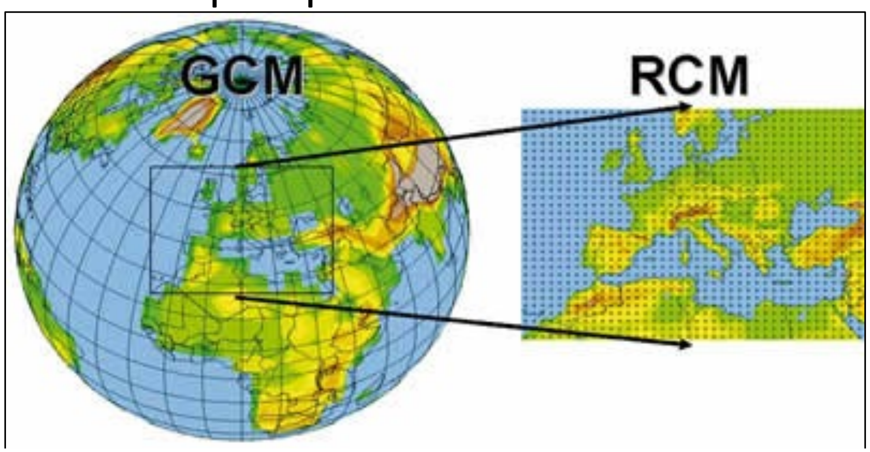
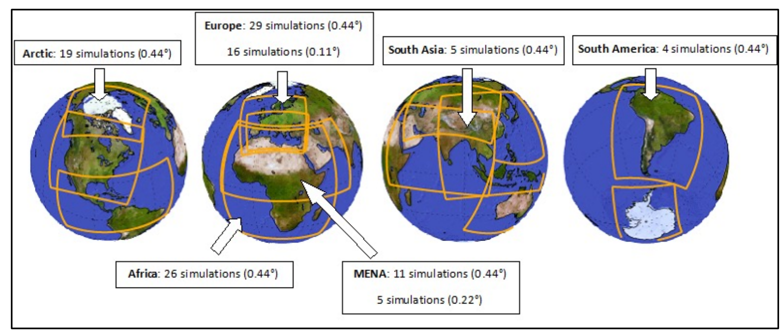
Added value of high-resolution datasets

- **Introduction**: The Coordinated Regional Climate Downscaling Experiment (CORDEX) provides higher-resolution Regional Climate Model (RCM) simulations for 14 domains around the world. In this project, we will first investigate added value of dynamical downscaling by evaluating CORDEX RCMs and EC-Earth GCM against obs4mips observations. We will use the Regional Climate Model Evaluation System (RCMES) which provides a framework for facilitating systematic evaluations of regional climate simulations using satellite observations. Then, we will learn about decomposing spatial variability in observed temperature trends at high spatial resolution of 5 km across multiple spatial scales.



An RCM with **much higher spatial resolution** and possibly **improved physical process** representation over the area desired for impacts assessment with the boundary values from GCMs.



http://www.cordex.org/

Datasets, Geographic foci

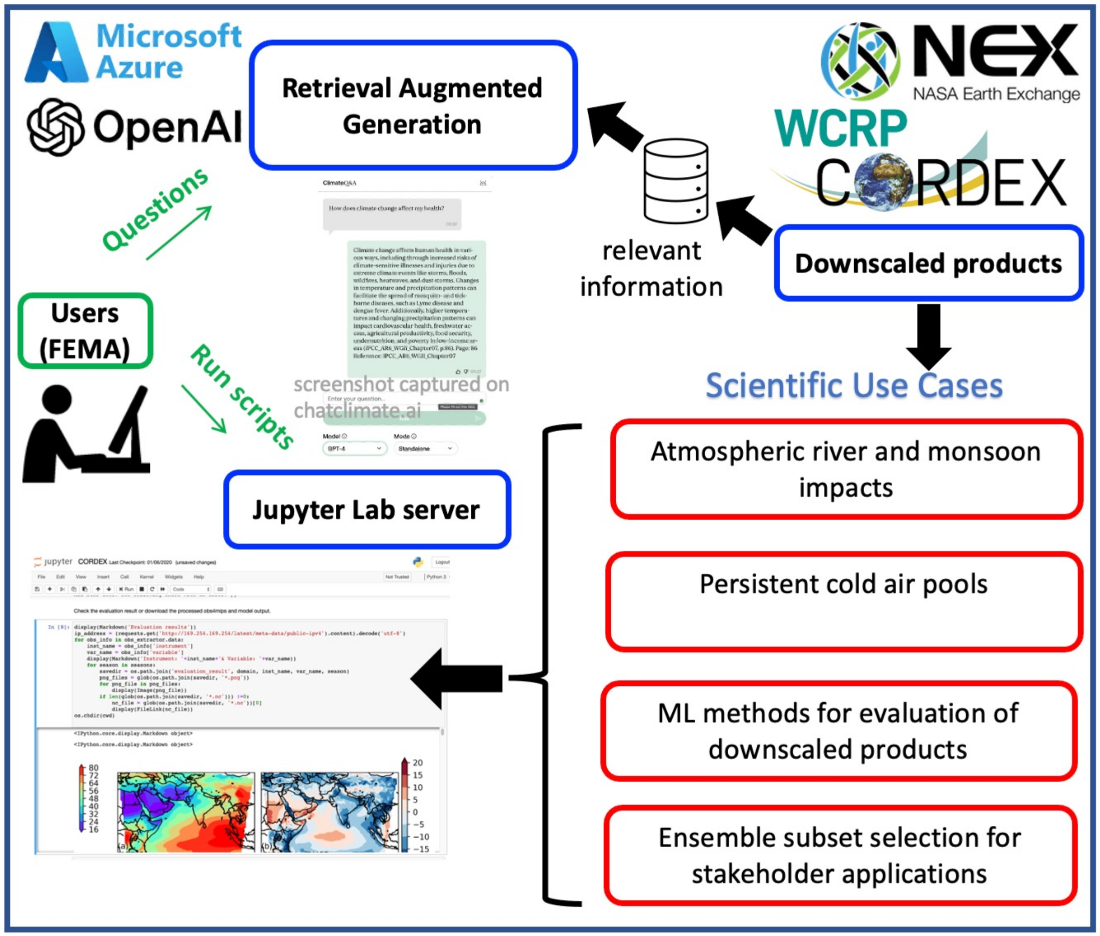
- **Datasets**:

1) obs4MIPs observations (e.g., precipitation from TRMM & GPCP, and OLR & Surface downwelling shortwave radiation from CERES),

2) **CORDEX historical simulations** and future projections (RCP 8.5) forced by the **EC-Earth GCM**,

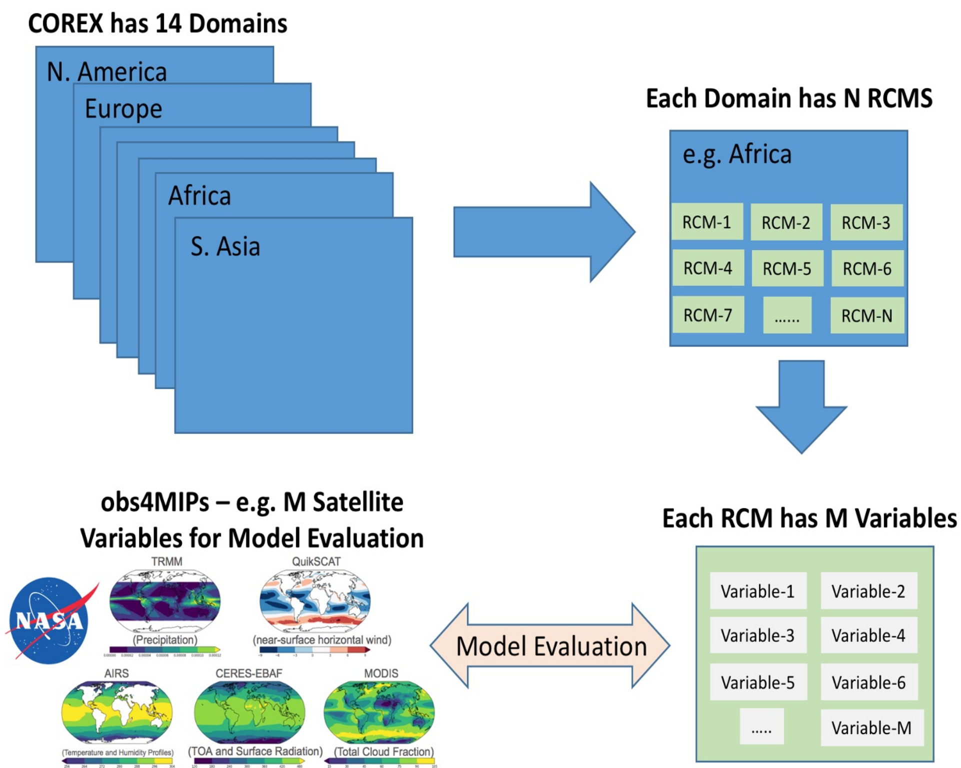
- **Geographic foci**: One of three CORDEX regions (Europe, Africa, and North America)

Regional Climate Model Evaluation System (https://rcmes.jpl.nasa.gov)

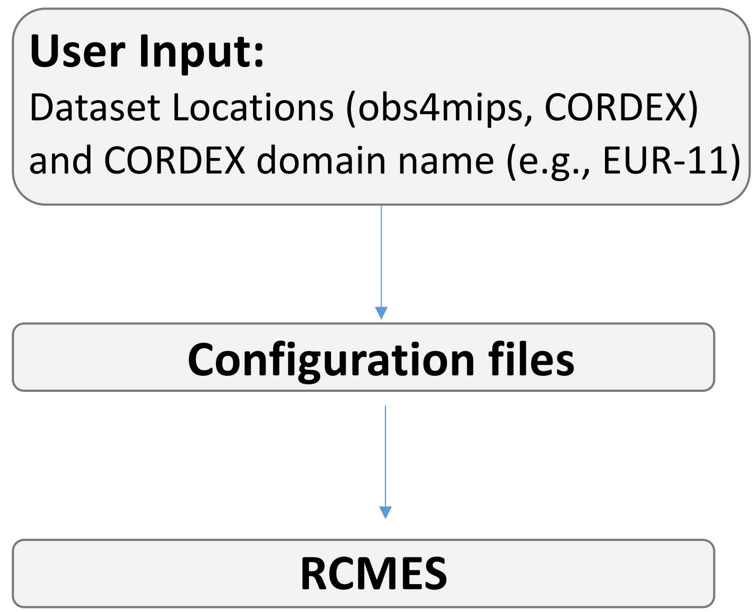


- The Regional Climate Model Evaluation System (RCMES) is NASA's enabling tool to support the United States National Climate Assessment (NCA).
- RCMES provides a framework for facilitating systematic evaluations of regional climate simulations, such as those from CORDEX, using satellite observations.
- Powered by an open-source Python library, Open Climate Workbench

Schematic of Multi-Domain, Multi-Model and Multi-Variate CORDEX Model Evaluation with Obs4MIPs

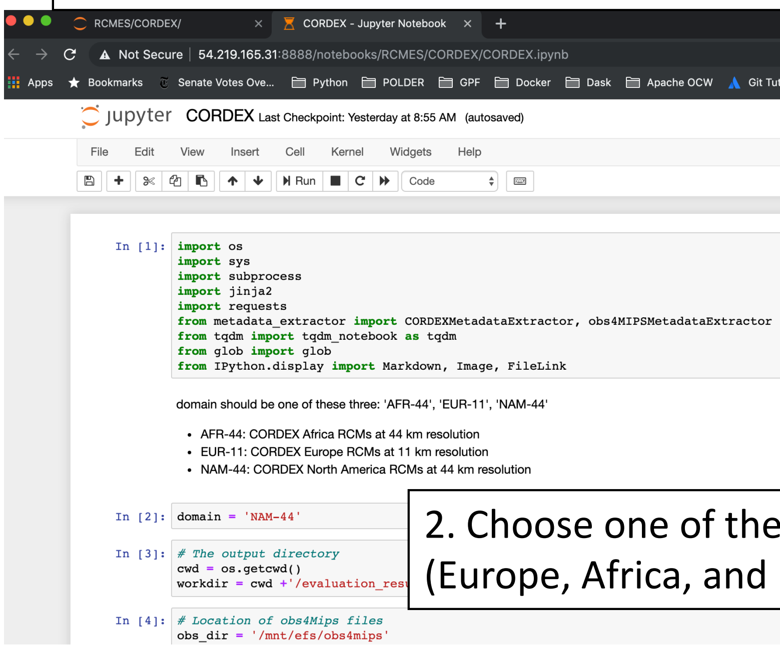


- A config file (a namelist file) in a YAML format is necessary to run each evaluation combination (CORDEX Domain, Season, Variable).



RCMES running on Amazon Web Service

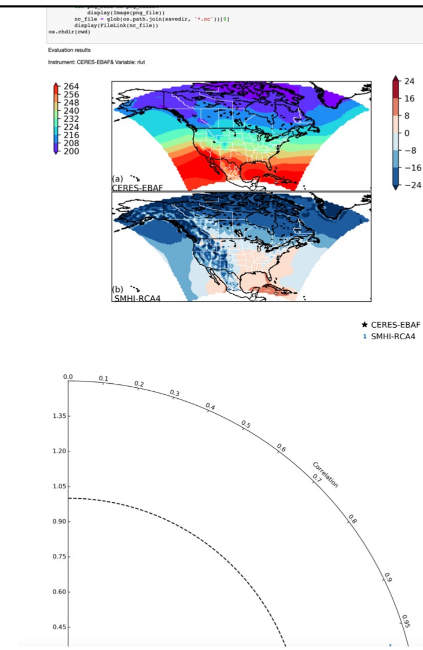
1. Use a web browser to connect to the summer school Jupyter Lab server



2. Choose one of the three CORDEX domains (Europe, Africa, and North America).

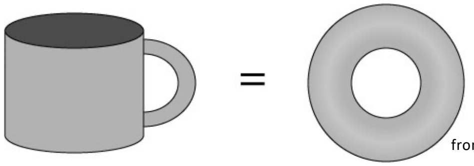
3. Run the Notebook script.

4. A model evaluation report will be generated. You can download the plots and netCDF files and use your script for further analysis.



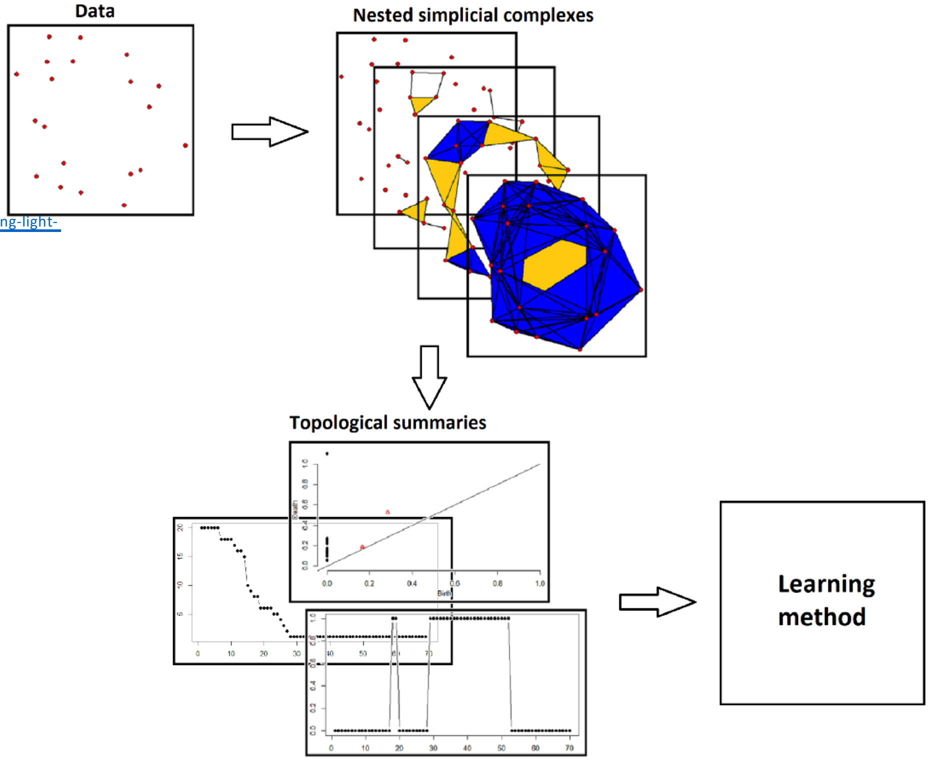
Introduction to Topological Data Analysis (TDA)

- Topology is the study of shape.



from https://skullsinthestars.com/2010/10/10/twisting-light-into-a-mobius-strip/

- TDA characterize the shape of n-dimensional point cloud data (i.e. data properties invariant under stretching, bending and rotation).
  - such shape characteristics (or topological summaries) include connected components (0^{th}), loops (1^{st}), and high-dimensional holes (k^{th})
  - TDA offers a compressed representation of the data with complicated shapes.



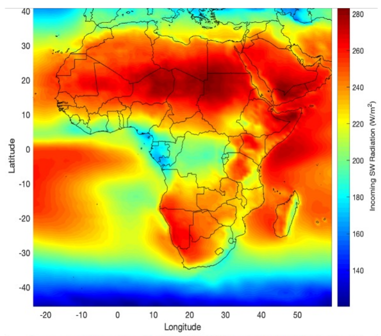
Courtesy of Dr. Ofori-Boateng

Can we use TDA to quantitatively compare 2-D maps from different sources?

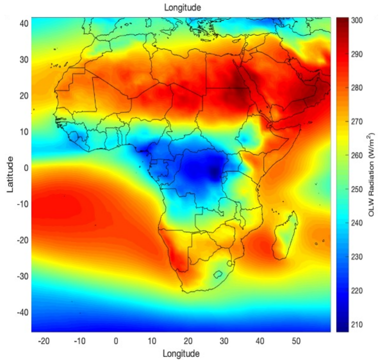
➔ Yes.

- Old school metrics for comparing spatial patterns in climate science: bias, root mean square error (RMSE), and pattern correlation coefficient

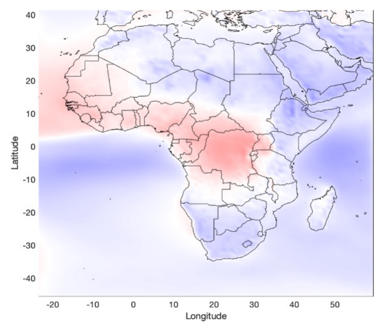
Data 1



Data 2

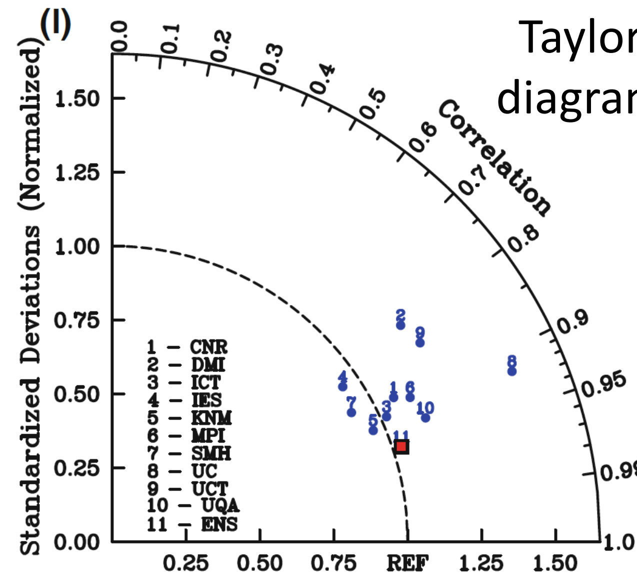


$$Bias = \overline{(Data\,1 - Data2)}$$



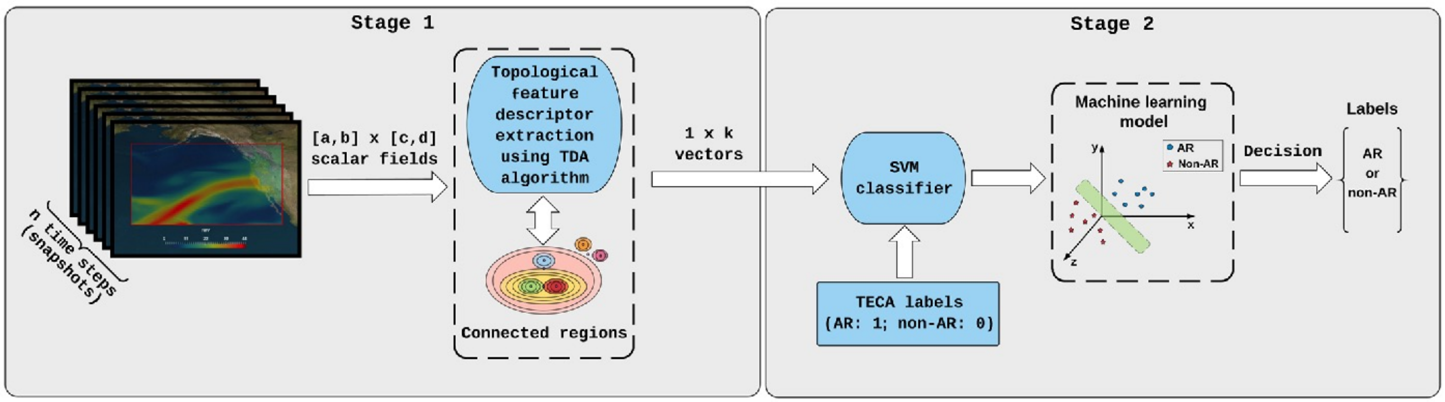
$$RMSE = \sqrt{\overline{(Data\,1 - Data2)^2}}$$

Taylor diagram



Applications of TDA to Earth Science

1. Muszynski et al. (2019), TDA and ML for recognizing atmospheric river (AR) patterns in large climate datasets



AR or non-AR?

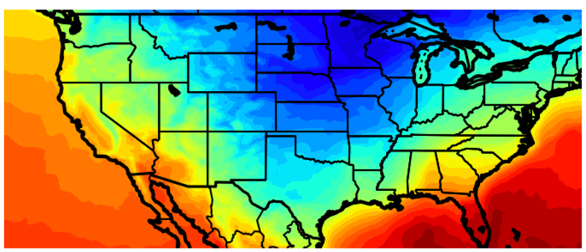
Figure 2 from Muszynski et al. (2019)

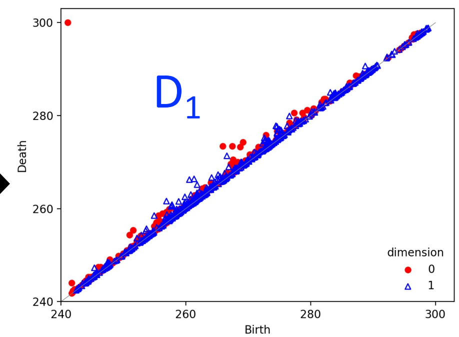
2. Kim and Vogel (2019), Deciphering active wildfires in the Southwestern USA using TDA

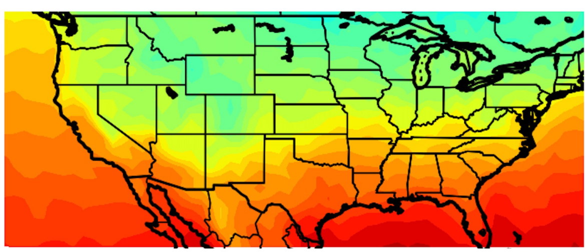
3. Ofori-Boateng et al. (2021), Application of Topological Data Analysis to Multi-Resolution Matching of Aerosol Optical Depth Maps

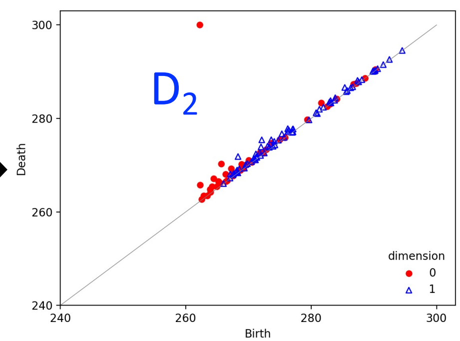
TDA-based similarity measure: Wasserstein distance

- In terms of the latent topology, two maps can be compared via Wasserstein distance (i.e., optimal transport) among their respective persistence diagrams (D_1 and D_2).









$$W_r(D_1, D_2) = \left(\inf_{\gamma} \sum_{x \in D_1} ||x - \gamma(x)||_{\infty}^{r} \right)^{1/r}$$

Questions

1. **Do RCMs simulate more realistic precipitation than GCMs?**
   - Select one of the CORDEX domains (Africa, Europe, or North America) and run RCMES to evaluate simulated precipitation from the EC-Earth GCM and RCMs against GPCP and TRMM observations.
2. **Do the CORDEX RCMs reproduce observed annual cycles in OLR at TOA and surface downwelling shortwave radiation from CERES?**
   - How can we explain these biases? Based on the biases, can we expect any substantial differences in other variables (e.g. cloud top heights and cloud fraction) between obs4mips and the RCMs?
3. **Can we use persistent homology (PH), one of TDA tools, to compress two-dimensional maps from satellite observations and climate models and evaluate simulated spatial patterns?**
   - Using the climatological maps of precipitation, OLR, and shortwave flux downward at the surface at their original spatial resolution, carry out the TDA: summarize key spatial patterns of the maps and calculate distances between persistence diagrams.
   - Is Wasserstein distance between persistence diagrams consistent with a root mean square error?

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