Future Climate

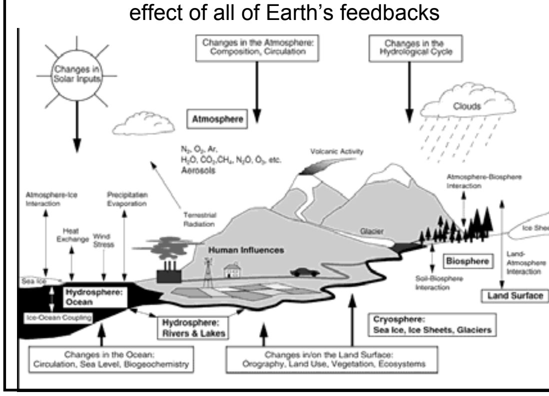
Summary of Observed Climate Changes

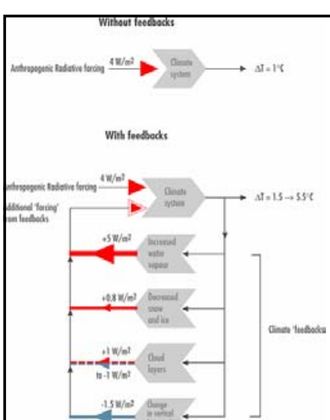
- Temperature increase over last 100 years was about 0.6 ˚C globally
  - All latitudes
  - All seasons
  - Both hemispheres
  - Land and Ocean
  - More at high NH latitudes
  - A few spots where it has cooled or stayed the same
  - Warming was not steady, with cooling in the 1940's - 1970's
- Arctic sea ice and NH snow cover has decreased (e.g. ~30% less sea ice thickness)
- ~2% increase in precipitation globally

General Circulation Models (GCMs)

- Computer models that solve equations that represent important Earth System Processes.
  - Needed to quantify complicated system of feedbacks
  - Have been developed by many scientific groups (~10-15 "Coupled" GCMs)
- 3-dimensional (latitude, longitude, vertical height)
- Types of GCMs:
  - A-GCMs: Models of atmosphere only
  - O-CGMs: Models of ocean only
  - AO-GCMs, or "coupled"-GCMs: Models of ocean and atmosphere

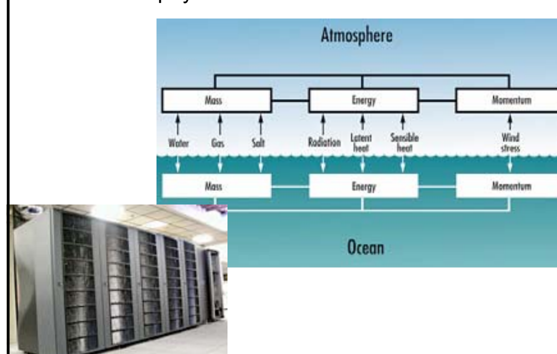
Models of the Earth System help us understand the net effect of all of Earth's feedbacks

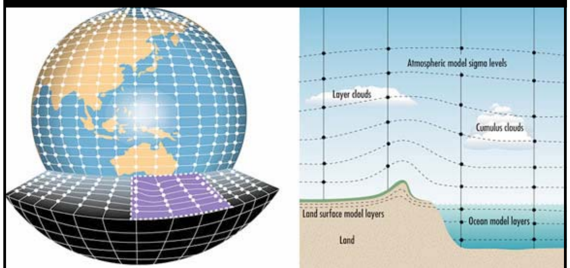




GCMs are needed to quantify complicated system of feedbacks

Models are a system of equations that represent basic physics of the environment





Model Components

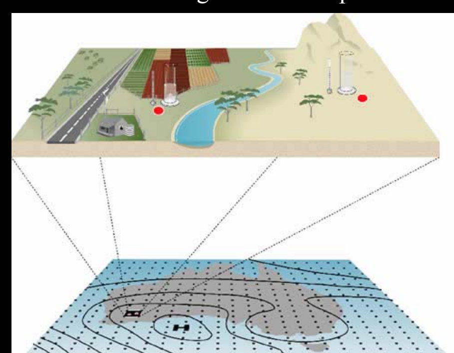
- "Coupled" models typically have fixed:
  - Topography, Ocean Bathymetry
  - Ice Sheet and Glacier distribution
- Basically everything else is calculated
  - Some part of the Earth system are well represented (e.g. current and winds)
  - Some part of the Earth system are more difficult to model (e.g. clouds, sea ice, vegetation changes)

Missing from most Coupled GCMs

•Stratospheric components
•Chemical reactions
•Interactive ice sheets
•Explicitly modeled sub-grid scale processes:
  –Any process that occurs on scales less than the size of a grid, are "parameterized", or estimated
  –Example: cloud formation

since "PARAMETERIZATIONS" are different in each model, models do not always agree with each other

Small scale changes cannot be predicted



Examples of "Parameterizations"

- Cloud formation (Clouds are smaller than a grid box)
  - Water molecules condensing around an aerosol (CCN) are not modeled
  - % of grid filled with a cloud will be calculated from temperature, vertical velocity, water vapor content
- Small scale turbulence/mixing (storms and ocean eddies)
  - Mixing of air and ocean parcels are not modeled
  - Degree of mixing calculated from temperature and pressure gradients, wind stress, etc.

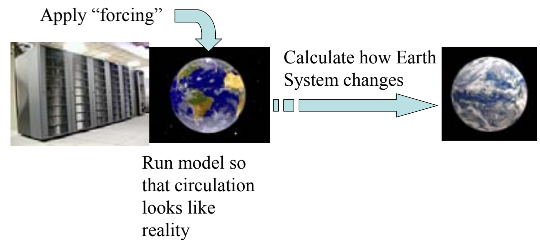
"Forcing" a model

- "Forcings" are the changes imposed on the model to see how climate reacts
- Examples of "forcings":
  - Changes in Greenhouse gas content
  - Changes in Aerosol content
  - Changes in Solar heating

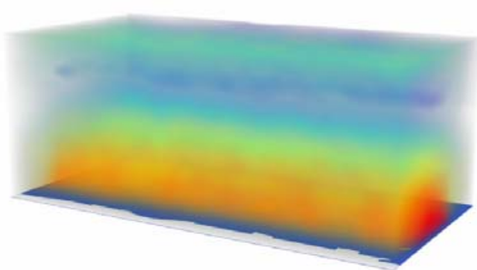
Running a Model

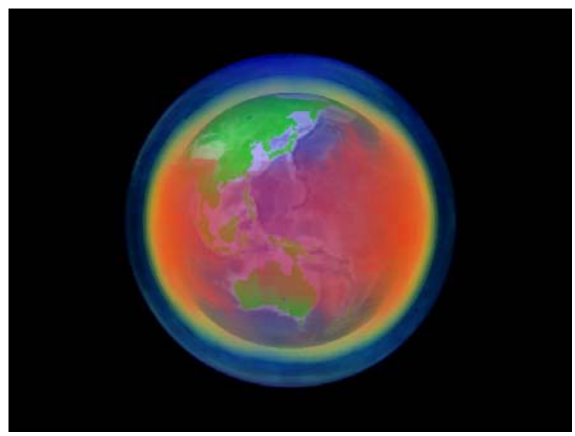
- Impose "Forcing" on model
- Calculate:
  - Temperature
  - Wind/Current velocity
  - Water vapor, and cloud coverage and type
  - Land characteristics such as Soil moisture, Vegetation type, Hydrology
  - Etc.

Running a Model



3-D GCM temperature

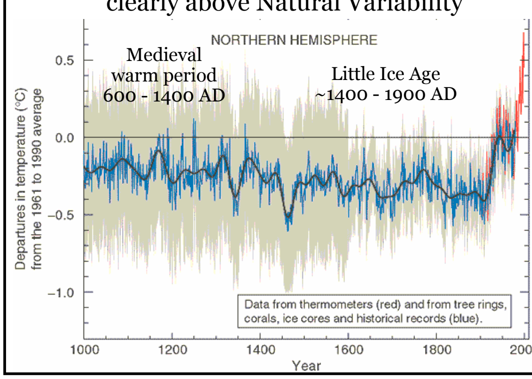




Important Questions:

- *How do we know observations from last 100 years are due to Enhanced Greenhouse Effect?*
  - Lessons from the Geologic Past
  - We should be able to model modern climate well. AND if we can model the last 100 years of observed changes, then we understand what caused them.
- *What will happen in the future?*
  - If our models can reproduce past and modern climate, then we can use them to predict the future.

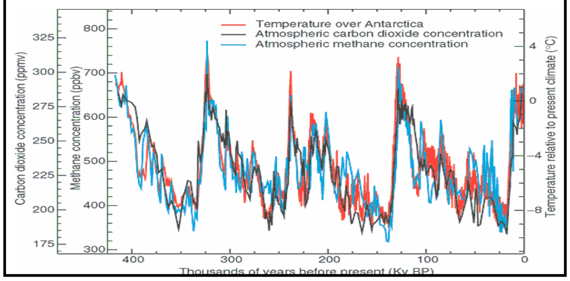
Recent Observed Global Temperature Rise is clearly above Natural Variability



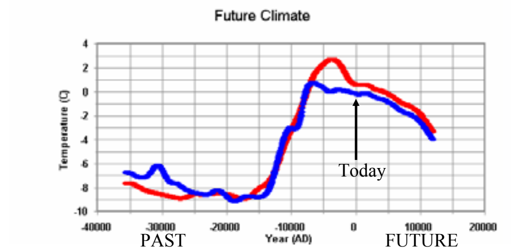
Methane today = 1700ppb

Antarctic Ice Core shows that climate is related to GHGs

CO_2 today = 365 ppm



Future Climate without GHG warming: heading into another ice age



BLUE: last glacial maximum to modern warm period transition
RED: previous glacial maximum to previous warm period transition

Important Questions:

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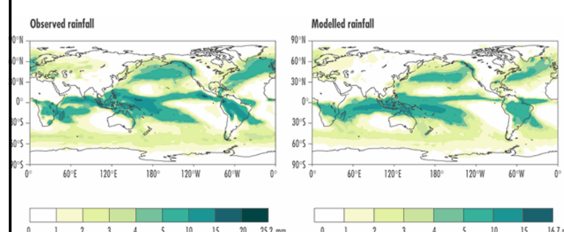
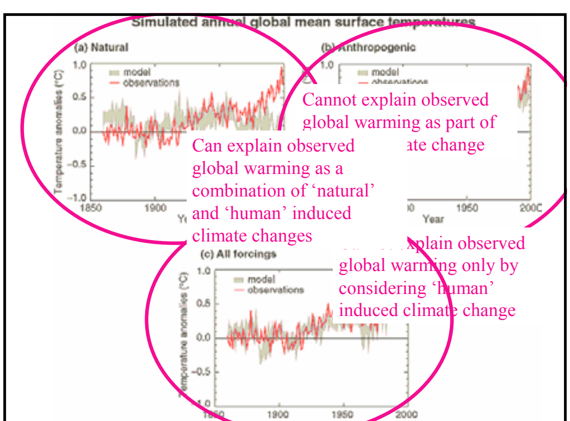
Models produce realistic climate





Model Verification

- Models do an excellent job of simulating last 150 years of global warming when increasing GHGs, aerosols, and natural forcings are used. Therefore:
  - GHG emissions must be an important forcing of Earth's global climate over the last 150 years!!

Important Questions:

- *How do we know observations from last 100 years are due to Enhanced Greenhouse Effect?*
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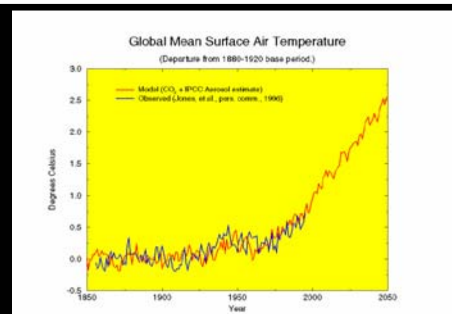
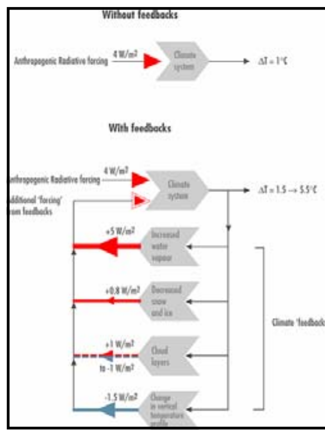


This model (red line) does a good job of predicting observed changes of last 150 years, and predicts another 2˚C warming in next 50 years. However, other models predict different amount of warming.

Doubled CO2 Runs

- Over a dozen models have been run in which CO2 was doubled. (2 X 290 ppm = 580 ppm)
  - They predict global temperature changes by 1.5 to 4.5 ˚C when CO2 = 580 ppm.
  - There are HUGE differences among these models regarding regional temp. and rainfall changes.
- Differences have to do with model design and parameterizations.
- We don't know which of these are trustworthy for predicting the future



Feedbacks aren't exactly the same in all models

Different models give different results

What Will Happen in Future?

Predictions of Furture depend on:

1. Future GHG emissions
   1. sociopolitical, economic forces?
2. Future Aerosol emissions (pollution)
   1. sociopolitical, economic forces?
3. Climate sensitivity (which model is used)
   1. depending on how processes are parameterized, models
   2. predict 1.5 - 4.5˚C for doubling CO2
4. Ice sheet models
   1. melting and flow parameters?

End up with RANGE OF POSSIBILITIES

Future GHG emissions

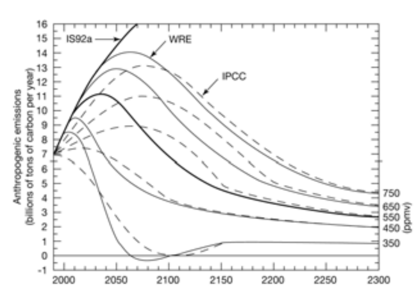


Figure 14.2 Different Emissions Scenarios: Depend mostly on how quickly we convert to alternate energy sources

Future accumulation in atmosphere

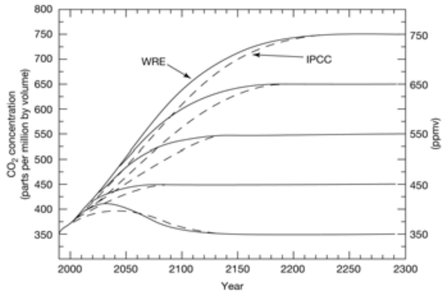
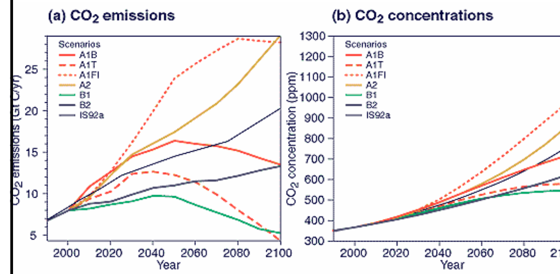


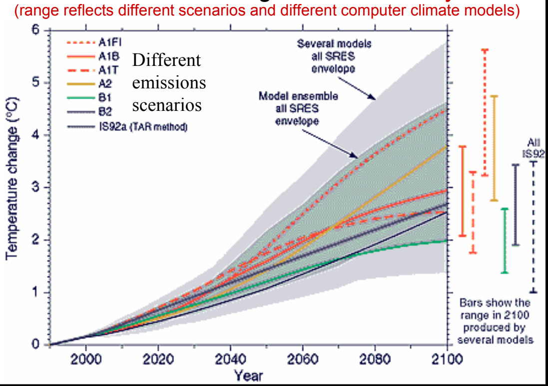
Figure 14.2: Accumulation of GHGs in atmosphere depending on emissions scenario that occurs in future

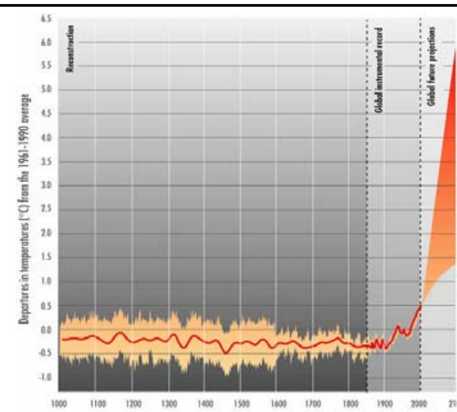
Focus on IPCC predicted Future Emissions - each curve is a different socioeconomic and political pathway

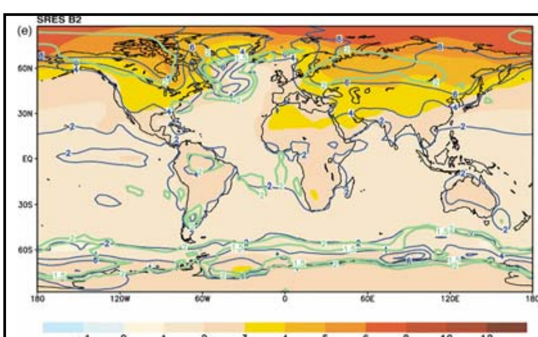


Future Global Warming: 1.4 to 5.8˚C by 2100

(range reflects different scenarios and different computer climate models)







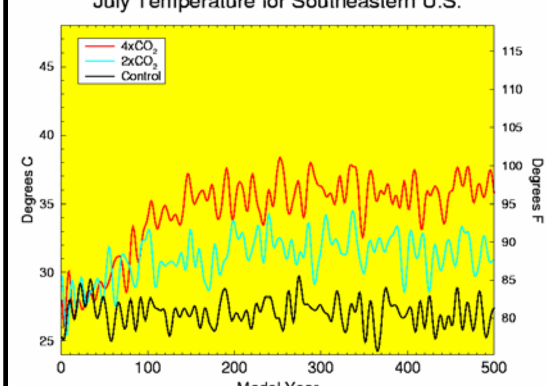
Predicted Temperature: 2071 to 2100 for B2 (medium scenari

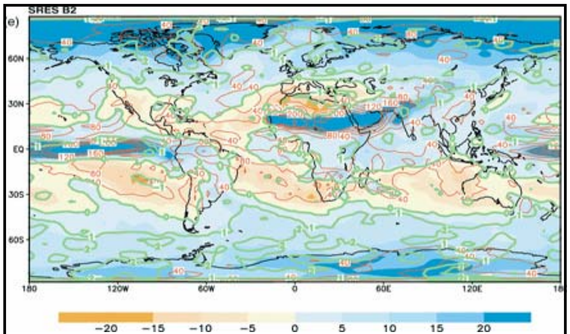
Filled in color contours: Average of all models

Blue contours: Range of predictions from all models

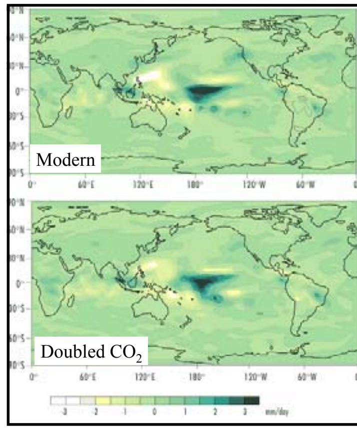
Green contours: “Noisiness” of predictions

July Temperature for Southeastern U.S.

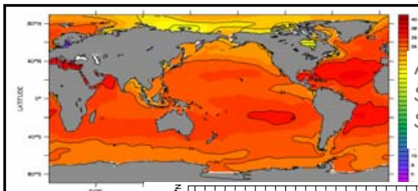




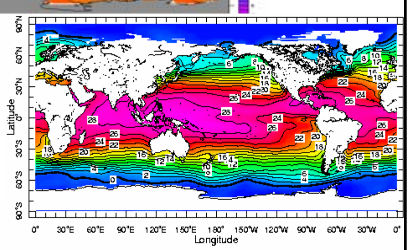
Predicted Precipitation: 2071 to 2100 for B2 (medium scenar
Filled in color contours: Average of all models
Red contours: Range of predictions from all models
Green contours: “Noisiness” of predictions



No differences in rainfall patterns during El Niños with global warming

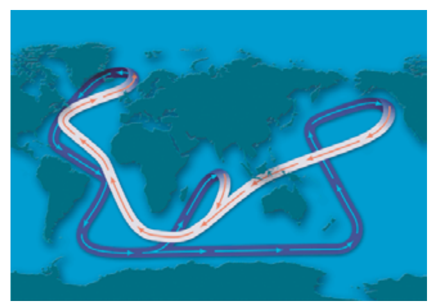


Annual Sea Surface Salinity

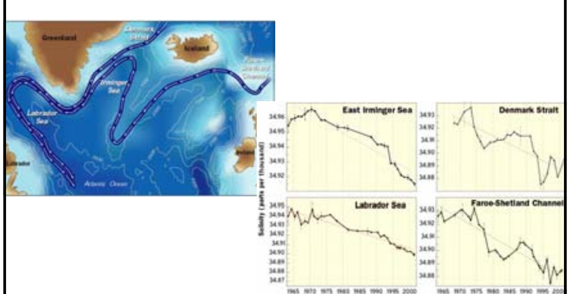


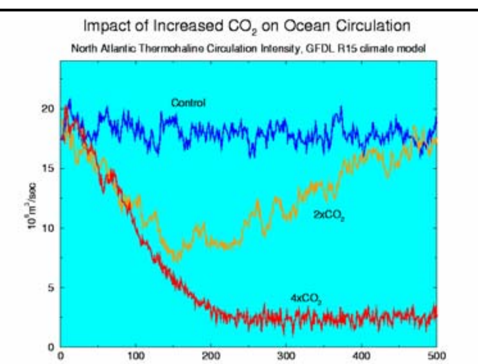
Annual Sea Surface Temperature

Global Ocean Conveyor Belt
represents net ocean circulation



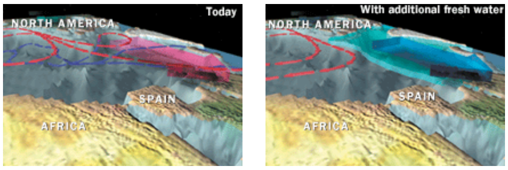
North Atlantic is getting fresher

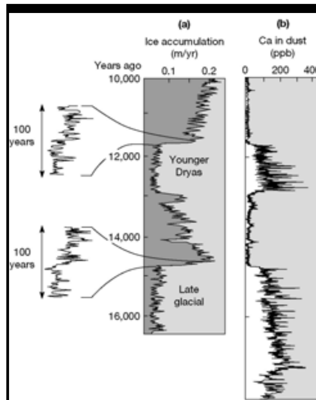




Global Ocean Conveyor Belt Will Slow Down

Demise of NADW?



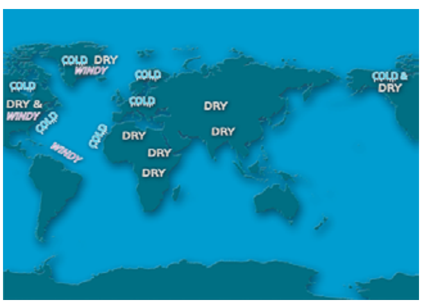


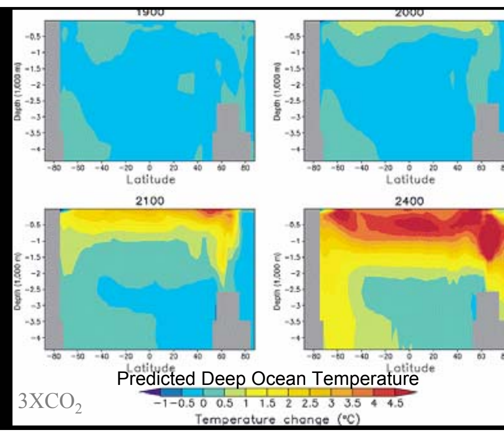
Younger Dryas:
Ice Cores show huge climate change in less than 100 years!

Climate feedbacks can cause 'abrupt' climate change.

Extreme cooling due to shut down of NADW

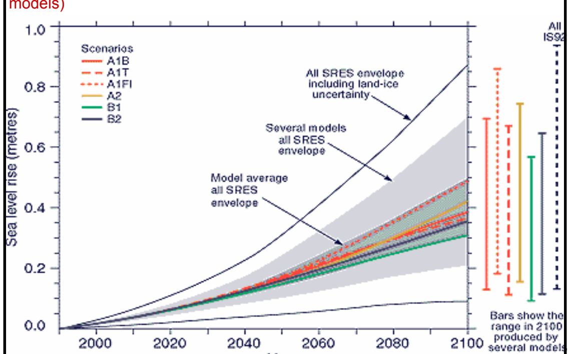
The Younger Dryas





Future Sea Level Rise: 9 to 88 cm by 2100

(range reflects different emissions scenarios, climate models, and ice melting models)



Greenland ice sheet contains water equivalent to 7.2 m of sea level rise.

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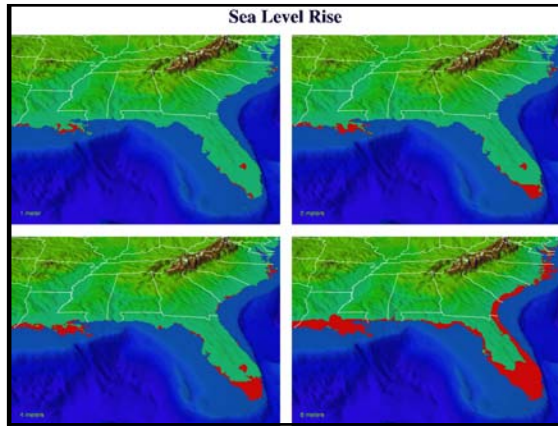
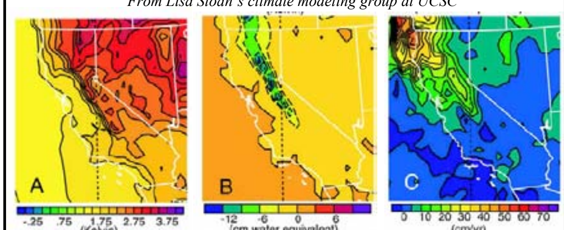


Maldives and other island nations will be influenced by even small changes in sea level

California climate change (with double CO_2, ~50 years from now)

From Lisa Sloan's climate modeling group at UCSC



Temperature | Snow | Rainfall

- -Warmer
- -Less snow in mountains, less spring and summer water availability
- -More rainfall
- -Need a new water management strategy

Summary

- Our models do a good job of simulating historical GLOBAL temperature change when GHGs, aerosols, and natural changes are imposed
- Regional changes are not well understood
- Global Predictions for 2100
- 1.4 to 5.8˚C warmer (more warming at high latitudes)
- 9 to 88 cm sea level rise
- Still a lot of work to do to understand feedbacks involving clouds, ice sheets, vegetation, ocean circulation, and regional/local changes