BioEarth

Biosphere-relevant earth system model

Sarah Anderson

BioEarth All Hands Meeting

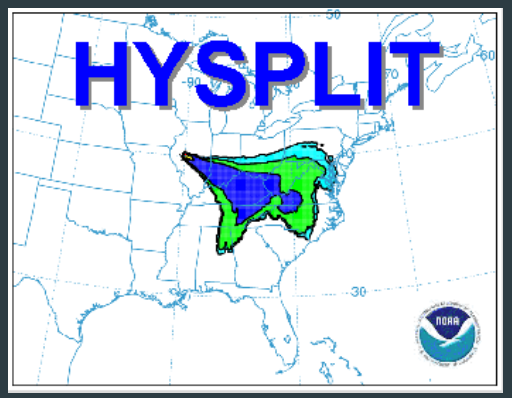
25 February 2016

Nitrogen

Atmosphere

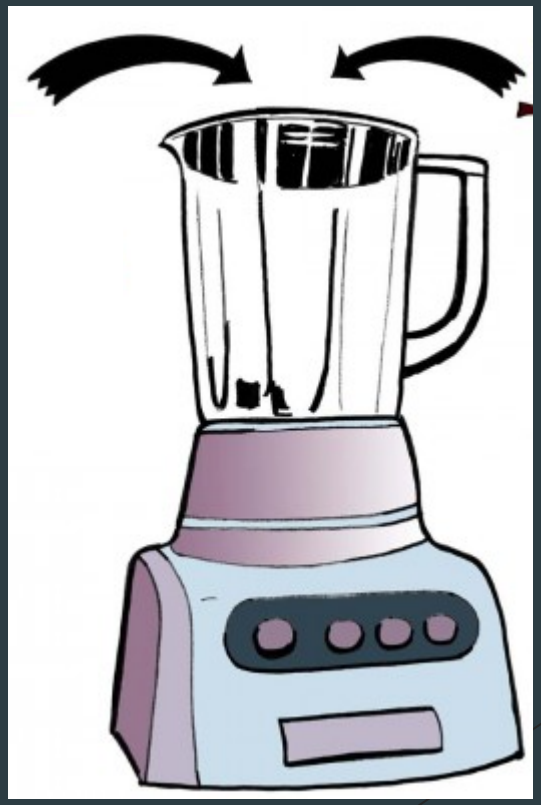
Water

Land Surface



Credit: ready.arl.noaa.gov

Credit: www.ie.unc.edul



Credit: R.Evans

Modeling Measuring

Credit: Paul A. Souders /Corbis

1
Analysis of Wet Deposition

2
Analysis of Biological Indicators

NADP Collector

Credit: Taylorryanmunson.tumblr.com

Credit: reddit.com

NO_3^-

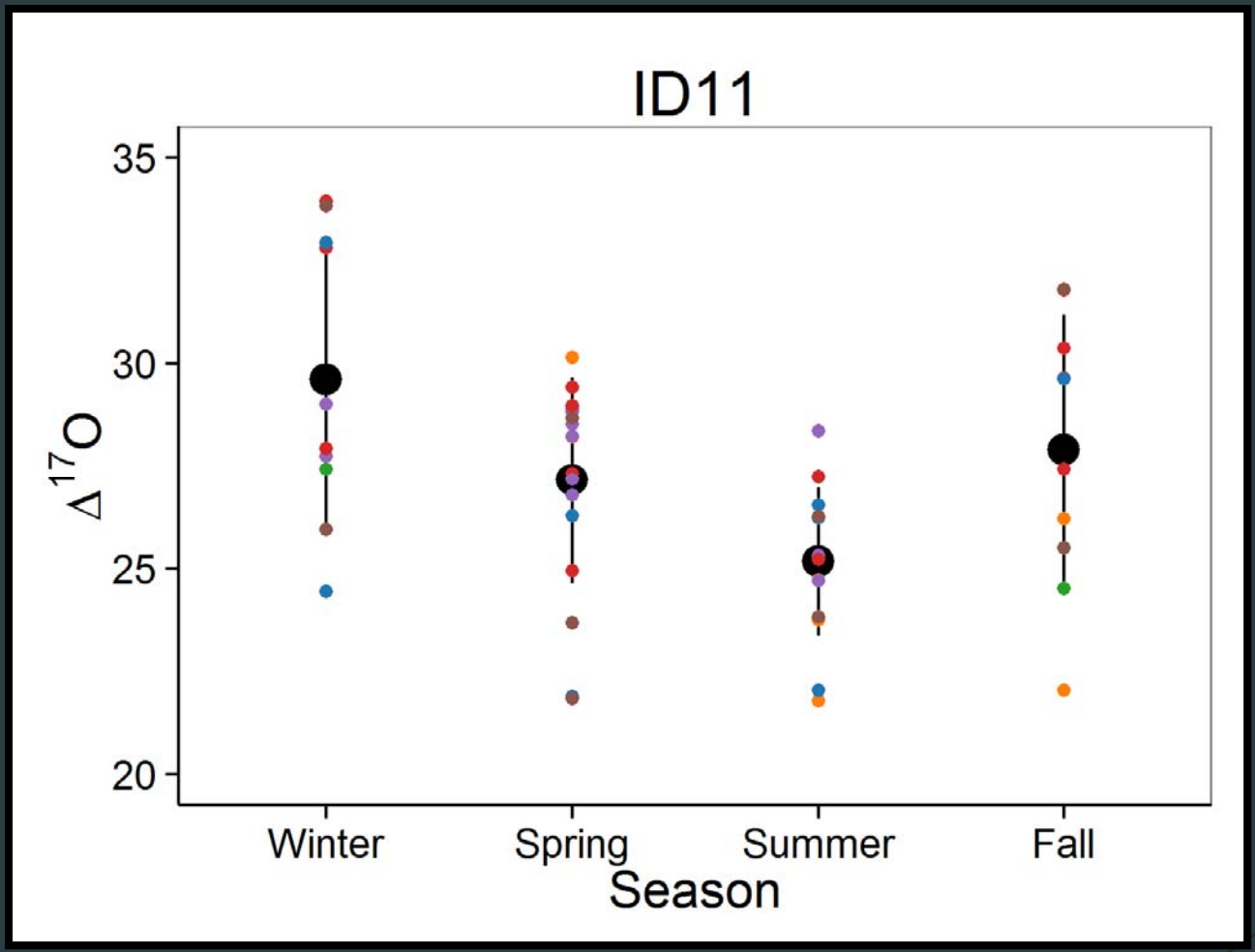
Credit: Topic Photo Agency/Corbis

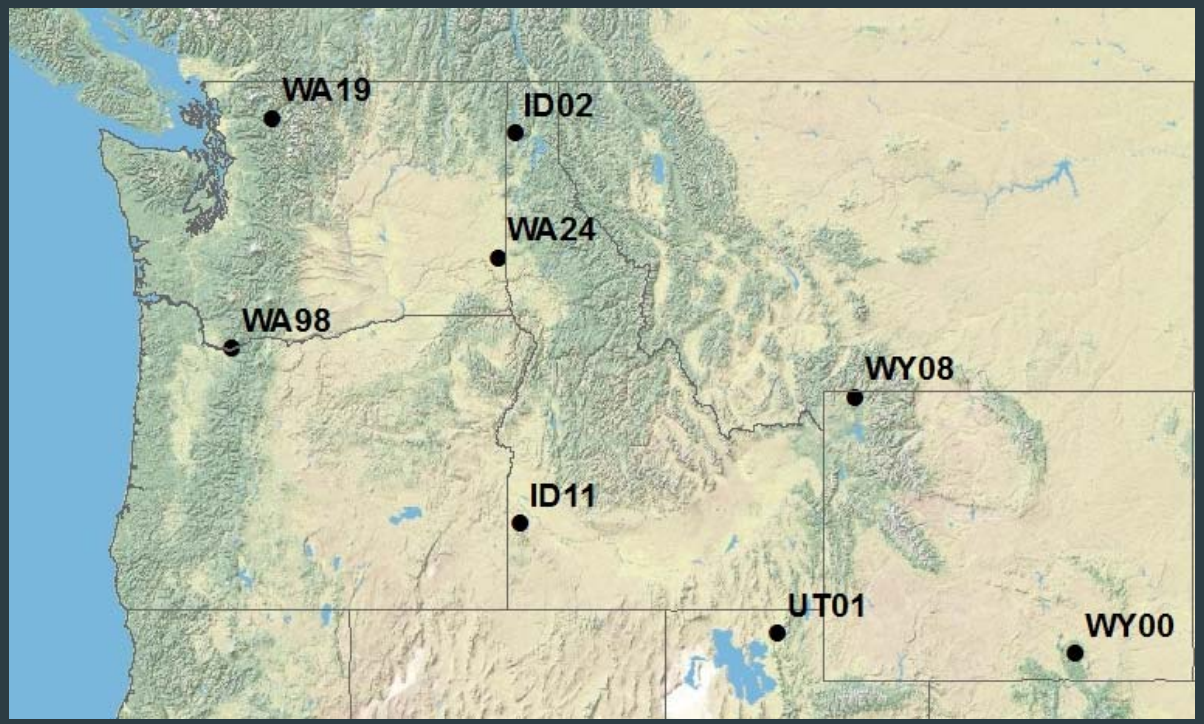
Oxidative State

$\Delta^{17}O$

↑ $\Delta^{17}O$ ↑ O_3

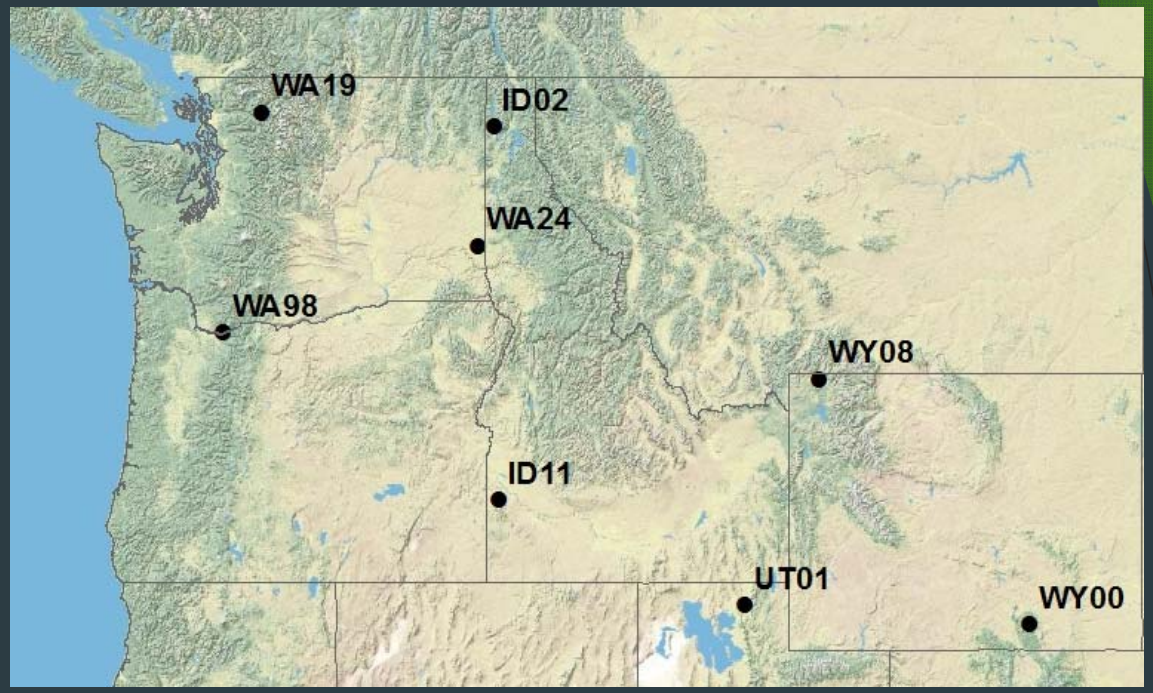
↓ $\Delta^{17}O$ ↓ O_3


ID11
35
30
25
20
$\Delta^{17}O$
Winter
Spring
Summer
Fall
Season

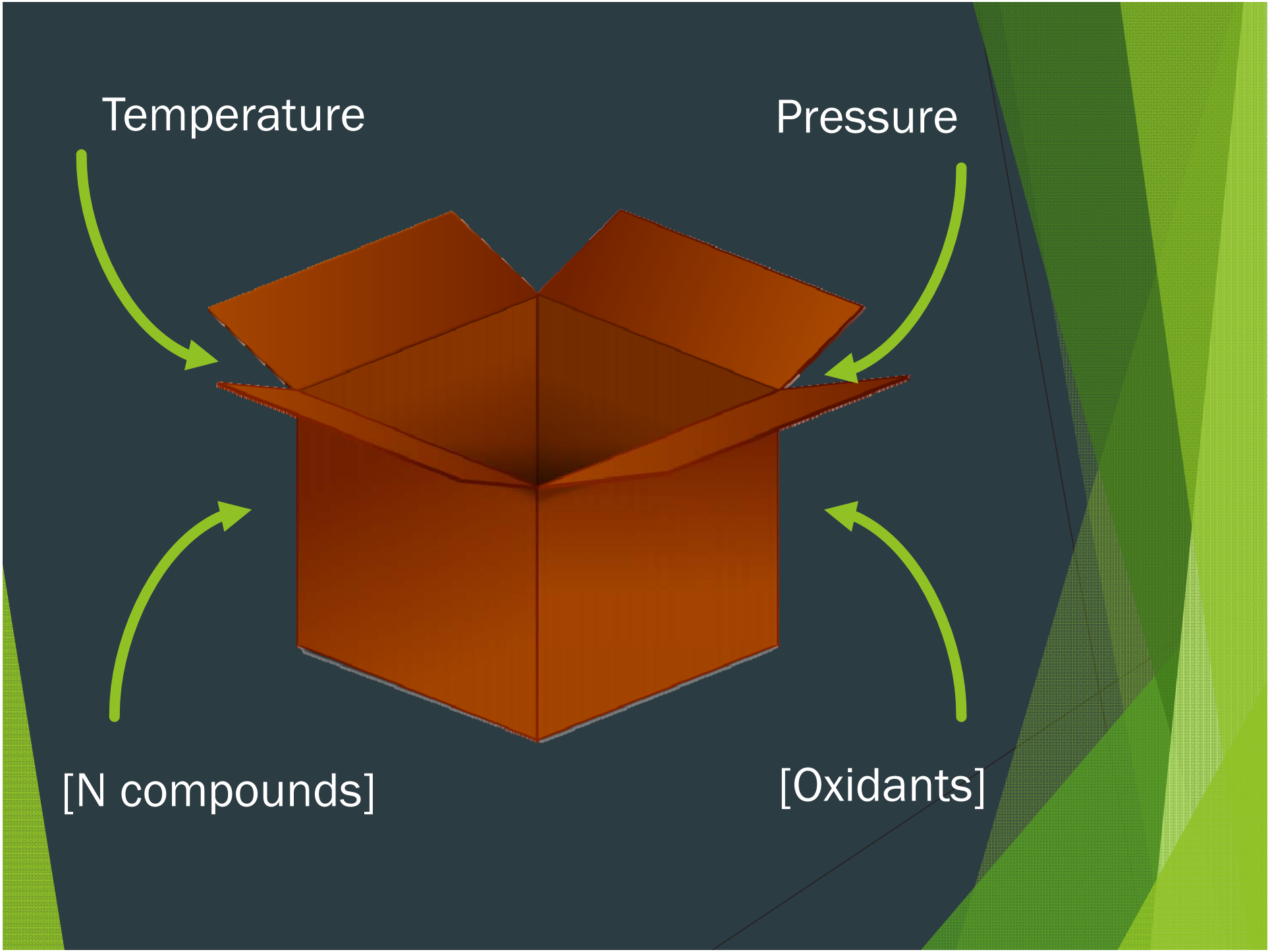


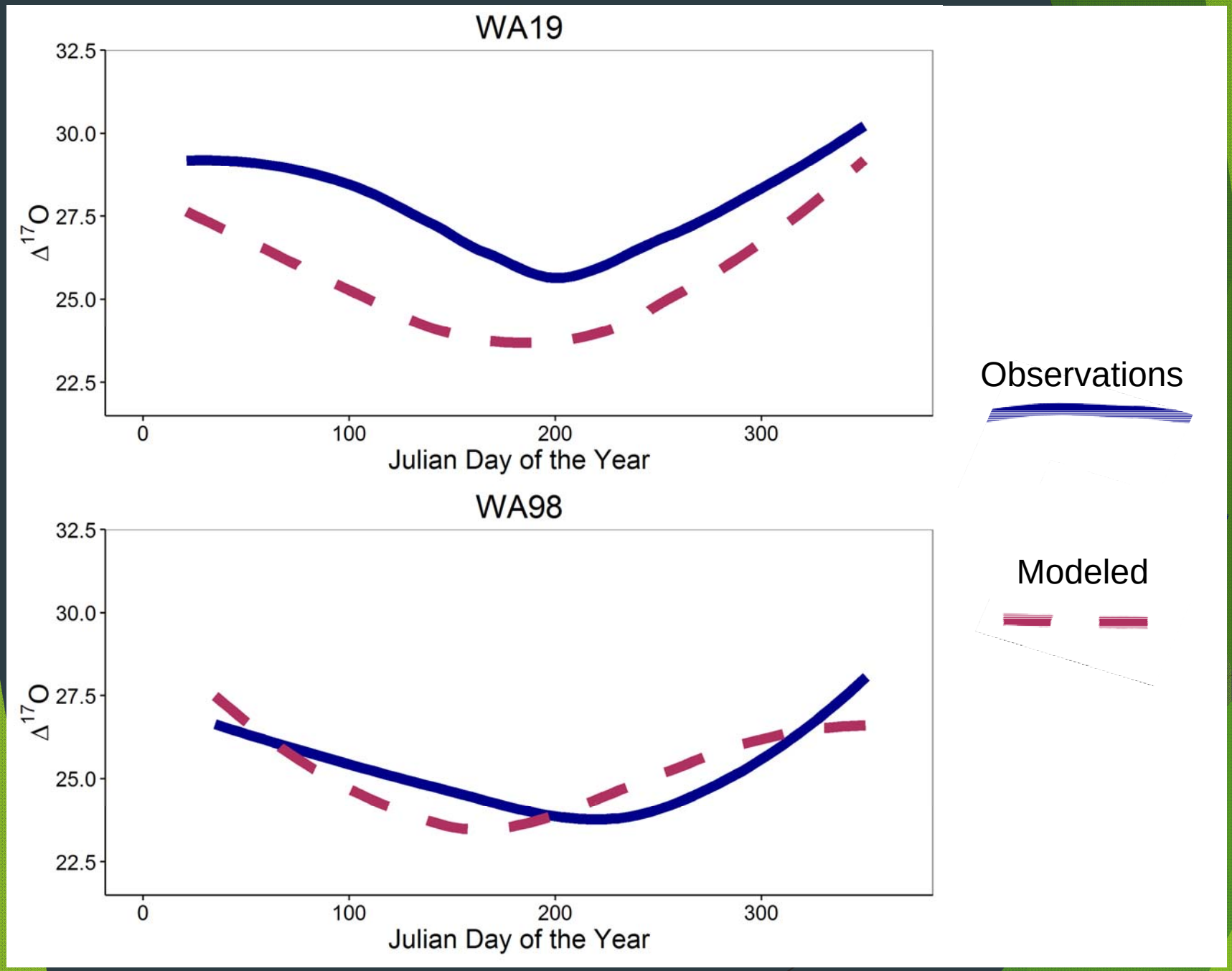
Year

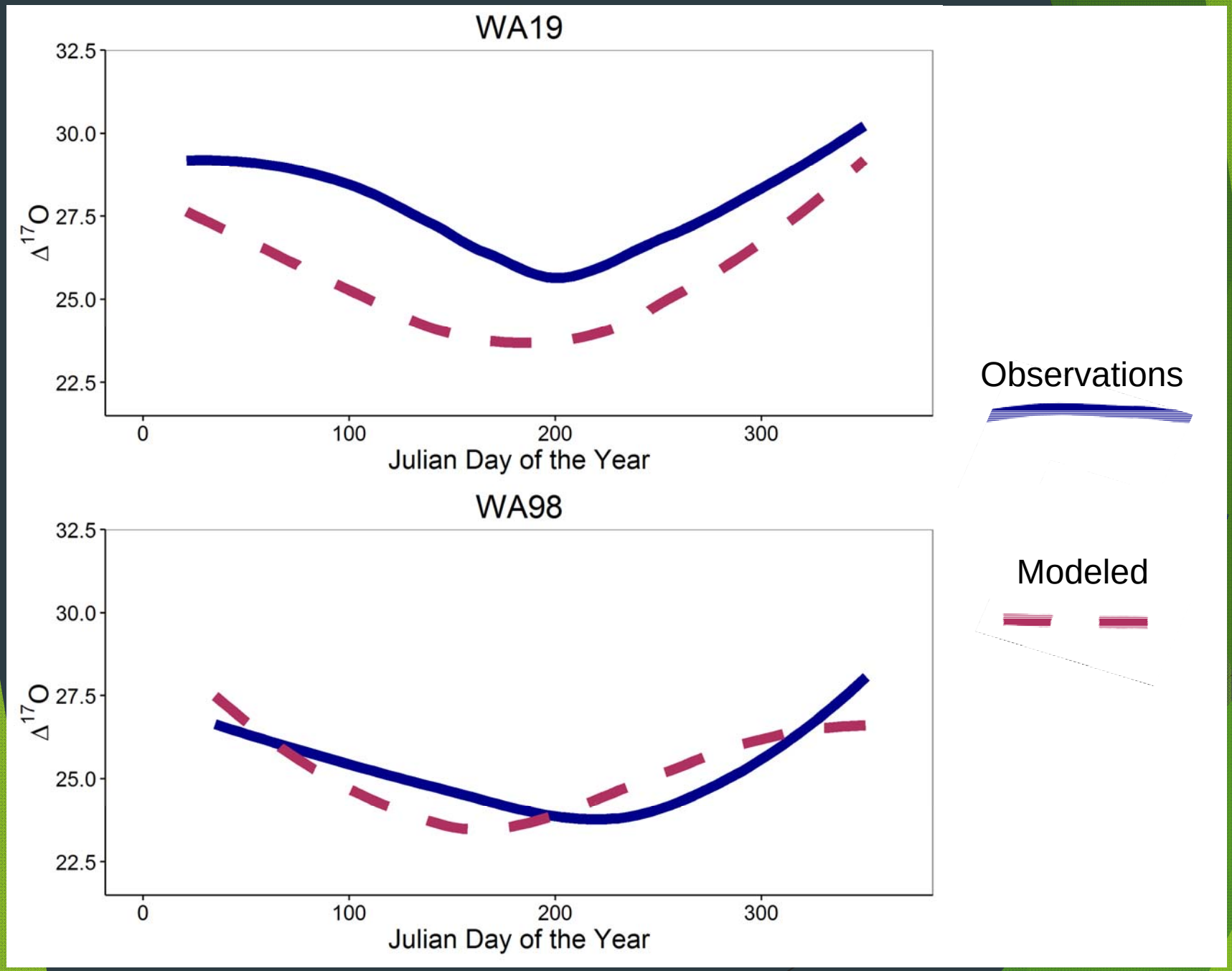
- 1997
- 1998
- 1999
- 2000
- 2003
- 2004



Spatial and Temporal Variation in Atmospheric Oxidation


Temperature
Pressure
[N compounds]
[Oxidants]


WA19
32.5
30.0
27.5
25.0
22.5
$\Delta^{17}O$
0
100
200
300
Julian Day of the Year
WA98
32.5
30.0
27.5
25.0
22.5
$\Delta^{17}O$
0
100
200
300
Julian Day of the Year
Observations
Modeled

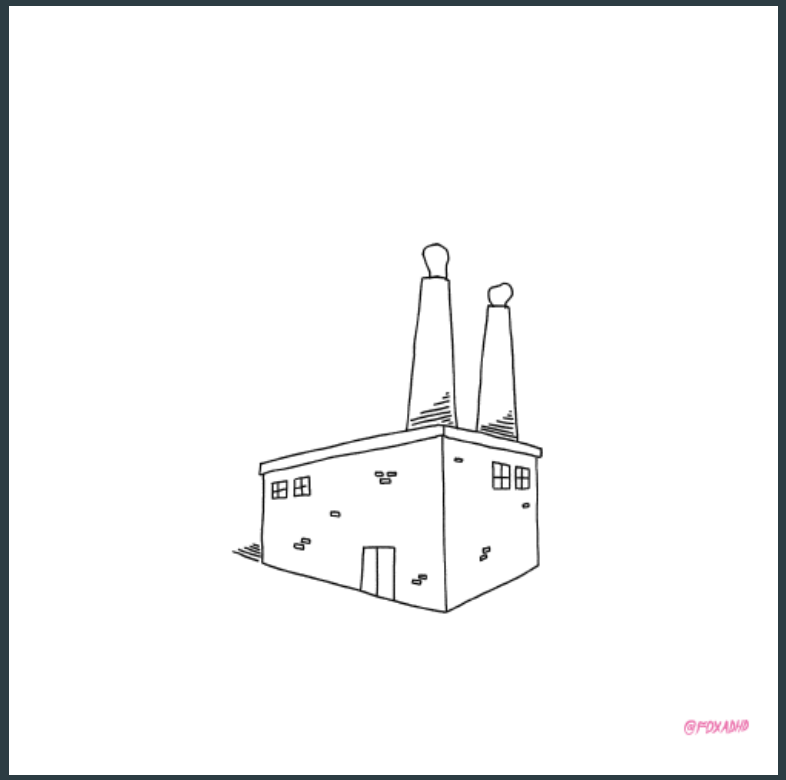

WA19
32.5
30.0
27.5
25.0
22.5
$\Delta^{17}O$
0
100
200
300
Julian Day of the Year
WA98
32.5
30.0
27.5
25.0
22.5
$\Delta^{17}O$
0
100
200
300
Julian Day of the Year
Observations
Modeled

Credit: Galen Rowell/Corbis

Credit: Terry Eggers/Corbis

$\Delta^{17}O\text{-}NO_3^-$

$\delta^{15}N\text{-}NO_3^-$



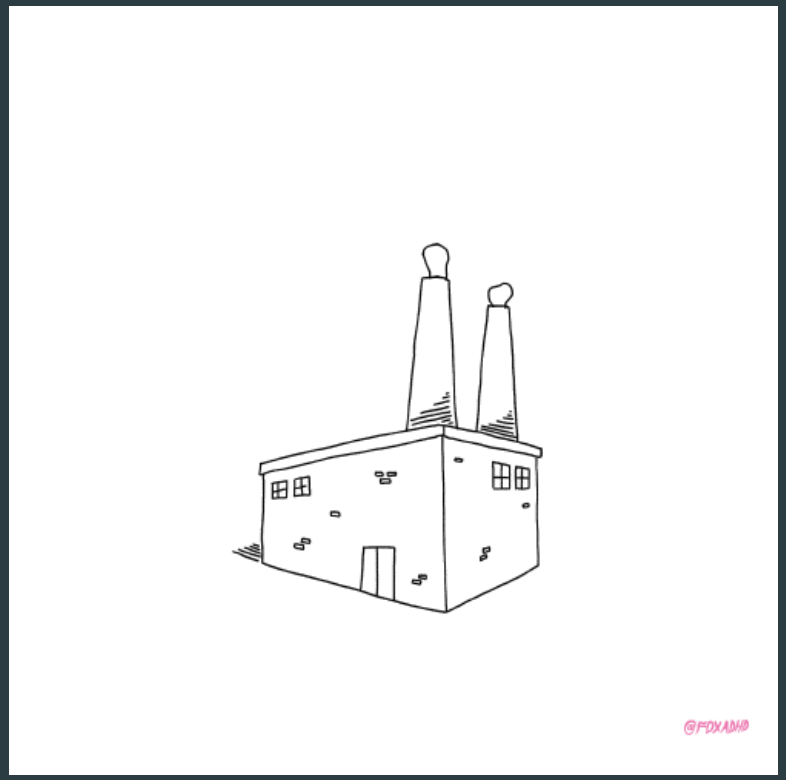
Credit: gifnews.tumblr.com

$\Delta^{17}O\text{-}NO_3^-$

$\delta^{15}N\text{-}NO_3^-$

$\delta^{15}N\text{-}NH_4^+$

$\delta^{15}N\text{-}N_{org}$

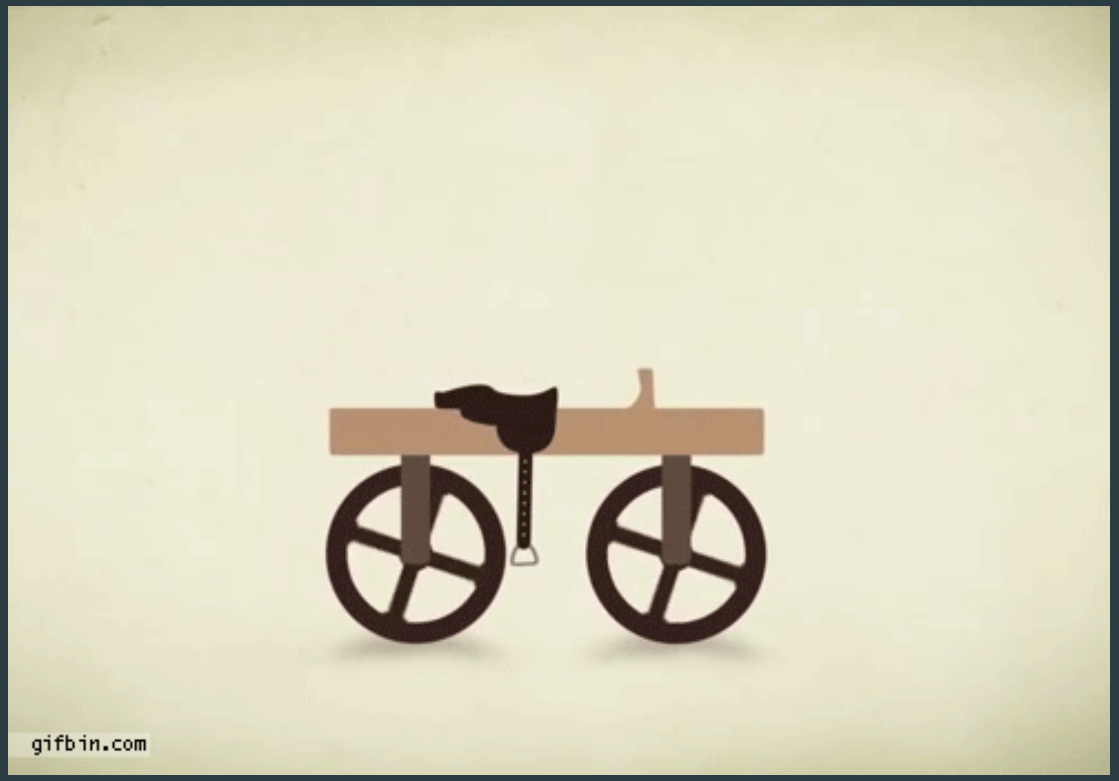


Credit: gifnews.tumblr.com

Credit: southwestcollectionarchives.tumblr

Credit: westword.com

Credit: tumblr.com



Credit: gifbin.com

Motivation

- Atmospheric N deposition has increased >3 times from the preindustrial level (Holland et al., 1999).
- Negative impacts: nutrient imbalance, losses of N-sensitive plant species, invasion of non-native species, soil and surface water acidifications (Galloway et al., 2008).
- N deposition is interlinked with complex processes such as emission, transport, transformation, and surface interactions that vary spatially and temporally (Sutton et al., 2014).
- Inter-annual variability plays an important role in watershed biogeochemical processes in the western U.S. (Fenn et al., 2003)
- Site specific N deposition data is needed for determining input levels of N at which effects occur and to predict where impacts can be expected (Cummings et al., 2014).

Research topic:

Effects of Climate and Meteorology on Atmospheric Nitrogen Deposition

1. Relationship between climate variability and N wet deposition in the contiguous U.S.
2. Atmospheric N budget over the Pacific Northwest during the El Nino Southern Oscillation years
3. Meteorological conditions that affect spatio-temporal variability of N deposition in the western U.S.

Tsengel Nergui, graduate student, Atmospheric Working Group, BioEarth
Dr. Serena H. Chung (Advisor)
Dr. Brian K. Lamb
Dr. Raymond D. Evans
Dr. Jennifer C. Adam

Topic 1: Climate Variability & N Wet Deposition

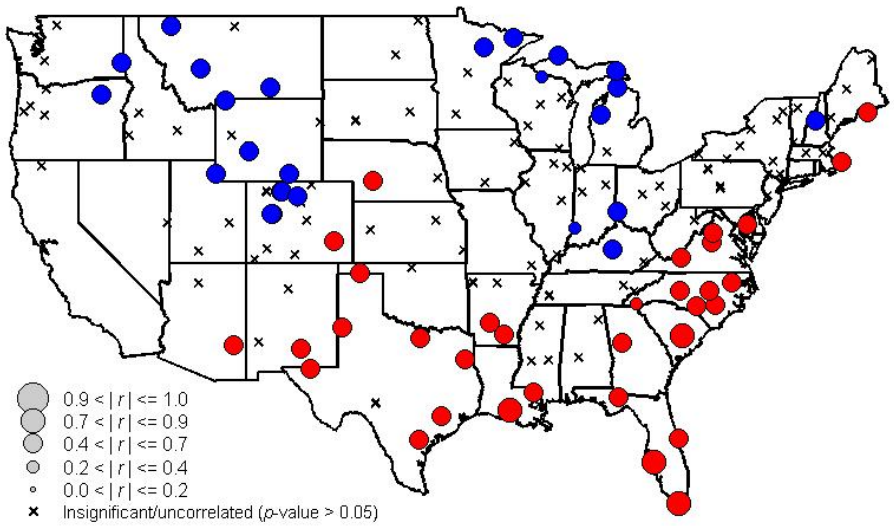
Data and Method

- NINO3.4 SST index for 1979-2012 from the NOAA/CPC
- Precipitation, NO_3^-, and NH_4^+ wet deposition at 151 NADP sites
- Precipitation from the RISM Group

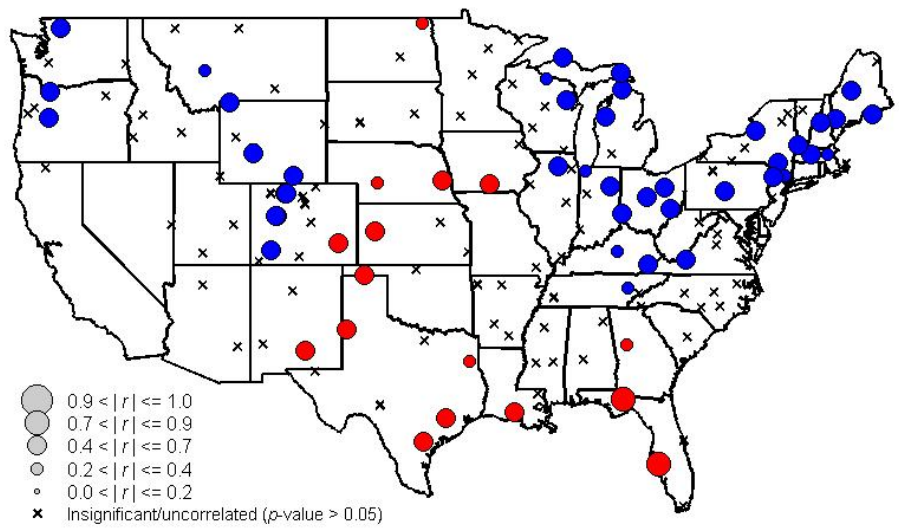
- Applied wavelet analysis to decompose time series into different temporal components
- Analyzed relationship between climate index and N wet deposition on a common temporal scale

Correlations between NINO3.4, Precipitation, and N Wet Deposition

a) NINO3.4 – Precipitation



b) NINO3.4 – N wet deposition

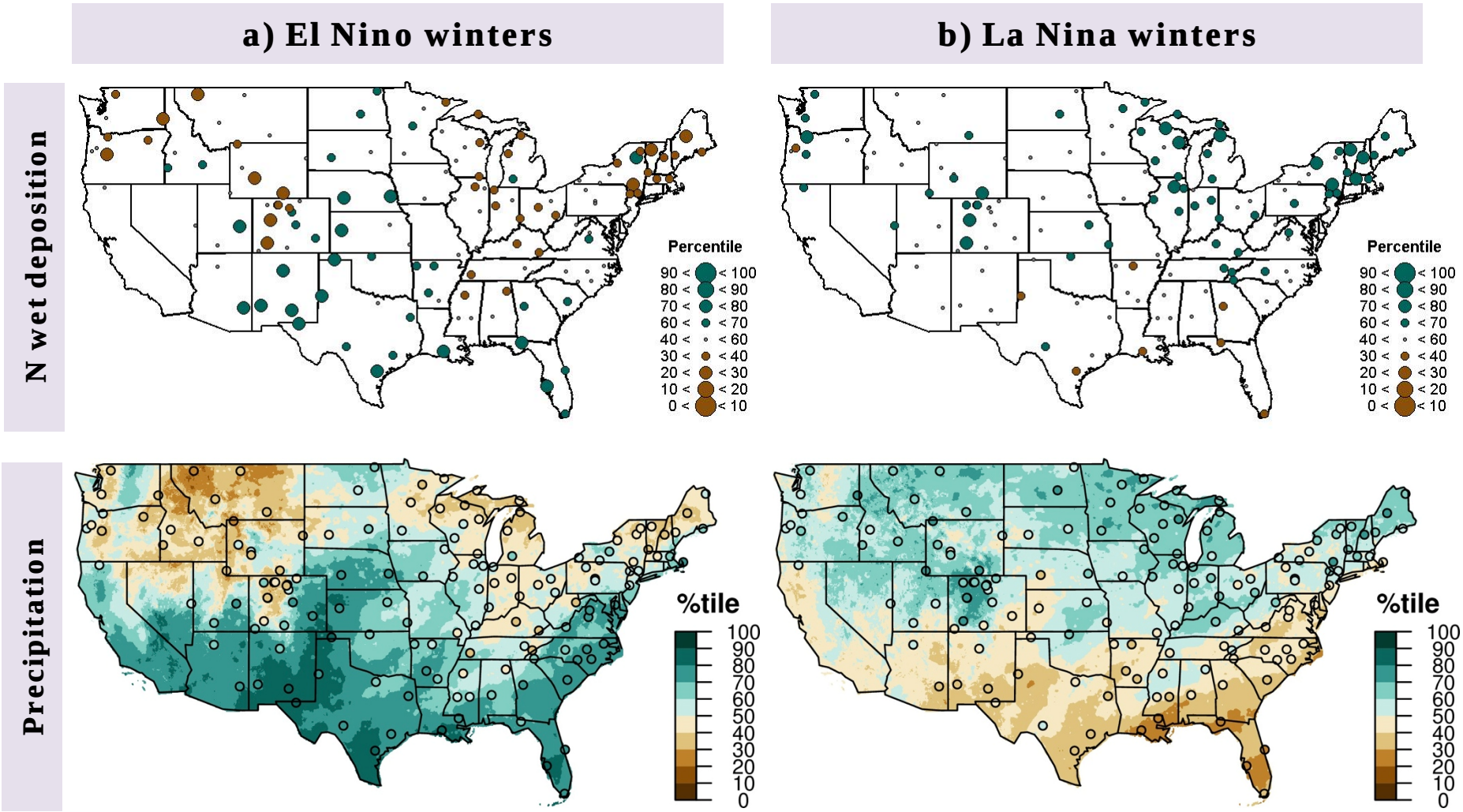


Wintertime correlations (*r*) between the 2- to 6-year band-pass filtered time series

negative correlation

positive correlation

Wintertime N wet deposition & precipitation anomalies



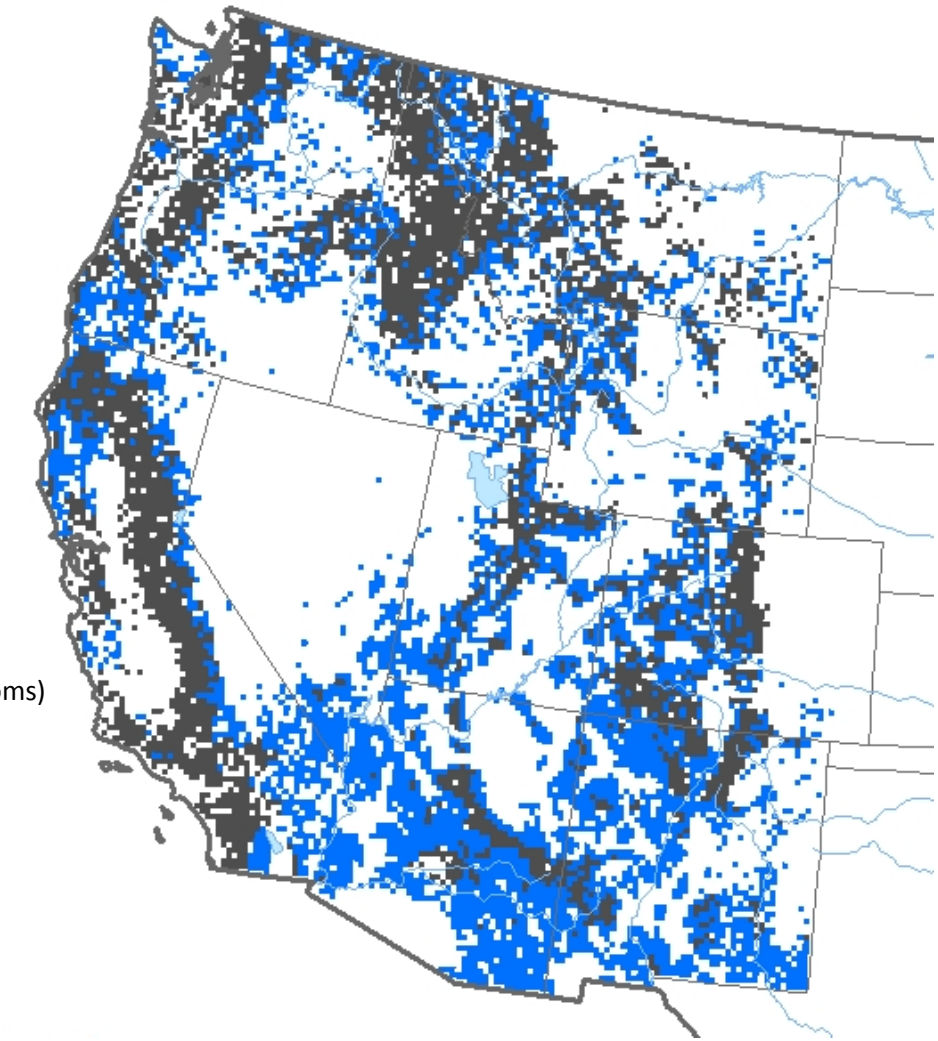
Wintertime N wet deposition rates (top row) and precipitation (bottom row) averaged over the (a) El Niño and (b) La Niña episodes

Findings: Climate Variability and N Wet Deposition

- The correlations between NINO3.4 & precipitation and between NINO3.4 & N wet deposition were the highest and most spatially extensive during winter, followed by spring.
- Identified regions where N wet deposition is sensitive to the inter-annual climate variability caused by ENSO.
  - Regions modulated by ENSO:
    - The Rocky Mountains
    - The Great Lakes
    - The Gulf states
  - Regions where ENSO-precipitation-N wet deposition connections were not found:
    - Pacific Northwest
    - Northeast

Topic 2-3: Atmospheric N Fluxes in the Western U.S.

Ecoregions affected
by atmospheric N deposition

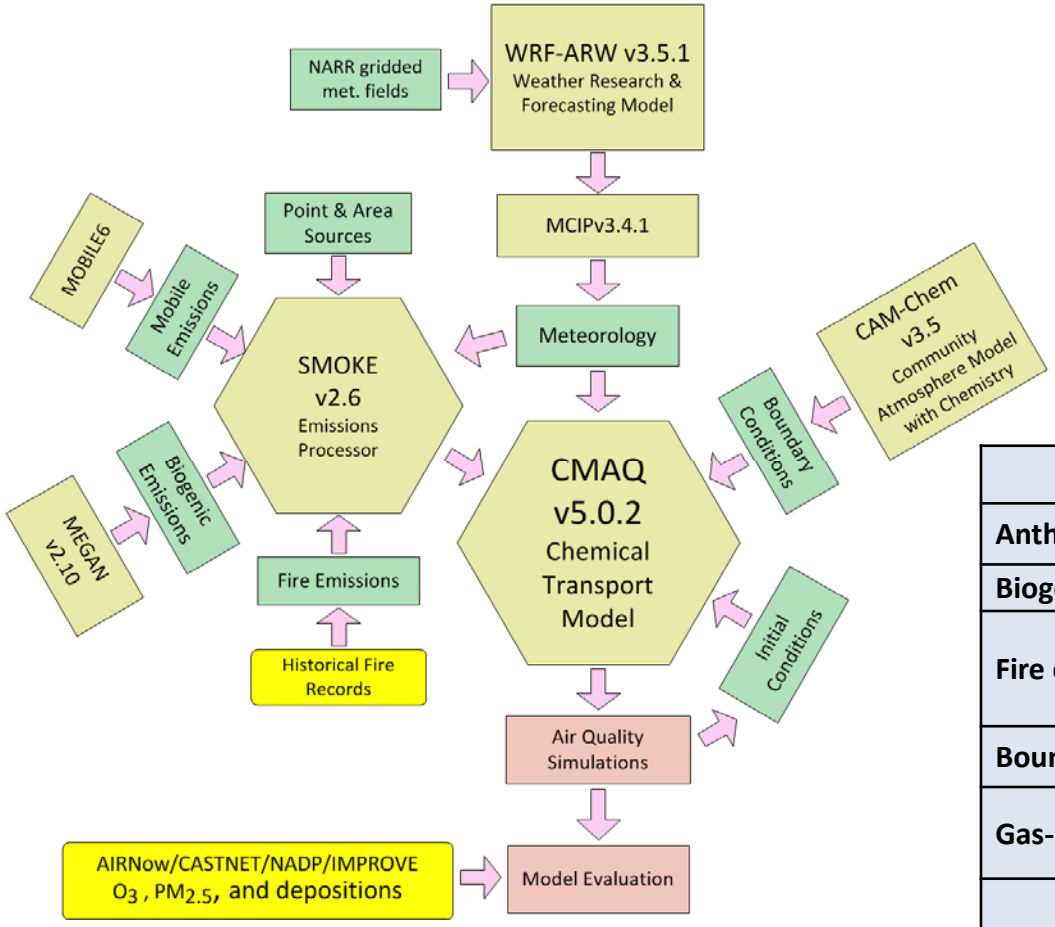


Legend

- Biogeochemical responses
  (N_2O emissions, NO_3 leaching, soil mineralization)
- Species responses
  (tissue N increase, nutrient imbalance for lichen and diatoms)

Synthesis of component specific empirical critical loads for US
GAP Analysis Land Cover Classification
Mean Annual Total N Deposition Estimates (2006-2008, EPA/V

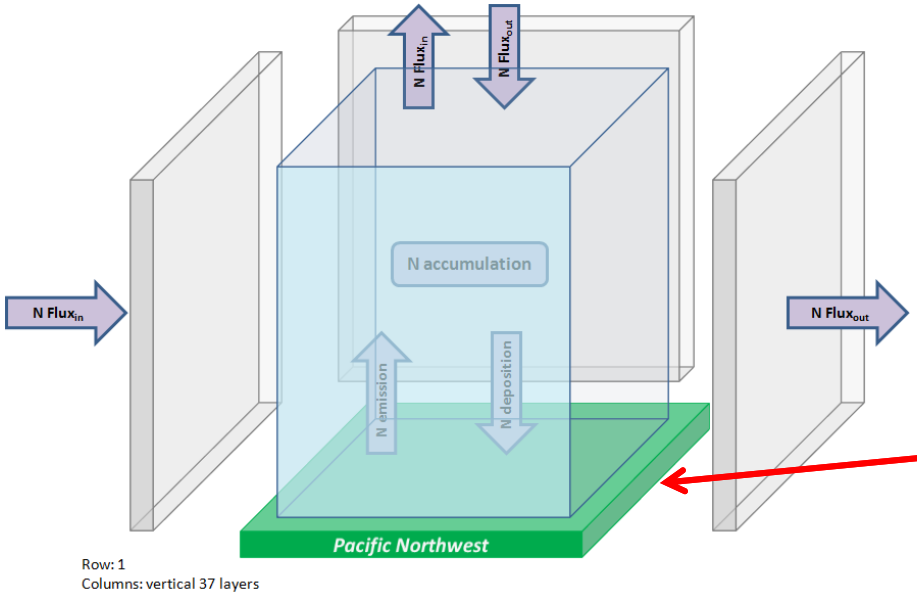
The WRF-MEGAN- SMOKE-CMAQ Modeling Framework

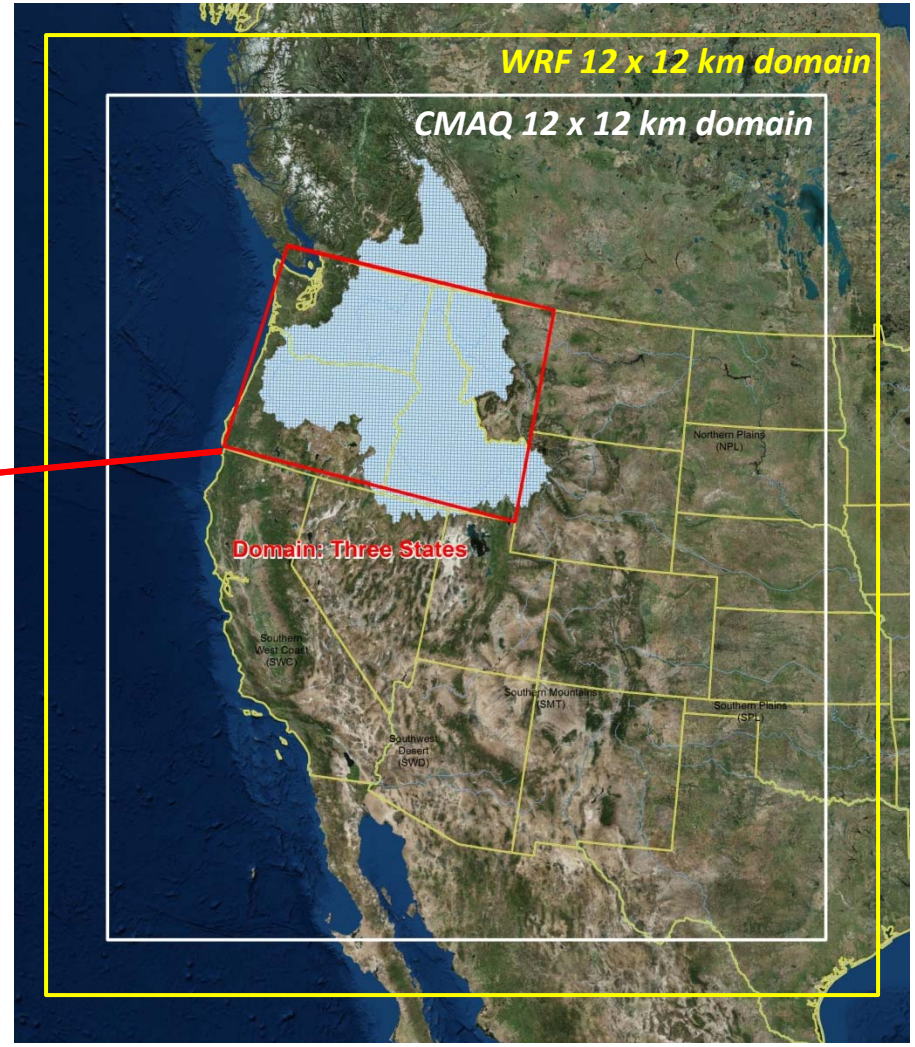


CMAQ configuration

CMAQ, version 5.0.2	
Anthropogenic emissions	NEI2002
Biogenic emissions	MEGAN, version 2.10
Fire emissions	BlueSky modeling framework with historical fire records
Boundary condition	CAM-Chem, version 3.5
Gas-phase chemistry	CB05 photochemical mechanism
Aerosol module	Fifth-generation of CMAQ aerosol mechanism
Cloud module	Asymmetric Convective Method (Pleim, 2007)

An Atmospheric N Budget over the Pacific Northwest

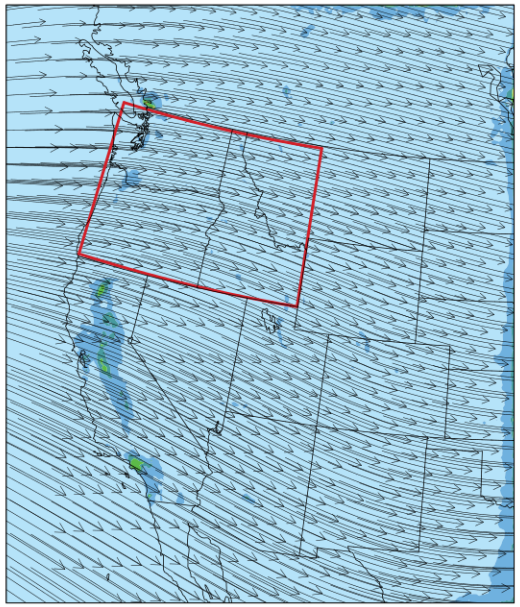




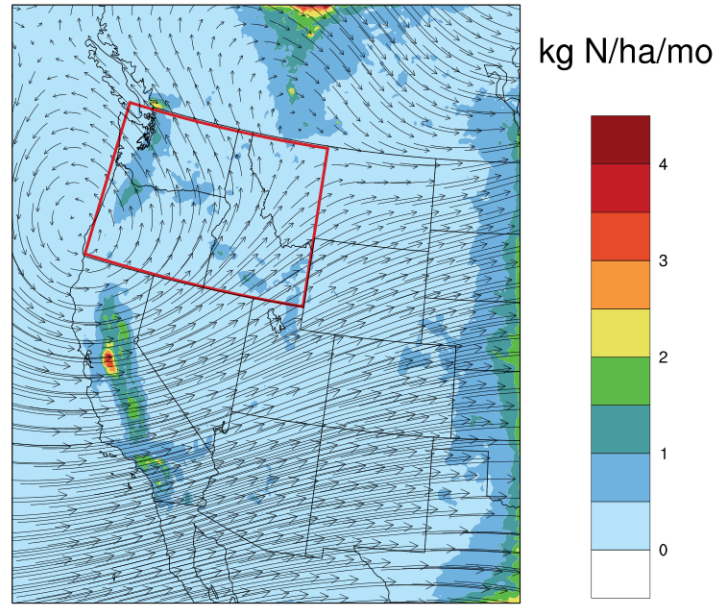
- Atmospheric N budgets in Washington, Oregon, and Idaho
- During the 1997/98 El Nino and the 1998/99 La Nino years

Preliminary Results for the 1997/98 El Nino

Monthly N Deposition Totals and Mean Wind Fields at ~300 mb



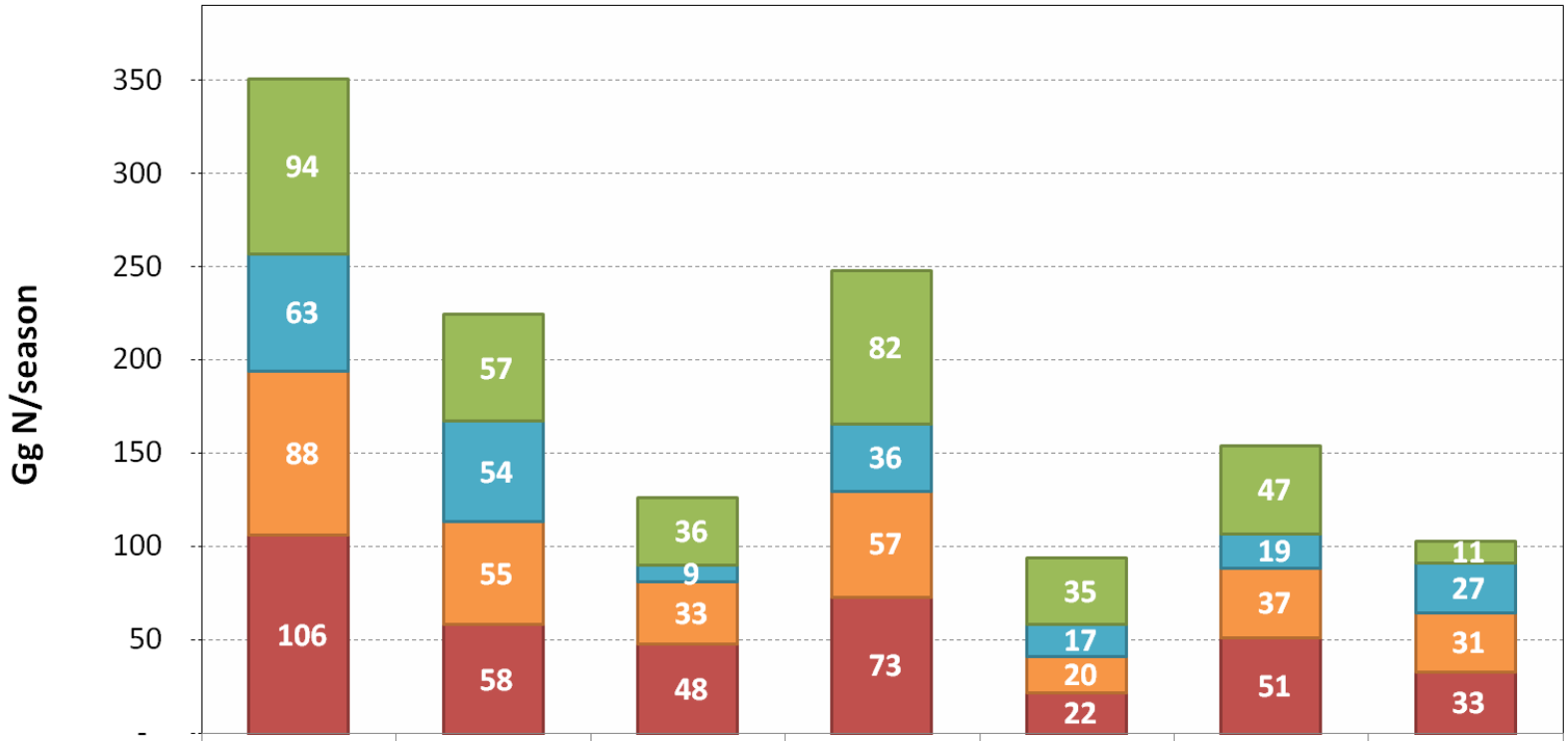
Jan 1998



May 1998

- In January 1998, northwesterly and westerly winds dominated in the upper troposphere.
- In May 1998, winds varied from southwesterly to southeasterly.

Seasonal N Budget in Washington, Oregon and Idaho



	Total N Emis	N emis_mb-egu-ind.	Nemis_ag-biogenic-fire	Total N dep	N wet dep	N dry dep	Net N transport
Spring 1998	94	57	36	82	35	47	11
Winter 1997 (El Nino)	63	54	9	36	17	19	27
Fall 1997	88	55	33	57	20	37	31
Summer 1997	106	58	48	73	22	51	33

Spatially and seasonally integrated atmospheric N fluxes in the 1997/98 El Nino year

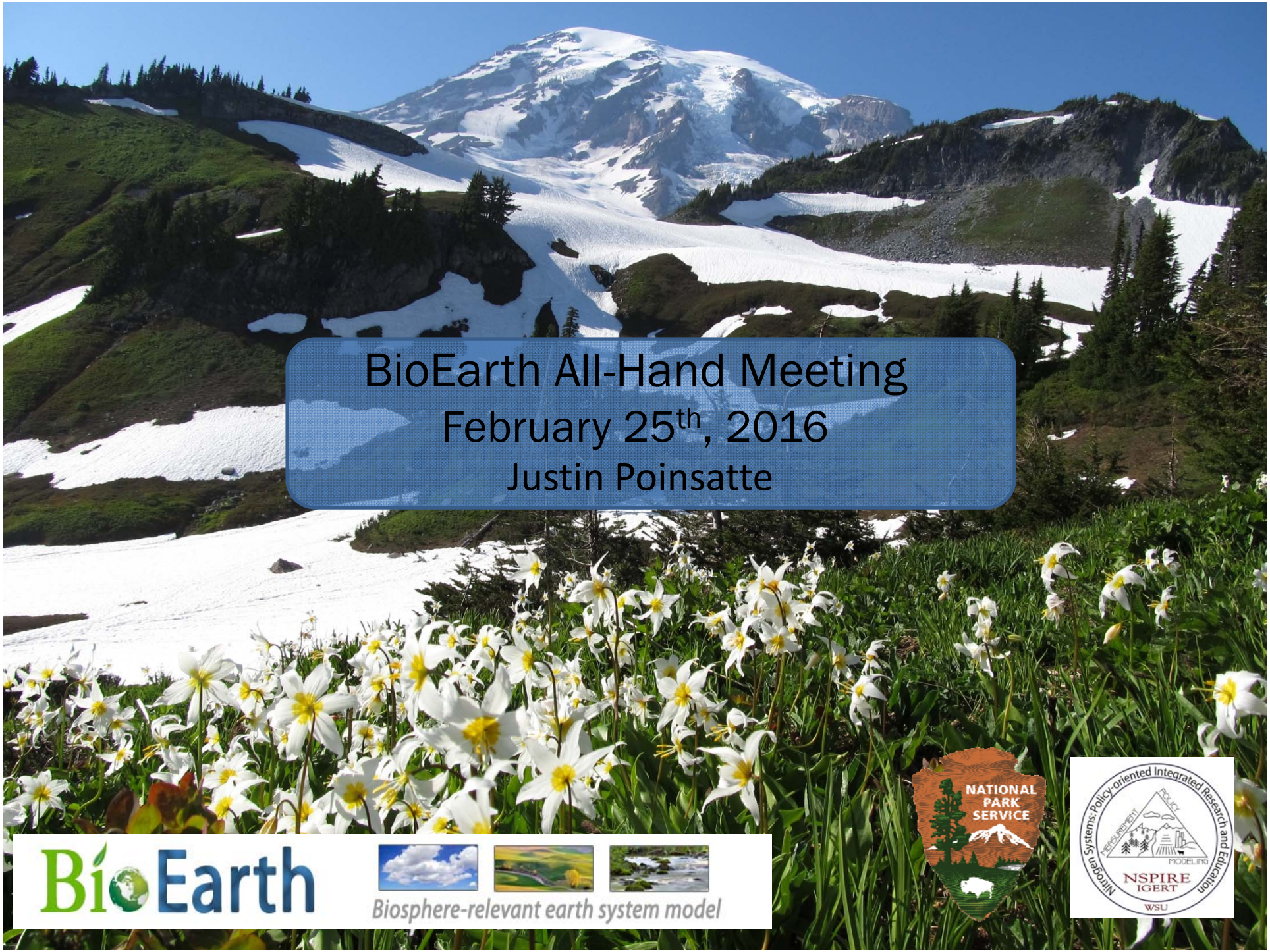
Summary

- Total N emissions in the three states was ~357 Gg N in 1998, with 96% from human activities.
- A total of 257 Gg N/year was deposited in the region (summer 1997 to spring 1998).
- Dry deposition was dominant (>60% of the total deposition) for all seasons.
- Regional N deposition was higher in warm seasons when upper level winds varied from southwesterly to northwesterly.

Future work

- Total N emissions from the agricultural sector will be adjusted.
- Transport of N in and out of the region still needs to be quantified.
- The simulation for the 1998/99 La Niña event is in progress.

The study results provide **a range of contributions of regional and imported N sources over the Pacific Northwest** during a strong ENSO event.



BioEarth All-Hand Meeting

February 25th, 2016

Justin Poinsatte

BioEarth

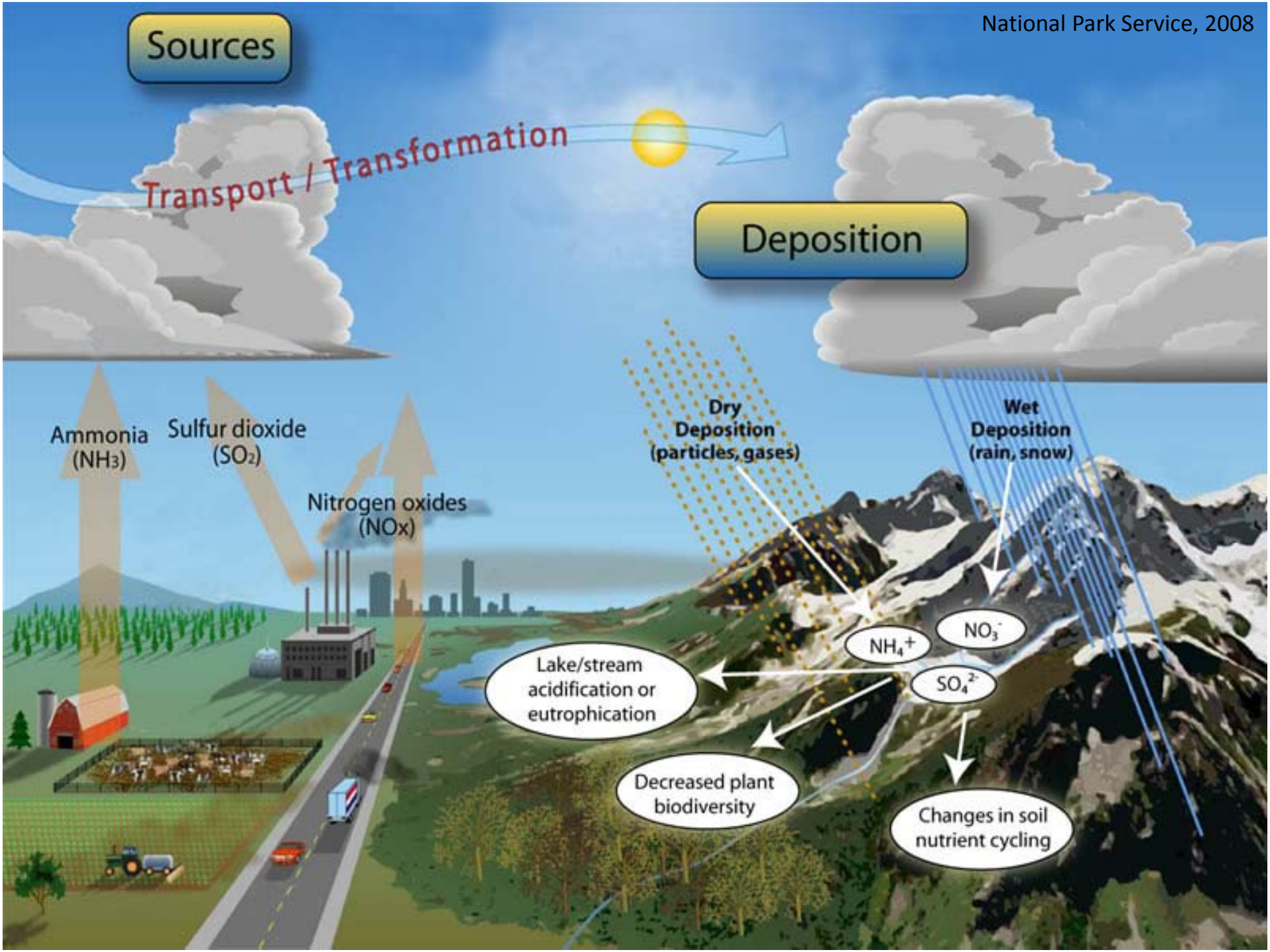
Biosphere-relevant earth system model

NATIONAL PARK SERVICE

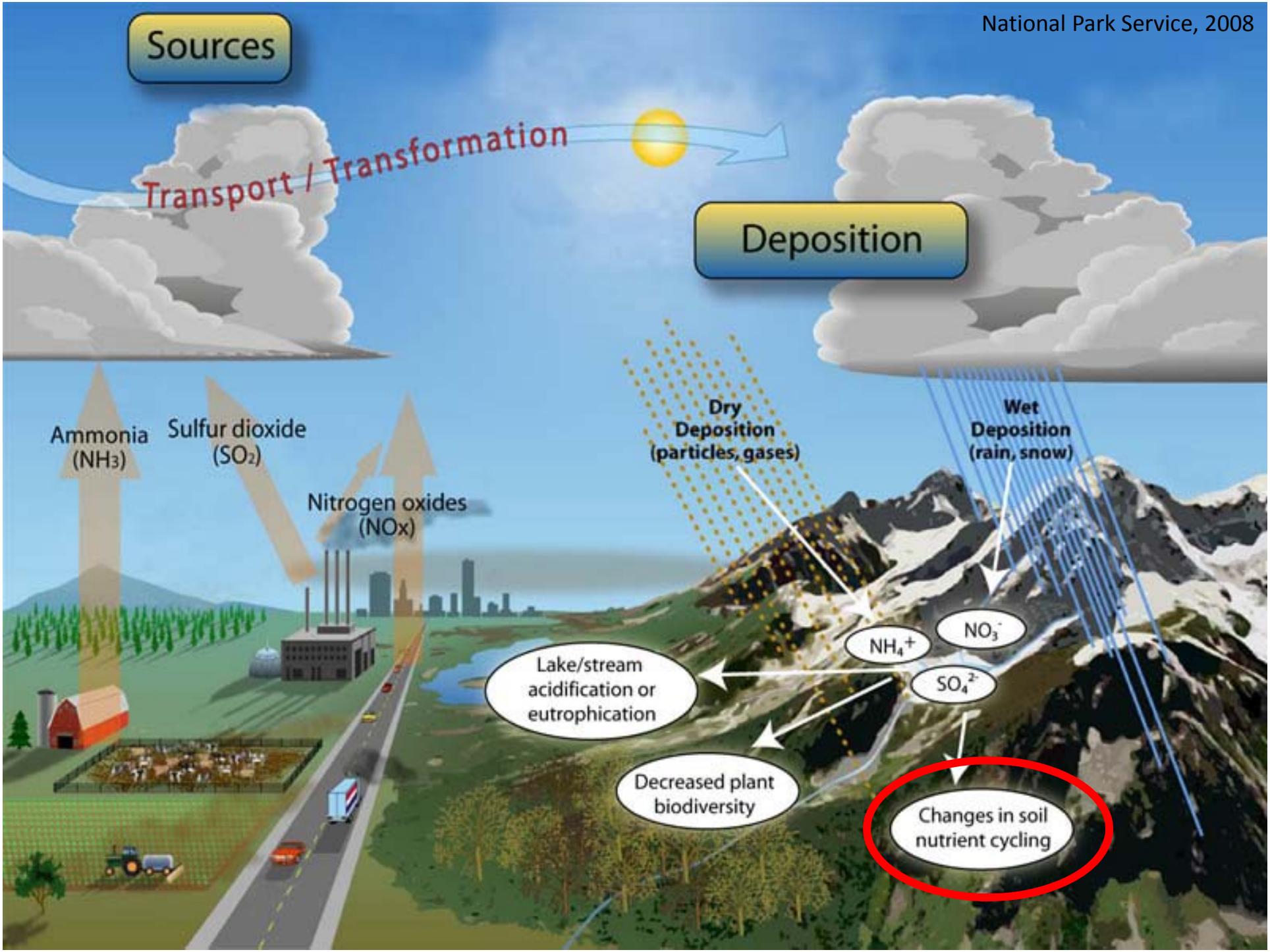
Nitrogen Systems: Policy-oriented Integrated Research and Education

NSPIRE IGERT WSU

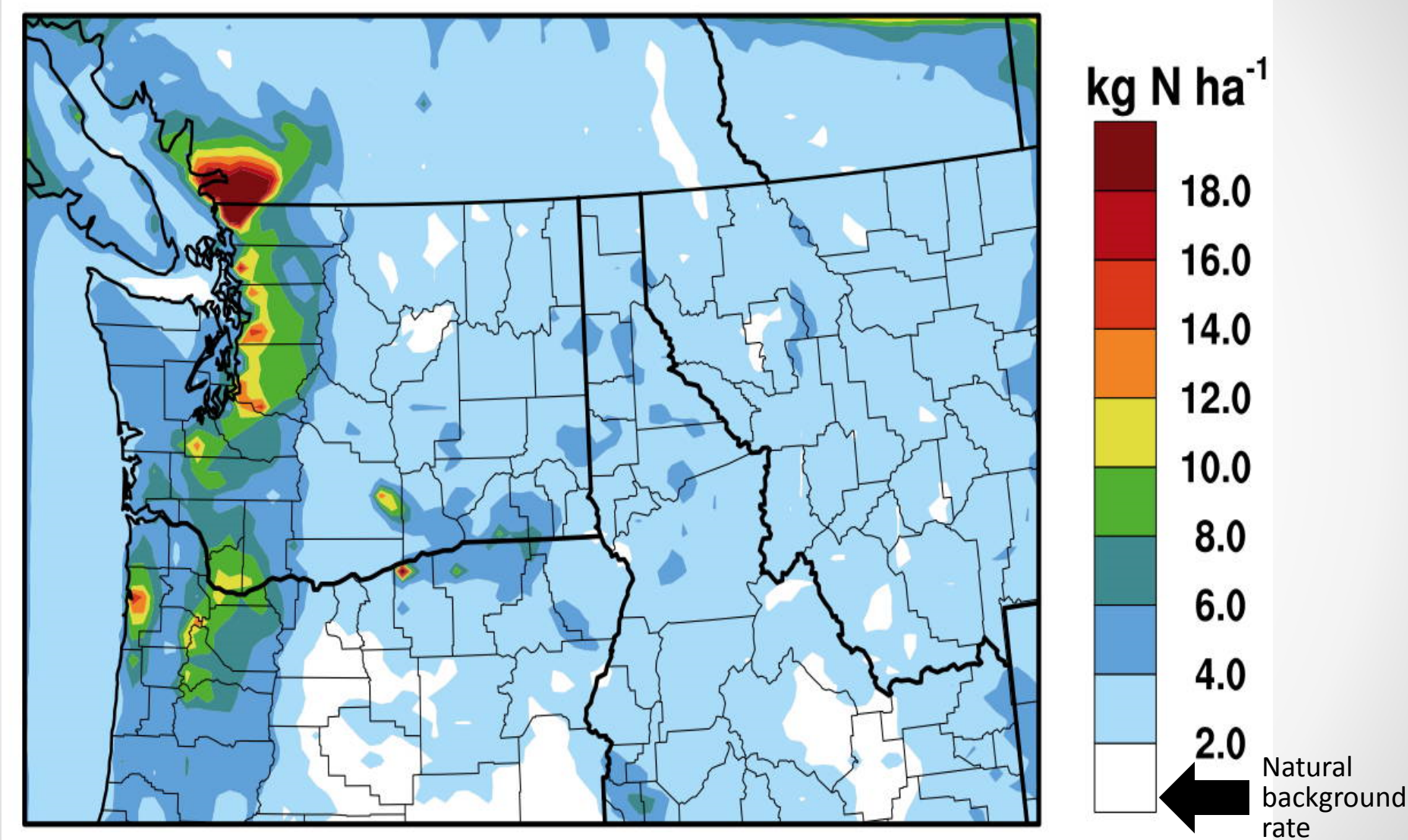
National Park Service, 2008



National Park Service, 2008

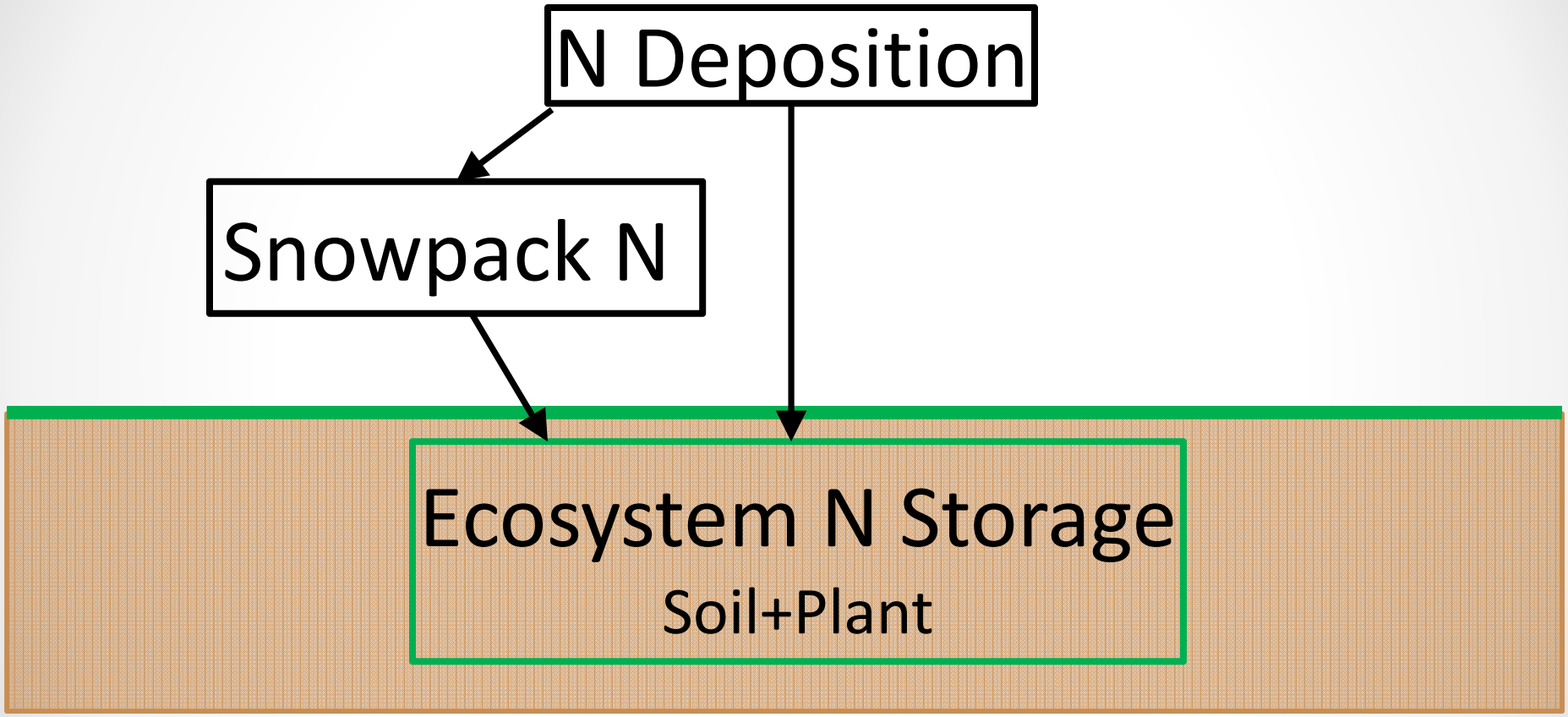


CMAQ Annual Total Inorganic Nitrogen (N) Deposition, 2008

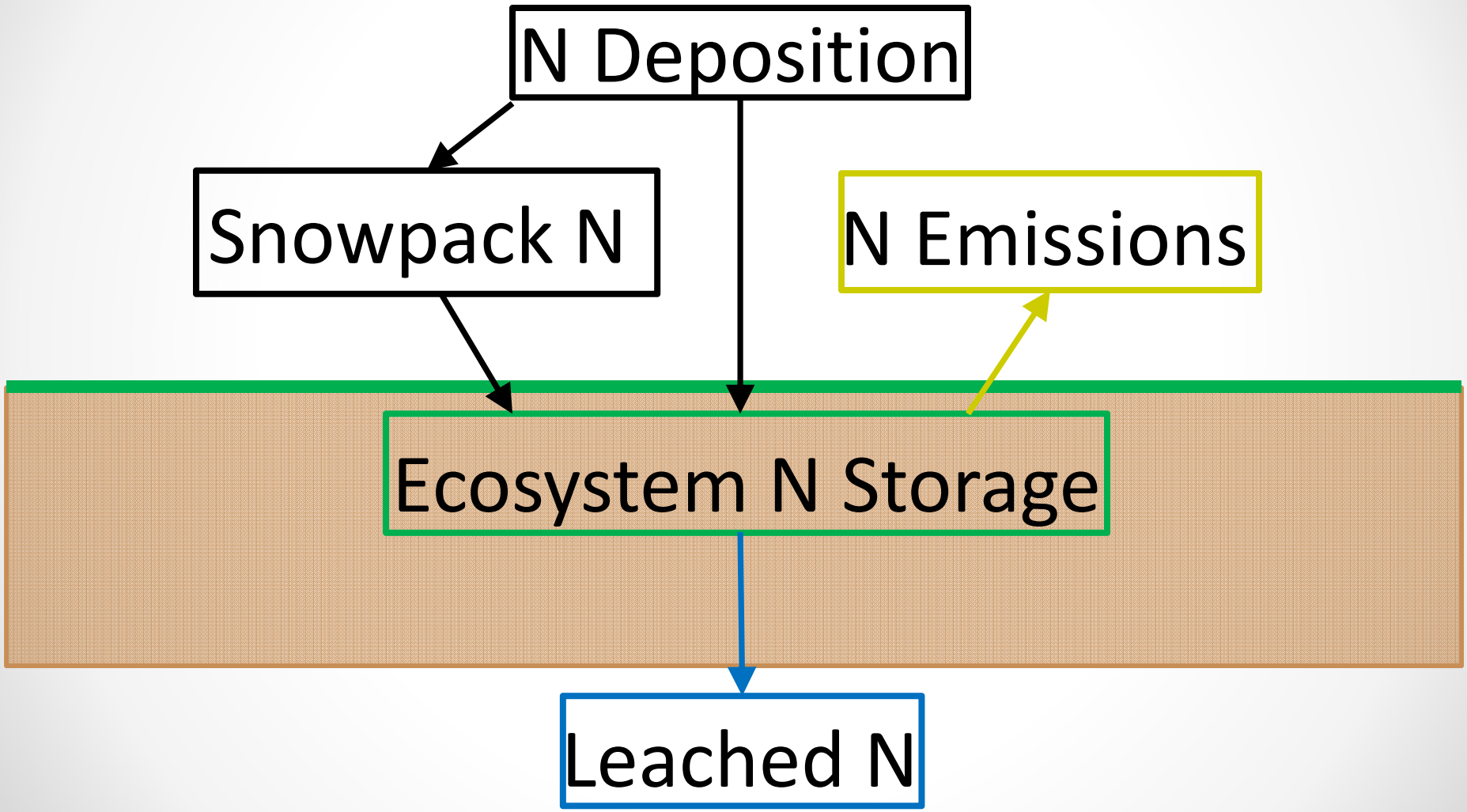


Chen et al., 2008; Herron-Thorpe et al., 2012

Deposition as Pulse Event



Deposition N Losses



Research Questions

What are the rates and sources of N deposition?

How does N deposition affect N storage and loss?

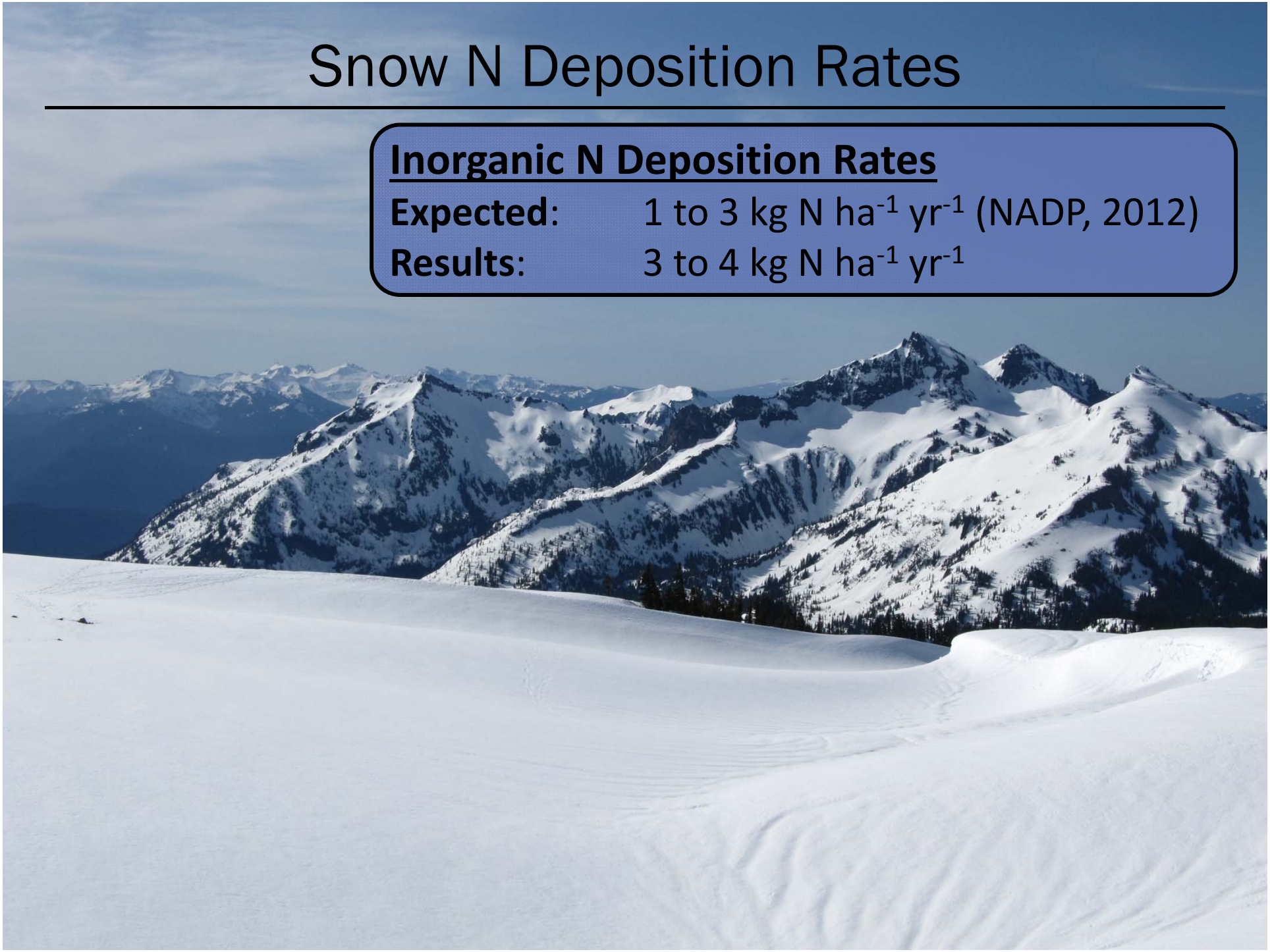
How will climate change affect ecosystem response?

Snow N Deposition Rates

Inorganic N Deposition Rates

Expected: 1 to 3 kg N ha^{-1} yr^{-1} (NADP, 2012)

Results: 3 to 4 kg N ha^{-1} yr^{-1}



Snow N Deposition Forms

Inorganic N Deposition Rates

Expected: 1 to 3 kg N ha^{-1} yr^{-1} (NADP, 2012)

Results: 3 to 4 kg N ha^{-1} yr^{-1}

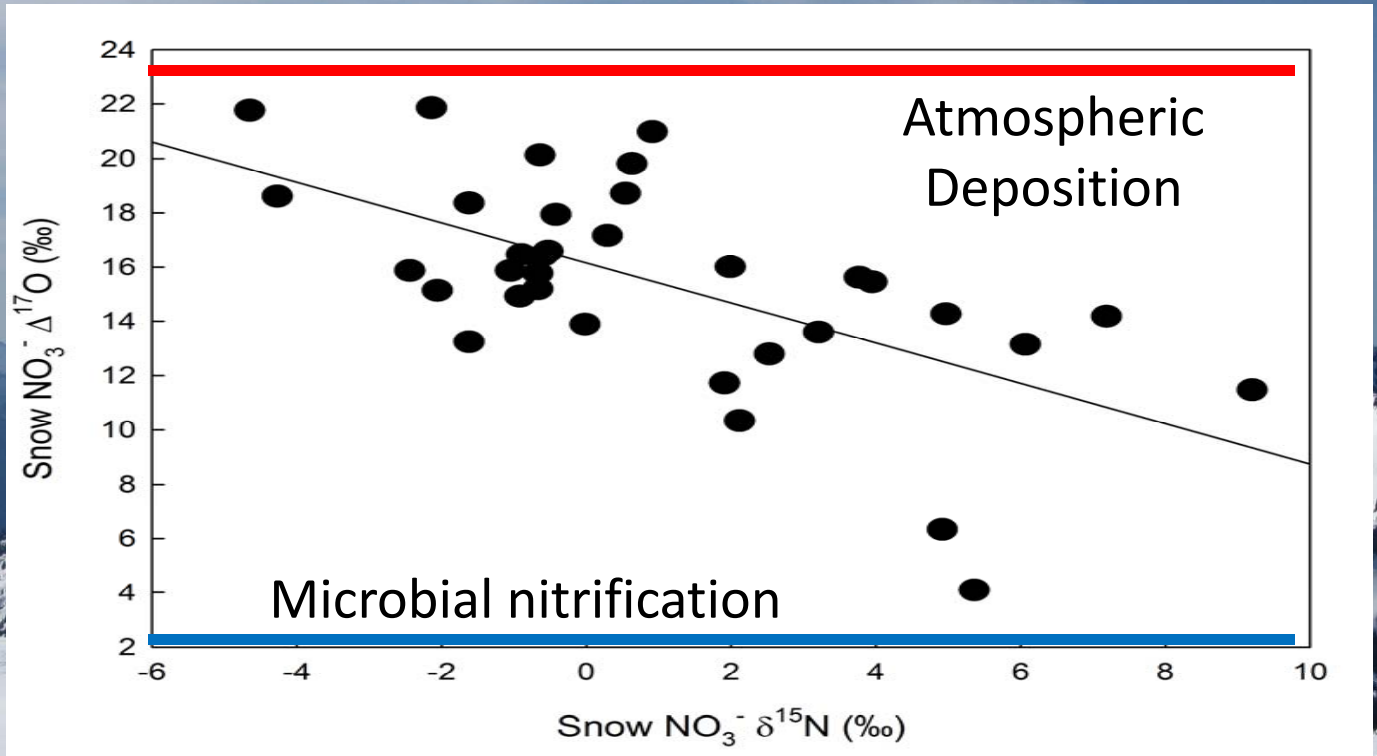
Inorganic N Deposition Forms

Expected: Majority NO_3^-

Results: ~60% Ammonium (NH_4^+)

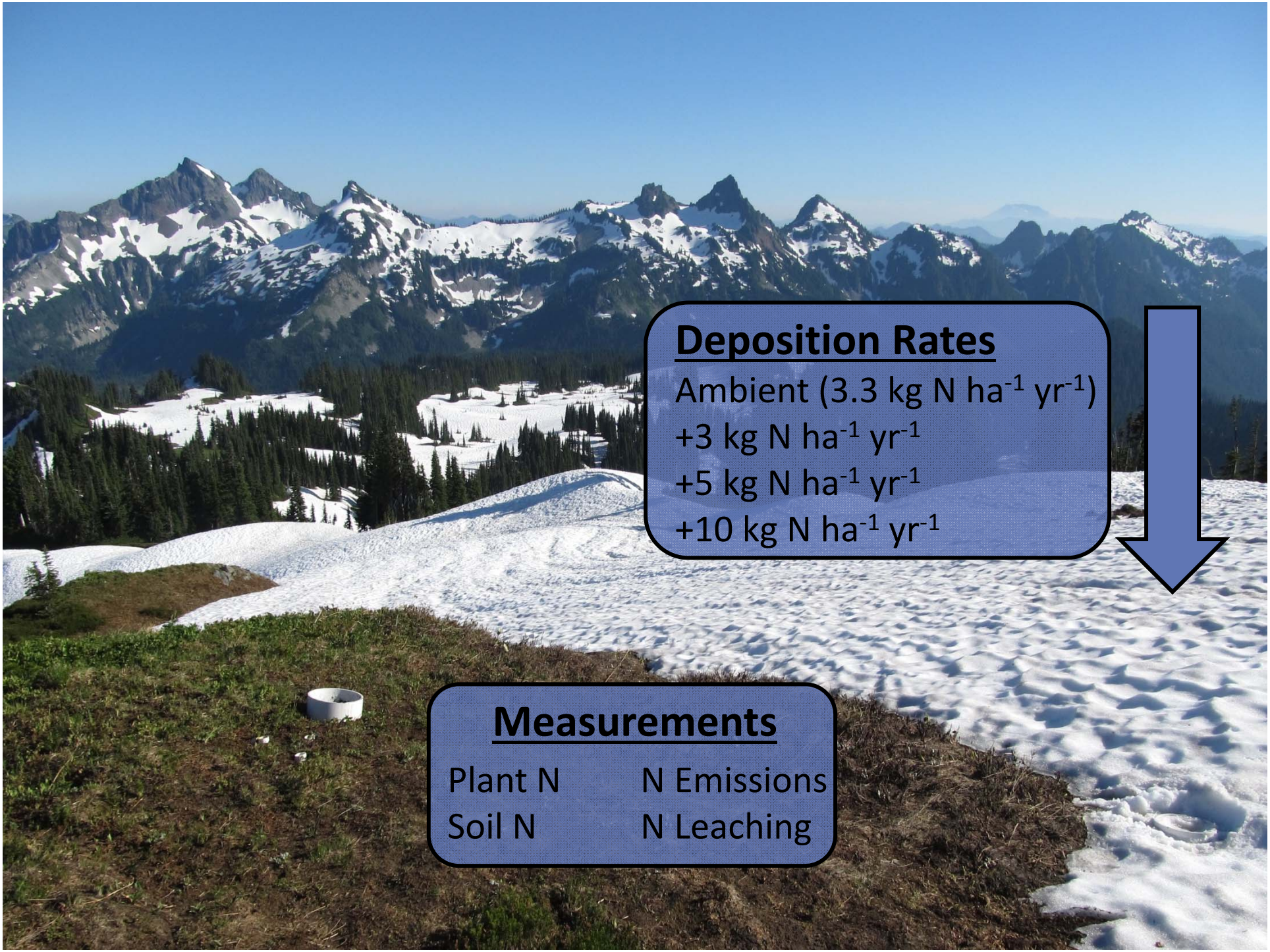
~40% Nitrate (NO_3^-)

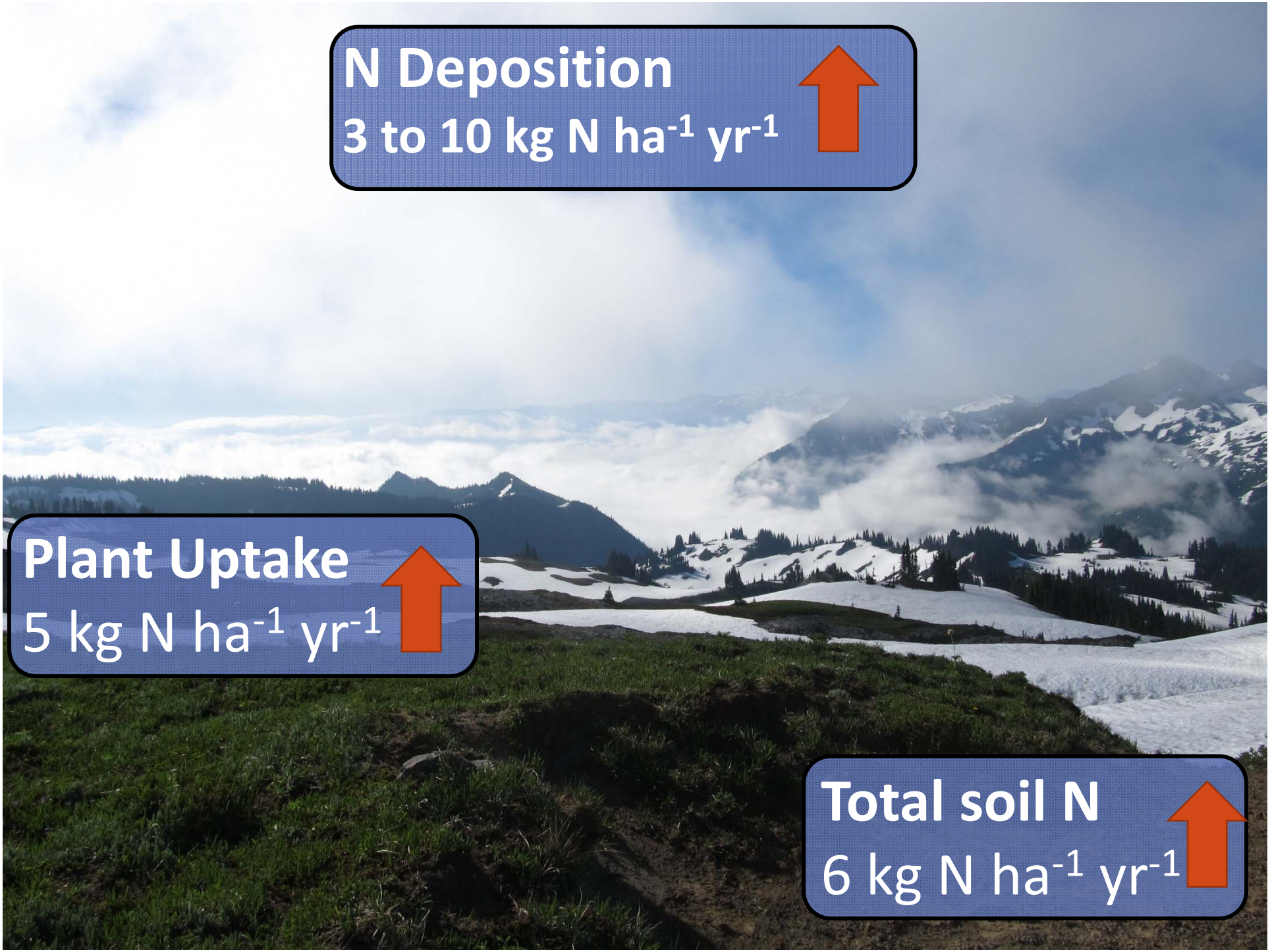
Snow N Deposition Sources

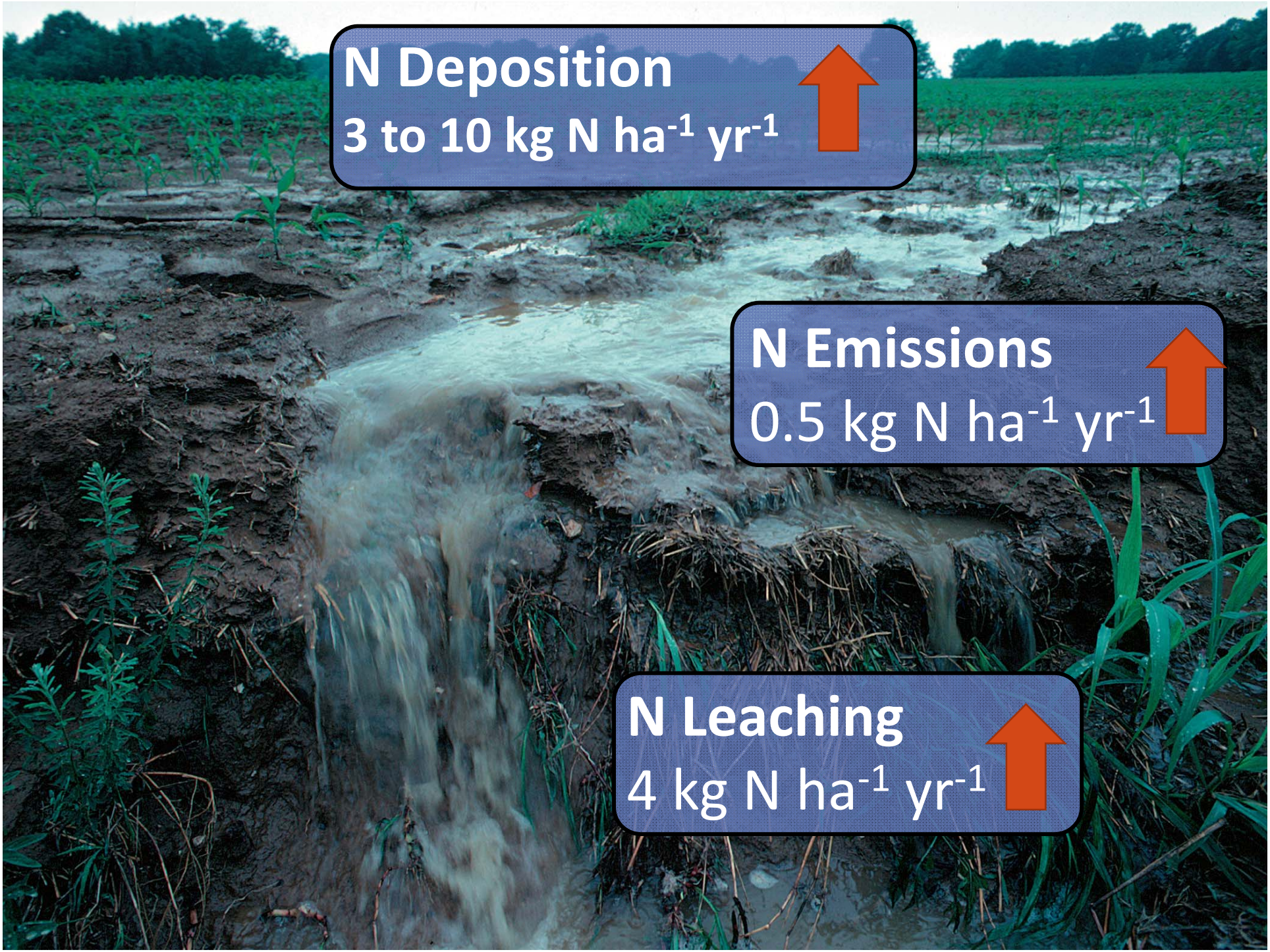


Expected: Snow NO_3^- to reflect atmospheric sources

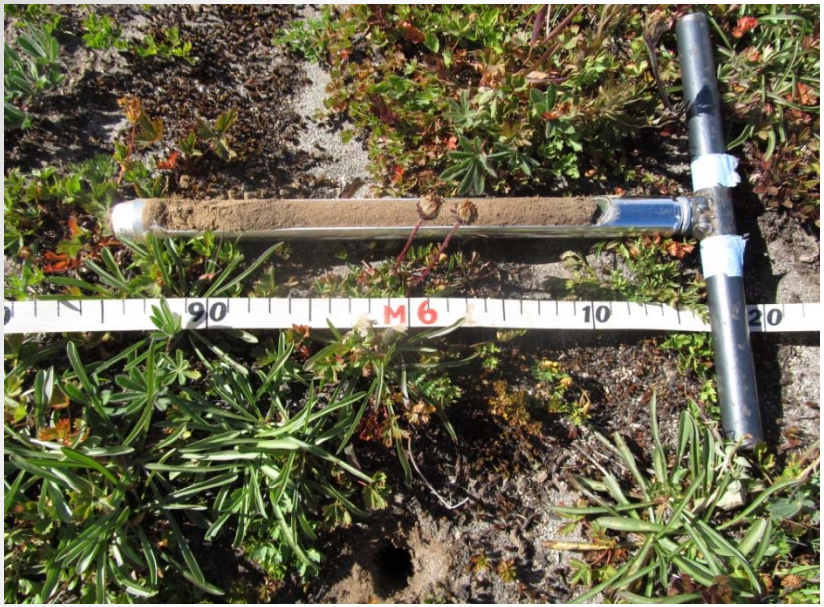
Results: Mix of atmospheric and microbial sources


Deposition Rates
Ambient (3.3 kg N ha-1 yr-1)
+3 kg N ha-1 yr-1
+5 kg N ha-1 yr-1
+10 kg N ha-1 yr-1
Measurements
Plant N
Soil N
N Emissions
N Leaching

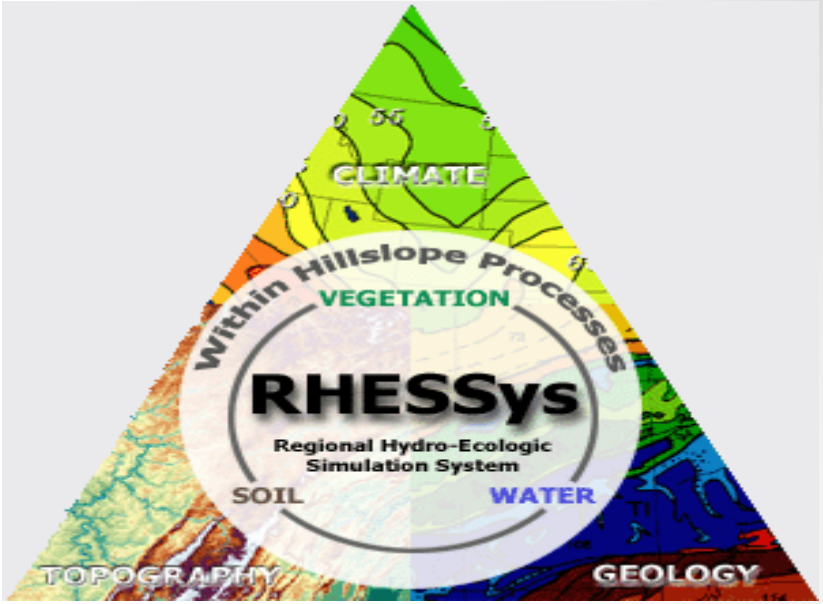

N Deposition
3 to 10 kg N ha-1 yr-1
Plant Uptake
5 kg N ha-1 yr-1
Total soil N
6 kg N ha-1 yr-1

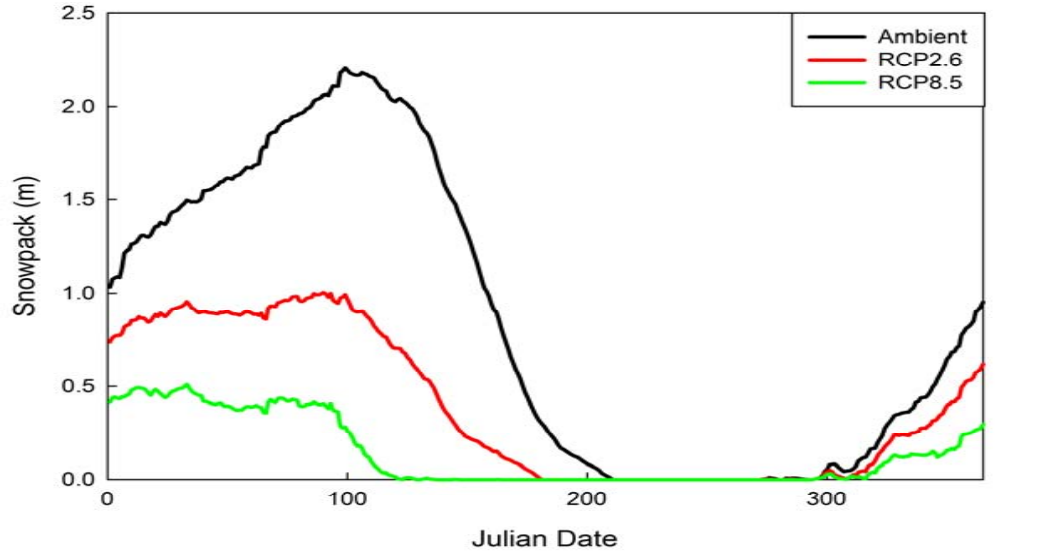

N Deposition
3 to 10 kg N ha-1 yr-1
N Emissions
0.5 kg N ha-1 yr-1
N Leaching
4 kg N ha-1 yr-1

Field Measurements



RHESSys Model





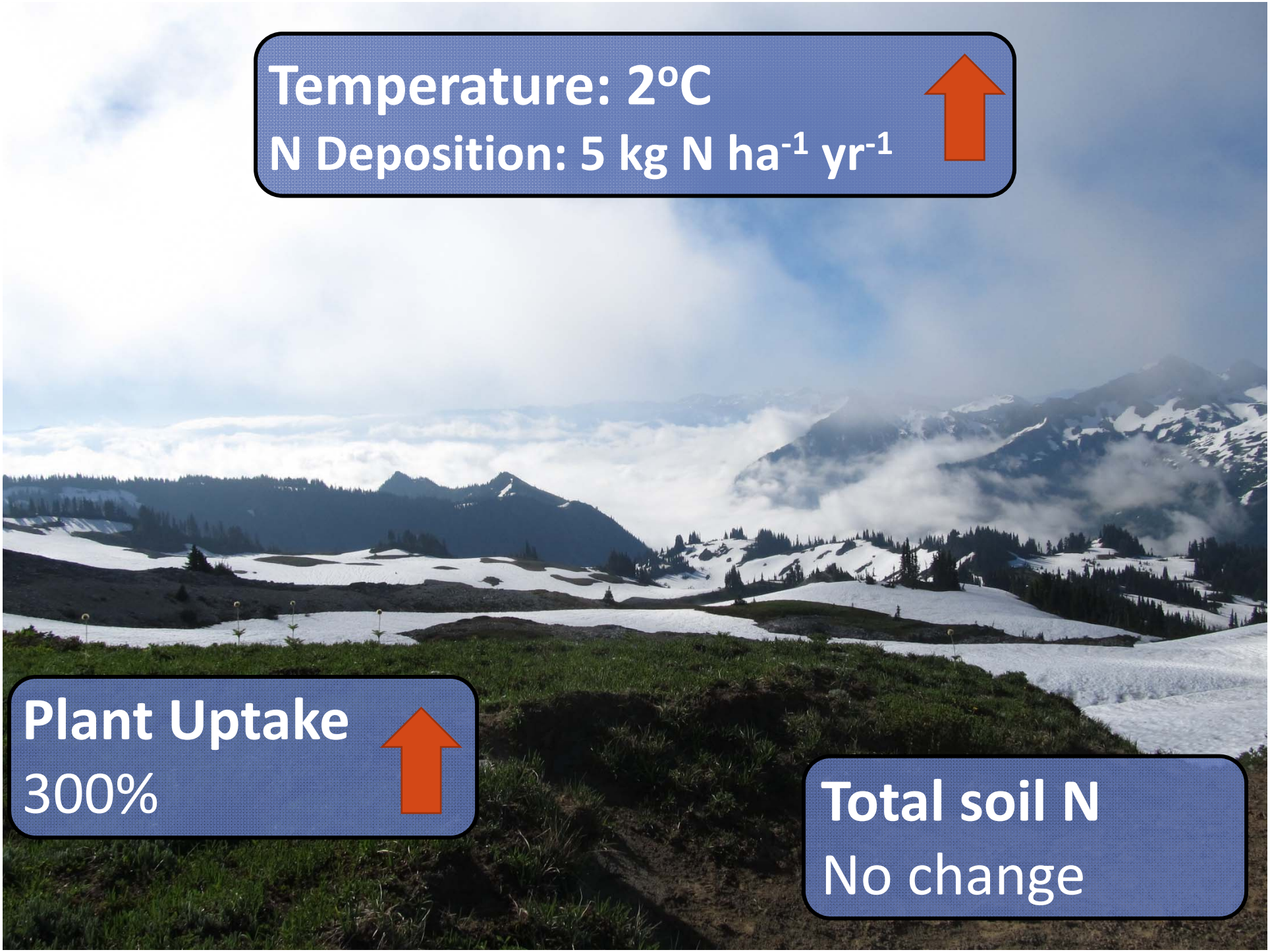
Climate Change Impacts

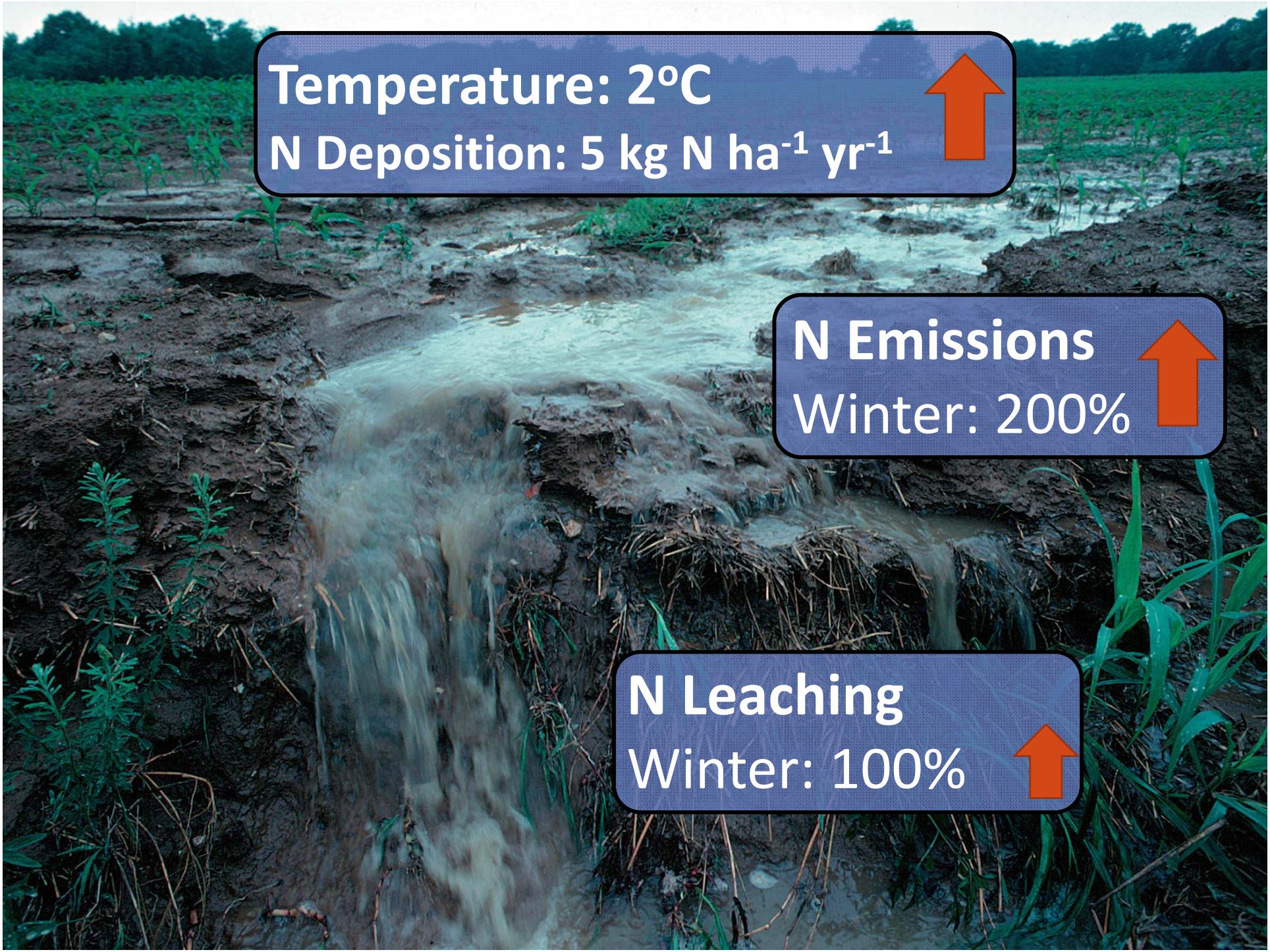
2014

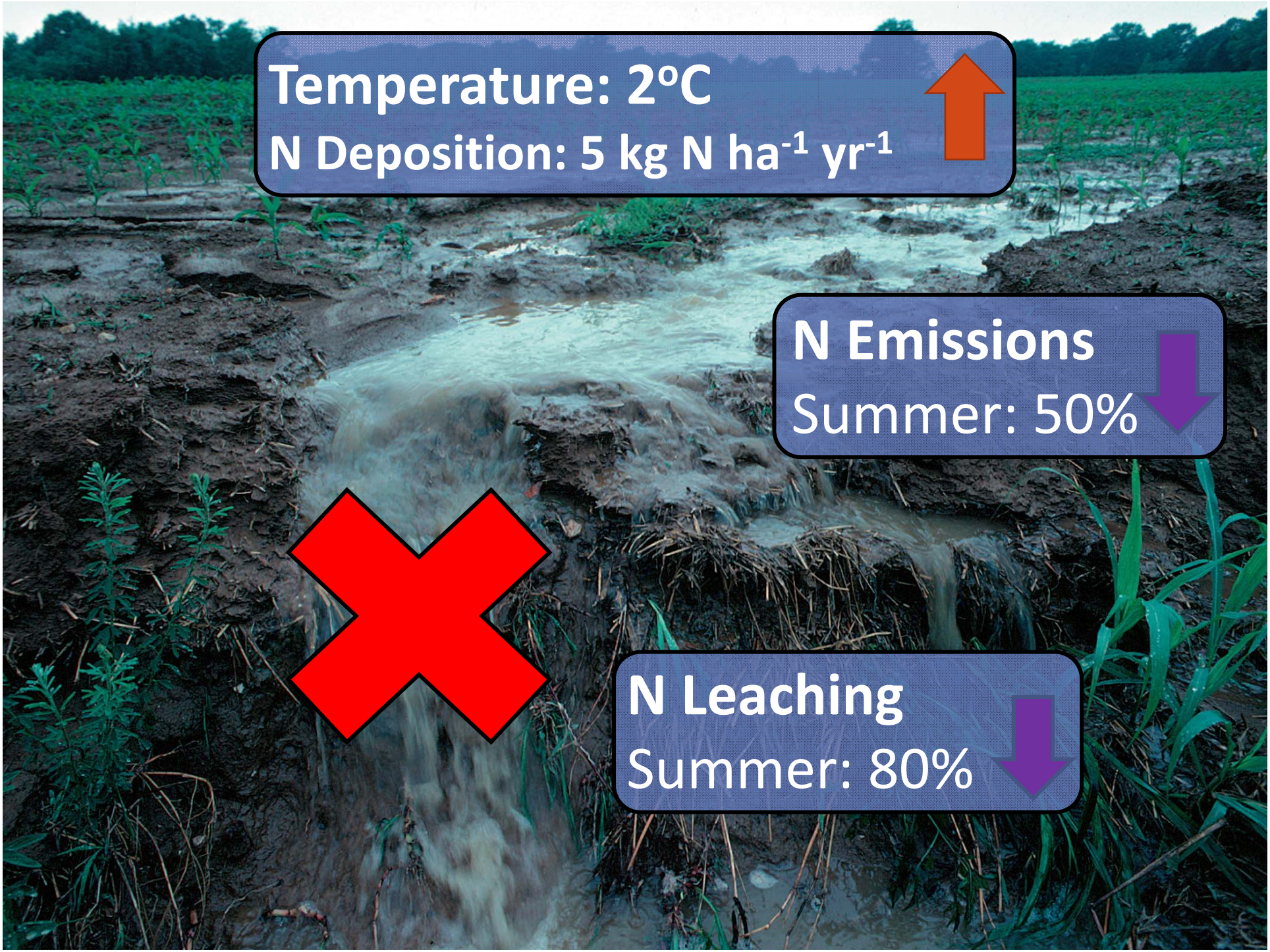
Summer Winter

2050

Summer Winter


Temperature: 2°C
N Deposition: 5 kg N ha-1 yr-1
Plant Uptake
300%
Total soil N
No change


Temperature: 2°C
N Deposition: 5 kg N ha-1 yr-1
N Emissions
Winter: 200%
N Leaching
Winter: 100%


Temperature: 2°C
N Deposition: 5 kg N ha-1 yr-1
N Emissions
Summer: 50%
N Leaching
Summer: 80%

Conclusions

- Ambient N deposition may be greater than previously projected
  - Further research needed to determine regional sources of NH_4^+
- Ecosystem N losses strongly affected by N deposition
  - Increased greenhouse gas production and watershed impairment at low deposition rates

Conclusions

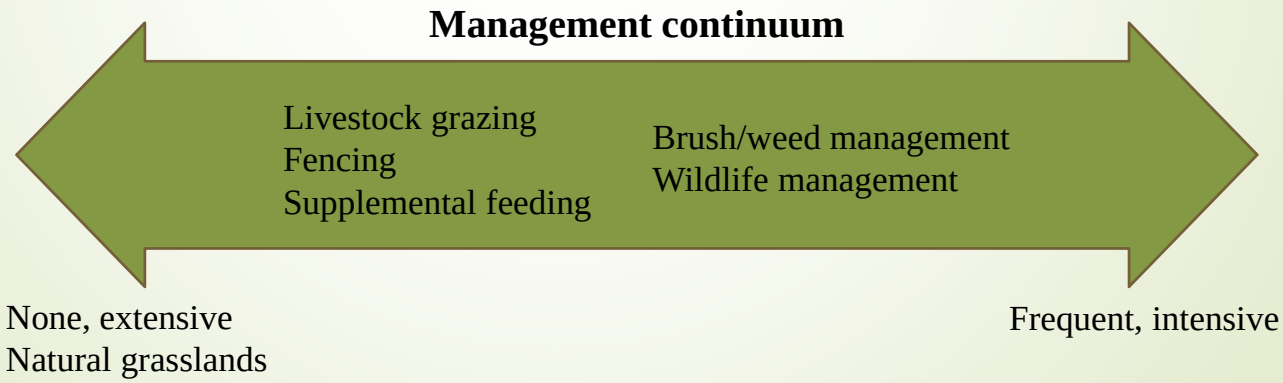
- Ambient N deposition may be greater than previously projected
  - Further research needed to determine regional sources of NH_4^+
- Ecosystem N losses strongly affected by N deposition
  - Increased greenhouse gas production and watershed impairment at low deposition rates
- Climate change can exacerbate ecosystem N loss
  - Decreased snowpack increases winter leaching and emissions
- Resource managers need to adapt to prepare for combined impacts of climate change and N deposition

Characterizing rangeland ecosystems and supporting sustainable management under a changing climate

Julian Reyes
Washington State University

What are rangelands?

- Vegetation: Presence of grasses, grass-like species, forbs, or shrubs
  - Low abundance of woody vegetation
- Climate: Mostly semi-arid to arid
- Land use: Mostly managed



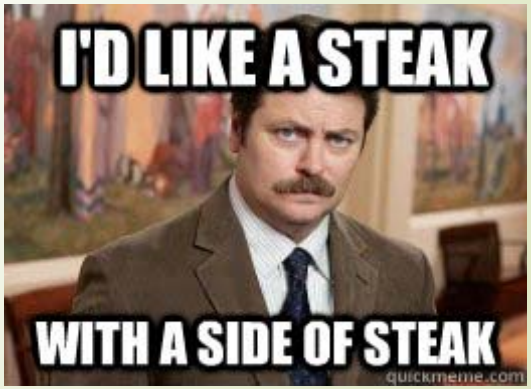
Why are rangelands important?

- Ecological services
  - Habitat
  - Forage
  - Carbon storage

http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=6463

Why are rangelands important?

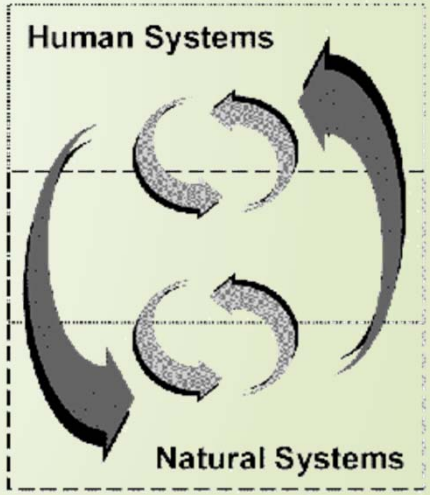
- Agricultural
  - Protein products
- Social/cultural
  - Recreation
  - Vistas



Overarching objectives

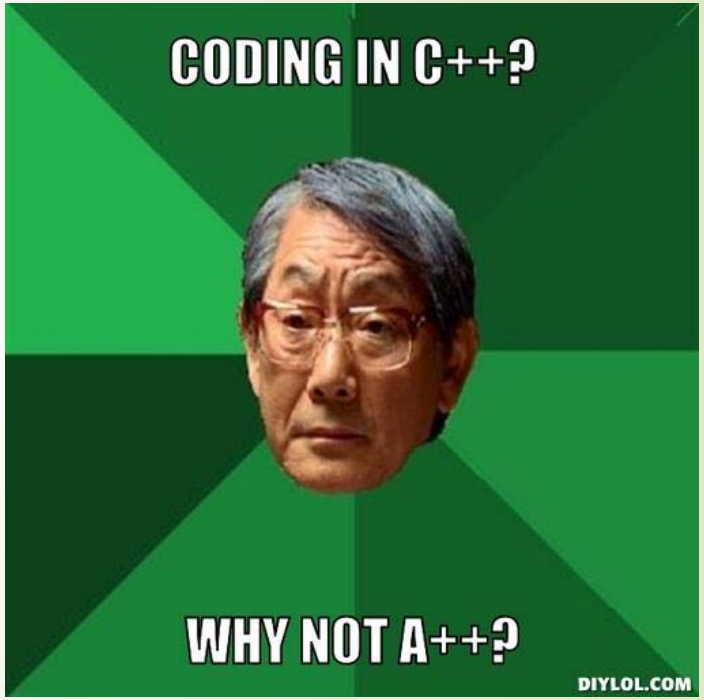
1) Understand coupled interactions among water, carbon, and nitrogen in rangelands; and
2) Assess rangelands' response to coupled changes in management and climate

>> to inform sustainable rangeland management



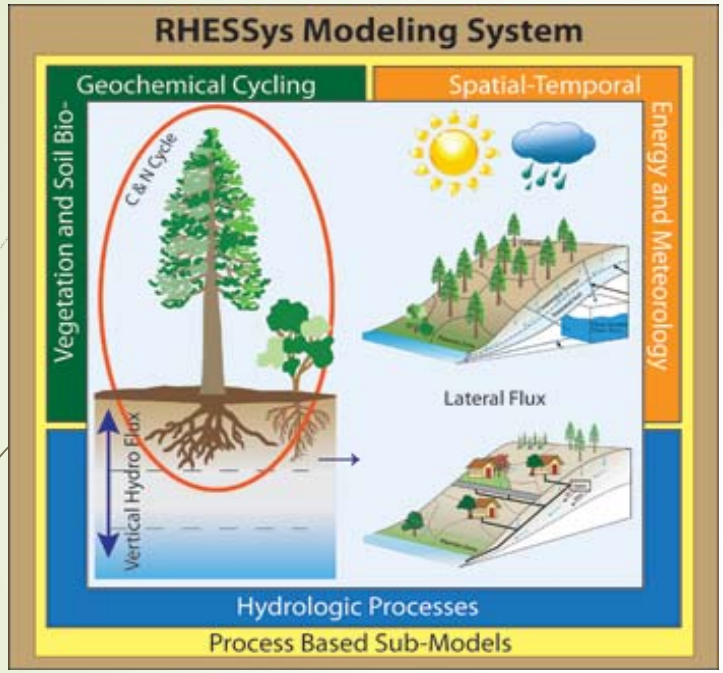
http://www.nsf.gov/pubs/2007/nsf07598/nsf07598.htm

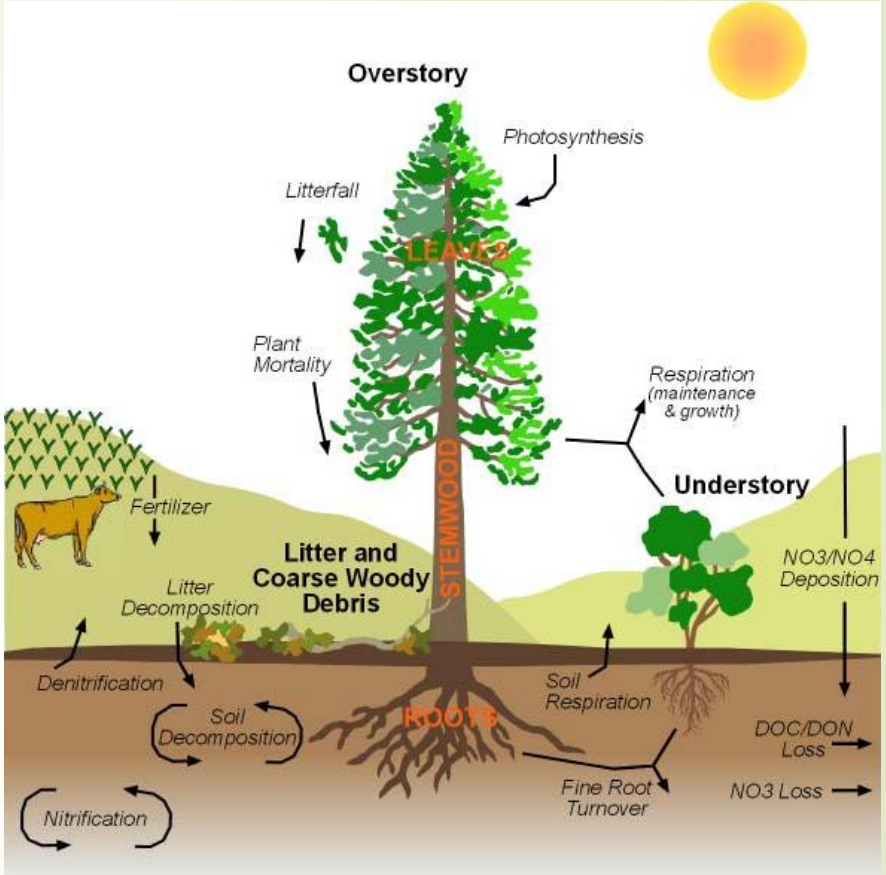
99 little bugs in the code.
99 little bugs in the code.
Take one down, patch it around.
127 little bugs in the code...


CODING IN C++?
WHY NOT A++?
DIYLOL.COM

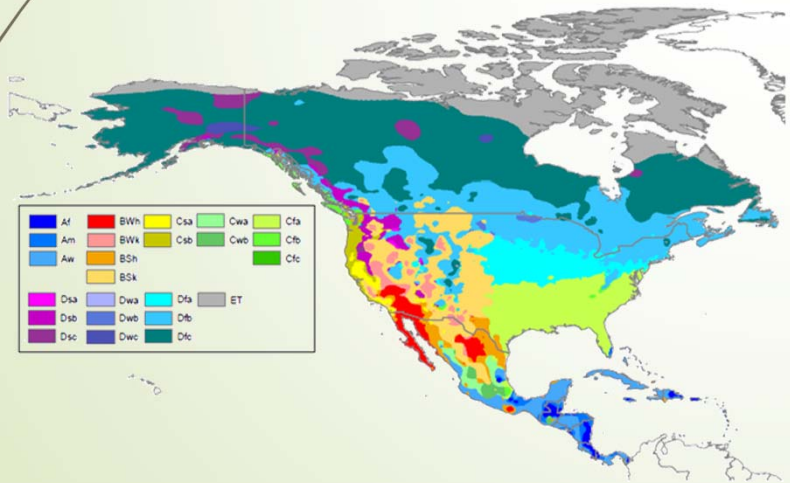
OH, YOU MODEL?
WHAT'S YOUR AGENCY? INSTAGRAM?

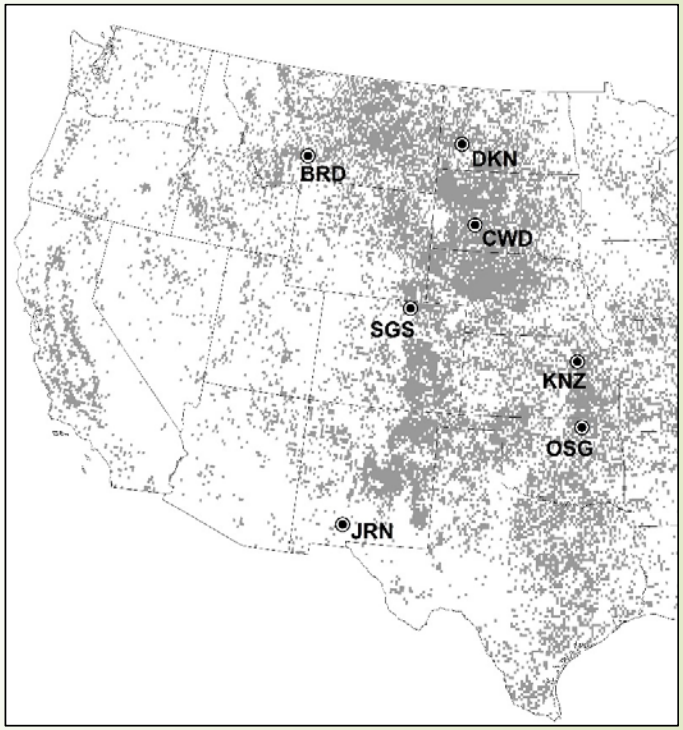
RHESSys



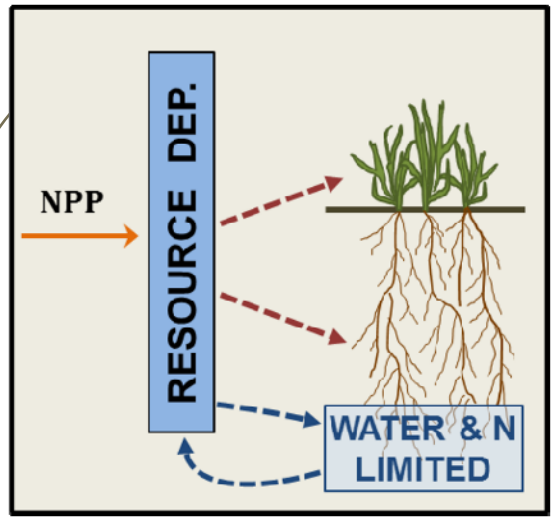


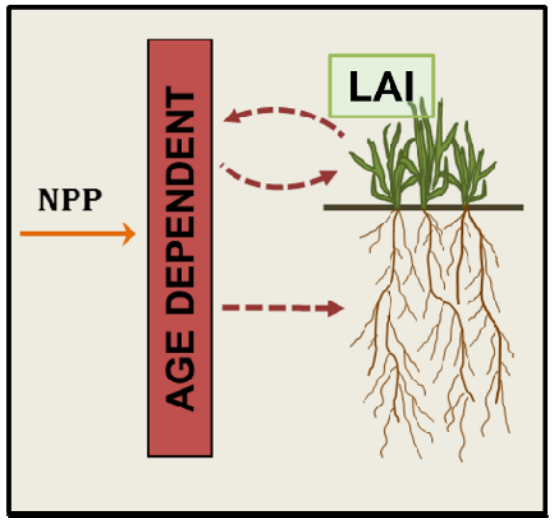
Regional Hydro-Ecologic Simulation System

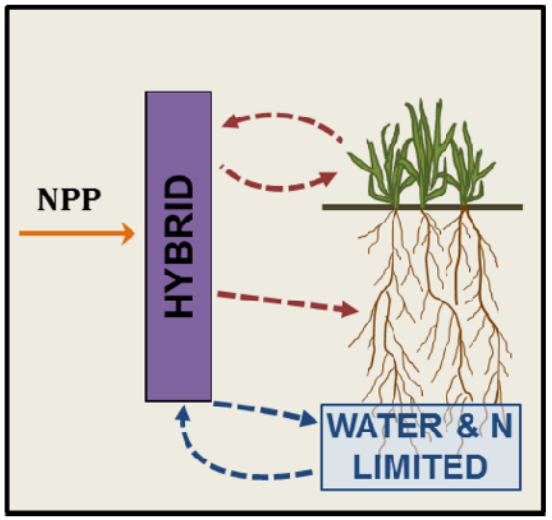

Af
Am
Aw
BWh
BWk
BSh
BSk
Csa
Csb
Cwa
Cwb
Cfa
Cfb
Cfc
Dsa
Dsb
Dsc
Dwa
Dwb
Dwc
Dfa
Dfb
Dfc
ET


BRD
DKN
CWD
SGS
KNZ
OSG
JRN

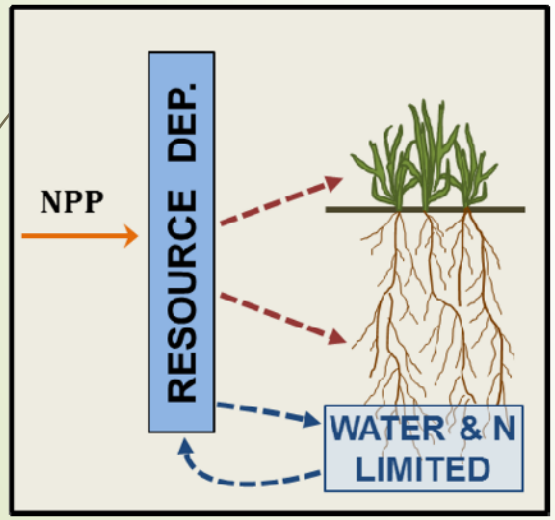
How do we allocate carbon between above and belowground plant compartments?

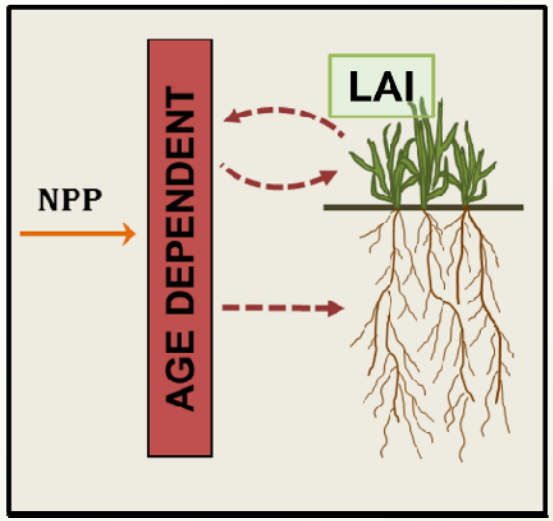


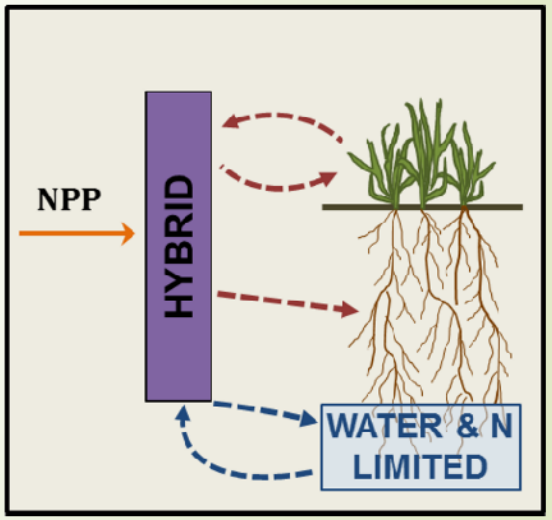


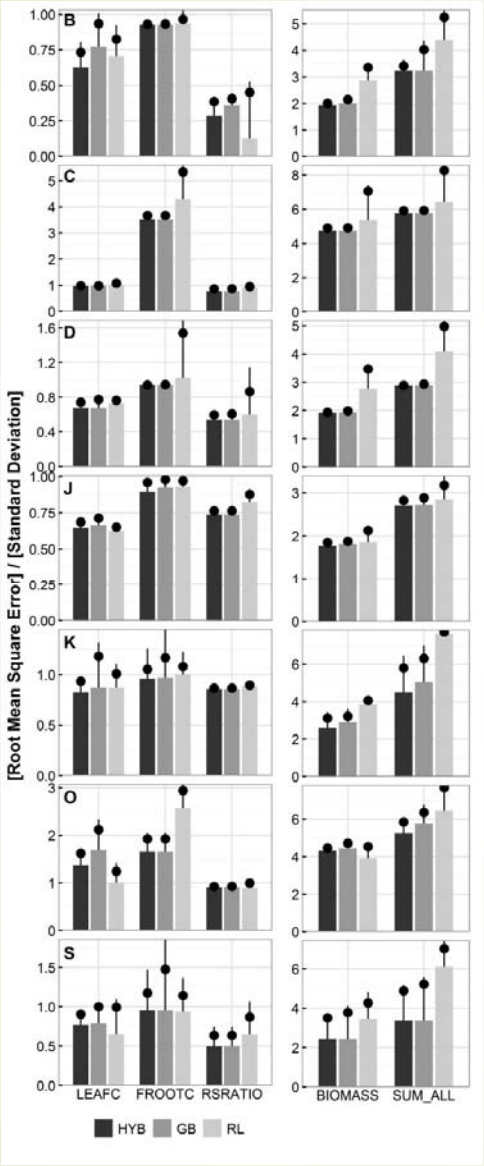


How do we allocate carbon between above and belowground plant compartments?

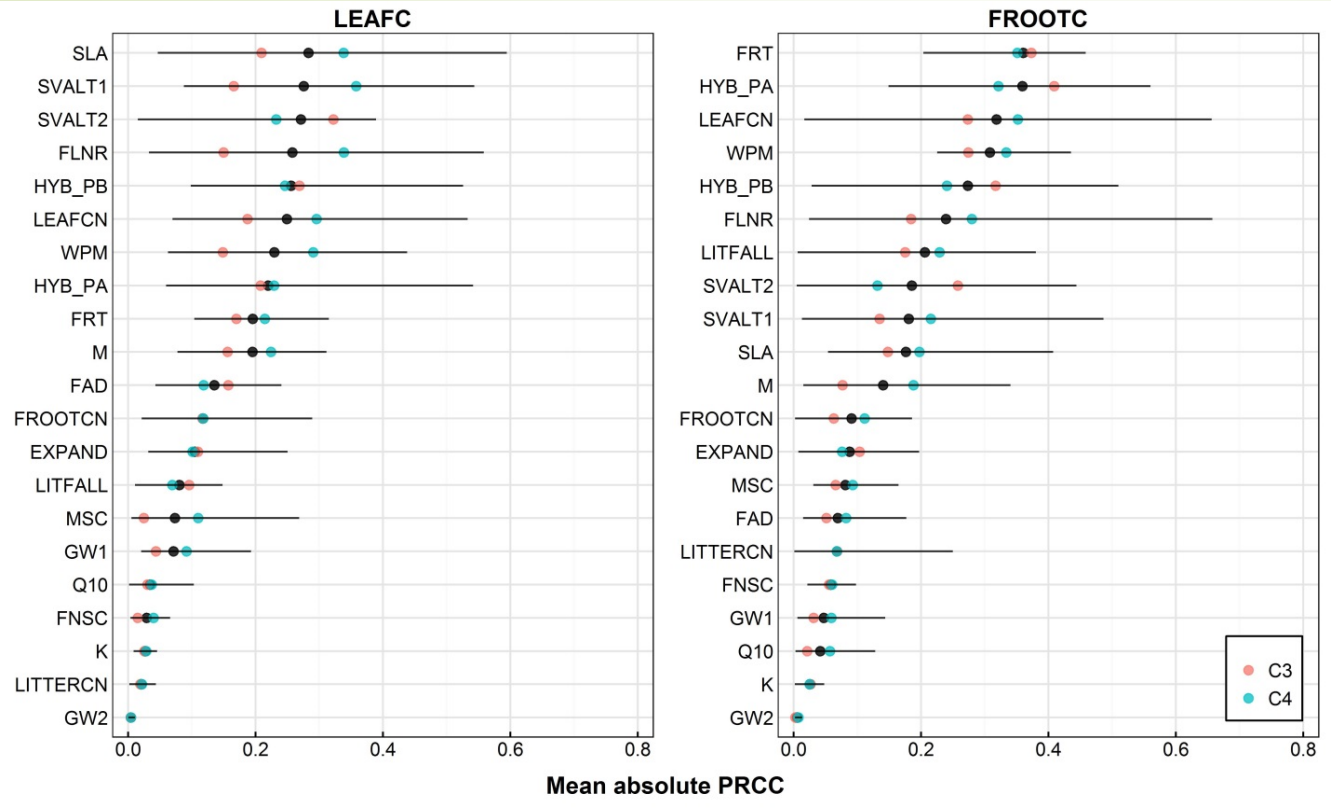




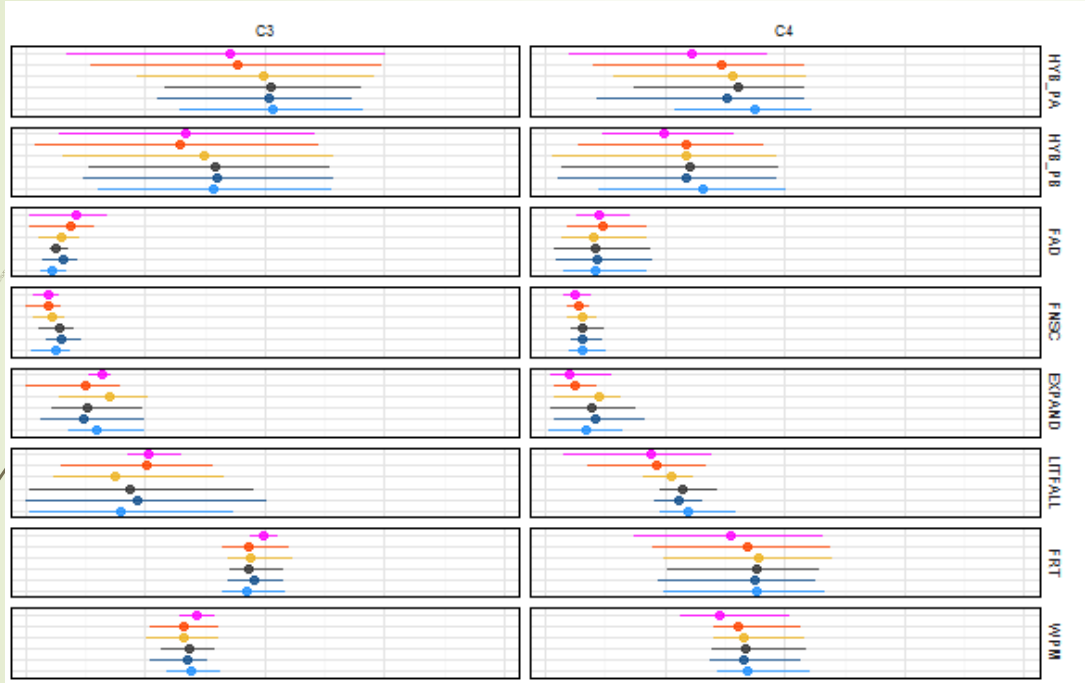




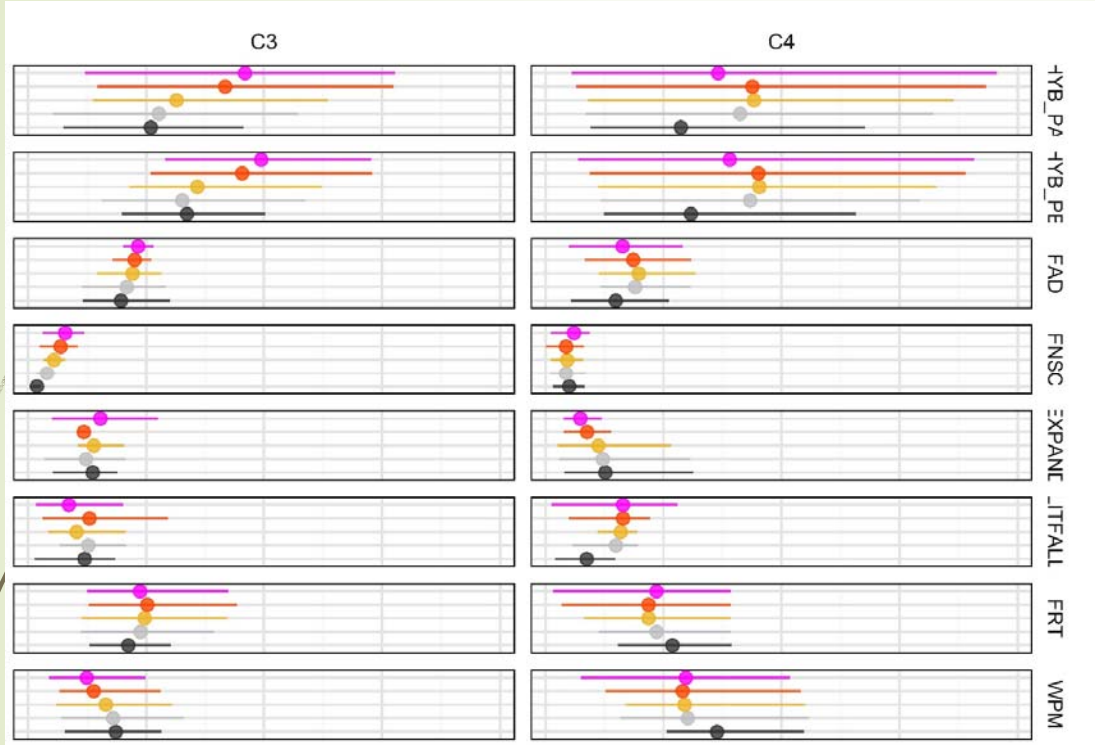
- Evaluation of the three allocation strategies used in RHESSys: HYBRID, GROWTH-BASED, and RESOURCE-LIMITED.
- We evaluated on aboveground biomass, belowground biomass, and the root/shoot ratio separately



- Under historical climate there are distinct differences in parameter importance between C3/C4 sites, as well as for output variables (i.e. LEAFC, FROOTC).



- High parameter importance for parameters that govern allocation function (HYB_PA, HYB_PB).
- Turnover and cycling of nutrients is important even under climatic changes.



- Parameter importance under changes in CO2 and temperature
- Non-monotonic shifts in importance for TxCO2 vs monotonic and linear

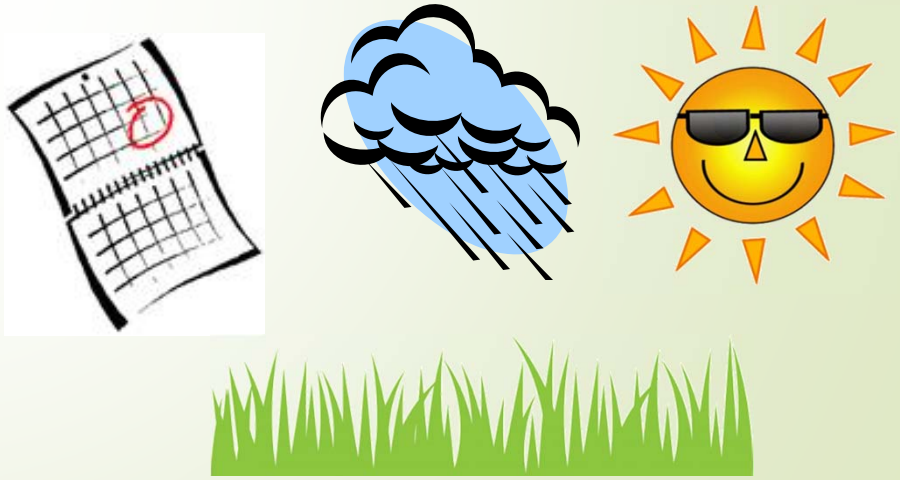
What grazing management principles are most effective in sustaining rangeland ecosystem function under climate variability?

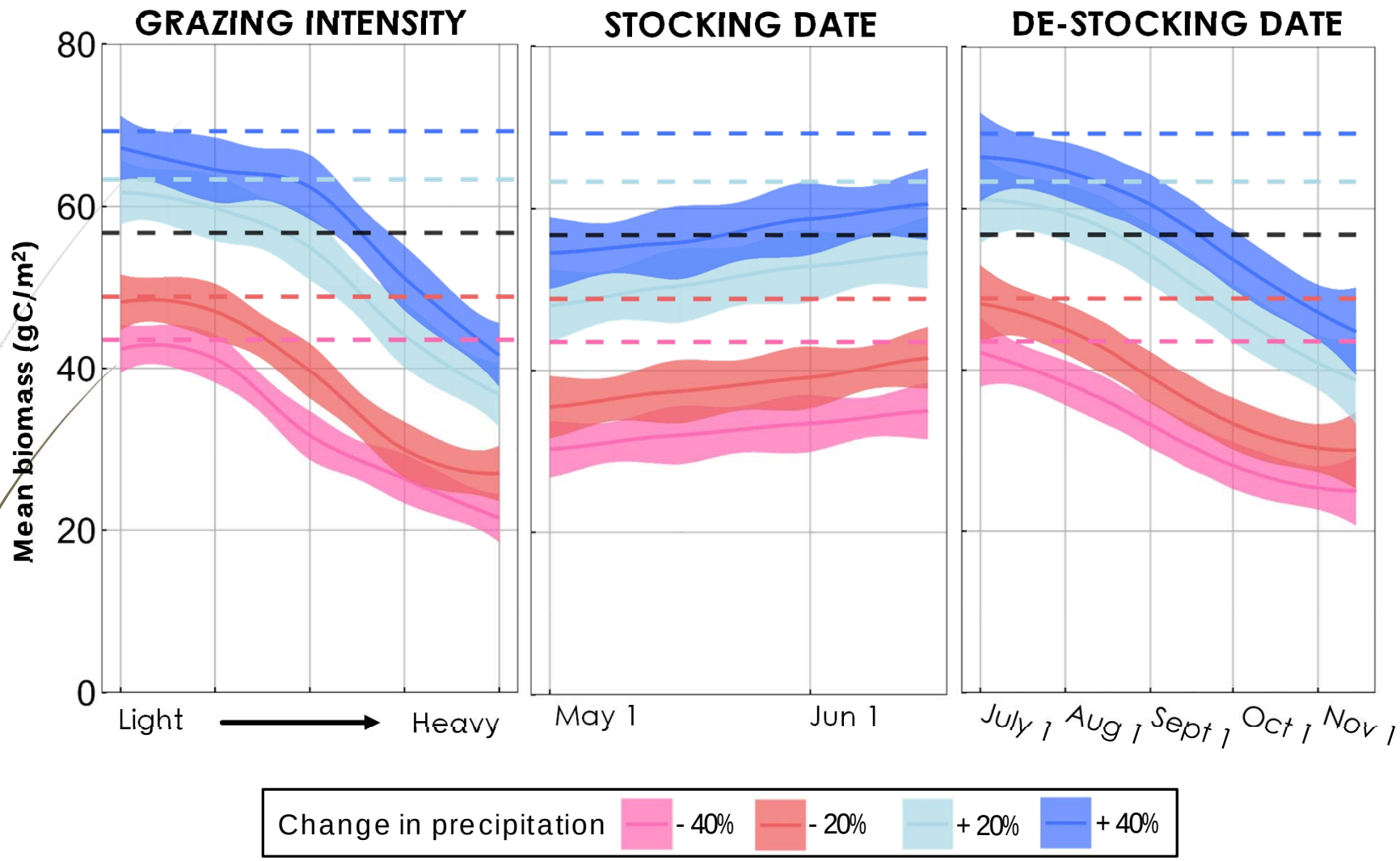
Decision variables

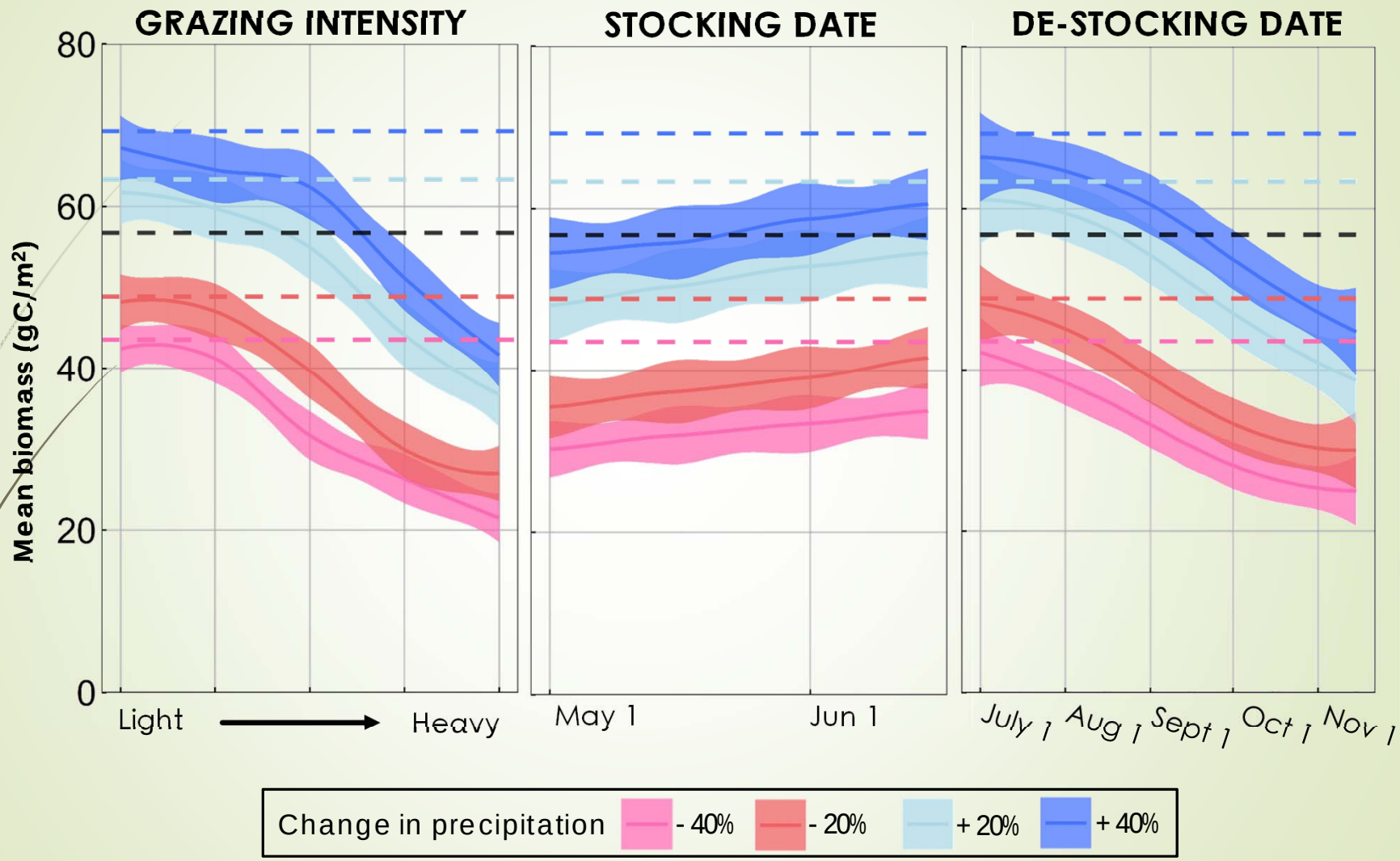
- Grazing intensity
- Stocking date (start date)
- Destocking date (end date)

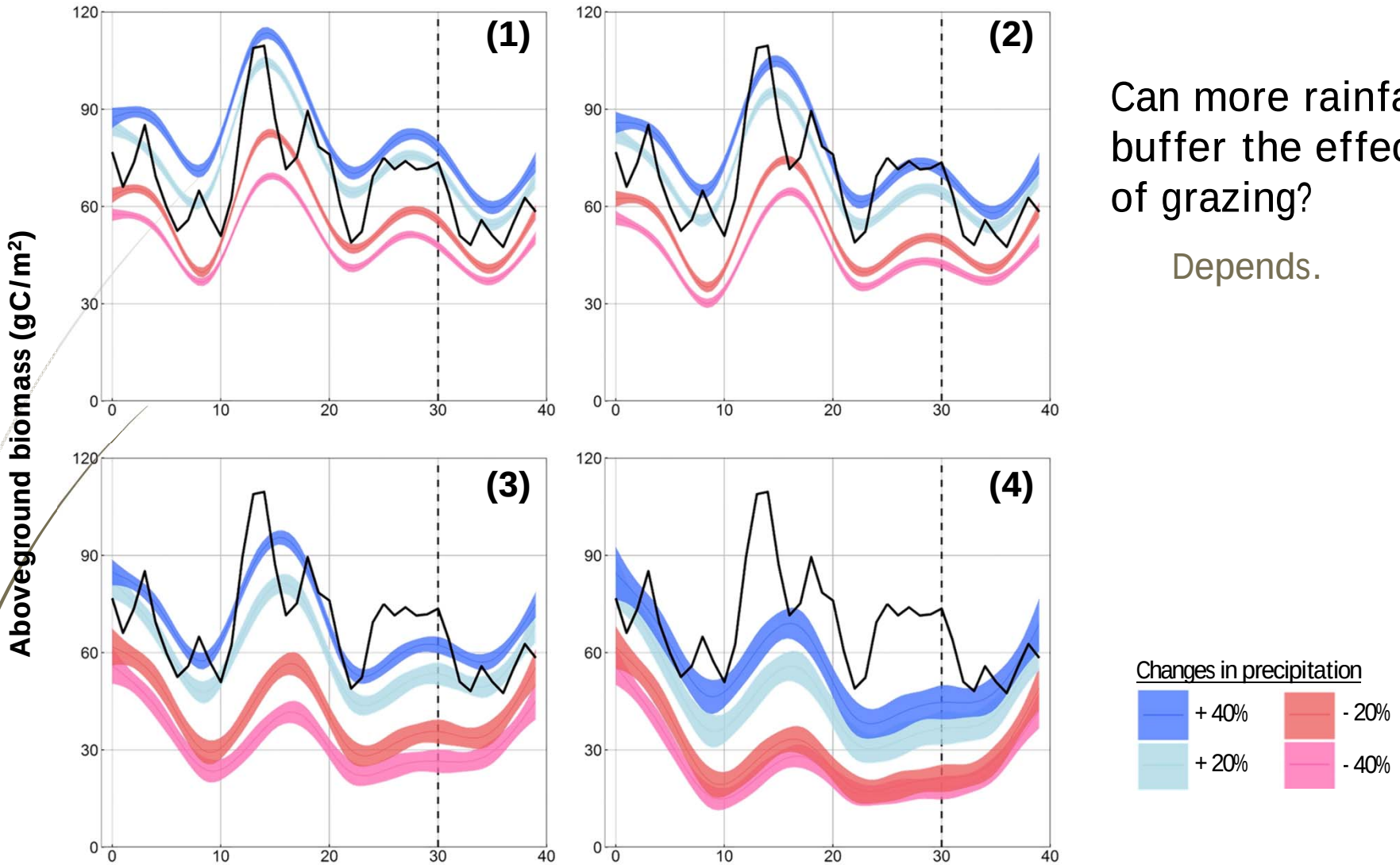
Independent (climatic) variables

- Precipitation
- Temperature



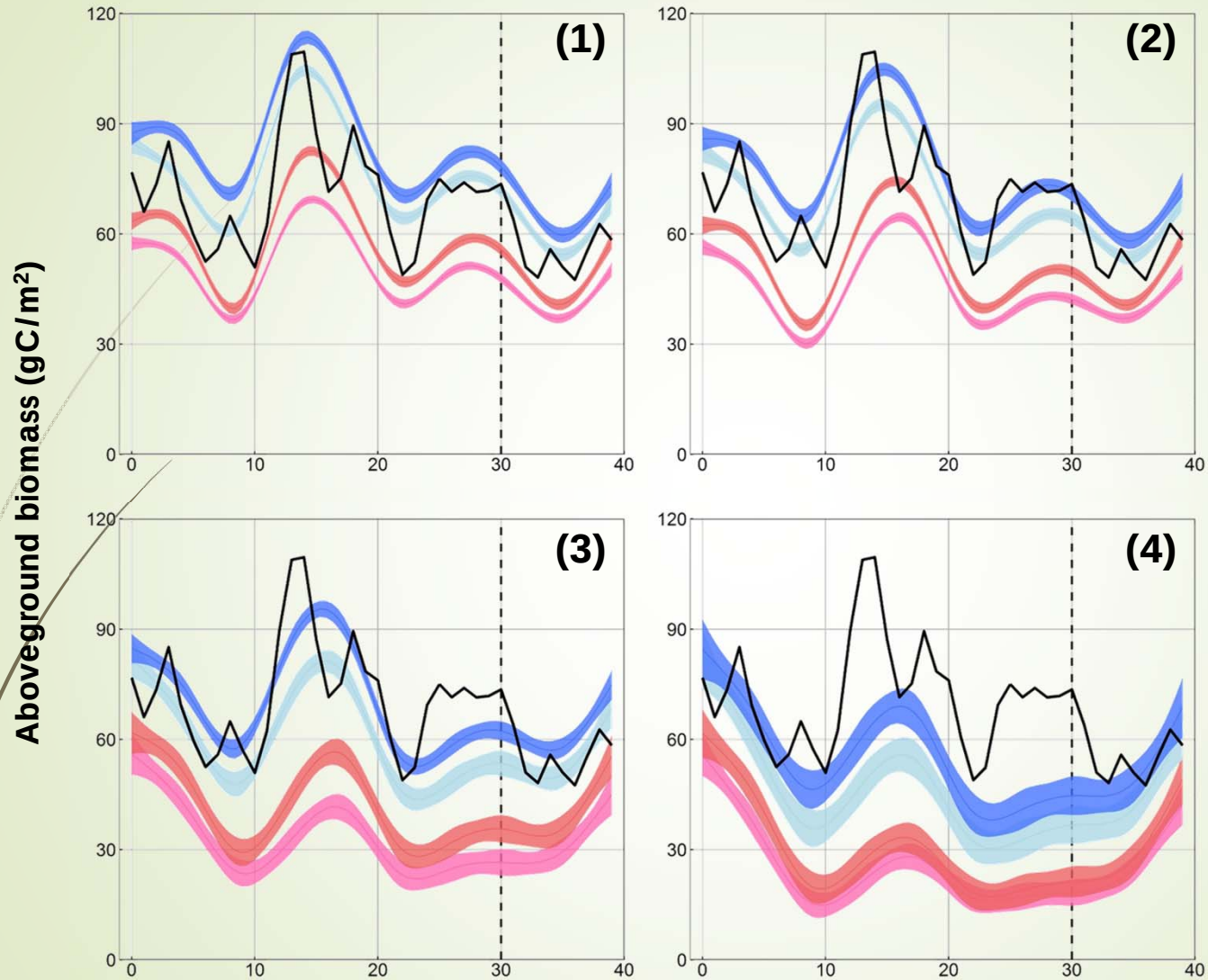

GRAZING INTENSITY
STOCKING DATE
DE-STOCKING DATE
Mean biomass (gC/m²)
80
60
40
20
0
Light
Heavy
May 1
Jun 1
July 1
Aug 1
Sept 1
Oct 1
Nov 1
Change in precipitation
- 40%
- 20%
+ 20%
+ 40%


GRAZING INTENSITY
STOCKING DATE
DE-STOCKING DATE
Mean biomass (gC/m²)
80
60
40
20
0
Light
Heavy
May 1
Jun 1
July 1
Aug 1
Sept 1
Oct 1
Nov 1
Change in precipitation
- 40%
- 20%
+ 20%
+ 40%



Can more rainfall buffer the effects of grazing?

Depends.



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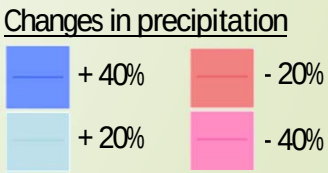
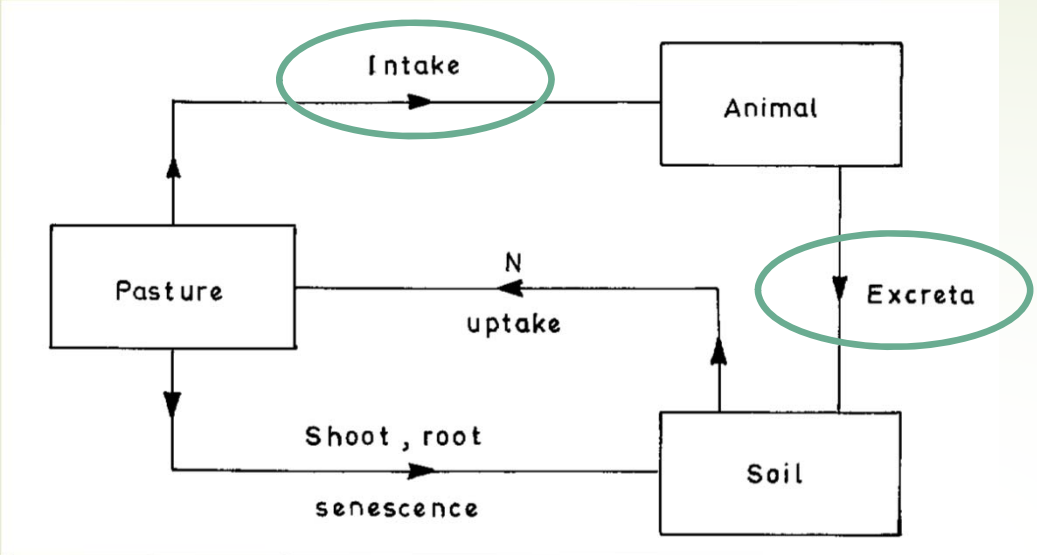
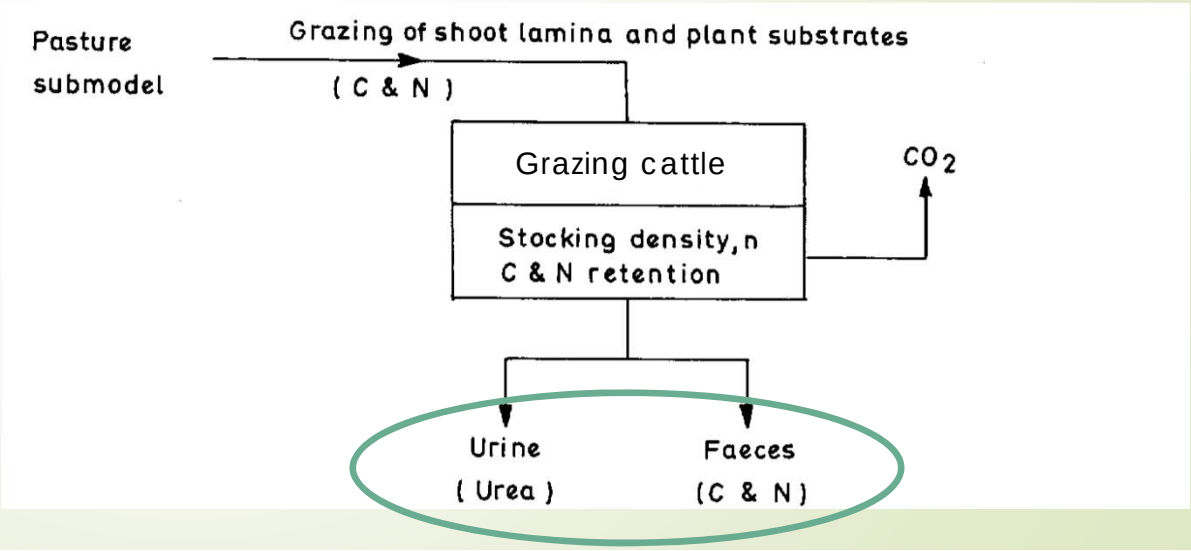



Intake
Animal
Pasture
N
uptake
Excreta
Shoot , root
senescence
Soil


Pasture
submodel
Grazing of shoot lamina and plant substrates
(C & N)
Grazing cattle
Stocking density, n
C & N retention
CO_2
Urine
(Urea)
Faeces
(C & N)

“Multi-scaled investigations of nutrient dynamics, water quality and quantity in the Pacific Northwest”

William M. Forney and Dr. John A. Harrison

Ignite Talk

Washington State University, Pullman

Feb. 25, 2016

The general importance of good water quality in the Columbia River Basin

- Economic value and ecosystem good and services
  - Clean surface water and groundwater
  - Suitable drinking water for private and public water supply
  - Viable commercial fisheries
  - Ecological niches for salmon, wildlife and aquatic habitat
  - Quality recreation opportunities and aesthetics
  - Human well-being and public health

http://www.moore.org/grants/list/GBMF670

Compton et. al., Ecology Letters, 2011;
Keeler et al., PNAS, 2012

Publications
Drs. Harrison, Compton, Adams, Moffett
Grad. Students: V. Rose, R. Norton

- Columbia River Basin Nitrogen budget inputs and improved conceptualization and application of regional Nutrient Export from WaterSheds-Dissolved Inorganic Nitrogen model.
- Using remote sensing products to understand water balances, nutrient dynamics, and Redfield-Brzezinksi ratios in two contrasting western rivers.
- Predictions of dissolved N, P and Si concentrations and loads, understanding their hydrologic and land use controlling factors, and testing theories such as the river continuum concept.
- Network streamflows, distribution systems, and nutrient dynamics of aquatic system components: expansion of theories such as the serial discontinuity concept and the field of riparian landscape ecology.
- Land use, lake morphometry, and water quality as predictors for the occurrence of cyanobacterial blooms in Pacific Northwest lakes

Improvements to the Nutrient Export from WaterSheds model in the Columbia River Basin

William M. Forney[1] and John A. Harrison
School of the Environment , Washington State University, Vancouver, WA
[1] william.forney@wsu.edu, (510) 381-1598

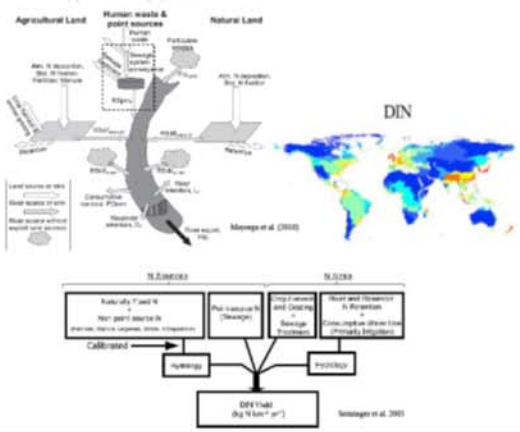
Introduction

- Why do water quantity, quality and their dynamics matter?
  - Water cycle acts as an agent of change in landscapes
  - Clean water is necessary for people and ecosystems (NRC, 2012)
  - Water body impairment from nutrient loading in Columbia River Basin (CRB)
  - Nutrient dynamics of dissolved inorganic nitrogen (DIN) of particular concern
- Two, novel research projects to inform sustainable resource management, system dynamics, and their interactions at multiple scales
  - Regional Earth System Modeling (BioEarth): $3M, 2011-2016.
  - Watershed Integrated Systems Dynamics Modeling (WISDM): $1.3M, 2012-2016.
- Prior applications of global DIN Nutrient Export from WaterSheds model (NEWS2-DIN) to regional scales in northern California watersheds, the Mississippi River Basin, and the CRB.
  - Prior research in the CRB demonstrated that NEWS2-DIN performs well for basins larger than 10,000 km², however, **for basins smaller than 10,000 km² it has no predictive power** (Nash-Sutcliffe efficiency equals or less than zero). (Miller unpub. Masters thesis, 2015)

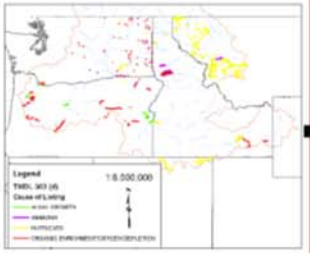
Primary research questions

- Do patterns of DIN yield and loads match known temporal and spatial trends of water quality impairment?
- What are the dominant dynamics of loading, transport and fate of DIN within the CRB and its subwatersheds?
- How can those dynamics and the knowledge gap between plot and global scales be understood better via improvements to NEWS2-DIN$_{CRB}$?
  - Previous lessons learned? Changes to the representation of nutrient processing? Acquisition of new data?

NEWS2-DIN: global to regional application



Study Site: Columbia River Basin (CRB)



Impaired waterbodies in the CRB

Inputs, variables, performance and sensitivities

Model feature type	Inputs	Processing and retention variables	Model efficiencies CRB/CA (R^2)	Model sensitivities CRB/CA (+5%)
Point	Sewage (TN_{sew})	Sewage to surface water (FE_{pnt})	0.71/0.49, NA	0.80/0.34, NA
	Fish farms (TN_{fish})	Wastewater treatment per County (T_N)	0.74/NA, NA	0.10/NA, NA
	Industrial facilities (TN_{fac})	Maximum possible wastewater treatment efficiency (max T_N)	0.75/NA, NA	0.06/NA, NA
Non-point source (NPS)	Fertilizer (TN_{fert})	NPS TN to surface waters (FE_{nps})	**0.31**/-**0.58**, NA	**3.65**/**5.34**, NA
	Manure (TN_{man})		**0.69**/**0.25**	**2.07**/**3.34**
	Agricultural N fixation (TN_{frcrop})		0.76/0.50	**2.22**/0.71
	Natural N fixation (TN_{frnat})		**0.69**/0.47	**2.94**/0.98
	Agricultural N deposition ($TN_{depcrop}$)		0.74/NA	0.19/NA
	Natural (non-ag) N deposition (TN_{depnat})		0.78/NA	1.86/NA
Biophysical	Runoff (R)	Riverine DIN exported (FE_{rpn}), watershed export (e)	**-14.11**/-**20.65**, NA, -**0.47**/**0.33**	**2.95**/**13.23**, NA, **5.00**/**5.00**
	Annual discharge/basin (Q_{out})	DIN lost in river processing (L), Runoff modulation (a)	NA, -**0.22**/**0.16**, **0.70**/NA	NA, **9.29**/**8.26**, **4.95**/NA
		DIN lost by consumptive use (Q_{cons})	0.76/-**0.40**	**3.66**/**53.54**
	Basin area (A)	River network processing (c and d)		**9.05**/**8.85**, 0.60/0.59
Management and anthropogenic influence	Crop harvest and export (TN_{exp})		**0.62**/**0.43**	**3.07**/**1.59**
	Depth of reservoir, i (h_i)	DIN retained in reservoirs (D)	NA, 0.75/**0.13**	NA, 0.89/**11.29**

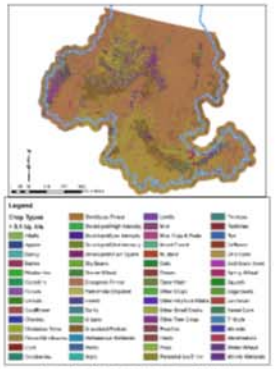
Definitions:

1) Efficiency: change in NSE (R^2) by removing variable from full models, where CRB = 0.75, CA = 0.49
2) Sensitivity: maximum percent change to DIN yield resulting from 5 percent increase in variable

Miller, 2014 and Goodwin 2010, unpub. Masters thesis

- Hydrology, runoff, river and watershed processing have the largest uncertainties
- Fertilizer and manure application are next largest opportunities for improvement, then natural and agricultural N fixation, and then crop harvest and export
- Agricultural and natural N deposition presents a limited opportunity

Preliminary results for NEWS2-DIN$_{CRB}$ improvements

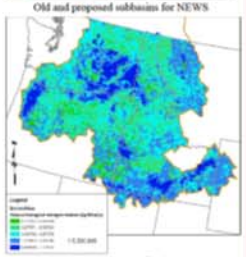


Crop classification for US portion of CRB

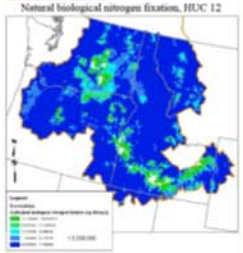
CDL Classification	Low Kg N/ha/yr	High Kg N/ha/yr	Median Kg N/ha/yr
Misc	234.2	280.2	232.2
Spring Wheat	112.1	237.8	184.9
Winter Wheat	112.1	237.8	184.9
Barley	112.1	237.8	184.9
Oats	112.1	237.8	184.9
Corn	44.8	241.0	142.9
Sweet Corn	44.8	241.0	142.9
Sugarbeets	145.7	190.5	168.1
Blueberries	112.1	184.9	148.5
Rye	134.5	179.3	156.9
Soft/Grass Seed	125.3	179.3	152.4
Christmas Trees	112.1	168.1	140.1
Hops	112.1	168.1	140.1
Grassland/ Pasture	112.1	134.5	123.3
Dry Beans	56.0	89.7	72.9
Onions	44.8	89.7	67.3
Radishes	56.0	84.1	70.1
Strawberries	28.0	56.0	42.0
Cherries	16.8	56.0	36.4
Peaches	16.8	56.0	36.4
Apples	16.8	56.0	36.4
Grapes	0.0	6.7	3.4
Clover/ Wildflowers	0.0	0.0	0.0
Alfalfa	0.0	0.0	0.0
Fallow/Idle Crop	0.0	0.0	0.0

Agricultural extension recommendations for N application
Jana Compton et al. In preparation

Old and proposed subbasins for NEWS



Natural biological nitrogen fixation, HUC 12



Cultivated biological nitrogen fixation, HUC 12

Lessons learned

1. Dominant N dynamics are identified and mostly represented
2. Prior regionalization efforts demonstrate opportunities for NEWS2-DIN$_{CRB}$
3. Data are available to support its improvement, and are easier to obtain than improved mechanistic representation of nutrient processing
4. Hydrologic dynamics via the variable infiltration capacity (VIC) model offer the biggest opportunity for model improvements

Next steps

Nutrient processing
-hydrology, watershed and river processing
-reservoir retention
-topographic complexity
-representation of seasonal dynamics

Input data
-Canada
-differential manure application
-water diversions
-stream representation and attribution
-alder mapping

Then: N dynamics α impairment

Acknowledgements: Funding was provided by NSF's Water and Sustainability Program and USDA's National Institute for Food and Agriculture. Thanks to Prof. Jenny Adams, Dr. Jana Compton, Dr. Michelle McCrackin, Cody Miller, Kara Goodwin, and our colleagues in the Global Change and Watershed Biogeochemistry Lab for their contributions to this work.

Cover Page for Proposal Submitted to the National Aeronautics and Space Administration

NASA Proposal Number

TBD on Submit

NASA PROCEDURE FOR HANDLING PROPOSALS

This proposal shall be used and disclosed for evaluation purposes only, and a copy of this Government notice shall be applied to any reproduction or abstract thereof. Any authorized restrictive notices that the submitter places on this proposal shall also be strictly complied with. Disclosure of this proposal for any reason outside the Government evaluation purposes shall be made only to the extent authorized by the Government.

SECTION I - Proposal Information

Principal Investigator	E-mail Address	Phone Number
John Harrison	john_harrison@vancouver.wsu.edu	360-546-9210

Street Address (1)	Street Address (2)
14204 NE Salmon Creek Ave	230B, VELS

City	State / Province	Postal Code	Country Code
Vancouver	WA	98686-9600	US

Proposal Title : Using remote sensing products to understand water balances, nutrient dynamics, and Redfield-Brzezinksi ratios in two contrasting western rivers.

Proposed Start Date	Proposed End Date	Total Budget
09 / 01 / 2016	08 / 31 / 2017	No budget required

SECTION II - Application Information

NASA Program Announcement Number	NASA Program Announcement Title
NESSF16	NASA Earth and Space Science Fellowship 2016

For Consideration By NASA Organization *(the soliciting organization, or the organization to which an unsolicited proposal is submitted)*

NASA , Headquarters , Science Mission Directorate

Date Submitted	Submission Method	Grants.gov Application Identifier	Applicant Proposal Identifier
	Electronic Submission Only		

Type of Application	Predecessor Award Number	Other Federal Agencies to Which Proposal Has Been Submitted
New		

International Participation	Type of International Participation
No	

SECTION III - Submitting Organization Information

DUNS Number	CAGE Code	Employer Identification Number (EIN or TIN)	Organization Type
041485301	0REV0		2A

Organization Name (Standard/Legal Name)	Company Division
Washington State University, Pullman	
Organization DBA Name	**Division Number**

Street Address (1)	Street Address (2)
240 FRENCH ADMINISTRATION BLDG	

City	State / Province	Postal Code	Country Code
PULLMAN	WA	99164	USA

SECTION IV - Proposal Point of Contact Information

Name	Email Address	Phone Number
John Harrison	john_harrison@wsu.edu	360-546-9210

SECTION V - Certification and Authorization

Certification of Compliance with Applicable Executive Orders and U.S. Code

By submitting the proposal identified in the Cover Sheet/Proposal Summary in response to this Research Announcement, the Authorizing Official of the proposing organization (or the individual proposer if there is no proposing organization) as identified below:

- certifies that the statements made in this proposal are true and complete to the best of his/her knowledge;
- agrees to accept the obligations to comply with NASA award terms and conditions if an award is made as a result of this proposal; and
- confirms compliance with all provisions, rules, and stipulations set forth in this solicitation.

Willful provision of false information in this proposal and/or its supporting documents, or in reports required under an ensuing award, is a criminal offense (U.S. Code, Title 18, Section 1001).

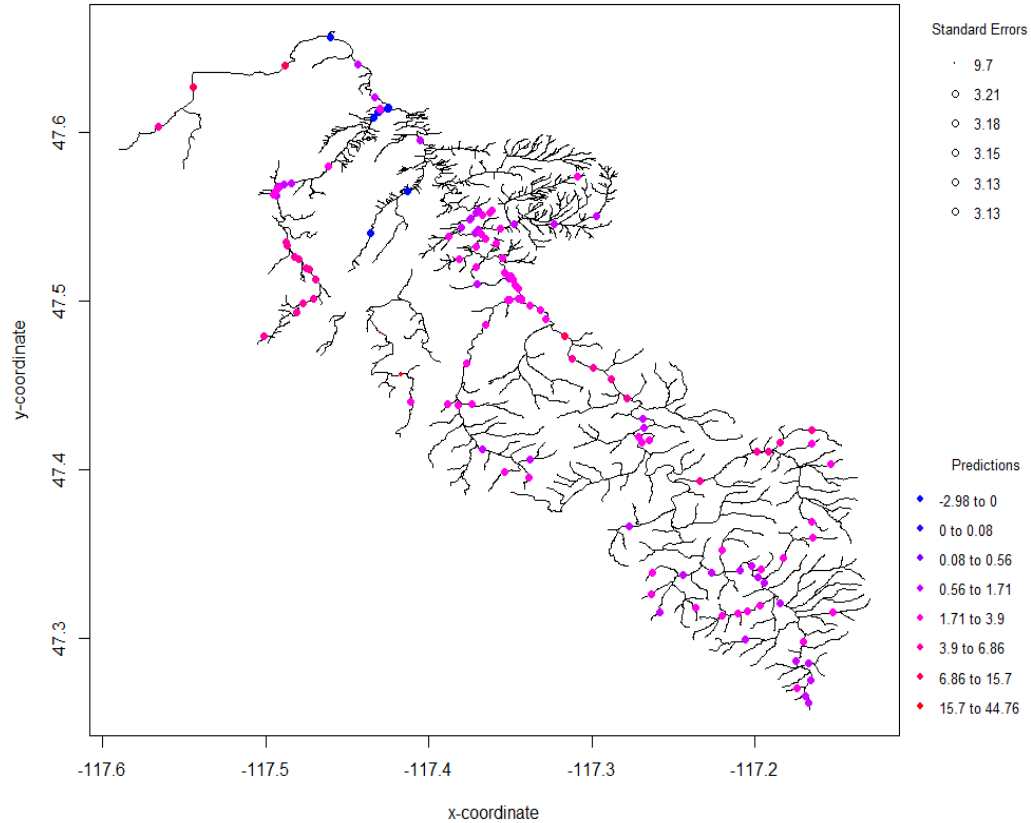
Authorized Organizational Representative (AOR) Name	AOR E-mail Address	Phone Number

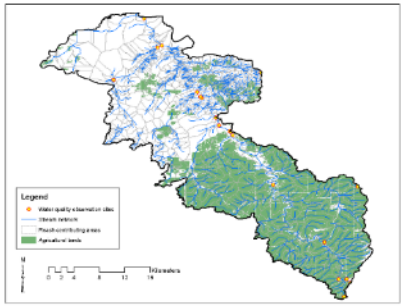
AOR Signature *(Must have AOR's original signature. Do not sign "for" AOR.)* Date

FORM NRESS-300 Version 3.0 Apr 09

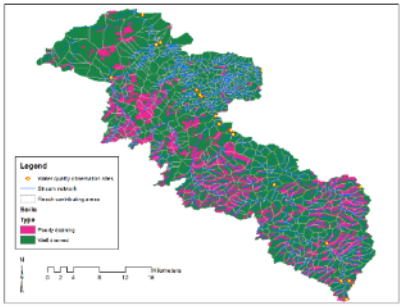
Using remote sensing products to understand water balances, nutrient dynamics, and Redfield-Brzezinksi ratios in two contrasting western rivers

Predictions of dissolved N, P and Si, understanding their hydrologic and land use controlling factors, and testing theories such as the river continuum concept.

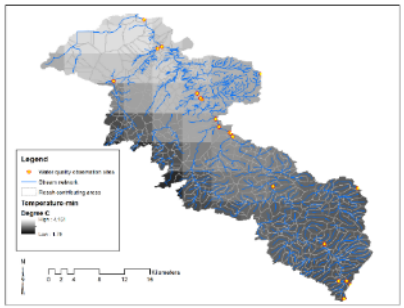




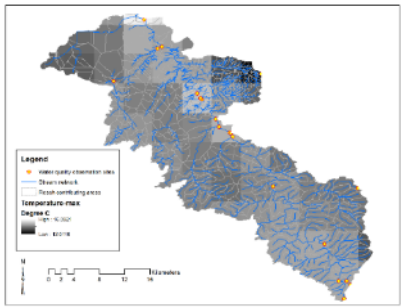
Agricultural lands



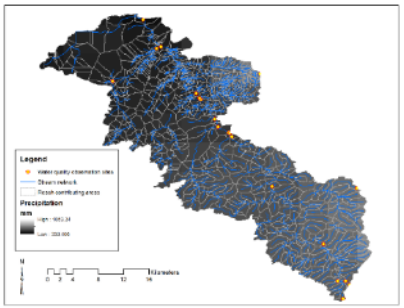
Poor draining soils



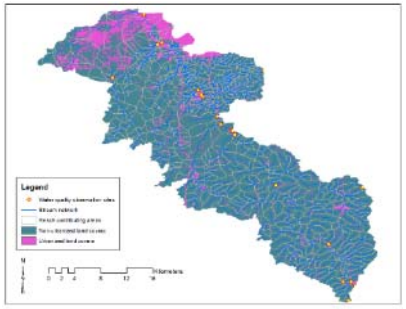
Temperature, min



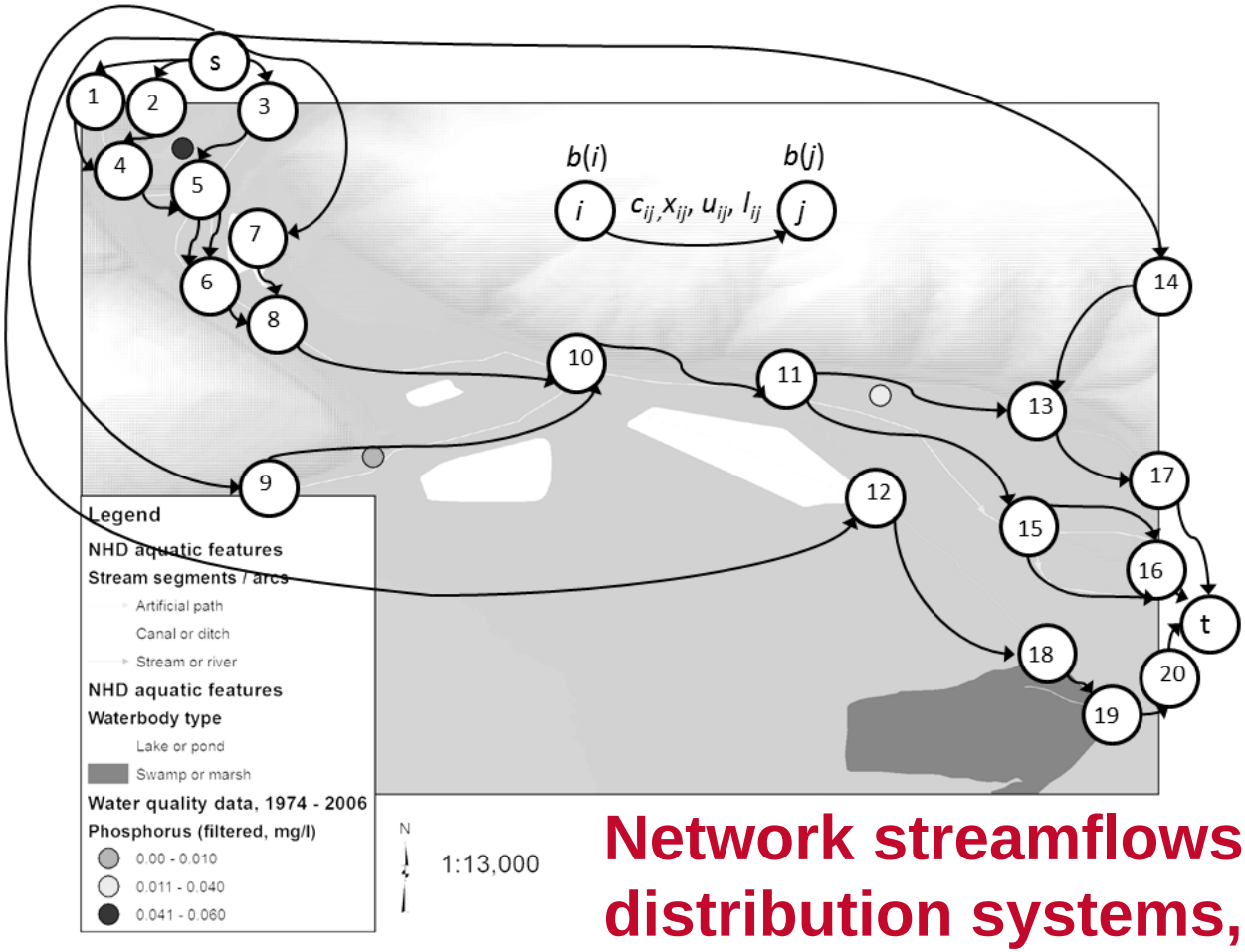
Temperature, max



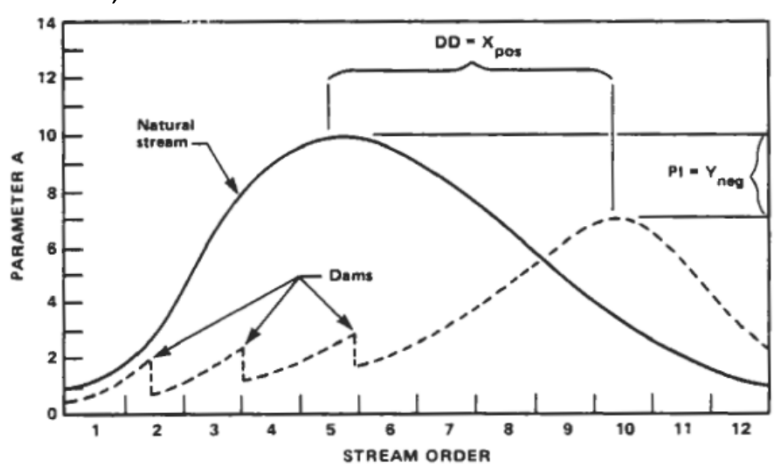
Precipitation



Developed lands



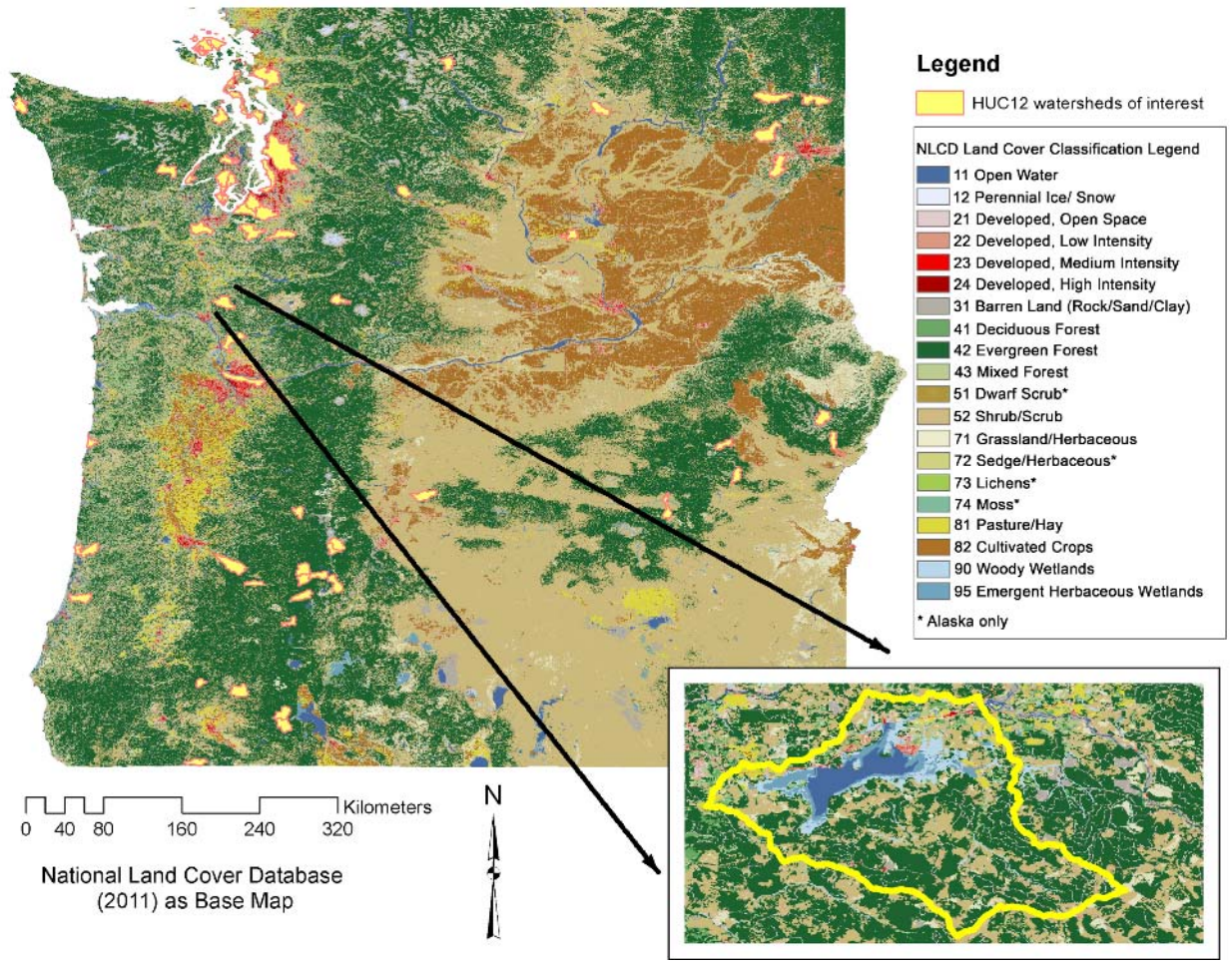
Ward and Stanford, 1983



Network streamflows, distribution systems, and nutrient dynamics of aquatic system components: expansion of theory such as the serial discontinuity concept and the field of riparian landscape ecology.

Land use, lake morphometry, and water quality as predictors for the occurrence of cyanobacterial blooms in Pacific Northwest lakes

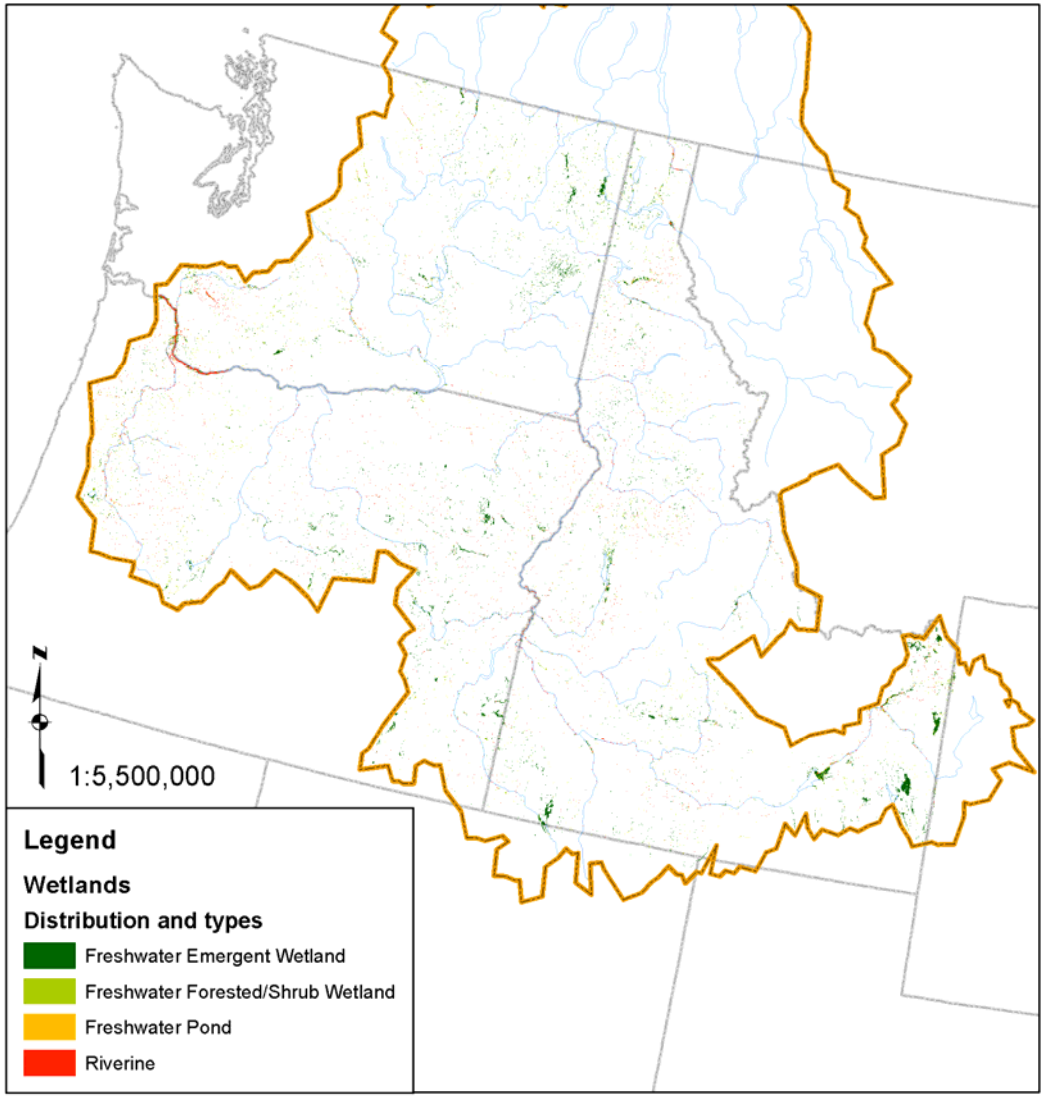
Variable	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-2.262184	0.919478	-2.460	0.01388 *
Drainage area (km^2)	0.006306	0.002426	2.599	0.00934 **
DIP load ($kg/km^2/yr$)	0.053812	0.031613	1.702	0.08871 .
Grassland.Herbaceous (%)	-61.370266	33.359740	-1.840	0.06582 .
Woody.Wetlands (%)	75.583887	30.796118	2.454	0.01411 *



Integration with BioEarth

- VIC modeling (RHESSys?)
- Regional N Budget (John et al.)
- Scenarios?

Integration with BioEarth...?



Wetlands of WA, ID, OR of the CRB

- Flow and N passing through wetlands
- Uptake and denitrification zones

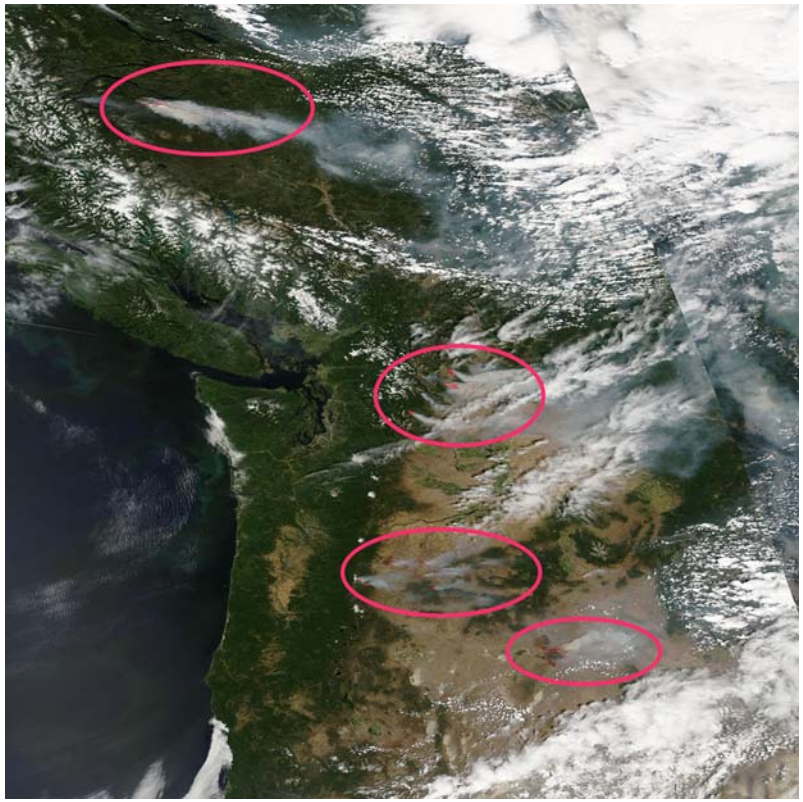
Impacts of wildfire aerosols on crop growth

Quentin Baret

WASHINGTON STATE UNIVERSITY

I. Introduction

- Wildfires in the western U.S. release a significant amount of aerosols into the atmosphere
- Critical phenomenon to study as the area burned by fires is expected to double by 2040s [1]
- Wildfires can last for several weeks and affect air quality, visibility, radiation, and potentially crop growth



Source: NASA's Terra satellite on Thursday, July 17, 2014

[1] Littell et al (2009)

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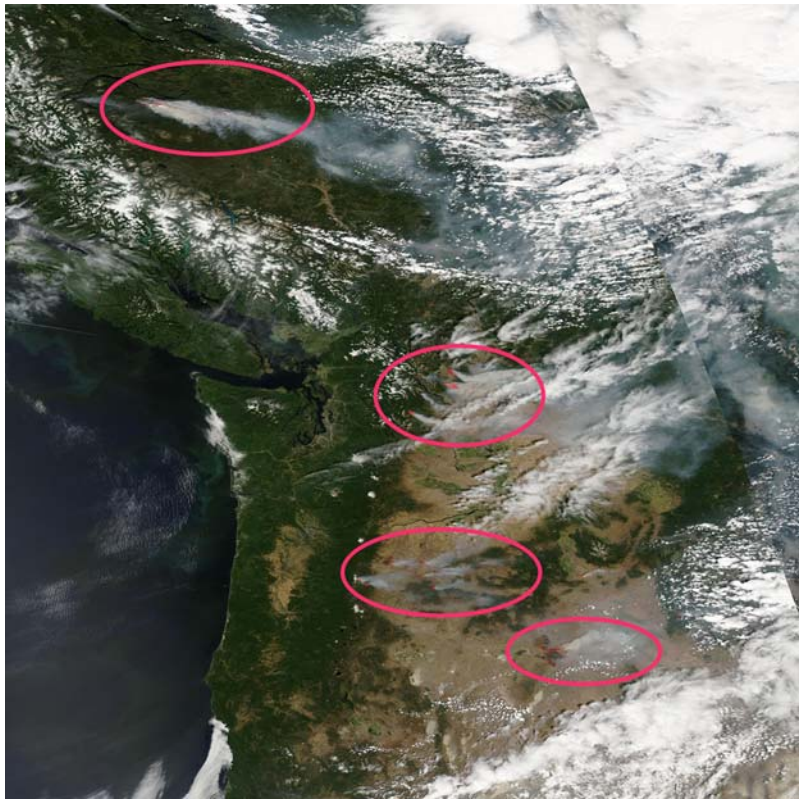

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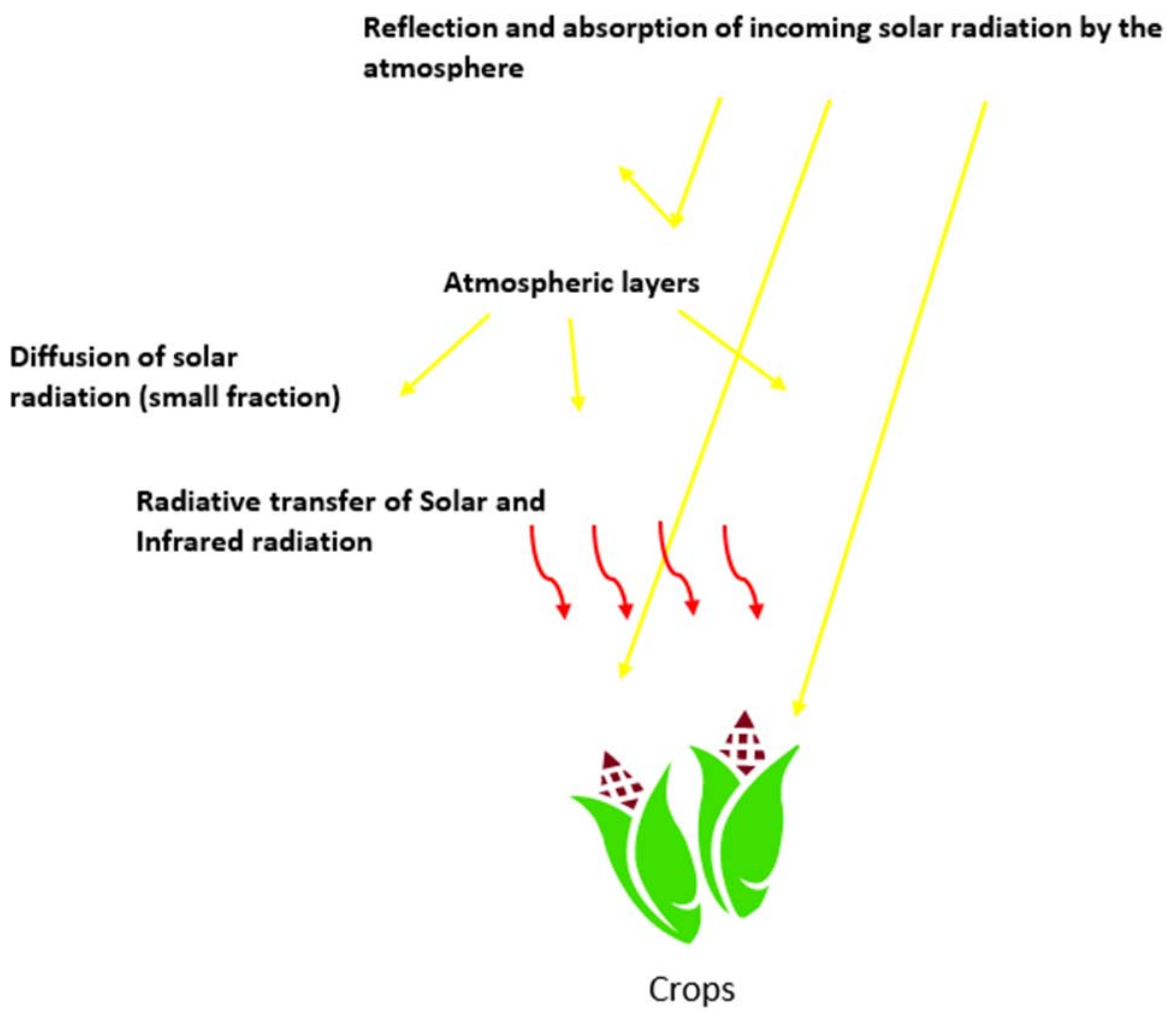
II. Radiative transfer



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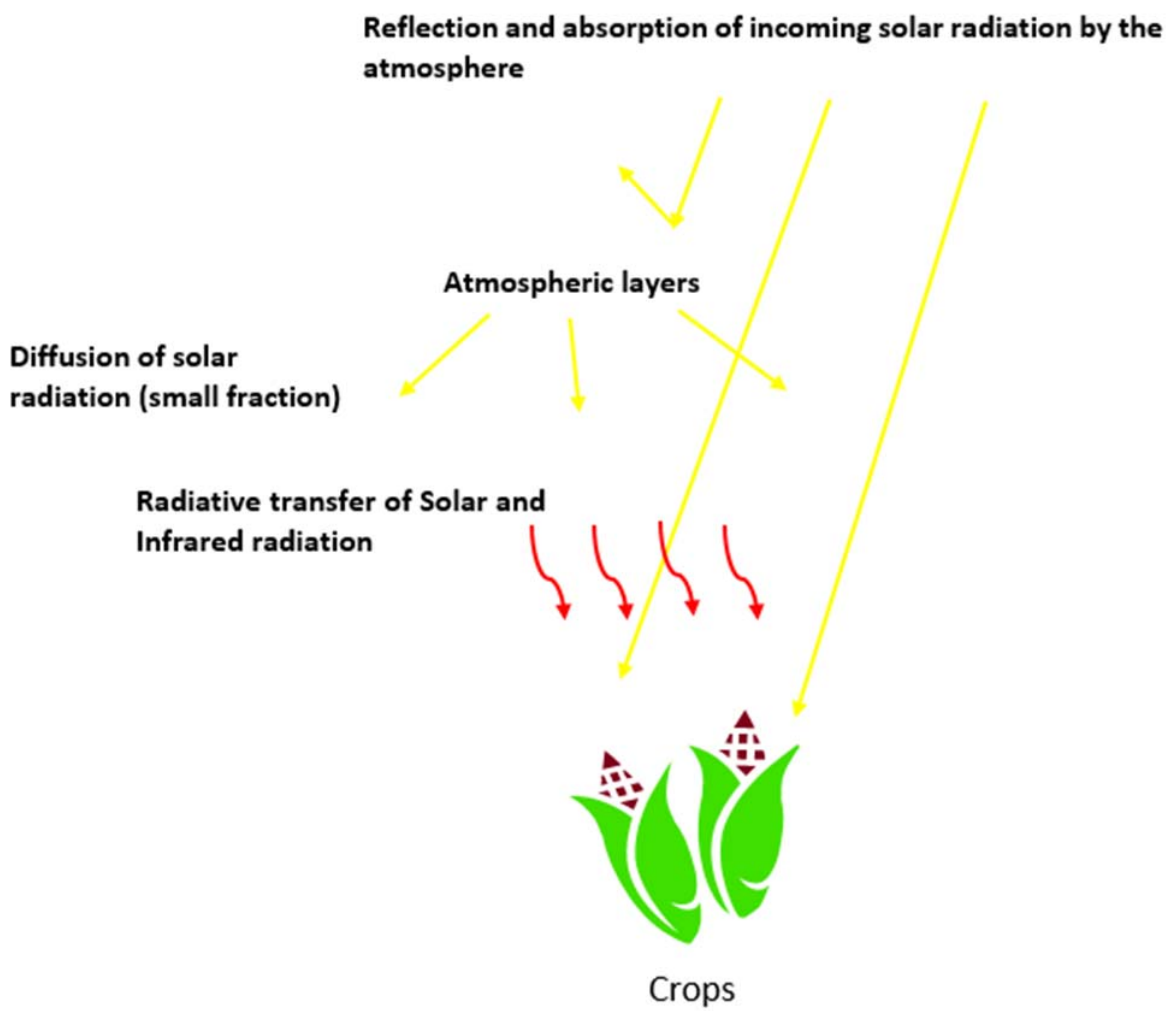

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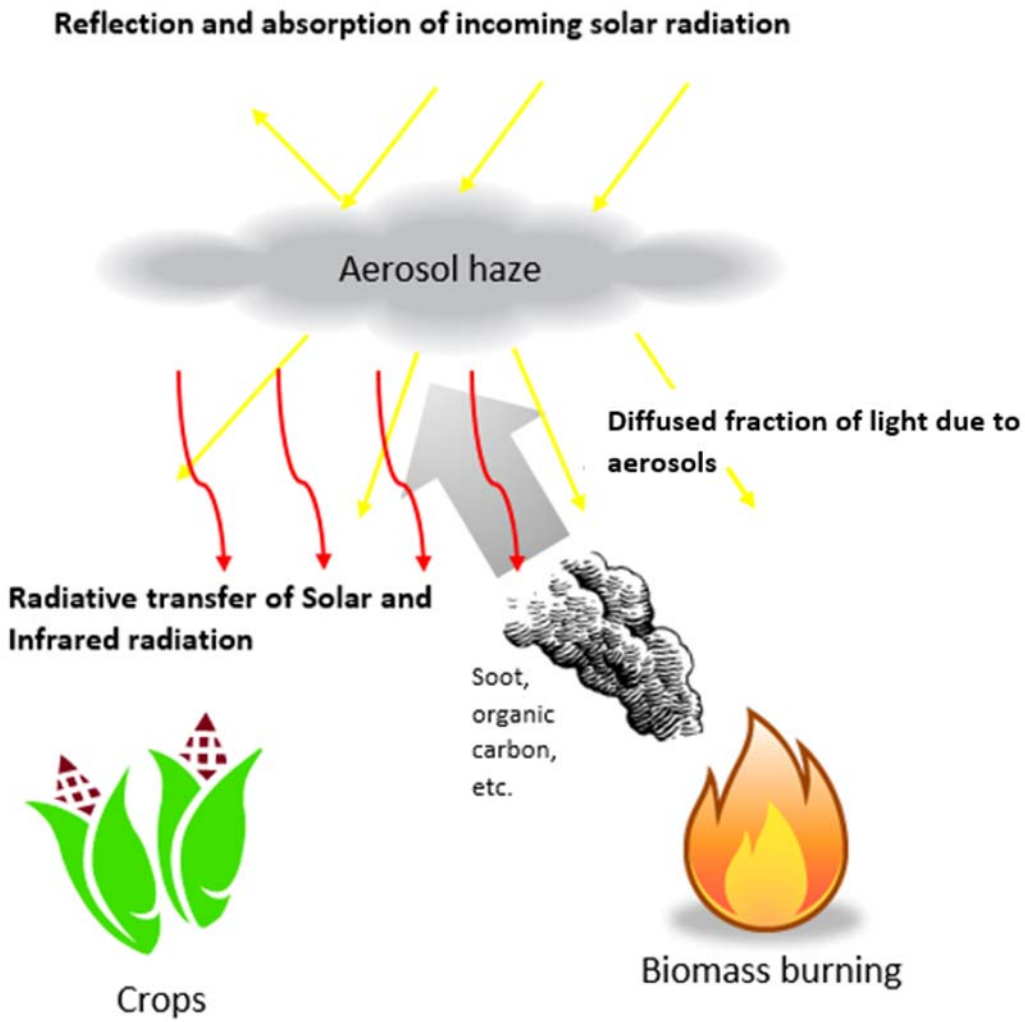

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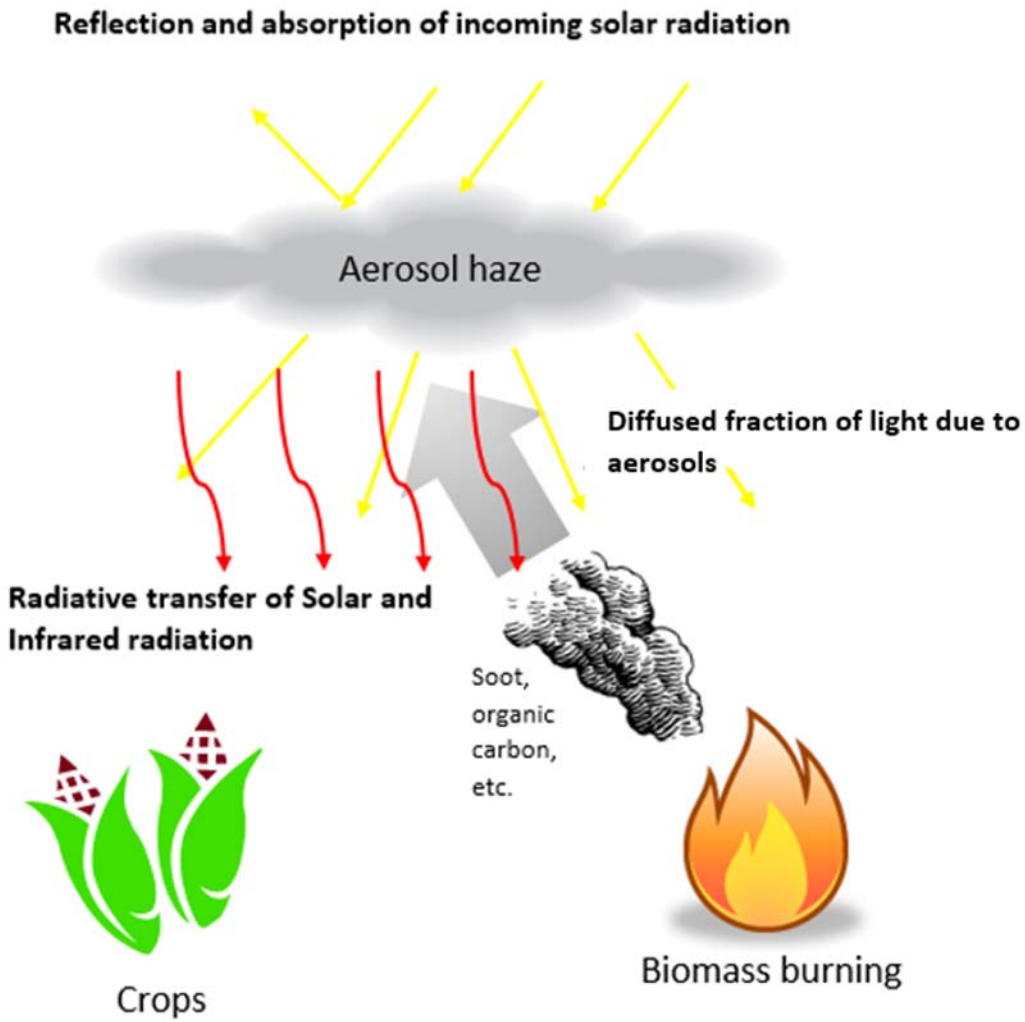
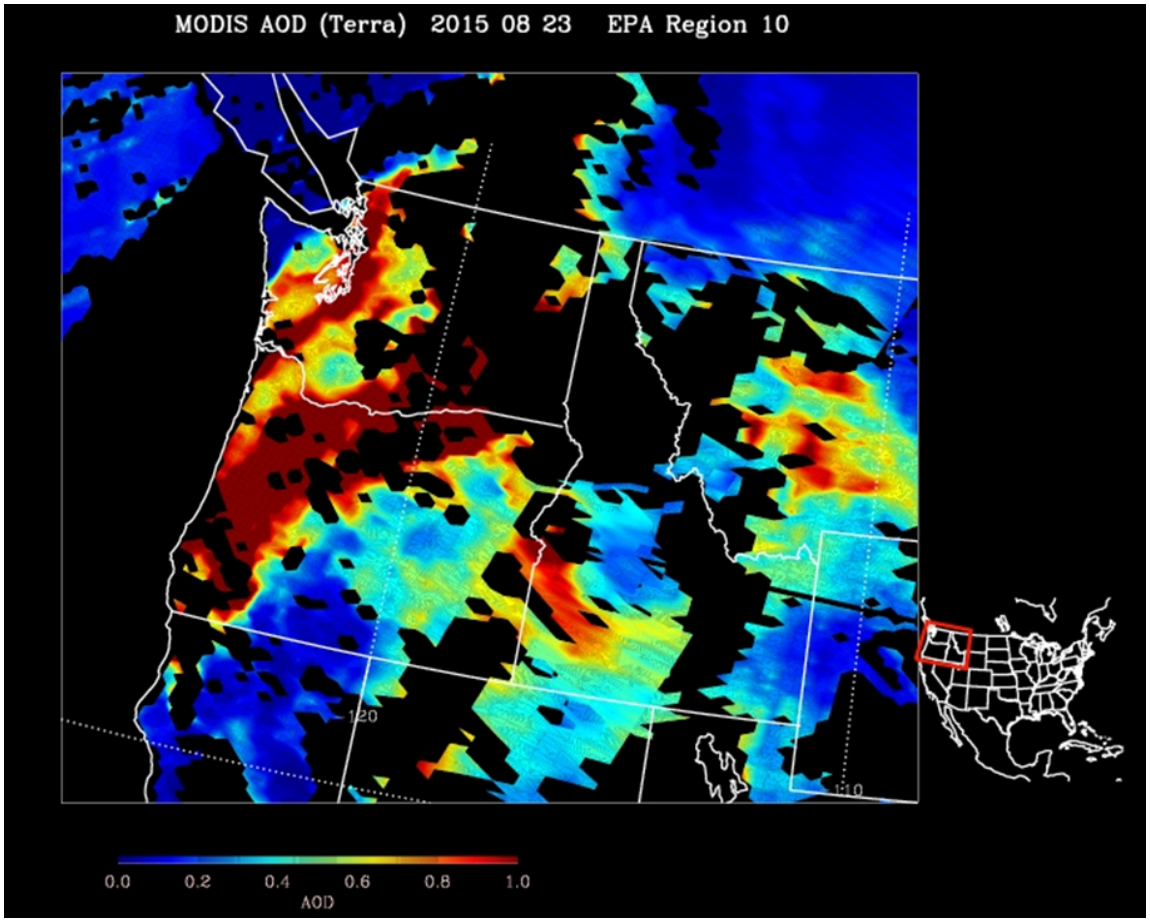


III. Satellite data from MODIS



Source: NESDIS NOAA website
http://www.star.nesdis.noaa.gov/smcd/spb/aq/index.php?plot_year=2015&plot_month=08&plot_day=23&plot_gmt=1215&product_gmt=2015&plot_type=mod_Region&region=10&product_date=20120801&product_id=1&goto_date=Go

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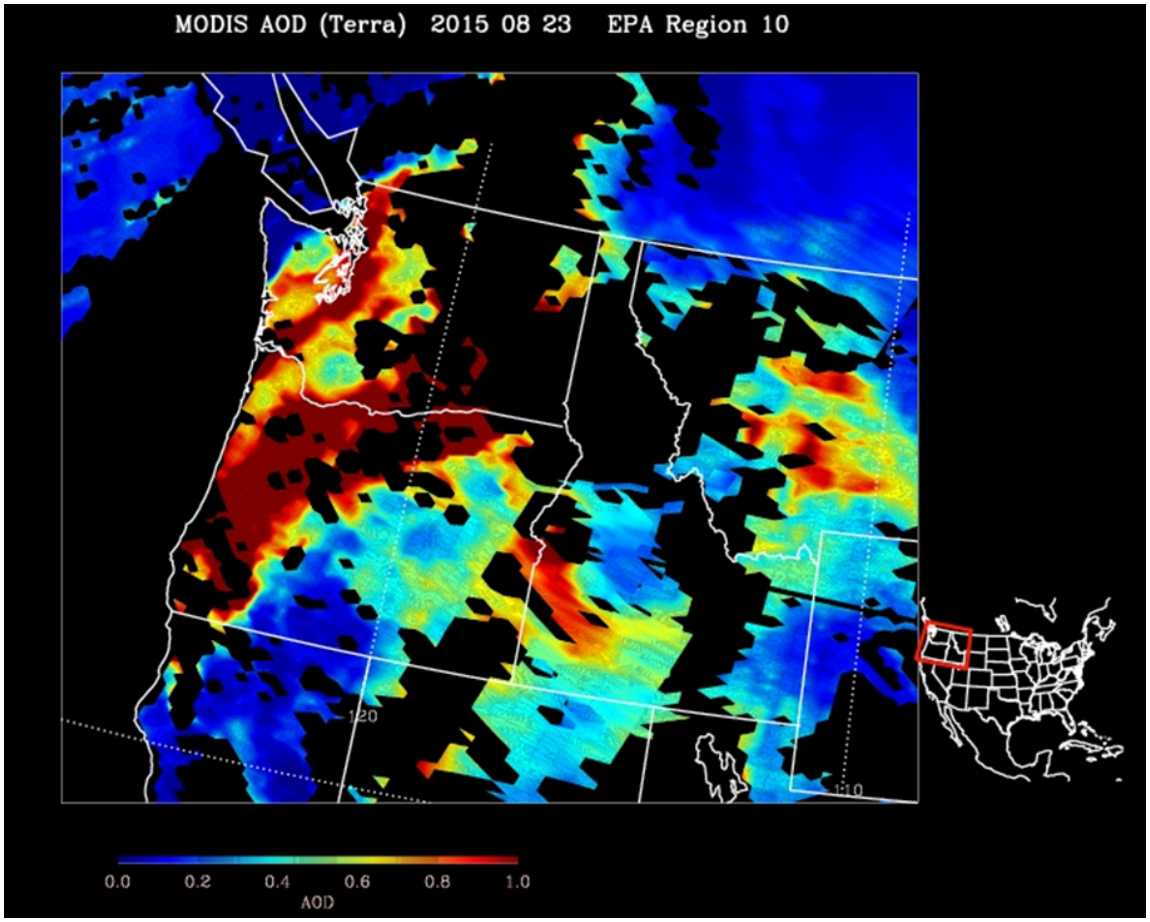

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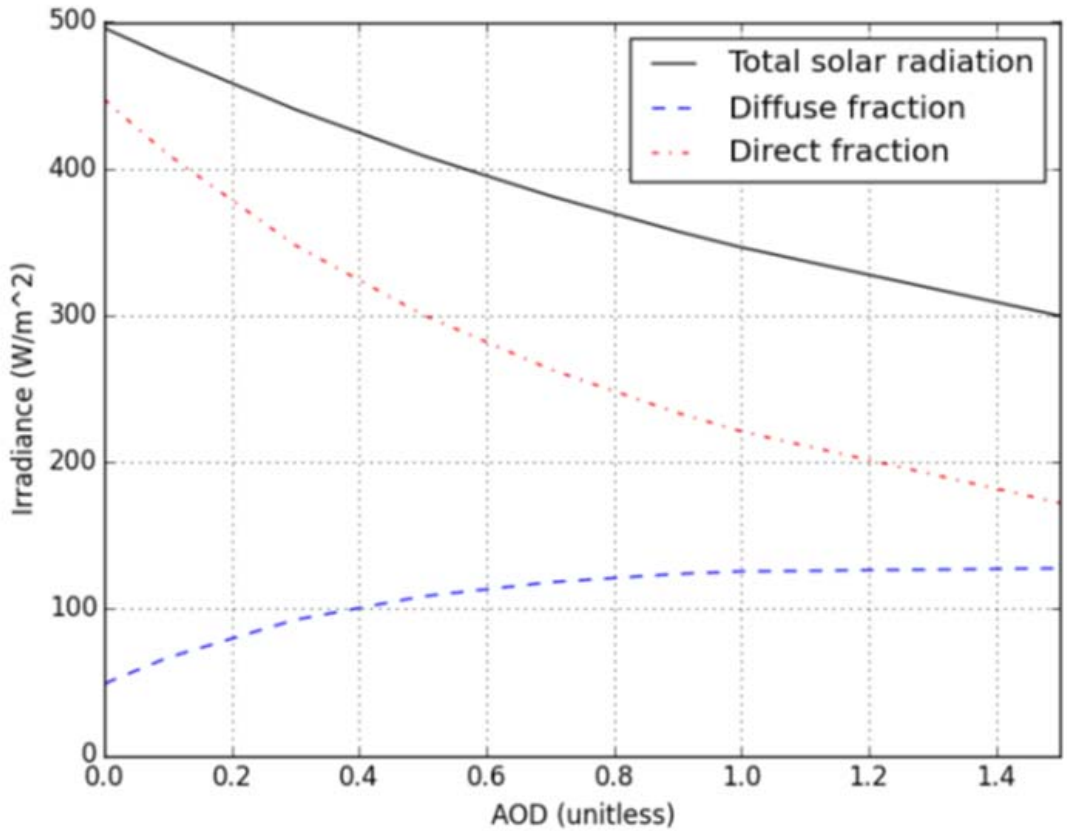
IV. Results from RRTM for Pullman

- Up to 40% decrease in the total radiation due to scattering and absorption by aerosols
- Increase in the diffuse fraction due to scattering (diffusion of the radiation)

Downwelling solar radiation at the surface (both diffuse and direct) as a function of aerosol optical depth (AOD). The solar zenith angle simulated was 60°



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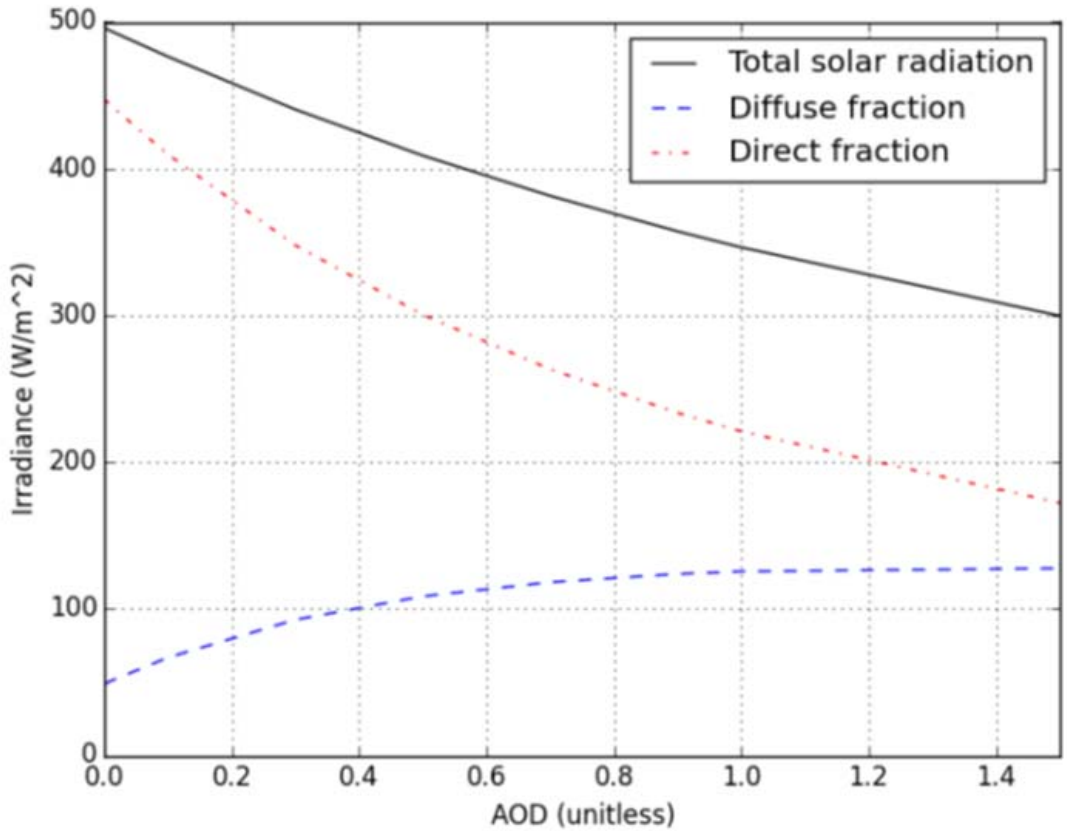

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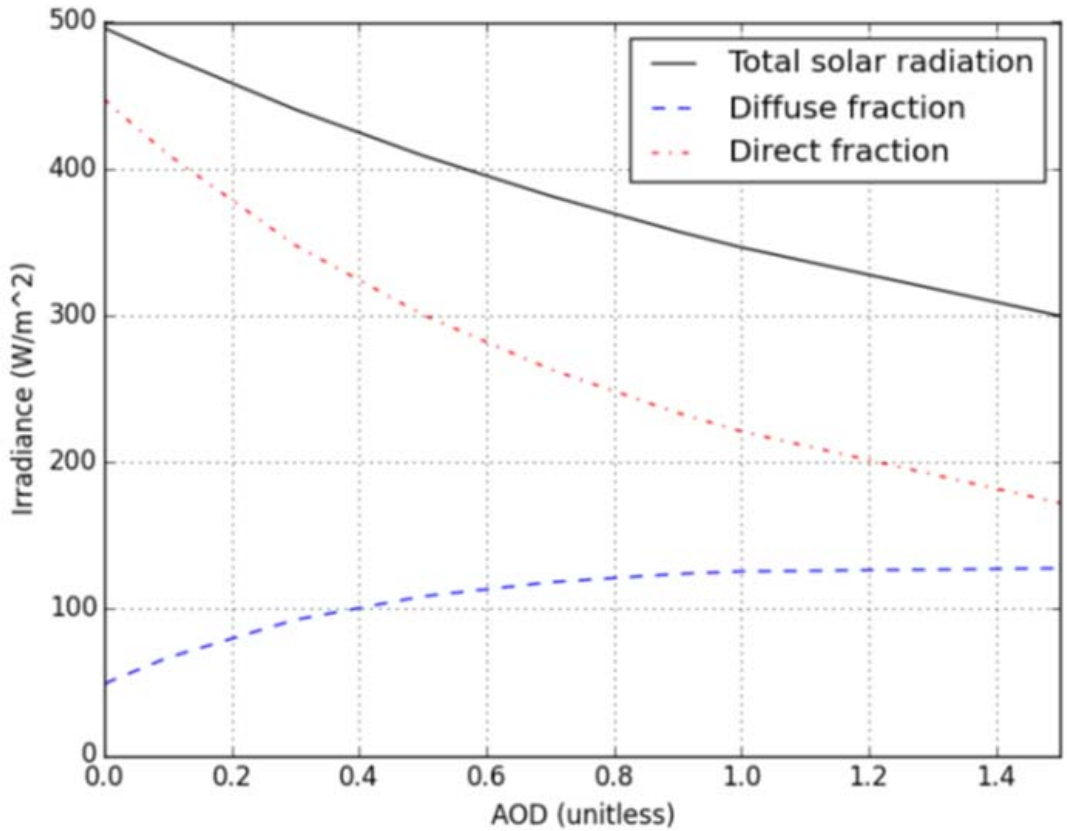

V. Scenarios for crop model

- 4 scenarios for the year 2015 during the months June, July and August:
  - No aerosol (for the entire year)
  - Low and constant aerosol load with AOD of 0.33 at 550 nm
  - Moderate and constant aerosol load with AOD of 0.67 at 550 nm
  - High and constant aerosol load with AOD of 1.0 at 550 nm

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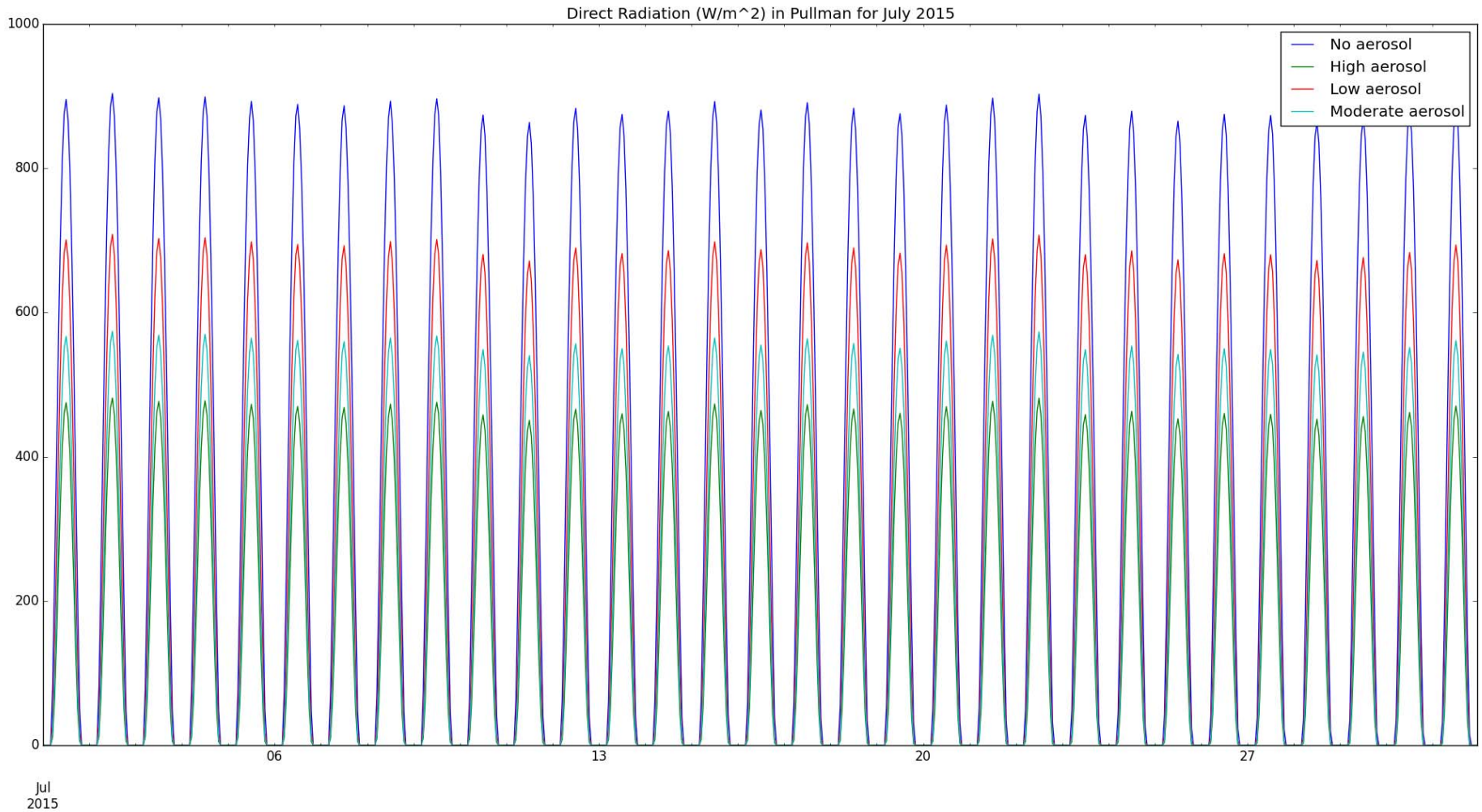
Direct Radiation (W/m²) in Pullman for the month of July in 2015



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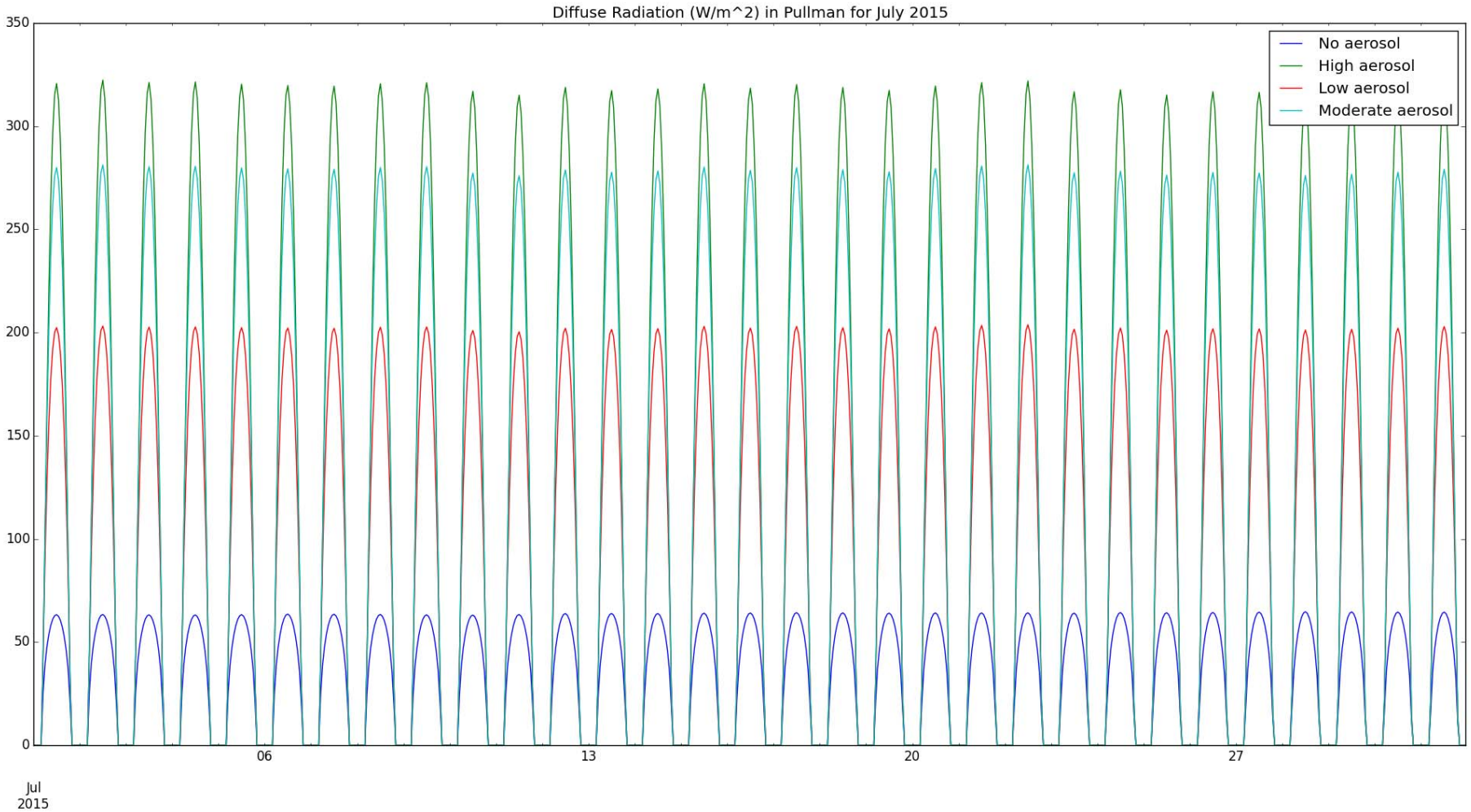
Diffuse Radiation (W/m²) in Pullman for the month of July in 2015



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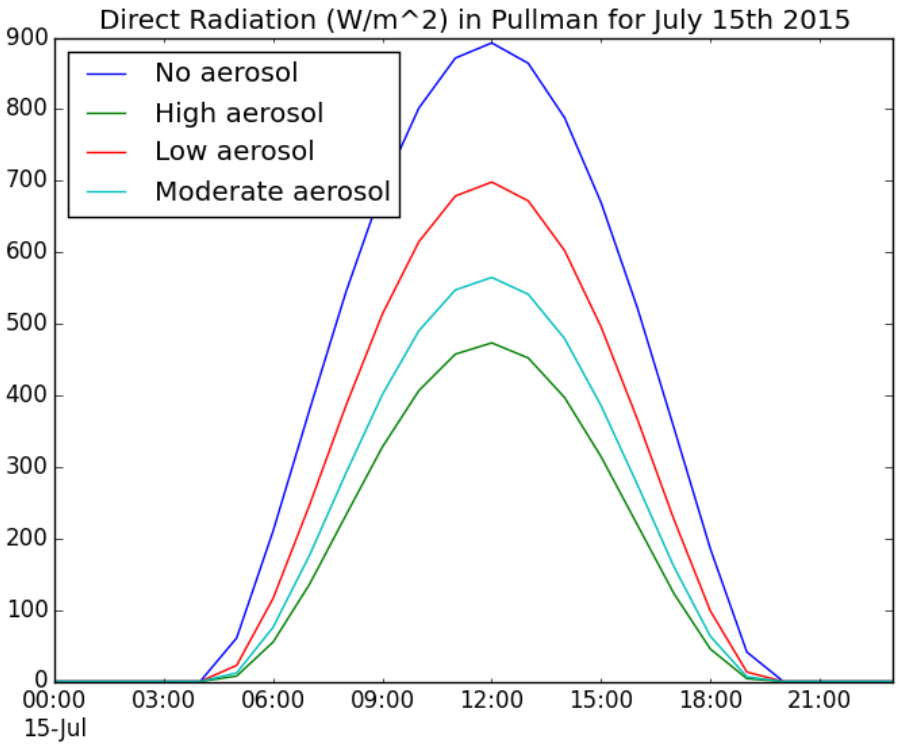

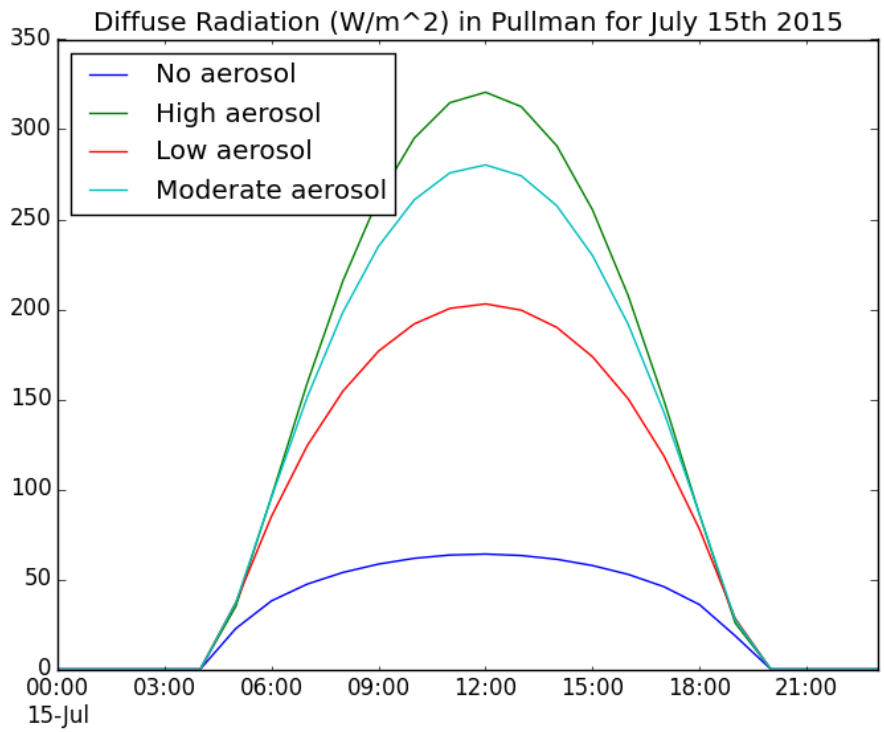

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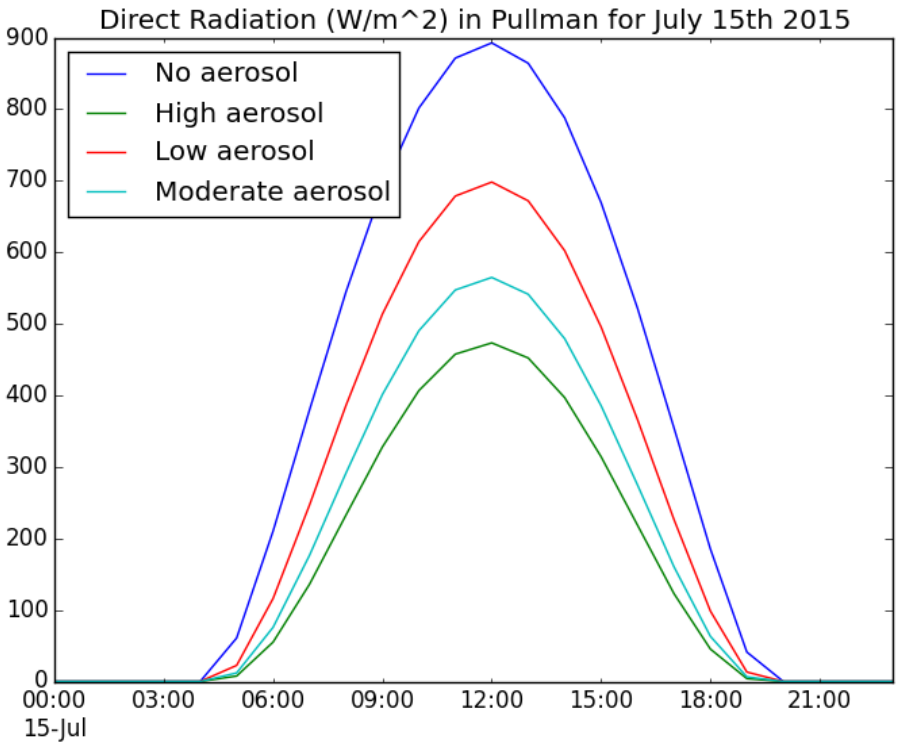

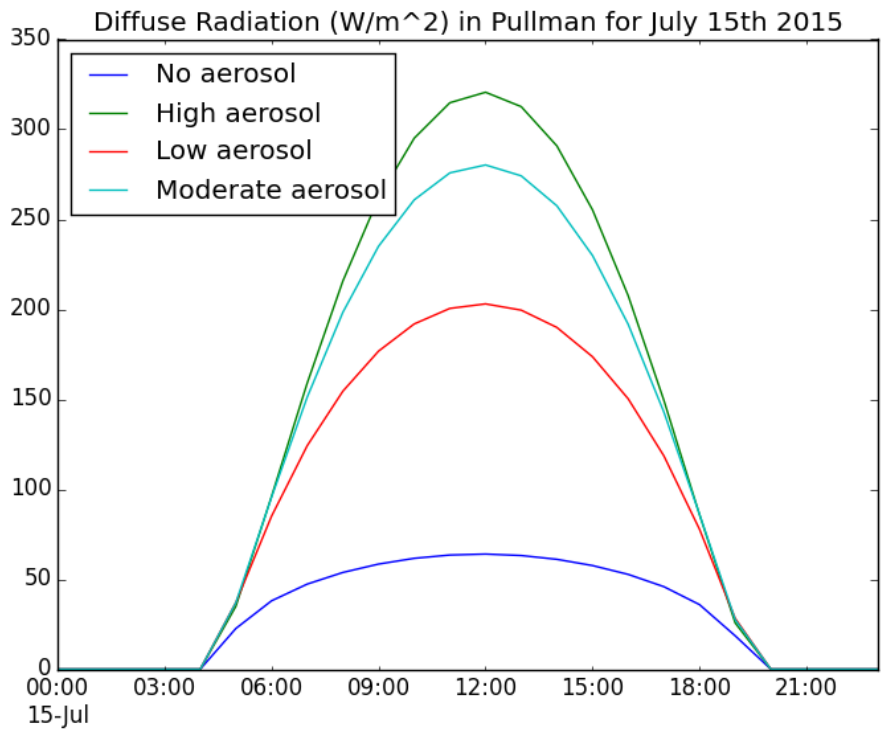

VI. Work in progress

- Leaf model from Dr. Stöckle to be used and maybe CropSyst in the coming weeks
- Sensitivity study
  - Changing the timing of wildfire aerosols (month by month)
  - Possibility in different effects related to the growing stage of the crop (wheat)
- Realistic scenario
  - Integration of the realistic aerosol parameters for 2015
  - Showing realistic and current impacts on wheat

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BioEarth – Economics

Overview

- Goal for end of BioEarth
  - Integrated hydrology-economics model
  - VIC-CropSyst provides
    - Location specific crop growth functions
    - Hydrology integrated with water rights to model water availability
  - Accurate representation of how ag production will vary with changing yield potential, drought, and external markets.

Update

- Work the past year has focused on finishing crop water yield curves.

- Yield Curves – key component of the integrated hydrology-economic model
  - allow deficit irrigation to be a management choice.
  - process for spatial aggregation from VIC-CropSyst to Economics.

Next 12 months

- **Spring, 2016**: Finalize yield curve fitting
- **Summer, 2016**: Finalize CRB/Ag economic model without connections to economy outside of CRB/Ag.
- **Fall, 2016**: Build capacity to embed CRB/Ag economic model in larger scale multi-region or global economic models of ag production.
  - USDA-ERS FARM Model
  - IFPRI Models
  - GTAP Models

Curve Fitting

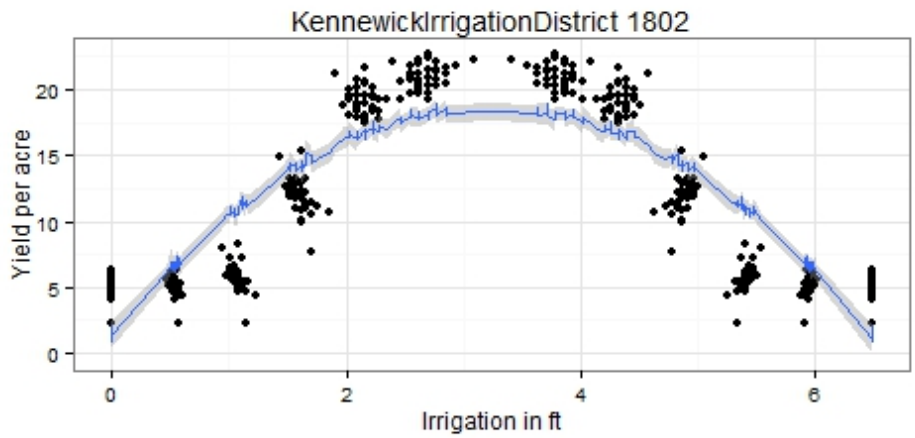
- y-axis: production/acre
- x-axis: irrigation intensity
- Challenge to get downward sloping portion of curve with VIC-CropSyst output.
- Solution: generate mirror image of yield at points above maximum potential yield.
- Polynomial degree:
  - Tradeoff between fit and ease in finding solutions in the model.

Yield "data points"

- Each data set of yield points.
  - Pool over years
  - Pool over space (Irrigation district or WRIA)

- Permits representing larger areas as single production entities in economic model.
  - Typically based on the spatial extent of water constraint.

Example



-42.7821
10.6251
-1.6397
0
0.0217
0.0055
1802
4

Papers

- Title: “Minimizing bias in representations of crop production in integrated hyrdology-economic models”

- Authors: Rajagopalan, Baddruozza, Brady, Adam,...

Papers

- Title: “Comparative Analysis of Watershed versus AEZ Approach to Spatial Aggregation in Climate Change Models of Agriculture”

- Authors: Long list

Papers

- Title: “Climate Change Mitigation Potential of Alternative Farm-Level Adaptation Strategies”
- Authors: Long list

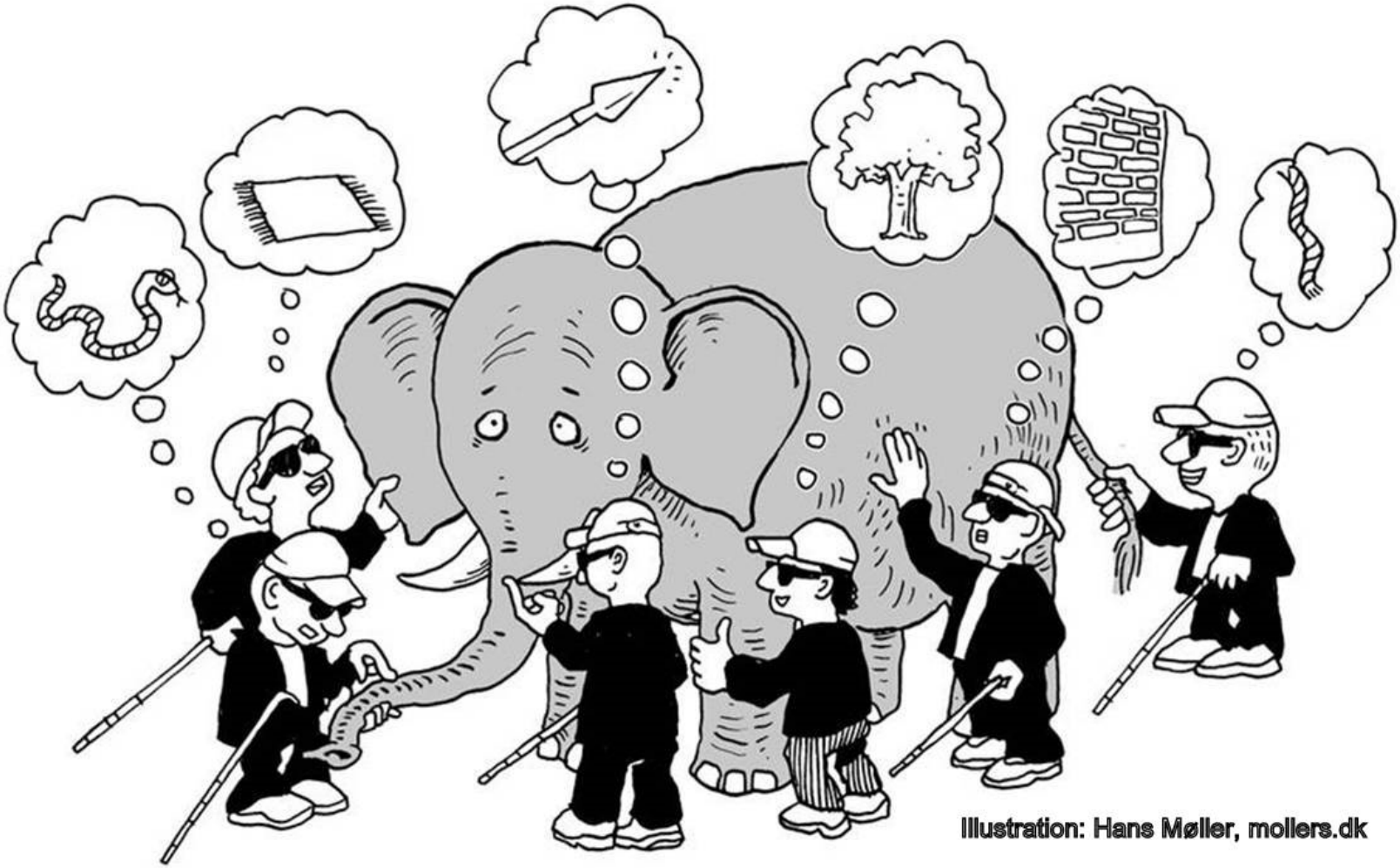
Modeling Agriculture Ecosystems In the Regional Earth System Modeling Framework:

From Field Practice, Regional Management, to Global Assessment

Mingliang Liu

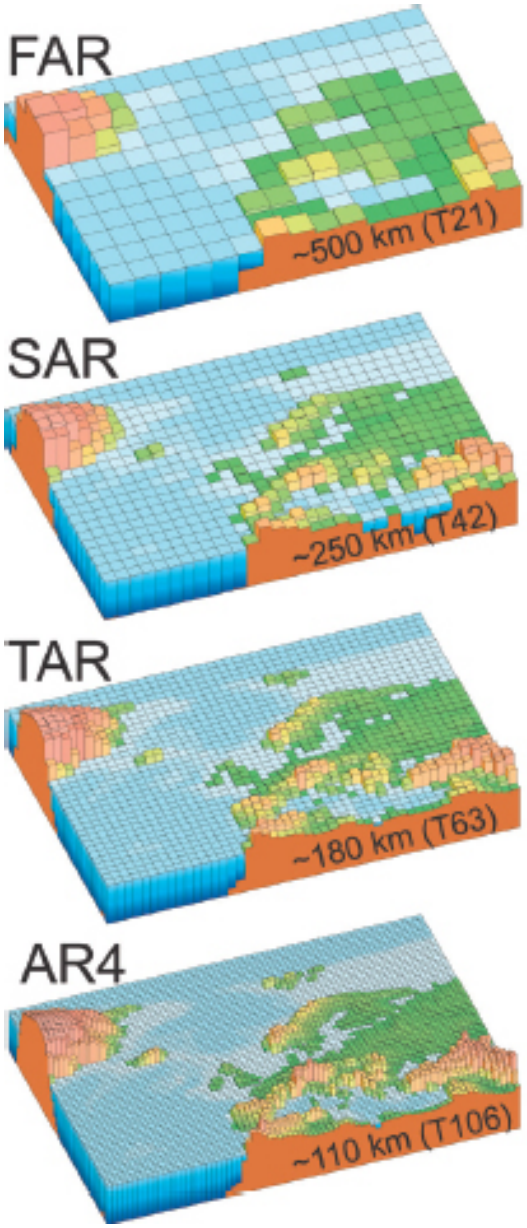
Feb. 25, 2016

BioEarth All-hand Meeting - Ignite Talk

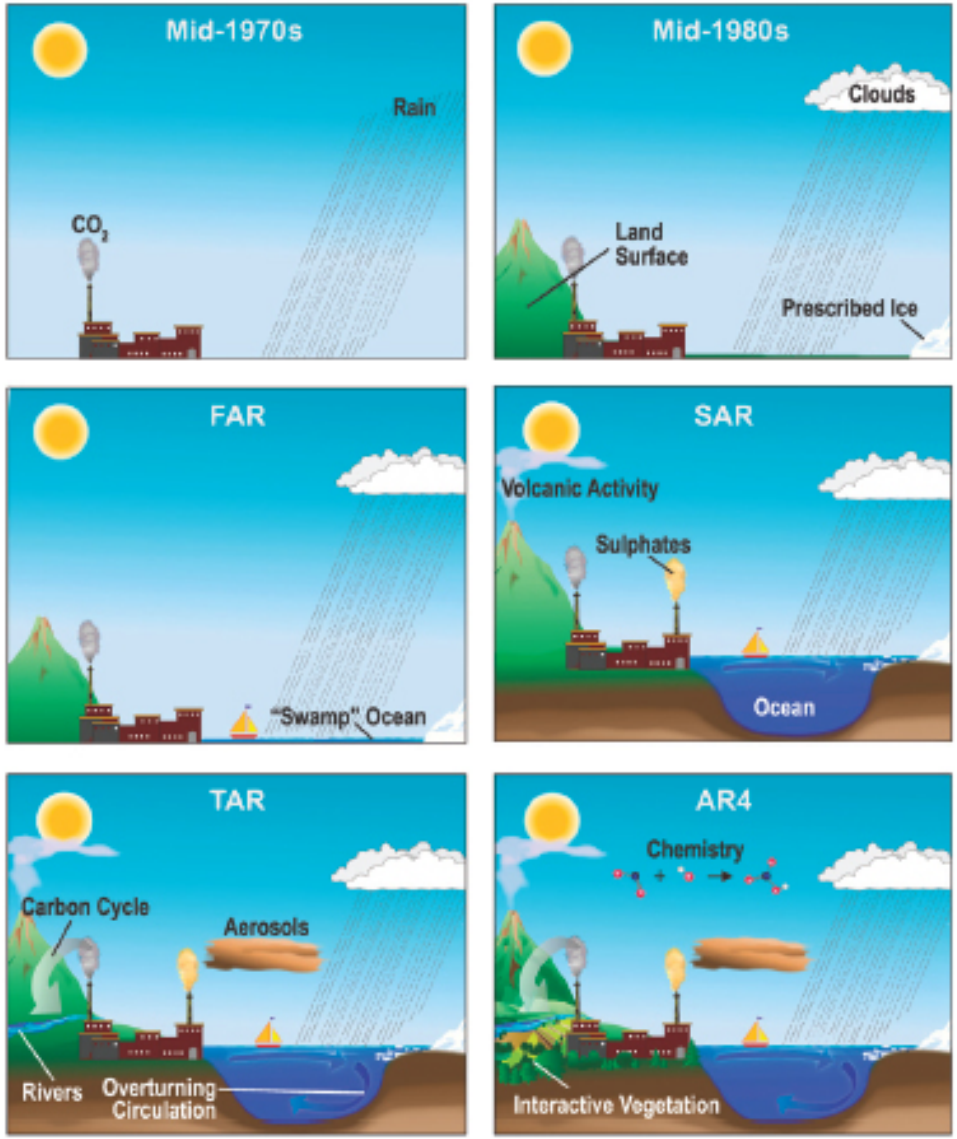


A model is *a description of a system*.

…they provide us with a means to visualize "the big picture"… models provide a vehicle for an enhanced understanding of how the environment works as a unit.
- Steven C. Chapra



The World in Global Climate Models

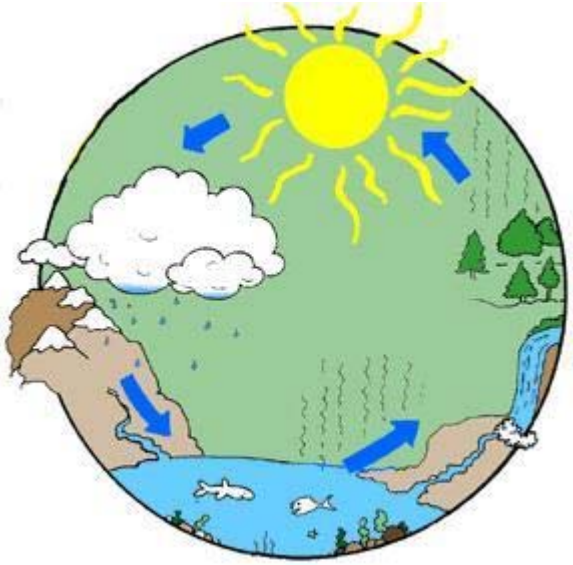


The challenge

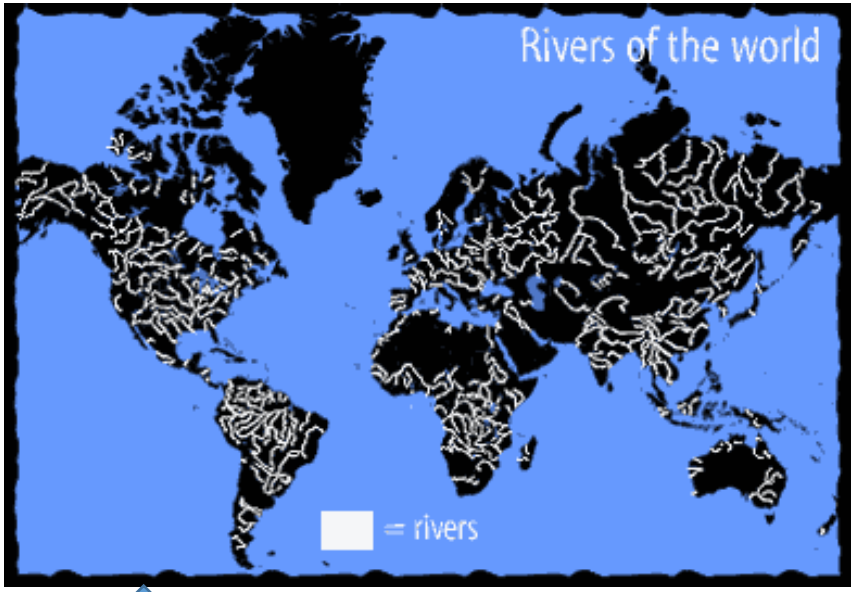
– FAO High-level Expert Forum, Rome 12-13, 2009

Agriculture in the 21st century faces multiple challenges: it has to produce more food and fibre to feed a growing population with a smaller rural labour force, more feedstocks for a potentially huge bioenergy market, contribute to overall development in the many agriculture-dependent developing countries, adopt more efficient and sustainable production methods and adapt to climate change.

Food and Agriculture Organization of the United Nations



http://www.dropbydrop.eu/en/mimicking-nature-integrate-your-home-hydrological-cycle_36390

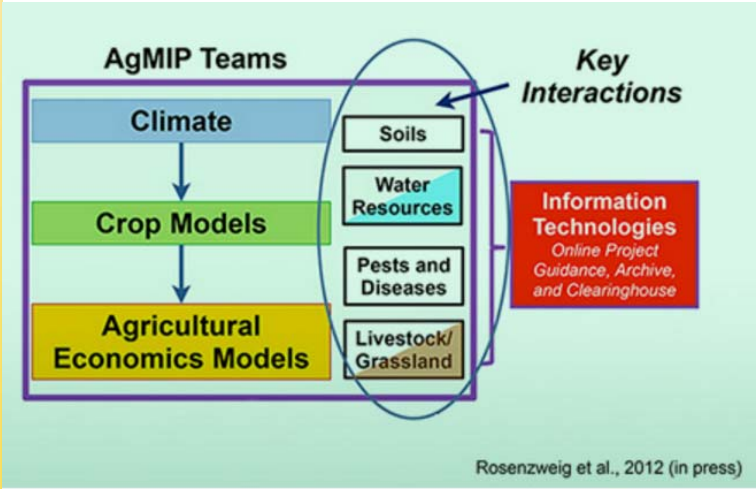


http://whyfiles.org/131fresh_water/2.html

http://ensia.com/voices/2014-the-year-of-family-farming/

AgMIP

The Agricultural Model Intercomparison and Improvement Project



The Agricultural Model Intercomparison and Improvement Project (AgMIP) is a major international collaborative effort to assess the state of global agricultural modeling and to understand climate impacts on the agricultural sector.

http://www.agmip.org/

Tian et al., 2015, GBC

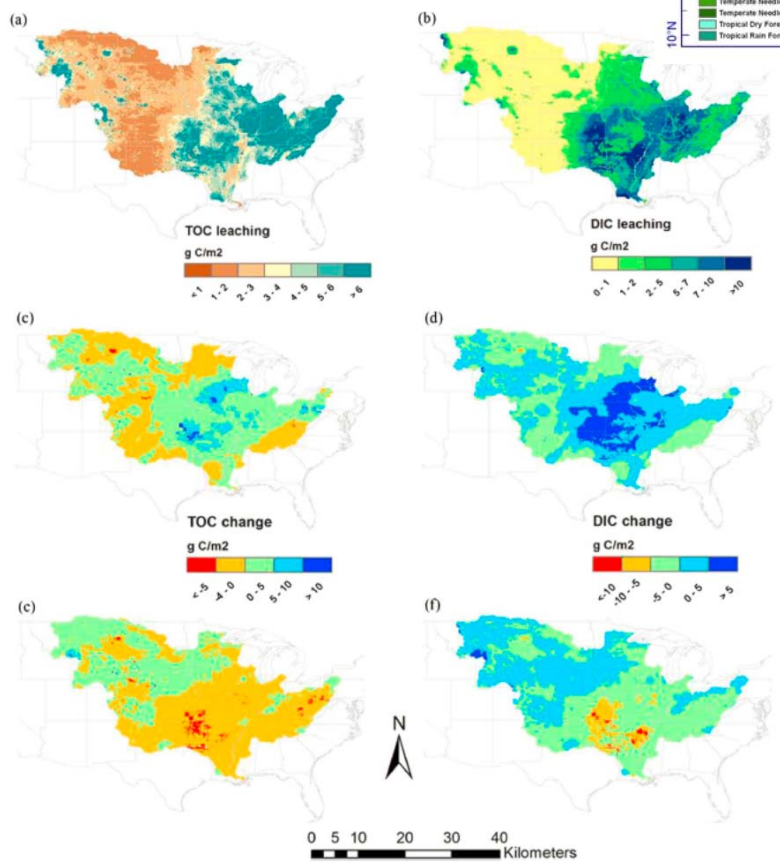
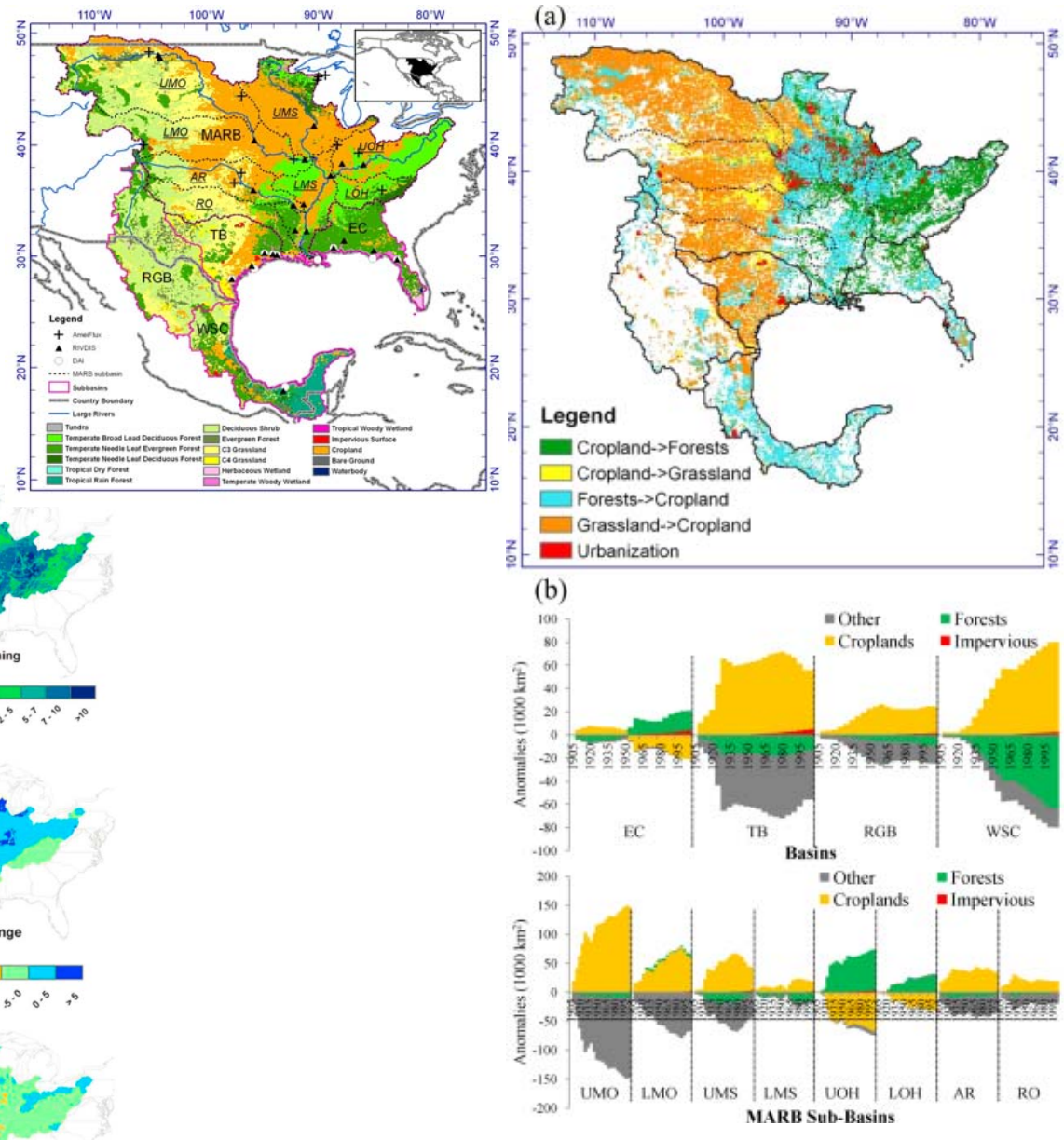


Figure 6. Spatial distributions of total organic carbon export (TOC, the sum of dissolved organic carbon and particulate organic carbon, g C m^{-2}), dissolved inorganic carbon export (DIC, g C m^{-2}), the average during 2001–2010 (a and b); and changes in (c and d) wet and (e and f) dry years relative to the 10 year average as simulated by DLEM.



Liu et al., 2013, WRR

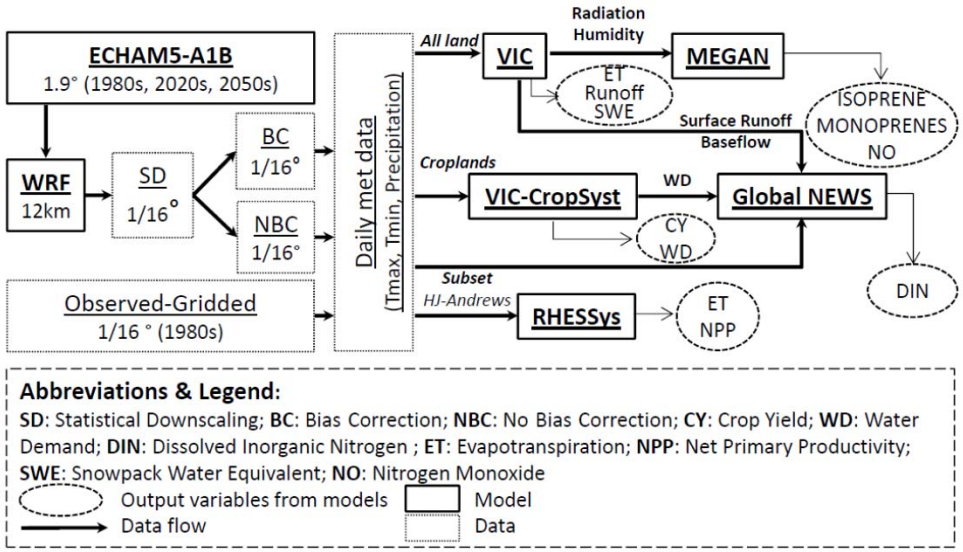


Fig. 2. Offline simulations and data flow for this study.

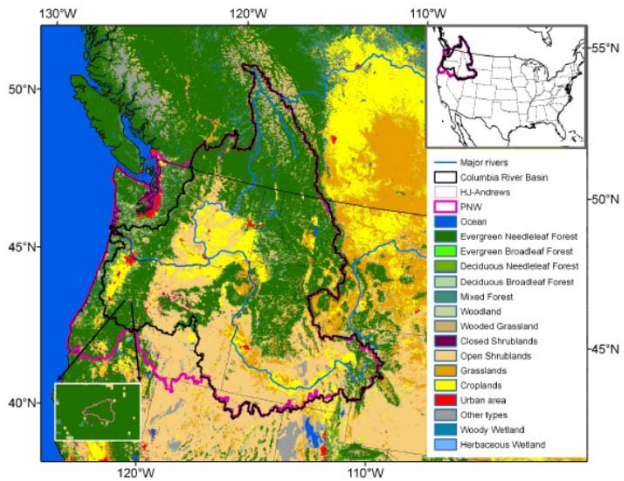
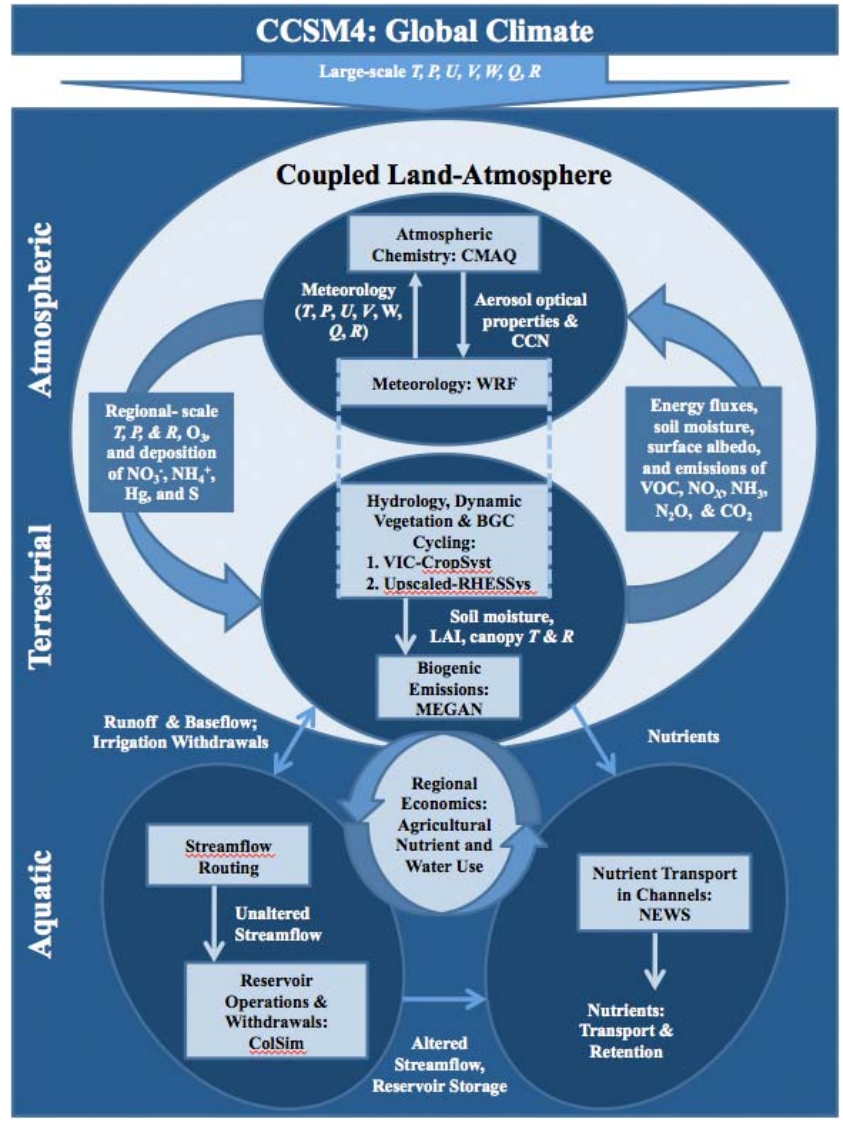


Fig. 1. Study area and simulation domain for this study. Pacific Northwest: VIC, VIC-CropSyst, and MEGAN domains; Columbia River basin: NEWS-DIN domain; HJ-Andrews: RHESSys domain.

Liu et al., 2014, Biogeosciences

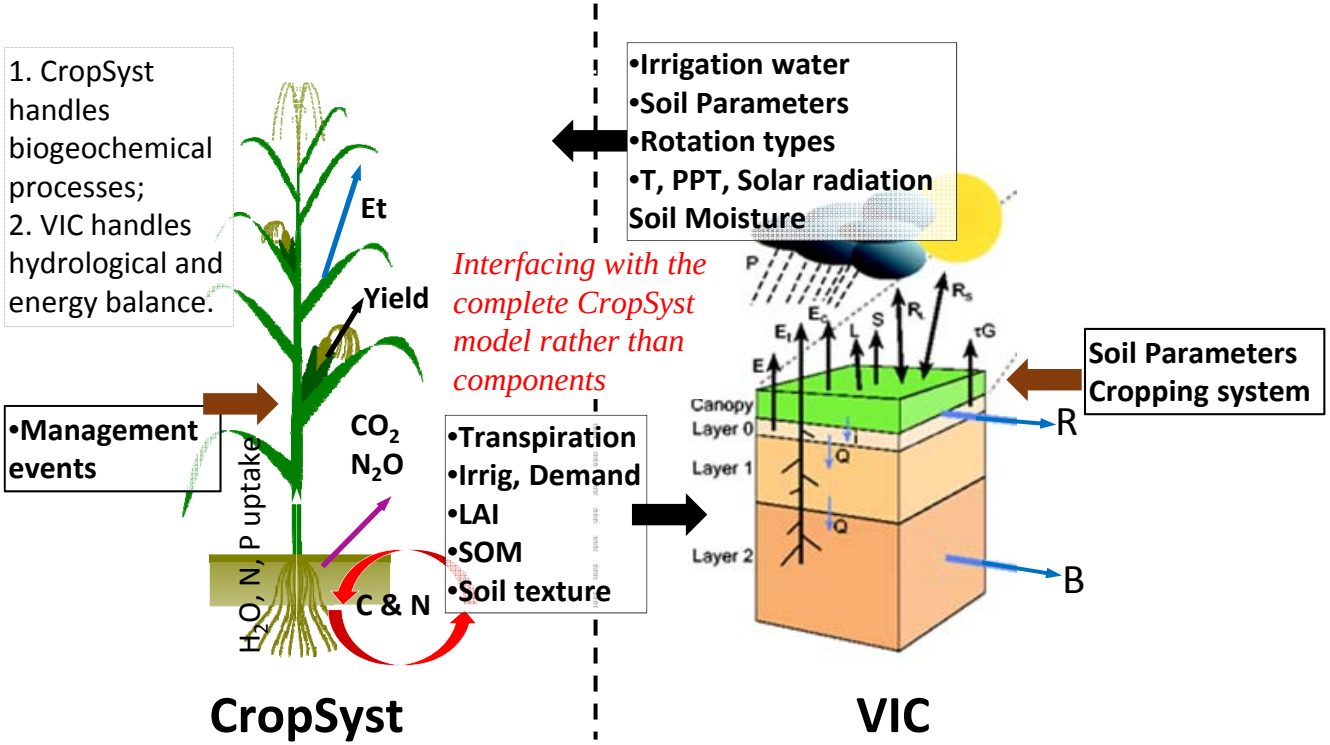


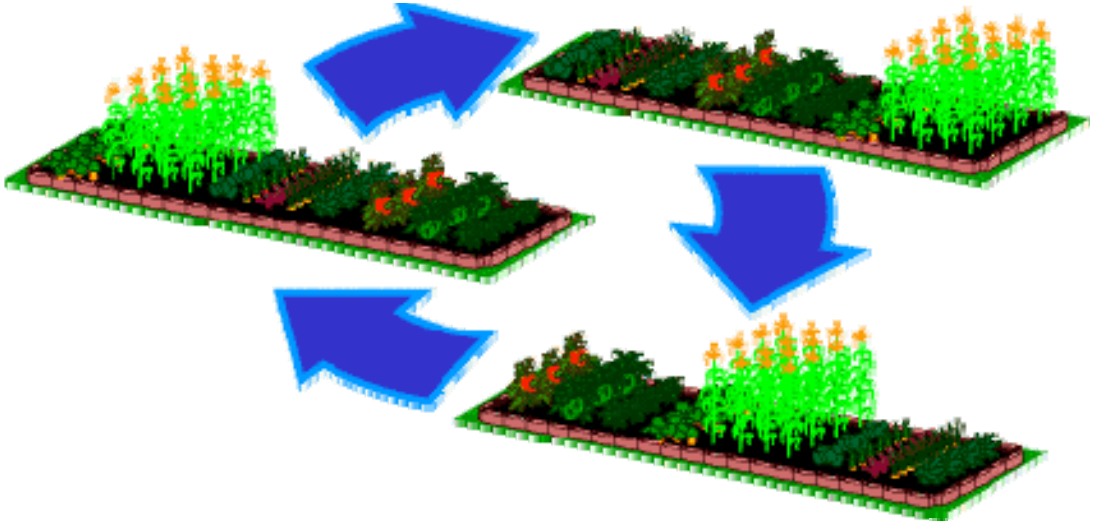
Adam et al., 2014, Climatic Change

VIC-CropSyst

Input: climate, managements, biophysical condition

Output: crop yield, water yield, water & N use efficiency, N leaching, soil erosion, irrigation water demand





http://www.ourveggiegarden.com/AnPlanRotation.html

- **Increases organic matter in the soil**
- **Improves soil structure**
- **Reduces soil degradation**
- **Control weeds and diseases**
- **Limit insect and other pest infestations**
- **Increasing fertility and reducing the need for synthetic fertilizers**

CROP ROTATION

Benefiting farmers, the environment and the economy

Pesticide Action Network Europe · Friends of the Earth Europe · IFOAM EU Group · APRODEV

July 2012

WHAT IS TILLAGE

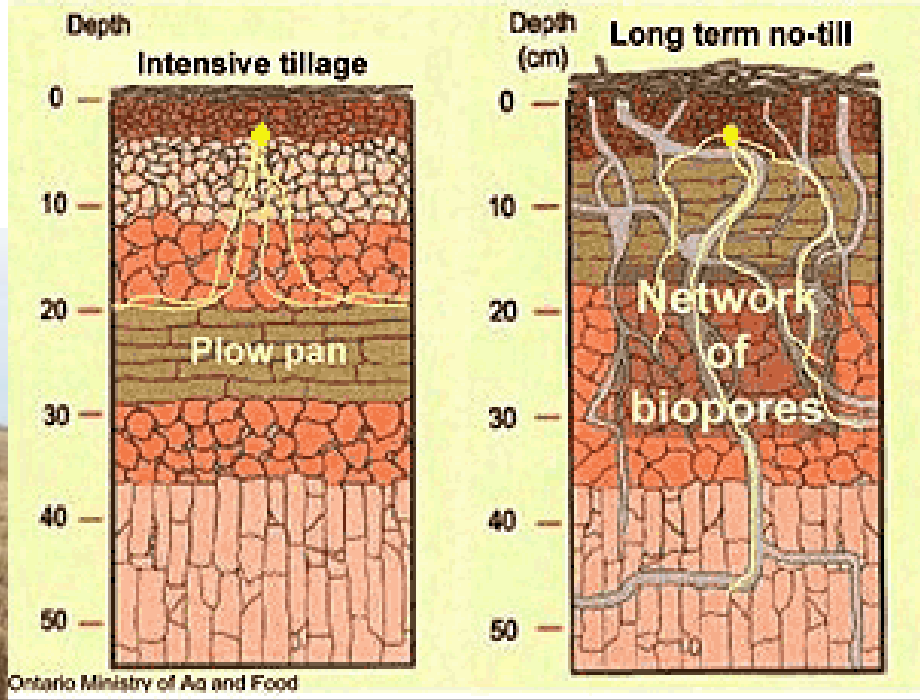
➢ **THE PHYSICAL MANIPULATION OF THE SOIL FOR THE PURPOSES OF:**

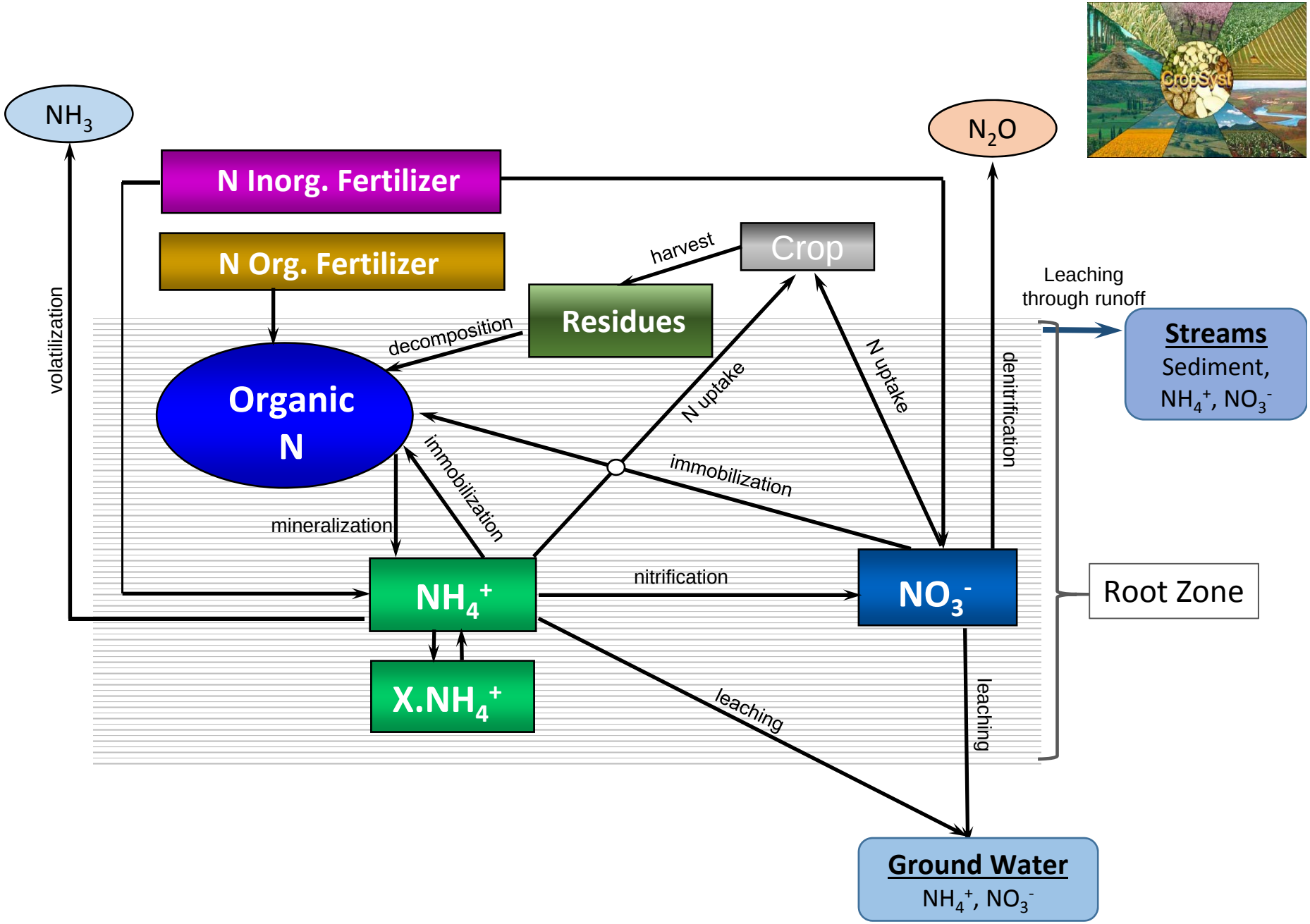
- **Management of previous crop residues**
- **Control of competing vegetation**
- **Incorporation of amendments**
- **Preparation of a seedbed**
- **Recreation for folks who don't fish or golf**

Marlon Winger - NRCS

SOIL PROPERTIES AFFECTED BY TILLAGE

- Crop residue cover
- Soil test measurements
- Nutrient availability
- Structure and aggregate stability
- Water relationships
- Temperature
- Strength

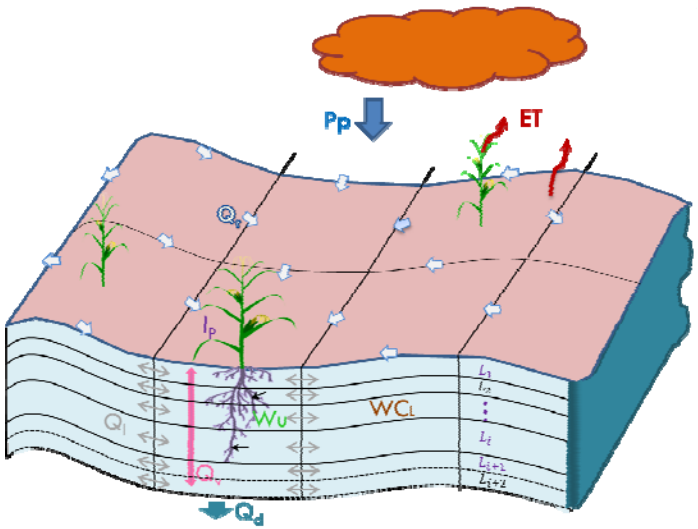




Nitrogen Cycling in CropSyst Model (Courtesy of Stöckle et al.)

MicroBasin

Fidel Maureira, Claudio Stöckle, Mingliang Liu, Roger Nelson, Erin Brooks & Rolf Sommer



Input: Precipitation (Rain and Snow) Snowmelt, Irrigation)

Flow and Storage:

ET – Evapotranspiration

I_p – Interception capacity by crop

Wu- Water uptake

Q_r – Overland Flow

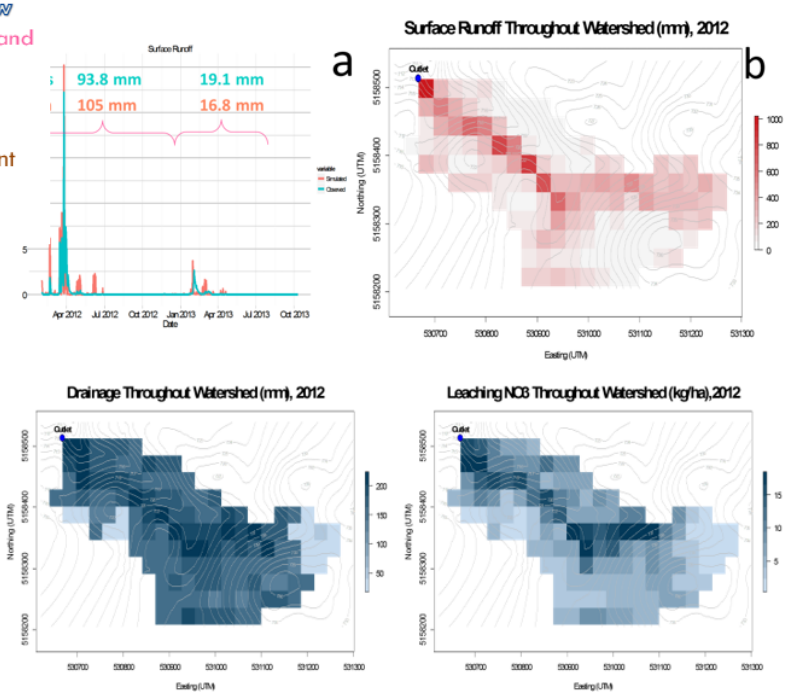
Q_v – Vertical Flow and Infiltration

Q_l – Lateral Flow

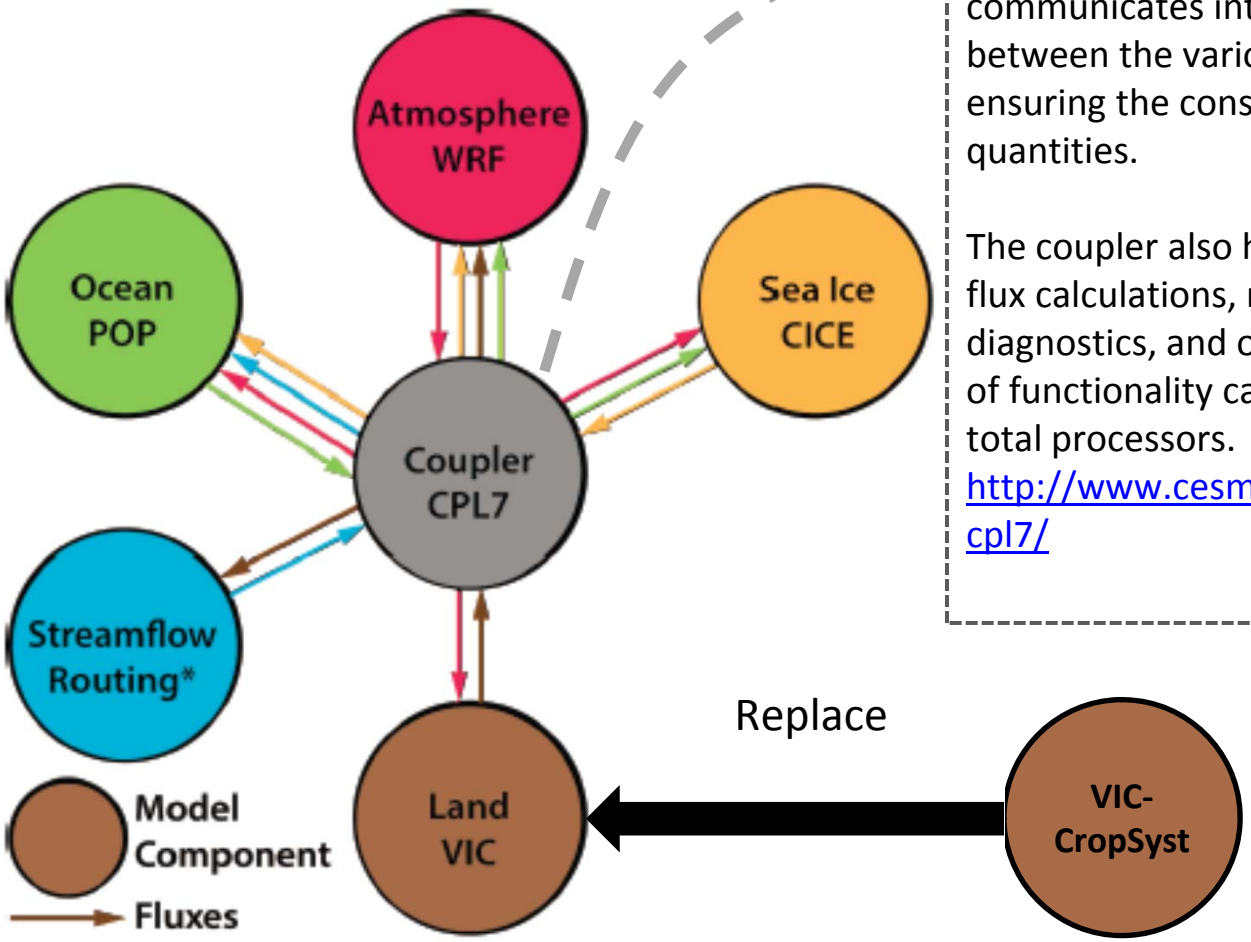
Q_d – Drainage

WC – Water content

L – Layer of soil



Simulated surface runoff (a), its spatial patterns (b), drainage (c) and NO3 Leaching (d) in three seasons of the year 2012 over the Leland watershed, ID



The coupler controls the execution and time evolution of the complete system by synchronizing and controlling the flow of data between the various components. It also communicates interfacial states and fluxes between the various component models while ensuring the conservation of fluxed quantities.

The coupler also has functionality to carry out flux calculations, mapping (regridding), diagnostics, and other calculations -- this type of functionality can be run on a subset of the total processors.
http://www.cesm.ucar.edu/models/cesm1.2/cpl7/

The Regional Arctic Climate Model (RASM)

(http://www.oc.nps.edu/NAME/RASM.htm)

Overarching Questions

- How agricultural managements could affect crop yields, carbon storage, GHG gas emissions, and water and nitrogen use efficiencies under various climate change scenarios;
- How agricultural ecosystems feedback to regional climate system through ET, changes in land cover type and seasonality, and gas emissions.

Appropriate responses to climate to ensure sustainable agricultural productivity

Keyvan Malek (PhD student)

Advisors:
Claudio Stockle,
Jennifer Adam

Washington State University

Climate Change Impacts agriculture

- Elevated CO2
- Higher Temperature
- Water Availability
- Frequency of Extreme

- Farmers make decisions to reduce negative impacts of climate change

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Adaptation to Climate Change

	Adaptation strategy
1	**Crop related adaptation strategies**
	i- cropping pattern
	ii- Cropping acreage and location of cropping activities
	iii- Timing of planting and harvesting date
	iv- using new variety of the same crop
2	**Long term strategic water management adaptations**
	i- Switching to New Irrigation Systems
3	**Seasonal adaptations to respond to temporal availability of water**
	i- Deficit irrigation magnitude
	ii- Deficit irrigation timing in a season
4	**Short term adaptations to minimize the impacts of heat stress**
	i- Supplementary/over irrigation
	ii- Irrigation frequency
	iii- Irrigation intensity

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Downstream Consequences of Adaptation

- Hydrologic cycle
  - Return flow
  - Change the timing of river flow
- Fluxes of water and energy to/from the atmosphere

➔ Changes in water availability and climatic conditions can exacerbate the impacts of climate change

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Objectives

1. Lack of an appropriate simulation tool
2. Climate change impacts on adaptation decisions
3. Downstream consequences

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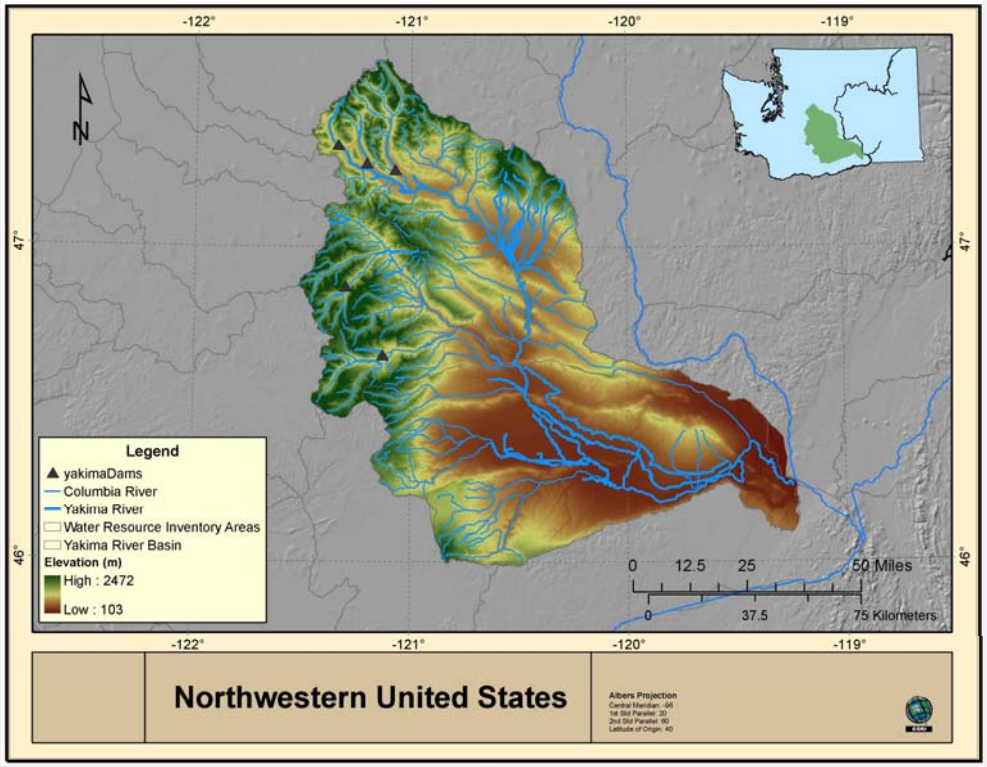
Yakima River Basin (YRB)

- **Some facts about YRB:**
  - Area: 16000 square km (476 *33 Km^2 gridcells)
  - Average Precipitation: 686 mm / yr
  - Has been ranked 1st county in many agricultural products in Washington State and US
  - 10% of employments directly in agriculture (USBR, 2002)
  - Income from irrigated crops: $1.3 B (USDA, 2007)



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Economic incentives of adaptation to climate change

Impacts of climate on water resources

Uncertainty in climate

Impacts of climate change on agriculture

Simulation tool

Water resource management

Cost and benefits

Land Atmospheric Interactions

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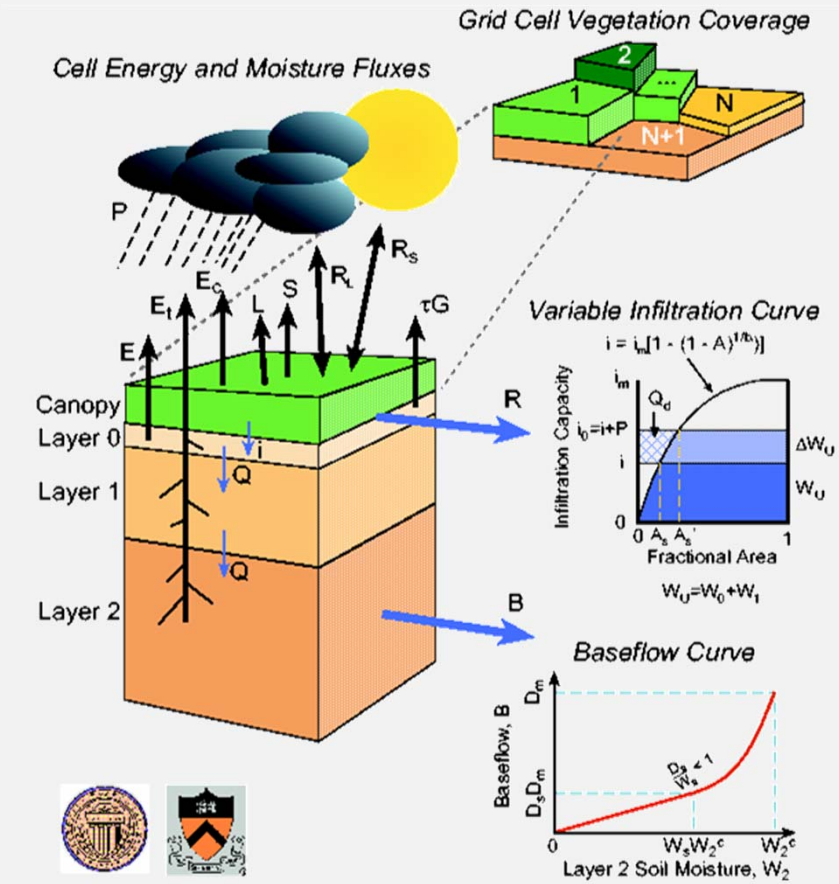
Hydrology and Crop System Models: VIC-CropSyst

VIC

Hydrology

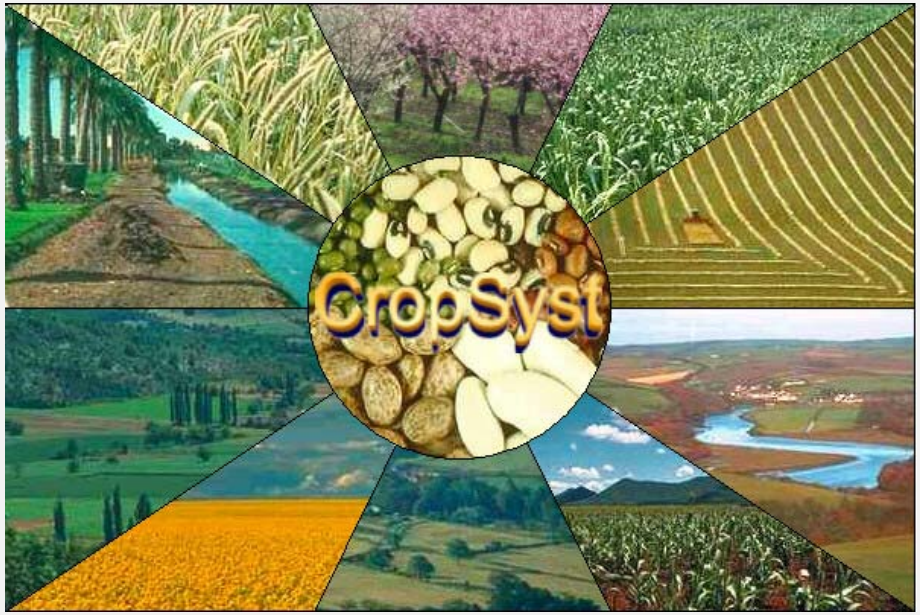
Liang et al, 1994 and Elsner et al, 2010



CropSyst

Cropping Systems

Stockle and Nelson 1994



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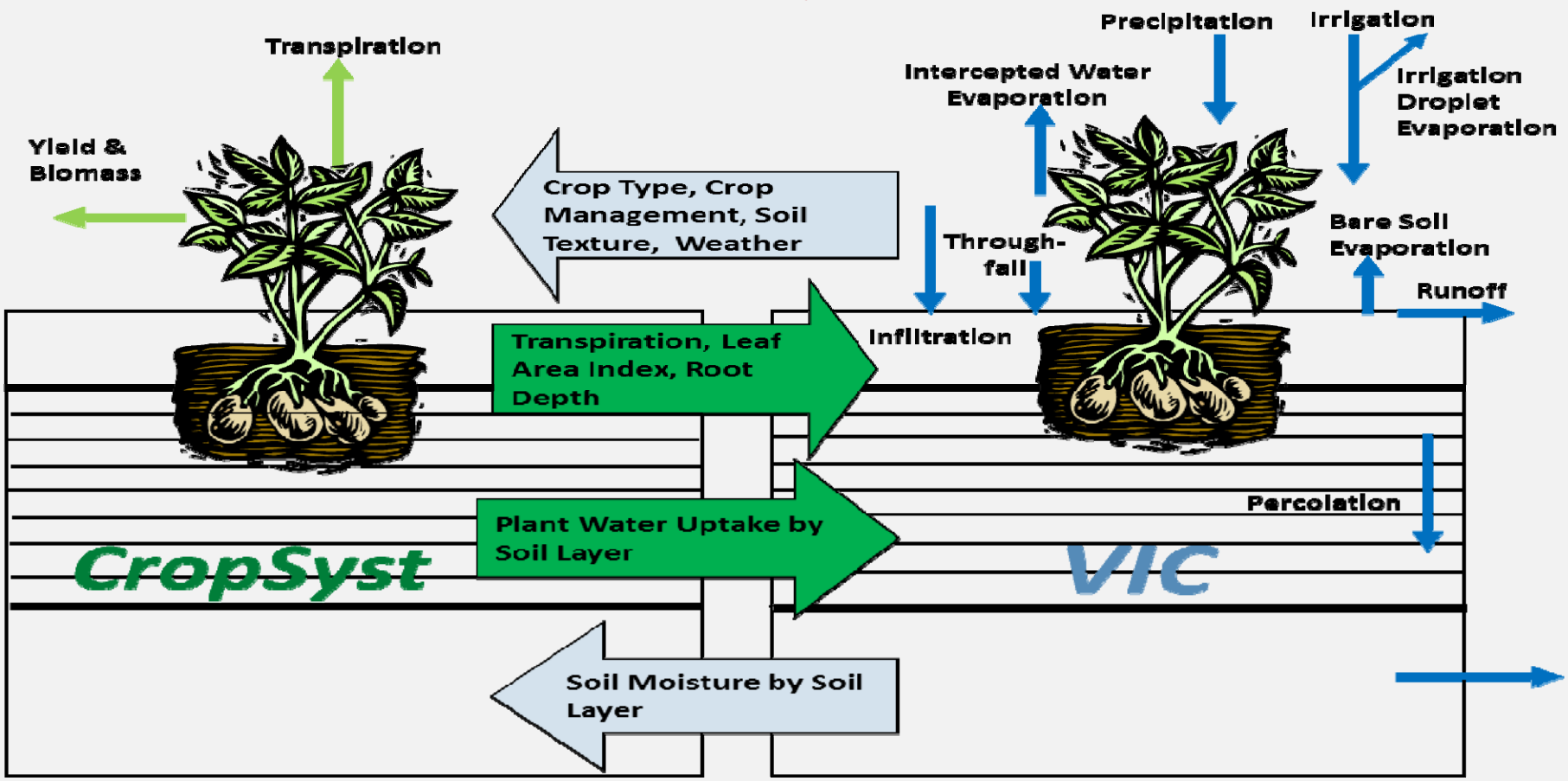
VIC-CropSyst



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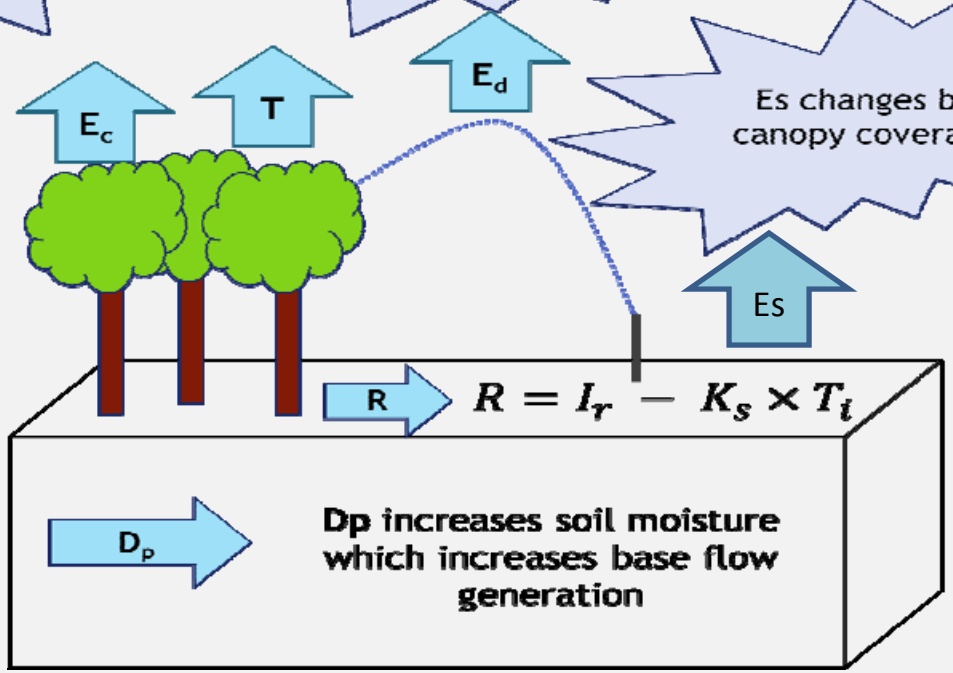
Simulation of Irrigation System Losses

Ec is calculated from intercepted water which depends on canopy coverage

$$E_d = ET_0\, A_p\, \frac{1}{D}^{\alpha}\, t^{\beta}$$

Es changes by canopy coverage



T: transpiration
Ec: evaporation from canopy intercepted water
Es: evaporation from soil
Ed : evaporation from irrigation droplets **
Dp: deep percolation loss
R : Runoff loss **
** processes that were developed in the current modeling effort

$$efficiency = 1 - \frac{E_d + E_s + E_c + R + D_p}{total\ applied\ water}$$

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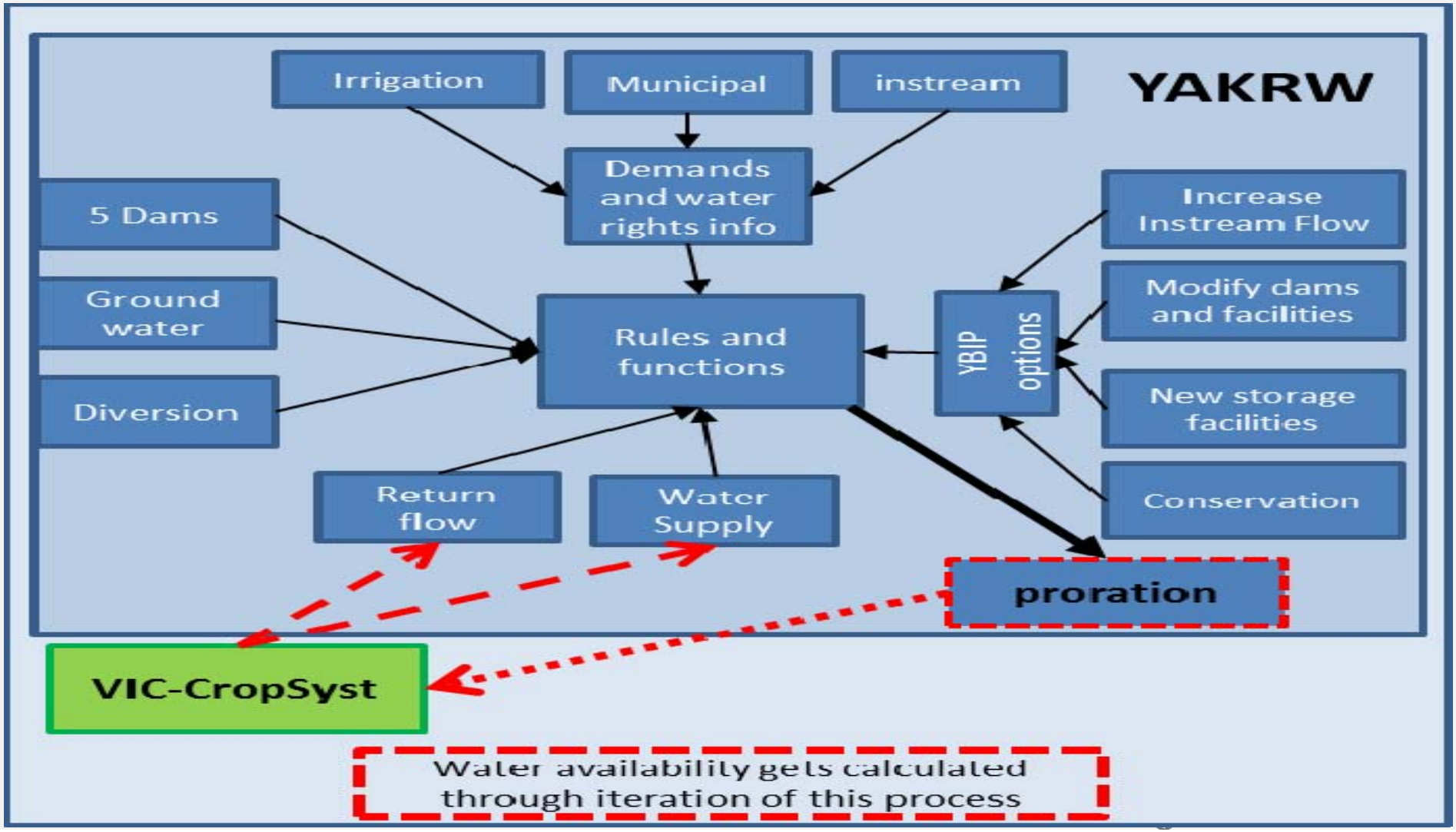
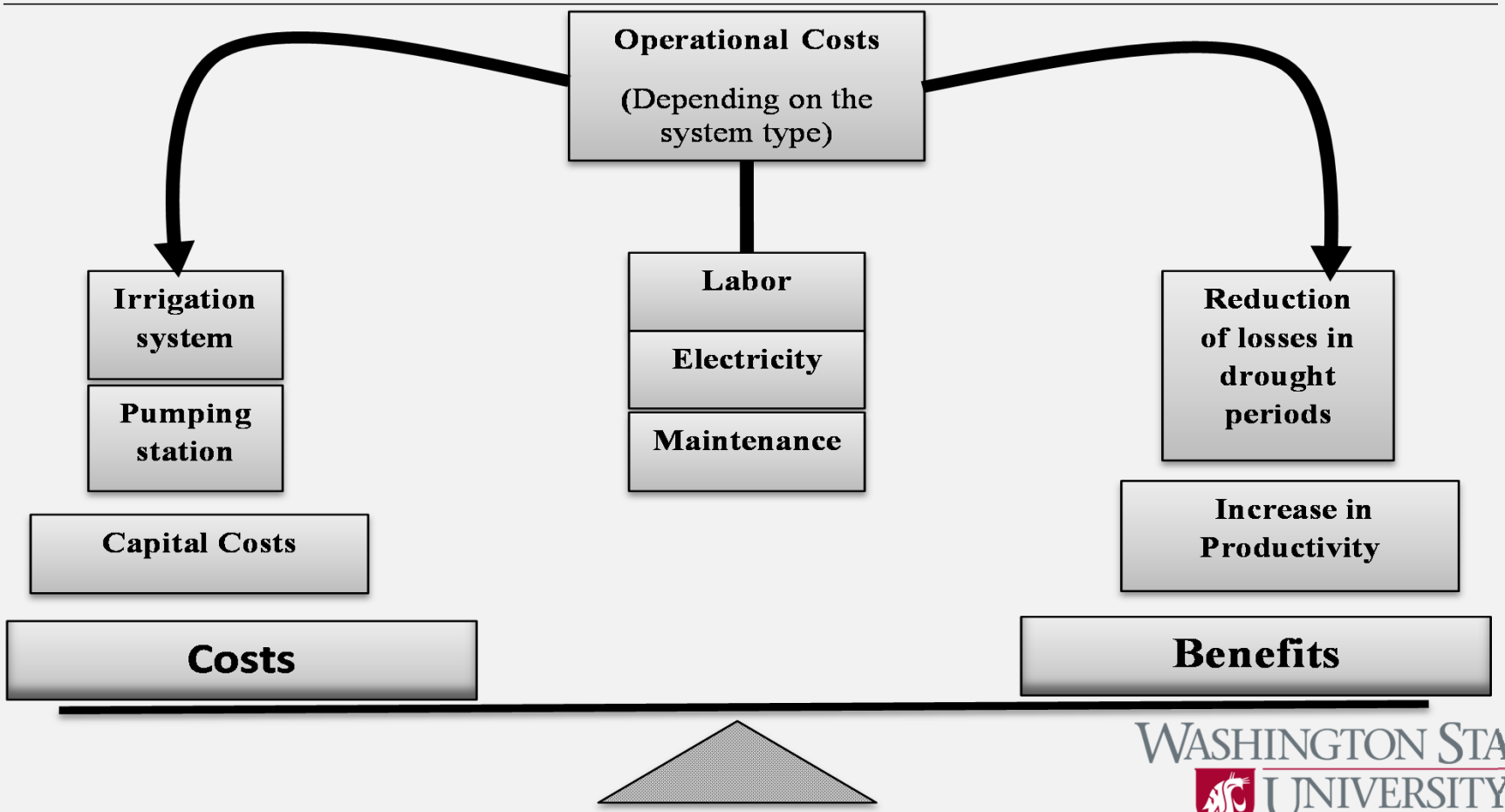
Yakima-RiverWare



Agricultural Spatial Economic Analysis Model (ASEAM)

- Model is Written in R
- It can be implemented for other adaptation decisions



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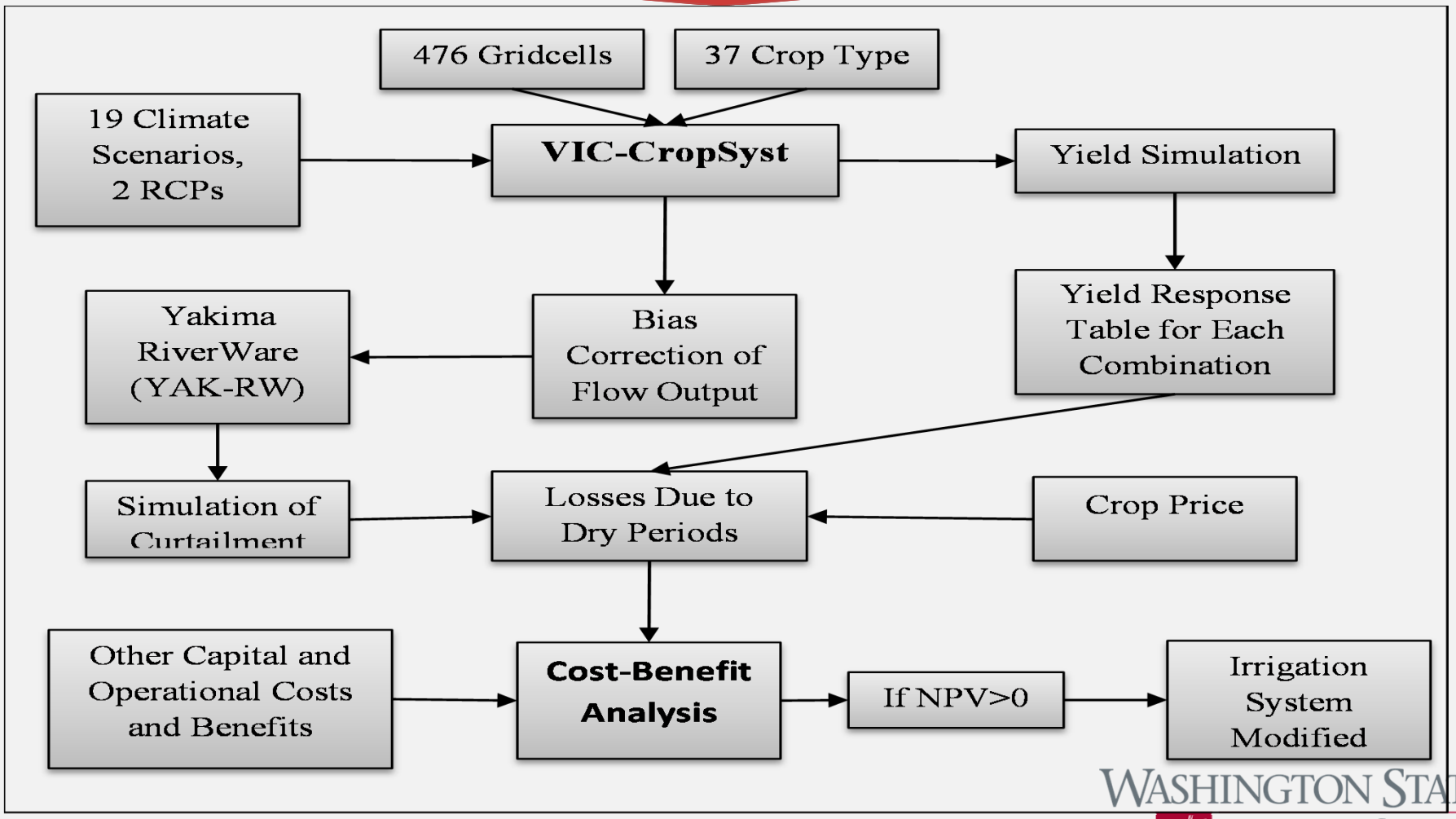
Modeling Platform: Agricultural Spatial Economic Analysis Model (ASEAM)



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Results

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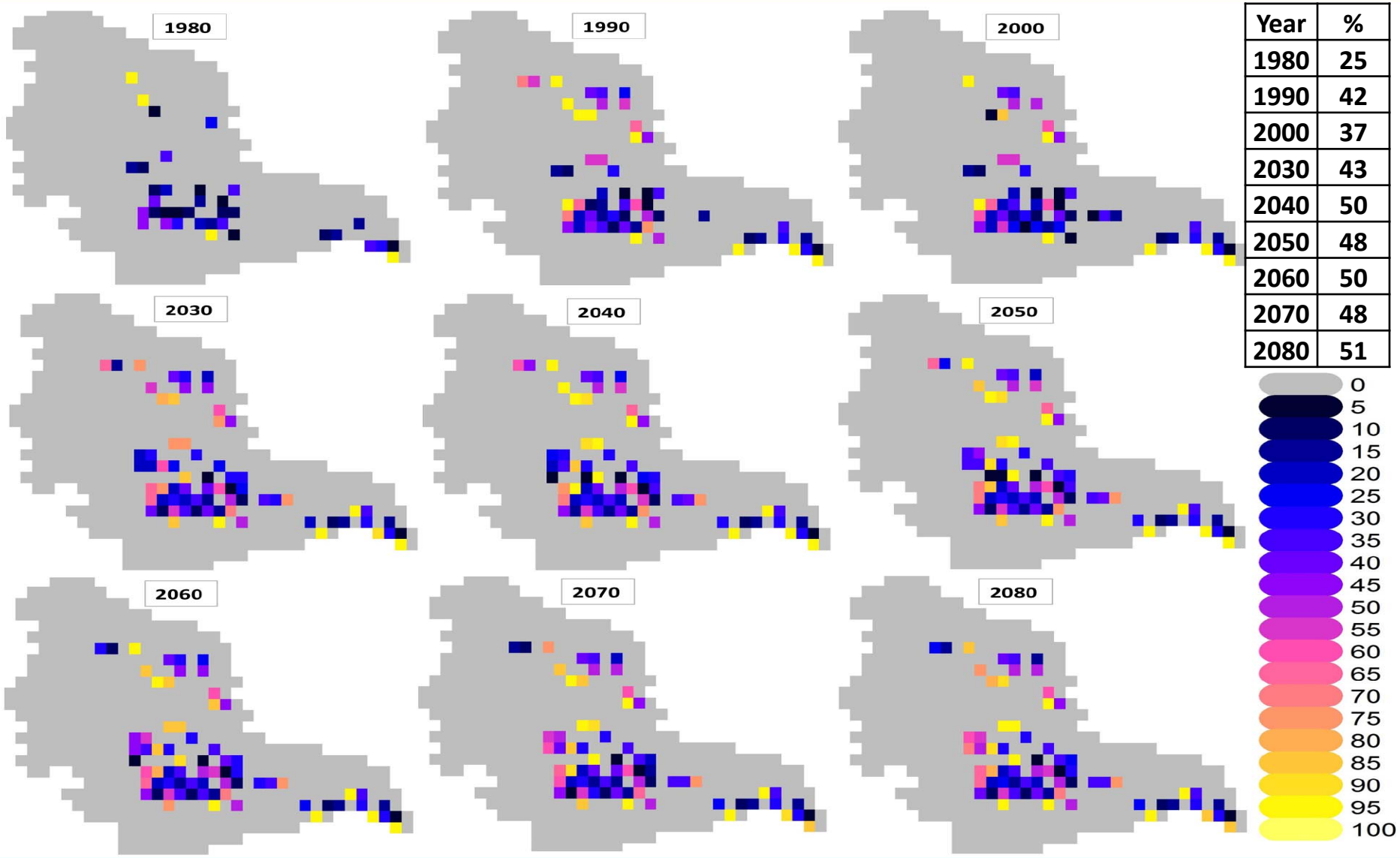
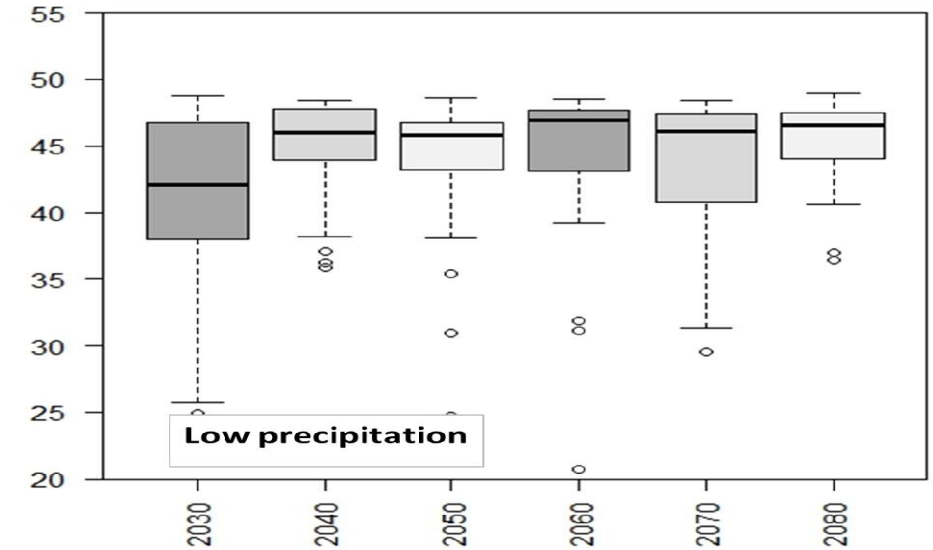
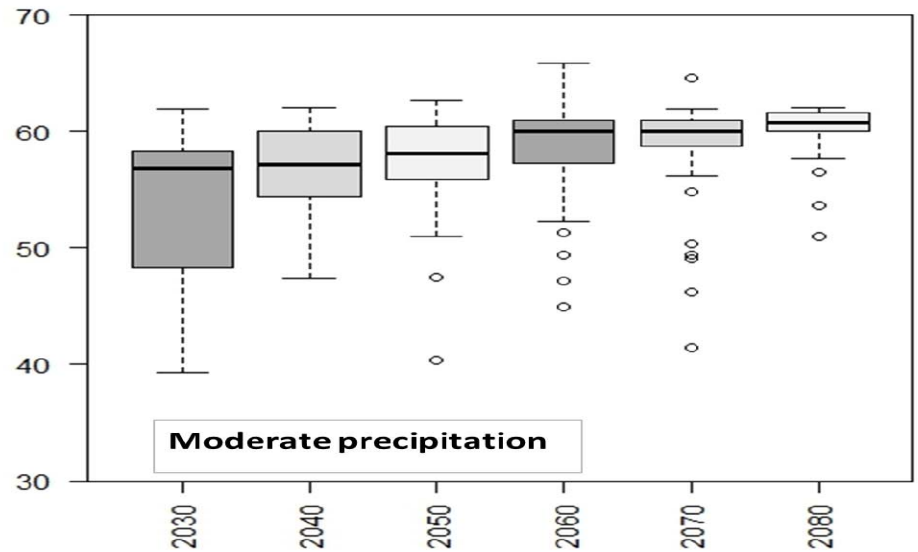
Percentage of Farmers in Each Gridcell Switching to New Irrigation Systems

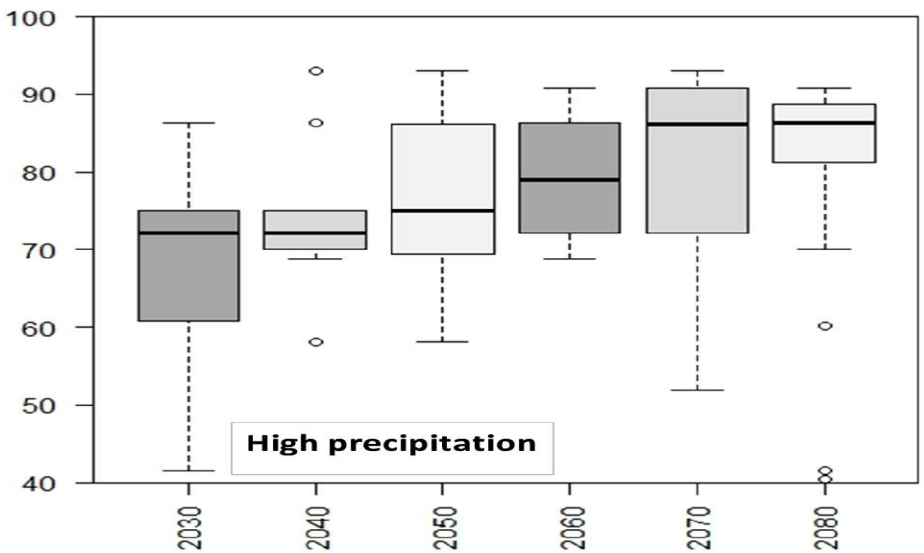


Year	%
1980	25
1990	42
2000	37
2030	43
2040	50
2050	48
2060	50
2070	48
2080	51

Different Climatic Conditions







High precipitation:

P>500 mm

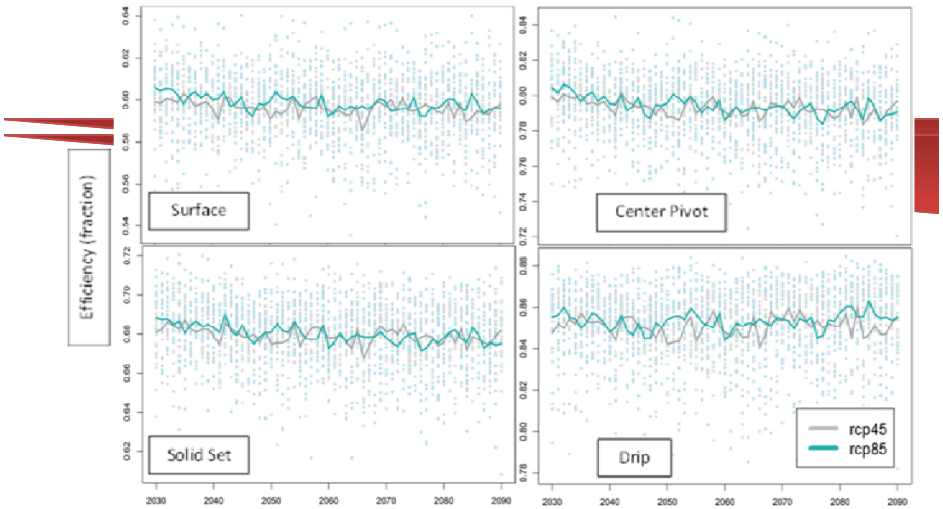
Moderate Precipitation

250< P < 500 mm

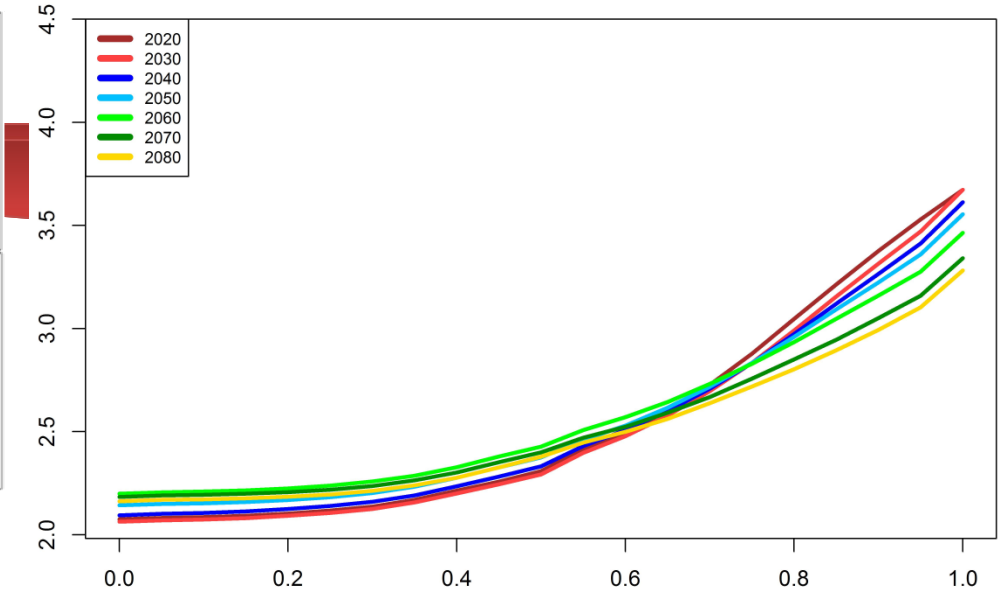
Low Precipitation:

P< 250 mm

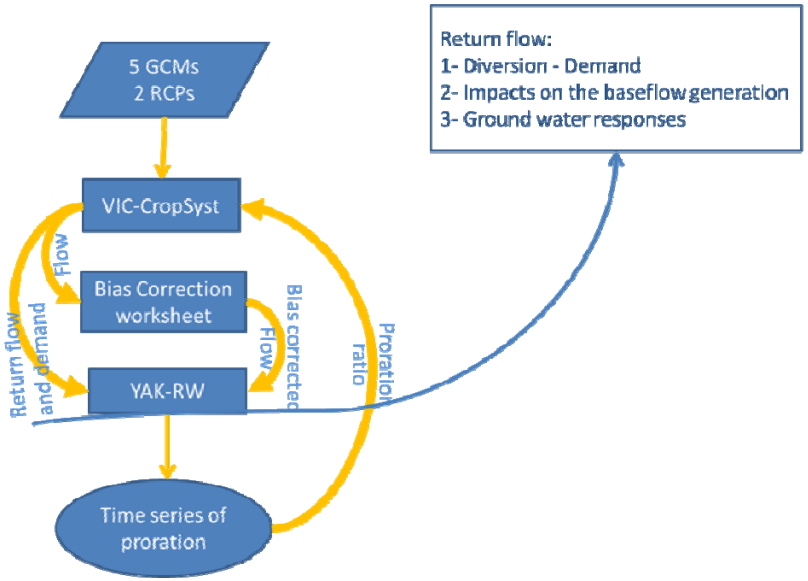
Impact of Climate Change on Irrigation Efficiency



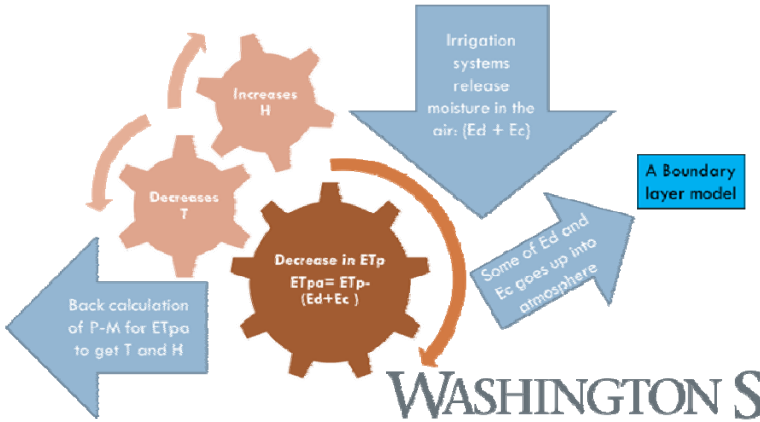
Yield Responses to water availability and deficit irrigation



Downstream Impacts of Adaptations (Irrigation decision)



Impact of irrigation on land atmospheric interactions



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THANKS!

BioEarth

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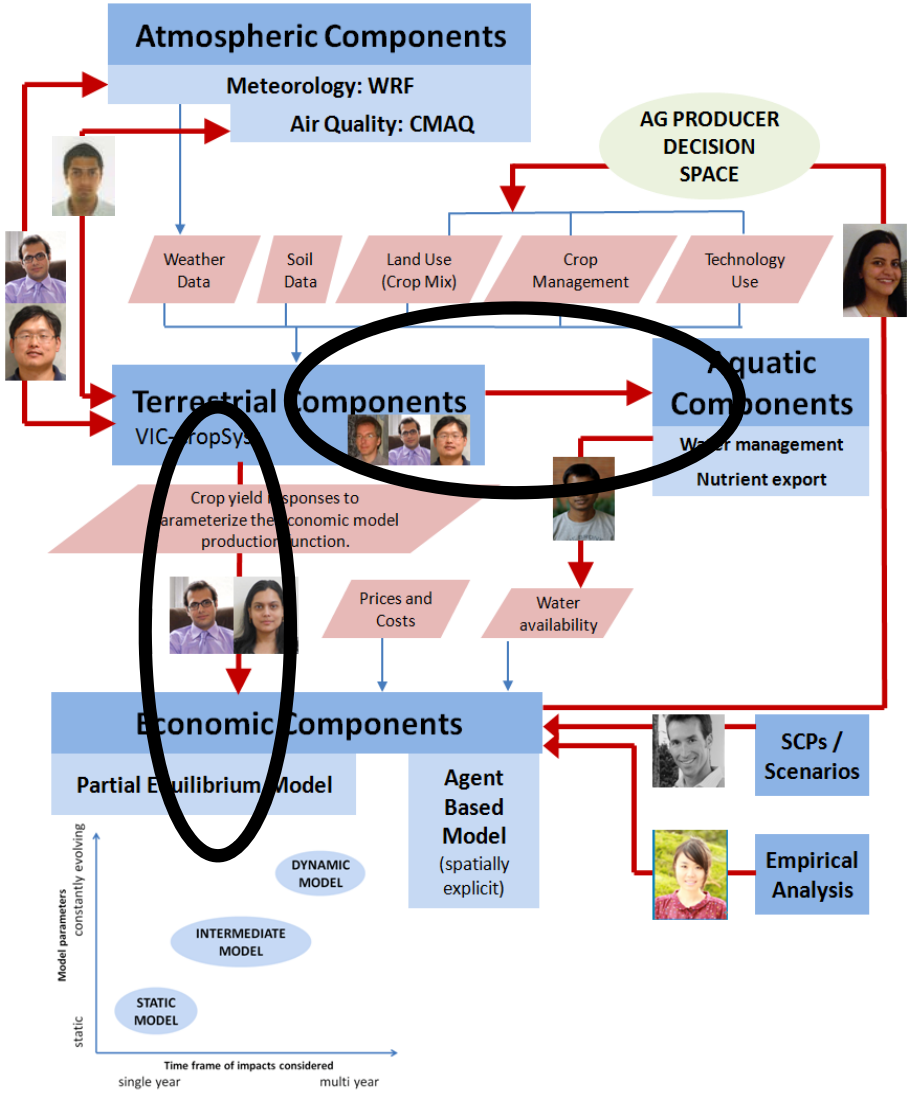
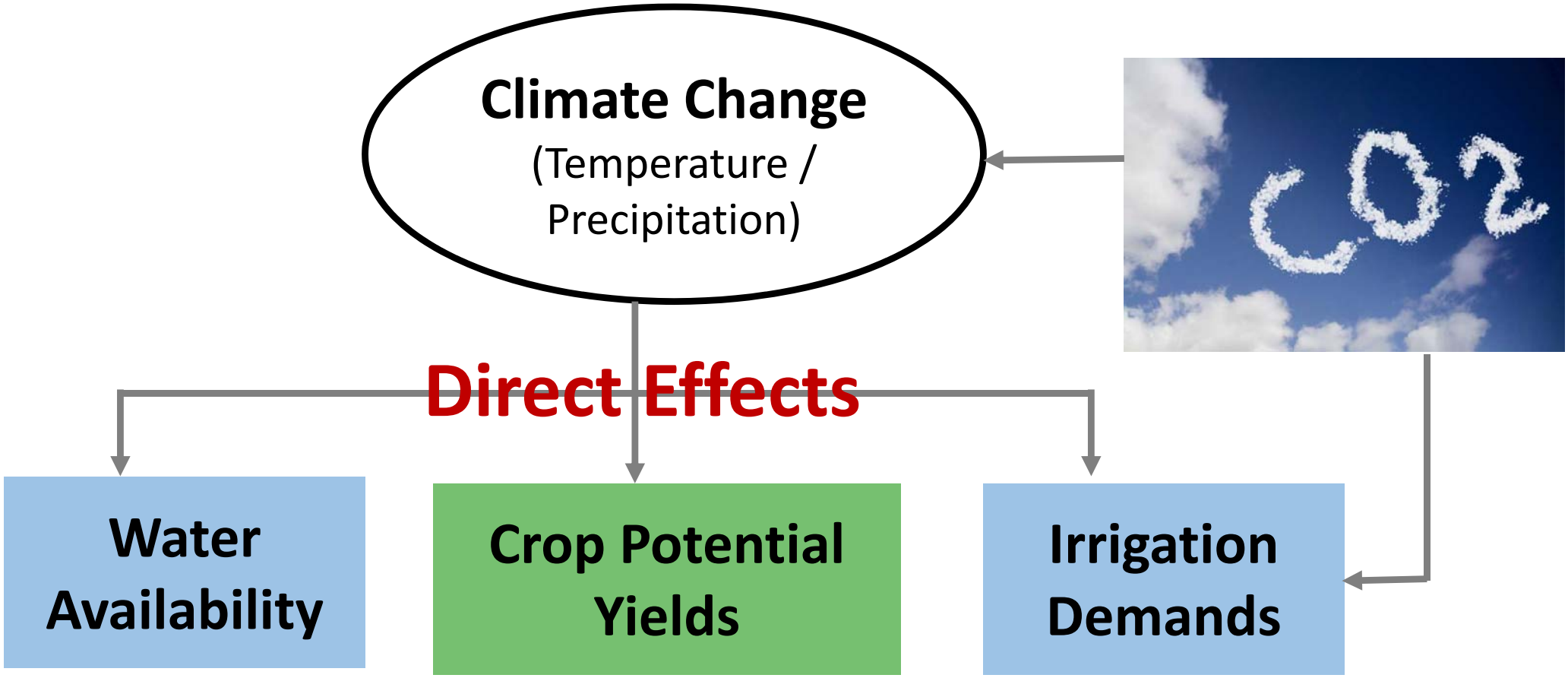
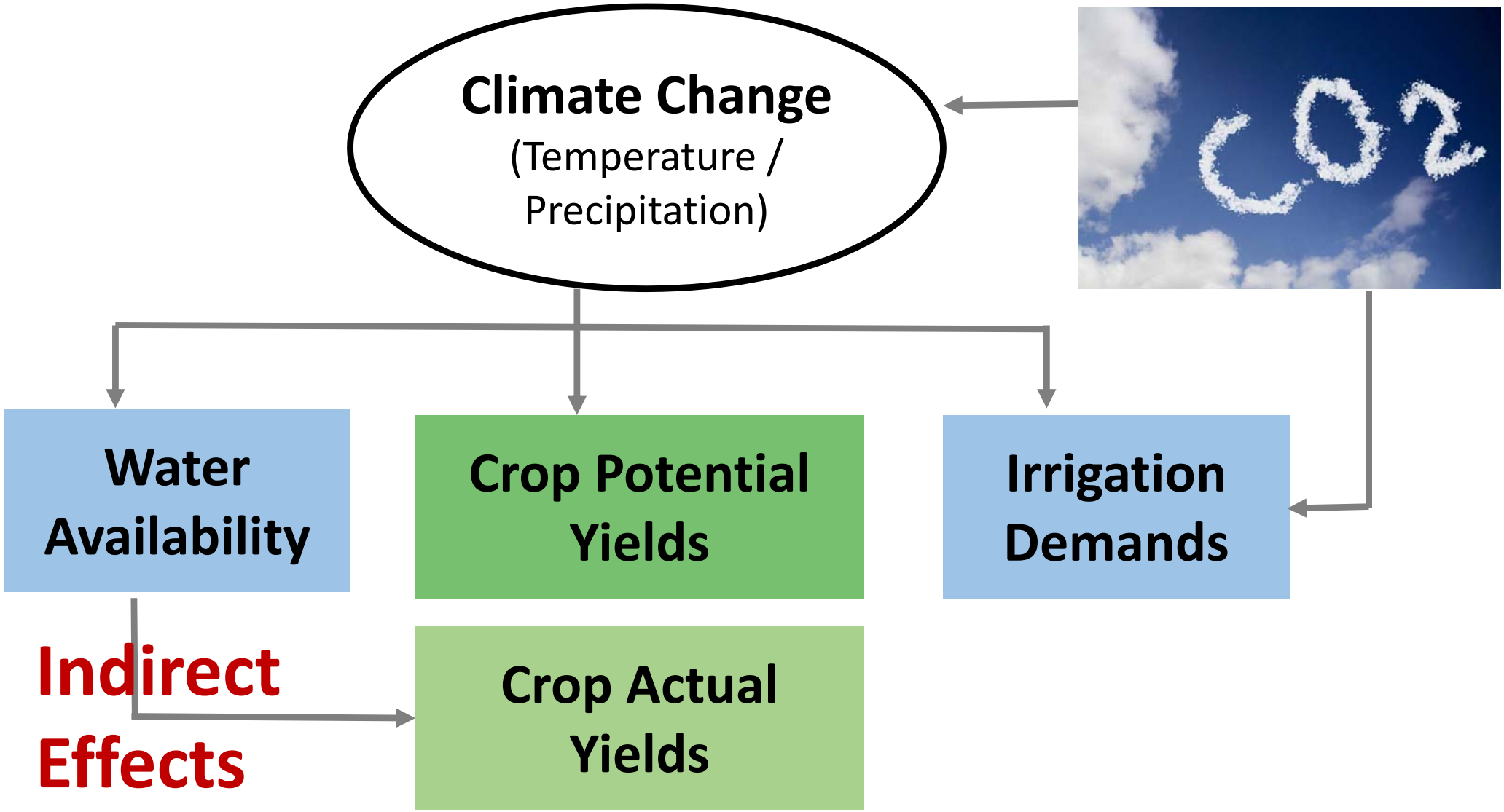


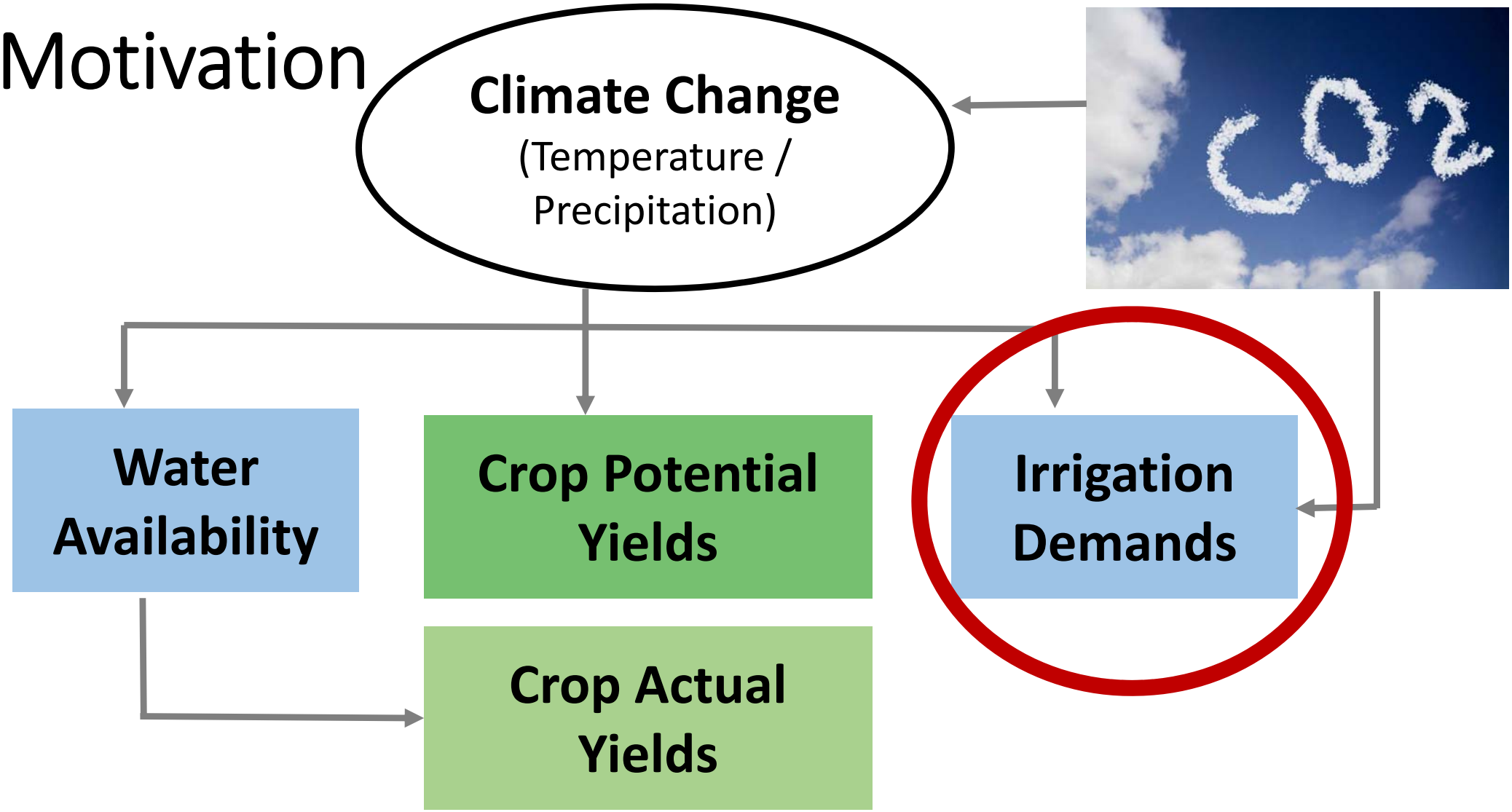
Kirti Rajagopalan

Terminology




Climate Change
(Temperature / Precipitation)
CO2
Water Availability
Crop Potential Yields
Irrigation Demands
Indirect Effects
Crop Actual Yields

Motivation


Climate Change
(Temperature / Precipitation)
CO2
Water Availability
Crop Potential Yields
Irrigation Demands
Crop Actual Yields

Motivation

Yield potential response to various factors can be non-linear, non-monotonic, competing, crop specific with regional differences.

The net response is unknown.

Potential for change in sign of response over time.

Implications for adaptation alternatives

Research Question 1

What are the direct impacts of climate change on crop yields and irrigation demands in the 2030s for the Columbia River basin?

Target Journal: Water Resources Research

Research Question 2

What are the indirect impacts of climate change on crop yields in the 2030s for the Columbia River basin?

Target Journal: Water Resources Research

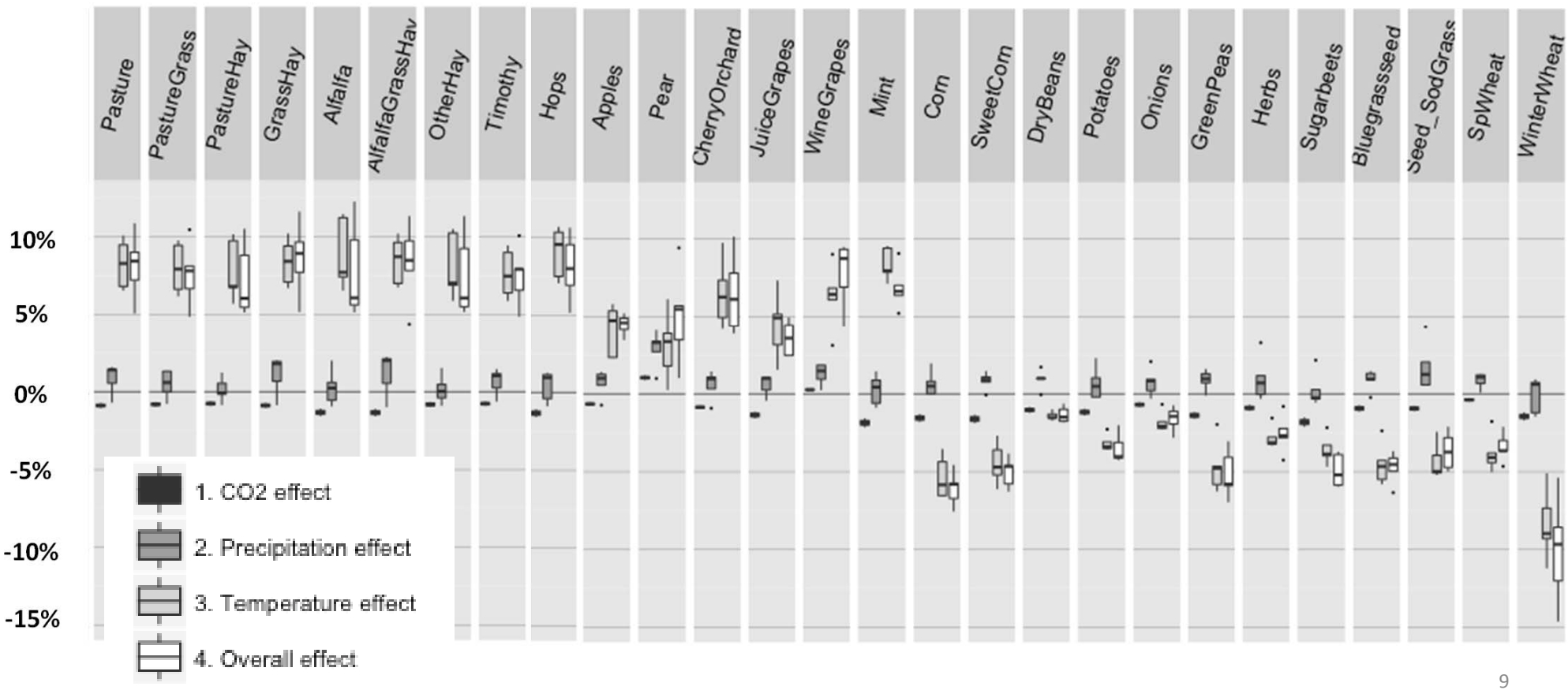
Research Question 3

How does the net response of climate change on crop yields evolve over time?

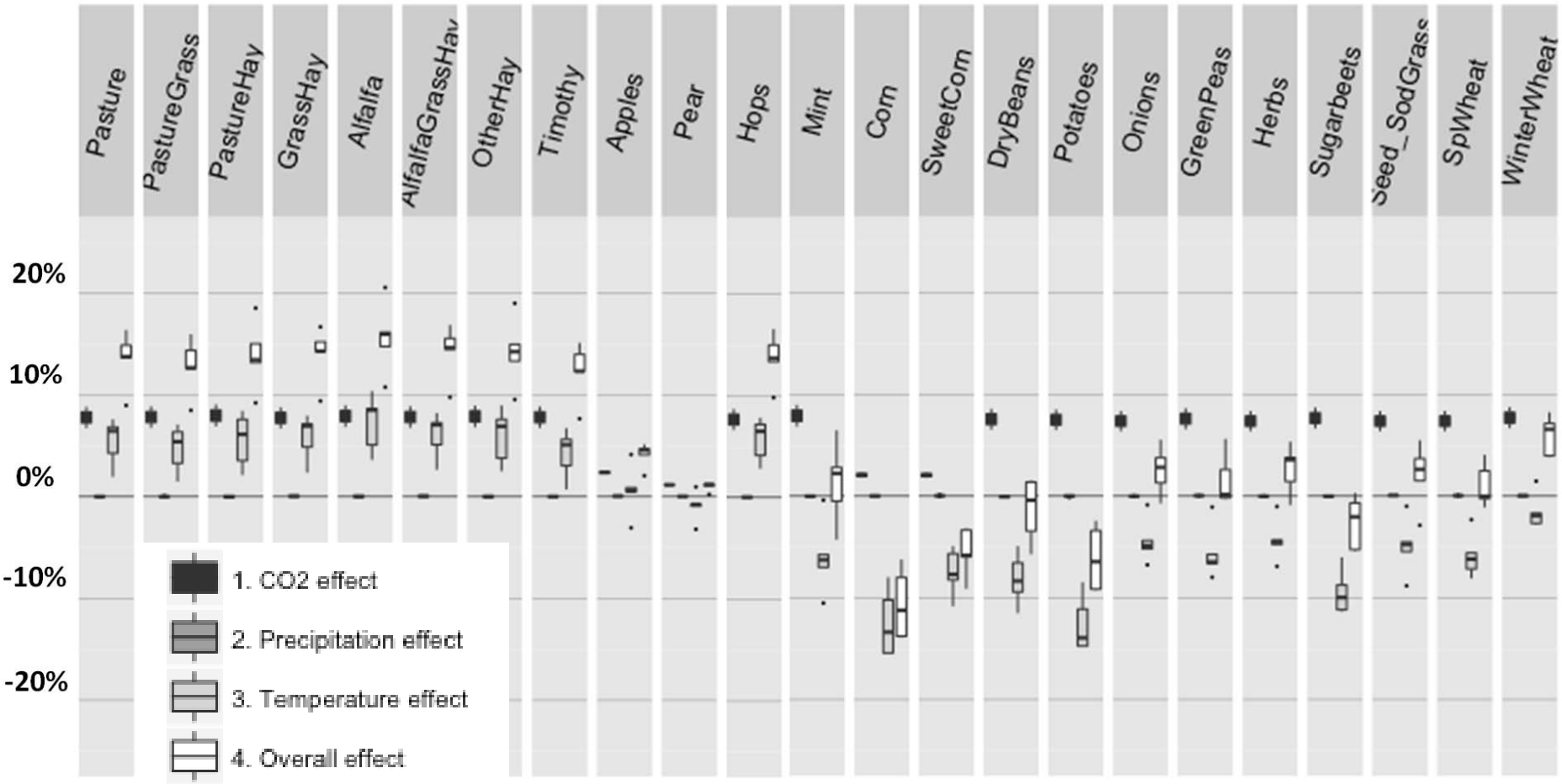
--Evaluate planting dates and crop varieties as adaptation alternatives.

Target Journal: Water Resources Research

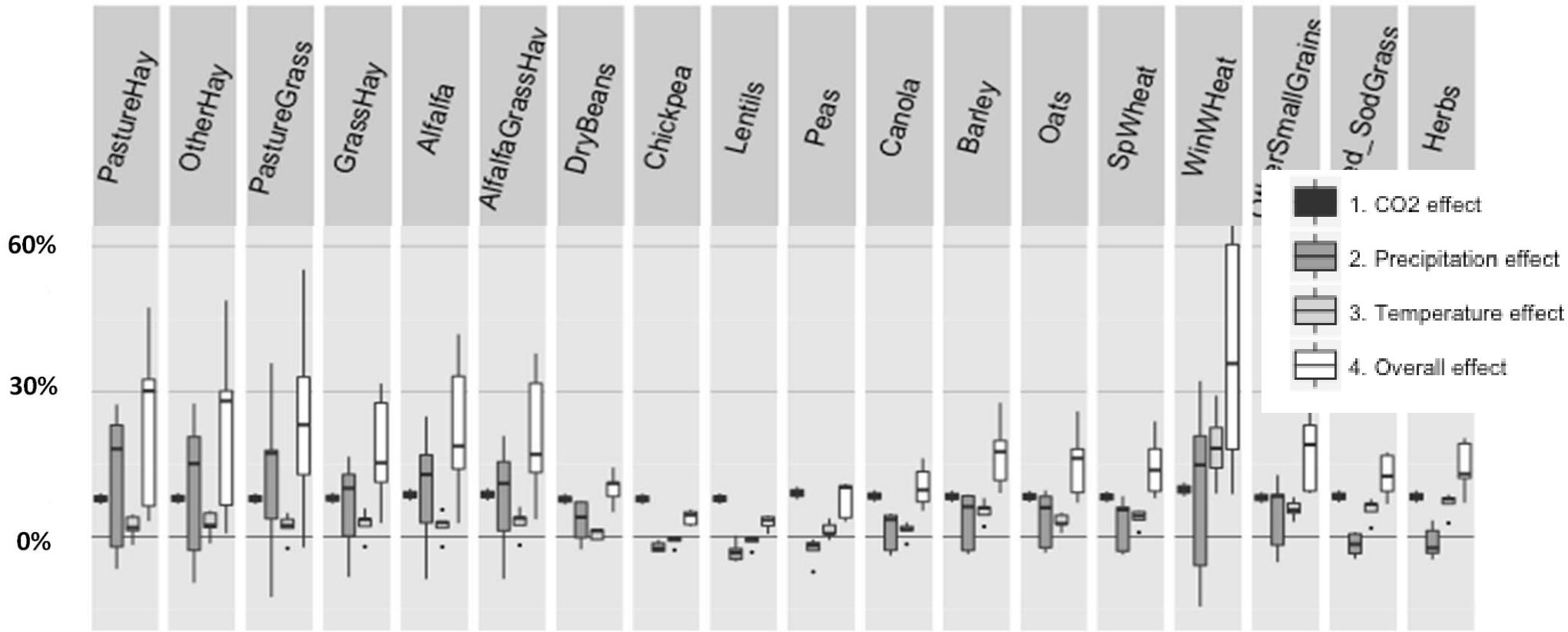
Changes in irrigation demand (%)



Changes in irrigated crop yields (%)

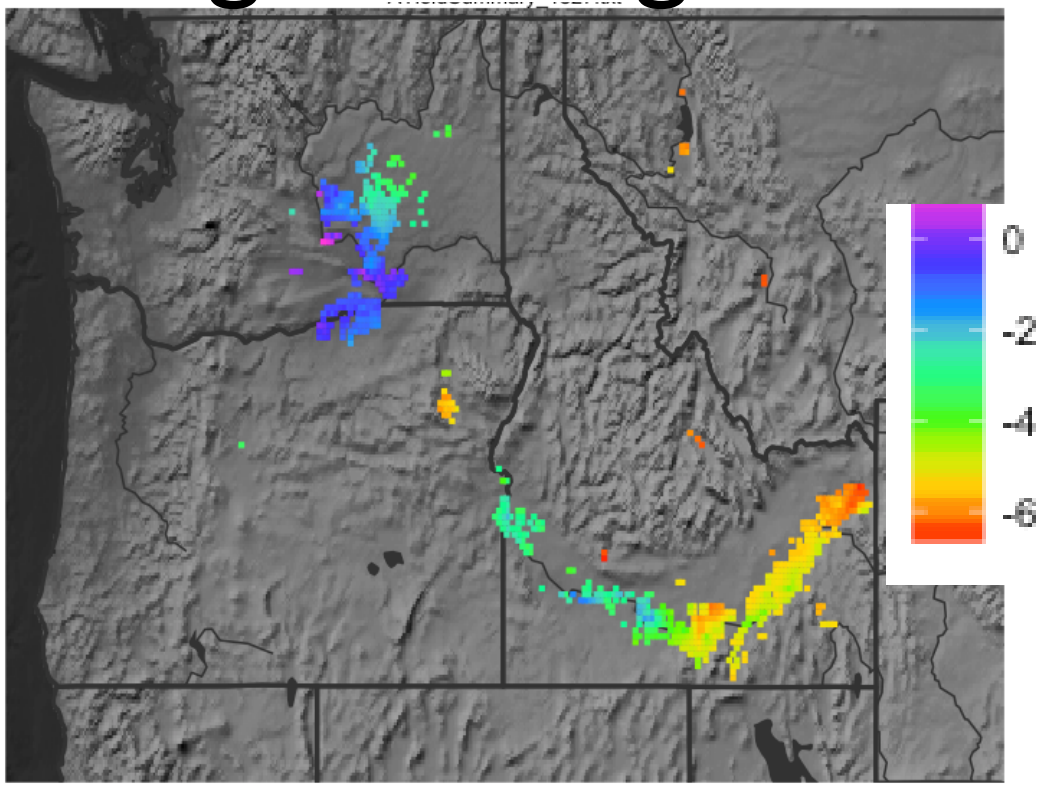


Changes in dryland crop yields (%)

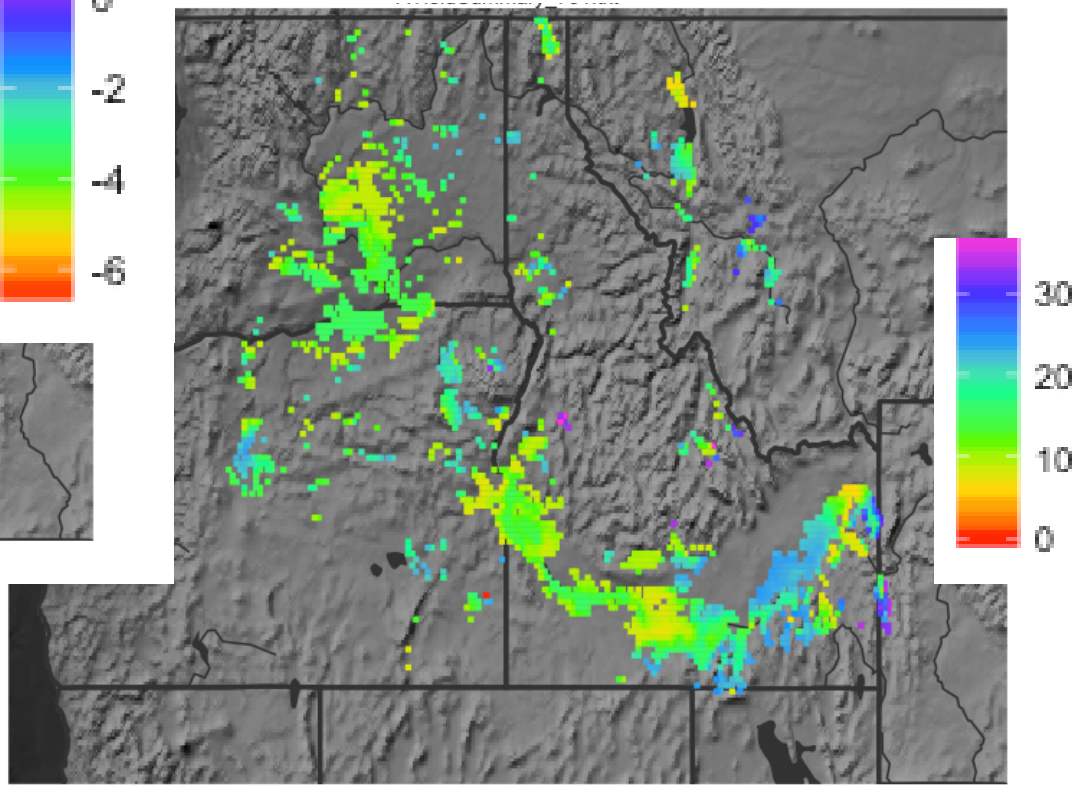


Changes in irrigated crop yields (%)

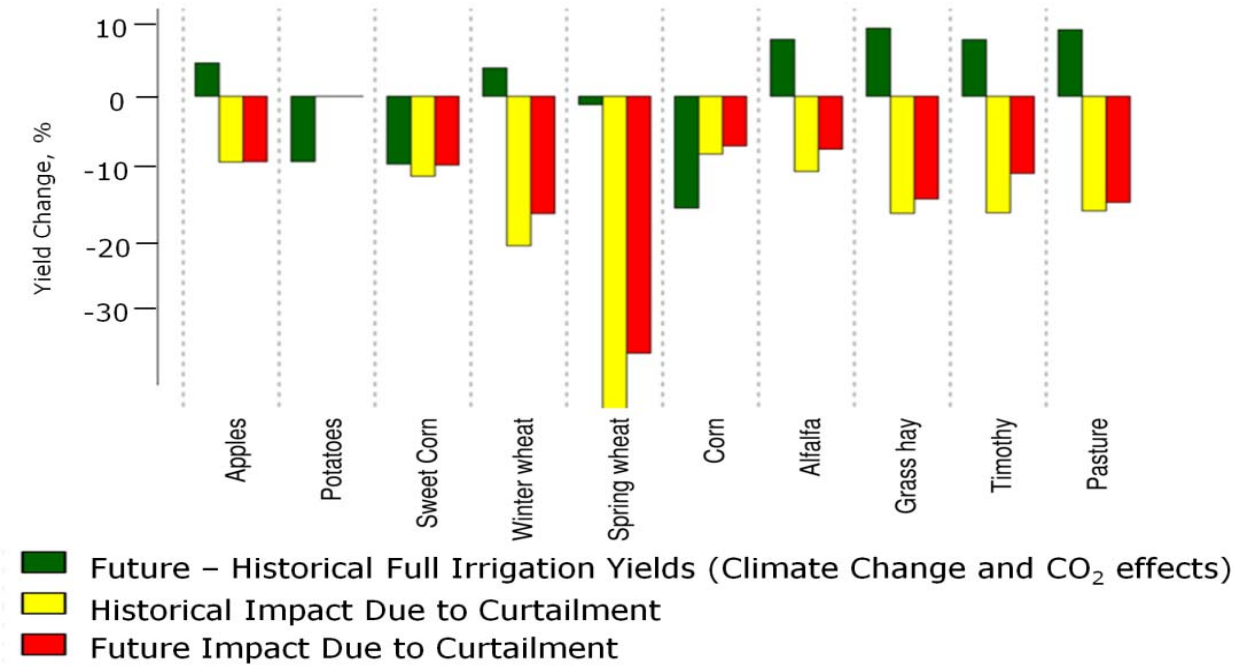
Potatoes



Alfalfa

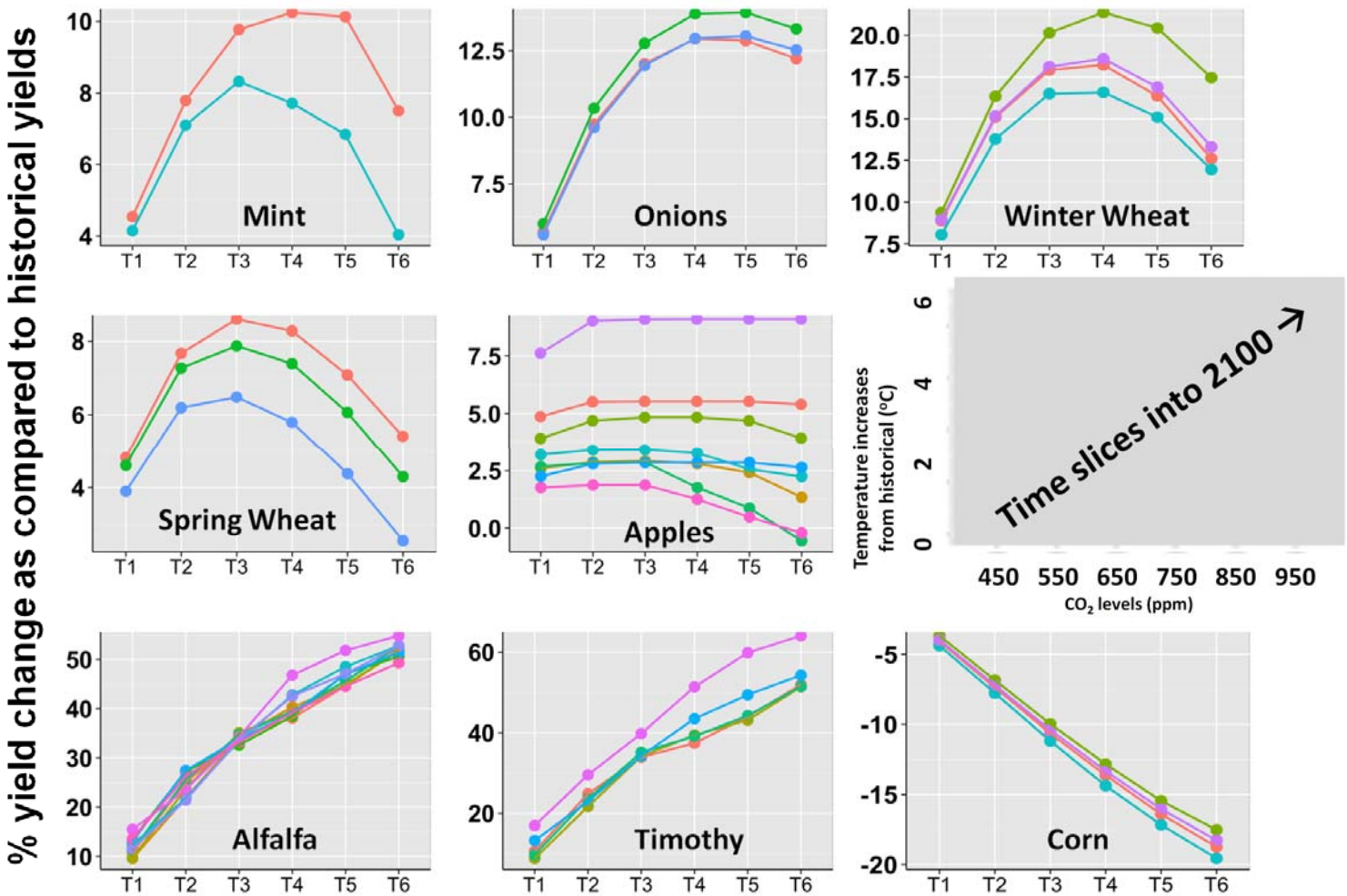


Yield reductions through changes in water availability



- Although frequency of curtailments are higher in the future, impacts on yields due to curtailment are not.

Changes in net response over time



Summary

Both positive and negative effects of climate change on agriculture in region

Crop and region specific differences.

-Important to consider spatially explicit cropland data in understanding regional effects.

Adaptation Considerations

Wicked problems require
interdisciplinary collaboration
Support decisions based on best available science & consideration of unintended consequences

We need to define:

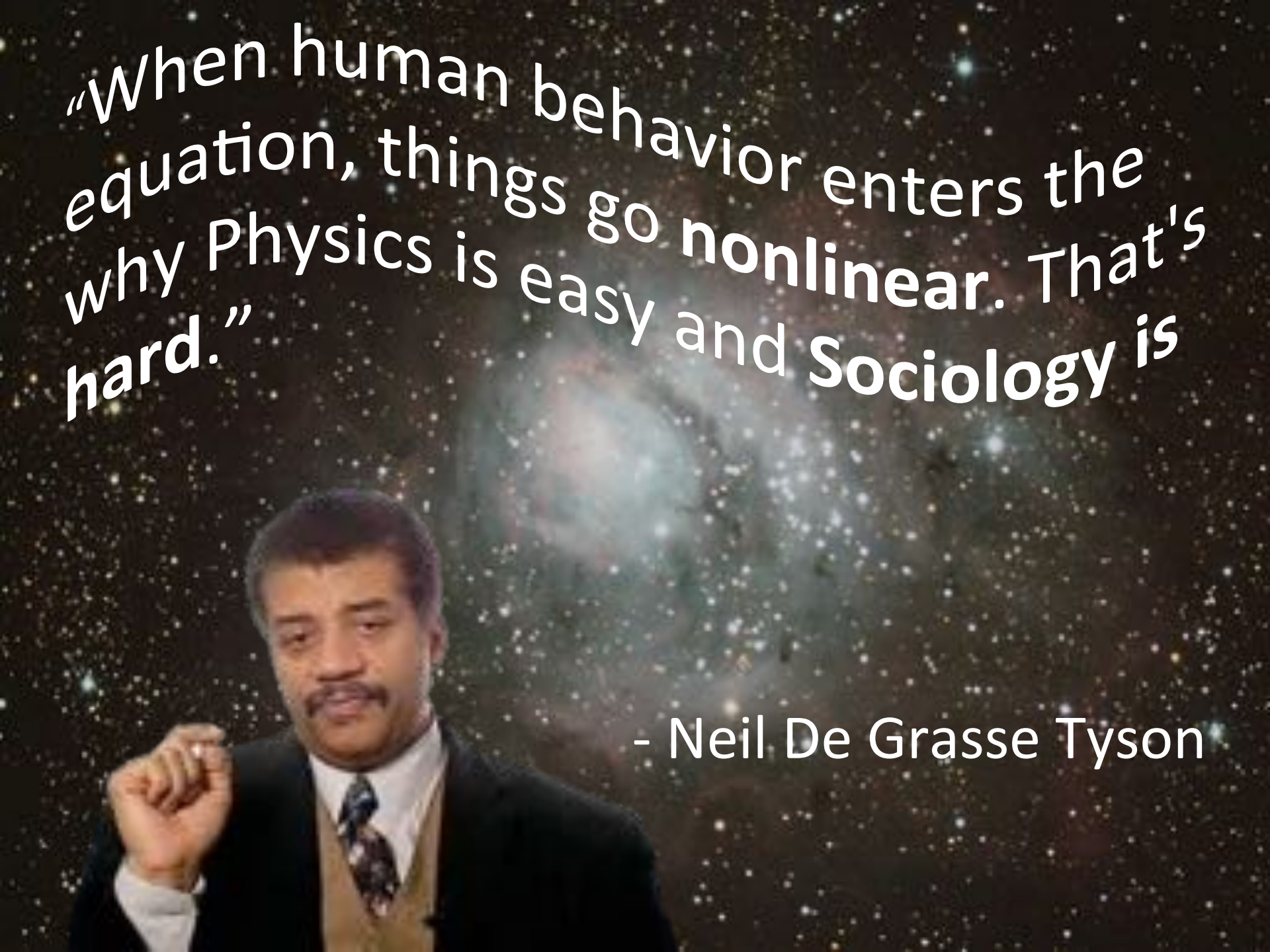
1. best practices
2. metrics for assessment

“Not rocket science”

But it does take time, communication skills and intentional planning

Who are decision-makers?

Potential for decision-makers to learn from models?


"When human behavior enters the equation, things go **nonlinear**. That's why Physics is easy and **Sociology is hard**."
- Neil De Grasse Tyson

Overarching goal:

Capture and synthesize what each of us learned about interdisciplinary modeling and stakeholder engagement

How has our work been informed by stakeholders' questions?

What outputs are we generating that
decision-makers will be interested in?

Improve efficiency and quality of collaboration with non-academic stakeholders

NATIONAL PARK SERVICE

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

USDA ars

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

DAIRY FARMERS OF WASHINGTON PRIDE

American Farmland Trust

THE CLIMATE TRUST

NEZ PERCE TRIBE TREATY OF 1855

DEPARTMENT OF ECOLOGY State of Washington

The Freshwater Trust

Spokane Regional Clean Air Agency

DEQ

YAKIMA BASIN FISH. FAMILIES. FARMS.

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF LAND MANAGEMENT

Opportunities to improve interdisciplinary collaboration?

Identify strategies for all of us to develop our boundary-spanning skills

Social science research expertise

*****

Communication skills

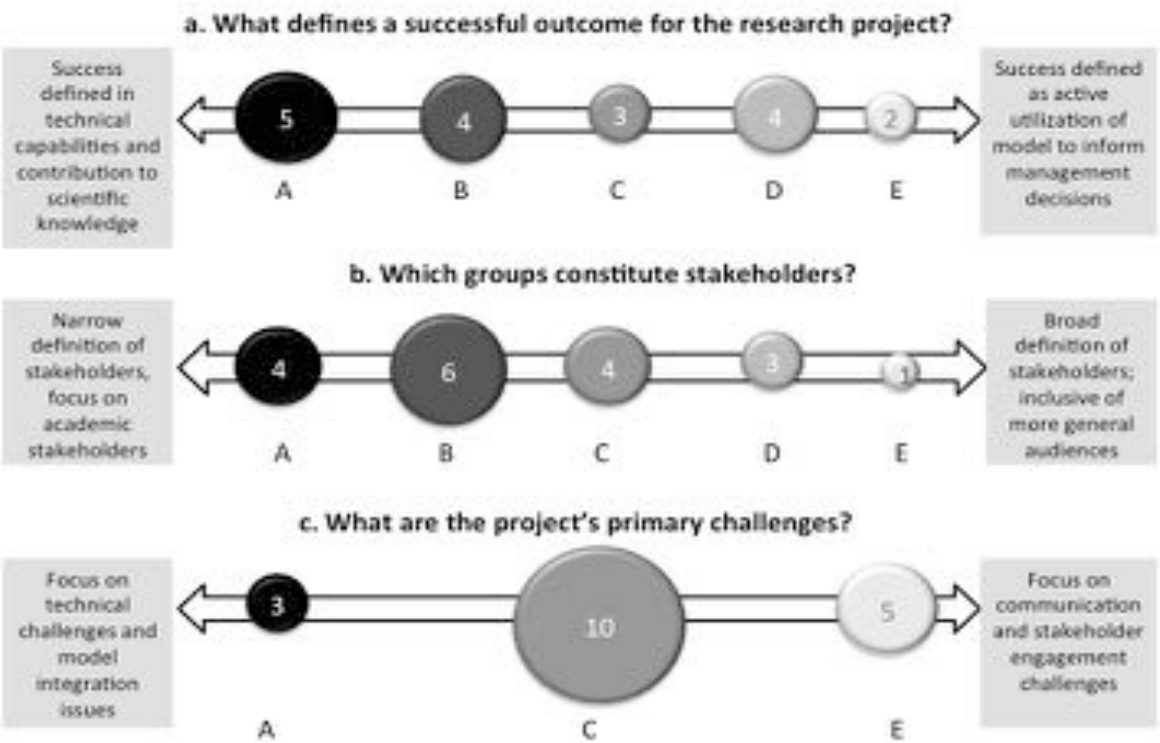
*****

Extension experience

Salient Accessible Usable

Publication 1: Researchers' perceptions

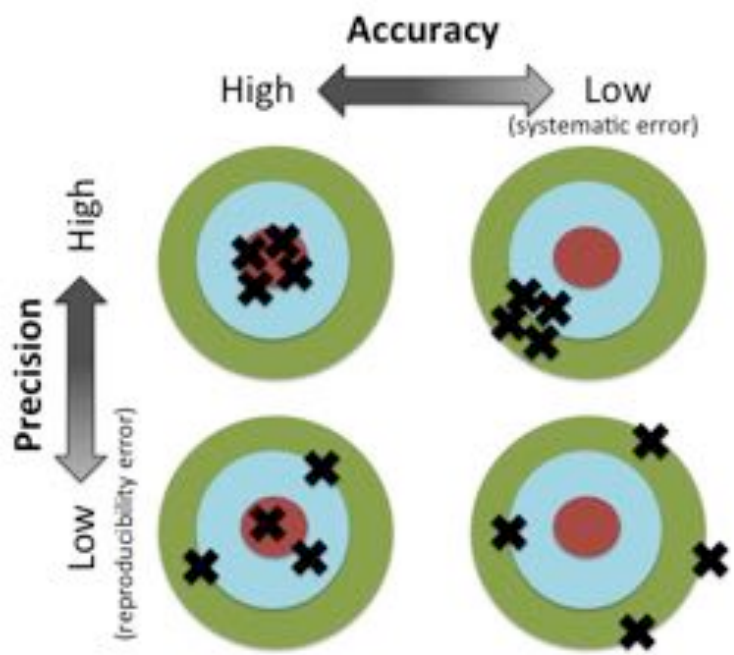
Allen, E., Kruger, C.E., Leung, F.Y., Stephens, J.C. (2013). **Diverse Perceptions of Stakeholder Engagement Within an Environmental Modeling Research Team.** *Journal of Environmental Studies and Sciences*, 3(3), 343-356.



Publication 2:

Environmental Modeling Factsheet

Allen, E., Yorgey, G., Rajagopalan, K., Kruger, C. (2015). **Modeling Environmental Change: A guide to understanding results from models that explore impacts of climate change on regional environmental systems.** *WSU Extension Publication.*



Publication 3:

Workshop summary reports

Allen, E., Kruger, C., Yorgey, G., Stephens, J., Harrison, J., Forney, W, Saari, B., Leung, F.Y. (2013, 2014, 2015). **BioEarth Stakeholder Advisory Workshops Synthesis Reports.** Washington State University.

BioEarth

Biosphere-relevant earth system model

2015 Water Quality Stakeholder Workshop Synthesis Report

Contents:

I. Stakeholders represented at the workshop

II. Dominant regional issues of concern

III. Information that could improve decision-making

IV. Recommendations about storyline and scenario development

V. Reflections on communication

Appendix: Proposed regional storylines

On March 12, 2015 the BioEarth project's communication and extension working group convened a stakeholder advisory workshop focused on water quality issues in the Pacific Northwest in order to build understanding among research team members of how the BioEarth integrated earth systems model might produce outputs that are relevant to the needs of decision-makers and other researchers concerned with intersections between water quality and regional environmental change. The workshop, held in Vancouver, WA brought together 20 stakeholders and 8 BioEarth researchers. This was the 6th and final workshop in a series of issue-based stakeholder meetings designed as a step toward greater information sharing and collaboration among university-based environmental modelers and stakeholders who can provide guidance and feedback to the modeling team and potentially use model results.

The workshop was designed to address three key objectives:

1. To understand current and future concerns about regional water quality (environmental, health, economic, resource availability, other problems)
2. To understand stakeholders' perspectives on decision making and what constitutes useable information
3. To guide the scenarios and issues the research team addresses in model development and application

I. Stakeholders represented at the workshops

Of the 105 individuals invited, 20 stakeholders were able to attend the workshop. Invited stakeholders consisted of government agencies, non-governmental organizations, research institutions and industry groups.

Federal Government Agencies: Environmental Protection Agency, Oak Ridge Institute for Science and Education, US Geological Survey

Tribal Government Representative: Columbia River Inter-Tribal Fish Commission

State Government Agencies: Oregon Department of Environmental Quality, Oregon Department of Agriculture, Washington State Department of Agriculture, Washington Ecology

Local Government Agencies: County Conservation Districts, Clean Water Services

Non-Governmental Organizations: Wild Fish Conservancy, Willamette Partnership, Lower Columbia River Estuary Partnership, Freshwater Trust

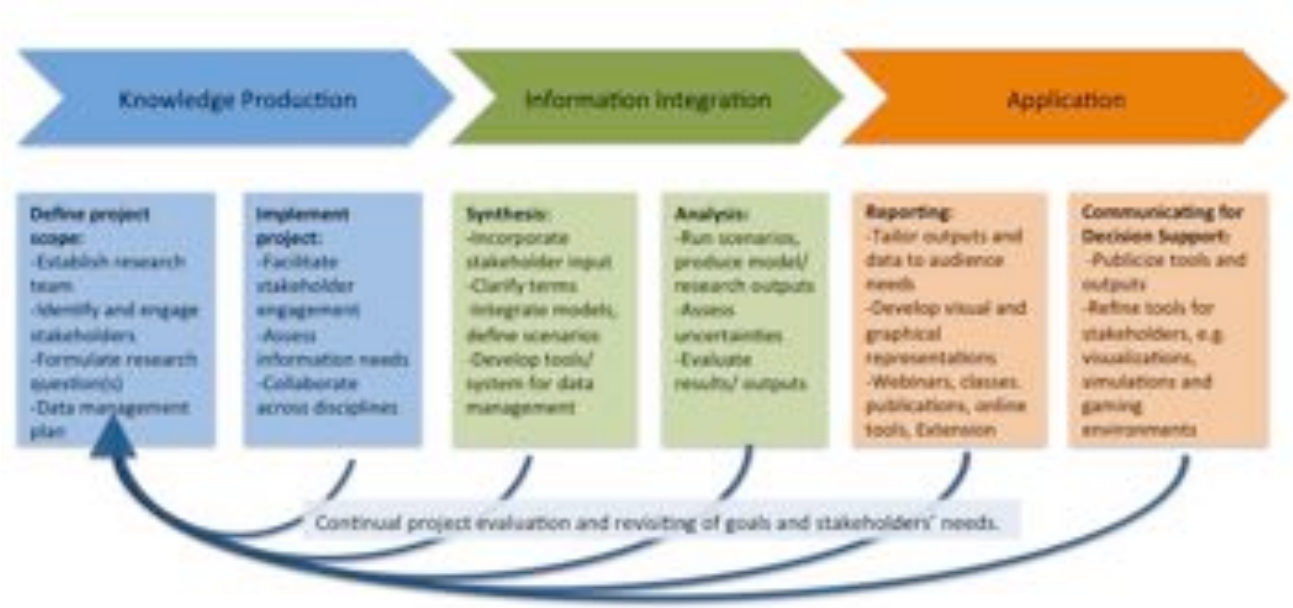
Industry, Environmental Consulting: Stillwater Sciences

Groups not represented at the stakeholder workshop, but recommended for future inclusion by attending stakeholders: USDA Natural Resources Conservation Service and Agricultural Research Service, tribal governments including water quality specialists from the Klamath Tribe, EPA Office of Environmental Assessment, private forest products and farming industry representatives, land owners, public water supply municipalities and other academic partners working on related water quality issues.

Citation: Allen, E., W. Forney, Harrison, J., C. Kruger, B. Saari, J. Stephens & G. Yorgey. (2015). *BioEarth Water Quality Stakeholder Advisory Workshop Synthesis Report*. Washington State University.

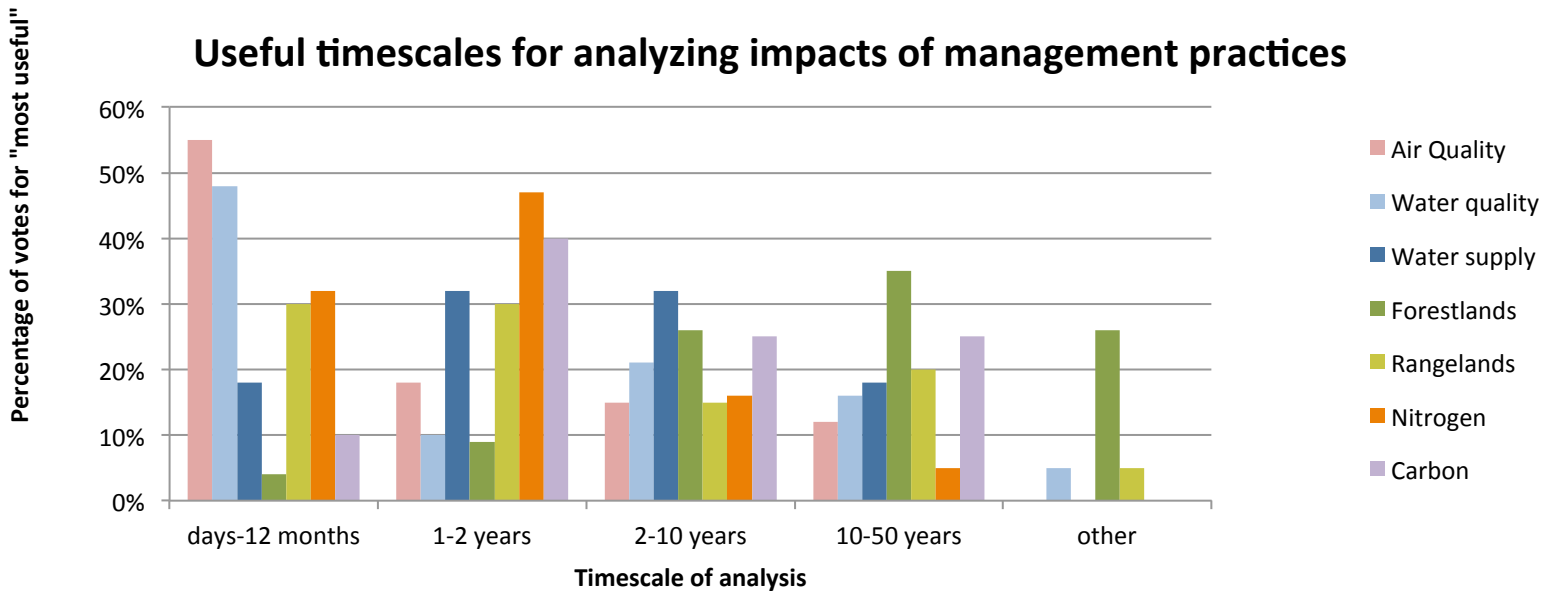
Publication 4: Usable climate science value chain

Allen, E. and J.C. Stephens. (2015). **Enhancing Usability of Climate Information and Models through Stakeholder Engagement**, in *Information, Models, and Sustainability: Policy Informatics in the Age of Big Data and Open Government Public Administration and Information Technology.* (PAIT) Book Series. Editors: Jing Zhang, Luis Luna-Reyes, Theresa A. Pardo, Djoko Sigit Sayogo.



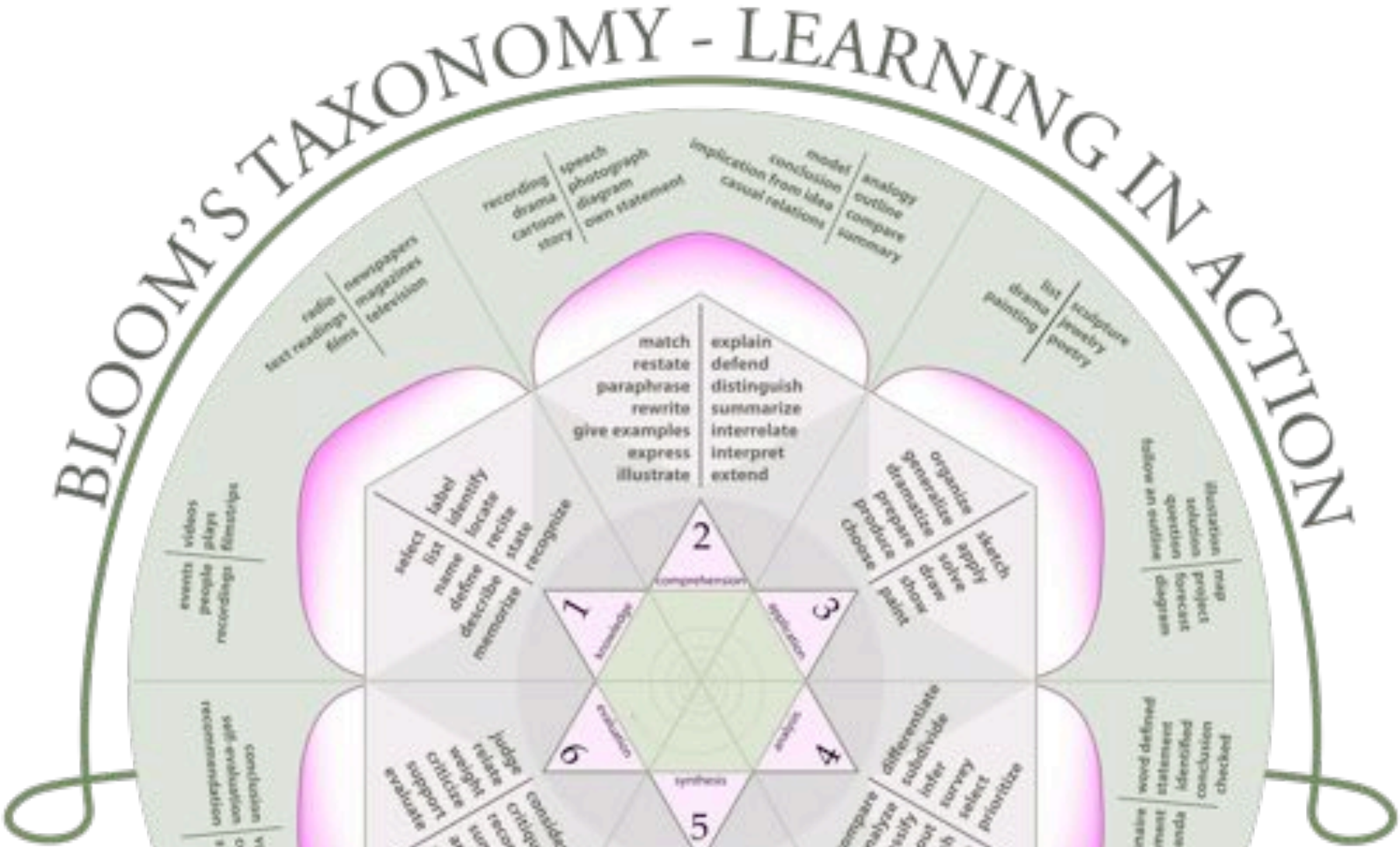
Publication 5: Northwest resource managers' information needs

Allen, E., Stephens, J.C., Yorgey, G., Kruger, C., Ahamed, S., Adam, J.C. (in review in Environmental Management). **Climate science information needs among Northwest U.S. natural resource decision-makers.**



Future publication:

Lessons learned and evolving perceptions



Future publication:
Comparison of approaches in REACCH, WISDM and BioEarth

PROCESS-ORIENTED ⟷ PRODUCT-ORIENTED

Collaborative system dynamics modeling

Stakeholders help define researchable questions

Regional Agricultural Pathways process

WISDM

BioEarth

REACCH
Regional Approaches to Climate Change –
PACIFIC NORTHWEST AGRICULTURE