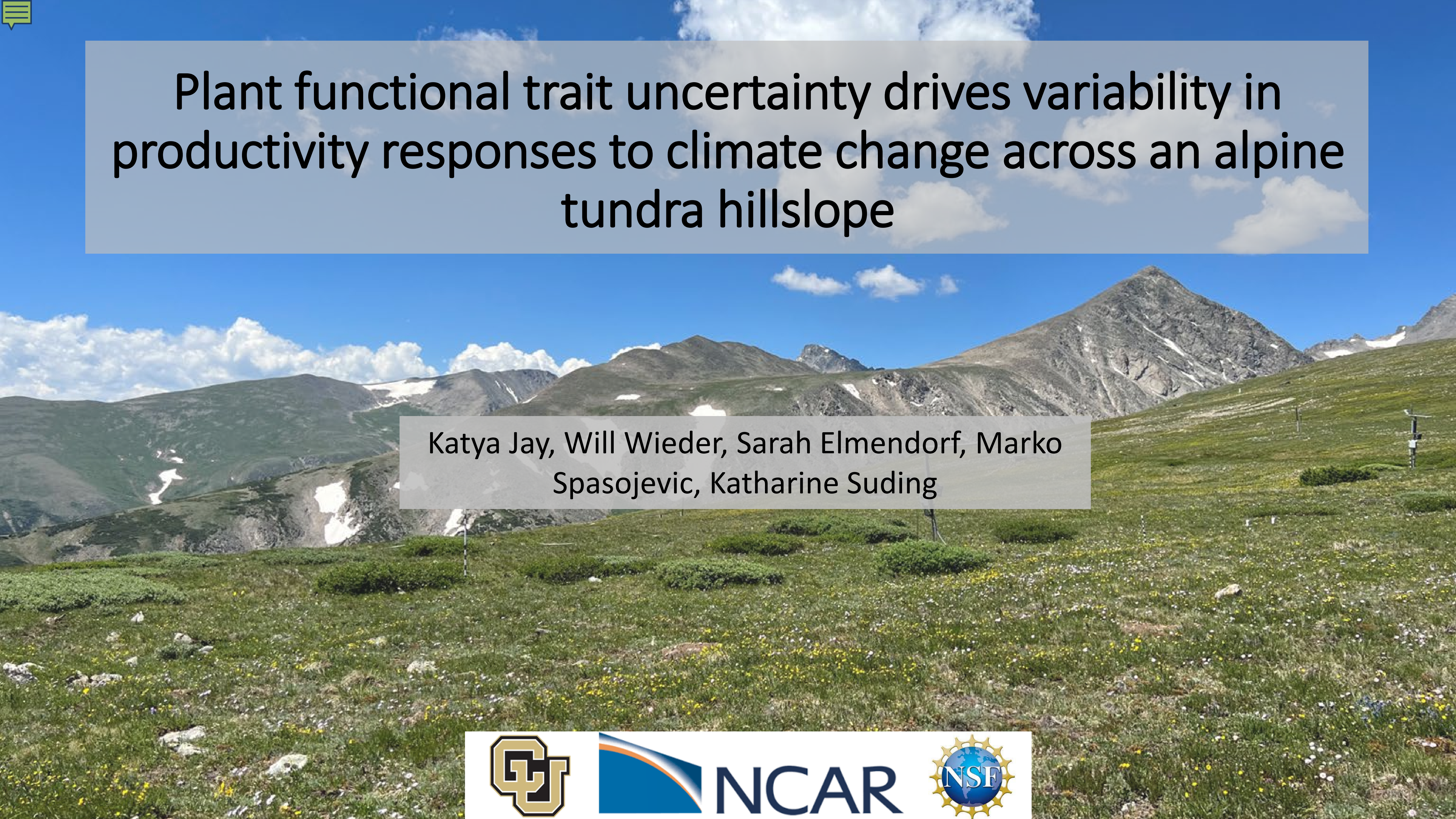
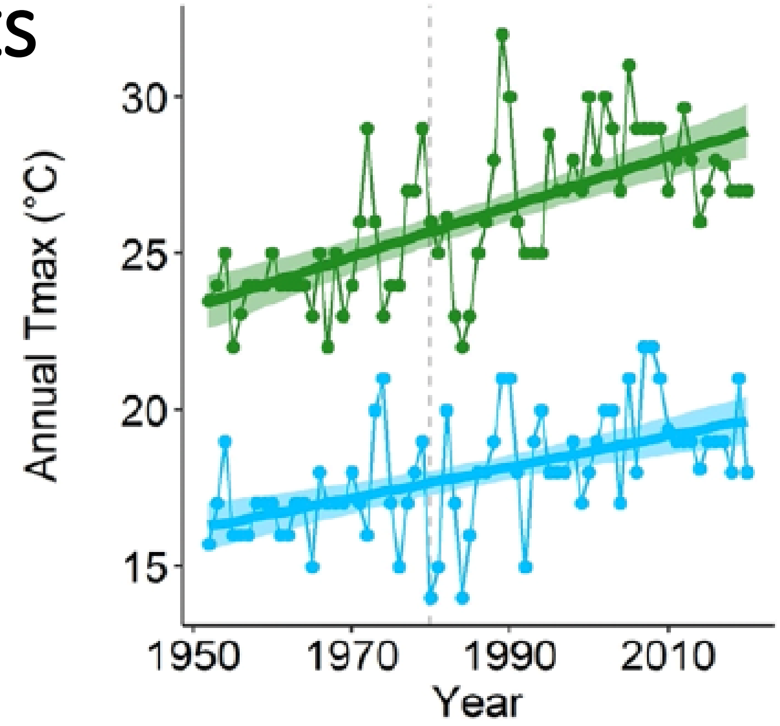
Plant functional trait uncertainty drives variability in productivity responses to climate change across an alpine tundra hillslope

Katya Jay, Will Wieder, Sarah Elmendorf, Marko Spasojevic, Katharine Suding

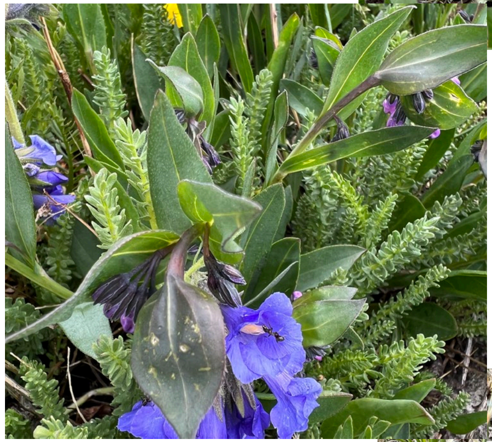


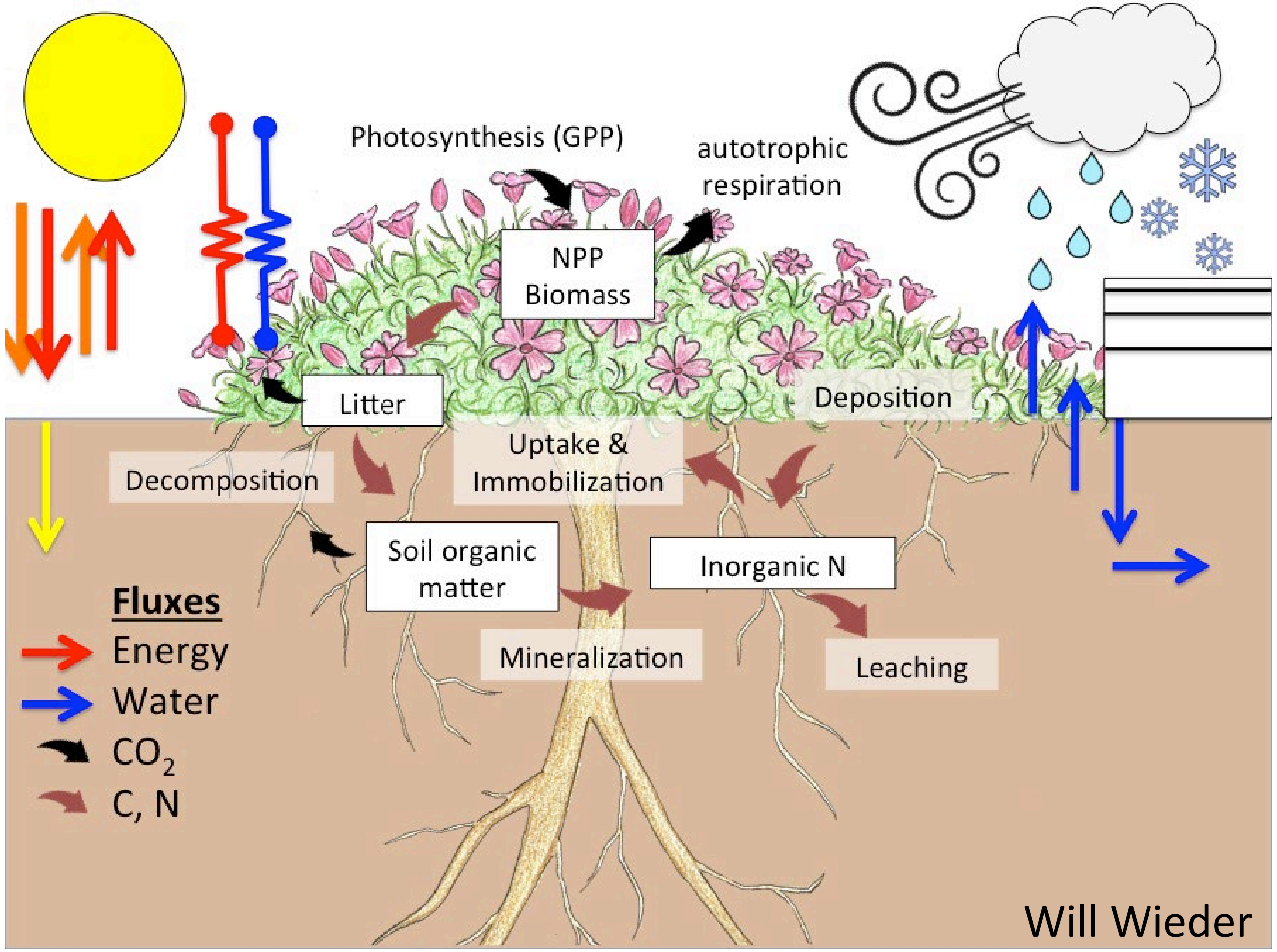
Niwot Ridge LTER: long-term measurements

Alpine ecosystems are changing rapidly



Diverse alpine growth strategies may not be captured by default PFTs





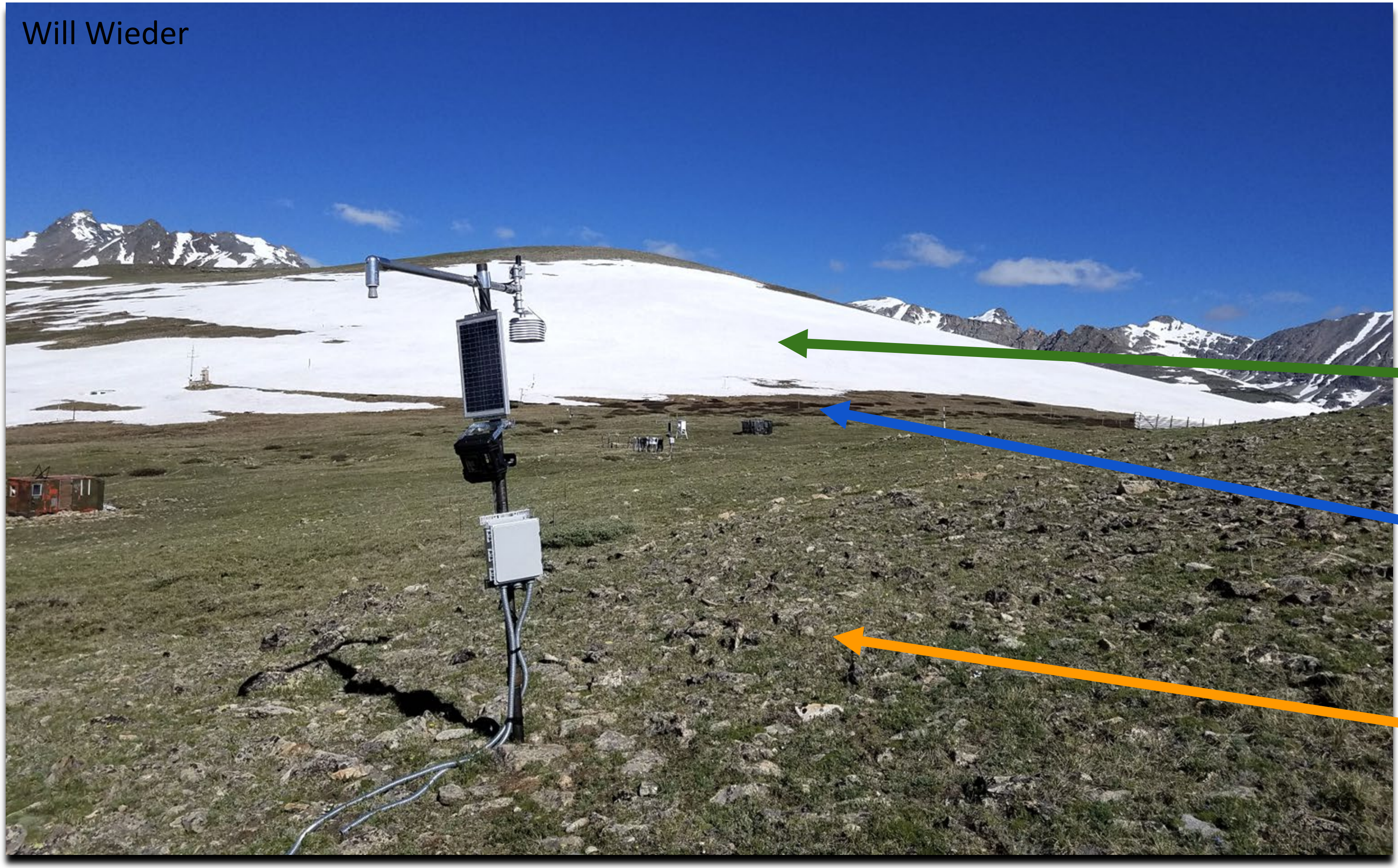
Objectives

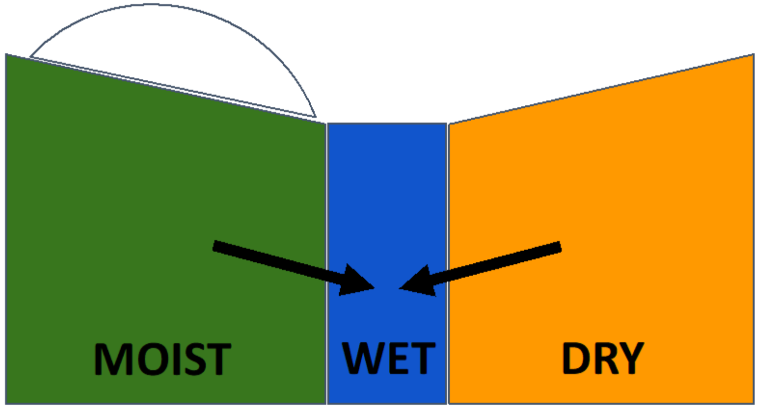
1. Incorporate site-level plant traits to improve model performance for a heterogeneous alpine ecosystem

2. Quantify the magnitude of trait uncertainty relative to forcing uncertainty under climate change

Niwot Ridge Representative Hillslope

"The Saddle"





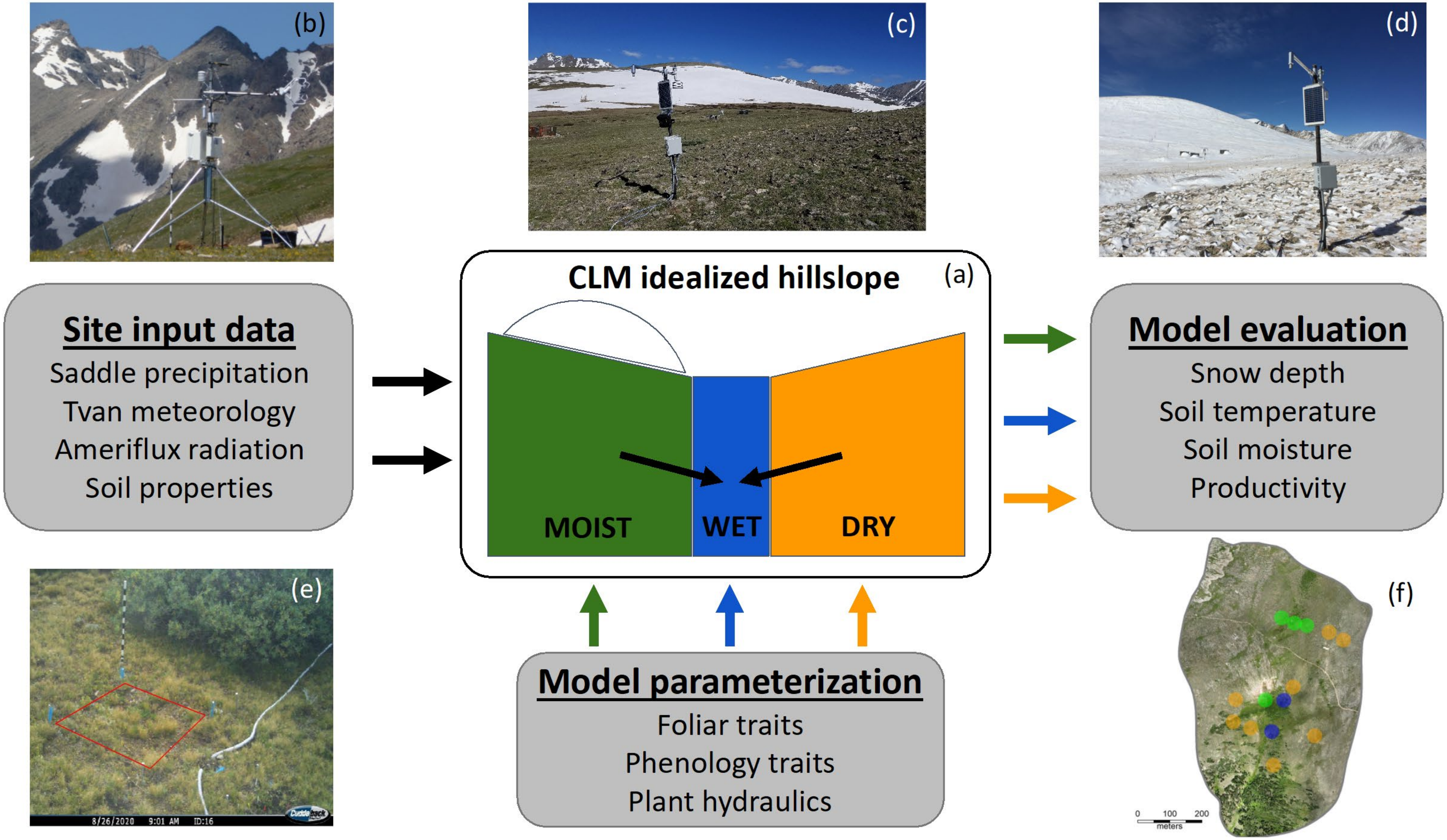
Moist Meadow

Resource-acquisitive plants

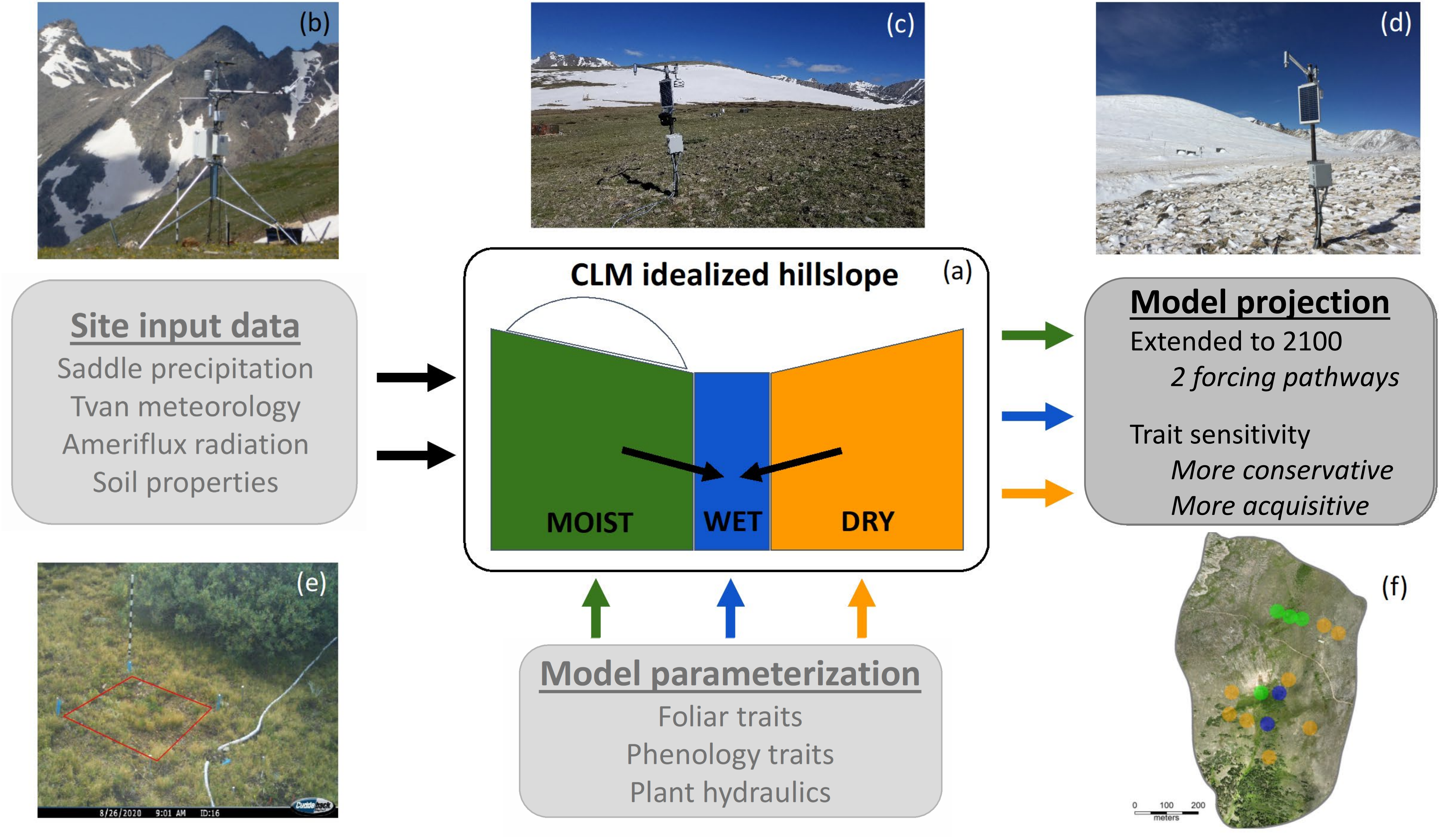
Wet Meadow

Dry Meadow

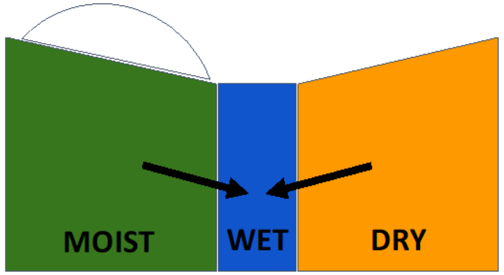
Conservative growth strategies

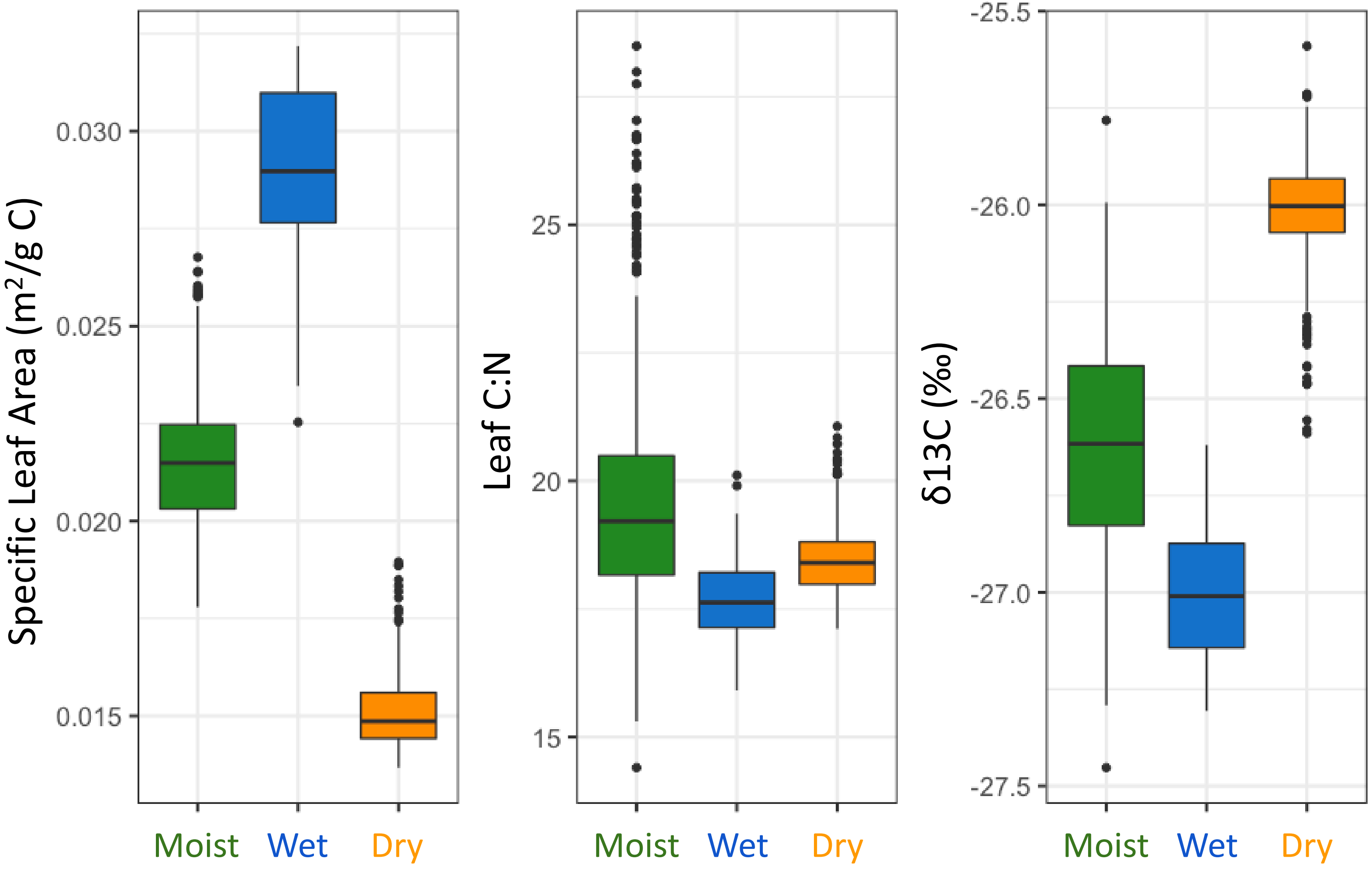


Jay et al. 2023, *JGR Biogeosciences*


(b)
(c)
(d)
Site input data
Saddle precipitation
Tvan meteorology
Ameriflux radiation
Soil properties
CLM idealized hillslope
(a)
MOIST
WET
DRY
Model projection
Extended to 2100
2 forcing pathways
Trait sensitivity
More conservative
More acquisitive
(e)
8/26/2020 9:01 AM ID:16
(f)
0 100 200
meters
Model parameterization
Foliar traits
Phenology traits
Plant hydraulics

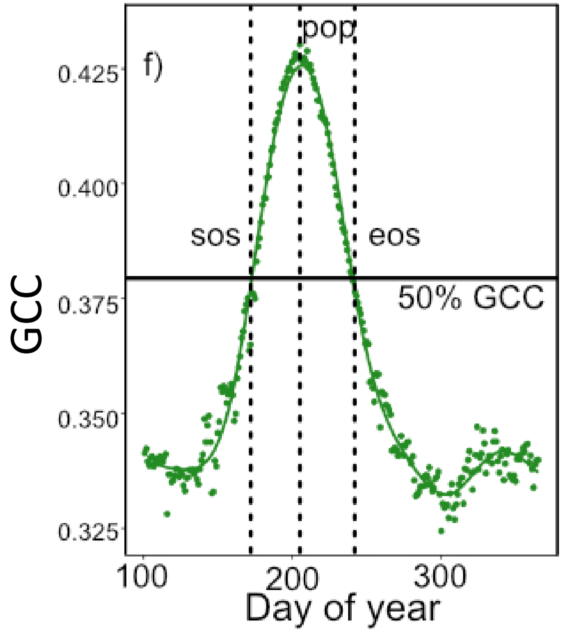
Parameterization using site-specific foliar traits





Parameterization using site-specific phenology

Phenology metrics vary between communities at Niwot



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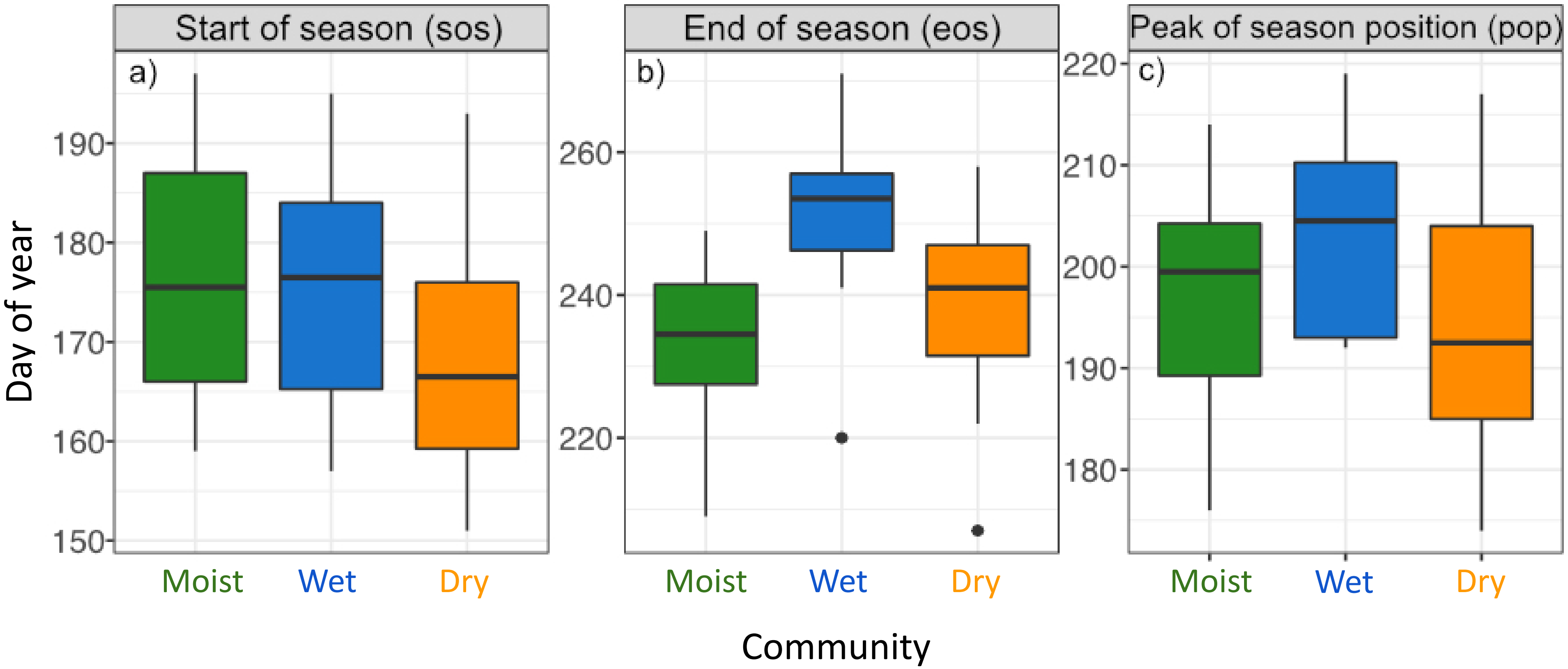
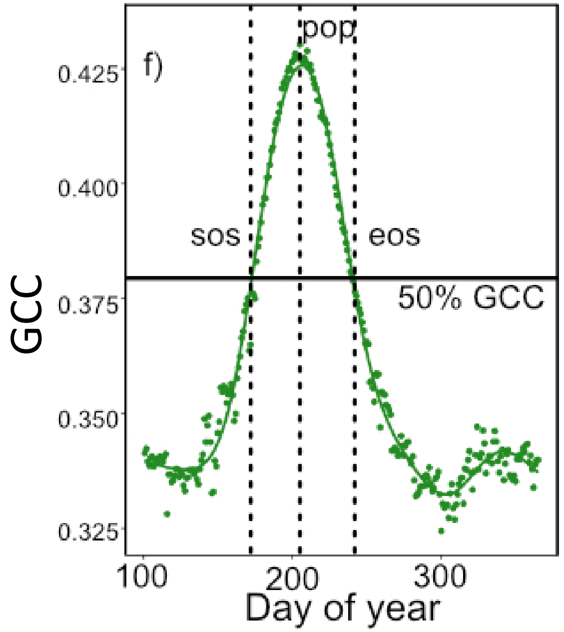
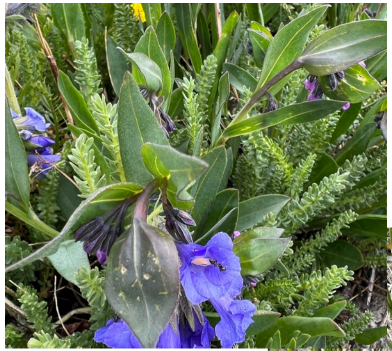
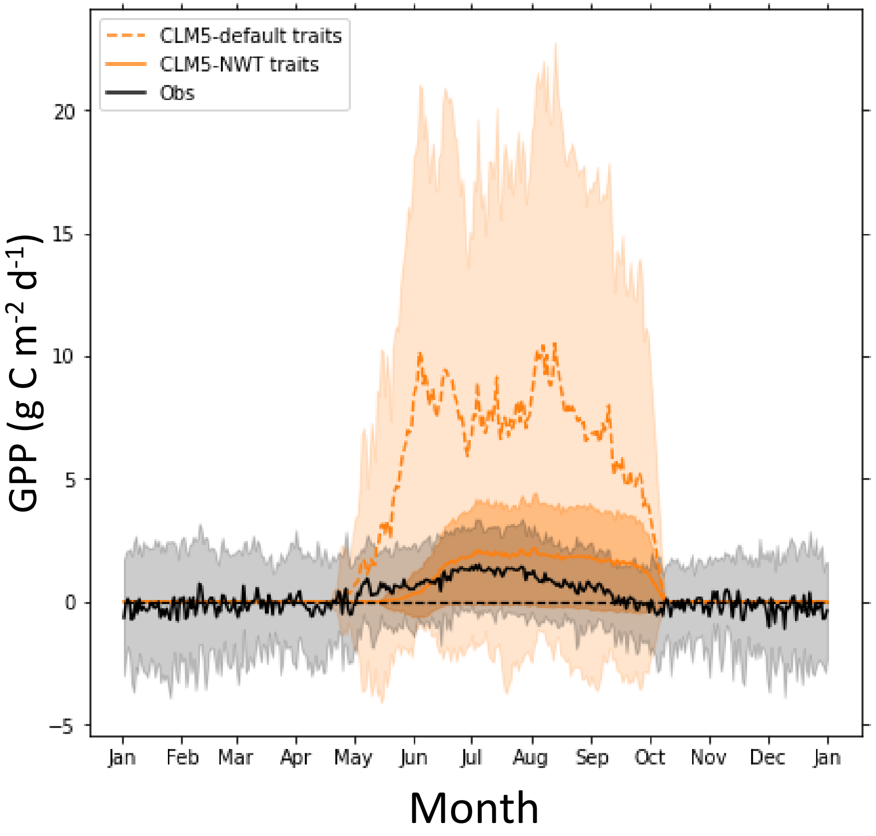
Phenology metrics vary between communities at Niwot





Evaluation: Simulations with NWT-specific traits show improved productivity estimates compared to those with default Arctic C3 grass





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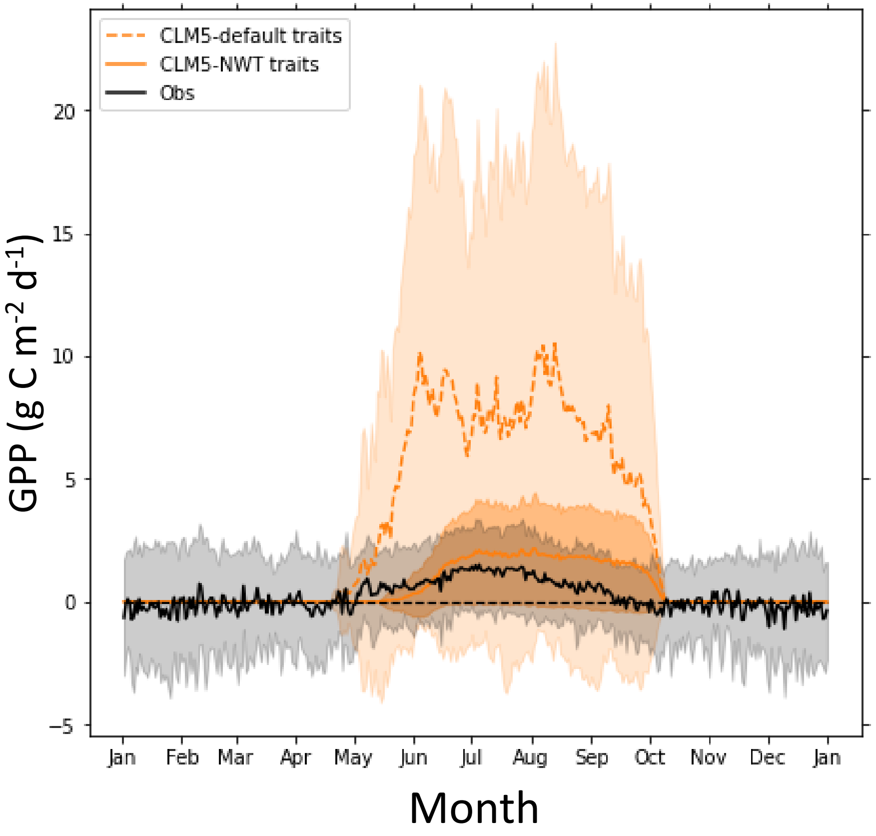
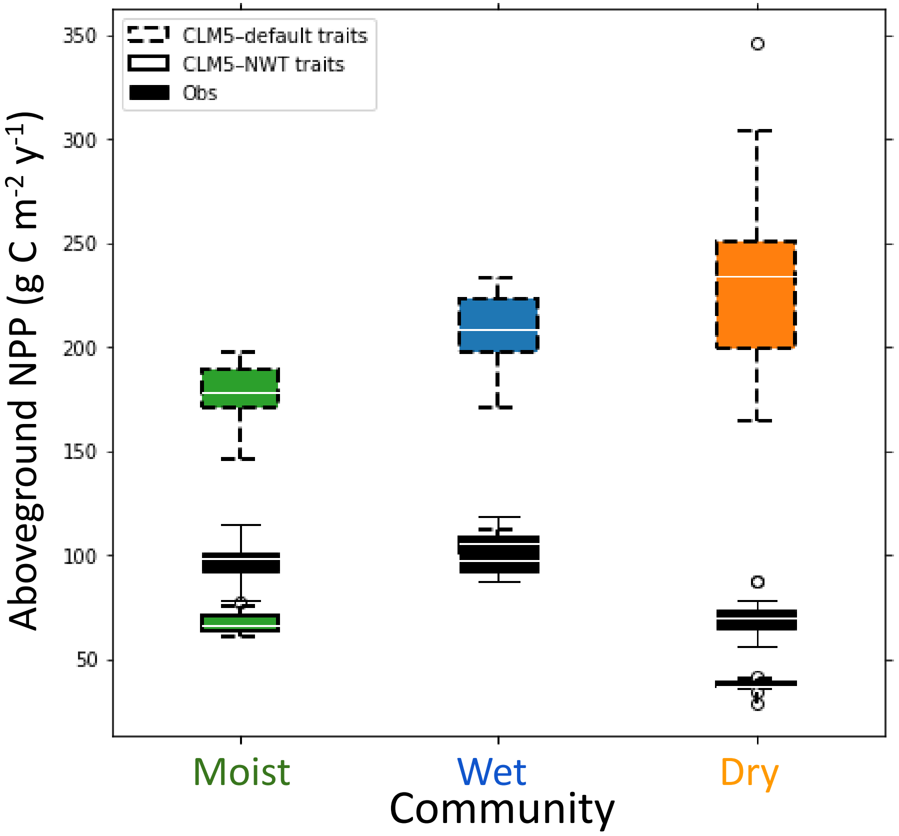




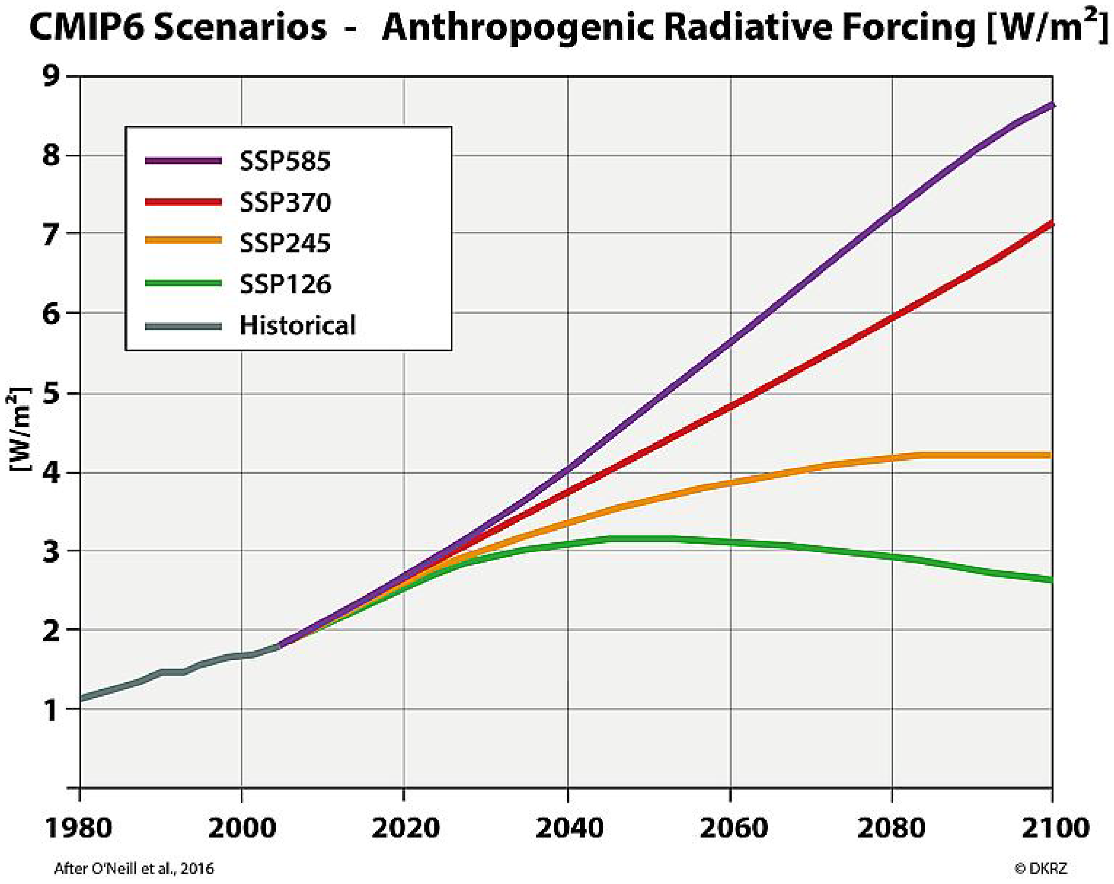
Projection: Quantifying trait uncertainty and forcing uncertainty under climate change

Trait experiments:

- *Control:* parameterized for site
- *Acquisitive:* ↑SLA, ↓leaf C:N, ↑kmax
- *Conservative:* ↓SLA, ↑leaf C:N, ↓kmax

2 forcing pathways to 2100:

	SSP2-4.5	SSP3-7.0
CO_2 (ppm)	602.8	867.2
Warming (˚C)	2.8	4.4



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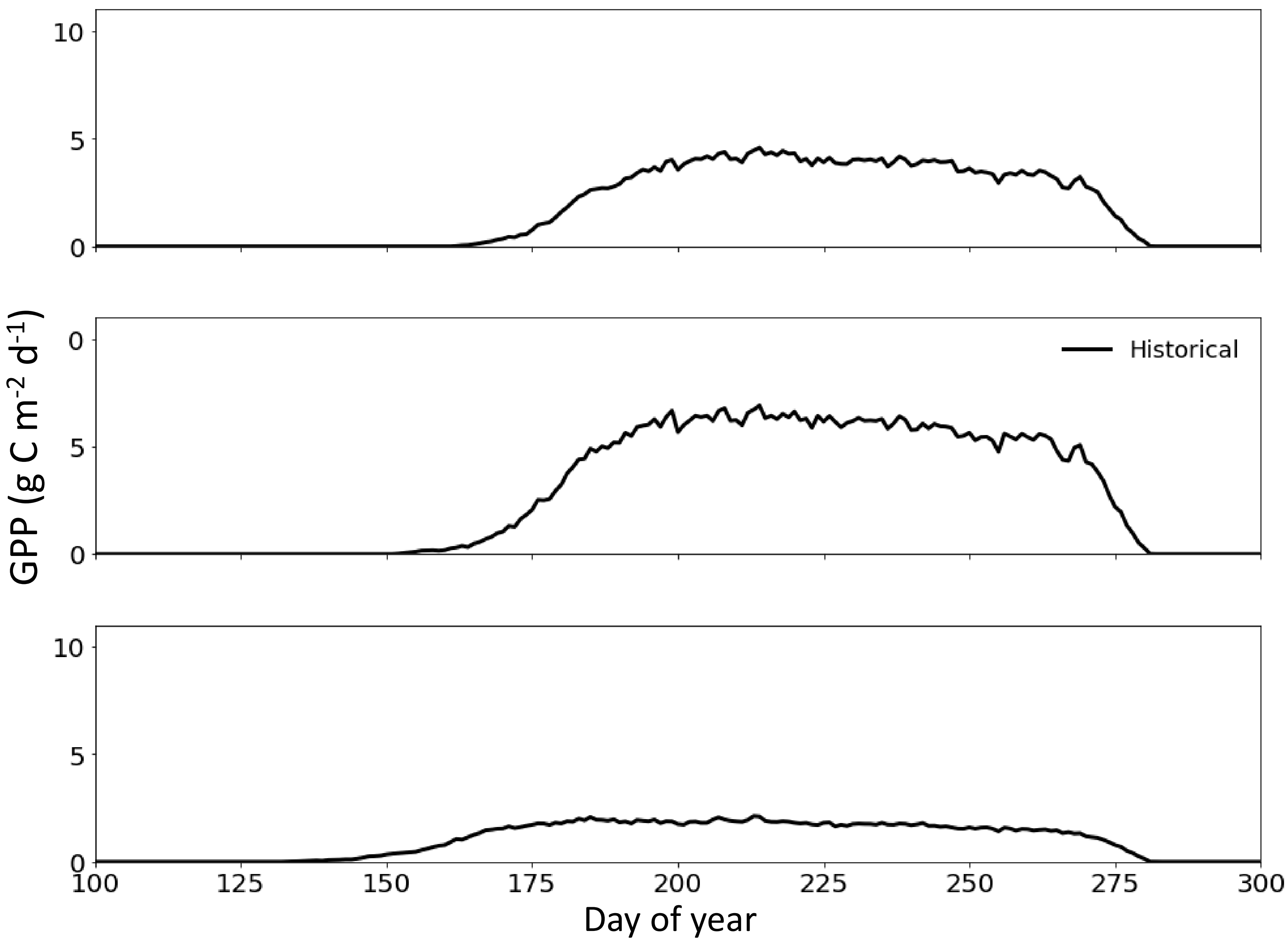
Uncertainty partitioning:

Between group

Within group

	Forcing pathway	
Experiment	SSP2-4.5	SSP3-7.0
Control	x_{11}	x_{12}
Acquisitive	x_{21}	x_{22}
Conservative	x_{31}	x_{32}
Mean	$x_{.1}$	$x_{.2}$
Variance	s^2_1	s^2_2

Projection: Trait sensitivity and forcing uncertainty in GPP

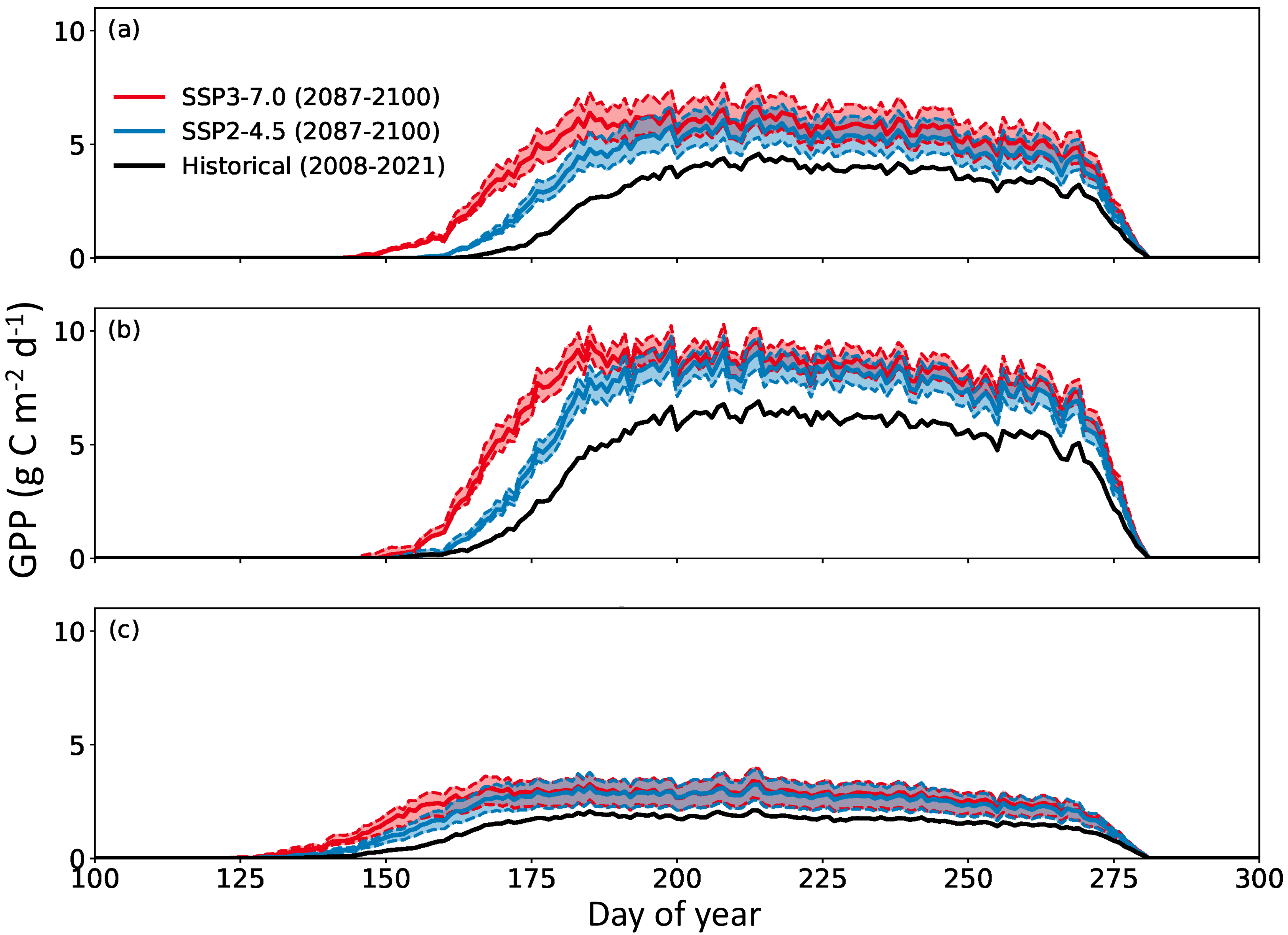


Moist

Wet

Dry

Projection: Trait sensitivity and forcing uncertainty in GPP



Moist

Wet

Dry

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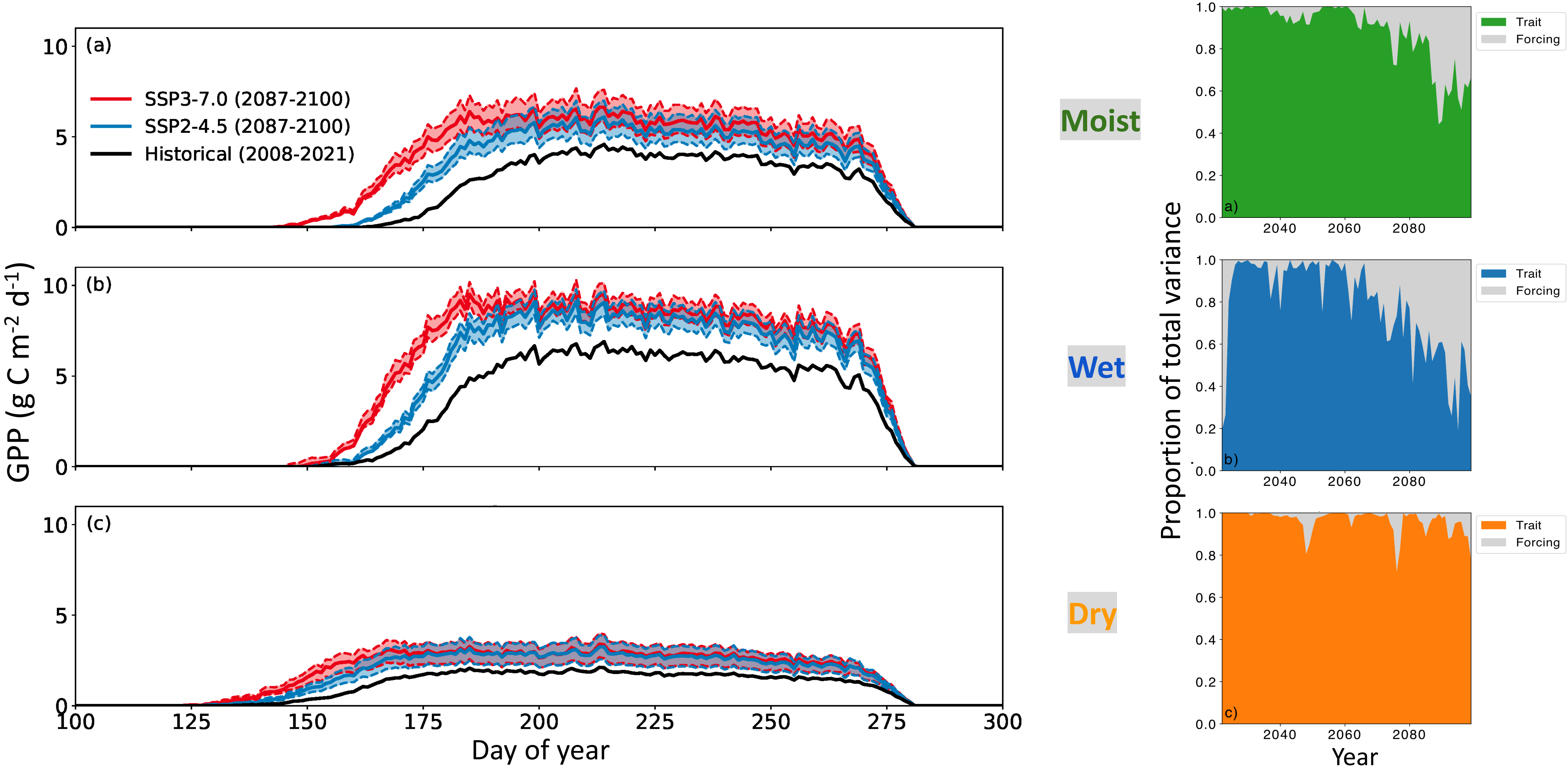
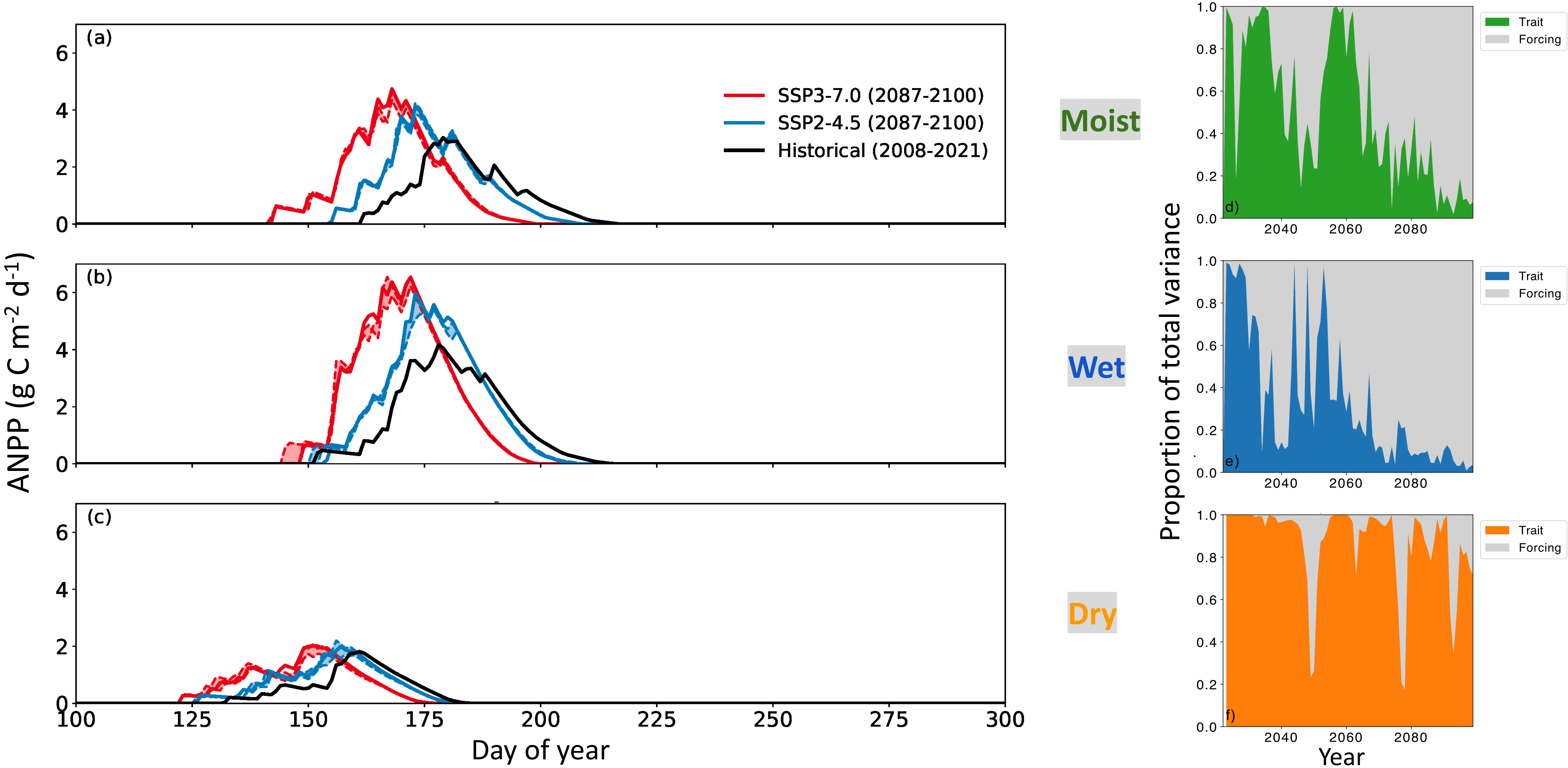


Projection: Trait sensitivity and forcing uncertainty in ANPP



Main takeaways

- Incorporating variability in foliar and phenology traits constrains carbon fluxes and improves representation of alpine tundra vegetation
- Plant trait uncertainty generally had a larger impact on productivity than climate scenario uncertainty, but the proportion varied between communities and carbon cycle metrics
- Trait uncertainty is likely being underestimated
- Next steps: Using FATES to allow communities and traits to change over time

Thanks for listening!

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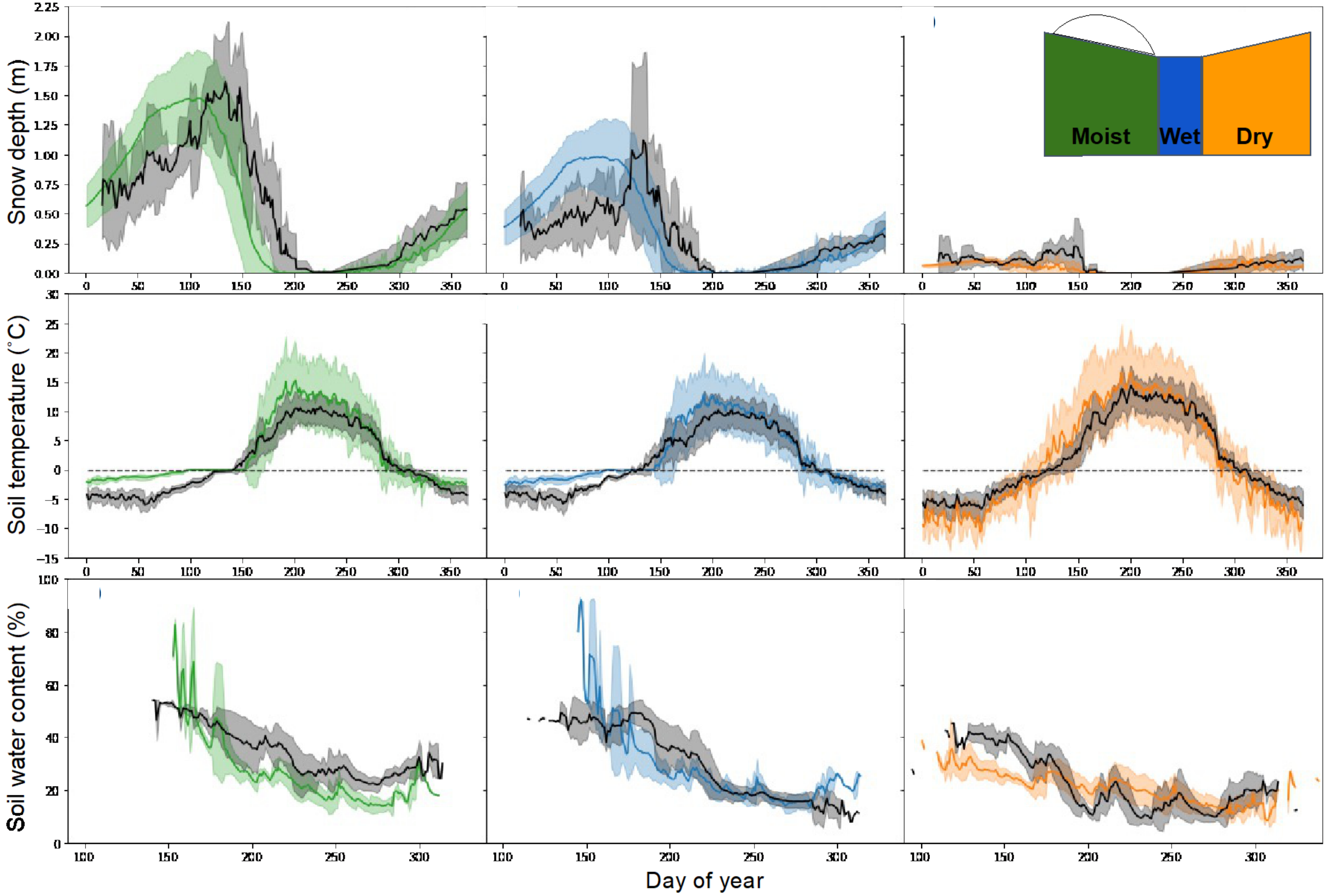
Model validation: Niwot Ridge LTER measurements



Jay et al. 2023

Uncertainty partitioning

Between group variation

Within group variation

	Climate	
Model	GSWP3	CRUNCEP
CLM4	x_{11}	x_{12}
CLM4.5	x_{21}	x_{22}
CLM5	x_{31}	x_{32}
Mean	$x_{.1}$	$x_{.2}$
Variance	s^2_1	s^2_2

Total uncertainty
Variance across the 6-member ensemble

Climate uncertainty
Variance of the GSWP3 and CRUNCEP multi-model means ($x_{.1}$, $x_{.2}$)

Model uncertainty
Average of the multi-model variances for GSWP3 and CRUNCEP (s^2_1, s^2_2)

This is equivalent to a fixed-effects single factor analysis of variance for k=2 groups with n=3 within each group

Bonan et al. 2019, *Global Biogeochemical Cycles*

Modifications to foliar, hydraulic, and photosynthetic parameters and soil properties

Parameter	**Description**	**Units**	**Moist Meadow**	**Wet Meadow**	**Dry Meadow**	**Default**
slatop[1]	specific leaf area	m^2/gC	0.0215	0.029	0.015	0.0402
leafcn[1]	leaf C:N	gC/gN	19.6	17.7	18.5	28.03
ndays_on[2]	# days to complete leaf onset	days	21	28	25	10
crit_onset_gdd_sf[2]	scale factor modifying GDD	unitless	1	1	1.7	1
kmax	plant maximum conductance	mm H_2O/mm H_2O/sec	2.42E-09	2.42E-09	2.30E-10	2.42E-09
krmax	root maximum conductance	mm H_2O/mm H_2O/sec	8.05E-11	8.05E-11	2.05E-11	8.05E-11
$jmaxb_0$	baseline proportion of N for electron transport	unitless	0.0225	0.0225	0.0225	0.0331
$jmaxb_1$	response of electron transport rate to light availability	unitless	0.1	0.1	0.1	0.1745
froot_leaf	new fine root C per new leaf C allocation	gC/gC	1.5	1.5	2	2
d_max	dry surface layer thickness	mm	10	10	10	15
h_bedrock	depth to bedrock	m	1.3	1	1	
wat_sat	water saturation (porosity)	m^3/m^3			wat_sat/2	
organic[3]	organic matter density	kg/ m^3	80.7	107.6	80.7	
sand[3]	percent sand	%	49.3	44.4	49.3	
clay[3]	percent clay	%	12.7	14	12.7	

Jay et al. 2023