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THE COMPENDIUM OF ADAPTATION MODELS FOR CLIMATE CHANGE: FIRST EDITION

THEA DICKINSON
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PREFACE

The climate system is dynamic affecting all aspects of our health, wealth, security and competitiveness. The climate has, is and will continue to change and change means adaptation. But which future adaptation pathway to choose is often a difficult and complex question with many options, collateral effects, investments and many partners. Adaptation science has a key and fundamental role in this process to help decision-makers choose the right pathway forward.

Adaptation models and tools have the ability to weigh many interacting factors to better understand the sensitivities and consequences of many driving forces, especially under climate change. Several different types of decision models currently contain only modest options for adaptation. In contrast, models that incorporate mitigation measures have rapidly developed in order to support the development of targeted policies and regulations and have arguably helped mitigation gain greater recognition by providing a range of desirable thresholds for greenhouse gas emission reductions. It is anticipated that the next generation of decision-support models will incorporate both adaptation and mitigation options within the context of sustainable development.

Clearly defining what constitutes an adaptation model is understandably difficult. Based on an initial survey of modelers and researchers, adaptation models can generally be separated into 4 broad categories - Impact Centered Models (ICMs); Adaptation Centered Models (ACMs); Evaluation Models; and Optimization Models. However, several other typologies can be used to further differentiate these models, including classifying them by sector and descriptive parameters.

This *Compendium of Adaptation Models,* First Edition, presents and summarizes 35 selected adaptation models. We welcome the opportunity to review and document other climate change adaptation models in preparation for the *Second Edition* and, of course, comments are always welcome.

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GLOSSARY OF MODEL ACRONYMS

ABMs	Agent Based Models
AD-DICE	Adaptation-Dynamic Integrated model of Climate and the Economy
AD-RICE	Adaptation–Regional Integrated model of Climate and the Economy
ACMs	Adaptation Centered Models
AMSD	Adaptation Mitigation and Sustainable Development
ASD	Automated Statistical Downscaling
BRDSEM	Berg River Dynamic Spatial Equilibrium Model
CALVIN	CALifornia Value Integrated Network
CanCLIM	Canada Climate
CanREM	Canadian Regional Energy Model
CIAM	Community Integrated Assessment Model
CLOUD	Climate Outlooks and Agent-Based Simulation of Adaptation in Africa
COBWEB	Complexity and Organized Behaviour Within Environmental Bounds
CRISTAL	Community-based Risk Screening – Adaptation and Livelihoods
DICE	Dynamic Integrated Model of Climate and the Economy
DIVA	Dynamic Interactive Vulnerability Assessment
EPIC	Erosion Productivity Impact Calculator
ESCAPE	Evaluation of Strategies to Address Climate Change by Adapting to and Preventing Emissions
Farm-Adapt	Future Agriculture Resource Model-Adapt
FUND2.9	Framework for Uncertainty, Negotiation and Distribution
IAM	Integrated Assessment Models
ICAM	Integrated Climate Assessment Model
ICLIPS	Integrated Assessment of Climate Protection Strategies
ICM	Impact Centered Models
IMAGE2.1	Integrated Model to Assess the Greenhouse Effect/Global Environment
ISIS	Information Society Integrated Systems
MAGICC	Model for the Assessment of Greenhouse gases Induced Climate Change
Mini-CAM	Mini-Climate Assessment Model
MPPACC	Model of Private Proactive Adaptation to Climate Change
OSWRM	Okanagan Sustainable Water Resources Model
PAGE2002	Policy Analysis for the Greenhouse Effect
REAM	Regional Energy Analysis Model
SWAP	Soil Water Atmosphere and Plant Model
TARGETS	Tool to Assess Regional and Global Environmental and health Targets for Sustainability
TEAM	Tool for Environmental Assessment and Management
TWA	Tolerable Windows Approach
UWF	Urban Water Futures

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Introduction

In recent years, the number of models that incorporate mitigation, described as an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2007), has rapidly escalated, while models that incorporate adaptation are still in the initial stages. Currently, several reasons exist for the prominence of mitigation and the neglect of adaptation, including:

The belief that adaptation decreases the urgency to mitigate, which acts as a deterrent to the promotion of adaptation as a response to climate change

- Misunderstanding and misinformation surrounding adaptation have led to criticisms by the public and media that it is a 'do nothing' approach
- Adaptation poses a problem for upscaling from the local to the regional or national level, it is not a simple top-down only approach
- The difficulty in measuring adaptation, which is exemplified in the proliferation of mitigation models compared to adaptation models
- Measurements of mitigation are quantifiable with concrete ways to mitigate (reduce) greenhouse gases

Adaptation is essential to decreasing the current and unavoidable impacts from climate change. The net benefits of adaptation are experienced earlier than those of mitigations as they are immediate (Berkhout, 2005). While mitigation measures can be implemented now, the residence time (atmospheric lifetime) of greenhouse gases, primarily carbon dioxide varies from 50-200 years (EPA, 2007), resulting in the benefits of emission reductions not being felt for decades. Since mitigation cannot reduce the *immediate* impacts of climate change, adaptation is an essential and urgent policy response. It is wise that adaptation be brought forward onto policy agendas and to media attention. Adaptation does not have to replace mitigation on political agendas; it is preferable that both adaptation and mitigation operate together within the context of sustainable development. In Canada, a combination of adaptation and mitigation responses has been captured by the group AMSD (climate change Adaptation, Mitigation and linkages with Sustainable Development). This group is promoting an integrated approach to exploring the linkages among climate change adaptation (A), mitigation (M) and sustainable development (SD).

For adaptation to be beneficial and cost effective, it should not be solely reactionary (i.e., after the impacts are realized), but rather proactive, anticipatory adaptation (Bower and Aerts 2006). Adapting to climate change can also decrease vulnerability to climatic variability and extreme events. Adaptation options termed win-win or no-regrets offer benefit regardless of the existence of climate change. These strategies incorporate adaptation into planning and would be beneficial and economically feasible even if future climate change impacts were not actualized. Delaying action on creating adaptation-focused agendas will only result in increased costs from climate change impacts and greater risk to humanity (Rosenberg, 1986).

Definitions

The following table summarizes key definitions.

TABLE 1. KEY DEFINITIONS

TERM	DEFINITION
Adaptation	Adapting to climate change refers to adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various type of adaptation can be distinguished, including anticipatory and reactive, private and public, and autonomous and planned adaptation (IPCC, 2001).
Climate Model	A climate model is commonly thought of as a numerical or mathematical representation of the physical, chemical and biological properties (atmosphere, ocean, ice and land surface) of a climatic system, which incorporates scenarios (coherent internally consistent and plausible descriptions of a possible forthcoming states of the world; Carter et al, 1994) allowing for the generation of future predictions (Santer et al., 1990).
Generic Model	A model is a representation, description or abstraction developed to illustrate a theory, system or concept. Models are diverse and range from qualitative and quantitative to computational and conceptual.
Mitigation	An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2007)
No-regrets Adaptation Options	Are fail-safe adaptation options. For example an infrastructure no-regret option would increase the durability and longevity of a building to climate variability over time.
Proactive Anticipatory Adaptation	This means implementing adaptive measures before the impacts expected occur therefore avoiding higher costs than would otherwise be incurred and damages to the economy (Berkhout, 2005).
Win-win Adaptation Options	Include green roofs (that decrease the energy consumption, stormwater runoff, air pollution and could help reduce the urban heat island), water conservation programs, (which aid in decreasing seasonal water shortages and the effects of drought) and the implementation of renewable energy (that are beneficial for the environment and can provide energy during grid power outages and storms).

Model Selection Methodology

Potential climate change models that included adaptation were selected as a result of an extensive scientific literature search and surveys of key experts and practitioners. Given that a model of adaptation has yet to be defined, the selection of models is perhaps larger than might first be assumed. This is a direct result of not eliminating models that contained adaptation in a minimal way, since these models could very well be the foundation models for complex adaptation solutions in later versions. There are many faces of adaptation models that perhaps look at adaptation in different but equally valuable ways. A model was classified as an adaptation model according to the following criteria:

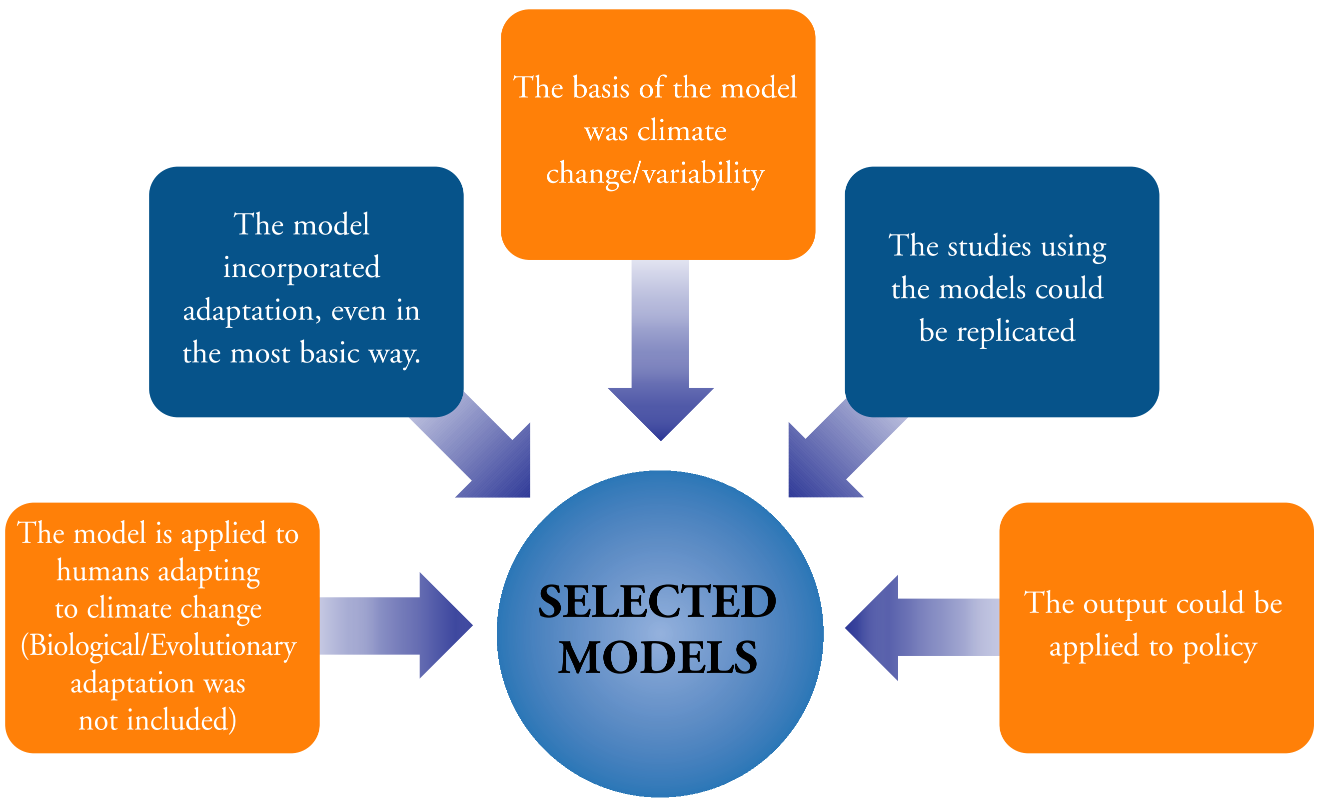


FIGURE 1.

CRITERIA FOR MODEL SELECTION

List of Models Surveyed

The following tables **(Table 2a and 2b)** provide the model name, the incorporation of adaptation and further information for each model surveyed.

TABLE 2. INCORPORATION OF ADAPTATION AND FURTHER INFORMATION

MODEL NAME	INCORPORATION OF ADAPTATION	FURTHER INFORMATION
ABMs	Simulates agent adaptation	http://www.lter.uaf.edu/pdf/1041_berman_nicolson_2004.pdf
AD-Dice	Policy/Decision Variable	http://ideas.repec.org/p/sgc/wpaper/126.html
AD-RICE	Policy/Decision Variable	http://www.fnu.zmaw.de/Working-papers.5675.0.html
ASD	Statistical downscaling	http://www.ccsn.ca/
BRDSEM	Estimate cost water man.	http://www.aiaccproject.org/working_papers/Working%20Papers/AIACC_WP31_Callaway.pdf
CALVIN	Adaptation assessment	http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/
CanCLIM	Assess adaptation options	http://waikato.ac.nz/igci/projects/canclim.htm
CanREM	Emissions targets	
CIAM	Adaptation module	http://www.tyndall.ac.uk/research/theme1/final_reports/it1_3.pdf
CLIMPACTS	Evaluates adaptation options	http://climsystems.com/site/products/?id=10
CLOUD	Social Response	http://www.geog.ox.ac.uk/research/projects/cloud/index.html
COBWEB	Agent adaptation	www.cobweb.ca
CRISTAL	Evaluate adaptation options	http://www.sei.se/index.php?section=climate&page=projdesc&projdescpage=99976
DIVA	Assess adaptation strategies	http://diva.demis.nl/
EPIC	Assess adaptation options	http://www.brc.tamus.edu/epic/
ESCAPE	Links several IAMs	http://sedac.ciesin.org/mva/iamcc.tg/TGsec4-2-5.html
ESPr	Assess adaptation strategy	www.greenroofs.org

TABLE 2. INCORPORATION OF ADAPTATION AND FURTHER INFORMATION

MODEL NAME	INCORPORATION OF ADAPTATION	FURTHER INFORMATION
FARM-Adapt	Cost effective adaptations	http://www.nottingham.ac.uk/environmental-modelling/
FUND2.9	Induced adaptation	http://fnu.zmaw.de/FUND.5679.0.html
ICAM2.5	Decision Variable	http://hdgc.epp.cmu.edu/models-icam/models-icam.html
ICLIPS	Assess policy (TWA)	http://www.pik-potsdam.de/~fuessel/download/help_iit/publications/
IMAGE2.1	Land allocation, expansion	http://www.mnp.nl/image/
ISIS	Socio-economic	http://w3g.gkss.de/staff/storch/pdf/kompl_Grossmann.pdf
MAGICC	Set of linked models	http://www.climatescience.gov/workshop2005/posters/P-WE1.21_Smith.J.pdf
MiniCAM 2.0	Induced adaptation	http://www.globalchange.umd.edu/data/models/MiniCAM.pdf
MPPACC	Adaptation assessment	http://diglib.uni-magdeburg.de/disssertationen/2005/torgrothmann.htm
OSWRM	Assessing adaptation options	http://www.ires.ubc.ca/aird (navigate to "completed projects")
PAGE2002	Incorporates adaptation policy	http://www.jbs.cam.ac.uk/people/faculty/hopec.html
RegIS2	Assess responses and options	http://www.silsoe.cranfield.ac.uk/iwe/projects/regis/regis2.htm
Ricardian	Assessing adaptation roles	http://ceepa.co.za/docs/CDPNo21.pdf
SimCLIM	Evaluates adaptation	http://climsystems.com/site/products/?id=9
SWAP-WSBM	Coupled with WSBM	http://www.geo.vu.nl/users/ivmadapt/downloads/Walawe_FinalReport.pdf
TARGETS	Decision Variable	http://sedac.ciesin.org/mva/iamcc.tg/TGsec4-2-7.html
TEAM	Assess strengths of adaptation	http://www.ecobilan.com/uk_team.php
UWF	Adaptation options	http://www.ires.ubc.ca/aird/documents/OKPIA_2004-06_FinalReport_HiRes.pdf

Defining Adaptation Modeling

As previously noted, the 'field' of adaptation modeling is diverse and undefined and what constitutes an adaptation model is open to various interpretations. Several different types of models are labeled 'adaptation models' increasing this state of confusion. This assessment suggests that adaptation models can be separated into two general categories: Adaptation Centered Models (ACMs) and Impact Centered Models (ICMs); where the main difference between the models is their treatment of adaptation.

Tables 3a and 3b summarize the main differences between ICMs and ACMs.

TABLE 3A. IMPACT CENTERED MODELS

IMPACT CENTERED MODELS (ICMS)	COMMENT
Models measure impacts of climate change; modeling impacts parameterizing adaptation	Impacts net of adaptation, not gross impacts Normative
Adaptation is incorporated in an unchanging equation assumed to take adaptation into account	This is not 'modeling adaptation'
Adaptation cannot be varied in the model	Parameter set or assumed at static level
The amount of adaptation (or net of achievement) is assumed and is not verified or nor does it have an empirical basis.	Thus, the output is based on the inclusion or exclusion of adaptation, but adaptation itself is not being modeled.
Example, In Rosenzweig and Parry, 1994, the assumptions included no adaptation, 50% adaptation and full adaptation.	

TABLE 3B. ADAPTATION CENTERED MODELS

ADAPTATION CENTERED MODELS (ACMS)	COMMENT
Allow for the variation of adaptation options or different levels of adaptation.	Allows for how much can be accomplished through adaptation; given the impacts, how much adaptation could or would occur
Adaptation can be manipulated, assessed and evaluated	Potential to demonstrate the strengths/ weaknesses of adapting to climate change
ACMs demonstrate the ability of adaptation to reduce climate change impacts.	ACMs are much more satisfactory than ICMs and they represent a more promising direction for future development.
Example, In the model PAGE2002 adaptation is included as a decision variable (Alberth and Hope, 2006)	

Typology

The previous binary classification between ICMs and ACMs is a preliminary categorization system; it does not provide information into the applicability of each model. Therefore, the models can be further differentiated by subcategories. The methodology of creating a typology for adaptation models assists a) in identifying gaps, b) sectors where adaptation models are deficient and abundant, and c) the direction of future research goals and requirements. Below is a suggested classification of adaptation models that is subsequently used to categorize each model. This typology was chosen for transparency and ease of use. Several other classifications could also be possible including ones based on risk and/or impacts resulting from climate change.

TABLE 4A AND 4B. MODEL SECTORS AND DESCRIPTIVE PARAMETERS

SECTORS
Agricultural (A)
Coastal (C)
Economic (E)
Forestry (F)
Human Health (H)
Hydrological (Hy)
Multi-Sectoral
Socio-Economic Systems (SES)

DESCRIPTORS
Agent Based (AB)
Behavioural (B)
Cost Benefit Analysis (CBA)
Integrated Assessment Model (IAM)
Optimization (O)
Qualitative (Ql)
Quantitative (Qn)
Simulation (S)

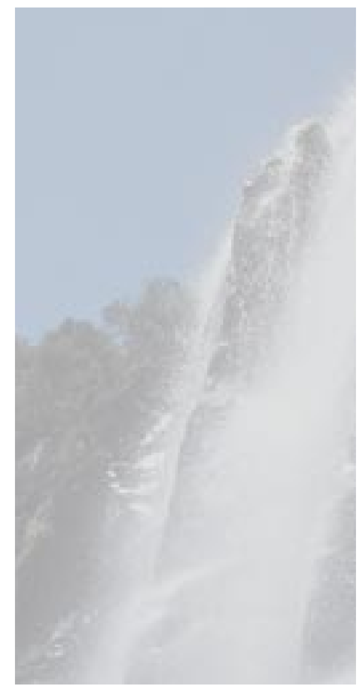
Integrated Assessment Models and Adaptation

Integrated assessment models (IAMs) bring together socio-economic dimensions of climate change with scientific aspects in order to assess policy options and environmental impacts of climate change (Weyant et al., 1996). They are used to assess climate change control policies (Weyant et al., 1996) to create interdisciplinary frameworks to address climate change problems including determining influential forces that make sectors sensitive to climate change and to quantify environmental and non-environmental problems resulting from climate change by ranking climate change control benefits and detriments in developed and developing countries (IPCC, 2001). IAMs can be divided into two distinct categories: evaluation and optimization.

TABLE 5. EVALUATION IAMS AND OPTIMIZATION IAMS: COMPARISON CHART

MODEL	EVALUATION IAMS	OPTIMIZATION IAMS
Use	To simulate and approximate the environmental results of a selected policy option and differing scenarios	To identify optimal policies of climate change control options
Scale	Solitary policy option or chosen scenario	Commonly global
Description	Follow the pattern of opening with assumptions of future events (socio-economic development) and then scenario – what scenarios are selected which are then analyzed and evaluated. which use calculations based on user-defined assumptions.	Attempt to determine the policy path that maximizes utility while imitating the effects of mitigation on the global economy. They are used in the analysis of policies that would decrease or increase the costs of meeting the objectives cost minimization within a set of specific constraints.
Example	IMAGE	DICE, RICE, and FUND

Model Representation and Gaps

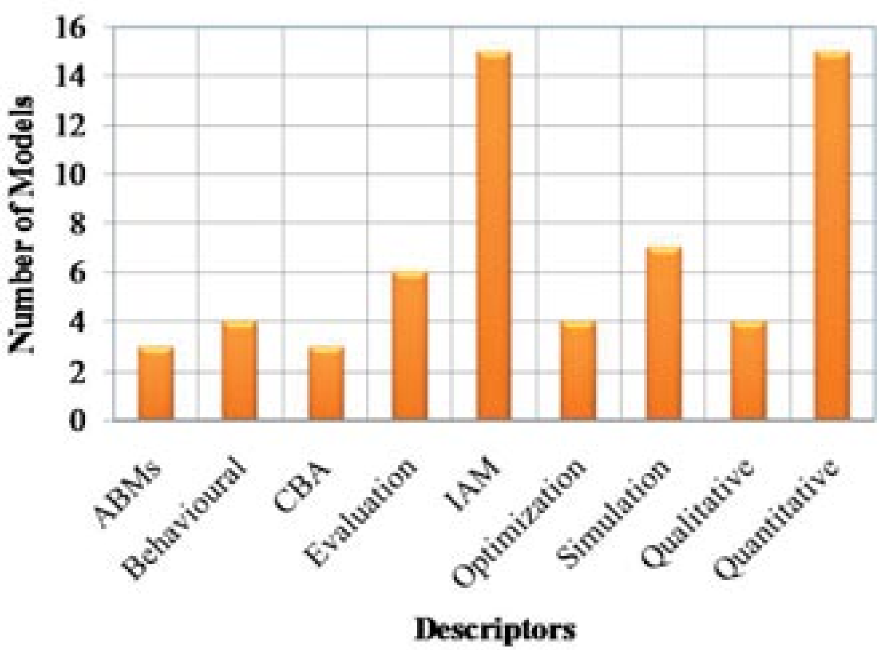


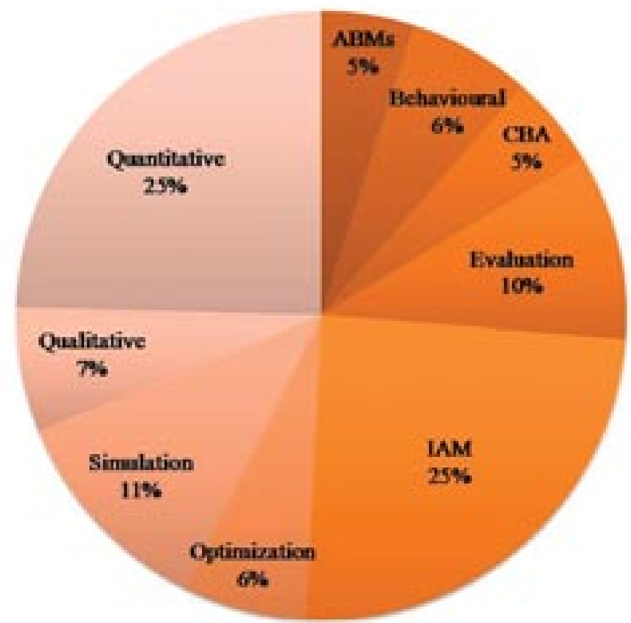
On the basis of this survey of adaptation modeling it becomes clear that there are sectors where models are prevalent **(see Graph 1a and 1b)** (economics) and sectors where they have yet to be fully embraced or developed at all including: tourism, aviation, health, transportation, extreme weather events, globalization, abrupt climate change and biodiversity. Ebi and Gamble, (2005) made a call for health models to incorporate adaptation; to date their call has not been answered.

Human behavior should be an essential component in adaptation models in order to accurately reflect society and individual agents. To demonstrate this requirement, two farmers given identical information about future climate change, will not act or respond identically. Models need to account for this indifference. They can both perceive this knowledge with differing confidence, thus having strikingly distinct responses. The varying degree to which humans respond to vulnerability and change is not static and it evolves over time. Lessons learned from previous years will be incorporated into their thought process for future years. A persons or an 'agents' perception of risk will alter their choice of whether to adapt. For instance farmers differ in confidence, education and understanding of weather and climate data; while their socio-economic status will alter their ability or willingness to adapt. Several other factors need to be considered including whether a farmer rents or owns property and/or equipment; their age and life experience; a commercial or family run farm and the size and financial success of it; available capital (current finances, present debt) and whether they are socially conservative or forward looking and innovative. Consequently, scenarios that only account for changes in climate (or the economy) and not human behavioural change over time will not be accurate.

The following graphs show the number of models for each descriptive parameter or sector and the representative percentage. The quantitative amounts in the graphs represent the number of models surveyed that contain the single parameter. Provided that a given model could fall into multiple categories, it is therefore possible that a model could be an IAM and also be Quantitative. Thus, the percentages represent the amount of times that a given model falls into any of the selected categories.

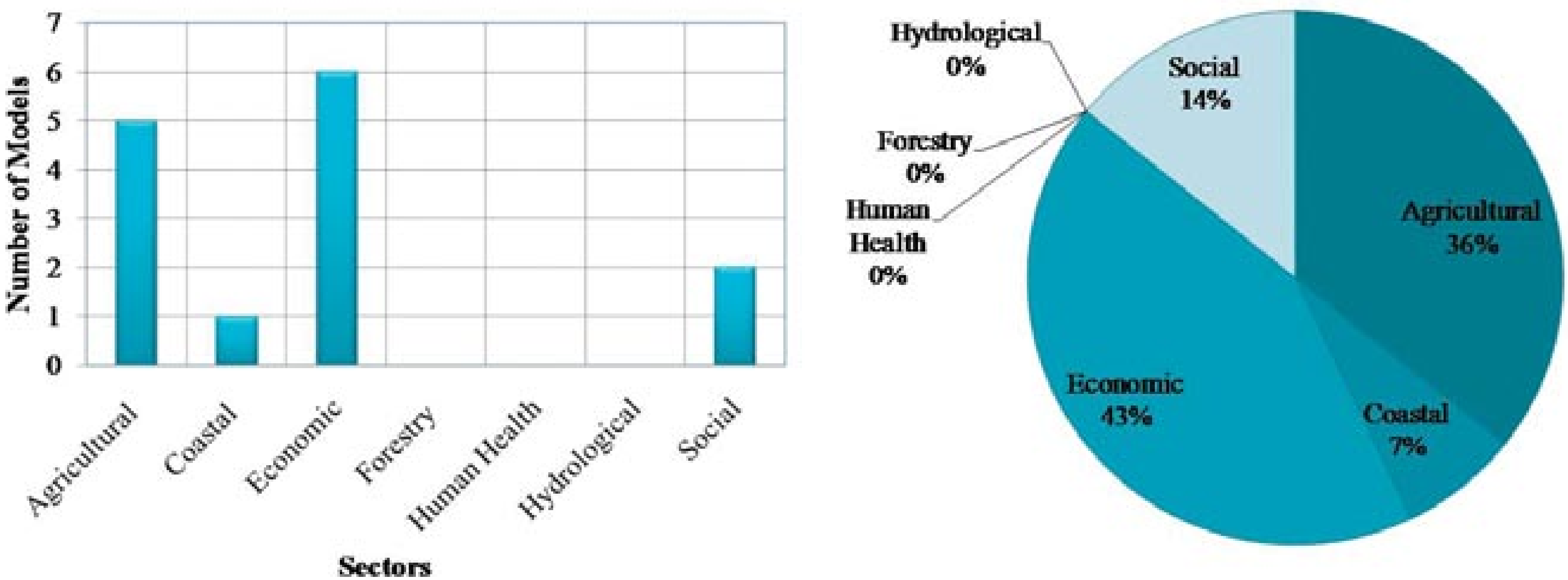
GRAPH 1A AND 1B. DESCRIPTIVE CLASSIFICATION REPRESENTATION





Adaptation models have primarily been created for economic and agricultural sectors with the mass being quantitative IAMs.

GRAPH 2A AND 2B. SECTOR CLASSIFICATION REPRESENTATION



The following tables **(Table 6a – 6e)** give the model name, descriptive summary and possible classifications.

TABLE 6. MODEL SUMMARIES

MODEL NAME	DESCRIPTION	CLASSIFICATION
ABMs	ABMs are computer models used to determine how humans (agents) respond to a variety of stimuli and scenarios of environmental and social conditions, including adapting to climate change and responses to adaptation strategies. Agents represent positions, boundaries, and actions of stakeholders, stimuli and scenarios of environmental and social conditions.	Agent Based Simulation Computational Behavioural
AD-Dice	AD-DICE utilizes the foundation of the original IAM DICE and modifies it by incorporating adaptation as a decision variable. This variable allows for trade-offs between adaptation and mitigation to be modeled since they are separate decision variables.	Quantitative Computational Economic, IAM
AD-RICE	AD-RICE takes the original RICE model and incorporates adaptation. The model contains an adaptation cost function and is able to demonstrate that adaptation reduces the gross damages from climate change	Quantitative Computational Economic, IAM
ASD	The ASD model determines statistical relationships between large-scale and local climate data with an easy to use graphical user interface for the statistical downscaling of GCM outputs to regional or local variables. The main advantage is the automatic selection of the predictor variables and sufficient statistical analyses	Computational Quantitative
BRDSEM	BRDSEM is a hydro-economic model which utilizes downscaled monthly precipitation and temperature information to assess the physical and economic impacts (benefits and costs associated with climate change) of a number of long-run and short-run adaptation options	Quantitative Cost-Benefit Analysis Economic
CALVIN	The CALifornia Value Integrated Network (CALVIN) is a statewide economic engineering optimization model. CALVIN was built to assess the ability of California's water supply system to adapt to climate change. CALVIN is explicitly adaptive	Quantitative Economic Optimization
CanCLIM	CanCLIM is an IAM developed for Canada to assess adaptation options and impacts to climate change. The model uses GIS, national and regional climate change scenarios and the ability to examine historical data from extreme events.	Computational Simulation, IAM

TABLE 6. MODEL SUMMARIES

MODEL NAME	DESCRIPTION	CLASSIFICATION
CanREM	CanREM/REAM are optimization models that provide scenarios of energy supply under different demand scenarios or constraints. The model adapts allocation of energy resources to meet the external environment, i.e. the demand or constraints on the system, i.e. emission targets.	Optimization
CIAM	CIAM is a forthcoming model from the Tyndall Centre's research which has been cited to be the new "core" of their research. The model will allow scientists to carry out a holistic investigation into adaptation strategies for climate change; being able to simulate adaptation options.	(Forthcoming model)
CLIMPACTS	CLIMPACTS is an IAM that performs integrated impact analysis and evaluates adaptation options; it is used to evaluate policy scenarios in response to climate change up to the year 2100. The model has three components and several adaptation options.	Computational Evaluation Simulation, IAM
CLOUD	CLOUD is an agent based model (ABM) that simplifies the behaviour of agricultural communities. Starting with fieldwork, the model incorporates economic, crop and adaptation modules along with common climate change scenarios. Social Responses to climate information; decision-making.	Agricultural Agent-Based Social Behavioural
COBWEB	COBWEB is an agent-based simulation that was developed to explore how complex systems that might include people, animals or bacteria adapt to environmental change and environmental variability. The model is very interactive, allowing the user to set many parameters (energy expenditure, resource growth rate, energy requirements) with an easy to use interface.	Agent-Based Simulation Computational Behavioural
CRISTAL	CRiSTAL is a user friendly program that aids in determining linkages between climate change and livelihoods. The model can be used by local communities, project planners and project managers to ensure that adaptation opportunities are maximized and maladaptation is minimized.	Qualitative Computational
DIVA	DIVA is a new tool for integrated assessment of coastal zones that will be released in late 2004. It is specifically designed to explore the vulnerability of coastal areas to sea level rise. It comprises a global database of natural system and socioeconomic factors, relevant scenarios, a set of impact-adaptation algorithms and a customized graphical-user interface.	Quantitative Computational Coastal, IAM

TABLE 6. MODEL SUMMARIES

MODEL NAME	DESCRIPTION	CLASSIFICATION
EPIC	EPIC is designed to quantify the costs of soil erosion and benefits of soil erosion research and control. This approach is useful for evaluating a limited number of agronomic adaptations to climate change, such as changes in planting dates, modifying rotations (i.e., switching cultivars and crop species), changing irrigation practices, and changing tillage operations.	Quantitative Computational Agricultural
ESCAPE	ESCAPE is a collaborative integrated assessment model containing components of IMAGE and MiniCAM. ESCAPE contains four world regions, separate modules for emissions, atmospheric chemistry and dynamics, and impacts.	Quantitative Computational, IAM
ESPr	ESP-r simulates the energy consumption of a building. The model evaluates the impact of an extensive green roof on energy consumption. The model can be used to evaluate green roofs in different climates or under climate change scenarios, when scenarios at the sub-daily time step become available.	Evaluation, Simulation
FARM-Adapt	FARM-Adapt is an optimization model that attempts to establish the least cost (profit foregone) and profitable adaptations. Several adaptation options are available. Farm-adapt uses Monte Carlo simulation to examine the most cost effective adaptations.	Quantitative Agricultural Monte-Carlo Optimization
FUND2.9	FUND2.9 is based on the original FUND model and is defined for 16 regions running from 1950-2300, in time-steps of years and has explicitly optimized adaptation for sea level rise. The model also considers agriculture, high winds, river floods, heat stress, cold stress, malaria and loss of biodiversity. Damages are expressed as currency.	Quantitative Economic Computational
ICAM2.5	ICAM is an impact centered model, analyzing uncertainty and climate change impacts. The model generates economic growth projections based on regional population growth and user specified assumptions. Adaptation policies are represented implicitly within the impact modules, so they cannot be varied explicitly	Evaluation Monte-Carlo, IAM
ICLIPS	ICLIPS is an IAM (the ICLIPS Impact Tools is a graphical to an extensive results database). The model was created to assist the UNFCCC decision making. ICLIPS adopts a different approach to integrating mitigation and impact/adaptation concerns, dealing with adaptation indirectly in the applications.	Computational Conceptual IAM

TABLE 6. MODEL SUMMARIES

MODEL NAME	DESCRIPTION	CLASSIFICATION
IMAGE2	IMAGE is a dynamic integrated assessment modeling framework for global change and a simulation model. The main objectives of IMAGE are to contribute to scientific understanding and support decision-making by quantifying the relative importance of major processes and interactions in the society-biosphere-climate system.	Computational Simulation IAM
ISIS	ISIS models may be used to describe different options for society to respond to emerging real or perceived environmental risks (for example, climate change). ISIS can be applied to a wide variety of problems related to climate change, natural risks and disasters. The model is structured around a seven-phase life cycle of a basic innovation.	Quantitative Computational Simulation
MAGICC	MAGICC is a set of linked simple models that, collectively, fall in the genre of a simple climate model, which can be used to aid in the assessment of adaptations to climate change. MAGICC is linked to SCENGEN, a global and regional scenario generator.	Computational, IAM
MiniCAM 2.0	Mini-CAM is a climate change IAM designed to examine long-term, large-scale changes in global and regional energy systems. It integrates MAGICC and SCENGEN models for climate and regional climate change analysis but has separate technology modules.	Computational, IAM
MPPACC	MPPACC looks at the psychological steps to responses to perception: risk perception and perceived adaptive capacity to climate change. The model includes objective adaptive capacity, adaptation appraisal and adaptation intention. All of these lead to an enabling or impeding adaptation output.	Behavioural Qualitative Social
OSWRM	OSWRM offers a learning tool for assessing the effectiveness of adaptation options within various scenarios of climate change and population growth for the Okanagan Basin, a semi-arid region located in British Columbia, Canada.	Evaluation, Computational
PAGE2002	PAGE2002 models adaptation strategies to show the benefits of adapting to climate change. PAGE2002 contains 8 world regions, all major GHGs, mitigation and adaptation costs, impacts (economic and non-economic) and a time scale till 2200.	Evaluation Optimization IAM

TABLE 6. MODEL SUMMARIES

MODEL NAME	DESCRIPTION	CLASSIFICATION
RegIS2	RegIS2 uses IAMs to evaluate local and regional sub-national scale impacts and adaptation options for agriculture biodiversity, coasts, flood plains, water resources, while also modeling "no adaptation" options for comparison	Quantitative Qualitative Computational IAM
Ricardian	Ricardian/Econometric models are manipulated with climate change scenarios to predict the economic costs of adaptation. The models can capture the full range of economic adaptations that farmers and supporting institutions are likely to use in response to climate change.	Quantitative Economic Agricultural
SimCLIM	SimCLIM can be used to support decision-making with its capacity to assess baseline climates and current variability and extremes. Adaptation measures can be tested for present day conditions and under future scenarios of climate change and variability and sea level rise.	Computational Simulation IAM
SWAP-WSBM	SWAP-WSBM is a coupled field scale modeling framework aids in evaluating impacts and adaptation strategies. They are used to analyze and understand current water resources issues, to analyze the impact of climate change and to evaluate adaptation strategies.	Quantitative Agricultural
TARGETS	The TARGETS model is used to study climate change, global change and sustainable development. TARGETS includes five interlinked "horizontal" modules representing population and health, energy and economics, biophysics, land and soils, and a water submodel.	IAM
TEAM	TEAM uses a multi-criteria approach for evaluating adaptation actions to address climate change impacts to water resources, coastal zones and agriculture. The user selects specific "strategies" or adaptation options and criteria and then assigns a relative score (excellent, good, fair, and poor) for how each strategy meets each criterion.	Qualitative Computational Quantitative
UWF	UWF examines future residential water sufficiency. The model integrates scenarios with adaptation options of interest to policymakers being represented as scenarios of housing density and demand side management.	Evaluation, Computational

THE COMPENDIUM OF ADAPTATION MODELS FOR CLIMATE CHANGE: FIRST EDITION

■ LIST OF MODELS SURVEYED

All model descriptions were extracted from peer review literature, model authors and corresponding websites. These have not been individually evaluated. Information has not been analyzed, revised or interpreted.

ABM (Agent Based Models)

ABMs are computer models used to determine how humans (agents) respond to a variety of stimuli and scenarios of environmental and social conditions, including adapting to climate change and responses to adaptation strategies. Agents represent positions, boundaries, and actions of stakeholders. ABMs are a means to realistically simulate the behavior of stakeholder networks in the context of the rules, norms, and shared strategies from social and economic institutions. They can be applicable globally, nationally or locally. The key input includes qualitative and quantitative data. The key output includes insight into how the decision making and implementation process occurs. ABMs have realistic socioeconomic pathways constructed as the outcome of multiple decisions.

To illustrate agent based social simulation can incorporate socioeconomic scenarios that are constructed as sets of rules regarding, for example, environmental values, regulation, and economic goals. An advantage of this approach is that the realization of socioeconomic scenarios is the outcome of stakeholder behavior rather than being exogenously imposed in a way that bears little relation to actual decision making processes.

■ Further Information

Online information can be obtained at the following site:

http://www.lter.uaf.edu/pdf/1041_berman_nicolson_2004.pdf

AD-DICE (Adaptation-Dynamic Integrated Model of Climate and the Economy)

AD-DICE (de Bruin et al., 2007) utilizes the foundation of the original IAM (Integrated assessment models (IAMs) bring together socio-economic dimensions of climate change with scientific aspects in order to assess policy options and environmental impacts of climate change) DICE and modifies it by incorporating adaptation as a decision variable. The original DICE model (Dynamic Integrated Model of Climate and the Economy) was developed by Nordhaus and published in a 1994 publication as one of the earliest integrated assessment models (Nordhaus, 1996). The DICE model is a dynamic optimization global model that includes economic and geophysical functions (Nordhaus 1992). In the DICE model utility is maximized and agents were assumed to adapt optimally (de Bruin, 2007). However, the original DICE model does not explicitly consider adaptation; it assumes that adaptation is optimal and is included in the damage function. A recent modification of this model came in 2007 (de Bruin et al., 2007), subsequently renamed AD-DICE (adaptation-DICE). AD-DICE is a computational, economic, IAM with a top-down apprach that models adaptation as a policy decision variable. This model allows for trade-offs between adaptation and mitigation to be modeled since they are separate decision variables.

Completed Case Study

AD-DICE explicitly shows the adaptation cost functions inplied in the DICE model. Applying five different scenarios (optimal controls; no controls; only adaptation; only mitigation) the model aided in the conclusions that the “only adaptation” option results in a higher utility than “only mitigation”, thus adaptation is a more cost effective control. The model also was able to show that the net benefits of mitigation up to 2050 are negative. When applied optimally, adaptation will reduce gross damages of climate change by on average 35%. The findings from the model support the statement that applying only adaptation is more beneficial than applying only mitigation, confirming the importance of adaptation as a control option in combating climate change up until 2100, where thereafter mitigation reduces damages (de Bruin, FC 2007).

■ Further Information

Online information can be obtained at the following site:

http:// econ.yale.edu/~nordhaus/homepage/dicemodels.htm

http://ideas.repec.org/p/sgc/wpaper/126.html

AD-RICE (Adaptation – Regional Integrated model of Climate and the Economy)

The original RICE model (Regional Integrated model of Climate and the Economy) was a model that analyzed different national strategies on climate change policy (Nordhaus, 1996). RICE can be summarized as a regional, dynamic, general equilibrium model of the economy which integrates economic activity with the sources, emissions and consequence of greenhouse-gas emissions and climate change. In the RICE model the world is divided into a number of regions. Each is endowed with an initial capital stock, population and technology (Nordhaus, 1996). The major economic choices faced by the nations in the RICE model are: to consume goods and services; to invest in productive capital; to slow climate change through reducing CO_2 emissions.

Climate Change Application

AD-RICE takes the original RICE model and incorporates adaptation as a decision variable. The model contains an adaptation cost function and is able to demonstrate the difference in adaptation costs of different regions implied in RICE (de Bruin et al., forthcoming). Furthermore different forms of cooperation in adaptation and mitigation are considered.

Further Information

Online information can be obtained at the following site:

www.enr.wur.nl/uk/staff/debruin (forthcoming)

http://www.fnu.zmaw.de/Working-papers.5675.0.html

http://www.econ.yale.edu/~nordhaus/homepage/dicemodels.htm

Automated Statistical Downscaling (ASD) model

An automated regression-based statistical downscaling model (ASD, Hessami et al., 2007), inspired by the existing Statistical DownScaling Model (SDSM; developed by Wilby et al., 2002) was developed within the Matlab environment (The Mathworks, 2002). The ASD model determines statistical relationships between large-scale (the predictors) and local (the predictand) climate data, with the final aim of the model being to provide high resolution future climate information by driving the calibrated statistical relationships with global climate model (GCM) predictors for future time periods.

ASD tool is an easy to use graphical user interface for the statistical downscaling of GCM outputs to regional or local variables. The model process can be conditional on the occurrence of an event (i.e. for precipitation) or unconditional (i.e. for temperature). Hence, the modelling of daily precipitation involves the following two steps: modeling precipitation occurrence followed by the modeling of precipitation amounts (if precipitation occurs). In order to run ASD you will need to provide daily observed local data (the predictand) and daily observed and GCM large-scale atmospheric data (the predictors).

The main advantage of the ASD model over other statistical downscaling methods is the automatic selection of the predictor variables, although for more experienced downscalers it provides sufficient statistical analyses for intervention to take place if so desired. Also, the model has a user-friendly graphic user interface and provide to the users various useful statistical criteria to evaluate the reliability of the downscaling variables compared to observed data, and different diagnostic criteria (mean, standard deviation and few extreme indices of both temperature and precipitation variables) to analyzed the outputs over the current and future periods. The ASD software also provides quantile-quantile plots as another means for examining the performance of the model.

Case Study Region used for the Assessment of ASD model

The performance of the ASD model has been assessed over two regions of Canada (i.e. in the Prairie Provinces, see Barrow, 2007, and in eastern Canada, see Gachon et al., 2005) and over one tropical area in western Africa (see Parishkura, 2007). Over eastern Canada and Africa, the ASD model has also been compared to the SDSM model. In all cases, the ASD model performs relatively well to downscale the daily temperature as well as the precipitation, including extreme indices. In general, the temperature-based extreme indices were most accurately reproduced, whilst for the precipitation based indices there tended to be excessive outliers (even when the median values were well-matched) indicating strong dispersion from the stochastic component of the model. This reflects that strong events of convective precipitation, especially in summer, are not generally captured by multilinear regression models (see Wilby et al., 2004).

A revised and updated version of the ASD model, following the recommandations made in the assessment report of Barrow (2007), is under development and will be available soon to download from the Climate Change Scenarios Network (www.ccsn.ca).

■ Further Information

Online information can be obtained at the following site:

http://www.cccsn.ca/

http://quebec.cccsn.ca/GAC/

BRDSEM (Berg River Dynamic Spatial Equilibrium Model)

In response to the requirement to demonstrate economic benefits and tradeoffs of development with climate change, the Berg River Dynamic Spatial Equilibrium Model (BRDSEM; an IAM) was developed. BRDSEM is used to assess the benefits and costs of specific adaptation measures. BRDSEM is a hydro-economic model which utilizes downscaled monthly precipitation and temperature information to assess the physical and economic impacts (benefits and costs associated with climate change) of a number of long-run and short-run adaptation options (Callaway and Hellmuth, 2006). The model evolved from those developed by Hurd et al., (2004). BRDSEM is applied to a selected basin, on a spatially-differentiated basis, and maintains climate accounts for estimating the economic value of climate change damages, the net economic benefits of avoiding these damages, and the imposed (unavoided) damages of climate change. The models key inputs are a regional climate model, a regional hydrologic model and inputs about polices, plans and technologies, which yields outputs of the measures of the economic value of water (i.e. net returnees to water) for water users, broken down by urban sectors and farm regions, the optimal storage capacity of the berg river dam. Various benefits and costs associated with climate change and adaptation for different adaptation measures (Callaway and Hellmuth, 2006).

Completed Case Study (also reported in the Stern Review)

Using BRDSEM the net benefits of adaptation measures (in response to climate change) of building the Berg River Dam was compared to replacing the existing regulatory framework for allocating water in the basin allocation of water to both urban and agricultural users, without the Berg River Dam. The study was completed by Callaway and Hellmuth (2006) on the water supply in the Berg River Basin in South Africa (Stern, 2006). The model incorporated adaptation to climate change by comparing the estimated benefit or cost measures for each proposed adaptation. These included development actions (assuming no climate change); net benefits of development actions; additional adaptation action (development and climate change); net benefits of adaptation (reduction in damages from adaptation minus costs of adapting); cost of not planning for climate change that does not occur; cost of planning for climate change that does occur. The inclusion of adapting to climate change illustrated the benefits of implementing both strategies at the same time; also illustrating an important point that the cost of *not* adapting to climate change is greater than the cost of adapting.

■ Further Information

Online information can be obtained at the following site:

http://www.hmtreasury.gov.uk/media/8A7/87/stern_review_supporting_technical_material_molly_hellmuth_231006.pdf

CALVIN (CALifornia Value Integrated Network)

The CALifornia Value Integrated Network (CALVIN) is a statewide economic engineering optimization model. CALVIN was built to assess the ability of California's water supply system to adapt to climate change. CALVIN is explicitly adaptive (Jenkins et al., 2001; Draper et al., 2003). CALVIN considers water supply and demand management activities required to adapt to climate change in order to minimize economic impact. The model allows for adaptation options to be modeled including: water allocation and markets, joint surface and groundwater operations, coordinated facility operations, urban conservation/use efficiencies, cropping changes and fallowing, agricultural water use efficiencies, new technologies, wastewater reuse and seawater desalination (Lund et al, 2007).

Completed Case Study

Tanaka et al., (2006), assessed climate change impacts on California, with and without adaptation. Five statewide scenarios were run using the CALVIN model: a) Base 2020: assumes continuation of current operation and policies; b) SWM 2020: assumes flexible and economically-driven operation and allocation policies; c) SWM 2100: extends the model to 2100; d) PCM 2100: runs using a dry and warm 2080–2099 climate warming hydrology scenario; and e) HCM 2100: employs a wet and warm 2080–2099 climate warming hydrology scenario. Water impacts and adaptations were set to be statewide. Multiple types and scales of economically-driven adaptations were incorporated into the model, rather than having a single adaptive response. The model results demonstrated that California's water system could adapt to the scenarios (including the most severe), but the adaptations are not without cost, however, if proper fiscal management is implemented the costs would not threaten the economy (Tanaka, 2006).

■ Further Information

Online information can be obtained at the following site:

http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/

CanCLIM (Canada)

CanCLIM is a modification CLIMPACTS that was developed for Canada to aid in assessing possible impacts of climate change and to assess options for adaptation to climate change. CLIMPACTS is software originally developed for New Zealand (now applied elsewhere). The model has a user-friendly graphic user interface (GUI), a customized geographical information system (GIS), national and regional climate change scenario generator for rapid generation of user-specified climate change scenarios, a capacity to analyze extreme climate events from historical data.

■ Further Information

Online information can be obtained at the following site:

http://www.waikato.ac.nz/igci/modelling/modelling.htm

http://www.waikato.ac.nz/igci/projects/canclim.htm

CanREM and REAM (Canadian Regional Energy Model and Regional Energy Analysis Model)

These are optimization models that provide scenarios of energy supply under different demand scenarios or constraints. Essentially, the model adapts allocation of energy resources to meet the external environment, i.e. the demand or constraints on the system, i.e. emission targets. The demand scenarios can be based on projected changes in climate and can take into account other changes in technology or society. CanREM, developed in collaboration with Environment Canada and the University of Regina, is primarily data driven, and may be quite sensitive to problems in the data. For this reason, it has been developed to incorporate both interval and fuzzy parameters. However, it can provide a very precise analysis from mined resources to final end uses of energy including climate change.

REAM is simpler, focusing on aggregate demand and as series of environmental weights. Although it cannot provide the precision of the future scenarios contained in CanREM, it can be run on a spreadsheet.

Completed Case Study

Lin, Q.C., Huang, G.H. and Bass, B. (2005) An Energy Systems Modeling Approach for the Planning of Power Generation: a North American Case Study. *International Journal of Computer Applications in Technology* 22: 151-159.

CanREM was used to look at future energy supplies in the Toronto-Niagara Region under different policy scenarios including the phase out of coal-fired electricity, meeting the Kyoto emission targets and encouraging the use of renewable resources. Overall, a policy based on the Kyoto targets was far more effective at encouraging the use of renewable resources then a policy directed specifically at this sector, and was as effective as a coal-phase out in reducing emissions.

■ Further Information

Online information can be obtained at the following site:

http://www.lter.uaf.edu/pdf/1041_berman_nicolson_2004.pdf

CIAM (Community Integrated Assessment Model)

The Community Integrated Assessment Model (CIAM) is a forthcoming model from the Tyndall Centre's research which has been cited to be the new “core” of their research. The model will allow scientists to carry out a holistic investigation into adaptation strategies for climate change; being able to simulate adaptation options. CIAM will merge climate models, socio-economic models, models of technological change, policy models, transport models, models of social behaviour and decision making, hydrological models, agricultural models, and models of climate change impacts such as biome shifts, human health and extreme events. The model will address the cost of adapting to climate change; stated to be more mathematically advanced than previous models allowing for the uncertainty to be analyzed with the improved mathematical depth.

■ Further Information

Online information can be obtained at the following site:

http://www.tyndall.ac.uk/research/theme1/final_reports/it1_3.pdf

CLIMPACTS (Climate Impacts)

CLIMPACTS is an IAM that performs integrated impact analysis and evaluates adaptation options; it is used to evaluate policy scenarios in response to climate change up to the year 2100. The model has three components a) a simple energy-balance, upwelling-diffusion global climate model, itself an integrated model containing gas cycle and radiative forcing models as well as a simple ocean-atmosphere model (2) a New Zealand climate scenario generator, consisting of both station time-series climate data, spatially-interpolated climatologies and downscaled patterns of climate change derived from complex general circulation model (GCM) experiments, as well as patterns of variability related to ENSO and the inter-decadal Pacific oscillation; and (3) a suite of impacts models related to pastoral, horticultural and arable crops and soils.

Adaptation options include integrated catchments management, changes to water pricing systems, water efficiency initiatives, building or rebuilding engineering structures, relocation of buildings, urban planning and management, and improved water supply measures in remote areas and low-lying islands. The financial exposure and cost involved in potential adaptations indicate a high vulnerability with respect to hydrology.

■ Further Information

Online information can be obtained at the following site:

http://climsystems.com/site/products/?id=10

CLOUD (Climate Outlooks and Agent-Based Simulation of Adaptation in Africa)

CLOUD is an agent based model (ABM) that simplifies the behaviour of agricultural communities. Starting with fieldwork, the model incorporates economic, crop and adaptation modules along with common climate change scenarios. The model is able to integrate the agent's memory if past climate variability. CLOUD explores climate change and adaptation while considering the agents behaviour (Bharwani, 2006). Adaptation options for the agent around agriculture and food security are incorporated into the model. The outputs of the model include characteristics of adaptation pathways. The central question or objective in CLOUD is, "to what extent might seasonal forecasts ensure adaptation to longer-term climate change, linking learning at the seasonal scale with the evolution of climate on longer-time-scales."

Completed Case Study

CLOUD was applied to adaptive farmer strategies in a Community Garden Project in Mangondi village, Limpopo Province, South Africa. The model contained farmer "agents" with differing wealth profiles. Fieldwork was conduced, farmers were interviewed, and the information gathered was used to develop economic, crop and adaptation modules. From climate change model experiments, climate scenarios were included. Past climate extremes are "remembered" by agents in the model and can allow for change of human behaviour and risk perception (Bharwani, 2006). The results of the agent-based model illustrate the impacts of such short-term adaptation strategies which contribute to long-term resilience under certain climate change conditions or conditions of climate variability. The short-term responses described in the previous sections, which are based on observations from fieldwork, have impacts which promote sustainability from seasonal to annual and decadal time-scales, as accumulated capital allows more innovative strategies to be pursued.

■ Further Information

Online information can be obtained at the following site:

http://www.geog.ox.ac.uk/research/projects/cloud/links.html

COBWEB (Complexity and Organized Behaviour Within Environmental Bounds)

COBWEB is short for Complexity and Organized Behaviour Within Environmental Bounds. It is and agent-based simulation that was developed to explore how complex systems that might include people, animals or bacteria adapt to environmental change and environmental variability. The COBWEB agents are powered by an artificial intelligence tool called a genetic algorithm, which is a behavioural strategy. These strategies are randomly created when we initialize the model. Agent strategies can be modified through communication with other agents, reproduction and new information from the environment. The resources, or the environmental variability, are simulated with another common AI tool, a cellular automaton. COBWEB is very interactive, allowing the user to set many parameters that either affect the agents or the resources. Parameters such as energy expenditure, resource growth rate, energy requirements for different actions and the energy derived from different resources are all accessed through a user interface that is very easy to use. The resulting population and resource patterns are determined by the interaction of the agents with each other, and with the environment. COBWEB is used both for research by both university and high school students and education on adaptation from Grades 4 through 4th year undergraduate courses.

Completed Case Study

Bass, B and Chan, E (2005) Complex Organization and Bifurcation Within Environmental Bounds COBWEB: An agent-based approach to simulating ecological adaptation, *Journal of Environmental Informatics.* 6(2).

This study used COBWEB to explore how invasive species are able to adapt to a new environment. The most common explanations such as higher reproductive rates, could not lead to a successful invasion. The only environmental change that led to a successful invasion was increasing the amount of stored energy in the invaded territory. When the resource base was sufficiently rich for indigenous as well as an invading species, the invader had a chance to colonize and out-compete the native species. COBWEB has also been used to simulate the emergence of cooperation or stealing under stress, to predict the minimum viable population to sustain a population, to simulate the spread of the flu virus (a study that received a gold medal at the Toronto Science and Technology Fair) and to study the emergence of group behaviour and central place hierarchies.

■ Further Information

Online information can be obtained at the following site:

www.cobweb.ca

CRiSTAL (Community-based Risk Screening – Adaptation and Livelihoods)

The notion that community-level projects could both lead to positive adaptation and or maladaptation by either increasing or decreasing vulnerability spurred the development of CRiSTAL; a user friendly program that aids in determining linkages between climate change and livelihoods. The model allows for the determination of whether a community level project is increasing the adaptive capacity or restricting it. The tool can be used by local communities, project planners and project managers to ensure that adaptation opportunities are maximized and maladaptation is minimized. The goals of CRiSTAL are to a) target aspects of a particular project that are directly related to adaptive capacity to climate change at the community scale; b) evaluate the specific effects of project activities on this capacity, and c) determine changes that could be made to improve the project's effect. The aim is to improve livelihoods by increasing adaptive capacity to climate change (see online source below).

Case Study

In Mali, increased drought, flooding and extreme heat are amongst the major climate changes, which will result in crop damage, loss of trees and social conflicts caused by drought; leading to surface water scarcity, reduced fish stocks, and income loss due to flooding; sick or weak livestock and reduced work and unemployment from extreme heat if proper adaptation measures are not taken. A working group applied CRiSTAL; the output determined that the chosen project activities effects on natural resources, physical capital, social capital and human resources were fairly positive. Limits of this model are funding for adaptation projects. Thus, only affordable adaptations were included into the model.

Based on the results from field tests, CRiSTAL is in the process of being revised, and partners will seek additional funds to apply to the tool at various project sites, moving towards implementing adaptation activities into field activities (see online source below).

■ Further Information

Online information can be obtained at the following site:

http://www.iisd.org/security/es/resilience/climate_phase_2.asp

http://www.sei.se/index.php?section=climate&page=projdesc&projdescpage=99976

DIVA (Dynamic Interactive Vulnerability Assessment)

DIVA is a global model developed specifically to assess adaptation strategies to climate change in coastal zones. DIVA was developed within the EU-funded DINAS-COAST project. DIVA is a tool for integrated assessment of coastal zones. It is specifically designed to explore the vulnerability of coastal areas to sea level rise. It comprises a global database of natural system and socioeconomic factors, relevant scenarios, a set of impact-adaptation algorithms and a customized graphical-user interface. Factors that are considered include erosion, flooding salinization and wetland loss. DIVA is inspired by the paper-based Global Vulnerability Assessment (Hoozemans et al., 1993), but it represents a fundamental improvement in terms of data, factors considered (which include adaptation) and use of PC technology.

■ Further Information

Online information can be obtained at the following site:

http://www.dinas-coast.net/

http://diva.demis.nl/

http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/dynamic_interactive_vulnerability_assessment__diva_.pdf

http://unfccc.int/files/national_reports/non-annex_i_natcom/cge/application/pdf/diva_print_me_first.pdf

EPIC (Erosion Productivity Impact Calculator)

EPIC is designed to quantify the costs of soil erosion and benefits of soil erosion research and control. This approach is useful for evaluating a limited number of agronomic adaptations to climate change, such as changes in planting dates, modifying rotations (i.e., switching cultivars and crop species), changing irrigation practices, and changing tillage operations (Adejuwon, 2006).

EPIC is site-specific, can be applied in various agricultural locations. Therefore, the parameter files are extremely sensitive to local conditions and EPIC can give grossly misleading results when relying on default settings as it is being tailored to different locations and cropping systems. The key inputs are quantitative data on climate, soils, and crop management, while the key outputs are response of crop yields, yield components, and irrigation requirements to climate change adaptations (Adejuwon, 2006). The EPIC 8120 model can analyze input five different ways: (i) estimation of crop productivity, i.e., the yield of the crop per unit area of land; (ii) estimation of total crop production within a given land area or territory;(iii) assessment of the impacts of climate variability and climate change on crop yields and crop production; (iv) assessment of the vulnerability of crop production systems to climate variability and climate change; and (v) assessment of adaptation options and strategies for managing the negative impacts of climate variability and climate change (Adejuwon, 2006). The inputs into EPIC include quantitative data on climate, soils, and crop management. The output includes crop yields, yield components, and irrigation requirements to climate change adaptations.

Completed Case Study

In a 1993 study by Easterling et al., long-term responses to climate change, adaptations, and short-term responses were investigated. The study used the EPIC model and four scenarios a) 2030: with no adaptation or CO_2 enrichment, b) 2030: no adaptation and higher CO_2 concentrations, c) 2030: with adaptation and d) 2030: with adaptation and higher CO_2. The scenarios were run and EPIC was able to demonstrate that adaptations to climate change are effective in decreasing impending impacts (Easterling et al., 1993).

■ Further Information

Online information can be obtained at the following site:

http://www.brc.tamus.edu/epic/

ESCAPE (Evaluation of Strategies to Address Climate Change by Adapting to and Preventing Emissions)

ESCAPE is a collaborative integrated assessment model containing components of IMAGE and MiniCAM. ESCAPE contains four world regions, separate modules for emissions, atmospheric chemistry and dynamics, and impacts. The framework for ESCAPE was used to create MAGICC (Model for the Assessment of Greenhouse gas Induced Climate Change) which is able to incorporate larger integrated frameworks developed by other institutes.

■ Further Information

Online information can be obtained at the following site:

http://sedac.ciesin.org/mva/iamcc.tg/TGsec4-2-5.html

ESP-r (Environmental Services Performance-research)

ESP-r simulates the energy consumption of a building. It was developed and is maintained by the University of Strathclyde, in Scotland. It has been modified so as to evaluate the impact of an extensive green roof on energy consumption. This particular modification is based on the contribution of each layer of a green roof expressed in terms of parameters such as thermal conductivity. Green roofs are viewed as an adaptation that cities can use to cope with changing extremes of precipitation and temperature. The model can be used to evaluate green roofs in different climates or under climate change scenarios, when scenarios at the sub-daily time step become available.

Completed Case Study

Saiz-Alcazar, S.. Kennedy, C, Bass, B.and Pressnail, K (2006) Comparitive Life Cycle Assessment of Standard and Green Roofs. *Environmental Science and Technology*. 40, 4312-4316.

This study evaluated the performance of a green roof against a standard roof using a number of measures including energy consumption. Using an eight-story residential building in Madrid, ESP-r simulated a small by significant difference in summer electricity consumption (6% reduction with a green roof) and peak demand (10% with a green roof). For the floor below the roof, the savings were over 20% and closer to 30% in the peak demand scenario.

■ Further Information

Further applications can be obtained from the *Proceedings of Greening Rooftops for Sustainable Communities* 2005 and 2006. These are available at the following site:

www.greenroofs.org

Farm-Adapt (Future Agricultural Resource Model-Adapt)

Farm-Adapt is an optimization model that attempts to establish the least cost (profit foregone) and profitable adaptations. The model maximizes farm net margin and income by selecting the optimal mix of crops, animals, labour, machinery, storage, housing and irrigation for a particular type of farm and has been used in policy-related and environmentally-based research (climate change impacts on farms, reducing greenhouse gas emissions and nitrate loss). Several adaptation options are available, including no adaptation, altering crop mix, timing, and machinery, capacities of irrigation and storage, to changing enterprises. Farm-adapt uses Monte Carlo simulation to examine the most cost effective adaptations.

Completed Case Study

In a recent publication, Farm-Adapt was used to determine the cost effectiveness of farmer adaptations to climate change; utilizing Monte Carlo simulation to determine cost benefits of specific adaptations. After running the model profitable (cost-effective) adaptation to reduce the environmental impact of farming were determined: cost-effective adaptations were to (i) eliminate intensive beef production, (ii) reduce stored manures and increase frequency of manure spreading, (iii) substitute concentrate feed for grass and conserved grass in milk production and (iv) apply less mineral nitrogen to grassland. The model allowed for the analysis of risk management on farms (farm business management) while, considering maladaptation in that the model takes mitigation factors into consideration. Thus, the adaptations chosen must be profitable, but not maladaptive (Gibbons et al., 2006).

■ Further Information

Online information can be obtained at the following site:

http://www.nottingham.ac.uk/ environmental-modelling

FUND2.9 (Framework for Uncertainty, Negotiation and Distribution)

FUND2.9 is based on the original FUND model and is defined for 16 regions running from 1950-2300, in time-steps of years and has explicitly optimized adaptation for sea level rise. The model, heavily studied by Richard Tol considers not only sea-level rise, but agriculture, high winds, river floods, heat stress, cold stress, malaria and loss of biodiversity. Damages are expressed as currency. The damage functions in FUND2.9 are second-order polynomials of either the rate of change, or the level of the global mean temperature, taking adaptation into consideration (Tol and Fankhauser, 1998; Tol, forthcoming).

Completed Case Study

Several studies can be cited for FUND. One study revealed that the impact of a 2.5°C increase in the global mean surface air temperature by 2050 would amount to about 1.5% of world income (Pearce et al, 1996). In response, a second study by Tol (forthcoming) showed that the implementation of adaptation would reduce impacts by a factor between 10 to a 100. Adaptation would come at a minor cost compared to the damage avoided and since the momentum of sea level rise is so large, mitigation can reduce impacts only to a limited extent (Tol, forthcoming). The use of FUND2.9 also showed that too much mitigation may actually have adverse effects as less adaptation can be undertaken, which leads to more net climate change damages (de Bruin, 2007)

■ Further Information

Online information can be obtained at the following site:

http://fnu.zmaw.de/FUND.5679.0.html

ICAM (Integrated Climate Assessment Model)

ICAM (various versions) is a simulation impact centered model, analyzing uncertainty and climate change impacts. The model generates economic growth projections based on regional population growth and user specified assumptions. Adaptation policies are represented implicitly within the impact modules, so they cannot be varied explicitly

ICAM-3 has seven geographic areas (essentially UN regions) and works in time steps of 5 yr to the year 2100. The model has been used to investigate greenhouse abatement, adaptation, and geoengineering options (Dowlatabadi et al. 1995; Scott, 1998). The market impacts reflect the value of lost economic output as a result of climate change, decrease over time due to adaptation (Dowlatabadi and Morgan 1995).

■ Further Information

Online information can be obtained at the following site:

http://hdgc.epp.cmu.edu/models-icam/models-icam.html

ICLIPS (Integrated Assessment of Climate Protection Strategies)

ICLIPS is an IAM (the ICLIPS Impact Tools is a graphical to an extensive results database). ICLIPS adopts a different approach to integrating mitigation and impact/adaptation concerns, dealing with adaptation indirectly in the applications. The framework couples many models within a 'tolerable windows approach' (TWA), or guardrail approach, that is, by clearly separating value judgments and scientific analysis. In order to achieve this goal, the first step is to start with a normative definition of constraints ("guardrails") that exclude those climate impacts and socio-economic consequences of mitigation measures that are perceived as intolerable by the policy makers. In subsequent steps, a model-based scientific analysis of the "causality chain" is carried out in order to derive the set of all admissible climate-protection strategies, i.e. the set of all policy paths that are compatible with the pre-defined constraints (Toth et al, 2002).

Further Information

Online information can be obtained at the following site:

http://www.pik-potsdam.de/~fuessel/

IMAGE2.1 (Integrated Model to Assess the Greenhouse Effect)

IMAGE is a dynamic integrated assessment modeling framework for global change and a simulation model. The main objectives of IMAGE are to contribute to scientific understanding and support decision-making by quantifying the relative importance of major processes and interactions in the society-biosphere-climate system. The model provides dynamic and long-term perspectives on the systemic consequences of global change, insights into the impacts of global change, a quantitative basis for analyzing the relative effectiveness of various policy options to address global change (Alcamo et al, 1998; see online source below).

In the IMAGE2.1 framework the general equilibrium economy model, WorldScan, and the population model, PHOENIX, feed the basic information on economic and demographic developments for 17 world regions into three linked subsystems: The Energy-Industry System (EIS), The Terrestrial Environment System (TES), and The Atmospheric Ocean System (AOS). Historical data for the 1765-1995 periods are used to initialize the carbon cycle and climate system. IMAGE 2.2 simulations cover the 1970-2100 periods. Data for 1970-1995 are used to calibrate EIS and TES. Simulations up to the year 2100 are made on the basis of scenario assumptions on, for example, demography, food and energy consumption and technology and trade (see online source below).

Completed Case Study

IMAGE is a large complex model, with many components. Natural vegetation will be directly impacted by climate change, more so than other sectors. Migration of plants (an adaptation mechanism) may occur as a result of impacts (drought, precipitation, heat stress). IMAGE is able to distinguish the ability of adaptation of natural vegetation. In a study, potential migration zones were calculated using maximum dispersal distances and migration rates. The model can determine the ability of the natural vegetation to adapt (by migration) to other 'cells' in the model (within the set migration zone). 'Cells' that are able to adapt will convert from the original to a new vegetation type using assumptions for transition periods. This allows the adaptive ability of vegetation to be assessed (see online source below).

Further Information

Online information can be obtained at the following site:

http://www.mnp.nl/image

http://www-iam.nies.go.jp/aim/AIM_workshop/GHG/KRAM.pdf

ISIS (Information Society Integrated Systems)

ISIS models may be used to describe different options for society to respond to emerging real or perceived environmental risks (for example, climate change). ISIS can be applied to a wide variety of problems related to climate change, natural risks and disasters. The model is structured around a seven-phase life cycle of a basic innovation. The first phase is the invention (a new adaptive market per say) that can change the economy and human life. The model replicates the process of mutual adaptation (similar to the diffusion of innovations). ISIS can duplicate massive expansion of a new adaptation, slow expansion and global expansion (Grossmann, 2001)

Completed Case Study

In Grossmann, (2001) a two-region world is analyzed using ISIS. For Region I a traditional economy is preferred and the region is at risk through environmental factors (e.g. climate change), versus Region II, which is significantly less developed and a reduced number of threats from natural forces. After the model is run, both environmental disasters and increased perception of risk (through experience and education) caused increased activity in Region II. Rather than increasing costs, the relocation of activity (adapting to climate change impacts) was economically more efficient in the long run, since it forced the investment into the most modern adaptive technology.

■ Further Information

Online information can be obtained at the following site:

http://w3g.gkss.de/staff/storch/pdf/kompl_Grossmann.pdf

MAGICC (Model for the Assessment of Greenhouse gas Induced Climate Change)

MAGICC is a set of linked simple models that, collectively, fall in the genre of a simple climate model. The model is used to evaluate adaptation strategies. MAGICC is not a General Circulation Model (GCM), but it uses a series of reduced-form models to emulate the behavior of fully three-dimensional, dynamic GCMs. MAGICC calculates the annual-mean global surface air temperature and global-mean sea-level implications of emissions scenarios for greenhouse gases and sulfur dioxide. Users are able to choose which emissions scenarios to use, or to define their own, and also to alter a number of model parameters to explore uncertainty. The model has been widely used by the IPCC in their various assessments.

SCENGEN, a global and regional scenario generator, is not a climate model; rather it is a simple database that contains the results of a large number of GCM experiments, as well as one observed global and four regional climate data sets. These various data fields are manipulated by SCENGEN, using the information about the rate and magnitude of global warming supplied by MAGICC and directed by the users choice of important climate scenario characteristics. SCENGEN has been developed over a number of years to operate in conjunction with MAGICC, but can be used on its own in a more limited function. SCENGEN has not been officially used by the IPCC, but nearly all of the data sets used by SCENGEN GCMs and observations have been used or assessed in different IPCC assessments including the Third Assessment Report due to be published in 2001. (Hulme et al., 2000)

■ Further Information

Online information can be obtained at the following site:

http://sedac.ciesin.columbia.edu/aiacc/toolkit.html

http://www.climatescience.gov/workshop2005/posters/P-WE1.21_Smith.J.pdf

Mini-CAM (Mini-Climate Assessment Model)

Mini-CAM is a climate change IAM. The model is designed to examine long-term, large-scale changes in global and regional energy systems where the characteristics of existing capital stocks are not the dominant factor in determining the dynamics of the energy system. It integrates MAGICC and SCENGEN models for climate and regional climate change analysis but has separate technology modules. It incorporates energy prices, emissions, temperature change, land-use. The model can be applied regionally and globally, containing detailed inforamion on 14 Regions (United States, Canada, Western Europe, Japan, Australia and New Zealand, Former Soviet Union, Eastern Europe, Latin America, Africa, Midle East, China [& Asian Reforming Economies], India, South Korea, Rest of South & East Asia). Mini-CAM runs in 15 year intervals between the years 1990-2095.

■ Further Information

Online information can be obtained at the following site:

http://www.globalchange.umd.edu/models/MiniCAM.pdf

http://www.pnl.gov/gtsp/research/minicam.stm

MPPACC (Model of Private Proactive Adaptation to Climate Change)

Risk perception and perceived adaptive capacity are important factors that until Grothmann and Patt, (2005), were not included in adaptation models to climate change. In an attempt to address psychological factors in adaptation, a socio-cognitive Model of Private Proactive Adaptation to Climate Change (MPPACC) was developed, based on the psychological model termed the "Protection Motivation Theory". The model looks at the psychological steps to responses to perception: risk perception and perceived adaptive capacity to climate change. The model follows a framework that sums up adaptive behavior to an adaptive or maladaptive end. The process model includes objective adaptive capacity (time, money, staying power, knowledge, entitlements, social and institutional support) and adaptation appraisal: perception adaptation efficacy, perceived self efficacy and perceived adaptation costs, adaptation incentives; avoidant maladaptation (fatalism, denial, wishful thinking); and adaptation intention. All of these lead to an enabling or impeding adaptation output.

Completed Case Study

Two examples were published in Grothmann and Patt, (2005), one from Germany and one from rural Zimbabwe. The former was a study of decisions to adapt to the threat of flooding in Cologne, Germany. The Cologne study showed that socio-cognitive factors did a better job of explaining adaptive behaviour than did objective socio-economic factors, such as home ownership and household income. The latter study is in a study of decisions to change farming practices to adapt to predictions of seasonal rainfall in Zimbabwe, where the model found a qualitative match between MPPACC and adaptive behaviour. The Zimbabwe case study showed how evidence of people's failure to adapt can be explained by cognitive factors. These initial case studies illustrated the importance of perceived adaptive capacity which has not been approached in other adaptation models at the time of the publication. Thus, the argument can be made that when modeling adaptation, socio-cognitive variables need to be incorporated.

■ Further Information

Online information can be obtained at the following site:

http://diglib.uni-magdeburg.de/disssertationen/2005/torgrothmann.htm

OSWRM (Okanagan Sustainable Water Resources Model)

Water resources systems are sensitive and vulnerable to climate change and development pressures. OSWRM offers a learning tool for assessing the effectiveness of adaptation options within various scenarios of climate change and population growth for the Okanagan Basin, a semi-arid region located in British Columbia, Canada. The model was constructed using a mediated modeling approach with local experts providing input throughout the process (Langsdale et al., 2006a,b; Langsdale, 2007). The model was constructed using STELLATM which accounts for changes in both natural and human-managed stocks and flows of water through the Okanagan system. OSWRM is not designed to be an operational tool, and this version (v. 1.62) does not include land use change and adaptation costs. Some aspects of the water system (e.g. groundwater) are simplified due to incomplete information.

Case Study

As part of a participatory integrated assessment of the Okanagan region (Cohen et al., 2004, 2006; Cohen and Neale, 2006), OSWRM was constructed by combining scenario-based impacts and adaptation information with local expert knowledge of the current state of the Okanagan water system (Langsdale, 2007). The current version of the model includes 3 climate scenarios, 3 population scenarios, and a wide range of options for managing residential and agricultural water demand, in-stream (conservation) flows for fish, storage capacity and storage release, mix of crop types, residential housing density, and access to Okanagan Lake. Some options are available as yes/no choices (e.g. access to Okanagan Lake), while others are selected through quantitative settings within specified limits. OSWRM v1.62 shows that within concurrent scenarios of climate warming and population growth, a broad portfolio of adaptation measures will be needed to offset projected increased risk of water shortage, which could occur as soon as the 2020s during relatively dry years (Langsdale et al, 2006b; Langsdale 2007). This portfolio would need to include some augmentation of current managed supply. Demand management, on its own, would not be sufficient.

■ Further Information

Online information can be obtained at the following site:

http://www.ires.ubc.ca/aird
(navigate to "completed projects")

http://www.adaptation.nrcan.gc.ca

PAGE2002 (Policy Analysis for the Greenhouse Effect)

In a 1998 survey of IAMs by Tol and Frankhauser 1998, the PAGE model was the only model where adaptation was said to be considered as a policy variable for all sectors (de Bruin, 2007) originally published by Hope, 1993. The PAGE model is an IAM, initially developed in 1991, which has been updated (PAGE95 and now PAGE2002) (Wahba and Hope, 2006). PAGE2002 models adaptation strategies to show the benefits of adapting to climate change. PAGE2002 contains 8 world regions, all major GHGs, mitigation and adaptation costs, impacts (economic and non-economic), a time scale till 2200. PAGE95 contains equations that model: Emissions of the primary greenhouse gases, he greenhouse effect, cooling from sulphate aerosols, regional temperature effects, non-linearity in the damage caused by global warming, regional economic growth, and adaptation to climate change (Hope et al, 1993; Wahba and Hope, 2006).

Completed Case Study

In the Hope et al., (1993) the PAGE model was used to assess the value of policies relating to climate change. The output illustrated that mitigation alone is not sufficient as a standalone measure. Aggressive adaptation is required. The study examined two different policies for adapting to climate change; extreme cases where in the first scenario, the policy implemented no adaptation and the latter implemented aggressive adaptive measures. By including an equation for the cost of adaptation, thus, investment in adaptive measures (e.g., the building of sea walls; development of drought resistant crops) can decrease the vulnerability to climate change before economic losses occur and also reduce the intensity of both noneconomic and economic impacts (Hope, 2006). The model output demonstrated that at a 5% discount rate, the costs of adaptation (ECU 0.3 trillion) is easily justifiable, since the total climate change damages were calculated to be ECU 17.5 trillion (the benefits from the reduction in economic impacts, less adaptation). Adapting to climate change is tremendously effective at decreasing world-wide impacts (Hope et al, 1993)

■ Further Information

Online information can be obtained at the following site:

http://www.jbs.cam.ac.uk/people/faculty/hopec.html

http://www.hmtreasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm

RegIS2

RegIS2 uses IAMs to evaluate local and regional sub-national scale impacts and adaptation options for agriculture biodiversity, coasts, flood plains, water resources, while also modeling "no adaptation" options for comparison (Holman, 2005). The model allows stakeholders to assess the impacts of future climate change on fluvial and coastal flooding, hydrology, biodiversity and agriculture. The meta-models are accessed via a GIS interface, produce coupled simulations of possible impacts under different climate scenarios for the 2020s and 2050s. The interface also allows users to analyze a range of possible adaptive responses and the influence of future policy and socioeconomic scenarios upon this response. RegIS2 uses the agriculture and land-use model IMPEL, the water model CRASH and the biodiversity SPECIES.

The second phase of the RegIS2 study will further develop the regional RegIS socio-economic scenarios within the context of the UKCIP Socio-economic scenarios for climate change impact assessment. The models in this study will be linked; the data (output) from one model drives another model and so forth.

■ Further Information

Online information can be obtained at the following site:

http://www.silsoe.cranfield.ac.uk/iwe/projects/regis/regis2.htm

http://wcrp.ipsl.jussieu.fr/Workshops/SeaLevel/Posters/8_6_Nicholls.pdf

Ricardian (Econometric)

Ricardian/Econometric models are manipulated with climate change scenarios to predict the economic costs of adaptation. They estimate structural relations between historical climate and agricultural land values under the presumption that such relations reflect a steady-state level of adaptation of regional farming systems to local climate characteristics. These relations are cross-sectional (i.e., units of observation are geographic areas) and the geographic variation in land values is assumed to be partly regulated by differences in the quality of climate inputs. Parameter estimates embed the relative efficiency of current adaptation to a range of climate conditions (cold and warm).

Ricardian/Econometric models can capture the full range of economic adaptations that farmers and supporting institutions are likely to use in response to climate change. They are particularly suited to analysis that assumes no change in real crop prices in response to climate change. These tools do not estimate the cost of adaptation

Ricardian/Econometric models have been used to estimate the economic cost/benefit of climate change for agriculture and forestry in the United States, Brazil, and India.

■ Further Information

Online information can be obtained at the following site:

http://ceepa.co.za/docs/CDPNo21.pdf

http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/economic_models_-_econometric__ricardian-based__models.pdf

SimCLIM

SimCLIM can be used to support decision-making with its capacity to assess baseline climates and current variability and extremes. Risks can be assessed both currently and in the future. Adaptation measures can be tested for present day conditions and under future scenarios of climate change and variability and sea level rise. With the program, users can conduct sensitivity analysis and examine sectoral impacts of climate change. SimCLIM supports integrated impact analysis at various scales.

Further Information

Online information can be obtained at the following site:

http://climsystems.com/site/products/?id=9

SWAP-WSBM (Soil Water Atmosphere and Plant model–Water and Salinity Basin Model)

SWAP-WSBM is a coupled field scale modeling framework aids in evaluating impacts and adaptation strategies. They are used to analyze and understand current water resources issues, to analyze the impact of climate change and, most importantly, to evaluate adaptation strategies.

Completed Case Study

Three time periods were considered where the 1961–1990 period was used to adjust climate change projections to local conditions and to provide a reference to compare expected changes in the near future (2010–2039) and distant future (2070–2099) (Droogers, 2004). The SWAP model was also applied in an adaptation study across seven contrasting basins in Africa, Asia, America, and Europe to explore how agriculture can respond to the projected changes in climate (Droogers and Aerts, 2003).

The SWAP model have been used extensively in climate change related studies. A study in Sri Lanka focused on adaptation strategies to climate change for rice cultivation, where the SWAP model was incorporated with a basin scale model to ensure that upstream—downstream processes of water resources were considered (Droogers, 2003).

Further Information

Online information can be obtained at the following site:

http://sedac.ciesin.columbia.edu/aiacc/progress/AF47_Jan04.pdf

TARGETS (Tool to Assess Regional and Global Environmental and health Targets for Sustainability)

The TARGETS model (Tool to Assess Regional and Global Environmental and health Targets for Sustainability), is used to study climate change, global change and sustainable development. TARGETS includes five interlinked "horizontal" modules representing population and health, energy and economics, biophysics, land and soils, and a water submodel. The model can be applied to a global scale or six regional sections (Rotmans et al., 1994).

Applications of TARGETS include research completed on individual and community level populations in Northern Ethiopia to determine how people (largely farmers) perceive the climate change (drought) and the environmental degradation, and how they adjust their life strategies, demographic behaviour (family formation, migration) in particular.

■ Further Information

Online information can be obtained at the following site:

http://sedac.ciesin.org/mva/iamcc.tg/TGsec4-2-7.html

TEAM (Tool for Environmental Assessment and Management)

TEAM uses a multi-criteria approach for evaluating actions to address climate change impacts to water resources, coastal zones and agriculture. The advantage of TEAM is that it provides an interactive format to help structure and define the decisions under consideration. The Tool for Environmental Assessment and Management (TEAM) was developed by Decision Focus, Inc. (DFI, 1996) for the US Environmental Protection Agency (USEPA) as a user-friendly software package to assist decision makers in evaluating strategies for adapting to climate change. The TEAM software includes components on coastal resources, water resources, and agriculture, as well as a generic assessment component. The software asks the user to enter information through a guided question-and-answer sequence and then uses a menu-driven graphic presentation of results for the evaluation of adaptation options. The user selects specific “strategies” or adaptation options and criteria and then assigns a relative score (excellent, good, fair, and poor) for how each strategy meets each criterion. In addition to qualitative rankings, the user has the option to enter absolute data for each strategy (e.g., dollar amounts) (Julius and Scheraga, 2000).

Completed Case Study

Adaptation of wheat, maize and cotton productivity (Eid et al. 1996, 1997e) to climate change in Egypt was studied through DSSAT3 and COTTAM models and through the TEAM (Tool for Environmental Assessment and Management decision model) (Susan 1996). Future strategies for adapting to climate change may involve the development of new, more heat-tolerant cultivars, and new crops (more cotton cultivation as an alternative to some maize and more winter legumes instead of some wheat). Changing the cotton crop practices (optimum sowing date, cultivars, and water amount and plant density) could allow farmers to benefit from climate change, increasing cotton productivity by about 29%.

■ Further Information

Online information can be obtained at the following site:

http∑ http://cfpub.epa.gov/gcrp (then > data, documents and tools > publications and presentations)

http://www.ecobilan.com/uk_team.php

http://www.ceepa.co.za/docs/CDPNo29.pdf

UWF - Urban Water Futures: A multivariate analysis of future residential water demand in the Okanagan Basin, British Columbia

The Urban Water Futures model was developed to examine the question of future residential water sufficiency by comparing scenarios of future demand to provincially-licensed supplies. The model integrates scenarios of climate change impacts, population growth, housing density and demand side management options (DSM). These component scenarios are based on published values including downscaled global climate model scenarios, census data, demographic trends and analyses of effectiveness of various water conservation measures. Model inputs include historical indoor and outdoor residential water use and climate data for the corresponding period. Adaptation options of interest to policymakers are represented as scenarios of housing density and demand side management. The effectiveness of combining various DSM techniques (water metering with pricing, water efficient fixtures, xeriscaping, public education) and increasing housing densities can be examined as options for adapting to the combined impacts of population growth and climate change.

Completed Case Study

Case studies were carried out for three water utilities in the Okanagan Basin of British Columbia, Canada: Town of Oliver, City of Penticton and City of Kelowna Water Utility. Each case study included:

- Three scenarios of population growth (low, medium and high);
- Two scenarios of housing density ("smart growth" and current preferences);
- Six scenarios of climate change (3 models: CGCM2, HADCM3 and CSIRO; 2 SRES scenarios: A2 and B2) and
- Up to seven scenarios of DSM (public education, metering with constant unit charge, metering with increasing block rate, high-efficiency plumbing fixtures and appliances, xeriscaping and a combination of options).

The model yielded a range of 252 scenarios of future annual water demand compared to baseline demand for the year 2001 and compared to licensed water supplies. In the "best case" scenarios with low population growth, combined DSM, smart growth housing and the least extreme climate change scenario, future water demand increased only slightly from current use or decreased below current use during the scenario period (2010 to 2069). In the "worst case" scenarios of high population growth, no DSM, current preferences housing and the most extreme climate change scenario, future water demand increased up to five-fold over 2001 water use and exceeded available licensed supply by the end of the scenario period.

This model was used as input to OSWRM (Langsdale et al., 2007).

Further Information

Online information can be obtained at the following site:

http://www.ires.ubc.ca/aird/documents/OKPIA_2004-06_FinalReport_HiRes.pdf

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