Changing Climate
and
Water Resources Management

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Western
UNIVERSITY · CANADA

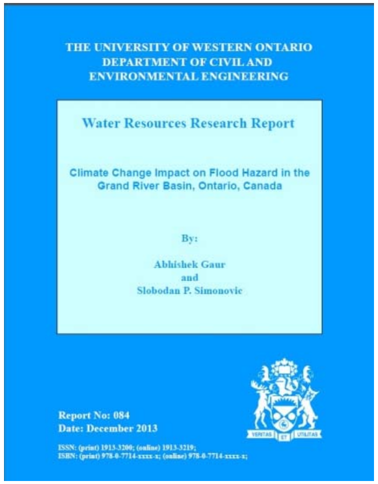
Building Resilient Communities
Pour construire des communautés solides

SLOBODAN P. SIMONOVIC

Introduction

- Computer-based research laboratory
- Research:
  - *Subject Matter* - Systems modeling; Risk and reliability; Water resources and environmental systems analysis; Computer-based decision support systems development.
  - *Topical Area* - Reservoirs; Flood control; Hydropower energy; Operational hydrology; Climatic Change; Integrated water resources management.
- ~ 70 research projects; ~ $7.5 M
- 3 visiting fellows, 11 PosDoc's, 17 PhD's and 36 MESc's
- 2 PosDoc's, 5 PhD's, and 3 MESc's
- Water Resources Research Reports – 84 volumes (~18,000 downloads since 2011)
- Access through my web page

FIDS
CELEBRATING
1989 - 2014


THE UNIVERSITY OF WESTERN ONTARIO
DEPARTMENT OF CIVIL AND
ENVIRONMENTAL ENGINEERING

Water Resources Research Report

Climate Change Impact on Flood Hazard in the Grand River Basin, Ontario, Canada

By:

Abhishek Gaur
and
Slobodan P. Simonovic

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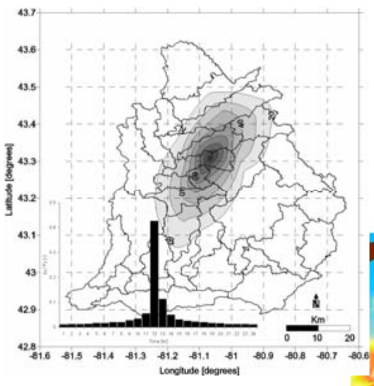
VERITAS ET UTILITAS

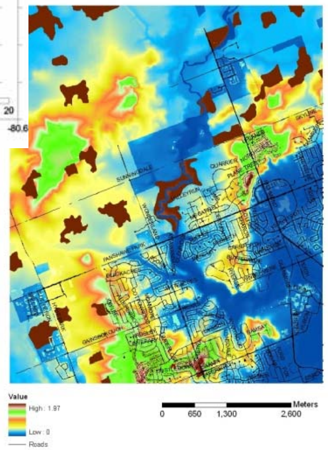
3 | SLOBODAN P. SIMONOVIC
Introduction

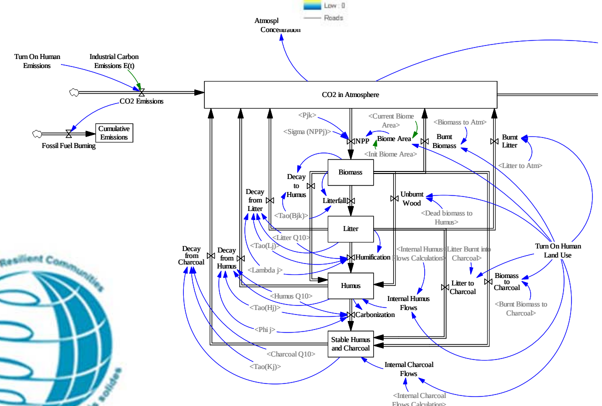
- > 400 professional publications
- 181 in peer reviewed journals
- 3 major textbooks

4 | SLOBODAN P. SIMONOVIC

Current research projects





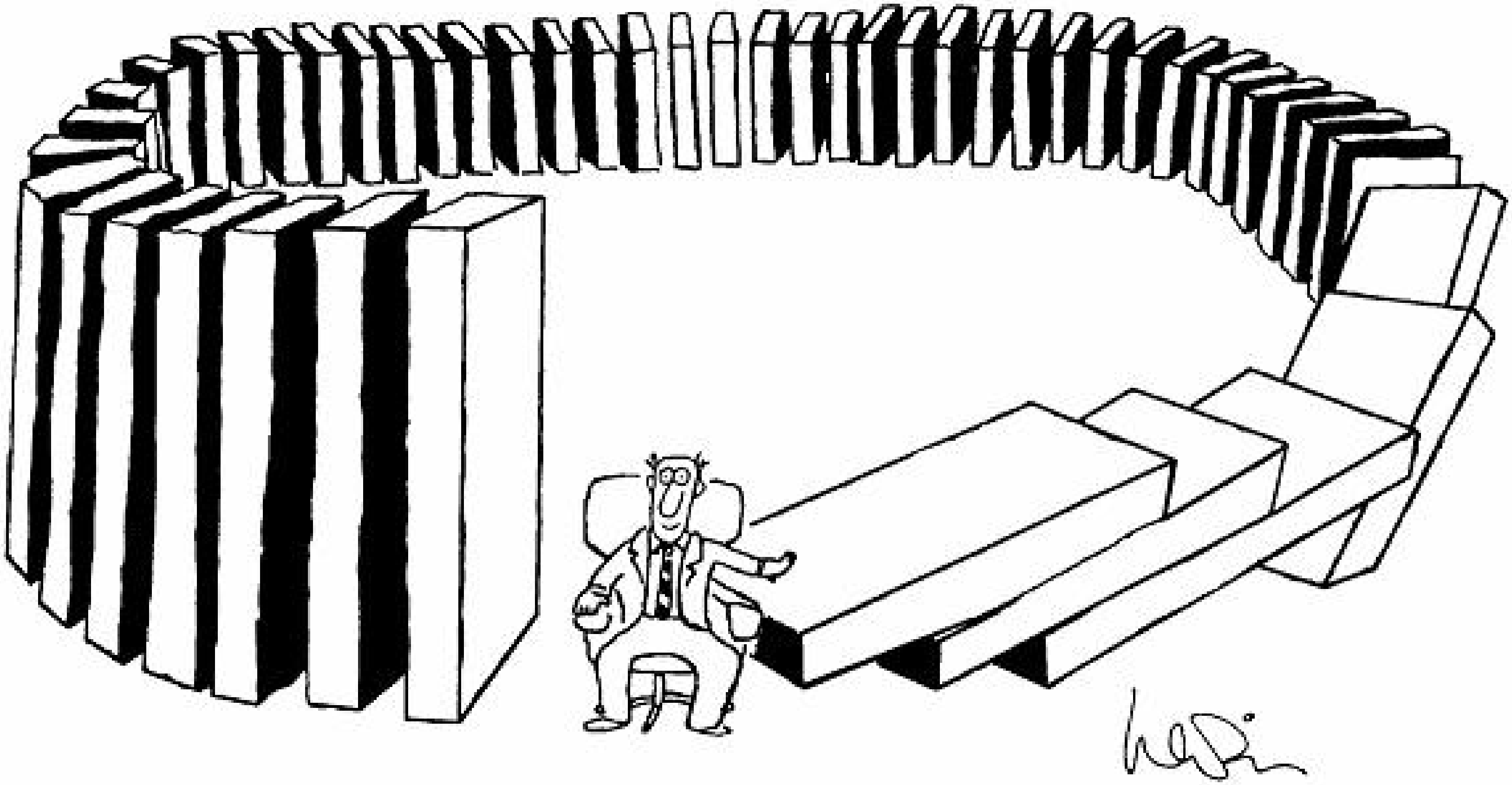


- Decision Support for Integrated Water Resources Management
- Coastal Cities at Risk - Building Adaptive Capacity for Managing Climate Change in Coastal Megacities (spatial and temporal modeling of resilience)
- Extreme Flow Uncertainty Under Changing Climatic Conditions
- Modeling Climate-Water-Food-Energy Nexus
- IDF curves under changing climate
- Simple proxies for risk analysis and natural hazard estimation

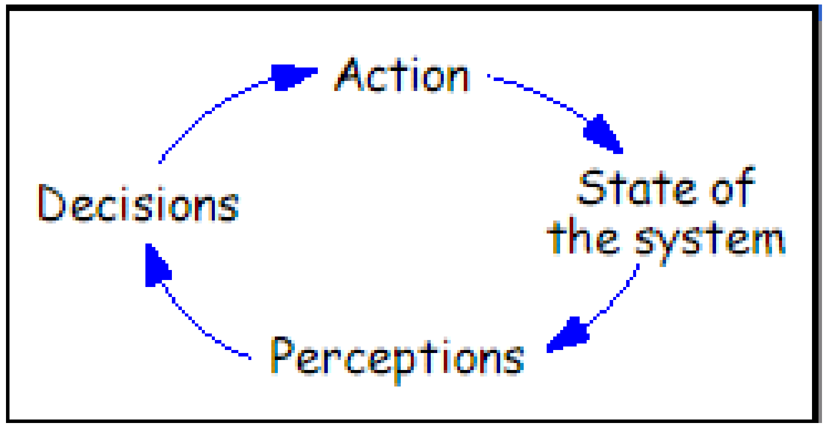
5| MAIN MESSAGES

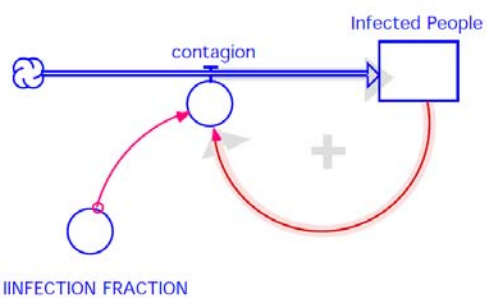
- It is all about feedbacks!
- Climate change is real and more serious than expected
  - Temperature
  - Concentration of GHG
  - Sea ice and glaciers
  - Sea level rise
- Climate change is hydrologic change
- Water management – what are we trying to manage?
- Systems approach – examples
  - Integrated system modeling of the social-economic-climatic system
  - Modeling impacts of climate change on management of water resources on a local scale
- It is all about feedbacks!

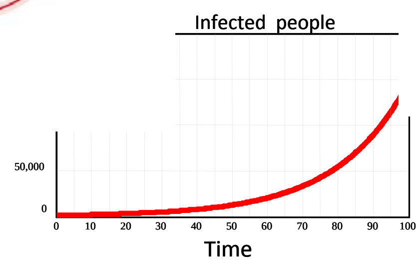
6| FEEDBACK

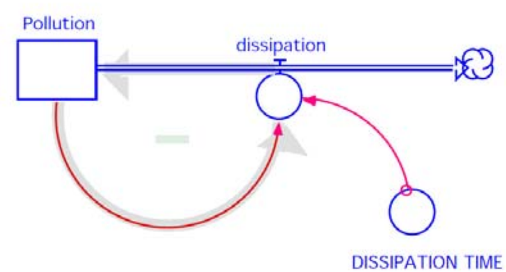


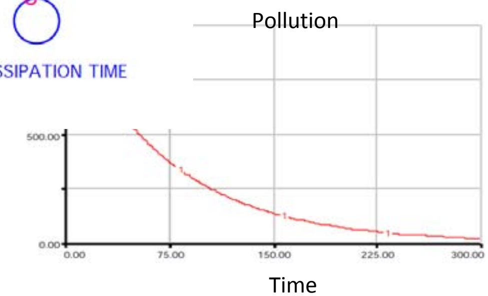
7| FEEDBACK


Action
State of the system
Perceptions
Decisions


Infected People
contagion
+
IINFECTION FRACTION


Infected people
50,000
0
0 10 20 30 40 50 60 70 80 90 100
Time

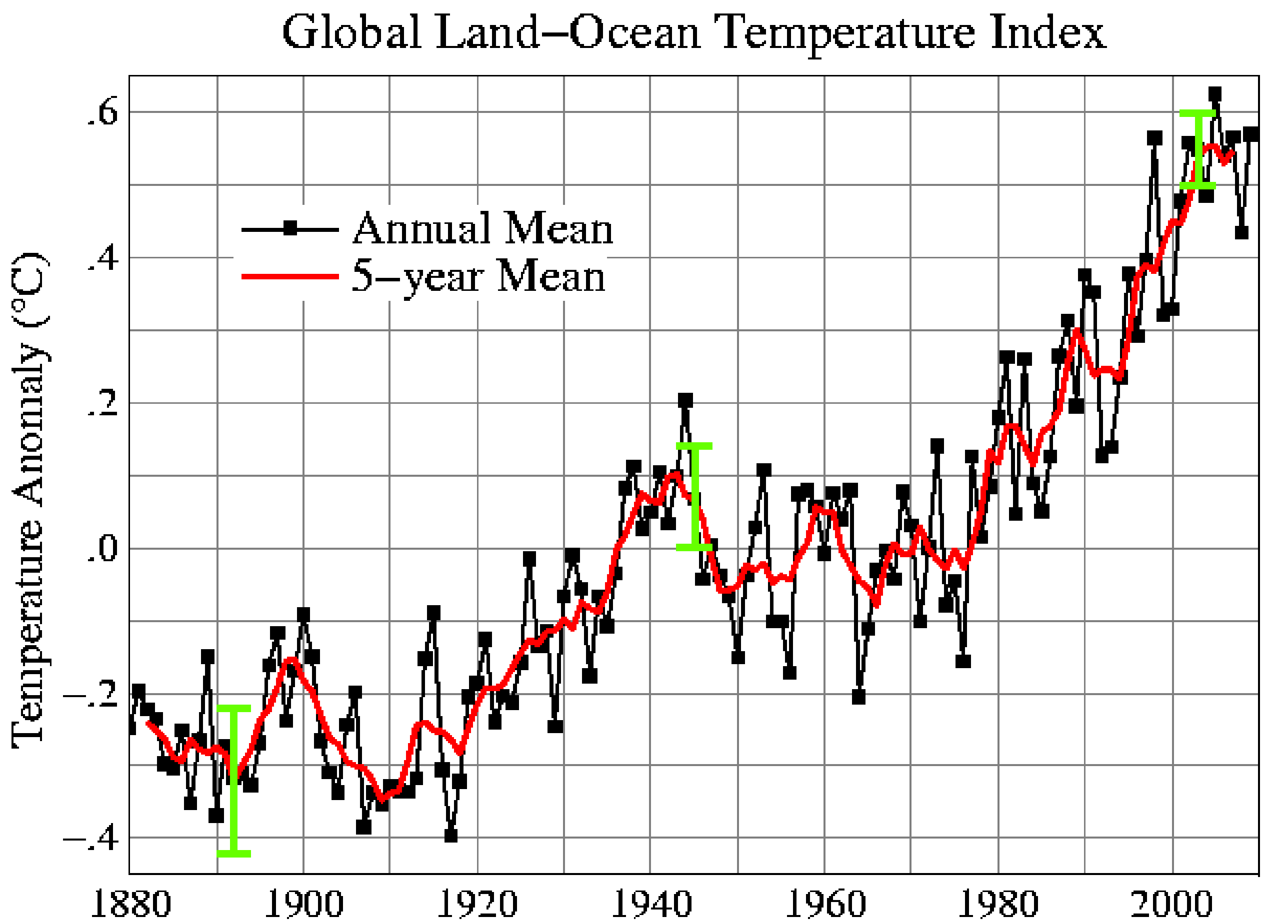

Pollution
dissipation
DISSIPATION TIME


Pollution
500.00
0.00
0.00 75.00 150.00 225.00 300.00
Time

8| CLIMATE CHANGE
We know

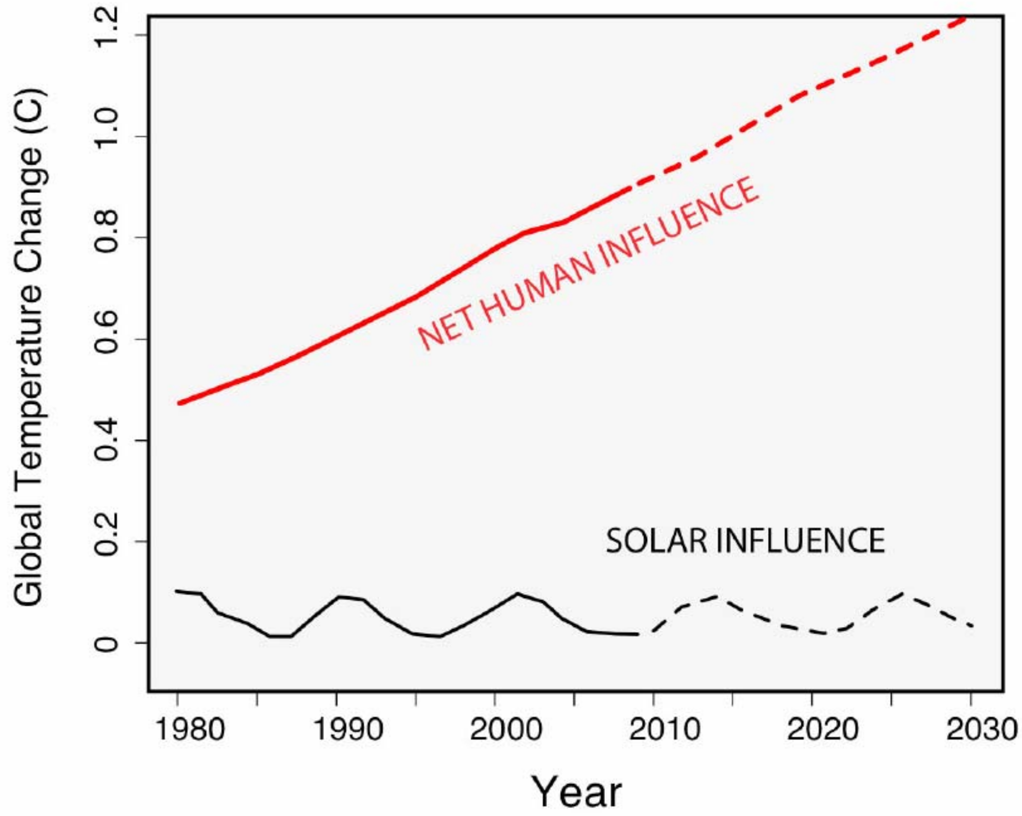
- "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level". *IPCC (2013)*
- "We underline that climate change is one of the greatest challenges of our time". *Copenhagen Accord (2009)*
- "Affirms that climate change is one of the greatest challenges of our time and that all Parties share a vision for long-term cooperative action…" *Cancun Agreement (2010)*
- " Adaptation must be addressed with the same priority as mitigation and requires appropriate institutional arrangements to enhance adaptation action and support". *Cancun Agreement (2010)*

9| CLIMATE CHANGE
We know



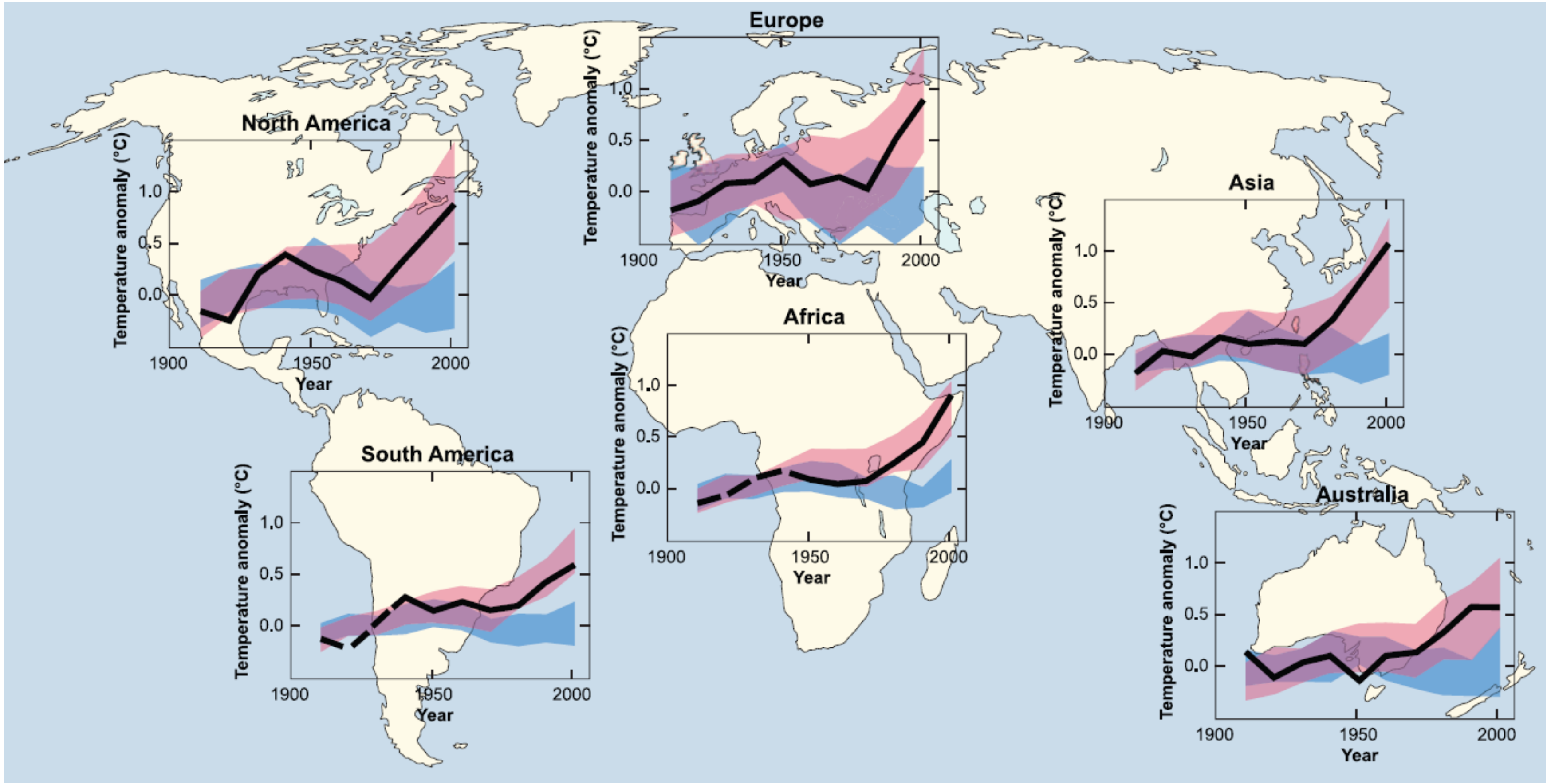
Hansen et al, Proc. Natl. Acad. Sci., (2006, updated 2013)

10 | CLIMATE CHANGE
We know



Lean and Rind, Geophysical Research Letters, (2008)

11 | CLIMATE CHANGE
We know

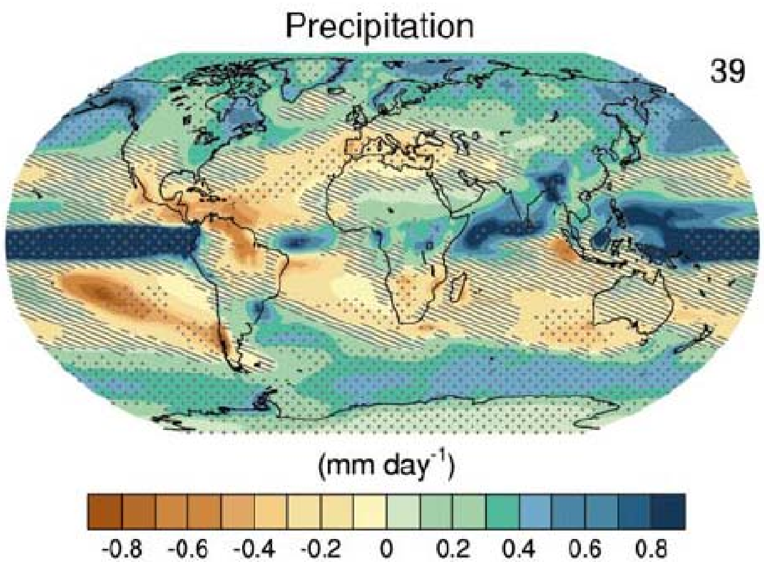


12 | CLIMATE CHANGE
We know

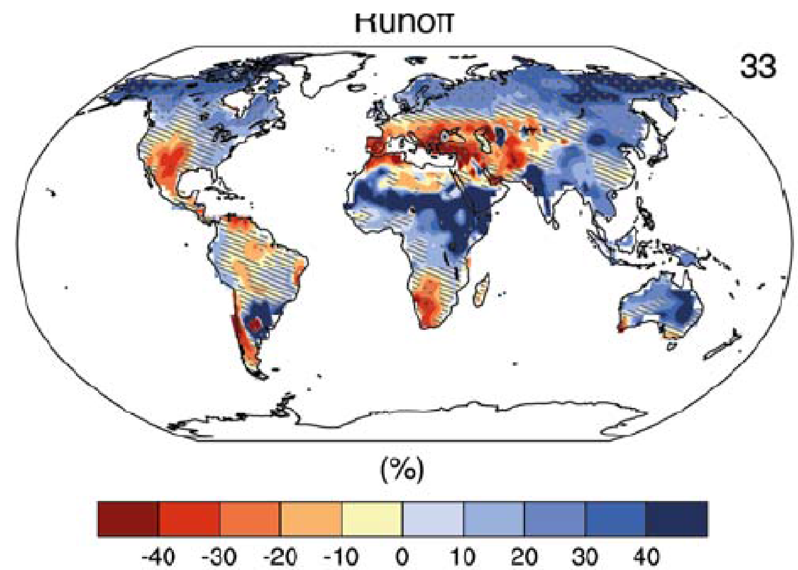
- Recent global temperatures demonstrate human-induced warming
  - Over the past 25 years temperatures have increased at a rate of 0.19°C per decade.
- Very good agreement with predictions based on greenhouse gas increases.
- Over the past ten years, despite a decrease in solar forcing, the trend continues to be one of warming.
- Natural, short-term fluctuations are occurring as usual, but there have been no significant changes in the underlying warming trend (~0.6^0C).

Copenhagen Diagnosis (2009)

CLIMATE CHANGE
We know



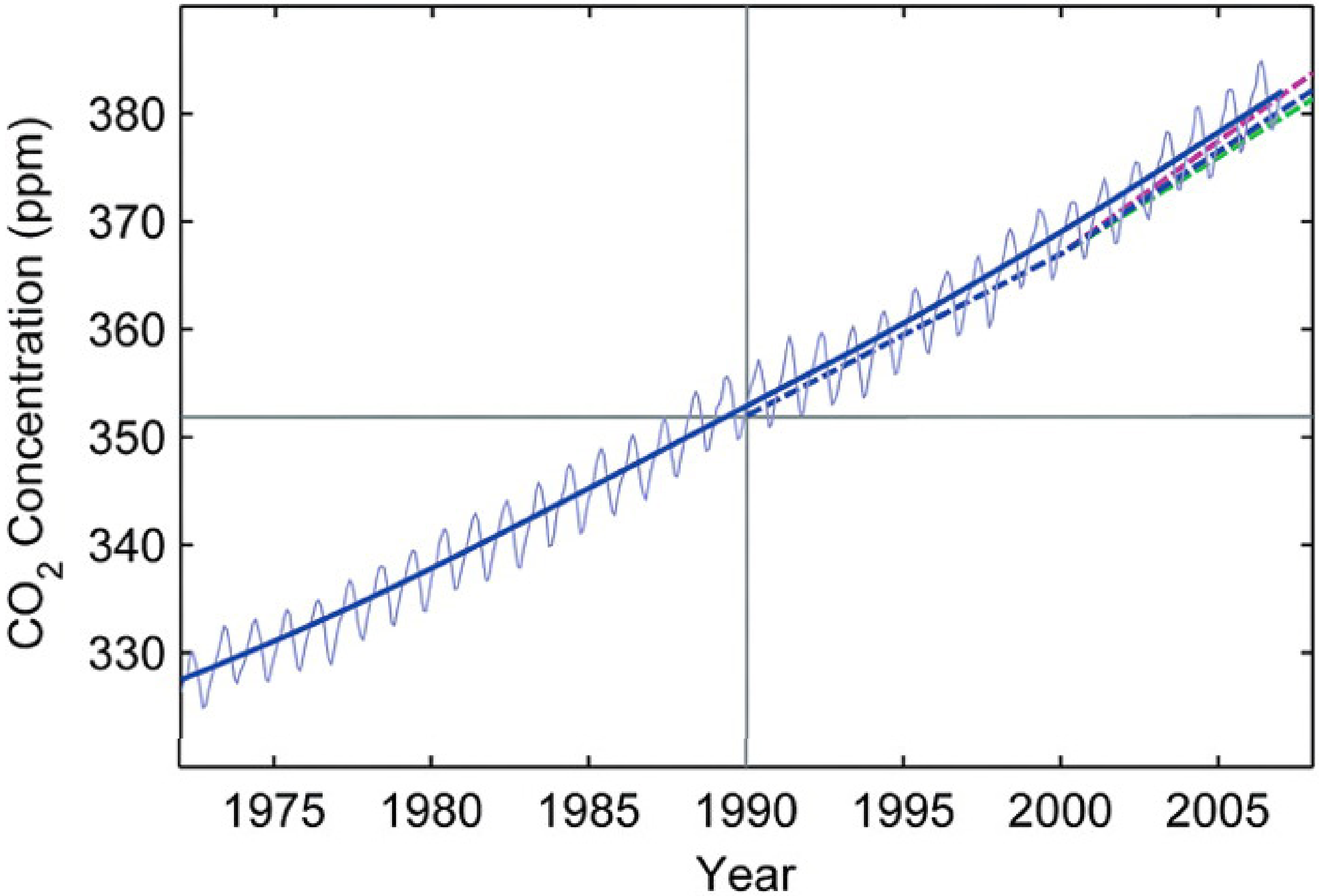
IPCC, 2013



IPCC, 2013

CLIMATE CHANGE

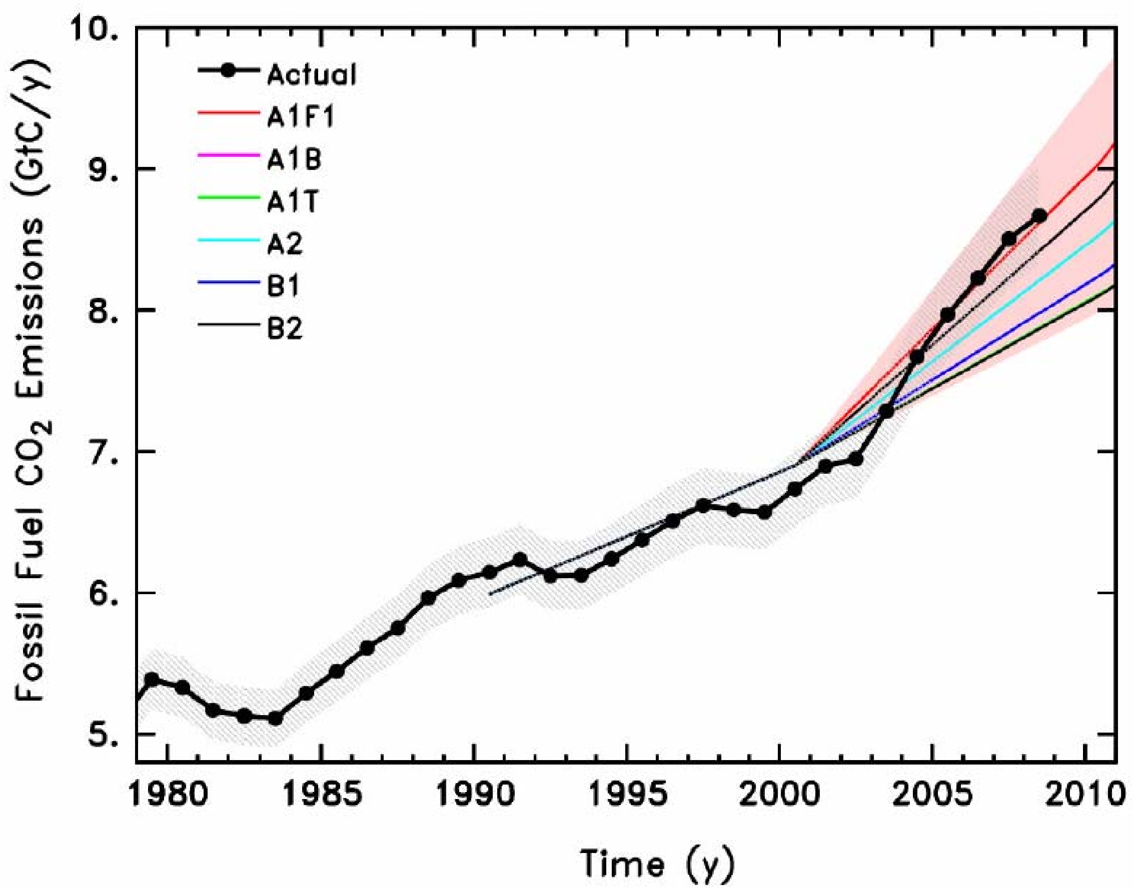
We know



Rahmstorf et al, Science, (2007)

CLIMATE CHANGE

We know



Le Quere et al, Nature Geosciences (2009)

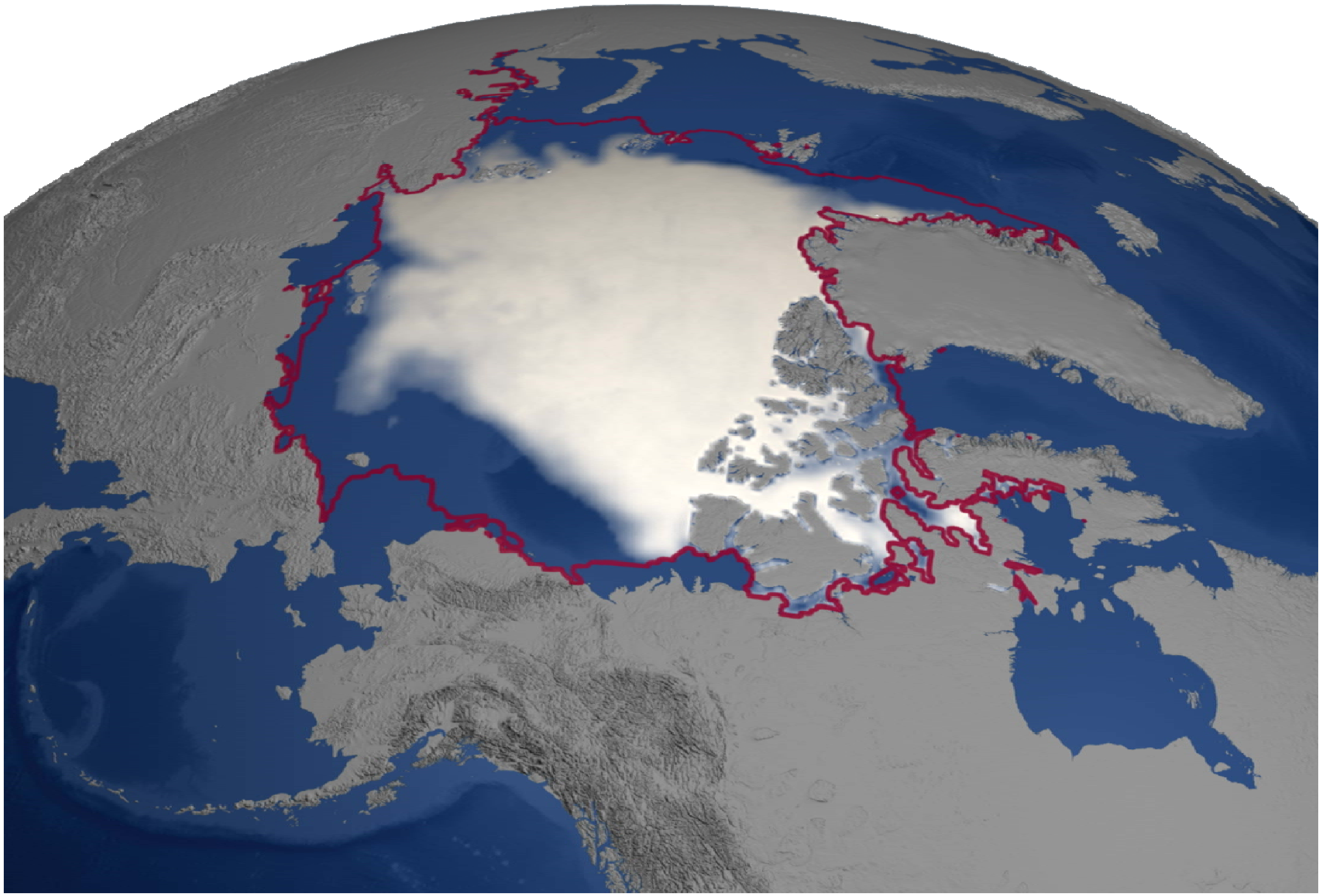
CLIMATE CHANGE

We know

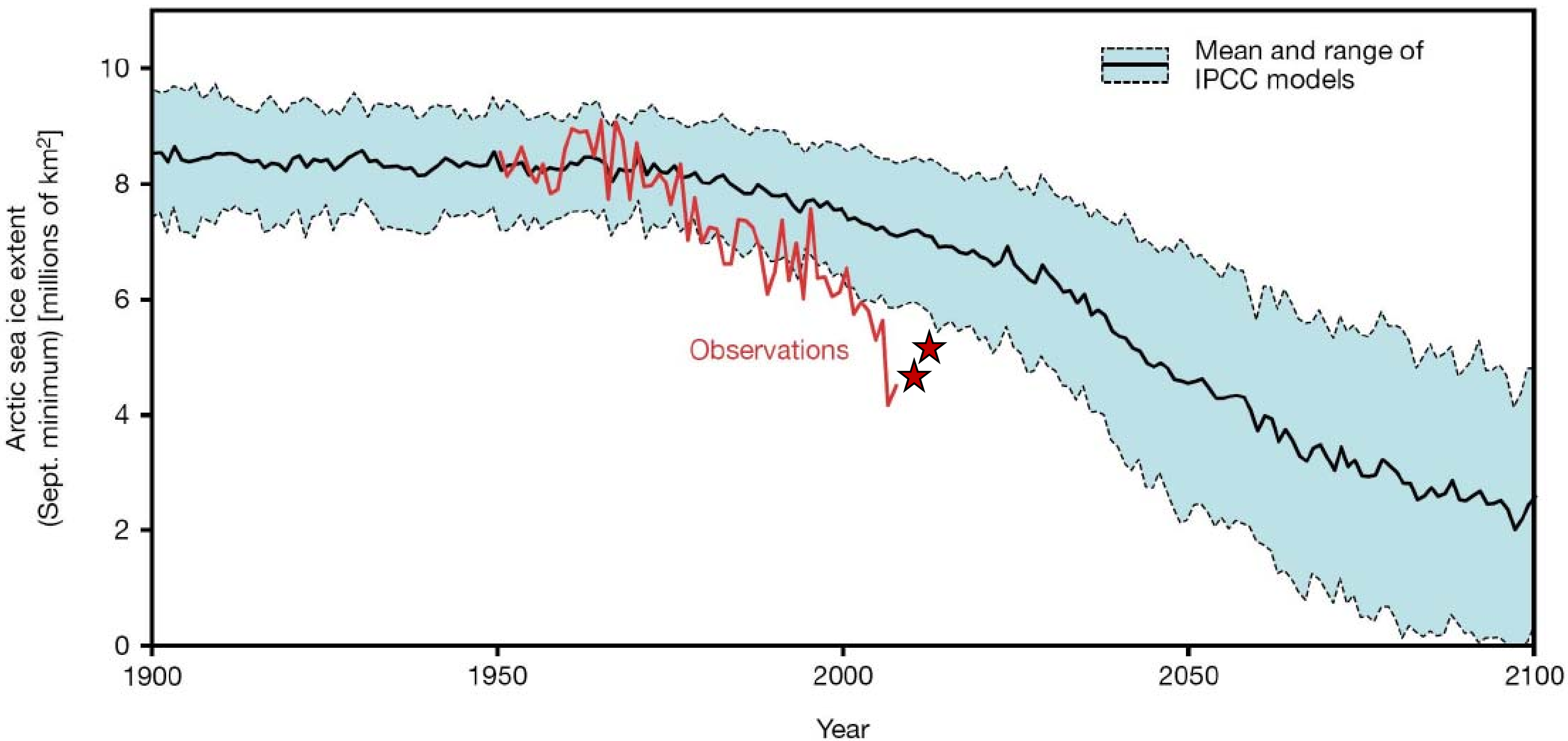
- Greenhouse gas emissions are surging
  - Global carbon dioxide emissions from fossil fuels in 2008 were nearly 40% higher than those in 1990.
- Even if global emission rates are stabilized at present-day levels, just 20 more years of emissions would give a 25% probability that warming exceeds 2°C, even with zero emissions after 2030.
- Every year of delayed action increases the chances of exceeding 2°C warming.

Copenhagen Diagnosis (2009)

CLIMATE CHANGE
We know



18 | CLIMATE CHANGE
We know



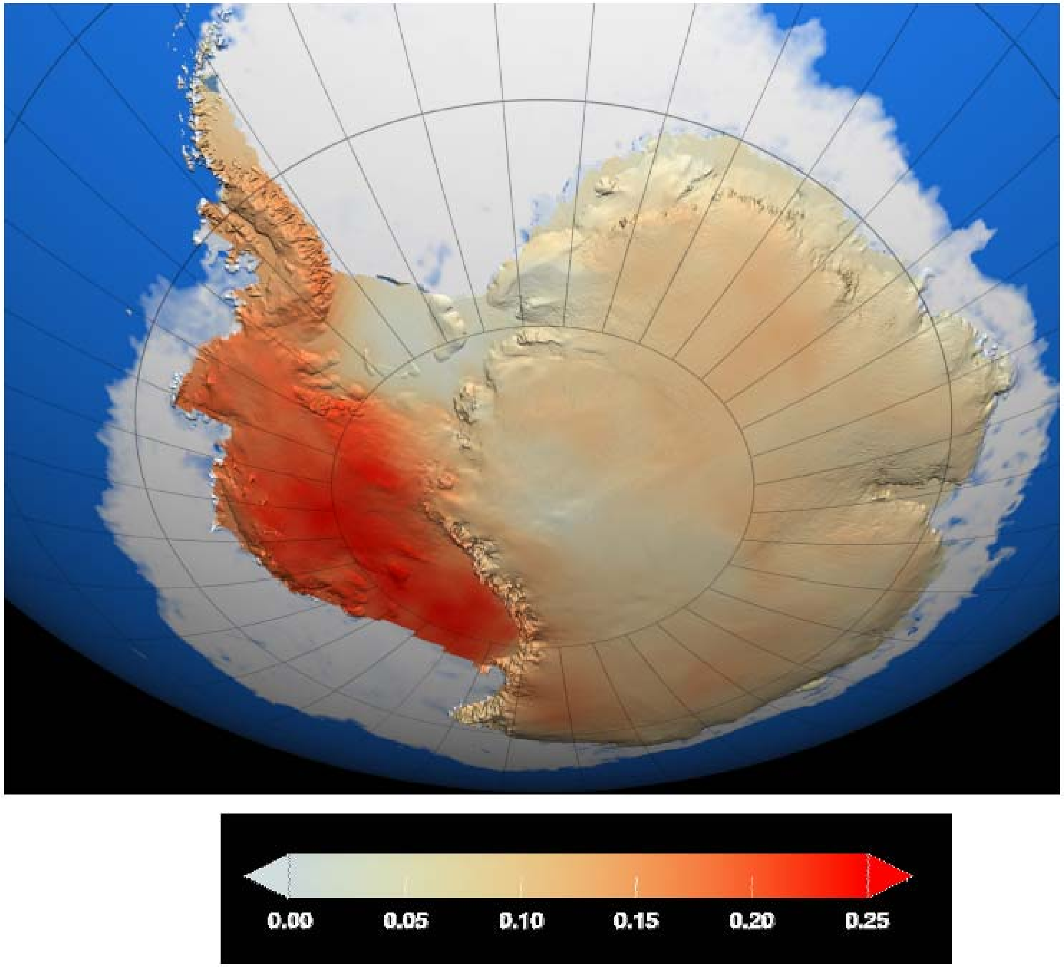
Stoeve et al, Geophysical Research Letters, (2007)

19 | CLIMATE CHANGE
We know

Melt descending
into a moulin,
a vertical shaft
carrying water
to ice sheet base -
Greenland

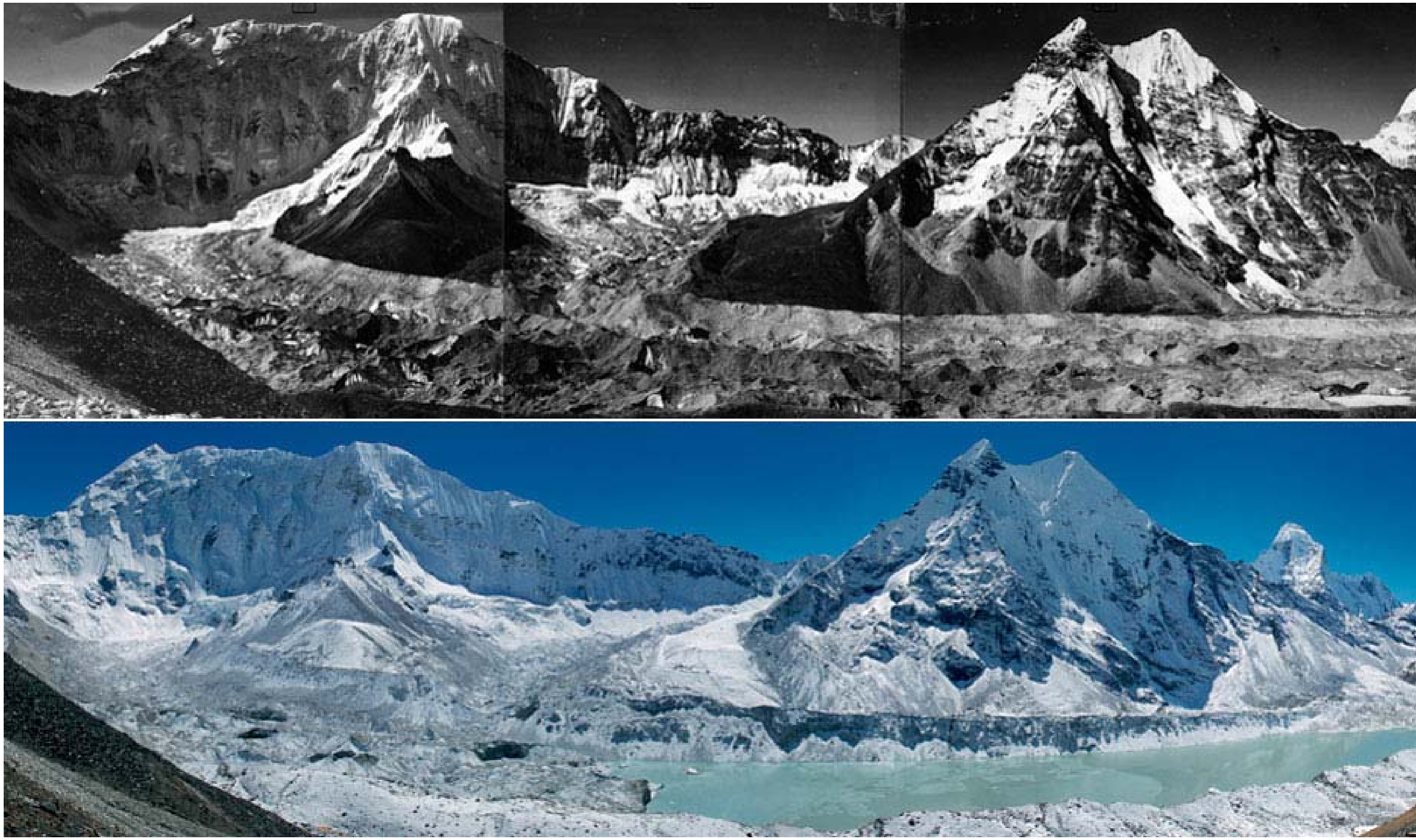
Roger Braithwaite, University of Manchester (UK)

CLIMATE CHANGE
We know



Steig et al, Nature, (2009)

CLIMATE CHANGE
We know



Photograph: Erwin Schneider/Alton Byers/The Mountain Institute

CLIMATE CHANGE

We know

1985 2005

BC (15,000)

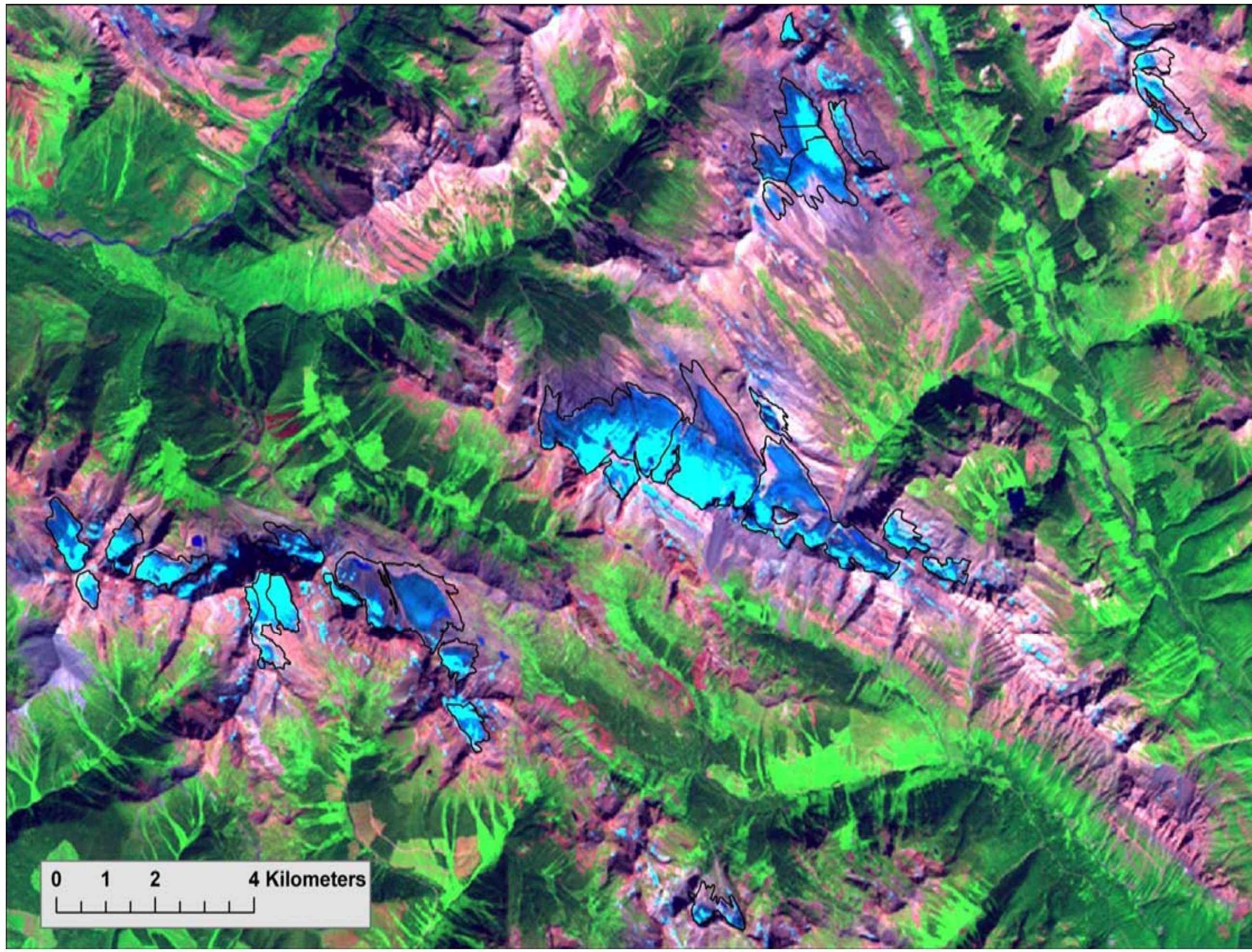
28300 25200 km2

-11.5%

AB (925)

1053 786 km2

-25.5%

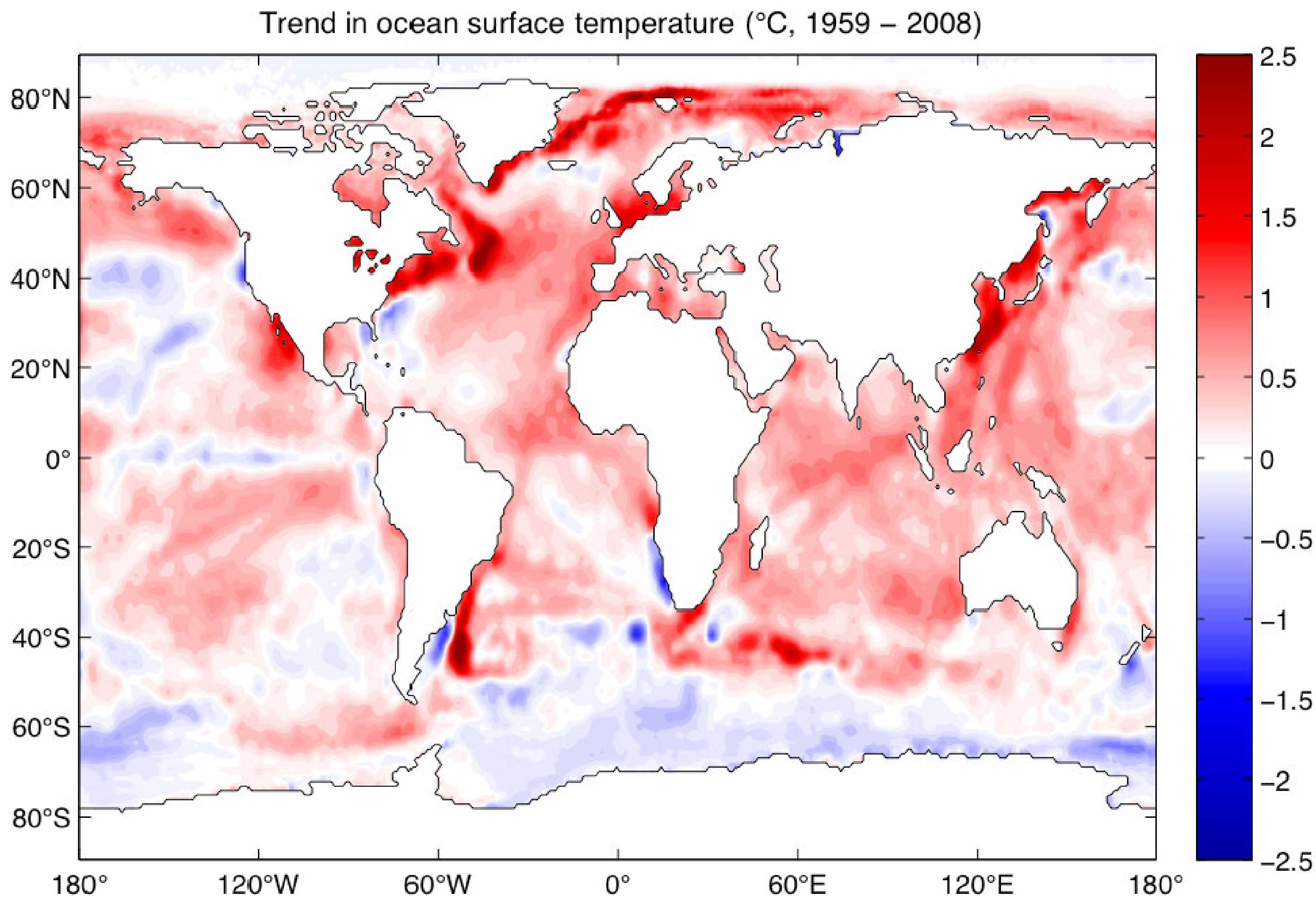


23 | CLIMATE CHANGE
We know

- Rapid Arctic sea-ice decline
  - Summer-time melting of Arctic sea-ice has accelerated far beyond the expectations of climate models.
  - The area of sea-ice melt during 2007-2009 was about 40% greater than the average prediction from IPCC AR4 climate models.
- Ice sheets, glaciers and ice caps are showing accelerated melting
  - The surface area of the Greenland ice sheet which experiences summer melt has increased by 30% since 1979.
  - Antarctica is also losing ice mass at increasing rate. Ice shelves (connections between continental ice sheets and the ocean) are destabilized (7 collapses in last 20 years)

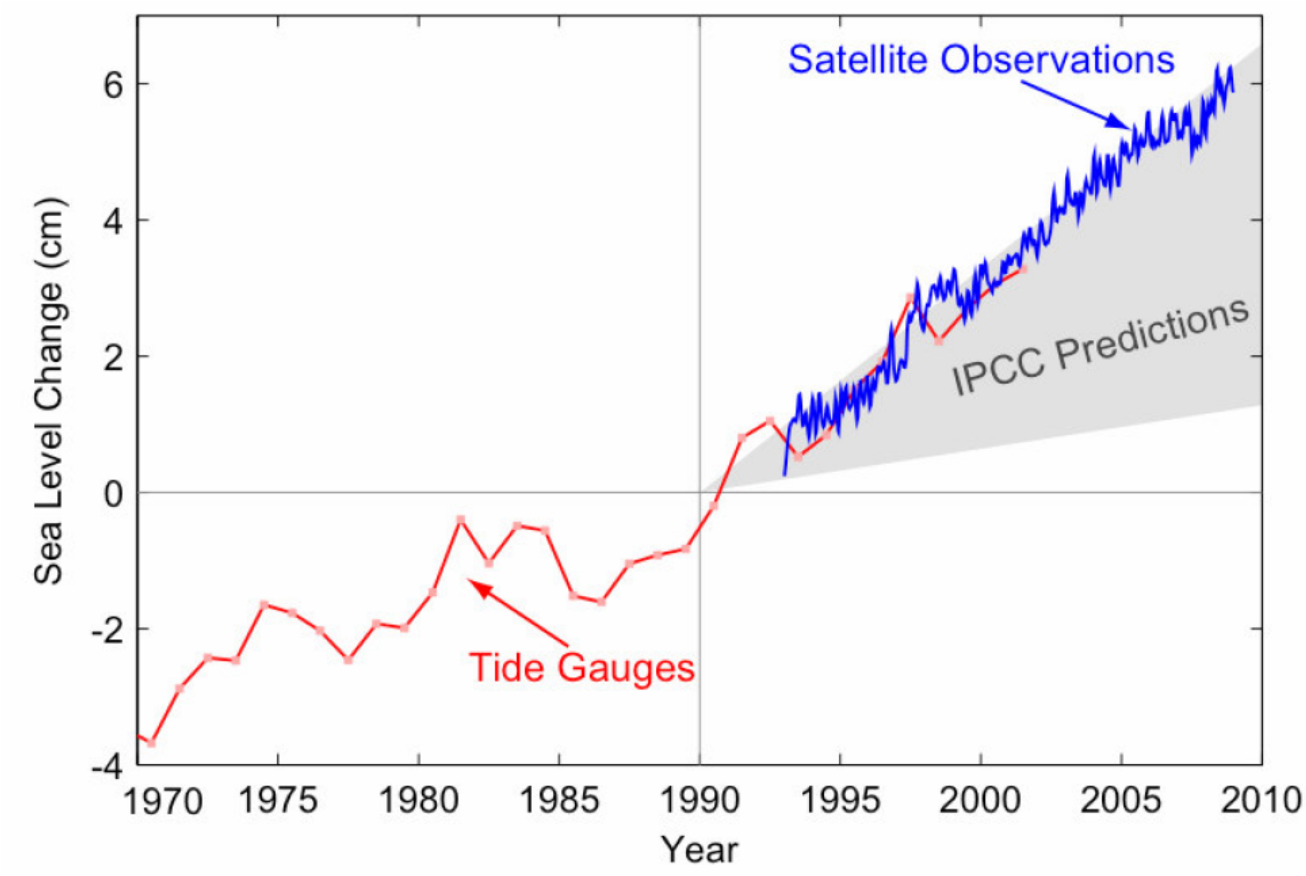
Copenhagen Diagnosis (2009)

CLIMATE CHANGE
We know



Copenhagen Diagnosis (2009)

25 | CLIMATE CHANGE
We know



Church and White , Geophysical Research Letters, (2006)
Cazenave et al, Global and Planetary Change, (2009)

CLIMATE CHANGE
We know

"Overall, these observational data underscore the concerns about global climate change. Previous projections, as summarized by IPCC, have not exaggerated but may in some respects even have underestimated the change, in particular for sea level."

Rahmstorf et al, Science, (2007)

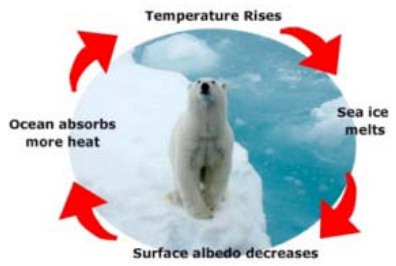
27 | FEEDBACKS
We know

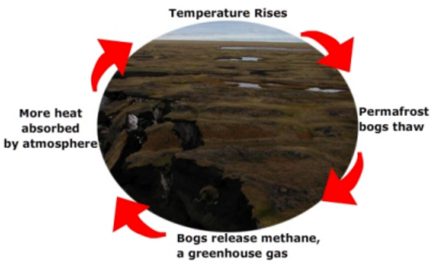
- *Interaction* between socio-economic and natural systems causes climate change

Climate Change → Social Adaptation

- *Interaction* determines the entire system's evolution

28 | FEEDBACKS
We know





- Strong positive feedbacks (amplification of the surface temperature response)
  - Higher temperature – Warmer oceans - Increase in evaporation - Water vapor increase (amount is function of temperature) – Temperature increase
  - Higher temperature – Snow and ice melt – Larger absorption of sunlight - Temperature increase
  - Higher ocean temperature – less algae – more heating
- Big and dangerous feedbacks (unstoppable if the temperature goes 2 – 3^{o}C up)
  - Higher temperature – Higher release of methane from the Arctic and the oceans – Higher temperature
  - Movement of climate zones – Change in vegetation distribution – Change of species distribution – Climate zone change

29 | FEEDBACKS

We know

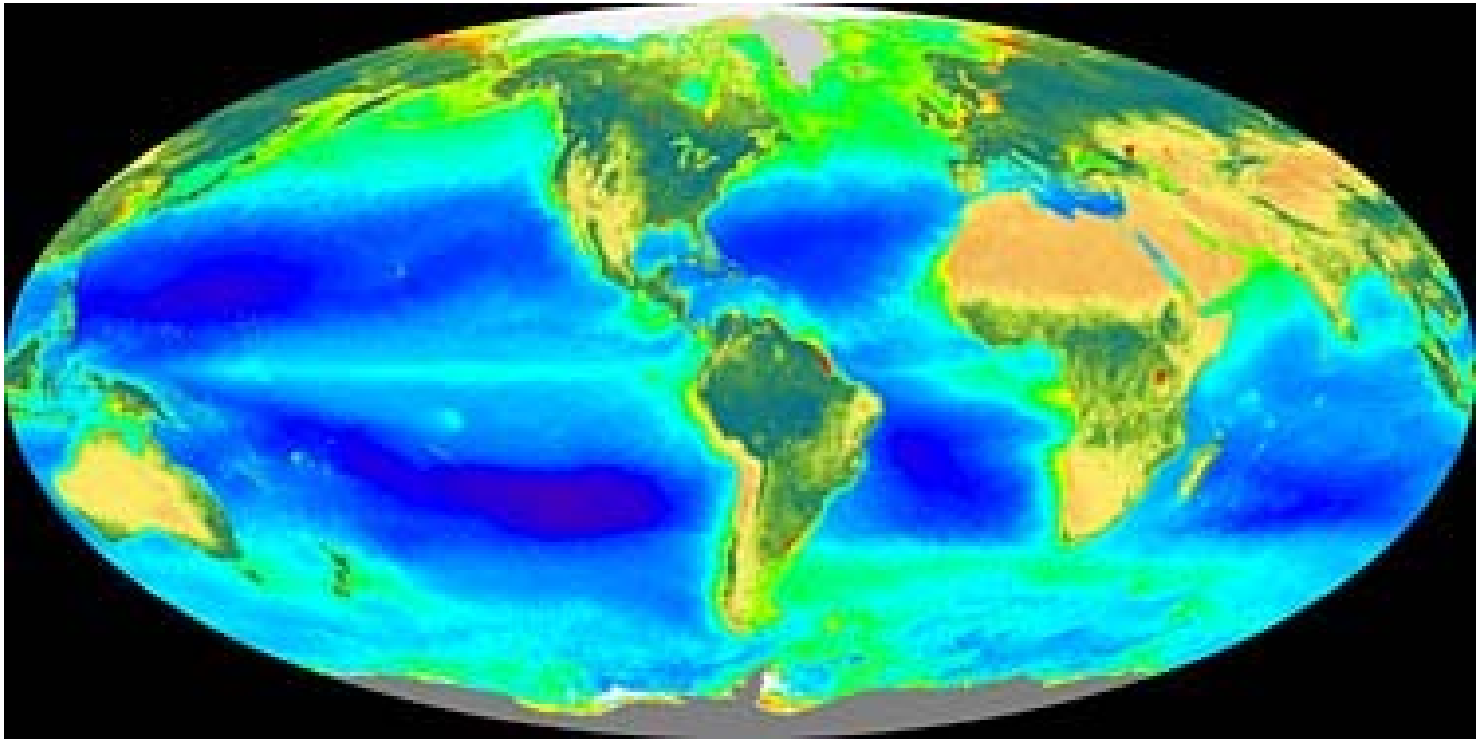
FEEDBACKS

We know

FEEDBACKS

We know

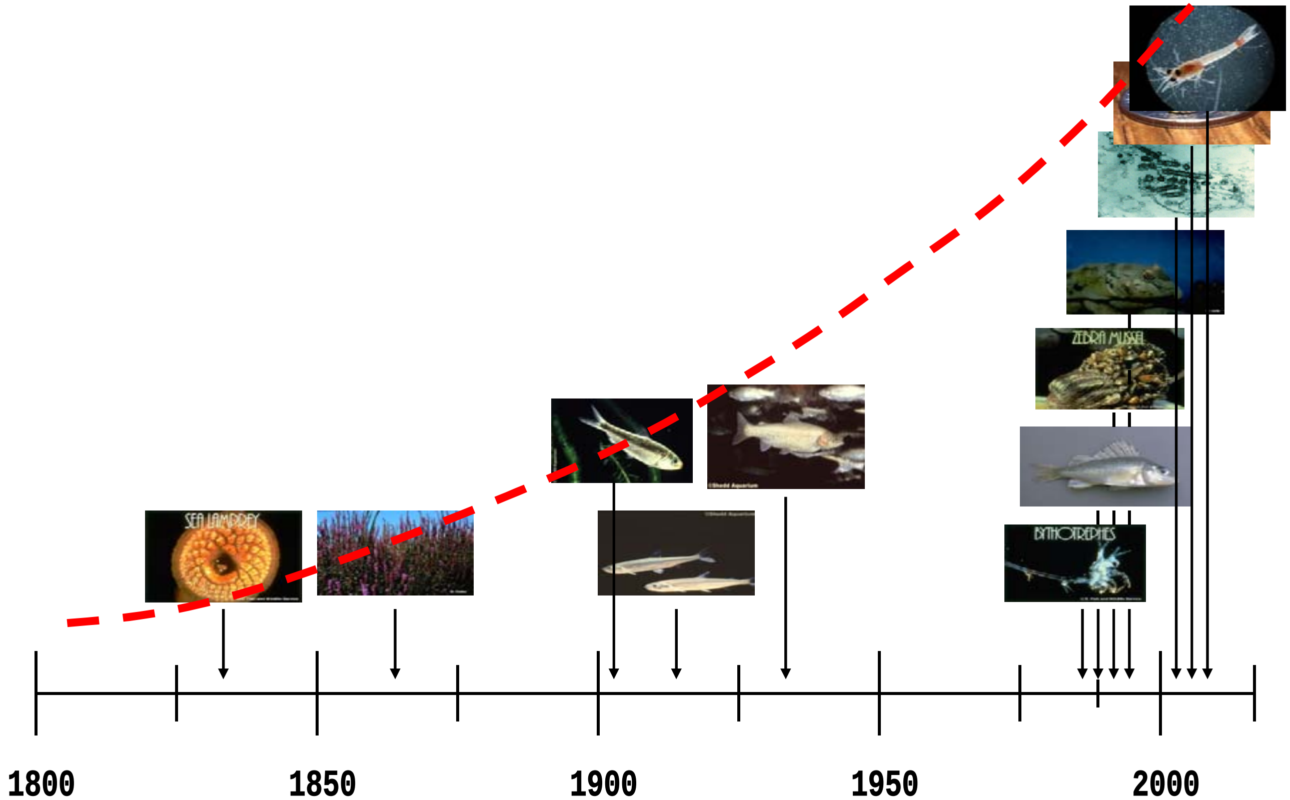
FEEDBACKS
We know



Polovina, Geophysical Research Letters, (2008)

33 | FEEDBACKS

We know



Mahon, (2009)

CLIMATE CHANGE

We don't know

- The speed at which the global average temperature will rise with change of CO_2 concentration (non-linear relationship).
- What are the tipping points for making dangerous feedbacks unstoppable.

WATER RESOURCES MANAGEMENT

Introduction

- Climate change is hydrologic change
- The most important climate feedbacks all include water – solid, liquid or gas form.
- Water is how the climate change meets people
- Each element of the Hydrologic Cycle is affected by changing climate
- Water is the delivery mechanism for many of the impacts of climate change

- There are observations that:
  - the present mid-latitude rain belt shifts northward;
  - snowmelt and spring runoff occur earlier than in the past;
  - evapotranspiration is greater, as it starts earlier and continues longer;
  - …

Lemmen abd Warren (eds), NRCan, (2004)

WATER RESOURCES MANAGEMENT
Questions

- Need for different view of management
  - How can we most effectively meet the demands for water of sufficient quantities and qualities at the times needed, both for humans and the environment, for current and future generations and at reasonable costs?
  - How can we identify the management and operating policies that best meet these needs?
  - How can we minimize the negative impacts of floods and droughts?

WATER RESOURCES MANAGEMENT

Possible answers

- Traditional view
  - We keep trying to manage environments (water, land, air, etc).
  - We keep trying to manage people within environments.
- It seems that every time we push at one point, it causes unexpected change elsewhere – first fundamental systems principle.
- The system in our focus is a social system. It describes the way water resources are used by people.
- The system exhibits a high level of complexity.
- It includes all sources of uncertainty: variability and ambiguity.

WATER RESOURCES MANAGEMENT

Possible answers

new thinking

Water Resources Management: A Systems View

One would expect that "water resources management" is the management of water resources. But the language behind the concept is simpler than the complex social and ecological systems in which water resources and people that govern them live. Prof. Slobodan Simonovic explains how a systems view can make sure that we understand what it is that we are trying to manage.

Freshwater sustains life and all social and environmental processes. Yet freshwater systems are imperiled, and this threatens both human well-being and the health of ecological systems. This crisis is caused by the ways in which we mismanage water.

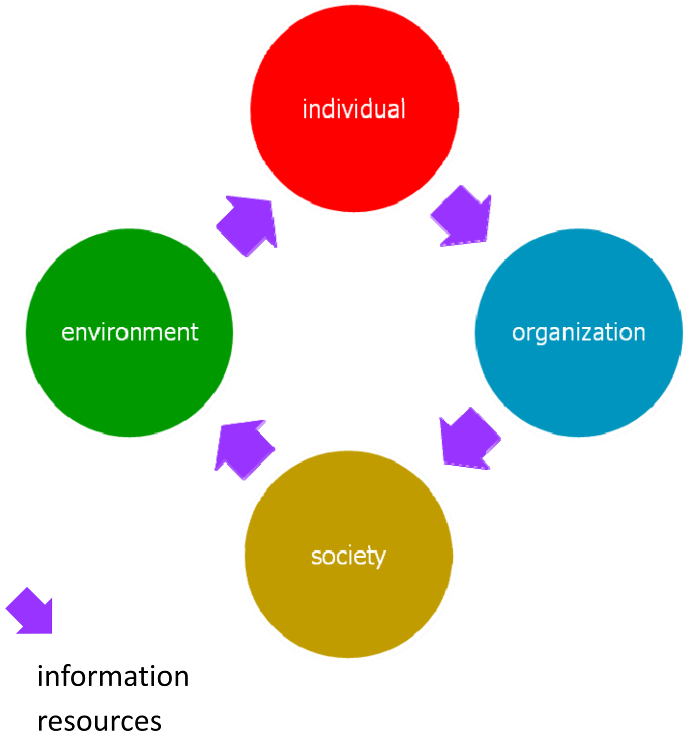
Mismanagement is caused by a faulty way they do. They are decision makers in their own right, with a direct role in water resources use and management. Organisations are the mechanisms people use to produce outcomes that individuals cannot produce. Organisations are structured to achieve goals. Structure defines information resources, information and values. These connect individuals, organisations, society and environment, linking the four subsystems. Only information and resource flows link people and organisations.

Value systems – the means through which different values are attached to in-

Stockholm Water Front, No.1, May 2009, page 12

WATER RESOURCES MANAGEMENT

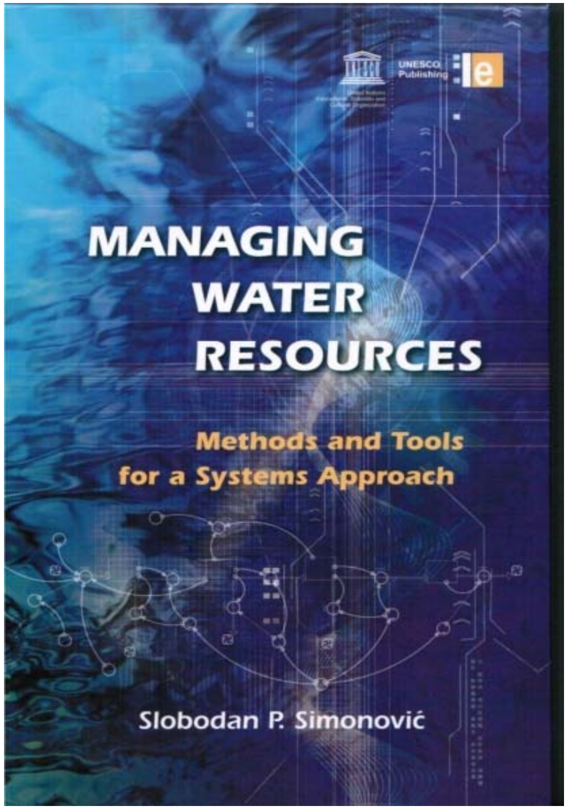
Possible answers



- Systems approach
- Water resources management as a process of managing the following subsystems:
  - Individuals
  - Organizations
  - Societies and
  - Environment.
- Flows connecting the subsystems:
  - Resource, and
  - Information.
- Information is used to determine resource use by subsystems.
- Values provide meaning to information flows.

WATER RESOURCES MANAGEMENT

Possible answers



- The systems approach establishes the proper order of inquiry and helps in the selection of the best course of action that will accomplish a prescribed goal:
  - by broadening the information base of the decision-maker;
  - by providing a better understanding of the system, and the interrelatedness of its component subsystems; and
  - by facilitating the prediction of the consequences of several alternative courses of action.

WATER RESOURCES MANAGEMENT

Possible answers

- Systems analysis tools
  - Simulation
  - Optimization
  - Multi-objective analysis
- Systems analysis tools
  - Deterministic
  - Stochastic
  - Fuzzy set based

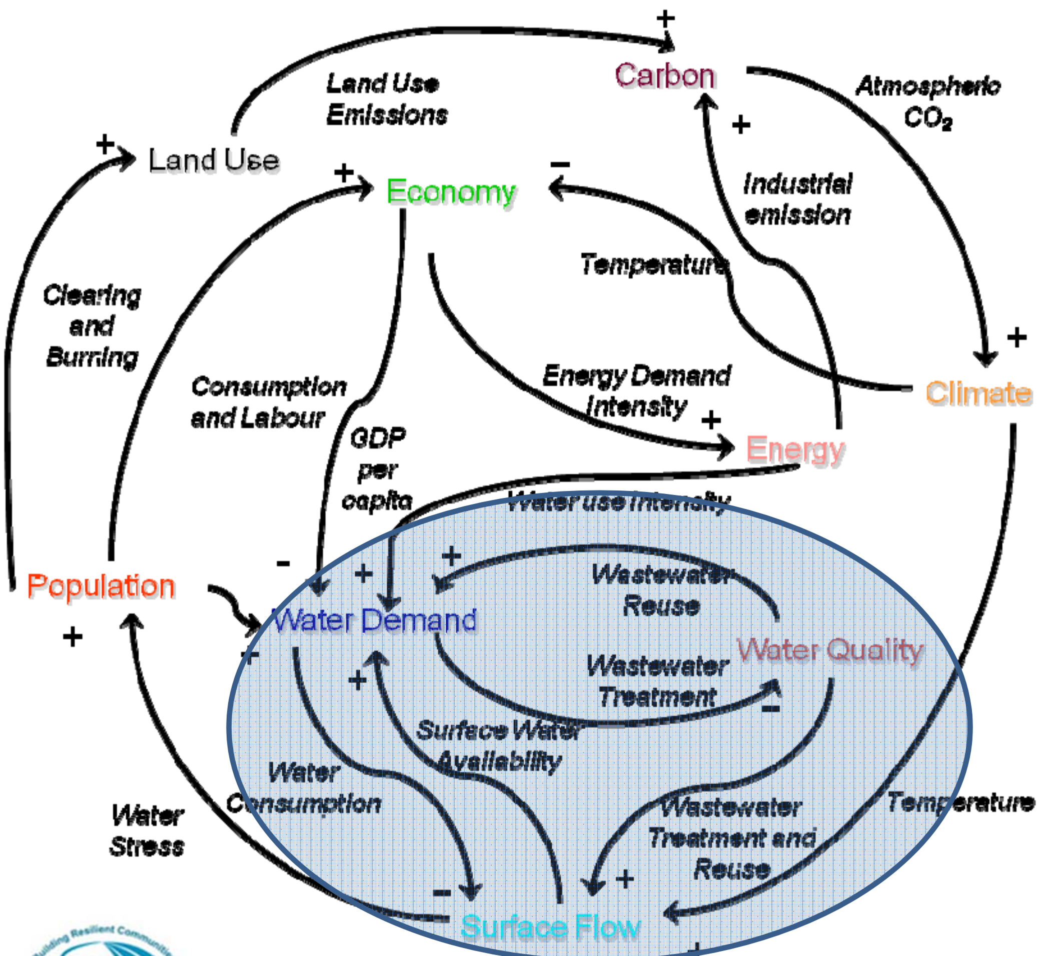
- Example 1

An Integrated System Dynamics Model of the Social-Economic-Climatic System - ANEMI

NSERC Strategic Research Grant

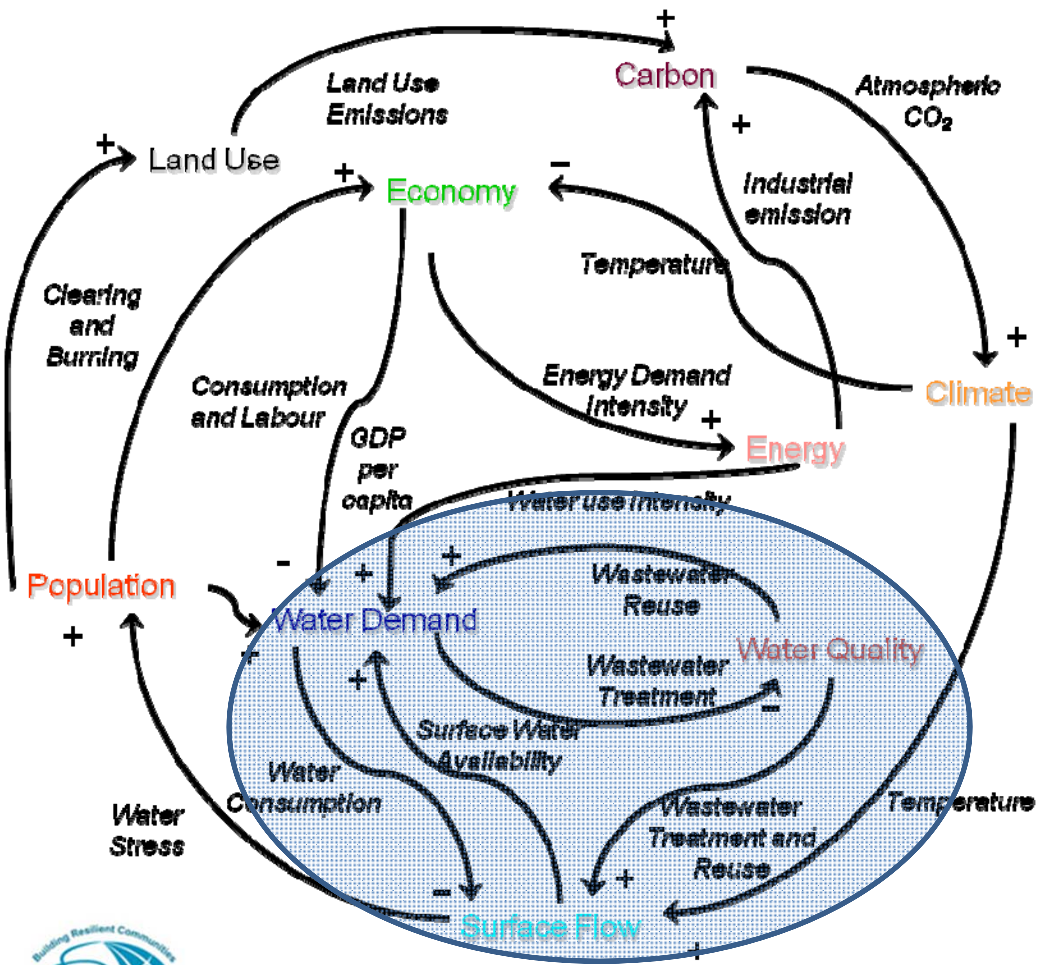
WATER RESOURCES MANAGEMENT

Examples - ANEMI



1. Carbon cycle
2. Climate
3. Water demand
4. Water quality
5. Available water
6. Population
7. Land use
8. Food production
9. Energy - Economy

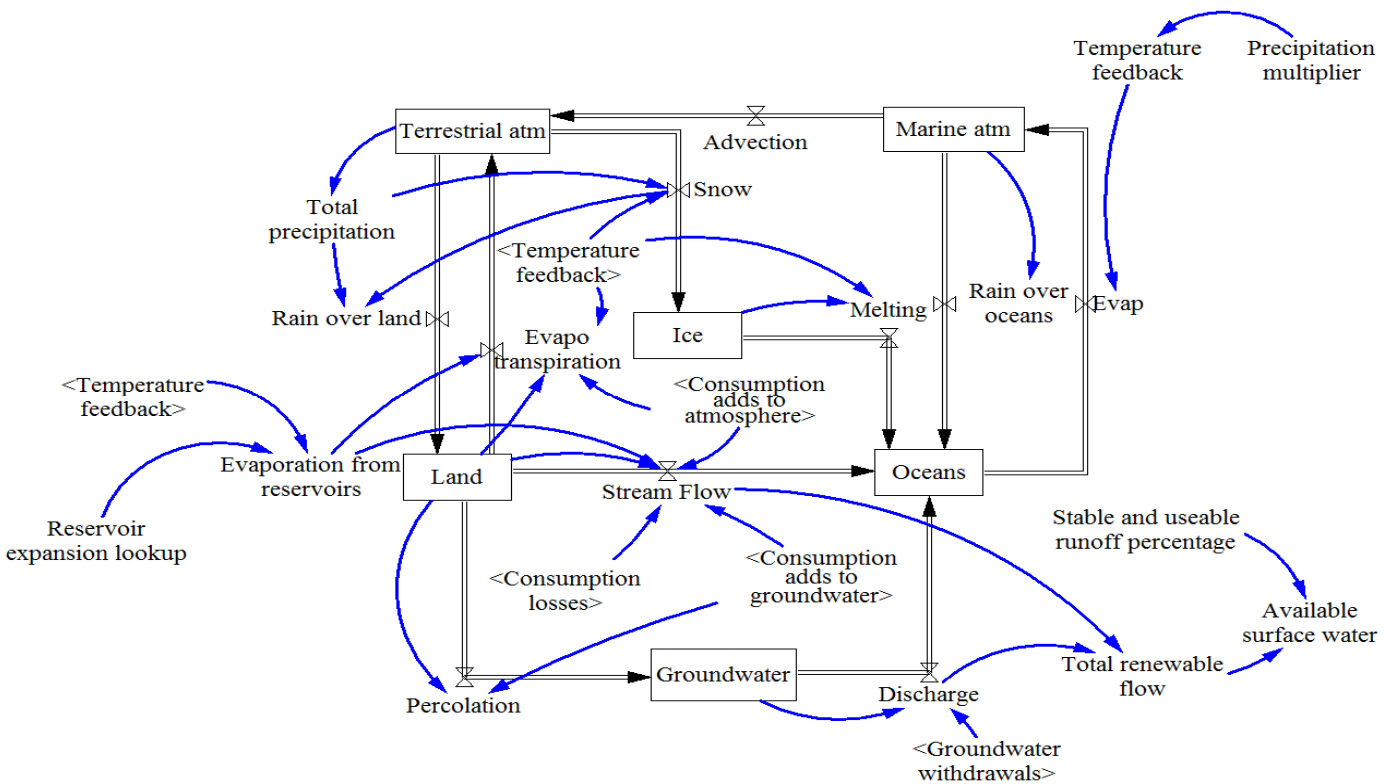
WATER RESOURCES MANAGEMENT
Examples - ANEMI



- Nine main sectors
- Model Elements:
  - 740 variables
  - 230 Stocks (many in arrays)
  - 2300 total
- 600 equations
  - 99 major equations
- Thousands of feedbacks
  - Population: 4468 loops
  - Water stress: 2756 loops
  - Economic output: 203 loops
  - Industrial emissions: 47 loops

WATER RESOURCES MANAGEMENT

Examples - ANEMI



WATER RESOURCES MANAGEMENT

Examples - ANEMI

- Available water resources
  - Two reservoirs (oceans and land surface)
  - Transfers (evaporation, evapotranspiration, advection, rainfall,
    - snow and ice melt, ground water percolation, and surface runoff into the oceans

$$A_M = \int (E_M - Adv - P_O) \cdot dt$$

$$A_L = \int (Adv + ET - P_R - P_S) \cdot dt$$

$$LS = \int (P_R - ET - SF - GP) \cdot dt$$

$$O = \int (SF + GD + P_O + M - E_M) \cdot dt$$

$$GS = \int (GP - GD) \cdot dt$$

$$IS = \int (P_S - M) \cdot dt$$

$$E_M = E_{M0} \cdot T_{feedback}$$

$$Adv = Adv_0 \cdot (1 + \delta_{adv} / 100)$$

$$P_O = P_{O0} \, {}^{A_M}\!/_{A_{M0}}$$

$$ET = ET_0 \cdot {}^{LS}\!/_{LS_0} \cdot T_{feedback} + E_{res} + C_{wa}$$

$$P_R = P_L - P_S + C_{wl}$$

$$GP = GP_0 \cdot {}^{LS}\!/_{LS_0} + C_{gw}$$

$$GD = GD_0 \cdot {}^{GS}\!/_{GS_0} + GW$$

$$M = M_0 \cdot {}^{IS}\!/_{IS_0} \cdot T_{feedback}{}^2$$

WATER RESOURCES MANAGEMENT

Examples - ANEMI

- Water use
  - Domestic
  - Industrial
  - Agricultural

$$W_{eff_d} = C_d + \delta_d R_{p_d}$$
$$W_{eff_i} = C_i + \delta_i R_{p_i}$$
$$W_{eff_a} = C_a + \delta_a R_{p_a} + \delta_r R_r + \delta_g R_g$$

- Water stress (> 0.2 'mid stress' - > 0.4 'severe stress')

$$wta = W/R$$

$$wta = \left(\sum_{d,i,a} W_{eff} \right) / R$$

WATER RESOURCES MANAGEMENT
Examples - ANEMI

Advances in Water Resources 34 (2011) 684–700

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Advances in Water Resources

journal homepage: www.elsevier.com/locate/advwatres

Global water resources modeling with an integrated model of the social–economic–environmental system

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A R T I C L E I N F O

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A B S T R A C T

Awareness of increasing water scarcity has driven efforts to model global water resources for improved insight into water resources infrastructure and management strategies. Most water resources models

- Integrated modeling approach
- Planning of water infrastructure
- Development of new water policy options

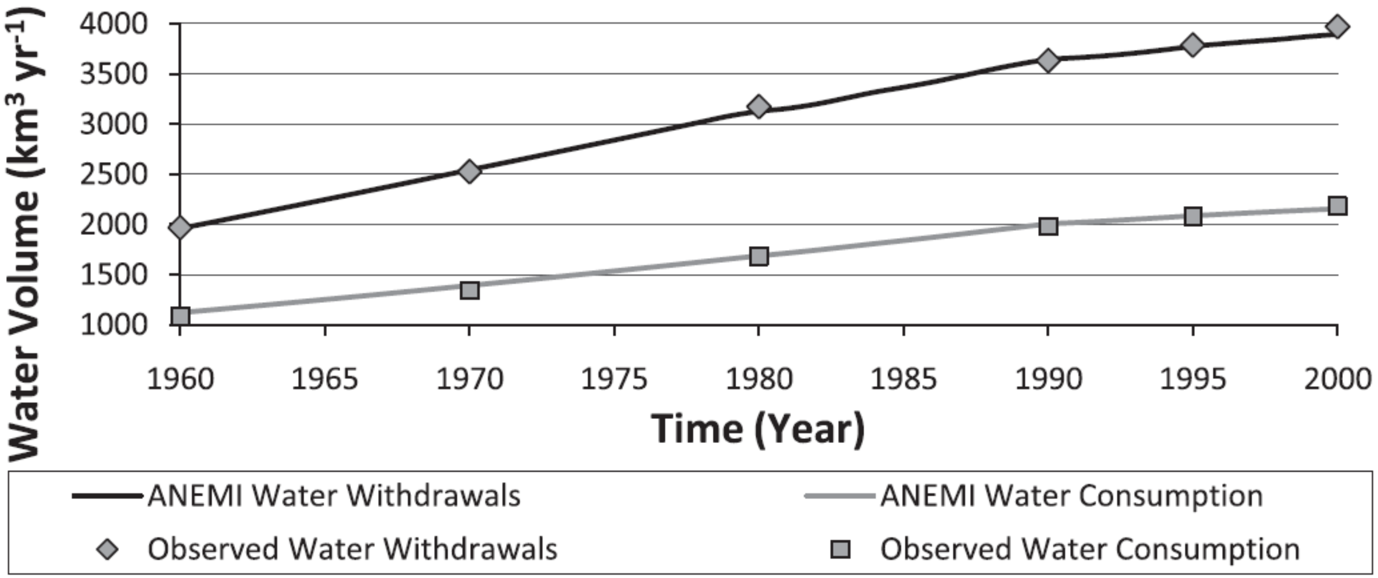
WATER RESOURCES MANAGEMENT
Examples - ANEMI

- Model use
  - Feedback tracing – 5 scenarios
  - Scenario 1 – low treatment, no reuse
  - Scenario 2 – high treatment, no reuse
  - Scenario 3 – irrigation expansion
  - Scenario 4 – more animals
  - Scenario 5 – dilution requirements
  - Reference simulation

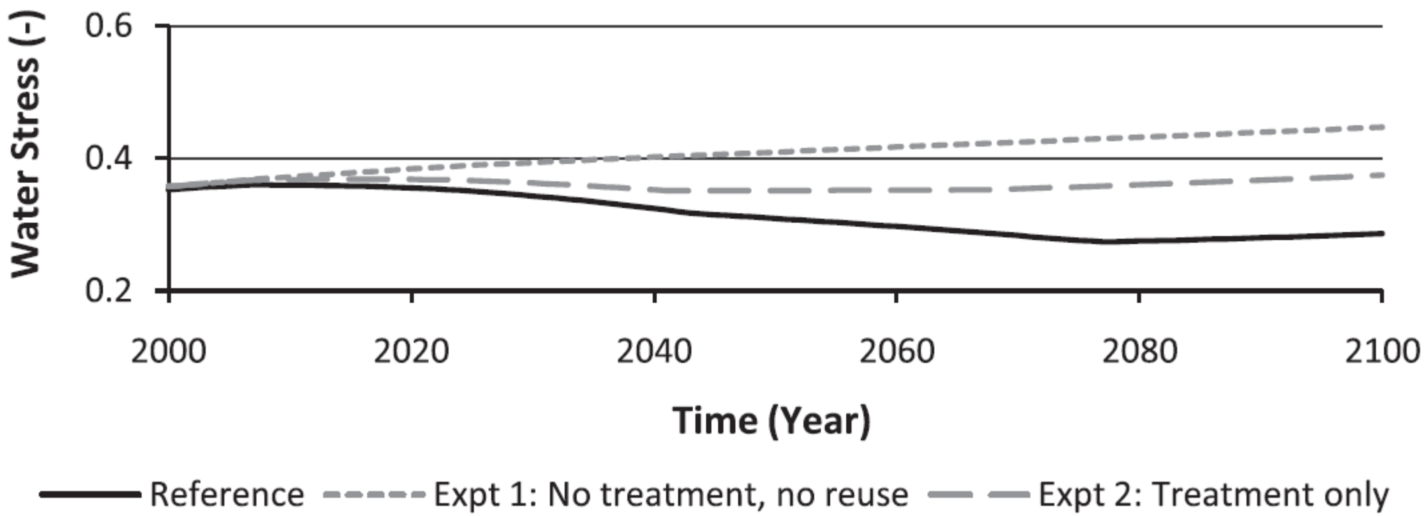


WATER RESOURCES MANAGEMENT

Examples - ANEMI



WATER RESOURCES MANAGEMENT
Examples - ANEMI

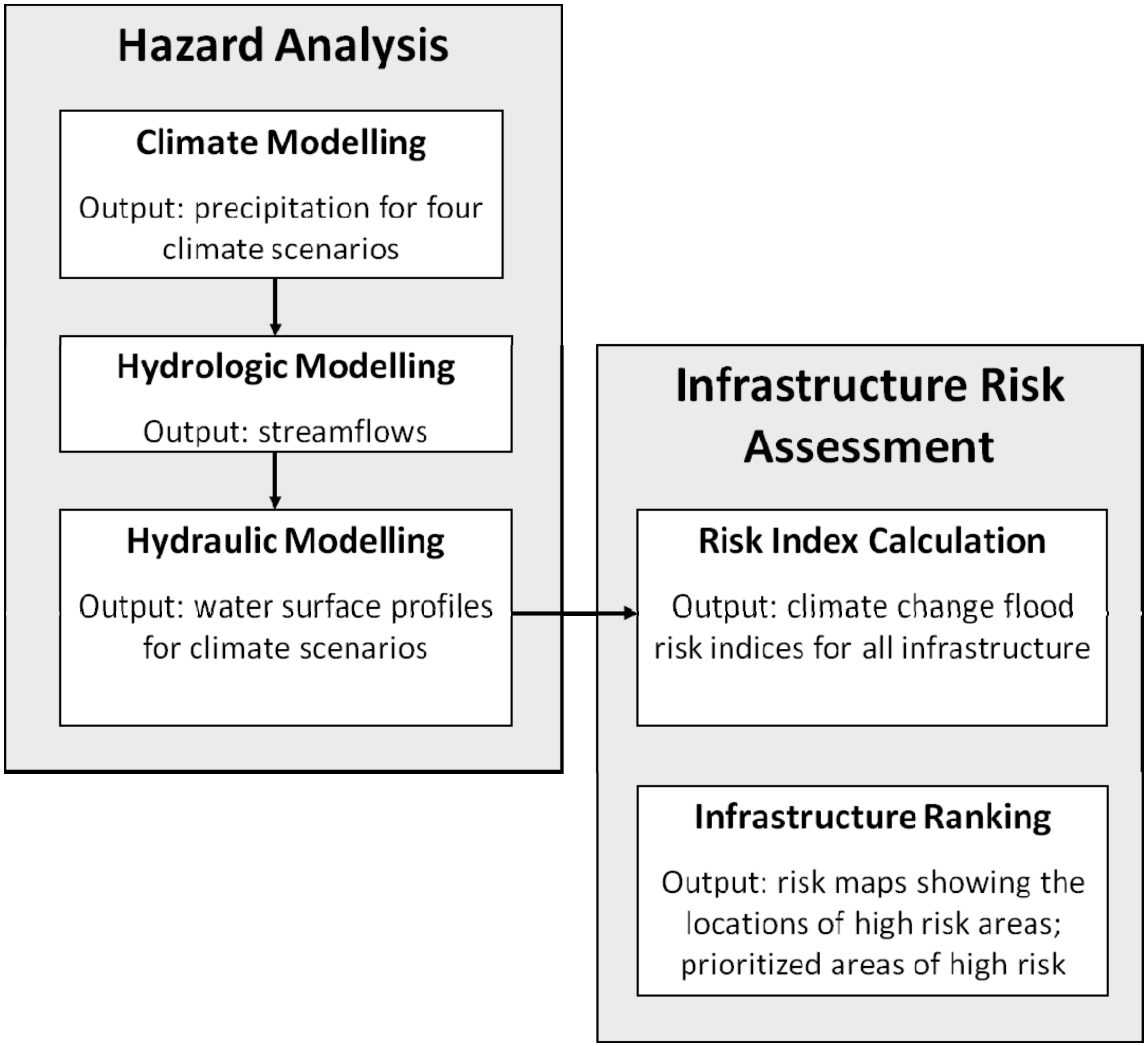


- Example 2

Understanding the impacts of climate change on management of water resources at a local scale

Two projects - *Canadian Foundation for Climate and Atmospheric Sciences*
Three projects – *City of London*

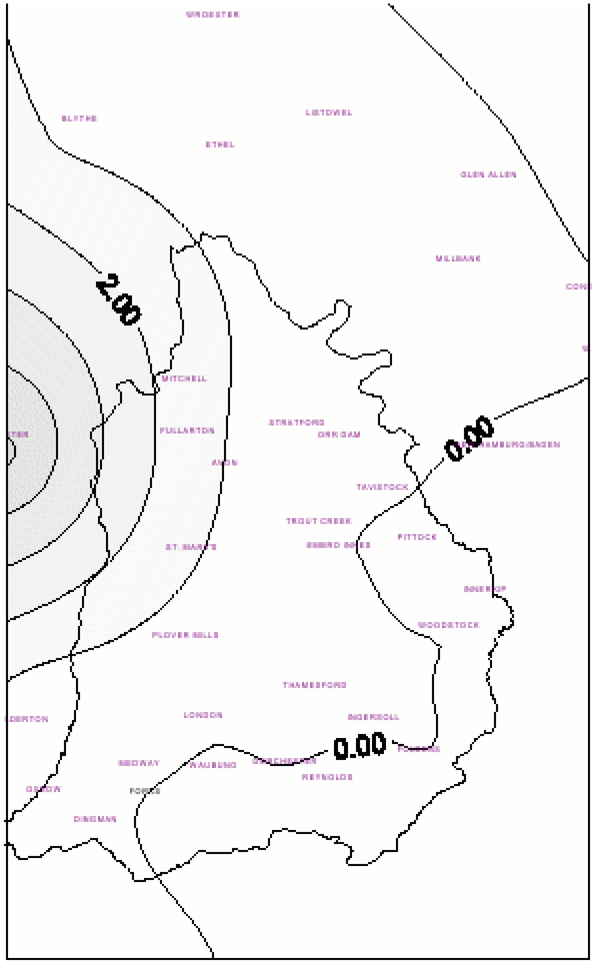
53 | WATER RESOURCES MANAGEMENT
Examples - City



WATER RESOURCES MANAGEMENT

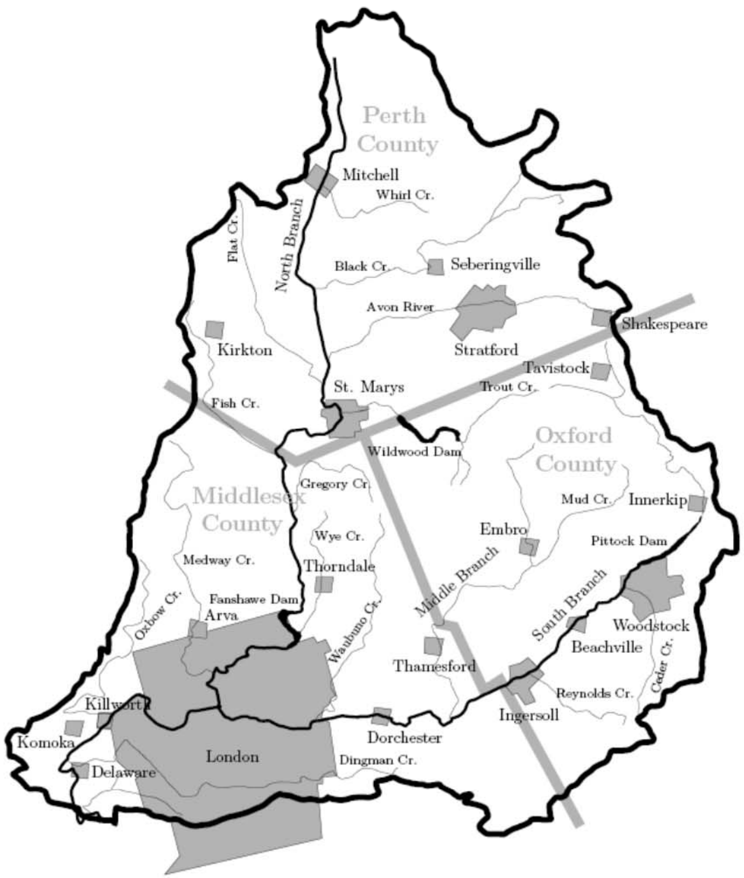
Examples - City

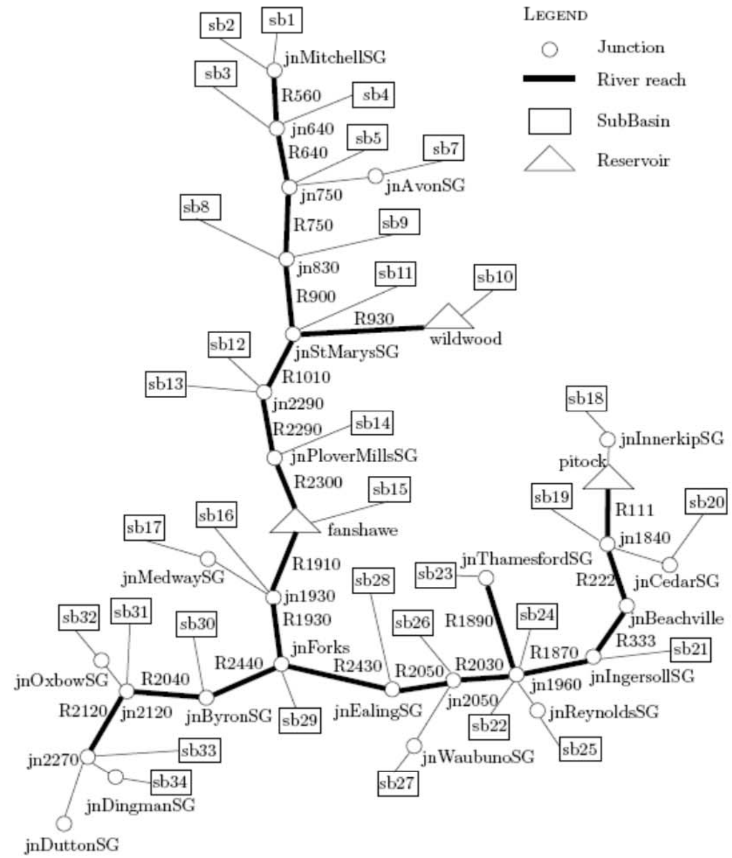
- Two climate scenarios
- Downscaling
  - historic data
  - GCM and
  - weather generator



55 | WATER RESOURCES MANAGEMENT

Examples - City

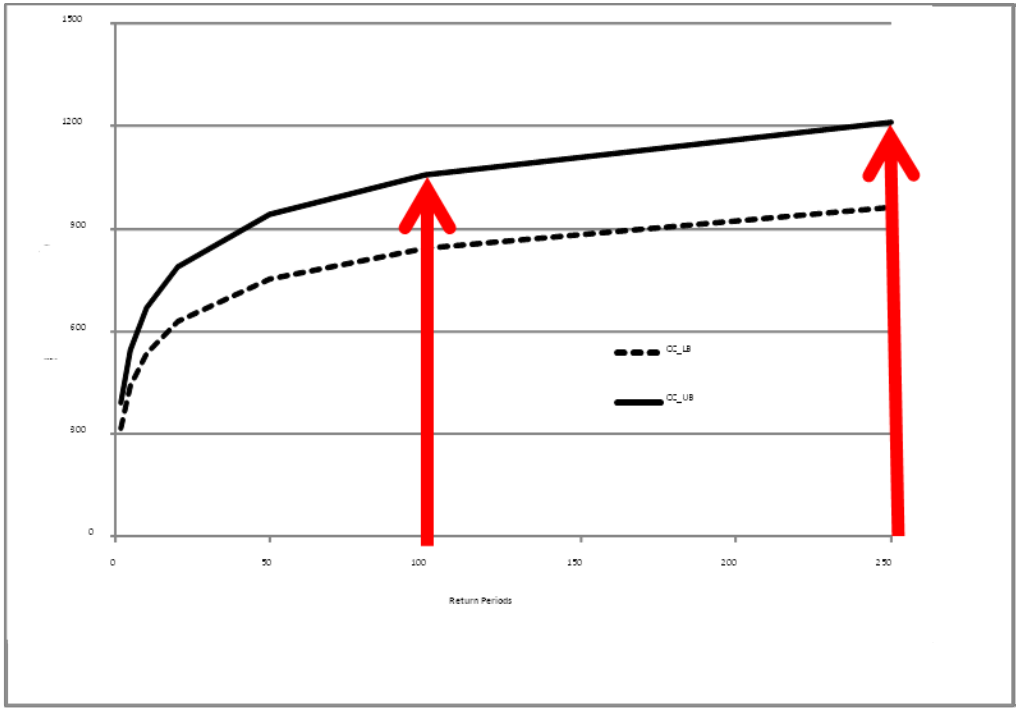




WATER RESOURCES MANAGEMENT

Examples - City

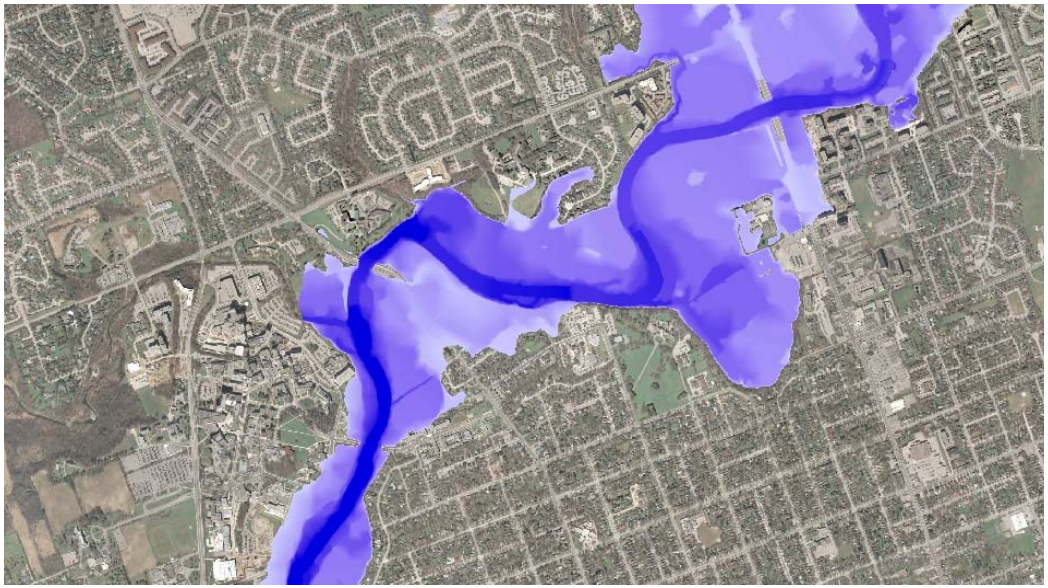
- Two hydrologic scenarios
  - 100 year
  - 250 year



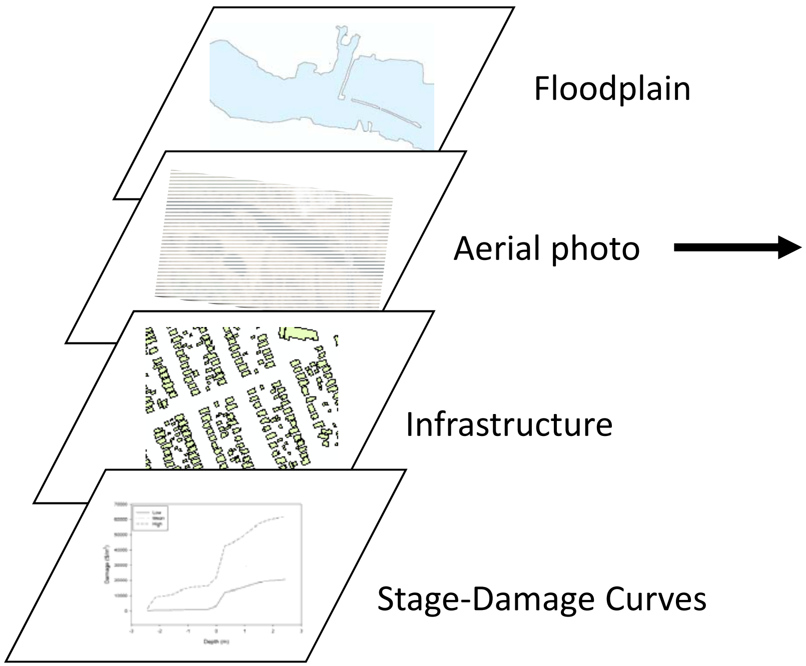

10PM - 6AM

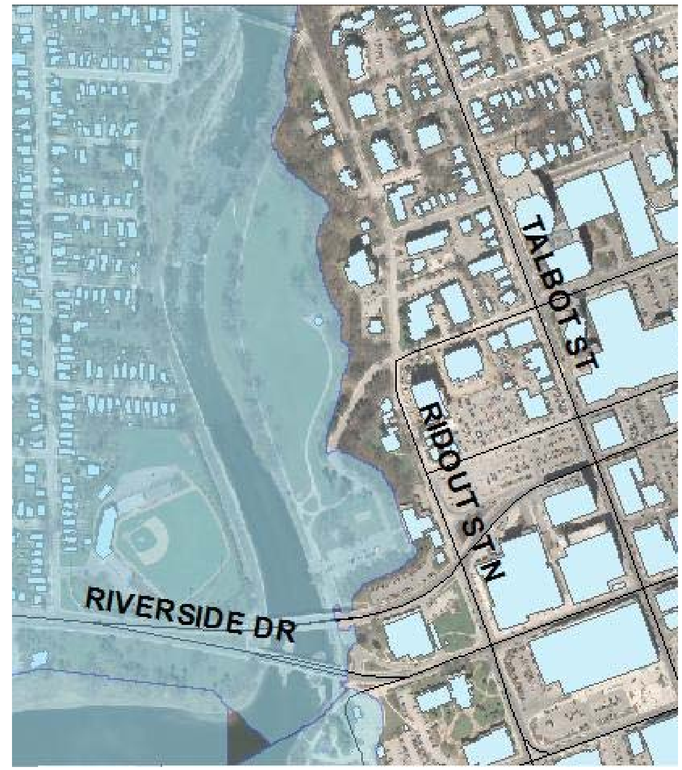
WATER RESOURCES MANAGEMENT

Examples - City



60 | WATER RESOURCES MANAGEMENT
Examples - City

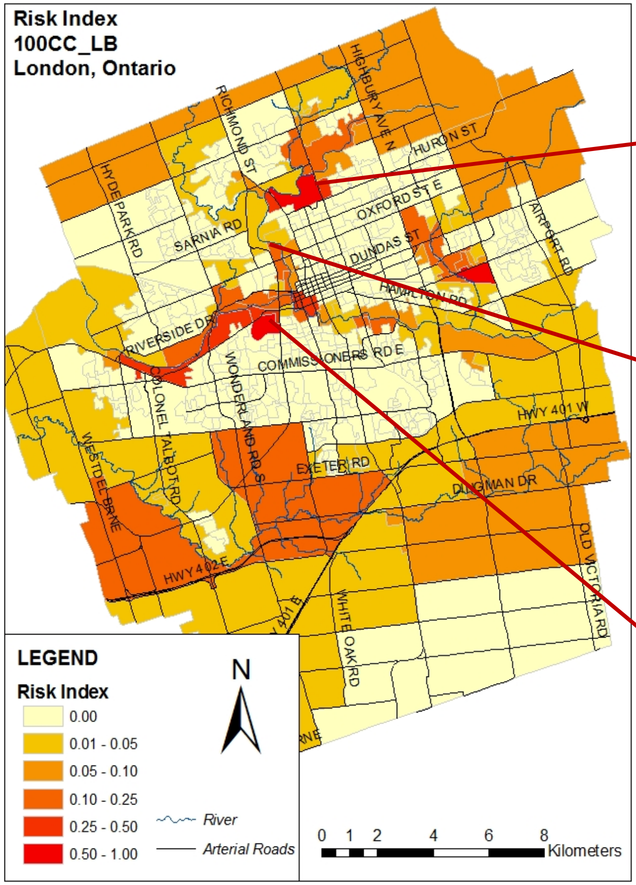




Identify inundated infrastructure

61 | WATER RESOURCES MANAGEMENT

Examples - City

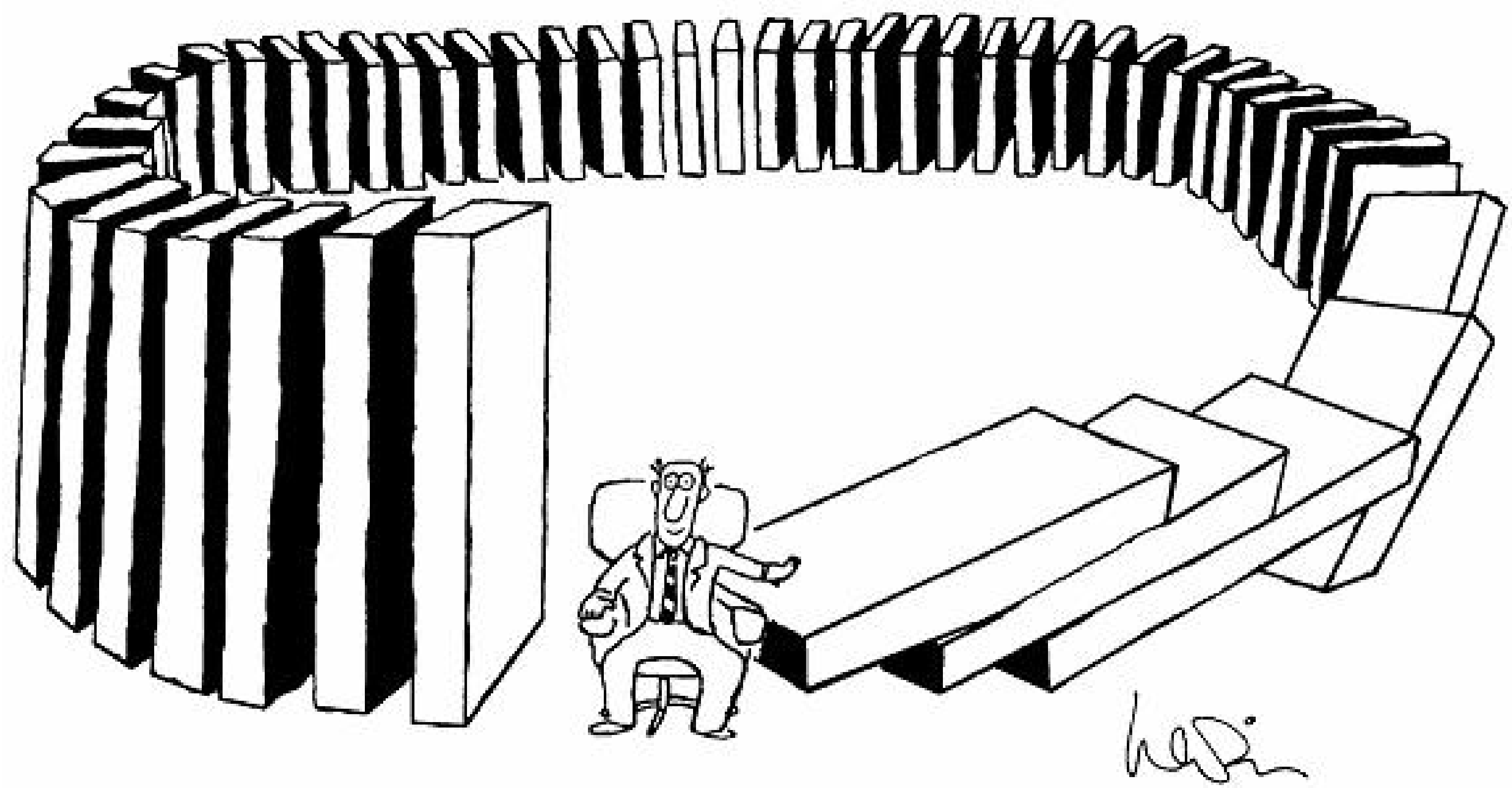


CLIMATE CHANGE AND WRM
What can we do?

- Do not forget – It is all about feedbacks!
  - Be aware of positive feedbacks.
  - Learn what are the tipping points of dangerous feedbacks.
  - Find out what are the tipping points that will make our politicians do something.
- It is not about the planet – it is about us!

CLIMATE CHANGE AND WRM

Feedback



CLIMATE CHANGE AND WRM

Resources

- IPCC (2013) Fifth Assessment Report, *Climate Change 2013: The Physical Science Basis,* *http://www.ipcc.ch*

- Hansen J. (2009) “Storms of my grandchildren”, Bloomsbury, http://www.columbia.edu/~jeh1/

- www.slobodansimonovic.com