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MODELING SOIL WATER DYNAMICS UNDER RAINFED AGRICULTURE TO MITIGATE CLIMATE CHANGE

By

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International Conference on Managing Soils for Food Security and Climate Change Adaptation and Mitigation

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Sequence

- Climatic Variability (Climate Change)
- Soil water dynamics
- Simulation Modelling
- Methodology
  - NEUTRON PROBE
  - APSIM
- Results and Discussion
- Conclusion

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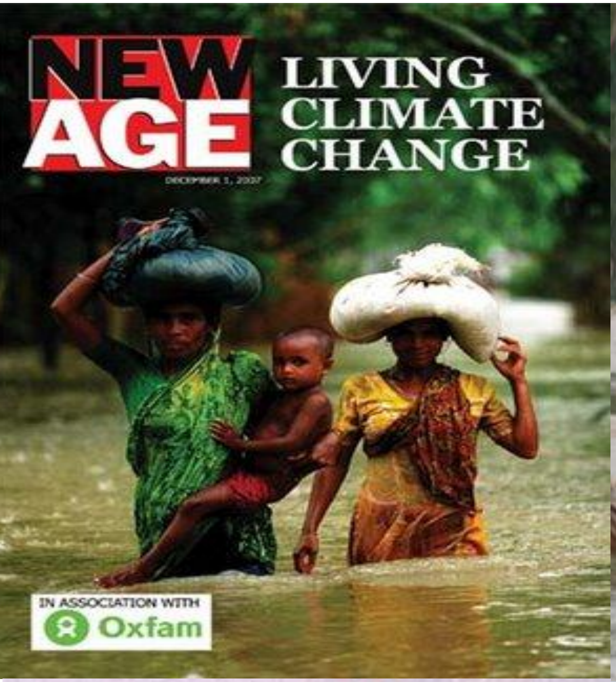

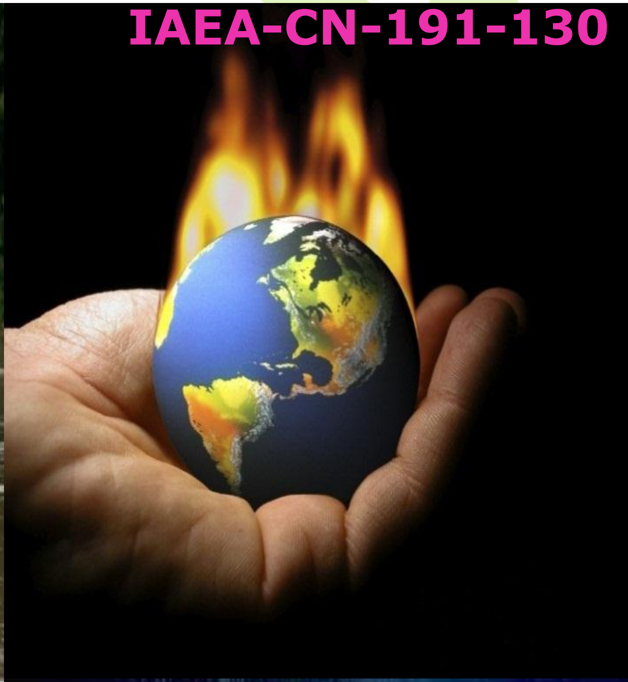

Climate Variability

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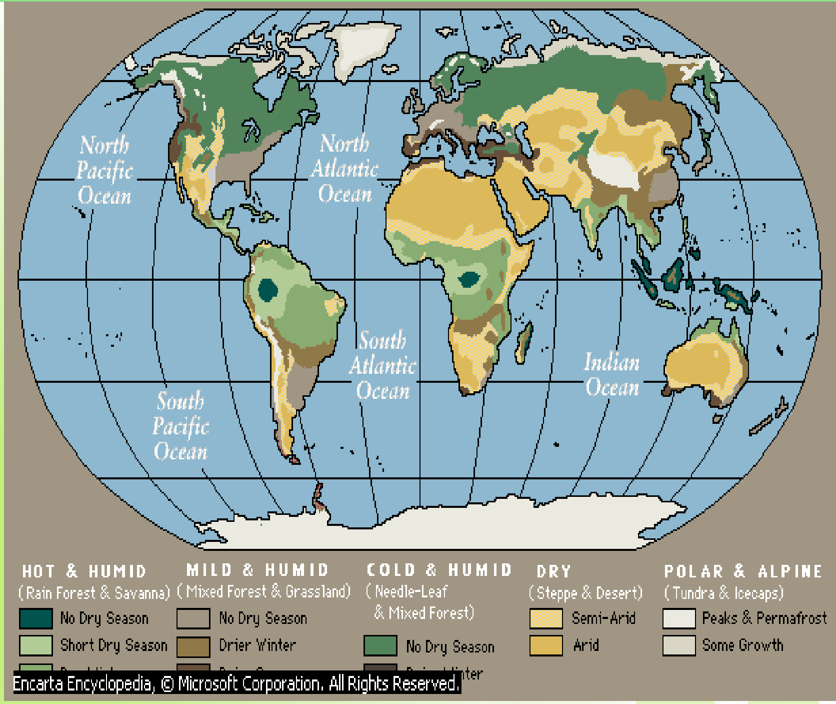
Climate - one of the known Risk Factors (Introduction)

Climate, the long-term effect of the sun's radiation on the rotating earth's varied surface and atmosphere. It can be understood most easily in terms of annual or seasonal averages of temperature and precipitation….



From a risk management perspective we **need** to understand existing <u>climate variability</u>

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Climate Variability and Rainfed Agriculture

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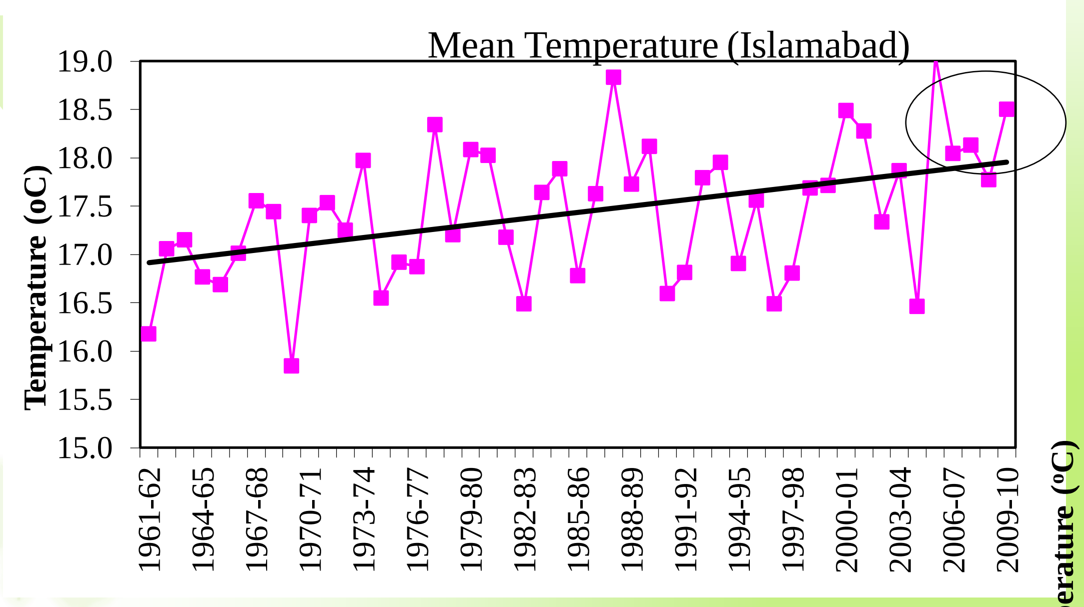
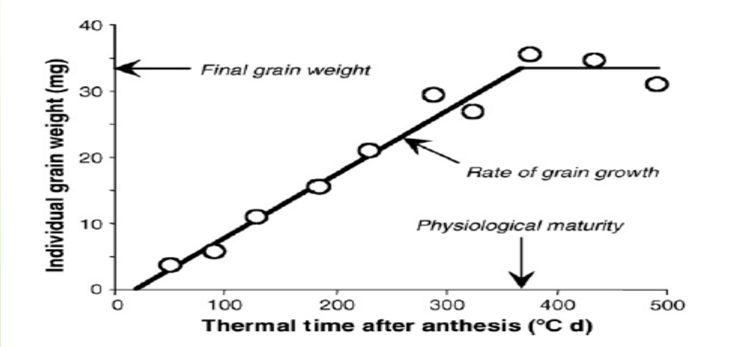
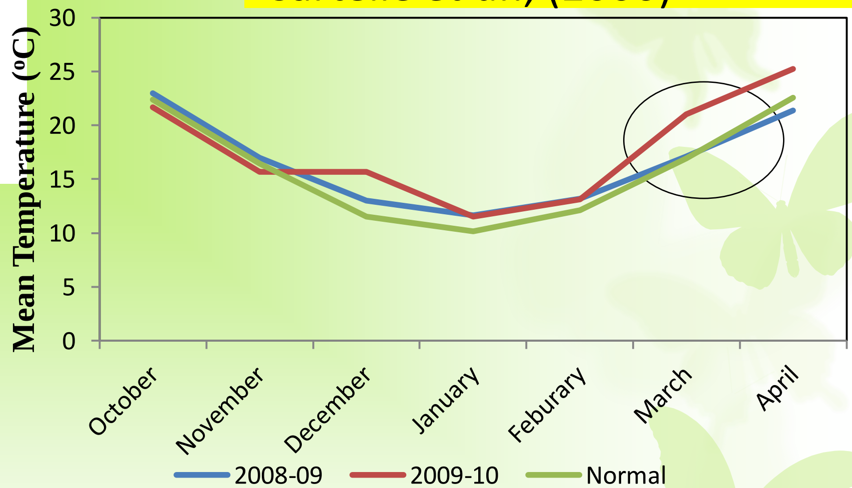
Enormous year-to-year climate variability





Cartelle *et al.*, (2006)



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Climate Variability and Rainfed Agriculture

Enormous year-to-year climate variability (October-April Rainfall)

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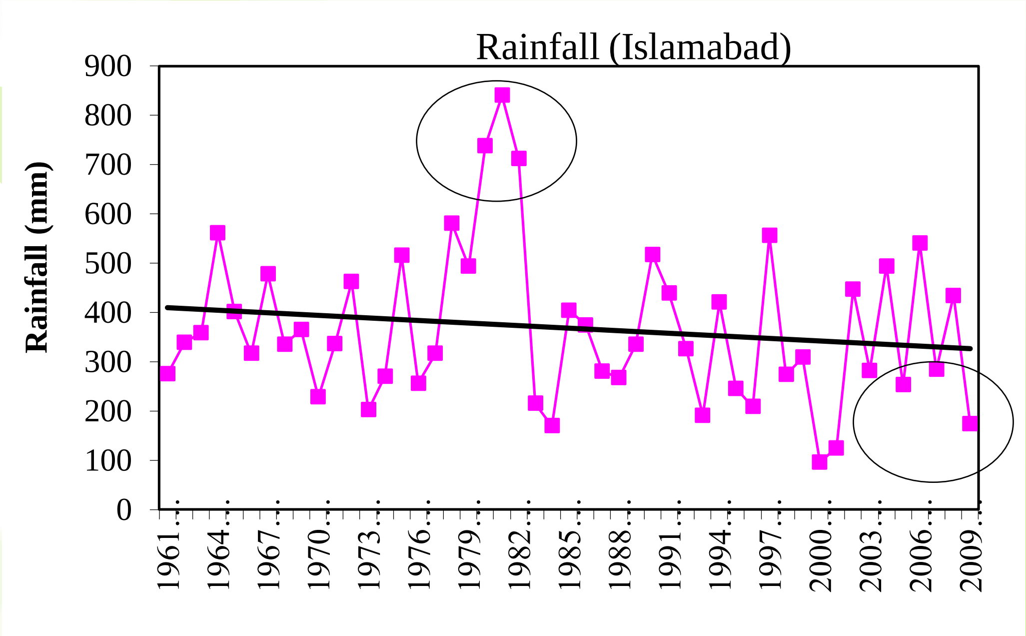

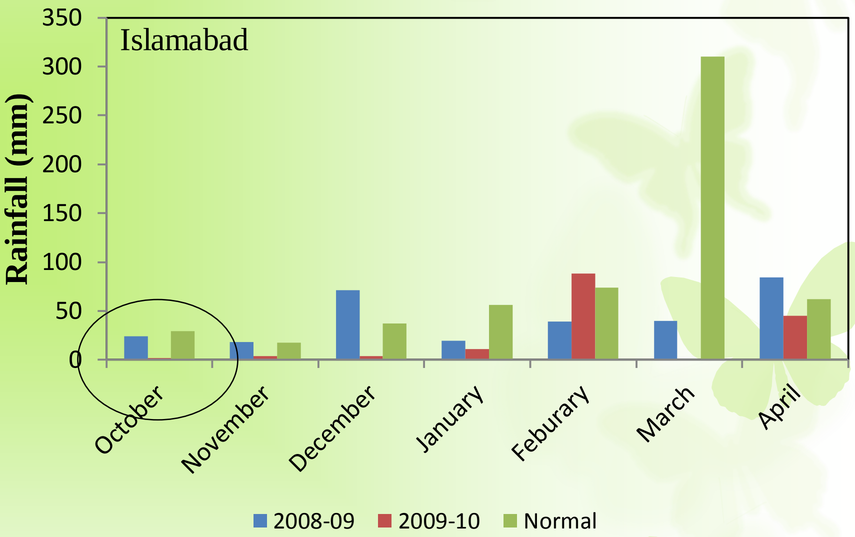

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Climate Variability and Rainfed Agriculture

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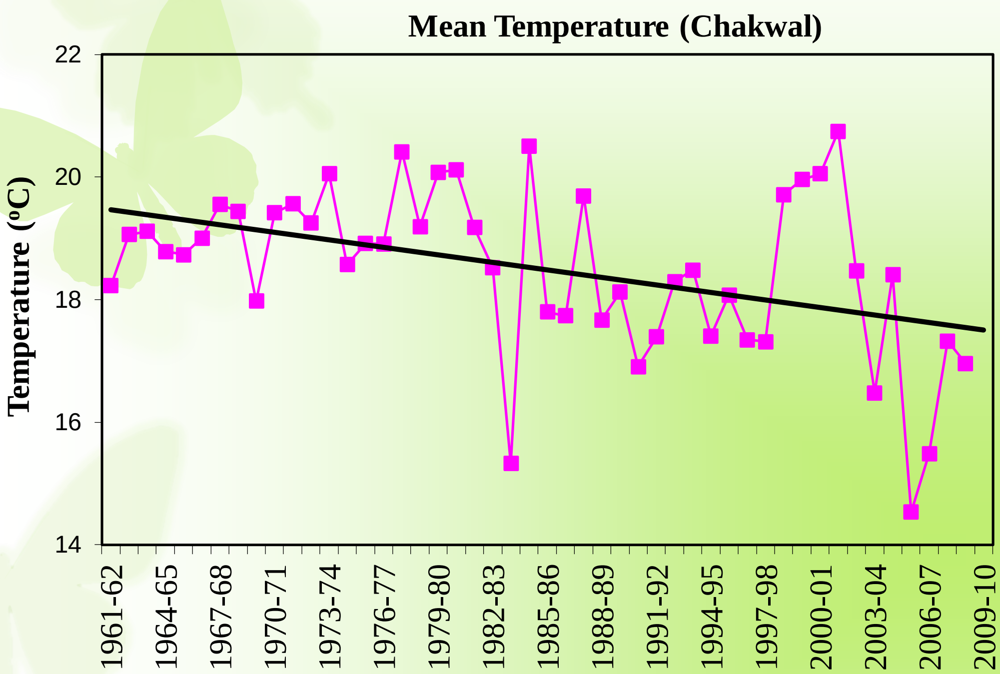

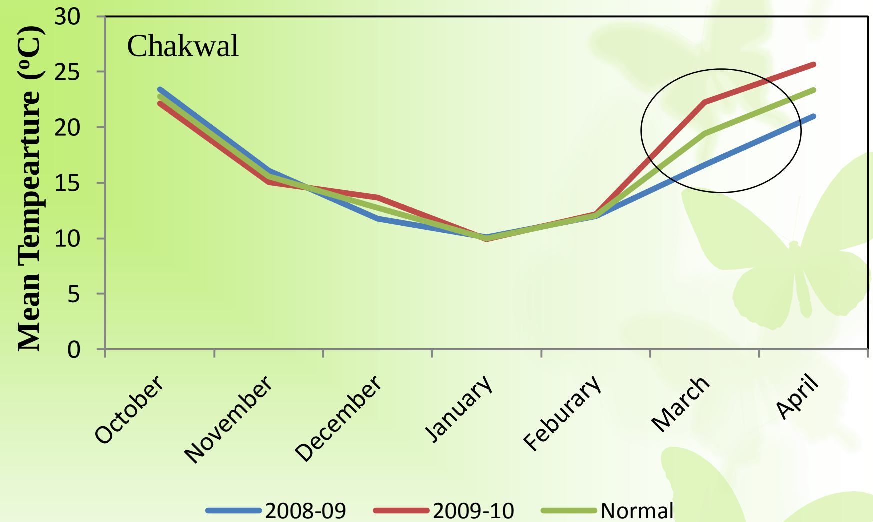

A major source of agricultural production variability

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Climate Variability and Rainfed Agriculture

Enormous year-to-year climate variability

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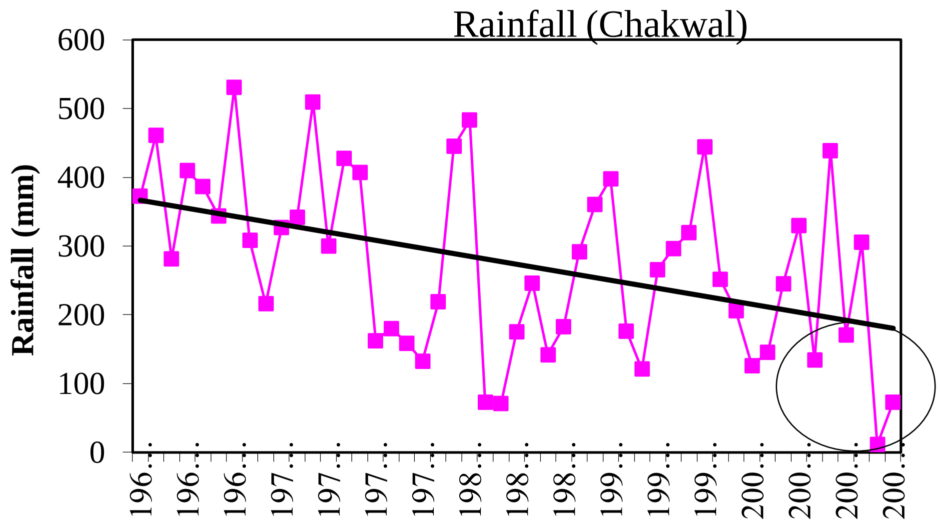

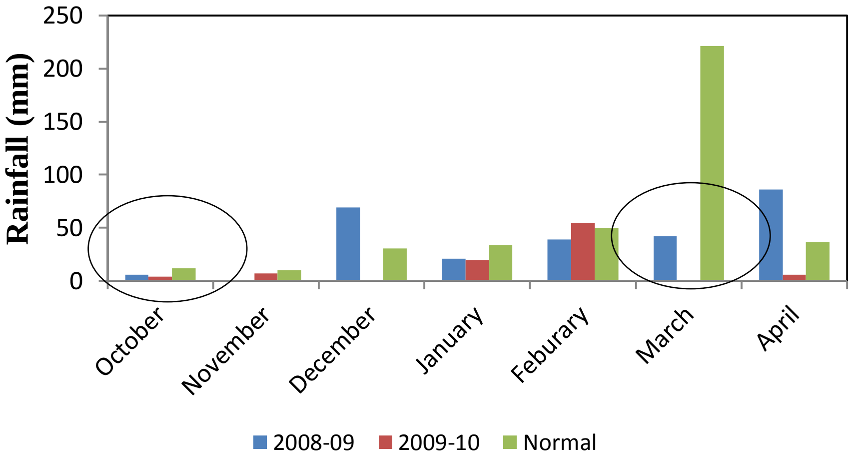

A major source of agricultural production variability

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Climate Variability and Rainfed Agriculture

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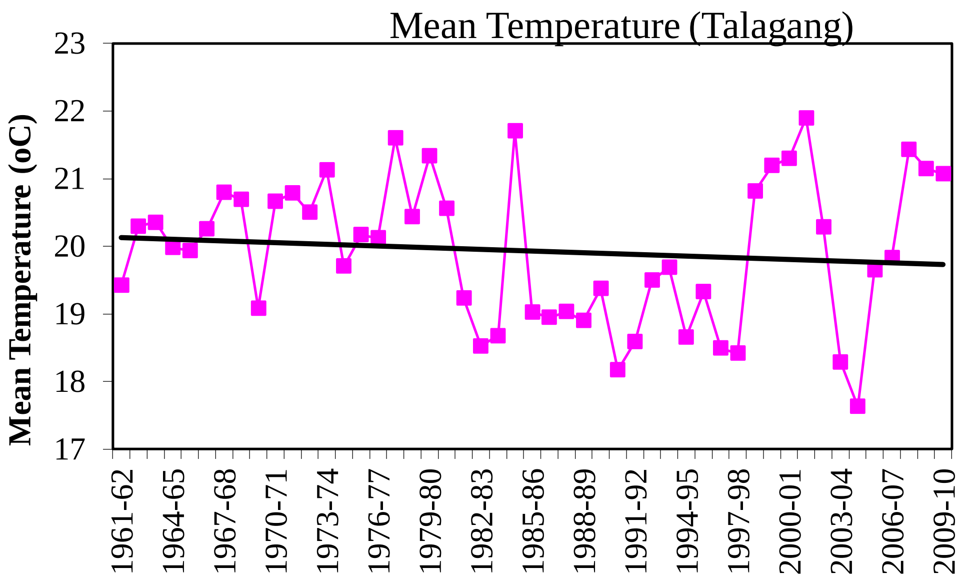
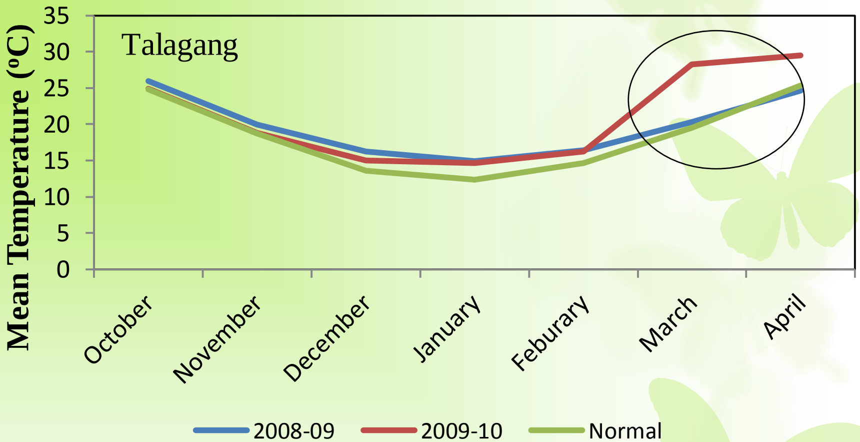
Enormous year-to-year Climate Variability





A major source of agricultural production variability

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Climate Variability and Rainfed Agriculture

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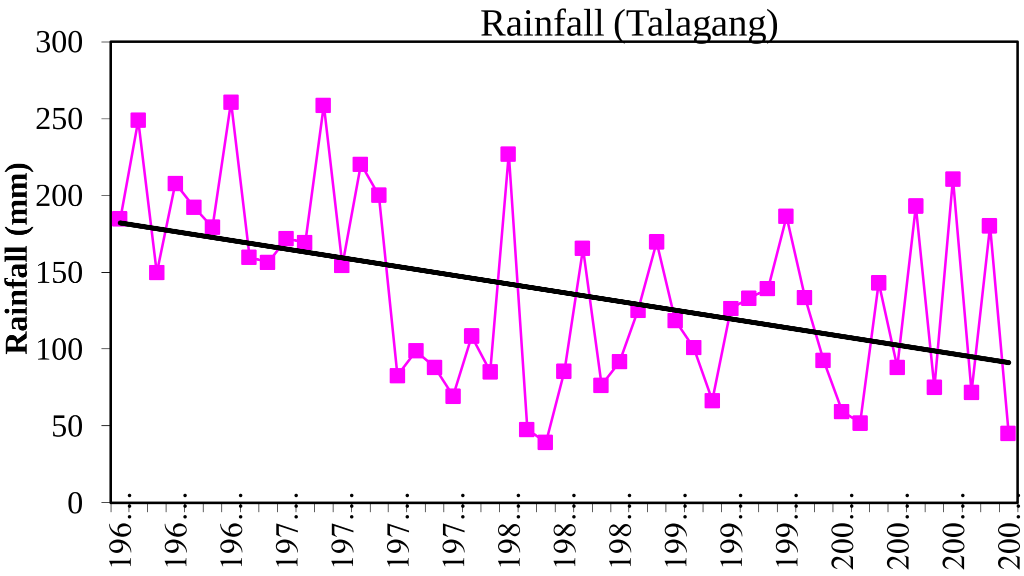

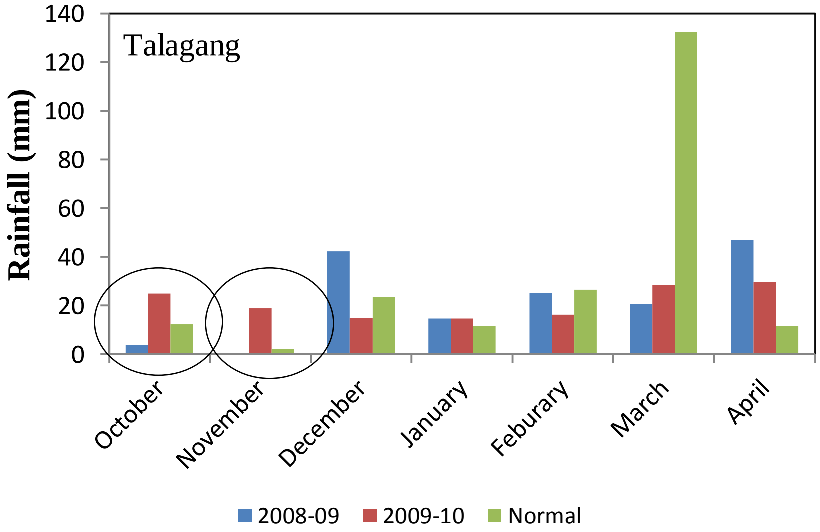

A major source of agricultural production variability

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Wheat Scenario in Pakistan

Scenarios	Average (tons/hectare)
	Wheat
Productivity Potential at Research Stations	6.5
Productivity at Progressive farmers	5.5
National Average Productivity	2.6
% Gap between progressive farmer and National average	52.5
% Gap between potential & National average	59.8

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Climate Variability

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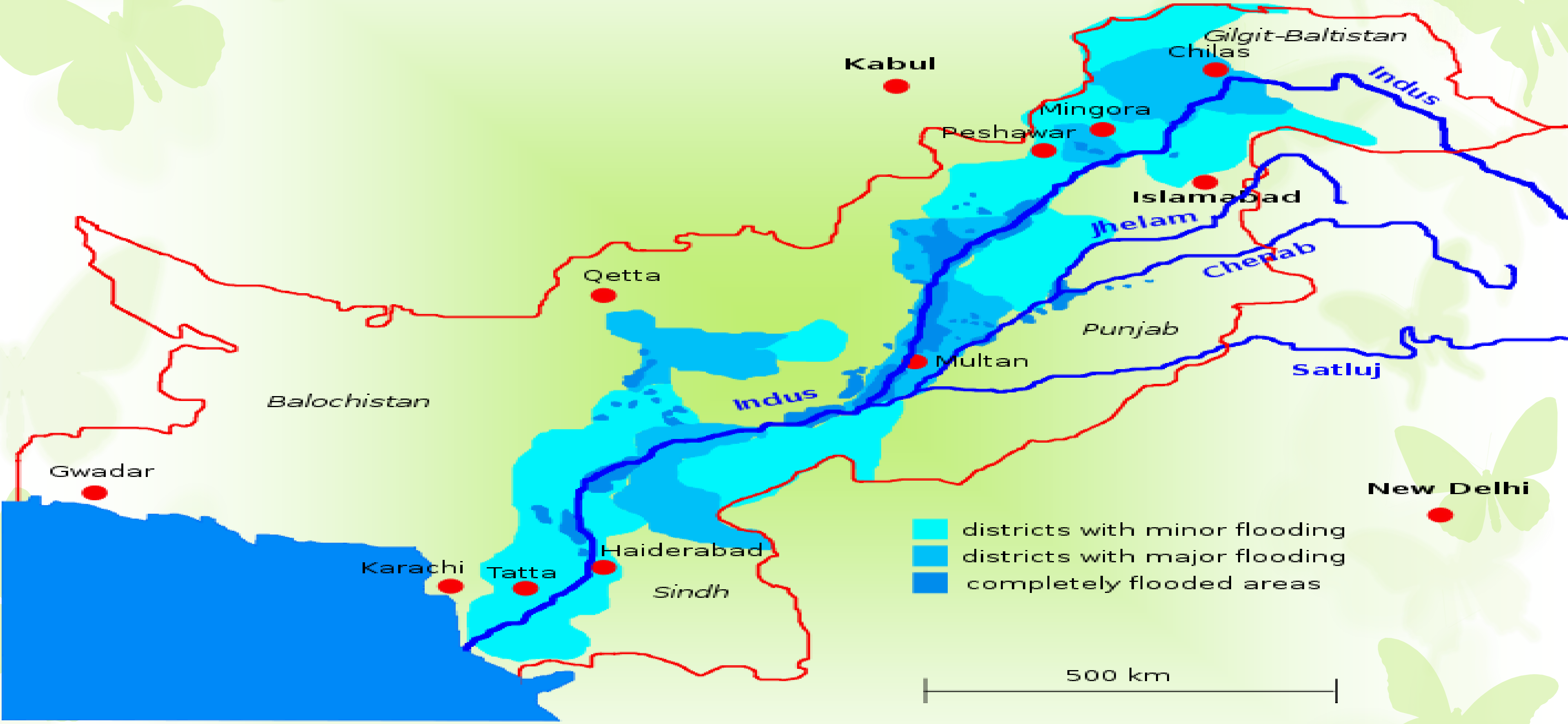
- 2010 Flood was driven by unprecedented monsoon rain
- Intense monsoon rains attributed to La Niña (NASA)



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Effects of Climate Events on Wheat Production in Rainfed Area

Cropping Year	*Climate Events*	*Yield (kg/ha)*	*% change*
1999-00	**Drought (Weak La- Nina)**	**1319**	**-25**
2000-01	**Drought + Terminal heat stress (Non El-Nino Drought)**	**534**	**-70**
2001-02	**Drought +Terminal heat stress (Non El-Nino Drought)**	**717**	**-59**
2002-03	**Drought (Moderate El-Nino)**	**1310**	**-25**
2003-04	**Terminal heat stress (Non El-Nino Drought)**	**1321**	**-25**
2004-05	**(Week El-Nino)**	**1730**	**-1**
2005-06	**Terminal heat stress (Non El-Nino Drought)**	**1354**	**-23**
2006-07	**Bumper Crop Year (Moderate El-Nino)**	**1755**	**=**
2007-08	**Frost + Terminal heat stress (Moderate La-Nina)**	**1205**	**-31**
2008-09	**Non El-Nino year**	**1465**	**017**
2009-10	**Drought (Moderate El-Nino)**	**945**	**-46**
2010-11	**Strong Lanina**	**1760**	+1
2011-12	**Terminal heat stress (Moderate El-Nina)**	**1200**	-31

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Effective Climate Risk Management requires

An understanding of management options in response to climate information,

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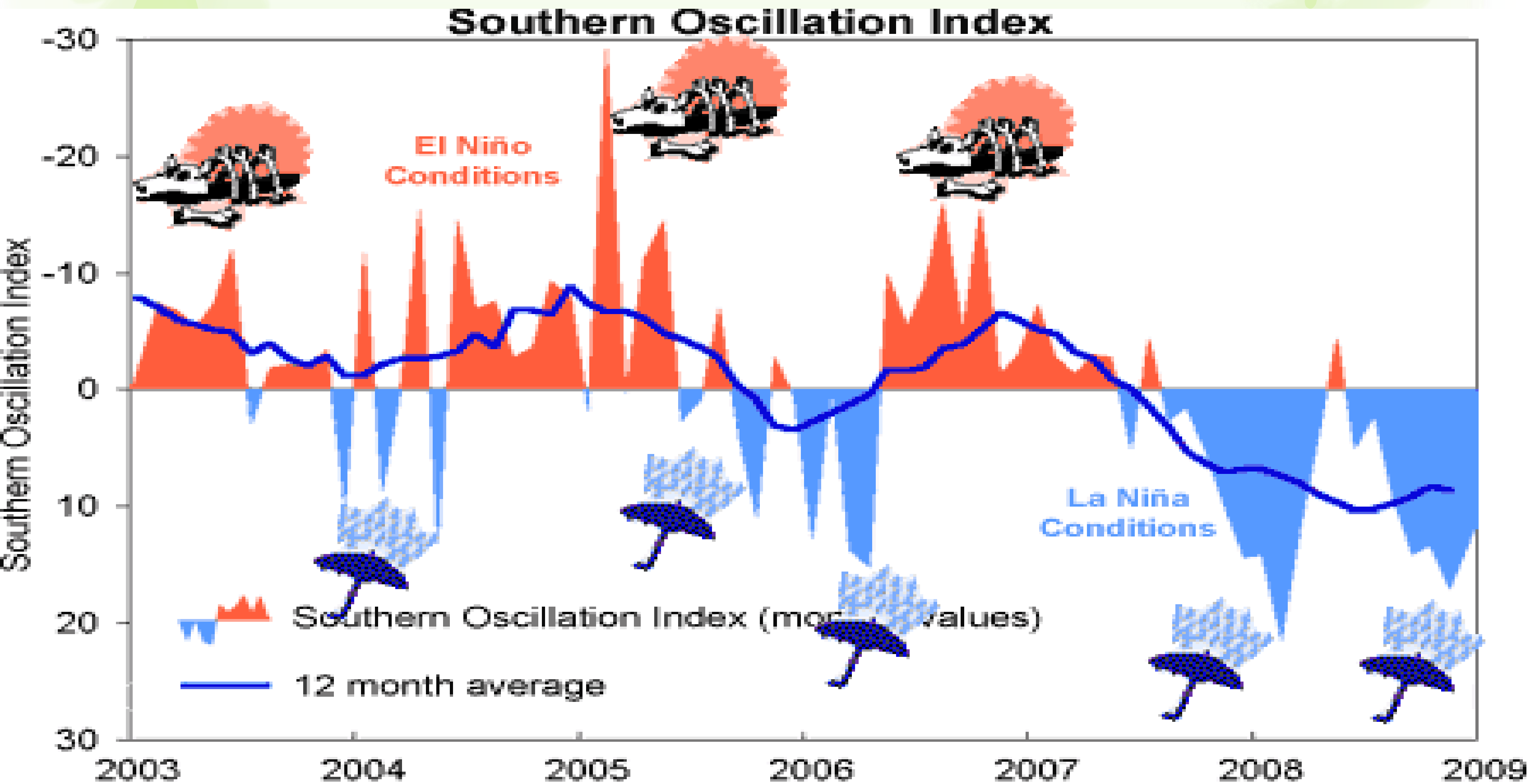
Understanding Climate Variability

- **SOI (Southern Oscillation Index)**
- **El Nino-Southern Oscillation (ENSO)**
- **IOD (Indian Ocean dipole)**

SOI



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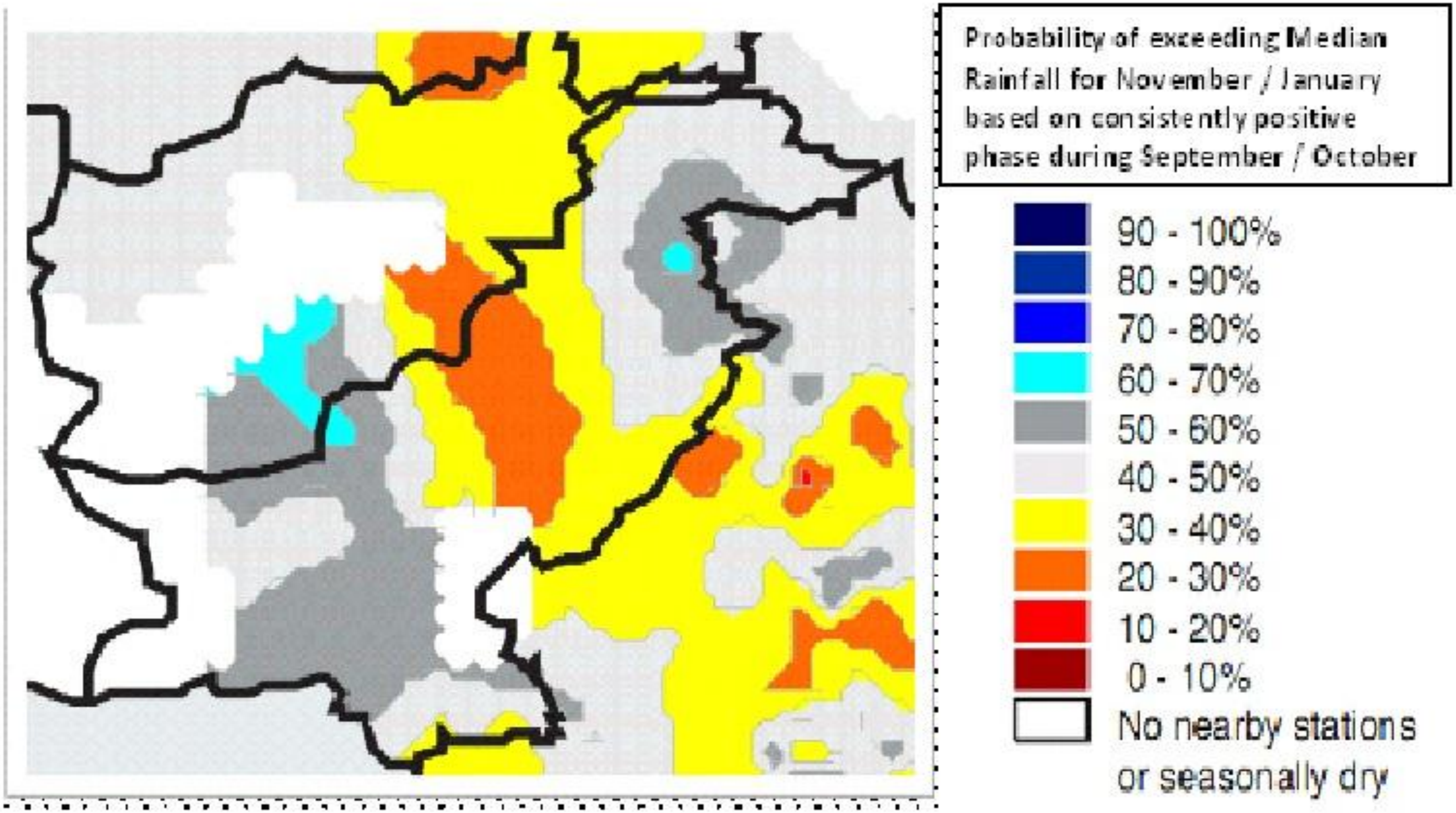
SOI use for Pakistan



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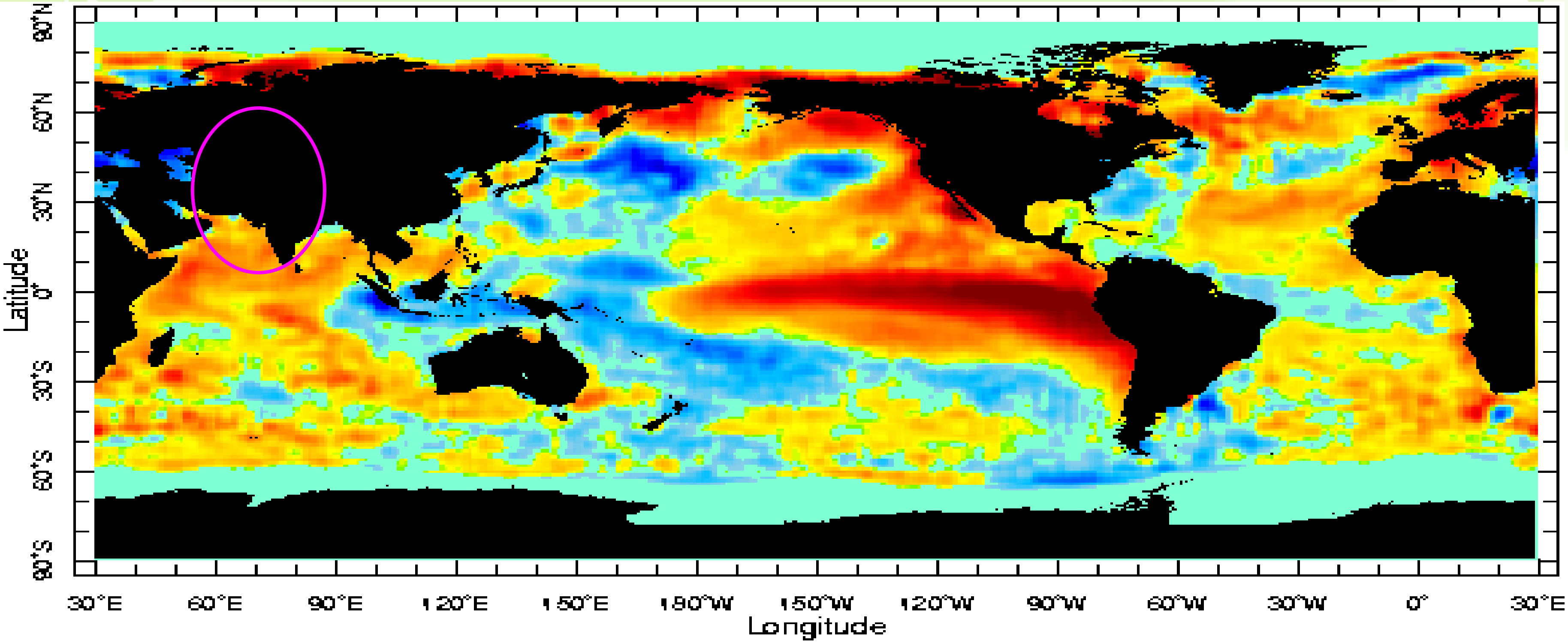
- Ocean - Atmosphere Interaction
- Largest known source of climate variability
- Global changes to rainfall, winds, pressure and temperature



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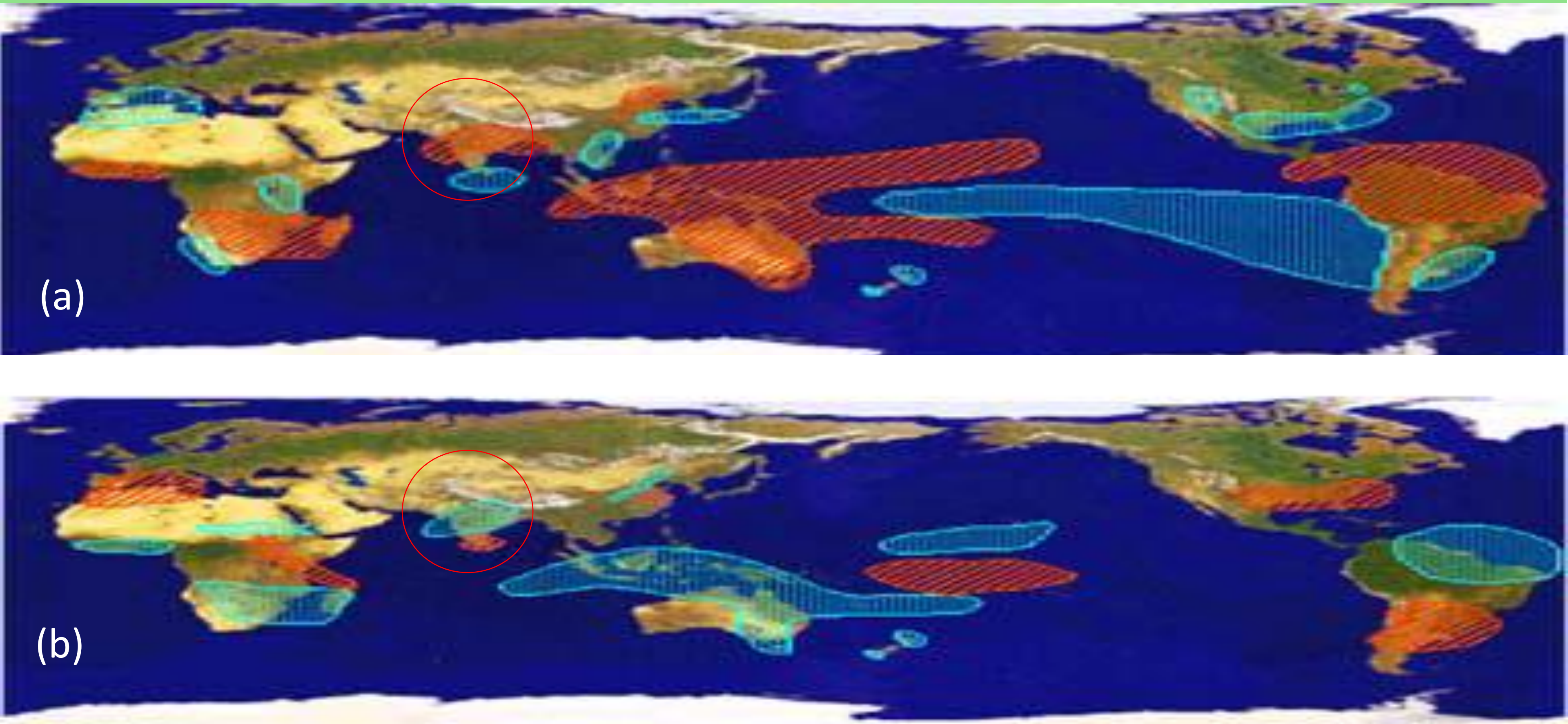
Understanding Climate Variability



Global impact (indicated as wetter or dryer weather conditions) of a ‘warm’ (a) El Nino and a ‘cold’ (b) La Nina) ENSO event (Clewett *et al.* 2002).

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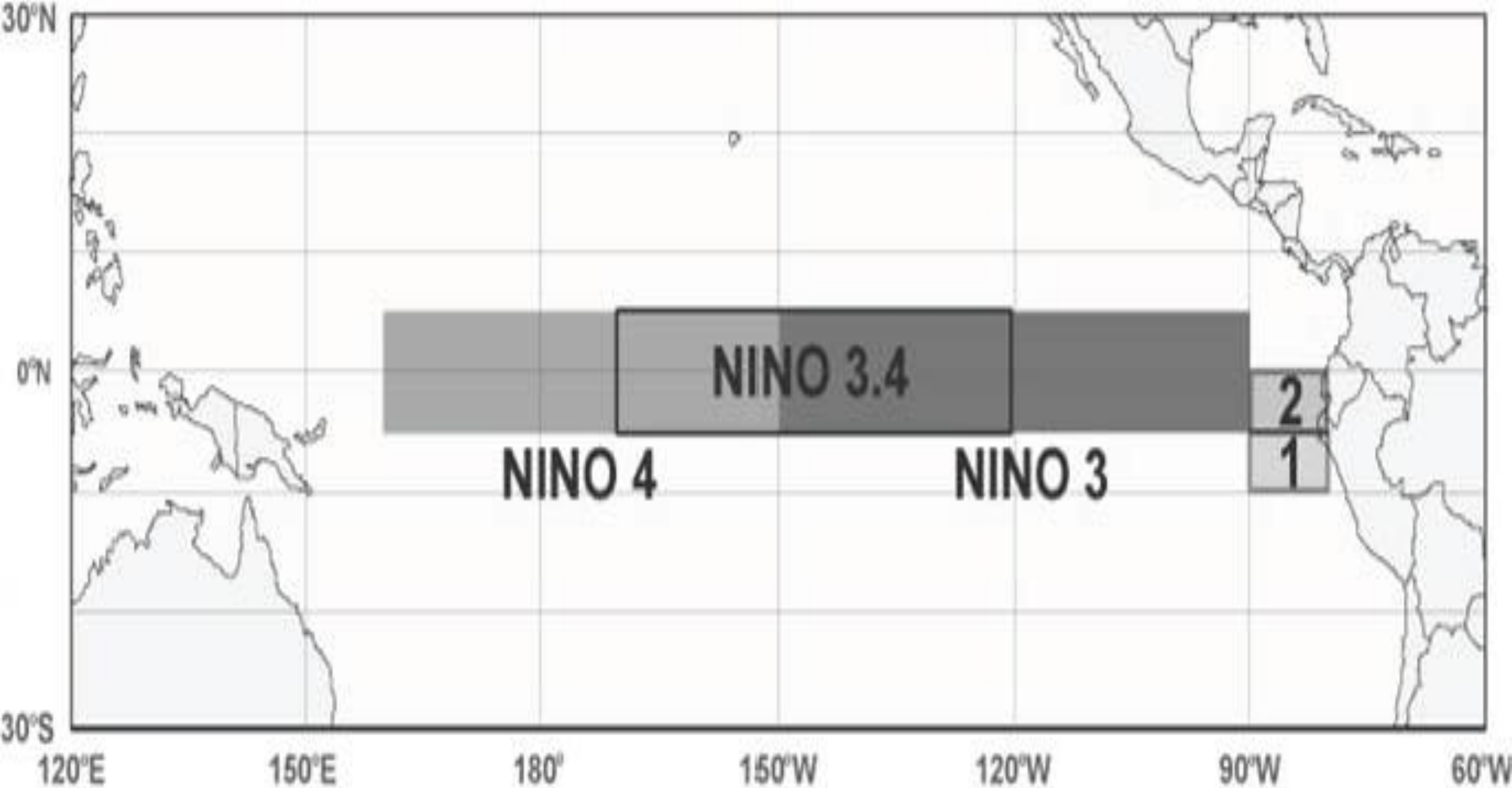
Understanding Climate Variability



Locations of average sea surface temperature locations for Niño 1, 2, 3, 3.4 and 4 (source: Bureau of Meteorology, Australia)

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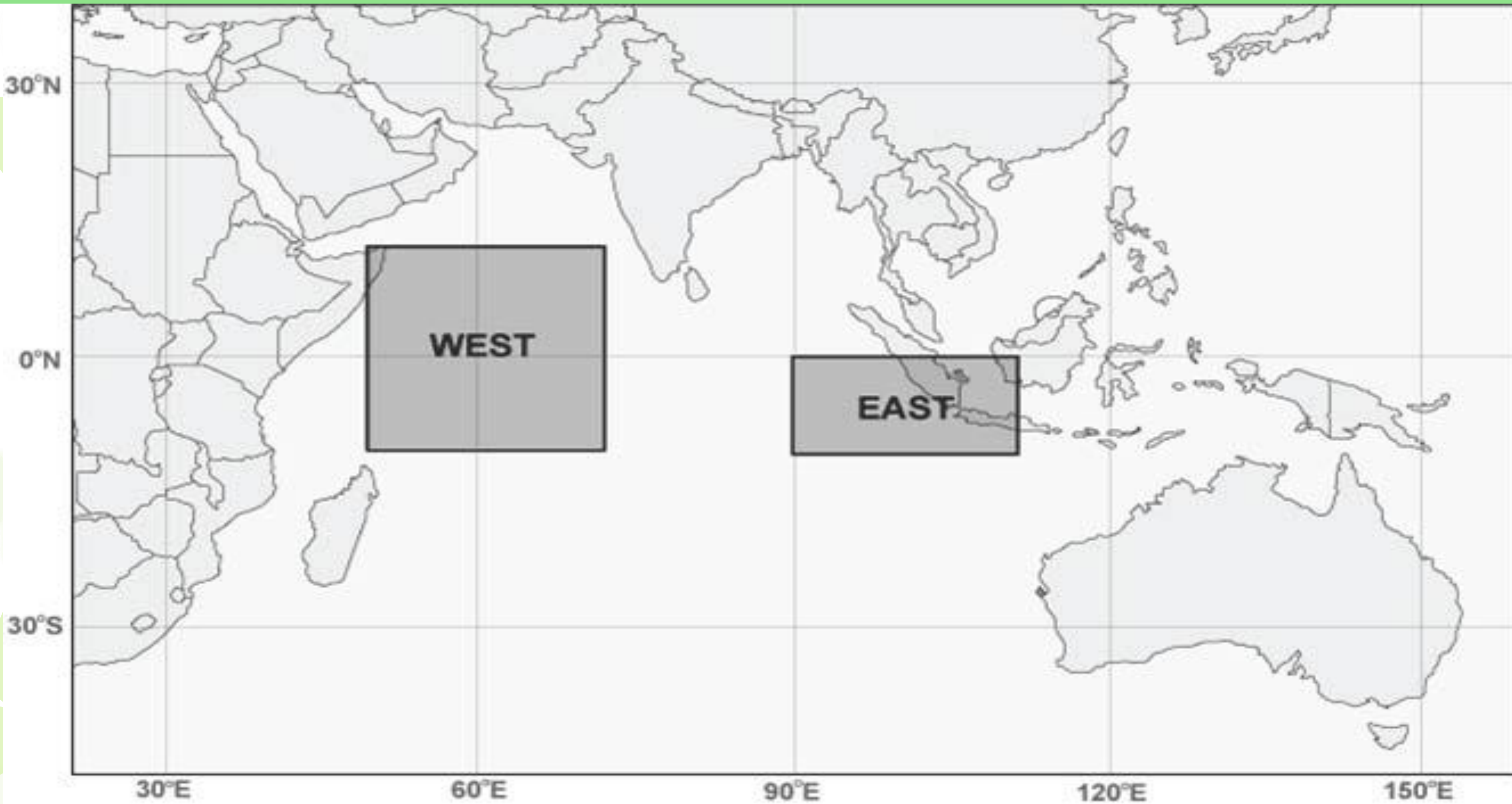
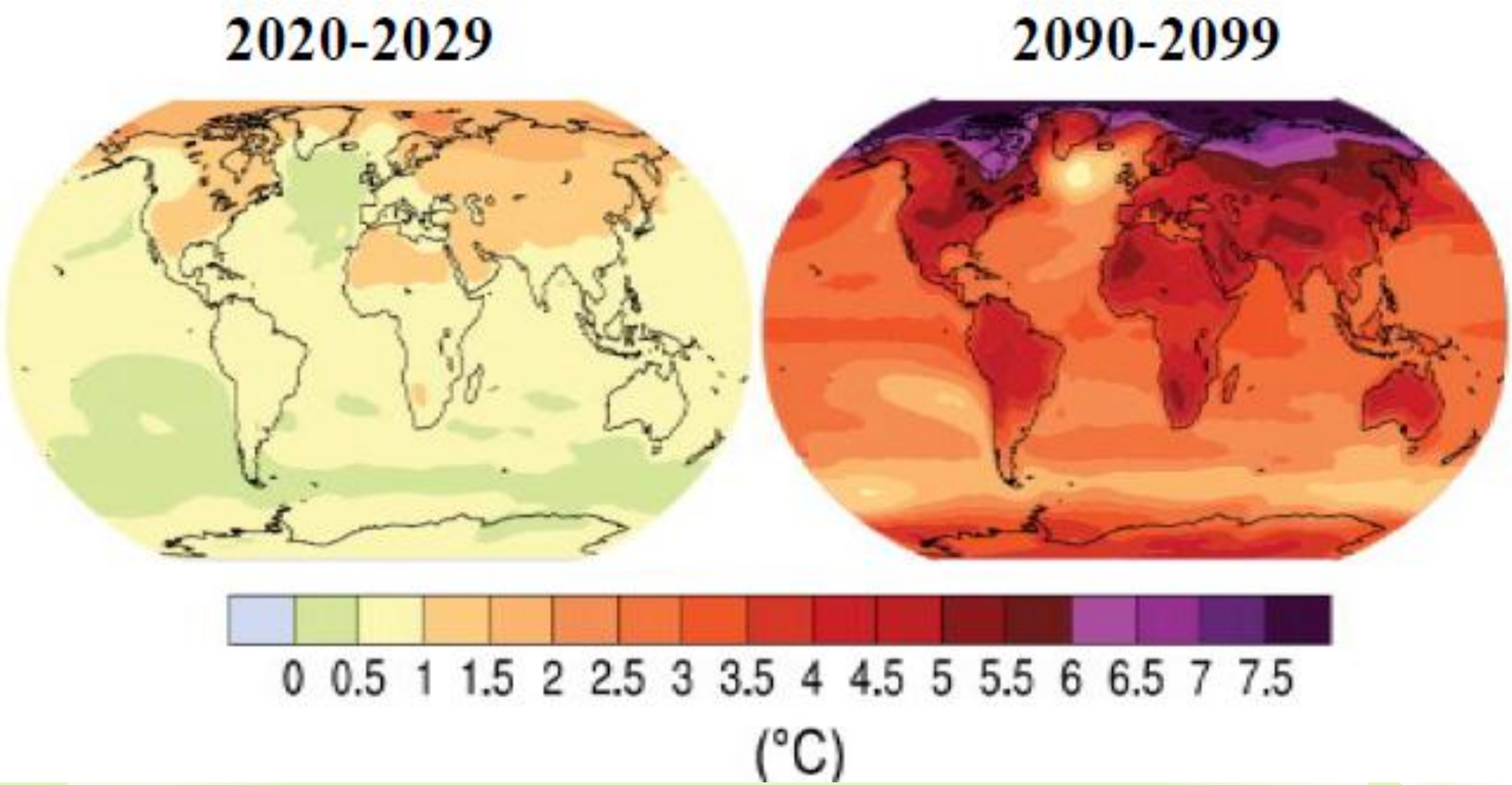
IOD



Locations of average sea surface temperature for IOD, (source: Bureau of Meteorology, Australia)

Long Term Climate Projections



http://data.giss.nasa.gov/gistemp/graphs/

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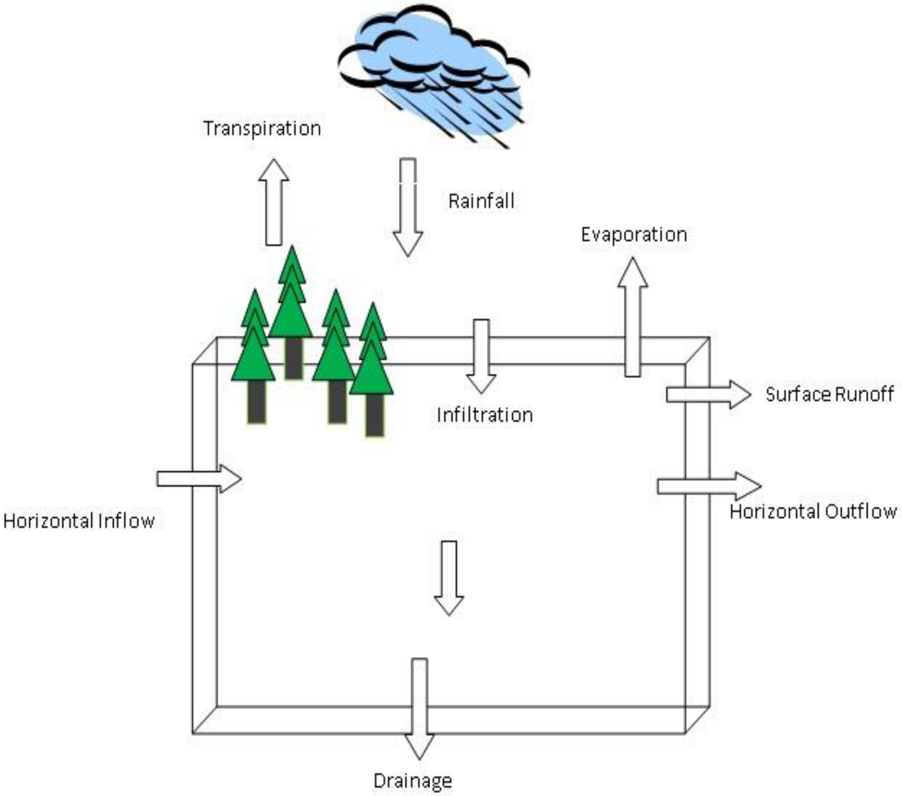
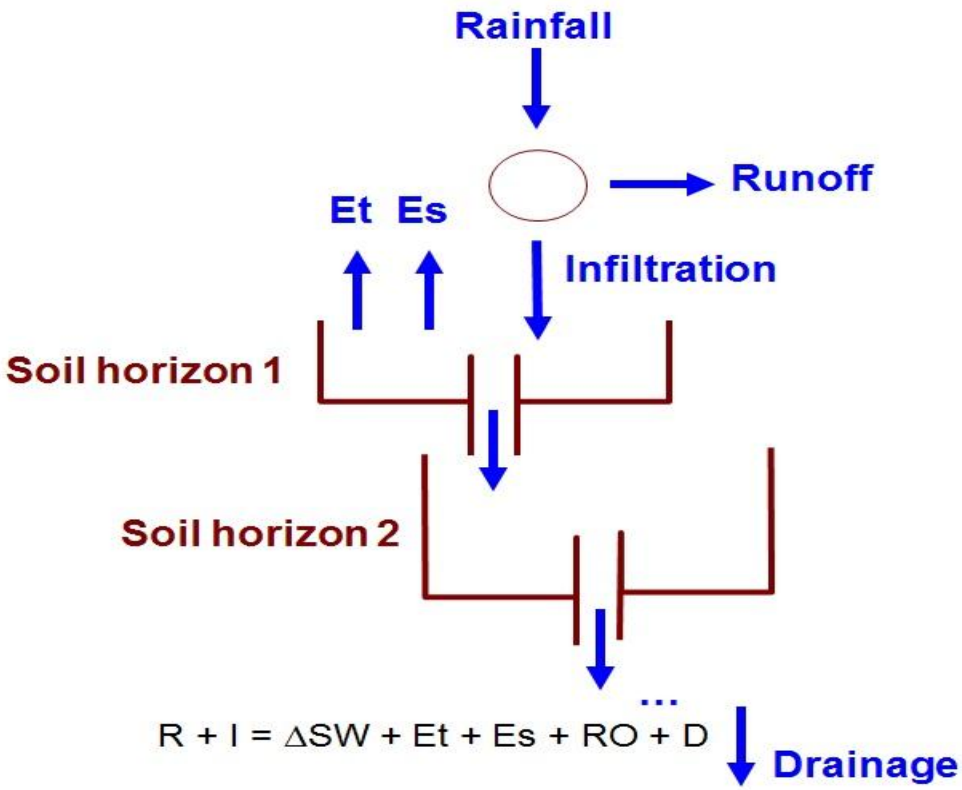
Soil Water Dynamics

- Water dynamics in the atmosphere-soil-plant (ASP) system
- Water the Scarce resource under changing climate
- Richards's equation
- Climate vulnerability threatens Pakistan's food production systems
- Rainfed areas under serious threat





Soil Water Dynamics under Climate Variability

1. **Experimental approach**
2. **Simulation Approach**

Simulation models emerged as a valuable tool for enhancing our understanding of soil water dynamics

- **Integration of the existing knowledge**
- **Used to explore the options and constraints**
- **Computer software with mathematical representations of major biological processes**
    - **Empirical model**
    - **Mechanistic model**

Computer simulation models are becoming a common tool in Agricultural Research and Teaching

Their uses has also extended to:

- **Agricultural planning**
- **Policy making**
- **Technology Transfer**
- **On-farm management**
- **Scenario Making**
- **Rainfall forecasting**
- **Soil water dynamics**

Modeling Types

Types of Modeling

- Statistical Models
- Mechanistic Models
- Process-Based Models
- Explanatory Models
- Descriptive Models
- Dynamic Models
- Stochastic Models
- Deterministic Models

Dynamic Modeling

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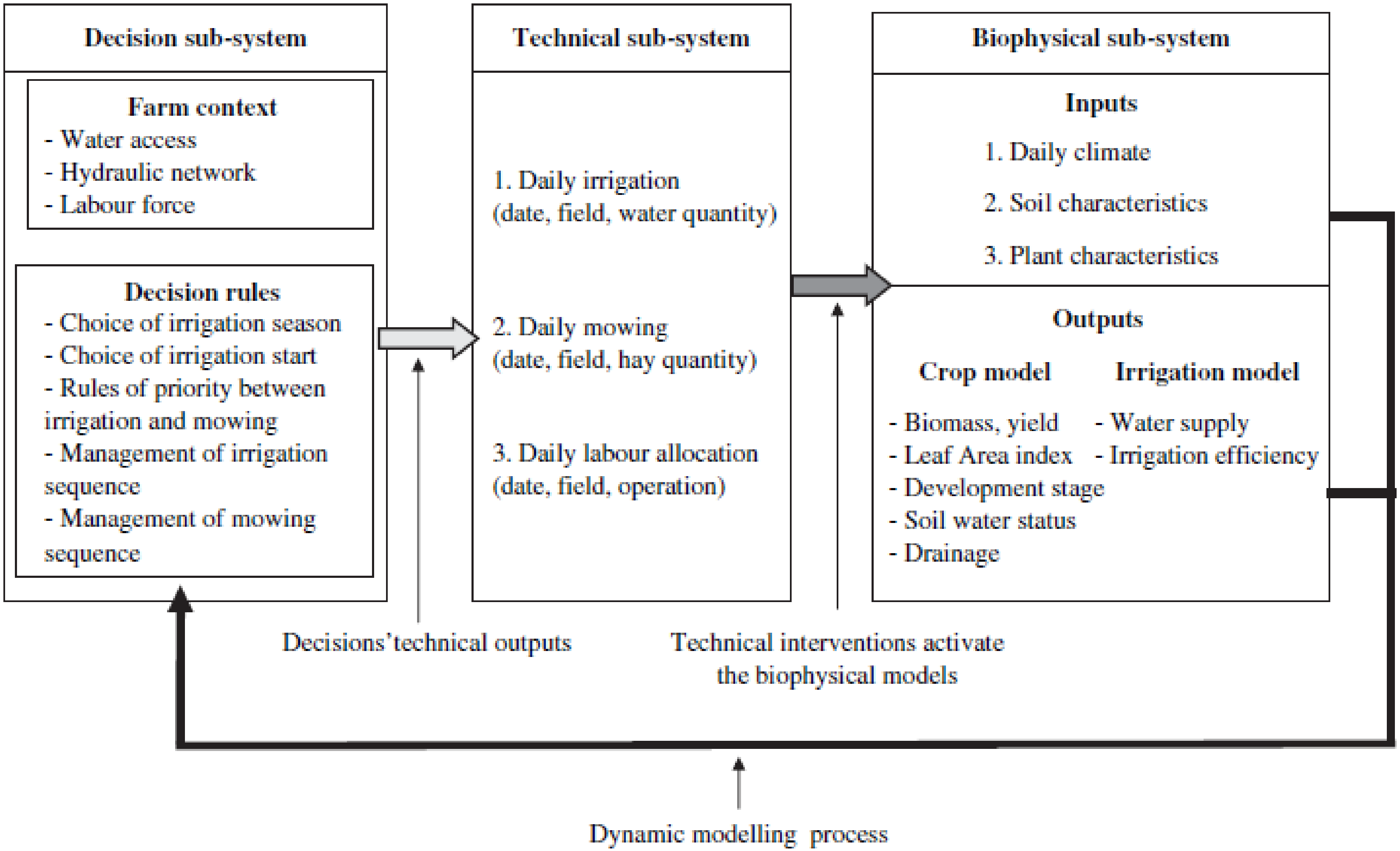

Characteristics of models with different Level of Complexity

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	Regression Model	Simple Crop Growth Model	Mechanistic Crop Growth Model
Category	Empirical	Crop Growth	Crop Process
Type	Statistical Static	→	Mechanistic, Dynamic
Relationships:	Empirical	→	Mechanistic
Scale:	Regional	Field	m^2 → Leaf
Time Step:	Seasonal	Daily	Hourly
Use:	Operational	Operational/ Research	Research
Character	Requires Data From Year Many years to Drive patameters to estimate Yield	(Yield, Water Use, Growth Stage, Leaf Area, etc.)	Broad Scope (Yield, ET, Soil Evap., Canopy Profiles, Soil and Canopy Fluxes, Stamatal Behavior, etc.)

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Dynamic Models in Research

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Models	
APSIM	McCown et al.,1996
GOSSYM	Whisler et al., 1986
Crop Water Budget Model	Ritchie, J.T., 1972
LINTUL	Spitters and Schapendonk, 1990
CropSyst	Stöckle et al., 2003
CERES	Ritchie and Otter, 1985
SPACSYS	Wu et al., 1998, 2007
sirius	Fletcher et al., 2009
CERES-Maize	Jones 1986
SVAT	Mo et al. (2005)
WOFOST	Supit et al., 2012
SPAc	Sus et al., 2010
DGVM	Yang et al.,2004
SPA	Williams et al., 1996
JULES	Hoof et al., 2011
EPIC	Williams et al.,1984
CROPSYST,	Stockle et al., 2003
STICS	Brisson et al., 1998,
DSSAT	Jones et al., 2003
MODERATO	Bergez et al., 2001
DECIBLE	Chatelin et al., 2005
SEPATOU	Cros et al., 2004
RICEPEST	Willocquet et al., 2000, 2002
WOFOST	Boogard et al., 1998
AFRCWHEAT2	Bussel et al 2010
SWAP	Vazifedoust et al., 2007
SVAT	Mo et al., 2005
GEPIC	Liu et al.,2007
InfoCrop	Aggarwal et al., 2006
WaterGAP	Alcamo et al., 2003

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Agricultural Production Systems Simulator (APSIM)

Simulates:

Mechanistic growth of crops, pastures, trees, weeds ...

Dynamics of populations

key soil processes (water, solutes, N, P, carbon, pH)

Surface residue dynamics & erosion

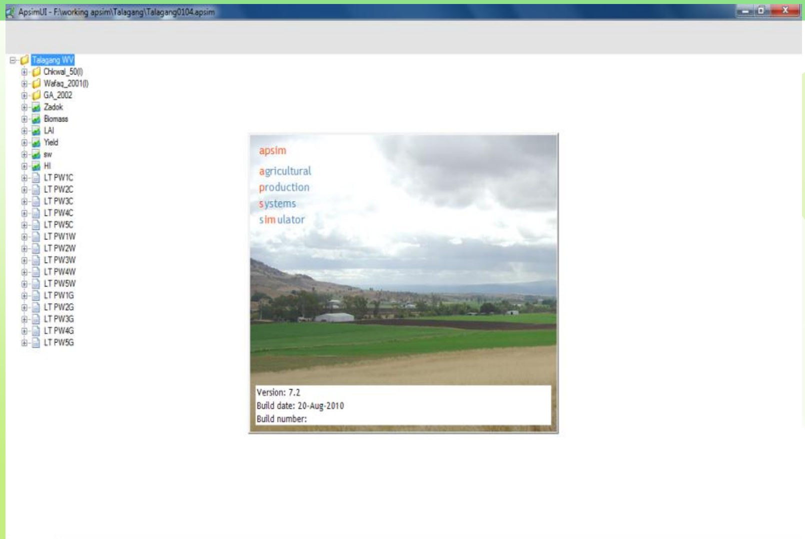
Dryland or irrigated systems

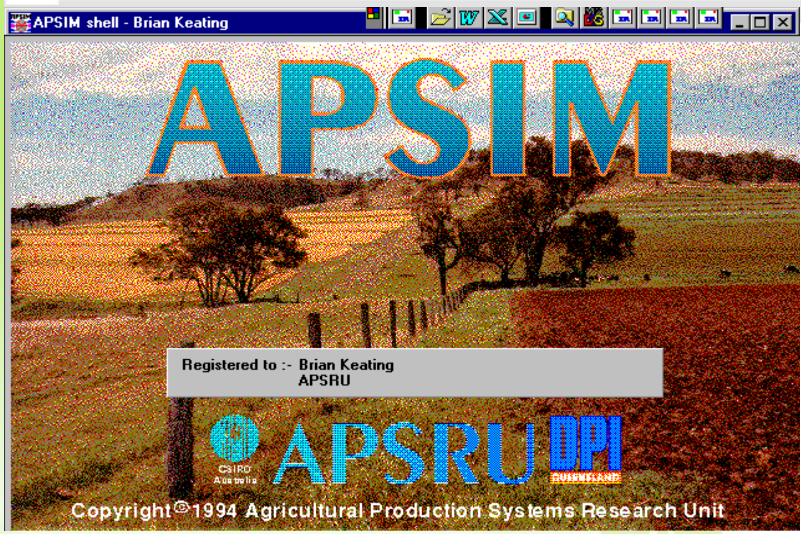
Range of management options

Crop rotations + fallowing + mixtures

Intercropping

Short or long term effects





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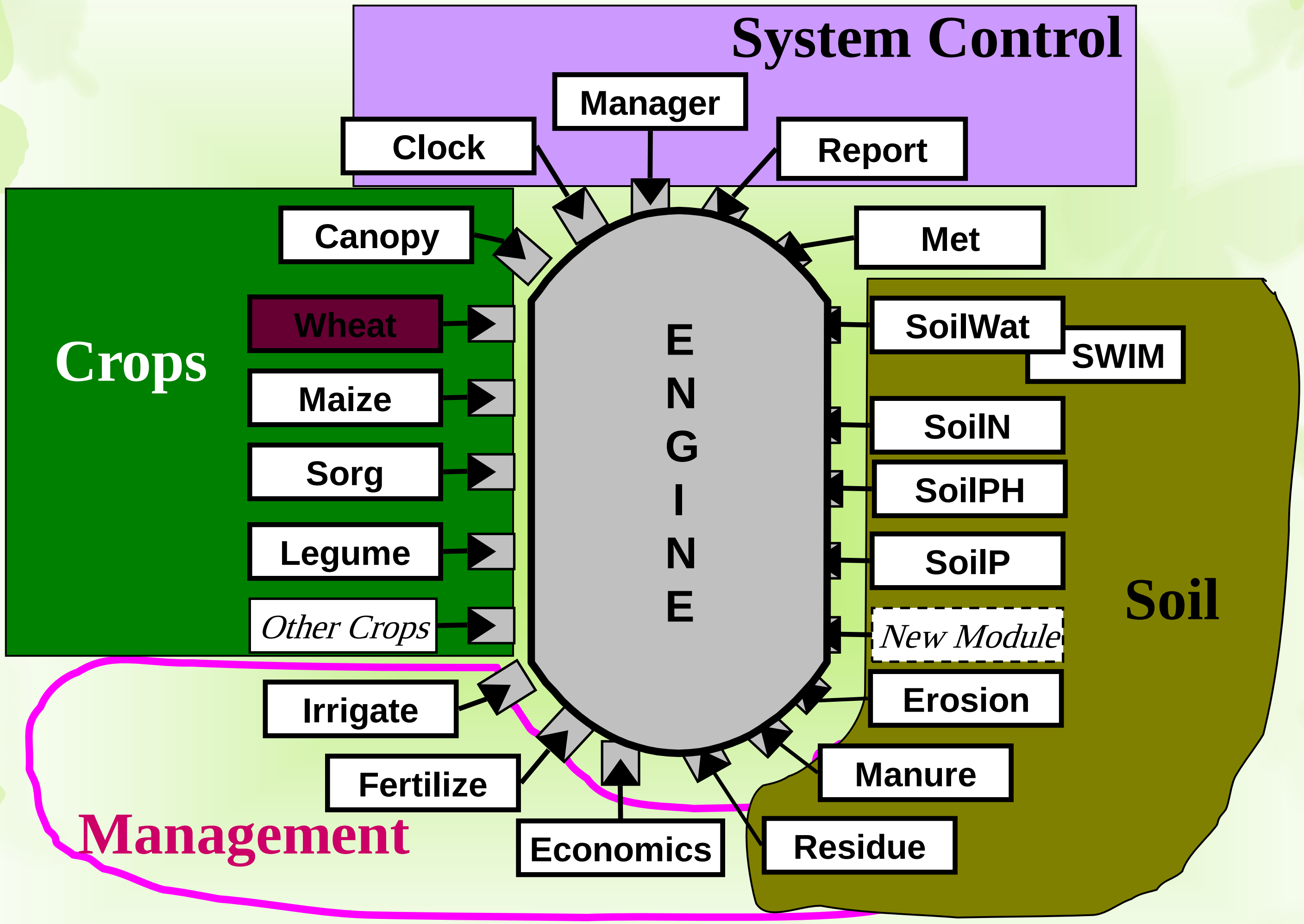
Agricultural Production Systems Simulator (APSIM)



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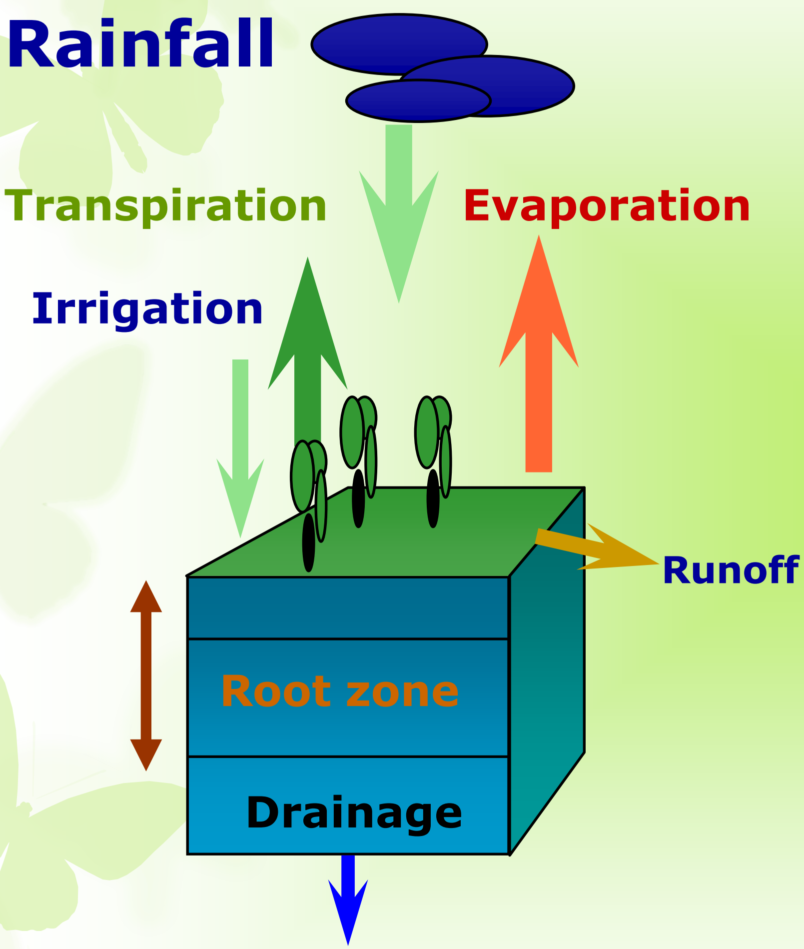
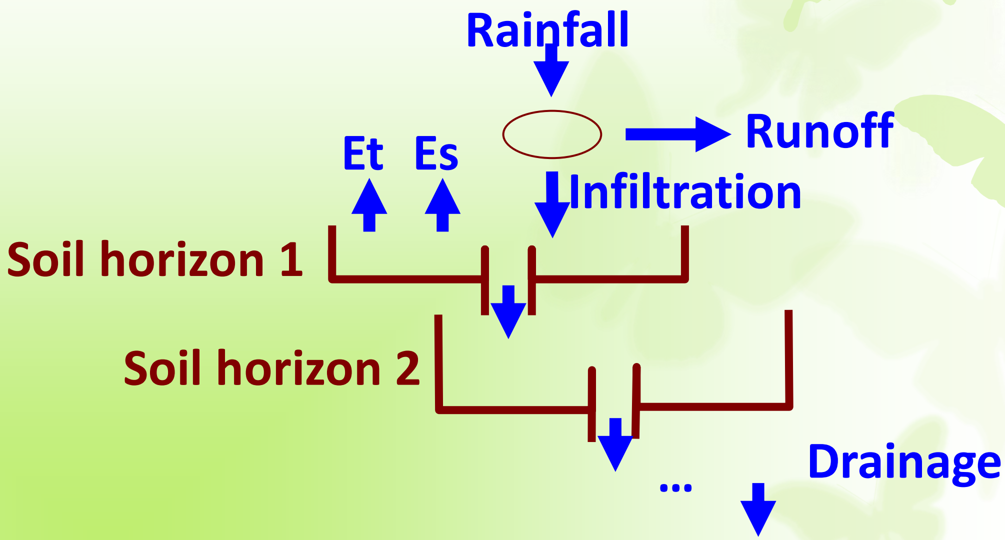
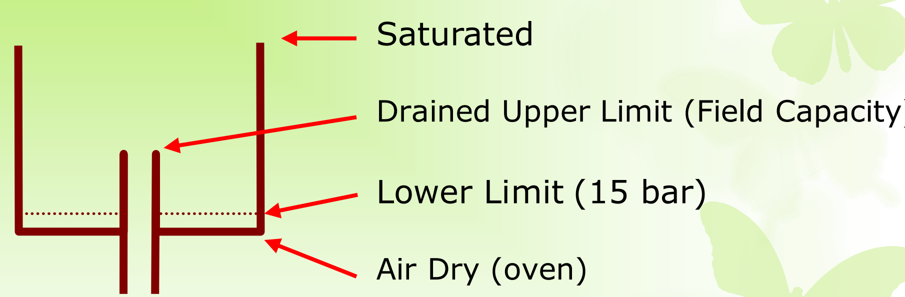
The Water Balance





$$R + I = \Delta SW + Et + Es + RO + D$$

Bucket size



WORKING DYNAMICS OF SOIL WATER AS DESCRIBED BY APSRU

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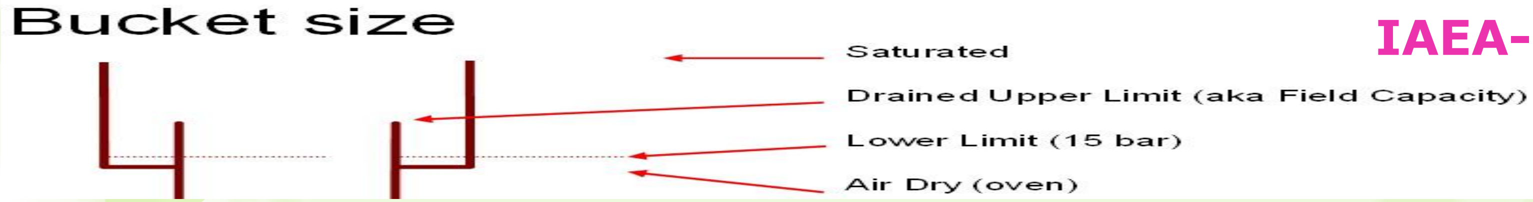
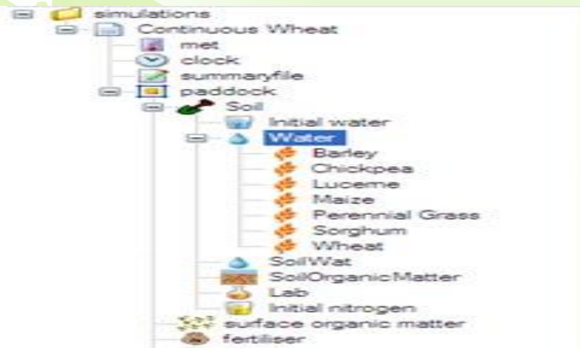
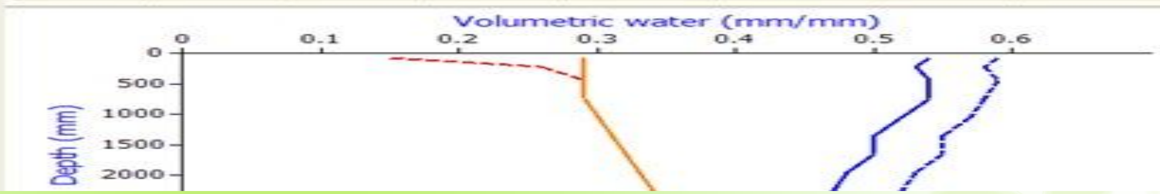
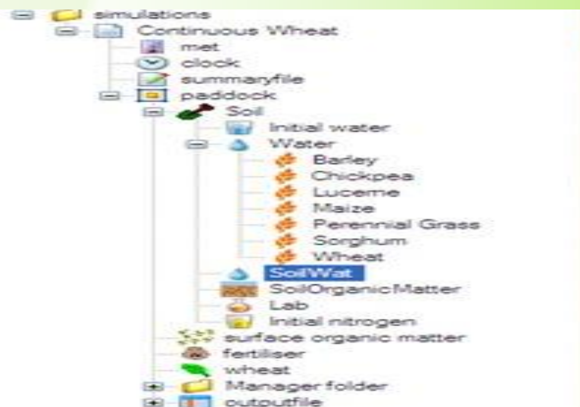




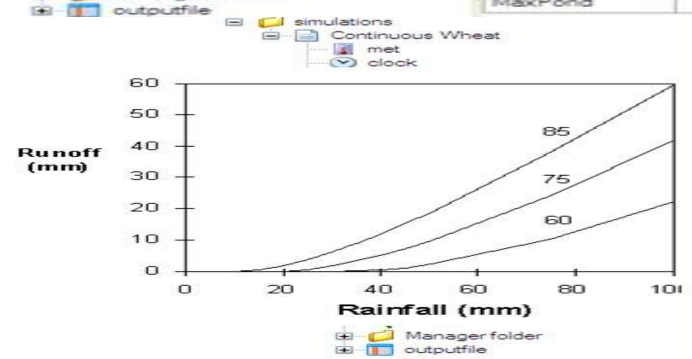
Depth (cm)	KS (mm/day)	BD (g/cc)	AirDry (mm/mm)	LL15 (mm/mm)	DUL (mm/mm)	SAT (mm/mm)	Barley LL (mm/mm)
0-15		1.020	0.150	0.290	0.540	0.590	0.29
15-30		1.030	0.260	0.290	0.530	0.580	0.29
30-60		1.020	0.290	0.290	0.540	0.590	0.32
Total:							





Description	Value
SummerCona	3.5
WinterCona	3.5
SummerU	6
WinterU	6
SummerDate	1-Nov
WinterDate	1-Apr
DiffusConst	40
DiffusSlope	16
Salb	0.13
Cn2Bare	73
CnRed	20
CnCov	0.8
CnCanopyFact	1
Slope	
DischargeWidth	
CatchmentArea	
MaxPond	

Depth (cm)	SWCON (0-1)	MWCON (0-1)	KLAT (mm/d)
0-15	0.300		
15-30	0.300		
30-60	0.300		
60-90	0.300		
90-120	0.300		
120-150	0.300		
150-180	0.300		
180-210	0.300		
210-240	0.300		
240-270	0.300		
270-300	0.300		



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Depth (cm)	SWCON (0-1)	MWCON (0-1)	KLAT (mm/d)
0-15	0.300		
15-30	0.300		
30-60	0.300		
60-90	0.300		
90-120	0.300		
120-150	0.300		
150-180	0.300		
180-210	0.300		
210-240	0.300		
240-270	0.300		
270-300	0.300		

Measurement of Soil water

- Gravimetric Method

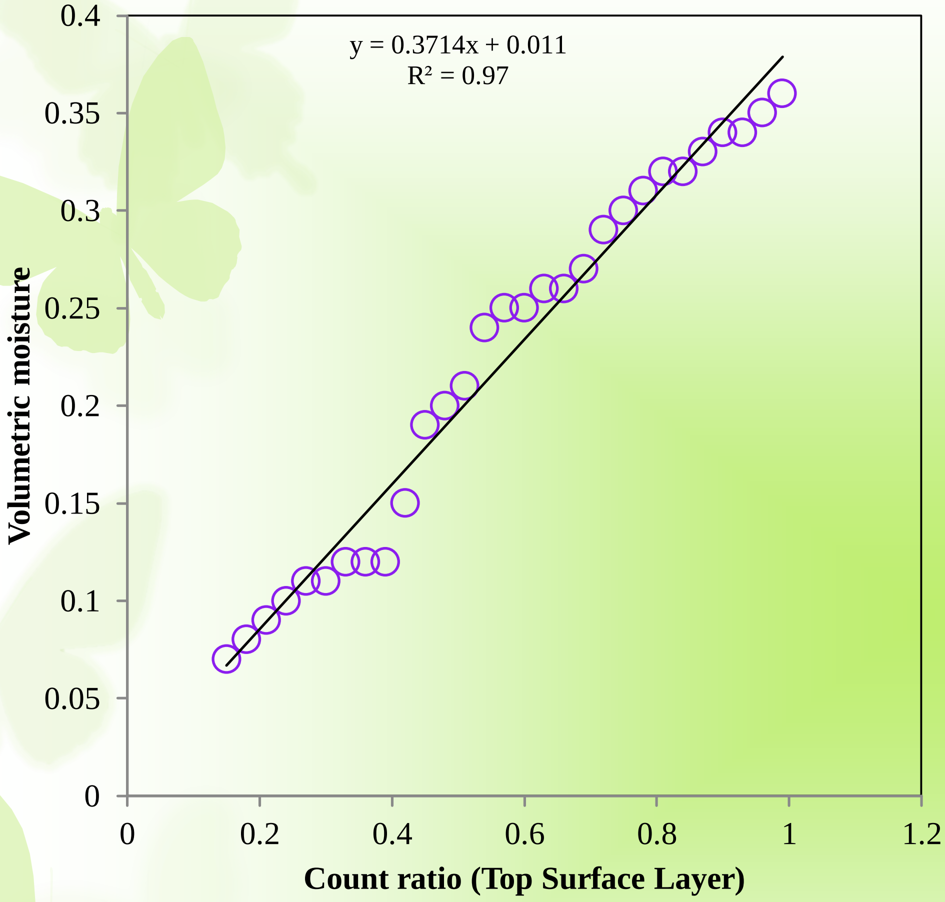
- Radiations Method
  - Neutron Probes
  - Gamma Probes

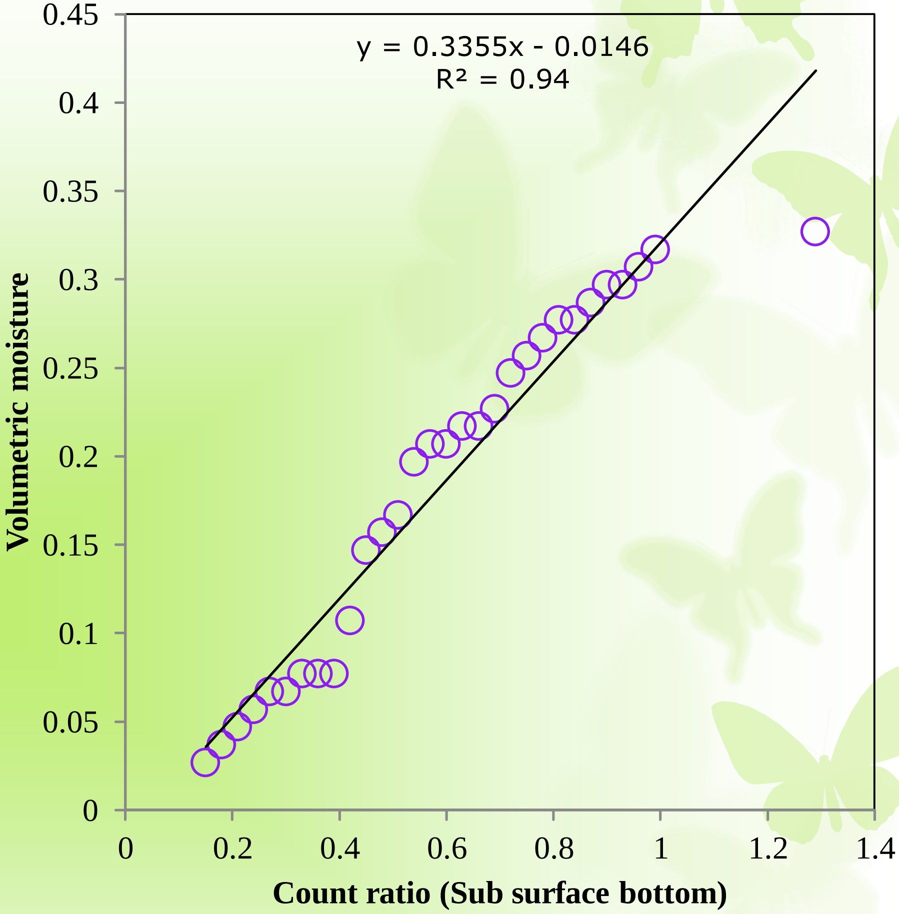
- Calibration of Neutron Probe
- Principle of Neutron Probe
  - Fast neutron → Moist soil → Source become surrounded by a cloud of slow neutron → Density of slow neutron is proportional to the concentration the moisture.
  - If soil is dry → Less hydrogen → Slow neutron density is low

- Method is fast, reliable and less expensive after initial investment

- Neutron Probe Calibration equation was developed by systematically filling drums with different uniform soil water contents, weighing the drums and measuring the volumetric soil water contents

Soil Moisture by Neutron Probe (CPN-503)





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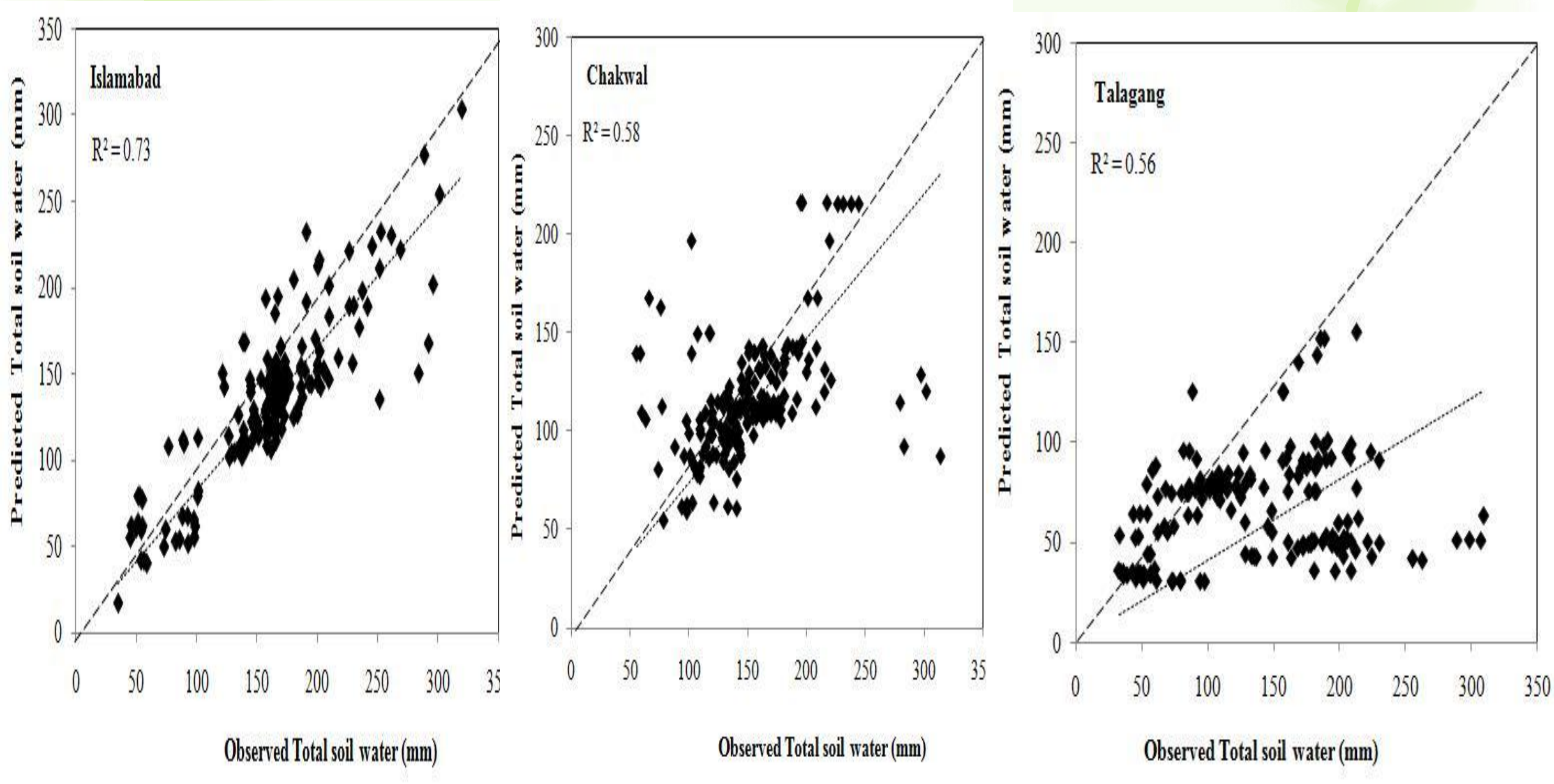
Parameterization and Evaluation of APSIM Model (Total Soil Water)



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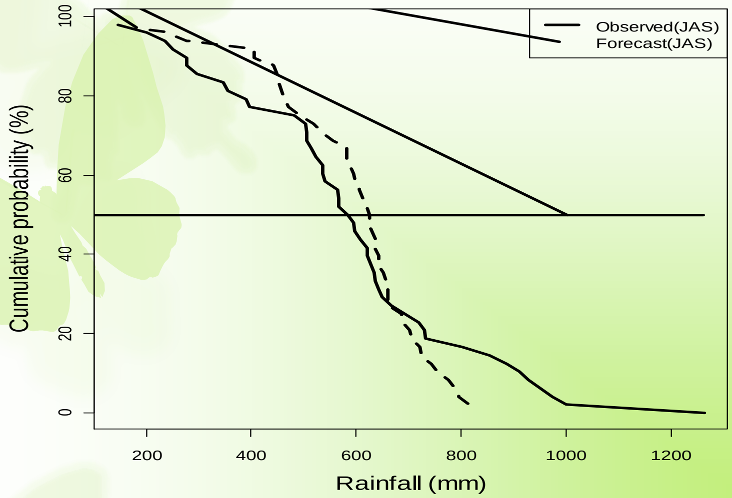
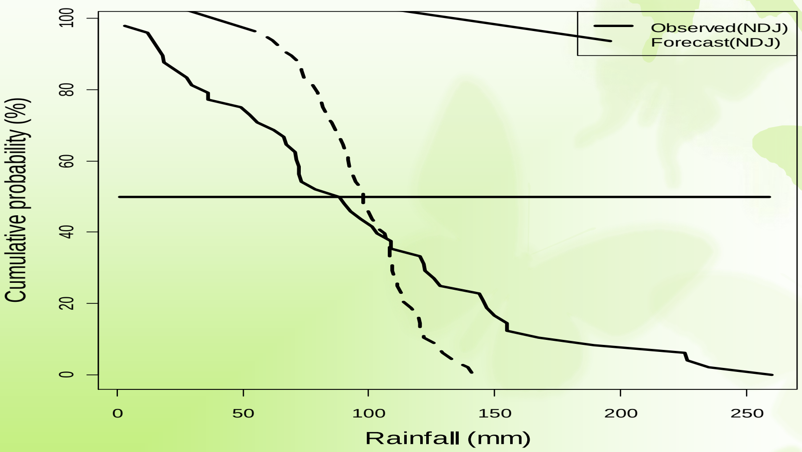
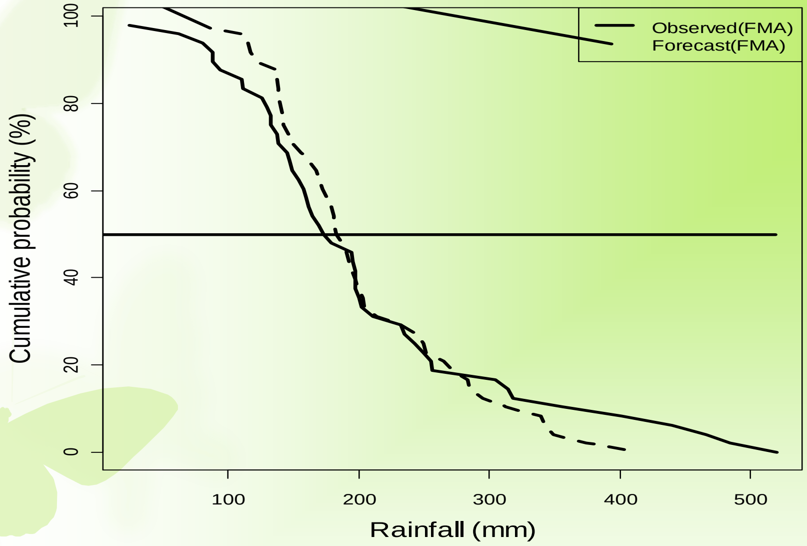
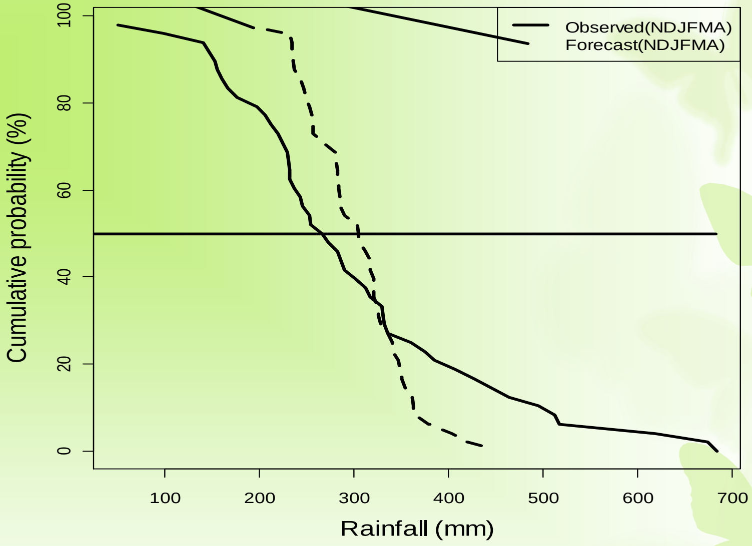
APSIM Model Utilization (Islamabad)









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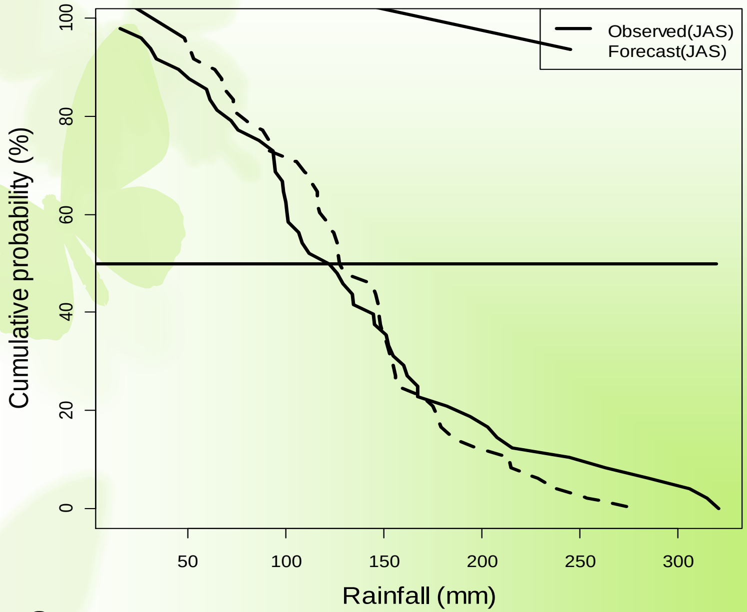
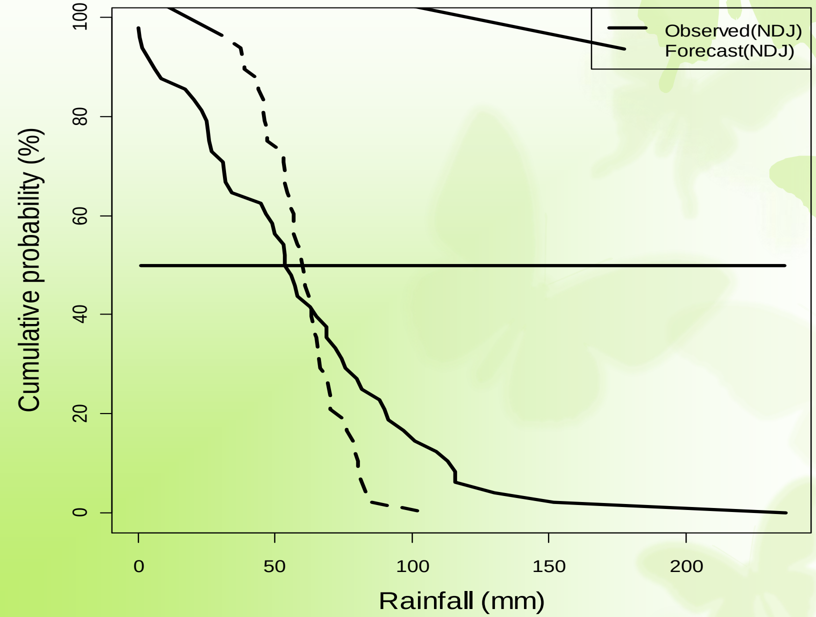
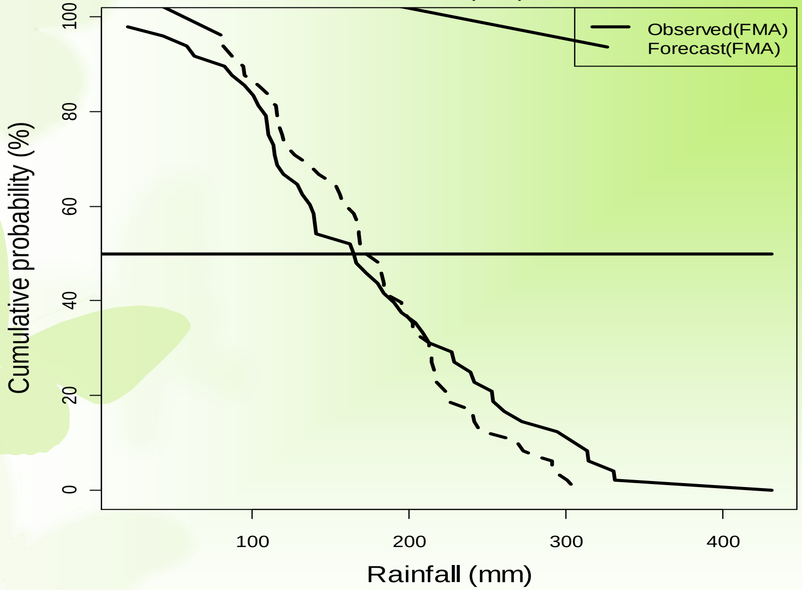
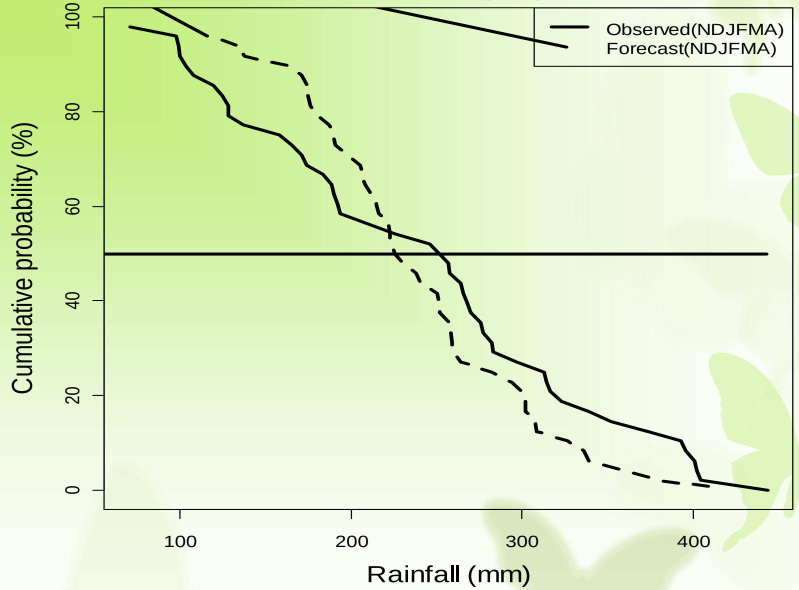
APSIM Model Utilization (Chakwal)









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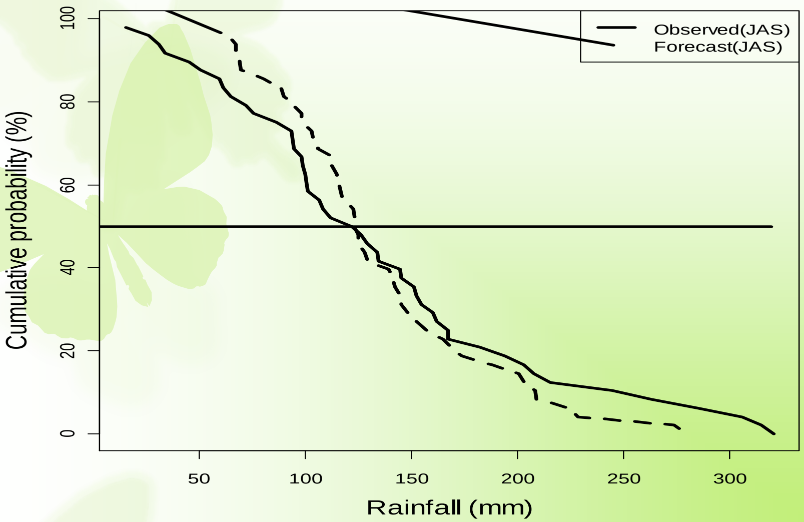
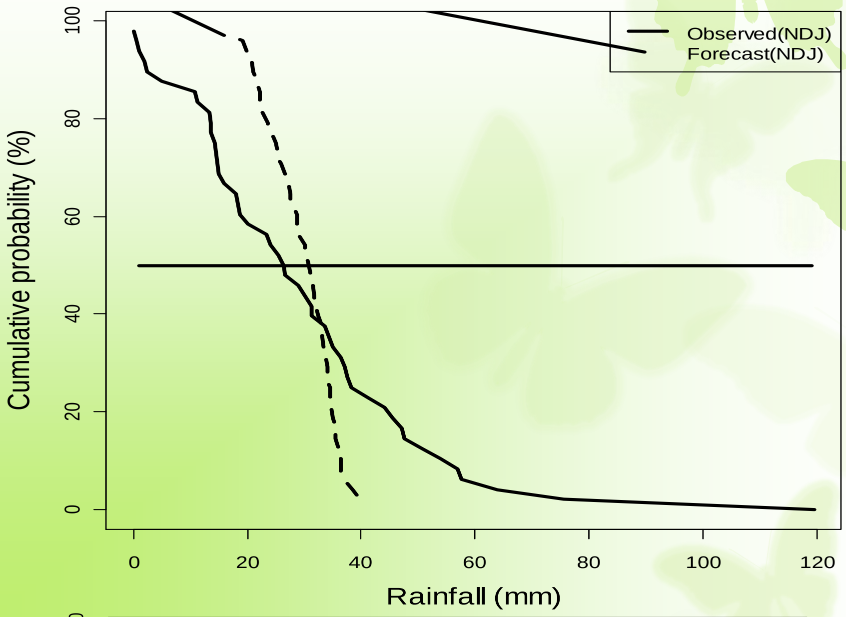
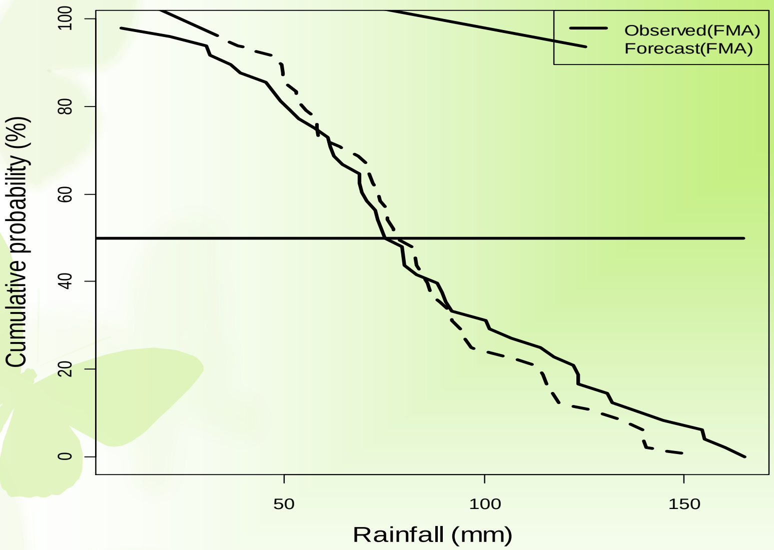
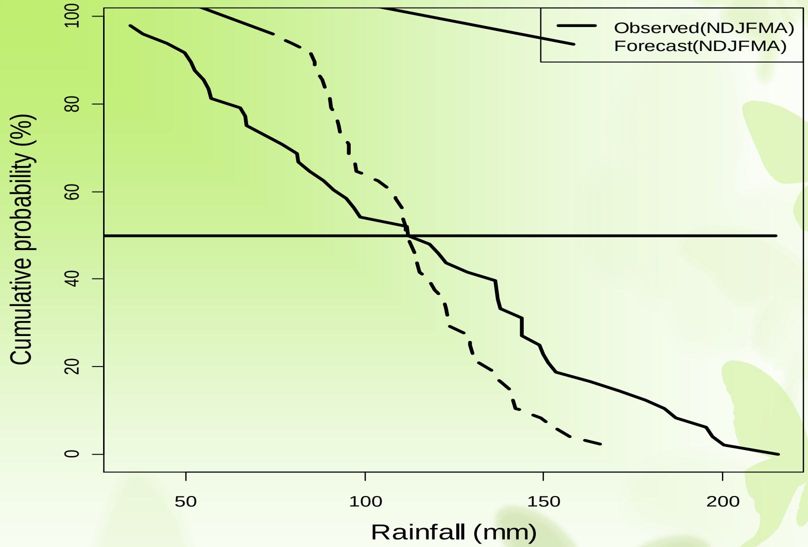
APSIM Model Utilization (Talagang)









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Decade wise simulation of Soil Water Dynamics by APSIM

Years	Infiltration (mm)	Drainage (mm)	Evapotranspiration (mm)	Runoff (mm)
2011-20	85.16	11.74	51.66	22.43
21-2030	47.04	8.79	55.11	0.05
31-2040	69.38	10.68	49.01	7.01
41-2050	62.59	8.19	53.68	25.9
51-2060	26.69	9.46	50.27	0.3
61-2070	85.04	14.91	50.57	7.55
71-2080	74.42	15	48.58	5.67
81-2090	21.6	8.93	53.6	0.4
91-2100	68.12	17.26	51.1	5.47

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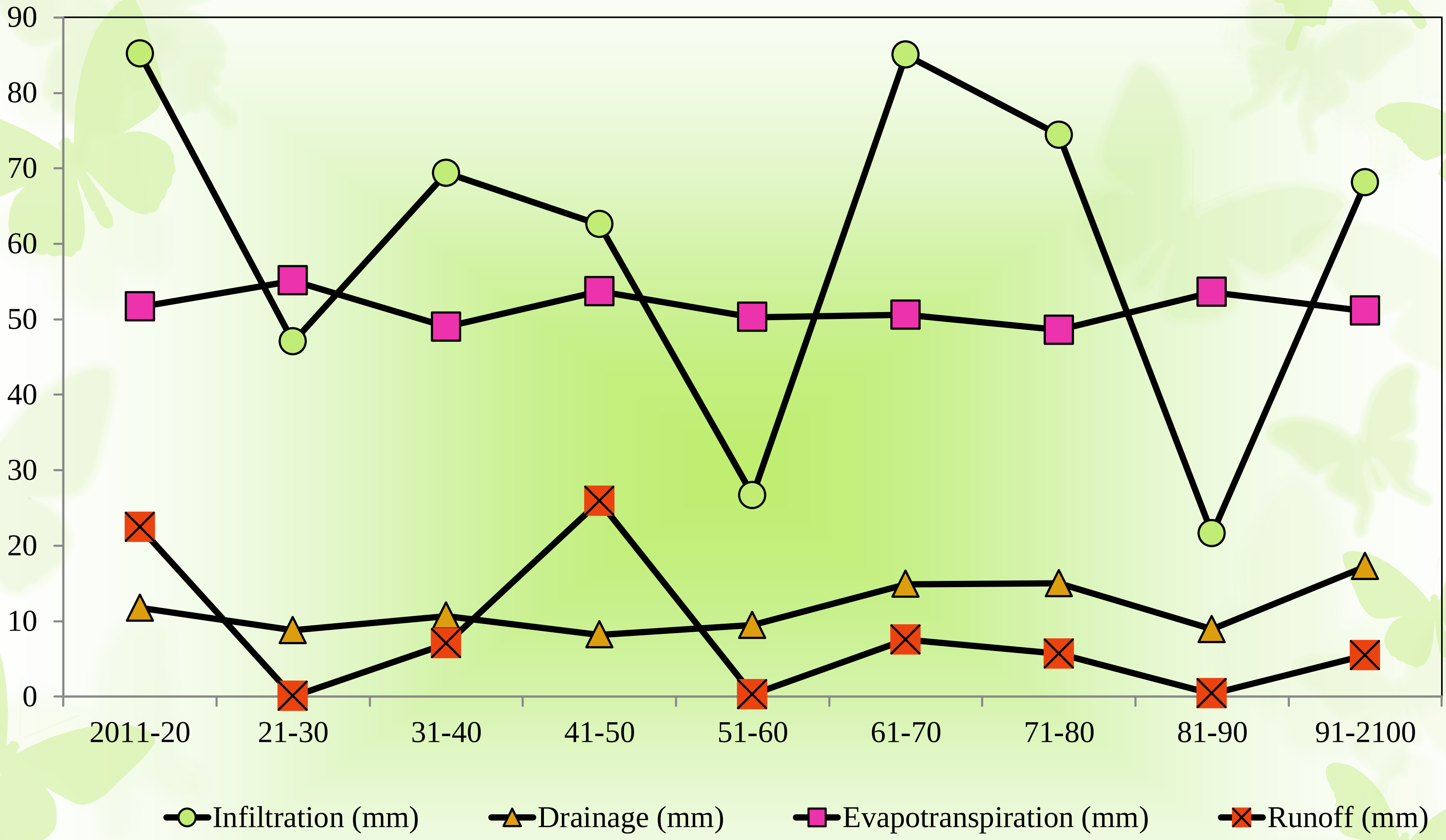
Long term simulation of Soil Water Dynamics by APSIM



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Conclusion

- Application of modern techniques like neutron probe at the different climatic zones will be helpful to design a soil water dynamic model and to parameterized different dynamic model like APSIM which could reduce climate-related risks and to manage the cropping systems more efficiently.

- It can be concluded that climate variability information may be utilized to improve the resilience of wheat crop yield in rainfed area while considering mitigation, adoption and technology transfer as an integrated approach.

- Use of crop simulation modelling an effective and sustained implementation of a road map to understand agricultural environment and climate change.

- Use crop simulation model as a tool to understand soil water dynamics, climate and crop management simultaneously to explore the potential yield.

- The ability to predict rainfall fluctuations in advance, suggests that there exists considerable potential to reduce agricultural environment vulnerability to climate variability through improved agricultural decision-making.

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- **Need to pay attention to a forecast of ENSO /IOD for the coming season as one part of risk management strategy.**

- **Simulation models and a better working knowledge of climate drivers are part of the toolkit for agronomists as they work with farmers to manage risk in a variable and non-stationary climate.**

- **APSIM as a daily time-step model can be used at many points as a risk management tool.**

- **Probabilistic climatic forecasting system and dynamic simulation modelling can aid decision making about crop choice, cropping sequence and management options.**

Thanks