Climate Change, Environment, Energy Study in Computational Science

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Joint Workshop on Large-scale Computer Simulation

ORNL, Tennessee, USA

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OUTLINE

- ***Background of climate change study***
  - **Climate and Energy**
  - **Climatic Effects**
    - **Heat waves as an example**
- ***Research problems and potential research approach***
- ***A past study we did for the IPCC A1B scenario***
- ***Current on-going study in CESM and its downscaling***
- ***Next Step ….***

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Background of Climate Change Study

Cloud Cover

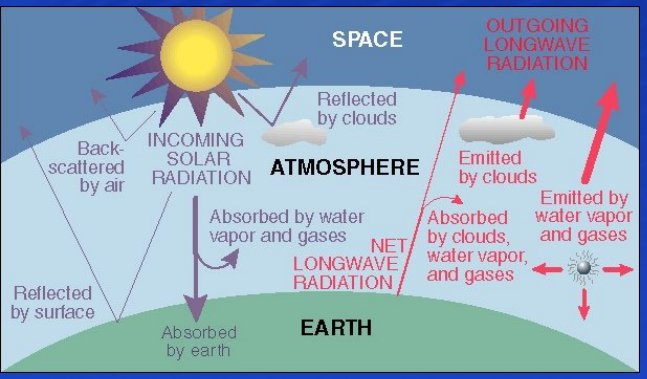
Precipitation

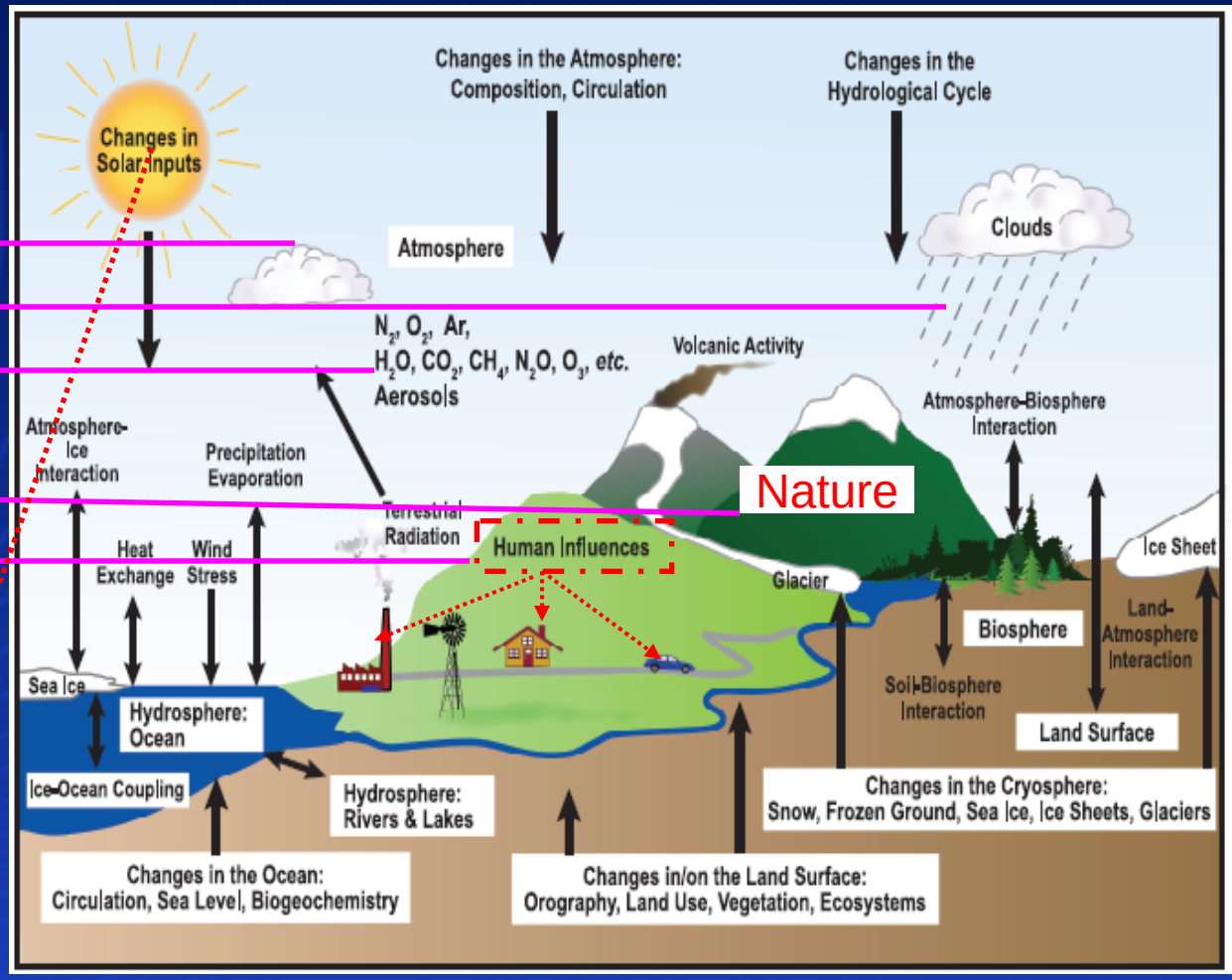
Chemistry

Biogenic Emissions

Anthropogenic Emissions

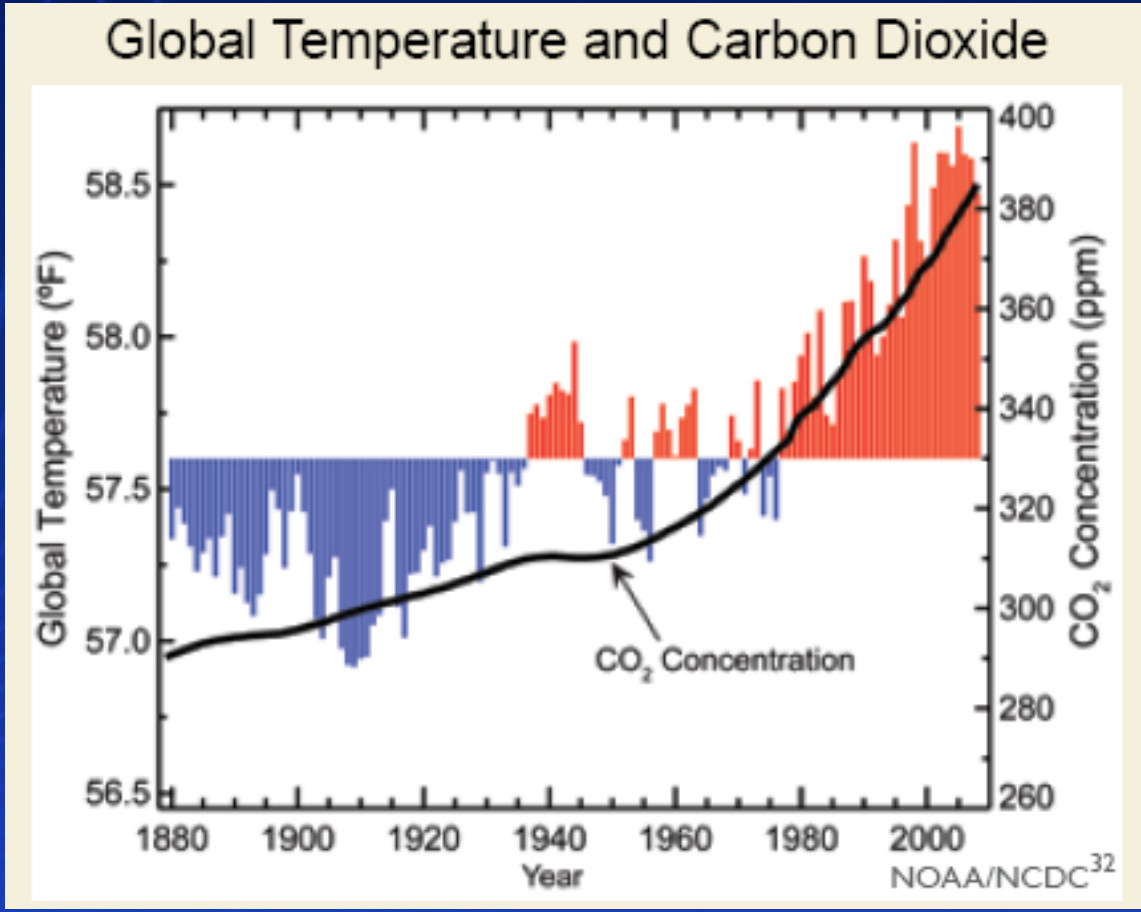
Solar Radiation





IPCC Fourth Assessment Report: Climate Change 2007 Working Group I Report "The Physical Science Basis"
Chapter 1 Historical Overview of Climate Change Science (Fig 1, p104)

Background of Climate Change Study



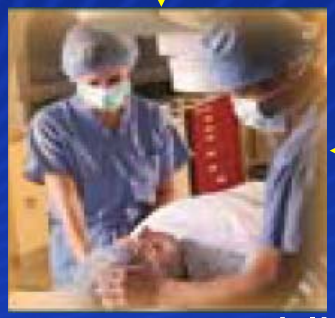
The increasing temperature trends correspond well with the increases of carbon dioxide

Impacts of Climate Change

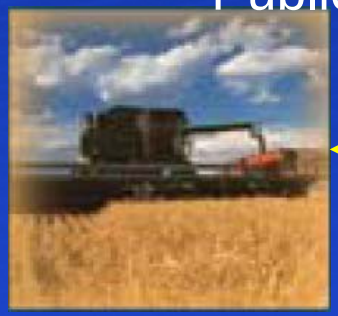
Climate Change

Energy

Air Quality



Public Health



Agriculture and Food

Water Resources and Water Quality

How might climate change affect energy production and supply in the United States?

Mechanisms Of Climate Impacts On Various Energy Supplies In The U.S.

Percentages Shown Are Of Total Domestic Consumption

T = water/air temperature
W= wind
H = humidity
P = precipitation
E = extreme weather events

Energy Impact Supplies		Climate Impact Mechanisms
Fossil Fuels (86%)	Coal (22%)	Cooling water quantity and quality (T), cooling efficiency (T, W, H), erosion in surface mining
	Natural Gas (23%)	Cooling water quantity and quality (T), cooling efficiency (T, W, H), disruptions of off-shore extraction (E)
	Petroleum (40%)	Cooling water quantity and quality, cooling efficiency (T, W, H), disruptions of off-shore extraction and transport (E)
	Liquified Natural Gas (1%)	Disruptions of import operations (E)
Nuclear (8%)		Cooling water quantity and quality (T), cooling efficiency (T, W, H)
Renewables (6%)	Hydropower	Water availability and quality, temperature-related stresses, operational modification from extreme weather (floods/droughts), (T, E)
	Biomass	
	• Wood and forest products	Possible short-term impacts from timber kills or long-term impacts from timber kills and changes in tree growth rates (T, P, H, E, carbon dioxide levels)
	• Waste (municipal solid waste, landfill gas, etc.)	n/a
	• Agricultural resources (including derived biofuels)	Changes in food crop residue and dedicated energy crop growth rates (T, P, E, H, carbon dioxide levels)
	Wind	Wind resource changes (intensity and duration), damage from extreme weather
	Solar	Insolation changes (clouds), damage from extreme weather
	Geothermal	Cooling efficiency for air-cooled geothermal (T)

(Source: EIA, 2004)

EIA, 2004a: *Annual Energy Review*, Washington, DC: Energy Information Administration.

Hurricane impact in 2005

Hurricane damage in the Gulf of Mexico – Mars platform

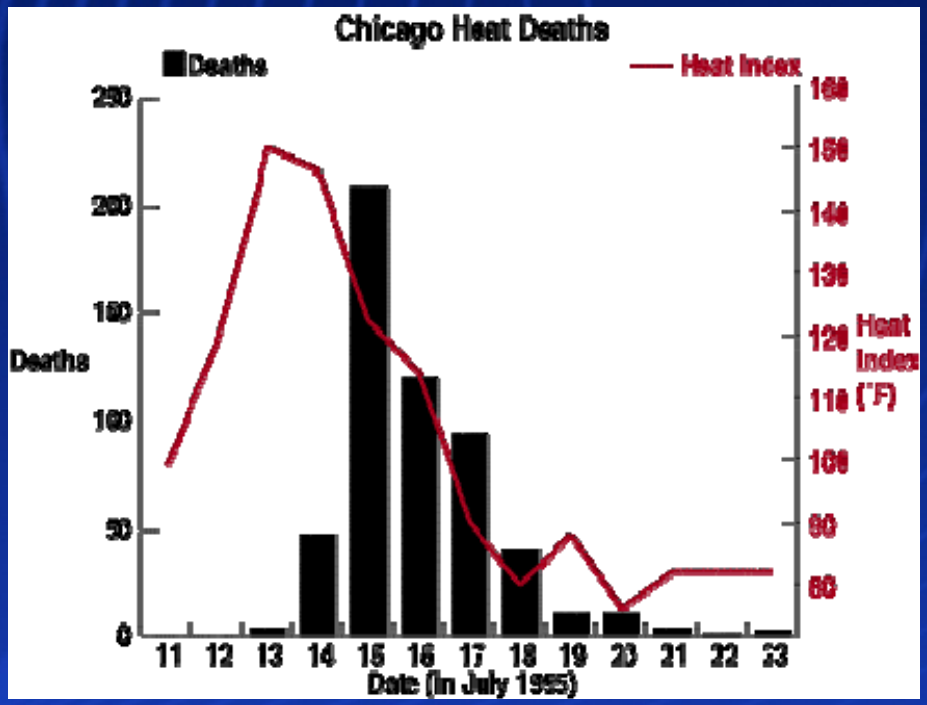
Before Hurricane

After Hurricane

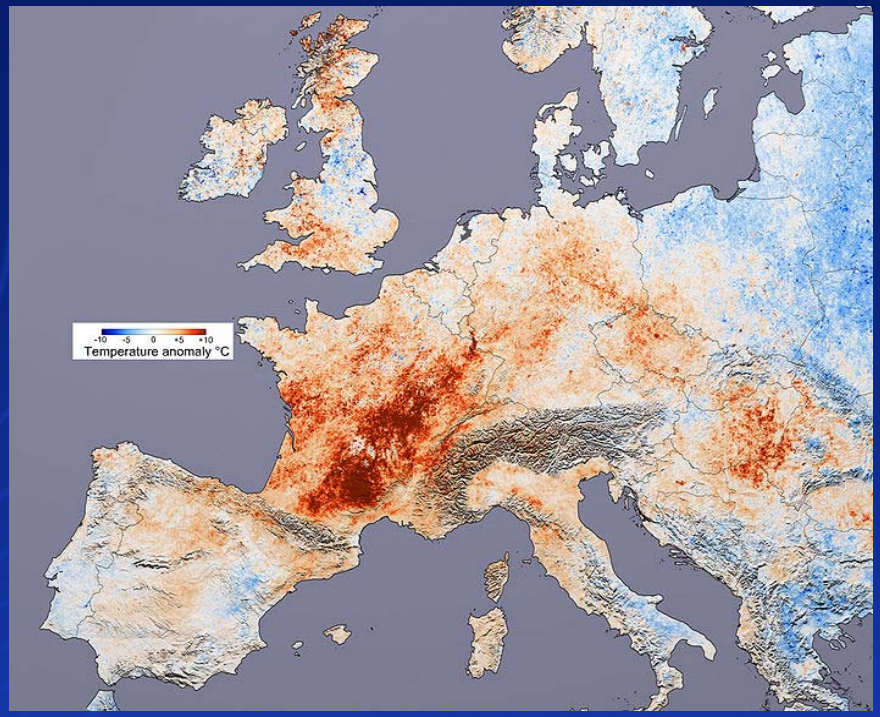
Mars deepwater platforms before and after the 2005 hurricanes. The $250 million Typhoon platform was so severely damaged that Chevron is working with the MMS to sink it as part of an artificial reef program in the GOM; the billion dollar plus Mars platform has been repaired and returned to production about 8 months post hurricane.

Source: US CCSP, 2008

Heat Wave Studies



Deaths in Chicago heat wave in 1995

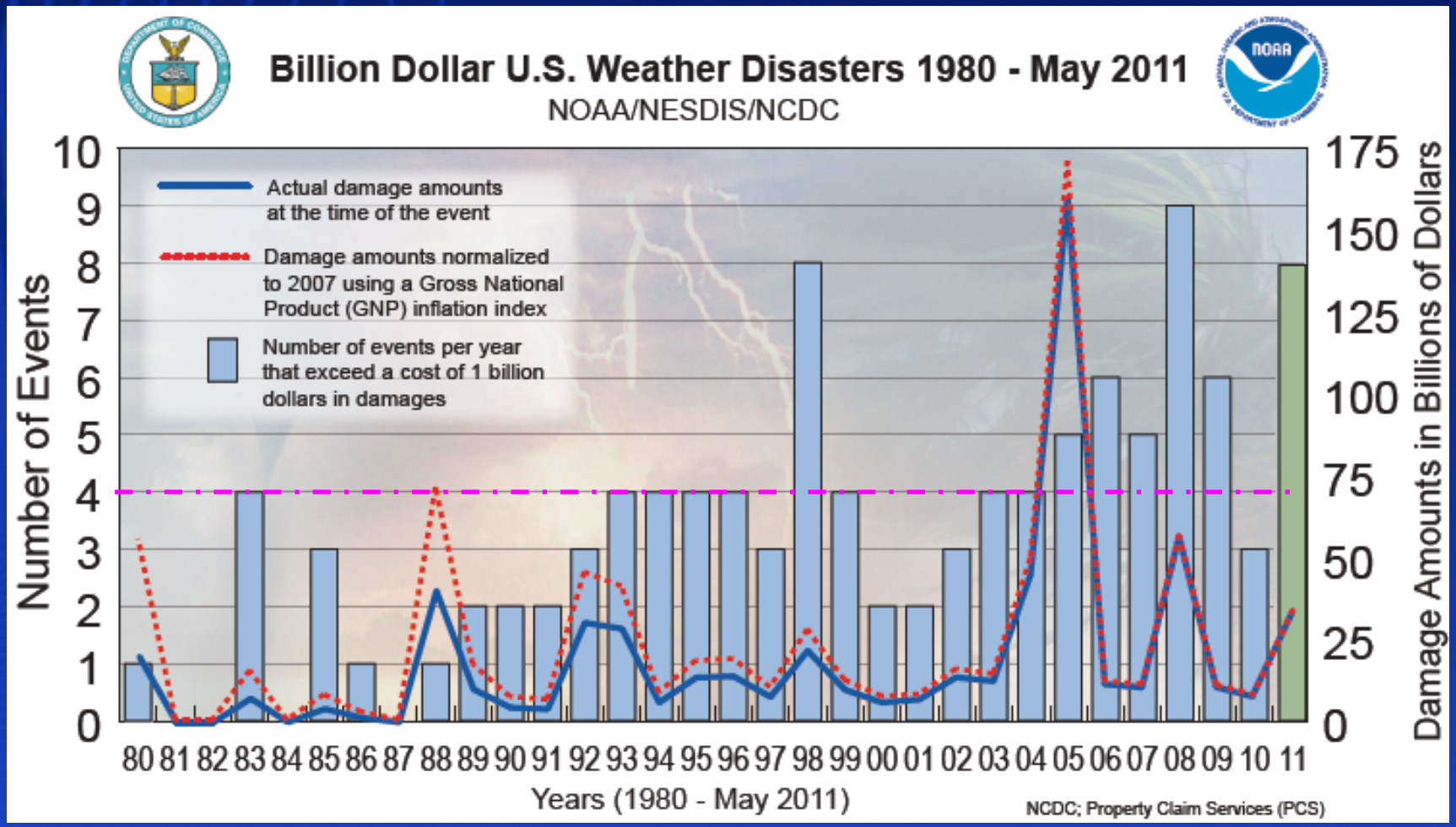


Deaths in West Europe heat wave in 2003

MODIS Image about 45,000 died

http://severe-wx.pbworks.com/w/page/15957981/Droughts-and-Heat-Waves

Impacts of Extreme Climate



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Research Questions

- Have the major terms of the system been accounted for?
  - Atm: radiation balance and CO_2 gases, moist physics and clouds aerosols and clouds, land surface storage and albedo
  - Forcing: solar cycle, volcanoes, emissions, land use change
  - Ocn/ice: sea and land ice coupled with sea level, dynamic coupling for ENSO, PDO, NAO, arctic oscillations
  - Chemical: Carbon and sulfur cycles, nitrogen and biogeochemical coupling, aerosols and dust deposition
- Can the uncertainty (error/bias) be quantified?
  - Comparison with observations
  - Inter-model comparisons
  - Predictability for various scales and time periods
- Are projections and forecasts useful?

Potential Research Approach

- Multiscale representations of the forcing of atmospheric dynamics from interactive chemical processes and the surface energy budget.
- Using local refinements of the spectral element cubed sphere grid and a multi-wavelet hierarchical basis that separates spatial scales in a discontinuous Galerkin (DG) formulation, will allow us to analyze and correlate the modes of forcing and coupled surface interaction that drive the decadal and regional climate.
- The inclusion of the numerical methods for chemical transport and reactive chemistry with locally conservative and high order methods, is an innovative feature of the proposed work with broader scientific implications. This is the next step beyond using the HOMME dycore in the CESM with chemistry.

Why or What is the Urgency?

- What is the information of policy makers (PMs) who need
  - Impacts in global, regional and urban scales
- Are global results sufficient to provide an insight on climate change?
  - Scalability issue in global model
- Environmental and social management is the key challenge for mitigating climate change in this end of century
  - Control emissions and land cover changes
- Predicting ***regional climate*** change and its consequences will have great utility in adapting to climate change
  - ***Air quality***, heat waves, floods, droughts, water supply planning, human health, etc.

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GLOBAL CHANGE AND AIR POLLUTION (GCAP)

Effects of 2000-2050 Global Change Ozone and Particulate Matter Air Quality in the United States

Daniel Jacob (PI), Loretta Mickley, *Harvard University*

Joshua Fu *, Yun-Fat Lam, *University of Tennessee*

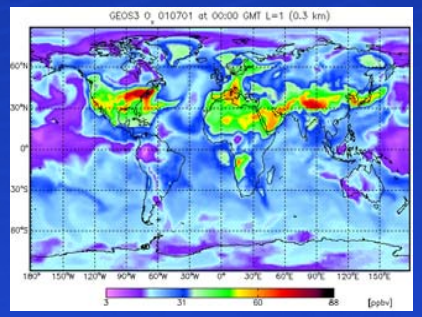
John Seinfeld, *California Institute of Technology*

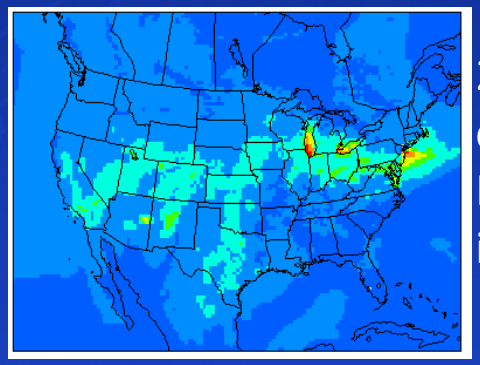
David Streets, *Argonne National Lab*

David Rind, *GISS/NASA*

2000-2050 change in climate

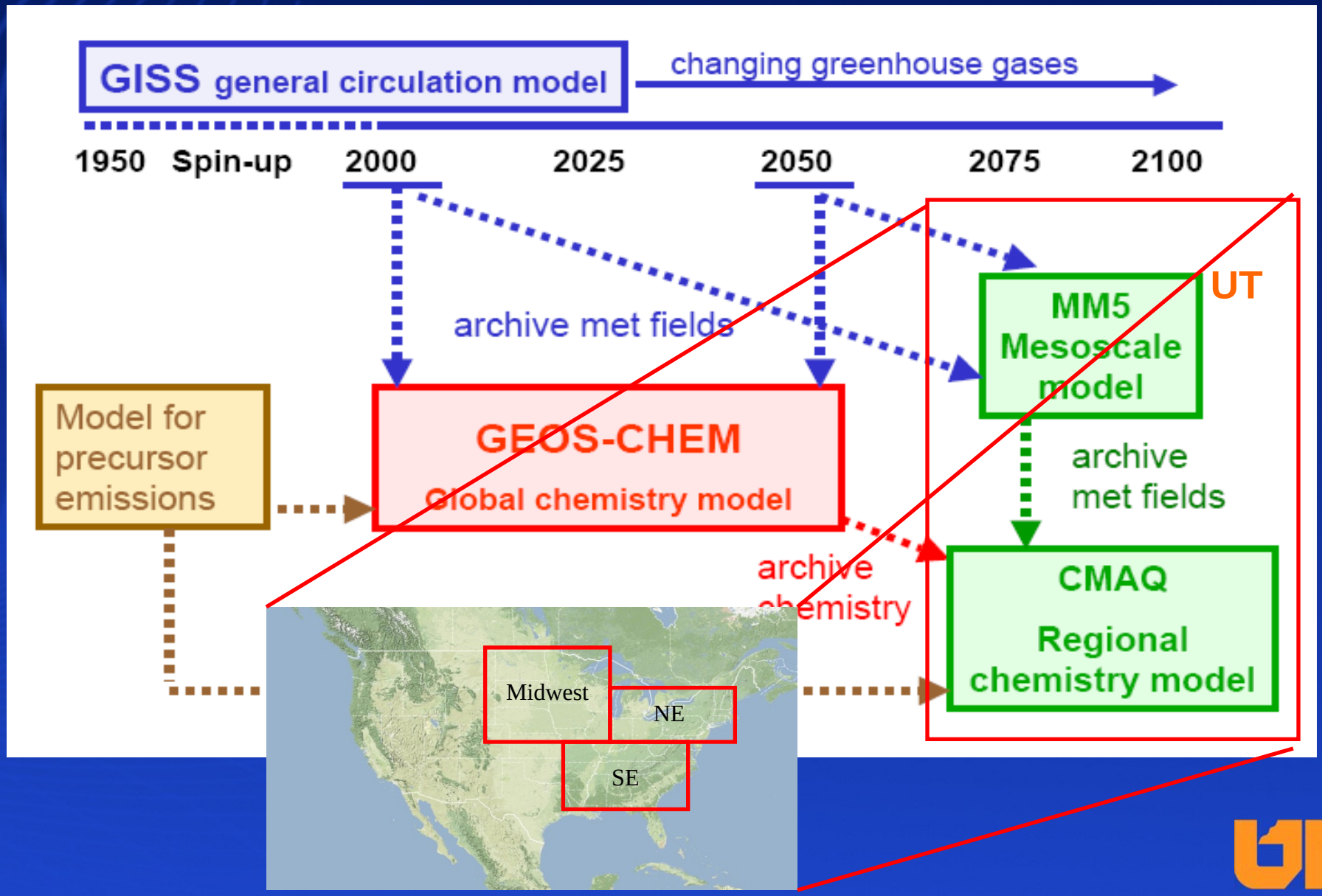
2000-2050 change in pollutant emissions





2000 – 2050 change of Ozone & $PM_{2.5}$ Air Quality in U.S.

Model Framework



Focus of this study

- Develop downscaling tools for evaluating future air quality.
- Investigate the future air quality in United States for year 2050 using regional air quality model, CMAQ & MM5.
- Study the effects of global warming in regional scale for both climate and air quality.
- Examine the effects of change of anthropogenic emissions to the future air quality.

Simulations Scenarios

2000 meteorology with 2000 emission

2050 meteorology with 2000 emission

Meteorological/Emission Contributions

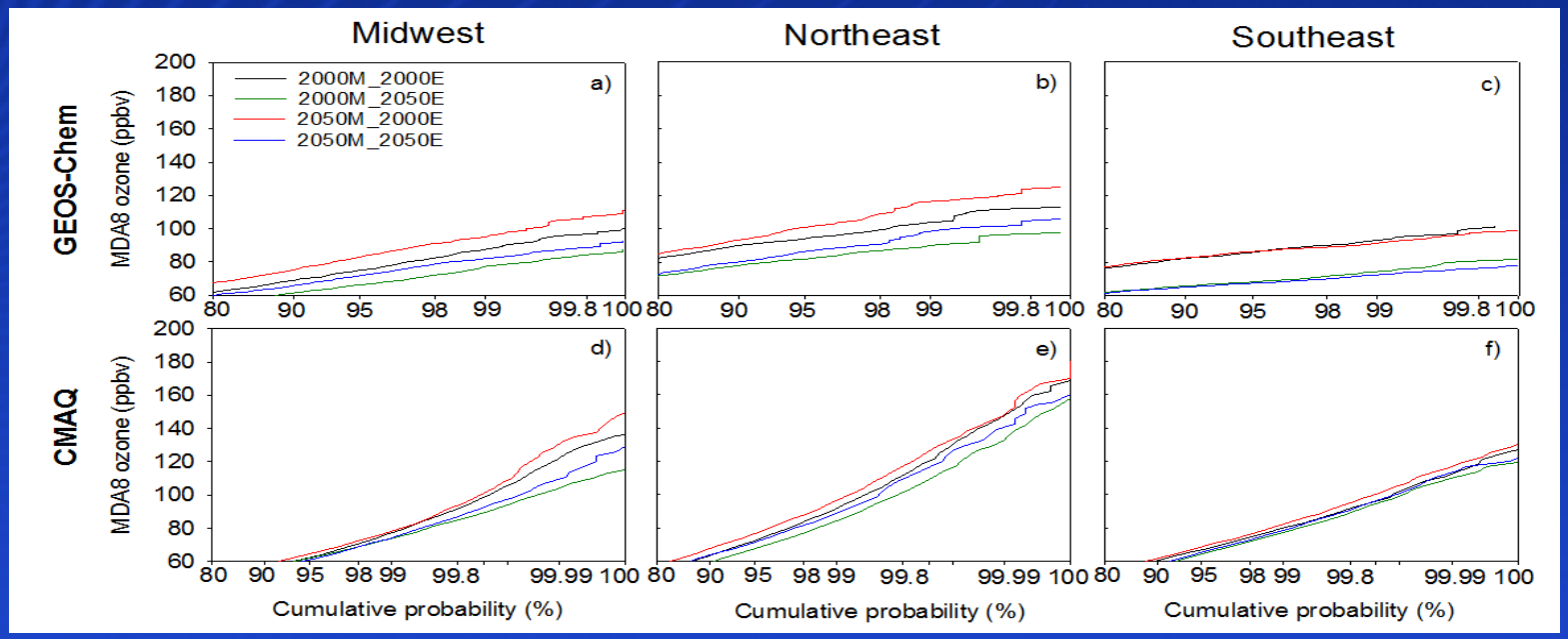
2000 meteorology with 2050 emission

2050 meteorology with 2050 emission

Scenario			Model			Scenario Index
Meteorology	Anthrop. Emission	Bio. Emission	GEOS-Chem	CMAQ		
2000	2000	MEGAN (2000)	4° x 5°	36km x 36km	12km x 12km	2000M_2000E_M
2000	2050	MEGAN (2050)	4° x 5°	36km x 36km	12km x 12km	2000M_2050E_M
2050	2000	MEGAN (2000)	4° x 5°	36km x 36km	12km x 12km	2050M_2000E_M
2050	2050	MEGAN (2050)	4° x 5°	36km x 36km	12km x 12km	2050M_2050E_M
2000	2000	BEIS (2000)	-	36km x 36km	-	2000M_2000E_B
2000	2050	BEIS (2050)	-	36km x 36km	-	2000M_2050E_B
2050	2000	BEIS (2000)	-	36km x 36km	-	2050M_2000E_B
2050	2050	BEIS (2050)	-	36km x 36km	-	2050M_2050E_B

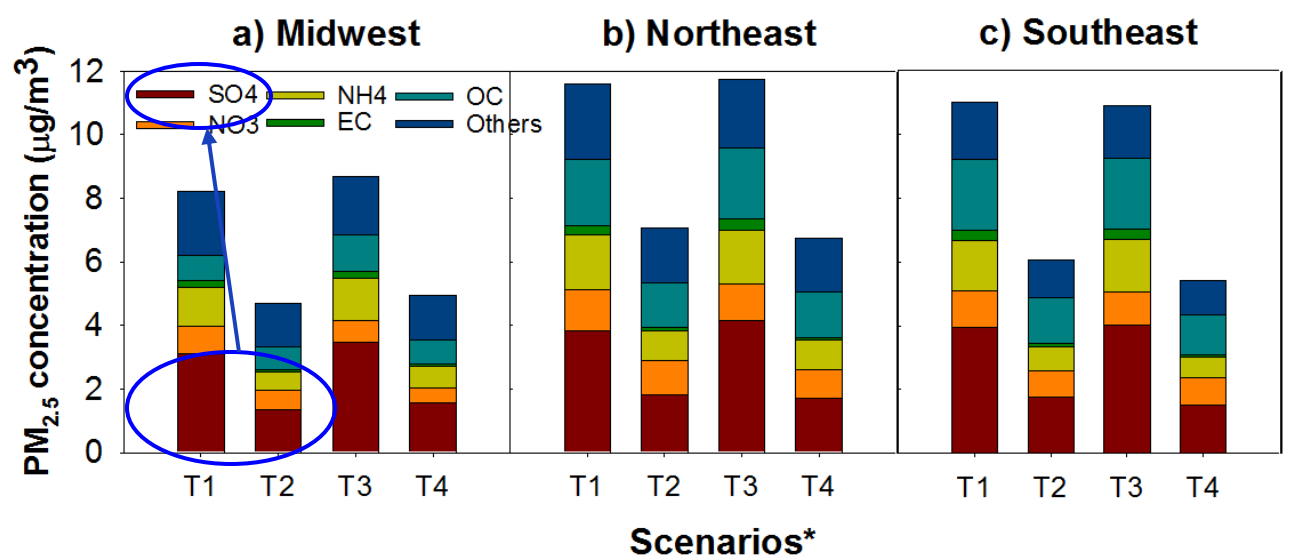
Results of CMAQ Scenarios (O_3)

MDA8 type	Domain	2000M_2000E		2000M_2050E		2050M_2000E		2050M_2050E	
		GEOS-Chem	CMAQ	GEOS-Chem	CMAQ	GEOS-Chem	CMAQ	GEOS-Chem	CMAQ
Max	MW	106	149	89	125	112	165	94	139
	NE	114	182	99	168	126	186	107	164
	SE-36km	103	132	82	126	100	135	80	126
	SE-12km	-	154	-	145	-	178	-	163
Avg	MW	52	54	49	48	55	55	51	50
	NE	66	57	60	50	69	59	62	52
	SE-36km	66	56	55	51	65	57	53	52
	SE-12km	-	51	-	46	-	50	-	48



Results of CMAQ Scenarios ($PM_{2.5}$)

PM2.5 type	Domain	2000M_2000E	2000M_2050E	2050M_2000E	2050M_2050E
Max	MW	127	130.2	96.1	102
	NE	119.3	116.8	116.6	117.7
	SE-36km	131.4	133.9	107.5	108.5
	SE-12km	115.7	104	105.3	102.5
Avg	MW	8.2	4.7	8.7	5
	NE	11.6	7.1	11.7	6.7
	SE-36km	11	6.1	10.9	5.4
	SE-12km	10.4	5.7	10.5	5.1



*T1 - 2000M_2000E, T2 - 2000M_2050E, T3 - 2050M_2000E, and T4 - 2050M_2050E

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Studies of global climate change and its application on regional downscaling

Joshua S. Fu[1], Yang Gao[1], John Drake[1] and Jean-Francois Lamarque[2]

[1]University of Tennessee

[2]The National Center for Atmospheric Research

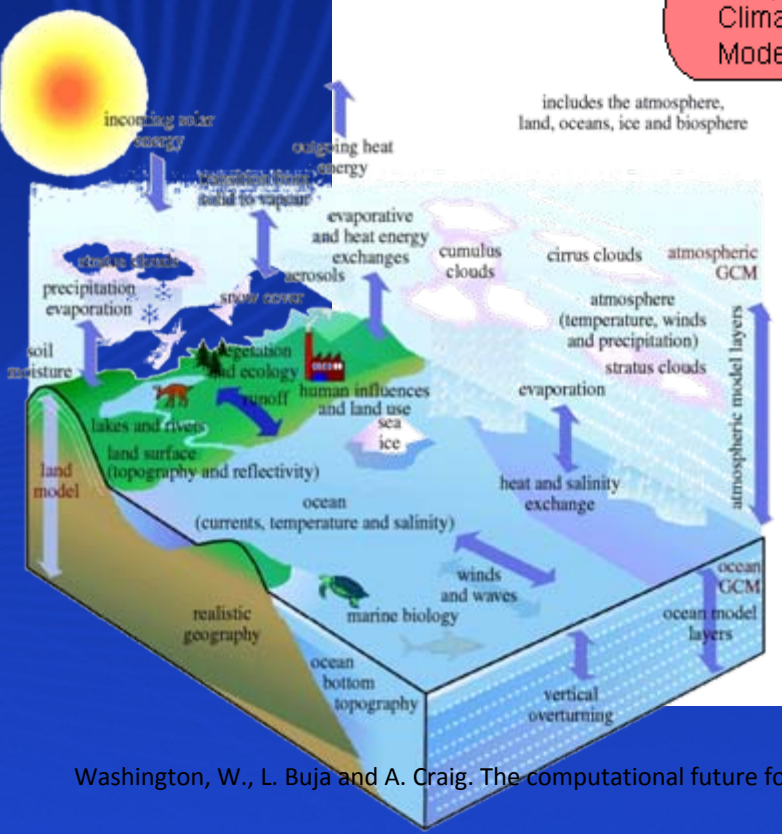
Oct 19, 2011

Benefits of Coupled Global-Regional Climate and Chemistry Models

- Demonstrating the usage of peta-scale application
- Pioneering of use of integrated chemical-dynamic coupling between the global and regional modeling systems at fine resolution
- Conducting detailed studies for general climate trends as well as the detailed climate conditions at the regional scale which can be used for emergency response
- Providing information for future regional flood and water quality control management
- Supporting study of ecological impacts on the local scale
- Evaluating future air quality trends for policy making
- Providing information for health-related studies

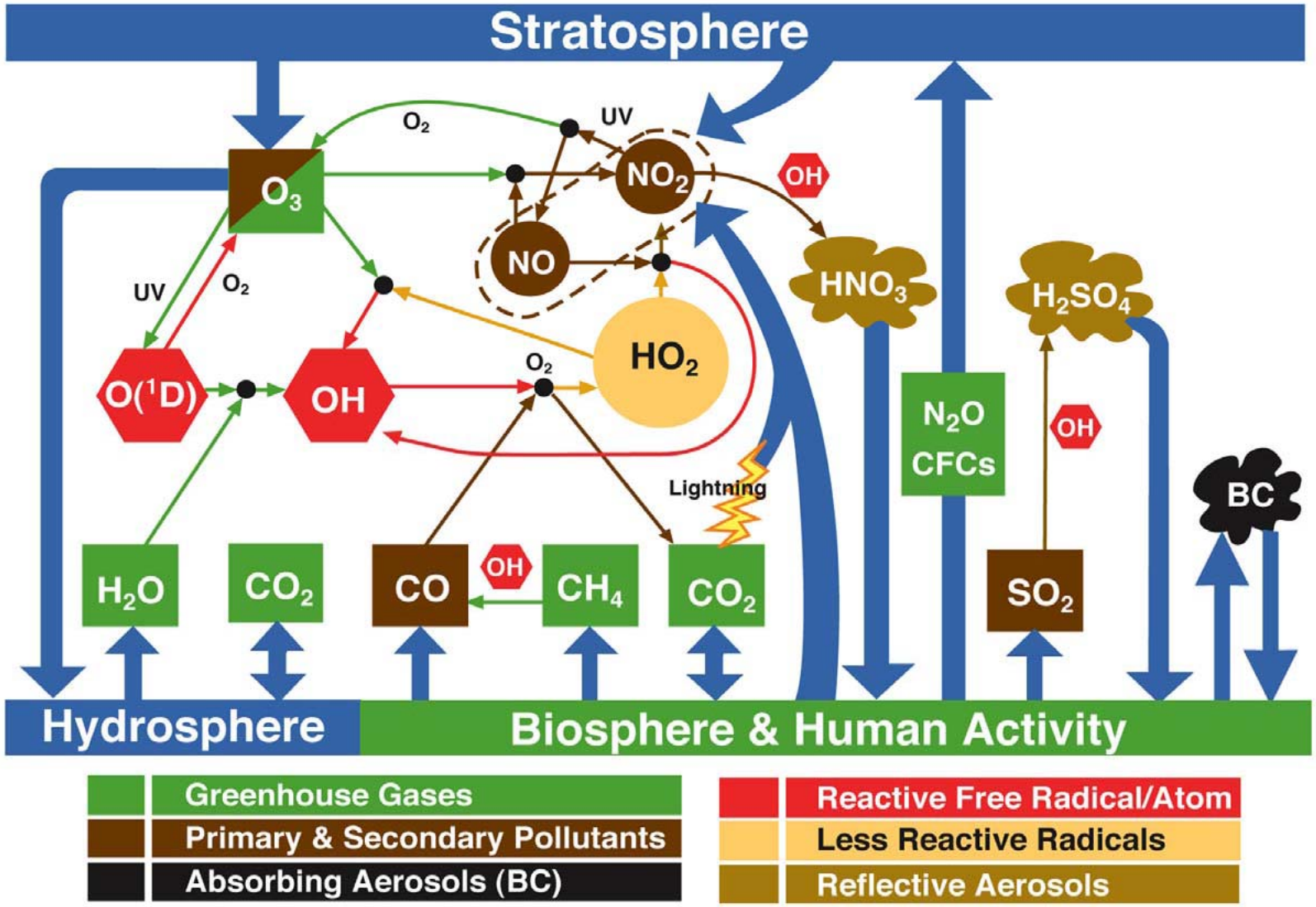
Timeline of the Evolution of Climate Modeling

Mid-1960s	Mid 1970s-1980s	1990s	Present Day	2000-2010
Atmosphere/ Land Surface	Atmosphere/ Land Surface/ Vegetation	Atmosphere/ Land Surface/ Vegetation	Atmosphere/ Land Surface/ Vegetation	Atmosphere/ Land Surface/ Vegetation
Ocean	Ocean	Ocean	Ocean	Ocean
	Sea Ice	Sea Ice	Sea Ice	Sea Ice
	Coupled Climate Model	Coupled Climate Model	Coupled Climate Model	Coupled Climate Model
		Sulfate Aerosol	Sulfate Aerosol	Sulfate Aerosol
		Carbon Cycle	Carbon Cycle	Carbon Cycle
			Dust/Sea Spray/Carbon Aerosols	Dust/Sea Spray/Carbon Aerosols
			Interactive Vegetation	Interactive Vegetation
			Biogeochemical Cycles	Biogeochemical Cycles
				Ice Sheet



Washington, W., L. Buja and A. Craig. The computational future for climate and Earth system models: on the path to petaflop and beyond, *Philosophical Transactions of the Royal Society A* 2009 367: 833-846.

Interactions Between Air Pollution and Climate



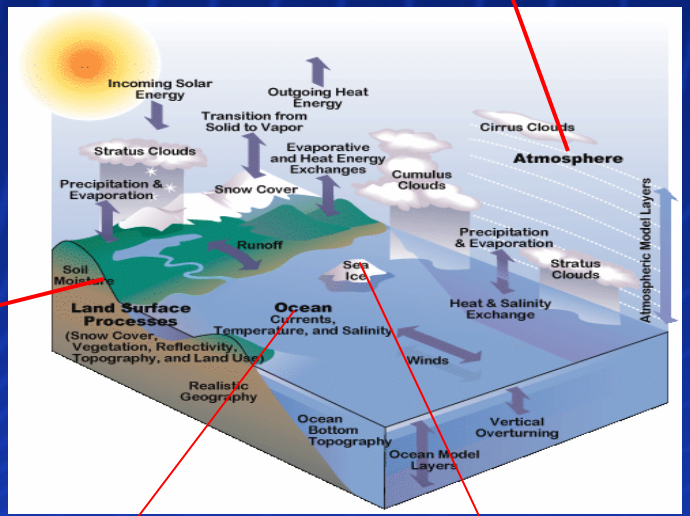
MIT Opencourseware, Atmospheric Physics and Chemistry, 2006

Linkage from Global Model to Regional Model

Community Earth System Model

CESM 1.0

Community Atmosphere Model (CAM)



Community Land Model (CLM)

Ocean component (POP)

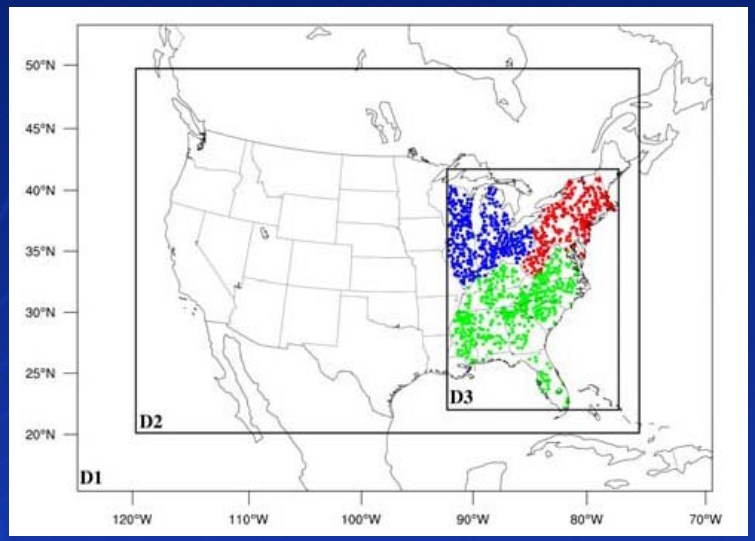
Community Sea Ice Model (CSIM)

Spatial Resolution: 0.9 x 1.25 degree (~100 x 140 km)

Temporal Resolution: 3 hourly/Daily/monthly average data

Regional Climate/Chem Model

WRF 3.2.1/CMAQ 4.7.1

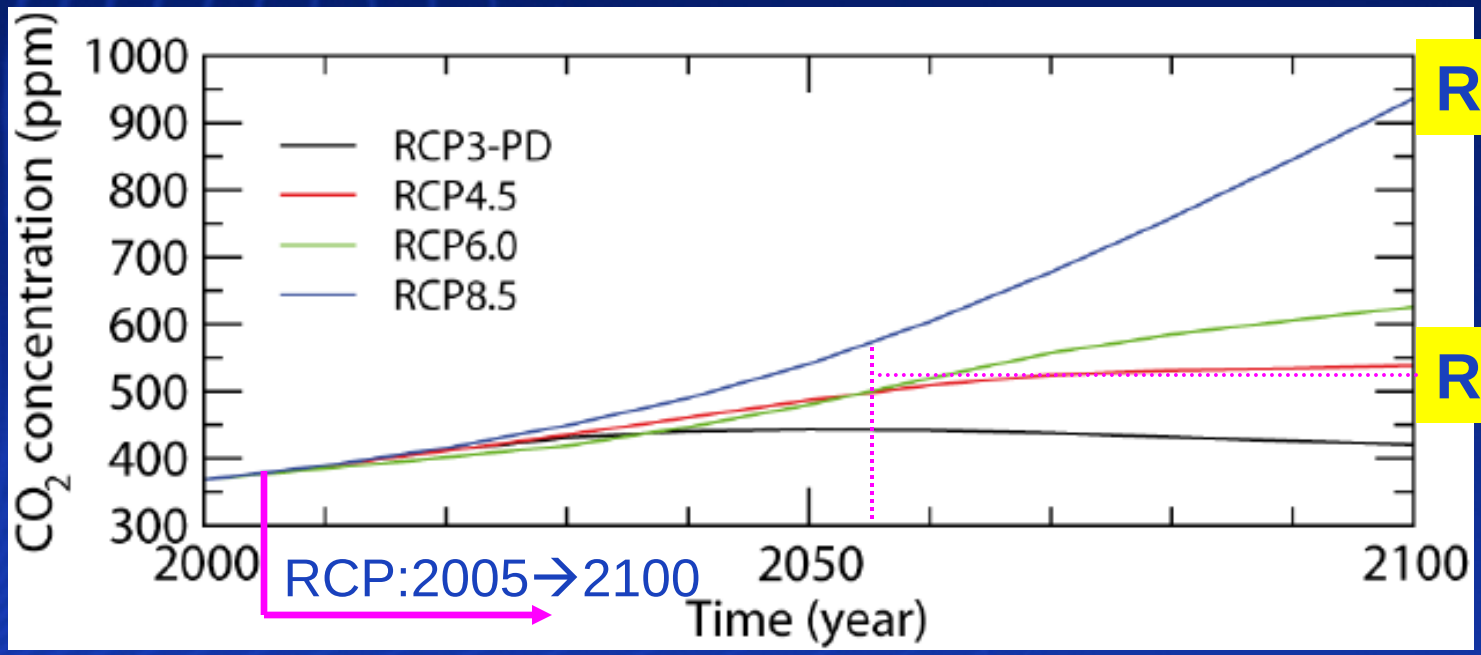


D1/D2/D3: 36-12-4 km

The points represent NCDC US COOP network station observation points in three regions:
Northeast (red color), Midwest (blue color) and Southeast (green color).

http://dss.ucar.edu (dataset number ds510.6)

Global Climate Simulation Scenarios



RCP 8.5

RCP 4.5

- Representative Concentration Pathways (RCP) 4.5

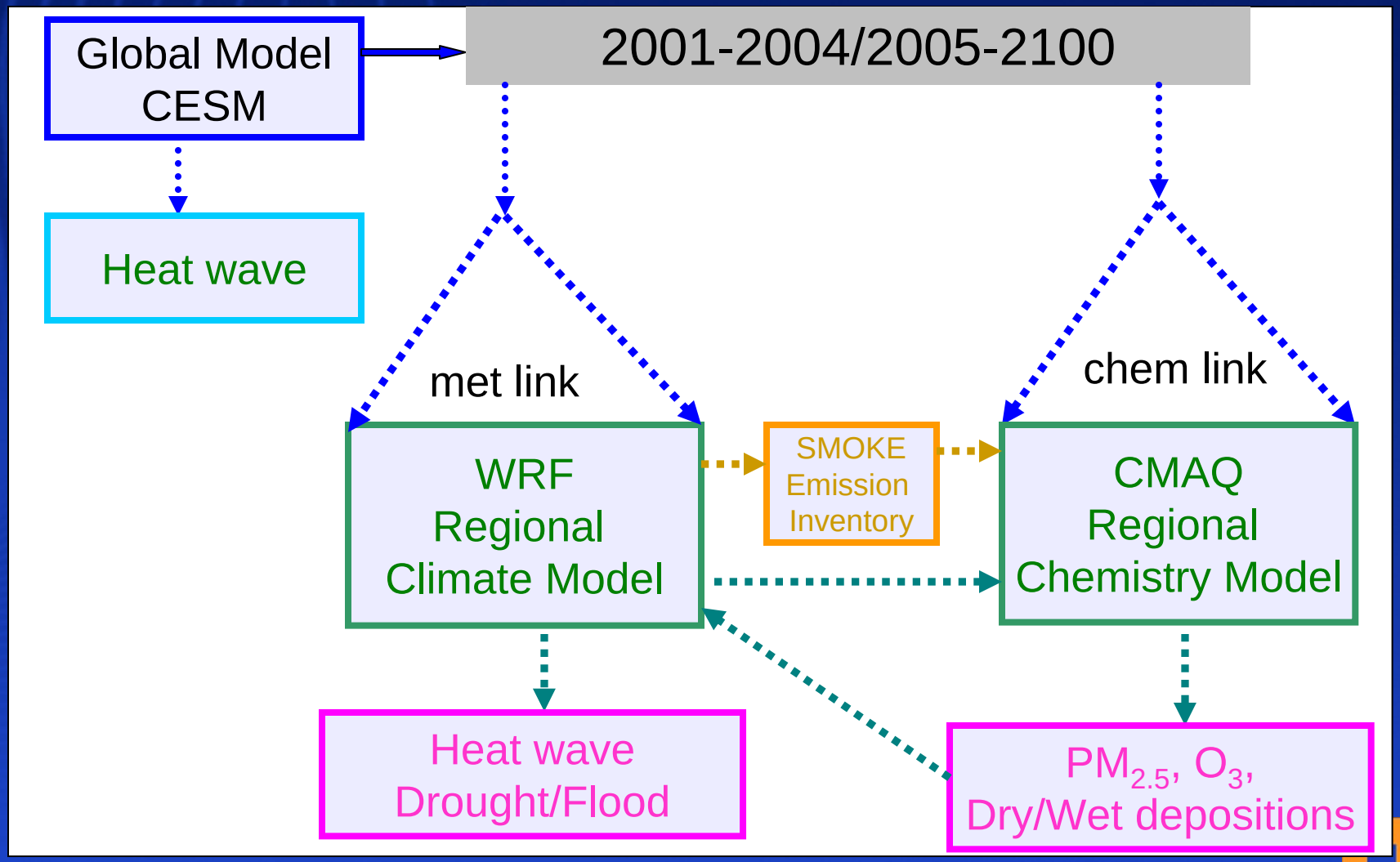
  Moderate emissions increasing scenario

- Representative Concentration Pathways (RCP) 8.5

  Fossil fuel intensive scenario

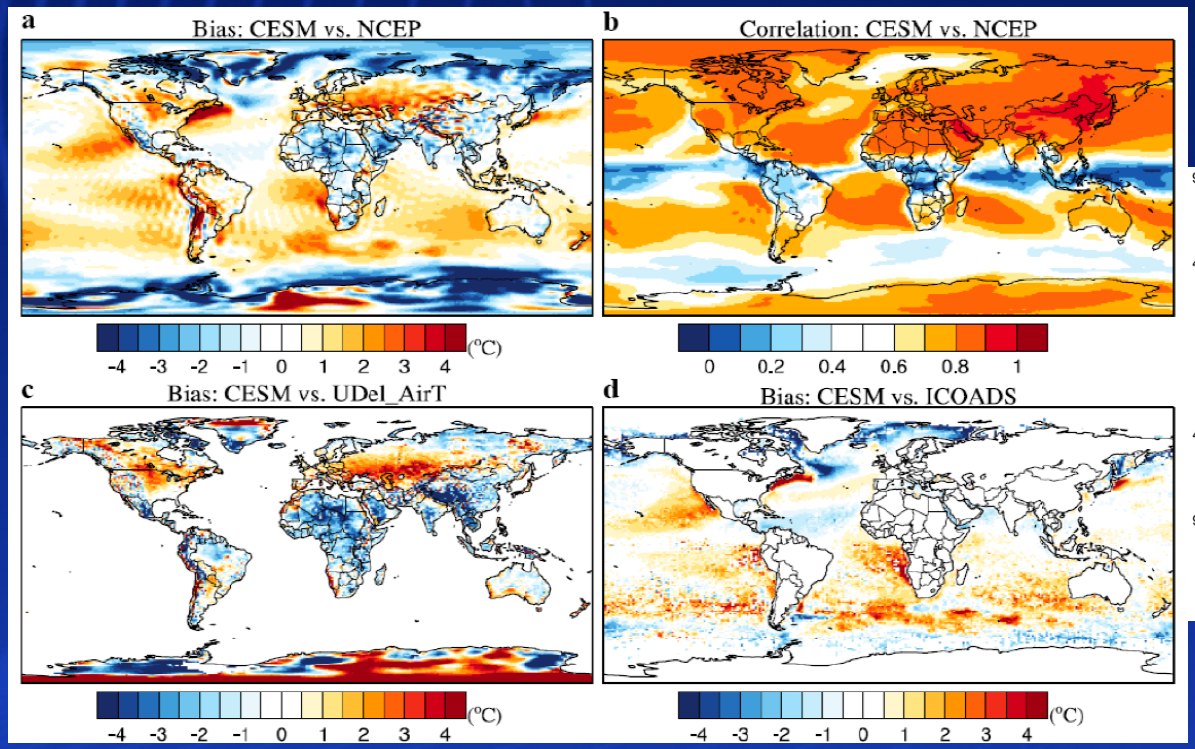
Source: http://stratus.astr.ucl.ac.be/textbook/pdf/Chapter_6.pdf

Overview of the Study

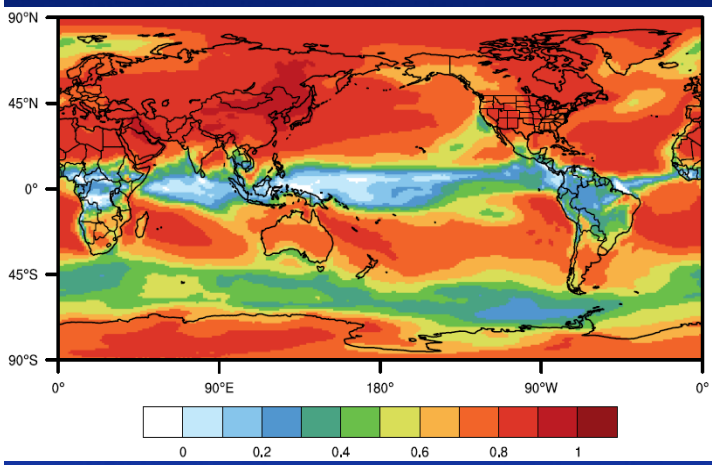


Evaluation of CESM in Present Climate

Daily average temperature at 2 meter from 2001-2010

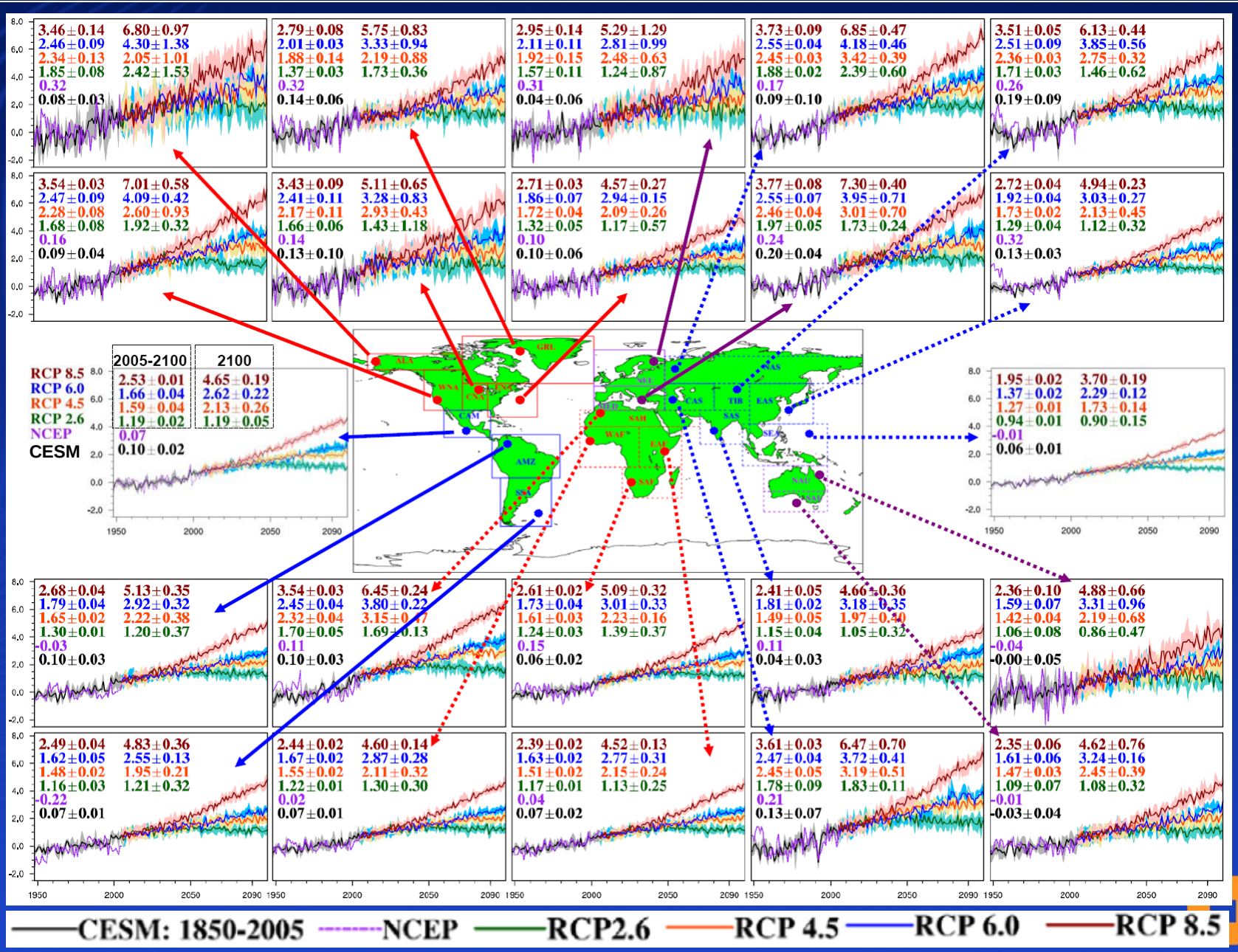


Correlation



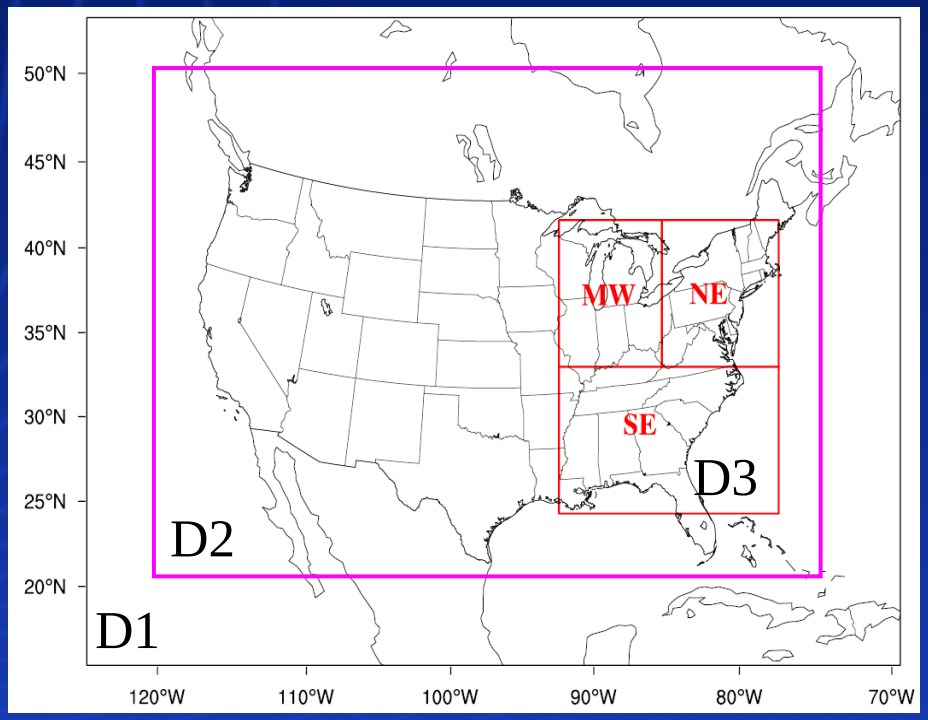
- ❖ **NCEP/NCAR Reanalysis and observational daily average data (2001-2010) was used to evaluate CESM output.**
- ❖ **The land mean bias is -0.2°C. The overall biases are within -1 to 1°C for majority of the areas and the correlation coefficient are mostly 0.8-0.9 except the tropical areas.**

Heat Wave intensity



Regional Simulation Domains

Regional Model WRF/CMAQ Simulation domains



D1: 36 km by 36 km

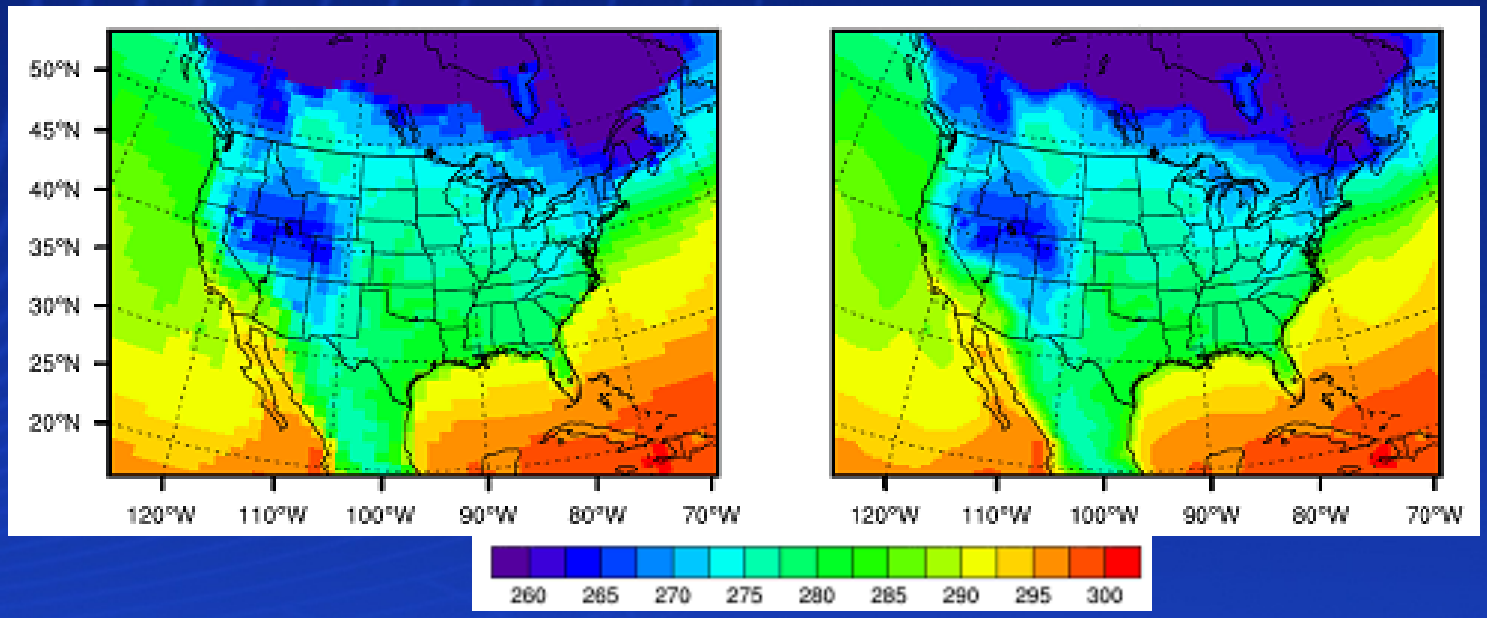
D2:12 km by 12km domain

D3: 4km by 4km Eastern US domain

Evaluation of Horizontal Patterns

Temperature (2 meter)

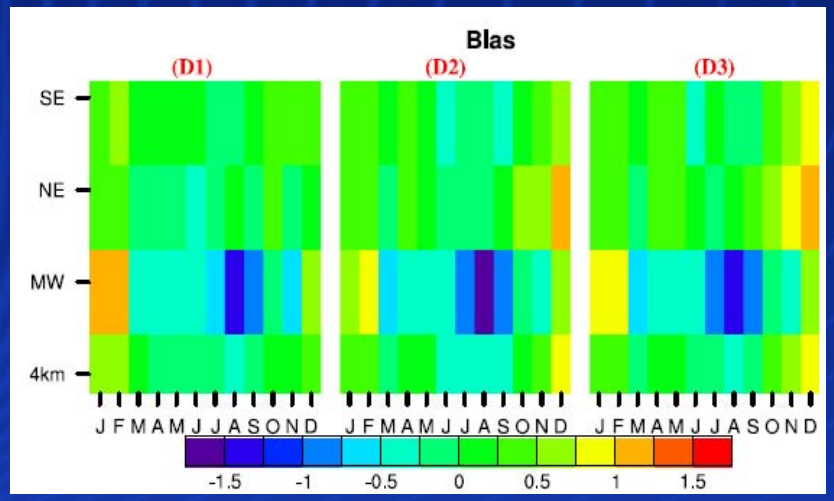
CESM WRF



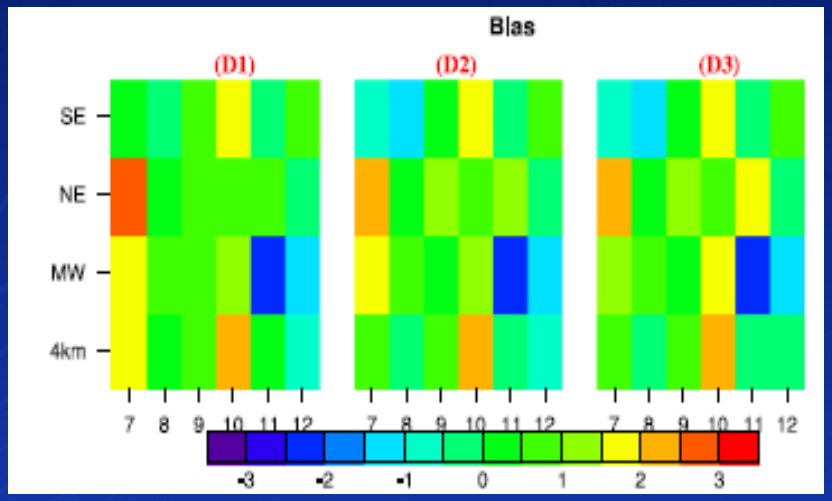
Statistical Evaluation of WRF Outputs

Temperature at 2 meter (unit: K)

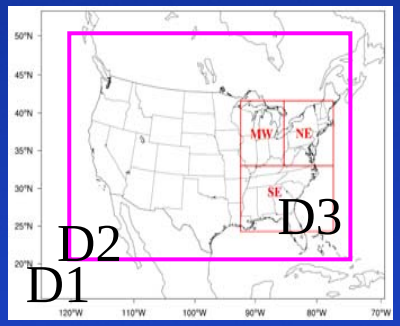
WRF vs. CESM



WRF vs. MADIS



The biases are mainly ranging from -1.0 to 1.0 K.



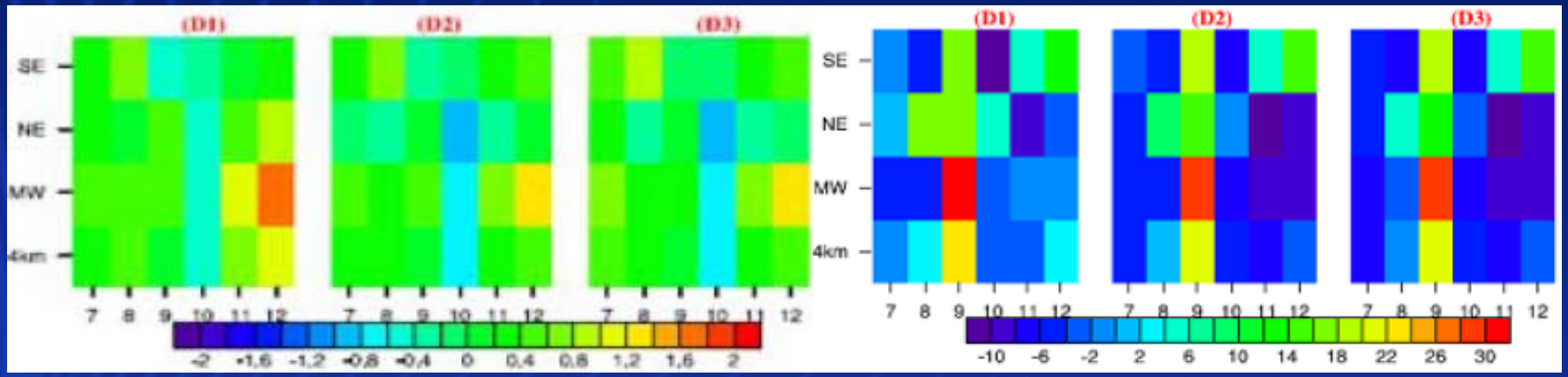
Benchmark: Temperature

Bias: $\leq \pm 0.5$ K

Emery, C.A., E. Tai, G. Yarwood. 2001. "Enhanced Meteorological Modeling and Performance Evaluation for Two Texas Ozone Episodes." Prepared for the Texas Natural Resource Conservation Commission, by ENVIRON International Corp, Novato, CA.

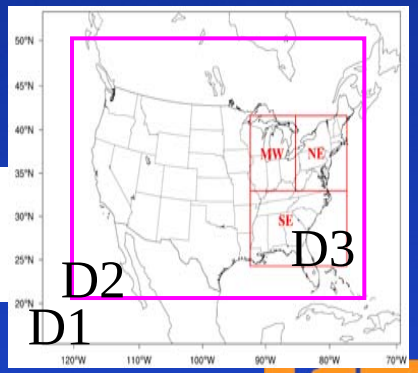
Statistical Evaluation of WRF Outputs

Wind Speed WRF vs. MADIS **Wind Direction**

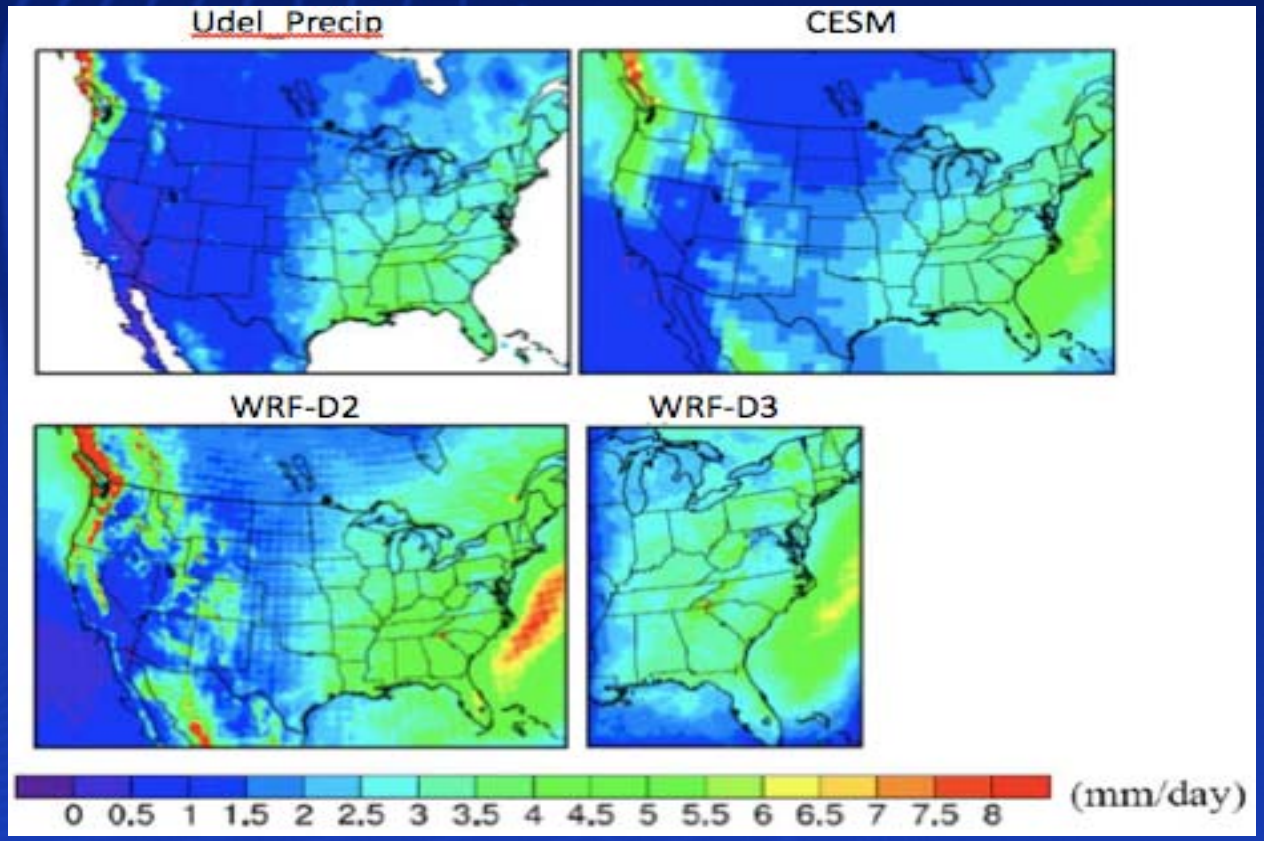


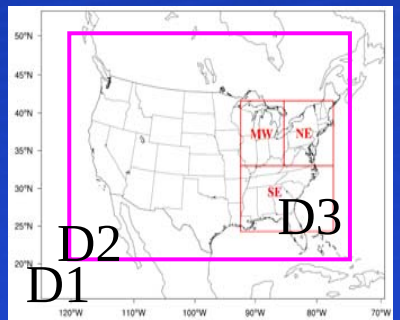
The biases are within -1.0 to 1.0 m/s for wind speed and ranging from -10 to 10 degrees for wind direction

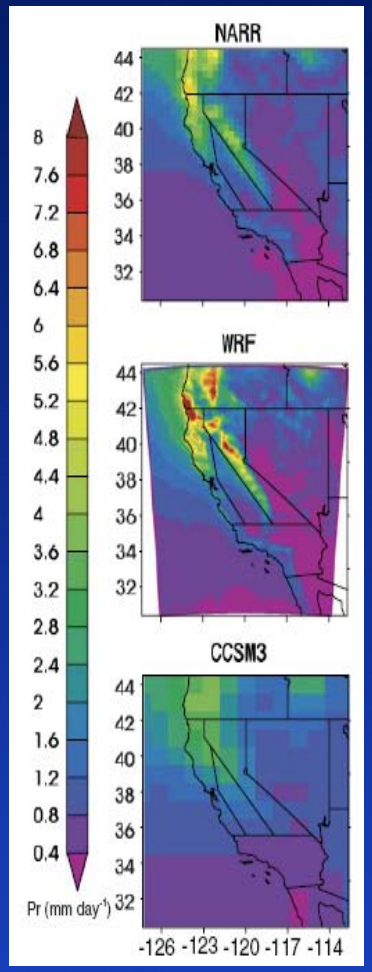
Benchmark:	Wind Speed	Wind Direction
Bias:	$\leq \pm 0.5$ K	$\leq$ 10 deg



CESM-WRF Rainfall Patterns



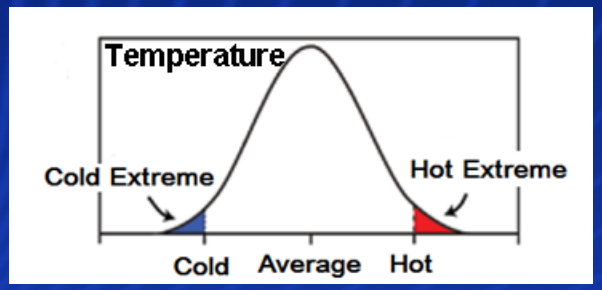




Caldwell et al., 2009

How to Define Heat Waves?

Probability Distribution



Source: CCSP, 2008

Continuous night minimum temperatures

- Two maximum daily temperature thresholds

T1 and T2 can be

a) fixed values 30º and 25 ºC

b) the 97.5th and 81st percentiles

A heat wave period is:

$$\begin{cases} \sum_{i=1}^{3} T_i \geq T1 \\ \dfrac{\sum_{i=1}^{n} T_i}{n} \geq T1 \\ \sum_{i=1}^{n} T_i \geq T2 \end{cases}$$

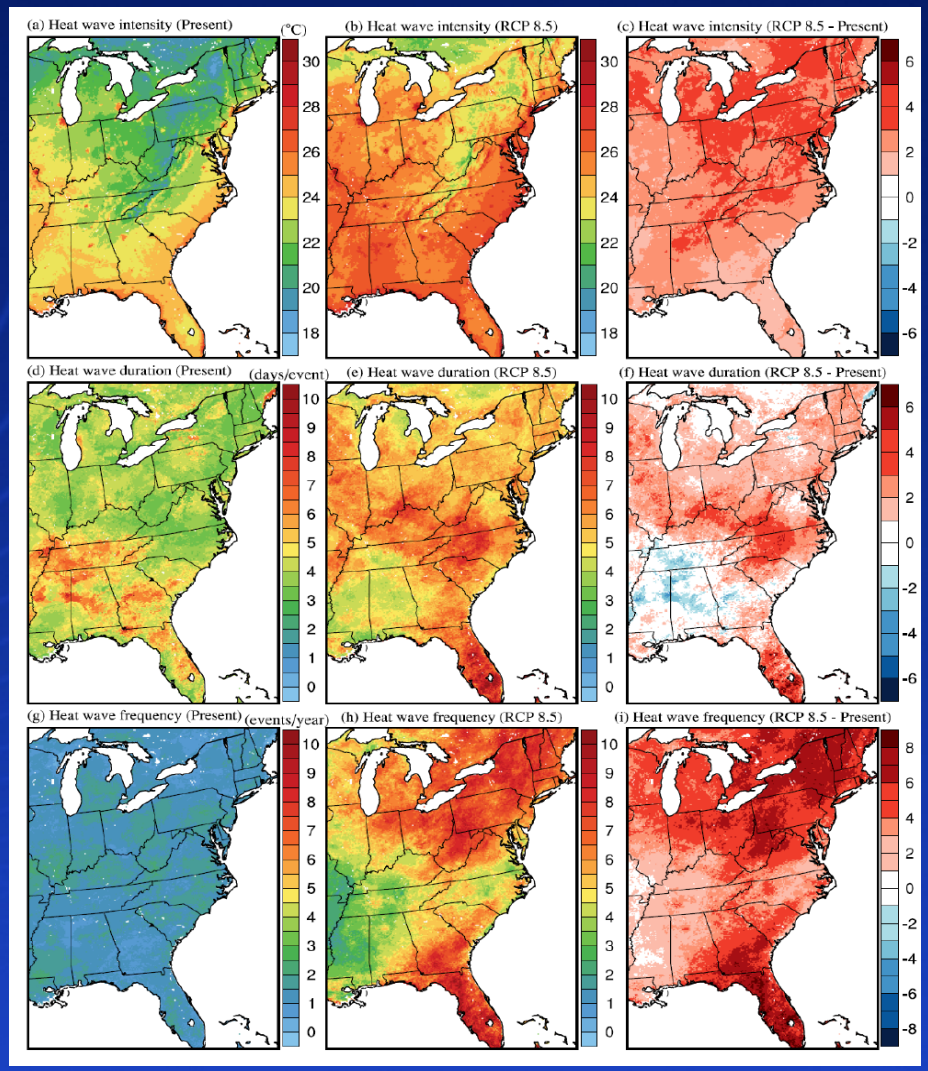
Wide Increase in Heat Wave Intensity, Duration and Frequency

Present RCP8.5 RCP8.5-Present

Heat wave intensity (ºC)

Heat wave duration (days/event)

Heat wave frequency (events/year)



City-Level Increase in Heat Wave Intensity, Duration and Frequency

Among the top 50 cities by population in US, 20 is located in the eastern US

http://en.wikipedia.org/wiki/List_of_United_States_cities_by_population

Evaluations of Heat Waves in CESM and WRF

Table 1. Evaluations of heat wave intensity, duration and frequency

Regions/States	Heat wave intensity (ºC)				Heat wave duration (days/event)				Heat wave frequency (events/year)			
	NCDC	CESM-NCDC	WRF-NCDC	%[1]	NCDC	CESM-NCDC	WRF-NCDC	%[1]	NCDC	CESM-NCDC	WRF-NCDC	%[1]
Northeast Region	**20.82**	**1.55**	**1.17**	**24.73**	**5.62**	**1.27**	**-0.41**	**67.72**	**1.44**	**-0.76**	**-0.29**	**62.17**
New Hampshire	19.22	2.21	1.91	13.57	5.42	-0.09	-1.01	91.09	1.53	-1.05	-0.35	66.67
Vermont	19.23	1.30	1.49	12.75	6.20	1.36	-0.83	38.97	1.41	-0.91	-0.44	51.65
Massachusetts	21.70	2.33	0.99	57.51	5.28	0.70	-0.46	34.29	1.26	-0.34	-0.27	20.59
Connecticut	21.28	1.44	0.99	31.25	5.55	-1.10	-1.07	2.73	1.41	-0.66	-0.27	59.09
New York	20.16	1.12	0.78	30.36	5.97	-0.73	-0.59	19.18	1.49	-0.91	-0.57	37.36
Pennsylvania	19.93	1.65	1.01	38.79	5.92	1.53	-1.13	26.14	1.5	-0.71	-0.17	76.06
New Jersey	22.17	1.75	1.48	15.43	5.47	0.73	-0.15	79.45	1.45	-0.93	-0.22	76.34
Maryland	23.24	1.01	1.50	32.67	6.27	4.34	-0.40	90.78	1.36	-0.53	-0.14	73.58
West Virginia	20.43	1.18	0.38	67.80	4.50	4.66	1.96	57.94	1.54	-0.78	-0.15	80.77
Midwest Region	**21.31**	**2.51**	**1.15**	**54.02**	**5.00**	**3.98**	**1.24**	**68.78**	**1.42**	**-0.23**	**-0.20**	**13.04**
Wisconsin	20.86	2.21	1.04	52.94	5.13	2.97	1.18	60.27	1.31	-0.26	-0.39	33.33
Michigan	20.18	2.47	1.93	21.86	4.92	3.00	1.14	62.00	1.4	-0.08	-0.07	12.50
Illinois	22.46	3.36	1.23	63.39	4.97	5.30	1.25	76.42	1.43	-0.24	-0.15	37.50
Indiana	21.94	2.53	0.89	64.82	5.00	5.95	1.29	78.32	1.51	-0.48	-0.21	56.25
Ohio	21.12	1.98	0.68	65.66	4.98	2.70	1.36	49.63	1.44	-0.09	-0.18	50.00
Southeast Region	**22.58**	**1.47**	**0.83**	**43.48**	**6.51**	**3.67**	**1.98**	**45.99**	**1.34**	**-0.34**	**-0.24**	**28.38**
Kentucky	22.28	1.82	0.57	68.68	6.56	6.15	1.93	68.62	1.26	-0.45	-0.01	97.78
Virginia	20.98	2.17	1.28	41.01	6.20	3.50	2.13	39.14	1.33	-0.39	-0.19	51.28
Tennessee	22.08	1.62	0.93	42.59	6.59	5.97	3.16	47.07	1.26	-0.26	-0.21	19.23
North Carolina	21.61	1.69	1.09	35.50	6.82	1.90	0.93	51.05	1.36	-0.2	-0.22	9.09
Mississippi	23.18	1.66	0.79	52.41	5.86	4.46	3.55	20.40	1.4	-0.33	-0.39	15.38
Alabama	22.78	1.04	1.10	5.45	5.06	3.53	2.34	33.71	1.47	-0.59	-0.49	16.95
Georgia	22.10	1.11	1.06	4.50	7.63	2.76	0.81	70.65	1.12	-0.09	-0.1	10.00
South Carolina	23.04	1.03	0.71	31.07	7.78	3.76	1.43	61.97	1.18	-0.35	-0.08	77.14
Florida	25.15	1.13	-0.03	97.35	6.05	1.04	1.58	34.18	1.64	-0.37	-0.48	22.92

[1]Values without highlight: indicating bias percentage improvement in WRF over CESM in comparison to NCDC data, with formula of (|CESM-NCDC|-|WRF-NCDC|)/|CESM-NCDC|.

Values highlight in yellow: indicating bias in CESM is smaller than WRF in comparison to NCDC, with formula of (|WRF-NCDC|-|CESM-NCDC|)/|WRF-NCDC|.

State-Level Increase in Heat Wave Intensity, Duration and Frequency

Table 2. Heat wave intensity, duration and frequency

Regions/States	Heat wave intensity (°C)			Heat wave duration (days/event)			Heat wave frequency (events/year)		
	Present	RCP 8.5	RCP 8.5 - Present	BASE	RCP 8.5	RCP 8.5 - Present	BASE	RCP8.5	RCP 8.5 - Present
Northeast Region	**21.81**	**24.85**	**3.05**	**3.61**	**5.53**	**1.92**	**1.24**	**7.03**	**5.79**
New Hampshire	21.16	24.23	3.07	3.22	5.35	2.13	1.29	7.41	6.12
Vermont	20.84	24.02	3.18	3.37	5.35	1.98	1.15	7.94	6.79
Massachusetts	22.21	25.05	2.84	3.60	5.47	1.87	1.02	7.13	6.11
Connecticut	22.45	25.43	2.98	3.68	5.71	2.03	1.24	6.53	5.29
New York	20.84	24.08	3.24	3.78	5.32	1.54	0.96	7.65	6.69
Pennsylvania	20.97	24.16	3.19	3.85	5.48	1.63	1.33	7.26	5.93
New Jersey	23.44	26.55	3.11	3.59	5.49	1.90	1.36	6.26	4.90
Maryland	23.26	26.33	3.07	3.91	5.67	1.76	1.34	5.89	4.55
West Virginia	21.08	23.82	2.74	3.53	5.96	2.43	1.45	7.16	5.71
Midwest Region	**22.26**	**25.05**	**2.78**	**3.86**	**5.65**	**1.78**	**1.23**	**5.57**	**4.34**
Wisconsin	21.63	24.61	2.98	3.64	5.63	1.99	0.97	5.23	4.26
Michigan	21.70	24.62	2.92	3.96	5.00	1.04	1.20	5.78	4.58
Illinois	23.48	25.74	2.26	3.97	5.94	1.97	1.32	4.50	3.18
Indiana	22.72	25.28	2.56	3.87	5.87	2.00	1.37	5.66	4.29
Ohio	21.79	24.99	3.20	3.88	5.80	1.92	1.30	6.70	5.40
Southeast Region	**23.53**	**25.99**	**2.46**	**4.55**	**5.78**	**1.23**	**1.25**	**5.02**	**3.77**
Kentucky	22.80	25.54	2.74	4.22	6.28	2.06	1.41	4.48	3.07
Virginia	22.50	25.43	2.93	3.70	6.00	2.30	1.38	5.38	4.00
Tennessee	23.00	25.69	2.69	5.47	5.46	-0.01	1.16	3.88	2.72
North Carolina	23.27	26.06	2.79	3.82	6.45	2.63	1.35	4.71	3.36
Mississippi	23.99	26.21	2.22	4.70	4.41	-0.29	1.35	2.93	1.58
Alabama	23.80	26.34	2.54	4.96	4.57	-0.39	1.12	4.33	3.21
Georgia	23.74	25.92	2.18	4.98	5.66	0.68	1.02	6.19	5.17
South Carolina	23.98	26.32	2.34	4.41	6.08	1.67	1.33	5.46	4.13
Florida	24.67	26.38	1.71	4.66	7.11	2.45	1.09	7.81	6.72

City-Level Increase in Heat Wave Intensity, Duration and Frequency

Table 3. Heat wave intensity, duration and frequency in top 20 cities by population in Eastern US

	Heat wave intensity (°C)				Heat wave duration (days/event)				Heat wave frequency (events/year)			
City	NCDC	CESM	WRF[1]	WRF[2]	NCDC	CESM	WRF[1]	WRF[2]	NCDC	CESM	WRF[1]	WRF[2]
New York	24.75	23.25	24.92	3.58	3.00	4.00	3.62	1.82	1.38	0.56	1.35	4.07
Chicago	24.80	25.05	26.20	3.34	3.67	4.25	3.60	1.37	1.25	1.5	1.15	5.05
Philadelphia	23.17	22.22	24.31	3.69	3.00	9.00	3.18	2.42	1.50	0.25	1.64	4.63
Jacksonville	24.91	26.75	25.02	1.81	3.88	6.75	4.57	1.60	1.50	1.00	1.08	5.28
Indianapolis	23.50	24.54	23.04	3.03	4.71	4.00	4.04	1.84	1.88	0.81	1.18	4.35
Columbus	21.75	23.54	21.94	3.63	4.74	3.67	3.61	2.55	1.46	1.50	1.36	5.03
Charlotte	22.81	24.00	22.96	2.62	5.00	5.83	3.75	4.25	1.25	1.00	1.29	3.30
Detroit	21.67	23.30	24.25	3.67	5.25	4.00	3.67	1.39	1.50	1.00	1.41	4.70
Memphis	25.37	25.75	25.07	2.18	6.67	9.50	5.52	0.09	1.50	1.25	1.14	1.70
Baltimore	23.85	23.17	23.99	3.65	4.67	4.33	3.46	1.95	1.13	0.88	1.44	5.09
Boston	22.29	24.87	23.06	3.41	3.00	6.35	3.55	1.27	1.22	1.16	1.16	5.22
Washington, D.C.	23.96	23.86	24.33	3.55	4.67	4.33	4.11	1.43	1.25	1.00	1.29	4.70
Nashville	22.54	24.32	23.46	3.21	6.75	6.50	5.26	0.19	1.15	1.20	1.14	2.46
Louisville	22.14	24.08	23.63	2.98	4.00	5.00	3.75	2.73	1.00	0.67	1.66	3.13
Milwaukee	21.51	22.01	23.18	3.51	4.30	6.00	3.76	0.95	1.47	1.08	1.10	4.70
Virginia Beach	24.53	26.83	24.85	2.10	3.00	5.67	3.08	1.80	1.00	1.00	0.44	5.14
Atlanta	22.22	22.80	23.83	3.08	5.25	5.50	4.66	0.72	1.00	1.25	1.19	3.69
Raleigh	22.93	24.43	23.54	2.89	3.00	4.95	3.25	3.27	1.75	1.92	1.53	2.46
Miami	27.41	27.53	26.05	2.40	3.00	3.00	3.91	3.72	1.75	1.00	0.85	7.55
Cleveland	22.59	21.60	23.04	3.71	3.50	6.25	3.83	1.73	1.17	1.25	1.20	5.25

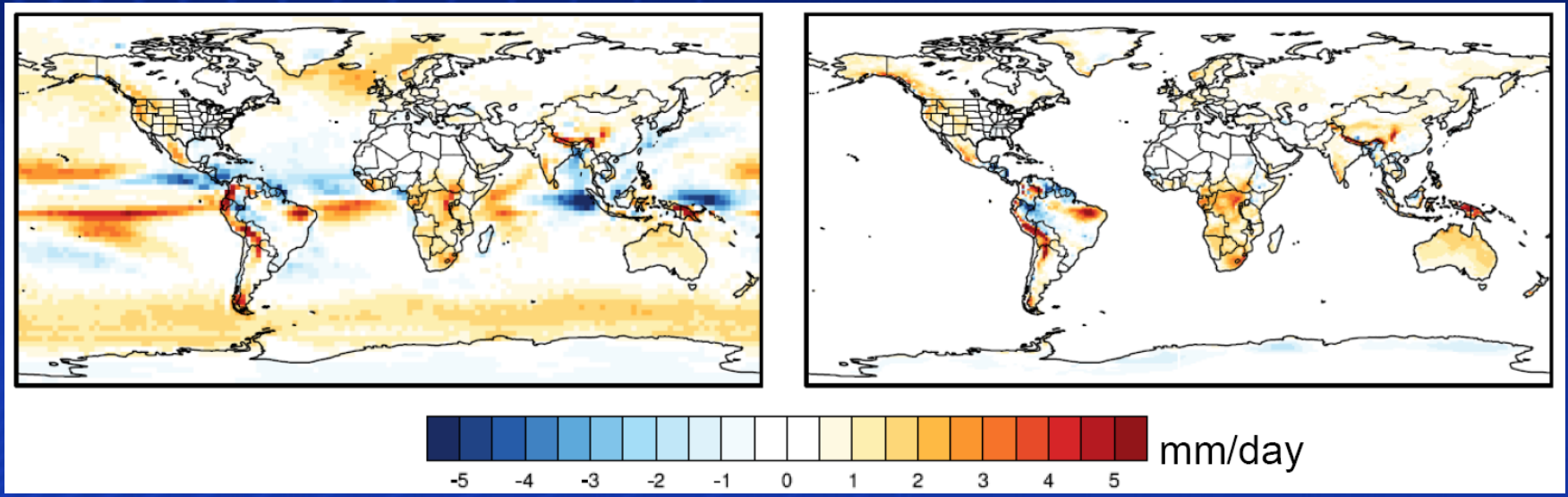
[1]The WRF indicates present period (2001-2004) from WRF simulations. Values in red indicate absolute bias in WRF is smaller than CESM in comparison to NCDC data.

[2]The WRF indicates the increase of future climate period (2057-2059) in RCP 8.5 in comparison to present climate (2001-2004).

Precipitation Comparisons

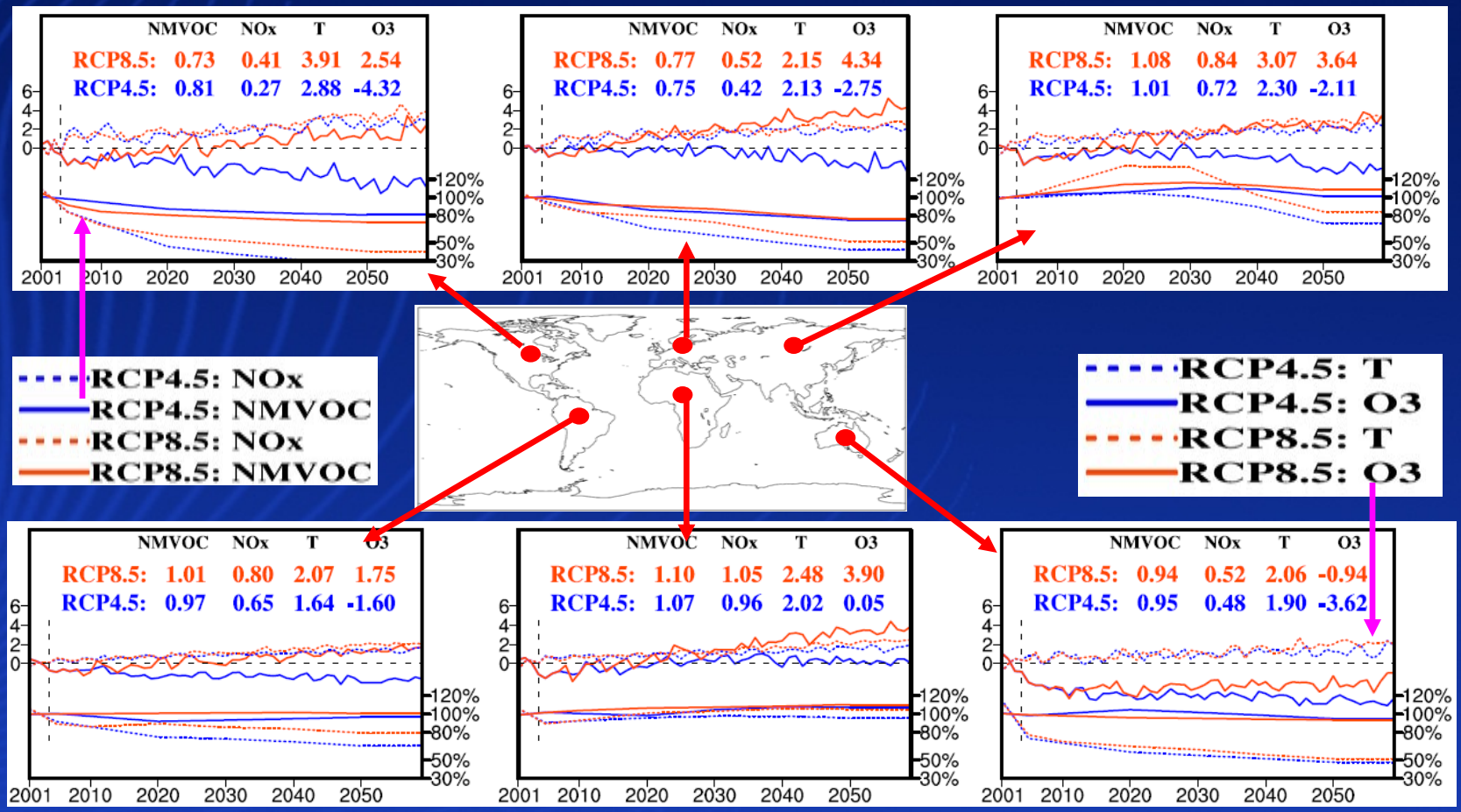
CESM vs. NCEP

CESM vs. UDel_Precip



Compared with both NCEP and real observational data, low bias was achieved from CESM outputs.

Climate Impact on Regional Air Quality



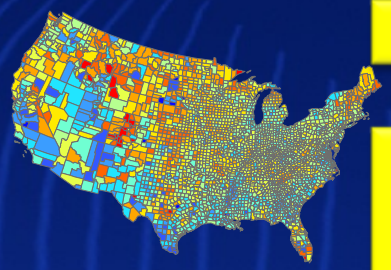
- The numbers below NMVOC and NOx indicate ratios of NMVOC and NOx emissions in 2059 to present (2001-2004)
- The numbers below T and O_3 indicate Temperature and ozone changes in 2059 in comparison to present (2001-2004)

OUTLINE

- ***Background of climate change study***
  - **Climate and Energy**
  - **Climatic Effects**
    - **Heat waves as an example**
- ***Research problems and potential research approach***
- ***A past study we did for the IPCC A1B scenario***
- ***Current on-going study in CESM and its downscaling***
- ***Next Step ….***

STORAGE: Simulation Testbed for Outage, Restoration, and Evolution of the Electric Grid: A Unique Model and Simulation System Couples Climate Change, Evolution of the Power Grid, with Population Reactions and Movements

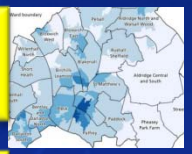
Steve Fernandez, ORNL



Layout T85, 4 km, 1 km grid cells

Catalog Attributes
1. Population
2. Centroid Lat/Long
3. Census Region
4. Utility District
5. Associated MSA - Alt

Convert Population Count to customer count (EC = P/BY)



Convert customer count to power demand [Avg. customer use * number of customers * (1 + % increase/100)]

Overlay locations (lat/long) of substations (o + n) within study area

Construct electrical service area using cellular automata approach

Is any Demand Unaccounted for?

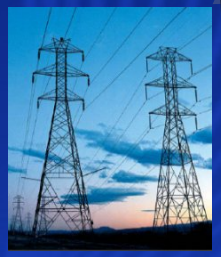
YES

Build average substation (1st centroid, then centroid of unassigned demand cells)

Transmission Capacity Adequate?

NO

Overlay new Transmission Lines In Existing Corridors



YES

NO

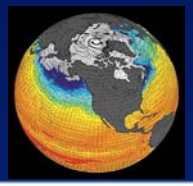
Generation capacity adequate?

YES

New Generation (Brownfield Locations)

New Fuel-mix Policy Adjustment

Calculate CO2 flux perturbation (MW_e over base - ϵ)



CESM (or interchangeable) Model to calculate temperature and/or precipitation increase

Convert Temperature increases to demand increase for power (% incr. = 5.33 – $0.067L_{CN}$)

Extreme climate and future environment in US

CESM general circulation model

IPCC AR5 RCP4.5 and 8.5 scenarios for greenhouse gases

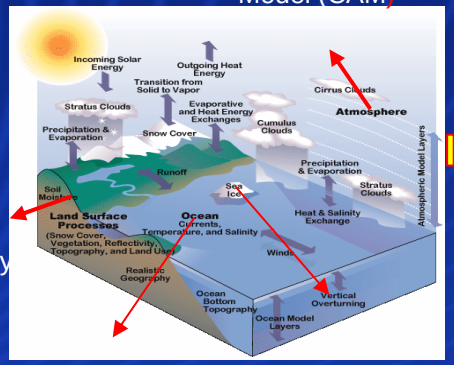
United States

1850 Spin-up 1950 1980 2000 2030 2050 2100

Global → Downscaling → Regional → Evaluation → Local phenomenon

Community Earth System Model (CESM 1.0)

Community Atmosphere Model (CAM)



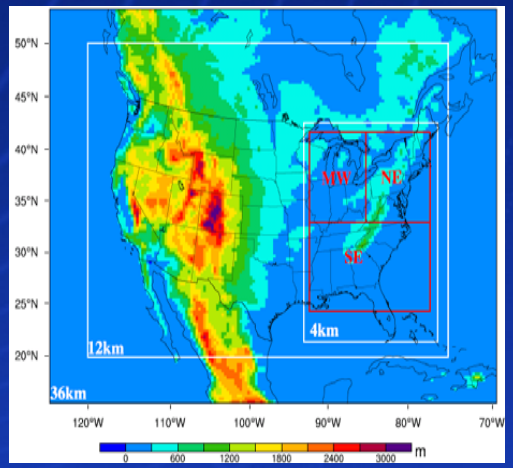
Community Land Model (CLM)

Ocean component (POP)

Community Sea Ice Model (CSIM)

Resolution: 100 km x 140 km

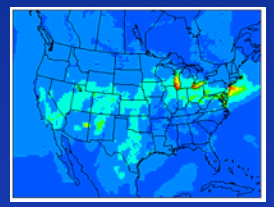
Regional Climate/Chem Model WRF 3.2.1/CMAQ 4.7.1



Resolution: 36/12/4 km x 36/12/4 km

Heat waves, floods and droughts

extreme Visibility & acid depositions



Air quality & health

- Downscaling applications coupling climate and air quality model, CESM to WRF, CESM to CMAQ.
- Evaluate the effect of U.S. climate changes under IPCC RCP8.5 for extreme events (i.e., heat waves, droughts and floods), monsoon weakening, regional visibility, air quality and health impacts.

Summary

- The global climate simulations show high heat wave duration increase in future climate conditions

- There is an tendency the wind speed will decrease in future climate

- Dynamical climate downscaling technique has been applied from CESM to WRF, and small bias between CESM and WRF proves the downscaled methodology

- The dynamical chemistry downscaling methodology has been developed and chemistry simulations have been conducted

- Computational time:
  - CESM: 2.1 million CPU hours on Jaguar
  - WRF and CMAQ: 6 million CPU hours on Kraken

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Ted Spiegel / Corbis file

Thank you for your attention!