New IAEA Coordinated Research Project (CRP):

Isotope Variability of Rain for Assessing Climate Change Impacts

CRP Project Code	F31006
Division	NAPC
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Detailed Proposal Information for Applicants:

Summary

Even though scientific uncertainties remain about the detailed extent as to which the hydrological cycle will be influenced by climate change induced impacts, general consensus prevails across the expert community that the predicted changes to the Earth's climate would have far reaching effects on the future availability of global freshwater resources. These impacts of climate change on freshwater systems and their management are mainly linked to the observed and projected increases in temperature, rising sea levels, and changes to the precipitation amounts and variability. In fact, there are several outstanding issues that need to be resolved to further improve the prediction on climate change impacts on global freshwater resources, and amongst them the limitation to our present understanding about the possible changes of precipitation amounts and their specific characteristics is one of the largest causes of these uncertainties.

Without data to better understand the different types of precipitation and suitable means for their interpretation progress cannot be made. This CRP aims to improve the capability and expertise among Member States in the use of environmental isotope techniques for better assessment and mapping of the different types of precipitation (e.g., high-intensity convective rain versus widespread but lower-intensity stratiform rainfall) and to better understand the possible range of changes to the rainfall characteristics (e.g., frequency, amount, duration, intensity).

During the CRP the following outputs are expected to be produced: (i) Reports on the use of isotope data in precipitation collected at various temporal resolutions to better delineate the factors controlling isotope variability in atmospheric waters. (ii) Compilation of new isotope data sets measured at small temporal resolution in climate sensitive areas as a key contribution to the GNIP database. (iii) Re-assessment of data repositories and weather observations for including more detailed hydro-meteorological information (precipitation characteristics) into an adapted isotope precipitation network database product. (vi) Technical reports summarizing major findings and best-practice guidelines on integrating environmental isotopes in precipitation with climate models and implications for assessing climate change impact.

Background situation analysis

According to the most recently published report "Global Warming of 1.5 °C" of the Intergovernmental Panel on Climate Change (IPCC), there is high confidence that human induced warming has reached approximately 1°C above pre-industrial levels in 2017 (0.87°C ±0.12°C) and that it is currently increasing at 0.2°C (±0.1°C) per decade (IPCC, 2018). The impacts of this climate change on freshwater systems and their management are mainly linked to the observed and projected increases in temperature, rising sea level (salinization of coastal aquifers), and precipitation amounts and variability. However, observed global changes in the water cycle, including precipitation, are generally considered more uncertain than observed changes in temperature (Hartmann et al., 2013; Stocker et al., 2013). Indeed there is high confidence that mean precipitation over the mid-latitude land areas of the Northern Hemisphere has increased since 1951 (Hartmann et al., 2013), while, conversely, for other latitudinal zones area-averaged long-term positive or negative trends have lower confidence due to limitations from data quality and data completeness, or because of disagreement amongst available estimates (Hartmann et al., 2013).

For evaluating future scenarios, the IPCC adopted four greenhouse gas concentration trajectories (Representative Concentration Pathways - RCPs) for serving its 5th Assessment Report (AR5) (Moss et al., 2008). In fact, across all four RCPs, global mean temperature is projected to rise by 0.3 to 4.8 C by the late-21st century (IPCC, 2013b). As a consequence, as global mean surface temperature increases, it is rated very likely that extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will become more intense and more frequent (Hartmann et al., 2013). Also, while monsoon winds are considered likely to weaken, monsoon precipitation is expected to intensify due to the increase in atmospheric moisture. However, projected changes in the global water cycle in response to the warming over the 21st century are not uniform. While the high latitudes and many mid-latitude wet regions are likely to experience an increase in annual mean precipitation, in particular under the RCP8.5 scenario (scenario with the highest increase of radiative forcing), in many mid-latitude and subtropical dry regions, mean precipitation will likely decrease (IPCC, 2013b).

From a thermodynamic point of view, because the saturation vapour pressure of air increases with temperature, it is expected that the amount of water vapour in air will increase with a warming climate. The saturation-specific humidity of the atmosphere is governed by the Clausius-Clapeyron (CC) equation, and it follows an approximately exponential relationship increasing by ~7% per degree at 0°C and ~6% per degree at 24°C (Westra et al., 2014). In fact, the magnitude of the observed global change in tropospheric water vapour of about 3.5% in the past 40 years is consistent with the observed temperature change of about 0.5°C during the same period, whereas the relative humidity has stayed approximately constant (Schleussner et al., 2017; Stocker et al., 2013).

Even in the hypothetical absence of larger changes to the general atmospheric circulation patterns, it is therefore expected that climate warming will cause an increase in the intensity of rainfall due to the enhanced transport of moisture into regions of net moisture convergence (Trenberth et al., 2003; Westra et al., 2014). However, empirical investigation into the Clausius-Clapeyron (CC) scaling hypothesis have as well provided emerging evidence of a super-CC scaling relationship for the specific case of extreme rainfall events. Multiple observational studies in particular indicated that the intensity of subdaily extreme rainfall is more sensitive to changes in local atmospheric temperature, with rates of increase of up to double the CC rate for temperature ranges between ca 12°C and 22°C, and decreases in rainfall intensities with temperature have been found above ca 24°C (Westra et al., 2014).

However, there are many limitations to our present understanding about the detailed physical nature of the observed or predicted intensification of rainfall. In order to better apply any types of scaling relationships to climate change predictions, further research is needed on this matter. In this regard, the use of environmental isotopes (^{2}H, ^{18}O, Tritium) constitutes a powerful tool for the investigation of atmospheric process and for the detailed examination of the formation of hydrometeors in particular. It has recently been demonstrated how the analysis of ^{18}O and Tritium can be deployed to discriminate the partitioning of precipitation into different rain types (Aggarwal et al., 2016), owing to differences in vertical air motions and microphysical processes governing the formation of high-intensity convective rain or widespread and continuous but lower-intensity stratiform rainfall. Such partitioning into rain types is indeed fundamental for understanding how the water cycle responds to changes in climate (Aggarwal et al., 2016).

Besides of the immediate applications in tracing the modern water cycle, precipitation stable isotopes are commonly used to interpret paleoclimate archives. Long term records of the oxygen isotope variability of palaeo-precipitation can be accessed from different paleoclimate archives, like speleothems (Atsawawaranunt et al., 2018; Wang et al., 2008), ice cores (Jouzel et al., 2007), tree rings (Treydte et al., 2007) and lake records (Von Grafenstein et al., 1999). Such records can provide a way to infer information about changes in the hydrological cycle and their possible links to climate, provided that an appropriate interpretation can be found (LeGrande and Schmidt, 2009). However, the detailed climatic causes of isotope fluctuations observed in these paleoclimate archives are a subject of ongoing debate, with interpretations ranging from temperature variations (at mid to high latitudes) and rainfall amount (at low latitudes) (Araguás-Araguás et al., 2000; Dansgaard, 1964), moisture source variations, changes in the atmospheric circulations, and shifts in the type of rainfall and / or in the durations of climatic seasons (Dayem et al., 2010).

In analogy to the conclusion drawn for variations in modern precipitation, it has recently been suggested that annual average ^{18}O recorded in proxy archives should actually reflect a change in the proportions of convective (higher ^{18}O) and stratiform (lower ^{18}O) precipitation (Aggarwal et al., 2016), which may or may not coincide with the conventional assumptions of wetter or drier conditions. In conclusion a more thorough understanding (and re-examination) of the sources of the oxygen isotope variability in such palaeo-precipitation archives is likely needed.

The fundamental reason for this proposal is that a comprehensive framework that adequately links observed isotope distributions in precipitation to the predictions of possible transformations of local, regional and global precipitation patterns under future climate change is still lacking. The objective of this CRP will thus be to address the aforementioned questions by using environmental isotopes to better evaluate sources, pathways and interactions of atmospheric vapour, and to improve our understanding about the current and future partitioning of precipitation into different rain types. All these questions are critical for understanding how the water cycle responds to changes in climate, and to elucidate the consequences of such variations.

The GNIP database has long been used for calibrating isotopic indicators from paleoclimate archives. Furthermore, GNIP is a key resource for calibrating and validating atmospheric general circulation models (GCMs) equipped with a water isotope distribution module (Hoffmann et al., 2005). However, GNIP is nowadays not yet sufficient for all applications. In specific, the GNIP database contains only limited information needed for a more detailed characterization of the rainfall, like the intensity, frequency and duration of rainfall events, and it does as well not provide any information about the rainfall type (or the partitioning into different rain types). This CRP therefore also aims to contribute (i) an improved motoring programme in critical areas, and (ii) for including more detailed hydro-meteorological information (precipitation characteristics) into an adapted or complementary isotope precipitation network database product (a more detailed definition of the required parameters will be subject to the first RCM).

Also from a technological point of view his proposal has a very favourable timing, because (i) new satellite data are now becoming available from Global Precipitation Measurement (GPM) project which is covering latitudes 60°N to 60°S (as opposed to the Tropical Rainfall Measuring Mission (TRMM) which was limited to latitudes 30°N to 30°S), (ii) the steadily improving techniques of ground based weather surveillance radar (WSR) systems and networks, and (iii) new cost-effective Water Isotope Laser Analyzer Systems being nowadays available in many member state countries.

Nuclear Component

The CRP involves measurement of naturally-occurring stable and radioactive isotopes (i.e. ^{18}O, ^{2}H, ^{3}H) of water in precipitation and water vapour, but possibly also in surface waters and groundwater. It also involves the numerical evaluation of isotopes in the water cycle.

CRP Overall Objectives

The overall objective of the CRP is to improve the capability and expertise among Member States in the use of isotope patterns observed in precipitation to better assess the impacts of climate change on water resources and water related infrastructures.

Specific Research Objectives

1. Improve the understanding of climate change impacts by using environmental isotopes to evaluate possible transformations of rainfall patterns on the local, regional and global scale and to investigate their likely causes.

2. To develop and strengthen the capabilities for integrating datasets from multiple sources, at different space and time scales and at varying quality levels, in order to leverage an improved understanding and interpretation of environmental isotopes in rainfall.

3. To develop best-practice guidelines on combining environmental isotopes and other indicators into a harmonized data product for assessing rainfall related climate change impacts in the framework of precipitation networks on the national and global level.

4. To strengthen the use of isotopes as an independent means of verification and to thereby more efficiently complement conventional hydro-meteorological observations in the validation of dynamic climate models and synoptic features of the atmospheric circulation.

Expected research outputs

1. Stable water isotope data and hydro-meteorological information will be generated from selected monitoring stations.

2. Re-assessment of existing data repositories and weather observations for including more detailed hydro-meteorological information (precipitation characteristics) into an adapted isotope precipitation network database product.

3. Reports (or publications) on the testing and assessment of the combined use of isotope and related hydro-meteorological data to evaluate and characterize the past, present and future impact of climate change on relevant precipitation characteristics.

4. Reports (or publications) indicating the contribution of isotope tools for better constraining the impact of climate change on water resources and water related infrastructures.

5. Technical document (or publication) describing best-practice guidelines for complementing precipitation network databases with the necessary environmental isotope data and other relevant hydro-meteorological parameters required for improved (more thorough) climate change assessments.

6. Technical reports (or publications) presenting the main findings, guidelines and recommendations, and improved and upgraded or complementary precipitation database products.

Expected research outcomes

1. Improved understanding amongst water experts and managers about the interpretation of environmental isotopes for the assessment of climate change impacts on water resources.

2. More experienced counterpart institutes able to independently deploy environmental isotopes for conducting assessments of climate change.

3. Better understanding by participating Member States about the possible impacts that climate change can take on the hydrological cycle and how it can affect water resources and water related infrastructures.

4. Improved knowledge about constraining the magnitude and rate of the change for supporting better mitigation and adaptation strategies.

Activities

Proposed Work Plan

ACTIVITY		2019				2020				2021				2022			
1.1	**Announcement** of CRP	**X**															
1.2	Selection of participants, awarding contracts and agreements		X														
1.3	Preparation of a preliminary work plan of activities		X	X													
1.4	Review of available infrastructure & monitoring stations, hydrological data and isotope information		X	X	X												
1.5	Data requirement analysis and preparation of monitoring programs definitions (identification of study areas, sampling sites, measurements, supplementary datasets).			X	X												
1.6	**1st** Research Coordination Meeting **(RCM)** in Vienna (Development of work plan)				**X**												
2.1	Preparation of detailed guidelines and final work plan of activities				X	X											
2.2	Implementation of field campaigns: Collection of samples and hydro-meteorological measurements at the monitoring sites					X	X	X	X	X	X	X	X				
2.3	Isotope analyses and other related data collection (and physical rainfall parameters)					X	X	X	X	X	X	X	X				
2.4	Re-assessment of existing data repositories and weather observations for required hydro-meteorological information and precipitation characteristics					X	X	X	X	X	X	X	X				
2.5	Isotope and other data processing and interpretation of results; submission of progress reports						X	X	X	X	X	X	X	X			
3.1	**2nd RCM**: Data analysis, interpretation, preliminary results									**X**							
3.2	Continuation of the monitoring program									X	X	X	X	X			
4.1	Preparation and submission of final reports													X	X	X	
4.1	**3rd (Final) RCM**															**X**	

Relevance to programme objectives

The proposal is in line with the objectives of the Subprograms 2.3.1.1 "IAEA isotope data networks for precipitation, rivers, and groundwater" and 2.3.2 "Isotope based assessment and management of water resources". In fact, there is an increasing concern among various stake holders for developing robust techniques to understand the possible impacts that climate change can take on the hydrological cycle and to better constrain the expected magnitude and the rate of the change. In order to develop adequate mitigation and adaptation strategies, Member States ultimately need to understand how climate change can affect water resources and water related infrastructures.

Explanation/Justification

Given the scope and work programme of the proposed CRP, a time frame of four years is foreseen to achieve meaningful results and outcomes.

Participation of Agency's laboratories

The Isotope Hydrology Laboratory will assist by providing assistance in analytical aspects to participating groups and laboratories.

Assumptions

- Interested participants from Member States are already engaged in assessment of rainfall characteristics and water resources using isotope techniques.
- Appropriate staffing is available for field and analytical work. Laboratory premises and computing facilities are available at participating institutes to monitor hydro-meteorological parameters and to conduct isotopic analyses.
- National authorities/institutes will provide all necessary permissions, sample collection support, and provide hydro-meteorological and climate data in a timely manner.
- There is effective research collaboration with meteorological institutes/departments and/or interested and competent professionals in the areas of meteorology, climatology, hydrology, and data interpretation, as well as a certain involvement with water resources management questions and climate change research.

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