Microwave Retrievals of Terrestrial Precipitation over Snow Covered Surfaces: A Lesson from the GPM Satellite

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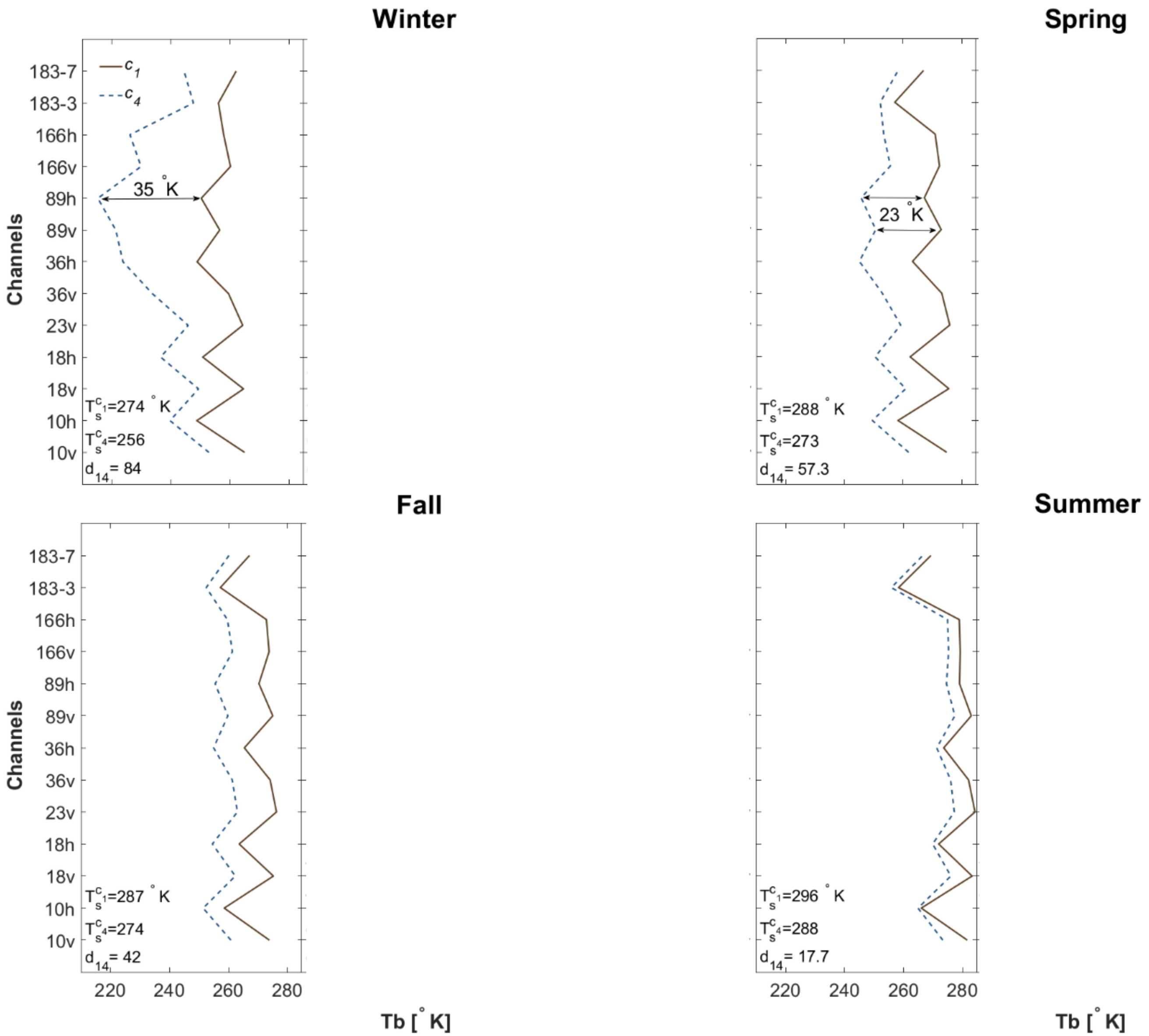
- **Data**
  - **GPM:** dual Frequency Radar precipitation product (2A-DPR) and calibrated passive brightness temperatures (1B-GMI) of all orbits in 2015.
  - **MODIS**: snow cover fraction (MOD10C1), skin temperature (MOD11C1) at 0.05-degree.
  - **MERRA-2:** surface skin temperature, 2-meter air temperature, total integrated atmospheric vapor, liquid, and ice water content are acquired from the 1-hourly single-level diagnostic products at resolution 0.625x0.5-degree.

- **Methodology**
  - **All data are mapped onto the DPR grids** at nominal resolution of 0.05-degree
  - **The 1-hourly MERRA-2** data are first interpolated linearly onto the GPM radar scanning times and then interpolated onto the radar spatial grids.
  - **The snowfall pixels** are those that are labeled with solid phase in 2A-DPR product and their 2-meter air temperatures are below 2C (Liu2009).
  - The skin temperatures are used to confine the study to **dry snow**, which is loosely defined as those snow-covered surfaces with sub-freezing skin temperatures.
  - All collocated data are then **stratified into a set of six disjoint land-atmosphere classes** of interest including ground (c_1) rain over ground (c_2), snowfall over ground (c_3), snow cover (c_4), rainfall over snow cover (c_5), and snowfall over snow cover (c_6).

- Precipitation Signal over Snow Cover

c_1: ground

c_4: snow cover



$$\left\|\overrightarrow{\mathrm{Tb}}\right\|_2^2 = \Sigma_{p=1}^{n} Tb_p^2$$

$$\overrightarrow{\mathrm{Tb}} = (Tb_1, Tb_2, \ldots, Tb_p)^T$$

$$d_{i,j} = \left\|\overrightarrow{\mathrm{Tb}}_{c_i} - \overrightarrow{\mathrm{Tb}}_{c_j}\right\|_2$$

- Precipitation Signal over Snow Cover

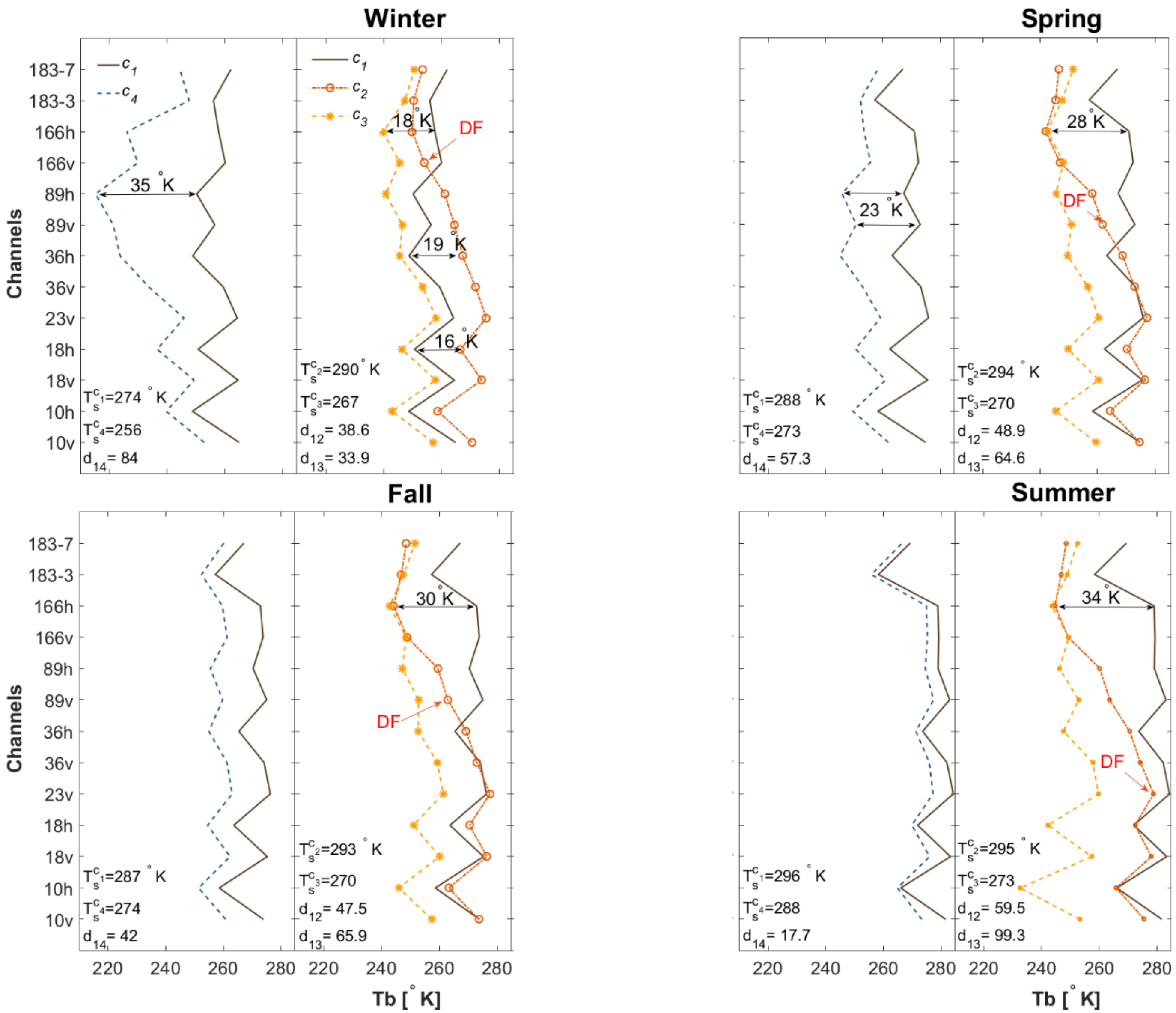
c_1: ground

c_4: snow cover

c_1: ground

c_2: rain+ground

c_3: snowfall+ground



- Precipitation Signal over Snow Cover

c_1: ground

c_4: snow cover

c_1: ground

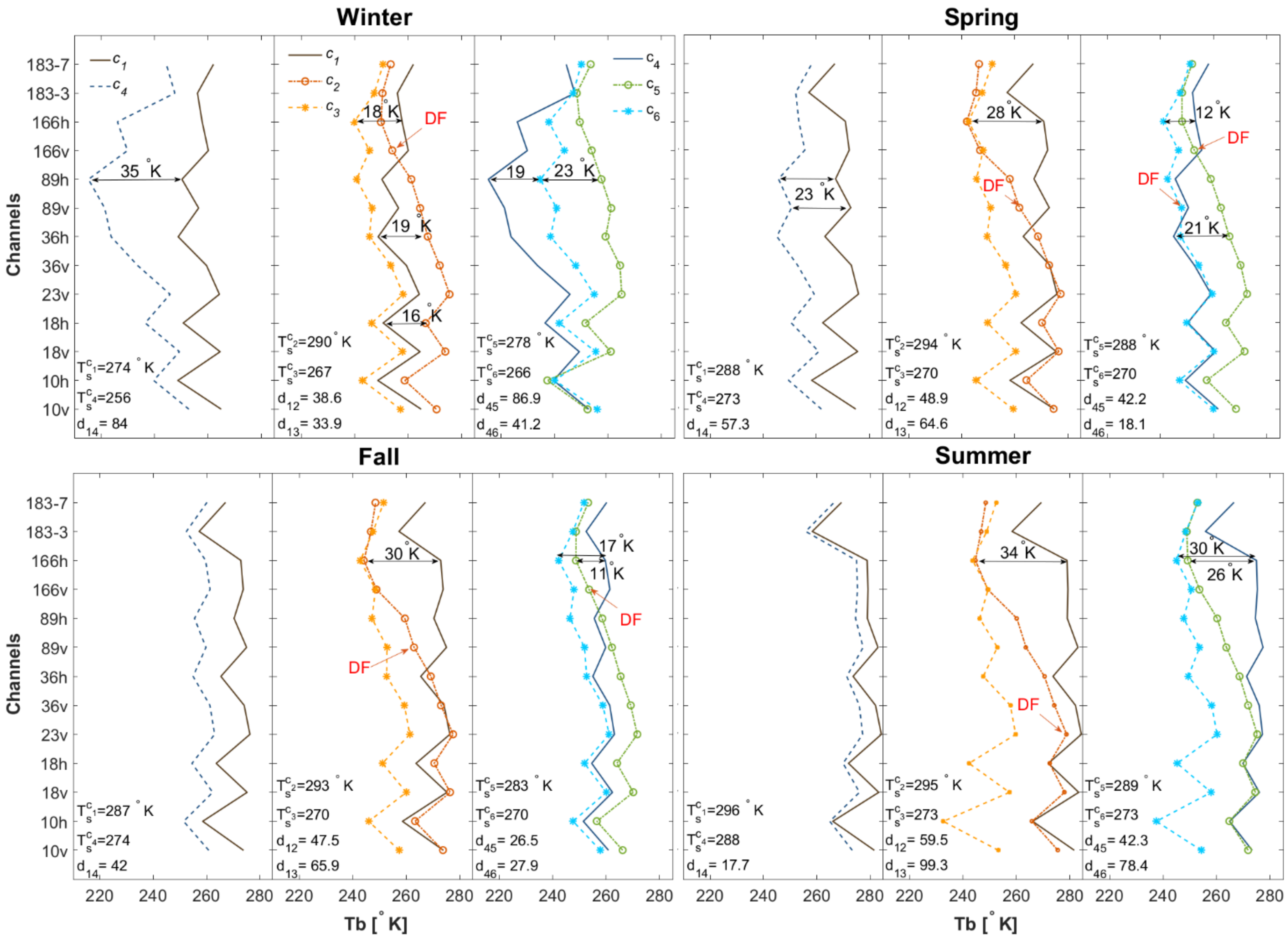
c_2: rain+ground

c_3: snowfall+ground

c_4: snow cover

c_5: rain+snow cover

c_6: snowfall+snow cover



- Precipitation Signal over Snow Cover

c_1: ground

c_4: snow cover

c_1: ground

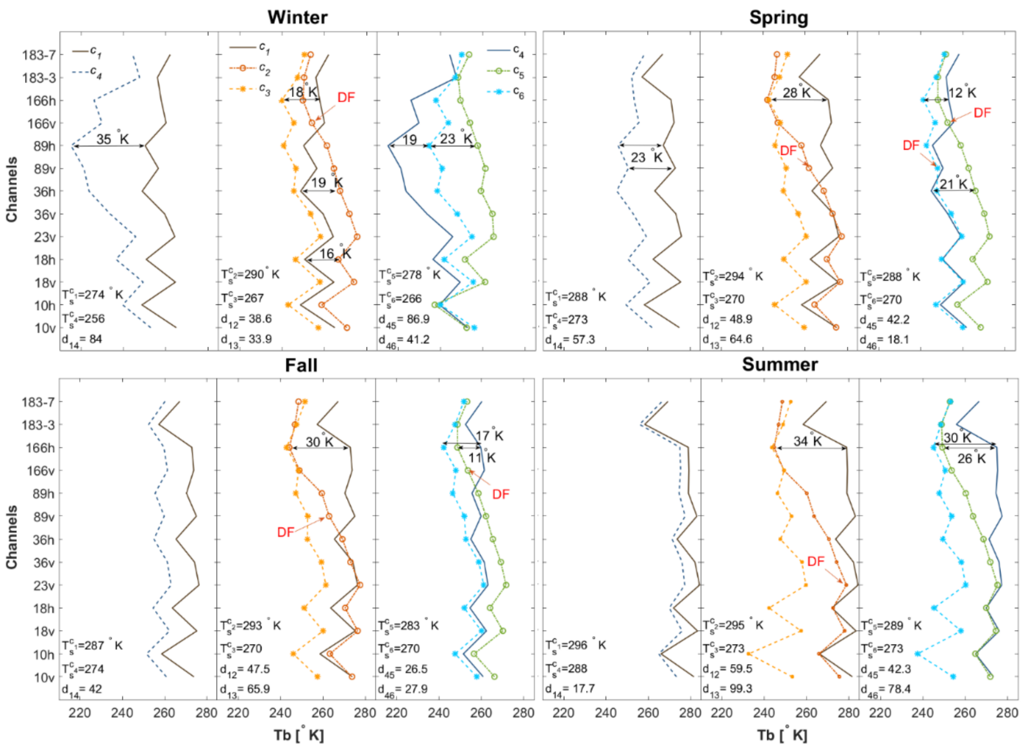
c_2: rain+ground

c_3: snowfall+ground

c_4: snow cover

c_5: rain+snow cover

c_6: snowfall+snow cover

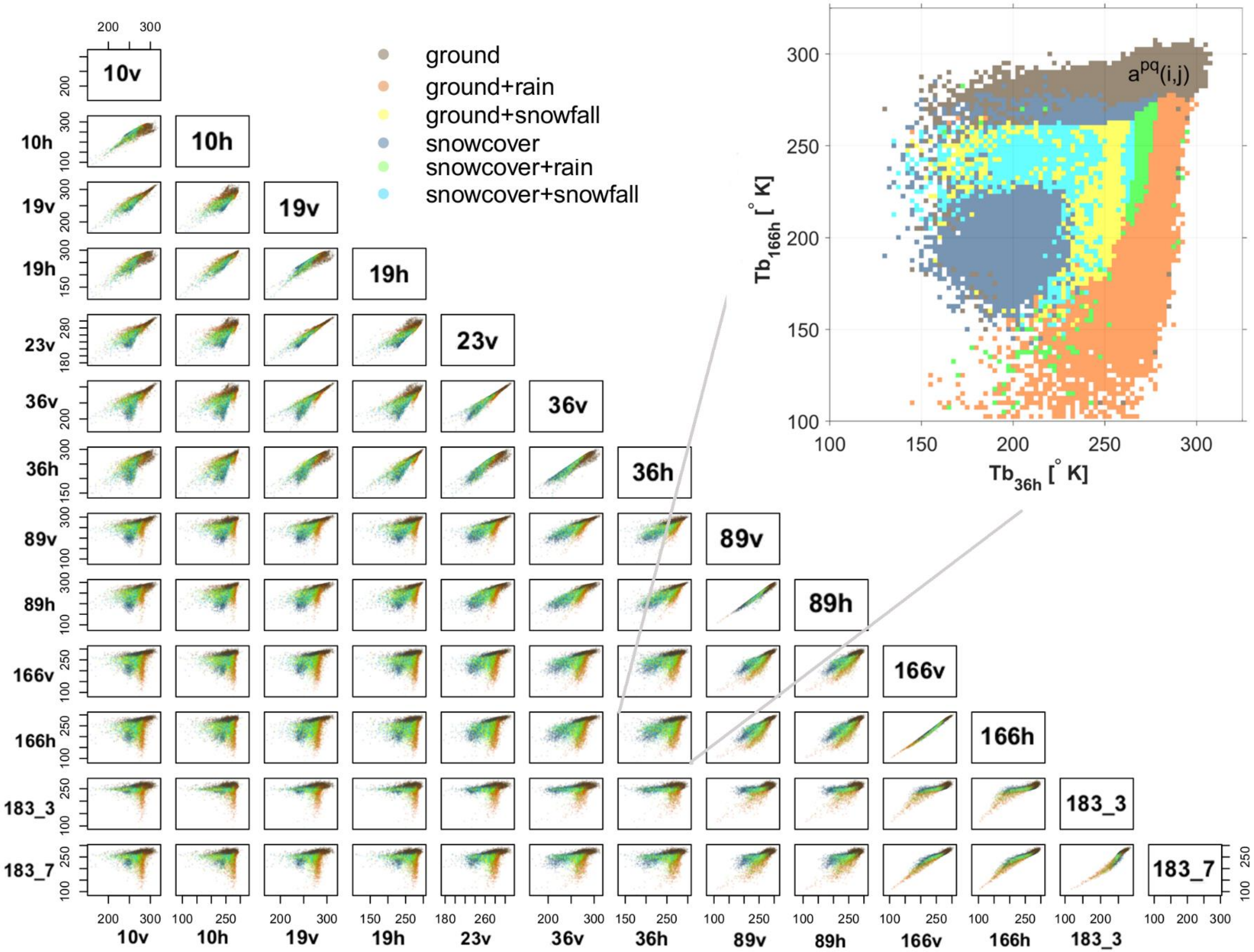


- Temporal dependence of the depression frequencies to snow cover dynamics and precipitation types.

- During the **winter, precipitation signal is warmer than the surface** and can be better distinguished from the from the emission of fresh snow cover than the emission of other surface types.

- **Note:** the mean total precipitable liquid water content of the snowfall pixels over snow cover in summer (95 gm-2) is higher than that of winter (65 gm-2), when no emission signal is detected.

- Channel Weights

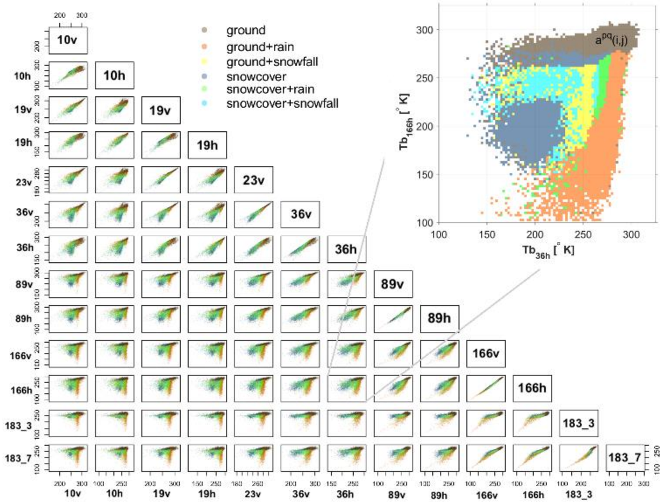


- The space is discretized into 2.5x2.5 degree.
- Each differential area is assigned to the class with the highest probability of occurrence.

$$A_{c_s}(p,\ q) = \Sigma_{i,j\in c_s} a^{pq}(i,\ j)$$

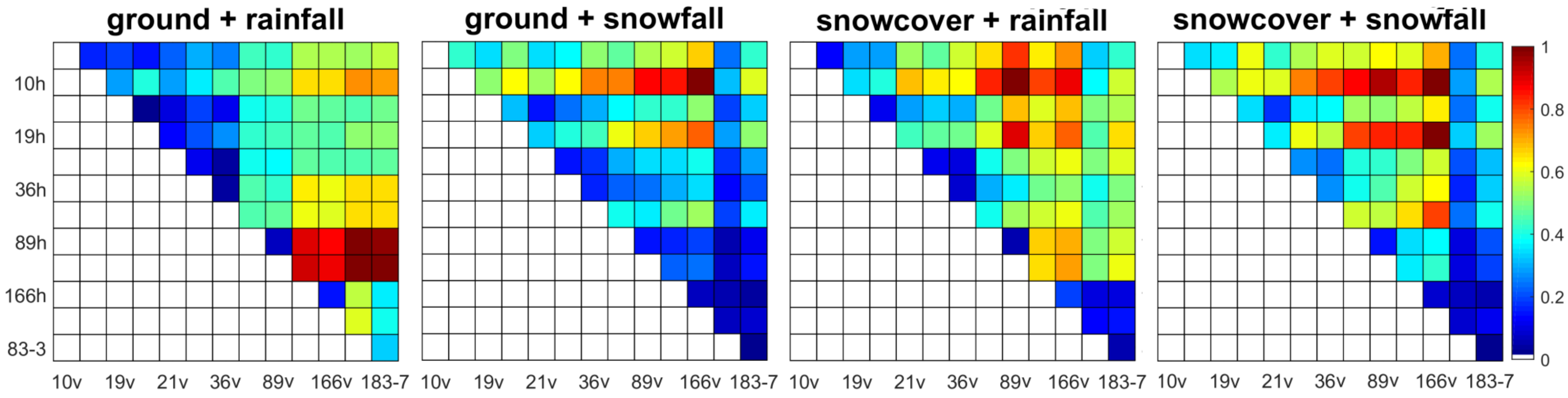
$$w_{c_s}(p,\ q) = A^{pq}_{c_s} / \max_{p,q}\left(A^{pq}_{c_s}\right)$$

- Channel Weights

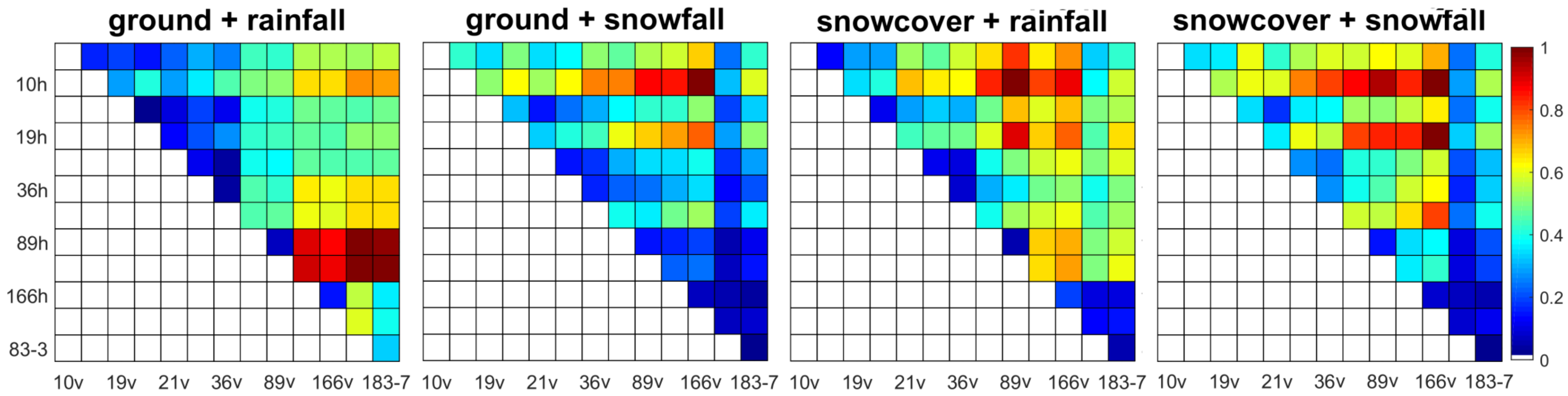


$$A_{c_s}(p,\ q) = \Sigma_{i,j\in c_s} a^{pq}(i,\ j)$$

$$w_{c_s}(p,\ q) = A^{pq}_{c_s} / \max_{p,q}\left(A^{pq}_{c_s}\right)$$



- Channel Weights



- Water vapor channels are important for detection of rainfall over ground (>89 GHz).
- **10 , 19 and 166 GHz are very important** channels for **snowfall detection** when **snow covers** the ground.
- Class specific weight matrix

$$\mathbf{W}_{c_s} = \left[w_{c_s}(p,\, q) \right]$$

$$\text{where } w_{c_s}(p,\, q) = w_{c_s}(q,\, p) \text{ and } w_{c_s}(p,\, p) = \Sigma_q\, w_{c_s}(p,\, q)$$

- Snowfall Detection

$$\mathcal{L} = \left\{\left(\overrightarrow{\mathrm{Tb}}^m,\, c_s^m\right)\right\}_{m=1}^{M}$$

$$\mathcal{L}^V = \left\{\left(\vec{\mathbf{y}}^n,\, x_s^n\right)\right\}_{n=1}^{N}$$

$$d_{c_s}^m = \left(\vec{\mathbf{y}} - \overrightarrow{\mathrm{Tb}}^m\right)^T \mathbf{W}_{c_s} \left(\vec{\mathbf{y}} - \overrightarrow{\mathrm{Tb}}^m\right)$$

k-nearest matching

		Predicted		
		c_1	c_2	c_3
Actual	c_1	0.88 (0.05)	0.05	0.07
	c_2	0.08	0.87 (0.03)	0.05
	c_3	0.01	0.01	0.98 (0.06)

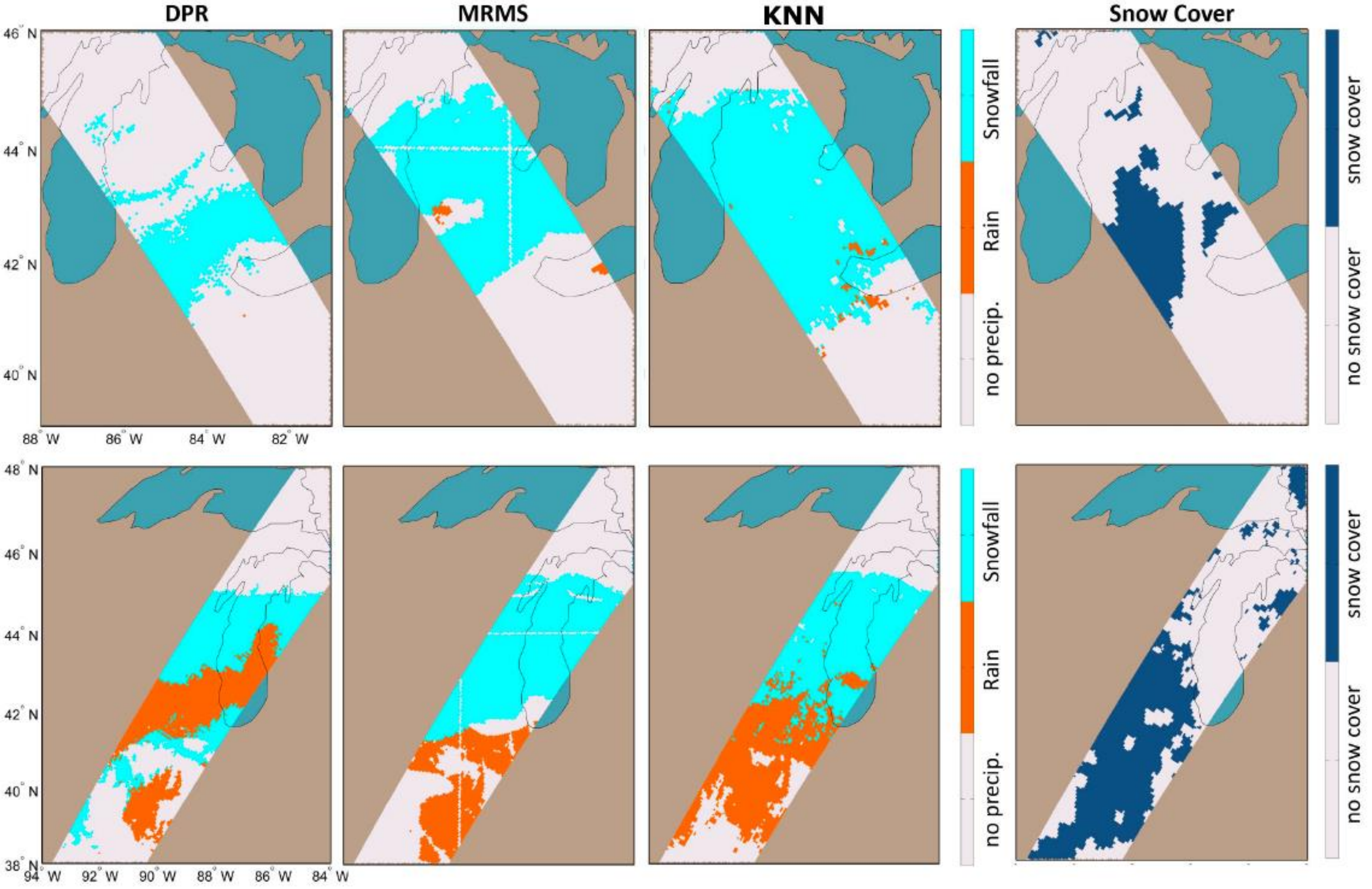
		Predicted		
		c_4	c_5	c_6
Actual	c_4	0.82 (0.05)	0.05	0.13
	c_5	0.06	0.89 (0.04)	0.05
	c_6	0.04	0.03	0.93 (0.09)

Table 1: The conditional probability of detection (false alarm), using the k-nearest neighbor approach for detection of ground (c_1), rain over ground (c_2), snowfall over ground (c_3), snow cover (c_4), rainfall over snow cover (c_5), and snowfall over snow cover (c_6). The probabilities are obtained knowing that whether snow cover exists or not.

- Snowfall Detection

2016/11/21
orbit #10412

2015/12/28
orbit #9833

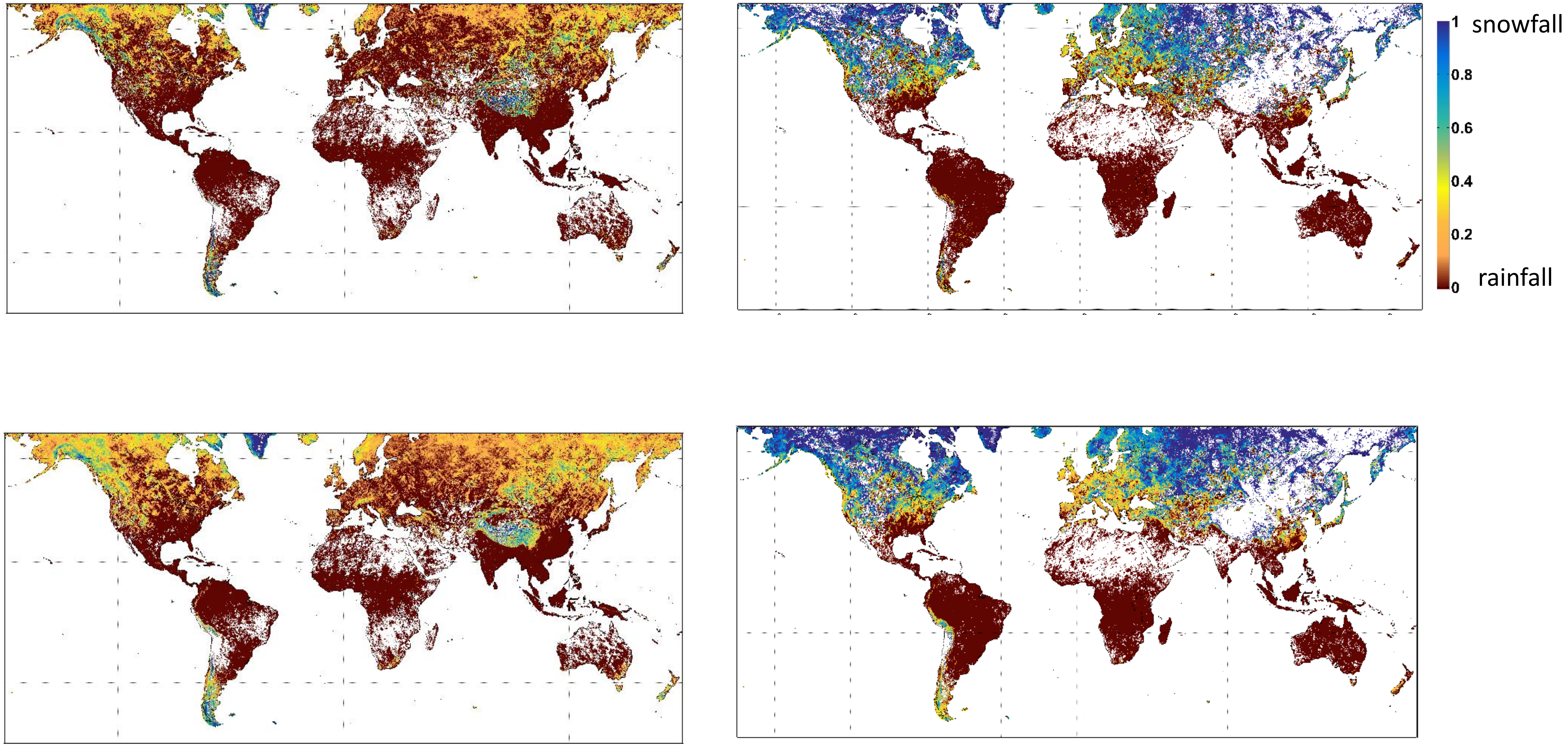


Phase Detection (Apr – Oct 2015)

Phase Detection (Nov – Mar 2016)

KNN

Fused
2A-DPR &
2B-GPROF



Thank You