Overcoming the pixel: a nonlocal formulation of GPM passive MW precipitation retrieval

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An underdetermined inversion problem

The direct problem:

Hydrometeors profile

Surface emissivity

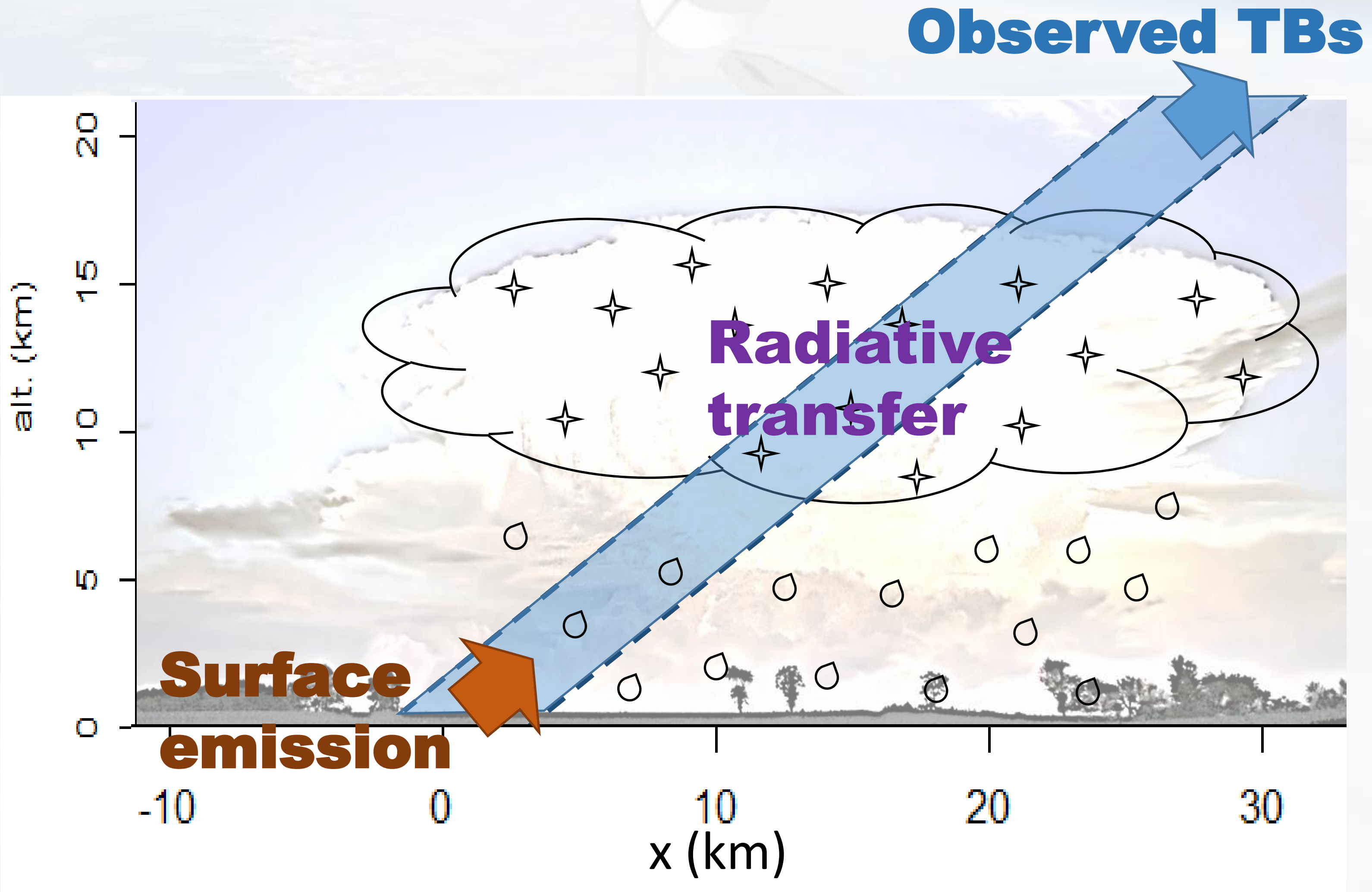
$$TB = f(R_C,E_S)$$

Resolved by radiative transfer models.

The inverse problem:

?

$$R_C = g(TB,E_S)$$



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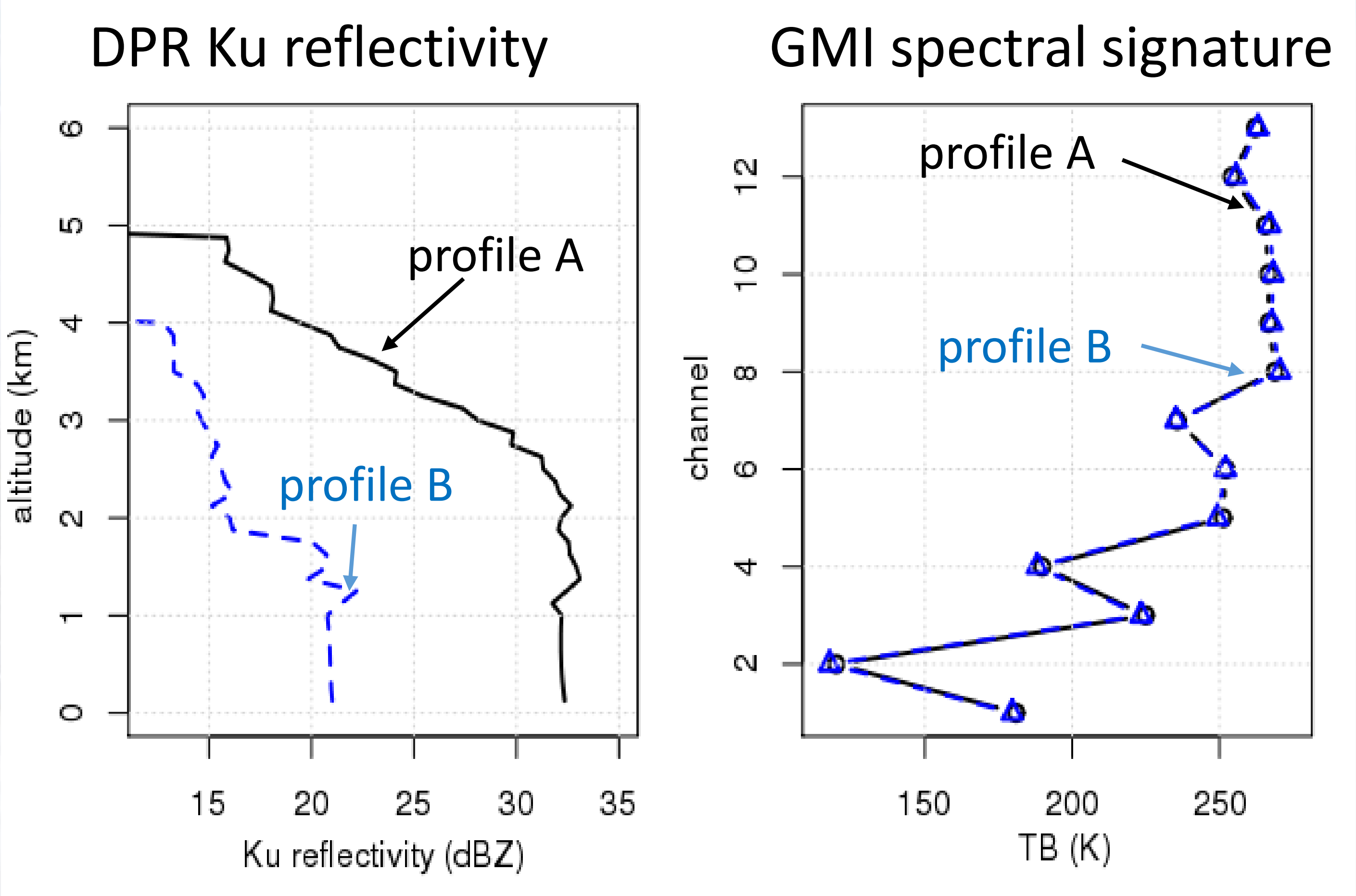


Different hydrometeor profiles

Same spectral signature

Retrieval from an a-priori database

Principle:

- Look for the solution among a set of previously observed atmospheric profiles: the **a-priori database**.
  e.g.: GPM DPR profiles associated to observed (or simulated) TBs.

- Select the appropriate profile based on the **radiometric distance** to the observation, i.e. a **vectorial distance in a *N*-dimensional space**, N = number of channels, ($N = 13$ for GMI).

$\Rightarrow$ The retrieval becomes an **interpolation problem** in the N-dimensional radiometric space.

Retrieval from an a-priori database

Retrieval as an interpolation problem:

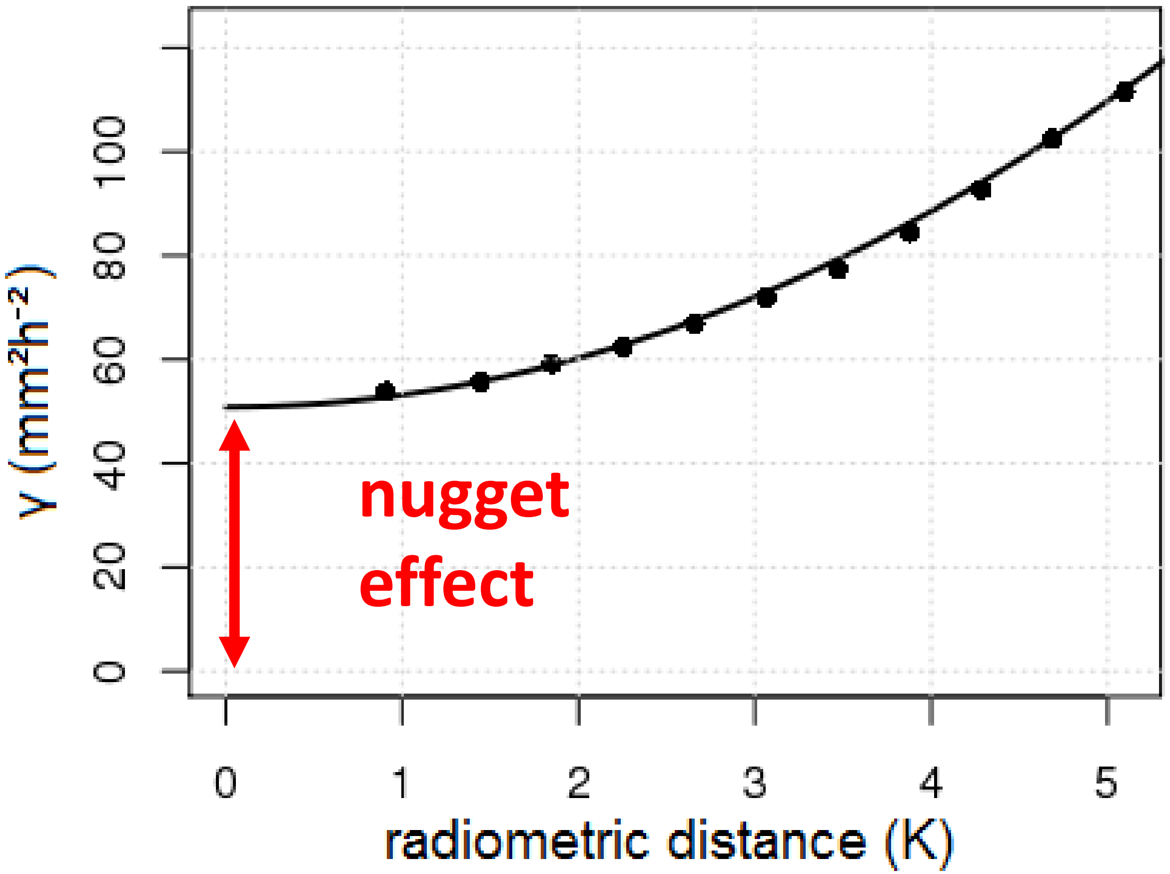
The function $R(\overrightarrow{TB})$ to interpolate is irregular (in the Lipschitz sense):

$$\left|\overrightarrow{TB_1} - \overrightarrow{TB_2}\right| \rightarrow 0$$

does not necessarily imply that

$$\left|R(\overrightarrow{TB_1}) - R(\overrightarrow{TB_2})\right| \rightarrow 0$$

variogram of *R(TB)* in the 13-D GMI TB space



Retrieval from an a-priori database

- Irregularity of $R\left(\overrightarrow{TB}\right)$ = **large uncertainty** on the retrieved R.

- Increasing the density of the database does not help much (because of the nugget effect).

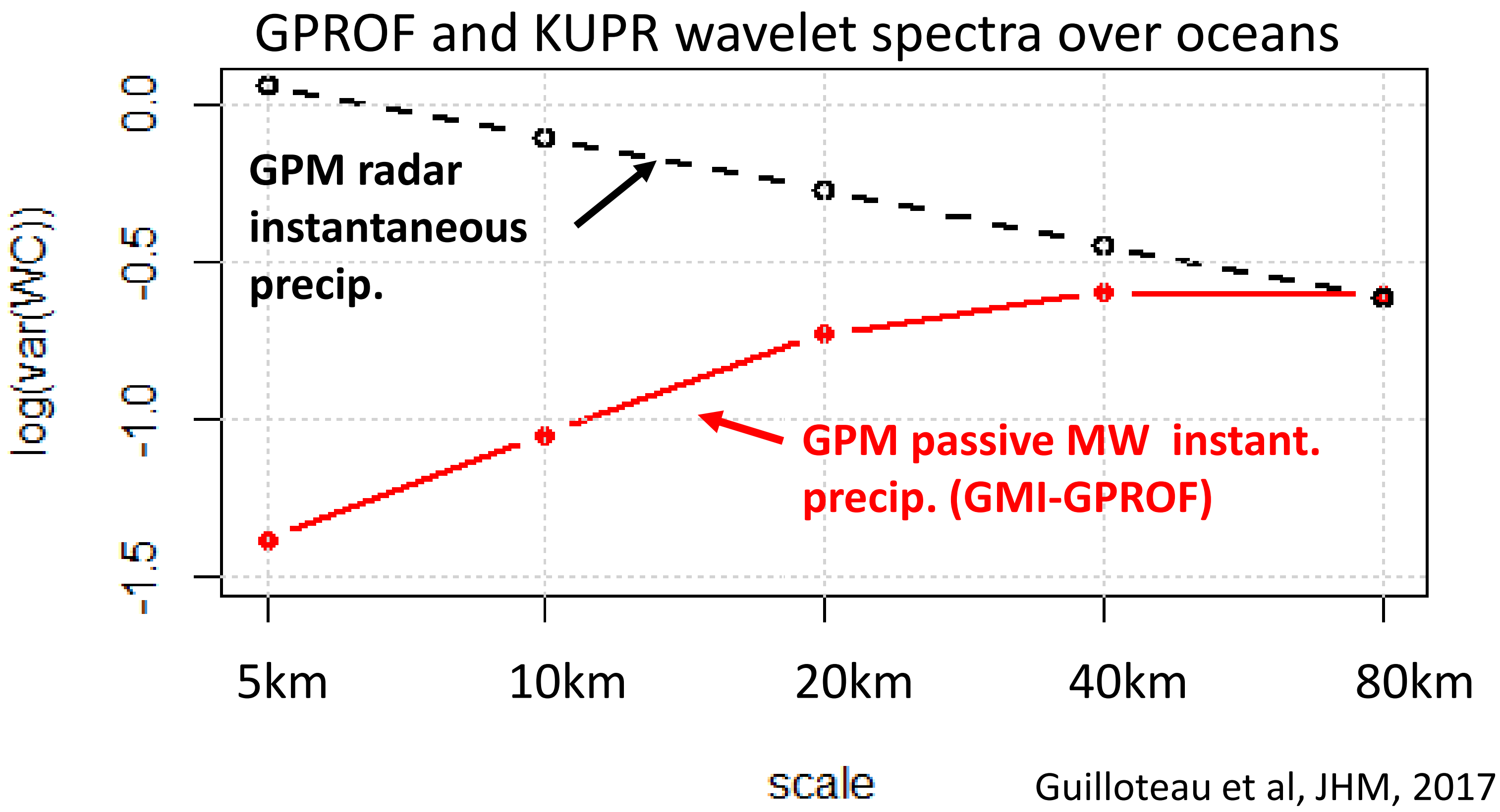
- Choosing a **smooth solution** (average or combination of several profiles of the databases) reduces the mean squared error but …

… poor performance for the retrieval of extremes.

Retrieval from an a-priori database

- Irregul… *R*.
- Increas… (becaus…
- Choosi… …everal profiles… …ut …

smooth relations in the TB space = spatially smooth retrieved precipitation fields



Guilloteau et al, JHM, 2017

⇒New information needed to reduce the uncertainty.

Adding new information

Supplementary information …

… can be obtained from **ancillary datasets**, e.g. surface type, environment parameters from reanalyses (CAPE, TPW, 2-m-temperature …).

… can be extracted from the **spatial variations of the TBs** in the **neighborhood** around the “pixel” of interest.

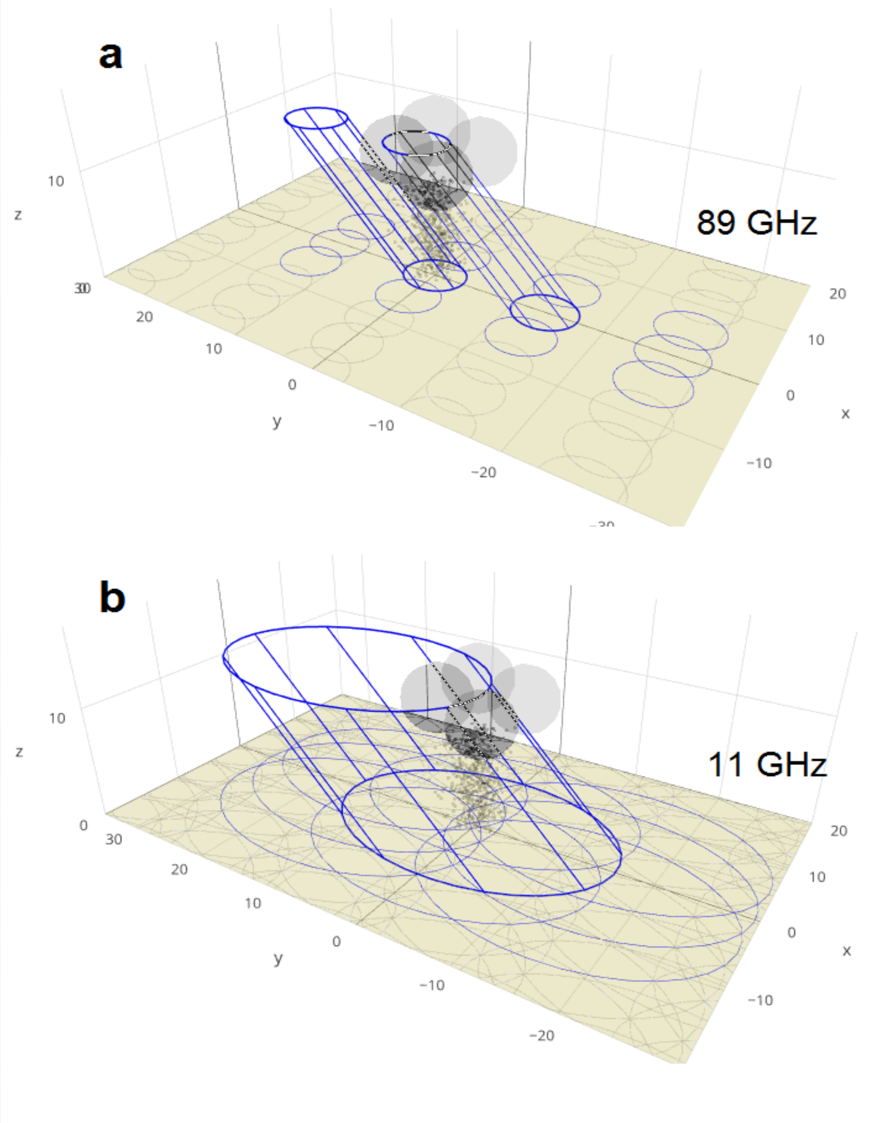
⇒ **New paradigm:**

- Current algorithms invert one “pixel” at a time and all “pixels” independently, ignoring the spatial structure of precipitation across adjacent “pixels”.

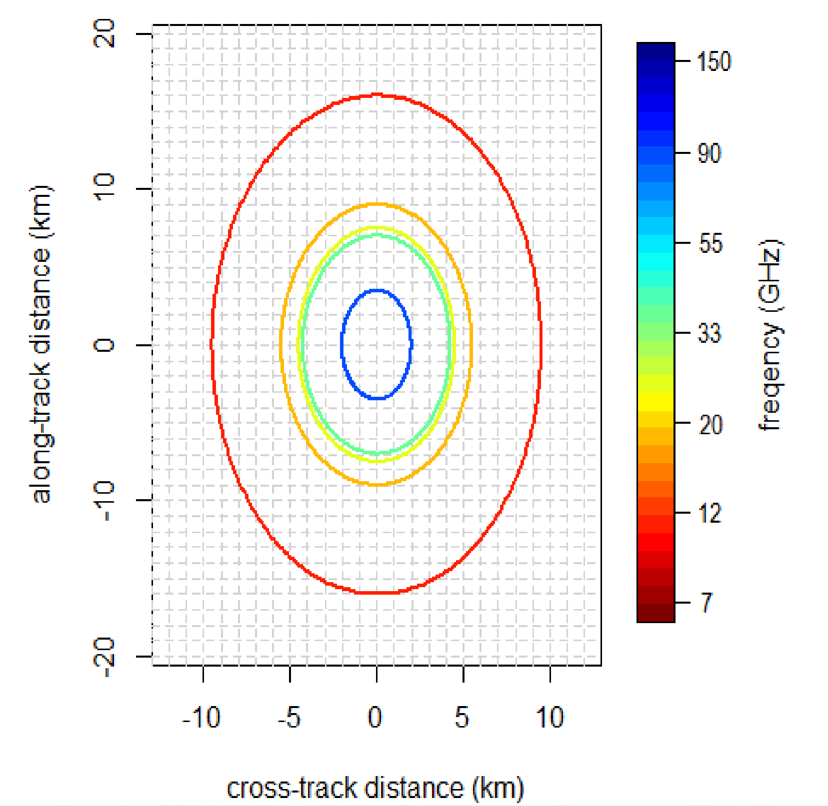
- **The “nonlocal” approach aims at overcoming the pixel-wise relations between TBs and precipitation**.

Why?: "nonlocal" information in observed TBs

Observation geometry



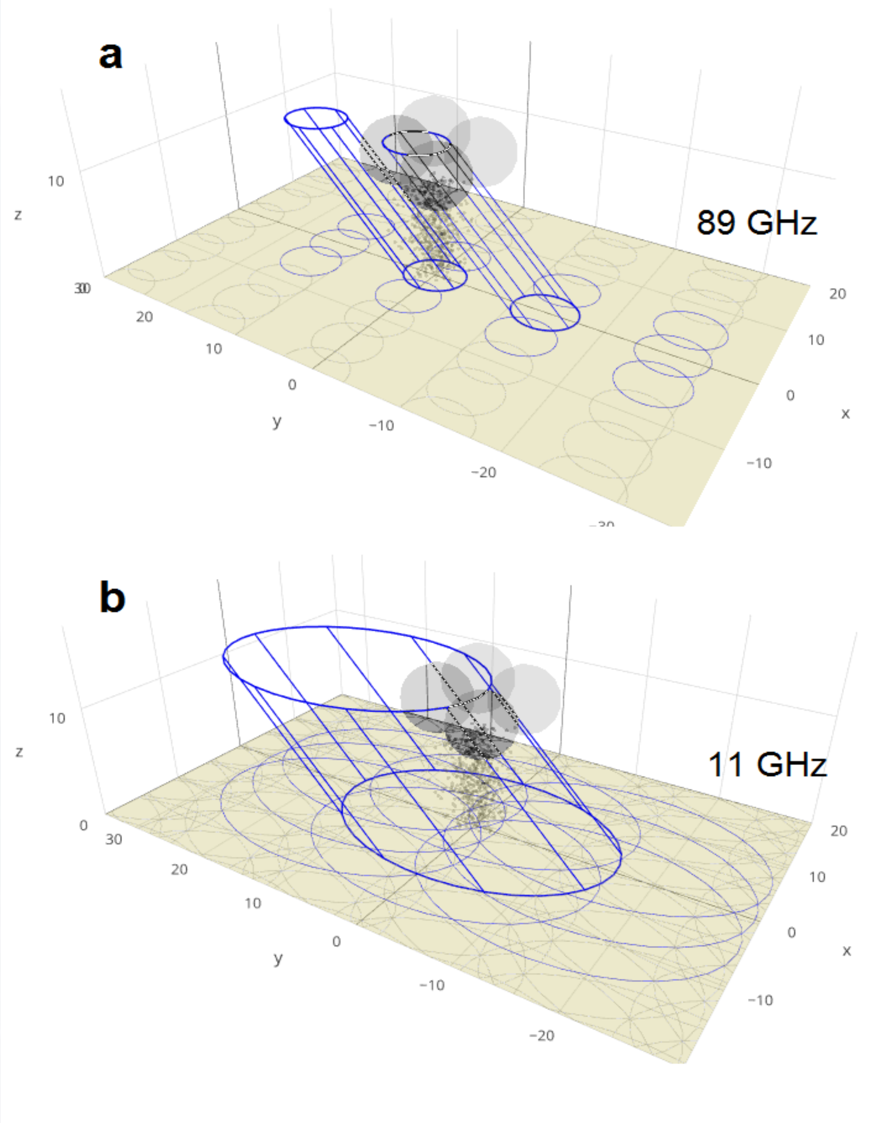
GMI footprints at various frequencies



What is the retrieval field of view? What defines the "pixel" and the retrieval "resolution"?

Why?: "nonlocal" information in observed TBs

Observation geometry



- **Low Frequencies** (<40 GHz)**:** Significant overlapping of the fields of view.

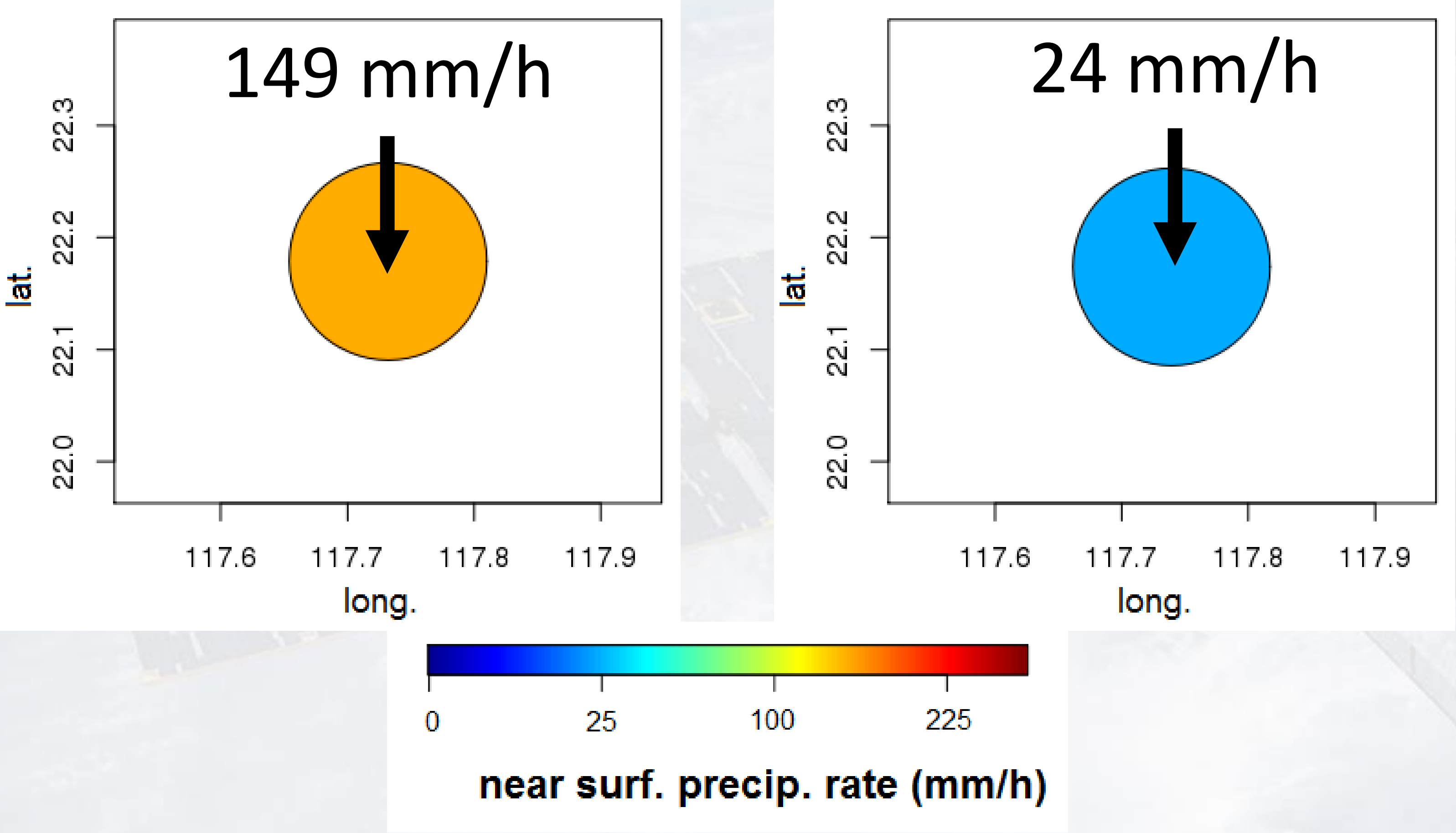
- **High Frequencies:** 53° Earth incident angle => a vertical atmospheric column always interpolated by at least two different fields of view.

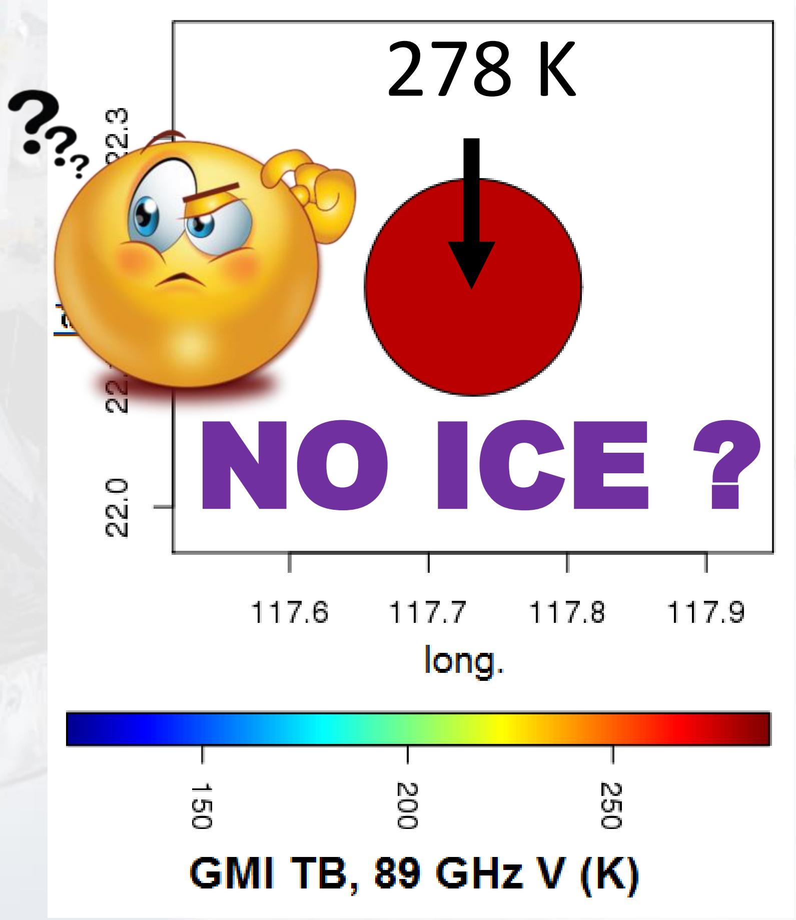
Different channels responding to different altitude levels => multi-spectral signature characterizing a vertical atmospheric column split across several pixels.

Why?: “nonlocal” information in observed TBs

Illustrative case study:

DPR / GMI GPROF / GMI 89 GHz V TB





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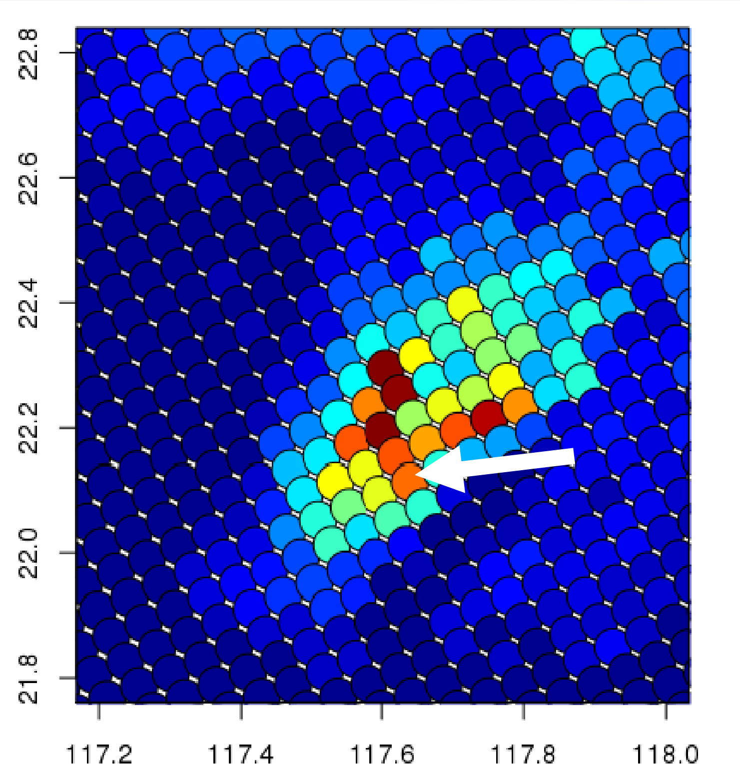
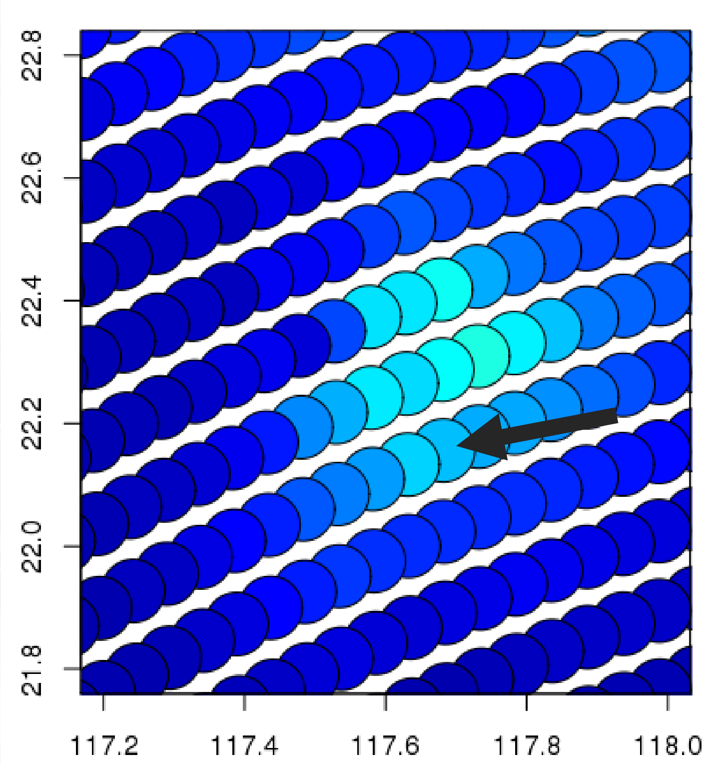
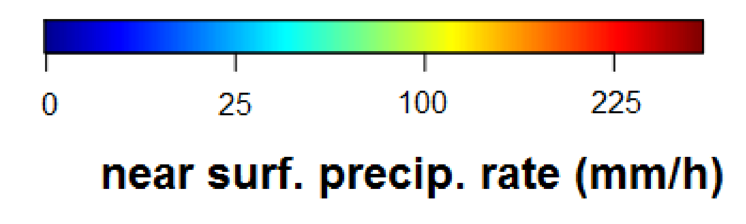
Illustrative case study:

DPR

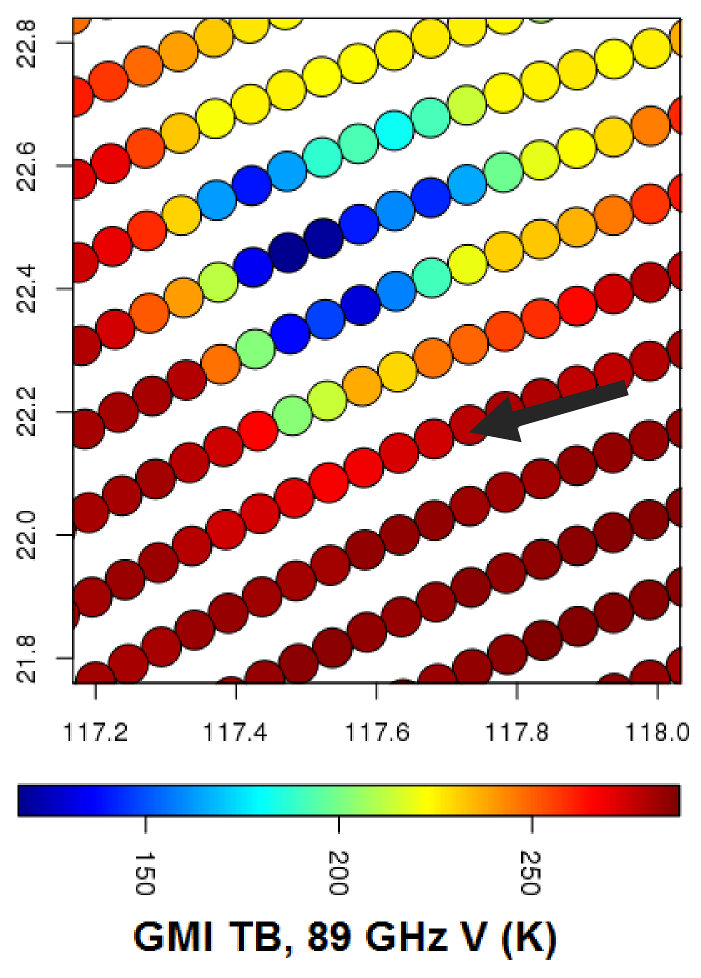


GMI GPROF



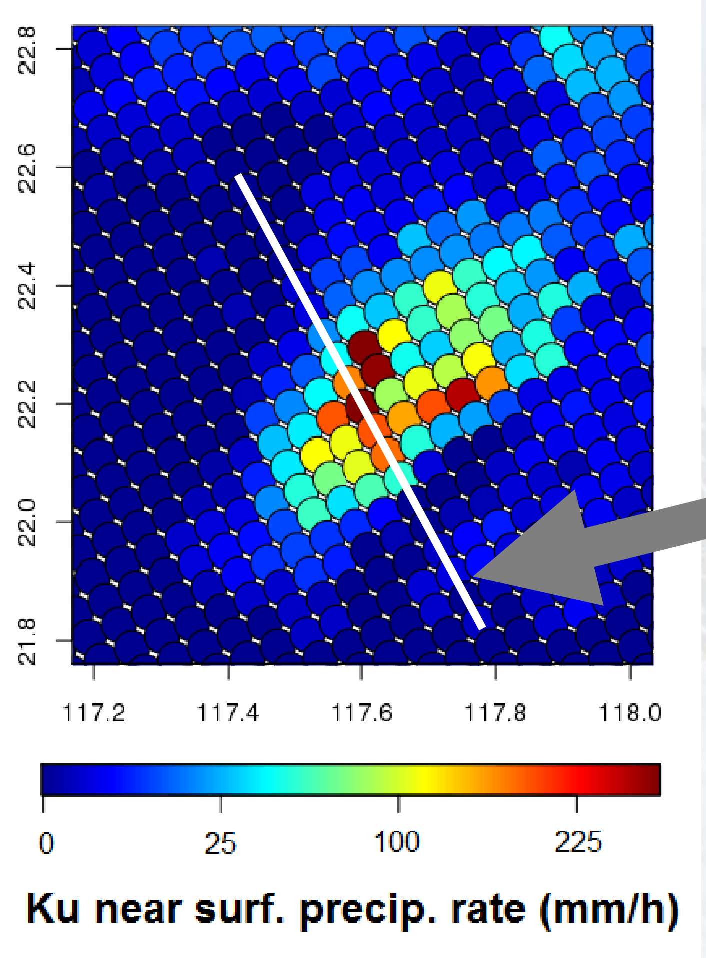


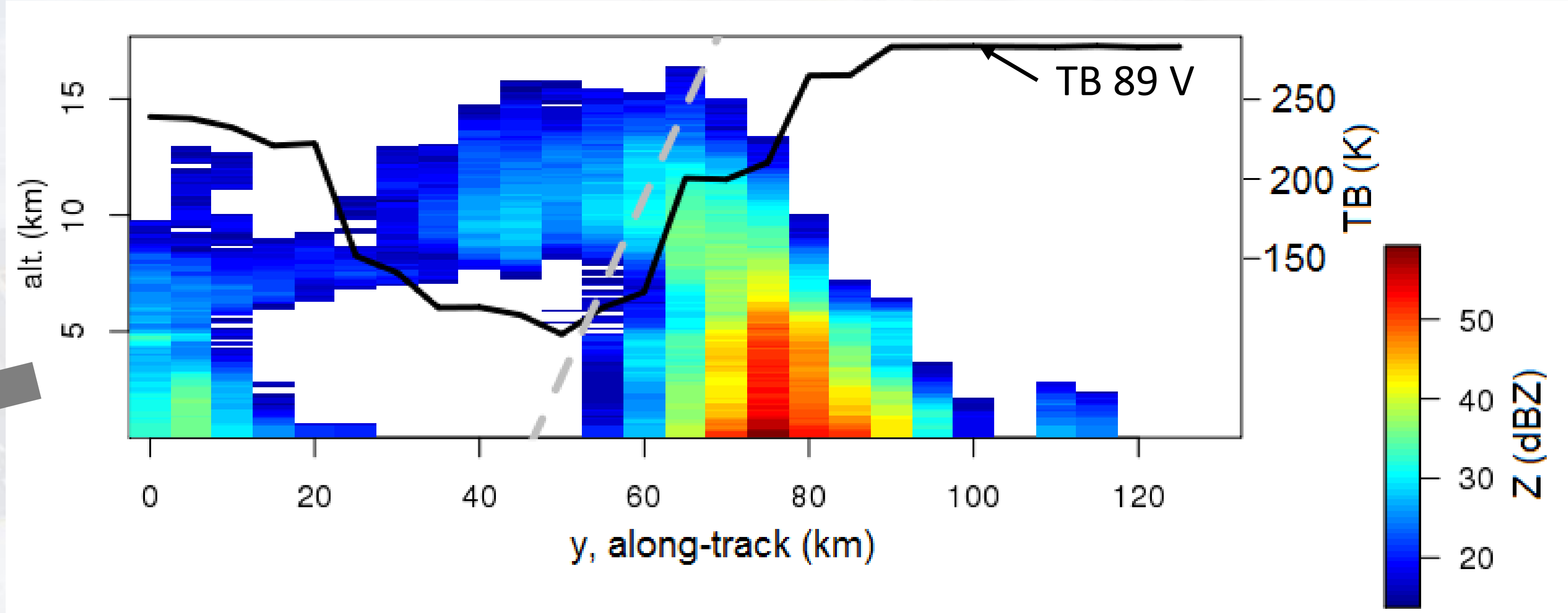
GMI 89 GHz V TB



Why?: “nonlocal” information in observed TBs

Three-dimensional structure of the system:





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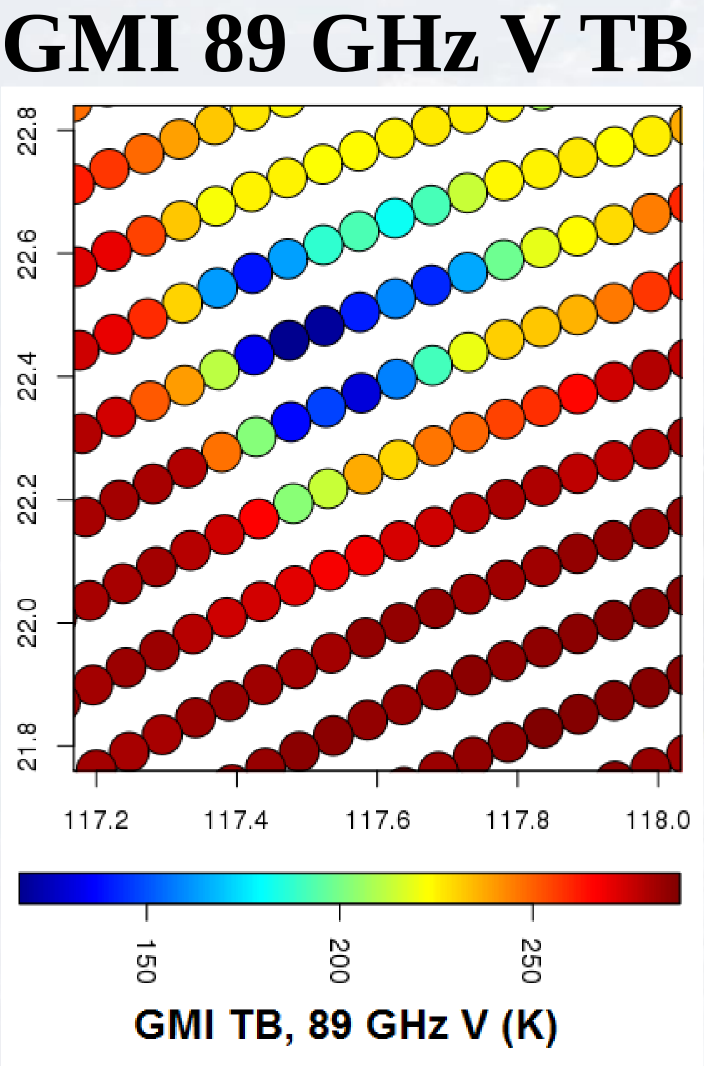
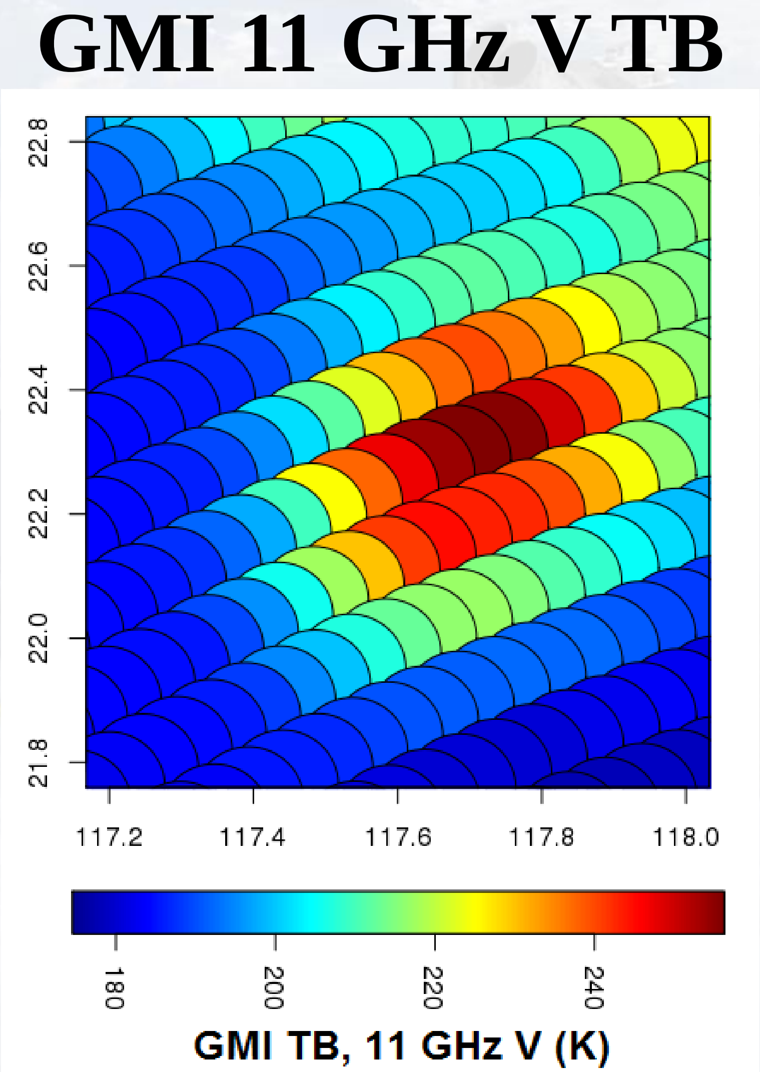
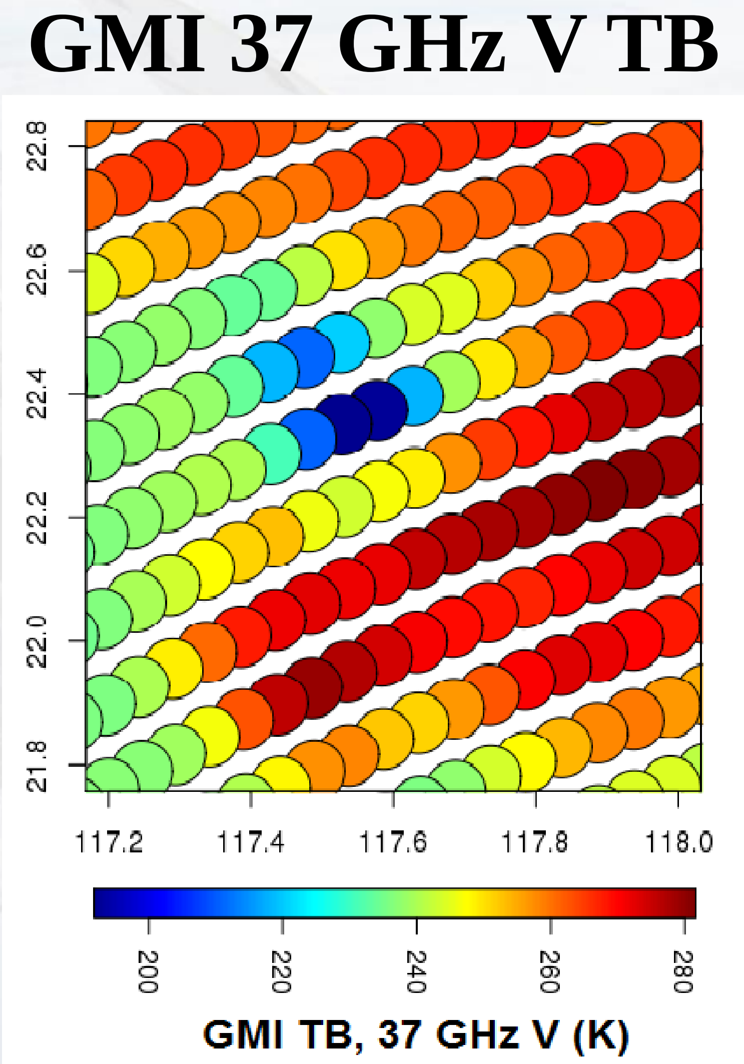
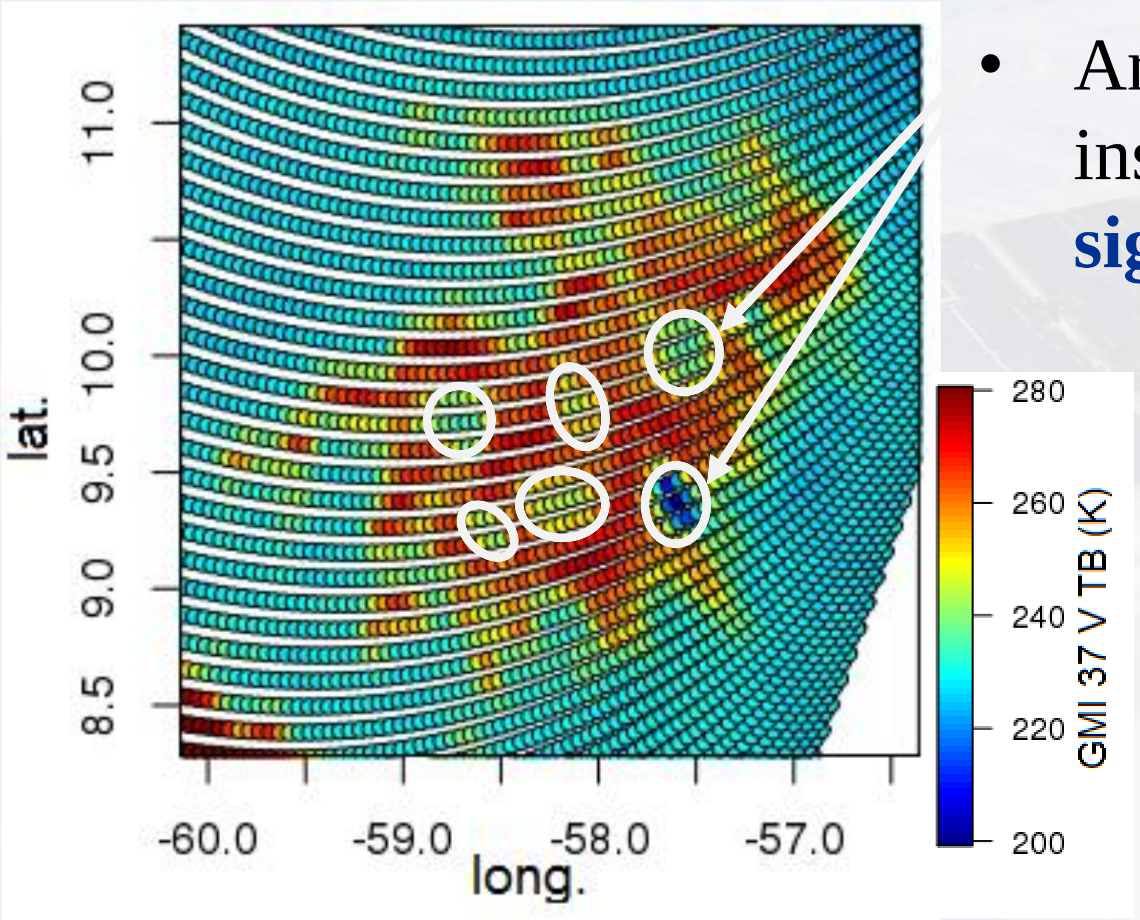






Why?: “nonlocal” information in observed TBs

- 37 GHz TB sensitive to both liquid emission and ice scattering.
  => Non-monotonic response to precipitation intensity.



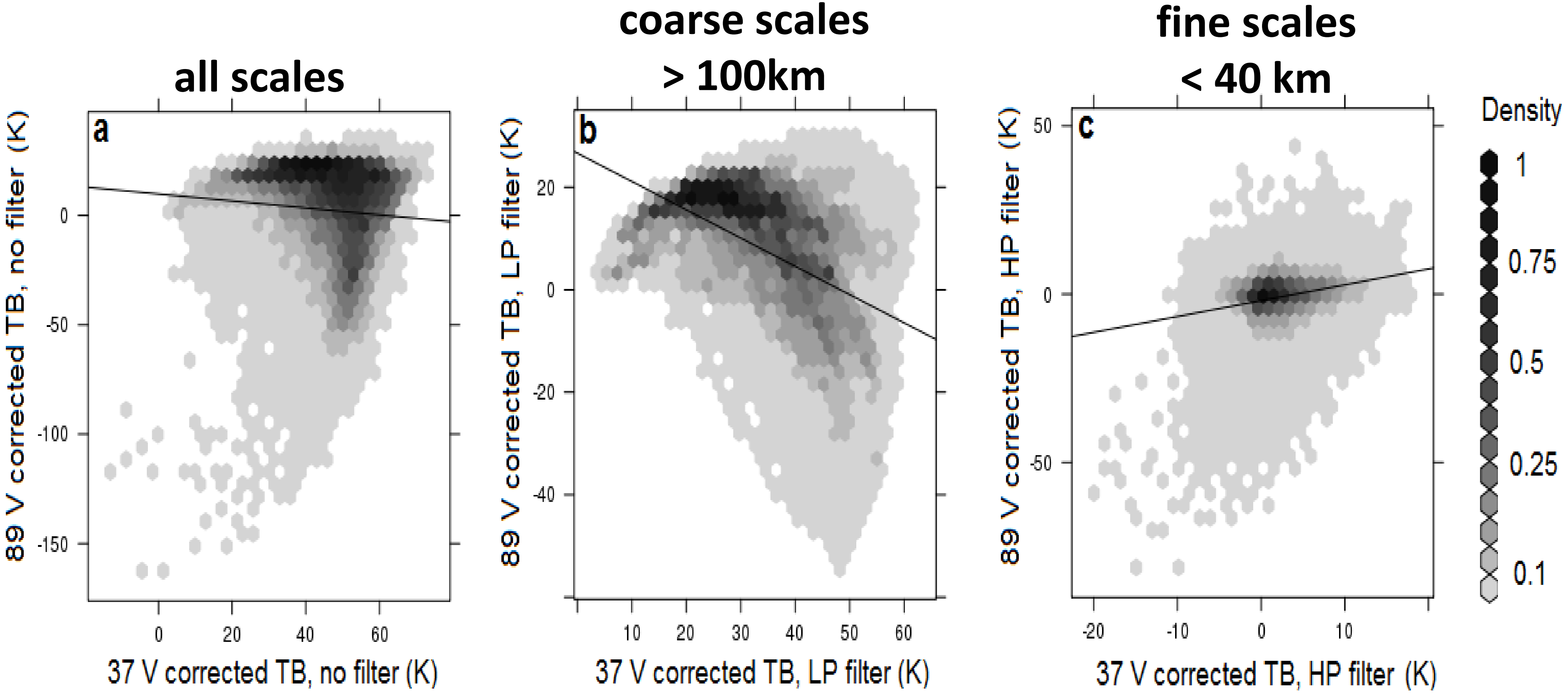
- Area with low / medium TBs embedded inside an area of high TBs = **geometric signature** of a convective cell.

$\Rightarrow$ **Specific TB patterns are the signatures of specific atmospheric features.**

$\Rightarrow$ **Scale dependence in the covariations of TBs and precipitation.**

Why?: “nonlocal” information in observed TBs

relations between TBs 37V and 89V as a function of the scale

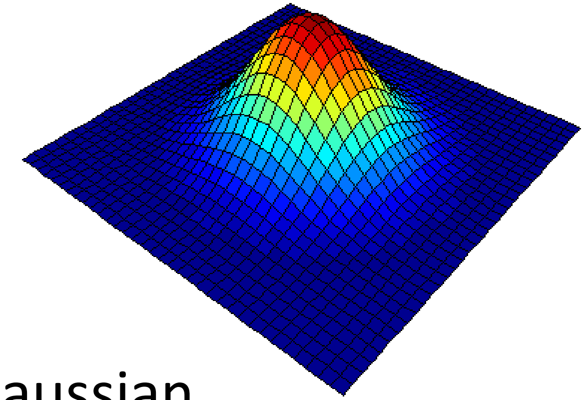


over ocean, TBs corrected from the influence of surface temperature

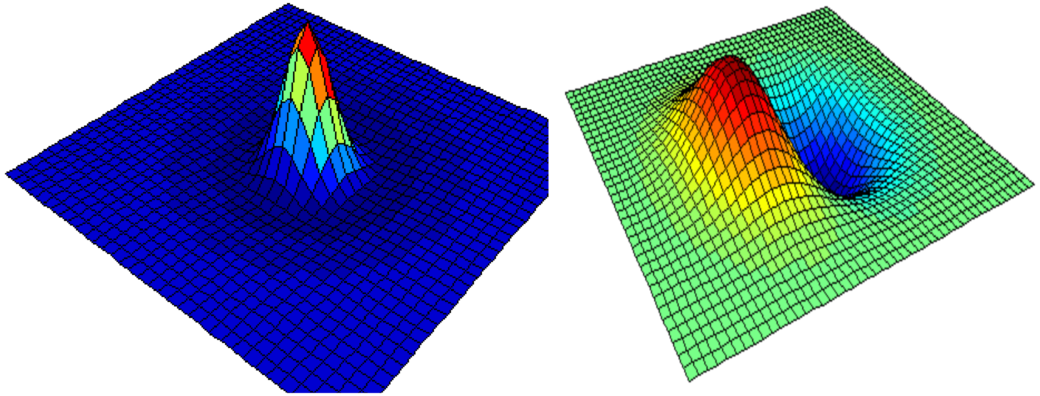
How?: extracting the nonlocal information

The spatial variability of the TBs around can be analyzed through **convolution filters**.

- Pattern extraction (with or without directionality parameter)
- Multiscale decomposition of the TB fields (orthogonal filters / wavelets)



Gaussian



Differences of Gaussians

How?: utilizing the nonlocal information

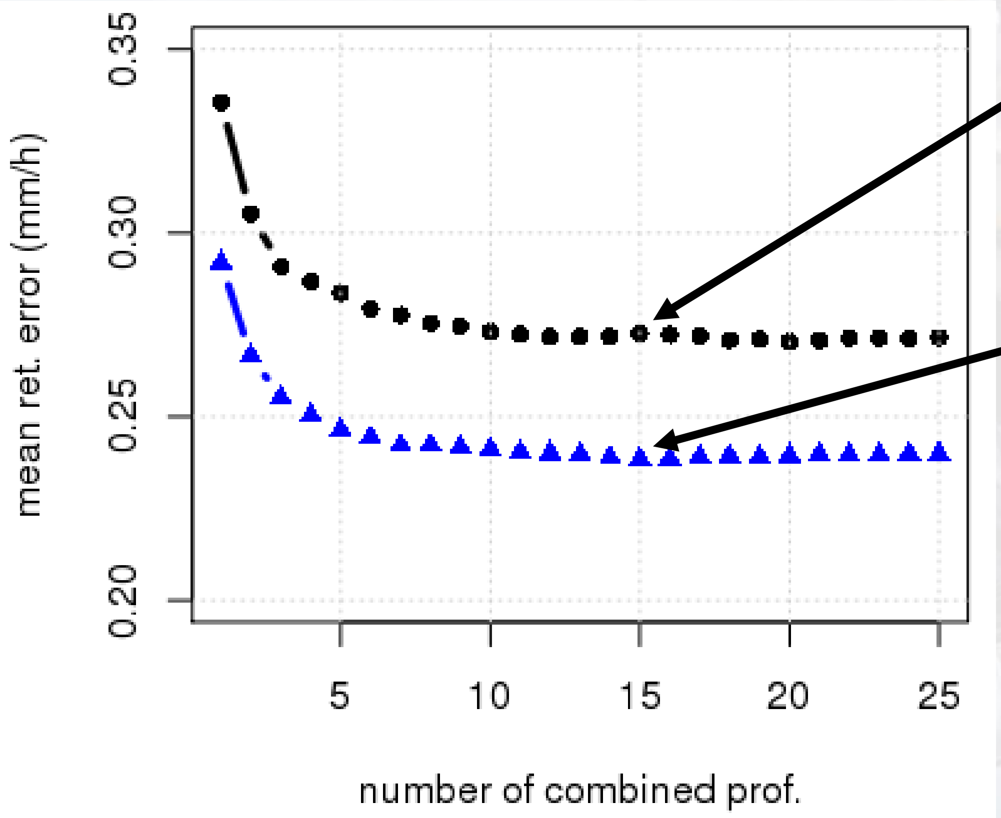
The nonlocal parameters derived from the spatial variations of the TBs can be used in various ways:

- By performing a pre-selection of the atmospheric profiles of the a-priori database before the retrieval, i.e. a first classification step.

- By including them in the observation vector to augment it and compute the radiometric distances in a higher-dimensional space to perform the retrieval.

Preliminary results

Retrieval from GMI over land with a 700 000 - profile a-priori database:



13 "pixel" TBs
+ 2m temp. + surf. type

13 "pixel" TBs
+ 2m temp. + surf. type
+ 3 nonlocal param. (at 37 and 89 GHz)

Conclusions

- Current algorithms perform pixel-wise retrievals associating the precipitation rate in a “pixel” only to the TBs observed inside the pixel.
- But the pixel exists within a context. TB fields have a spatial organization reflecting the spatial organization of precipitation. **⇒ There is information outside of the pixel**.

+ With the scanning geometry of GMI and other similar instruments the pixel is ill-defined.

- Information from outside the pixel can be extracted (e.g. using convolution filters) to better constrain the inversion and reduce the retrieval uncertainty.