AGRON 590

Global and regional climate modeling

Two main multi-model archives

CMIP3: Simulations performed used in the IPCC Fourth Assessment Report.

– Simulations were completed around 2005.

CMIP5: Simulations used in the IPCC Fifth Assessment Report.

– Most of the models are updated versions of ones in CMIP3.

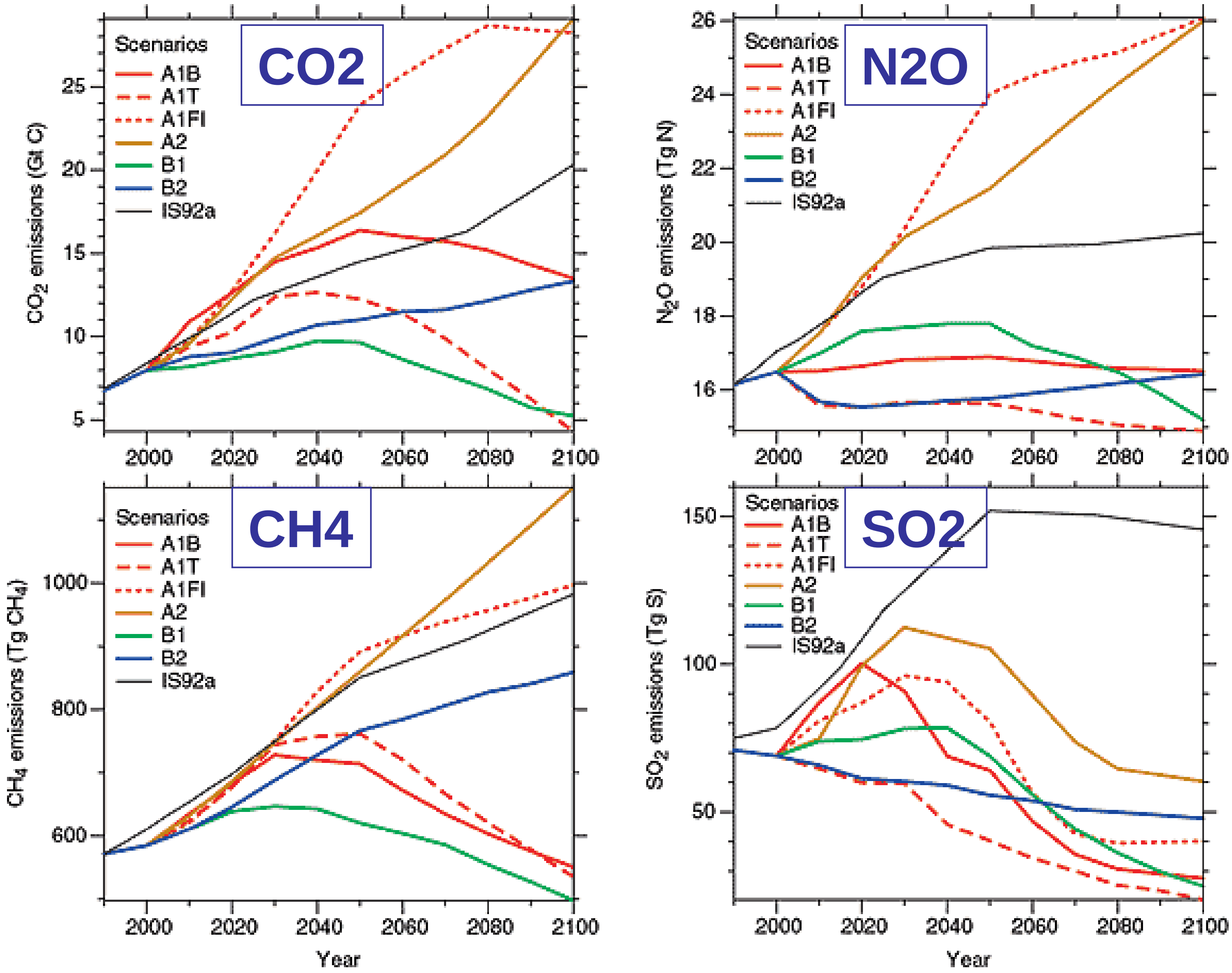
– Most simulations completed around 2011.

CMIP3 scenarios

Based on "storylines" of economic development and geopolitical organization.

	Globalization	Regional / national focus
Economic Growth	**A1** A1T, A1FI, A1B T=emissions decline after mid-century due to technology improvements FI = Fossil fuel Intensive B = Balanced	**A2** high CO_2 emissions
Sustainability	**B1** CO_2 emissions decline after mid-2100s	**B2** low CO_2 emissions (but no decline)

SRES (CMIP3) emission scenarios



CMIP3 Models (IPCC Fourth Assessment Report)

Model	Horizontal grid, lat/lon
BCC-CM1, China	~1.9x1.9
BCCR-BCM2.0, Norway	~1.9x1.9
CCSM3, USA	~1.4x1.4
CGCM3.1(T47), Canada	~2.5x2.5
CGCM3.1(T63), Canada	~1.9x1.9
CNRM-CM3, France	~1.9x1.9
CSIRO-Mk3.0, Australia	~1.9x1.9
CSIRO-Mk3.5, Australia	~1.9x1.9
ECHAM5/MPI-OM, Germany	~1.9x1.9
ECHO-G, Germany/Korea	~4x4
FGOALS-g1.0, China	~2.8x2.8
GFDL-CM2.0, USA	2x2.5
GFDL-CM2.1, USA	2x2.5
GISS-AOM, USA	3x4
GISS-EH, USA	4x5
GISS-ER, USA	4x5

CMIP3 Models (IPCC Fourth Assessment Report)

Model	Horizontal grid, lat/lon
INGV-SXG, Italy	~2.8x2.8
INM-CM3.0, Russia	4x5
IPSL-CM4, France	2.5x3.75
MIROC3.2(hires), Japan	~1.1x1.1
MIROC3.2(medres), Japan	~2.8x2.8
MRI-CGCM2.3.2, Japan	~2.8x2.8
PCM, USA	~2.8x2.8
UKMO-HadCM3, UK	2.5x3.75
UKMO-HadGEM1, UK	1.25x1.875

CMIP5 RCPs

Instead of "storylines" use Representative Concentration Pathways (RCPs) based on **radiative forcing** by 2100.

Radiative forcing is change in the input of radiant energy at the tropopause relative to pre-industrial conditions.

- Current radiative forcing is 2.3 W m^{-2}.

Standard RCPs are 8.5, 6.0, 4.5 and 2.6 W m^{-2} at 2100.

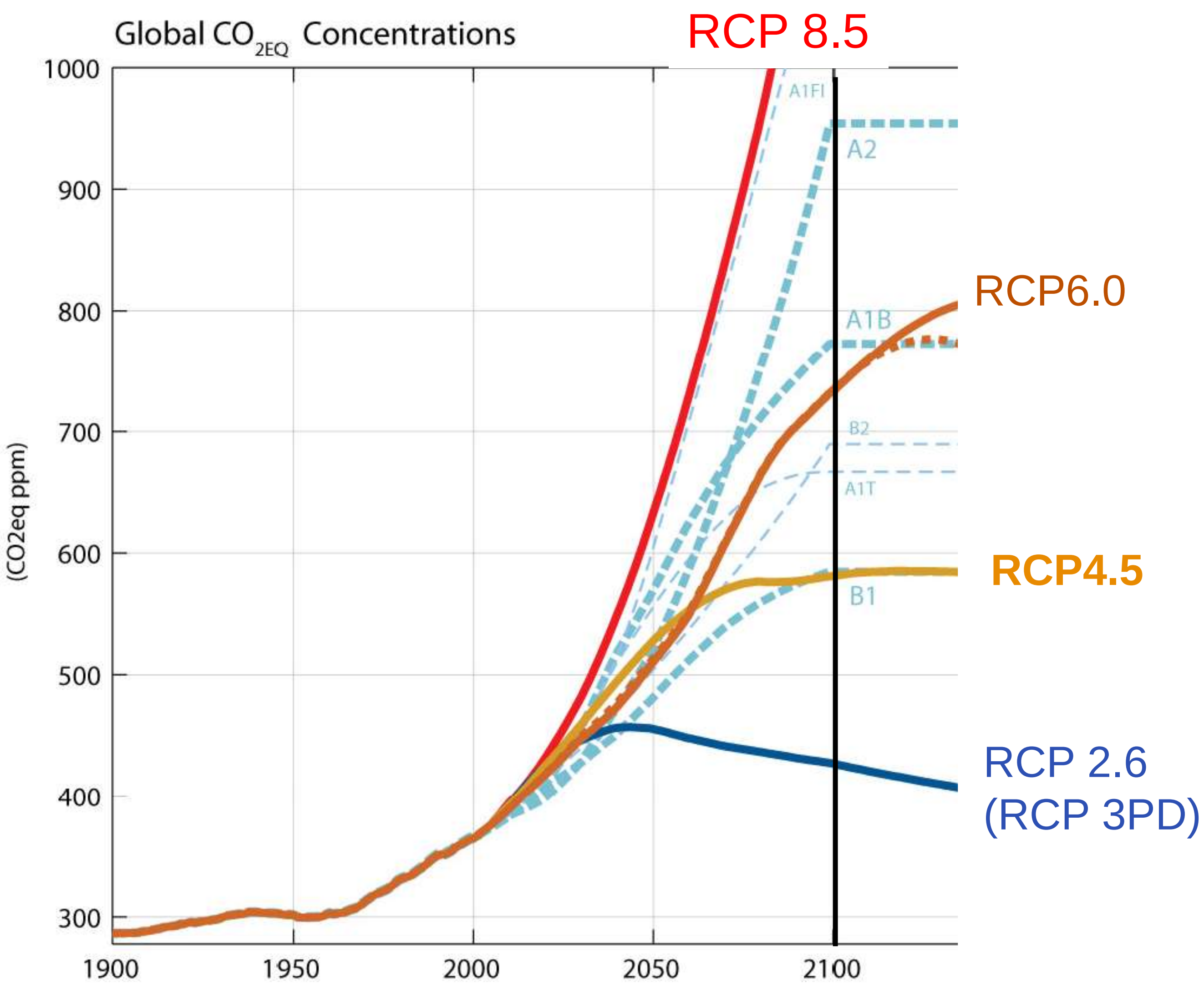
RCP8.5 ~ A1FI

RCP6.0 ~ between A1B and B2

RCP4.5 ~ B1

RCP2.6 (also called RCP3PD) is lower than any SRES scenario

CMIP5 RCPs and corresponding CO_2 equivalent concentrations



CMIP5 scenarios

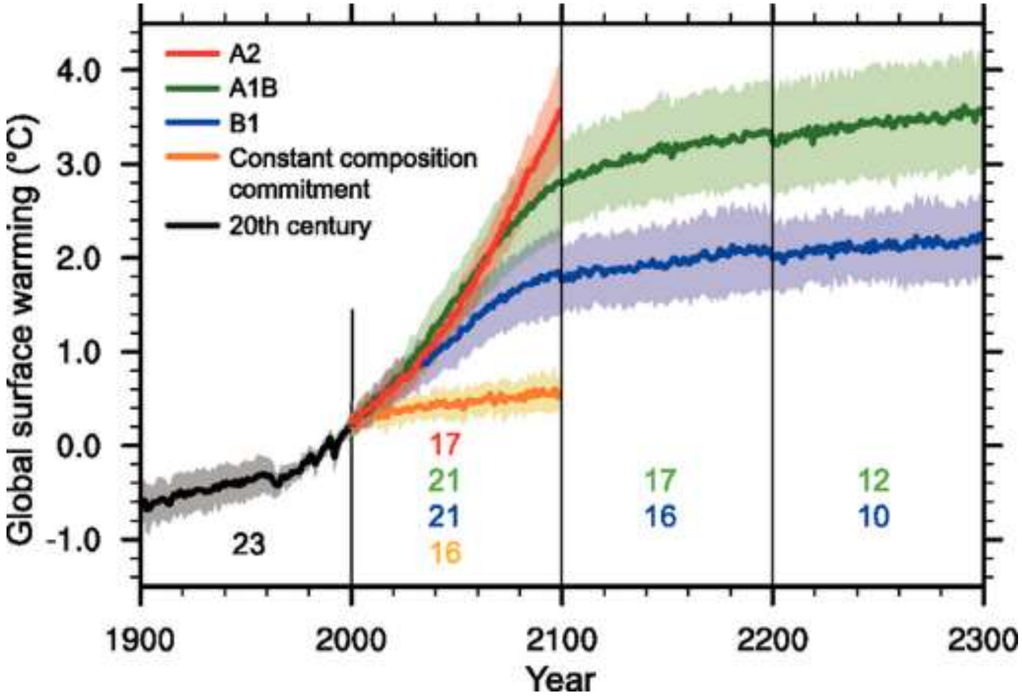
Instead of "storylines" use Representative Concentration Pathways (RCPs).

Basis for each RCP is **radiative forcing** by 2100.

Radiative forcing is change in the input of radiant energy at the tropopause relative to pre-industrial conditions.

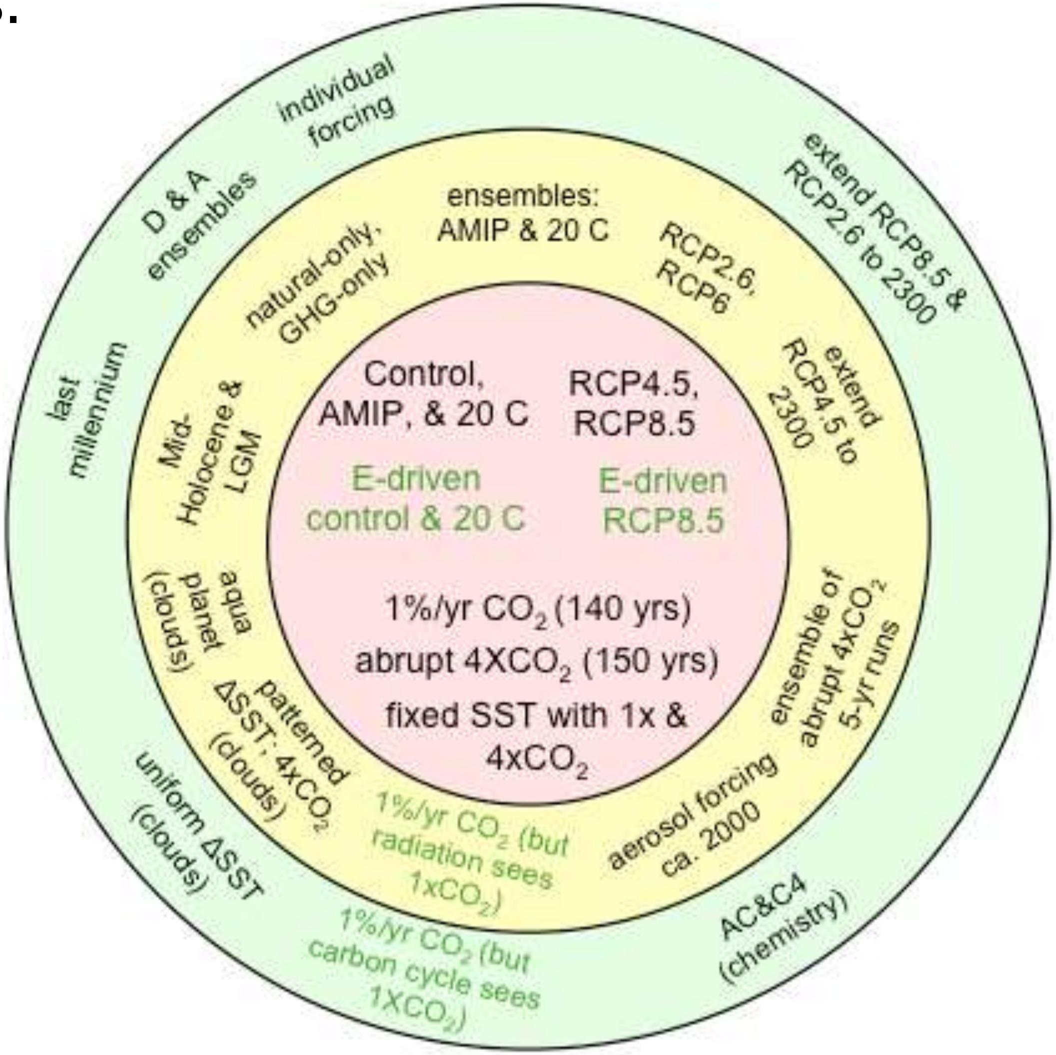
- Current radiative forcing is 2.3 W m^{-2}.

Variations between models usually are greater than variations between scenarios until late 21st century



CMIP5 runs

Many different experiments. Build outward from core experiments.



CMIP5 Models (IPCC Fifth Assessment Report)

Model	
BCC-CSM1.1(m), China	
BNU-ESM, China	
CCCma-CanAM4, Canada	
CCCma-CanCM4, Canada	
CCCma-CanESM2, Canada	
CESM1 (BGC), USA	
CESM1 (CAM5), USA	
CESM1 (CAM5.1, FV2), USA	
CESM1 (FASTCHEM)	
CESM1 (WACCM)	
CFSv2, USA	
CMCC-CESM, Italy	
CMCC-CM, Italy	
CMCC-CMS, Italy	
CNRM-CM5, France	
CNRM-CM5-2, France	

CMIP5 Models (IPCC Fifth Assessment Report)

Model	
CSIRO-ACCESS1.0, Australia	
CSIRO-ACCESS1.3, Australia	
CSIRO-Mk3.6.0, Australia	
EC-EARTH, Europe	
FGOALS-g2, China	
FGOALS-gl, China	
FGOALS-s2, China	
FIO-ESM, China	
GEOS-5, USA	
GFDL-CM2.1	
GFDL-CM3	
GFDL-ESM2G	
GFDL-ESM2M	
GFDL-HIRAM-C180	
GFDL-HIRAM-C360	

CMIP5 Models (IPCC Fifth Assessment Report)

Model	
GISS-E2-H, USA	
GISS-E2-H-CC, USA	
GISS-E2-R, USA	
GISS-E2-R-CC, USA	
INM-CM4, Russia	
IPSL-CM5a-LR, France	
IPSL-CM5a-MR, France	
IPSL-CM5b-LR, France	
MIROC-ESM, Japan	
MIROC-ESM-CHEM, Japan	
MIROC4h, Japan	
MIROC5, Japan	
HadCM3, UK	
HadCM3Q, UK	
HadGEM2-A, UK	
HadGEM2-CC, UK	
HadGEM2-ES, UK	

CMIP5 Models (IPCC Fifth Assessment Report)

Model	
HadGEM2-AO, Korea	
MPI-ESM-LR, Germany	
MPI-ESM-MR, Germany	
MPI-ESM-P, Germany	
MRI-AGCM3.2H, Japan	
MRI-AGCM3.2S, Japan	
MRI-CGCM3, Japan	
MRI-ESM1, Japan	
NCAR-CCSM4, USA	
NCC-NORESM1-M	
NCC-NORESM1-ME	
NICAM.09, Japan	

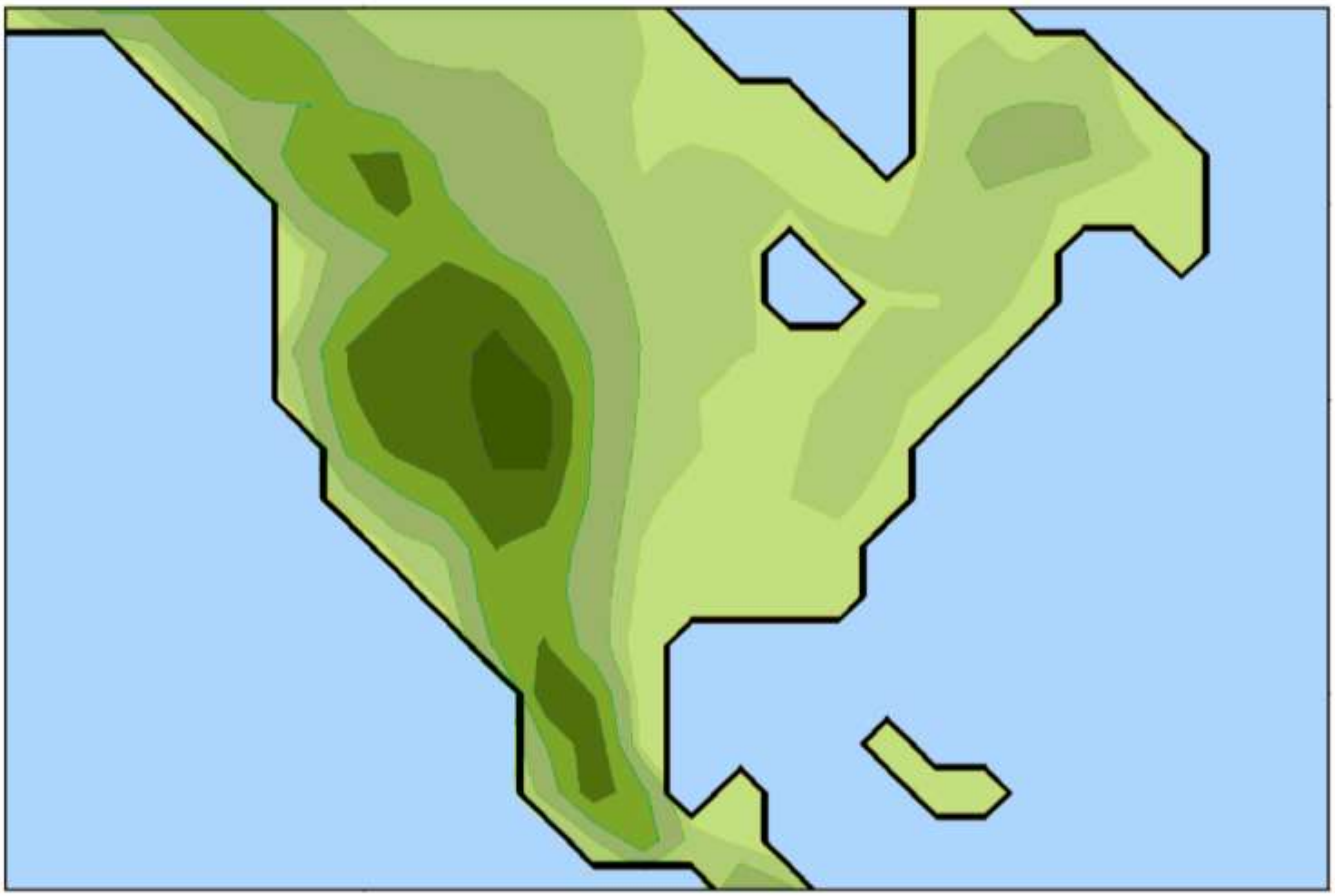
Regional climate: The problem

Global climate models project climate change using discretized forms of governing physical equations.

- Values are computed for grid cells about 100 to 300 km apart.
- Solutions are reasonably accurate only for features at least 4 grid cells wide.

But climate impacts and policy responses take place at regional scales: cities, states, nations. How do we bridge from global to regional scales?

Land-sea boundaries and terrain in the Hadley Centre climate model HadCM3



What do we do?

The obvious (and best) solution is to run the model with finer grid spacing. But…

Computational needs increase inversely with the **cube** of the horizontal grid spacing: if grid spacing is halved we need

- twice as many points in the north-south direction,
- twice as many points in the east-west direction, and
- twice as many steps to march the solution forward to a given time (for numerical stability).

Result is 2 x 2 x 2 = 2^3 = 8 times as much computing time (and four times as much memory).

Two main approaches for extracting finer-scale information from global climate models

Empirical / statistical downscaling:

Post-process the global model data to derive inferences about smaller scales.

There are many approaches: simple "delta" change methods, regression models, bias correction, neural networks…

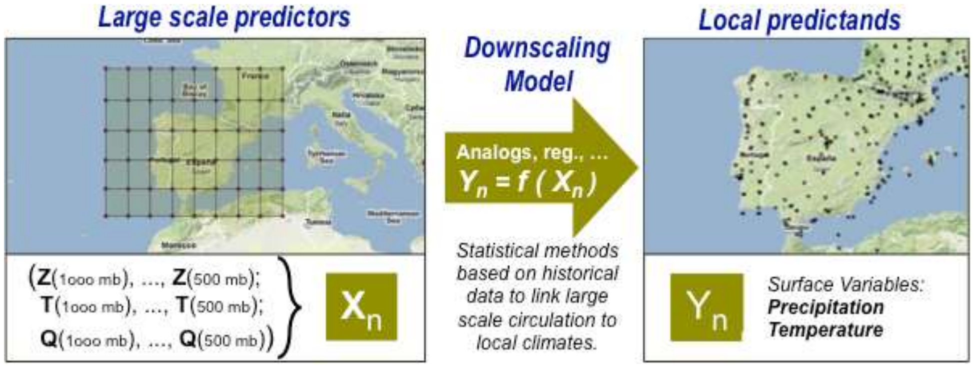
Dynamical downscaling:

Run a dynamical model with finer grid spacing that focuses on the region or period of interest.

Statistical downscaling

- Develop a statistical transfer function that relates a local variable (predictand) to a large scale variable or variables (predictors) .

- Calibrate the transfer function using available observations.



- Apply this relationship to the model's future values of the predictor variables.

Advantages and disadvantages of statistical downscaling

- Modest requirements in terms of human and computational effort.
- Can be applied to point locations or small regions where we have a record of our predictand.
- Assumes that statistical transfer functions calibrated in the current climate will continue to apply in the future.
- Assumes that the climate model projections of the predictor variables are accurate.

Dynamical downscaling

Use a physically-based model similar to the global model, but focus computational resources on the region or period of interest.

Physical basis means the models **should** be more general than statistical methods.

Three main approaches:

- ✧ Use a fine-resolution global model, but for a **short period** (years to decades).
- ✧ Use a global model with fine resolution in one or more regions of interest and coarser resolution elsewhere.
- ✧ Use a fine-resolution model but with a domain covering only the region of interest.

Use a high-resolution global model, but only for a short period

This is called a "time slice" simulation.

Since the period of simulation is shorter, we can use finer grid spacing.

The simulation has to be initialized from a coarser long-term simulation:

- Usually these are atmosphere-only models, as the ocean can take a long time to reach equilibrium.
- Ocean is taken from the coarser long-term model.

Use a global model with variable resolution ("stretched grid" model)

Fine resolution in a region of interest, and coarser resolution in other parts of the globe.

The same dynamical model is used for both the region of interest and the rest of the globe.

Traveling weather features can be distorted when moving through different parts of the grid

Parameterizations of physical processes often behave differently at different resolutions.

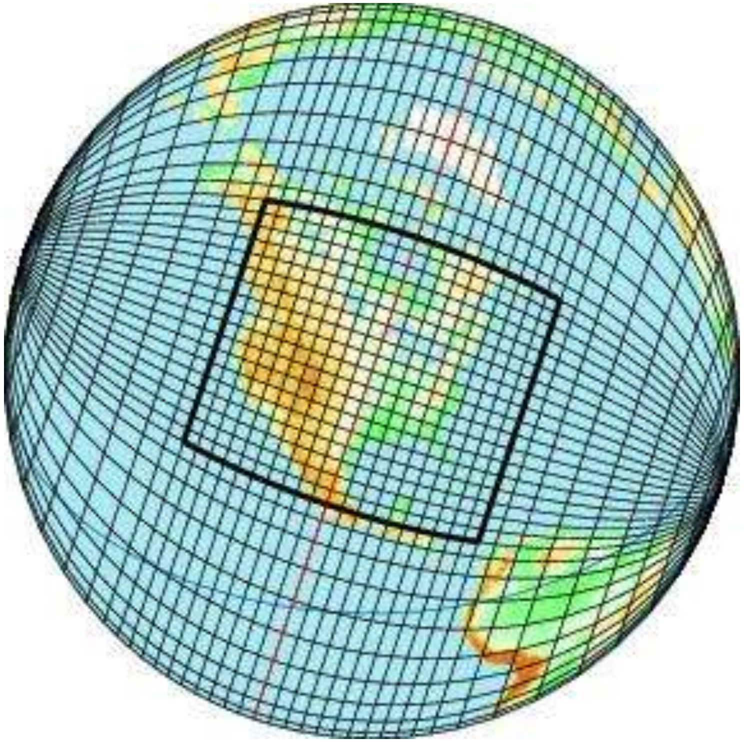


Figure from Canadian Meteorological Centre.

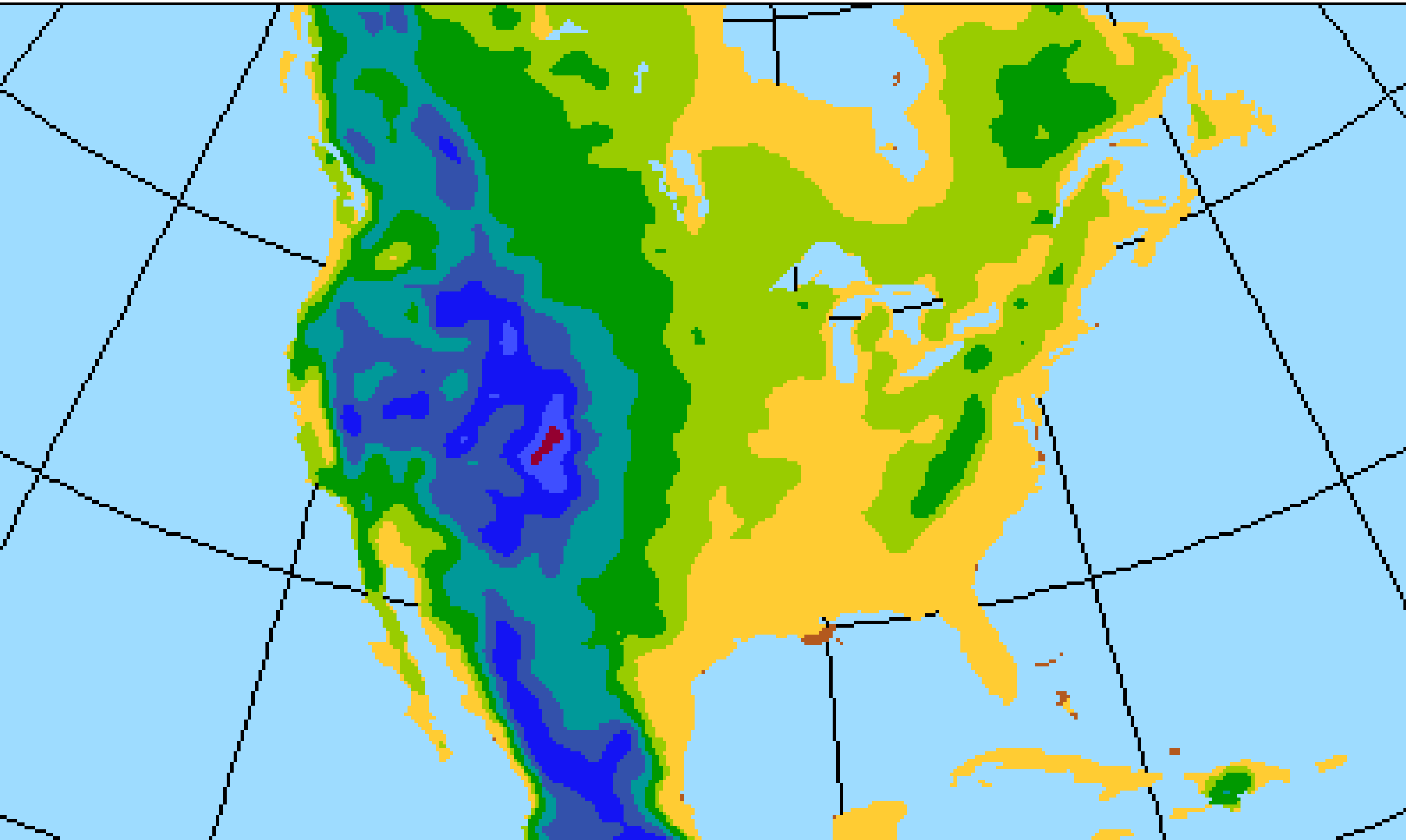
Use a high-resolution model covering only the region of interest

This is called nested regional climate modeling (among other terms).

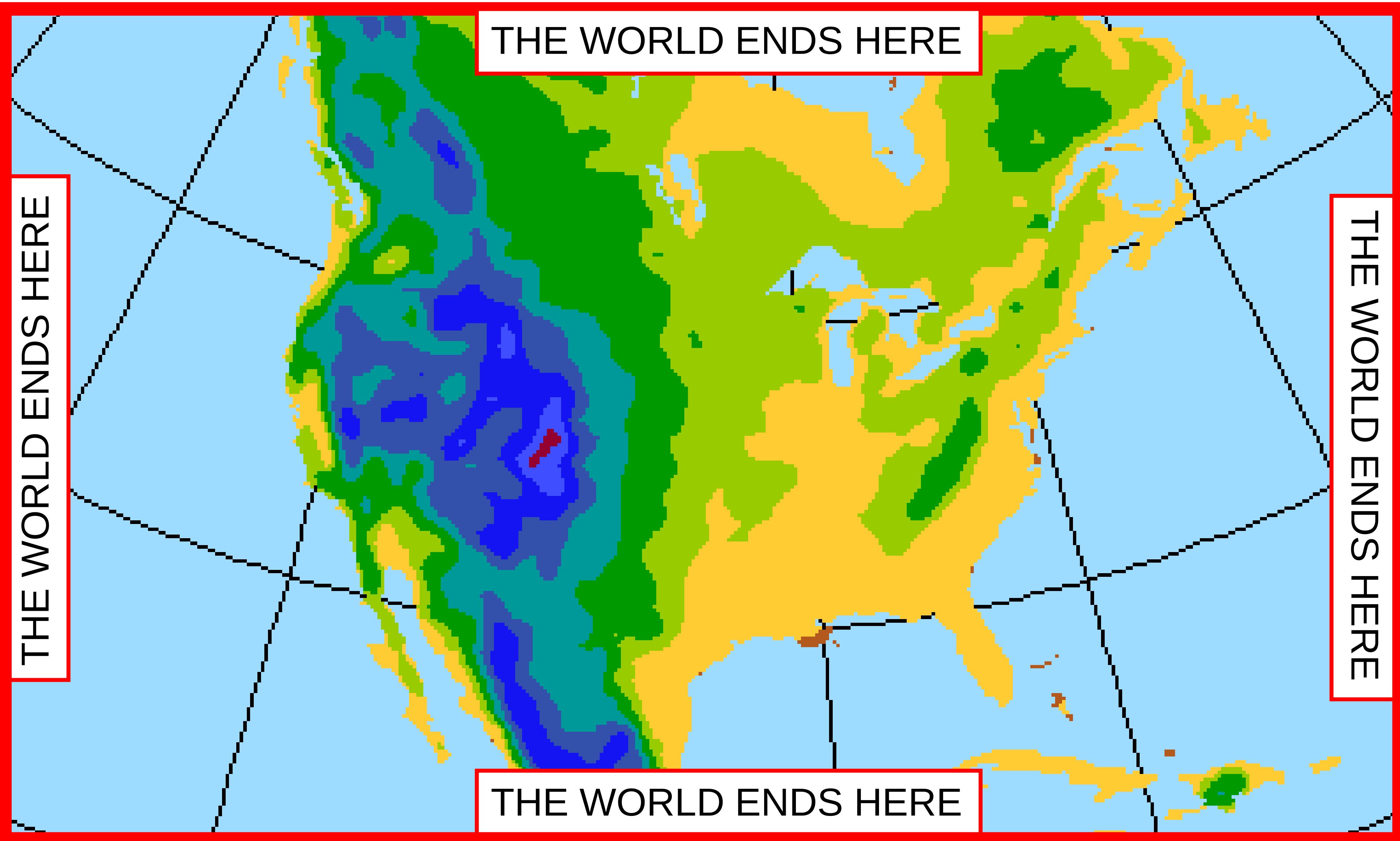
Since we are simulating only a limited region we can use a finer grid over that region.

This is the most commonly used dynamical downscaling approach at present.

Limited area models allow finer resolution grids to be used (50 km spacing shown)

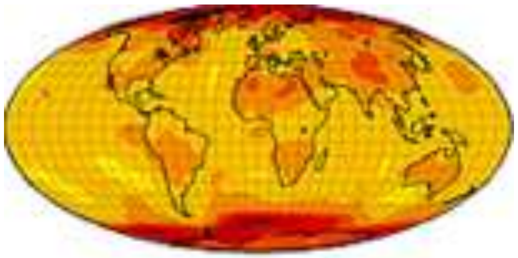


A problem: Regional models don't know about the world outside unless we tell them.

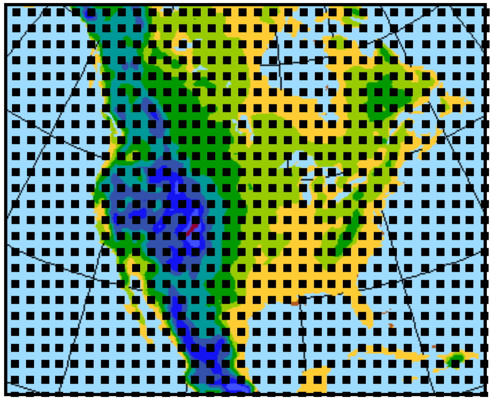


Regional climate models depend on global models

Run the global model, storing output several times per day (usually every 6 hours).

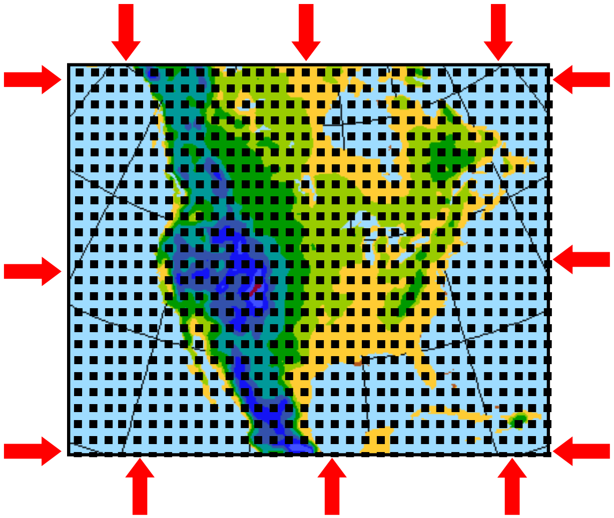


Initialize the regional model by interpolating global model results to the regional model grid.



Periodically **update** the regional model around its lateral boundaries using results from the global model.

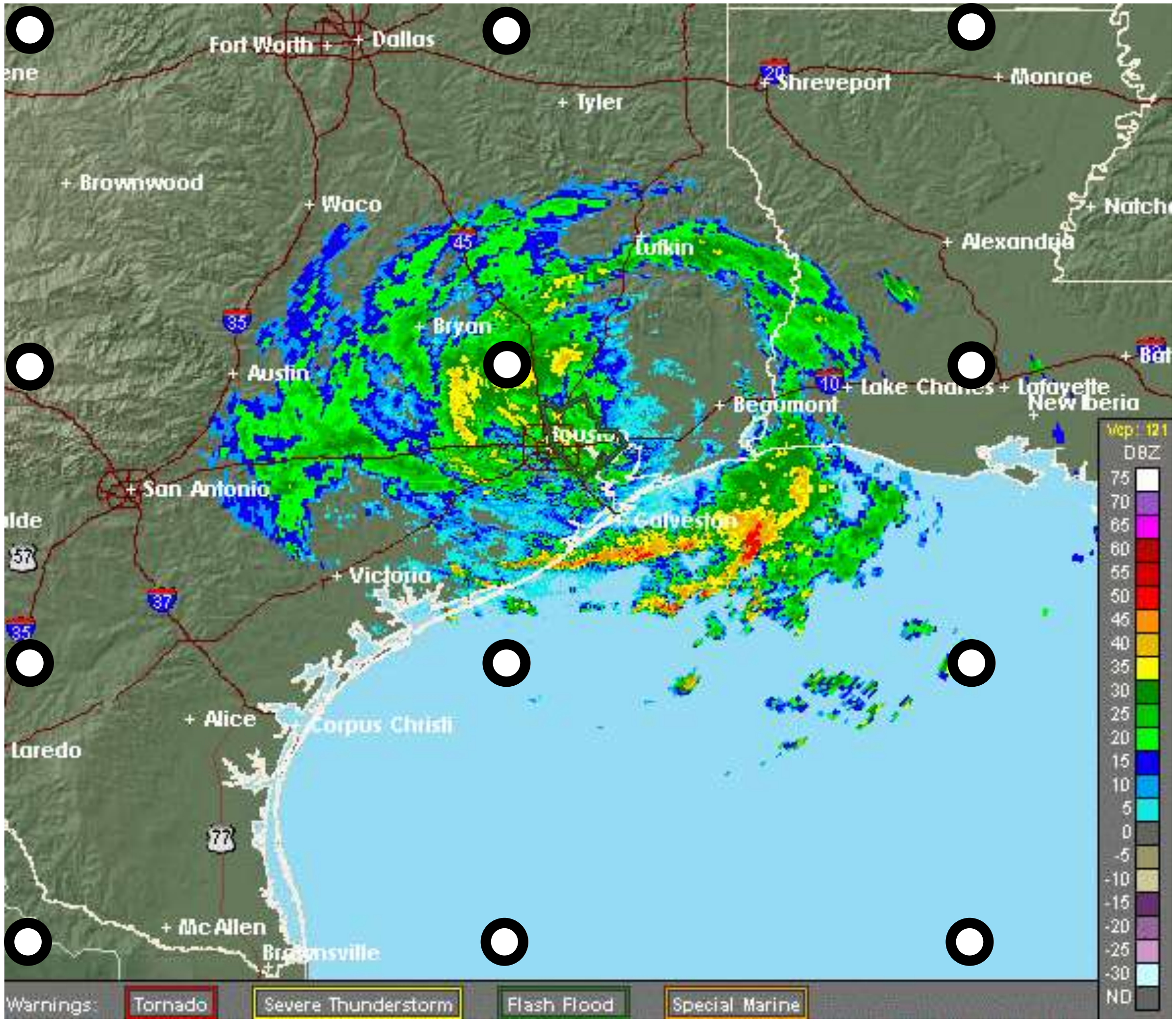
results from global model



Advantages and disadvantages of high-resolution limited area models

- Can include terrain and coastlines with much finer detail than global models.
- Produce physically consistent results for variables that do not have observed records needed for statistical methods.
- Can resolve atmospheric circulation in more detail, even predicting phenomena that are completely absent in global models.
  - ✧ Example: Tropical cyclones.

HadCM3 grid spacing relative to Tropical Storm Edouard



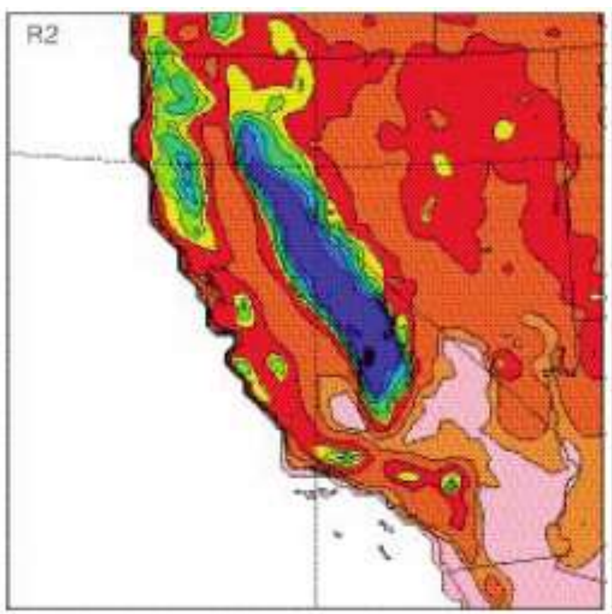
Advantages and disadvantages of high-resolution limited area models

- Computational requirements are less than if fine resolution is global.
- Computational requirements still are very high.
- Quality of the regional solution is closely tied to quality of the global solution that provides the initial and boundary values.

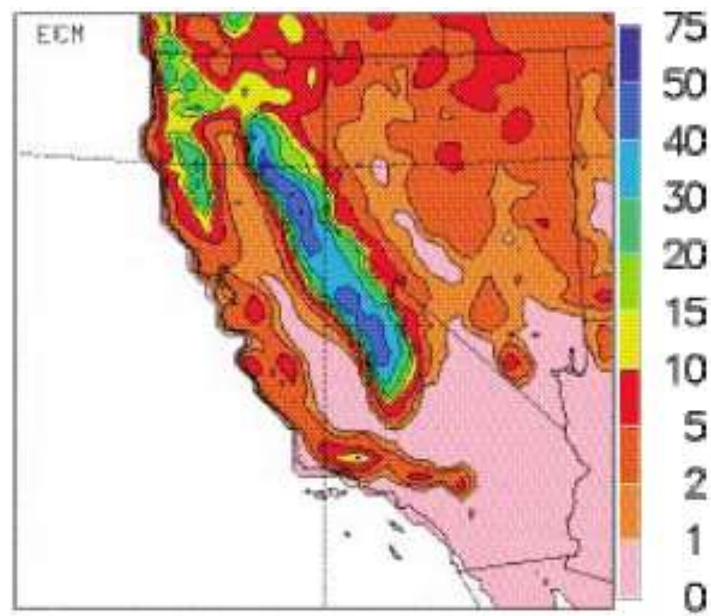
Regional models are sensitive to the source of boundary data

J. Kim, simulation of February 1986 case using 18 km grid spacing.

Uses the same limited area model but with boundary conditions from two different analyses of observations.



Using NCEP-DOE Reanalysis 2 as boundary conditions



Using ERA Reanalysis as boundary conditions

Collaborative regional climate modeling programs

There are several regional climate modeling programs in which different models are used to simulate the same region and period.

Issues examined in these programs include:

- ✧ Does the additional detail of the regional model represent useful information or is it just "noise" on top of the GCM?
- ✧ When driving a regional climate model with a GCM, which model dominates error and variability?
- ✧ Is temporal character of variability improved (such as precipitation frequency, or frequency of extreme events)?

North American Regional Climate Change Assessment Program (NARCCAP)

- Explore combined uncertainties from driving regional climate models with global climate model projections.
- Develop multiple high resolution regional climate scenarios over North America for use in impacts models.

	RCM 1	RCM 2	RCM 3	RCM 4
GCM 1	RCM1GCM1	RCM2GCM1	RCM3GCM1	RCM4GCM1
GCM 2	RCM1GCM2	RCM2GCM2	RCM3GCM2	RCM4GCM2
GCM 3	RCM1GCM3	RCM2GCM3	RCM3GCM3	RCM4GCM3
GCM 4	RCM1GCM4	RCM2GCM4	RCM3GCM4	RCM4GCM4

The Coordinated Regional Downscaling Experiment (CORDEX)

CORDEX is the largest cooperative dynamical downscaling project to date.

Models from many different groups around the world are simulating climate for multiple regions covering each continent.

CORDEX domains

Domains cover most of the inhabited regions of the world, plus Arctic and Antarctica.