TEMPEST EXTREMES

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U.S. Department of Energy | Office of Science
HYPERFACETS
A Framework for Improving Analysis and Modeling of Earth System and Intersectoral Dynamics at Regional Scales

U.S. DEPARTMENT OF ENERGY
Office of Science

Overview

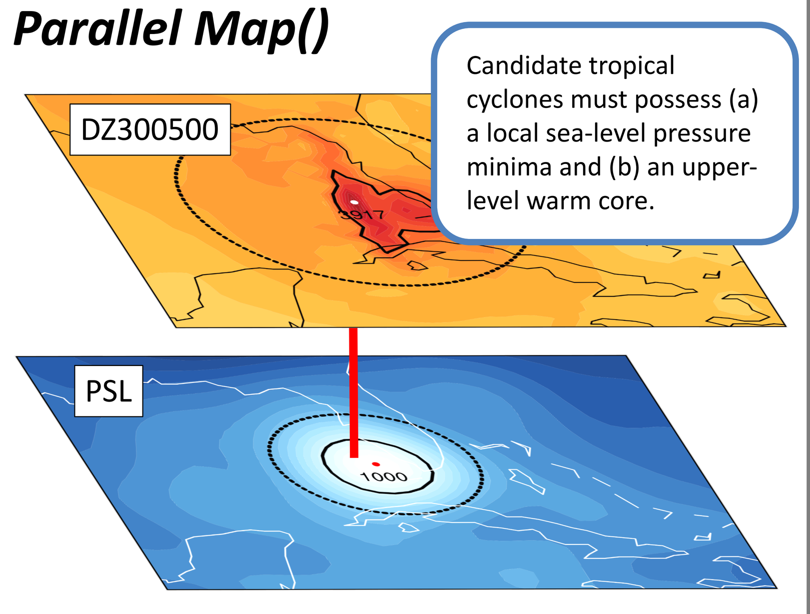
Motivation

Object identification, characterization, and tracking are fundamental techniques for the analysis of Earth system data. Heuristic algorithms have been traditionally employed to isolate and characterize these features, with numerous examples in the literature of tracking algorithms for tropical cyclones, extratropical cyclones, tropical easterly waves, monsoonal depressions, atmospheric rivers, atmospheric blocking, mesoscale convective systems, and others. Nonetheless, as they are typically developed as experimental software, the employ of these codes is often difficult and time consuming. To this end, TempestExtremes has been developed as a general-purpose package for the application of such heuristic algorithms, featuring a wide array of functionality that supports unstructured grids and massive parallelization.

MapReduce

TempestExtremes consists of a suite of flexible detection and characterization kernels developed for processing large climate datasets. The package uses an algorithmic framework known as "MapReduce" to first detect candidate events at individual times using specified criteria. Stitching is then used to assess the evolution of related detections over time. The result is an objective calculation of the climate indicator that can be automated and parallelized for multiple datasets.

Parallel Map()



Serial Reduce()

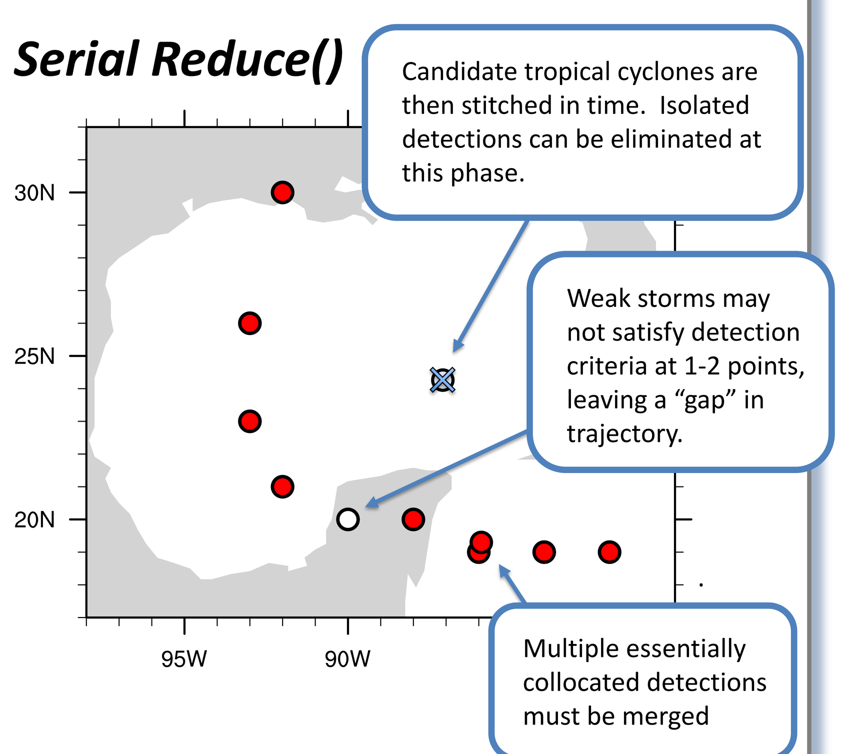
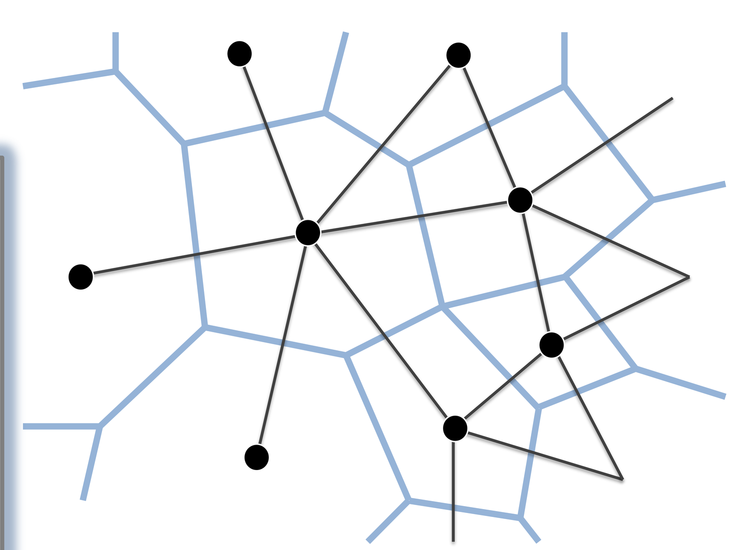


Figure Above: An example of the MapReduce paradigm used by TempestExtremes for feature identification and tracking.

Figure Below: The core algorithms all support data output on unstructured / native grids. Consequently, errors that may arise from regridding are avoided.



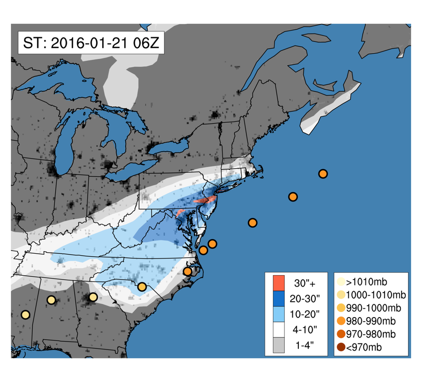
Component Architecture

To allow for easy interchange of model components and physical parameterizations, the architecture is formulated using object-oriented C++ for optimal performance. Future work will target the development of python interfaces to the low-level executables.

Executable	Description
DetectNodes	General-purpose command-line-based pointwise feature detector, supporting MPI parallelization.
StitchNodes	Connects pointwise features in time to create and filter tracks.
NodeFileEditor	Apply post-processing calculations to nodefiles, e.g. for radial wind profiles, accumulated cyclone energy, etc.
NodeFileFilter	Manufacture masking files based on pointwise features.
HistogramNodes	Develop 2D histograms based on the density of nodal features.
DetectBlobs	General-purpose command-line based areal feature detector.
StitchBlobs	Connects areal features in time and space, producing a unique identifier for each feature.

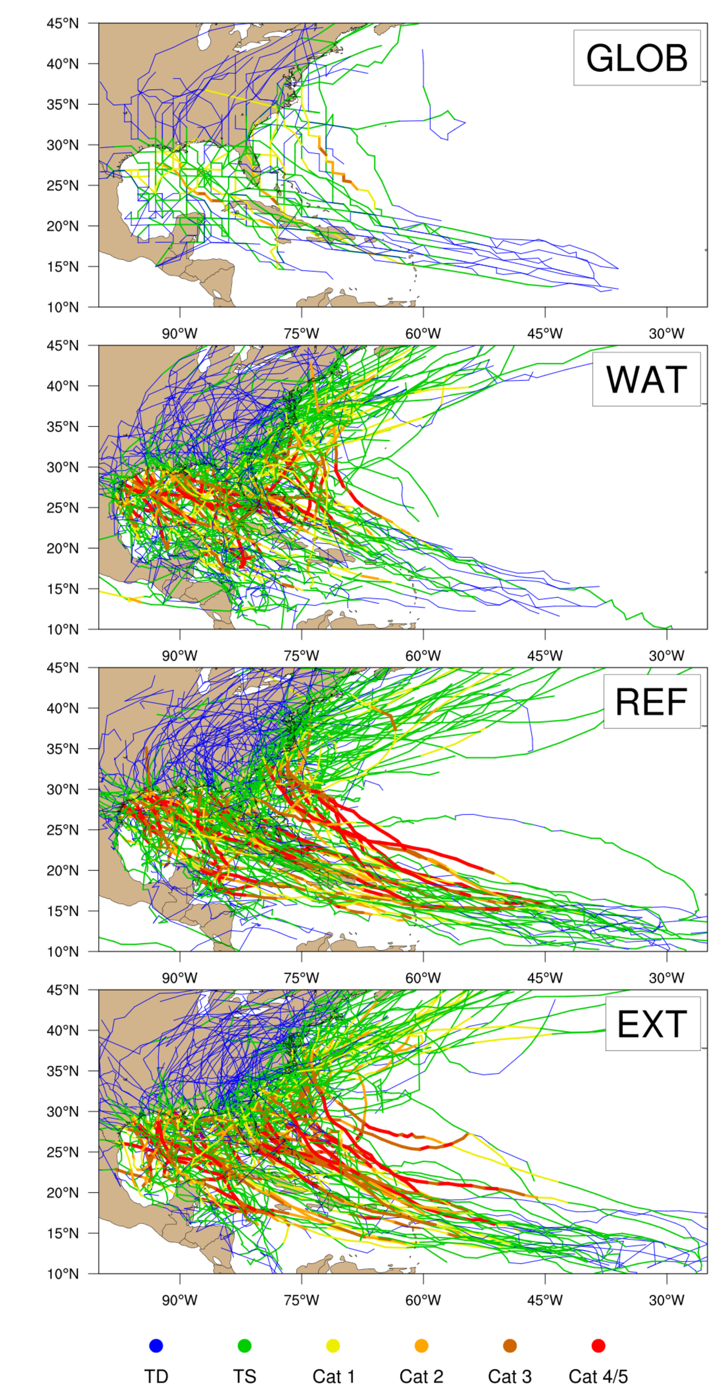
Extensions

Extensions are available from the broader community for characterizing additional features such as extratropical cyclones / regional snowstorms (Zarzycki, C.M., 2018. Projecting Changes in Societally Impactful Northeastern US Snowstorms. *Geophysical Research Letters*, *45*(21), pp.12-067).



Pointwise Features

Tropical Cyclones



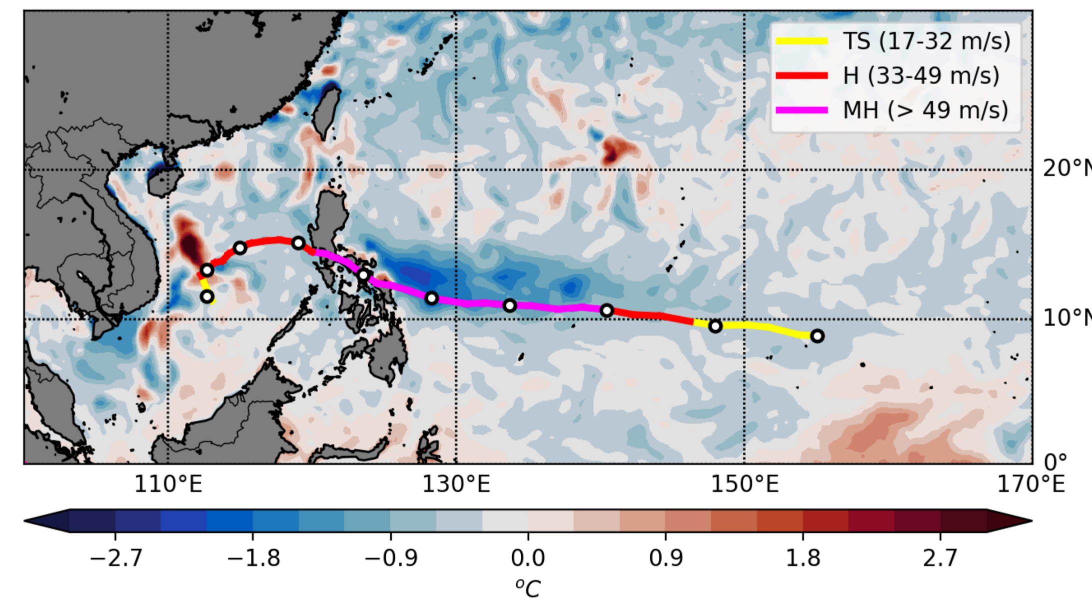


Figure Above: The track of the strongest tropical cyclone (TC) in the high-resolution E3SM, produced using TempestExtremes. Background colors represent cooling of sea-surface temperatures induced by the storm. Figure courtesy of Karthik Balaguru.

See poster A11Q-2737

Figure Left: Continental United States landfalling TC tracks for 1985-2014 from four CESM simulations using unstructured grids. The colors of the track lines represent the intensity of the storm as measured by the Saffir-Simpson scale. Tracking is performed directly on the unstructured grid. Figure courtesy of Alyssa Stansfield.

See poster A43O-3015

Figure Below Left: Observed overland precipitation extracted using TempestExtremes from tracked storms using (left) radius of 8m/s wind and (right) a fixed 500km radius. Figure courtesy of Alyssa Stansfield.

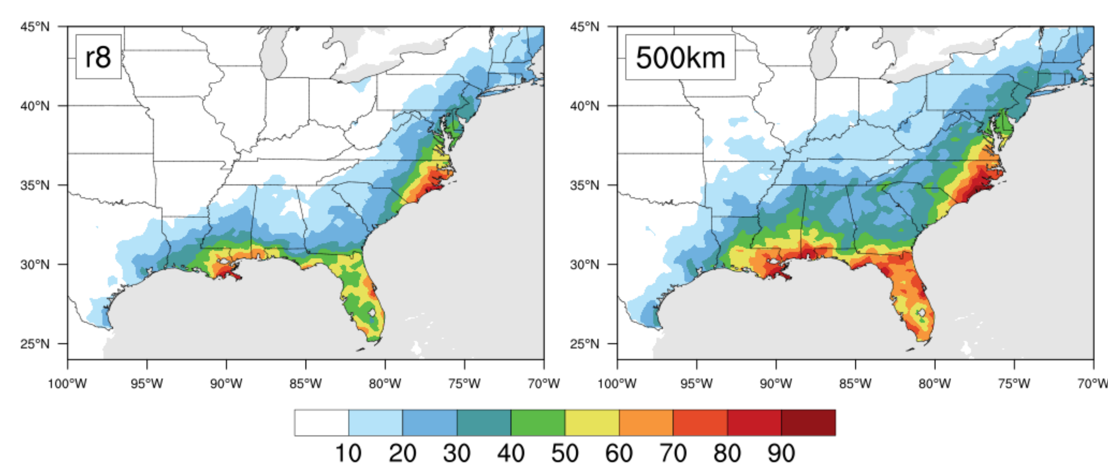


Figure Below: Evaluation of tropical storm spatial climatology (pattern correlation) for various current-generation reanalyses using TempestExtremes. Figure courtesy of Colin Zarzycki.

	Track	Genesis	U10	SLP
CFSR	0.96	0.25	0.75	0.66
JRA	0.98	0.37	0.58	0.77
MERRA	0.75	0.08	0.17	0.18
MERRA2	0.93	0.39	0.66	0.66
ERA5	0.97	0.54	0.70	0.74
ERAI	0.93	0.22	0.60	0.70
NARR	0.63	0.04	0.52	0.49
20CR	0.96	0.62	0.79	[illegible]

Worse Performance — Better Performance

See poster A33K-3003

Monsoonal Depressions

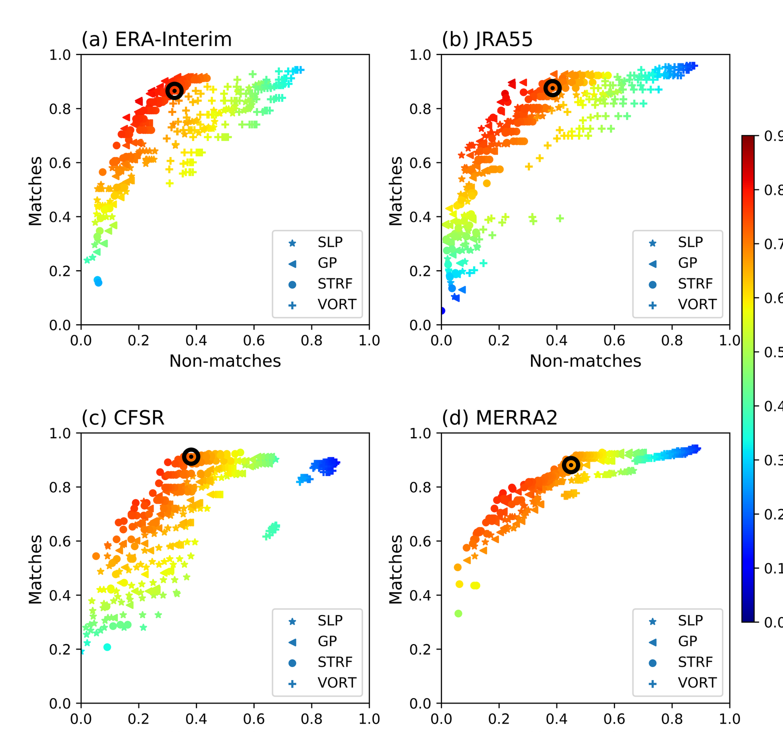
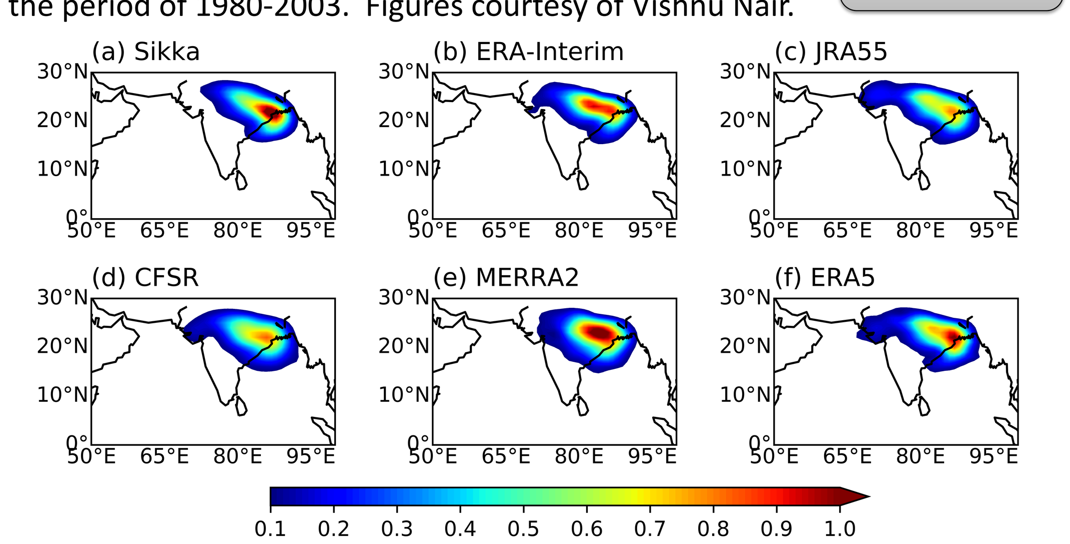


Figure Left: Skill scores (matches and non-matches) between TempestExtremes tracked monsoonal depressions and the Sikka dataset. Various variables and thresholds (sea-level pressure, geopotential, streamfunction, and vorticity) were investigated to identify the optimal algorithm.

Figure Below: Track density of low-pressure systems for the period of 1980-2003. Figures courtesy of Vishnu Nair.

See poster A23H-3009



Areal Features

Atmospheric Rivers

See poster A21T-2794

Figure Right: Objects identified as atmospheric rivers using the TempestExtremes AR tracking algorithm applied to IVT. Tropical cyclones, also typically associated with high IVT, are filtered using the TC tracking capability. Figure courtesy of Beth McClenny.

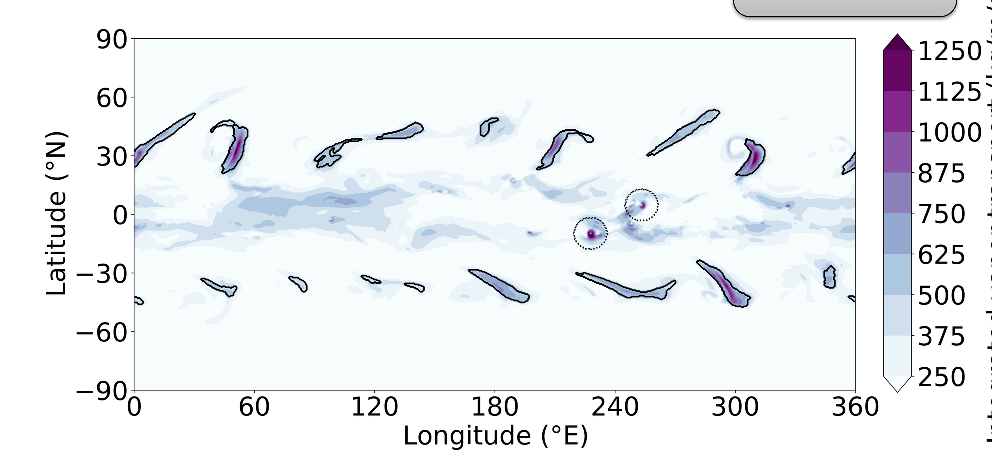


Figure Right: Temporal tracking of an atmospheric river object through its lifetime using an overlap criteria and TempestExtremes' StitchBlobs functionality. Figure courtesy of Alan Rhoades.

See talk GC24A-04

See poster H33I-2047

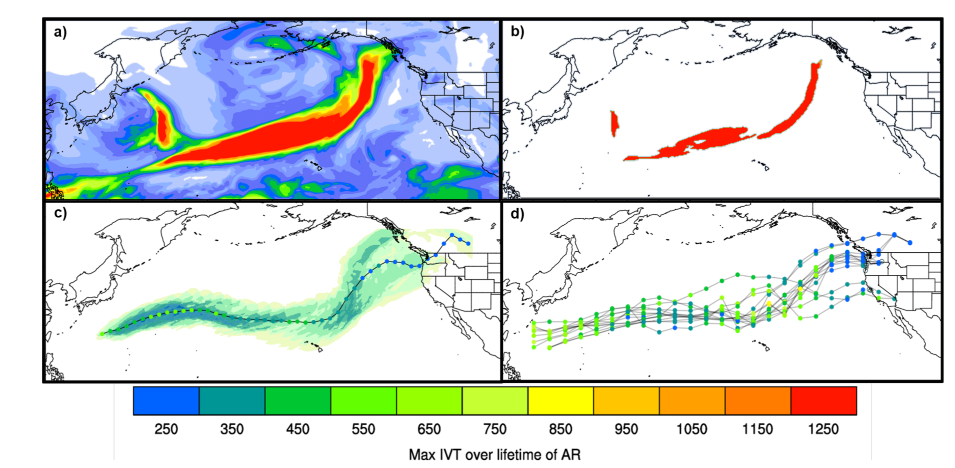
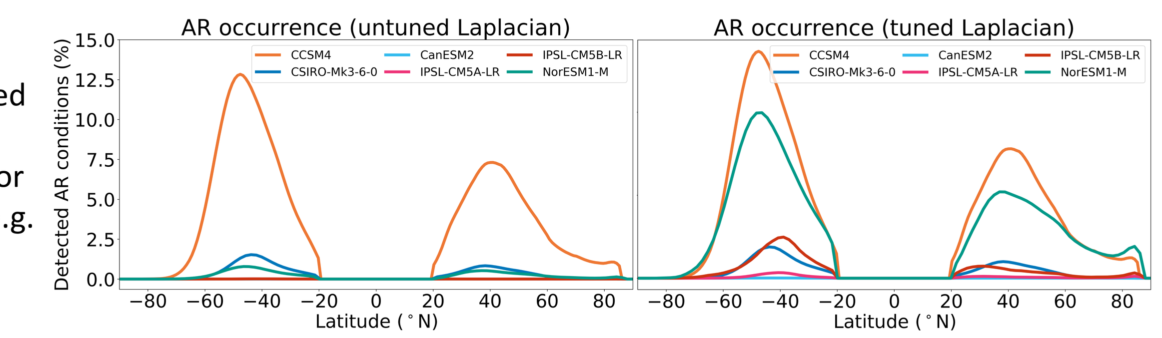


Figure Right: Thresholds for AR detection are tuned on the command line to increase detection rate for coarse resolution data (e.g. CMIP5/6).



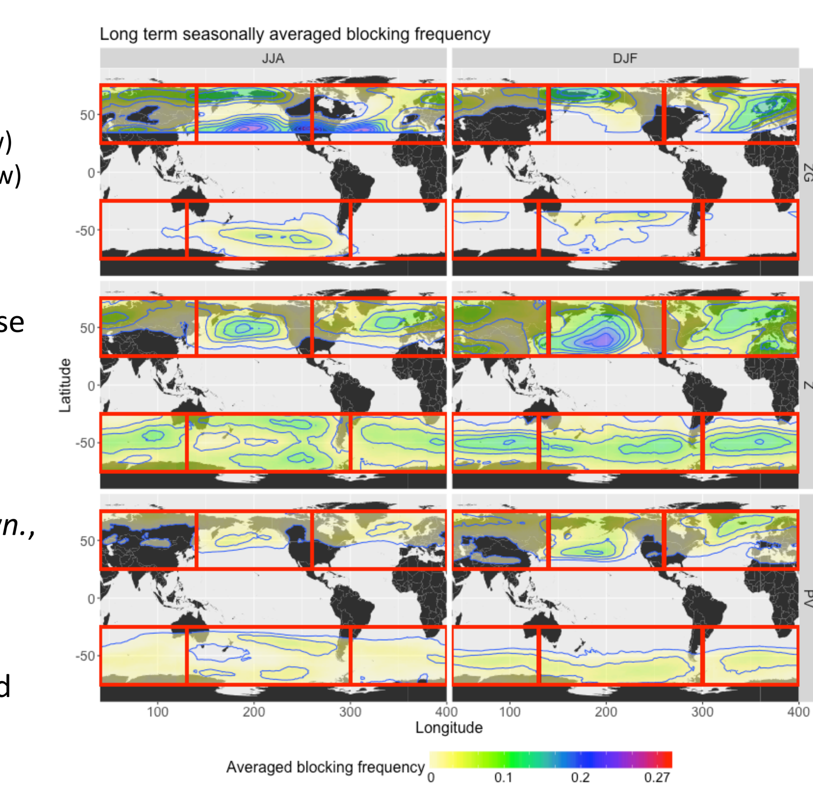
Atmospheric Blocking

Figure (Right): Three detection algorithms implemented to understand differences:

- **Tibaldi and Molteni 1990** (ZG, Z500 gradient, top row)
- **Dole and Gordon 1983** (Z*, Z500 anomaly, middle row)
- **Schwierz et al. 2004** (PV*, PV anomaly, bottom row)

All 3 algorithms tested on ERA-Interim data (1980-2005 and Ridiculously Resilient Ridge case study)

- Results in Pinheiro, M.C., P.A. Ullrich, and R. Grotjahn (2019) "Atmospheric blocking and intercomparison of objective detection methods: Flow field characteristics" *Clim. Dyn.*, doi: 10.1007/s00382-019-04782-5.
- Resultant blocking climatologies of three algorithms show varying agreement
- Differences in both averaged climatology and per-timestep detection results



Software Availability

All software is freely available and open source for general employ.

git clone https://github.com/paullric/tempestextremes.git

Contact

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