Genetics and physiology of cold stress in grapevine

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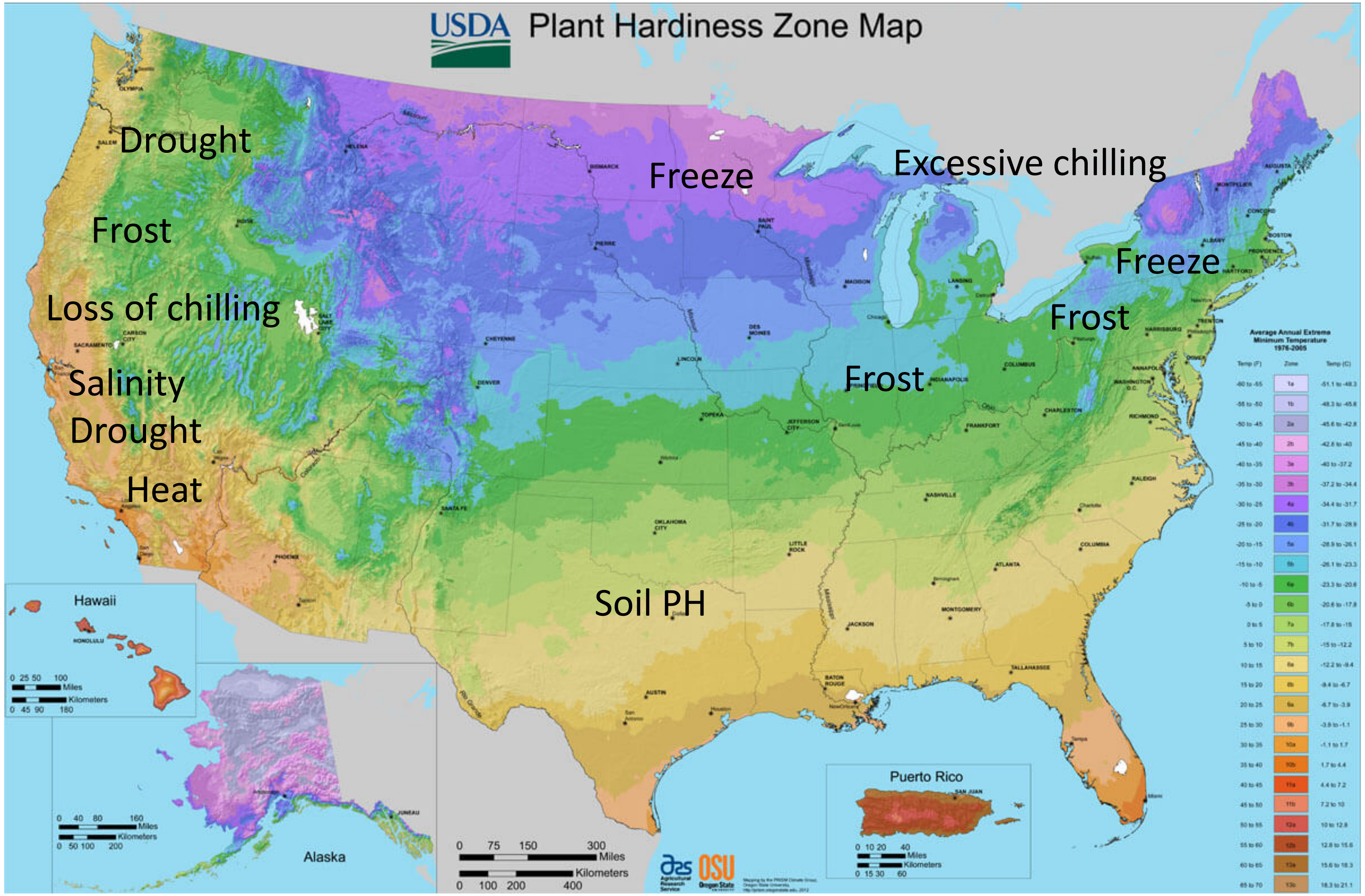
USDA United States Department Of Agriculture
Agricultural Research Service

Abiotic stress limits grapevine production

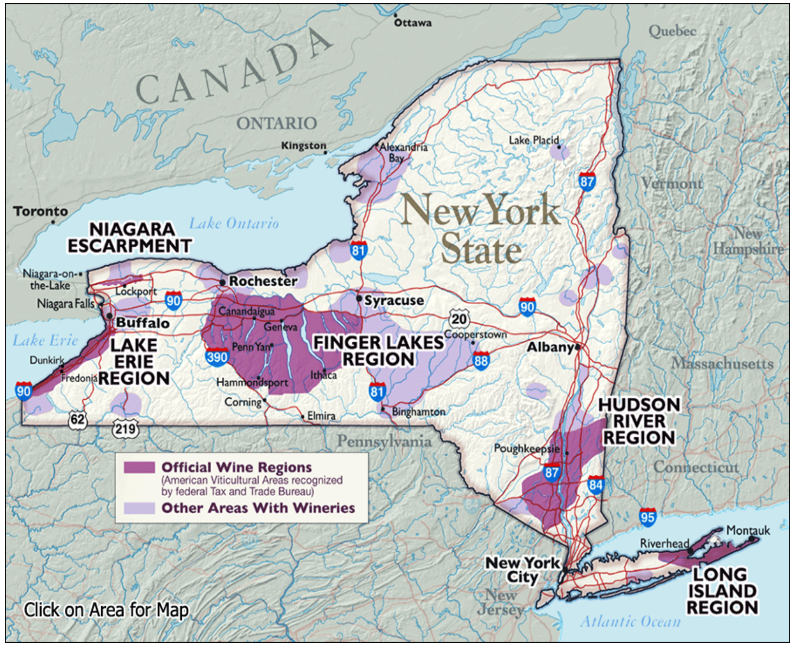
- Drought (roots, leaves)
- Temperature (buds, trunks, leaves, fruit)
- Salinity (roots, leaves)
- Acidity/Alkalinity (roots)
- Excess water (roots, trunks)

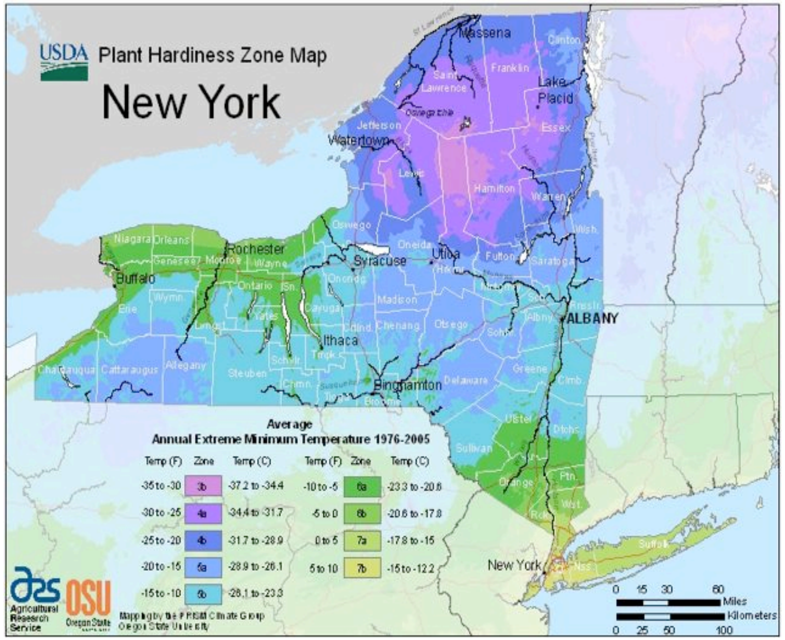
- ~70 million dollars in losses depending on year and stress

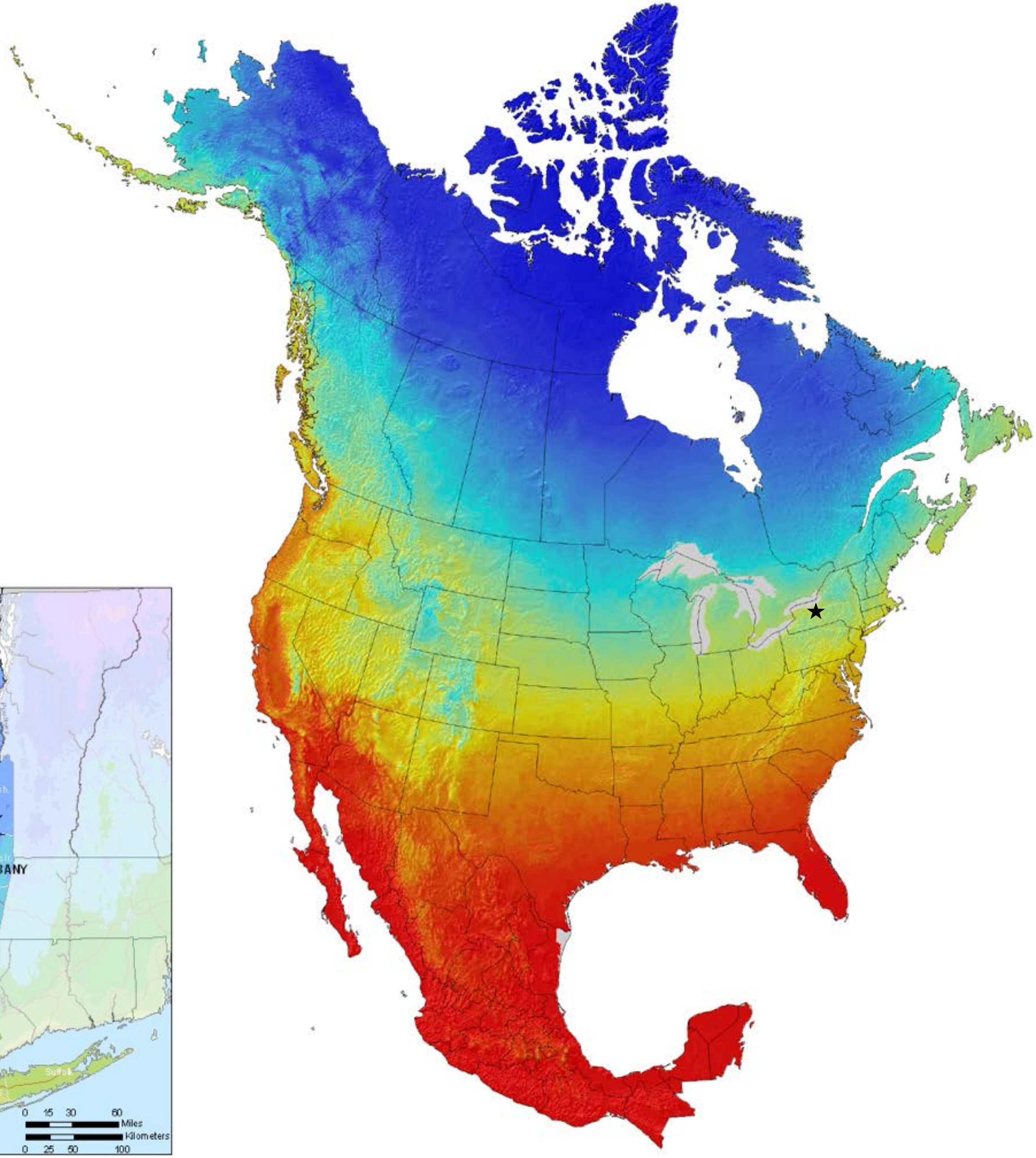


- Temperature is one of the primary limiting agents affecting agriculture

- NY Grape value 52-70 million dollars; USDA NASS 2010-2012
- Annual Losses due to winter injury >15M annually







Spring Cold Snap Damages California Vineyards – Wine Business

Frost wipes out juice grapes in SW Michigan – Michigan Radio

Late frost damage a blow to area vineyards – Green Bay Press Gazette (Wisconsin)

Central Coast (California) Vineyards Hit by Severe Frost

Fears of drop in Arizona wine grapes after freeze – AZCentral.com

Shumer, Gillibrand to New York State: Issue Disaster Declaration to Expedite Federal Aid in Western New York Impacted by Crop Freeze

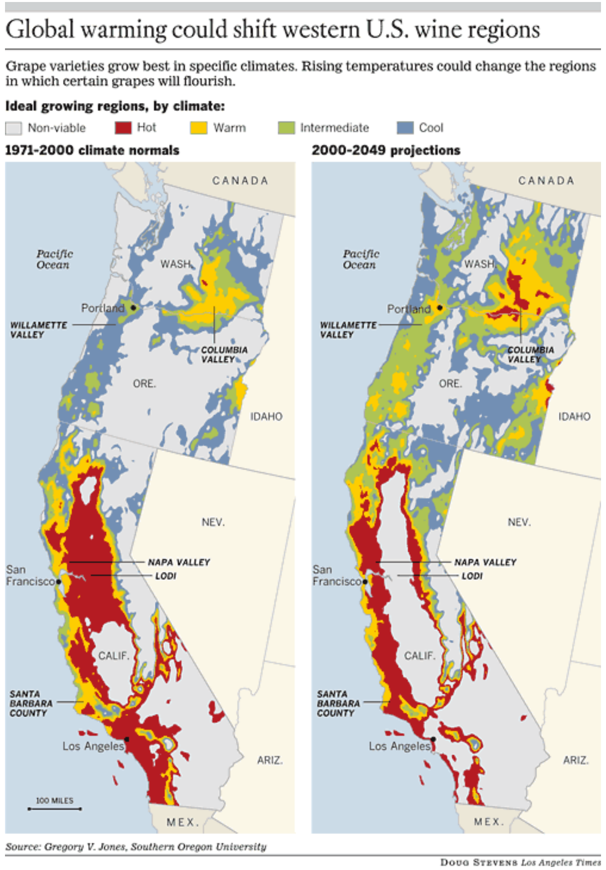
Hard April frosts could spell trouble for Virginia wineries

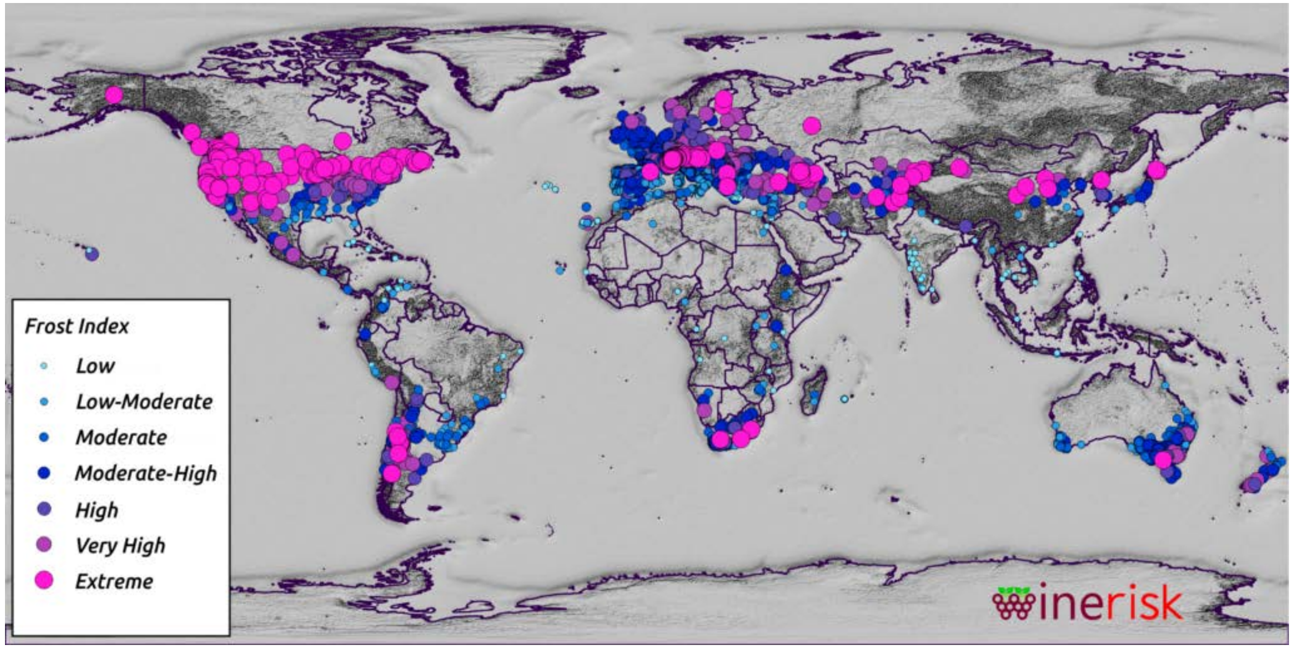
Late frost wreaks havoc on Ohio's grapes

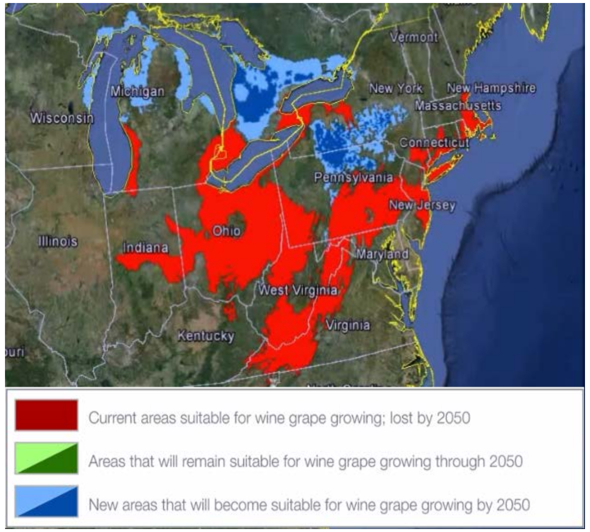
Napa wine industry warned of future climate threat – Napa Valley Register

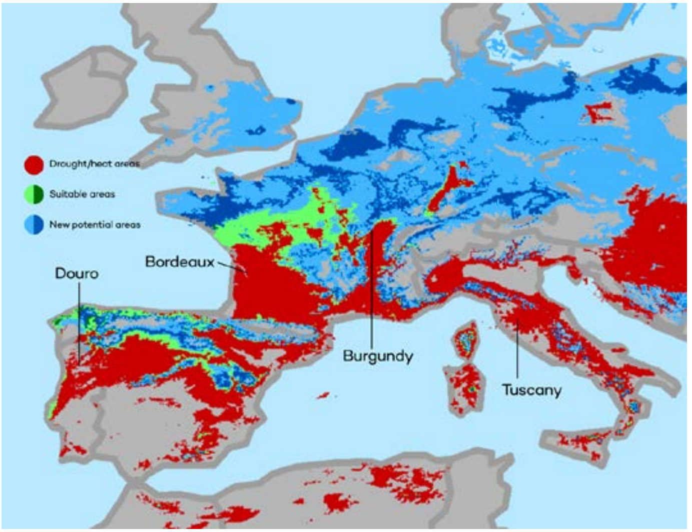
California drought will impact Texas wines – The Courier

Low temperature associated stresses impact all grape production regions in some way. Freeze injury, dormancy, frost









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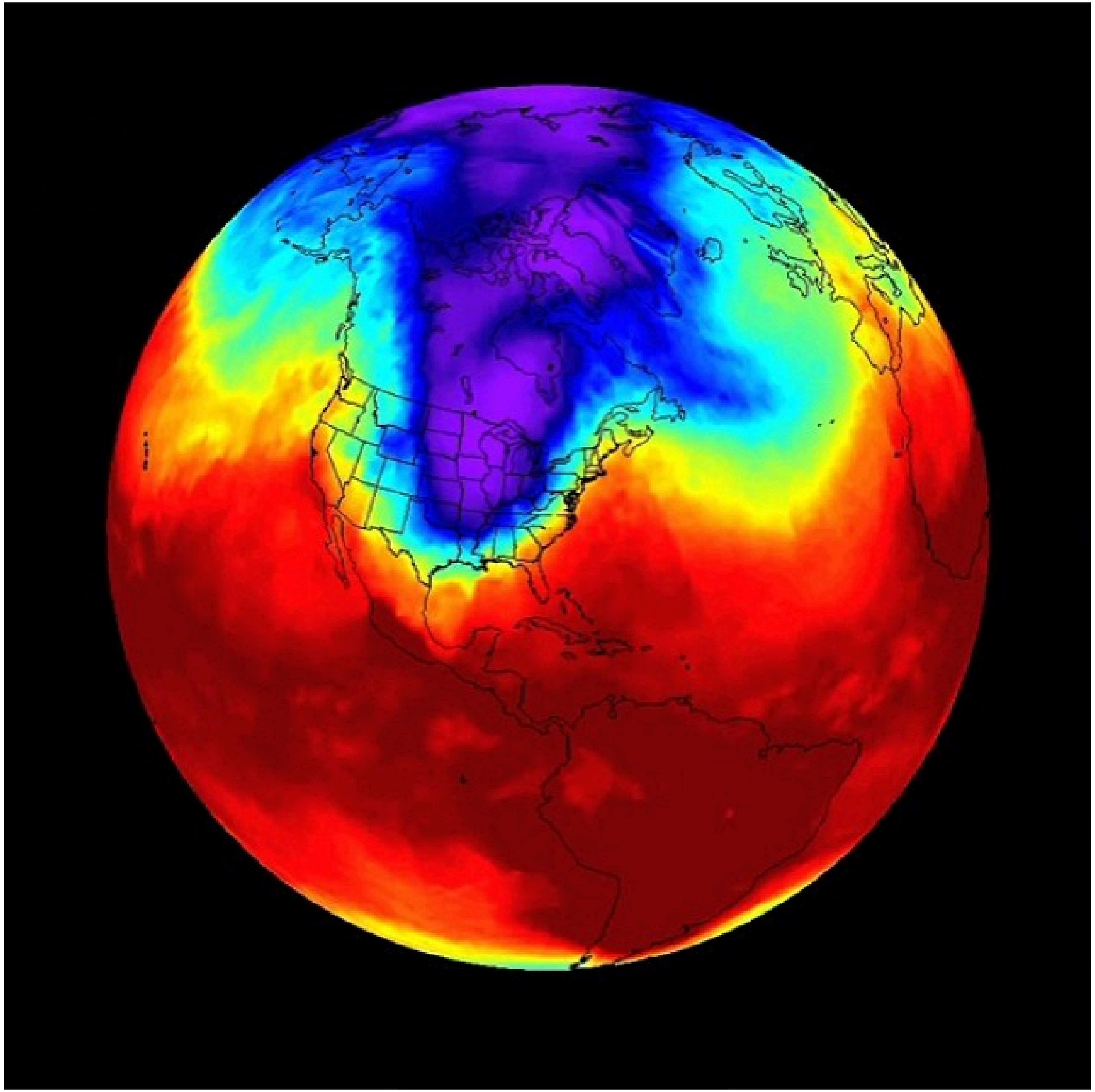
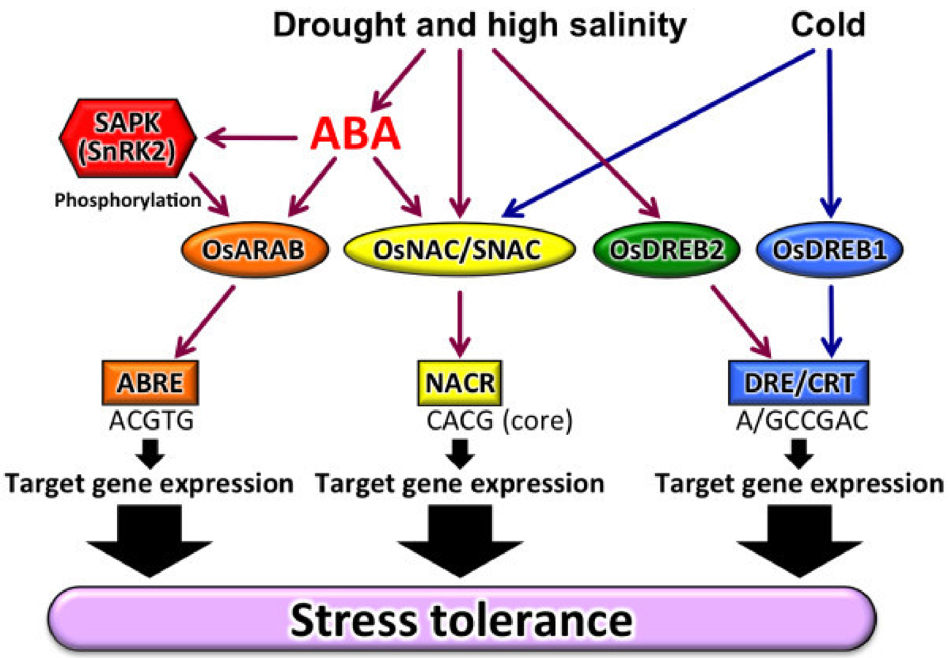
http://wineeconomist.com/category/climate-change/ http://chesapeakeclimate.org/blog/study-va-md-vineyards-dead-by-2050/



Primary research program

- Major questions regarding cold hardiness in grapevine:
    - What are the actual phenotypes of cold hardiness?
    - Photoresponse/Acclimation: increases preparedness for winter conditions
    - Dormancy: prevents changes in physiology during warming events
    - Freeze resistance: dormant bud can supercool and survive sub-freezing
    - Deacclimation/Budburst: appropriate timing of budburst to avoid frost

    - What is the genetic architecture of these traits?
    - Polygenic trait with significant cross talk with other stresses and with growth
    - Expression of phenotype is dependent on genotype AND environment

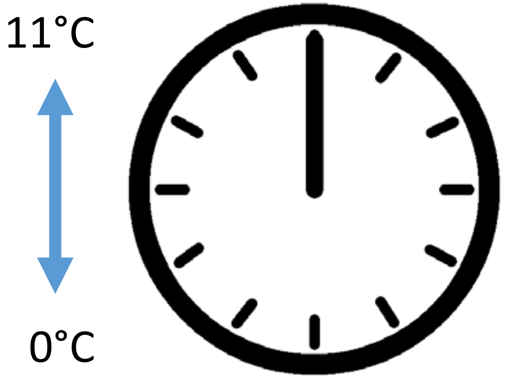


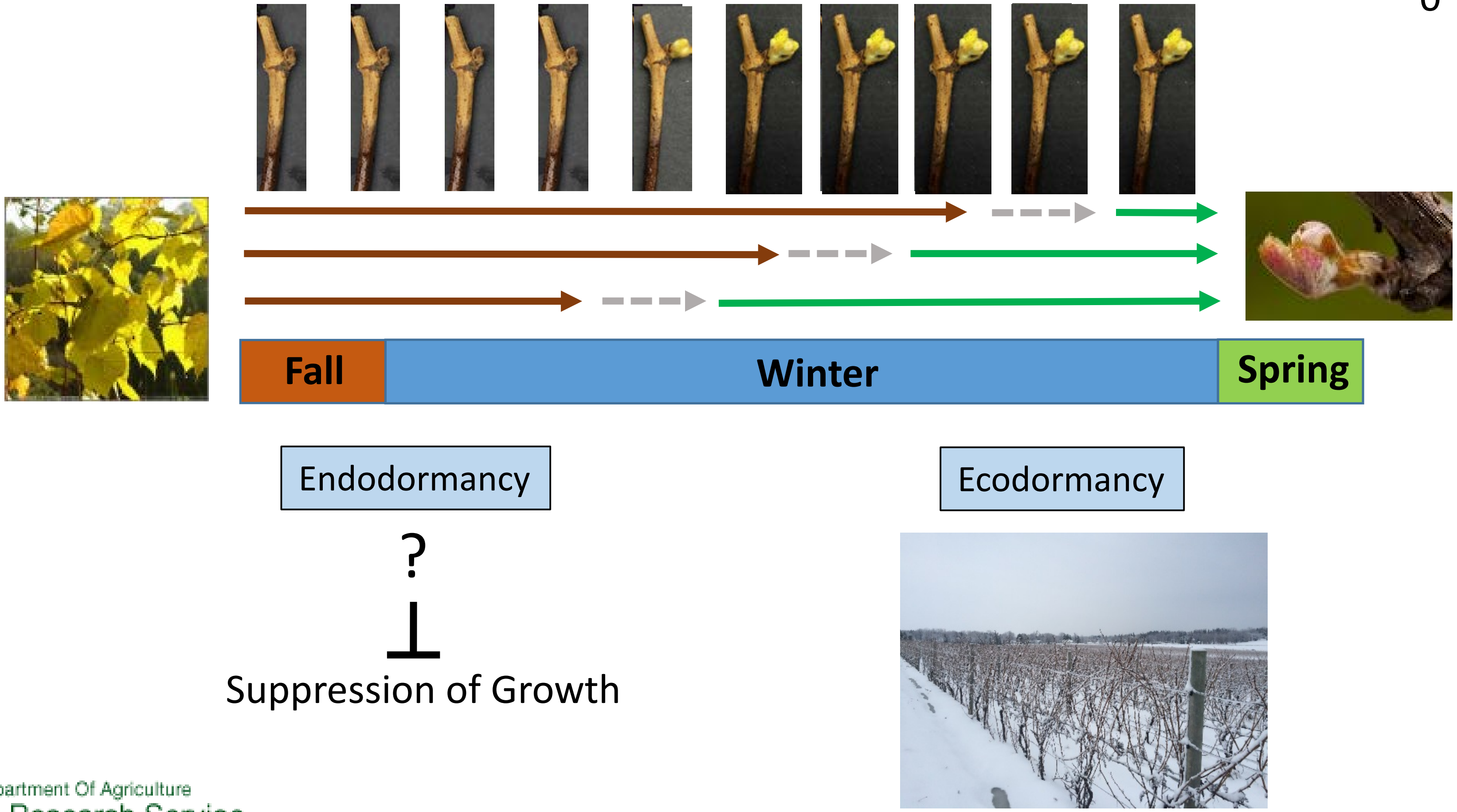
- Addressing industry needs with regard to cold hardiness.
  - Clarify the basic scientific foundation of cold hardiness in grape
  - Varieties with improved freeze resistance, increased dormancy in the north, and decreased dormancy in hot climates
  - Models to predict damage risk
  - Viticulture methods to mitigate cold events and/or warm events
  - Interaction of cold and drought response

- **Dormancy**: A period during the life cycle where growth, development, and physical activity are temporarily stopped. Essential in grapevine to assure flower and fruit.

Dormancy and Chilling Requirement

- Buds measure length of winter
- Start tracking temperature below 11 °C (51.8 °F).
- Stop tracking temperature below freezing.





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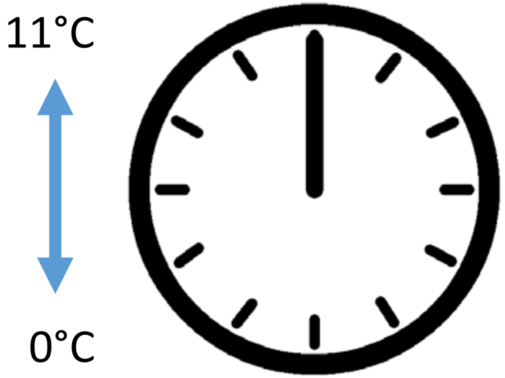
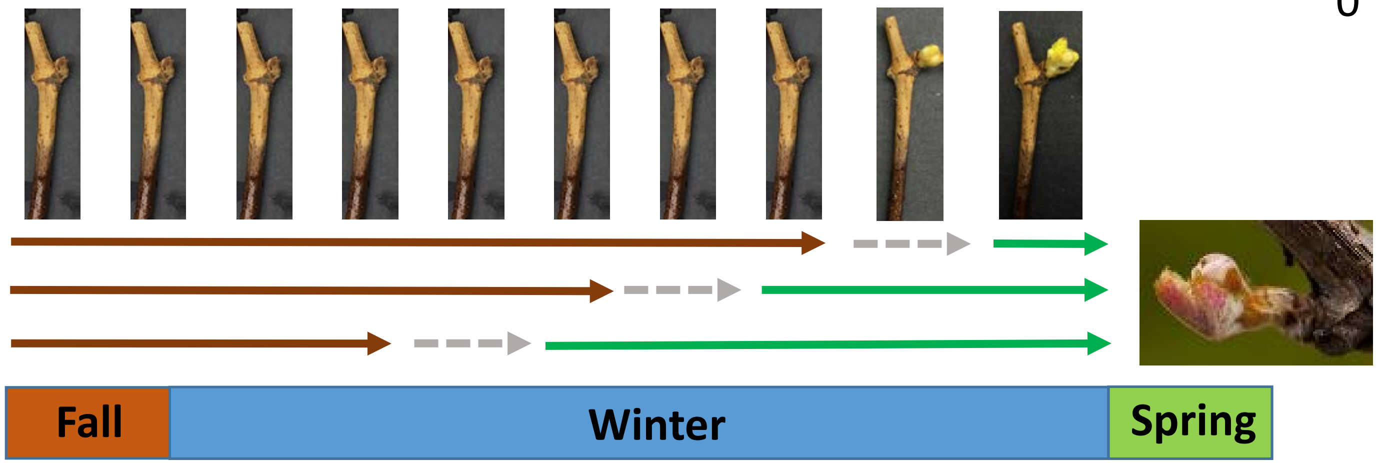


Genetic

Environment



Warm winters in cold regions, cold winters in warm regions; more chilling

Climate predictions: more chilling in the North, less in the South

Endodormancy

?

⊥

Suppression of Growth

Ecodormancy

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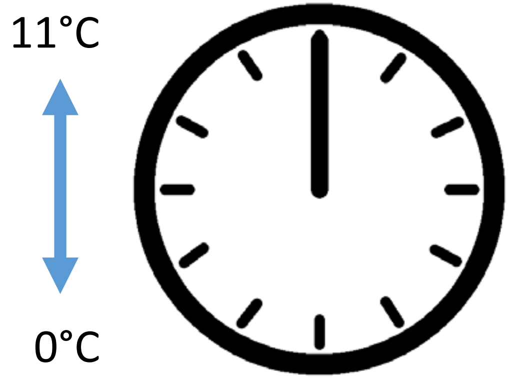

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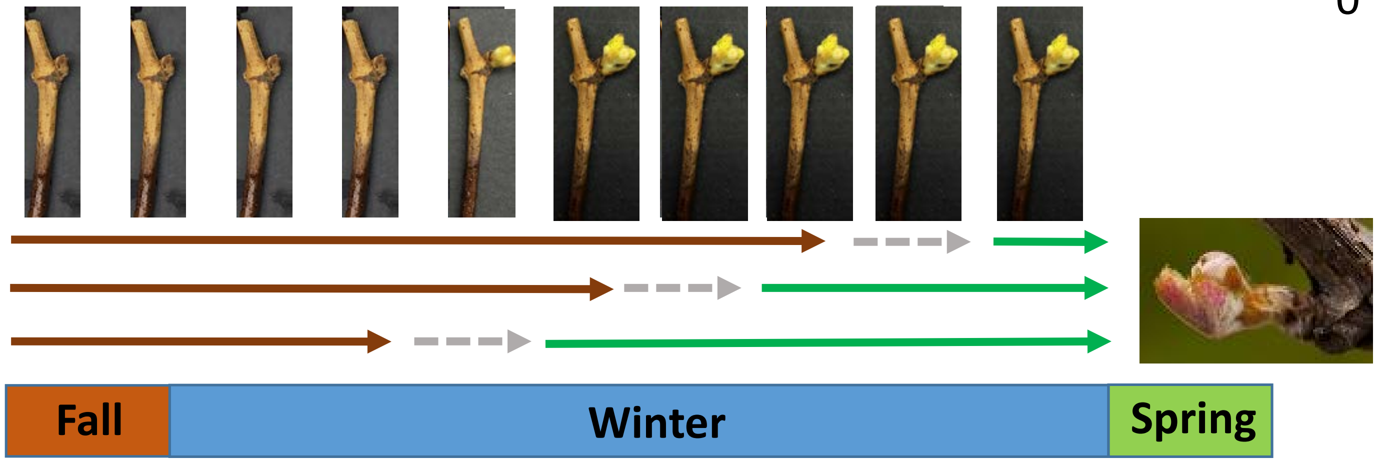

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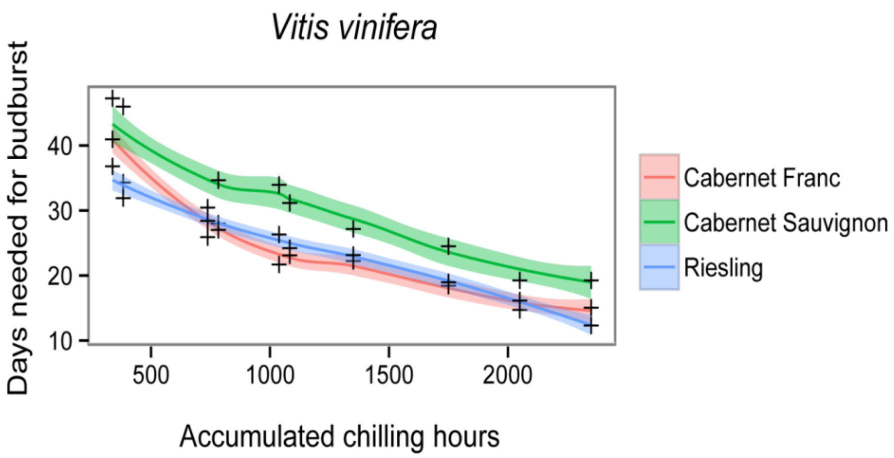
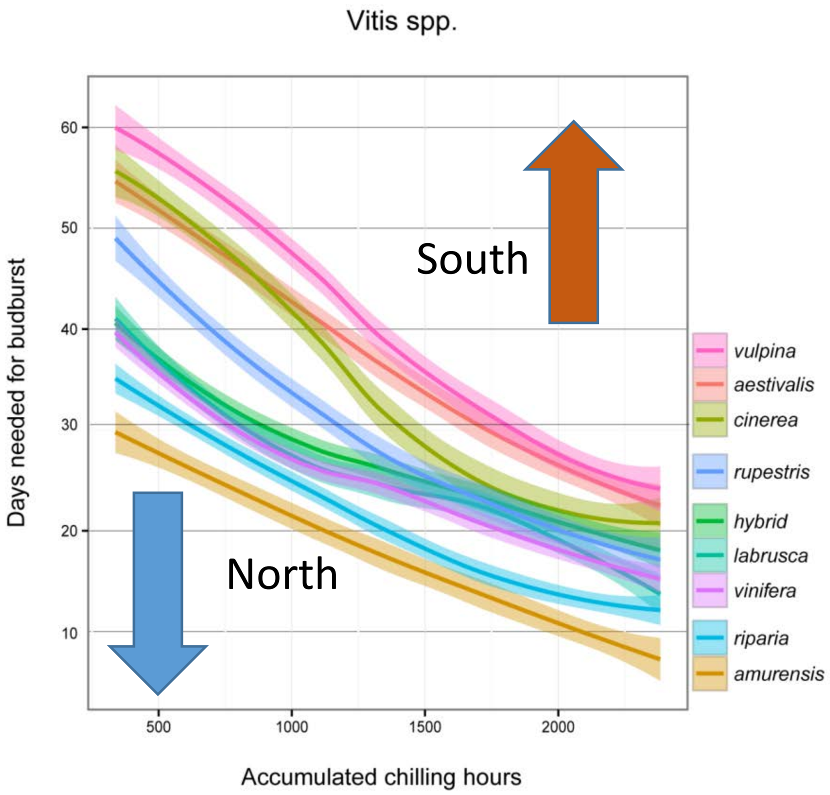


Full Chilling

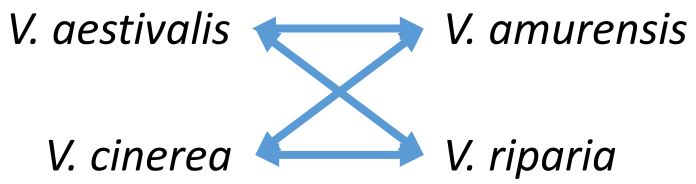
Insufficient Chilling



Potential geographic gradient of response

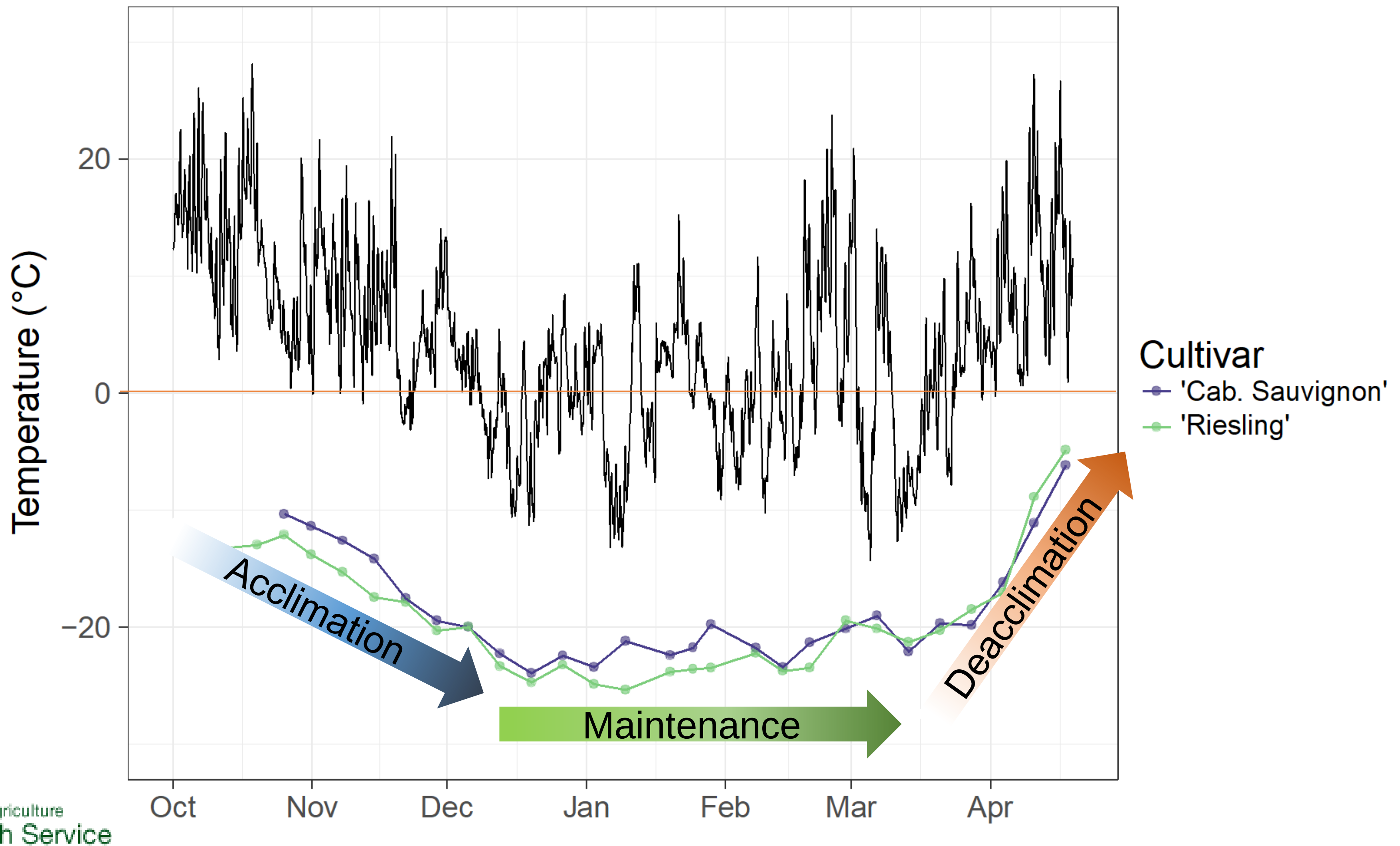
Newly identified cold hardy, increased dormancy *V. riparia*. Currently being tested in NY breeding program

F1 crosses



Accesion	GEO	SLOPE	Y-INT	Chilling Requirement
MAN711	Manitoba	-0.0067	27.6	15
ND271	North Dakota	-0.0129	32.3	338
QUE345	Quebec	-0.0100	31.5	353
ND275	North Dakota	-0.0112	32.4	388
MT270	Montana	-0.0113	32.5	396
WY710	Wyoming	-0.0103	32.2	405
MT272	Montana	-0.0116	33.6	479
MAN260	Manitoba	-0.0116	33.6	483
CO435	Colorado	-0.0113	33.9	519
TX587	Texas	-0.0116	34.2	535
MO439	Missouri	-0.0128	35.0	543
MAN259	Manitoba	-0.0138	35.8	566
MT346	Montana	-0.0143	36.2	574
MT350	Montana	-0.0133	35.7	577
ND353	North Dakota	-0.0104	34.0	581
MT273	Montana	-0.0135	36.6	634
NY189	New York	-0.0132	36.7	655
UN897	Unknown	-0.0122	36.0	659
MN261	Minnesota	-0.0118	35.8	659
MN258	Minnesota	-0.0116	35.7	660
KS456	Kansas	-0.0115	35.7	668
MT269	Montana	-0.0125	36.5	680
QUE167	Quebec	-0.0117	36.4	714
ND373	North Dakota	-0.0159	39.4	717
CO437	Colorado	-0.0116	36.4	723
MT276	Montana	-0.0146	39.1	759
ND344	North Dakota	-0.0134	38.3	771
ND374	North Dakota	-0.0141	39.0	780
ONT586	Ontario	-0.0145	40.6	868
IL354	Illinois	-0.0146	40.7	871
IA054	Iowa	-0.0131	39.7	896
WI562	Wisconsin	-0.0137	40.7	925
NY369	New York	-0.0158	43.7	990
MN262	Minnesota	-0.0140	41.9	994
NE622	Nebarska	-0.0155	44.3	1049
IL457	Illinois	-0.0157	45.4	1104
IA653	Iowa	-0.0141	44.0	1135
IL347	Illinois	-0.0168	48.2	1198
MT274	Montana	-0.0128	43.7	1231
MO455	Missouri	-0.0135	45.2	1276
IL438	Illinois	-0.0127	44.3	1287
KS440	Kansas	-0.0186	52.0	1290

Dormant Bud Cold Hardiness



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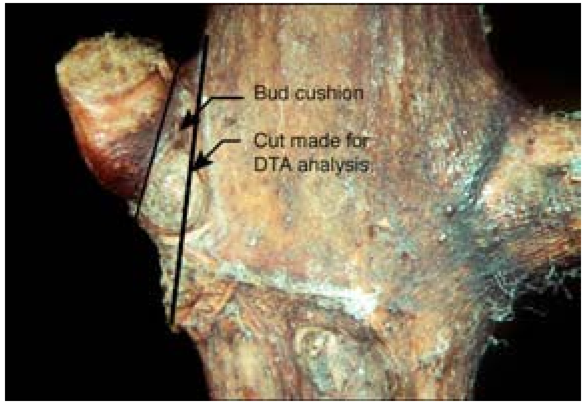
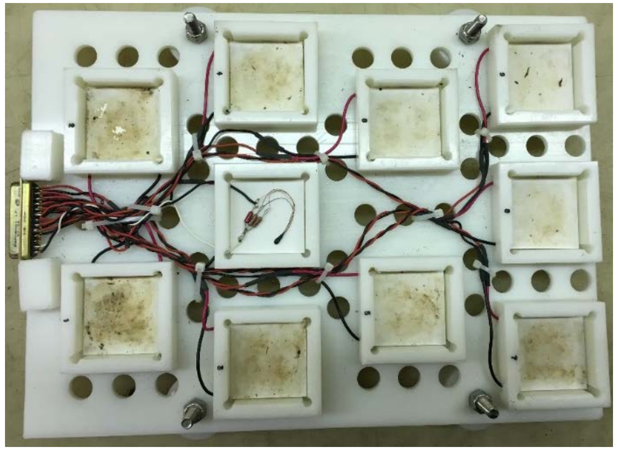
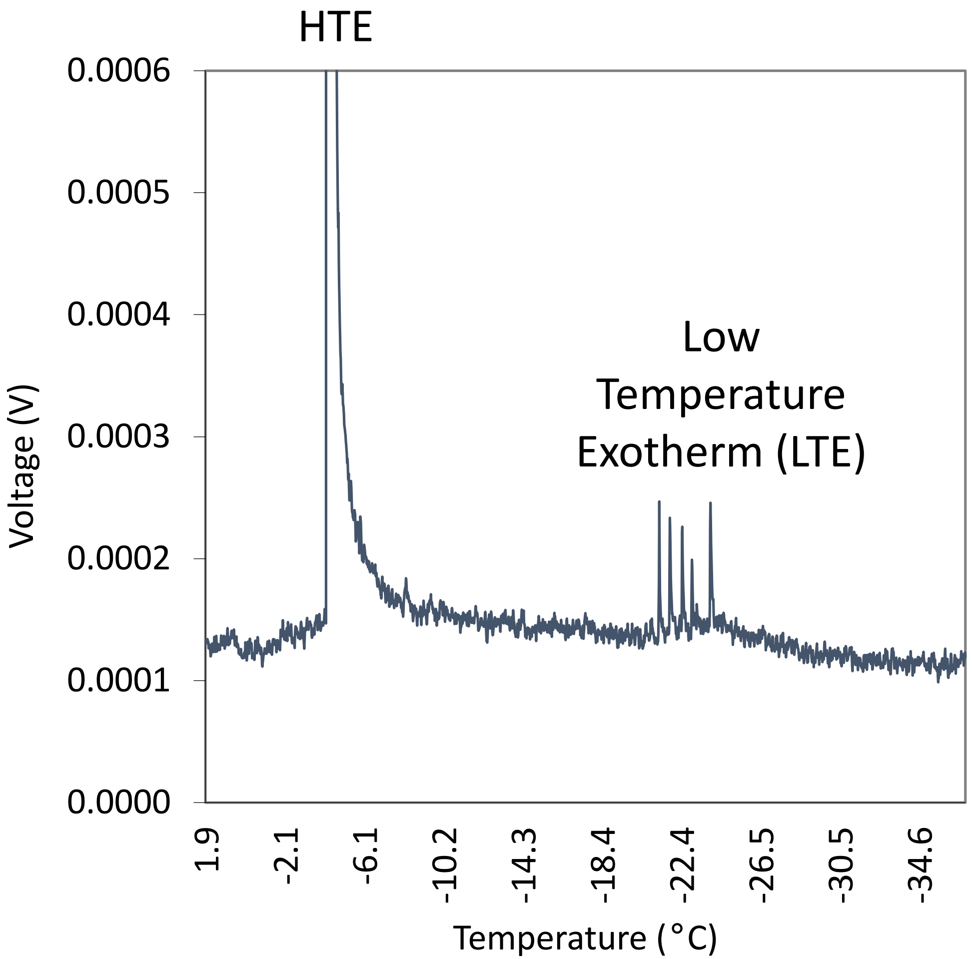
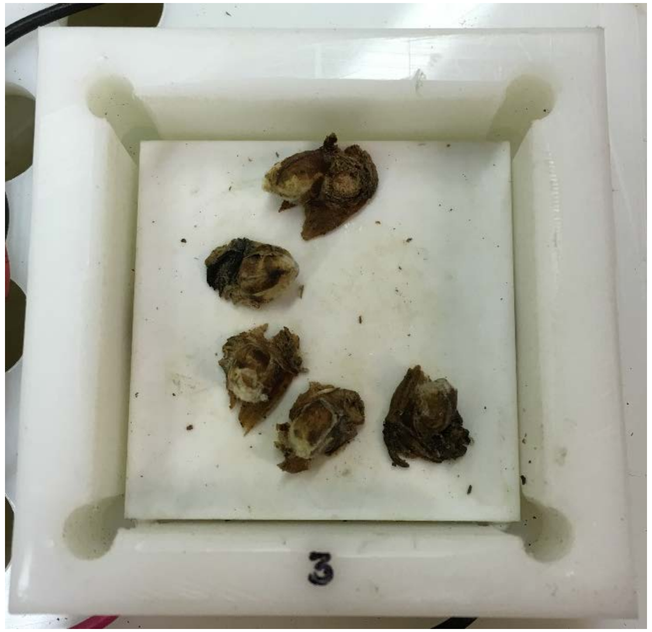


Bud cushion
Cut made for
DTA analysis





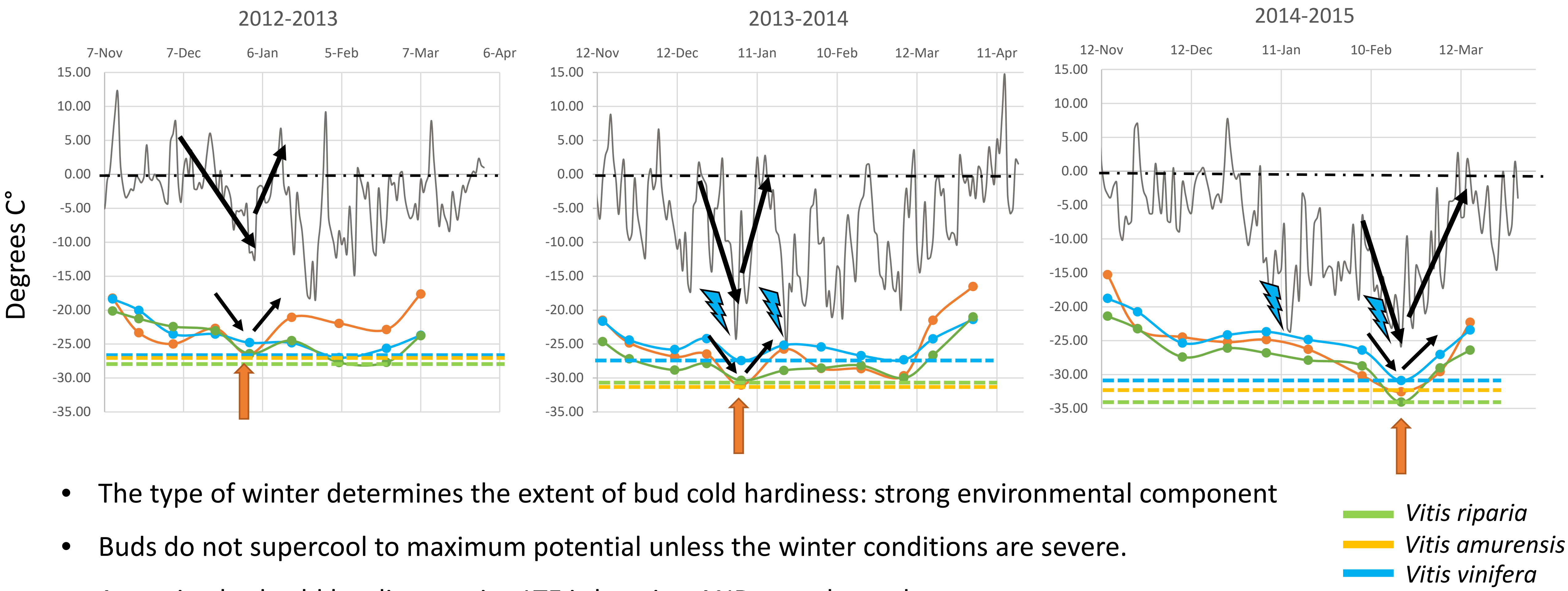
HTE
Low
Temperature
Exotherm (LTE)
Voltage (V)
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
1.9
-2.1
-6.1
-10.2
-14.3
-18.4
-22.4
-26.5
-30.5
-34.6
Temperature (°C)



3

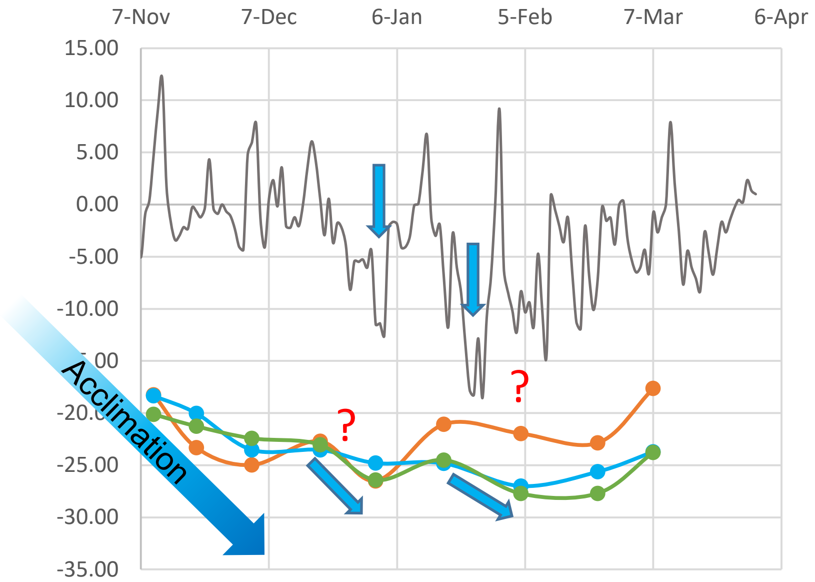
25.4C

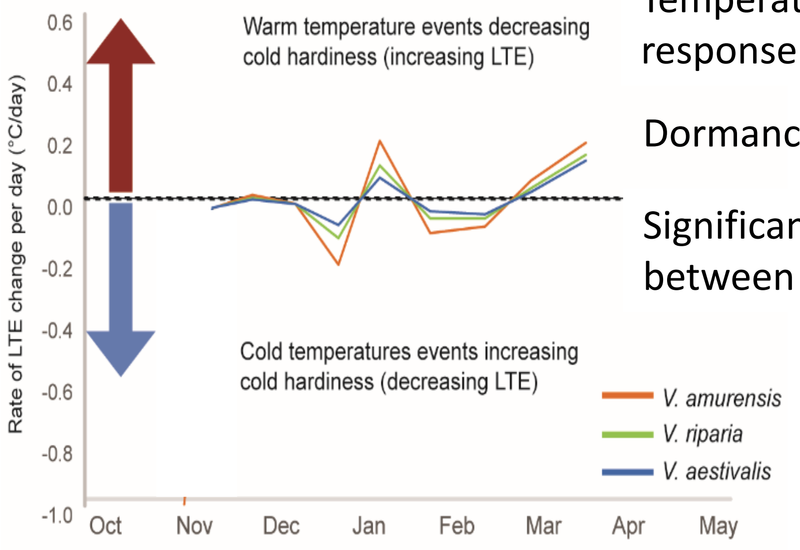
Tracking Bud Survival



- The type of winter determines the extent of bud cold hardiness: strong environmental component
- Buds do not supercool to maximum potential unless the winter conditions are severe.
- Assessing bud cold hardiness using LTE is location AND year dependent.
- What is the genetic architecture of this trait?

Acclimation rate: Understand phenotype, understand genetic control



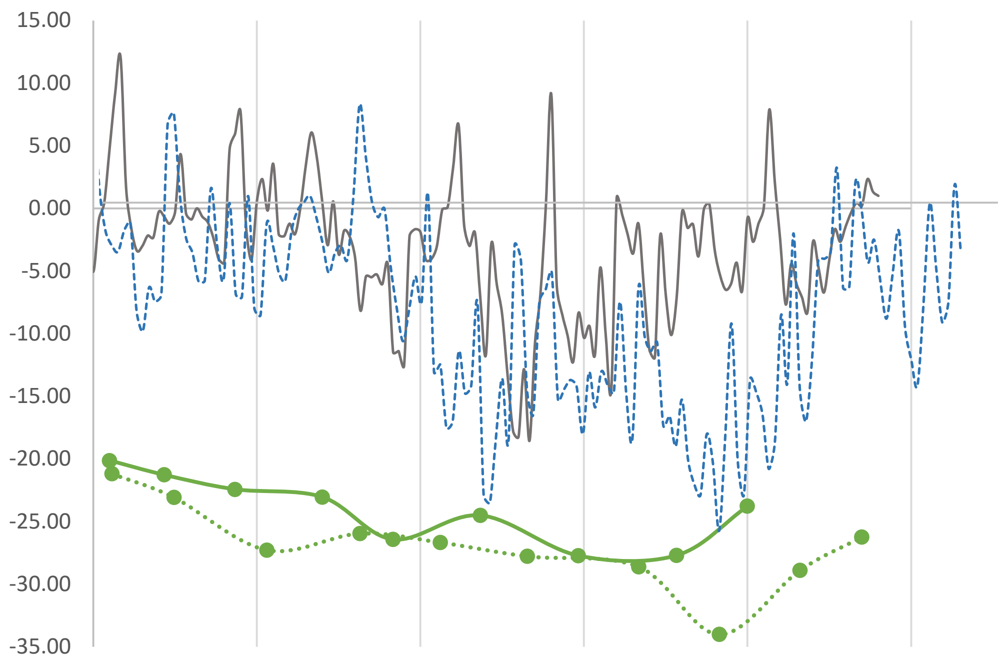


Temperature perception and response component: 60%

Dormancy/Time: 30%

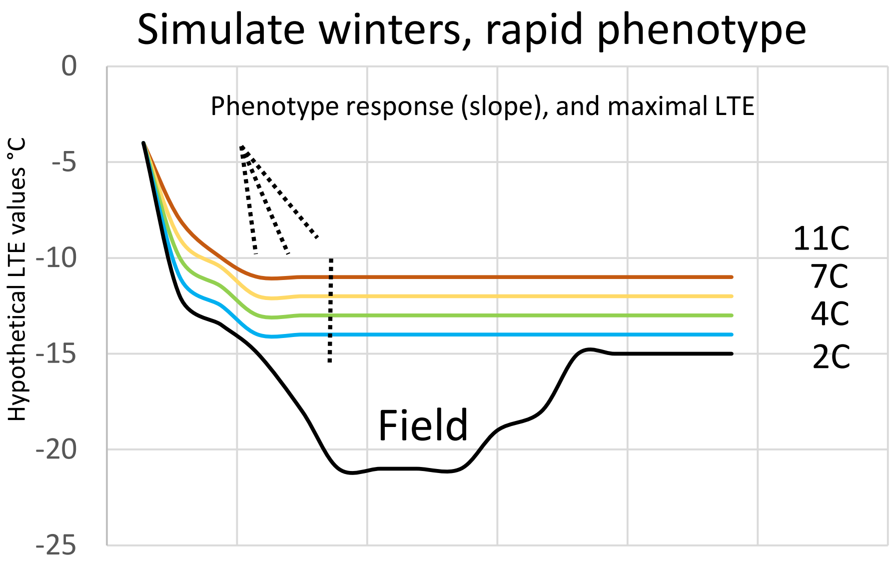
Significant difference between species

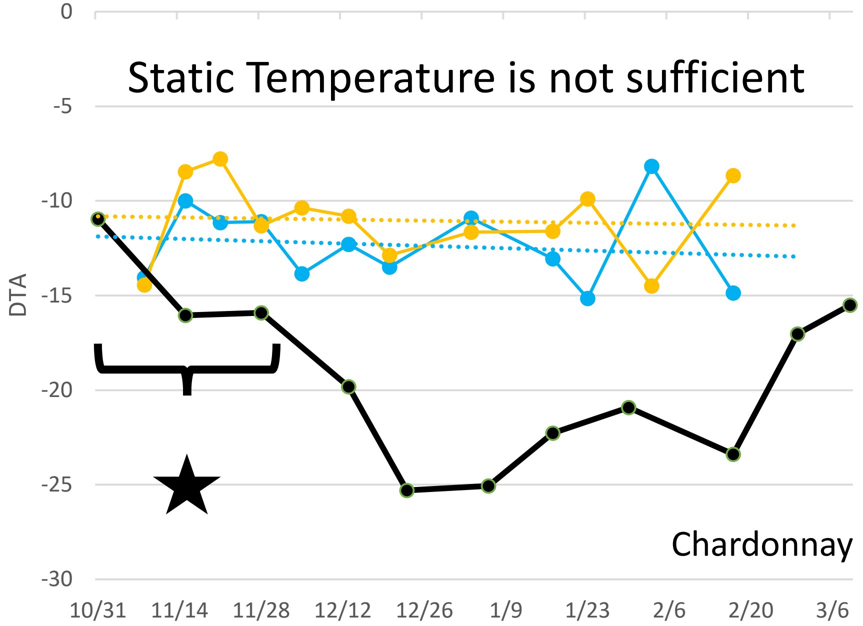
Cold winters = Deeper cold hardiness



Can we develop new phenotyping methods under controlled conditions?

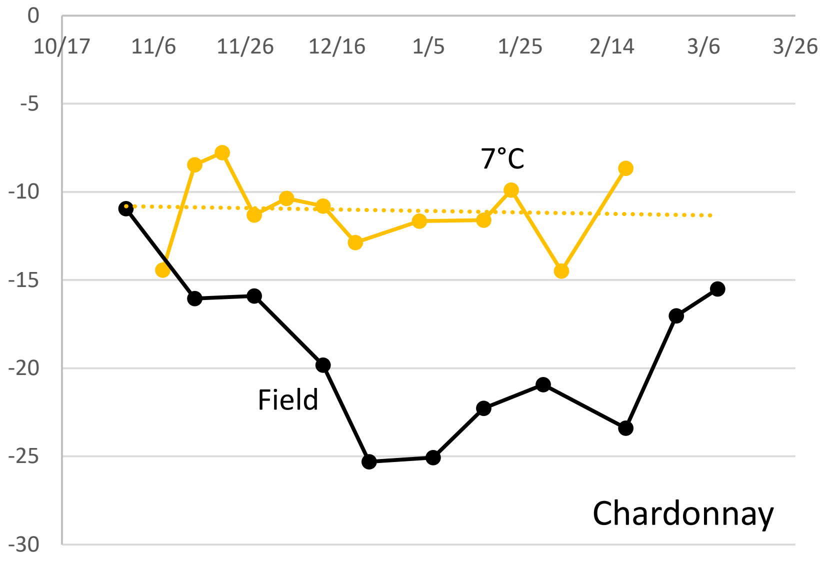
Acclimation rate: Understand phenotype, understand genetic control

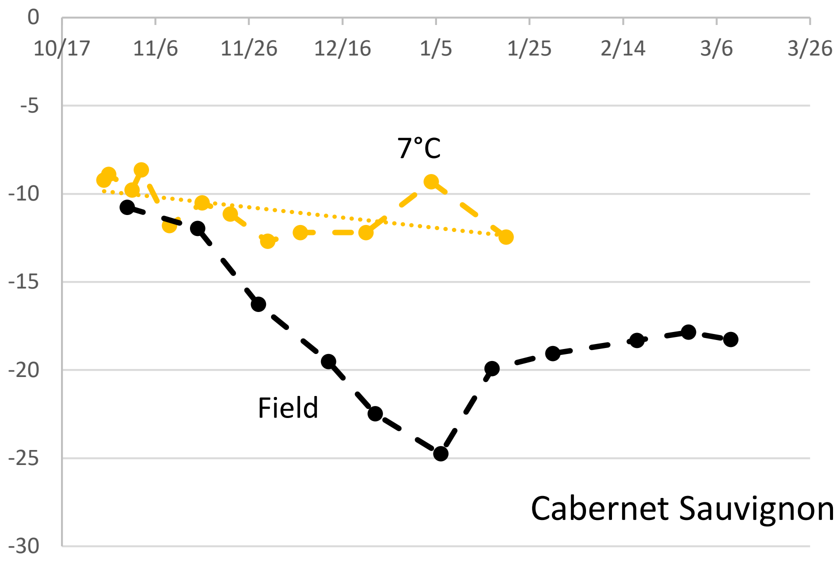




Average Field Temp = 7°C

Average daily temperature swing = ±5 °C





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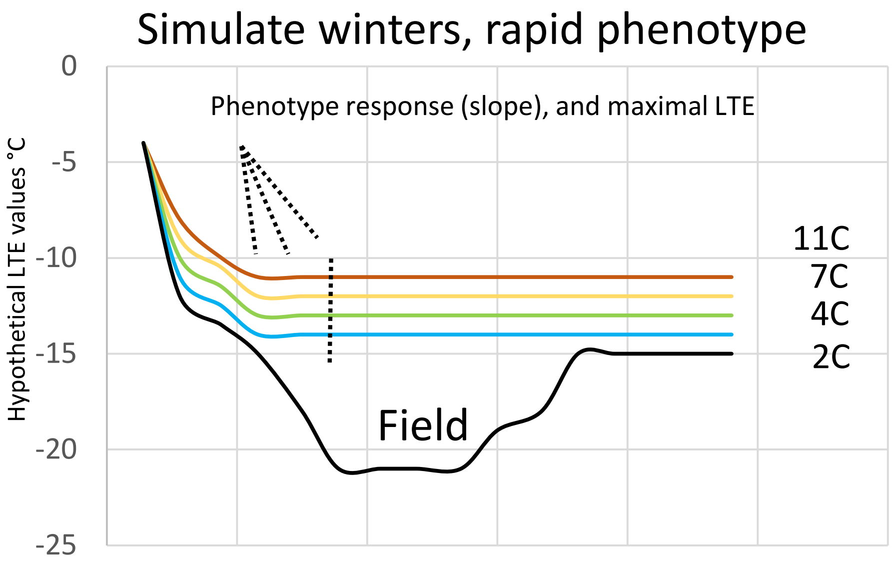
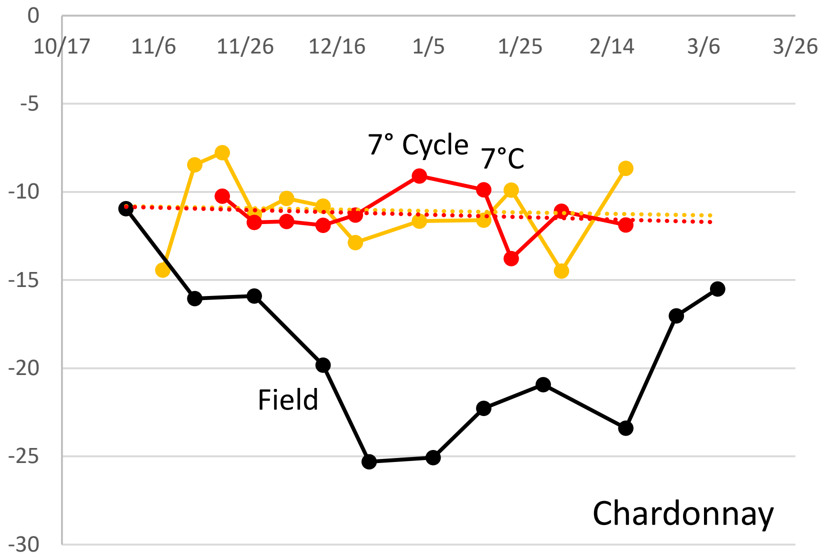
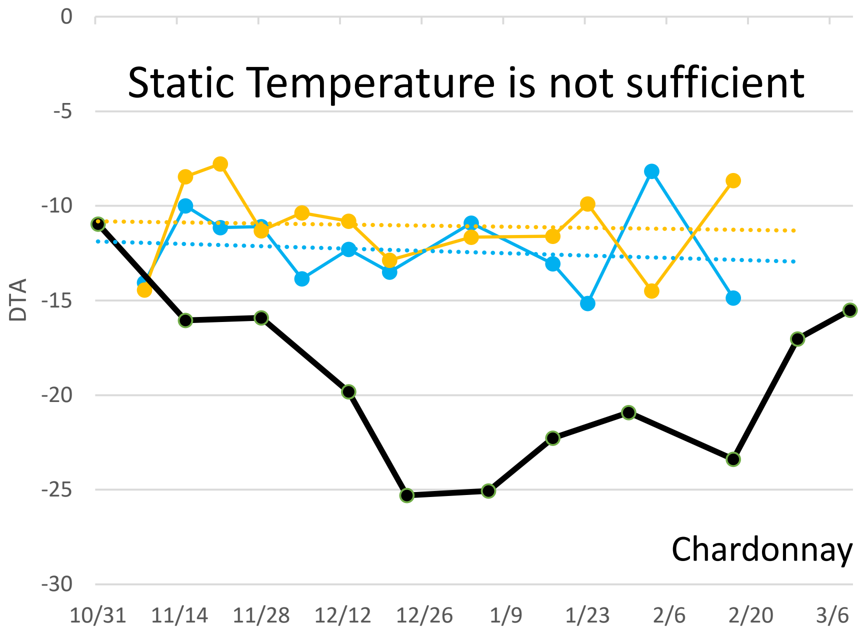
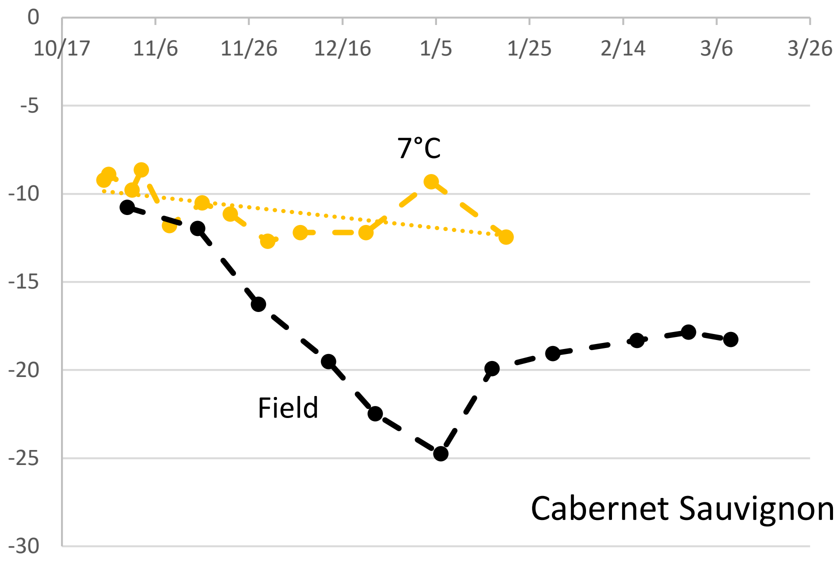






Average Field Temp = 7°C

Average daily temperature cycle = 5 °C



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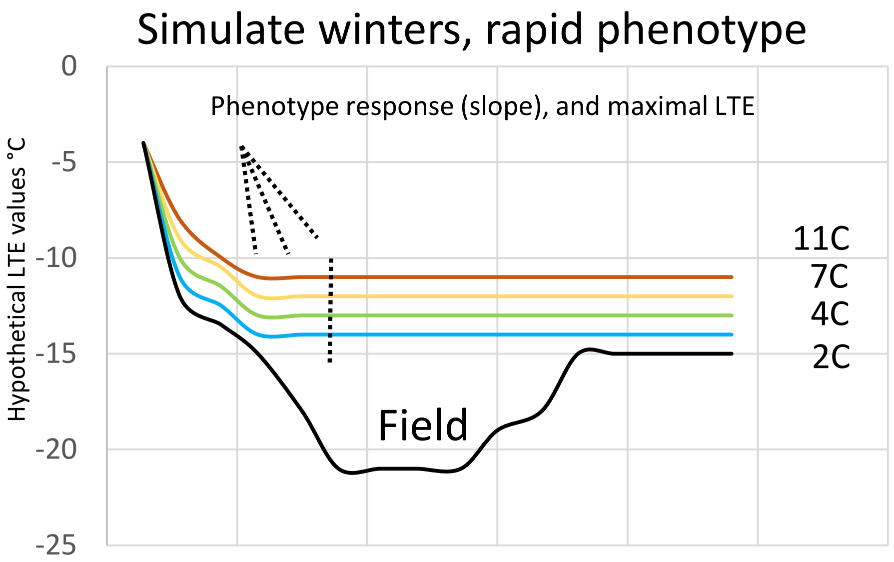
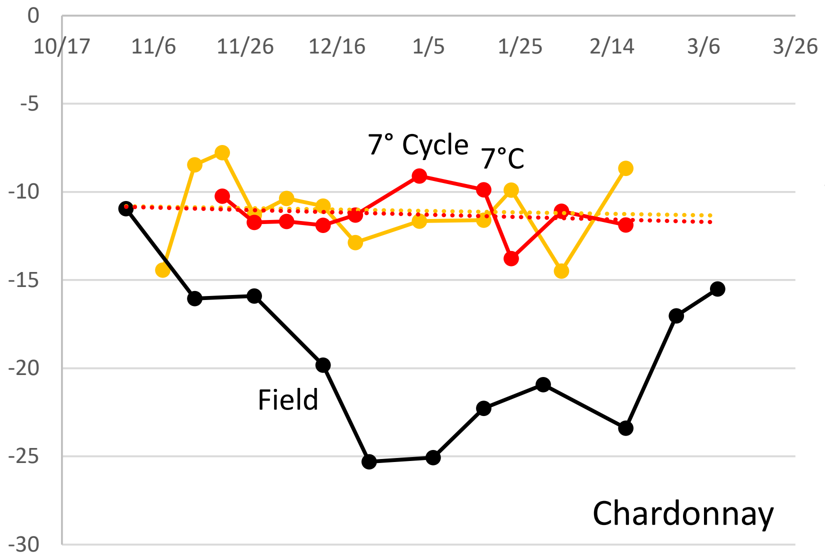
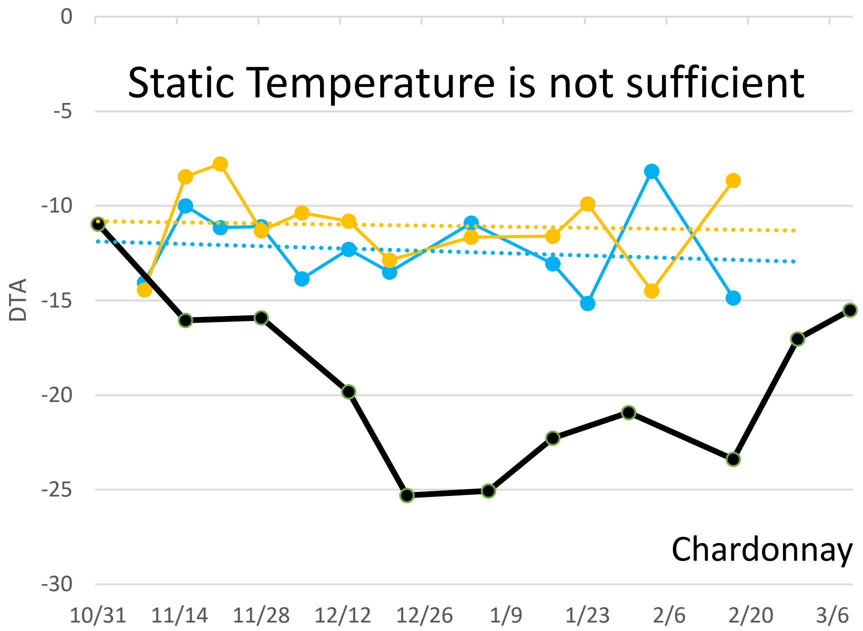
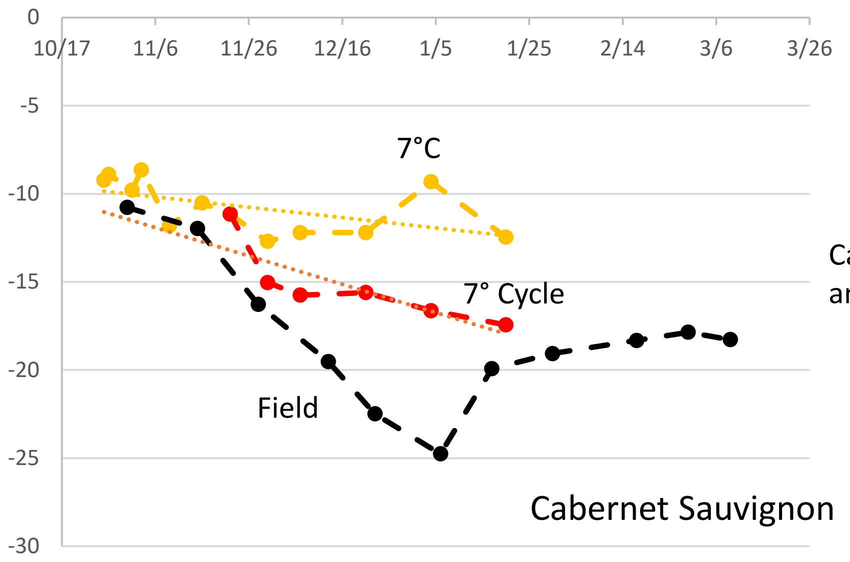




20 cultivated and hybrid cultivars and *V. riparia*





Cabernet Sauvignon and *V. aestivalis*

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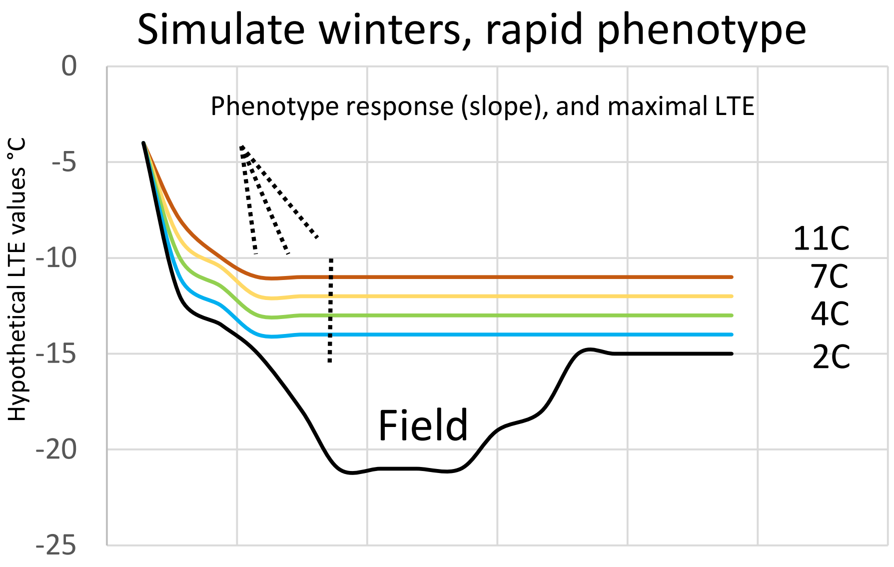
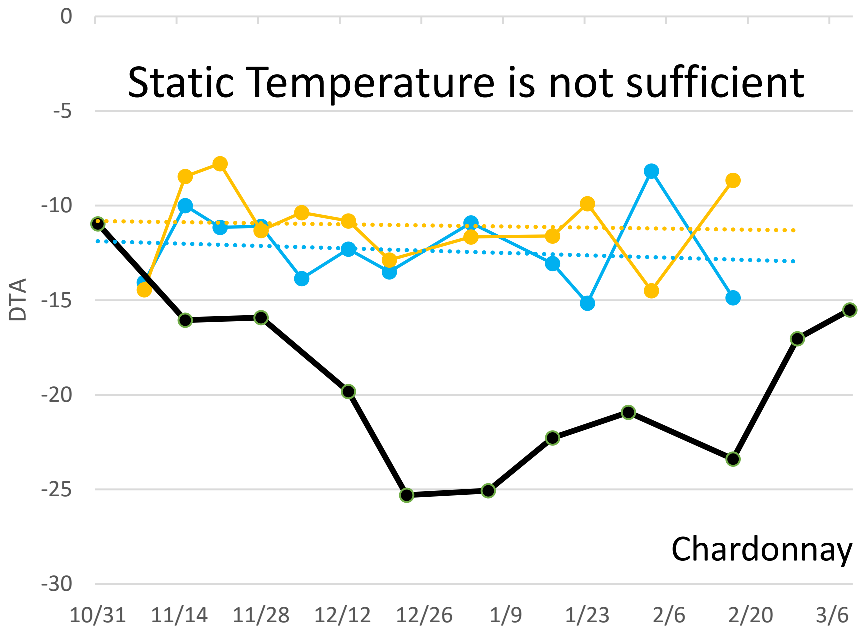
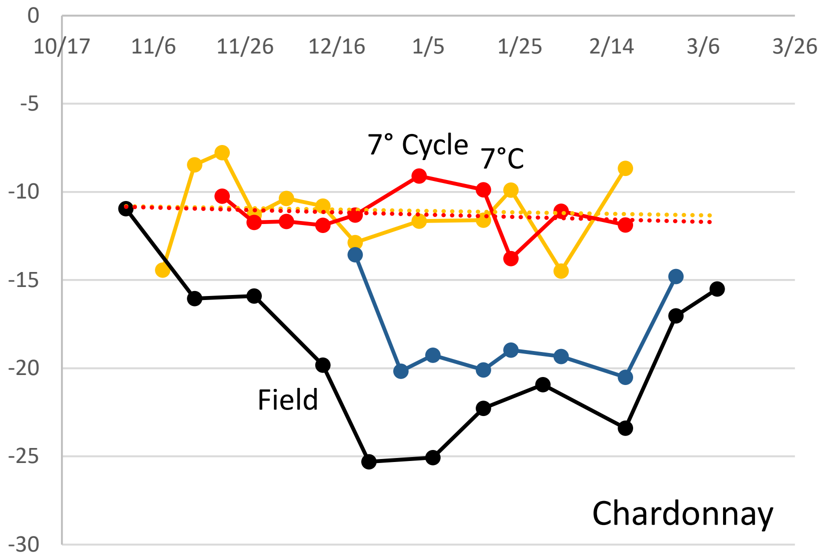
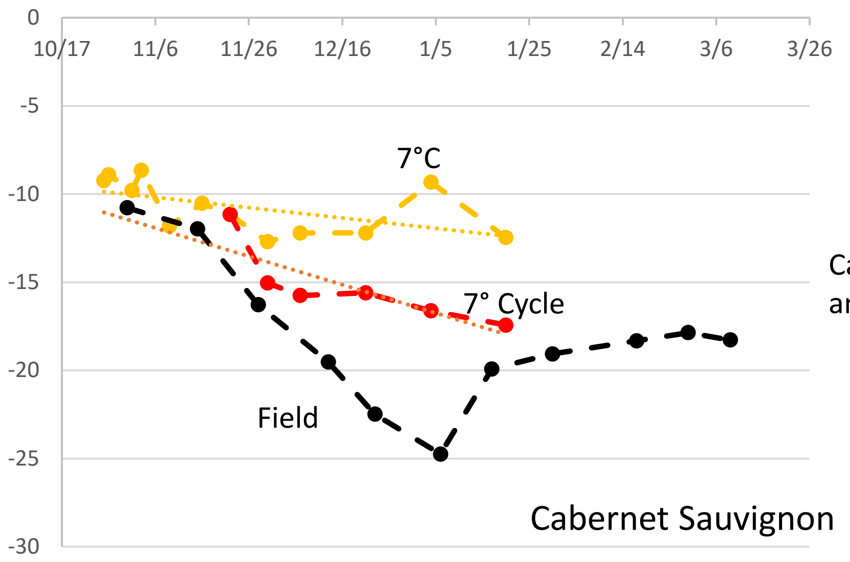






20 cultivated and hybrid cultivars

“Nonresponsive” buds still able to gain supercooling if exposed to enough stress



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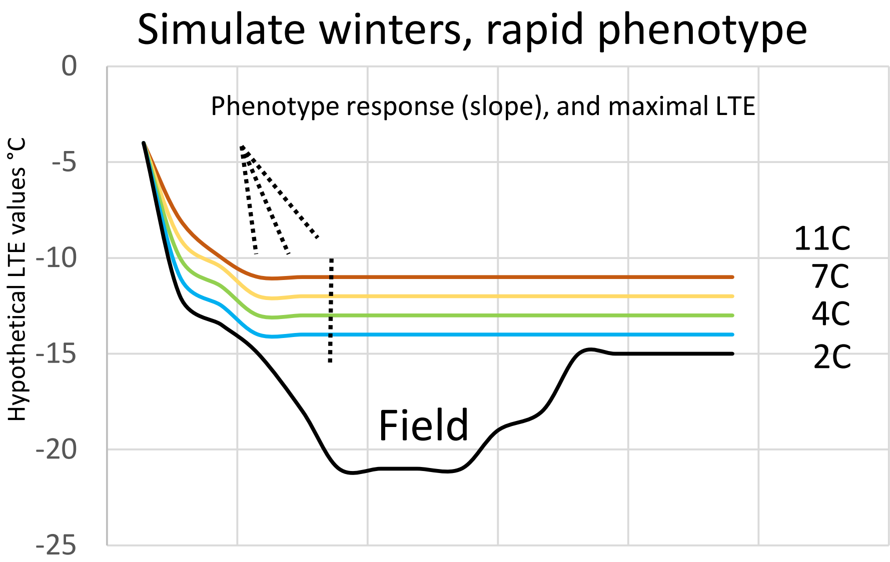
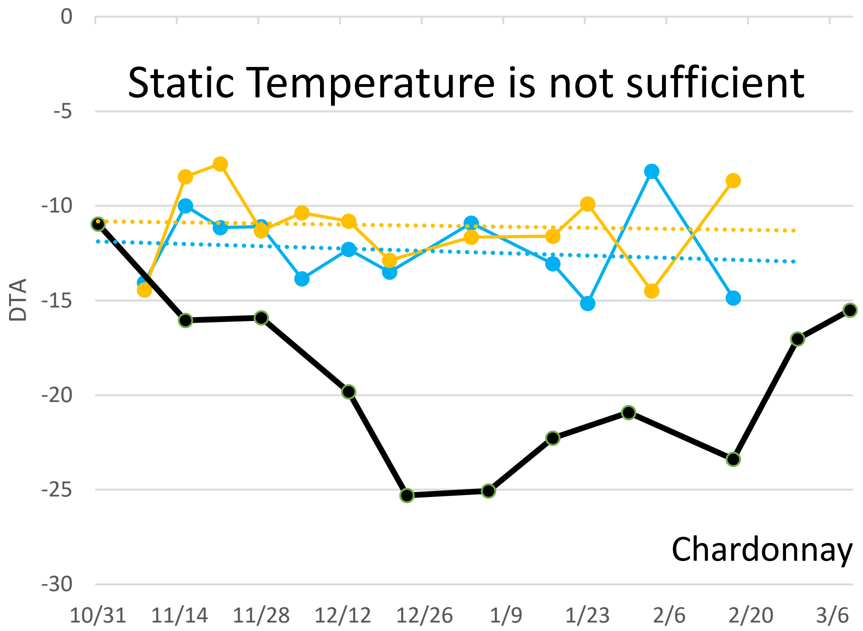
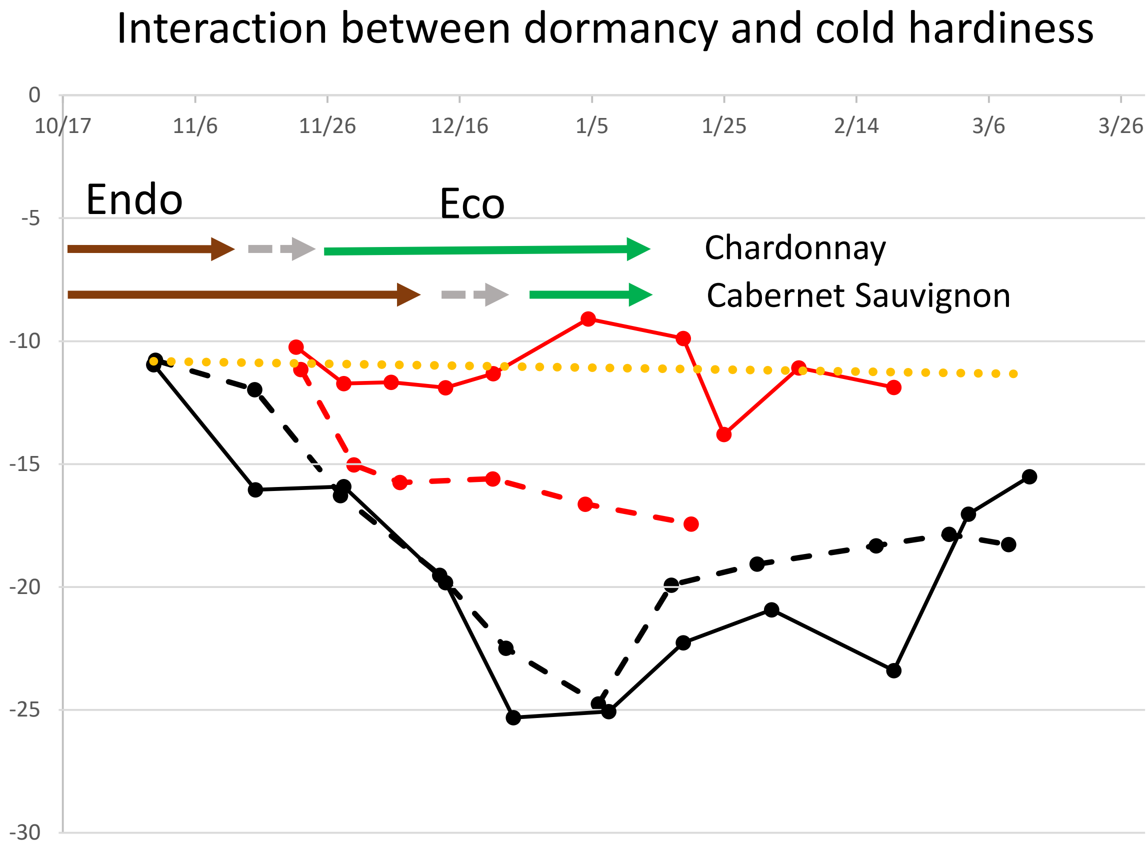
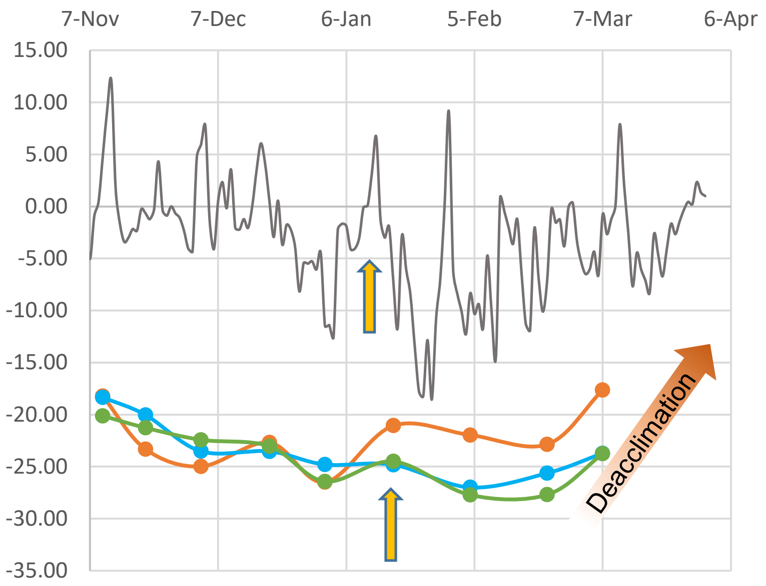


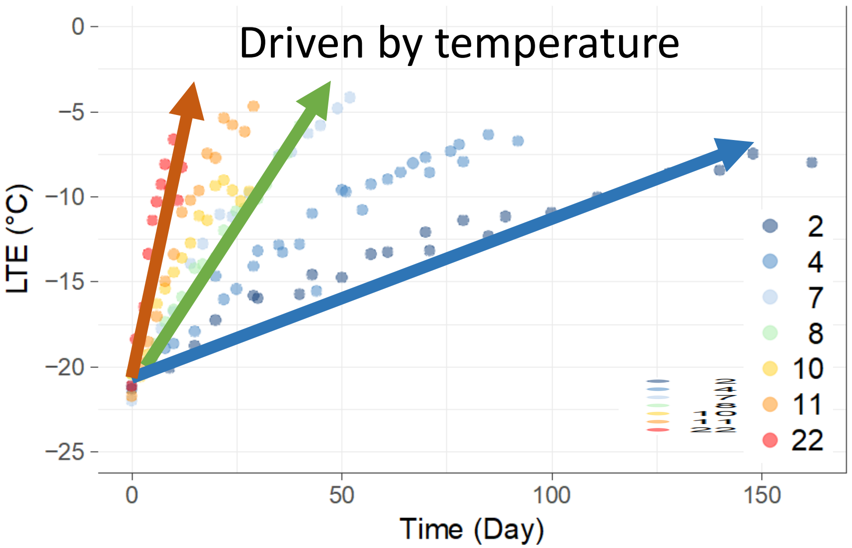


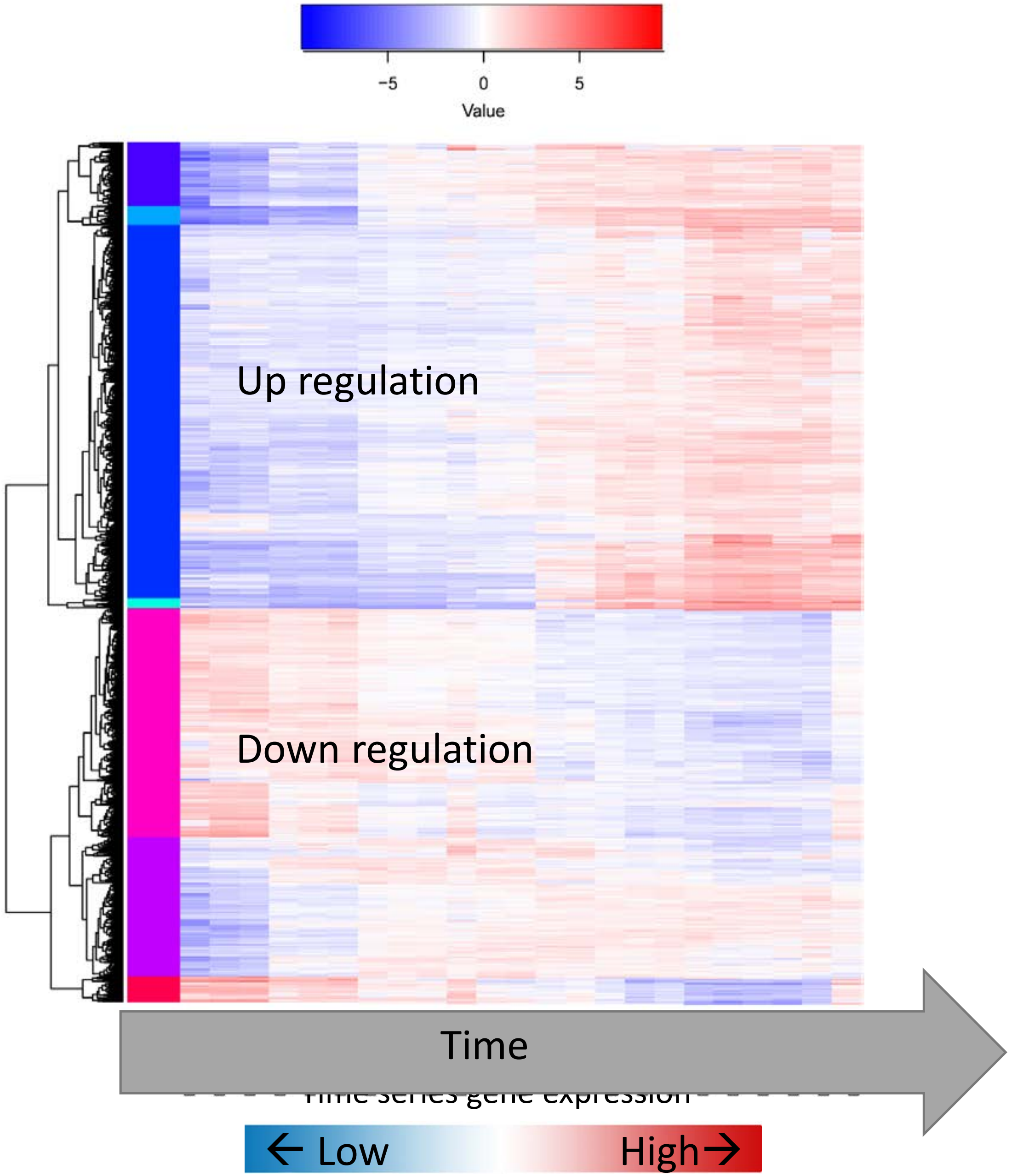


Ongoing verification of this interaction suggests that fall acclimation should be our target for improvement.

Deacclimation rate: Understand phenotype, understand genetic control







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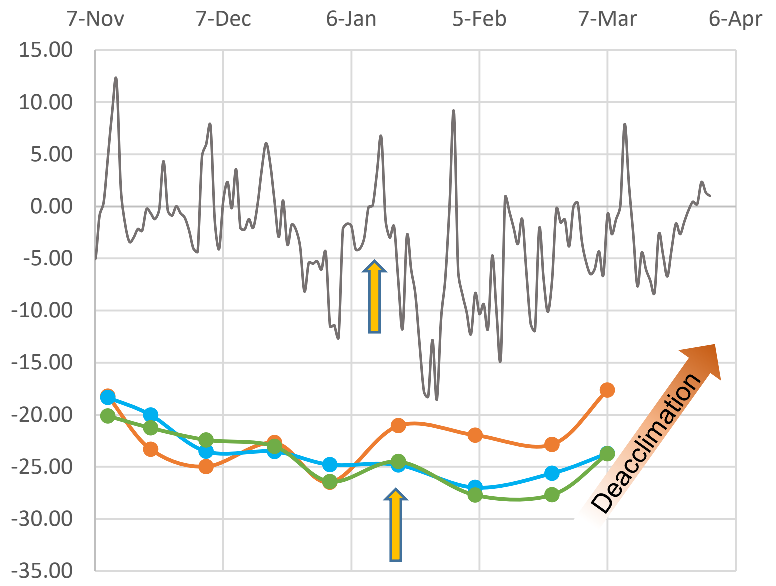
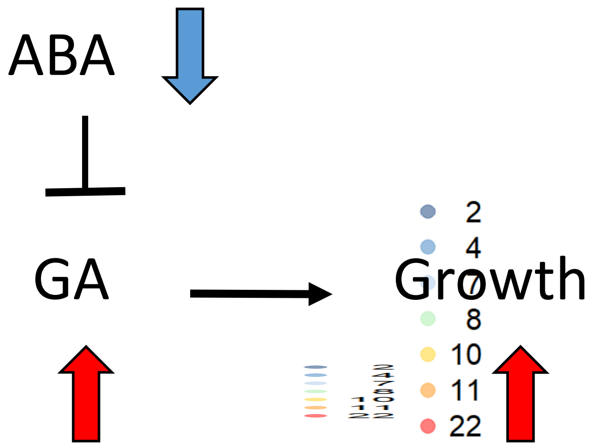
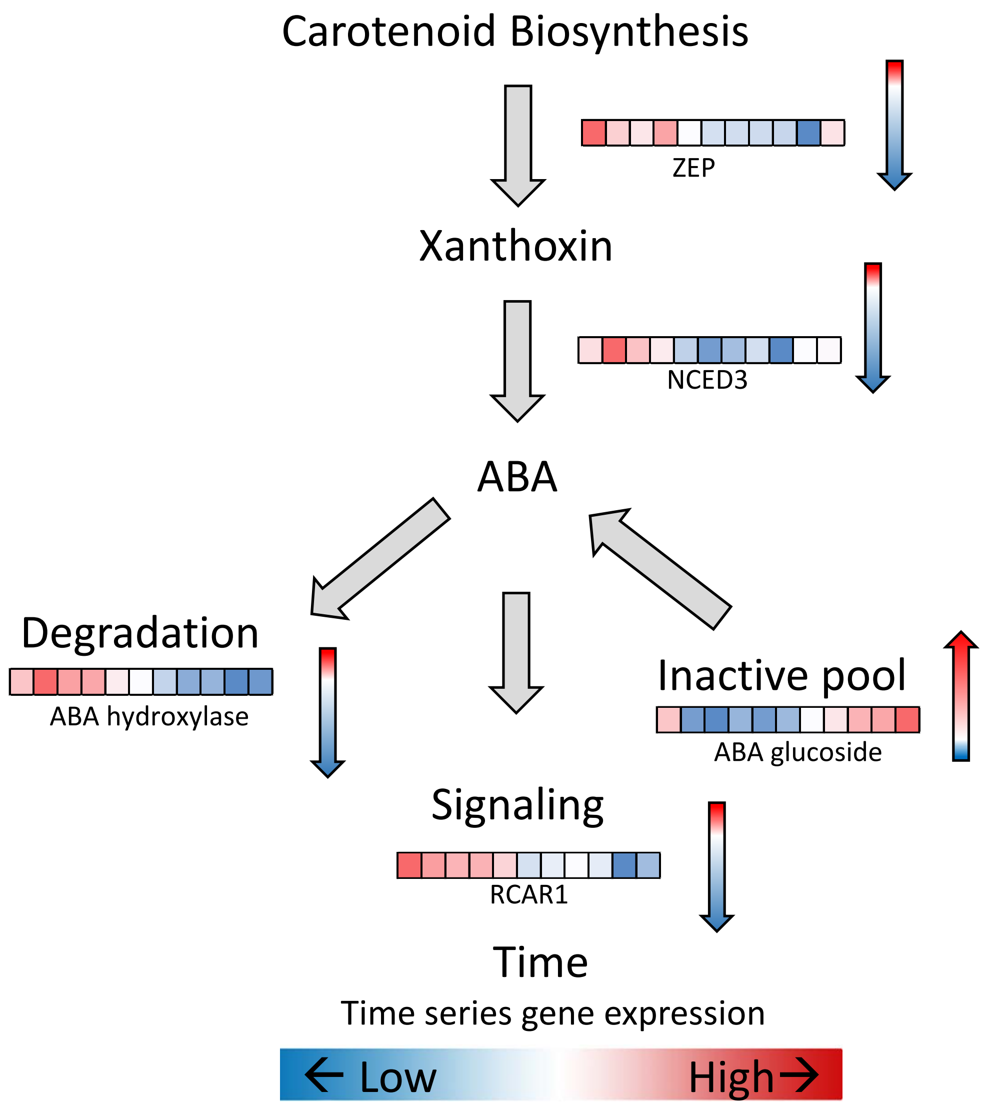


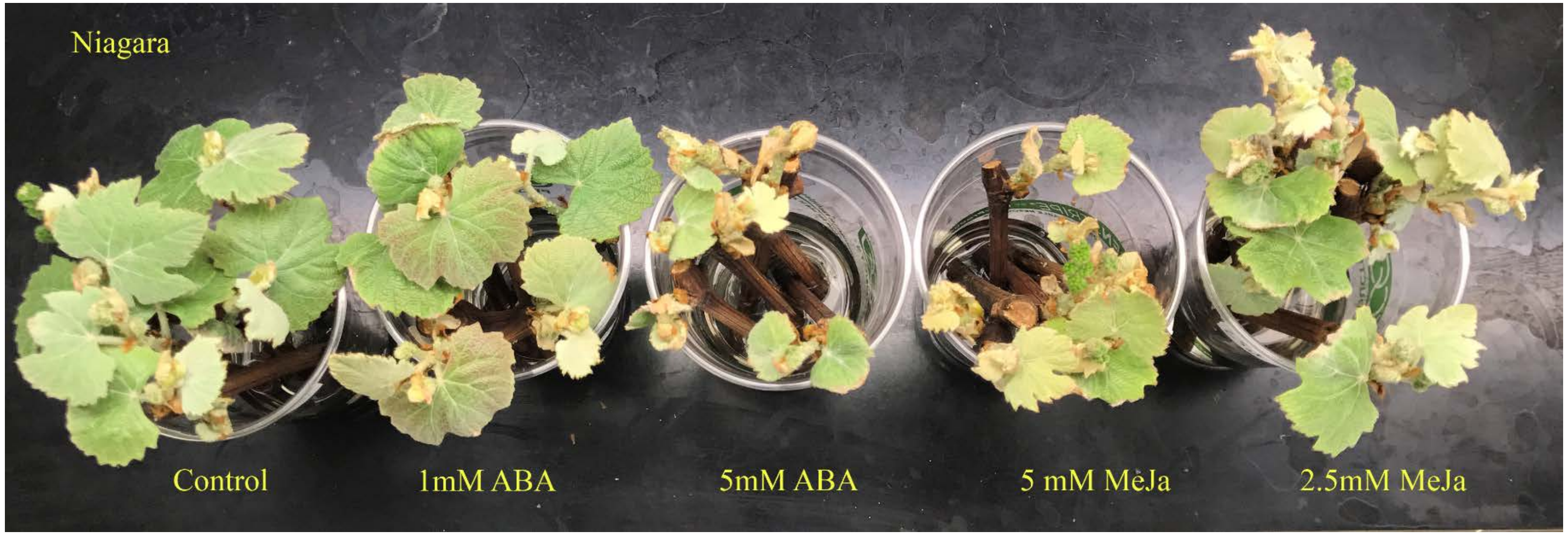


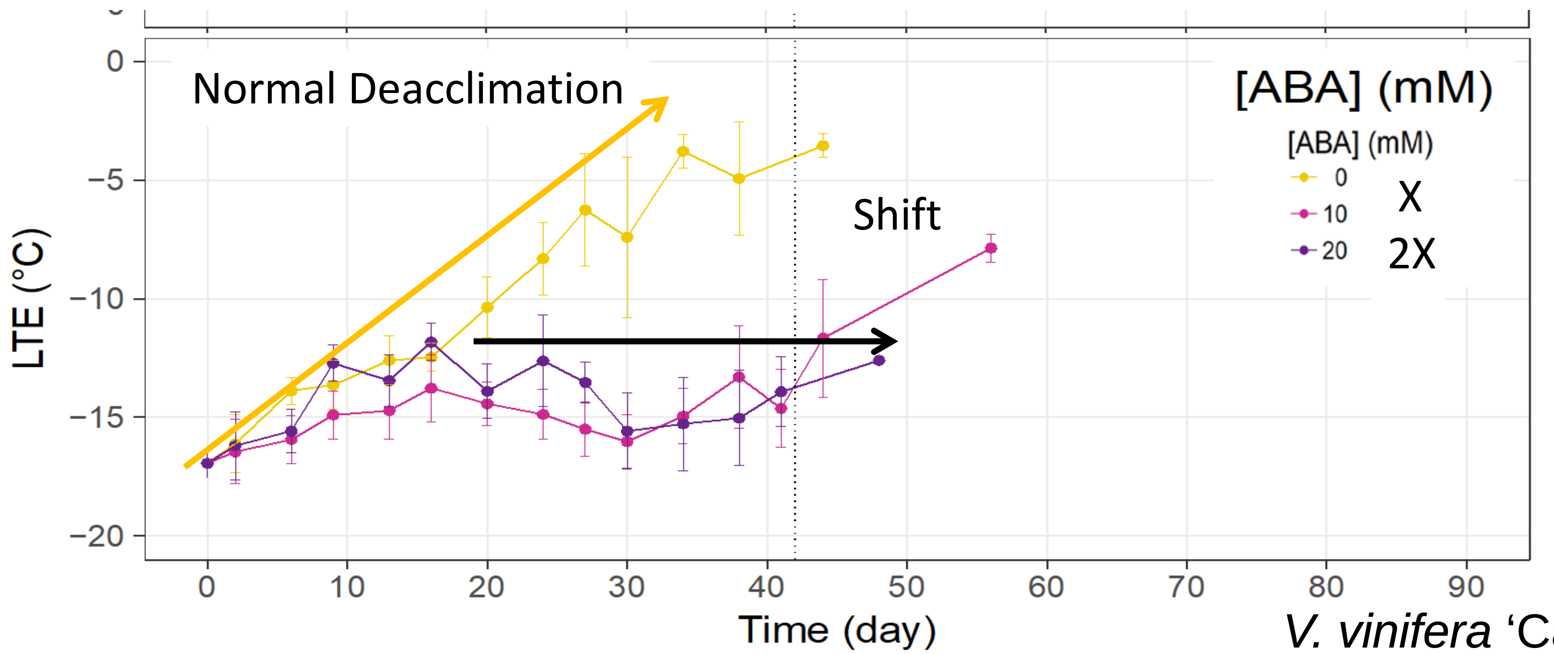
ABA synthesis and signaling pathway

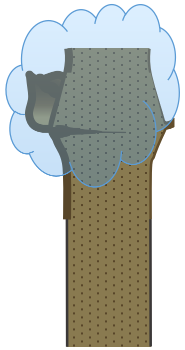


Translate genomics to field mitigation: Identification of plant hormones that delay budburst and delay deacclimation

Ongoing field tests of ABA and MeJA for deacclimation and budburst control







V. vinifera ‘Cabernet Franc’

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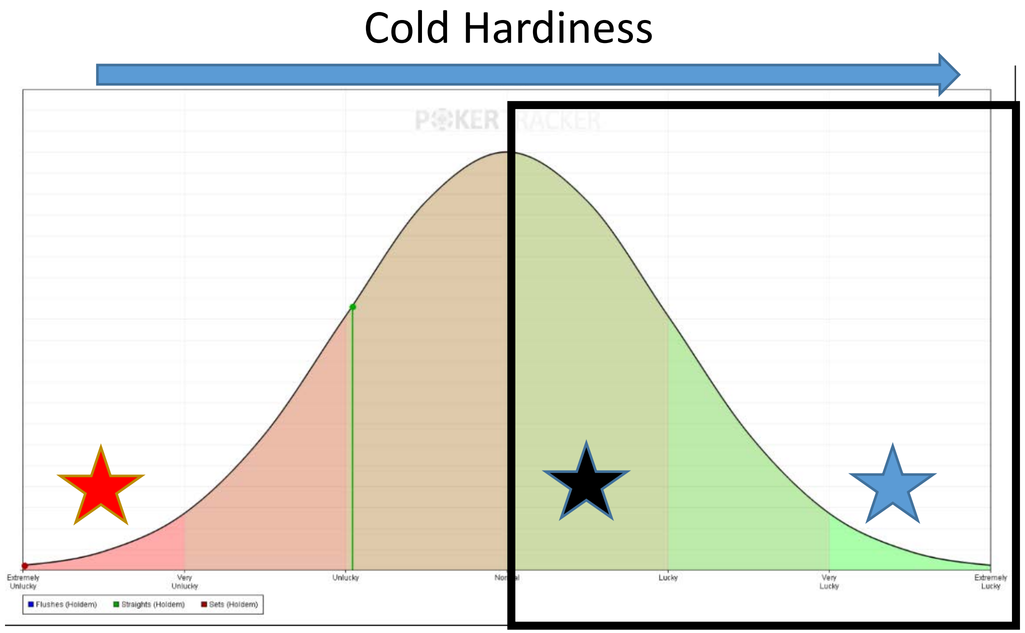
Cold hardiness challenges

- Complex phenotype. Comprised of multiple intersecting physiological and developmental processes
- Extreme impact of environment on genotype -> phenotype. Replication is problematic
- Logistics (human and equipment) is problematic for doing whole family studies.
- Need to do controlled studies but whole vine not logistically feasible.
- Climate limits field based studies.

Moving Forward: Determining the genetic architecture of cold hardiness

QTL mapping of cold hardiness

Cross			Trait
V. hybrid 'Frontenac'	x	*V. vinifera* 'Nimrang'	Winter survival Freeze resistance
V. vinifera 'Muscat of Alexandria'	x	*V. riparia*	Winter survival Freeze resistance
	x	*V. labrusca*	Winter survival Freeze resistance
	x	*V. cinerea*	Dormancy Freeze resistance



Current mapping families are made between Cold hardy, and moderately cold hardy parents because the families must survive NY winters.

Need to cross the phenotypic ends to identify genetic loci with greatest effect in order to leverage the phenotypic tools we have.

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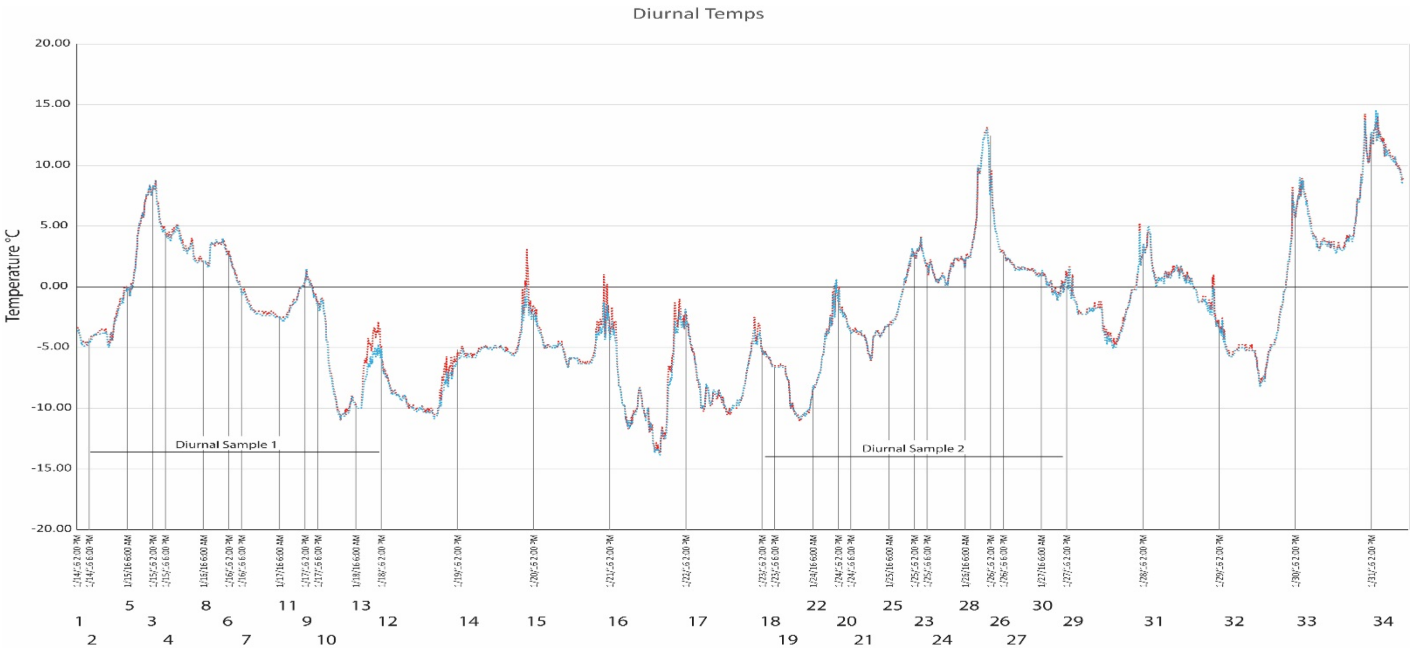
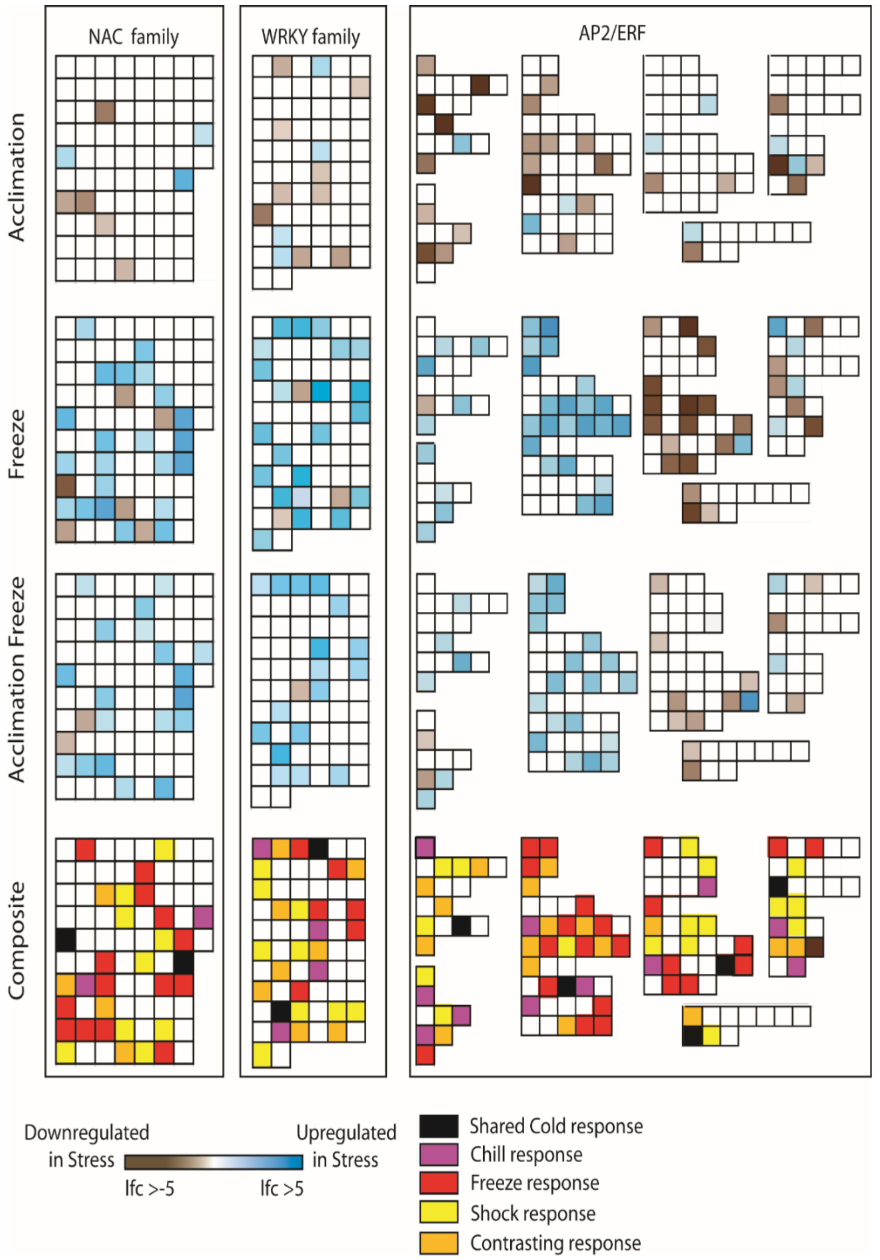
Transcriptomics

- Examination of gene expression patterns throughout winter as temperatures fluctuate.
- Examination of gene expression during controlled acclimation.
- Evaluation of gene expression during transition between dormancy states.





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Candidate gene evaluation

- Transgenic overexpression of EARLY BUDBURST (*EBB1*) and COLD BINDING FACTOR (*CBF*) genes from poplar and peach, in grapevine.
  - Overexpression of these genes in apple alter dormancy and freeze resistance
  - Major regulator genes such as EBB1 and CBF often increase freeze resistance but also impact other aspects of physiology due to crosstalk

- Arabidopsis overexpression of candidate cryo-proteins identified in grapevine. *VvKIN* family of genes respond to cold treatment and increase freeze resistance in other crop species.
  - Downstream genes like the KIN genes are less likely to be detrimental as they are not regulators and don't participate in crosstalk.

Major collaborations and funding

- Anne Fennell – South Dakota State University; Cold hardiness, dormancy, photoresponse, transcriptomics, genomics
- Krista Shelli – Parma, ID USDA-ARS; Drought and dormancy interaction, transcriptomics
- Bruce Reisch, Tim Martinson – Cornell University; Cold hardiness, dormancy, phenotyping
- Michela Centinari – Pennsylvania State; Frost resistance, viticultural testing
- Michael Wisniewski – Kearneysville, WV USDA-ARS; transgenic evaluation of candidate genes for dormancy and cold hardiness.

NSF – PGRP: Adapting Perennial Crops for Climate Change: Graft Transmissible Effects of Rootstocks on Grapevine Shoots.

- Allison Miller – St. Louis University; Misha Kwasniewski – University of Missouri; Laszlo Kovacs – Missouri State University; Dan Chitwood –Michigan State; Anne Fennell – South Dakota State University

Irrigation/Drought effects, Genotype x environment interaction, phenology, ionomics, transcriptomics, Rootstock x Scion, Rootstock x Scion x environment, mapping of scion traits based on rootstock genetic variation.

- USDA-SCRI (Vitisgen 1, Vitisgen 2)
- NSF-PGRP (Adapting Perennial Crops for Climate Change; 1.13 M)
- New York Wine and Grape Foundation (Reducing frost risk in grapevine through controlling budburst with Jasmonic and Salicylic acid)

Questions?

USDA

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