IDENTIFICATION AND ASSESSMENT OF CLIMATE PHYSICAL RISKS METHODOLOGY 2019

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1. INTRODUCTION

In Colombia, 47% of the territory has high and very high risk values of suffering the impacts of Climate Change. The greatest sign of climate risk is the phenomenon of climate variability in the tropical strip of the Pacific Ocean, which occurs on the inter-annual scale with the cycle known as "El Niño" and its opposite phase "La Niña". These cycles are reflected in extreme events such as droughts, fires, floods and mass removals, considered as climatic impacts that deserve permanent analysis to reduce losses and damages.

In the case of the hydrocarbon sector, for example, the winter wave of La Niña from 2010-2011, estimated losses in destroyed and damaged oil production areas of more than $ 7,000 million, damage to pipelines for more than $ 160,000 million and storage tanks of approximately $ 12.5 billion. Additionally, real production did not reach the target production for some months; Ecopetrol reported a drop in consumption of 3.9 kbpd, which represented a loss of $ 19,893 million and higher transportation costs for domestic supply of $ 29,242 million (IDB-CEPAL, 2012).

On the other hand, in the El Niño dry season of the 2014-2016 period, the fluvial transport of hydrocarbons on the Magdalena River was seriously affected by the decrease in the level to its historical lows that interrupted the passage in some points, incurring high costs for the use of land transport (UNGRD, 2016).

Given the above context, for Ecopetrol it is essential to recognize the vulnerability to variability and climate change to which people, infrastructure and potential impacts to operations and the environment are exposed. Taking into account that for each region the climatic dynamics is different, the vulnerability and risk analysis was carried out to define measures in order to increase resilience and compatibility with the climate.

2. VARIABILITY AND CLIMATE CHANGE

Climate is one of the environmental factors that affects different aspects of the territory. In a recurrent or cyclical way, climatic anomalies occur that impact in different ways and degrees the human and productive systems in a territory; the fluctuations that these anomalies generate are called climate variability. On the other hand, in the long term, weather conditions are gradually changing due to the so-called climate change, which will also increasingly affect the population and its activities in future periods of time.

The Colombian territory is influenced by the interannual variability of the Pacific Ocean, particularly by the extreme phases of El Niño and La Niña (ENSO Cycle)[1]. Under conditions of El Niño phenomenon,

[1] ENSO: El Niño-Southern Oscillation. To define the occurrence of El Niño (hot phase) and La Niña (cold phase) episodes in the tropical Pacific, the Oceanic Index of the Child (INO) is used, which analyzes the average anomaly of 0.5 degrees or more, which occurs during three consecutive months at the sea surface (SST) in the El Niño region. The phenomenon is categorized as weak, moderate and strong (Tapia, 2000) as follows: Strong events report coastal seawater surface temperatures between 3 to 5 degrees Celsius above normal, during several months of the summer

there is normally a precipitation deficit in the Caribbean, Andean, central and northern regions of the Pacific region, in the Orinoquía and Amazonia there is excess precipitation. Under the influence of the La Niña phenomenon, the response is inverse, abundant rainfall in much of the country, with less influence in the Orinoquía and Amazon regions. These phenomena of climatic variability do not inhibit the rainy or drought seasons typical of the country.

The extreme phases of climate variability produce socioeconomic impacts both in the territories and in the sectors, which in some cases take on the magnitude of a disaster. Cycles of climate variability and their extremes are unavoidable, but it is possible to reduce their negative impact by managing the risk associated with their extreme phases (El Niño and La Niña phenomena). Since the climate in the territories is changing, it is necessary to prepare for the new conditions through adaptation.

The country has been preparing to face extreme climatic events and the gradual transformation of the climate, in 2012 the National Planning Department formulated the National Plan for Adaptation to Climate Change (PNACC), in 2015 the Ministry of Environment and Sustainable Development developed the "Guide to include the climate change variable in new projects, works or activities", ", and in 2016 the National Policy on Climate Change, in 2017 the department of Santander launched the Comprehensive Plan for the Management of Territorial Climate Change and in In 2018, the Ministry of Mines and Energy formulated the Comprehensive Climate Change Plan for the mining and energy sector (PICCME) adopted by Resolution 40807 of August 2, 2018, which incorporates the methodological component for the vulnerability analysis and climate change at the sectoral level.

The aforementioned documents consider the following concepts for the analysis of climate vulnerability and risk:

Risk: result of the interaction between defined physical threats and an exposed system, taking into account the properties of the system in terms of its vulnerability to these threats.

Hazards: latent danger that a physical event of natural origin, or caused, or induced by human action accidentally, is presented with a sufficient severity to cause loss of life, injury or other impacts on health, as well as damage and losses in assets, infrastructure, livelihoods, service delivery and environmental resources. Within the framework of adaptation to climate change, threats correspond to climate events that include: climate change, climate variability and extreme climate events. "(DNP, MADS, IDEAM, UNGRD, 2013, p. 25).

Exposure: it is defined in the following paragraph: "A good part of the social impacts and the increase in economic losses associated with climatic events are the consequence of an increase in exposure, that is, a greater presence of people, communities, natural resources and environmental services, infrastructure or economic, social or cultural assets in places that could be affected by the climate".

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and autumn seasons. of the southern hemisphere. Moderate events manifest coastal sea surface temperatures in the range of 2 to 3 degrees Celsius above normal, in the summer and autumn seasons of the southern hemisphere. Weak events, manifest coastal sea surface temperatures in the range of 1 to 2 degrees Celsius above normal, in the summer and autumn seasons of the southern hemisphere.

Vulnerability: it is made up of sensitivity and adaptability.

- **Sensitivity**: refers to the physical predisposition of the human being, the infrastructure or the ecosystems to be affected by a threat, due to the context and intrinsic conditions that enhance the effect of the threat.

- **Adaptation capacity**: defined as the capacity of a system and its parts to anticipate, absorb, accommodate or recover from the effects of a disturbance in a timely and efficient manner. This includes the ability to preserve, restore or modify, and enhance its basic functions and structures.

The previous concepts are collected in the following formula:

Los anteriores conceptos quedan recogidos en la siguiente fórmula:

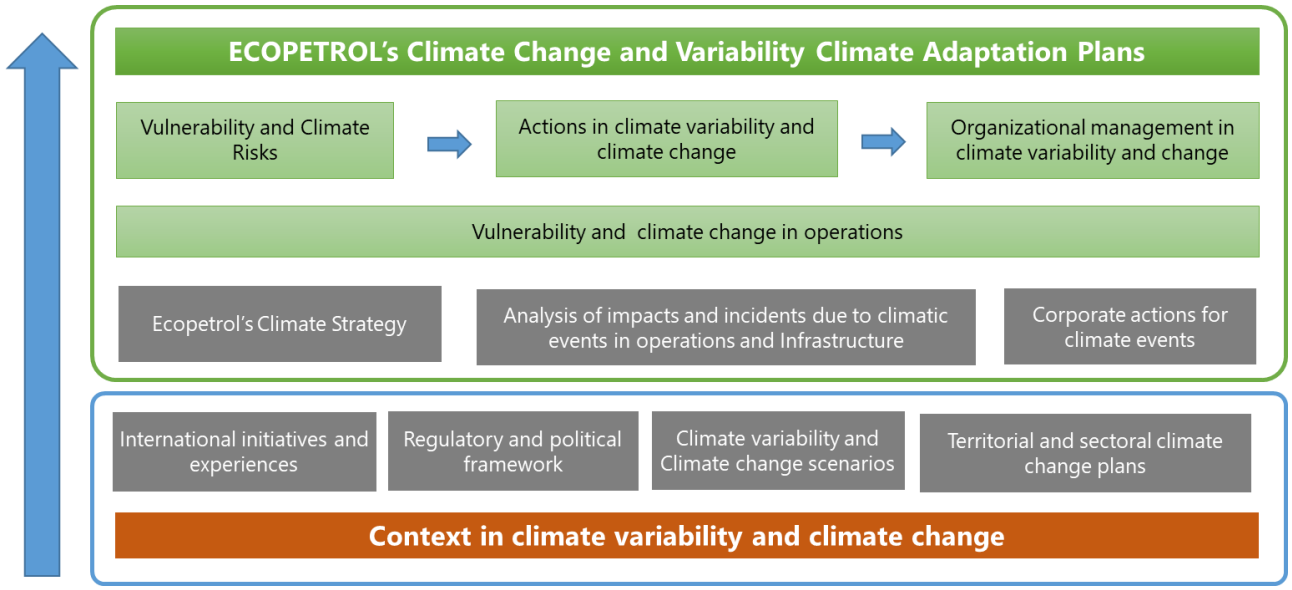
$$Risks = f\ (\text{Hazard}\ (Exposure), Vulnerability)$$
$$Vulnerability = f\ (\text{Sensitivity, Adaptation capacity})$$

Based on the above, a methodological model is built for Ecopetrol to formulate the Climate Change and Climate Variability Adaptation Plans, which considers the different climate dynamics and particularities of the regions where the company has operations.

3. METHODOLOGICAL MODEL FOR THE FORMULATION OF THE PLAN OF ADAPTATION TO CLIMATE VARIABILITY AND CHANGE

The model developed for Ecopetrol includes the representative elements of the documents developed at the national level.

Graph 1. Methodological model for the formulation of Ecopetrol's Regional Adaptation Plans



Source: Ecopetrol

Within the methodology proposed for the formulation plans, the following most relevant events were defined [2]:

Floods: These are water levels above normal due to the overflowing of rivers due to torrential rains or rising tides above the usual level. Floods can be sudden or slow and in mountainous areas there can be torrential floods. (UNGRD, 2016).

Water shortage (drought): Droughts are seasons of low water availability, reduced rainfall, low soil humidity and decrease in bodies of water. Drought can cause a shortage of water for domestic, agricultural, industrial and energy consumption. (UNGRD, 2016).

Mass movements - landslides: These are ground, soil or rock displacements that can occur in hillside areas. They are activated by rains, earthquakes and most of the time by human activity. (UNGRD, 2016)..

Forest fires: Forest fire is the fire that spreads without control, consuming plant material located in forest areas, with an environmental function and whose size is greater than 0.5 ha. (UNGRD, 2016).

[2] Taken from the adaptation component of the Climate Change Management Plan for the Mining-Energy sector (MinMinas, 2018)

For the assessment of the threat and vulnerability for the events listed above, in scenarios of variability and climate change on Ecopetrol's infrastructure, the following considerations are taken into account:

a. Reference cartography

- Virtual maps of official entities for extreme weather events: fires, water shortages, floods and mass removal.
- Map of Ecopetrol's infrastructure at the level of licensed areas.
- Maps of temperature and precipitation changes for the El Niño and Niña climate variability phenomenon for its weak, moderate and strong categories.
- Prospective map of the alteration of temperature and precipitation for the 2011-2040 scenario (RCP 6.0) of climate change[3].

b. Analysis Unit

The analysis of climate variability and change for Ecopetrol's operations is based on the licensed areas and corresponding assets.

The results presented in the following chapter correspond to the description of the behavior (scenario) of a threatening event in conditions of alteration of temperature and / or precipitation in both variability and climate change, therefore, it is not a prediction, nor a probabilistic estimation, which would require more specialized and detailed studies.

The images of the reference cartography are presented in **Annex 1**.

3.1 Assessment of hazard, vulnerability and risks

The following describes the method of assessing the threat, vulnerability and climate risk, for the El Niño phenomenon, La Niña and the 2011-2040 climate change scenario for Ecopetrol.

3.1.1 Threat

The threat was assessed based on the exposure of Ecopetrol's licensed areas with respect to the occurrence of the most threatening events for the region and the influence of climate variability scenarios (El Niño / La Niña phenomenon) and climate change (Scenario 2011-2040) in relation to the alteration of the variables of temperature (° C) and precipitation (%).

[3] In the case of the crossing of cartographic information for climate change. Ecopetrol adopts **the RCP 6.0 (Representative Concentration Pathways)** scenario in accordance with the sectorial plan and the Third National Communication on Climate Change, which assumes a stabilization of Greenhouse Gas emissions after 2100 with the following considerations: Great dependence on fossil fuels, intermediate energy intensity, increased farmland use and decreased grassland use, stable methane emissions, CO2 emissions peak in 2060, 75% above current levels, and then drop to 25%.

According to the threatening event (water shortage, flooding, mass movements and forest fires), the variable (precipitation or temperature) with the highest incidence in the scenarios of variability and climate change was defined for Ecopetrol and the region:

Table 1. Relationship of climatic variables with threatening events

Climate Variability (El Niño phenomenon)		
Event	**Temperature**	**Precipitation**
Water shortage (drought)		X
Forest fires	X	
Climate Variability (La Niña phenomenon)		
Event	**Temperature**	**Precipitation**
Flood		X
Mass movements		X
Cambio climático (Escenario 2011-2040)		
Event	**Temperature**	**Precipitation**
Water shortage (drought)	X	X
Flood	X	X
Mass movements	X	X
Forest fires	X	X
Sea level rise	X	X

To relate the qualification of the threat of the event that is determined in: Very Low, Low, Moderate, High and Very High, with the alteration of the precipitation or temperature, the following correlation scale was carried out.

Table 2. Correlation scale between the qualification of the threat of the event with the alteration of precipitation and / or temperature in an El Niño phenomenon.

Precipitation (%)					
Event threat assessment	Strong deficit <40%	Deficit 40 - 80%	Normal 80 - 120%	Excess 120 - 160%	Strong Excess >160%
Very low	Low	Low	Low	Very Low	Very Low
Low	Moderate	Low	Low	Low	Very Low
Moderate	High	Moderate	Moderate	Moderate	Low
High	Very high	High	Moderate	Moderate	Moderate
Very high	Very high	Very high	High	High	Moderate

Temperature (°C)					
Event threat assessment	Strong warming >0.5	Warming 0.2 a 0.5	Normal -0.2 a 0.2	Cooling -0.5 a -0.2	Strong cooling <-0.5
Very low	Low	Low	Low	Very Low	Very Low
Low	Moderate	Low	Low	Low	Very Low
Moderate	High	Moderate	Moderate	Moderate	Low
High	Very high	High	Moderate	Moderate	Moderate
Very high	Very high	Very high	High	High	Moderate

Table 3. Correlation scale between the ratings of the threat of the event with the alteration of precipitation in a La Niña phenomenon.

Precipitation (%)					
Event threat assessment	Strong Excess >160%	Excess 120 - 160%	Normal 80 - 120%	Deficit 40 - 80%	Strong deficit <40%
Very low	Low	Low	Low	Very Low	Very Low
Low	Moderate	Low	Low	Low	Very Low
Moderate	High	Moderate	Moderate	Moderate	Low
High	Very high	High	Moderate	Moderate	Moderate
Very high	Very high	Very high	High	High	Moderate

In the case of climate change scenarios, the cartographic information of the prospective susceptibility of the Climate Change Management Plan for the Mining-Energy sector is taken as a basis for the prioritized events. The scenario selected for the analysis corresponds to 2011-2040, which already correlates the changes in temperature and precipitation for threatening events, therefore, no additional correlation is required.

3.1.2 Vulnerability

Vulnerability was assessed based on the sensitivity that corresponds to the "susceptibility or predisposition of the threatened system and that may be affected". Accordingly, the susceptibility of Ecopetrol's operation to suffer damages depends on its strength or, on the contrary, on its weakness as an economic system to deal with the effects of the materialization of the threat.

The strength of the system is given by its structure, that is, a system will be stronger the more structured it is. For Ecopetrol it has been determined under the following aspects:

Table 4. Sensitivity indicators

Category	Measurement criteria	%	Indicator
Technical operation	Incidents by climatic variables (precipitation / drought) reported	0,20	No. Environmental incidents due to rainfall or droughts per year / No. total incidents per year
	Use of water resources for the operation	0,30	Level of participation in the use of water resources
Production	Participation production	0,30	% of regional participation on national production
Environmental management	Environmental Management System	0,20	Existence and implementation of the EMS

The ability to adapt corresponds to the ability of the affected system to face and recover from an event that materializes the threat. For this exercise, the ability to adapt is associated with the availability of resources in general.

The response capacity is given by the resources, tools and instruments available to Ecopetrol to deal with the materialization of threats, and has been defined under the following aspects:

Table 5. Adaptation capacity indicators

Category	Measurement criteria	%	Indicator
Operative resources	Risk prevention and control strategy inherent to operations	0,30	Respuesta al control asociado al KRI Probabilidad de Ocurrencia de Eventos Climáticos Extremos
	Legal restrictions on water resources	0,50	Capacidad de respuesta a las restricciones legales en situaciones críticas asociadas a temporadas de lluvia o sequía para descarga de vertimientos o captaciones
Operative Management	Responsiveness to the control associated with the KRI - Probability of Occurrence of Extreme Weather Events	0,20	Procesos de capacitación, sensibilización y divulgación en fenómenos de variabilidad y cambio climático en cada gerencia/total de gerencias de la VR

To determine the vulnerability rating, the following correlation scale is applied, between sensitivity and adaptive capacity.

Table 6. Vulnerability Component Correlation Scale

Vulnerability		Capacidad de adaptación				
		Very low	Low	Moderate	High	Very high
Sensibilty	Very low	Moderate	Moderate	Low	Very low	Very low
	Low	High	Moderate	Low	Low	Muy baja
	Moderate	High	High	Moderate	Low	Low
	High	Very high	High	High	Moderate	Low
	Very high	Very high	Very high	High	Moderate	Moderate

3.1.3 Climate Risk

Climate risk corresponds to the result between threat (exposure) and vulnerability. In other words, the greater the threat and vulnerability, the greater the impact on Ecopetrol's operations and infrastructure. To determine the risk rating, the following correlation scale between threat and vulnerability is applied.

Tabla 7. Climate risk components correlation scale

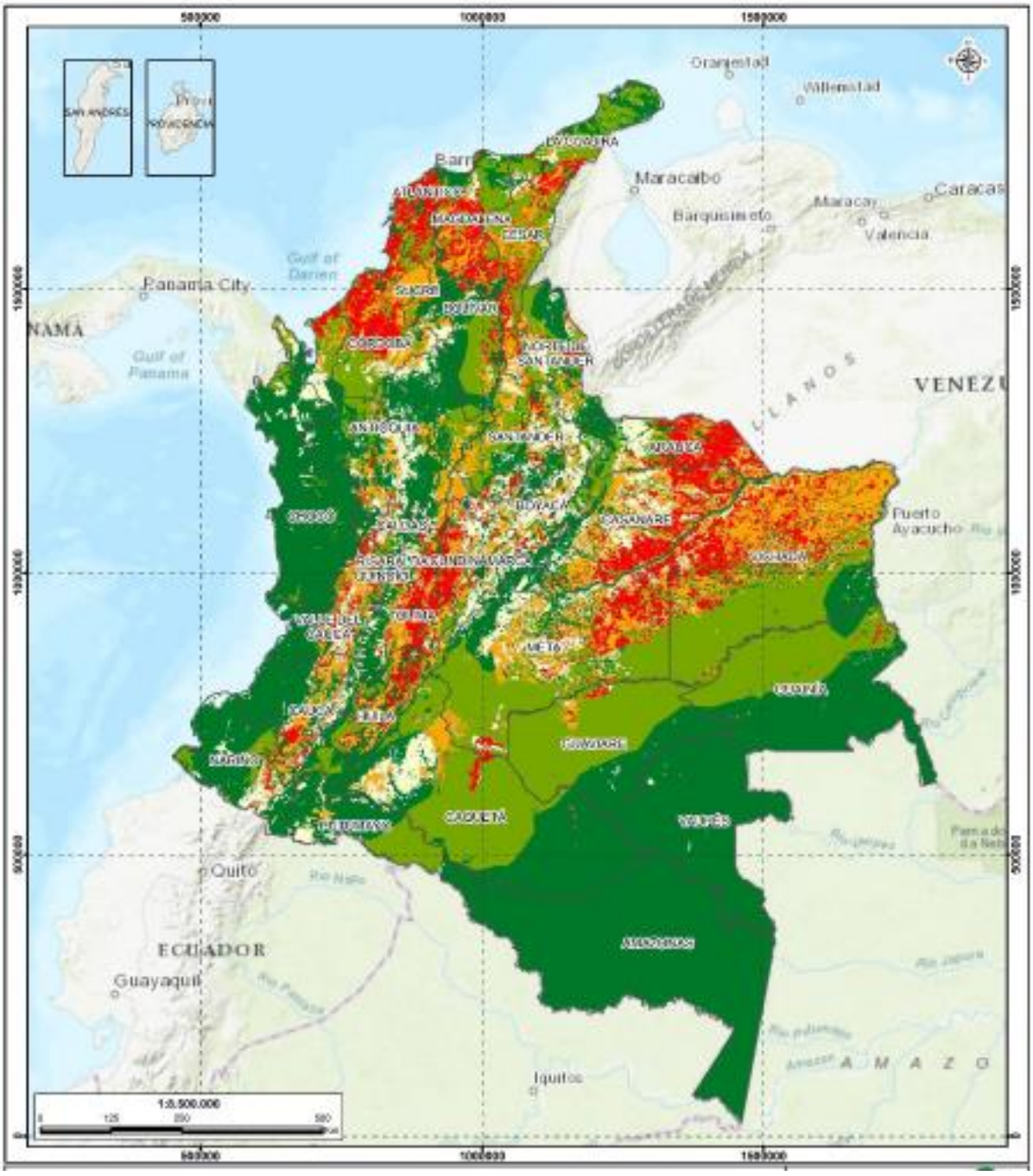
Risk		Threat grade				
		Very high	High	Moderate	Low	Very low
Vulnerability	Very low	Moderate	Moderate	Low	Very low	Very low
	Low	High	Moderate	Low	Low	Muy baja
	Moderate	High	High	Moderate	Low	Low
	High	Very high	High	High	Moderate	Low
	Very high	Very high	Very high	High	Moderate	Moderate

The calculation reports of the analysis of threat, vulnerability and climate risk for the El Niño and La Niña phenomena and the climate change scenario 2011-2040 for each region, can be found in **Annex 2**.

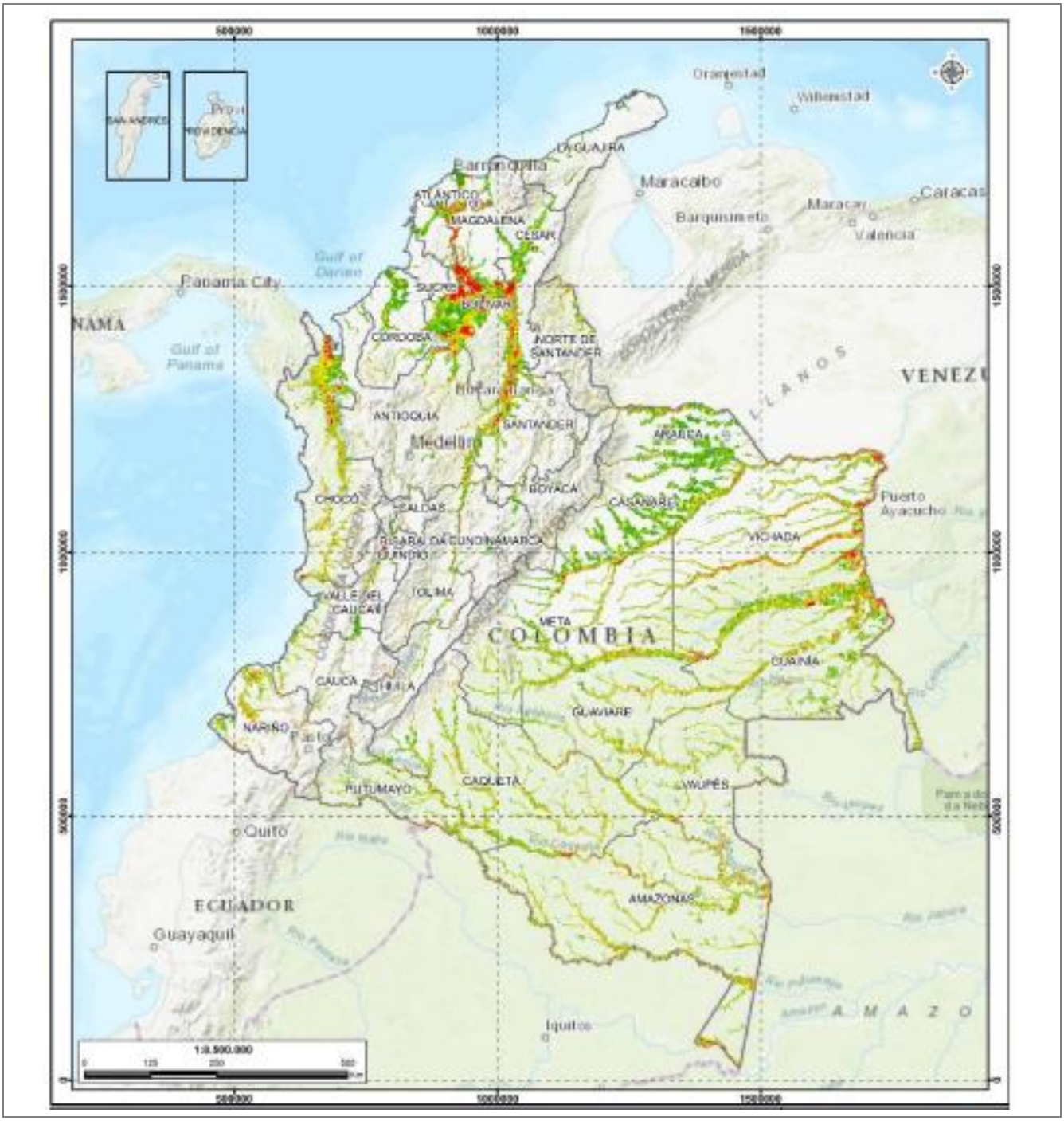
Anexo 1. Información cartográfica para variabilidad y cambio climático

1. 1. Virtual maps to extreme weather events

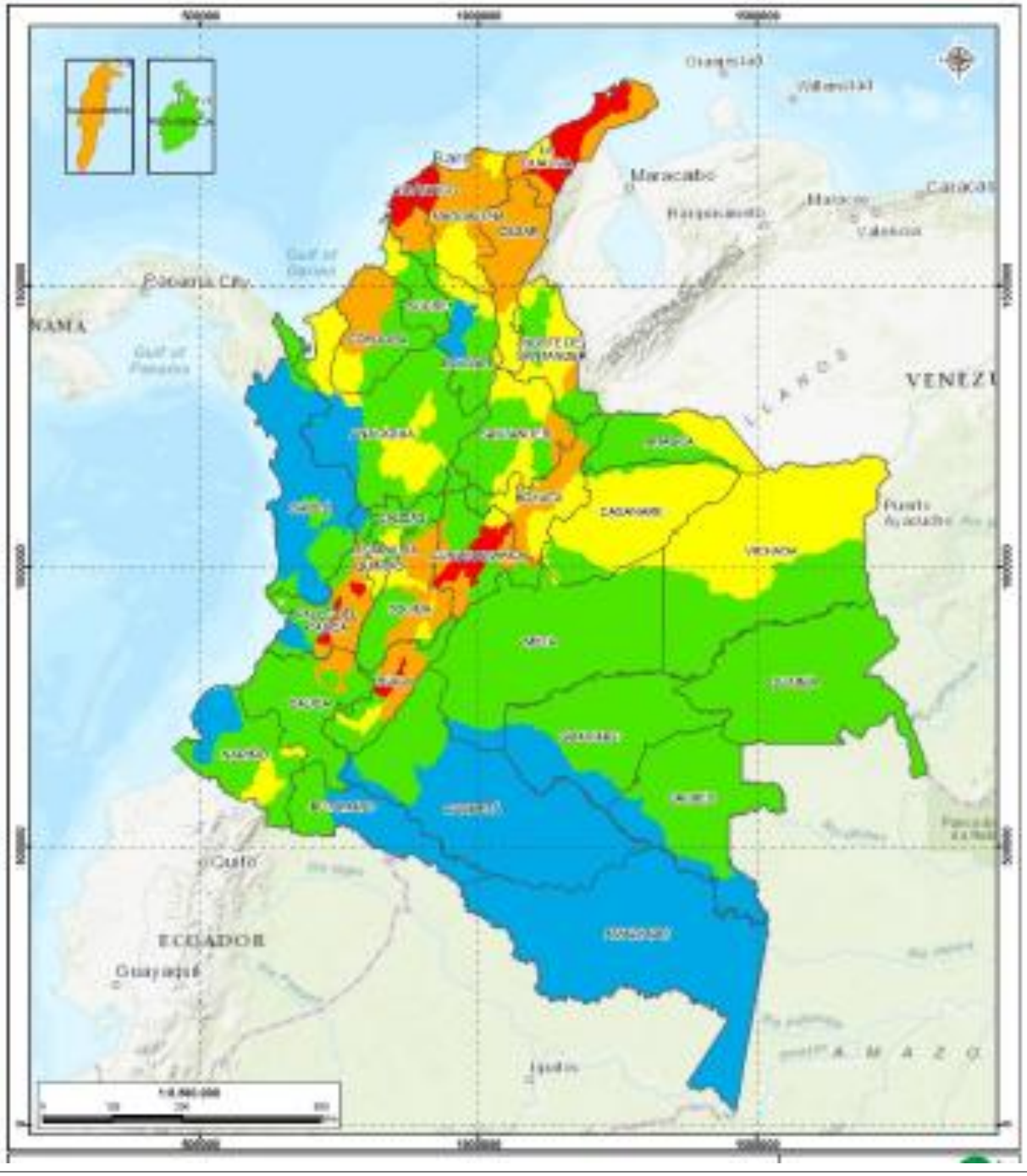
VIRTUAL THREAT FROM FOREST FIRES



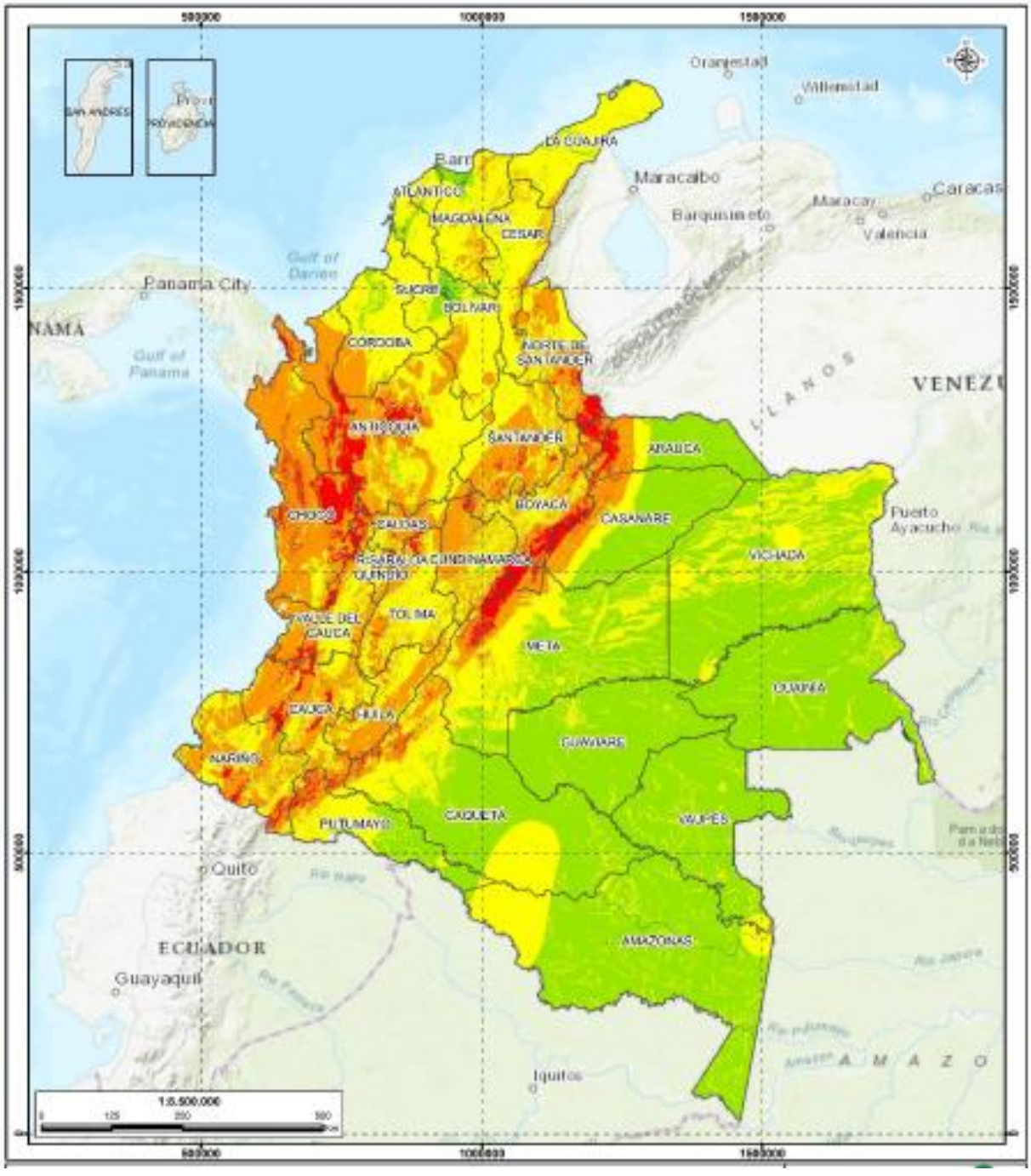
VIRTUAL THREAT FROM FLOODS


Oranjestad
Willemstad
Barranquilla
Maracaibo
Caracas
Barquisimeto
Maracay
Valencia
Panama City
Gulf of Darien
Gulf of Panama
VENEZU
LLANOS
COLOMBIA
Medellín
Bucaramanga
Puerto Ayacucho
Quito
ECUADOR
Guayaquil
Iquitos
AMAZONAS
LA GUAJIRA
ATLÁNTICO
MAGDALENA
CESAR
SUCRE
BOLÍVAR
CÓRDOBA
NORTE DE SANTANDER
ANTIOQUIA
SANTANDER
ARAUCA
BOYACÁ
CASANARE
CHOCÓ
CALDAS
RISARALDA
CUNDINAMARCA
QUINDÍO
TOLIMA
VALLE DEL CAUCA
META
VICHADA
GUAINÍA
CAUCA
HUILA
GUAVIARE
NARIÑO
PUTUMAYO
CAQUETÁ
VAUPÉS
1:8.500.000

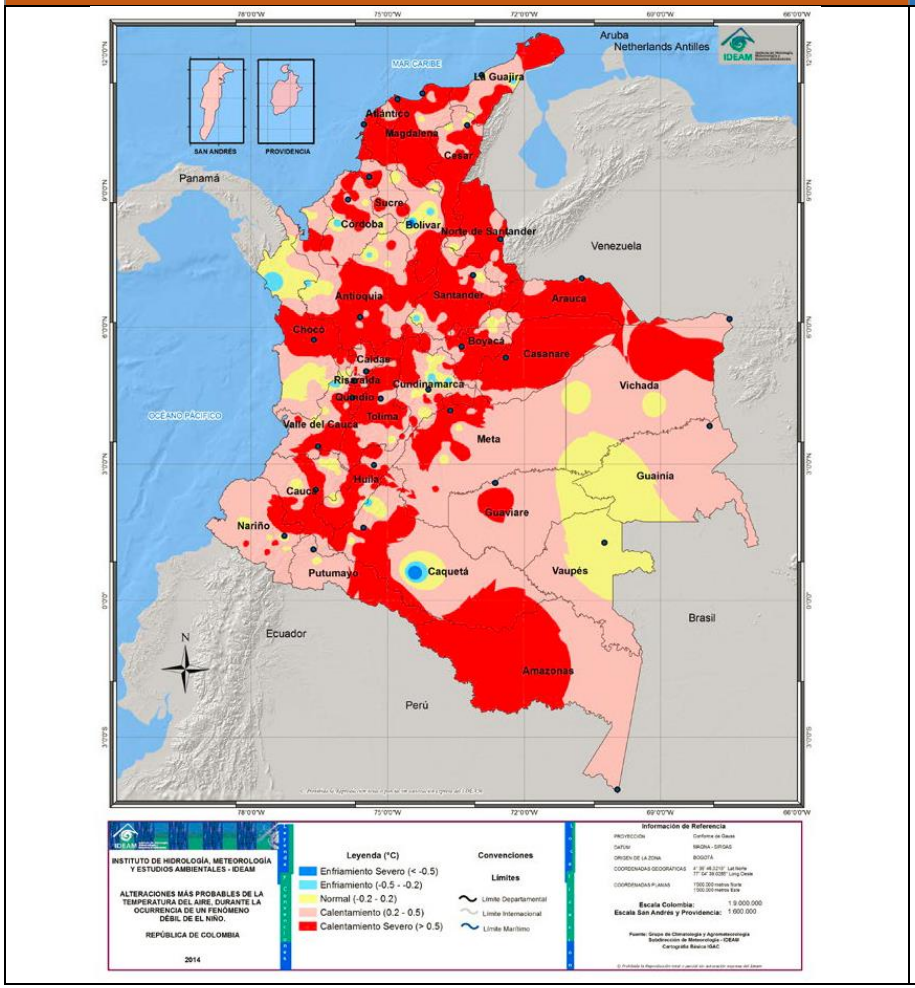
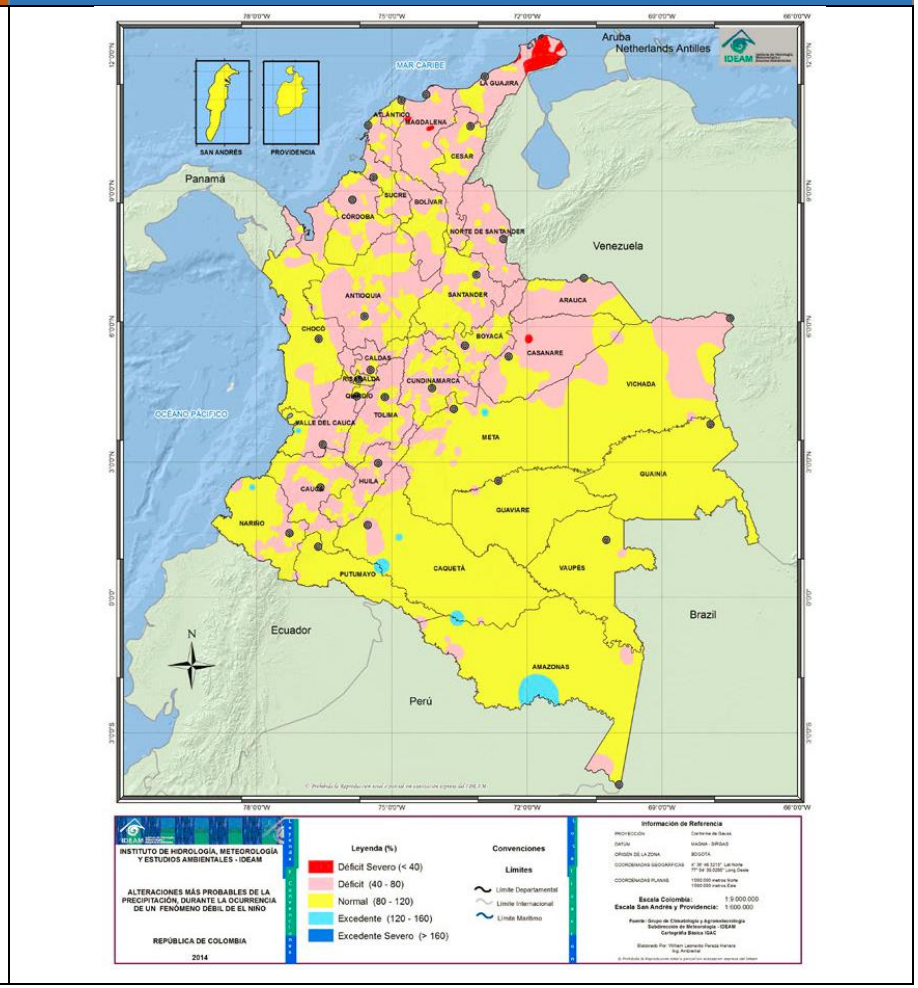
VIRTUAL THREAT DUE TO WATER SHORTAGES

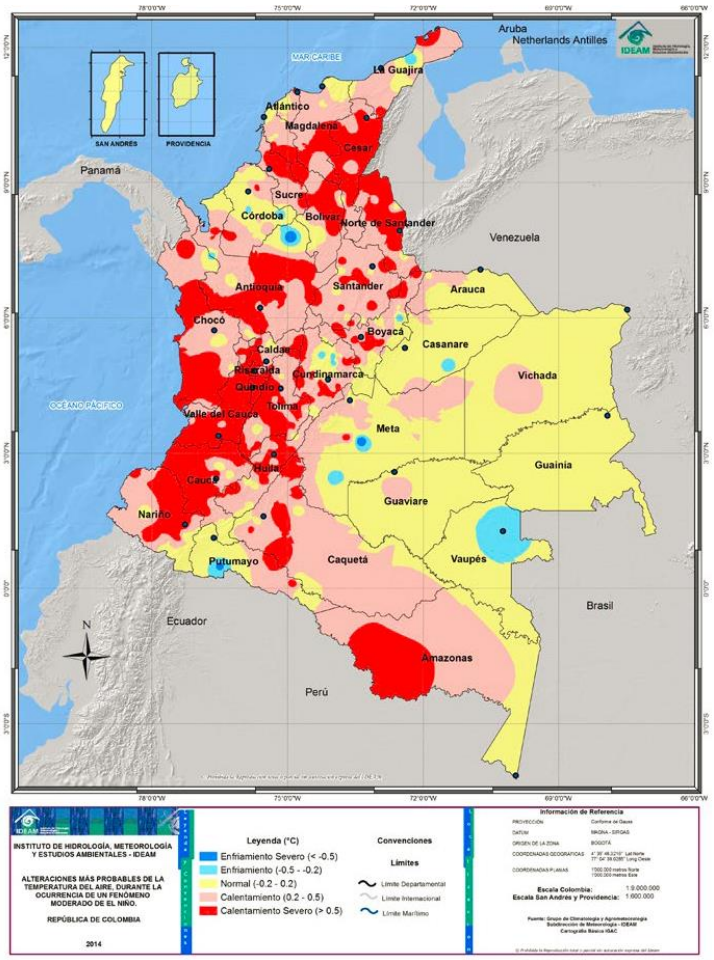
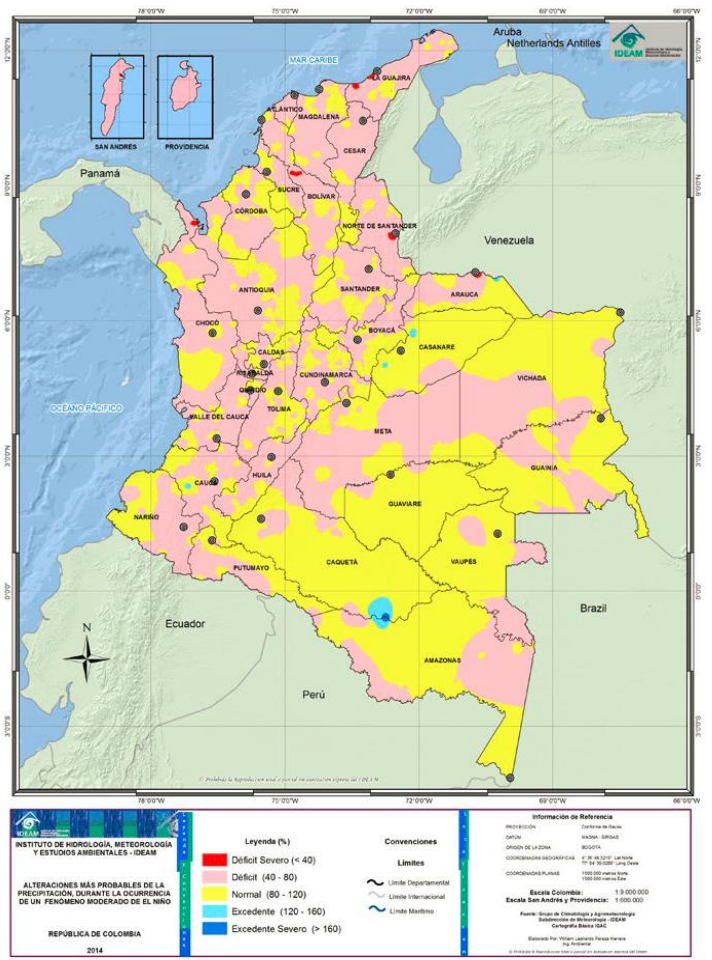


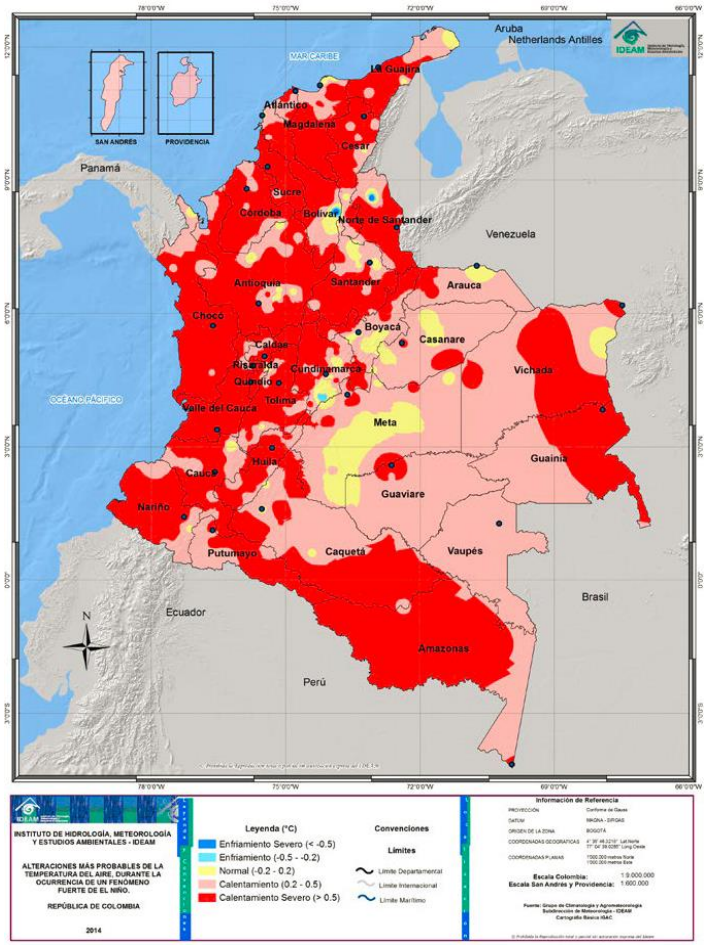
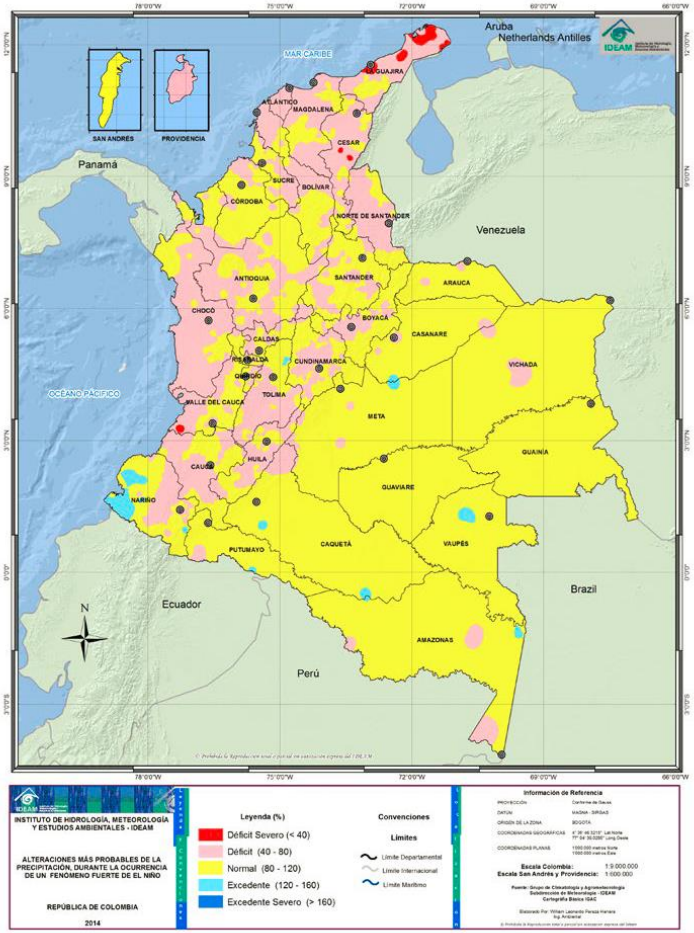
VIRTUAL THREAT FROM MASS MOVEMENTS



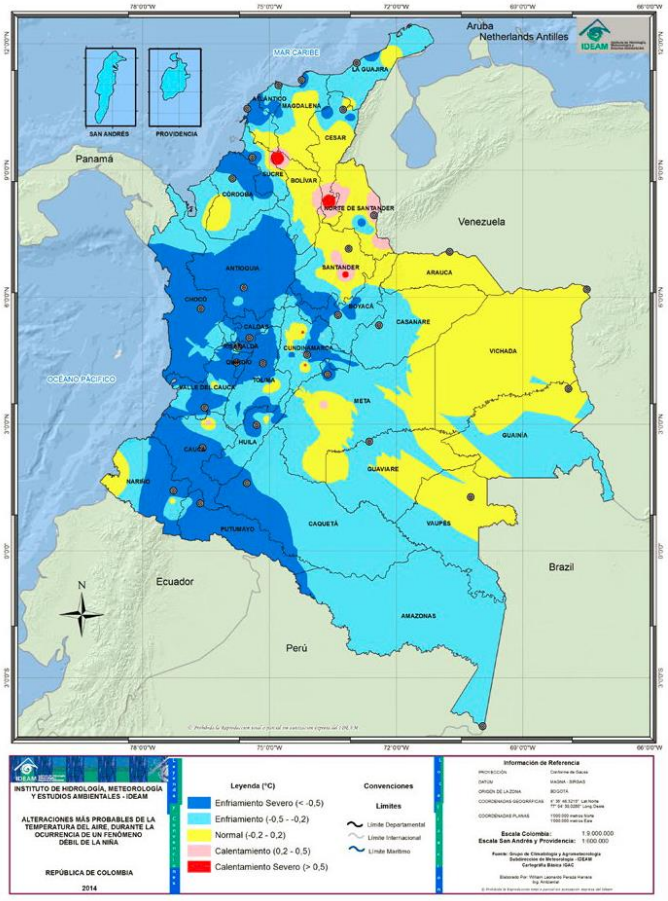
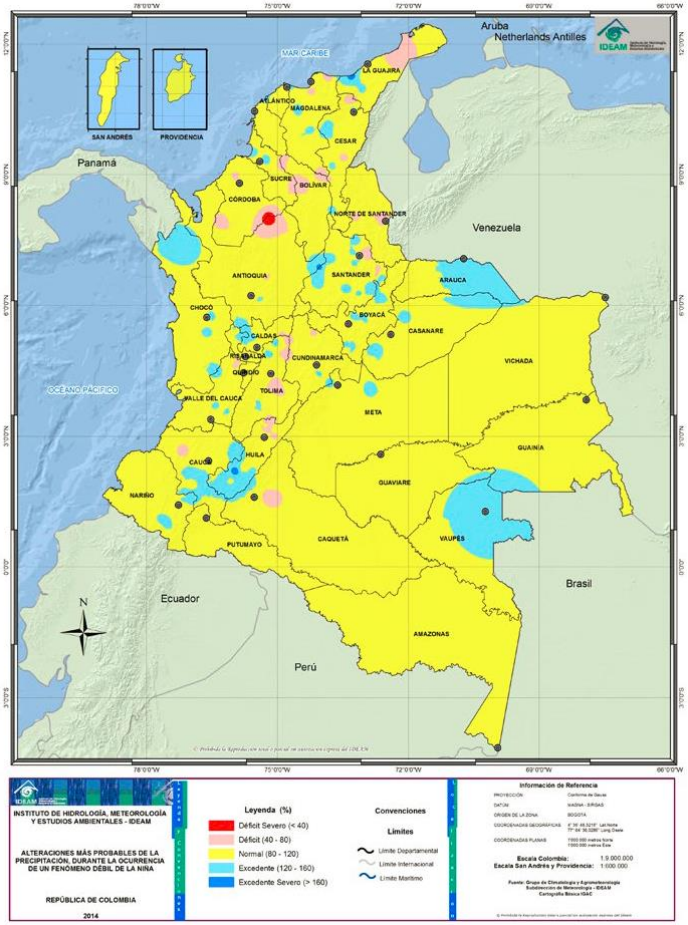
2. El Niño Niña phenomenon

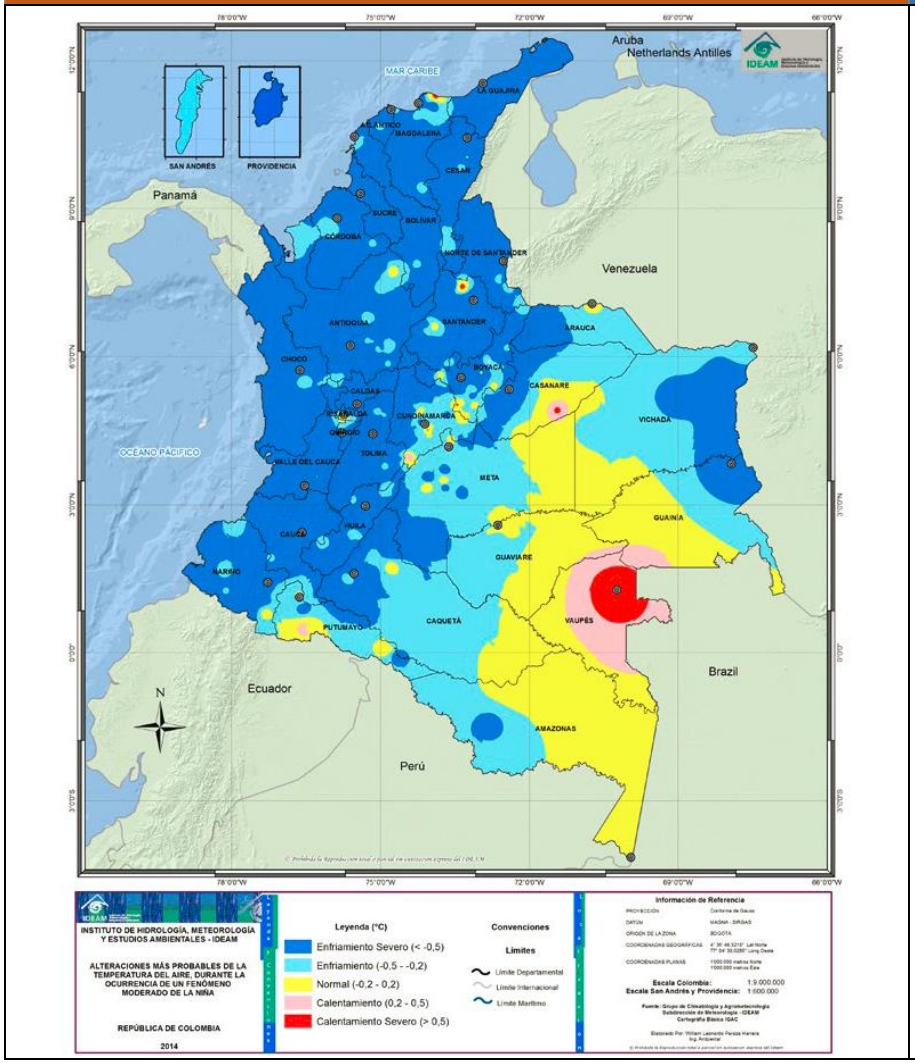
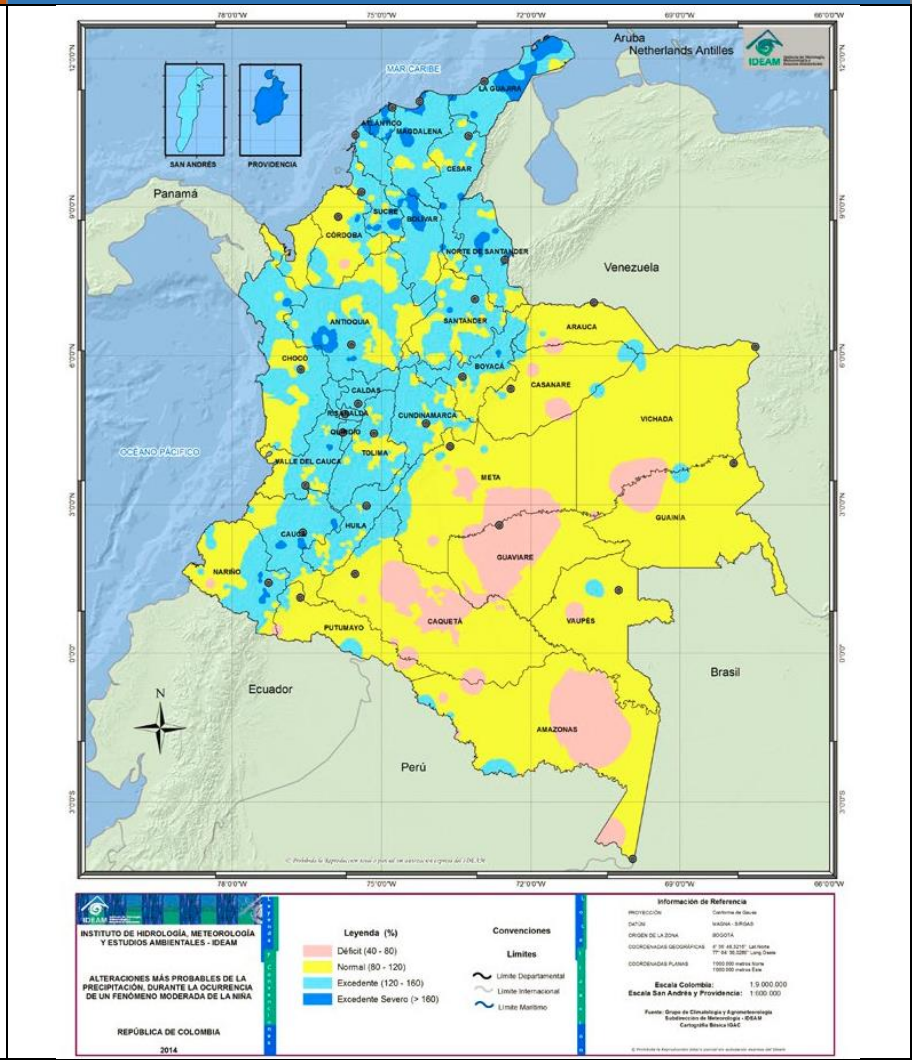
Alteración más probable de la temperatura del aire durante la ocurrencia de un fenómeno DÉBIL de El Niño	Alteración más probable de la precipitación durante la ocurrencia de un fenómeno DÉBIL de El Niño
	

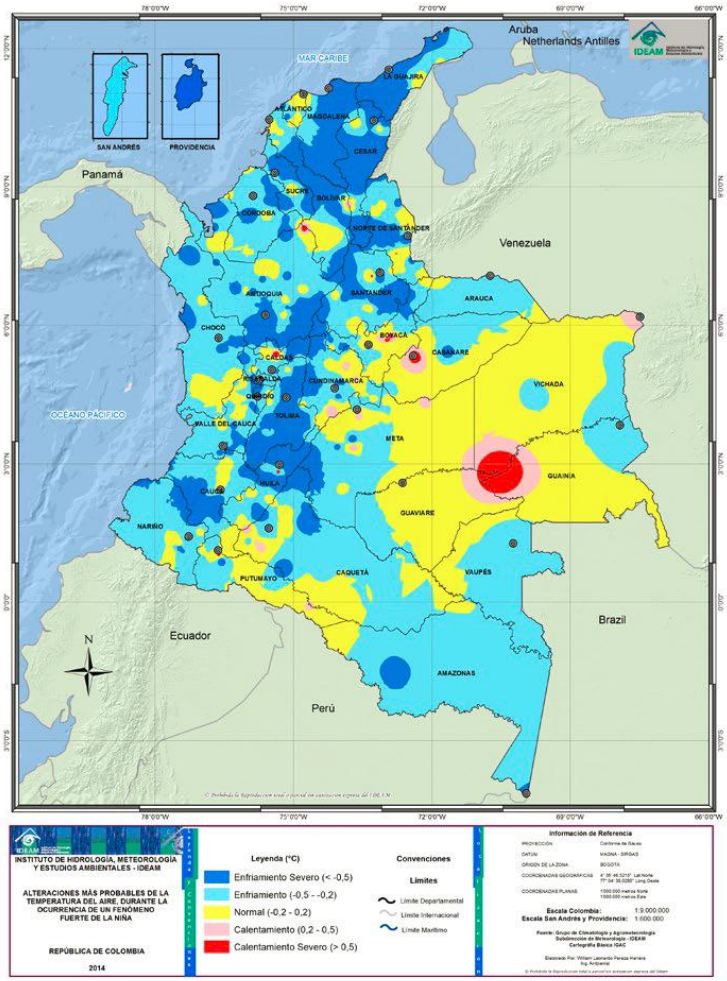
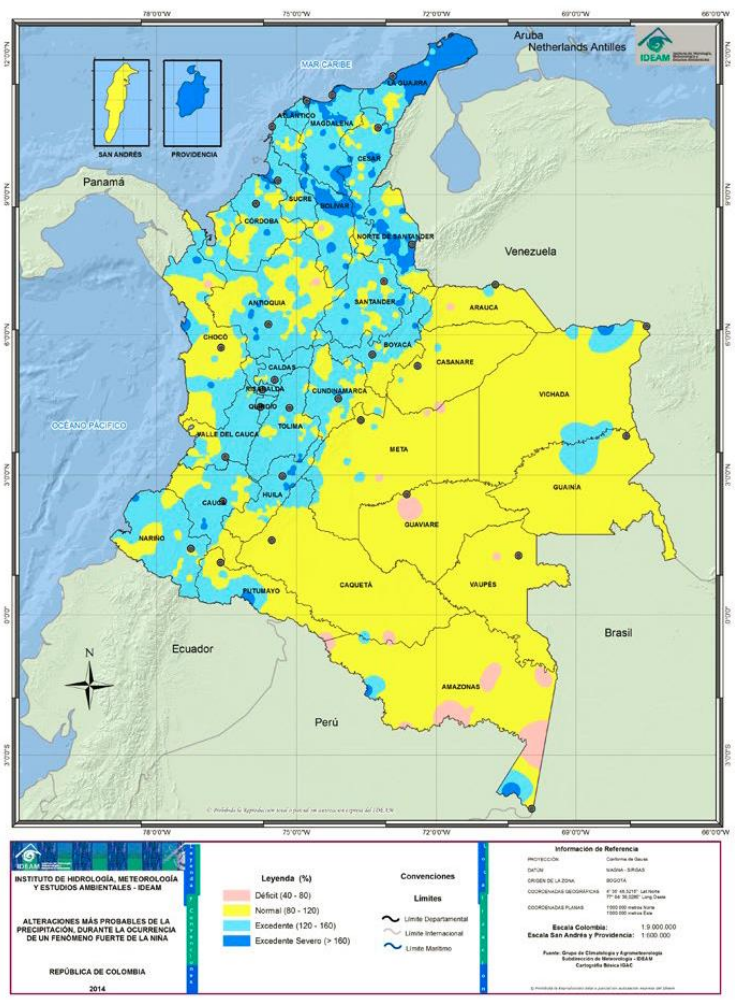
Alteración más probable de la temperatura del aire durante la ocurrencia de un fenómeno MODERADO de El Niño	Alteración más probable de la precipitación durante la ocurrencia de un fenómeno MODERADO de El Niño
	

Alteración más probable de la temperatura del aire durante la ocurrencia de un fenómeno FUERTE de El Niño	Alteración más probable de la precipitación durante la ocurrencia de un fenómeno FUERTE de El Niño
	

3. La Niña phenomenon

Alteración más probable de la temperatura del aire durante la ocurrencia de un fenómeno DÉBIL de La Niña	Alteración más probable de la precipitación durante la ocurrencia de un fenómeno DÉBIL de La Niña
	

Alteración más probable de la temperatura del aire durante la ocurrencia de un fenómeno MODERADO de La Niña	Alteración más probable de la precipitación durante la ocurrencia de un fenómeno MODERADO de La Niña
	

Alteración más probable de la temperatura del aire durante la ocurrencia de un fenómeno FUERTE de La Niña	Alteración más probable de la precipitación durante la ocurrencia de un fenómeno FUERTE de La Niña
	

4. Climate change scenarios

For the analyzes, the climate change scenario maps are used for the temperature and precipitation variables of RCP 6.0 for the period 2011-2040.

Climate change scenario to 2040 for temperature change	Climate change scenario to 2040 for precipitation change