Towards sparse coding of rainfall spectral atoms: A TRMM legacy

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Outline

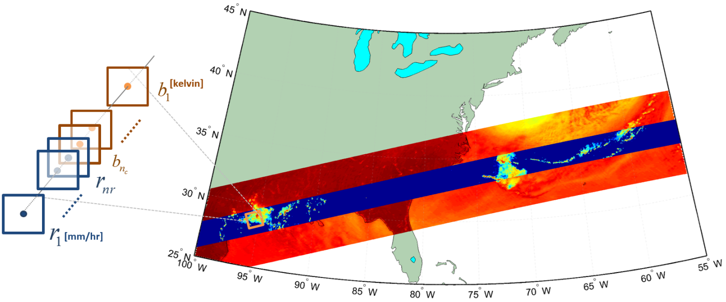
ShARP: latest update

- A demo MATLAB code will be released next week.
- A new paper: On evaluation of ShARP over coastal zones and snow-covered lands.

Coding rainfall spectral atoms

- Guiding physically-based retrievals
- New directions in retrieval methods

Shrunken locally linear embedding Algorithm for Retrieval of Precipitation



- **Dictionaries:**

$$\textbf{Tb:} \qquad \mathbf{B} = [\mathbf{b}_1 | \mathbf{b}_2 | \ldots | \mathbf{b}_{M-1} | \mathbf{b}_M] \in \mathfrak{R}^{n_c \times M}$$

$$\textbf{Rainfall:} \qquad \mathbf{R} = [\mathbf{r}_1 | \mathbf{r}_2 | \ldots | \mathbf{r}_{M-1} | \mathbf{r}_M] \in \mathfrak{R}^{n_r \times M}$$

where $\mathbf{r}_i = (r_{1i},\ r_{2i},\ \ldots,\ r_{n_r i})^T$ and $\mathbf{b}_i = (b_{1i},\ b_{2i},\ \ldots,\ b_{n_c i})^T$

ShARP: Some Details

- **Detection Step:**
  - o for a given $\mathbf{y} \in \mathfrak{R}^{n_r}$ and the dictionary pairs $\mathbf{B} = \{\mathbf{b}_i\}_i^M$, $\mathbf{R} = \{\mathbf{r}_i\}_i^M$
  - o find TB sub-dictionary: $\mathbf{B}_{\mathcal{S}} = [\mathbf{b}_1|\mathbf{b}_2|\ldots|\mathbf{b}_K] = \{\mathbf{b}_k\}_{k=1}^K$, where $\mathbf{b}_k$ are the k-nearest neighbors of $\mathbf{y}$
  - o obtain the rainfall sub-dictionary: $\mathbf{R}_{\mathcal{S}} = [\mathbf{r}_1|\mathbf{r}_2|\ldots|\mathbf{r}_K] = \{\mathbf{r}_k\}_{k=1}^K$
  - o rain/no-raining detection by a probabilistic vote rule

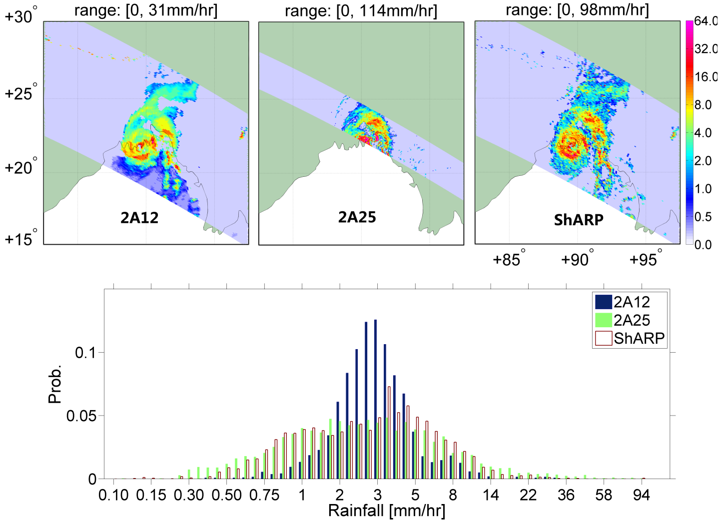
- **Estimation Step:**

$$\begin{aligned} \underset{\mathbf{c}}{\text{minimize}} \quad & \left\| \mathbf{W}^{1/2} (\mathbf{y} - \mathbf{B}_{\mathcal{S}}\mathbf{c}) \right\|_2^2 + \lambda_1 \|\mathbf{c}\|_1 + \lambda_2 \|\mathbf{c}\|_2^2 \\ \text{subject to} \quad & \mathbf{c} \succeq 0, \;\; \mathbf{1}^{\mathrm{T}}\mathbf{c} = 1. \end{aligned}$$

o ℓ_2-norm: $\|\mathbf{c}\|_2^2 = \Sigma_i |c_i|^2$ and ℓ_1-norm: $\|\mathbf{c}\|_1 = \Sigma_i |c_i|$.
o estimate of rainfall profile: $\hat{\mathbf{x}} = \mathbf{R}_{\mathcal{S}}\hat{\mathbf{c}}$.

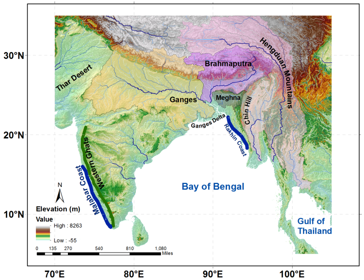
ShARP: storm-scale

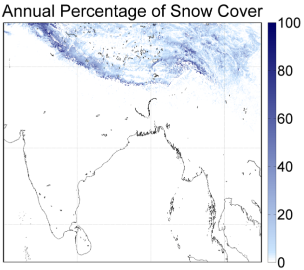
- Cyclone Sidr (10/15/2007), 13:59 UTC

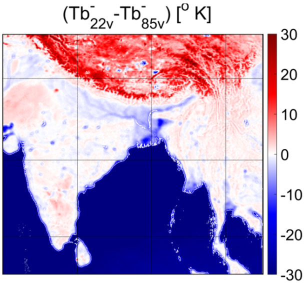


ShARP: continental-scale

- Study area, annual MODIS snow cover and TMI-Scattering Index in 2013

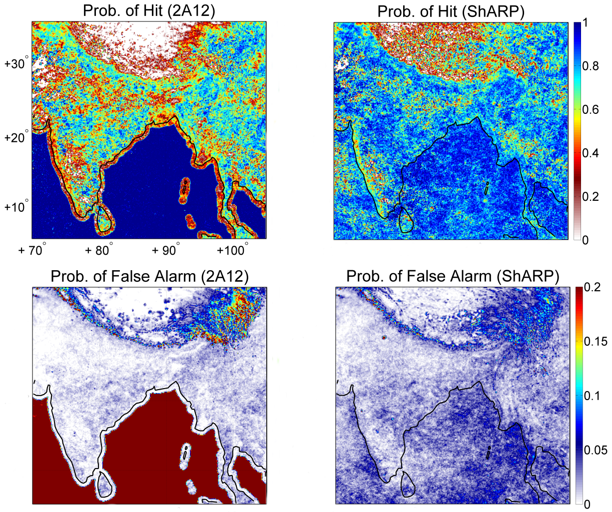






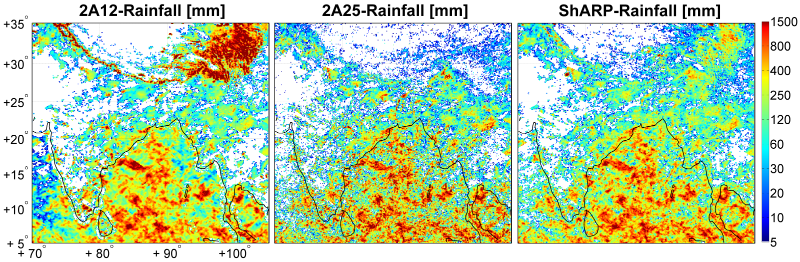
ShARP: continental-scale

- Probability of hit – (all overpasses in 2013 while PR is the reference over land)
- Probability of false alarm

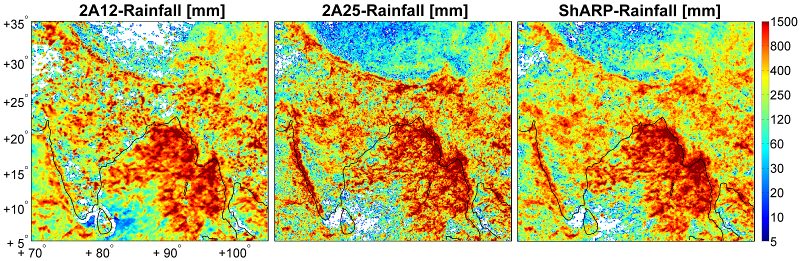


ShARP: continental-scale

- **Oct-Nov-Dec (2013)**



- **Jul-Aug-Sep (2013)**



ShARP: continental-scale

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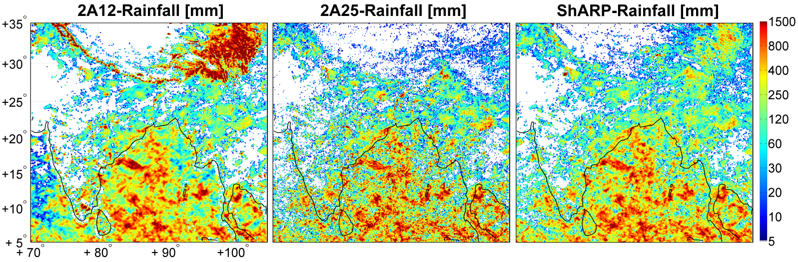

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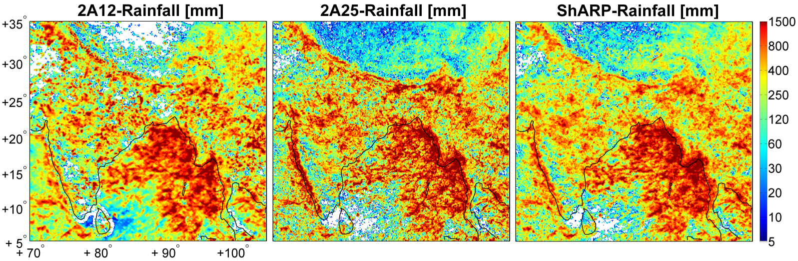
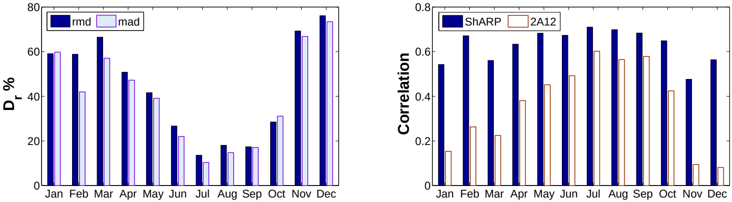


ShARP: continental-scale

- **Error metrics (2013)**

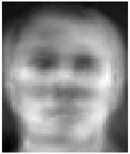


1- Ebtehaj, A.M., R.L. Bras, E. Foufoula-Georgiou (2015), Shrunken locally linear embedding for passive microwave retrieval of precipitation, *IEEE Trans. on Geosci. and Remote Sens.*vol 53(7), doi:10.1109/TGRS.2014.2382436.

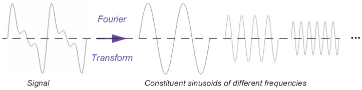
2- Ebtehaj, A.M., R.L. Bras, E. Foufoula-Georgiou (2015), On evaluation of ShARP passive rainfall retrievals over snow-covered land surfaces and coastal zones, arxiv.org/abs/1503.05495.

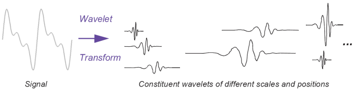
Why Rainfall Atoms?

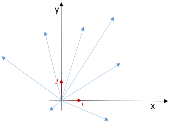
- **Goals**
  - o guiding physically based retrieval approaches.
  - o new directions for precipitation retrieval.
- **Idea:**



A Similarity Metric







How can we learn a compact set of rainfall spectral atoms?

Spectral Atoms and a Rain/No-rain Detection Algorithm

- **notations:**

  pixel-level spectral observations: $\mathbf{y} = [\mathsf{Tb}_{10v},\, \ldots,\, \mathsf{Tb}_{85h}]^T \in \mathfrak{R}^9$

  rainfall profile: $\mathbf{x} = [r_1,\, r_2,\, \ldots,\, r_n]^T \in \mathfrak{R}^n$

  raining (r) and dry (d) spectral atoms: $\mathbf{D}_{\mathrm{T}}^{\{\mathrm{r},\,\mathrm{d}\}} = [\mathbf{d}_{\mathrm{T}1}|\mathbf{d}_{\mathrm{T}2}|\ldots|\mathbf{d}_{\mathrm{T}K}] \in \mathfrak{R}^{9\times K}$

- **estimating raining and dry atoms via sparse coding**

$$\begin{aligned} \underset{\mathbf{D}_{\mathrm{T}},\,\mathbf{c}_i}{\text{minimize}} \quad & \sum_{i=1}^{M} \left\| \mathbf{y}_i^{\{\mathrm{r},\,\mathrm{d}\}} - \mathbf{D}_{\mathrm{T}}^{\{\mathrm{r},\,\mathrm{d}\}} \mathbf{c}_i \right\|_2^2 \\ \text{subject to} \quad & \|\mathbf{c}_i\|_0 \le k_0,\ \mathbf{c}_i \succeq 0,\ \mathbf{1}^{\mathrm{T}}\mathbf{c}_i = 1. \end{aligned}$$

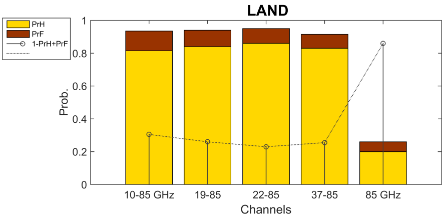
- **rain/no-rain detection:**

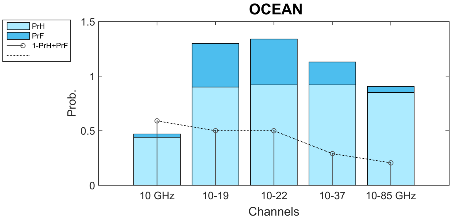
$$\begin{aligned} j_{\mathbf{y}} = \underset{j\in\{\mathrm{r},\,\mathrm{d}\},\,\mathbf{c}}{\text{argmin}} \quad & \left\| \mathbf{y} - \mathbf{D}_{\mathrm{T}}^{j}\mathbf{c} \right\|_2^2 \\ \text{subject to} \quad & \mathbf{c} \succeq 0,\ \mathbf{1}^{\mathrm{T}}\mathbf{c} = 1. \end{aligned}$$

where the set $\{\mathrm{r},\,\mathrm{d}\}$ denotes the raining (r) and dry (d) classes.

Channels and Number of Atoms

- Over land (22-85 GHz) — Over ocean (1-85 GHz)

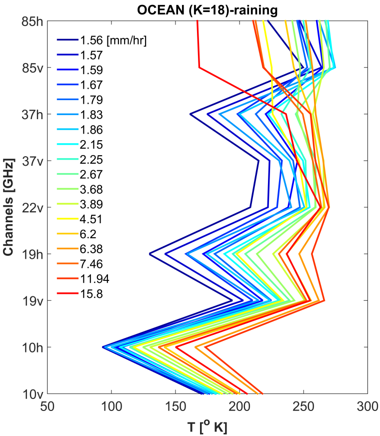


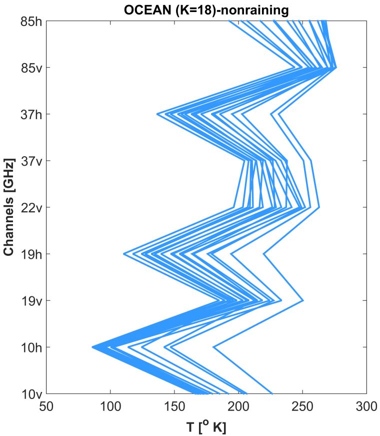


- Number of the rainfall atoms: $\sim 2\times$ number of channels
  - o K=10 rainfall atoms over land
  - o K=18 rainfall atoms over ocean

Rainfall Spectral Atoms – Over Ocean

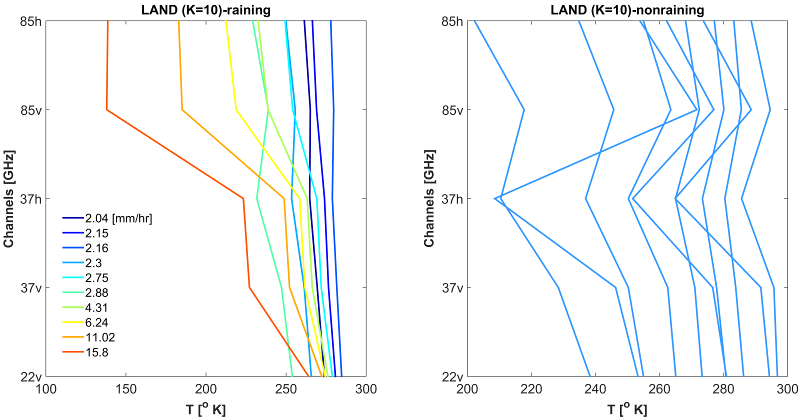
- Obtained from 250 randomly sampled orbits in 5 years of TMI-PR overlapping obs.





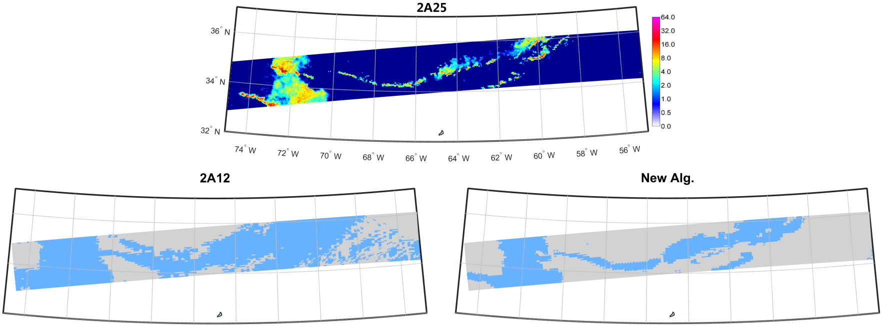
Rainfall Spectral Atoms – Over Land

- Obtained from 250 randomly sampled orbits in 5 years of TMI-PR overlapping obs.



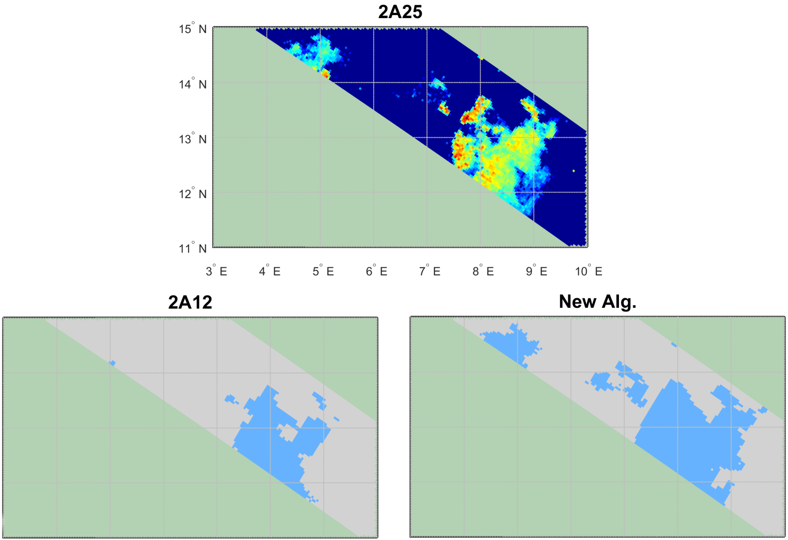
A Detection Experiment–Ocean

- A storm track – 1998/06/28.03357



A Detection Experiment–Land

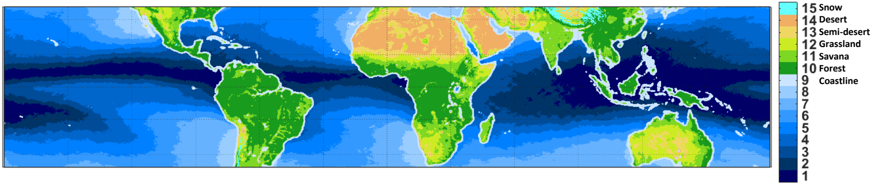
- A storm track – 1998/06/28.03357



Earth Surface Radiation Classes using TMI Overpasses

- Rainfall atoms for different earth surface types (currently working)

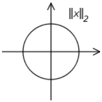
BT segmentation (Euclidean)

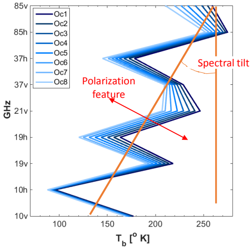


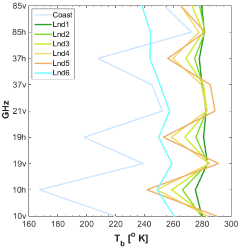
- 6 land surface classes + coastline
- 8 ocean surface class

- Note: We are classifying on unit sphere to minimize the effects of surface temperature.

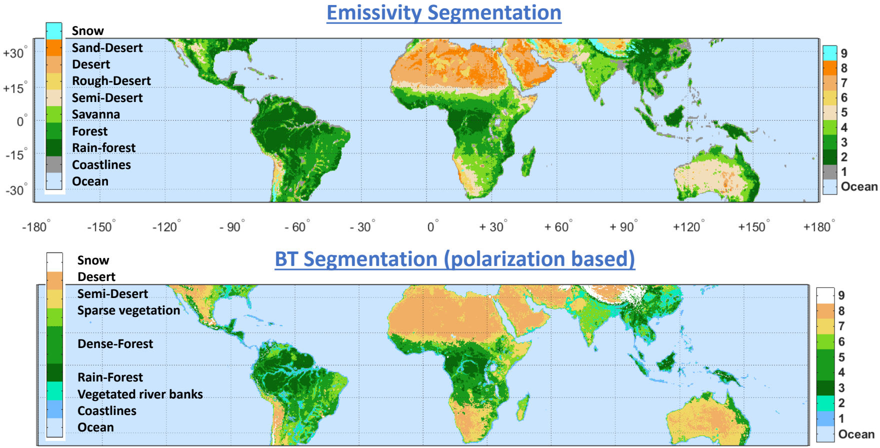
$$x_1^2 + x_2^2 + \cdots + x_n^2 = 1$$







Land Surface Emissivity Classes



AMSR-E emissivity data by Hamid Norouzi at CUNY.

Current and Future Works

- Obtaining the spectral atoms for different land surface classes.
- Providing physical insights by studying the precipitation vertical profile of the spectral atoms.
- Designing the estimation part, emphasizing on low and extreme rainfall.
- Studying rainfall eigen-spectrum via PCA.

Thank You