HLS Snow Dynamics Validation

Mitchell T. Bonney

Created: July 8, 2026

Last updated: August 6, 2026

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]

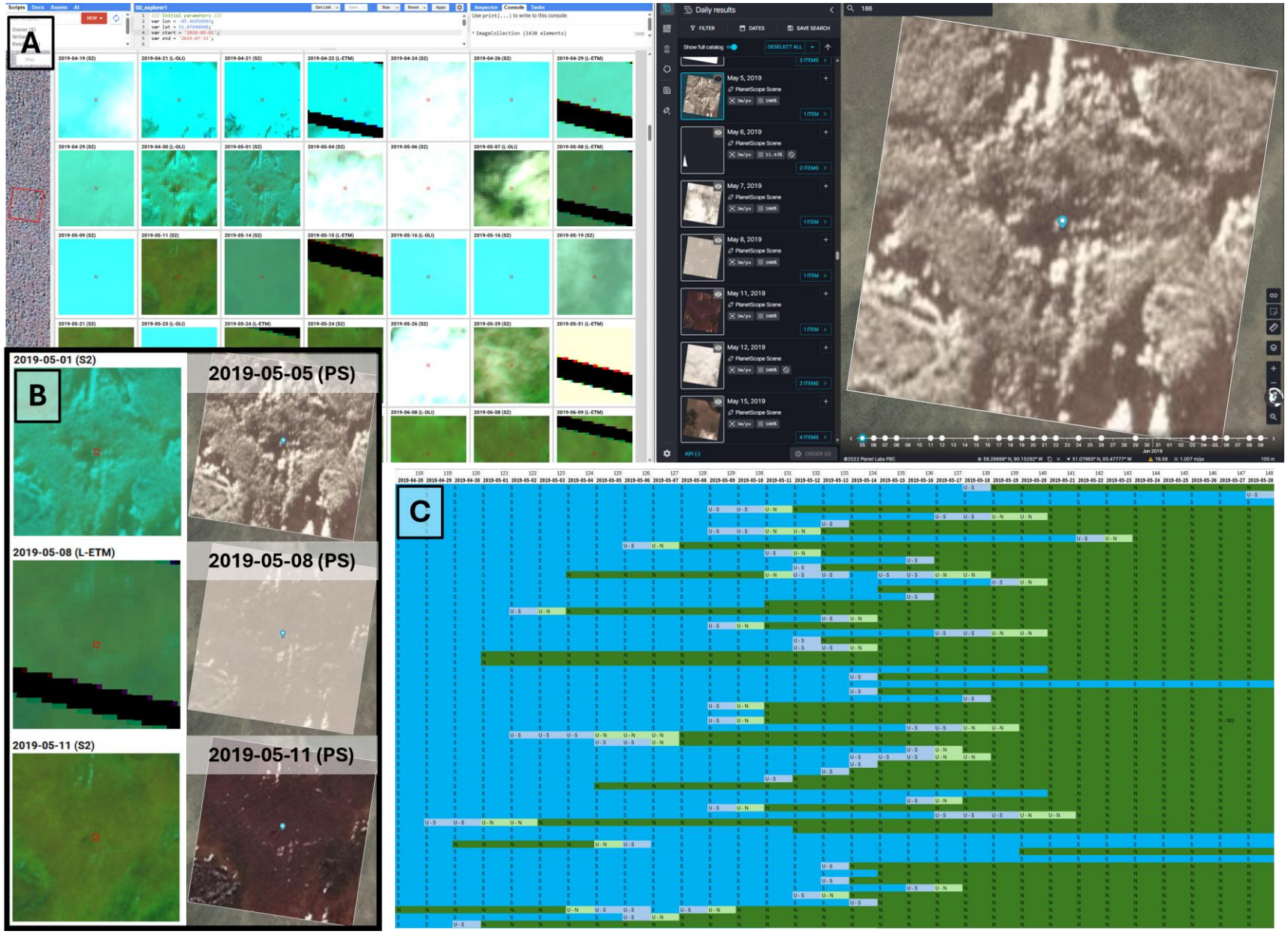
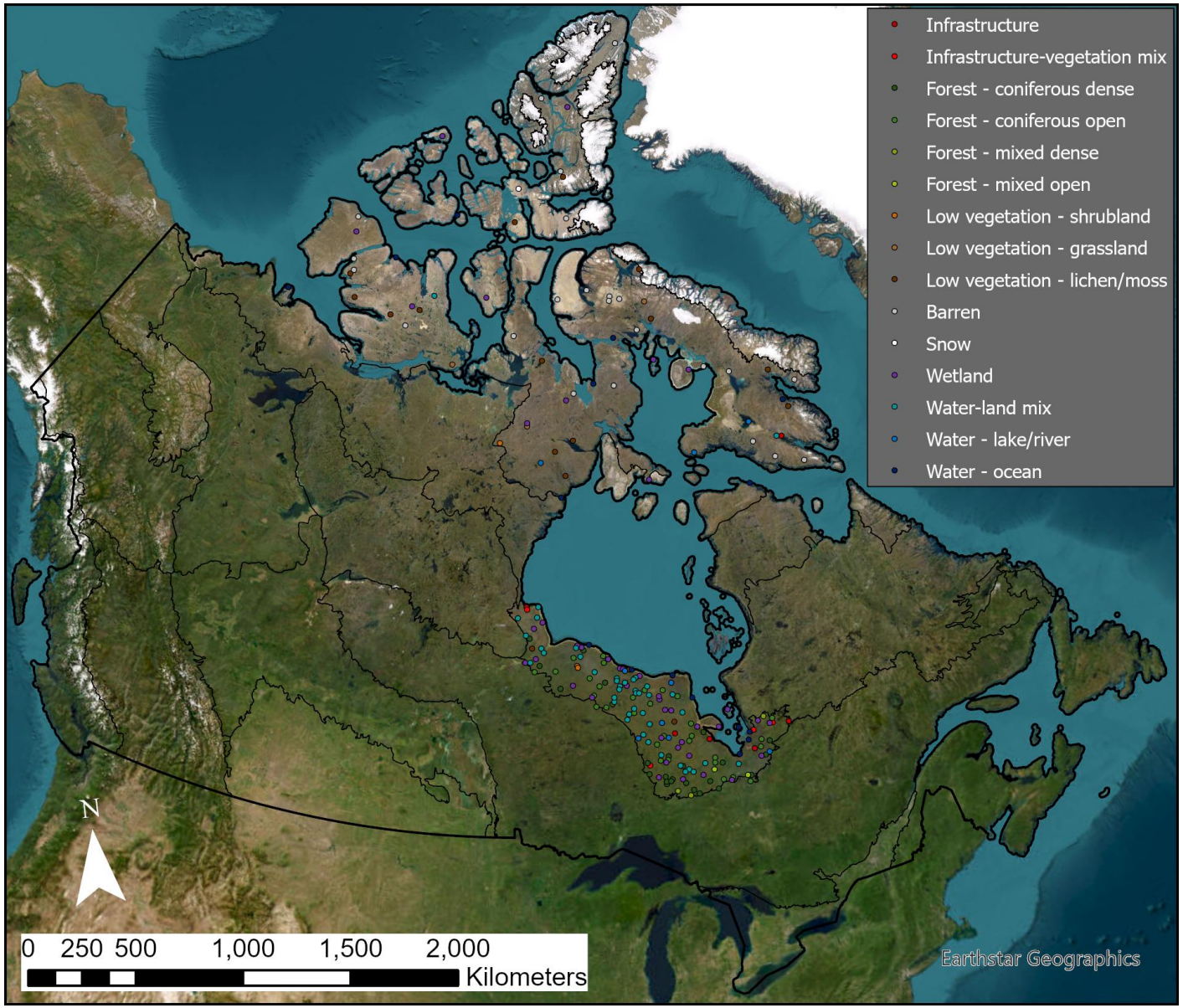


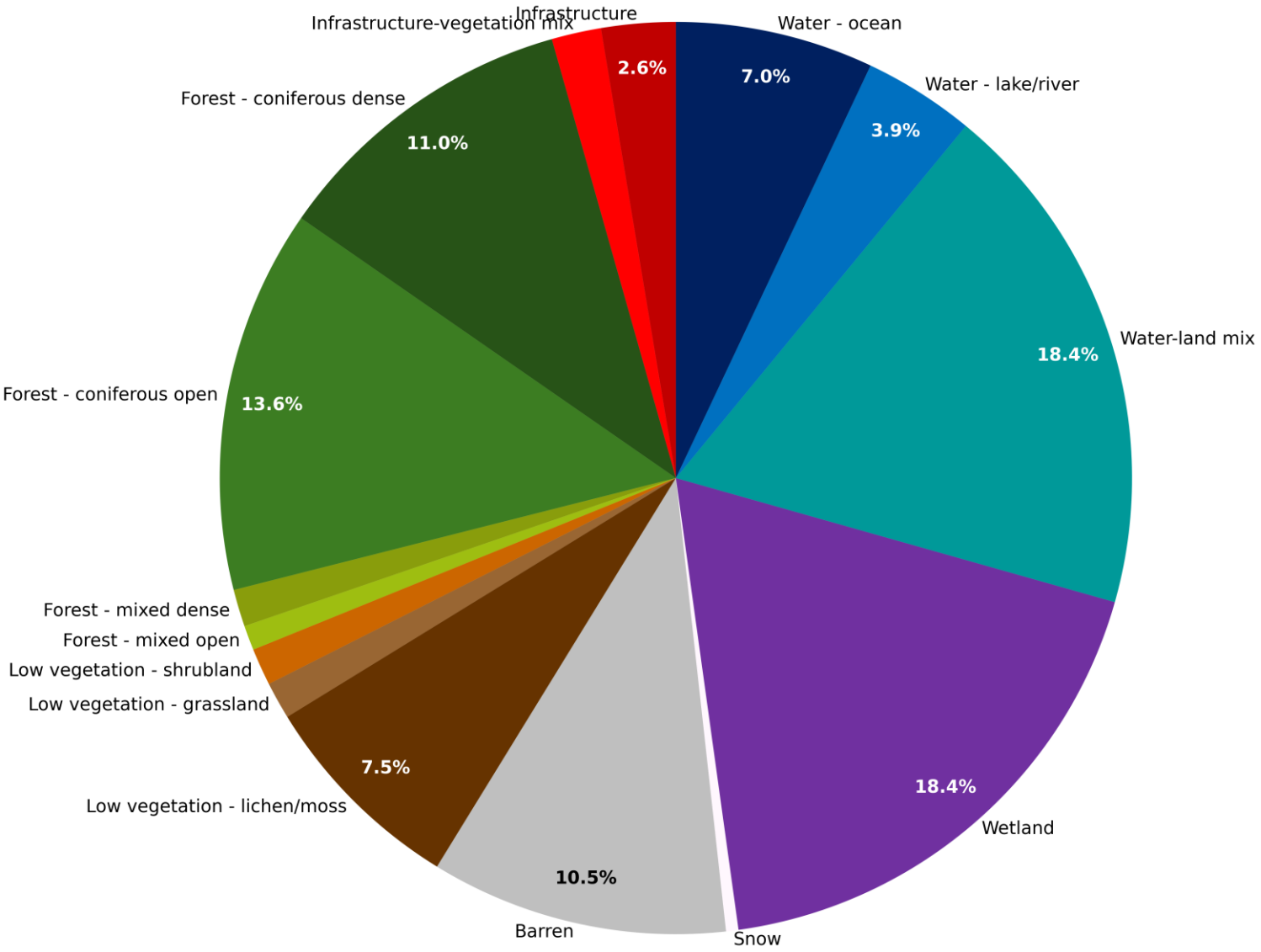
Fig. A17. Example of high-resolution imagery time-series interpretation procedure. (A) Interpretation workflow for the 2019 snow melt period over a grassy lowland sample pixel, with Sentinel-2 and Landsat 7-9 Google Earth Engine script on the left and Planet Insights Platform on the right. (B) Six high-leverage 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.

National Validation

- Interpretation of high-res imagery time-series: **228/5000 (4.6%)**
  - 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: 67/677
  - Pacific Maritime: 0/168
  - Prairies: 0/274
  - Southern Arctic: 0/456
  - Taiga Cordillera: 0/184
  - Taiga Plains: 0/325
  - Taiga Shield: 0/644

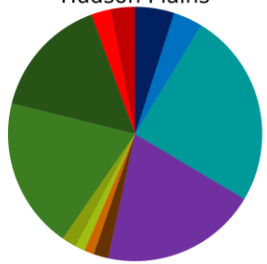


Overall class distribution

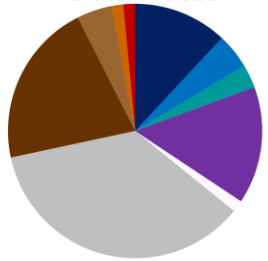


Arctic Cordillera | Atlantic Maritime | Boreal Cordillera

Boreal Plains | Boreal Shield | Hudson Plains



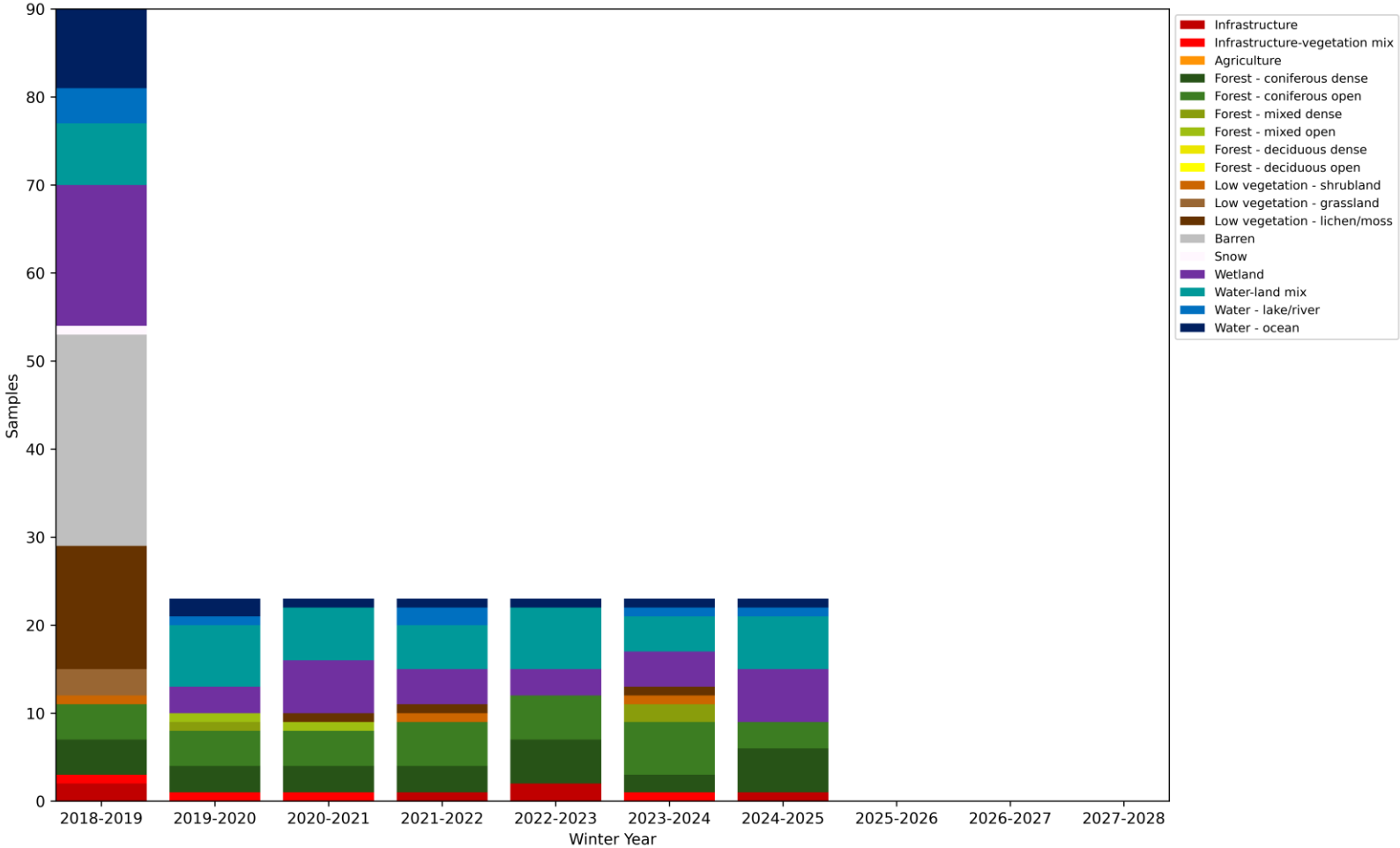
Mixedwood Plains | Montane Cordillera | Northern Arctic

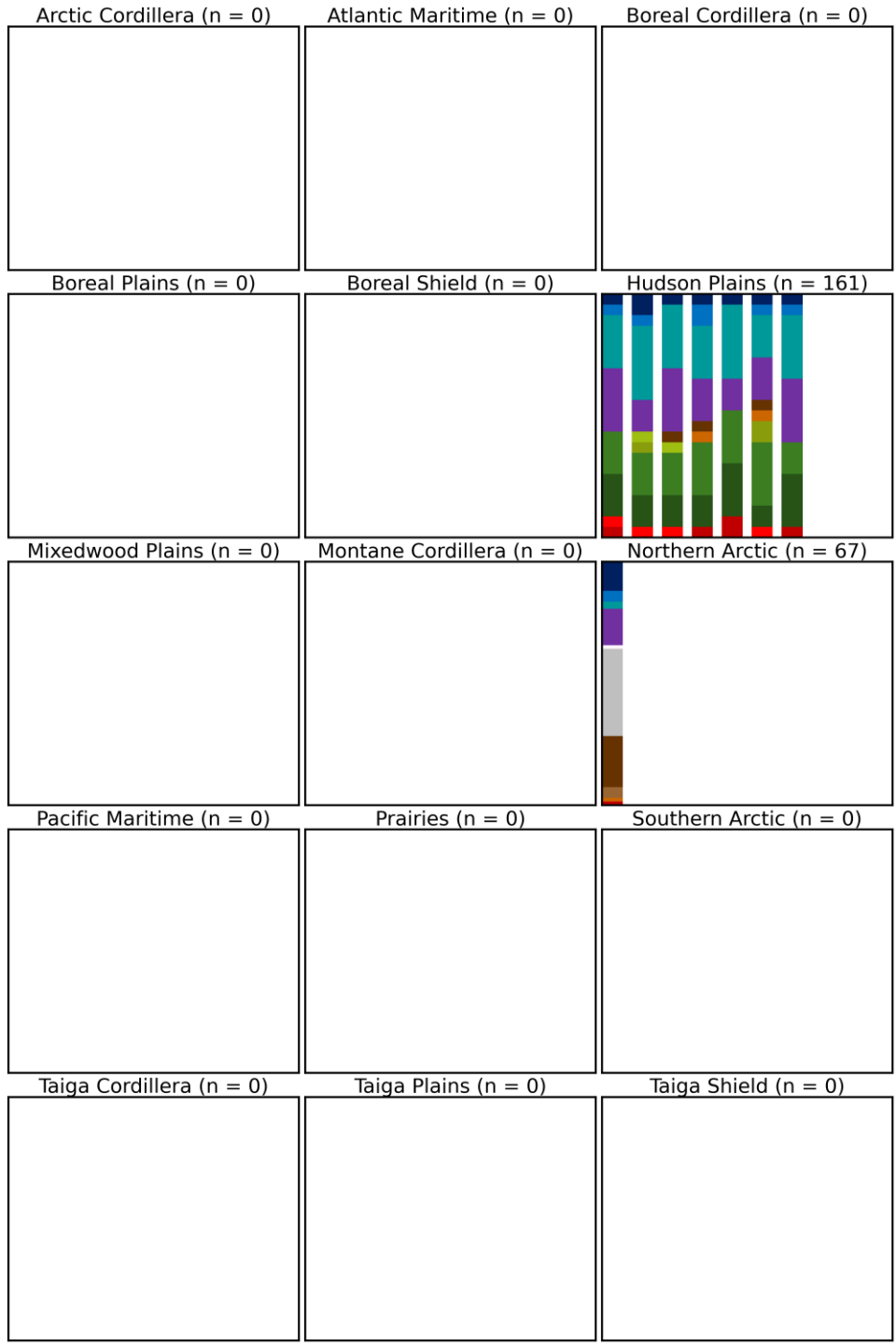


Pacific Maritime | Prairies | Southern Arctic

Taiga Cordillera | Taiga Plains | Taiga Shield

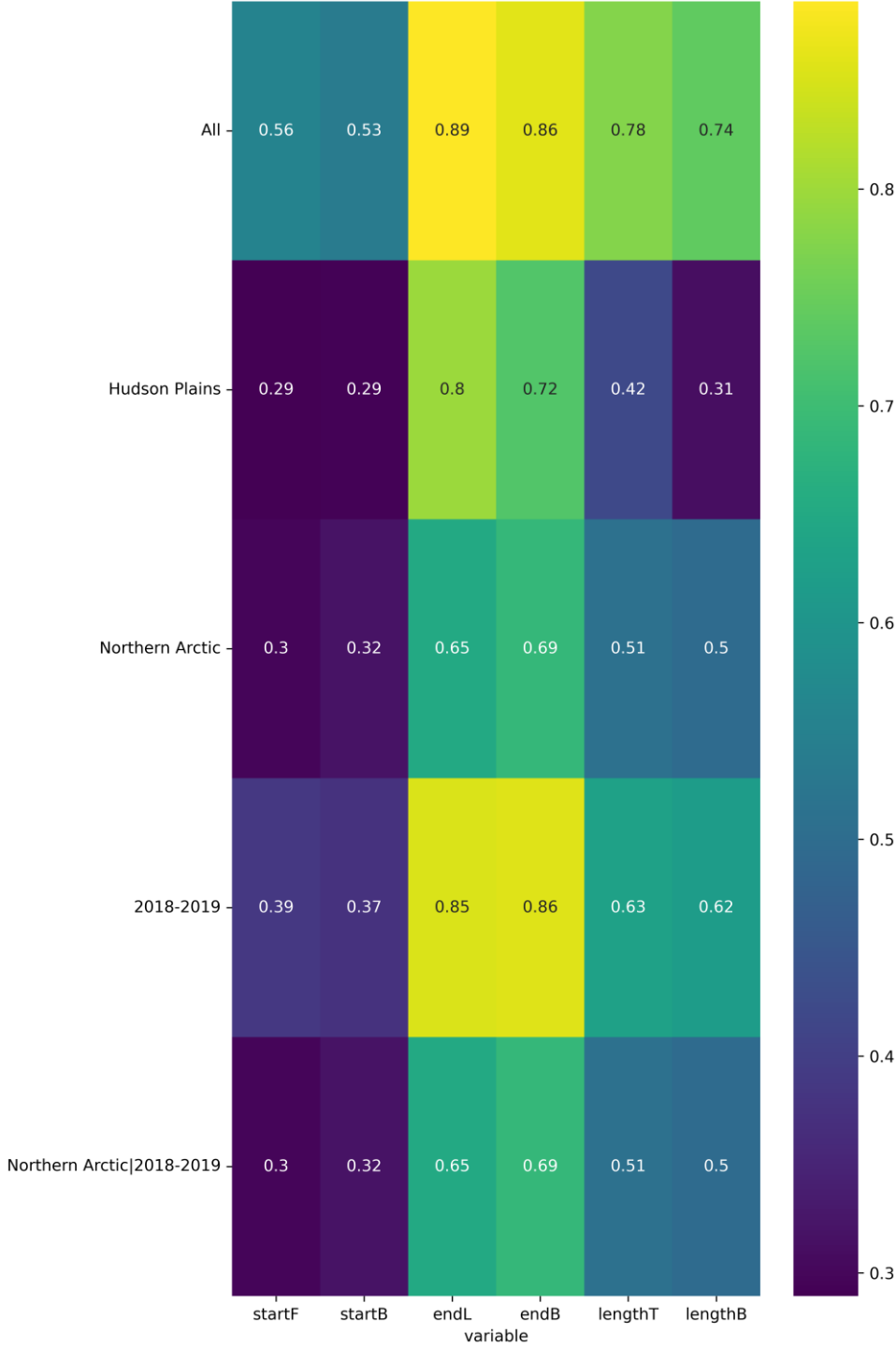
Class distribution (by winter year)





Regression Statistics: R^2

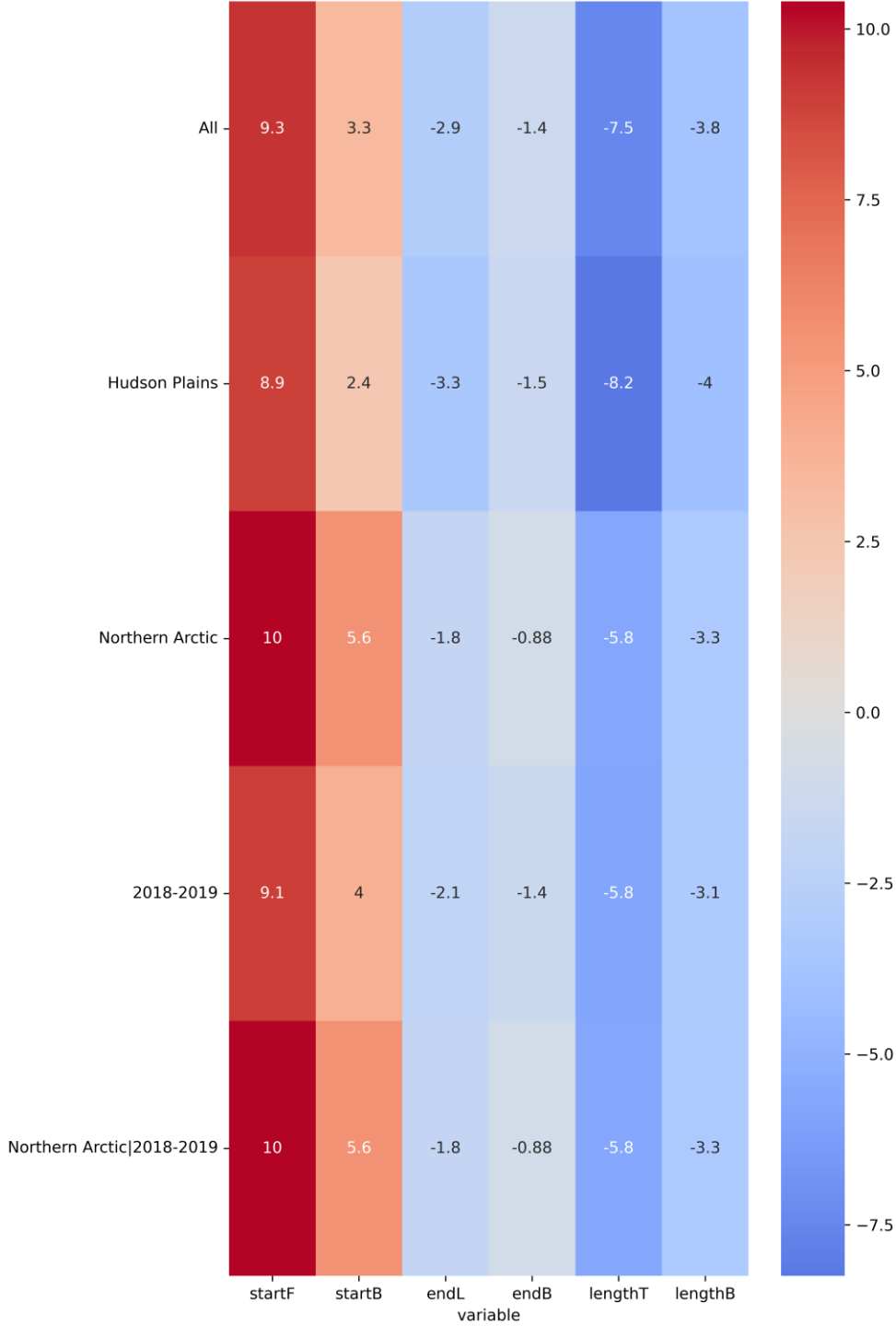
- Only shown if n ≥ 50
  - **Note**: Some samples are not included in statistics because either model or reference did not record a value for a given variable (i.e., perennial or snow free scenarios). See All Samples observed vs predicted plots vs. pred plots for details.
- Best performance for snow end
- Performance increases for almost all variables and sample subsets if high uncertainty samples are removed (see observed vs predicted plots below)



Regression Statistics: Bias

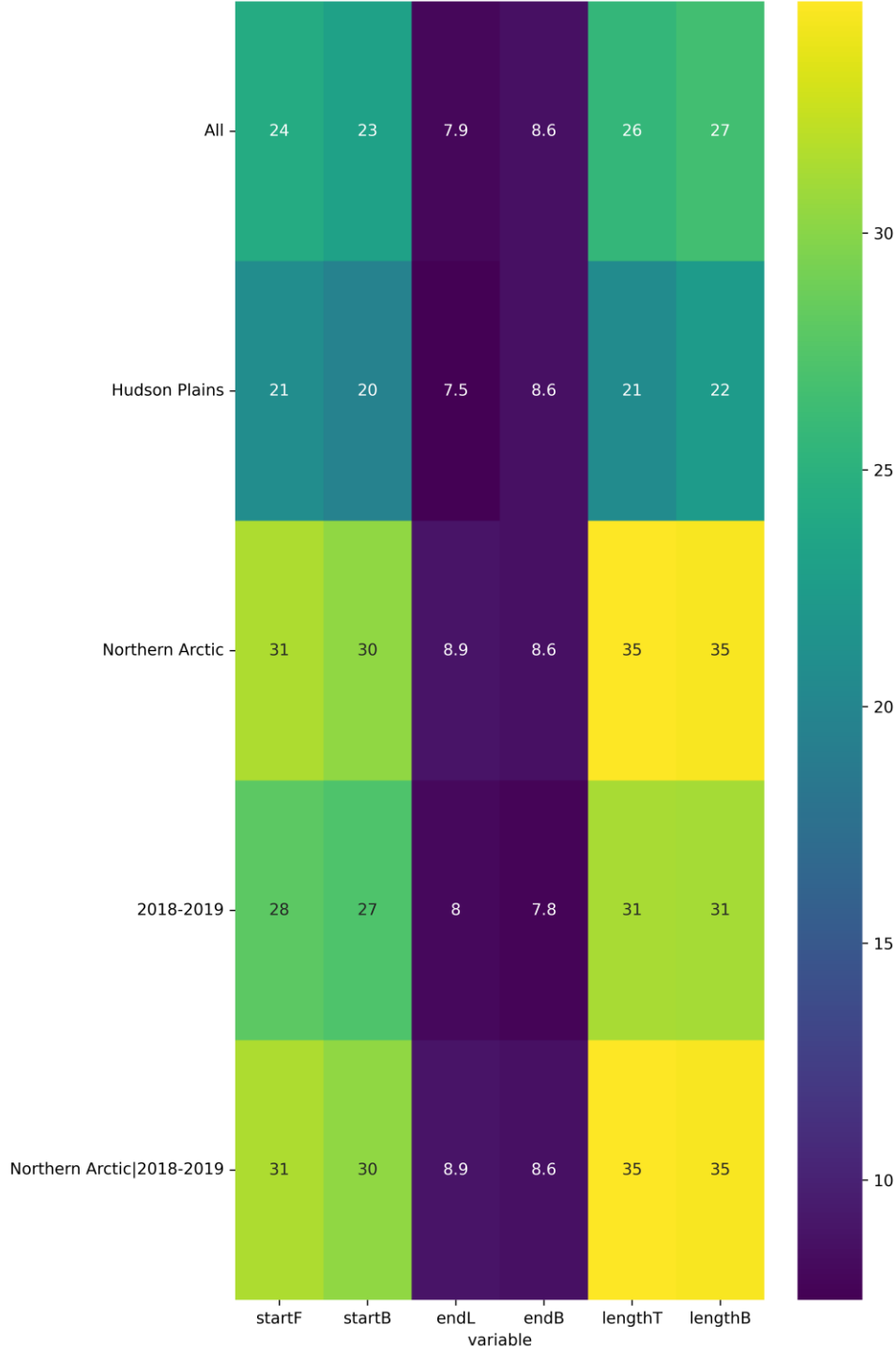
Mean of residuals

- Only shown if n ≥ 50
  - **Note**: Some samples are not included in statistics because either model or reference did not record a value for a given variable (i.e., perennial or snow free scenarios). See All Samples observed vs predicted plots vs. pred plots for details.
- Performance increases for almost all variables and sample subsets if high uncertainty samples are removed (see observed vs predicted plots below)



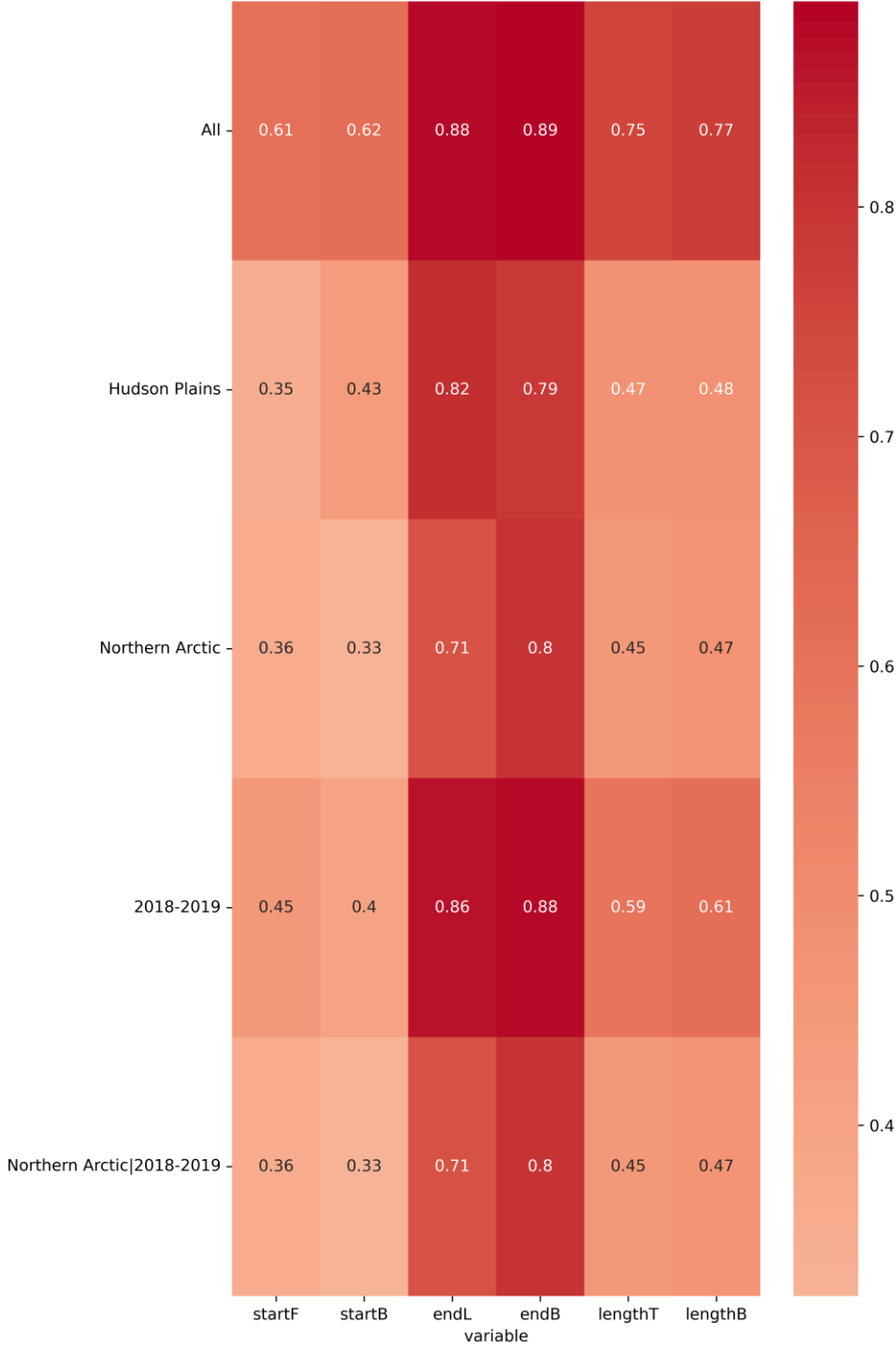
Regression Statistics: RMSE

- Only shown if n ≥ 50
  - **Note**: Some samples are not included in statistics because either model or reference did not record a value for a given variable (i.e., perennial or snow free scenarios). See All Samples observed vs predicted plots vs. pred plots for details.
- Best performance for snow end
- Performance increases for almost all variables and sample subsets if high uncertainty samples are removed (see observed vs predicted plots below)



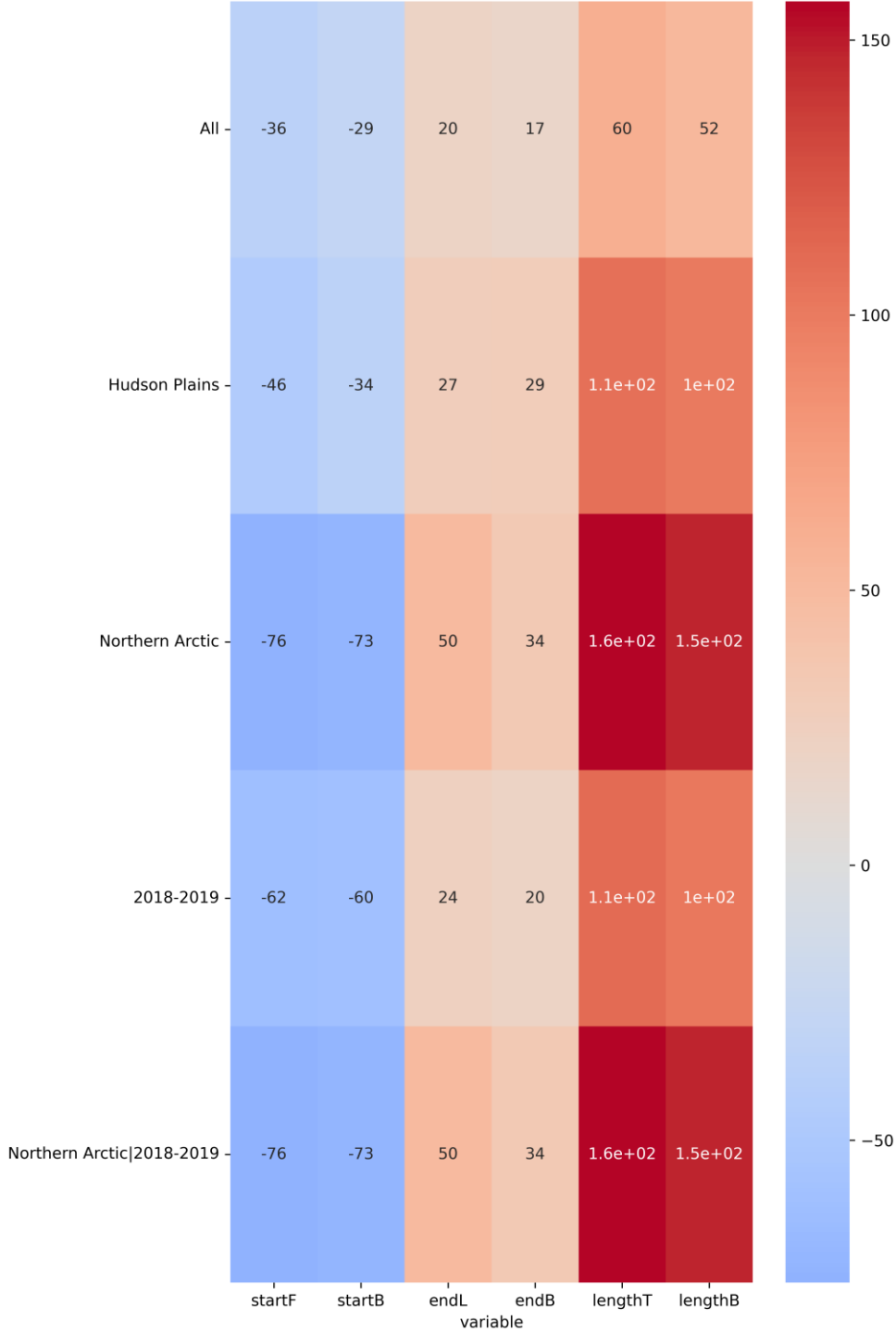
Regression Statistics: Slope

- Only shown if n ≥ 50
  - **Note**: Some samples are not included in statistics because either model or reference did not record a value for a given variable (i.e., perennial or snow free scenarios). See All Samples observed vs predicted plots vs. pred plots for details.
- Best performance for snow end
- Performance increases for almost all variables and sample subsets if high uncertainty samples are removed (see observed vs predicted plots below)



Regression Statistics: Intercept

- Only shown if n ≥ 50
  - **Note**: Some samples are not included in statistics because either model or reference did not record a value for a given variable (i.e., perennial or snow free scenarios). See All Samples observed vs predicted plots vs. pred plots for details.
- Performance increases for almost all variables and sample subsets if high uncertainty samples are removed (see observed vs predicted plots below)



By metric results

- startF: observed vs predicted plots
  - Perennial and snow free samples have no date
- startB: observed vs predicted plots
  - Perennial and snow free samples have no date
- endL: observed vs predicted plots
  - Perennial and snow free samples have no date
- endB: observed vs predicted plots
  - Perennial and snow free samples have no date
- lengthT: observed vs predicted plots
- lengthB: observed vs predicted plots
- periods: Agreement % tables
- status: Agreement % tables

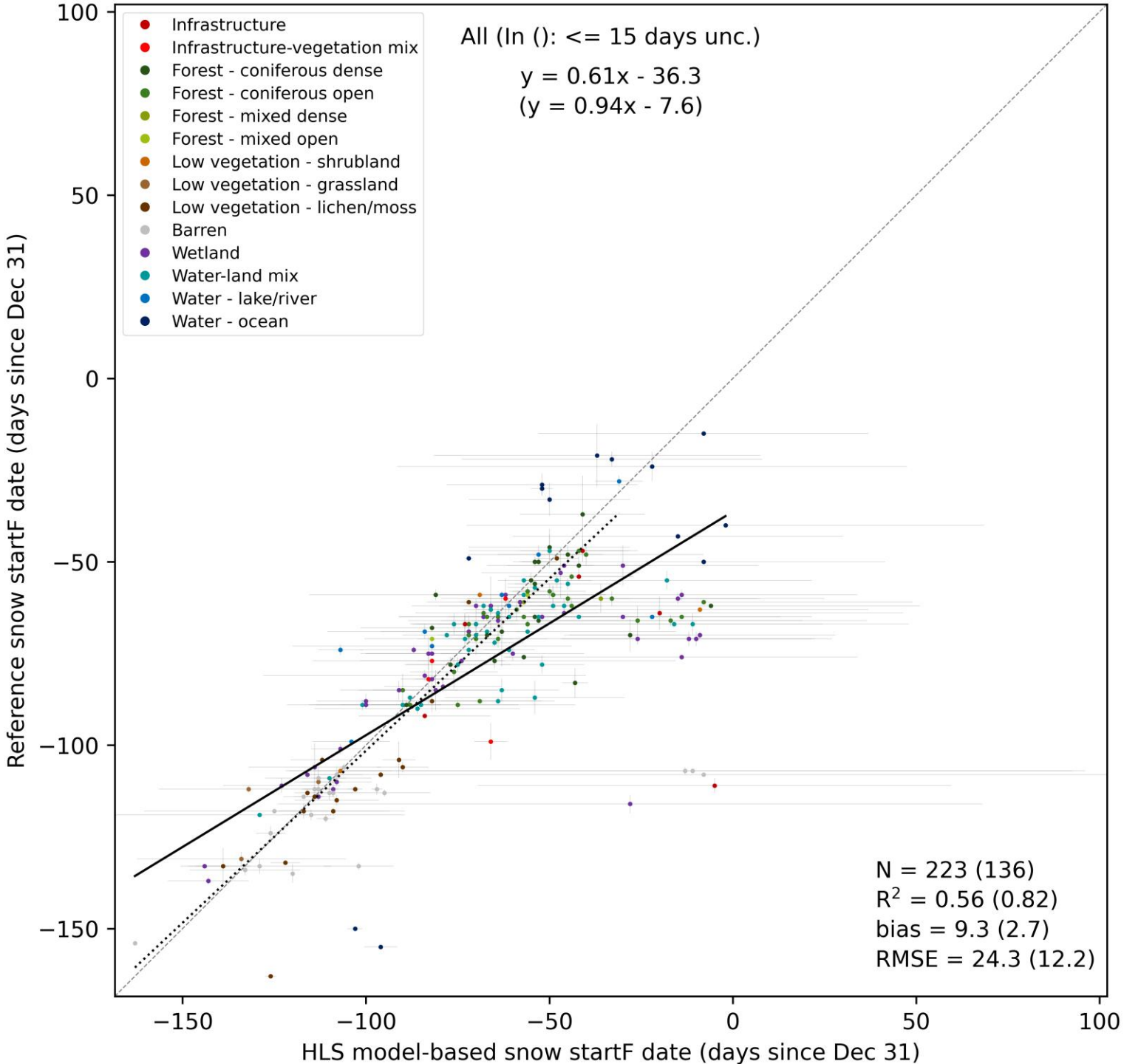
Observed vs. predicted plots:

- Statistics
  - Linear regression equation
    - y = slope(x) + intercept
  - N: Number of samples
  - R^2: Coefficient of determination
  - bias: Mean of residuals
  - RMSE: Root mean squared error
  - Statistics in parentheses are results if filtering by a given uncertainty value
- Linear regression lines
  - Solid: All samples
  - Dotted: Filtered by given uncertainty value
- Grey lines for each marker represent the uncertainty for both model (horizontal) and reference (vertical) measurements

All Samples

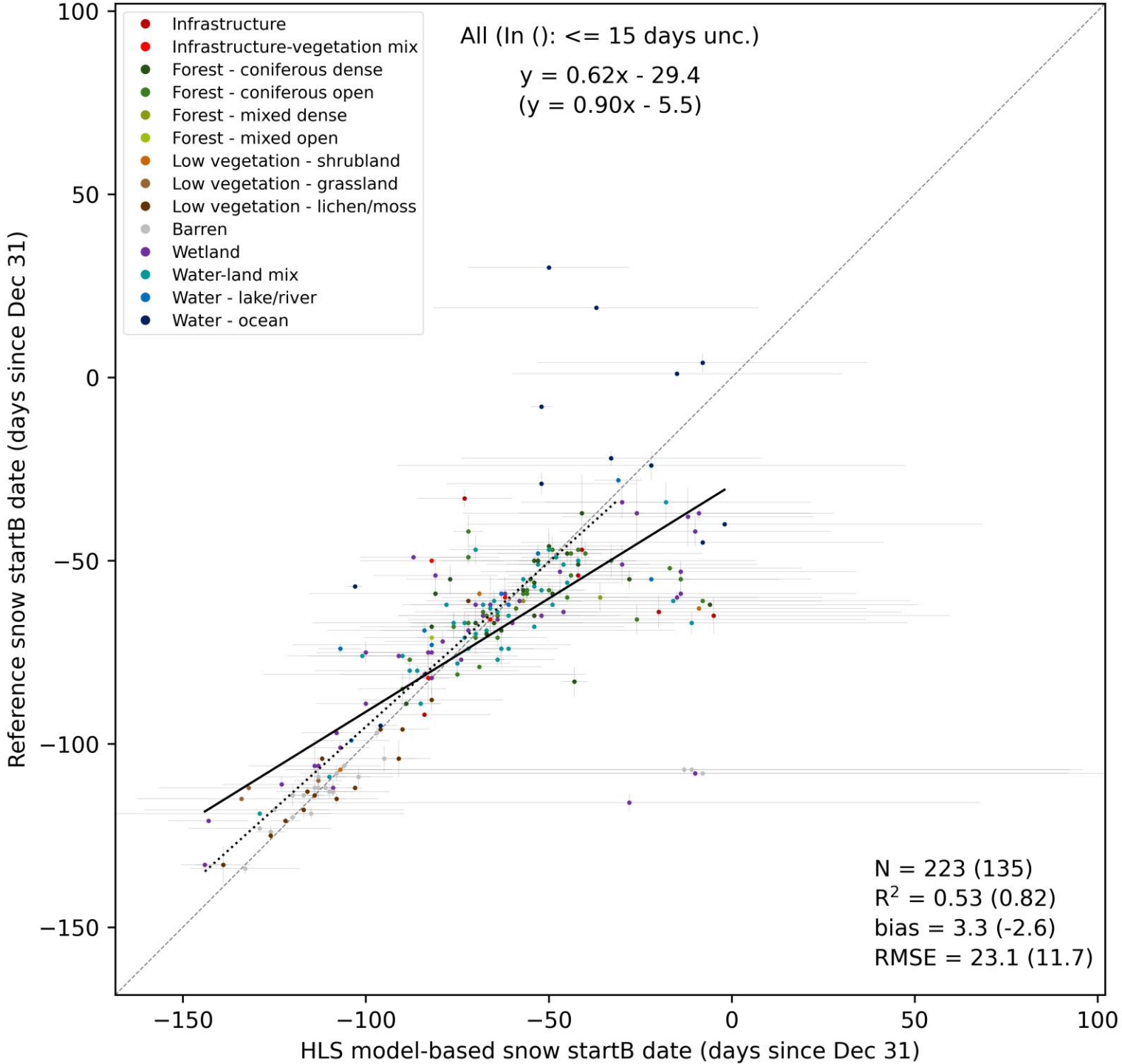
startF

- 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
- Samples not included because either model or reference recorded no startF date: 5 (2.2%)
  - Both model and reference recorded no startF date: 2 (40.0%)
  - Only model recorded no startF date: 3 (60.0%)
  - Only reference recorded no startF date: 0 (0.0%)



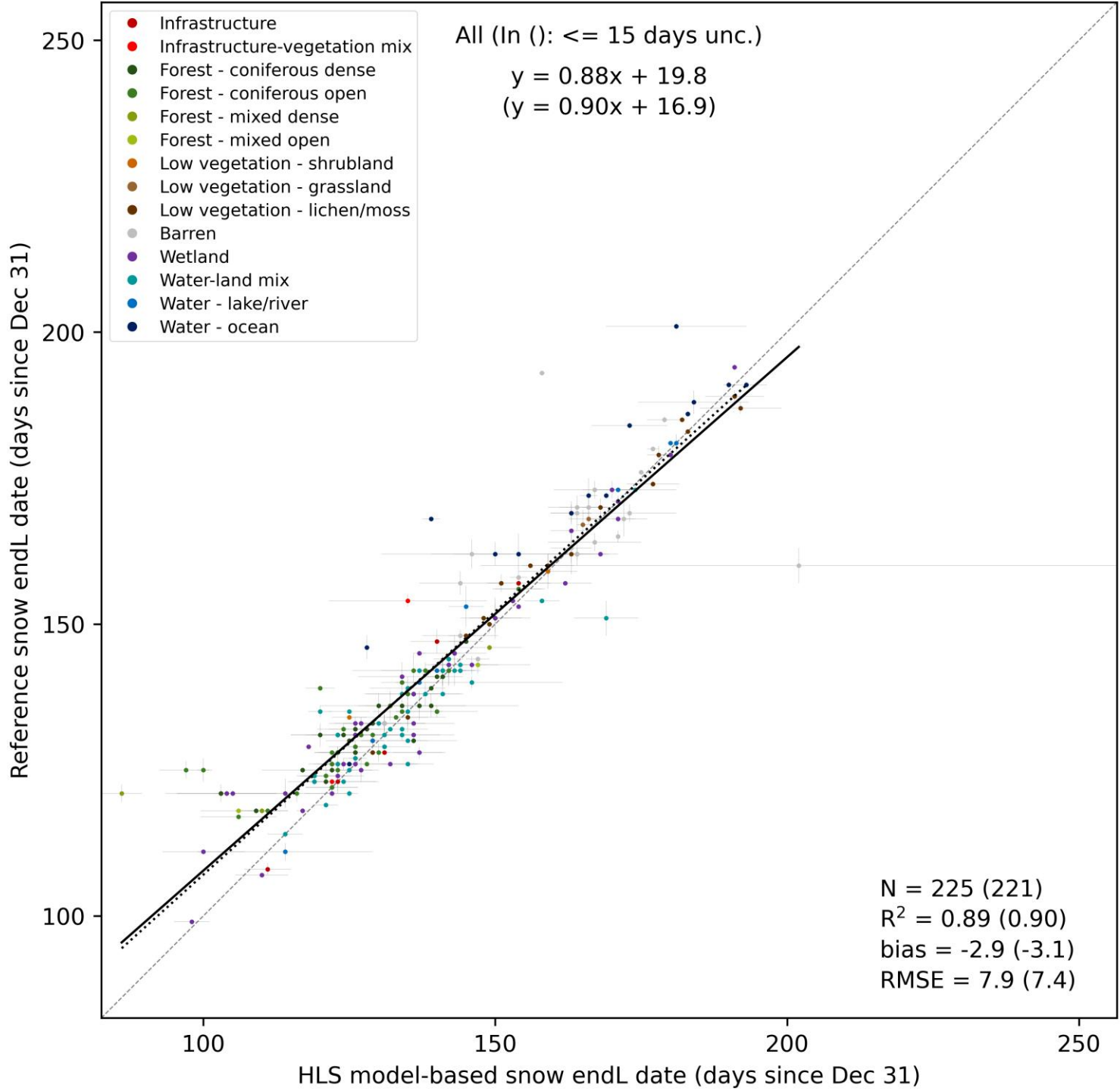
startB

- 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
- Samples not included because either model or reference recorded no startB date: 5 (2.2%)
  - Both model and reference recorded no startB date: 2 (40.0%)
  - Only model recorded no startB date: 3 (60.0%)
  - Only reference recorded no startB date: 0 (0.0%)



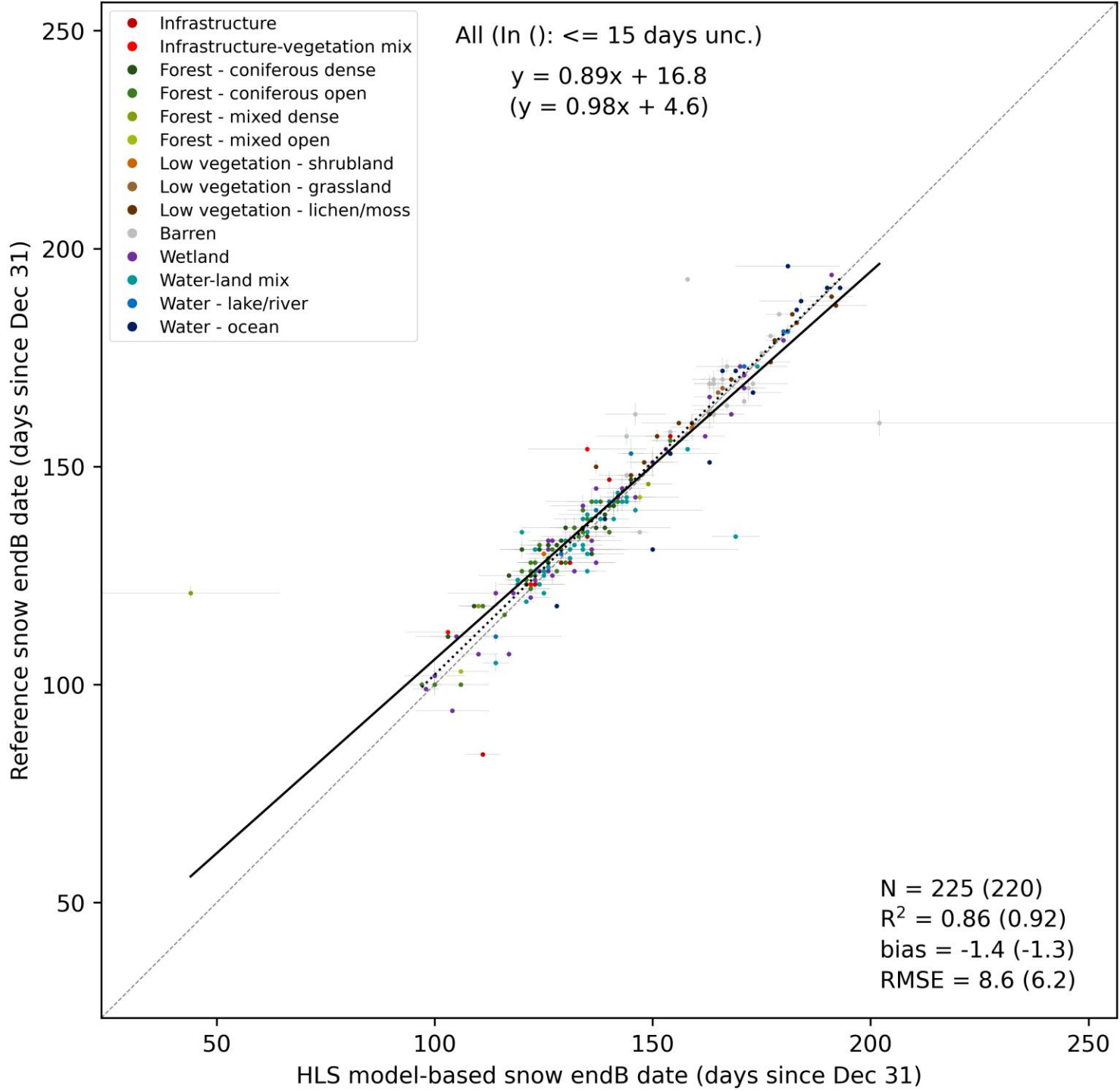
endL

- Best performing metric
- Model underestimates snow end date in some forest samples due to difficulties observing remaining snow under canopy in spring
- High uncertainty in some barren samples (e.g., sandy beaches) due to snow misclassification in non-winter months
- Samples not included because either model or reference recorded no endL date: 3 (1.3%)
  - Both model and reference recorded no endL date: 2 (66.7%)
  - Only model recorded no endL date: 1 (33.3%)
  - Only reference recorded no endL date: 0 (0.0%)



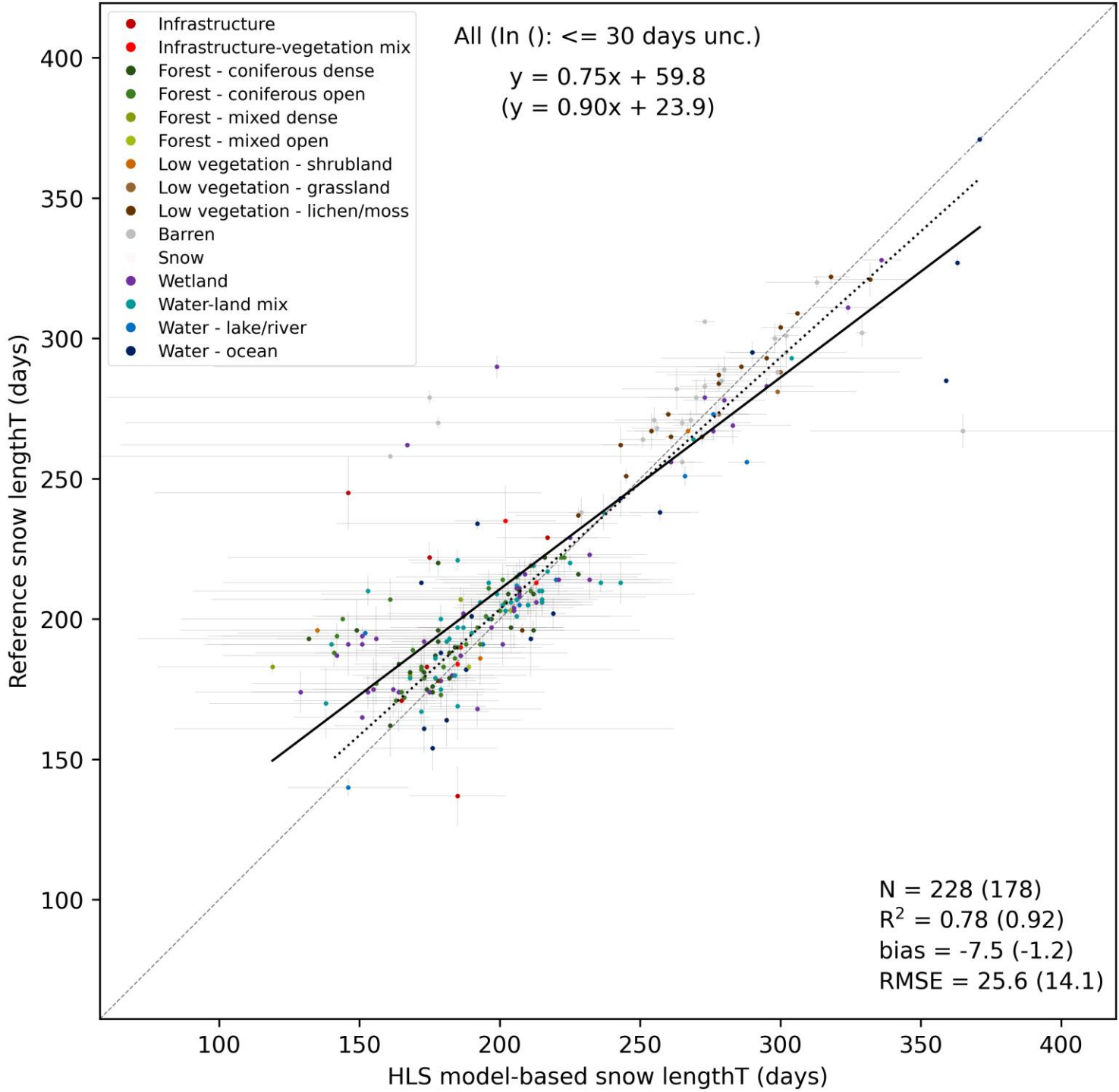
endB

- Strong performing metric
- Model underestimates snow end date in some forest samples due to difficulties observing remaining snow under canopy in spring
- High uncertainty in some barren samples (e.g., sandy beaches) due to snow misclassification in non-winter months
- Samples not included because either model or reference recorded no endB date: 3 (1.3%)
  - Both model and reference recorded no endB date: 2 (66.7%)
  - Only model recorded no endB date: 1 (33.3%)
  - Only reference recorded no endB date: 0 (0.0%)



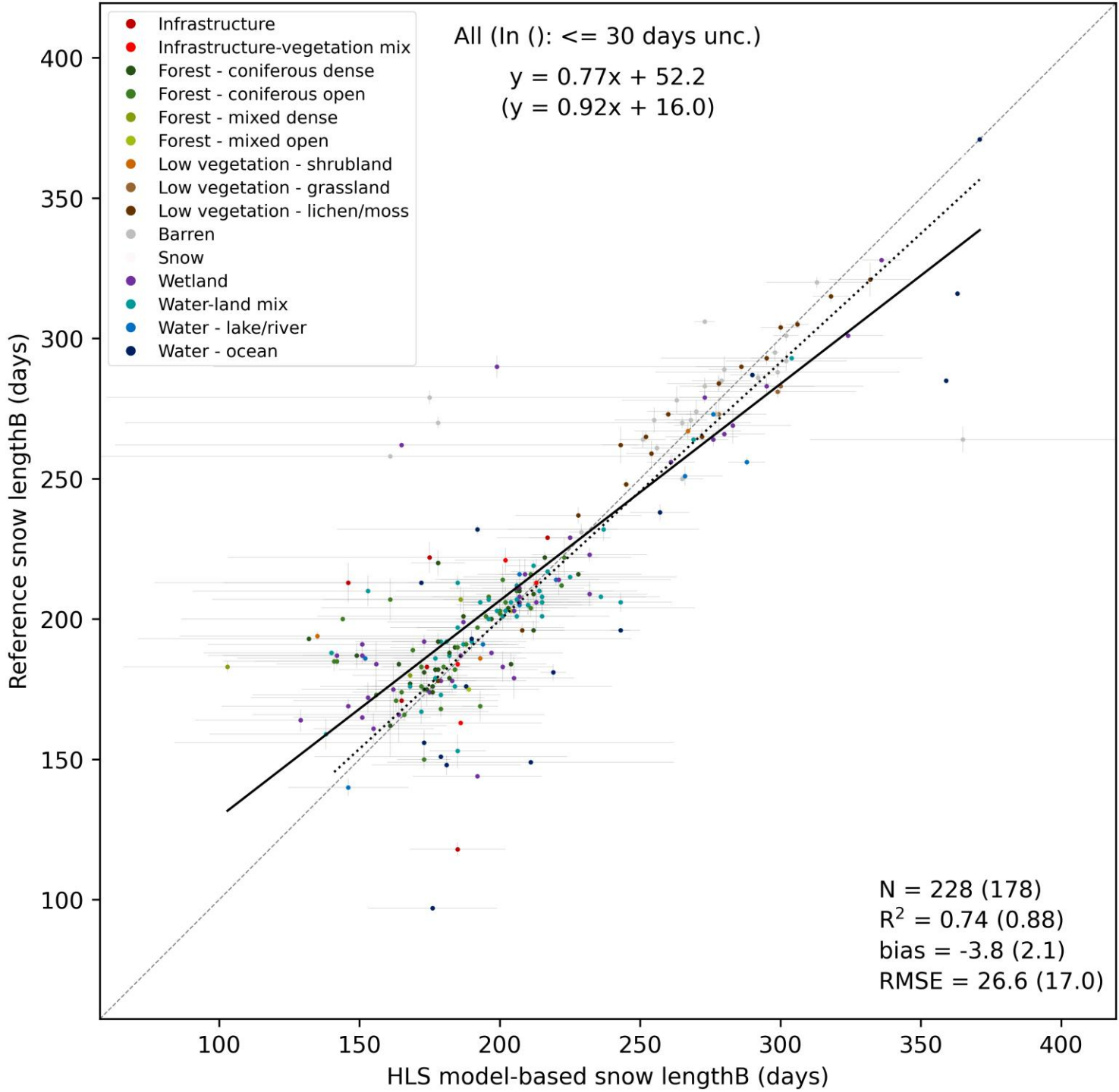
lengthT

- Higher uncertainty because it is a combination of start and end
  - Performance falls between start and end
- Samples not included because either model or reference recorded no lengthT date: 0 (0.0%)



lengthB

- Higher uncertainty because it is a combination of start and end
  - Performance falls between start and end
- Samples not included because either model or reference recorded no lengthB date: 0 (0.0%)



periods

	All Samples
One period (observed)	97.8% (n = 134)
Two+ periods (observed)	1.1% (n = 94)

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

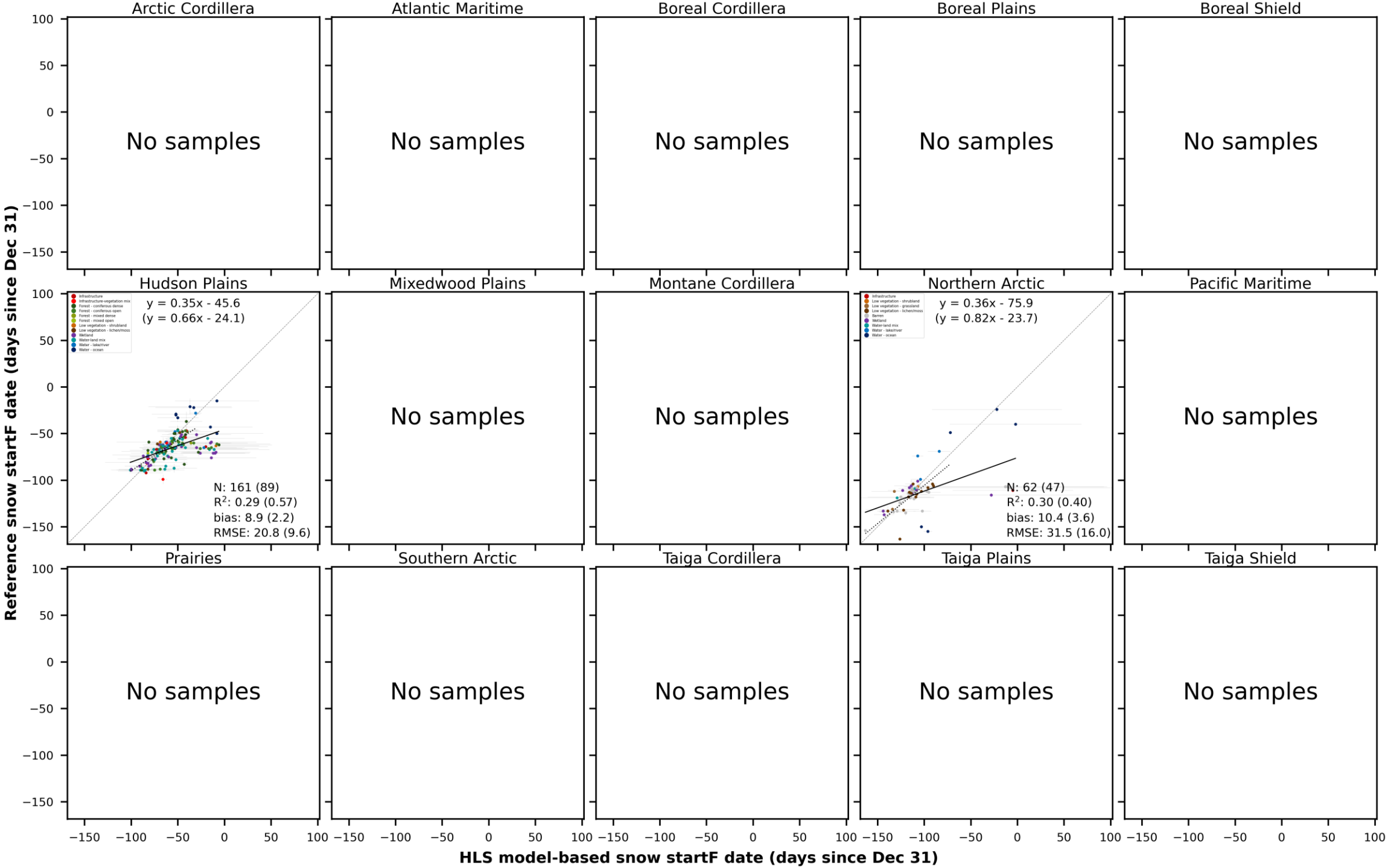
status

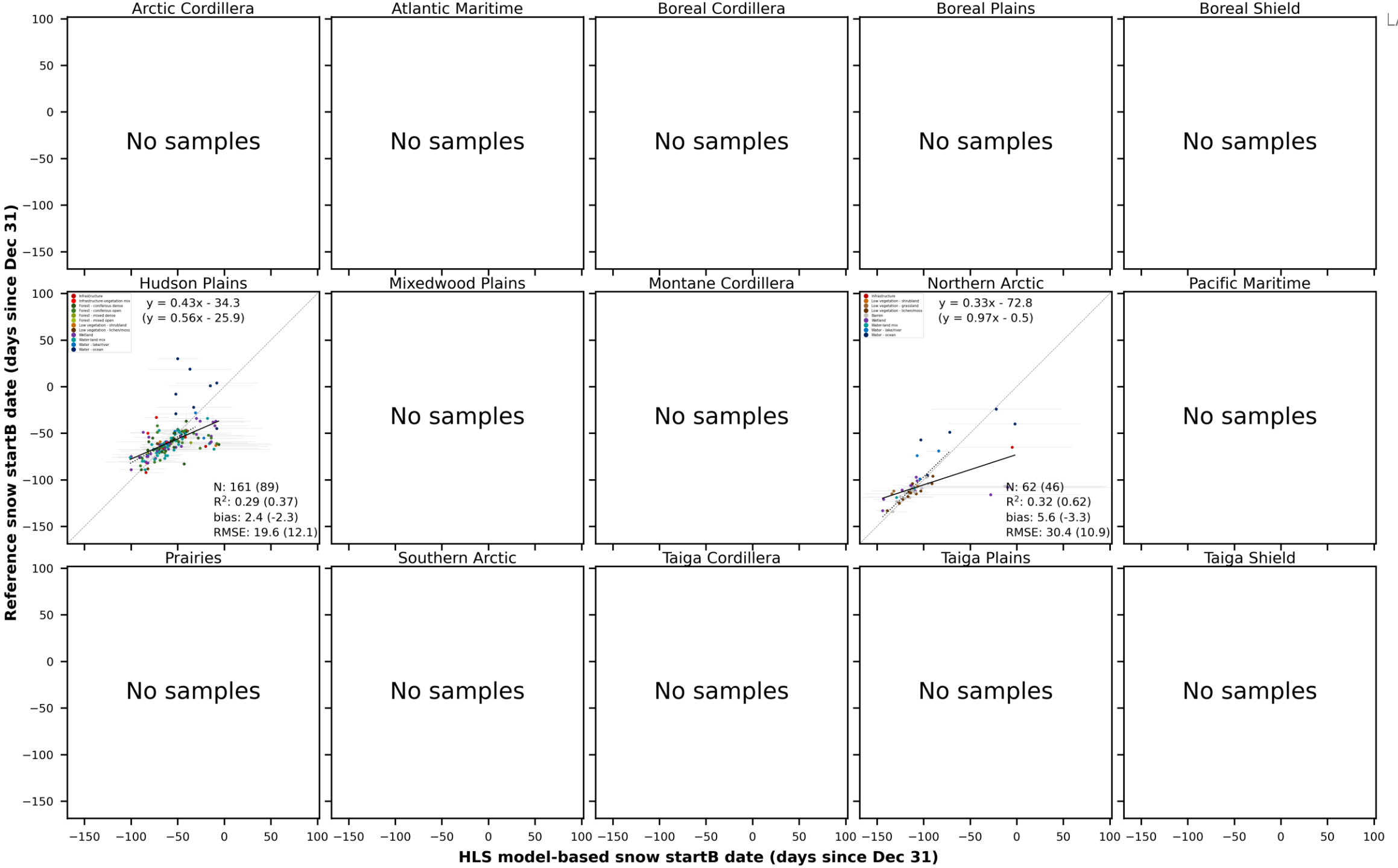
	All Samples
Seasonal snow (observed)	98.5% (n = 204)
Perennial snow (observed)	100% (n = 2)
Inconsistent perennial snow (observed)	72.7% (n = 22)
Snow free (observed)	No snow free samples
Ephemeral snow (observed)	No ephemeral snow samples

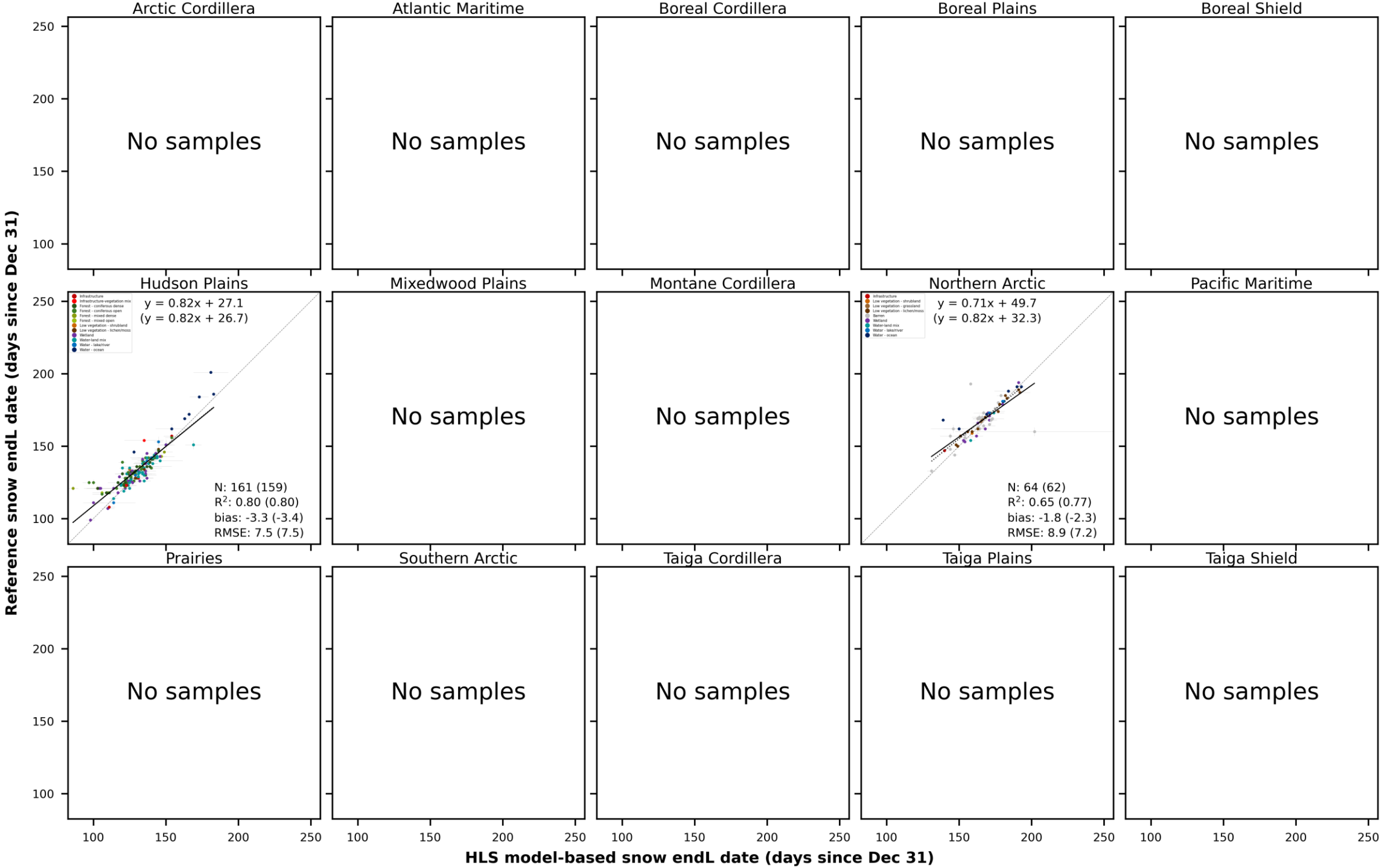
For each observed category, what % of the time did the model agree?

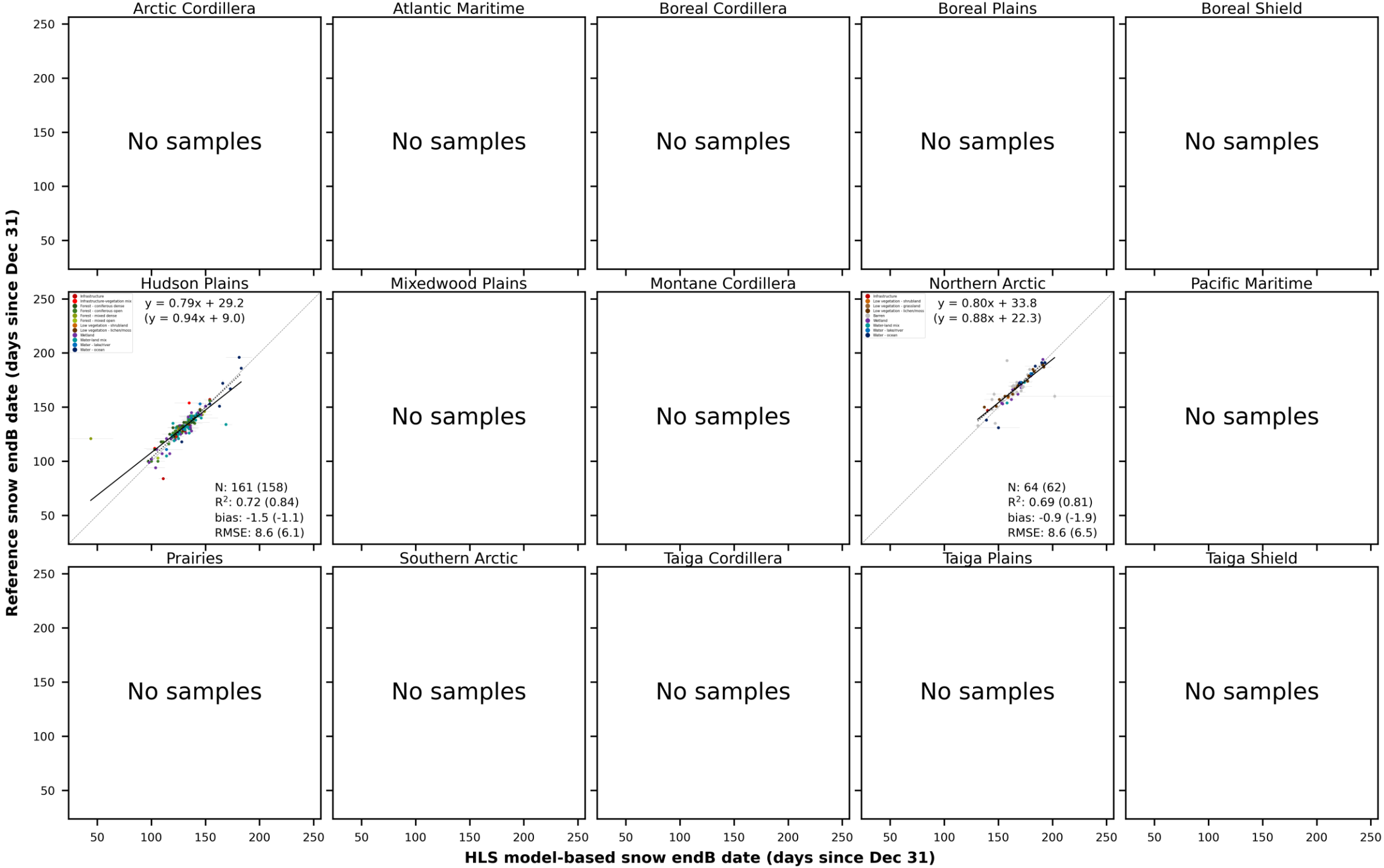
- Only seasonal snow has been observed (so far), and the model agrees in almost every case

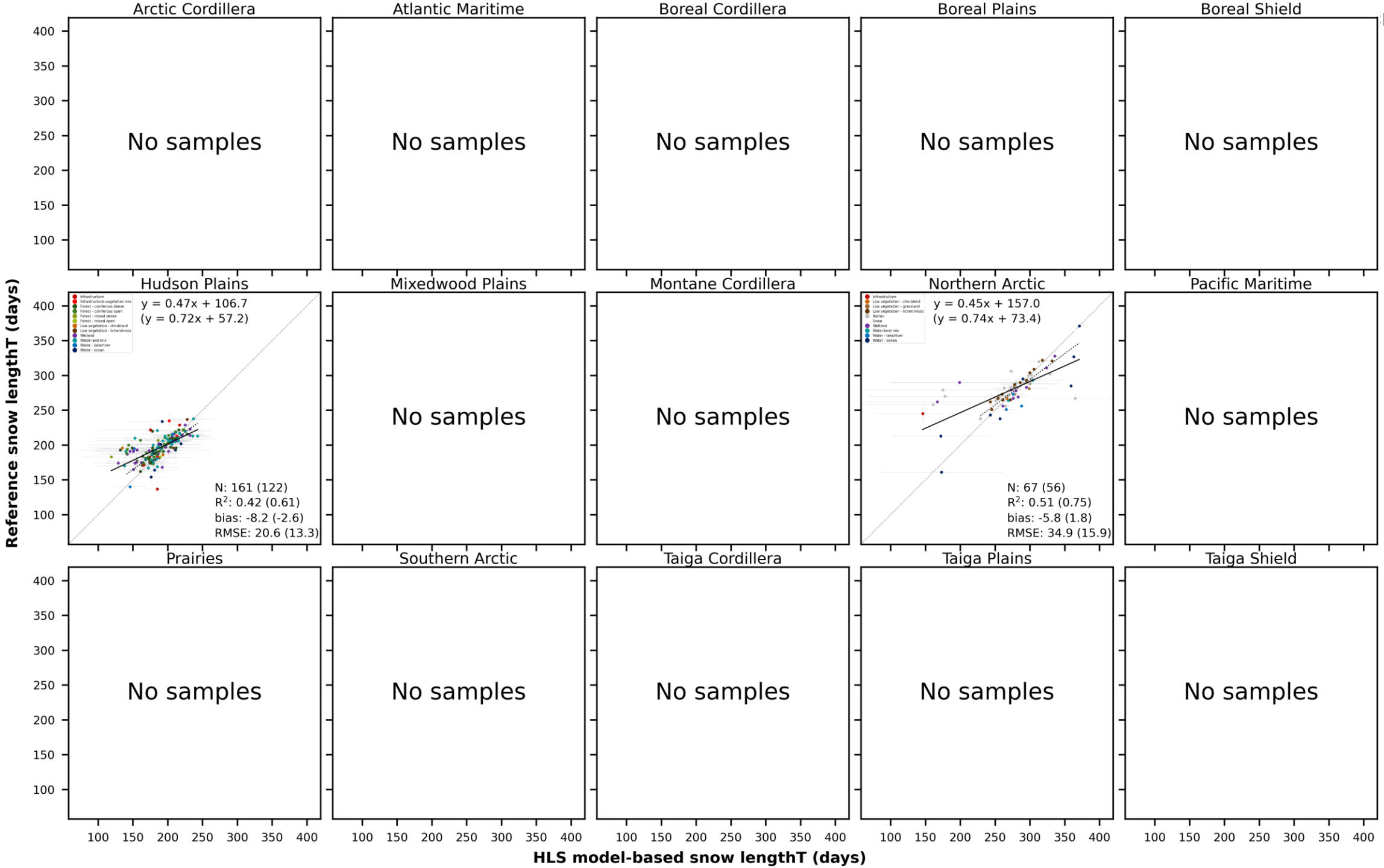
By Ecozone

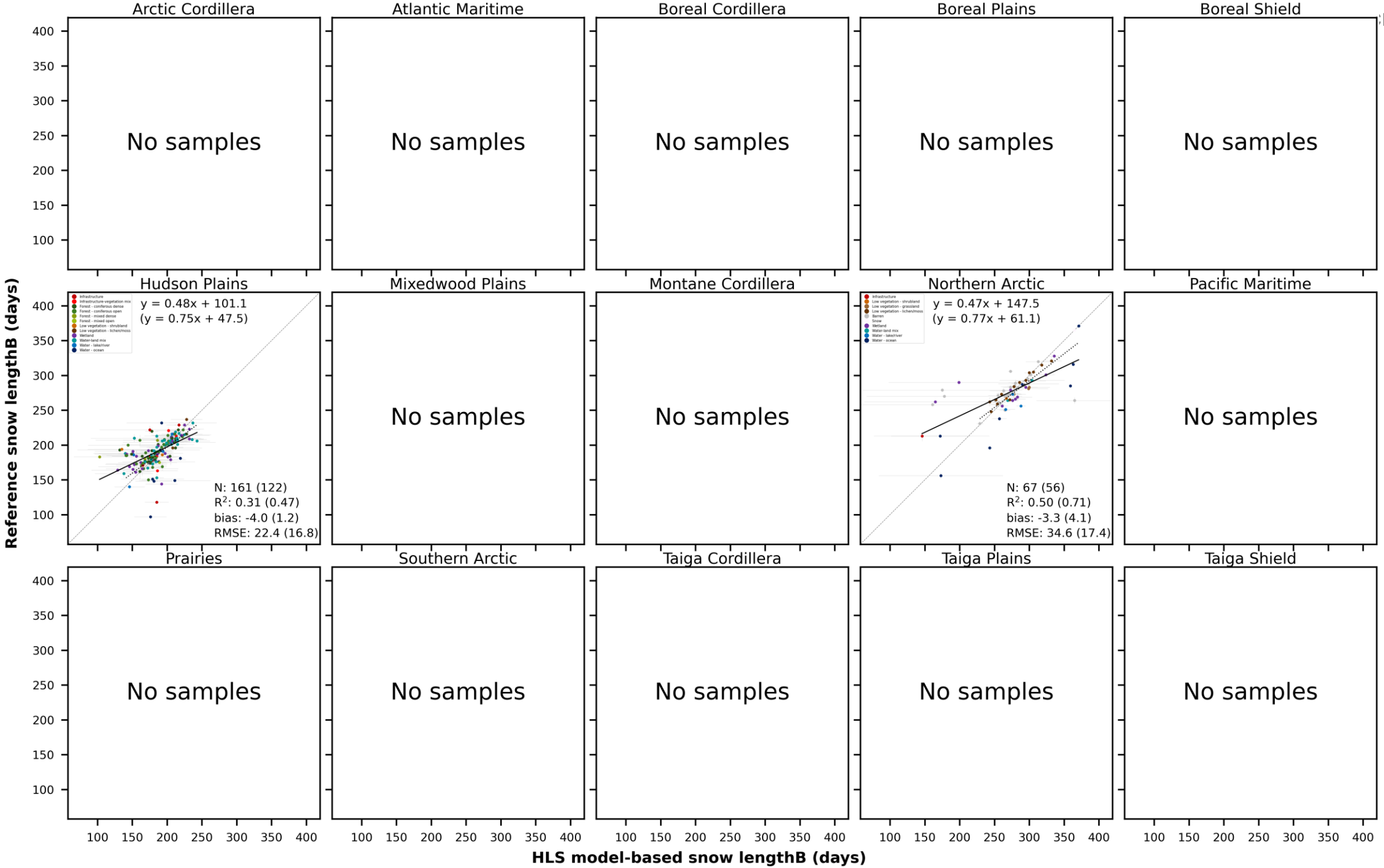

Arctic Cordillera
Atlantic Maritime
Boreal Cordillera
Boreal Plains
Boreal Shield
Hudson Plains
Mixedwood Plains
Montane Cordillera
Northern Arctic
Pacific Maritime
Prairies
Southern Arctic
Taiga Cordillera
Taiga Plains
Taiga Shield
No samples
y = 0.35x - 45.6
(y = 0.66x - 24.1)
N: 161 (89)
R²: 0.29 (0.57)
bias: 8.9 (2.2)
RMSE: 20.8 (9.6)
y = 0.36x - 75.9
(y = 0.82x - 23.7)
N: 62 (47)
R²: 0.30 (0.40)
bias: 10.4 (3.6)
RMSE: 31.5 (16.0)
Reference snow startF date (days since Dec 31)
HLS model-based snow startF date (days since Dec 31)
100
50
0
−50
−100
−150


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
No samples
y = 0.43x - 34.3
(y = 0.56x - 25.9)
N: 161 (89)
R²: 0.29 (0.37)
bias: 2.4 (-2.3)
RMSE: 19.6 (12.1)
y = 0.33x - 72.8
(y = 0.97x - 0.5)
N: 62 (46)
R²: 0.32 (0.62)
bias: 5.6 (-3.3)
RMSE: 30.4 (10.9)
Reference snow startB date (days since Dec 31)
HLS model-based snow startB date (days since Dec 31)
100
50
0
−50
−100
−150


Arctic Cordillera
No samples
Atlantic Maritime
No samples
Boreal Cordillera
No samples
Boreal Plains
No samples
Boreal Shield
No samples
Hudson Plains
y = 0.82x + 27.1
(y = 0.82x + 26.7)
N: 161 (159)
R²: 0.80 (0.80)
bias: -3.3 (-3.4)
RMSE: 7.5 (7.5)
Mixedwood Plains
No samples
Montane Cordillera
No samples
Northern Arctic
y = 0.71x + 49.7
(y = 0.82x + 32.3)
N: 64 (62)
R²: 0.65 (0.77)
bias: -1.8 (-2.3)
RMSE: 8.9 (7.2)
Pacific Maritime
No samples
Prairies
No samples
Southern Arctic
No samples
Taiga Cordillera
No samples
Taiga Plains
No samples
Taiga Shield
No samples
100
150
200
250
Reference snow endL date (days since Dec 31)
HLS model-based snow endL date (days since Dec 31)


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
No samples
y = 0.79x + 29.2
(y = 0.94x + 9.0)
N: 161 (158)
R²: 0.72 (0.84)
bias: -1.5 (-1.1)
RMSE: 8.6 (6.1)
y = 0.80x + 33.8
(y = 0.88x + 22.3)
N: 64 (62)
R²: 0.69 (0.81)
bias: -0.9 (-1.9)
RMSE: 8.6 (6.5)
Reference snow endB date (days since Dec 31)
HLS model-based snow endB date (days since Dec 31)
50
100
150
200
250


Arctic Cordillera
No samples
Atlantic Maritime
No samples
Boreal Cordillera
No samples
Boreal Plains
No samples
Boreal Shield
No samples
Hudson Plains
y = 0.47x + 106.7
(y = 0.72x + 57.2)
N: 161 (122)
R2: 0.42 (0.61)
bias: -8.2 (-2.6)
RMSE: 20.6 (13.3)
Mixedwood Plains
No samples
Montane Cordillera
No samples
Northern Arctic
y = 0.45x + 157.0
(y = 0.74x + 73.4)
N: 67 (56)
R2: 0.51 (0.75)
bias: -5.8 (1.8)
RMSE: 34.9 (15.9)
Pacific Maritime
No samples
Prairies
No samples
Southern Arctic
No samples
Taiga Cordillera
No samples
Taiga Plains
No samples
Taiga Shield
No samples
Reference snow lengthT (days)
HLS model-based snow lengthT (days)
100
150
200
250
300
350
400


Arctic Cordillera
No samples
Atlantic Maritime
No samples
Boreal Cordillera
No samples
Boreal Plains
No samples
Boreal Shield
No samples
Hudson Plains
y = 0.48x + 101.1
(y = 0.75x + 47.5)
N: 161 (122)
R2: 0.31 (0.47)
bias: -4.0 (1.2)
RMSE: 22.4 (16.8)
Mixedwood Plains
No samples
Montane Cordillera
No samples
Northern Arctic
y = 0.47x + 147.5
(y = 0.77x + 61.1)
N: 67 (56)
R2: 0.50 (0.71)
bias: -3.3 (4.1)
RMSE: 34.6 (17.4)
Pacific Maritime
No samples
Prairies
No samples
Southern Arctic
No samples
Taiga Cordillera
No samples
Taiga Plains
No samples
Taiga Shield
No samples
Reference snow lengthB (days)
HLS model-based snow lengthB (days)
100
150
200
250
300
350
400

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	95.5% (n = 44)	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	4.3% (n = 23)	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

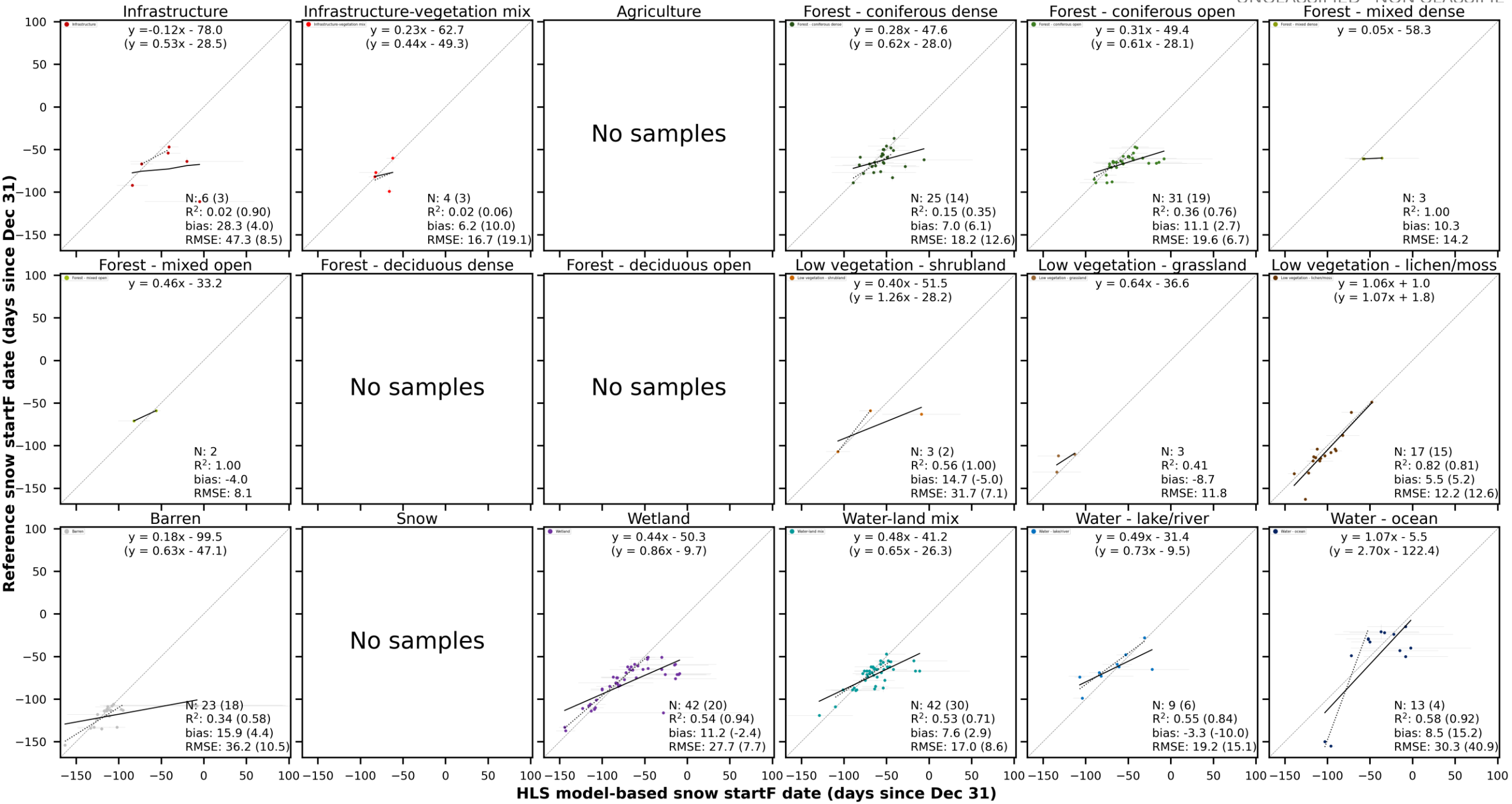
	Arctic Cordillera	Atlantic Maritime	Boreal Cordillera	Boreal Plains	Boreal Shield	Hudson Plains	Mixedwood Plains	Montane Cordillera	Northern Arctic	Pacific Maritime	Prairies	Southern Arctic	Taiga Cordillera	Taiga Plains	Taiga Shield
Seasonal snow (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	99.4% (n = 161)	n = 0	n = 0	95.3% (n = 43)	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	100% (n = 3)	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	72.7% (n = 22)	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
Ephemeral 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

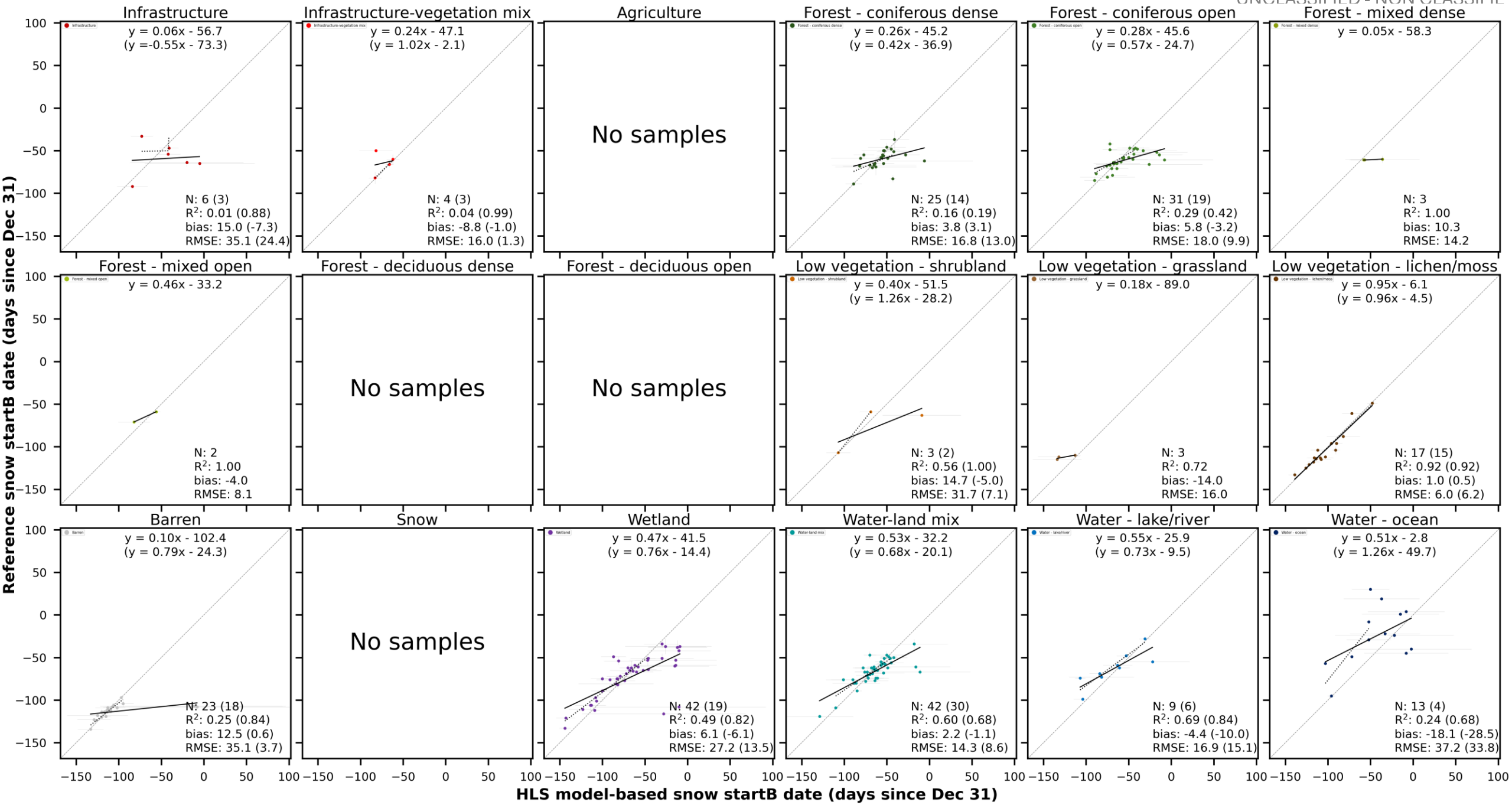
For each observed category, what % of the time did the model agree?

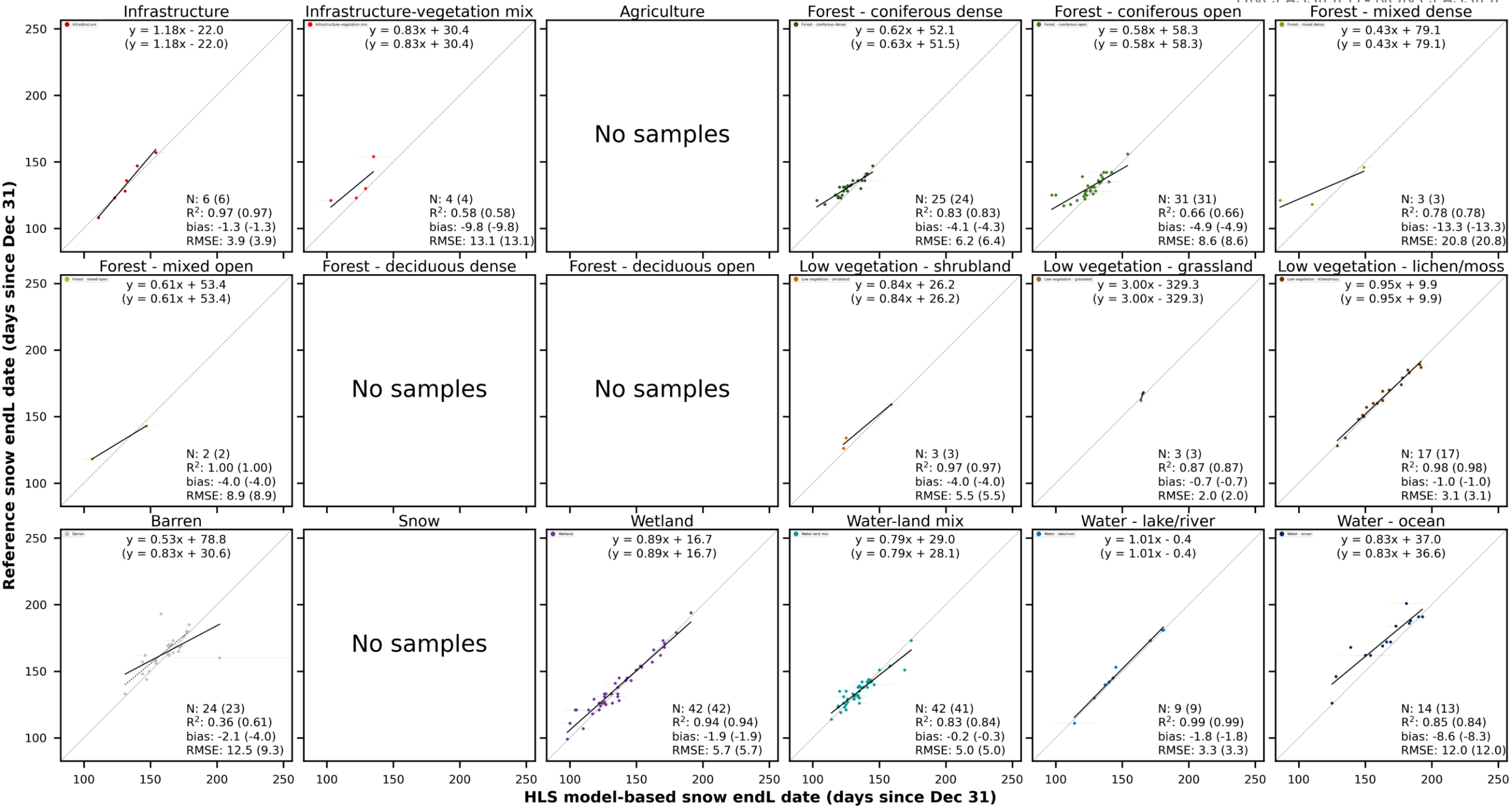
By Class

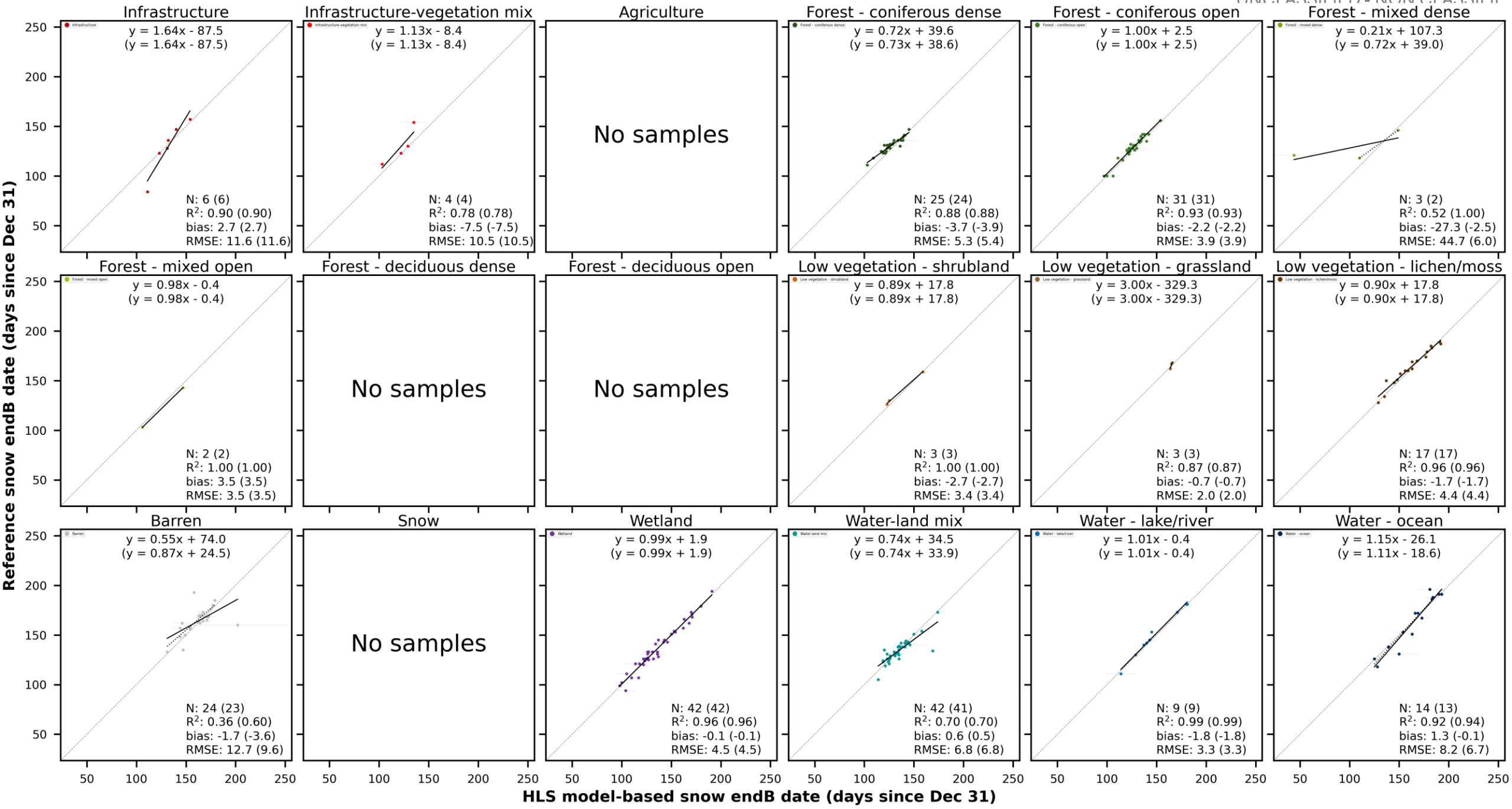
Note:

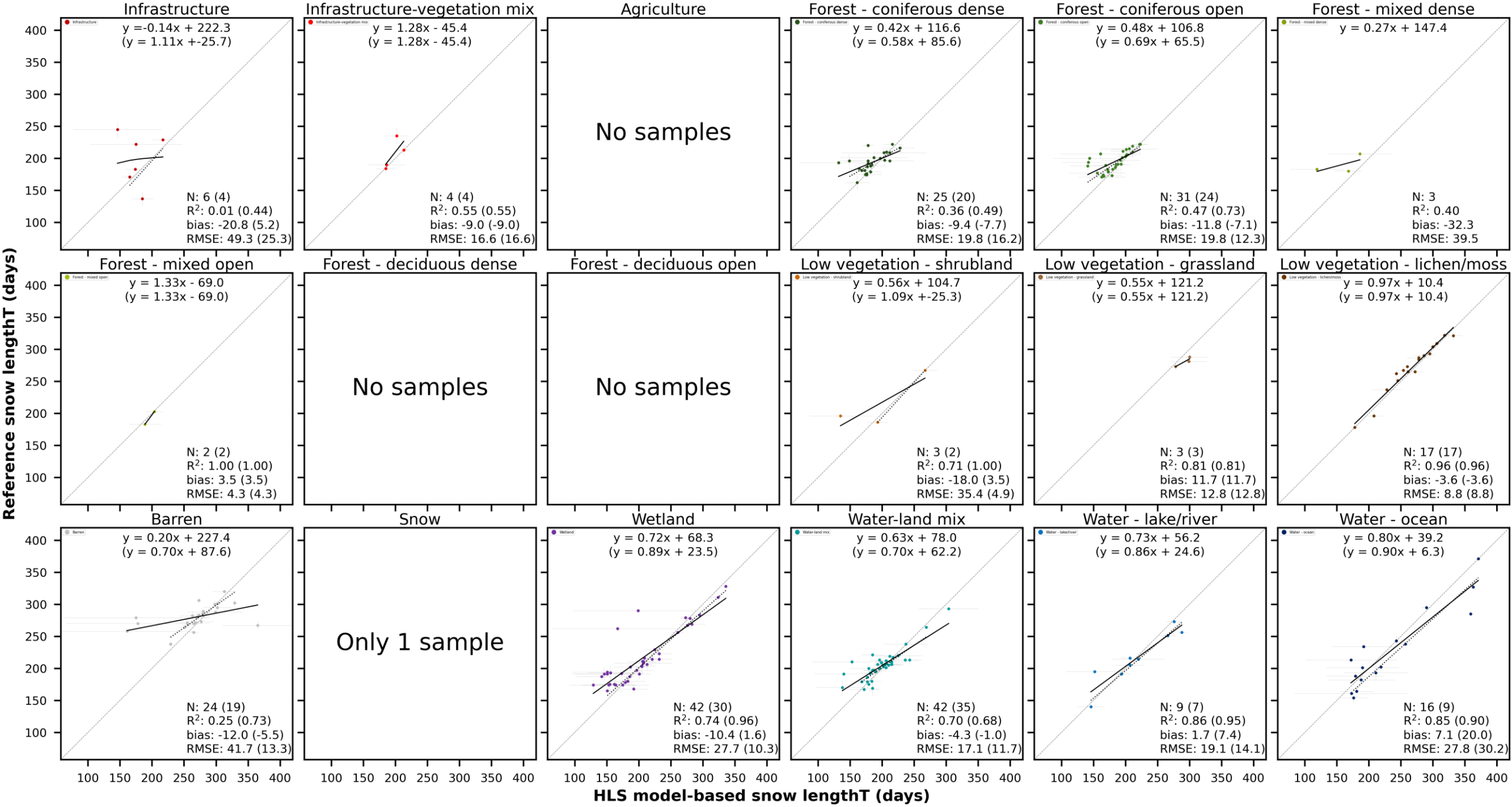
- 100% of Snow samples lack either start or end dates due to perennial snow conditions
- >10% of Water – ocean samples lack either start or end dates due to perennial snow conditions

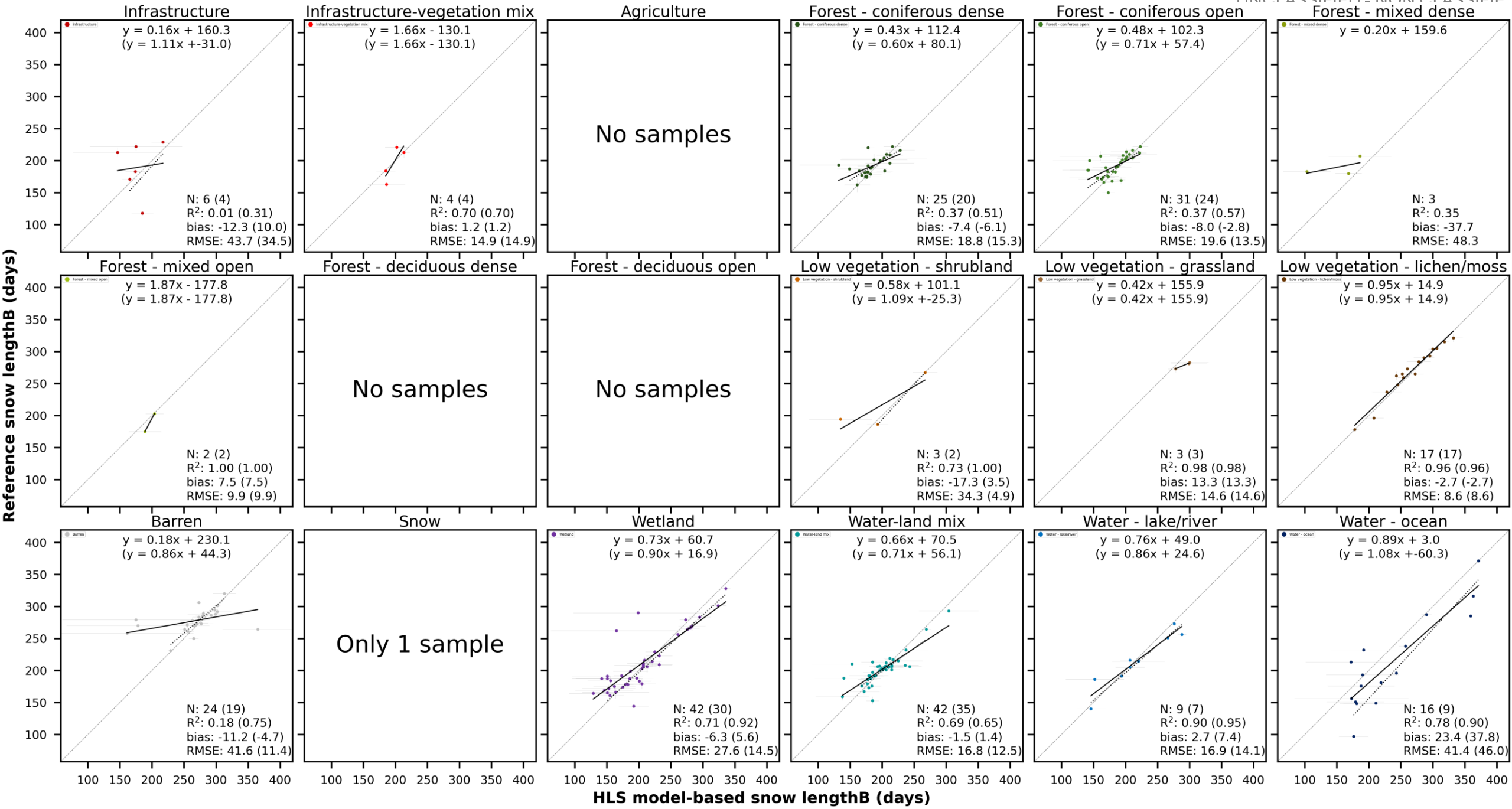












periods

	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 = 2)	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 = 2)	100% (n = 2)	91.7% (n = 12)	100% (n = 15)	100% (n = 1)	95.8% (n = 24)	100% (n = 22)	100% (n = 8)	100% (n = 4)
Two+ periods (observed)	0% (n = 1)	0% (n = 1)	0% (n = 5)	11.1% (n = 9)	n = 0	0% (n = 18)	0% (n = 20)	0% (n = 1)	0% (n = 12)

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

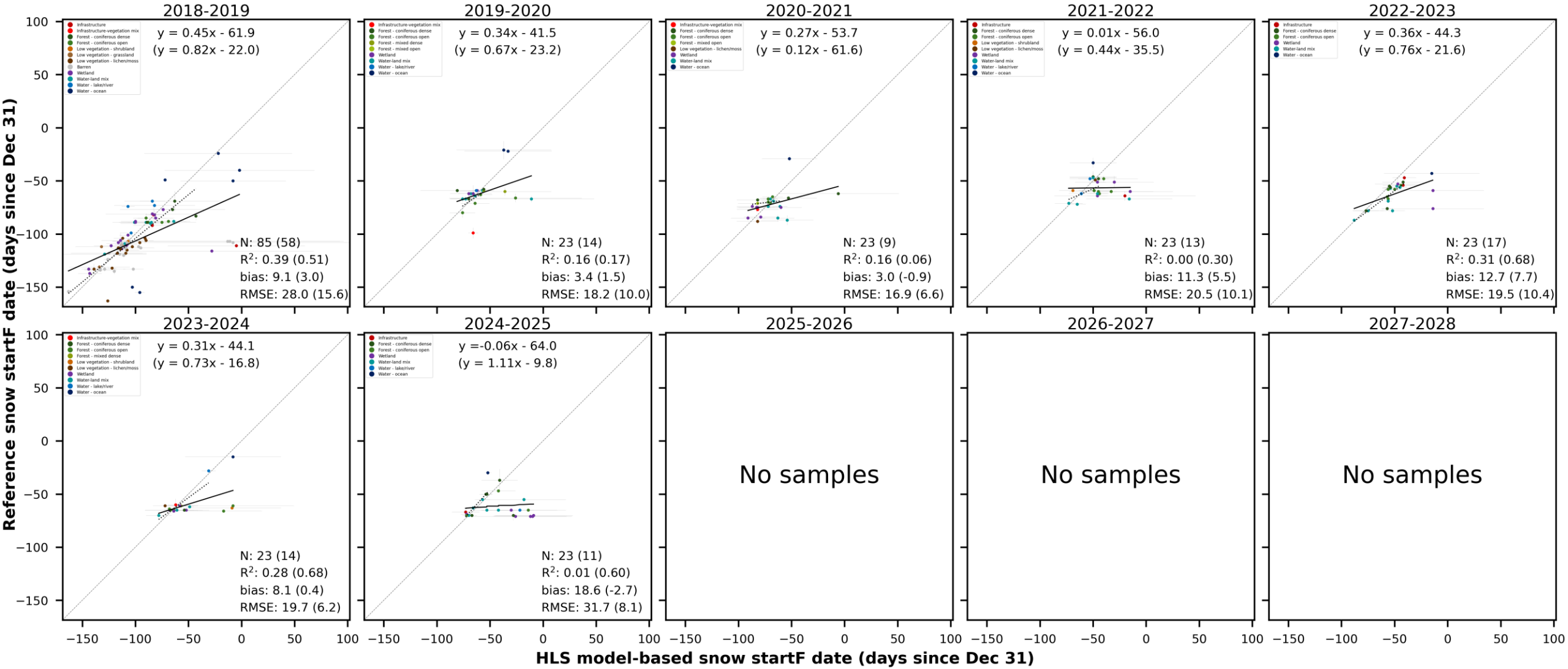
status

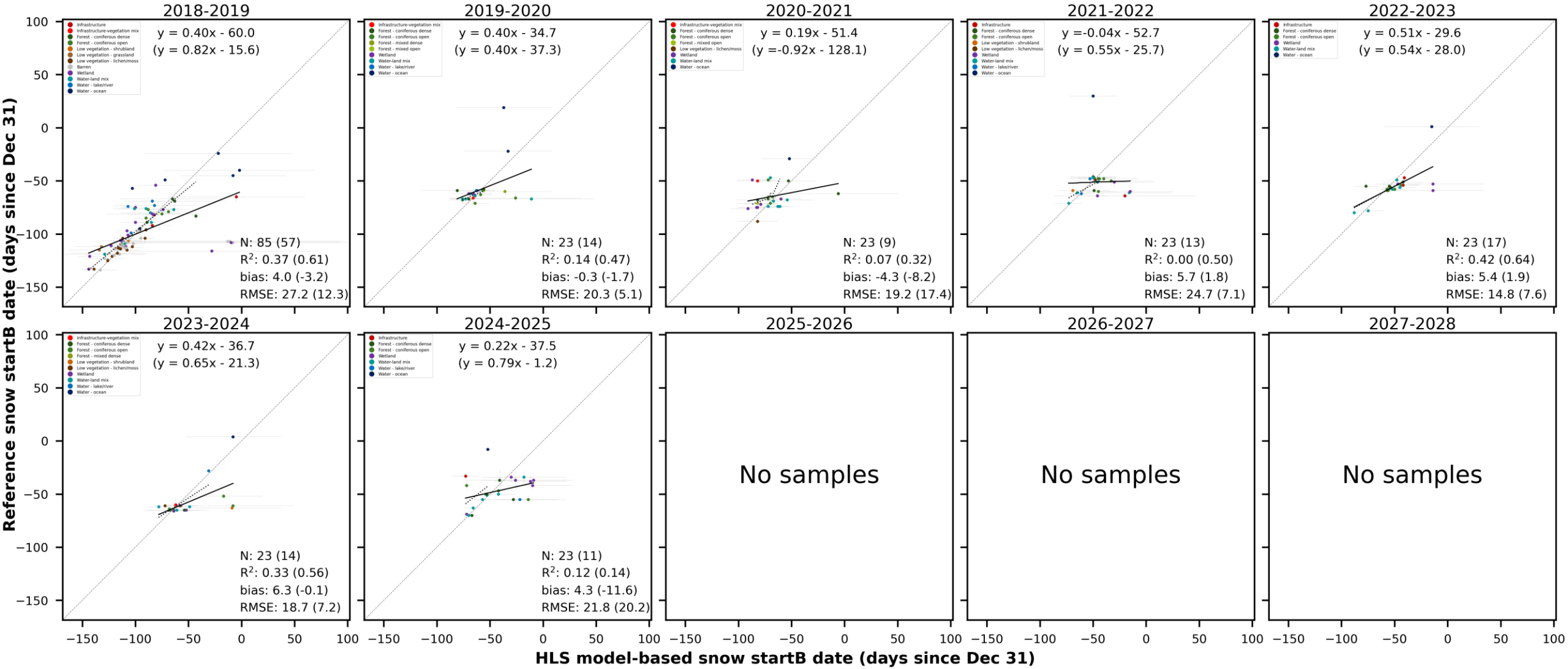
For each observed category, what % of the time did the model agree?

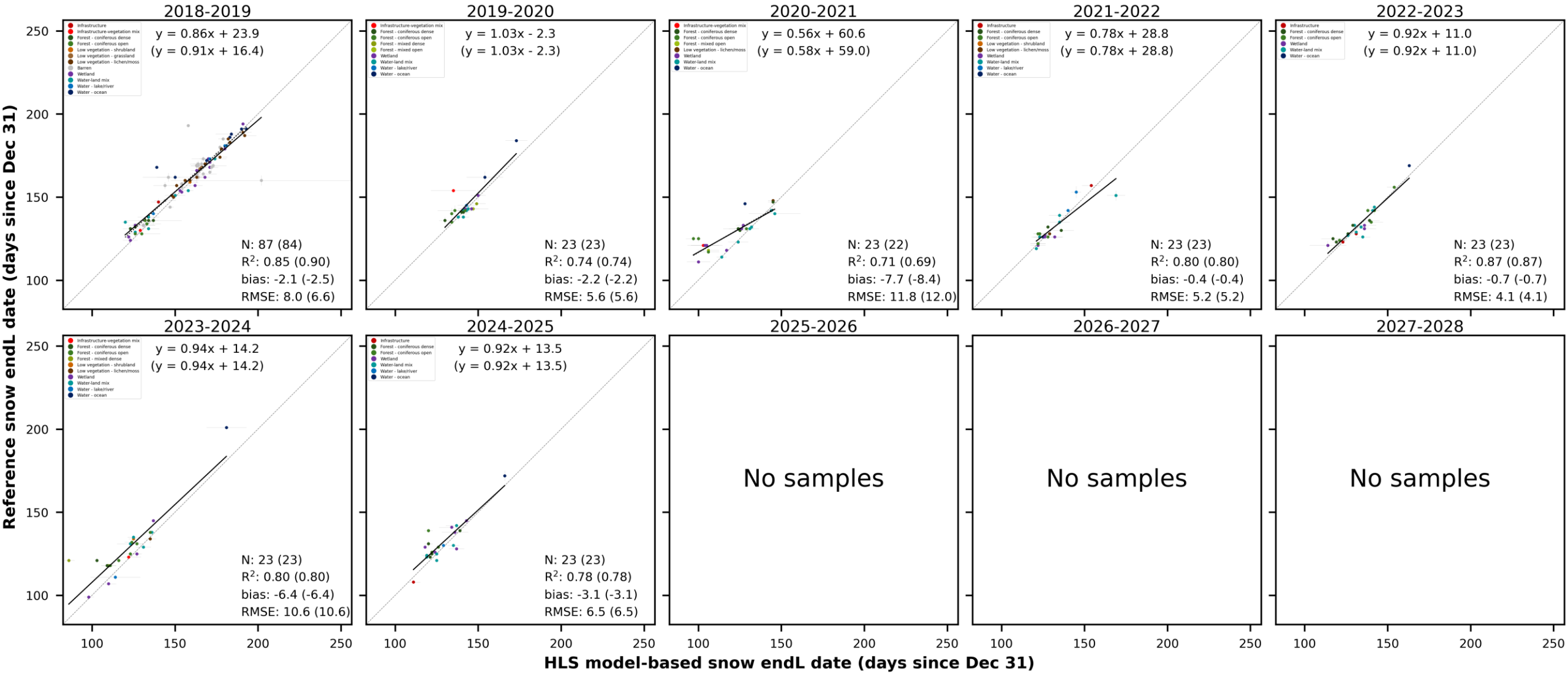
	Infrastructure	Infrastructure-vegetation mix	Agriculture	Forest - coniferous dense	Forest - coniferous open	Forest - mixed dense	Forest - mixed open	Forest - deciduous dense	Forest - deciduous open
Seasonal snow (observed)	100% (n = 6)	100% (n = 4)	n = 0	100% (n = 25)	100% (n = 31)	100% (n = 3)	100% (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
Ephemeral snow (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0

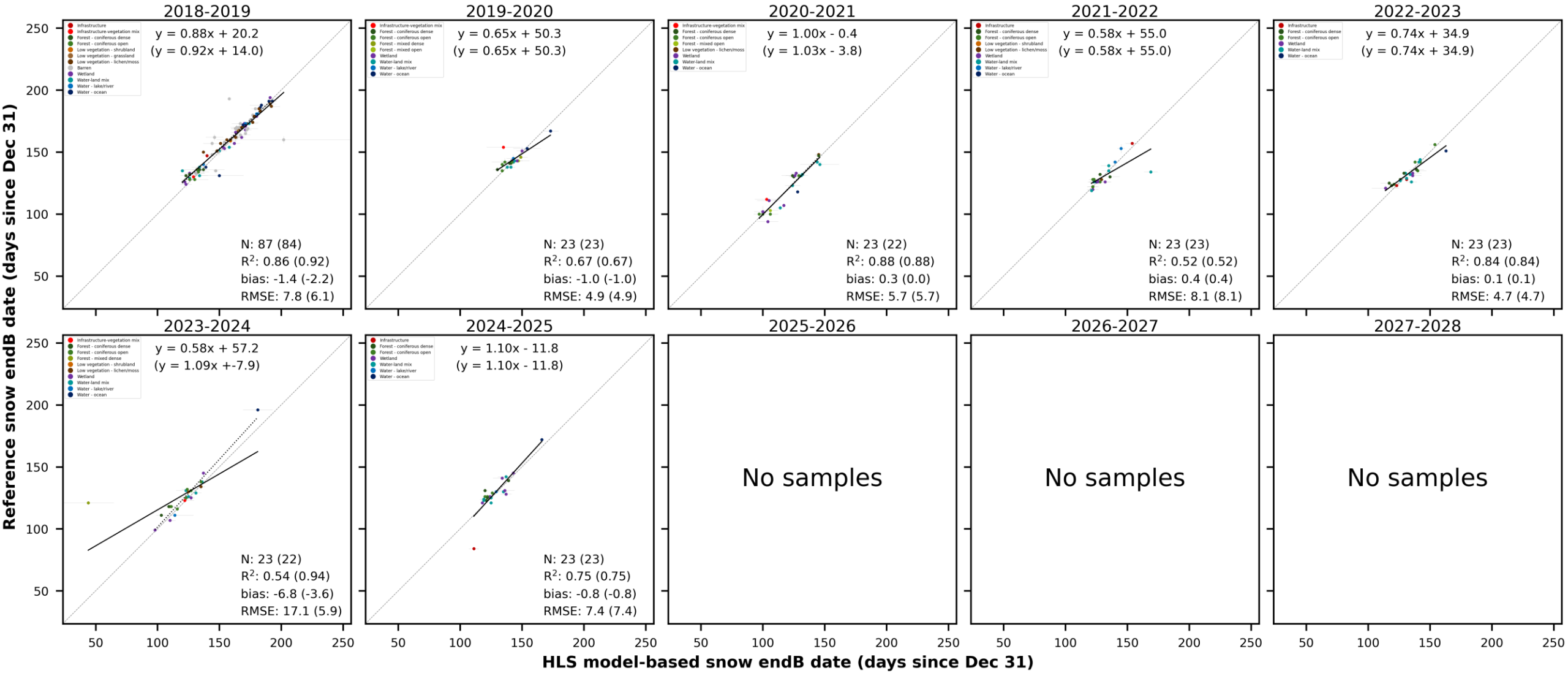
	Low vegetation - shrubland	Low vegetation - grassland	Low vegetation - lichen/moss	Barren	Snow	Wetland	Water-land mix	Water - lake/river	Water - ocean
Seasonal snow (observed)	100% (n = 3)	100% (n = 2)	100% (n = 12)	100% (n = 18)	n = 0	92.5% (n = 40)	100% (n = 42)	100% (n = 6)	100% (n = 10)
Perennial snow (observed)	n = 0	n = 0	n = 0	n = 0	100% (n = 1)	n = 0	n = 0	n = 0	100% (n = 1)
Inconsistent perennial snow (observed)	n = 0	100% (n = 1)	60% (n = 5)	66.7% (n = 6)	n = 0	100% (n = 2)	n = 0	66.7% (n = 3)	80% (n = 5)
Snow free (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0
Ephemeral snow (observed)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0

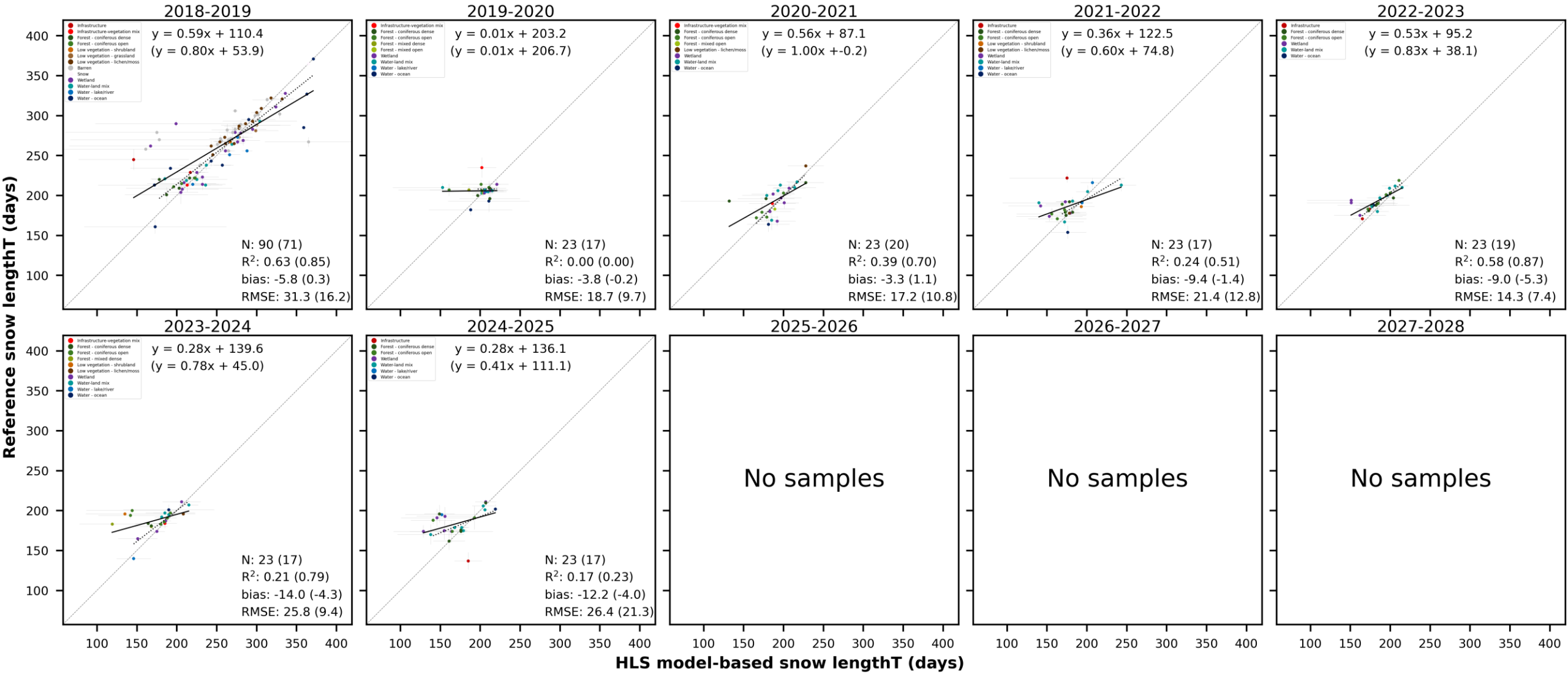
By Winter Year

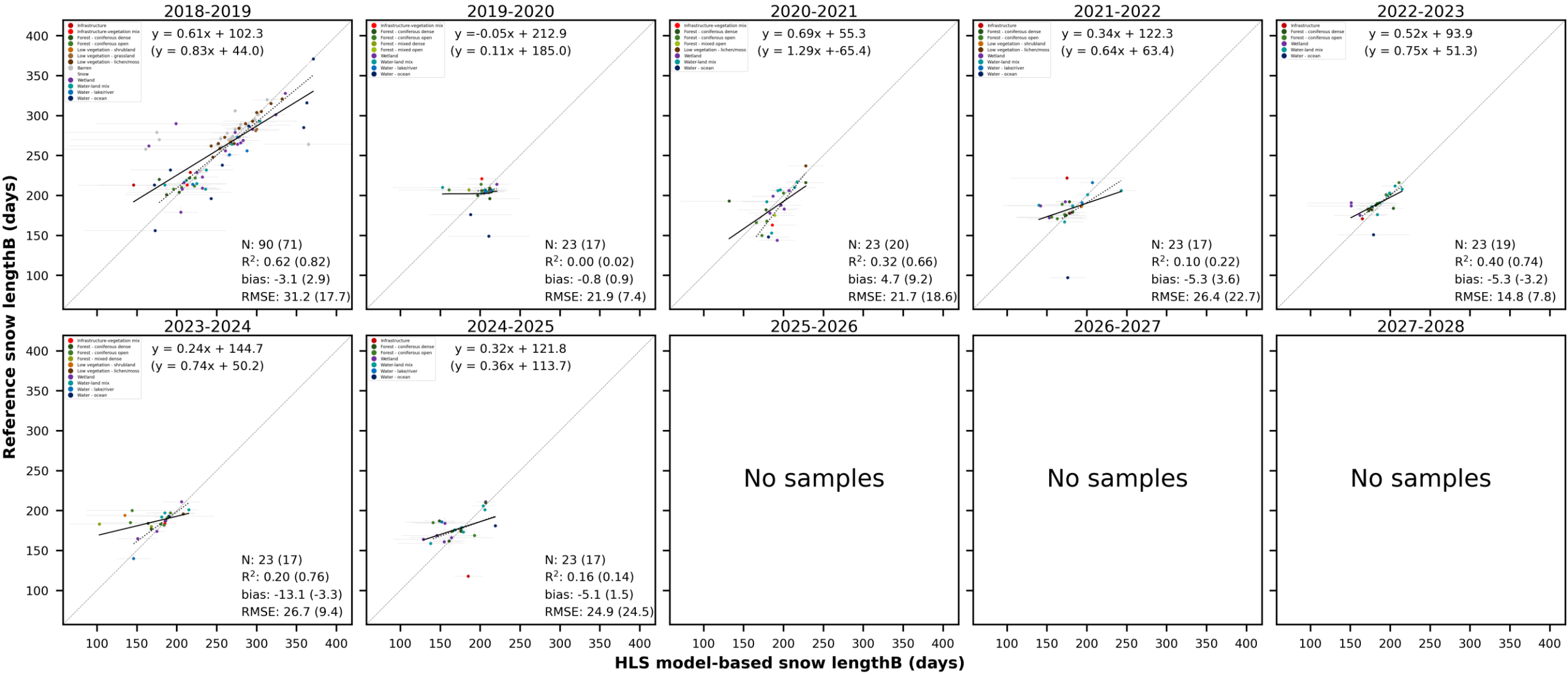

2018-2019
y = 0.45x - 61.9
(y = 0.82x - 22.0)
N: 85 (58)
R²: 0.39 (0.51)
bias: 9.1 (3.0)
RMSE: 28.0 (15.6)
2019-2020
y = 0.34x - 41.5
(y = 0.67x - 23.2)
N: 23 (14)
R²: 0.16 (0.17)
bias: 3.4 (1.5)
RMSE: 18.2 (10.0)
2020-2021
y = 0.27x - 53.7
(y = 0.12x - 61.6)
N: 23 (9)
R²: 0.16 (0.06)
bias: 3.0 (-0.9)
RMSE: 16.9 (6.6)
2021-2022
y = 0.01x - 56.0
(y = 0.44x - 35.5)
N: 23 (13)
R²: 0.00 (0.30)
bias: 11.3 (5.5)
RMSE: 20.5 (10.1)
2022-2023
y = 0.36x - 44.3
(y = 0.76x - 21.6)
N: 23 (17)
R²: 0.31 (0.68)
bias: 12.7 (7.7)
RMSE: 19.5 (10.4)
2023-2024
y = 0.31x - 44.1
(y = 0.73x - 16.8)
N: 23 (14)
R²: 0.28 (0.68)
bias: 8.1 (0.4)
RMSE: 19.7 (6.2)
2024-2025
y =-0.06x - 64.0
(y = 1.11x - 9.8)
N: 23 (11)
R²: 0.01 (0.60)
bias: 18.6 (-2.7)
RMSE: 31.7 (8.1)
2025-2026
No samples
2026-2027
No samples
2027-2028
No samples
Reference snow startF date (days since Dec 31)
HLS model-based snow startF date (days since Dec 31)
100
50
0
−50
−100
−150


2018-2019
y = 0.40x - 60.0
(y = 0.82x - 15.6)
N: 85 (57)
R²: 0.37 (0.61)
bias: 4.0 (-3.2)
RMSE: 27.2 (12.3)
2019-2020
y = 0.40x - 34.7
(y = 0.40x - 37.3)
N: 23 (14)
R²: 0.14 (0.47)
bias: -0.3 (-1.7)
RMSE: 20.3 (5.1)
2020-2021
y = 0.19x - 51.4
(y =-0.92x - 128.1)
N: 23 (9)
R²: 0.07 (0.32)
bias: -4.3 (-8.2)
RMSE: 19.2 (17.4)
2021-2022
y =-0.04x - 52.7
(y = 0.55x - 25.7)
N: 23 (13)
R²: 0.00 (0.50)
bias: 5.7 (1.8)
RMSE: 24.7 (7.1)
2022-2023
y = 0.51x - 29.6
(y = 0.54x - 28.0)
N: 23 (17)
R²: 0.42 (0.64)
bias: 5.4 (1.9)
RMSE: 14.8 (7.6)
2023-2024
y = 0.42x - 36.7
(y = 0.65x - 21.3)
N: 23 (14)
R²: 0.33 (0.56)
bias: 6.3 (-0.1)
RMSE: 18.7 (7.2)
2024-2025
y = 0.22x - 37.5
(y = 0.79x - 1.2)
N: 23 (11)
R²: 0.12 (0.14)
bias: 4.3 (-11.6)
RMSE: 21.8 (20.2)
2025-2026
No samples
2026-2027
No samples
2027-2028
No samples
Reference snow startB date (days since Dec 31)
HLS model-based snow startB date (days since Dec 31)


2018-2019
y = 0.86x + 23.9
(y = 0.91x + 16.4)
N: 87 (84)
R2: 0.85 (0.90)
bias: -2.1 (-2.5)
RMSE: 8.0 (6.6)
2019-2020
y = 1.03x - 2.3
(y = 1.03x - 2.3)
N: 23 (23)
R2: 0.74 (0.74)
bias: -2.2 (-2.2)
RMSE: 5.6 (5.6)
2020-2021
y = 0.56x + 60.6
(y = 0.58x + 59.0)
N: 23 (22)
R2: 0.71 (0.69)
bias: -7.7 (-8.4)
RMSE: 11.8 (12.0)
2021-2022
y = 0.78x + 28.8
(y = 0.78x + 28.8)
N: 23 (23)
R2: 0.80 (0.80)
bias: -0.4 (-0.4)
RMSE: 5.2 (5.2)
2022-2023
y = 0.92x + 11.0
(y = 0.92x + 11.0)
N: 23 (23)
R2: 0.87 (0.87)
bias: -0.7 (-0.7)
RMSE: 4.1 (4.1)
2023-2024
y = 0.94x + 14.2
(y = 0.94x + 14.2)
N: 23 (23)
R2: 0.80 (0.80)
bias: -6.4 (-6.4)
RMSE: 10.6 (10.6)
2024-2025
y = 0.92x + 13.5
(y = 0.92x + 13.5)
N: 23 (23)
R2: 0.78 (0.78)
bias: -3.1 (-3.1)
RMSE: 6.5 (6.5)
2025-2026
No samples
2026-2027
No samples
2027-2028
No samples
Reference snow endL date (days since Dec 31)
HLS model-based snow endL date (days since Dec 31)
100
150
200
250


2018-2019
y = 0.88x + 20.2
(y = 0.92x + 14.0)
N: 87 (84)
R²: 0.86 (0.92)
bias: -1.4 (-2.2)
RMSE: 7.8 (6.1)
2019-2020
y = 0.65x + 50.3
(y = 0.65x + 50.3)
N: 23 (23)
R²: 0.67 (0.67)
bias: -1.0 (-1.0)
RMSE: 4.9 (4.9)
2020-2021
y = 1.00x - 0.4
(y = 1.03x - 3.8)
N: 23 (22)
R²: 0.88 (0.88)
bias: 0.3 (0.0)
RMSE: 5.7 (5.7)
2021-2022
y = 0.58x + 55.0
(y = 0.58x + 55.0)
N: 23 (23)
R²: 0.52 (0.52)
bias: 0.4 (0.4)
RMSE: 8.1 (8.1)
2022-2023
y = 0.74x + 34.9
(y = 0.74x + 34.9)
N: 23 (23)
R²: 0.84 (0.84)
bias: 0.1 (0.1)
RMSE: 4.7 (4.7)
2023-2024
y = 0.58x + 57.2
(y = 1.09x +-7.9)
N: 23 (22)
R²: 0.54 (0.94)
bias: -6.8 (-3.6)
RMSE: 17.1 (5.9)
2024-2025
y = 1.10x - 11.8
(y = 1.10x - 11.8)
N: 23 (23)
R²: 0.75 (0.75)
bias: -0.8 (-0.8)
RMSE: 7.4 (7.4)
2025-2026
No samples
2026-2027
No samples
2027-2028
No samples
Reference snow endB date (days since Dec 31)
HLS model-based snow endB date (days since Dec 31)
50
100
150
200
250


2018-2019
y = 0.59x + 110.4
(y = 0.80x + 53.9)
N: 90 (71)
R²: 0.63 (0.85)
bias: -5.8 (0.3)
RMSE: 31.3 (16.2)
2019-2020
y = 0.01x + 203.2
(y = 0.01x + 206.7)
N: 23 (17)
R²: 0.00 (0.00)
bias: -3.8 (-0.2)
RMSE: 18.7 (9.7)
2020-2021
y = 0.56x + 87.1
(y = 1.00x +-0.2)
N: 23 (20)
R²: 0.39 (0.70)
bias: -3.3 (1.1)
RMSE: 17.2 (10.8)
2021-2022
y = 0.36x + 122.5
(y = 0.60x + 74.8)
N: 23 (17)
R²: 0.24 (0.51)
bias: -9.4 (-1.4)
RMSE: 21.4 (12.8)
2022-2023
y = 0.53x + 95.2
(y = 0.83x + 38.1)
N: 23 (19)
R²: 0.58 (0.87)
bias: -9.0 (-5.3)
RMSE: 14.3 (7.4)
2023-2024
y = 0.28x + 139.6
(y = 0.78x + 45.0)
N: 23 (17)
R²: 0.21 (0.79)
bias: -14.0 (-4.3)
RMSE: 25.8 (9.4)
2024-2025
y = 0.28x + 136.1
(y = 0.41x + 111.1)
N: 23 (17)
R²: 0.17 (0.23)
bias: -12.2 (-4.0)
RMSE: 26.4 (21.3)
2025-2026
No samples
2026-2027
No samples
2027-2028
No samples
Reference snow lengthT (days)
HLS model-based snow lengthT (days)
100
150
200
250
300
350
400


2018-2019
y = 0.61x + 102.3
(y = 0.83x + 44.0)
N: 90 (71)
R²: 0.62 (0.82)
bias: -3.1 (2.9)
RMSE: 31.2 (17.7)
2019-2020
y =-0.05x + 212.9
(y = 0.11x + 185.0)
N: 23 (17)
R²: 0.00 (0.02)
bias: -0.8 (0.9)
RMSE: 21.9 (7.4)
2020-2021
y = 0.69x + 55.3
(y = 1.29x +-65.4)
N: 23 (20)
R²: 0.32 (0.66)
bias: 4.7 (9.2)
RMSE: 21.7 (18.6)
2021-2022
y = 0.34x + 122.3
(y = 0.64x + 63.4)
N: 23 (17)
R²: 0.10 (0.22)
bias: -5.3 (3.6)
RMSE: 26.4 (22.7)
2022-2023
y = 0.52x + 93.9
(y = 0.75x + 51.3)
N: 23 (19)
R²: 0.40 (0.74)
bias: -5.3 (-3.2)
RMSE: 14.8 (7.8)
2023-2024
y = 0.24x + 144.7
(y = 0.74x + 50.2)
N: 23 (17)
R²: 0.20 (0.76)
bias: -13.1 (-3.3)
RMSE: 26.7 (9.4)
2024-2025
y = 0.32x + 121.8
(y = 0.36x + 113.7)
N: 23 (17)
R²: 0.16 (0.14)
bias: -5.1 (1.5)
RMSE: 24.9 (24.5)
2025-2026
No samples
2026-2027
No samples
2027-2028
No samples
Reference snow lengthB (days)
HLS model-based snow lengthB (days)
100
150
200
250
300
350
400

periods

	2018-2019	2019-2020	2020-2021	2021-2022	2022-2023	2023-2024	2024-2025	2025-2026	2026-2027	2027-2028
One period (observed)	96.4% (n = 56)	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)	2.9% (n = 34)	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)	95.5% (n = 66)	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)	100% (n = 2)	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0
Inconsistent perennial snow (observed)	72.7% (n = 22)	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
Ephemeral snow (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

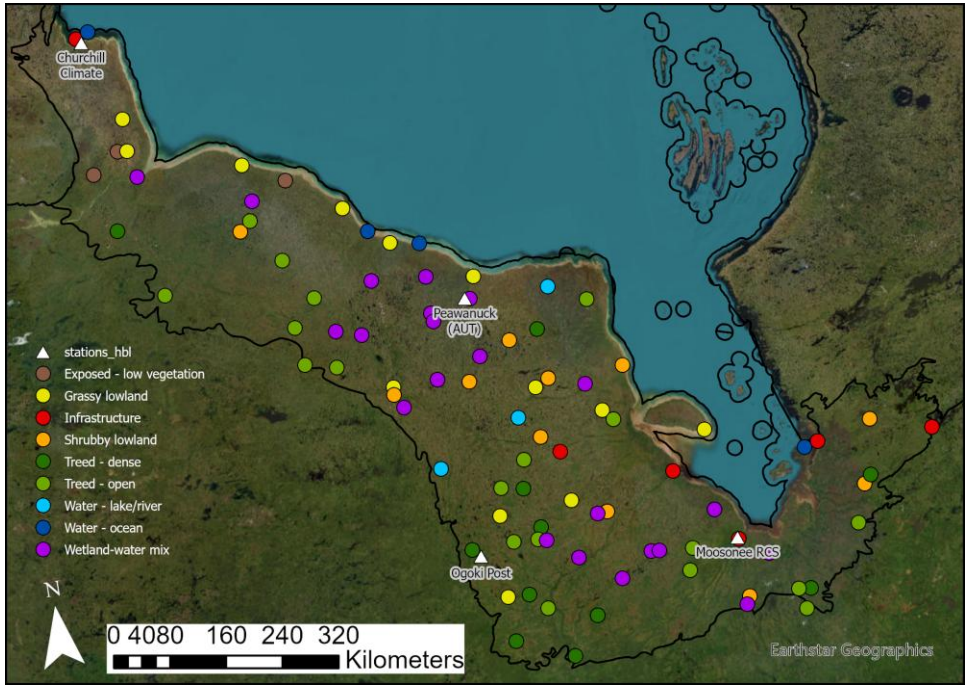
- Daily snow-depth from weather stations
  - Four stations in Hudson Plains analyzed
  - Not a lot for Canada – each site may require some manual adjustments for geolocation and/or measurement error
- Trail cameras: TBD (not many for Canada)
- Coincident very high-resolution validation: TBD

Areas of improvement

- Identification of short-term (<2 weeks) snow/non-snow periods
  - E.g., shifting sea ice
- Performance in areas with dense tree canopy
  - Model does not observe snow under canopy
- Lack of imagery in winter darkness period decreases start performance in far north
  - HLS sun angle filtering removes many potentially useful images
- Performance in areas with complex terrain
  - Topographic shading often classified as clouds/shadow or water

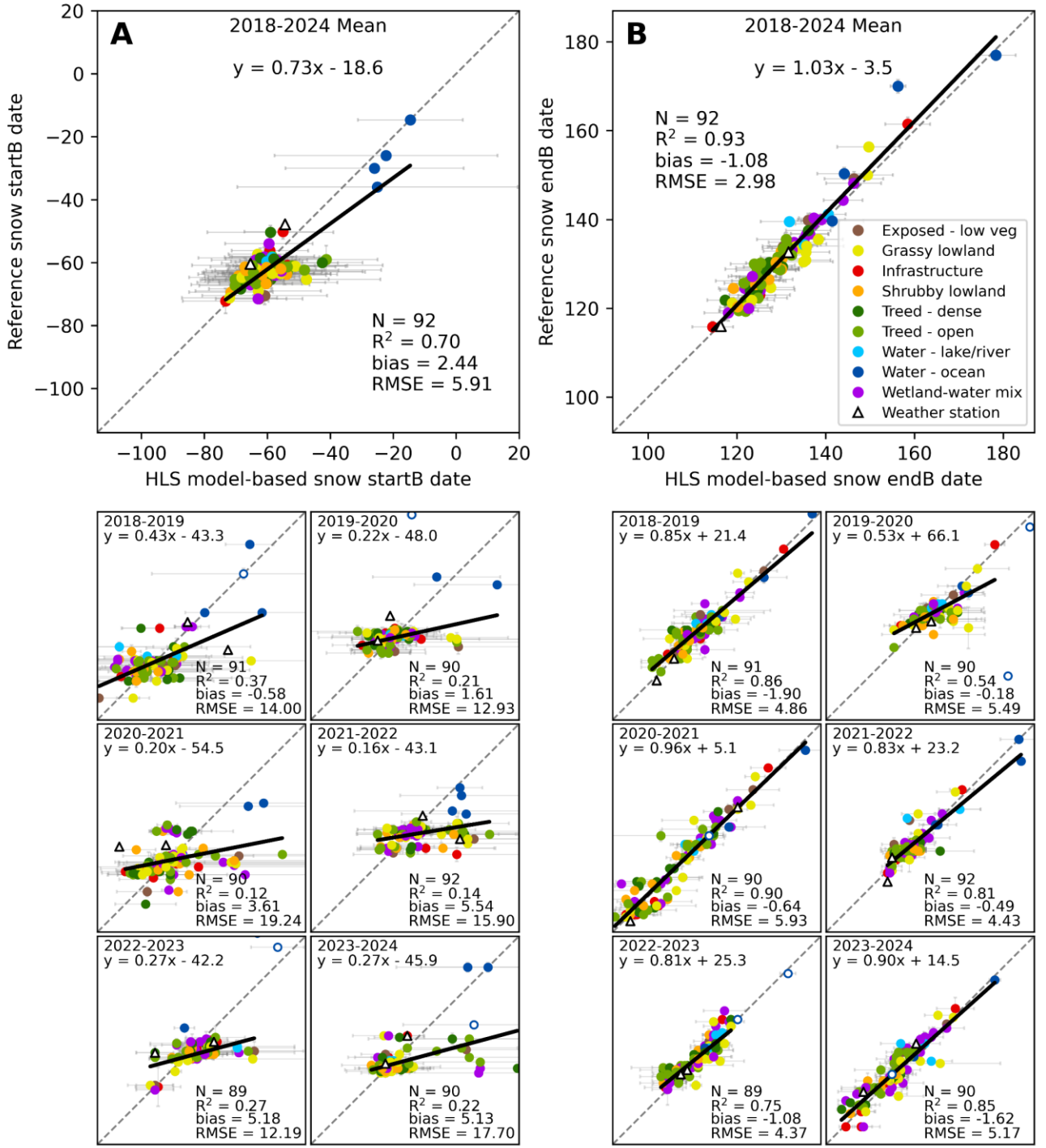
Initial Hudson Plains validation

- 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



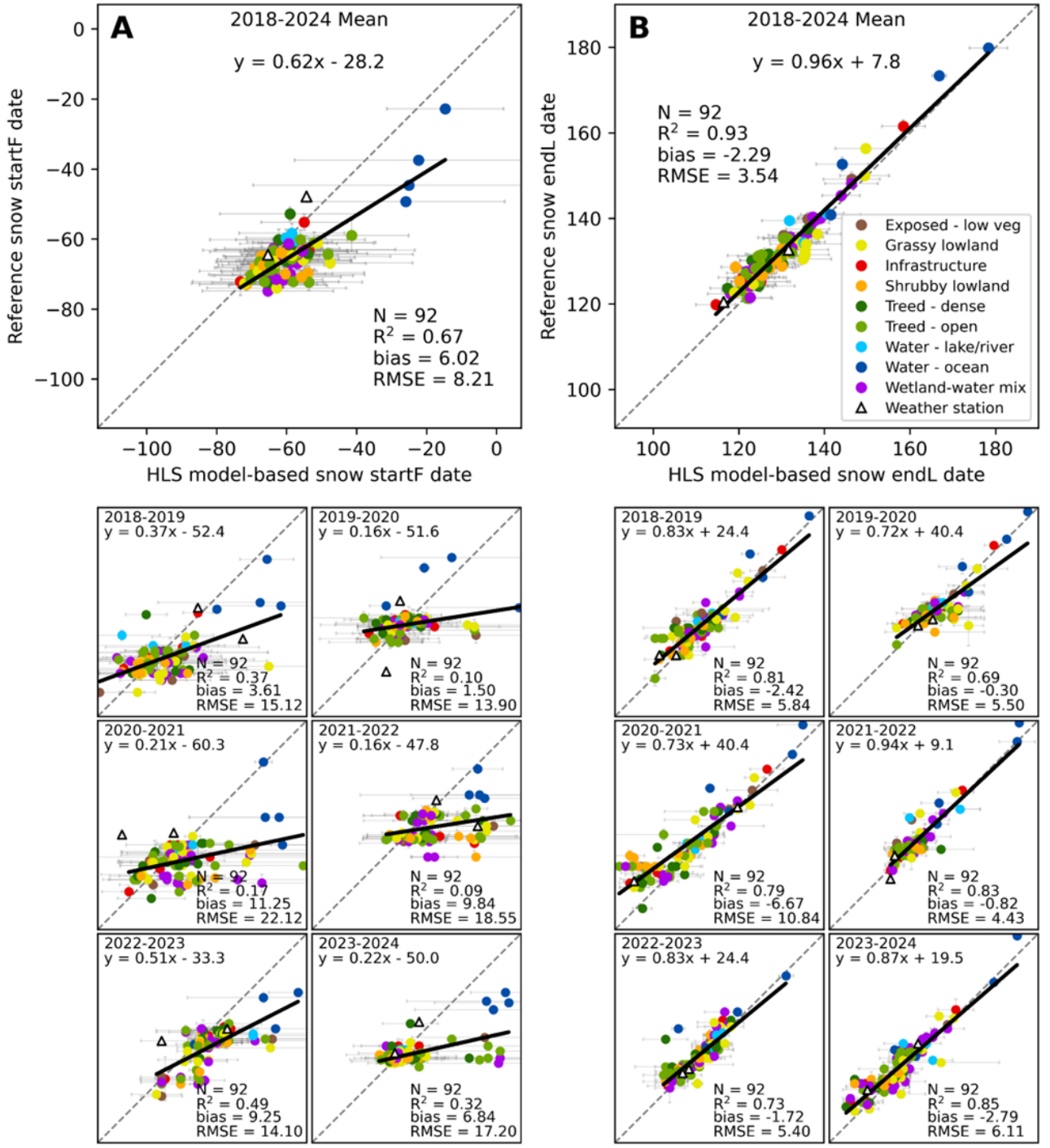
Initial Hudson Plains validation (Paper)

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).