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Analysis of Changes in Location-Specific Extreme Precipitation Using an Ensemble of Global Climate Model Output from the Coupled Model Intercomparison Project, Phase 5 (CMIP5)

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Overview

- Climate models indicate that an increase in global mean temperature will lead to increased frequency and intensity of storms of a variety of types.
- Determine if rain gage data from Philadelphia International Airport indicates an increase in extreme precipitation over two thirty year periods.
- Compare the results of the statistical analysis of the observational data with results for the same period produced by CMIP5 global climate models
- Determine bias between historical and modeled data to forecast historical data into the future.

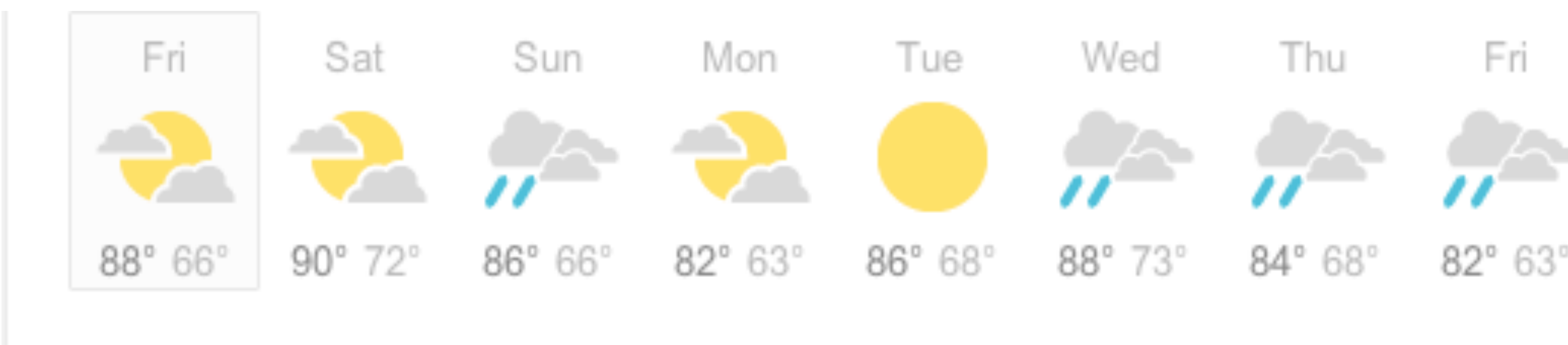
Procedure

- Two thirty year periods, 1956-1985 and 1976-2005, were used to determine if the there has been an increase in extreme precipitation events.
- Statistical models Generalized Extreme Value Theory (GEV), Log Pearson Type III (LP3), and General Pareto (GP) were used to analyze observational data and results from CMIP5 GCMs.
- Determine bias between observational and model data to forecast observational data into future

What Causes Rain?

Precipitation forms when water droplets in clouds grow and combine to become so large that their fall speed exceeds the updraft speed in the cloud, and they then fall out of the cloud[1]

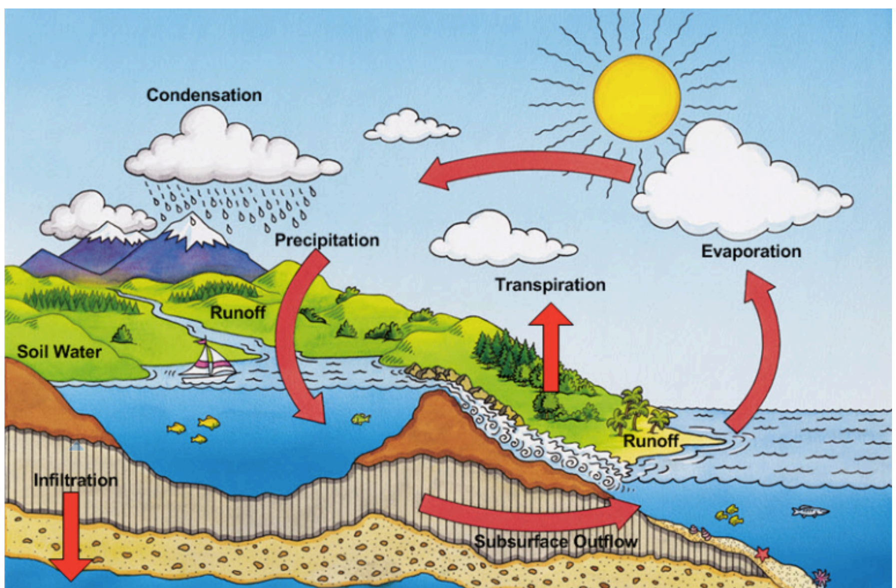
The more water vapor there is below the cloud , and the stronger the updrafts that cause this water vapor to condense into cloud water, the more likely it is that precipitation will form.[1]



What is Water Vapor?

- Water vapor is a gas and its pressure contributes to the total atmospheric pressure. The amount of water in the air is related directly to the partial pressure exerted by the water vapor in the air and is therefore a direct measure of the air water content.[1]

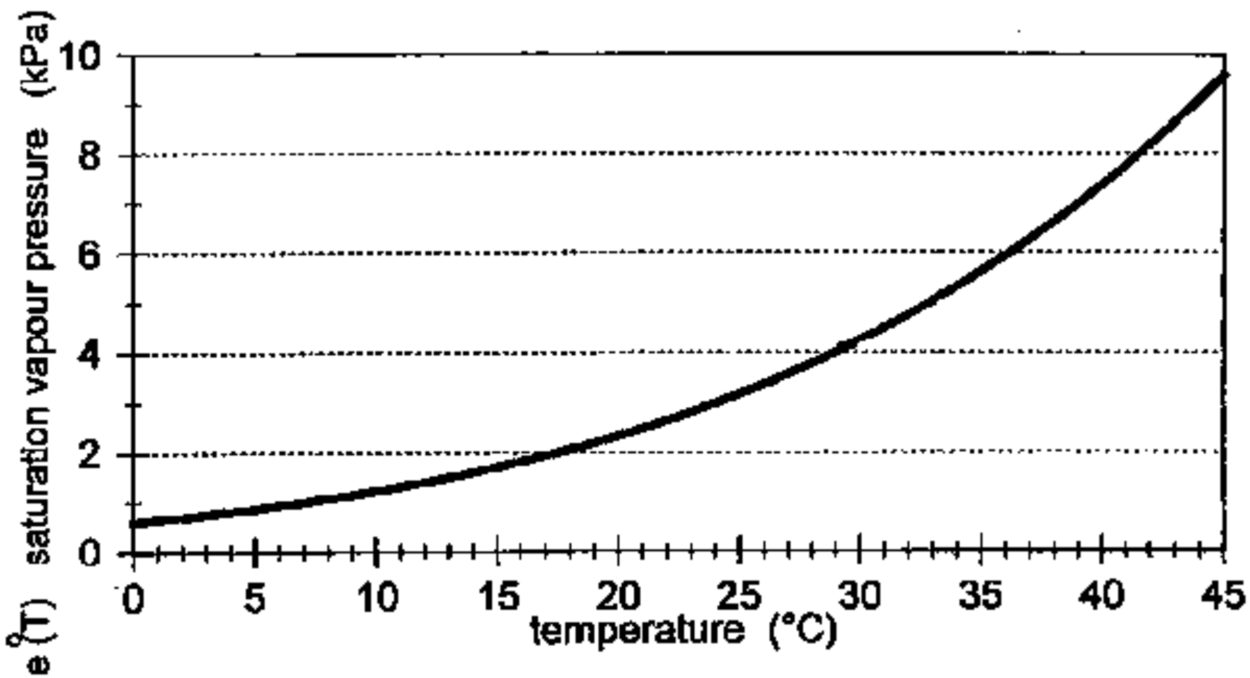
- All of the precipitation that falls originated as water vapor that was evaporated from the surface of the Earth.[1]



Higher Temperatures, More Water Vapor

- Water is more quickly evaporated with higher temperatures[2]
- $p = \rho RT$ Ideal Gas Law

FIGURE 11. Saturation vapour pressure shown as a function of temperature: e°(T) curve



Philly is getting Hot

- *Gao et al.*, 2012 show that Philadelphia, PA is expected to have increased heat wave intensity (°C), heat wave duration, and heat wave frequency.[3]

Table 2. Heat wave intensity, duration and frequency.

	Heat wave intensity (°C)			Heat wave duration (days/event)			Heat wave frequency (events/yr)		
Regions/states	Present	RCP 8.5	RCP 8.5—Present	Present	RCP 8.5	RCP 8.5—Present	Present	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

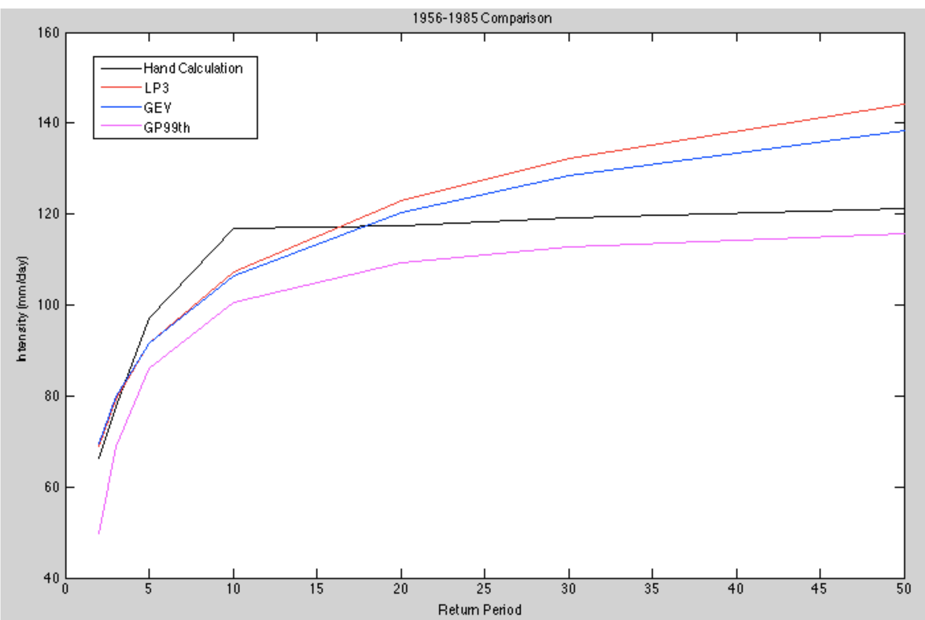
Statistics to Prove Increased Frequency of Extreme Precipitation

- I utilized three different right tailed statistical distributions to analyze frequency versus intensity of two thirty year periods.
- 1956-1985
- 1976-2005
- Generalized Extreme Value Theory (GEV) :: Annual Maxima
- Log Pearson Type III (LP3) :: Annual Maxima
- Generalized Pareto (GP) :: 99th Percentile

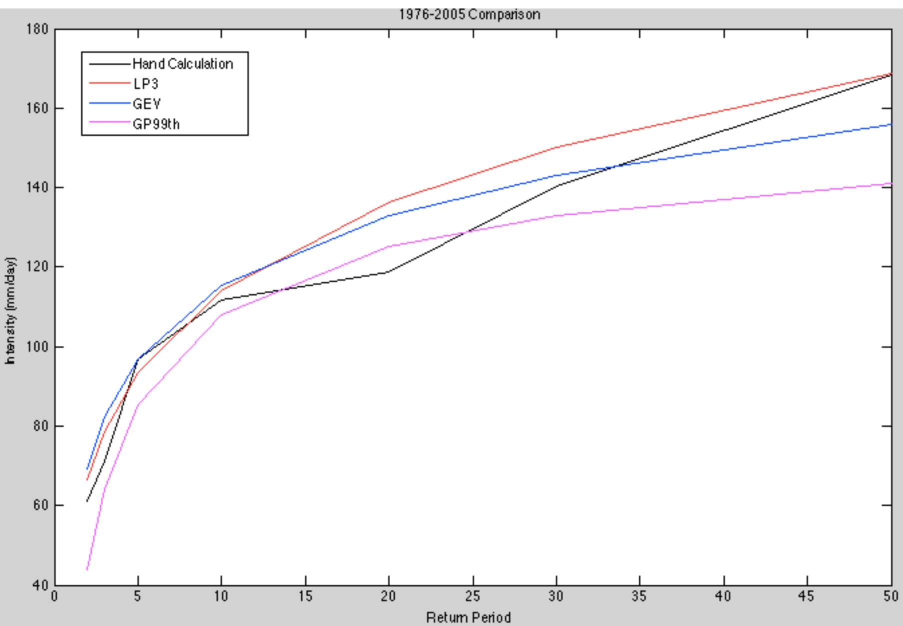
Which did the Best?

- LP3 overestimates extreme precipitation
- GP underestimates extreme precipitation
- For the use of water planning, it is best to consider the most extreme possibility, therefore LP3 is chosen for analysis purposes

1956-1981

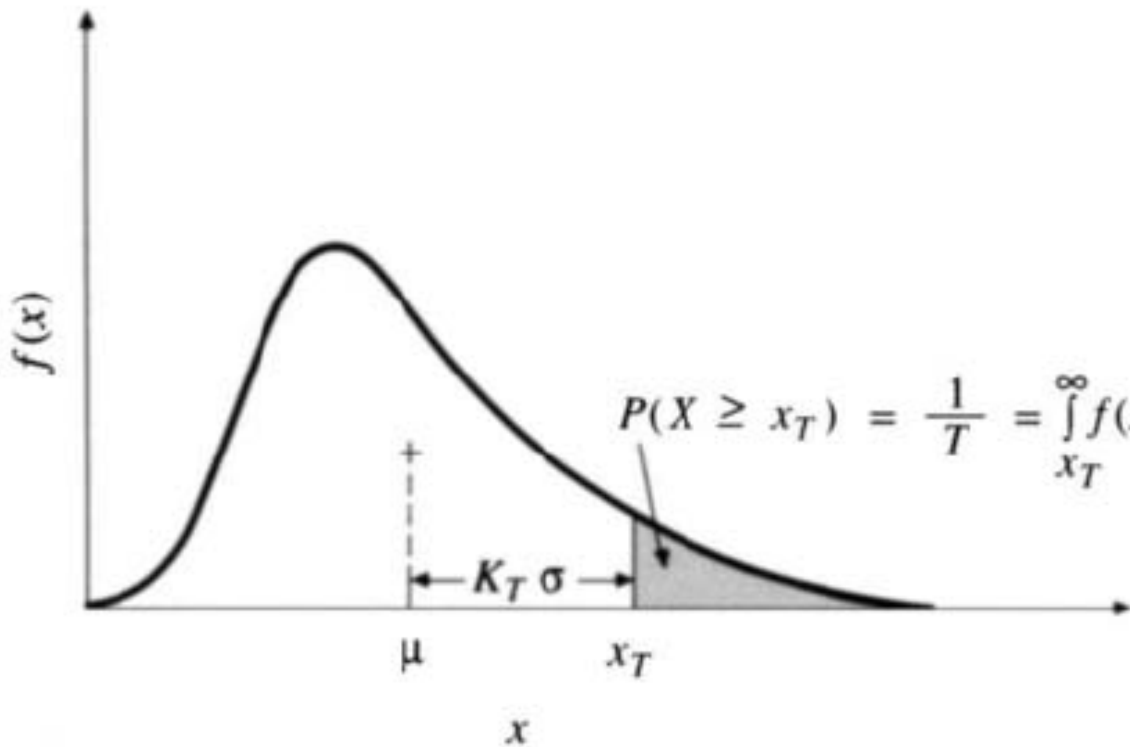


1976-2005



Log Pearson Type III[4]

- Variables
  - y_{bar} ,Mean
  - s_y, Standard Deviation
  - k, Kurtosis
  - Cs, Skew
  - K_T, Frequency Factor
  - Y_T , log value of data
  - X_T , Extreme Rainfall
  - T, Return Period



T: An estimate of how long it will be between rainfall events of a given magnitude.

Log Pearson Equation[4]

$$y = \log x$$

$$w = \left[\ln\left(\frac{1}{p^2}\right)\right]^2 \quad (0 < p \leq 0.5\ )$$

$$p = 1 - p \quad (p > 0.5)$$

$$z = w - \frac{2.515517 + 0.802853w + \ 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3}$$

$$K_T = z + (z^2 -1)k + 1/3(z^3 -6z)k^2 - (z^2 -1)k^3 + zk^4 + 1/3k^5$$

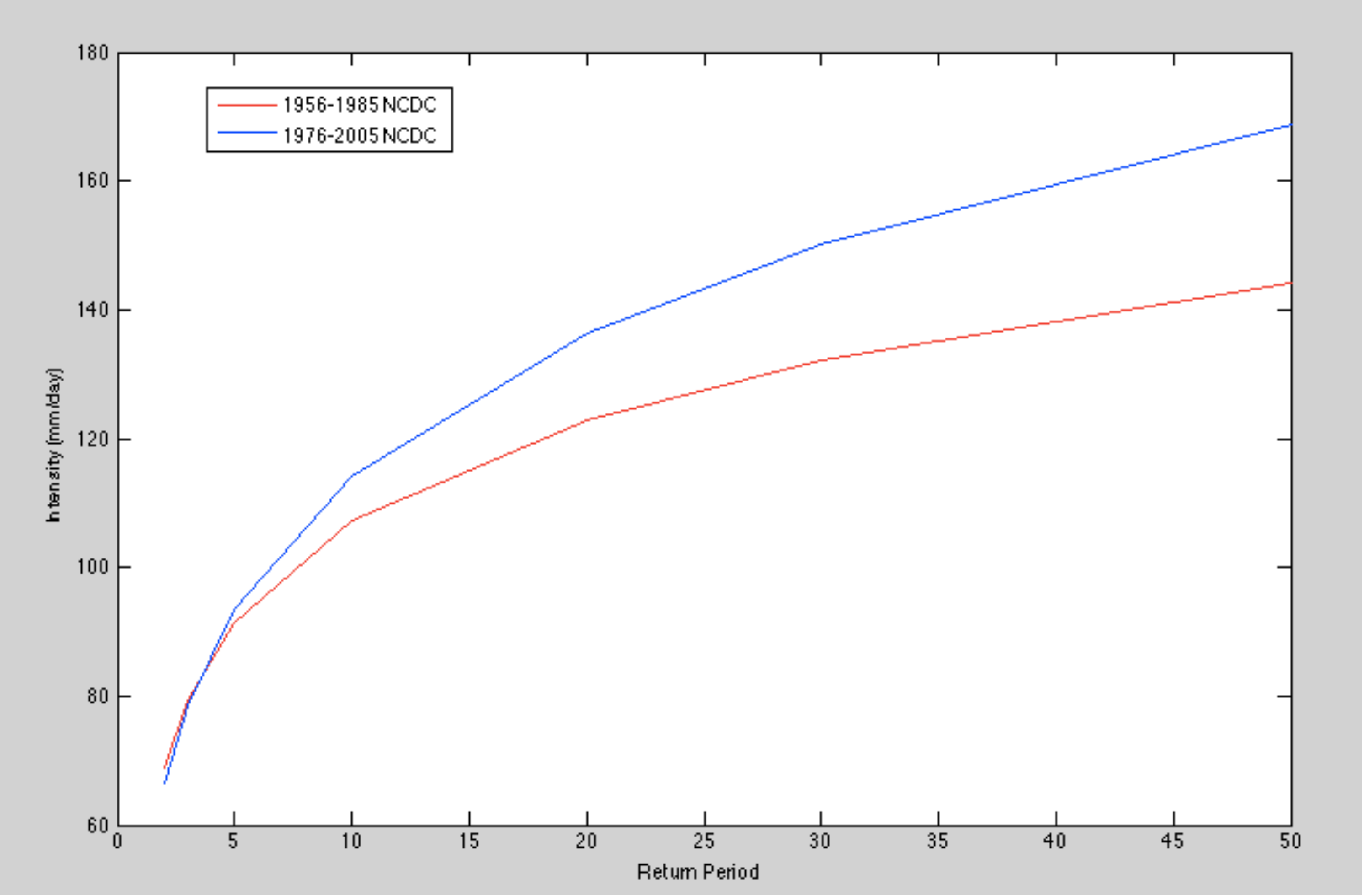
$$k = \frac{Cs}{6}$$

$$y_T = y_{bar} + K_T s_y$$

$$X_T = 10^{Y_T}$$

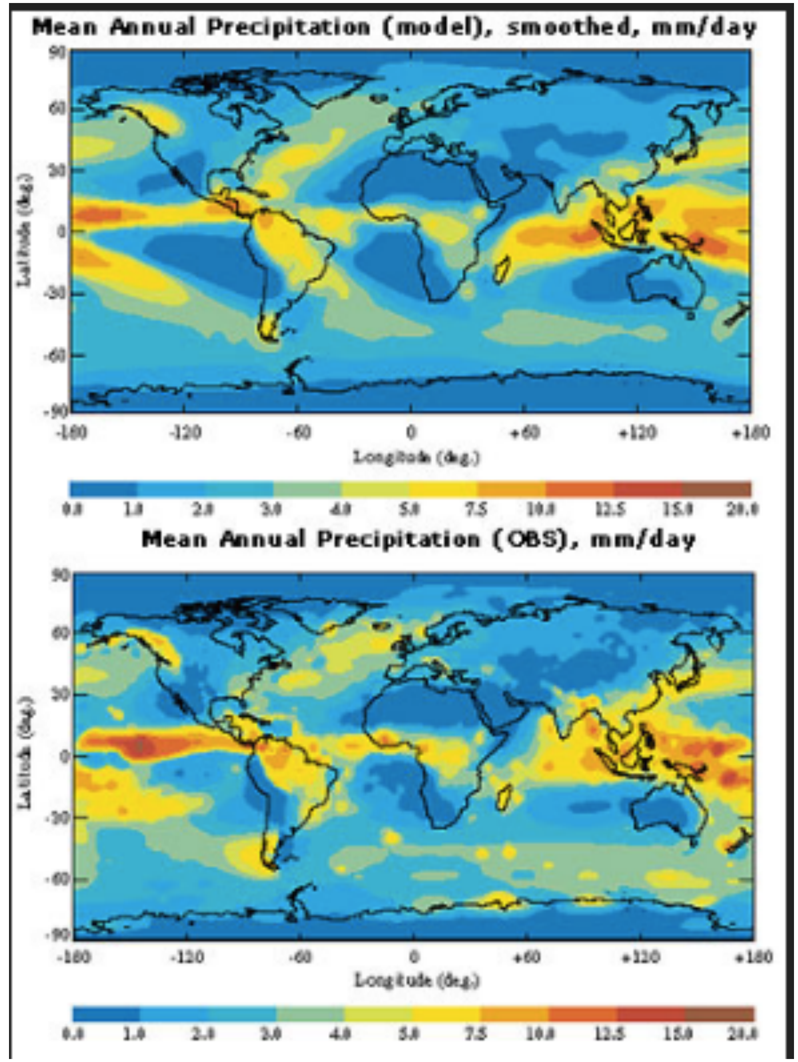
Log Pearson Type III Analysis

All figures created in Matlab



But I Want to Know the Future!

- Water planners need to know what will happen in the future to best plan water resources today
- Climate models are designed to forecast climate through climate physics, historical data, land characteristics, etc..
- Global Climate Models (GCMs) are lower resolution and create global climate forecasts



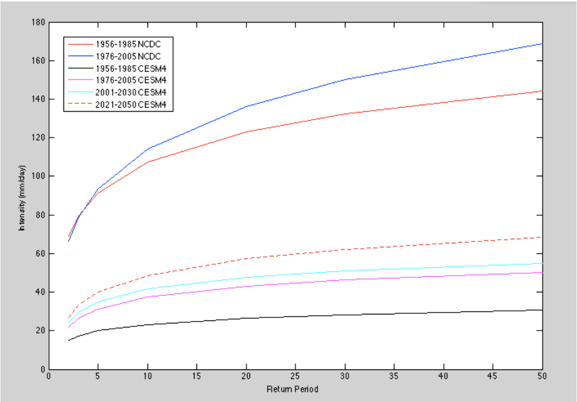
CMIP5 Global Climate Models

- Coupled Model Intercomparison Project Phase 5
- CMIP5 will notably provide a multi-model context for[5]
  - 1) assessing the mechanisms responsible for model differences in poorly understood feedbacks associated with the carbon cycle and with clouds
  - 2) examining climate "predictability" and exploring the ability of models to predict climate on decadal time scales, and, more generally
  - 3) determining why similarly forced models produce a range of responses.

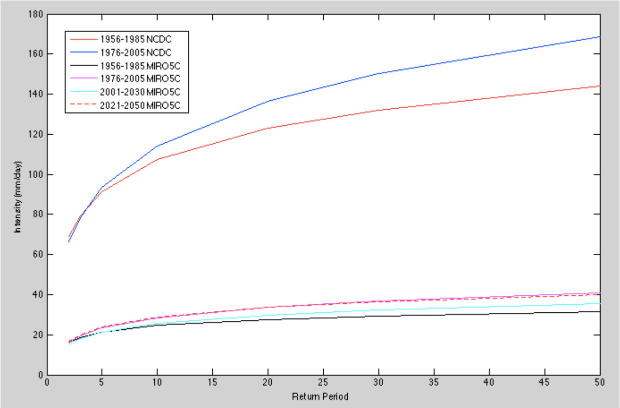
CMIP5 Models Used

- MRI-CGCM3
- MIROC5
- CCSM4
- All models greater than 1.5° Resolution
- Higher Resolution yields better accuracy

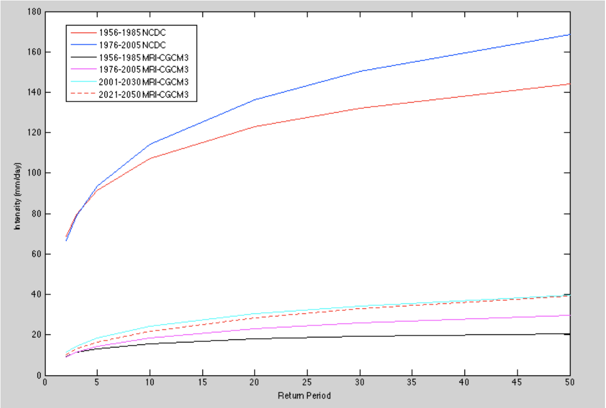
CCSM4



MIROC5



MRI-CGCM3



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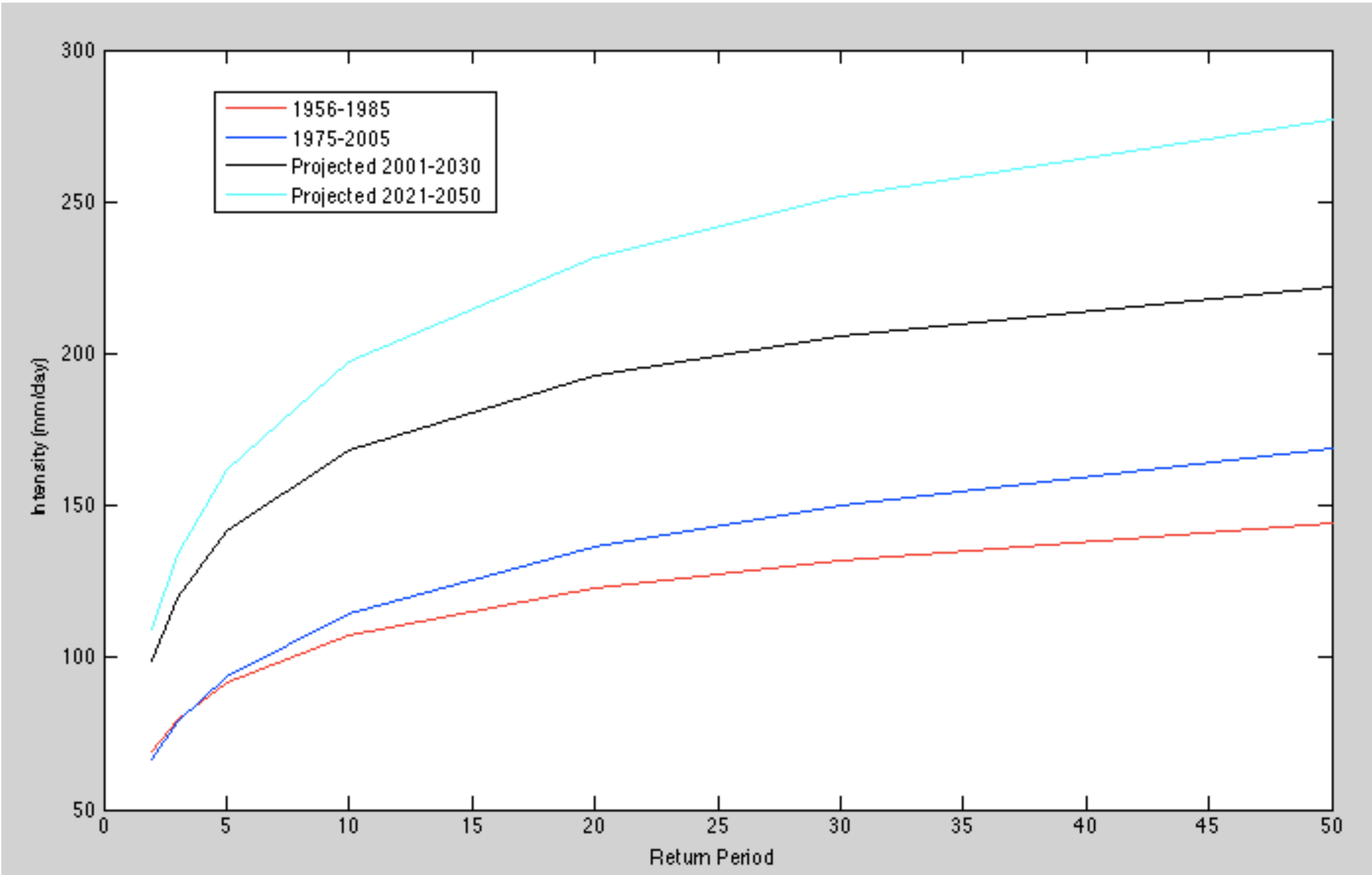
How To Use These Outputs?

"There is empirical evidence from various areas of numerical modeling that a multi-model average yields better prediction or compares more favorably to observations than a single model."[6]

	Model Bias						Bias Average
Return Year	Bias CCSM 56	Bias MRI 56	Bias MIRO 56	Bias CCSM 76	Bias MRI 76	Bias MIRO 76	CCSM+MIRO
2	4.562669143	7.35231621	4.239085957	3.03114591	7.300051648	4.106851635	3.984938161
3	4.570436045	7.081016432	4.24017787	2.977198216	6.891568696	4.040352032	3.957041041
5	4.589916144	6.923021027	4.275620918	2.982824354	6.539965135	4.010032067	3.964598371
10	4.624419322	6.85597171	4.352360423	3.058843548	6.20305945	4.014697865	4.01258029
20	4.664095742	6.877818886	4.447783344	3.164183816	5.954086446	4.049044768	4.081276917
30	4.688920424	6.916856379	4.509666501	3.24357587	5.834527399	4.07847259	4.130158846
50	4.721516789	6.9865106	4.592751022	3.356207577	5.703850835	4.12320856	4.198420987

4.05 Averaged Bias

Results


300
250
200
150
100
50
Intensity (mm/day)
0
5
10
15
20
25
30
35
40
45
50
Return Period
1956-1985
1975-2005
Projected 2001-2030
Projected 2021-2050

Conclusions

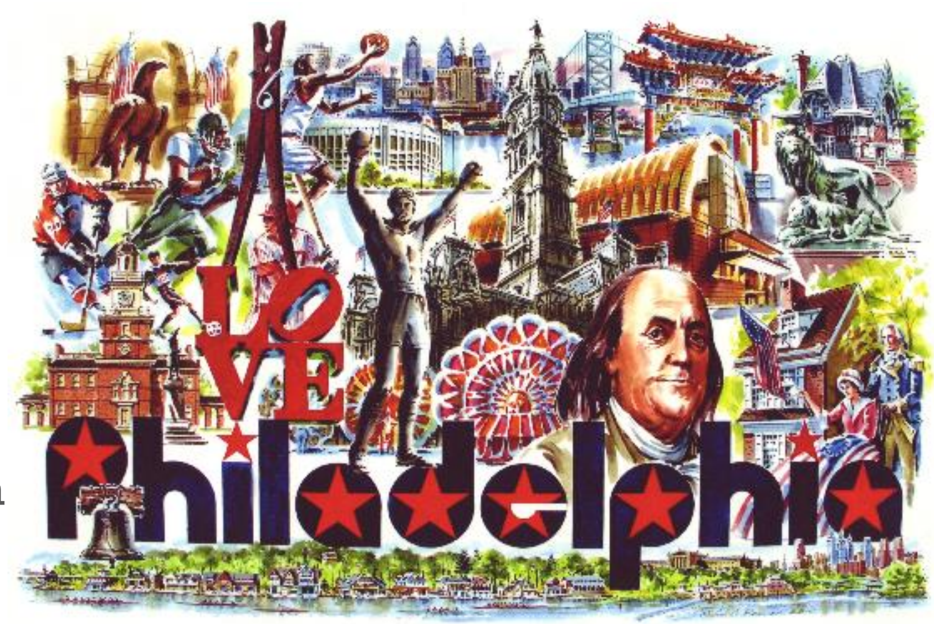
- Frequency of extreme precipitation increased during second thirty year period, 1976-2005
- GCMs severely underestimate extreme precipitation due to their low resolution
- CCSM4 and MIROC5 performed the best compared to historical data. MRI-CGCM3 performed the worst
- 4.05 averaged bias between historical data and GCM data
- As great as a 45% increase in intensity of extreme precipitation events

Future Work

- Since GCMs severely underestimate extreme precipitation, more accurate results will be generated through a higher resolution model, WRF Regional Climate Model

- Extreme Precipitation causes wastewater treatment plants to act quickly and allocate storage when large inflows surge into the system. We will determine if system will be adequate in the future.

- We will forecast extreme precipitation into the future using WRF for Philadelphia, Pennsylvania and analyze the future costs for Philadelphia Water Departments treatment of wastewater.



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- 1) http://www.weatherquestions.com/What_causes_precipitation.htm
- 2) http://www.fao.org/docrep/x0490e/x0490e07.htm
- 3) Gao, Y., J. S. Fu, Y. Liu, and J. F. Lamarque. "Projected Changes of Extreme Weather Events in the Eastern United States Based on a High Resolution Climate Modeling System." *Environmental Research Letter* (2012): n. pag. Print.
- 4) Chow, Ven Te, David R. Maidment, and Larry W. Mays. *Applied Hydrology*. New York: McGraw-Hill, 1988. Print.
- 5) http://cmip-pcmdi.llnl.gov/cmip5/index.html?submenuheader=0
- 6) Knutti, Reto, Reinhard Furrer, Claudia Tebaldi, Jan Cermak, and Gerald A. Meehl. "Challenges in Combining Projections from Multiple Climate Models." *Journal of Climate* 23.10 (2010): 2739-758. Print.