FWI 4 ADI

Or…

Lessons learned from an attempt to make sense of a complex mess

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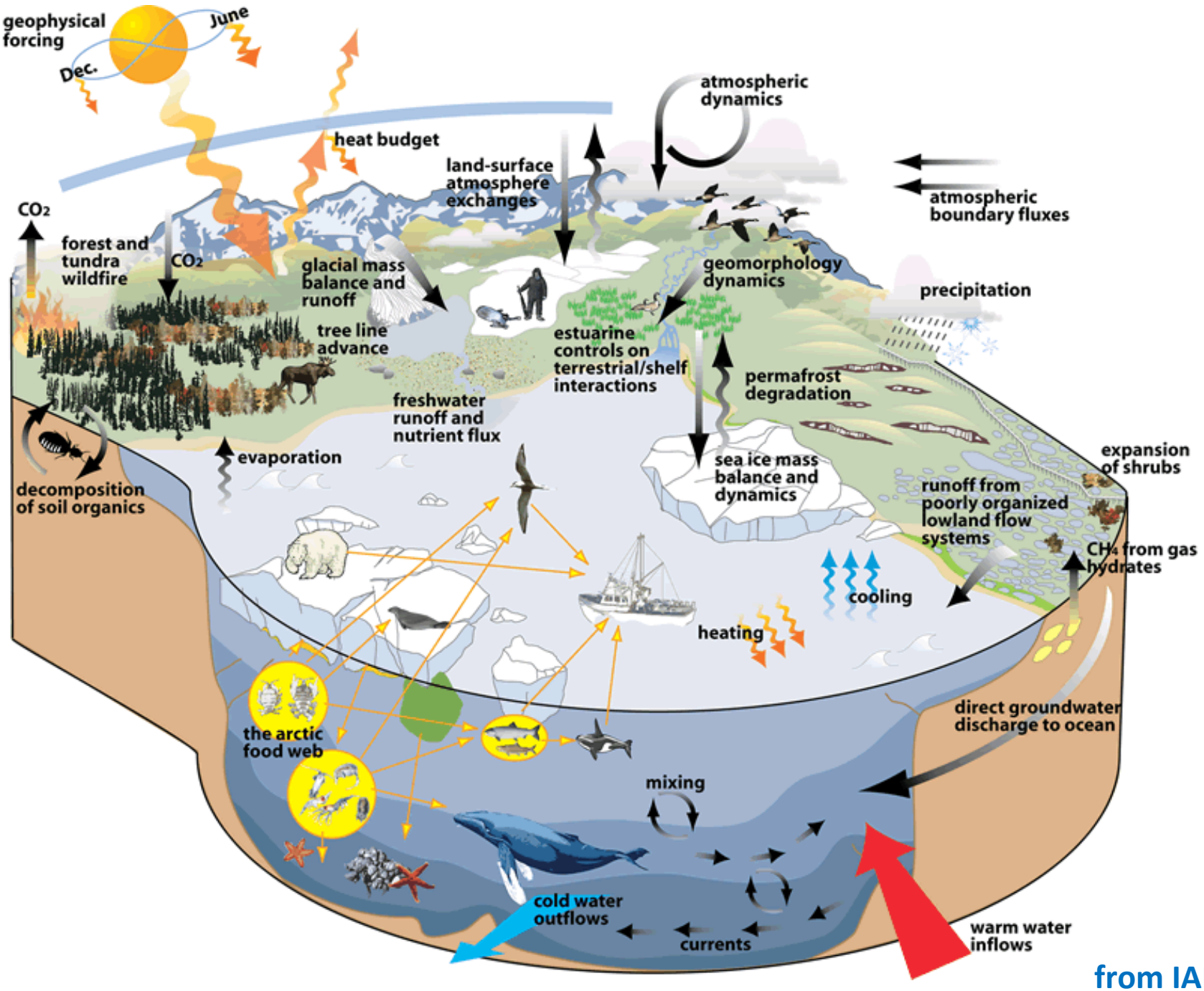
y Chris Linder, WHOI


geophysical forcing
June
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heat budget
atmospheric dynamics
land-surface atmosphere exchanges
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CO_2
forest and tundra wildfire
CO_2
glacial mass balance and runoff
geomorphology dynamics
precipitation
tree line advance
estuarine controls on terrestrial/shelf interactions
permafrost degradation
freshwater runoff and nutrient flux
evaporation
sea ice mass balance and dynamics
expansion of shrubs
decomposition of soil organics
runoff from poorly organized lowland flow systems
CH_4 from gas hydrates
cooling
heating
the arctic food web
direct groundwater discharge to ocean
mixing
cold water outflows
currents
warm water inflows

from IARC

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, G04019, doi:10.1029/2008JG000902, 2009

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An arctic hydrologic system in transition: Feedbacks and impacts on terrestrial, marine, and human life

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Received 25 November 2008; revised 13 July 2009; accepted 10 August 2009; published 9 December 2009.

[1] The pace of change in the arctic system during recent decades has captured the world's attention. Observations and model simulations both indicate that the arctic experiences an amplified response to climate forcing relative to that at lower latitudes. At the core of these changes is the arctic hydrologic system, which includes ice, gaseous vapor in the atmosphere, liquid water in soils and fluvial networks on land, and the freshwater content of the ocean. The changes in stores and fluxes of freshwater have a direct impact on biological systems, not only of the arctic region itself, but also well beyond its bounds. In this investigation, we used a heuristic, graphical approach to distill the system into its fundamental parts, documented the key relationships between those parts as best we know them, and identified the feedback loops within the system. The analysis illustrates relationships that are well understood, but also reveals others that are either unfamiliar, uncertain, or unexplored. The graphical approach was used to provide a visual assessment of the arctic hydrologic system in one possible future state in which the Arctic Ocean is seasonally ice free.

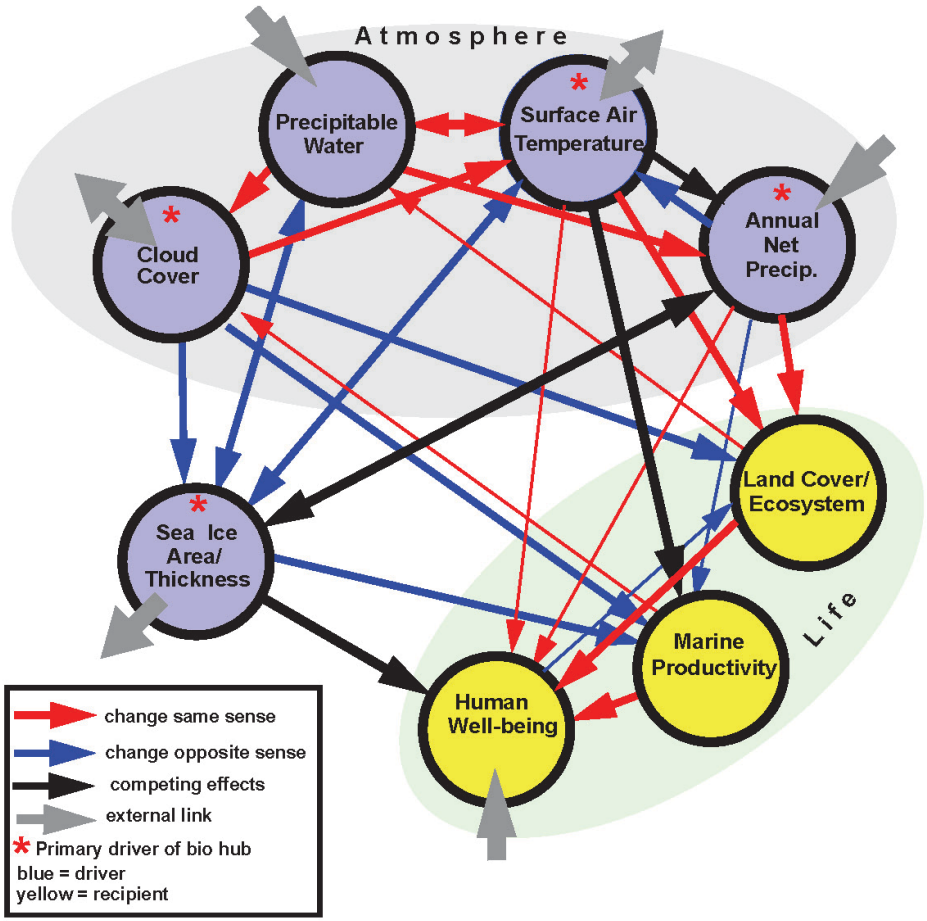
Goal of study:

- Fly over system at 50,000 feet
- Distill Arctic hydrological system into fundamental elements within 3 main sub-systems: atmosphere, ocean, and terrestrial
- Characterize interactions among those elements within each sub-system based on published literature
- Identify feedbacks that directly affect living parts of system: marine productivity, terrestrial vegetation, and humans

Arguably the reason we're doing all this research is to understand how changes in the physical system will affect living organisms, including ourselves.

This is a powerful focusing concept.

Atmospheric Component



Each element or "hub" must:

- ✓ Capture unique characteristics of system
- ✓ Connect strongly to other hubs
- ✓ Exhibit change as increase or decrease

Red arrows => change same sign

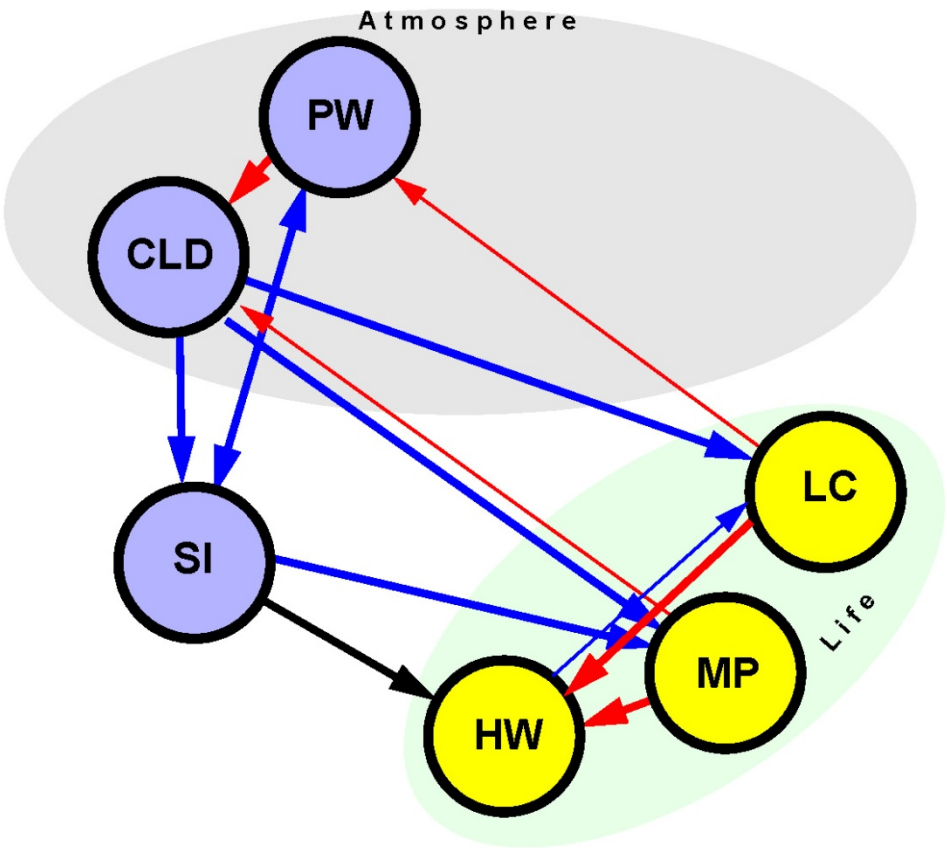
Blue arrows => opposite

Black arrows => competing

Blue hubs => drivers

Yellow hubs => recipients

Atmospheric Component

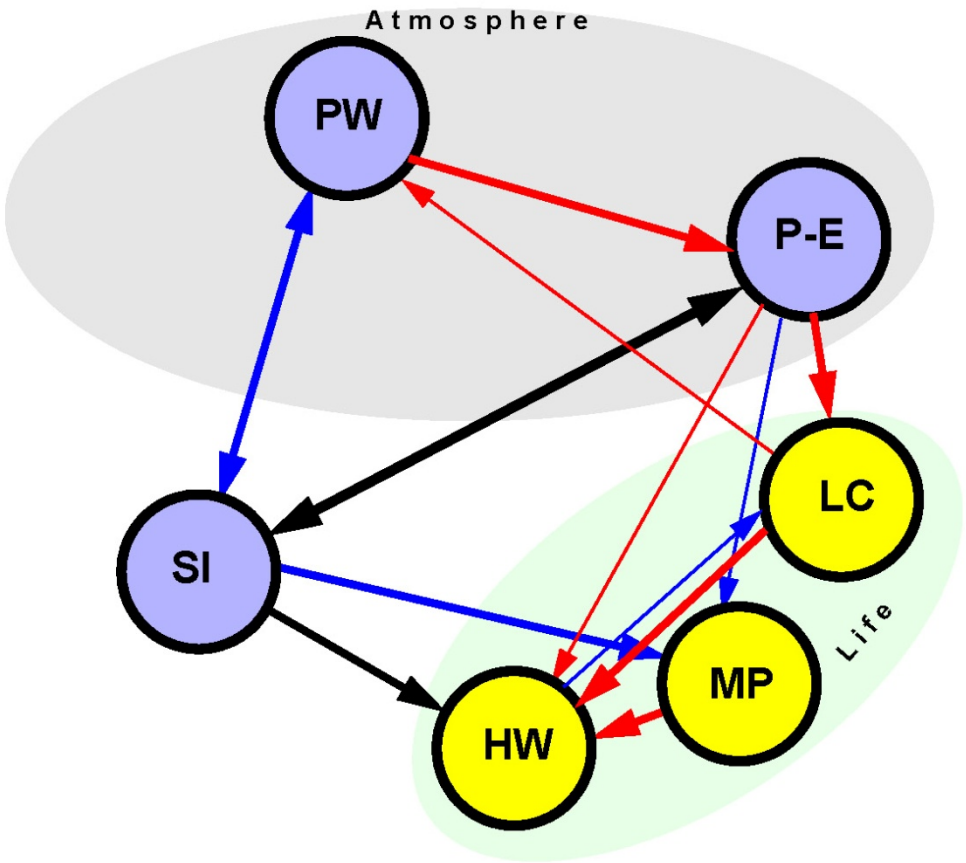


Feedbacks:

- Closed loops that have strong links to life hubs
- For example, this feedback says reduced sea ice leads to increased water vapor and cloud amount, which further reduces sea ice: a positive feedback.
- Influence on life hubs:
  - Marine: competing
  - Land Cover: negative
  - Human: competing

Key questions: Will this feedback contribute to increase or decrease in marine productivity?
Will net effect of feedback on humans be positive or negative?

Atmospheric Component



Feedbacks:

- Closed loops that have strong links to life hubs
- This feedback says reduced sea ice leads to increased water vapor and net precipitation, but there are competing effects of net precip on sea ice.
  => Feedback sign unknown.
- Influence on life hubs:
  - Marine: unknown
  - Land cover: unknown
  - Human: unknown

Link between net precipitation and sea ice is source of uncertainty

Key findings germane to ADI:

General

- Atmospheric hubs are always net drivers, and all are linked with global system
- Life hubs are always net responders
- Many feedbacks contain uncertain or competing relationships => ripe targets for aiming ADI – variables AND covariability with others
- Some links between hubs change sign over time, with uncertain spatial scales and timing and uncertain impacts
- Many feedbacks disappear in a future with drastically reduced permanent ice

Key findings germane to ADI:

Atmospheric sub-system

- Has 7 feedbacks that affect life hubs, all are positive except 1
- Five involve sea ice
- Key sources of uncertainty:
  - Precipitation amount, phase, and timing
  - Seasonal and regional effects of cloud changes on marine and terrestrial plants

Key findings germane to ADI:

Ocean sub-system

- 5 feedbacks, all involve sea ice
- 4 have unknown impacts on marine productivity, all have unknown impacts on humans
- Key sources of uncertainty:
  - Effects of precip and ice melt on mixed-layer stratification
  - Effects of stratification on heat storage
  - Factors limiting phytoplankton abundance
  - Competing effects of ice loss on coastal communities

Key findings germane to ADI:

Terrestrial sub-system

- 4 feedbacks, all involve vegetation
- 3 have unknown impacts on vegetation and humans
- Key sources of uncertainty:
  - Effects of precipitation amount, type, and timing on vegetation and active-layer depth
  - Relationship between active-layer depth and vegetation
  - Changing relationships between permafrost and vegetation

Photo from Dan White, UAF

Science questions emerging from uncertainties in feedbacks linked to life:

1. How is precip changing on ice and land?
2. Are precip changes slowing or enhancing ice loss?
3. What is relative importance of primary factors affecting marine productivity in the Arctic?
4. How is ice loss affecting precipitation, locally and remotely?
5. How are regional-varying changes in mixed-layer stratification and heat storage affecting sea ice?
6. Does ice loss enhance or degrade human well-being?

More science questions emerging from uncertainties in feedbacks linked to life:

7. Are precip changes slowing or enhancing permafrost degradation?
8. How is land cover responding to changing precipitation (amount, phase, timing)?
9. How does changing active layer/permafrost affect vegetation?
10. How does changing surface water (storage, permeability, runoff) affect human well-being?
11. Is atmosphere and ocean circulation changing? Is sea ice a responder or driver?
12. How do feedbacks vary regionally and seasonally?

How to prioritize?

An anthropocentric approach…

Which hubs and interactions affect humans most?

- Sea ice: shipping, resource extraction, fishing, global circulation patterns
- Marine productivity: commercial and local fishing
- Freshwater on land: drinking water, infrastructure, land travel

The diagrams show drivers of those hubs, and feedbacks help reveal the largest uncertainties:

- **Sea ice:** water vapor, clouds, P-E, SAT, and ocean mixed-layer heat storage (winds, currents)
- **Marine productivity:** sea ice area, clouds, SAT, ML heat storage, ML freshwater
- **Freshwater on land:** land cover, permafrost, active-layer depth, SAT