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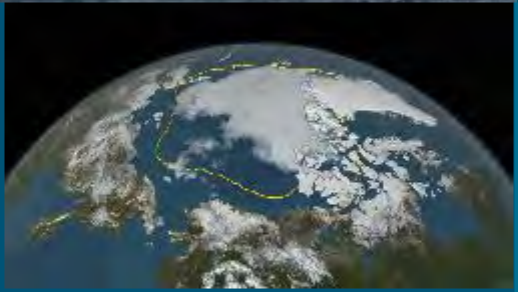
National security implications from tipping events centered in Arctic waters



PRESENTED BY

Diana Bull, Kara Peterson, George Backus, Jasper Hardesty, Amy Powell
Asmeret Naugle, & William Hart

PRESENTATION FOR

The Effects of Climate Change on the World's Oceans
Session 16: Climate, oceans and security
June 4th 2018

U.S. DEPARTMENT OF ENERGY NNSA

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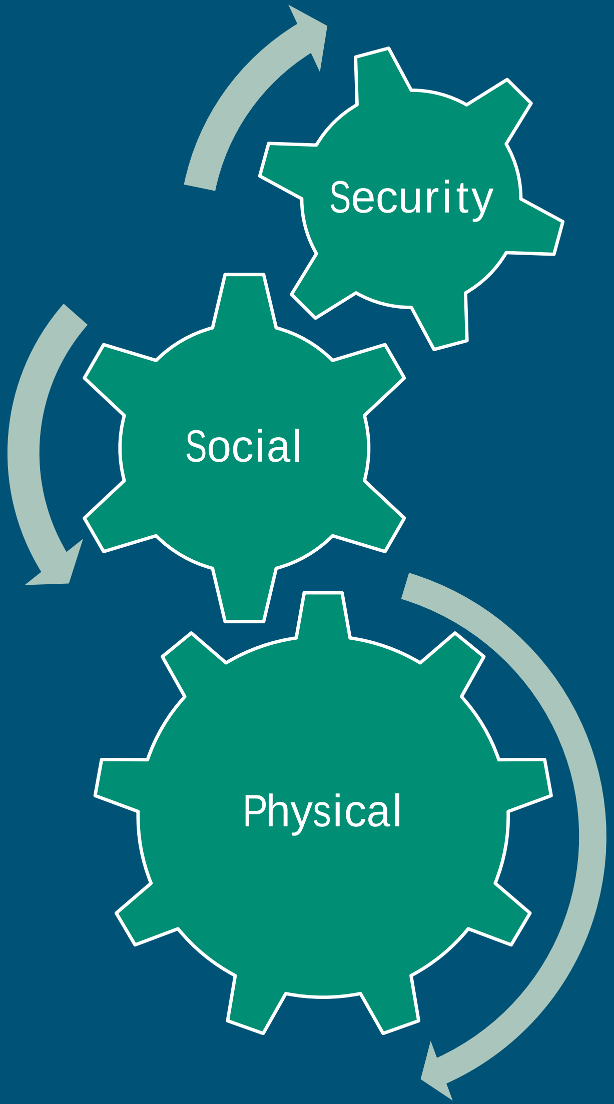
Motivating Question: When, where, and to what degree might national security risks arise around the world from changes in Arctic waters?

Overview of connections
- Arctic changes rippling into global climate
- Systems approach
- Sources of uncertainty

Physical Modeling
- State of the Art
- Needed Enhancements

Anticipatory Security and Climate Decision Tool
- Climate exacerbating global security concerns
- Anticipatory framework to test risk mitigation techniques



Work is partially supported by the Laboratory Directed Research and Development program at Sandia National Laboratories.

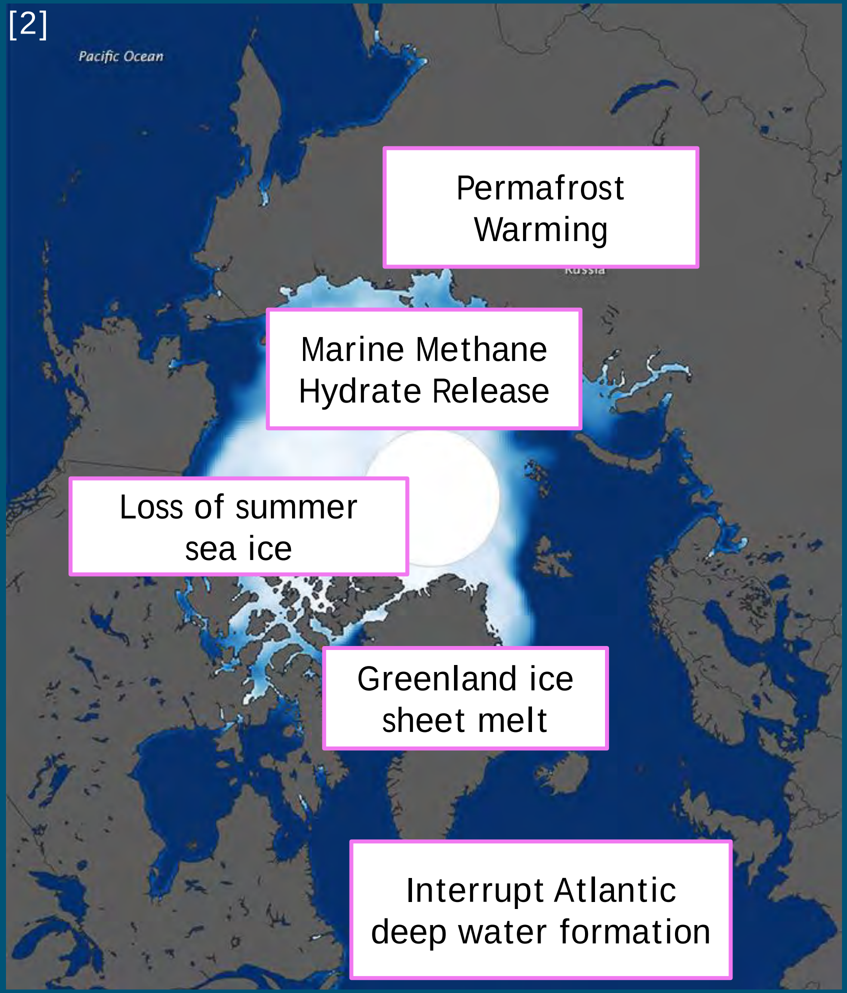
The Arctic Environment is Rapidly Changing

The Arctic is warming at ***2-3 times*** the rate of the rest of the US

What happens in the Arctic ***does not*** stay in the Arctic

Regional Changes Lead to Global Effects: Environmental Connection

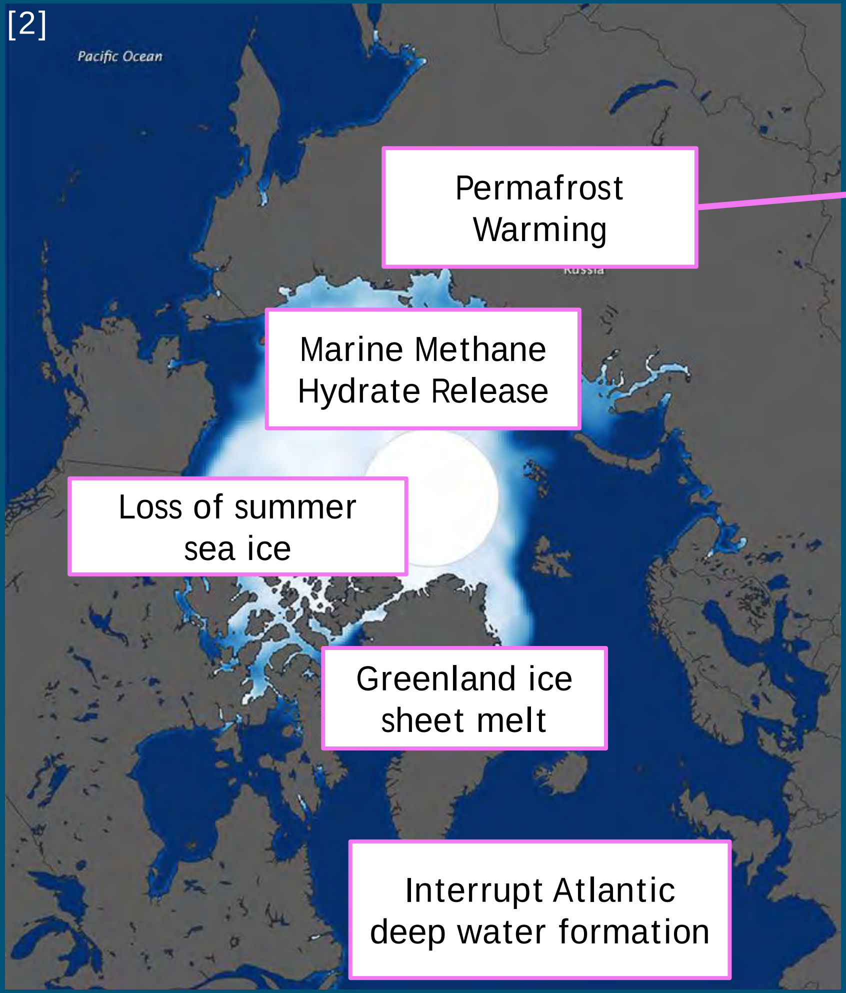
Changes in the Arctic Impact the Entire Earth System [1]



Regional Changes Lead to Global Effects: Environmental Connection

Changes in the Arctic Impact the Entire Earth System [1]

[2]



Global Effects:
Significant greenhouse gas release; changes in hydrology/nutrient loads; increased erosion nutrient loading; ocean acidification; potential release of ancient pathogens [3,4,5,6,7,8]

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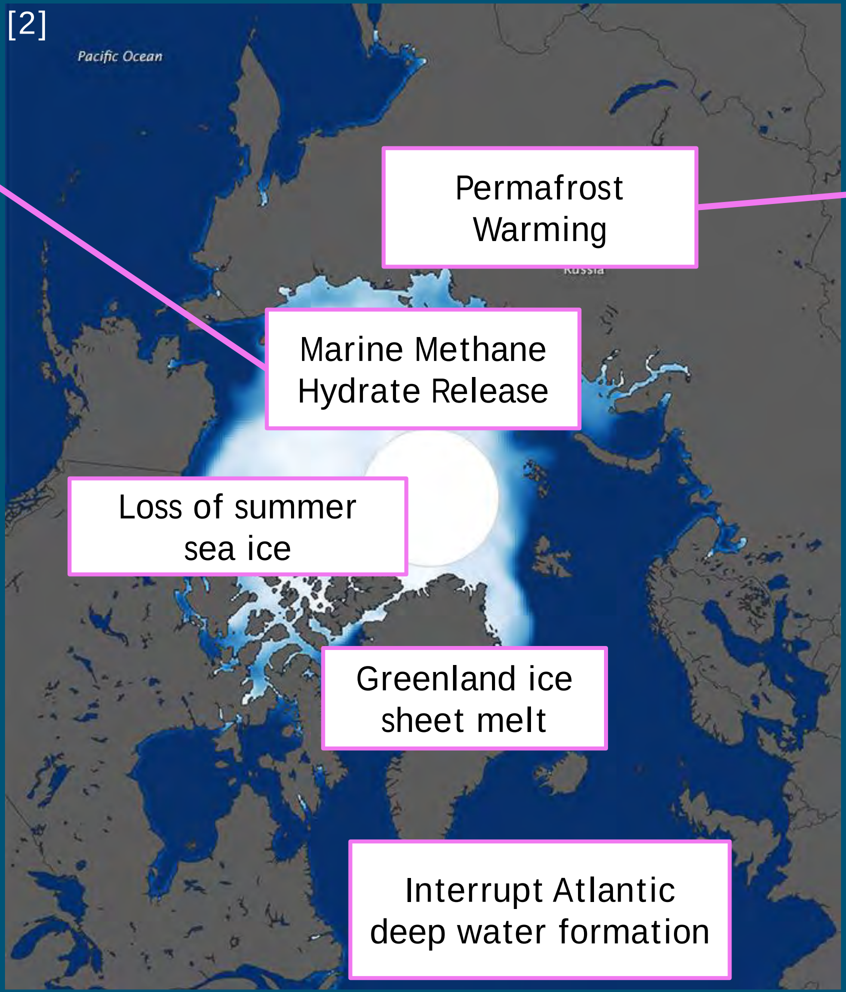

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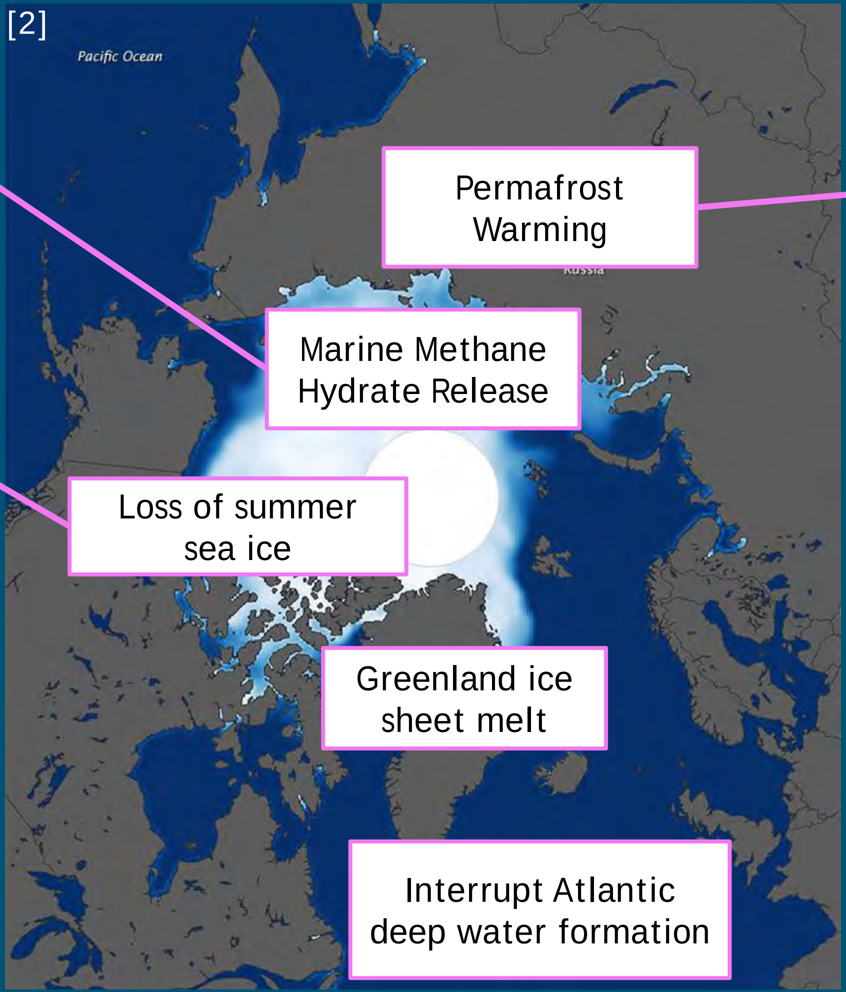

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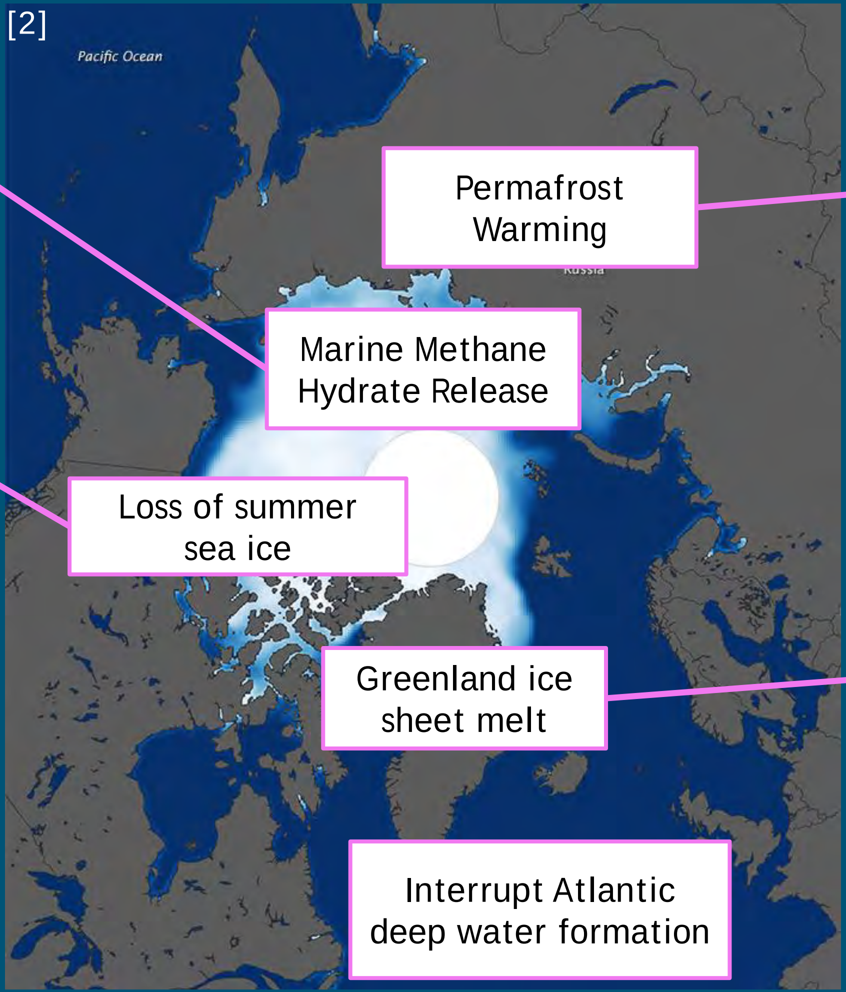

Permafrost Warming

Marine Methane Hydrate Release

Loss of summer sea ice

Greenland ice sheet melt

Interrupt Atlantic deep water formation

Global Effects:
Significant greenhouse gas release; changes in hydrology/nutrient loads; increased erosion nutrient loading; ocean acidification; potential release of ancient pathogens [3,4,5,6,7,8]

Global Effects:
Sea level rise; ocean current alterations (temperature and salinity changes) [14,15,16,17]

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Shutdown of Atlantic thermohaline circulation (THC) leading to
Regional cooling; significant weather shifts in the N. hemisphere [18, 19, 20]

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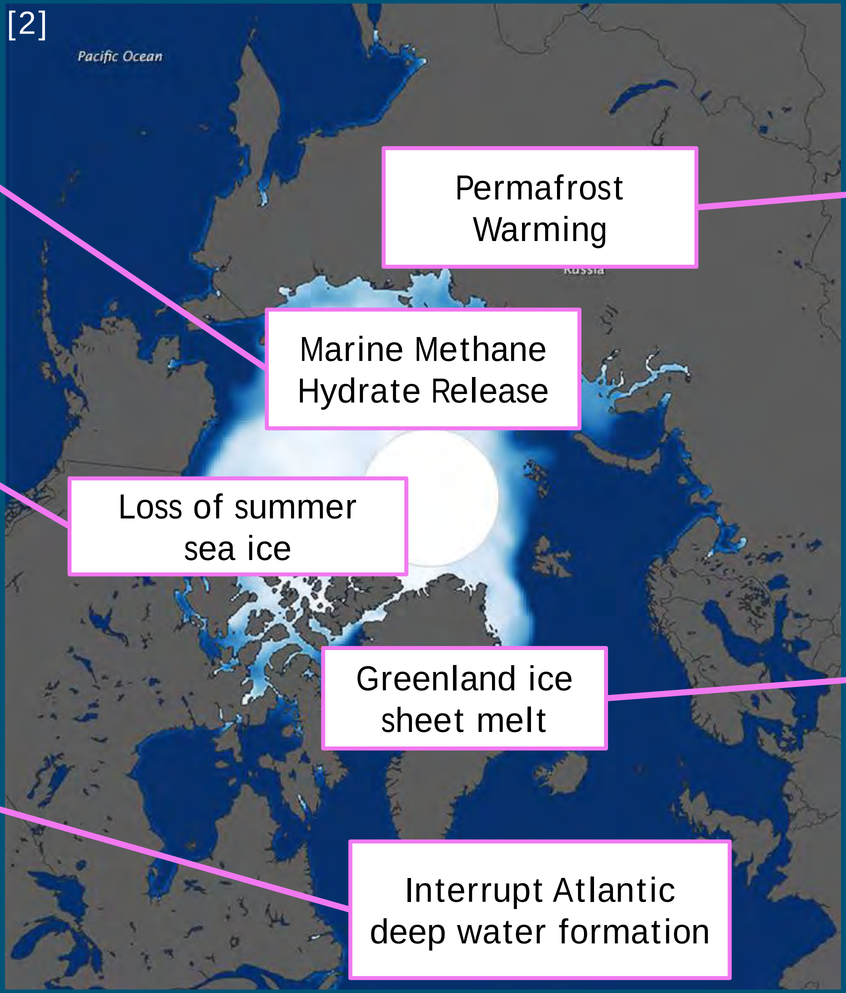

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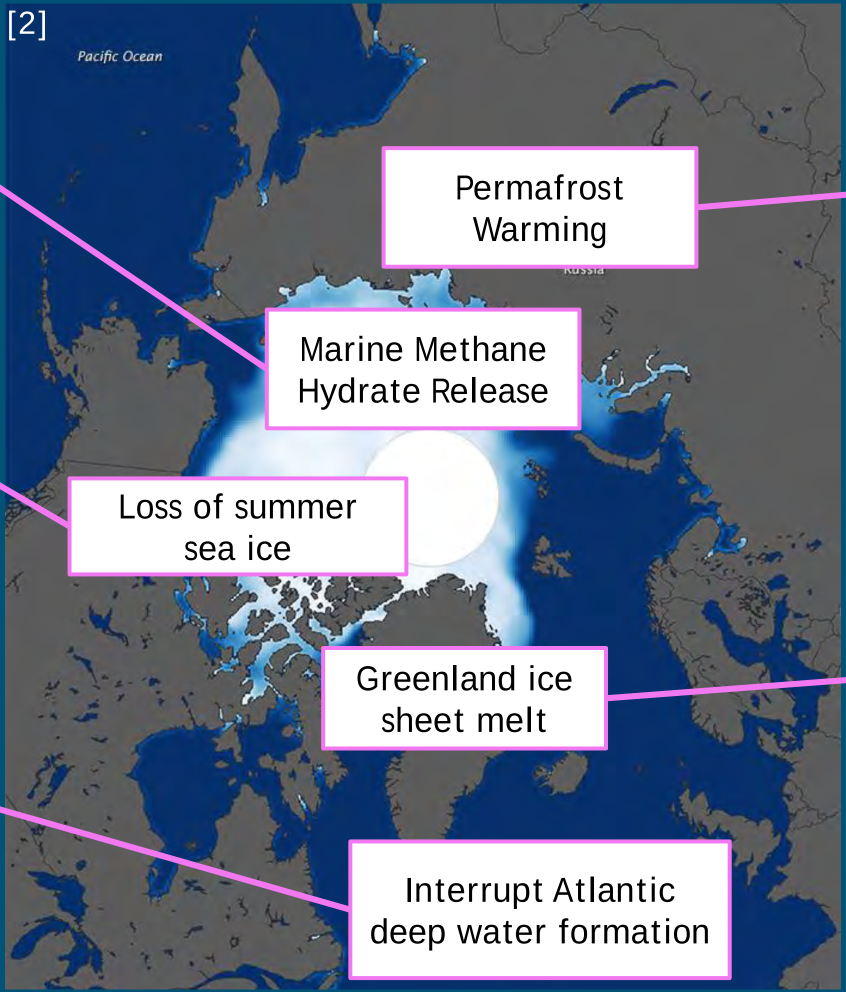

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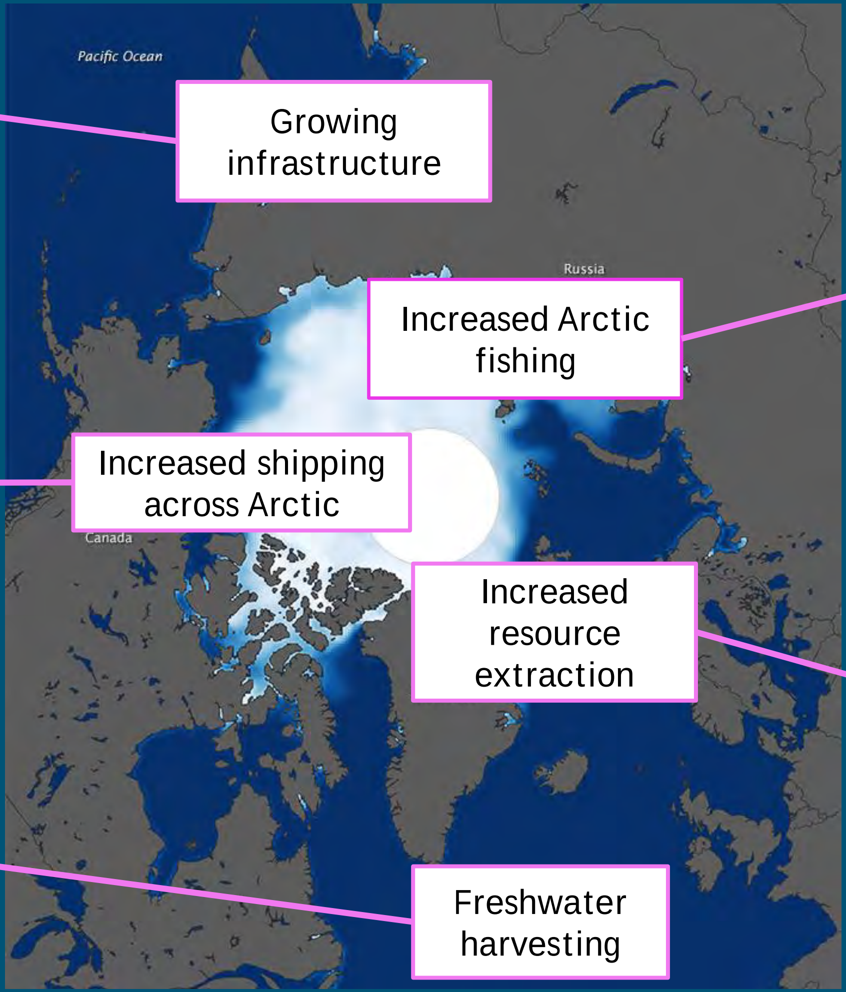
"Given the huge complexity of comprehensive process-based climate models …the uncertainties associated with the possible future occurrence of abrupt shifts are large and not well quantified." [21]

Socio-economic-political Changes Lead to Regional Effects: System Connection

Activity in the Arctic Impacts Environmental Conditions

Regional Effects:
Localized warming of permafrost near foundations; ecosystem alterations; increased population

Growing infrastructure



Regional Effects:
Ecosystem alterations; increased population; subsistence & recreational use impacts

Increased Arctic fishing

Regional Effects:
Release of black soot; ecosystem alterations; subsistence & recreational use impacts; increased population

Increased shipping across Arctic

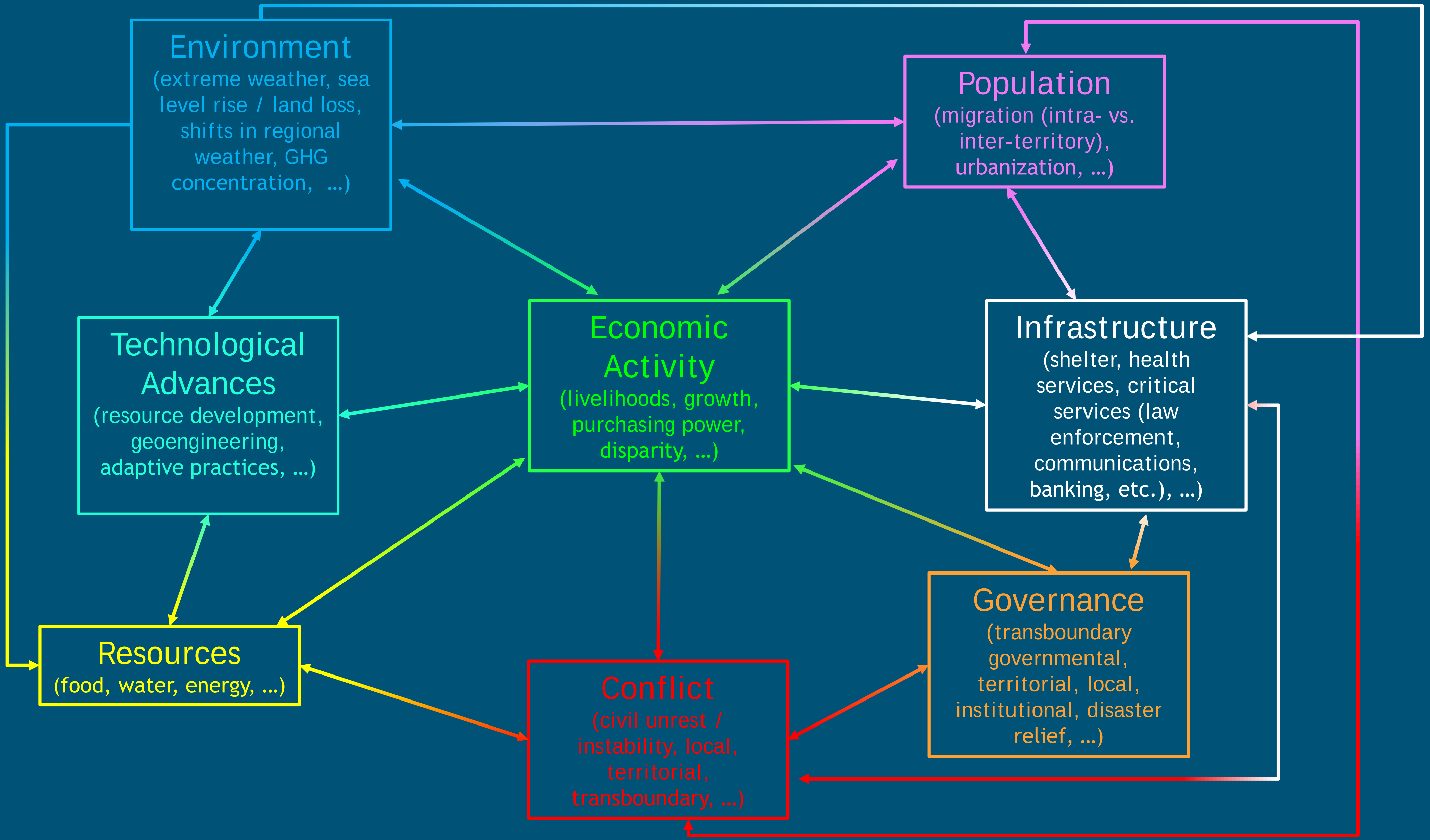
Increased resource extraction

Regional Effects:
Ecosystem alterations, sea ice sensitivity, subsistence & recreational use impacts; increased population

Regional Effects:
Removal of fresh water in form of ice; ecosystem alterations; subsistence & recreational use impacts

Freshwater harvesting

System Analysis: Connection between Global Environmental Changes & Social Factors



System Analysis: Sources of Uncertainty

Physical Systems

- Inaccurate or incomplete models
  - Highly complex
  - Inability to include all contributing factors
    - Lack of knowledge about contributing factors
    - Inherent uncertainty in contributing factors (for example, weather)
  - Resolution requirements (spatial scales & computing power)
- Availability of calibration/validation data
- Strong dependence on initial conditions

Socio-economic-political Systems

- Looser concepts of causality
- Lack of universality
- Inaccurate or incomplete models
  - Highly complex
  - Inability to include all contributing factors
    - Lack of knowledge about contributing factors
    - Inherent uncertainty in contributing factors
- Availability of calibration/validation data
- Strong dependence on history and initial conditions

Full System

- Mixed-modeling approach
  - Physical sciences with social sciences
  - Models may utilize different methods
  - All sub-models have associated uncertainty
- Multi –spatial and –temporal scales
  - Feedbacks between systems, inclusive of delays, spanning multiple scales
- Increased complexity can lead to difficulty in interpretation
- Validation increases in difficulty
  - Validation of sub-models is insufficient – full system model must also be validated

Approach towards Physical Environment Systems

State of the Art Physical Modeling

Earth System Models

Understand the dynamics of the physical components of the climate system: atmosphere, ocean, land, ice (sea and land), and biogeochemical cycles.

Goal: decadal & centurial predictions of global climate

- Spatial Resolution: 100's of km
- Physics: Simplified parameterizations of unresolved processes appropriate to spatial scale
- Examples: E3SM (DOE), CESM (NCAR), NESM (Navy), GFDL (NOAA)

Challenges: data processing / analytics; computational expense limits resolution and ability to capture important small-scale processes

Regional Models

Often, high resolution versions of the ESMs in a geographically limited area

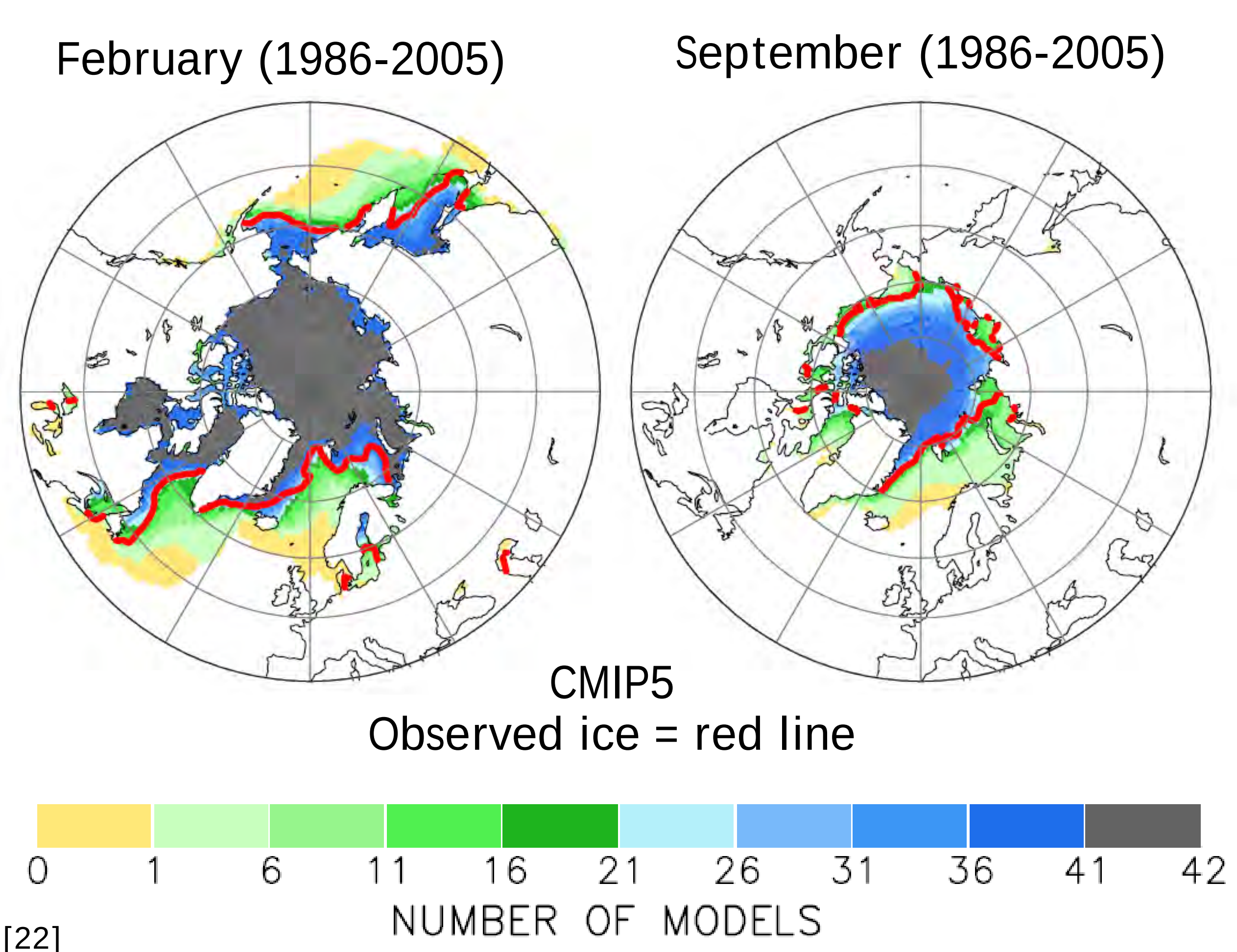
Goal: seasonal & decadal predictions of region

- Spatial Resolution: 10's of km
- Physics: Typically similar parameterizations as their parent ESM model
- Examples: RASM (DOE/NPS), …

Challenges: data processing / analytics; effectuating results in ESM's

State of the Art Physical Modeling

Earth System Models



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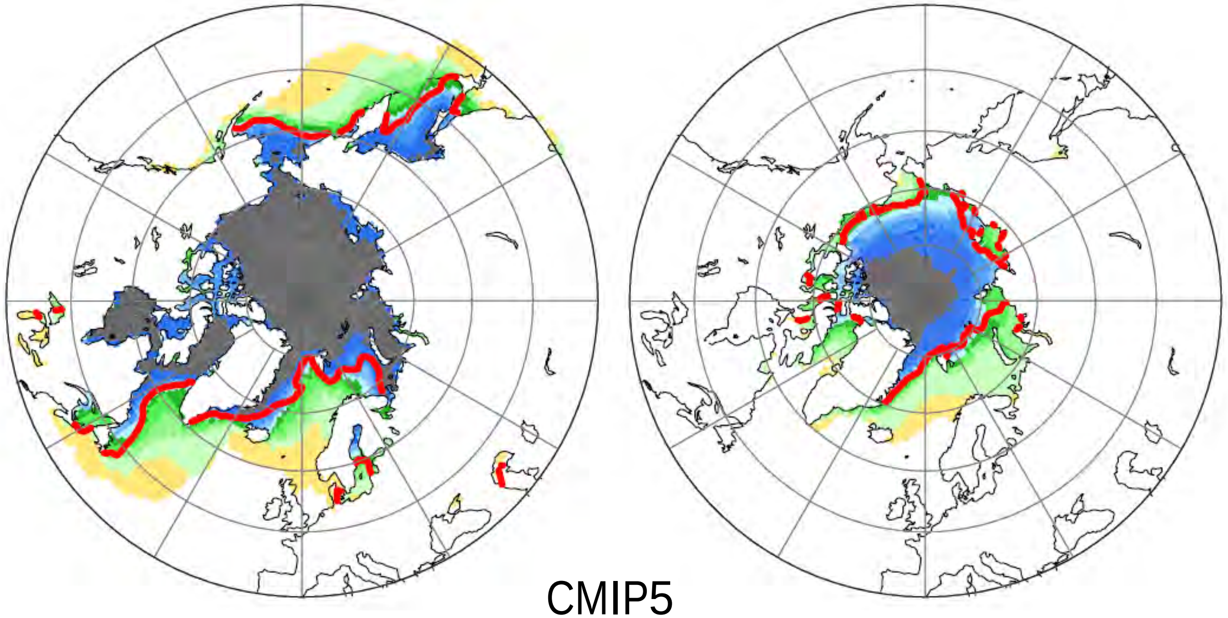
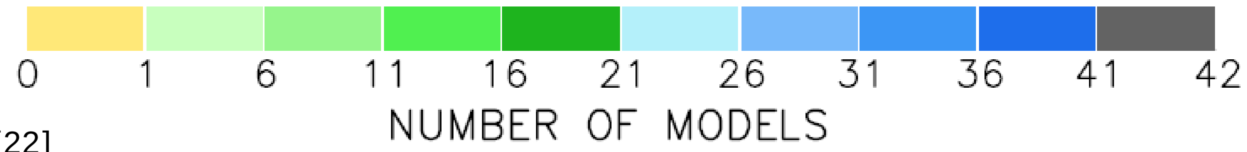
State of the Art Physical Modeling

Earth System Models

February (1986-2005) September (1986-2005)



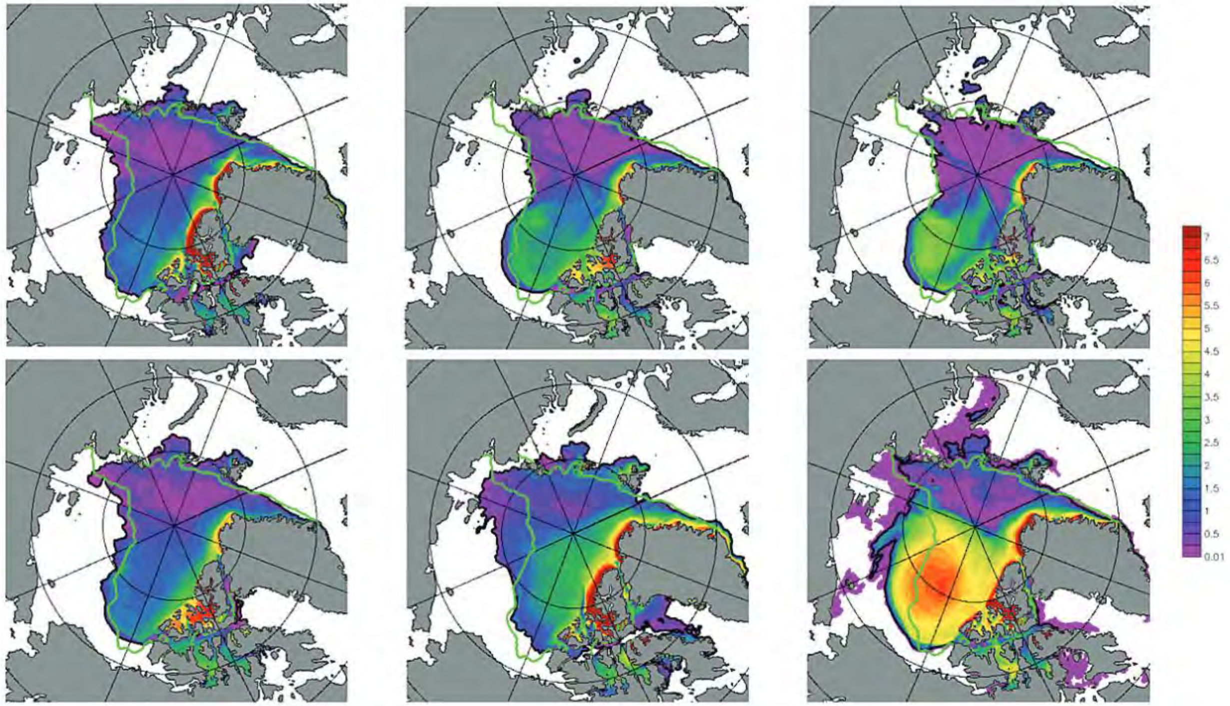
CMIP5
Observed ice = red line



[22]

Regional Models

September 2007



RASM distinct initialization conditions
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[23]

State of the Art Physical Modeling

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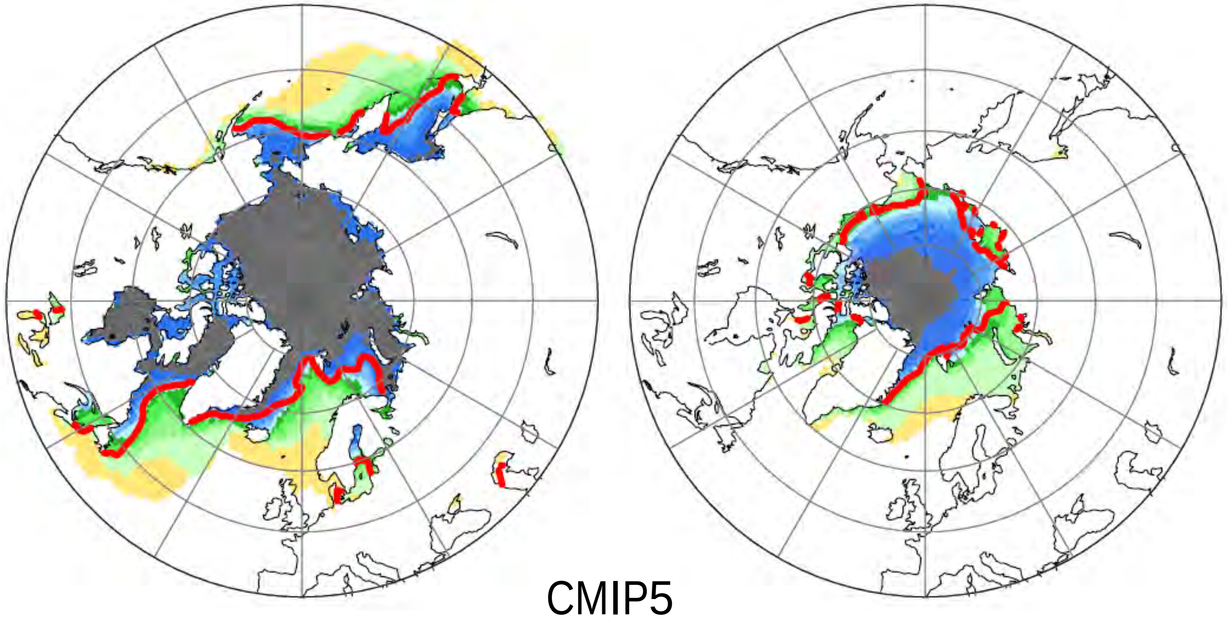

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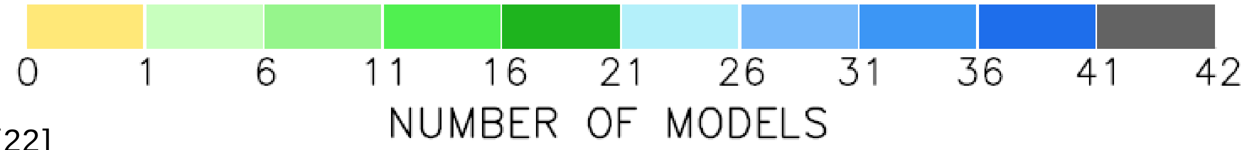

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Regional Models

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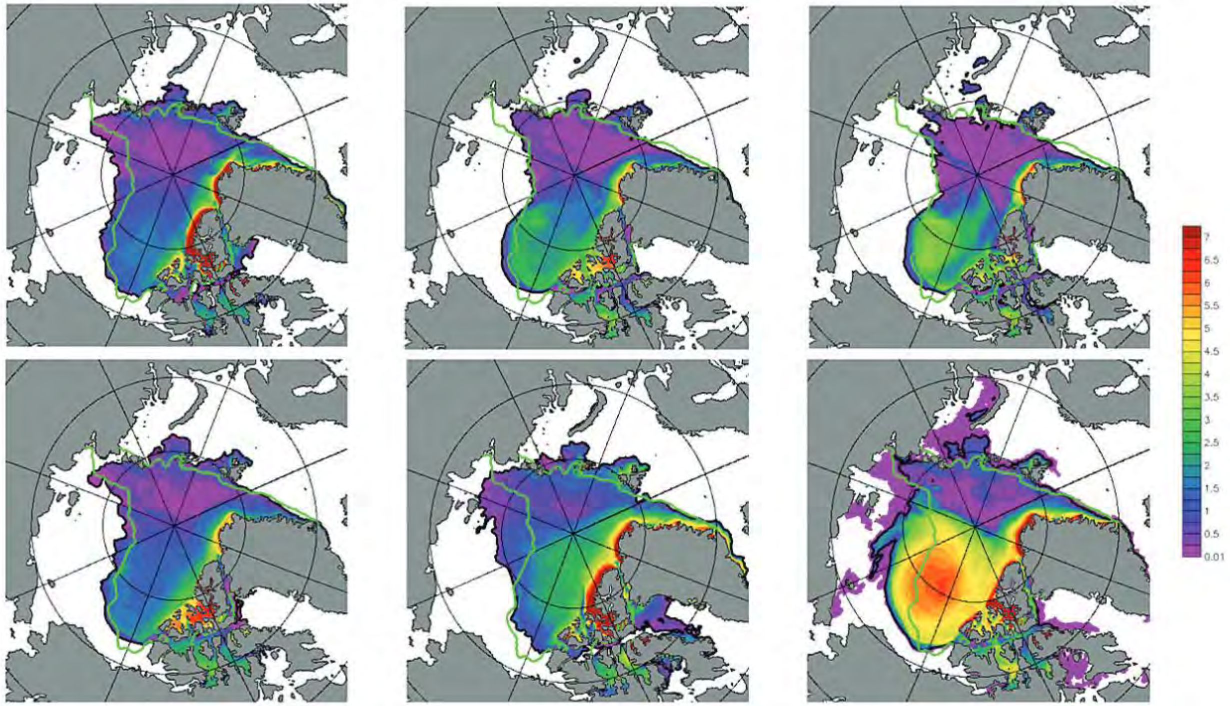

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Key Physical Modeling Enhancements

Process Models

Don't just increase the resolution—enhance the physics!

- Add new process models to capture dynamics of changing Arctic (e.g. ocean waves, ice floes, hydrology and 3D heat flow, eddy resolved mixing, etc.)
- Incorporate feedbacks between physical systems key to evolving dynamics (e.g. ice floe distribution and waves, ice concentration and humidity in atmosphere, etc.)

Computational Architecture

Couple these enhanced models ***back into*** the global simulations

- Develop ***scale-aware variable resolution*** architecture: alter the underlying physics to match the resolution ensuring continuous & conservative coupling between resolutions

Data Analytics

Develop analysis tools to identify critical parameters and changes whilst tracing downstream implications

Uncertainty Quantification

Evaluate sensitivities of critical parameters and evaluate skill with validation data

Development of an Anticipatory Security and Climate Decision Tool

Key Factors in Global Security

Governance

- Influencing factors: cooperation mechanisms, strength and breadth of existing institutions, policy response effect, scale of problem (spatial, economic, population percentage), …

Resources

- Uncontested access to and ability to produce / procure food, water, and energy at sufficient caloric levels and purity to maintain health of population, …

Economy

- Maintenance of livelihoods and purchasing power, overall growth of the economy, disparity minimizing policies, …

Infrastructure

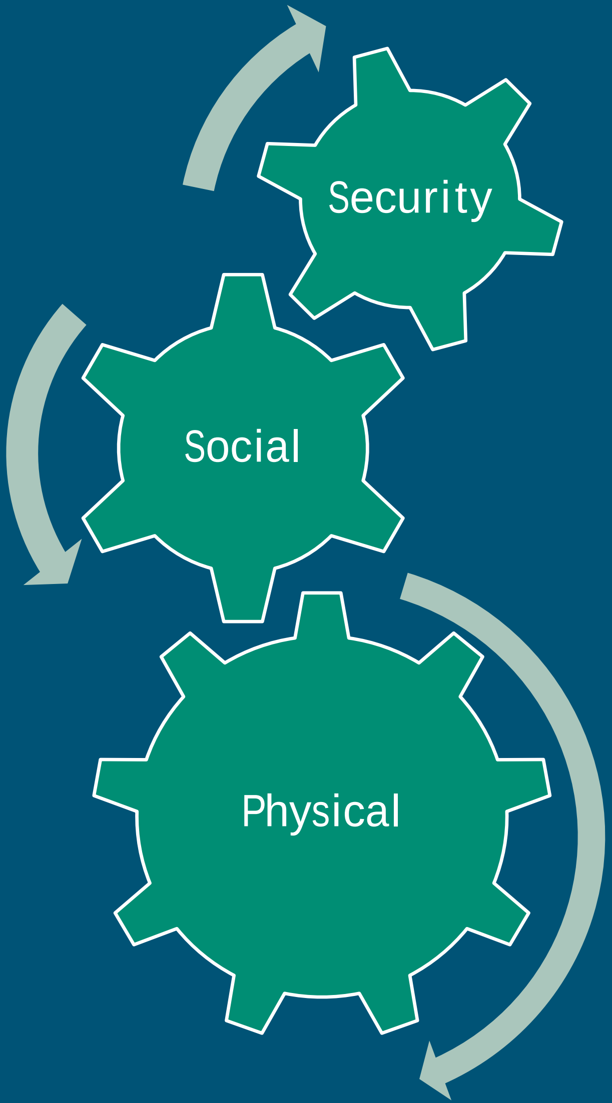
- Integrity and availability of: personal shelter, health services, critical services (law enforcement, banking, etc.), …

Population

- Rates of population shifts through migration (intra- vs. inter-territory) and urbanization, duration of resettlement, shifts in cultural identification, …

Conflict

- Influencing factors: resource stability, health of economy, personal health, infrastructure, discrimination, …



Both magnitude and rate of change affect security outcomes

State of the Art Approaches

Case studies

- Often limited in focus (e.g. water stress, food security, destruction of property)
  [Table 12.1 in 24 has comprehensive list of references]
- Often selective in scope of inclusion (e.g. not identifying drivers of water shortage, just outcomes)
- Often too specific to assist in anticipatory decisions not directly related to case study

Broad coupling [24, 25, 26, 27]

- Qualitatively linking dynamics between environmental changes and socio-economic-political changes
- Often too generalized or reliant upon weakly validated correlations to assist in anticipatory decisions

Fifth Assessment Report of the IPCC.

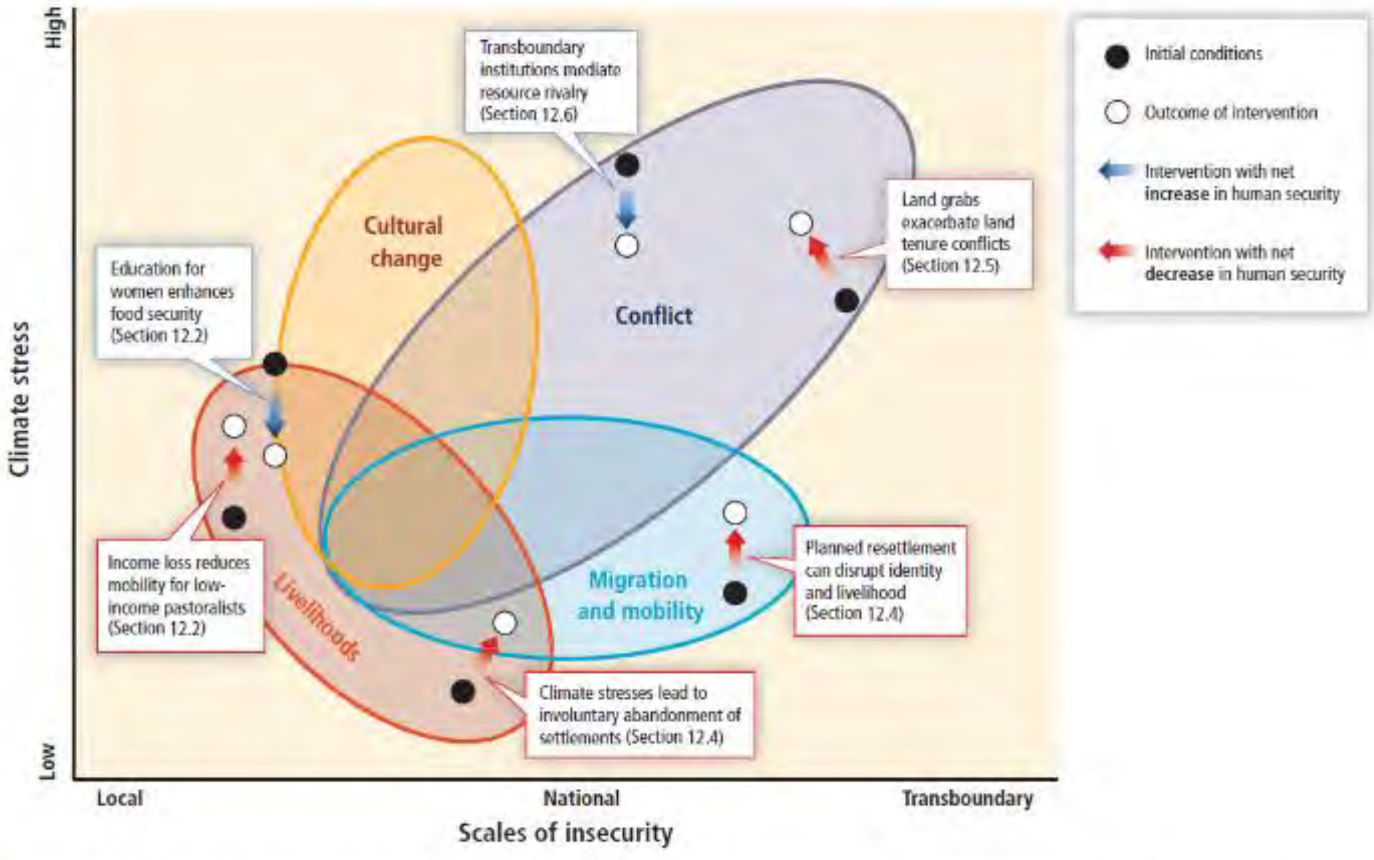
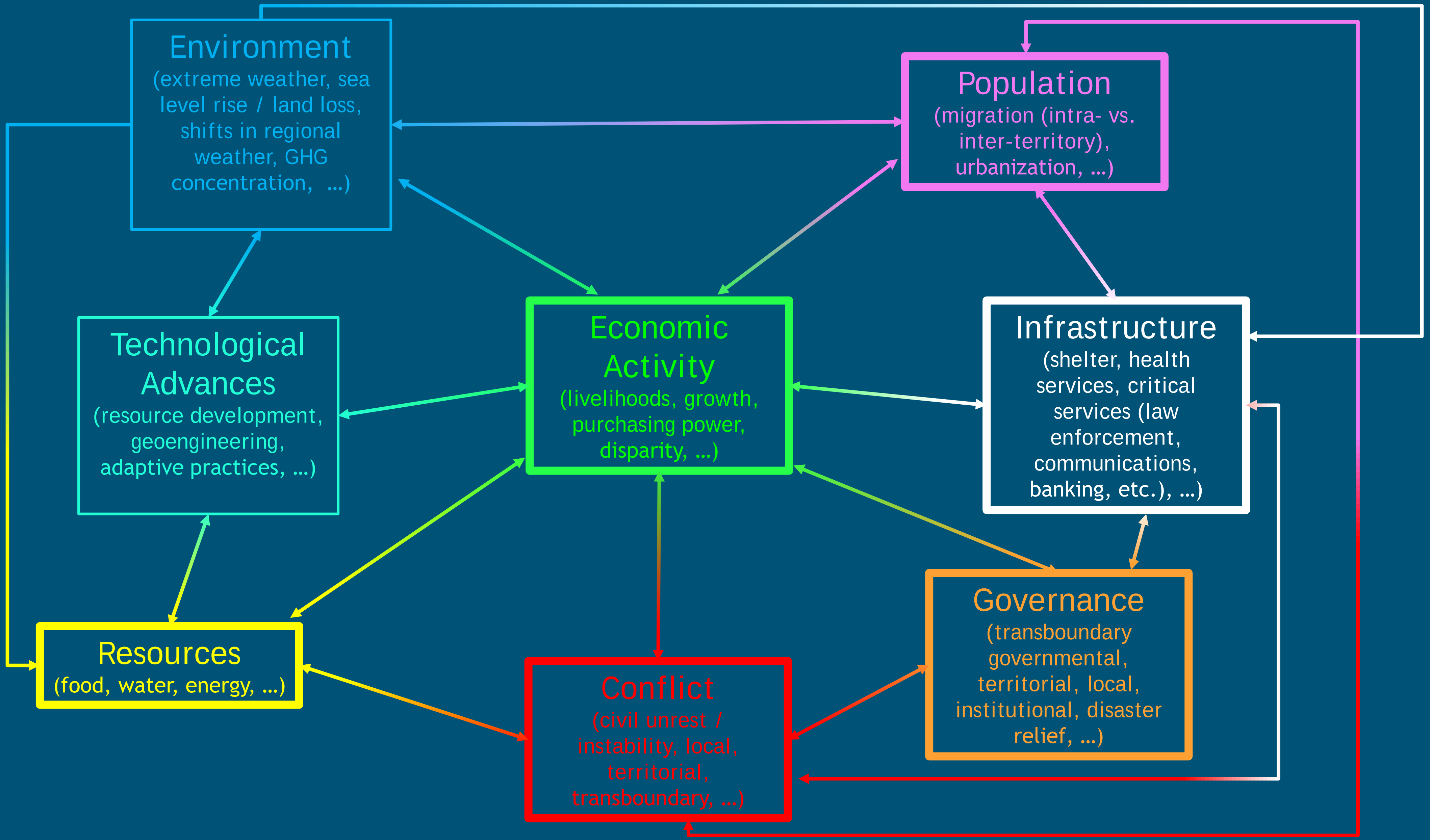


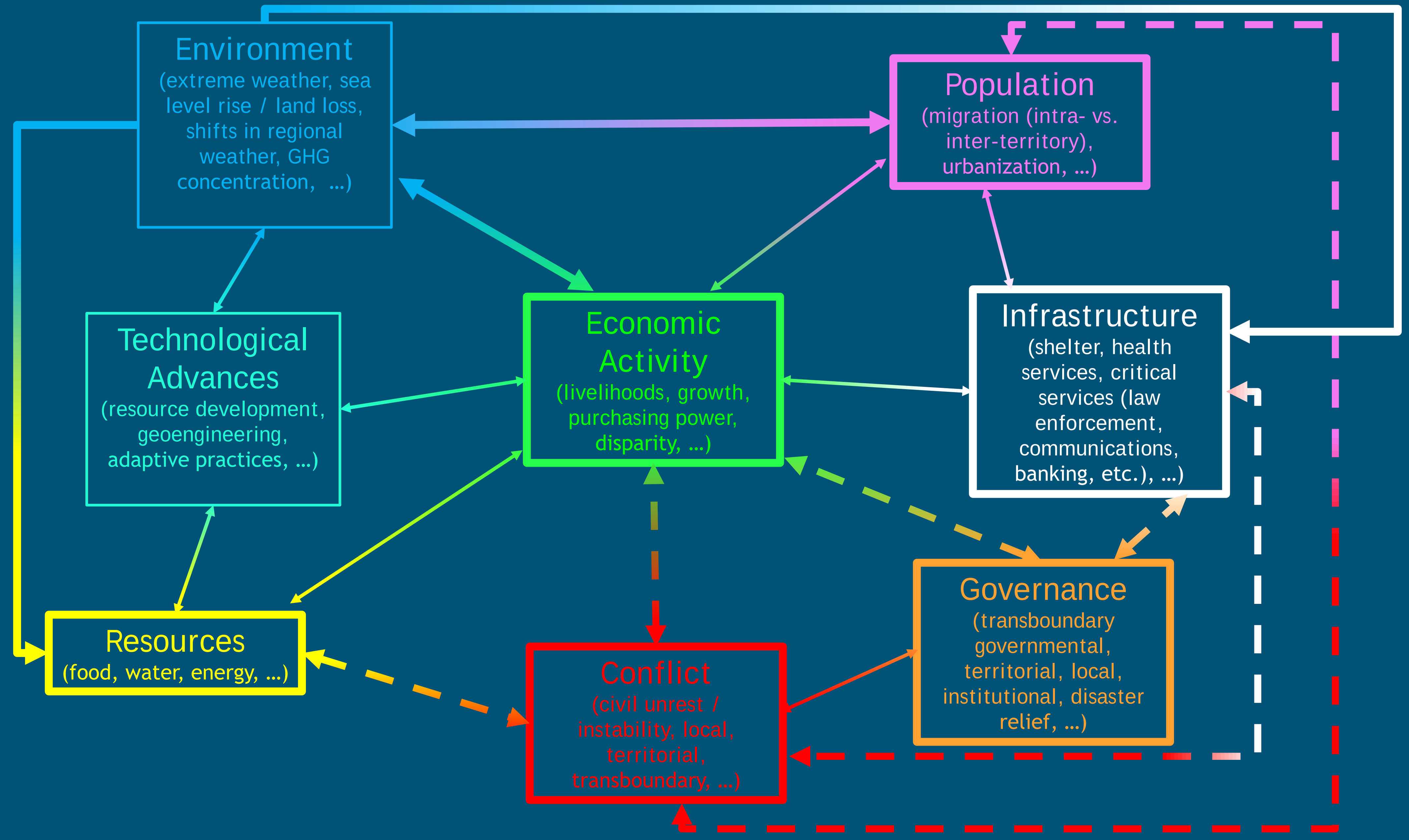
Figure 12-3 | Synthesis of evidence on the impacts of climate change on elements of human security and the interactions between livelihoods, conflict, culture, and migration. Interventions and policies indicated by difference between initial conditions (solid black) and outcome of intervention (white circles). Some interventions (blue arrows) show net increase human security while others (red arrows) lead to net decrease in human security.

[24]

System Dynamics: Security Factors

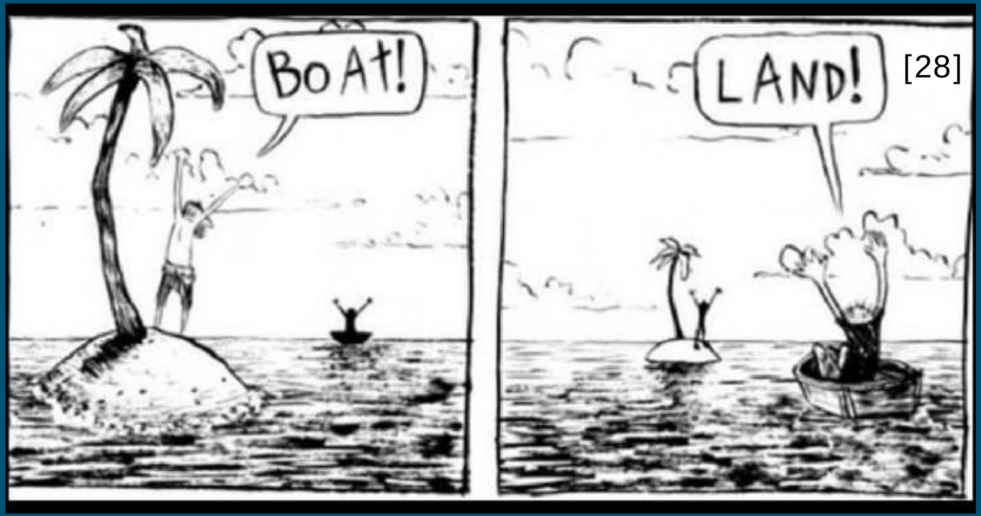


System Dynamics: Linking Environment to Security Factors

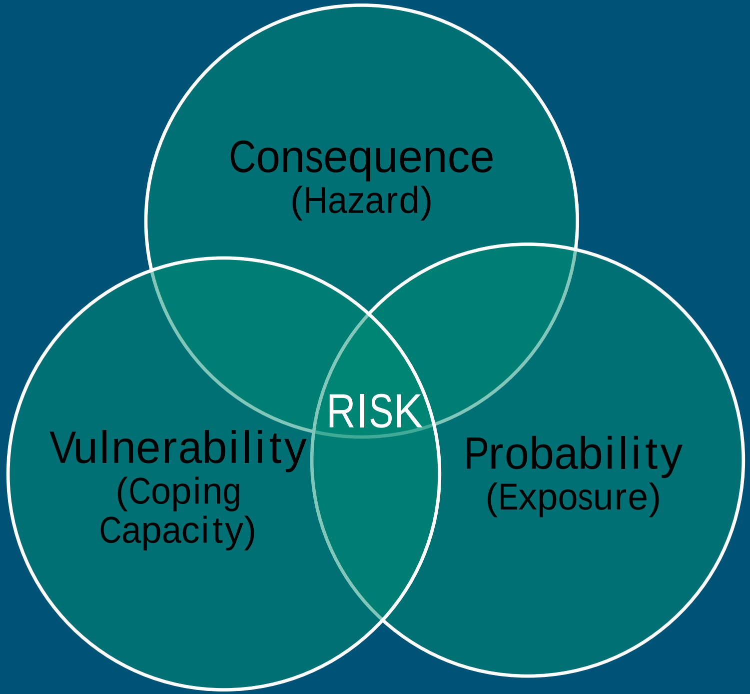


Set the perspective

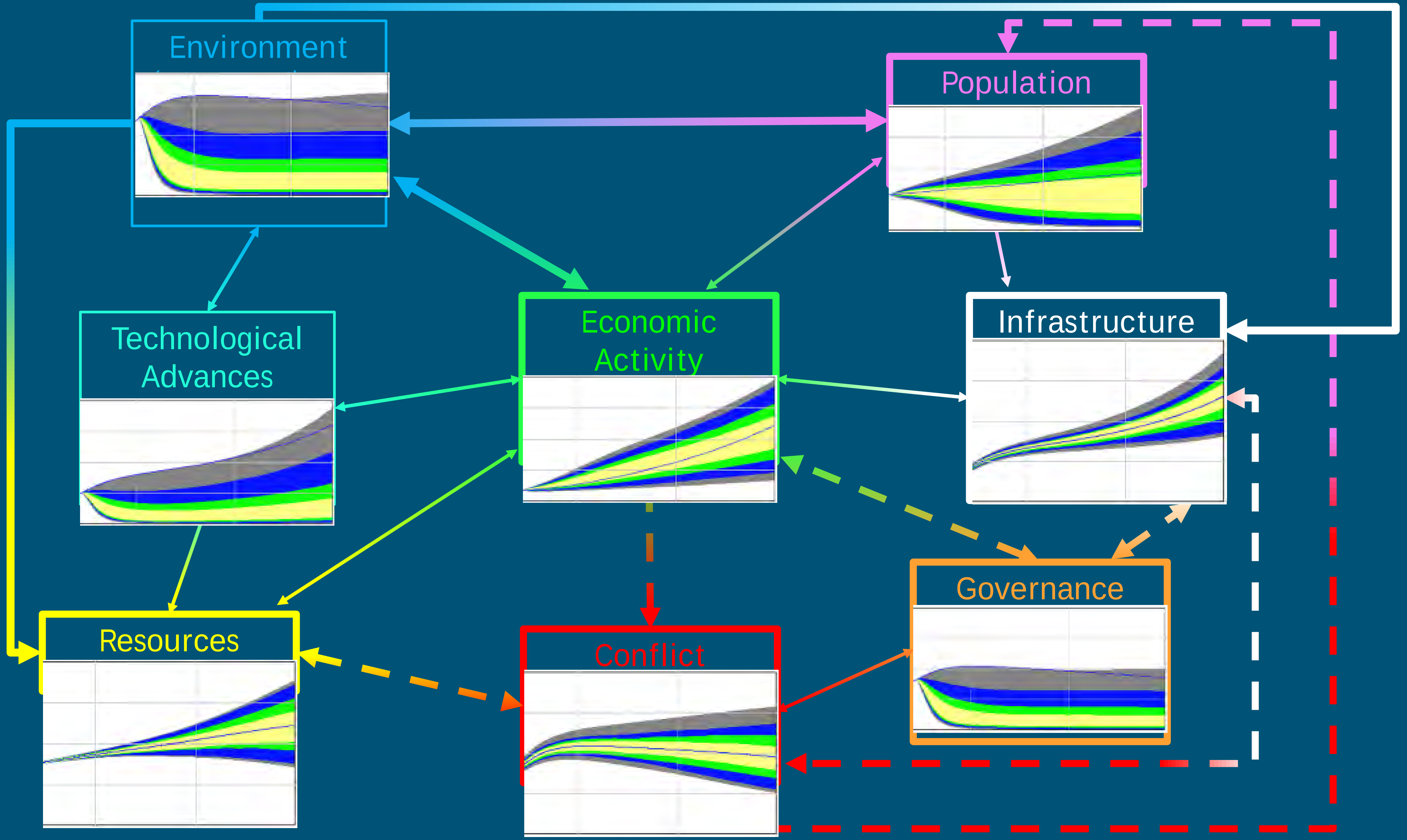
Prioritize the problems to be addressed by identifying and engaging relevant stakeholders
- Characterize consequence metrics for stakeholders (e.g. safety, monetary, assets, etc.)
  - Establish unacceptable consequences
- Establish constraints for mitigation (e.g. monetary, diplomatic, personnel deployments, etc.)



Configure the system dynamics model
- Prioritize information in model for stakeholder perspective
- Employ actuarial techniques to establish risk assessments from model outputs
  - Consequences directly related to magnitudes from model output



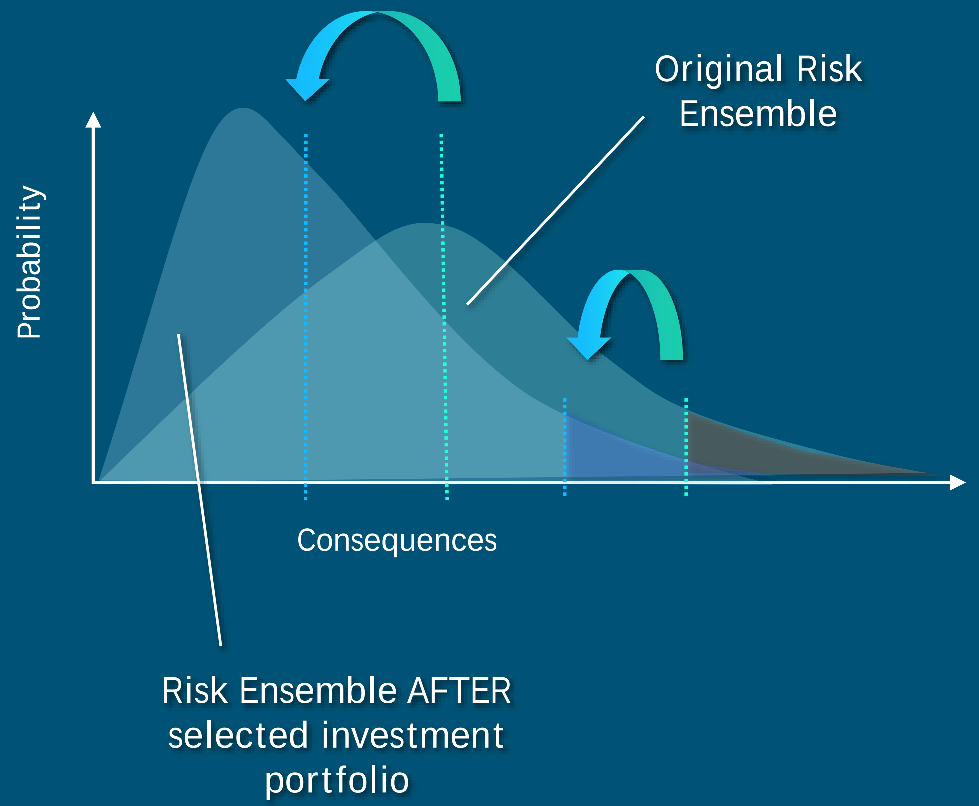
System Dynamics Output: Quantitative forecasts inclusive of uncertainty



Decision making under uncertainty

Translate system dynamics outputs

- Develop risk assessments
  - Establish vulnerability
- Quantify mitigation constraints



Develop risk-mitigation decisions

- Progressively Hedged Decisions: based on the ***consequences*** that will occur over the lifetime of the risk assessment and optimized to minimize the overall risk of the entire ensemble
  - Optimization based on risk assessment and constraints
  - Automated mechanism based on mathematical framework catered to stochastic problems

"balance the risk of having inadequate capabilities or insufficient capacity when required to operate in the region with the opportunity cost of making premature and/or unnecessary investments" [29]

Security and Climate Decision Tool—An Anticipatory Framework

Identify problem

- Identify consequences of interest to stakeholders (stability of water-sharing agreements, loss of national security infrastructure (e.g. naval bases), etc.)

Evaluate System Dynamics

- Configure system dynamics models to incorporate relevant physical and socio-political-economic dependencies

System Dynamics Model

Physical Modeling

- Reduce uncertainty in physical modeling
  - High-resolution regional model coupled into the earth system models
  - Process models that resolve feedbacks at relevant spatial and temporal scales

Social Modeling

- Incorporate tunable socio-political-economic models catered to the time-frame and locations
  - Employ sensitivity analysis to identify / refine driving variables

Risk & Constraints

- Employ uncertainty in system dynamics model to develop robust and quantitative risk assessments
- Establish mitigation constraints

Optimal Decision

- Employ optimization framework (progressively hedged decisions) to maximize responsiveness to *entire* risk assessment

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QUESTIONS

System Dynamics Modeling

Identifies and models feedback and dependencies between disparate sectors to develop quantitative anticipatory analysis

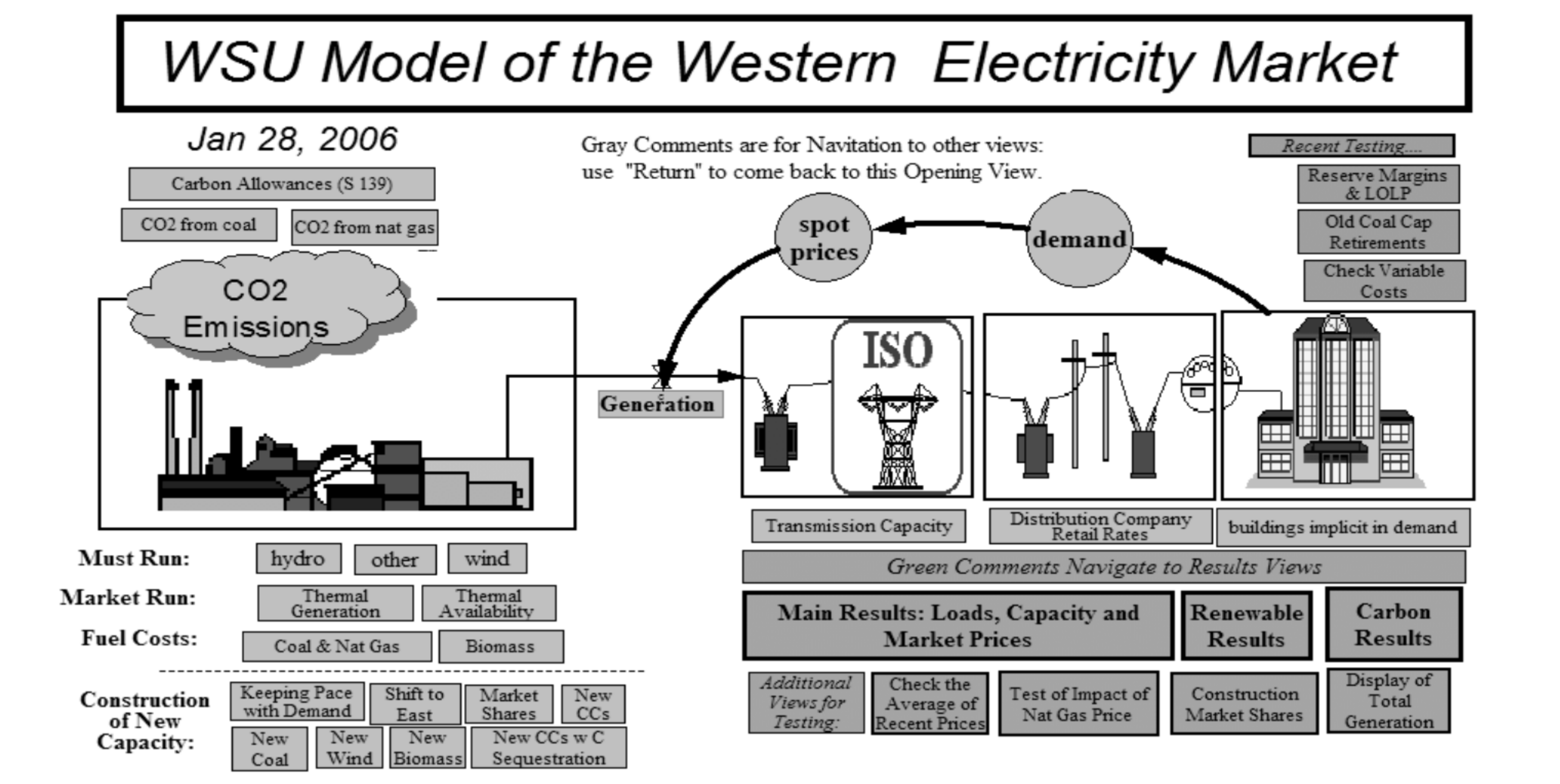
Can integrate uncertainty through risk analysis, policy analysis, scenario analysis, sensitivity analysis…

Mixed-modeling can incorporate models of all system aspects

- For example, can integrate hard physical sciences with social disciplines
- Examples:
  - Energy systems: Dimitrovski, A., Ford, A., & Tomsovic, K. (2006). An interdisciplinary approach to long-term modelling for power system expansion. *International journal of critical infrastructures*, *3*(1-2), 235-264.
  - Climate policy: Sterman, J., Fiddaman, T., Franck, T., Jones, A., McCauley, S., Rice, P., ... & Siegel, L. (2012). Climate interactive: the C-ROADS climate policy model. *System Dynamics Review*, *28*(3), 295-305.
  - Climate-induced migration: Naugle, A., Backus, G. A., Tidwell, V. C., Kistin-Keller, E., & Villa, D. (2018). A regional model of climate change and human migration. Accepted to *International Journal of System Dynamics Applications*.

Mixed Modeling: Examples

Energy systems: Dimitrovski, A., Ford, A., & Tomsovic, K. (2006). An interdisciplinary approach to long-term modelling for power system expansion. *International journal of critical infrastructures*, *3*(1-2), 235-264.



Mixed Modeling: Examples

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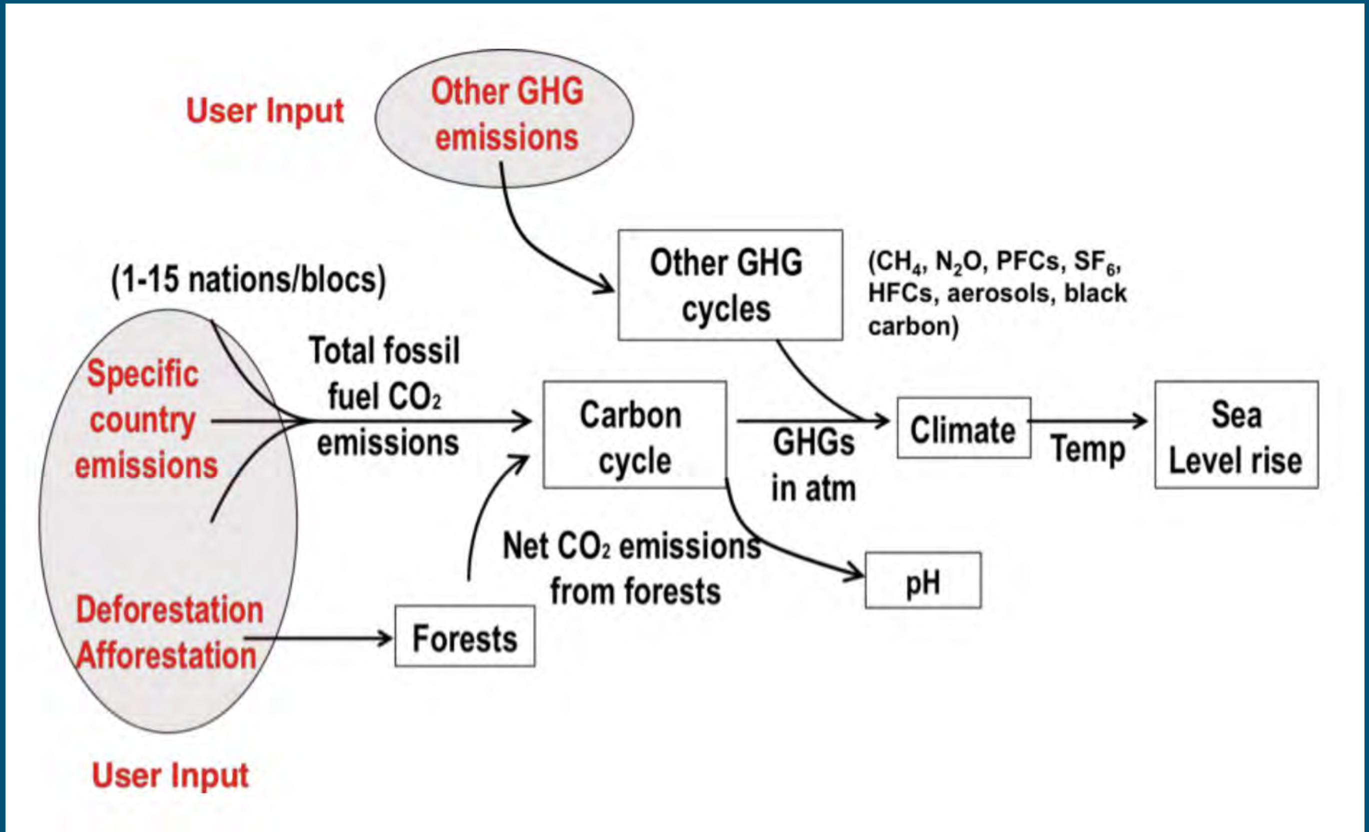

Mixed Modeling: Examples

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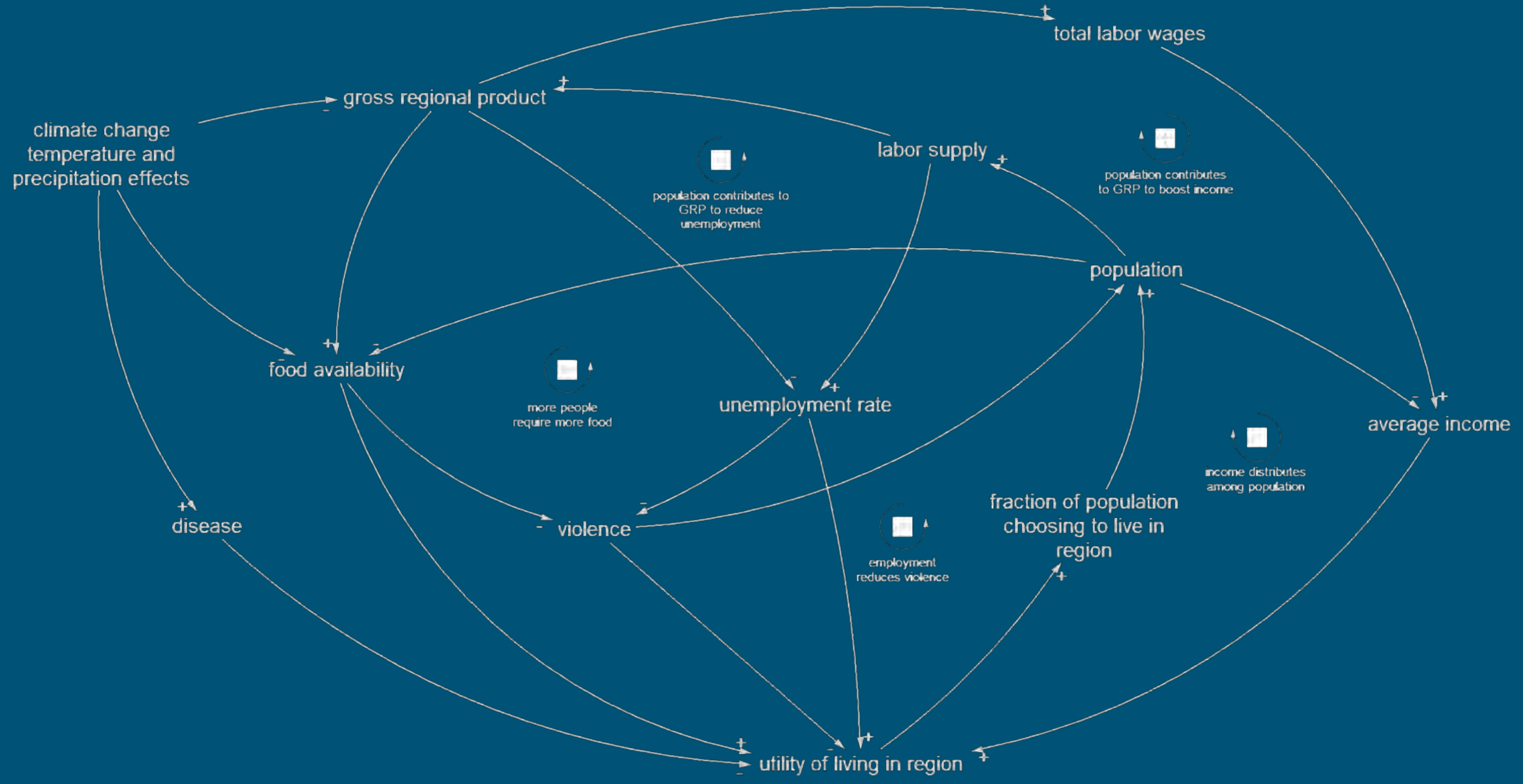


Progressively Hedged Decision Examples

Satellite Scheduling:

- C.G. Valicka, D. Garcia, A. Staid, J.P. Watson, G. Hackebeil, S. Rathinam, and L. Ntaimo. Models for Optimal Constellation Scheduling Under Weather Uncertainty. European Journal of Operational Research – Under Review.

Power Grid Planning:

- F.D. Munoz and J.P. Watson (To Appear). A Scalable Solution Framework for Stochastic Transmission and Generation Planning Problems. Computational Management Science. 2015.

Power Grid Management:

- K. Cheung, D. Gade, C. Silva-Monroy, S.M. Ryan, J.P. Watson, R.J.B. Wets, and D.L. Woodruff (2015). Toward Scalable Stochastic Unit Commitment - Part 2: Solver Configuration and Performance Assessment. Energy Systems, Vol. 6, No. 3, pp. 417–438.

Power Grid Resiliency:

- R. Guttromson and J.P. Watson (2016). Defining, Measuring and Improving Resilience of Electric Power Systems. In Smart Grid Handbook, Volume II, Part 3, Chapter 39. Eds: C-C. Liu, S. McArthur, and S-J. Lee. Wiley.
- J.P. Watson, R. Guttromson, C. Silva-Monroy, R. Jeffers, K. Jones, J. Elison, C. Rath, J. Gearhart, D. Jones, T. Corbet, C. Hanley, and L-T. Walker (2014). Conceptual Framework for Developing Resilience Metrics for the Electricity, Oil, and Gas Sectors in the United States. Sandia National Laboratories Technical Report, No. SAND2014-18019.

Progressively Hedged Decision Examples

Forestry Planning

- F.B. Veliz, J.P. Watson, A.Weintraub, R.J.B. Wets, and D.L. Woodruff (To Appear). Stochastic Optimization Models in Forest Planning: A Progressive Hedging Approach. Annals of Operations Research.

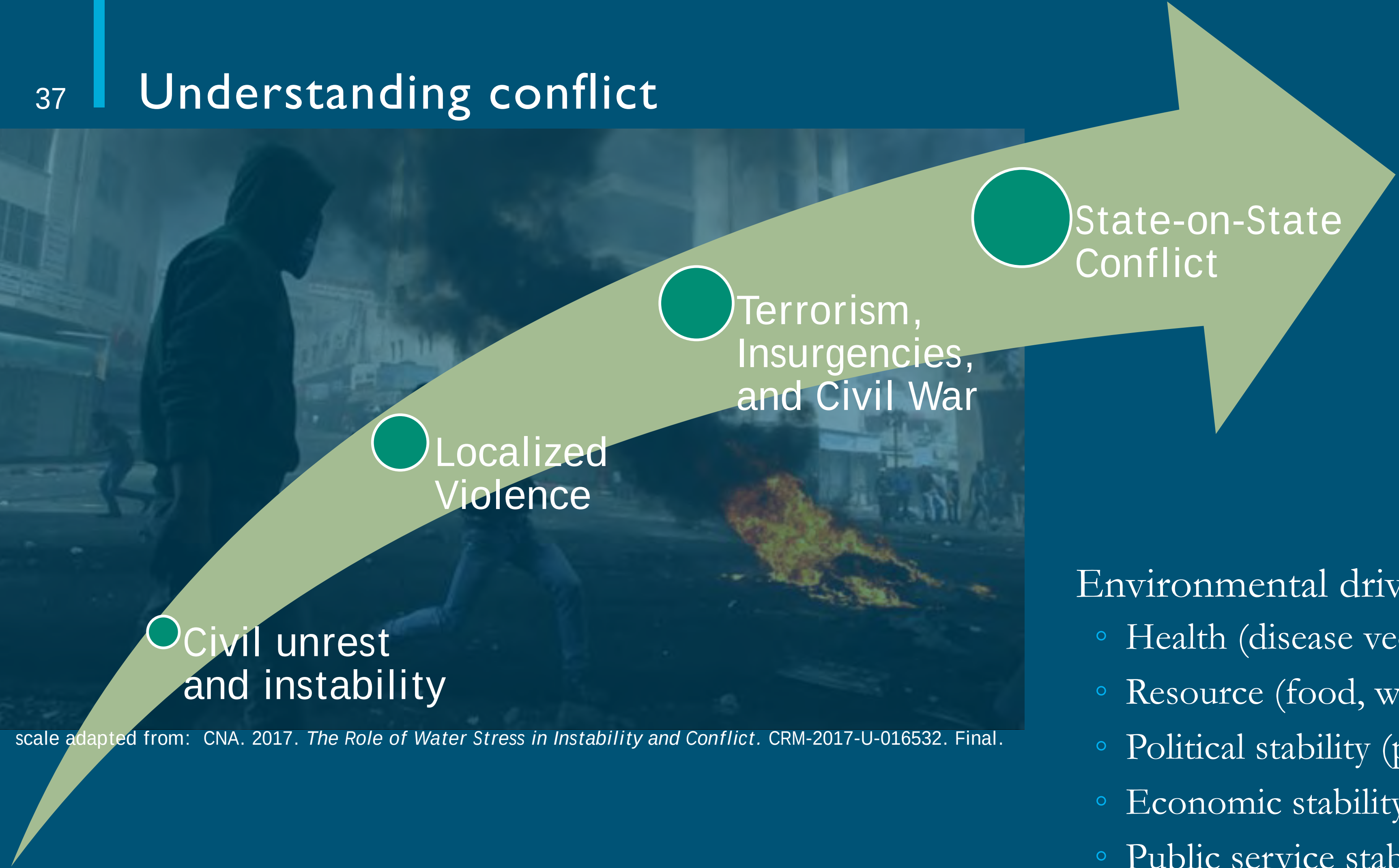
Water Security

- Designing contamination warning systems for municipal water networks using imperfect sensors J Berry, RD Carr, WE Hart, VJ Leung, CA Phillips, JP Watson Journal of Water Resources Planning and Management 135 (4), 253-263
- Sensor network design of contamination warning systems: A decision framework R Murray, R Janke, WE Hart, JW Berry, T Taxon, J Uber American Water Works Association. Journal 100 (11), 97
- Sensor placement in municipal water networks JW Berry, L Fleischer, WE Hart, CA Phillips, JP Watson Journal of Water Resources Planning and Management 131 (3), 237-243

Pyomo

- Pyomo: Optimization modeling software that includes mature capabilities for modeling and solving stochastic optimization problems. ***Pyomo won an R&D100 Award in 2016.***
- Hart, W.E., C.D. Laird, J.-P. Watson, D.L. Woodruff, G.A. Hackebeil, B.L. Nicholson, and J.D. Siirola, Pyomo – Optimization Modeling in Python. Second Edition. Vol. 67. Springer (2017)
- Watson, J.-P., Woodruff, D.L. and Hart, W.E., PySP: modeling and solving stochastic programs in Python, Mathematical Programming Computation, Vol. 4, No. 2, pp. 109-149 (2012)
- Watson, J.-P. and Woodruff, D.L., Progressive hedging innovations for a class of stochastic mixed-integer resource allocation problems, Computational Management Science, Vol. 8, No. 4, pp. 355-370 (2011)

Understanding conflict



scale adapted from: CNA. 2017. *The Role of Water Stress in Instability and Conflict*. CRM-2017-U-016532. Final.

Environmental drivers of conflict [24]:

- Health (disease vectors, nutrition, safety, sanitation, shelter)
- Resource (food, water, energy) stability
- Political stability (personal safety)
- Economic stability
- Public service stability

'Universal' drivers of conflict [Halvard Bauhaug]:

- history of violence,
- low level development,
- poor governance,
- discrimination,
- horizontal (inter-group) inequalities (economic and political terms)

Potential Arctic Tipping events

Candidate Control Parameter(s)	Qualitative change in Arctic system state (Tipping Element)	Resultant global physical effects	Socio-Economic Impacts
Freshwater Input DEPENDENT UPON: SALINITY, MASS, TEMPERATURE, AND VELOCITY OF INCOMING CURRENTS; ATMOSPHERIC PATTERNS;	Shutdown / reversal of Atlantic thermohaline circulation (THC) SYSTEM VARIABLE: THC	Regional cooling; significant weather shifts in the N. hemisphere; alteration to / loss of critical habitats;	Dramatic shifts in world-wide natural resource availability (water and food) along with altering suitability of landscapes supporting human life inducing migration
Ice Sheet Temperature DEPENDENT UPON: ATMOSPHERIC TEMP.; INCIDENT RADIANCE; MASS OF ICE; SALINITY, MASS, TEMPERATURE, AND VELOCITY OF SEA WATER INTERACTING WITH ICE SHEET	Greenland ice sheet melt SYSTEM VARIABLE: ICE VOLUME	Sea level rise; ocean current alterations; alteration to / loss of critical habitats; alteration to atmospheric patterns	Coastal inundation around the world, dramatic shifts in world-wide natural resource availability (water and food)
Permafrost Temperature DEPENDENT UPON: ATMOSPHERIC TEMP.; INCIDENT RADIANCE; SNOW AND VEGETATION COVER; ICE CONTENT AND SEDIMENT TYPE COMPOSING PERMAFROST	Permafrost thaw SYSTEM VARIABLE: PERMAFROST DISTRIBUTION AND EXTENT	Significant greenhouse gas release; alteration to vegetation and critical habitat; changes in hydrology; increased erosion	Instability of national security infrastructure in region (DEW line radars, etc.); dramatic shifts in world-wide natural resource availability (water and food) along with altering suitability of landscapes supporting human life
Ocean Temperature DEPENDENT UPON: ATMOSPHERIC TEMP.; INCIDENT RADIANCE; SALINITY, MASS, TEMPERATURE, AND VELOCITY OF INCOMING CURRENTS; WAVE ENERGY; MASS OF ICE;	Loss of summer sea ice SYSTEM VARIABLE: SEA ICE VOLUME	Mid-latitude weather changes and alteration to atmospheric patterns; ocean current alterations; alteration to / loss of critical habitats	increasing regional conflicts over Arctic resources; loss of biological resources; increased drought and loss of agriculture at mid-latitudes,