Hydrometeorological Extremes and Open Science: A Computational Framework for Resilience

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Roots for Resilience Program (R4R)

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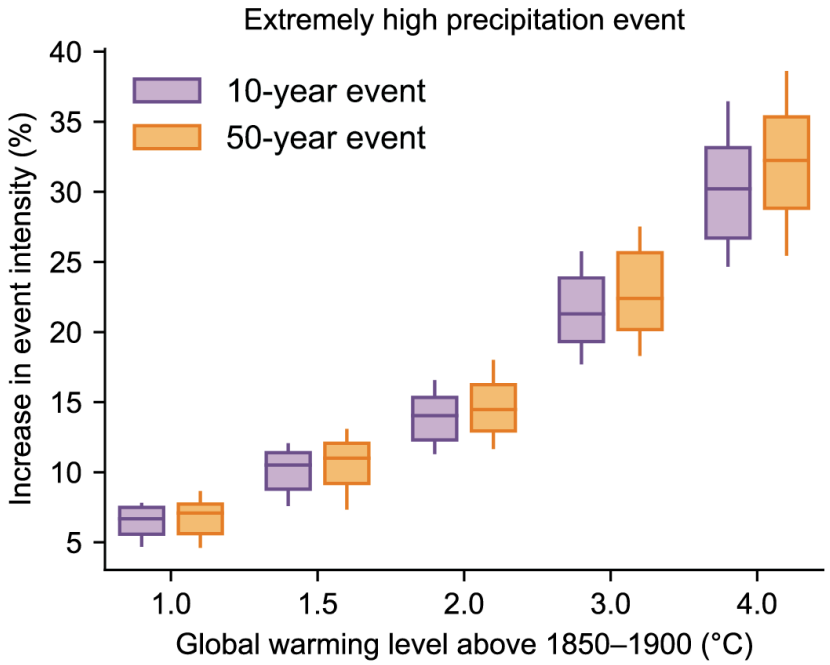
UA SCIENCE
Hydrology & Atmospheric Sciences
RESEARCH & PARTNERSHIPS
Data Science Institute

Outline

- Research highlights:
  - From short-term forecasts to climate projections in arid regions
  - Hydrometeorological extremes in a warming climate
- Computational and operational challenges
- Root for Resilience(R4R) and Foundational Open Science Skills (FOSS) training program and resources

Hydrometeorological extremes in a warming climate

- Climate change **intensifies extremes** due to increase in atmospheric moisture (7% more for every 1°C):
  - Extreme precipitation intensification from **4% to 8% per °C** (AR6) .
  - A **once every 10-year** event becomes **twice** as likely, and a once in a **50-year** event becomes **three times** as likely to happen (4°C) .
- Hydroclimate extremes in regions of **complex terrain** pose challenges for forecasting and risk assessment:
  - **Sparse observations** and **terrain-driven dynamics** challenge modeling accuracy



Seneviratne et al., 2021

The Technical Landscape

Data Sources

- Station data: Precipitation, temperature
- Gridded and Satellite: Daymet, GPMF
- Global and Regional Models: NA-CORDEX, LOCA, GEFS, CFS

Computational models

- Atmospheric : Convective-Permitting Weather Research and Forecasting (WRF)
- Hydrological : Rural Engineering with 5 Daily Parameters (GR5J)
- Analysis scope: Short term, S2S, and climate change projections

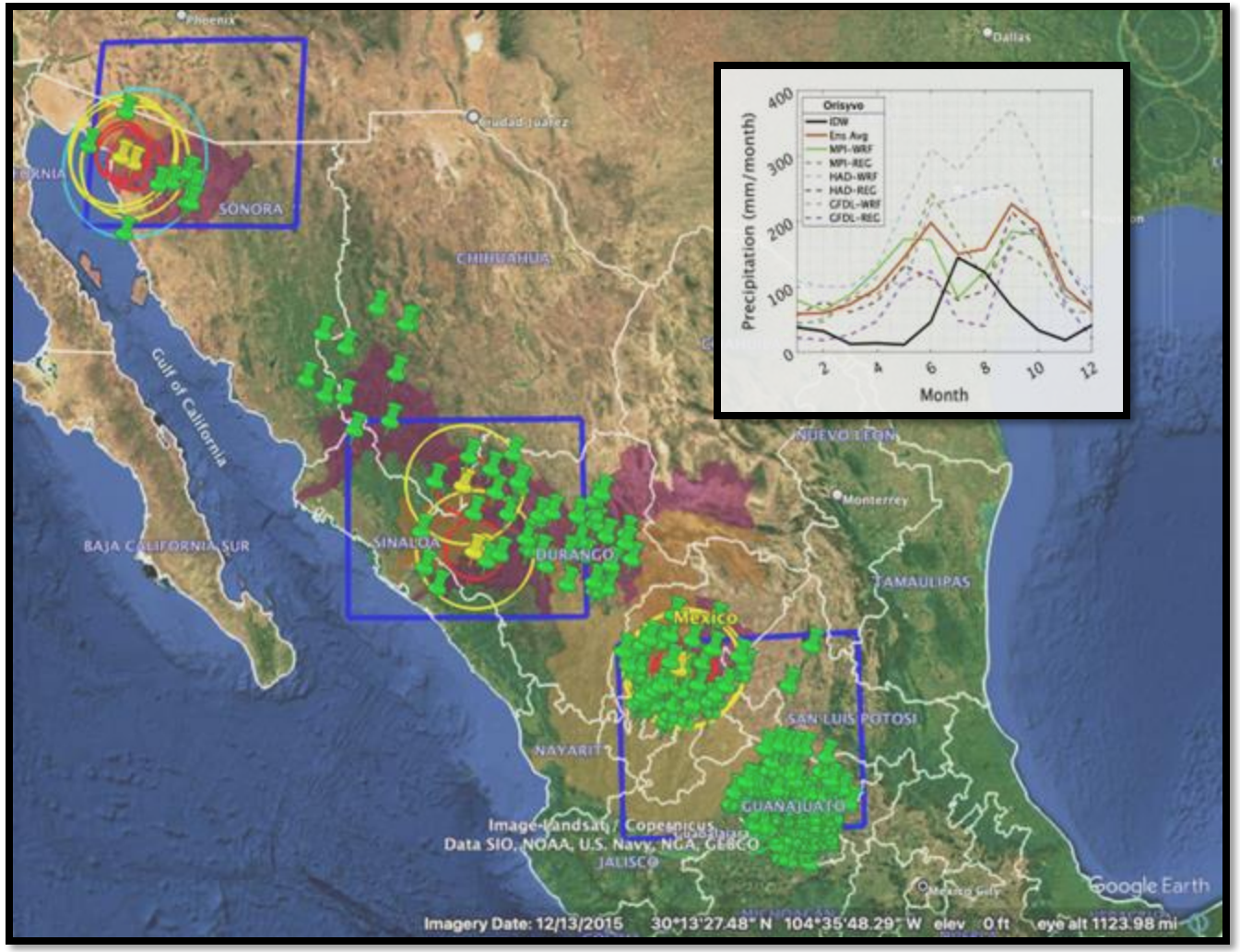
Operational workflow

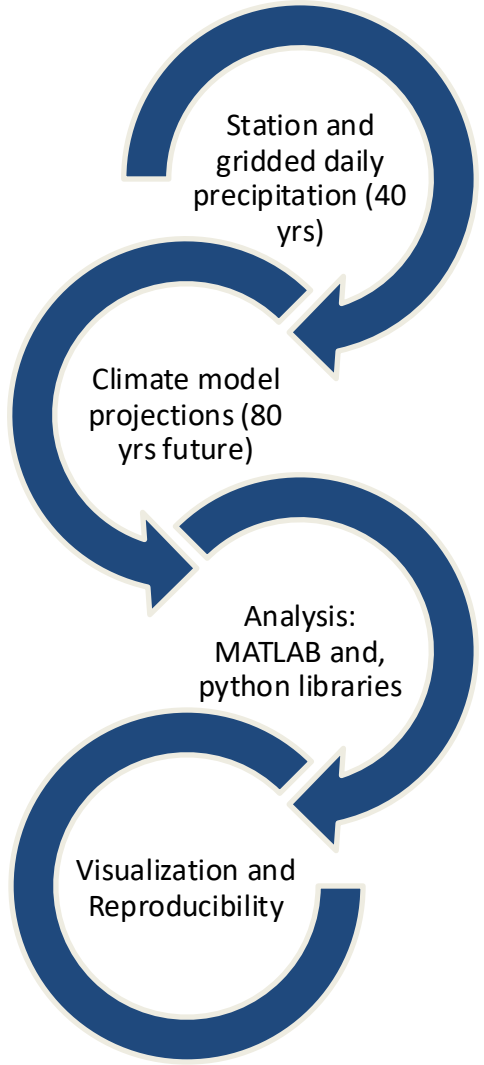
- HPC Job Management: High-resolution modeling, ensemble approach
- Workflow automatization and sharing: Script pre-processing, model simulations, and analysis

Software

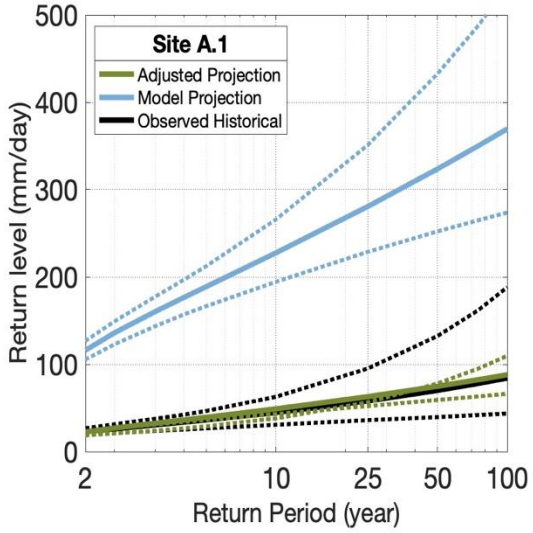
- Languages: Python, MATLAB, R
- Environment: Shell and Supercomputers

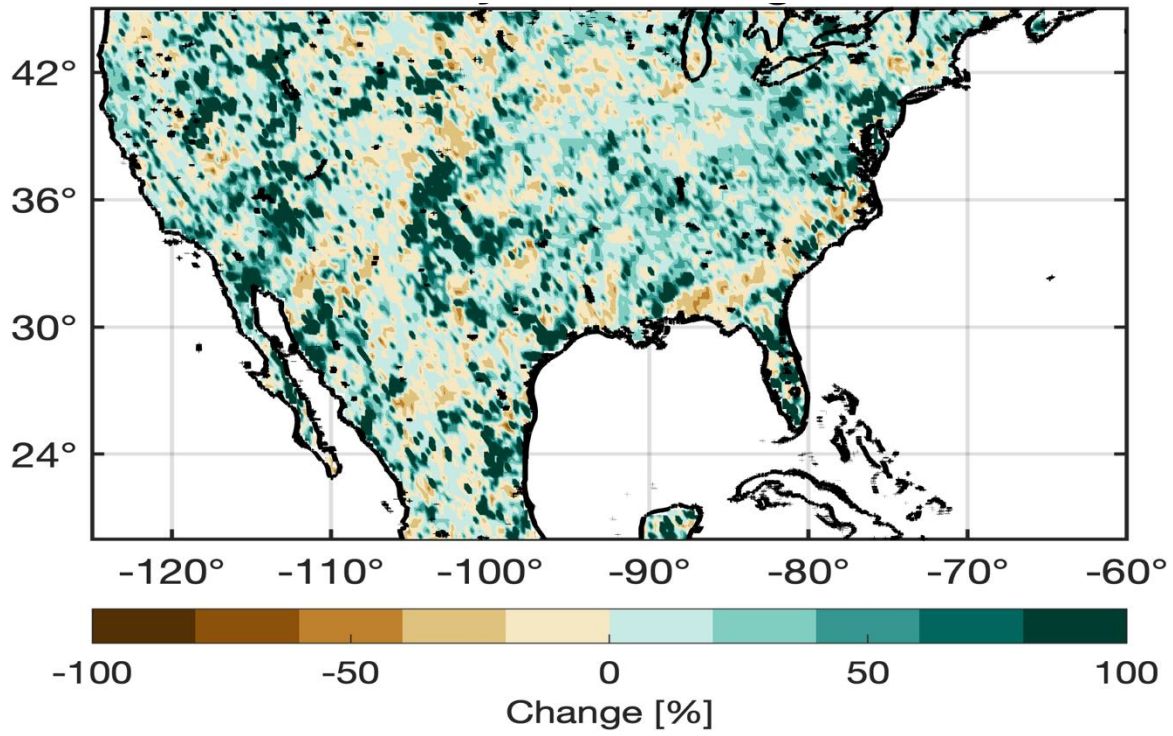
P01: Projected changes in extreme precipitation

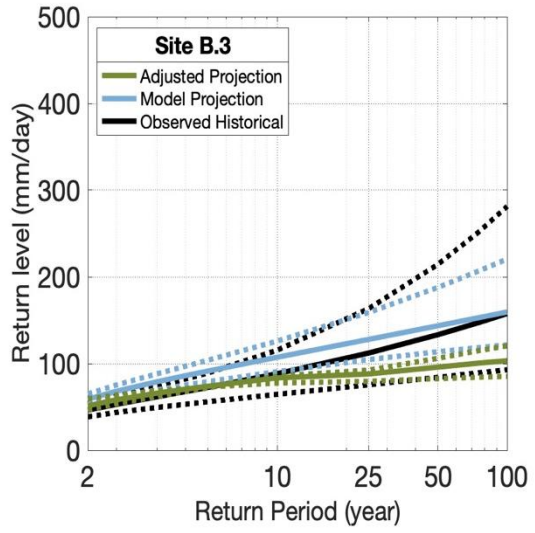




P01: Projected changes in extreme precipitation





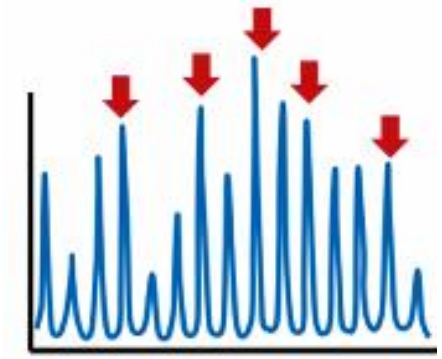


Objective: To provide regionalized insights into extreme precipitation trends by evaluating historical and future changes

Fierro et al. 2025 (in preparation)

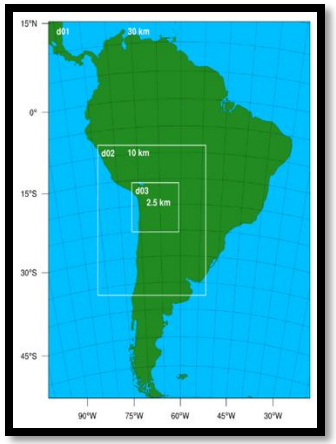
P02: Hydroclimate modeling system

(1) Selection of Major Streamflow Events (2010-2020)

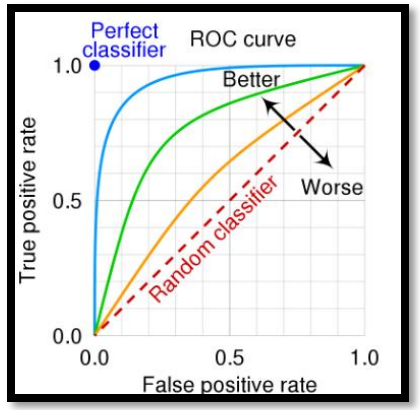


03/13/2012
03/25/2015
07/12-13/2015
08/09/2015
02/24/2016
01/22/2017
01/26/2017
02/01/2019

(2) Regional climate ensemble modeling at convective permitting scale (WRF-ARW)



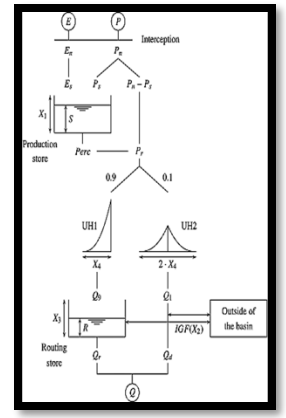
(3) Forecast Performance Evaluation against observation (GPMF)



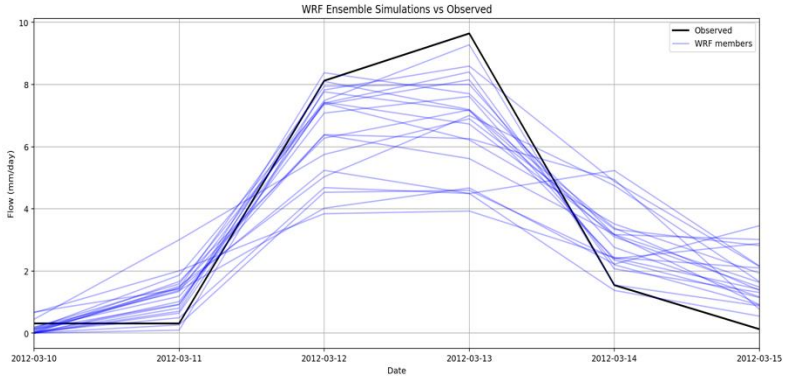
- Binary skill score metric
- ROC

(4) Hydrologic streamflow simulation (GR4J) using

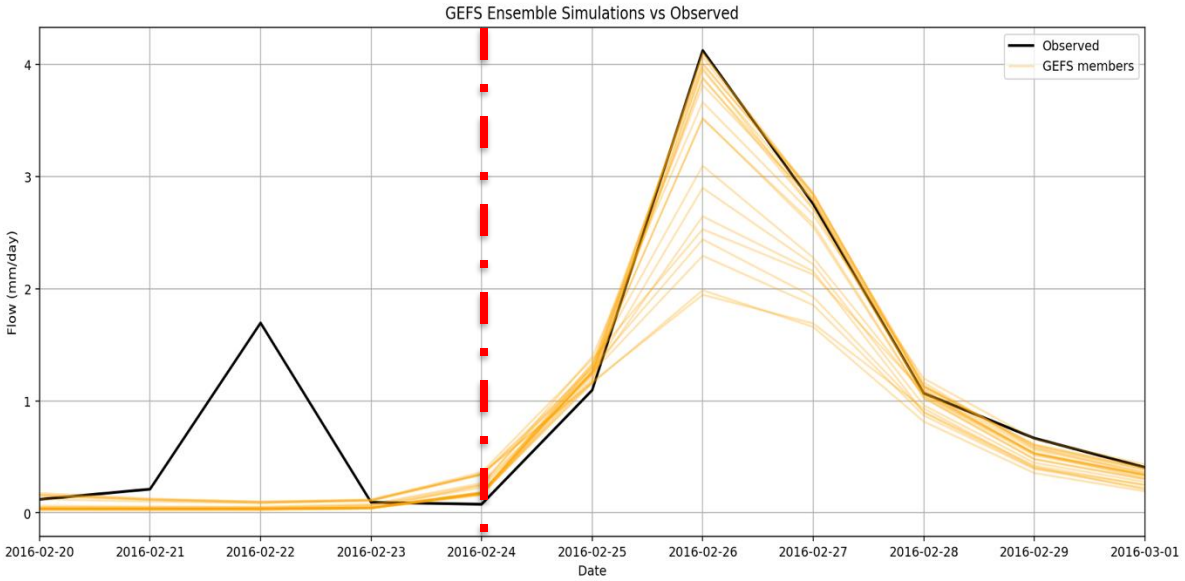
- Rio Camarones river basin (DGA)
- WRF output
- Precipitation, Average
- PE

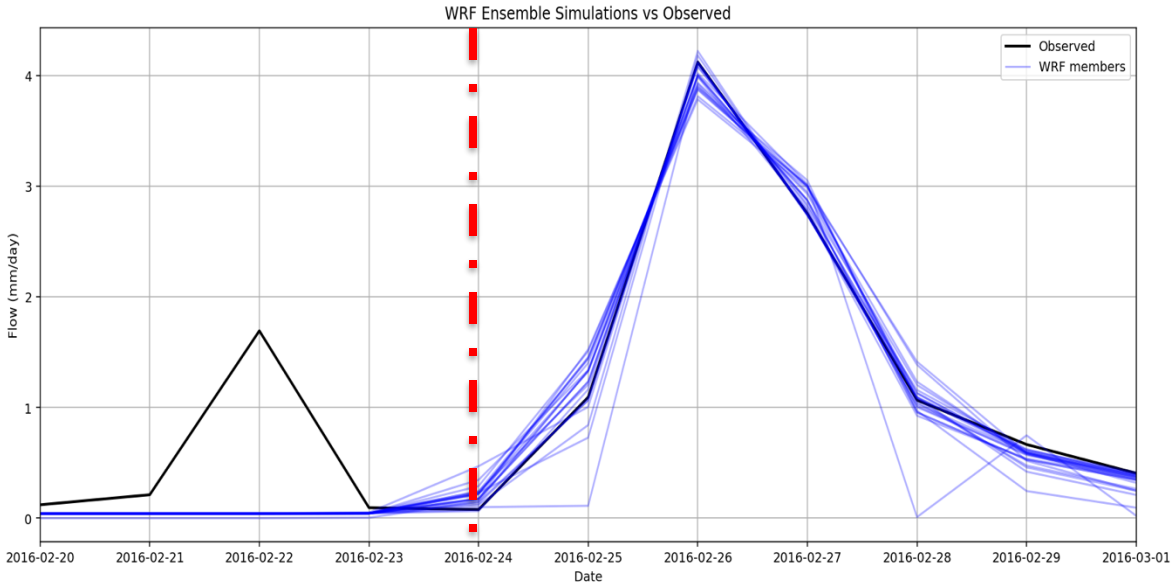


(5) Streamflow simulation forecast



P02: Hydroclimate modeling system

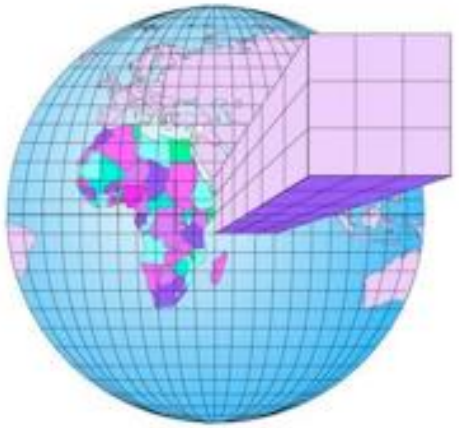




Objective: To develop a high-resolution forecasting system that integrates convective-permitting modeling and hydrologic simulation to improve real-time flash flood prediction in a climate-vulnerable and data-scarce region of northern Chile.

Fierro et al. 2025 (in preparation)

Computational Bottlenecks in Hydro-meteorological Research

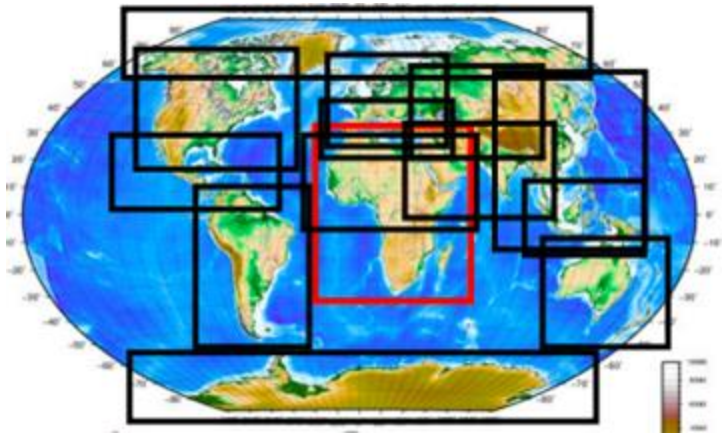


Data production and processing

Model simulations and datasets models at different time- and spatial-scales.

Great computational power demanded.

Different time- and spatial-scales for models and observations.

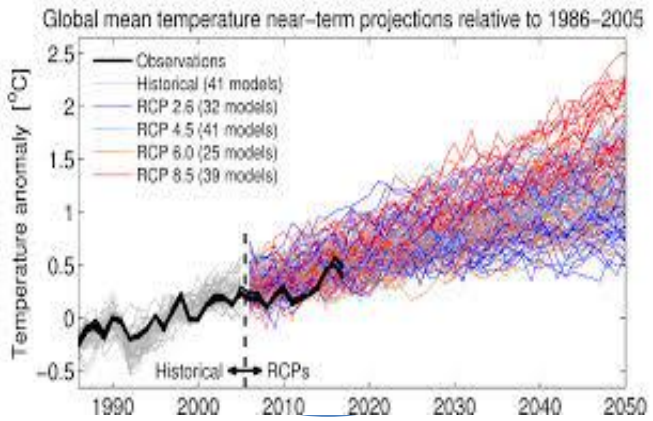


Data curation and evaluation

Missing or inconsistent observations for model calibration and validation.

Balancing acquiring high-quality data with the need for reliable initial conditions.

Methods for long-term data curation and archival.



Data Visualization

High-resolution and large-ensemble simulations.

Transference of large files between computational environments.

Root for Resilience (R4R) Program

The Roots for Resilience program provides training and support to select graduate students on open, reproducible science, computational infrastructure and AI tools to enhance research focused on environmental and societal resilience.

- Leads: Sharon Collinge (AIR), Tina L. Johnson (DSI), Maliaca Oxnam (DSI), Anna Seiferle-Valencia (AIR)

RESEARCH & PARTNERSHIPS
Data Science Institute

CYVERSE®

Arizona Institute for Resilience

Foundational Open Science Skills (FOSS)

https://datascience.arizona.edu/r4r-cohorts

- CyVerse's (10 week) virtual workshop.
  - Best practices in open science, computational infrastructure, and AI tools.
  - Discussions with cohort and invited data scientists.
- R4R core objective:
  - Train a collaborative cohort in advanced data science, AI, and FAIR data principles.
  - Foster interdisciplinary research focused on environmental and societal resilience challenges.

R4R Training and Skills

Foundations of Open Science

Open Science Principles

Data Management & Documentation

Research Pipelines

Version Control (GitHub)

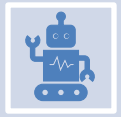
Software Environments

Containerization (Docker, Singularity)

High-Performance Infrastructure

High-Performance Computing (HPC)

Cloud & Collaborative Platforms (CyVerse)



AI, LLMs & Visualization Tools

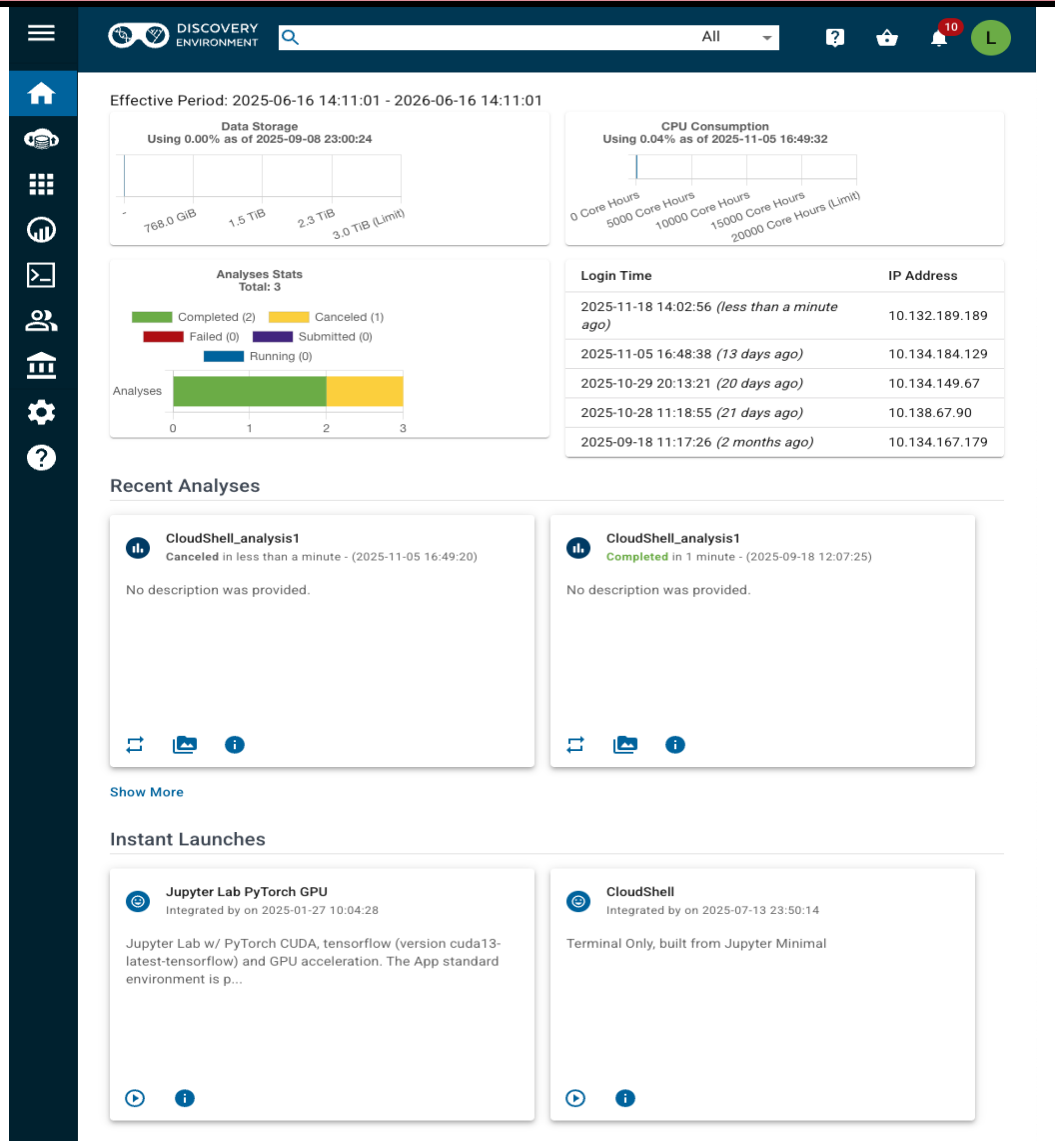
Applications

Data Visualization

High-Performance Infrastructure

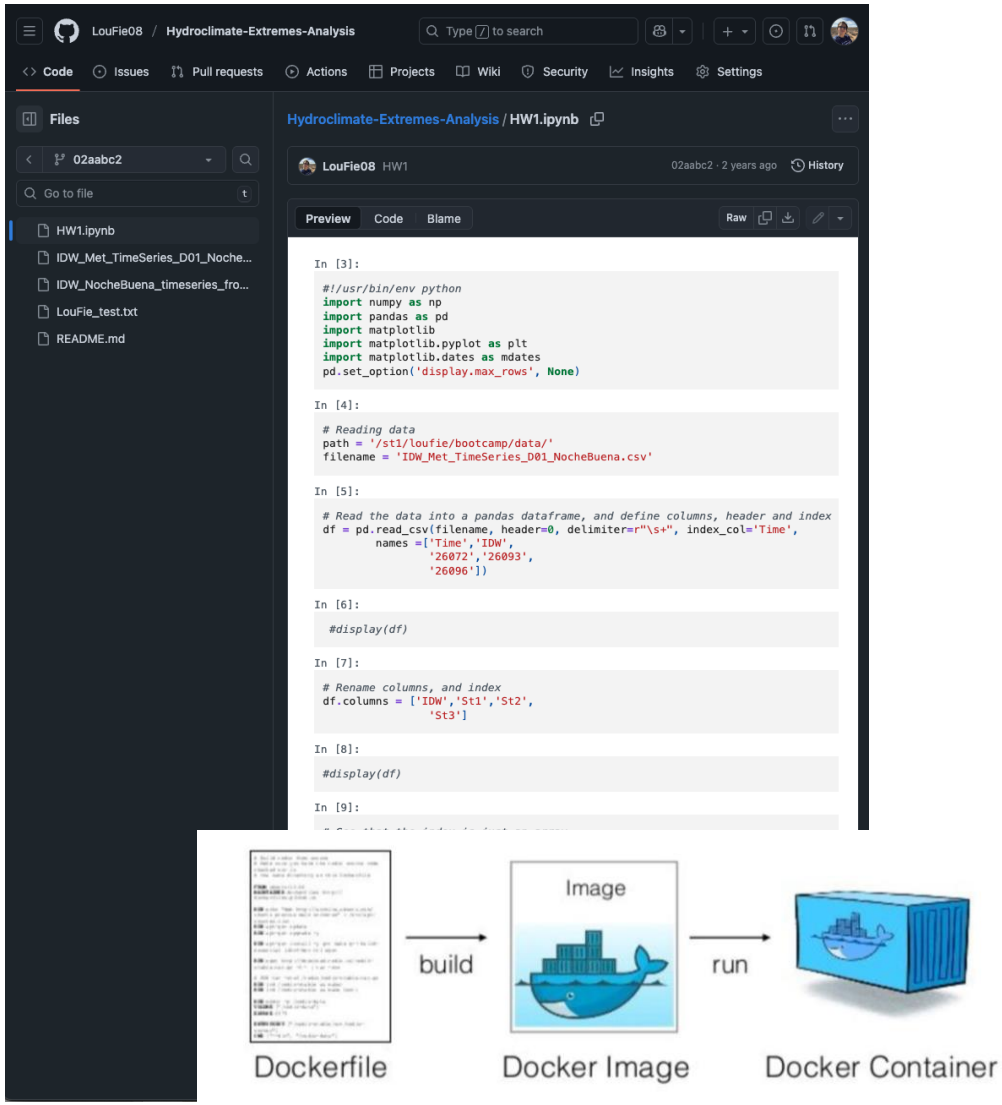
- Remote & Collaborative Platforms: CyVerse
  - Cyberinfrastructure designed to tackle large-scale scientific datasets
  - Free access for UA students, faculty, and staff
  - 3 TB of data storage, 20,000 compute units/year, run 4 concurrent jobs, workshops

- UArizona High-Performance Computing (HPC):
  - El Gato (1888 TC), Ocelote (11724 TC), and Puma (30720 TC)
  - Scale up and out data storage, processing and workflow automation



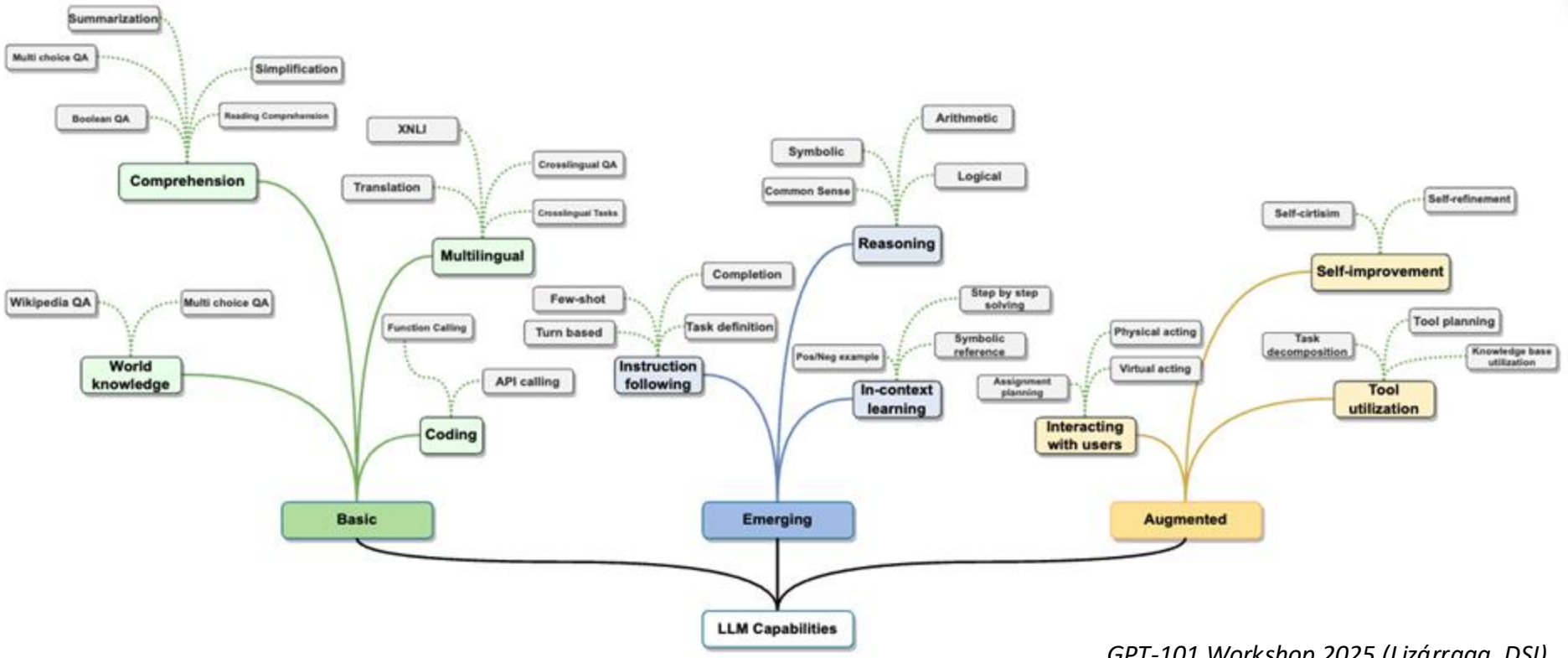
Research Pipeline

- Version Control: GitHub
  - Free, fast, and easy to build platform and template use
  - Separate space for documentation or websites
- Software Environments: Python and R
  - Isolated, project-specific spaces with customized dependencies and software versions
  - Infrastructure for computing operations and user interactions.
- Containerization: Docker
  - Unit of software that packages up code and all its dependencies
  - Ease of sharing, platform independence, version control, scalability, isolation



Large Language Models (LLMs)

AI systems trained to understand and generate human-like text (from internet) using massive datasets and billions of parameters.

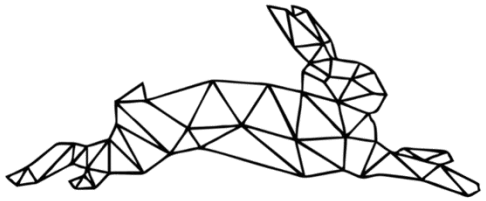


GPT-101 Workshop 2025 (Lizárraga, DSI)

When used responsibly, it can support open models and data, accelerate discovery, and aid in the evaluation of research... But you must be cautious because they can generate biased or false information.

Large Language Models (LLMs)

- Prompt Engineering: technique to craft effective instructions
  - Context Role Action Format Tone Framework
  - Student AI Guidelines and Principles
- Research and analysis:
  - Trace and spot unexplored or emerging areas: ResearchRabbit
  - Find details and skim specific sections in research papers: NotebookLM, Perplexity/ChatGPT/ Gemini
- Write and Editing
  - Draft summaries, refine complex concepts, and improve clarity and tone (Gemini/ChatGPT/Grammarly).
- Code Development:
  - Generate, translate, and debug code: Claude/Copilot
  - VS Code and GitHub CodeSpaces: Integration through Application Programing Interface (API): Google AI Studio, Ollama, OpenAI, Anthropic

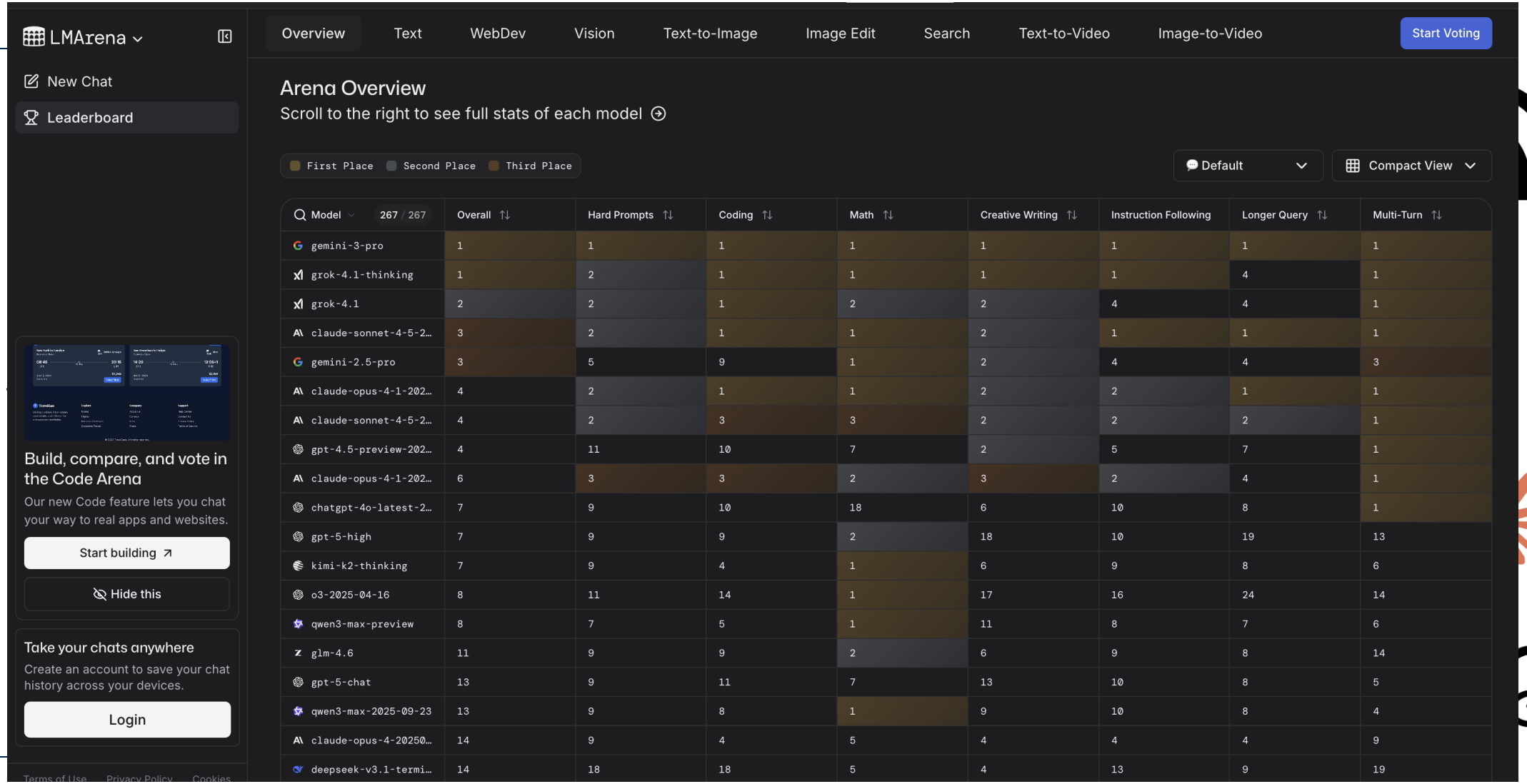






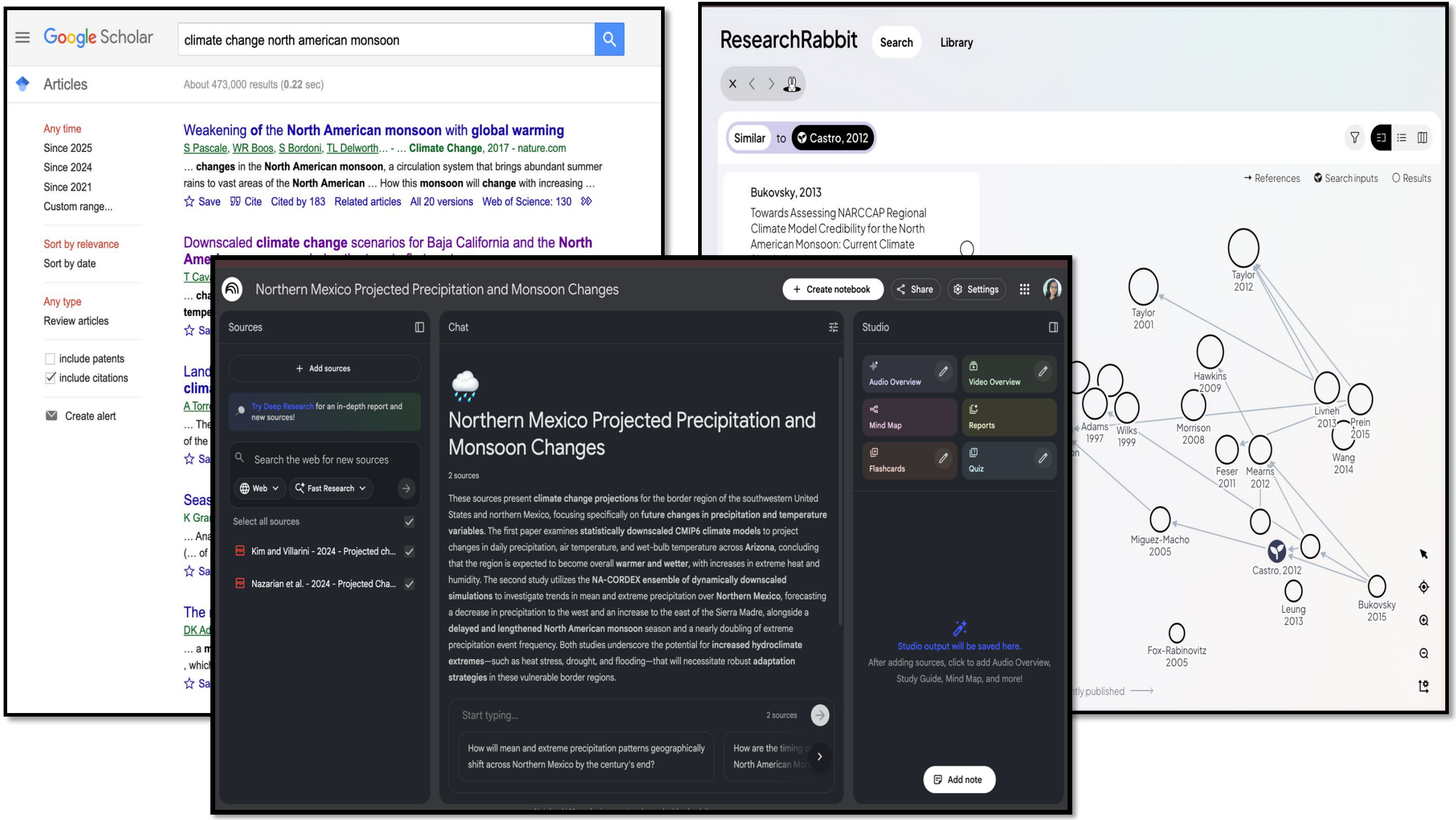
https://lmarena.ai/leaderboard

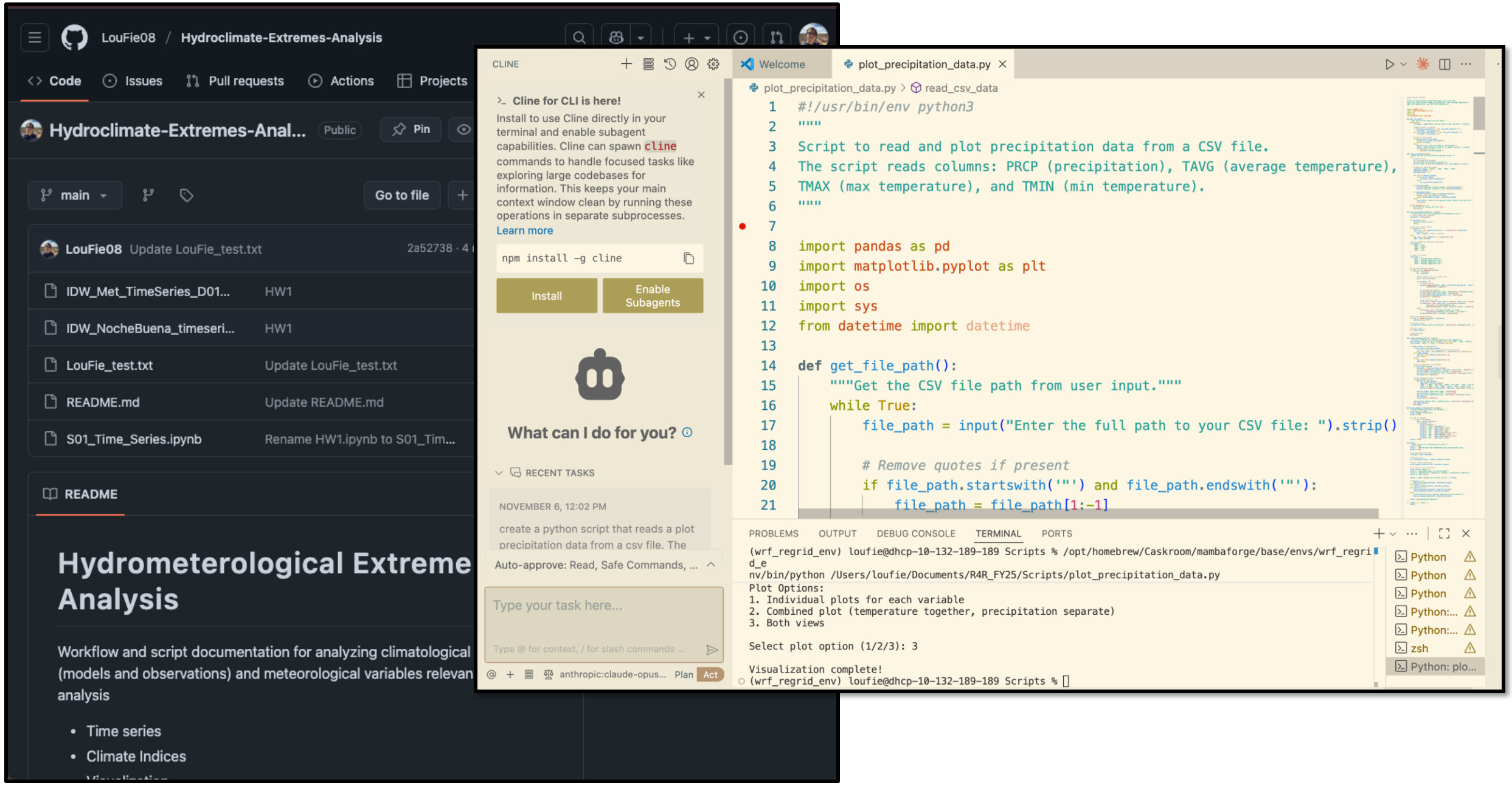
Large Language Models (LLMs)



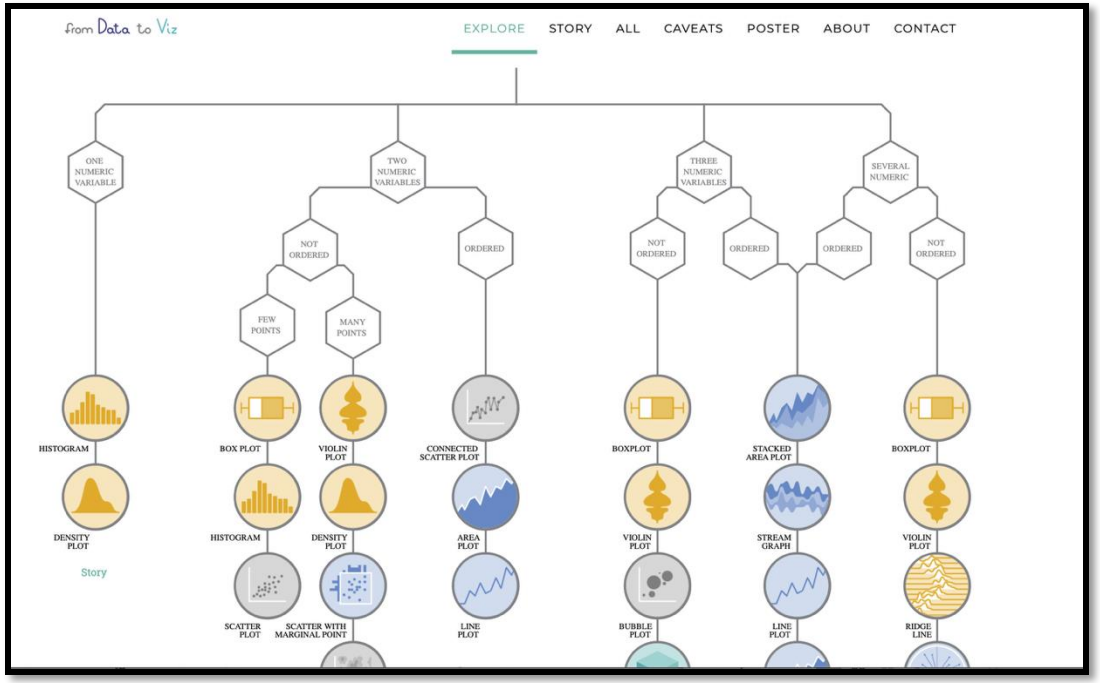
Model 267 / 267	Overall	Hard Prompts	Coding	Math	Creative Writing	Instruction Following	Longer Query	Multi-Turn
gemini-3-pro	1	1	1	1	1	1	1	1
grok-4.1-thinking	1	2	1	1	1	1	4	1
grok-4.1	2	2	1	2	2	4	4	1
claude-sonnet-4-5-2…	3	2	1	1	2	1	1	1
gemini-2.5-pro	3	5	9	1	2	4	4	3
claude-opus-4-1-202…	4	2	1	1	2	2	1	1
claude-sonnet-4-5-2…	4	2	3	3	2	2	2	1
gpt-4.5-preview-202…	4	11	10	7	2	5	7	1
claude-opus-4-1-202…	6	3	3	2	3	2	4	1
chatgpt-4o-latest-2…	7	9	10	18	6	10	8	1
gpt-5-high	7	9	9	2	18	10	19	13
kimi-k2-thinking	7	9	4	1	6	9	8	6
o3-2025-04-16	8	11	14	1	17	16	24	14
qwen3-max-preview	8	7	5	1	11	8	7	6
glm-4.6	11	9	9	2	6	9	8	14
gpt-5-chat	13	9	11	7	13	10	8	5
qwen3-max-2025-09-23	13	9	8	1	9	10	8	4
claude-opus-4-20250…	14	9	4	5	4	4	4	9
deepseek-v3.1-termi…	14	18	18	5	4	13	9	19

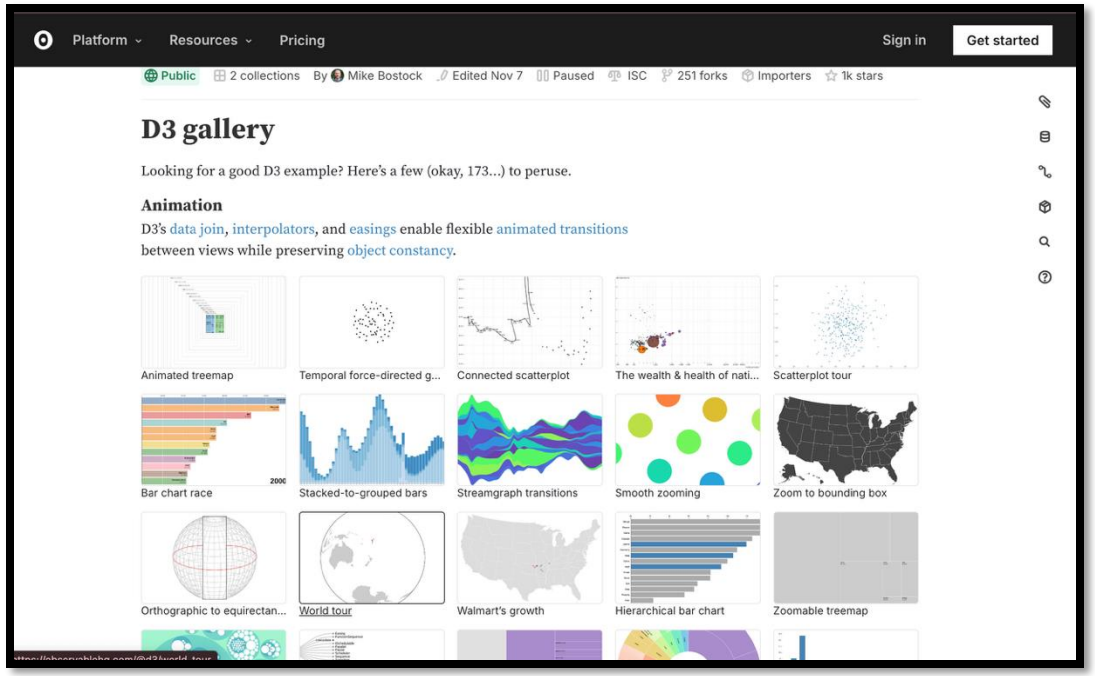
https://lmarena.ai/leaderboard


Google Scholar
climate change north american monsoon
Articles
About 473,000 results (0.22 sec)
Any time
Since 2025
Since 2024
Since 2021
Custom range...
Sort by relevance
Sort by date
Any type
Review articles
include patents
include citations
Create alert
Weakening of the North American monsoon with global warming
S Pascale, WR Boos, S Bordoni, TL Delworth... - ... Climate Change, 2017 - nature.com
... changes in the North American monsoon, a circulation system that brings abundant summer rains to vast areas of the North American ... How this monsoon will change with increasing ...
Save Cite Cited by 183 Related articles All 20 versions Web of Science: 130
Downscaled climate change scenarios for Baja California and the North
ResearchRabbit
Search
Library
Similar to Castro, 2012
References
Search inputs
Results
Bukovsky, 2013
Towards Assessing NARCCAP Regional Climate Model Credibility for the North American Monsoon: Current Climate
Taylor 2012
Taylor 2001
Hawkins 2009
Livneh 2013
Prein 2015
Wang 2014
Adams 1997
Wilks 1999
Morrison 2008
Feser 2011
Mearns 2012
Miguez-Macho 2005
Castro, 2012
Leung 2013
Bukovsky 2015
Fox-Rabinovitz 2005
Northern Mexico Projected Precipitation and Monsoon Changes
Create notebook
Share
Settings
Sources
Add sources
Try Deep Research for an in-depth report and new sources!
Search the web for new sources
Web
Fast Research
Select all sources
Kim and Villarini - 2024 - Projected ch...
Nazarian et al. - 2024 - Projected Cha...
Chat
Northern Mexico Projected Precipitation and Monsoon Changes
2 sources
These sources present climate change projections for the border region of the southwestern United States and northern Mexico, focusing specifically on future changes in precipitation and temperature variables. The first paper examines statistically downscaled CMIP6 climate models to project changes in daily precipitation, air temperature, and wet-bulb temperature across Arizona, concluding that the region is expected to become overall warmer and wetter, with increases in extreme heat and humidity. The second study utilizes the NA-CORDEX ensemble of dynamically downscaled simulations to investigate trends in mean and extreme precipitation over Northern Mexico, forecasting a decrease in precipitation to the west and an increase to the east of the Sierra Madre, alongside a delayed and lengthened North American monsoon season and a nearly doubling of extreme precipitation event frequency. Both studies underscore the potential for increased hydroclimate extremes—such as heat stress, drought, and flooding—that will necessitate robust adaptation strategies in these vulnerable border regions.
Start typing...
2 sources
How will mean and extreme precipitation patterns geographically shift across Northern Mexico by the century's end?
Studio
Audio Overview
Video Overview
Mind Map
Reports
Flashcards
Quiz
Studio output will be saved here.
After adding sources, click to add Audio Overview, Study Guide, Mind Map, and more!
Add note


LouFie08 / Hydroclimate-Extremes-Analysis
Code
Issues
Pull requests
Actions
Projects
Hydroclimate-Extremes-Anal...
Public
Pin
main
Go to file
LouFie08 Update LouFie_test.txt
2a52738 · 4
IDW_Met_TimeSeries_D01... HW1
IDW_NocheBuena_timeseri... HW1
LouFie_test.txt Update LouFie_test.txt
README.md Update README.md
S01_Time_Series.ipynb Rename HW1.ipynb to S01_Tim...
README
Hydrometeorological Extreme Analysis
Workflow and script documentation for analyzing climatological (models and observations) and meteorological variables relevan analysis
Time series
Climate Indices
CLINE
Cline for CLI is here!
Install to use Cline directly in your terminal and enable subagent capabilities. Cline can spawn cline commands to handle focused tasks like exploring large codebases for information. This keeps your main context window clean by running these operations in separate subprocesses.
Learn more
npm install -g cline
Install
Enable Subagents
What can I do for you?
RECENT TASKS
NOVEMBER 6, 12:02 PM
create a python script that reads a plot precipitation data from a csv file. The
Auto-approve: Read, Safe Commands, ...
Type your task here...
Type @ for context, / for slash commands ...
anthropic:claude-opus...
Plan
Act
Welcome
plot_precipitation_data.py
plot_precipitation_data.py > read_csv_data
#!/usr/bin/env python3
"""
Script to read and plot precipitation data from a CSV file.
The script reads columns: PRCP (precipitation), TAVG (average temperature),
TMAX (max temperature), and TMIN (min temperature).
"""
import pandas as pd
import matplotlib.pyplot as plt
import os
import sys
from datetime import datetime
def get_file_path():
"""Get the CSV file path from user input."""
while True:
file_path = input("Enter the full path to your CSV file: ").strip()
# Remove quotes if present
if file_path.startswith('"') and file_path.endswith('"'):
file_path = file_path[1:-1]
PROBLEMS
OUTPUT
DEBUG CONSOLE
TERMINAL
PORTS
(wrf_regrid_env) loufie@dhcp-10-132-189-189 Scripts % /opt/homebrew/Caskroom/mambaforge/base/envs/wrf_regrid_e
nv/bin/python /Users/loufie/Documents/R4R_FY25/Scripts/plot_precipitation_data.py
Plot Options:
1. Individual plots for each variable
2. Combined plot (temperature together, precipitation separate)
3. Both views
Select plot option (1/2/3): 3
Visualization complete!
(wrf_regrid_env) loufie@dhcp-10-132-189-189 Scripts %
Python
Python
Python
Python:...
Python:...
zsh
Python: plo...

Visualization Toolkit





[Data to Viz]

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Efficiency: Maximizing data ink

Conclusions

- Hydro-meteorological **research** can be **computational challenging** due to manage massive datasets, and complex multi-scale models.

- There are easy-to-access tools that can help to easy the burden. Platforms like R4R, FOSS, and CyVerse provide easy-to-access tools and training in Open Science, AI, and HPC to manage data, speed up analysis, and create impactful visualizations.

- By integrating some of these tools with a computational framework, we can create research pipelines that are **reproducible, scalable, and impactful** in addressing environmental and societal resilience.

Hsin-I Chang (HAS)
Advisor

Thank you!!

Chris Castro (NCAR)
Advisor

Contact: lourdesfierro@arizona.edu

Michele Cosi (DSI)
Instructor

Tina Johnson (DSI)
R4R Program Manager

Jeff Gillan (Cyverse)
Instructor

References

- Seneviratne, S.I., X. Zhang, M. Adnan, W. Badi, C. Dereczynski, A. Di Luca, S. Ghosh, I. Iskandar, J. Kossin, S. Lewis, F. Otto, I. Pinto, M. Satoh, S.M. Vicente-Serrano, M. Wehner, and B. Zhou, (2021). Chapter 11: Weather and Climate Extreme Events in a Changing Climate. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1513–1766, doi:10.1017/9781009157896.013.