Climate change influences on the annual onset of Lyme disease in the United States

Andrew J. Monaghan[1], Sean M. Moore[2], Kevin M. Sampson[1], Charles B. Beard[3], and Rebecca J. Eisen[3]

[1-]National Center for Atmospheric Research, Boulder, CO
[2-]Johns Hopkins School of Public Health, Baltimore, MD
[3-]Centers for Disease Control and Prevention, DVBD, Fort Collins, CO

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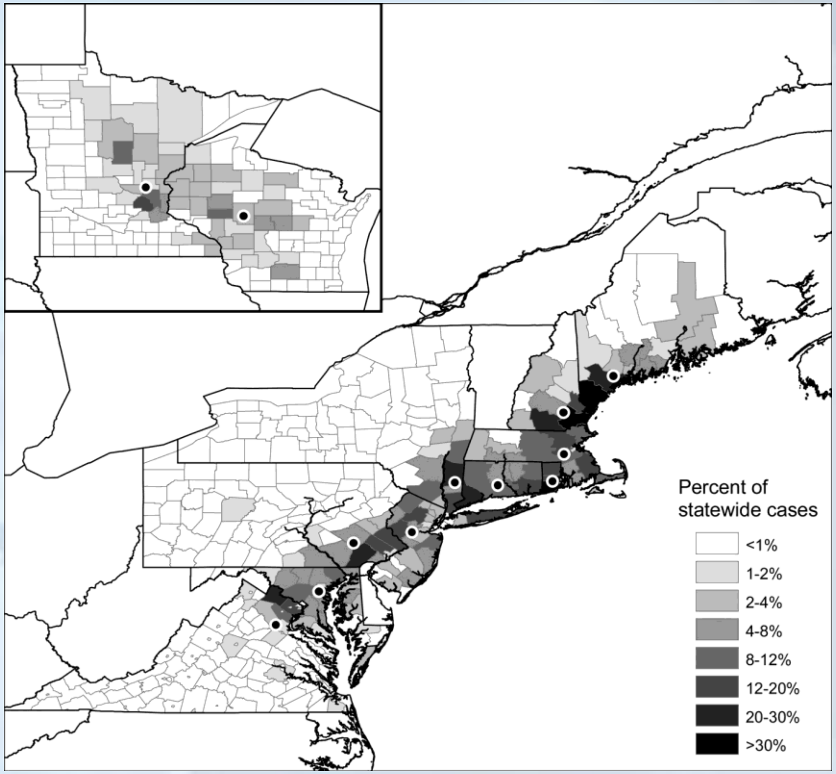
Acknowledgements: Mary Hayden (NCAR), Paul Mead (CDC), WCRP (CMIP5), U.S. DOE PCMDI, NNDSS

Tube to Work Day hits Boulder Creek on Tuesday

Source: Boulder Daily Camera, 7-13-2015

Background

- Lyme disease is a tick-borne zoonotic disease caused by the bacterial spirochete *Borrelia burgdorferi.*
- Lyme disease is the most common vector-transmitted disease in the U.S. and has been increasing in incidence and geographic distribution.
- 95% of cases are concentrated in 13 states in the Northeast and Midwest. →
- Occurrence is highly seasonal, mainly in summer months.
- Seasonality of Lyme disease is related to the life cycle of its primary vector, *Ixodes scapularis*. Previous work has shown a linkage between meteorological factors and the life cycle.

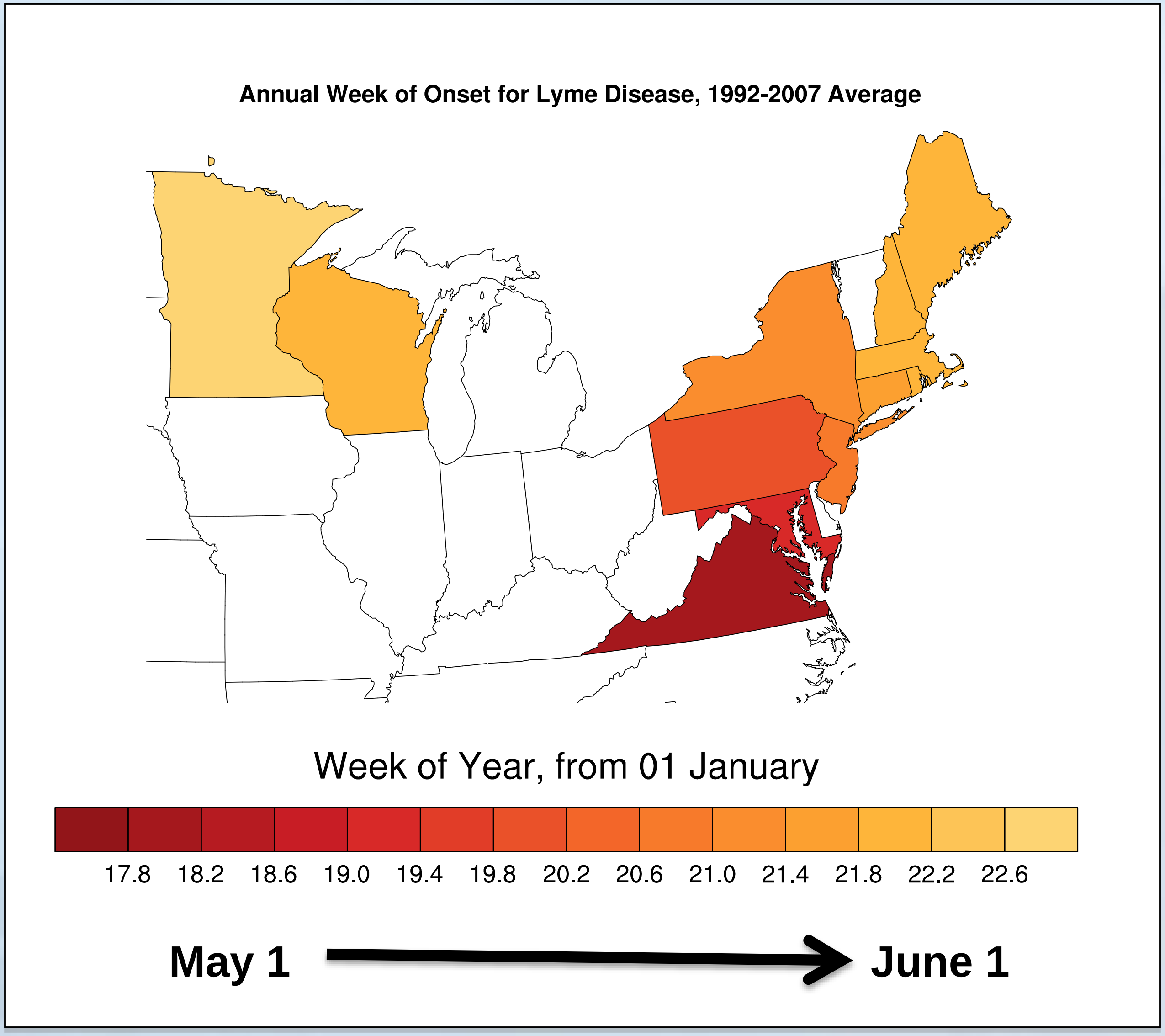


Moore et al. (2014, AJTMH)

Research Question

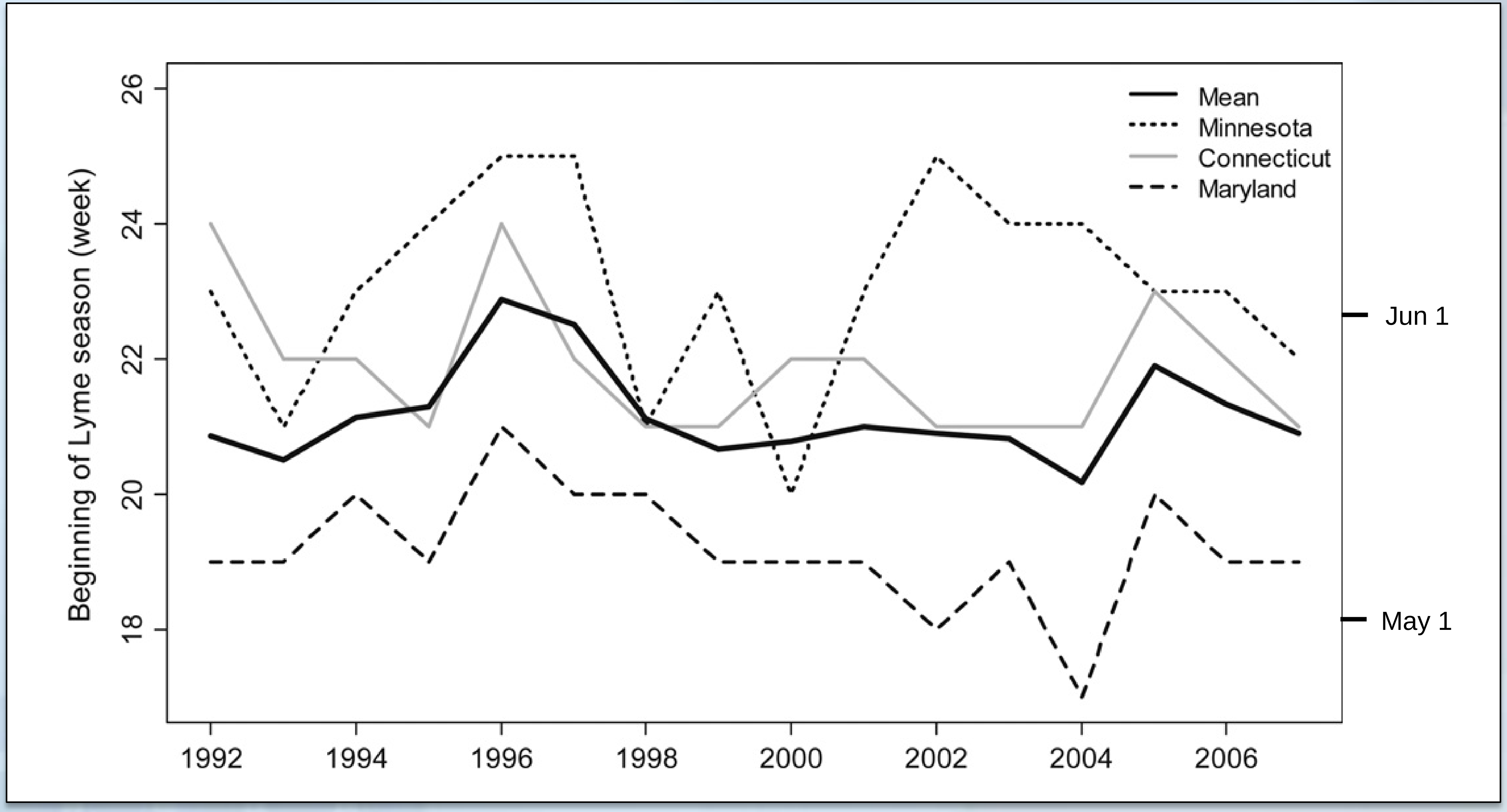
How will 21st century climate change impact the timing of the annual springtime onset of Lyme disease cases in the United States?

Lyme Disease: Annual Week of Onset



Moore et al. (2015, AJTMH)

Annual variability of Lyme disease onset



Moore et al. (2014, AJTMH)

Methods

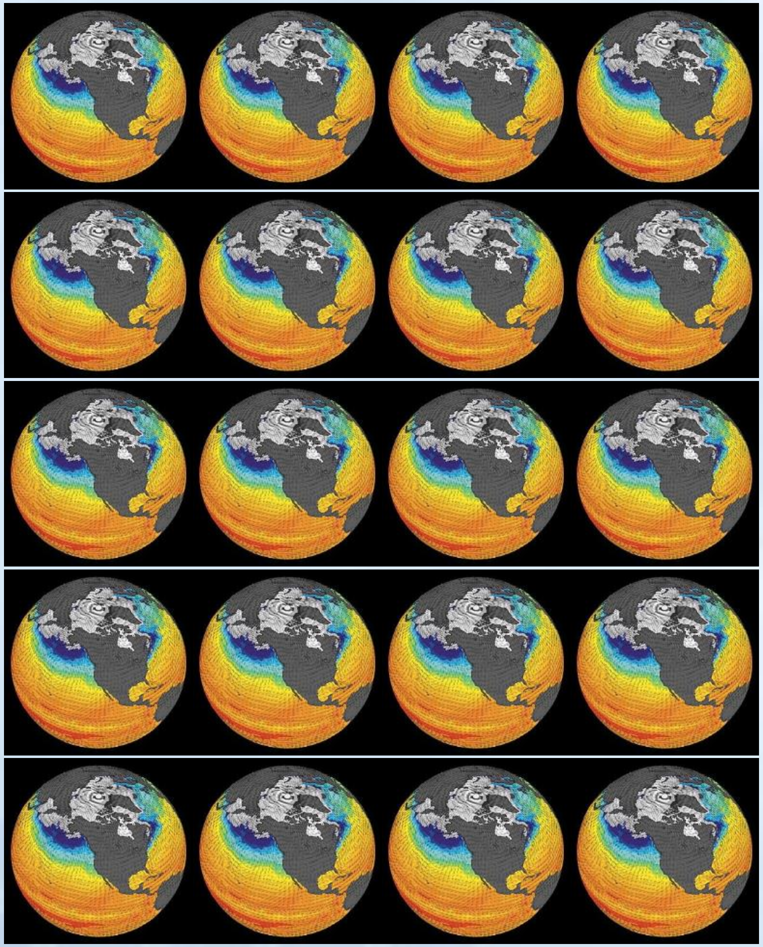
1. Employed best fit empirical model of Moore et al. (2014) that describes Lyme onset week using meteorological variables.
   - Model fit with 195,000 physician-diagnosed (rash) or lab-confirmed Lyme disease cases reported to the NNDSS between 1992-2007.

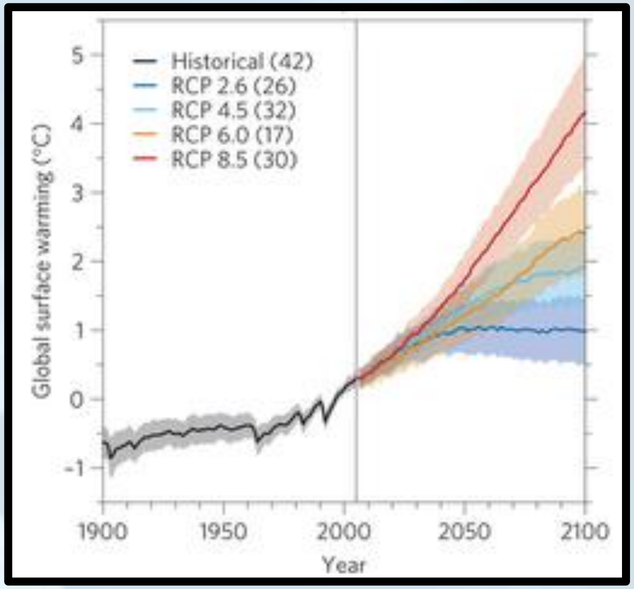
2. Obtained estimates of future meteorological variables from downscaled simulations from five global climate models and four greenhouse gas emissions scenarios (http://gdo-dc.ucllnl.org).
   - Used CMIP5 models that informed IPCC Fifth Assessment Report.
   - Used Representative Concentration Pathway (RCP) scenarios: 2.6, 4.5, 6.0, 8.5.

3. Drove the Moore et al. (2014) Lyme onset model with the downscaled global climate model simulations to project changes in Lyme onset week for 2 periods:
   - 2025-2040.
   - 2065-2080.

Monaghan et al. (2015, submitted to TTBD)

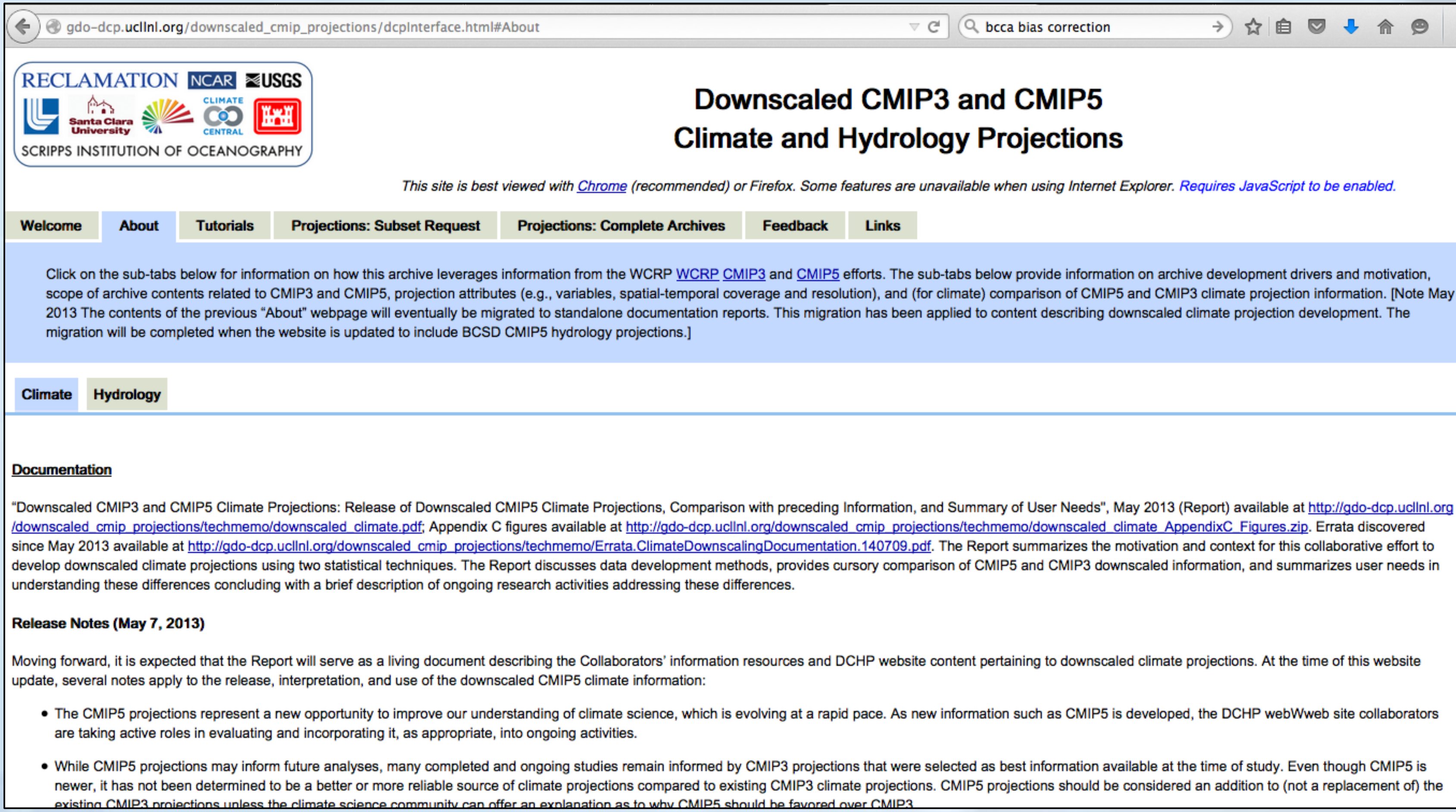
Global model projections of future climate





www.globalchange.umich.edu; Knutti and Sedlacek (2013; Nature Climate Change)

Downscaled Global Model Projections



gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html#About

bcca bias correction

RECLAMATION NCAR USGS

Santa Clara University

CLIMATE CENTRAL

SCRIPPS INSTITUTION OF OCEANOGRAPHY

Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections

This site is best viewed with Chrome (recommended) or Firefox. Some features are unavailable when using Internet Explorer. Requires JavaScript to be enabled.

Welcome | About | Tutorials | Projections: Subset Request | Projections: Complete Archives | Feedback | Links

Click on the sub-tabs below for information on how this archive leverages information from the WCRP WCRP CMIP3 and CMIP5 efforts. The sub-tabs below provide information on archive development drivers and motivation, scope of archive contents related to CMIP3 and CMIP5, projection attributes (e.g., variables, spatial-temporal coverage and resolution), and (for climate) comparison of CMIP5 and CMIP3 climate projection information. [Note May 2013 The contents of the previous "About" webpage will eventually be migrated to standalone documentation reports. This migration has been applied to content describing downscaled climate projection development. The migration will be completed when the website is updated to include BCSD CMIP5 hydrology projections.]

Climate | Hydrology

Documentation

"Downscaled CMIP3 and CMIP5 Climate Projections: Release of Downscaled CMIP5 Climate Projections, Comparison with preceding Information, and Summary of User Needs", May 2013 (Report) available at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/techmemo/downscaled_climate.pdf; Appendix C figures available at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/techmemo/downscaled_climate_AppendixC_Figures.zip. Errata discovered since May 2013 available at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/techmemo/Errata.ClimateDownscalingDocumentation.140709.pdf. The Report summarizes the motivation and context for this collaborative effort to develop downscaled climate projections using two statistical techniques. The Report discusses data development methods, provides cursory comparison of CMIP5 and CMIP3 downscaled information, and summarizes user needs in understanding these differences concluding with a brief description of ongoing research activities addressing these differences.

Release Notes (May 7, 2013)

Moving forward, it is expected that the Report will serve as a living document describing the Collaborators' information resources and DCHP website content pertaining to downscaled climate projections. At the time of this website update, several notes apply to the release, interpretation, and use of the downscaled CMIP5 climate information:

- The CMIP5 projections represent a new opportunity to improve our understanding of climate science, which is evolving at a rapid pace. As new information such as CMIP5 is developed, the DCHP webWweb site collaborators are taking active roles in evaluating and incorporating it, as appropriate, into ongoing activities.
- While CMIP5 projections may inform future analyses, many completed and ongoing studies remain informed by CMIP3 projections that were selected as best information available at the time of study. Even though CMIP5 is newer, it has not been determined to be a better or more reliable source of climate projections compared to existing CMIP3 climate projections. CMIP5 projections should be considered an addition to (not a replacement of) the existing CMIP3 projections unless the climate science community can offer an explanation as to why CMIP5 should be favored over CMIP3.

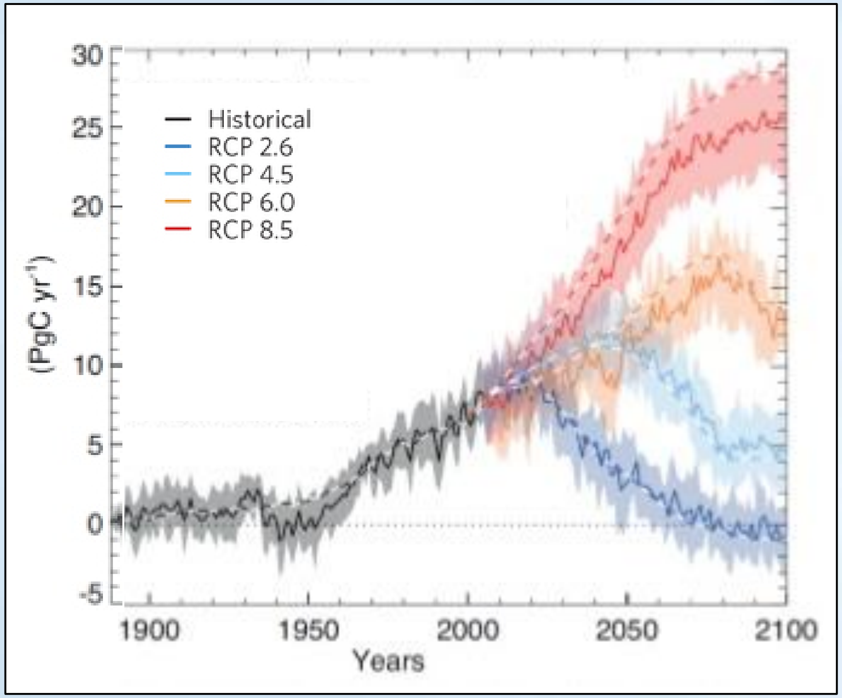
Other notable data sources: NASA DCP30 (1-km CONUS monthly) and NASA GDDP (Daily 25-km global)

The five models we used

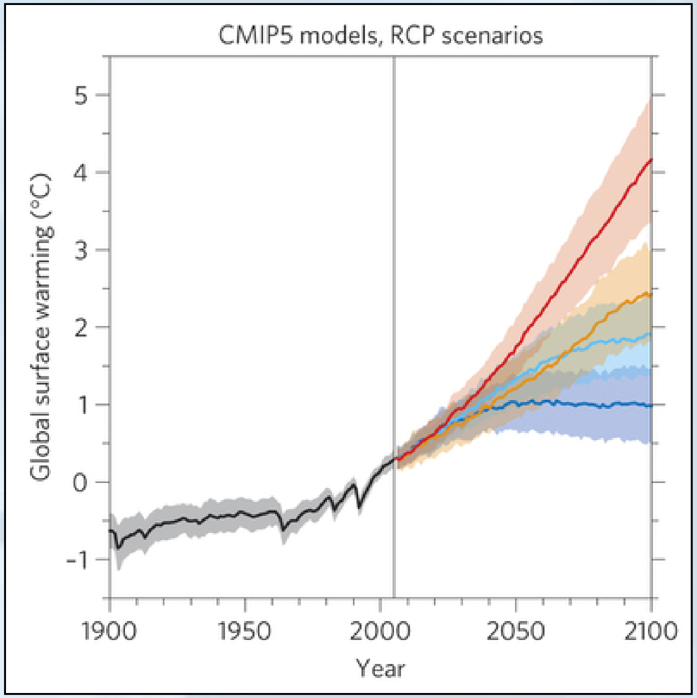
Modeling Center (or Group)	Institute ID	Model Name
Community Earth System Model Contributors	NSF-DOE-NCAR	CESM1(CAM5)
NOAA Geophysical Fluid Dynamics Laboratory	NOAA GFDL	GFDL-CM3
NASA Goddard Institute for Space Studies	NASA GISS	GISS-E2-R
Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	MOHC/INPE	HadGEM2-ES
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and	MIROC	MIROC5

The RCP Scenarios

Fossil Fuel Emissions



Global Average Warming



Knutti and Sedlacek (2012, N. Clim. Ch.), IPCC Fifth Assessment Rpt, WG1 (2013)

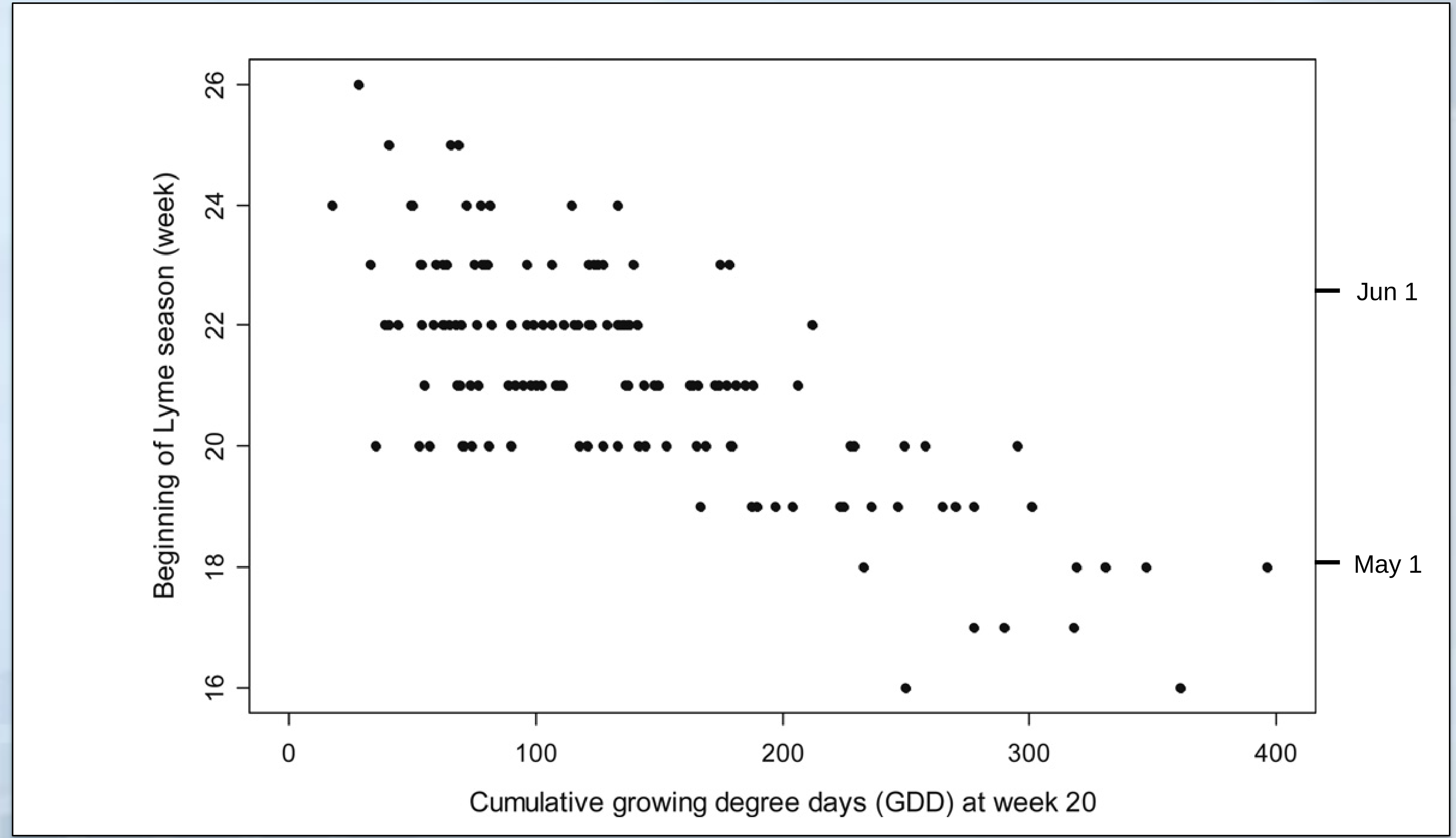
Model results of Moore et al. (2014)

Model parameters	Parameter estimates	95% Confidence interval
Week 20 cumul. GDD	–0.014	–0.016 to –0.011
Mean SD before onset	0.945	0.696–1.194
Cumul. precip. after Week 8	0.009	0.007–0.011
Distance to coastline	0.093	0.055–0.131

An earlier beginning to the Lyme disease season is associated with higher GDDs through week 20, higher humidity, lower rainfall, and proximity to the Atlantic coast.

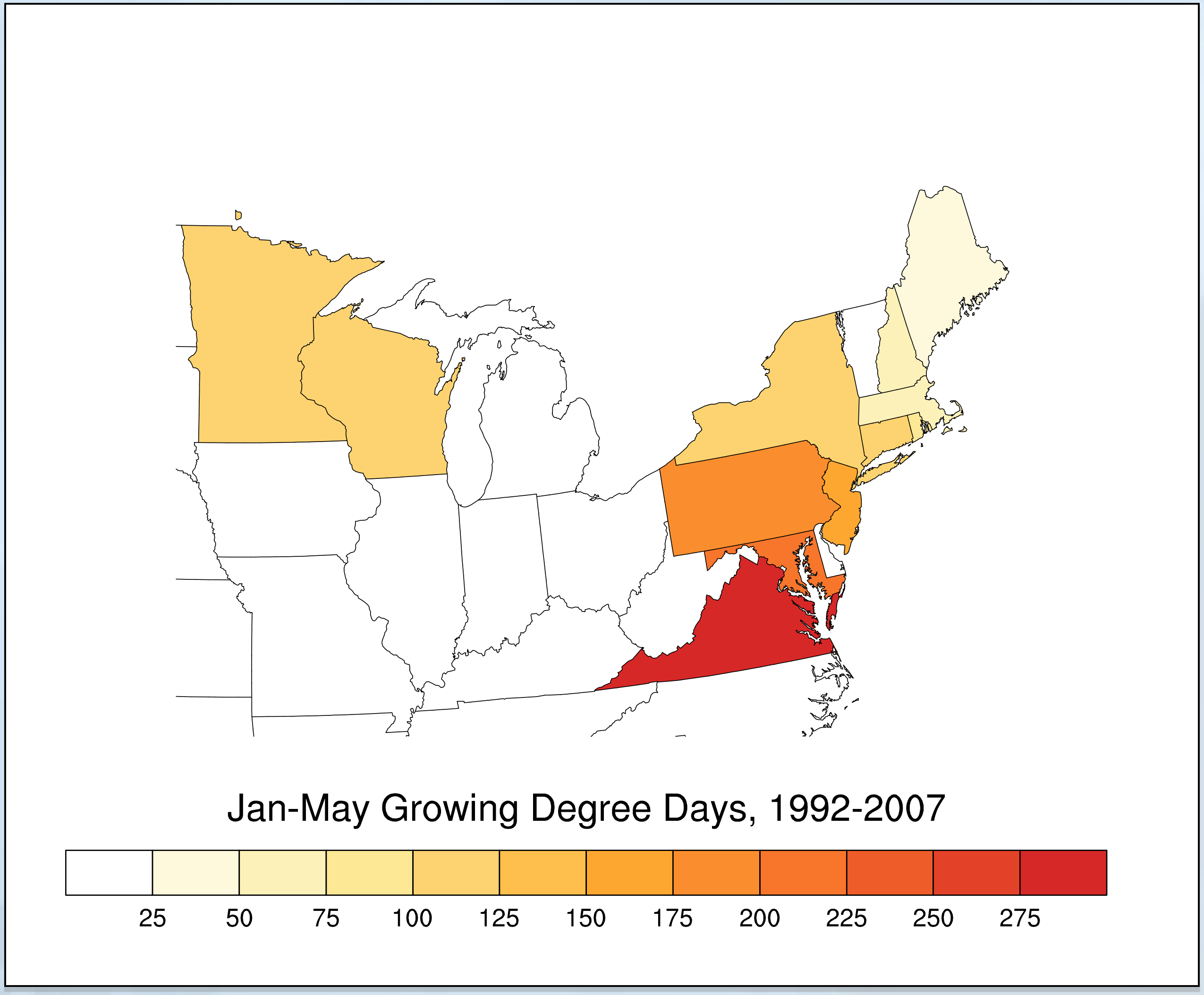
Moore et al. (2014, AJTMH)

Lyme disease onset versus cumulative growing degree days



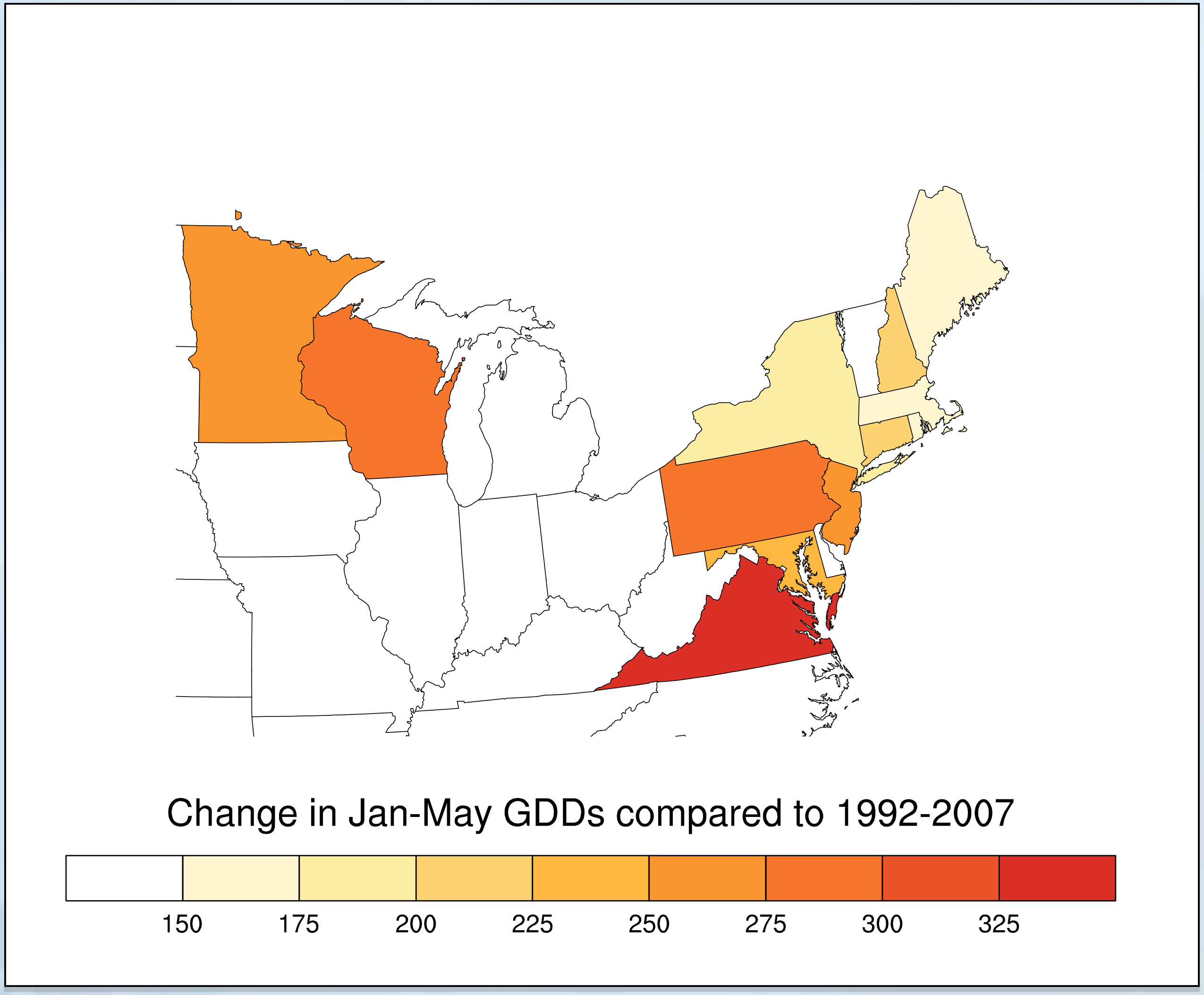
Moore et al. (2014, AJTMH)

Average Jan-May Growing Degree Days, 1992-2007



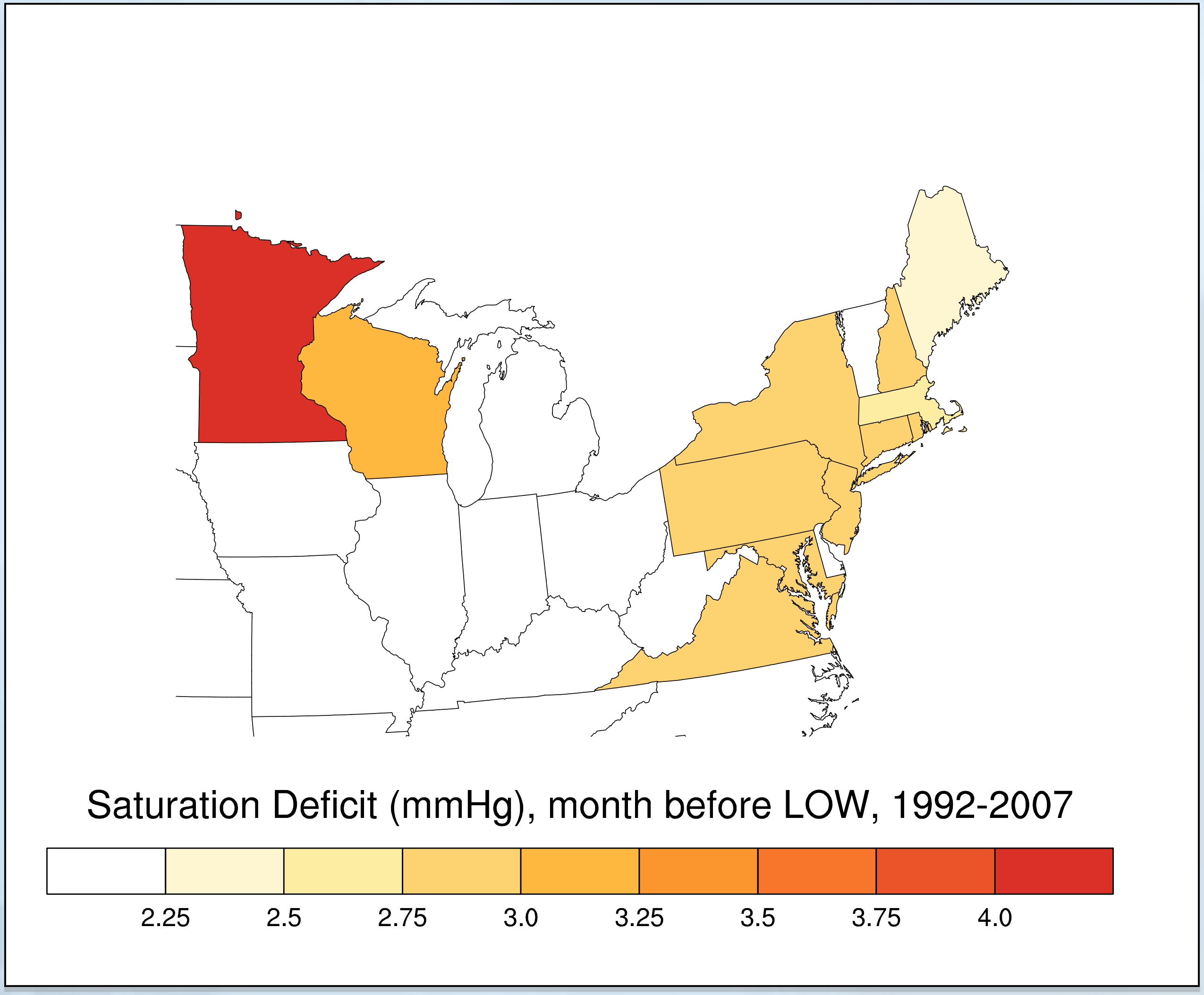
Monaghan et al. (2015, TTBD)

2065-2080 Change in Jan-May Growing Degree Days



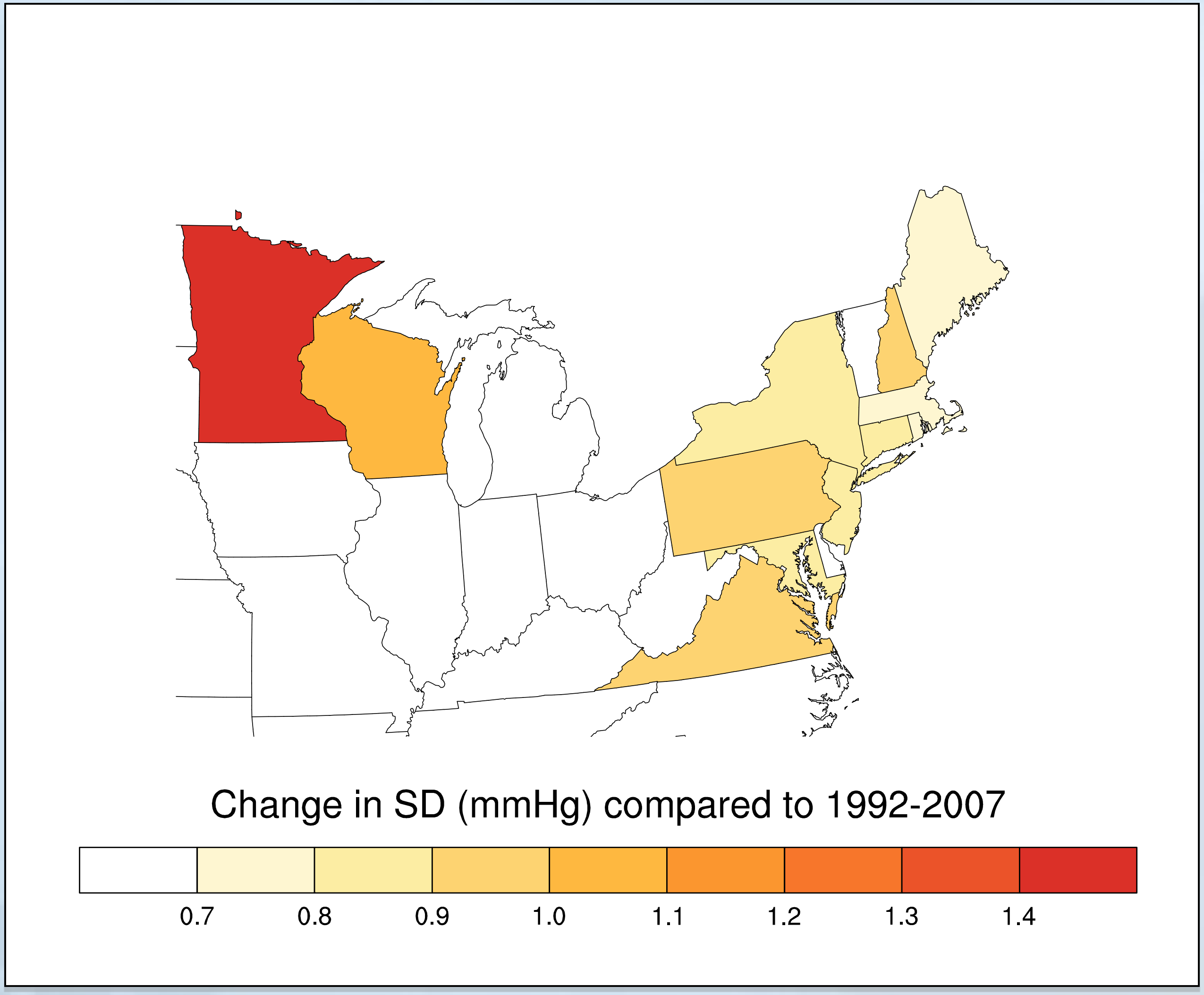
Monaghan et al. (2015, TTBD)

Average Saturation Deficit 1 month prior to LOW, 1992-2007



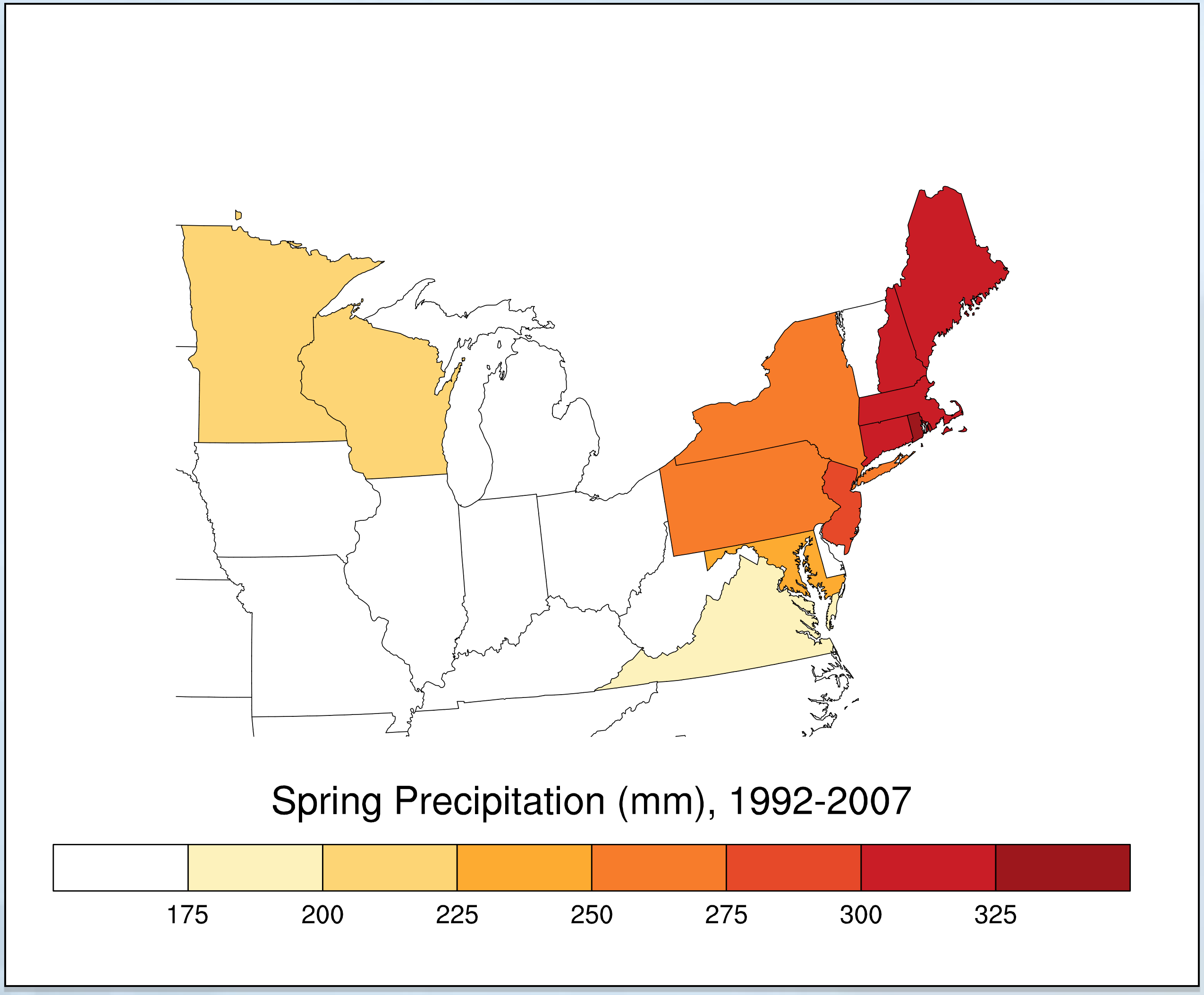
Monaghan et al. (2015, TTBD)

2065-2080 Change in Saturation Deficit 1 month prior to LOW



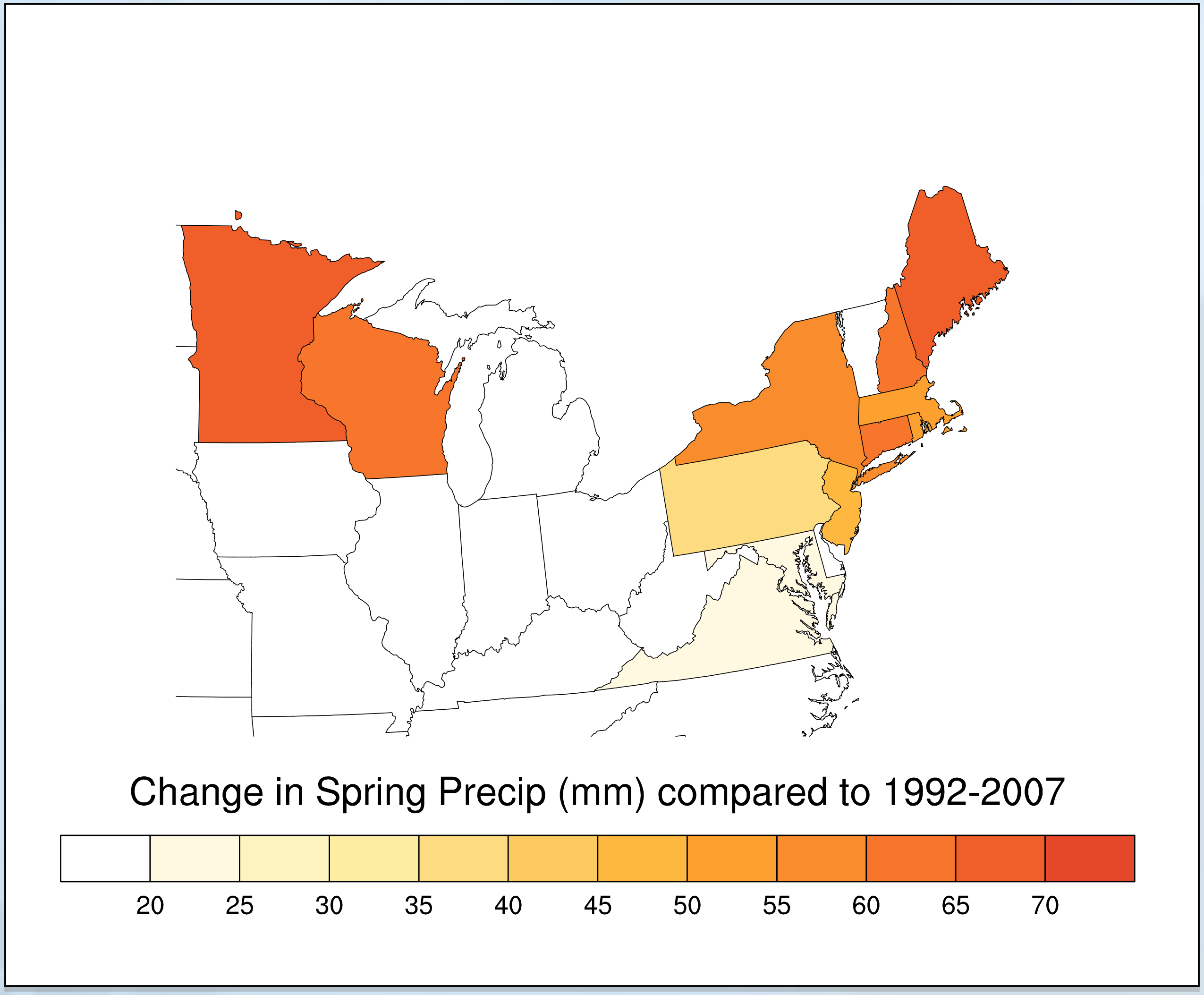
Monaghan et al. (2015, TTBD)

Average Spring Precipitation, 1992-2007



Monaghan et al. (2015, TTBD)

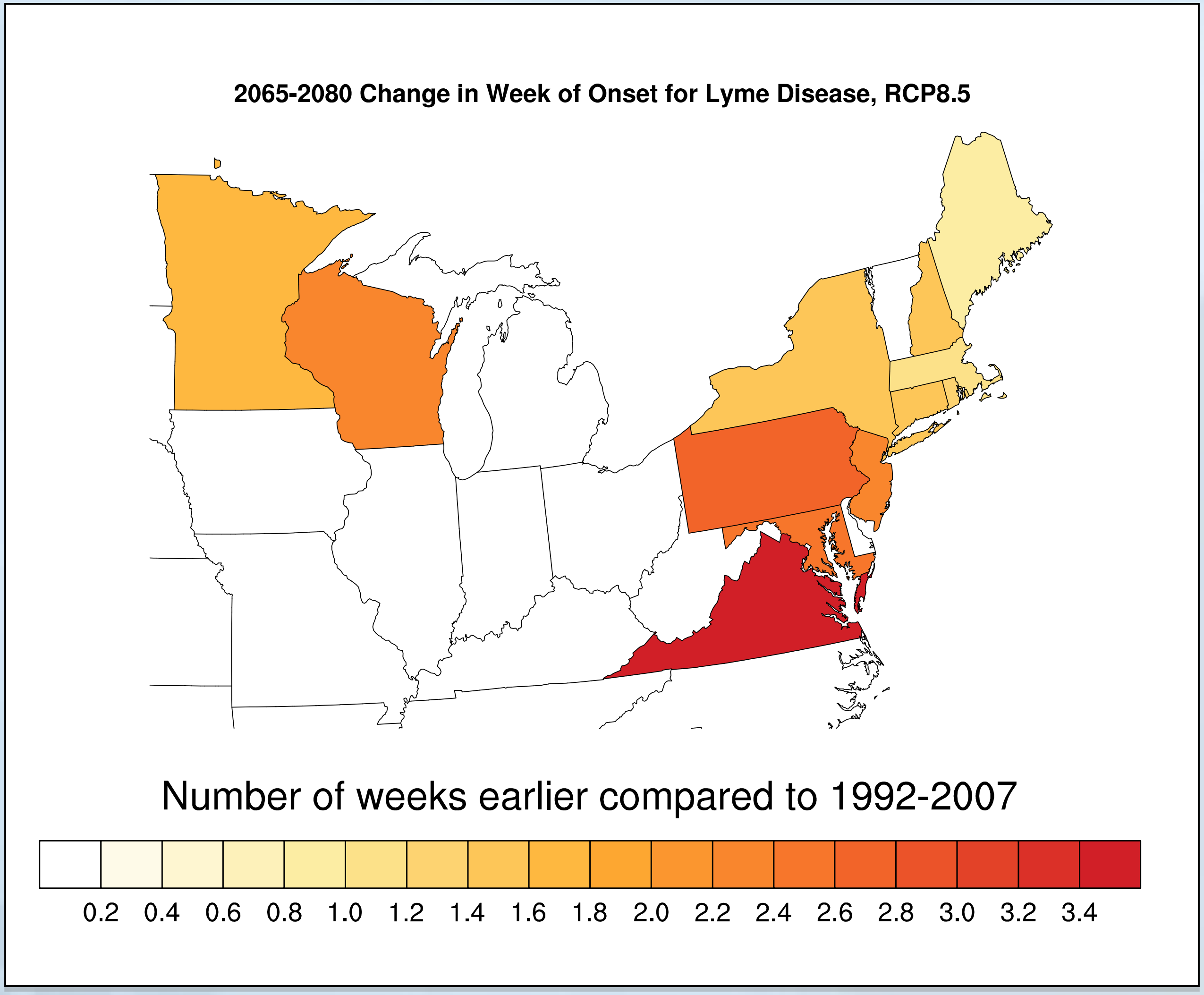
2065-2080 Change in Spring Precipitation



Monaghan et al. (2015, TTBD)

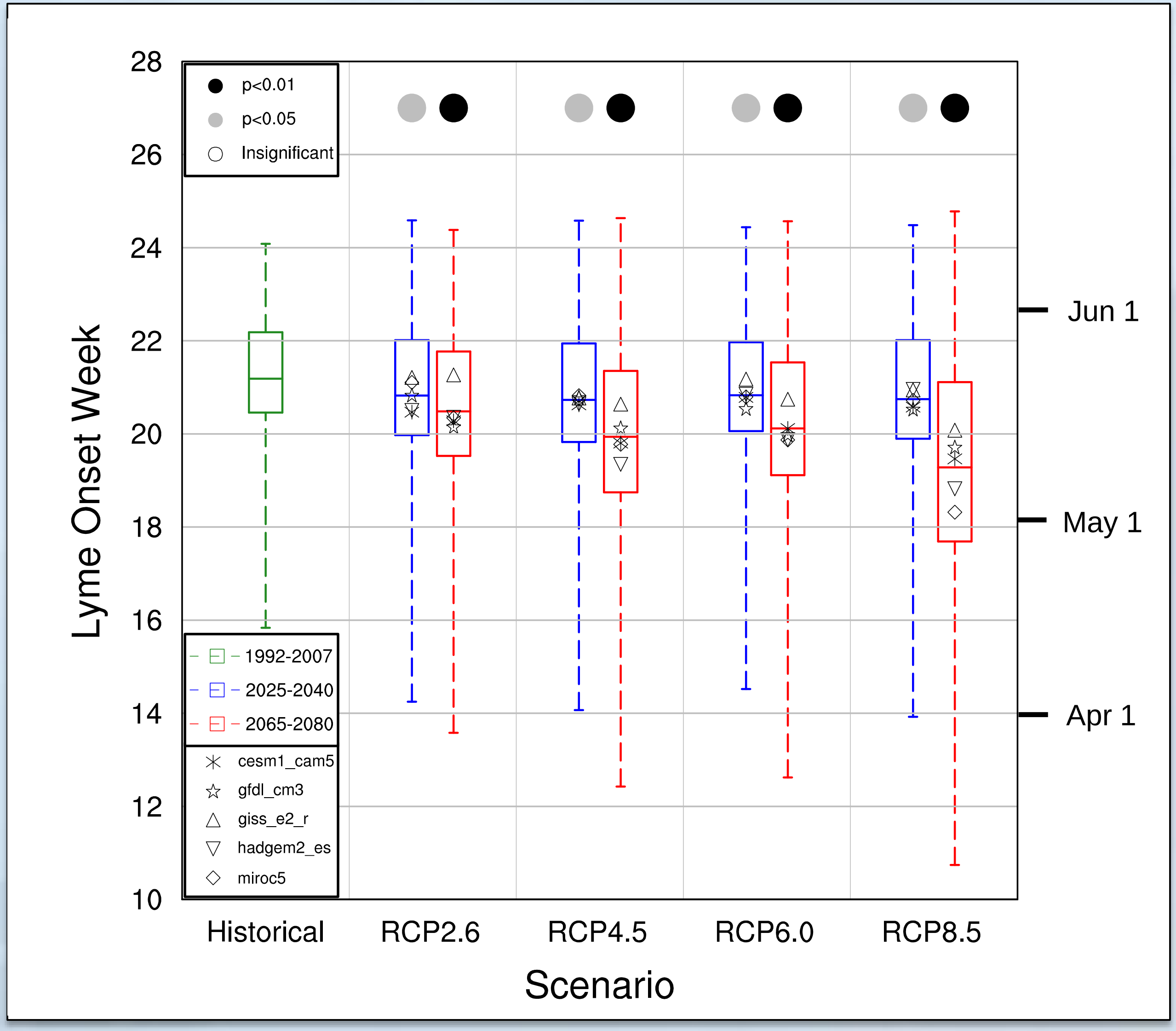
For my next slide....

Lyme Disease: Future Changes in Onset



Monaghan et al. (2015, TTBD)

Historical and future dates for Lyme onset week (all states)



Monaghan et al. (2015, submitted to TTBD)

Summary

- The national average annual onset week of Lyme disease is projected to become 0.4-0.5 weeks earlier for 2025-2040 ($p<0.05$), and 0.7-1.9 weeks earlier for 2065-2080 ($p<0.01$), with the largest shifts for scenarios with the highest greenhouse gas emissions.

- The more southerly mid-Atlantic States exhibit larger shifts compared to the Northeastern and upper Midwestern States.

- Winter and spring temperature increases primarily cause the earlier onset. Greater spring precipitation and changes in humidity partially counteract the temperature effects.

- The results suggest 21st century climate change will make environmental conditions suitable for earlier annual onset of Lyme disease cases in the United States with possible implications for the timing of public health interventions. Limitations….

- Contact: monaghan@ucar.edu

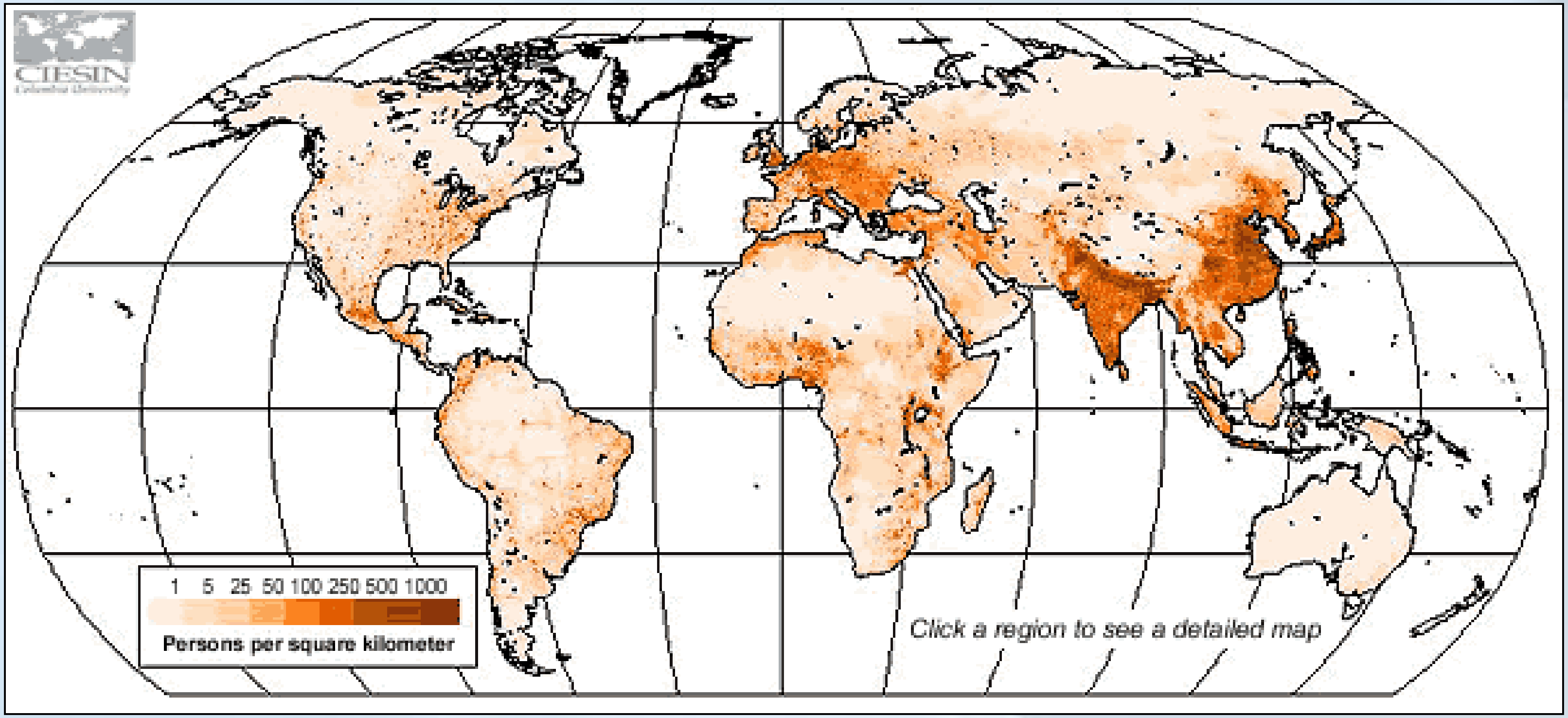
Works Cited:

Moore, S.M., R.J. Eisen, A.J. Monaghan, and P.S. Mead, 2014: Meteorological influences on the seasonality of Lyme Disease in the United States. *Am. J. Trop. Med. Hyg.*, 90, 486-496. doi:10.4269/ajtmh.13-0180.

Monaghan, A.J., S.M. Moore, K.M. Sampson, C.B. Beard, and R.J. Eisen, 2015: Climate change influences on the annual onset of Lyme disease in the United States. *Ticks and Tick-Borne Diseases*, 6, 615-622.

Extra Slides

Gridded global population estimates



- 7.5 arc minute (~15-km) global gridded population projections
- Available for each of the 5 Shared Socioeconomic Pathways (SSPs)
- Available for each decade from 2000-2100 (e.g., 2010, 2020, …2090, 2100)
- Contact Bryan Jones at CUNY/NCAR (bjones@ucar.edu)

Image courtesy of CIESIN, Columbia U.

Historical and future dates for Lyme onset week (each state)

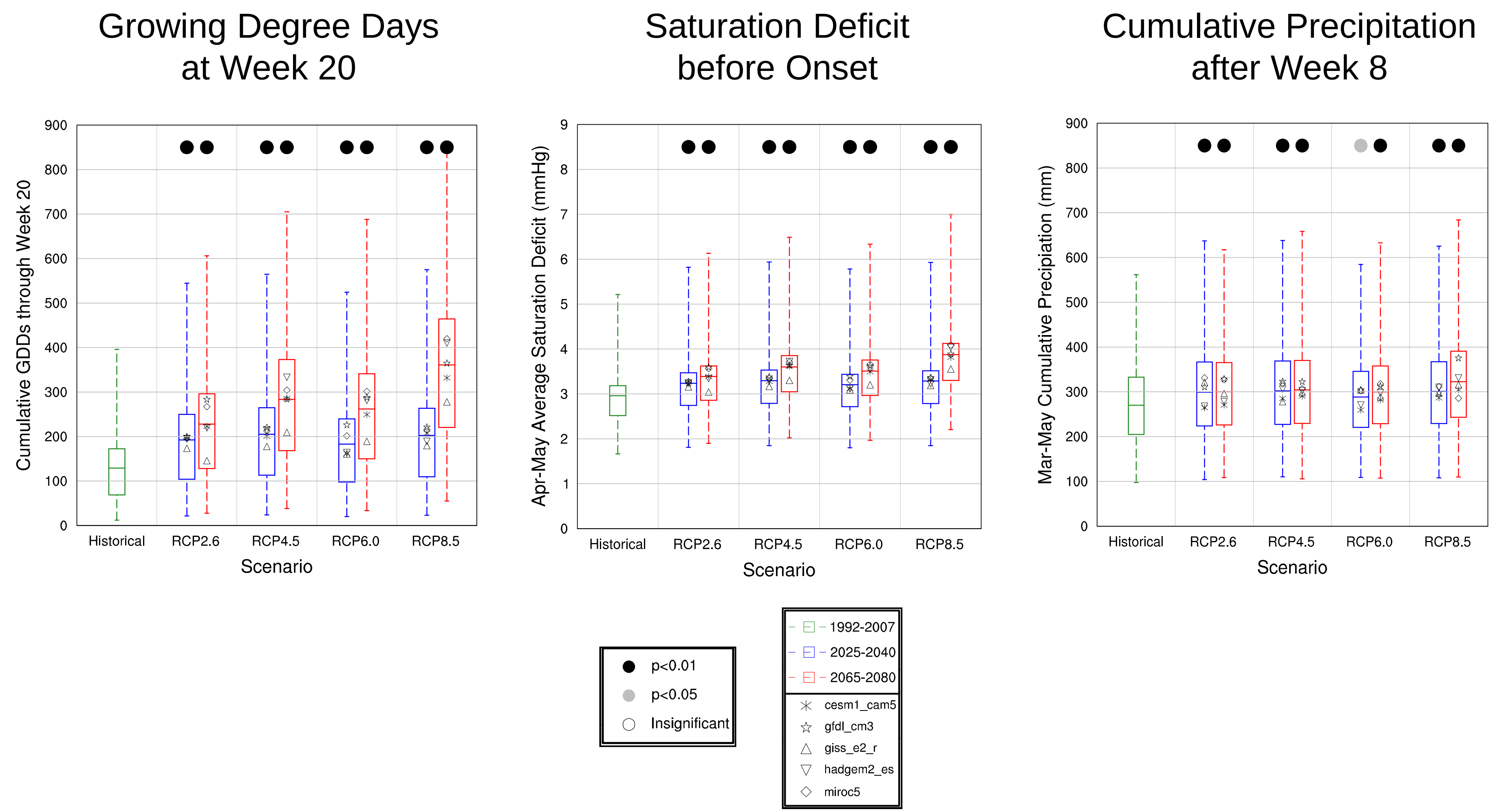
Table 1. The Baseline (1992-2007) Lyme Onset Week (LOW) and the future departure from the Baseline for the AOGCM multi-model mean LOW for 2025-2040 and 2065-2080 for each of the RCP scenarios.

REGION	STATE	LOW: 1992-2007 Baseline (Week-of-year)	ΔLOW: 2025-2040 minus 1992-2007 (Δ Weeks)				ΔLOW: 2065-2080 minus 1992-2007 (Δ Weeks)			
			RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
MIDWEST	MN	22.8 ± 0.8	-0.5	-0.5	-0.3	-0.4	-0.8	-1.3	-1	-1.8
	WI	21.9 ± 0.7	-0.6	-0.7	-0.3	-0.6	-1	-1.5	-1.2	-2.3
NORTH	ME	22.0 ± 0.9	0.1	0	-0.1	0	-0.2	-0.4	-0.3	-0.9
	MA	22.0 ± 0.6	-0.1	-0.1	-0.3	-0.1	-0.3	-0.7	-0.6	-1.1
	NH	22.2 ± 0.8	-0.1	-0.2	-0.3	-0.2	-0.5	-0.9	-0.8	-1.5
EAST	CT	21.7 ± 0.7	-0.1	-0.2	-0.2	-0.2	-0.4	-1	-0.8	-1.5
	RI	21.9 ± 0.6	-0.1	-0.2	-0.2	-0.1	-0.3	-0.8	-0.7	-1.3
	NJ	20.7 ± 0.9	-0.4	-0.6	-0.4	-0.6	-0.8	-1.5	-1.3	-2.3
	NY	21.3 ± 0.8	-0.2	-0.3	-0.2	-0.2	-0.5	-1	-0.8	-1.5
	PA	20.2 ± 0.9	-0.7	-0.8	-0.6	-0.8	-1.1	-1.9	-1.7	-2.8
MID-ATL	MD	19.2 ± 1.2	-0.6	-0.6	-0.4	-0.7	-1	-1.6	-1.5	-2.5
	VA	18.2 ± 1.0	-1.1	-1.1	-0.8	-1.3	-1.5	-2.3	-2.2	-3.5
NATIONAL	--	21.2 ± 0.8	-0.4	-0.5	-0.4	-0.4	-0.7	-1.2	-1.1	-1.9

*Future values with statistically significant change ($p<0.05$) compared to 1992-2007 are underlined.

Monaghan et al. (2015, submitted to TTBD)

Historical and future values of meteorological variables (all states)



Monaghan et al. (2015, submitted to TTBD)

Table 2. State- and national-level historical (1992-2007) mean ± standard deviation for LOW and associated climate variables. DIST is included for completeness.

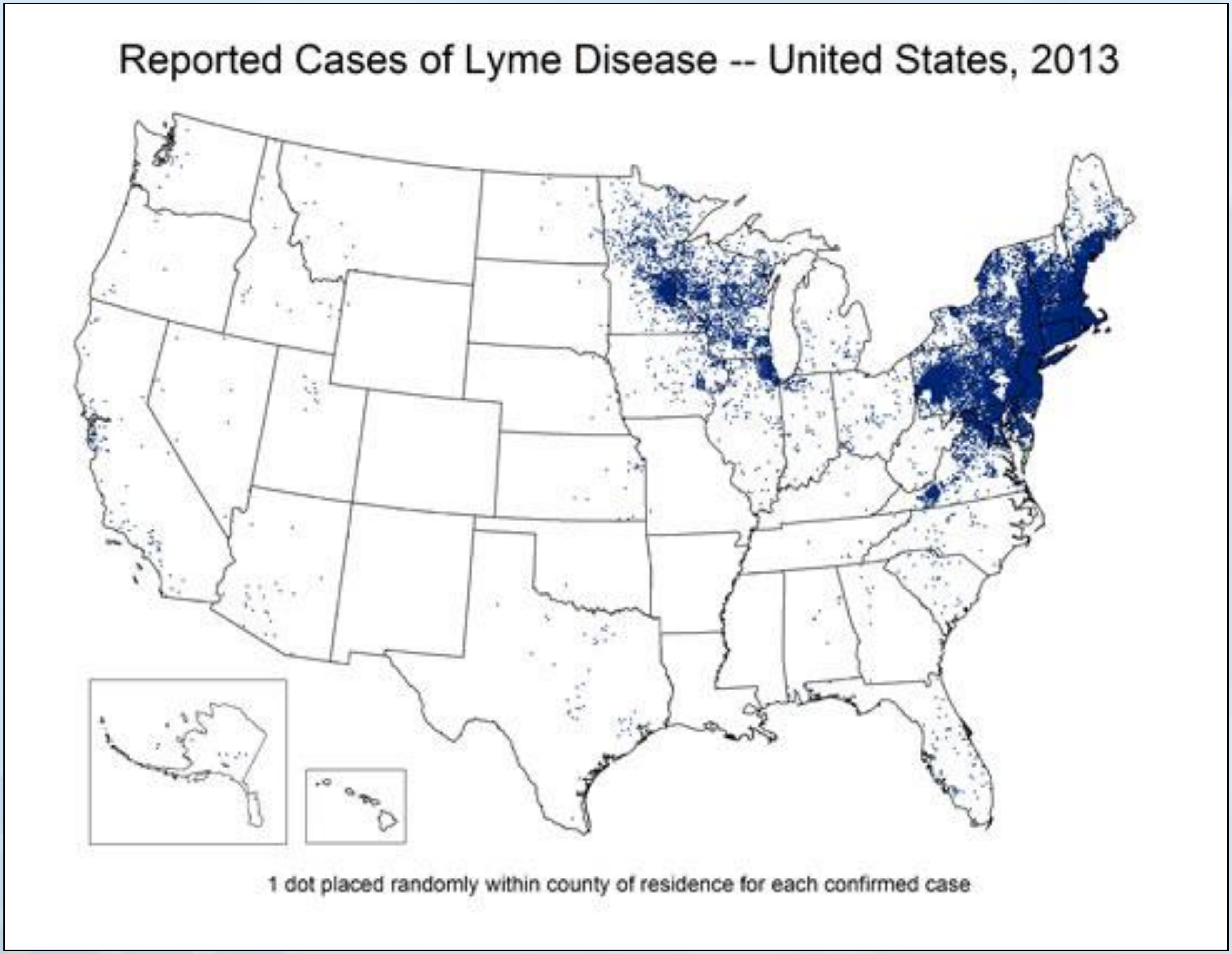
REGION	STATE	LOW (Weeks)	$T_{JAN-MAY}$ (^oC)	GDD_{W20} (GDDs)	SD_{M5} (mmHg)	$PRCP_{AW8}$ (mm)	DIST (deg)
MIDWEST	MN	22.8 ± 0.8	0.1 ± 1.8	120 ± 51	4.2 ± 0.5	207 ± 61	11.45
	WI	21.9 ± 0.7	0.5 ± 1.7	106 ± 46	3.1 ± 0.5	205 ± 41	11.72
NORTH	ME	22.0 ± 0.9	1.8 ± 1.2	44 ± 27	2.3 ± 0.5	323 ± 96	0.18
	MA	22.0 ± 0.6	4.3 ± 1.1	75 ± 31	2.7 ± 0.4	322 ± 61	0.31
	NH	22.2 ± 0.8	2.6 ± 1.1	70 ± 36	2.8 ± 0.5	325 ± 83	0.60
EAST	CT	21.7 ± 0.7	4.6 ± 1.1	105 ± 35	3.0 ± 0.5	309 ± 58	0.34
	RI	21.9 ± 0.6	5.0 ± 1.0	89 ± 30	2.8 ± 0.4	330 ± 67	0.12
	NJ	20.7 ± 0.9	6.0 ± 1.1	154 ± 45	3.0 ± 0.5	276 ± 67	0.35
	NY	21.3 ± 0.8	4.8 ± 1.1	105 ± 37	2.8 ± 0.4	274 ± 60	0.54
	PA	20.2 ± 0.9	6.1 ± 1.2	176 ± 50	3.0 ± 0.4	252 ± 68	0.64
MID-ATL	MD	19.2 ± 1.2	8.3 ± 1.0	224 ± 57	2.9 ± 0.5	228 ± 77	0.06
	VA	18.2 ± 1.0	8.8 ± 1.0	281 ± 59	3.0 ± 0.6	189 ± 60	0.30
NATIONAL	--	21.2 ± 0.8	4.4 ± 1.2	129 ± 42	3.0 ± 0.5	270 ± 67	2.22

Table 4. As in Table 3, but for the RCP8.5 scenario.*

!!	!!	Change: 2065-2080 minus 1992-2007					Contribution of change to ΔLOW		
REGION	STATE	ΔLOW	$\Delta T_{JAN\text{-}MAY}$	ΔGDD_{W20}	ΔSD_{M5}	$\Delta PRCP_{AW8}$	of ΔGDD_{W20}	of ΔSD_{M5}	of $\Delta PRCP_{AW8}$
!!	!!	(Weeks)	(^{o}C)	(GDDs)	(mmHg)	(mm)	(Weeks)	(Weeks)	(Weeks)
MIDWEST	MN	-1.8	5.4	274	1.45	69	-3.8	1.4	0.6
	WI	-2.3	5.3	278	1.09	61	-3.9	1.0	0.6
NORTH	ME	-0.9	4.9	158	0.74	70	-2.2	0.7	0.6
	MA	-1.1	4.3	168	0.80	55	-2.4	0.8	0.5
	NH	-1.5	4.8	213	0.91	64	-3.0	0.9	0.6
EAST	CT	-1.5	4.2	205	0.87	65	-2.9	0.8	0.6
	RI	-1.3	3.9	175	0.73	55	-2.5	0.7	0.5
	NJ	-2.3	4.1	251	0.88	47	-3.5	0.8	0.4
	NY	-1.5	4.4	199	0.86	57	-2.8	0.8	0.5
	PA	-2.8	4.2	286	0.93	39	-4.0	0.9	0.4
MID-ATL	MD	-2.5	3.9	250	0.83	25	-3.5	0.8	0.2
	VA	-3.5	4.0	326	0.93	22	-4.6	0.9	0.2
NATIONAL	--	-1.9	4.4	232	0.92	53	-3.2	0.9	0.5

*Future values with statistically significant change ($p<0.05$) compared to 1992-2007 are underlined.

Observed Lyme Disease Cases, U.S.



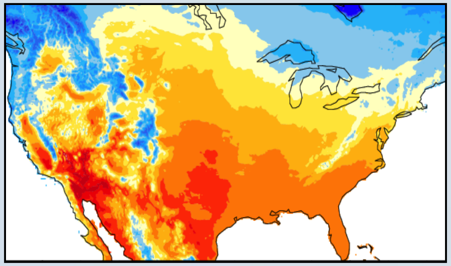
http://www.cdc.gov/lyme/stats/maps/map2013.html

Moore et al. (2014)

Objective: Identify the meteorological factors associated with the timing of the primary Lyme disease season, with the goal of using this knowledge to improve the timing of control and prevention efforts.

Methods

- Used county-level cases from 12 states with date-of-onset reported to the National Notifiable Disease Surveillance System between 1992-2007 (N = 195,765). Physician-diagnosed (from rash) or laboratory-confirmed (*B. burgdorferi* infection)
- Calculated timing of annual onset, peak and cessation of LD cases for each state. Results for onset are shown here
- Defined week-of-onset of LD season as the week in which case increases accelerated at their most rapid pace



- Used weekly temperature (max/min/mean), rainfall (cumulative), growing degree days (mean and cumulative) and humidity variables from the NASA North American Land Data Assimilation System (NLDAS)
- Generalized linear mixed-effects regression modeling (GLMM) was used to fit the meteorological models of annual Lyme disease onset for an overall model (all 12 states) and four regional models. Overall model results are shown here.

Moore et al. (2014, AJTMH)

Model results of Moore et al. (2014)

TABLE 4

Best fit models with the beginning week of the Lyme disease season as the response variable*

Model	Number of parameters	Adj. R^2	AIC	ΔAIC	Model parameters	Parameter estimates	95% Confidence interval
1	4	0.785	368.4	0	Week 20 cumul. GDD	–0.014	–0.016 to –0.011
					Mean SD before onset	0.945	0.696–1.194
					Cumul. precip. after Week 8	0.009	0.007–0.011
					Distance to coastline	0.093	0.055–0.131
2	4	0.784	369.4	1.0	Week 20 cumul. GDD	–0.014	–0.016 to –0.012
					Mean SD before onset	0.932	0.683–1.181
					Cumul. precip. after Week 8	0.009	0.008–0.011
					Longitude	–0.052	–0.090 to –0.014
3	4	0.773	376.7	8.3	Weeks to 150 GDD	0.530	0.445–0.614
					Mean SD before onset	1.062	0.801–1.322
					Cumul. precip. after Week 8	0.010	0.008–0.012
					Distance to coastline	0.098	0.059–0.137
4	4	0.772	377.3	8.9	Weeks to 150 GDD	0.568	0.487–0.648
					Mean SD before onset	1.055	0.792–1.318
					Cumul. precip. after Week 8	0.010	0.008–0.012
					Longitude	–0.056	–0.078 to –0.033

*Number of model parameters, model adjusted r^2, AIC, and ΔAIC values and parameter estimates with 95% confidence intervals for all models with ΔAIC < 10. ΔAIC represents the difference between a model's AIC value and the AIC value of the best fit overall model. Italicized parameters are not statistically different from 0 at α = 0.05 confidence level.

An earlier beginning to the Lyme disease season is associated with higher GDDs through week 20, higher humidity, lower rainfall, and proximity to the Atlantic coast.

Moore et al. (2014, AJTMH)