


*Ensuring Water in a Changing World*


**(“Critical Downstream Issues”)**

**Climate Change & The Global Water Cycle:  
The Latest News From Earth & Space**

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



AIHA -Yuma Pacific Southwest Section 2008 Annual Meeting  
The Crown Plaza, Irvine, California  
January 24<sup>th</sup>, 2008

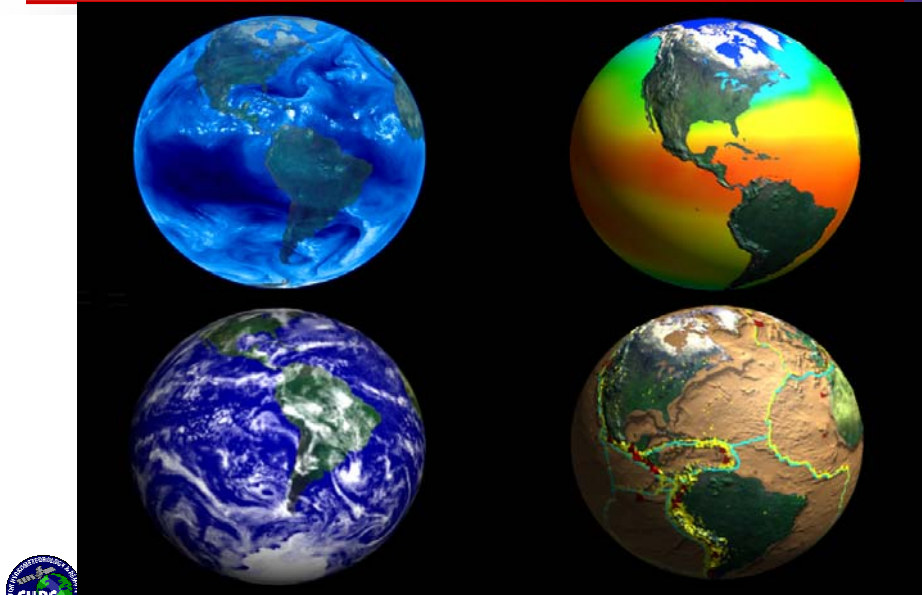


**CHRS & Affiliated Activities in the Educational Team (UA)**



 and many more ...

## *A Unique Planet: Blue, Green and alive!*

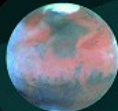


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## *Atmosphere of Earth vs. Mars and Venus*

### Planets and atmospheres

**Mars**  
Thin atmosphere  
(Almost all CO<sub>2</sub> in ground)  
Average temperature : - 50°C



**Earth**  
0,03% of CO<sub>2</sub> in the atmosphere  
Average temperature : + 15°C



**Venus**  
Thick atmosphere  
containing 96% of CO<sub>2</sub>  
Average temperature : + 420°C



**Earth's atmosphere:**  
78% nitrogen, 21% oxygen, and 1% other gases



GRAPHIC DESIGN : PHILIPPE REKACIEWICZ

Sources: Calvin J. Hamilton, Views of the solar system, [www.planetscapes.com](http://www.planetscapes.com); Bill Arnett, The nine planets, a multimedia tour of the solar system, [www.seds.org/bills/nineplanets.html](http://www.seds.org/bills/nineplanets.html)

## Distribution of Freshwater

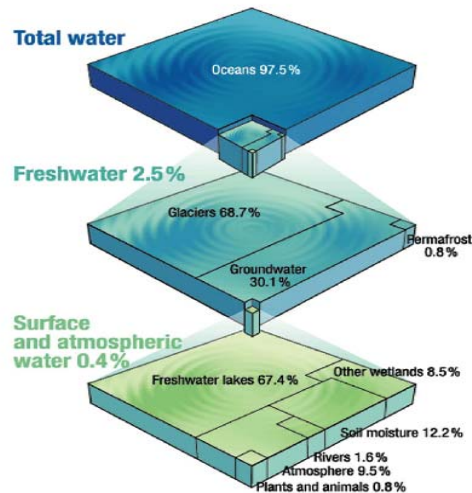


Figure 4.1:  
**Global distribution of the world's water**

Source: Data from Shiklomanov and Rodhe, 2003.  
Freshwater has a global volume of 35.2 million cubic kilometres (km<sup>3</sup>).




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# *The Big Question as to Whether Our Planet Is Warming Up and The Hydrologic Cycle is Intensifying, has been addressed by The Recent IPCC Report*





## Evidence for reality of climate change: *Glaciers Melting*



1909



Muir Glacier, Alaska



2004



2000

Toboggan Glacier Alaska



A. Circa 1900  
Photo Source: Munich Society for Environmental Research

1900



B. Recent

2003

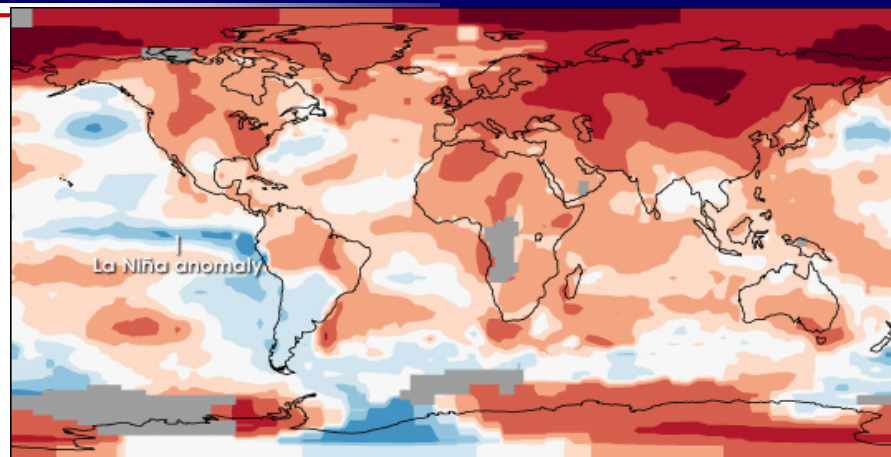
Alpine glacier, Austria



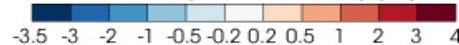
*Provided By: Kevin Trenberth*

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## Global Temperature Anomalies: 2007



Surface Temperature Anomaly ( $^{\circ}\text{C}$ )



*Tied (with 1998) for the second warmest year  
(2005 Warmest)*

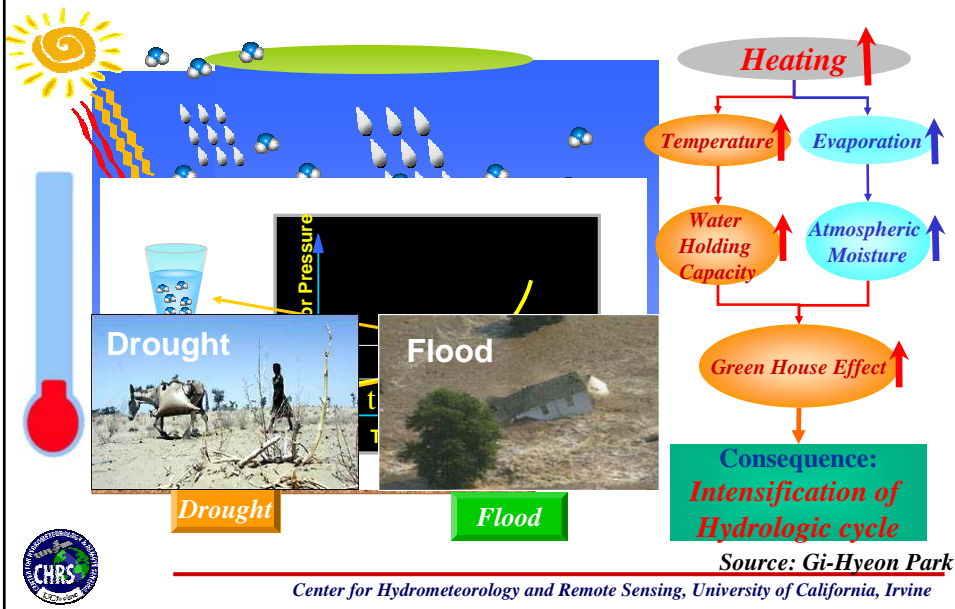
*Source: NASA GISS 2007*



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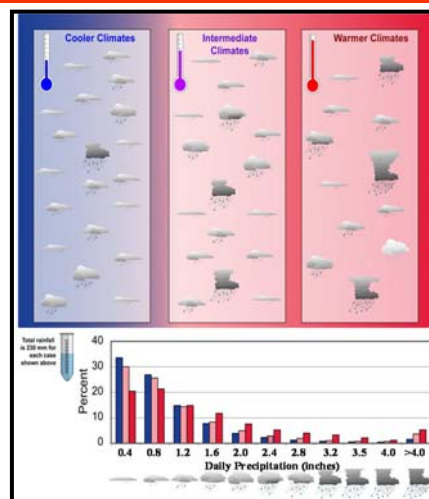
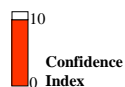
## Global Warming And Hydrologic Cycle Connection



## Observed changes: Heavy Precipitation

### Facts from Observations

- From 1908-2002:
  - Total annual precipitation across the contiguous U.S. increased 7%
  - Heavy daily Precipitation events have increased by 20%
- Rainfall associated with warmer climates are more due to extreme events compared to colder climates



Source: Tom Karl NCDC-NOAA 2007

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## *Record Floods: Among the worst Natural Disasters*



Flooding in Tana River Valley, Kenya, due to extended and unseasonal rain

## *Los Angeles (1955)*



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## Observed changes: Drought Reconstruction

### Drought as documented in the paleoclimatic record?

- Within the past millennium there have been severe droughts in both the western U.S. and Midwest that have lasted for multiple decades (50 years).

10  
5 Confidence  
0 Index



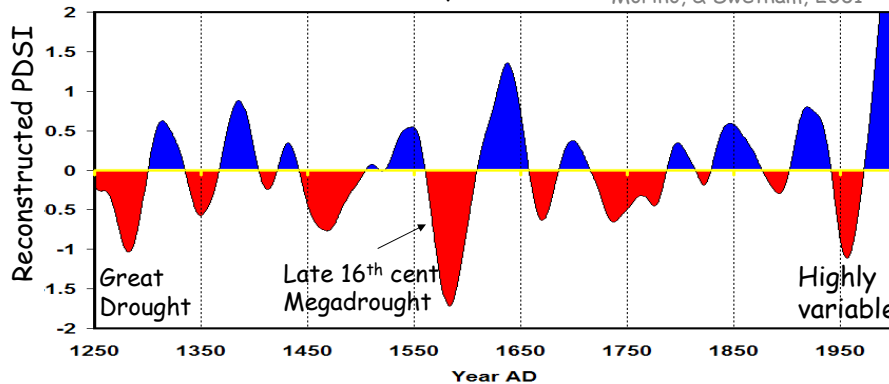
Source: Tom Karl NCDC-NOAA 2007  
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## Recent US Southwest Drought in Historical Context



Middle Rio Grande Basin, NM AD

Grissino-Mayer, Baisan, Morino, & Swetnam, 2001





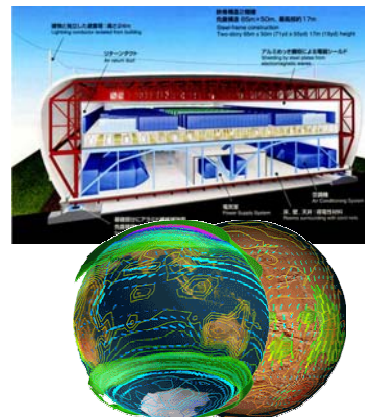
## Challenge of predicting the future Climate:

***While we Attempt to Improve Our Scientific Understanding of the Climate System, We Face Major Issues With Uncertainties in Information We Can Provide to “Users”***

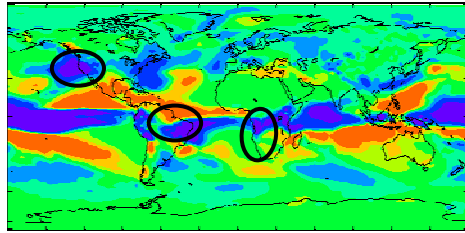


## Climate Predictions into the Future!

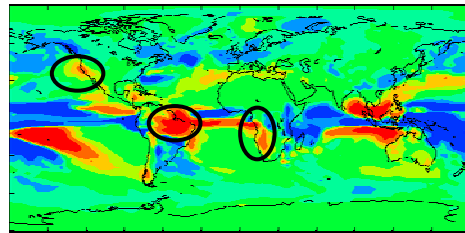
***Some Results at the Seasonal to Inter-annual and Longer time Scales:***



## Climate model Predictions about the future? → globally



**DJF Precipitation Changes**  
**CM2 - Old model**



**CM3 - Updated model**

**Significant differences**  
**in regional outcomes!**

Units: millimetres per day Mean: 0.2 Min: -6.0 Max: 8.5



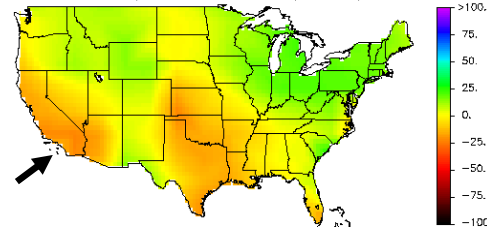
Source: Hadley Center (Climate Change Projections)

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## What do climate models tell us about the future?

**Model annual precipitation**  
**trends over 21<sup>st</sup> century**

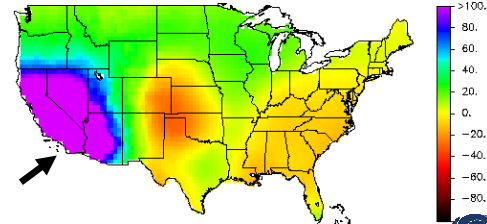
HadCM3 Precipitation % Trend (Annual)



**Hadley Center:**  
**Southwest dries out**

**What to tell water managers?**

CGCM1 % Trend in Precipitation (Annual)



**Canadian Center:**  
**Southwest extremely wet**

Source: US National Assessment Report, 2000



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## *Recent Extreme Conditions in the U.S. Southwest*



*Normal Years*

*Sever Multi-year  
Drought through  
2004*

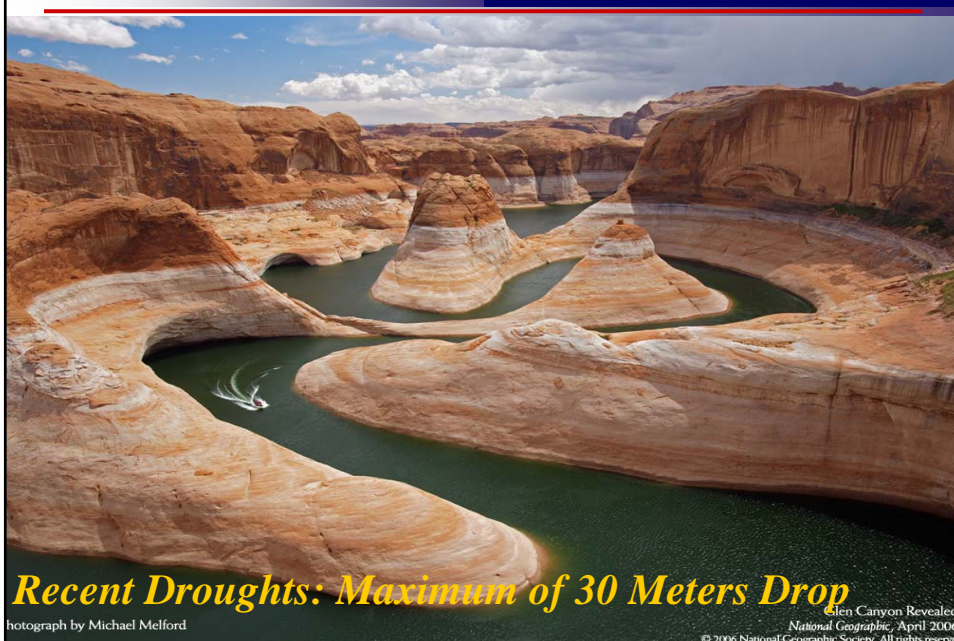
**Lake Powell, Colorado River, USA**



*Source: J. Kane SRP 2004*

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## *Lake Powell – Glenn Canyon Dam*



***Recent Droughts: Maximum of 30 Meters Drop***

photograph by Michael Melford

Glen Canyon Revealed.  
National Geographic, April 2006  
© 2006 National Geographic Society. All rights reserved.



## 2005 Record Rains in California

Precipitation Accumulation from 1/6/2005



5	25	50	75	100	125	150	175	225
5	25	50	75	100	125	150	175	225

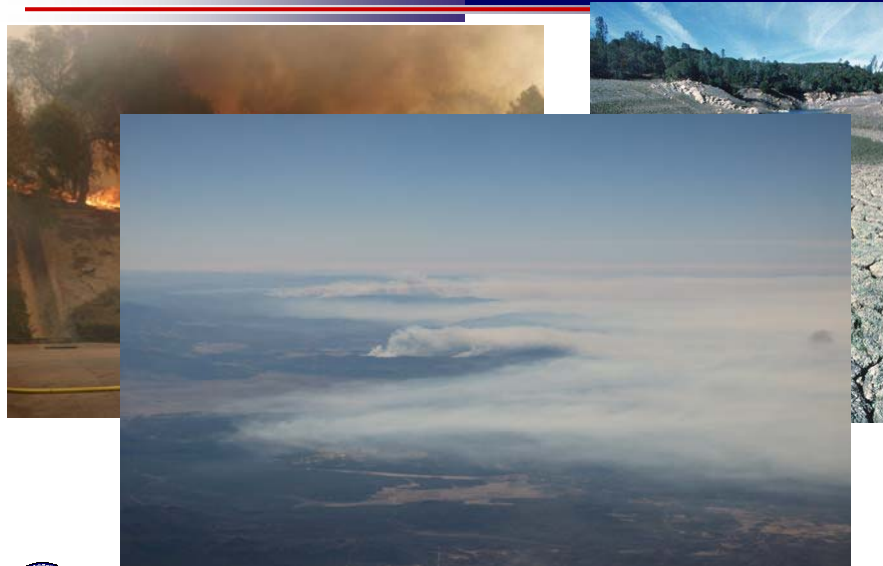


Courtesy: NASA's ESE



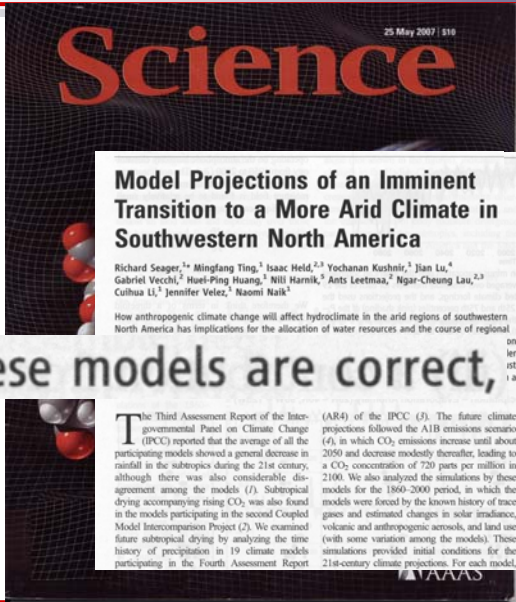
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## 2007: Lowest Rainfall on Record in California



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## Eye-Catching Article in Science Magazine



**Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America**

Richard Seager,<sup>1,2</sup> Mingfang Ting,<sup>3</sup> Isaac Held,<sup>4,5</sup> Yechanan Kushnir,<sup>1</sup> Jian Lu,<sup>4</sup> Gabriel Vecchi,<sup>2</sup> Hui-Ping Huang,<sup>1</sup> Nili Harnik,<sup>3</sup> Ants Leetmaa,<sup>2</sup> Ngar-Cheung Lau,<sup>2,3</sup> Cuihua Li,<sup>3</sup> Jennifer Velez,<sup>3</sup> Naomi Naik<sup>1</sup>

How anthropogenic climate change will affect hydroclimate in the arid regions of southwestern North America has implications for the allocation of water resources and the course of regional

**If these models are correct,**

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) reported that the average of all the participating models showed a general decrease in rainfall in the subtropics during the 21st century, although there was also considerable disagreement among the models (1). Subtropical drying accompanying rising CO<sub>2</sub> was also found in the models participating in the second Coupled Model Intercomparison Project (2). We examined future subtropical drying by analyzing the time history of precipitation in 19 climate models participating in the Fourth Assessment Report (AR4) of the IPCC (3). The future climate projections followed the A1B emissions scenario (4), in which CO<sub>2</sub> emissions increase until about 2050 and decrease modestly thereafter, leading to a CO<sub>2</sub> concentration of 720 parts per million in 2100. We also analyzed the simulations by these models for the 1860–2000 period, in which the models were forced by the known history of trace gases and estimated changes in solar irradiance, volcanic and anthropogenic aerosols, and land use (with some variation among the models). These simulations provided initial conditions for the 21st-century climate projections. For each model, precipitation minus the evaporation ( $P - E$ ), averaged over this region for the period common to all of the models (1900–2098). The median, 25th, and 75th percentiles of the model  $P - E$  distribution and the median of  $P$  and  $E$  are shown. For cases in which there were multiple simulations with a single model, data from these simulations were averaged together before computing the distribution.  $P - E$  equals the moisture convergence by the atmospheric flow and (over land) the amount of water that goes into runoff.

In the multimodel ensemble mean, there is a transition to a sustained drier climate that begins in the late 20th and early 21st centuries. In the ensemble mean, both  $P$  and  $E$  decrease, but the former decreases by a larger amount.  $P - E$  is primarily reduced in winter, when  $P$  decreases and  $E$  is unchanged or modestly increased, whereas in summer, both  $P$  and  $E$  decrease. The annual mean reduction in  $P$  for this region, calculated from rain gauge data within the Global Historical Climatology Network, was 0.09 mm/day between 1932 and 1939 (the Dust Bowl drought) and 0.13 mm/day between 1948 and 1957 (the 1950s Southwest drought). The ensemble median reduction in  $P$  that drives the reduction in  $P - E$  reaches 0.1 mm/day in midcentury, and one quarter of the models reach this amount in the early part of the current century. The annual mean  $P - E$  difference between 20-year periods in the 21st century and the 1950–2000 climatology for the 19 models are shown in Fig. 2. Almost all models have a drying trend in the American Southwest, and they con-

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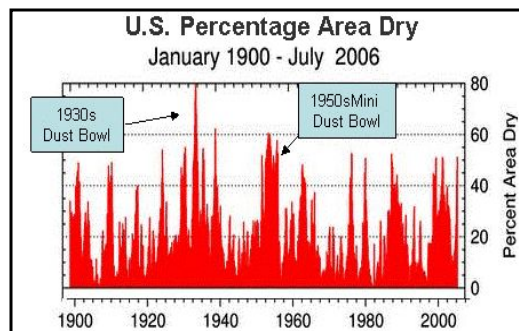
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## Observed changes: Drought

### Drought activity during the 20<sup>th</sup> and early 21<sup>st</sup> Century

- U.S. droughts show pronounced multi-year to multi-decadal variability, but no convincing evidence for long-term trends toward more or fewer events.

10  
5  
0  
Confidence  
Index



Based on Palmer Drought Index  
Moderate to Extreme Drought



Source: Tom Karl NCDC-NOAA 2007

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## *Relationship: Drought, Forest Health, Fire*



Flagstaff, AZ



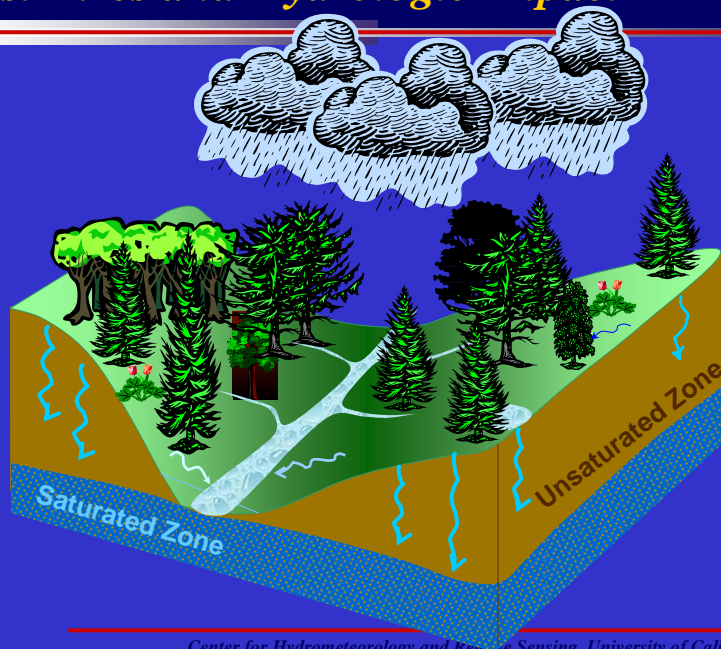
Arrowhead Lake, CA

*Drought Weakens Tree's Tolerance to Beetle Attack, Causing High Tree Mortality, Perfect Target for Forest Fire*



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## *Forest Fires and Hydrologic Impact*



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## Post Fire Processes



## Increased Sediment Transport





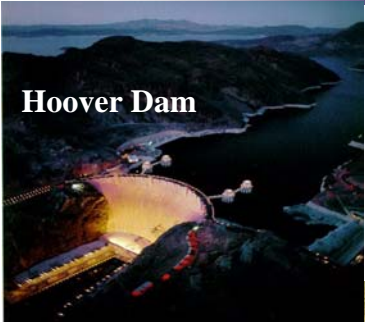
  
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# *Common Practices in Factoring in Climate:*


## *Engineering Approach: Control, Store, Recycle, Transport & Use for Multi-Purposes*




*A Century of Water Resources Development: Engineering success!*




**Hoover Dam**




**Glen Canyon Dam**



**Central Arizona Project Aqueduct**

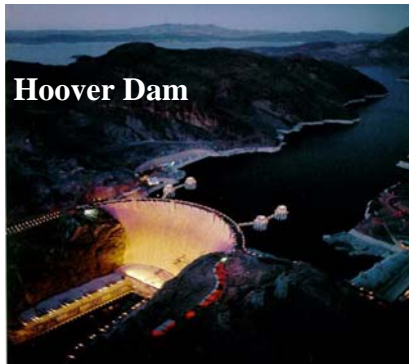


  
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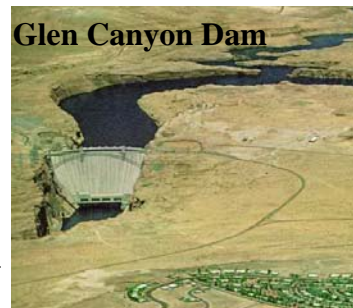
## Built-In Resiliency in water resources Systems!



**Hoover Dam**

Time of Construction = 1935  
 Total Storage Capacity = 38.6 BCM  
 Annual Inflow = 15.4 BCM  
 Drainage Area = 432,500 Km<sup>2</sup>  
**Time to fill = 2.5 Years**  
 Power Generation = 2,074 MW

Time of Construction = 1963  
 Total Storage Capacity = 33.3 BCM  
 Annual Inflow = 15.4 BCM  
 Drainage Area = 280,570 Km<sup>2</sup>  
**Time to fill = 2.24 Years**  
 Power Generation = 1,356 MW



**Glen Canyon Dam**



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## Many Advances in Water Treatment: \$\$\$?

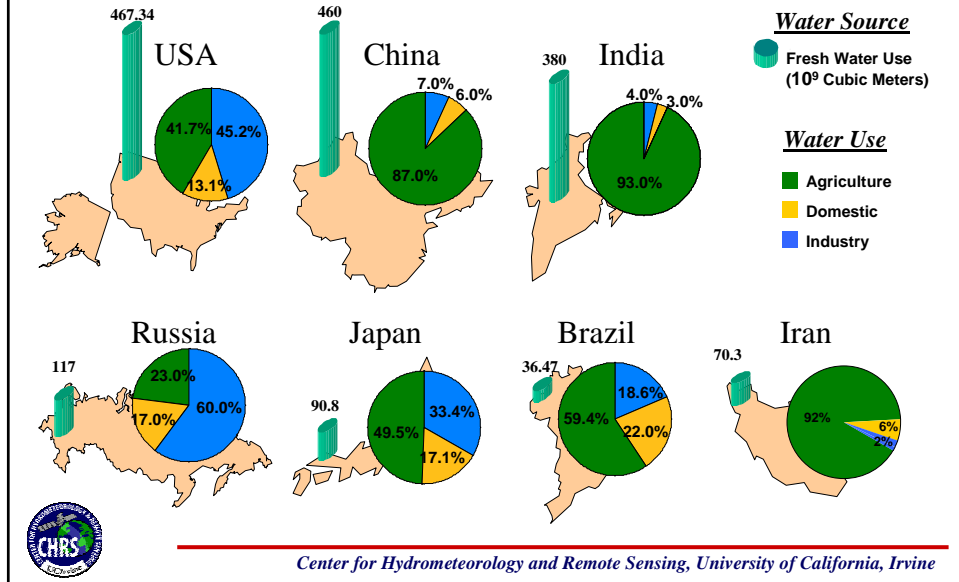


Water treated on site at a rubber factory, Malaysia

© Mark Edwards/CHRS Database



## Distribution of Fresh Water Use



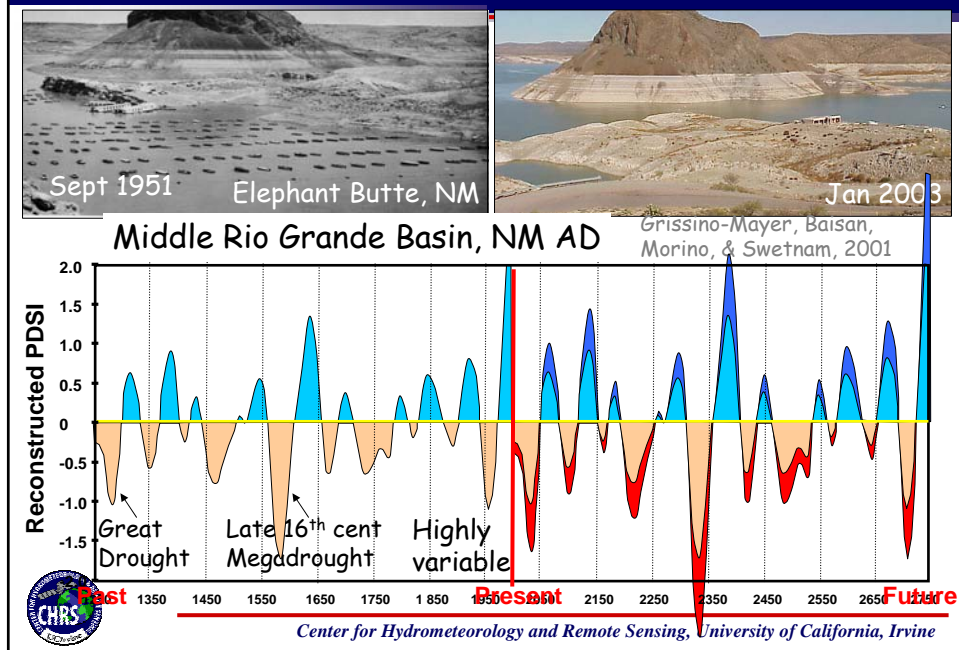
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# Current Practices in Factoring in Climate:

## In Water Resources and Hydrologic Planning

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## Potential Hydrologic Implications: Needs Work!



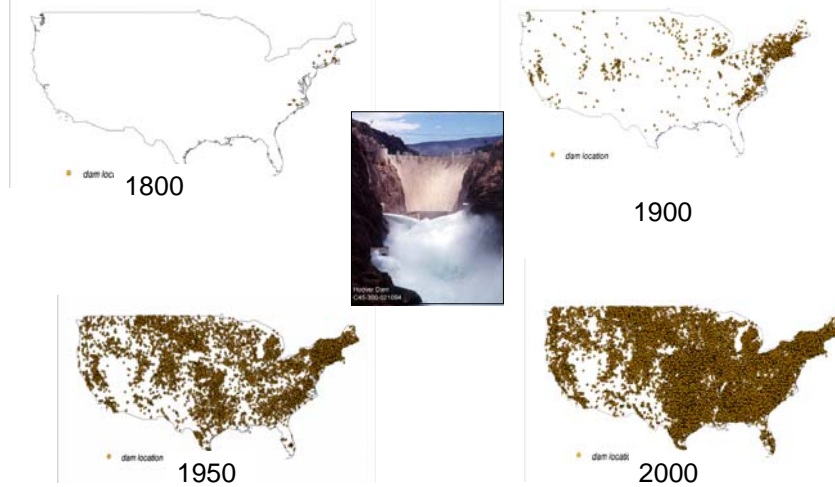
The slide features a background image of a desert landscape with mountains in the distance. A blue gradient overlay covers the bottom two-thirds of the slide. The text on the slide is:

*What is the Big Deal About  
Characterizing the Long-  
Term Uncertainties in  
Hydro-Climate Variables?*

In the top right corner of the slide, there is a logo for 'SAHRA' (Sahara Hydrologic Assessment and Remote Sensing) and a logo for 'CHRS' (Center for Hydrometeorology and Remote Sensing) in the bottom right corner.

## Impact on Design and Operation of Global Infrastructure

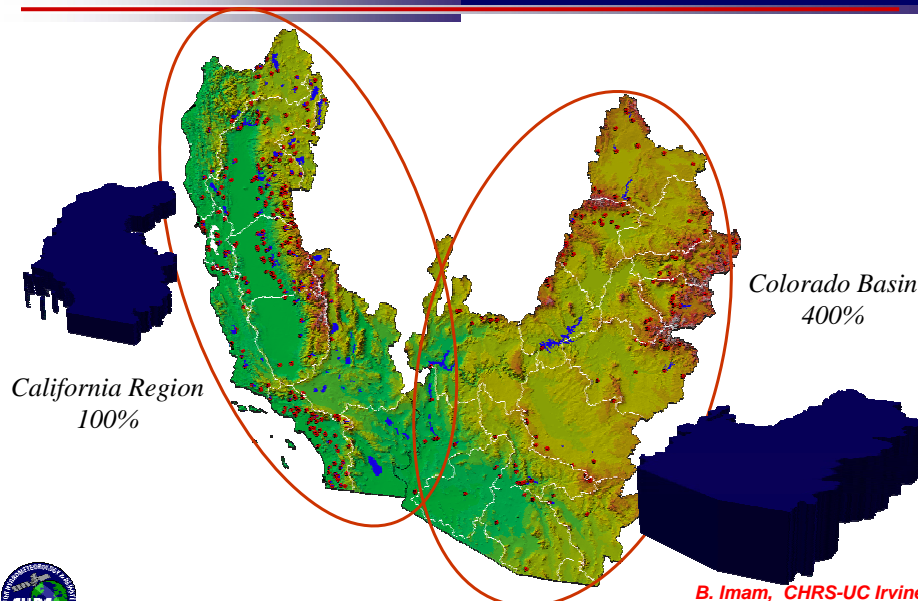
### More than 70,000 Dams in the U.S.



Provided by: C. J. Vörösmarty

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

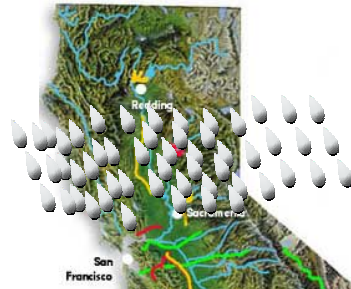
## Storage Capacity/Streamflow Relationship



B. Imam, CHRS-UC Irvine

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## Supply and Demand Variability of California



Nearly 75% of our supply is in Northern half

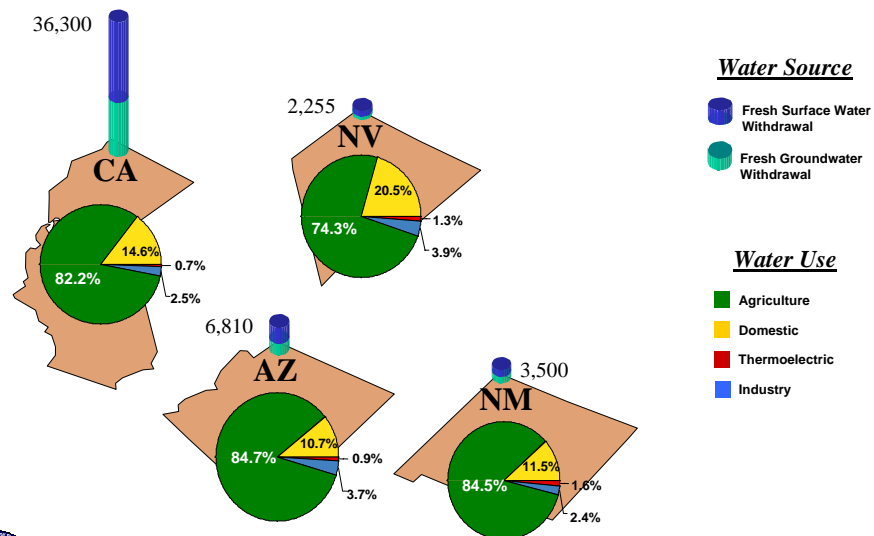


Almost 65% of our demand is in the Southern half and likely to grow with projected urban growth



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## Major Water Use Categories

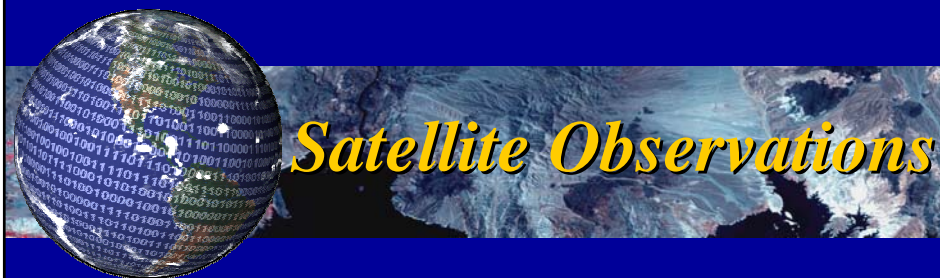


Data in Million Gallon/Day. Source: USGS Water Use Report 1995

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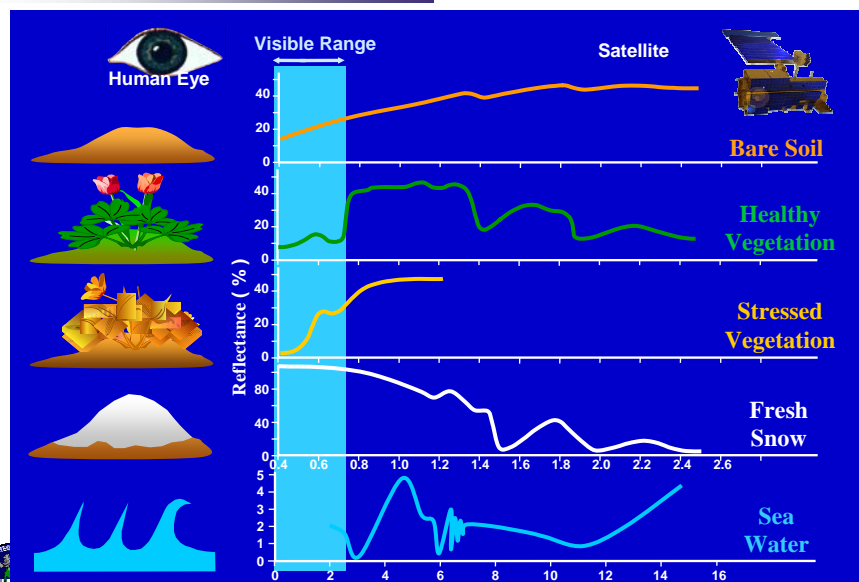


# “News From Space”



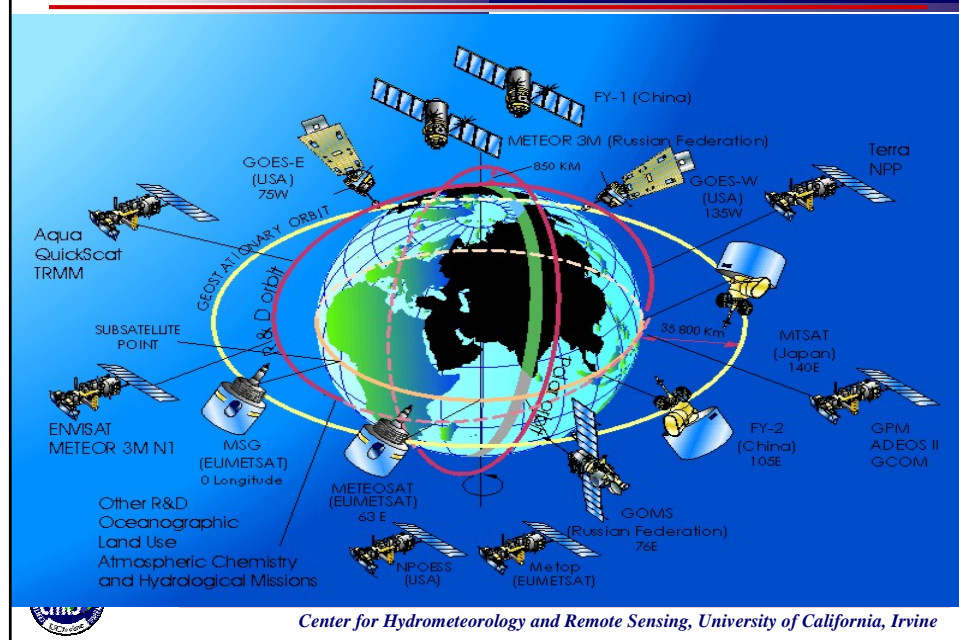
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## Remote Sensing Systems (Spectral Signal)

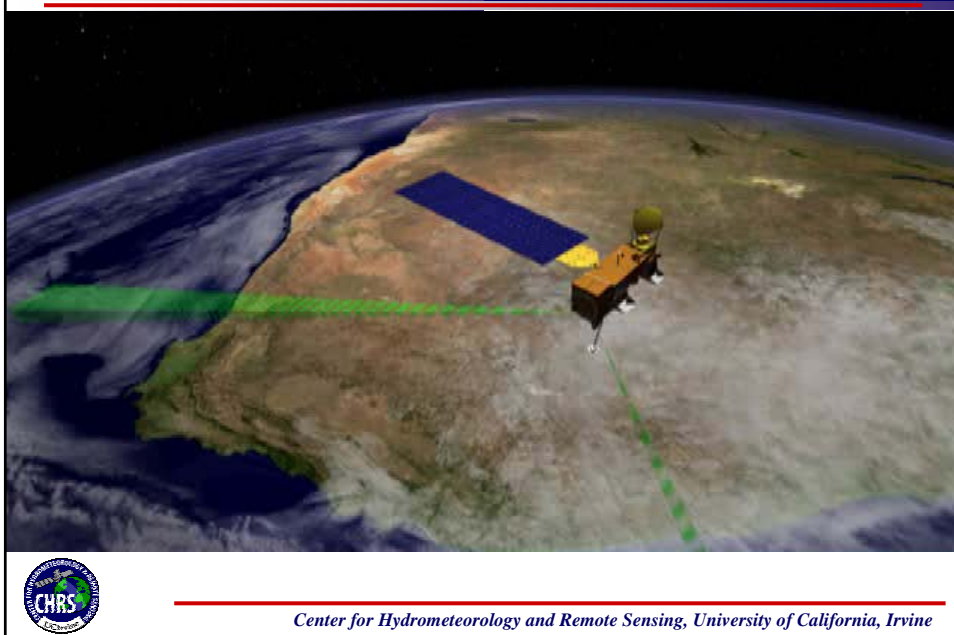


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## Current Meteorological and Earth Observing Satellites in Space



## Different Instruments Measure Different Things

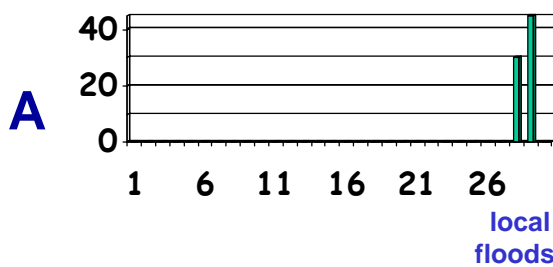


## A Key Requirement!



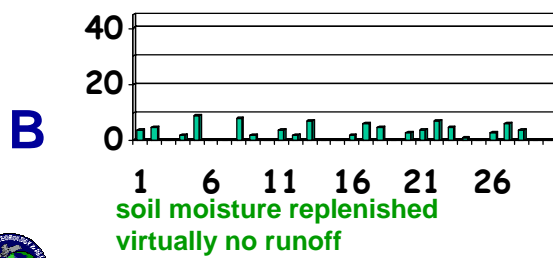
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## Temporal Scale Importance: Daily Precip. at 2 stations



**Monthly  
Amount 75 mm**

Frequency 6.7%  
Intensity 37.5 mm



**Amount 75 mm**

Frequency 67%  
Intensity 3.75 mm

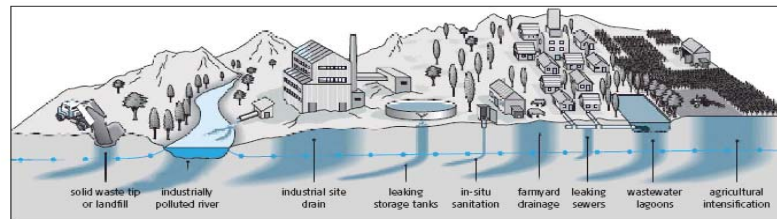


Source: K. Trenberth, NCAR

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# Water Quality Concerns

Figure 4.8: **Primary sources of groundwater pollution**



Note: This figure illustrates the type of sources that should be inventoried for cataloging potential sources of groundwater contamination.  
Source: Foster et al., 2002.



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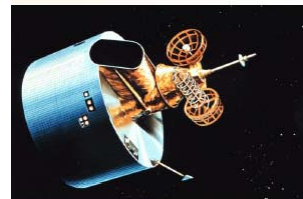
## Precipitation Observations: Which to trust??



Rain Gauges



WSR-88D Radar



Satellite



Sources: R. Fulton, D.-J. Seo, and J. Breidenbach, AMS Short-Course on QPE/QPF, 2002

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## TRMM DATA Swath

Courtesy: NASA's ESE



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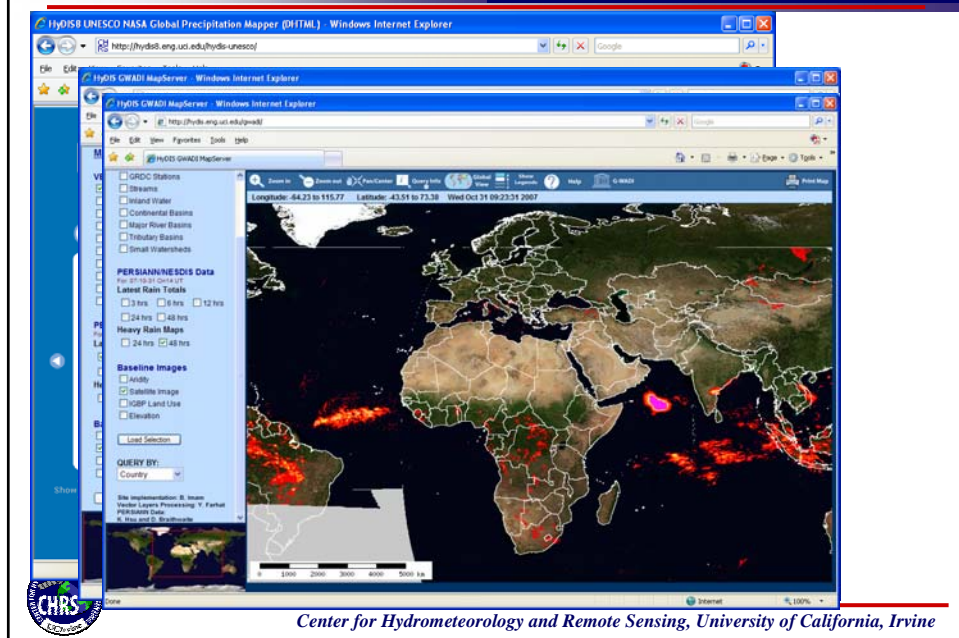
## TRMM Radar Capabilities: Katrina August 2005

Courtesy: NASA's ESE



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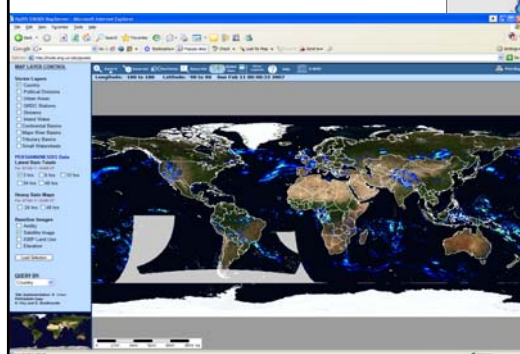
## Satellite Products: Promising future



## Some of the UCI-CHRS Rainfall Data Products

Animations of PERSIANN/CCS Images  
25km, 6 hour rainfall



<http://hydis8.eng.uci.edu/GCCS/>



G-WADI GeoServer:  
Near real-time 4km, 30 minute


<http://hydis8.eng.uci.edu/gwadi/>

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*Use of Satellite Precipitation Products  
for Hydrologic Applications:*

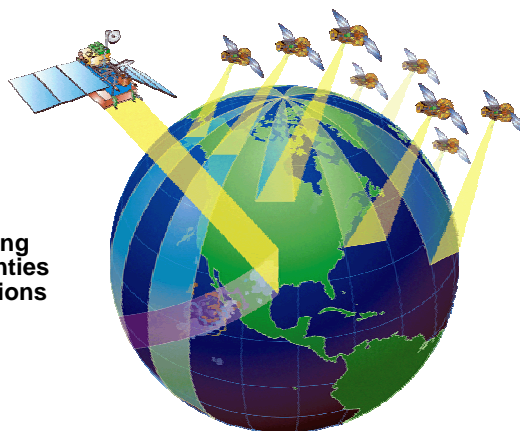
***Very Promising***



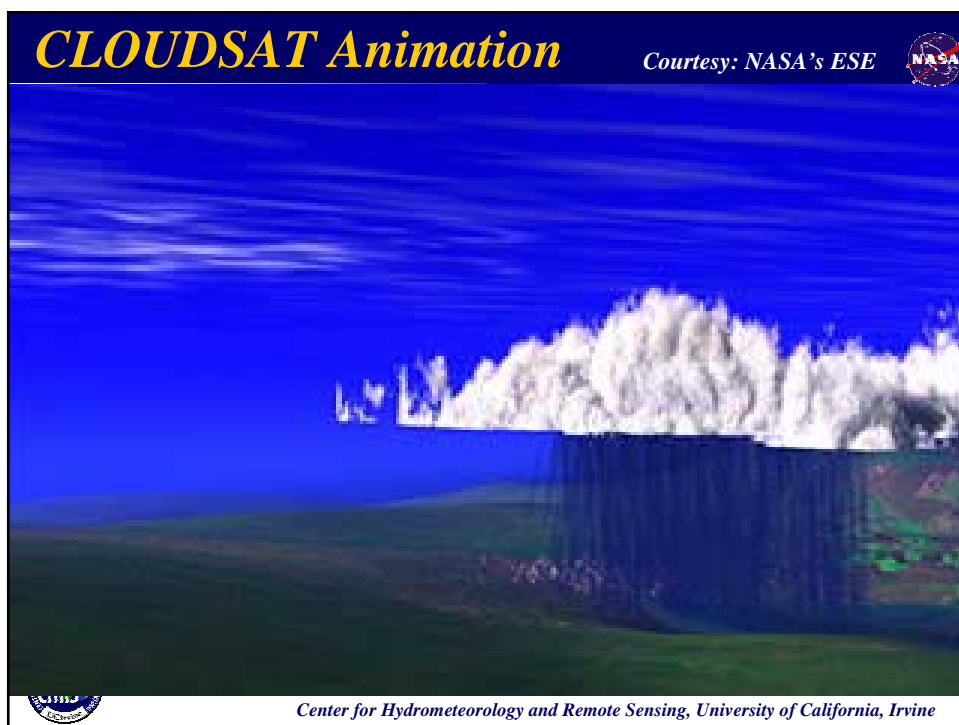
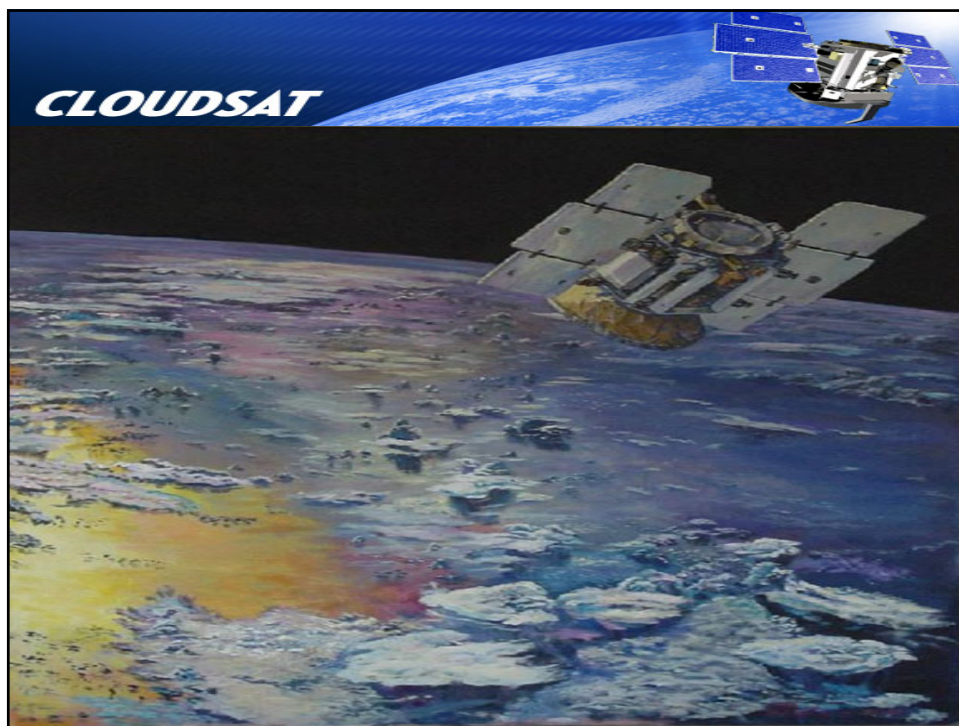
## ***GPM Mission: Target Date 2012?***

### **OBJECTIVES**

- 1 Main satellite + 8 Smaller Satellites \
- Provide sufficient global sampling to significantly reduce uncertainties in short-term rainfall accumulations

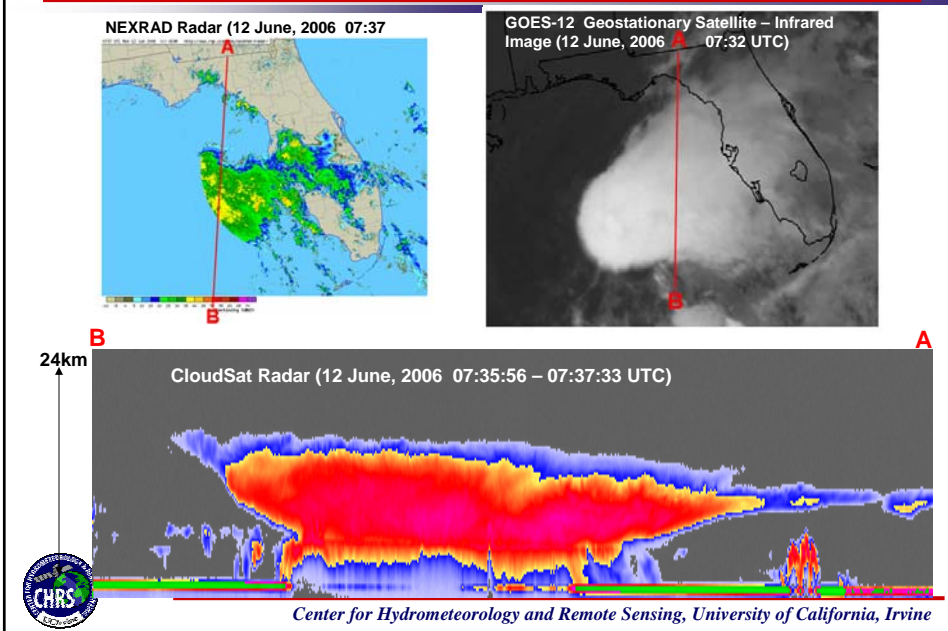


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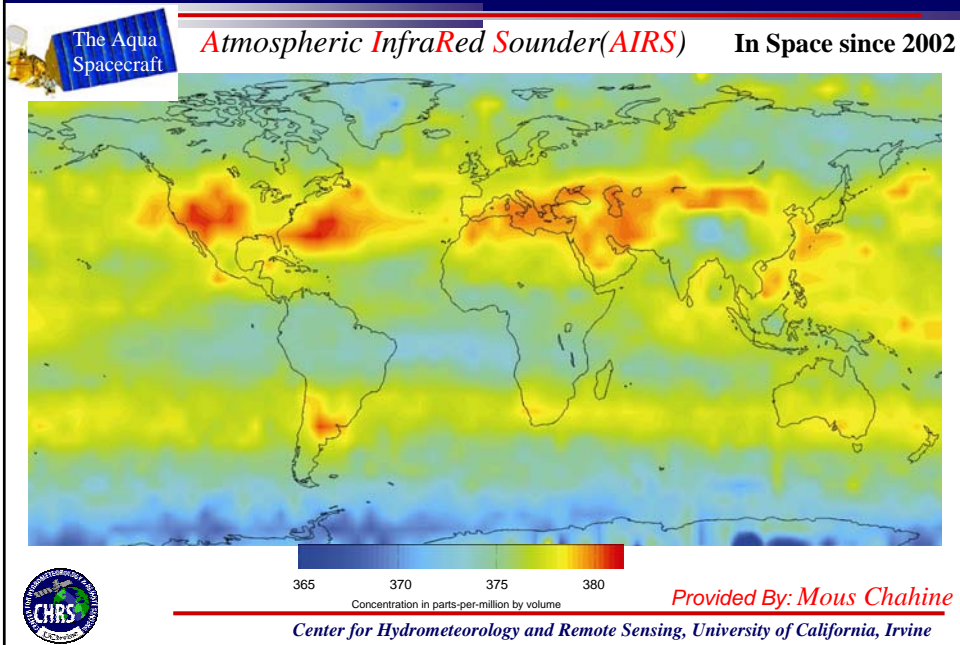




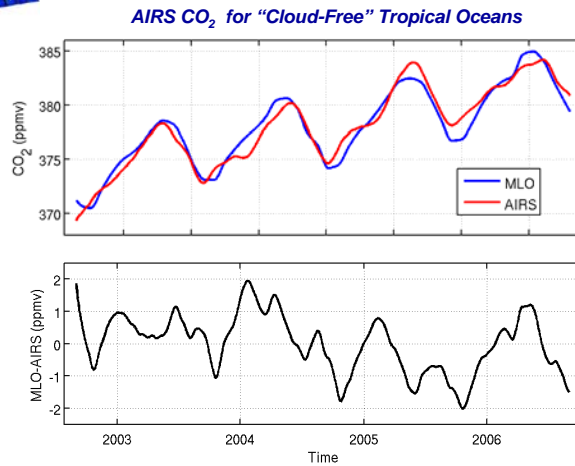
## CloudSat View of Tropical Storm Alberto



## NASA AIRS Mid-Tropospheric Carbon Dioxide: July 2003



## Comparison of CO<sub>2</sub> Annual Variations -- Mona Loa Observatory (MLO) and AIRS

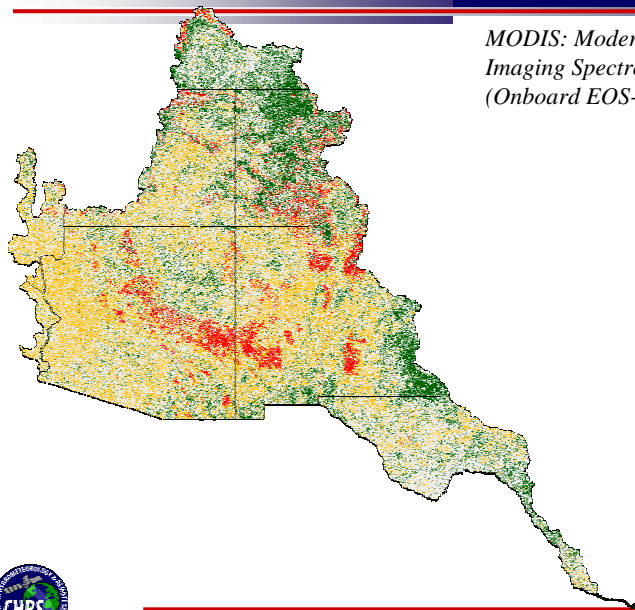


Larrabee Strow, U Maryland

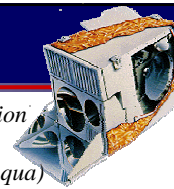
Provided By: Mous Chahine

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

## Early Detection of "Wild-Fire" Risk



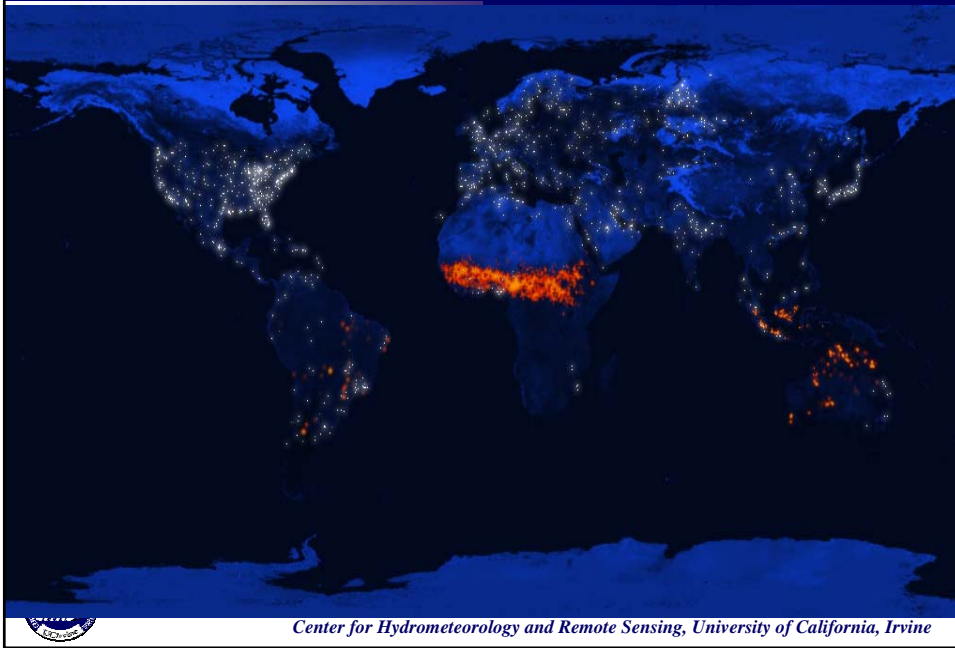
MODIS: Moderate Resolution  
Imaging Spectrometer  
(Onboard EOS-TERRA & Aqua)



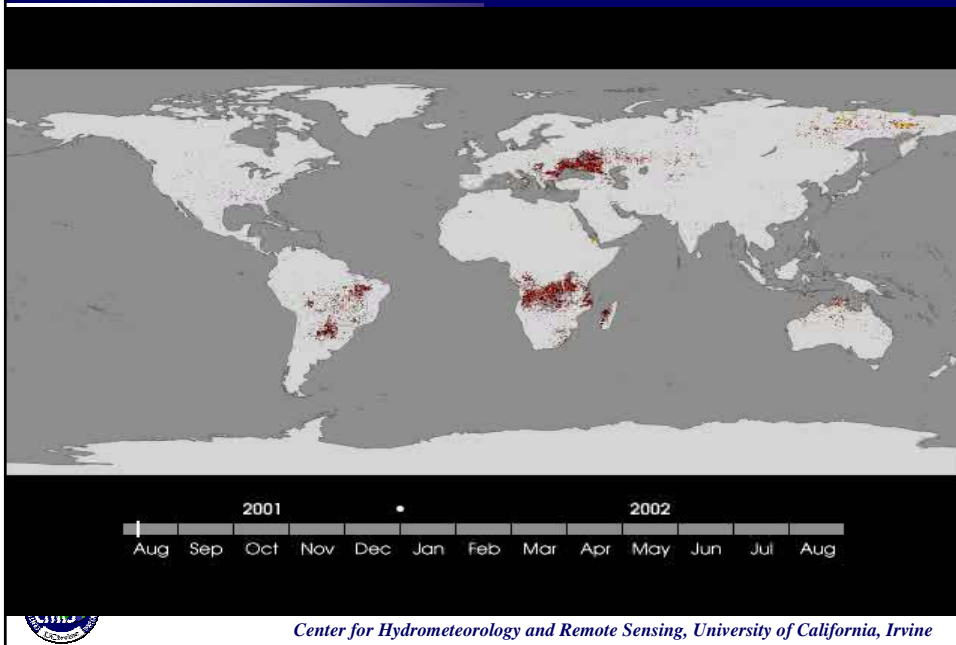
B. Imam, CHRS-UC Irvine

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

## *Global Fire Map from Space*



## *Monitoring of Global Fires from Space*

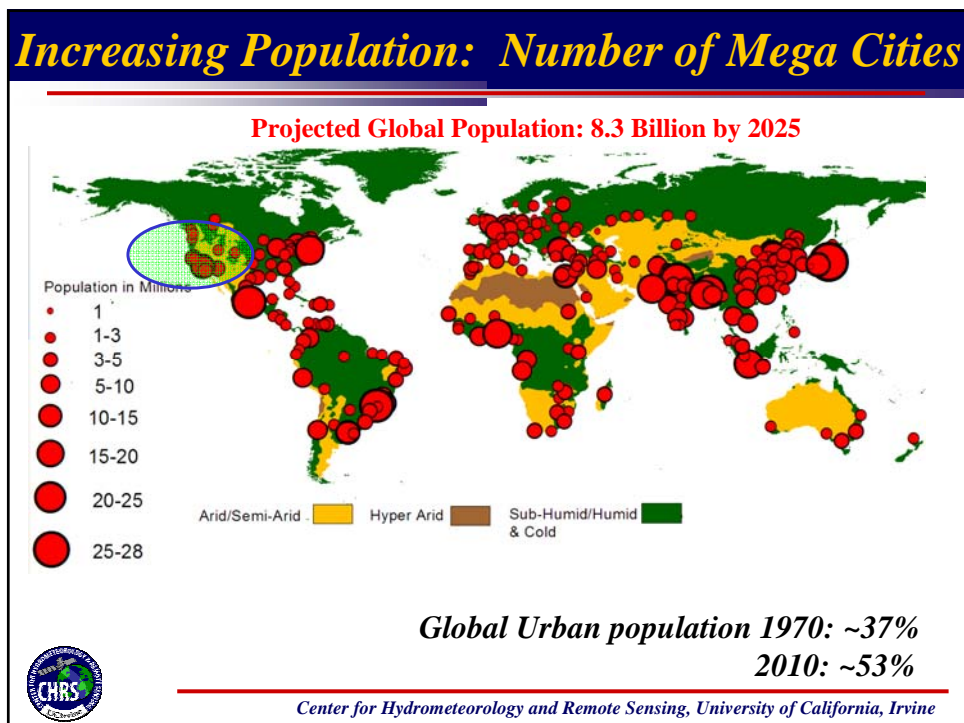





*In Brief:*

*While some of these results are based  
on very short life span of recent Earth  
Observing missions*

***They Are Very  
Promising!***



## Urban Effect on Rainfall



Courtesy: NASA's ESE



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## Approaching Climate- and Weather-Scale Issues in planning

**Simulation of Net Infiltration Over the Proposed Nuclear Waste Repository Site: Yucca Mountain, Nevada  
( Time Horizon: 10,000 years)**

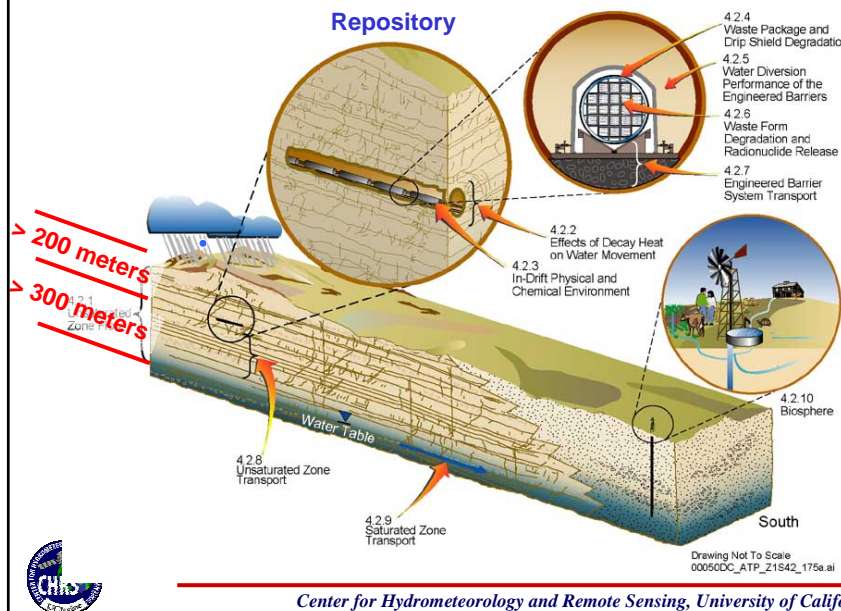
### Climate Scenarios:

- *Present-Day climate to persist for the next 400 to 600 yrs.*
- *Followed by Warmer and Wetter Monsoon climate (Lasting 900 to 1400 years)*
- *Followed by Cooler and Wetter Glacial-Transition Climate*



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# Yucca Mountain: Nuclear Waste Repository



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# CHRS Web Site



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