CERI
COLD REGION

Impact assessment of climate change on the blowing-snow events in Hokkaido with a large ensemble meteorological dataset

大規模アンサンブル気候予測データによる北海道の吹雪イベントに対する気候変動の影響評価

Sugawara, K., M. Inatsu, and Y. Harada, 2024: Climate change assessment on blowing snow in Hokkaido using a large ensemble dataset. *Scientific Online Letters on the Atmosphere (SOLA)*, in press.

Kuniyasu Sugawara[1, 2*], Masaru Inatsu[2], Yusuke Harada[1]

1. Civil Engineering Research Institute for Cold Region (CERI), PWRI, Japan
2. Hokkaido University

Blowing snow

- Snow particles are blown through the air with wind … Blowing snow
- Blowing snow without snowfall … Drifting snow
- Cause of traffic accidents on winter road

Photo by CERI

Photo by Hokkaido Regional Development Bureau

Purpose

- Climate change has affected the phenomena in the cryosphere.
- Some studies focused on a climatological change effect of blowing snow **frequency**. (e.g., Greaves et al. 2023; Browne and Chen 2023)

Our purpose

To reveal the possible impact of climate change on the **magnitude** of blowing snow events across a wide probability spectrum

- Use a large number of ensemble meteorological dataset called d4PDF
- Focus on the four sites in Hokkaido taking into account the historical record of blowing snow intensity and diverse synoptic characteristics

Ensemble dataset | d4PDF

Database for Policy Decision-Making for Future Climate Change

(Mizuta et al. 2017; Fujita et al. 2019)

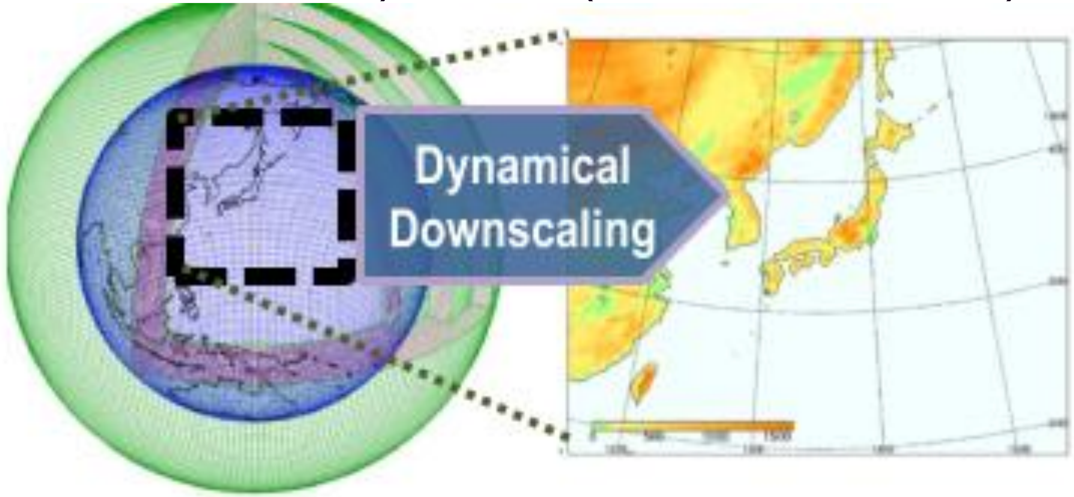
d4PDF

SOUSEI Program for Risk Information on Climate Change 気候変動リスク情報創生プログラム

SI-CAT

Global experiment (60-km resolution)

Regional experiments (**20-km** resolution)



Ishii and Mori, 2020: d4PDF: large-ensemble and high-resolution climate simulations for global warming risk assessment. *PEPS*, **7**, 58.

Regional experiments

- Historical experiment (HIST run) **50** members → 1951−2010 (current climate)
- +2-K experiment (+2K run) **54** members → 2040s (the RCP8.5 scenario)

Equivalent to …

1 ensemble member contains **60**-years simulated data.

d4PDF enables quantitative evaluation of phenomena occurring at low probability.

Severity of blowing snow

Snow transport rate Q_h (kg m^{-1} h^{-1}; STR)

Omiya et al. (2018); Takechi et al. (2023)

$$Q_h = \underbrace{5.12PU_{10}}_{Q_f} + \underbrace{2.81 \times 10^{-3}U_{10}^{4.4}}_{Q_d}$$

P : snowfall (mm h^{-1})
U_{10} : 10-m wind speed (m s^{-1})

Q_f : Snowfall term

Q_d : Drifting term

- $Q_h > 300$ (kg m^{-1} h^{-1}) corresponds to the hourly mean visibility of less than 50 m.

(Kajiya et al. 2004; Harada et al. 2023)

Hardly recognizing a lattice tower

Photo by Dr. Sakurai (CERI)

Severity of blowing snow

Blowing snow can be identified by the following decision tree (Takeuchi et al. 1986; Takechi et al. 2023)

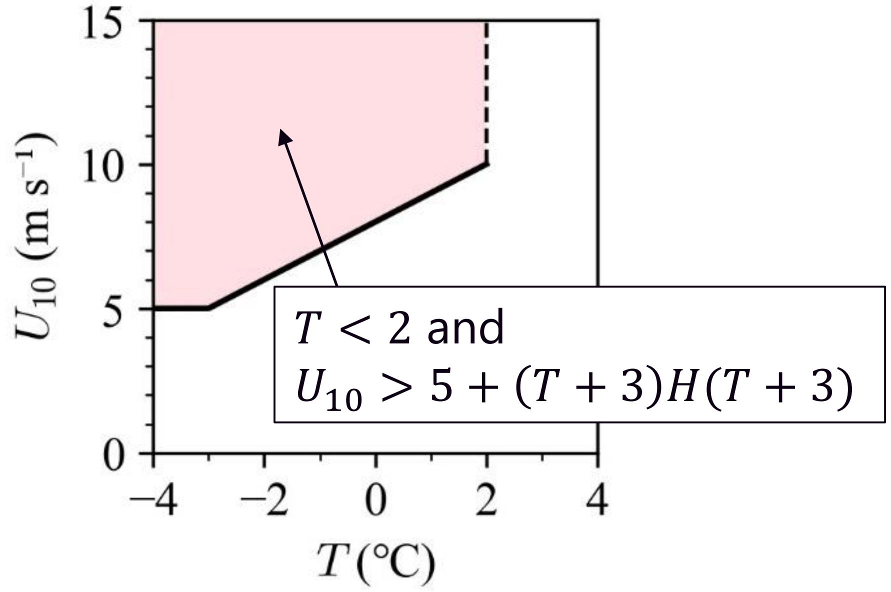
$P > 0$

Yes → $T < 2$

No → All of the following are met

- $T < 2$
- $U_{10} > 5 + (T + 3)H(T + 3)$
- $T_{max} < 2$
- $t_s \leq 48$
- $S_D > 0$

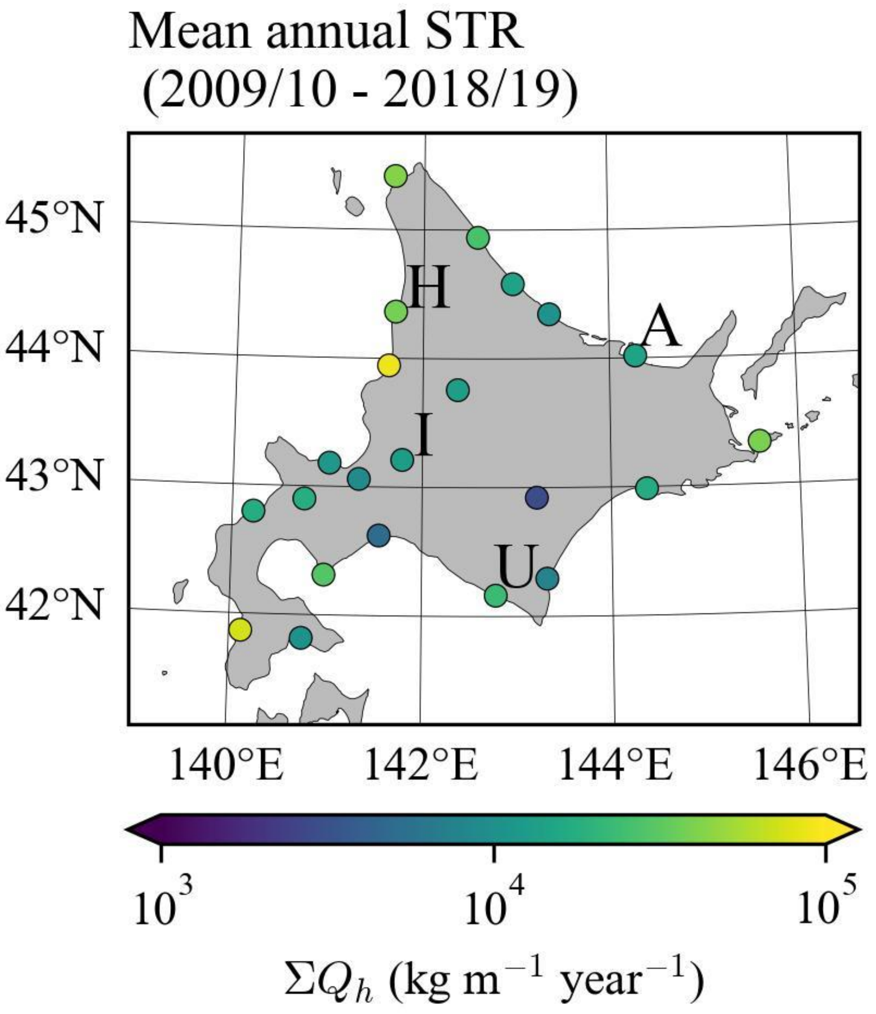
P : Snowfall (mm h^{-1})
U_{10} : 10-m wind speed (m s^{-1})
T : Air temperature (℃)
T_{max} : Maximum temperature after snowfall termination (℃)
t_s : Elapsed time from snowfall termination (h)
S_D : Snow depth (cm)
H : Heaviside's hyper function



Target sites and Data

Target sites : AMeDAS Haboro(H), Abashiri(A), Urakawa(U), and Iwamizawa(I)

- Based on 10-year mean annual STR
  * 1 winter = November 1−March 31



Analyzed data

	AMeDAS	d4PDF
Temperature (℃)	Observed data	2-m air temperature
Wind speed (m s^{-1})	Corrected to a 10-m data based on observed data	10-m wind speed
Snowfall (mm h^{-1})	Time difference of snow depth (1 cm of snow = 1 mm of water)	Precipitation of snow

* d4PDF data was extracted by the inverse distance weighting method

Bias correction (month by month)

- Temperature … Offsetting the mean and factoring the standard deviation (Wilby et al. 2004)

$$\hat{T} = \overline{T_o} + \frac{\sigma[T_o]}{\sigma[T_{m,h}]}(T - \overline{T_{m,h}})$$

T: d4PDF data (historical/+2-K)
T_o: Observed data
$T_{m,h}$: d4PDF in historical experiment
Overbar (¯) : Monthly climatology
$\sigma[]$: Monthly standard deviation

- Wind speed and precipitation of snow … Quantile delta mapping (QDM; Cannon et al. 2015)

$$\hat{x}_{m,p} = x_{m,p} \cdot \frac{F_o^{-1}[F_{m,p}[x_{m,p}]]}{F_{m,h}^{-1}[F_{m,p}[x_{m,p}]]}$$

HIST run

$$\hat{x}_{m,h} = x_{m,h} \cdot \frac{F_o^{-1}\left[F_{m,h}[x_{m,h}]\right]}{F_{m,h}^{-1}\left[F_{m,h}[x_{m,h}]\right]} = F_o^{-1}\left[F_{m,h}[x_{m,h}]\right]$$

F: Cumulative distribution function
(In this study … gamma function)

Subscripts
o: Observed data
m, p: Modeled data in a projected period (+2-K climate)
m, h: Modeled data in a historical period (current climate)

Estimation of snow cover

- The presence of snow cover was diagnosed based on the degree-days method (Kominami et al. 2005; Inatsu et al. 2016)

$$\frac{dS_D}{dt} = \underbrace{-\alpha S_D}_{\text{Compaction}} - \underbrace{\beta H(S_D \cdot \bar{T})\bar{T}}_{\text{Melting}} + \underbrace{S_F}_{\text{Snowfall}}$$

S_D: Daily snow depth (cm)
$\bar{T}$: Daily mean temperature (℃)
S_F: Daily snowfall (cm)
α : Compaction rate of snow cover (2% day^{-1})
β : Daily snow melt above 0 ℃ (cm ℃$^{-1}$ day^{-1})
$H(\cdot)$: Heaviside's hyper function

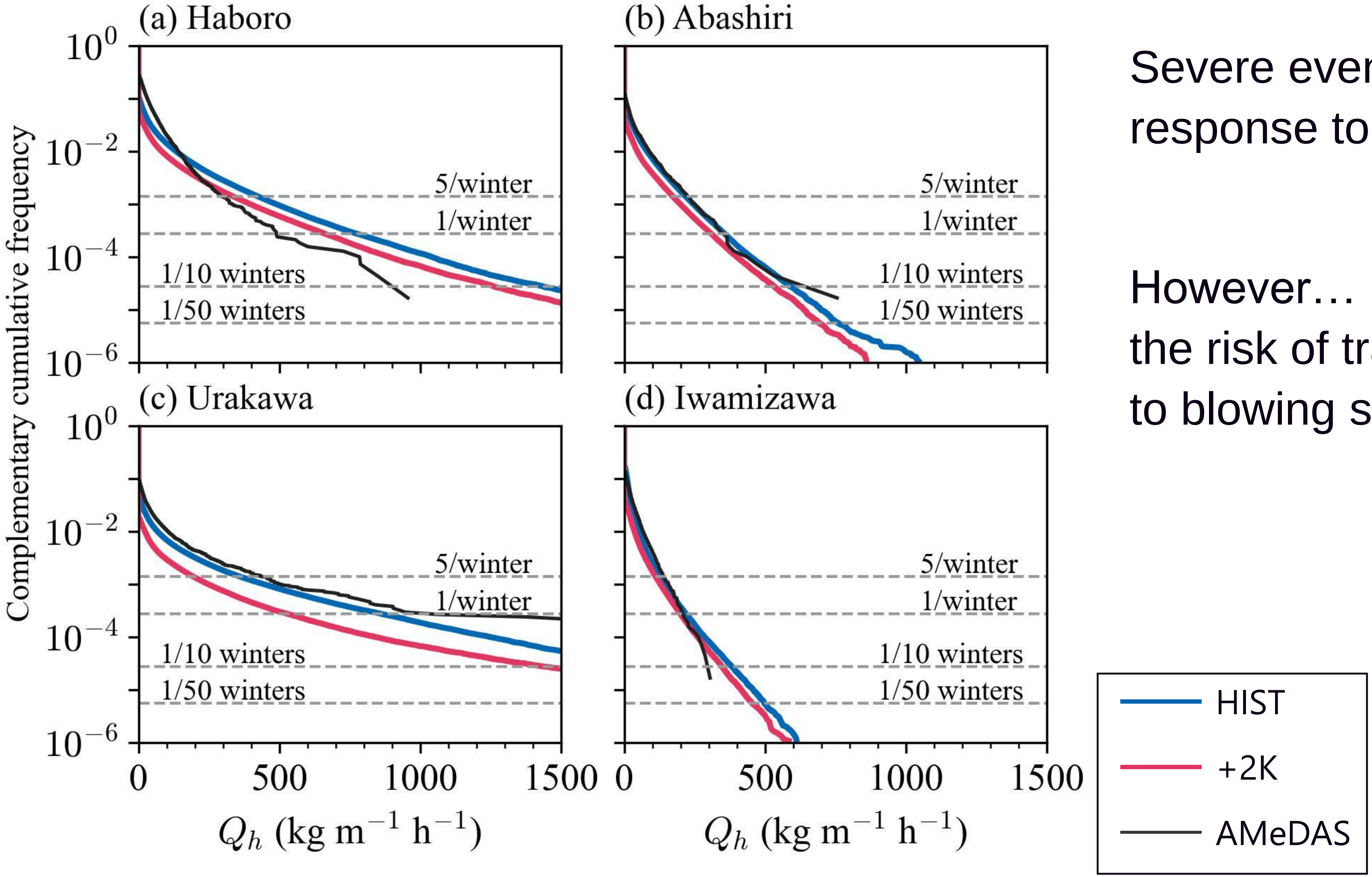
- β value was estimated for 10 winter seasons based on the observation.

Station	β (cm ℃$^{-1}$ day^{-1})
Haboro	1.45
Abashiri	1.78
Urakawa	3.87
Iwamizawa	2.50

- Snow depth estimation: **daily**

Interpolated into **hourly** data to estimate hourly STR.

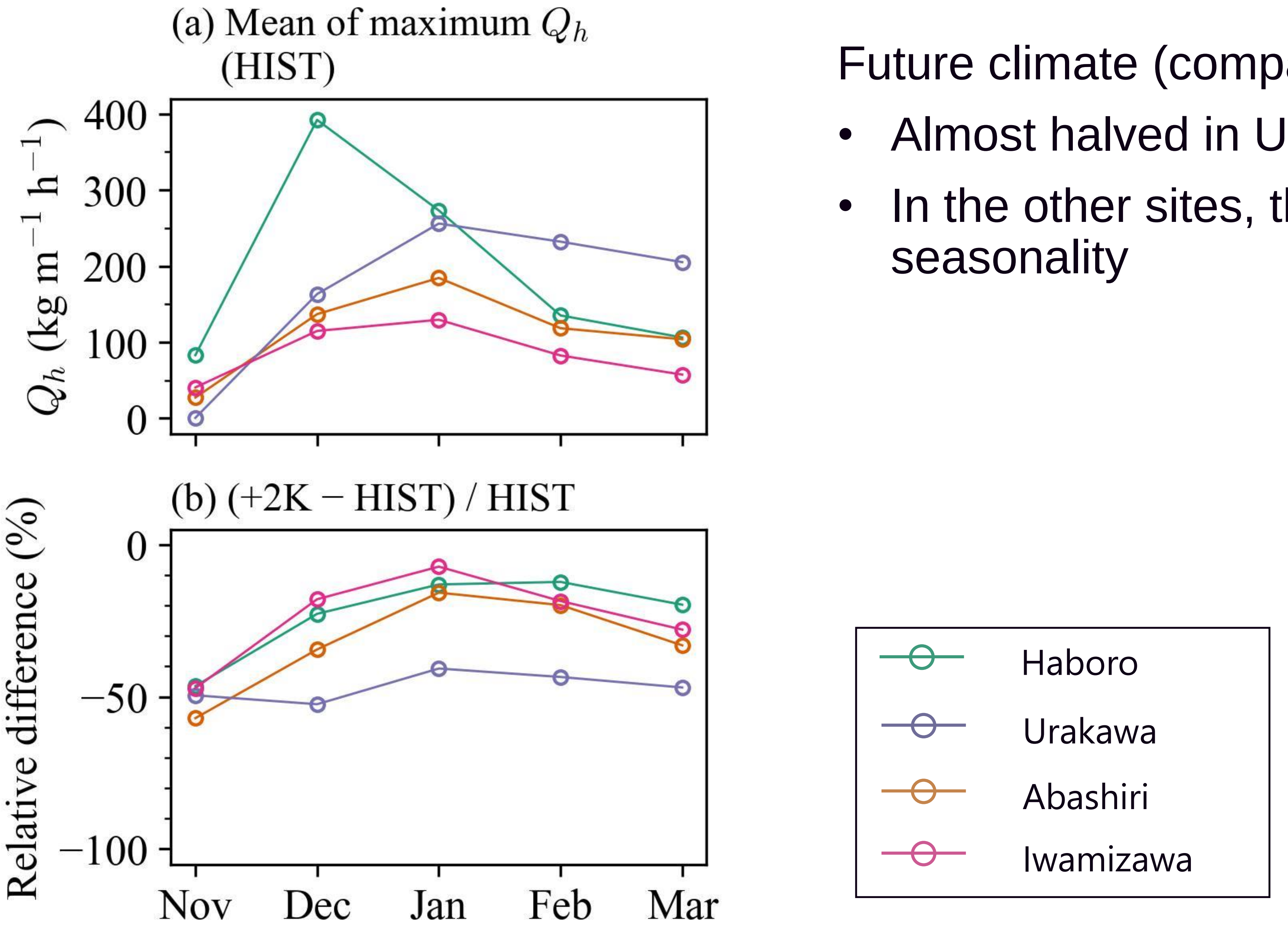
Hourly STR



Severe events became rarer in response to global warming.

However…
the risk of traffic accidents due to blowing snow would remain.

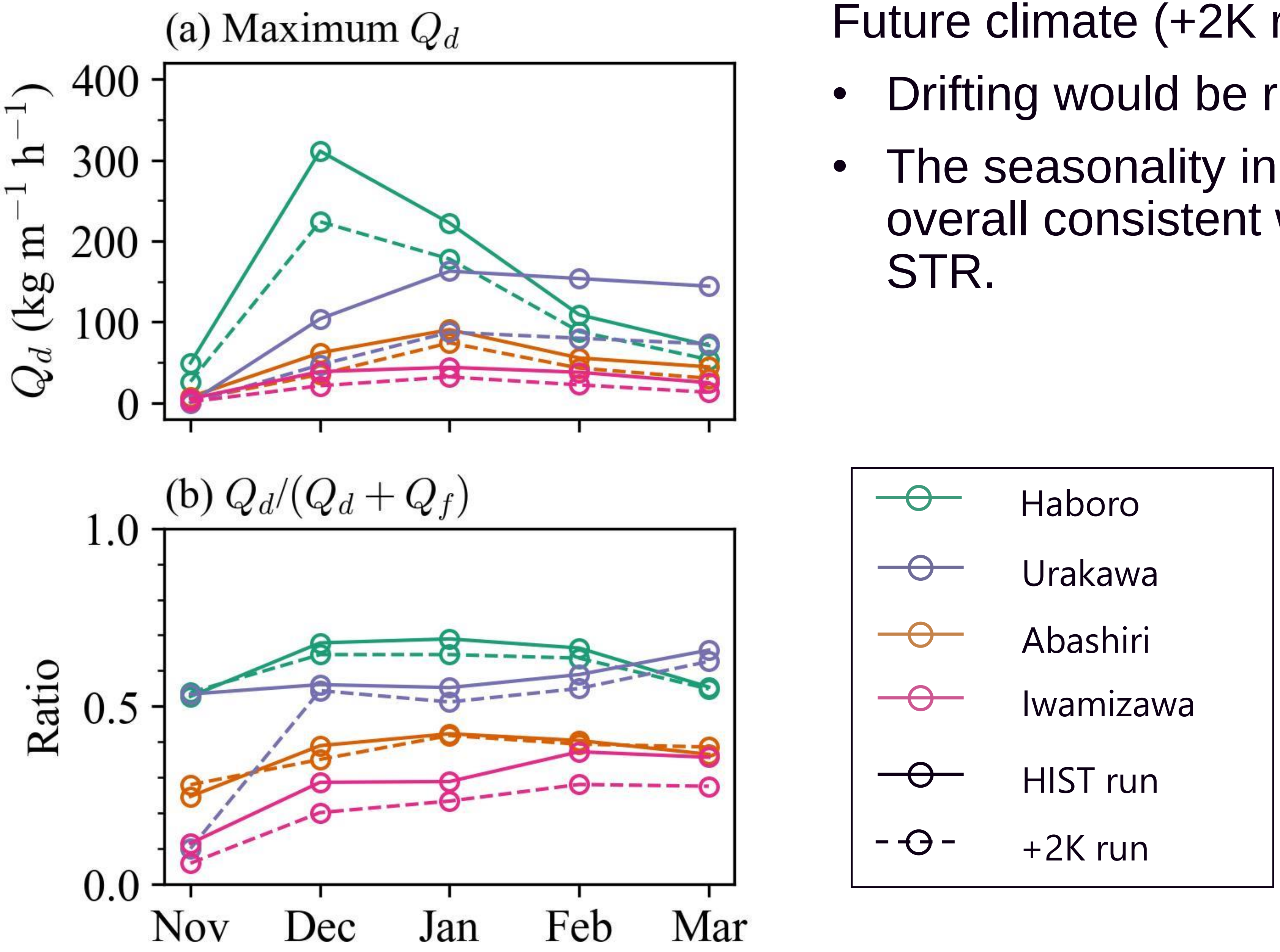
Monthly maximum Q_h (ensemble mean)



Future climate (compared to current climate)

- Almost halved in Urakawa
- In the other sites, the reduction exhibited seasonality

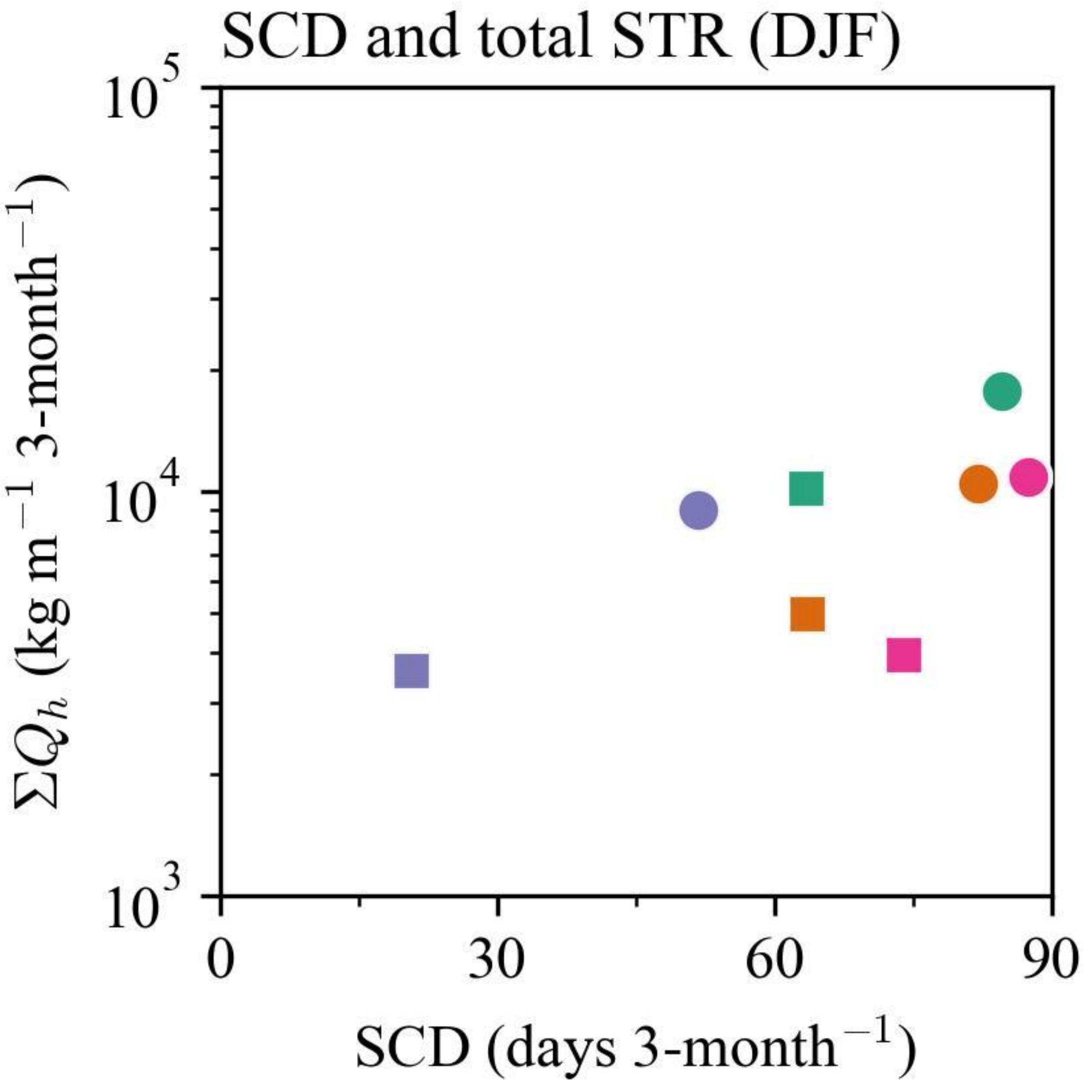
Drifting term (Q_d)



Future climate (+2K run)

- Drifting would be reduced at all sites
- The seasonality in drifting's reduction was overall consistent with the seasonality in total STR.

Snow-covered duration (SCD) and STR



In Urakawa …

- SCD was 30 days shorter than the other sites. (HIST run)
- SCD would decrease to 20.3 days (+2K run)

Haboro
Urakawa
Abashiri
Iwamizawa
HIST run
+2K run

Conclusion

- We have estimated the impact of climate change on blowing snow intensity (STR) across a wide probability spectrum in four targeted sites of Haboro, Abashiri, Urakawa, and Iwamizawa in Hokkaido using d4PDF.

- We found severe blowing snow events would become rarer in response to global warming.

- The blowing snow at Urakawa was most declined than any other sites.
  This reduction would be related to the decrease in the snow-covered duration (SCD).