Center for Western Weather and Water Extremes

SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Observing and Detecting ARs:

IVT Atmospheric Rivers Using "CONNected objECT (CONNECT)" Segmentation and Characterization Approach

August 11, 2016
International Atmospheric River Conference

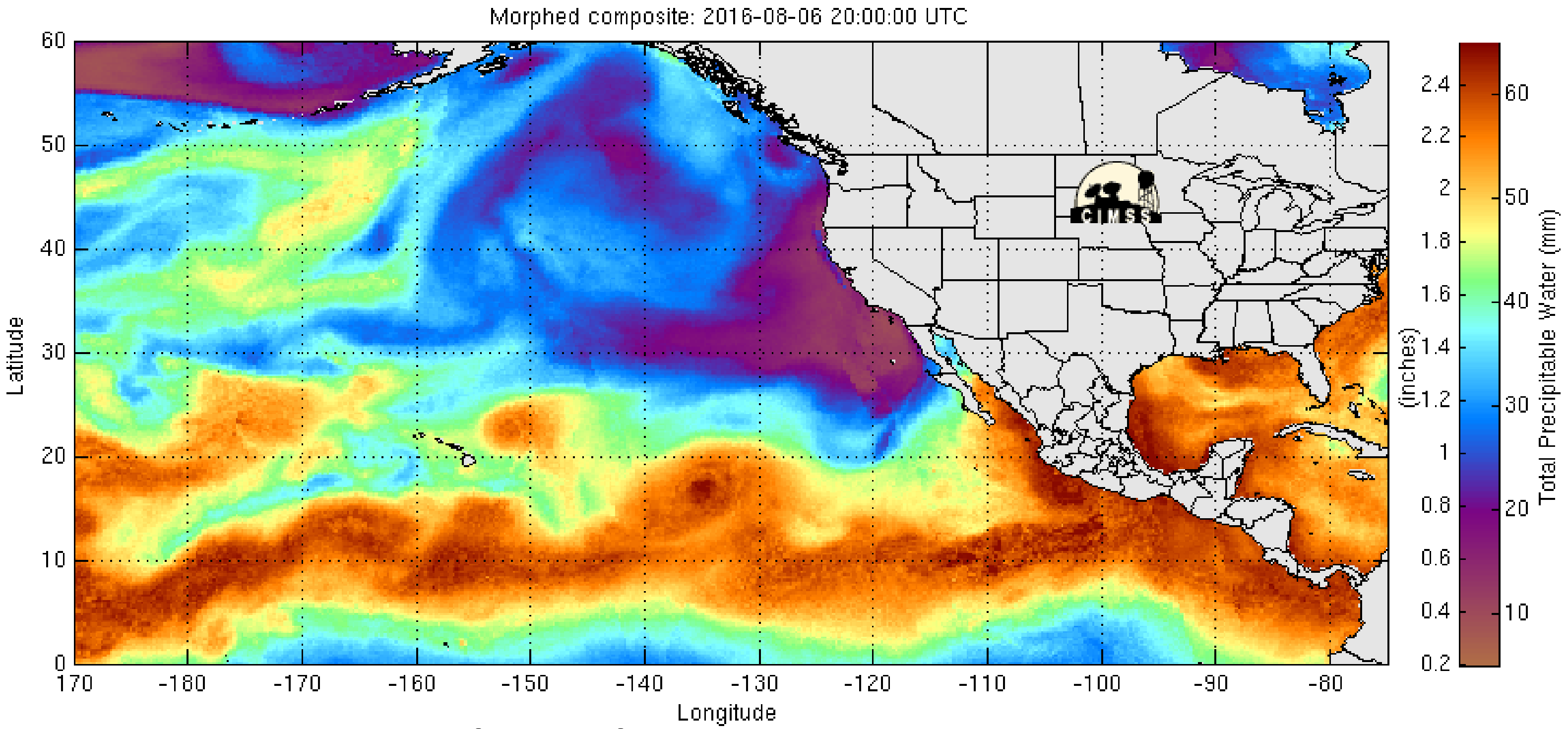
Scott L. Sellars, Phu Nguyen, Brian Kawzenuk, F. Martin Ralph and Soroosh Sorooshian

Outline

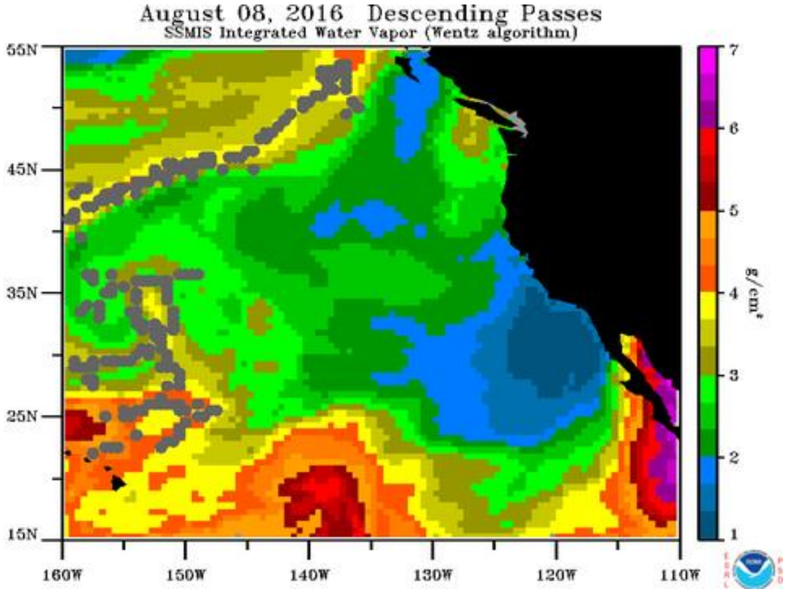
- Motivation
- Object-based approaches
- CONNECT object segmentation and characterization
  - Describe the approach
  - Applied to precipitation
  - Apply to Integrated Water Vapor Transports (IVT)
- “Connecting” to other catalogs and approaches

Motivation

- Effort to count large scale phenomena
- Wick et al., 2013



* CIMIS - **SSMI/SSMIS/AMSR2-derived Total Precipitable Water**

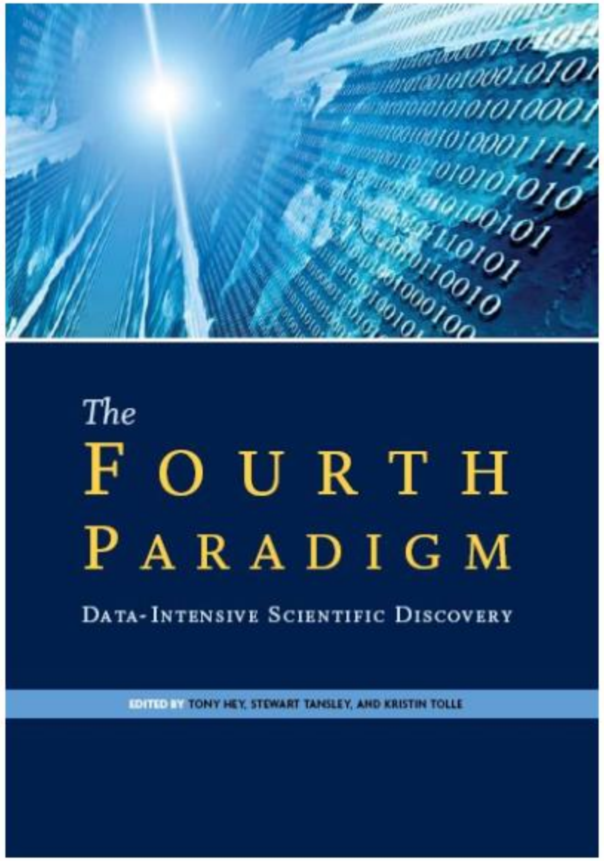


*ESRL –
Automated Atmospheric River Detection

CW3E

The Fourth Paradigm

- How can we learn from the vast amounts of earth and environmental science data…?
  - **The Fourth Paradigm**
    - **“Data-Intensive Scientific Discovery”**
- Bottom line: Rethink how we structure our data:
  - Where do ARs originate from?
  - What initiated them?
  - Which physical process matters most?
  - What modulates their frequency?
- Think of ARs as objects



***Hey et al. 2009**

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Object oriented data analysis

- Verification
  - Brown et al. 2004; Davis et al. 2006a,b; Mittermaier and Bullock 2013
- Pattern Detection
  - Camargo et al. 2007, 2008; Gaffney et al. 2007
- Prediction
  - Gray et al. 2004, Klotzboch and Gray 2004, Wang et al. 2009
- Blob Analysis and Tracking
  - Hodges et al. 1996, Kossin et al. 2012, Kossin and Emanuel, 2014

What is an “object”?

- “a thing that you can see and touch and that is not alive” – Merriam-Webster

Label: CAR

Describe it using “characteristics” or “features”

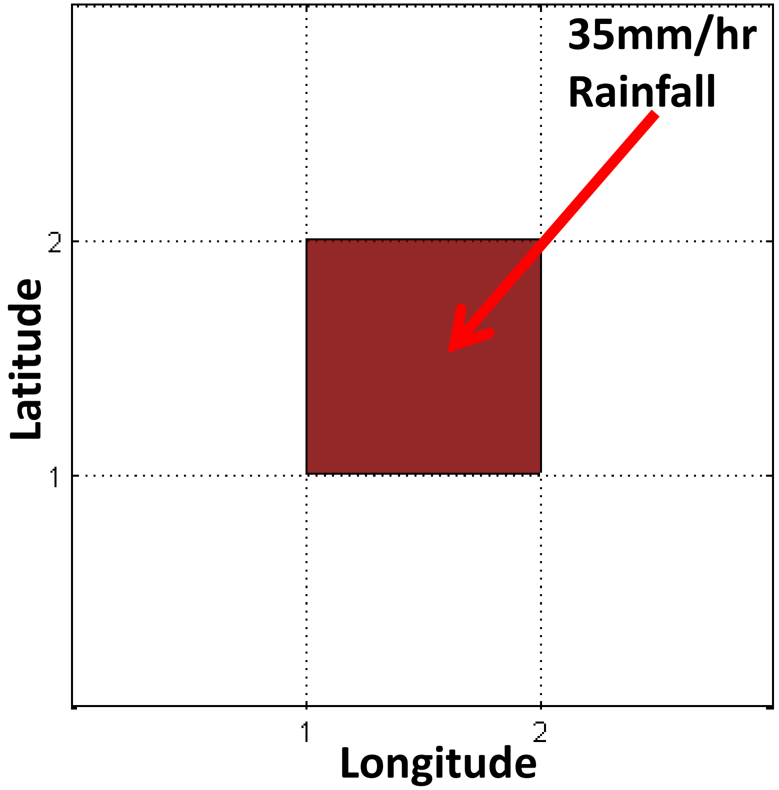
- Color
- Weight
- Type of engine
- Capacity
- Area
- MPG



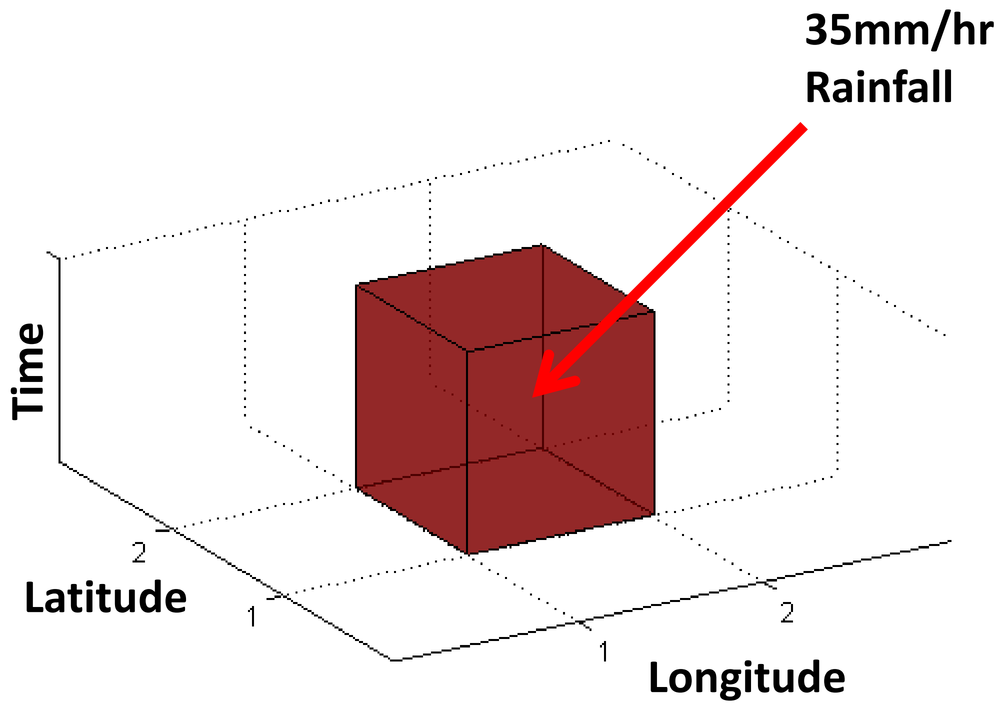


CONNected objECT (CONNECT): 4D approach

a) Traditional Approach (pixel)



b) 4-Dimensional Approach (voxel)



- 12 edges
- 6 faces

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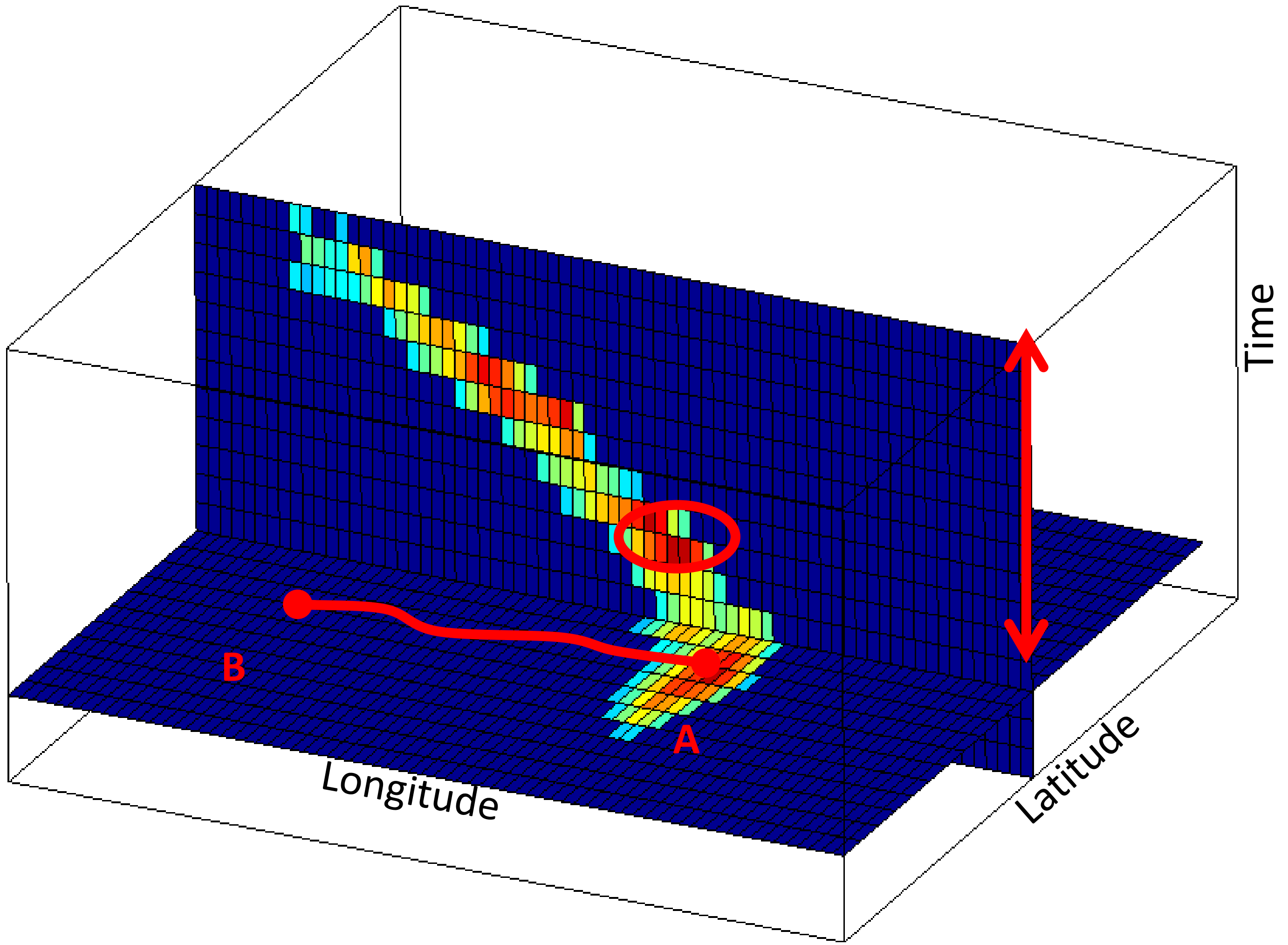
4D: “Synthetic” precipitation object

Set Criteria:

1) **1mm/hr**
2) **Must exist for 24hr**

Calculate Characteristics:

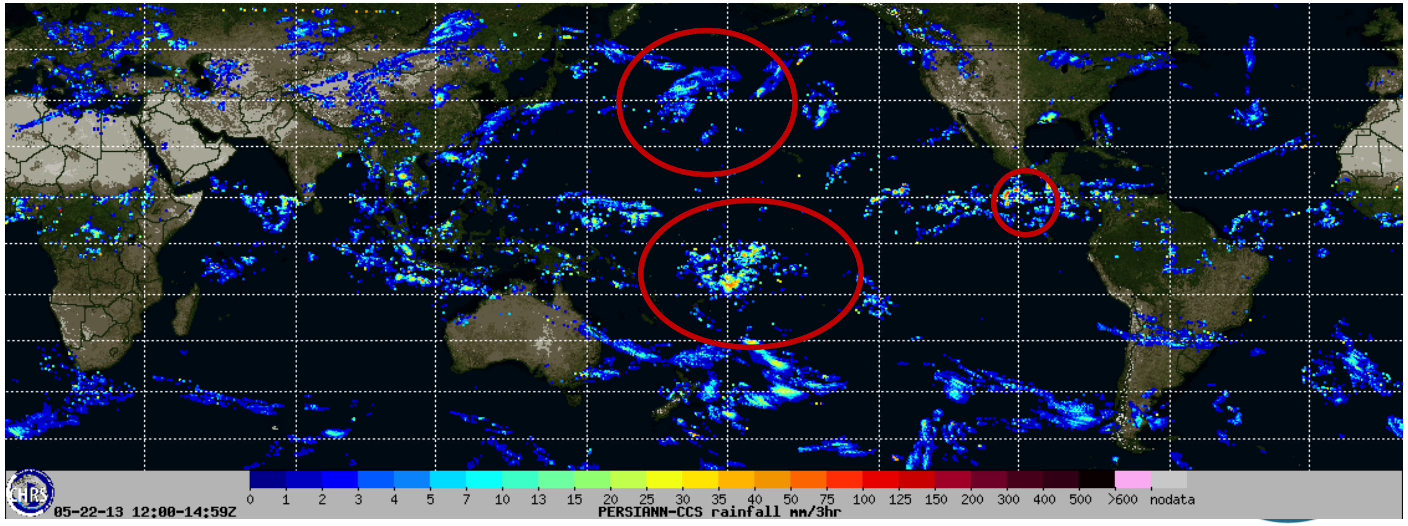
1) **Max Intensity**
2) **Duration**
3) **Track**
4) **Speed**
5) **Average Intensity**
6) **ENSO Phase**



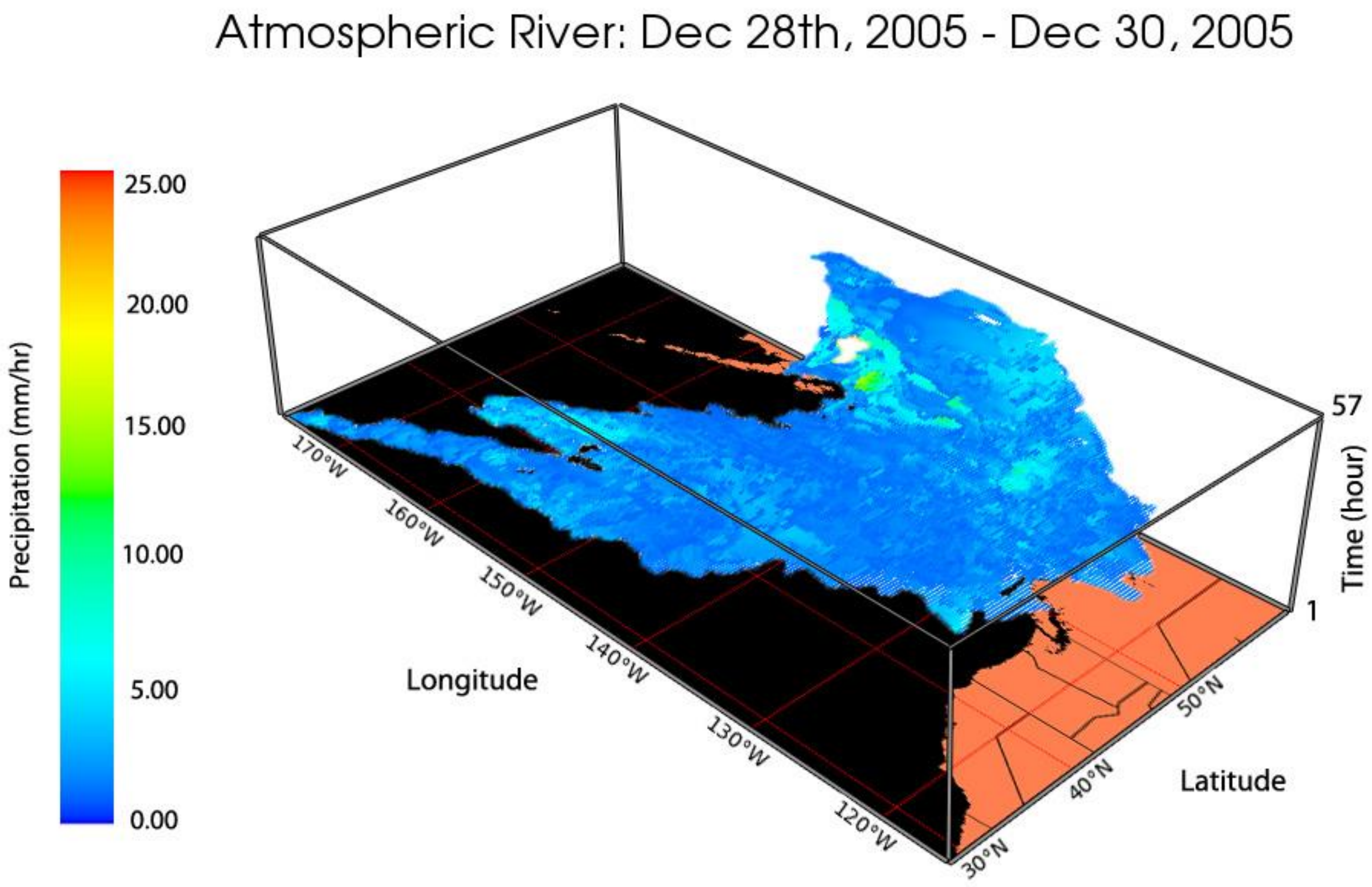
PERSIANN - CONNected precipitation objECT (CONNECT)

Team: Wei Chu, Scott Sellars, Phu Nguyen, Xiaogang Gao, Kuo-lin Hsu, and Soroosh Sorooshian

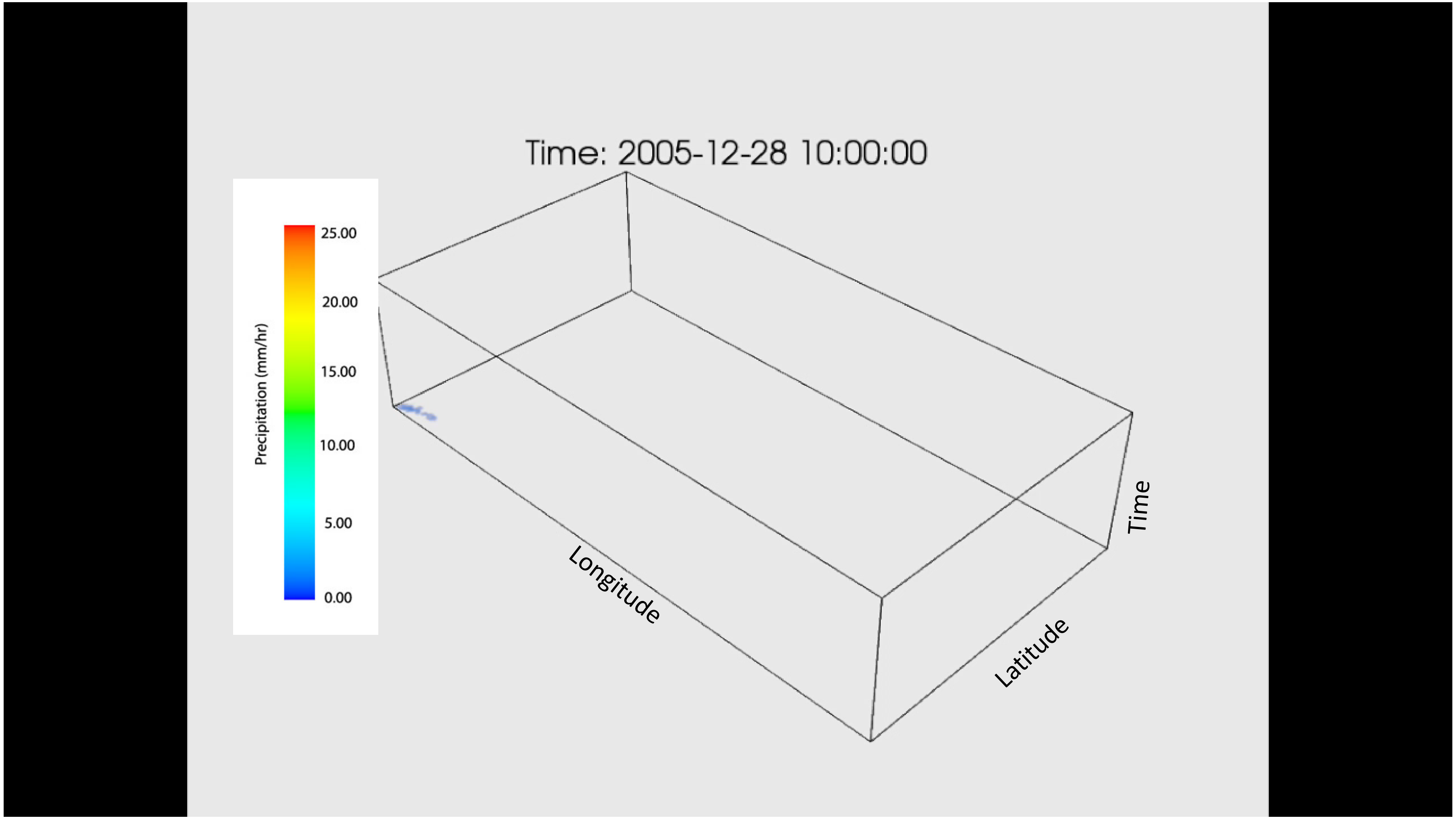
- Harnesses the capabilities of remote sensing information
- Near Global Precipitation Data (10+ Years)
- Hourly **Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN)** precipitation data (mm/hour) (Hsu et al. 1996)
- Parameters:
  - 0.25 degree (~25kmx25km)
  - 60^0 North - 60^0 South
  - 01 March 2000 – 01 January 2011
- Store in **PostgreSQL** database
- Sellars et al., 2013



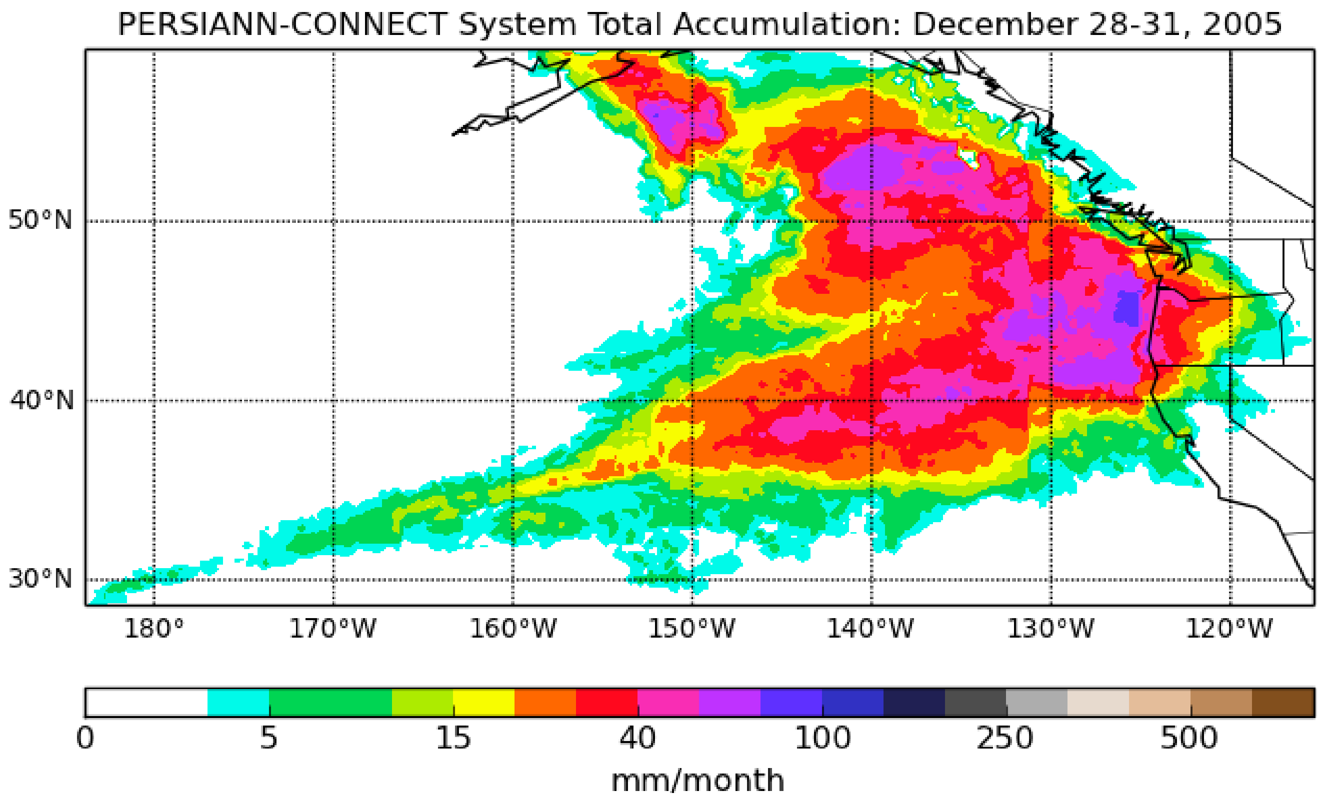
4-D Precipitation object example



4-D Precipitation object example



4-D Precipitation Object Precipitation Accumulation Map



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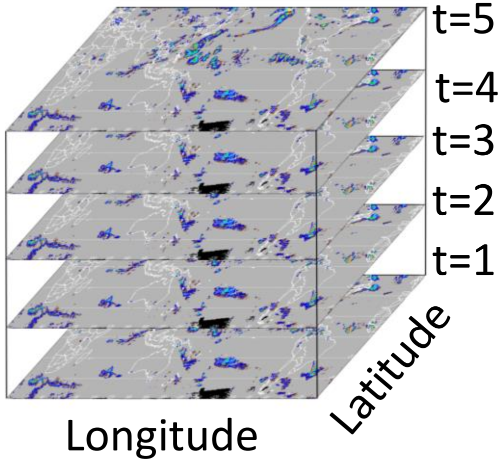
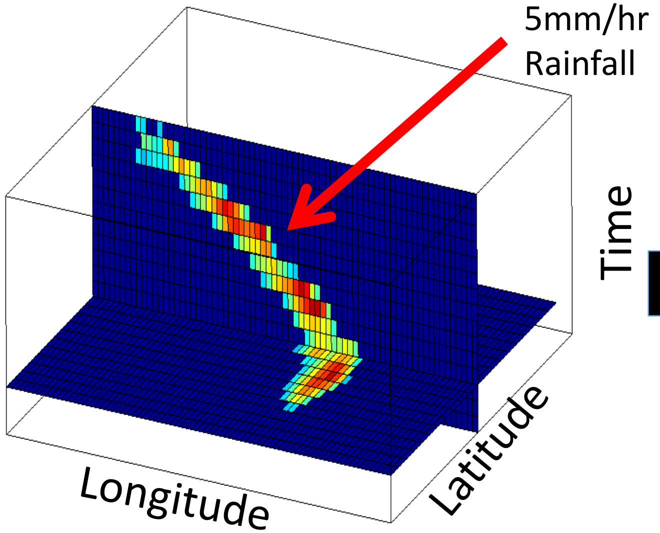
Recap: Object segmentation and storage

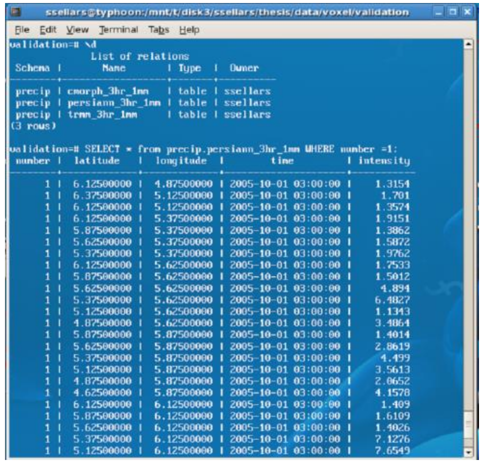
Data Cube:
10+ Years of Data



CONNECT:
Object Segmentation



Object Storage
(PostgreSQL)



```
sseliars@typhoon:/mnt/t/disk3/ssellars/thesis/data/voxel/validation
File  Edit  View  Terminal  Tabs  Help
validation=# \d
              List of relations
 Schema |        Name        | Type  |  Owner
--------+--------------------+-------+----------
 precip | cmorph_3hr_1mm     | table | ssellars
 precip | persiann_3hr_1mm   | table | ssellars
 precip | trmm_3hr_1mm       | table | ssellars
(3 rows)

validation=# SELECT * from precip.persiann_3hr_1mm WHERE number =1;
 number |  latitude    |  longitude   |        time          | intensity
--------+--------------+--------------+----------------------+----------
      1 |  6.12500000  |  4.87500000  | 2005-10-01 03:00:00  |   1.3154
      1 |  6.37500000  |  5.12500000  | 2005-10-01 03:00:00  |    1.701
      1 |  6.12500000  |  5.12500000  | 2005-10-01 03:00:00  |   1.3574
      1 |  6.12500000  |  5.37500000  | 2005-10-01 03:00:00  |   1.9151
      1 |  5.87500000  |  5.37500000  | 2005-10-01 03:00:00  |   1.3862
      1 |  5.62500000  |  5.37500000  | 2005-10-01 03:00:00  |   1.5872
      1 |  5.37500000  |  5.37500000  | 2005-10-01 03:00:00  |   1.9762
      1 |  6.12500000  |  5.62500000  | 2005-10-01 03:00:00  |   1.7533
      1 |  5.87500000  |  5.62500000  | 2005-10-01 03:00:00  |   1.5012
      1 |  5.62500000  |  5.62500000  | 2005-10-01 03:00:00  |    4.894
      1 |  5.37500000  |  5.62500000  | 2005-10-01 03:00:00  |   6.4827
      1 |  5.12500000  |  5.62500000  | 2005-10-01 03:00:00  |   1.1343
      1 |  4.87500000  |  5.62500000  | 2005-10-01 03:00:00  |   3.4864
      1 |  5.87500000  |  5.87500000  | 2005-10-01 03:00:00  |   1.4014
      1 |  5.62500000  |  5.87500000  | 2005-10-01 03:00:00  |   2.8619
      1 |  5.37500000  |  5.87500000  | 2005-10-01 03:00:00  |    4.499
      1 |  5.12500000  |  5.87500000  | 2005-10-01 03:00:00  |   3.5613
      1 |  4.87500000  |  5.87500000  | 2005-10-01 03:00:00  |   2.0652
      1 |  4.62500000  |  5.87500000  | 2005-10-01 03:00:00  |   4.1578
      1 |  6.12500000  |  6.12500000  | 2005-10-01 03:00:00  |    1.409
      1 |  5.87500000  |  6.12500000  | 2005-10-01 03:00:00  |   1.6109
      1 |  5.62500000  |  6.12500000  | 2005-10-01 03:00:00  |   1.4026
      1 |  5.37500000  |  6.12500000  | 2005-10-01 03:00:00  |   7.1276
      1 |  5.12500000  |  6.12500000  | 2005-10-01 03:00:00  |   7.6549
```

Data

1. 60N-60S, 0-360 lat and long
2. Hourly time step
3. March 1st, 2000 to January 1st, 2011

Set Object Criteria:

1. Each voxel must have 1mm/hr
2. Each object must exist for 24 hours
3. 6 voxel connections (i.e. voxel face connections)

Calculate Characteristics

Database Indexes:

1. Object ID Number
2. Latitude (of each voxel in objects)
3. Longitude (of each voxel in objects)
4. Time (hour)
5. Precipitation Intensity (mm/hour)

~1.2 billion rows, 55,000+ Objects

Sellars et al., 2013 AGU EOS

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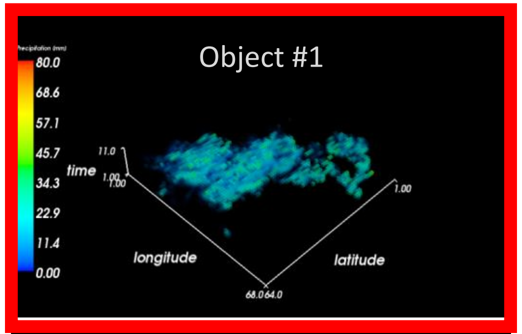
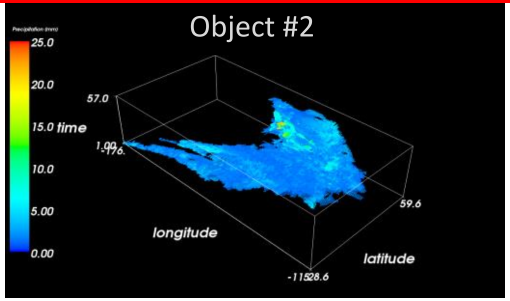
#1

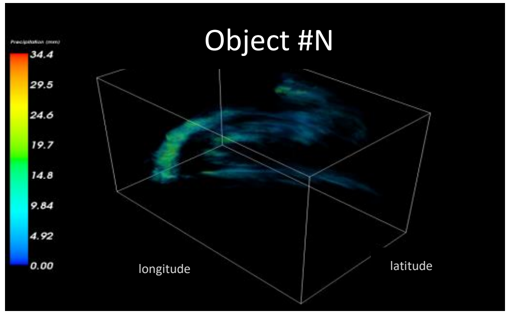




.....
.....

.....

#N



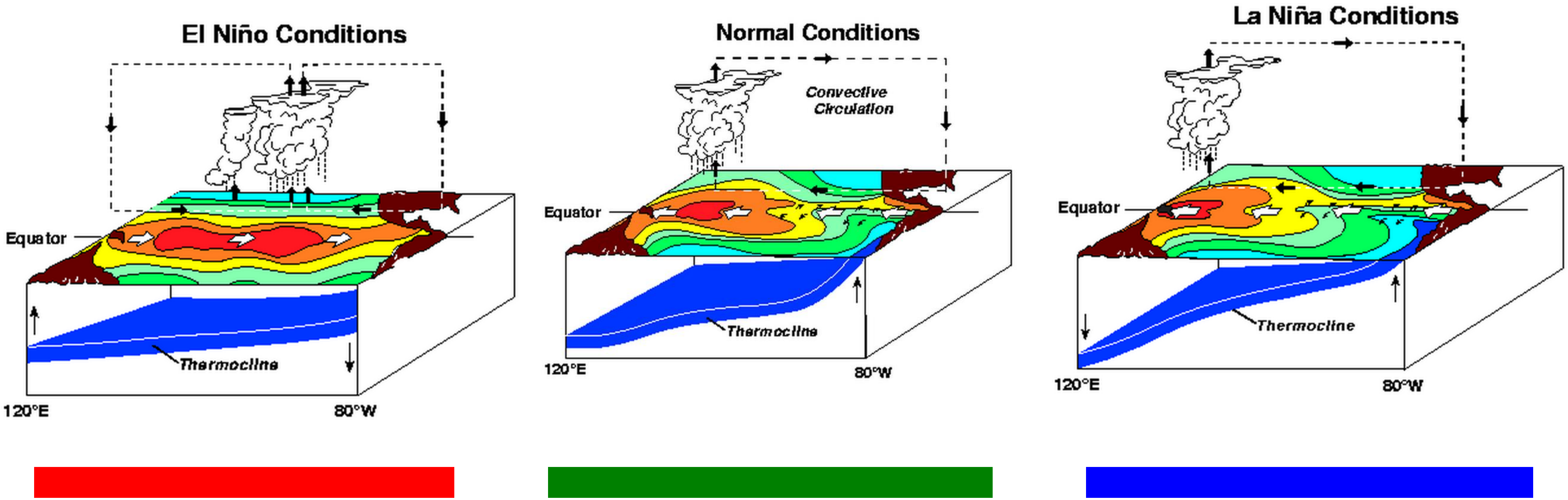
d "features"

$$\mathbf{X} = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_d^1 \\ x_1^2 & x_2^2 & \cdots & x_d^2 \\ \vdots & & & \\ x_1^N & x_2^N & \cdots & x_d^N \end{bmatrix}$$

N # of objects

What can we learn from this Nxd matrix?

El Nino Southern Oscillation



*http://www.pmel.noaa.gov/tao/elnino/nino-home.html

Physical impacts of ENSO objects (Western U.S.)

	Avg intensity (mm h^{-1})	Max intensity (mm h^{-1})	Speed (km h^{-1})	Hit California	Volume (km^3)	Duration (h)	Lat centroid (°N)	Lon centroid (°W)
ENSO								
El Niño (185)	2.5	16.9	44.6	73.5%	95.05	62.7	39.8	206.5
Neutral (248)	2.5	**15.3**	43.7	**65.3%**	**60.75**	54.4	40.3	211.3
La Niña (193)	2.6	**19.3**	46.9	70.5%	90.97	62.1	39.3	207.3

Bold letters indicate statistical significance at the 95% level.

El Nino/La Nina phases of ENSO have objects that are **larger**, **faster**, **longer lasting**, and begin slightly further east in the Pacific Ocean.

Sellars et al. 2015 JHM

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Is there more AR specific variable? IVT!

- Apply CONNECT to IVT.
- We are using NASA MERRA V2 (1980-2012)
  - Goddard Earth Observing System Data Assimilation System Version 5 (GEOS-5)
  - Incremental Analysis Updates (IAU) to slowly adjust the model states toward the observed state.
  - 3-hourly at the full spatial resolution (1/2 degrees latitude × 2/3 degrees longitude).
  - Atmospheric diagnostic variables on 42 pressure levels.

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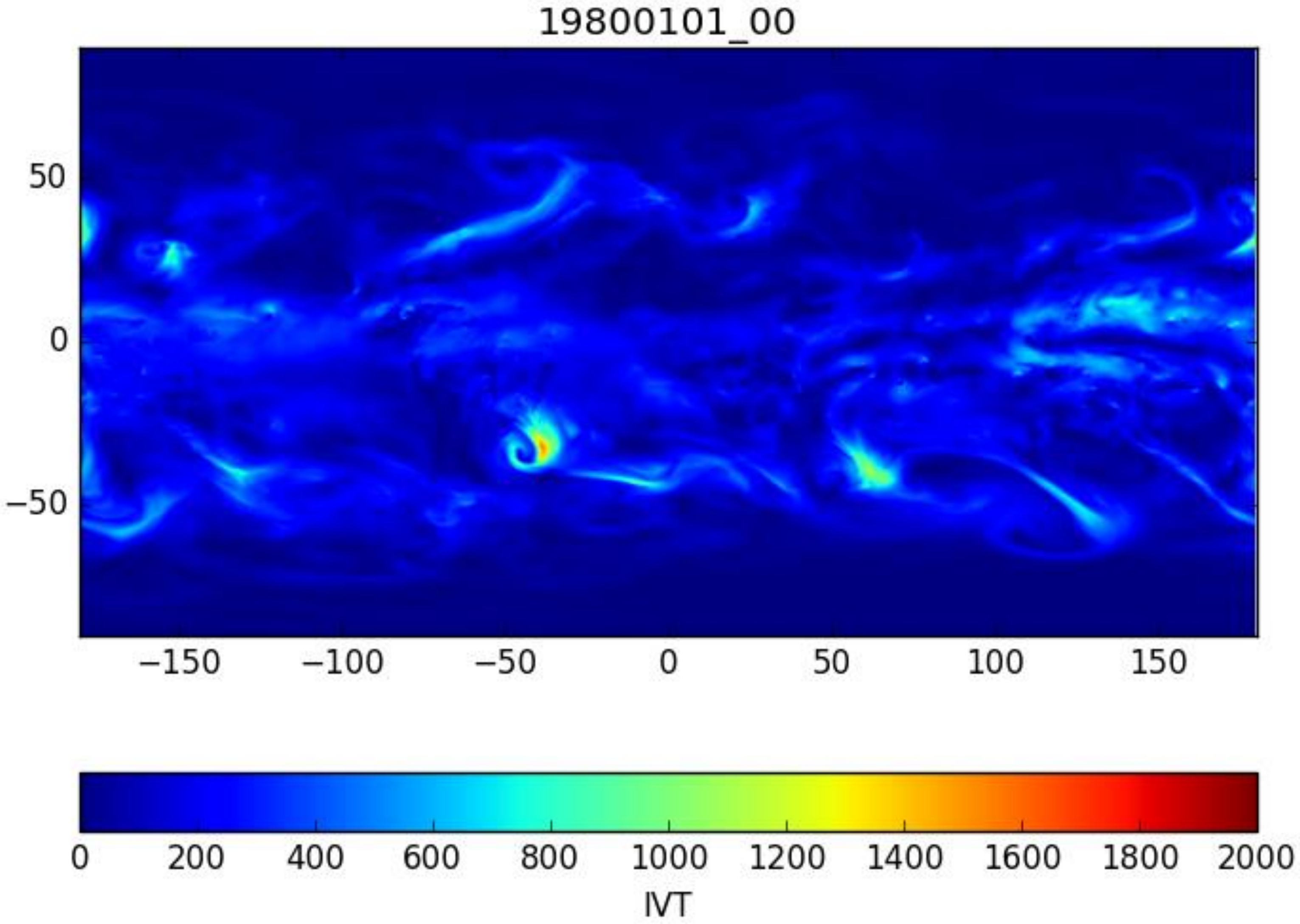
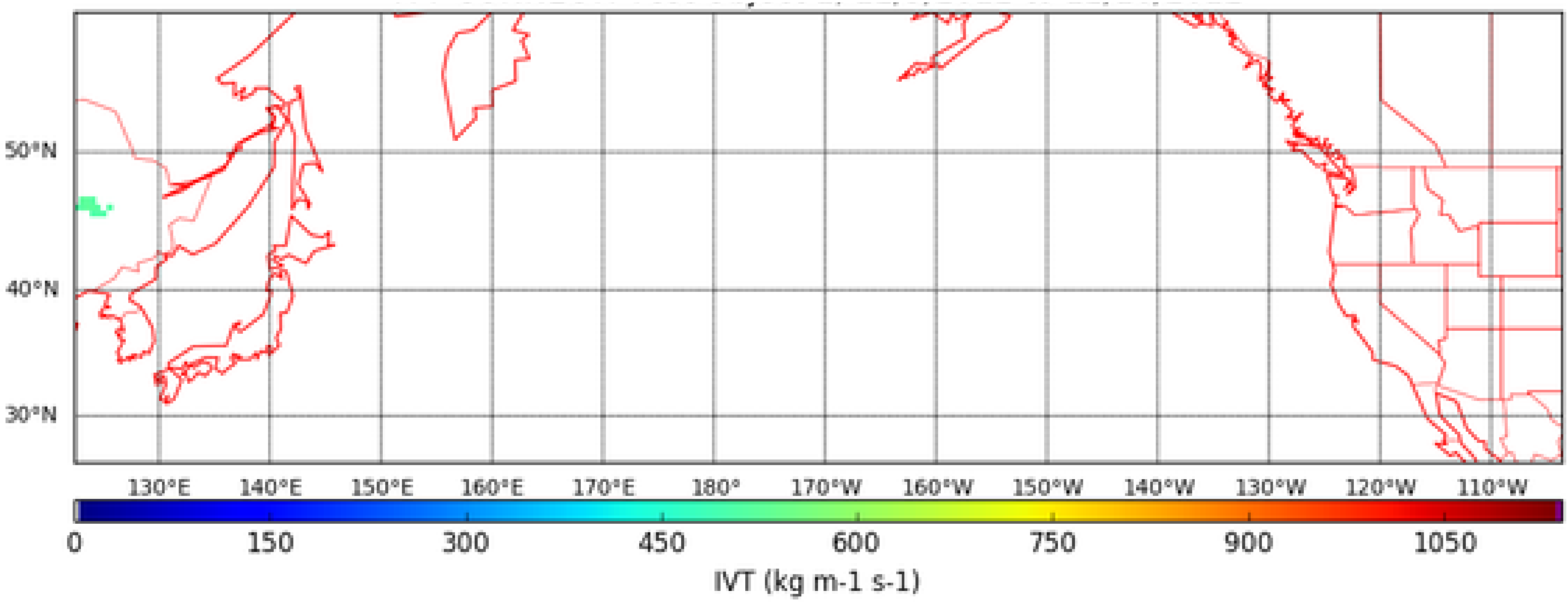
NASA MERRA2 IVT (kg m-1 s-1)



IVT-CONNECT Object #265: 500 kg m-1 s-1

1980-05-17 15:00:00 to 1980-05-23 18:00:00



obj_avg_intensity	645.2713828
obj_cent_lat	43.59437939
obj_cent_lon	193.1811606
obj_duration	130
obj_end_lat_centriod	52.45833333
obj_end_lon_centriod	254.625
obj_id	265
obj_max_intensity	1135.1936
obj_median_intensity	606.06395
obj_start_lat_centriod	44.66346154
obj_start_lon_centriod	123.6826923
obj_stddev_intensity	126.6141508
obj_timeofyear	5
obj_volume	8850.703604

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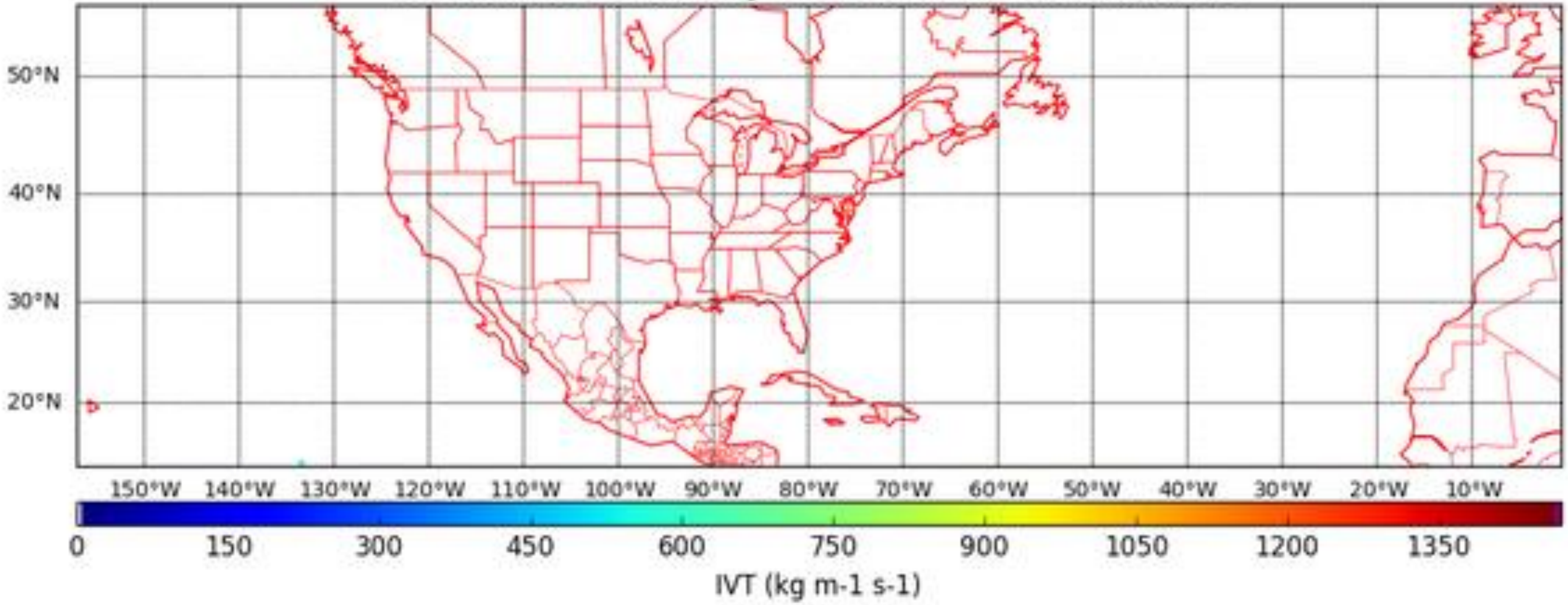
IVT-CONNECT Object #1424: 500 kg m-1 s-1

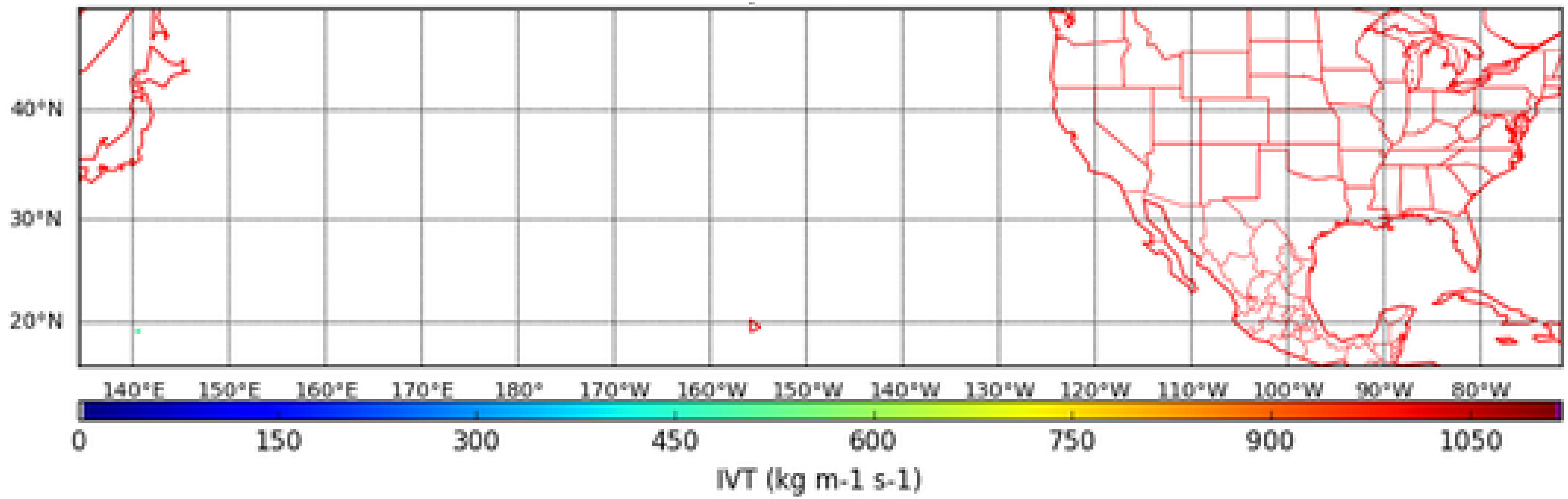
1981-12-28 15:00:00 to 1982-01-13 12:00:00



obj_avg_intensity	707.1792532
obj_cent_lat	40.25953546
obj_cent_lon	274.0469186
obj_duration	382
obj_end_lat_centriod	40.16666667
obj_end_lon_centriod	343.6666667
obj_id	1424
obj_max_intensity	1466.6749
obj_median_intensity	659.39985
obj_start_lat_centriod	13.875
obj_start_lon_centriod	226.125
obj_stddev_intensity	175.1814777
obj_timeofyear	12
obj_volume	32330.46751

IVT-CONNECT Object #2767: 500 kg m-1 s-1

1983-12-03 15:00:00 to 1983-12-16 12:00:00



obj_avg_intensity	608.8536938
obj_cent_lat	34.78758607
obj_cent_lon	180.5145256
obj_duration	310
obj_end_lat_centriod	45.57954545
obj_end_lon_centriod	287.0113636
obj_id	2767
obj_max_intensity	1113.8579
obj_median_intensity	587.0118
obj_start_lat_centriod	17.625
obj_start_lon_centriod	138.875
obj_stddev_intensity	90.24293891
obj_timeofyear	12
obj_volume	12433.93403

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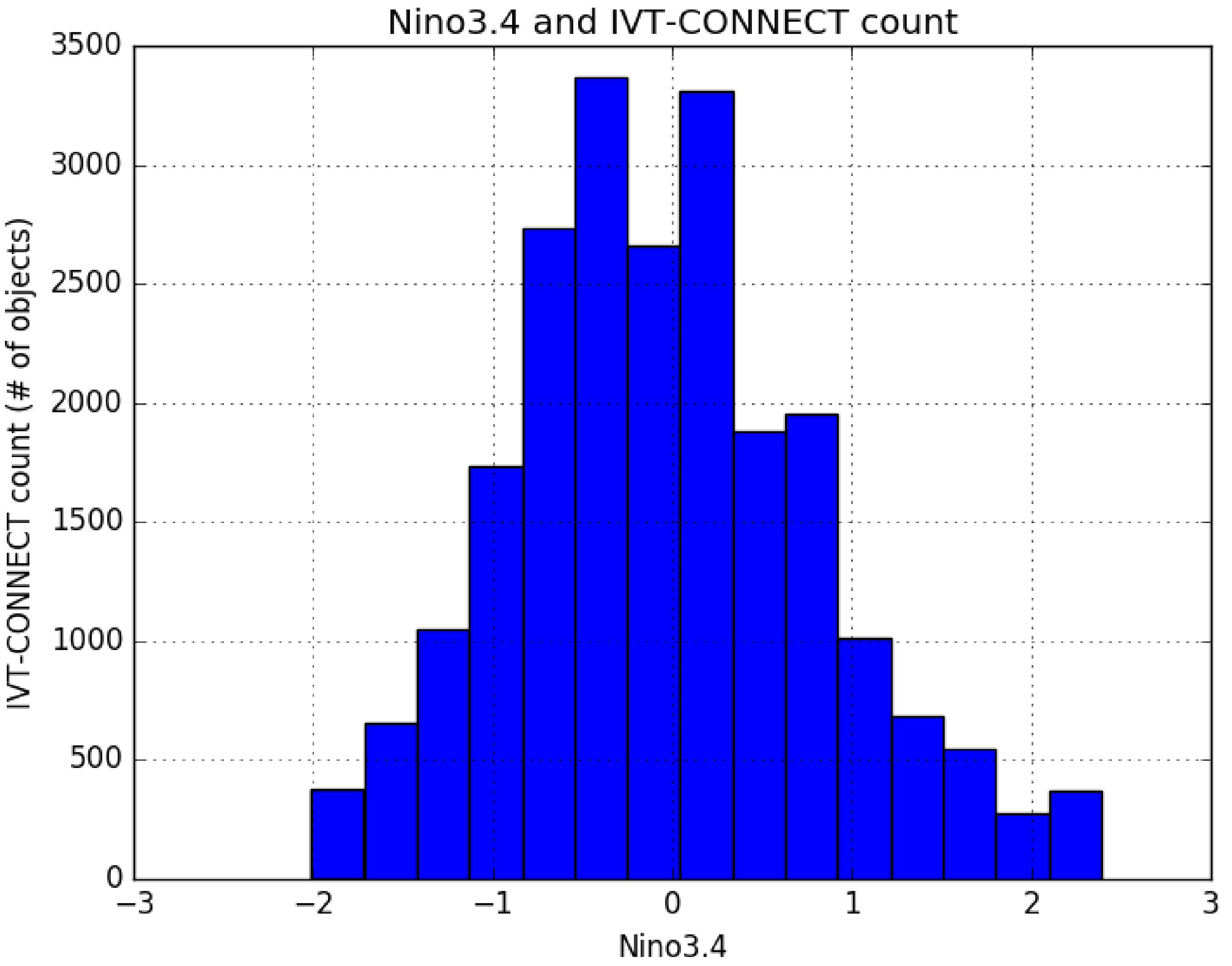
Summary stats IVT-CONNECT (1980-2012)

- Using 500kg m-1 s-1 threshold (CONNECT criteria) and 24 hour min
  - 22625 IVT objects from
  - Mean duration: 168.19 hours
  - Maximum IVT: 4452.90 kg m-1 s-1
  - Mean of the maximum IVT: 1151.38 kg m-1 s-1
  - Mean ENSO state: -.04C



Nino3.4 and IVT-CONNECT count
IVT-CONNECT count (# of objects)
3500
3000
2500
2000
1500
1000
500
0
−3
−2
−1
0
1
2
3
Nino3.4

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Summary

- Object data and high dimensional characteristics provides unique insights into ARs and other phenomena
  - Look at other variables:
    - Latent heat flux, sensible heat flux and potential energy objects?
- Empirical studies (e.g., Sellars et al., 2015) show impacts of climate on physical characteristics.
- Building an observational database that can be searched (PERSIANN-CONNECT: http://connect.eng.uci.edu/)
  - Deep dive into what is an atmospheric river
    - What are the dominant features?
    - Do they have connections to other variables/fields?
- As we track ARs, we may find that the the dynamics are impacted by very different phenomena

Thank you!

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Funding Acknowledgements:
NASA Earth and Space Science Fellowship 2014 (NESSF)
Public Impact Fellowship 2014 – University of California, Irvine
Cooperative Institute for Climate Studies (CICS) (NOAA award NA09NES4400006)
U.S. Army Research Office (Award W911NF-11-1-0422)
NASA (award NNS09AO67G)

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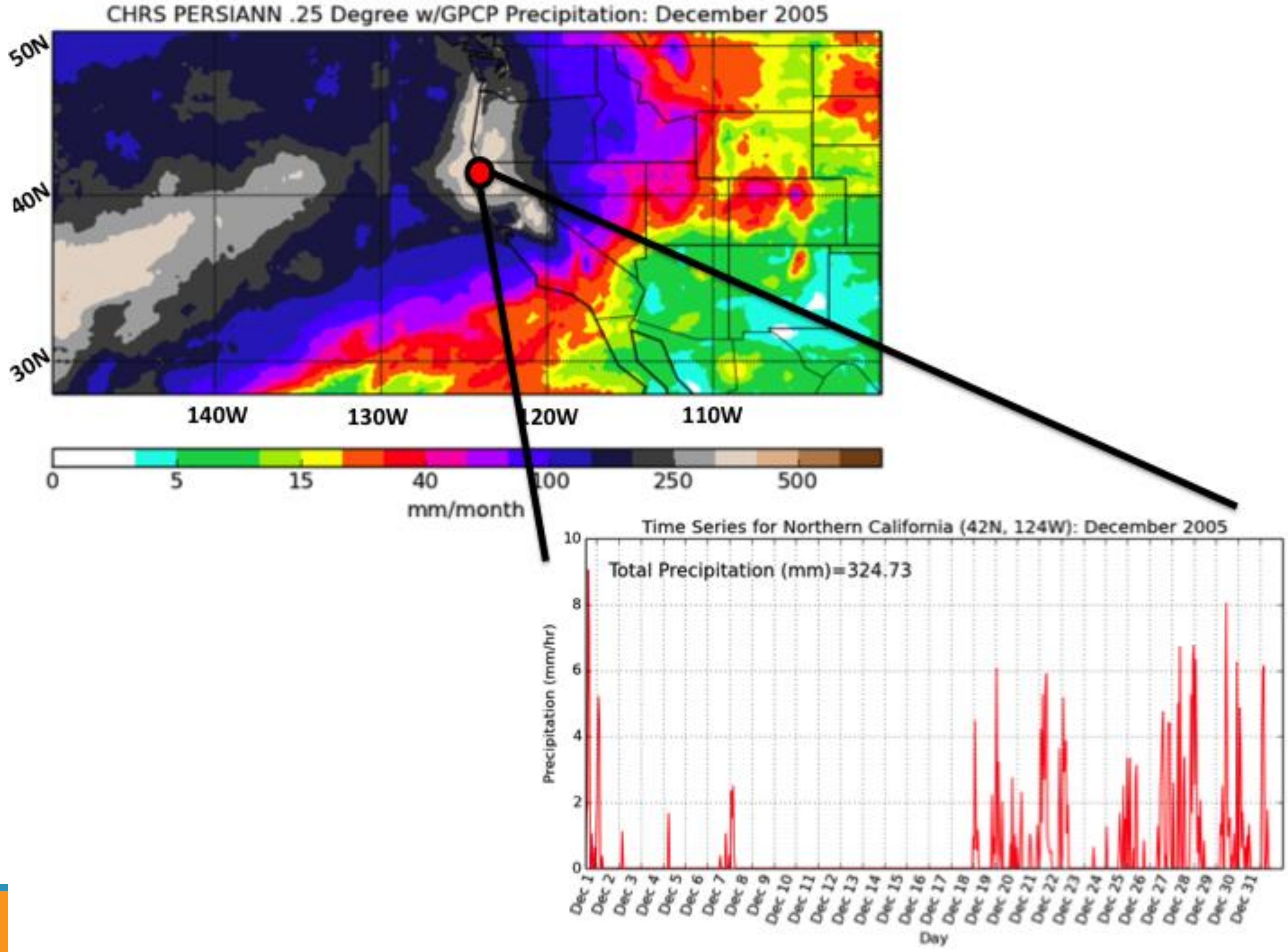
BACKUP SLIDES

Collaborators

- University of California, Irvine
  - Phu Nguyen
  - Xiaogang Gao
  - Soroosh Sorooshian

- Calit2, UCSD
  - John Graham et al.,



CHRS PERSIANN .25 Degree w/GPCP Precipitation: December 2005
50N
40N
30N
140W
130W
120W
110W
0
5
15
40
100
250
500
mm/month
Time Series for Northern California (42N, 124W): December 2005
Total Precipitation (mm)=324.73
Precipitation (mm/hr)
10
8
6
4
2
0
Dec 1
Dec 2
Dec 3
Dec 4
Dec 5
Dec 6
Dec 7
Dec 8
Dec 9
Dec 10
Dec 11
Dec 12
Dec 13
Dec 14
Dec 15
Dec 16
Dec 17
Dec 18
Dec 19
Dec 20
Dec 21
Dec 22
Dec 23
Dec 24
Dec 25
Dec 26
Dec 27
Dec 28
Dec 29
Dec 30
Dec 31
Day

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Eos, Vol. 94, No. 32, 6 August 2013

EOS
EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 94 NUMBER 32
6 August 2013
PAGES 277–288

Computational Earth Science: Big Data Transformed Into Insight

PAGES 277–278

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

attributes and statistics representing the existence of the entity in space and/or time—for example, a storm, an earthquake, an ecological region, or a sea surface temperature anomaly. The attributes and statistics associated with these objects can be analyzed using statistical modeling algorithms to identify structural relationships between different characteristics, as well as time periods corresponding to different physical systems and phenomena interactions, leading to enhanced knowledge of what trends the data hold.

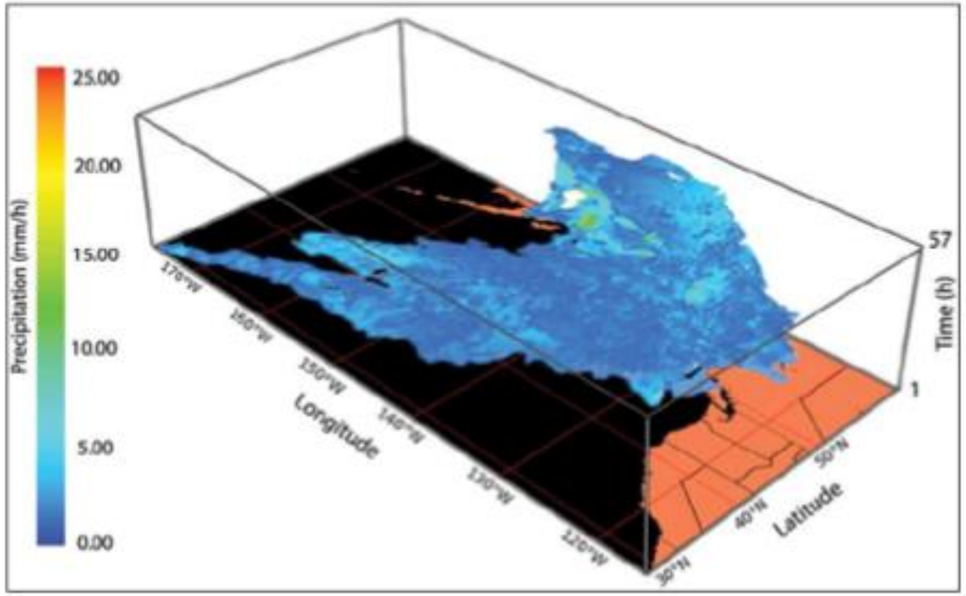

Fig. 1. A connected four-dimensional atmospheric river, or "precipitation object," extracted from the PostgreSQL database. The atmospheric river originated in the eastern Pacific and affected the western United States from 28 to 30 December 2005.

***Sellars et al. 2013 AGU EOS**

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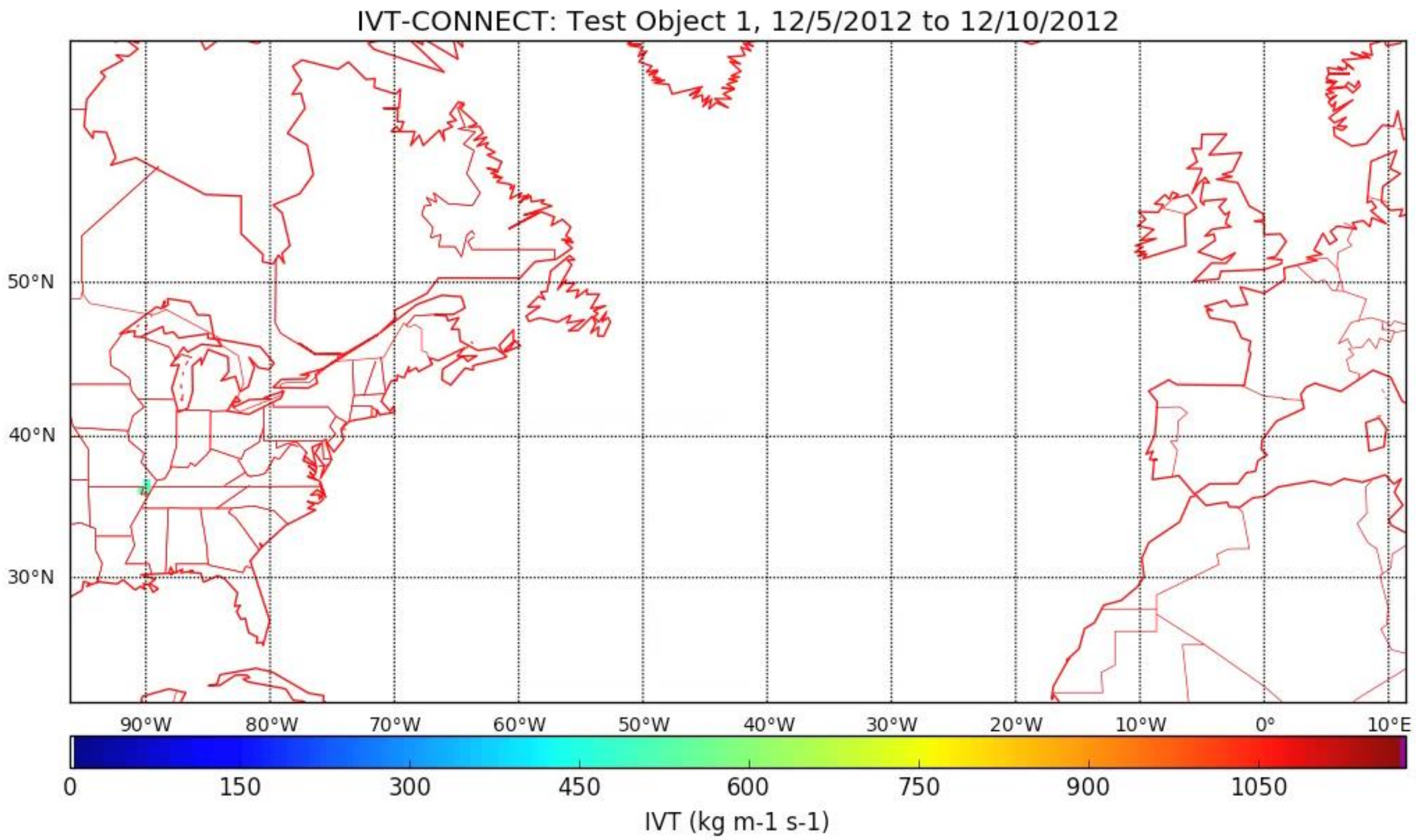
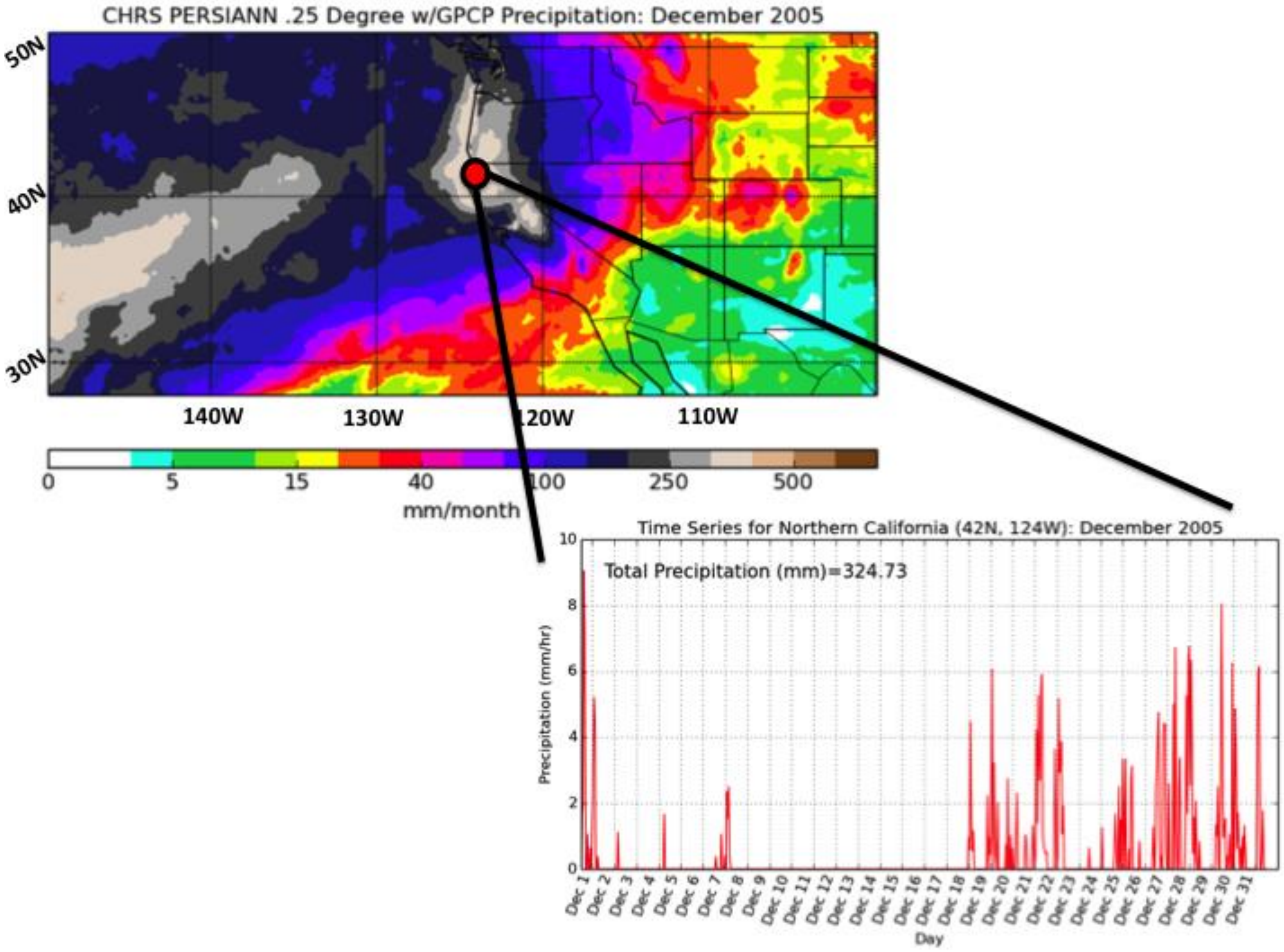
IVT-CONNECT Object #12: 500 kg m-1 s-1




CHRS PERSIANN .25 Degree w/GPCP Precipitation: December 2005
50N
40N
30N
140W
130W
120W
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5
15
40
100
250
500
mm/month
Time Series for Northern California (42N, 124W): December 2005
Total Precipitation (mm)=324.73
Precipitation (mm/hr)
10
8
6
4
2
0
Dec 1
Dec 2
Dec 3
Dec 4
Dec 5
Dec 6
Dec 7
Dec 8
Dec 9
Dec 10
Dec 11
Dec 12
Dec 13
Dec 14
Dec 15
Dec 16
Dec 17
Dec 18
Dec 19
Dec 20
Dec 21
Dec 22
Dec 23
Dec 24
Dec 25
Dec 26
Dec 27
Dec 28
Dec 29
Dec 30
Dec 31
Day

Object characteristics

TABLE A.1: 4D Precipitation Object Features

Object Features		
Climate Features	Physical Features	Reanalysis Features
ANOM12	Avg Intensity	d_-102.5x15.0_130.0x12.5
ANOM3	Cenroid Latitude	d_-102.5x15.0_150.0x15.0
ANOM34	Centroid Longitude	d_-12.5x45.0_-10.0x67.5
ANOM4	Duration	d_-15.0x77.5_-12.5x45.0
CAR	Ending Latitude - Centroid	d_-155.0x40.0_60.0x12.5
NTA	Ending Longitude Centroid	d_-157.5x67.5_170.0x35.0
AAO	Id	d_-160.0x75.0_130.0x42.5
AMMSST	Max Intensity	d_-160.0x75.0_170.0x35.0
AMON	Median Intensity	d_-162.5x22.5_-157.5x67.5
AO	Speed	d_-167.5x55.0_170.0x35.0
EA	Starting Latitude Centroid	d_-167.5x55.0_175.0x20.0
EPO	Starting Longitude Centroid	d_-180.0x67.5_-162.5x22.5
GLAAM	Standard deviation Intensity	d_-180.0x67.5_130.0x42.5
GMSST	Time of Year	d_-180.0x67.5_170.0x35.0
MEI	Volume	d_-180.0x67.5_175.0x20.0
MJO RMM1		d_-27.5x35.0_-10.0x67.5
MJO RMM2		d_-45.0x37.5_-10.0x67.5
MJO Amplitude		d_-50.0x17.5_-35.0x52.5
MJO Phase		d_-90.0x20.0_130.0x12.5
NAO		d_-90.0x20.0_150.0x15.0
NP		d_110.0x25.0_132.5x80.0
ONI		d_112.5x32.5_132.5x80.0
PDO		d_130.0x42.5_132.5x80.0
PNA		d_55.0x57.5_95.0x35.0
QBO		d_65.0x72.5_110.0x25.0
SOI		d_65.0x72.5_112.5x32.5
Solar		d_65.0x72.5_95.0x35.0
SW MONSOON		
TNA		
TNI		
TSA		
WHWP		
WP		

Gather characteristics from each object:

$$\mathbf{X} = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_d^1 \\ x_1^2 & x_2^2 & \cdots & x_d^2 \\ \vdots & & & \\ x_1^N & x_2^N & \cdots & x_d^N \end{bmatrix}$$

N = # of events
d = # of dimensions (72 in this case)

Not apples to apples, but…