CGI2024

Seasonal Terrain Texture Synthesis via Köppen Periodic Conditioning

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Background (1/2)

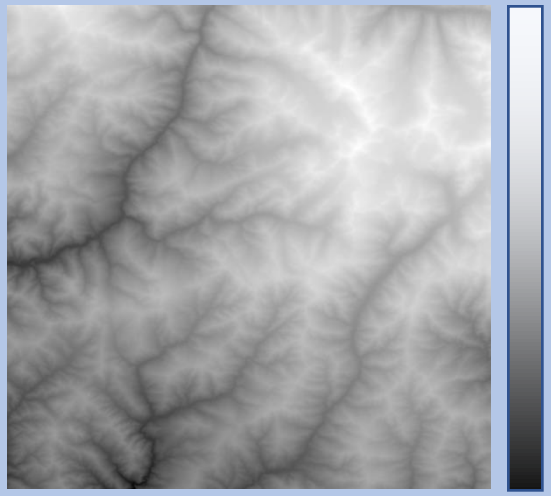
- Wide range of earth landscapes due to terrain, climate and seasons
  - Benefits for content creation if it can be reproduced in CG

Terrain landscapes

Background (1/2)

- Terrain landscapes can be represented by textures and heightfields

Texture



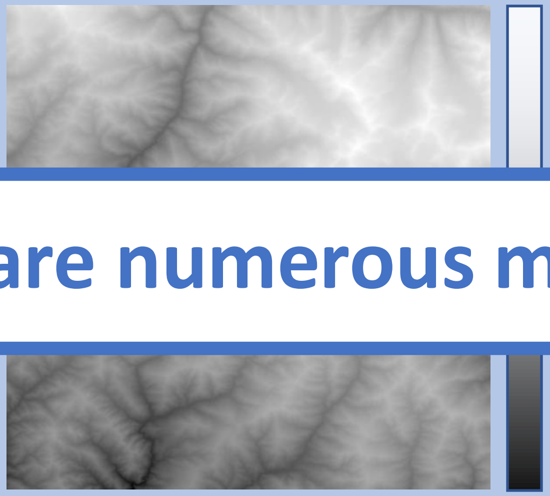
Heightfield

3D terrain model

Background (1/2)

- Terrain landscapes can be represented by textures and heightfields

Texture



Heightfield

3D terrain model

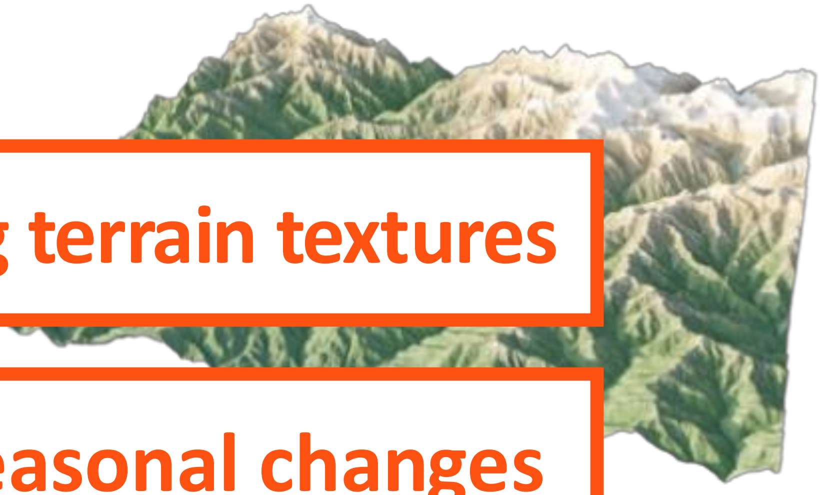
☺ **There are numerous methods for generating heightfields**

Background (1/2)

- Terrain landscapes can be represented by textures and heightfields

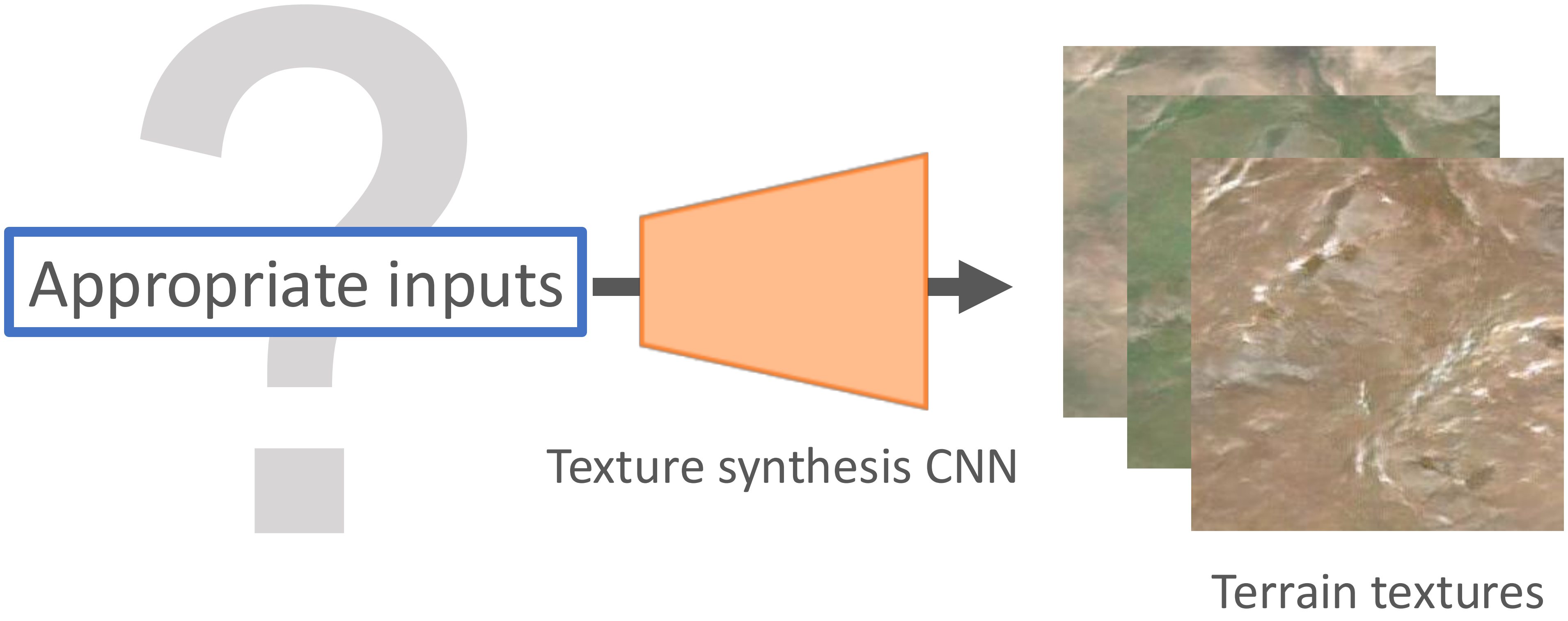
☹ **Only a few methods for synthesizing terrain textures**

☹ **Existing methods cannot handle seasonal changes**



Our Goal

- Synthesizing seasonal transition of terrain textures.



No prior studies on season-controllable terrain texture synthesis

Our Goal

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- Synthesizing seasonal transition of terrain textures

Our result: textured 3D terrain model with seasonal transition

Related Work (1/2)

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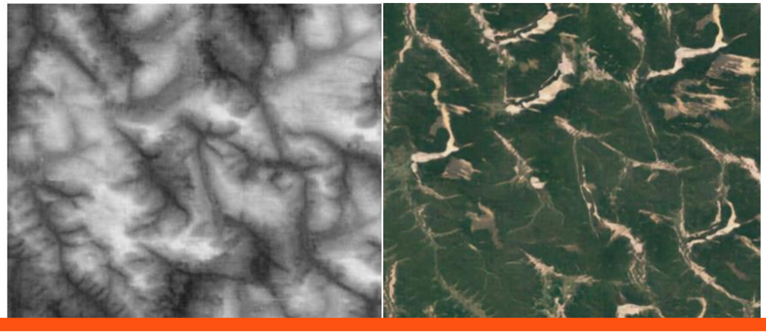
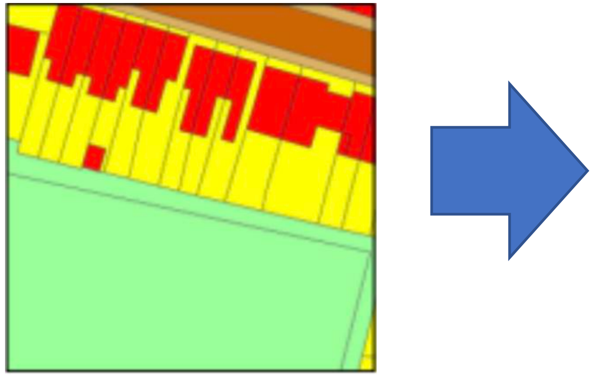
- Generating terrain heightfields & textures via deep learning [Spick+, 2019]



☹ **Cannot account for climatic or seasonal changes**

- Synthesizing satellite images from label maps [Zhu+, 2021]

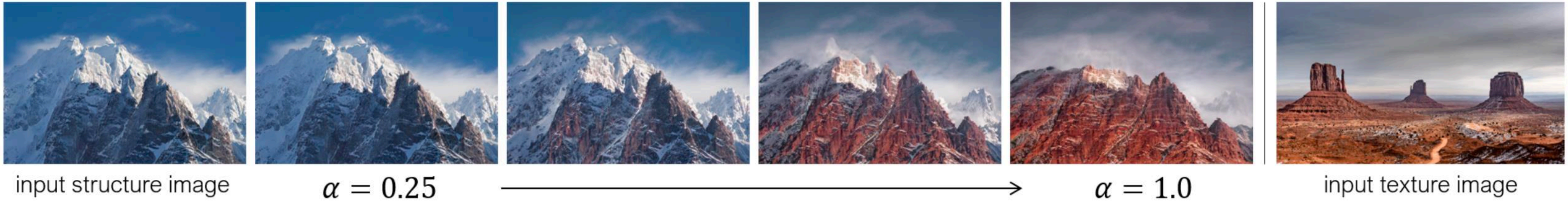


Input

Output

Related Work (2/2)

- Image-to-image translation using reference images [Park+, 2020]
  - **Can change the season of the image**



☹ **Requires input & reference images**

What Affects Terrain Appearance?

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- Primary factors: **Vegetation** and **snow cover**
  - Causes appearance differences by climate and seasons
- **Vegetation:** *Köppen climate classification* focuses on vegetation differences
  - Classifies by **temperature** and **precipitation** per month of the year
  - **Temperature** and **precipitation** also affect **snow cover**
- **Snow cover:** Also affected by **heightfield** and **insolation**
  - **Heightfield**: **Snow** accumulates at higher elevations
  - **Isolation**: **Snow** melts faster on slopes exposed to direct sunlight

Affecting factors: temperature, precipitation, heightfield, and insolation

How Can We Control Seasons?

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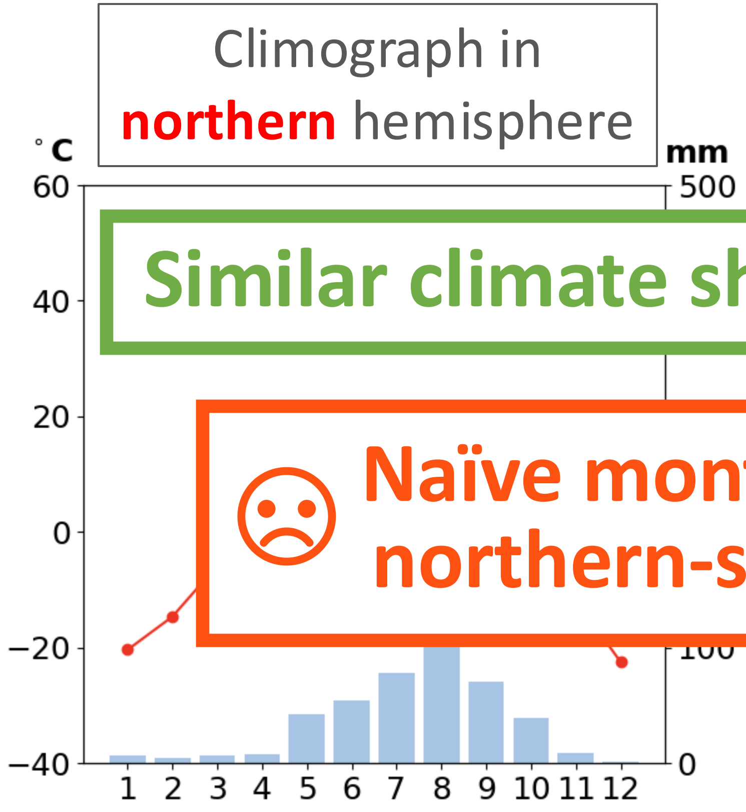
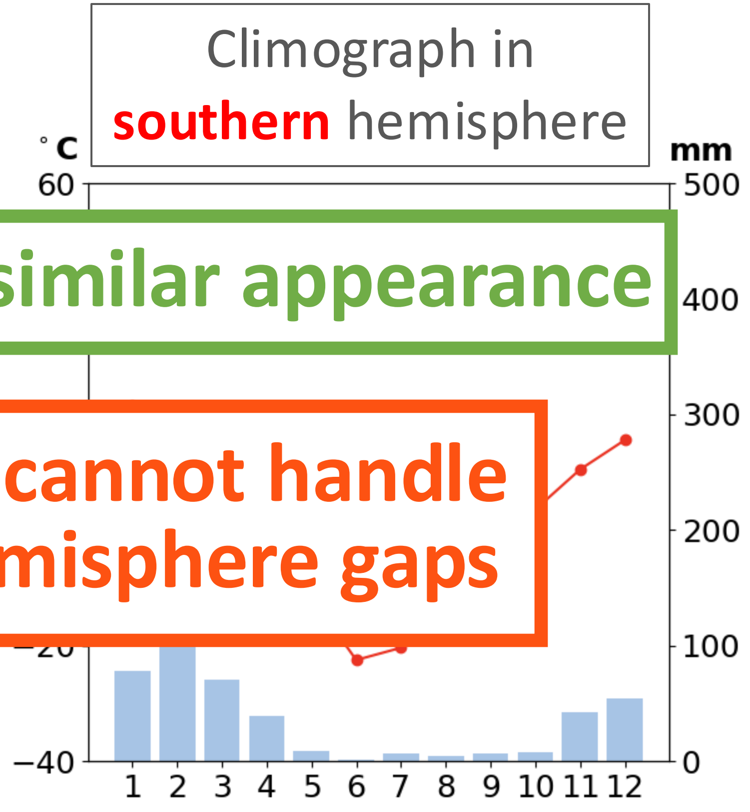
- Ground surface conditions are also affected by **seasons**; how to control?
- Naïve season control: **indexing by month**
  - e.g., month index = 8 (Aug.) → summer, month index = 12 (Dec.) → winter





Similar climate should yield similar appearance

☹ **Naïve month indexing cannot handle northern-southern hemisphere gaps**

Our Challenge

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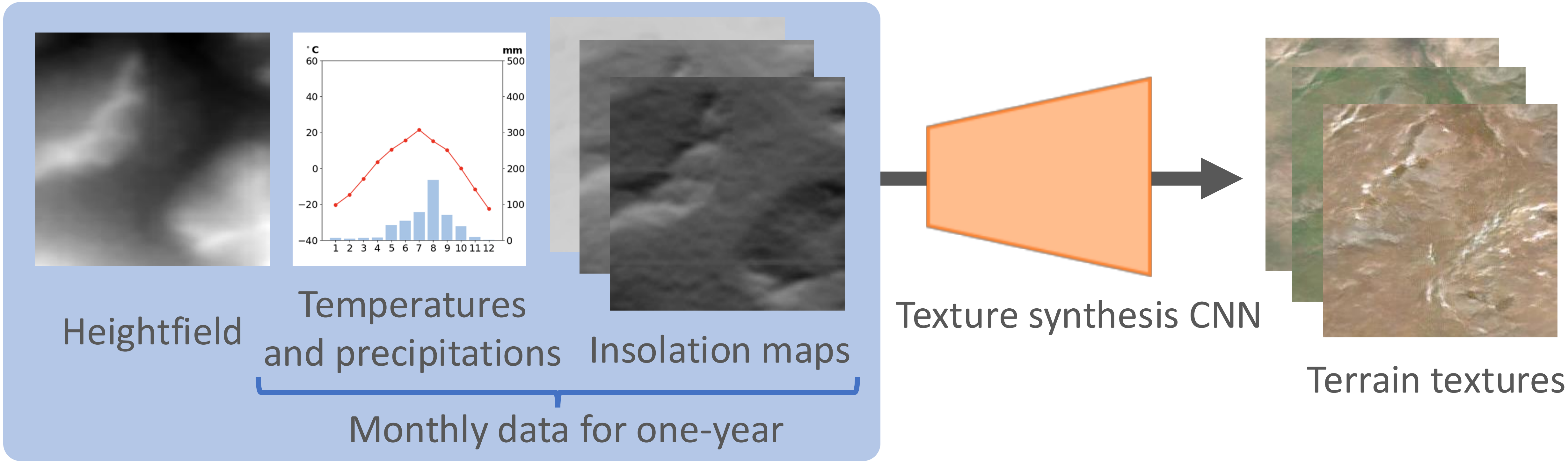
- Design of a seasonal control method without explicit temporal information



Input

Köppen Periodic Conditioning

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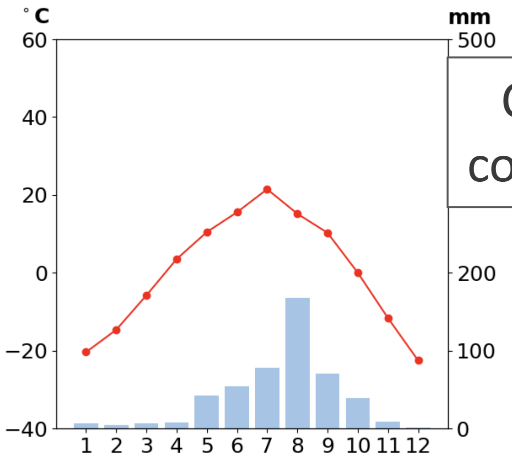
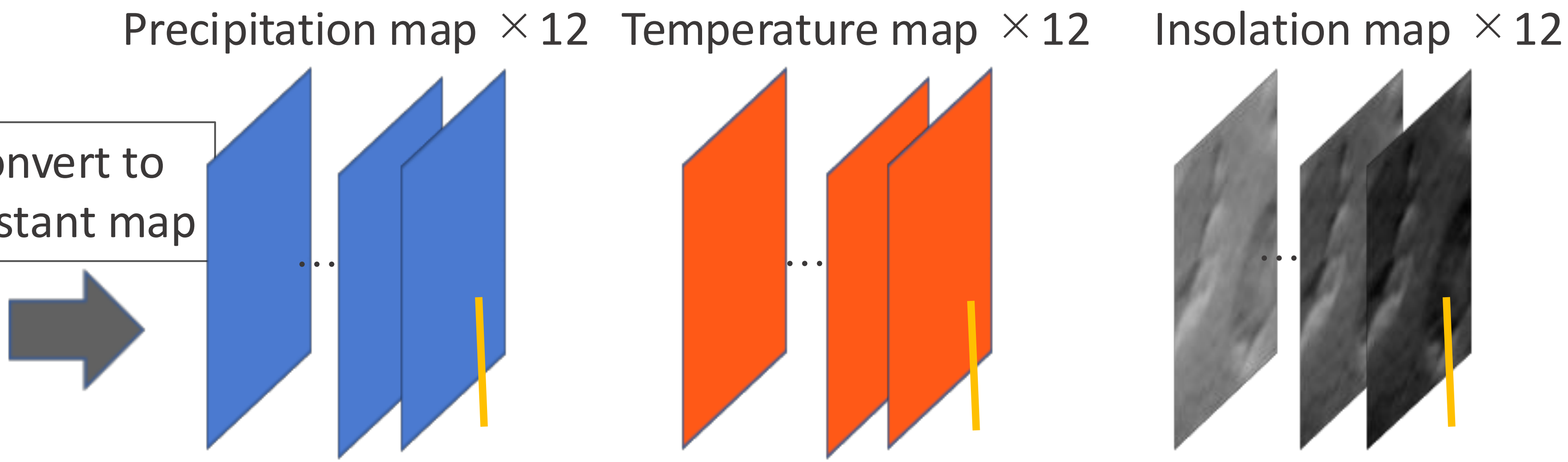
- Specifies which month's texture is synthesized according to **input order of monthly data**



Monthly temperatures and precipitations

Convert to constant map



Precipitation map of month *m*

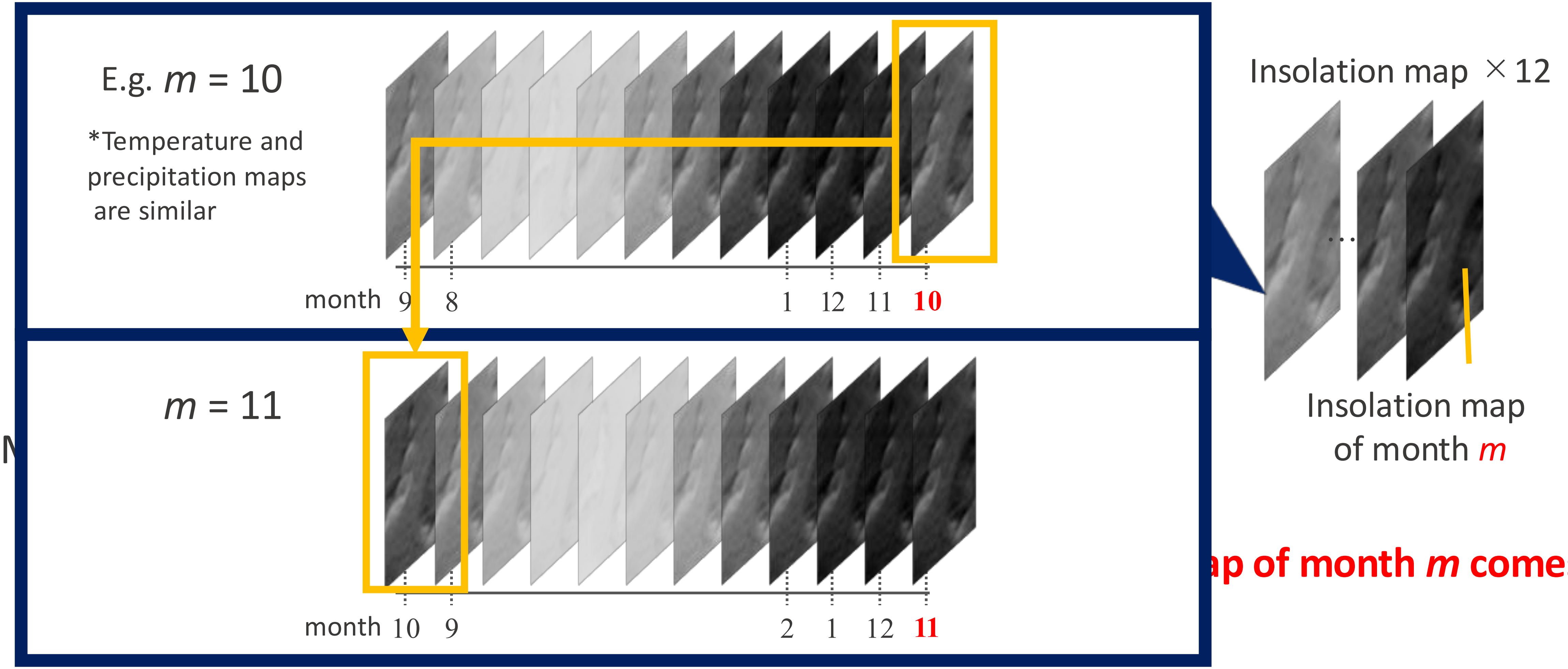
Temperature map of month *m*

Insolation map of month *m*

To synthesize a texture for month *m*, we sort input *s.t.* each map of month *m* comes first

Köppen Periodic Conditioning

- Specifies which month's texture is synthesized according to **input order of monthly data**



ap of month m comes first

Köppen Periodic Conditioning

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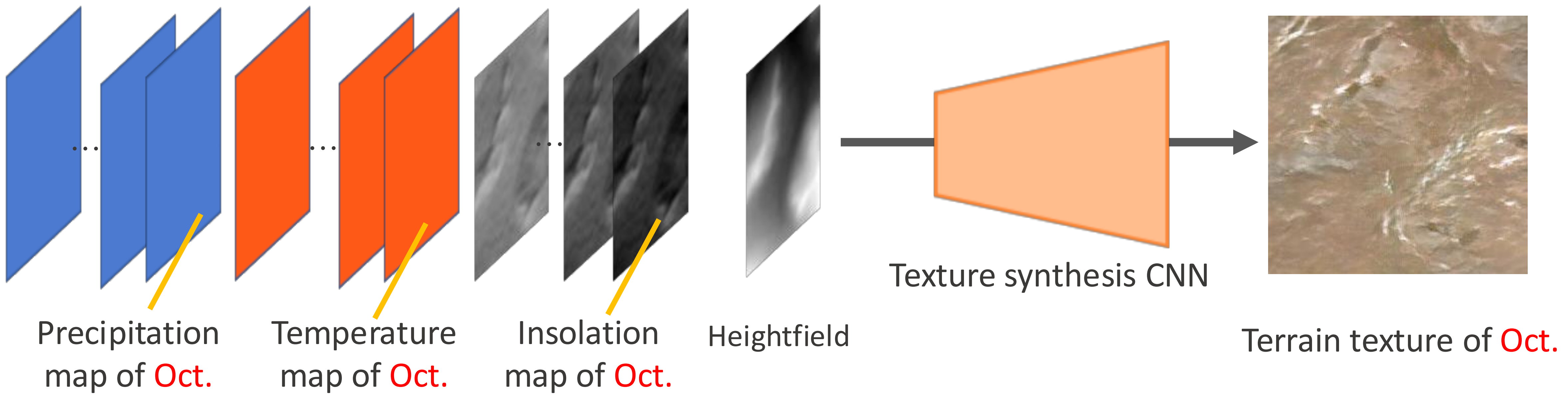
- Specifies which month's texture is synthesized according to **input order of monthly data**

- All maps are concatenated in the channel direction and fed to the network



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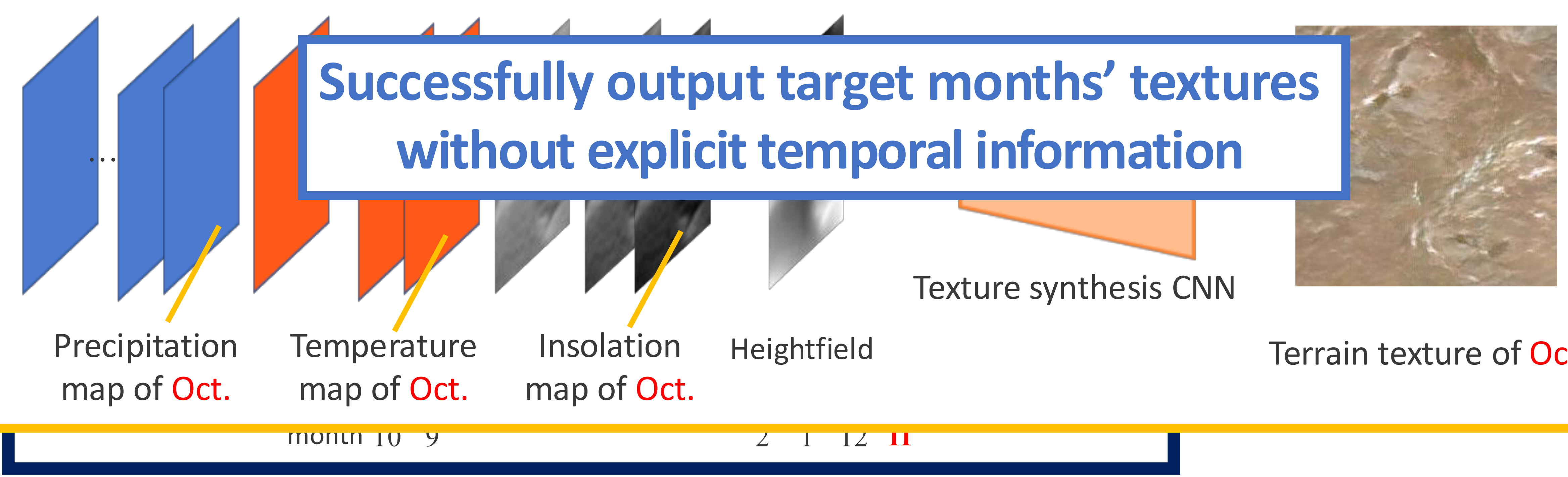

Latent-Space Texture Interpolation

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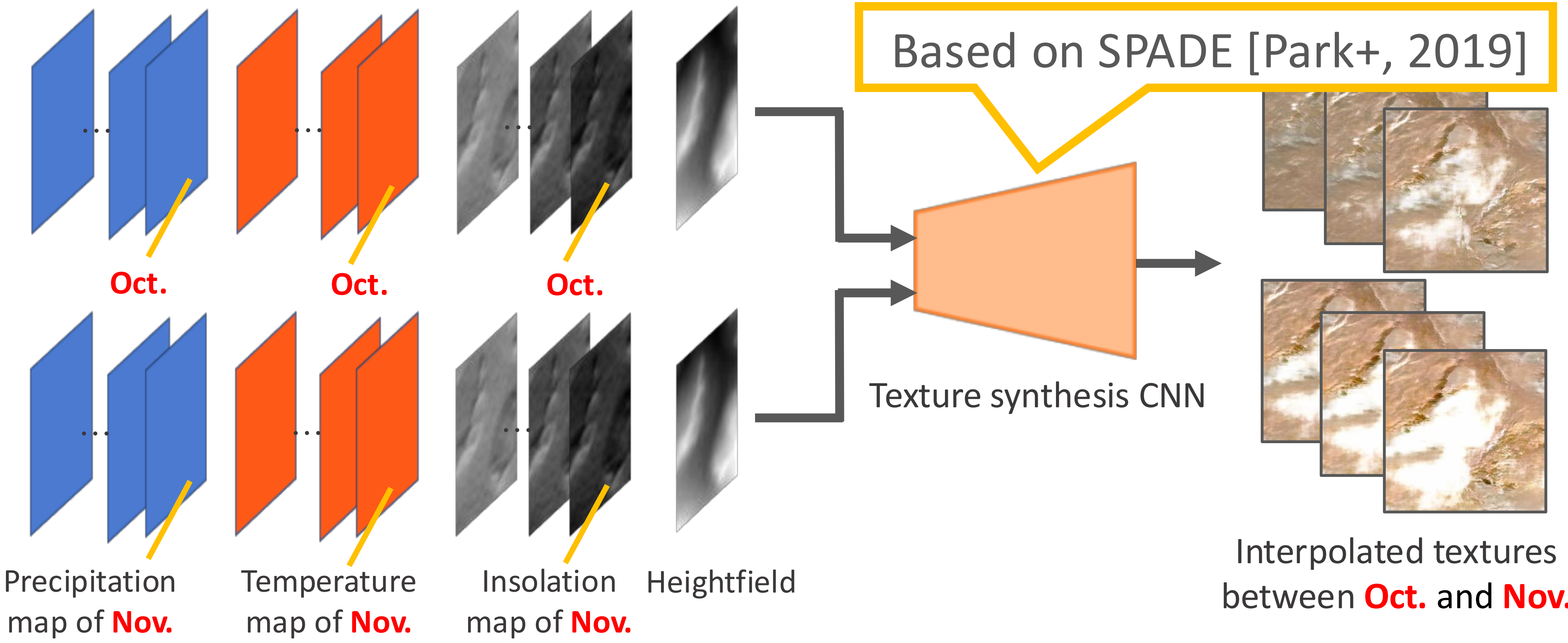
- **Plausibly interpolate** textures between two consequtive months **in latent space**
  - Utilize the latent space of the SPADE architecture [Park+, 2019] (see our paper)



Dataset

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- Heightfield, temperature, precipitation, and terrain texture
  - Build a dataset based on actual measurements using Google Earth Engine

	Data source
Heightfield	NASADEM
Temperature	ERA5-Land
Precipitation	
Terrain texture	satellite images of the Sentinel-2 (spatial resolution: 10m)

- Insolation maps: calculated from heightfield and latitude by ray casting

Experimental Setting

- Compared the following input conditions as an ablation study
  - Heightfield was used as input for all conditions

Condition	input
(1) $T'_{12} + P'_{12} + M$	Temperature (T'_{12}) and precipitation (P'_{12}) for one year and month (M)
(2) $T_1 + P_1$	Temperature (T_1) and precipitation (P_1) for one month
(3) L + M	Latitude (L) and month (M)
(4) $T_{12} + P_{12}$	Periodically-rotated temperature (T_{12}) and precipitation (P_{12}) for one year
Ours ($T_{12} + P_{12} + S_{12}$)	Periodically-rotated temperature (T_{12}), precipitation (P_{12}) and insolation (S_{12}) for one year

Quantitative Comparison

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- Used five evaluation metrics
  - Best scores are highlighted in red

Condition	RMSE↓	SSIM↑	LPIPS↓	∂AD↓	∂SSIM↓
(1) $T'_{12} + P'_{12} + M$	64.3	**0.57**	0.47	123.3	0.13
(2) $T_1 + P_1$	75.7	0.52	0.49	124.8	0.16
(3) $L + M$	66.8	0.55	0.46	**116.9**	0.14
(4) $T_{12} + P_{12}$	61.1	0.52	**0.44**	120.8	**0.11**
Ours ($T_{12} + P_{12} + S_{12}$)	**59.3**	0.52	**0.44**	123.3	**0.11**

Quantitative Comparison

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Condition	RMSE↓	SSIM↑	LPIPS↓	∂AD↓	∂SSIM↓
(1) T'[illegible] + P'[illegible] + M	64.3	**0.57**	[illegible]	[illegible]	0.13
(2) [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(3) [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(4) [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ou[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

- Defined to evaluate accucacy of texture differences

G : Ground truth T : Synthesized texture m : Month index

$$\partial\mathrm{AD} = \mathbb{E}\left[\left|\underbrace{|G_{m+1} - G_m|}_{}\, - \underbrace{|T_{m+1} - T_m|}_{}\right|\right]$$

$$\partial\mathrm{SSIM} = \mathbb{E}\left[\left|\underbrace{\mathrm{SSIM}(G_{m+1} - G_m)}_{} - \underbrace{\mathrm{SSIM}(T_{m+1} - T_m)}_{}\right|\right]$$

Difference of GT textures Difference of synthesized textures

Quantitative Comparison

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(1) $T'_{12} + P'_{12} + M$	64.3	**0.57**	0.47	123.3	0.13
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For the accuracy of each single texture

Quantitative Comparison

CGI2024

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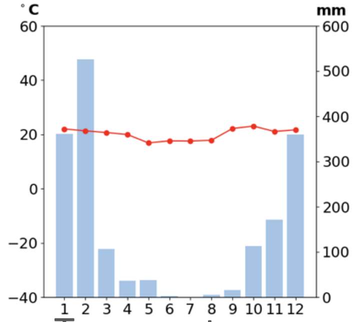
☺ **"Ours" was best in most metrics**

Qualitative Comparison (1/2)

- Compared with the conditions **WITHOUT** 12-month input

Heightfield



Temperatures and precipitations

(2) $T_1 + P_1$

(3) L + M

Ours

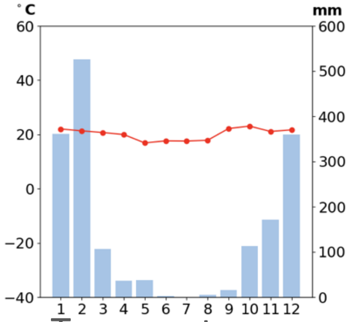
GT

1 2 3 4 5 6 7 8 9 10 11 12

Qualitative Comparison (1/2)

- Compared with the conditions **WITHOUT** 12-month input

Heightfield



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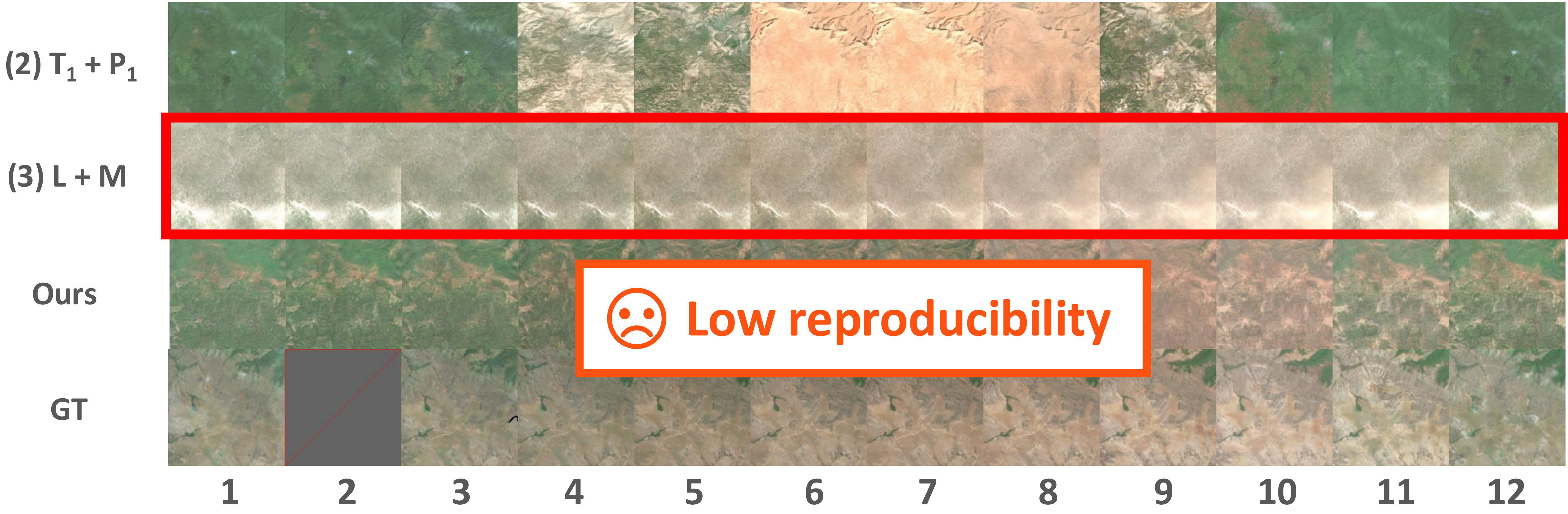

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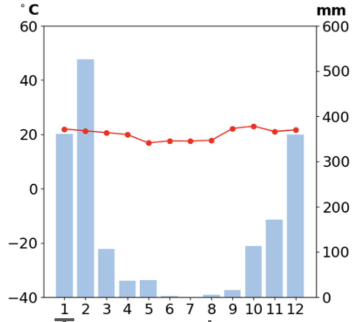

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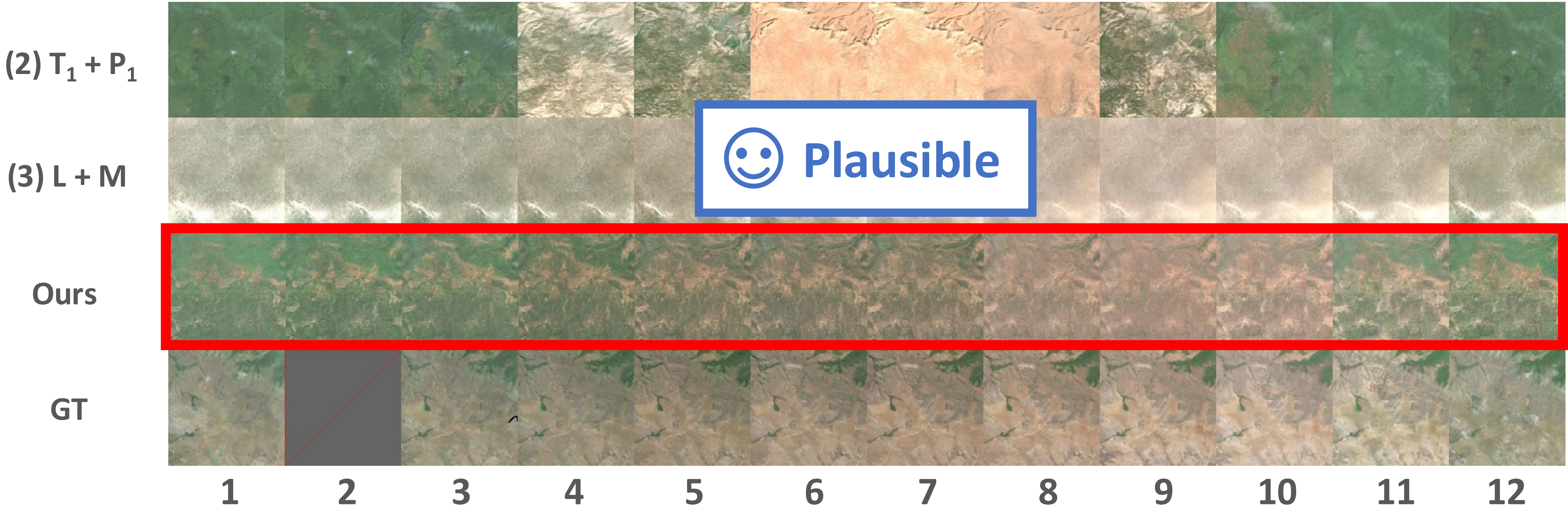

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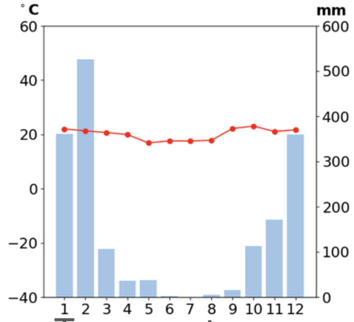


Temperatures and precipitations

(1) $T'_{12} + P'_{12} + M$

(4) $T_{12} + P_{12}$

Ours

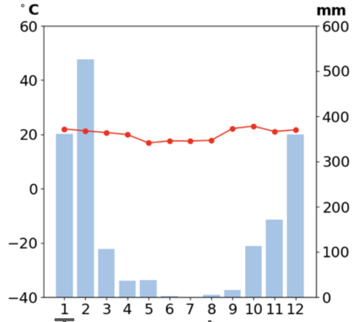
GT

1 2 3 4 5 6 7 8 9 10 11 12

Qualitative Comparison (1/2)

- Compared with the conditions **WITH** 12-month input

Heightfield



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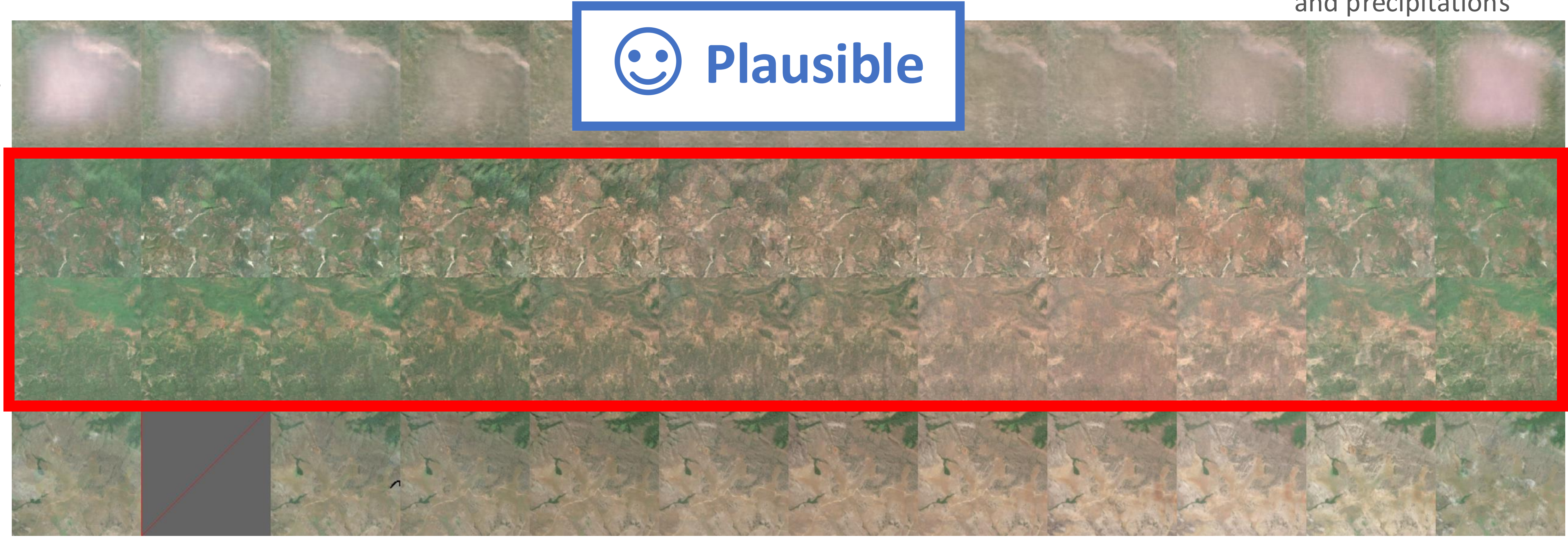


(1) $T'_{12} + P'_{12}$ + M

(4) $T_{12} + P_{12}$

Ours

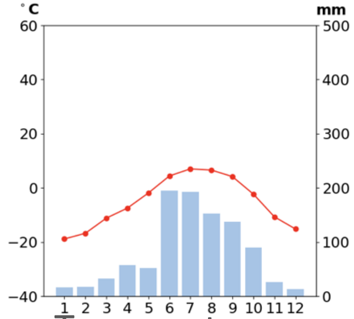
GT

1 2 3 4 5 6 7 8 9 10 11 12

Qualitative Comparison (2/2)

- Validation of the insolation maps

Heightfield



Temperatures and precipitations

(4) $T_{12} + P_{12}$ (w/o S_{12})

Ours (w/ S_{12})

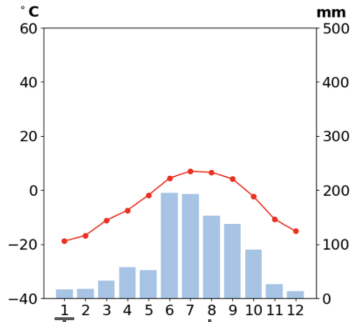
GT

1 2 3 4 5 6 7 8 9 10 11 12

Qualitative Comparison (2/2)

- Validation of the insolation maps

Heightfield

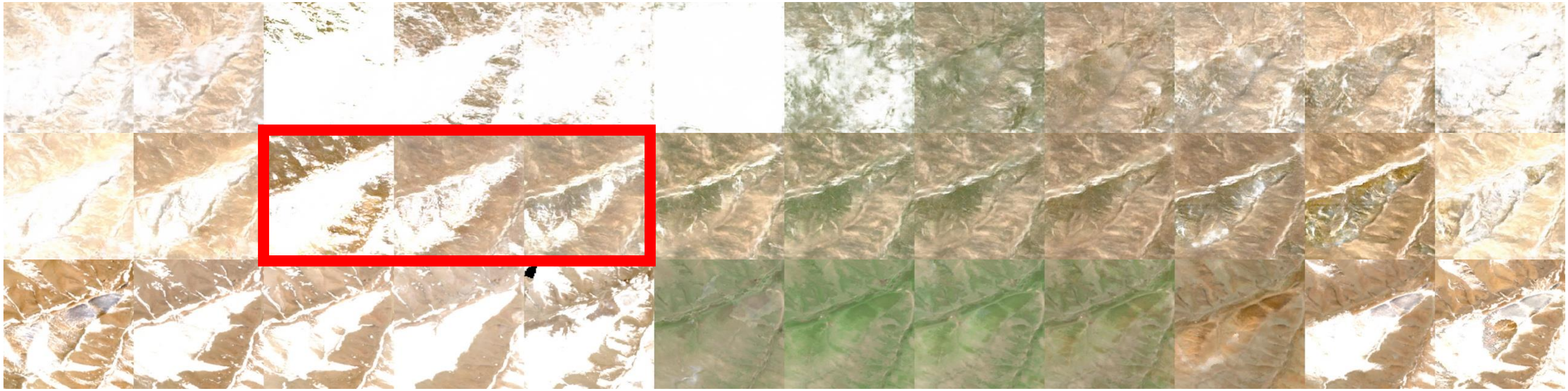


Temperatures and precipitations

(4) $T_{12} + P_{12}$ (w/o S_{12})

Ours (w/ S_{12})

GT



1 2 3 4 5 6 7 8 9 10 11 12

☺ **Reproduces snowmelt better**

Conclusion

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- **First method to synthesize seasonal transition of terrain textures**
  - Seasons are controlled by the input order of monthly temperature, precipitation, and insolation maps of one year
  - Monthly temperature and precipitation are essential to reflect seasons
  - Monthly insolation maps are useful for snow reproduction
- **Continuous seasonal changes via latent-space interpolation**

Thank You for Your Attention

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Please visit our project page!

https://www.cgg.cs.tsukuba.ac.jp/~tossy/pub/seasonal_terrain_texture/

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