

PROBABILISTIC DROUGHT RISK MODEL FOR THE AGRICULTURE SECTOR

What is a probabilistic drought model?

It is a methodology to evaluate regional droughts events that have not happened yet, through the generation of future climate conditions that combines precipitation deficits with higher than average temperatures for a certain period of time, in a particular geographic area.

Using the information of future stochastic events, a prospective drought assessment for the agriculture sector can be performed to evaluate crop damages and quantify losses. For example, the total yield reduction due to water stress can be calculated for the cropland of a region or the entire country, for the different

crop growth stages. Also, the reduction in livestock production can be quantified from the reduction on grassland available for animals during drought events.

How is drought risk quantified?

An innovative probabilistic model for drought hazard and risk assessment is applied, being the first fully probabilistic approach for drought modeling. The next image shows a summary of the methodology for agricultural drought risk assessment.

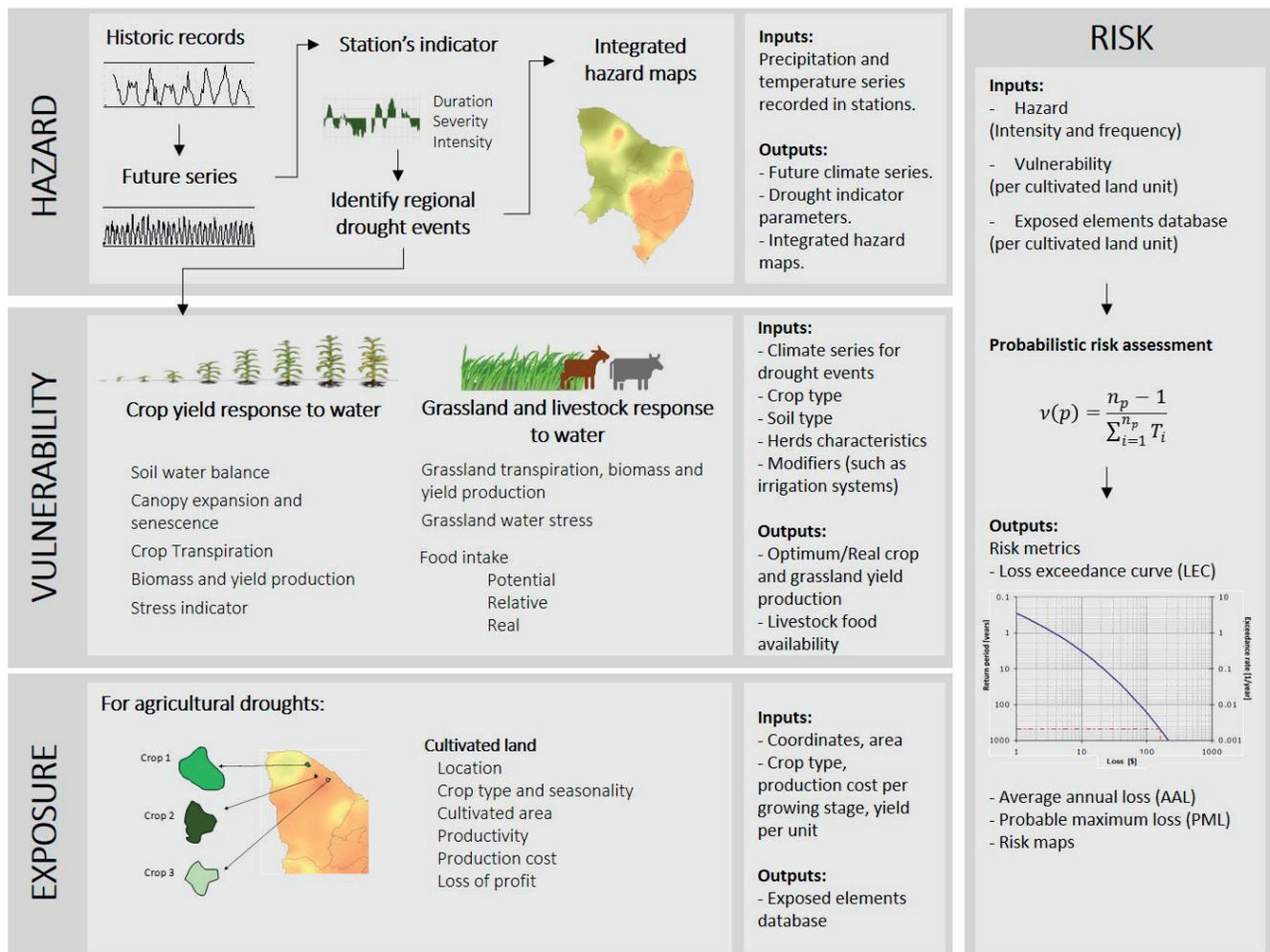
First, **hazard** is modeled from precipitation and temperature historical records, by generating thousands of simulations using



a stochastic climate generator. From the simulated climate, hundreds of synthetic droughts are identified using a wide variety of drought indices proposed in recent literature. Next, a database of **exposed elements** is created with information of location, crop characteristics (type and seasonality), area, yield and production cost of each cultivated unit area. For the particular case of livestock, data on grassland (location, quality of grass) and herds (number of animals, physical characteristics) are needed to estimate the difference between food intake (dry matter demand) and grass availability. Later, **crop vulnerability** is estimated as the difference between the optimal yield production (with no restrictions for water or nutrients availability) and yield production under water deficit, by

using state-of-the-art water response models, which are calibrated for better performance under different water availability scenarios. Finally, drought **risk** is assessed in terms of economic losses due to yield reduction. Risk is quantified in a fully probabilistic way, following the framework of Ruin theory, which is the base of many catastrophe models for the insurance and financial sector. Risk metrics such as the Average Annual Loss (AAL) or the Probable Maximum Loss (PML) are delivered as comprehensive risk indices.

Climate change can be incorporated to compare how hazard changes under uncertain future climate. Consequently, the results of drought risk assessments can be compared to establish to what extend a projection on



rising temperatures and decreasing rainfall can increase severity and frequency of water stress events.

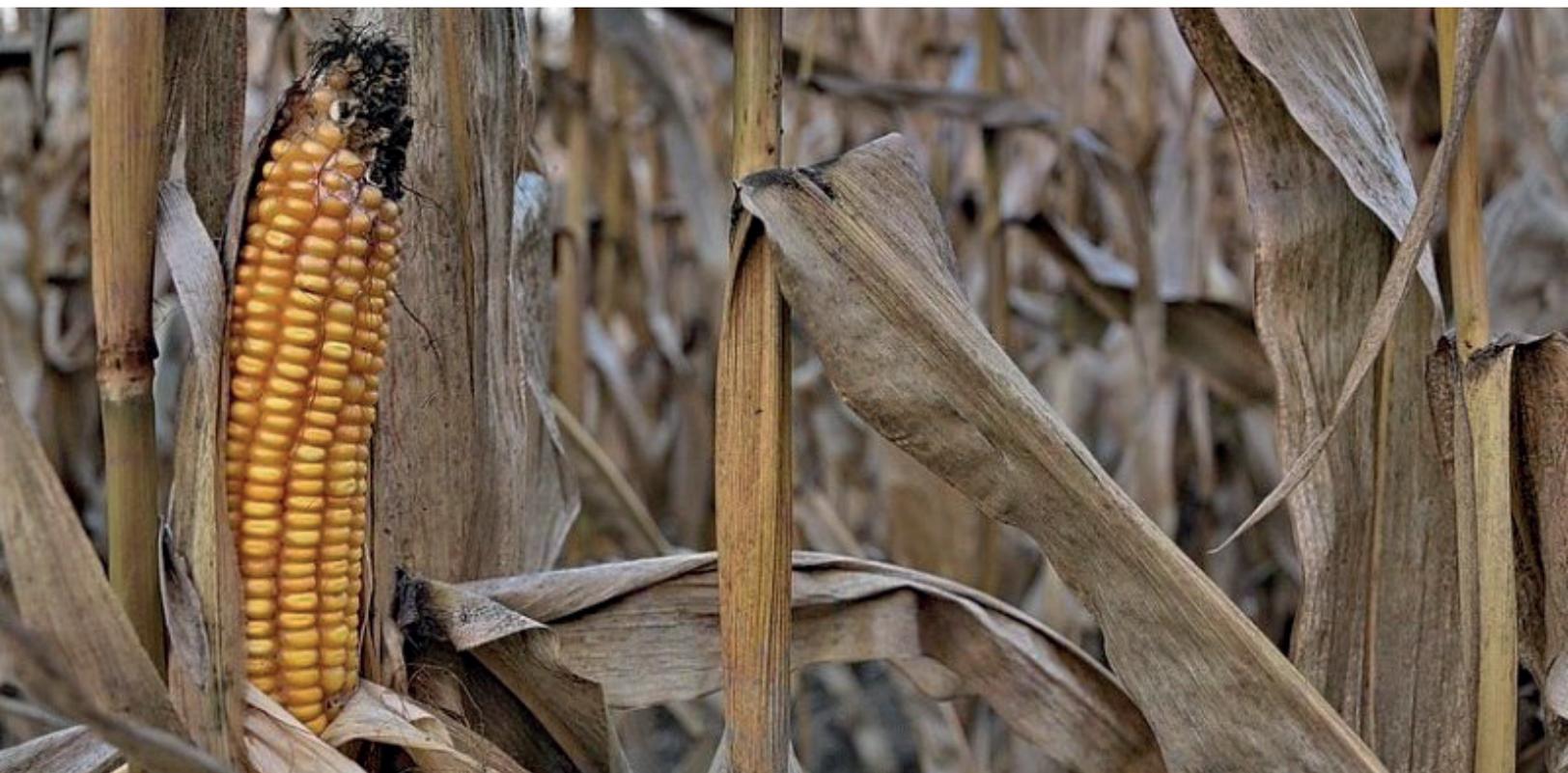
This methodology does not aim to forecast the occurrence of hazardous events. Also, the estimation of economic impacts for the agricultural sector is limited to the estimation of losses associated to the difference between the optimal harvest and the one reached under water stress conditions, valued according to production costs. Losses associated with a decrease in product quality, which may imply a lower sale price, are not considered. Losses are assumed to be a product of the threatening event and do not consider external factors such as market variations, disease outbreaks or pests, among others.

Due to the complexity of droughts as hazardous phenomena and the interactions between the socio-ecological systems during these events, research on drought risk is limited worldwide. However, quantifying risk and its hazard, exposure, and vulnerability components brings tools to make decisions which aim to reduce the social vulnerability when droughts occur.

Some applications of the drought risk model results are:

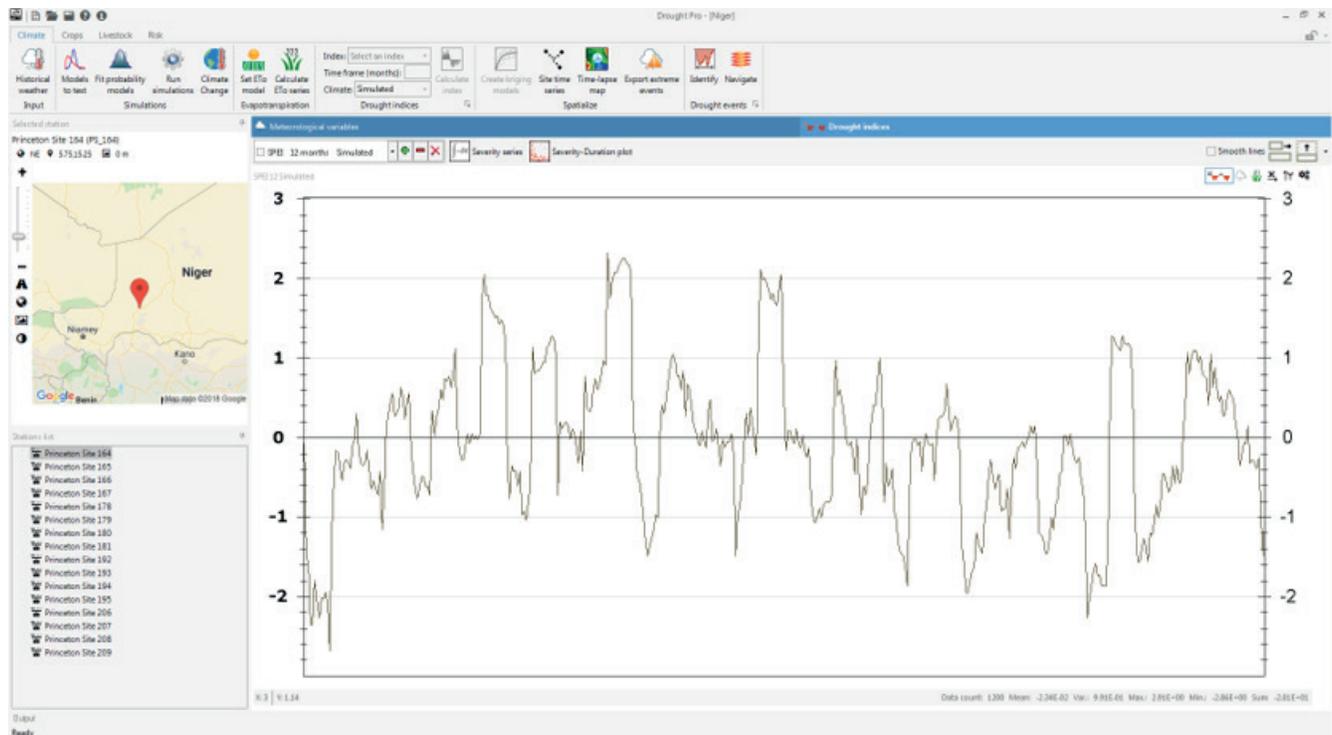
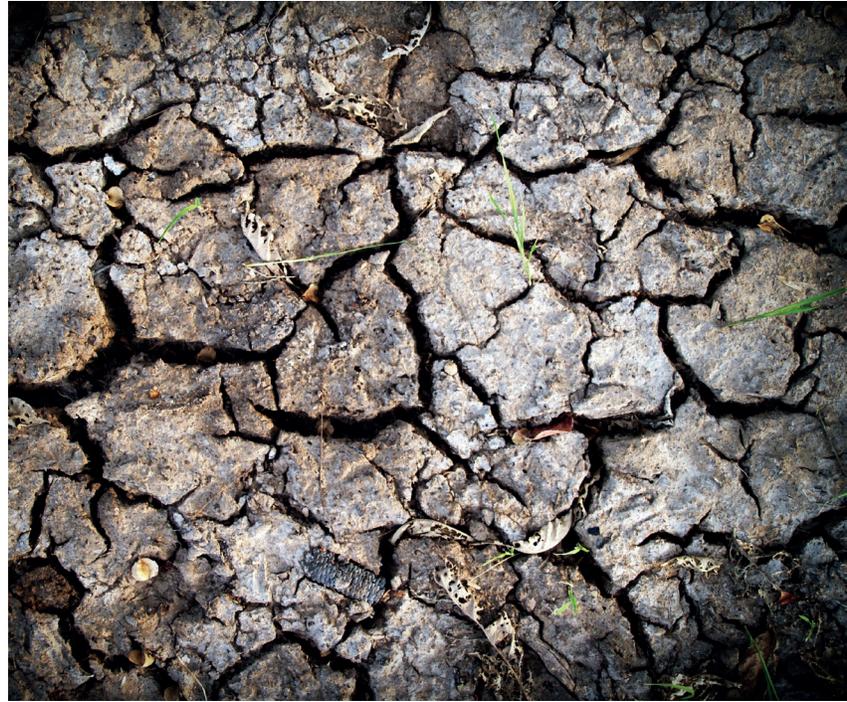
- Land planning using integrated hazard maps: Where and which crops can be sown to reduce the expected losses? Where is the optimal location to establish new agro-industrial projects? In which regions of a country is imperative to use drought-resistant seeds?
- Infrastructure project investment: Which irrigation district must be prioritized?
- Agriculture insurance to transfer risk: Which is the pure risk premium?
- Cost-benefit analysis for crop management initiatives (irrigation, reservoir construction, fertilizers, crop rotation).
- Climate variability adaptation strategies.
- Loss estimation for the livestock sector associated with the reduction of available food (cattle grazing).

These applications can be developed in the local, subnational or national scales by public or private initiatives. This is not a forecasting model, and then it cannot be used as an early warning system.



Drought Pro: a software for drought risk assessment

Drought Pro is a software developed by INGENIAR Risk Intelligence, that implements the abovementioned probabilistic drought risk assessment methodology. It estimates losses in crops and livestock exposed to drought events, making use of vulnerability models that relate the available water deficit for the crop with its growth and crop production. The following figure shows an example screen of Drought Pro for the evaluation of crop drought risk. Drought Pro allows you to store, edit and update information on hazard, exposure, vulnerability and risk. This software is an independent platform, developed with advanced programming tools.



Drought Risk assessment: case studies

The probabilistic risk assessment methodology for droughts was published in Bernal et al. (2017) and implemented in the software Drought Pro (G. Bernal et al., 2018). It has been used to estimate drought risk assessment for the agriculture sector in Central America, Uruguay, Niger and Kazakhstan. The final reports of the mentioned projects can be accessed online at <https://www.researchgate.net/project/Drought-hazard-and-risk-assessment-New-probabilistic-and-holistic-methodology-Evaluacion-de-amenaza-y-riesgo-por-sequia-Nueva-metodologia-probabilista-y-holistica>.

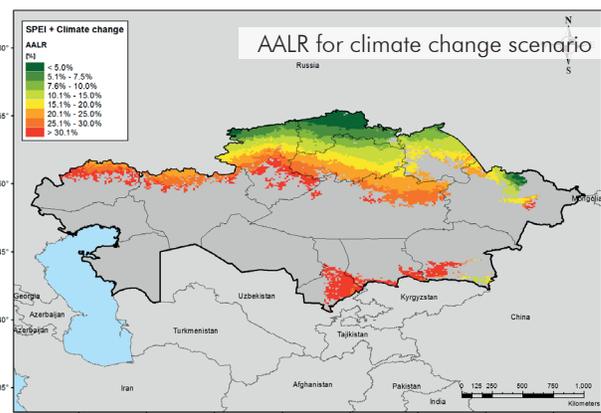
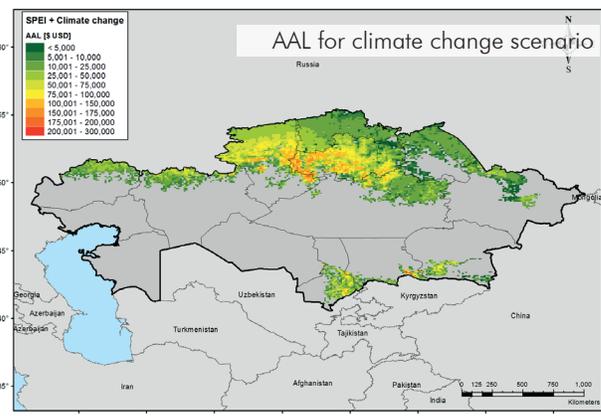
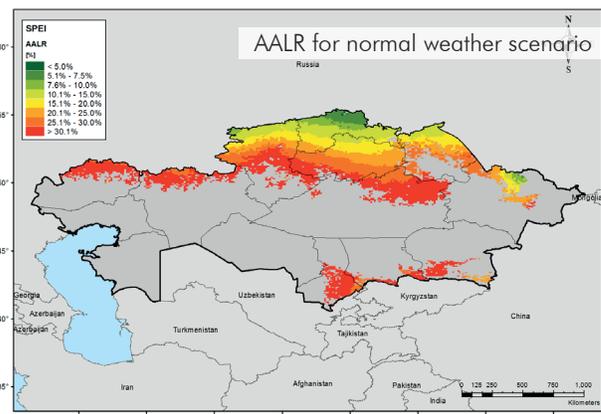
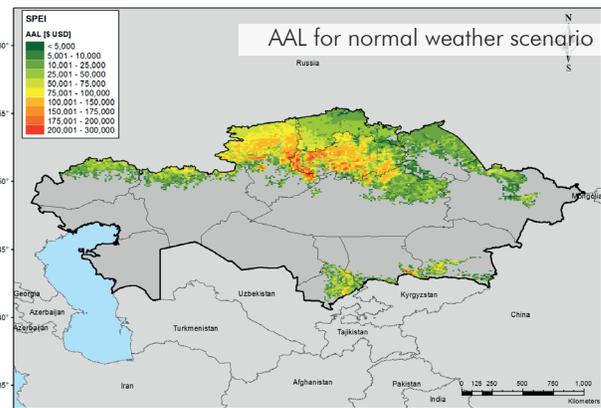
Agricultural Drought Risk: the case of Kazakhstan.

Prepared for the UN Economic and Social Commission for Asia and the Pacific – ESCAP (2018)

A fully probabilistic drought risk model has been used to estimate the economic losses over vulnerable and exposed cultivated land units of rainfed spring wheat crops in Kazakhstan, for both the current weather conditions and considering the potential effects of climate change in the region. This study was part of the project: “Development of multi-hazard risk assessment for Central and East Asian countries in the Asia Pacific region” by the UN Economic and Social Commission for Asia and the Pacific – ESCAP.

The risk results for the drought risk assessment in the wheat crops in Kazakhstan are presented in the following maps as the Average Annual Loss, total in US dollars and relative to its exposed value, for the normal weather and climate change scenarios. These maps are useful to identify drought prone areas in the country and prioritize adaptation and transformation initiatives to reduce vulnerability.

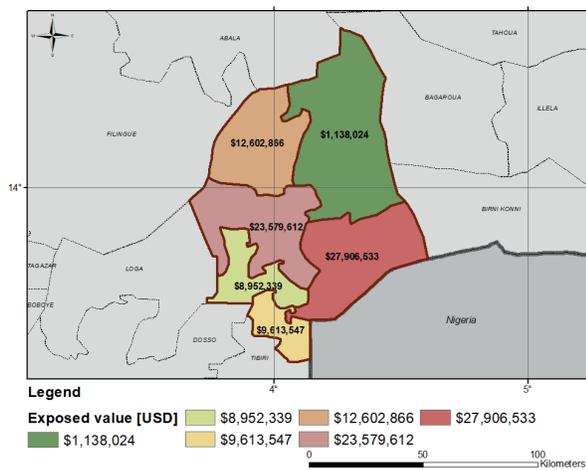
AAL (Average Annual Loss)
AALR (Relative Average Annual Loss)



Estimated risk of loss of Mil production due to changes in precipitation.

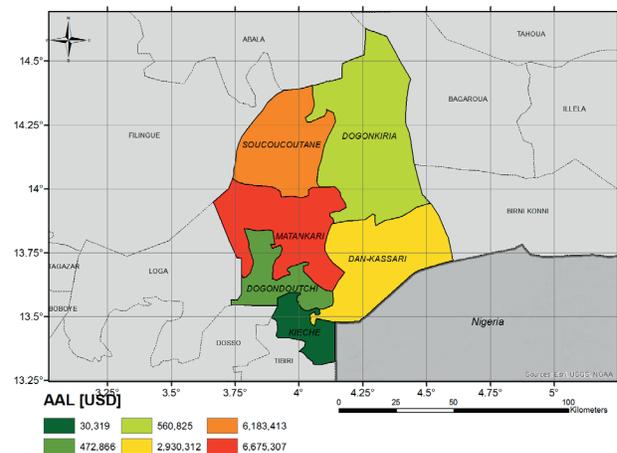
Prepared for the University of Geneva-UNIGE. (2018)

This project aims to address the challenge to assess drought risk for the Dogondoutchi Department in the Dosso Region of the Republic of the Niger. The case study limits to rainfed millet production and assess crop yield reduction under water stress conditions. This study was part of the project: "Niger



disaster risk information system" (Contract reference Grant S1-32CPL-000315) by the UN Environment Science Division and the University of Geneva.

The maps that resulted from the drought risk assessment in the millet crops in the Dogondoutchi department in Niger are presented in the following figure. Data was aggregated to municipal level in the Dogondoutchi department. Results show the most drought prone areas in this department.

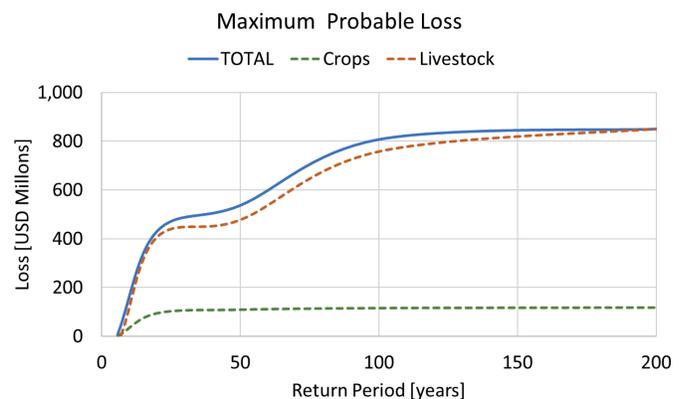


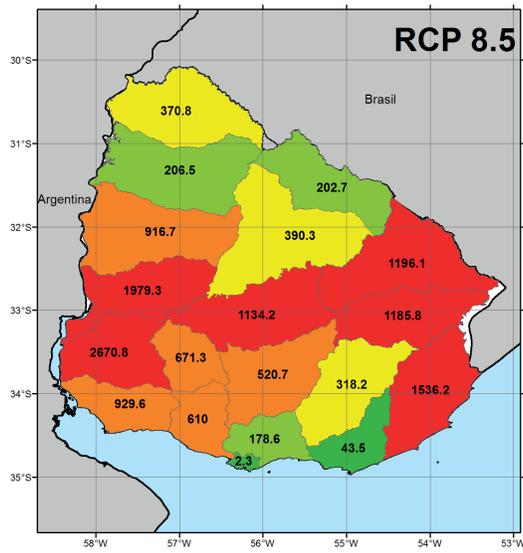
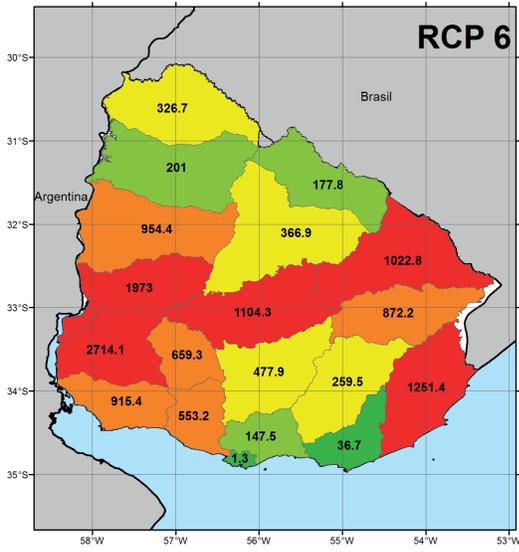
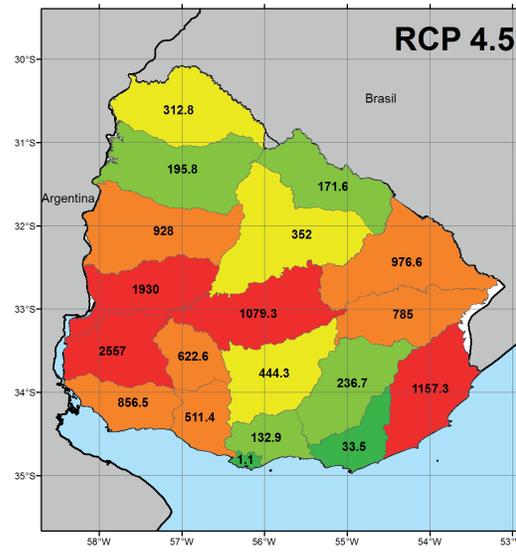
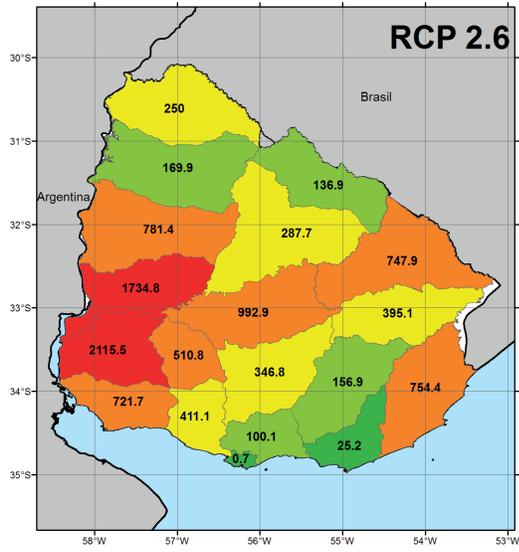
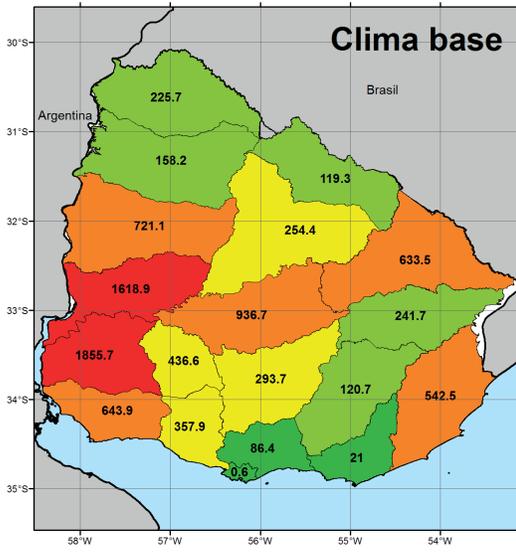
Disaster Risk Profile for Uruguay. Impacts on crop and livestock production.

Prepared for the Inter-American Development Bank. (2017-2018)

The objective of this project was to assess drought risk in Uruguay. Drought risk assessment was performed to a stock of crops selected considering food security (subsistence farming) and their role in national economy (national and international trade). Additionally, livestock, as a main agriculture activity of the country, was included in the analysis to estimate the reduction in meat production due to a reduction in the amount of food (grass dry matter) available for the animals. The Project included the potential effects of climate change projections (increasing temperature and variable precipitation) besides the analysis under current normal weather conditions. It

was shown that the effect of climate change is still uncertain and adds a layer of complexity to current vulnerabilities and risks. The following graph shows the Probable Maximum Loss Curve for the livestock production, crop production and total. Also, the following maps shows the results of the average annual loss by department (Green is lower risk and red is higher risk).





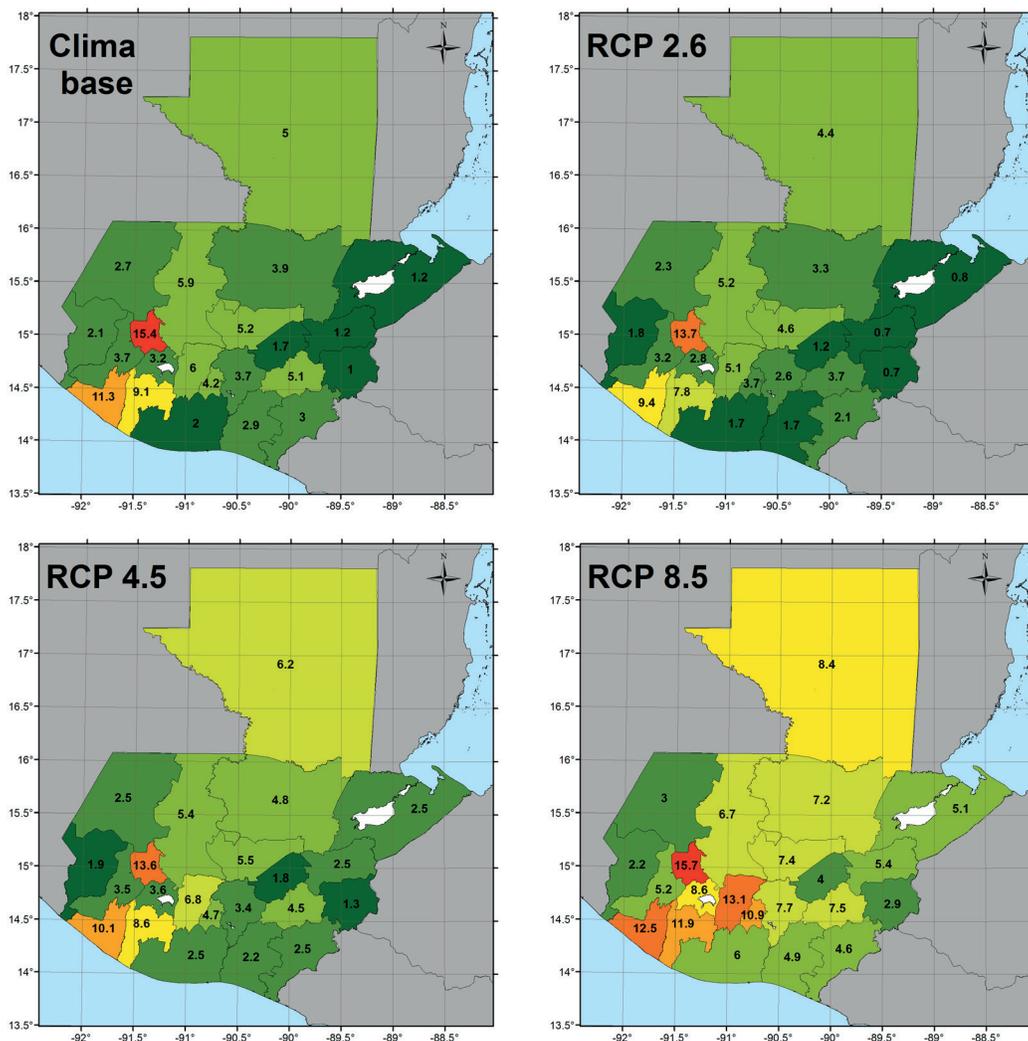
Disaster Risk Profile for the North Region of Central America (Drought in the Trifinio region).

Prepared for the Inter-American Development Bank. (2017-2018)

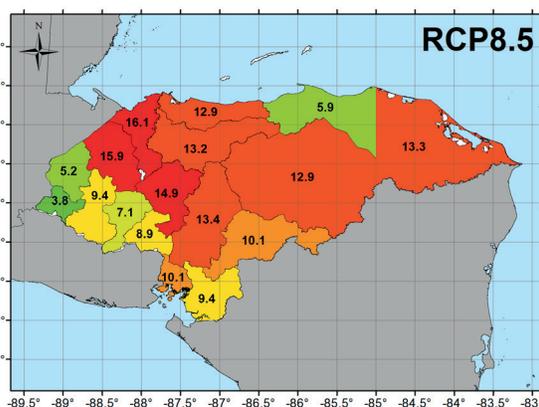
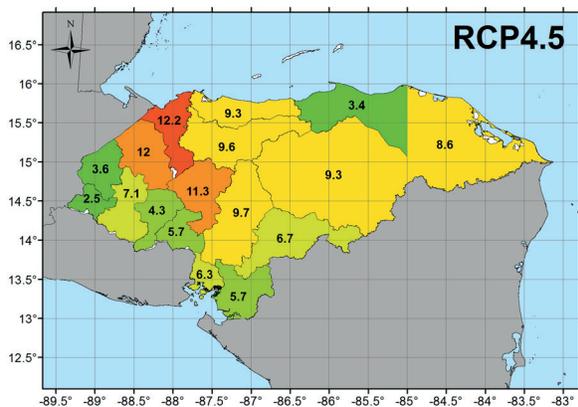
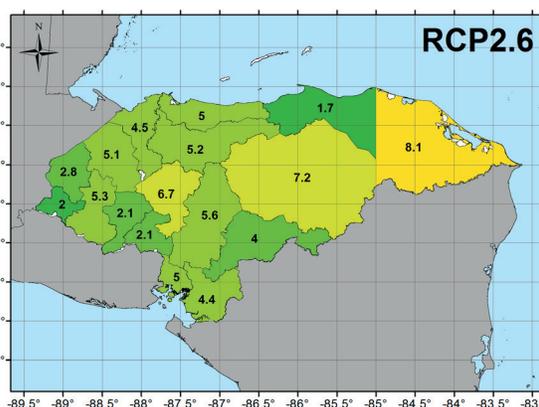
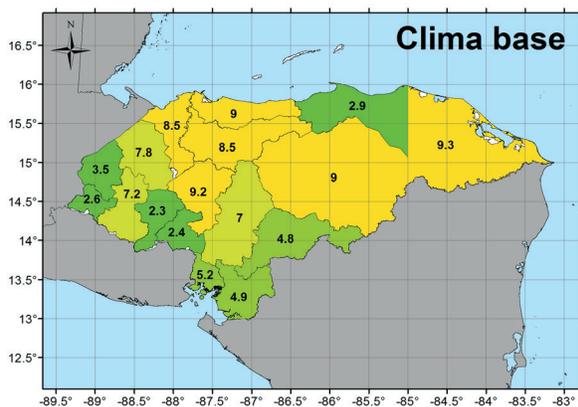
The objective of this project was to assess drought risk in El Salvador, Guatemala and Honduras, countries where is located the Dry corridor, an affected area by extreme climate-related hazards. Drought risk assessment was performed to a stock of crops selected by country considering food security (subsistence

farming) and their role in national economy (national and international trade). The Project included the potential effects of climate change projections (increasing temperature and variable precipitation) besides the analysis under current normal weather conditions. It was shown that the effect of climate change is still uncertain and adds a layer of complexity to current vulnerabilities and risks. The following maps shows the results, for each country, of the average annual loss by department. (Green is lower risk and red is higher risk).

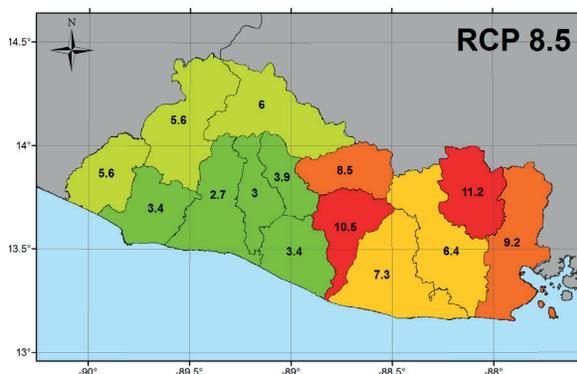
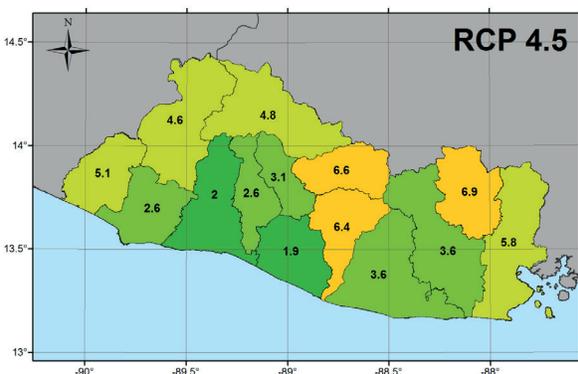
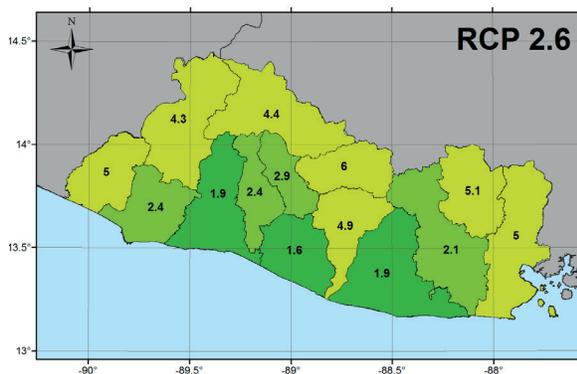
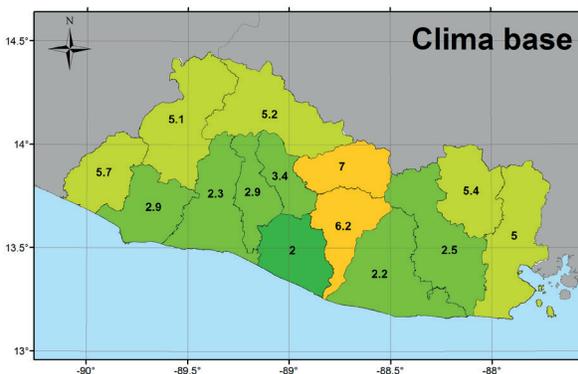
GUATEMALA



HONDURAS



EL SALVADOR



About Drought Pro

Drought Pro implements the probabilistic drought risk assessment methodology in the agricultural sector proposed by Bernal et.al. (2017). Drought Pro makes use of AquaCrop .NET as a calculation engine for response to crop water. AquaCrop .NET is an independent development of INGENIAR Risk Intelligence, based on the AquaCrop-OS software, developed by Tim Foster et.al. (2017).
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<http://www.ingeniar-risk.com/servicios/software/capra/drought-pro>

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Foster, T., Brozović, N., Butler, A.P., Neale, C.M.U., Raes, D., Steduto, P., Fereres. E., Hsiao, T.C. (2017) *AquaCrop-OS: An open source version of FAO's crop water productivity model*. *Agricultural Water Management*. 181: 18-22.

