Climate Modeling on Future Architectures

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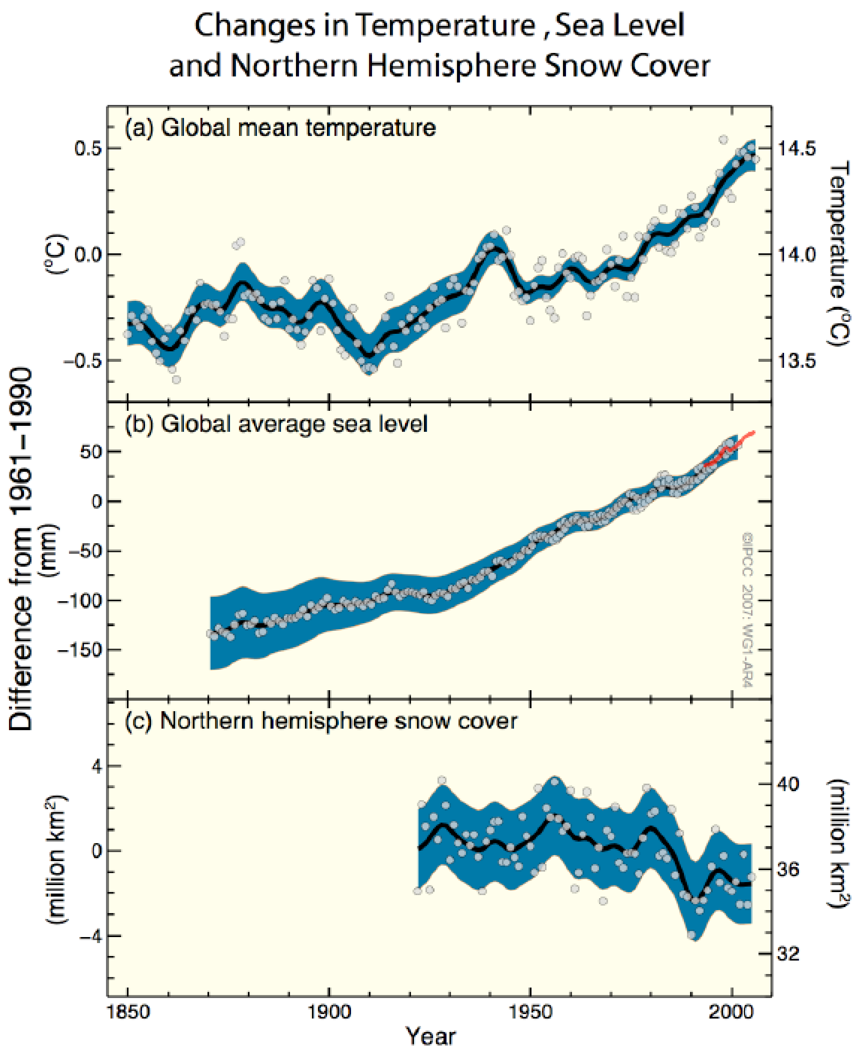
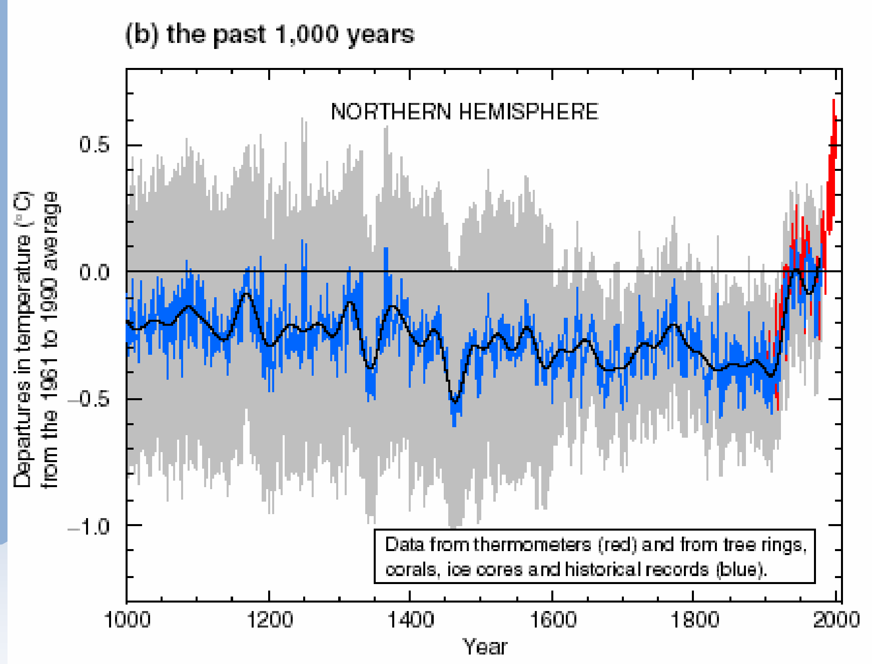
LAUR-07-06895

Climate Change is Observed



Climate change observed at global scales with increases of surface temperatures, sea level rise and decreasing snow cover



IPCC 2007, 2002
Nobel Peace Prize 2007

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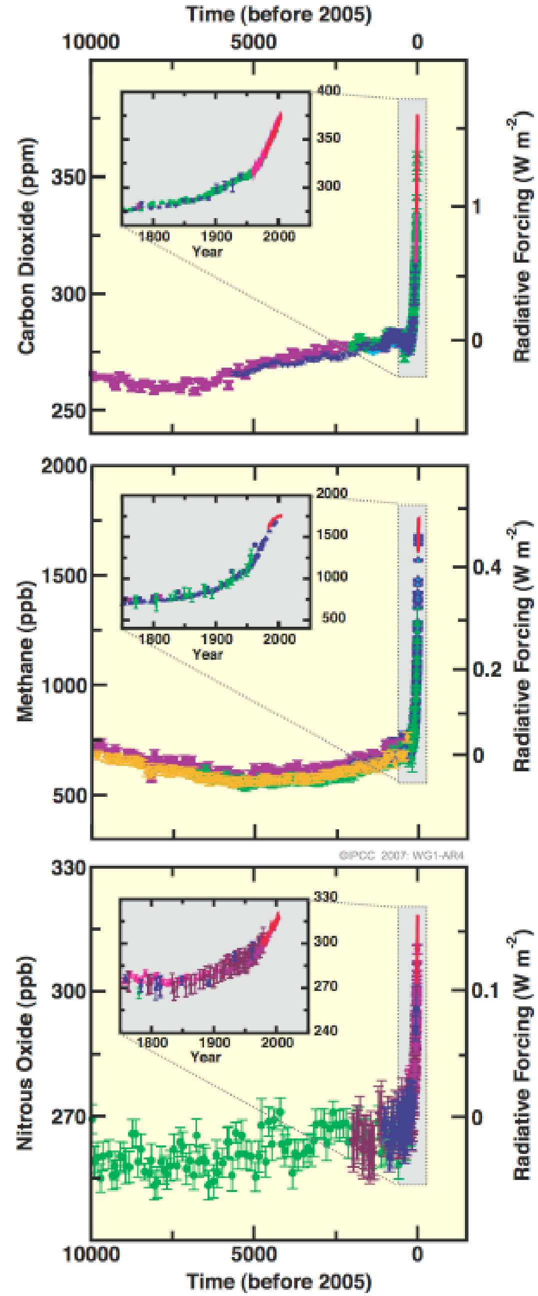
Greenhouse Gases are Cause

- CO_2 – 379ppm in 2005
  - Exceeds values for last 650,000 years
  - Fossil fuels primary source
    - 6.4 Gt/year 1990s
    - 7.2 Gt/year 2000s
  - Land use (1.6 GtC/yr)
- Methane
  - 1772 ppb 2005 (700 pre-ind)
  - Agriculture is primary source

ppm – parts/million
Ppb – parts/billion
GtC – billion (giga) tons Carbon

Changes in Greenhouse Gases from ice-Core and Modern Data



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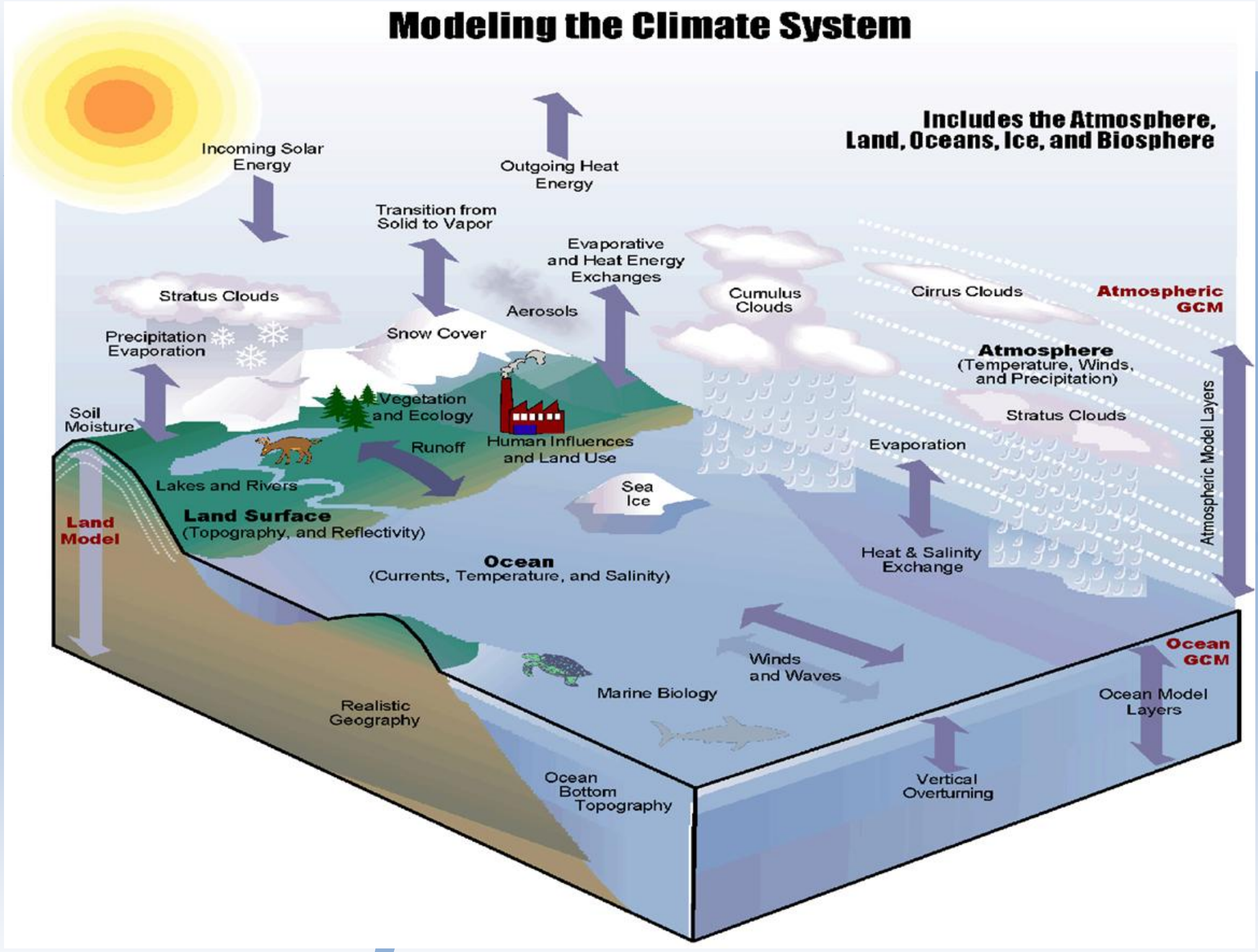
Climate Models as Tools



- Integrates knowledge of climate system
- Used to understand and quantify feedbacks

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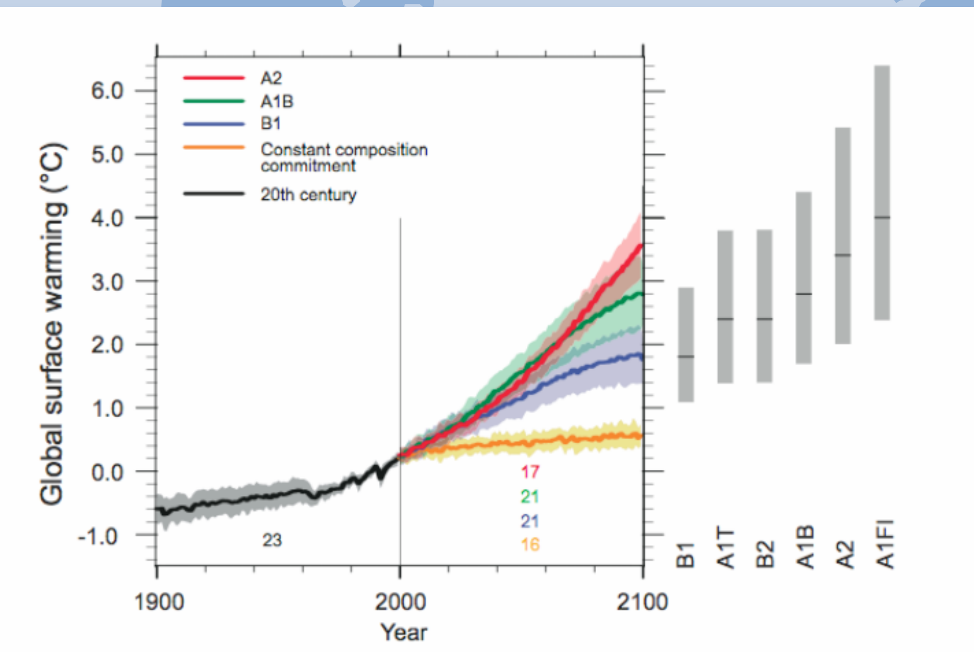
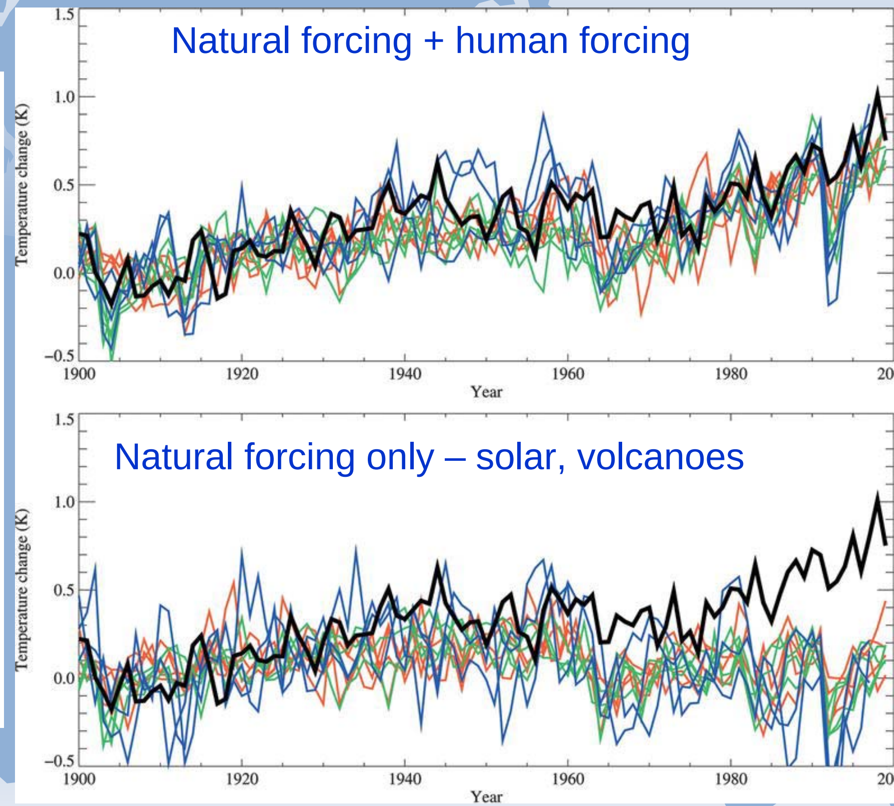
Use of Climate Models

Projection of Future Change



Intergovernmental Panel on Climate Change: Fourth Assessment (www.ipcc.ch)

Determine Causes, Attribution



Solid black line is observational record
Other lines are ensemble of model results
Observations can only be explained by increased human influence.

From Stott et al. 2006

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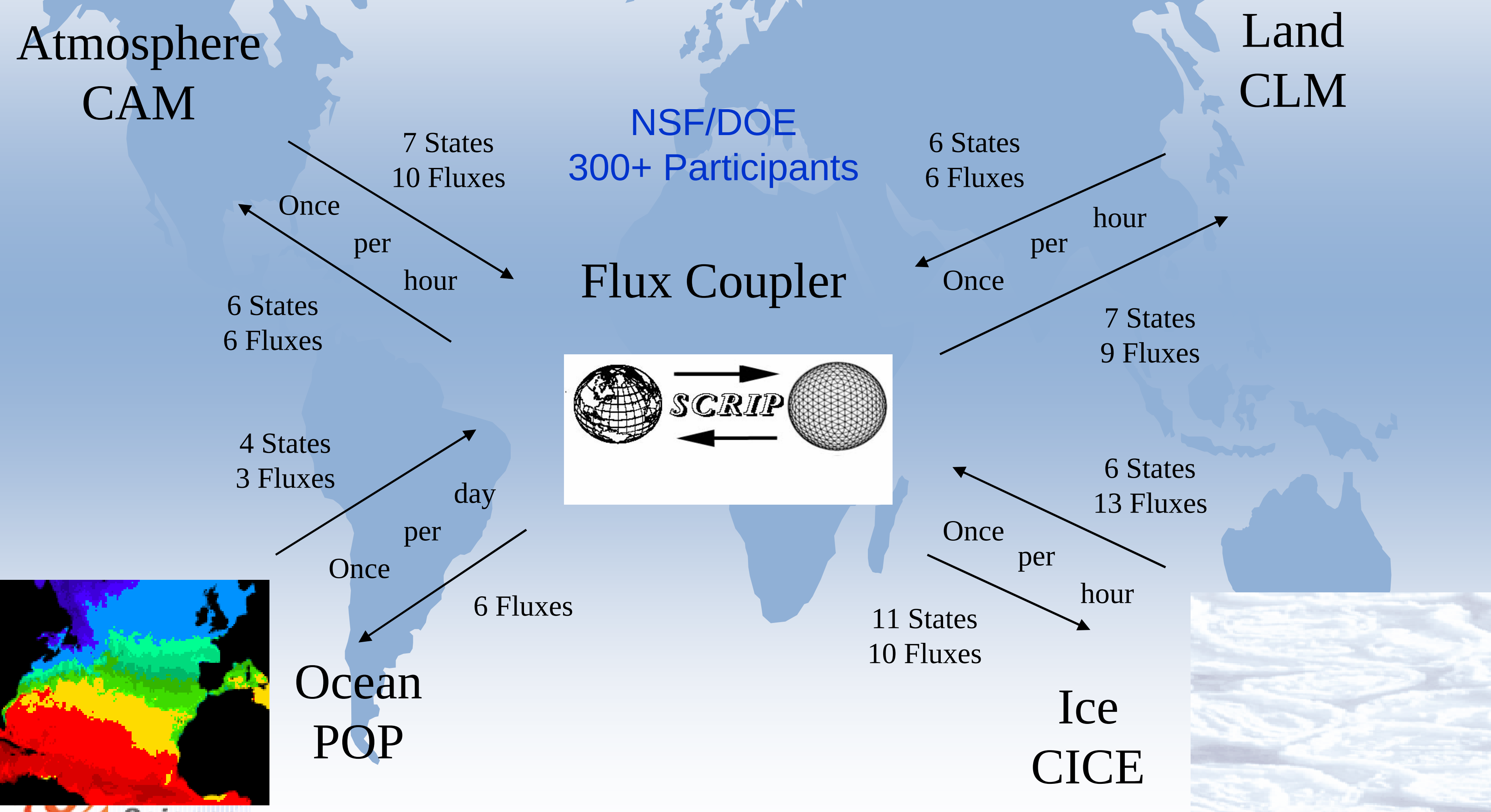
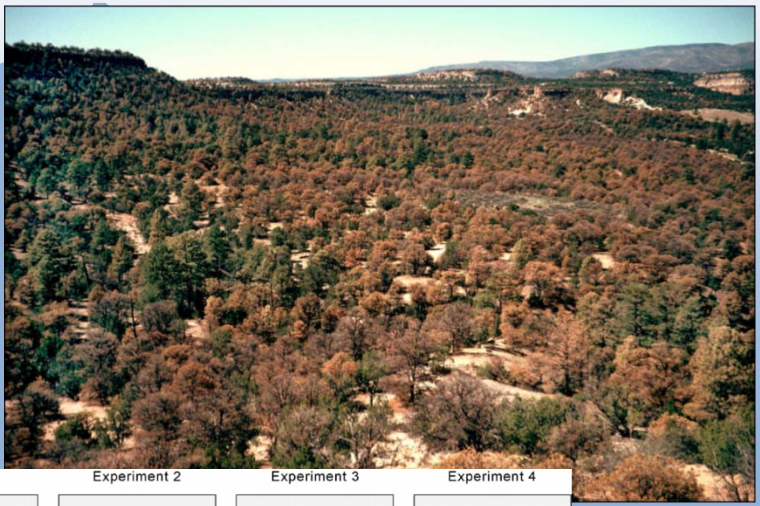
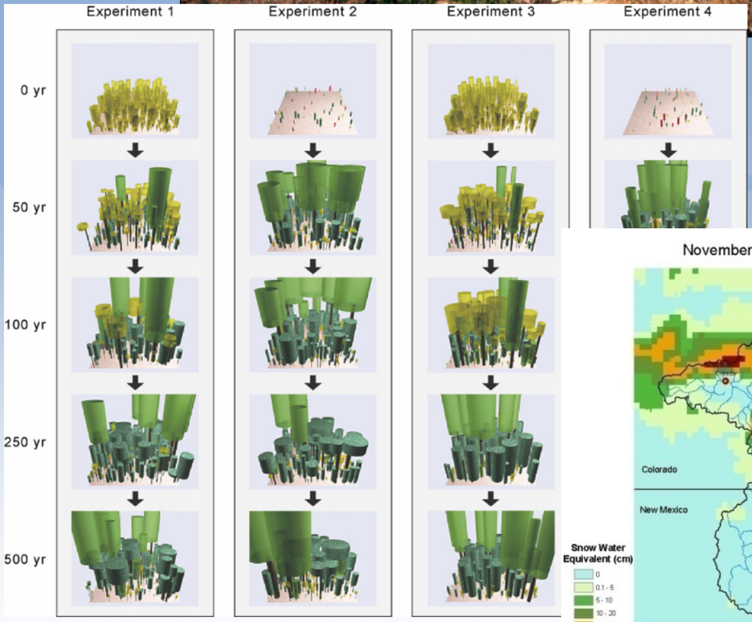
Community Climate System Model

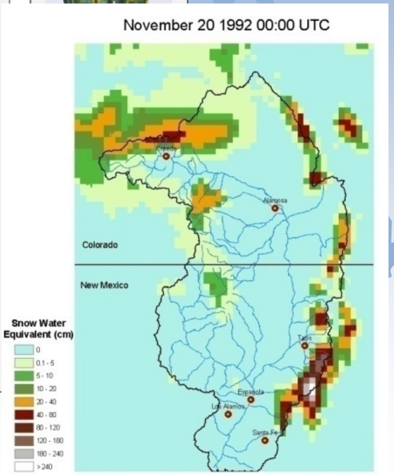


Regional Prediction

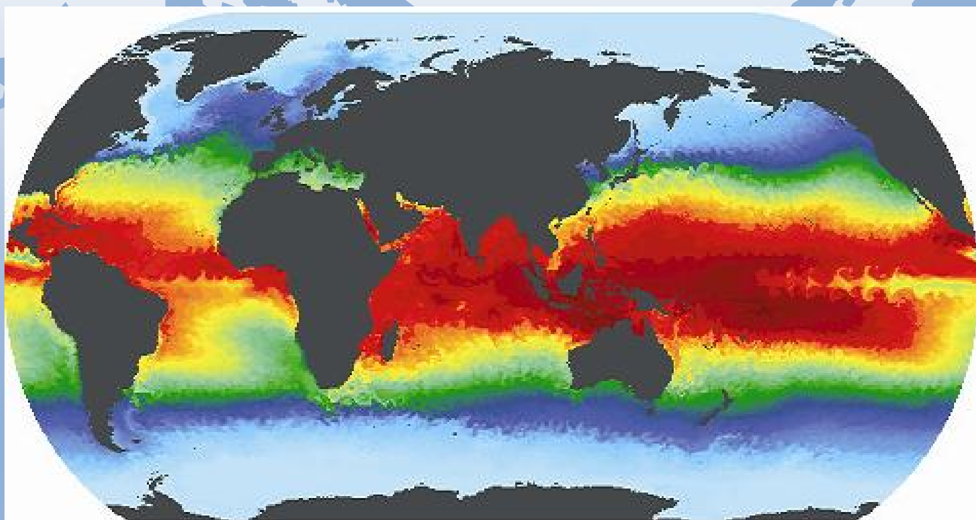
- Impacts at regional scales
- Resolution
  - 10 km (10x)
- Dynamic vegetation
  - Large-scale changes in ecosystems
  - Agent/individual models?
- Improved groundwater/ water cycle





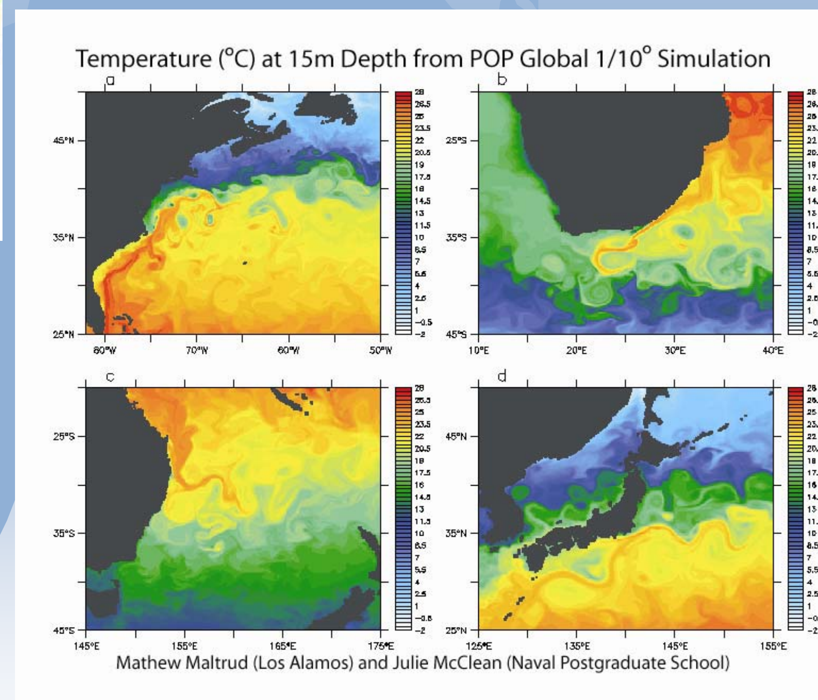


Eddy-resolving Ocean Modeling



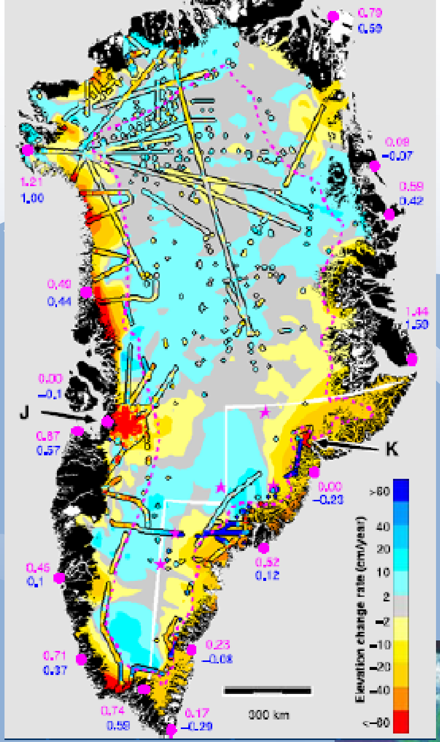
10km resolution (10x climate)

Resolving eddies necessary for accurate simulation of currents and their role in sea ice edge and deep water formation.



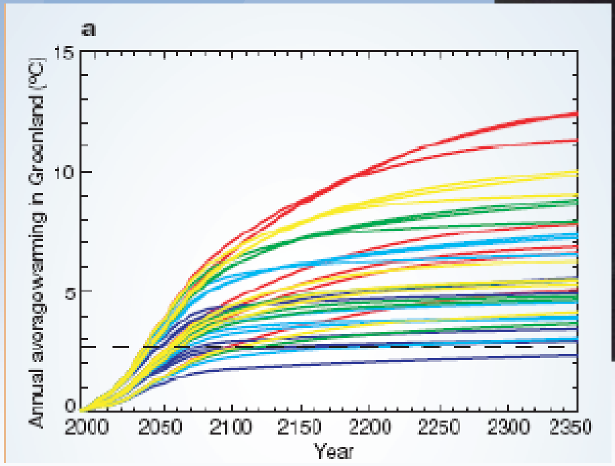
Ice Sheets and Sea Level Rise

- Largest missing piece of physical climate in current models
- Needed for sea level rise prediction
- 6m of sea level rise if Greenland melts, 6m if W. Antarctic ice sheet melts
- Slow melt over 1000 years or more rapid?
- Threshold of no return?
- Small-scale ice sheet dynamics, ocean/ice interaction, disparate timescales
- Variable coastlines, topography

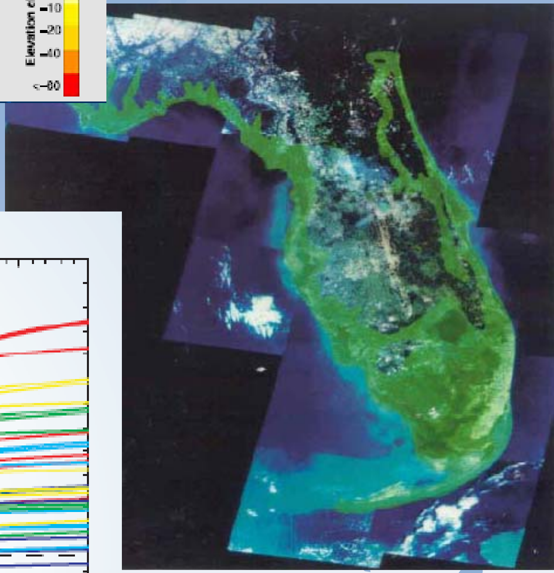


Greenland ice sheet melting observations from Krabill et al. 2004

Red indicates rapid melting
2007 rate highest observed



Gregory et al. 2004



Stephen Leatherman

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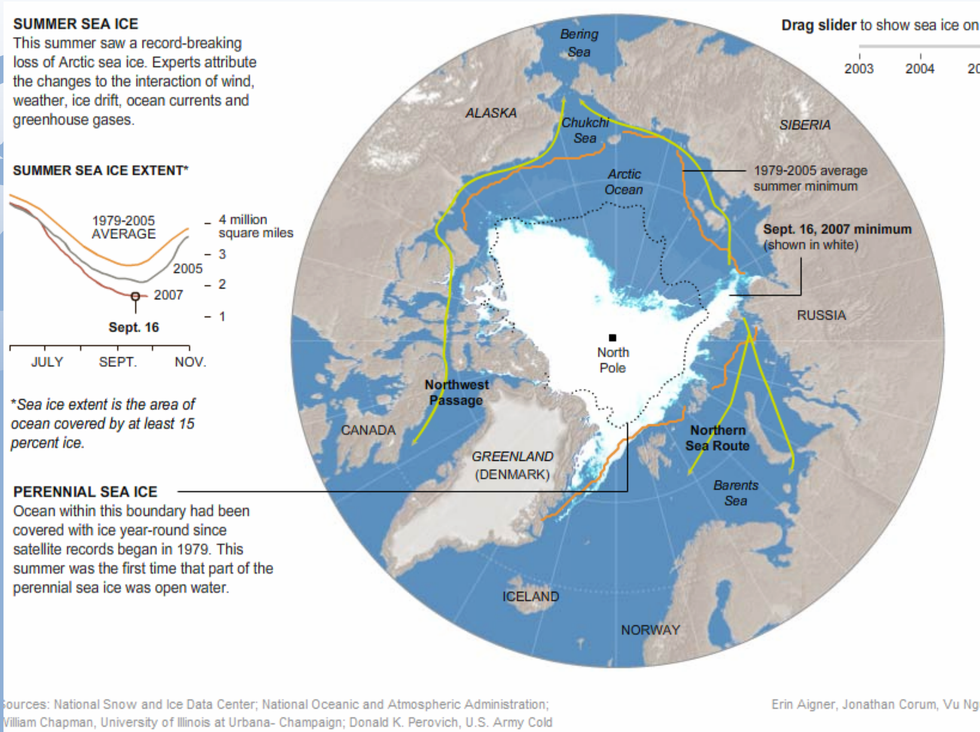
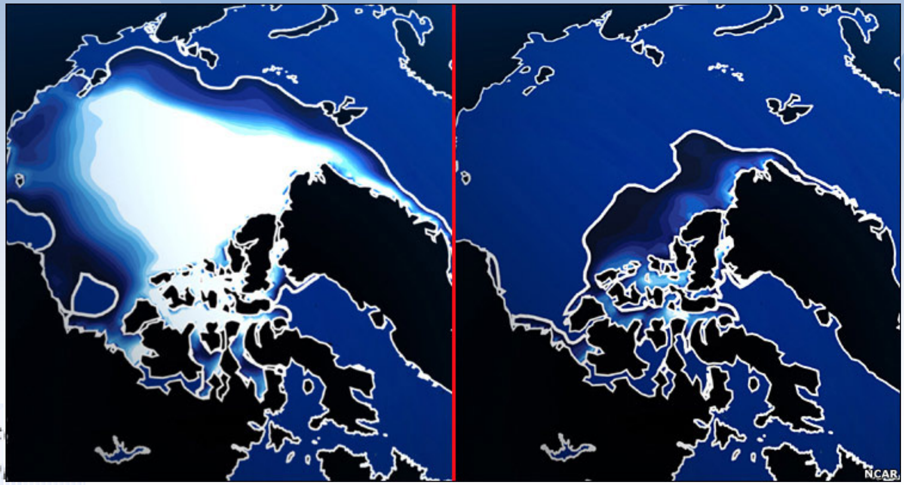
Sea Ice

NY Times, 10/1/07

- Poles warm almost 2x faster
- Large ice feedbacks
- Ice free summer by 2050
- Record low arctic ice in 2007
- Impacts
  - Ecosystems (polar bears, walrus)
  - Oil, resource extraction
  - Ocean thermohaline circulation
- Need mechanisms for faster ice melt (algae, cracks, etc.)





Nearly ice-free summertime arctic predicted by CCSM (with LANL ocn and ice models) between 2000-2040, much of it within a decade due to ice thinning combined with pulse of warm water input (M. Holland et al.)

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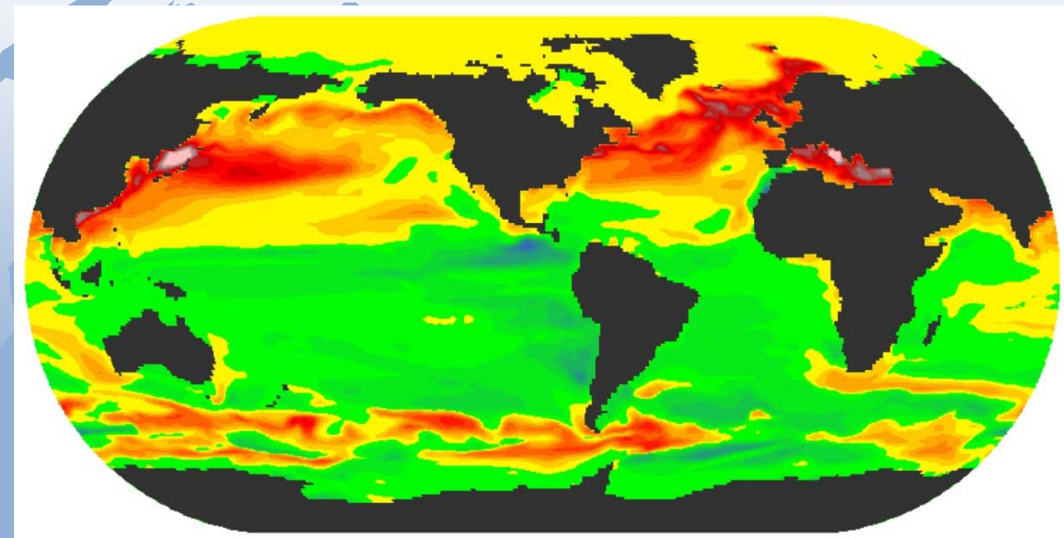
Chemical/Biogeochemical Models

- Coupling ocean biogeochemistry with extensive atmospheric chemistry and land biogeochemistry
  - Carbon and sulfur cycles
  - Needed to assess ability of oceans and land to sequester carbon
  - Aerosol direct/indirect (reduced precipitation?)
  - Projections with specified emissions
  - Methane hydrates/clathrates
  - Ocean acidification
  - Engineered climate
- Many tracers
  - 100x atm, 20x ocean
  - Many reactions
  - Metagenomics



Flux of CO_2 at ocean surface
Red/yellow – CO_2 leaving ocean
Green/blue – ocean uptake of CO_2

Coral bleaching

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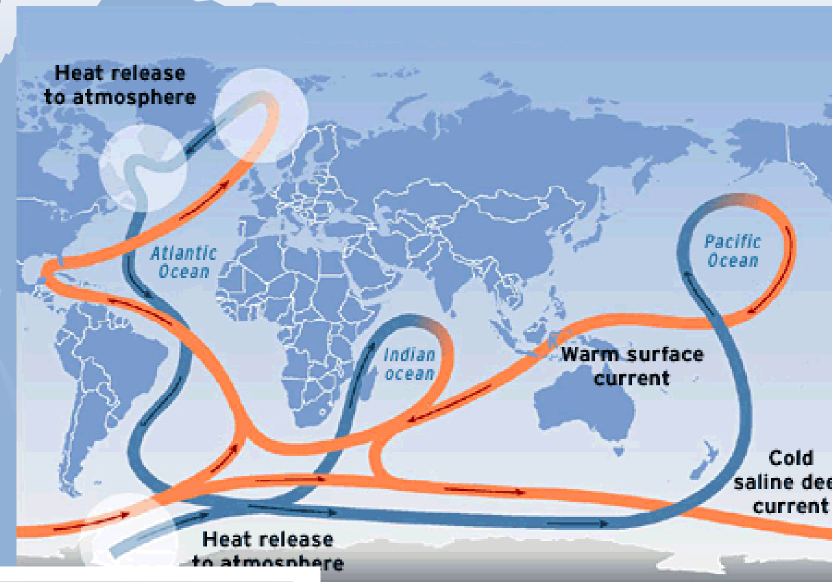
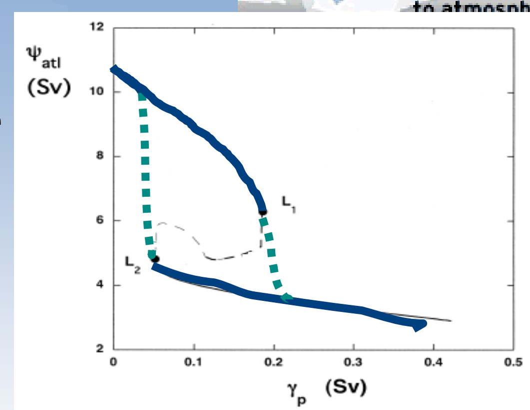
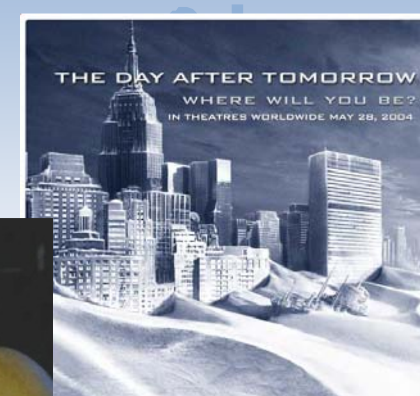
Abrupt change: Ocean Thermohaline Circulation

- Carries large fraction of heat from equator to poles
- Responsible for mild climate of Europe, NE US
- Driven by formation of cold, salty water in N. Atlantic and Antarctica
- Abrupt scenario:
  - Large influx of fresh water due to ice melt, increased precipitation
  - Prevents formation of dense water
  - THC slows/shuts down in response
  - Impacts on Europe, NE US and overall atmospheric circulation
- Implicated in past abrupt climate shifts
- Current models predict weakening, then recovery
- Implicit models/parameter continuation

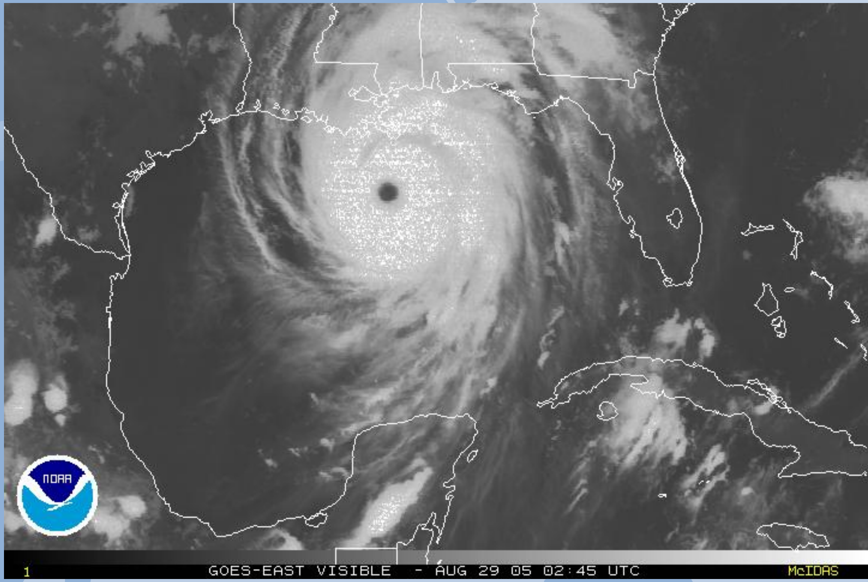






Extreme Events and Impacts

- Extremes
  - Hurricanse, droughts, high/low temps, frost dates, etc.
- Global forcing at large scale
- High resolution for dynamics
- Coastal models for impacts
- Connections to economic, infrastructure models
  - Falwell effect?
- Statistics at the tails of distribution – model distributions



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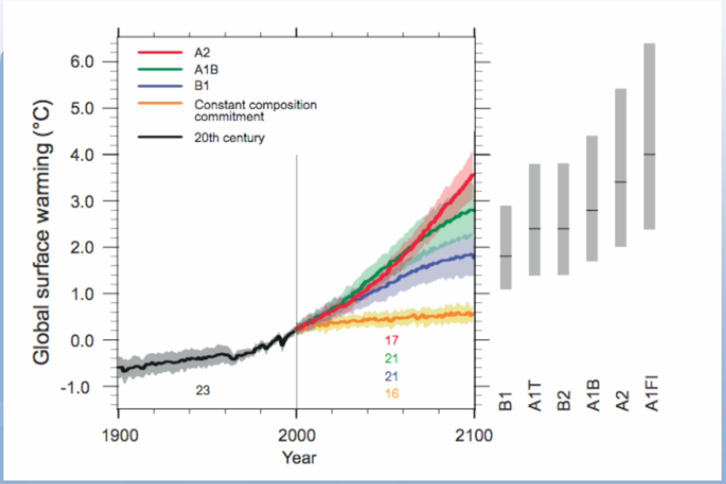
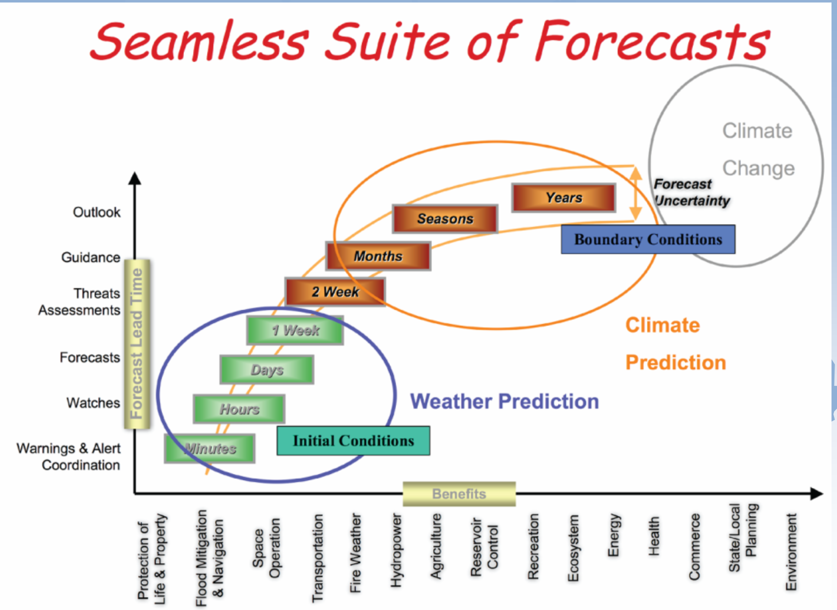
Assessments

- More ensembles
  - Integrated ensembles
  - 2-10x
- Decadal prediction
  - Data assimilation
  - 3-10x?
  - Massive data stream
- Error propagation/estimation
- Rapid turnaround to respond to policy-maker queries





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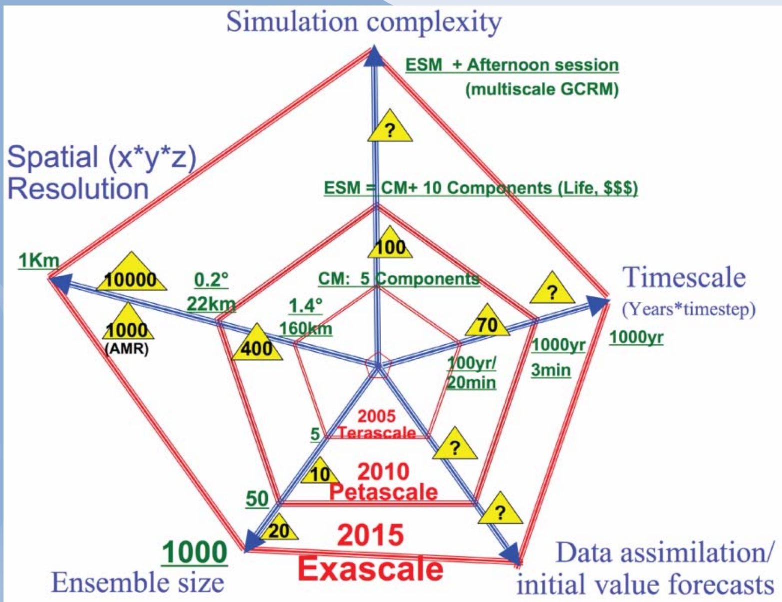
Computing needs (10^{10}-10^{12})

- Resolution (10^3-10^5)
  - x100 horiz, x10 timestep, x5-10 vert
  - Regional prediction (10km)
  - Eddy resolving ocean (< 10km)
- Completeness (10^2)
  - Biogeochem (30-100 tracers, interactions)
  - Ice sheets
- Fidelity (10^2)
  - Better cloud processes, dynamic land, etc.
- Increase length/number of ensembles (10^3)
  - Run length (x100)
  - Number of scenarios/ensembles (x10)
  - Data assimilation (3-10x)
- Data requirements have similar factors
  - 35 TB currently, distributed
  - More for assimilation



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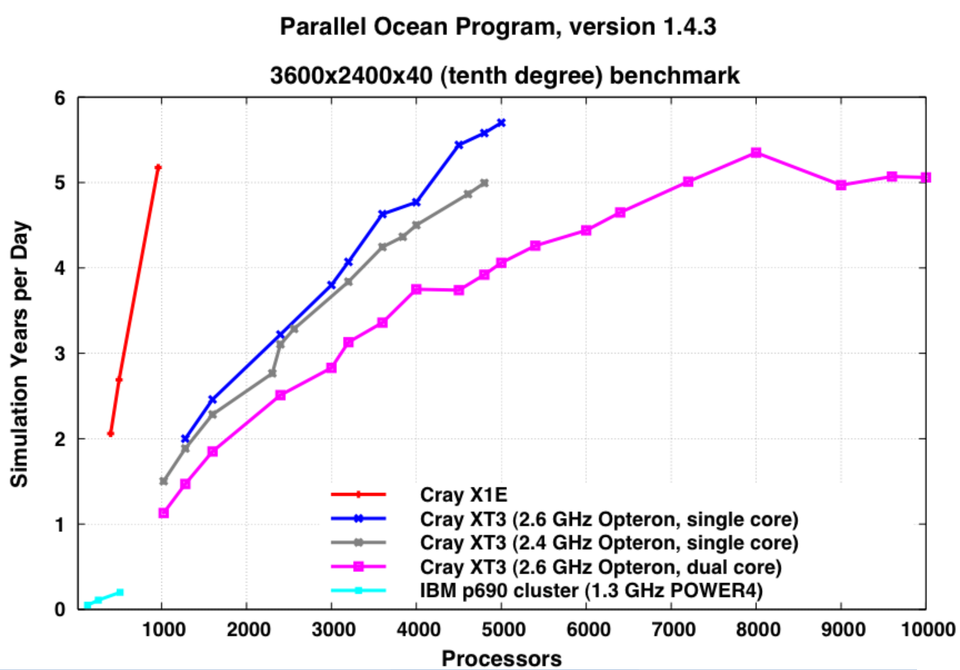
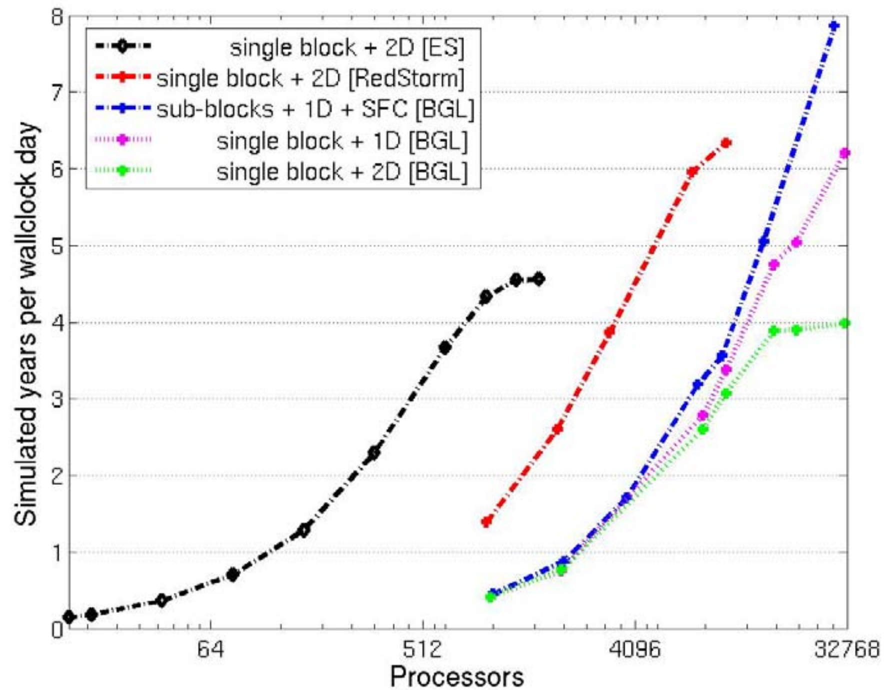
Scaling to Large Processor Counts



Effective for high resolution, multiple scenarios…but can't scale time (1hr to 7 min)



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Future Architectures

- Large processor counts
- Hybrids, power envelope
  - Difficulties due to low memory/bandwidth
  - No kernel
  - Increased work per grid point, time integration
- Unknown future
  - Machines
  - Algorithms (50/50 rule)
  - Abstractions (adaptation strategies)
  - Programming models, non-traditional approaches