Model for Predicting Rainfall by Fuzzy Set Theory Using USDA Scan Data

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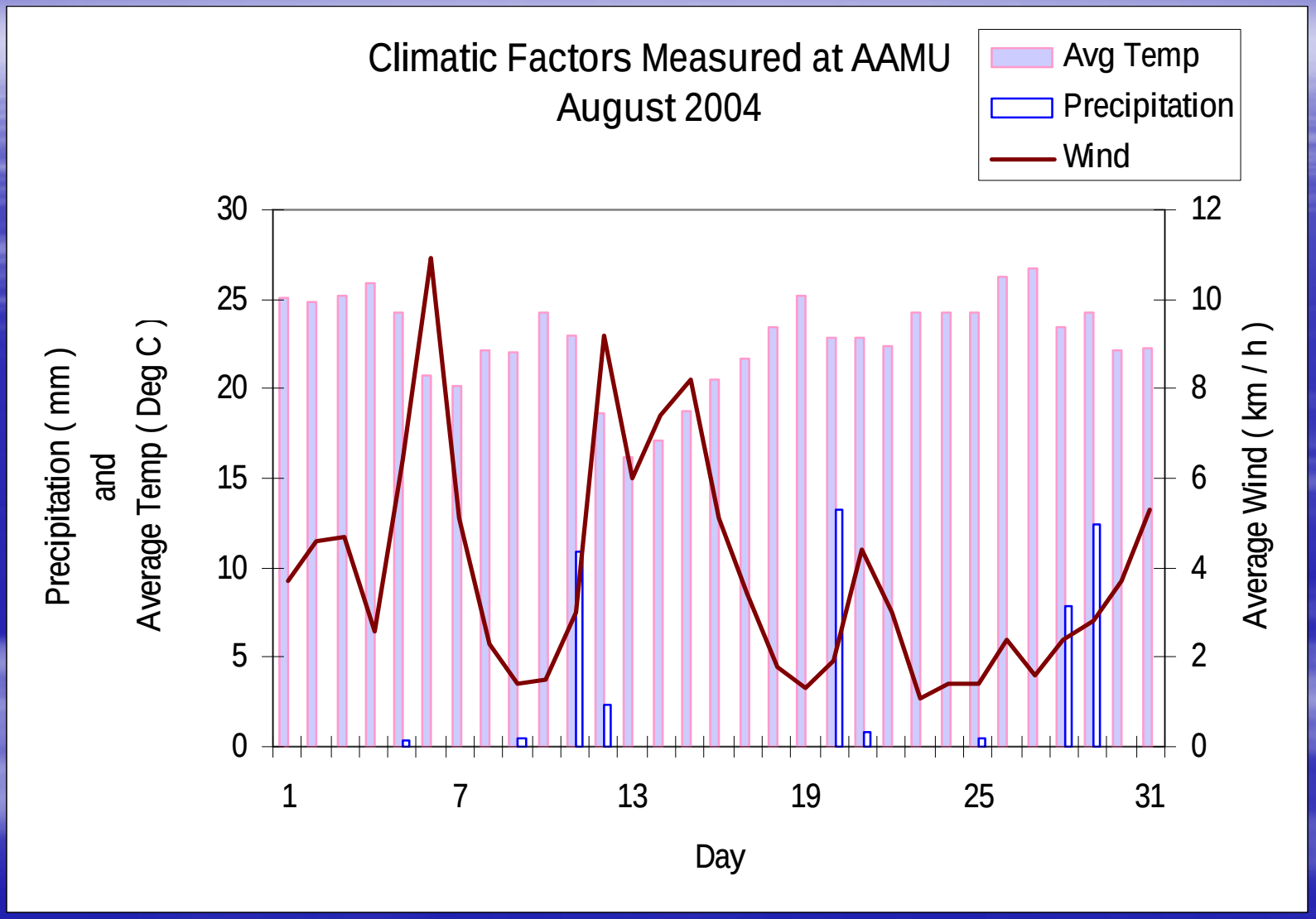
Research Sites

1. AAMU Campus

2. Bragg Farm

3. WATARS Farm


Climatic Factors Measured at AAMU
August 2004
Avg Temp
Precipitation
Wind
Precipitation (mm)
and
Average Temp (Deg C)
Average Wind (km / h)
Day
30
25
20
15
10
5
0
12
10
8
6
4
2
0
1
7
13
19
25
31

Conditions:

(1) Temperature i

If average temperature on ith day < temperature on (i-1) th day Then Temperature i is 1 else 0.

(2) Wind i

If Wind Speed on the ith day > Wind Speed on (i-1)th day Then Windi-1 is 1 else 0

Inference:

If results of conditions 1 and 2 are 1 Then

Rainfall i is 1 else 0

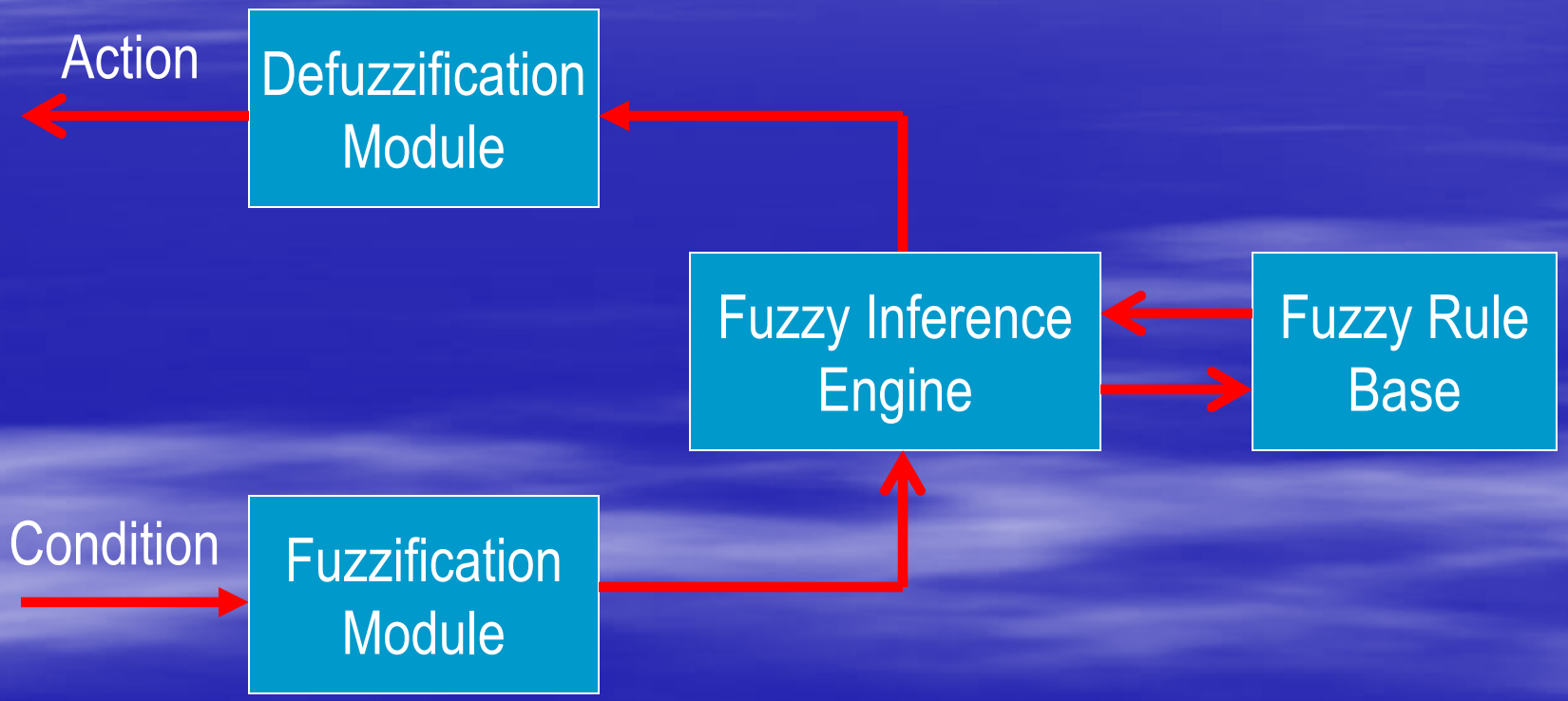
Basic operations involved in modeling with Fuzzy Set Theory

1. Fuzzification

2. Min-Max Composition

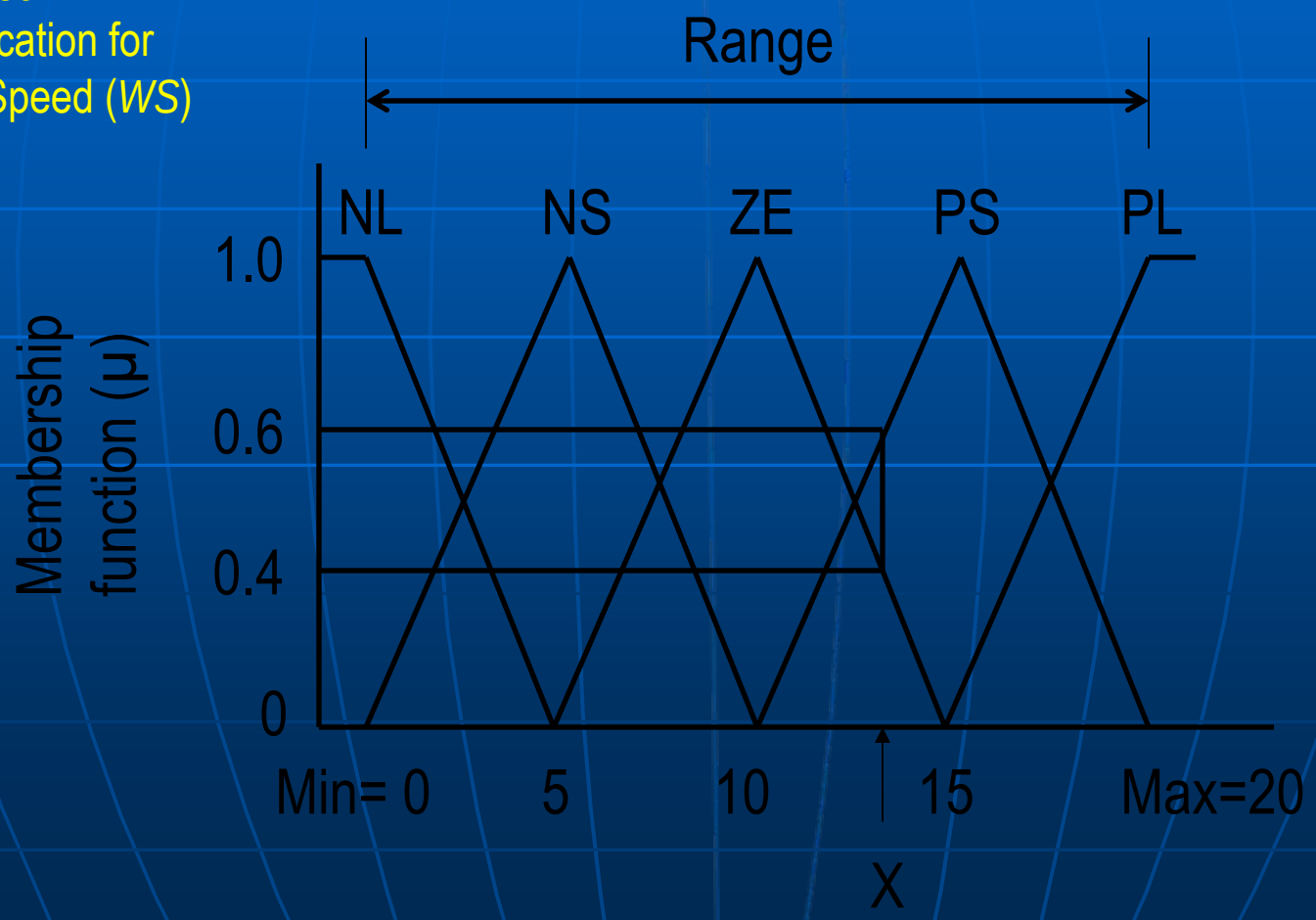
3. Defuzzification

Different modules of fuzzy inference model



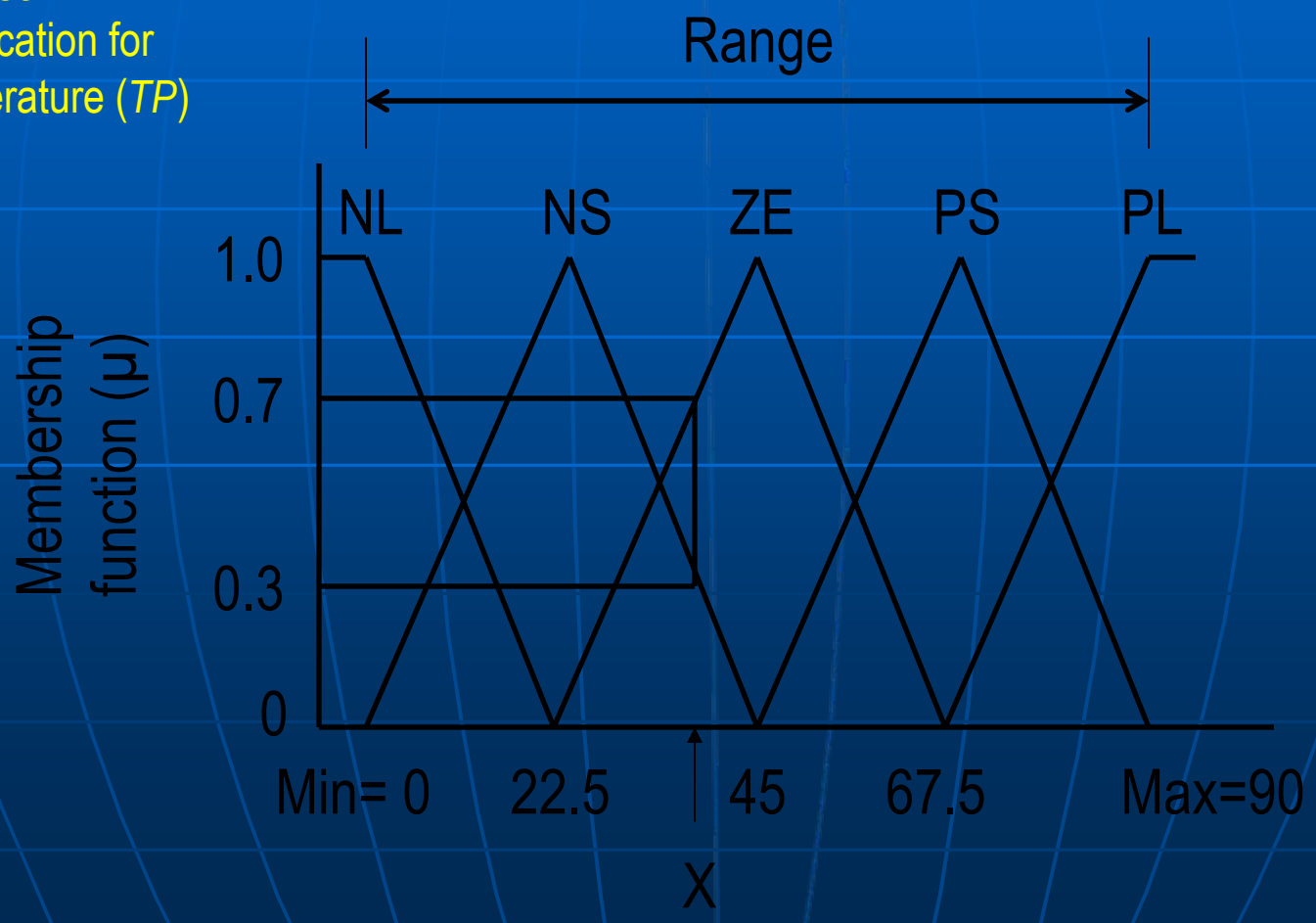
Triangular functional diagram and method for calculating membership function (μ) and corresponding fuzzy levels

Suppose:
Fuzzification for
Wind Speed (*WS*)

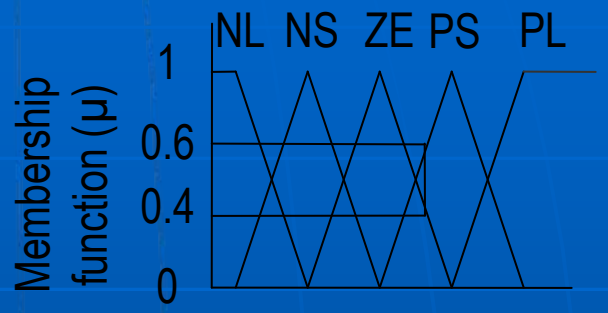


Triangular functional diagram and method for calculating membership function (μ) and corresponding fuzzy levels

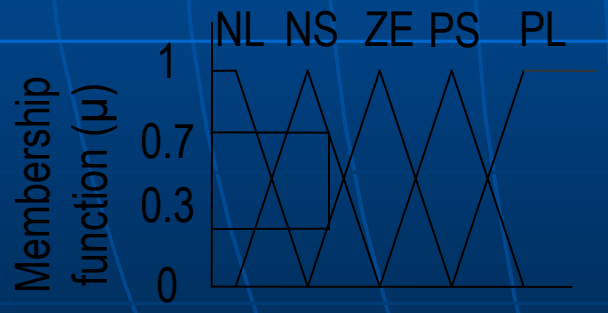
Suppose:
Fuzzification for
Temperature (*TP*)



Wind speed (*WS*)

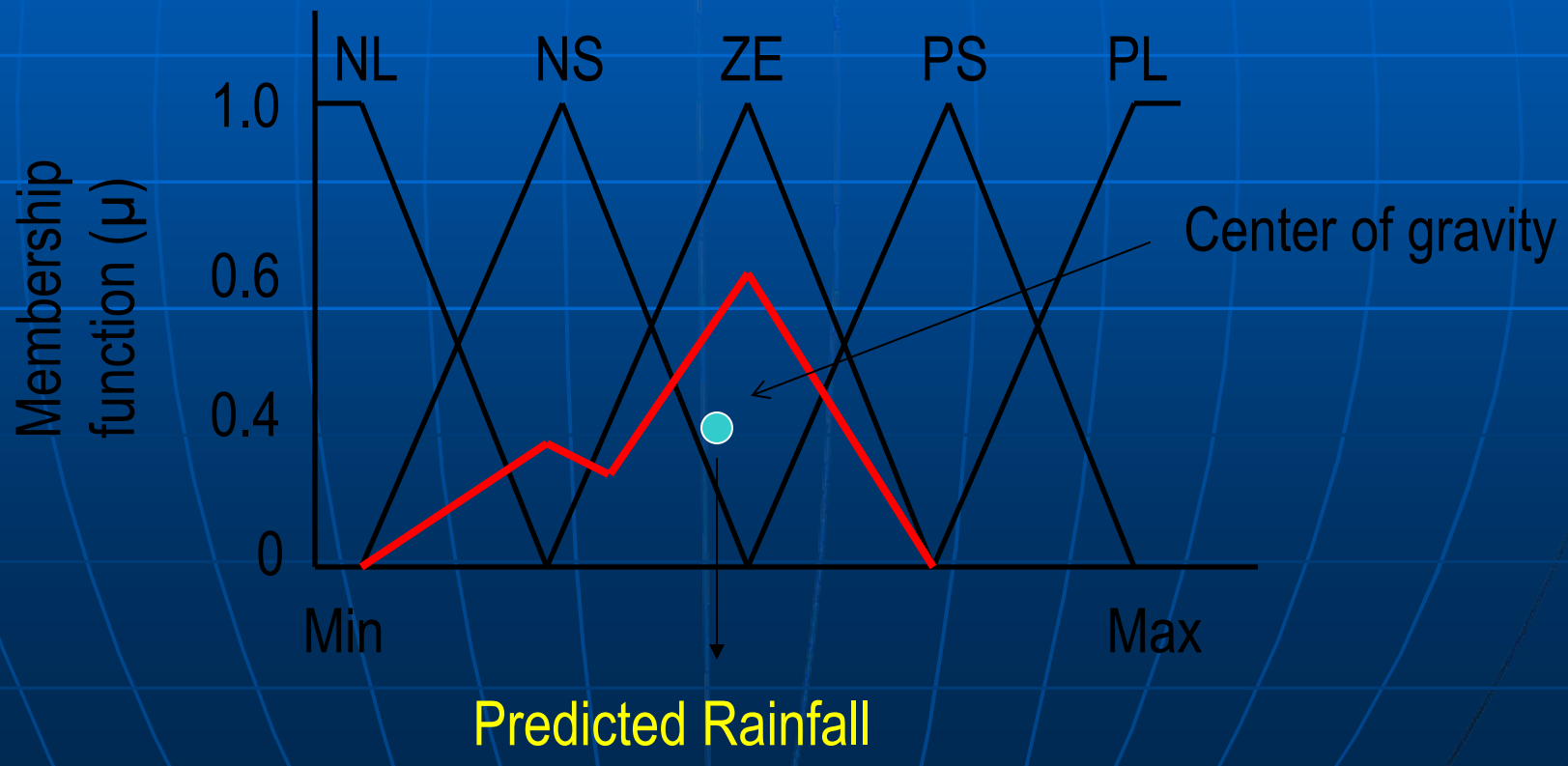


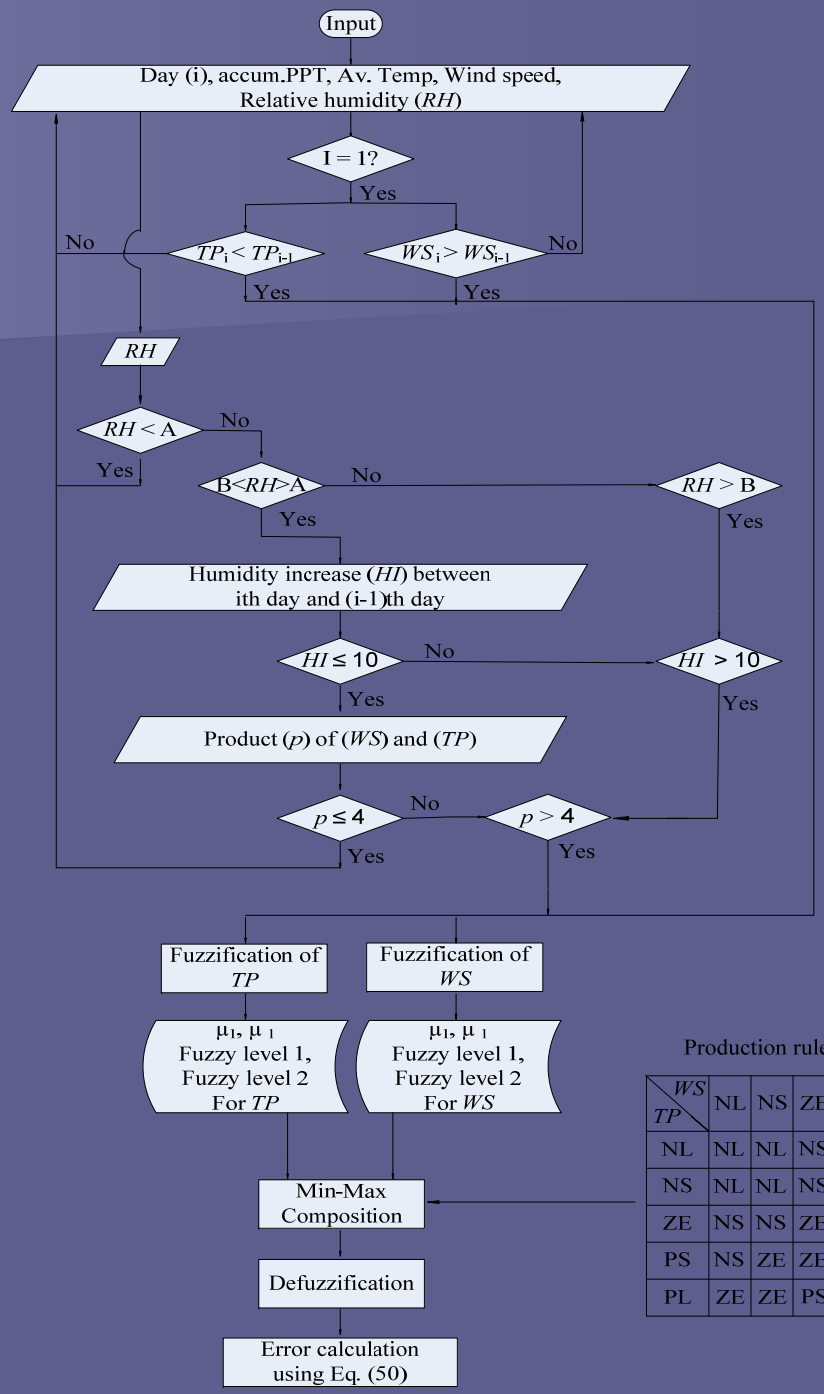
Temperature (*TP*)



TP \ *WS*	NL	NS	ZE 0.4	PS 0.6	PL
NL					
NS 0.7			NS 0.4	ZE 0.6	
ZE 0.3			ZE 0.3	ZE 0.3	
PS					
PL					

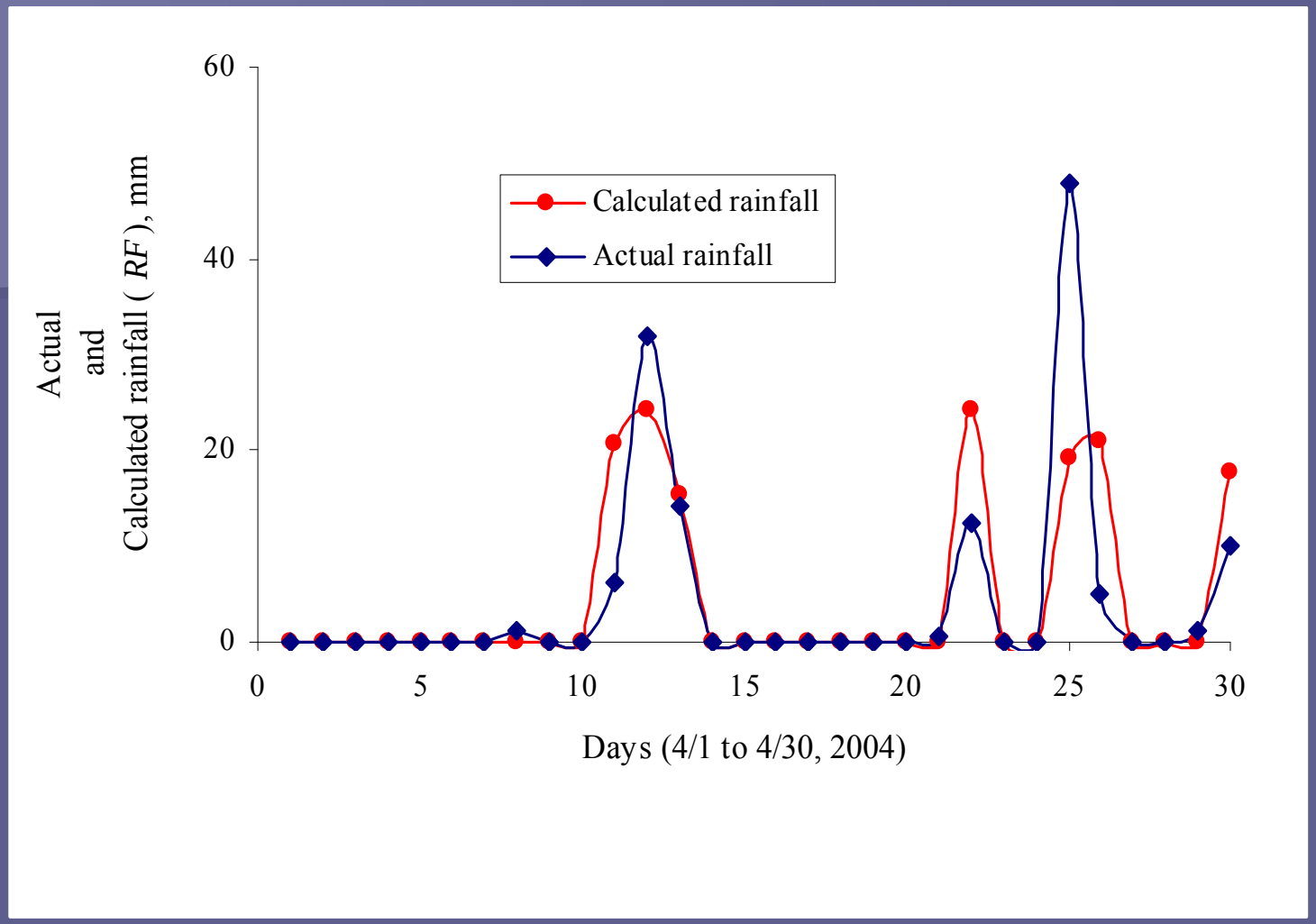
Defuzzification for Rainfall





Production rule table

TP \ WS	NL	NS	ZE	PS	PL
NL	NL	NL	NS	NS	ZE
NS	NL	NL	NS	ZE	ZE
ZE	NS	NS	ZE	ZE	PS
PS	NS	ZE	ZE	PS	PS
PL	ZE	ZE	PS	PS	PL



Actual and calculated amount of rainfall (*RF*) in mm during April 1 to 30 in 2004 using USDA scan data of 2004 from AAMU campus

Left bound (A) Right bound (B)

Relative Humidity (*RH*)

Zone of No-rainfall | Zone of possibility of rainfall | Zone of rainfall

Humidity increase (*HI*)

≤ -10 | >10

If *SR*<40 possibility of rainfall else no rain | Zone of possibility of rainfall

1. If (Humidity increase + Humidity) > 100
2. (Humidity + 5) > 90

Then Heavy Rainfall (*RF*) Level 4 (PS)

Product (*p*)

≤ 5 | >5

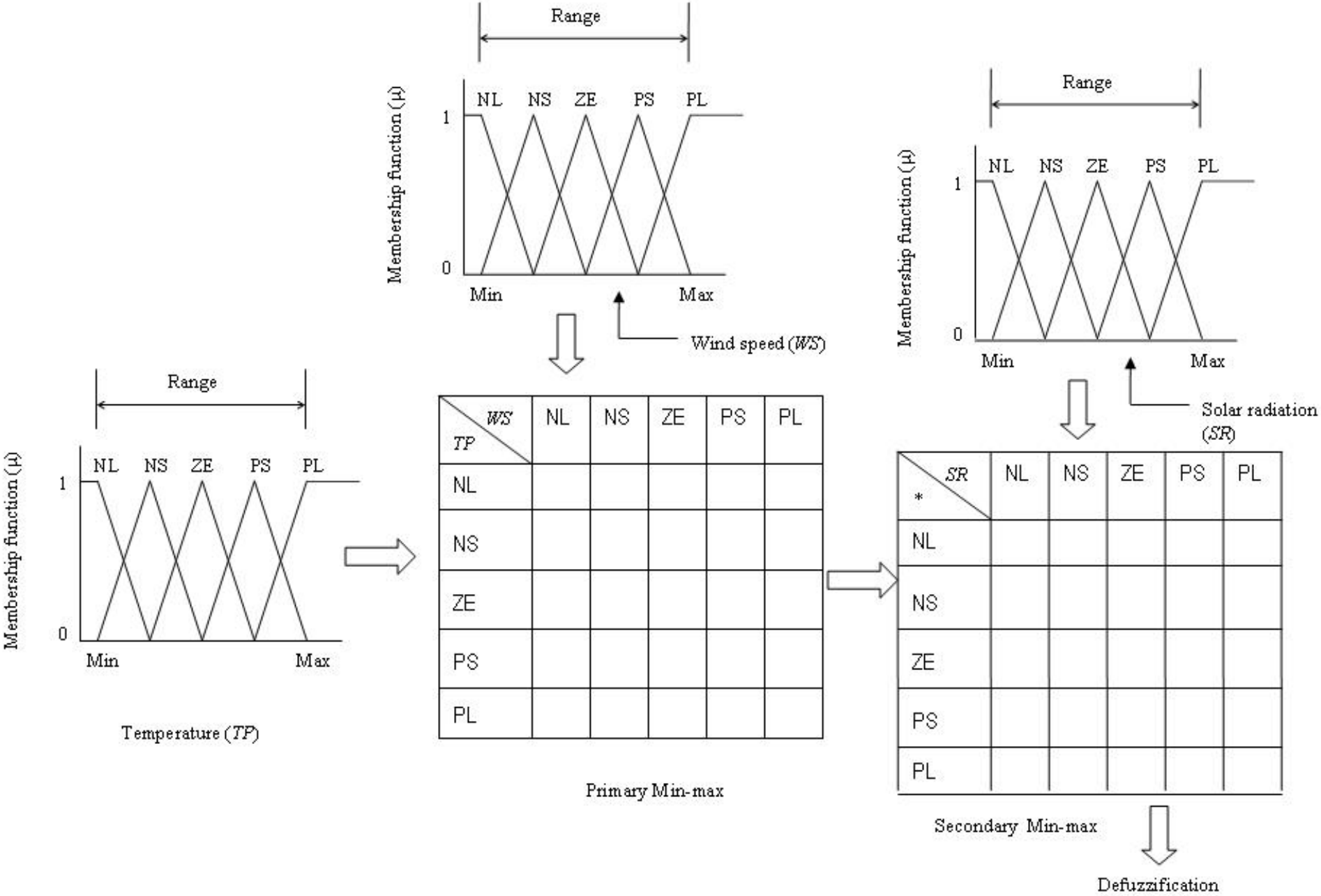
Zone of No-rainfall | Zone of rainfall

1. If (WS) not ↑ and (*TP*) not ↓
2. *SR* > 100

Then Light Rainfall (*RF*) Level 1 (NS)

	(A)	(B)
Jan 1 to Apr 31	70	85
May 1 to Sep 30	80	90
Oct 1 to Dec 31	75	90

Values and ranges of the factors for predicting Rainfall (*RF*)


Range
NL NS ZE PS PL
1
0
Membership function (μ)
Min
Max
Wind speed (WS)
Range
NL NS ZE PS PL
1
0
Membership function (μ)
Min
Max
Solar radiation (SR)
Range
NL NS ZE PS PL
1
0
Membership function (μ)
Min
Max
Temperature (TP)
WS
TP
NL NS ZE PS PL
NL
NS
ZE
PS
PL
Primary Min-max
SR
*
NL NS ZE PS PL
NL
NS
ZE
PS
PL
Secondary Min-max
Defuzzification

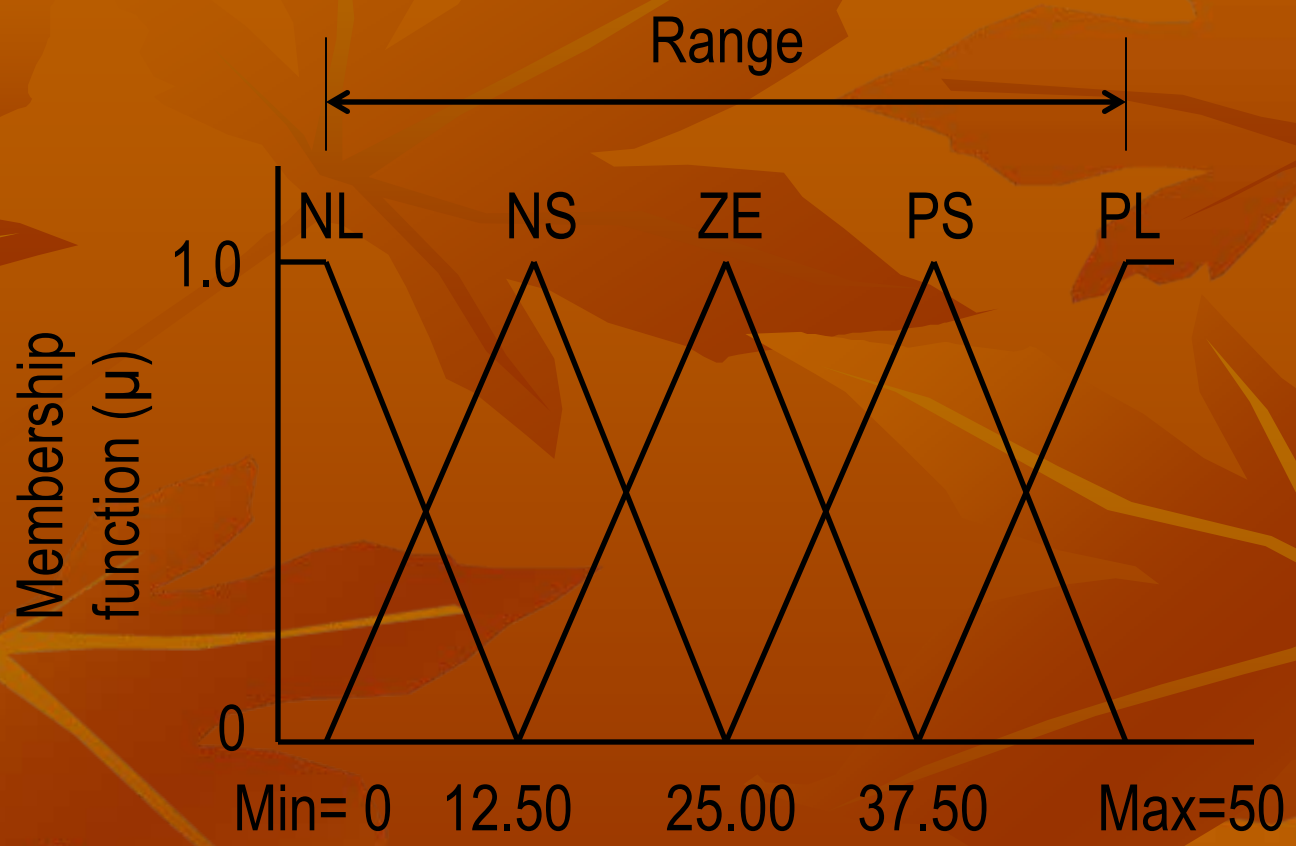
$$\boldsymbol{Error} = \frac{\sum_{i=1}^{n} \boldsymbol{abs}(\boldsymbol{RF}_{a_i} - \boldsymbol{RF}_{c_i})}{\sum_{i=1}^{n} \boldsymbol{RF}_{a_a}} \times 100\%$$

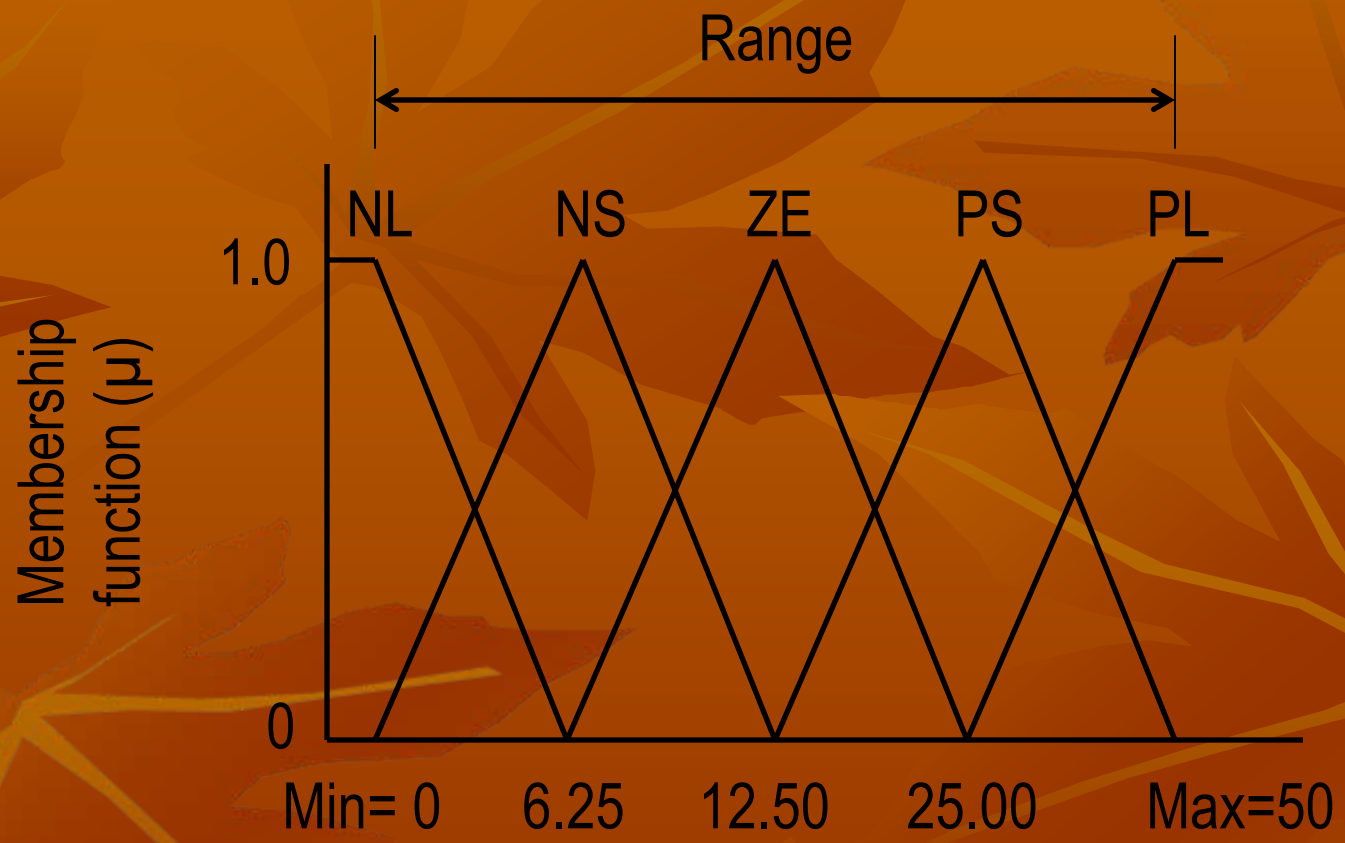
Here,

RF_{a_i} is the actual amount of rainfall in mm,

RF_{c_i} is the calculated amount of rainfall in mm.

"n" is total number of data.


Range
NL
NS
ZE
PS
PL
1.0
0
Membership function (μ)
Min= 0
12.50
25.00
37.50
Max=50


Range
NL
NS
ZE
PS
PL
1.0
0
Membership function (μ)
Min= 0
6.25
12.50
25.00
Max=50

Comparison of the distribution of data caused by two different sub-range selections for the model using USDA scan data from Alabama A & M University (AAMU) Campus for years 2004 and 2005

AAMU 2004							
Available data distribution				Uniformity in data distribution			
Ranges	No. of rainy days	No. of actual rainy days	(%)	Ranges	No. of rainy days	No. of actual rainy days	(%)
0 to 12.50	98	133	73.68	0 to 6.25	76	133	57.14
12.50 to 25.00	15		11.28	6.25 to 12.50	22		16.54
25.00 to 37.50	12		9.02	12.50 to 25.00	15		11.28
37.50 to 50.00	2		1.50	25.00 to 50.00	14		10.53

AAMU 2005							
Available data distribution				Uniformity in data distribution			
Ranges	No. of rainy days	No. of actual rainy days	(%)	Ranges	No. of rainy days	No. of actual rainy days	(%)
0 to 12.50	95	125	76.00	0 to 6.25	76	125	60.80
12.50 to 25.00	16		12.80	6.25 to 12.50	20		16.00
25.00 to 37.50	11		8.80	12.50 to 25.00	16		12.80
37.50 to 50.00	2		1.60	25.00 to 50.00	13		10.40

Results of the model using USDA data from AAMU campus

Year	No. of Actual Rainy day	No. of calculated Rainy day	Actual amount of Rain water (mm)	Calculated amount of Rain water (mm)	Error (%)	Remarks
2003	91	91	1344	1357	1.20	
2004	90	86	1465	1433	2.19	
2005	80	71	1003	912	9.60	

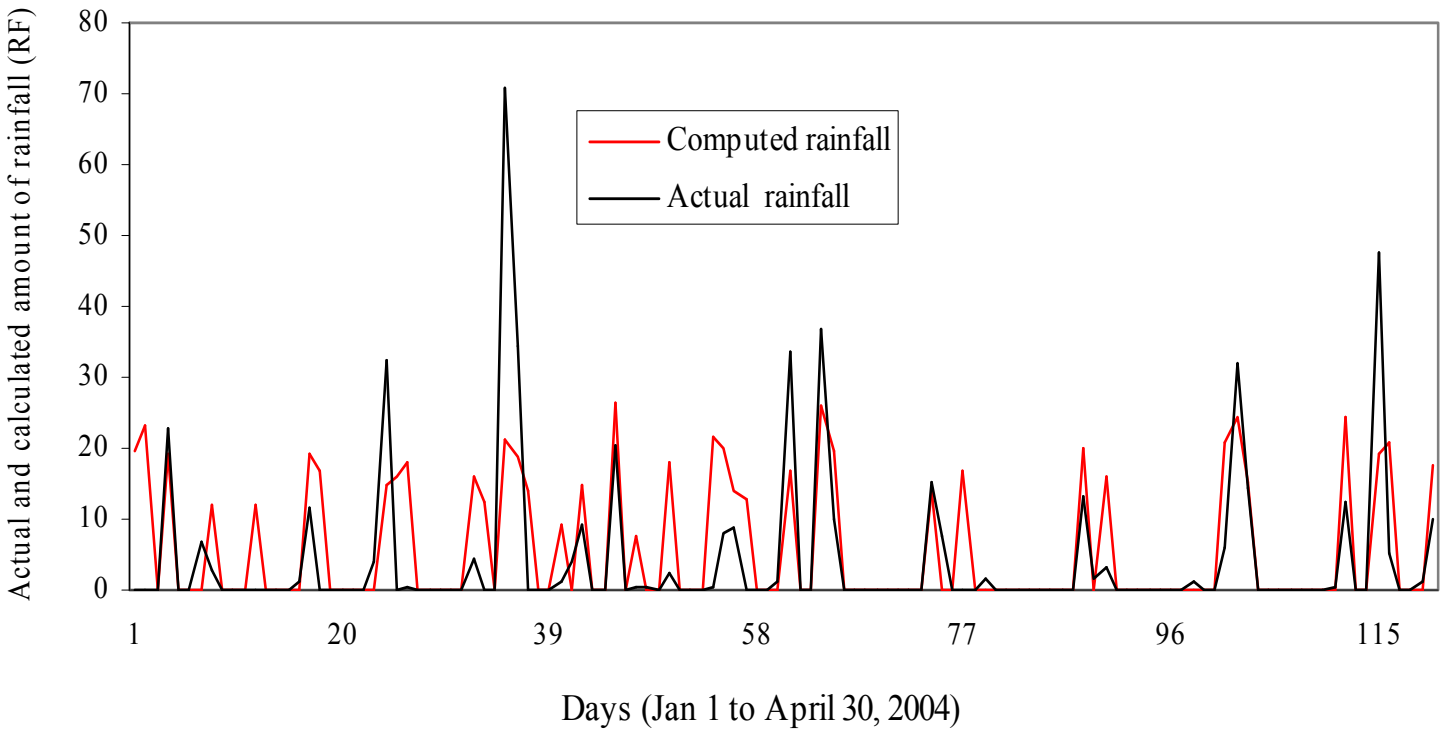
Results of the model using USDA data from Bragg farm

Year	No. of Actual Rainy day	No. of calculated Rainy day	Actual amount of Rain water (mm)	Calculated amount of Rain water (mm)	Error (%)	Remarks
2004	92	82	1505	1349	10.37	
2005	72	61	1020	901	11.67	
2006	76	43	1005	749	25.52	

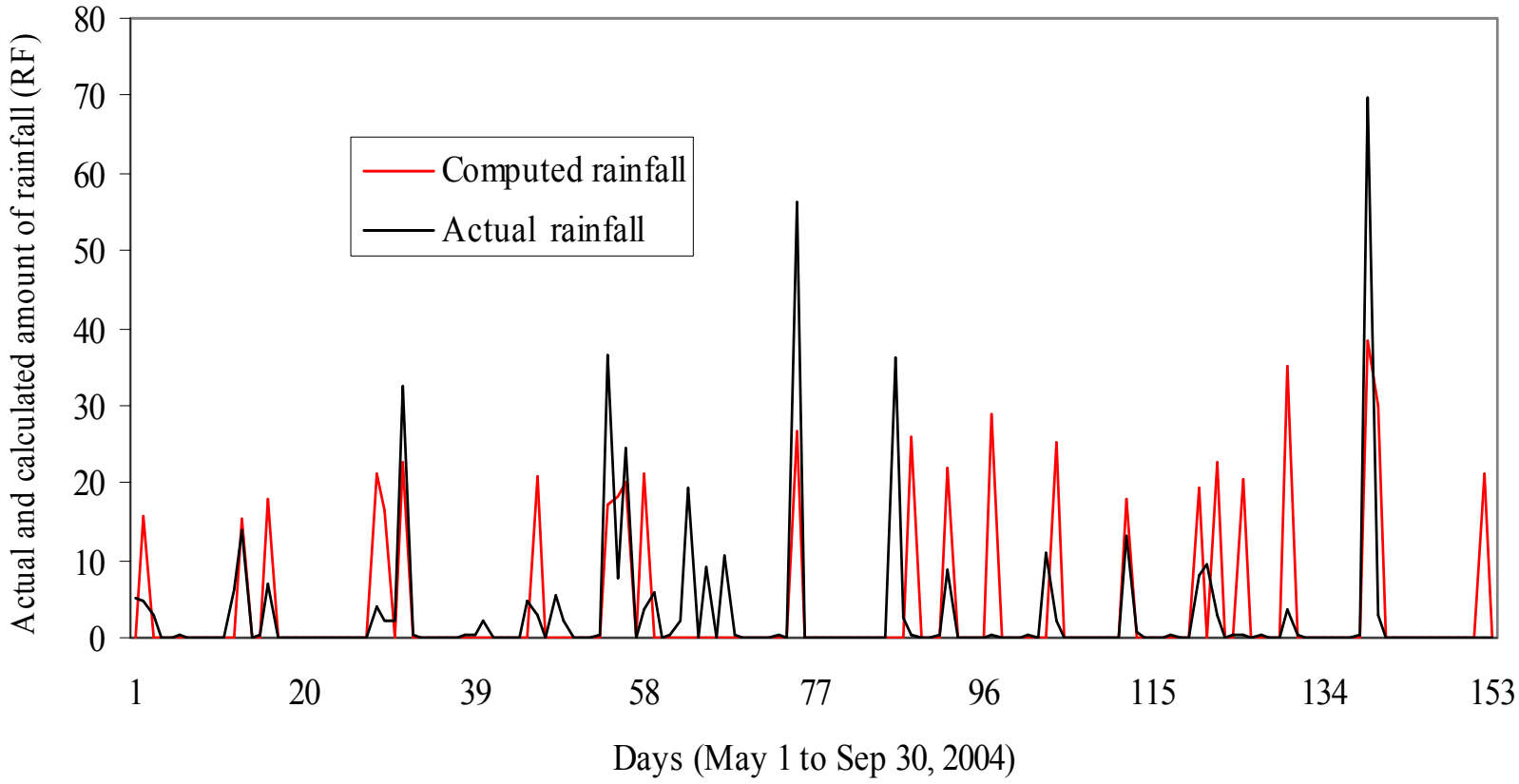
Results of the model using USDA data from WATAR farm

Year	No. of Actual Rainy day	No. of calculated Rainy day	Actual amount of Rain water (mm)	Calculated amount of Rain water (mm)	Error (%)	Remarks
2003	93	84	1442	1396	3.20	
2004	80	87	1369	1450	5.90	
2005	78	73	1021	1004	1.66	

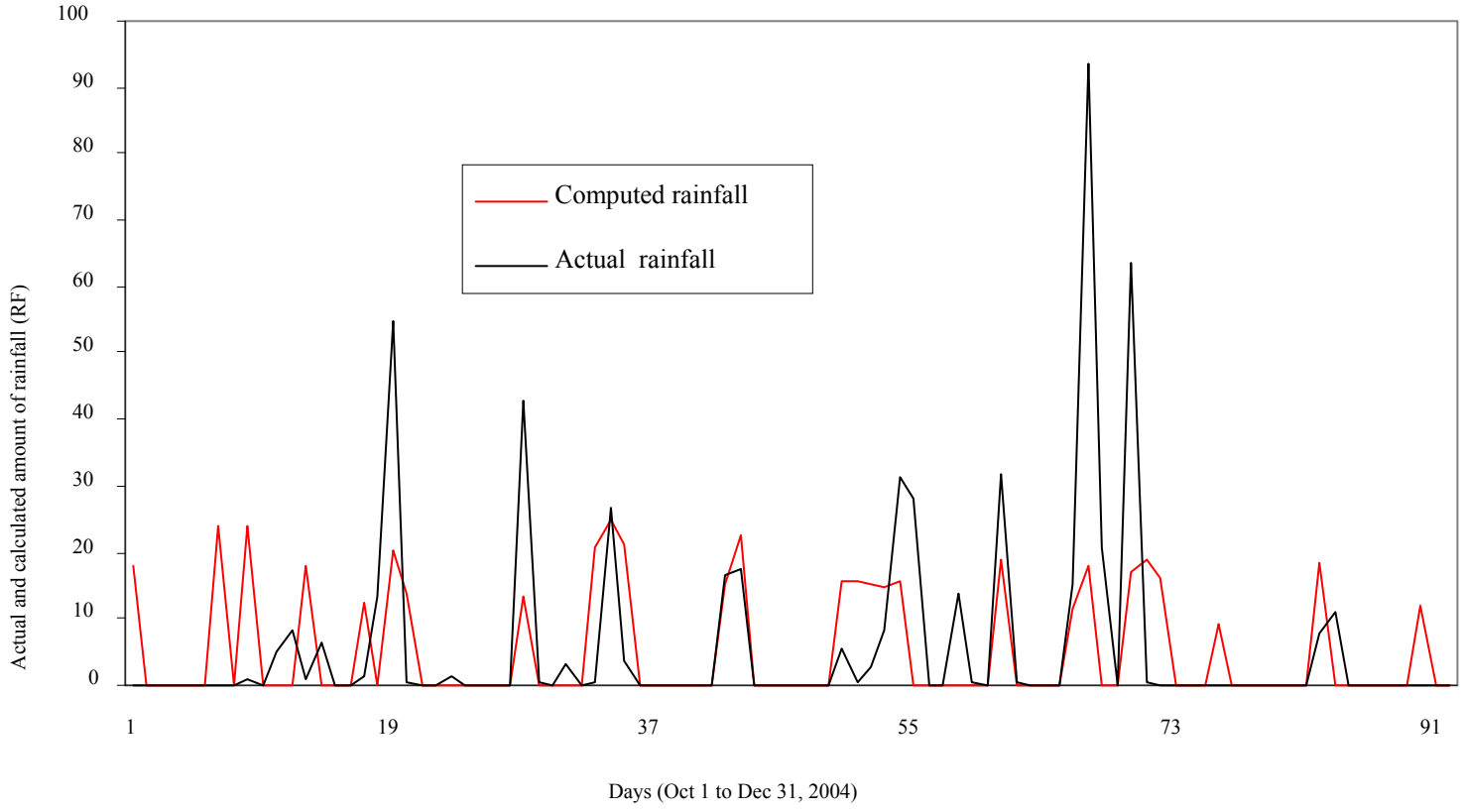
Graph showing actual and calculated amount of rainfall using USDA scan data from Jan 1 to April 30 for 2004 from AAMU campus



Graph showing actual and calculated amount of rainfall using USDA scan data from May 1 to Sep 30 for 2004 from AAMU campus

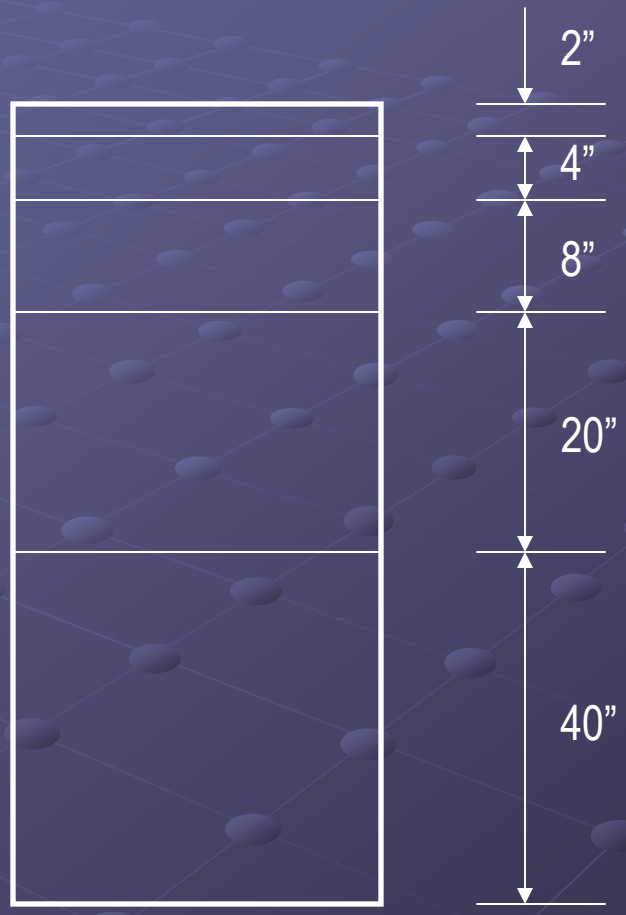


Graph showing actual and calculated amount of rainfall using USDA scan data from Oct 1 to Dec 31 for 2004 from AAMU Campus



Soil Moisture Availability

Depth of individual layer of the soil profile for measuring temperatures



Consideration:

A year divided into 5 sub-seasons

Jan 1 to Mar 15:	1st	to	74th days	→	Season 1
Mar 16 to Jun 15:	75th	to	166th days	→	Season 2
Jun 16 to Sep 15:	167th	to	258th days	→	Season 3
Sep 16 to Nov 15:	259th	to	334th days	→	Season 4
Nov 16 to Dec 31:	335th	to	365th days	→	Season 5

Threshold values of Precipitation (PPT):

Layer	Depth	Threshold PPT
1	2”	4 mm
2	4”	8 mm
3	8”	12 mm
4	20”	16 mm
5	40”	20 mm

Production Rule Table for Prediction of Soil Moisture

Soil Temperature °C (ST) \ Consecutive number of no Rainfall day (NoCNRD)	NL	NS	ZE	PS	PL
NL	PL	PS	ZE	NS	NS
NS	PL	PS	ZE	NS	NL
ZE	PL	PS	ZE	NS	NL
PS	PS	ZE	NS	NL	NL
PL	PS	ZE	NS	NL	NL

Computing Consecutive number of no Rainfall day (NoCNRD)

For Layer 1 at depth 2”					
If T.R.A. is in:	(0, TRA_Max)	(TRA_Max, 2*TRA_Max)	(2*TRA_Max, 3*TRA_Max)	(3*TRA_Max ,4*TRA_Max)	(4*TRA_Max ,5*TRA_Max)
do:	Add 1 to NoCNRD*	None	None	None	None
For Layer 2 at depth 4”					
If T.R.A. is in:	(0, TRA_Max)	(TRA_Max, 2*TRA_Max)	(2*TRA_Max, 3*TRA_Max)	(3*TRA_Max ,4*TRA_Max)	(4*TRA_Max ,5*TRA_Max)
do:	Add 1 to NoCNRD*	Add 1 to NoCNRD*	None	None	None
For Layer 3 at depth 8”					
If T.R.A. is in:	(0, TRA_Max)	(TRA_Max, 2*TRA_Max)	(2*TRA_Max, 3*TRA_Max)	(3*TRA_Max ,4*TRA_Max)	(4*TRA_Max ,5*TRA_Max)
do:	Add 1 to NoCNRD*	Add 1 to NoCNRD*	Add 1 to NoCNRD*	None	None
For Layer 4 at depth 20”					
If T.R.A. is in:	(0, TRA_Max)	(TRA_Max, 2*TRA_Max)	(2*TRA_Max, 3*TRA_Max)	(3*TRA_Max ,4*TRA_Max)	(4*TRA_Max ,5*TRA_Max)
do:	Add 1 to NoCNRD*	Add 1 to NoCNRD*	Add 1 to NoCNRD*	Add 1 to NoCNRD*	None
For Layer 5 at depth 40”					
If T.R.A. is in:	(0, TRA_Max)	(TRA_Max, 2*TRA_Max)	(2*TRA_Max, 3*TRA_Max)	(3*TRA_Max ,4*TRA_Max)	(4*TRA_Max ,5*TRA_Max)
do:	Add 1 to NoCNRD*	Add 1 to NoCNRD*	Add 1 to NoCNRD*	Add 1 to NoCNRD*	None

* If TRA > Threshold precipitation

$$Error = \frac{\sum_{i=1}^{n}(SM_{a_i} - SM_{c_i})}{\sum_{i=1}^{n} SM_{a_a}} \times 100\%$$

Here,

SM_{a_i} is the actual volume of soil moisture (%),

SM_{c_i} is the calculated volume of soil moisture (%).

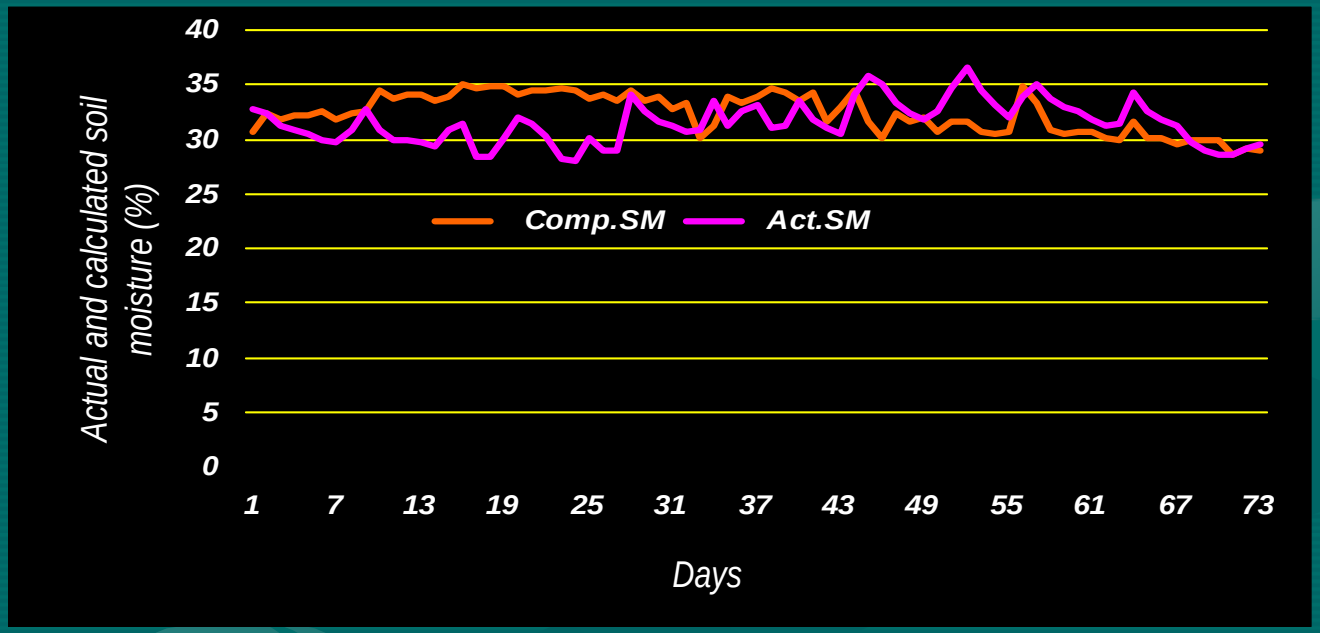
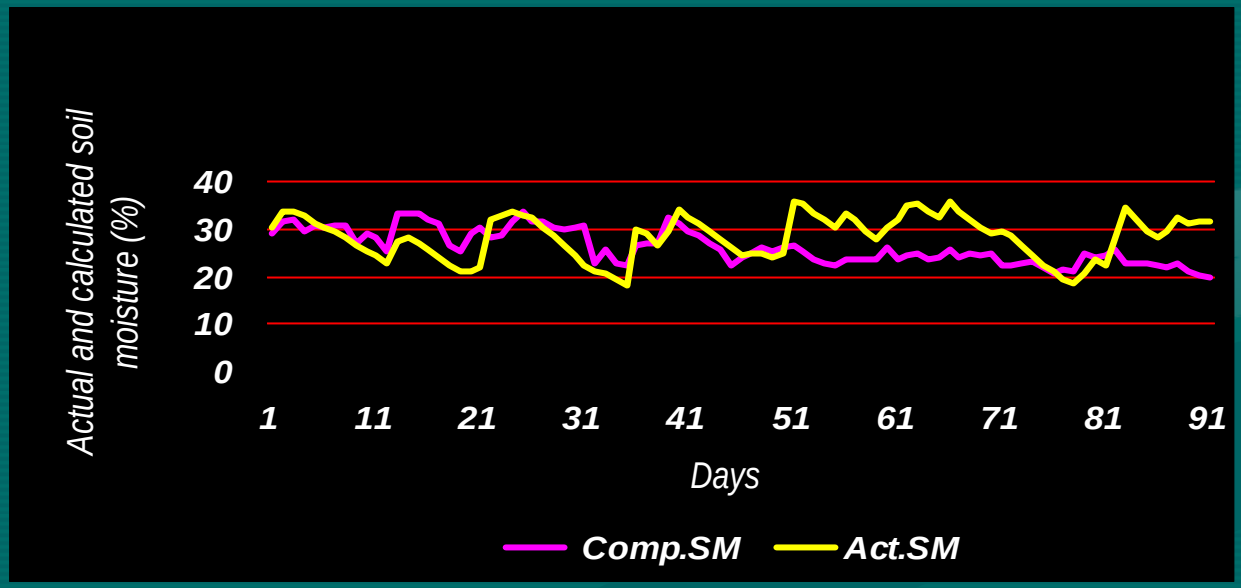
"n" is total number of data.

Season	Error (%)				
	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
1	0.66 2.61	2.13 33.22	1.96 -10.37	-1.58 -18.56	-1.52 -2.80
2	-9.31 2.29	-9.86 2.63	-2.78 -6.74	-1.18 -12.10	-1.33 -1.92
3	12.10 2.10	13.28 -8.81	-1.56 -6.15	-6.25 -9.62	-3.77 -3.22
4	-21.92 3.73	-16.28 3.73	0.10 -2.97	-10.36 -2.39	-4.55 -3.43
5	-5.16 4.65	-4.32 -1.92	-4.32 -3.39	-7.59 -2.64	-8.43 -3.50

USDA Scan Data AAMU 2003

USDA Scan Data AAMU 2004

Soil moisture 2003 AAMU USDA Scan Data
Layer 1 Season 1



Soil moisture 2003 AAMU USDA Scan Data
Layer 1 Season 2