

# Improving CFS Precipitation and 2m Temperature Anomaly Outlooks from Week-1 to Week-6 with Machine Learning

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NOAA Center for Weather and Climate Prediction

# Outline

- **Motivation**
- **NN Basic**
- **Preliminary Results**
- **Summary**

# Motivation

Demand for S2S P & T2m Fcst Steadily Increasing

Problem: **Low Forecast Skill**

Post-Processing:

Data Sets

$$\{ (f_1, f_2, \dots, f_n)_p, O_p \}_{p=1,2,\dots,N}$$

Where

$f_1, f_2, \dots, f_n$  -- predictors: 1999-2019 daily BC CFSv2 Week 1-6 P & T2m fcsts, .....

$O_p$  -- predictands: 1999-2019 daily Week 1-6 P & T2m Obs

Mapping:  $O = M(F)$

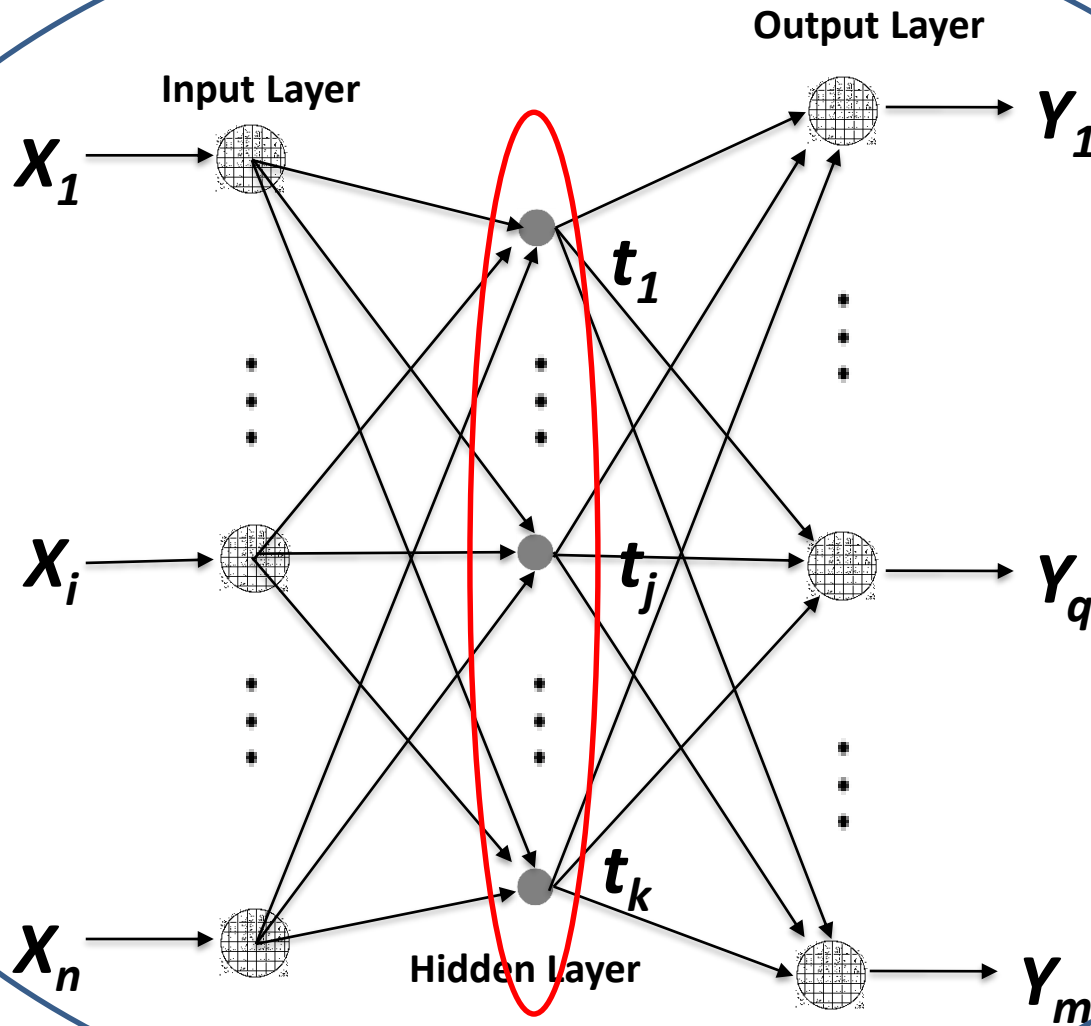
*Traditional method: MLR -- MOS*

*Can AI or Machine Learning beat BC CFS?*

**Big Data!!!**

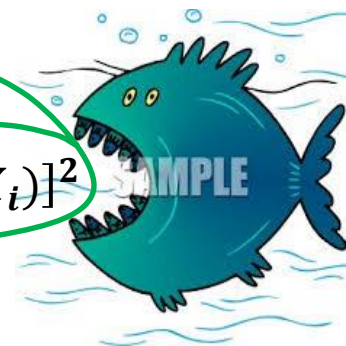
**Predictors**

**Predictands**

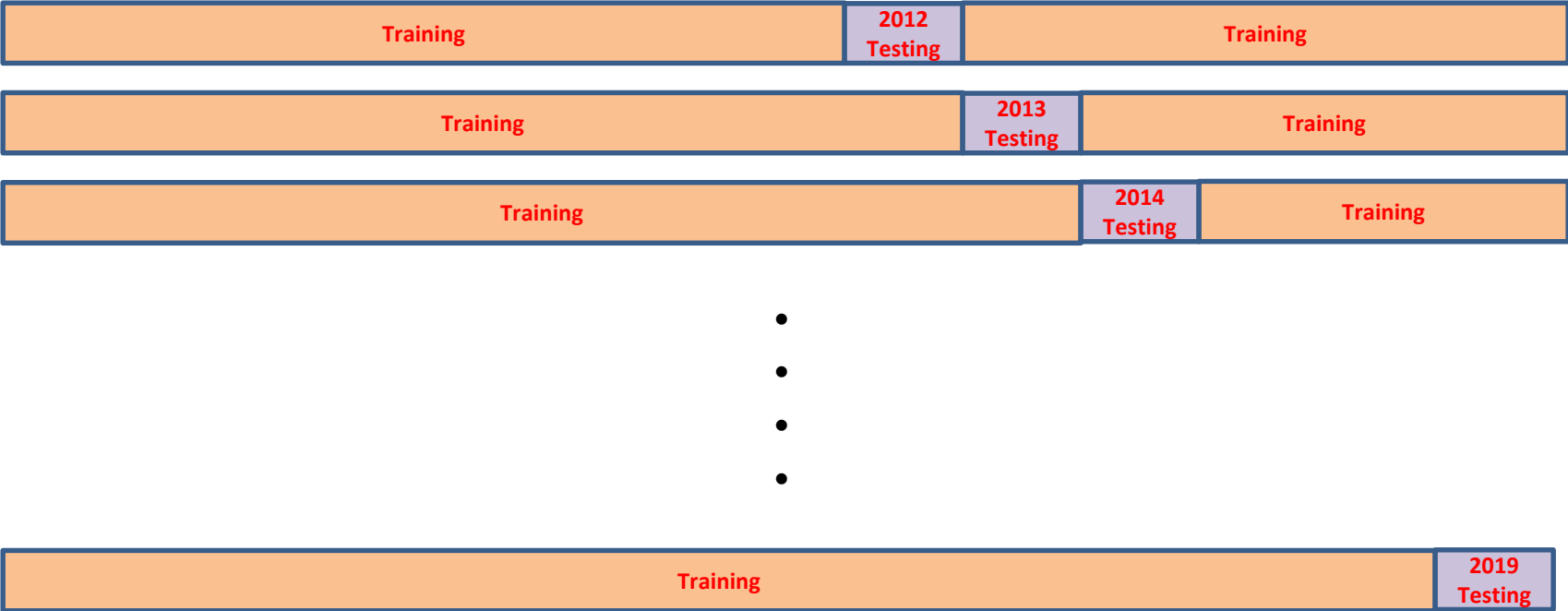


- Non-linear impact
- Pattern relationship
- Co-variability

$$E = \frac{1}{N} \sum_{i=1}^N [Z_i - NN(X_i)]^2$$



# 8 Years Cross-Validation

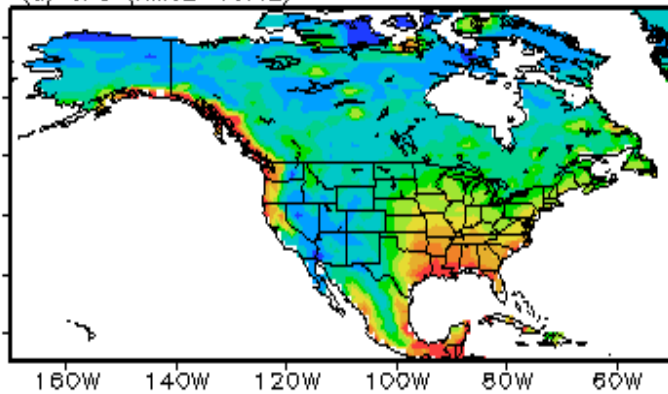


1999 – 2019 daily Week 1-6 forecasts = 6 x 7670 daily samples over North America

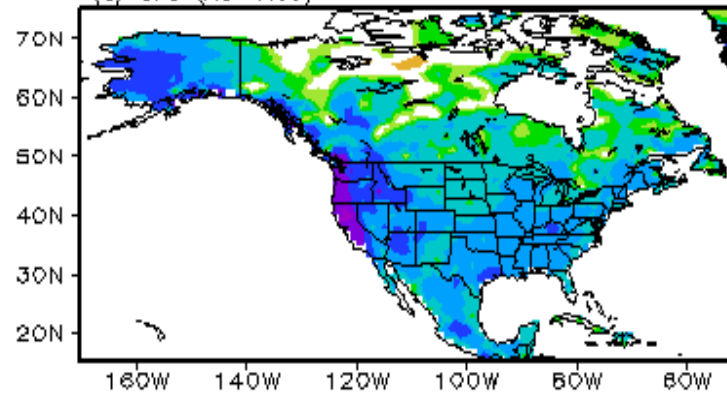


# Forecast Week-1 P Daily RMSE (mm) & AC (2012-2019)

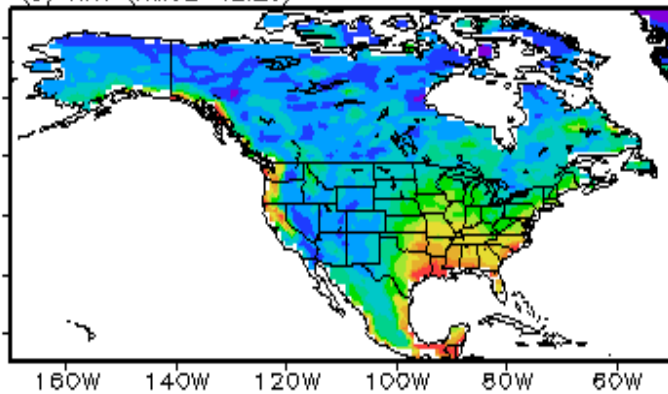
(a) CFS (RMSE=15.42)



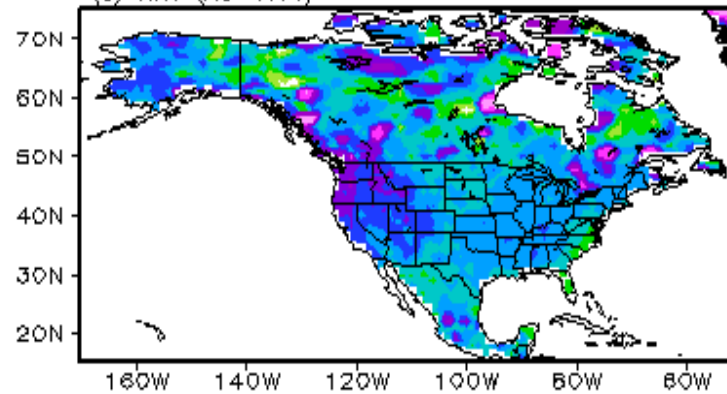
(d) CFS (AC=0.35)



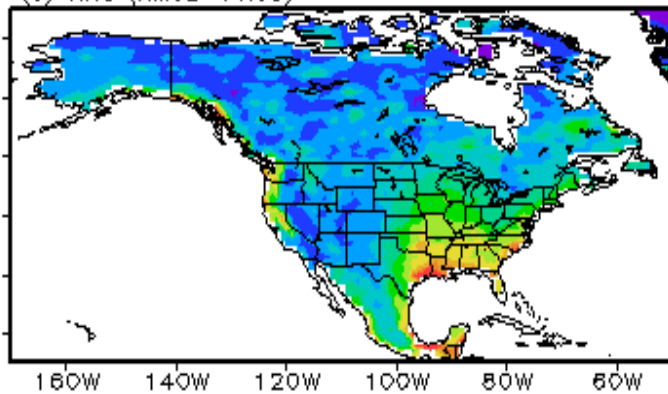
(b) NNv (RMSE=12.20)



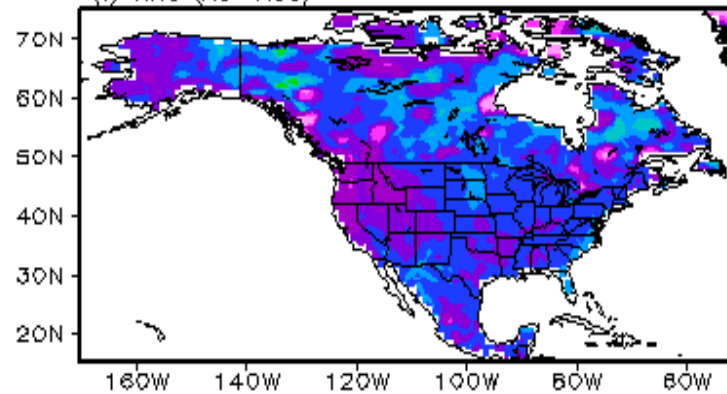
(e) NNv (AC=0.44)



(c) NNd (RMSE=11.08)



(f) NNd (AC=0.58)

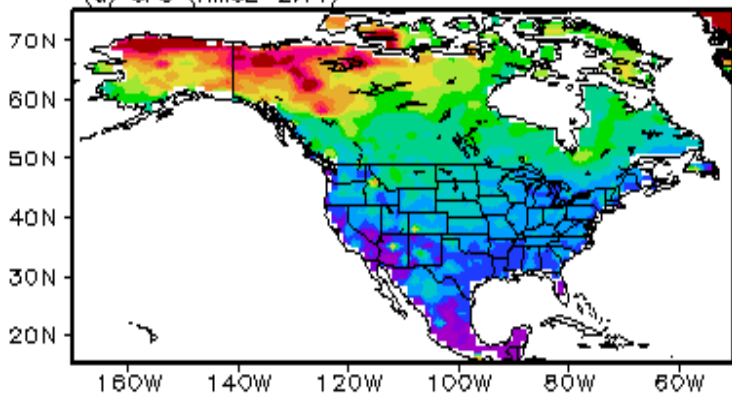


CFS: Bias corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent Test

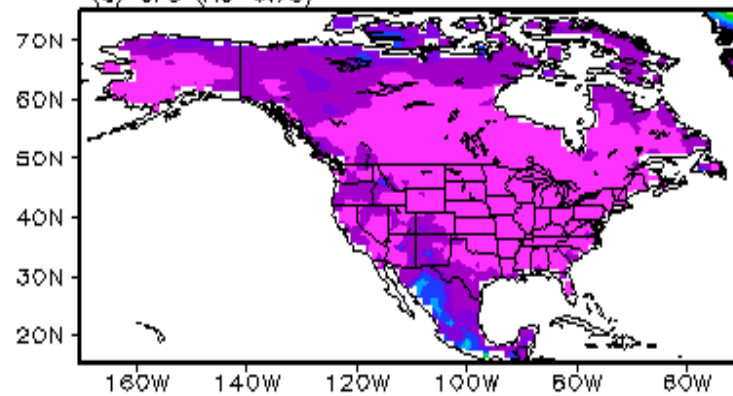


# Forecast Week-1 T2m Daily RMSE (°C) & AC (2012-2019)

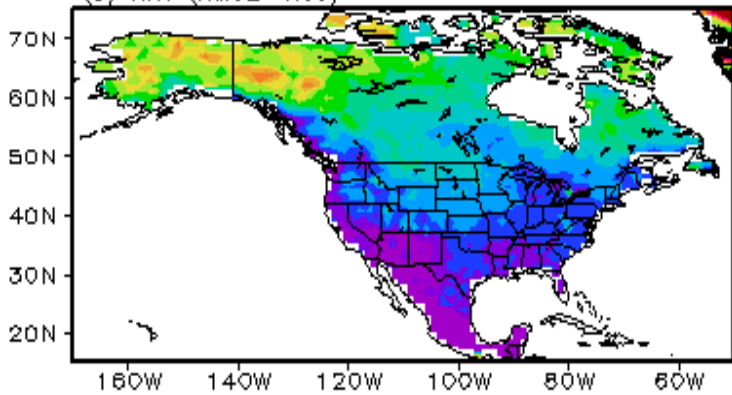
(a) CFS (RMSE=2.11)



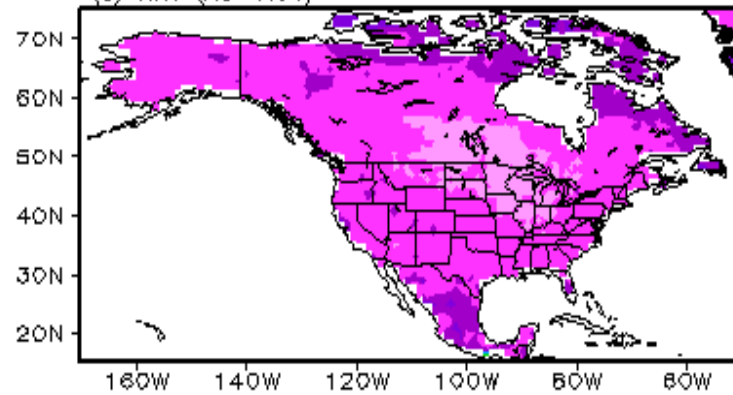
(d) CFS (AC=0.78)



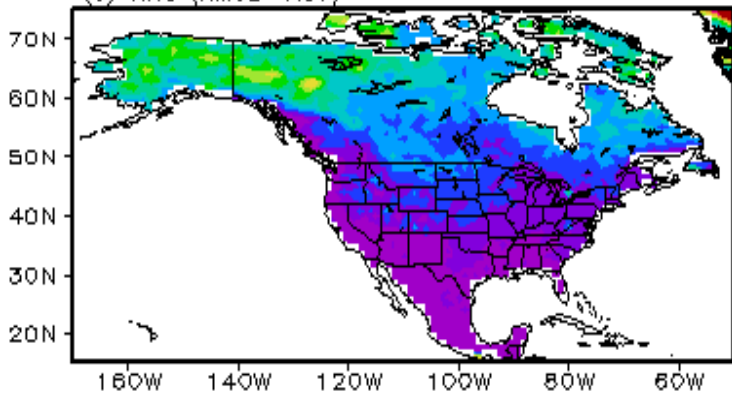
(b) NNv (RMSE=1.83)



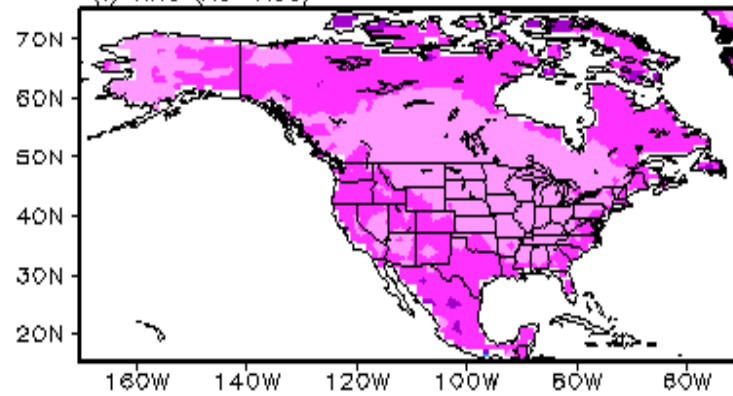
(e) NNv (AC=0.84)



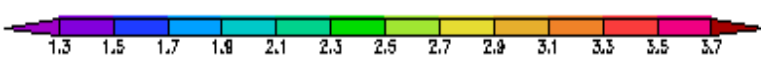
(c) NNd (RMSE=1.57)



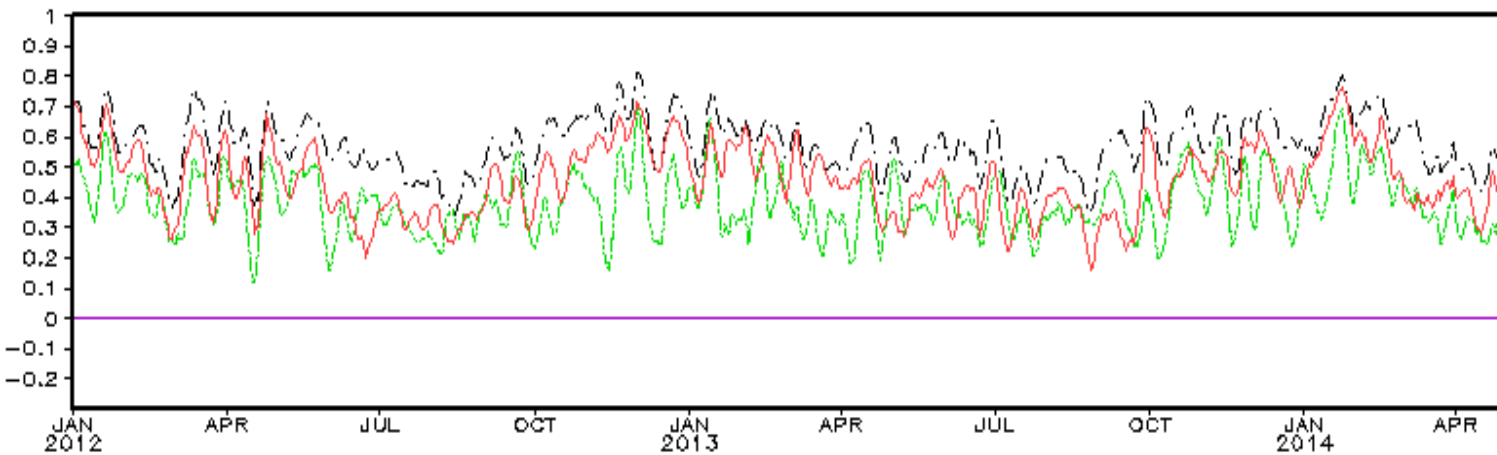
(f) NNd (AC=0.88)



CFS: Bias corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent Test

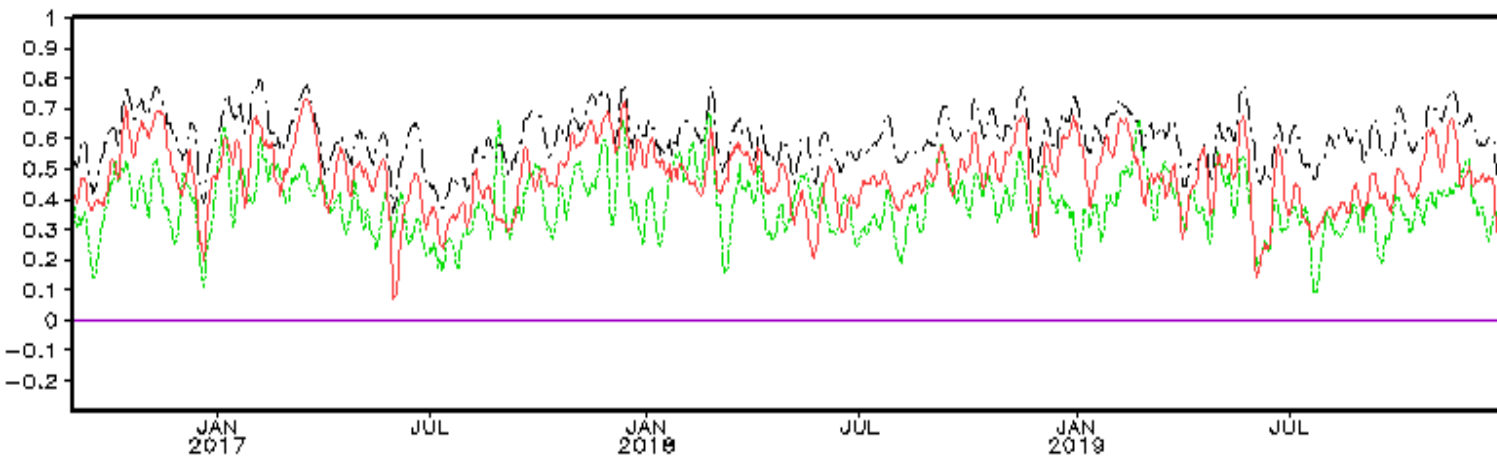
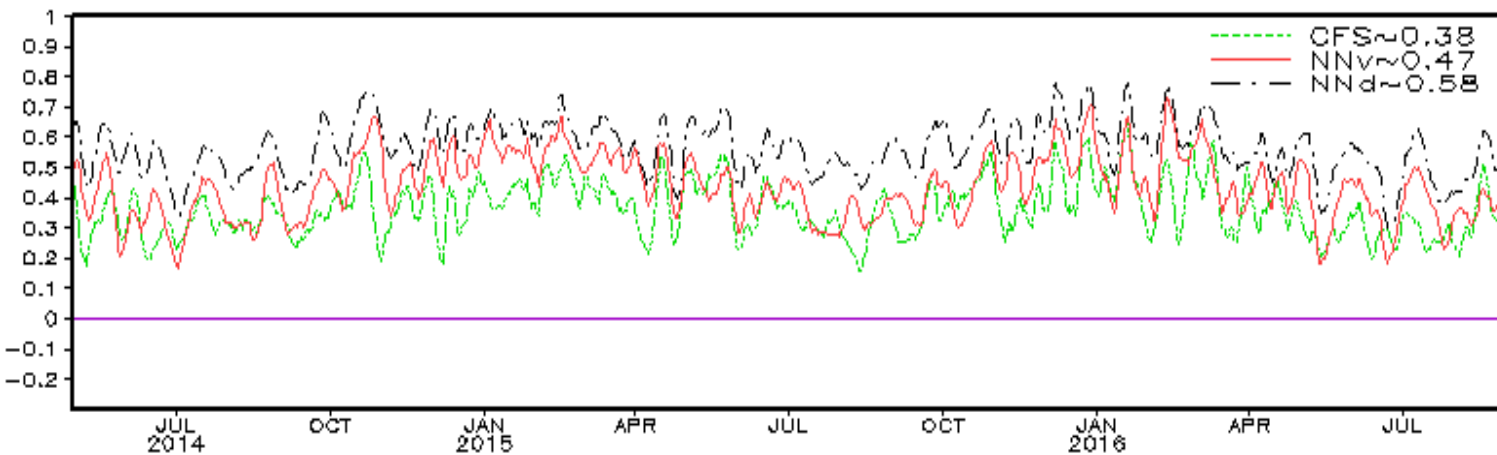


Time Series of Forecast Week-1 P Daily Spatial Anomaly Correlation



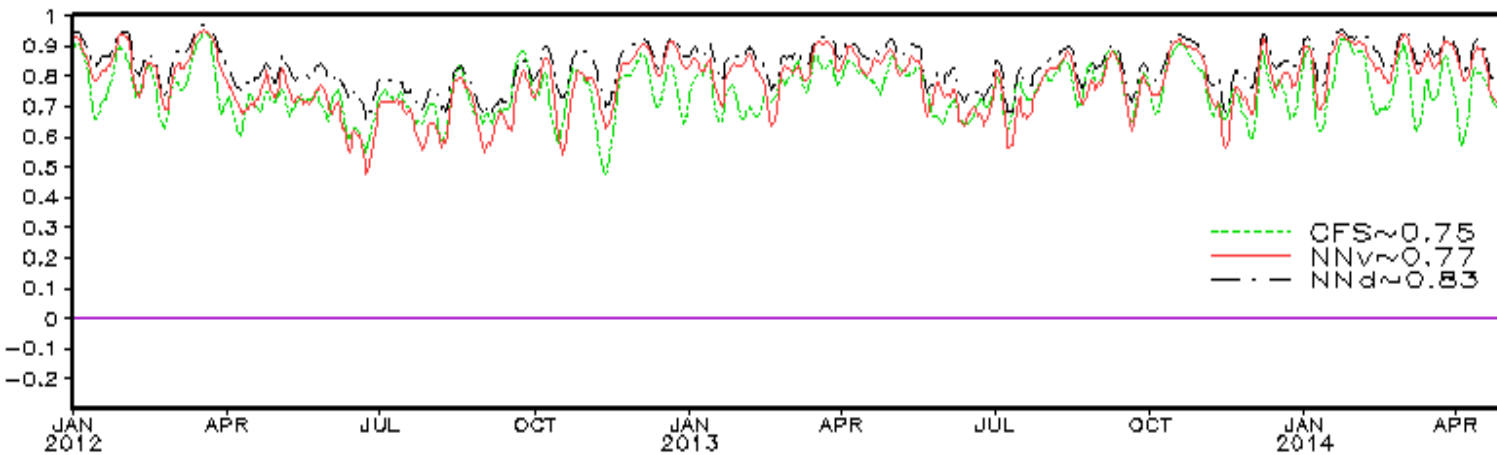
**North American  
Domain**

**CFS: Bias Corrected  
NNv: Yearly Cross-Validation  
NNd: Dependent: 2012-2019**



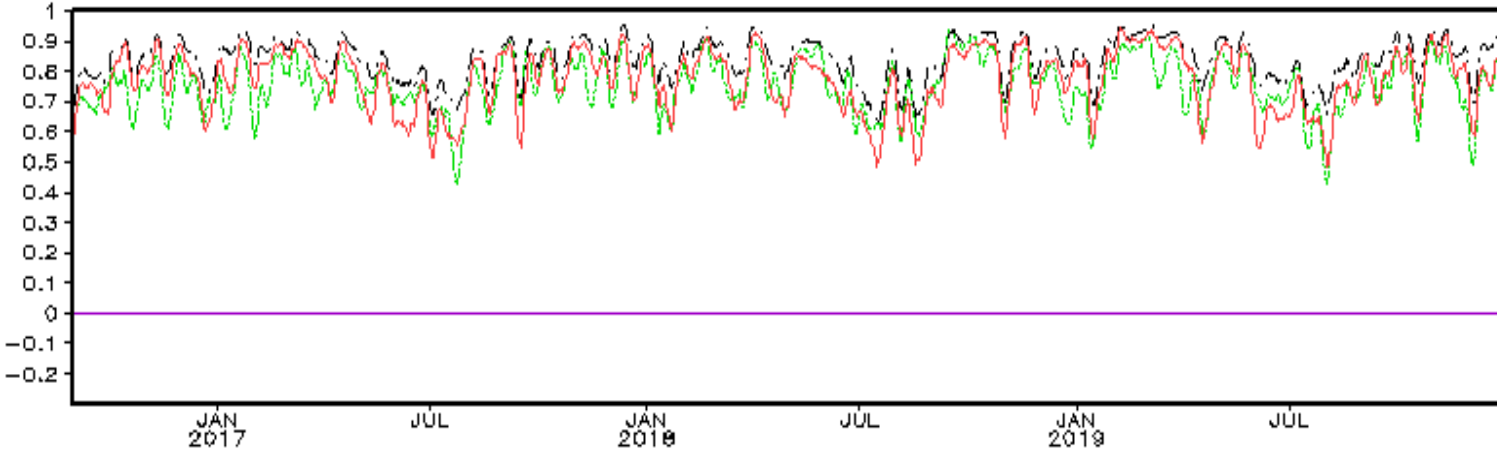
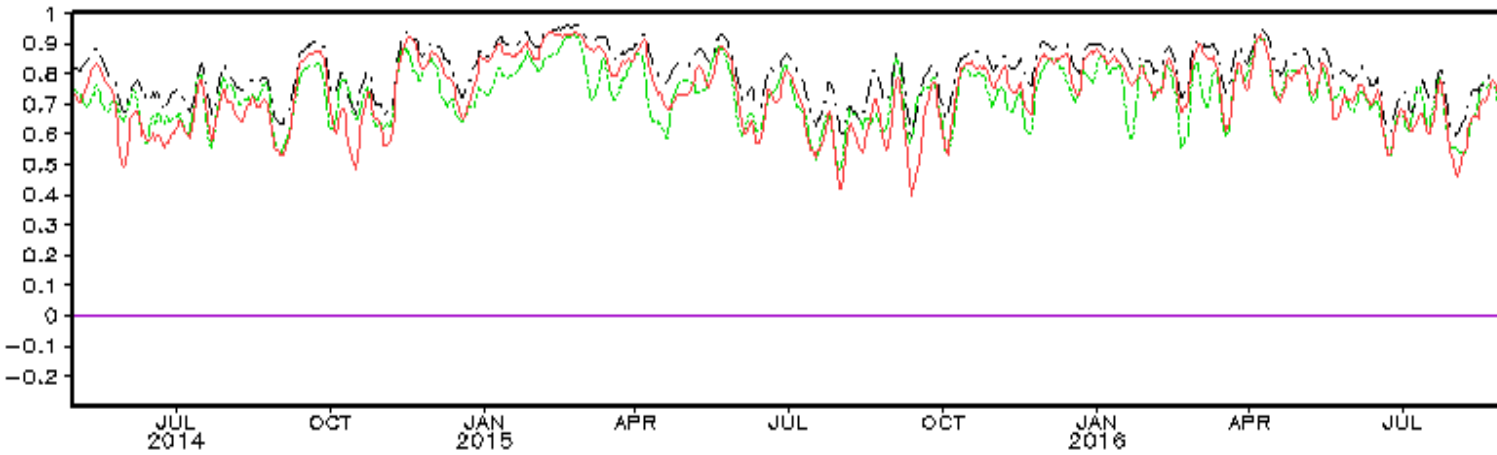


Time Series of Forecast Week-1 T2m Daily Spatial Anomaly Correlation

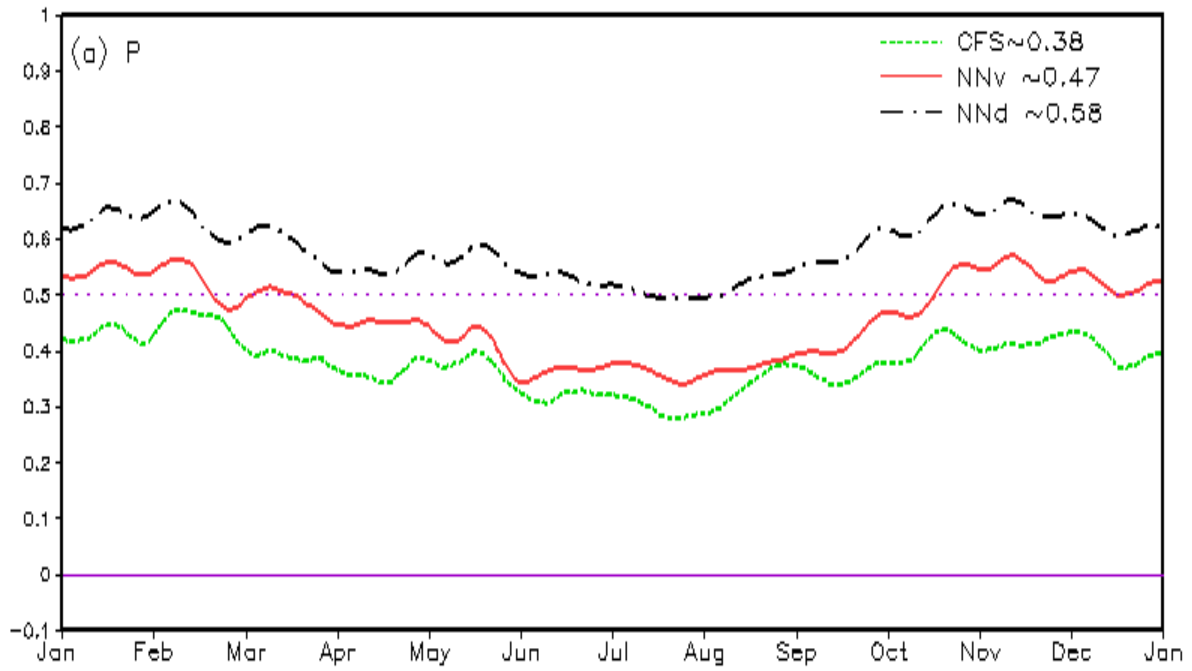


**North American Domain**

CFS: Bias Corrected  
NNv: Yearly Cross-Validation  
NNd: Dependent: 2012-2019

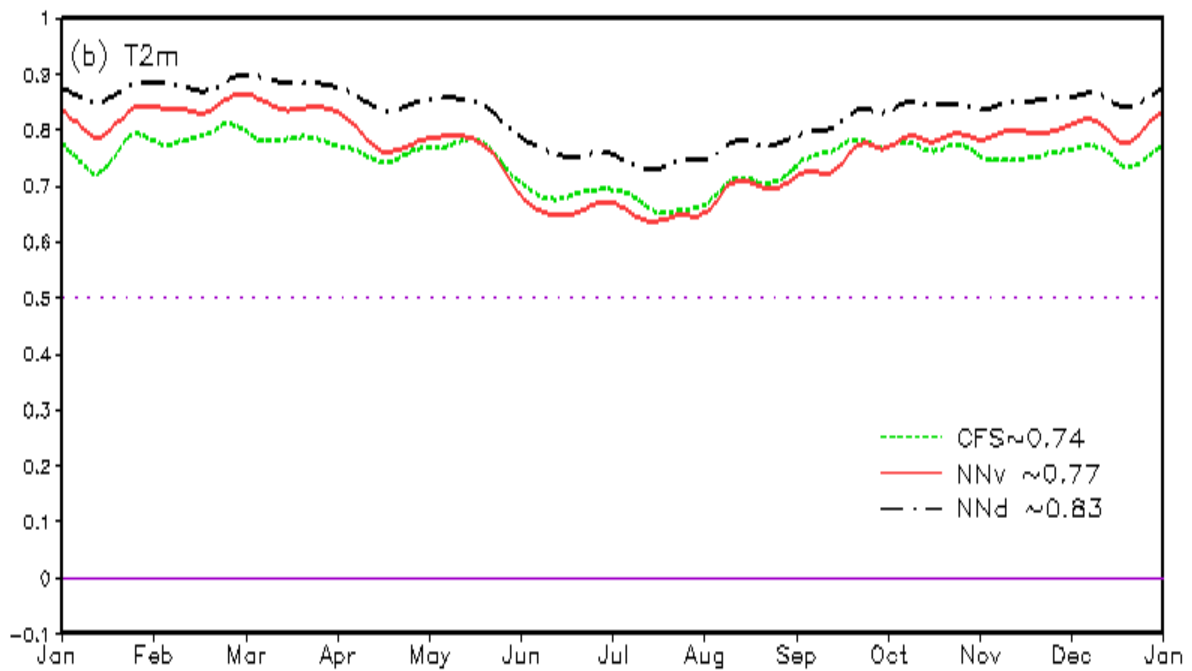


Forecast Week-1 P & T2m Daily Spatial Anomaly Correlation (2012-2019)



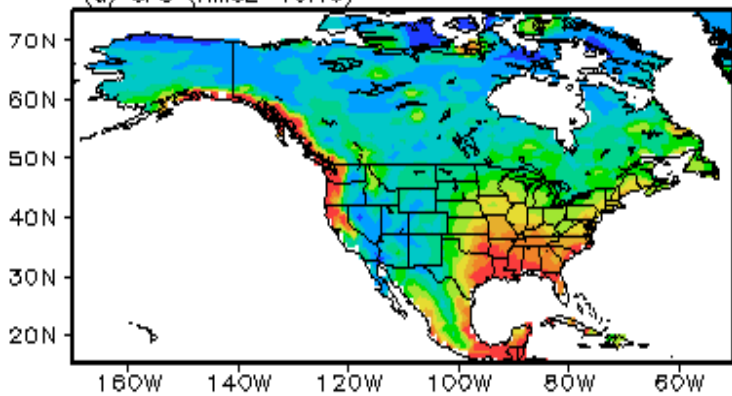
**North American Domain**

CFS: Bias Corrected  
NNv: Yearly Cross-Validation  
NNd: Dependent: 2012-2019

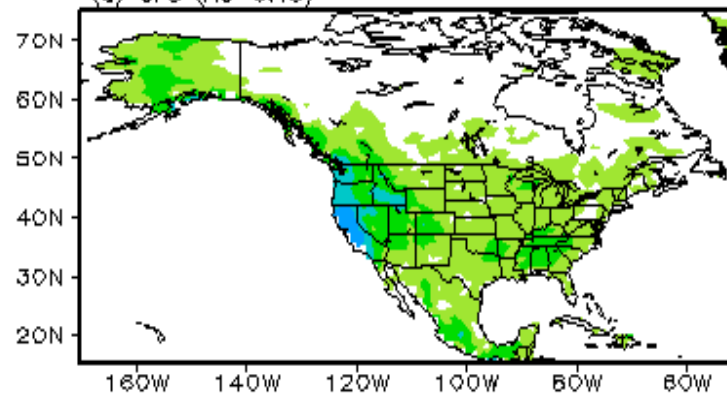


# Forecast Week-2 P Daily RMSE (mm) & AC (2012-2019)

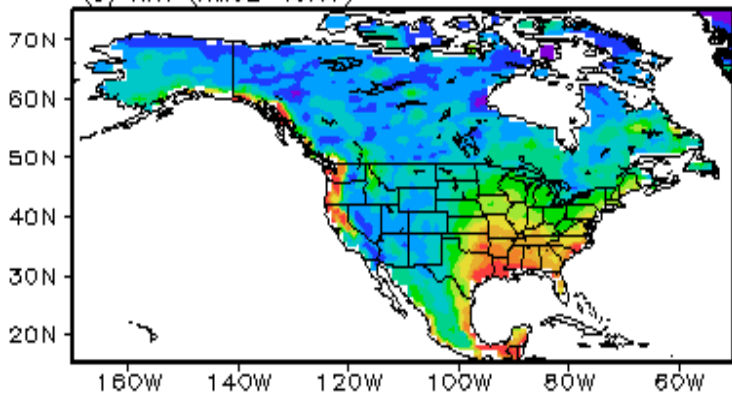
(a) CFS (RMSE=16.16)



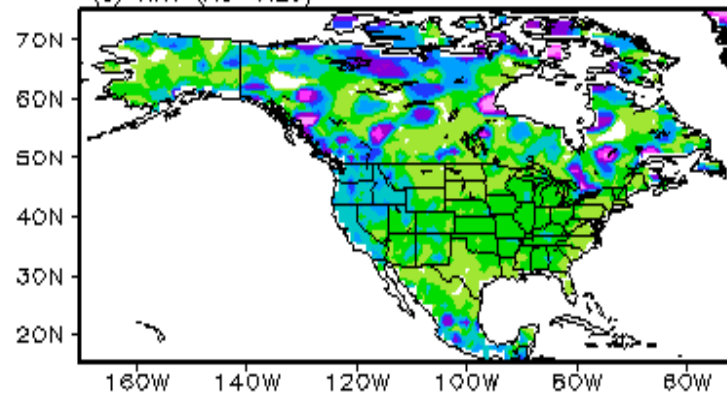
(d) CFS (AC=0.13)



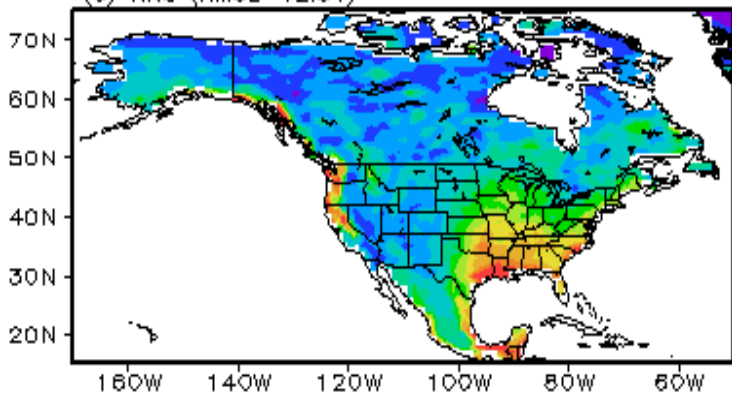
(b) NNv (RMSE=13.07)



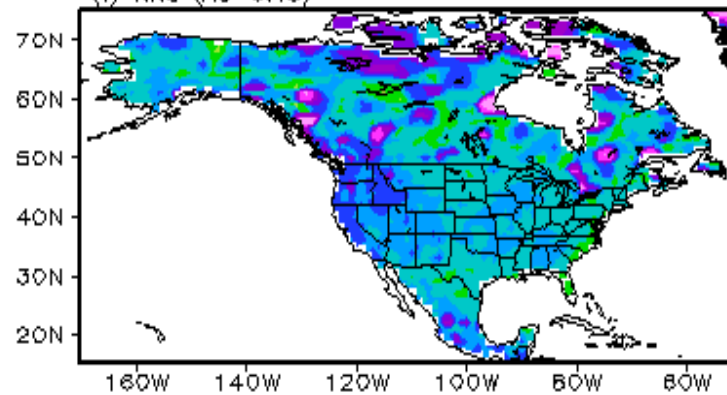
(e) NNv (AC=0.29)



(c) NNd (RMSE=12.31)



(f) NNd (AC=0.43)

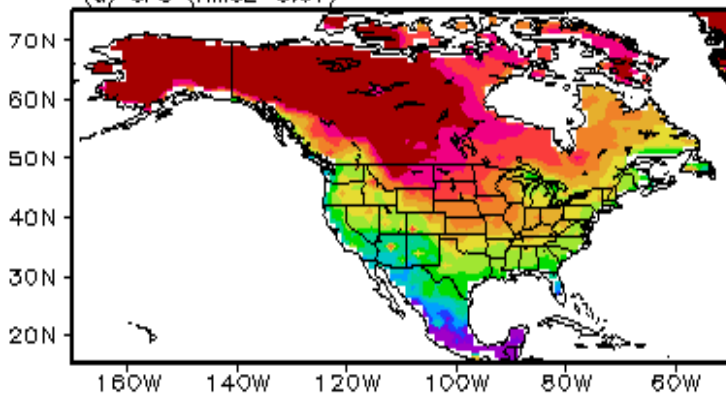


CFS: Bias corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent Fest

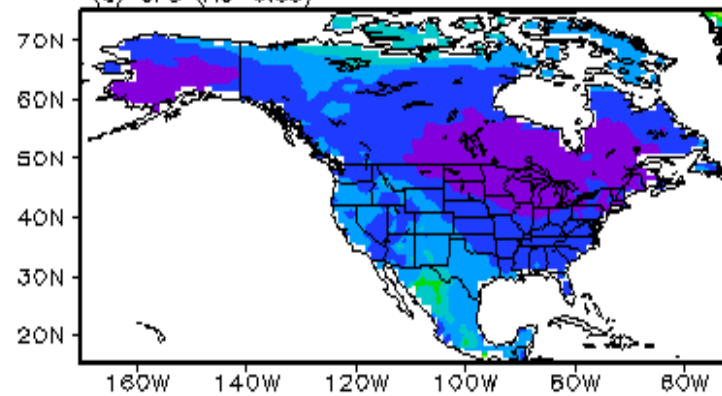


# Forecast Week-2 T2m Daily RMSE (°C) & AC (2012-2019)

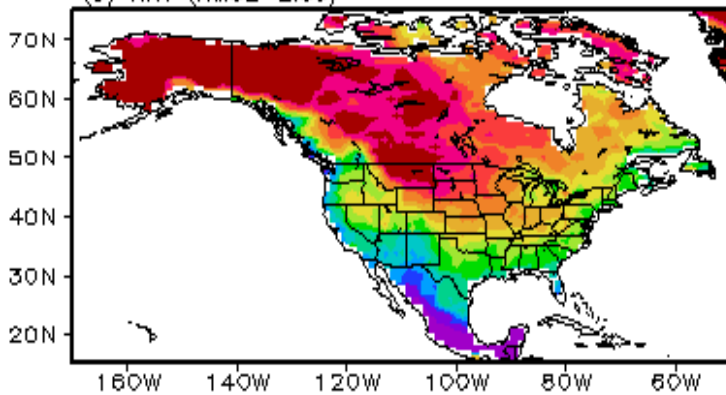
(a) CFS (RMSE=3.07)



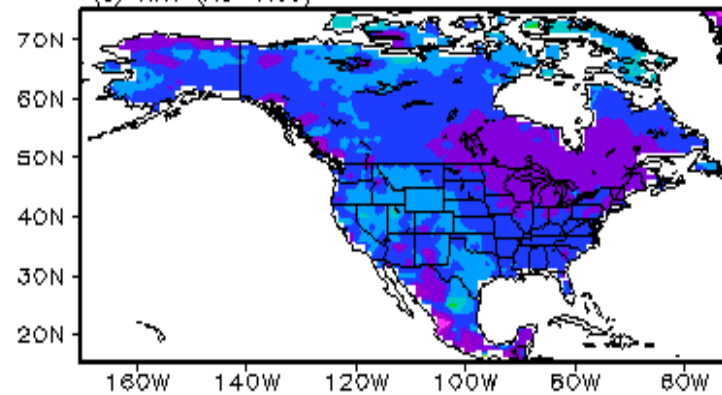
(d) CFS (AC=0.53)



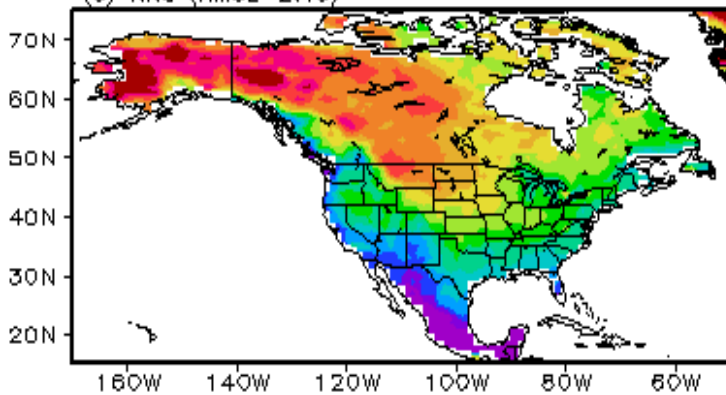
(b) NNv (RMSE=2.89)



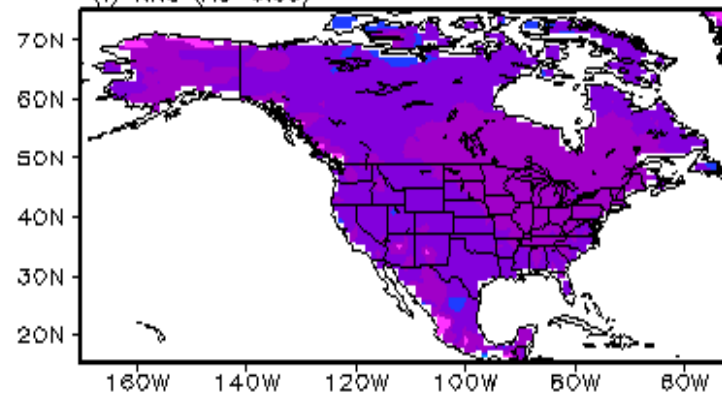
(e) NNv (AC=0.55)



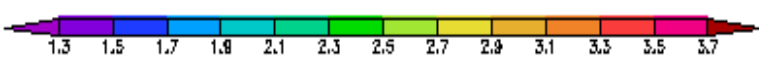
(c) NNd (RMSE=2.49)



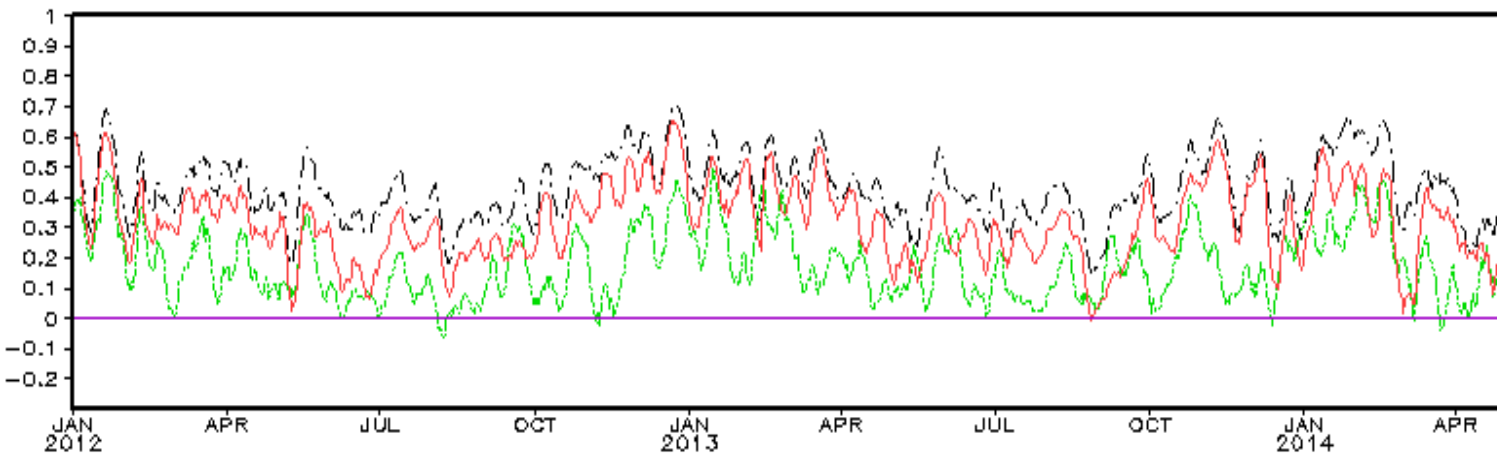
(f) NNd (AC=0.69)



CFS: Bias corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent Test

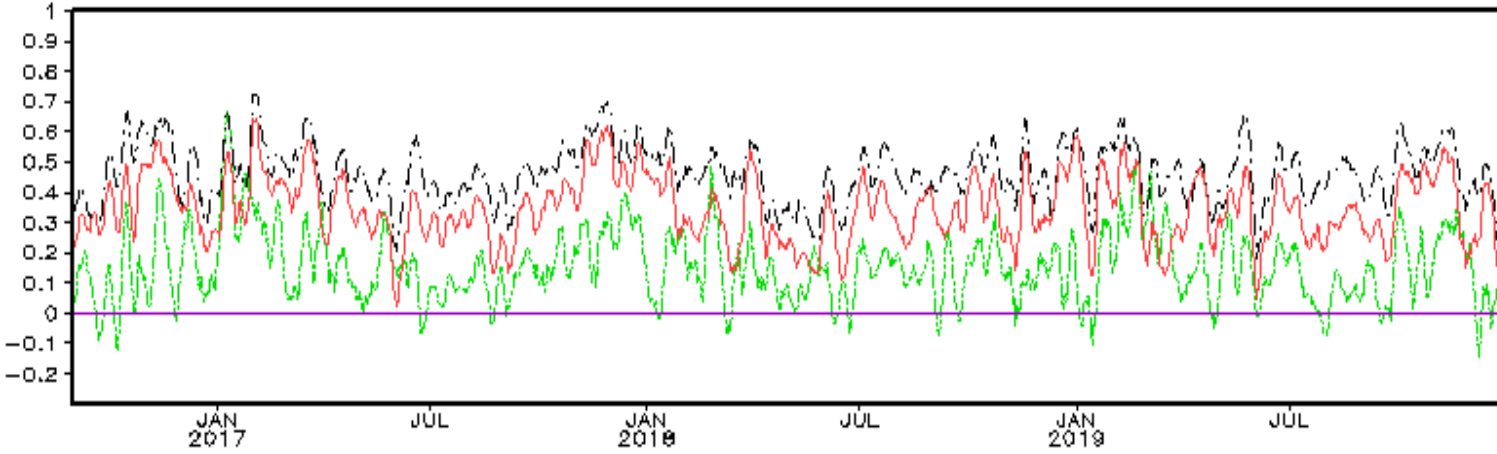
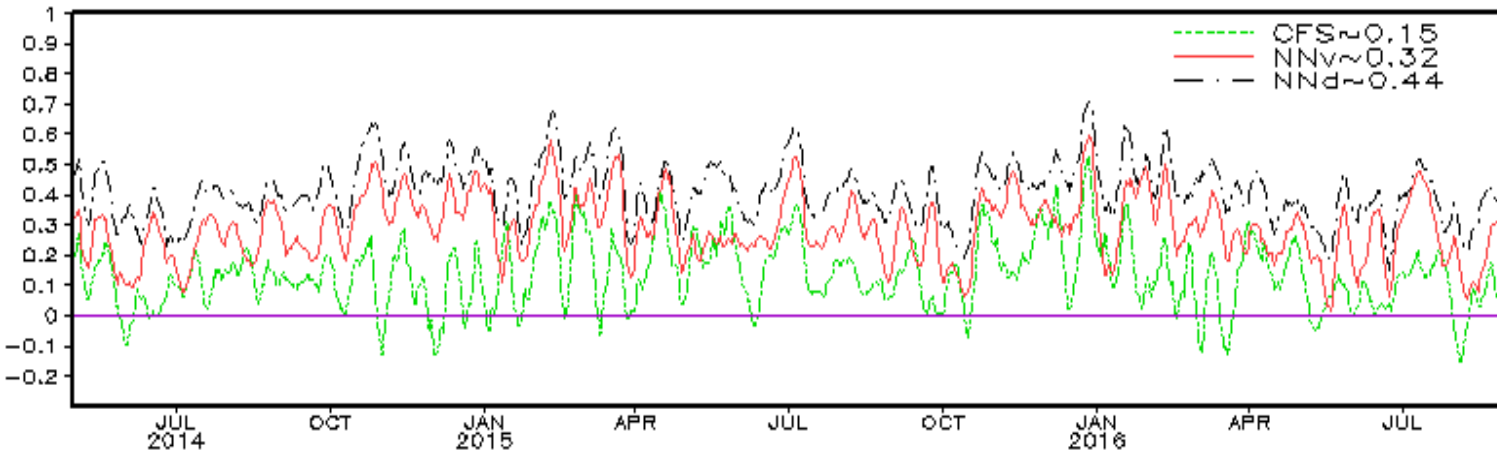


Time Series of Forecast Week-2 P Daily Spatial Anomaly Correlation

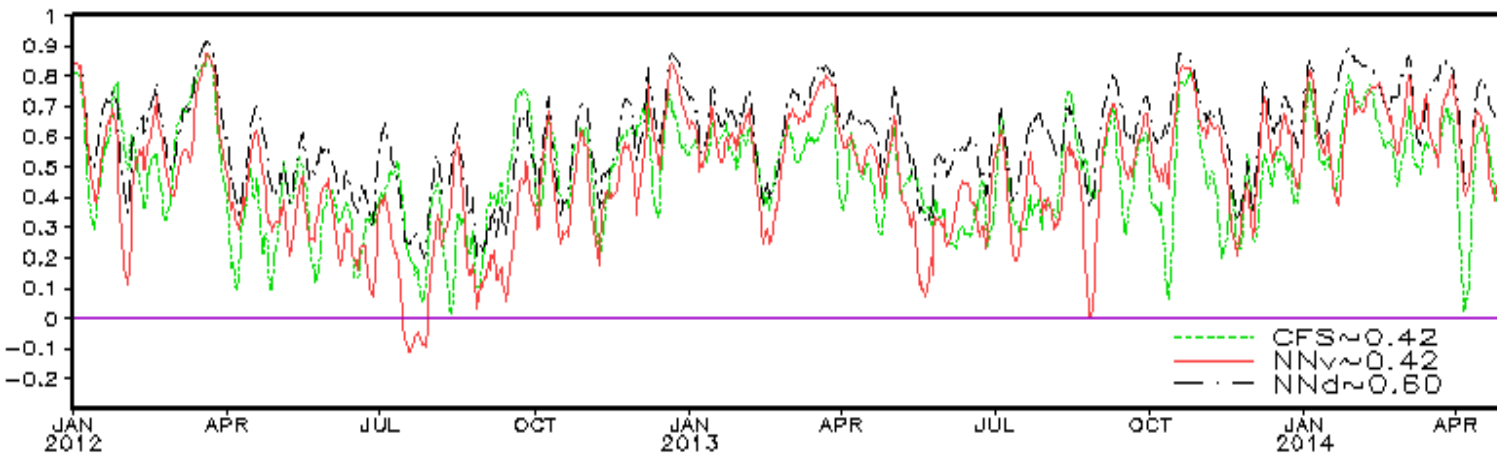


**North American  
Domain**

CFS: Bias Corrected  
NNv: Yearly Cross-Validation  
NNd: Dependent: 2012-2019

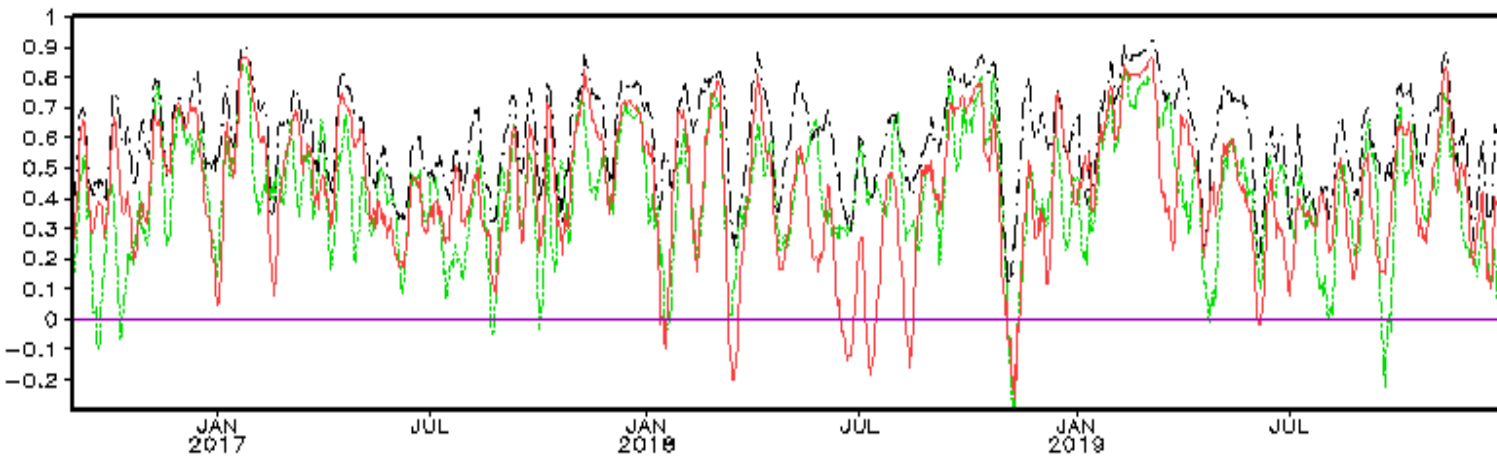
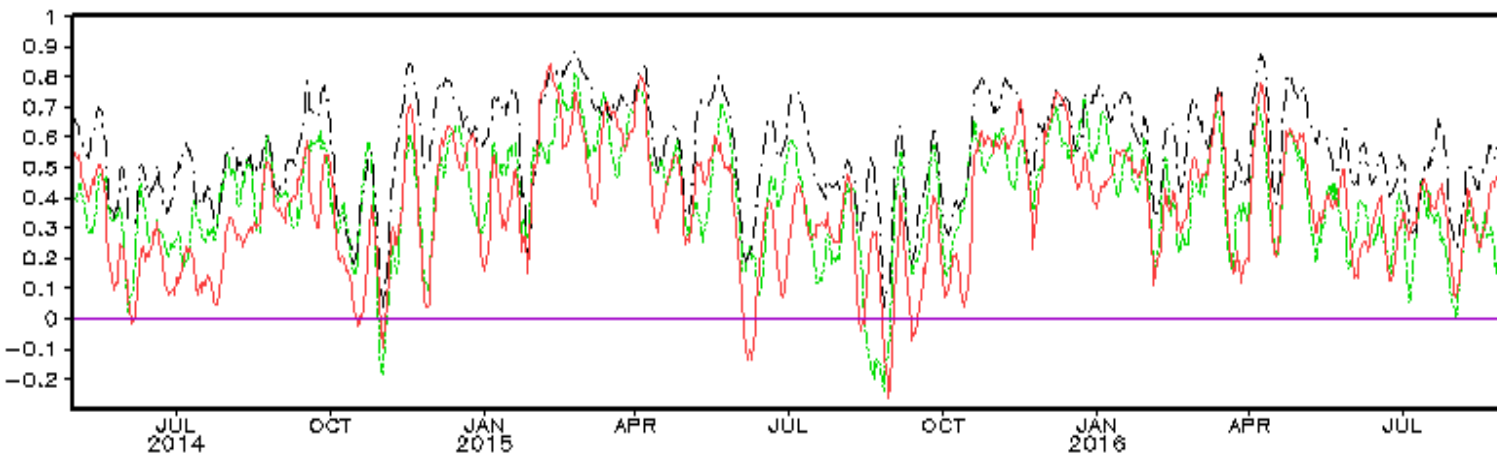


# Time Series of Forecast Week-2 T2m Daily Spatial Anomaly Correlation

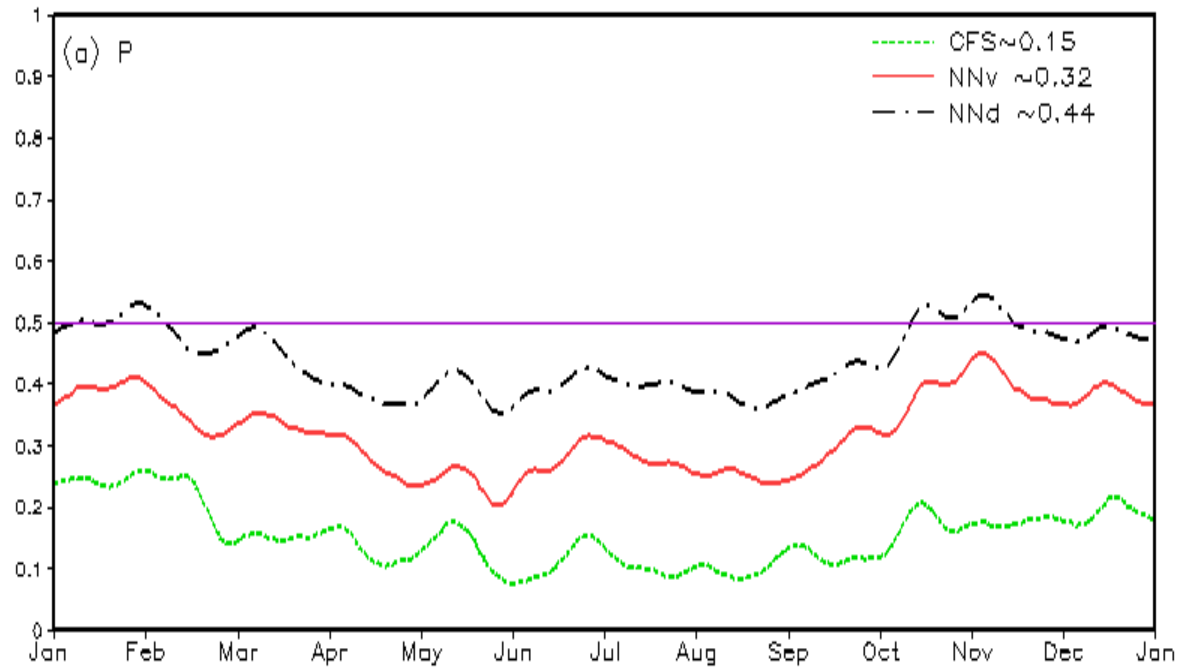


## North American Domain

CFS: Bias Corrected  
NNv: Yearly Cross-Validation  
NNd: Dependent: 2012-2019

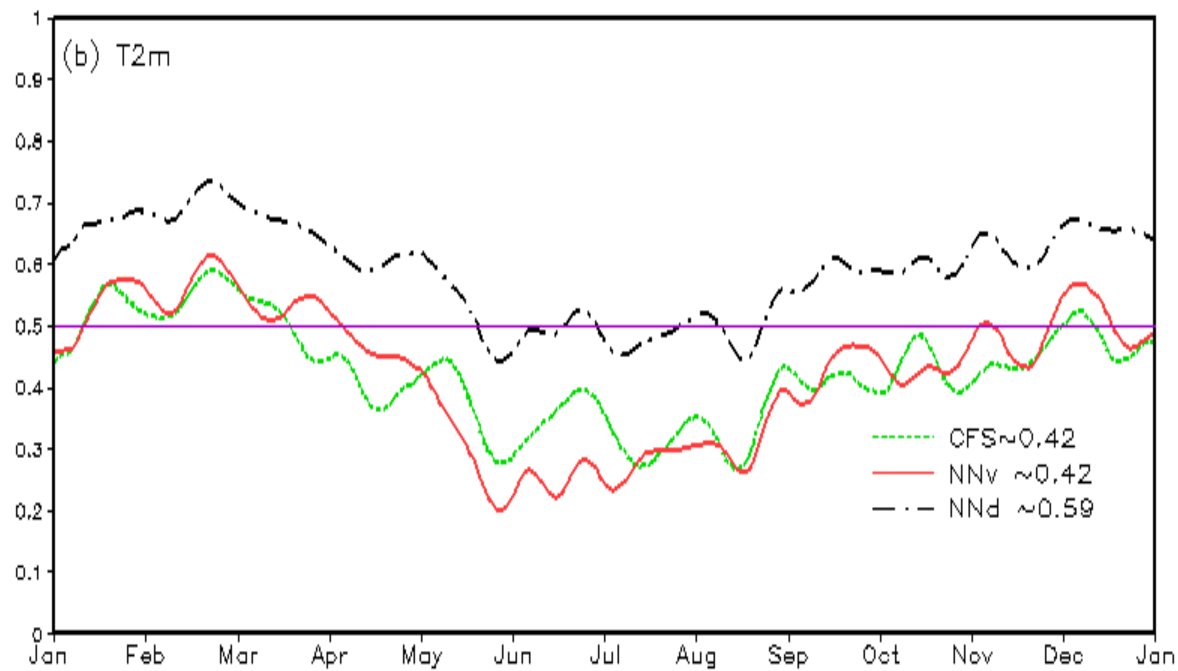


Forecast Week-2 P & T2m Daily Spatial Anomaly Correlation (2012-2019)



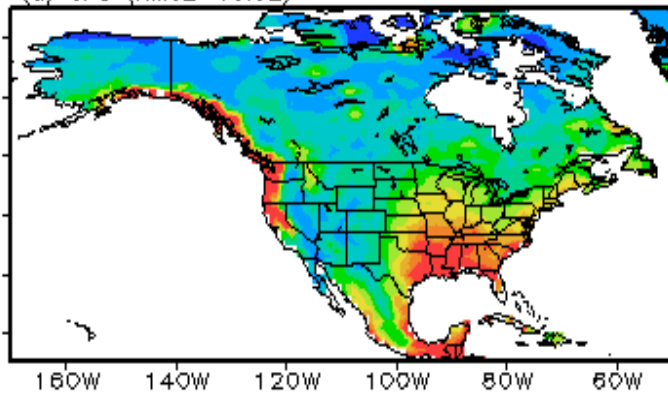
**North American Domain**

CFS: Bias Corrected  
NNv: Yearly Cross-Validation  
NNd: Dependent: 2012-2019

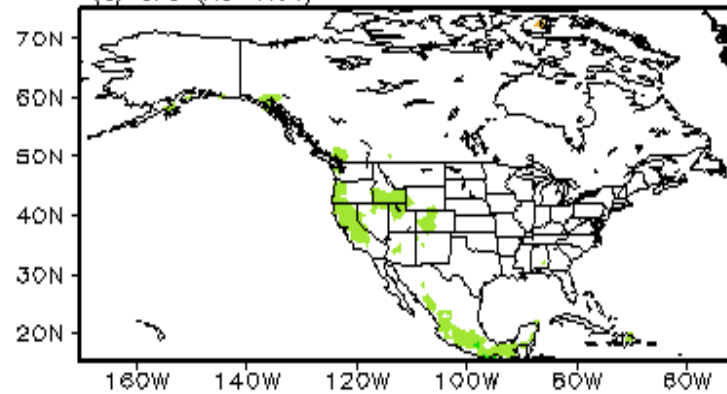


# Forecast Week-3 P Daily RMSE (mm) & AC (2012-2019)

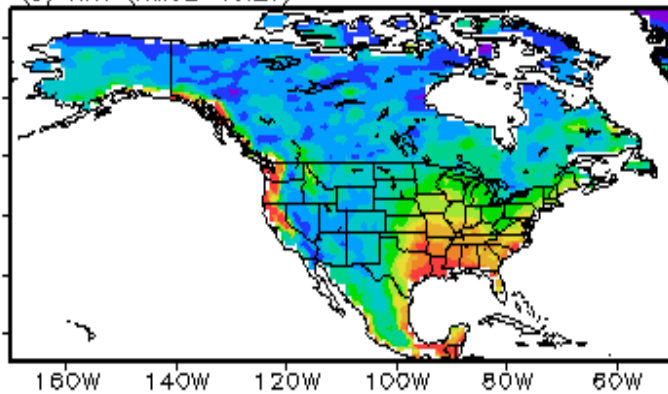
(a) CFS (RMSE=16.32)



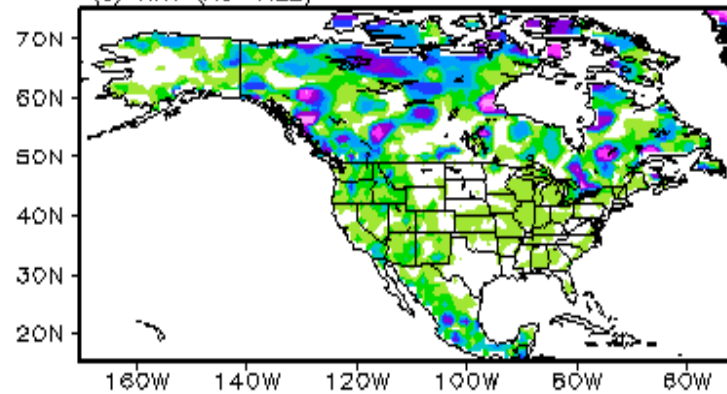
(d) CFS (AC=0.04)



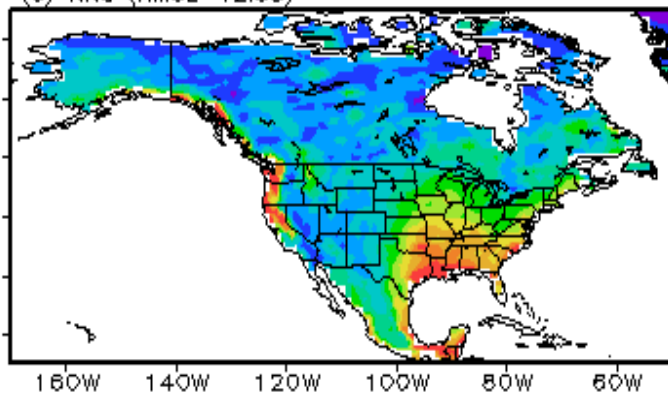
(b) NNv (RMSE=13.29)



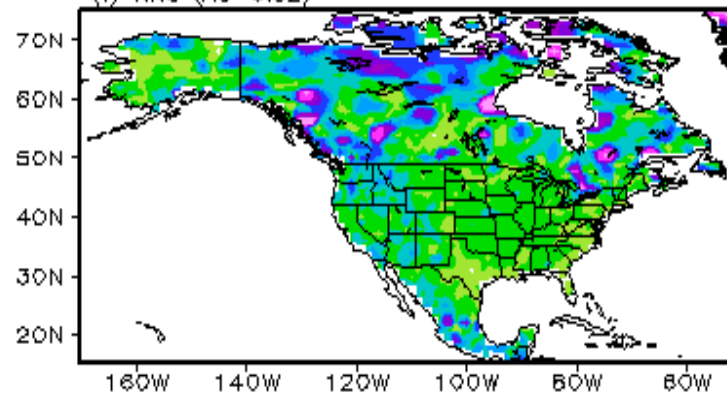
(e) NNv (AC=0.22)



(c) NNd (RMSE=12.88)



(f) NNd (AC=0.32)



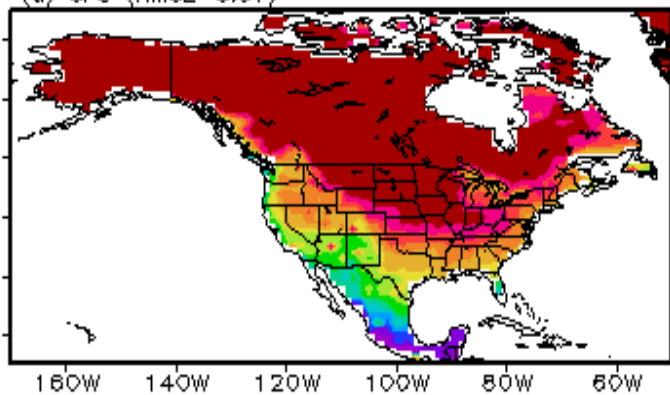
CFS: Bias corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent Fest



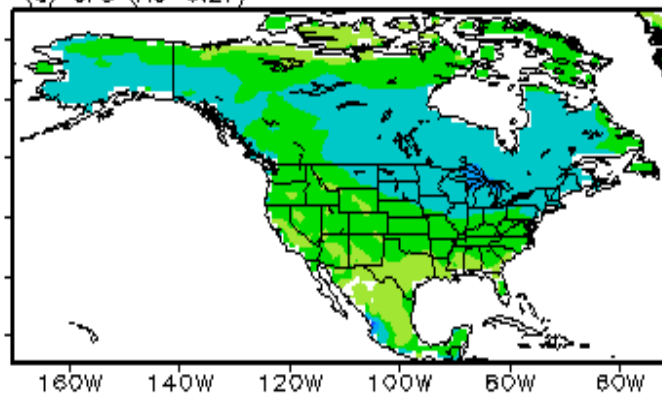


# Forecast Week-3 T2m Daily RMSE (°C) & AC (2012-2019)

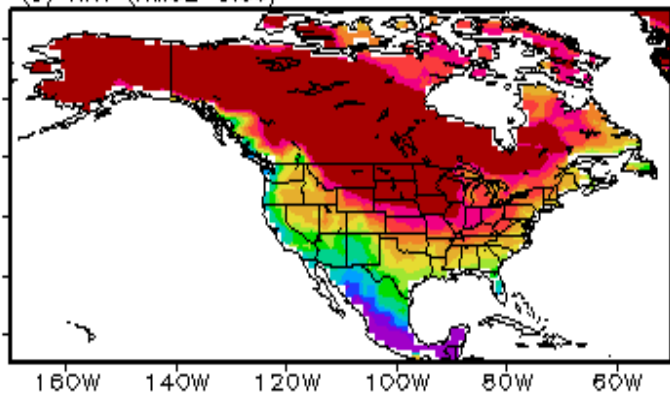
(a) CFS (RMSE=3.57)



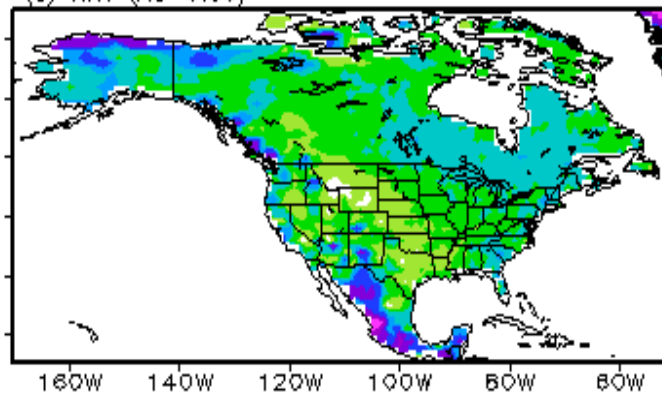
(d) CFS (AC=0.27)



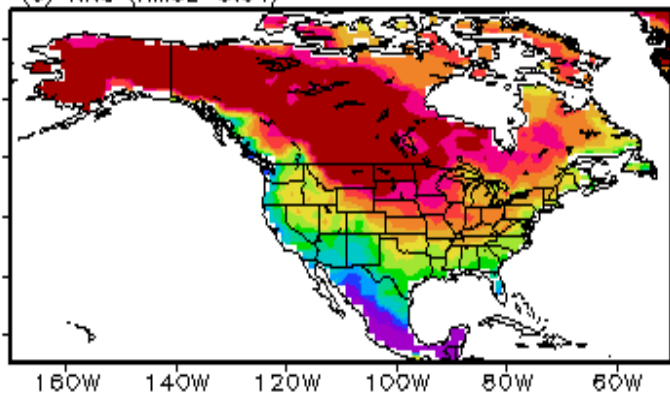
(b) NNv (RMSE=3.30)



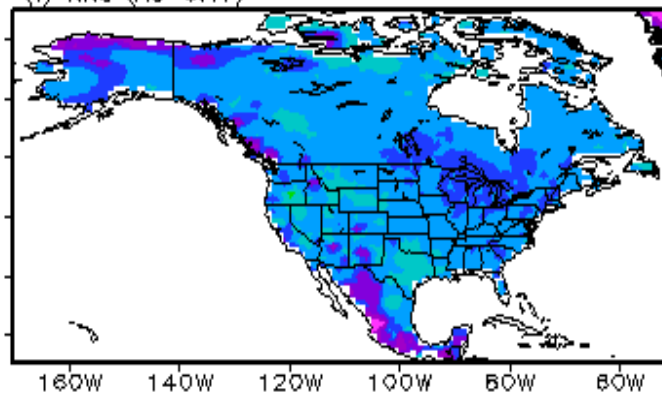
(e) NNv (AC=0.30)



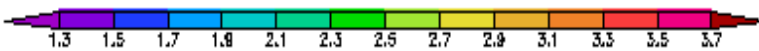
(c) NNd (RMSE=3.04)



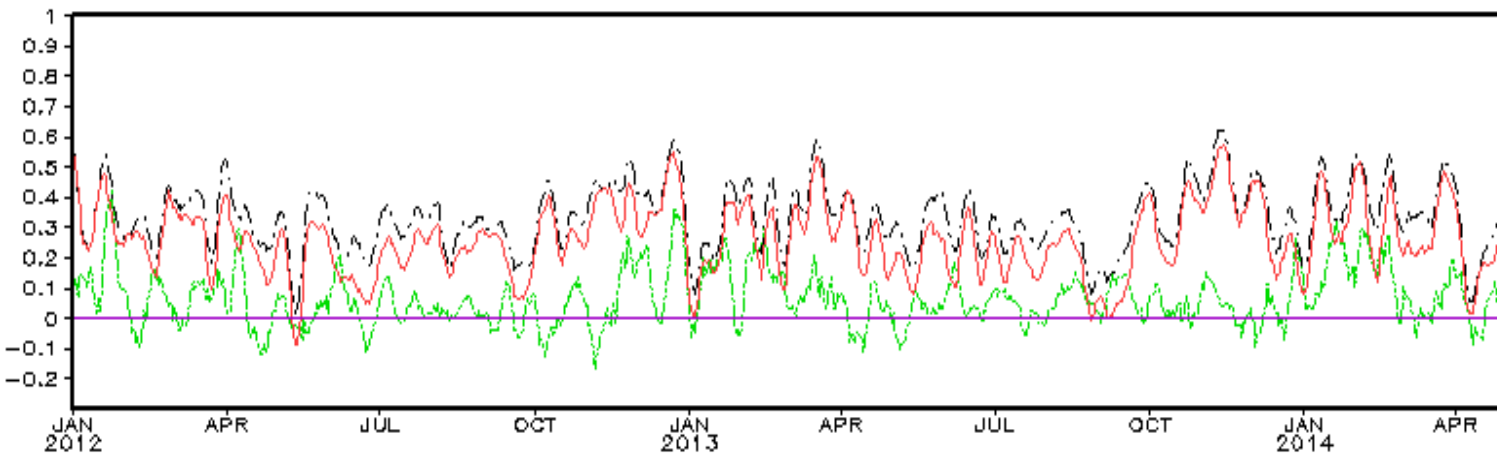
(f) NNd (AC=0.47)



CFS: Bias corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent Test

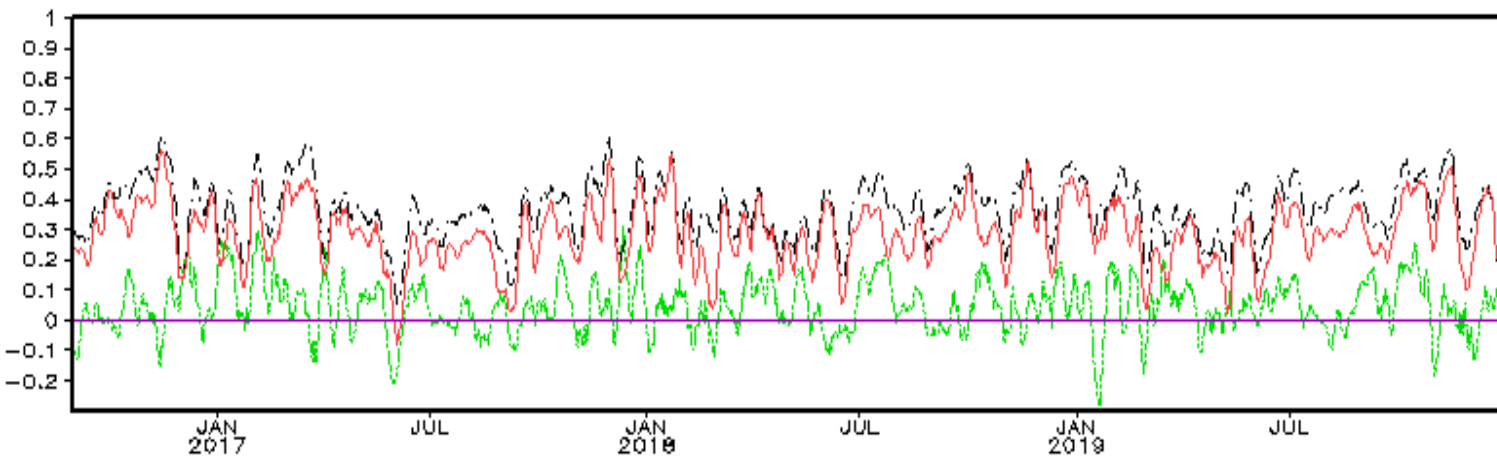
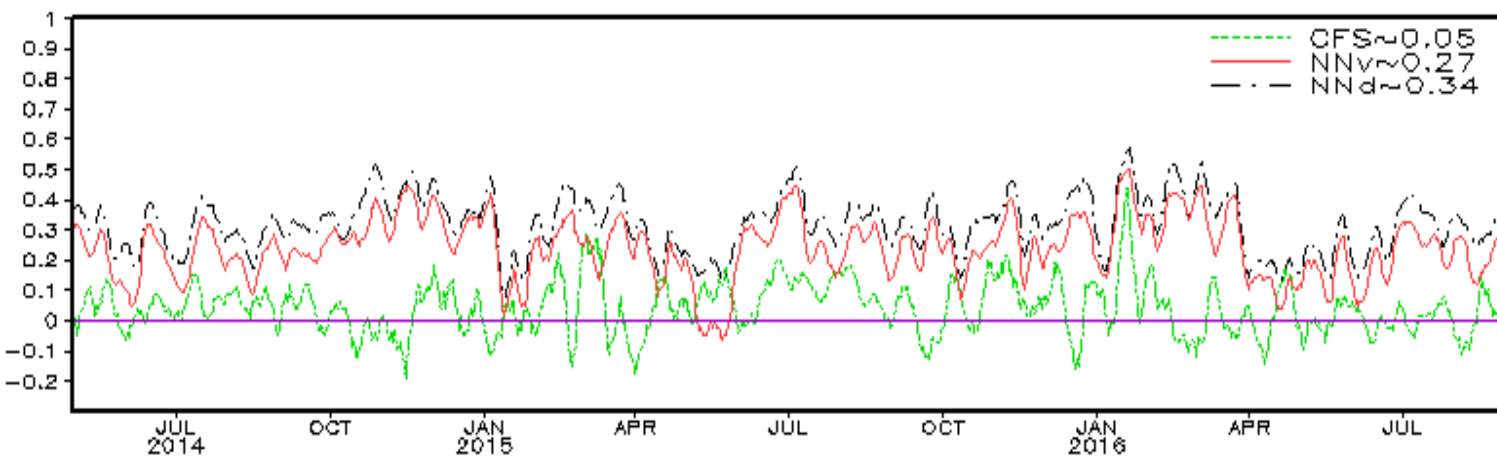


# Time Series of Forecast Week-3 P Daily Spatial Anomaly Correlation

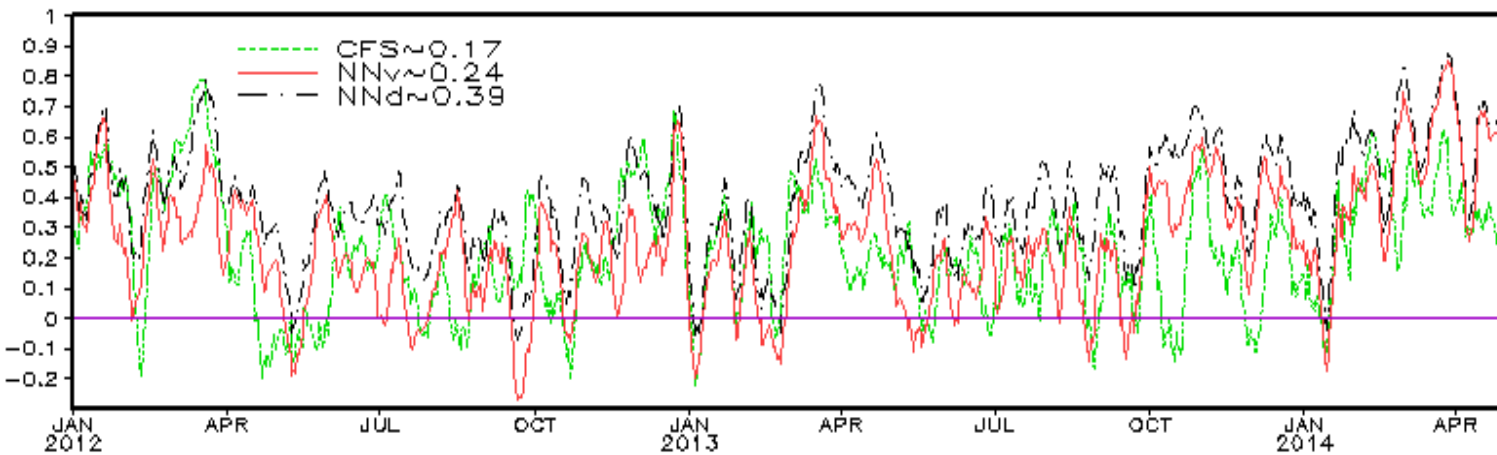


## North American Domain

CFS: Bias Corrected  
NNv: Yearly Cross-Validation  
NNd: Dependent: 2012-2019

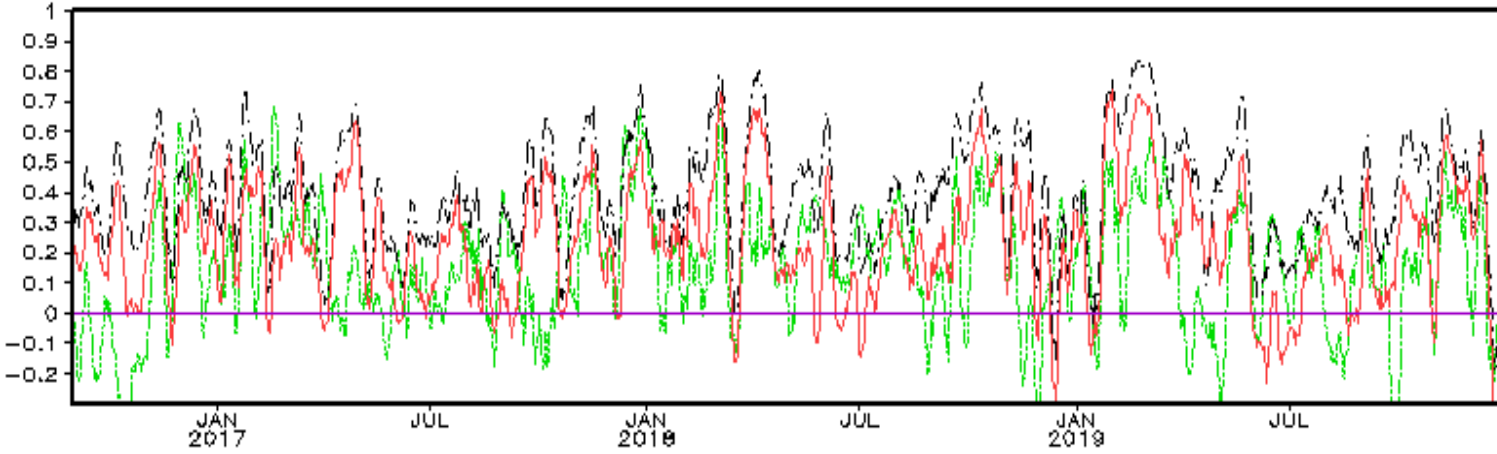
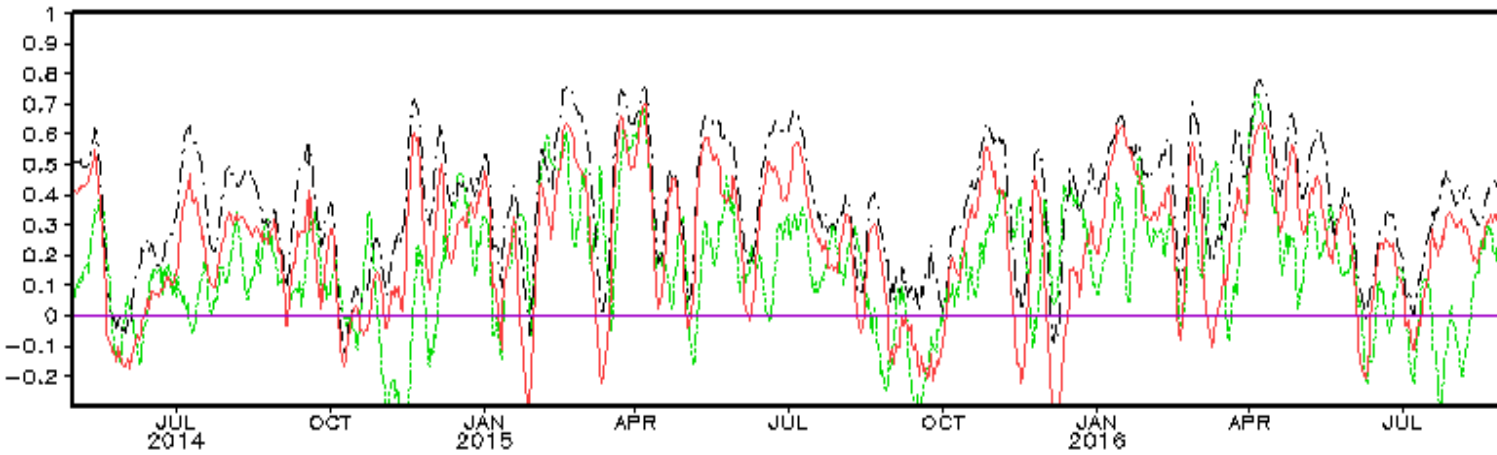


Time Series of Forecast Week-3 T2m Daily Spatial Anomaly Correlation

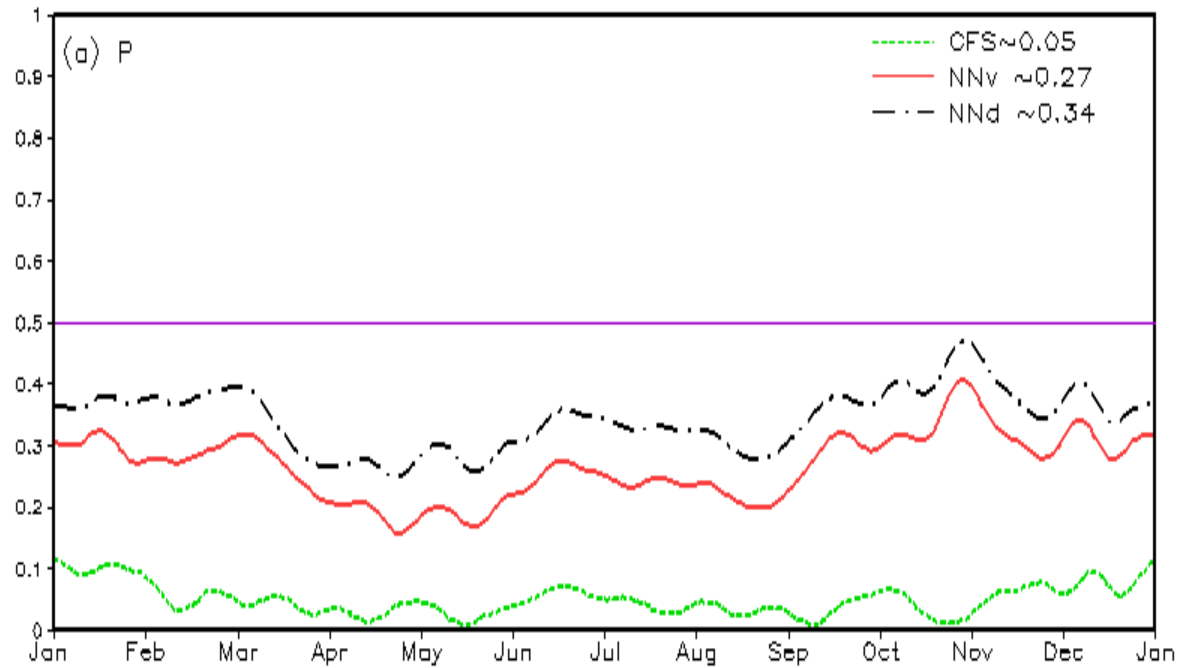


**North American Domain**

CFS: Bias Corrected  
NNv: Yearly Cross-Validation  
NNd: Dependent: 2012-2019

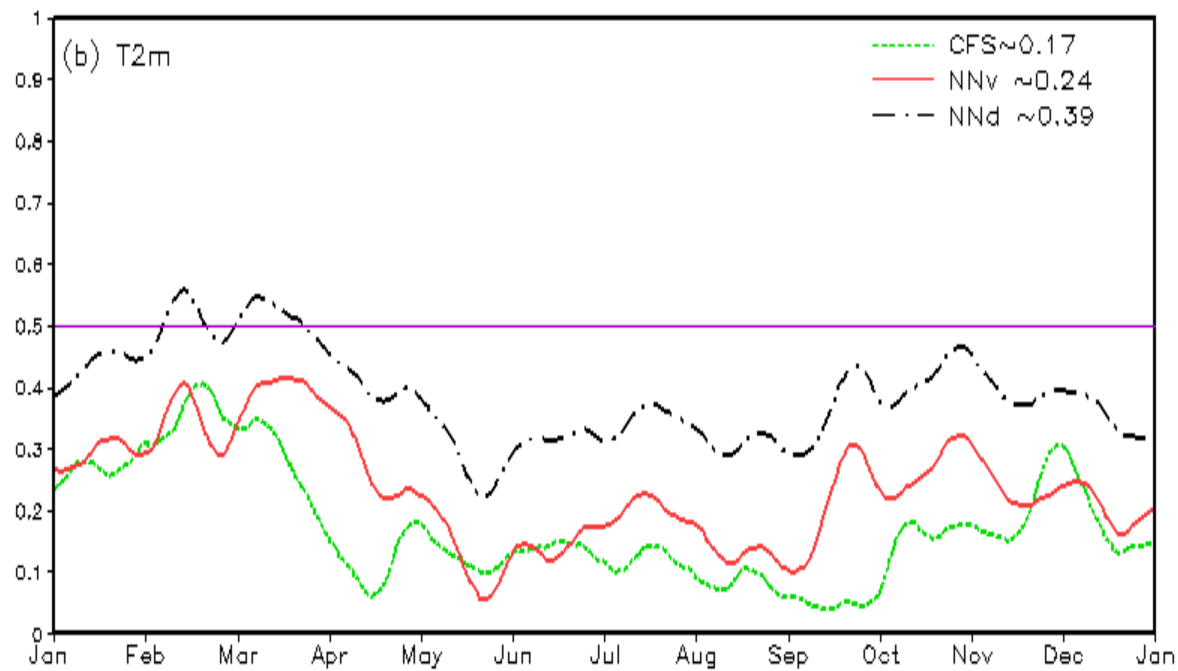


Forecast Week-3 P & T2m Daily Spatial Anomaly Correlation (2012-2019)



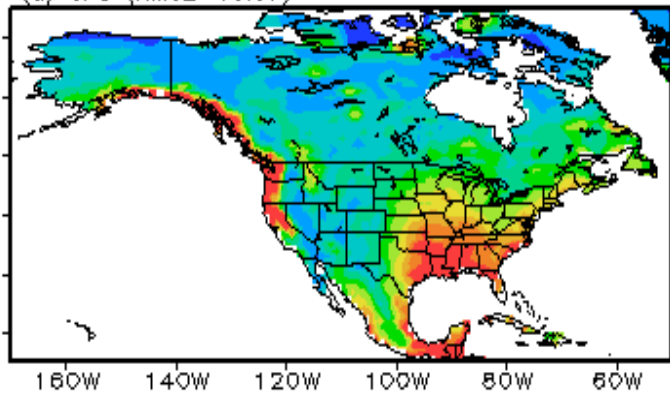
**North American Domain**

CFS: Bias Corrected  
NNv: Yearly Cross-Validation  
NNd: Dependent: 2012-2019

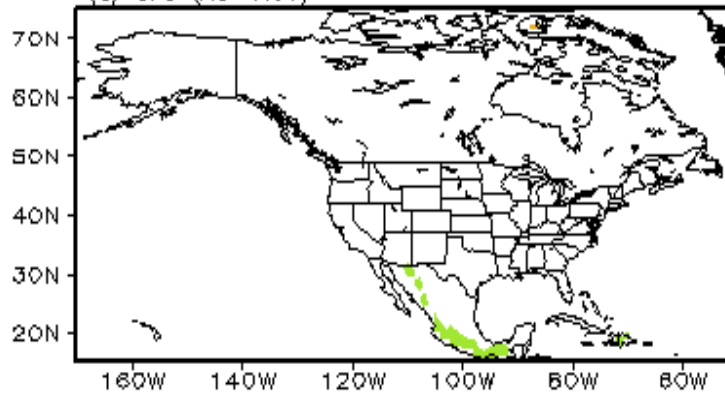


# Forecast Week-4 P Daily RMSE (mm) & AC (2012-2019)

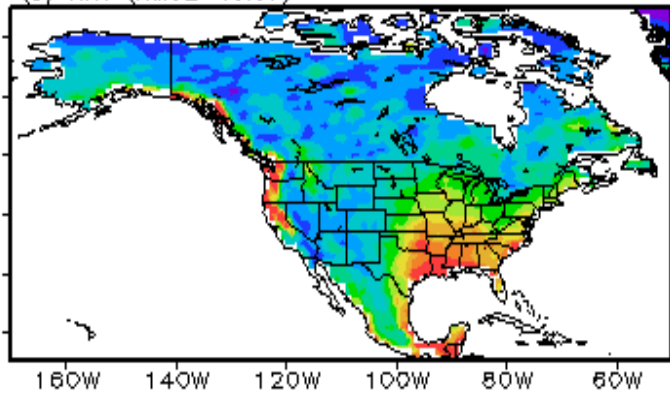
(a) CFS (RMSE=16.37)



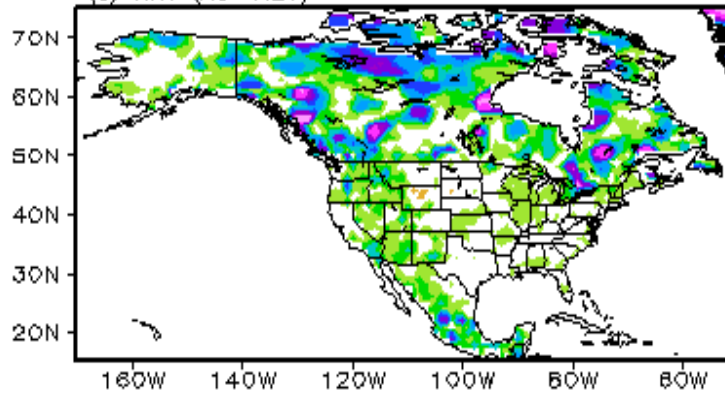
(d) CFS (AC=0.01)



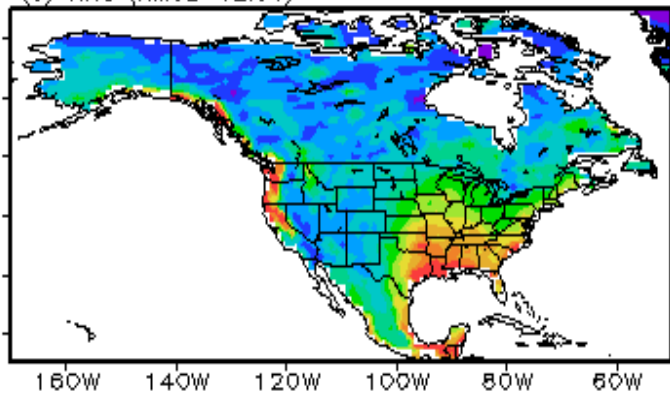
(b) NNv (RMSE=13.37)



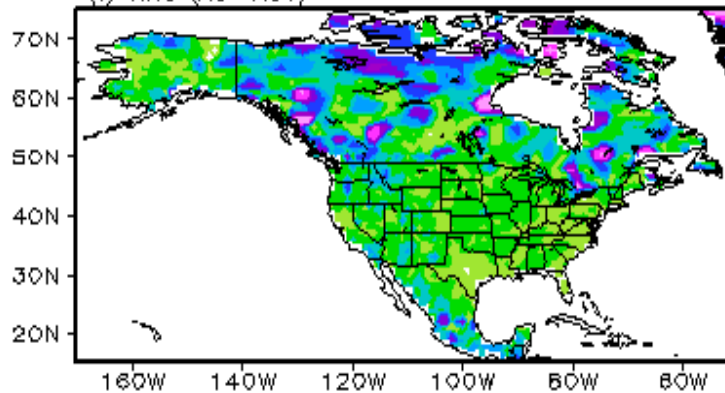
(e) NNv (AC=0.20)



(c) NNd (RMSE=12.91)



(f) NNd (AC=0.31)

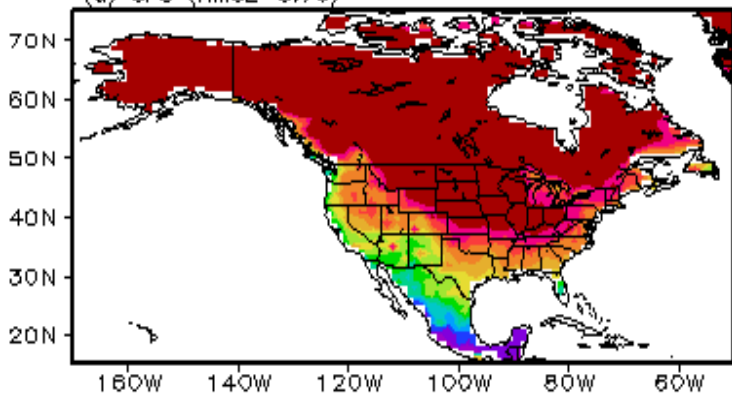


CFS: Bias corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent Fest

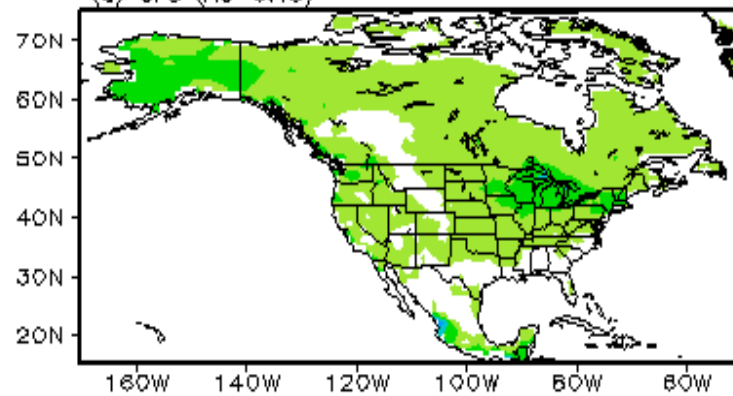


# Forecast Week-4 T2m Daily RMSE (°C) & AC (2012-2019)

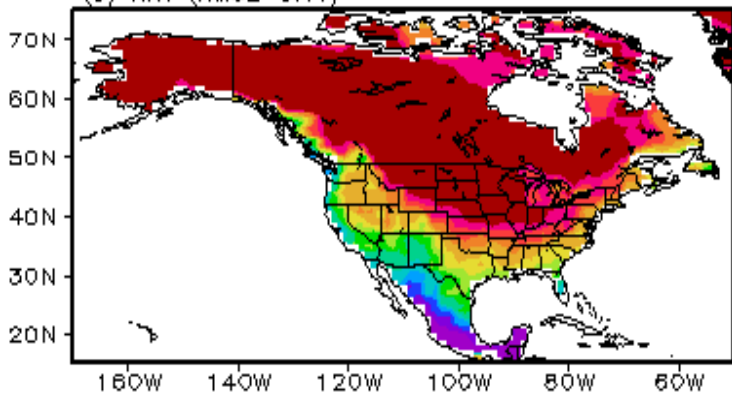
(a) CFS (RMSE=3.76)



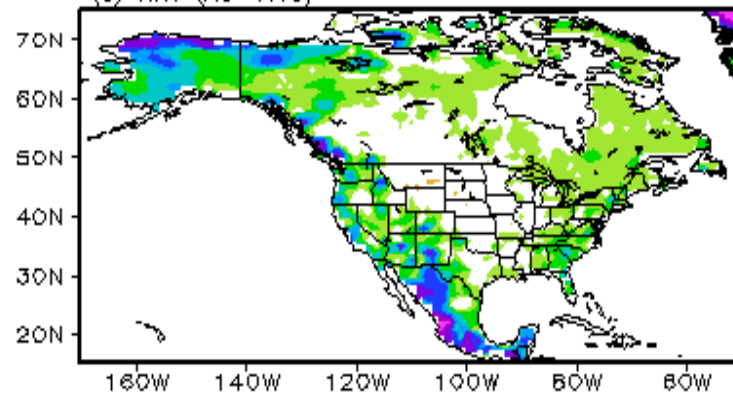
(d) CFS (AC=0.15)



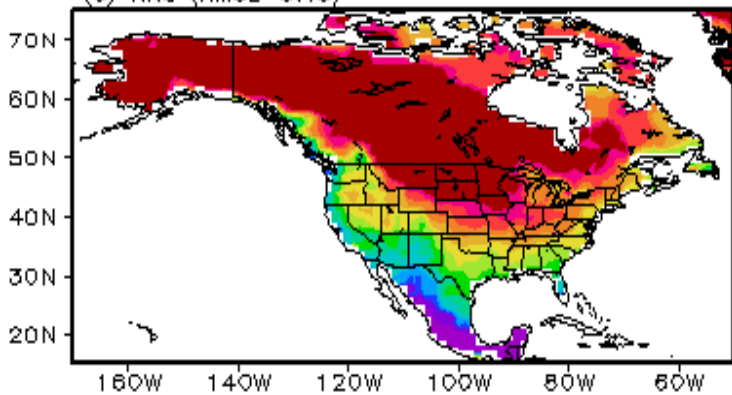
(b) NNv (RMSE=3.41)



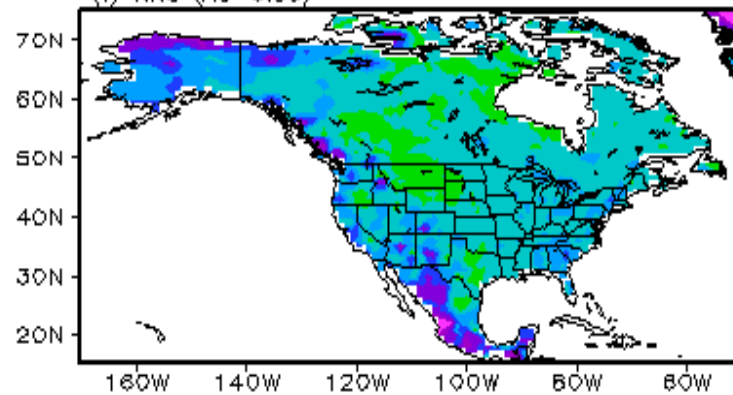
(e) NNv (AC=0.18)



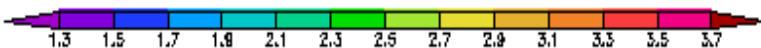
(c) NNd (RMSE=3.18)



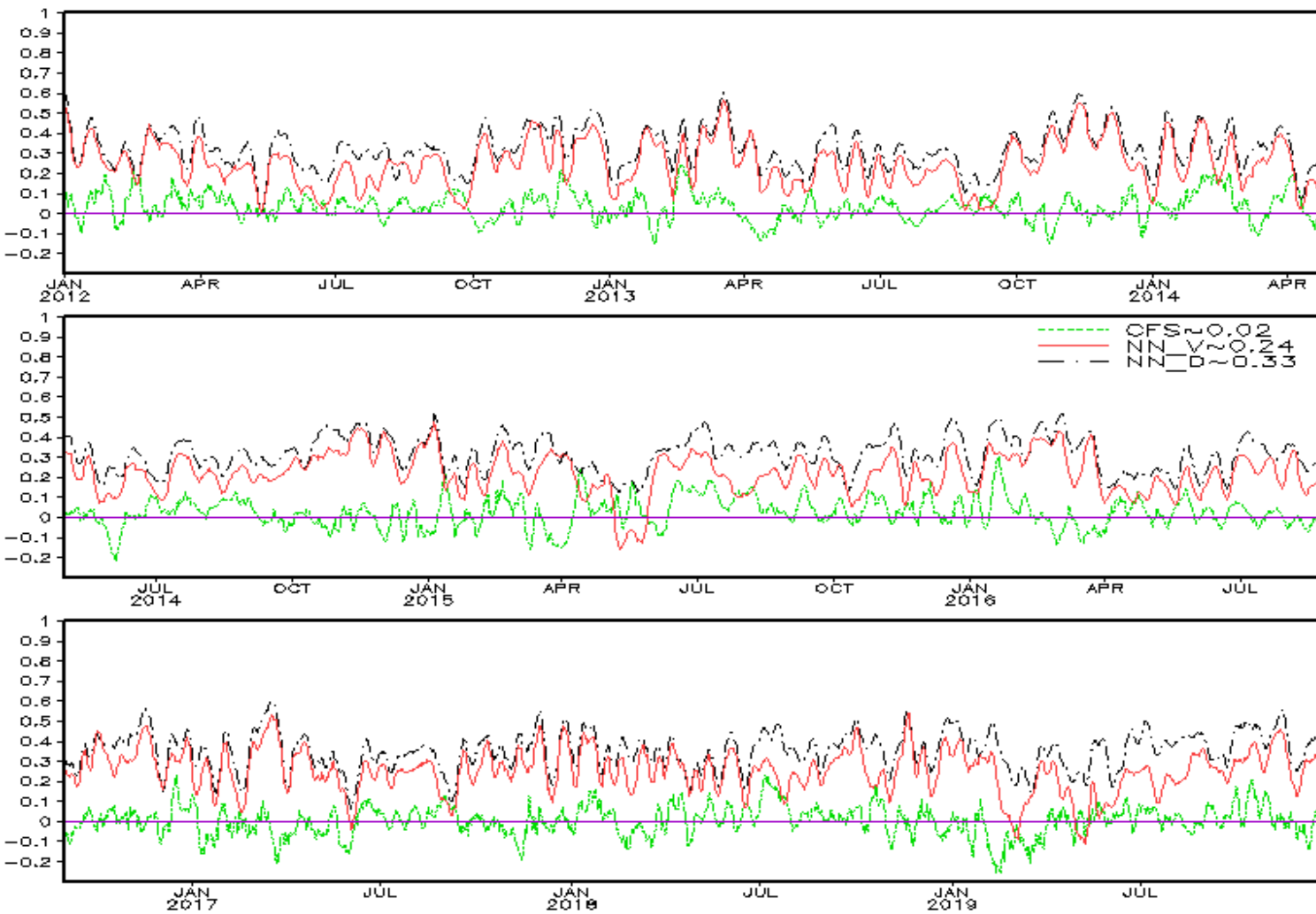
(f) NNd (AC=0.39)



CFS: Bias corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent Test



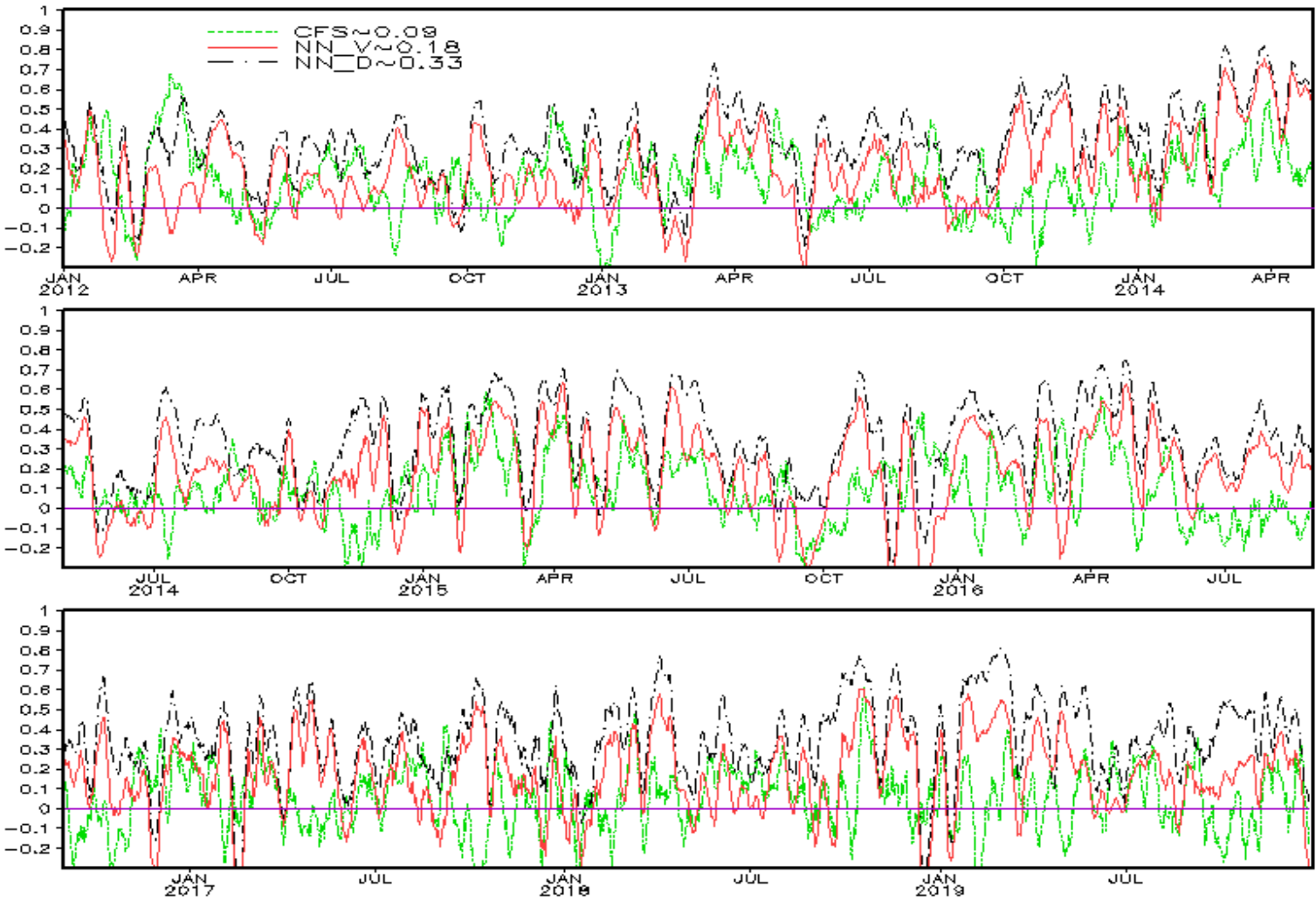
Time Series of Forecast Week-4 P Daily Spatial Anomaly Correlation



**North American Domain**

CFS: Bias Corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent: 2012-2019

Time Series of Forecast Week-4 T2m Daily Spatial Anomaly Correlation

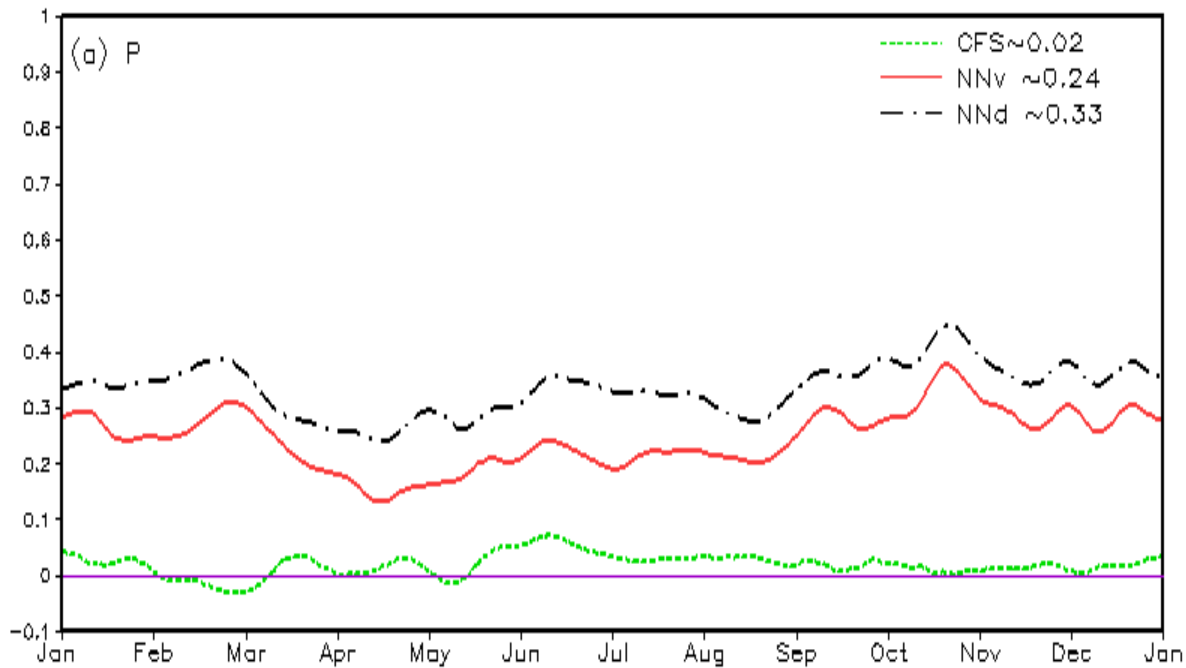


**North American Domain**

CFS: Bias Corrected  
NNv: Yearly Cross-Validation  
NNd: Dependent: 2012-2019

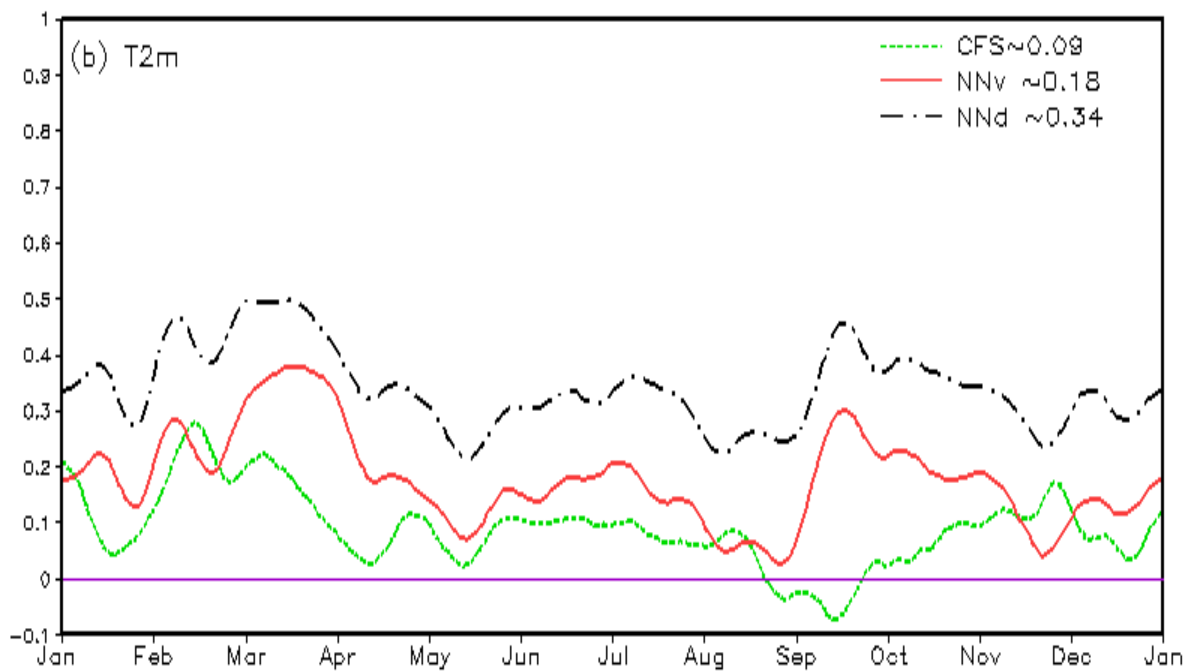


Forecast Week-4 P & T2m Daily Spatial Anomaly Correlation (2012-2019)

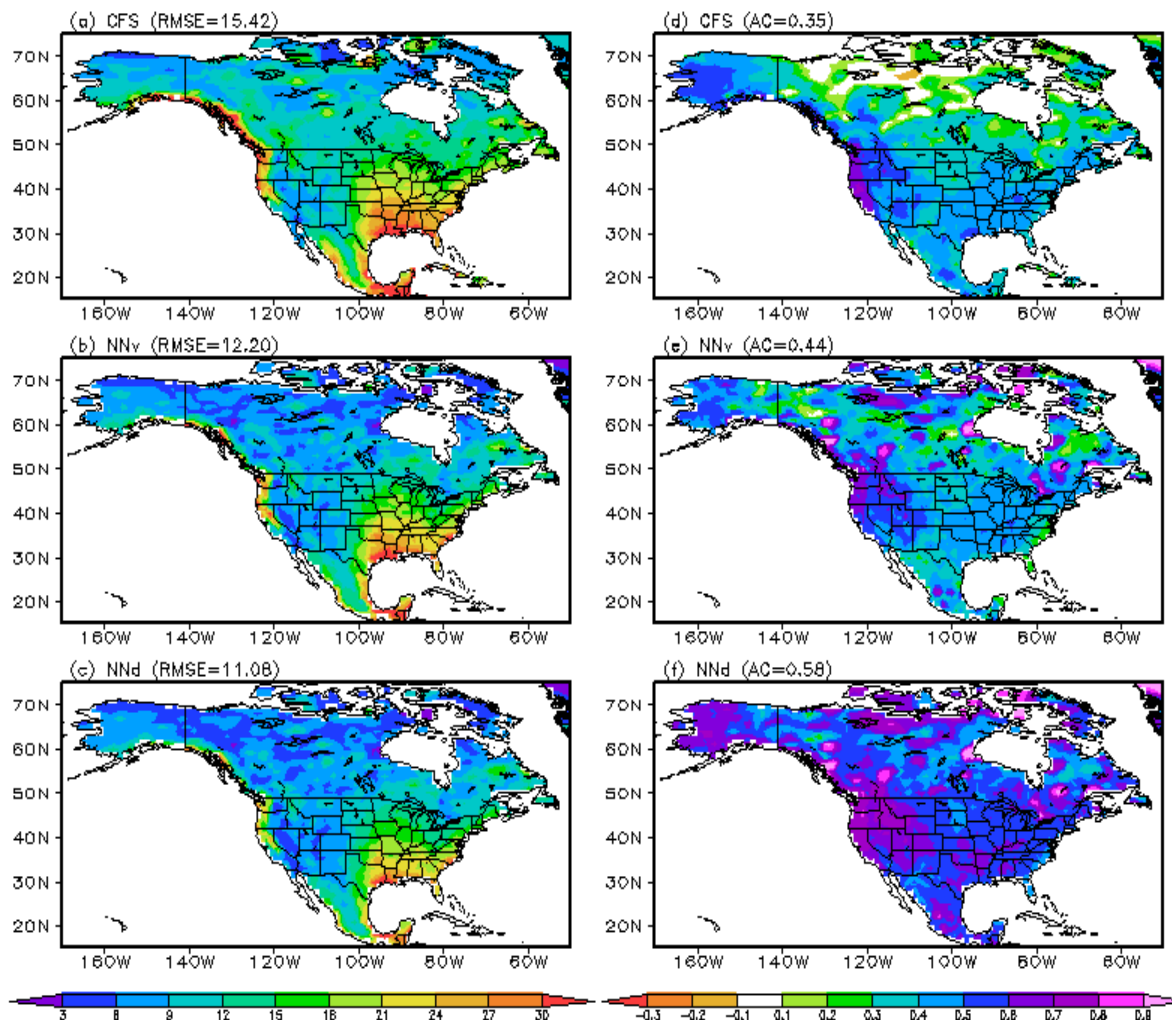


**North American Domain**

CFS: Bias Corrected  
NNv: Yearly Cross-Validation  
NNd: Dependent: 2012-2019

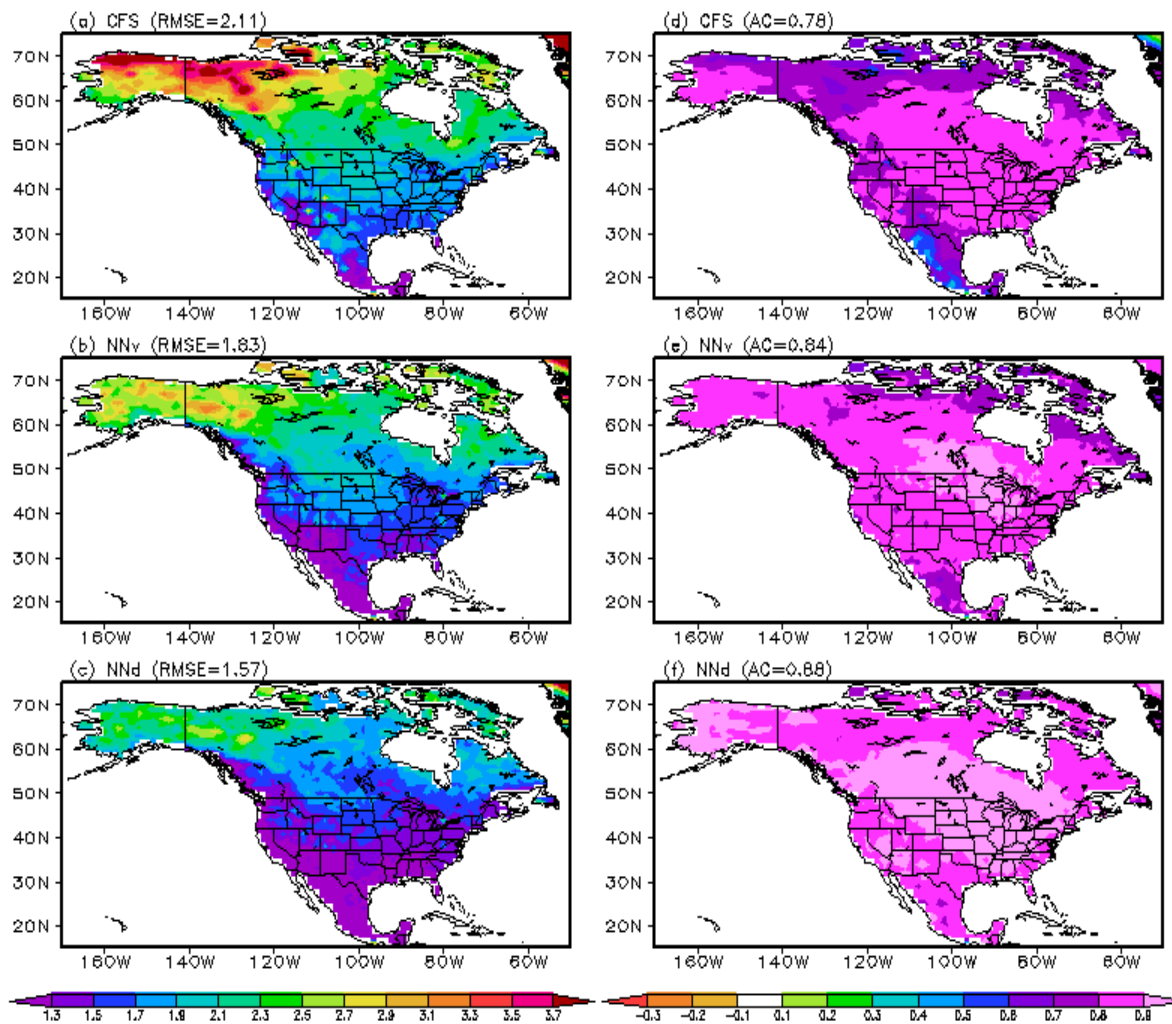


Forecast Week-1 P Daily RMSE (mm) & AC (2012-2019)



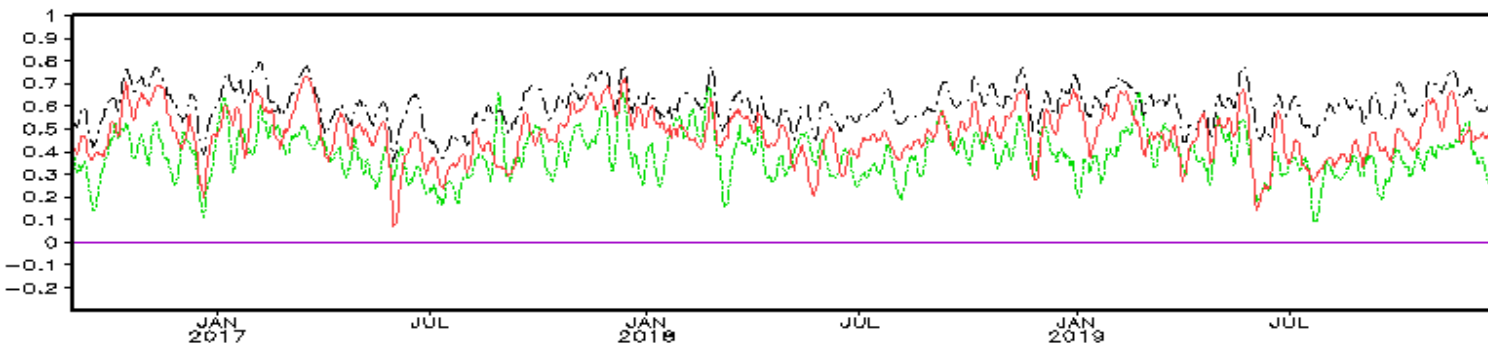
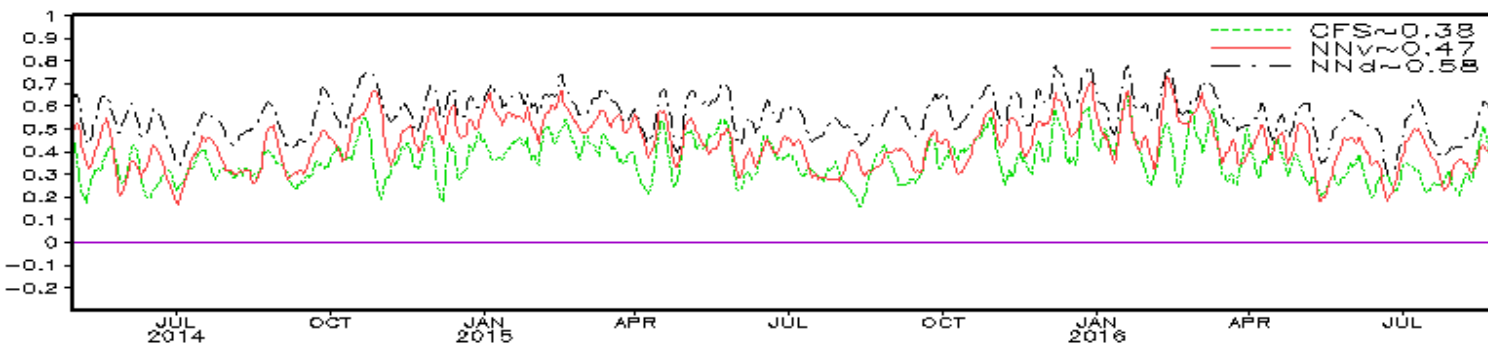
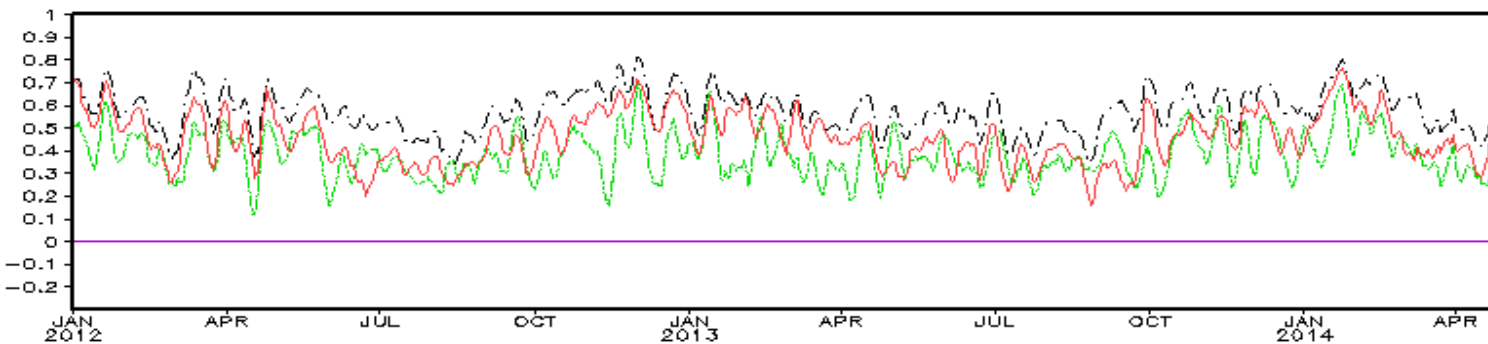
CFS: Bias corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent Fcst

Forecast Week-1 T2m Daily RMSE (°C) & AC (2012-2019)



CFS: Bias corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent Fcst

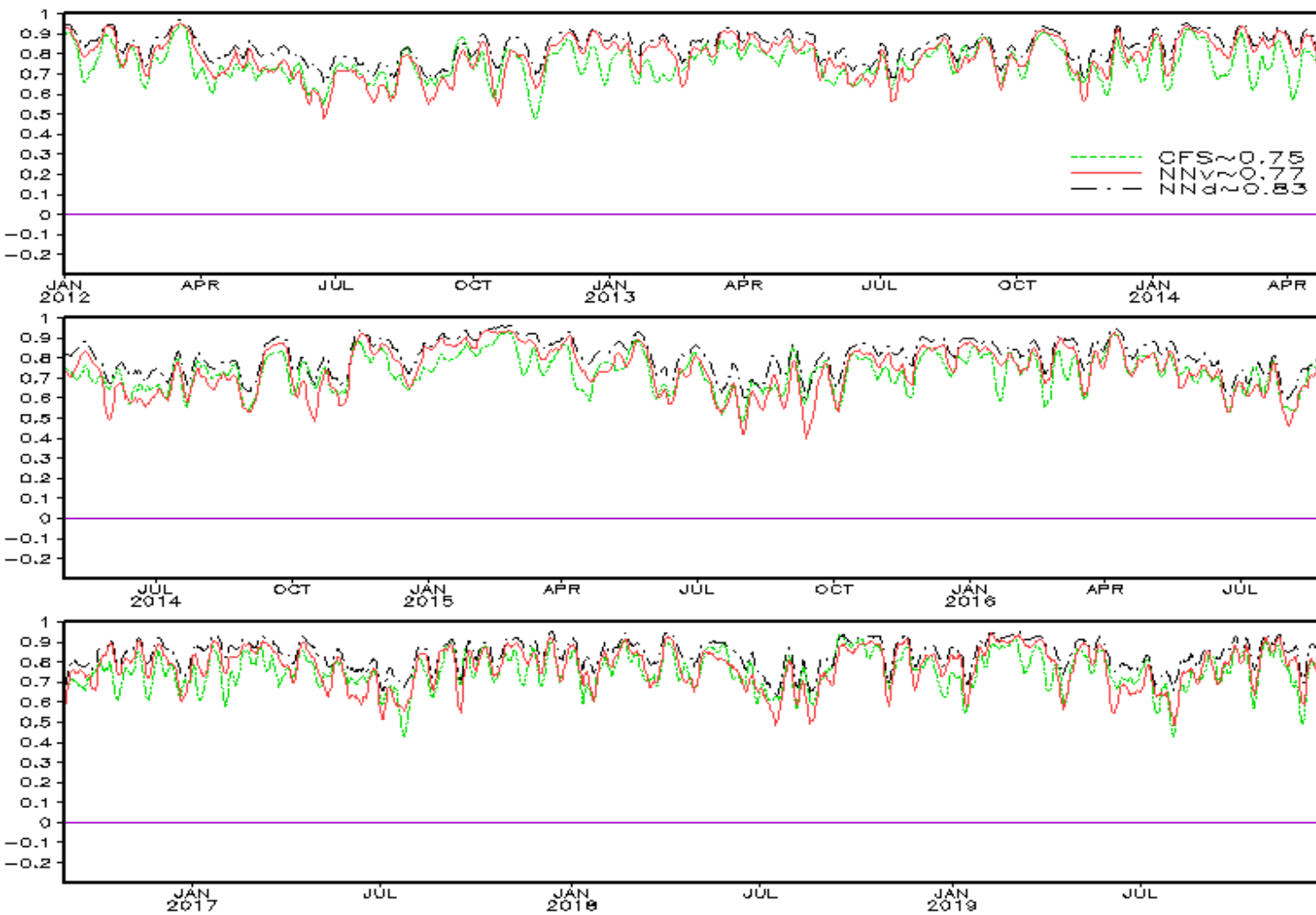
Time Series of Forecast Week-1 P Daily Spatial Anomaly Correlation



**North American Domain**

CFS: Bias Corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent: 2012-2019

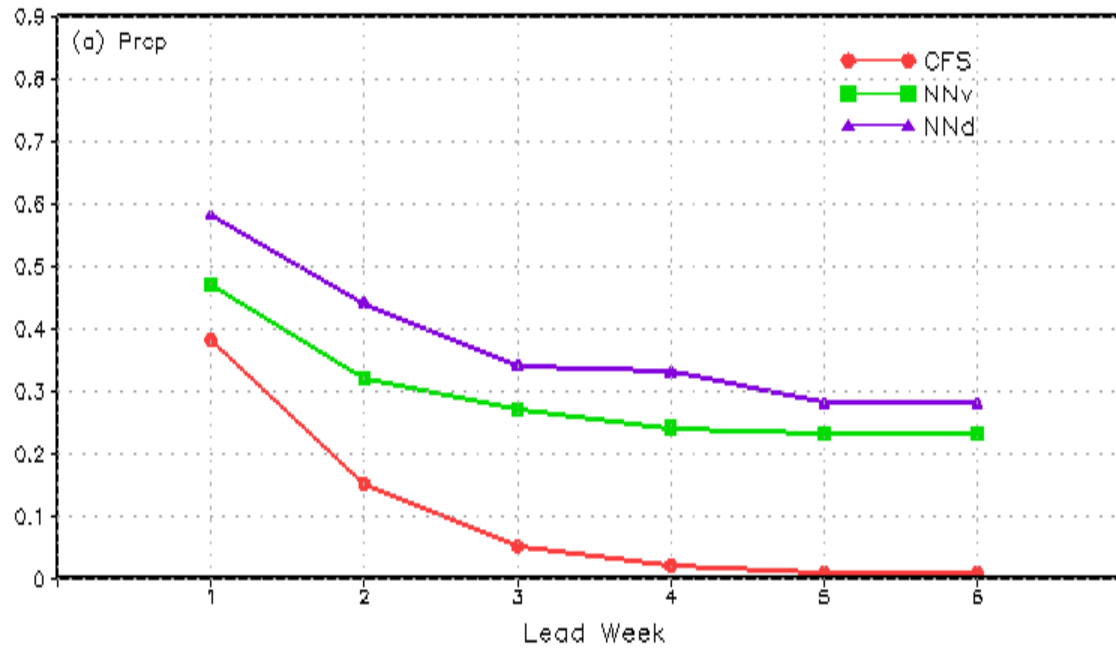
Time Series of Forecast Week-1 T2m Daily Spatial Anomaly Correlation



**North American Domain**

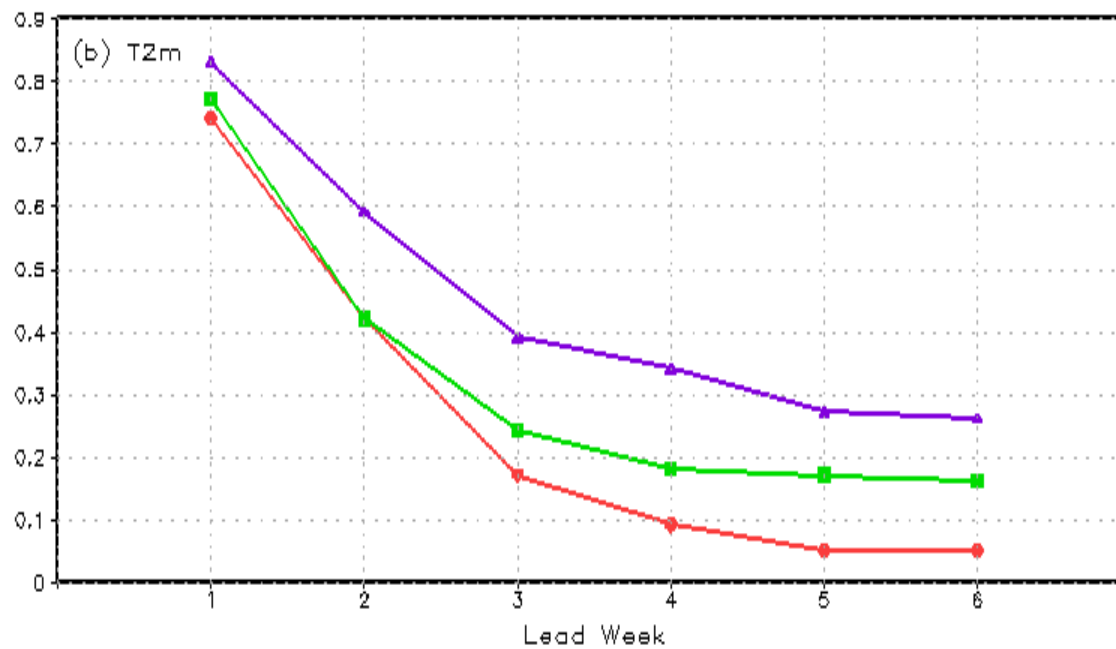
CFS: Bias Corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent: 2012-2019

Forecast Week 1–6 Spatial Anomaly Correlations (2012–2019)

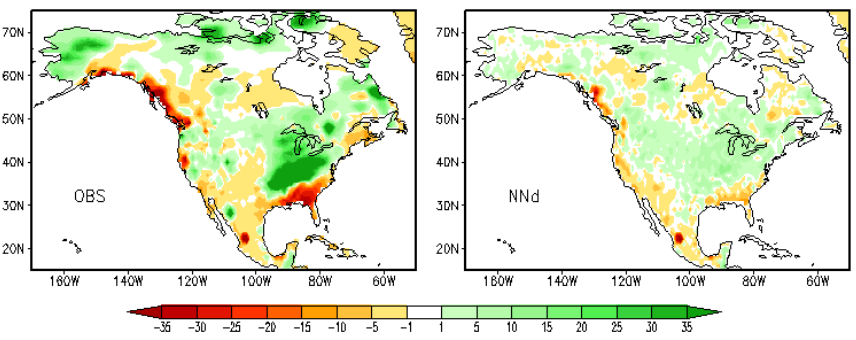


**North American Domain**

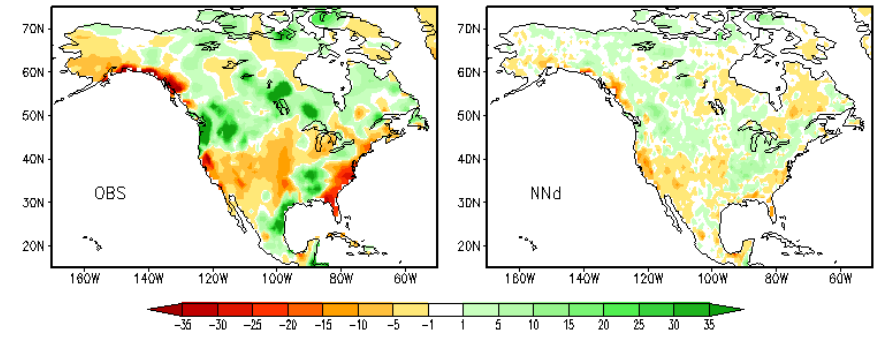
CFS: Bias Corrected  
 NNv: Yearly Cross-Validation  
 NNd: Dependent: 2012-2019



Observed and Forecast Week 5 Prcp Anomalies (mm) 09Jan2019

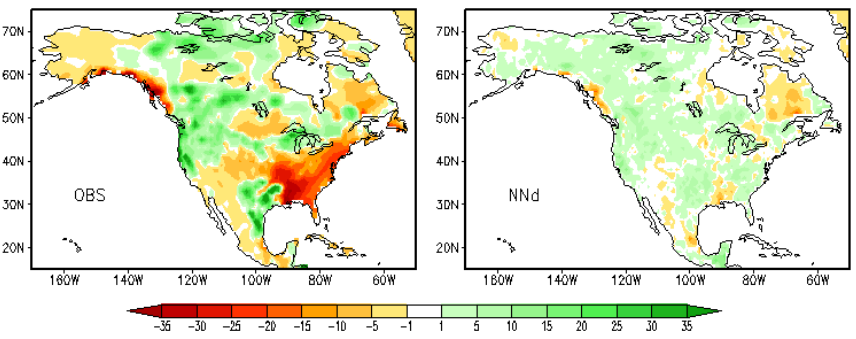


Observed and Forecast Week 5 Prcp Anomalies (mm) 06Feb2017

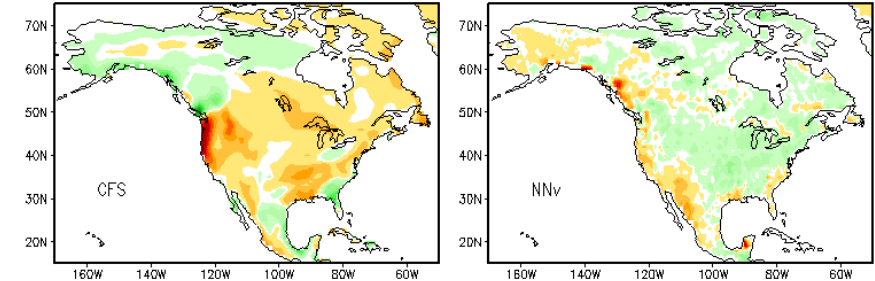
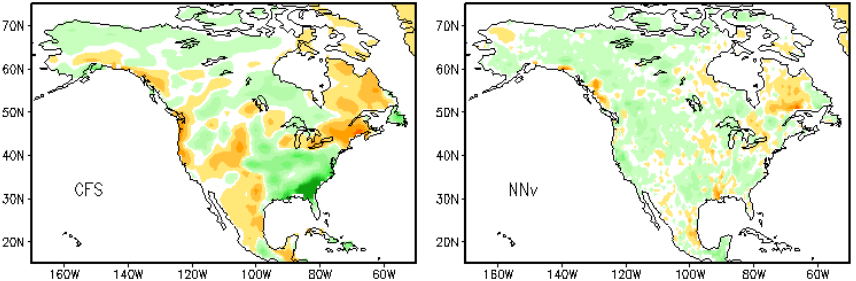
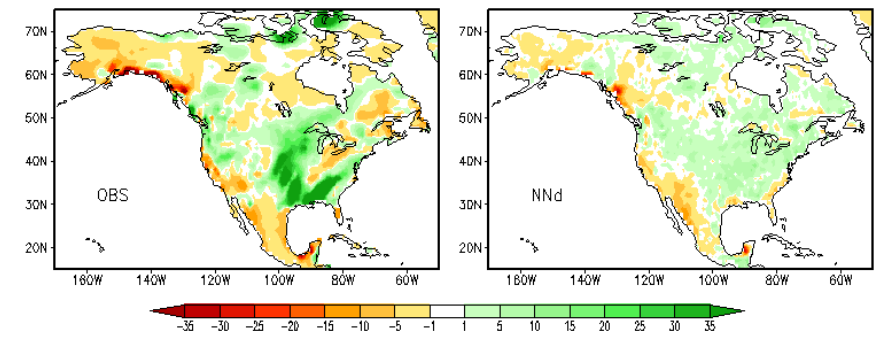


## Week-5 Prcp Forecasts

Observed and Forecast Week 5 Prcp Anomalies (mm) 12Mar2017



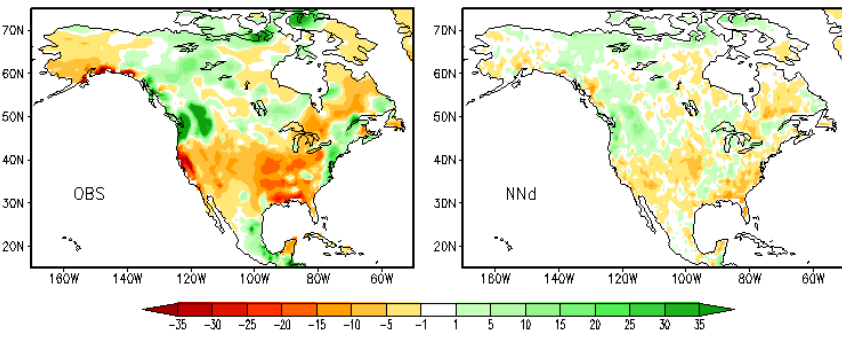
Observed and Forecast Week 5 Prcp Anomalies (mm) 25Nov2018



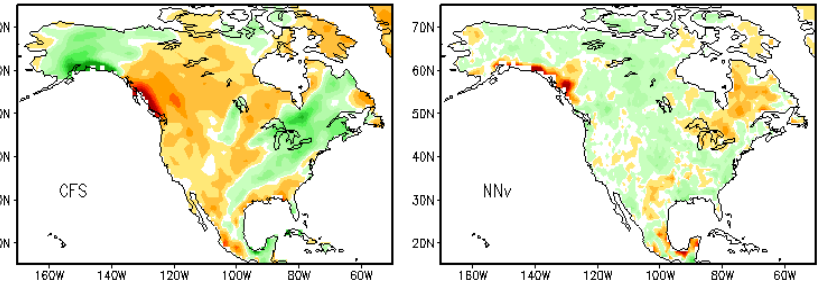
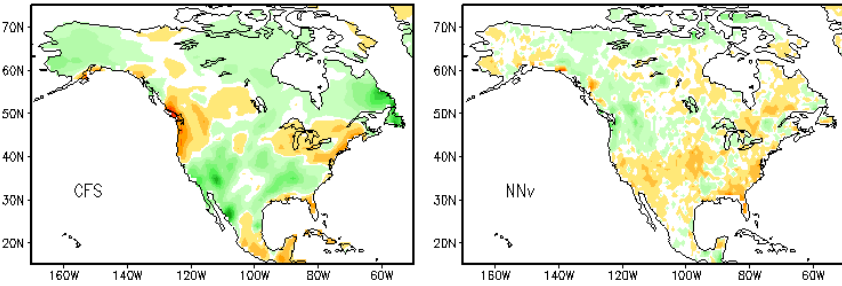
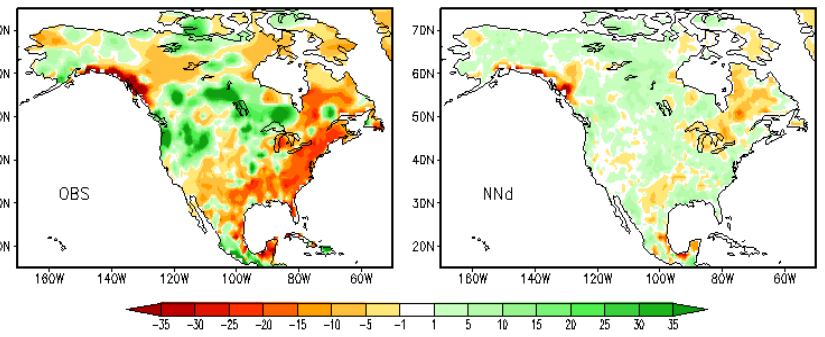




Observed and Forecast Week 6 Prcp Anomalies (mm) 05Feb2017

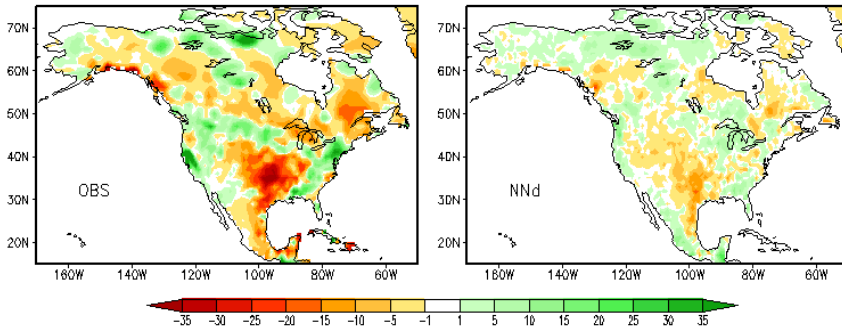


Observed and Forecast Week 6 Prcp Anomalies (mm) 13Aug2017

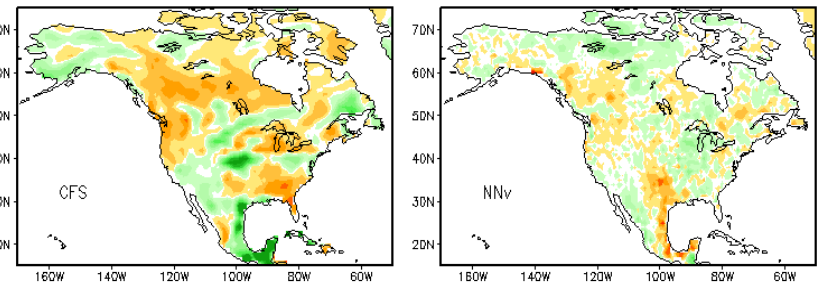
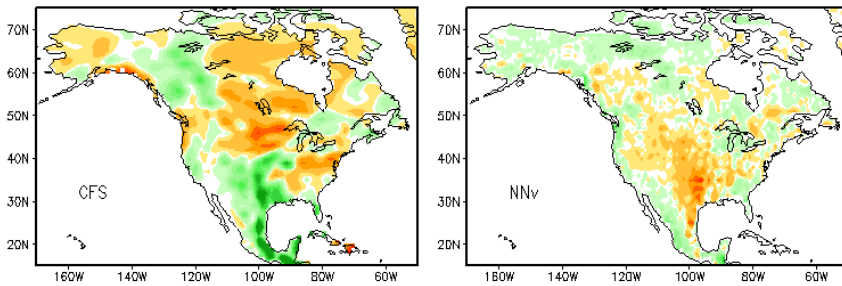
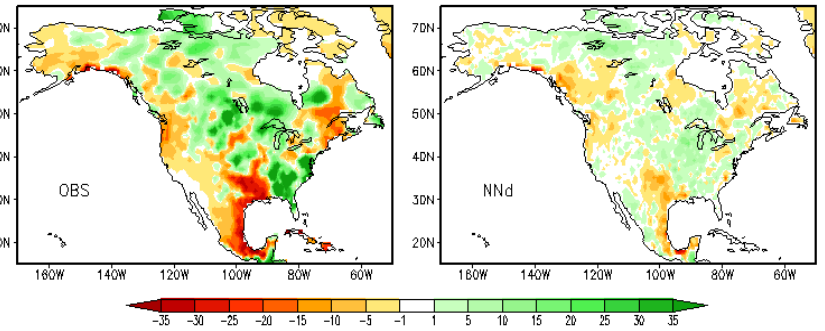


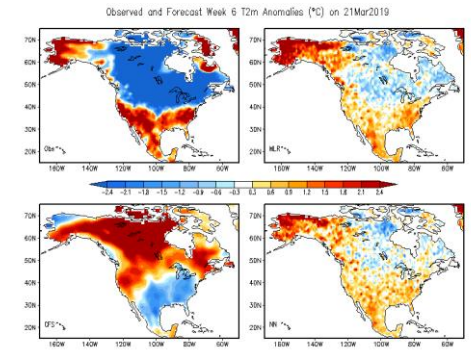
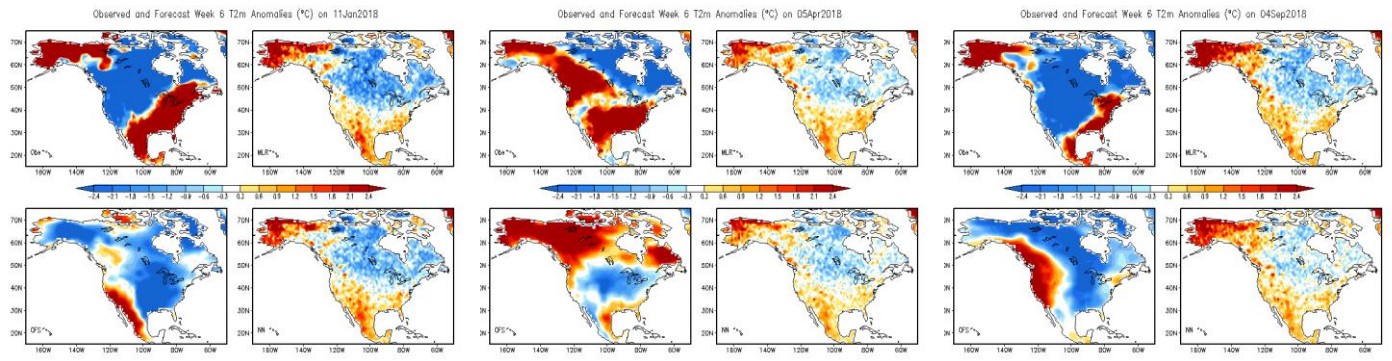
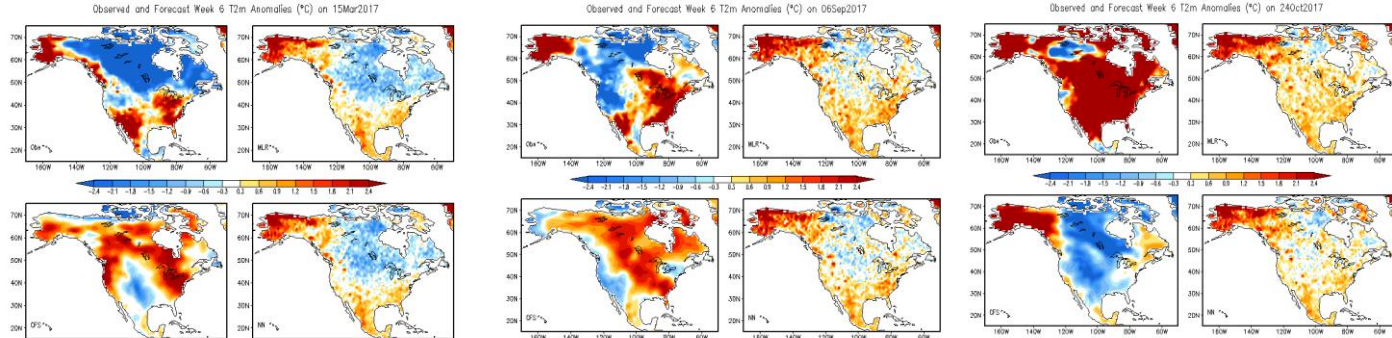
## Week-6 Prcp Forecasts

Observed and Forecast Week 6 Prcp Anomalies (mm) 07Apr2019

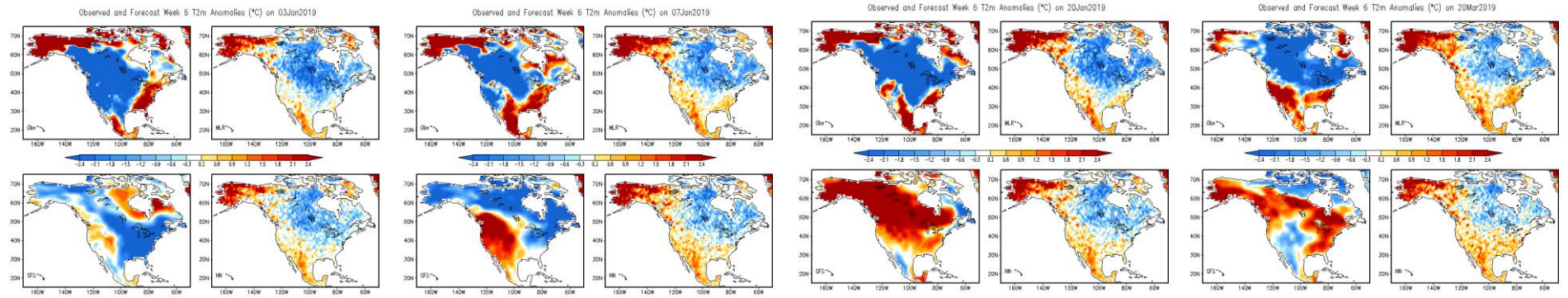


Observed and Forecast Week 6 Prcp Anomalies (mm) 24Apr2018





# Week-6 2m Temperature Forecasts



# Summary

## 1. NN advantages

**Flexible** nonlinear tool & Easy to handle **BIG DATA**

## 2. Unique & beneficial NN architectures: account for

**Non-Linear Impact, Pattern Relationship, Co-Variability**

## 3. NN **Significantly Improves** CFS Week 1-6 P & T2m Fcsts

more sophisticated info hidden behind multiple dimensional big data  
can be extracted by NN

## 4. NN can perform more complicated corrections

by reversing incorrect forecast patterns, hardly done by traditional MLR

## 5. Forecast skills in Week 3-6 ranges have similar tendency

good forecasts in Week 3 tend to be good up to Week 6