

HLS Snow Dynamics Validation

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Method

- Interpretation of dense high-resolution imagery time-series to determine (as close as possible) true snow dynamics
 - Vantor: < 1 m
 - PlanetScope: 3 m
 - Sentinel-2: 10 m
 - Landsat 7-9: 30 m
- Full details in [Monitoring snow cover dynamics at 30-m resolution in higher latitude regions using Harmonized Landsat Sentinel-2](#)

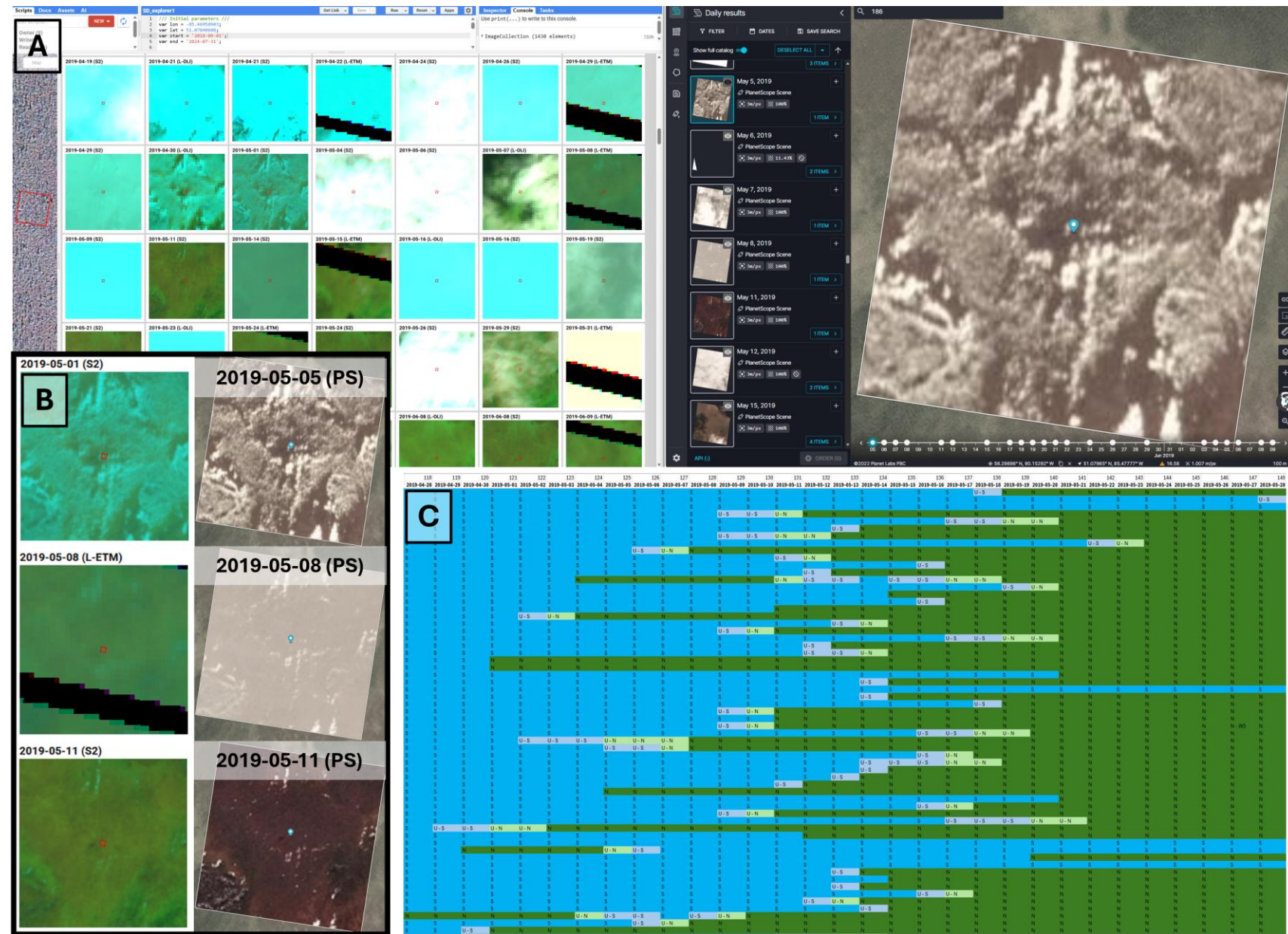
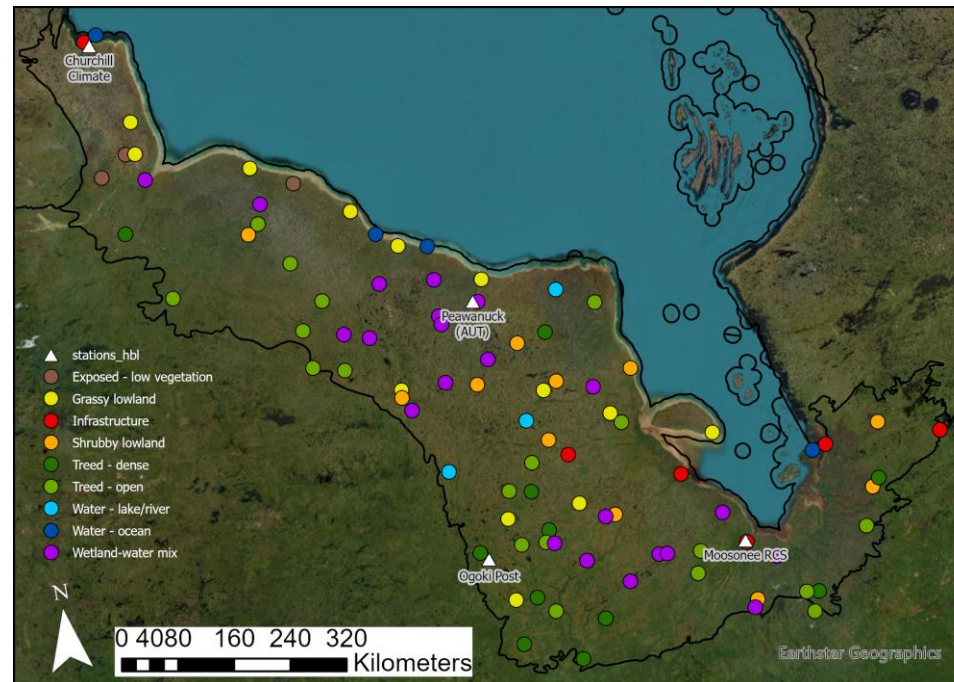


Fig. A17. Example of high-resolution imagery time-series interpretation procedure. (A) Interpretation workflow for the 2019 snow melt period over a grassy lowland sample pixel, with Sentinel-2 and Landsat 7-9 Google Earth Engine script on the left and Planet Insights Platform on the right. (B) Six high-leverage time-steps from May 1 to May 11, 2019. The snow end(B/L) date was determined to be May 6, with an uncertainty of one day. (C) How interpretations were recorded for each date as either S (blue), N (green), U-S (lighter blue), or U-N (lighter green) over the 2019 snow melt period for a subset of sample pixels. The middle date of odd-length uncertain periods was given to U-S since it is more likely for snow to be not-visible in these images but there on the ground in small quantities than the alternative.

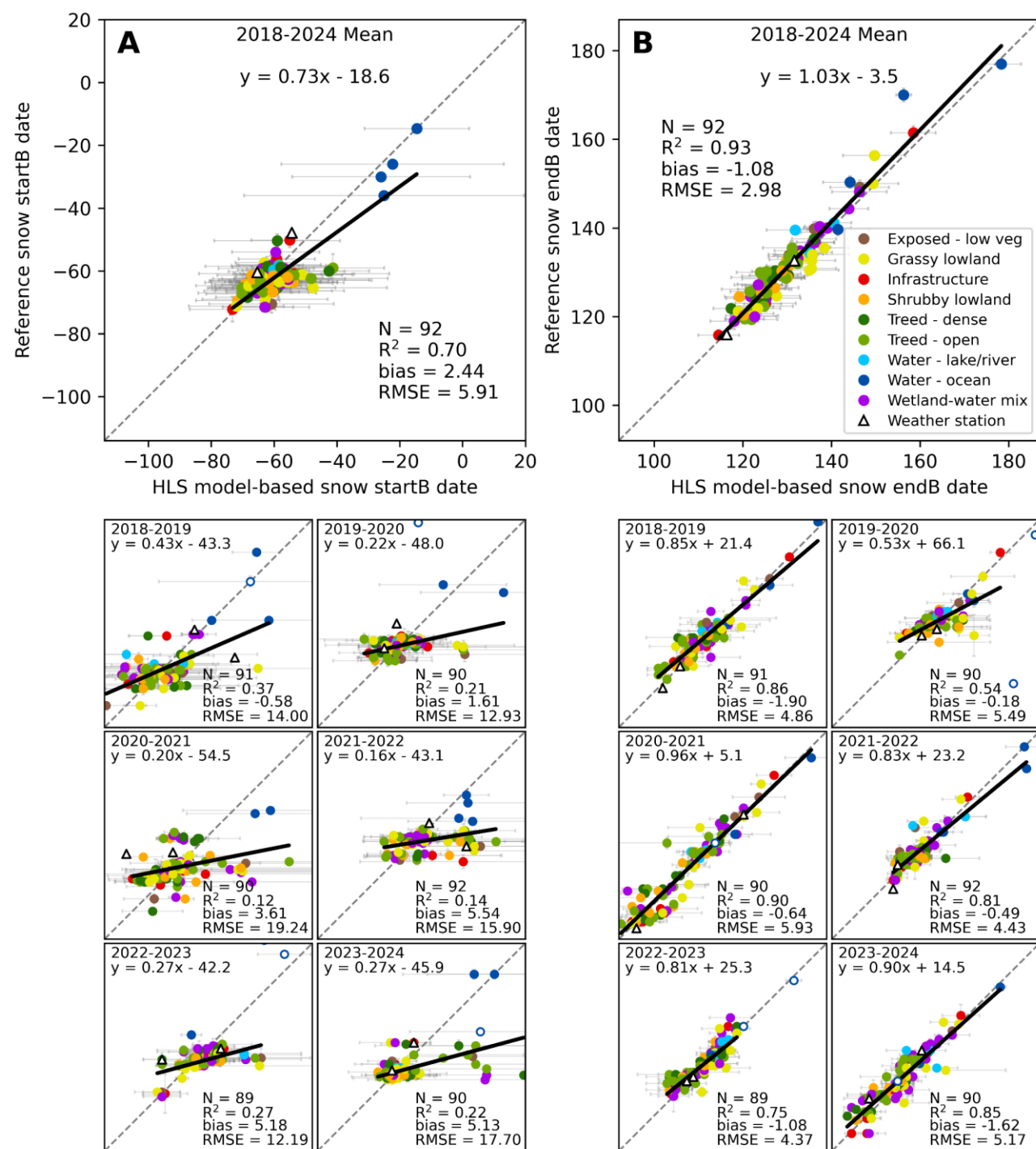
Initial Hudson Plains validation

- Completed as part of: [Monitoring snow cover dynamics at 30-m resolution in higher latitude regions using Harmonized Landsat Sentinel-2](#)
 - 92 Sites, 2018-2019 to 2023-2024 winter years and interannual



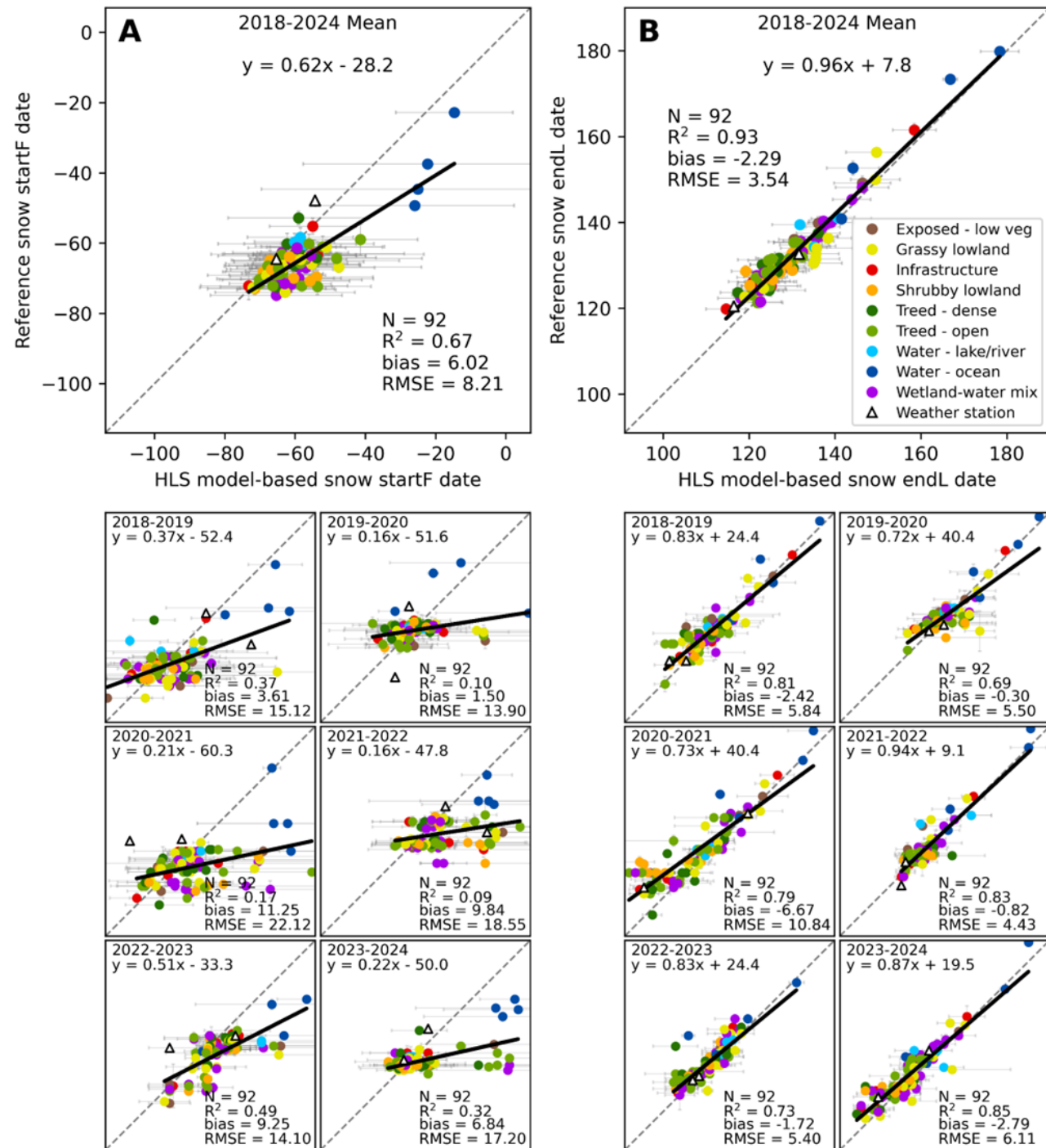
Initial Hudson Plains validation (Paper)

Observed (imagery time-series interpretation reference) vs. predicted (HLS model-based) plots, multi-yearly (2018-2024, top) and for each snow-year (2018-2019 to 2023-2024, bottom). (A) Snow startB. (B) Snow endB. Snow-year plots have the same ranges as multi-year plots. Sample points (N = 92) are coloured by assessment group (Fig. A16). Sample points include error bars, with the x-direction quantifying model uncertainty and the y-direction quantifying interpretation uncertainty (Fig. A17). Data from two weather stations are shown but not included in statistics. Hollow-blue points are water – ocean samples where sea ice dynamics led to mid-winter non-snow interpretations for the given snow-year (e.g., short-duration polynyas). These points were also not included in statistics for biggest-period metrics, which can be noted by reduced sample sizes in some snow-years. Several of these points fall outside the plotting area. For startB: 2019-2020 ($x = -71$, $y = 31$), 2020-2021 ($-18, 37$; $-9, 29$), 2022-2023 ($-11, 22$; $-18, 28$), 2023-2024 ($-2, 52$). For endB: 2019-2020 (92,77), 2020-2021 (175,76), 2022-2023 (96,79), 2023-2024 (180,26). See Figs. A33 and A34 for other metrics.



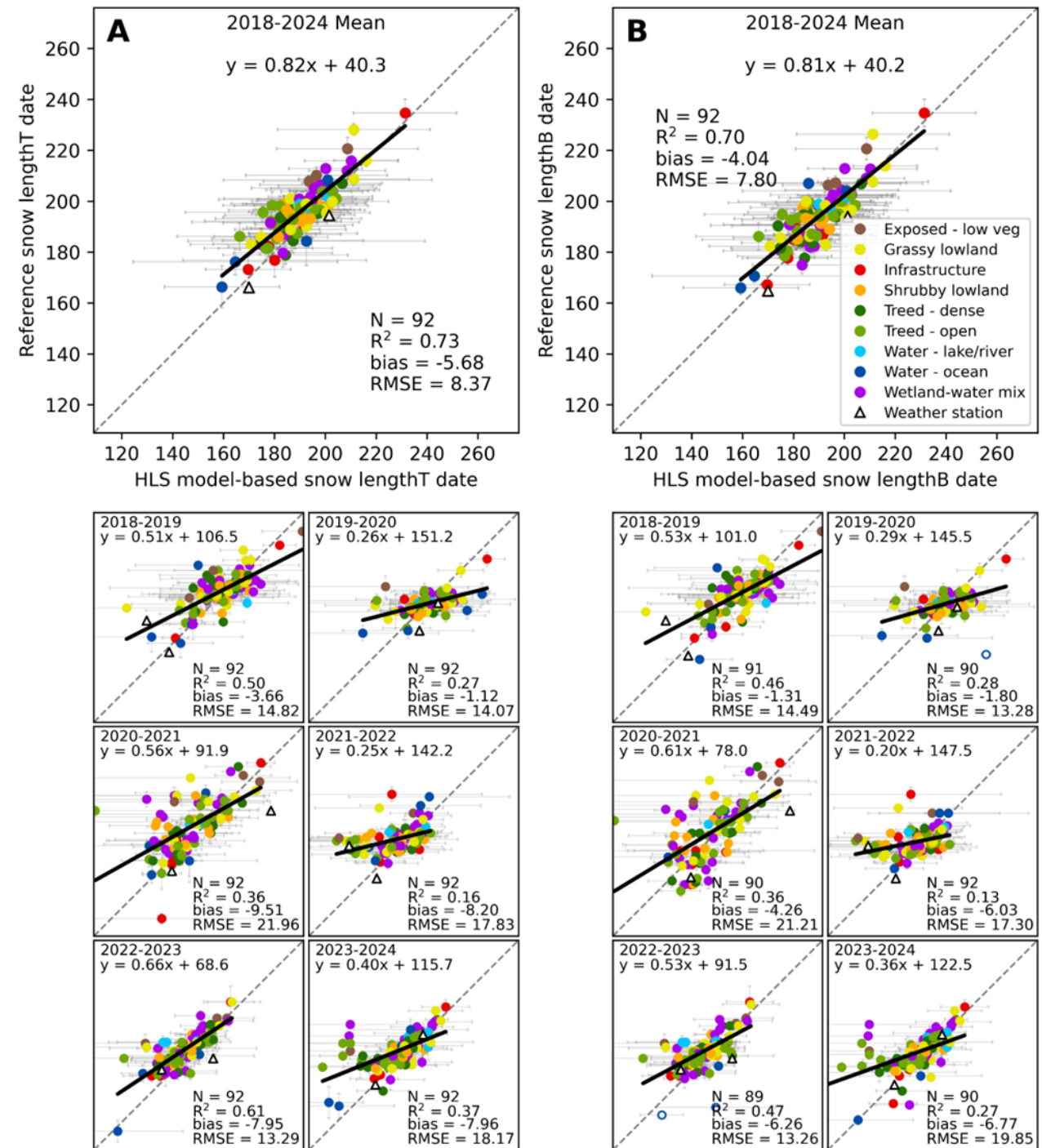
Initial Hudson Plains validation (Paper)

Observed (imagery time-series interpretation reference) vs. predicted (HLS model-based) plots, multi-yearly (2018-2024, top) and for each snow-year (2018-2019 to 2023-2024, bottom). (A) Snow startF. (B) Snow endL. Format matches previous, except there are no hollow-blue points because water – ocean samples with mid-winter non-snow interpretations do not impact startF or endL.



Initial Hudson Plains validation

Observed (imagery time-series interpretation reference) vs. predicted (HLS model-based) plots, multi-yearly (2018-2024, top) and for each snow-year (2018-2019 to 2023-2024, bottom). (A) Snow lengthT. (B) Snow lengthB. Format matches previous, except there are no hollow-blue points for lengthT because water – ocean samples with mid-winter non-snow interpretations do not impact it much. Several sample points for lengthB fall outside the plotting area: 2018-2019 (113,98), 2019-2020 (x = 247, y = 82), 2020-2021 (155,100; 185,48), 2022-2023 (108,58), 2023-2024 (125,73; 190,64; 98,184).

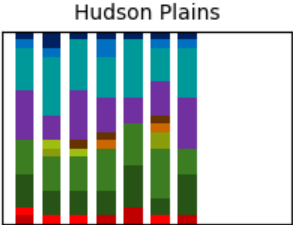
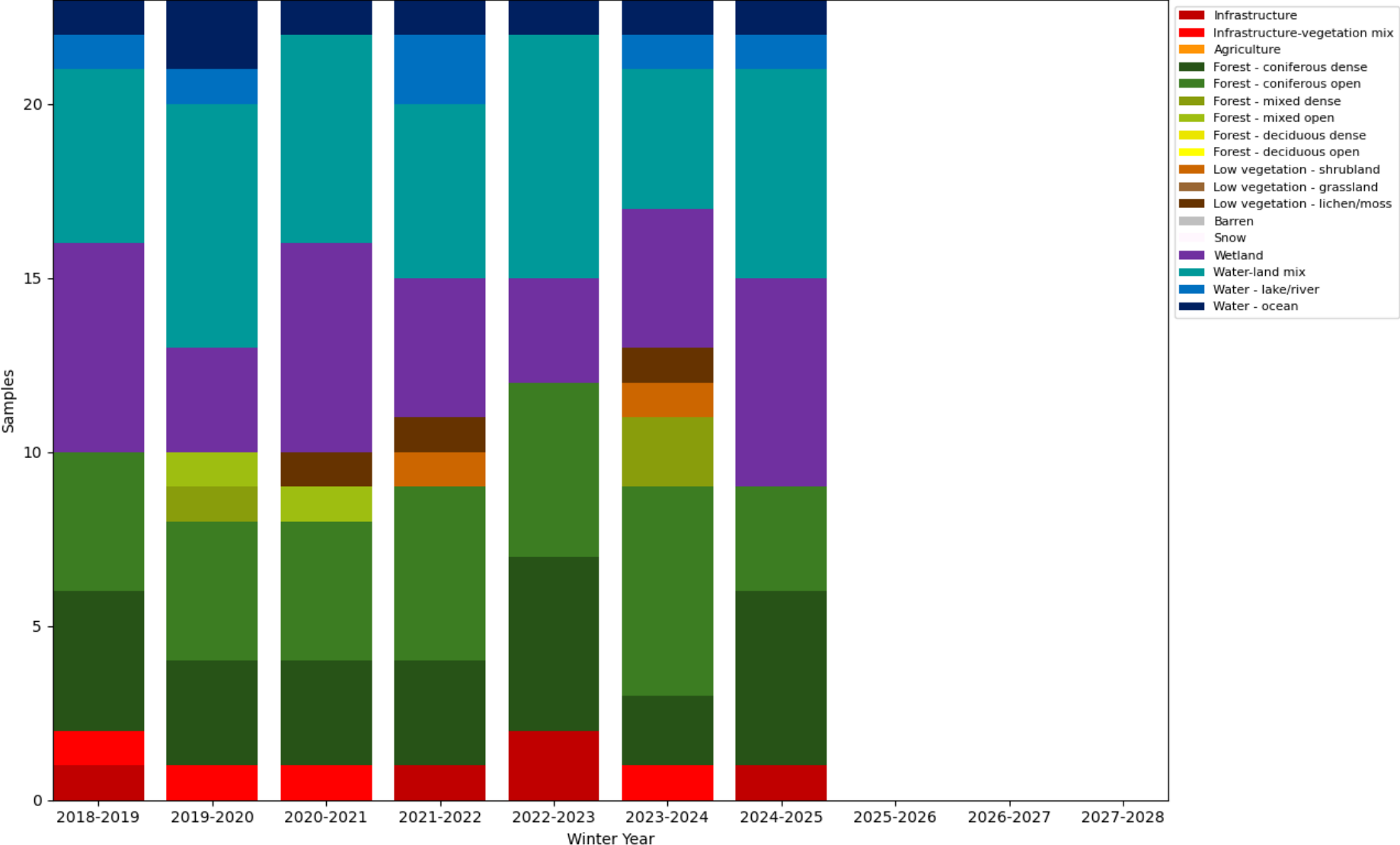


National Validation

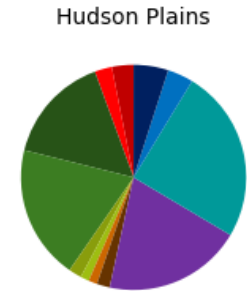
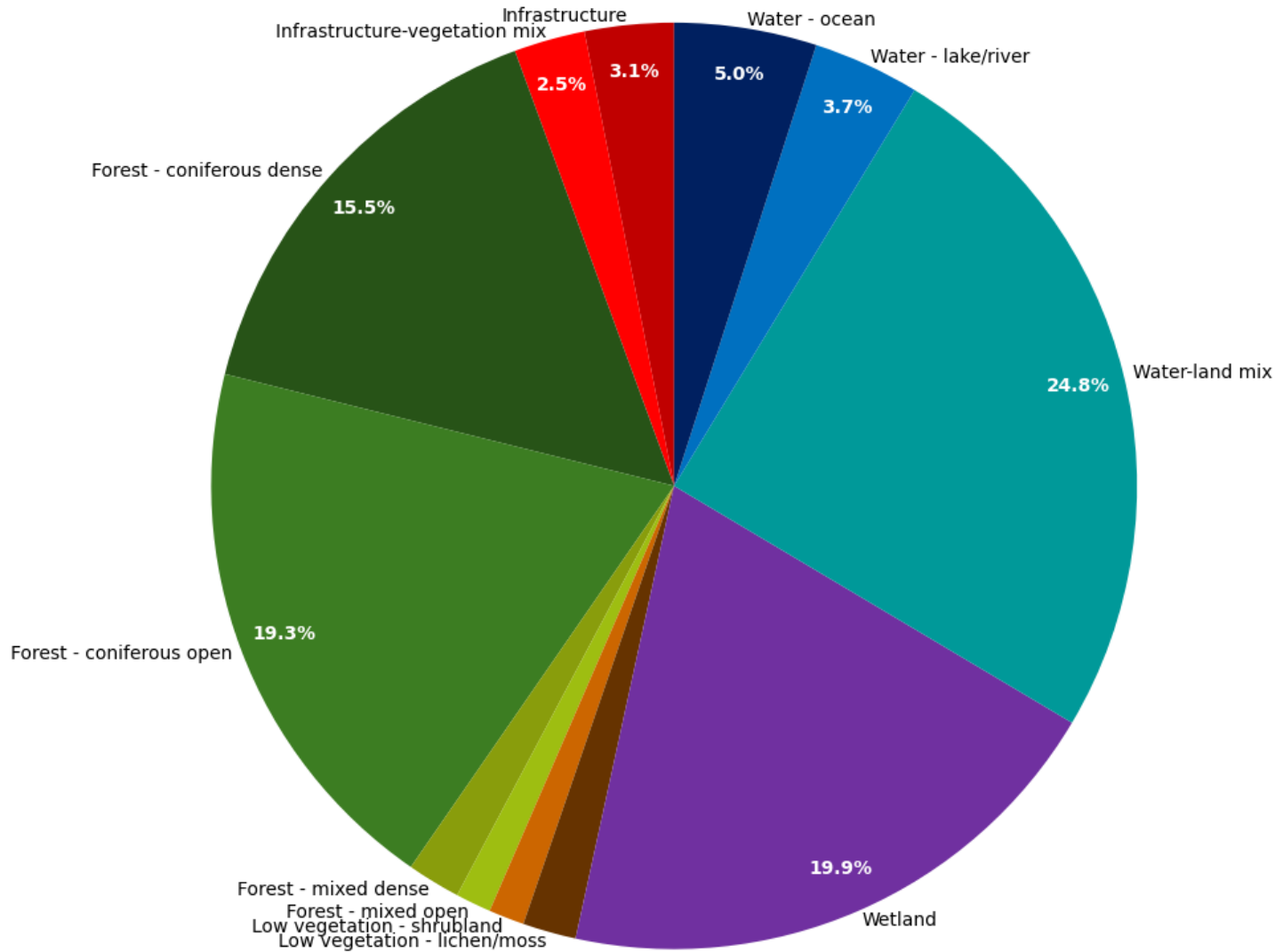
- Interpretation of high-resolution imagery time-series: **161/5000**
 - Arctic Cordillera: 0/170
 - Atlantic Maritime: 0/165
 - Boreal Cordillera: 0/241
 - Boreal Plains: 0/357
 - Boreal Shield: 0/700
 - Hudson Plains: 161/230
 - Mixedwood Plains: 0/134
 - Montane Cordillera: 0/276
 - Northern Arctic: 0/677
 - Pacific Maritime: 0/168
 - Prairies: 0/274
 - Southern Arctic: 0/456
 - Taiga Cordillera: 0/184
 - Taiga Plains: 0/325
 - Taiga Shield: 0/644



Sample Statistics

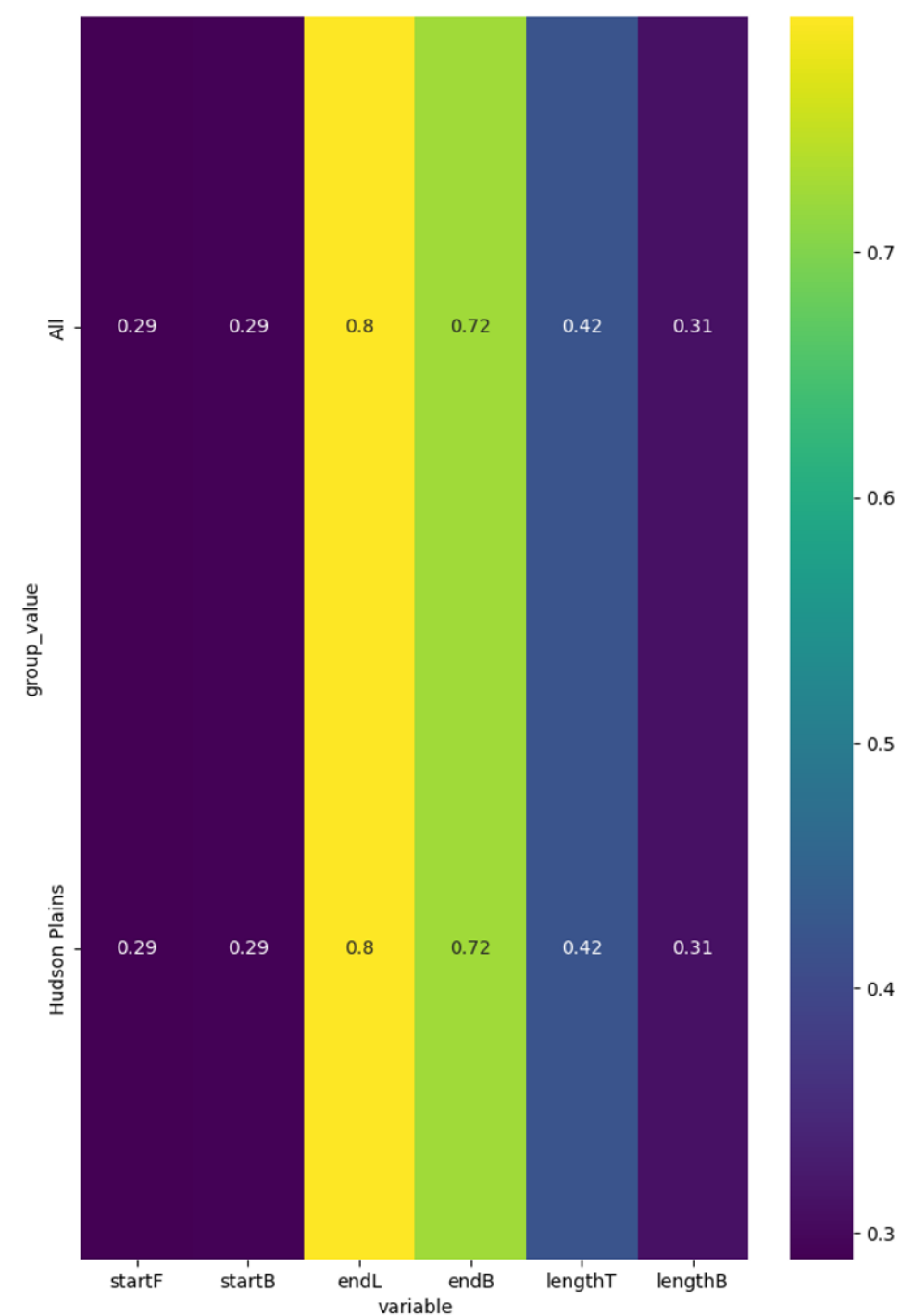


Sample Statistics



Regression Statistics: R^2

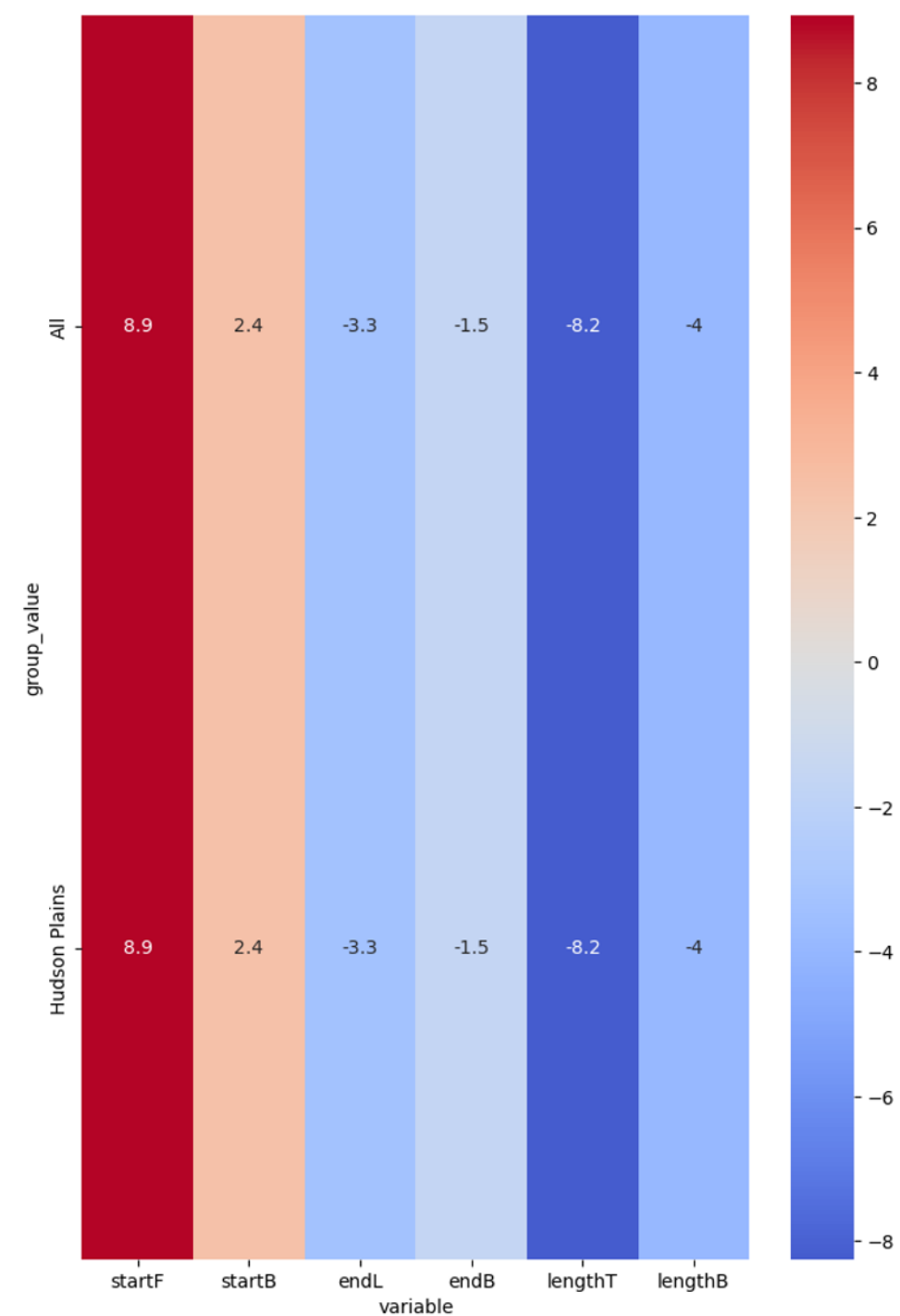
- Only shown if $n \geq 50$
- Best performance for snow end



Regression Statistics: Bias

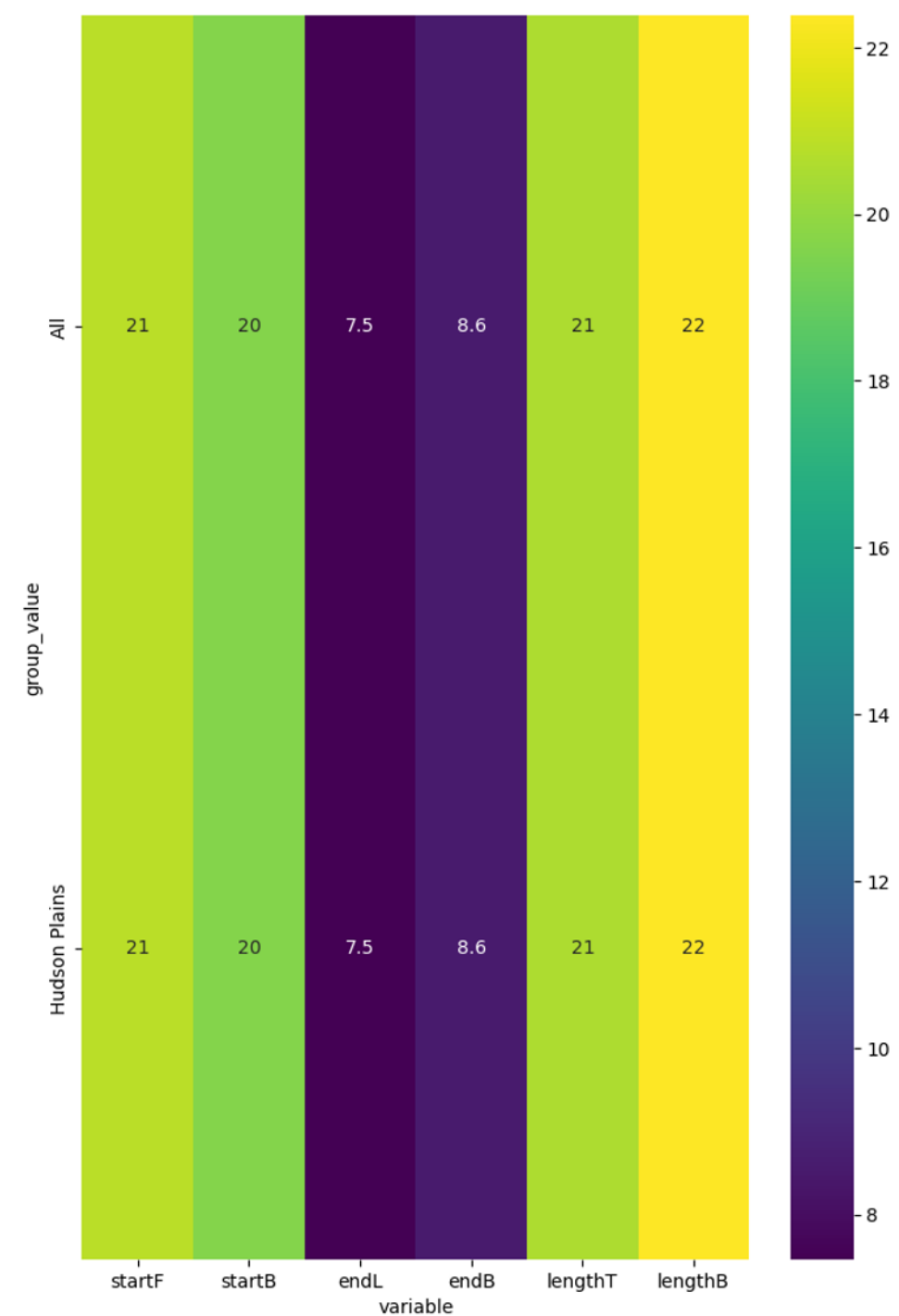
Mean of residuals

- Only shown if $n \geq 50$



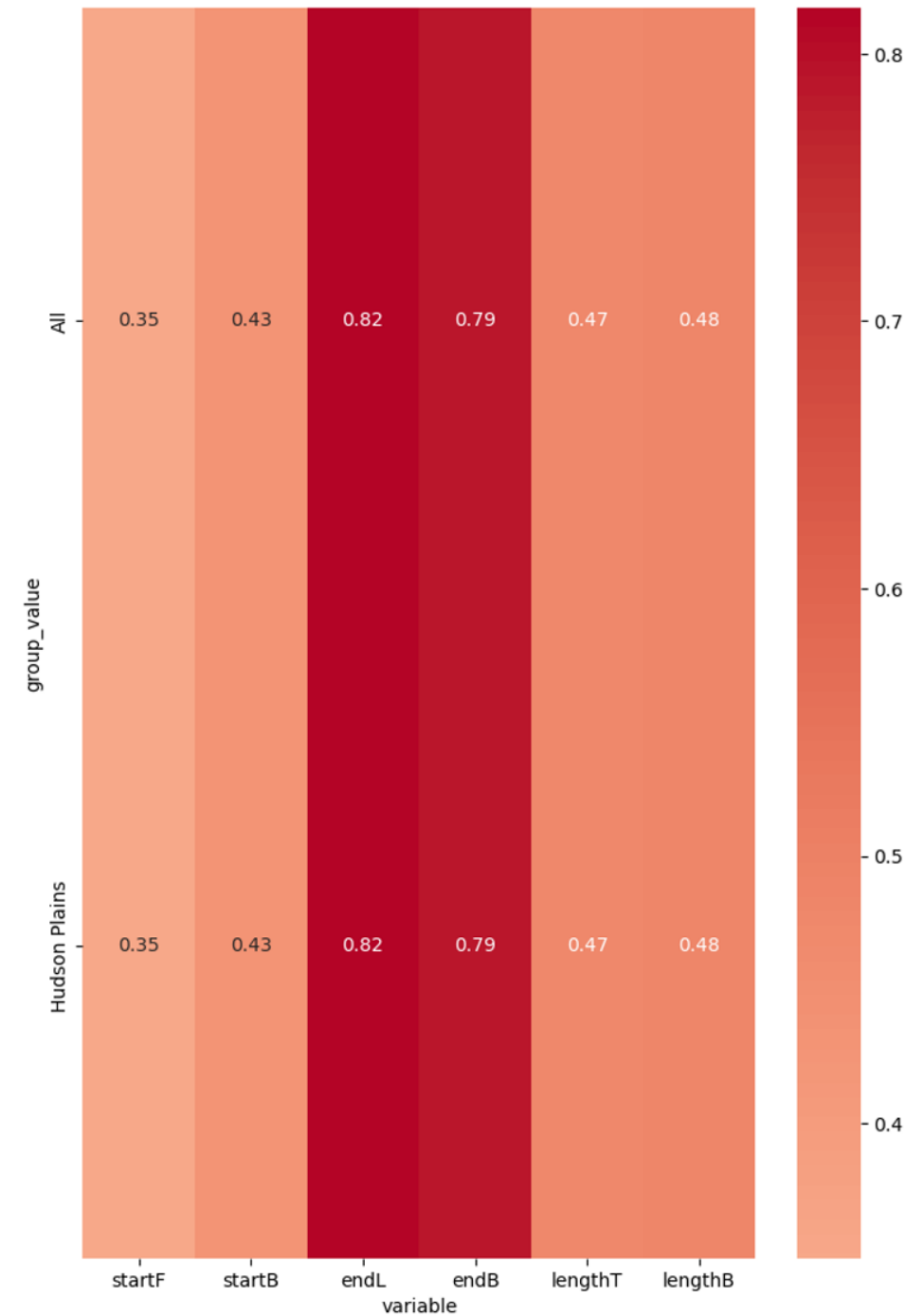
Regression Statistics: RMSE

- Only shown if $n \geq 50$
- Best performance for snow end



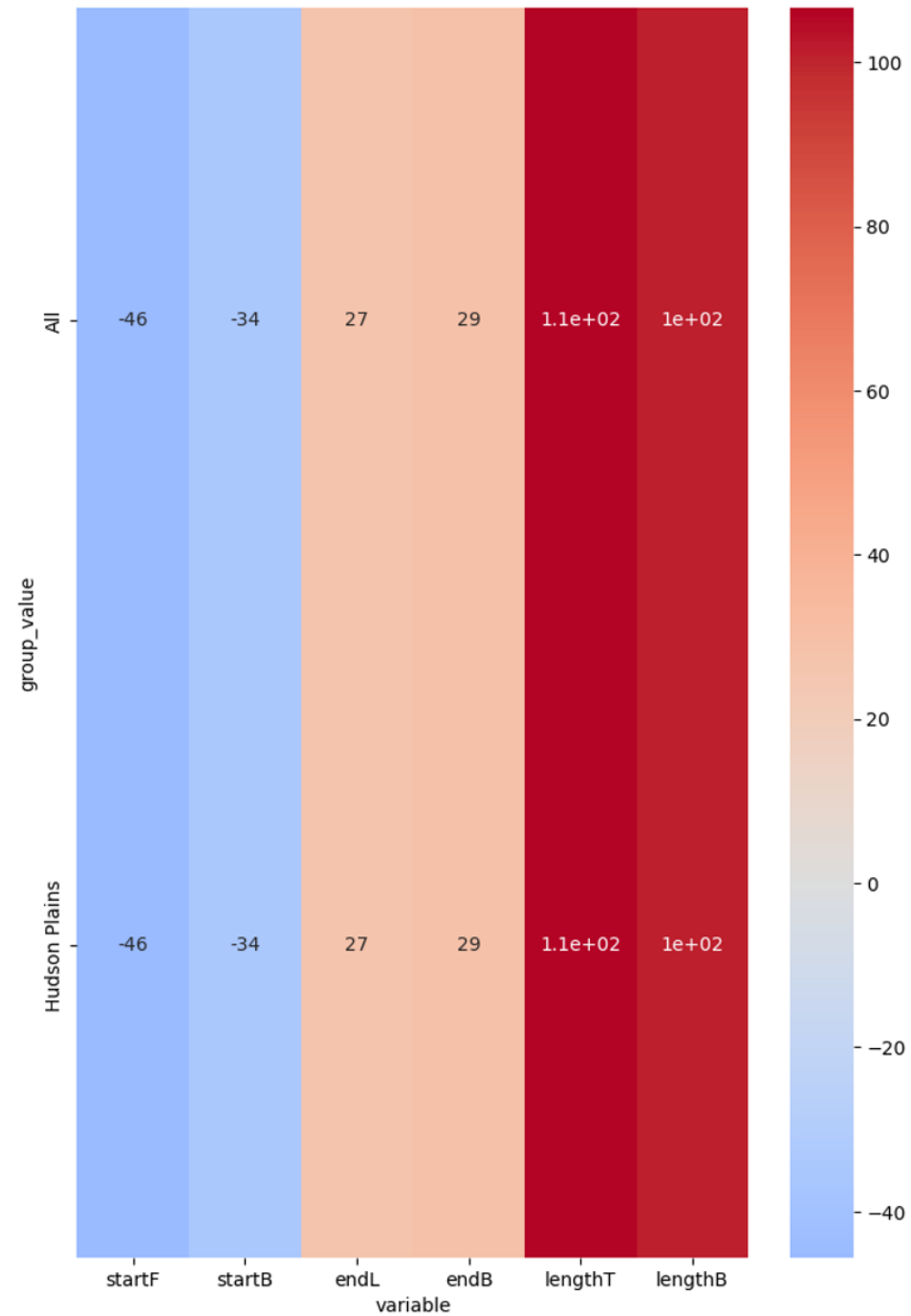
Regression Statistics: Slope

- Only shown if $n \geq 50$
- Best performance for snow end



Regression Statistics: Intercept

- Only shown if $n \geq 50$



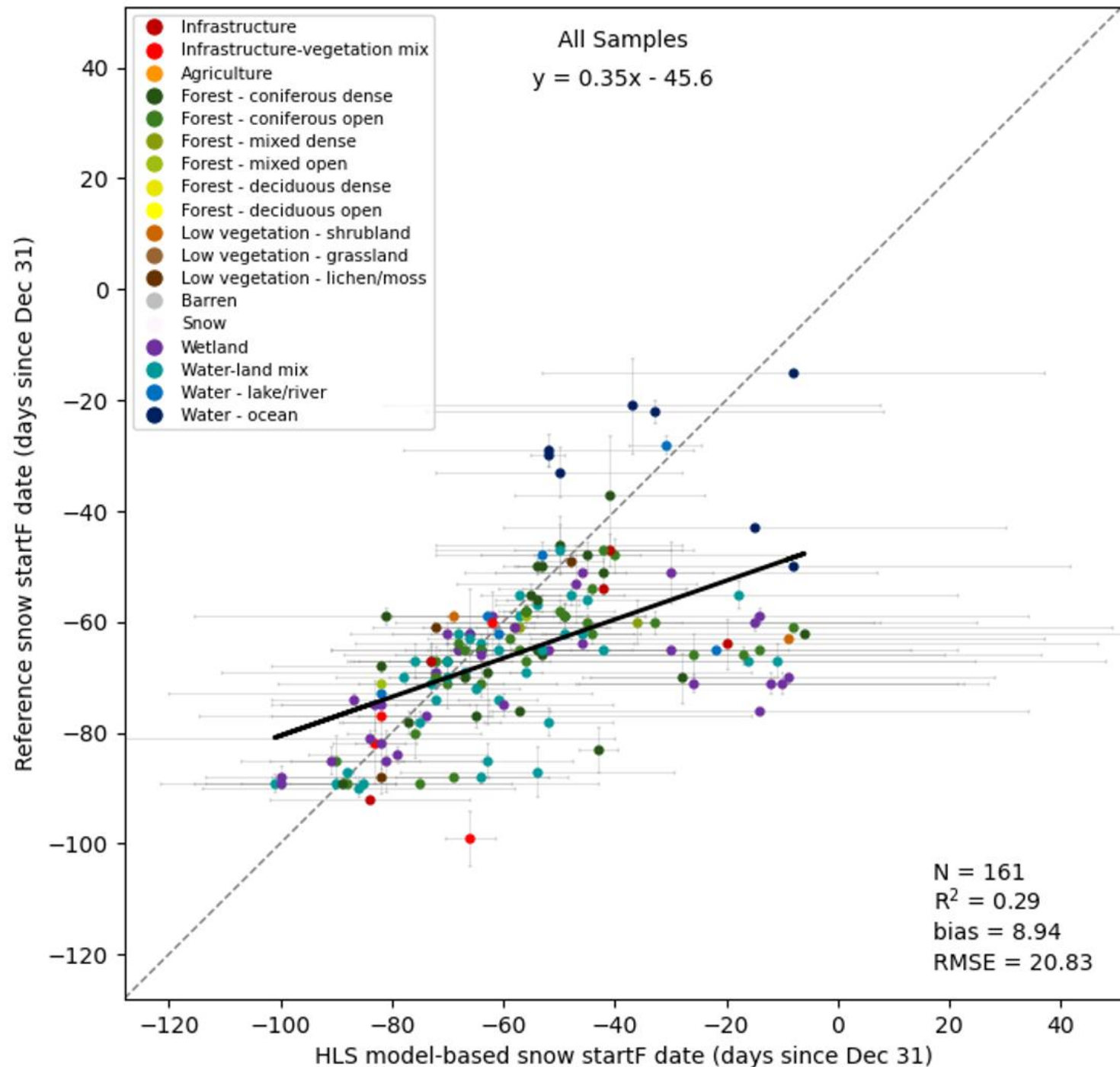
By metric results

- startF: observed vs predicted plots
- startB: observed vs predicted plots
- endL: observed vs predicted plots
- endB: observed vs predicted plots
- lengthT: observed vs predicted plots
- lengthB: observed vs predicted plots
- periods: Agreement % tables
- status: Agreement % tables

All Samples

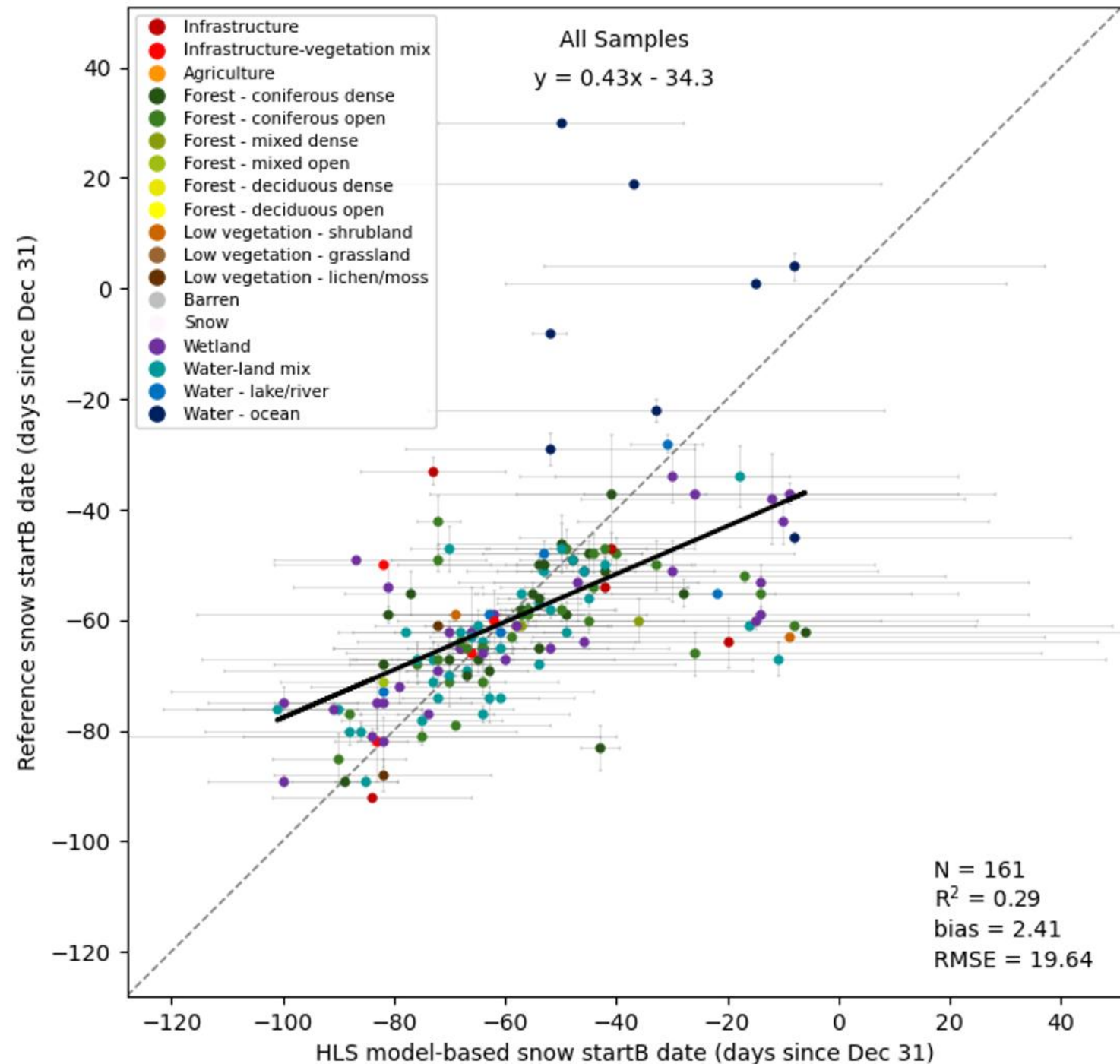
startF

- Late snow start dates and associated high uncertainties from model due to lack of snow observations before winter darkness period
- Cloudier in fall than spring



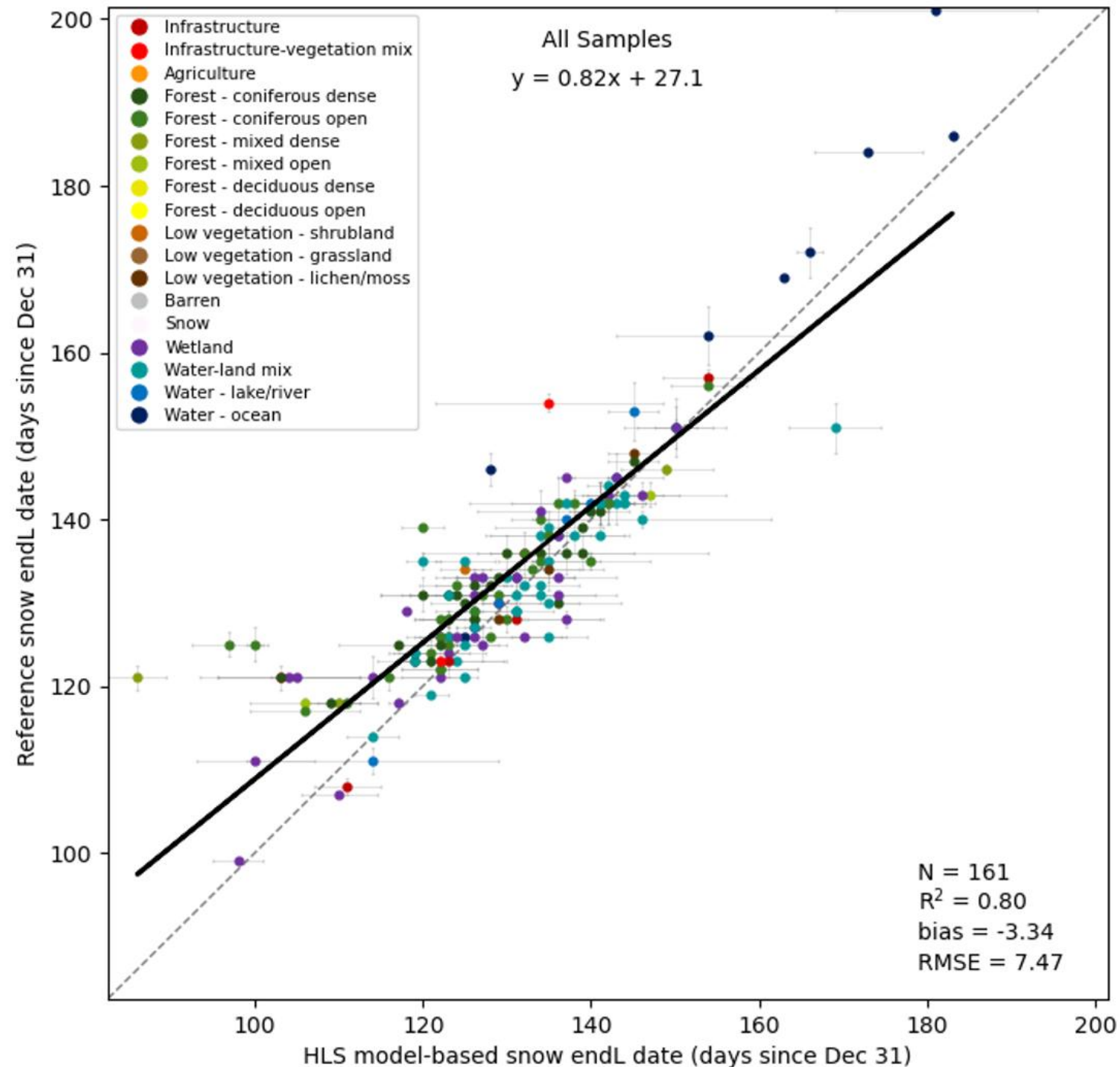
startB

- Late snow start dates and associated high uncertainties from model due to lack of snow observations before winter darkness period
- Cloudier in fall than spring
- Complex sea ice dynamics (i.e., multiple short duration ice free periods in winter) impact some ocean samples



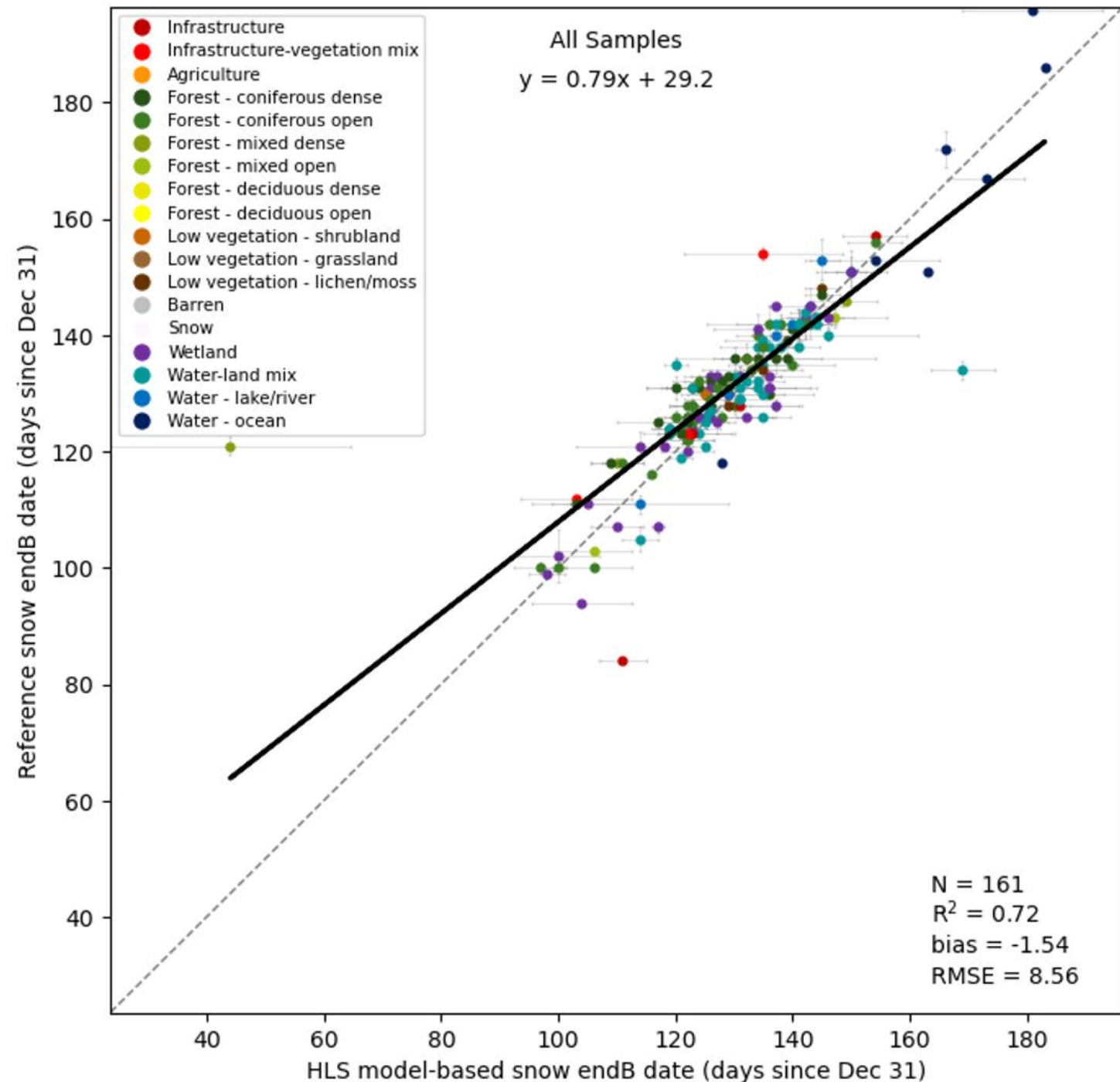
endL

- Best performing metric
- Model underestimates snow end date in some forest samples due to difficulties observing remaining snow under canopy in spring



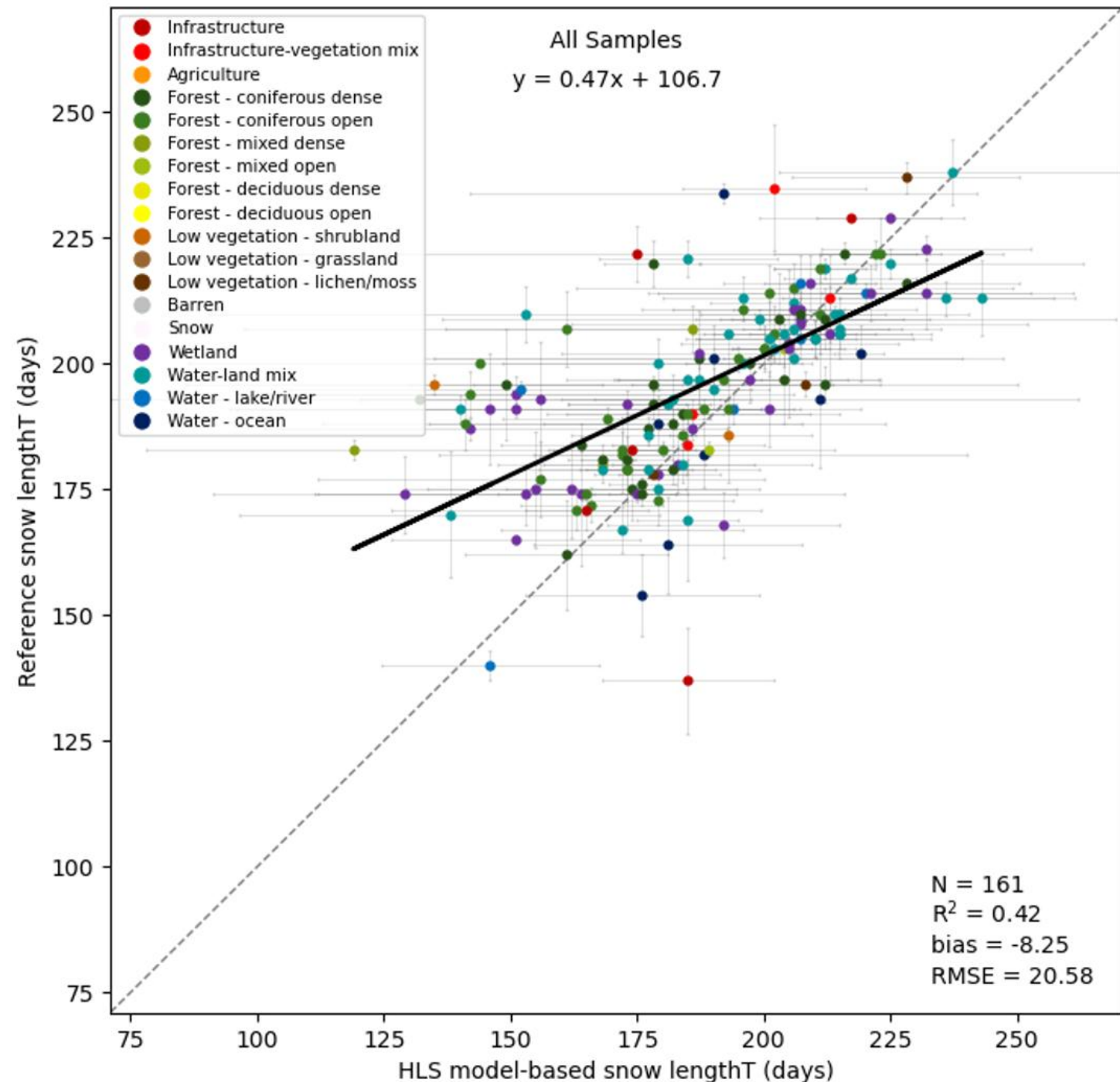
endB

- Strong performing metric
- Model underestimates snow end date in some forest samples due to difficulties observing remaining snow under canopy in spring



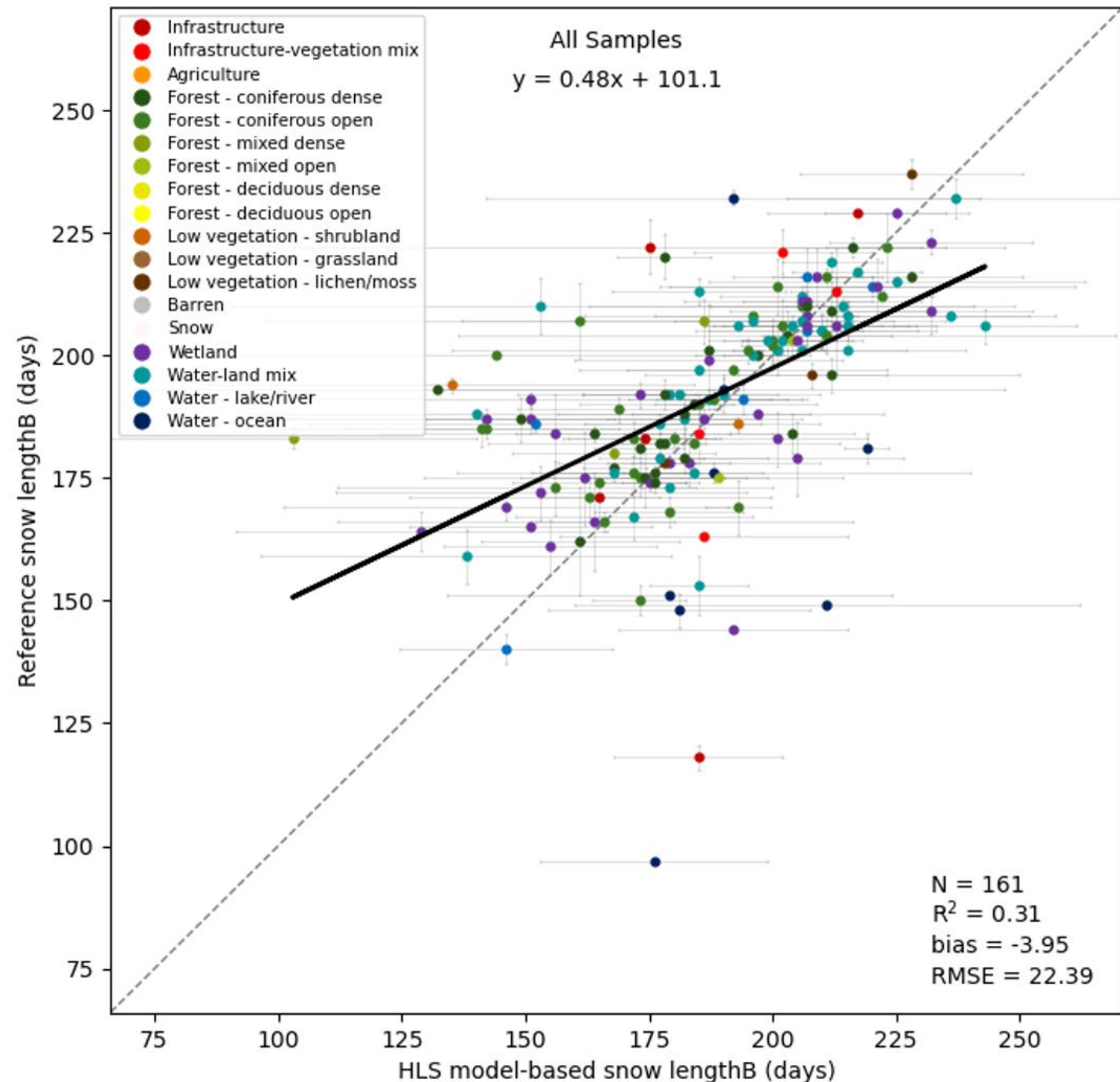
lengthT

- Higher uncertainty because it is a combination of start and end
 - Performance falls between start and end



lengthB

- Higher uncertainty because it is a combination of start and end
 - Performance falls between start and end



periods

	All Samples
One period (observed)	98.9% (n = 90)
Two+ periods (observed)	0.0% (n = 71)

For each observed category, what % of the time did the model agree?

- Almost every time a single snow period occurred in a winter, a single snow period was recorded by the model
- However, the model failed to record multiple snow periods every time one occurred
 - This is because these additional snow periods were generally short (<1-2 weeks) and did not persist long enough to accumulate multiple snow observations from HLS

status

	All Samples
Seasonal snow (observed)	99.4% (n = 161)
Perennial snow (observed)	No perennial samples
Inconsistent perennial snow (observed)	No inconsistent perennial samples
Snow free (observed)	No snow free samples
Ephemeral snow (observed)	No ephemeral snow samples

For each observed category, what % of the time did the model agree?

- Only seasonal snow has been observed (so far), and the model agrees in almost every case

By Ecozone

startF

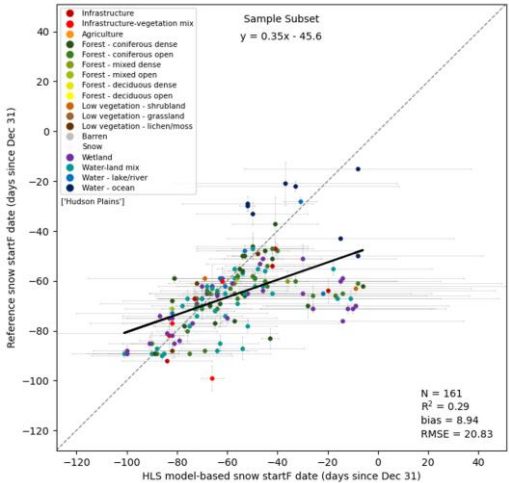
No Arctic
Cordillera
samples

No Atlantic
Maritime
samples

No Boreal
Cordillera
samples

No Boreal Plains
samples

No Boreal Shield
samples



No Mixedwood
Plains
samples

No Montane
Cordillera
samples

No Northern
Arctic samples

No Pacific
Maritime
samples

No Prairies
samples

No Southern
Arctic samples

No Taiga
Cordillera
samples

No Taiga Plains
samples

No Taiga Shield
samples

startB

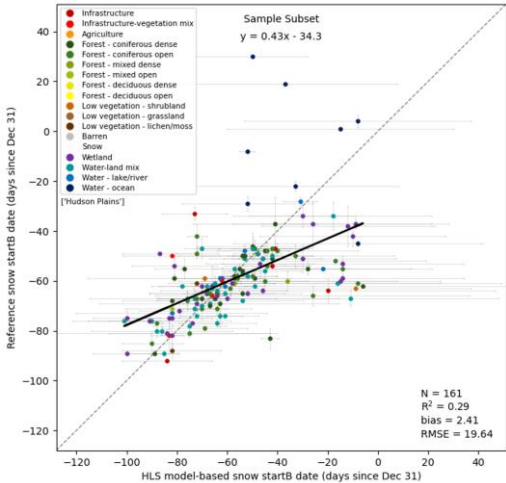
No Arctic
Cordillera
samples

No Atlantic
Maritime
samples

No Boreal
Cordillera
samples

No Boreal Plains
samples

No Boreal Shield
samples



No Mixedwood
Plains
samples

No Montane
Cordillera
samples

No Northern
Arctic samples

No Pacific
Maritime
samples

No Prairies
samples

No Southern
Arctic samples

No Taiga
Cordillera
samples

No Taiga Plains
samples

No Taiga Shield
samples

endl

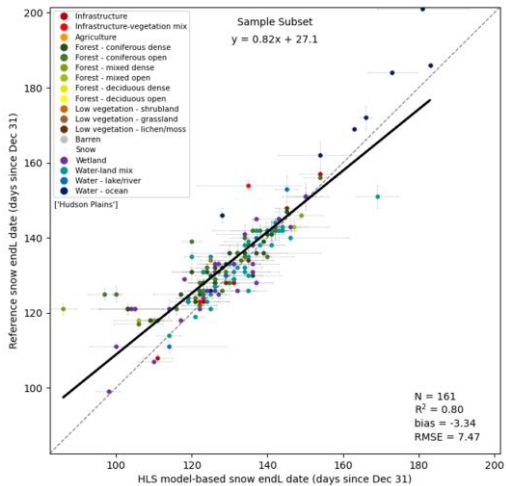
No Arctic
Cordillera
samples

No Atlantic
Maritime
samples

No Boreal
Cordillera
samples

No Boreal Plains
samples

No Boreal Shield
samples



No Mixedwood
Plains
samples

No Montane
Cordillera
samples

No Northern
Arctic samples

No Pacific
Maritime
samples

No Prairies
samples

No Southern
Arctic samples

No Taiga
Cordillera
samples

No Taiga Plains
samples

No Taiga Shield
samples

endB

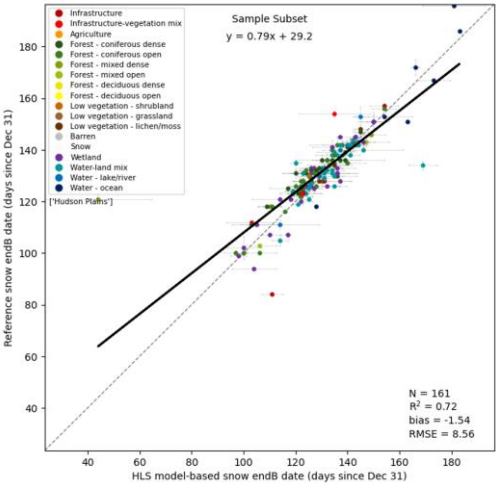
No Arctic
Cordillera
samples

No Atlantic
Maritime
samples

No Boreal
Cordillera
samples

No Boreal Plains
samples

No Boreal Shield
samples



No Mixedwood
Plains
samples

No Montane
Cordillera
samples

No Northern
Arctic samples

No Pacific
Maritime
samples

No Prairies
samples

No Southern
Arctic samples

No Taiga
Cordillera
samples

No Taiga Plains
samples

No Taiga Shield
samples

lengthT

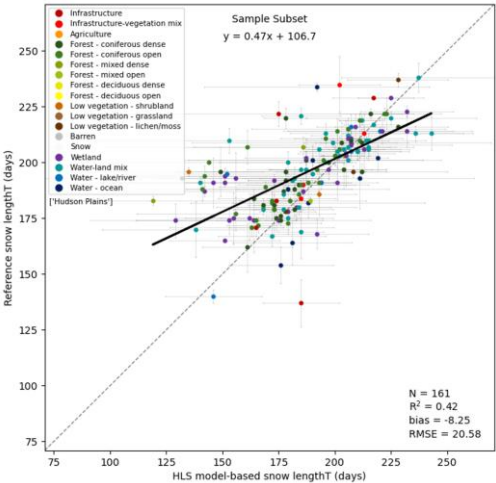
No Arctic
Cordillera
samples

No Atlantic
Maritime
samples

No Boreal
Cordillera
samples

No Boreal Plains
samples

No Boreal Shield
samples



No Mixedwood
Plains
samples

No Montane
Cordillera
samples

No Northern
Arctic samples

No Pacific
Maritime
samples

No Prairies
samples

No Southern
Arctic samples

No Taiga
Cordillera
samples

No Taiga Plains
samples

No Taiga Shield
samples

lengthB

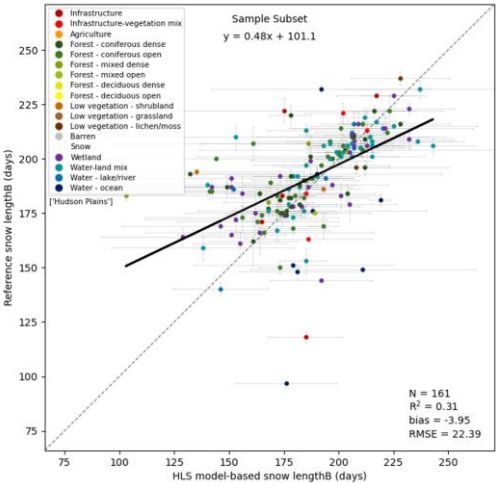
No Arctic
Cordillera
samples

No Atlantic
Maritime
samples

No Boreal
Cordillera
samples

No Boreal Plains
samples

No Boreal Shield
samples



No Mixedwood
Plains
samples

No Montane
Cordillera
samples

No Northern
Arctic samples

No Pacific
Maritime
samples

No Prairies
samples

No Southern
Arctic samples

No Taiga
Cordillera
samples

No Taiga Plains
samples

No Taiga Shield
samples

periods

	Arctic Cordillera	Atlantic Maritime	Boreal Cordillera	Boreal Plains	Boreal Shield	Hudson Plains	Mixedwood Plains	Montane Cordillera	Northern Arctic	Pacific Maritime	Prairies	Southern Arctic	Taiga Cordillera	Taiga Plains	Taiga Shield
One period (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	98.9% (n = 90)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0
Two+ periods (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	0.0% (n = 71)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0

For each observed category, what % of the time did the model agree?

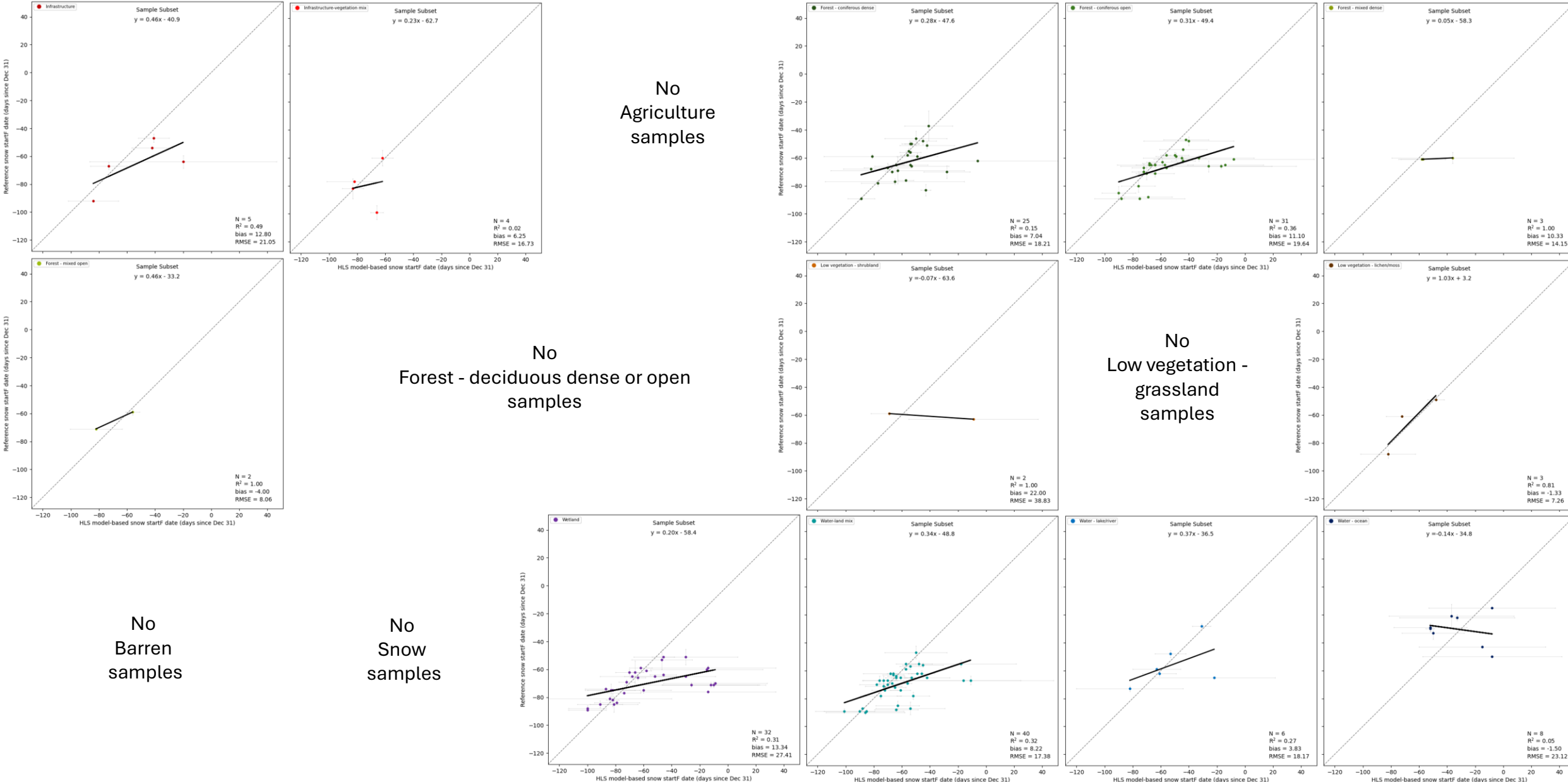
status

	Arctic Cordillera	Atlantic Maritime	Boreal Cordillera	Boreal Plains	Boreal Shield	Hudson Plains	Mixedwood Plains	Montane Cordillera	Northern Arctic	Pacific Maritime	Prairies	Southern Arctic	Taiga Cordillera	Taiga Plains	Taiga Shield
Seasonal snow (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	99.4% (n = 161)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0
Perennial snow (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0
Inconsistent perennial snow (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0
Snow free (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0

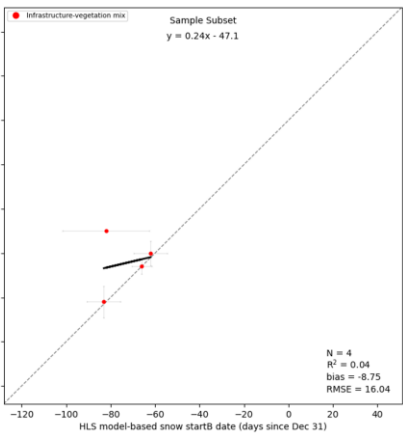
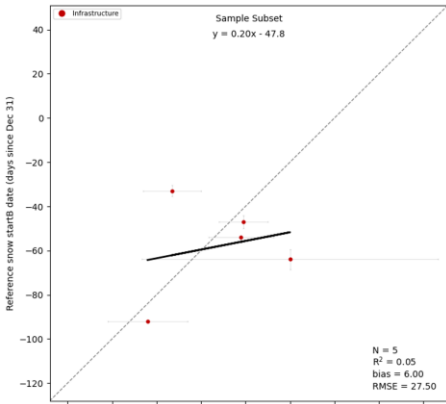
For each observed category, what % of the time did the model agree?

By Class

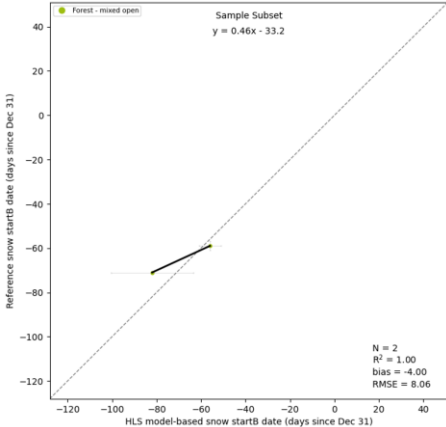
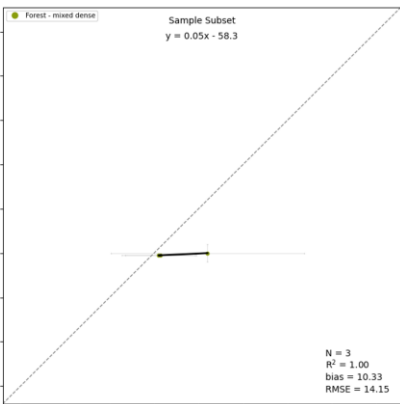
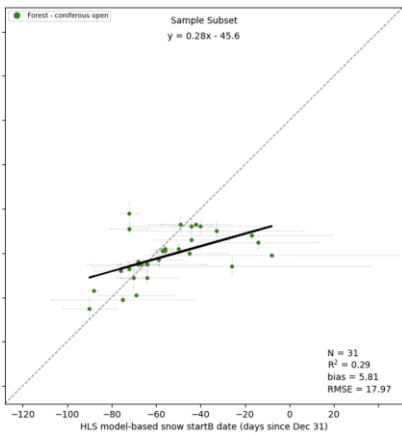
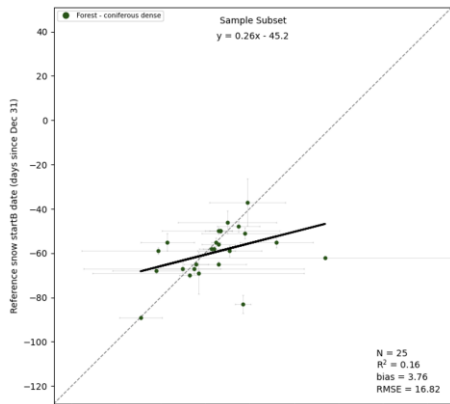
startF



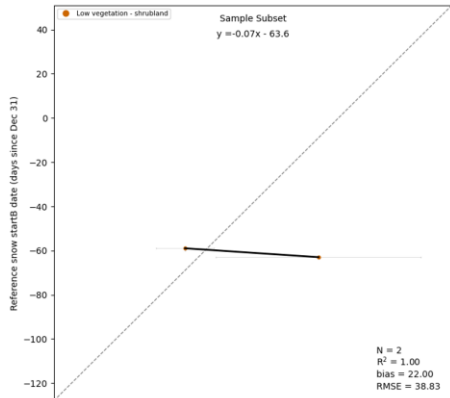
startB



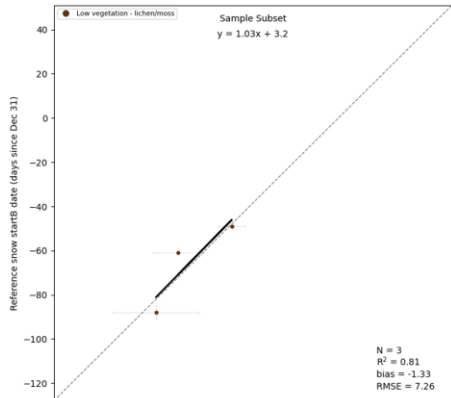
No
Agriculture
samples



No
Forest - deciduous dense or open
samples

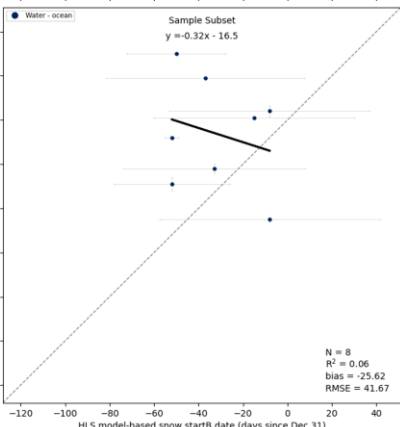
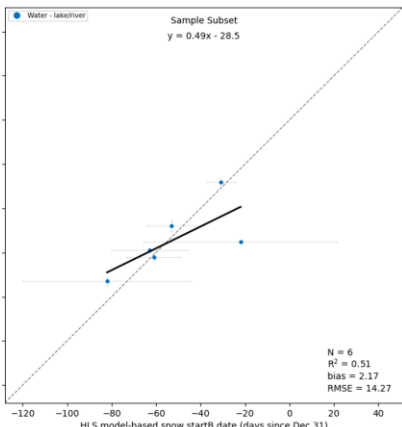
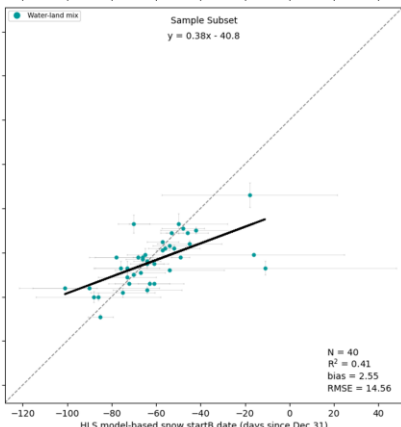
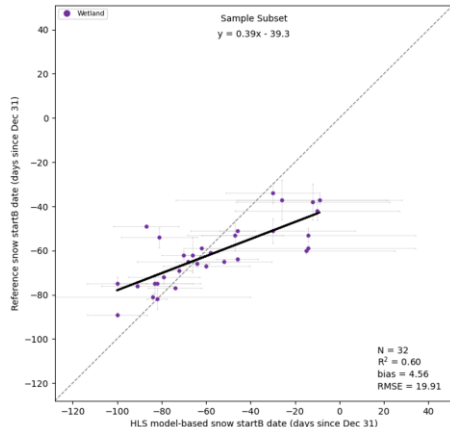


No
Low vegetation -
grassland
samples

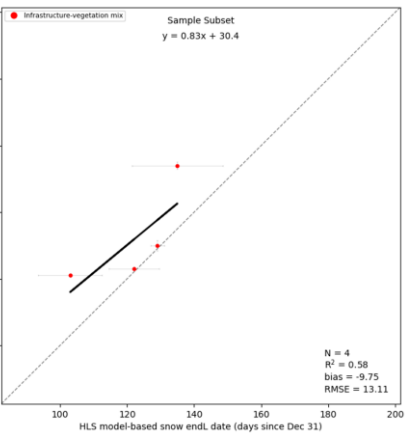
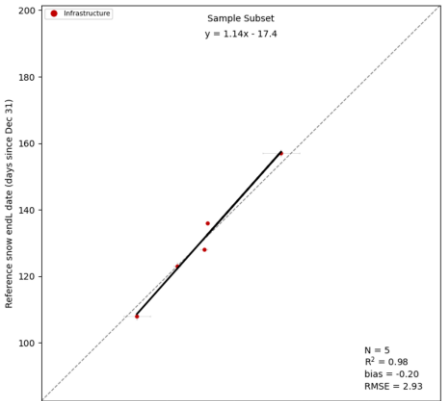


No
Barren
samples

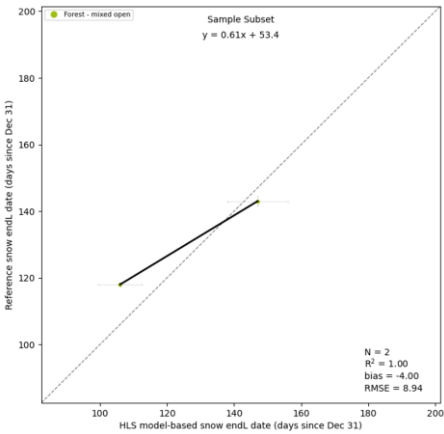
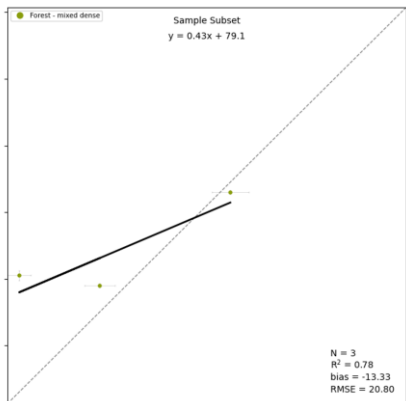
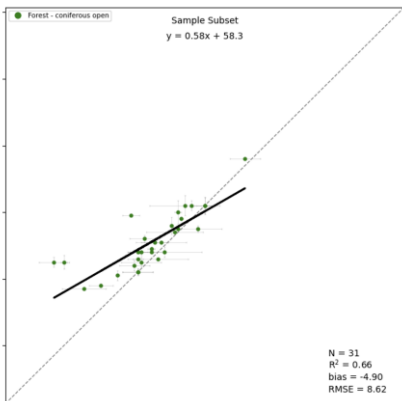
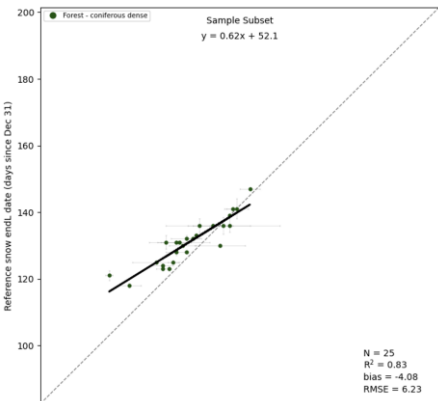
No
Snow
samples



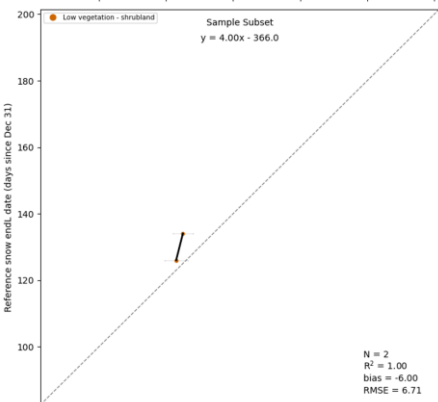
endL



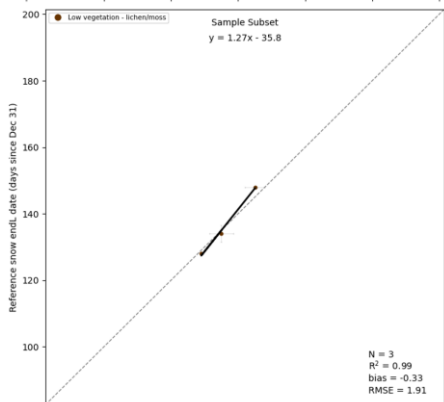
No
Agriculture
samples



No
Forest - deciduous dense or open
samples

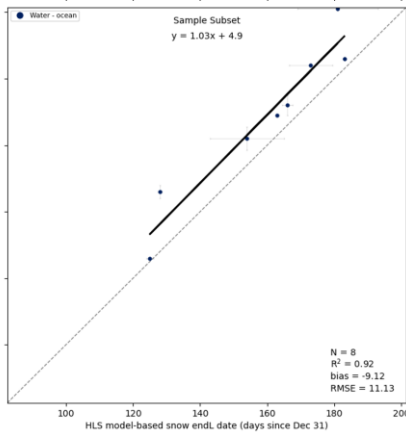
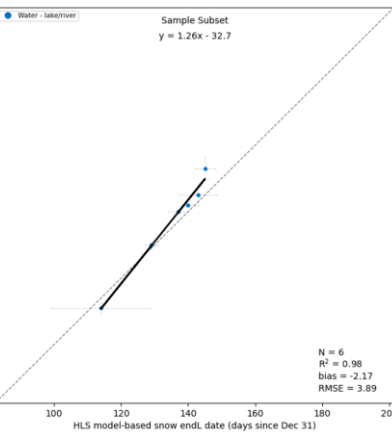
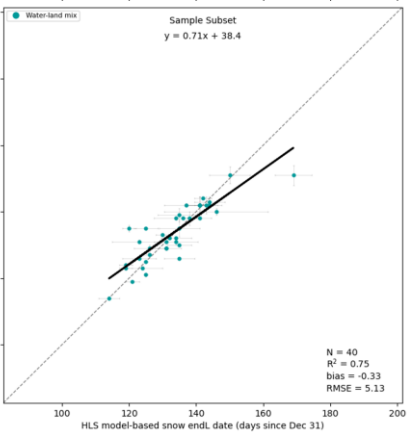
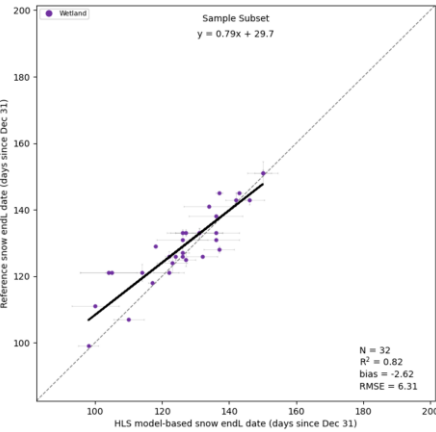


No
Low vegetation -
grassland
samples

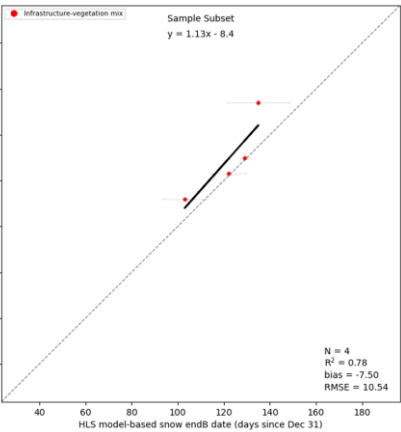
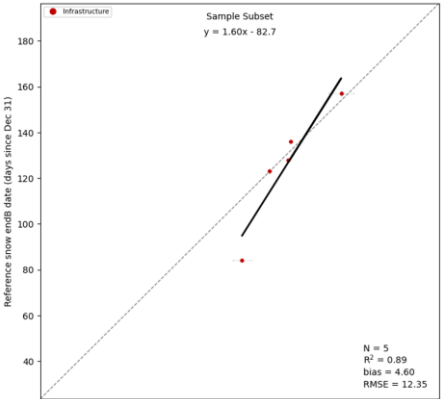


No
Barren
samples

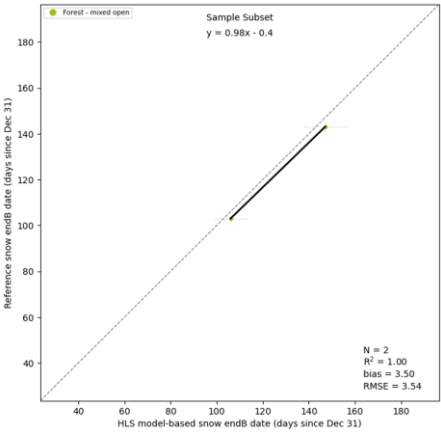
No
Snow
samples



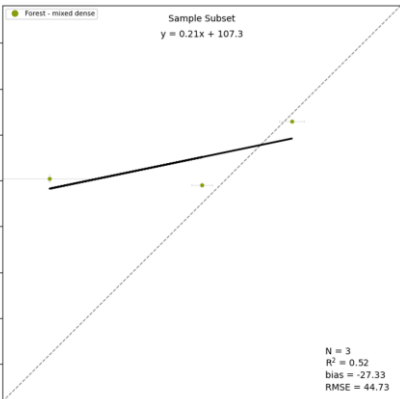
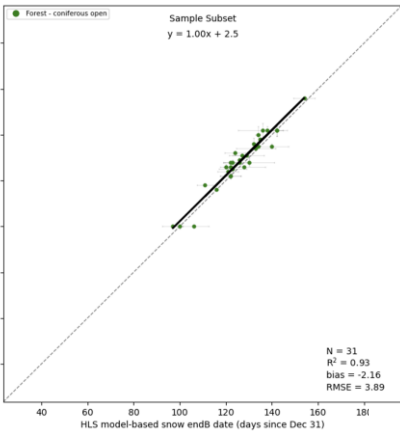
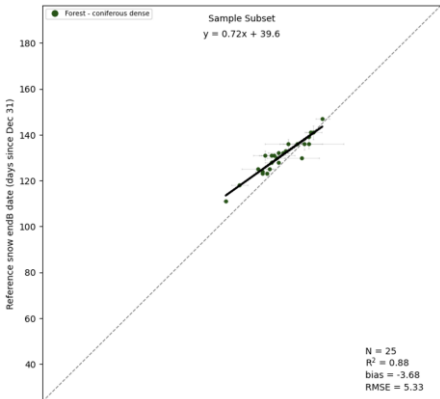
endB



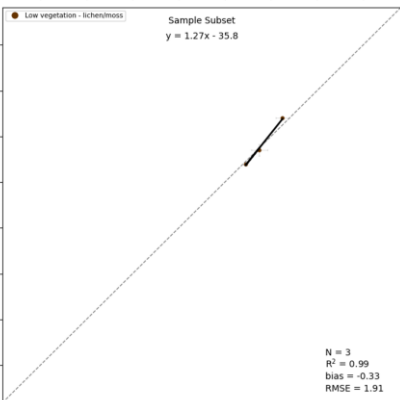
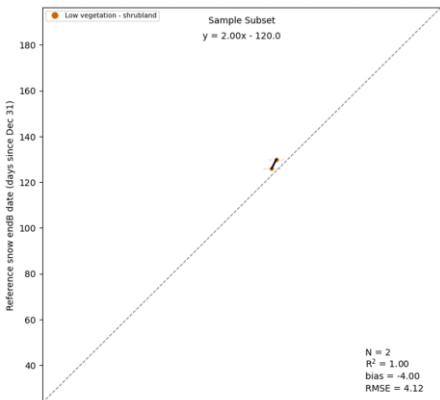
No
Agriculture
samples



No
Forest - deciduous dense or open
samples

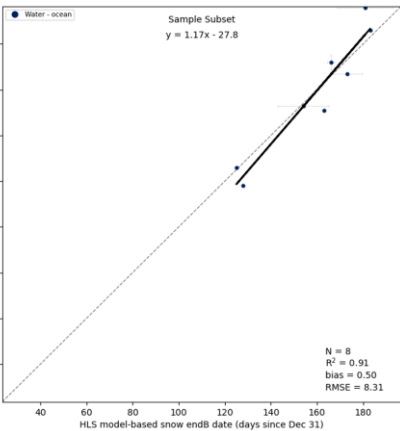
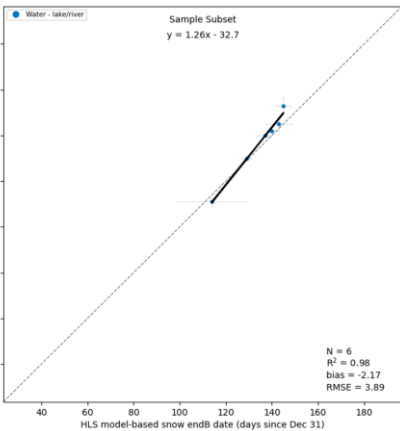
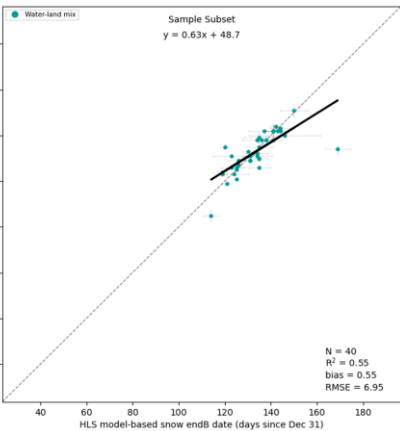
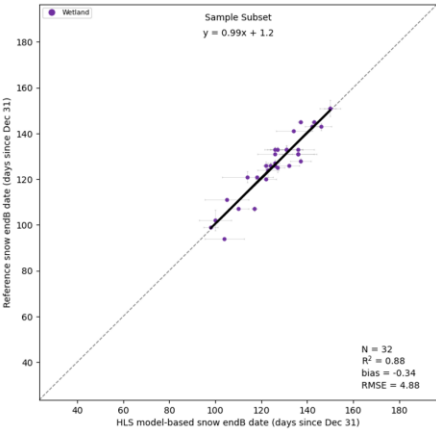


No
Low vegetation -
grassland
samples

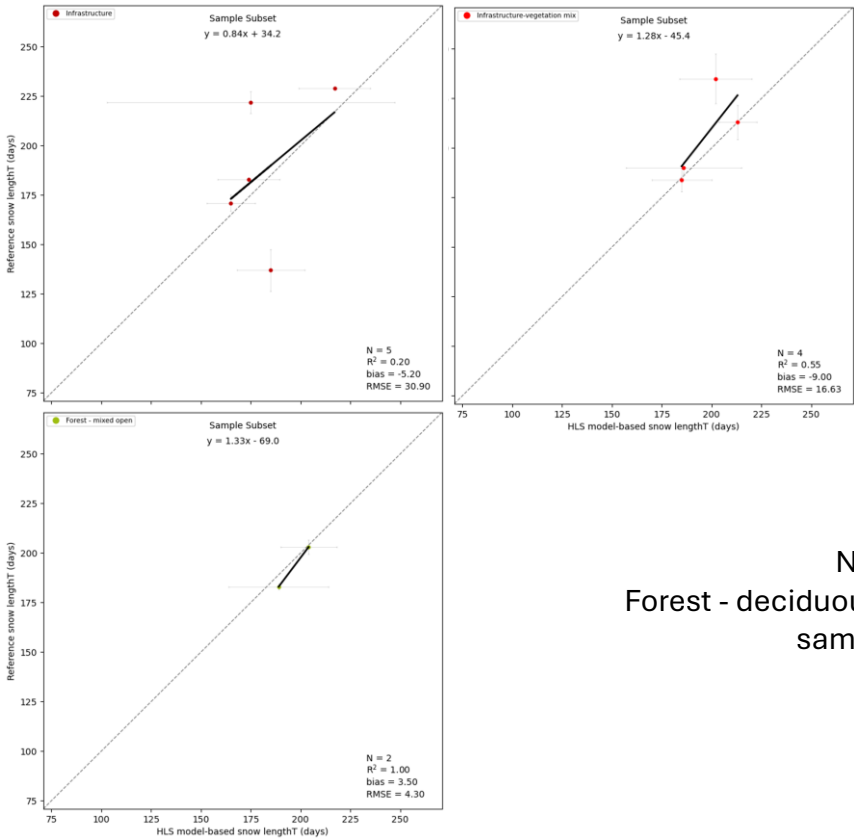


No
Barren
samples

No
Snow
samples



lengthT

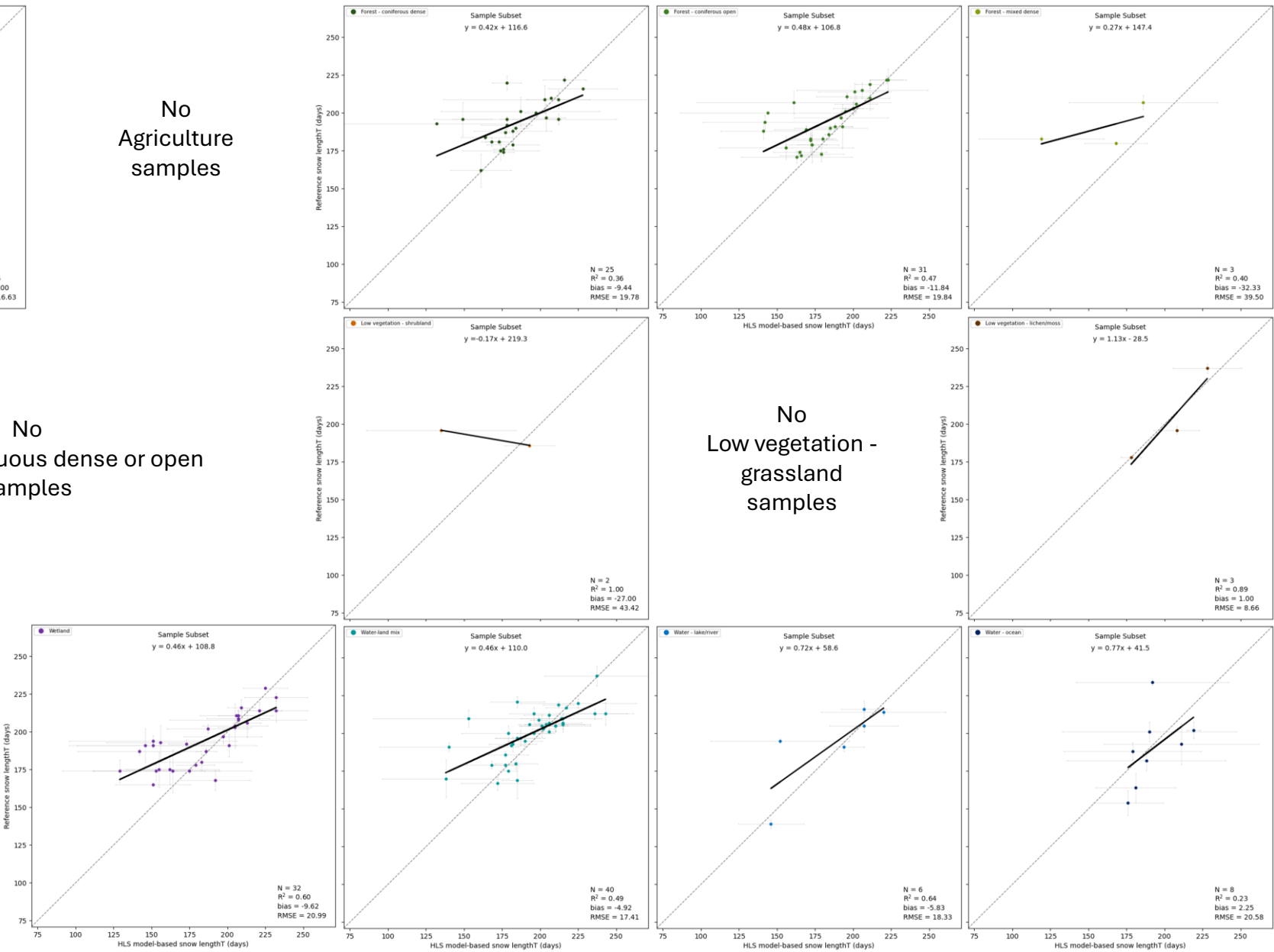


No
Agriculture
samples

No
Forest - deciduous dense or open
samples

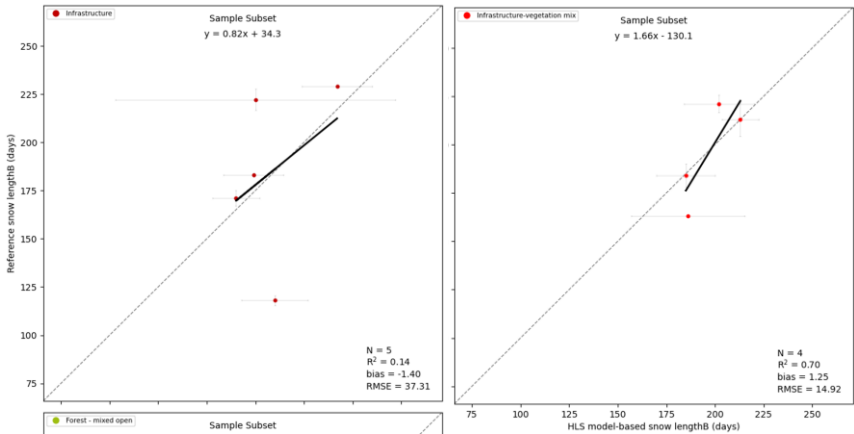
No
Barren
samples

No
Snow
samples

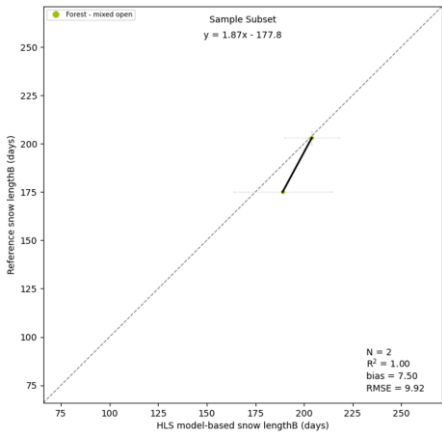


No
Low vegetation -
grassland
samples

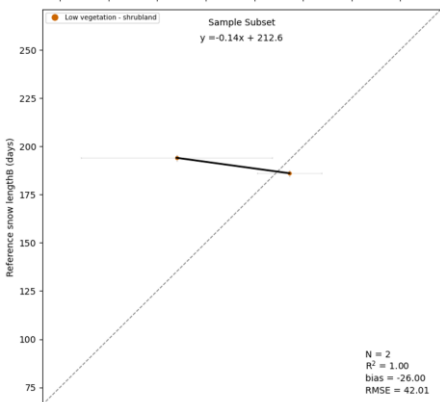
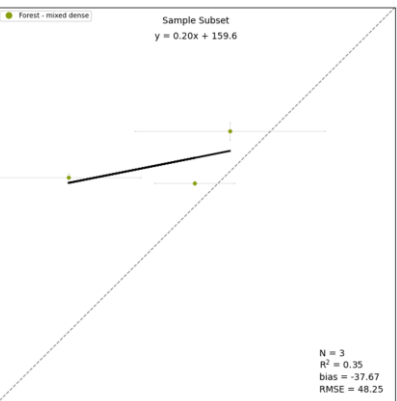
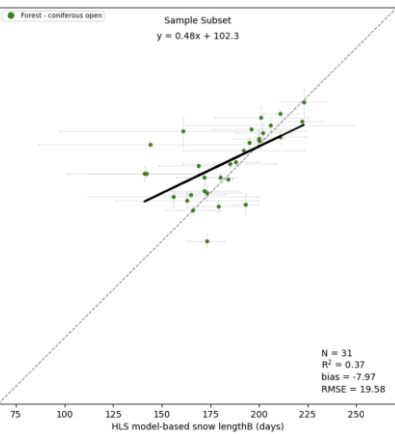
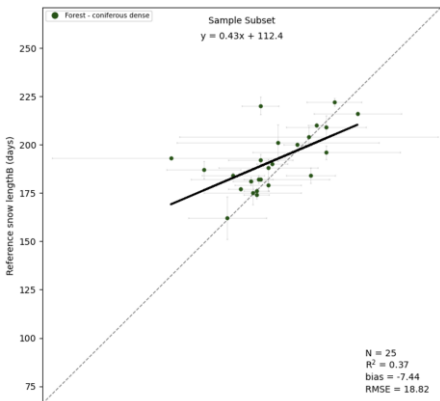
lengthB



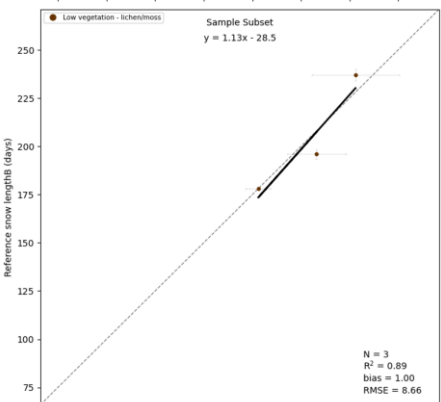
No
Agriculture
samples



No
Forest - deciduous dense or open
samples

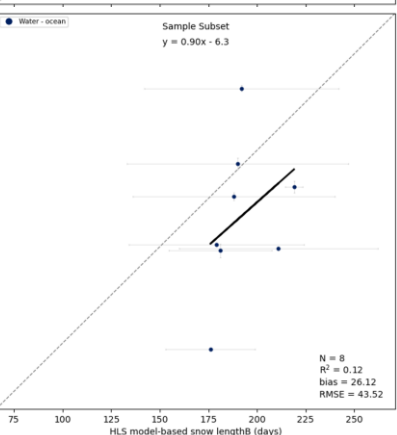
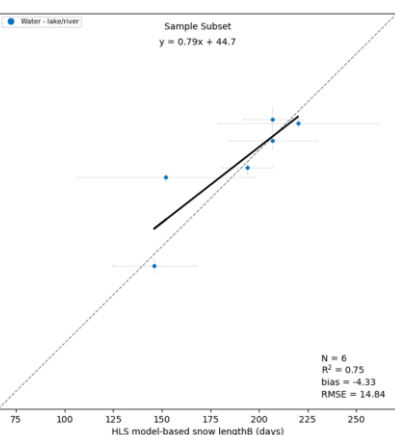
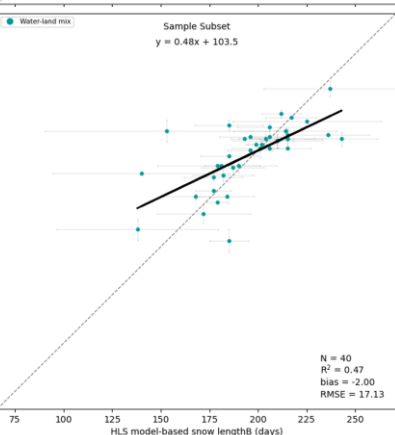
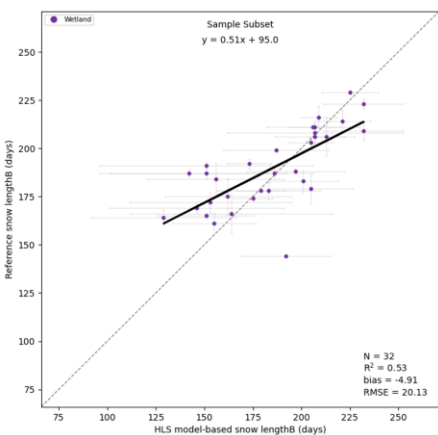


No
Low vegetation -
grassland
samples



No
Barren
samples

No
Snow
samples



periods

	Infrastructure	Infrastructure-vegetation mix	Agriculture	Forest - coniferous dense	Forest - coniferous open	Forest - mixed dense	Forest - mixed open	Forest - deciduous dense	Forest - deciduous open
One period (observed)	100% (n = 4)	100% (n = 2)	n = 0	100% (n = 19)	100% (n = 15)	66.7% (n = 3)	100% (n = 1)	n = 0	n = 0
Two+ periods (observed)	0% (n = 1)	0% (n = 2)	n = 0	0% (n = 6)	0% (n = 16)	n = 0	0% (n = 1)	n = 0	n = 0

	Low vegetation - shrubland	Low vegetation - grassland	Low vegetation - lichen/moss	Barren	Snow	Wetland	Water-land mix	Water - lake/river	Water - ocean
One period (observed)	100% (n = 1)	n = 0	100% (n = 3)	n = 0	n = 0	100% (n = 17)	100% (n = 20)	100% (n = 5)	n = 0
Two+ periods (observed)	0% (n = 1)	n = 0	n = 0	n = 0	n = 0	0% (n = 15)	0% (n = 20)	0% (n = 1)	0% (n = 8)

For each observed category, what % of the time did the model agree?

status

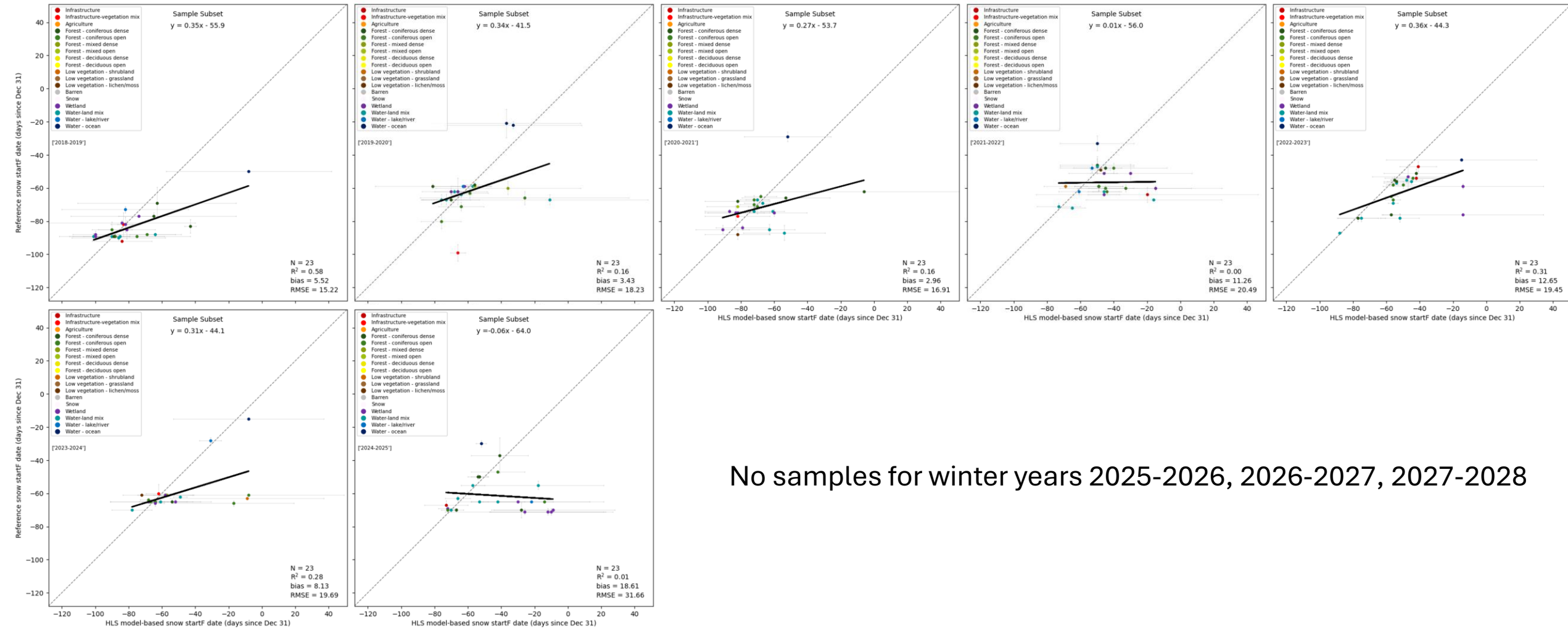
	Infrastructure	Infrastructure-vegetation mix	Agriculture	Forest - coniferous dense	Forest - coniferous open	Forest - mixed dense	Forest - mixed open	Forest - deciduous dense	Forest - deciduous open
Seasonal snow (observed)	100% (n = 5)	100% (n = 4)	n = 0	100% (n = 25)	100% (n = 31)	100% (n = 3)	100% (n = 2)	n = 0	n = 0
Perennial snow (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0
Inconsistent perennial snow (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0
Snow free (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0

	Low vegetation - shrubland	Low vegetation - grassland	Low vegetation - lichen/moss	Barren	Snow	Wetland	Water-land mix	Water - lake/river	Water - ocean
Seasonal snow (observed)	100% (n = 2)	n = 0	100% (n = 3)	n = 0	n = 0	96.9% (n = 32)	100% (n = 40)	100% (n = 6)	100% (n = 8)
Perennial snow (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0
Inconsistent perennial snow (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0
Snow free (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0

For each observed category, what % of the time did the model agree?

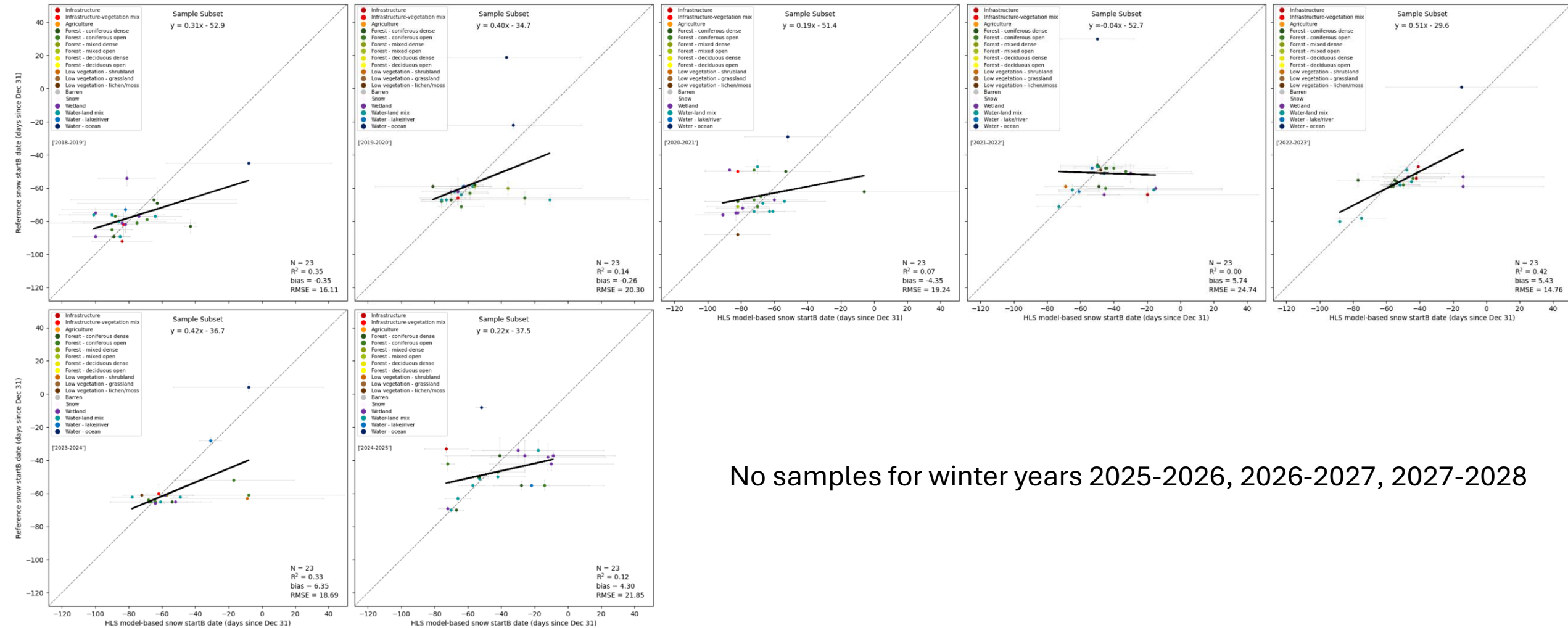
By Winter Year

startF

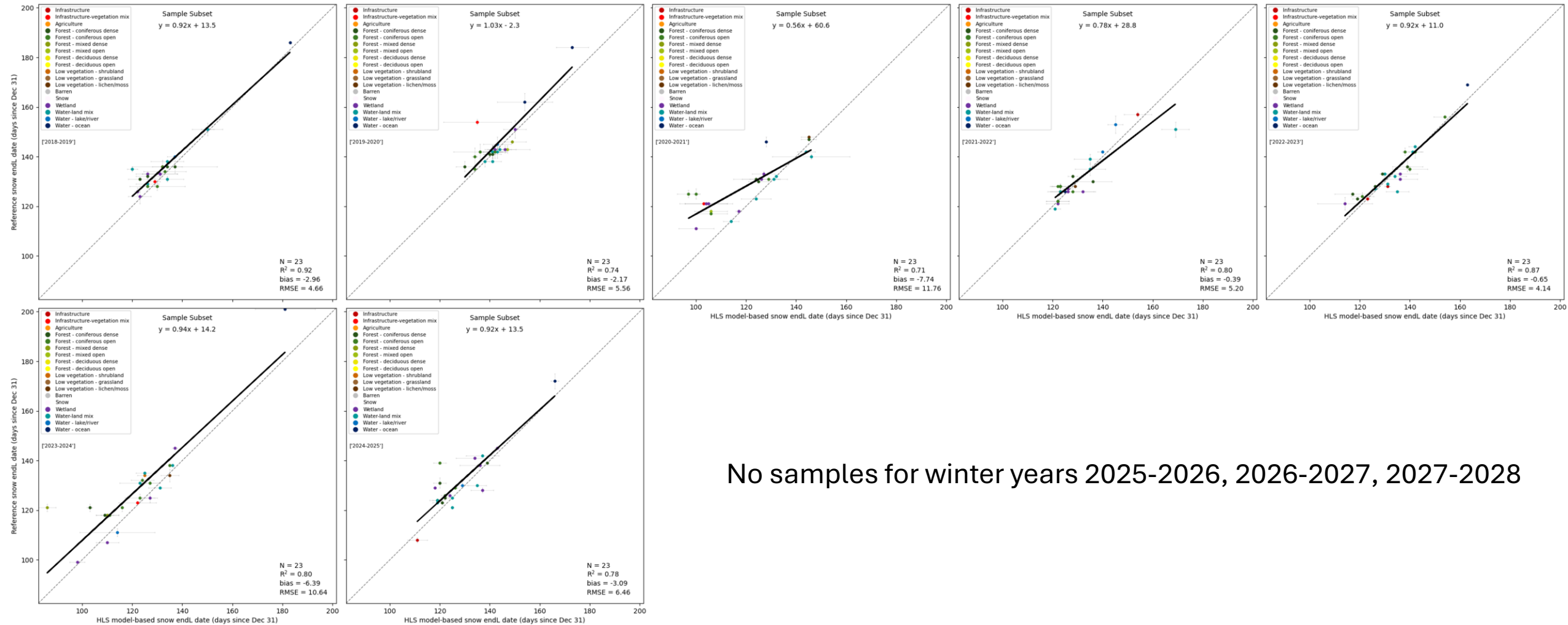


No samples for winter years 2025-2026, 2026-2027, 2027-2028

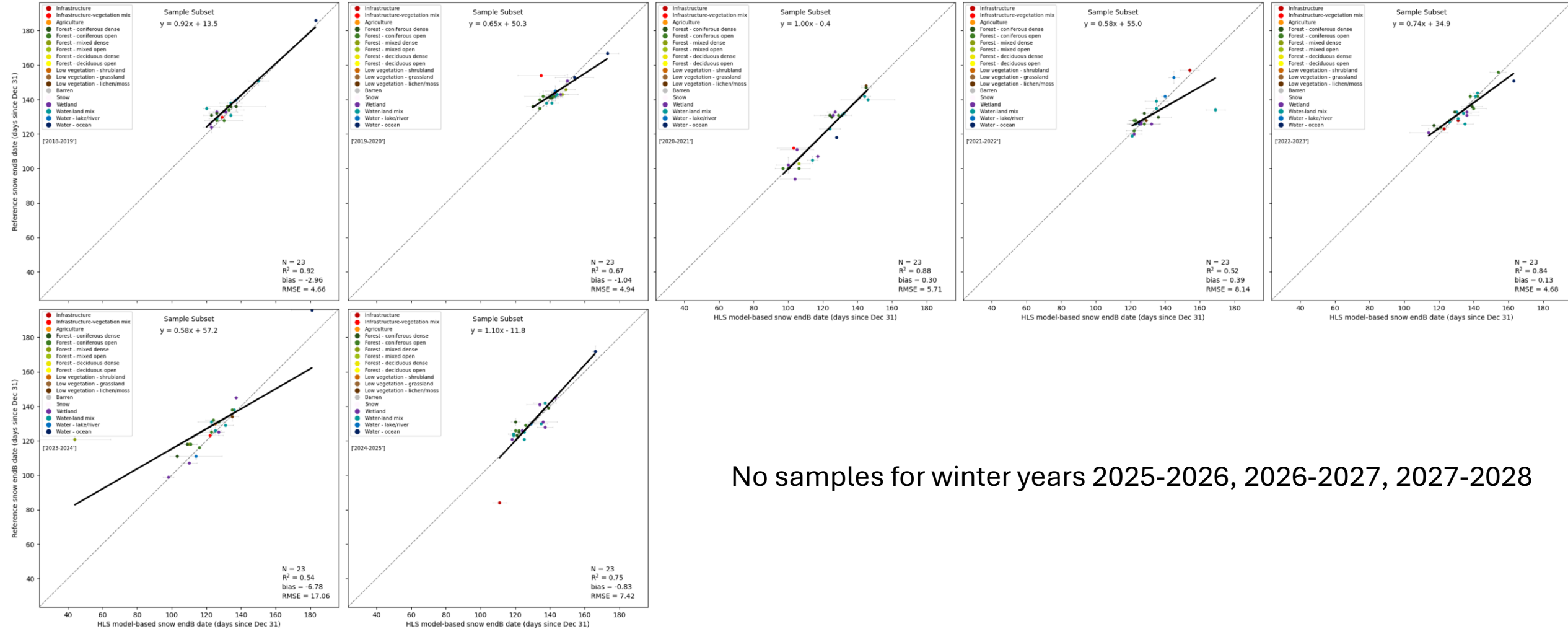
startB



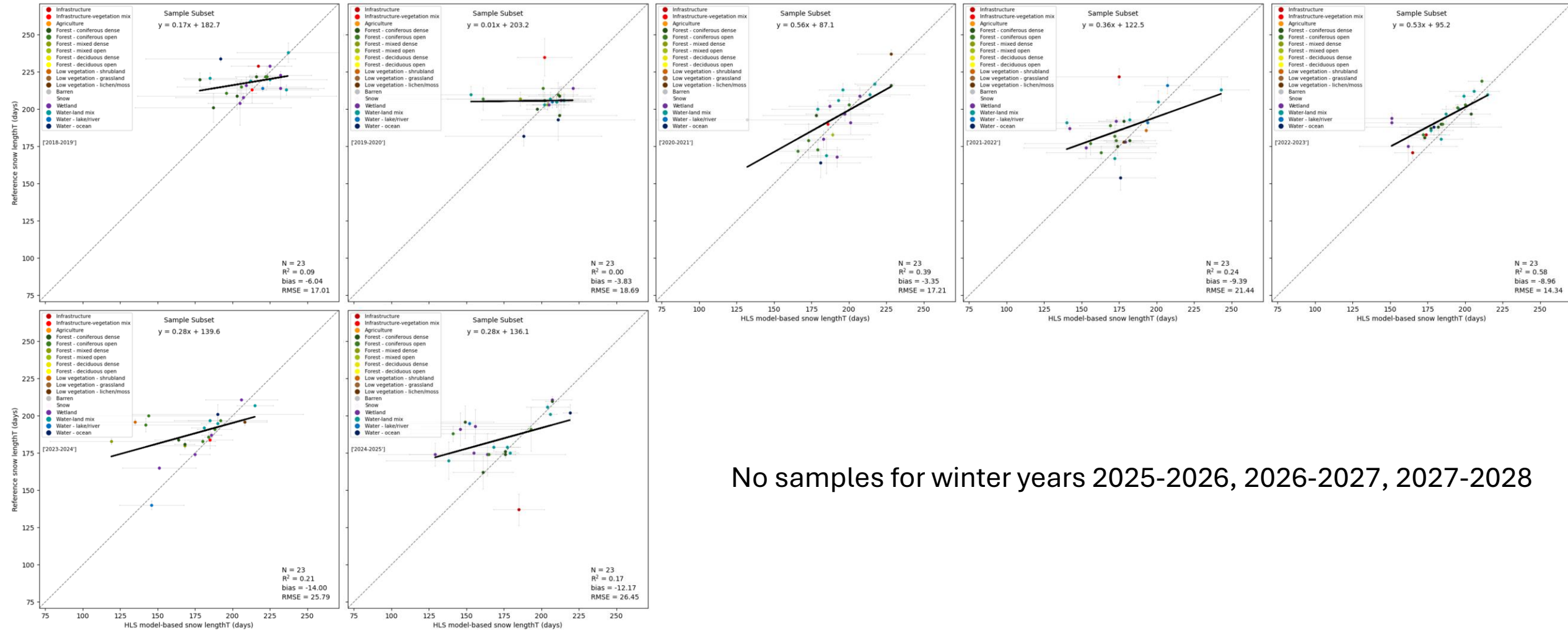
endL



endB

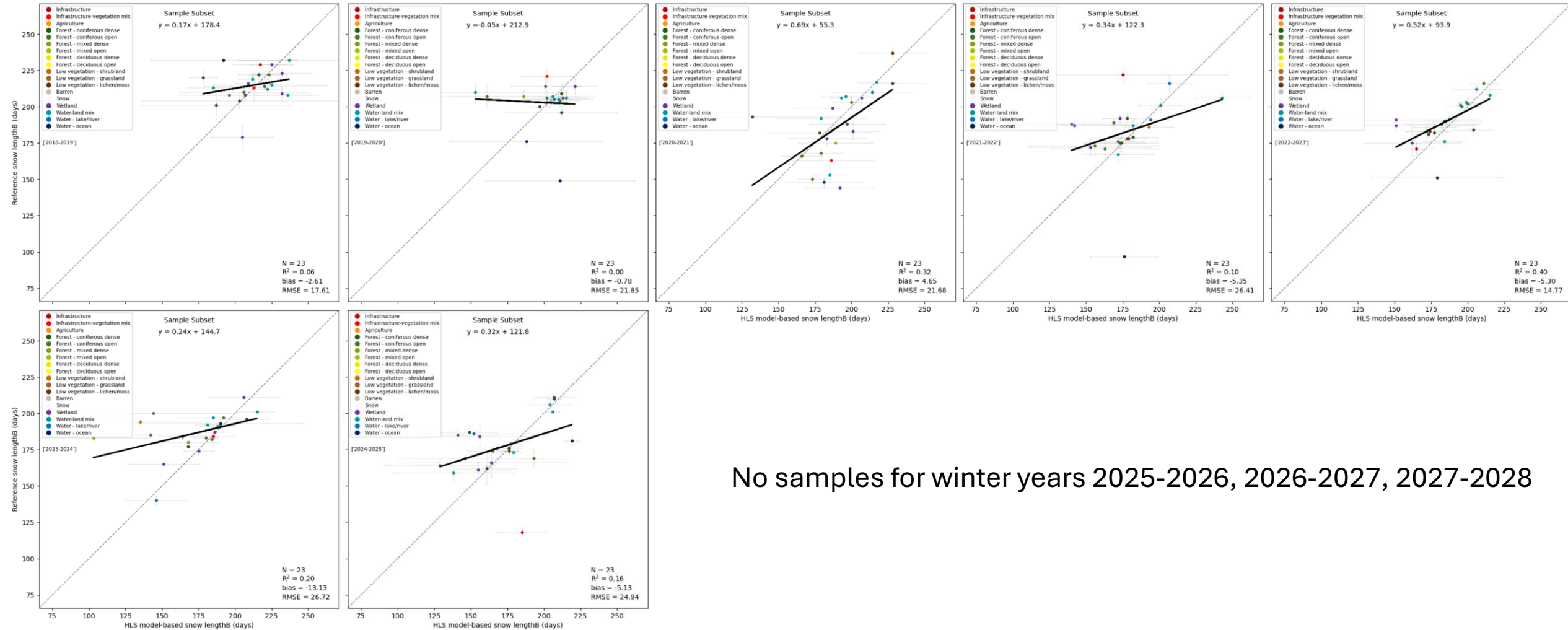


lengthT



No samples for winter years 2025-2026, 2026-2027, 2027-2028

lengthB



No samples for winter years 2025-2026, 2026-2027, 2027-2028

periods

	2018-2019	2019-2020	2020-2021	2021-2022	2022-2023	2023-2024	2024-2025	2025-2026	2026-2027	2027-2028
One period (observed)	100% (n = 12)	100% (n = 19)	100% (n = 7)	100% (n = 14)	100% (n = 13)	93.8% (n = 16)	100% (n = 9)	n = 0	n = 0	n = 0
Two+ periods (observed)	0% (n = 11)	0% (n = 4)	0% (n = 16)	0% (n = 9)	0% (n = 10)	0% (n = 7)	0% (n = 14)	n = 0	n = 0	n = 0

For each observed category, what % of the time did the model agree?

status

	2018-2019	2019-2020	2020-2021	2021-2022	2022-2023	2023-2024	2024-2025	2025-2026	2026-2027	2027-2028
Seasonal snow (observed)	95.7% (n = 23)	100% (n = 23)	100% (n = 23)	100% (n = 23)	100% (n = 23)	100% (n = 23)	100% (n = 23)	n = 0	n = 0	n = 0
Perennial snow (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0
Inconsistent perennial snow (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0
Snow free (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0

For each observed category, what % of the time did the model agree?

Other validation options

- Daily snow-depth from weather stations
 - Four stations in Hudson Plains analyzed
- Trail cameras: TBD (not many for Canada)
- Coincident very high-resolution validation: TBD