Modeling Precipitation in the Northeast United States

Lori Fomenko

Outline

- Objectives of this project
- Data sources and types of data used
- Models and Methodology
- Key Results
- Challenges
- Conclusions and Further Research

Objectives

- Are there significant differences between individual stations within cities and/or between individual stations and the citywide average?
- Do major cities like Boston and NYC get significantly more annual precipitation than the Northeast region or Tri-State area on average?
- How do GCMs compare to observations in representing historical annual precipitation amounts?
- Is annual precipitation expected to increase in the future under the current emission scenario (RCP 8.5)?
- How well are GCMs and RCMs able to capture individual events?

Source and Type of Data

- Land-based Station data from Global Historical Climatological Network Database for individual stations in NYC and BOS
  - Source: Mapping Tool for daily Precipitation available at https://gis.ncdc.noaa.gov/maps/ncei/cdo/daily
- Gridded surface meteorological observational dataset (MetData)
  - Source: (http://metdata.northwestknowledge.net/)
  - Key Details
    - Training data for downscaling GCM output to macav2-metdata product
    - 4 km (1/24 deg) spatial resolution, daily timescale
    - Bias-corrected mesoscale reanalysis and assimilation data
    - Validated against various station networks (RAWS,Agrimet,AgWeatherNet, and USHCN-2)

Models

- Macav2-Metdata product for downscaled GCM output
  - Historical runs (1991-2005) and future projections (2041-2060)
    - Models included for historical projections (1991-2005): CCSM4, CNRM-CR5, GFDL-ESM2M, HadGem2-ES365, MRI-CGCM3, NorESM1M,MIROC5,and MIROC-ESM
    - Model used for bias-corrected future projection: CCSM4, r6i1p1 ensemble used for MACA downscaling from (1.25 deg x 0.94 deg) to 4 km resolution
  - Source: MACA Data Portal (http://maca.northwestknowledge.net/data_portal.php)
- RCM output
  - RCM3 model run
    - Precipitation output from Atmospheric Model (ATM) and Land Surface Model (SRF)
    - NNRP2: NCEP reanalysis dataset used for ICBCs (2.5 degree grid resolution)
    - LAMCON Projection and 60 km grid spacing
    - Modeled over all study domains, but centered at clat = 42 and clon = -73

Methodology

- Domains

Area	Lat Bounds(min, max)	Lon Bounds (min, max)	RegCM B.C.s (lat,lon)
Northeast Region	37, 48	-79,-67	Same
Tri-State Area	38.7,43.5	-75.3,-70.3	Same
Boston	42.18,42.57	-71.19,-70.98	(41.9,42.9), (-71.6,-70.6)
NYC	40.47,40.94	-74.11,-73.68	(40.4,41.4), (-74.5,-73.5)

Methodology

- Objective 1
  - Select desired stations in BOS and NYC and download GHCN station data (1997-2016). Quality control of data, look for missing data (days, months, years, etc.). Choose stations with continuous data throughout period.
  - Determine matching grid cell in gridded MetData dataset, and average the precipitation values over that grid cell to get one representative point.
  - Compare GHCN station data with grid-averaged MetData at daily timescale, and isolate one year to compare trends at daily timescale. If MetData effectively captures observed precipitation, use MetData for comparison between stations.
  - Determine if any significant differences exist between individual stations and between individual stations and the city average across a grid containing all stations by conducting ANOVA analysis.

Methodology

- Objective 2
  - Define boundaries for all four study domains and find annual averages for each.
  - Plot annual average precipitation over 1991-2005 (same years as GCM runs)
  - Conduct ANOVA analysis between regions to determine if any differences between the means are significant
- Objective 3
  - Compare historical GCM runs output with MetData for 1991-2005, area-averaged annual precipitation with the same boundaries for each study domain
  - If no obvious correlation in interannual precipitation variability, choose one GCM for bias correction.
- Objective 4
  - Choose GCM (CCSM4) and correct bias based on difference between historical model projection and observed precipitation (1991-2005) for each domain
  - Plot historical GCM run and bias-corrected GCM output, and future model projection and future bias-corrected GCM projection (2041-2060)

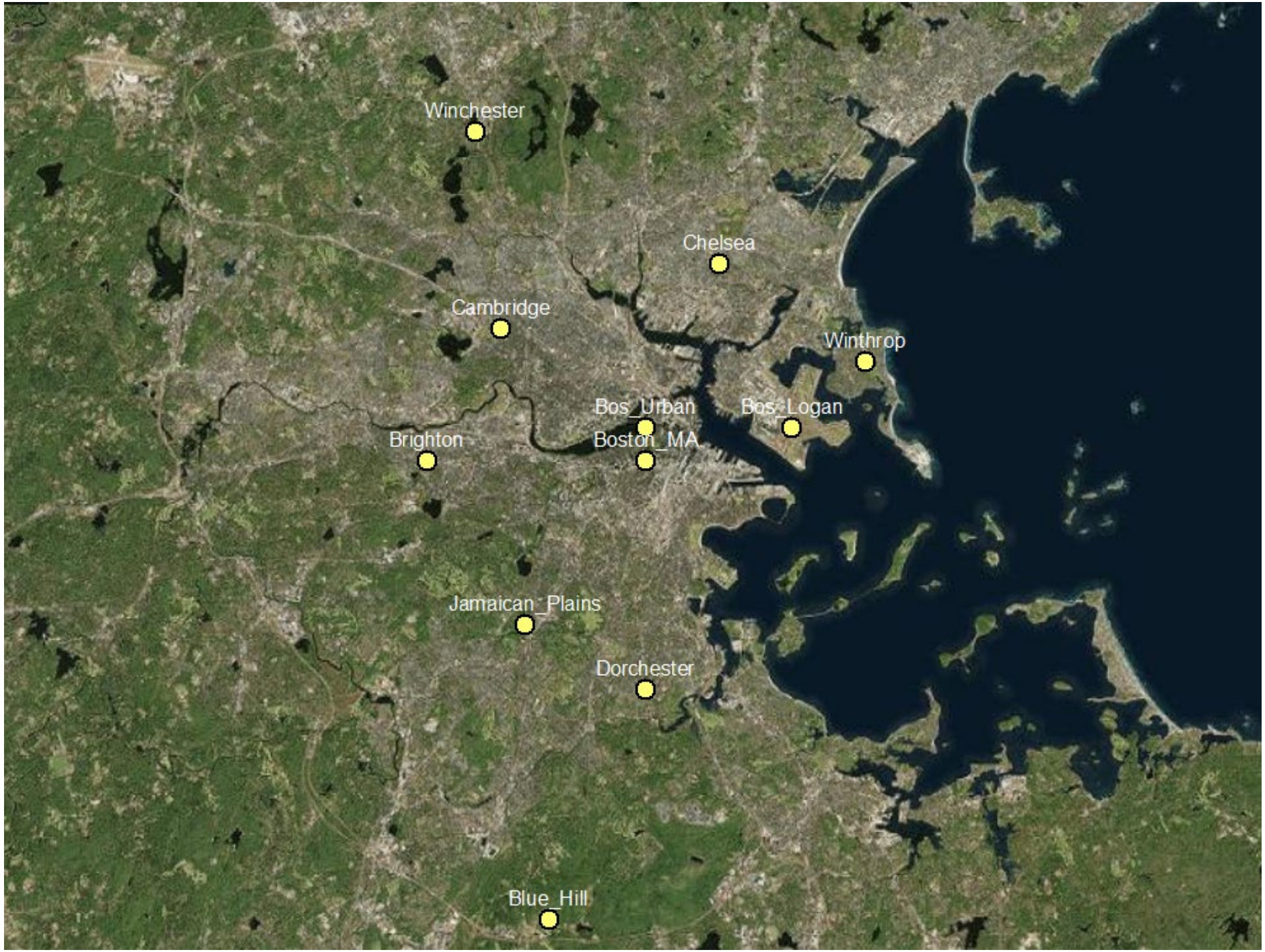
Methodology

- Objective 5
  - Choose event within time period (1991-2005) to investigate.
  - Run RCM3 from 2005100700 to 2005101200
  - Compare resulting precipitation patterns and average precipitation per 3 hour increment and daily for both ATM and SRF output over all study areas
  - Compare RCM output with observations over period (daily) for all domains
  - Compare GCM output with observations over period (daily) for all domains

iproj	LAMCON	Map projection
iy	74	# grid points in y direction
jx	85	# grid points in x direction
ds	60.0	Grid point separation (km)
clat	42	Central latitude of domain (deg)
clon	-73	Central longitude of domain (deg)
ntypec	10	Resolution of the global terrain and land-use data
IDATE1	2005100700	Simulation start date
IDATE2	2005101200	Simulation end date
SSTTYP	OI_WK	SST dataset
DATTYP	NNRP2	Global analysis dataset

Key Results

- Are there significant differences between individual stations within cities and/or between individual stations and the citywide average?


Winchester
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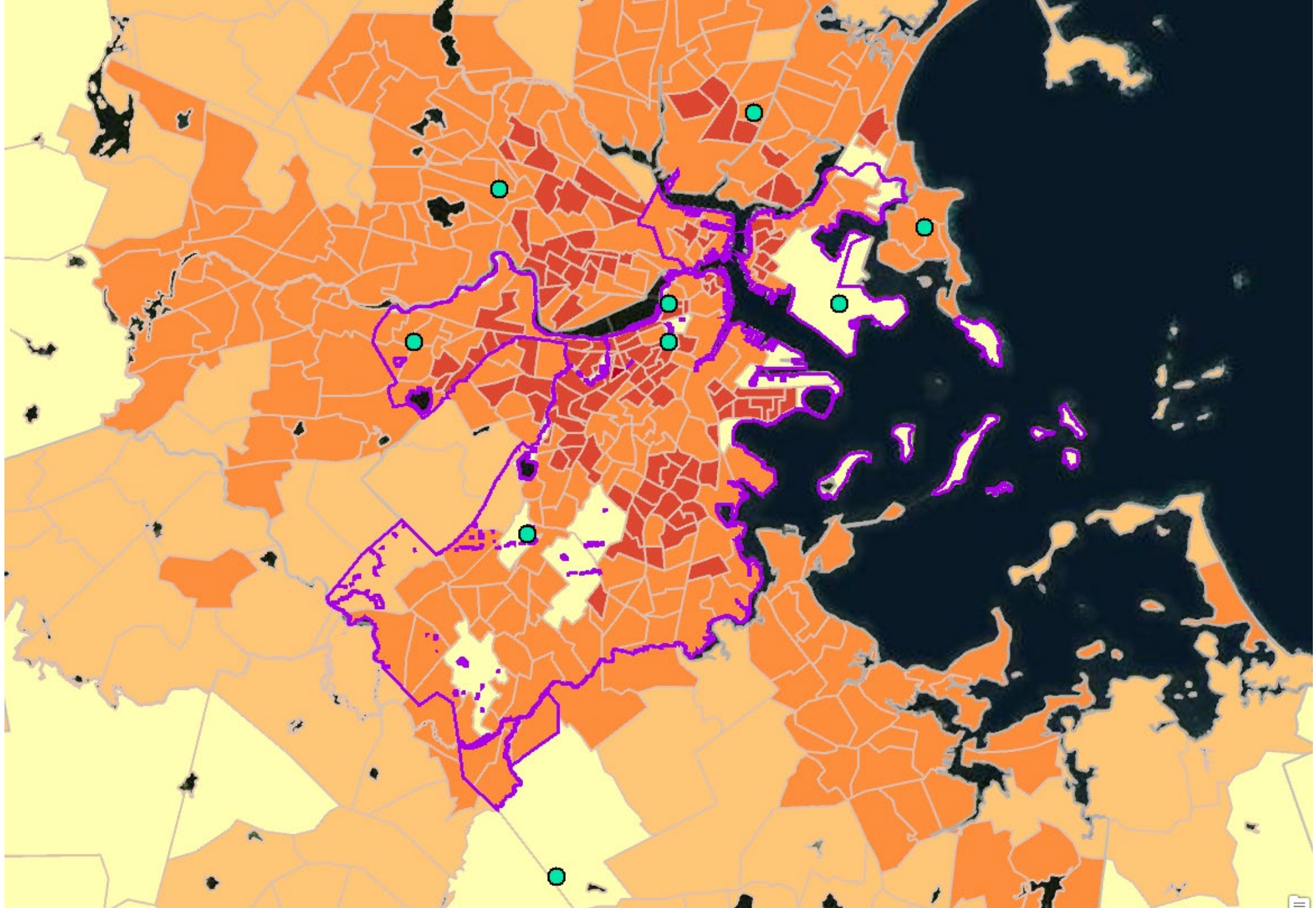
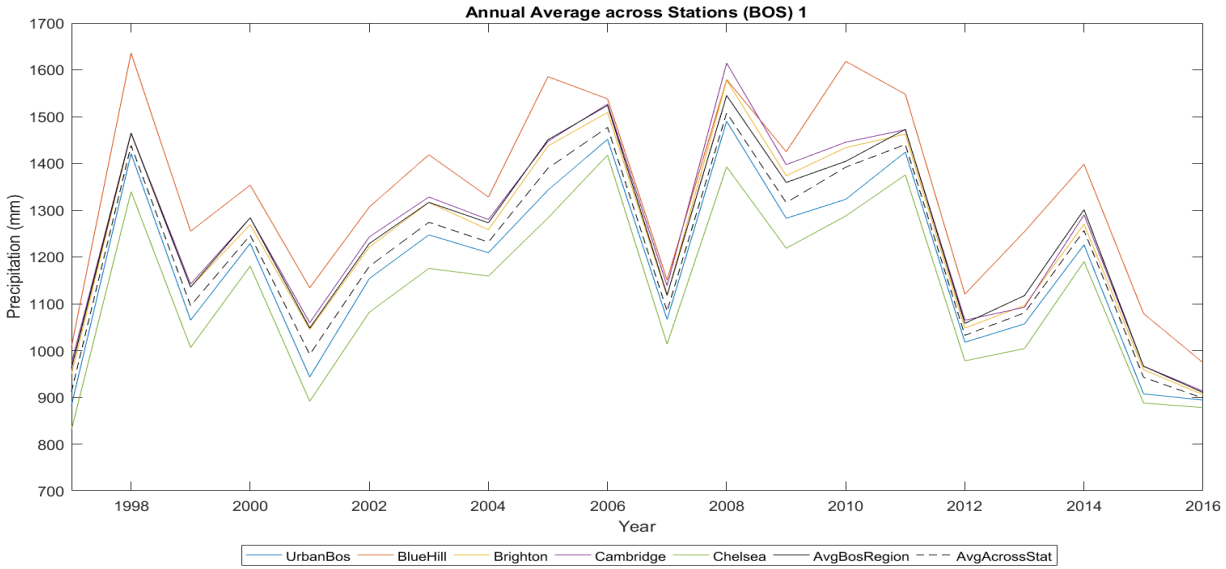
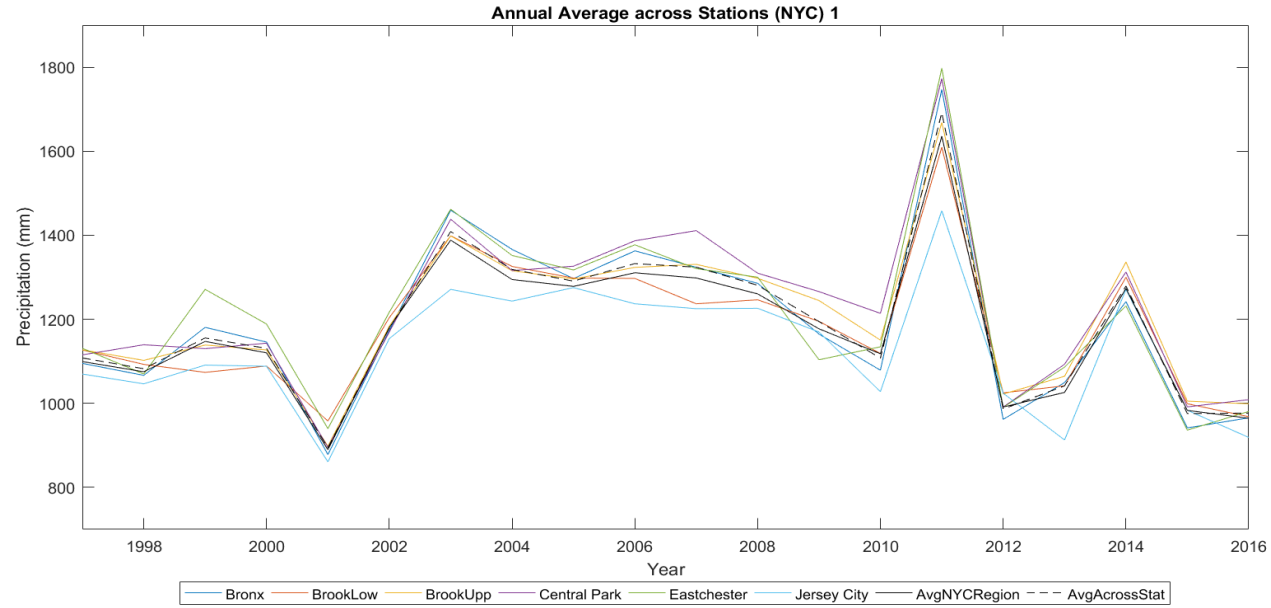
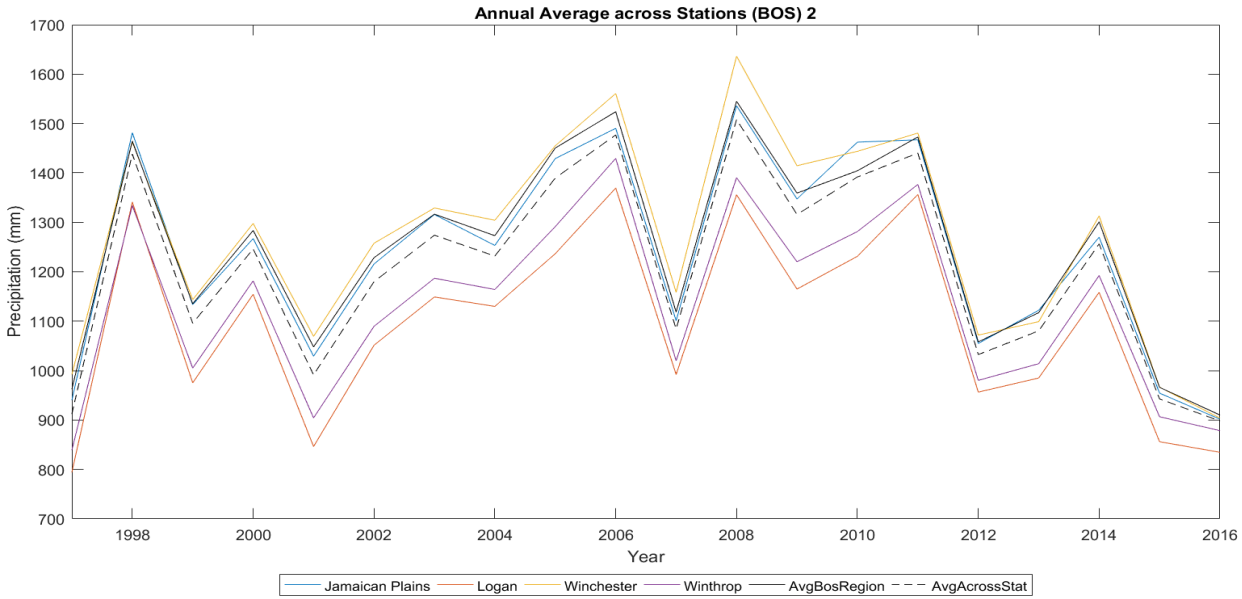
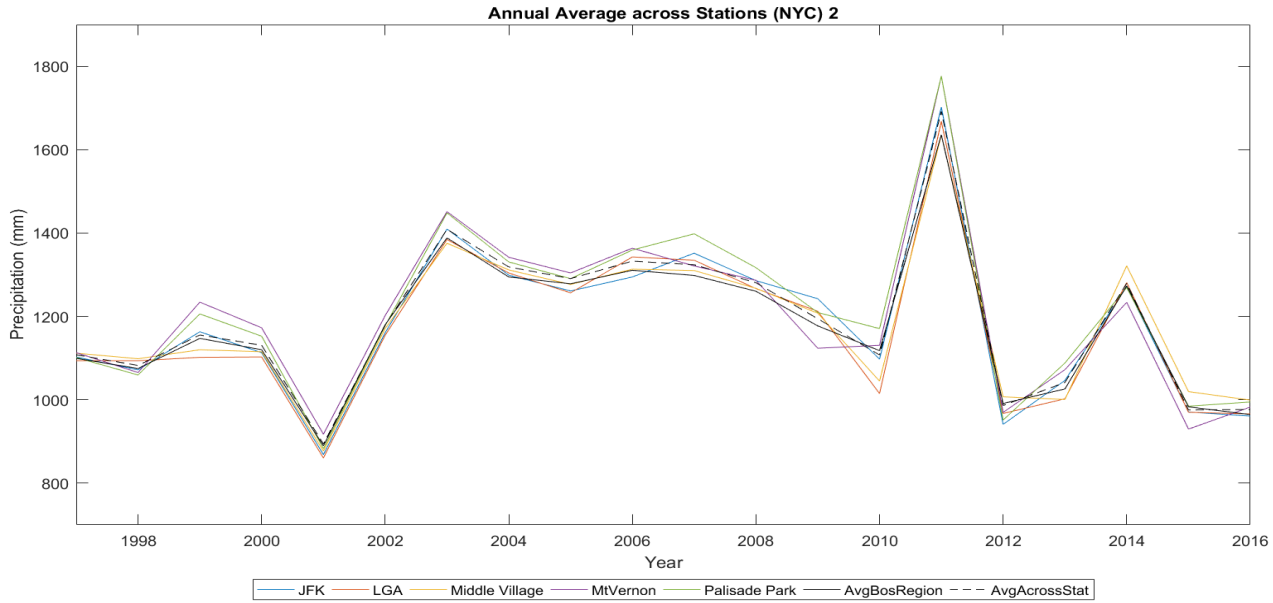
Cambridge
Winthrop
Bos_Urban
Bos_Logan
Brighton
Boston_MA
Jamaican_Plains
Dorchester
Blue_Hill

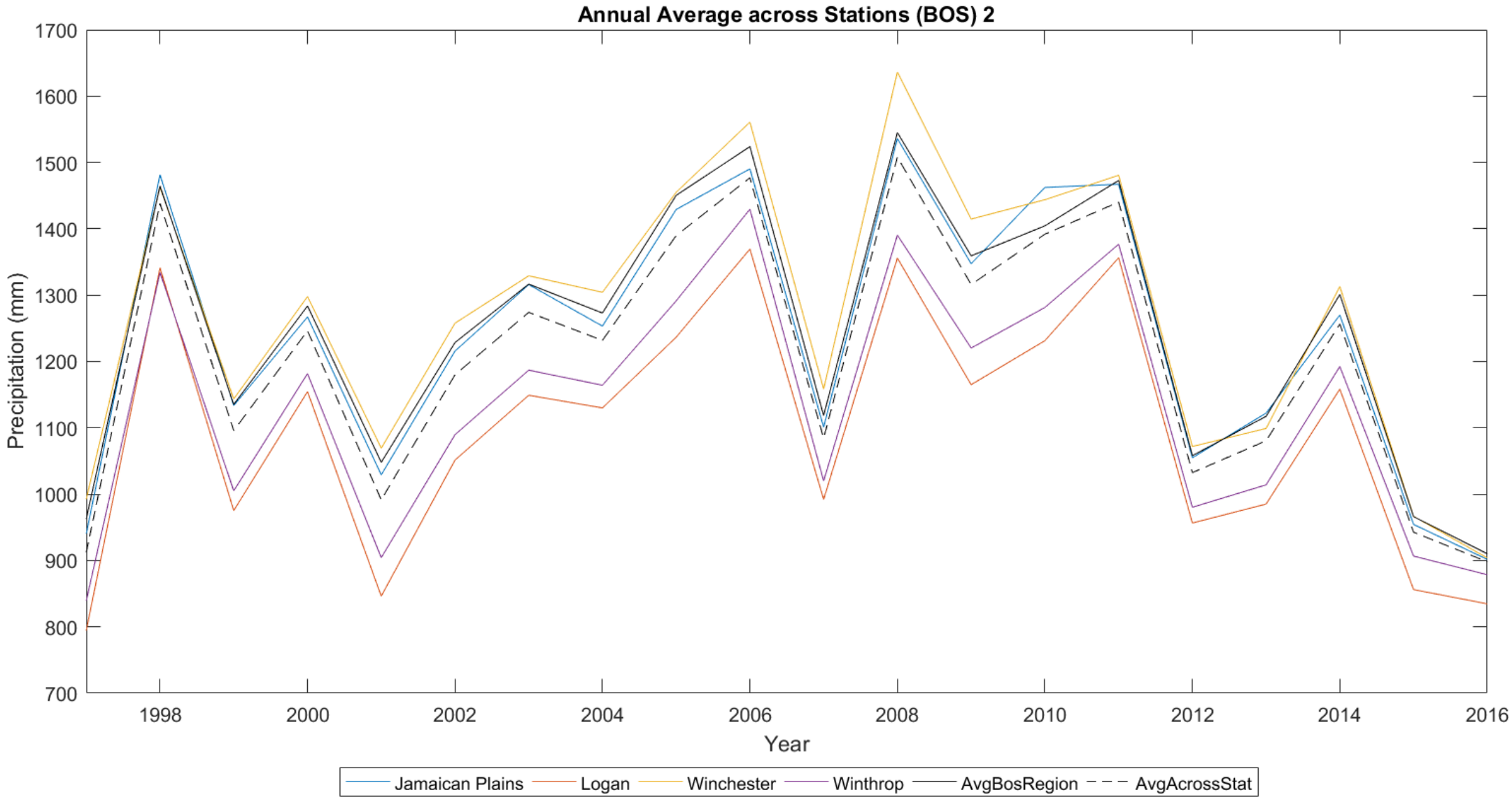


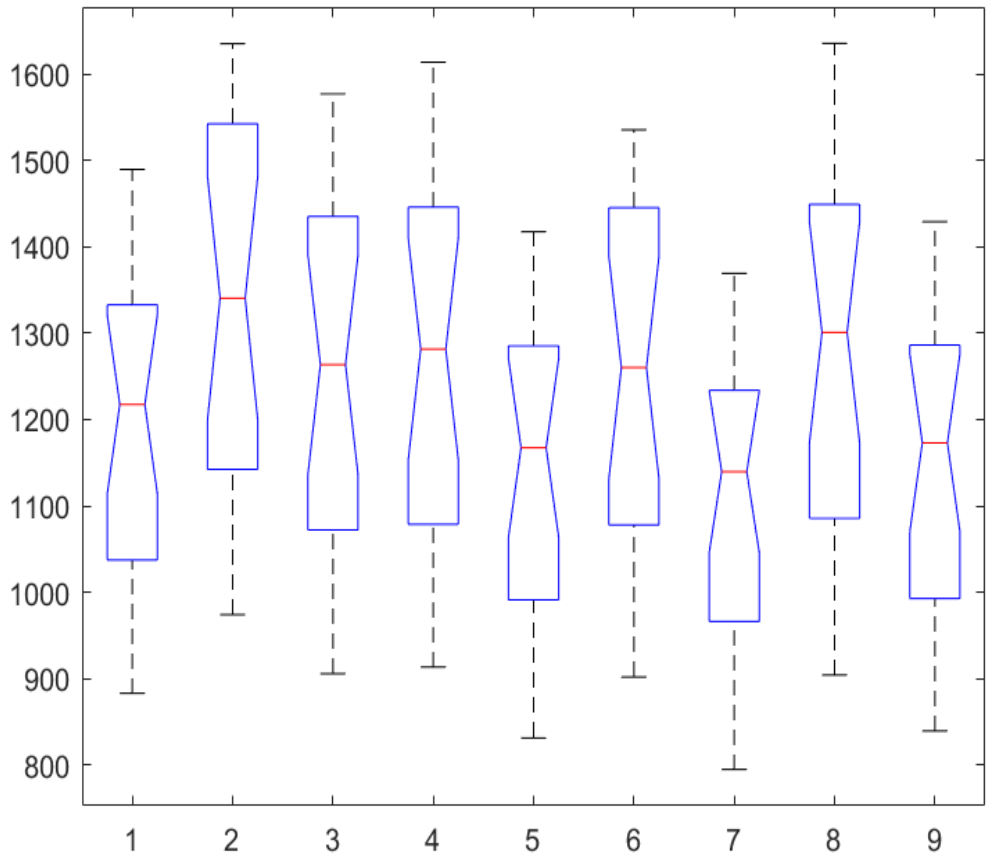

Annual Average across Stations (BOS) 1
Precipitation (mm)
Year
UrbanBos
BlueHill
Brighton
Cambridge
Chelsea
AvgBosRegion
AvgAcrossStat

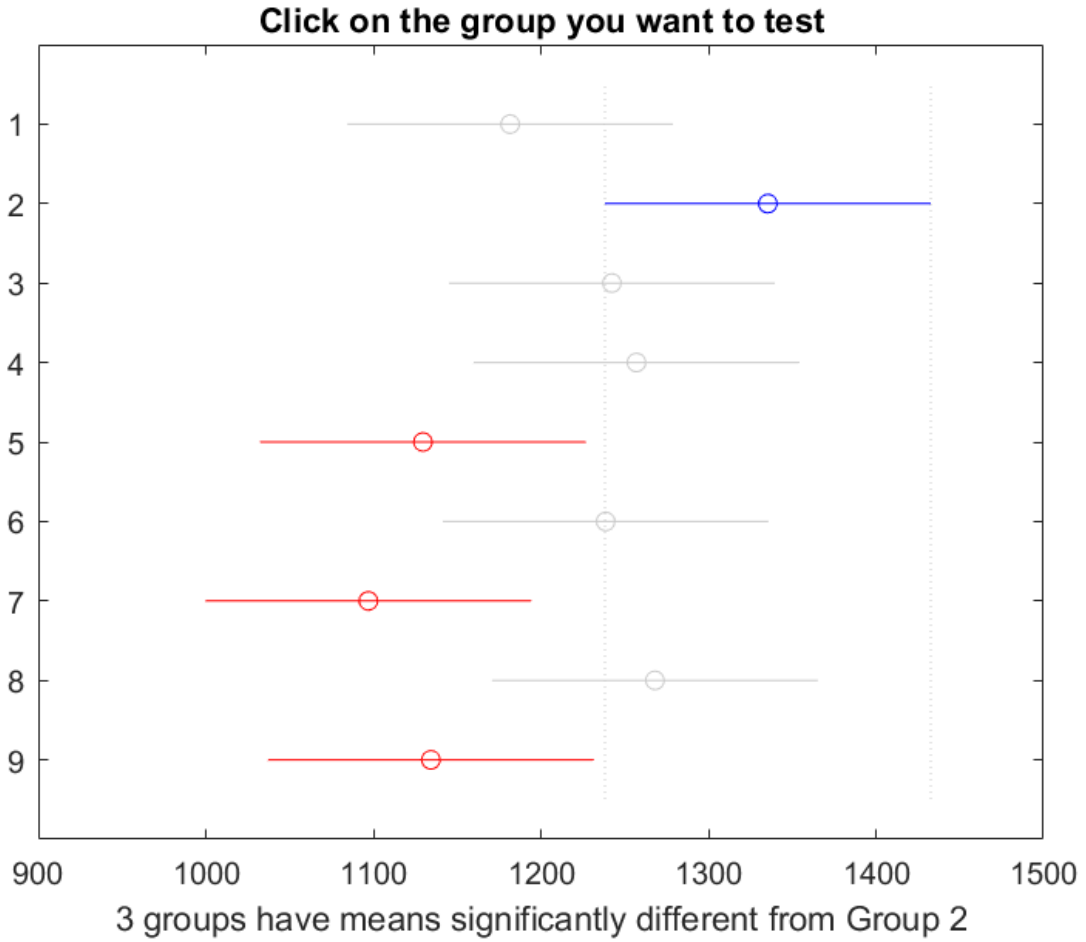

Annual Average across Stations (NYC) 1
Precipitation (mm)
Year
Bronx
BrookLow
BrookUpp
Central Park
Eastchester
Jersey City
AvgNYCRegion
AvgAcrossStat


Annual Average across Stations (BOS) 2
Precipitation (mm)
Year
Jamaican Plains
Logan
Winchester
Winthrop
AvgBosRegion
AvgAcrossStat


Annual Average across Stations (NYC) 2
Precipitation (mm)
Year
JFK
LGA
Middle Village
MtVernon
Palisade Park
AvgBosRegion
AvgAcrossStat


Annual Average across Stations (BOS) 2
Precipitation (mm)
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year
Jamaican Plains
Logan
Winchester
Winthrop
AvgBosRegion
AvgAcrossStat

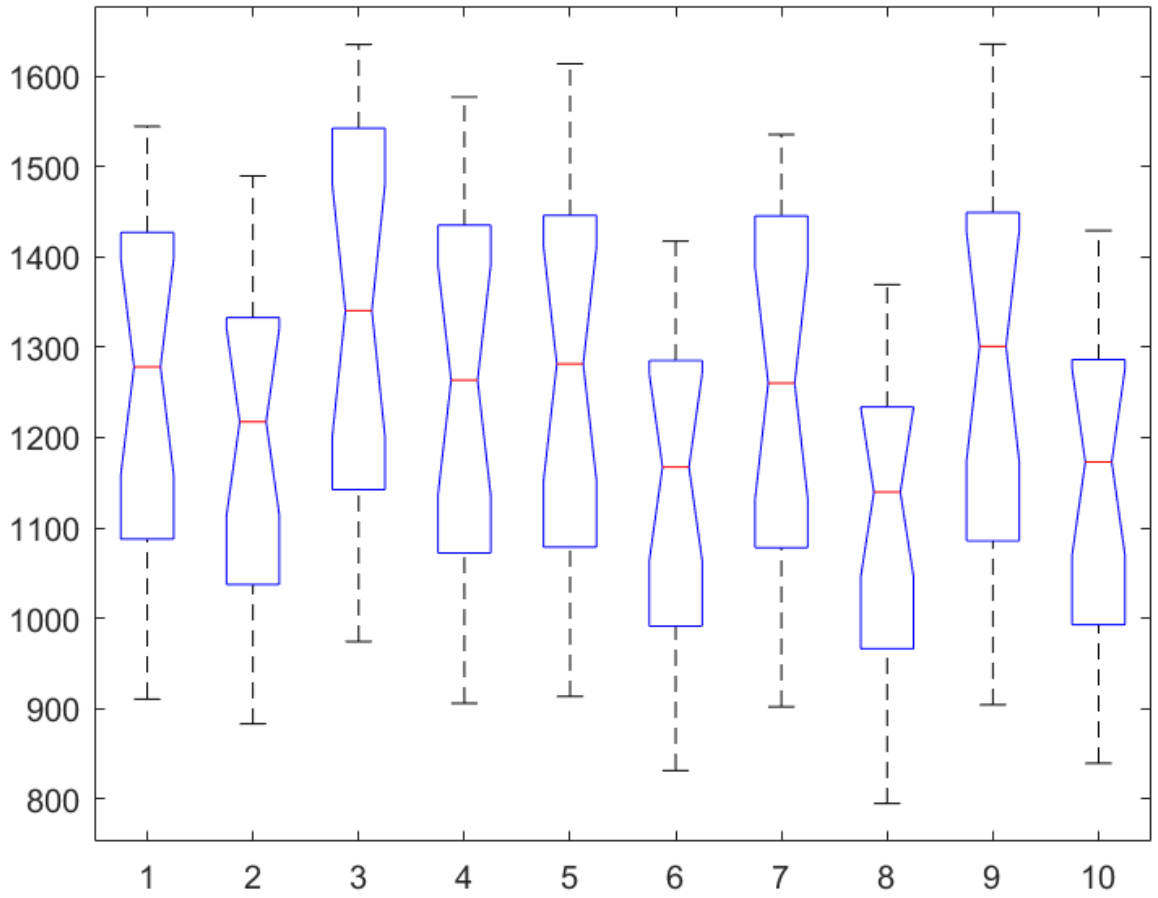


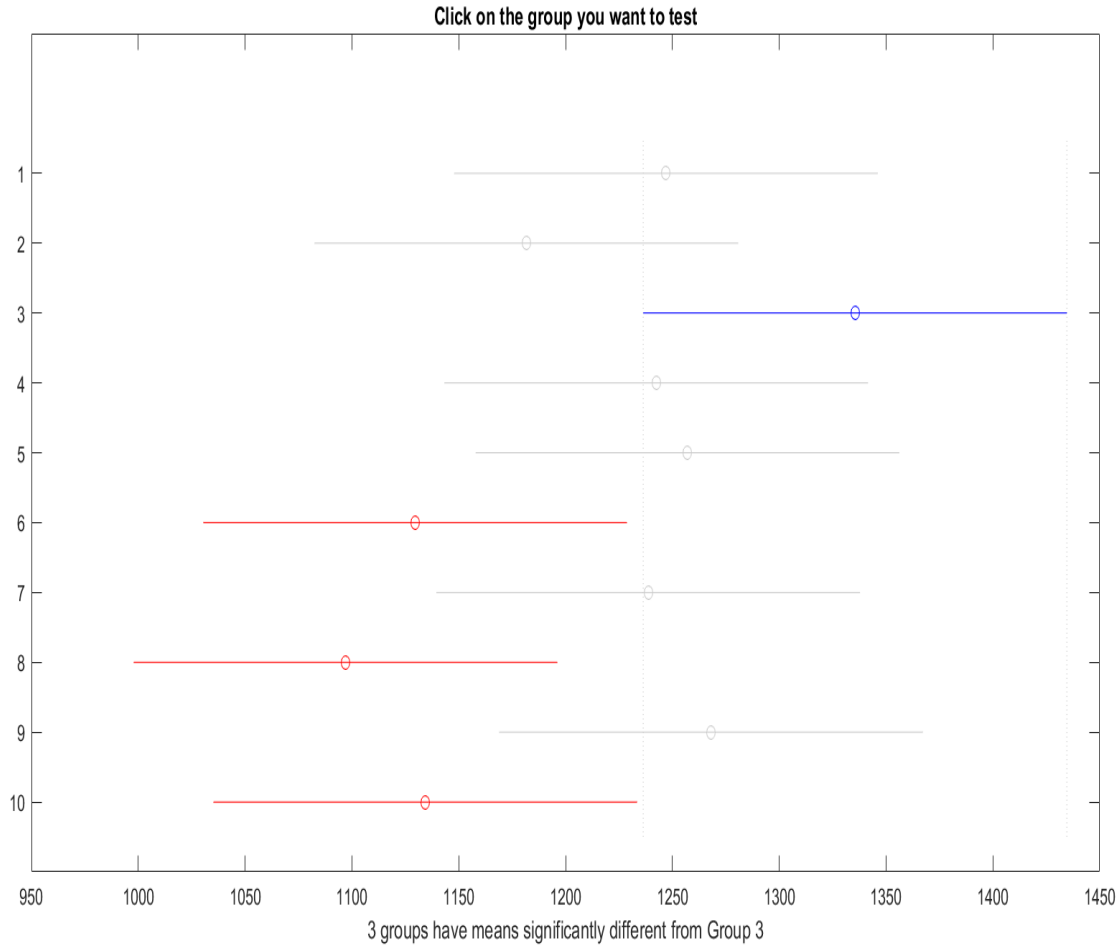


ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	979332.3	8	122416.5	3.12	0.0026
Error	6718881.9	171	39291.7		
Total	7698214.3	179			

1	2	3	4	5	6	7	8	9
UrbBos	BlueHill	Brighton	Cambridge	Chelsea	Jamaican Plains	Logan	Winchester	Winthrop



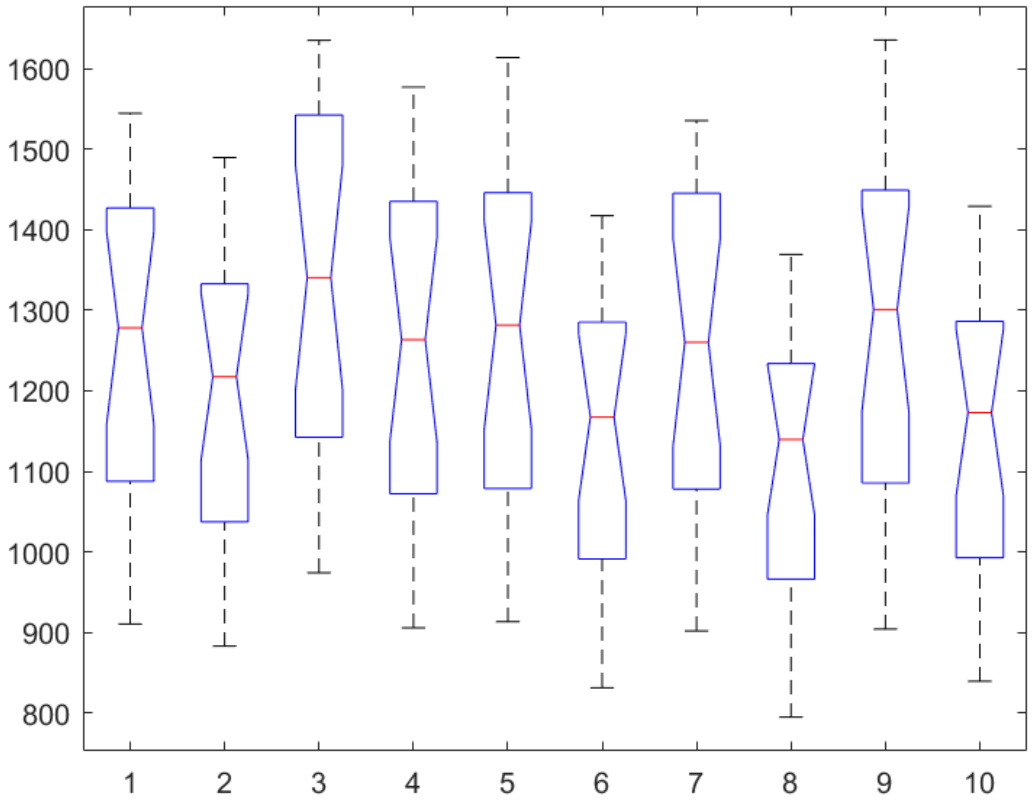


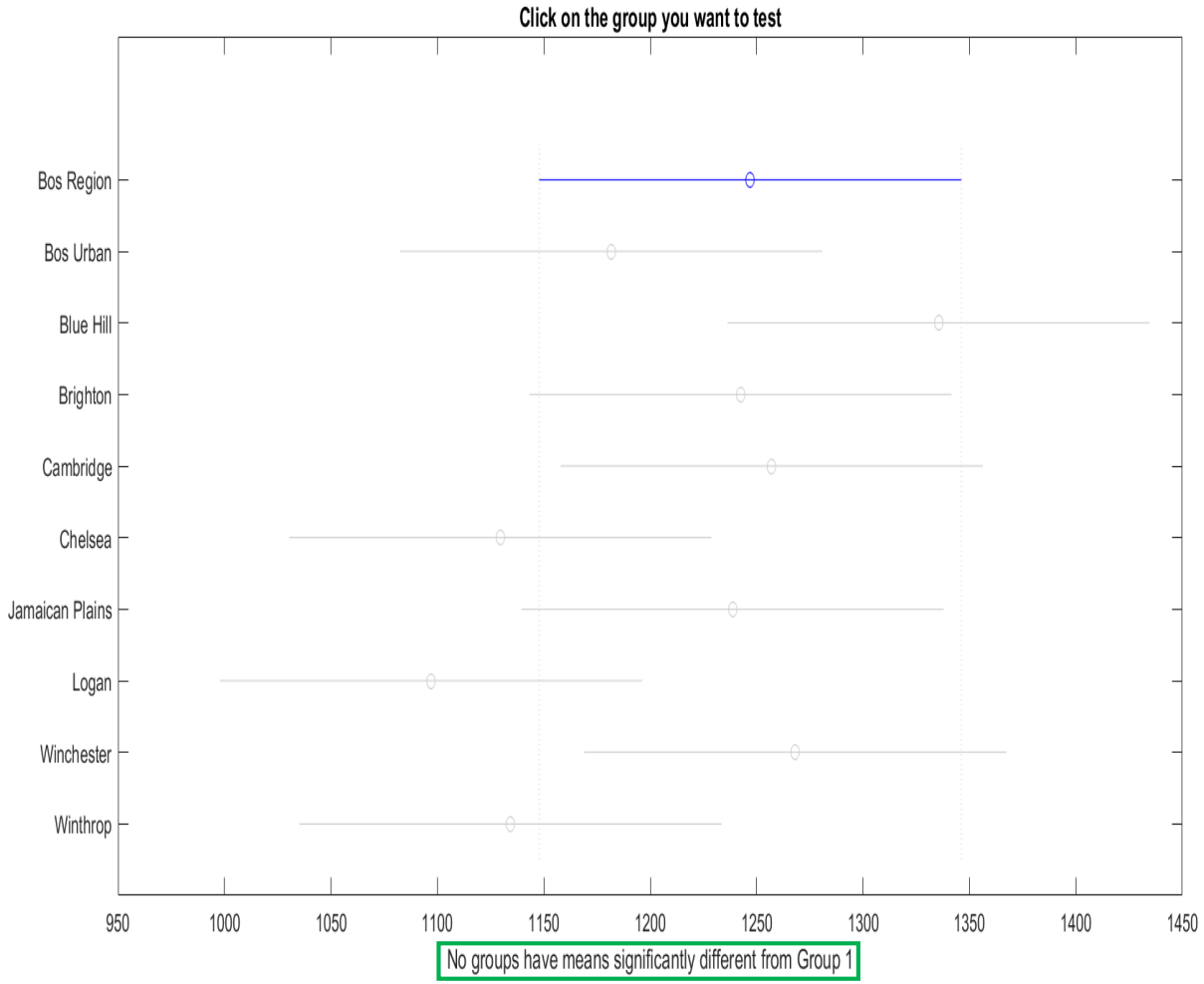
ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	1.00481e+06	9	111645.8	2.84	0.0037
Error	7.46592e+06	190	39294.3		
Total	8.47074e+06	199			

1	2	3	4	5	6	7	8	9	10
Bos Region	UrbBos	BlueHill	Brighton	Cambridge	Chelsea	Jamaican Plains	Logan	Winchester	Winthrop

1	2	3	4	5	6	7	8	9	10
Bos Region	UrbBos	BlueHill	Brighton	Cambridge	Chelsea	Jamaican Plains	Logan	Winchester	Winthrop





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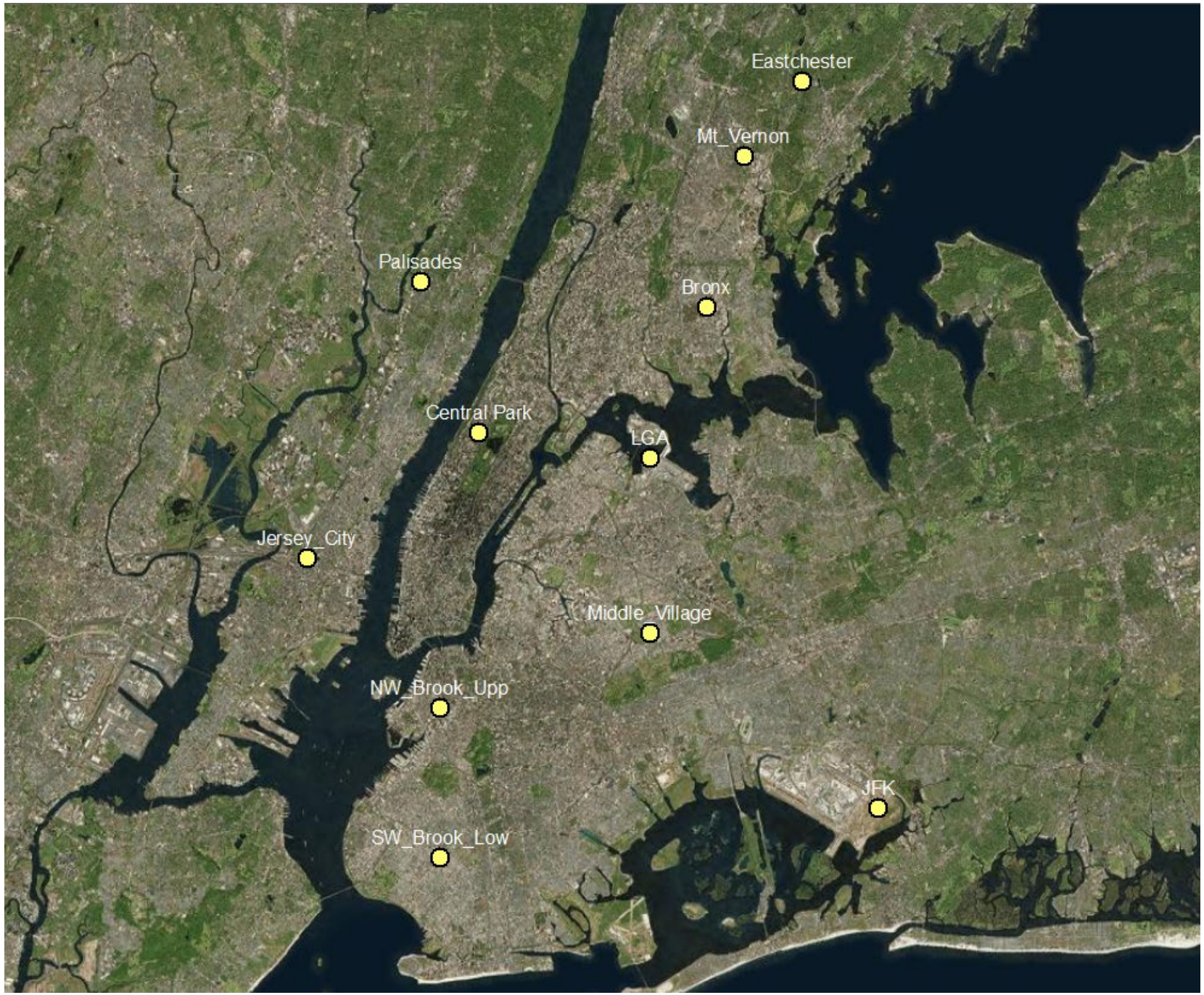
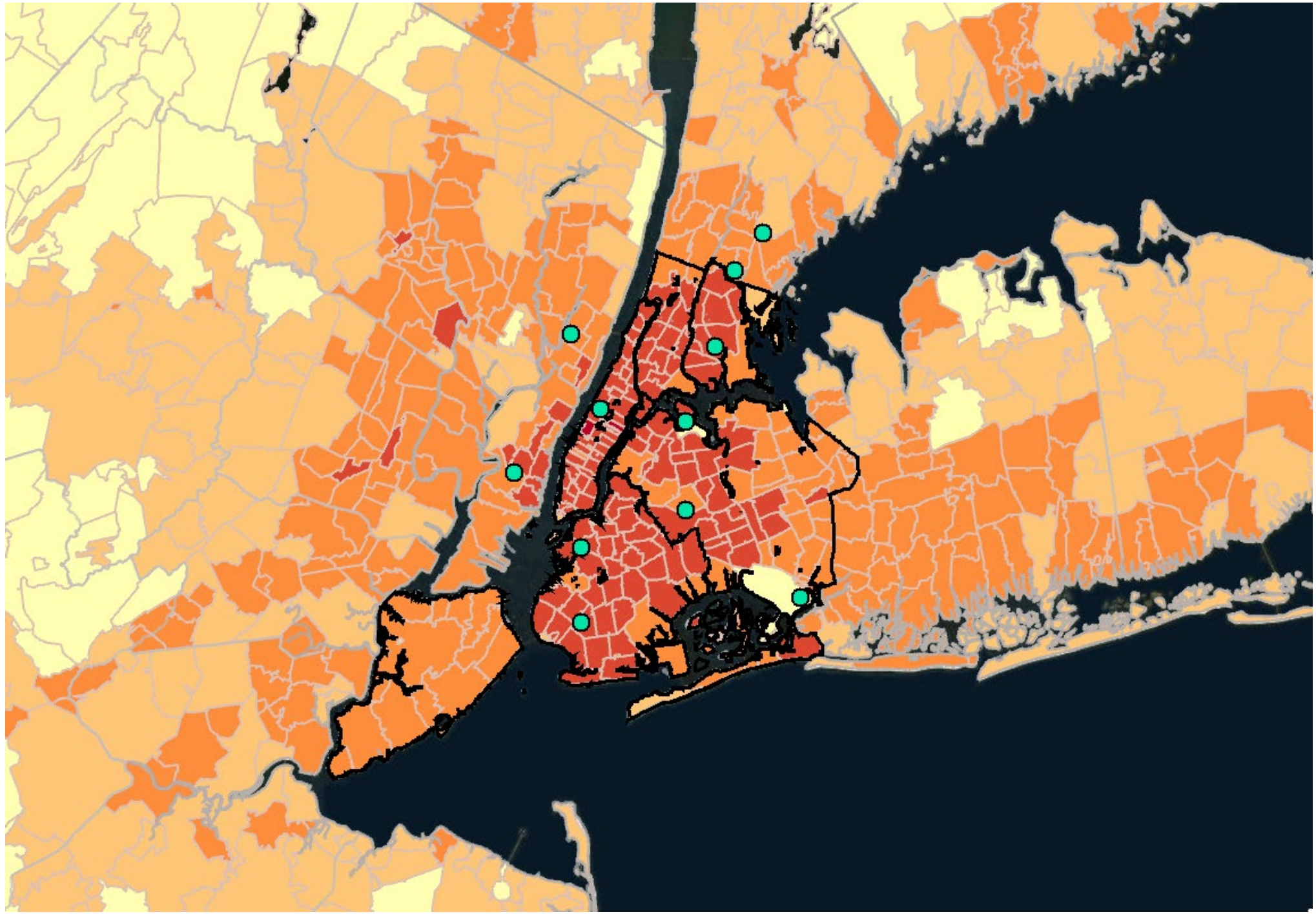
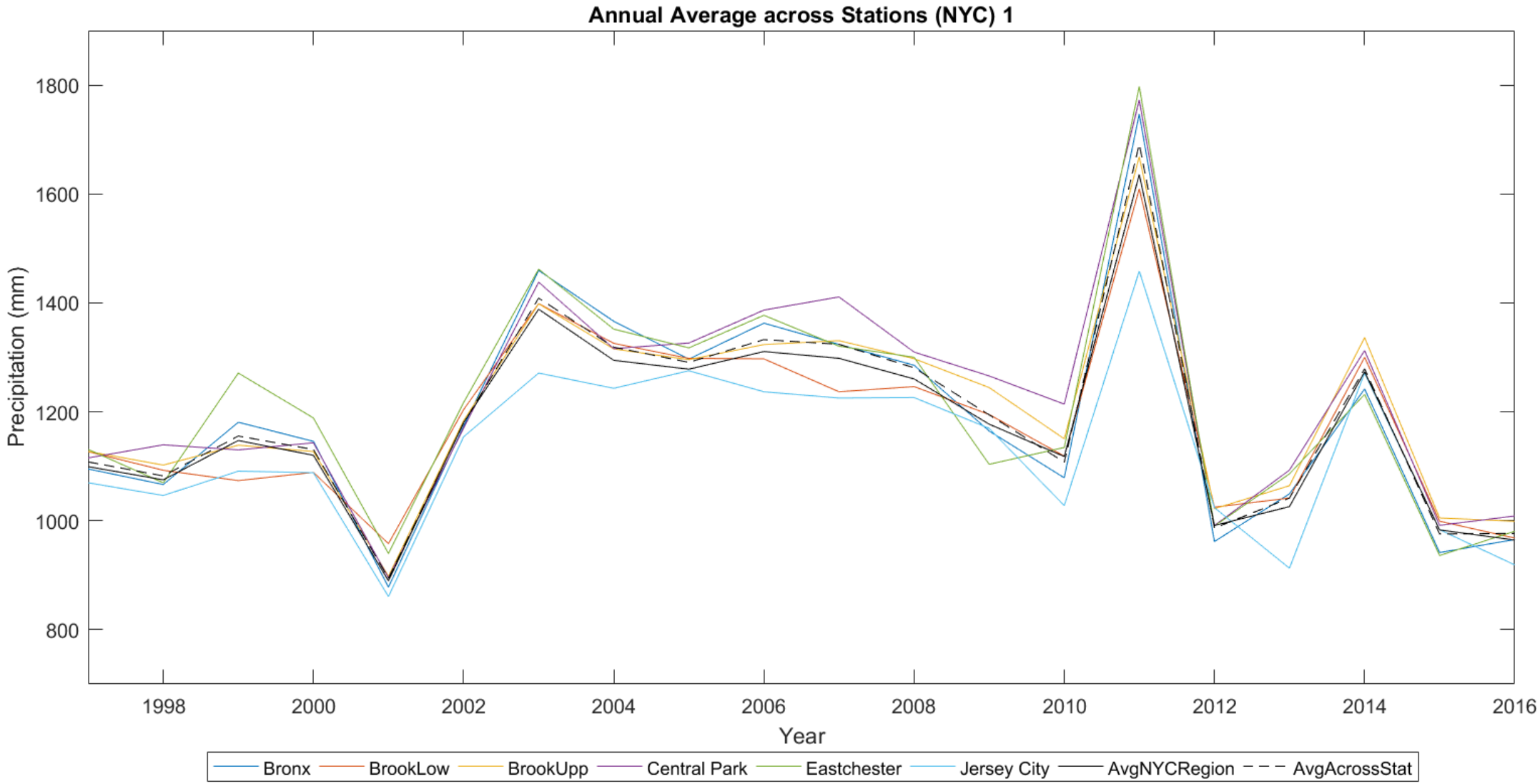
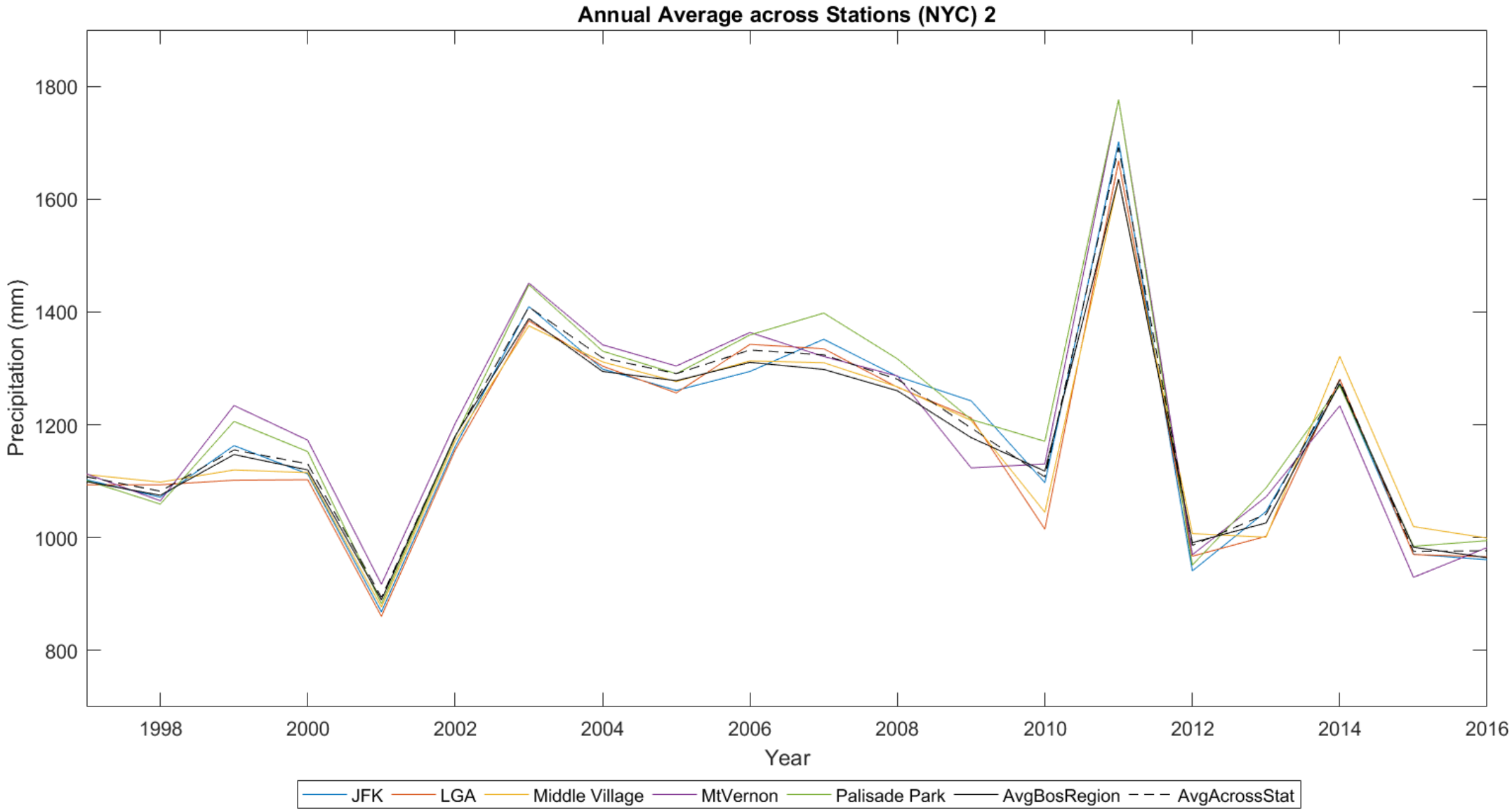
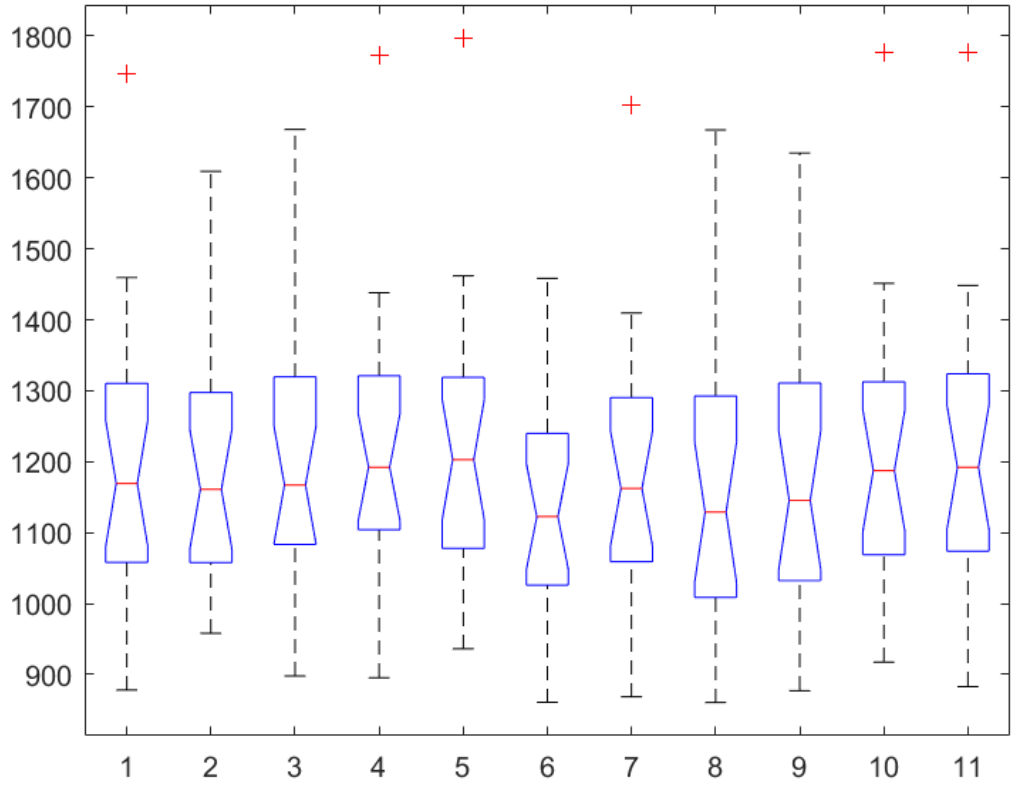

Eastchester
Mt_Vernon
Palisades
Bronx
Central Park
LGA
Jersey_City
Middle_Village
NW_Brook_Upp
JFK
SW_Brook_Low




Annual Average across Stations (NYC) 1
Precipitation (mm)
1800
1600
1400
1200
1000
800
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year
Bronx
BrookLow
BrookUpp
Central Park
Eastchester
Jersey City
AvgNYCRegion
AvgAcrossStat


Annual Average across Stations (NYC) 2
Precipitation (mm)
1800
1600
1400
1200
1000
800
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year
JFK
LGA
Middle Village
MtVernon
Palisade Park
AvgBosRegion
AvgAcrossStat

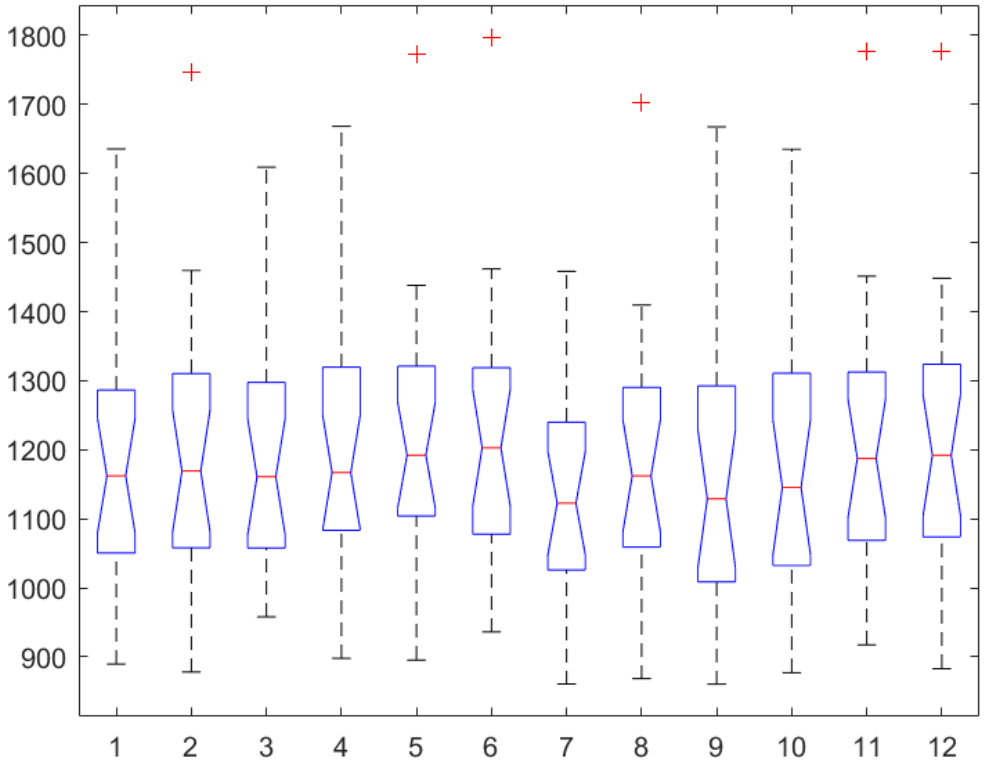
1	2	3	4	5	6
Bronx	BrooklynLower	BrooklynUpper	Central Park	Eastchester	Jersey City
7	8	9	10	11	
JFK	LGA	Middle Village	Mt Vernon	Palisades	



ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	130983.3	10	13098.3	0.37	0.9596
Error	7461349.8	209	35700.2		
Total	7592333.1	219			

1	2	3	4	5	6
NYC Region	Bronx	BrooklynLower	BrooklynUpper	Central Park	Eastchester
7	8	9	10	11	12
Jersey City	JFK	LGA	Middle Village	Mt Vernon	Palisades

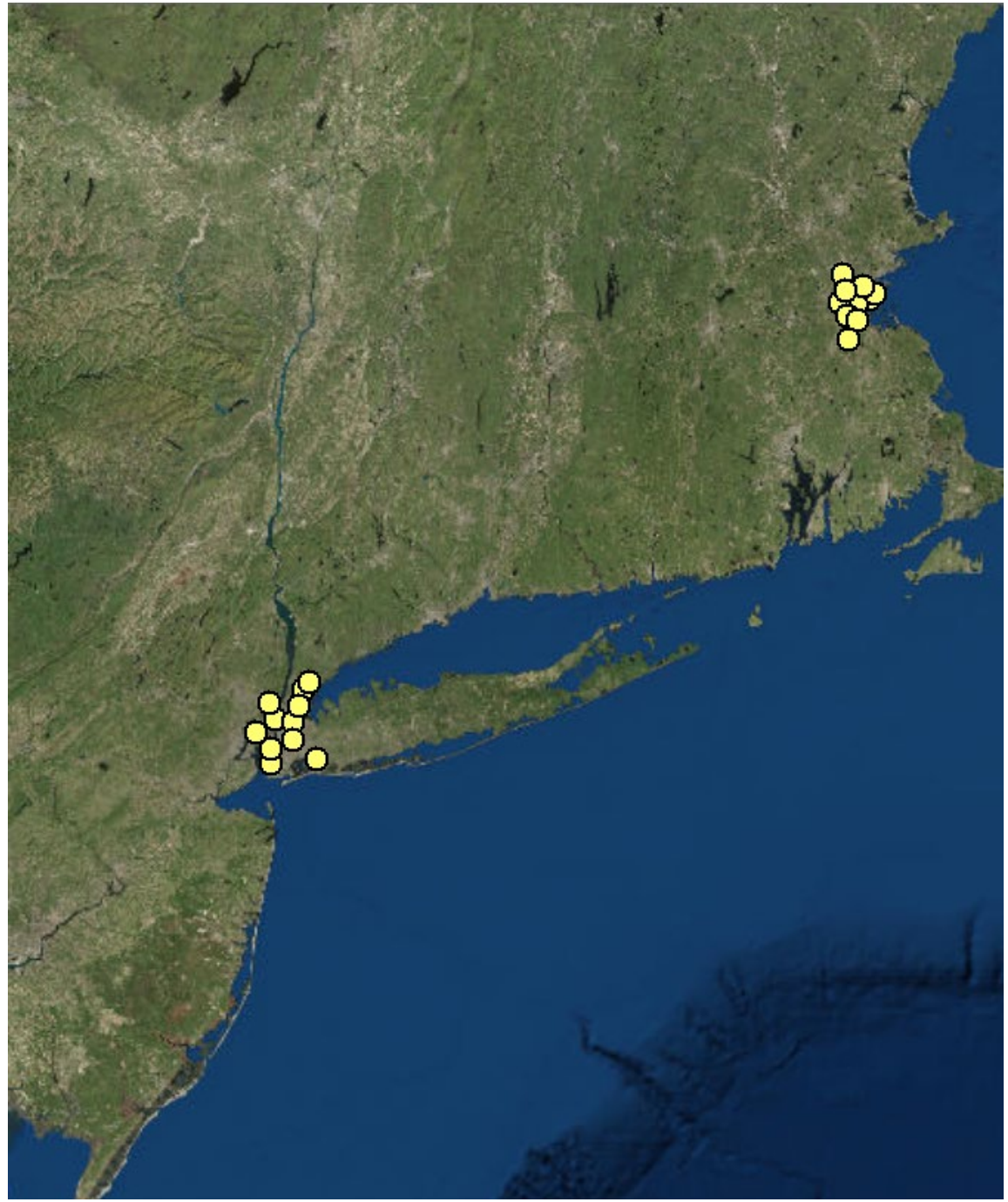


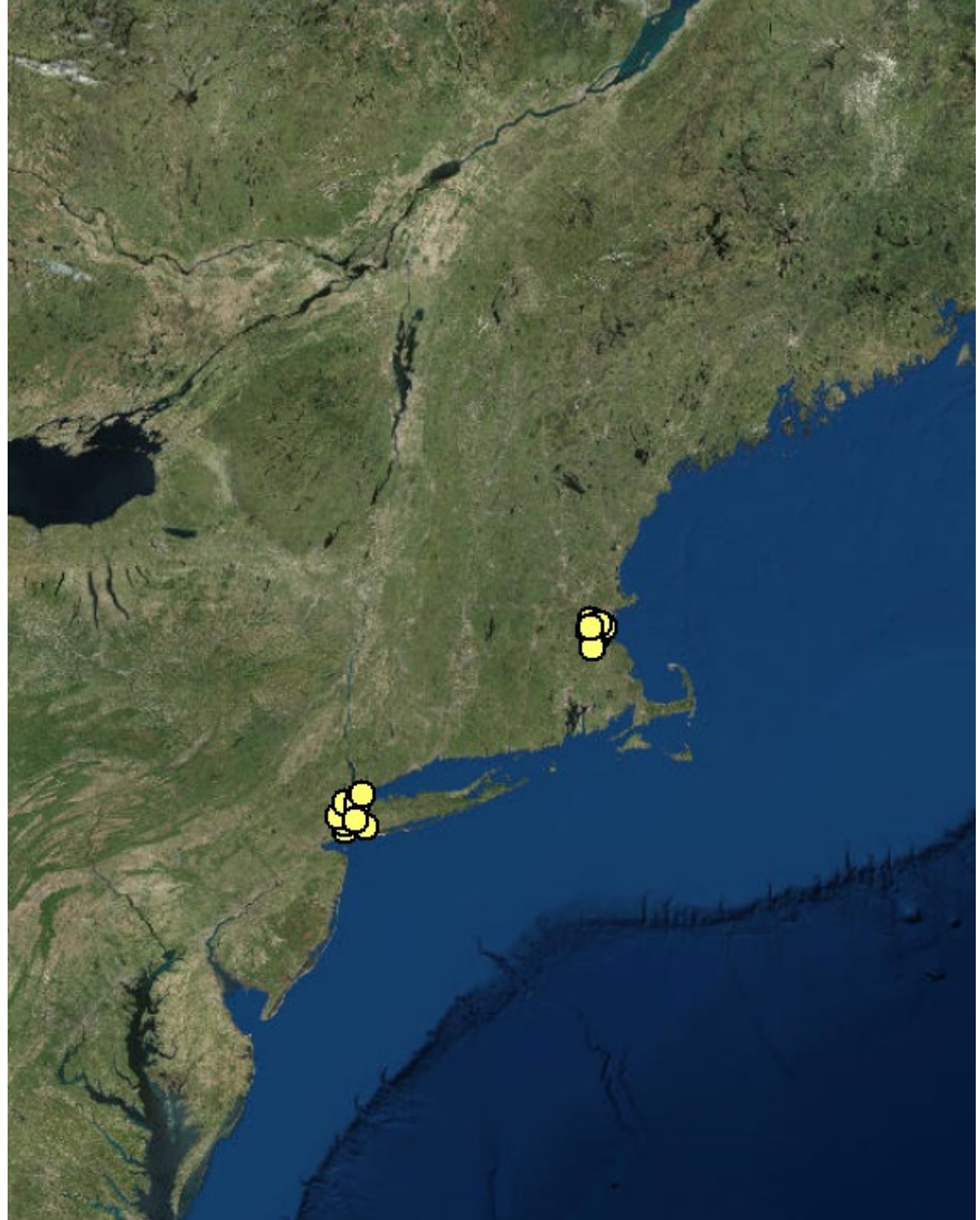
ANOVA Table

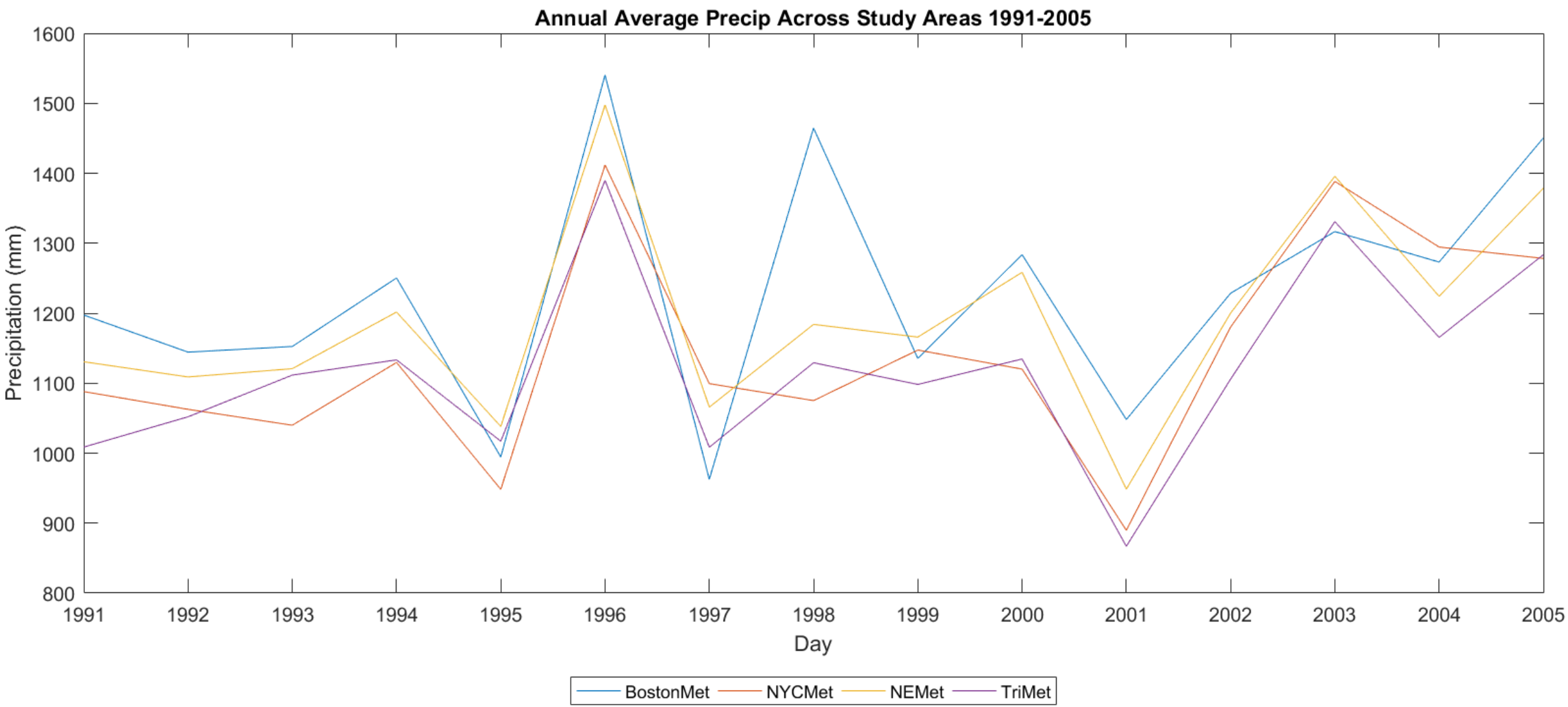
Source	SS	df	MS	F	Prob>F
Columns	133790.8	11	12162.8	0.35	0.9744
Error	8035840.9	228	35244.9		
Total	8169631.8	239			

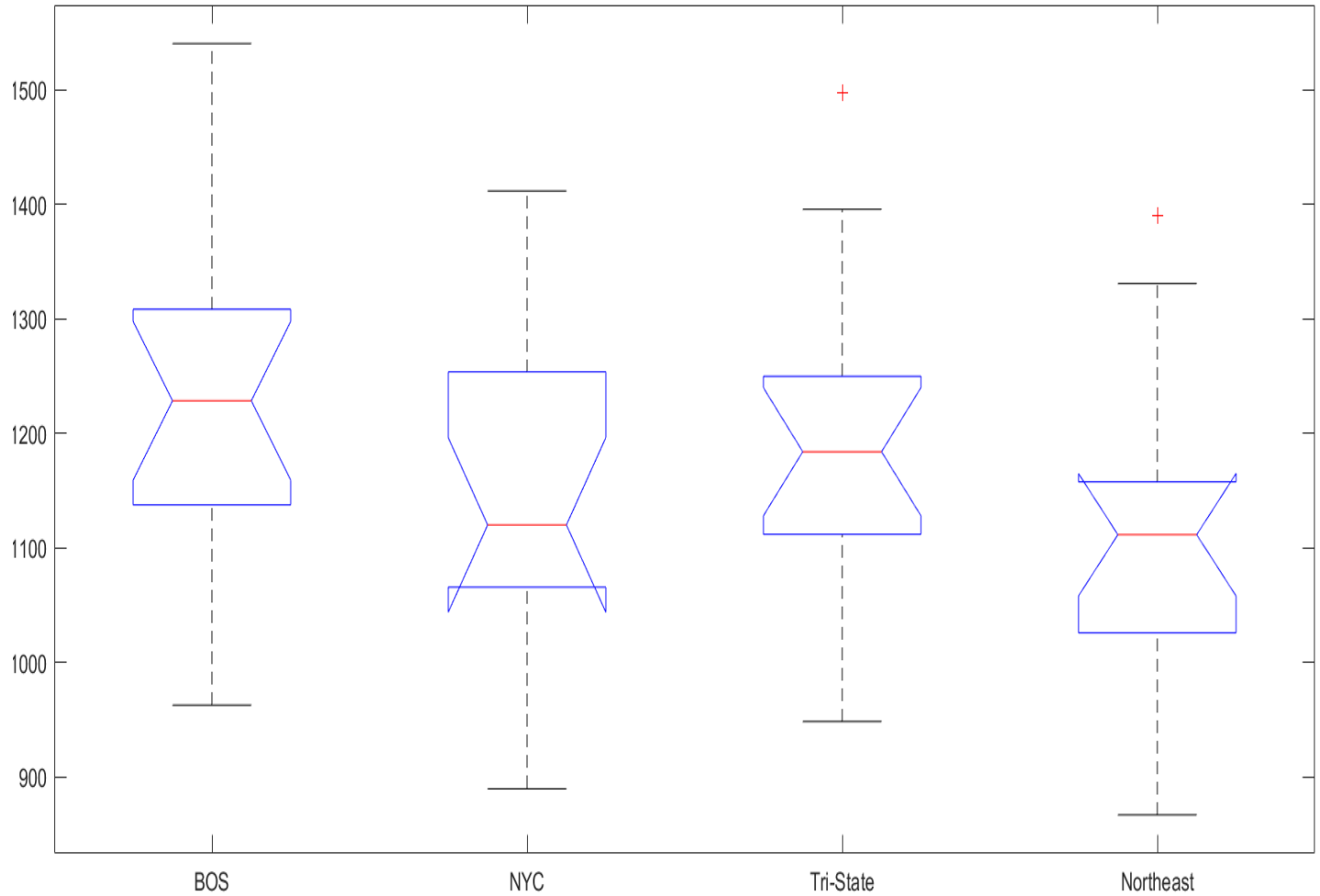
Key Results

- Do major cities like Boston and NYC get significantly more annual precipitation than the Northeast region or Tri-State area on average?






Annual Average Precip Across Study Areas 1991-2005
Precipitation (mm)
1600
1500
1400
1300
1200
1100
1000
900
800
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Day
BostonMet
NYCMet
NEMet
TriMet

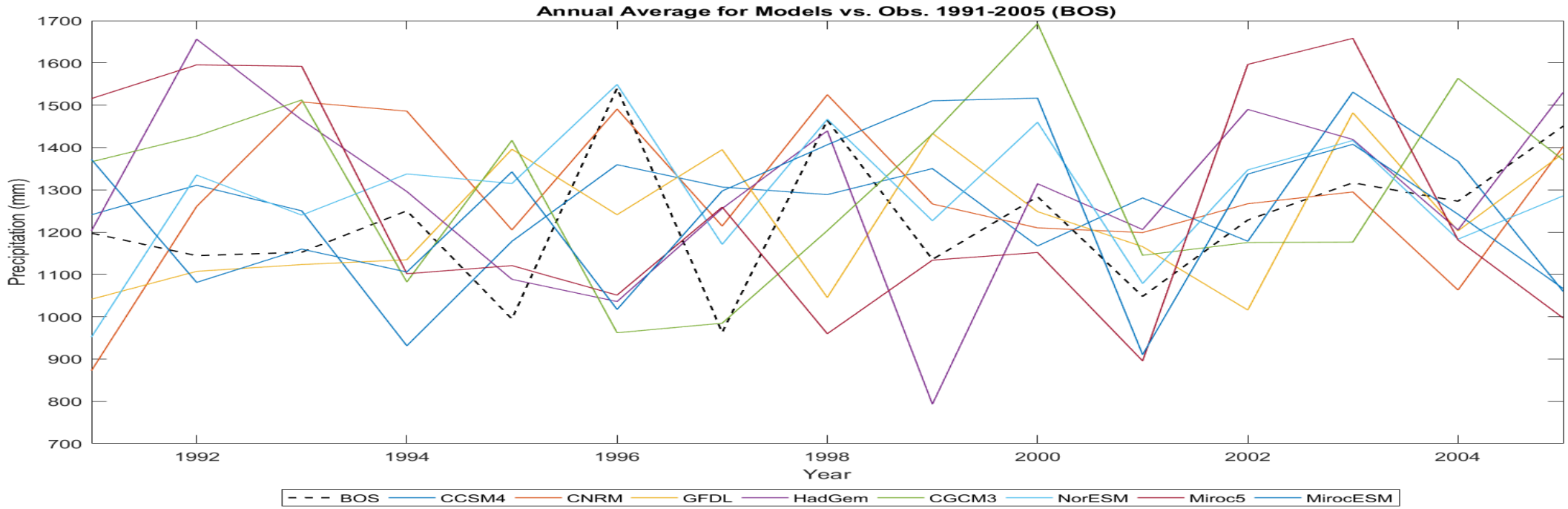


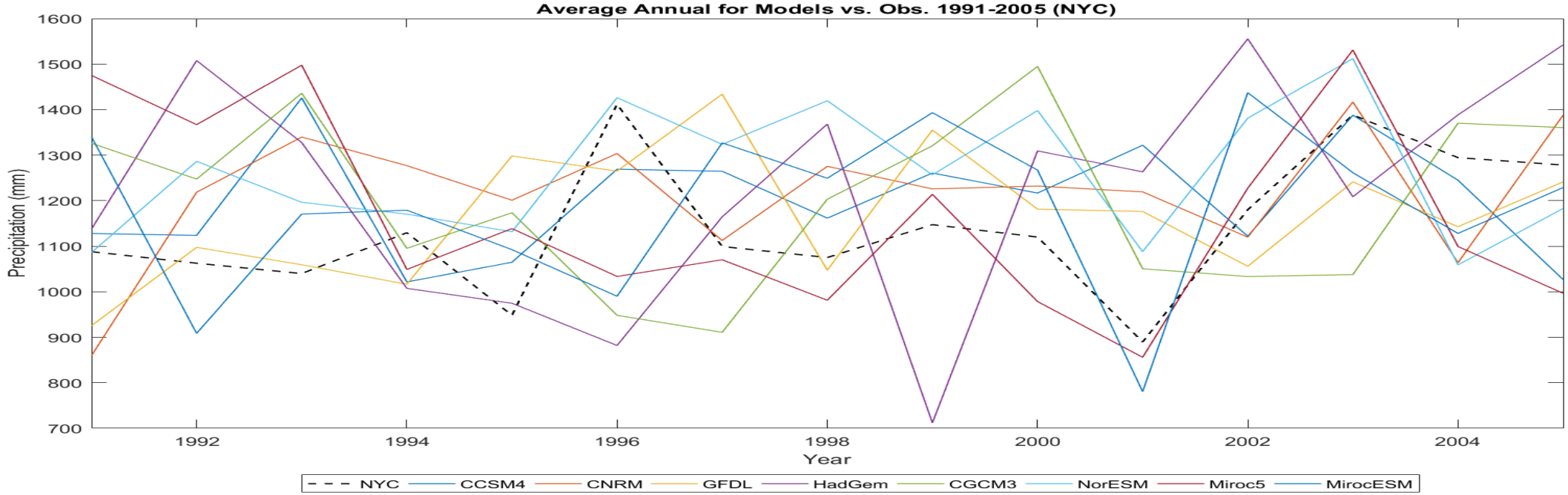
ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	106322.8	3	35440.9	1.6	0.2003
Error	1242508.2	56	22187.6		
Total	1348831	59			

Key Results

- How do GCMs compare to observations in representing historical annual precipitation amounts?


Annual Average for Models vs. Obs. 1991-2005 (BOS)
Precipitation (mm)
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
1992
1994
1996
1998
2000
2002
2004
Year
BOS
CCSM4
CNRM
GFDL
HadGem
CGCM3
NorESM
Miroc5
MirocESM


Average Annual for Models vs. Obs. 1991-2005 (NYC)
Precipitation (mm)
1600
1500
1400
1300
1200
1100
1000
900
800
700
1992
1994
1996
1998
2000
2002
2004
Year
NYC
CCSM4
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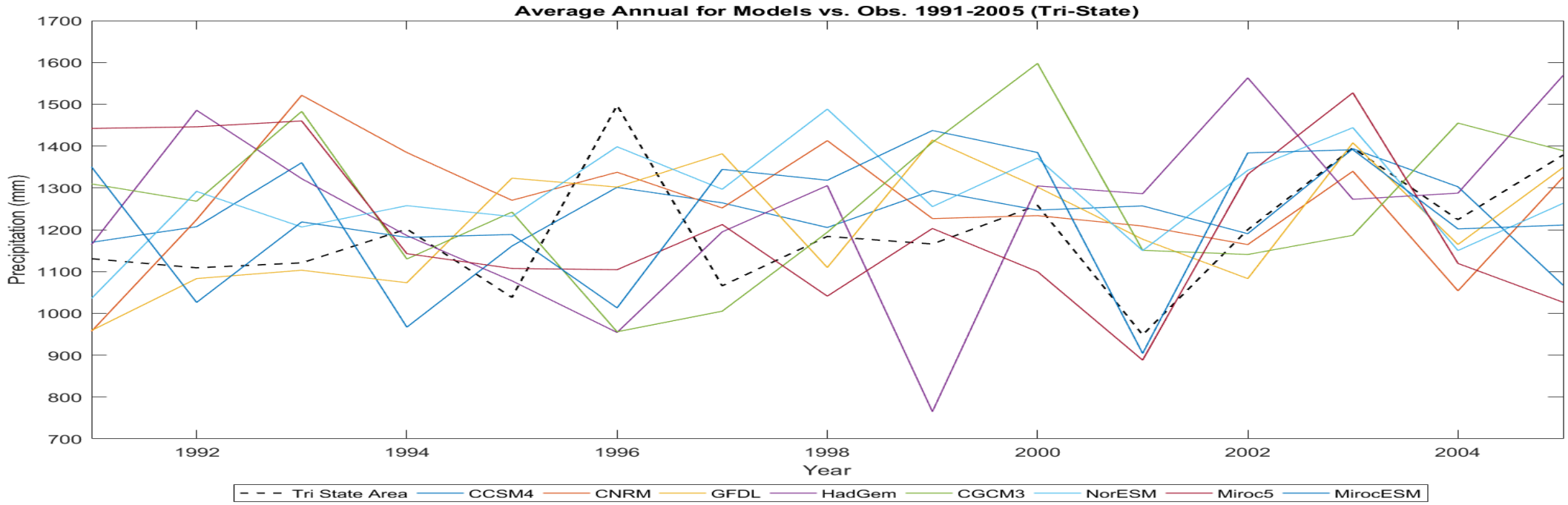
GFDL
HadGem
CGCM3
NorESM
Miroc5
MirocESM


Average Annual for Models vs. Obs. 1991-2005 (Tri-State)
Precipitation (mm)
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
1992
1994
1996
1998
2000
2002
2004
Year
Tri State Area
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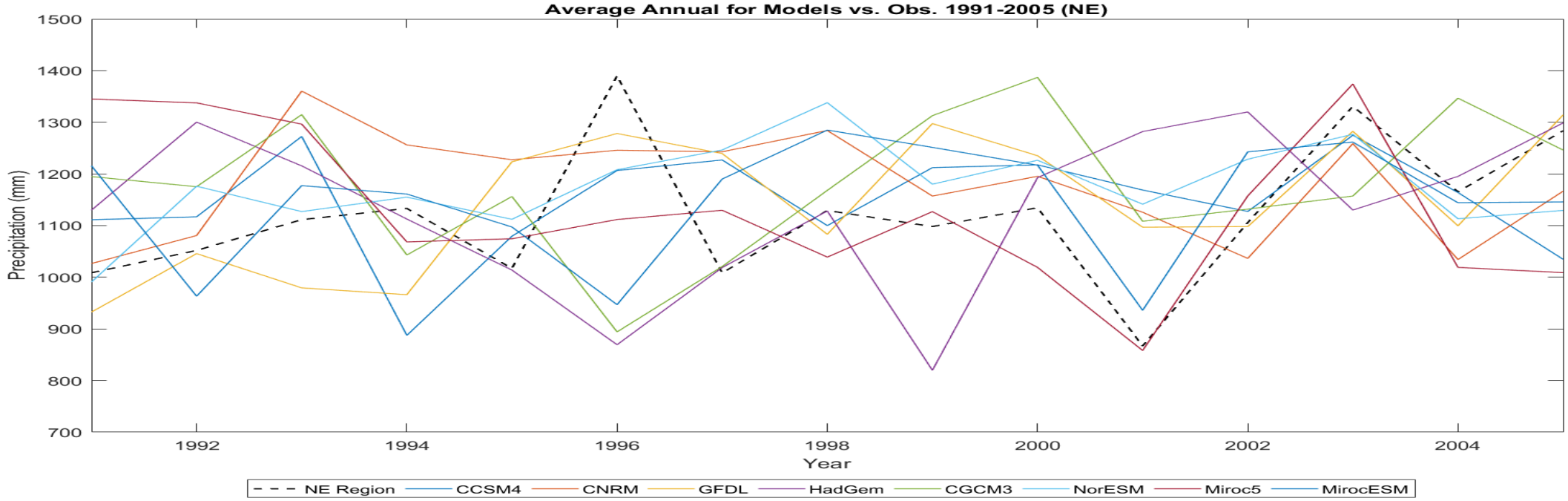
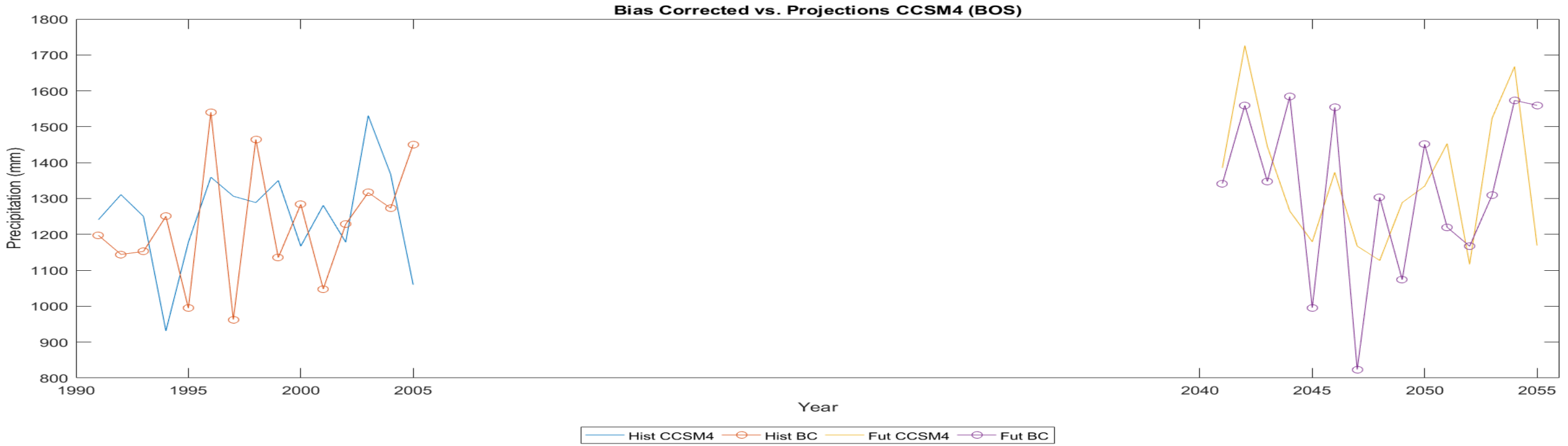
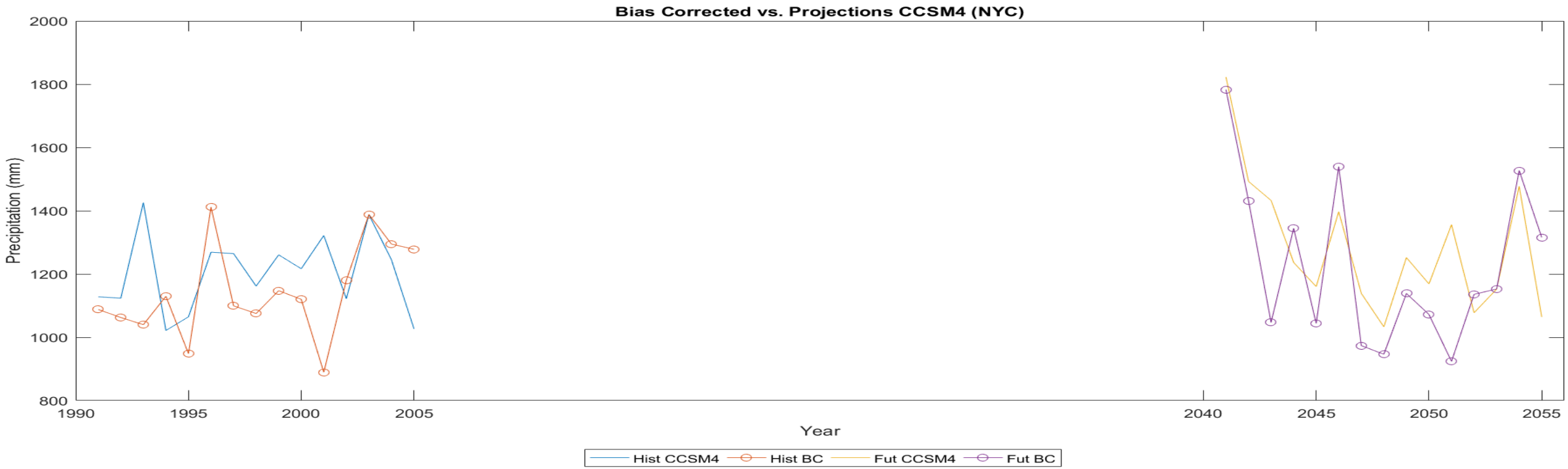
GFDL
HadGem
CGCM3
NorESM
Miroc5
MirocESM

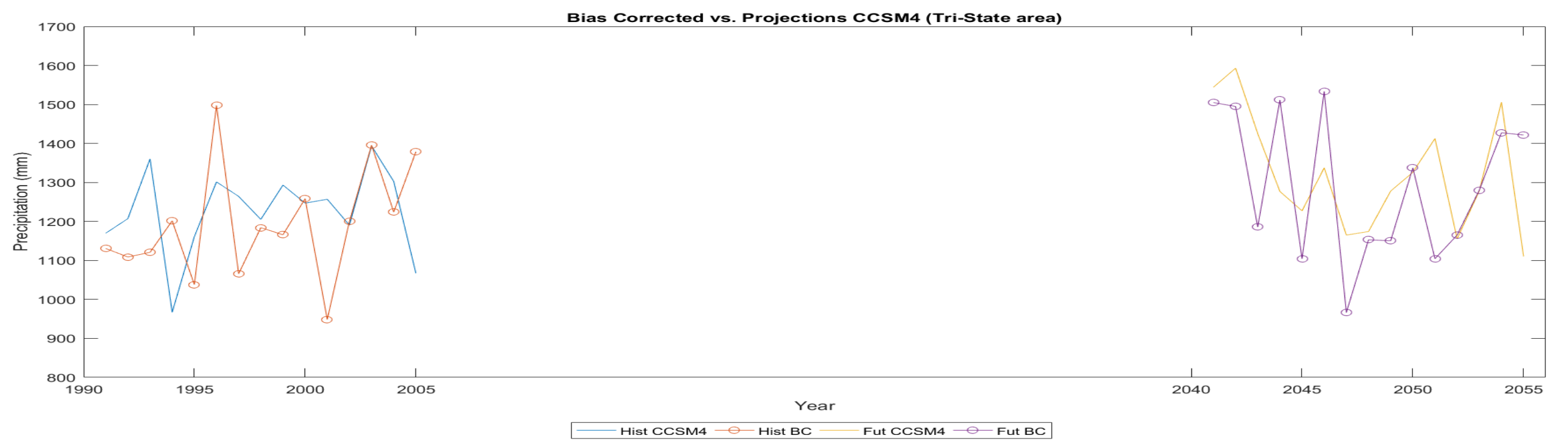

Average Annual for Models vs. Obs. 1991-2005 (NE)
Precipitation (mm)
1500
1400
1300
1200
1100
1000
900
800
700
1992
1994
1996
1998
2000
2002
2004
Year
NE Region
CCSM4
CNRM
GFDL
HadGem
CGCM3
NorESM
Miroc5
MirocESM

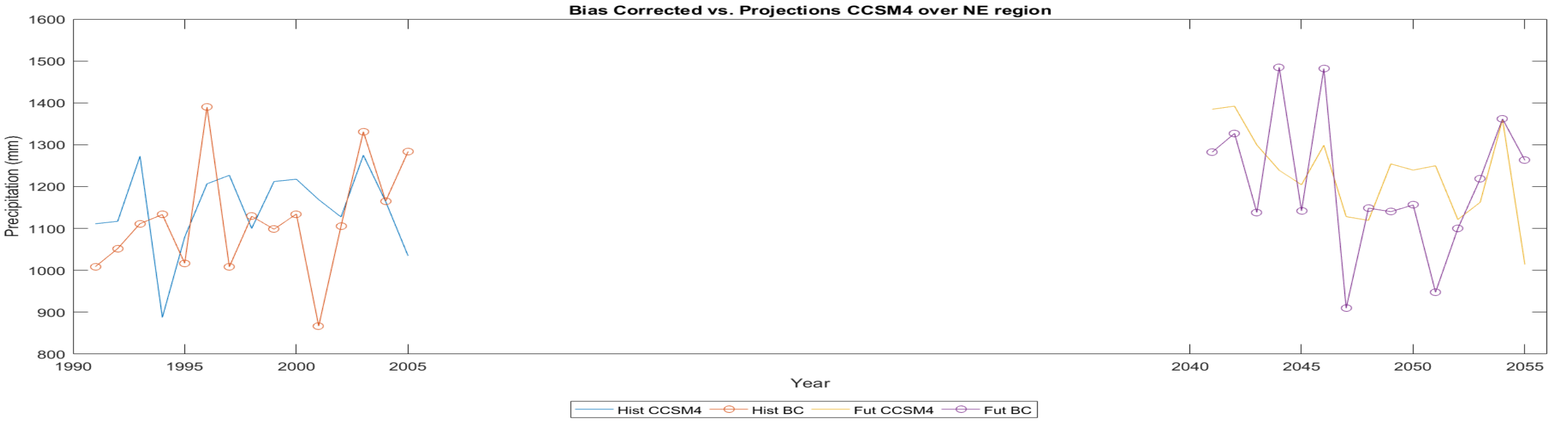
Key Results

- Is annual precipitation expected to increase in the future under the current emission scenario (RCP 8.5)?


Bias Corrected vs. Projections CCSM4 (BOS)
Precipitation (mm)
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
1990
1995
2000
2005
2040
2045
2050
2055
Year
Hist CCSM4
Hist BC
Fut CCSM4
Fut BC

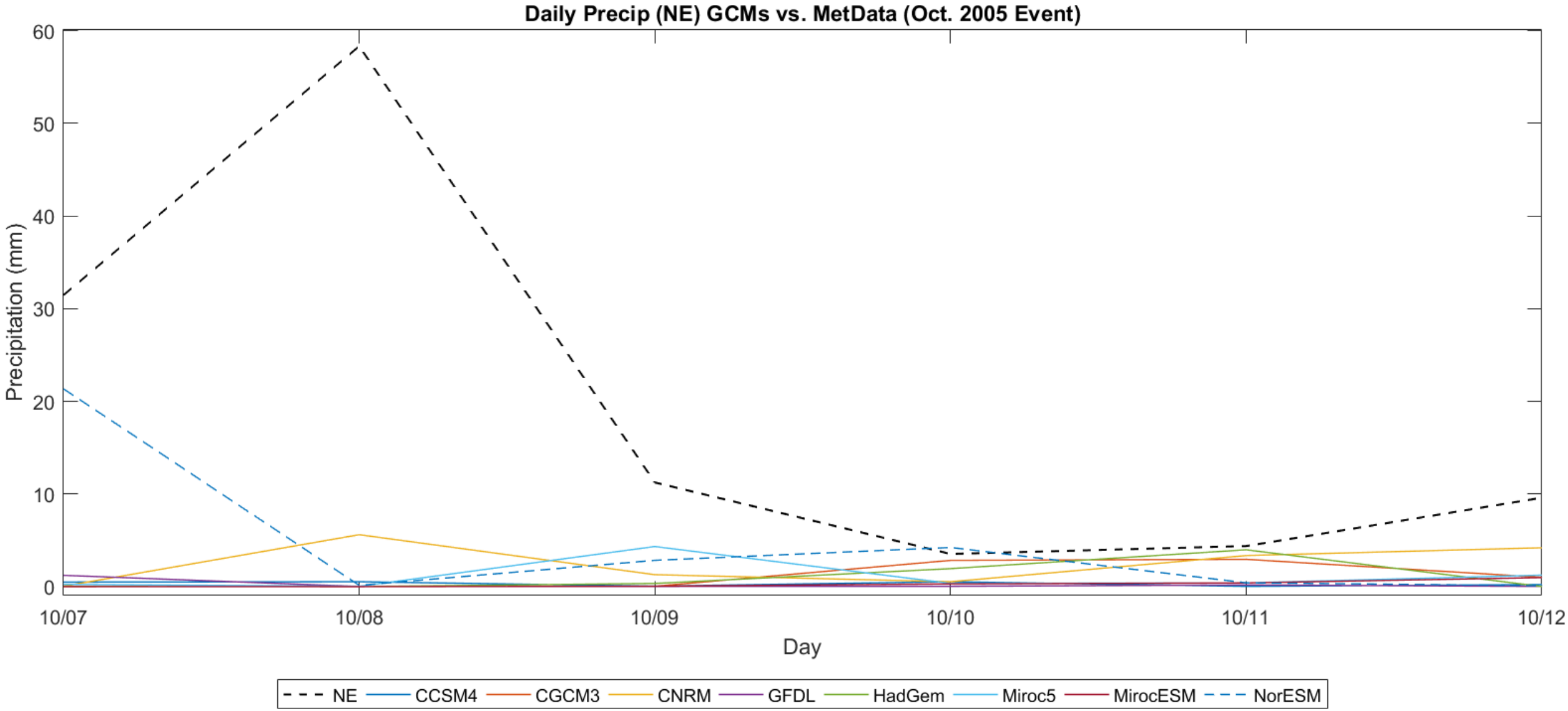

Bias Corrected vs. Projections CCSM4 (NYC)
Precipitation (mm)
2000
1800
1600
1400
1200
1000
800
1990
1995
2000
2005
2040
2045
2050
2055
Year
Hist CCSM4
Hist BC
Fut CCSM4
Fut BC


Bias Corrected vs. Projections CCSM4 (Tri-State area)
Precipitation (mm)
1700
1600
1500
1400
1300
1200
1100
1000
900
800
1990
1995
2000
2005
2040
2045
2050
2055
Year
Hist CCSM4
Hist BC
Fut CCSM4
Fut BC

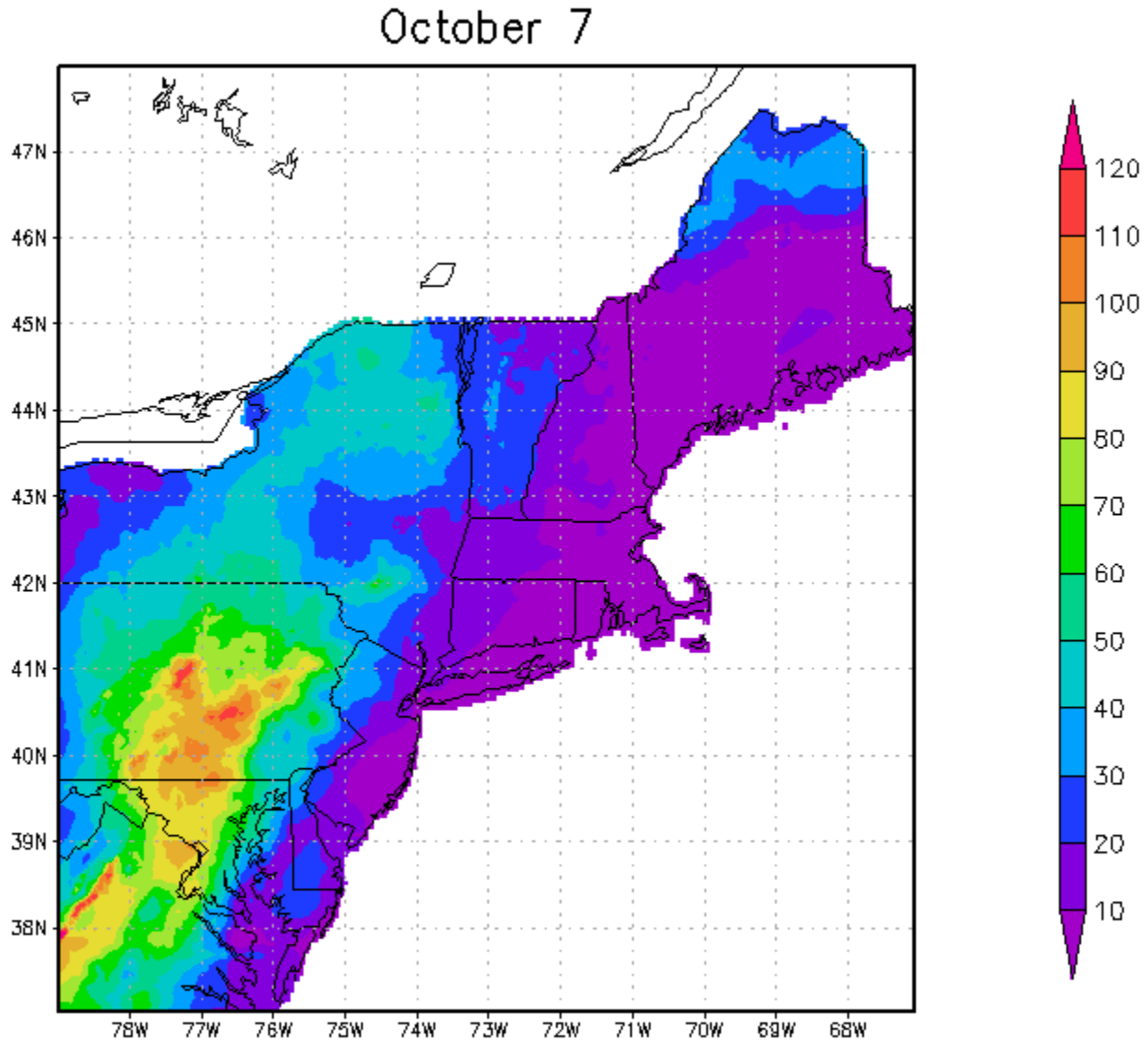

Bias Corrected vs. Projections CCSM4 over NE region
Precipitation (mm)
1600
1500
1400
1300
1200
1100
1000
900
800
1990
1995
2000
2005
2040
2045
2050
2055
Year
Hist CCSM4
Hist BC
Fut CCSM4
Fut BC

Key Results

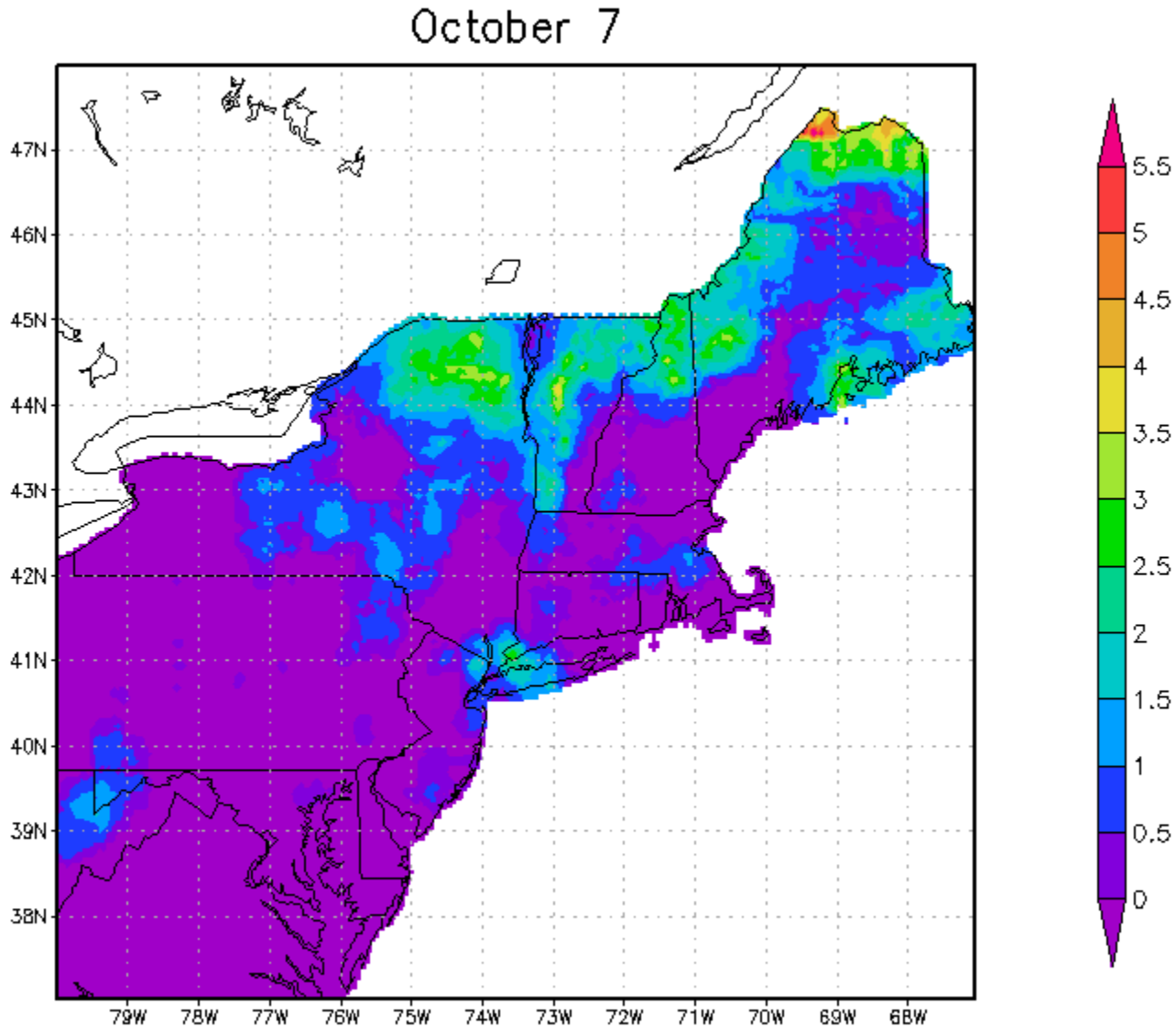
- How well are GCMs and RCMs able to capture individual events?


Daily Precip (NE) GCMs vs. MetData (Oct. 2005 Event)
Precipitation (mm)
60
50
40
30
20
10
0
10/07
10/08
10/09
10/10
10/11
10/12
Day
NE
CCSM4
CGCM3
CNRM
GFDL
HadGem
Miroc5
MirocESM
NorESM

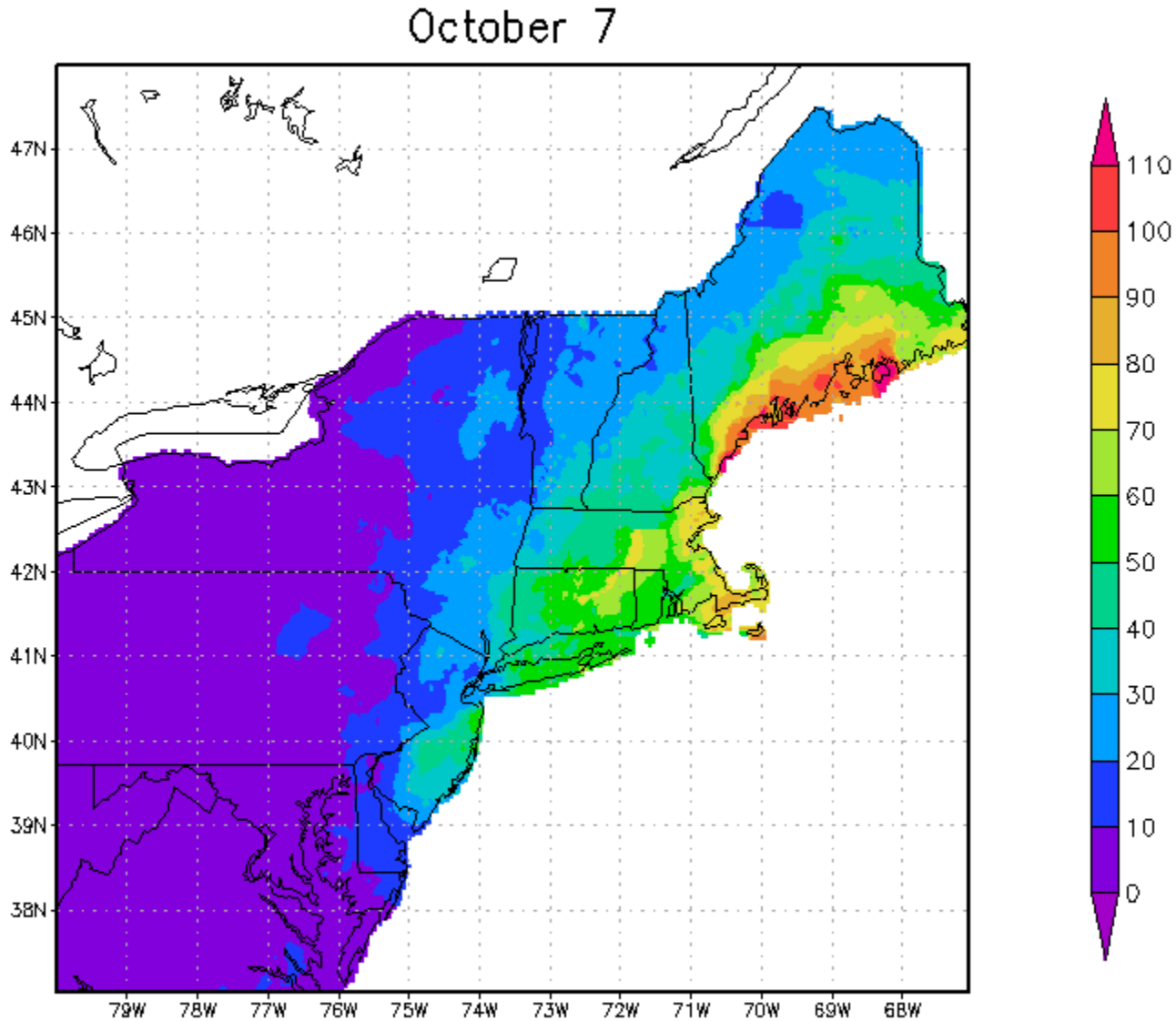
Observed (MetData)



GCM output - CCSM4

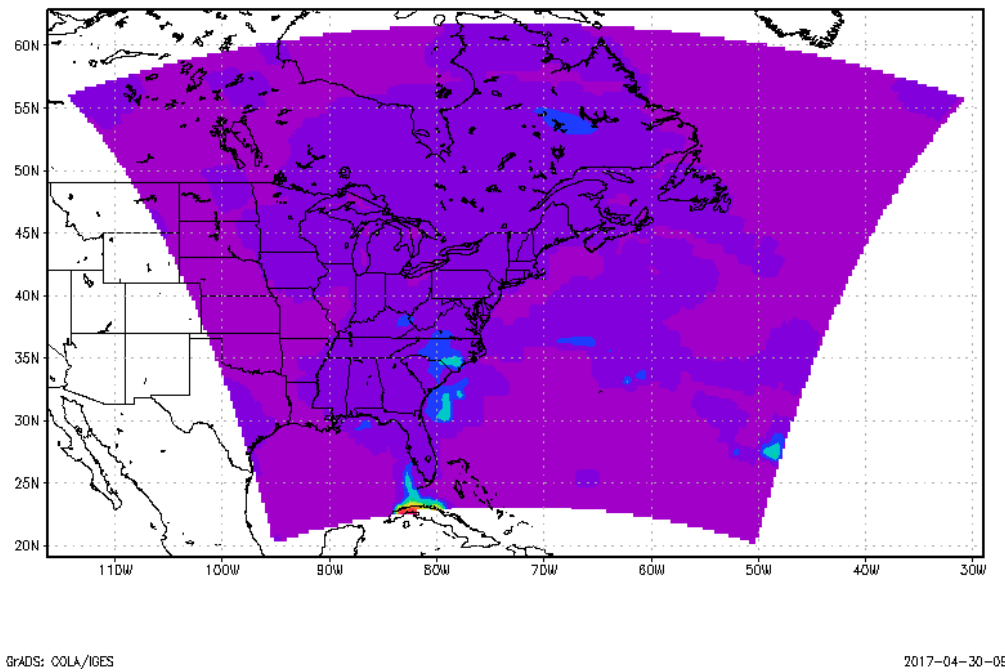


GCM output - NorESM



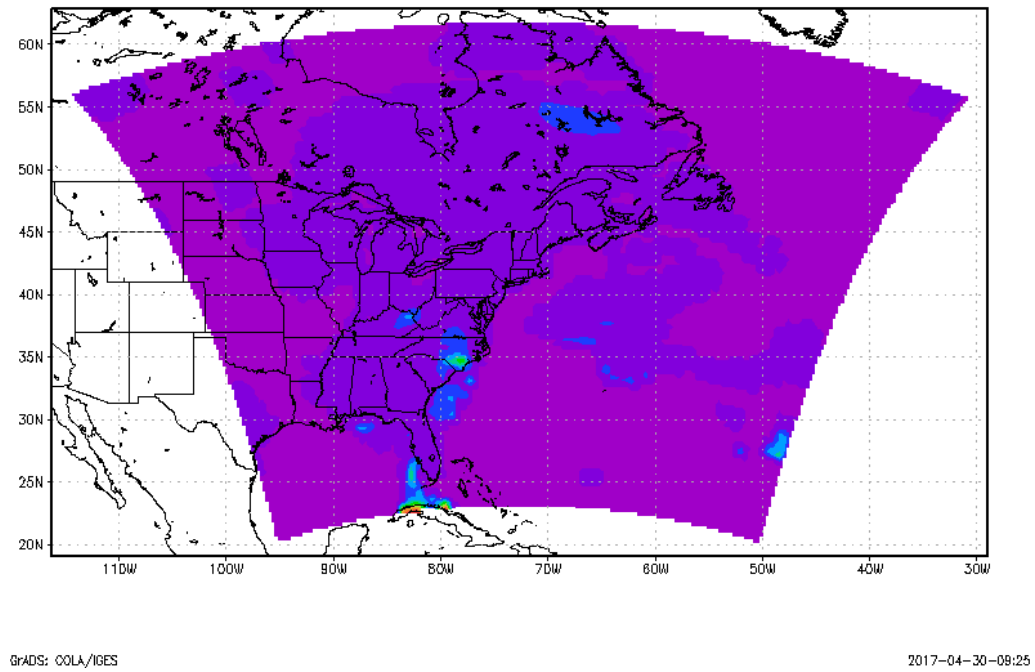
Full Domain RCM run centered on NYC

Atmospheric Model Output



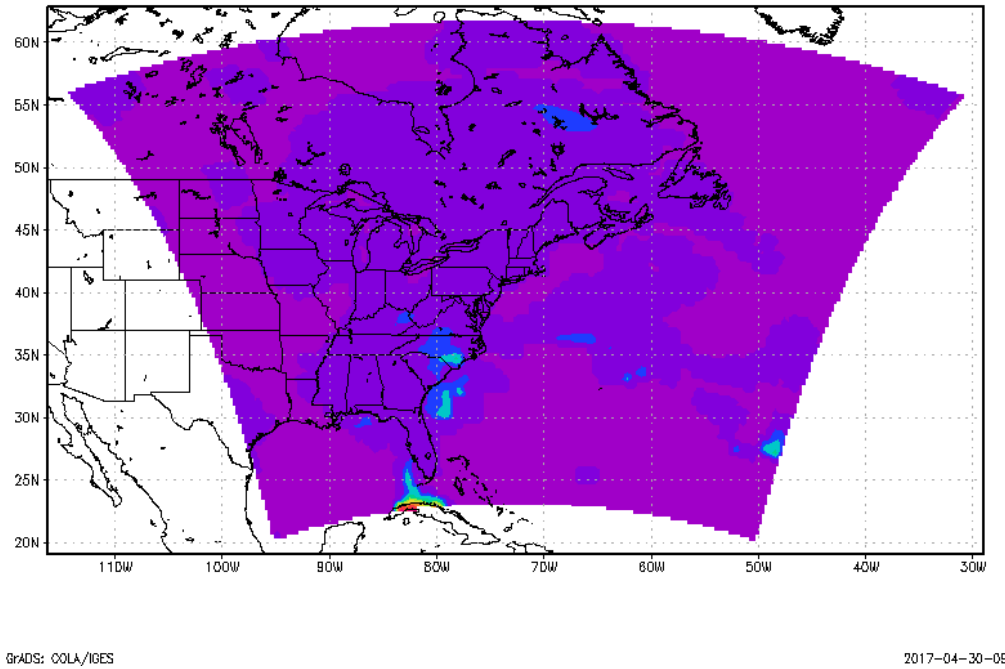
Full Domain RCM run centered on NYC

Land Surface Model Output

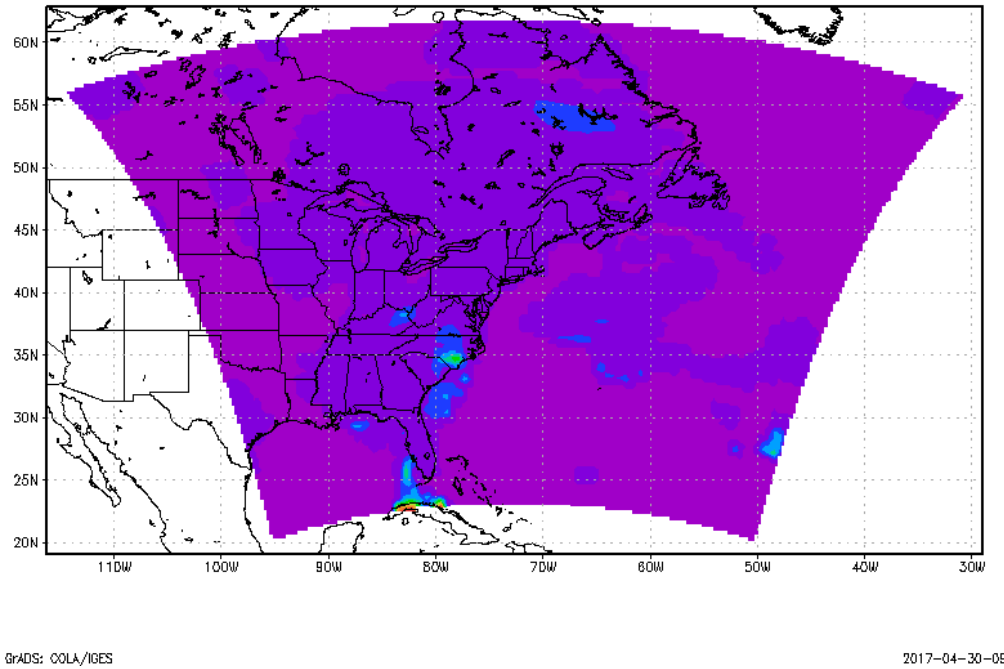


Full Domain RCM run centered on NYC

Atmospheric Model Output

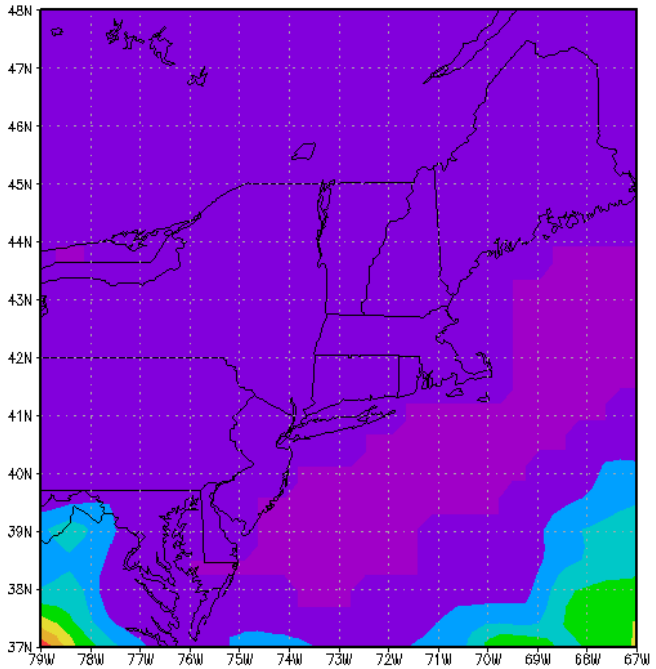


Land Surface Model Output



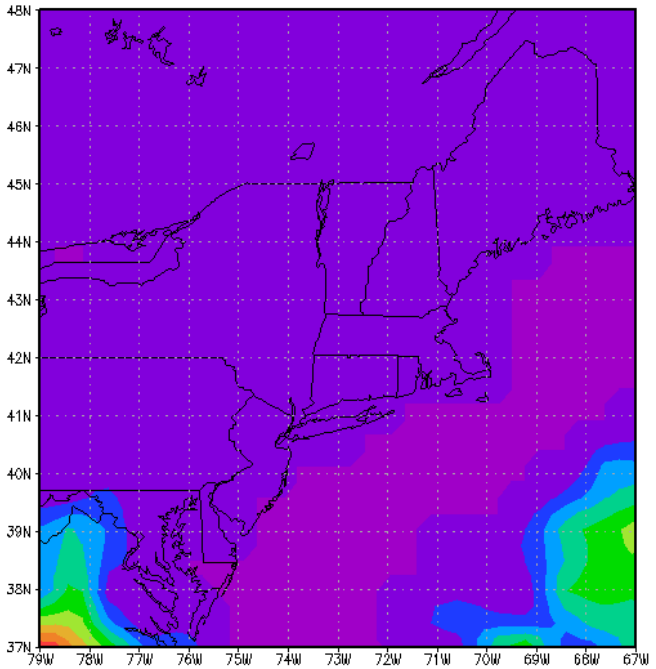
Northeast Region

Atmospheric Model Output



GrADS: COLA/IGES 2017-04-30-09:28

Land Surface Model Output



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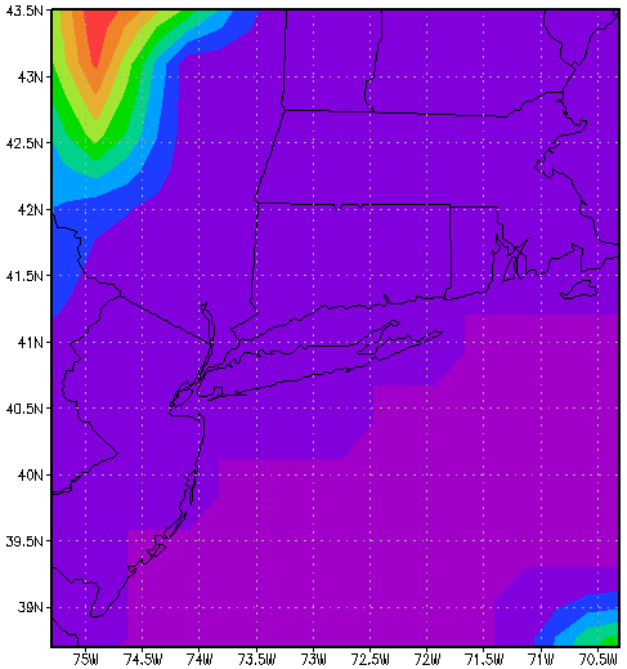
Tri-State Area

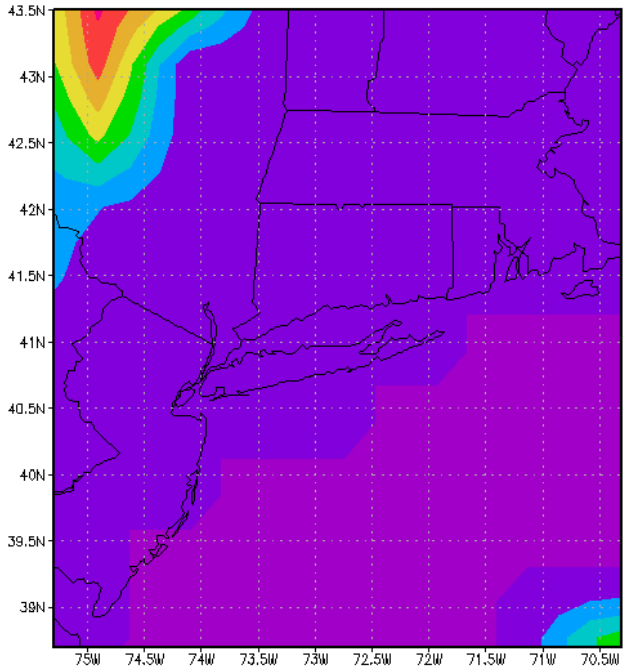
Atmospheric Model Output



GrADS: COLA/IGES

2017-04-30-09:40

Land Surface Model Output



GrADS: COLA/IGES

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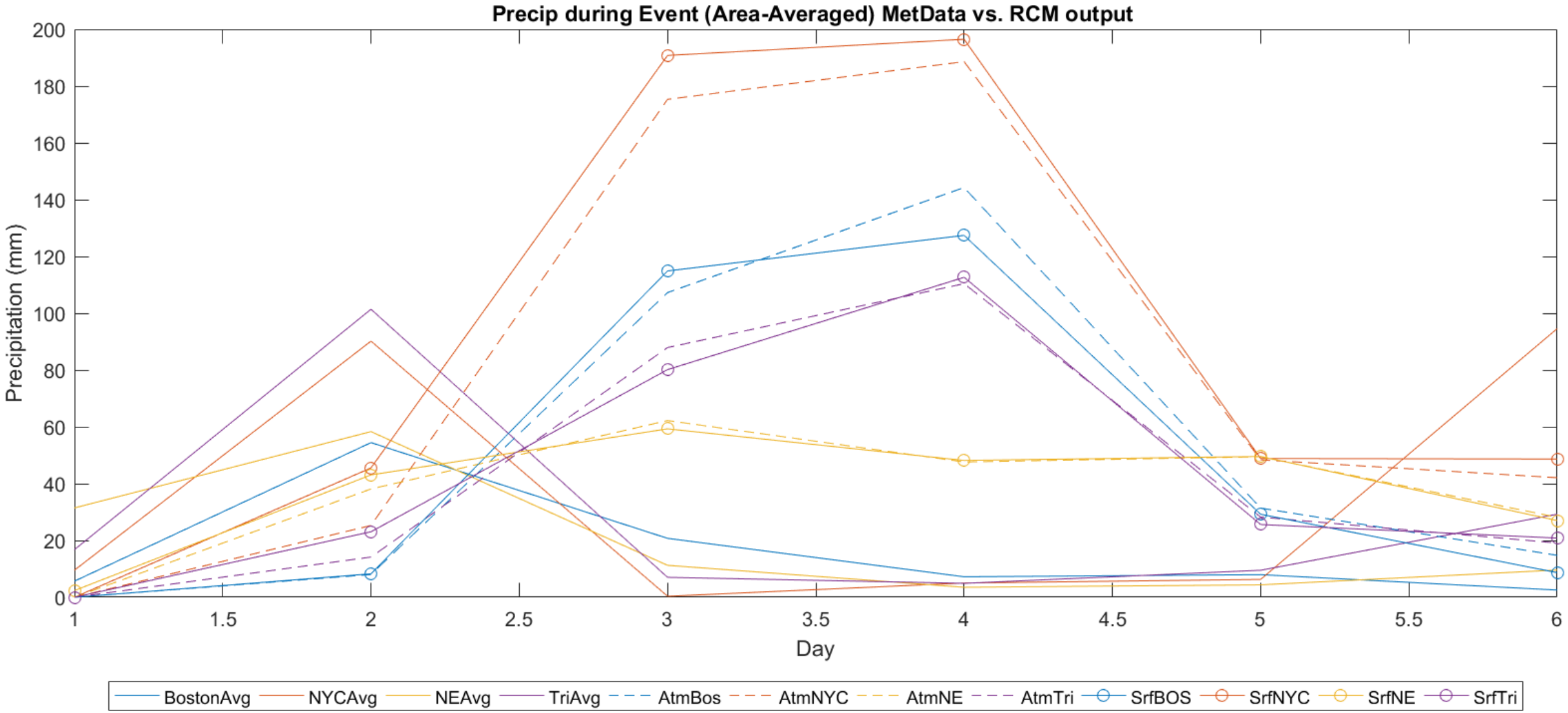

Precip during Event (Area-Averaged) MetData vs. RCM output
Precipitation (mm)
Day
0
20
40
60
80
100
120
140
160
180
200
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
BostonAvg
NYCAvg
NEAvg
TriAvg
AtmBos
AtmNYC
AtmNE
AtmTri
SrfBOS
SrfNYC
SrfNE
SrfTri

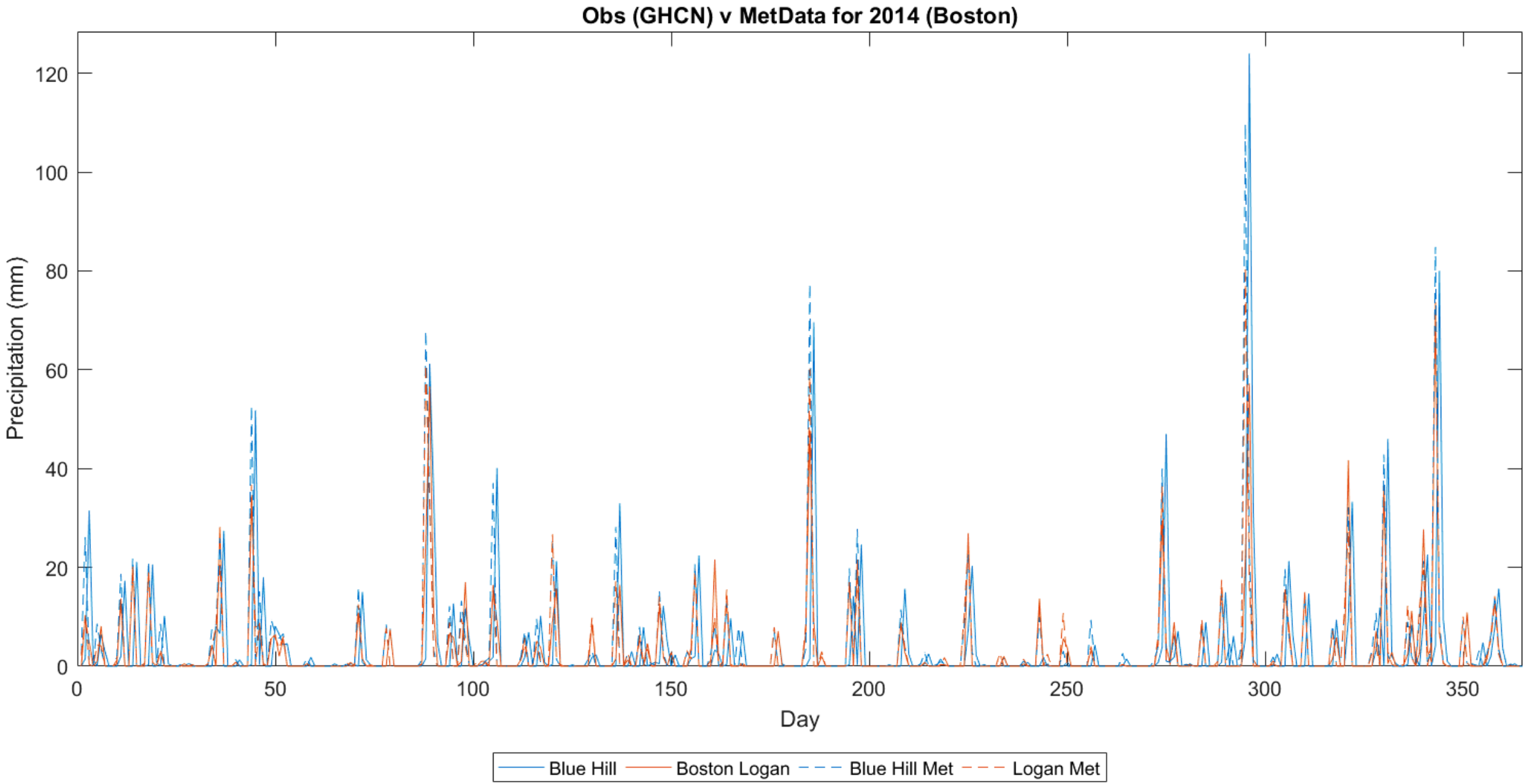
Challenges

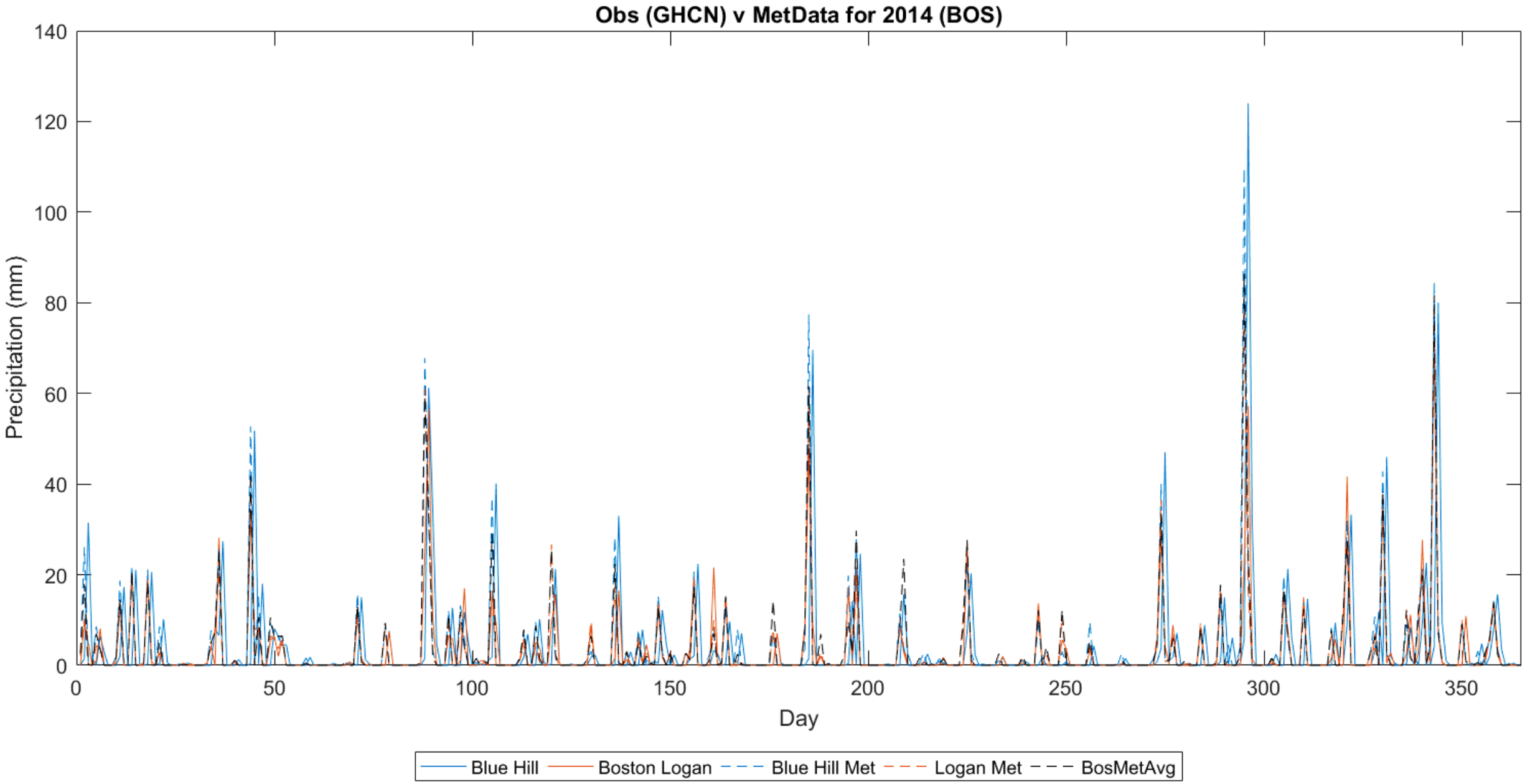
- Results not conclusive
- Difference in domain size, boundary conditions, model uncertainties, resolution, missing data, etc.
- Models are not particularly skillful at representing processes, especially in smaller domains like BOS and NYC
- Interannual variability for precipitation is particularly difficult to model in the Northeast region and GCMs do not reflect observations very well
- Attribution of changes in precipitation are difficult to quantify
- Difficult to compare events at daily rather than hourly scale
- So much to do, so little time

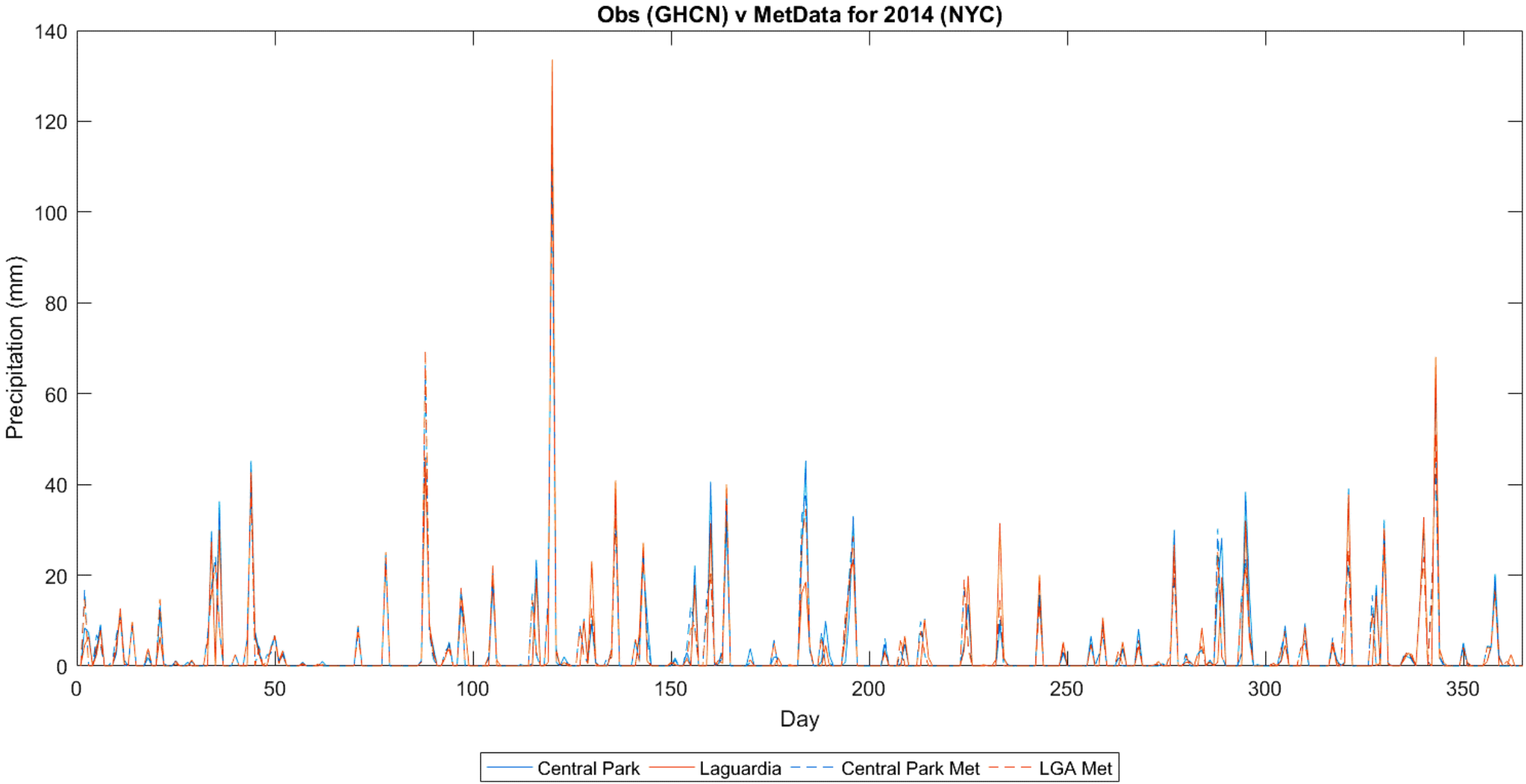
Conclusions and Further Research

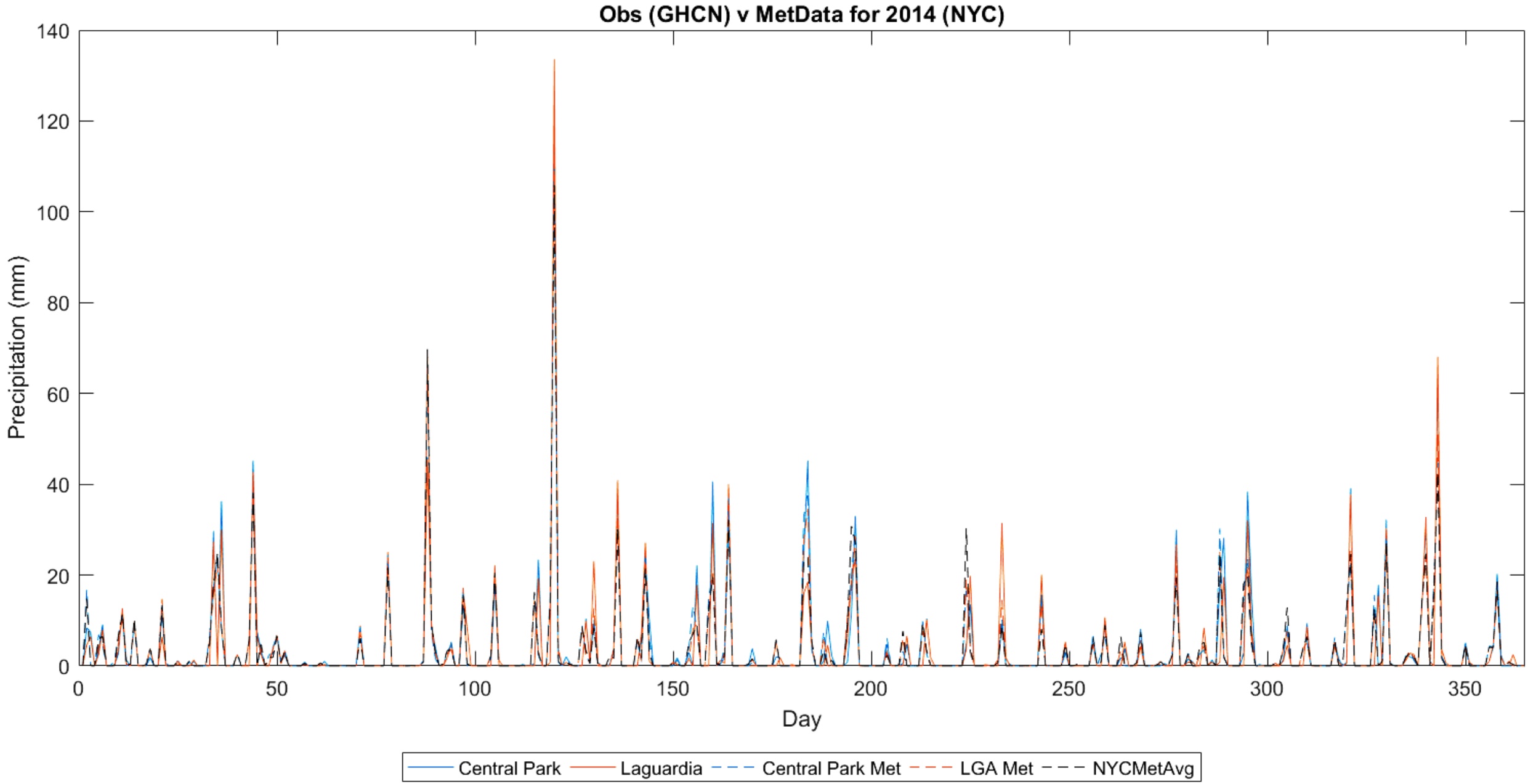
- There are some significant differences between annual averages of individual stations located throughout the Boston area, but not significantly different from the regional mean for the study domain
- The Boston domain had higher annual precipitation on average compared to the other study domains from 1991-2005, but not a significant difference
- The selected GCMs had some difficulty capturing the observed interannual precipitation variability for the study period (1991-2005)
- It is unclear whether average annual precipitation is expected to increase overall for the Northeast region in the future
- The RCM was better able to capture some of the observed precipitation during the October 2005 event.
- More research needs to be done on the Northeast region in general for future precipitation extremes, as well as urban areas and whether or not they are expected to see increases in frequency and magnitude of precipitation in the future.

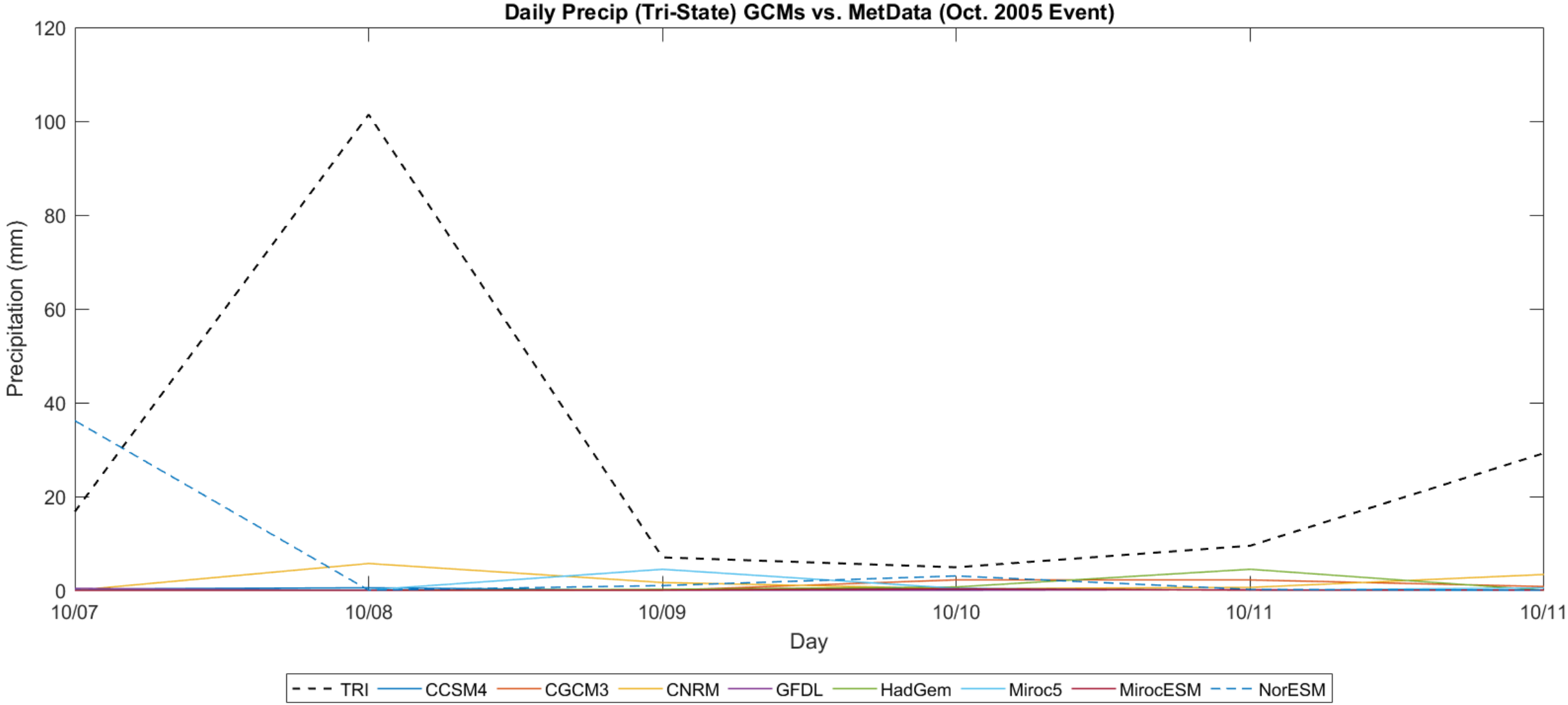
Supplementary Slides

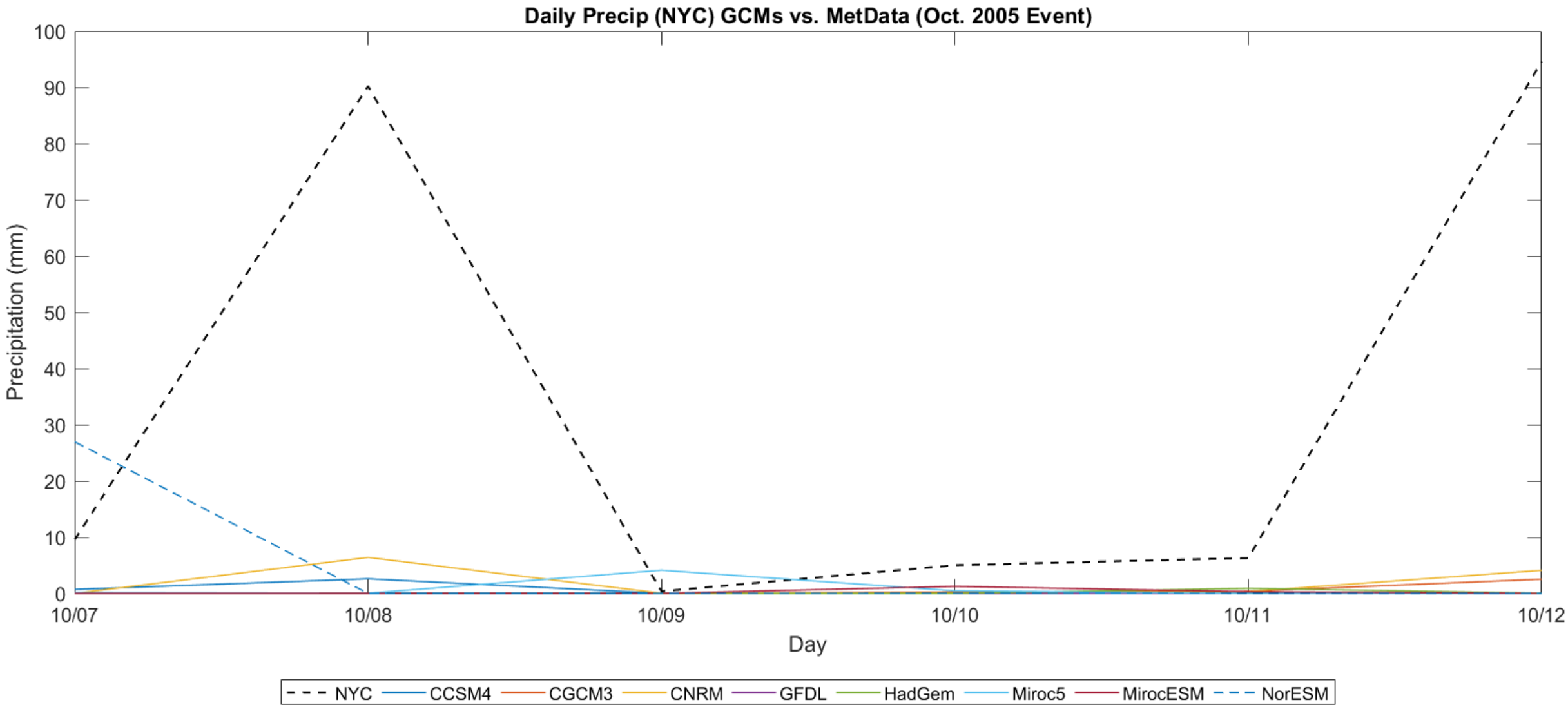

Obs (GHCN) v MetData for 2014 (Boston)
Precipitation (mm)
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
Day
Blue Hill
Boston Logan
Blue Hill Met
Logan Met

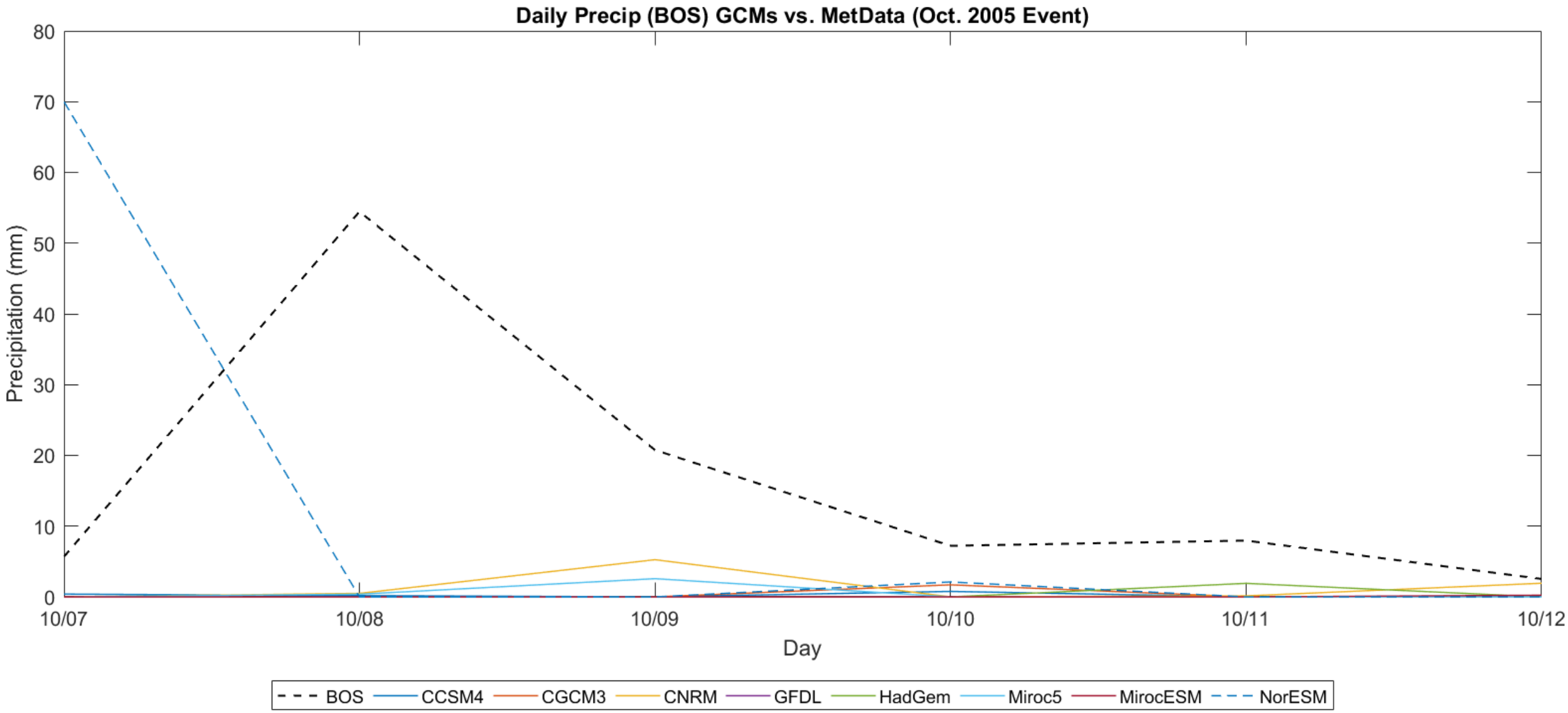

Obs (GHCN) v MetData for 2014 (BOS)
Precipitation (mm)
Day
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
Blue Hill
Boston Logan
Blue Hill Met
Logan Met
BosMetAvg


Obs (GHCN) v MetData for 2014 (NYC)
Precipitation (mm)
Day
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
Central Park
Laguardia
Central Park Met
LGA Met


Obs (GHCN) v MetData for 2014 (NYC)
Precipitation (mm)
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
Day
Central Park
Laguardia
Central Park Met
LGA Met
NYCMetAvg

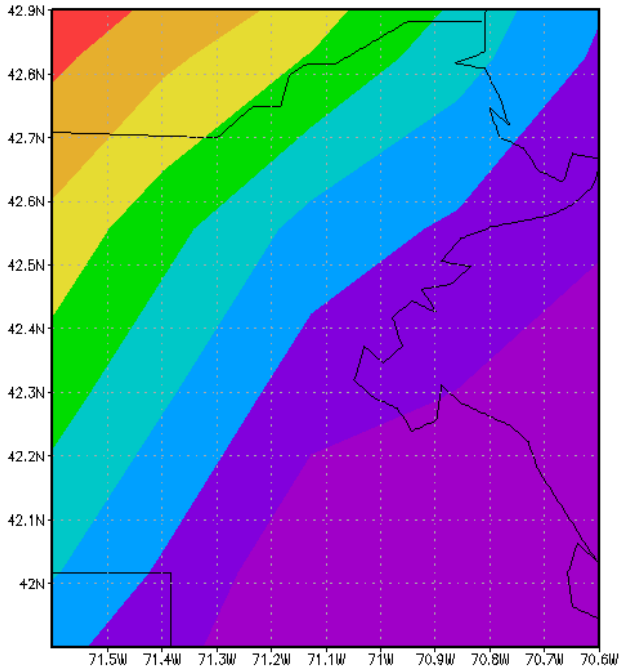

Daily Precip (Tri-State) GCMs vs. MetData (Oct. 2005 Event)
Precipitation (mm)
120
100
80
60
40
20
0
10/07
10/08
10/09
10/10
10/11
10/11
Day
TRI
CCSM4
CGCM3
CNRM
GFDL
HadGem
Miroc5
MirocESM
NorESM


Daily Precip (NYC) GCMs vs. MetData (Oct. 2005 Event)
Precipitation (mm)
100
90
80
70
60
50
40
30
20
10
0
10/07
10/08
10/09
10/10
10/11
10/12
Day
NYC
CCSM4
CGCM3
CNRM
GFDL
HadGem
Miroc5
MirocESM
NorESM


Daily Precip (BOS) GCMs vs. MetData (Oct. 2005 Event)
Precipitation (mm)
80
70
60
50
40
30
20
10
0
10/07
10/08
10/09
10/10
10/11
10/12
Day
BOS
CCSM4
CGCM3
CNRM
GFDL
HadGem
Miroc5
MirocESM
NorESM

Boston

Atmospheric Model Output



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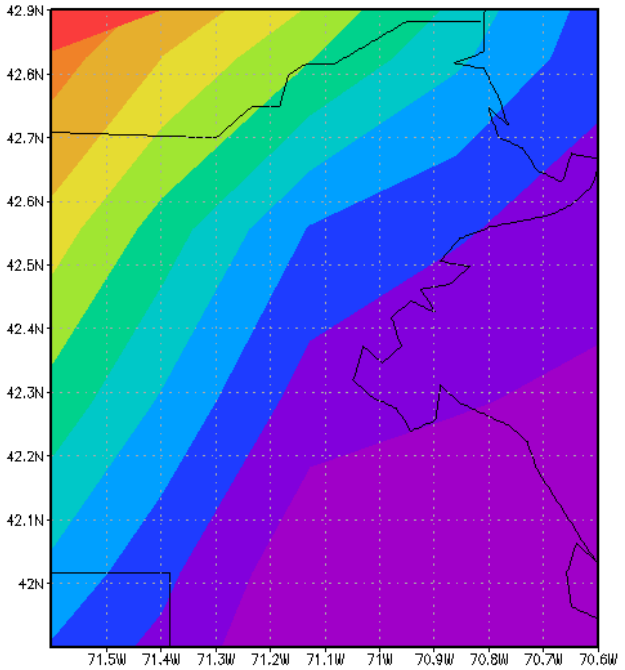
Land Surface Model Output



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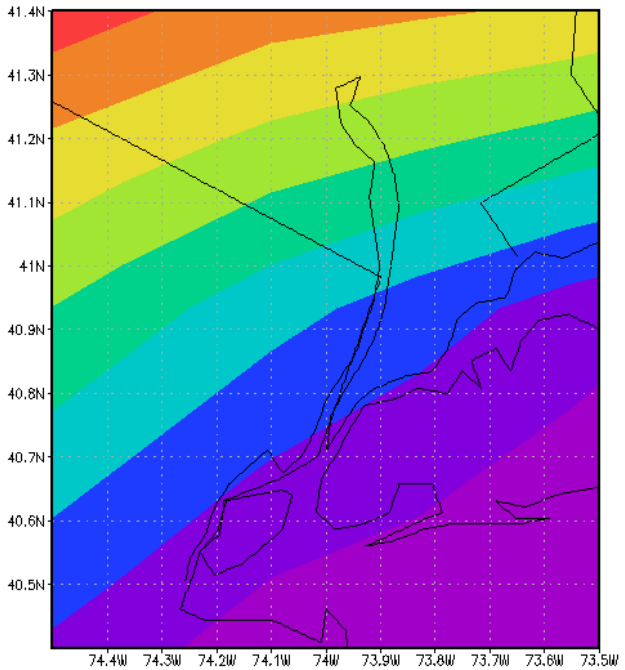
NYC

Atmospheric Model Output



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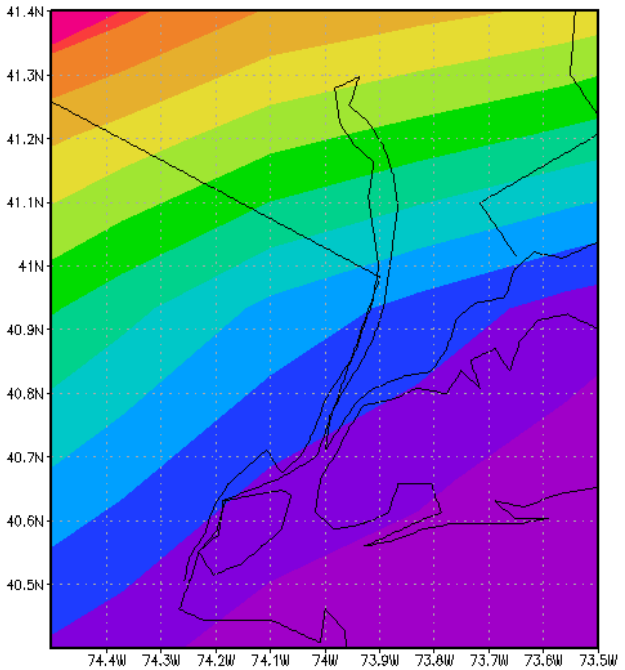
Land Surface Model Output



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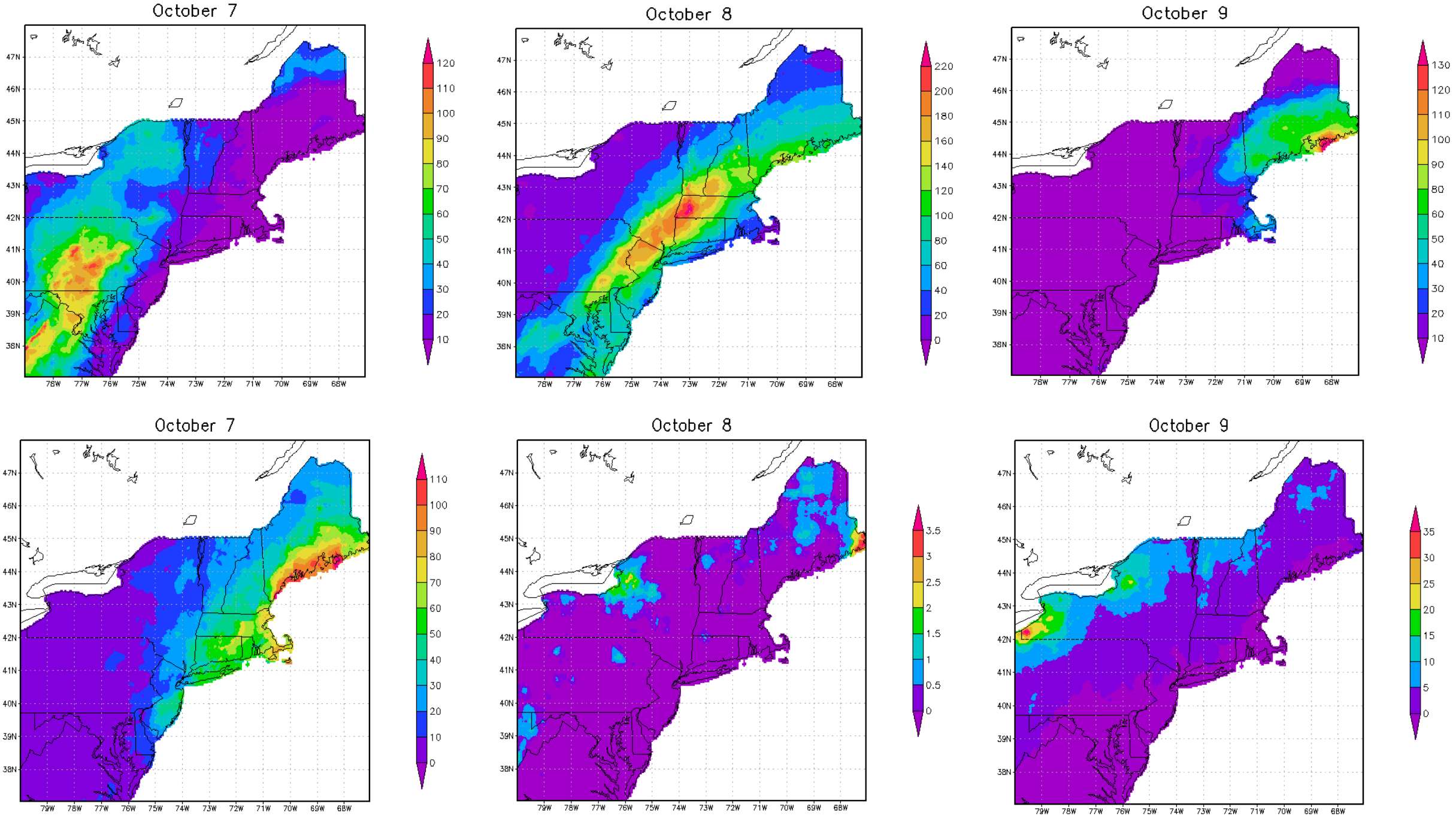
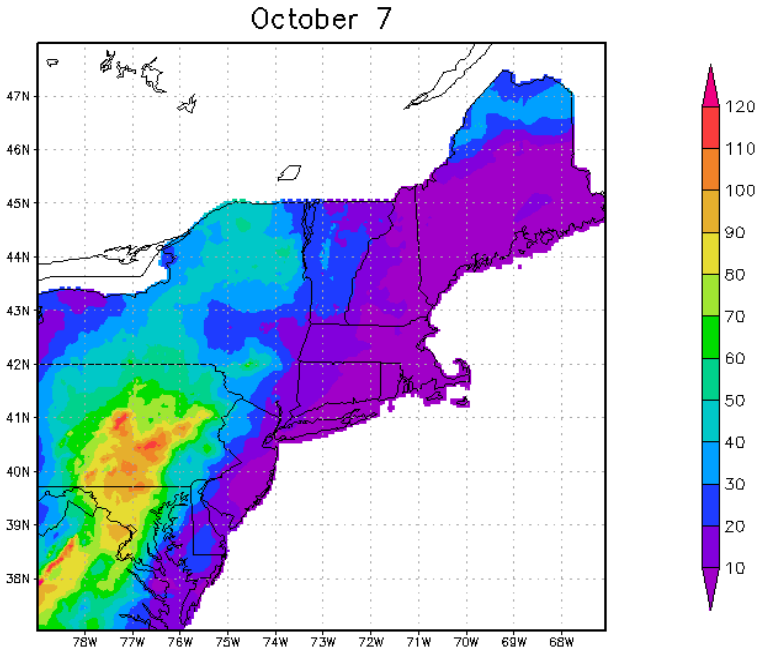
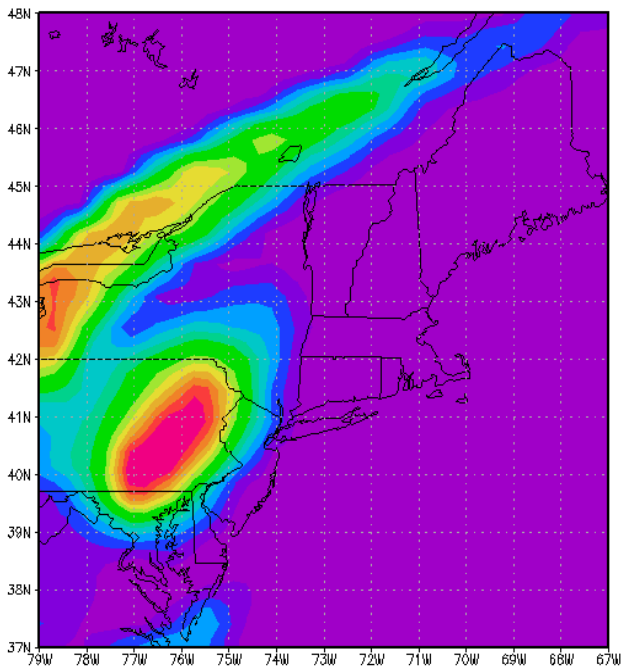
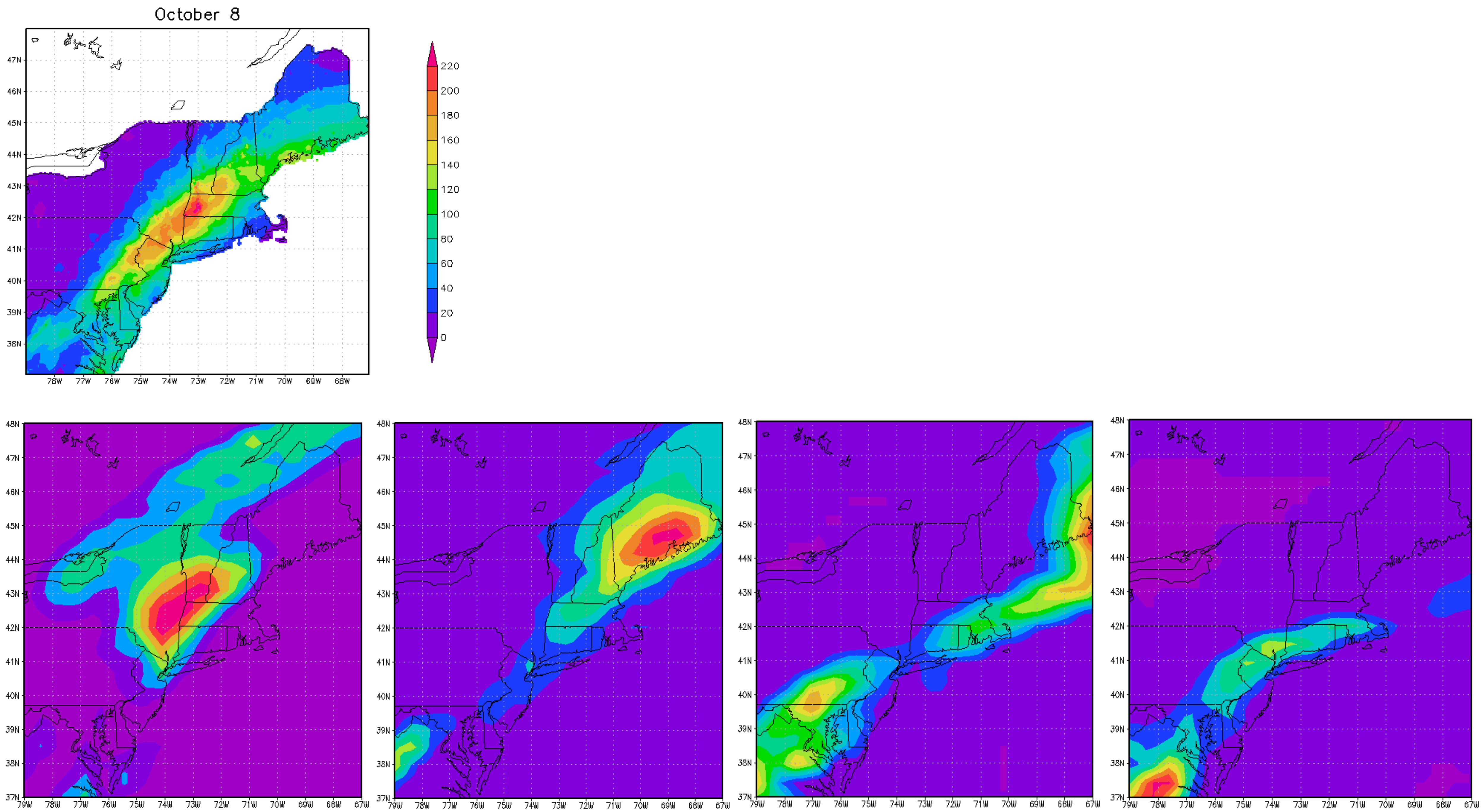
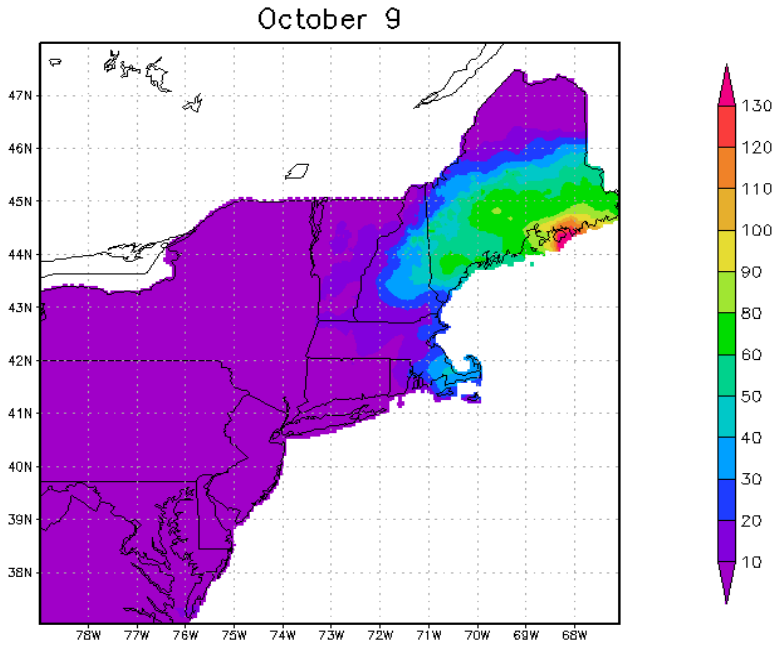
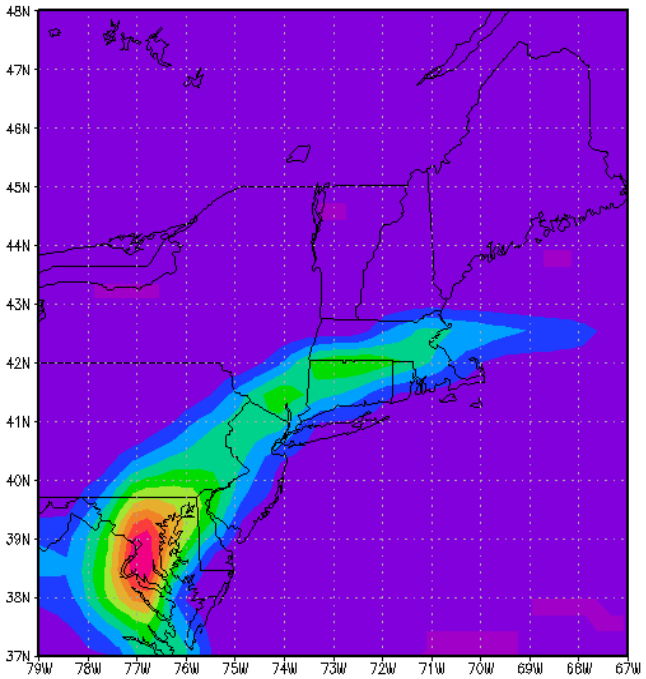

October 7
October 8
October 9
October 7
October 8
October 9


October 7
47N
46N
45N
44N
43N
42N
41N
40N
39N
38N
78W
77W
76W
75W
74W
73W
72W
71W
70W
69W
68W
120
110
100
90
80
70
60
50
40
30
20
10


48N
47N
46N
45N
44N
43N
42N
41N
40N
39N
38N
37N
79W
78W
77W
76W
75W
74W
73W
72W
71W
70W
69W
68W
67W


October 8
220
200
180
160
140
120
100
80
60
40
20
0


October 9
47N
46N
45N
44N
43N
42N
41N
40N
39N
38N
78W
77W
76W
75W
74W
73W
72W
71W
70W
69W
68W
130
120
110
100
90
80
60
50
40
30
20
10


48N
47N
46N
45N
44N
43N
42N
41N
40N
39N
38N
37N
79W
78W
77W
76W
75W
74W
73W
72W
71W
70W
69W
68W
67W