



“Building an Atmospheric Rivers Catalog Using Big Data Approach”

CHRS - CONNECT and PERSIANN CDR

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Phu Nguyen

Hao Liu

*Center for Hydrometeorology and Remote Sensing
University of California Irvine*



*“Improving Sub-Seasonal & Seasonal Precipitation
Forecast for drought Preparedness”*

DWR-WSWC Workshop, San Diego CA May 28th, 2015



University of California Merced Graduate (Adjunct) Past



and many more ...

Prediction Requirements for Water Resources

Short Range —————> Long Range

hours ----> days ----> weeks ---> months --> seasons --> years -----> decades

Mid-range

Long-range

Prediction Requirements for Water Resources

Short Range —————> Long Range

hours ----> days ----> weeks ---> months --> seasons --> years -----> decades

Flash Flood Wa

Flash Flood Gu

Head

Flood

sts

ow Melt Forecasts

ply Volume

Mid-range

ents

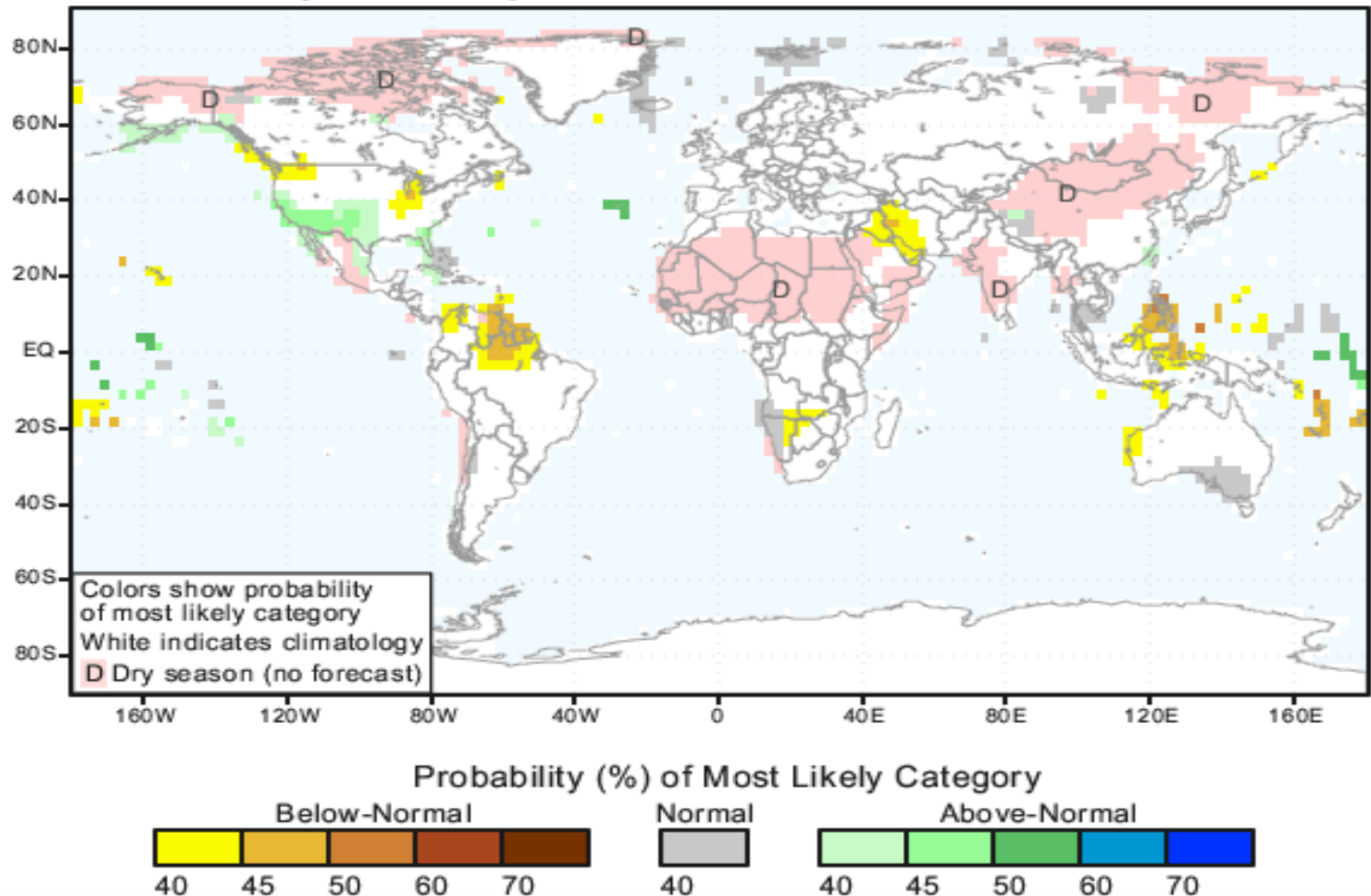


Center for Hy

University of California, Irvine

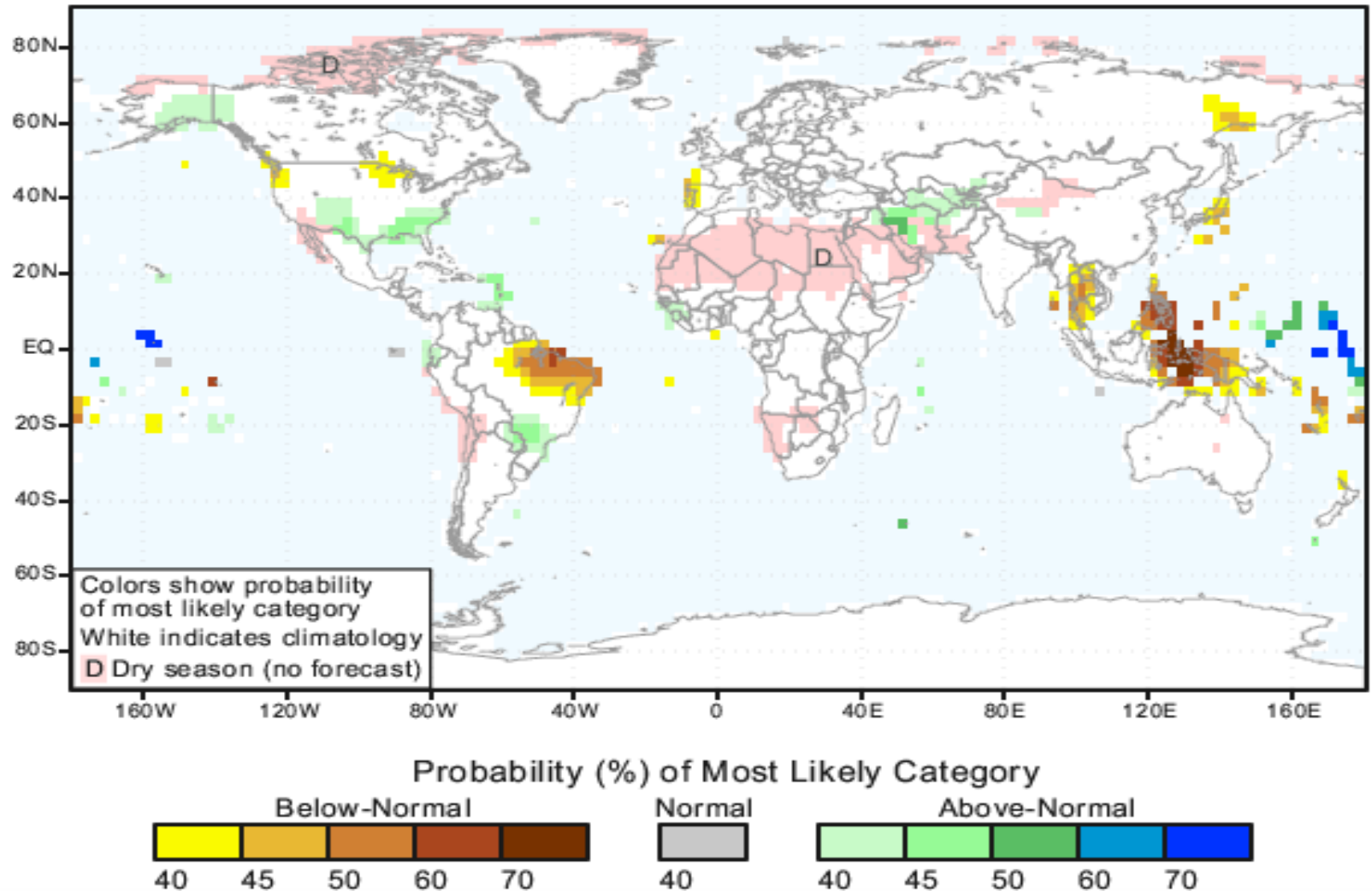
IRI 3-Month Multi-Model Probability Precipitation Forecast

IRI Multi-Model Probability Forecast for Precipitation
for January-February-March 2015, Issued December 2014



IRI 3-Month Multi-Model Probability Precipitation Forecast

IRI Multi-Model Probability Forecast for Precipitation
for April-May-June 2015, Issued March 2015



Climate-Scale approaches to addressing hydrologic extremes

Short Range —>Long Range

hours ----> days ----> weeks ---> months --> seasons --> years -----> decades

Flash Flood Warning

Flash Flood Guidance

Headwater Guidance

Flood Forecast Guidance

Reservoir Inflow Forecast

Spring Snow

Water Supply

Long-range

Forecast Requirement



Hydrologically-Relevant Climate Variables

*Climate Models Projections
of Future Precipitation
Patterns and Amounts?*



Western U.S. future model projections



Dr. Chiyuan Miao - BNU



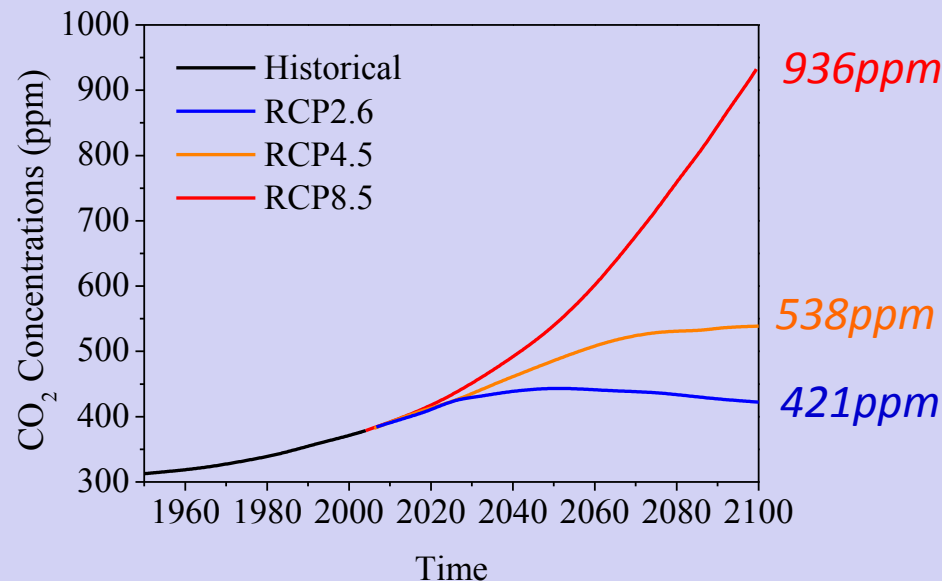
Future Modeling Scenarios – IPCC AR5

Representative Concentration Pathways (RCP) Scenarios:

RCP2.6: represent ‘low’ scenarios featured by the radiative forcing of 2.6 W/m^2 by 2100, the resulting CO_2 -equivalent concentrations is 421 ppm in the year 2100 .

RCP4.5: represent ‘medium’ scenarios featured by the radiative forcing of 4.5 W/m^2 by 2100, the resulting CO_2 -equivalent concentrations is 538 ppm in the year 2100 .

RCP8.5: represent ‘high’ scenarios featured by the radiative forcing of 8.5 W/m^2 by 2100, the resulting CO_2 -equivalent concentrations is 936 ppm in the year 2100 .

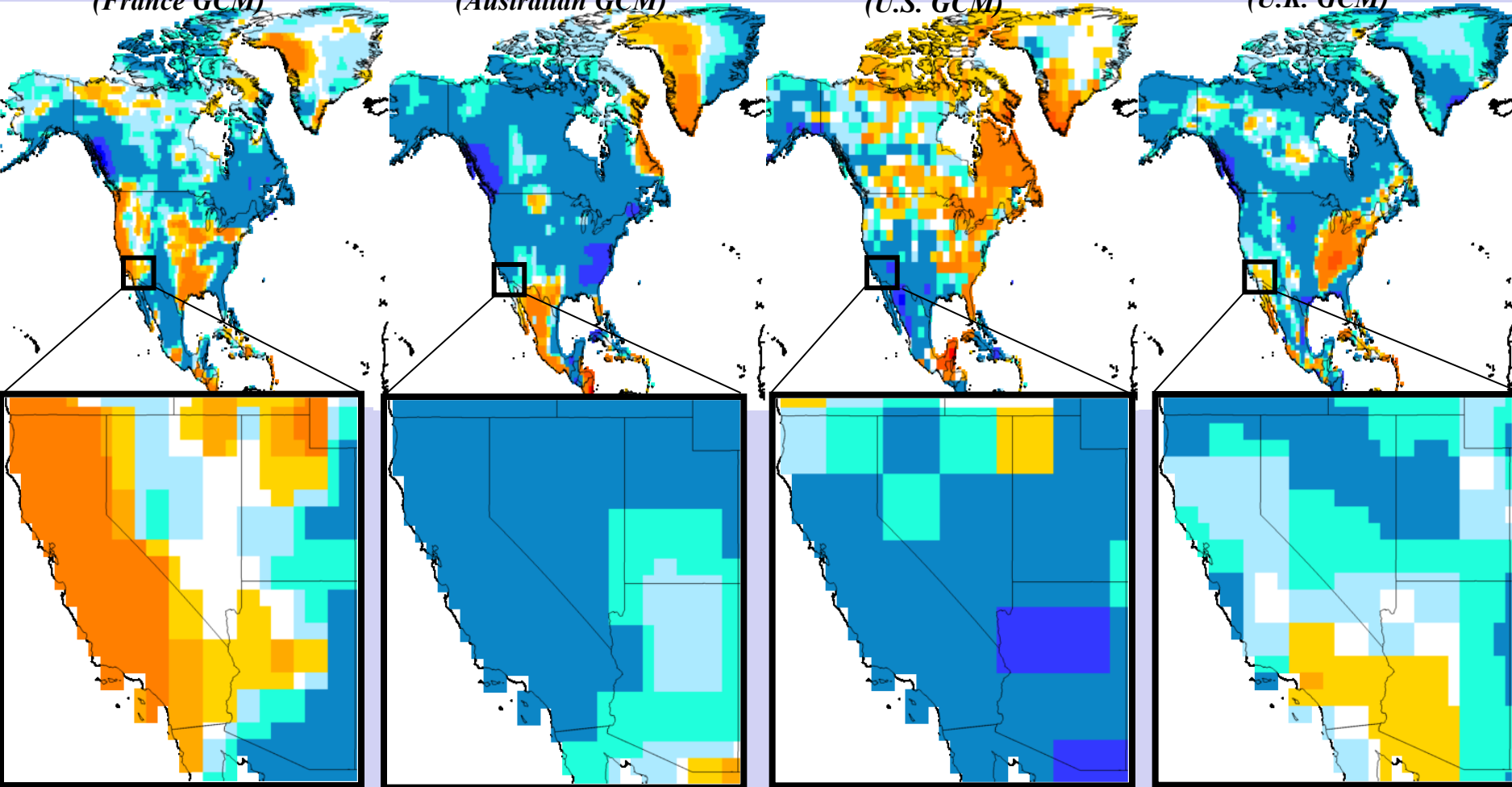


CNRM-CM5
(France GCM)

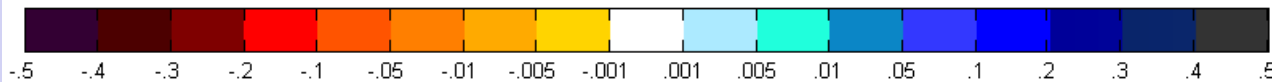
CSIRO-MK-3.6.0
(Australian GCM)

GISS-E2-R
(U.S. GCM)

HadGEM2-ES
(U.K. GCM)



Precipitation change (mm per day per decade)

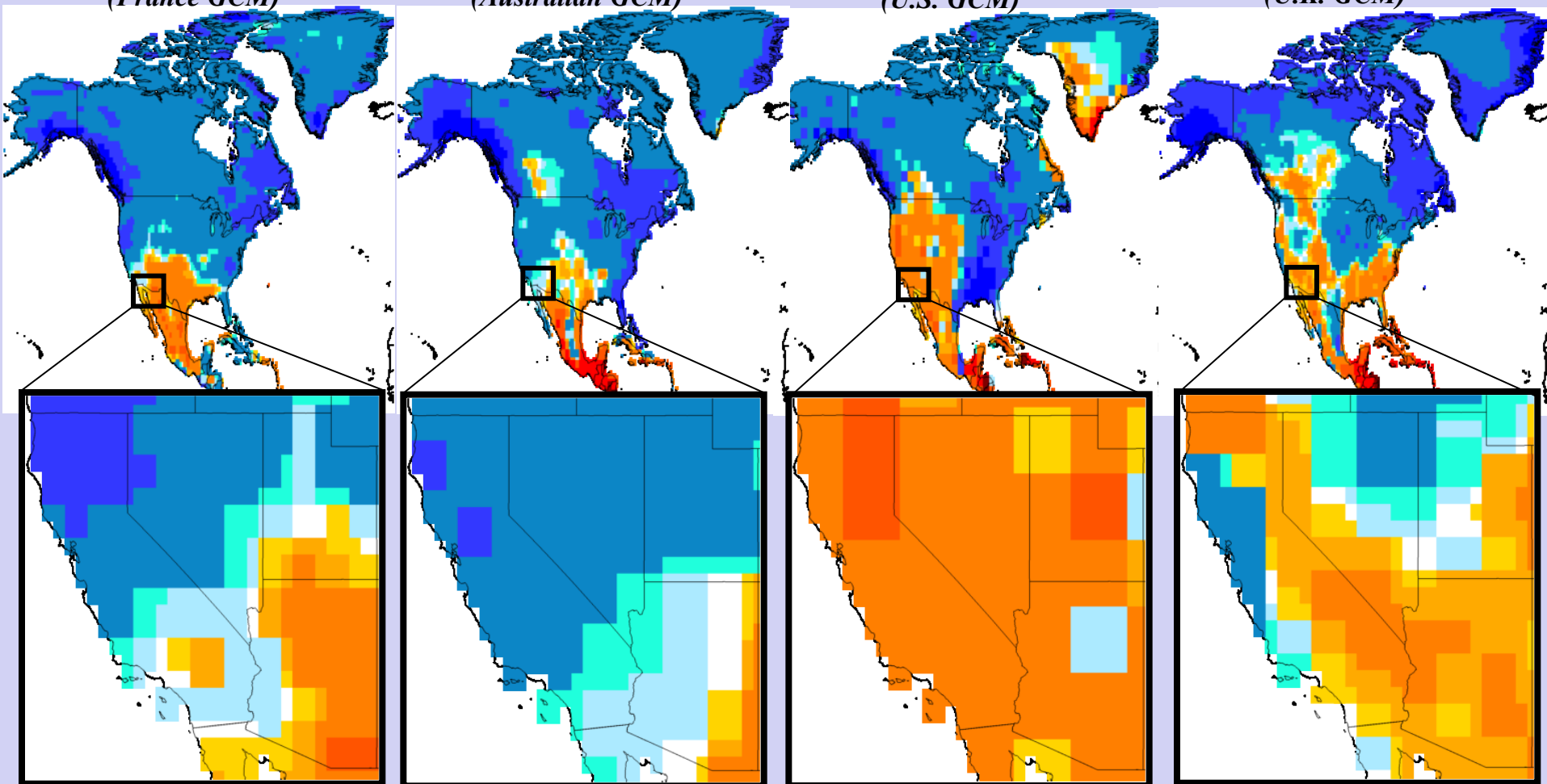


CNRM-CM5
(France GCM)

CSIRO-MK-3.6.0
(Australian GCM)

GISS-E2-R
(U.S. GCM)

HadGEM2-ES
(U.K. GCM)

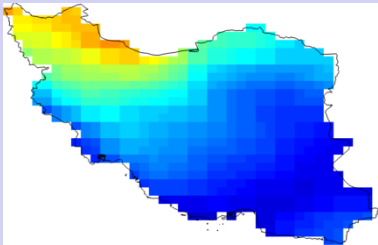


Precipitation change (mm per day per decade)

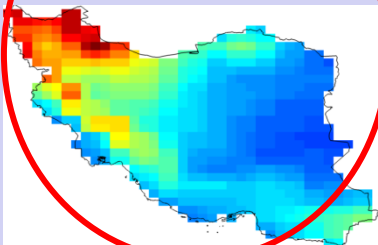


Model historical simulation (1983-2005)

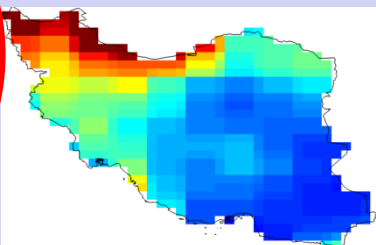
bcc_csm1_1_m
(Chinese GCM)



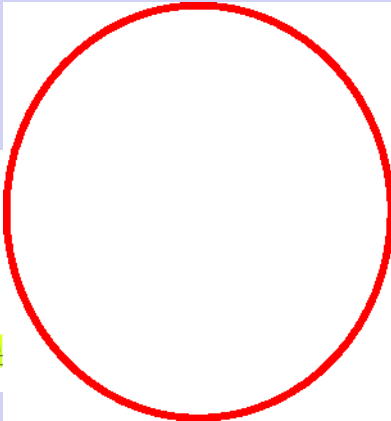
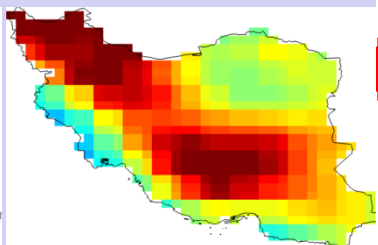
CCSM4
(NCAR, USA GCM)



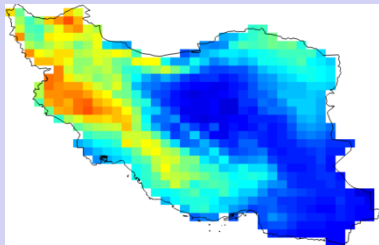
HadGEM2-ES
(U.K GCM)



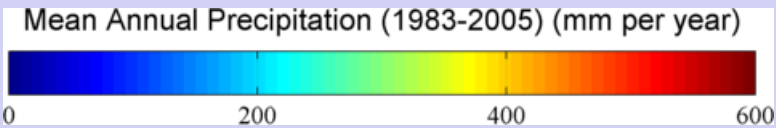
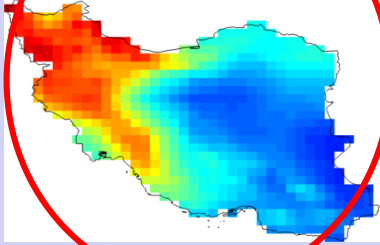
MIROC5
(Japan GCM)



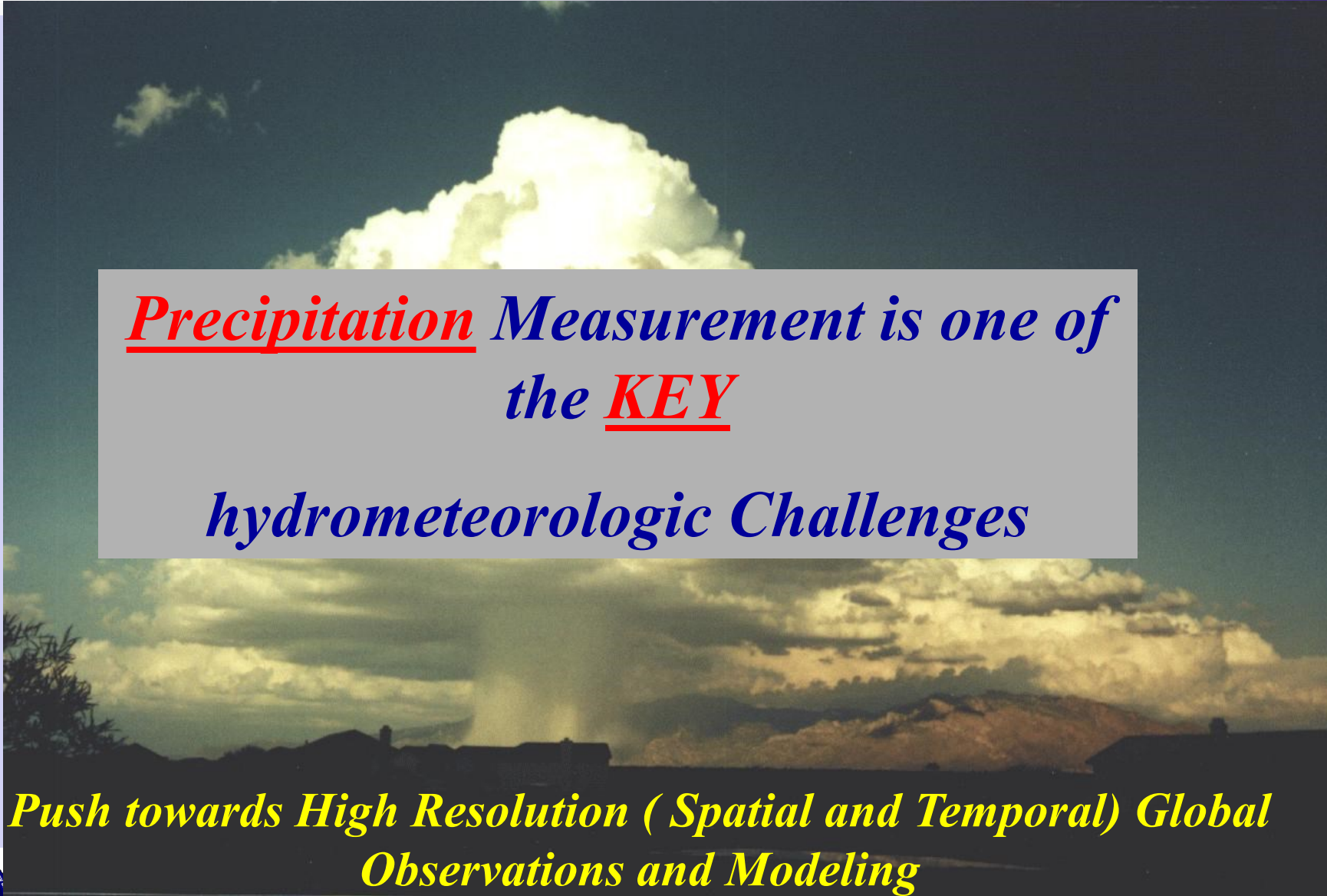
Observation
(CRU Dataset)



Remotely Sensed Estimates
(PERSIANN-CDR)



A Key Requirement!



*Precipitation Measurement is one of
the KEY
hydrometeorologic Challenges*

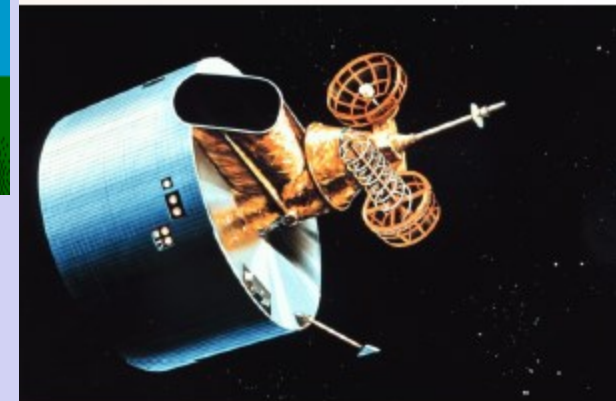
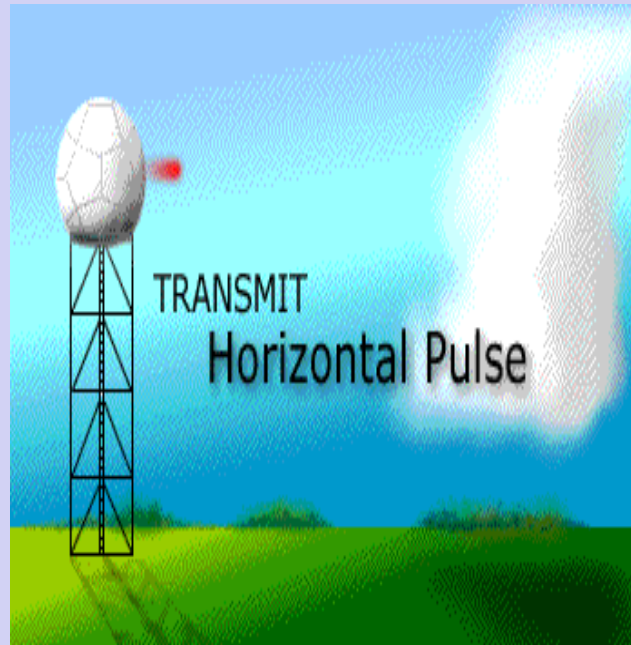
*Push towards High Resolution (Spatial and Temporal) Global
Observations and Modeling*



Precipitation Observations: Which to trust??



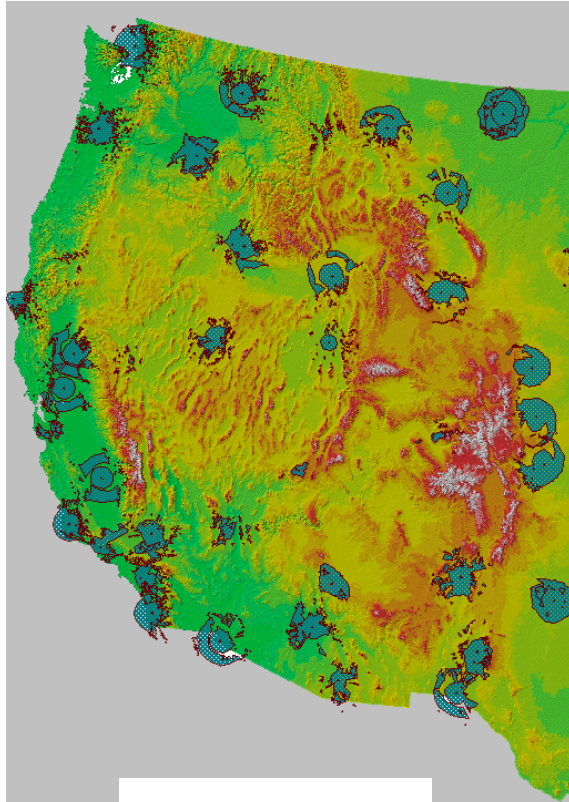
Rain Gauges



Satellite

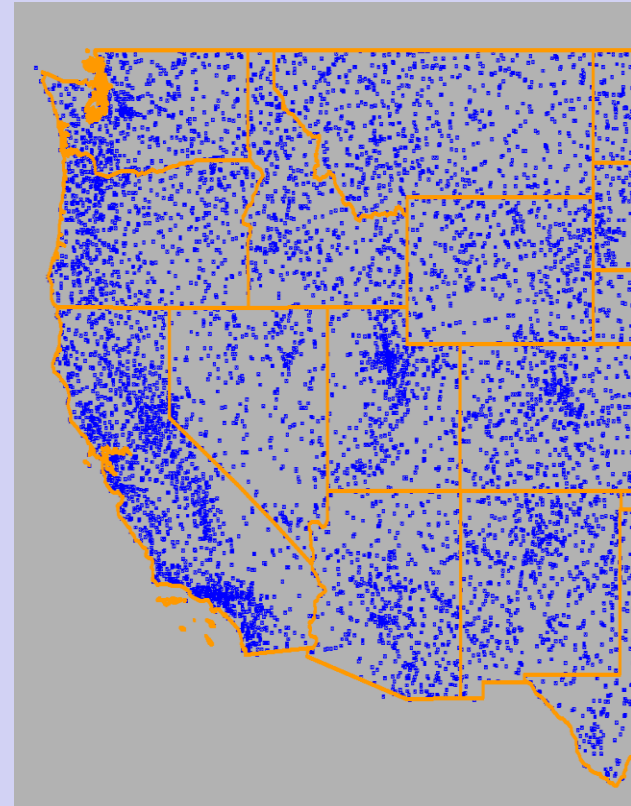


Coverage of the WSR-88D and gauge networks



1 km AGL

Maddox, et al., 2002



***Daily precipitation
gages (1 station per 600 km²
for Colorado River basin)
hourly coverage
even more sparse***



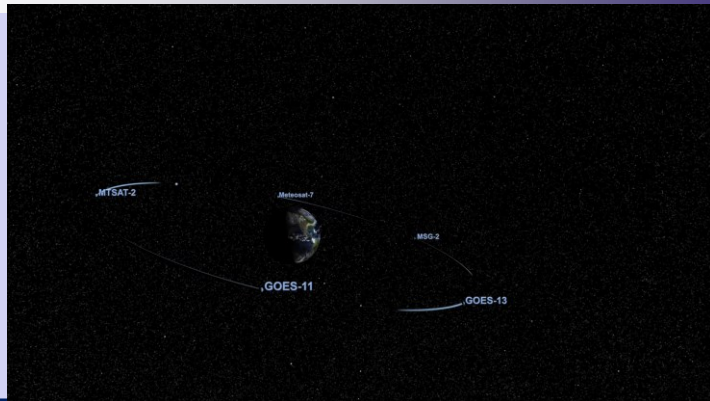
Space-Based Observations



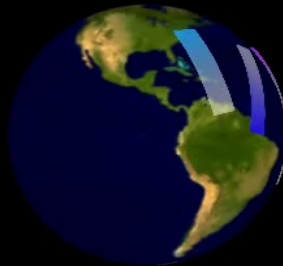
Satellite Observations: Rainfall Estimation



Satellite Data for Precipitation estimation



*Geostationary IR
Cloud top data
15-30 minute temporal
resolution*



*Passive Microwave (SSM/I)
Some characterisation of rainfall
~2 overpasses per day per
spacecraft, moving to 3-hour
return time (GPM)*



*TRMM precipitation RADAR
3D imaging of rainfall
1-2 days between overpasses
(S-35°N-35 °)*



Geostationary Satellites Infrared (IR) Channel Tb



Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN)



PERSIANN System

Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks



Kuolin Hsu
Algorithm Development

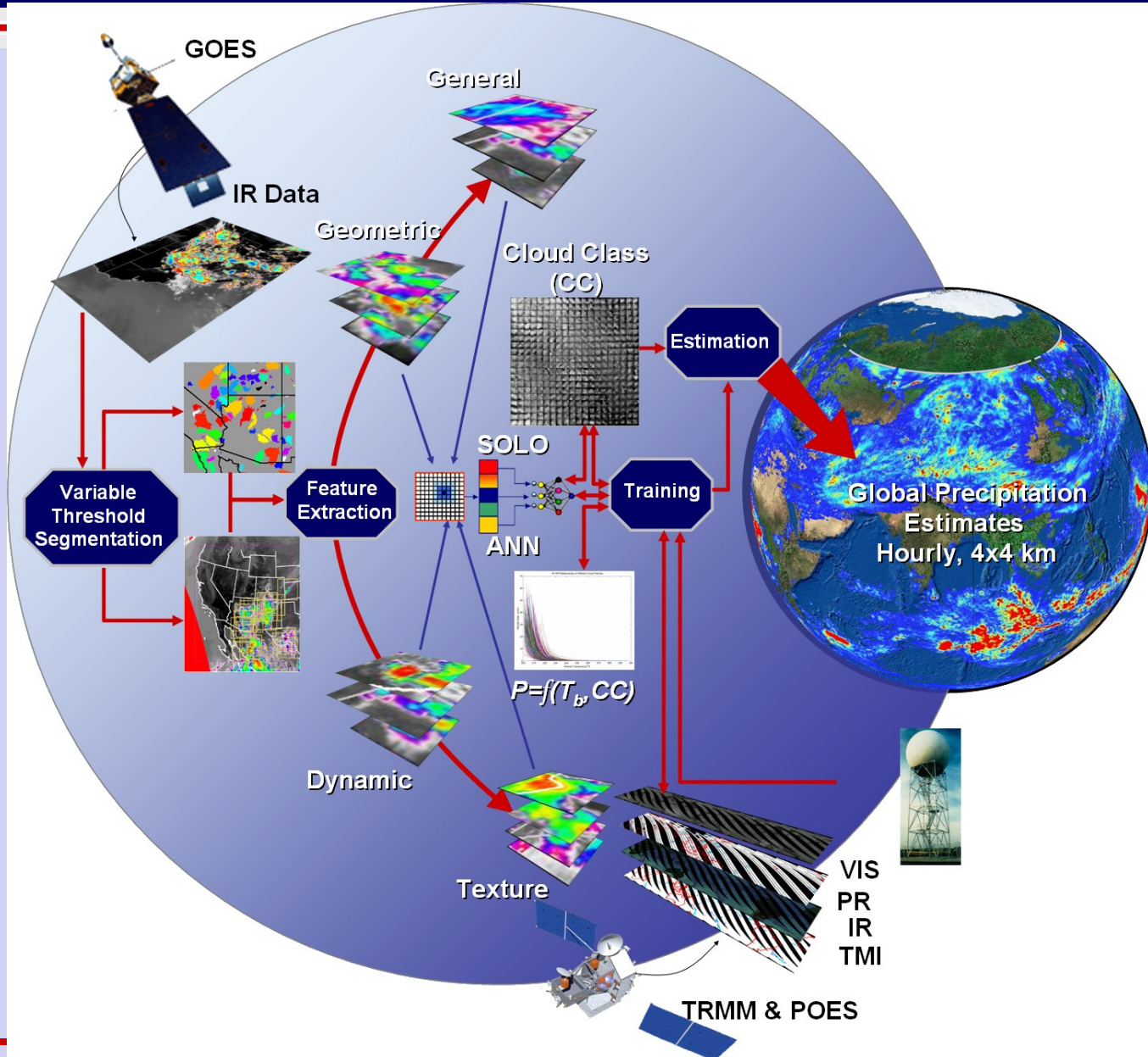


Bisher Imam
G-WADI site development



Center for Hydrometeorology and Remote Sensing, University of California, Irvine

PERSIANN-CCS (Real-time 4 km)



PERSIANN Extensions: Climate-Related



- *PERSIANN-CONNECT*
- *PERSIANN-CDR*



PERSIANN-CONNECTed precipitation objECT

EOS

EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

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VOLUME 94 NUMBER 32 6 AUGUST 2013

Computational Earth Science: Big Data Transformed Into Insight

More than ever in the history of science, researchers have at their fingertips an unprecedented wealth of data from continuously orbiting satellites, weather monitoring instruments, ecological observatories, seismic stations, moored buoys, floats, and even model simulations and forecasts. With just an internet connection, scientists and engineers can access atmospheric and oceanic gridded data and time series observations, seismographs from around the world, minute-by-minute conditions of the near-Earth space environment, and other data streams that provide information on events across local, regional, and global scales. These data sets have become essential for monitoring and understanding the associated impacts of geological and environmental phenomena on society.

This increasing amount of data has led us

If such algorithms are run in a computer environment designed to home in on characteristics of objects or events of interest, then the data can be crunched even more efficiently, allowing insights from big data to be revealed at a quicker pace. Such machine learning evolved from artificial intelligence research and focuses on developing models that are based on the behaviors and characteristics of empirical data. Capturing the behaviors and characteristics from data and determining their underlying probability distributions can provide new knowledge regarding the object or characteristic of interest. Typically, the properties or "true" underlying probability distributions of the observed variable of interest are not explicitly known. However, by seeking to define or describe these underlying probability distributions, data mining can help scientists

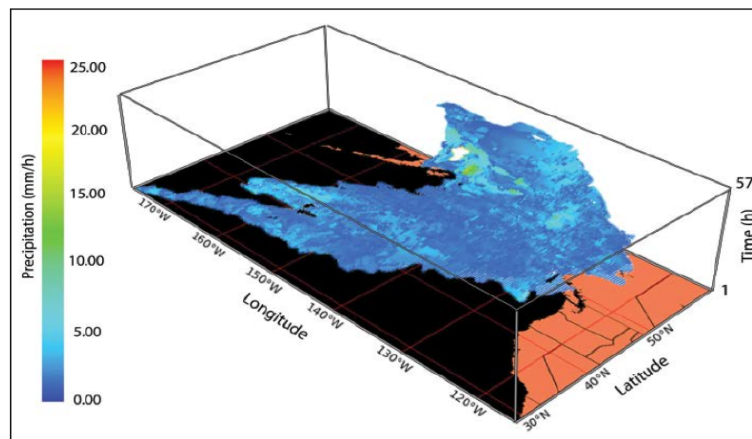
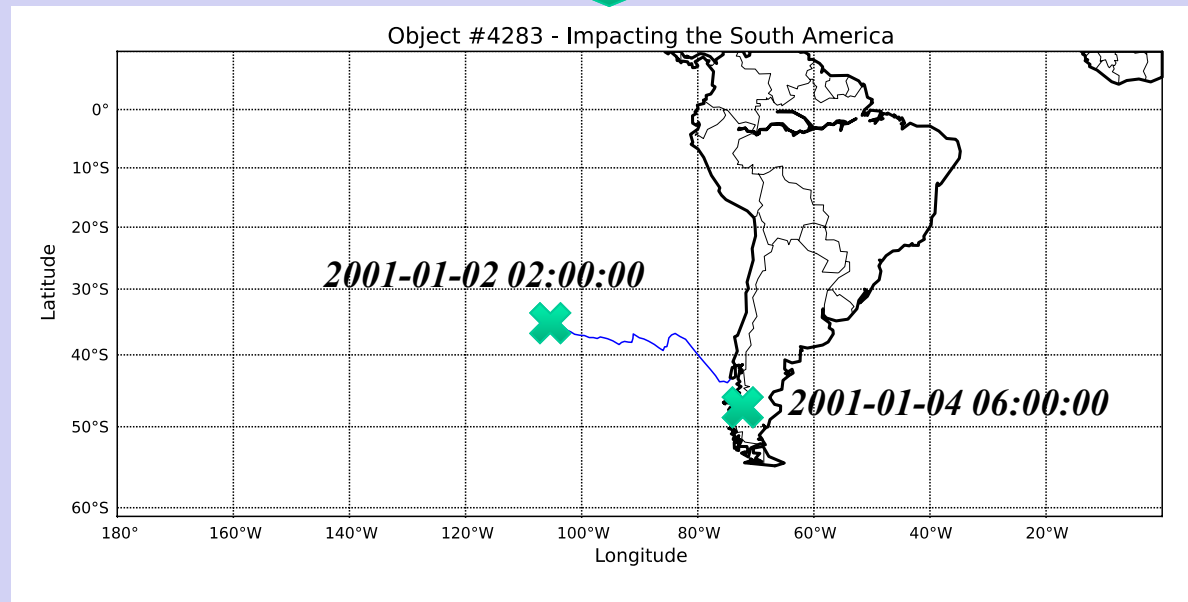
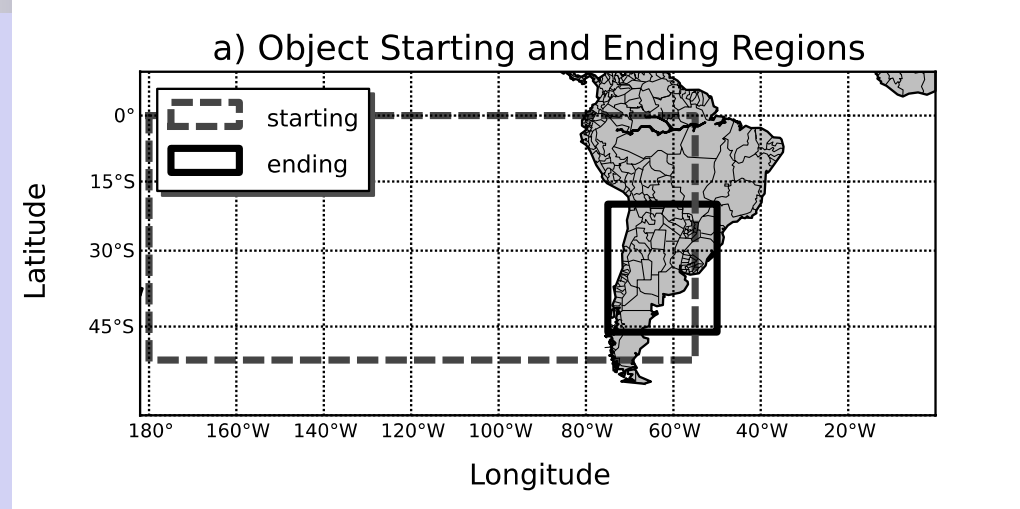


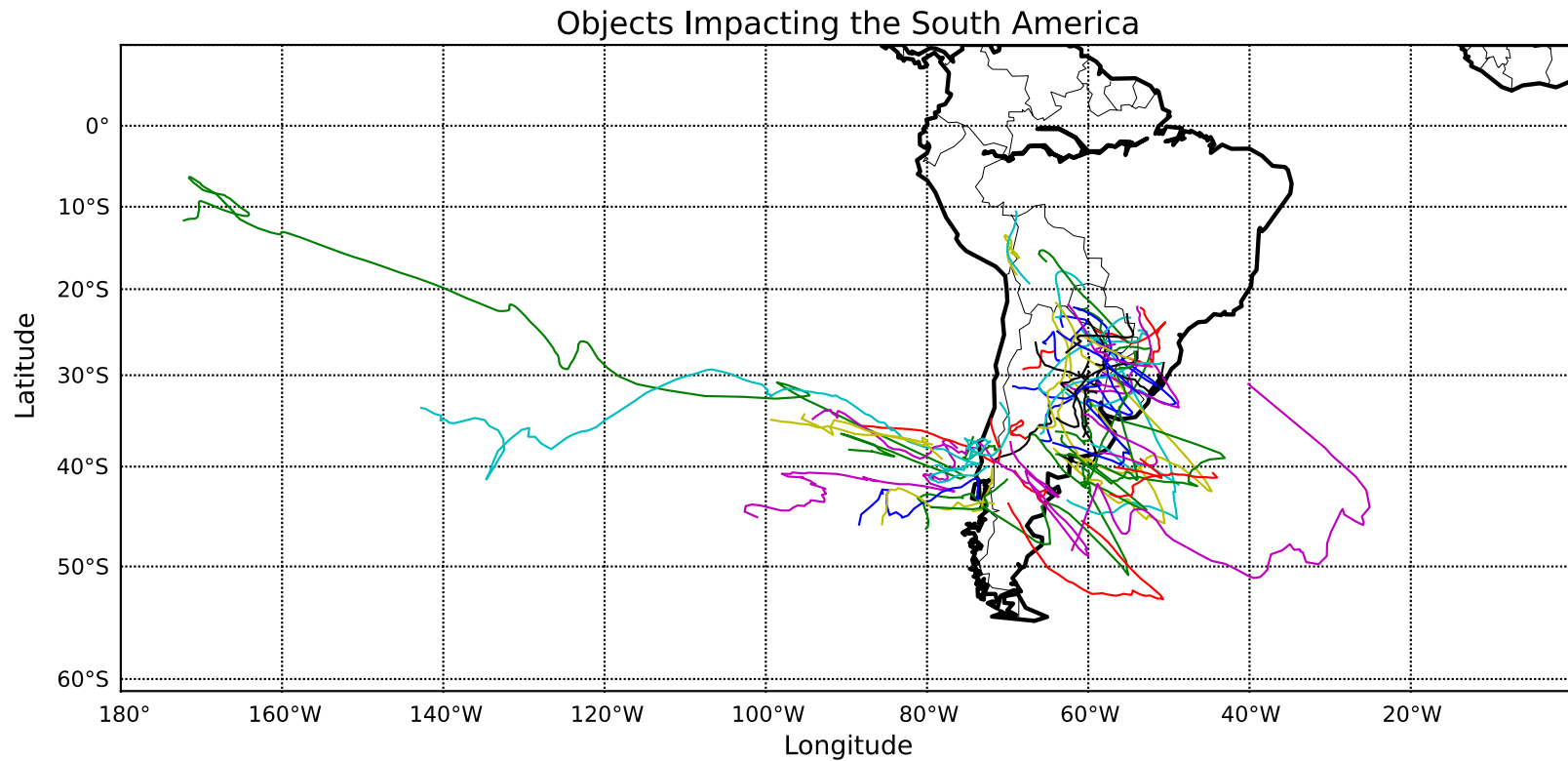
Fig. 1. A connected four-dimensional atmospheric river, or "precipitation object," extracted from the PostgreSQL database. The atmospheric river originated in the eastern Pacific and affected the western United States from 28 to 30 December 2005.

***Sellars, S., P. Nguyen, W. Chu, X. Gao, K. Hsu, and S. Sorooshian (2013),
Computational Earth Science: Big Data Transformed Into Insight, EOS Trans. AGU, 94(32),277**

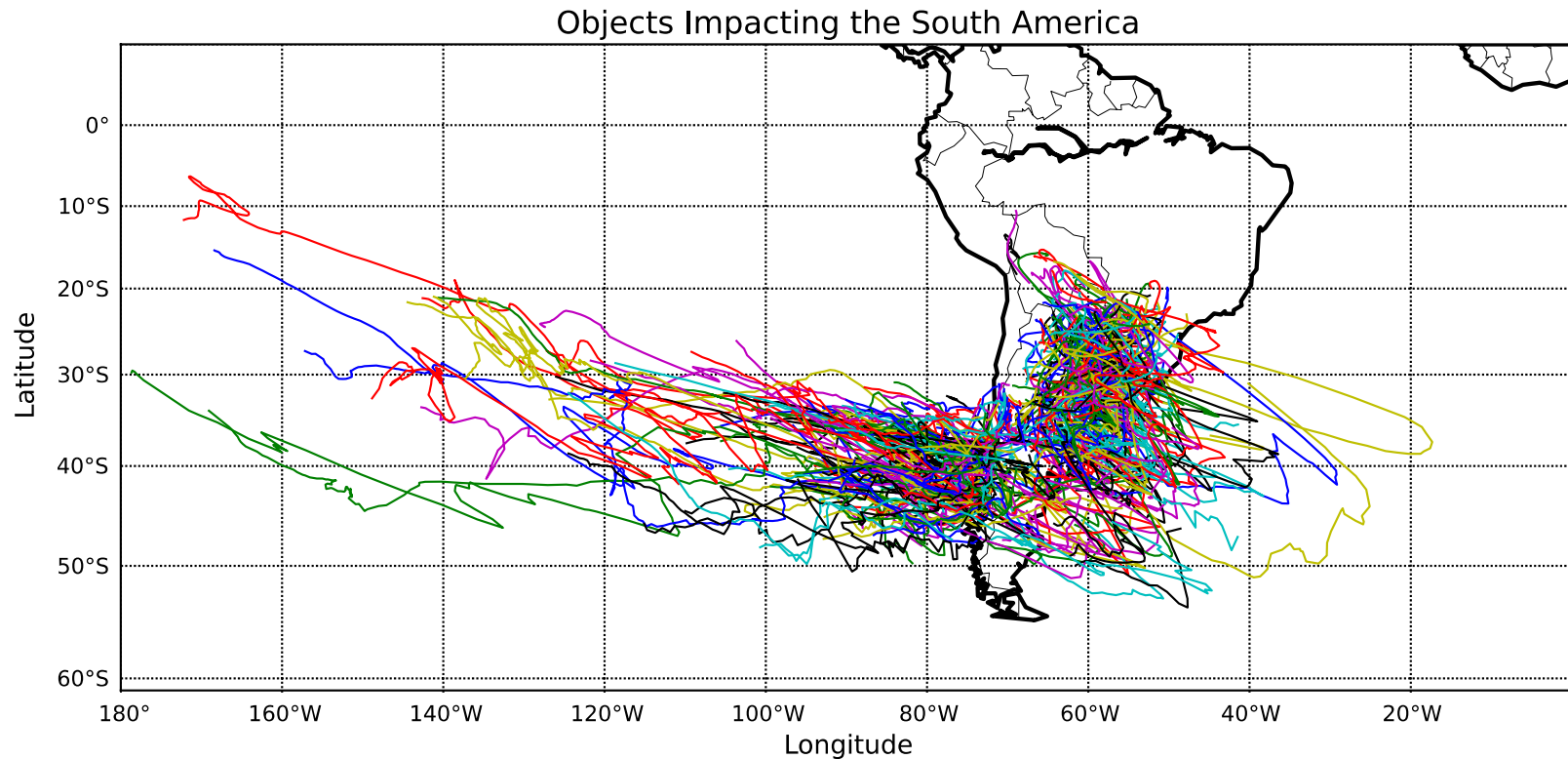
Regional Search: Specific Storm



Regional Search: 2001 Storms



Regional Search: All Storms (2000-2010)



PERSIANN -CDR

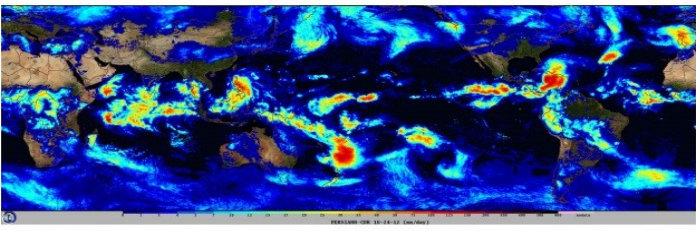
<http://www.ncdc.noaa.gov/cdr/operationalcdrs.html>

NOAA'S NATIONAL CLIMATIC DATA CENTER

NOAA's Climate Data Record (CDR) Program

PRECIPITATION ESTIMATION FROM REMOTE SENSING INFORMATION USING ARTIFICIAL NEURAL NETWORK

PERSIANN



PERSIANN CLIMATE DATA RECORD SPECIFICATIONS

- 0.25-deg * 0.25-deg (60°S–60°N latitude and 0°–360° longitude)
- Daily Product
- 1980–present
- Updated Monthly

INPUTS TO THE PERSIANN CLIMATE DATA RECORD

- GridSat-B1 CDR (IRWIN)
- GPCP 2.5-deg Monthly Data

SOME USES OF THE PERSIANN CLIMATE DATA RECORD

- Climatologists can perform long-term climate studies at a finer resolution than previously possible.
- Hydrologists can use PERSIANN-CDR for rainfall-runoff modeling in regional and global scale, particularly in remote regions.
- Performing extreme Event Analysis (intensity, frequencies, and duration of floods and droughts).
- Water Resources Systems Planning and Management

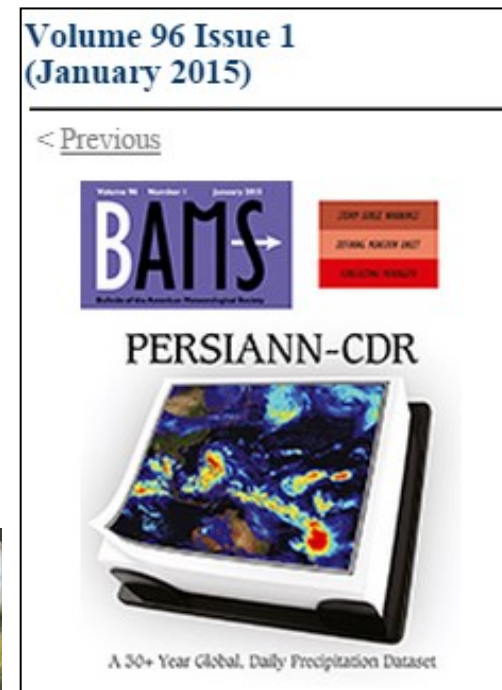
PERSIANN CLIMATE DATA RECORD
<http://www.ncdc.noaa.gov/cdr/operationalcdrs.html>

CLIMATE DATA RECORD PROGRAM INFORMATION
<http://www.ncdc.noaa.gov/cdr/index.html>

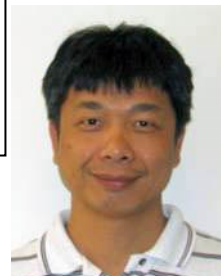
www.climate.gov
www.ncdc.noaa.gov

Protecting the past... Revealing the future
September 2013

- *Daily Precipitation Data*
- *Data Period: 1983~2014*
- *Coverage: 60°S ~ 60°N*
- *Spatial Resolution: 0.25°x0.25°*



Ashouri, Hsu et al., BAMS, 2015.



PERSIANN-CDR: PERSIANN Climate Data Record

<http://www.ncdc.noaa.gov/cdr/operationalcdrs.html>



[Home](#) [Operational CDRs](#) [Developmental CDRs](#) [Opportunities](#) [Library](#)

[SEARCH NCDC](#)

CLIMATE DATA RECORD PROGRAM

[Serving the Public](#)

[Data](#)

[Development Guidelines](#)

[Contact Us](#)

News

[Climate Data and Applications Workshop - A Focus on Precipitation - Dec 3-4, 2013](#)

[Congratulations Cheng-Zhi Zou](#)

[2013 CDR Annual Meetings Presentations now available](#)

Operational Climate Data Records (CDRs)

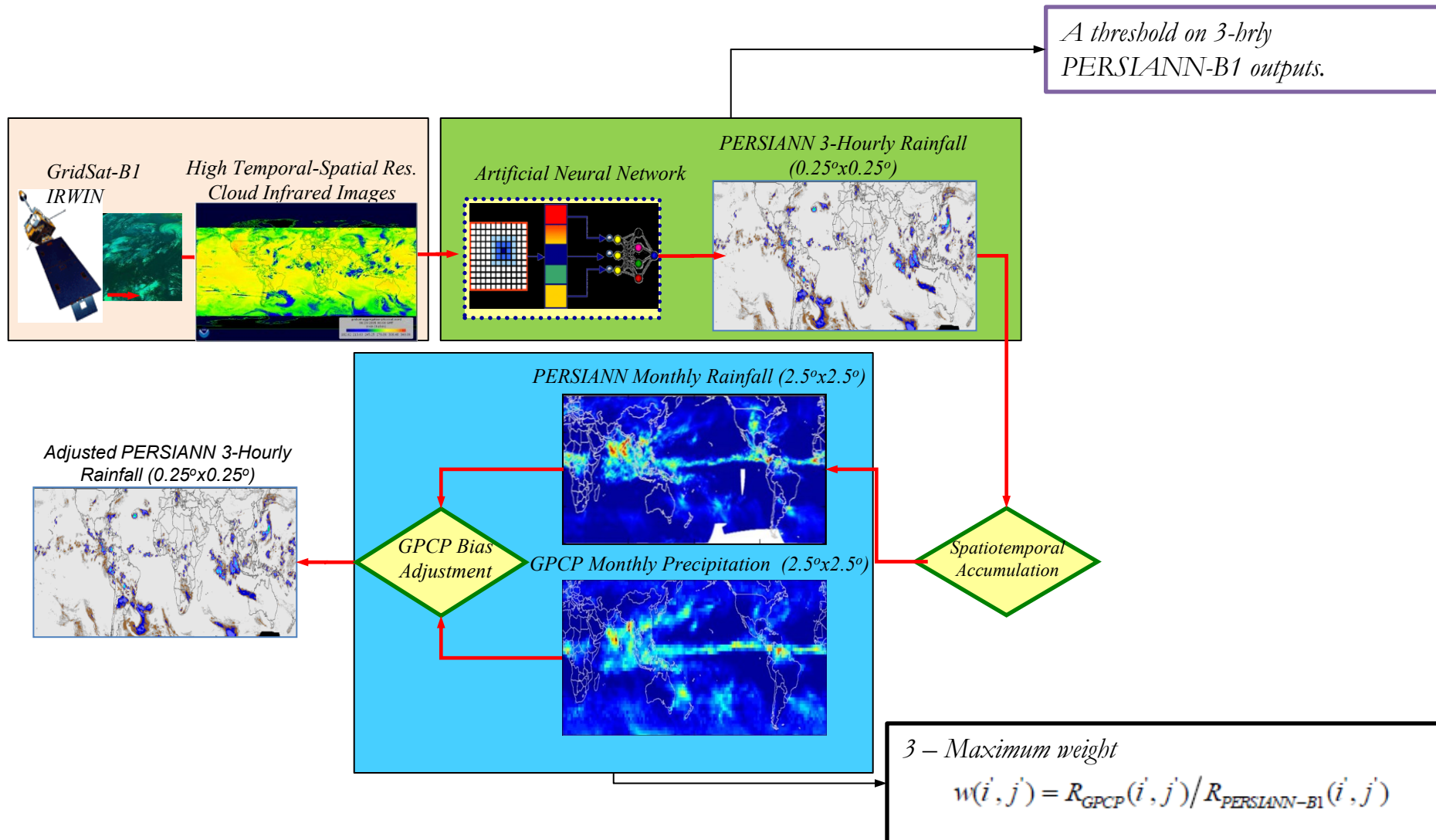
In addition to embracing the National Research Council CDR definition ([Climate Data Records from Environmental Satellites: Interim Report 2004](#)), NOAA operational CDRs are routinely assessed for quality and systematically generated. The first step in establishing an operational CDR includes public posting of the source code that generated the CDR dataset, the dataset itself, and supporting documentation through a six-phase Research-to-Operations process that is described in the [Developers Guidelines](#).

Once posted to the NCDC webpage, the CDRs are grouped by Fundamental CDRs and Thematic (Atmospheric, Oceanic, and Terrestrial) CDRs. Fundamental CDRs are sensor data (e.g. calibrated radiances, brightness temperatures) that have been improved and quality controlled over time, together with the ancillary data used to calibrate them. Thematic CDRs are geophysical variables derived from the FCDRs, such as sea surface temperature and sea ice concentration, and they are specific to various disciplines. Thematic CDRs are often generated by blending satellite observations, in-situ data, and/or model output.

Atmospheric CDRs	Information	Serving Public	Available Data Access	Source Code	Documentation
Aerosol Optical Thickness	Overview Contact Us Registration		Use Agreement THREDDS FTP		Algorithm Description Data Flow Diagram Maturity Matrix
Mean Layer Temperatures - RSS	Overview Contact Us Registration		Use Agreement THREDDS FTP		Algorithm Description Data Flow Diagram Maturity Matrix
Mean Layer Temperatures - UAH	Overview Contact Us Registration		Use Agreement THREDDS FTP		Algorithm Description Data Flow Diagram Maturity Matrix
Outgoing Longwave Radiation	Overview Contact Us Registration		Use Agreement THREDDS FTP		Algorithm Description Data Flow Diagram Maturity Matrix
Precipitation - PERSIANN-CDR	Overview Contact Us Registration		Use Agreement THREDDS FTP		Algorithm Description Data Flow Diagram Maturity Matrix

 Center for Hydrometeorology and Remote Sensing, University of California, Irvine

PERSIANN-CDR Algorithm

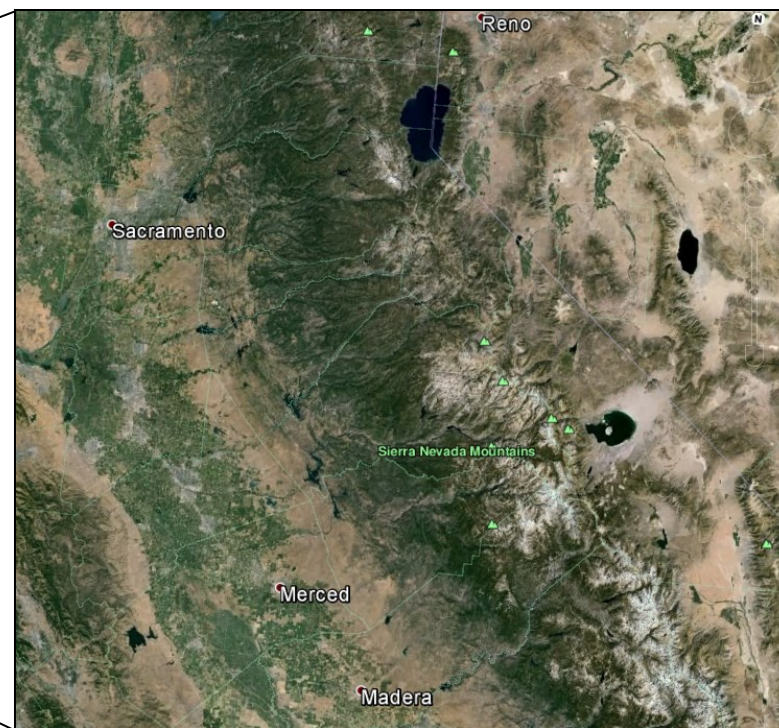




Sierra-Nevada Mountain Region

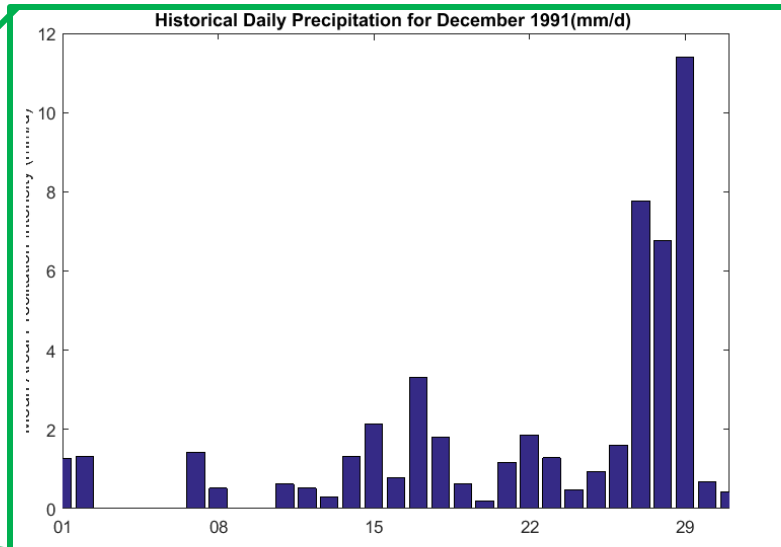
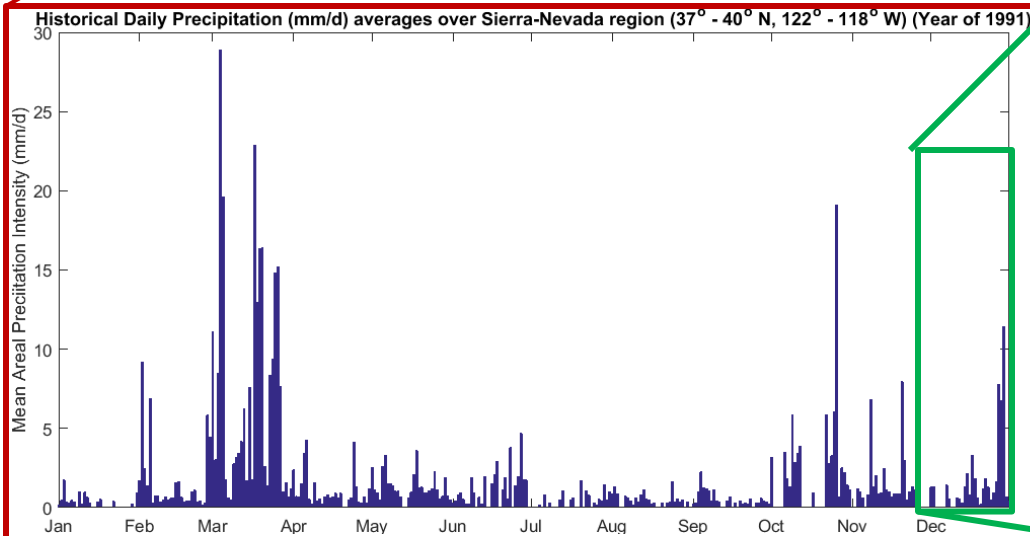
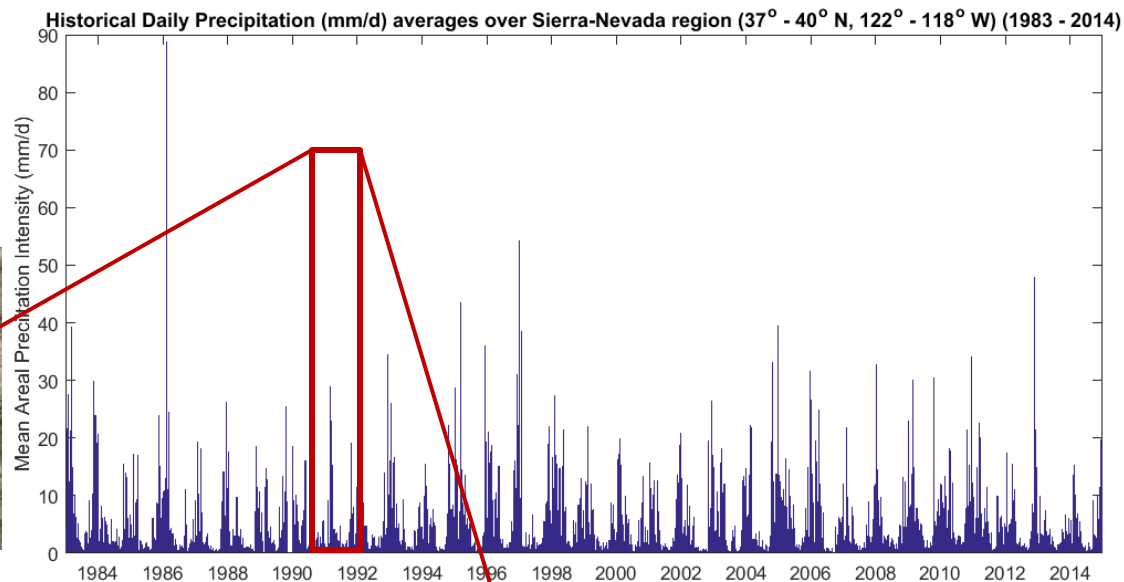
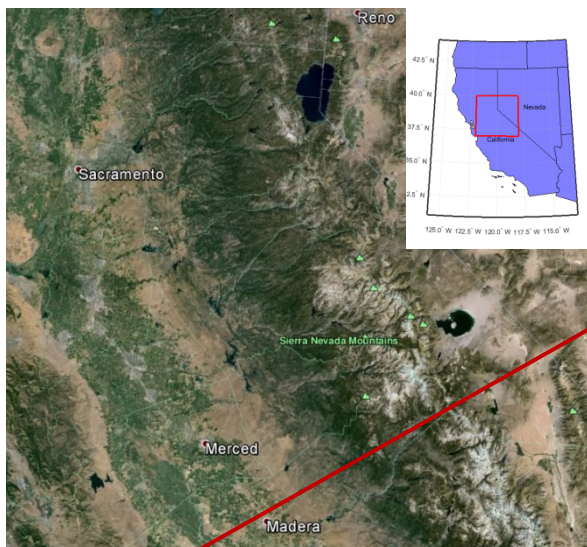
Area: 63,100 square kilometers (24,370 sq mi)

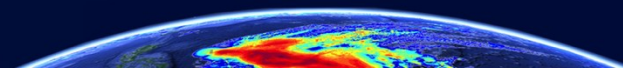
Length: 400 mile, Width: 64 mile.



Source: Google Earth

Sierra-Nevada Mountain (California and Nevada)





DEMO

CHRS CONNECT Database



PERSIANN - CONNECTed precipitation objECT (CONNECT) Dataset

Location

North

60

West

0



East

360

-60

South

Time

Please define the start and end period (YYYY-MM-DD HH:MM:SS):

Start Date:

End Date:

Intensity

Please set minimum and maximum precipitation intensity criteria (mm/hr):

Min Intensity

1

Max Intensity

200

Download Options

Download Options:

☒ Download raw object data

☒ Download statistics data

Submit

CHRS CONNECT Interface

The screenshot displays the CHRS CONNECT web interface, a platform for researching extreme precipitation events. The interface is divided into several functional areas, each highlighted with a red line and a label:

- Navigation Bar:** Located at the top left, it includes links for Home, Info, Tutorial, and About Us.
- Dataset Selection:** A dropdown menu labeled "Select Dataset" currently shows "PERSIANN-CONNECT".
- Search Method:** A section with two radio buttons: "Event Name/ID:" and "Event Features:". The "Event Name/ID:" option is selected, with a text input field for "Name/#".
- Spatial Selection:** A dropdown menu for "Event Features:" is set to "California". Below it, a "Coordinate" section has input fields for "32.500" and "42.000", and "235.000" and "246.000".
- Time Period:** A "Date" section with "Start Date" and "End Date" input fields.
- Add Features:** A button labeled "Add Features" with a plus icon.
- Base maps:** A central map area showing a satellite view of the United States. A red rectangle highlights the state of California. The map is sourced from Google and includes a copyright notice: "Map data ©2015 Google, INEGI Imagery ©2015 TerraMetrics".
- Visualization Tools:** A panel on the right side of the map. It includes a "Satellite" button, a "Speed" slider set to "Medium", and two toggle switches for "Tracking" and "Rain Total", both currently set to "OFF".
- List of Events Found:** A section labeled "Results" at the bottom of the visualization panel, which is currently empty.
- Download Results:** A "Download" button located at the bottom right of the interface.

The interface also features a header with the CHRS logo and the text "CHRS CONNECT A Global Extreme Precipitation Event Database" and "Inspiring research on climate and water resources". At the bottom, there is a section for "OUR SPONSORS" with logos for various organizations including NASA, NOAA, and the U.S. Department of the Interior.

Search Extreme Precipitation Events

Extreme precipitation events can be searched using event IDs or features. Event IDs are the unique numbers indicating each event in the database.

Steps to search events using event features:

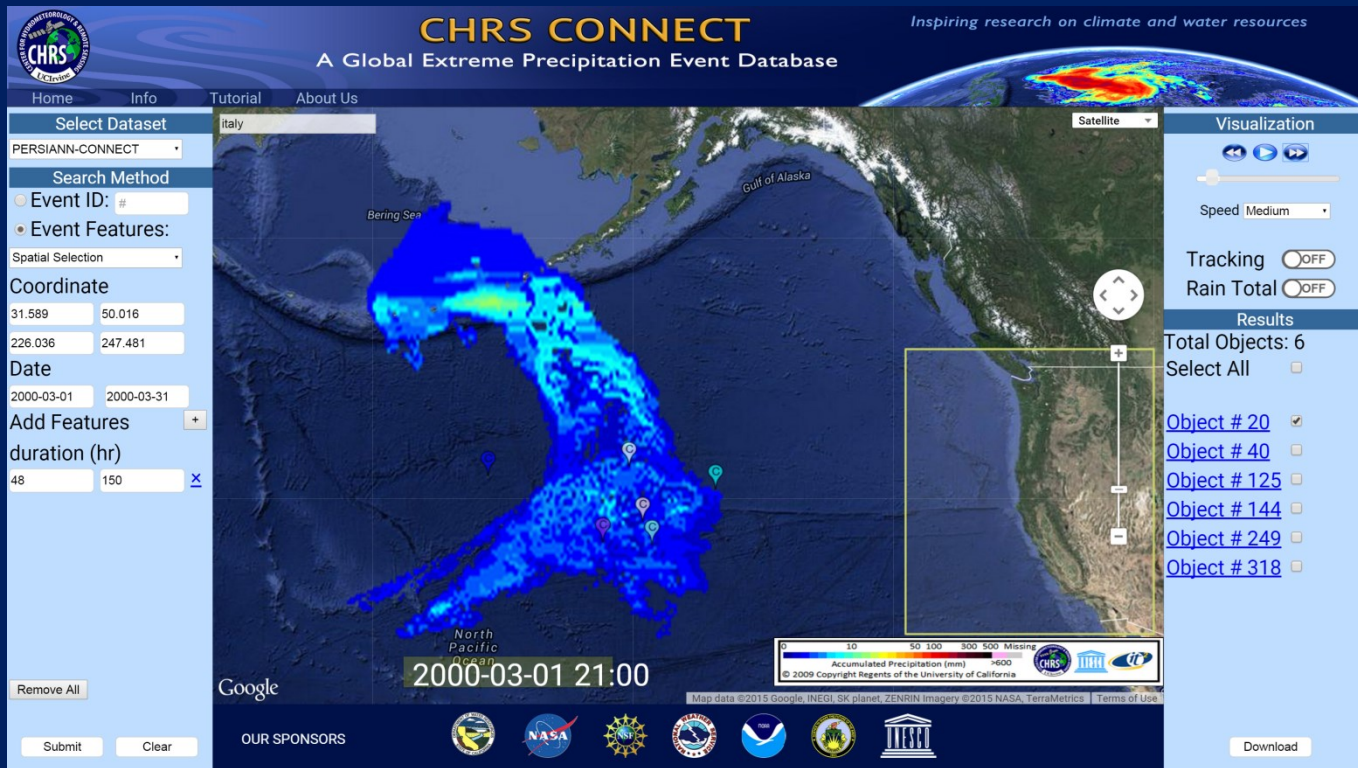
- Select a dataset (PERSIANN-CONNECT or PERSIANN-CDR-CONNECT)
- Select a region by using Spatial Selection → Select One Region/Start-End Region → Draw a region (if One Region selected) or 2 regions (if Start-End Region selected).
- Select Start and End dates
- Add event features for searching (optional)
- Submit
- Extreme precipitation events will appear as markers on the map and on the result tab

Interactive Functionalities for Events



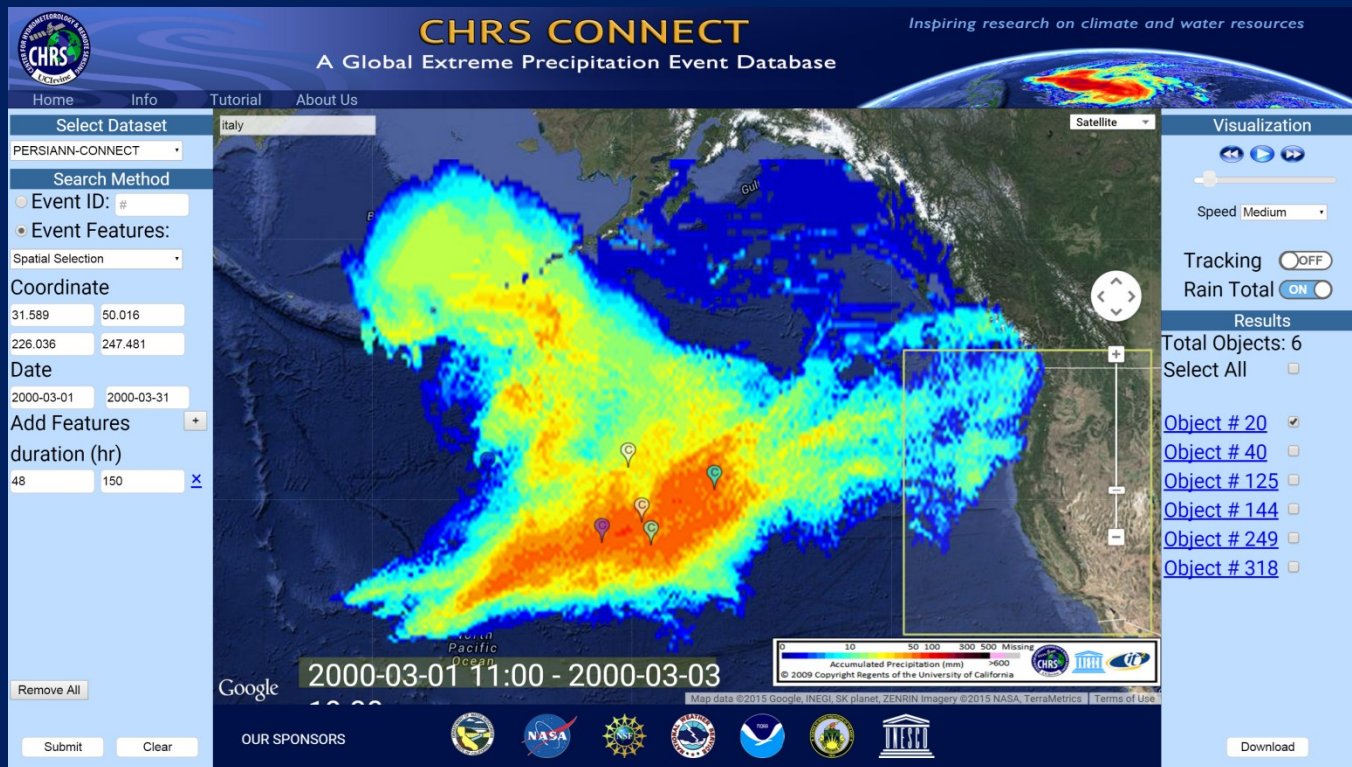
- Select an event by clicking the checkbox next to the object
- Users can show either animation, tracking, or rain total of an event
- Hover over an event marker and the same event on the result tab will be highlighted, vice-versa

Animation



- Select an event to animate (only 1 event can be animated at a time)
- Click on the Play button to animate the event
- Event information and a legend will appear while the event is animating
- Change speed of an event animation by selecting a speed mode (slow, medium, fast)

Rain Total



- Select an event to show rain total (only 1 event can be shown at a time)
- Turn Rain Total button on to show the rain total
- Event rain total will appear on the map along with a legend

Tracking



- Select event(s) to show tracking (multiple event can be selected)
- Turn Tracking button on to show tracking of selected events
- Event tracks will be displayed on the map

Statistics



- Users can click on a marker to display statistic table of an event
- Users can also click on an event on the Result tab to display statistics
- Even statistics can be downloaded by selecting events and clicking on the Download button

Download

The screenshot displays the CHRS CONNECT website interface. A central map shows a satellite view of the Pacific Ocean. A 'Download' dialog box is overlaid on the map, containing a list of event IDs and timestamps, a text input field for an email address, and 'Submit' and 'Close' buttons. The website's left sidebar includes search filters for dataset, search method, event ID, event features, spatial selection, coordinate, date, and duration. The right sidebar shows visualization options like speed, tracking, and rain total, along with a results section listing objects and their download links. The top navigation bar includes links for Home, Info, Tutorial, and About Us.

CHRS CONNECT
A Global Extreme Precipitation Event Database

Home Info Tutorial About Us

Select Dataset
PERSIANN-CONNECT

Search Method
Event ID: #
Event Features:
Spatial Selection
Coordinate
Date
Add Features
duration (hr)

Remove All
Submit Clear

Download

☒	249,2000-03-22 15:00:00,2000-03-25 04:00:00,16463.7
☒	318,2000-03-27 20:00:00,2000-03-31 09:00:00,8339.78

To receive a link to download your data, please enter your email in the box below and click the submit button.

Email address:

Visualization
Speed Medium
Tracking OFF
Rain Total OFF
Results
Total Objects: 6
Select All ☒
[Object # 20](#) ☒
[Object # 40](#) ☒
[Object # 125](#) ☒
[Object # 144](#) ☒
[Object # 249](#) ☒
[Object # 318](#) ☒

OUR SPONSORS

- Download dialog box will appear after clicking on Download button
- Type in an email address and click Submit button to receive event statistics
- Users can just click on Submit button without an email address to download event statistics straight to the local computer

Search Events by Names



Search Location

The screenshot displays the CHRS CONNECT website, a Global Extreme Precipitation Event Database. The interface includes a navigation bar with links to Home, Info, Tutorial, and About Us. A search bar at the top left contains the text "Italy", which is circled in red. Below the search bar, there are sections for "Select Dataset" (showing "PERSIANN-CONNECT"), "Search Method" (with options for Event ID and Event Features), "Coordinate" (with input fields for Start Lat, End Lat, Start Lon, and End Lon), "Date" (with input fields for Start Date and End Date), and "Add Features" (with a duration in hours). A "Remove All" button is located below these sections. The main map area shows a satellite view of Europe and North Africa, with a red circle highlighting the location of Italy. The map includes labels for various countries and bodies of water. On the right side, there is a "Visualization" panel with controls for Speed (Medium), Tracking (OFF), and Rain Total (OFF). A "Results" section is also visible. At the bottom, there is a "Download" button and a section for "OUR SPONSORS" featuring logos for NASA, NOAA, and other organizations.

- Type in a location
- The map will center to that location

UCI PERSIANN-CONNECT on Studying the Atmospheric River Events

**WSWC/CDWR Workshop on Sub-Seasonal and Seasonal
Precipitation Forecasting**

May 28th, 2015

Soroosh Sorooshian, Phu Nguyen, Hao Liu

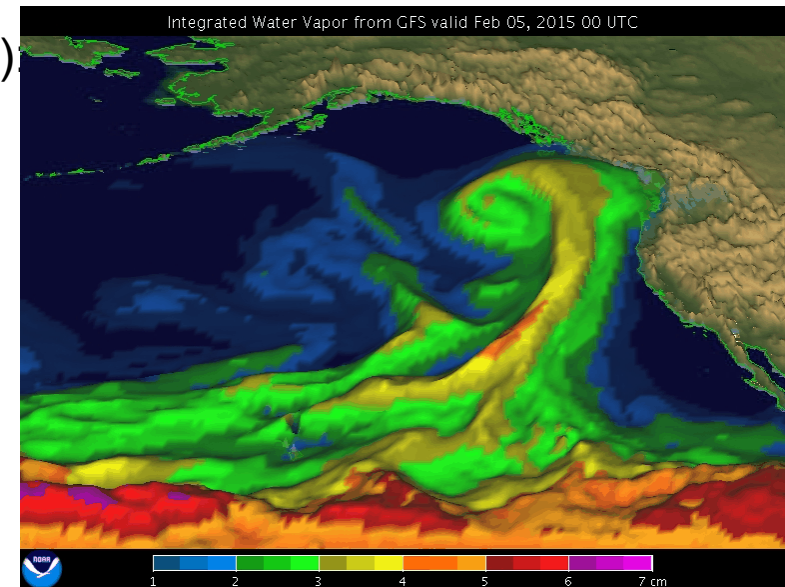
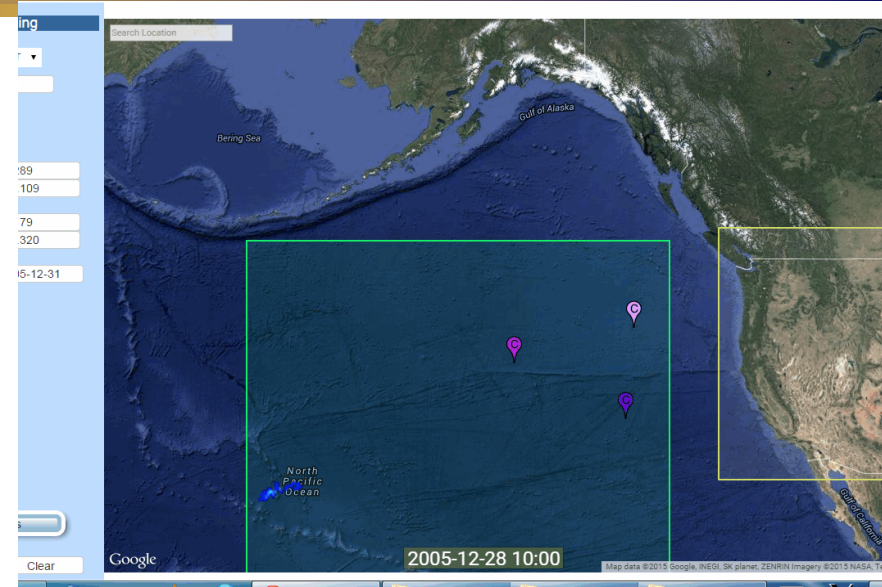
**Department of Civil and Environmental Engineering
University of California, Irvine**



Center for Hydrometeorology and Remote Sensing, University of California, Irvine

Background: PERSIANN-CONNECT and Atmospheric Rivers

- PERSIANN-CONNECT's advantages:
 - High temporal-resolution
 - Object-oriented database
 - Track-based and regional search function
 - Unique event ID
- PERSIANN-CONNECT's functionalities:
 - Archive and retrieve the historic events
 - Visualization
 - Scientific research
- Atmospheric River (AR, Dettinger et al, 2011)
 - Water vapor flux (using polar-orbit satellite)
 - Water vapor band that is above a threshold
 - 1000 km wide, 2000 km long
 - Contribute 30 ~50% of California's precipitation

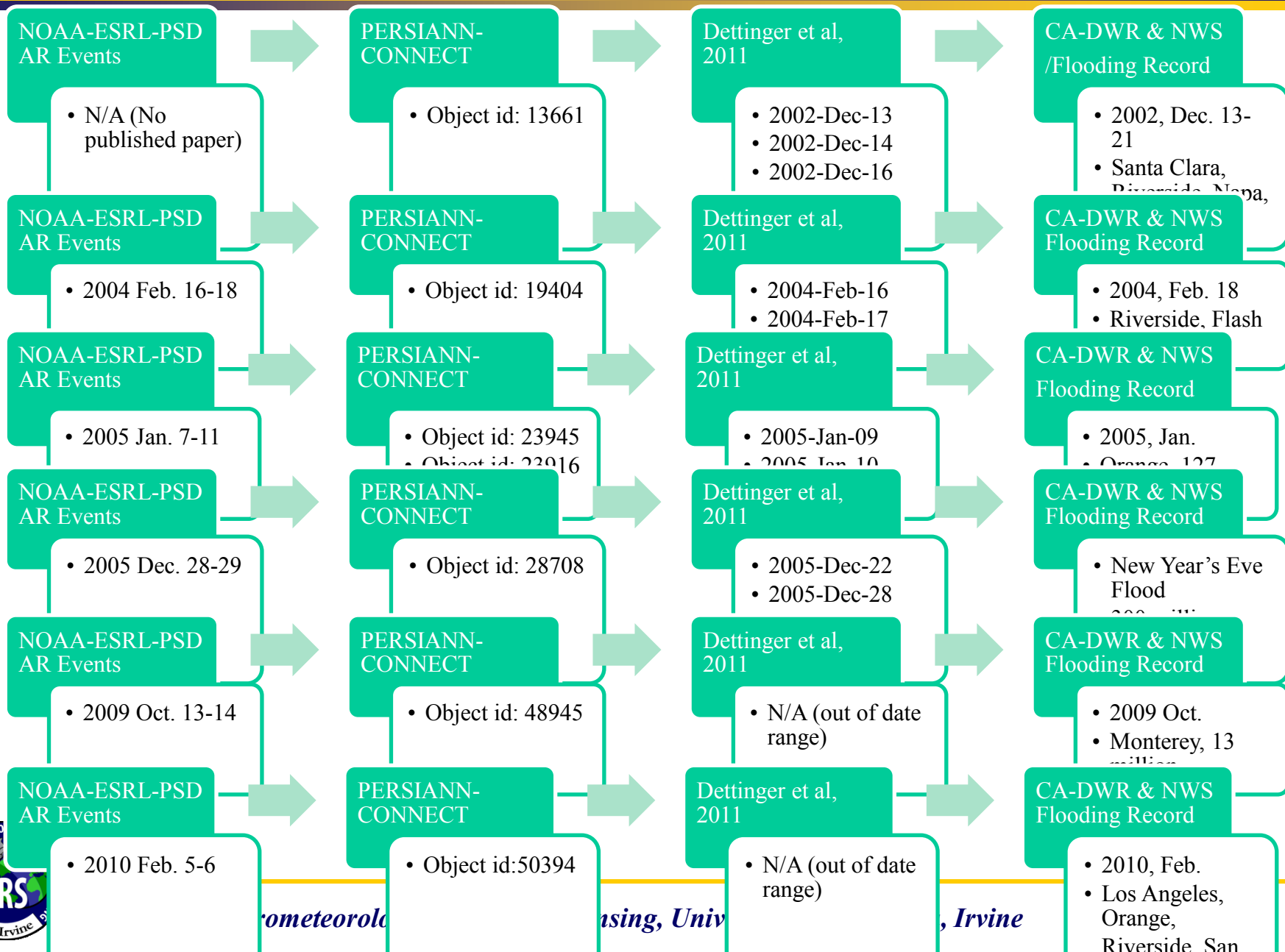


Building a Complete AR Database

- AR event database: PERSIANN-CONNECT and other available resources
- UCI PERSIANN-CONNECT:
 - Precipitation- based AR database (under-developing)
- UCSD-SCRIPPS (Dettinger et al. 2011):
 - SSM/I-based AR events dates
 - Flux of integrated water vapor flux (1000km wide, 2000 km long,)
 - 162 **days** in CA (1998-2008)
 - RS daily-average water vapor flux
- NOAA ESRL PSD (<http://www.esrl.noaa.gov/psd/atmrivers/events/>):
 - Research publication –based AR database
 - 8 AR **events** in CA (1986-2010)
- CA-DWR & U.S. NWS historical flooding events
 - For cross-reference purposes
 - 1193 flooding **records** in CA (1806-2013)



AR events retrieved from the PERSIANN-CONNECT



AR events visualization using PERSIANN-CONNECT: 2004 Feb.

NOAA-ESRL-
PSD AR Events

- 2004 Feb. 16-18

PERSIANN-
CONNECT

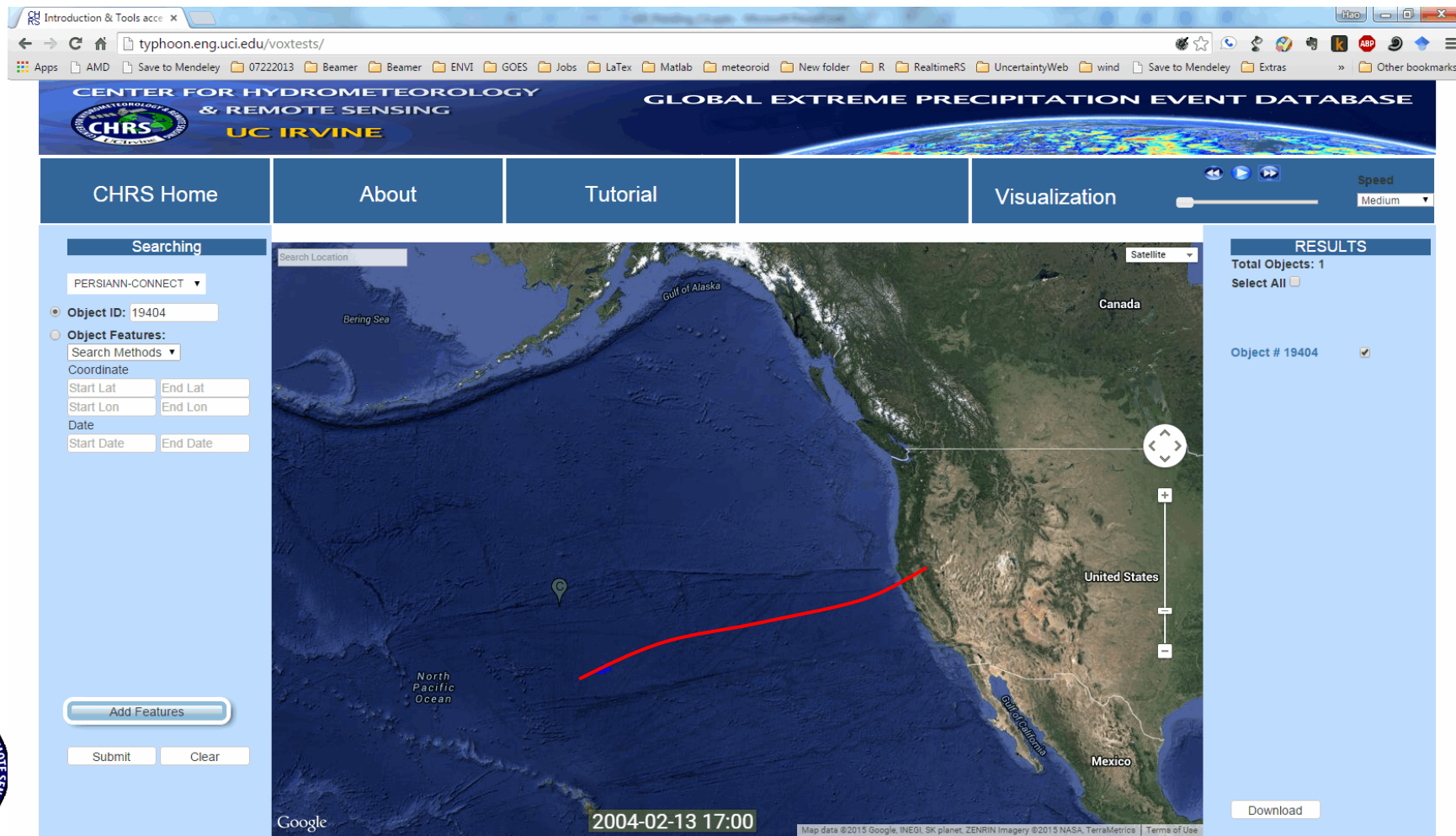
- Object id: 19404

Dettinger et al,
2011

- 2004-Feb-16
- 2004-Feb-17

CA-DWR
Flooding Record

- 2004, Feb. 18
- Riverside, Flash



AR event visualization using PESIANN-CONNECT: 2005 Dec.

NOAA-ESRL-
PSD AR Events

- 2005 Dec. 28-29

PERSIANN-
CONNECT

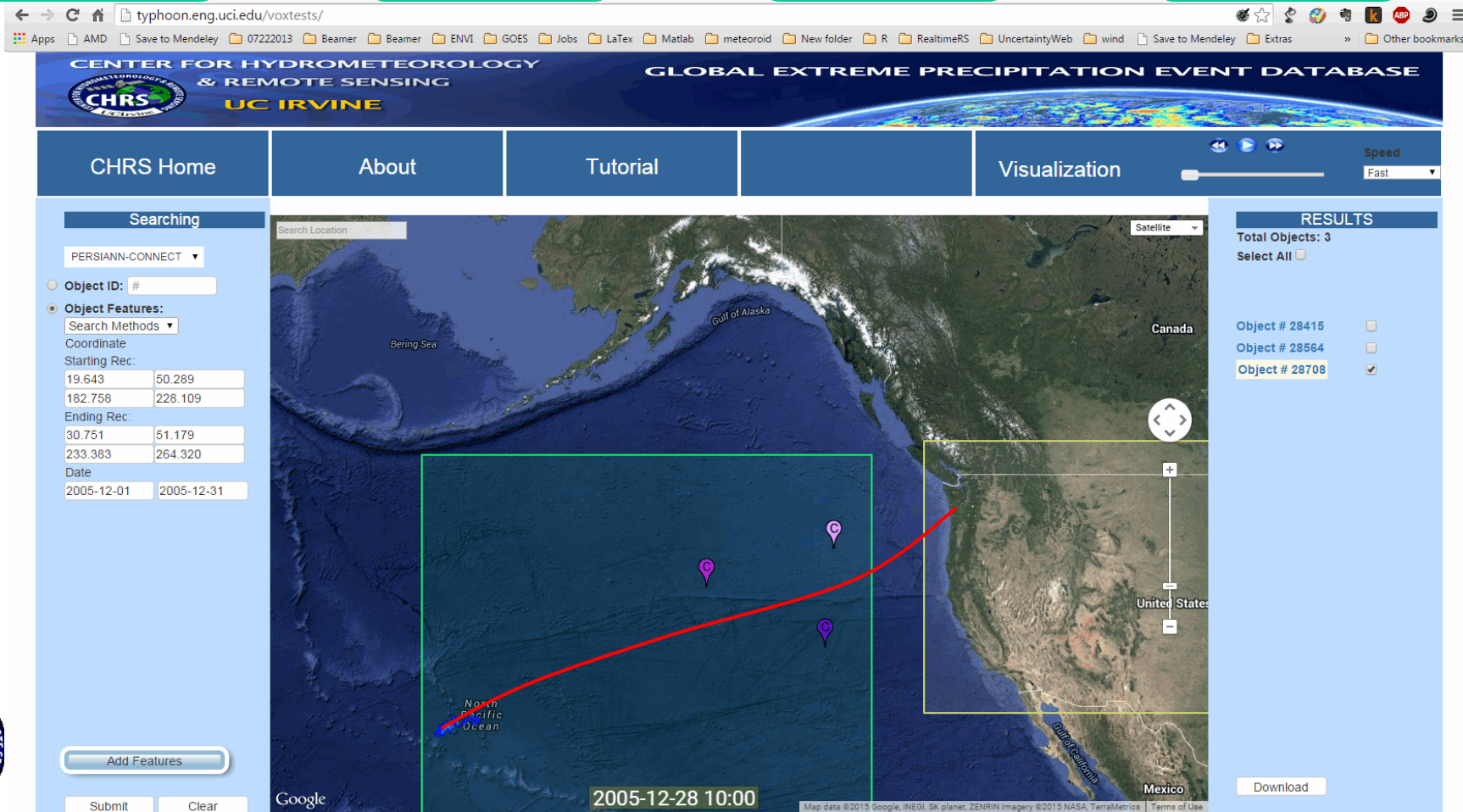
- Object id: 28708

Dettinger et al,
2011

- 2005-Dec-22
- 2005-Dec-28
- 2005-Dec-30
- 2005-Dec-31

CA-DWR
Flooding Record

- New Year's Eve Flood
- 300 million statewide

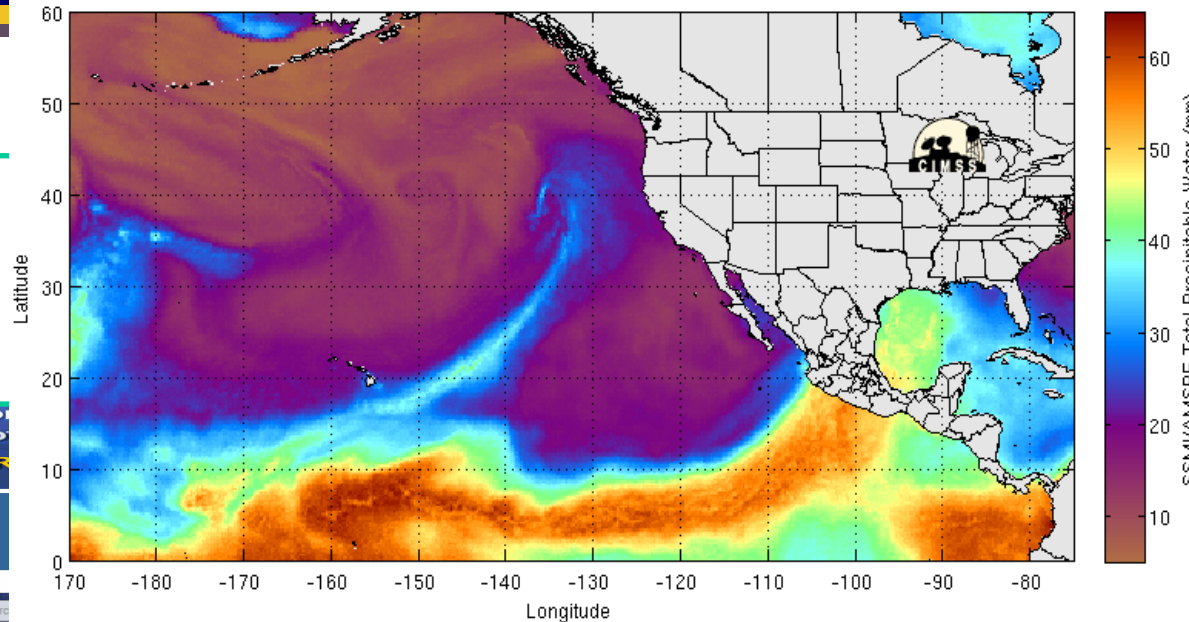


Understand the rainfall processes caused by the AR events

NOAA-ESRL-PSD AR Events

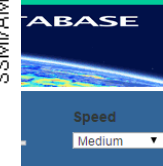
- 2010 Feb. 5-6

Morphed composite: 2010-02-04 07:00:00 UTC



AR Record

2010, Feb.
Los Angeles,
Orange,
Riverside, San
Diego

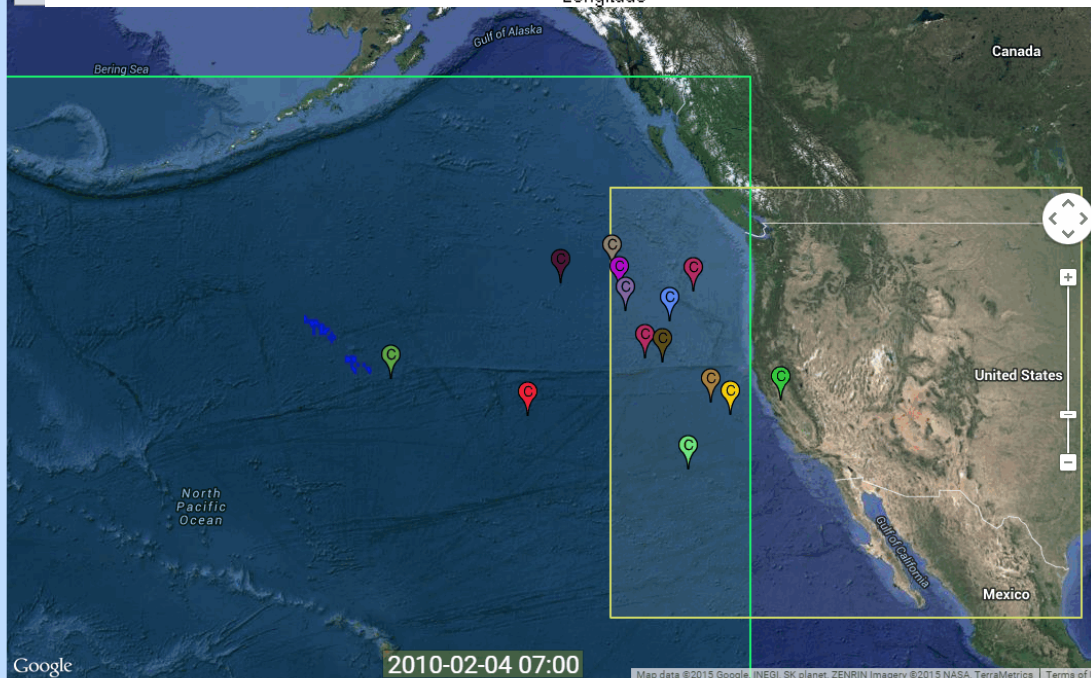


RESULTS

Select All ☐

- Object # 50131 ☐
- Object # 50162 ☐
- Object # 50205 ☐
- Object # 50232 ☐
- Object # 50239 ☐
- Object # 50250 ☐
- Object # 50344 ☐
- Object # 50370 ☐
- Object # 50394 ☒
- Object # 50397 ☐
- Object # 50423 ☐
- Object # 50478 ☐
- Object # 50494 ☐
- Object # 50531 ☐

Download



Map data ©2015 Google, INEGI, SK planet, ZENRIN Imagery ©2015 NASA, TerraMetrics | Terms of Use

Conclusions

- **PERSIANN-CONNECT records the flooding ARs at early stage**
 - High temporal resolution
 - Good tracking capability

Developing an AR-classification algorithms based on PERSIANN-CONNECT:

- **Useful attributes:**
 - Moving directions and moving speeds
 - Total rainfall amount



Thank you



Center for Hydrometeorology and Remote Sensing, University of California, Irvine

*Thank You for Your
Presence and Listening*

08/14/2009

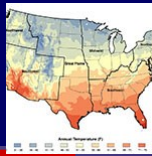
Somewhere in New Mexico, USA - Photo: J. Sorooshian

*Back up
slides*



Regional Climate Trends and Scenarios: The Southwest U.S.

USGCRP July 30, 2013



Precipitation

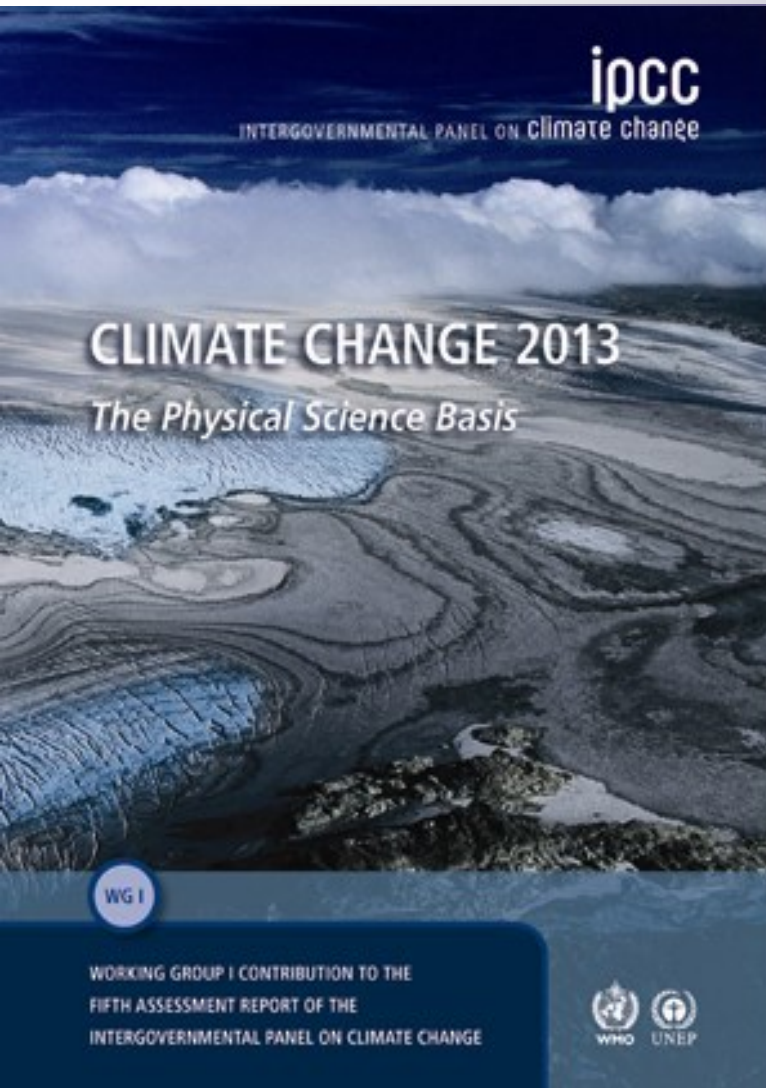
- *“Precipitation does not exhibit any obvious long-term trends for the Southwest U.S., except for Fall, which shows a slight upward trend. Trends are not statistically significant for any season.*
- *The region experienced its wettest conditions in the 1980s and 1990s (coinciding with a shift in Pacific climate in 1976, after which El Niño became much more frequent), but has dried in the last decade.*

Extremes

- *There is not a statistically significant trend in the occurrence of extreme precipitation events in the Southwest.”*



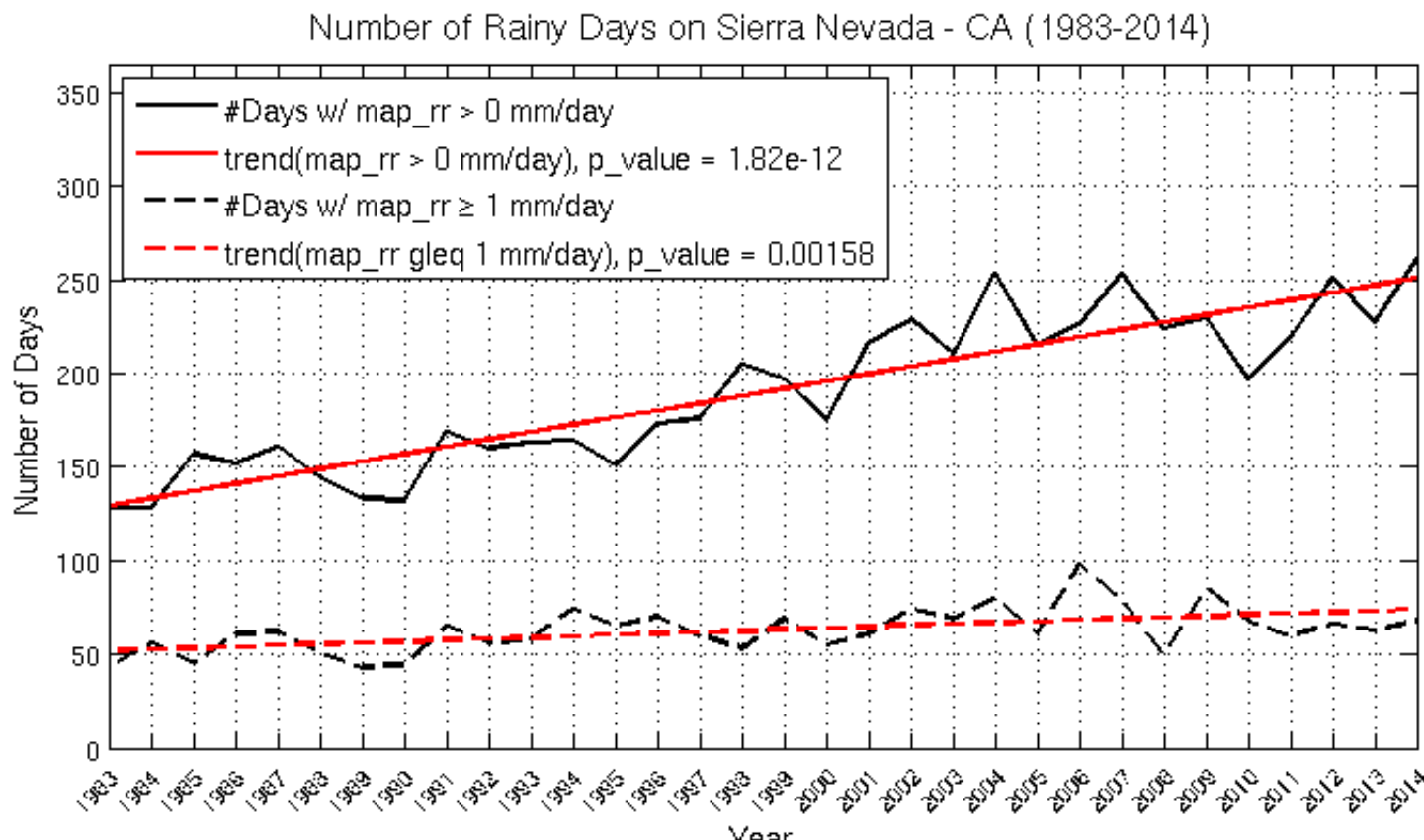
Recently Released IPCC Report (AR5) - Sept. 2013



- *“It is likely that since 1950 the number of heavy precipitation events over land has increased in more regions than it has decreased.”*
- *“There is medium confidence that human influence on climate has affected stream flow and evapotranspiration in limited regions of middle and high latitudes of the Northern Hemisphere.”*
- *“In summary, there continues to be a lack of evidence and thus low confidence regarding the sign of trend in the magnitude and/or frequency of floods on a global scale”*

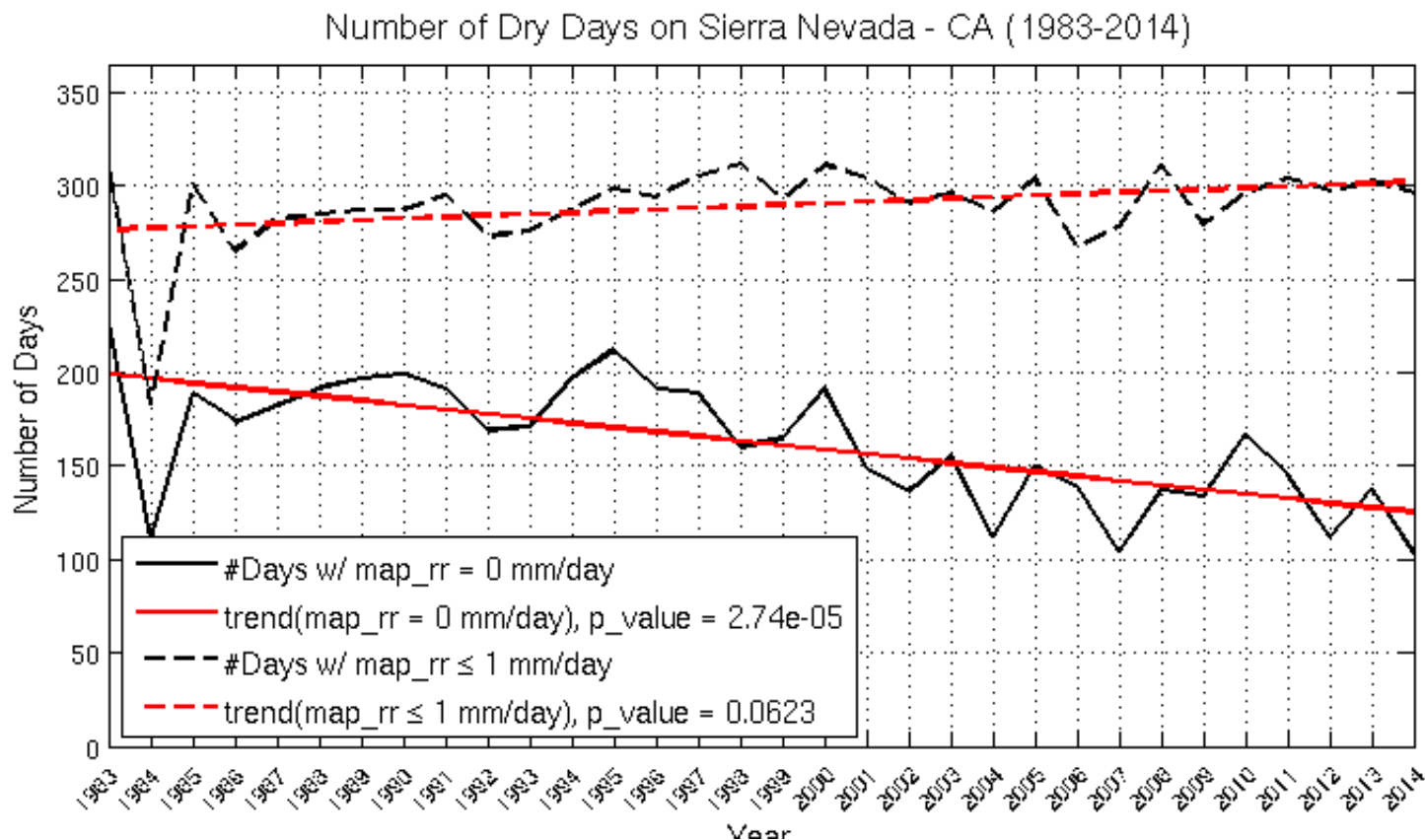


Trend in the number of Rainy days



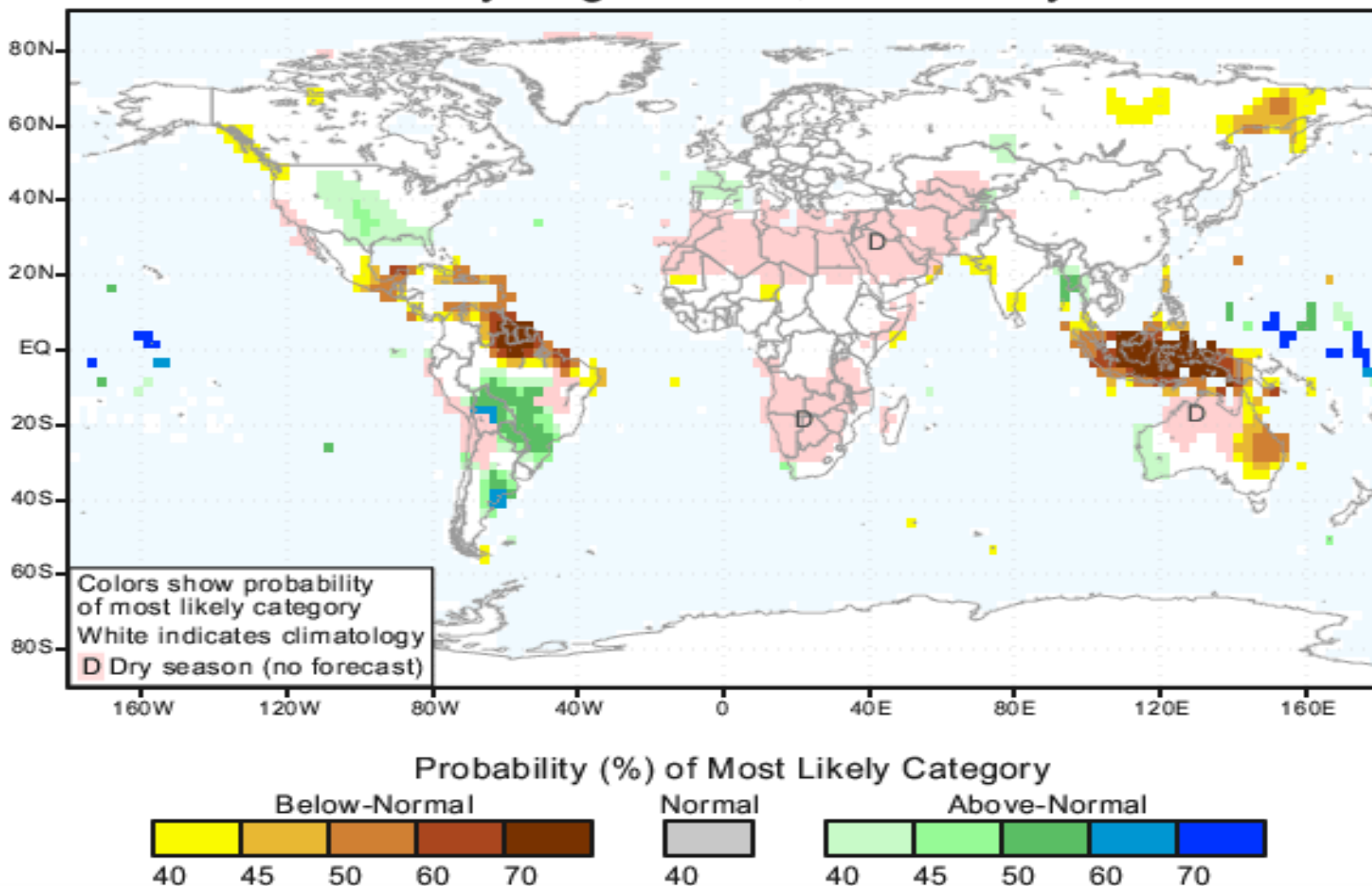
At a 5% significance level (95% CI), the **positive** trends in the number of rainy days are statistically significant.

Trend in the number of dry days



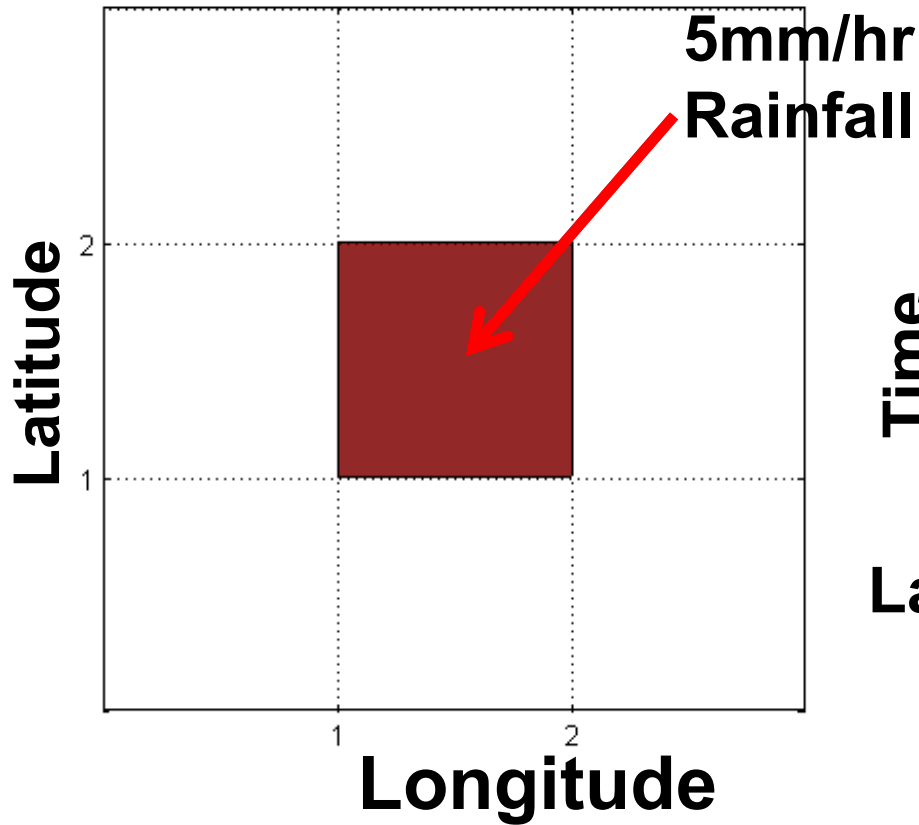
At a 5% significance level (95% CI), the **negative** trend in the number of dry days (mean areal precip. = 0 mm/day) is statistically significant.

IRI Multi-Model Probability Forecast for Precipitation for June-July-August 2015, Issued May 2015

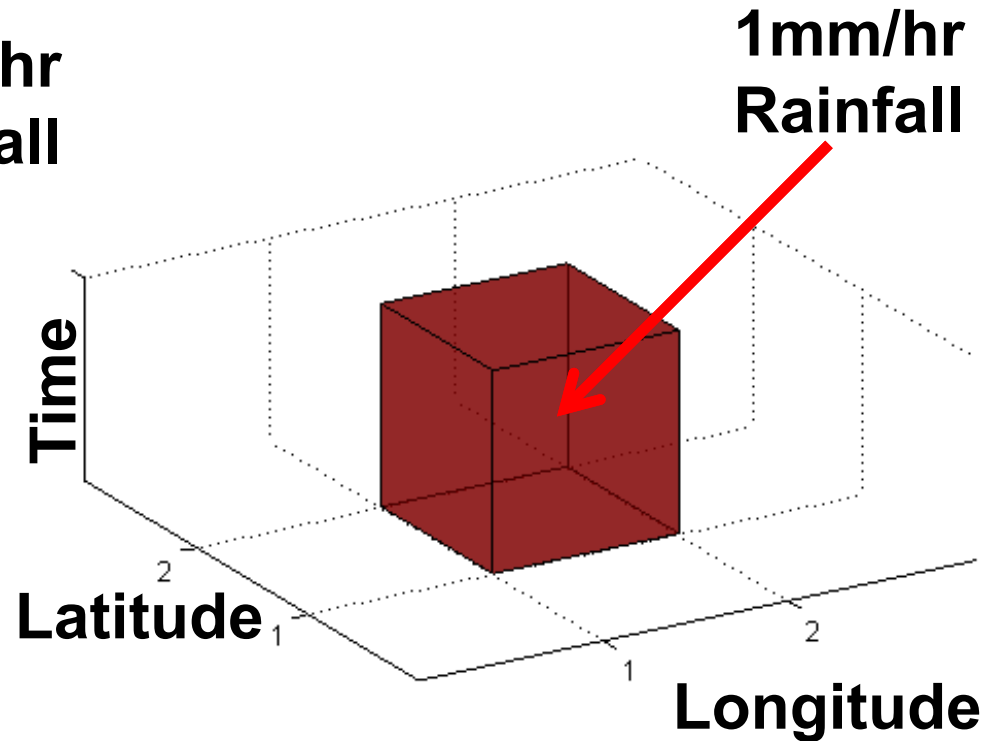


Object Based Approach: 4-D

Traditional

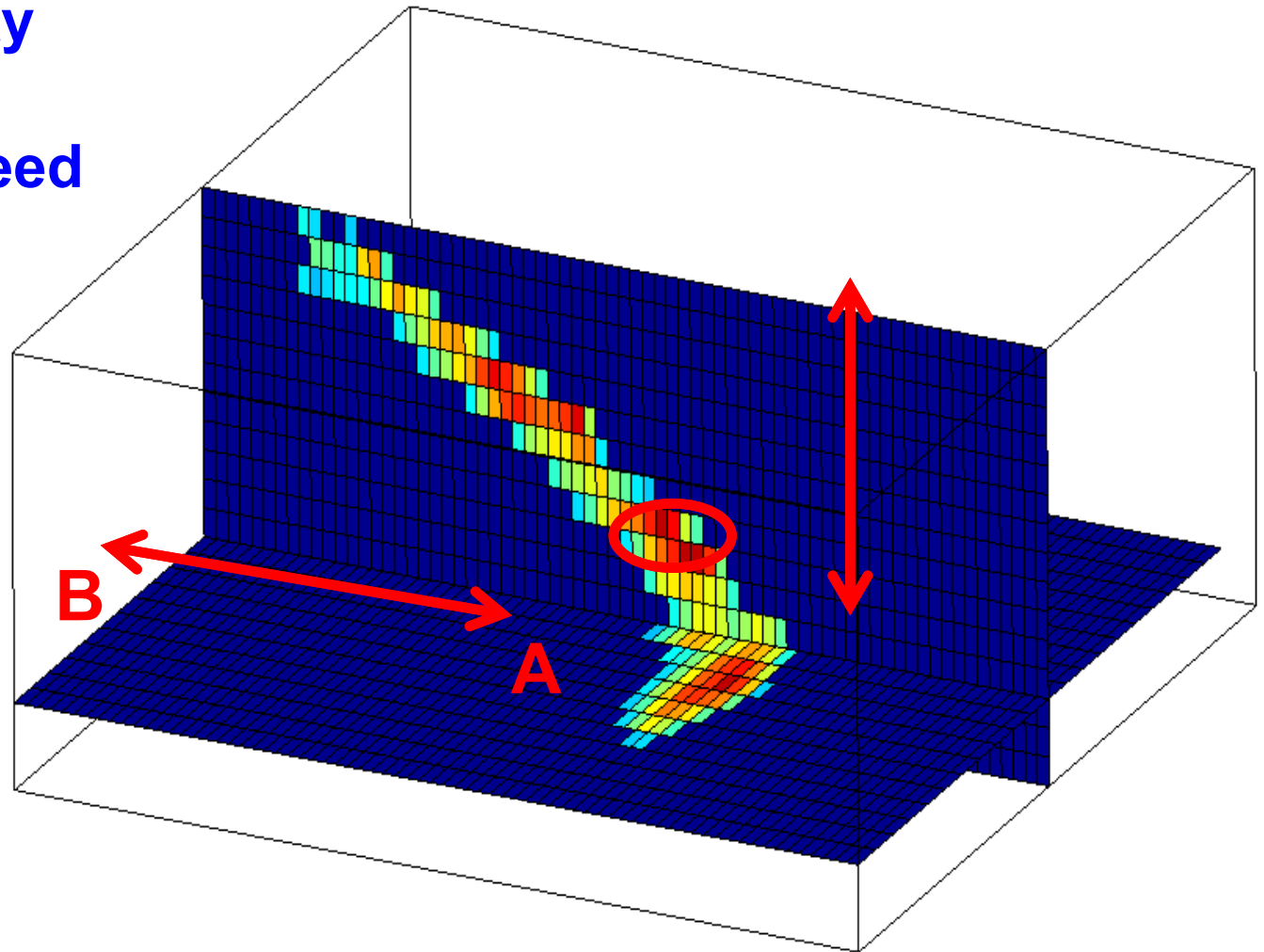


4 Dimensional Approach



4-D Objects Characteristics

- 1) Max Intensity
- 2) Duration
- 3) Average Speed



4-D Objects Characteristics: Nxd

- 1) Volume
- 2) Max Intensity
- 3) Average Intensity
- 4) Duration
- 5) Average Speed
- 6) Centroid Lat
- 7) Centroid Lon
- ...
- ...
- 58) NINO3+4,
- 59) NINO4
- 60) Start Centroid Latitude

N = # of events

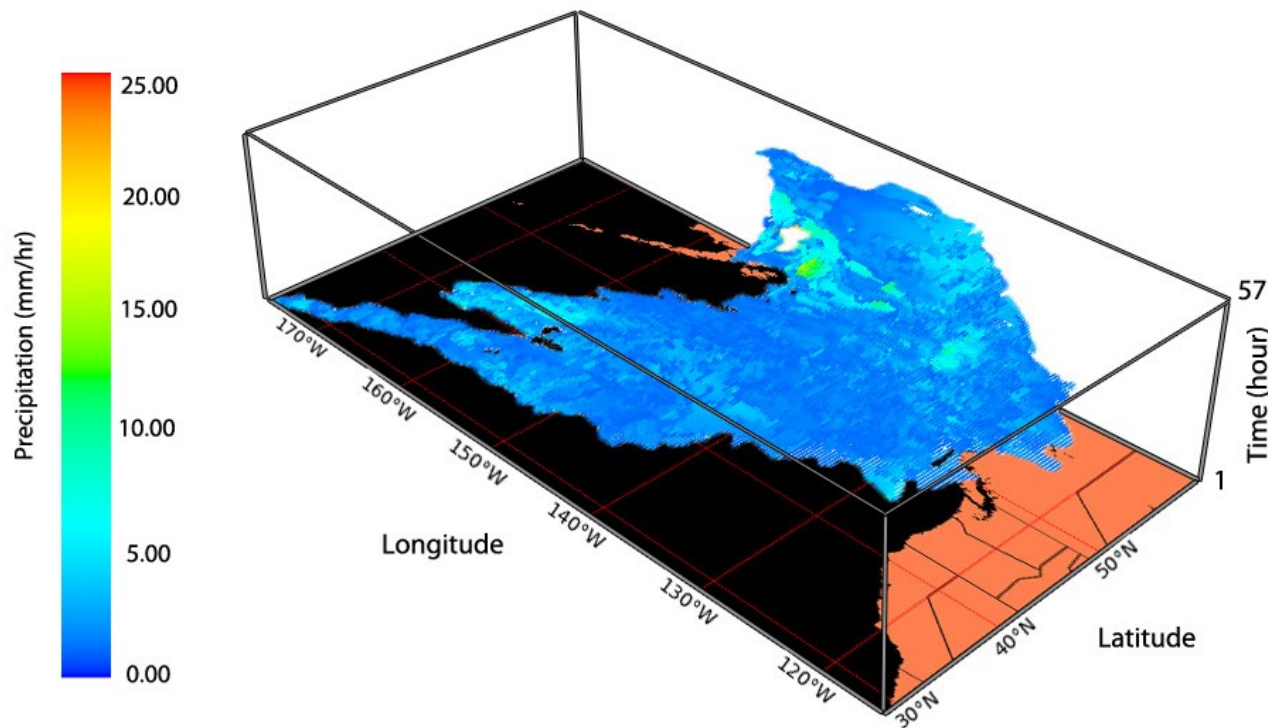
d = # of dimensions (60 in this case)

Nxd Matrix

$$\mathbf{X} = \begin{bmatrix} X_1^1 & X_2^1 & \cdots & X_d^1 \\ X_1^2 & X_2^2 & \cdots & X_d^2 \\ \vdots & & & \\ X_1^N & X_2^N & \cdots & X_d^N \end{bmatrix}$$

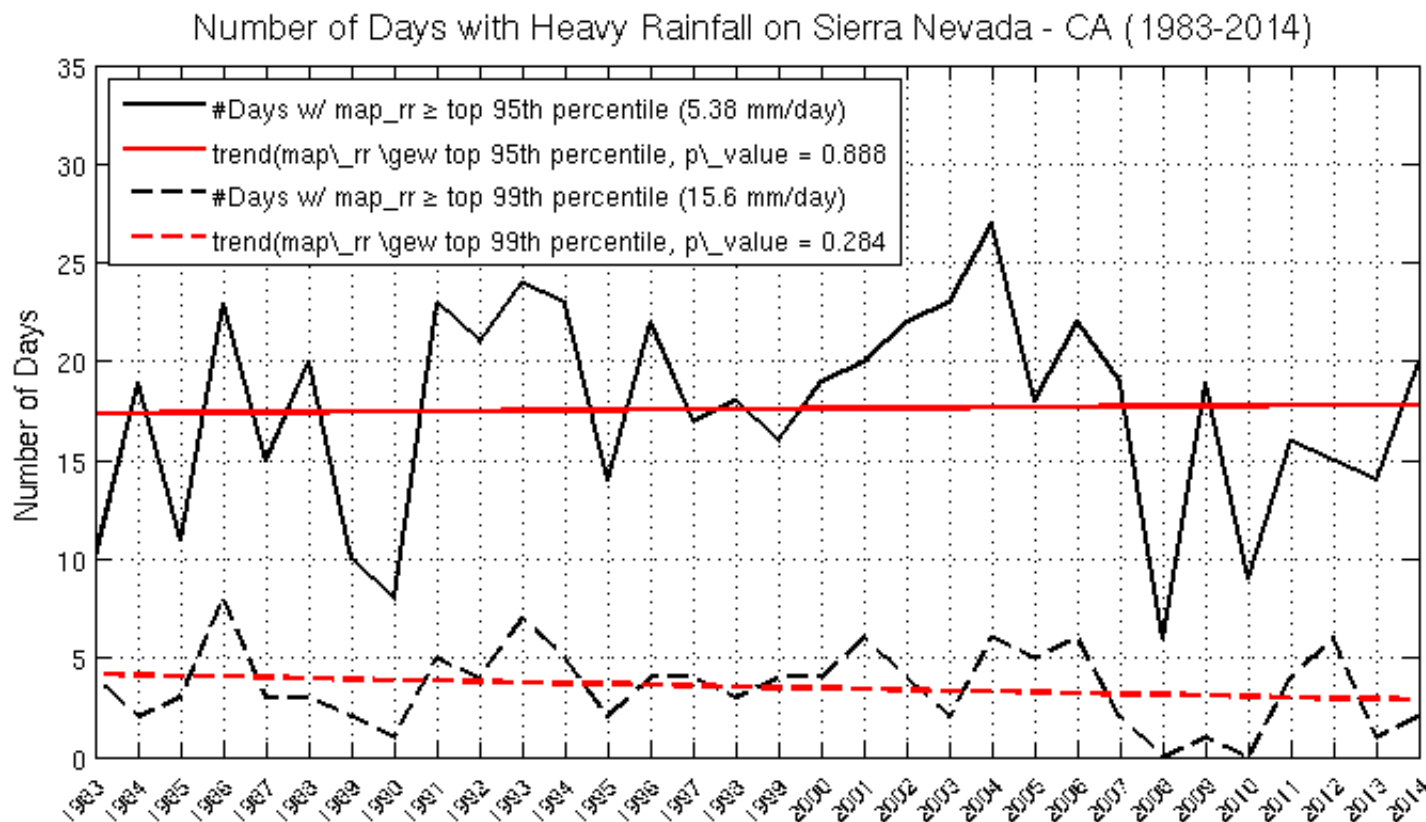
4-D Object: Atmospheric River Example

Atmospheric River: Dec 28th, 2005 - Dec 30, 2005



Sellars, S., P. Nguyen, W. Chu, X. Gao, K. Hsu, and S. Sorooshian (2013),
Computational Earth Science: Big Data Transformed Into Insight, EOS Trans. AGU, 94(32),277

Trend in the number of heavy rainy days



Though a reduction in extreme precipitation events is identified in the recent years (after 2007), at a 5% significance level (95% CI), none of the above trends is statistically significant.