



## **Estimating Regions' Relative Vulnerability to Climate Damages in the CRED Model**

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### **Abstract**

Developed for use in the CRED integrated assessment model, VI-CRED is an index of vulnerability to climate change, with the advantage of simplicity and transparency as compared to more complicated indices with dozens of components. VI-CRED apportions economic damages from climate change among world regions on the basis of differences in vulnerable sectors' contribution to gross domestic product, share of population living at less than 5 meters above sea level, and access to freshwater resources. Its results are broadly similar to those of other indices, but it assigns a more prominent role to water scarcity and, for this reason, includes the Middle East among the most vulnerable regions.

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## **1. Introduction**

Climate change threatens the livelihoods of people around the world. Hotter temperatures, rising sea levels and more severe storms will increase the likelihood, extent, and intensity of regional droughts, floods, famine and disease. While some regions will adapt to extreme weather occurrences and long-term climate change, others will suffer serious damages, even in the face of the least severe climate change still thought possible. In general, richer regions – where a broad set of adaptation measures is affordable – will be more resilient to climate change than poorer regions – where adoption of protective measures against climate damages will be unlikely without international support.

The United Nations Framework Convention on Climate Change has recognized this disparity as an international dilemma, calling on high-income nations “to assist developing countries that are particularly vulnerable to the adverse effects of climate change” (United Nations 1994). If high-income countries are to follow through with this objective, some measure of climate change vulnerability must be established and agreed upon. The International Panel on Climate Change (IPCC) has defined climate vulnerability as “the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change” (IPCC 2007, WGII, Chapter 19). Unfortunately, this definition only hints at a systematic way to measure and compare the vulnerabilities of different regions (see, for example, Klein 2009). To meet this need, researchers from several institutes around the world have begun to develop indices to quantify climate-change vulnerability.

A climate-change vulnerability index estimates each region’s or country’s relative susceptibility to damages, and has a use both in modeling the economic impacts of climate change and in policy decisions regarding the equitable distribution of resources for adaptation. As international funds for adaptation become available, pressure has mounted to identify the most vulnerable nations – those to be prioritized – in a reliable and uniform way (Persson et al. 2009; Klein 2010). A climate-change vulnerability index identifies areas where adaptation is urgent and time-sensitive, and where policy intervention is, therefore, most critical. A vulnerability index also can reveal feedback effects, or the impacts of a confluence of biophysical and socioeconomic stressors, shedding light on the interplay between the political, social, economic and environmental realms.

After reviewing the current literature of climate-change vulnerability indices, this article introduces a new vulnerability index developed for use in the Climate and Regional Economics of Development (CRED), a recently developed integrated assessment (or climate-economics) model (Ackerman, Stanton and Bueno 2011b; 2011a). The CRED vulnerability index (VI-CRED) is composed of measures of climate-sensitive economic sectors as a percentage of gross domestic product (GDP), share of population living at less than 5 meters above sea level, and freshwater resources per capita. Results of CRED’s vulnerability index are presented by region, and compared with the results of other indices.

## **2. Measuring Climate Vulnerability**

Climate-change vulnerability indices combine a variety of economic, social, environmental and political data to estimate countries’ or regions’ likely risk of climate damages.<sup>1</sup> Some include a wide array of indicators and serve as holistic depictions of a multitude of climate-change risks, while others

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<sup>1</sup> Reducing vulnerability, therefore, may include both climate change adaptation and disaster risk reduction, a point discussed in detail in Ireland (2010).

are designed to gauge a single threat. Most share common elements that provide the means to examine key climate vulnerabilities from two important perspectives: adaptive capacity, and measures of sensitivity to damages. A few vulnerability indices layer the effects of globalization on top of climate change to reveal doubly exposed hotspots of vulnerability.

### *Adaptive capacity*

The IPCC (2007) defines adaptive capacity as “the ability or potential of a system to respond successfully to climate variability and change”. Where long-term impacts are explicitly considered, as in the concept of “sustainable adaptation” discussed by Erikson and Brown (2011) and Erikson et al. (2011), adaptive capacity includes an important generational component. Common traits include human and social capital, wealth, technology, and the quantity and quality of infrastructure. These traits are among those included in Maplecroft’s (a private consulting firm) vulnerability index (Maplecroft 2010; 2011); the Tyndall Center’s Social Vulnerability Index (Vincent 2004); the Center for International Climate and Environmental Research’s (CICERO) vulnerability index (O’Brien et al. 2004); the Water Systems Analysis Group’s climate and water vulnerability index (Vörösmarty et al. 2000); DARA’s Climate Vulnerability Monitor (DARA and Climate Vulnerable Forum 2010); and Germanwatch’s global climate risk index (Harmeling 2010). The structures of these six indices are outlined below:

- Maplecroft’s index uses social, economic and environmental indicators to assess global climate-change vulnerability at a national level.
- The Tyndall Centre’s Social Vulnerability Index (SVI) evaluates social vulnerability to climate change, at the national level, across Africa.
- CICERO’s index describes India’s agricultural vulnerability to climate change and globalization at the district level.
- The Water Systems Analysis Group’s climate and water vulnerability index analyzes the links between water sensitivity and dependency at the regional level.
- DARA’s Climate Vulnerability Monitor (CVM) evaluates the global impact of climate change on human health, weather, human habitat, and economics at a national level.
- Germanwatch’s global climate risk index (CRI) calculates nations’ vulnerability in terms of historical fatalities and economic losses due to extreme weather events.

Vulnerability indices frequently couple demographic information with measures of regional capacity, which describe the ability of populations to shift production, create or improve necessary infrastructure, address health issues, and respond to the increasing frequency and magnitude of extreme events under climate change. For example, the Maplecroft and Tyndall indices incorporate conflict, population patterns, institutions and governance assumptions into adaptive capacity. The Tyndall SVI gauges health vulnerability in inverse proportion to the share of GDP spent on public health. The use of demographic information stems from the idea that indicators of past socioeconomic achievements translate into future adaptive success.

### *Sensitivity to damages*

Measures of sensitivity and exposure to climate damages describe the persistent and sometimes irreversible character of future impacts. Agricultural sectors and water distribution systems are particularly sensitive to environmental conditions. Even slight variations in climate may lead to sharp disruptions in crop production or water availability. These shocks will challenge farmers to adapt to higher temperature extremes, increasing mean temperatures, and monsoon variability, which may

require major shifts of production over a short period of time. Agricultural vulnerability is captured by CICERO's district-level index for India (O'Brien et al. 2004).

More generally, market sensitivity to climate change is an indicator of economic vulnerability and long-term capacity to compete in international markets. The Fourth IPCC Assessment Report recognizes other at-risk economic sectors in addition to agriculture and acknowledges that aggregate effects due to climate change are uncertain. These sectors include energy, construction, insurance, tourism and recreation, which are vital components of economies and the response of which to climate change is difficult to forecast (IPCC 2007). When environmental resources are made less predictable and more difficult to sustain by climate change, the livelihoods of hundreds of millions around the world are threatened. The Maplecroft vulnerability index includes human sensitivity to variations in natural resources (Maplecroft 2010).

The availability of freshwater resources is particularly sensitive to climate change, yet few indices consider the sustainability of drinking and irrigation water supplies. There are deep concerns among populations that rely on glacial-fed water sources about the irreversibility of diminishing water supplies due to glacial melting, and similar fears are felt by millions who rely on monsoon rains (IPCC 2007). The Tyndall SVI calculates the level of overall natural resource dependence as the rural share of the population, relating a higher rural share to greater vulnerability (Vincent 2004).

The index developed by the Water Systems Analysis Group looks at the relationship between water sensitivity and dependency (Vörösmarty et al. 2000). This relationship represents the "degree to which humans interact with a sustainable water supply" by considering water reuse and the ratio between water demand and water supply for domestic, industrial, and agricultural uses. The analysis concludes that the rates of population growth and economic development, as opposed to climate change itself, are the primary drivers that will dictate the ratio of water demand to water supply over the next 25 years.

Other indices incorporate changes in water scarcity from a solely environmental perspective. The DARA CVM includes changes in water-related extreme events coupled with gradual environmental degradation – for example, desertification – as primary water-related drivers of human impacts (DARA and Climate Vulnerable Forum 2010).

In addition, sea-level rise threatens coastal populations with permanent inundation, increased severity of storm-surge floods, and groundwater salination. Within 2°C of warming above preindustrial temperatures, hundreds of millions of people would face reduced water supply due to coastal saltwater infiltration (IPCC 2007). A Tyndall Centre research project analyzes sea-level and wave changes around the United Kingdom by modeling the North Atlantic Oscillation and its contribution to increasing westerly winds. This model – unrelated to the Tyndall SVI – offers a fine-tuned assessment of coastal vulnerability with respect to changes in regional climate (Tsimplis et al. 2005). The Germanwatch global CRI, on the other hand, analyses extreme weather vulnerability in terms of historical fatalities and economic losses (Harmeling 2010). This global climate-risk index focuses on expectations of infrequent but catastrophic events, as opposed to continuous weather-related threats.

### *Globalization*

Beyond measures of adaptive capacity and sensitivity, some climate vulnerability indices incorporate factors related to the globalization of markets. The Tyndall SVI measures global interconnectivity as the difference between nations' imports and exports. The more negative the trade balance, the higher the degree of climate vulnerability. Although the interaction between globalization and climate change

may be uncertain and at times controversial,<sup>2</sup> developing nations are likely to be disproportionately vulnerable to economic relations – for better or for worse – and this vulnerability would be compounded by climate change (Vincent 2004).

Similarly, the CICERO index explores this relationship by examining the effects of trade liberalization in India and finds that certain crops are more vulnerable to foreign competition. One example arose in the market for edible oils and oilseeds, where liberalization in the late 1990s led to a crash in domestic oilseed prices due to the inexpensive imports of Malaysian palm oil (O'Brien et al. 2004). CICERO more generally defines regions that have low crop productivity or are close to international ports as particularly vulnerable to climate damages.

### **3. CRED's Vulnerability Index**

CRED is an integrated assessment (or climate-economics) model designed to highlight issues of international equity while using the most up-to-date estimates of physical climate impacts and emissions abatement costs (Ackerman, Stanton, and Bueno 2011a; 2011b). CRED's damage function is generically similar to, though more flexible than, the DICE model damage function (Nordhaus 2008), in which global GDP net of damages is a function of 1) the size of the economy prior to climate damages, and 2) temperature increases due to climate change. In CRED, a range of values are available for the parameters controlling the level of damages – from matching the DICE damage function to a "Hanemann-Weitzman" damage function that results in damages roughly double those of DICE at low temperatures, rising up to catastrophic levels – not possible to model in DICE – at higher temperatures (Ackerman, Stanton and Bueno 2011a).

CRED's vulnerability index (VI-CRED) apportions climate damages among the nine world regions modeled in CRED: Africa, China, Developing Asia/Pacific, Eastern Europe, Europe, Latin American and the Caribbean, Middle East, Other High Income, and United States.<sup>3</sup> It could easily be extended to more disaggregated regions, and to most of the world's individual countries. In CRED, regional climate damages are global damages apportioned to each region based on that region's vulnerability index, or VI-CRED. Four factors govern regions' shares of global climate damages in CRED: GDP, the share of GDP originating in agriculture and tourism (the most climate-sensitive industries), the share of the population at less than 5 meters above sea level, and freshwater resources per person.

In CRED, regional climate vulnerability does not vary over time or by scenario; CRED employs a single set of regional vulnerability index values for all 300 years modeled, using country-level data calibrated to 2005. The actual regional damage shares of global damages, however, do vary by scenario in relation to differences in regional GDP growth rates. At present, data limitations and an inability to forecast such fine-tuned data indicators impede modeling changes in regional vulnerability over time; this is a potential area of development for the CRED model.

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<sup>2</sup> IPCC (2007) states that trade liberalization may increase adaptive capacity while also increasing emissions due to transport.

<sup>3</sup> Africa includes Sub-Saharan and North Africa; China includes Hong Kong but not Taiwan or Macau; Eastern Europe includes Russia and non-EU Eastern Europe, i.e., European ex-USSR, ex-Yugoslavia, and Albania; Europe includes EU-27, Norway, Switzerland, Iceland, and Turkey; Latin America and the Caribbean includes Puerto Rico and all Virgin Islands; Middle East excludes North Africa; Other High Income includes Canada, Japan, South Korea, Australia, and New Zealand; Developing Asia/Pacific includes South and Southeast Asia, Taiwan, Asian ex-USSR and the Pacific; and United States excludes Puerto Rico and smaller island territories such as Guam and American Samoa.

## *Data*

VI-CRED brings together data the composition of GDP, the distribution of population relative to elevation, and the availability of freshwater resources. All data are for the year 2005 except where explicitly stated. In CRED, country-level data are mapped to nine regions, and the extent of country coverage within regions is permitted to vary by variable based on data availability: different sources provide data for somewhat different sets of countries within each region.

The share of GDP from the agricultural and tourism sectors is taken from the World Bank's *2008 World Development Indicators*, supplemented for missing data by other sources like World Resources Institute's EarthTrends database;<sup>4</sup> where 2005 data were unavailable, the average of the shares available for the years 2000 through 2004 was used instead (or last available year's data). The share of population living below a 5-meter elevation is taken from PLACE II (Socioeconomic Data and Applications Center, Columbia University 2010). Freshwater scarcity, measured as the ratio of people to available water, is the inverse of "water resources: total renewable per capita (actual)" per year from the Food and Agriculture Organization of the United Nations AQUASTAT database,<sup>5</sup> and is for the most recent data year available from 2003 to 2007.

## *Methodology*

VI-CRED combines three factors of climate damage vulnerability for each of nine world regions (see Table 1 for values of all three factors by region):

- Vulnerable sectors' share of GDP: The sum of the agriculture and tourism sectors' contribution to regional GDP. These values range from 18.5 and 16.1 percent of GDP in Africa and Developing Asia/Pacific, respectively, to 2.2 percent in the United States.
- Share of population living below 5-meter elevation: Ranging from 11.4 percent in the Other High Income region to 2.4 percent in Eastern Europe; weighted by national GDP, these percentages are 12.1 percent and 2.7 percent, respectively.
- Number of people per thousand cubic meters per year of available freshwater resources: Ranging from 0.79 in the Middle East to 0.03 in the Latin America and the Caribbean, weighted by population; and 18.30 in the Middle East to 0.07 in Eastern Europe, weighted by national GDP. This measure is the inverse of the more intuitive measure water availability per person; we use "people per water availability" so that a larger value means greater vulnerability, matching the other factors.

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<sup>4</sup> World Resources Institute (2007), <http://earthtrends.wri.org>.

<sup>5</sup> Food and Agriculture Organization of the United Nations (n.d.), <http://www.fao.org/nr/water/aquastat/main/index.stm>.

Table 1: Vulnerability data

	Tourism Share of GDP	Agriculture Share of GDP	Vulnerable Sectors' Share of GDP	GDP-Weighted Share of Population < 5m	GDP-Weighted People per 1,000 Cubic Meters of Freshwater
<b>Africa</b>	3.4%	15.1%	18.5%	4.7%	1.40
<b>China</b>	1.9%	11.2%	13.1%	9.4%	0.43
<b>Developing Asia/Pacific</b>	2.7%	13.4%	16.1%	9.3%	0.70
<b>Eastern Europe</b>	2.2%	6.2%	8.4%	2.7%	0.07
<b>Europe</b>	2.6%	2.2%	4.8%	8.4%	0.36
<b>Latin America/Caribbean</b>	1.9%	5.5%	7.4%	4.3%	0.16
<b>Middle East</b>	2.5%	4.7%	7.3%	7.4%	18.30
<b>Other High Income</b>	0.9%	2.0%	2.9%	12.1%	0.27
<b>United States</b>	1.0%	1.2%	2.2%	4.1%	0.10
<b>World</b>	1.8%	3.6%	5.4%	7.4%	0.71

Sources: As described in text above.

Each of these three factors is converted into a regional component index, X-index<sub>i</sub>, where i denotes the region, which ranges from 0 in the least vulnerable region to 1 in the most vulnerable:<sup>6</sup>

$$(1) X\text{-index}_i = \frac{(X_i - X_{\min})}{(X_{\max} - X_{\min})}$$

The difference between each region's data value and the minimum global value for that data point is divided by the data range, or the difference between the global maximum and minimum values. For each region, VI-CRED is the average of the three component indices (VI<sub>i</sub>):

$$(2) VI_i = \frac{\text{Vulnerable sectors index}_i + \text{Low-elevation population index}_i + \text{Water availability index}_i}{3}$$

This method of normalization follows that of the United Nations Development Programme's Human Development Index, among other indices.<sup>7</sup> Table 2 reports the resulting values of these three composite indices and their unweighted average, the VI-CRED, the values of which range from 0.43 in Africa to 0.06 in the United States.

<sup>6</sup> In the water vulnerability index, 1 person/1000 m<sup>3</sup>/year – the Falkenmark indicator of water scarcity (Rijsberman 2006; Falkenmark et al. 1989) – is substituted for X<sub>max</sub> in equation (1), and all regions with water availability less than 1000 m<sup>3</sup>/person/year are assigned an index of 1.0, the maximum level of vulnerability.

<sup>7</sup> See United Nations Development Programme (2011).

Table 2: Index values

	Vulnerable Sectors' Share of GDP Index	Share < 5m Population Index	Inverse Water Availability Index	VI-CRED
<b>Africa</b>	0.24	0.05	1.00	0.43
<b>China</b>	0.17	0.09	0.43	0.23
<b>Developing Asia/Pacific</b>	0.20	0.09	0.70	0.33
<b>Eastern Europe</b>	0.11	0.03	0.07	0.07
<b>Europe</b>	0.06	0.08	0.36	0.17
<b>Latin America/Caribbean</b>	0.09	0.04	0.16	0.10
<b>Middle East</b>	0.09	0.07	1.00	0.39
<b>Other High Income</b>	0.04	0.12	0.27	0.14
<b>United States</b>	0.03	0.04	0.10	0.06
<b>World</b>	0.07	0.07	0.71	0.29

Source: Authors' calculations.

In each CRED model scenario, total global damages are allocated to regions in proportion both to regional output and the VI-CRED (where  $VI_i$  is raised to the power of  $\alpha$ , an ad hoc scaling factor)<sup>8</sup>:

$$(3) \text{ Regional damage index}_{t,i} = \frac{VI_i^\alpha * \text{Output}_{t,i}}{\sum_i (VI_i^\alpha * \text{Output}_{t,i})}$$

$$(4) \text{ Damages}_{t,i} = \text{Regional damage index}_{t,i} * \text{Global damages}_t$$

In Equations (3) and (4), regional output is gross output before damage losses are considered. Since the regional damage index is defined to sum to one, regional damages sum to global damages. Regional output net of damages is regional gross output minus regional damages. Output net of damages is the total available for savings and consumption:

$$(5) \text{ Output net of damages}_{t,i} = \text{Output}_{t,i} - \text{Damages}_{t,i}$$

Damages differ greatly by scenario. Using the DICE damage function<sup>9</sup> (CRED v.1.3 allows for the choice of several damage functions; see Ackerman, Stanton and Bueno 2011a) and the median, 3°C,

<sup>8</sup> The scaling factor  $\alpha$ , restricted to values  $\alpha < 1$ , is included in CRED to avoid projected damages exceeding regional output in the most vulnerable regions (see Ackerman, Stanton and Bueno 2011a).

<sup>9</sup> Called "Nordhaus-Nordhaus" in Ackerman, Stanton and Bueno (2011a).

climate sensitivity<sup>10</sup>, total global climate damages are 4.0 percent of global GDP in 2105 in the no-policy business-as-usual scenario (using a pure rate of time preference of 3.0 percent<sup>11</sup>), and 1.5 percent under the maximum abatement policy (which includes cross-regional investment and a 0.1 percent pure rate of time preference). Table 3 reports each region's climate damages as a percent of regional GDP in the year 2105 for these two CRED scenarios.

*Table 3: Regional Climate Damages as a Percent of Regional GDP 2105*

	<b>Business-As-Usual</b>	<b>Maximum Abatement</b>
<b>Africa</b>	9.5%	3.6%
<b>China</b>	5.4%	2.0%
<b>Developing Asia/Pacific</b>	7.5%	2.8%
<b>Eastern Europe</b>	1.7%	0.6%
<b>Europe</b>	4.0%	1.5%
<b>Latin America/Caribbean</b>	2.5%	0.9%
<b>Middle East</b>	8.7%	3.3%
<b>Other High Income</b>	3.4%	1.2%
<b>United States</b>	1.5%	0.5%
<b>World</b>	4.0%	1.5%

Source: Authors' calculations.

As a share of each region's GDP, CRED projects that climate damage impacts in 2105 will be highest in Africa (followed by the Middle East and Developing Asia/Pacific) and lowest in the United States (followed by Eastern Europe) in both scenarios. With maximum abatement, these damage shares of regional output drop by nearly two thirds in all regions.

In contrast, regional shares of global damages in 2105 – as shown in Table 4 – are largest in Europe, followed by Africa and Developing Asia/Pacific in both scenarios (comprising nearly two-thirds of all global damages among them; Eastern Europe, Latin America/Caribbean and China together account for just 11 percent of global damages in that year. The share of global damages for Africa and Developing Asia/Pacific is higher by approximately one-third in the maximum abatement scenario compared to the business-as-usual scenario – though the absolute value of damages in both regions are a third less in the maximum abatement scenario (and up to 60 percent less in several other regions). China's share also rises under maximum abatement, but less so; all other regions' shares of global damages drop by about one-fifth, except the United States, where the share dips only slightly.

<sup>10</sup> Climate sensitivity is the expected long-term change in temperature resulting from a doubling of carbon dioxide in the atmosphere. Its value is uncertain, but the broad outline of its distribution is well known. See Roe and Baker (2007) and Ackerman, Stanton and Bueno (2011a).

<sup>11</sup> The pure rate of time preference is a key component of the discount rate. It determines the degree to which future differences in per capita consumption levels are considered in determining the optimal abatement policy. See Ackerman, Stanton and Bueno (2011a).

Table 4: Regional Climate Damages as a Percent of Global Damages 2105

	<b>Business-As-Usual</b>	<b>Maximum Abatement</b>
<b>Africa</b>	15.0%	20.4%
<b>China</b>	6.0%	6.7%
<b>Developing Asia/Pacific</b>	14.9%	19.6%
<b>Eastern Europe</b>	0.6%	0.5%
<b>Europe</b>	29.9%	24.0%
<b>Latin America/Caribbean</b>	4.6%	3.7%
<b>Middle East</b>	10.0%	8.1%
<b>Other High Income</b>	9.0%	7.4%
<b>United States</b>	10.0%	9.7%

Source: Authors' calculations.

#### 4. Comparing VI-CRED, Maplecroft and DARA

Vulnerability indices include a wide range of different components and, often, some of the same components based on different data sources. The VI-CRED, Maplecroft, and DARA indices are suitable for comparison because each measures a range of different climate-change vulnerability factors for all world regions. VI-CRED measures climate-sensitive industries as a percentage of GDP, the share of population living below 5-meter elevation above sea level, and freshwater resources per capita. The Maplecroft vulnerability index uses 42 political, economic, social, and environmental indicators to calculate vulnerability risks at a national level.<sup>12</sup> The DARA CVM climate vulnerability monitor is composed of similar habitat and economic indicators, and also includes factors related to weather and human health (DARA and Climate Vulnerable Forum 2010).

VI-CRED and DARA indicators are measured using different techniques (the Maplecroft methodology is not publicly available). VI-CRED, DARA, and Maplecroft results are calculated at the country level and each index aggregates countries into larger regions differently, making final results difficult to compare. Nonetheless, a rough comparison can offer valuable insights into vulnerability measurement across a collection of institutions.

VI-CRED's regional ranking is based on the regions' the final values shown in Table 2. The DARA vulnerability results are separated into four categories: health impacts, weather disasters, habitat loss and economic stress. Each category is ranked on a low (1) to acute (8) scale, and an overall ranking is determined by a weighted average. On account of the DARA scaling system, many countries receive the same overall score, and it is not possible to differentiate rankings at the country level.

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<sup>12</sup> Limited results are available at <http://www.maplecroft.com>. See Maplecroft (2011).

Table 5 reports rankings for the countries or regions most vulnerable to climate change according to these three indices; a complete list of the DARA and VI-CRED rankings is included, but the Maplecroft list shown here includes only the ten countries most vulnerable to climate change. Regional rankings vary among the three indices. VI-CRED ranks Africa as most vulnerable to climate change, while DARA and Maplecroft (with the exception of Haiti) rank countries in Africa and, to a somewhat lesser degree, South Asia as most vulnerable.

Table 5: Comparison of Vulnerability Index Rankings

VI-CRED		Maplecroft		DARA	
1	Africa	1	Haiti	1	Central Africa
2	Middle East	2	Bangladesh	1	East Africa
3	Developing Asia/Pacific	3	Zimbabwe	1	West Africa
4	China	4	Sierra Leone	1	South Asia
5	Europe	5	Madagascar	2	Pacific
6	Other High Income	6	Cambodia	2	North Africa
7	Latin America/Caribbean	7	Mozambique	3	South-East Asia
8	Eastern Europe	8	DR Congo	3	Southern Africa
9	United States	9	Malawi	3	Central America
		10	Philippines	4	Eastern Europe
		...		4	Russia and Central Asia
				4	South America
				5	Caribbean
				5	East Asia
				6	Southern Europe
				6	North America
				6	Middle East
				6	Australasia
				7	Northern Europe
				7	Western Europe

Note: Shades of grey highlight CRED's most vulnerable regions (Africa, followed by the Middle East, then Developing Asia/Pacific). Source: Authors' calculations, DARA and Climate Vulnerable Forum (2010), and Maplecroft (2011).

Except for the Middle East, regional rankings by the DARA and VI-CRED indices are broadly similar, while the Maplecroft country-level ranking does not lend itself to a direct regional comparison – although most of the top-ranked countries are in Africa and Developing Asia/Pacific.<sup>13</sup> In DARA and VI-CRED, Africa and Developing Asia/Pacific are extremely vulnerable, while northern and western Europe have lower scores. DARA's North American and CRED's United States vulnerability levels are in agreement, but further disaggregation of the DARA North American profile to the country level reveals that the United States' vulnerability is ranked relatively higher than in CRED. This is due to DARA's prediction of extreme habitat loss in the future, not included in VI-CRED. In general, these

<sup>13</sup> Haiti's first place in the latest Maplecroft ranking (it was seventh in the prior one) likely reflects the devastating effects of its massive 2010 earthquake.

two indices are widely comparable on a regional level, but country-level discrepancies can be obscured in the aggregation process.

Two significant differences between DARA and CRED vulnerability rankings are highlighted in these summary results. First, DARA predicts moderate economic losses and water resource stress to Russia and Eastern Europe from climate change, while VI-CRED ranks this region as next to least vulnerable (with nearly the same index value as the United States) due to its small coastal population at low elevations and relatively high renewable water per capita. This result may be partially driven by differences in the definition of regions; in CRED, Eastern Europe is dominated by Russia, while DARA's Eastern Europe excludes Russia.<sup>14</sup> Secondly, the VI-CRED calculation of Middle East climate vulnerability is driven by water scarcity, which weighs heavily in its ranking as the second most vulnerable region (with a VI-CRED value of 0.39 vs. Africa's 0.43). The DARA CVM ranks the region as third most vulnerable for desertification (a component index within the CVM), behind Southern Africa and South Asia, but other factors in the CVM score the Middle East among the least vulnerable regions, lowering its overall ranking.

The number of indicators included in an index may be responsible for important differences in scoring among vulnerability indices: more components add detail but make results more difficult to interpret. The integration of a wide range of factors can have the effect of disguising areas in which climate damages might be catastrophic. The number of parameters in a climate change vulnerability index directly influences the sensitivity of the results to any one parameter (O'Brien et al. 2004; Sullivan and Meigh 2005).

## **5. Conclusions and Policy Recommendations**

VI-CRED differs from earlier climate-change vulnerability indices in its reliance on a small set of limited but important indicators: climate-sensitive industries, the share of population at low elevations, and freshwater availability. Other indices contain more variables, making them richer in detail, but more difficult to interpret. VI-CRED indicators are quantifiable, simple, and easily relatable to climate-change vulnerability. In addition, the data used in VI-CRED is publicly available for most countries around the world. This means that it would be possible to present CRED results at the national level – an important step for further development of this model. (At present national data are compiled and aggregated to calculate the regional VI-CRED index values, but have not been published at the national level.)

VI-CRED is well-suited for use in CRED because it combines three climate-change vulnerability factors into a single well-defined index. All VI-CRED indicators have important implications for climate-change policy and are easy to update as new information becomes available. The transparent structure of VI-CRED is also important in making CRED a useful tool for policymakers. Knowledge of freshwater scarcity is crucial for international negotiations. Effective water resource policy can prevent international conflicts over freshwater allocation, which in turn alleviates climate change stress. Future trade policies will impact climate-sensitive industries, and sea-level rise will impair unprepared coastal populations living close to sea level. VI-CRED allows the CRED integrated assessment model to estimate regional climate-change damages, highlight equity concerns, and identify the regions and countries where policy intervention is most crucial.

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<sup>14</sup> DARA, however, awards Russia the same vulnerability score as it does Eastern Europe.

## References

- Ackerman, F., Stanton, E.A. and Bueno, R. (2011a). "CRED: A new model of climate and development." *Ecological Economics* in press. DOI:16/j.ecolecon.2011.04.006.
- Ackerman, F., Stanton, E.A. and Bueno, R. (2011b). *CRED v.1.3 Technical Report*. Somerville, MA: Stockholm Environment Institute-U.S. Center. Available at <http://sei-us.org/publications/id/411>.
- DARA and Climate Vulnerable Forum (2010). "Climate Vulnerability Monitor 2010: The State of the Climate Crisis." <http://daraint.org/climate-vulnerability-monitor/climate-vulnerability-monitor-2010/>.
- Eriksen, S. and Brown, K. (2011). "Sustainable adaptation to climate change." *Climate and Development* 3(1), 3–6. DOI:10.3763/cdev.2010.0064.
- Eriksen, S., Aldunce, P., Sekhar Bahinipati, C., et al. (2011). "When not every response to climate change is a good one: Identifying principles for sustainable adaptation." *Climate and Development* 3(1), 7–20. DOI:doi:10.3763/cdev.2010.0060.
- Falkenmark, M., Lundqvist, J. and Widstrand, C. (1989). "Macro-scale water scarcity requires micro-scale approaches." *Natural Resources Forum* 13(4), 258–67. DOI:10.1111/j.1477-8947.1989.tb00348.x.
- Harmeling, S. (2010). "Global Climate Risk Index 2011: Who suffers most from extreme weather events? Weather-related loss events in 2009 and 1990 to 2009." *Germanwatch Briefing Paper*. Available at <http://www.germanwatch.org/klima/cr11.pdf>.
- Intergovernmental Panel on Climate Change (2007). *Climate Change 2007 – IPCC Fourth Assessment Report*. Cambridge, UK: Cambridge University Press.
- Ireland, P. (2010). "Climate change adaptation and disaster risk reduction: Contested spaces and emerging opportunities in development theory and practice." *Climate and Development* 2(4), 332–45. DOI:10.3763/cdev.2010.0053.
- Klein, R. (2010). "Linking adaptation and development finance: A policy dilemma not addressed in Copenhagen." *Climate and Development* 2(3), 203–6.
- Klein, R. (2009). "Identifying Countries that are Particularly Vulnerable to the Adverse Effects of Climate Change: An Academic or a Political Challenge?" *The Carbon & Climate Law Review* 3(3), 284–91. Available at <http://93.91.26.29/content/lex/cclr/2009/00000003/00000003/art00008>.
- Maplecroft (2011). "World's fastest growing populations increasingly vulnerable to the impacts of climate change – 4th global atlas reports." [http://maplecroft.com/about/news/ccvi\\_2012.html](http://maplecroft.com/about/news/ccvi_2012.html).
- Maplecroft (2010). "Big economies of the future - Bangladesh, India, Philippines, Vietnam and Pakistan - most at risk from climate change." <http://www.maplecroft.com/about/news/ccvi.html>.
- Nordhaus, W.D. (2008). *A Question of Balance: Economic Modeling of Global Warming*. New Haven, CT: Yale University Press.
- O'Brien, K., Leichenko, R., Kelkar, U., et al. (2004). "Mapping vulnerability to multiple stressors: Climate change and globalization in India." *Global Environmental Change* 14(4), 303–13. DOI:10.1016/j.gloenvcha.2004.01.001.
- Persson, Å., Klein, R.J.T., Kehler Siebert, C., et al. (2009). *Adaptation Finance under a Copenhagen Agreed Outcome*. SEI Research Report. Stockholm: Stockholm Environment Institute. Available at <http://sei-international.org/publications?pid=1309>.
- Rijsberman, F. (2006). "Water scarcity: Fact or fiction?" *Agricultural Water Management* 80(1-3), 5–22. DOI:10.1016/j.agwat.2005.07.001.
- Roe, G.H. and Baker, M.B. (2007). "Why Is Climate Sensitivity So Unpredictable?" *Science* 318(5850), 629–32. DOI:10.1126/science.1144735.

Socioeconomic Data and Applications Center, Columbia University (2010). "PLACE II: Population, Landscape, and Climate Estimates." *National Aggregates of Geospatial Data Collection*.  
<http://sedac.ciesin.columbia.edu/place/>.

Tsimplis, M.N., Wolff, D.K., Osborn, T.J., et al. (2005). "Toward a vulnerability assessment of the UK and northern European coasts: The role of regional climate variability." *Philosophical Transactions of the Royal Society* 363(1831), 1329–58. Available at <http://dx.doi.org/10.1098/rsta.2005.1571>.

United Nations (1994). *United Nations Framework Convention on Climate Change*. Available at [http://unfccc.int/essential\\_background/convention/items/2627.php](http://unfccc.int/essential_background/convention/items/2627.php).

United Nations Development Programme (2011). *Sustainability and Equity: A Better Future for All*. Human Development Report 2011. New York, NY. Available at <http://hdr.undp.org/en/reports/global/hdr2011/>.

Vincent, K. (2004). "Creating an index of social vulnerability to climate change in Africa."  
<http://www.tyndall.ac.uk/content/creating-index-social-vulnerability-climate-change-africa>.

Vörösmarty, C.J., Green, P., Salisbury, J. and Lammers, R.B. (2000). "Global Water Resources Vulnerability from Climate Change and Population Growth." *Science* 289(5477), 284–88. Available at <http://dx.doi.org/10.1126/science.289.5477.284>.