Aiming at an alpine wide assessment of the temporal changes in the distribution of snow depth using quantile regression:

Results from a case study in the southern alps

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Motivation

Why snow?

Expectations with changing climate:

- Less snow (temperatures rising)
- More snow (winter precipitation increasing)

How much can already be seen in past station data?

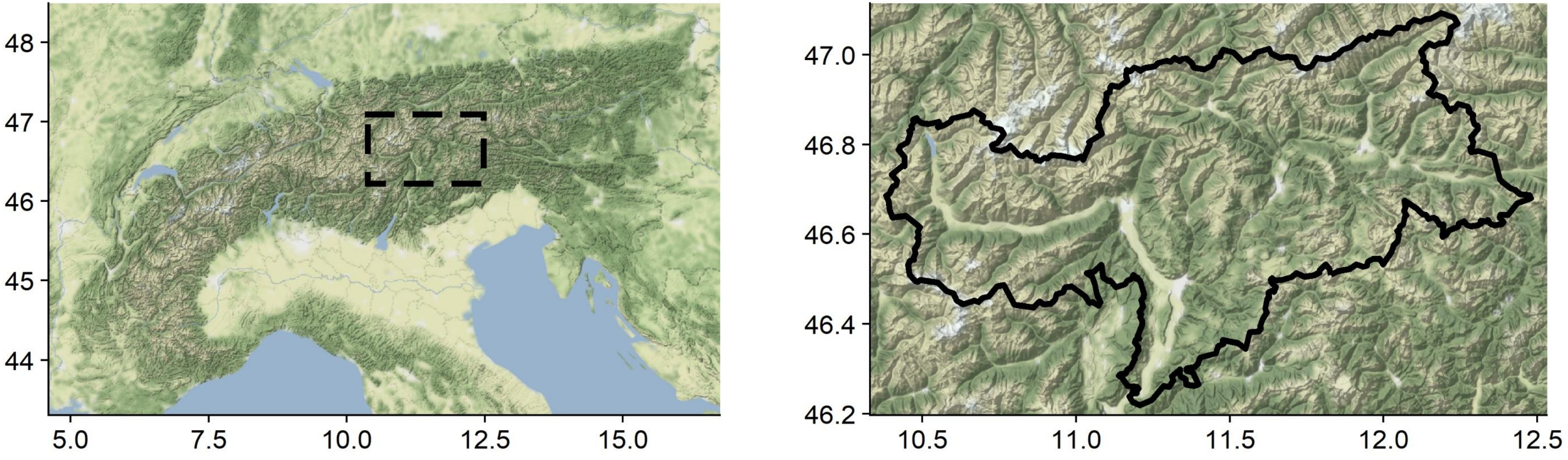
Why alpine wide?

Excellent (sub-)country studies covering the whole alps already exist:

- Can be summarized qualitatively
- Hard to summarize quantitatively (because different winter seasons, parameters, statistics)

A unified approach covering the whole alps would yield a comprehensive view.

Case study area



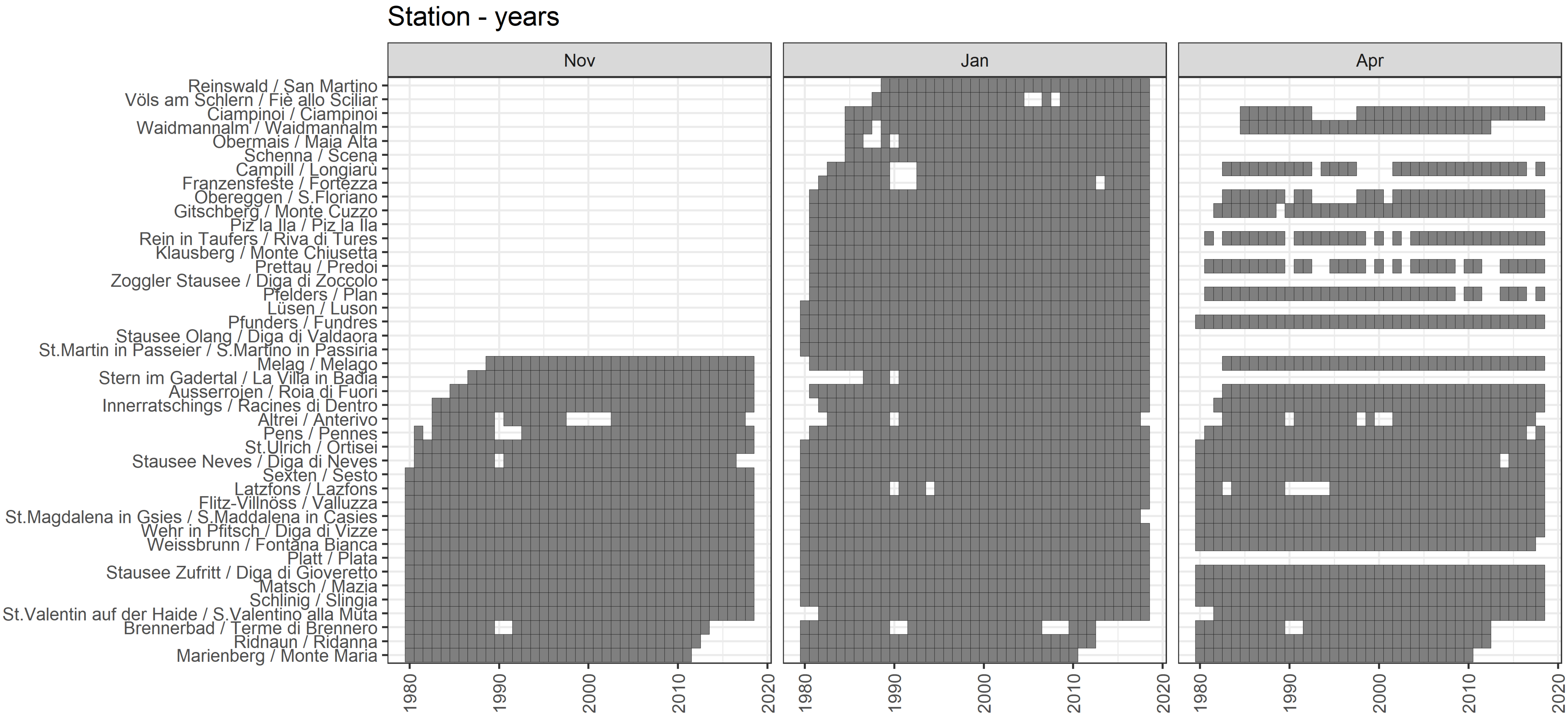
Data

Source: Hydrological office of Bolzano, Italy
Parameter: Snow depth (HS)
Time period: 1980-01-01 – 2019-07-14
Time frequency: Daily
Number of stations: (initial) 101 -> (after QC/subset) 42

Three step data processing:

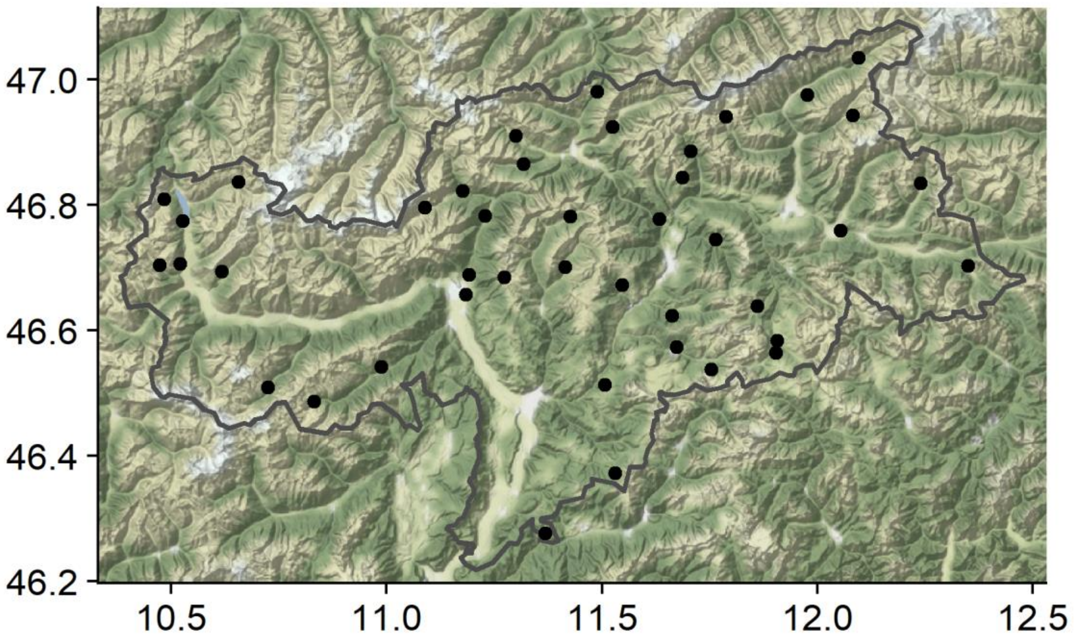
1. Basic QC & pre-subsetting
2. Gapfilling
3. Final subsetting

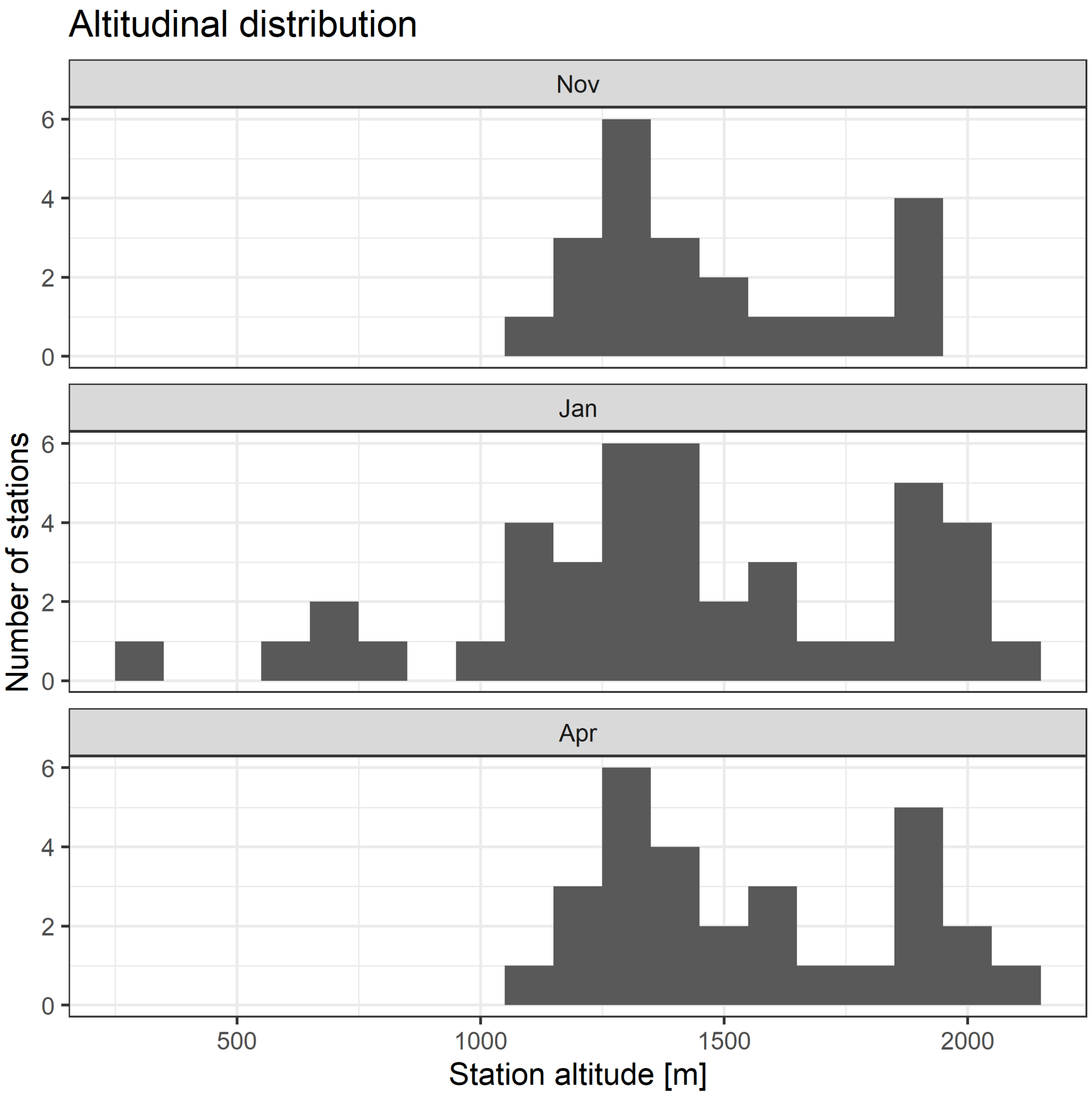
Data



Station - years
Nov
Jan
Apr
Reinswald / San Martino
Völs am Schlern / Fiè allo Sciliar
Ciampinoi / Ciampinoi
Waidmannalm / Waidmannalm
Obermais / Maia Alta
Schenna / Scena
Campill / Longiarù
Franzensfeste / Fortezza
Obereggen / S.Floriano
Gitschberg / Monte Cuzzo
Piz la Ila / Piz la Ila
Rein in Taufers / Riva di Tures
Klausberg / Monte Chiusetta
Prettau / Predoi
Zoggler Stausee / Diga di Zoccolo
Pfelders / Plan
Lüsen / Luson
Pfunders / Fundres
Stausee Olang / Diga di Valdaora
St.Martin in Passeier / S.Martino in Passiria
Melag / Melago
Stern im Gadertal / La Villa in Badia
Ausserrojen / Roia di Fuori
Innerratschings / Racines di Dentro
Altrei / Anterivo
Pens / Pennes
St.Ulrich / Ortisei
Stausee Neves / Diga di Neves
Sexten / Sesto
Latzfons / Lazfons
Flitz-Villnöss / Valluzza
St.Magdalena in Gsies / S.Maddalena in Casies
Wehr in Pfitsch / Diga di Vizze
Weissbrunn / Fontana Bianca
Platt / Plata
Stausee Zufritt / Diga di Gioveretto
Matsch / Mazia
Schlinig / Slingia
St.Valentin auf der Haide / S.Valentino alla Muta
Brennerbad / Terme di Brennero
Ridnaun / Ridanna
Marienberg / Monte Maria
1980
1990
2000
2010
2020

Data


47.0
46.8
46.6
46.4
46.2
10.5
11.0
11.5
12.0
12.5


Altitudinal distribution
Nov
Jan
Apr
Number of stations
0
2
4
6
500
1000
1500
2000
Station altitude [m]

Quantile Regression: Intro

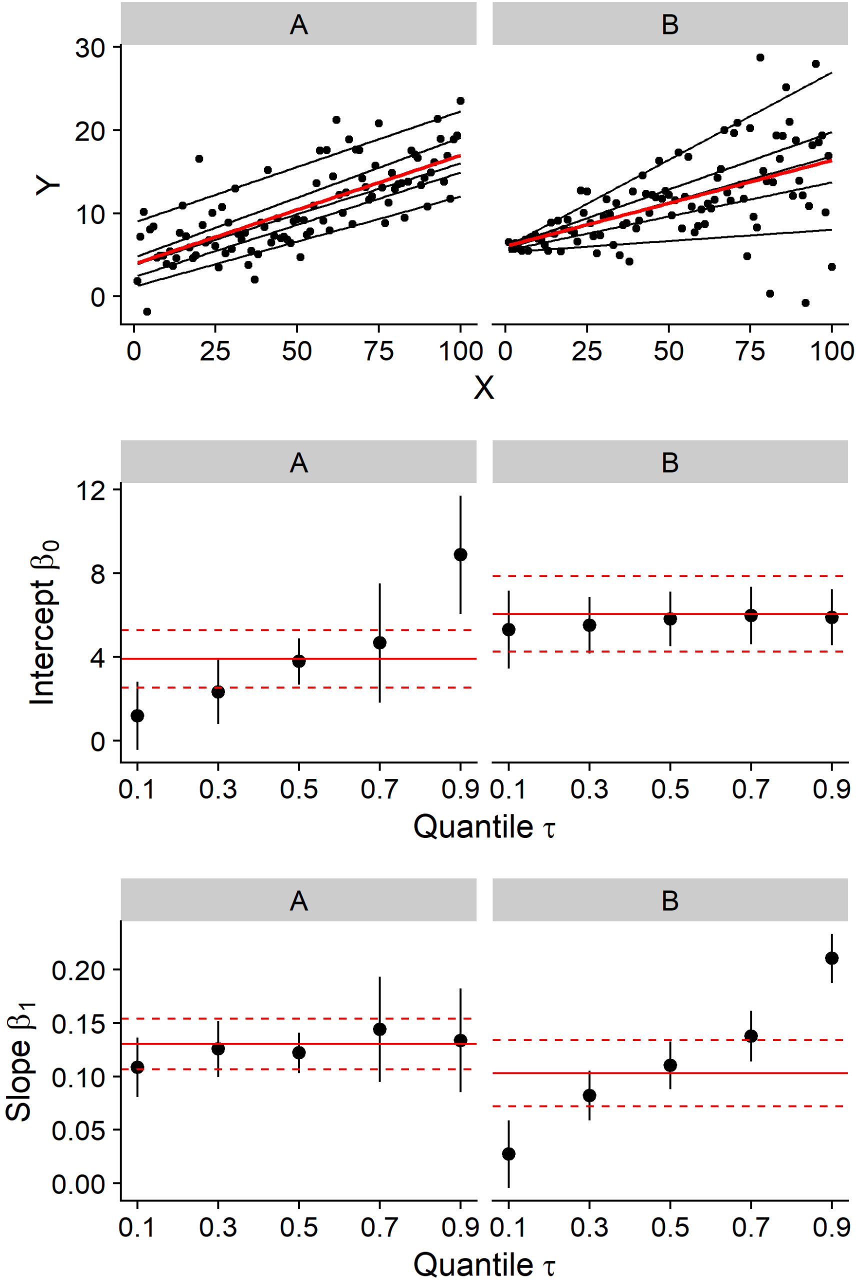
- Statistical regression technique
- Allows differing coefficients (trends) by quantile (tau) of response variable:

$$Q_y(\tau|X) = \beta_0(\tau) + \beta_1(\tau)X_1 + \beta_2(\tau)X_2 + \cdots$$

compared to OLS, which models the mean:

$$E(y|X) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots$$

- Suited for
  - Heterogenic variances
  - Modelling changes in the distribution



Quantile Regression: Model setup

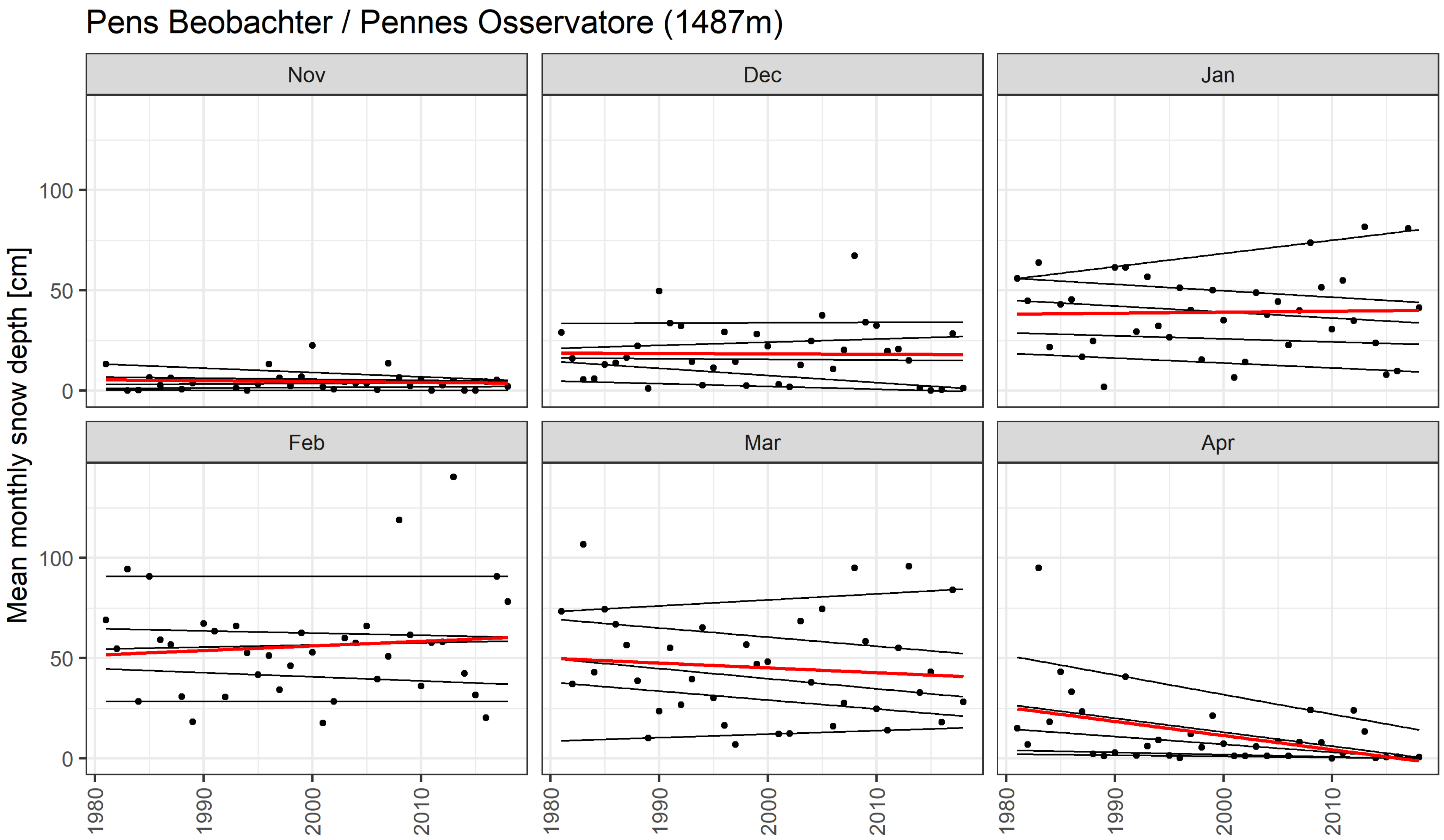
- Separate models by
  - Station
  - Month
- Covariate is season-year only
  (e.g. Sep 2013-May 2014 all have season-year 2013)
- Five quantiles:

$$\tau \in (0.1, 0.3, 0.5, 0.7, 0.9)$$

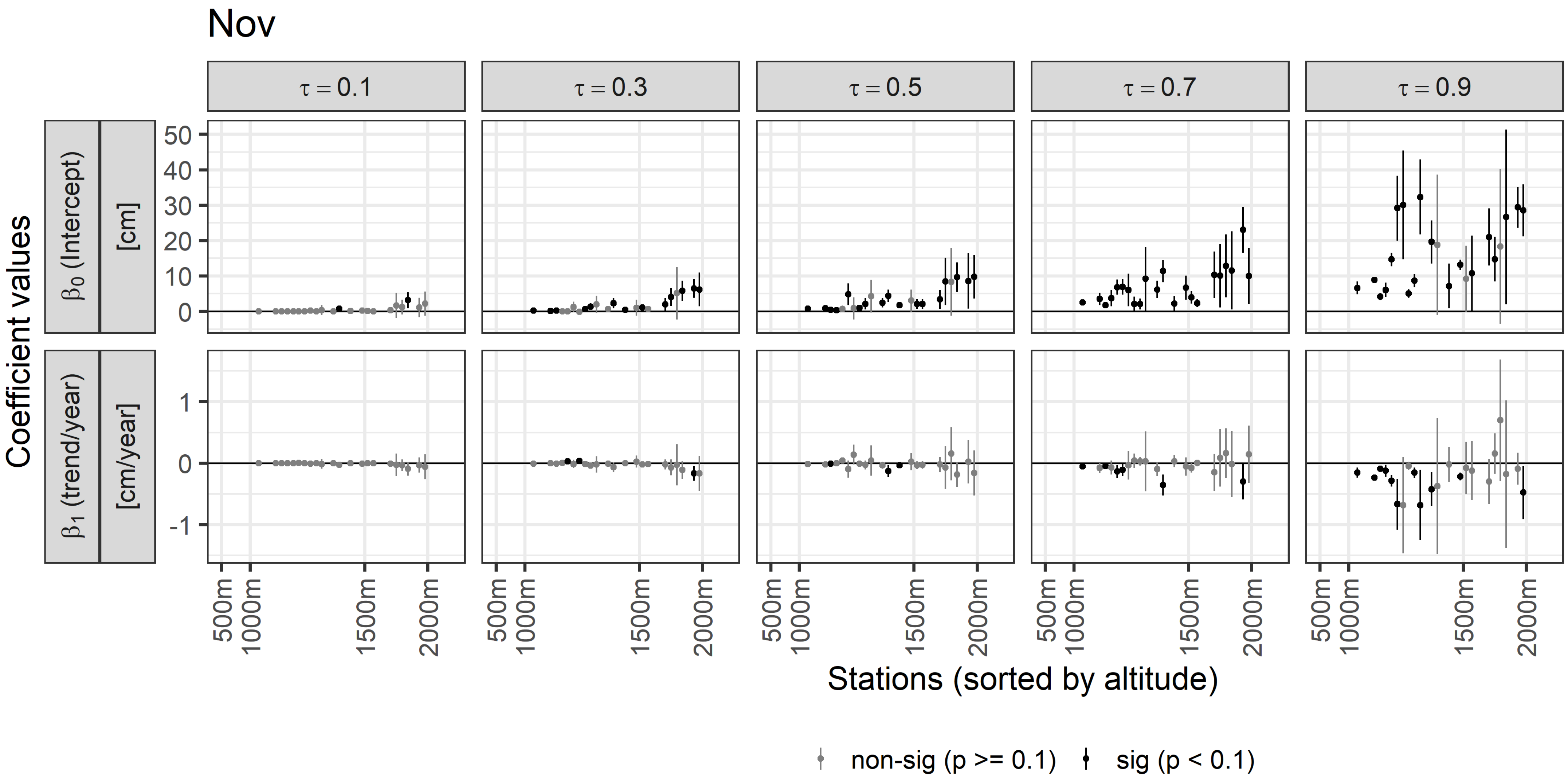
- Model formula:

$$Q_{HS_i}(\tau|X) = \beta_0(\tau) + \beta_1(\tau) seasonyear_i \quad \text{for} \quad i \in 1, \ldots, n$$

Quantile Regression: Real data example

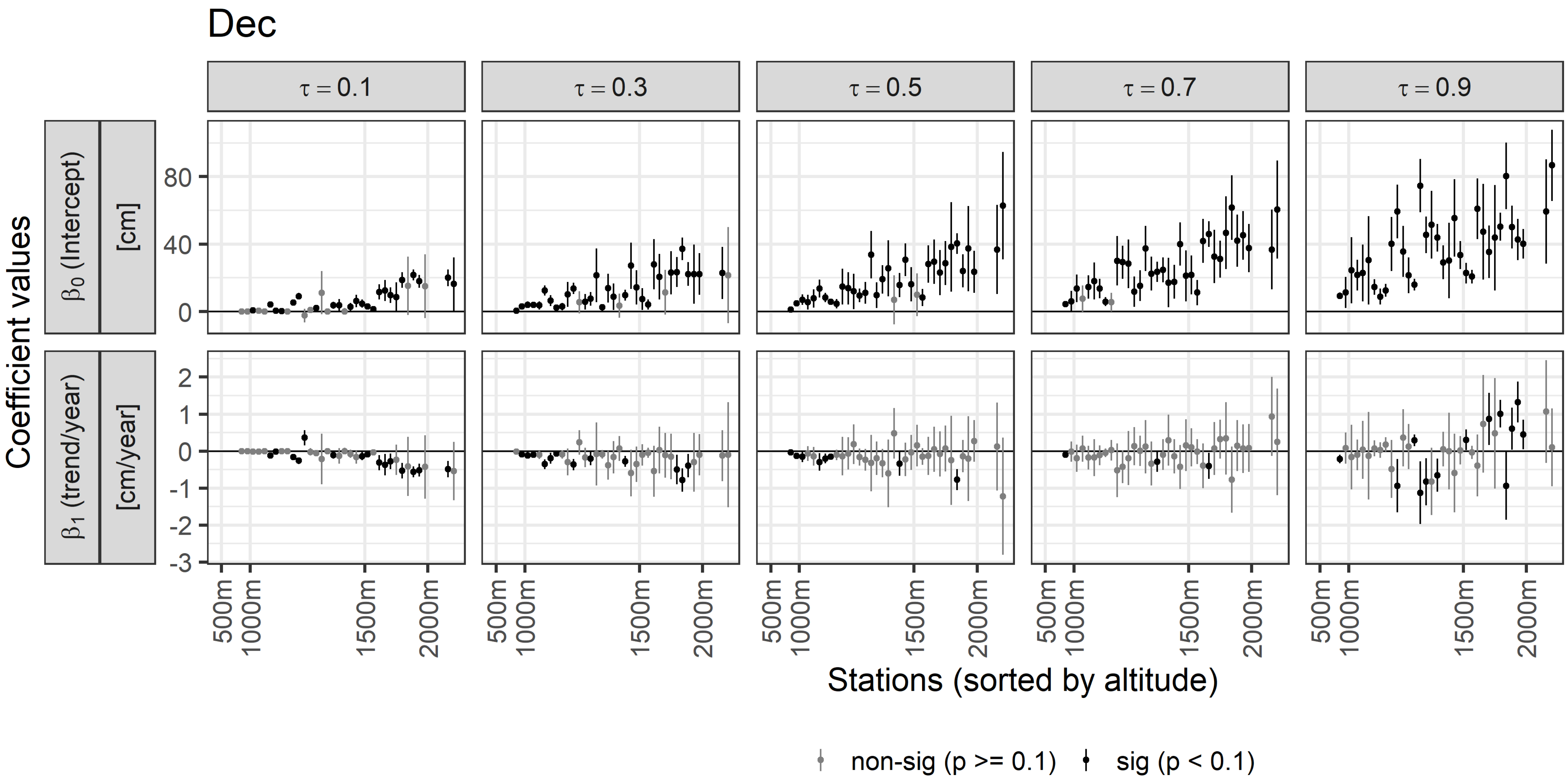


Results

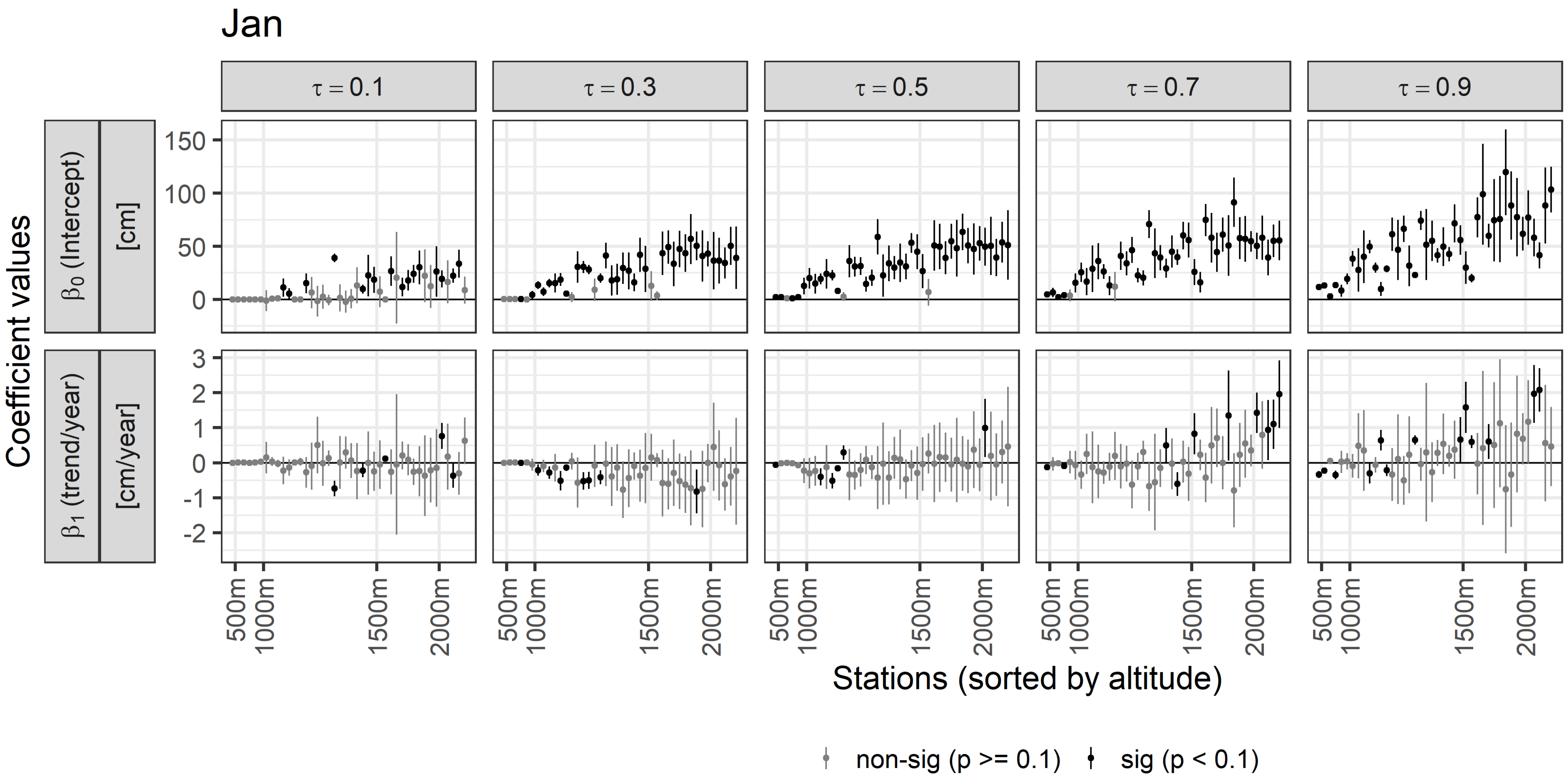


Nov
τ = 0.1
τ = 0.3
τ = 0.5
τ = 0.7
τ = 0.9
Coefficient values
β0 (Intercept)
[cm]
β1 (trend/year)
[cm/year]
50
40
30
20
10
0
1
0
-1
500m
1000m
1500m
2000m
Stations (sorted by altitude)
non-sig (p >= 0.1)
sig (p < 0.1)

Results

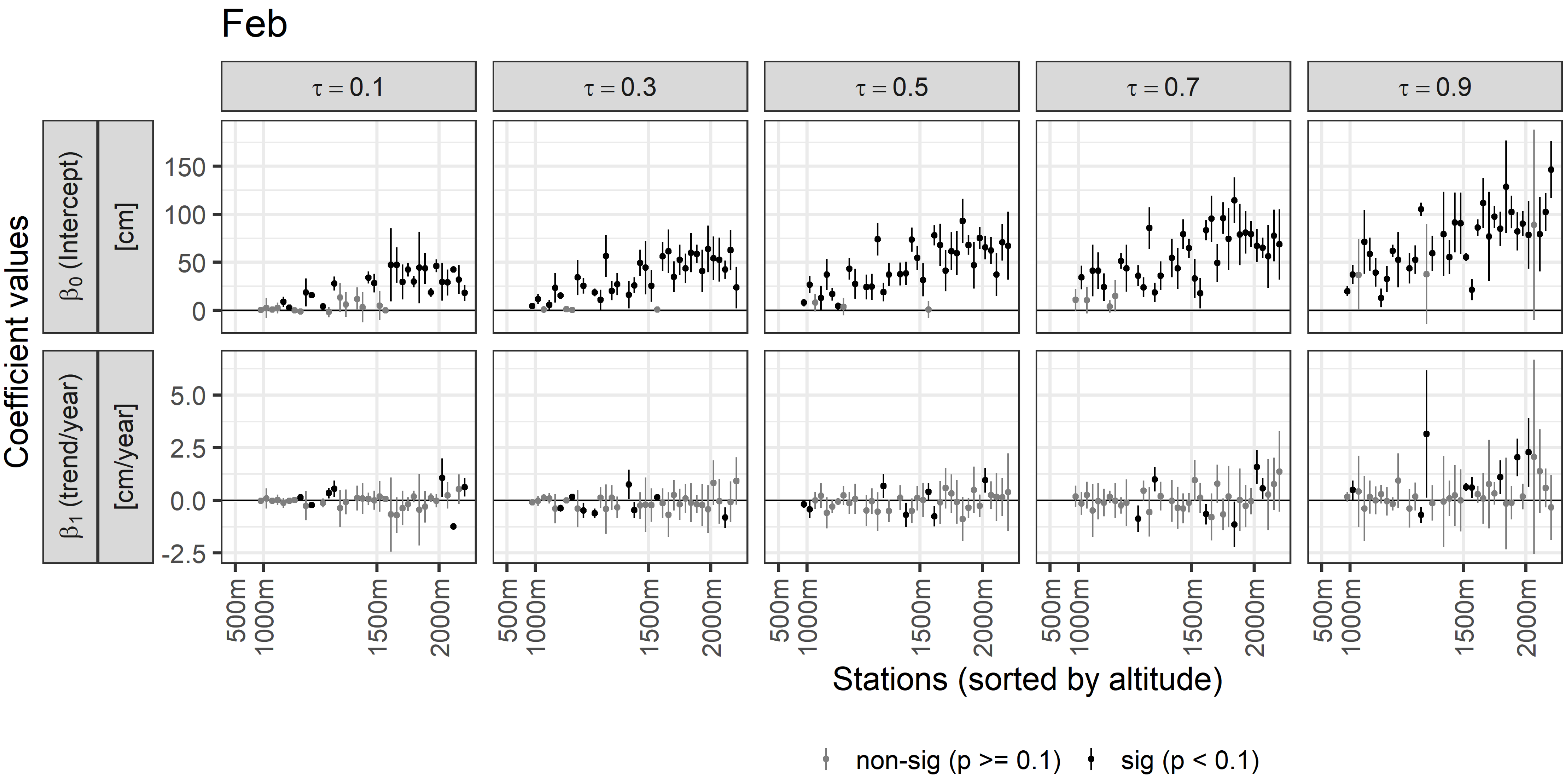

Dec
τ = 0.1
τ = 0.3
τ = 0.5
τ = 0.7
τ = 0.9
Coefficient values
β0 (Intercept)
[cm]
β1 (trend/year)
[cm/year]
80
40
0
2
1
0
-1
-2
-3
500m
1000m
1500m
2000m
Stations (sorted by altitude)
non-sig (p >= 0.1)
sig (p < 0.1)

Results



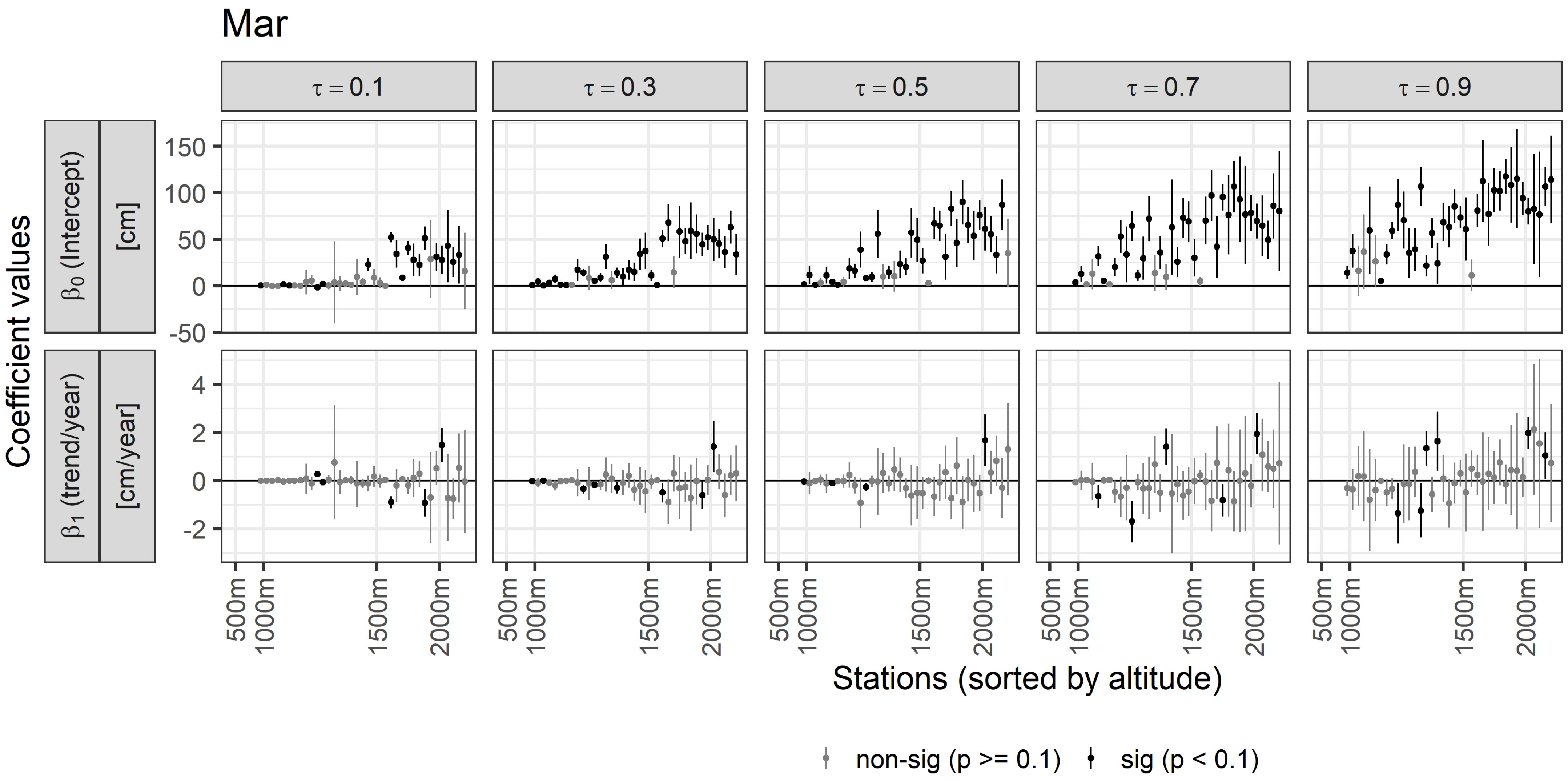
Jan
τ = 0.1
τ = 0.3
τ = 0.5
τ = 0.7
τ = 0.9
Coefficient values
β0 (Intercept)
[cm]
β1 (trend/year)
[cm/year]
150
100
50
0
3
2
1
0
-1
-2
500m
1000m
1500m
2000m
Stations (sorted by altitude)
non-sig (p >= 0.1)
sig (p < 0.1)

Results



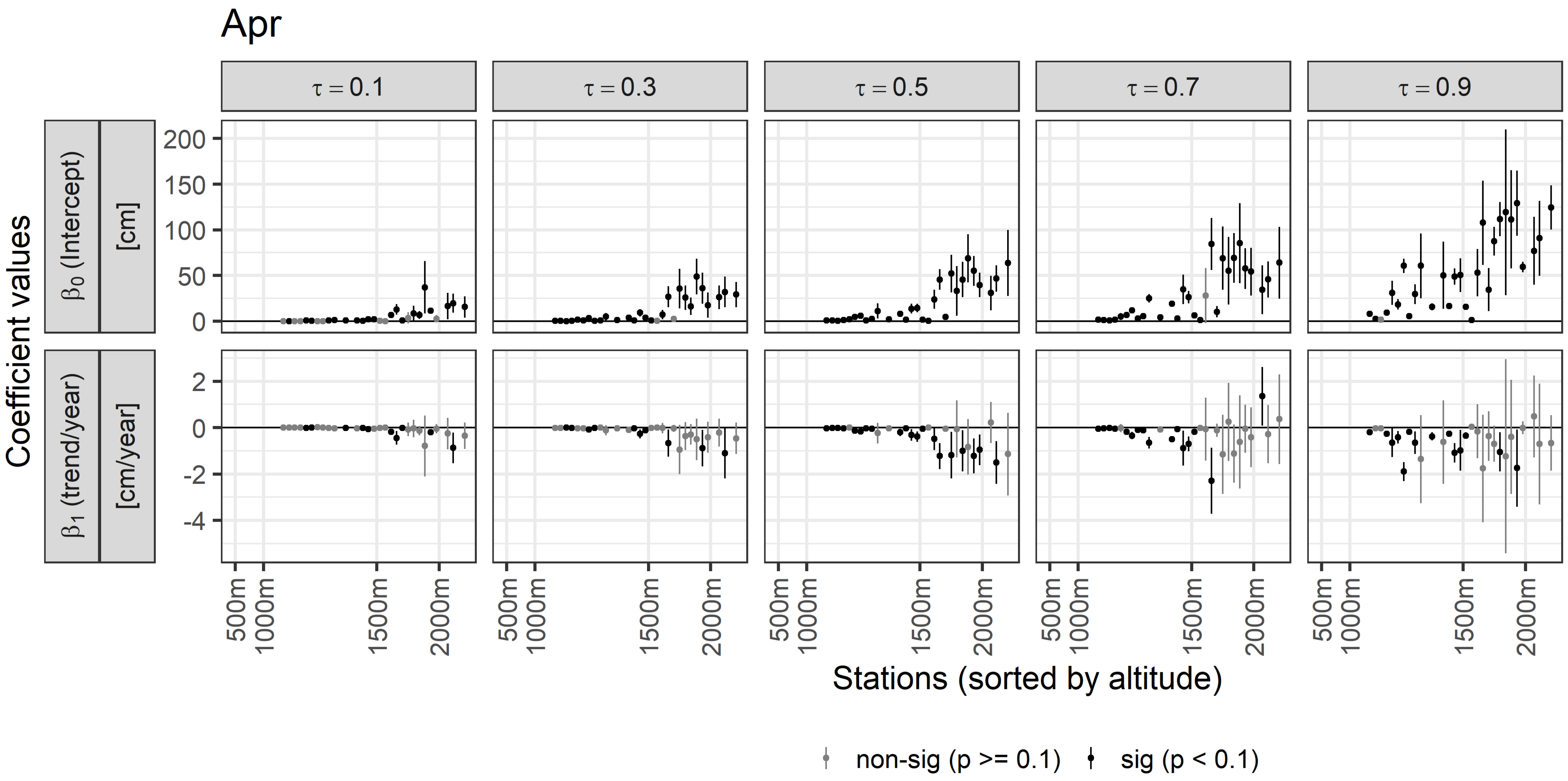
Feb
τ = 0.1
τ = 0.3
τ = 0.5
τ = 0.7
τ = 0.9
Coefficient values
β0 (Intercept)
[cm]
β1 (trend/year)
[cm/year]
150
100
50
0
5.0
2.5
0.0
-2.5
500m
1000m
1500m
2000m
Stations (sorted by altitude)
non-sig (p >= 0.1)
sig (p < 0.1)

Results



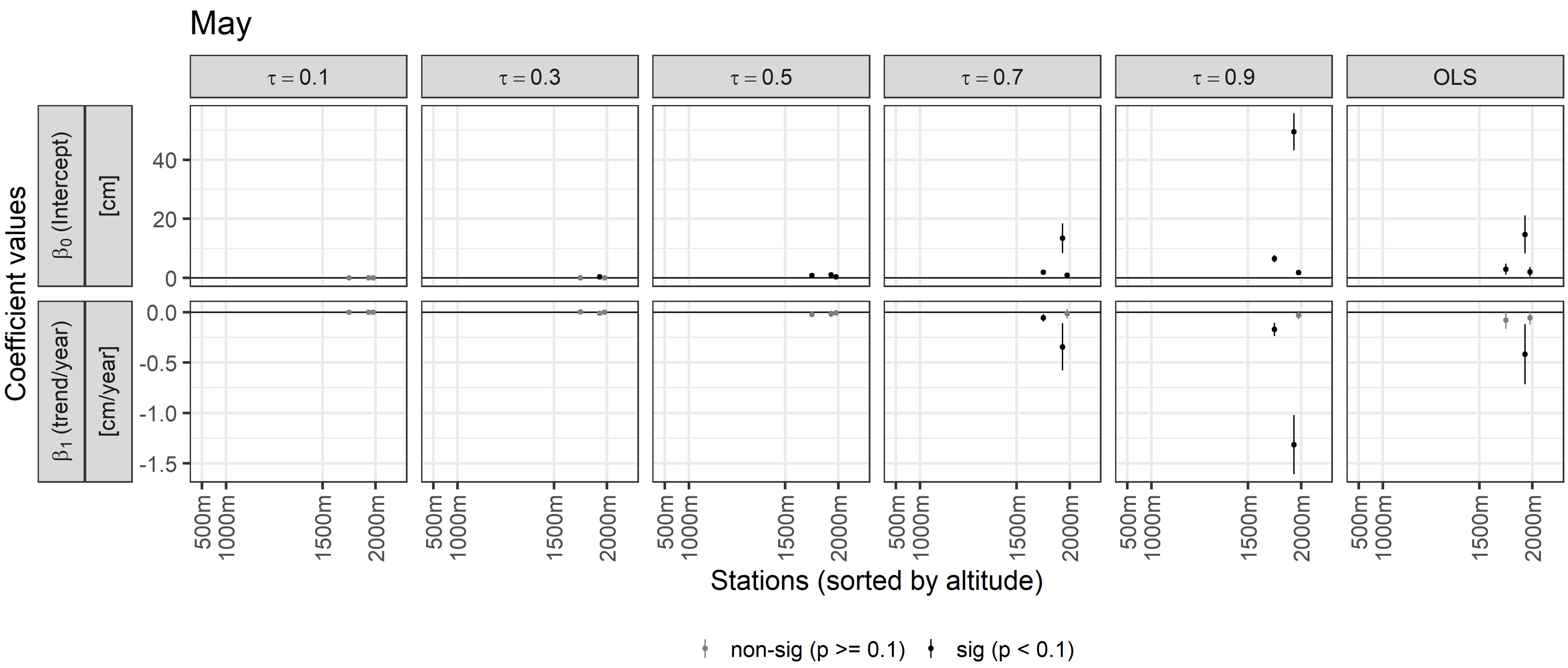
Mar
τ = 0.1
τ = 0.3
τ = 0.5
τ = 0.7
τ = 0.9
Coefficient values
β0 (Intercept)
[cm]
β1 (trend/year)
[cm/year]
150
100
50
0
-50
4
2
0
-2
500m
1000m
1500m
2000m
Stations (sorted by altitude)
non-sig (p >= 0.1)
sig (p < 0.1)

Results



Apr
$\tau = 0.1$
$\tau = 0.3$
$\tau = 0.5$
$\tau = 0.7$
$\tau = 0.9$
Coefficient values
β_0 (Intercept)
[cm]
β_1 (trend/year)
[cm/year]
200
150
100
50
0
2
0
-2
-4
500m
1000m
1500m
2000m
Stations (sorted by altitude)
non-sig (p >= 0.1)
sig (p < 0.1)

Results



May
τ = 0.1
τ = 0.3
τ = 0.5
τ = 0.7
τ = 0.9
OLS
Coefficient values
β0 (Intercept)
[cm]
β1 (trend/year)
[cm/year]
40
20
0
0.0
-0.5
-1.0
-1.5
500m
1000m
1500m
2000m
Stations (sorted by altitude)
non-sig (p >= 0.1)
sig (p < 0.1)

Conclusion

Results indicate

- Strongest decreases of snow depth in April-May
- Decreases in winter snow depth for low&mid-altitudes (< ~1500m) (temperature dominated); with some exceptions
- Increased variability in winter for high altitudes (> ~1500m) (because of increased persistence? precipitation dominated)

Quantile regression

- Is a useful tool to quantify changes in past snow depth
- Can provide a more comprehensive view of trends compared to OLS

Outlook

We aim to

- Collect more snow depth data (starting at least before 1990) in the alps
- Check the robustness of the trends (-> sensitivity analysis)
- With more data, also evaluate trend magnitude by latitude and longitude

We are looking for collaborators

- With local/regional expertise
- Possibly with access to historical data

Contact

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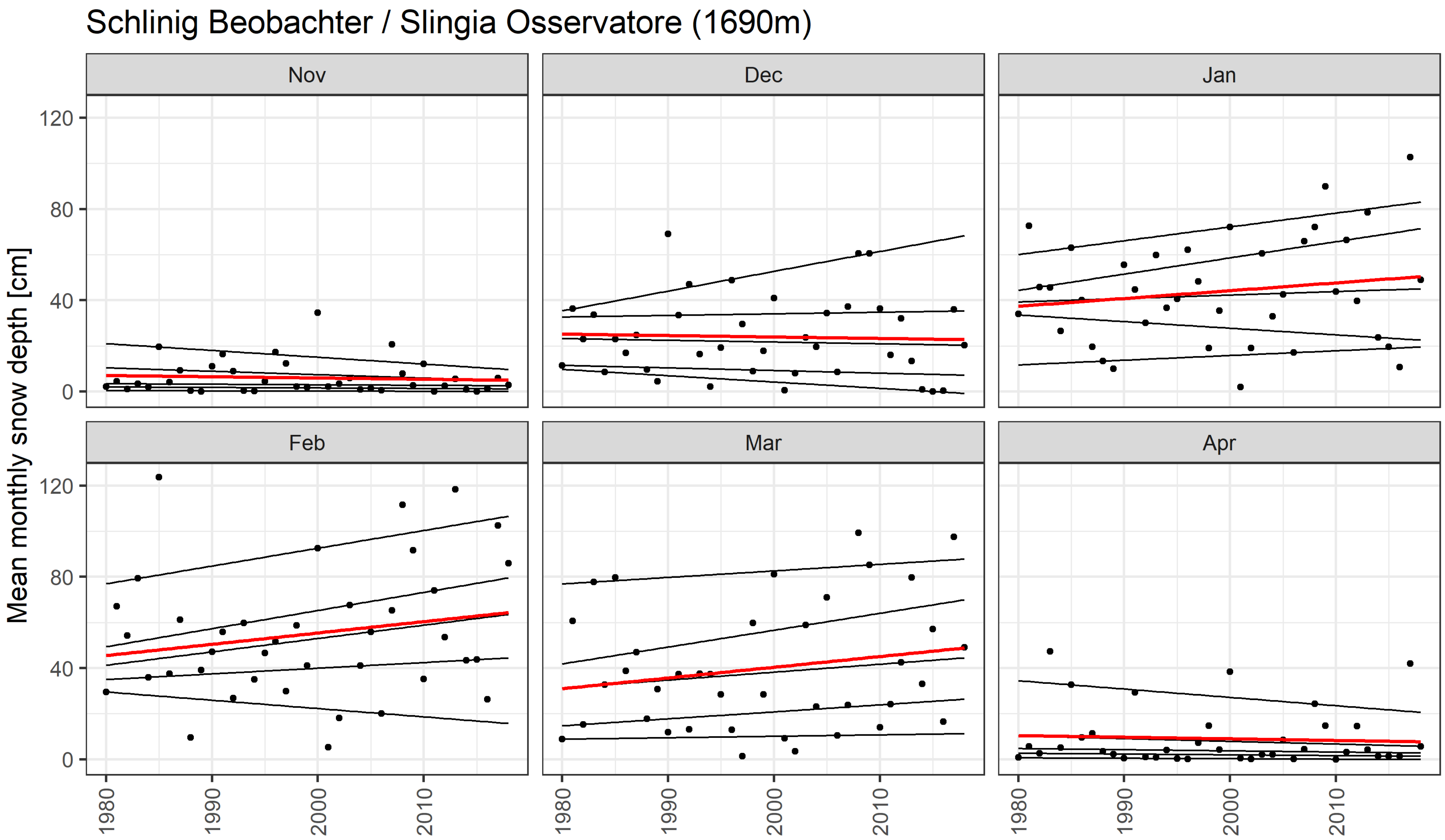
Data (preprocessing)

1. Initial QC & pre-subsetting
    - Basic snow melt/accumulation tresholds
    - Start year <= 1990, end year >= 2010, min number of years >= 20
    - At least 8 years for each 15-year window
2. Gapfilling
    - Weighted mean of up to 3 reference stations
    - 21 year window * x days around gap (until non-missing 150 values)
    - At least 80% data in common and correlation > 0.8
3. Final subsetting
    - Months: September - May; minimum 90% daily values for each (-> calculate monthly averages)
    - At least 6 years for each 11-year window
    - At least 3 years in the first and last 5 years
    - At least 9 years with non-zero monthly averages

Quantile Regression: Real data example



Quantile Regression: Real data example