Seasonal forecasting of Ethiopian summer rainfall using SST

Gulilat Tefera Diro, David Grimes and Emily Black

Department of Meteorology
University of Reading

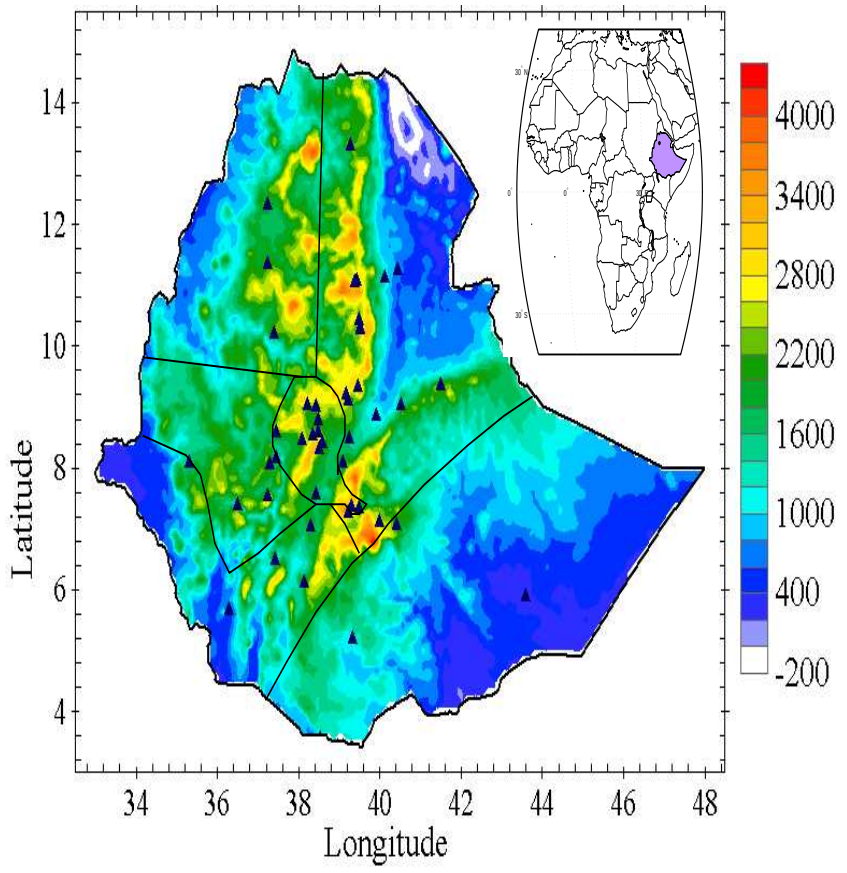
Outline of the talk

- Introduction
- Homogeneous rainfall zones
- Predictor Identification and Selection
- Forecasting Models
- Is there any skill at all?
- Link between SST and rainfall
- Conclusions and Future direction

Introduction

Motivation

- Sectors like agriculture, energy and health are sensitive to rainfall
- Rainfall is highly variable
  - Need for early warning system!



Objective

- To develop a localised (as opposed to large scale) seasonal forecasting system suitable for operational application by considering the spatial variation of rainfall.

Identifying homogeneous rainfall zones

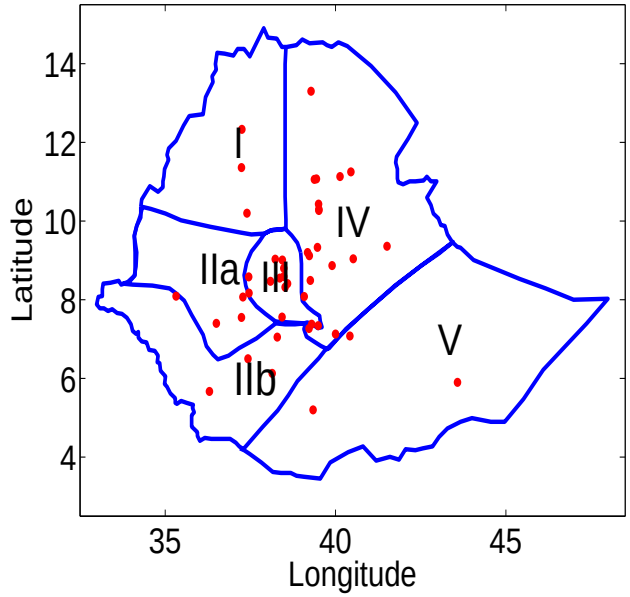
Determining and selecting of predictors

Model development

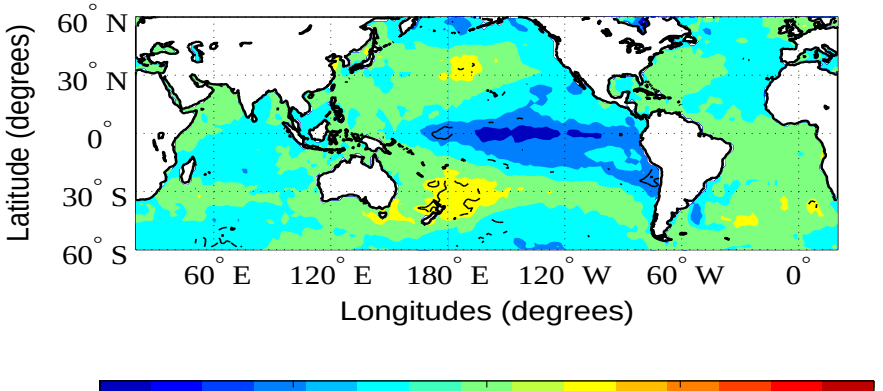
Skill Assessment

Identifying homogeneous rainfall zones

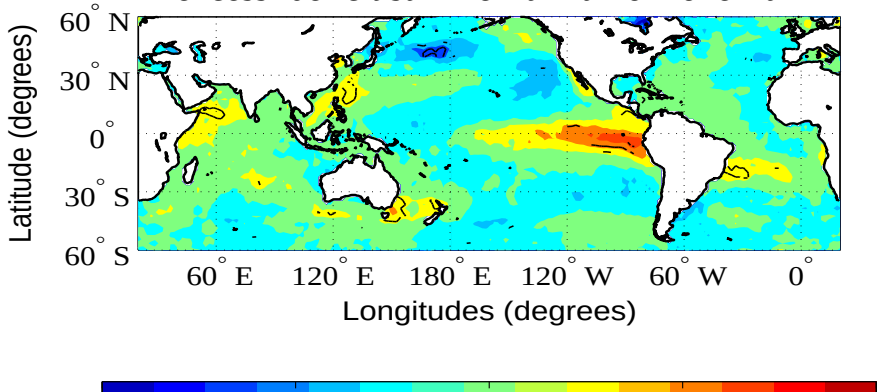
- Averaging over large area is good but should be done cautiously!
- Zoning is carried out based on:
  - Seasonal cycle
  - Inter-annual variability (Gissila et al., 2004)



Composite of previous winter SST based on excess−deficit summer rainfall of of zone I

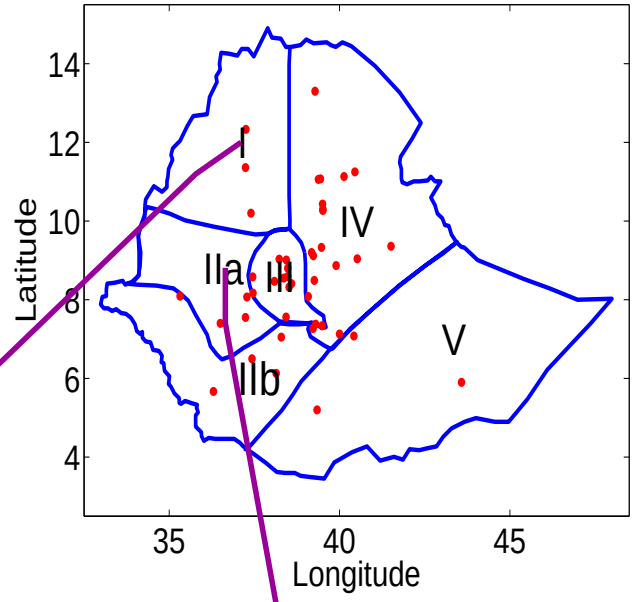


Composite of previous winter SST based on excess−deficit summer rainfall of zone IIa

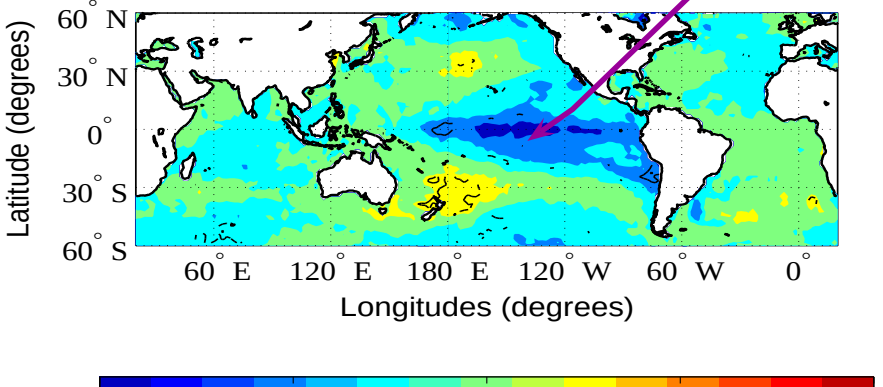


Identifying homogeneous rainfall zones

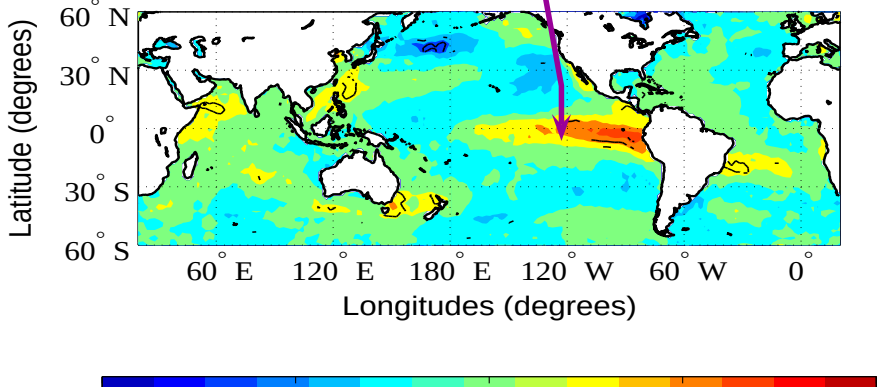
- Averaging over large area is good but should be done cautiously!
- Zoning is carried out based on:
  - Seasonal cycle
  - Inter-annual variability (Gissila et al., 2004)



Composite of previous winter SST based on excess−deficit summer rainfall of of zone I



Composite of previous winter SST based on excess−deficit summer rainfall of zone IIa



Identifying homogeneous rainfall zones

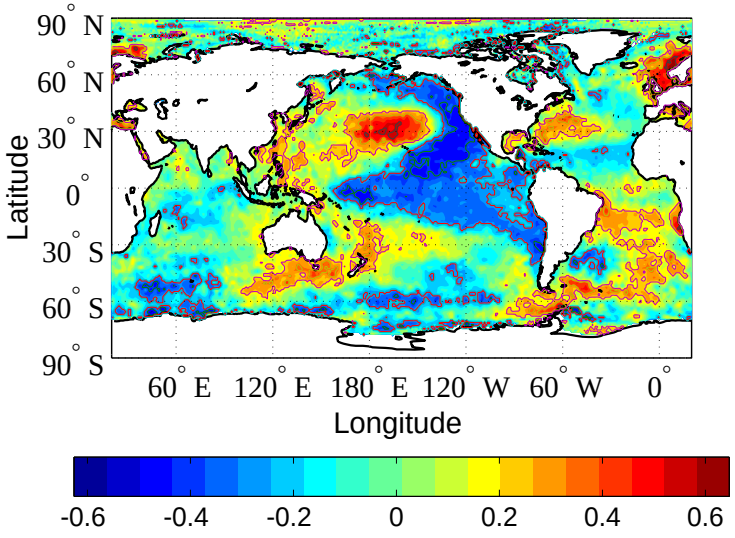
Determining and selecting of predictors

Model development

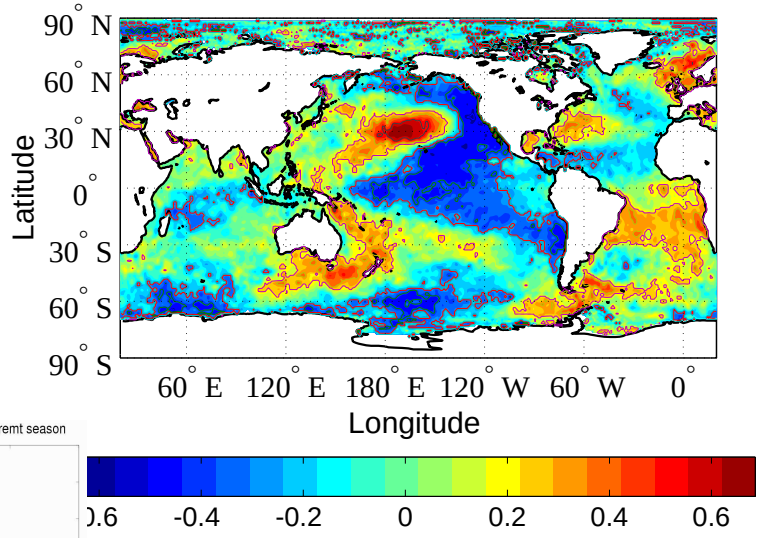
Skill Assessment

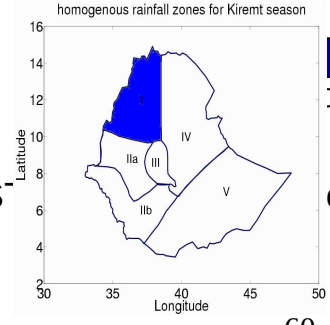
Predictors Identification

Correlation of Zone I ranfall with February SST

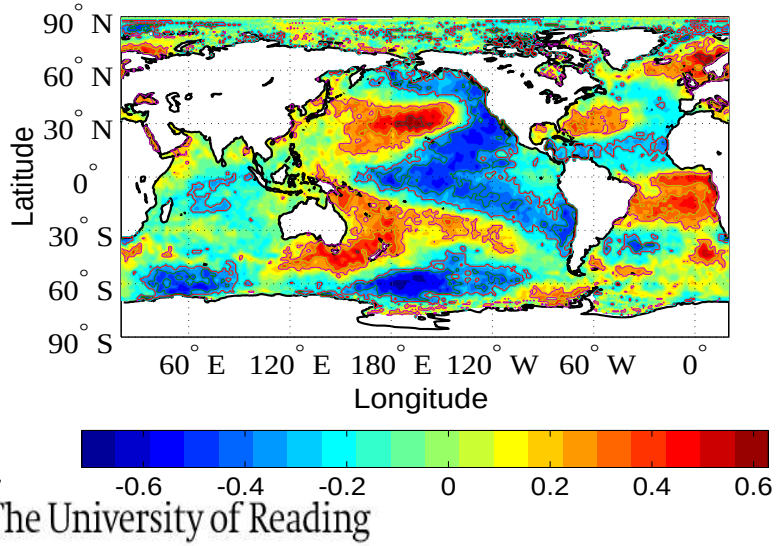


Correlation of Zone I ranfall with March SST

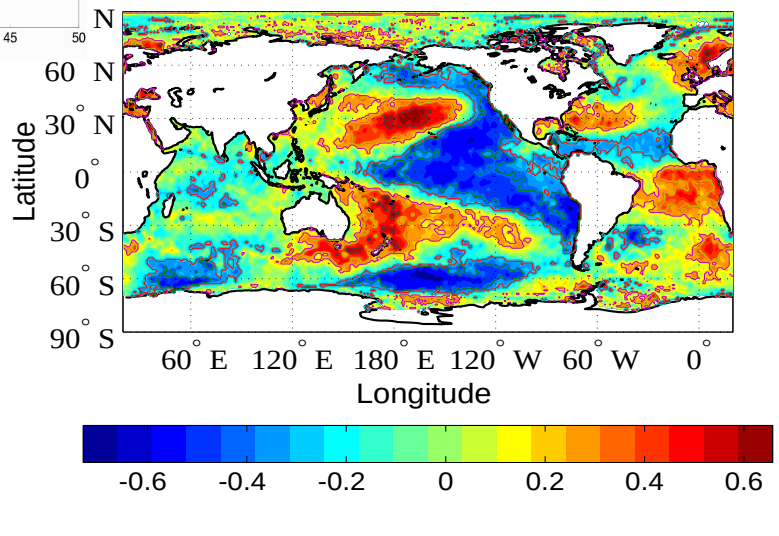




Correlation of Zone I ranfall with April SST

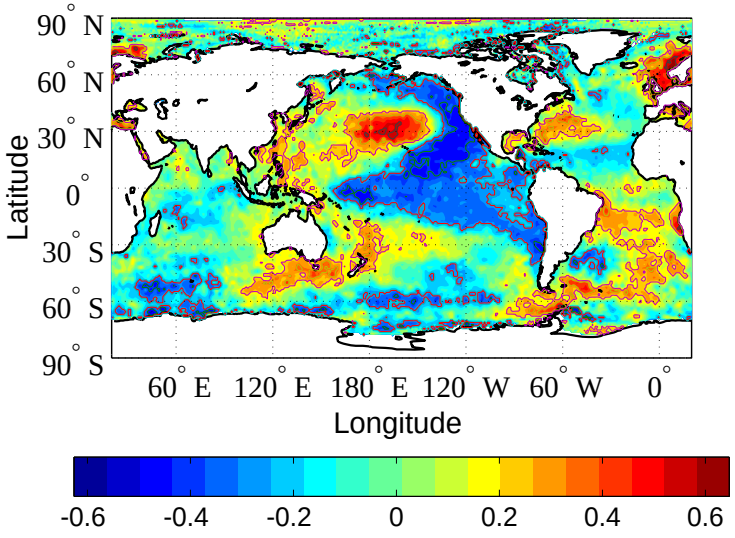


Correlation of Zone I ranfall with May SST

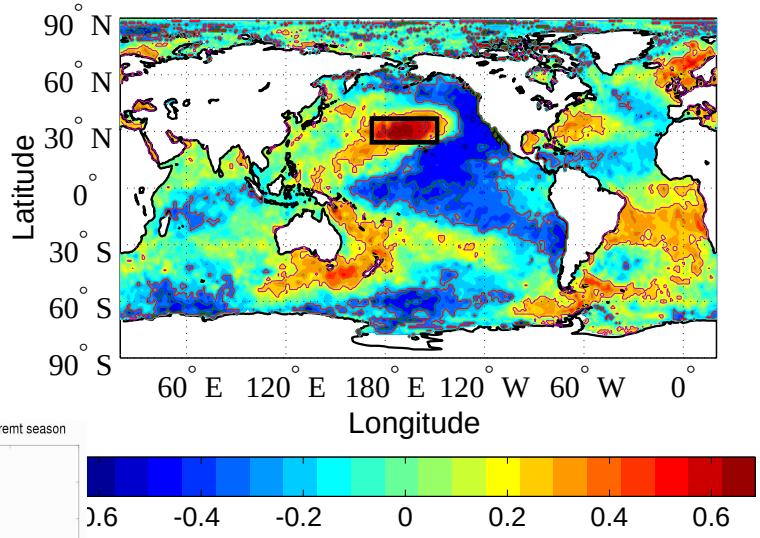


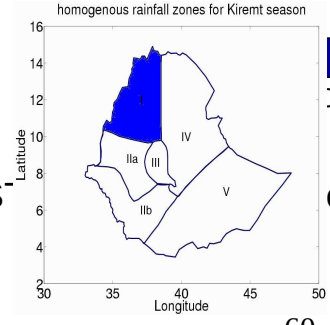
Predictors Identification

Correlation of Zone I ranfall with February SST

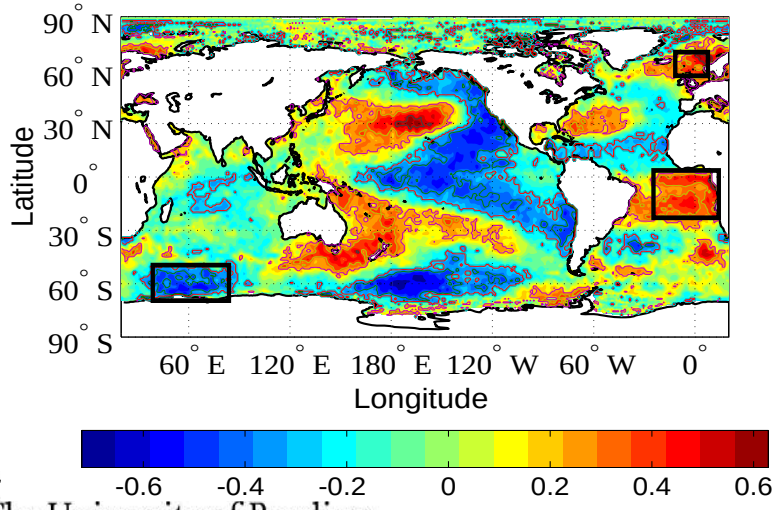


Correlation of Zone I ranfall with March SST

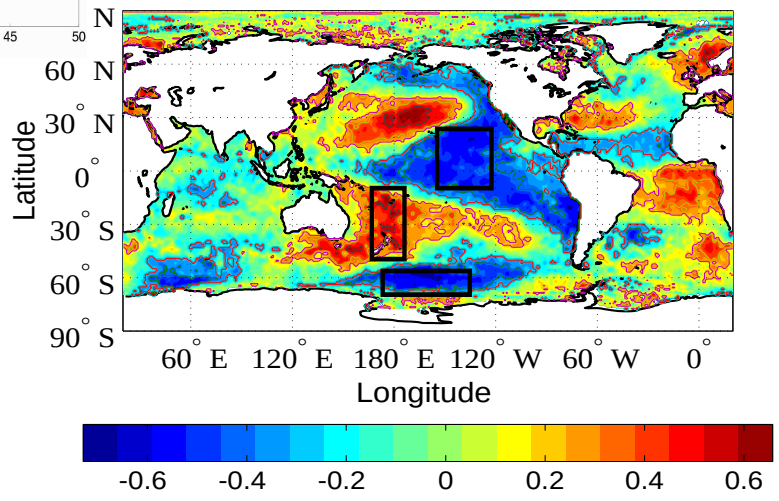




Correlation of Zone I ranfall with April SST



Correlation of Zone I ranfall with May SST

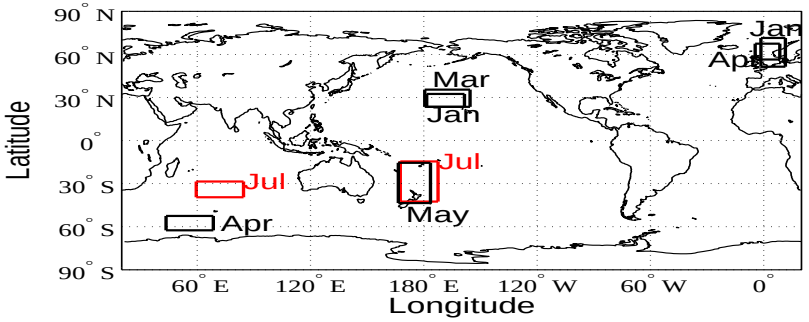


Selection procedure

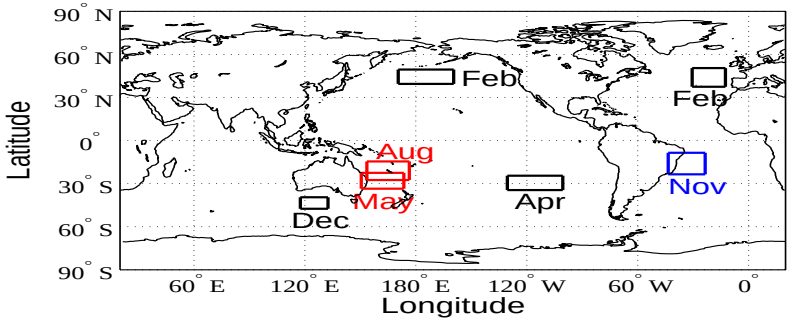
- Selection of 'best' predictors is done using stepwise regression by fixing the significant level ($\alpha = 0.15$)
- Two sets of Predictors (A and B) are created by:
  - A: Excluding predictors from contemporaneous season
  - B: Including predictors from contemporaneous season

Selected Predictors

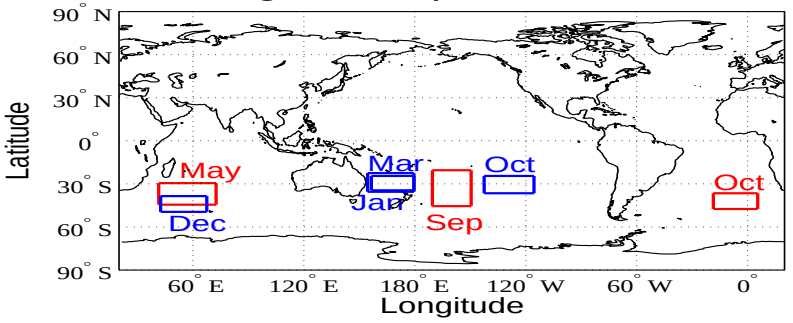
Location & lag time of predictors for Zone I



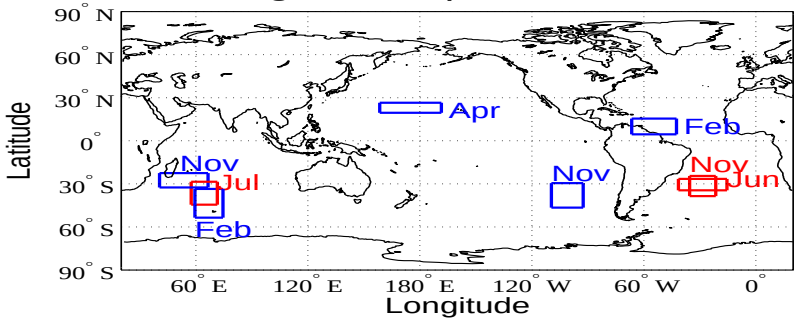
Location & lag time of predictors for Zone IIa



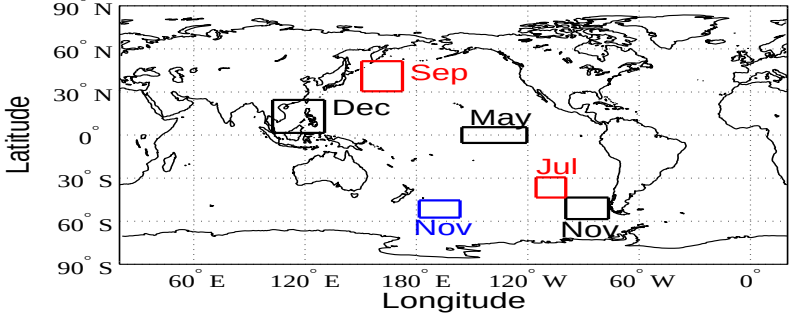
Location & lag time of predictors for Zone IIb

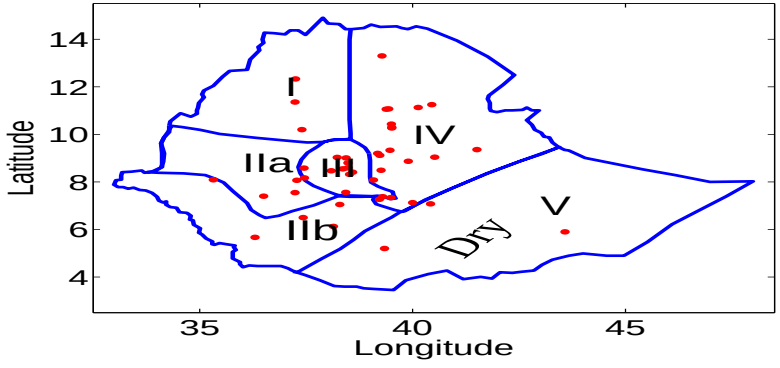


Location & lag time of predictors for zone III



Location & lag time of predictors for Zone IV





Including Contemporaneous Season

Excluding Contemporaneous season

Common to both

Identifying homogeneous rainfall zones

Determining and selecting of predictors

Model development

Skill Assessment

Forecasting Models

- Multiple Linear Regression (MLR)

$$Y = \beta_o + \sum_{i=1}^{n} \beta_i X_i + \epsilon$$

Y = Rainfall ; X= predictors (SSTA); ϵ= residuals; β = regression parameter

- Linear Discriminant Analysis (LDA)

$$Pr(W_i|X) = \frac{q_i f_i(X)}{\sum_j q_j f_j(X)} \quad ; \quad ln(f_i(X)) = \alpha_{i1}x_1 + \alpha_{i2}x_2 + \ldots + \alpha_{in}x_n + \Gamma_i$$

$$Pr(W_i|X) = \frac{e^{d_i}}{\sum_j e^{d_j}} \quad ; where \quad d_i = \alpha_{i1}x_1 + \alpha_{i2}x_2 + \ldots + \alpha_{in}x_n + \Gamma_i + ln(q_i)$$

Where $\alpha_{ij} = S_{ij}^{-1}\bar{x}_i$ and $\Gamma_i = -\frac{1}{2}\bar{x}_i^T S^{-1}\bar{x}_i$

d=discriminant score, q = apriori probability, W = category, f = density function

Identifying homogeneous rainfall zones

Determining and selecting of predictors

Model development

Skill Assessment

Skill assessment-I

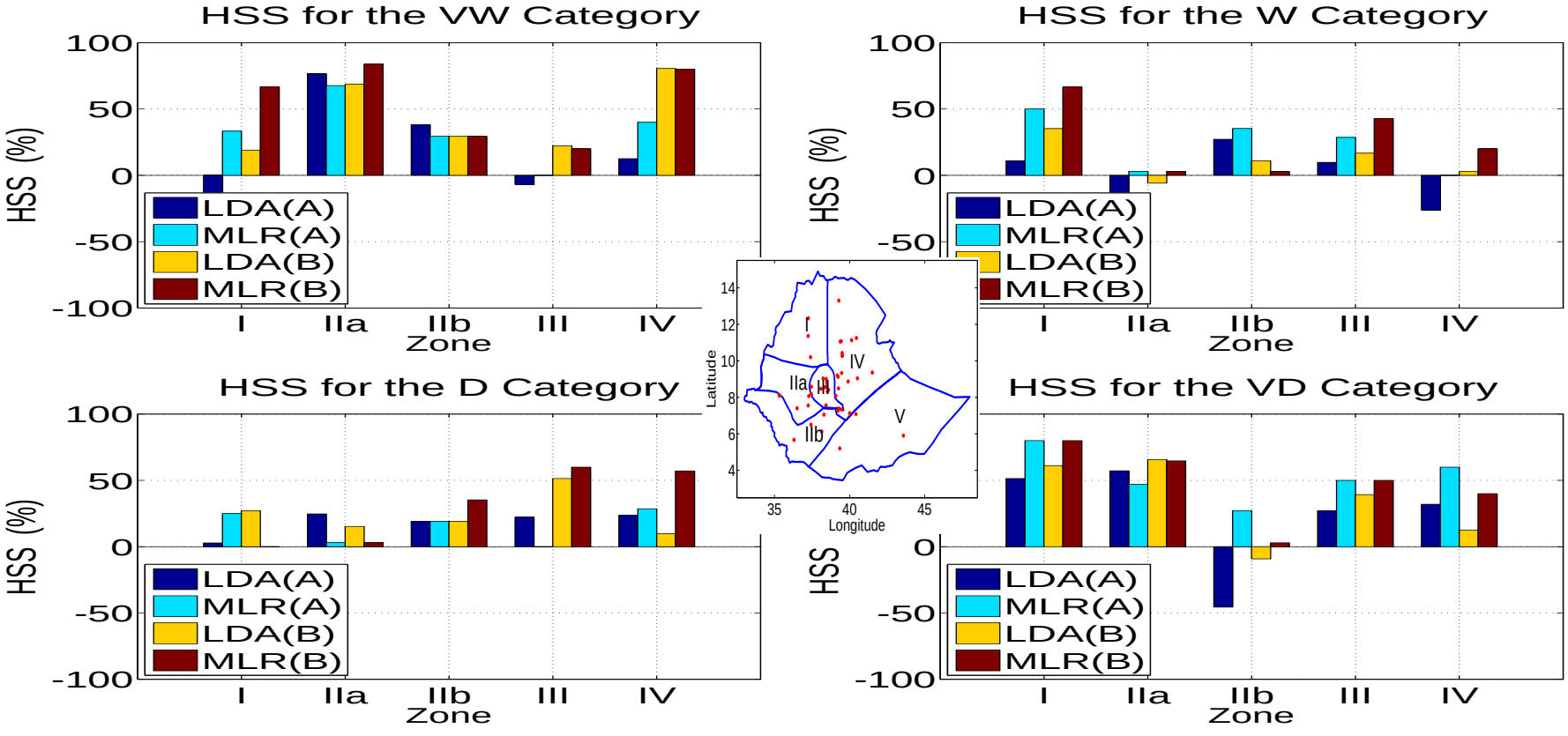
- Cross-validation
- Bring the forecast from both models into categorical form
- 1. Relative operational characteristics (ROC) score
  - compare with a random forecast
  - For skillful forecast → ROC score (0.5,1]

	Dry		Normal		Wet	
JJAS	LDA	MLR	LDA	MLR	LDA	MLR
Set A	0.72	0.73	0.50	0.56	0.76	0.77
Set B	0.74	0.76	0.60	0.64	0.82	0.83

  - Lower skill in the near Normal category
  - Wet category has higher skill than dry category

Skill assessment -II

- 2. Heidke Skill Score (HSS)
  - compare with persistence forecast
  - For skillful forecast → HSS(0,1]



- LDA performs less well compared to the MLR

Link between SST and Rainfall-Composite approach

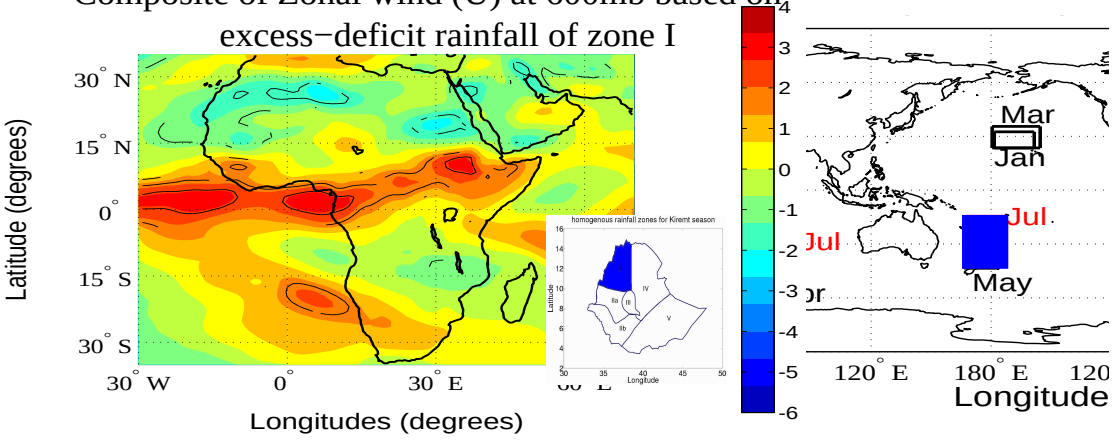
To understand the link between the predictors (remote SSTs) and Ethiopian rainfall two sets of composites have been used.

- Composites of atmospheric variables based on excess/deficit rainfall years
  - To identify the large scale atmospheric variables responsible for the rainfall variability
- Composites of atmospheric variables based on warm/cold SST years over the regions used as predictors
  - To identify the role of each predictor on the large scale atmospheric features

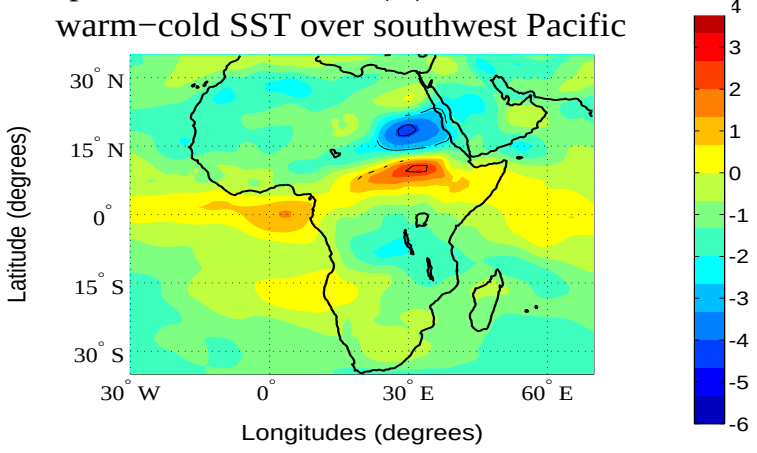
Link between SST and rainfall-I

Southwest sub-tropical Pacific SST - African Easterly Jet - Rainfall

Composite of Zonal wind (U) at 600mb based on excess−deficit rainfall of zone I



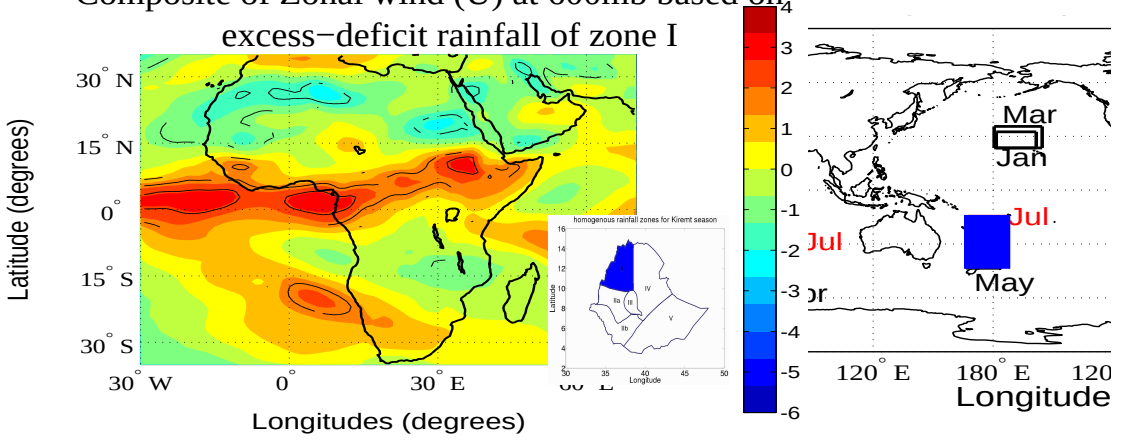
Composite of Zonal wind (U) at 600mb based on warm−cold SST over southwest Pacific



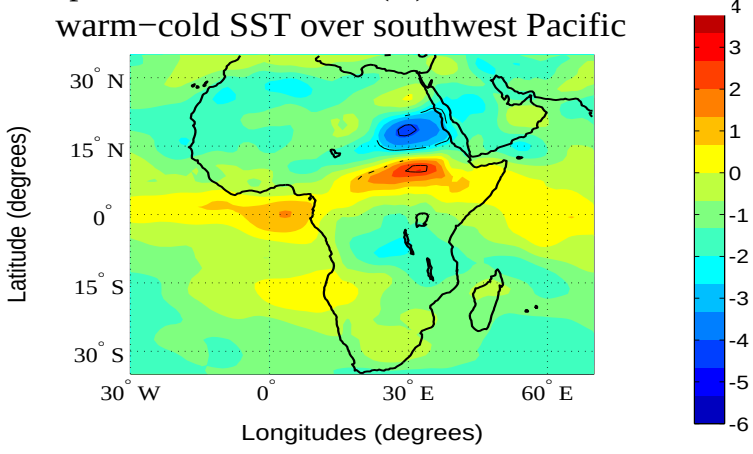
Link between SST and rainfall-I

Southwest sub-tropical Pacific SST - African Easterly Jet - Rainfall

Composite of Zonal wind (U) at 600mb based on excess−deficit rainfall of zone I

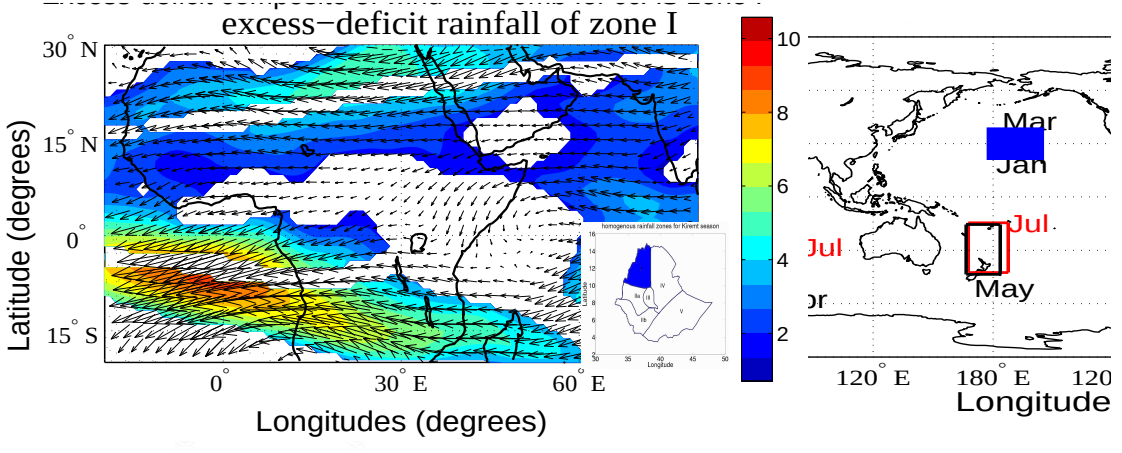


Composite of Zonal wind (U) at 600mb based on warm−cold SST over southwest Pacific

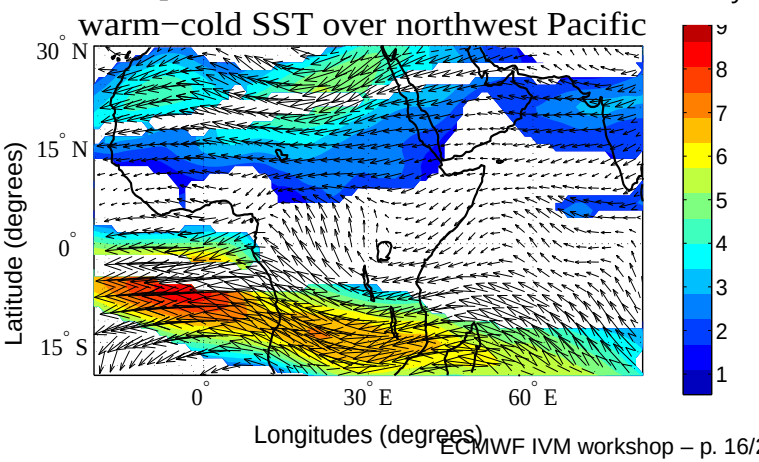


Northwest sub-tropical Pacific SST - Tropical easterly Jet - Rainfall

Composite of wind at 200mb based on excess−deficit rainfall of zone I



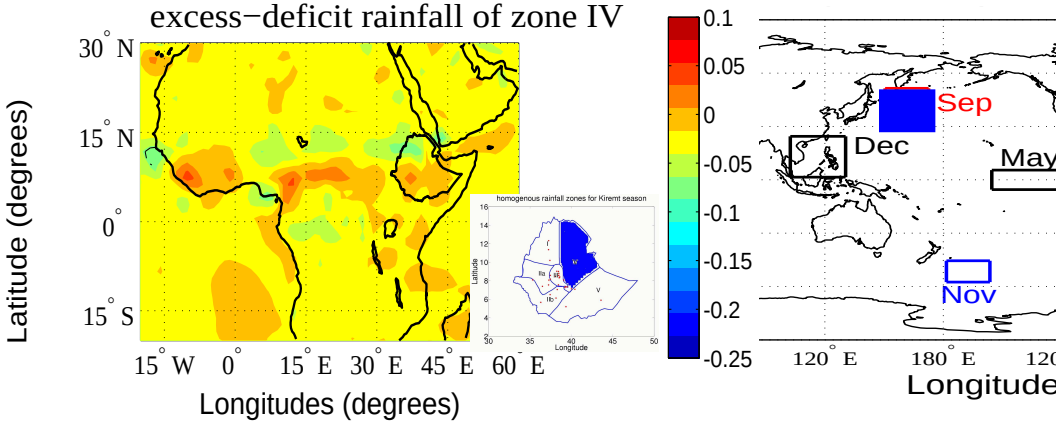
Composite of wind at 200mb based on warm−cold SST over northwest Pacific



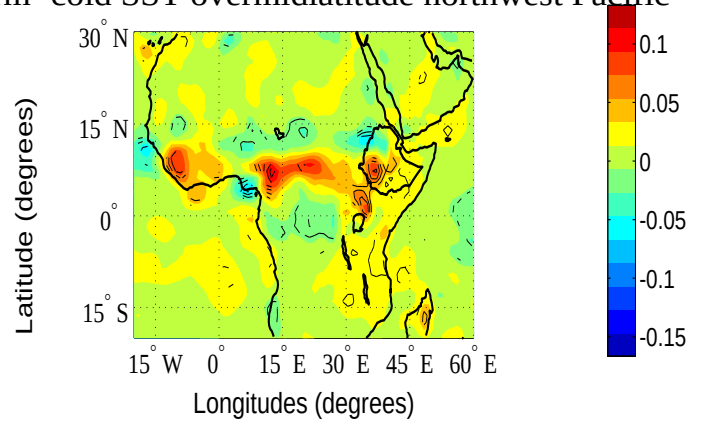
Link between SST and Rainfall-II

Mid-latitude Northwest Pacific SST - ITCZ - Rainfall

Composite of vertical wind (pa/sec) at 500mb based on excess−deficit rainfall of zone IV



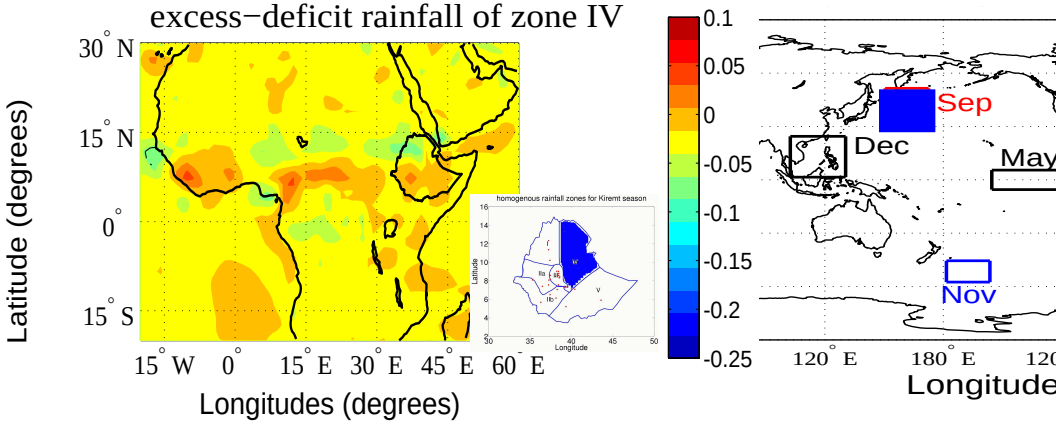
Composite of vertical wind (pa/sec) at 500mb based on warm−cold SST overmidlatitude northwest Pacific



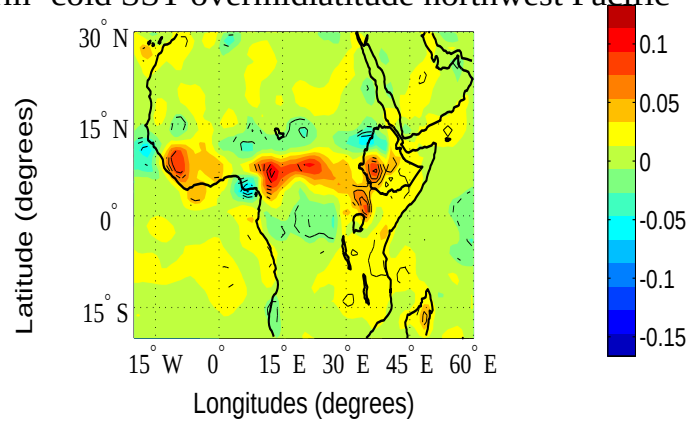
Link between SST and Rainfall-II

Mid-latitude Northwest Pacific SST - ITCZ - Rainfall

Composite of vertical wind (pa/sec) at 500mb based on excess−deficit rainfall of zone IV

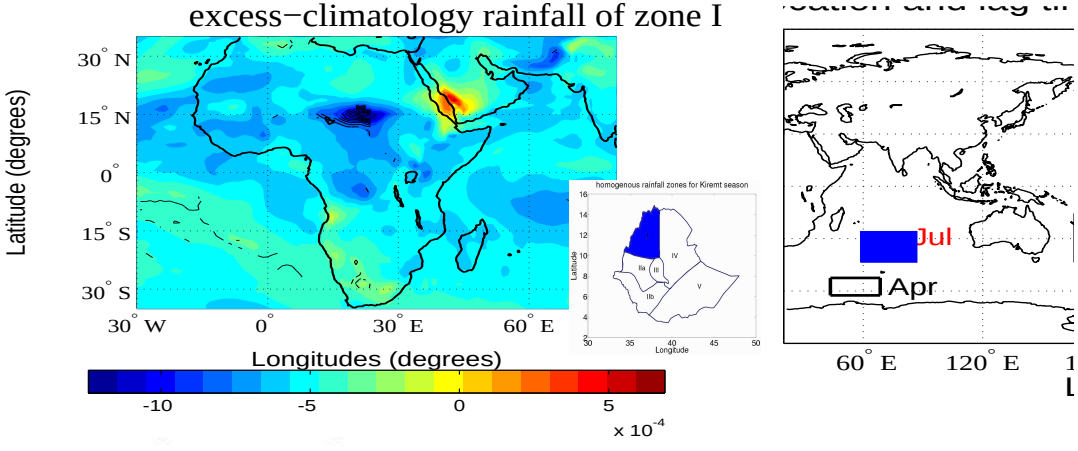


Composite of vertical wind (pa/sec) at 500mb based on warm−cold SST overmidlatitude northwest Pacific

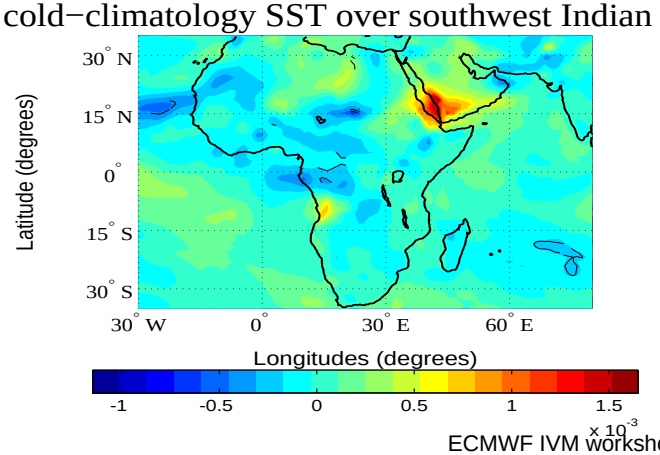


South west Indian Ocean SST - Humidity - Rainfall

Composite of humidity (kg/kg) at 850mb based on excess−climatology rainfall of zone I



Composite of humdity (kg/kg) at 850mb based on cold−climatology SST over southwest Indian Ocean



Summary and conclusions

- Due to high spatial variation forecasting should be done for each homogeneous rainfall zones separately
- Generally both models are better than random, climatology or persistence
- Most of the time MLR tends to outperform LDA
- Models that include predictors from contemporaneous season has got better skill

Summary and conclusions

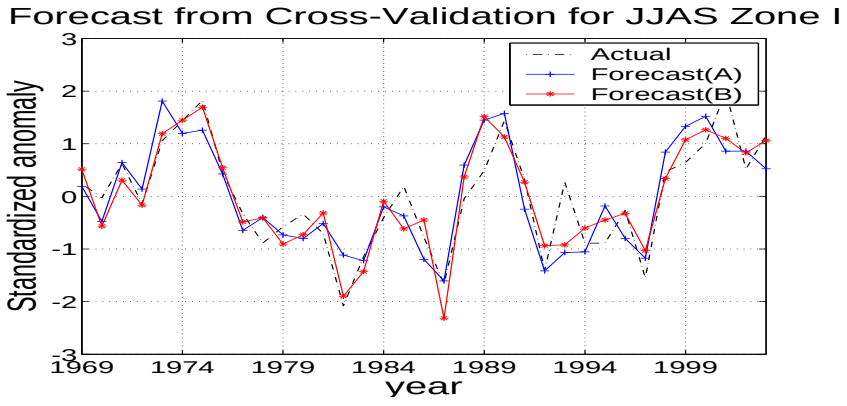
- Due to high spatial variation forecasting should be done for each homogeneous rainfall zones separately
- Generally both models are better than random, climatology or persistence
- Most of the time MLR tends to outperform LDA
- Models that include predictors from contemporaneous season has got better skill
- SSTA over regions of predictors are linked to rainfall via large scale atmospheric features. For example SSTA over:
  - SW Pacific is associated with N-S displacement of AEJ
  - NW Pacific is associated with change in strength of TEJ
  - Mid-lat. NW Pacific is associated with N-S shift of ITCZ
  - SW IO is associated with humidity anomaly over Red Sea

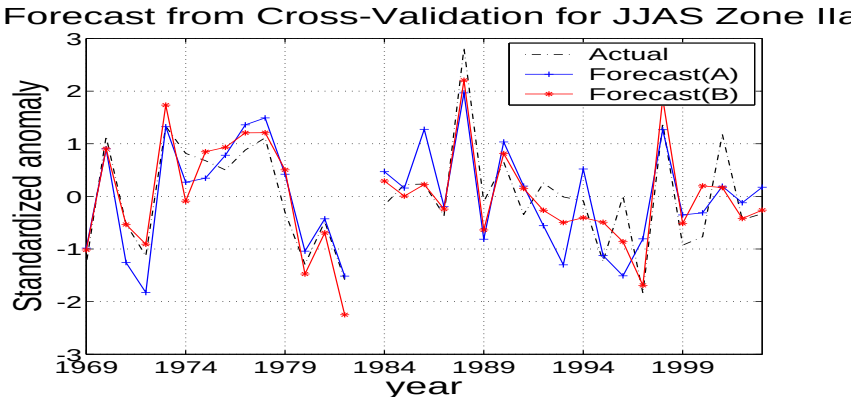
Future work

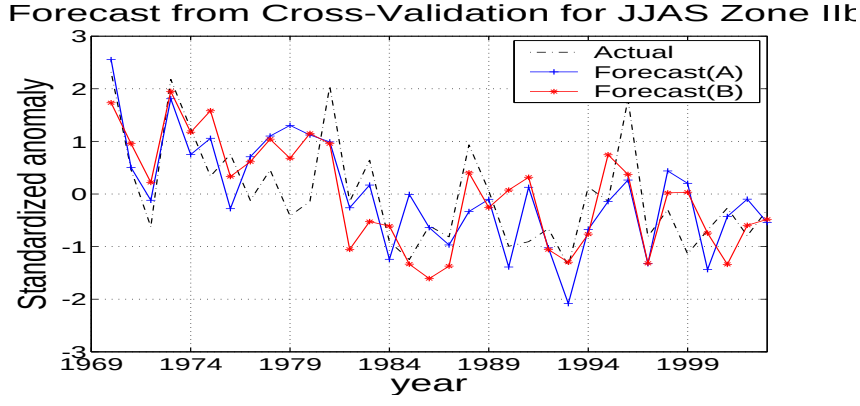
- Modify the seasonal forecast by using additional atmospheric parameter and compare with the one already done
- Carry out idealised SST experiments for different regions of oceans to understand the mechanisms

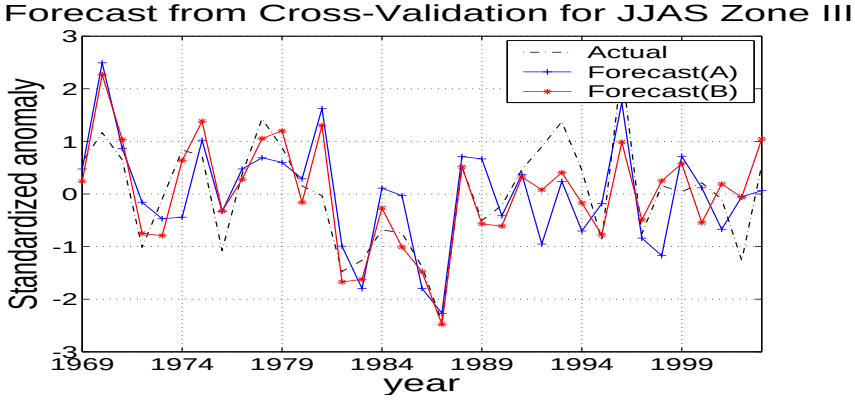
Thanks

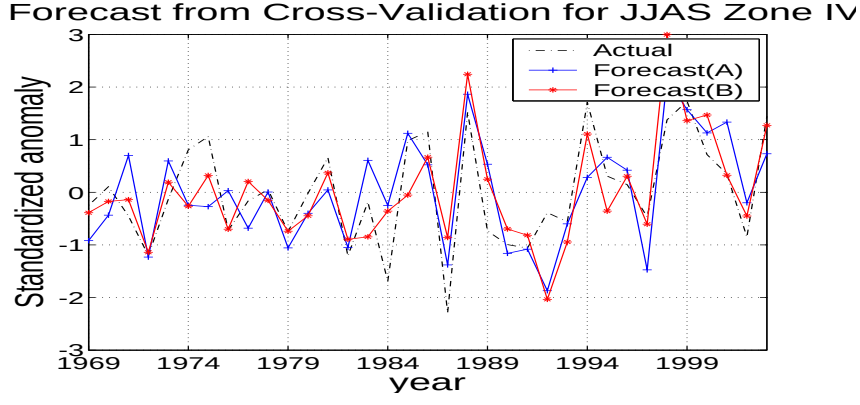
Cross-validation of MLR

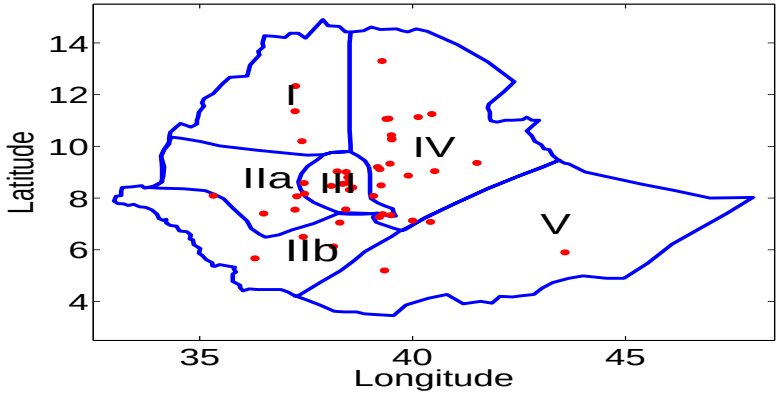








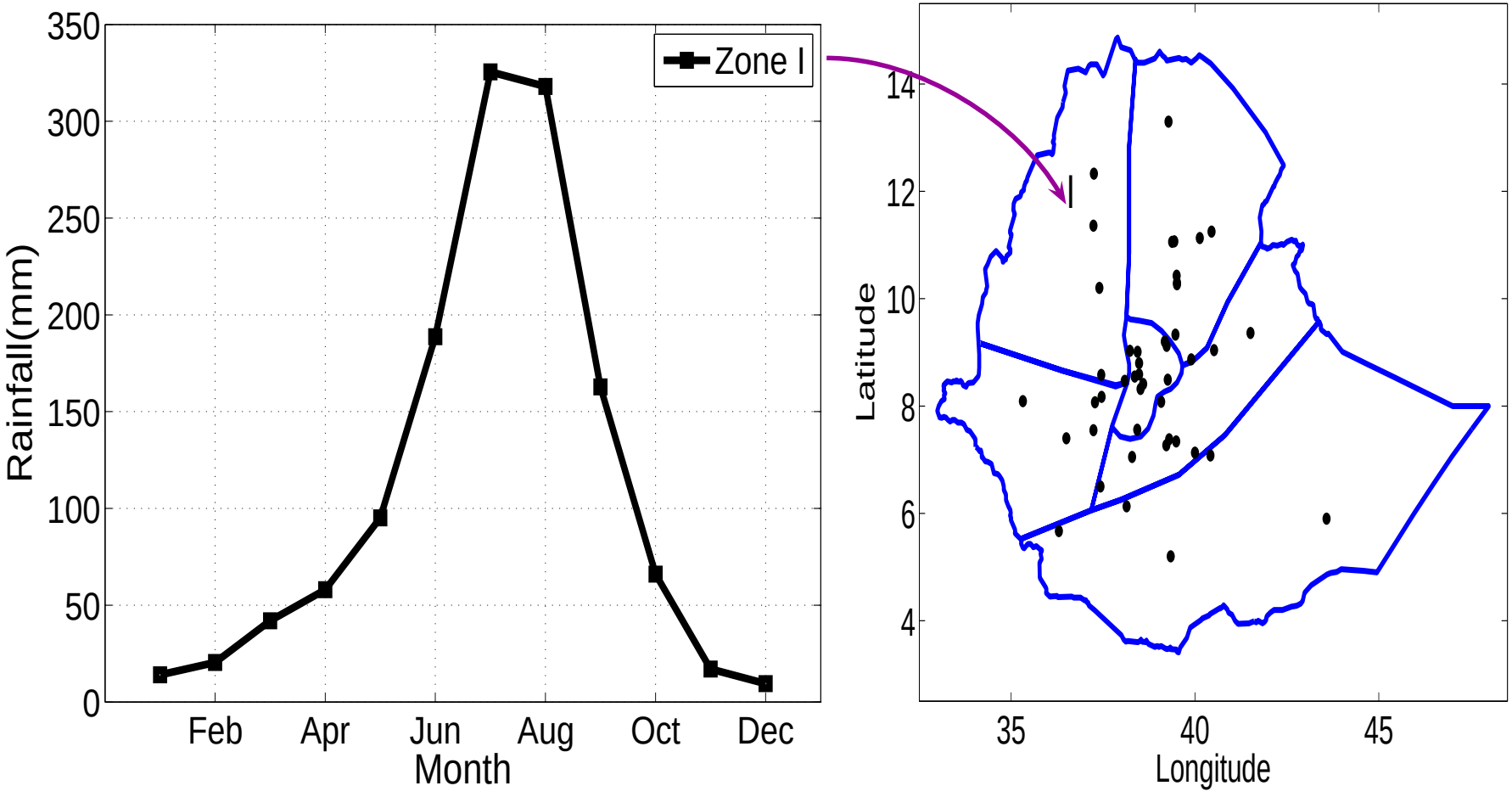




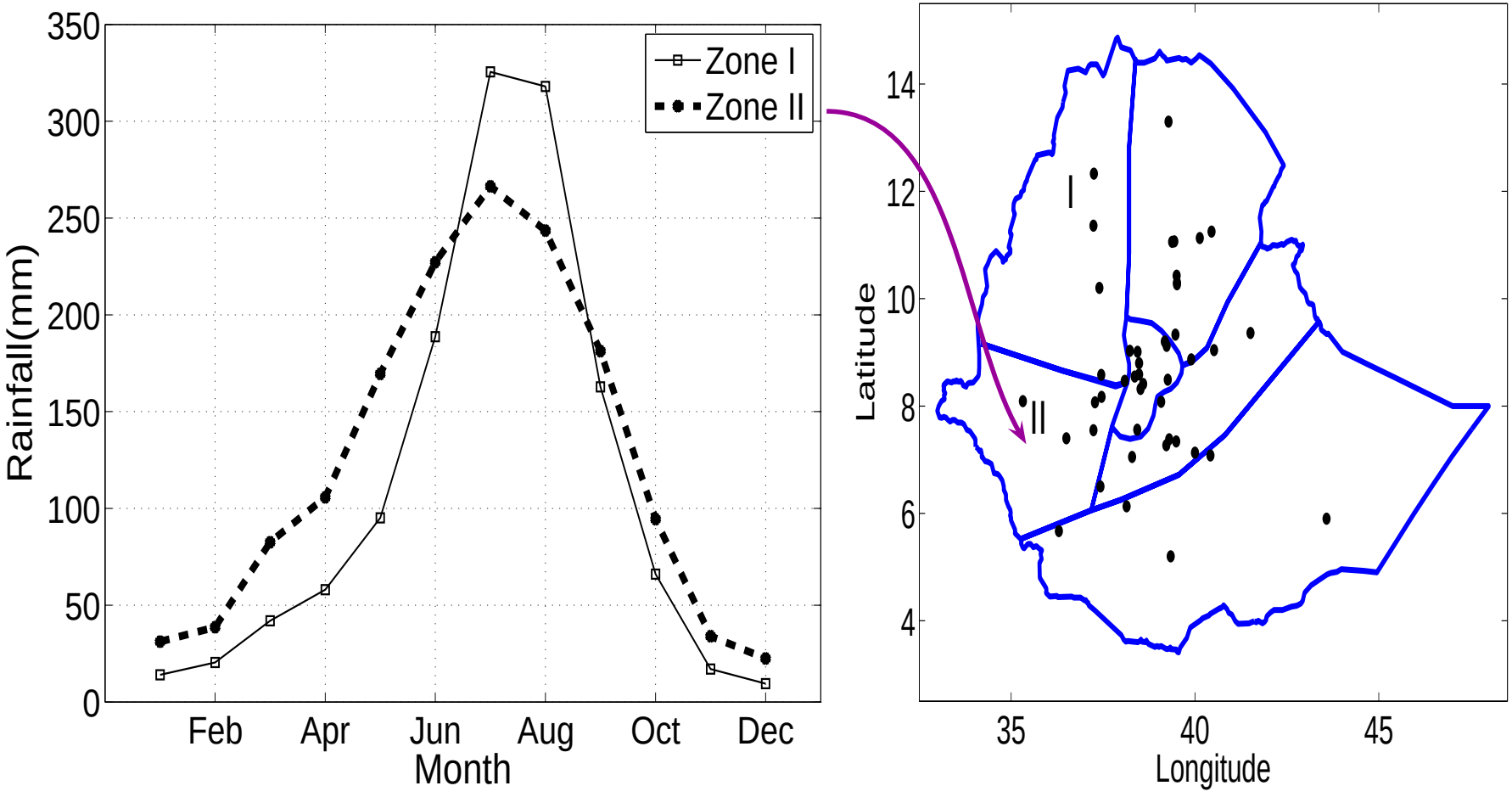
ROC score: Quint

	Very Dry		Dry		Normal		Wet		Very Wet	
Kiremt	LDA	MLR	LDA	MLR	LDA	MLR	LDA	MLR	LDA	MLR
Set A	0.70	0.76	0.56	0.59	0.47	0.51	0.48	0.58	0.68	0.70
Set B	0.68	0.75	0.66	0.63	0.54	0.54	0.56	0.61	0.75	0.79

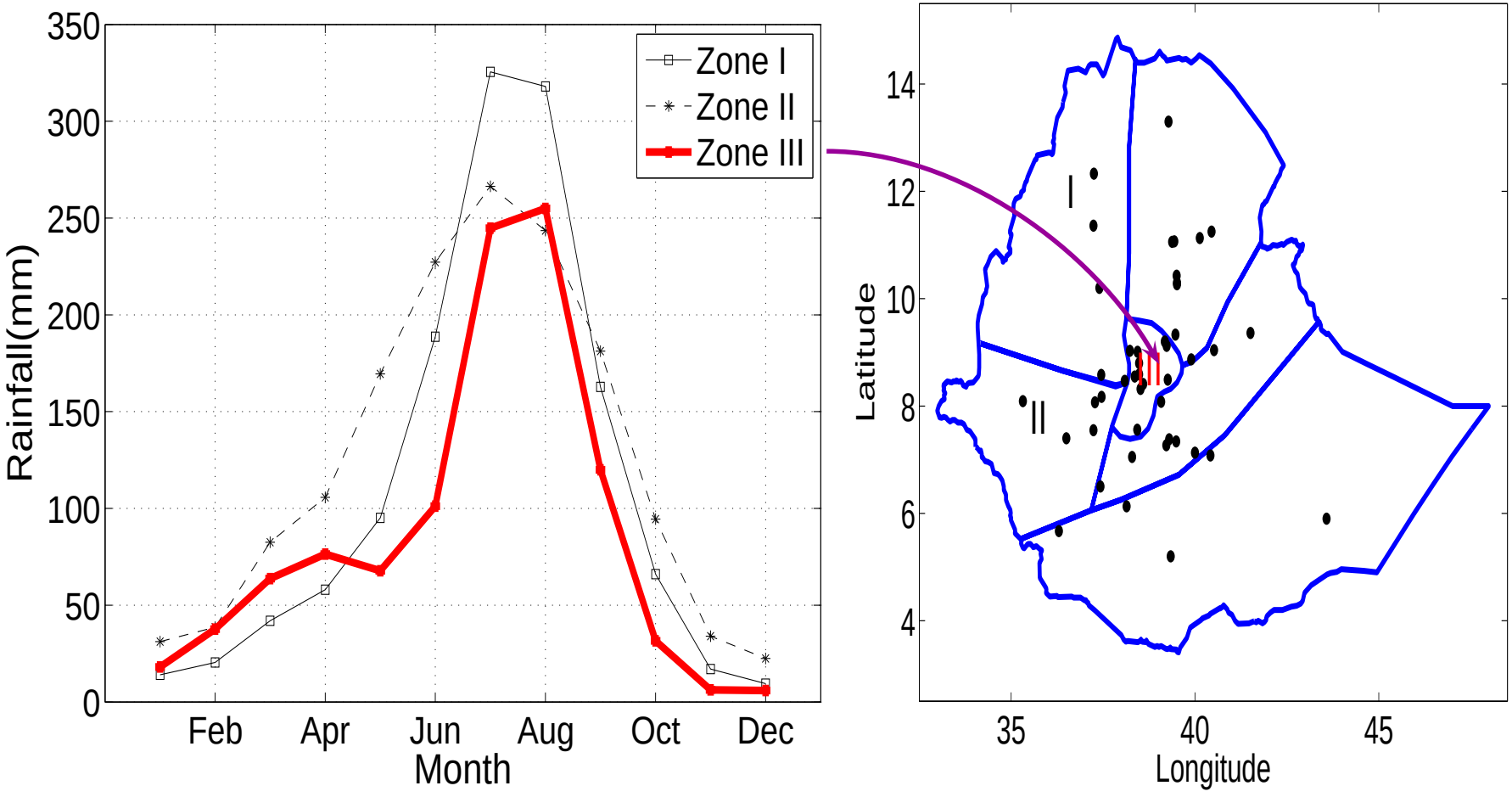
Seasonal Cycle



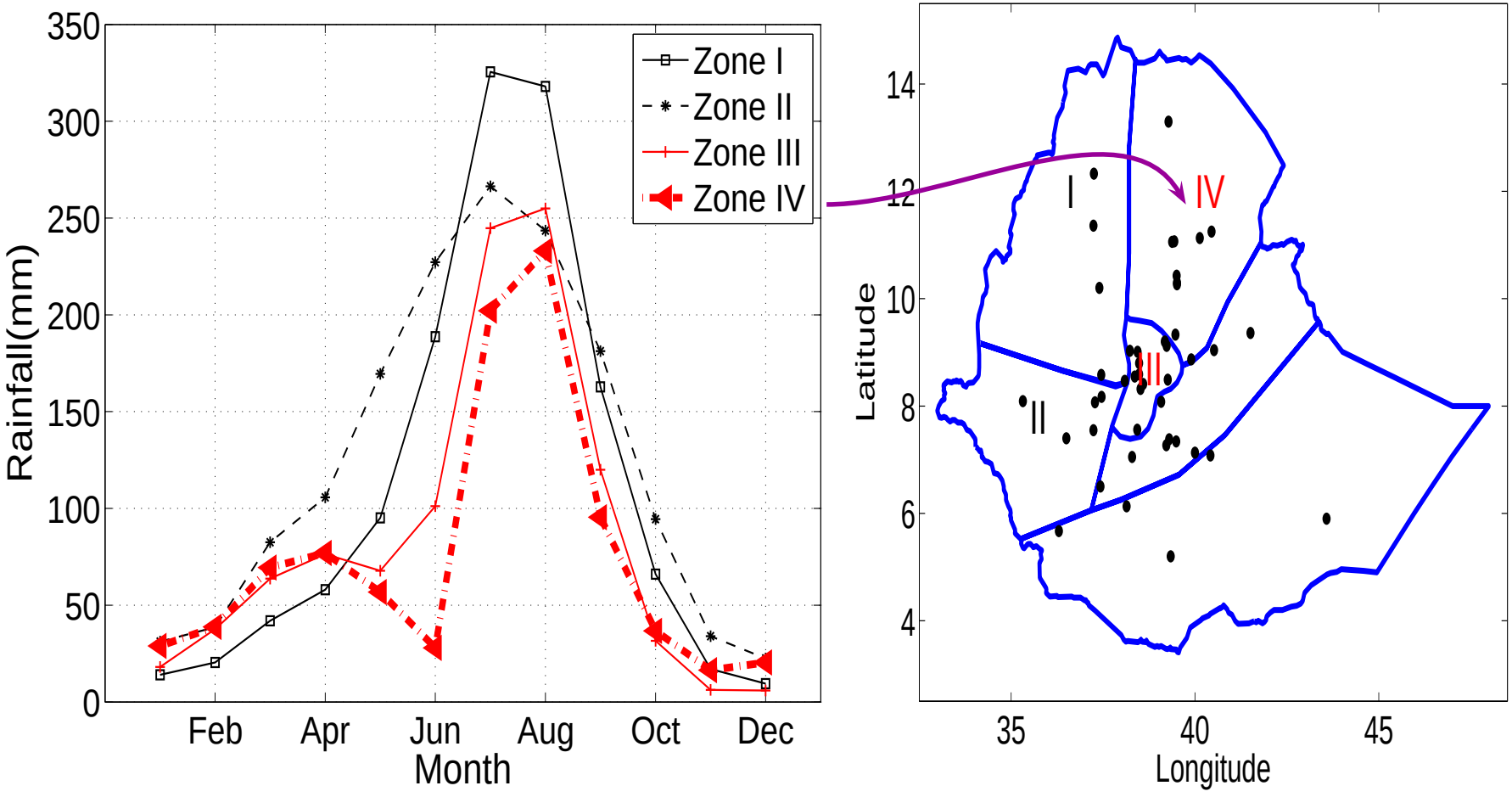
Seasonal Cycle



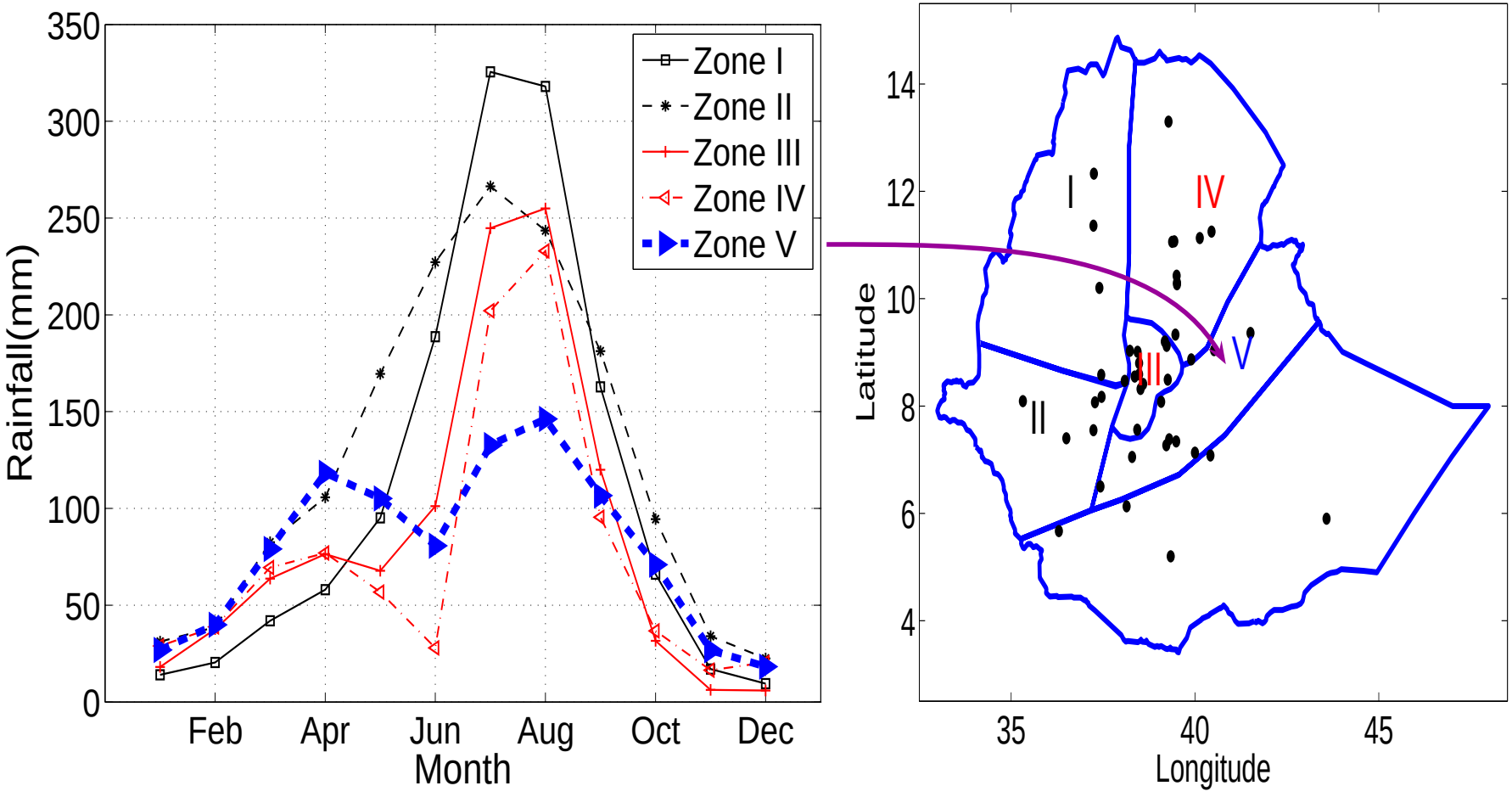
Seasonal Cycle



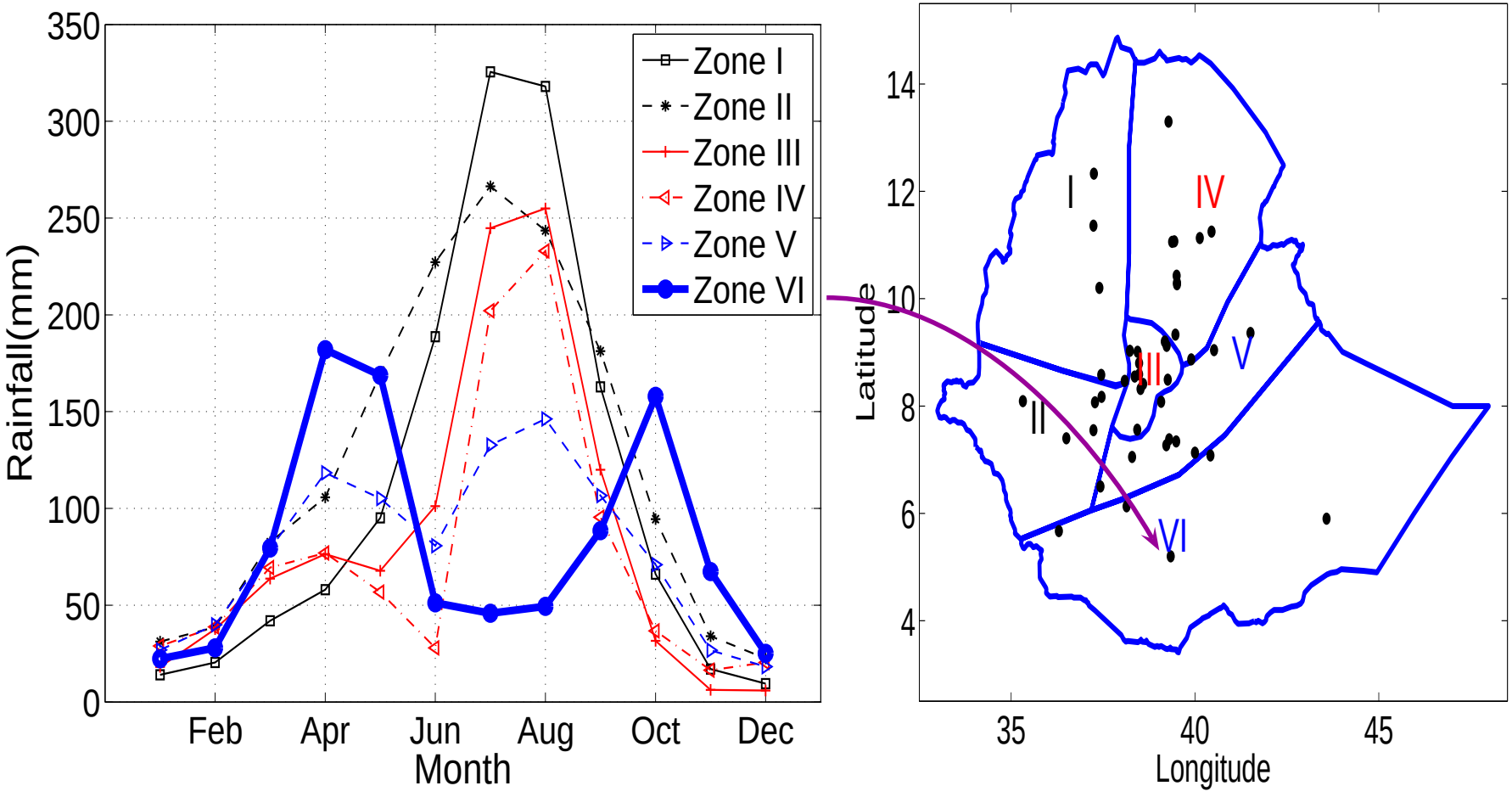
Seasonal Cycle



Seasonal Cycle

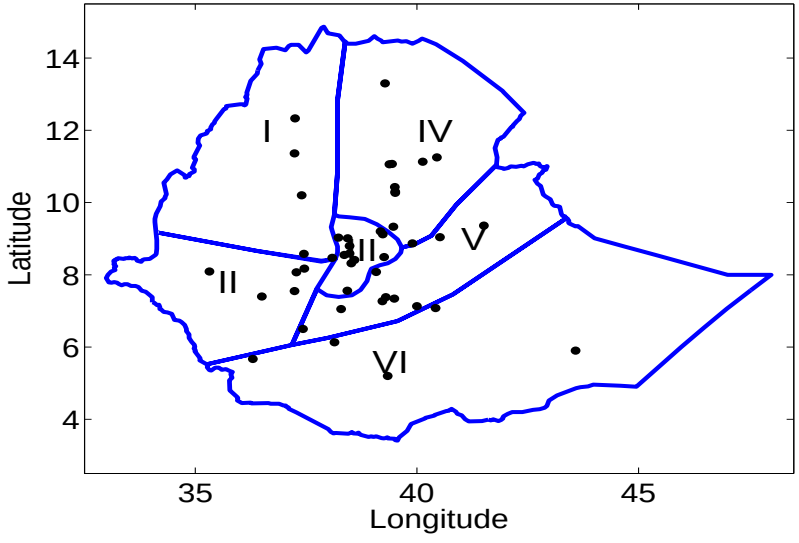


Seasonal Cycle



Inter-annual variability (cross-correlation)

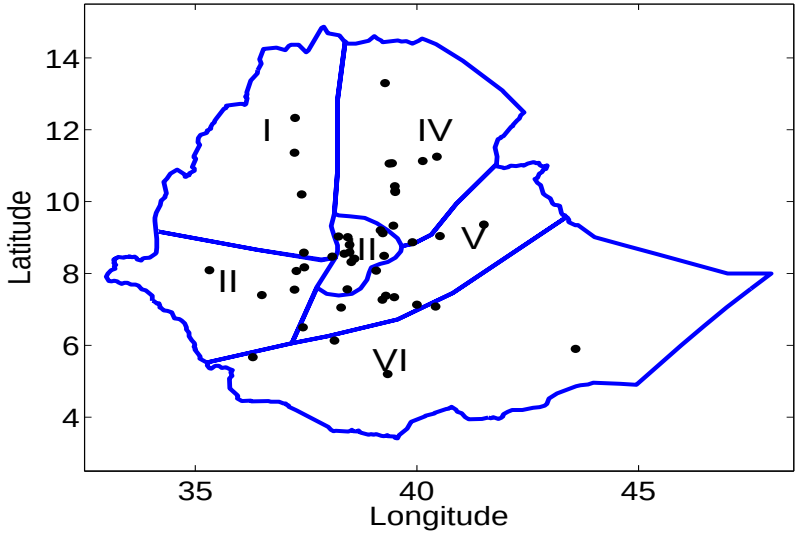
Kiremt	ZI	ZII	ZIII	ZIV	ZV	ZVI
ZI	0.03	0.08	0.17	0.12	0.08	-0.09
ZII	0.08	0.13	0.14	0.10	0.18	0.07
ZIII	0.17	0.14	0.27	0.23	0.21	0.02
ZIV	0.12	0.10	0.23	0.51	0.24	0.00
ZV	0.08	0.18	0.21	0.24	0.20	0.12
ZVI	-0.09	0.07	0.02	0.00	0.12	0.15



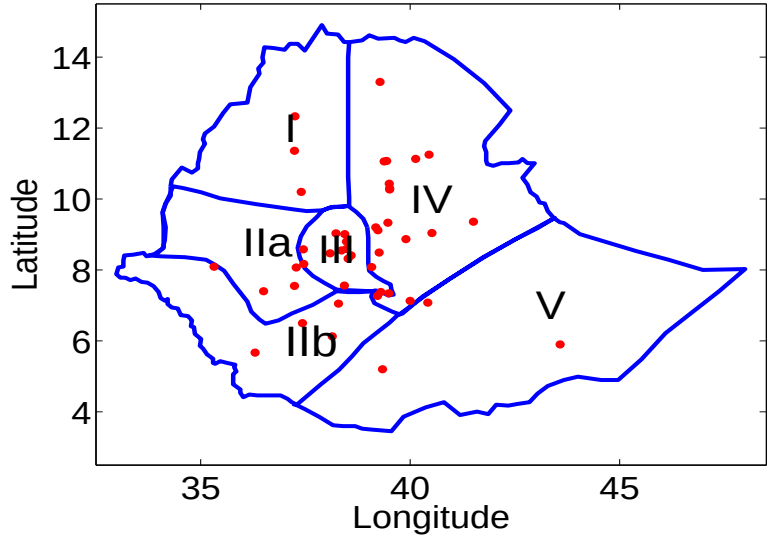
Inter-annual variability (cross-correlation)

Kiremt	ZI	ZII	ZIII	ZIV	ZV	ZVI
ZI	0.03	0.08	0.17	0.12	0.08	-0.09
ZII	0.08	0.13	0.14	0.10	0.18	0.07
ZIII	0.17	0.14	0.27	0.23	0.21	0.02
ZIV	0.12	0.10	0.23	0.51	0.24	0.00
ZV	0.08	0.18	0.21	0.24	0.20	0.12
ZVI	-0.09	0.07	0.02	0.00	0.12	0.15

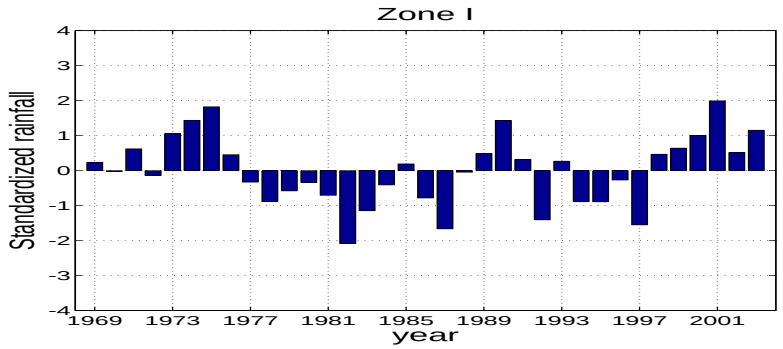
Kiremt	ZI	ZIIa	ZIIb	ZIII	ZIV	ZV
ZI	0.26	0.16	0.02	0.16	0.16	-0.06
ZIIa	0.16	0.24	0.15	0.15	0.14	0.05
ZIIb	0.02	0.15	0.33	0.16	0.13	0.08
ZIII	0.16	0.15	0.16	0.25	0.17	-0.08
ZIV	0.16	0.14	0.13	0.17	0.31	-0.06
ZV	-0.06	0.05	0.08	-0.08	-0.06	0.14

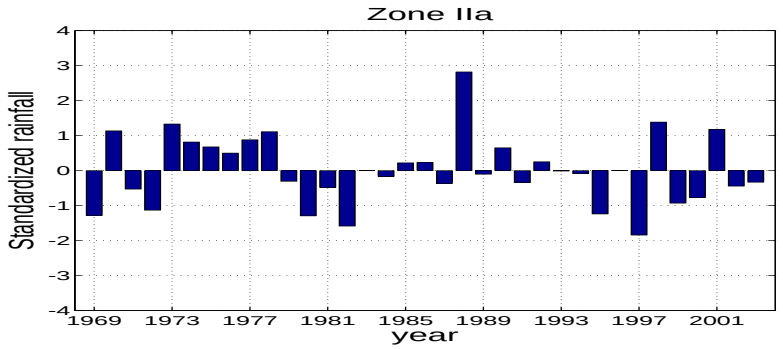


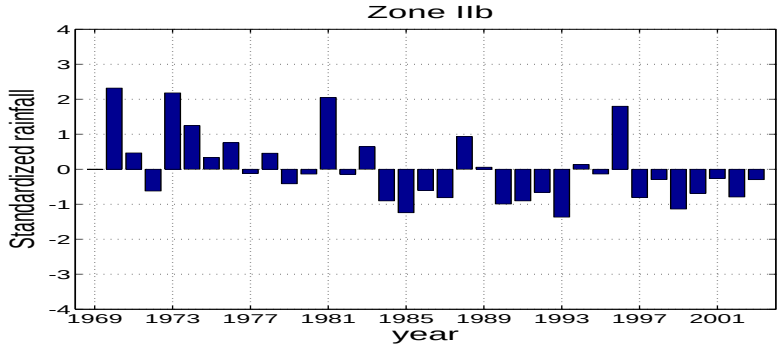
⇒

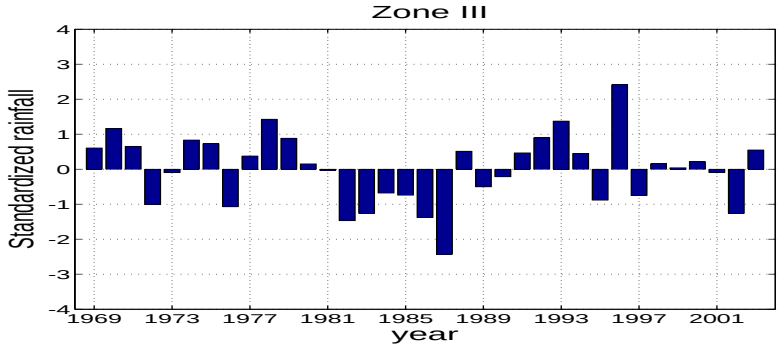


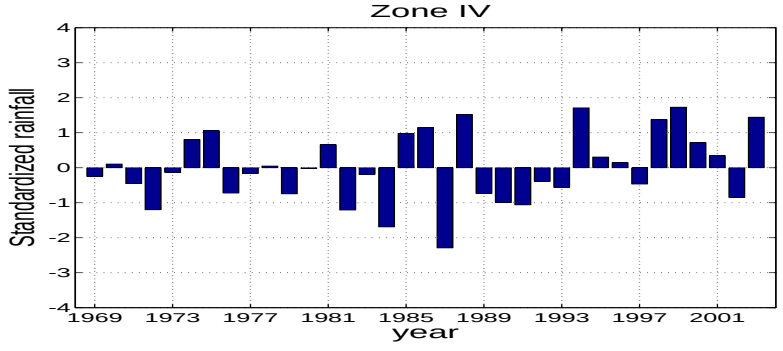
Summer rainfall of the Homogeneous zones

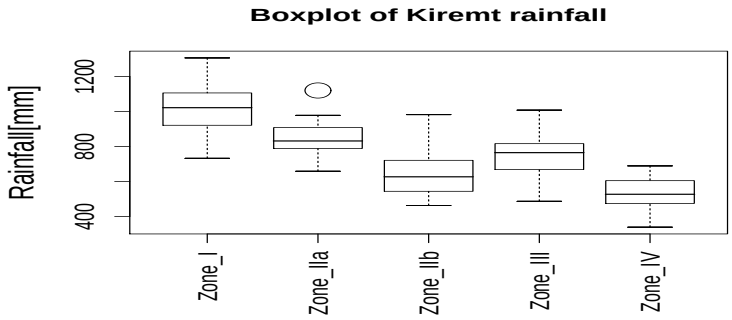












distribution of predictors