2012, Pekárová et al., 2015). In Hungary, flooding was caused by a high-precipitation thunderstorm at Mátrakeresztes on 18 April 2005 (Horváth et al., 2007) with an estimated 111 mm of precipitation. Flash floods also occurred in southwest of Hungary at Villány on 4 August 2011 and on 17 August 2015 at Lake Balaton in Budapest (the precipitation maxima were about 115 mm in both situations).

There are some non-convective events, which can resemble flash floods. These can occur in winter period on warm fronts and can be accompanied by melting of snow, which can also cause sudden rise of water level. Their predictability is, similarly to ice jam floods, dependent on detailed analyses of snow cover and its water content and on the temperature distribution.

Flash floods are sometimes accompanied by mudflows and landslides. There have been attempts to predict landslides (Krol and Bernard, 2012) using a combination of precipitation estimates (now casts) and landslide hazard index maps obtained from geographical and geological (e.g., soil-measurement) data.

5.8.2.2. Knowledge gaps and relevance

Because of their small scale, accurate forecasting of flash floods represents a much bigger problem than forecasting of large-scale floods. Currently, this is one of the biggest challenges in meteorology and hydrology. The convective nature of most of the events implies that their realistic simulation requires high resolution (at least 1 km in horizontal) non-hydrostatic models with explicit description of convection. Such models (AROME, WRF, MM5) are already available and enable very short- or short-range forecasts up to 48 hours. In some cases, also hydrostatic NWP models with parameterized convection (e.g., ECMWF, ALADIN) can forecast high precipitation but mostly in situations with fronts or mesoscale systems of larger scales or if the convective precipitation is mixed with rain that is stratiform cloudiness and orographically enhanced. Even if the general atmospheric conditions for convection and flash floods are well described by NWP models, there is high uncertainty about the position, translation and intensity of the simulated thunderstorms or thunderstorm systems. On the other hand, hydrological forecasting of flash floods would need almost exact meteorological inputs, since these mostly develop on very small river catchments. From a climatology point of view, even reconstruction of some past small-scale floods is problematic.

The density of synoptic, climatological or hydrological measurements is often not dense enough to observe the precipitation extremes. This information used to be supplemented from radar measurements. However, the precipitation and radar reflectivity relationship depends on the microphysics of the observed cloud (hail, snow, graupel contents and their size) and the estimates can be affected by attenuation of radar signals (by orography or precipitation systems in the foreground).

5.8.2.3. Potential activities

One possibility to overcome the forecast uncertainty is the Ensemble Prediction System (EPS) approach at high resolution (Szűcs et al., 2015) but this requires a lot of computing power. Another possibility is to use nowcasting approaches based on the extrapolation of radar measurements and precipitation estimations (QPF). The advantage is the more precise localization of the events and faster processing of results. However, such nowcasting systems are unable to predict the dynamical development of thunderstorms and their forecast range is limited to 1-2 hours (Horváth et al., 2015). Nowcasting systems (e.g., INCA, MEANDER) can also be linked with hydrological models (INCA-CE, 2012). In such systems, EPS techniques are also recommended, because the propagation of the forecast precipitation is uncertain even at nowcasting range. Besides rainfall-runoff models, precipitation forecasts can be also combined with retention potential maps or flash-flood vulnerability maps based upon hydrological and geographical information (Kobold and Brilly 2006; Hazlinger 2012; Kubeš et al., 2004; Hegedüs et al., 2013).

Similarly to large-scale floods, it is possible to diagnose the environment from which the severe convective storms and flood events form (Borga et al., 2011). This could give at least qualitative information, whether there are any trends in the conditions favorable for such types of storms. The basic parameter is buoyancy characterized by CAPE index (surface-based, mixed-layer or maximum unstable CAPE). The storm-motion can be estimated from density-averaged wind and total perceptible water (TPW) can be calculated as well. It has to be taken into account that in some flash flood situations the maxima of these parameters (sources) can be eventually dislocated but buoyancy or moisture can be transported to the area, where the thunderstorm form. Some heavy precipitation thunderstorms (e.g. HP supercells) form in environments of strong wind shear. These can also produce flash floods under certain conditions (Doswell, 1996) but in the area of Carpathian region, most of the events are related to multi-cell thunderstorms.

5.8.2.4. Expected outcomes

Further progress is expected in the development of high-resolution numerical models, which could eventually operate with horizontal resolutions of 1 km or less within the next 5-10 years. This might enable more realistic simulation of flash flood-producing thunderstorms. Nevertheless, better specification of the initial and boundary conditions will also be needed, as well as improvements in the parameterization of turbulence, microphysical properties and physical-dynamical feedbacks. Further increase of observations density (radars, lidars, wind profilers, surface weather stations) will be also necessary for this purpose. Thus, significant improvement in flash flood forecasting will require a longer time as in the case of large-scale floods.

At the beginning, EPS approaches could be more successful, when coupled with hydrological models. Simultaneously, environmental characteristics for flash floods that could be used for estimation of their climatological trends could also be studied.

5.8.3. Other kinds of floods

There are flood types that are not directly related to precipitation. For example, at seasides or big lakes, flooding of the shores can be caused by the storm-surge effect (i.e., sustained, very high wind speed). Such situations can be induced by large-scale windstorms, at the flank of deep cyclones or high anticyclones. Flooding occurred during the 2010 Zsófia and 2014 Yvette windstorms at Lake Balaton. However, previous high water levels were also contributors to this flooding. This kind of flooding is relatively rare and maybe less significant than large-scale floods and flashfloods, however, it still represents a potential civil protection risk, and that is why it is worth studying.

Flooding can also occur during dam failures due to erosion, earthquakes and other, not primarily weather-related causes. However, high amounts of precipitation are always a factor and increase the potential for such events.

5.9. Regulation of Danube and tributaries: management of floodplains

As we expressed in the beginning of this White Book, the Pannonian Basin (Central Danubian) represents an ideal natural laboratory for the analysis of hydrological and climatological phenomena. Regarding the hydrological characteristics, one must begin with the fact that the area drains from the Danube and its tributaries, so all flood analyzes should begin there. As we know the Danube is the 29th longest river globally and drains in regions of 19 countries and 10 eco-regions.

5.9.1. Background

Since the middle of the 19th Century, the knowledge of floodplains has significantly improved. Non-structural flood mitigation measures and a new understanding of the possible human reactions have recognized the ecological importance of the floodplains. Even with these advances there are several questions that need to be resolved, such as whether hydro- and morpho-dynamics should be increased or decreased, and to what extent a floodplain can be used by integrating various conflicting needs, ecological, safety and navigation interests. (Buijse, et al., 2002)
The majority of the large rivers in Europe have been significantly regulated over past centuries. It is almost impossible to find large rivers with natural runoff because all are influenced in

bigger or smaller extent by large dams and reservoirs, inter-basin diversions and water abstractions (Tockner et al., 2008).

In recent years all flooding events are studied in light of climate change. This is not easy because the climate is naturally variable. River channels adjust to changes in flow regime, which is influenced by changes in climate. In general, studies have suggested that future climate will have greater extremes of weather (IPCC, 2007a,), including more high intensity rainfall events. This is likely to lead to an increase in flooding, particularly while a channel adjusts (if it can) to the changing flow regime (Davie, 2008).

Due to the historical development of agriculture in the alluvial plains, the conversion of rivers to waterways for navigation, and the settlements defense, floodplains have been "trained" for centuries. Today, about 50% of the total European human population lives on former floodplains, so approximately 50% of the original wetlands and up to 95% of riverine floodplains have been permanently lost. In 45 European countries, 88% of the alluvial forests have disappeared from their potential range (Hughes 2003). As a consequence, the riverine floodplains are among the most endangered landscapes worldwide. In most riverine systems, hydrological connectivity between the river and its floodplain is restricted to groundwater and geomorphological dynamics are mostly absent. The examples of river floodplain restoration and rehabilitation in Europe are few and mostly recent (WWF, 1992).

Generally, restoration and rehabilitation projects will be a very long-term process and because of the characteristic complexity of floodplains and our limited scientific understanding of their spatio-temporal subtleties, long term future planning is significantly constrained.

5.9.2. Knowledge gaps and relevance

Riverine floodplains and deltas are among the least studied ecosystems but are the most threatened. We must analyze the use of remote sensing for assessing floodplains spatial and temporal evolution in the context of increasingly growing available data for the area (with good resolution in time and space). Hydrological analysis must start in the upper basin of the rivers, where the anthropic impact is smaller, and we must concentrate also on smaller time steps (at least daily), monthly averages loose significant variations in the natural flow.

5.9.3. Proposed activities

Hydrological modeling should account for these changes in the flood plains and also the anthropic impact on the discharge values. In some countries, there are assessments regarding the natural or unimpaired flow values and these could be used to evaluate the magnitude of human impact and would also help future flood plain management systems.

The restoration of flood plains has various impacts on rivers and interdisciplinary studies must oversee the ecological impacts and the hydrological consequences of such measures.

For sustainable flood plain management, we need to understand flood plain and river interactions. The first step toward this goal is the modeling and prediction of floods.

5.9.4. Expected outcomes

- Better understanding the behavior of the river-floodplain system
- Better hydrological modeling and improved hydrometeorological forecasts
- Building the scientific case for the better floodplain management
- Free data series for future various analyses.

6. FQ5: Education, knowledge transfer and outreach

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Key topics:

- Higher education in meteorology and climatology in PannEx region: present status
- Development of higher education in meteorology under the framework of PannEx project
- Knowledge transfer
- Outreach to scientific community, public authorities and decision makers

6.1. Education

6.1.1. Status of higher education in meteorology and hydrology in PannEx countries

Qualified and competent personnel are essential to the success of National Hydro-Meteorological Services (NMHSs) around the world. Also, due to the high level of cooperation needed in the international fields of meteorology and hydrology, similar scientific achievements should be acquired by students before being hired by these institutions.

Successful international training of personnel is of a great importance for developing countries, to enhance capabilities of NHMSs. Since 1985 a few worldwide surveys on the training requirements, opportunities and capabilities have been undertaken by the WMO Secretariat in order to assess its members' training requirements from an international perspective and provide a basis for adjustments and improvements in the planning and implementation of the WMO's Education and Training Programme.

According to the Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology (WMO- No. 1083) (WMO, 2012), qualification requirements for a meteorologist include completion of the BIP-M programme for personnel with a university-level degree in meteorology or completion of a condensed BIP-M programme for personnel with postgraduate diploma or a master degree in meteorology (Zhi et al., 2012). For hydrologists (H) or hydrological technicians (HT), the basic education requirements should be developed according to the *Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology, Volume II: Hydrology* (WMO - 258) (WMO, 2003) and according to the *Guide to Hydrological Practices, Volume I: Hydrology – From Measurement to Hydrological Information* and *Volume II: Management of Water Resources and Application of Hydrological Practices* (WMO - No. 168) (WMO, 2008, 2009). Under these circumstances, we consider that a detailed analysis of the system of higher education in meteorology-climatology and hydrology is absolutely necessary in the PannEx countries, followed by a harmonization and cooperation under the framework of PannEx initiative.

A quick overview has been completed for nine countries in the region (Austria, Croatia, Czech Republic, Hungary, Serbia, Slovakia, Slovenia, Romania and Ukraine) and differences have been identified. Affiliation of study programs is very different from one country to another both for meteorology and for hydrology.

6.1.2. Education in meteorology

The study programs are present usually in faculties of Mathematics and Physics, Geophysics, Earth Sciences, Natural Sciences, and Geography. Below it is a list of main domains, where Meteorology is studied:

- Natural Science (Austria);
- Faculty of Natural Sciences and Mathematics, Physics Department (Croatia, Split);
- Faculty of Science, Department of Geophysics (Croatia, Zagreb);
- Faculty of Mathematics and Physics (Czech Republic);
- Faculty of Sciences (Hungary);
- Faculty of Geography (Romania);
- Faculty of Physics (Romania, for doctoral studies, exclusively);
- Faculty of Physics, Institute of Meteorology (Serbia, Belgrade);
- Faculty of Science, Department of Physics (Serbia, Novi Sad);
- Faculty of Mathematic, Physics and Informatics (Slovakia);
- Faculty of Mathematics and Physics, Department of Physics (Slovenia);
- Earth Science Department (Hungary, Ukraine).

As a synthesis, 18 universities were found to provide higher education in meteorology at different levels (Bachelor, Master, and Doctoral) in PannEx area, are:

- *three in Austria*: University of Vienna, University of Innsbruck, University of Graz
- *two in Croatia*: University of Zagreb and University of Split;
- *one in Czech Republic*: Charles University in Prague;
- *three in Hungary*: Eötvös Loránd University, University of Debrecen, and University of Szeged;
- *three in Romania*: University of Bucharest, Babes-Bolyai University of Cluj-Napoca, and Alexandru Ioan Cuza University of Iasi;
- *two in Serbia*: University of Belgrade and University of Novi Sad;
- *one in Slovakia*: Comenius University in Bratislava;
- *one in Slovenia*: University of Ljubljana;
- *four in Ukraine*: Odessa State Environmental University, Hydrometeorological Institute, Oles Honchar Dnipro National University, Taras Shevchenko National University of Kyiv, Yuriy Fedkovych Chernivtsi National University.

In some universities, students can choose among more than one field of atmospheric science for PhD. studies in the same university (e.g., University of Bucharest where two PhD. study programs can be followed by students in two different faculties: Meteorology and Climatology in Faculty of Geography and Atmosphere Physics in the Faculty of Physics). Unfortunately, very little information is available in English on universities websites, so that a detailed analysis of specific study programs could not be achieved until now. Cooperation between universities is necessary to harmonize the study programs at different levels and could be developed under the framework of PannEx. The following is a list of universities and programs that have been identified (the countries are listed in alphabetical order).

Austria

Bachelor studies

- University of Vienna, Meteorology http://studienwahl.at/studies/natural-sciences/705-meteorology-2-3-wien.en.html
- University of Innsbruck, Atmosphere Sciences http://studienwahl.at/studies/natural-sciences/74-atmosphere-sciences-2-3-innsbruck.en.html
- University of Graz, Environmental Systems Sciences – Geography http://studienwahl.at/studies/natural-sciences/2344-environmental-systems-sciences-geography-2-3-graz.en.html

Master studies

- University of Vienna, Meteorology http://studienwahl.at/studies/706-meteorology-12-3-wien.en.html
- University of Innsbruck, Atmosphere Sciences
- University of Graz, Environmental Systems Sciences – Geography http://studienwahl.at/studies/natural-sciences/2346-environmental-systems-sciences-geography-12-3-graz.en.html

Doctoral studies

- University of Innsbruck, Atmosphere Sciences http://studienwahl.at/studies/natural-sciences////286-doctoral-programme-in-atmosphere-sciences-4-3-innsbruck.en.html
- University of Graz, Climate Change (https://dk-climate-change.uni-graz.at/en/)
- University of Vienna Natural Sciences (https://imgw.univie.ac.at/en/studies/administrated-studies/doctoral-programme/)

Czech Republic

Bachelor studies

No program identified.

Master studies

- Charles University in Prague, Faculty of Mathematics and Physics
-

Doctoral studies

- Charles University in Prague, Faculty of Mathematics and Physics
- http://www.mff.cuni.cz/studium/uchazec/obory-nmgr.htm#toc-meteorologie-a-klimatologie (in Czech language)
- http://www.mff.cuni.cz/to.en/studium/uchazec/obory-phd.htm#toc-meteorology-and-climatology (in English)

Croatia

Bachelor studies

- University of Zagreb, Faculty of Science, Department of Geophysics (http://www.pmf.unizg.hr/geof/en).

Master studies

- University of Zagreb, Faculty of Science, Department of Geophysics
- University of Split, Faculty of Natural Sciences and Mathematics, Physics Department, (master degree in Environmental Physics): http://fizika.pmfst.hr/okolis/english/index.php

Doctoral studies

- University of Zagreb, Faculty of Science, Department of Geophysics

Hungary

Bachelor studies. Meteorology can be chosen for specialization as in BSc in Earth Science at:

- Eötvös Loránd University, Budapest (list of courses can be found at http://nimbus.elte.hu/oktatas/bsc_description.html
- University of Debrecen.
- At the University of Szeged meteorology-related specialization is BSc in Geosciences, Geography (dedicated meteorology specialization is not offered).

Master studies

- Eötvös Loránd University, Budapest, with two specializations:
- climate researcher
- weather forecaster.
- The curriculum can be found at http://nimbus.elte.hu/oktatas/msc_description.html
- University of Szeged, Geosciences, Geography

Doctoral studies: Meteorology is part of the Earth Sciences Doctoral Program at:

- Eötvös Loránd University, Budapest. This is considered the most relevant program, however,
- At other universities, some PhD research topics are related to meteorology, e.g.
- University of Debrecen
- University of Szeged (rather climatology)
- University of Pécs (rather cloud physics). http://www.doktori.hu/index.php?menuid=351&cid=247&lang=EN

Romania

In Romania, in most of the situations Bachelor and Master study programs in Meteorology-Climatology are combined with those in Hydrology.

Bachelor studies

- University of Bucharest, Faculty of Geography http://geo.unibuc.ro/201603/plan_de_invatamant_licenta_h_m.pdf
- Babeș-Bolyai University of Cluj-Napoca, Faculty of Geography http://geografie.ubbcluj.ro/docs/invatamant/Planuri%20inv_valabile%20pentru%20anul%20III%20din%20anul%20univ%202015-2016/Plan%20inv%20LICENTA%202013-2014/HM%2013-14.pdf
- Alexandru Ioan Cuza University of Iasi, Faculty of Geology and Geography, Department of Geography http://www.geo.uaic.ro/ro/programe-de-studii/programe-studii-de-licenta/plan-de-invatamant-curricula

Master studies

- University of Bucharest, Faculty of Geography http://geo.unibuc.ro/201603/plan_inv_master_climatologie_si_resurse_de_apa.pdf
- Babeș-Bolyai University of Cluj-Napoca, Faculty of Geography http://geografie.ubbcluj.ro/docs/invatamant/Planuri%20inv.%20valabile%20pentru%20anul%20II%20%20din%20anul%20univ%202015-2016/Master%202014-2015/RRMH%20ro%20cj.pdf

Doctoral studies

- University of Bucharest, Faculty of Geography and Faculty of Physics http://geo.unibuc.ro/prezentare_programe_doctorat.html
- Babeș-Bolyai University of Cluj-Napoca, Faculty of Geography http://geografie.ubbcluj.ro/?page_id=3599
- Alexandru Ioan Cuza University of Iasi, Faculty of Geology and Geography, Department of Geography http://www.geo.uaic.ro/ro/programe-de-studii/scoala-doctorala

Serbia

Bachelor studies

- University of Belgrade, Faculty of Physics (Institute of Meteorology) http://www.ff.bg.ac.rs/Engleski/Study/Undergraduate.html
- University of Novi Sad, Faculty of Science, Department of Physics (programs in physics but with module in meteorology) https://www.pmf.uns.ac.rs/en/about_us/departments/physics , http://www.df.uns.ac.rs/en/studies

Master studies

- University of Belgrade, Faculty of Physics (Institute of Meteorology) http://www.ff.bg.ac.rs/Engleski/Study/Master.html
- University of Novi Sad, Faculty of science, Department of Physics (programs in physics but with module in meteorology) https://www.pmf.uns.ac.rs/en/about_us/departments/physics , http://www.df.uns.ac.rs/en/studies

Doctoral studies

- University of Belgrade, Faculty of Physics (Institute of Meteorology) http://www.ff.bg.ac.rs/Engleski/Doctoral/Doctoral.html
- University of Novi Sad, Faculty of science, Department of Physics, program name is Meteorology and environmental modeling

Slovakia

Bachelor studies

No program identified.

Master studies

- Comenius University in Bratislava, Faculty of Mathematic, Physics and Informatics http://fmph.uniba.sk/studium/magisterske-studium/enviromentalna-fyzika-obnovitelne-zdroje-energie-meteorologia-a-klimatologia

Doctoral studies

- Comenius University in Bratislava, Faculty of Mathematic, Physics and Informatics http://fmph.uniba.sk/studium/doktorandske-studium/meteorologia-a-klimatologia/

Slovenia

Bachelor studies

- University of Ljubljana, Faculty of Mathematics and Physics, Meteorology with Geophysics http://www.fmf.uni-lj.si/en/study-physics/meteorology-geophysics-I-cycle/

Master studies

No program identified.

Doctoral studies

- University of Ljubljana, Faculty of Mathematics and Physics, Physics, Meteorology (postgraduate studies)

Ukraine

Bachelor studies

- Odessa State Environmental University, Hydrometeorological Institute http://osenu.odeku.edu.ua/#1482350583655-f7fcd28a-bc3f
- Taras Shevchenko National University of Kyiv, The Faculty of Geography http://www.geo.univ.kiev.ua/en/

- Oles Honchar Dnipro National University , Geologic-Geographic Faculty http://www.dnu.dp.ua/en/geologic_geographic_faculty
- Yuriy Fedkovych Chernivtsi National University, Department of Hydrometeorology and Water Resources http://www.chnu.cv.ua/index.php?page=/en/general

Master studies

- Odessa State Environmental University, Hydrometeorological Institute http://osenu.odeku.edu.ua/ - 1482349719884-e12e908e-5d72Taras Shevchenko National University of Kyiv, The Faculty of Geography http://www.geo.univ.kiev.ua/en/
- Oles Honchar Dnipro National University , Geologic-Geographic Faculty http://www.dnu.dp.ua/en/geologic_geographic_faculty
- Yuriy Fedkovych Chernivtsi National University, Department of Hydrometeorology and Water Resources http://www.chnu.cv.ua/index.php?page=/en/general

Doctoral studies

- Odessa State Environmental University, Hydrometeorological Institute http://osenu.odeku.edu.ua/#1482349719884-e12e908e-5d72
- Taras Shevchenko National University of Kyiv, The Faculty of Geography**,** http://www.geo.univ.kiev.ua/en/

Isolated courses of Basic in Meteorology or Climatology are taught also in other study programs in the up-mentioned universities or in others in the area, as in Agriculture sciences (Agro- meteorology), Earth sciences (Climatology), Geography (Meteorology-Climatology, Urban Climate), Chemistry (Chemistry of the atmosphere) etc.

6.1.3. Education in hydrology

The study programs are present usually in faculties of Mathematics and Physics, Geophysics, Earth Sciences, Natural Sciences, Geography etc. Below it is a list of main domains, where Hydrology is studied:

- Faculty of Science Department Physical Geography and Geo-ecology, Faculty of Mining and Geology VŠB, Czech University of Life Sciences Prague (Czech Republic);
- Faculty of Science, Department of Geography (Croatia, Zagreb)
- Department of Geography, University of Zadar (Croatia, Zadar)
- Institute of Earth Sciences Karl-Franzens-University (Austria, Graz)
- Research Center of Hydraulic Engineering - Technical University of Wien (Austria, Wien)
- Faculty of Civil Engineering Department of Hydraulic and Water Resources Engineering (Hungary, Ukraine)
- Faculty of Engineering and Information Technology (Hungary, Pecs)
- Department of Hydrogeology and Engineering Geology (Hungary, Miskolc)
- Faculty/Department of Geography (Bucharest, Cluj-Napoca, Iasi)
- Faculty of Civil Engineering (Romania, Cluj-Napoca and Timisoara)
- Faculty of Hydrotechnics (Romania, Bucharest)
- Faculty of Hydrotechnics, Geodesy and Environmental Engineering (Romania, Iasi)
- Faculty of Mining & Geology (FMG) Department of Hydrogeology (Serbia, Belgrade)
- Faculty of science, Department of Geography (Serbia, Nis)
- Faculty of Civil Engineering, Environmental Engineering (Slovakia, Bratislava)
- Faculty of Natural Sciences (Slovakia, Ostrava)
- Faculty of Civil and Geodetic Engineering (Slovenia, Ljubljiana)
- School of Environmental Sciences, University of Nova Gorica (Slovenia)
- Hydrometeorological Institute (Ukraine)

As a synthesis, 25 universities were found to provide higher education in Hydrology at different levels (Bachelor, Master, and Doctoral) in PannEx area, are:

- *two in Austria*: Technical University of Wien and the University of Graz.
- *two in Croatia*: University of Zagreb and University of Zadar;
- *four in Czech Republic*: Charles University in Prague, Technical University of Ostrava, Czech University of Life Sciences Prague, Institute of Geophysics Polish Academy of Sciences;
- *four in Hungary*: Budapest University of Technology and Economics, University of Pécs, University of Miskolc, Szent István University;
- *seven in Romania*: University of Bucharest, Babes-Bolyai University of Cluj-Napoca, and Alexandru Ioan Cuza University of Iasi, Technical University of Cluj-Napoca, Timisoara, Iasi and Bucharest
- *two in Serbia*: University of Belgrade and University of Nis;
- *two in Slovakia*: Slovak University of Technology in Bratislava, Comenius University in Bratislava;
- *two in Slovenia*: University of Ljubljana, University of Nova Gorica;
- *two in Ukraine*: Odessa State Environmental University, Hydrometeorological Institute, Kyiv National University.

Austria

Bachelor studies

- Research Center of Hydraulic Engineering
  Institute of Hydraulic Engineering and Water Resources Management
  http://www.kw.tuwien.ac.at/lehre/lvas/
- KARL-FRANZENS-UNIVERSITÄT GRAZ
  Institute of Earth Sciences http://erdwissenschaften.uni-graz.at/lehre/BSC-Geowissenschaften2017_46.%20Sondernummer_(25.f).pdf

Master studies

- Research Center of Hydraulic Engineering
  Institute of Hydraulic Engineering and Water Resources Management
  http://www.kw.tuwien.ac.at/lehre/dissertationen/
- KARL-FRANZENS-UNIVERSITÄT GRAZ
  Institute of Earth Sciences
  http://erdwissenschaften.uni-graz.at/lehre/Curriculum_Master_2013_10_01.pdf

Doctoral studies

- Research Center of Hydraulic Engineering
  Institute of Hydraulic Engineering and Water Resources Management
  http://www.kw.tuwien.ac.at/en/teaching/topics-for-doctors-theses/
- Centre for Water Resource Systems at the Vienna University of Technology
  http://www.waterresources.at/index.php?id=5&tx_ttnews%5Btt_news%5D=40&cHash=08404ecc7732a1e2433ae50ce4807b78

Czech Republic

Bachelor studies

- Charles University, Prague Faculty of Science Department Physical Geography and Geo-ecology, https://www.natur.cuni.cz/eng/study/prospective_students/bsc.-study
- Faculty of Mining and Geology VŠB - Technical University of Ostrava
  https://www.hgf.vsb.cz/en/offers-of-studies/bachelors-study/
- Czech University of Life Sciences Prague
  https://www.fzp.czu.cz/en/r-9408-study/r-9495-study-programmes/r-9744-bachelor-s-study-programmes/r-9751-water-management

Master studies

- Charles University, Prague Faculty of Science Department Physical Geography and Geo-ecology https://www.natur.cuni.cz/eng/study/prospective_students/msc.-study
- Faculty of Mining and Geology VŠB - Technical University of Ostrava https://www.hgf.vsb.cz/en/offers-of-studies/CondMaster
- Czech University of Life Sciences Prague https://www.fzp.czu.cz/en/r-9408-study/r-9495-study-programmes/r-9745-master-s-degree-programmes/r-9768-land-and-water-management

Doctoral studies

- Charles University, Prague Faculty of Science Department Physical Geography and Geo-ecology https://www.natur.cuni.cz/eng/study/prospective_students/ph.d.-study/ph.d.-programmes
- Institute of Geophysics Polish Academy of Sciences http://www.igf.edu.pl/offer-research-and-teaching.php
- Faculty of Mining and Geology VŠB - Technical University of Ostrava https://edison.sso.vsb.cz/cz.vsb.edison.edu.study.prepare.web/StudyPlan.faces?studyPlanId=19685&sortBy=block&locale=en
- Czech University of Life Sciences Prague https://www.fzp.czu.cz/en/r-9408-study/r-9495-study-programmes/r-9746-phd-doctoral-degree-programmes/r-9773-water-regime-improvement-in-landscape

Croatia

Bachelor studies (Undergraduate)

- University of Zagreb, Faculty of Science, Department of Geography http://www.pmf.unizg.hr/geog/en/study_programmes
- Department of Geography, University of Zadar http://www.unizd.hr/Portals/0/ms/odjeli/Geography_16_17_ENG.PDF

Master studies (Graduate)

- University of Zagreb, Faculty of Science, Department of Geography http://www.pmf.unizg.hr/geog/en/study_programmes
- Department of Geography, University of Zadar http://www.unizd.hr/Portals/0/ms/odjeli/Geography_16_17_ENG.PDF

Doctoral studies

- University of Zagreb, Faculty of Science, Department of Geography http://www.pmf.unizg.hr/geog/en/study_programs/doctoral/study_modules/environmental_studies

Hungary

https://www.budapestwatersummit.hu/knowledge-and-technology/water-education-in-hungary/

Bachelor studies

- Budapest University of Technology and Economics Faculty of Civil Engineering Department of Hydraulic and Water Resources Engineering http://vit.bme.hu/vit/courses?language=en
- University of Pécs
Faculty of Engineering and Information Technology https://english.mik.pte.hu/civil-engineer
Faculty of Sciences, Institute of Geography
http://international.pte.hu/bsc_in_earth_sciences

- University of Miskolc Department of Hydrogeology and Engineering Geology http://www.hidrotanszek.hu/english-version/

Master studies

- Budapest University of Technology and Economics Faculty of Civil Engineering Department of Hydraulic and Water Resources Engineering http://vit.bme.hu/vit/courses?language=en
- University of Pécs
  Faculty of Engineering and Information Technology https://english.mik.pte.hu/civil-engineer
  Faculty of Sciences, Institute of Geography
  http://international.pte.hu/bsc_in_earth_sciences
- University of Miskolc
  Faculty of Earth Science and Engineering http://www.uni-miskolc.hu/courses-in-english
  Department of Hydrogeology and Engineering Geology
  http://www.hidrotanszek.hu/bemutatkozunk/oktatas/

Doctoral studies

- Budapest University of Technology and Economics Faculty of Civil Engineering Department of Hydraulic and Water Resources Engineering http://vit.bme.hu/vit/courses?language=en
- University of Miskolc Faculty of Earth Science and Engineering http://www.uni-miskolc.hu/courses-in-english
- Szent István University http://sziu.hu/doctoral-studies

Romania

In Romania, in most of the situation Bachelor and Master study programs in Meteorology-Climatology are combined with those in Hydrology.

Bachelor studies

- University of Bucharest, Faculty of Geography http://geo.unibuc.ro/201603/plan_de_invatamant_licenta_h_m.pdf
- Babeș-Bolyai University of Cluj-Napoca, Faculty of Geography http://geografie.ubbcluj.ro/docs/invatamant/Planuri%20inv_valabile%20pentru%20anul%20III%20din%20anul%20univ%202015-2016/Plan%20inv%20LICENTA%202013-2014/HM%2013-14.pdf
- Alexandru Ioan Cuza University of Iasi, Faculty of Geology and Geography, Department of Geography http://www.geo.uaic.ro/ro/programe-de-studii/programe-studii-de-licenta/plan-de-invatamant-curricula
- Technical University of Bucharest Faculty of Hydrotechnics http://hidrotehnica.utcb.ro/analitice.htm
- Technical University "Gh. Asachi" Iasi, Faculty of Hydrotechnics, Geodesy and Environmental Engineering http://www12.tuiasi.ro/facultati/hidro/index.php?page=1158
- Technical University of Cluj-Napoca, Faculty of Civil Engineering, Hydraulic engineering and construction (ACH). https://constructii.utcluj.ro/oferta-educationala.html
- POLITEHNICA University of Timişoara, Faculty of Civil Engineering, Hydraulic Developments and Structures, http://www.ct.upt.ro/studenti/files/Description%20ACH.pdf

Master studies

- University of Bucharest, Faculty of Geography http://geo.unibuc.ro/201603/plan_inv_master_climatologie_si_resurse_de_apa.pdf
- Babeș-Bolyai University of Cluj-Napoca, Faculty of Geography http://geografie.ubbcluj.ro/docs/invatamant/Planuri inv. valabile pentru anul II din anul univ 2015-2016/Master 2014-2015/RRMH ro cj.pdf

- Technical University of Bucharest Faculty of Hydrotechnics http://hidrotehnica.utcb.ro/analitice.htm
- Tehnical University "Gh. Asachi" Iasi, Faculty of Hydrotechnics, Geodesy and Environmental Engineering http://www12.tuiasi.ro/facultati/hidro/index.php?page=334
- POLITEHNICA University of Timişoara, Faculty of Civil Engineering, Hydraulic arrangements optimization, http://www.ct.upt.ro/studenti/files/Description%20OSH.pdf

Doctoral studies

- University of Bucharest, Faculty of Geography and Faculty of Physics http://geo.unibuc.ro/prezentare_programe_doctorat.html
- Babeș-Bolyai University of Cluj-Napoca, Faculty of Geography http://geografie.ubbcluj.ro/?page_id=3599
- Alexandru Ioan Cuza University of Iasi, Faculty of Geology and Geography, Department of Geography http://www.uaic.ro/en/studies/faculties/faculty-geography-geology/
- Technical University of Bucharest Faculty of Hydrotechnics http://hidrotehnica.utcb.ro/doctorat.htm
- Technical University "Gh. Asachi" Iasi, Faculty of Hydrotechnics, Geodesy and Environmental Engineering http://www12.tuiasi.ro/facultati/hidro/index.php?page=335

Serbia

Bachelor studies

- University of Belgrade Faculty of Mining & Geology (FMG) Department of Hydrogeology http://www.rgf.bg.ac.rs/dhg/ENGLESKI/teaching_activity.html
- University of Niš, Faculty of science, Department of Geography http://wpresspmf.pmf.ni.ac.rs/?page_id=4046&lang=en

Master studies

- University of Belgrade Faculty of Mining & Geology (FMG) Department of Hydrogeology http://www.rgf.bg.ac.rs/dhg/ENGLESKI/teaching_activity.html

Doctoral studies

- University of Belgrade Faculty of Mining & Geology (FMG) Department of Hydrogeology http://www.rgf.bg.ac.rs/dhg/ENGLESKI/teaching_activity.html

Slovakia

Bachelor studies

- Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Environmental Engineering http://www.svf.stuba.sk/en/foreign-students/bachelors-degree-study-program/accredited-bachelors-degree-study-programs.html?page_id=1924
- Comenius University, Faculty of Natural Sciences http://fns.uniba.sk/en/study/uchadzaci-o-studium/bsc/study-programmes-in-english/eng-environmental-studies/courses-and-study-programme/

Master studies

- Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Environmental Engineering http://www.svf.stuba.sk/en/foreign-students/masters-degree-study-programs.html?page_id=2126

Doctoral studies

- Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Environmental Engineering http://www.svf.stuba.sk/en/foreign-students/doctoral-degree-study-program/accredited-doctoral-degree-study-programs.html?page_id=4096#wre

Ukraine

Bachelor studies

- Odessa State Environmental University, Hydro-meteorological Institute
- Kyiv National University

Master studies

- Odessa State Environmental University, Hydro-meteorological Institute

Doctoral studies

- Odessa State Environmental University, Hydro-meteorological Institute

The main limitation of this overview is that very little information is available in English on the universities' websites, so that a detailed analysis of specific study programs could not be achieved until now. Under the present status, in some countries, legislation is very restrictive regarding access to data for education and research, even though there are protocols between universities and national Met and Hydro Services. This should be an important challenge in the next future. At present, there are countries where there is no protocol regarding hiring procedures between universities and the national hydro-met services as there are in other domains (e.g., justice, police, army).

6.1.4. Higher education in meteorology and hydrology development under the framework of PannEx

This PannEx initiative could be extremely beneficial in the fields of Education in Meteorology and Hydrology due to close cooperation among universities, national hydro-met services, the WMO Training Division and the WMO Education and Training Office.
Actions to be done:

- Harmonization of the study programs at all levels (Bachelor, Master and PhD.) in participating countries according to the WMO-No. 1083 and national regulations by cooperation among universities in PannEx area and WMO Department for Training and Education that could be strengthen in order to achieve this goal. Even though changing a study program plan could be difficult and time-consuming due to national regulations, the duration of PannEx program of about 10 years, could be beneficial, since usually, in all European countries every 5-10 years, the study programs should be up-dated; under these circumstances, preliminary discussion, during PannEx workshops among universities and

WMO-ETO representatives could be extremely beneficial; the analysis of study programs plans and syllabus would help to find gaps in subjects that are recommended by WMO ETO and thus to develop online-modules on specific topics, so that the students achieve qualification requirements for a Meteorologist according to WMO and UNESCO recommendation (WMO, 2003, 2008, 2009, 2012, 2015; UNESCO 2015a, b); moreover, by using WMO Global campus, some online courses could become available;

- Establishing protocols for organizing exchanges of professors among the universities in PannEx area; for this purpose, some other inter-universities programs can be used, such as Erasmus, Erasmus+, and CEEPUS.
- Establishing protocols for organizing exchanges of MSc. and PhD. students among the universities in PannEx area; the above-mentioned programs can be also used for students' exchange;
- Organizing two PhD "schools" per year (e.g., one virtual, on modeling and theoretical topics, and one by personal presence, on observational techniques organized as a "summer school" by universities of countries participating in the project);
- Encouraging students to choose PhD. and MSc. dissertations on topics similar to those of PannEx project and involving them in research activities of the project;
- Organizing one training school per year for employees in Meteorology and Hydrology services by universities in cooperation with NMHSs in the PannEx countries.
- Encouraging the double coordination of PhD. studies among universities in PannEx area;
- Organizing training courses of trainers where to be taught issues in Meteorology related to PannEx program topics, by experts from PannEx area or from outside; after the second PannEx workshop, officials of EUMETSAT and EUMETCAL declared that the two entities are supportive of training opportunities for PannEx countries, both for NMHS employees and academic scientists. Relevant training plans are available through the EUMETSAT training calendar; the EUMETSAT noted possibilities, in particular, that training/education for satellite image processing and data applications. About "training of trainers", a visiting fellowship scheme at the EUMETSAT may be utilized, for in-depth training and applications of satellite data processing and related research; also support has already received by PannEx experts for a training on agriculture under changing climate that held in November 2016, in Slovenia.
- Using the GLOBE program.

6.2. Knowledge transfer

Knowledge transfer during the PannEx project will be focused on a few directions:

- From professor to young generations of students (BSc, MSc. and PhD students); it could be done by direct support during face-to-face summer schools or online (online summer school, WMO Global Campus, online modules etc.)
- From researchers in other regions of Europe or of the world where similar projects were or are under development to PannEx countries researchers, through workshops (organizing PannEx workshops/conferences once per year seems to be achievable);
- From PannEx researchers to stakeholders in the PannEx region (in workshops we can organize a session for stakeholders) and identification of new directions to be studied in order to improve the community needs for scientific based information by submitting periodical reports to stakeholders;
- From stakeholders to researchers in PannEx area in order to identify new directions to be studied so can improve the community needs for scientific based information (e.g. in workshops we can organize a session for stakeholders).
- Defining early-on protocols on how to get and share data and algorithms related to PannEx activities (we would stress open-data and open-code approach).

- PannEx community will develop a catalogue of data needed for PannEx project implementation.
- The ECMWF recommended making full use of existing data sets that are freely available for research purposes, and managed by ECMWF. These include S2S and reanalysis data.
- Developing a platform for data upload-download to be used for research and education.
- Defining metadata for our modeling and observational products.

6.3. Outreach

Outreach of scientific results to the community and decision makers is of great importance in order to adopt the best adaptation strategies in the area under study. Under these circumstances, we have been identified few activities:

Outreach to scientific community:

- Organizing special issues in national and international journals once per year on various topics and subtopics: *Quaternary International*, *Idojaras*, *Geographia Technica*, *Riscuri si catastrofe, Geofizika, Hrvatski meteorološki časopis* etc.
- Organizing PannEx sessions in high visibility international conferences (e.g., EGU and EMS).
- Organizing PannEx sessions in regional conferences (e.g., Air and Water – Components of the Environment).
- Contributing in various ways to GEWEX and WCRP visibility in all our activities.

Outreach to public authorities and decision makers:

- Delivering *Special Reports* to the public authorities at local/regional/national level focusing the main results of the research activities in the project in the field of agriculture, health, atmosphere protection etc..
- Inviting representatives of public authorities at local/regional/national level to PannEx workshops for direct communication and to identify the needs for scientific support from PannEx experts.

Outreach to large community:

- Organizing active project webpage and Facebook, Twitter, Google+ profiles: new content added weekly/monthly.
- Preparing and releasing newsletters to community (to be delivered 2 or 3 three times per year in the media).
- Inviting media to PannEx workshops;
- Organizing press conference during PannEx meeting events.

7. CC1: Data and knowledge rescue and consolidation

Coordinator: Zita Bihari
Contributors: Monika Lakatos, Zita Bihari, Gabriella Szepszo, Tamás Weidinger, Vladimir Djurdjevic, Branka Ivančan-Picek, Blaženka Matjačić

Key topic:

- Special observation and data analysis

7.1. Background

The source of measurements are different observation networks, such as automatic weather stations, climatological stations, precipitation stations, synoptic, radiosonde stations, radar, air quality network, hydrological network (surface water, ground water, discharge), road stations, lightening network, UV stations, sodar, FLUXNET stations and background air quality stations. The operational observational network is working well at the basin scale in the territories of Check Republic, Austria, Slovakia, Hungary, Ukraine, Romania, Serbia, Bosnia and Hercegovina, Montenegro, Croatia and Slovenia.

Austria: 250 AWS synop-qualified, dense hydrological network, 5 meteorological radars, 4 radiosonde stations (Vienna, Linz, Graz, Innsbruck), private networks, dense air, water and soil quality networks. Zentralanstalt für Meteorologie und Geodynamik (www.zamg.ac.at)
The Environment Agency Austria (Umweltbundesamt) operates the Austrian background-monitoring network. Air pollutants and meteorological parameters are measured at seven stations. Air pollution control in Austria is the responsibility of the individual countries. At the air quality stations the parameters SO_2, NOx, CO, O_3, PM_{10}, $PM_{2.5}$ are measured. Additionally the meteorological parameters wind speed, wind direction, temperature and at a few stations radiation balance, global radiation and relative humidity are observed. A detailed overview of the position of the measuring points and the measured parameters can be found in the report ” AIR QUALITY MONITORING SITES IN AUSTRIA 2017”
http://www.umweltbundesamt.at/fileadmin/site/publikationen/REP0607.pdf

Croatia: 34 main meteorological stations, 66 AWS, 105 climatological stations, 297 rain gauges, 2 radiosonde stations (Zagreb-Maksimir, Zadar-Zemunik), 2 meteorological radars (Bilogora, Osijek), dense hydrological network.
Air Quality network: 20 air quality monitoring stations.
Croatian Meteorological and Hydrological Service (http://meteo.hr/)

Hungary: 116 AWS, 141 Hydro-station, 15 agrometeorological station, 446 rain gauges, 2 radiosonde stations: Budapest and Szeged, radar: 4, UV stations: 5, road stations: 213, urban climate measuring network: Szeged, storm watching station and lightning network, Agromet + special soil station (Debrecen), Wind profiler (Szeged, Siofok), Microwave radiometer profiler (Szeged), 3 Sodar (Debrecen, Budapest, Paks), BpART (Air quality station at ELTE Budapest), 3 FLUXNET stations.
Air quality network: 6 background air quality monitoring stations
Hungarian Meteorological Service (www.met.hu)

Romania: Meteorological: 127 AWS, 31 classic weather stations (23 synoptic), and 12 climatological stations.
Air quality network: 142 fixed + 7 mobile AWS (SO_2, NOx, CO, O_3, PM_{10}, $PM_{2.5}$, C_6H, Pb).
National Meteorological Administration of Romania (www.meteoromania.ro)

Slovenia: 13 synoptic, 26 climatological, 176 precipitation, 32 AWS.
Slovenian Environment Agency (www.arso.gov.si)

Serbia: 32 main meteorological stations (hourly data), 63 climatological stations, 400 pluviometric stations, 27 automatic gauges, 1 radiosonde station, no info on road networks, phenological program (52 stations), 16 radar (12 S-band).
Hydro network: surface water: 190, ground water: 400, discharge: 160, 66 automatic stations.
Air quality network: Operative stations: 28 to 39: SO_2, NO_2, CO, PM_{10}, O_3.
Republic Hydrometeorological Service of Serbia (http://www.hidmet.gov.rs/index_eng.php)

7.2. The CARPATCLIM gridded historical dataset based on in-situ observation (http://www.carpatclim-eu.org/pages/home/)

The PannEx region is fragmented by boundaries and the data policy is strict in the Carpathian Basin, except in Slovenia. The CARPATCLIM data set is a good example to overcome on this.

The CARPATCLIM area covers approximately 500000 km^2, the data set is daily, homogenized (MASH, Szentimrey, 2008; Lakatos et al., 2013), harmonized and gridded (MISH, Szentimrey and Bihari, 2007). It consists of several ECV: temperature (maximum, minimum, average), precipitation, 10 m and 2 m wind speed, 10 m wind direction, maximum 10 m wind speed, sunshine duration, cloud cover, global radiation, relative humidity, air pressure, vapour pressure, snow depth (modelled), and an extensive number of climate indices (37 indices, including 7 drought indices). The gridded fields are based on a dense station network consisting of 415 climate stations and 904 precipitation stations. Time resolution is daily, and covering the period of 1961-2010. The CARPATCLIM consortium (led by HMS) consists of 9 participant countries in the larger Carpathian region, financed by the Joint Research Centre (JRC). (http://www.carpatclim-eu.org/pages/home/).

The DanubeClim is the follow up project of CARPATCLIM. The DanubeClim is the extension of the CARPATCLIM area for the region of Republic of Serbia, Republic of Srpska and Montenegro. The methods are the same as in CARPATCLIM were.
The daily Potential Evaporation (PET) as an additional parameter were derived from CARPATCLIM database according to Zotarelli et al., 2010 to support the estimation of the energy budget components in Lakatos et al., 2018 (Figure 3).

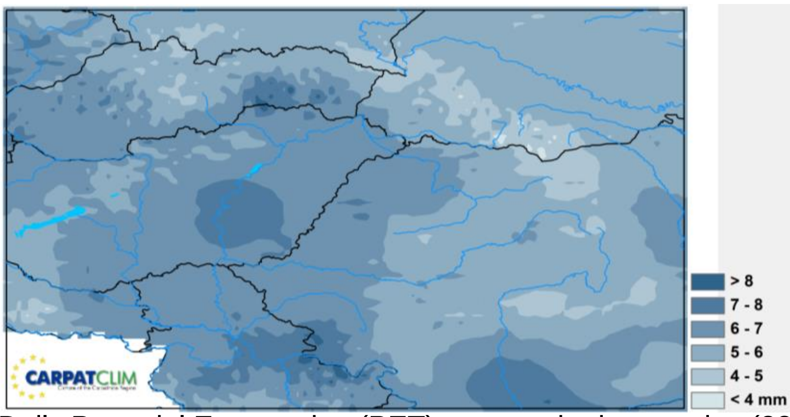

Figure 3: Daily Potential Evaporation (PET) map on the hottest day (22 July) in the heat wave in 2017 based on CARPATCLIM data. (Lakatos et al., 2018).

CARPATCLIM is used for several national and international projects:

The CARPATCLIM data set was extended all of Hungary for many meteorological variables. These data are referred to as CARPATCLIM/HU and were provided by the National Adaptation

Geo-Information System (NAGiS; http://nater.mfgi.hu/en). Based on NAGiS, many impact studies were carried out for various sectors like hydrology, agriculture, ecology, tourism, human health.

The CARPATCLIM/HU data set was used for validation of RCM results in the framework of the RCMGiS EEA project entitled "New Climate Scenarios for the Carpathian Basin" (EEA-C13-10; 2014–2016; www.met.hu/RCMTeR/en). In the project climate simulations were performed on 10 km horizontal resolution using the recent versions of ALADIN-Climate and RegCM regional climate models adapted at the Hungarian Meteorological Service and at the Eötvös Loránd University, Department of Meteorology, respectively.

The CARPATCLIM observational data set is part of a pan-European observational data set collected within the VALUE COST action (Validating and Integrating Downscaling Methods for Climate Change Research; ES1102; 2012–2015; www.value-cost.eu).

The same methods as those used in CARPATCLIM were employed to extend the gridded data for the whole territory of Romania. The resolution is 0.1° and daily data are available for nine variables (mean, maximum and minimum temperature, soil temperature, precipitation, air pressure, relative humidity, sunshine duration, cloud cover). They gridded data were derived from 162 direct measurement points (weather stations), so the results should be more accurate compared to the gridded data from the original CARPATCLIM/HU database (Dumitrescu and Birsan, 2015).

7.3. Regional Climate Model Projections

Many regional climate model projections have been conducted and are still ongoing in the EURO-CORDEX and Med-CORDEX initiative. These simulations cover Europe with 10 and 50 km resolution, applying RCP scenarios for anthropogenic forcing.
Existing regional cooperation and recent projects

- *SEEVCCC*: South East European Climate Change Center in Belgrade (http://www.seevccc.rs/)
- *Drought Management Centre for South East Europe in Ljubljana* (http://www.dmcsee.org/)
- *WMO Instrumentation Centres* in Bratislava and in Ljubljana (http://www.wmo.int/pages/prog/www/IMOP/instrument-reg-centres.html)
- *Earth Observation Data Centre on Water Resources Monitoring* in Vienna (https://www.eodc.eu/)
- *Consortiums* (past and present): *CARPATCLIM/HU* (www.carpatclim-eu.org), *EURO-CORDEX* (http://www.euro-cordex.net/), *Med-CORDEX* (https://www.medcordex.eu), *CECILIA* (http://www.cecilia-eu.org/), ALADIN (http://www.umr-cnrm.fr/aladin/?lang=en)
- *EU FP4 Graminae*: GRassland AMmonia INteractions Across Europe, funded by Fourth Framework Programme of European Community
- *EU FP5 GreenGrass*: sources and sinks of greenhouse gases from managed European grasslands and mitigation scenarios funded by Fifth Framework Programme of European Community (http://cordis.europa.eu/project/rcn/61293_en.html)
- *EU FP6 NitroEurope IP* (or NEU for short) is an integrated project for integrated European research into the nitrogen cycle (http://www.nitroeurope.eu/)
- *EU FP7 CLIM-RUN:* Climate Local Information in the Mediterranean region Responding to User Needs (http://cordis.europa.eu/project/rcn/99345_en.html)
- *EU FP7 ECLAIRE*: Effects of Climate Change on Air Pollution and Response Strategies for European Ecosystems - is a four year project funded by the EU's Seventh Framework Programme for Research and Technological Development (http://www.eclaire-fp7.eu/)
- *EU FP7 GEOLAND2*: towards an operational GMES Land Monitoring Core Service (2008-2012) (http://cordis.europa.eu/result/rcn/140496_en.html)

- *EU FP7 IMAGINES*:- Implementation of Multi-scale AGricultural INdicators Exploiting Sentinels (http://www.fp7-imagines.eu/)
- *COST ES0804*: Advancing the integrated monitoring of trace gas exchange Between Biosphere and Atmosphere (ABBA) 2008-2013 (http://www.cost.eu/COST_Actions/essem/ES0804)
- *DMCSEE*: Drought Management Centre for South- East Europe (South East Europe Transnational Programme, 2009-2012) (http://www.met.hu/doc/DMCSEE/DMCSEE_final_publication.pdf)
- GLOBE: The Global Learning and Observations to Benefit the Environment (GLOBE) Program (https://www.globe.gov/)
- *HORIZON2020/GEOCRADLE* (www.geocradle.eu): Coordinating and integrating state-of-the-art Earth Observation Activities in the regions of North Africa, Middle East, and Balkans and Developing Links with GEO related initiatives towards GEOSS (http://geocradle.eu/en/)
- *HORIZON 2020/ EU-CIRCLE*: a pan-European framework for strengthening Critical Infrastructure resilience to climate change () (http://www.eu-circle.eu/)
- *ORIENTGATE:* Integrating Climate Knowledge into Planning (South East Europe Transnational Programme, 2012-2014) (http://climate-adapt.eea.europa.eu/metadata/projects/integrating-climate-knowledge-into-planning)
- *The DanubeClim*: extension of CARPATCLIM project

7.4. Knowledge gaps and relevance

Observed meteorological data are essential in understanding water cycle and energy fluxes at the surface and in the atmosphere. International data exchange often blocks although the national data policy of meteorological services. The data exchange and its availability for research disposal are essential. There have been successful efforts in the recent past in the region as examples to foster bilateral data exchange of meteorological data. Gathering a similar amount of information for other disciplines (water, soil and air quality) is needed. The list of research projects and singular infrastructures in the basin is not complete, completion of the lists are necessary.

7.5. Potential activities

The available data for research purposes has to cover a time period from several months to long term and the temporal resolution from hourly to yearly. The area could be composed of pilot areas for the whole region with a spatial resolution of approximately 1 km – 50km, depending upon the focus of the research. Internal agreements for data usage are necessary in PannEx activities to research disposal. In the Pannonian Basin the CARPATCLIM and DanubeClim (ongoing project) data sets are (or will be) freely available and could also be the base of the research in the PannEx initiative.

- Get more precise information on the national networks and each country's singular structures
- Analyze weaknesses and strengths of the networks
- Build a database of stations rich in metadata
- Assessing data availability (e.g., meteorological, hydrological)
- Extension of CARPATCLIM/DanubeClim data
- Phrasing internal agreements on data usage in the PannEx community
- Selecting areas that have good data series for pilot studies
- Collecting publications about recent projects and existing methods related to water cycle in the region.

7.6. Expected outcomes

- List of national networks and data sets (e.g., meteorological, hydrological) for the region
- Have a complete list of research/singular infrastructures in the basin
- Good quality harmonized historical climatological dataset for the region (DanubeClim)
- List of potential pilot areas
- Internal agreement on data policy
- List of recent projects and existing methods related to water cycle in the region.

8. CC2: Process modeling

Contributors: Joan Cuxart, Helga Toth, Nandor Fodor, Jan Polcher and Andrej Ceglar

Key topics:
- Quantifying surface energy and water budgets
- Atmospheric chemistry
- Land-atmosphere interactions
- Precipitating systems
- Crop modeling
- Hydrological modeling

8.1. Introduction

The different flagship questions that form the backbone of PannEx need to have a proper representation of the basic mechanisms intervening, as well as an adequate treatment of them in the different tools to be used, namely in numerical modeling and in data analysis. Agronomy, air quality, sustainable development and water management rely largely on the quality of weather and hydrological forecasts, as well as on Climate System modeling when considering longer time-scales, and need highly performing air chemistry and crop modeling.
As a general statement, most of the processes of interest as they are now included in models are strong simplifications of the actual complicated non-linearly interacting processes in the Earth system. Observed and modeled budgets do not always coincide. The problem of adequately estimating the amount of precipitation and evapotranspiration still remains and the land-surface processes that are so relevant for hydrological and crop modeling need further refinement. To properly handle these issues is of outmost importance. A good representation of the Atmospheric Boundary Layer (ABL) is needed for understanding the relevant processes at night. Water management, especially for crops and floods, is an interdisciplinary problem that involves a large number of processes that must be adequately represented, especially precipitation and evapotranspiration. PannEx offers the opportunity to study some of these processes in detail due to the excellent observational network in the basin and its confined topography. This makes it an almost closed basin for several processes that are a subject of the study, such as the water budget. In addition, the relatively flat and homogeneous central part of the basin allows for point studies that are representative of the extensive area. It is proposed that in the frame of this action, special interest is devoted to the following subjects: (i) quantifying surface energy and water budgets; (ii) atmospheric chemistry; (iii) land-surface interactions; (iv) precipitating systems; (v) crop modeling; and (vi) hydrological modeling.

8.2. Background

The scientific community has a long record of high quality research in the selected subjects and includes groups that have had sustained activities in this region for decades. In addition, there have been international efforts in the fields of climate and hydrology that have led to well established cooperation. More specifically, we can cite the ensemble of meteorological and hydrological services of the area that are responsible for the observational network and the analysis of the data. They have been cooperating transnationally, as well maintaining, improving and running the operational and climate models that are used as basic information tools for many applications. In the universities and research centers of the area, there are a number of scientific teams that explore specific processes using advanced equipment, either instrumental or numerical, covering widely the processes of interest, from the point of view of the environmental physics and chemistry, but also from the ones of agronomy or water management.
The capacity of the community is state-of-the-art and ready to push forward the knowledge as needed for its area. International cooperation is well established with room for further growing.

8.3. Established knowledge, gaps and relevance. Potential activities.

Here a very short summary of the state-of-the-art on each selected process is given and the current status in the area is outlined.

(i) Quantifying surface energy and water budgets: the basic inputs for the energy and the water budgets are respectively, the radiation and the precipitation measurements. The other terms of the water budget are usually derived from the outputs of numerical models. To trust a model, it must provide realistic budgets. Therefore, researchers monitor the quality of the model outputs by comparing them to available observations and identify shortcomings and corrective actions. On the other hand, current theories and numerical schemes have a lot of room for improvement and specific experiments are needed. In the Basin there are a very few measurement points for water budgets and they are essentially used for relatively short-lived research experiments. Thus far, there are no permanent sites. Experimental data, including turbulent heat and water vapor fluxes, rely on adequate representation of the ABL.,Soil characteristics and vertical profiling of the ABL and above are necessary for proper model validation and verification.

(ii) Atmospheric chemistry: the main sources of chemical reactions are either anthropic (e.g., air pollution in cities and industries, transport, dispersion of aerosols and chemical compounds used in agronomy) or natural (e.g., dust transported from desert areas, smoke from forest fires, biogenic emissions). Some compounds react in the presence of light and generate harmful species that can be transported to areas distant from the sources. Others may acidify rain. These compounds affect plants, causing damages to the agronomical sector and also pose health threats to humans and animals. Deposition over land and dissolution in water may cause durable harm to soils and water reserves. The local impacts from air pollution is mostly governed by ABL transport and mixing processes, whereas long-distance transport takes place above the ABL. Monitoring of air quality is a major issue that is essentially well covered in the area by the national networks. There are several research groups in the Basin specifically dedicated to this issue. A primary problem is that these efforts are made at the national level and there has been little cross-border cooperation so far.

(iii) Land-surface interactions: the modeling and understanding of the Earth system relies on the proper representation of each of its components and of the interactions between them. Customarily the interaction between the ground or water and the atmosphere is made through the evaluation of the exchange fluxes of matter and energy. Atmospheric modeling is at a very mature stage, disposing of a large number of observational data to check and initialize the numerical simulations. The soil component is a very complex system, heterogeneous and largely under-sampled. The exchange of fluxes between both components rely too critically on approximations (empirical and ad-hoc) on the processes taking place, due to lack of information or understanding of the multiple processes intervening simultaneously, both at the ABL surface layer or at the top layers of the soil. Specific studies on these exchange processes are needed that combine a strong experimental approach with theoretical and modeling studies. Furthermore, biogenic emissions must be monitored and quantified, with the aim of incorporating the related processes into models. These studies could be made in agreement with those related to the energy and water surface budgets described in (i). The existing research community in the Pannonian Basin is active, especially at the universities, and has performed several studies in recent years.
It is also worth noting that the large quasi-homogeneous plain at the center of the basin is ideal for testing remote sensing of surface properties. One possible way to model and understand the basics of the land-surface processing is to use the results of related projects.

For example, in the framework of the European project, IMAGINES (2012-2016), the Hungarian Meteorological Service (HMS) is modeling above-ground biomass, the surface fluxes (carbon and water) and the associated root-zone soil moisture at the regional scale (spatial resolution of 8 km x 8 km) in quasi real time using a land-surface model with satellite measurements, and a model that incorporates photosynthesis and vegetation evolution with satellite data (SM and LAI) as input. Such efforts may provide links to the crop modeling effort described below.

(iv) Precipitating systems: the Pannonian Basin is at the crossroads of several climatic regions, the Mediterranean sea to the south of the Dynarides, its western part open to the Atlantic flows and its Eastern regions are strongly influenced by the high-pressure systems that are usually formed over central Eurasia. Frontal passages in the cold seasons and convective precipitation in the warm part of the year are the usual regimes. However, depending on the particular weather evolution of each year, different severe weather events may occur, from drought to flooding, often very near in time. It remains an open question if these regimes and the corresponding extremes may vary with the current ongoing climate change. The region has a very good observational system of precipitation, with a dense network of rain gauges and precipitation radars. Weather forecasting is state-of-the-art and several consortia exist (using ALADIN and COSMO), stimulating cooperation in the area. Climatological research on precipitation regimes, extremes and future evolution is very active as well. A challenge in the region is to harmonize the different data sources and make the information at basin scale available to the research community. In what refers to the processes to study in detail, experimental studies of convective systems and of persistent fog events would probably be those of most interest for the area.

(v) Crop modeling: Crop models simulate crop development and growth and estimate crop yield as a function of weather conditions, soil conditions, and choice of crop management practices. Process based crop models explain crop growth on the basis of the underlying processes, such as photosynthesis, respiration and how these processes are influenced by environmental conditions. Besides crop yields these models are capable of calculating components of soil water, heat, nutrient and carbon balance. There are quite a few thoroughly tested, comprehensive crop models available; many of these models have already been successfully applied in the Pannonian Basin (e.g., WOFOST crop model). Integrated biophysical modeling platforms, such as BioMA (http://bioma.jrc.ec.europa.eu) are designed and developed for parameterizing and running modeling solutions based on biophysical models. BioMA is also operationally used in JRC to provide real time agricultural monitoring and crop yield forecasting over Europe, including southeastern European countries. The use of dynamic, mechanistic crop and cropping system simulation models has become increasingly important in climate change impact and risk assessment studies. Coupled with gridded climatic and soil databases crop models are able to predict the potential impact of climate change on plant (e.g., biomass formation) and soil processes (e.g., nitrate leaching) on various scales, and could be used for elaborating adaptation and mitigation options. Crop modeling should follow continuous efforts to account for crop-specific impacts related to extreme climate events on growth processes, such as heat stress impacts around flowering and others, interactions between processes (under different fertilization inputs, differing carbon dioxide concentrations). Additionally, while most of the crop growth simulation models have been developed and evaluated at field scale, they are usually applied in large areas that require application of proper scaling methods. On the other hand, the complexity of climate change impacts and adaptations for managing climate risks and improving food security calls for more integrated modeling and quantitative assessment approaches that go beyond the sole biophysical aspects of crop and cropping systems. The so-called integrated assessment modeling is gaining more and more attention in climate impact studies with crop models forming an integral part of the modeling chain. PannEx offers an excellent opportunity to advance crop modeling as well as integrated assessment efforts, as crop modeling can clearly benefit from meteorological, agronomical and air quality experimental and modeling outcomes.

(vi) Hydrological modeling: The Pannonian Basin essentially represents the central part of the Danube watershed, between Vienna in the northwest and the Iron Gates Dam in the southeast, where most of the water converges. Water management is an old practice in this area and human activities have a clear impact on the basin hydrology and need for close monitoring. Flooding may affect any part of the basin, but the lower areas in the southeast tend to be most vulnerable. The hydrological observational network is very complete in the region and there is a sustained and high-level activity in the hydro-meteorological services and the related research activities. Hydrological modeling is developing fast and it is being coupled to atmospheric outputs so that alerts can be issued in time. There exist several national and international institutions devoted to the control and management of the main rivers, such as the Sava and the Danube Commissions.

8.4. Expected outcomes

A successful development of the above-described plan would lead to a number of outcomes. Some of them may be:

- An improved understanding of the processes which govern the water cycle and food production in the region and how these processes will be affected by global change;
- The establishment of well-connected transnational research groups process-oriented, using regional data, well connected to the rest of the EU research community and with global impact;
- The creation of some stable research infrastructures, such as long-term observing networks covering the needs of the various communities and experimental sites accessible to the researchers;
- Fostering interdisciplinary interaction, since most disciplines need input from the others to proceed further, also aiming to a better integration of the geo- and socio-economic sciences;
- The creation of basin-scale databases and research efforts, breaking the invisible borders that limit scientific cooperation between the different national scientific communities.

9. CC3: Development and validation of modeling tools

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Key topics:

- Large-scale circulation: from weather to seasonal
- Climate change: decadal to centennial

9.1. Introduction

The Crosscutting 3 (CC3) activity “development and validation of modeling tools” will organize PannEx contributions by developing and evaluating modeling tools with a specific focus on weather prediction and climate projection systems. Other types of weather-related models are also discussed in this Chapter and will benefit by the contributions of other PannEx CCs and FQs (e.g., development of high resolution gridded precipitation products such as CARPATCLIM or data assimilation of new region-wide observational systems). The focus of CC3 activity is motivated by the following ideas:

1. Five WCRP Grand Challenges where PannEx (as a potential GEWEX RHP) and **CC3** can directly contribute to **1-a)**, **1-c)** and **1-e)**.
   1-a) Cloud, Circulation and Climate Sensitivity.
   1-b) Melting Ice and Global Consequences.
   1-c) Understanding and Predicting Weather and Climate Extremes.
   1-d) Regional Sea-Level Change and Coastal Impacts.
   1-e) Changes in Water Availability.

2. Four WCRP/GEWEX science questions where PannEx and **CC3** can directly contribute to all four science questions.
   2-a) Observations and Predictions of Precipitation**:** *How can we better understand and predict precipitation variability and changes?*
   2-b) Global Water Resource Systems**:** *How do changes in land surface and hydrology influence past and future changes in water availability and security?*
   2-c) Changes in Extremes**:** *How does a warming world affect climate extremes, esp. droughts, floods, and heat waves, and how do land area processes, in particular, contribute?*
   2-d) Water and Energy Cycles and Processes**:** *How can understanding of the effects and uncertainties of water and energy exchanges in the current and changing climate be improved and conveyed?*

3. *Seven WCRP/GEWEX imperatives* where PannEx can contribute all seven imperatives, while **CC3** can directly contribute to imperatives from **3-c)** to **3-g).**
   3-a) Data Sets: Foster development of climate data records of atmosphere, water, land, and energy-related quantities, including metadata and uncertainty estimates.
   3-b) Analysis: Describe and analyze observed variations, trends, and extremes (such as heat waves, floods, and droughts) in water and energy related quantities.
   3-c) Processes: Develop approaches to improve process-level understanding of energy and water cycles in support of improved land and atmosphere models.
   3-d) Modeling: Improve global and regional simulations and predictions of precipitation, clouds, and land hydrology, and thus the entire climate system, through accelerated development of models of the land and atmosphere.
   3-e) Applications: Attribute causes of variability, trends, and extremes, and determine the predictability of energy and water cycles on global and regional bases in collaboration with the wider WCRP community.

3-f) Technology Transfer: Develop new observations, models, diagnostic tools and methods, data management, and other research products for multiple uses and transition to operational applications in partnership with climate and hydro-meteorological service providers.

3-g) Capacity Building: Promote and foster capacity building through training of scientists and outreach to the user community.

9.2. Background

Several research and operational groups/institutions are active in NWP model development and its applications (Bajić et al. 2010; Tudor et al. 2016a; Tudor et al. 2016b) and RCM development and application (Bartholy et al. 2009; Branković et al. 2012; Heinrich and Gobiet, 2012; Belda et al. 2015; Ceglar et al 2015). There are also notable contributions in the PB to seasonal forecast development and application, and application of intermediate to complex GCMs (e.g., Herceg Bulić and Kucharski, 2013). We will refer to some of the published work by researchers from the PB on the following topics, but also on pan-European studies that took into account processes over the Pannonian Basin:

a) LAM NWP: active modeling groups, model development and data assimilation.

Some specific elements of the PB climatology are hard to reproduce by the NWP model (e.g., fog in Tudor et al., 2005; Tudor 2010). Convection-permitting NWP brings the benefits of better prediction of high-precipitation events (HPE), and data assimilation of radar data provides significant improvements to the forecasting of HPEs (Stanešić and Brewster, 2016).
Recent discoveries have proven that dust aerosols are very efficient ice nuclei and important for heterogeneous cloud glaciation, even in regions distant from desert sources. A new generation of ice nucleation parameterizations, including dust as an ice nucleation agent, opens the way for more accurate treatment of cold cloud formation in atmospheric models. Using such parameterizations (SEEVCCC/RHMSS - South East European Virtual Climate Change Center, Republic Hydro-meteorological Service of Serbia), we have developed a regional dust-atmospheric modeling system (NCEP/NMM-DREAM8 model) capable of predicting dust-induced ice nucleation in real-time (Nickovic et. al 2016). The model has been in operational use since 2011 and its domain covers the Mediterranean region, which is directly exposed to Saharan dust transport. In addition, there are a lot of operational products, such as surface dust concentration (used for dust meteo-alarm and potential influence on human health), dry deposition and aerosol optical depth. Model results are continuously validated against satellite and ground-based cloud-ice-related measurements. Predicted ice nuclei concentration shows a reasonable level of agreement when compared against observed spatial and temporal patterns of cloud ice water. The developed methodology permits the use of ice nuclei as input into cloud microphysics schemes of atmospheric models, expecting therefore to improve cloud and precipitation predictions. SEEVCCC/RHMSS also plans to introduce dust-radiation feedback effects into the modeling system.

Direct and indirect aerosol effects (aerosol cloud interaction) are a subject of our research and one of the key climate change factors according to the IPCC reports.
The second main part of our operational and research activities is the development of the HYPROM model as a component of the atmosphere-hydrology system, and designed for the routine prediction of overland water flow.
As a state of the art fully dynamic hydro-meteorological system (including full dynamic governing equations), it could be used both for short-range forecasts (e.g., flash floods), and climate prediction (e.g., floodplains) mapping and flows of large slow river watersheds.

This research strongly follows the increasing need of the community for the better prediction of extreme hydro-meteorological events that have increased over the past decades as a consequence of climate change. It could be highly beneficial for governmental structures and decision makers to appropriately assess the water balance and other hydrology related issues.

Several countries in the Pannonian Basin, especially Hungary, Croatia, Serbia, are strongly affected by low cloud situations that develop during winter anticyclonic cases. In such situations low cloud cover can persist for 7-10 days. This is very poorly forecasted by operational NWP models (both global and limited area models). At the Hungarian Meteorological Service, research in connection with this topic began in 2012, using the operational ALADIN/AROME modeling system (Mile et al. 2015, Szintai et al, 2015). Results obtained during a two-year bilateral French-Hungarian project indicate that several components of the modeling system could cause a bad representation of low clouds. However, the largest improvement could be obtained by fine-tuning the microphysical scheme of the model (Szintai et al. 2014).

The C-SRNWP (Coordination of Short Range Numerical Weather Prediction) project (srnwp.met.hu) of EUMETNET is the main vehicle for the cooperation between the European limited area modeling consortia (the main developing entities of short range numerical weather prediction models). These numerical weather prediction consortia are the ALADIN, COSMO, HIRLAM, LACE, SEECOP projects and the UK Met Office. The primary task of C-SRNWP is to enhance SRNWP related information and knowledge exchange between members, thus this already existing cooperation of operational LAM NWP groups (within PannEx, LACE, SEECOP and COSMO is represented) could help the success of the PannEx initiative. Currently, the C-SRNWP Project is coordinated by the Hungarian Meteorological Service.

b) Regional seasonal forecasts: activities of South East European Virtual Climate Change Center and additional studies.

There are operational seasonal forecasts performed by the South East European Virtual Climate Change Center. Additional studies include dynamical downscaling of ECMWF forecasts (Patarčić and Branković, 2011).

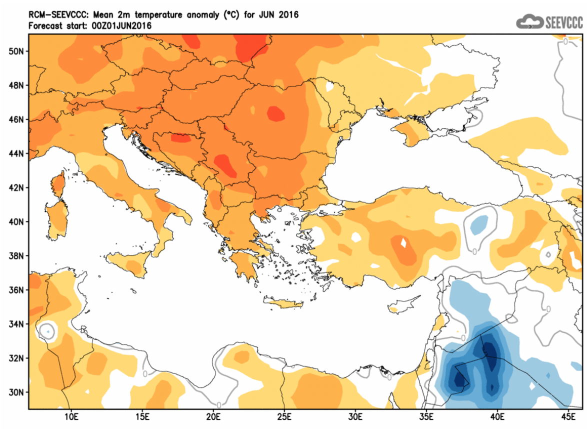
Regional climate models (seasonal forecasts) provide a statistical summary of the atmosphere and ocean state for coming seasons. RCM-SEEVCCC LRF (Long Range Forecast – Seasonal Forecast) is a two-way regional coupled model, with Eta/NCEP limited area model, as its atmospheric part, and Princeton Ocean Model as its ocean part. Both models are well known and have been extensively verified. Exchange of atmospheric fluxes and SST (Sea Surface Temperature) are performed at every atmospheric physics time step (order of minutes). Exchanged fluxes are calculated without any additional parametrization. Additional information about the model can be found at http://www.seevccc.rs/?p=18. The model has been used for seasonal forecasts (http://www.seevccc.rs/?p=7) and climate projections (http://www.seevccc.rs/?p=347).

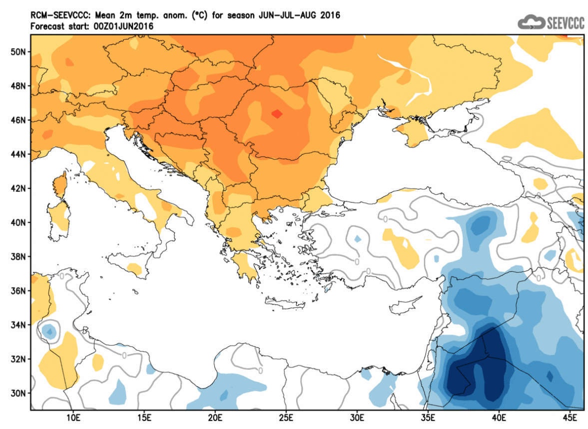
Operational seasonal forecasts include the following characteristics:

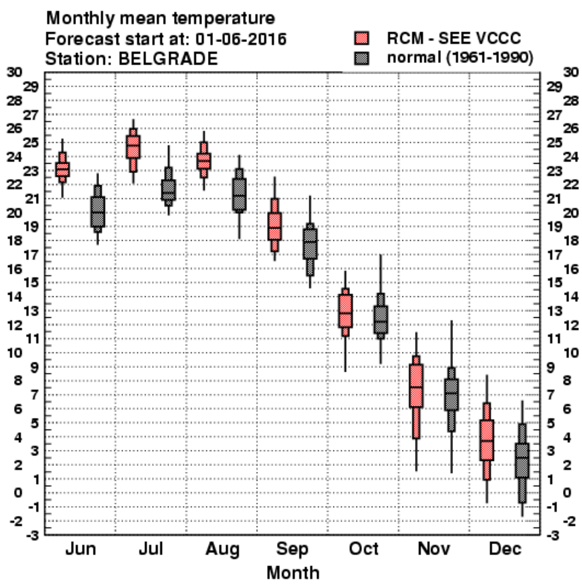
- Model start: On about the tenth day of each month (computation lasts approximately 2.5 days).
- Forecast duration: 7 months ahead (approximately 215 days).
- Model resolution: around 35 km atmosphere ; ~20 km ocean.

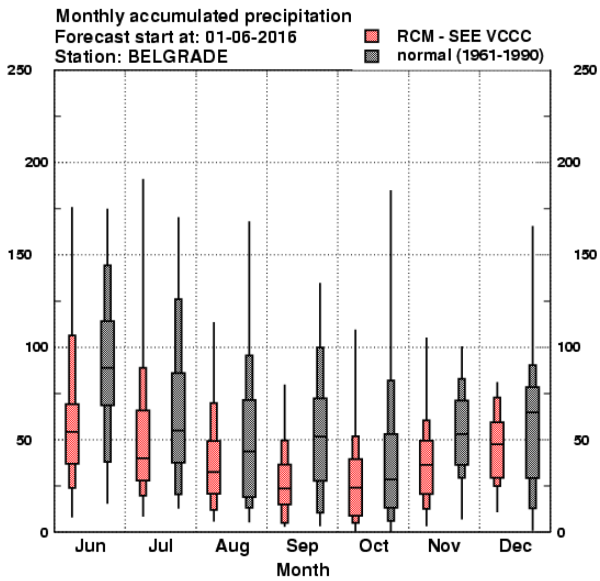
- Model domain: Euro-Mediterranean region extended toward Caspian Sea.
- 51 ensemble members.
- Initial and boundary conditions: ECMWF seasonal forecast resolution of 125 km.
- Results prepared for the Southeastern European region.

Available products:
Mean ensemble maps - both for month and three months (season); parameters: mean 2-m temperature, precipitation accumulation, temperature anomaly and precipitation anomaly with respect to CRU data from 1961-1990).









c) WCRP/CORDEX, short paragraphs on PRUDENCE, CECILIA, ENSEMBLES, EURO-CORDEX and MED-CORDEX results over the region

Climatology of the PB has been explored in pan-European modeling projects and initiatives (e.g., Jacob et al. 2013 (EURO-CORDEX), Ruti et al. 2015 (Med-CORDEX)) and more regional focused modeling projects (CECILIA; Belda et al. 2015). Spatial resolution is generally more than 10 km in RCM simulations. Even at this resolution, many local aspects of the PB climatology can be described and PB is an excellent test-bed for RCM model development (e.g., Torma et al. 2008; Torma et al. 2010).

d) Intermediate complexity GCMs

The impact of global and hemispheric modes of the internal variability (e.g., ENSO, NAO) can be detected over the PB. Studies of this type were performed by Herceg Bulić and Kucharski (2013).

e) Coupled modeling systems and application of NWP and RCM products:

The PB is a region of strong coupling between weather/climate processes and various hydrological and ecological systems. This is analyzed in many region-specific or pan-European studies. However, general regional Earth system model are still lacking.

- weather/climate – regional crop/plant/forest production: e.g., Ceglar and Kajfež-Bogataj (2012), Ruml et al. (2012), Stojanović et al. (2013), Mihailović et al. (2015).
- weather/climate – regional hydrology: Ceglar and Rakovec (2015).
- weather/climate – regional air chemistry: Katragkou et al. (2010); Huszar et al. (2012).
- weather/climate – energy production: Pašičko et al. (2012).

f) Assessing benefits of improving the resolution of NWP and climate model outputs:

Whether the selected location in PB is in completely flat, hilly or proximate to steep terrain, the effect of increasing the horizontal NWP and climate model resolution may or may not bring improvement to statistical scores (e.g., Horvath et al., 2012, Güttler et al., 2015). As shown in other regions, this is in most part related to phase errors that exist due to imperfect initial and lateral boundary conditions, as well as other model deficiencies which can propagate non-locally in model solutions (e.g., Horvath et al., 2012). Further studies that assess the benefits of improving the model resolution and study differences when improving the resolution in different types of topography are essential in showing the benefits of higher-resolution weather and climate modeling.

g) Post-processing and statistical downscaling of NWP and climate model outputs

Even with increases in model resolution to kilometer and hector scales, there still remain uncertainties and errors in model solutions. These errors can be reduced by localizing the model outputs with the use of measured data at the studied location through so-called post-processing and statistical downscaling. Some typical applications of these methods include the Kalman filter, model output statistics, analogue ensemble, use of principal component analysis and others (e.g., Delle Monache et al., 2011; Gutiérrez et al., 2013). The added value of these methods in PB has to be compared and assessed with respect to the most important weather and climate variables.

h) Uncertainty assessment for RCM projections: Climate projection uncertainties emerge from the natural variability, the description of physical processes and anthropogenic activity in models. Hawkins and Sutton (2009, 2011) quantified uncertainties for mean temperature and precipitation projections for the 21st Century over different regions in the world based upon results of global climate model simulations with three (A1B, A2, B1) SRES emission scenarios available in the CMIP3 database. Szabó and Szépszó (2016) adapted this method for the Carpathian region using CMIP5 GCM outputs and EURO-CORDEX RCM outputs. They concentrated on three main issues: (1) fractions of total uncertainty and its seasonal variation with lead time from 2000 over the Carpathian region compared to projections over Northern and Southern Europe; (2) limitations in theoretically reducible uncertainty through model development; (3) quantifying the ratio of projected change and total uncertainty (signal-to-noise ratio, when results are significant or robust) and time horizons when future precipitation and temperature changes exceed natural variability (time of emergence, when major impacts happen more likely).

9.3. Knowledge gaps and relevance

New high-resolution modeling and observational products from the PB can contribute to evaluation and development of the following modeling systems:

- Global NWP models.
- Global seasonal forecasts.
- Global decadal forecasts.
- Global climate projections.
- Global re-analyses.
- Regional re-analyses.
- Multimodel RCMs studies for the purpose of the climate extreme attribution and uncertainty estimations.
- Mesoscale NWP models.

While most of these modeling systems acquire large organizational and human resources, PB researchers can (and do) contribute to the active use and validation of these projects. This would help to reduce model errors specific to this region (e.g., summer dry bias in several generations of the RCMs over the PB (Kotlarski et al. 2014).)

9.4. Potential activities

Specific and innovative contributions of the active and future research groups from the PB can include:

- Convective-permitting (~1-3 km) RCM simulations over PB (cf. Prein et al. 2013; Ban et al. 2014; Prein et al. 2015).
- Valuation of NWP and RCM models using observations produced by PannEx. There is also opportunity for innovative data assimilation efforts based on the future observational products
- Development of the seamless prediction system over the PB (e.g., same model used for both NWP seasonal forecast and climate projections).
- Development and evaluation of RCM (and NWP) models with online and offline coupling with crop, hydrological, air chemistry and dynamic vegetation models.
- The use (and development) of OpenIFS and its evaluation over the Pannonian Basin could be explored in PannEx.
- All modeling activities could be jointly organized as a special ECMWF research projects where specific disk and CPU time quota can be acquired.
- Climate prediction.net-type of experiments over the PB.

- Systematic evaluation of the impact of model resolution (e.g., 27-9-3-1-0.3 km) on the accuracy of the model output.
- Evaluation and comparison of different post-processing and statistical downscaling tools over the PB basin.
- Comparative uncertainty assessment to estimate the added value of high-resolution RCMs in uncertainty issues with respect to GCM results; development of an objective method for quantification of projection uncertainties using the experiences in the ensemble approach of numerical weather prediction.

9.5. Expected outcomes

- Reduction of model systematic errors (from weather to climate models) over the PB (cf. Vautard et al. 2013; Kotlarski et al. 2014).
- Description of the uncertainties of weather to climate prediction systems on all time-scales over the PB and an objective method for quantification of climate projection uncertainties. (cf. Hawkins and Sutton, 2009).
- Active contribution of PannEx-CC3 researchers to WCRP/CORDEX.
- Active contribution of PannEx-CC3 researchers to WCRP/GEWEX.
- Active contribution of PannEx-CC3 researchers to other PannEx-CCs and PannEx-FQs.

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Annex 2 – Abbreviations and Acronyms

ABL - Atmospheric Boundary Layer
ABRACOS - Anglo Brazilian Amazonian Climate Observational Study
AgMIP - Agricultural Model Intercomparison and Improvement Project
AirBase - European Air Quality Database
ALADIN - Aire Limitée Adaptation Dynamique Development International
App - Application
AROME - Application of Research to Operations at Mesoscale
ARPEGE - Action de Recherche Petite Echelle Grande Echelle
AWS - Automatic Weather Station/System

BAU - Business As Usual
BC - Black carbon
Biome-BGC - Terrestrial ecosystem process model
BioMA - Biophysical Models Applications
BIP-M - Basic Instruction Package – Meteorology
BOREAS - The Boreal Ecosystem-Atmosphere Study
BSc - Bachelor of Science
BSRN - Baseline Surface Radiation Network
BpART - Budapest platform for Aerosol Research and Training

CA - Conservation Agriculture
CAMS - Copernicus Atmosphere Monitoring Service
CAPE - Convective Available Potential Energy
CARPATCLIM - Climate of the Carpathian region
CC - Crosscuts
CDD - Cooling Degree Days
CECILIA - Central and Eastern Europe Climate Change Impact and Vulnerability Assessment
CEE - Central and Eastern Europe
CEEPUS - Central European Exchange Program for University Studies
ClimPACT2 - A software tool for calculating climate extremes indices
CLIM4ENERGY - A service providing climate change indicators tailored for the energy sector
CM SAF - Satellite Application Facility on Climate Monitoring
CMIP - Coupled Model Intercomparison Project
CORDEX - Coordinated Regional Climate Downscaling Experiment
COSMO - Consortium for Small-scale *Modelling*
COST - European Cooperation in Science and Technology
COST ES 0602 - Towards a European Network on Chemical Weather Forecasting and Information Systems
COST ES 1006 - Evaluation, Improvement and Guidance for the use of Local-scale Emergency Prediction and Response tools for Airborne Hazards in Built Environments
CREMAP - Calibration-Free Evapotranspiration Mapping
C-SRNWP - Cooperation - Short Range Numerical Weather Prediction
C3S - Copernicus Climate Change Service

DanubeClim - Climate of the Danube Region, an extension of the CARPATCLIM Project
DEFRA - Department for Environment, Food & Rural Affairs
DHMZ - Državni hidrometeorološki zavod (In Croatian) (Meteorological and Hydrological Service of Croatia)
DMCSEE - Drought Management Centre for South East Europe
DNDC - DeNitrification DeComposition; a process-based model of greenhouse gas fluxes from agricultural soils
DNI - Direct Normal Irradiance
DWD - Deutscher Wetterdienst (In German)

EC - European Commission
ECEM - European Climatic Energy Mixes
ECMWF - European Centre for Medium-Range Weather Forecasts
ECV - Essential Climate Variables
EEA - European Environment Agency
EGU - European Geophysical Union
ELTE - Eötvös Loránd University
EMEP - European Monitoring and Evaluation Programme
EMEP4HR - High Resolution Environmental Modelling and Evaluation Programme for Croatia
EMS - European Meteorological Society
ENSEMBLES - ENSEMBLE-based Predictions of Climate Changes and their Impacts
ENSO - El Niño-Southern Oscillation
E-OBS - High- resolution gridded data set of daily climate over Europe
EPS - Ensemble Prediction System
ESMAP - Energy Sector Management Assistance Program
ETO - Education and Training Office
EU – European Union
EUMETCAL - International Cooperation Network for Meteorological and Hydrological Training
EUMETSAT - European Organization for the Exploitation of Meteorological Satellites
EURO-CORDEX - Coordinated Downscaling Experiment - European Domain
EVALO - Planning software for iPhone App (abbreviation in Germany)
EWS - Early Warning System

FLake - One-dimensional freshwater lake model
FLUXNET - Integrating Worldwide CO_2 Water and Energy Flux Measurements
FP4 Graminae - GRassland AMmonia INteractions Across Europe
FP5 CarboEurope IP - Integrated Project, Assessment of the European Terrestrial Carbon Balance
FP6 NitroEurope IP - NitroEurope Integrate Project, The nitrogen cycle and its influence on the European greenhouse gas balance
FP7 ECLAIRE - Effects of Climate Change on Air Pollution and Response Strategies for European Ecosystems
FQ - Flagship Question
FVCOM - The Unstructured Grid Finite Volume Community Ocean Model

GASS - Global Atmosphere System Study
GAW - Global Atmosphere Watch
GCM - Global Climate Model
GDAP - GEWEX Data and Assessments Panel
GEBA - Global Energy Balance Archive
GEWEX - Global Energy and Water Exchanges
GFCS - Global Framework for Climate Services
GHI - Global Horizontal Irradiance
GHG - Greenhouse Gases

GHP - GEWEX Hydroclimatology Panel
GLASS - Global Land-Atmosphere System Study
GLOBE - Global Learning and Observation to Benefit the Environment program
GOS - Global Observing System

HDD - Heating Degree Days
HMS - Hungarian Meteorological Service
HP Supercell - High Precipitation Supercell
HPE - High-Precipitation Events
HPP - HydroPower Plant
HT - Hydrological Technicians
HU - Hungary
HyMeX - HYdrological cycle in the Mediterranean EXperiment
HYPROM - HYdrology surface- runoff PROgnostic Model

ICPDR - International Commission for the Protection of the Danube River
IDMP CEE - Integrated Drought Management Programme for Central and Eastern Europe
IMAGINES - Implementation of Multi-scale Agricultural Indicators Exploiting Sentinels
INCA-CE - Integrated Nowcasting Through Comprehensive Analysis – Central Europe
IPC - International Planning Committee
IPCC - Intergovernmental Panel on Climate Change
IPCC GHG Inventories - Intergovernmental Panel on Climate Change Greenhouse Gases Inventories
IPM - Integrated Pest Management program
IRENA - International Renewable Energy Agency
IWRM - Integrated Water Resources Management

JRC - Joint Research Centre

KPMG - Klynveld Peat Marwick Goerdeler (International Dutch accounting firm)
LACE (or RC-LACE) - Regional Co-operation for Limited Area modelling in Central Europe
LAI – Leaf Area Index
LAM – Limited Area Model
LM - Lokal-Modell (In German)
LRF - Long Range Forecast
LTER – Long Term Ecological Research

MACC – Monitoring Atmospheric Composition and Climate
MASH - Multiple Analyses of Series for Homogenization
MEANDER - MEsoscale Analysis, Nowcasting and DEcision Routines
Med-CORDEX - Mediterranean Coordinated Regional Downscaling Experiment
MISH - Meteorological Interpolation based on Surface Homogenized Data Basis
MSc - Master of Science

NAGiS -National Adaptation Geo-Information System
NAO - North Atlantic oscillation
NATO – North Atlantic Treaty Organization
NCEP - National Centers for Environmental Prediction
NDVI - Normalized Difference Vegetation Index
NEESPI – Northern Eurasian Earth Science Partnership Initiative
NMHS - National Meteorological and Hydrological Services
NMM - Nonhydrostatic Mesoscale Model

NMMB - Non-hydrostatic Multi-scale Model on the B-grid
NOAA - National Oceanic and Atmospheric Administration

NWP - Numerical Weather Prediction

OECD - Organisation for Economic Co-operation and Development
OpenIFS – Open Integrated Forecasting System

PB - Pannonian Basin
PBL - Planetary Boundary Layer
PhD - Philosophiæ Doctor
PM - Particulate Matter
PRUDENCE - Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects
PV - Photovoltaics
PV-GIS - Photovoltaic Geographical Information System

QPF - Quantitative Precipitation Forecast

RC-LACE - Regional Centre for Limited Area modelling in Central Europe
RCM - Regional Climate Model
RCMGiS - New climate change scenarios for the Carpathian-basin region based on changes of radiation balance
RCP - Representative Concentration Pathways
RE - Renewable Energy
RegCM - Regional Climate Model
REN21 - Renewable Energy Policy Network for the 21st Century
RES - Renewable Energy Service
RHMSS - South East European Virtual Climate Change Center, Republic Hydrometeorological Service of Serbia
RHP - Regional Hydro-climate Project
R&D - Research and Development

SC - Sava Commission
SDGs - Sustainable Development Goals
SEECOP Consortium - South-East European Consortium for Operational weather Prediction
SEEVCCC - South East European Climate Change Center (hosted by Republic Hydrometeorological Service of Serbia, RHMSS)
SM - Soil Moisture
SMA - (System, Mess and Anlagentechnik (In German), Solar Technology AG
SPI - Science-Policy-Interface
SRES - Special Report on Emissions Scenarios
SSR - Solar Surface Radiation
SST - Sea Surface Temperature
SVAT - Soil-surface Vegetation Atmosphere Transport
SWAT - Soil and Water Assessment Tool
S2S - Sub-seasonal to-Seasonal Prediction Project

TPW - Total Precipitable Water

UHI - Urban Heat Island
UN - United Nations
UNEP - United Nations Environment Programme
UNESCO - United Nations Educational, Scientific and Cultural Organisation
UNFCCC - United Nations Framework Convention on Climate Change

VALUE COST action - Validating and Integrating Downscaling Methods for Climate Change Research COST action

WatBal Model - Water Balance Model
WATCAP - Water and Climate Adaptation Plan for the Sava River Basin
WB - White Book
WCRP - World Climate Research Programme
WFD - Water Framework Directive
WISC - Windstorm Information Service
WMO - World Meteorological Organization
WOFOST - WOrld FOod STudies
WRDC - World Radiation Data Centre
WRF - Weather Research and Forecasting
WWF - World Wildlife Fund

The

World Climate Research Programme (WCRP)

facilitates analysis and prediction of Earth system change for use in a range of practical applications of direct relevance, benefit and value to society.

WCRP
World Climate Research Programme