For office use only	Team Control Number	For office use only
T1 ________________	**79839**	F1 ________________
T2 ________________		F2 ________________
T3 ________________	Problem Chosen	F3 ________________
T4 ________________	**E**	F4 ________________

2018
MCM/ICM
Summary Sheet

Summary

In the past few decades, climate changes around the world have become an increasingly severe global issue, playing a more and more significant role in economic development, social stability, and ecological health.

In task 1, we build a mathematical model concerning climate changes and the vulnerability of a state. We present an in-depth analysis of the relevancy between climate changes and state's fragility both theoretically and experimentally via a modeling approach named **C**limate **C**hange **A**ware **V**ulnerability Model (CCAV). We import several concepts to quantify the vulnerability of a state : **Exposure** (E), **Sensitivity** (S) and **Resilience** (R). We give explicit definitions of all variables, clear-cut equations and detailed input data source for calculation. With the help of a flow chart, users can better understand how our model works and with a thorough analysis of equations, users can understand why our model works well. Then we use the model to calculate the average score of three continents to estimate the division values for classifying countries into fragile, vulnerable and stable ones.

In task 2, we select Chad as the object of our case study. First we define a numerical measure **R**elative **F**ragility **M**etrics (RFM) for the yearly change ratio of vulnerability. Then we run an empirical study and a two-stage user study on our result and the **F**ragile **S**tate **I**ndex (FSI) using RFM. The result shows that the CCAV can generate results similar with FSI.

In task 3, we select Haiti as another case. Similar with task 3, we perform a numerical study and a two-stage user study. The result shows that CCAV created more comfortable and reliable results than FSI. By then, we choose a value at $\pm 3\%$ **RFM** as a threshold for the cannot-ignored impact of climate change.

In task 4, we find that intervention including actual measures and precautionary measures have a positive effect on vulnerability by decreasing the exposure(E) and increasing the resilience(R). To be exact, taking two European Countries as a example, we use **regression analysis** to discover a relationship between **Environmental protection expenditure(EPE)** and **GHG net emissions**. By analyzing the declining speed of vulnerability we find an elbow point to present the optimal year in which both the total cost and vulnerability is minimum.

In task 5, we discuss the performance of CCAV on smaller and larger scales respectively. We come to a conclusion that on a national scale, our model has the best performance because the influence of external factors such as support from vicinity, are mostly weakened. When the "state" becomes bigger or smaller, the influences of non-climatic factors begin to increase, and cannot be ignored in the vulnerability. In order to fit our model with different scales, we need to quantify the external non-climatic factors.

Finally, we analyze the strengths and weaknesses of the model we built in this paper, and give our thoughts about future work.

CCAV: Climate Change Aware Vulnerability for Demonstrating Regional Stability and National Fragility

Team 79839

February 13, 2018

Contents

1 Introduction

1.1 Background

In the past few decades, climate changes around the world have become an increasingly severe global issue. The effects caused by climate changes include but not limited to global warming, acidic rain, greater greenhouse gases concentration and sea level rise. More frequent extreme weathers such as El Niño and La Niña phenomena around the ocean and unstable environment have already affected not only the ecological system but also the social circumstances in many different regions seriously [19], e.g. more than 530,000 people died as a direct consequence of almost 15,000 extreme weather events, and losses of more than USD 2.5 trillion (in PPP) were caused from 1992 to 2011 globally[11], millions of people in the areas of Northeastern United States and Canada were locked in serious snowstorms[14] faced up with heavy casualties and economic losses, while more than 39 million people may be hit with food shortage and economic ruin because large swathes of Africa are experiencing severe droughts[10].

The fragility of a “state” refers to the inability of the governmental apartment to provide basic essentials such as food, water and emergency medical care to the suffering people when climate shocks occur to the specific area. According to the evidence report of the Intergovernmental Panel on Climate Change (IPCC) of the United Nation[7], these climate changes are increasingly been indicated or understood as a region-aware security issue which plays a significant role in economic development, social stability, population and ecological health.The net damage costs of climate change are likely to be significant.

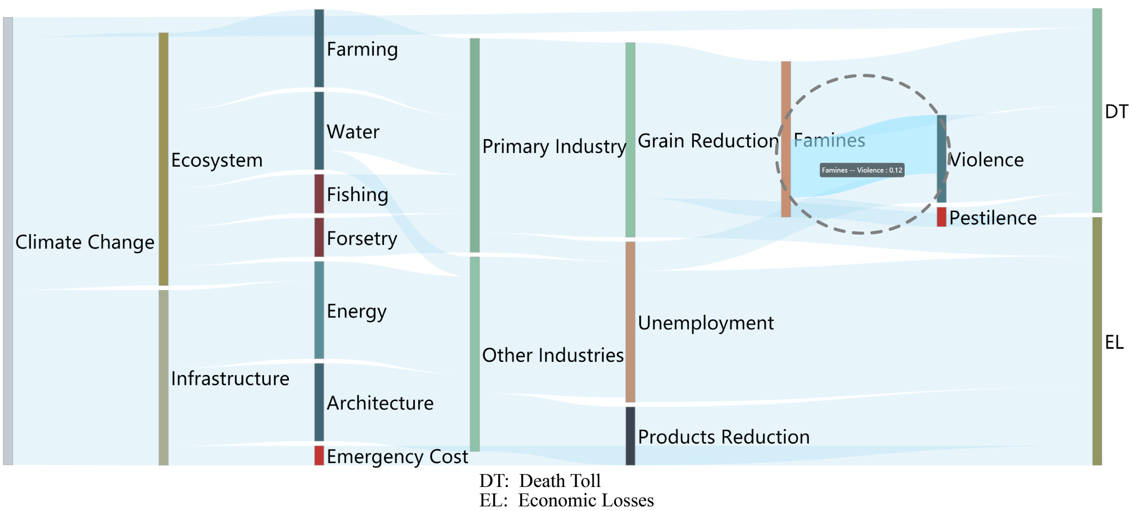

Figure 1: An interactive sankey diagram of relevant factors which could be effected by the climate change. The widths of the band means influences, e.g. the selected band (circled) shows that famines contributes 0.12 to violence.

1.2 Problem Analytic

In spite of many previous works showing the evaluation criterion of fragility and conflicted states[18, 8, 21, 16, 12], it is still not clear what a role climate change really plays on the oscillations for fragile condition of a state.

Climate changes such as floods, storms or averaged sea level changes can make direct consequences and subsequent influences to damage the ecosystem and infrastructures. These damages can be summarized as follows:

- **Death toll**
  - **Instant death**
    The mortality increases due to climate shocks like floods, storms and other catastrophes.
  - **Indirect death**
    The death toll caused by a series of consequences of climate changes in lack of emergency assistance and medicine, food and water shortage, pestilence, violence and so on.
- **Economic losses**
  - **Infrastructure damage**
    The destruction of buildings, roads, bridges and other engineering structures.
  - **Emergency assistance cost**
    The financial spending during post-disaster rescue operation such as rescue personnel and supplies.
  - **Subsequent GDP decrease**
    The long-term economic impact of climate changes on various industries, especially first industry.

These climate changes have straight-forward bad effects on primary industry (e.g. agriculture), and will also reduce the gross annual value of secondary and tertiary industries (e.g. manufacturing and services) by destroying the production facilities, lacking clean water and reducing consumer spending. On the other hand, these damages may cause famines, which could lead to serious conflict or even violence in many fragile “state” with high possibility. Fig. 1 provides an interactive framework about how climate change influences fatalities and economic losses by a series of factors.

Thus, it’s significant to propose an effective processing to demonstrate highly useful and cost-efficient recommendations for the fragile states to reduce its instability. For strong and stable regions, to better understand hidden features of the relations between different human factors and to resolve the side-effects successfully is also a highly valuable topic.

In this work, we present an in-depth analysis of the relevancy between climate changes and state’s fragility both theoretically and experimentally via a modeling approach named Climate Change Aware Vulnerability (CCAV), then we discuss the robustness of our model. In detail, we provide a new perspective for mathematically modeling the influences of climate change to regional instability using multiple metrics and identifying its stable condition in Sec. 3. We run 2 case studies in Sec. 4 on 2 states selected from the Fragile State Index[15] (Chad and Haiti), by conducting numerical comparisons and user judgments using 10 years national dataset, to evaluate CCAV model via the past climate conditions. In Sec. 5, according to the modeling results, we discuss different ways that governance and human intervention could affect our model and provide interventions for state-oriented interventions on harm reduction. Then, we demonstrate the extension-ability of CCAV measure by conducting small and large scale analysis in Sec. 6. Finally, we indicate the strengths and weaknesses in Sec. 7 and conclude this paper and future works in Sec. 8.

2 Assumptions

- Statistical errors are not considered in data processing. The data sources are believable and actual.
- To complete random missing data, we use interpolation method.
- There is a relatively stable political and economic environment for Chad and Haiti over a few decades.
- Large-scale geological changes and other unpredictable large-scale disasters are impossible to happen during several hundred years.
- In recent years, there is no country being split into many countries or annexed by other countries.

Under the above basic assumptions, we can set out to construct our model.

3 Mathematical Model

In this section, we introduce a model which is constructed from several aspects to evaluate the vulnerability of a state as well as notice the direct or indirect impact of climate change.

3.1 Types and Effects for Climate Change

Climate change, a multi-scale global problem that is characterized by diverse factors, multiple stresses and multiple time scales, can be mainly classified into two types: **climate extreme** and **long-term climate change**.

According to the IPCC Synthesis Report[17], the definition of climate extreme (extreme weather or climate event) is an event which rarely happens at a particular place or in a particular time of year (e.g. floods and heat wave). On the contrary, long-term climate changes tend to be more gradual and incremental.

The influence caused by these long-term changes such as globally averaged combined land and ocean surface temperature anomaly, can be more conspicuous only when the changes accumulated to a certain extent.

3.2 CCAV: Climate Change Aware Vulnerability Model

The glossary of last IPCC Synthesis Report[17] defines **Vulnerability** (to climate change) as follows: the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and to adapt.

Based on the well-defined **Vulnerability**, we propose a model to measure the vulnerability of a state: **C**limate **C**hange **A**ware **V**ulnerability Model (CCAV). CCAV is designed to help people better understand the significance of climate changes and find practical countermeasures. Fig. 2 shows a general pipeline of CCAV. In this model, we treat the vulnerability of a system as a factor which is determined by exposure to hazard, sensitivity to the environment and the resilience that a system performs. Before we take a deeper look at our model, several important concepts must be defined specifically:

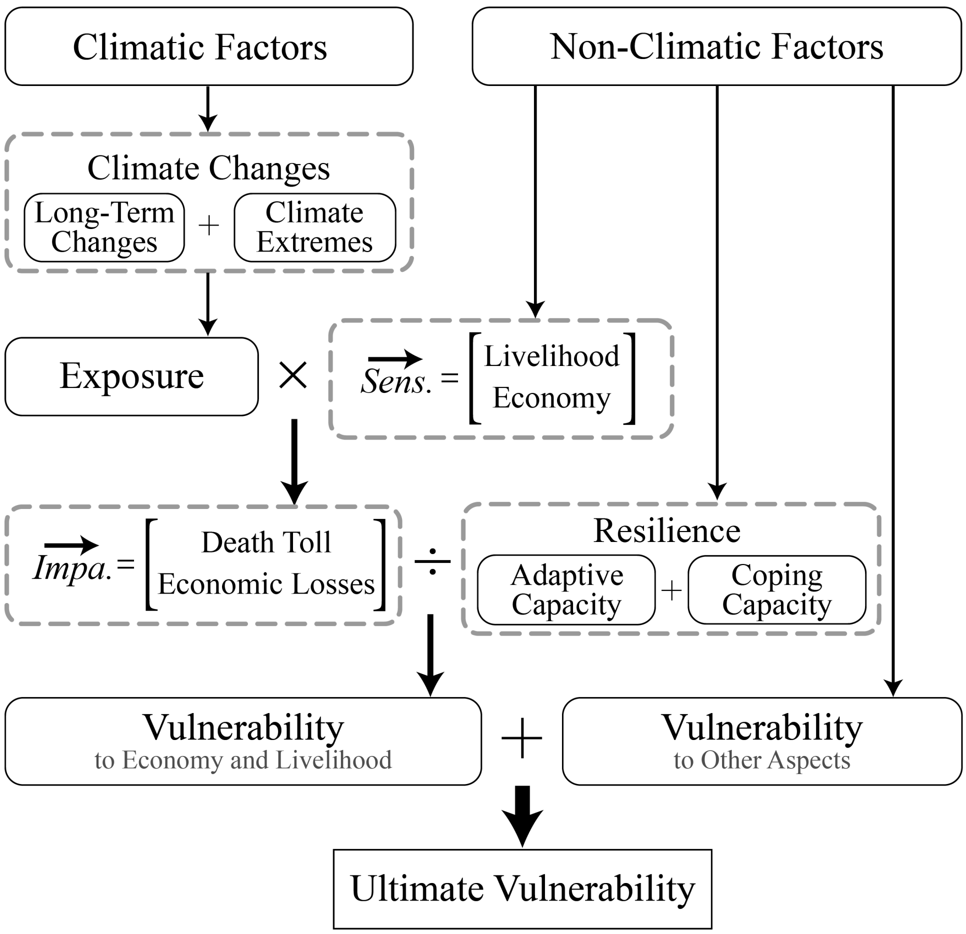

Figure 2: A flow chart for generalizing our mathematical model.

Exposure (E) means the characteristics of stresses which are mainly generated by the climate changes, development of society, government policy or other factors.

Sensitivity (S) is defined as a degree of a system's endurance and resistance when faced up with a disturb or shock.

Resilience (R) refers to the ability to adjust or recover when a system suffers from perturbations. It includes **coping capacities** and **adaptive capacities**.

We notice that there are two types of climate change (climate extremes and long-term climate changes) which play a significant role in vulnerability through both directly and indirectly influencing the stresses that a system faces (Exposure), a global-scale continents-based example as shown in Fig. 3. Concerning what we pointed out at the beginning (climate change influences fatalities and economic losses eventually), we divided the vulnerability into three main parts: vulnerability of livelihood, vulnerability of economy and vulnerability of other aspects.

3.2.1 The General Function of Vulnerability

Generally, we use a function where the key parameters of vulnerability in a system are the stress to which it is exposed (E), its sensitivity (S) and its resilience (R).

In consideration of climate changes, both climate extremes and long-term climate changes have direct or indirect influences in exposure (E). Thus in our model, we use two kinds of exposure to represent the total exposure that a system confronts: **exposure to climate extremes** (E_{ce}) and **exposure to long-term climate changes** (E_{lt}).

$$E = E_{ce} + E_{lt} \tag{1}$$

As for S, we quantify the sensitivity of a state from five different perspectives, which covers A) Public infrastructure, B) Housing conditions, C) Lifespan, D) Poverty and dependencies, E) Economic capacity and income distribution. In the following content, we will show that these 5 indicators are partly used respectively for livelihood and economy (only 3 of them will be used for each), thus we get different sensitivity values for livelihood and economy.

Particularly, we define a term Impact (I) to represent the cooperative effect of both the exposure (E) and sensitivity (S) in Eq. 2.

$$I = E * S \tag{2}$$

As for resilience, we apply two parameters AC and CC. AC is the abbreviation of Adaptive Capacity and CC is the abbreviation of Coping Capacity. Adaptive Capacity is measured by five factors: A) Education and research, B) Gender equity, C) Environmental status / Ecosystem protection, D) Adaptation strategies and E) Investment. Similarly, we define Coping Capacity as a combination of 5 factors:

Figure 3: A sun burst visualization for demonstrating the most important climate factors in different regions by country. The inner circle shows different continents, the center circle shows the mainly climate factors in this continent, the outer circle illustrate countries suffered from the attached factor.

A) Government and authorities, B) Disaster preparedness and early warning, C) Medical services, D) Social networks, E) Material coverage. Resilience can be expressed as the sum of Adaptive Capacity and Coping Capacity:

$$R = AC + CC \tag{3}$$

Finally, we use the quotient of impact (I) and resilience (R) as our result of measurement of the fragile degree of a state:

$$\vec{V} = \frac{\vec{I}}{R} = \frac{(I_{LIV}, I_{ECO}, I_{Others})}{R} = (V_{LIV}, V_{ECO}, V_{Others}) \tag{4}$$

3.2.2 The Vulnerability of Livelihood V_{LIV}

The vulnerability of livelihood is calculated from exposure (E), Sensitivity (S) and Resilience (R).

- Exposure of Livelihood exposed to climate extremes

  For the E_{ce}, in order to calculate exposure to climate extremes at the national scale, several spatial data sources are needed such as information regarding the gridded population and frequency of each climate extreme and its spatial extent. Hazards of great spatial extent attain relatively high values according to their potential to affect all people in the respective area. Therefore, to determine exposure (E) more accurately at a national level, the calculation of the ratio of people exposed to climate extremes is required, which involves the consideration of land area exposed and population distribution. We use **Damage** (D) to indicate the number of people exposed to each of these climate extremes, especially several representative hazards such as cold wave (D_{cw}), heat wave (D_{hw}), floods (D_{floods}), droughts ($D_{droughts}$), cyclone ($D_{cyclone}$), storms (D_{storm}), wildfire (D_{wf}), earthquakes (D_{eq}) and so on. On this occasion, people in exposure to climate extremes specifically refers to the average death toll caused by each natural hazards.

  $$D = \{D_{cw}, D_{hw}, D_{floods}, D_{droughts}, D_{cyclone}, D_{storm}, D_{wf}, D_{eq}, ...\} \tag{5}$$

  Meanwhile, considering the likelihood of climate extremes, We use **Possibility**(P) to denote it, which means the probability of each hazard happening to a state.

  $$P = \{P_{cw}, P_{hw}, P_{floods}, P_{droughts}, P_{cyclone}, P_{storm}, P_{wf}, P_{eq}, ...\} \tag{6}$$

  The sum of the product that damage caused by each hazard and the Possibility of each hazard represents Exposure (i refers to climate extremes type and n refers to the number of the climate extremes):

  $$E_{ce} = \sum_{i=1}^{n} D_i * P_i \tag{7}$$

- Exposure of Livelihood to long-term climate changes

  As for E_{lt}, we also use Eq.(6) to calculate. However, on this occasion, the meanings of terms **D** and **P** are slightly different. Instead of using indicators of extreme climate shocks, we employ long-term indicators including sea level rise, land and ocean surface temperature anomaly, CO_2 concentration and precipitation. For instance, we consider the population exposed by 1m sea level rise, calculated by extracting the exposed population information from the 1m inundation file and the population dataset.

- Sensitivity for Livelihood

  With regard to Sensitivity for livelihood, we employ the variable S_{LIV} to represent it. We elaborately pick three factors relative to livelihood: Housing conditions(D), Lifespan(E) and Poverty and dependencies(F). We use the following equation to calculate S_{LIV}: (the definition of all indicators are shown in Table. 1)

$$S_{LIV} = \frac{1}{3}D + \frac{1}{3}E + \frac{1}{3} * (\frac{1}{2}F1 + \frac{1}{2}F2) \tag{8}$$

- Resilience of the state

  As is shown in Eq. 9, 10, to find the resilience of the state, we should respectively calculate adopting capacity AC and coping capacity CC. We use the following two equations to calculate: (the definition of all indicators are shown in Table. 1)

$$AC = \frac{1}{4} * \sum_{i=1}^{2} Li + \frac{1}{4} * \sum_{i=1}^{2} Mi + \frac{1}{4} * \sum_{i=1}^{4} Ni + \frac{1}{4} * \sum_{i=1}^{3} Oi \tag{9}$$

$$CC = \frac{1}{4} * \sum_{i=1}^{3} Hi + \frac{1}{4}I + \frac{1}{4} * \sum_{i=1}^{2} Ji + \frac{1}{4}K \tag{10}$$

  Then we can get a score of resilience (R) of a state by adding AC and CC. With three variables E, S_{LIV}, and R, we can quantify the vulnerability of livelihood of a state.

3.2.3 The Vulnerability of Economy V_{ECO}

Apart from livelihood, we also take the vulnerability of economy into consideration. Similarly, exposure (E), Sensitivity (S) and Resilience (R) are respectively calculated and used in our model.

- Exposure of Economy to climate extremes

  We use the same equation from Eq. 7, where the meaning of possibilities P_i of each weather extreme events remain the same while the definition of damage D_i slightly changes. We use the indicator B (Losses per GDP in % caused by hazards) to quantify the economy losses caused by climate extremes.

- Exposure of Economy to long-term climate changes

  The calculation of this part is almost the very same as calculating Exposure of Livelihood to long-term climate changes, but for the definition of damage changed to the economic losses. It is commonly considered that the influences of long-term, world wide climate changes are more obvious in the economic field. Problems such as warmer and more acidic ocean, have impacted domains like sea farming badly. As a result, long-term effects in the economy will be more magnified than in livelihood.

- Sensitivity for Economy

  Similar to 3.2.2, we employ the variable S_{ECO} to represent sensitivity for economy. At this time, we choose 3 different factors relative to economy: Public infrastructures (C), Poverty and dependencies (F) and Economic capacity and income distribution (G). We use the following equation to calculate S_{LIV}: (the definition of all indicators are shown in Table 8)

$$S_{LIV} = \frac{1}{3}D + \frac{1}{3} * (\frac{1}{2}F1 + \frac{1}{2}F2) + \frac{1}{3} * (\frac{1}{2}G1 + \frac{1}{2}G2) \tag{11}$$

- Resilience of the state

  A Resilience of a state is a synthetical measurement of its elasticity confronting all thinkable climate shocks, which is applicable not only in livelihood but also economy. So we use the very same calculated value of *R* in livelihood part to calculate.Then we quantify the vulnerability of economy of a state using the variables E, S_{ECO} , and R in the same way.

3.2.4 The Vulnerability of Other Aspects V_{Others}

In most cases, climatic factors play an important role in affecting a state's economy and livelihood, by which means affect the vulnerability of a state. In these cases, the influence of other factors can be negligible or be represented as a constant.

However, apparently in some cases, non-climatic factors determine a lot. For example, countries like Iraq and Syria are embroiled in wars for several years and as a result, their vulnerabilities strikingly rise during those years. Therefore, we can not exclude these non-climatic factors. If we use a constant to represent V_{Others}, the result can be inaccurate. So we can apply some other index, which does not concern climatic factors, such as Fragile State Index, to the value of V_{Others}.

3.3 Validating the Model

To identify **when a state is fragile, vulnerable, or stable**, we use statistic methods and go beyond the limits of countries. We calculate the weighted average score of vulnerabilities of 3 continents: Africa, South America and Europe as the estimated values of fragility, vulnerability and stability. We use the population of each country as the weight, since most of our data is based on per capita (which can be proved in Table.1). In addition, the value range of CCAV is scaled from 0 to 100, where larger value represents more vulnerability.

We calculate the average value *V1* between Africa and South America, as well as the average value *V2* between South America and Europe. When the vulnerability score of a state is below *V1*, we can call it a fragile state. When a country's score is between *V1* and *V2*, it is a vulnerable state. If the score hits *V2*, then the stableness of the state is considered rather high.

After calculation, we got the value of *V1 = 77*, *V2 = 42*. Thus, for a specific state, after we calculate its vulnerability score (V_x), we can determine its vulnerability grade by the following equation:

$$VulnerabilityGrade = \begin{cases} stable & V_x < V2 \\ vulnerable & V2 \leq V_x < V1 \\ fragile & V1 \leq V_x \end{cases} \tag{12}$$

Our model shows that climate change increases fragility by means of influencing **economy and livelihood directly**.

Furthermore, **indirect** influences can be reflected in data used in the calculation of Sensitivity and Resilience, e.g., 1) population without access to an improved water source and 2) population without access to improved sanitation. To be more specific, climatic factors can influence **demographic, sociopolitical, technological, and biophysical performances** of a state as other factors and indicators.

4 Case Study

We run the case studies for our approach in three different steps. First, we define a numerical measure named **Relative Fragility Metrics** (**RFM**) of a state computed by $(F_i - F_{i-1})/F_i$ (F_i refers to the vulnerability value of the year i calculated by different models). This metric aims to compare our model and existing Fragile State Index (FSI)[15] on same criteria. Second, we present quantitative results with 2 different states: Chad, ranking No.8 of the FSI 2017, and Haiti, ranking No.11 of the FSI 2017. And finally we discuss the results of the qualitative case study by performing two comparisons:

(i) with the **RFM** numerical measure (Sec. 4.3),

(ii) based on human judgments with inviting 11 students majored relevant to state vulnerability (Sec. 4.4).

The purpose of these studies is to compare our CCAV approach with the widely-used FSI rankings and the really international situation.

4.1 Case Study on Chad

The Republic of Chad (Chad) is a landlocked country in Central Africa and the fifth largest of Africa in terms of area. As one of the poorest and most corrupt countries in the world, Chad government does not have enough financial supports for climate change forecasting and disaster prevention[20]. We run the CCAV model on the climate and non-climate parameters of Chad from 2006 to 2017 via the Fig 2 processing, and compare our results with the FSI ranking.

The results of CCAV (blue line in Fig. 4(a)) of Chad is obviously to show that the nation-wide drought and flood heavily influences its vulnerability. If we do not consider about the droughts' and floods' impact, the vulnerability value will reduce to 1.73% from 4.39% in 2015. And via observing the change of RFM, it's clear that a large-scale climate change may cause an unpredictable damage.

4.2 Case Study on Haiti

The Republic of Haiti (Haiti) is a sovereign state located on the island of Hispaniola in the Greater Antilles archipelago of the Caribbean Sea. It has the lowest Human Development Index and is the poorest country in the Americas. It suffers from a series of extreme climate changes including the 2010 Haiti earthquake which is the most severe disaster and humanitarian crisis that the United Nations has ever faced and makes Haiti's government structures and infrastructure almost totally destroyed[2]. Through taking the climate factors and other aspects of Haiti from 2006 to 2017, we compute the CCAV result and compare it with the FSI ranking.

According to the results of CCAV (blue line in Fig. 4(b)), we can find that the year 2011, that is to say, the level of a catastrophic magnitude 7.0 Mw earthquake is what kind of climate change that increases the fragility of Haiti immediately. Experimentally, we choose a value at ±3% **RFM** as a threshold of the time when climate change has a cannot-ignored impact on national fragility.

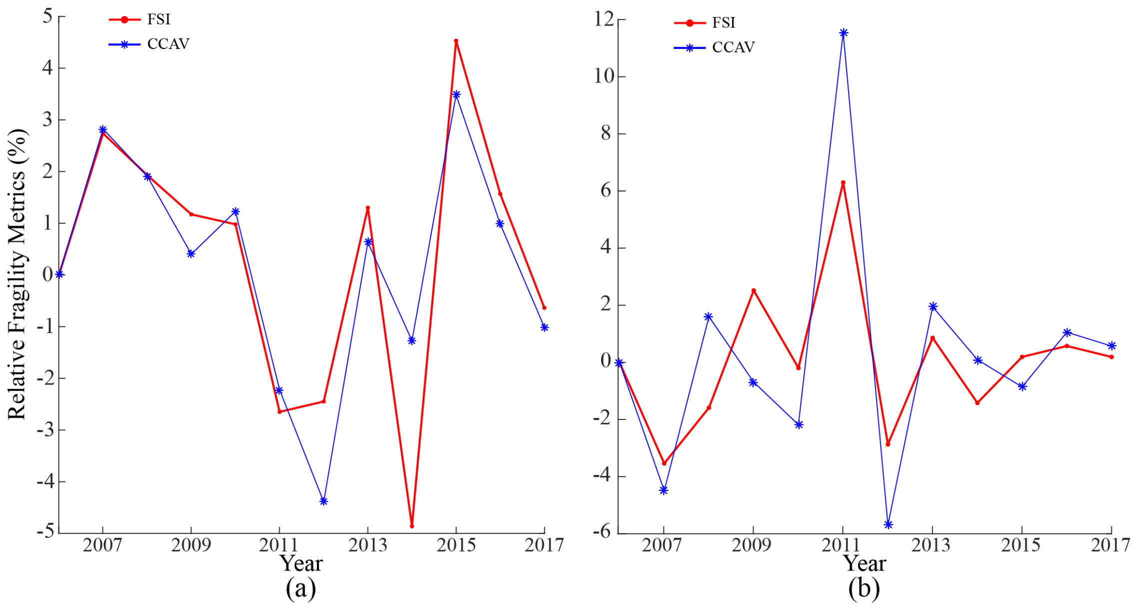

Figure 4: Results comparison. The stared blue line shows the **RFM** trend of CCAV, while the dotted red line shows the FSI trend. (a) is the results of Chad, and (b) is with Haiti.

4.3 Comparison with Numerical Measure

First, we conduct a numerical comparison of CCAV and FSI using the **RFM** measure, as the results show in Fig. 4. Whereas Fig. 4(a) demonstrates the **RFM** trend in Chad, while Fig. 4(b) shows the trend in Haiti both from 2006 to 2017.

The average difference between CCAV and FSI is 0.81% for Chad and 1.83% for Haiti counted by **RFM**. So it's clear that our CCAV model can compute similar results with the state-of-the-art FSI approach in most instances. In addition, our model also can illustrate more about the impact of climate changes, e.g. the extreme nationality destroying[13, 6] caused by 2010 Haiti earthquake via the **RFM** of CCAV in 2011 from Fig. 4(b) with 11.55%.

4.4 Comparison with Human Judgments

By then, we design a two-stage user study using these results. In the first stage of this study, our goal is to evaluate how well CCAV approaches perform in tasks related to measuring national vulnerability. For instance, users might hold the impression of a state's vulnerability previously, then users can response us how similar the CCAV's and FSI's **RFM** results are with his/her acknowledge for a score of 1-5. When it comes to the second stage, we wanted to determine the climate-highlight part of CCAV is useful or not through user's response about whether CCAV is better for the explicit difference (mainly the Haiti Earthquake 2010) than FSI for a yes or no.

Overall, we invited 11 students participants (7 undergraduates, 3 master students and 1 Ph.D. candidate) to our study. All participants worked or majored in some sort of region stability related profession, such as international political affairs or social economics, and had different interests, such as interactive user-interface design. At the very beginning, we introduced them a brief introduction including the definition and influence of climate changes, national condition varying in recent years of Chad and Haiti, and the meaning of the results of CCAV and FSI model.

We followed recent recommendations of statistical analysis practices and used an estimation-based approach with effect sizes and confidence intervals[1]. This approach overcomes several biases and limitations of classical null hypothesis testing with p-values (NHST) [4, 5].

The summarized results are shown as follows:

- **Stage-1**
  For the Haiti result, the average score of CCAV is 4.6, while the average score of FSI is 3.9. Then the average score of CCAV is 3.5, which of FSI is 3.8 for Chad.
- **Stage-2**
  10 users of 11 agree that the climate change aware representation can provide a better understanding of the Haiti result. And 6 users think that the different part of the Chad result is useful.

Finally we compute the valuable level for each result, as shown in Fig. 4. For the Chad result in Stage-1, FSI is only slightly better than CCAV. Bur for the Haiti result, the effect is much more pronounced and CCAV created more comfortable and reliable results. Then for Stage-2, the study shows a similar result. That is, CCAV computes a much better understanding result than FSI for Haiti, and can perform similarly with FSI for Chad.

5 State Driven Interventions

- The effect of intervention

  Before we discussed the effect of man-made interventions, we defined several terms as follows:

  Intervention: An anthropogenic intervention to reduce the pollution sources or diminish the generation of greenhouse gases.

  current measure: activities that actually avoid adverse climate impacts on a system by reducing its exposure or increasing its resilience to climatic hazards.(e.g. reducing the burning of fossil-fuel and using renewable energies)

  precautionary measure: activities that have a anticipated effect on exposure and resilience, such as scientific research, awareness raising and the establishment of institutions, information networks, and legal frameworks for action[9].

  In order to show the active influence of man-made interventions, we considered those elements mentioned above into our model. The specific details can be seen in Fig. 5

  In our model, when a actual measure or a precautionary measure was developed and implemented, it will directly or indirectly reduce the GHG emissions primarily. As a result, the stress of this system will decreasing correspondingly which leads to the reduce of Impact as well. Simultaneously, the resilience of this system will improved. According to the Eq. 4 ,when the value of $\vec{I}$ descended and the value of the R ascended, obviously, the vulnerability of this system will go down. In other word, the effect of intervention prevents a country from becoming a fragile state.

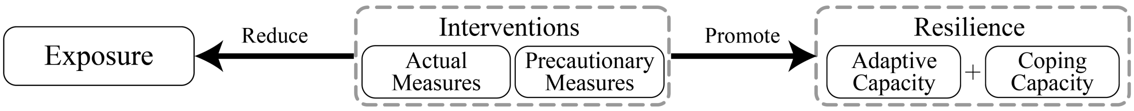

Figure 5: Human interventions, including actual measures and precautionary measures, reduce the influence of climate factor (Exposure) and promote the impact on non-climate factor (Resilience).

- Predict the total cost of intervention

  In this part, we take several countries in Europe as a example, to predict the cost of intervention. First, based on the Environmental protection expenditure(EPE) and the GHG net emissions/removals by LUCF, we use regression analysis to discover a relationship between EPE and GHG net emissions per year. Simultaneously, we gave the vulnerability of the two countries: Czech and Finland.

  After analysing Fig. 6, we can find out that with the increasing of EPE (dataset from [3]), the declining speed of vulnerability will reach a turning point. This turning point represents the optimal year in which the speed of vulnerability decline starts to slow down, or we can call it an "elbow" point.

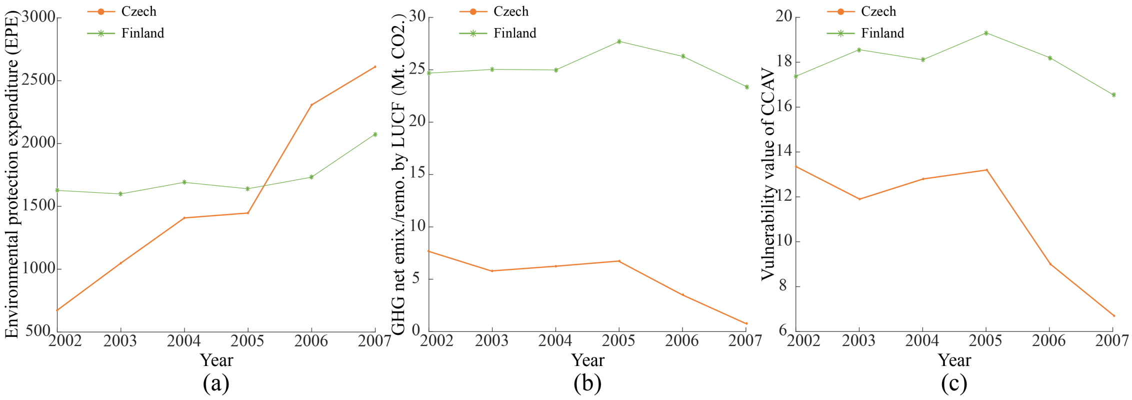

Figure 6: Intervention relations to climate changes' impact of Finland and Czech from 2002 to 2007. (a) is the time-variance environmental protection expenditure (EPE), (b) is the GHG net emissions/removals by LUCF (Mt of CO2 equivalent), (c) is the changes of CCAV computed vulnerability.

6 Extensions on Smaller and Larger Scales

6.1 Extension on Cities: Take Wenchuan, China as Example

In the first place, most of the data used in our model can be measured in a smaller scale. Some countries such as Monaco and Vatican are not much bigger than a metropolis, with even smaller population. In this sense, our model seems to have the ability to fit smaller-scale problems.

However, taking Wenchuan, China as an example. On May 12th , 2008, a worst earthquake in the past decades struck Wenchuan, Sichuan Province, China. The city suffered great casulties and economic loss. The Chinese government paid high attention to the rescuing and rebuilding work. Within 5 years, with the great help of neighboring provinces and direct support from Chinese government(over 41130 rebuilding projects), the living condition of inhabitants recovered to its normal level before the earthquake.

We can see from the recovery process of Wenchuan that for a city, support from vicinity is rather important, as well as the support from the government. These are very important external factors that should be taken into consideration.

6.2 Extension on Continents

There are 3 main reasons why our model does not fit for this problem.

- Allowing for the limitation of local weather extremes or natural disasters on geography, very few events can have an impact on a continental scale. In consequence, the vulnerability score of a continent will not be as sensitive to climate factors as the score of a country.
- When using data of each indicator, we in fact evaluate the average perfor-

mance of all the countries in this continent. Therefore, differences between countries will be wiped out, vulnerability of all continents will be similar.

- Cooperation and conflict within a continent is also important. In a continent where cooperation rarely occurs, or a continent full of conflicts, when a climate hazard happens, countries do not take actions positively to help each other through the hard time. On the contrary, in a continent full of reciprocity, a country can recover rapidly from losses. Benefitting from this virtuous circle, the overall vulnerability of the continent will go low.

Conclusion on model extension

In conclusion, our model **can not work well on smaller or larger scales.** To achieve the goal of extending our model in different scales, we must take external factors into account, and quantify the influence of these factors. Specifically, when treating a smaller state like a city, we must consider the **support this city can get from its vicinity and its government**, which can be quantified by several indicators, such as Rebuilding financial allocation($), Rescue Manpower(person), etc. On the other hand, when treating a larger state like a continent, we should add to our model the **cooperation and conflict inside a continent** as well as **the limited effect of local climate shocks on the whole continent**. On a national scale, the influences of non-climatic external factor such as support from vicinity, are weakened to the minimum. As a result, our model performs best on the national scale.

7 Strengths and Weaknesses

7.1 Strengths

- **Improve the quality of fragility state index algorithm**
  The CCAV model takes climate changes into account and measures the cost of climate prevention and controlling. Balancing the cost and the benefit, it would be more convincing to put climate changes as a factor when measuring a state fragility.

- **Wider coverage of parameters in the model**
  Compared to previous fragility model, CCAV model involves more parameters. Taking more indexes and other statistical data of a state into consideration, the measurement of our model is more thorough.

7.2 Weaknesses

- **partial unspecified definition** The definition with regard to vulnerability of other aspects are not clearly defined in our model,thus we put forward several solutions to represent the vulnerability in other aspects as a temporary solution.

- **Subjectivity** Some subjective methods are used in the model, moreover, some indicators are selected based on common sense. Some results may not be very convincing.
- **Loss of data source** Although we have tried our best. Time is limited, and some data are missed. As a result, the missing data can still bring errors to our result.

8 Future Work

The impact of climate change has been underestimated in the previous evaluation of state stability or fragility. Our CCAV model demonstrates both climate shocks and long-term climate changes influence state vulnerability in economy and livelihood by quantifying multi-dimensional records and indexes. And the model performs well in the following case study.

More statistical data will be need in the future research of relevancy between state fragility and climate changes, especially the potential cost of climate shocks. Each component of the model should be more detailed and the correlation between them can be reduced.

An interesting found

Those extreme fragile state should be our priority when picking up research object as a case study. However, we meet resistance in the process of data searching. The more fragile a state is, the less its statistical data would be. Unstable society, extreme poverty, lack of governance makes the procedure of data collection so hard. Besides the model, the absence of Statistical data itself reflects the vulnerability of a state to some extent.

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Appendices

Table 1: parameter explanation and data source

Indicator	Data source	Definition	Unit	Transformation method
A	01	Deaths per 100,000 inhabitants		Scale to 0-1
B	01	Losses per GDP in %	%	Scale to 0-1
C1	02, 04	population without access to improved sanitation	%	Scale to 0-1
C2	02, 04	population without access to an improved water source	%	Scale to 0-1
D	03	Population living in slums	%	Scale to 0-1
E	02	Life expectancy at birth	Years	Min-Max Normalization
F1	05	Dependency ratio	Ratio	Min-Max Normalization
F2	02, 06	Extreme poverty population	%	Scale to 0-1
G1	02	GDP per capita(PPP)	US$(PPP)	Logarithm and Scale to 0-1
G2	02, 07	GINI index		Scale to 0-1

01: Climate Risk Index (20 years), GermanWatch CRI Report
02: World Development Indicators, World Bank

Indicator	Data source	Definition	Unit	Transformation method
H1	08	Corruption Perceptions Index	0-10	Scale to 0-1
H2a	02	Public management and institutional cluster averages	0-6	Scale to 0-1
H2b	02	Business Facilitation Index	0-1	
I	02	Disaster risk reduction progress score	0-5	Scale to 0-1
J1	10	Number of physicians per 10,000 inhabitants		Scale to 0-1, Max: 1-100
J2	10	Number of hospital beds per 10,000 inhabitants		Scale to 0-1, Max:1:10000
K	11	Insurance	0-6	Scale to 0-1
L1	12	Adult literacy rate	P%	Scale to 0-1
L2	12	Combined gross school enrollment	Ratio	Min-Max Normalization
M1	12	Gender parity in education	Ratio	Min-Max Normalization
M2	13	National Parliament female share	%	Scale to 0-1
N1	14	Renewable internal freshwater resources	0-100	Scale to 0-1
N2	14	Biodiversity and habitat protection	0-100	Scale to 0-1
N3	14	Forest management	0-100	Scale to 0-1
N4	14	Agricultural management	0-100	Scale to 0-1
O1	10	Public health expenditure	US$ (PPP)	Logarithm and Scale to 0-1
O2	05	Life expectancy at birth	Years	Logarithm and Scale to 0-1
O3	10	Private health expenditure	US$ (PPP)	Logarithm and Scale to 0-1

03: https://www.statista.com/
04: WHO/UNICEF Joint Monitoring Programme (JMP)
05: Human Development Index, UNDP
06: Human Development Report
07: UN WIDER
08: Transparency International
09: http://fundforpeace.org/fsi/
10: World Health Statistics
11: Munich Re
12: UNESCO Institute for Statistics
13: Millenium Development Goals Indicators
14: Environment Performance Index