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Use of Experimental Design in Climate Change Experiments: Examples from NARCCAP and NA-CORDEX

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National Center for Atmospheric Research

EMF Week 2
Snowmass, CO
August 2, 2013

Outline

- Introduction to downscaling
- NARCCAP brief overview
- Sample Matrices from European Programs
- New program NA-CORDEX

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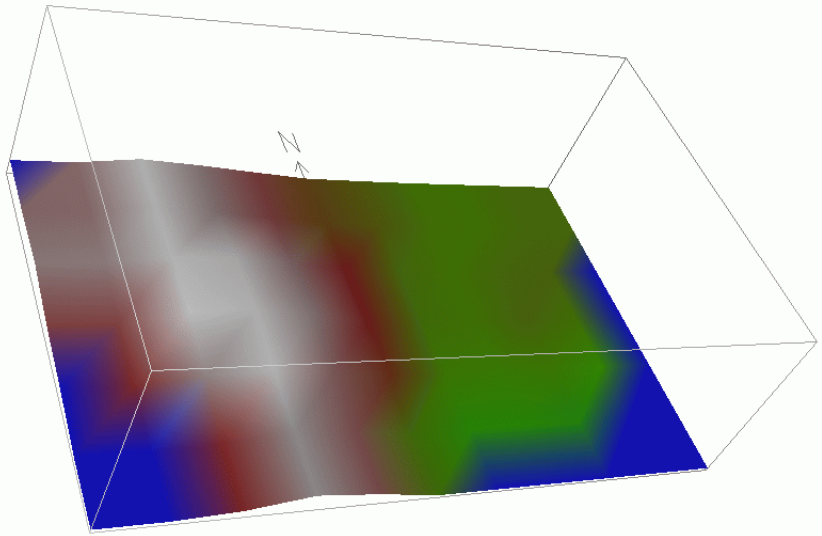
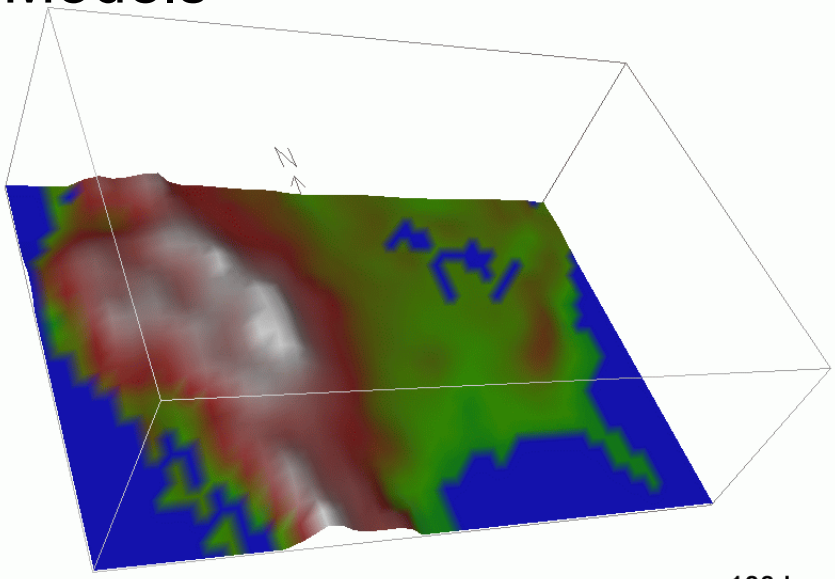
Increasing Spatial Scale of Global Climate Models through Application of Regional Climate Models

Dynamical Downscaling

Global Climate Models



400 km



100 km

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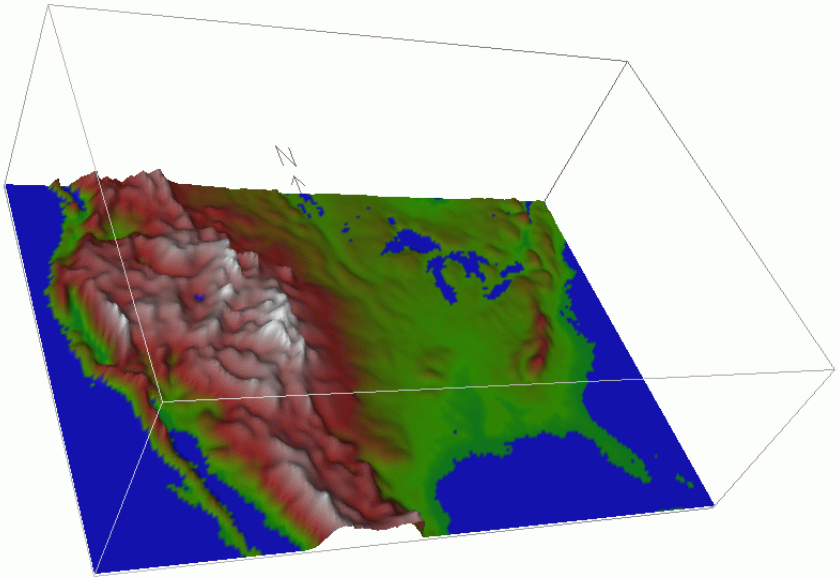
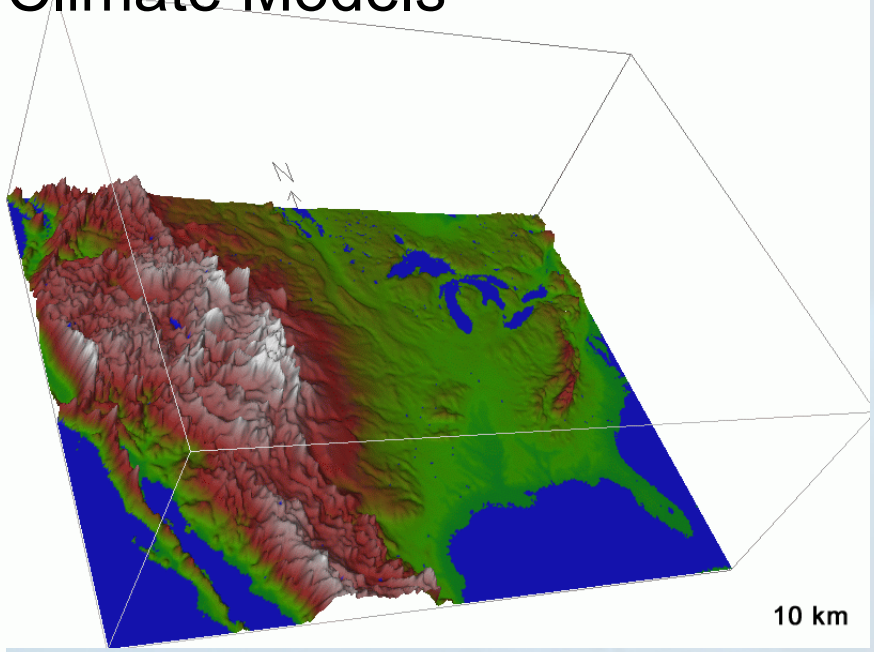
Regional Climate Models



25 km



10 km

Regional Modeling Strategy

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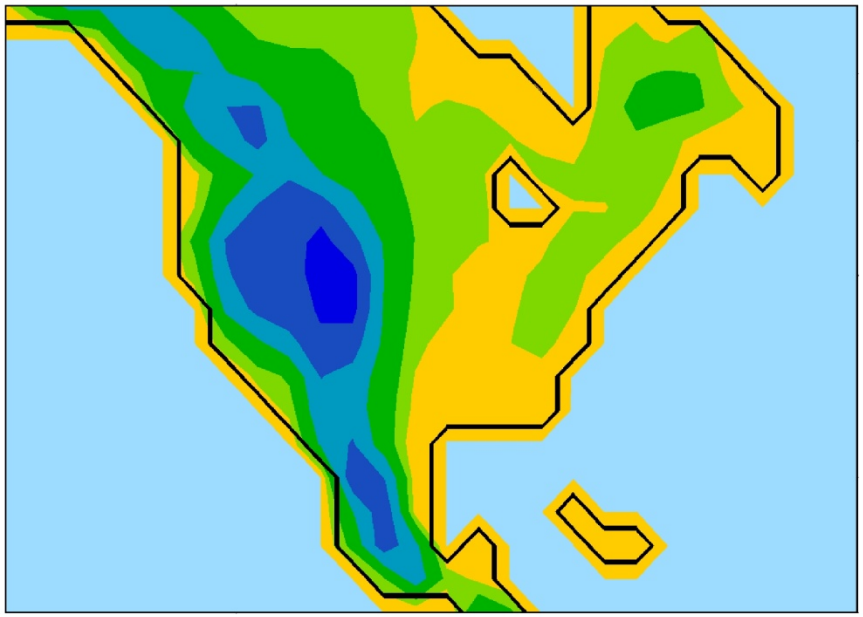
Nested regional modeling technique

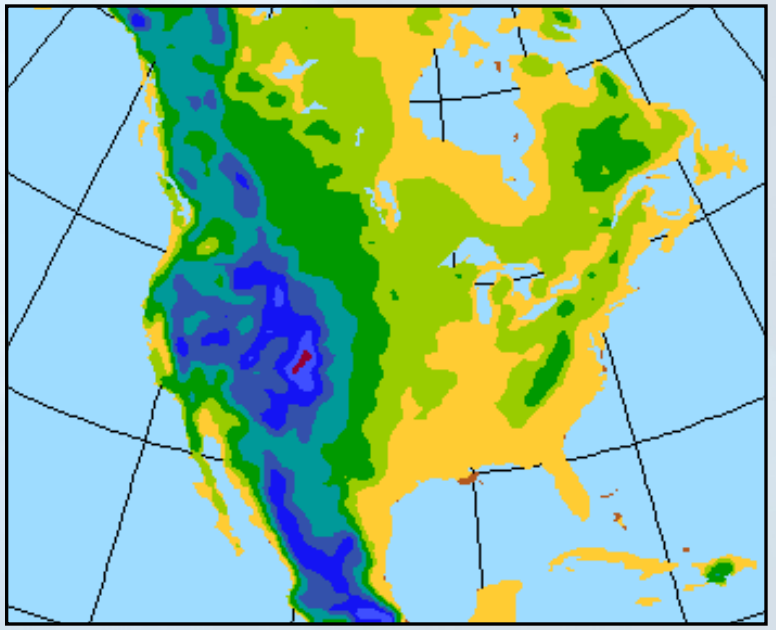
- Global model provides:
  - initial conditions – soil moisture, sea surface temperatures, sea ice
  - lateral meteorological conditions (temperature, pressure, humidity) every 6-8 hours.
  - Large scale response to forcing (100s kms)
- Regional model provides finer scale (10s km) response

Advantages of higher resolution



North America at typical global climate model resolution

Hadley Centre AOGCM (HadCM3), 2.5˚ (lat) x 3.75˚ (lon), ~ 280 km



North America at 50 km grid spacing

The North American Regional Climate Change Assessment Program (NARCCAP)

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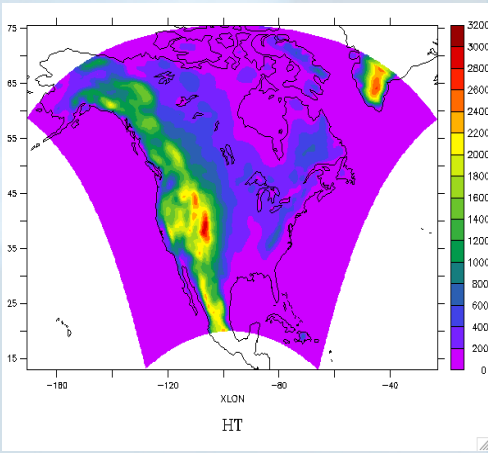
www.narccap.ucar.edu

- Explores multiple uncertainties in regional and global climate model projections
  - 4 global climate models x 6 regional climate models



- Develops multiple high resolution (50 km) regional climate scenarios for use in impacts and adaptation assessments

- Evaluates regional model performance to establish credibility of individual simulations for the future

- Participants: Iowa State, PNNL, LLNL, UC Santa Cruz, Scripps, Ouranos (Canada), UK Hadley Centre, NCAR

- Initiated in 2006, funded by NOAA-OGP, NSF, DOE, USEPA-ORD – 5-year program

NARCCAP Domain

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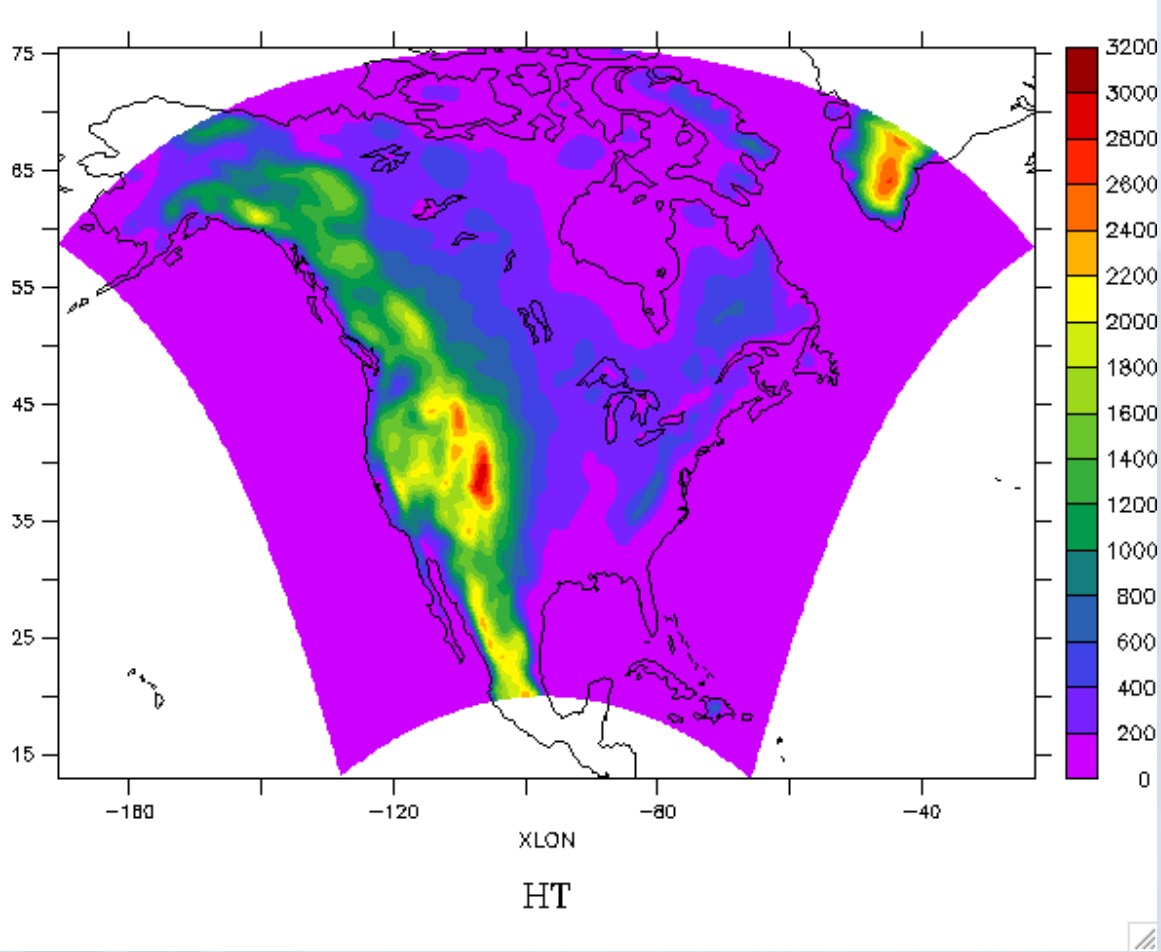

Organization of Program

- *Phase I:* 25-year simulations using NCEP-Reanalysis 2 boundary conditions (1979—2004)
- *Phase II*: Climate Change Simulations (A2 SRES Scenario)
  - Phase IIa: RCM runs (50 km res.) nested in AOGCMs current (30 yrs) and future (30 yrs)
  - Phase IIb: Time-slice experiments at 50 km res. (GFDL AM2.1 and NCAR CAM3) -- for comparison with RCM runs
- Quantification of uncertainty at regional scales – probabilistic approaches
- Scenario formation and provision to impacts community led by NCAR – *53 different variables saved at 3-hr intervals*
- Opportunity for double nesting (over sub-regions) to include participation of other RCM groups

NARCCAP PLAN – Phase II

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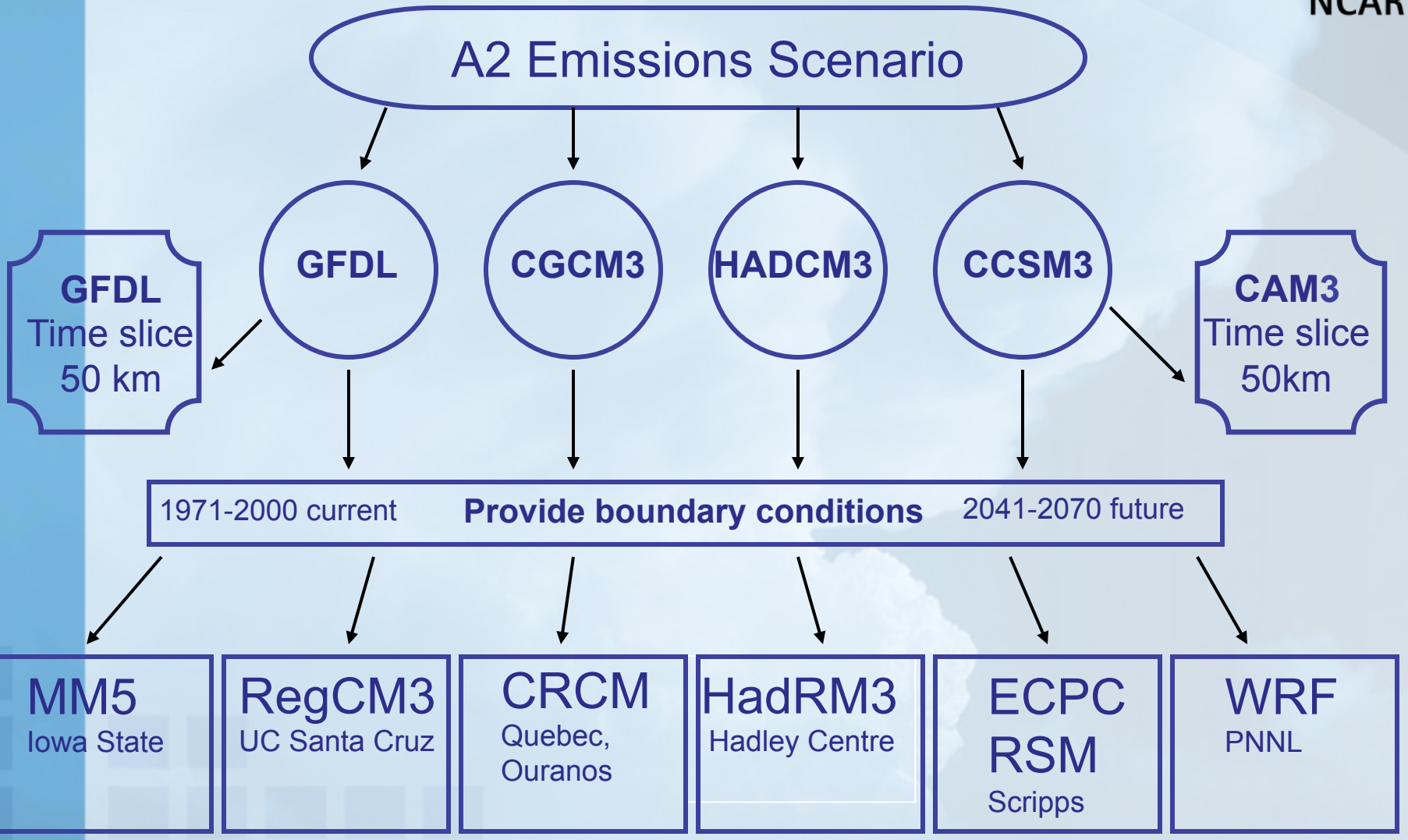

NARCCAP Experimental Design

A2 Emissions Scenario

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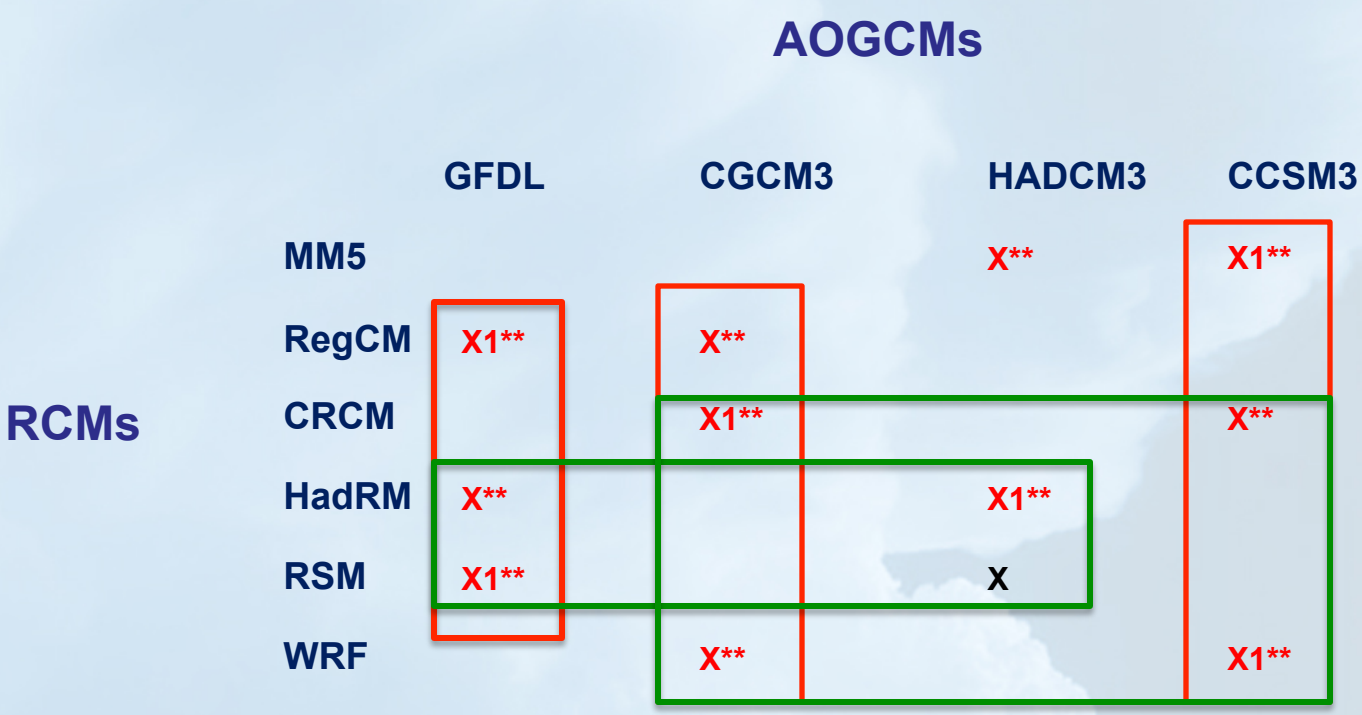

1 = chosen first GCM

Red = run completed
** = data loaded

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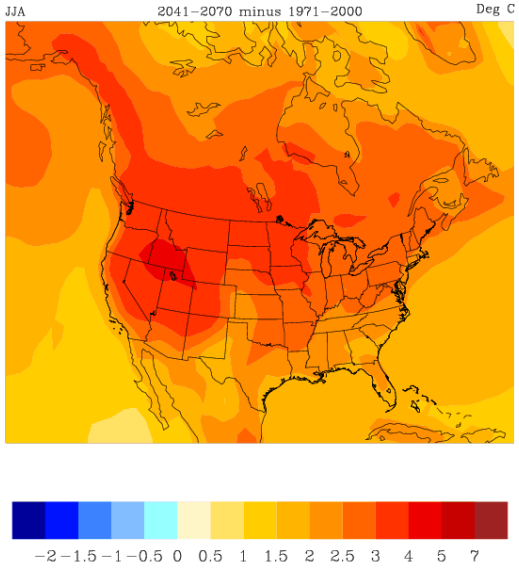
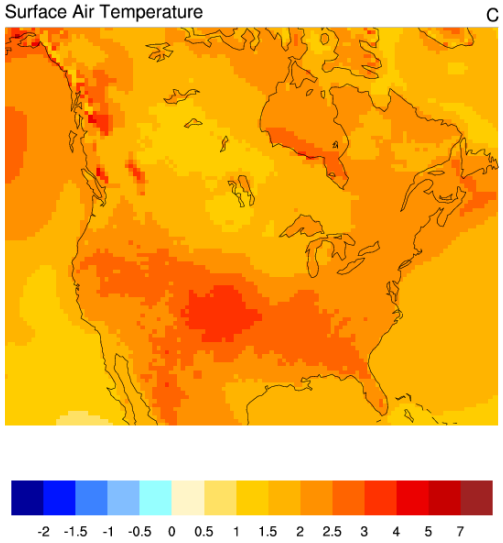
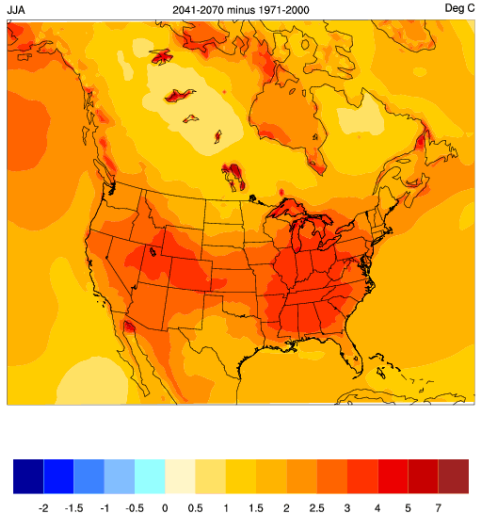
CCSM Change In Seasonal Avg Temp



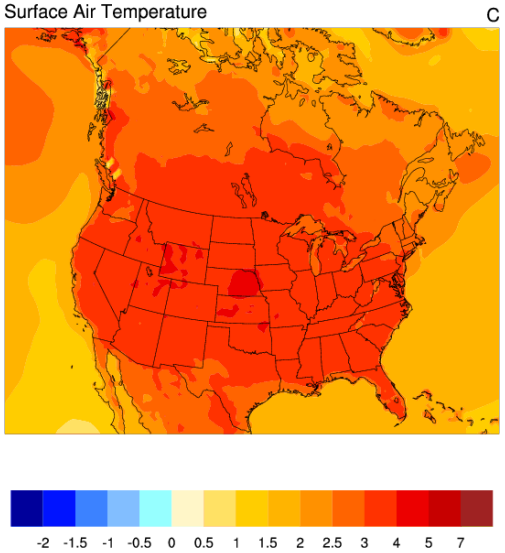
MM5I+CCSM Change in JJA Avg Temp



WRFG+ccsm Change In Seasonal Avg Temp



CRCM+CCSM Change in JJA Avg Temp



CCSM-driven change in summer temperature

Advantages of Experimental Design

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- More robust estimates of error due to missing cells
- Particularly important for determining the relative contribution of the different factors in ANOVA – also provides more robust results

Analysis of Variance

[Observed variance in a variable is partitioned into different components attributable to different sources of variations]

- Focuses on three sources of variation
  - AOGCMs
  - RCMs
  - Error or residual term
- Postulates that total variation in RCM output can be decomposed into these three terms
- Performed seasonally for temperature and precipitation (over sub-regions)

NARCCAP ANOVA Results
Temperature

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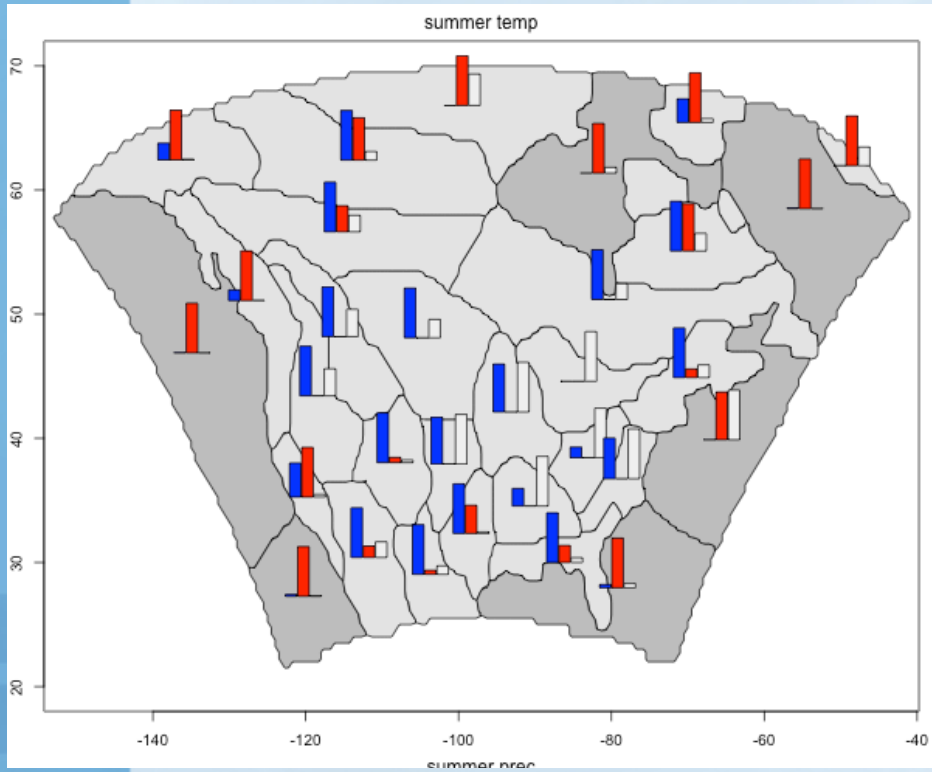
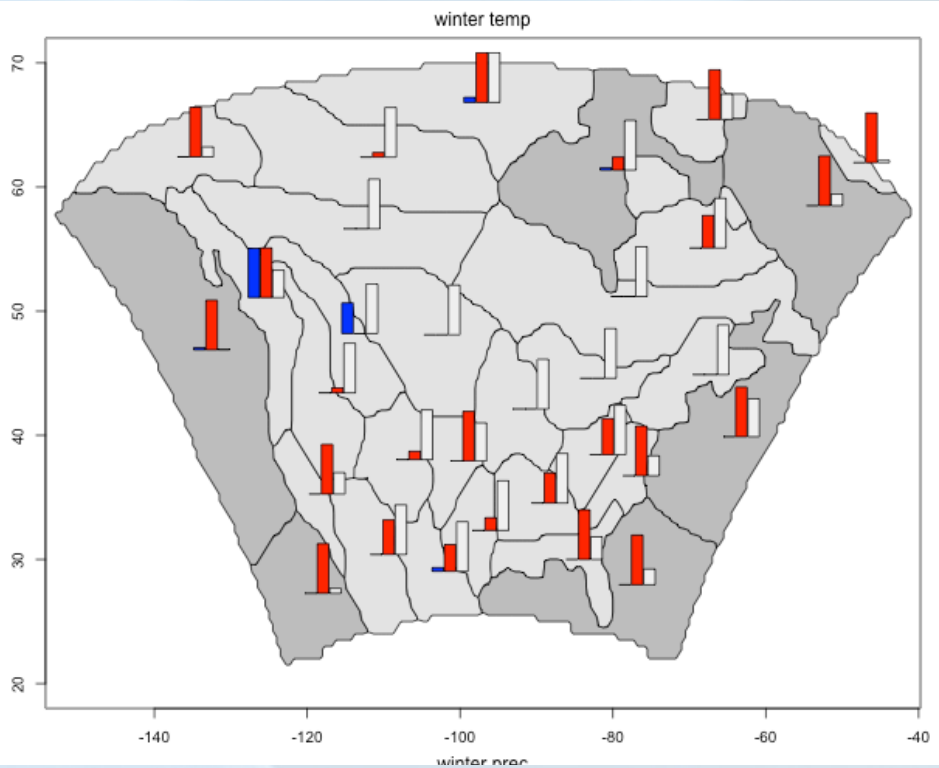
Summer



Winter



Red = contribution from GCMs
Blue = contribution from RCMs
White = remainder variance

S. Sain, NCAR
In Mearns et al., 2013

Climate Change Conclusions

- The RCMs tend to intensify patterns of change in precipitation (i.e., greater decreases in summer; greater increases in winter) compared to GCMs
- RCMs dominate overall variance in summer (for temperature and precipitation) and GCMs are dominant in winter
- But more process level studies will be necessary to determine if RCM changes are more credible than those of GCMs

Mearns et al., 2013 CCLe

RCM-GCM Matrix from Prudence

	CNRM	DMI	ETHZ	GKSS	HC	ICTP	KNMI	MPI	SMHI	UCM
A2+HadAM3H		3	1	1	3	1	1	1	1	1
A2+ECHAM4		1							1	
A2+ARPEGE3	1									
B2+HadAM3H					1	1			1	1
B2+ECHAM4		1							1	
B2+ARPEGE3	3									

Déqué et al., 2005
PRUDENCE

RCM-GCM Matrix from ENSEMBLES

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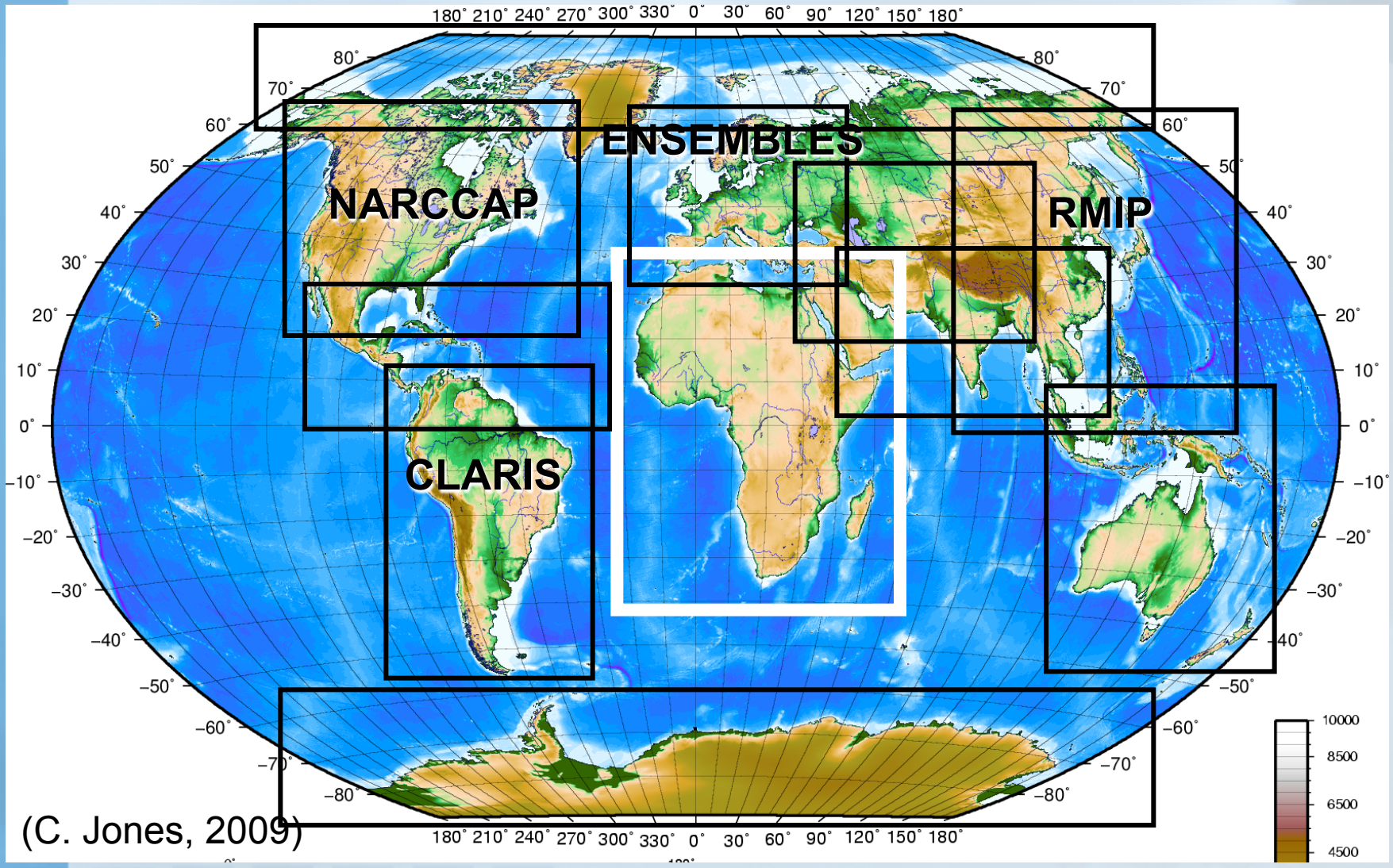
Table 1 The RCM × GCM matrix; label X indicates that the corresponding RCM × GCM pair was available in ENSEMBLES at the time of the study

	BCM	CNRM	HC-lo	HC-med	HC-hi	MPI
C4I					X	
CNRM		X				
DMI	X	X				X
ETHZ				X		
HC-lo			X			
HC-med				X		
HC-hi					X	
ICTP						X
KNMI						X
METN	X			X		
MPI						X
SMHI	X		X			X
UCLM				X		

Déqué et al., 2011 ENSEMBLES

Coordinated Regional Downscaling Experiment (CORDEX)
~ Regions ~



General Aims and Plans for CORDEX

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Provide a set of *regional climate scenarios* covering the period 1950-2100, for the majority of the populated land-regions of the globe.

Make these *data sets readily available and useable* to the impact and adaptation communities.

Provide a *generalized framework for testing and applying* regional climate models and downscaling techniques for both the recent past and future scenarios.

Foster coordination between regional downscaling efforts around the world and *encourage participation* in the downscaling process of local scientists/organizations

Progress in Other Regions (Examples)

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1. Africa (10 RCMs)
   - Initial focus
   - Workshops promoting analyses by Africans

2. Euro-CORDEX (9 distinct RCM + variants)
   - Runs at 0.44˚, 0.22˚ and (in process) 0.11˚

3. South America (7 RCMs)
   - Built off CLARIS
   - Publications submitted

4. CORDEX South Asia
   - Workshop Feb 2012
   - Workshop planned for Aug 2013

Progress in Other Regions (Examples)

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5. CORDEX Arctic (~ 5 RCMs)
   - Workshop March 2012
   - Mtg. @ WCRP CORDEX Brussels (Nov 2103)

6. Med-CORDEX (9 RCMs, 12 A-O RCMs)
   - Add to original regions
   - Built off funded program

7. East Asia (7 RCMs)
   - Built partly off APN RMIP program
   - Workshops: Sep 2011, Nov 2012, Brussels 2013

8. CORDEX-SEA [Oceania]
   - Tentative new region
   - Building from funded program

WCRP CORDEX: A Coordinated Regional Downscaling Experiment ~ North America Program ~

Executive Committee

W. J. Gutowski, Jr. – Iowa State Univ. (Co-Chair)

Linda Mearns – NCAR (Co-Chair)

David Behar – San Francisco Public Utilities Commission

Lawrence Buja – NCAR

Dennis Lettenmaier – Univ. WA

Ruby Leung – PNNL

Greg Garfin – Univ. AZ

Details at: http://wcrp-cordex.ipsl.jussieu.fr/
(Search: "WCRP CORDEX climate")

Priorities of Uncertainties

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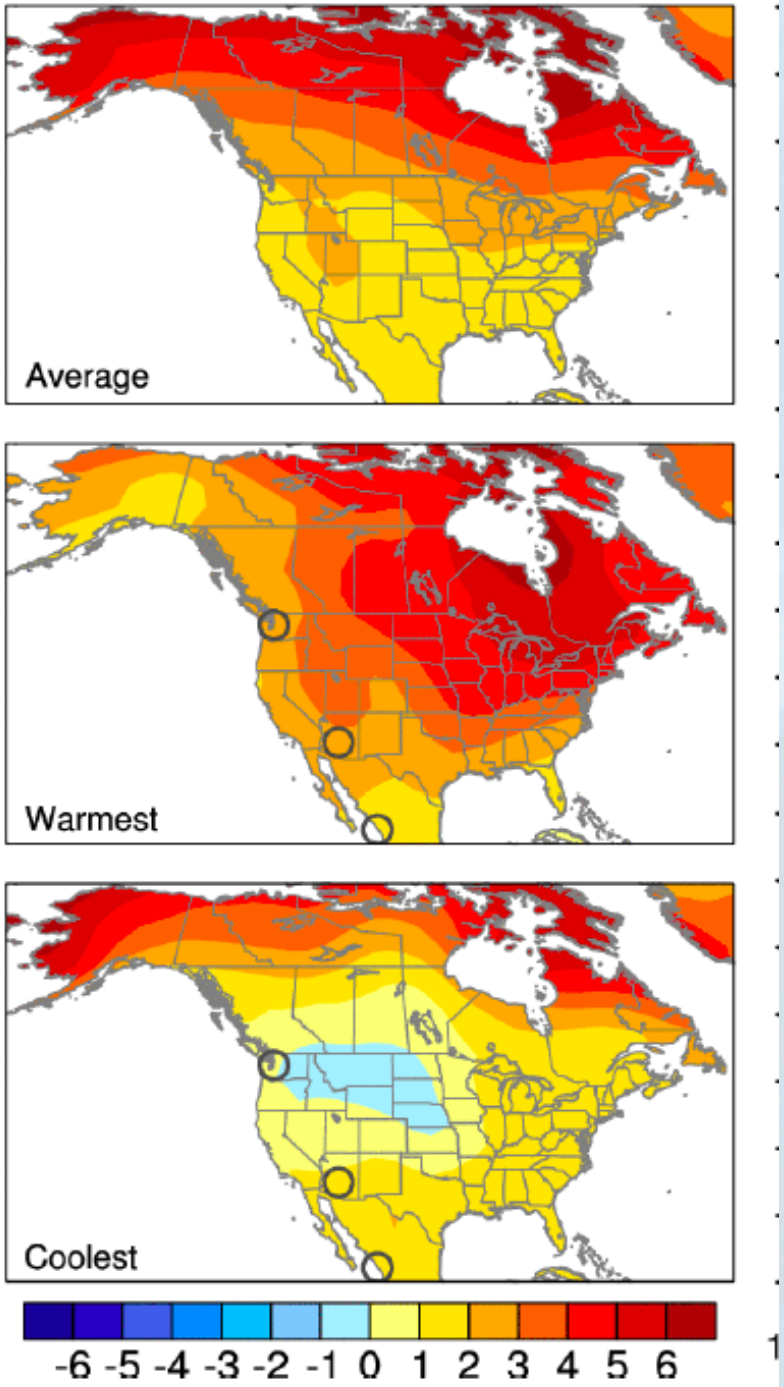
- Sampling range of GCMs
- Sampling range of RCMs
  - And investigating multiple resolutions
- Internal variability (i.e., sampling multiple realizations of single GCM)
  - This element has been under-explored in GCMs and RCMs
- RCPs - lower priority – not important until after 2050 – much might be gleaned from pattern scaling from one RCP to another

DJF Temperature Trend (Deg. C per 55 years – (2005 - 2060)



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CCSM3
AIB Scenario

40-member ensemble

Deser et al., 2012 Nature Climate Change

NA-CORDEX

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Some Basics

- 5 different RCMs
- 6 different GCMs
- 150 years 1950-2100 each simulation
- High representative concentration pathway (RCP 8.5) (future scenario)
- Two spatial resolutions 25 km and 12 km
- ERA-Interim runs (20 years) at 50, 25, 12 km
- In planning phase – proposal being written

Topography of the US at two Different Spatial Resolutions

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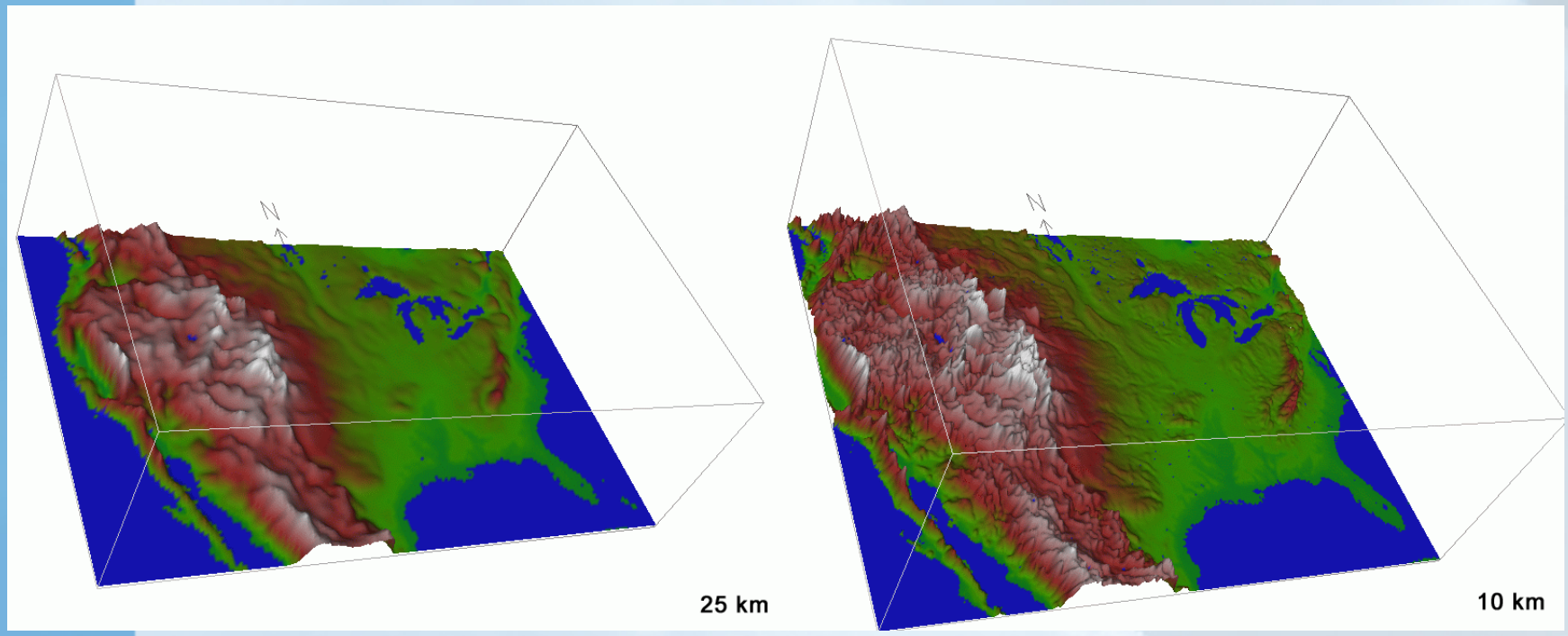

Regional Climate Models

How much more meaningful information about future climate do we obtain at higher resolutions?

Value of Scenarios of Experimental Designs

- Provides series of options based on different funding possibilities
- Clearly presents what can be explored (e.g., GCM, RCM, and interaction effects; or GCM, RCM, remainder term) and degree of error in calculations based on matrix density

Scenarios of Experiments

- Common to all: ERA-Interim driven runs – at 3 resolutions: 50, 25,12 km for all RCMs (total of 300 years).
- Assume a fairly even sampling of GCMs and RCMs (based on Mearns et al. 2013 results)
- Then three possible experimental designs based primarily on different sampling schemes for 25 and 12 km simulations
- All will include similar sampling of internal variability

Scenario I

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5 RCMS, 6 GCMs, full matrix at 25 km = 30 simulations, 150 years each; half matrix (15 simulations at 12 km). IV – from two GCMs, 3 additional realizations, each RCM at 25 km

50 km	RCM1	RCM2	RCM3	RCM4	RCM5
ERA-I	1	1	1	1	1

25 km	RCM1	RCM2	RCM3	RCM4	RCM5
ERA-I	1	1	1	1	1
GCM1*	4	4	4	4	4
GCM2*	4	4	4	4	4
GCM3	1	1	1	1	1
GCM4	1	1	1	1	1
GCM5	1	1	1	1	1
GCM6	1	1	1	1	1

Scenario 1 (cont'd)

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12 km	RCM1	RCM2	RCM3	RCM4	RCM5
ERA-I	1	1	1	1	1
GCM1*	1	1			1
GCM2*	1	1			
GCM3	1		1		1
GCM4		1		1	
GCM5			1	1	1
GCM6			1	1	

Total years: 9,000 at 25 km; 2,250 at 12. Half of years at 25 km are the IV runs.

Scenario II

25 km	RCM1	RCM2	RCM3	RCM4	RCM5
ERA-I	1	1	1	1	1
GCM1*	4		4		4
GCM2*		4		4	
GCM3	1	1			
GCM4	1	1			1
GCM5			1	1	1
GCM6			1	1	

Half fraction

12 km	RCM1	RCM2	RCM3	RCM4	RCM5
ERA-I	1	1	1	1	1
GCM1*	1		1		1
GCM2*		1		1	
GCM3	1	1			
GCM4	1	1			1
GCM5			1	1	1
GCM6			1	1	

Half fraction

Total years:
4,500 at 25
2,250 at 12

Scenario IIIa

25 km half fraction as in Scenario II and 1/3 fraction (10 simulations) at 12 km

3a: 2/3 fraction

12 km	RCM1	RCM2	RCM3	RCM4	RCM5
ERA-I	1	1	1	1	1
GCM1*	1		1		1
GCM2*		1		1	
GCM3	1				
GCM4		1			1
GCM5			1		
GCM6				1	

Years:
4,500 at 25
1,500 at 12

Activities

- NA-CORDEX Meetings Feb. 19, 2013 and June 21, 2013 at NCAR – to further develop integrated plans/proposal to send to agencies, non-profits,etc.
- Survey of potential users – to determine more detailed user needs
- Coordination with groups already producing simulations
- Discussion with agency program managers on level of interest

THE END

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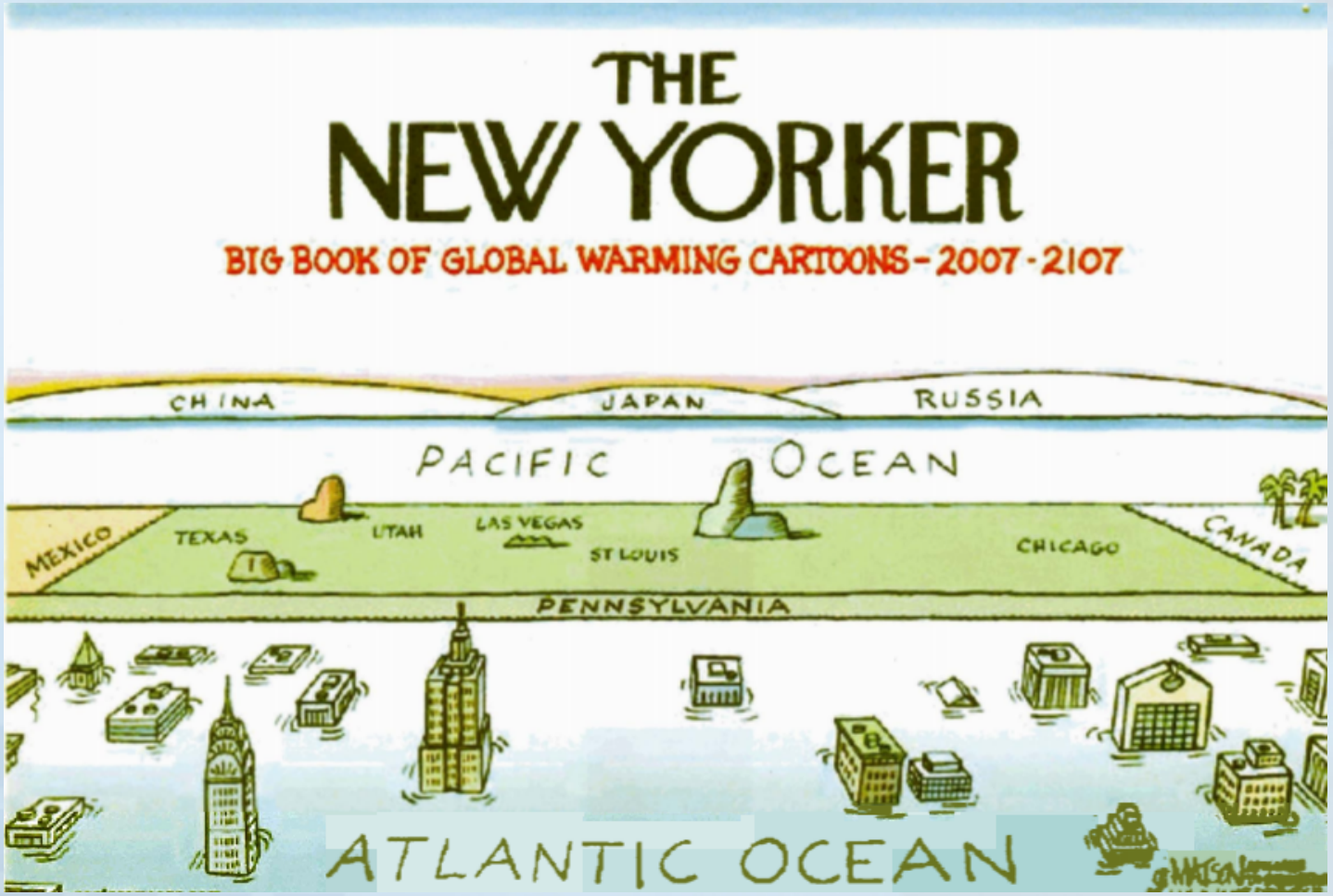
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