Mitigation and Adaptation Studies

Mitigation and Adaptation Studies

Class 2: The Challenge we are facing

Mitigation and Adaptation Studies

Class 2: The Challenge we are facing

Contents:

- The Challenge
- Mitigation and Adaptation - some definitions
- Adaptation Science
- Practicalities

Our Quest for Sustainable Development

Our Quest for Sustainable Development

"Sustainable Development is a development that meets the needs of the presence while safeguarding Earth's life-support system, on which the welfare of current and future generations depends."

Griggs et al., 2013

Our Quest for Sustainable Development

"Sustainable Development is a development that meets the needs of the presence while safeguarding Earth's life-support system, on which the welfare of current and future generations depends."

Griggs et al., 2013

Our Quest for Sustainable Development

"Sustainable Development is a development that meets the needs of the presence while safeguarding Earth's life-support system, on which the welfare of current and future generations depends."

Griggs et al., 2013

Our Quest for Sustainable Development

"Sustainable Development is a development that meets the needs of the presence while safeguarding Earth's life-support system, on which the welfare of current and future generations depends."

Griggs et al., 2013

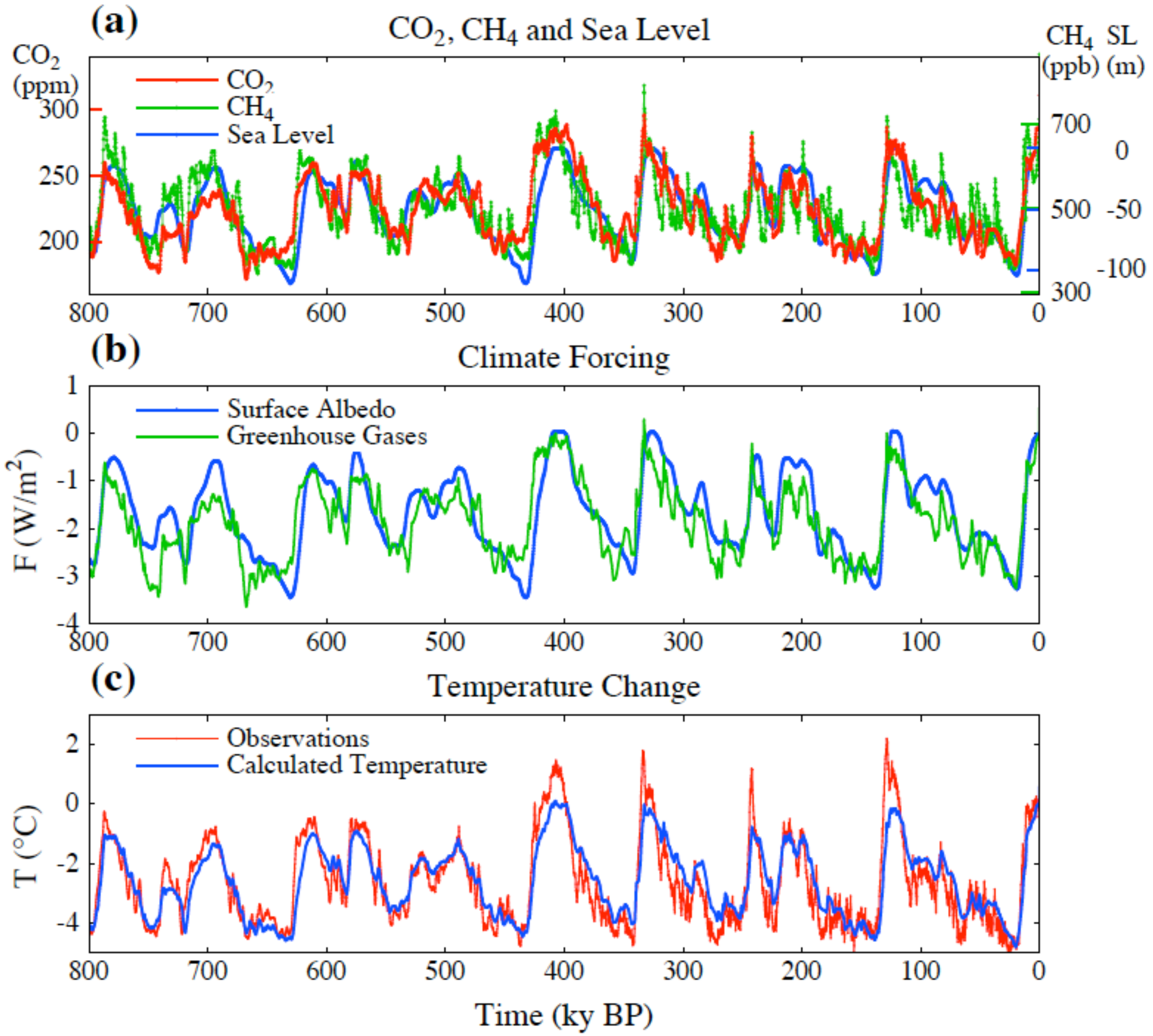
The Earth's Life-Support System

The Earth's Life-Support System

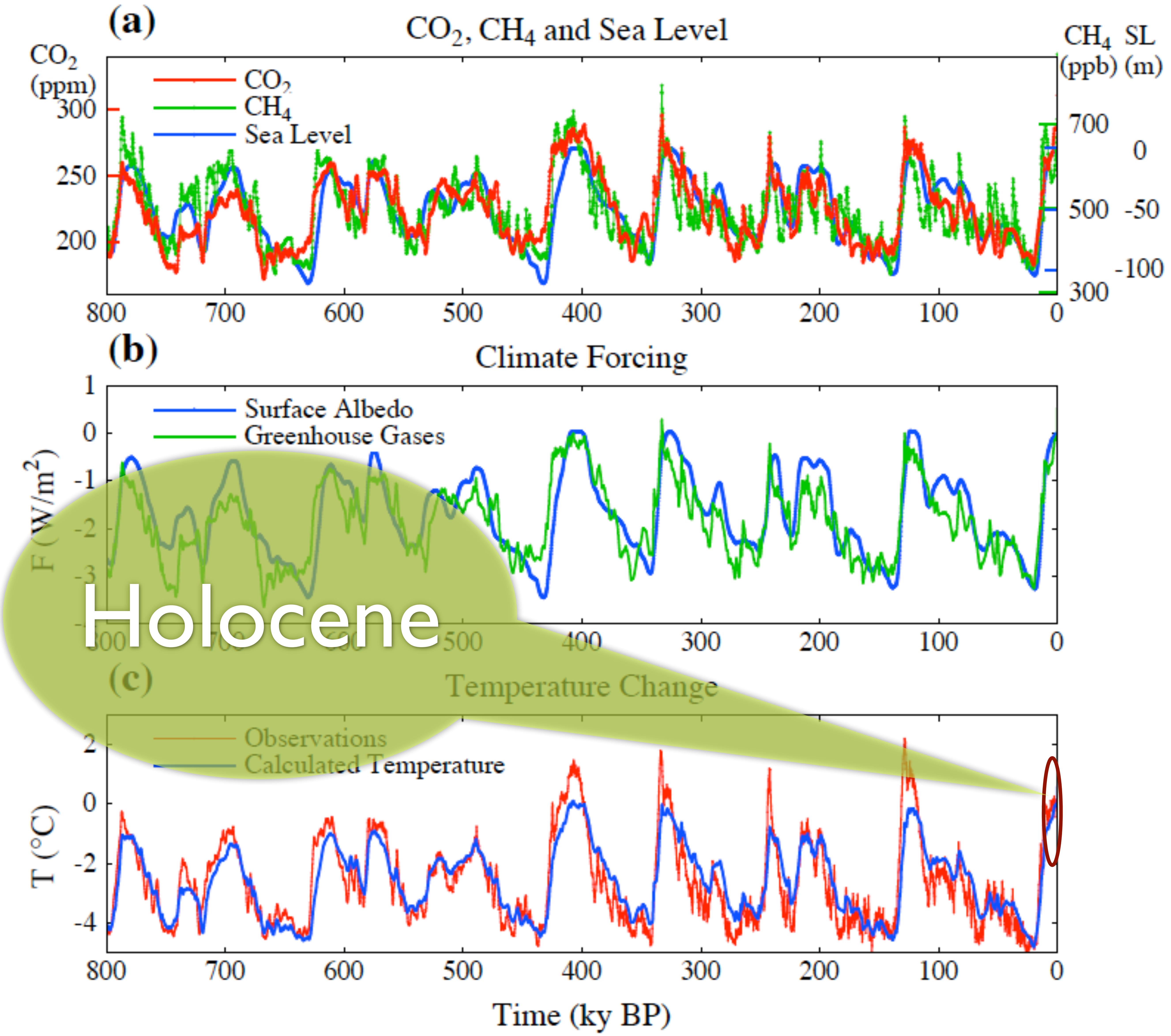
Five questions to address:

- What is the baseline?
- What is the syndrome?
- What is the diagnosis?
- What is the Prognosis?
- Is there a therapy and what would that be?

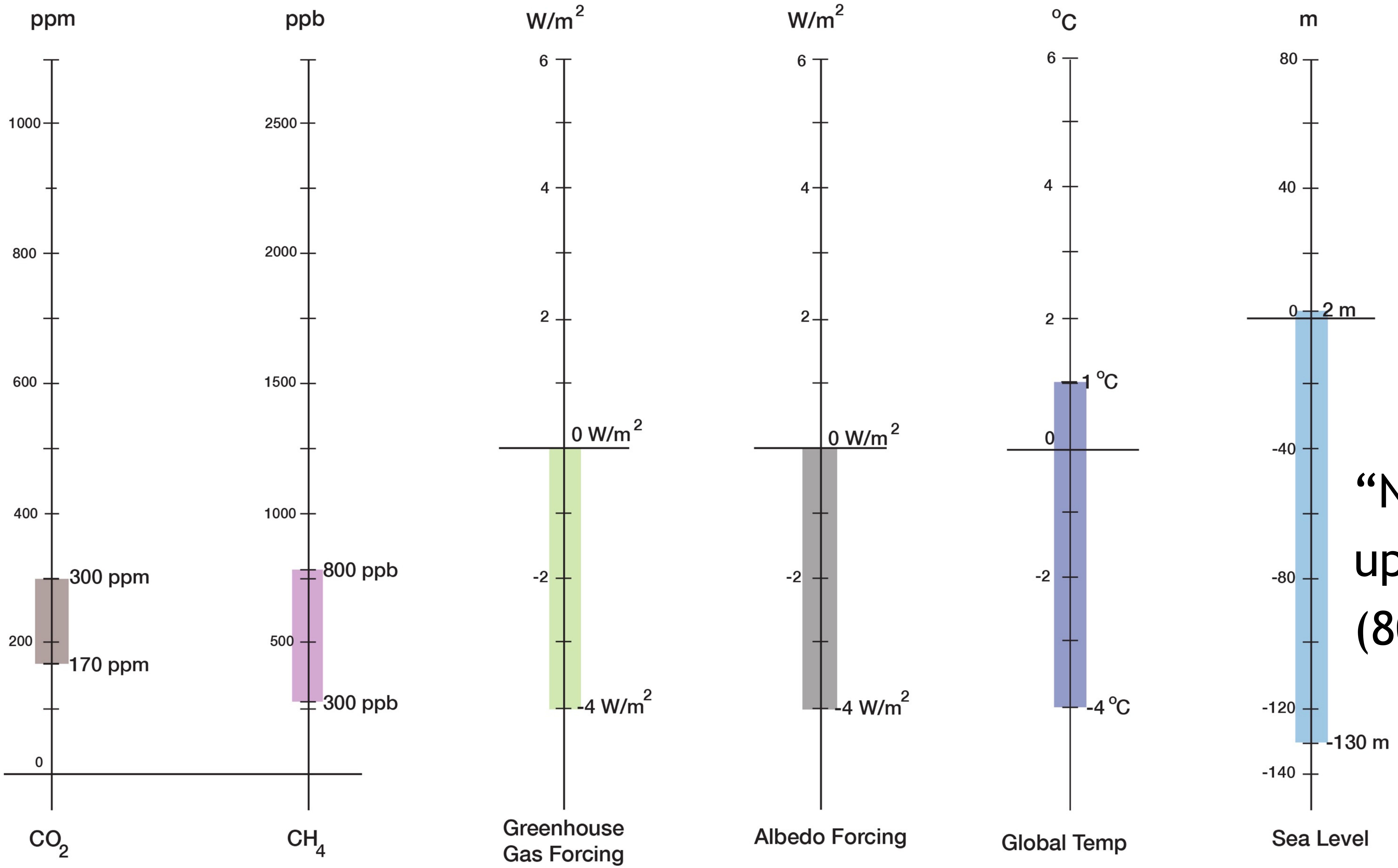
The Baseline: Past Climate Change



The Baseline: Past Climate Change

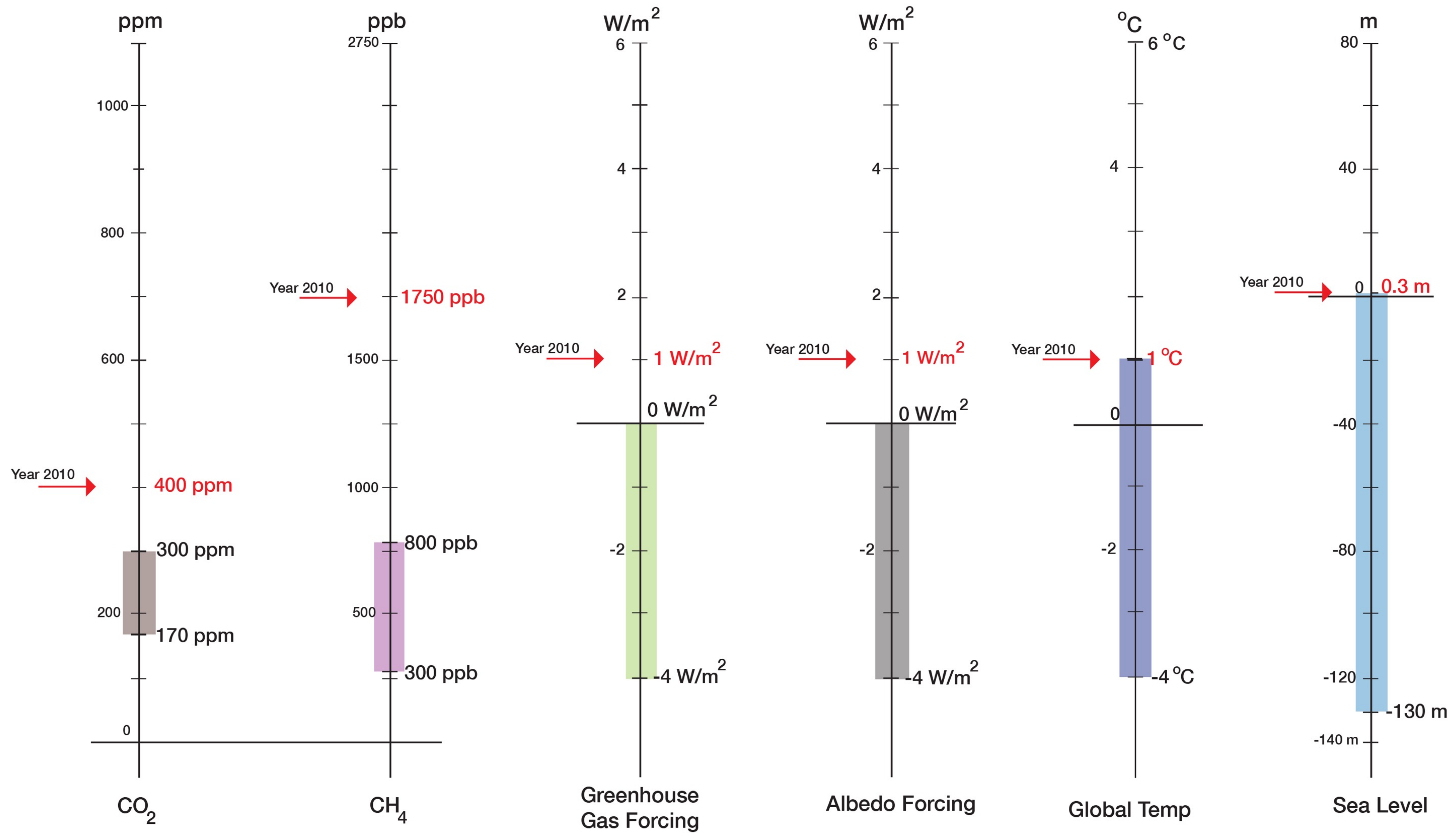


The Baseline: Past Climate Change



"Normal Range"
up to 1900
(800,000 years)

The Syndrome: Recent Climate and Global Change

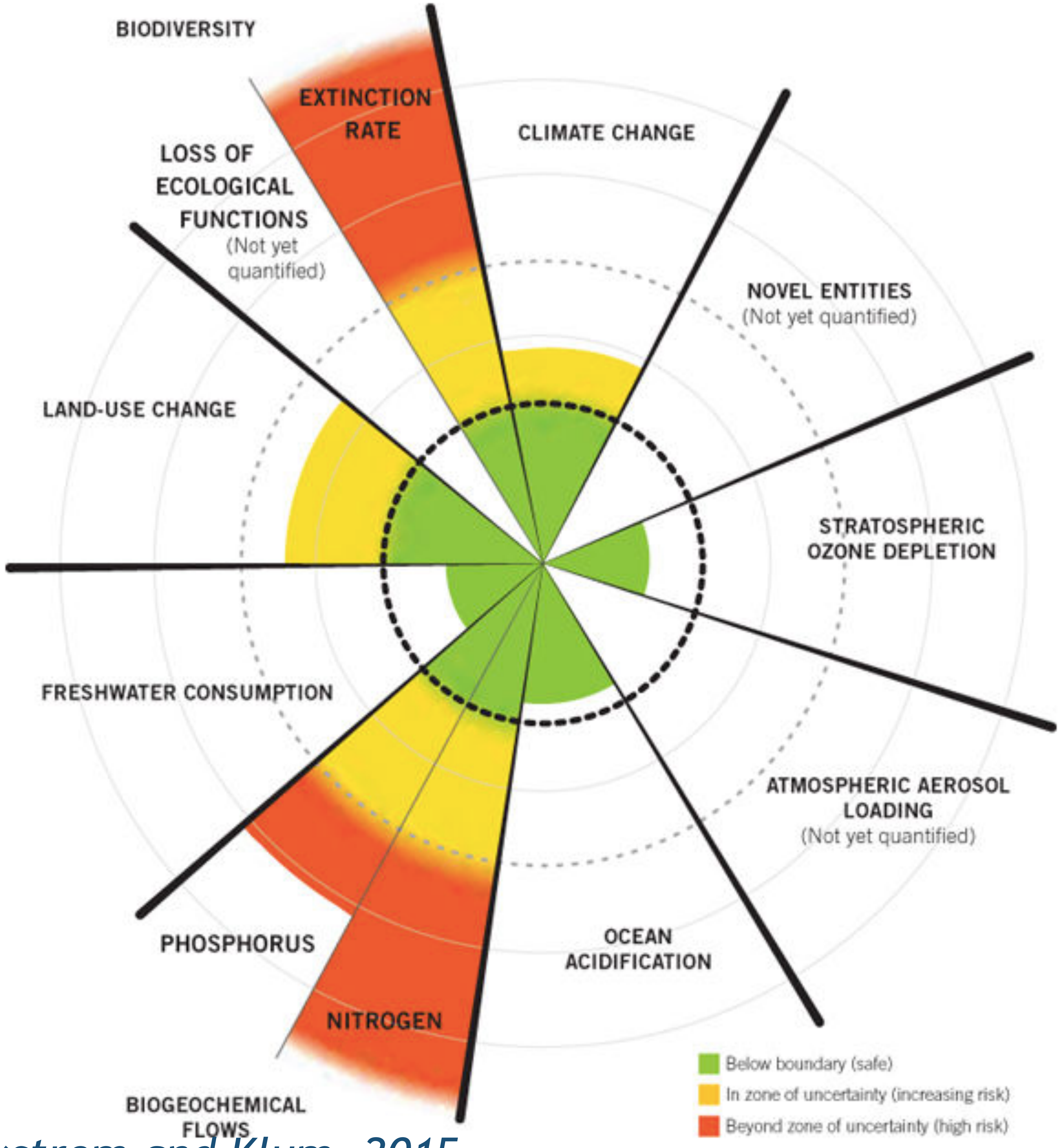


"Current State"

"Normal Range" up to 1900 (800,000 years)

The Diagnosis: Leaving the “Safe Operating Space”

The Diagnosis: Leaving the "Safe Operating Space"



Rockstrom and Klum, 2015

We are moving out of the Holocene and the "safe operating space for humanity" (Rockstroem et al., 2009):

Climate Change (***)

Ocean acidification (**)

Stratospheric ozone depletion (*)

Nitrogen (******) and Phosphorous cycles (**)

Global freshwater (*)

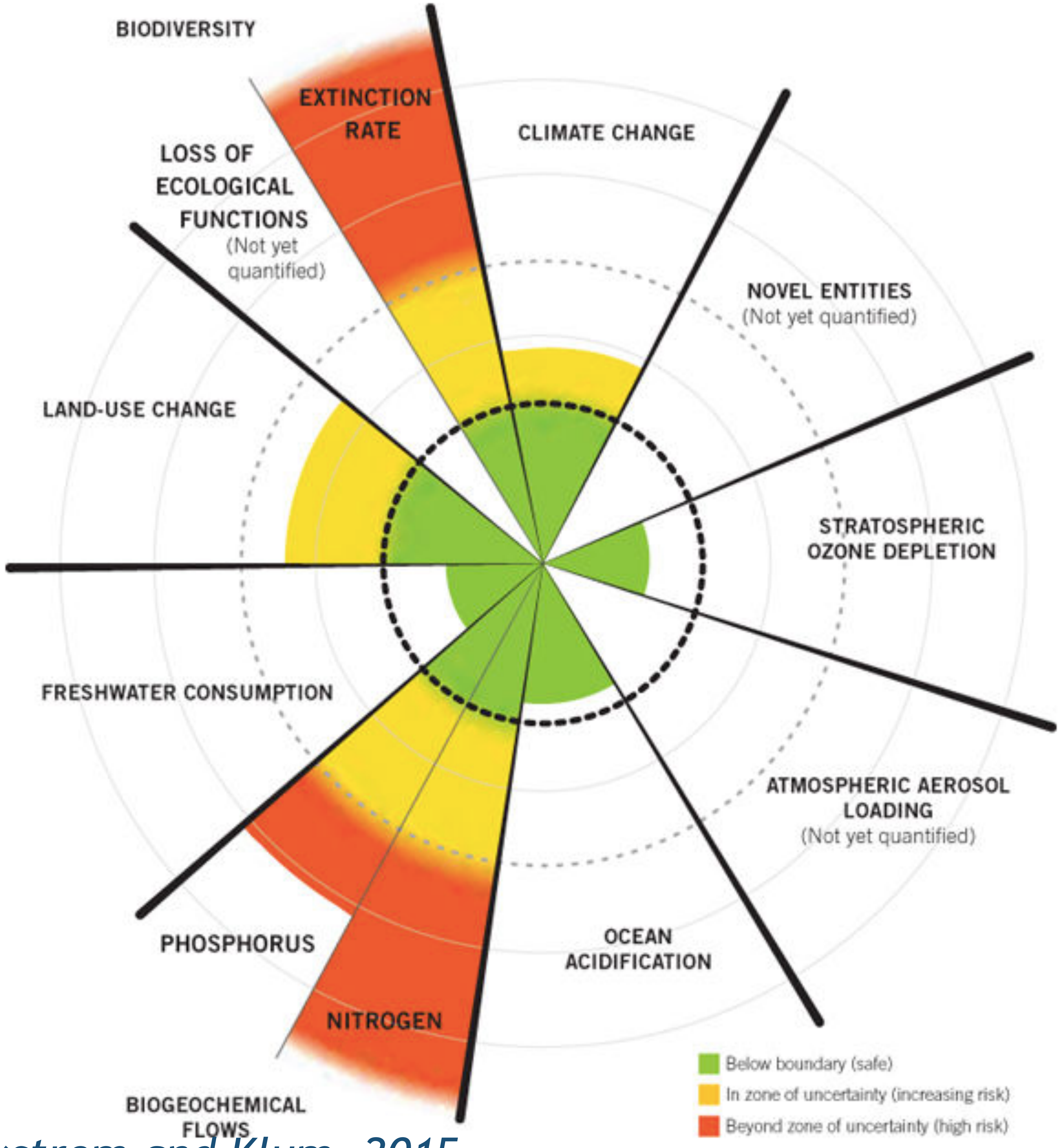
Change in land use (*)

Biodiversity loss (*******)

Atmospheric aerosols (?)

Chemical pollution (?)

The Diagnosis: Leaving the "Safe Operating Space"



Rockstrom and Klum, 2015

We are moving out of the Holocene and the "safe operating space for humanity" (Rockstroem et al., 2009):

Climate Change (***)

Ocean acidification (**)

Stratospheric ozone depletion (*)

Nitrogen (******) and Phosphorous cycles (**)

Global freshwater (*)

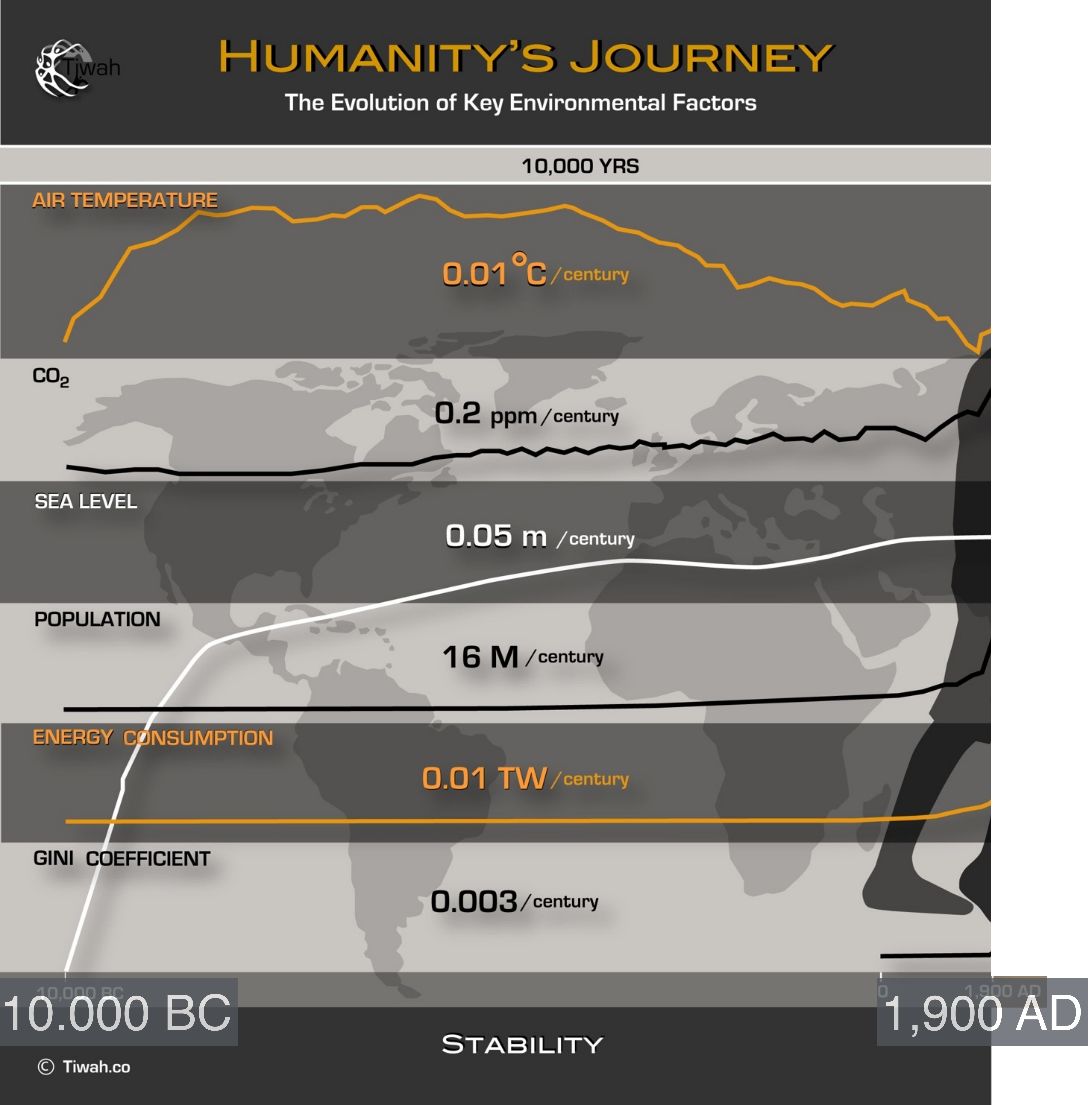
Change in land use (*)

Biodiversity loss (*******)

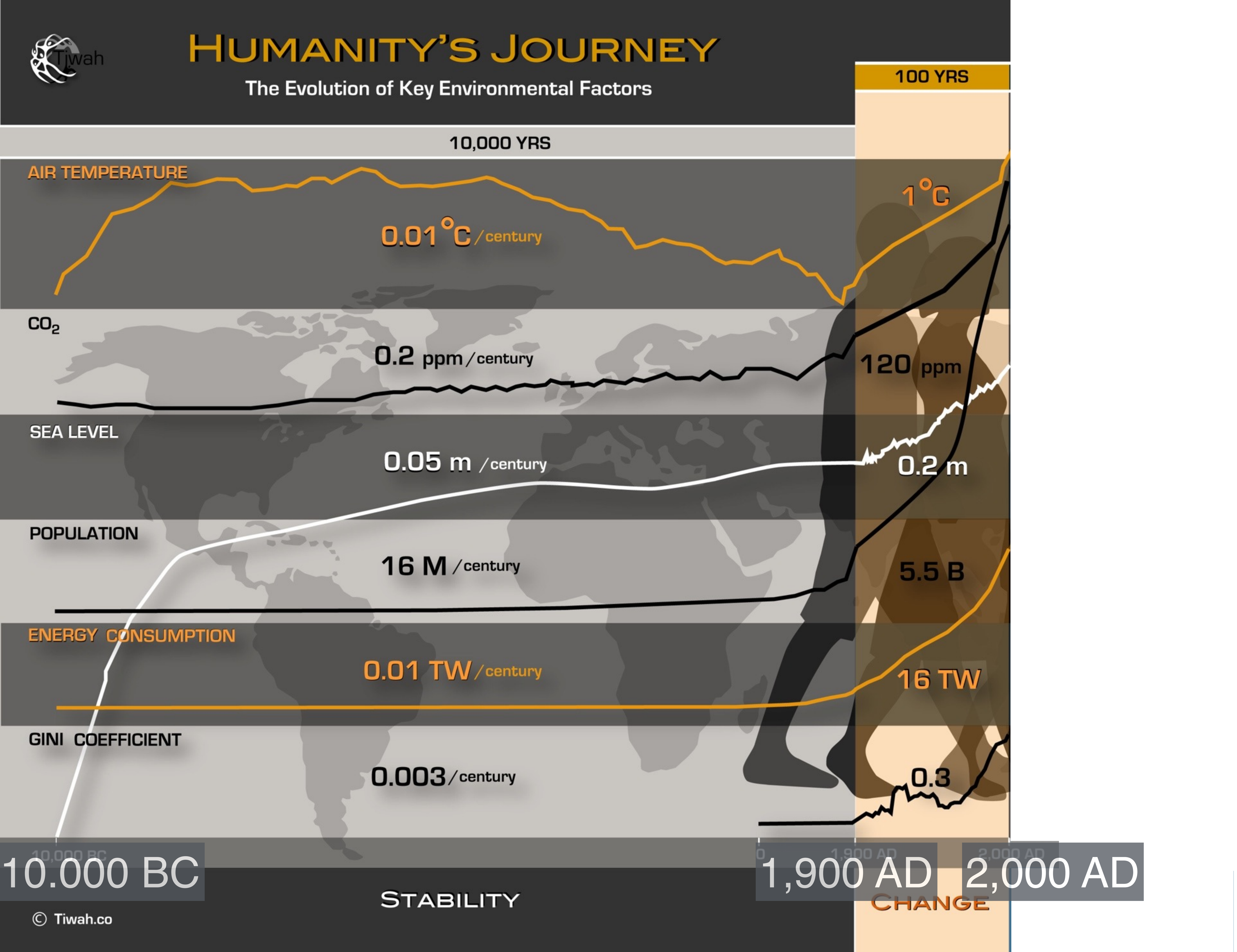
Atmospheric aerosols (?)

Chemical pollution (?)

Climate change and sea level rise are symptoms, not the cause, the "sickness."



Tiwah
HUMANITY'S JOURNEY
The Evolution of Key Environmental Factors
10,000 YRS
AIR TEMPERATURE
0.01 °C / century
CO_2
0.2 ppm / century
SEA LEVEL
0.05 m / century
POPULATION
16 M / century
ENERGY CONSUMPTION
0.01 TW / century
GINI COEFFICIENT
0.003 / century
10.000 BC
1,900 AD
STABILITY
© Tiwah.co



Tiwah
HUMANITY'S JOURNEY
The Evolution of Key Environmental Factors
10,000 YRS
100 YRS
AIR TEMPERATURE
0.01 °C / century
1 °C
CO_2
0.2 ppm / century
120 ppm
SEA LEVEL
0.05 m / century
0.2 m
POPULATION
16 M / century
5.5 B
ENERGY CONSUMPTION
0.01 TW / century
16 TW
GINI COEFFICIENT
0.003 / century
0.3
10.000 BC
1,900 AD
2,000 AD
STABILITY
CHANGE
© Tiwah.co

Tiwah

Humanity's Journey

The Evolution of Key Environmental Factors

	10,000 YRS	100 YRS	
AIR TEMPERATURE °C / century	0.01	1.0	100 X Faster
CARBON DIOXIDE ppm/ century	0.2	120	600 X Faster
SEA LEVEL metres / century	0.05	0.2	4 X Faster
POPULATION millon/ century	16	5500	350 X Faster
ENERGY CONSUMPTION Terra Watts / century	0.01	16	1600 X Faster
GINI COEFFICIENT / century	0.003	0.3	100 X Faster

10,000 BC | 0 | 1,900 AD | 2,000 AD | FUTURE

10.000 BC | 1,900 AD | 2,000 AD

STABILITY | CHANGE | UNCERTAINTY

Humanity's Journey

The Evolution of Key Environmental Factors

	10,000 YRS	100 YRS	
AIR TEMPERATURE °C / century	0.01	1.0	100 X Faster
CARBON DIOXIDE ppm/ century	0.2	120	600 X Faster
SEA LEVEL metres / century	0.05	0.2	4 X Faster
POPULATION millon/ century	16	5500	350 X Faster
ENERGY CONSUMPTION Terra Watts / century	0.01	16	1600 X Faster
GINI COEFFICIENT / century	0.003	0.3	100 X Faster

10,000 BC — 1,900 AD — 2,000 AD — FUTURE

10.000 BC | 1,900 AD | 2,000 AD

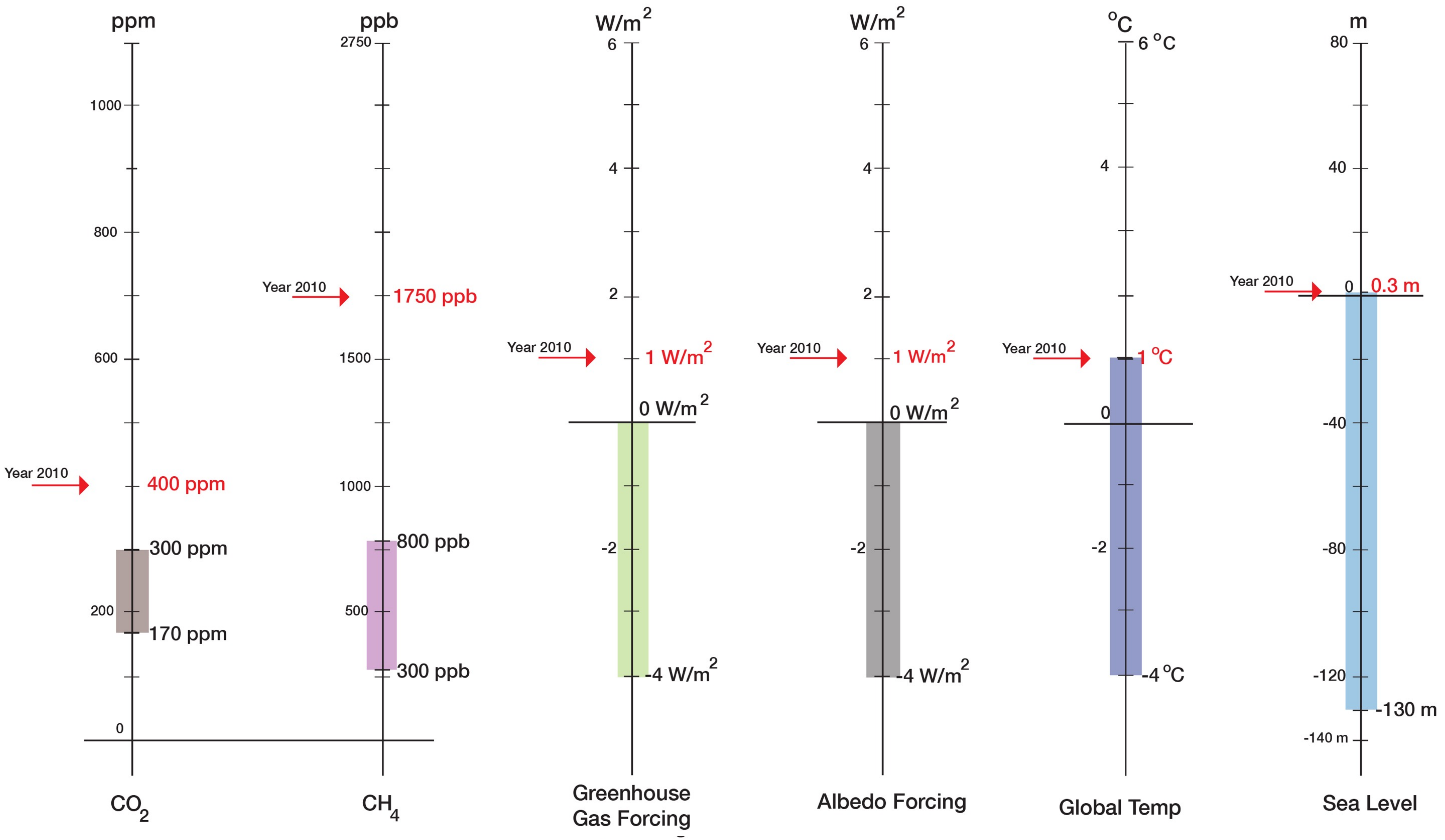
STABILITY | CHANGE | UNCERTAINTY

Holocene: Stability

20th and 21st Century: Change, imbalance

Future: Uncertainty

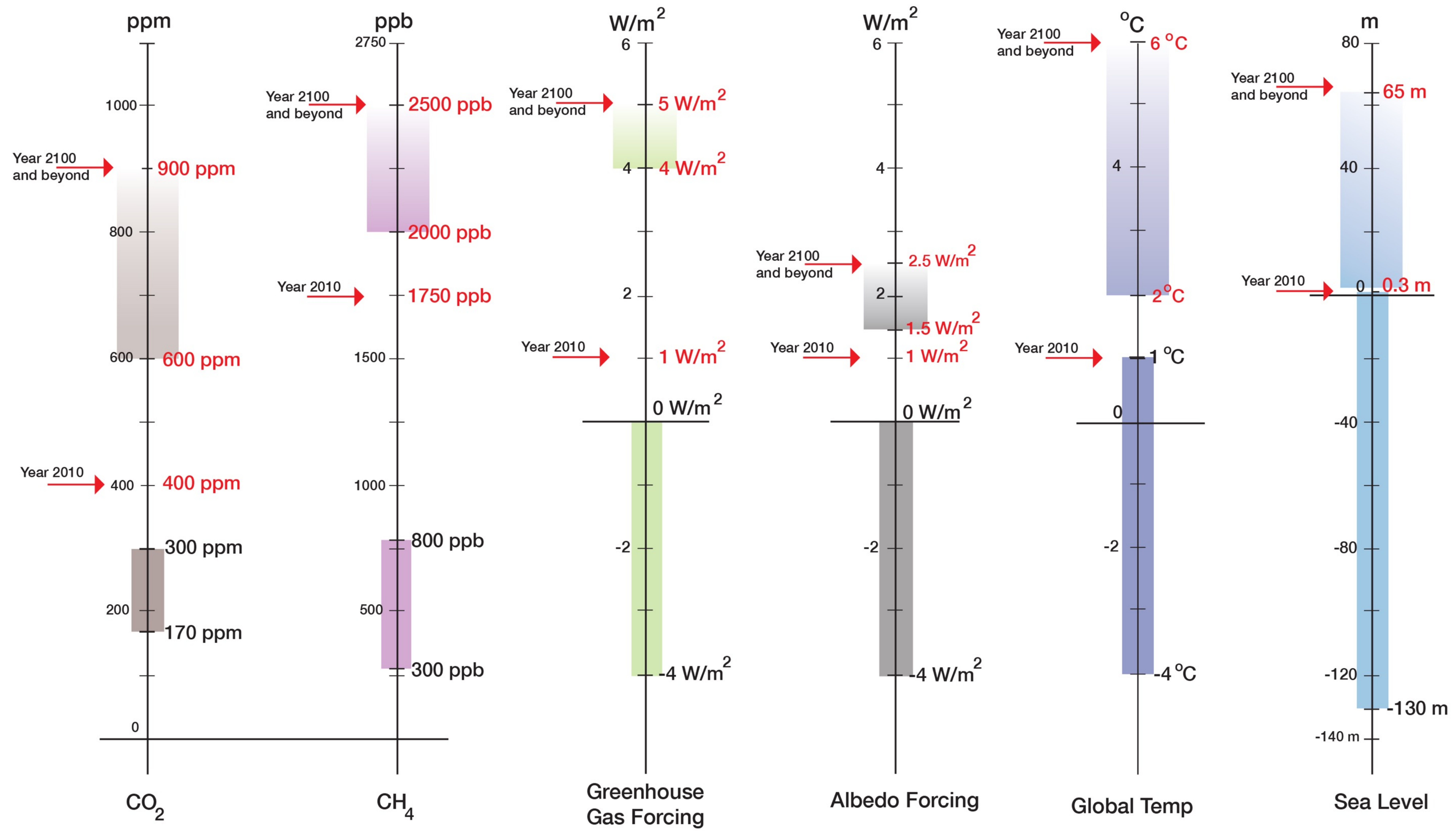
The Prognosis: Anticipating Surprises



"Current State"

"Normal Range" (800,000 years)

The Prognosis: Anticipating Surprises

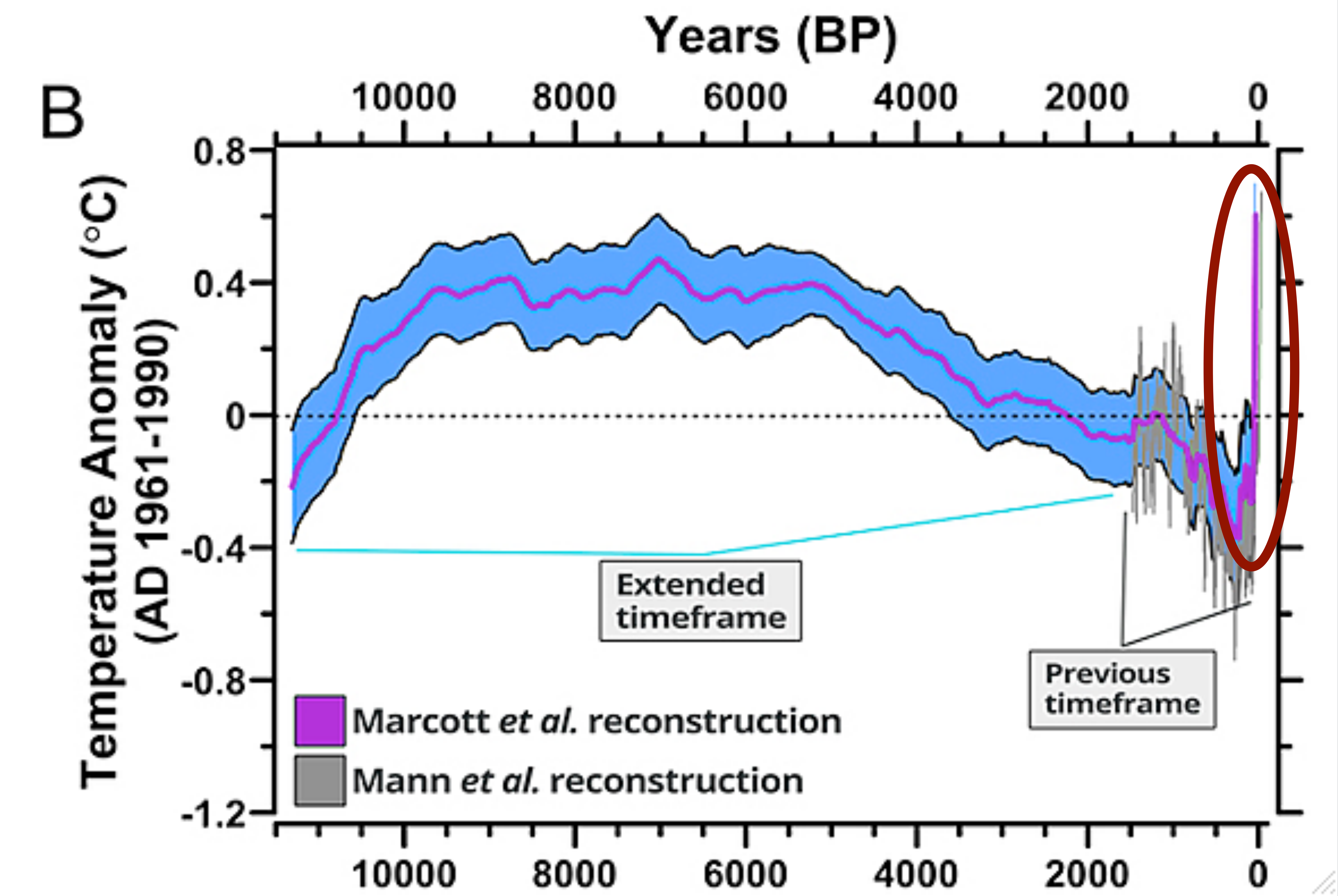


“Prognosis”

“Current State”

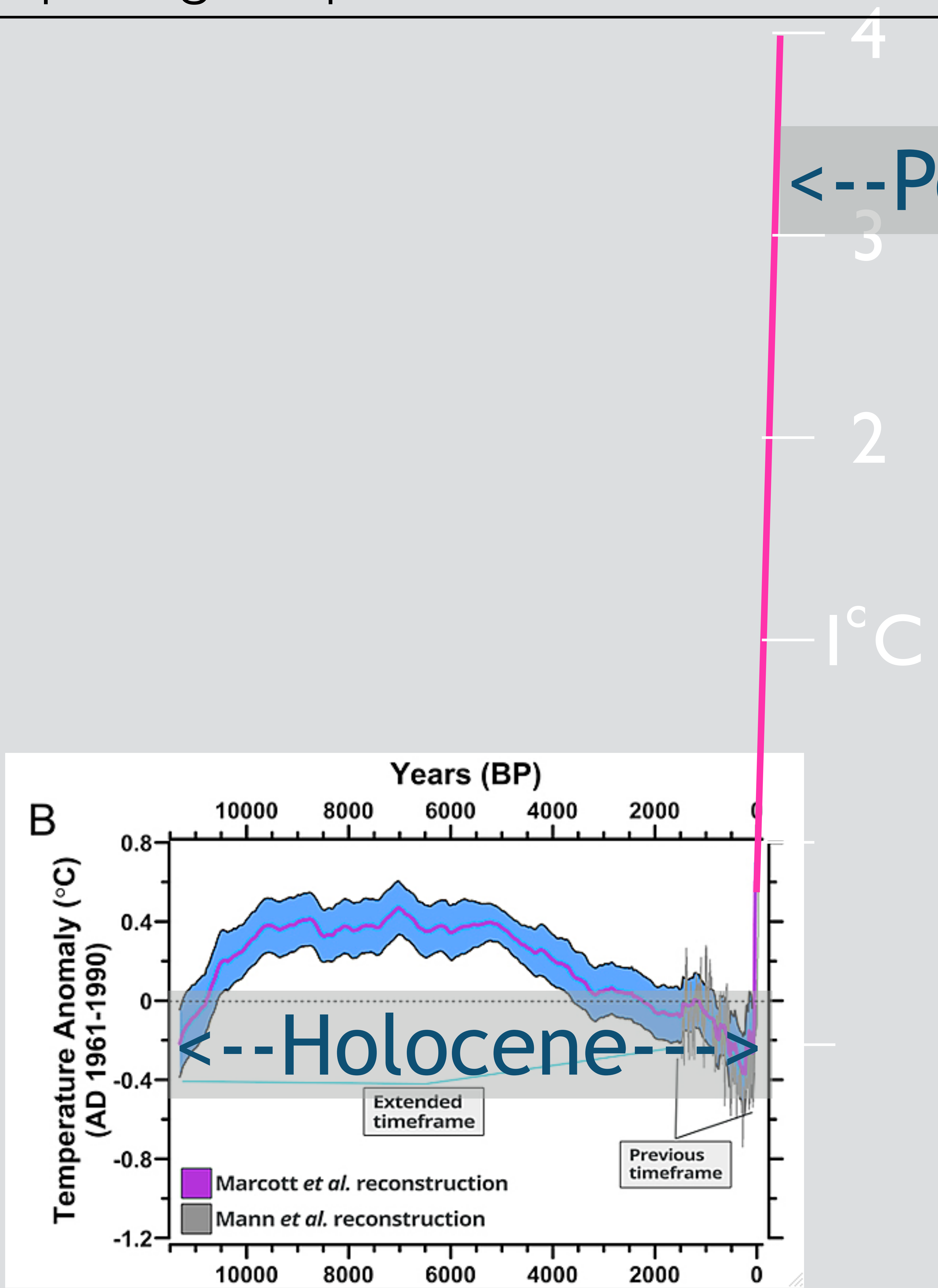
“Normal Range” (800,000 years)

The Prognosis: Anticipating Surprises



Marcott et al., 2013

The Prognosis: Anticipating Surprises



IPCC Assessment:
Very Likely by 2100

Marcott et al., 2013

The Therapy: Lifestyle Changes

The Therapy: Lifestyle Changes

Economy is the link between humanity and Earth's life-support system

Economy is the link between humanity and Earth's life-support system

Economy **for** humanity:
"An economy that meets our needs while safeguarding Earth's life-support system, on which the welfare of current and future generations depends."

The Therapy: Lifestyle Changes

Economy is the link between humanity and Earth’s life-support system

Economy **for** humanity:
“An economy that meets our needs while safeguarding Earth’s life-support system, on which the welfare of current and future generations depends.”

“What is good for Earth’s life support system is good for humanity”

Mitigation and Adaptation - Some Definitions

Mitigation and Adaptation - Some Definitions

Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

BARRIERS TO CLIMATE CHANGE ADAPTION: A DIAGNOSTIC FRAMEWORK

Prepared for: California Energy Commission

Prepared by: Lawrence Berkeley National Laboratory

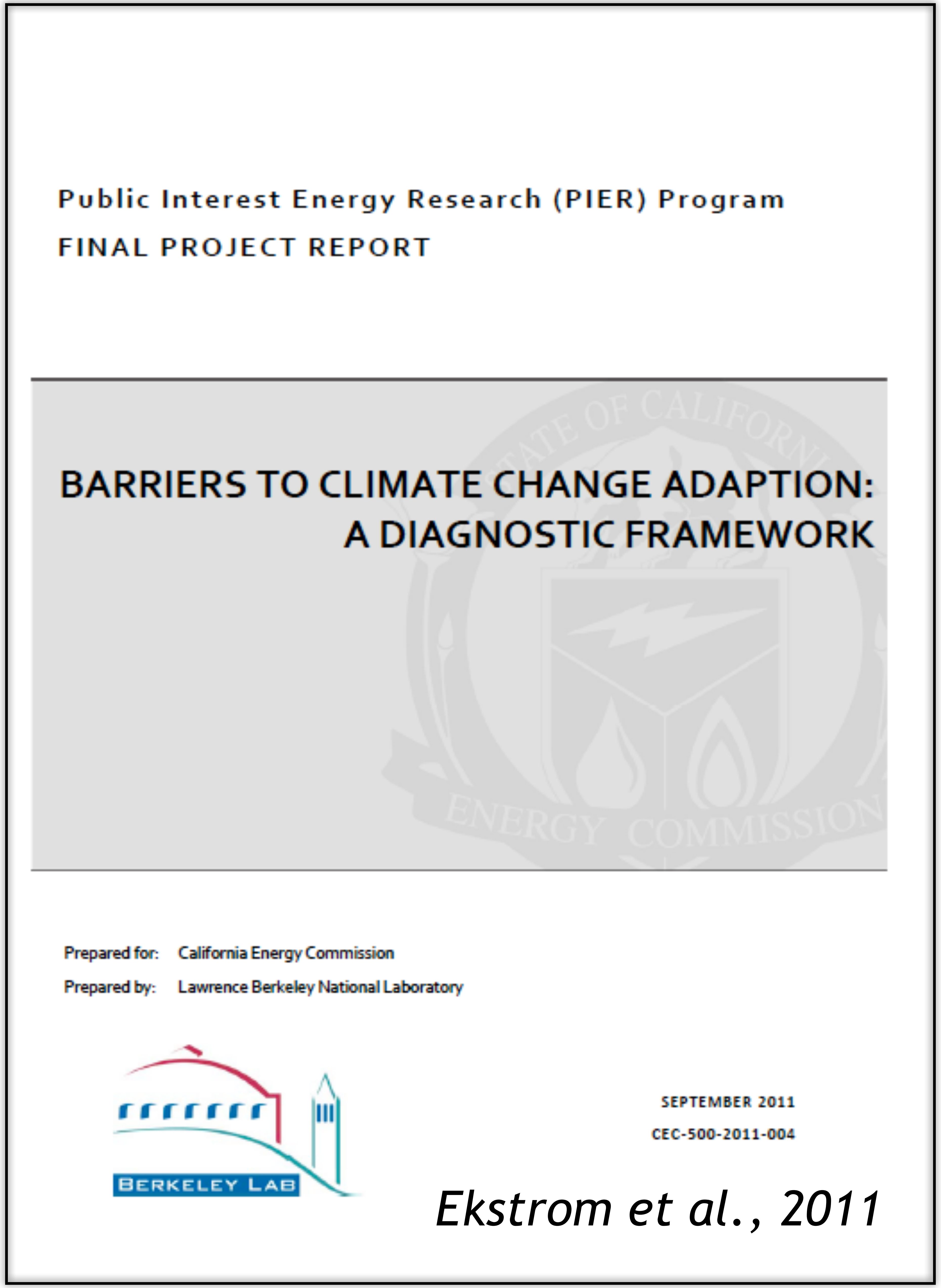
BERKELEY LAB

SEPTEMBER 2011

CEC-500-2011-004

Ekstrom et al., 2011

Mitigation and Adaptation - Some Definitions



Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

BARRIERS TO CLIMATE CHANGE ADAPTION: A DIAGNOSTIC FRAMEWORK

Prepared for: California Energy Commission

Prepared by: Lawrence Berkeley National Laboratory

SEPTEMBER 2011

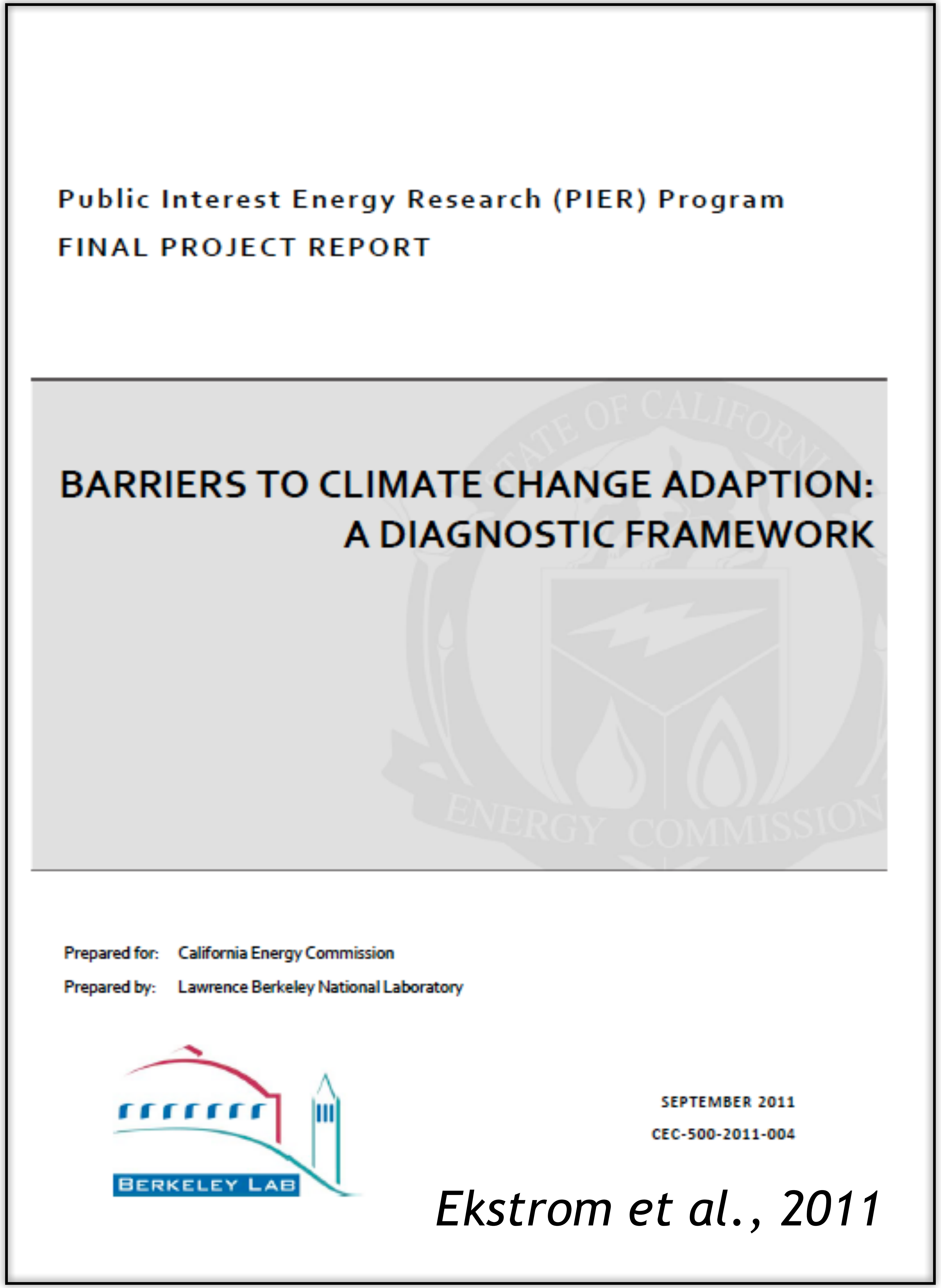
CEC-500-2011-004

Ekstrom et al., 2011

Early usage in discussions of environmental hazards and changes (1980-ies):

- adjustments: short-term, relatively small-scale or minor changes;
- adaptation: longer-term, more systemic changes

Mitigation and Adaptation - Some Definitions


Public Interest Energy Research (PIER) Program
FINAL PROJECT REPORT

BARRIERS TO CLIMATE CHANGE ADAPTION:
A DIAGNOSTIC FRAMEWORK

Prepared for: California Energy Commission
Prepared by: Lawrence Berkeley National Laboratory

BERKELEY LAB

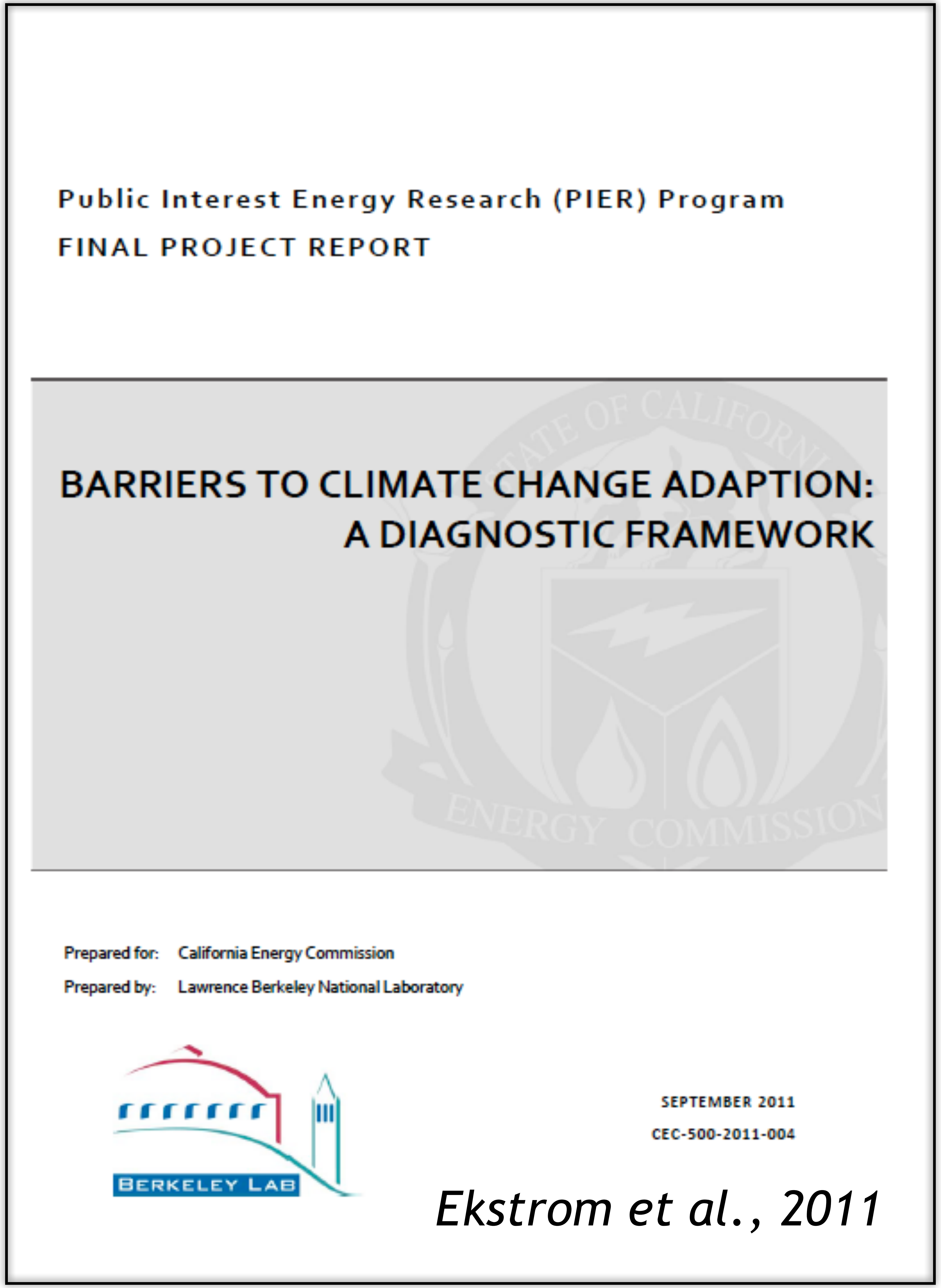
SEPTEMBER 2011
CEC-500-2011-004

Ekstrom et al., 2011

Early usage in discussions of environmental hazards and changes (1980-ies):
- adjustments: short-term, relatively small-scale or minor changes;
- adaptation: longer-term, more systemic changes

Lack of foresight/forward-looking capacity limited science to reactive adjustments/adaptation.

Mitigation and Adaptation - Some Definitions


Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

BARRIERS TO CLIMATE CHANGE ADAPTION:
A DIAGNOSTIC FRAMEWORK

Prepared for: California Energy Commission

Prepared by: Lawrence Berkeley National Laboratory

BERKELEY LAB

SEPTEMBER 2011

CEC-500-2011-004

Ekstrom et al., 2011

Early usage in discussions of environmental hazards and changes (1980-ies):
- adjustments: short-term, relatively small-scale or minor changes;
- adaptation: longer-term, more systemic changes

Lack of foresight/forward-looking capacity limited science to reactive adjustments/adaptation.

More recent studies do not distinguish between adjustments and adaptation in response to stimulus.

Mitigation and Adaptation - Some Definitions

Public Interest Energy Research (PIER) Program
FINAL PROJECT REPORT

BARRIERS TO CLIMATE CHANGE ADAPTION: A DIAGNOSTIC FRAMEWORK

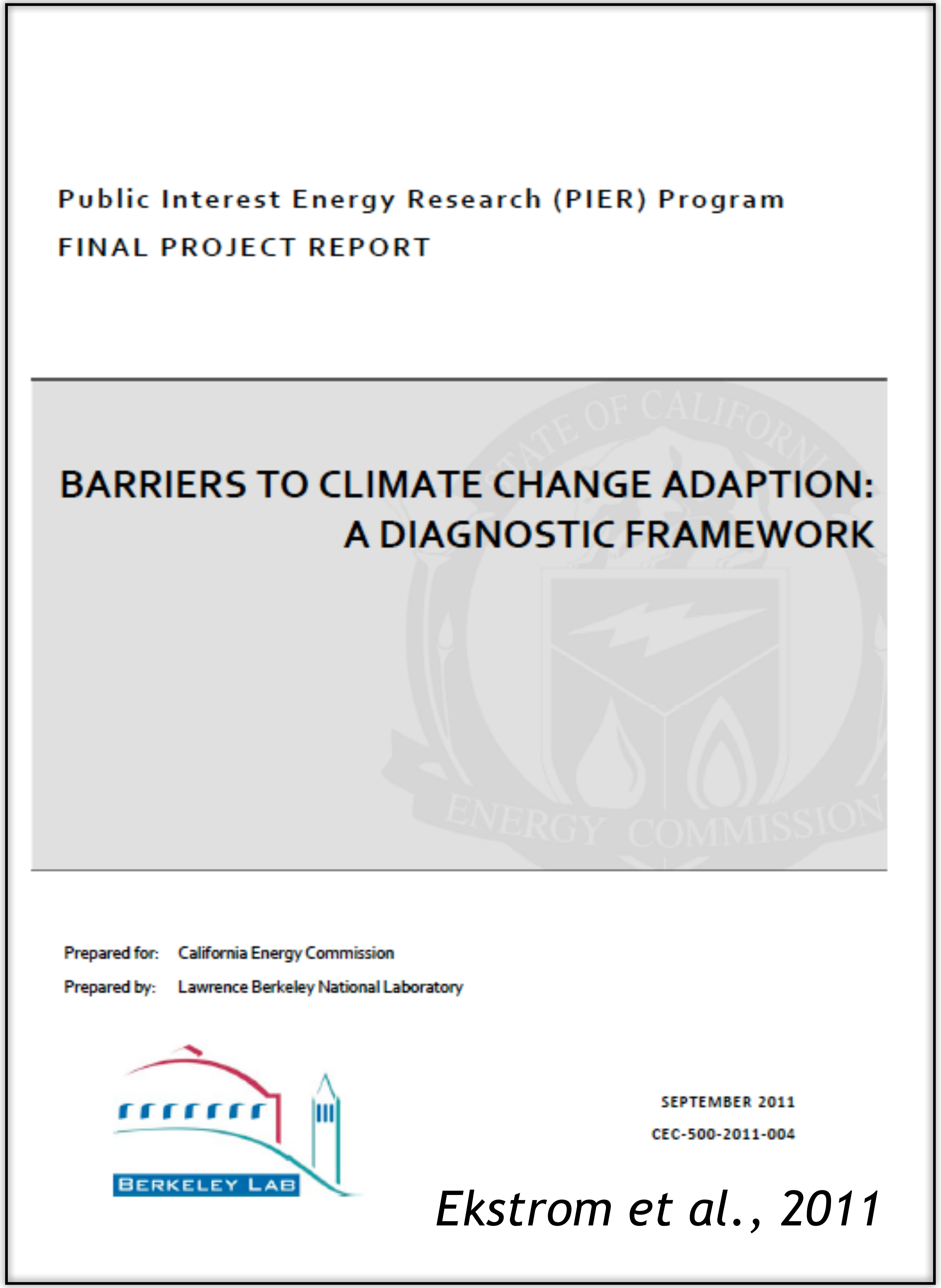
Prepared for: California Energy Commission
Prepared by: Lawrence Berkeley National Laboratory

BERKELEY LAB

SEPTEMBER 2011
CEC-500-2011-004

Ekstrom et al., 2011

Mitigation and Adaptation - Some Definitions


Public Interest Energy Research (PIER) Program
FINAL PROJECT REPORT

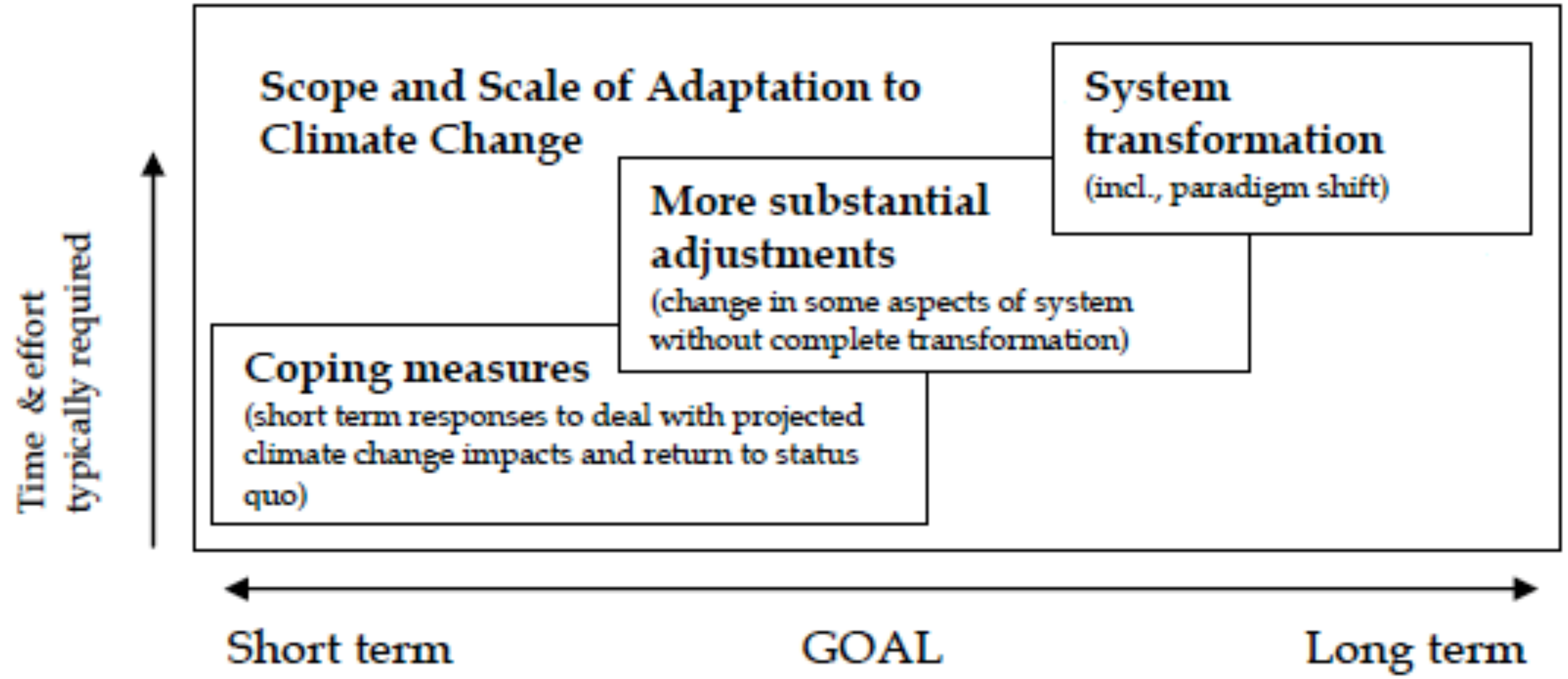
BARRIERS TO CLIMATE CHANGE ADAPTION:
A DIAGNOSTIC FRAMEWORK

Prepared for: California Energy Commission
Prepared by: Lawrence Berkeley National Laboratory

BERKELEY LAB

SEPTEMBER 2011
CEC-500-2011-004

Ekstrom et al., 2011



Mitigation and Adaptation - Some Definitions

Mitigation and Adaptation - Some Definitions

Mitigation:

1. the act of mitigating, or lessening the force or intensity of something unpleasant, as wrath, pain, grief, or extreme circumstances: Social support is the most important factor in the mitigation of stress among adolescents.
2. the act of making a condition or consequence less severe: the mitigation of a punishment.
3. the process of becoming milder, gentler, or less severe.
4. a mitigating circumstance, event, or consequence.

Mitigation and Adaptation - Some Definitions

Mitigation and Adaptation - Some Definitions

Adaptation:

1. the act of adapting.
2. the state of being adapted; adjustment.
3. something produced by adapting: an adaptation of a play for television.
4. Biology:

a. any alteration in the structure or function of an organism or any of its parts that results from natural selection and by which the organism becomes better fitted to survive and multiply in its environment.

b. a form or structure modified to fit a changed environment.

c. the ability of a species to survive in a particular ecological niche, especially because of alterations of form or behavior brought about through natural selection.

5. Physiology: the decrease in response of sensory receptor organs, as those of vision, touch, temperature, olfaction, audition, and pain, to changed, constantly applied, environmental conditions.

Source: http://dictionary.reference.com/browse/adaptation

Mitigation and Adaptation - Some Definitions

Mitigation and Adaptation - Some Definitions

We can characterize:

- **mitigation** as a more "**external**" process that protects the organism by reducing a threat or severe condition;
- **adaptation** as a more "**internal**" process that alters an organism or its behavior.

Mitigation and Adaptation - Some Definitions

We can characterize:

- **mitigation** as a more "**external**" process that protects the organism by reducing a threat or severe condition;
- **adaptation** as a more "**internal**" process that alters an organism or its behavior.

Contemporary usage reflects this:

- **mitigation** points to a process of **reducing a threat** or the **impacts** and preventing something from happening,
- **adaptation** is more used for processes that enable an organism or system to **handling certain conditions and the changes** in these conditions.

Mitigation and Adaptation - Some Definitions

Mitigation and Adaptation - Some Definitions

Successful adaptation does reduce impacts and disaster risk, and so does mitigation.

Mitigation and Adaptation - Some Definitions

Successful adaptation does reduce impacts and disaster risk, and so does mitigation.

Impact **mitigation** seems to have the goal to **reduce a threat and to prevent impacts**, and it often involves protection, engineering, technology, etc.

If these measures fail (e.g., a storm surge comes over a dike or breaks through), the disaster is normally exaggerated because preparedness for this case is low.

Adaptation seems to be more focused on **changes in human behavior** or use, while mitigation of impacts is more often used to refer to changes in the built environment.

Adaptation has the goal to accept the changing conditions by changing our behavior or use of the built environment or our exposure to new hazards (retreat).

s reduce impacts and disaster risk, and so does mitigation.

have the goal to **reduce a threat and to prevent impacts**, tion, engineering, technology, etc.

a storm surge comes over a dike or breaks through), the erated because preparedness for this case is low.

ore focused on **changes in human behavior** or use, while re often used to refer to changes in the built environment.

accept the changing conditions by changing our behavior or use of the built environment or our exposure to new hazards (retreat).

Mitigation and Adaptation - Some Definitions

s reduce impacts and disaster risk, and so does mitigation.

have the goal to **reduce a threat and to prevent impacts**, tion, engineering, technology, etc.

a storm surge comes over a dike or breaks through), the erated because preparedness for this case is low.

ore focused on **changes in human behavior** or use, while re often used to refer to changes in the built environment.

accept the changing conditions by changing our behavior ment or our exposure to new hazards (retreat).

Mitigation and Adaptation - Some Definitions

s … sk, and so does mitigation.

… **and to prevent impacts,**

t … c.

… e or breaks through), the

e … r this case is low.

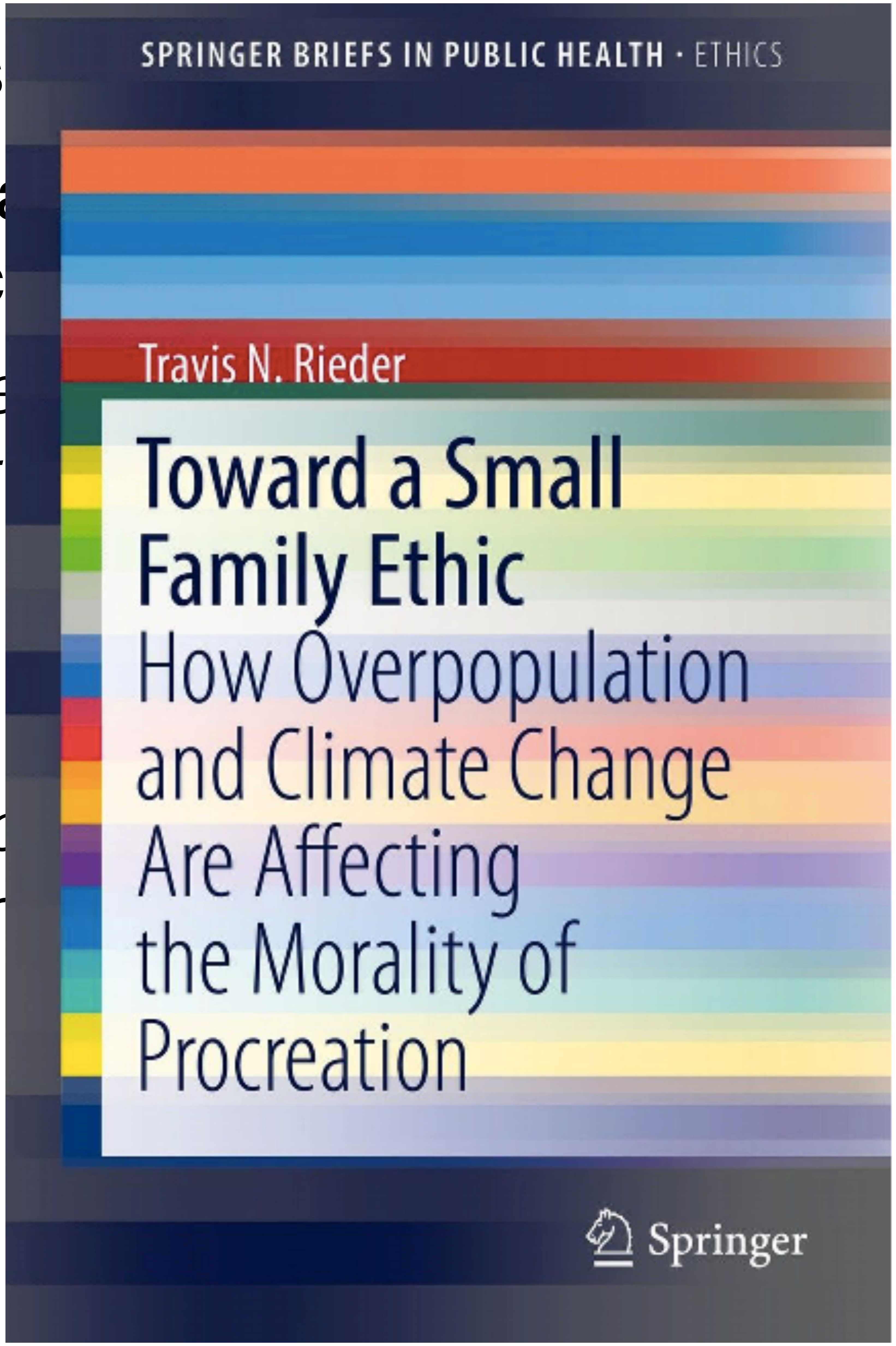
… **behavior** or use, while

r … in the built environment.

accept the changing conditions by changing our behavior

ment or our exposure to new hazards (retreat).

Mitigation and Adaptation - Some Definitions



accept the changing conditions b
ment or our exposure to new hazar

Mitigation and Adaptation - Some Definitions

Mitigation and Adaptation - Some Definitions

Intergovernmental Panel on Climate Change (IPCC):

- **climate change mitigation**: the process of mitigating (i.e., reducing) climate change mainly by reducing the climate forcing that results from increasing atmospheric concentration of Greenhouse Gases (GHG) or other anthropogenic forcing factors, such as albedo changes.

In a more general sense, **climate change mitigation** is any action taken to permanently eliminate or **reduce the long-term risk and hazards of climate change**.

- **climate change adaptation**: the process of enabling the built environment, social communities, and ecosystems to function and exist under the changing climate conditions that could not be mitigated.

Climate change adaptation refers to **adjustments in natural and human systems** in response to actual or anticipate climate stimuli or their effects, which moderate harm or exploit beneficial opportunities.

It is interesting to note that in some groups, climate change mitigation is equated to a reduction of fossil fuels and carbon dioxide emissions, neglecting the fact that 35-45% of the climate forcing results from non-CO_2 GHGs (Ripple et al., 2013).

Mitigation and Adaptation - Some Definitions

Mitigation and Adaptation - Some Definitions

Insurance industry:

- mitigation denotes activities, efforts, and investments that reduce the likelihood (probability) or consequences (severity) of a threat.
- adaptation: not explicitly used widely.

Mitigation and Adaptation - Some Definitions

Insurance industry:

- mitigation denotes activities, efforts, and investments that reduce the likelihood (probability) or consequences (severity) of a threat.
- adaptation: not explicitly used widely.

Risk is the product of hazard probability, vulnerability, and exposed assets.

For most natural hazards:

- we have little means to impact hazard probability,
- we can reduce vulnerability: often equates to mitigating impacts of the hazard
- we can reduce exposure: requires a change in life and land use (adaptation).

Mitigation and Adaptation - Some Definitions

Disaster Communities:

- mitigation: process of preventing a hazardous situation turning into a crisis or disaster;
- adaptation: refers to the process of handling the crisis.

Insurance industry:

- mitigation denotes activities, efforts, and investments that reduce the likelihood (probability) or consequences (severity) of a threat.
- adaptation: not explicitly used widely.

Risk is the product of hazard probability, vulnerability, and exposed assets.

For most natural hazards:

- we have little means to impact hazard probability,
- we can reduce vulnerability: often equates to mitigating impacts of the hazard
- we can reduce exposure: requires a change in life and land use (adaptation).

Although insurances do not use the term adaptation, it is implicitly addressed as a way of reducing disaster risk.

Mitigation and Adaptation - Some Definitions

Mitigation and Adaptation - Some Definitions

At all levels we always have the choice to:

- mitigate (prevent) or
- adapt (manage),

with rather different social, economic, and environmental consequences.

Mitigation and Adaptation - Some Definitions

At all levels we always have the choice to:
- mitigate (prevent) or
- adapt (manage),

with rather different social, economic, and environmental consequences.

Our language should be flexible enough to reflect these choices.

For the course, we therefore consider three terms as relevant, combining:
- the definition of (climate) change mitigation (including speed of change);
- a narrower definition of (climate) change adaptation as system transformation;
- mitigation of (climate) change impacts (in the sense of crisis management and disaster risk reduction)

Mitigation and Adaptation - Some Definitions

Mitigation and Adaptation - Some Definitions

Definitions:

Definitions:

1. **Mitigation of Change**: actions that limit and reduce changes/degradations in the Earth's life-support system.
2. **Mitigation of impacts**: actions that aim to protect against certain levels of impacts resulting from degradation of the Earth’s life-support system, including climate change and/or SLR.
3. **Adaptation**: systemic transformations that increase our preparedness for a wide range of probable changes and allow us to cope with the changes if and when they happen.

Adaptation Science

POLICYFORUM

CLIMATE CHANGE

Hell and High Water: Practice-Relevant Adaptation Science

Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options.

R. H. Moss,*† G. A. Meehl, M. C. Lemos, J. B. Smith, J. R. Arnold, J. C. Arnott, D. Behar, G. P. Brasseur, S. B. Broomell, A. J. Busalacchi, S. Dessai, K. L. Ebi, J. A. Edmonds, J. Furlow, L. Goddard, H. C. Hartmann, J. W. Hurrell, J. W. Katzenberger, D. M. Liverman, P. W. Mote, S. C. Moser, A. Kumar, R. S. Pulwarty, E. A. Seyller, B. L. Turner II, W. M. Washington, T. J. Wilbanks

Informing the extensive preparations needed to manage climate risks, avoid damages, and realize emerging opportunities is a grand challenge for climate change science. U.S. President Obama underscored the need for this research when he made climate preparedness a pillar of his climate policy. Adaptation improves preparedness and is one of two broad and increasingly important strategies (along with mitigation) for climate risk management. Adaptation is required in virtually all sectors of the economy and regions of the globe, for both built and natural systems (*1*).

However, without the appropriate science delivered in a decision-relevant context, it will become increasingly difficult—if not impossible—to prepare adequately (*2*). We suggest a number of measures to hasten the development of science to correct maladaptations to current climate variability and support society's increasing need to adapt to a changing climate, drawing on lessons from experience, insights from related endeavors such as sustainability science (*3*), and input from scientific and stakeholder communities.

The entrance to a garage in Lower Manhattan on 31 October, 2012, as New York City began clean-up after Hurricane Sandy.

Adaptation Planning, Information Gaps, and the Need for Adaptation Science

Initial adaptation planning is occurring in some sectors, such as water resource management, forestry, insurance, and coastal zone management. A limited but growing number of states and cities are developing adaptation plans. U.S. federal agencies have implemented sustainability plans that include mitigation and adaptation (*4*).

There are serious science gaps, however (*5*, *6*). In many communities, decision-makers lack climate information or the means to apply it. In others, knowledge of current or potential future impacts exists, but not in a form or context that decision-makers can assimilate or act on in advance. In still others, engineering innovations are needed, as well as social science knowledge, to guide technology deployment and adjustments to management, investments, and public policy.

A key characteristic of emerging adaptation science is that it is both basic—in that it contributes to understanding fundamental physical, environmental, and socioeconomic research questions—and applied, because it is problem focused. Scientists and practitioners "coproduce" relevant research by jointly defining questions and maintaining frequent interactions (*7*). Coproduction is challenging to implement and sustain because participants often have different roles, vocabularies, interests, methods, and incentives. The effectiveness of communications and deliberative processes among scientists and practitioners requires empirical evaluation (*8*).

To support the wide range of necessary adjustments, we outline a comprehensive, integrated approach to research in social, physical, environmental, engineering, and other sciences. We describe adaptation science research needed to understand decision processes and information requirements, identify vulnerabilities, improve foresight about climate risks and other stressors, and understand barriers and options for adaptation.

Understand Decision Processes and Knowledge Requirements

Adaptation science research must clarify what types of scientific information are required for improved decision-making. Decision-makers are concerned with cost, feasibility, social acceptance, tradition, and other factors. To close a "usability gap," scientific information must fit into existing contexts (*9*). Organizational, cognitive, political, ethnographic, and decision sciences research is needed to clarify the problem, the values of participants, and the context in which the information will be applied. Understanding perception and apprehension of climate change risks is also a priority.

Identify Vulnerabilities

Research to characterize vulnerability and adaptive capacity focuses on pinpointing infrastructure, economic sectors, geo-

*Full affiliations for all authors are provided in the supplementary materials. †Corresponding author. E-mail: rhm@pnnl.gov

Moss et al., 2013
Published on November 8, 2013 in *Science*

Adaptation Science

POLICYFORUM

CLIMATE CHANGE

Hell and High Water: Practice-Relevant Adaptation Science

Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options.

R. H. Moss,*† G. A. Meehl, M. C. Lemos, J. B. Smith, J. R. Arnold, J. C. Arnott, D. Behar, G. P. Brasseur, S. B. Broomell, A. J. Busalacchi, S. Dessai, K. L. Ebi, J. A. Edmonds, J. Furlow, L. Goddard, H. C. Hartmann, J. W. Hurrell, J. W. Katzenberger, D. M. Liverman, P. W. Mote, S. C. Moser, A. Kumar, R. S. Pulwarty, E. A. Seyller, B. L. Turner II, W. M. Washington, T. J. Wilbanks

Informing the extensive preparations needed to manage climate risks, avoid damages, and realize emerging opportunities is a grand challenge for climate change science. U.S. President Obama underscored the need for this research when he made climate preparedness a pillar of his climate policy. Adaptation improves preparedness and is one of two broad and increasingly important strategies (along with mitigation) for climate risk management. Adaptation is required in virtually all sectors of the economy and regions of the globe, for both built and natural systems (*1*).

However, without the appropriate science delivered in a decision-relevant context, it will become increasingly difficult—if not impossible—to prepare adequately (*2*). We suggest a number of measures to hasten the development of science to correct maladaptations to current climate variability and support society's increasing need to adapt to a changing climate, drawing on lessons from experience, insights from related endeavors such as sustainability science (*3*), and input from scientific and stakeholder communities.


The entrance to a garage in Lower Manhattan on 31 October, 2012, as New York City began clean-up after Hurricane Sandy.

Adaptation Planning, Information Gaps, and the Need for Adaptation Science

Initial adaptation planning is occurring in some sectors, such as water resource management, forestry, insurance, and coastal zone management. A limited but growing number of states and cities are developing adaptation plans. U.S. federal agencies have implemented sustainability plans that include mitigation and adaptation (*4*).

There are serious science gaps, however (*5*, *6*). In many communities, decision-makers lack climate information or the means to apply it. In others, knowledge of current or potential future impacts exists, but not in a form or context that decision-makers can assimilate or act on in advance. In still others, engineering innovations are needed, as well as social science knowledge, to guide technology deployment and adjustments to management, investments, and public policy.

A key characteristic of emerging adaptation science is that it is both basic—in that it contributes to understanding fundamental physical, environmental, and socioeconomic research questions—and applied, because it is problem focused. Scientists and practitioners "coproduce" relevant research by jointly defining questions and maintaining frequent interactions (*7*). Coproduction is challenging to implement and sustain because participants often have different roles, vocabularies, interests, methods, and incentives. The effectiveness of communications and deliberative processes among scientists and practitioners requires empirical evaluation (*8*).

To support the wide range of necessary adjustments, we outline a comprehensive, integrated approach to research in social, physical, environmental, engineering, and other sciences. We describe adaptation science research needed to understand decision processes and information requirements, identify vulnerabilities, improve foresight about climate risks and other stressors, and understand barriers and options for adaptation.

Understand Decision Processes and Knowledge Requirements

Adaptation science research must clarify what types of scientific information are required for improved decision-making. Decision-makers are concerned with cost, feasibility, social acceptance, tradition, and other factors. To close a "usability gap," scientific information must fit into existing contexts (*9*). Organizational, cognitive, political, ethnographic, and decision sciences research is needed to clarify the problem, the values of participants, and the context in which the information will be applied. Understanding perception and apprehension of climate change risks is also a priority.

Identify Vulnerabilities

Research to characterize vulnerability and adaptive capacity focuses on pinpointing infrastructure, economic sectors, geo-

*Full affiliations for all authors are provided in the supplementary materials. †Corresponding author. E-mail: rhm@pnnl.gov

CREDIT: STAN HONDA/AFP/GETTY IMAGES/NEWSCOM

Moss et al., 2013
Published on November 8, 2013 in *Science*


POLICYFORUM

CLIMATE CHANGE

Hell and High Water: Practice-Relevant Adaptation Science

Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options.

R. H. Moss,*† G. A. Meehl, M. C. Lemos, J. B. Smith, J. R. Arnold, J. C. Arnott, D. Behar, G. P. Brasseur, S. B. Broomell, A. J. Busalacchi, S. Dessai, K. L. Ebi, J. A. Edmonds, J. Furlow, L. Goddard, H. C. Hartmann, J. W. Hurrell, J. W. Katzenberger, D. M. Liverman, P. W. Mote, S. C. Moser, A. Kumar, R. S. Pulwarty, E. A. Seyller, B. L. Turner II, W. M. Washington, T. J. Wilbanks

Informing the extensive preparations needed to manage climate risks, avoid damages, and realize emerging opportunities is a grand challenge for climate change science. U.S. President Obama underscored the need for this research when he made climate preparedness a pillar of his climate policy. Adaptation improves preparedness and is one of two broad and increasingly important strategies (along with mitigation) for climate risk management. Adaptation is required in virtually all sectors of the economy and regions of the globe, for both built and natural systems (*1*).

However, without the appropriate science delivered in a decision-relevant context, it will become increasingly difficult—if not impossible—to prepare adequately (*2*). We suggest a number of measures to hasten the development of science to correct maladaptations to current climate variability and support society's increasing need to adapt to a changing climate, drawing on lessons from experience, insights from related endeavors such as sustainability science (*3*), and input from scientific and stakeholder communities.

The entrance to a garage in Lower Manhattan on 31 October, 2012, as New York City began clean-up after Hurricane Sandy.

Adaptation Planning, Information Gaps, and the Need for Adaptation Science

Initial adaptation planning is occurring in some sectors, such as water resource management, forestry, insurance, and coastal zone management. A limited but growing number of states and cities are developing adaptation plans. U.S. federal agencies have implemented sustainability plans that include mitigation and adaptation (*4*).

There are serious science gaps, however (*5*, *6*). In many communities, decision-makers lack climate information or the means to apply it. In others, knowledge of current or potential future impacts exists, but not in a form or context that decision-makers can assimilate or act on in advance. In still others, engineering innovations are needed, as well as social science knowledge, to guide technology deployment and adjustments to management, investments, and public policy.

A key characteristic of emerging adaptation science is that it is both basic—in that it contributes to understanding fundamental physical, environmental, and socioeconomic research questions—and applied, because it is problem focused. Scientists and practitioners "coproduce" relevant research by jointly defining questions and maintaining frequent interactions (*7*). Coproduction is challenging to implement and sustain because participants often have different roles, vocabularies, interests, methods, and incentives. The effectiveness of communications and deliberative processes among scientists and practitioners requires empirical evaluation (*8*).

To support the wide range of necessary adjustments, we outline a comprehensive, integrated approach to research in social, physical, environmental, engineering, and other sciences. We describe adaptation science research needed to understand decision processes and information requirements, identify vulnerabilities, improve foresight about climate risks and other stressors, and understand barriers and options for adaptation.

Understand Decision Processes and Knowledge Requirements

Adaptation science research must clarify what types of scientific information are required for improved decision-making. Decision-makers are concerned with cost, feasibility, social acceptance, tradition, and other factors. To close a "usability gap," scientific information must fit into existing contexts (*9*). Organizational, cognitive, political, ethnographic, and decision sciences research is needed to clarify the problem, the values of participants, and the context in which the information will be applied. Understanding perception and apprehension of climate change risks is also a priority.

Identify Vulnerabilities

Research to characterize vulnerability and adaptive capacity focuses on pinpointing infrastructure, economic sectors, geo-

*Full affiliations for all authors are provided in the supplementary materials. †Corresponding author. E-mail: rhm@pnnl.gov

CREDIT: STAN HONDA/AFP/GETTY IMAGES/NEWSCOM

There is an urgent need for "practice-relevant adaptation science"

Moss et al., 2013
Published on November 8, 2013 in *Science*

POLICYFORUM

CLIMATE CHANGE

Hell and High Water: Practice-Relevant Adaptation Science

Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options.

R. H. Moss,*† G. A. Meehl, M. C. Lemos, J. B. Smith, J. R. Arnold, J. C. Arnott, D. Behar, G. P. Brasseur, S. B. Broomell, A. J. Busalacchi, S. Dessai, K. L. Ebi, J. A. Edmonds, J. Furlow, L. Goddard, H. C. Hartmann, J. W. Hurrell, J. W. Katzenberger, D. M. Liverman, P. W. Mote, S. C. Moser, A. Kumar, R. S. Pulwarty, E. A. Seyller, B. L. Turner II, W. M. Washington, T. J. Wilbanks

Informing the extensive preparations needed to manage climate risks, avoid damages, and realize emerging opportunities is a grand challenge for climate change science. U.S. President Obama underscored the need for this research when he made climate preparedness a pillar of his climate policy. Adaptation improves preparedness and is one of two broad and increasingly important strategies (along with mitigation) for climate risk management. Adaptation is required in virtually all sectors of the economy and regions of the globe, for both built and natural systems (1).

However, without the appropriate science delivered in a decision-relevant context, it will become increasingly difficult—if not impossible—to prepare adequately (2). We suggest a number of measures to hasten the development of science to correct maladaptations to current climate variability and support society's increasing need to adapt to a changing climate, drawing on lessons from experience, insights from related endeavors such as sustainability science (3), and input from scientific and stakeholder communities.

The entrance to a garage in Lower Manhattan on 31 October, 2012, as New York City began clean-up after Hurricane Sandy.

Adaptation Planning, Information Gaps, and the Need for Adaptation Science

Initial adaptation planning is occurring in some sectors, such as water resource management, forestry, insurance, and coastal zone management. A limited but growing number of states and cities are developing adaptation plans. U.S. federal agencies have implemented sustainability plans that include mitigation and adaptation (4).

There are serious science gaps, however (5, 6). In many communities, decision-makers lack climate information or the means to apply it. In others, knowledge of current or potential future impacts exists, but not in a form or context that decision-makers can assimilate or act on in advance. In still others, engineering innovations are needed, as well as social science knowledge, to guide technology deployment and adjustments to management, investments, and public policy.

A key characteristic of emerging adaptation science is that it is both basic—in that it contributes to understanding fundamental physical, environmental, and socioeconomic research questions—and applied, because it is problem focused. Scientists and practitioners "coproduce" relevant research by jointly defining questions and maintaining frequent interactions (7). Coproduction is challenging to implement and sustain because participants often have different roles, vocabularies, interests, methods, and incentives. The effectiveness of communications and deliberative processes among scientists and practitioners requires empirical evaluation (8).

To support the wide range of necessary adjustments, we outline a comprehensive, integrated approach to research in social, physical, environmental, engineering, and other sciences. We describe adaptation science research needed to understand decision processes and information requirements, identify vulnerabilities, improve foresight about climate risks and other stressors, and understand barriers and options for adaptation.

Understand Decision Processes and Knowledge Requirements

Adaptation science research must clarify what [illegible] scientific information are [illegible] for improved decision-making. Decision-makers are concerned with cost, feasibility, social acceptance, tradition, and other factors. To close a "usability gap," scientific information must fit into existing contexts (9). Organizational, cognitive, political, ethnographic, and decision sciences research is needed to clarify the problem, the values of participants, and the context in which the information will be applied. Understanding perception and apprehension of climate change risks is also a priority.

Identify Vulnerabilities

Research to characterize vulnerability and adaptive capacity focuses on pinpointing infrastructure, economic sectors, geo-

*Full affiliations for all authors are provided in the supplementary materials. †Corresponding author. E-mail: rhm@pnnl.gov

The rele

A key characteristic of emerging adaptation science is that it is both basic—in that it contributes to understanding fundamental physical, environmental, and socioeconomic research questions—and applied, because it is problem focused. Scientists and practitioners "coproduce" relevant research by jointly defining questions and maintaining frequent interactions (7). Coproduction is challenging to implement and sustain because participants often have different roles, vocabularies, interests, methods, and incentives. The effectiveness of communications and deliberative processes among scientists and practitioners requires empirical evaluation (8).

Published on November 8, 2013 in *Science*

POLICYFORUM

CLIMATE CHANGE

Hell and High Water: Practice-Relevant Adaptation Science

Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options.

R. H. Moss,*† G. A. Meehl, M. C. Lemos, J. B. Smith, J. R. Arnold, J. C. Arnott, D. Behar, G. P. Brasseur, S. B. Broomell, A. J. Busalacchi, S. Dessai, K. L. Ebi, J. A. Edmonds, J. Furlow, L. Goddard, H. C. Hartmann, J. W. Hurrell, J. W. Katzenberger, D. M. Liverman, P. W. Mote, S. C. Moser, A. Kumar, R. S. Pulwarty, E. A. Seyller, B. L. Turner II, W. M. Washington, T. J. Wilbanks

Informing the extensive preparations needed to manage climate risks, avoid damages, and realize emerging opportunities is a grand challenge for climate change science. U.S. President Obama underscored the need for this research when he made climate preparedness a pillar of his climate policy. Adaptation improves preparedness and is one of two broad and increasingly important strategies (along with mitigation) for climate risk management. Adaptation is required in virtually all sectors of the economy and regions of the globe, for both built and natural systems (*1*).

However, without the appropriate science delivered in a decision-relevant context, it will become increasingly difficult—if not impossible—to prepare adequately (*2*). We suggest a number of measures to hasten the development of science to correct maladaptations to current climate variability and support society's increasing need to adapt to a changing climate, drawing on lessons from experience, insights from related endeavors such as sustainability science (*3*), and input from scientific and stakeholder communities.

The entrance to a garage in Lower Manhattan on 31 October, 2012, as New York City began clean-up after Hurricane Sandy.

Adaptation Planning, Information Gaps, and the Need for Adaptation Science

Initial adaptation planning is occurring in some sectors, such as water resource management, forestry, insurance, and coastal zone management. A limited but growing number of states and cities are developing adaptation plans. U.S. federal agencies have implemented sustainability plans that include mitigation and adaptation (*4*).

There are serious science gaps, however (*5*, *6*). In many communities, decision-makers lack climate information or the means to apply it. In others, knowledge of current or potential future impacts exists, but not in a form or context that decision-makers can assimilate or act on in advance. In still others, engineering innovations are needed, as well as social science knowledge, to guide technology deployment and adjustments to management, investments, and public policy.

A key characteristic of emerging adaptation science is that it is both basic—in that it contributes to understanding fundamental physical, environmental, and socioeconomic research questions—and applied, because it is problem focused. Scientists and practitioners "coproduce" relevant research by jointly defining questions and maintaining frequent interactions (*7*). Coproduction is challenging to implement and sustain because participants often have different roles, vocabularies, interests, methods, and incentives. The effectiveness of communications and deliberative processes among scientists and practitioners requires empirical evaluation (*8*).

To support the wide range of necessary adjustments, we outline a comprehensive, integrated approach to research in social, physical, environmental, engineering, and other sciences. We describe adaptation science research needed to understand decision processes and information requirements, identify vulnerabilities, improve foresight about climate risks and other stressors, and understand barriers and options for adaptation.

Understand Decision Processes and Knowledge Requirements

Adaptation science research must clarify what types of scientific information are required for improved decision-making. Decision-makers are concerned with cost, feasibility, social acceptance, tradition, and other factors. To close a "usability gap," scientific information must fit into existing contexts (*9*). Organizational, cognitive, political, ethnographic, and decision sciences research is needed to clarify the problem, the values of participants, and the context in which the information will be applied. Understanding perception and apprehension of climate change risks is also a priority.

Identify Vulnerabilities

Research to characterize vulnerability and adaptive capacity focuses on pinpointing infrastructure, economic sectors, geo-

*Full affiliations for all authors are provided in the supplementary materials. †Corresponding author. E-mail: rhm@pnnl.gov

There is an urgent need for "practice-relevant adaptation science"

Moss et al., 2013
Published on November 8, 2013 in *Science*

Adaptation Science

POLICYFORUM

CLIMATE CHANGE

Hell and High Water: Practice-Relevant Adaptation Science

R. H. Moss,*† G. A. Meehl, M. C. Lemos, J. B. Smith, J. R. Arnold, J. C. Arnott, D. Behar, G. P. Brasseur, S. B. Broomell, A. J. Busalacchi, S. Dessai, K. L. Ebi, J. A. Edmonds, J. Furlow, L. Goddard, H. C. Hartmann, J. W. Hurrell, J. W. Katzenberger, D. M. Liverman, P. W. Mote, S. C. Moser, A. Kumar, R. S. Pulwarty, E. A. Seyller, B. L. Turner II, W. M. Washington, T. J. Wilbanks

Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options.

Informing the extensive preparations needed to manage climate risks, avoid damages, and realize emerging opportunities is a grand challenge for climate change science. U.S. President Obama underscored the need for this research when he made climate preparedness a pillar of his climate policy. Adaptation improves preparedness and is one of two broad and increasingly important strategies (along with mitigation) for climate risk management. Adaptation is required in virtually all sectors of the economy and regions of the globe, for both built and natural systems (*1*).

However, without the appropriate science delivered in a decision-relevant context, it will become increasingly difficult—if not impossible—to prepare adequately (*2*). We suggest a number of measures to hasten the development of science to correct maladaptations to current climate variability and support society's increasing need to adapt to a changing climate, drawing on lessons from experience, insights from related endeavors such as sustainability science (*3*), and input from scientific and stakeholder communities.

The entrance to a garage in Lower Manhattan on 31 October, 2012, as New York City began clean-up after Hurricane Sandy.

Adaptation Planning, Information Gaps, and the Need for Adaptation Science

Initial adaptation planning is occurring in some sectors, such as water resource management, forestry, insurance, and coastal zone management. A limited but growing number of states and cities are developing adaptation plans. U.S. federal agencies have implemented sustainability plans that include mitigation and adaptation (*4*).

There are serious science gaps, however (*5*, *6*). In many communities, decision-makers lack climate information or the means to apply it. In others, knowledge of current or potential future impacts exists, but not in a form or context that decision-makers can assimilate or act on in advance. In still others, engineering innovations are needed, as well as social science knowledge, to guide technology deployment and adjustments to management, investments, and public policy.

A key characteristic of emerging adaptation science is that it is both basic—in that it contributes to understanding fundamental physical, environmental, and socioeconomic research questions—and applied, because it is problem focused. Scientists and practitioners "coproduce" relevant research by jointly defining questions and maintaining frequent interactions (*7*). Coproduction is challenging to implement and sustain because participants often have different roles, vocabularies, interests, methods, and incentives. The effectiveness of communications and deliberative processes among scientists and practitioners requires empirical evaluation (*8*).

To support the wide range of necessary adjustments, we outline a comprehensive, integrated approach to research in social, physical, environmental, engineering, and other sciences. We describe adaptation science research needed to understand decision processes and information requirements, identify vulnerabilities, improve foresight about climate risks and other stressors, and understand barriers and options for adaptation.

Understand Decision Processes and Knowledge Requirements

Adaptation science research must clarify what types of scientific information are required for improved decision-making. Decision-makers are concerned with cost, feasibility, social acceptance, tradition, and other factors. To close a "usability gap," scientific information must fit into existing contexts (*9*). Organizational, cognitive, political, ethnographic, and decision sciences research is needed to clarify the problem, the values of participants, and the context in which the information will be applied. Understanding perception and apprehension of climate change risks is also a priority.

Identify Vulnerabilities

Research to characterize vulnerability and adaptive capacity focuses on pinpointing infrastructure, economic sectors, geo-

*Full affiliations for all authors are provided in the supplementary materials. †Corresponding author. E-mail: rhm@pnnl.gov

There is an urgent need for "practice-relevant adaptation science"

Adaptation requires science that analyses decisions, identifies vulnerabilities, improves foresight, and develops options

Moss et al., 2013
Published on November 8, 2013 in *Science*

Adaptation Science

POLICYFORUM

CLIMATE CHANGE

Hell and High Water: Practice-Relevant Adaptation Science

Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options.

R. H. Moss,*† G. A. Meehl, M. C. Lemos, J. B. Smith, J. R. Arnold, J. C. Arnott, D. Behar, G. P. Brasseur, S. B. Broomell, A. J. Busalacchi, S. Dessai, K. L. Ebi, J. A. Edmonds, J. Furlow, L. Goddard, H. C. Hartmann, J. W. Hurrell, J. W. Katzenberger, D. M. Liverman, P. W. Mote, S. C. Moser, A. Kumar, R. S. Pulwarty, E. A. Seyller, B. L. Turner II, W. M. Washington, T. J. Wilbanks

Informing the extensive preparations needed to manage climate risks, avoid damages, and realize emerging opportunities is a grand challenge for climate change science. U.S. President Obama underscored the need for this research when he made climate preparedness a pillar of his climate policy. Adaptation improves preparedness and is one of two broad and increasingly important strategies (along with mitigation) for climate risk management. Adaptation is required in virtually all sectors of the economy and regions of the globe, for both built and natural systems (*1*).

However, without the appropriate science delivered in a decision-relevant context, it will become increasingly difficult—if not impossible—to prepare adequately (*2*). We suggest a number of measures to hasten the development of science to correct maladaptations to current climate variability and support society's increasing need to adapt to a changing climate, drawing on lessons from experience, insights from related endeavors such as sustainability science (*3*), and input from scientific and stakeholder communities.

The entrance to a garage in Lower Manhattan on 31 October, 2012, as New York City began clean-up after Hurricane Sandy.

Adaptation Planning, Information Gaps, and the Need for Adaptation Science

Initial adaptation planning is occurring in some sectors, such as water resource management, forestry, insurance, and coastal zone management. A limited but growing number of states and cities are developing adaptation plans. U.S. federal agencies have implemented sustainability plans that include mitigation and adaptation (*4*).

There are serious science gaps, however (*5*, *6*). In many communities, decision-makers lack climate information or the means to apply it. In others, knowledge of current or potential future impacts exists, but not in a form or context that decision-makers can assimilate or act on in advance. In still others, engineering innovations are needed, as well as social science knowledge, to guide technology deployment and adjustments to management, investments, and public policy.

A key characteristic of emerging adaptation science is that it is both basic—in that it contributes to understanding fundamental physical, environmental, and socioeconomic research questions—and applied, because it is problem focused. Scientists and practitioners "coproduce" relevant research by jointly defining questions and maintaining frequent interactions (*7*). Coproduction is challenging to implement and sustain because participants often have different roles, vocabularies, interests, methods, and incentives. The effectiveness of communications and deliberative processes among scientists and practitioners requires empirical evaluation (*8*).

To support the wide range of necessary adjustments, we outline a comprehensive, integrated approach to research in social, physical, environmental, engineering, and other sciences. We describe adaptation science research needed to understand decision processes and information requirements, identify vulnerabilities, improve foresight about climate risks and other stressors, and understand barriers and options for adaptation.

Understand Decision Processes and Knowledge Requirements

Adaptation science research must clarify what types of scientific information are required for improved decision-making. Decision-makers are concerned with cost, feasibility, social acceptance, tradition, and other factors. To close a "usability gap," scientific information must fit into existing contexts (*9*). Organizational, cognitive, political, ethnographic, and decision sciences research is needed to clarify the problem, the values of participants, and the context in which the information will be applied. Understanding perception and apprehension of climate change risks is also a priority.

Identify Vulnerabilities

Research to characterize vulnerability and adaptive capacity focuses on pinpointing infrastructure, economic sectors, geo-

*Full affiliations for all authors are provided in the supplementary materials. †Corresponding author. E-mail: rhm@pnnl.gov

CREDIT: STAN HONDA/AFP/GETTY IMAGES/NEWSCOM

There is an urgent need for "practice-relevant adaptation science"

Adaptation Planning, Information Gaps, and the Need for Adaptation Science

Moss et al., 2013
Published on November 8, 2013 in *Science*

POLICYFORUM

CLIMATE CHANGE

Hell and High Water: Practice-Relevant Adaptation Science

Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options.

R. H. Moss,*† G. A. Meehl, M. C. Lemos, J. B. Smith, J. R. Arnold, J. C. Arnott, D. Behar, G. P. Brasseur, S. B. Broomell, A. J. Busalacchi, S. Dessai, K. L. Ebi, J. A. Edmonds, J. Furlow, L. Goddard, H. C. Hartmann, J. W. Hurrell, J. W. Katzenberger, D. M. Liverman, P. W. Mote, S. C. Moser, A. Kumar, R. S. Pulwarty, E. A. Seyller, B. L. Turner II, W. M. Washington, T. J. Wilbanks

Informing the extensive preparations needed to manage climate risks, avoid damages, and realize emerging opportunities is a grand challenge for climate change science. U.S. President Obama underscored the need for this research when he made climate preparedness a pillar of his climate policy. Adaptation improves preparedness and is one of two broad and increasingly important strategies (along with mitigation) for climate risk management. Adaptation is required in virtually all sectors of the economy and regions of the globe, for both built and natural systems (*1*).

However, without the appropriate science delivered in a decision-relevant context, it will become increasingly difficult—if not impossible—to prepare adequately (*2*). We suggest a number of measures to hasten the development of science to correct maladaptations to current climate variability and support society's increasing need to adapt to a changing climate, drawing on lessons from experience, insights from related endeavors such as sustainability science (*3*), and input from scientific and stakeholder communities.

The entrance to a garage in Lower Manhattan on 31 October, 2012, as New York City began clean-up after Hurricane Sandy.

Adaptation Planning, Information Gaps, and the Need for Adaptation Science

Initial adaptation planning is occurring in some sectors, such as water resource management, forestry, insurance, and coastal zone management. A limited but growing number of states and cities are developing adaptation plans. U.S. federal agencies have implemented sustainability plans that include mitigation and adaptation (*4*).

There are serious science gaps, however (*5*, *6*). In many communities, decision-makers lack climate information or the means to apply it. In others, knowledge of current or potential future impacts exists, but not in a form or context that decision-makers can assimilate or act on in advance. In still others, engineering innovations are needed, as well as social science knowledge, to guide technology deployment and adjustments to management, investments, and public policy.

A key characteristic of emerging adaptation science is that it is both basic—in that it contributes to understanding fundamental physical, environmental, and socioeconomic research questions—and applied, because it is problem focused. Scientists and practitioners "coproduce" relevant research by jointly defining questions and maintaining frequent interactions (*7*). Coproduction is challenging to implement and sustain because participants often have different roles, vocabularies, interests, methods, and incentives. The effectiveness of communications and deliberative processes among scientists and practitioners requires empirical evaluation (*8*).

To support the wide range of necessary adjustments, we outline a comprehensive, integrated approach to research in social, physical, environmental, engineering, and other sciences. We describe adaptation science research needed to understand decision processes and information requirements, identify vulnerabilities, improve foresight about climate risks and other stressors, and understand barriers and options for adaptation.

Understand Decision Processes and Knowledge Requirements

Adaptation science research must clarify what types of scientific information are required for improved decision-making. Decision-makers are concerned with cost, feasibility, social acceptance, tradition, and other factors. To close a "usability gap," scientific information must fit into existing contexts (*9*). Organizational, cognitive, political, ethnographic, and decision sciences research is needed to clarify the problem, the values of participants, and the context in which the information will be applied. Understanding perception and apprehension of climate change risks is also a priority.

Identify Vulnerabilities

Research to characterize vulnerability and adaptive capacity focuses on pinpointing infrastructure, economic sectors, geo-

*Full affiliations for all authors are provided in the supplementary materials. †Corresponding author. E-mail: rhm@pnnl.gov

There is an urgent need for "practice-relevant adaptation science"

Identifying Vulnerabilities

Moss et al., 2013
Published on November 8, 2013 in *Science*

Adaptation Science

There is an urgent need for "practice-relevant adaptation science"

POLICYFORUM

CLIMATE CHANGE

Hell and High Water: Practice-Relevant Adaptation Science

Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options.

R. H. Moss,*† G. A. Meehl, M. C. Lemos, J. B. Smith, J. R. Arnold, J. C. Arnott, D. Behar, G. P. Brasseur, S. B. Broomell, A. J. Busalacchi, S. Dessai, K. L. Ebi, J. A. Edmonds, J. Furlow, L. Goddard, H. C. Hartmann, J. W. Hurrell, J. W. Katzenberger, D. M. Liverman, P. W. Mote, S. C. Moser, A. Kumar, R. S. Pulwarty, E. A. Seyller, B. L. Turner II, W. M. Washington, T. J. Wilbanks

Informing the extensive preparations needed to manage climate risks, avoid damages, and realize emerging opportunities is a grand challenge for climate change science. U.S. President Obama underscored the need for this research when he made climate preparedness a pillar of his climate policy. Adaptation improves preparedness and is one of two broad and increasingly important strategies (along with mitigation) for climate risk management. Adaptation is required in virtually all sectors of the economy and regions of the globe, for both built and natural systems (1).

However, without the appropriate science delivered in a decision-relevant context, it will become increasingly difficult—if not impossible—to prepare adequately (2). We suggest a number of measures to hasten the development of science to correct maladaptations to current climate variability and support society's increasing need to adapt to a changing climate, drawing on lessons from experience, insights from related endeavors such as sustainability science (3), and input from scientific and stakeholder communities.

The entrance to a garage in Lower Manhattan on 31 October, 2012, as New York City began clean-up after Hurricane Sandy.

CREDIT: STAN HONDA/AFP/GETTY IMAGES/NEWSCOM

Adaptation Planning, Information Gaps, and the Need for Adaptation Science

Initial adaptation planning is occurring in some sectors, such as water resource management, forestry, insurance, and coastal zone management. A limited but growing number of states and cities are developing adaptation plans. U.S. federal agencies have implemented sustainability plans that include mitigation and adaptation (4).

There are serious science gaps, however (5, 6). In many communities, decision-makers lack climate information or the means to apply it. In others, knowledge of current or potential future impacts exists, but not in a form or context that decision-makers can assimilate or act on in advance. In still others, engineering innovations are needed, as well as social science knowledge, to guide technology deployment and adjustments to management, investments, and public policy.

A key characteristic of emerging adaptation science is that it is both basic—in that it contributes to understanding fundamental physical, environmental, and socioeconomic research questions—and applied, because it is problem focused. Scientists and practitioners "coproduce" relevant research by jointly defining questions and maintaining frequent interactions (7). Coproduction is challenging to implement and sustain because participants often have different roles, vocabularies, interests, methods, and incentives. The effectiveness of communications and deliberative processes among scientists and practitioners requires empirical evaluation (8).

To support the wide range of necessary adjustments, we outline a comprehensive, integrated approach to research in social, physical, environmental, engineering, and other sciences. We describe adaptation science research needed to understand decision processes and information requirements, identify vulnerabilities, improve foresight about climate risks and other stressors, and understand barriers and options for adaptation.

Understand Decision Processes and Knowledge Requirements

Adaptation science research must clarify what types of scientific information are required for improved decision-making. Decision-makers are concerned with cost, feasibility, social acceptance, tradition, and other factors. To close a "usability gap," scientific information must fit into existing contexts (9). Organizational, cognitive, political, ethnographic, and decision sciences research is needed to clarify the problem, the values of participants, and the context in which the information will be applied. Understanding perception and apprehension of climate change risks is also a priority.

Identify Vulnerabilities

Research to characterize vulnerability and adaptive capacity focuses on pinpointing infrastructure, economic sectors, geo-

*Full affiliations for all authors are provided in the supplementary materials. †Corresponding author. E-mail: rhm@pnnl.gov

Understanding Decision Processes and Knowledge Requirements

Moss et al., 2013
Published on November 8, 2013 in *Science*

Adaptation Science

POLICYFORUM

graphic areas, population groups, and ecosystems at greatest risk of harm (*10*). Two challenges are to:

Improve data, methods, and scenarios for research on vulnerability and resilience of human and natural systems. A georeferenced data system for factors such as population, economic status, preparedness, natural capital, and location of sensitive infrastructure needs to be established and maintained to identify vulnerable human communities and environments. Effective response will be aided by understanding the extent to which vulnerability arises from poverty, under-investment, environmental factors, and their interactions with climate variability and change.

Identify climate thresholds in vulnerable systems. Knowledge of climate and related thresholds, points at which fundamental transformations occur in natural or human systems as climate changes, will improve resource management and inform debates about future atmospheric greenhouse gas stabilization. Coupled with time-dependent climate scenarios, improved knowledge of climate thresholds may help in estimating when effects could occur and thus facilitate setting adaptation priorities.

Adaptation Science in Action

Scientists and practitioners are collaborating on research and applications to support climate change preparedness and address other nonclimate issues. Case examples document research and actions, such as plans and projects, but do not yet provide evidence of improved outcomes. Improved methods and data are needed for evaluating results (*29*).

- Well before Hurricane Sandy, New York City established a task force of city officials, utilities, commercial firms, and researchers to support formulation of adaptation options for vital infrastructure.
- Major urban water utilities, university-based research centers, and private-sector firms in the United States are collaborating to pilot applications of climate science and water utility modeling applications to quantify impacts of climate change on their water systems and evaluate adaptation strategies.
- Researchers in Australia developed a plant functional trait database and modeled habitat suitability under climate scenarios for naturalized and invasive plants to enable land managers to make better-informed decisions about land management at a national and regional level.

- Researchers and local practitioners in the Vietnamese city of Hue and the Bangladeshi city of Satkhira collaborated to assess climate-related risks, identify adaptation strategies, and strengthen local capacity to manage the interaction of rapid development and climate impacts.
- Researchers worked with small-scale farmers and agricultural extension officials in sub-Saharan Africa to provide a bridge between scientific and indigenous knowledge of drought onset and coping strategies to improve delivery of drought prediction information for vulnerable, rain-fed farming operations.

Improve Foresight About Climate Hazards and Other Stressors

Physical and biological scientists must study climate processes and develop models to deliver insights about climate features, including temperature and precipitation extremes, and related processes such as evolution of ecosystems, sea level rise, and other first-order effects. Social sciences can characterize human contributions to climate change through emissions and land use and inform mechanisms for improving interactions between climate scientists and potential users (*11*). Research challenges include:

Understand recent and potential future changes in extreme climate events. Extremes occur on many spatial and time scales. They include heat waves, droughts, floods, storms, and other events that have major effects on human and natural systems. There is evidence that many of these extremes are intensifying (*1*, *12*). A concerted focus on detecting changes in extremes and improving predictive products can provide important inputs to adaptation planning and preparedness.

Improve integration of weather and climate information. Common elements of initializing predictions with observations and providing probabilistic weather and climate information across time scales can constitute a unified approach for weather forecasts and climate predictions (*13*, *14*). Decadal climate predictions with next-generation, high-resolution global climate models [e.g., (*15*)] have the potential to produce probabilistic near-term climate information over the next decade and improve insight into future conditions to which human societies will have to adapt (*16*). Research is needed to formulate methods for presenting global climate model information in probabilistic form and applying that information to risk assessment and management (*17*).

Tailor climate information to facilitate its application in decision-making. Sustained interactions among researchers and decision-makers are needed not only to understand how climate affects assets or resources but also to identify how climate information can be used in decisions (*18*). In addition to global climate models, other tools can produce relevant information, such as less computationally intensive intermediate-complexity models [e.g., to assess uncertainty (*19*)], qualitative scenario planning approaches (*20*), and decision-analytic approaches to use climate model information in ways that supplement conventional scenario-led studies [e.g., (*17*)]. Climate and decision scientists can tailor information for application through downscaling of climate model data [e.g., (*21*)] or running fully dynamical nested numerical models at regional or finer grid spacings [e.g., the North American Regional Climate Change Assessment Program (*22*)].

Establish climate information services at the national and international level to translate and communicate adaptation science to public and private sector decision-makers. The Global Framework for Climate Services (*23*) provides a foundation for climate services being developed in many countries. Development of climate services should engage decision-makers, researchers, and others to ensure that products are relevant, uncertainties are explicit, and a portfolio of products that combine monitoring and projections are useable to decision-makers. The U.S. National Academy of Sciences has emphasized the need for climate services (*24*), and the U.S. Global Change Research Program (USGCRP) has made climate adaptation science that would use climate information a focus of its 10-year plan (*25*). Current funding levels are inadequate and declining, and incentives and means to engage with stakeholders are lacking, inhibiting service development and delivery (*5*, *26*).

Identify Barriers, Broaden the Range of Adaptation Options, and Promote Learning

Options need to be studied to guide adjustments in technology, management practices, public policy, standards, institutions, gover-

PHOTO CREDIT: HCONGTHANH/ISTOCKPHOTO

There is an urgent need for "practice-relevant adaptation science"

Moss et al., 2013
Published on November 8, 2013 in *Science*

Adaptation Science

POLICYFORUM

graphic areas, population groups, and ecosystems at greatest risk of harm (*10*). Two challenges are to:

Improve data, methods, and scenarios for research on vulnerability and resilience of human and natural systems. A geo-referenced data system for factors such as population, economic status, preparedness, natural capital, and location of sensitive infrastructure needs to be established and maintained to identify vulnerable human communities and environments. Effective response will be aided by understanding the extent to which vulnerability arises from poverty, under-investment, environmental factors, and their interactions with climate variability and change.

Identify climate thresholds in vulnerable systems. Knowledge of climate and related thresholds, points at which fundamental transformations occur in natural or human systems as climate changes, will improve resource management and inform debates about future atmospheric greenhouse gas stabilization. Coupled with time-dependent climate scenarios, improved knowledge of climate thresholds may help in estimating when effects could occur and thus facilitate setting adaptation priorities.

Adaptation Science in Action

Scientists and practitioners are collaborating on research and applications to support climate change preparedness and address other nonclimate issues. Case examples document research and actions, such as plans and projects, but do not yet provide evidence of improved outcomes. Improved methods and data are needed for evaluating results (*29*).

- Well before Hurricane Sandy, New York City established a task force of city officials, utilities, commercial firms, and researchers to support formulation of adaptation options for vital infrastructure.
- Major urban water utilities, university-based research centers, and private-sector firms in the United States are collaborating to pilot applications of climate science and water utility modeling applications to quantify impacts of climate change on their water systems and evaluate adaptation strategies.
- Researchers in Australia developed a plant functional trait database and modeled habitat suitability under climate scenarios for naturalized and invasive plants to enable land managers to make better-informed decisions about land management at a national and regional level.

- Researchers and local practitioners in the Vietnamese city of Hue and the Bangladeshi city of Satkhira collaborated to assess climate-related risks, identify adaptation strategies, and strengthen local capacity to manage the interaction of rapid development and climate impacts.
- Researchers worked with small-scale farmers and agricultural [illegible] sub-Saharan Africa to provide a bridge between scientific and indigenous [illegible] onset and coping strategies to improve delivery of drought prediction information [illegible], rain-fed farming operations.

PHOTO CREDIT: HCONGTHANH/ISTOCKPHOTO

Improve Foresight About Climate Hazards and Other Stressors

Physical and biological scientists must study climate processes and develop models to deliver insights about climate features, including temperature and precipitation extremes, and related processes such as evolution of ecosystems, sea level rise, and other first-order effects. Social sciences can characterize human contributions to climate change through emissions and land use and inform mechanisms for improving interactions between climate scientists and potential users (*11*). Research challenges include:

Understand recent and potential future changes in extreme climate events. Extremes occur on many spatial and time scales. They include heat waves, droughts, floods, storms, and other events that have major effects on human and natural systems. There is evidence that many of these extremes are intensifying (*1*, *12*). A concerted focus on detecting changes in extremes and improving predictive products can provide important inputs to adaptation planning and preparedness.

Improve integration of weather and climate information. Common elements of initializing predictions with observations and providing probabilistic weather and climate information across time scales can constitute a unified approach for weather forecasts and climate predictions (*13*, *14*). Decadal climate predictions with next-generation, high-resolution global climate models [e.g., (*15*)] have the potential to produce probabilistic near-term climate information over the next decade and improve insight into future conditions to which human societies will have to adapt (*16*). Research is needed to formulate methods for presenting global climate model information in probabilistic form and applying that information to risk assessment and management (*17*).

Tailor climate information to facilitate its application in decision-making. Sustained interactions among researchers and decision-makers are needed not only to understand how climate affects assets or resources but also to identify how climate information can be used in decisions (*18*). In addition to global climate models, other tools can produce relevant information, such as less computationally intensive intermediate-complexity models [e.g., to assess uncertainty (*19*)], qualitative scenario planning approaches (*20*), and decision-analytic approaches to use climate model information in ways that supplement conventional scenario-led studies [e.g., (*17*)]. Climate and decision scientists can tailor information for application through downscaling of climate model data [e.g., (*21*)] or running fully dynamical nested numerical models at regional or finer grid spacings [e.g., the North American Regional Climate Change Assessment Program (*22*)].

Establish climate information services at the national and international level to translate and communicate adaptation science to public and private sector decision-makers. The Global Framework for Climate Services (*23*) provides a foundation for climate services being developed in many countries. Development of climate services should engage decision-makers, researchers, and others to ensure that products are relevant, uncertainties are explicit, and a portfolio of products that combine monitoring and projections are useable to decision-makers. The U.S. National Academy of Sciences has emphasized the need for climate services (*24*), and the U.S. Global Change Research Program (USGCRP) has made climate adaptation science that would use climate information a focus of its 10-year plan (*25*). Current funding levels are inadequate and declining, and incentives and means to engage with stakeholders are lacking, inhibiting service development and delivery (*5*, *26*).

Identify Barriers, Broaden the Range of Adaptation Options, and Promote Learning

Options need to be studied to guide adjustments in technology, management practices, public policy, standards, institutions, gover-

There is an urgent need for "practice-relevant adaptation science"

Improve Forsight About Climate Hazards and Other Stressors

Moss et al., 2013
Published on November 8, 2013 in *Science*

Adaptation Science

POLICYFORUM

graphic areas, population groups, and ecosystems at greatest risk of harm (*10*). Two challenges are to:

Improve data, methods, and scenarios for research on vulnerability and resilience of human and natural systems. A geo-referenced data system for factors such as population, economic status, preparedness, natural capital, and location of sensitive infrastructure needs to be established and maintained to identify vulnerable human communities and environments. Effective response will be aided by understanding the extent to which vulnerability arises from poverty, under-investment, environmental factors, and their interactions with climate variability and change.

Identify climate thresholds in vulnerable systems. Knowledge of climate and related thresholds, points at which fundamental transformations occur in natural or human systems as climate changes, will improve resource management and inform debates about future atmospheric greenhouse gas stabilization. Coupled with time-dependent climate scenarios, improved knowledge of climate thresholds may help in estimating when effects could occur and thus facilitate setting adaptation priorities.

Adaptation Science in Action

Scientists and practitioners are collaborating on research and applications to support climate change preparedness and address other nonclimate issues. Case examples document research and actions, such as plans and projects, but do not yet provide evidence of improved outcomes. Improved methods and data are needed for evaluating results (*29*).

- Well before Hurricane Sandy, New York City established a task force of city officials, utilities, commercial firms, and researchers to support formulation of adaptation options for vital infrastructure.
- Major urban water utilities, university-based research centers, and private-sector firms in the United States are collaborating to pilot applications of climate science and water utility modeling applications to quantify impacts of climate change on their water systems and evaluate adaptation strategies.
- Researchers in Australia developed a plant functional trait database and modeled habitat suitability under climate scenarios for naturalized and invasive plants to enable land managers to make better-informed decisions about land management at a national and regional level.

- Researchers and local practitioners in the Vietnamese city of Hue and the Bangladeshi city of Satkhira collaborated to assess climate-related risks, identify adaptation strategies, and strengthen local capacity to manage the interaction of rapid development and climate impacts.
- Researchers worked with small-scale farmers and agricultural extension officials in sub-Saharan Africa to provide a bridge between scientific and indigenous knowledge of drought onset and coping strategies to improve delivery of drought prediction information for vulnerable, rain-fed farming operations.

Improve Foresight About Climate Hazards and Other Stressors

Physical and biological scientists must study climate processes and develop models to deliver insights about climate features, including temperature and precipitation extremes, and related processes such as evolution of ecosystems, sea level rise, and other first-order effects. Social sciences can characterize human contributions to climate change through emissions and land use and inform mechanisms for improving interactions between climate scientists and potential users (*11*). Research challenges include:

Understand recent and potential future changes in extreme climate events. Extremes occur on many spatial and time scales. They include heat waves, droughts, floods, storms, and other events that have major effects on human and natural systems. There is evidence that many of these extremes are intensifying (*1*, *12*). A concerted focus on detecting changes in extremes and improving predictive products can provide important inputs to adaptation planning and preparedness.

Improve integration of weather and climate information. Common elements of initializing predictions with observations and providing probabilistic weather and climate information across time scales can constitute a unified approach for weather forecasts and climate predictions (*13*, *14*). Decadal climate predictions with next-generation, high-resolution global climate models [e.g., (*15*)] have the potential to produce probabilistic near-term climate information over the next decade and improve insight into future conditions to which human societies will have to adapt (*16*). Research is needed to formulate methods for presenting global climate model information in probabilistic form and applying that information to risk assessment and management (*17*).

Tailor climate information to facilitate its application in decision-making. Sustained interactions among researchers and decision-makers are needed not only to understand how climate affects assets or resources but also to identify how climate information can be used in decisions (*18*). In addition to global climate models, other tools can produce relevant information, such as less computationally intensive intermediate-complexity models [e.g., to assess uncertainty (*19*)], qualitative scenario planning approaches (*20*), and decision-analytic approaches to use climate model information in ways that supplement conventional scenario-led studies [e.g., (*17*)]. Climate and decision scientists can tailor information for application through downscaling of climate model data [e.g., (*21*)] or running fully dynamical nested numerical models at regional or finer grid spacings [e.g., the North American Regional Climate Change Assessment Program (*22*)].

Establish climate information services at the national and international level to translate and communicate adaptation science to public and private sector decision-makers. The Global Framework for Climate Services (*23*) provides a foundation for climate services being developed in many countries. Development of climate services should engage decision-makers, researchers, and others to ensure that products are relevant, uncertainties are explicit, and a portfolio of products that combine monitoring and projections are useable to decision-makers. The U.S. National Academy of Sciences has emphasized the need for climate services (*24*), and the U.S. Global Change Research Program (USGCRP) has made climate adaptation science that would use climate information a focus of its 10-year plan (*25*). Current funding levels are inadequate and declining, and incentives and means to engage with stakeholders are lacking, inhibiting service development and delivery (*5*, *26*).

Identify Barriers, Broaden the Range of Adaptation Options, and Promote Learning

Options need to be studied to guide adjustments in technology, management practices, public policy, standards, institutions, gover-

PHOTO CREDIT: HCONGTHANH/ISTOCKPHOTO

There is an urgent need for "practice-relevant adaptation science"

Identify Barriers, Broaden the Range of Adaptation Options, and Promote Learning

Moss et al., 2013

Published on November 8, 2013 in *Science*

Adaptation Science

There is an urgent need for “practice-relevant adaptation science”

POLICYFORUM

graphic areas, population groups, and ecosystems at greatest risk of harm (*10*). Two challenges are to:

Improve data, methods, and scenarios for research on vulnerability and resilience of human and natural systems. A geo-referenced data system for factors such as population, economic status, preparedness, natural capital, and location of sensitive infrastructure needs to be established and maintained to identify vulnerable human communities and environments. Effective response will be aided by understanding the extent to which vulnerability arises from poverty, under-investment, environmental factors, and their interactions with climate variability and change.

Identify climate thresholds in vulnerable systems. Knowledge of climate and related thresholds, points at which fundamental transformations occur in natural or human systems as climate changes, will improve resource management and inform debates about future atmospheric greenhouse gas stabilization. Coupled with time-dependent climate scenarios, improved knowledge of climate thresholds may help in estimating when effects could occur and thus facilitate setting adaptation priorities.

Adaptation Science in Action

Scientists and practitioners are collaborating on research and applications to support climate change preparedness and address other nonclimate issues. Case examples document research and actions, such as plans and projects, but do not yet provide evidence of improved outcomes. Improved methods and data are needed for evaluating results (*29*).

- Well before Hurricane Sandy, New York City established a task force of city officials, utilities, commercial firms, and researchers to support formulation of adaptation options for vital infrastructure.
- Major urban water utilities, university-based research centers, and private-sector firms in the United States are collaborating to pilot applications of climate science and water utility modeling applications to quantify impacts of climate change on their water systems and evaluate adaptation strategies.
- Researchers in Australia developed a plant functional trait database and modeled habitat suitability under climate scenarios for naturalized and invasive plants to enable land managers to make better-informed decisions about land management at a national and regional level.
- Researchers and local practitioners in the Vietnamese city of Hue and the Bangladeshi city of Satkhira collaborated to assess climate-related risks, identify adaptation strategies, and strengthen local capacity to manage the interaction of rapid development and climate impacts.

- Researchers worked with small-scale farmers and agricultural extension officials in sub-Saharan Africa to provide a bridge between scientific and indigenous knowledge of drought onset and coping strategies to improve delivery of drought prediction information for vulnerable, rain-fed farming operations.

Improve Foresight About Climate Hazards and Other Stressors

Physical and biological scientists must study climate processes and develop models to deliver insights about climate features, including temperature and precipitation extremes, and related processes such as evolution of ecosystems, sea level rise, and other first-order effects. Social sciences can characterize human contributions to climate change through emissions and land use and inform mechanisms for improving interactions between climate scientists and potential users (*11*). Research challenges include:

Understand recent and potential future changes in extreme climate events. Extremes occur on many spatial and time scales. They include heat waves, droughts, floods, storms, and other events that have major effects on human and natural systems. There is evidence that many of these extremes are intensifying (*1*, *12*). A concerted focus on detecting changes in extremes and improving predictive products can provide important inputs to adaptation planning and preparedness.

Improve integration of weather and climate information. Common elements of initializing predictions with observations and providing probabilistic weather and climate information across time scales can constitute a unified approach for weather forecasts and climate predictions (*13*, *14*). Decadal climate predictions with next-generation, high-resolution global climate models [e.g., (*15*)] have the potential to produce probabilistic near-term climate information over the next decade and improve insight into future conditions to which human societies will have to adapt (*16*). Research is needed to formulate methods for presenting global climate model information in probabilistic form and applying that information to risk assessment and management (*17*).

Tailor climate information to facilitate its application in decision-making. Sustained interactions among researchers and decision-makers are needed not only to understand how climate affects assets or resources but also to identify how climate information can be used in decisions (*18*). In addition to global climate models, other tools can produce relevant information, such as less computationally intensive intermediate-complexity models [e.g., to assess uncertainty (*19*)], qualitative scenario planning approaches (*20*), and decision-analytic approaches to use climate model information in ways that supplement conventional scenario-led studies [e.g., (*17*)]. Climate and decision scientists can tailor information for application through downscaling of climate model data [e.g., (*21*)] or running fully dynamical nested numerical models at regional or finer grid spacings [e.g., the North American Regional Climate Change Assessment Program (*22*)].

Establish climate information services at the national and international level to translate and communicate adaptation science to public and private sector decision-makers. The Global Framework for Climate Services (*23*) provides a foundation for climate services being developed in many countries. Development of climate services should engage decision-makers, researchers, and others to ensure that products are relevant, uncertainties are explicit, and a portfolio of products that combine monitoring and projections are useable to decision-makers. The U.S. National Academy of Sciences has emphasized the need for climate services (*24*), and the U.S. Global Change Research Program (USGCRP) has made climate adaptation science that would use climate information a focus of its 10-year plan (*25*). Current funding levels are inadequate and declining, and incentives and means to engage with stakeholders are lacking, inhibiting service development and delivery (*5*, *26*).

Identify Barriers, Broaden the Range of Adaptation Options, and Promote Learning

Options need to be studied to guide adjustments in technology, management practices, public policy, standards, institutions, gover-

PHOTO CREDIT: HCONGTHANH/ISTOCKPHOTO

Moss et al., 2013
Published on November 8, 2013 in *Science*

Adaptation Science

There is an urgent need for “practice-relevant adaptation science”

POLICYFORUM

nance, and incentives to facilitate adaptation. Four priorities are to:

Identify, explain, and explore opportunities to overcome barriers to adaptation. Existing laws, regulations, and other practices can limit adaptation. These include legal and financial mechanisms, from local to international jurisdictions. Research is needed to identify these barriers and develop solutions to minimize or surmount them.

Develop technologies and performance standards. A changed climate system with conditions never before experienced by human societies may alter effectiveness of historically successful adaptation approaches and limit types of adaptation (*27*). Adaptation options are needed that are robust to different climate and socioeconomic development pathways, and are thus effective in both the short-term and the long-term (e.g., improved water distribution or desalination systems, and advances in electricity generation, transmission, and distribution). Organizations and processes for establishing manufacturing, building, and other standards (e.g., the International Organization for Standardization) could contribute to the development of adaptation options.

Develop indicators and monitoring and evaluation systems. Monitoring and evaluation will help track progress in enhancing resilience, prioritizing adaptation funding, and evaluating effectiveness of adaptation options. For adaptation options related to infrastructure and some natural resources, relevant indicators are relatively easy to quantify. For measures focused on governance or livelihoods, indirect proxy variables must be defined. Case studies dominate adaptation evaluations, with little comparative research on implementation (*28*).

Learn from experience. A number of knowledge platforms are beginning to catalog and evaluate experiences to promote information exchange and learning. Learning and disseminating of lessons needs to be accelerated to improve decision-making. Enabling private companies to share experiences without damaging commercial interests is a particular challenge.

Measures to Establish Adaptation Science

First steps in establishing institutions to conduct and support adaptation science are taking place. In the United States, “mission” agencies—including the Environmental Protection Agency, the National Oceanic and Atmospheric Administration (NOAA), and the Department of the Interior—have supported the use of scientific information in adaptation. The Regional Integrated Sciences and Assessments Program, Climate Science Centers, and other efforts aim at developing a collaborative framework between research and practice (*29*). The European Union has provided research funding and launched an information portal (www.eea.europa.eu/themes/climate/european-climate-adaptation-platform-climate-adapt). Germany, the United Kingdom, and other countries are moving forward to establish services (e.g., www.climate-service-center.de). Australia has made adaptation a priority (www.csiro.au/Outcomes/Climate/Adapting.aspx).

Advances in adaptation science will not happen without two transformational changes: (i) an institutional structure to catalyze, coordinate, evaluate, and encourage the use of advances in adaptation science; and (ii) an increase in funding. National Research Council reports [e.g., (*6*)] and recommendations of a U.S. federal interagency committee (*30*) provide detailed recommendations that would help advance climate adaptation science.

One U.S. approach could be a national institute on climate preparedness composed of research and applications centers for adaptation in priority sectors or challenges. The institute would be geographically distributed and function in some ways similar to the National Institutes of Health. It would build on the current USGCRP, agency sectoral or regional research centers, and regional nodes for the National Climate Assessment’s sustained assessment process. Providing sufficient resources for collaboration and learning would facilitate research on coupled systems and offer an opportunity to better connect adaptation science to interagency programs.

More broadly, sustained support for problem-oriented fundamental research on adaptation needs to be increased at research agencies. A particular challenge is to develop effective approaches to learn from adaptation practice as well as published research. Progress toward achieving the goal of adapting to changing climate will require demonstrating tangible benefits for society by connecting research and applications.

References and Notes

1. IPCC, *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, C. B. Field *et al.*, Eds. (Cambridge Univ. Press, Cambridge, UK, and New York, NY, USA, 2012).
2. R. A. Kerr, *Science* 334, 1052 (2011).
3. W. C. Clark, N. M. Dickson, *Proc. Natl. Acad. Sci. U.S.A.* 100, 8059 (2003).
4. R. Bierbaum *et al.*, *Mitig. Adapt. Strategies Glob. Change* 18, 361 (2013).
5. National Research Council, *America’s Climate Choices: Adapting to the Impacts of Climate Change* (National Academies Press, Washington, DC, 2010).
6. National Research Council, *America’s Climate Choices: Advancing the Science of Climate Change* (National Academies Press, Washington, DC, 2010).
7. L. Dilling, M. C. Lemos, *Glob. Environ. Change* 21, 680 (2011).
8. N. Pidgeon, B. Fischhoff, *Nat. Clim. Change* 1, 35 (2011).
9. M. C. Lemos, C. J. Kirchhoff, V. Ramprasad, *Nat. Clim. Change* 2, 789 (2012).
10. P. C. Stern *et al.*, *Nat. Clim. Change* 3, 607 (2013).
11. National Research Council, *America’s Climate Choices: Informing an Effective Response to Climate Change* (National Academies Press, Washington, DC, 2010).
12. F. W. Zwiers *et al.*, in *Climate Science for Serving Society*, G. R. Asrar, J. W. Hurrell, Eds. (Springer, Dordrecht, NL, 2013), pp. 339–389.
13. T. N. Palmer, F. J. Doblas-Reyes, A. Weisheimer, M. J. Rodwell, *Bull. Am. Meteorol. Soc.* 89, 459 (2008).
14. J. Hurrell *et al.*, *Bull. Am. Meteorol. Soc.* 90, 1819 (2009).
15. D. M. Smith *et al.*, *Clim. Dyn.* (2012). 10.1007/s00382-012-1600-0
16. G. A. Meehl *et al.*, *Bull. Am. Meteorol. Soc.* (2013). 10.1175/BAMS-D-12-00241.1
17. C. Brown, W. Werick, W. Leger, D. Fay, *J. Am. Water Resour. Assoc.* 47, 524 (2011).
18. S. Tang, S. Dessai, *Weather Clim. Soc.* 4, 300 (2012).
19. F. Kucharski *et al.*, *Bull. Am. Meteorol. Soc.* 94, 25 (2013).
20. E. L. Tompkins, R. Few, K. Brown, *J. Environ. Manage.* 88, 1580 (2008).
21. R. L. Wilby, H. J. Fowler, in *Modelling the Impact of Climate Change on Water Resources*, 1st ed., F. Fung, A. Lopez, M. New, Eds. (Blackwell Publishing Ltd., Chichester, West Sussex, 2011), pp. 34–85.
22. L. O. Mearns *et al.*, *Bull. Am. Meteorol. Soc.* 93, 1337 (2012).
23. C. Hewitt *et al.*, *Nat. Clim. Change* 2, 831 (2012).
24. National Research Council, *A National Strategy for Advancing Climate Modeling* (National Academies Press, Washington, DC, 2012).
25. USGCRP, National Global Change Research Plan 2012-2021: A Strategic Plan for the U.S. Global Change Research Program. (2012). Available at: http://library.globalchange.gov/u-s-global-change-research-program-strategic-plan-2012-2021
26. National Research Council, *Informing Decisions in a Changing Climate* (National Academies Press, Washington, DC, 2009).
27. K. Dow *et al.*, *Nat. Clim. Change* 3, 305 (2013).
28. S. C. Moser, M. Boykoff, Eds., *Successful Adaptation to Climate Change: Linking Science and Practice in a Rapidly Changing World.* (Routledge, London, 2013).
29. R. S. Pulwarty *et al.*, in *Integrated Regional Assessment of Global Climate Change*, C. G. Knight, J. Jager, Eds. (Cambridge Univ. Press, Cambridge, UK, 2009), pp. 367–393.
30. Council on Environmental Quality (CEQ), Progress Report of the Interagency Adaptation Task Force: Recommended Action in Support of a National Climate Change Adaptation Strategy (White House Council on Environmental Quality, Washington, DC, 2010).

Acknowledgments: The authors acknowledge the Aspen Global Change Institute (AGCI) and its director, John Katzenberger, for hosting a workshop that laid the foundations for this paper, along with the attendees who contributed to discussions. A portion of this research was supported by the Office of Science, Biological and Environmental Research, U.S. Department of Energy. Funding for the AGCI workshop was provided by NASA. The views expressed in this article are those of the authors and do not necessarily reflect the positions of their institutions.

Supplementary Materials

www.sciencemag.org/content/342/6159/696/suppl/DC1

10.1126/science.1239569

Moss et al., 2013
Published on November 8, 2013 in *Science*

POLICYFORUM

nance, and incentives to facilitate adaptation. Four priorities are to:

Identify, explain, and explore opportunities to overcome barriers to adaptation. Existing laws, regulations, and other practices can limit adaptation. These include legal and financial mechanisms, from local to international jurisdictions. Research is needed to identify these barriers and develop solutions to minimize or surmount them.

Develop technologies and performance standards. A changed climate system with conditions never before experienced by human societies may alter effectiveness of historically successful adaptation approaches and limit types of adaptation (*27*). Adaptation options are needed that are robust to different climate and socioeconomic development pathways, and are thus effective in both the short-term and the long-term (e.g., improved water distribution or desalination systems, and advances in electricity generation, transmission, and distribution). Organizations and processes for establishing manufacturing, building, and other standards (e.g., the International Organization for Standardization) could contribute to the development of adaptation options.

Develop indicators and monitoring and evaluation systems. Monitoring and evaluation will help track progress in enhancing resilience, prioritizing adaptation funding, and evaluating effectiveness of adaptation options. For adaptation options related to infrastructure and some natural resources, relevant indicators are relatively easy to quantify. For measures focused on governance or livelihoods, indirect proxy variables must be defined. Case studies dominate adaptation evaluations, with little comparative research on implementation (*28*).

Learn from experience. A number of knowledge platforms are beginning to catalog and evaluate experiences to promote information exchange and learning. Learning and disseminating of lessons needs to be accelerated to improve decision-making. Enabling private companies to share experiences without damaging commercial interests is a particular challenge.

Measures to Establish Adaptation Science

First steps in establishing institutions to conduct and support adaptation science are taking place. In the United States, "mission" agencies—including the Environmental Protection Agency, the National Oceanic and Atmospheric Administration (NOAA), and the Department of the Interior—have supported the use of scientific information in adaptation. The Regional Integrated Sciences and Assessments Program, Climate Science Centers, and other efforts aim at developing a collaborative framework between research and practice (*29*). The European Union has provided research funding and launched an information portal (www.eea.europa.eu/themes/climate/european-climate-adaptation-platform-climate-adapt). Germany, the United Kingdom, and other countries are moving forward to establish services (e.g., www.climate-service-center.de). Australia has made adaptation a priority (www.csiro.au/Outcomes/Climate/Adapting.aspx).

Advances in adaptation science will not happen without two transformational changes: (i) an institutional structure to catalyze, coordinate, evaluate, and encourage the use of advances in adaptation science; and (ii) an increase in funding. National Research Council reports [e.g., (*6*)] and recommendations of a U.S. federal interagency committee (*30*) provide detailed recommendations that would help advance climate adaptation science.

One U.S. approach could be a national institute on climate preparedness composed of research and applications centers for adaptation in priority sectors or challenges. The institute would be geographically distributed and function in some ways similar to the National Institutes of Health. It would build on the current USGCRP, agency sectoral or regional research centers, and regional nodes for the National Climate Assessment's sustained assessment process. Providing sufficient resources for collaboration and learning would facilitate research on coupled systems and offer an opportunity to better connect adaptation science to interagency programs.

More broadly, sustained support for problem-oriented fundamental research on adaptation needs to be increased at research agencies. A particular challenge is to develop effective approaches to learn from adaptation practice as well as published research. Progress toward achieving the goal of adapting to changing climate will require demonstrating tangible benefits for society by connecting research and applications.

References and Notes

1. IPCC, *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, C. B. Field *et al.*, Eds. (Cambridge Univ. Press, Cambridge, UK and New York, NY, USA, 2012).
2. R. A. Kerr, *Science* 334, 1052 (2011).
3. W. C. Clark, N. M. Dickson, *Proc. Natl. Acad. Sci. U.S.A.* 100, 8059 (2003).
4. R. Bierbaum *et al.*, *Mitig. Adapt. Strategies Glob. Change* 18, 361 (2013).
5. National Research Council, *America's Climate Choices: Adapting to the Impacts of Climate Change* (National Academies Press, Washington, DC, 2010).
6. National Research Council, *America's Climate Choices: Advancing the Science of Climate Change* (National Academies Press, Washington, DC, 2010).
7. L. Dilling, M. C. Lemos, *Glob. Environ. Change* 21, 680 (2011).
8. N. Pidgeon, B. Fischhoff, *Nat. Clim. Change* 1, 35 (2011).
9. M. C. Lemos, C. J. Kirchhoff, V. Ramprasad, *Nat. Clim. Change* 2, 789 (2012).
10. P. C. Stern *et al.*, *Nat. Clim. Change* 3, 607 (2013).
11. National Research Council, *America's Climate Choices: Informing an Effective Response to Climate Change* (National Academies Press, Washington, DC, 2010).
12. F. W. Zwiers *et al.*, in *Climate Science for Serving Society*, G. R. Asrar, J. W. Hurrell, Eds. (Springer, Dordrecht, NL, 2013), pp. 339–389.
13. T. N. Palmer, F. J. Doblas-Reyes, A. Weisheimer, M. J. Rodwell, *Bull. Am. Meteorol. Soc.* 89, 459 (2008).
14. J. Hurrell *et al.*, *Bull. Am. Meteorol. Soc.* 90, 1819 (2009).
15. D. M. Smith *et al.*, *Clim. Dyn.* (2012). 10.1007/s00382-012-1600-0
16. G. A. Meehl *et al.*, *Bull. Am. Meteorol. Soc.* (2013). 10.1175/BAMS-D-12-00241.1
17. C. Brown, W. Werick, W. Leger, D. Fay, *J. Am. Water Resour. Assoc.* 47, 524 (2011).
18. S. Tang, S. Dessai, *Weather Clim. Soc.* 4, 300 (2012).
19. F. Kucharski *et al.*, *Bull. Am. Meteorol. Soc.* 94, [illegible] (2013).
20. [illegible] K. Brown, *J. Environ. Manage.* 88, 1580 (2008).
21. R. L. Wilby, H. J. Fowler, in *Modelling the Impact of Climate Change on Water Resources*, 1st ed., F. Fung, A. Lopez, M. New, Eds. (Blackwell Publishing Ltd., Chichester, West Sussex, 2011), pp. 34–85.
22. L. O. Mearns *et al.*, *Bull. Am. Meteorol. Soc.* 93, 1337 (2012).
23. C. Hewitt *et al.*, *Nat. Clim. Change* 2, 831 (2012).
24. National Research Council, *A National Strategy for Advancing Climate Modeling* (National Academies Press, Washington, DC, 2012).
25. USGCRP, National Global Change Research Plan 2012-2021: A Strategic Plan for the U.S. Global Change Research Program. (2012). Available at: http://library.globalchange.gov/u-s-global-change-research-program-strategic-plan-2012-2021
26. National Research Council, *Informing Decisions in a Changing Climate* (National Academies Press, Washington, DC, 2009).
27. K. Dow *et al.*, *Nat. Clim. Change* 3, 305 (2013).
28. S. C. Moser, M. Boykoff, Eds., *Successful Adaptation to Climate Change: Linking Science and Practice in a Rapidly Changing World*. (Routledge, London, 2013).
29. R. S. Pulwarty *et al.*, in *Integrated Regional Assessment of Global Climate Change*, C. G. Knight, J. Jager, Eds. (Cambridge Univ. Press, Cambridge, UK, 2009), pp. 367–393.
30. Council on Environmental Quality (CEQ), Progress Report of the Interagency Adaptation Task Force: Recommended Action in Support of a National Climate Change Adaptation Strategy (White House Council on Environmental Quality, Washington, DC, 2010).

Acknowledgments: The authors acknowledge the Aspen Global Change Institute (AGCI) and its director, John Katzenberger, for hosting a workshop that laid the foundations for this paper, along with the attendees who contributed to discussions. A portion of this research was supported by the Office of Science, Biological and Environmental Research, U.S. Department of Energy. Funding for the AGCI workshop was provided by NASA. The views expressed in this article are those of the authors and do not necessarily reflect the positions of their institutions.

Supplementary Materials
www.sciencemag.org/content/342/6159/696/suppl/DC1

10.1126/science.1239569

There is an urgent need for "practice-relevant adaptation science"

One U.S. approach could be a national institute on climate preparedness composed of research and applications centers for adaptation in priority sectors or challenges. The institute would be geographically distributed and function in some ways similar to the National Institutes of Health.

Moss et al., 2013
Published on November 8, 2013 in *Science*

Adaptation Science

POLICYFORUM

nance, and incentives to facilitate adaptation. Four priorities are to:

Identify, explain, and explore opportunities to overcome barriers to adaptation. Existing laws, regulations, and other practices can limit adaptation. These include legal and financial mechanisms, from local to international jurisdictions. Research is needed to identify these barriers and develop solutions to minimize or surmount them.

Develop technologies and performance standards. A changed climate system with conditions never before experienced by human societies may alter effectiveness of historically successful adaptation approaches and limit types of adaptation (*27*). Adaptation options are needed that are robust to different climate and socioeconomic development pathways, and are thus effective in both the short-term and the long-term (e.g., improved water distribution or desalination systems, and advances in electricity generation, transmission, and distribution). Organizations and processes for establishing manufacturing, building, and other standards (e.g., the International Organization for Standardization) could contribute to the development of adaptation options.

Develop indicators and monitoring and evaluation systems. Monitoring and evaluation will help track progress in enhancing resilience, prioritizing adaptation funding, and evaluating effectiveness of adaptation options. For adaptation options related to infrastructure and some natural resources, relevant indicators are relatively easy to quantify. For measures focused on governance or livelihoods, indirect proxy variables must be defined. Case studies dominate adaptation evaluations, with little comparative research on implementation (*28*).

Learn from experience. A number of knowledge platforms are beginning to catalog and evaluate experiences to promote information exchange and learning. Learning and disseminating of lessons needs to be accelerated to improve decision-making. Enabling private companies to share experiences without damaging commercial interests is a particular challenge.

Measures to Establish Adaptation Science

First steps in establishing institutions to conduct and support adaptation science are taking place. In the United States, "mission" agencies—including the Environmental Protection Agency, the National Oceanic and Atmospheric Administration (NOAA), and the Department of the Interior—have supported the use of scientific information in adaptation. The Regional Integrated Sciences and Assessments Program, Climate Science Centers, and other efforts aim at developing a collaborative framework between research and practice (*29*). The European Union has provided research funding and launched an information portal (www.eea.europa.eu/themes/climate/european-climate-adaptation-platform-climate-adapt). Germany, the United Kingdom, and other countries are moving forward to establish services (e.g., www.climate-service-center.de). Australia has made adaptation a priority (www.csiro.au/Outcomes/Climate/Adapting.aspx).

Advances in adaptation science will not happen without two transformational changes: (i) an institutional structure to catalyze, coordinate, evaluate, and encourage the use of advances in adaptation science; and (ii) an increase in funding. National Research Council reports [e.g., (*6*)] and recommendations of a U.S. federal interagency committee (*30*) provide detailed recommendations that would help advance climate adaptation science.

One U.S. approach could be a national institute on climate preparedness composed of research and applications centers for adaptation in priority sectors or challenges. The institute would be geographically distributed and function in some ways similar to the National Institutes of Health. It would build on the current USGCRP, agency sectoral or regional research centers, and regional nodes for the National Climate Assessment's sustained assessment process. Providing sufficient resources for collaboration and learning would facilitate research on coupled systems and offer an opportunity to better connect adaptation science to interagency programs.

More broadly, sustained support for problem-oriented fundamental research on adaptation needs to be increased at research agencies. A particular challenge is to develop effective approaches to learn from adaptation practice as well as published research. Progress toward achieving the goal of adapting to changing climate will require demonstrating tangible benefits for society by connecting research and applications.

References and Notes

1. IPCC, *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, C. B. Field *et al.*, Eds. (Cambridge Univ. Press, Cambridge, UK, and New York, NY, USA, 2012).
2. R. A. Kerr, *Science* 334, 1052 (2011).
3. W. C. Clark, N. M. Dickson, *Proc. Natl. Acad. Sci. U.S.A.* 100, 8059 (2003).
4. R. Bierbaum *et al.*, *Mitig. Adapt. Strategies Glob. Change* 18, 361 (2013).
5. National Research Council, *America's Climate Choices: Adapting to the Impacts of Climate Change* (National Academies Press, Washington, DC, 2010).
6. National Research Council, *America's Climate Choices: Advancing the Science of Climate Change* (National Academies Press, Washington, DC, 2010).
7. L. Dilling, M. C. Lemos, *Glob. Environ. Change* 21, 680 (2011).
8. N. Pidgeon, B. Fischhoff, *Nat. Clim. Change* 1, 35 (2011).
9. M. C. Lemos, C. J. Kirchhoff, V. Ramprasad, *Nat. Clim. Change* 2, 789 (2012).
10. P. C. Stern *et al.*, *Nat. Clim. Change* 3, 607 (2013).
11. National Research Council, *America's Climate Choices: Informing an Effective Response to Climate Change* (National Academies Press, Washington, DC, 2010).
12. F. W. Zwiers *et al.*, in *Climate Science for Serving Society*, G. R. Asrar, J. W. Hurrell, Eds. (Springer, Dordrecht, NL, 2013), pp. 339–389.
13. T. N. Palmer, F. J. Doblas-Reyes, A. Weisheimer, M. J. Rodwell, *Bull. Am. Meteorol. Soc.* 89, 459 (2008).
14. J. Hurrell *et al.*, *Bull. Am. Meteorol. Soc.* 90, 1819 (2009).
15. D. M. Smith *et al.*, *Clim. Dyn.* (2012). 10.1007/s00382-012-1600-0
16. G. A. Meehl *et al.*, *Bull. Am. Meteorol. Soc.* (2013). 10.1175/BAMS-D-12-00241.1
17. C. Brown, W. Werick, W. Leger, D. Fay, *J. Am. Water Resour. Assoc.* 47, 524 (2011).
18. S. Tang, S. Dessai, *Weather Clim. Soc.* 4, 300 (2012).
19. F. Kucharski *et al.*, *Bull. Am. Meteorol. Soc.* 94, 25 (2013).
20. E. L. Tompkins, R. Few, K. Brown, *J. Environ. Manage.* 88, 1580 (2008).
21. R. L. Wilby, H. J. Fowler, in *Modelling the Impact of Climate Change on Water Resources*, 1st ed., F. Fung, A. Lopez, M. New, Eds. (Blackwell Publishing Ltd., Chichester, West Sussex, 2011), pp. 34–85.
22. L. O. Mearns *et al.*, *Bull. Am. Meteorol. Soc.* 93, 1337 (2012).
23. C. Hewitt *et al.*, *Nat. Clim. Change* 2, 831 (2012).
24. National Research Council, *A National Strategy for Advancing Climate Modeling* (National Academies Press, Washington, DC, 2012).
25. USGCRP, National Global Change Research Plan 2012-2021: A Strategic Plan for the U.S. Global Change Research Program. (2012). Available at: http://library.globalchange.gov/u-s-global-change-research-program-strategic-plan-2012-2021
26. National Research Council, *Informing Decisions in a Changing Climate* (National Academies Press, Washington, DC, 2009).
27. K. Dow *et al.*, *Nat. Clim. Change* 3, 305 (2013).
28. S. C. Moser, M. Boykoff, Eds., *Successful Adaptation to Climate Change: Linking Science and Practice in a Rapidly Changing World*. (Routledge, London, 2013).
29. R. S. Pulwarty *et al.*, in *Integrated Regional Assessment of Global Climate Change*, C. G. Knight, J. Jager, Eds. (Cambridge Univ. Press, Cambridge, UK, 2009), pp. 367–393.
30. Council on Environmental Quality (CEQ), Progress Report of the Interagency Adaptation Task Force: Recommended Action in Support of a National Climate Change Adaptation Strategy (White House Council on Environmental Quality, Washington, DC, 2010).

Acknowledgments: The authors acknowledge the Aspen Global Change Institute (AGCI) and its director, John Katzenberger, for hosting a workshop that laid the foundations for this paper, along with the attendees who contributed to discussions. A portion of this research was supported by the Office of Science, Biological and Environmental Research, U.S. Department of Energy. Funding for the AGCI workshop was provided by NASA. The views expressed in this article are those of the authors and do not necessarily reflect the positions of their institutions.

Supplementary Materials
www.sciencemag.org/content/342/6159/696/suppl/DC1

10.1126/science.1239569

There is an urgent need for "practice-relevant adaptation science"

Moss et al., 2013
Published on November 8, 2013 in *Science*

Adaptation Science

Five Fields:

- Assessing the hazards
- Knowing the vulnerabilities
- Having foresight
- Understanding decision making
- Developing options

Practicalities

Practicalities

- Reading the reading material is important:
  - Questions to be answered are based on the reading material
  - Written answers need to be provided on Tuesdays
  - Answers will be discussed in the Wednesday classes
- Selecting a topic for the student project:
  - Should be done soon.
  - Will be the basis for the paper and the presentation
- Feel free to contact me/us if there are issues/questions
- Communication by e-mail is the best way to reach me
- Some material will be made available on the workspace at http://www.mari-odu.org/academics/2017s_adaptation