

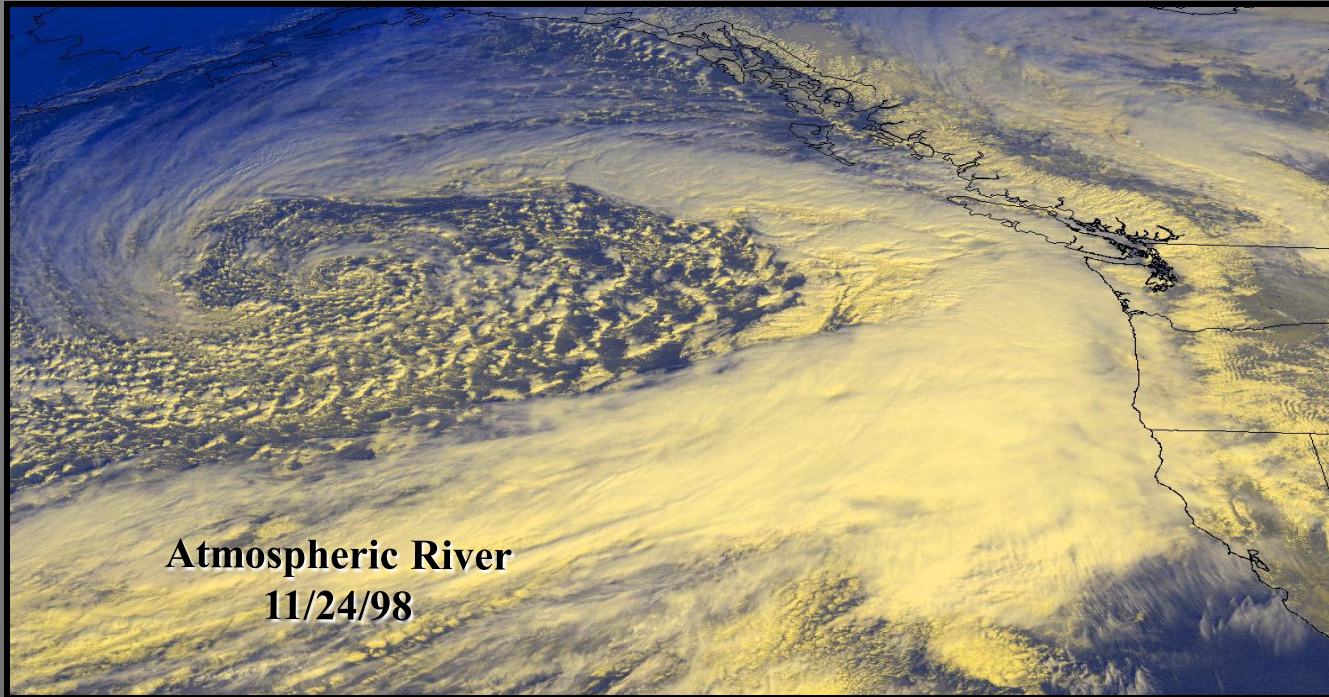


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Impacts of Atmospheric Rivers on Flooding the Northwest

Seattle Water Supply Operating Board

Nov 5th, 2009



Atmospheric River
11/24/98

Larry Schick

Meteorologist, Water Management
Army Corps of Engineers - Seattle



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NW Weather and Hydrology



- Winter rain: Western WA & OR
- “Flashy” basins; flood develops 12-36hrs
- Intense rainfall – from Atmospheric Rivers
- Steep terrain means rapid runoff concentration

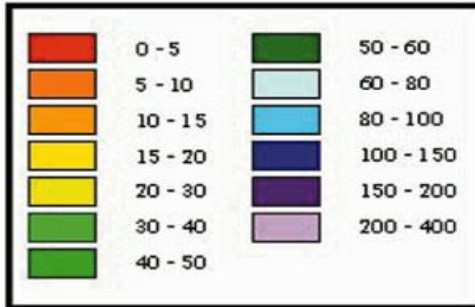


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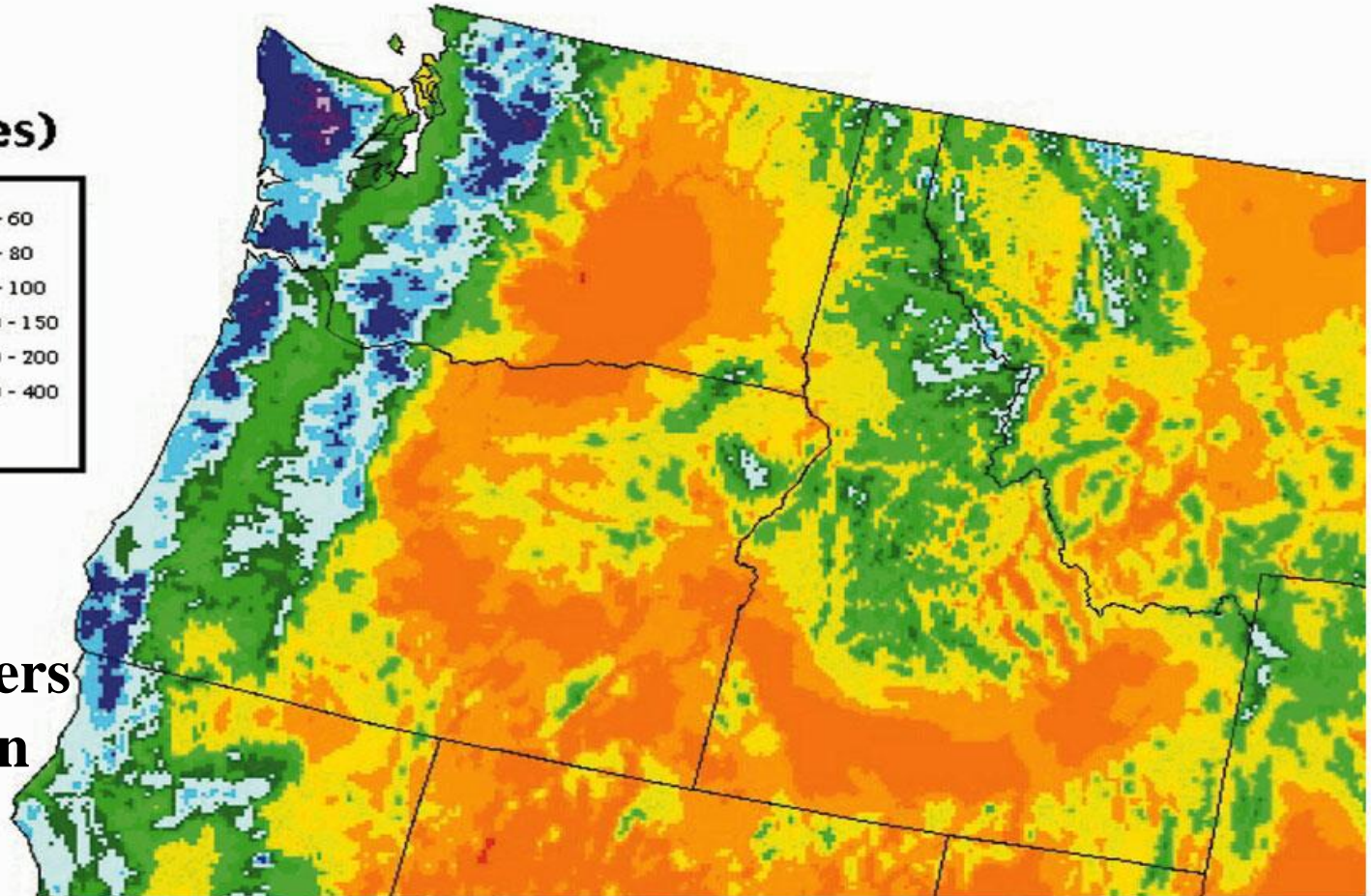
NW Weather and Hydrology

Average Annual Precipitation, Pacific Northwest, 1961-1990

Legend (inches)



- Wet / Mild
- Dry Summers
- Winter Rain



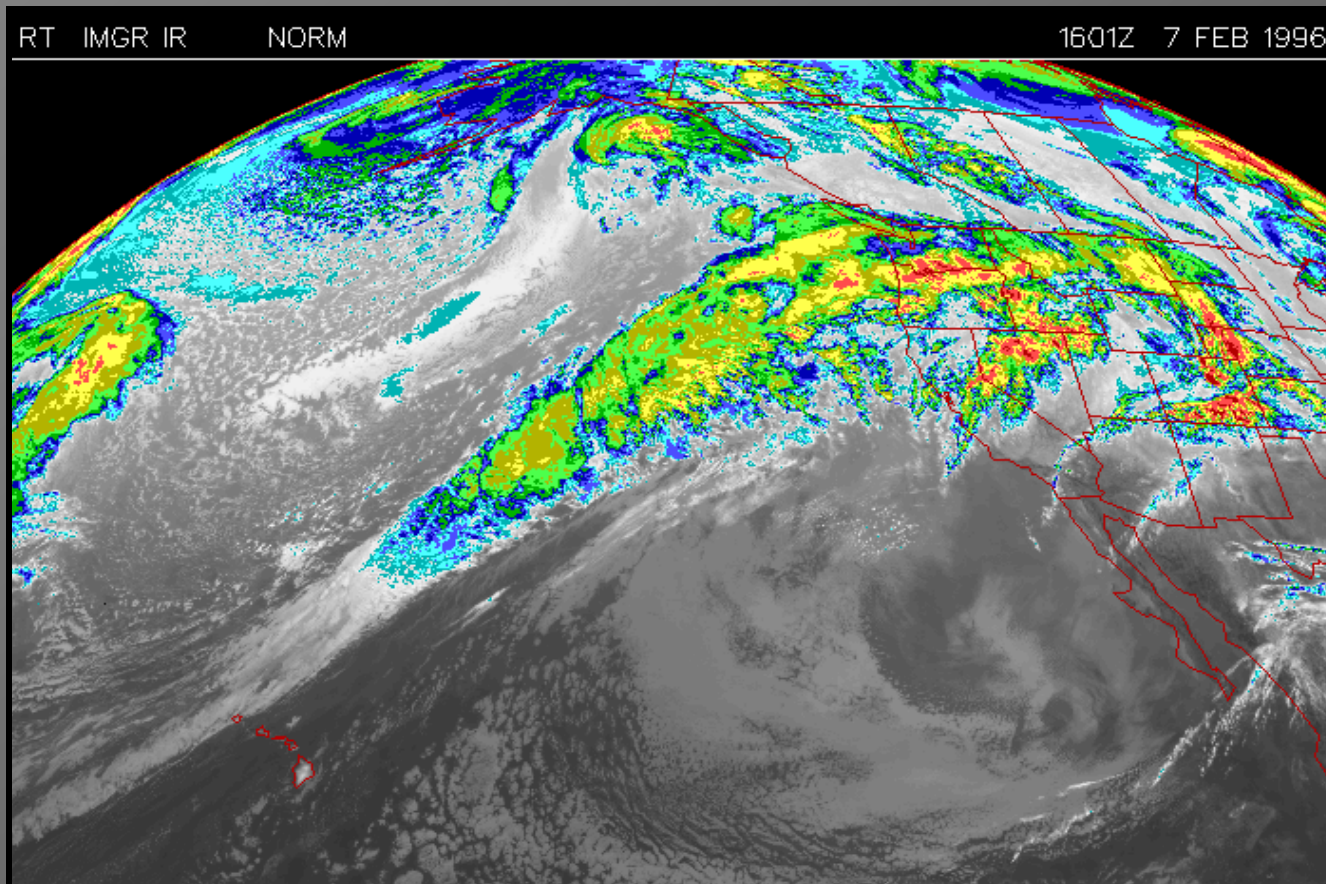
The Cascade mountains divide the wetter west from the drier east. Source: Mapping by C. Day, graphic by G. Taylor and J. Aiken, copyright ' 2000, Oregon State University.



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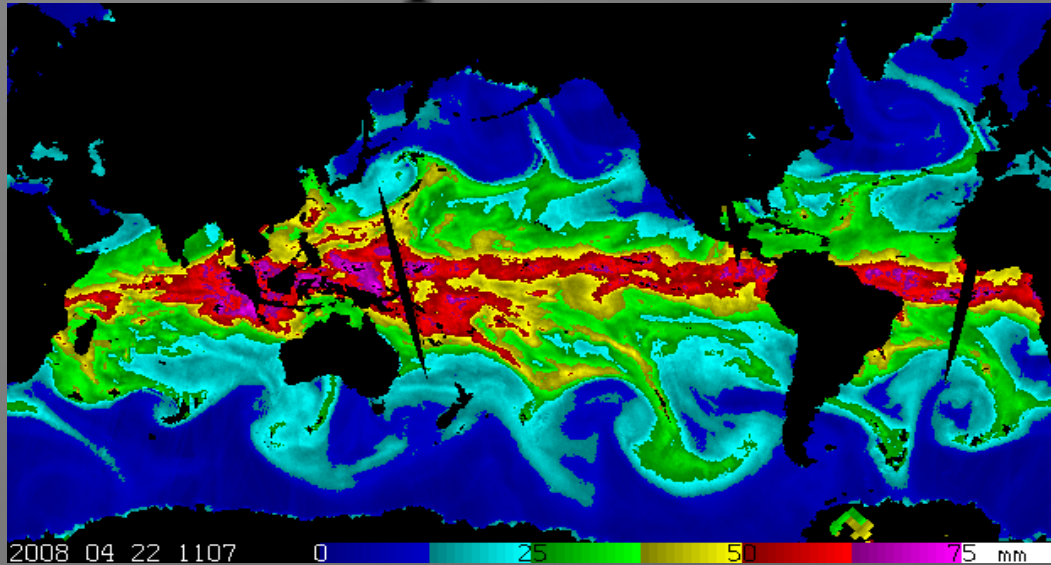
What is an Atmospheric River (AR)?

What is the Pineapple Express?





Atmospheric Rivers



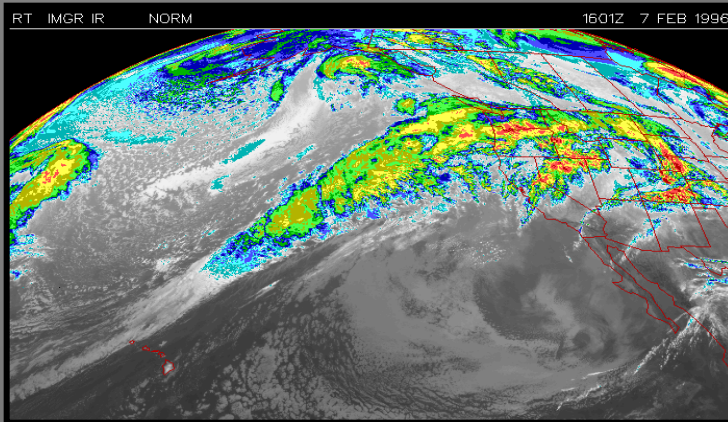
- Elongated, narrow, water vapor transport (< 200 miles wide, > 2000 miles long).
- Warm ($+ 10$ degrees) and moist ($> 2\text{cm}$ IWV)
- Strong low level winds (850mb jet)
- Moisture Source: Local & regional convergence
“Pineapple Express” when near Hawaii
tropical moisture source



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All Major Western Washington Floods are caused by Intense Atmospheric Rivers

Rivers in the Sky



Result in Flooding

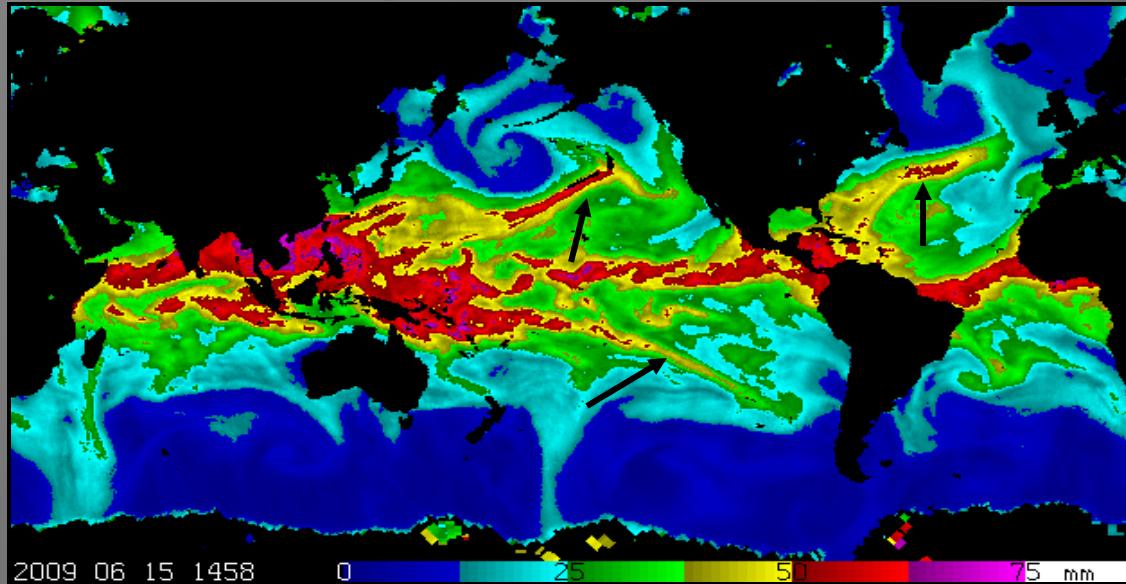




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Atmospheric Rivers

A key to understanding West Coast extreme precipitation

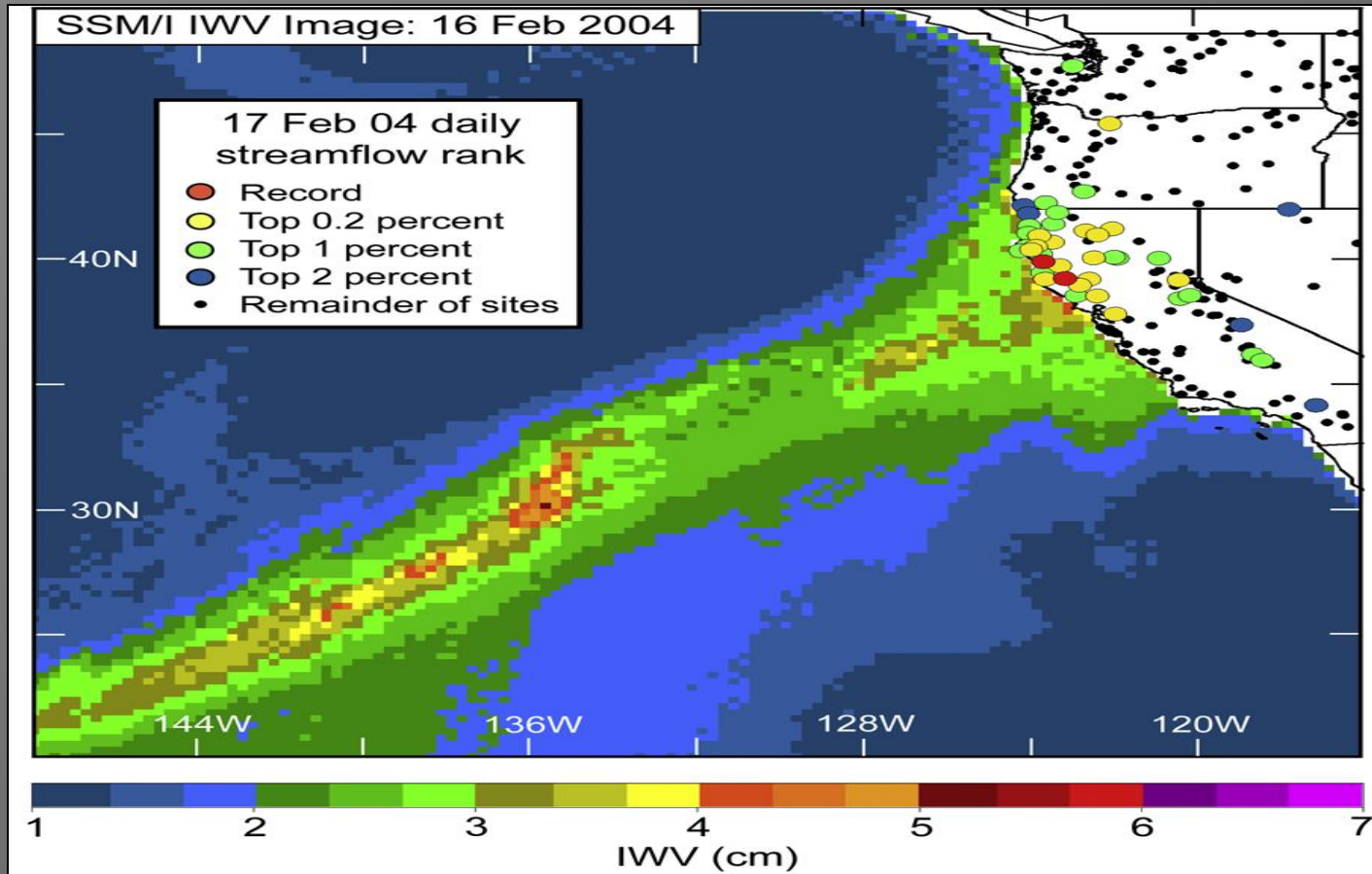


- Occur year round
- Most intense for NW, October – March.
- Often set rainfall records
- Always associated with NW winter flooding



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Atmospheric River and Flooding





Atmospheric Rivers

- Occupy 10% of the mid-latitudes
- Carry 90% of poleward moisture – a link between weather and climate
- 3-5 atmospheric rivers per hemisphere
- Transports three times as much water as the Mississippi
- One hundred yard wide pipe gushing water at 30 mph



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HEAVY RAIN, BREEZY
High, 52. Low, 45.
> LOCAL B14

WEDNESDAY, JANUARY 7, 2009

The Seattle Times



Independent and locally owned since 1896 | seattletimes.com
1.5 million readers weekly in Western Washington, in print and online

75¢

DOWNPOUR

Deluge will hit Cascade snowpack

BY SANDI DOUGHTON
Seattle Times science reporter

Cities across Western Washington are bracing for another slap from a season that has already dealt the region a series of nasty blows.

This time, the pain will come in the form of drenching rain followed by floods and the threat of landslides and avalanches, forecasters warned Tuesday. Some rivers, particularly in Lewis County, could reach record levels, and it's possible Interstate 5 near Centralia could be submerged again — as it was for sev-

Flooding may close I-5 again at Centralia

eral days in December 2007.

Major flooding also was forecast on the Skagit River near Concrete, the Snohomish River near Monroe, the Tolt River near Carnation, and the Snoqualmie River near Carnation and Snoqualmie Falls.

Please see > **FLOODING, A6**

WEB EXTRA

The latest forecast, traffic alerts and a list of flooding-related resources are at seattletimes.com



COURTNEY BLETHER / THE SEATTLE TIMES

High winds and rain on Tuesday caused cars to inch along the 520 bridge.

City never responded to Metro's plea to plow

CALLS WEREN'T RETURNED, BUS-SYSTEM CHIEF SAYS

Poor communication crippled transit snow plan

BY EMILY HEFFTER
Seattle Times staff reporter

A chaotic command center and poor communication with Seattle road crews kept so many buses out of service that Metro's emergency snow plan was all but useless during the Christmas snowstorm that stranded thousands of riders, a Metro official said Tuesday.

King County Metro General Manager Kevin Desmond told the City Council that

Please see > **METRO, A6**

Contribute significantly to seasonal rainfall and snow pack

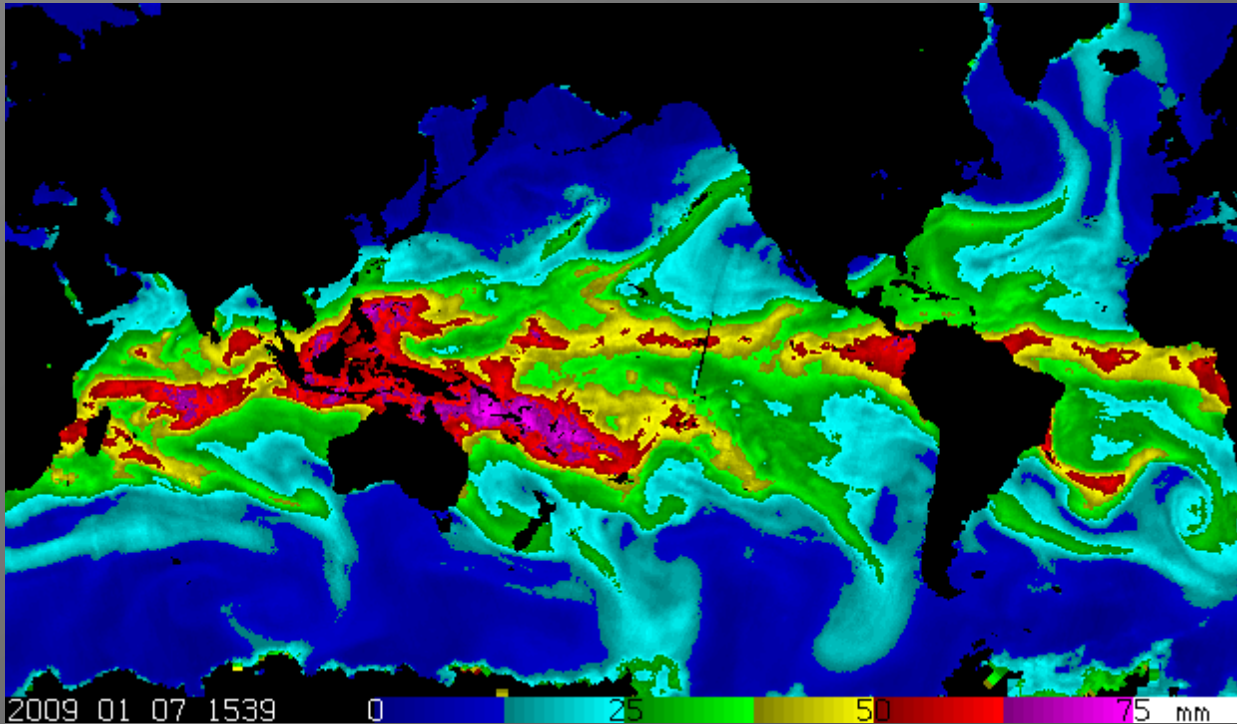
Produce intense, extreme precipitation
Results in flooding and landslides



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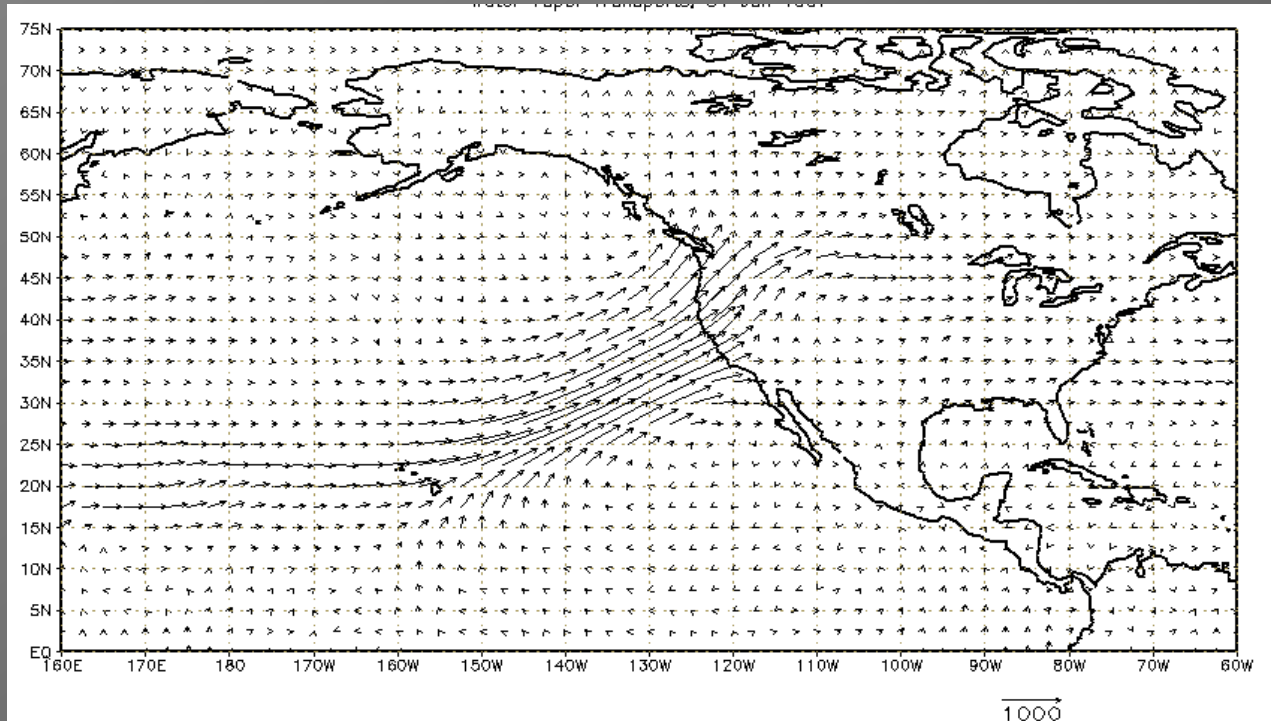
Atmospheric River Detection

- Passive Microwave Satellite Imagery
SSM/I and AMSU or Blending





Pineapple Express is a type of Atmospheric River

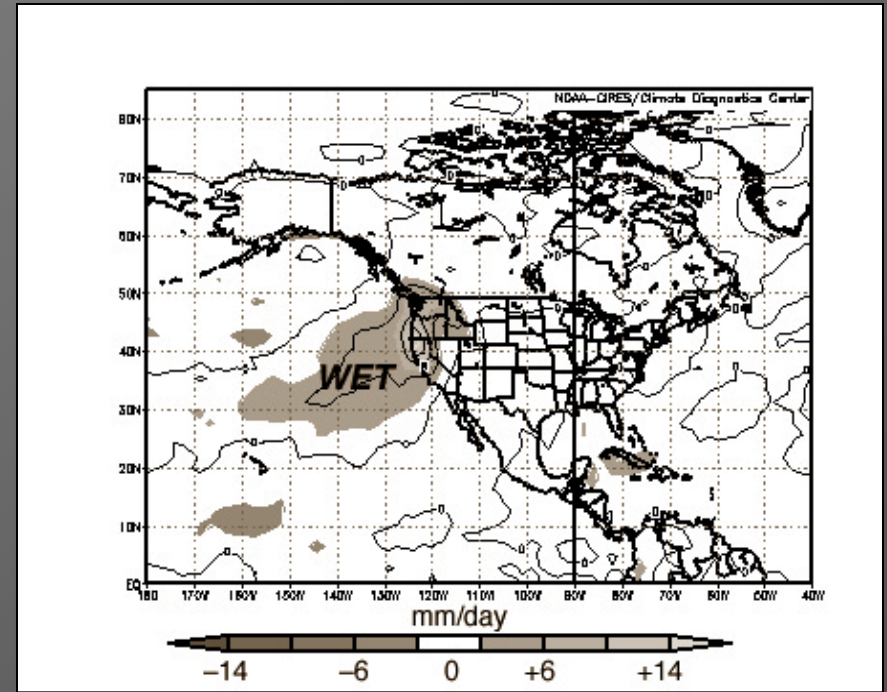
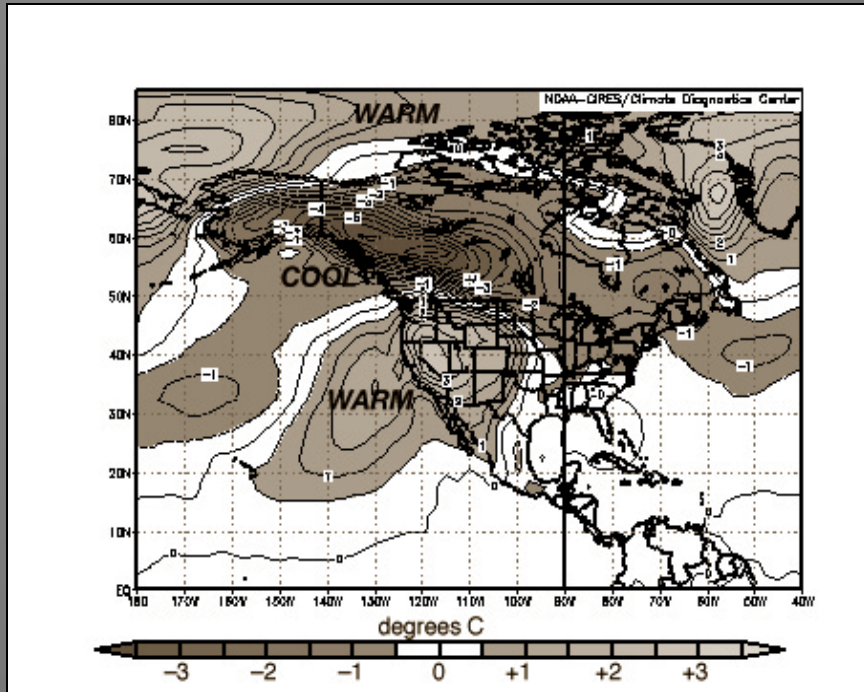


**Atmospheric river which originates near Hawaii ,
tapping tropical moisture.**



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Atmospheric River Anomalies





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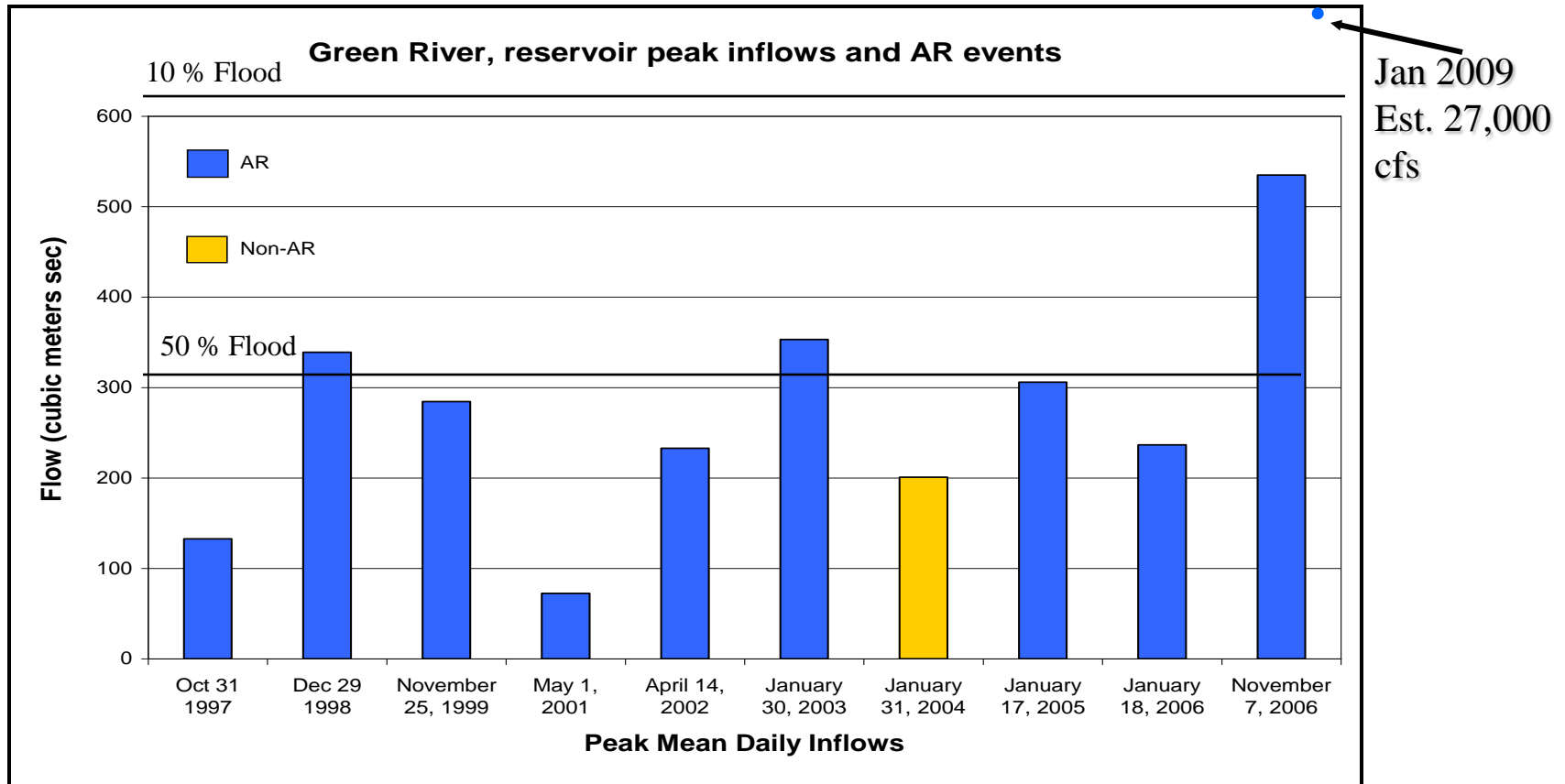
Method of Study

Match peak annual flow with known
atmospheric river patterns for water year
1997 - 2008



Locations of river basins in study

Peak Annual Flow and AR Events Green River Inflows



The largest floods were atmospheric rivers



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Results

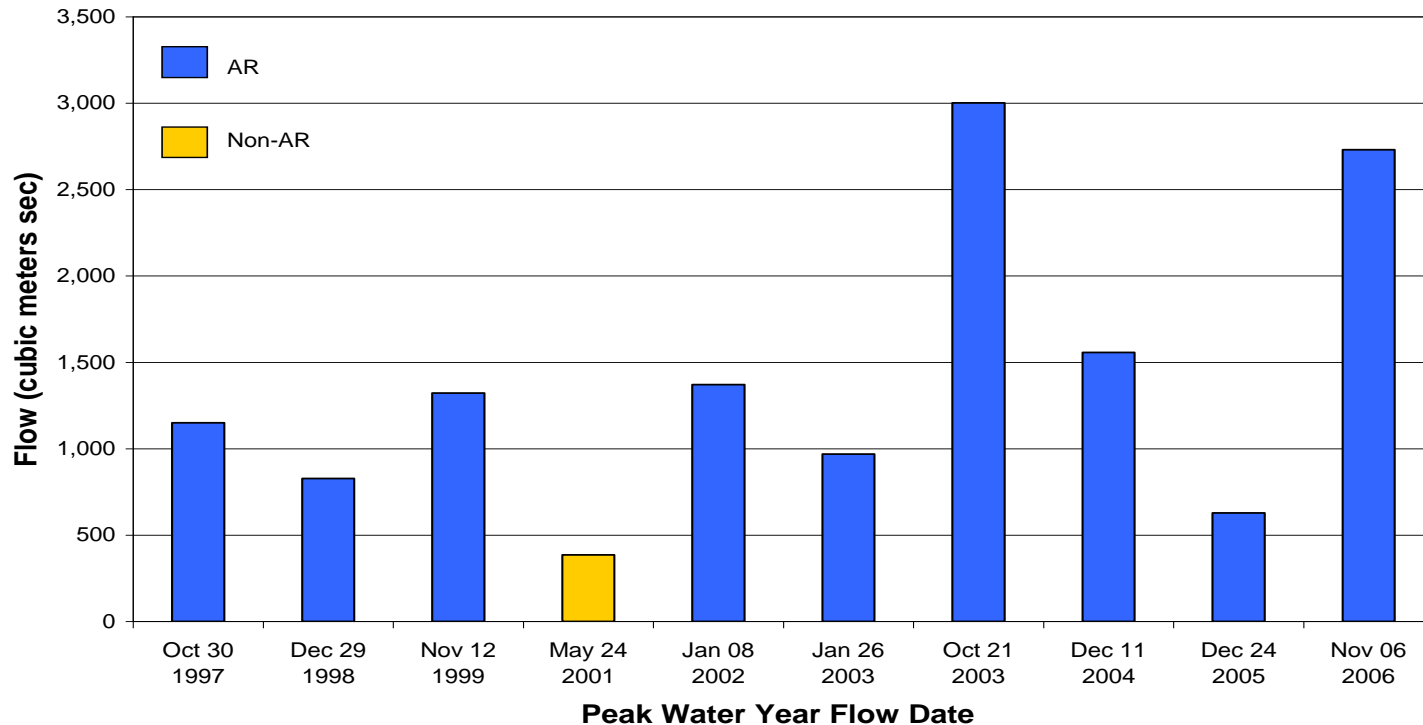
Atmospheric river weather patterns were responsible for all major floods and most modest floods



*Mud Mountain Dam -- Enumclaw, WA
Nov. 2006 - Evacuation discharge of 12,000 cfs, after AR induced flood peak*

Peak Annual Flow and AR Events

Skagit Basin, peak Sauk River flows and AR Events

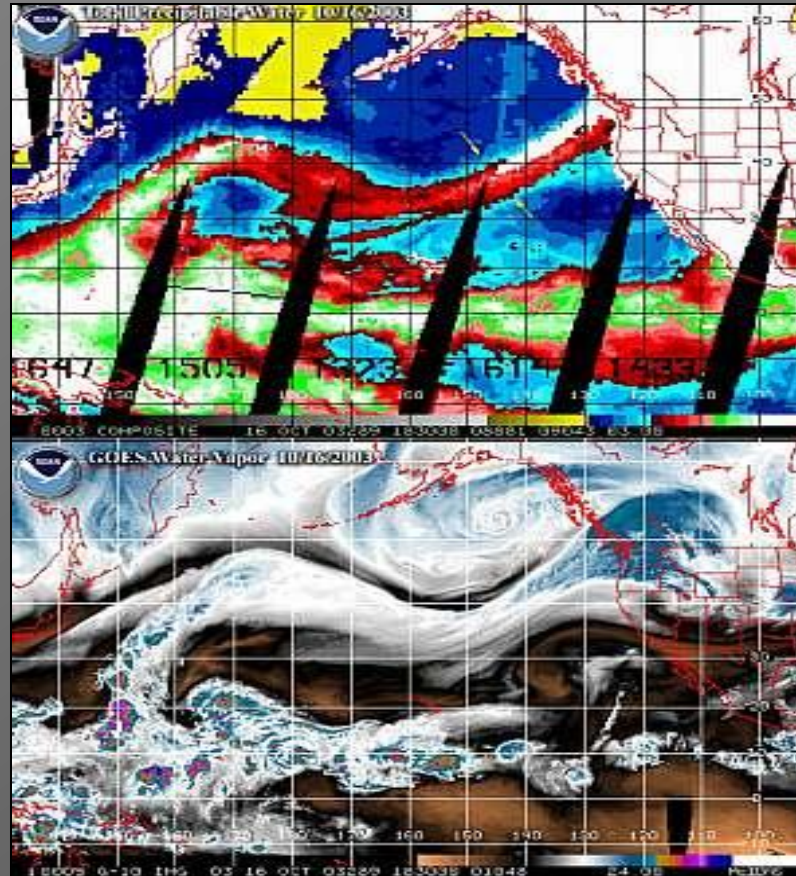


All floods are AR events. Oct. 21, 2003 occurred without antecedent flood conditions

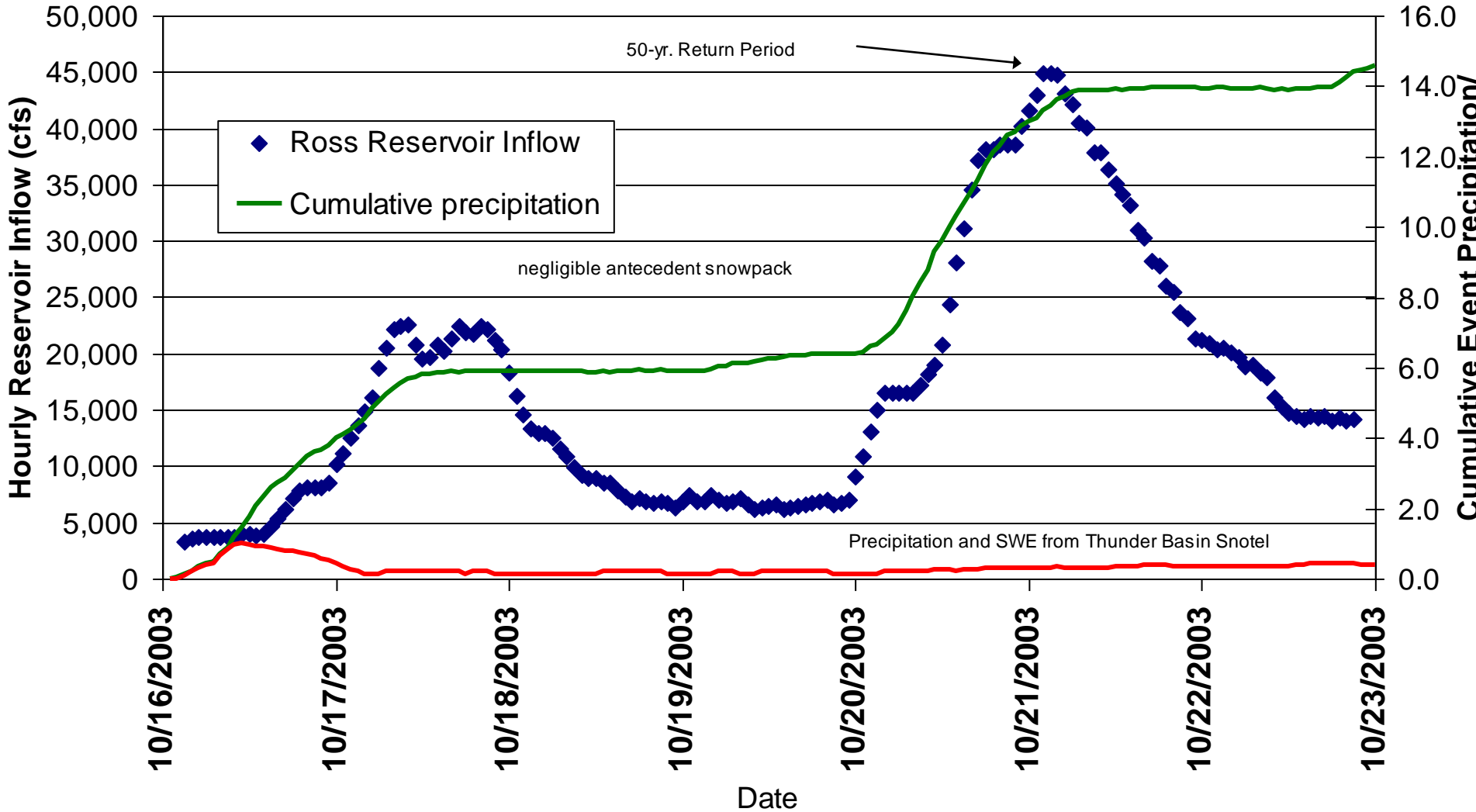


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Atmospheric River October 2003

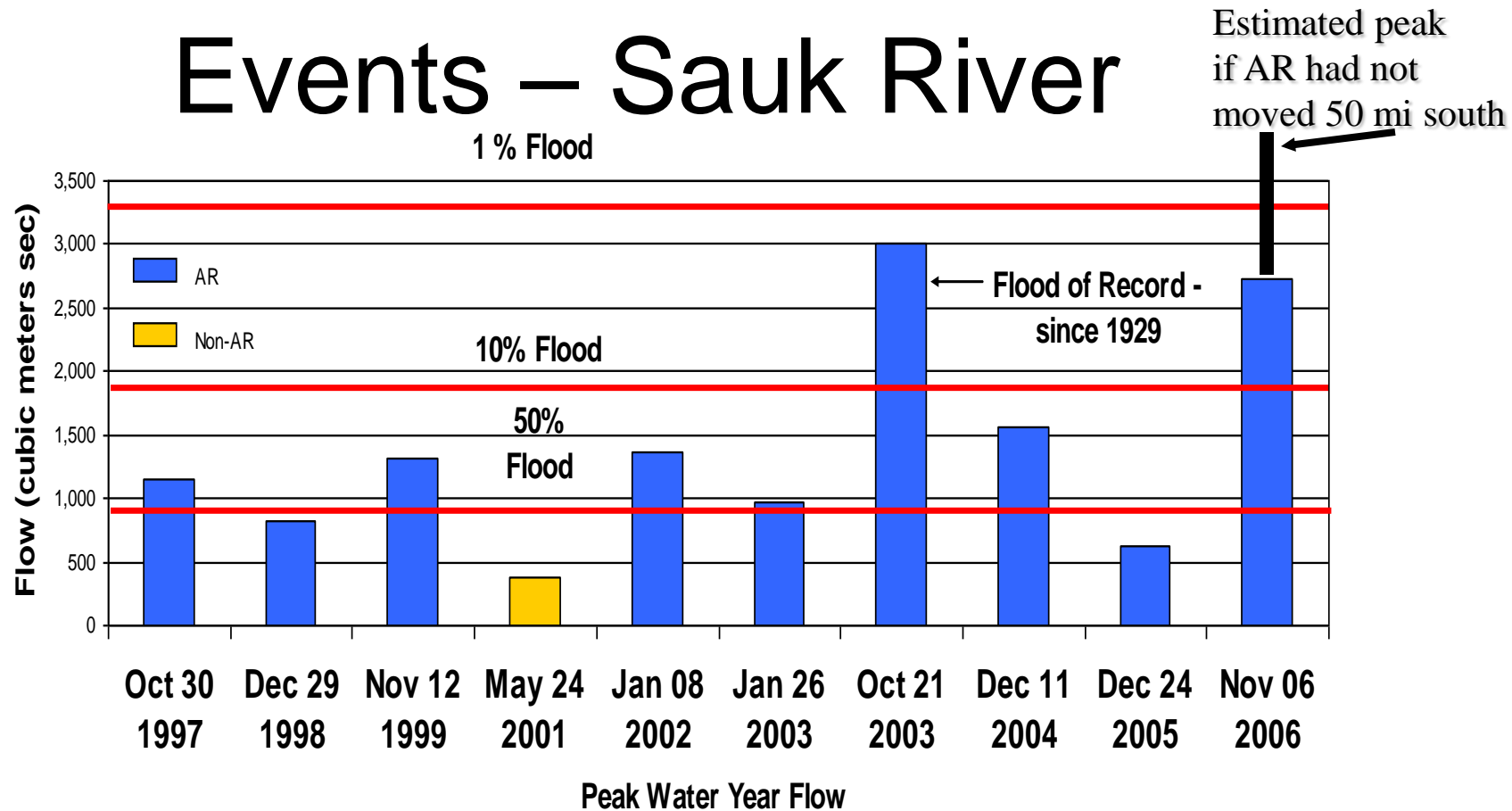


October 2003 Flood Event Skagit River Basin, WA



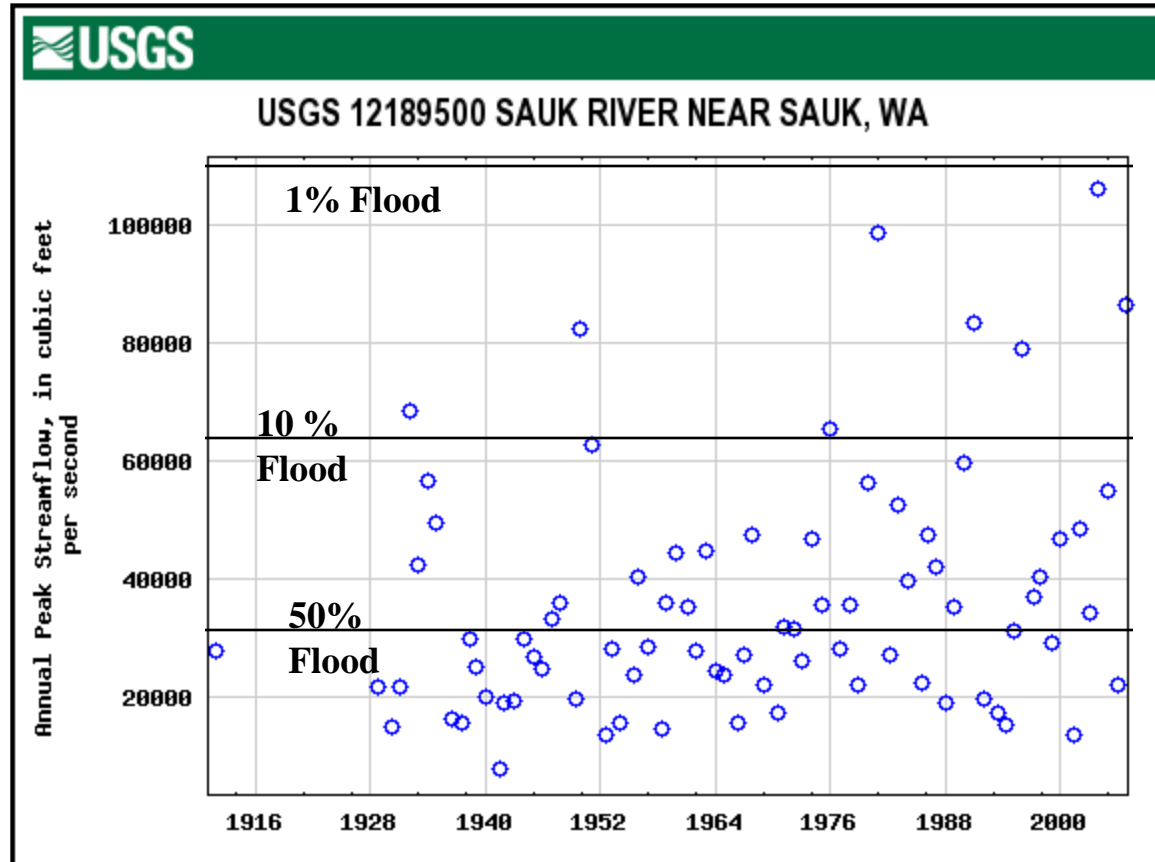
Major flooding caused solely by an AR without antecedent flood conditions

Peak Annual Flow and AR Events – Sauk River



All floods are AR Events. Oct. 21, 2003 occurred without antecedent flood conditions

Annual Peak Flow Sauk River

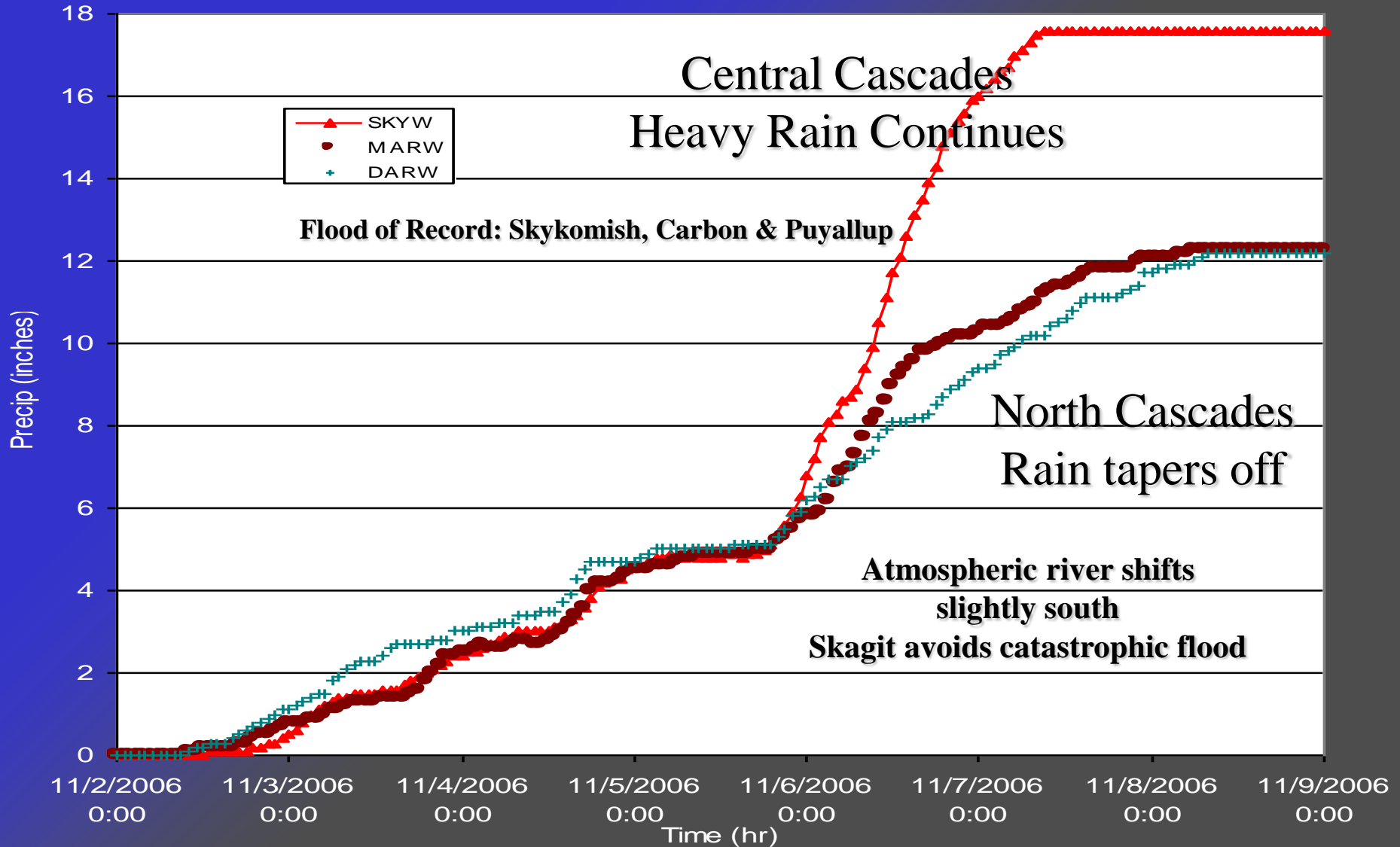




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Precipitation

Rainfall





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Skykomish River

November 2006 – record 129,000cfs



Courtesy of Professor Paddle Website



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of Engineers

White River, OR

SE side of Mt Hood, HWY 35

← Downstream



November 2006
After Nov 7th AR



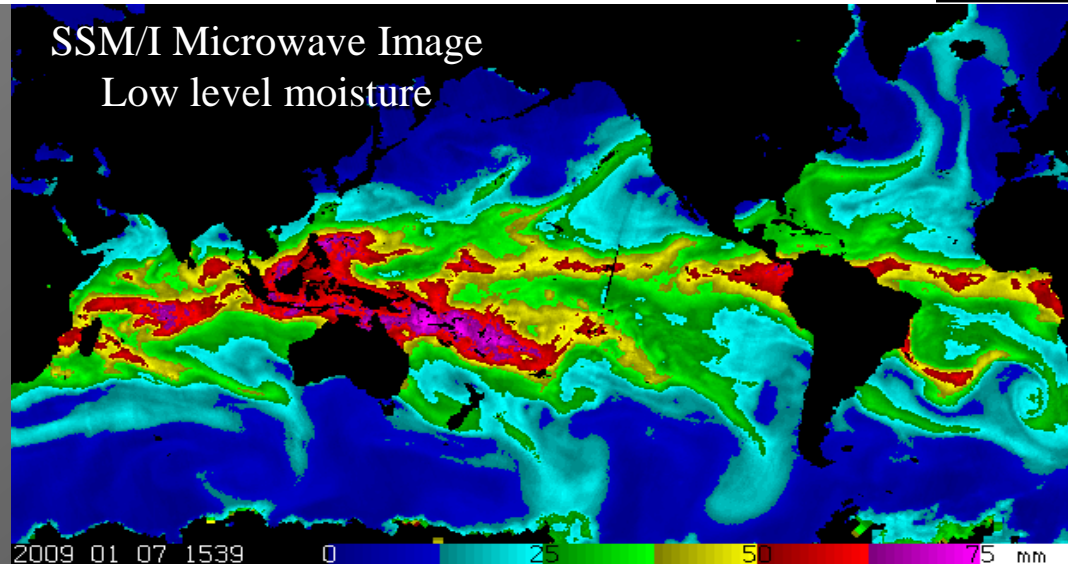
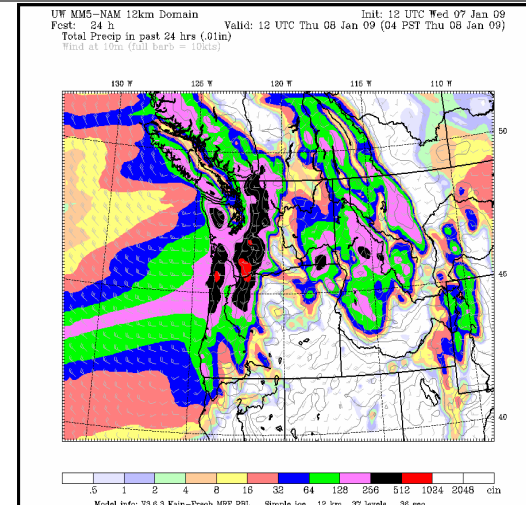
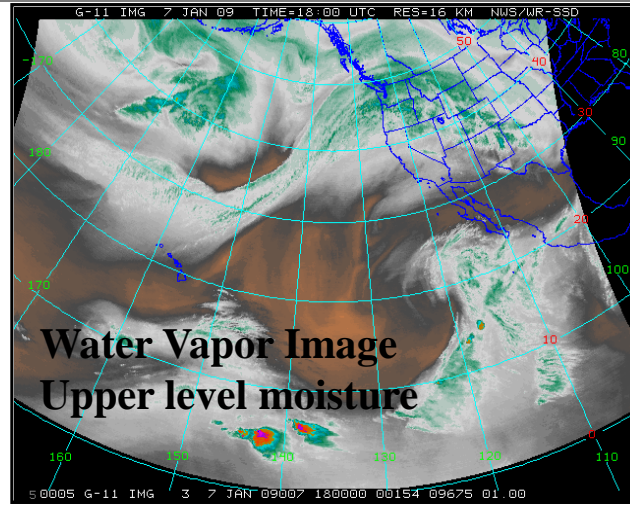
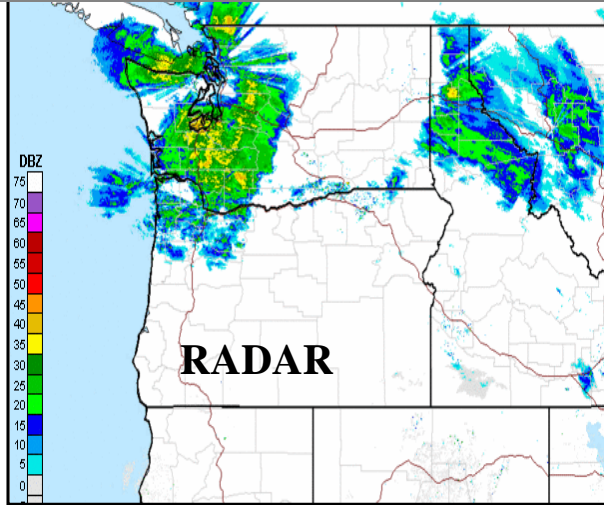
April 2008
After clean up



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January 2009 Flood

24 hour rainfall Forecast model





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Conclusions



- All major floods in Western Washington were caused by atmospheric rivers
- Major flooding can be caused solely by an AR without typical pre - existing flood conditions. ARs are a necessary and sufficient condition for flooding
- Understanding the nature of ARs will assist forecasters evaluating flood potential
- Basin orientation, narrowness and specific location of AR core precipitation should be noted and respected.



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Amazing ARs



Continuous Intense Rainfall

- .10 -.30 / hr - common - (12 -72 hrs)

AR Core

- .30 - .50 / hr – not unusual – (6-24hrs)
- .60 -1.20 / hr – occasional – (few hours)

Storm Totals (24-72hrs)

10'' - 40''



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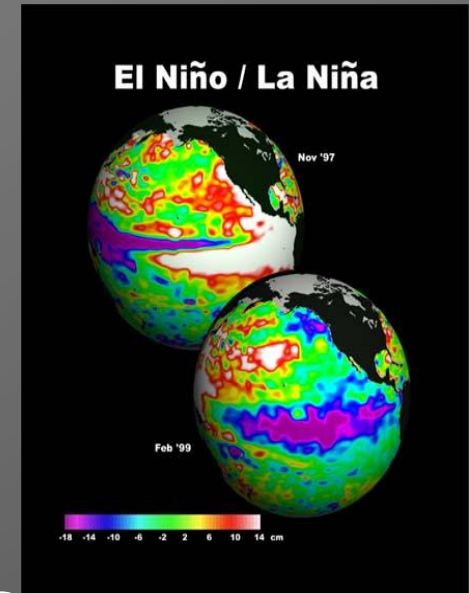
ARs and ENSO

ENSO Neutral: Most Extreme ARs
West Coast (California & NW)

La Nina: Pacific NW – Highest Frequency ARs
California – Lowest Frequency ARs

El Nino: California – Highest Frequency ARs
Pacific NW – Lowest Frequency of ARs

MJO Connection - Currently Researched





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Amazing ARs



24 hour rainfall

- Cushman Dam (760ft): 13.10” Dec 2007
- Seattle (100ft): 5.02” Oct 20, 2003
- Shelton (20ft): 7.68” Dec 2007
- Raccoon Creek (1086ft) 9.29” – 10hrs Dec 2007



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NW Flooding Myths



Rain Causes Major Flooding

Rain on Snow and resulting Snow Melt
Causes Flooding



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NW Flooding Myths



Rain Causes Major Flooding

INTENSE Rain causes Major Flooding

Rain on Snow and resulting Snow Melt
Causes Flooding

Snowmelt contributes 10 – 20% of runoff



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Amazing ARs



Not just Rain – INTENSE Rain
November 2006

Wettest of any month on Record

- Seattle – 15.59”
- Cascades foothills: 27.35”

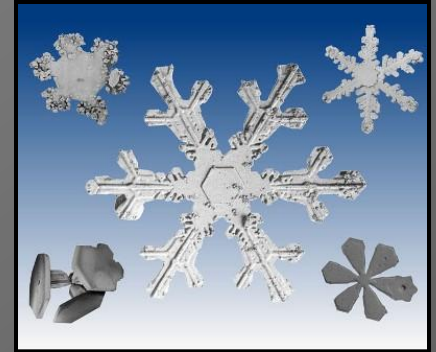
Only one flood: Nov 6 -7 – One atmospheric river



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Amazing ARs

Impact on Snow



Depends on elevation and AR core location

Increases snowpack

Melts snowpack (limited)

Absorbs & stores rainfall into snowpack

January 2009 Washington Cascades - all three effects



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Amazing ARs

Avalanche Risk Increases

- Heavy snow or rain
- High winds
- Warmer temperatures

Road Closures More Likely



Interstate 90 - Snoqualmie Pass, WA
Elevation 3000ft



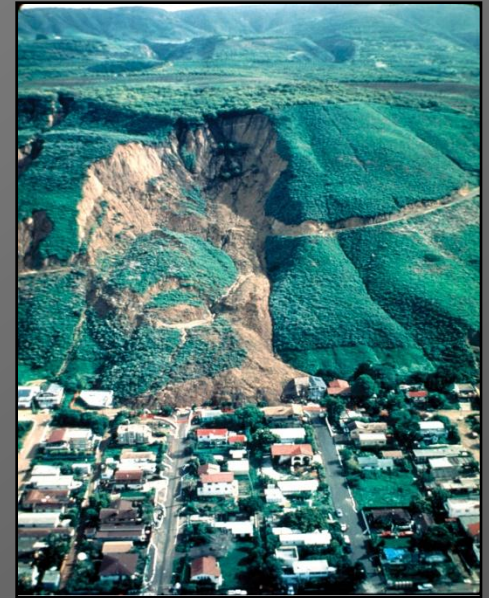
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Amazing ARs

Landslide Risk Increases

Heavy rain on saturated slopes

1500+ landslides western Washington
January 2009 AR



Southern
California
January 2005 AR





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ARs – What's Next?



AR Rapid Instrumentation Deployment – Western WA Nov 2009
WA Coast/HH Dam to support NWS/Army Corps from NOAA/ESRL

AR Detection, Magnitude, Evaluation, Research
NOAA / ESRL

AR Imagery
CIRA Program, Colorado State and NOAA

AR magnitude/frequency & Climate Change
University of Washington



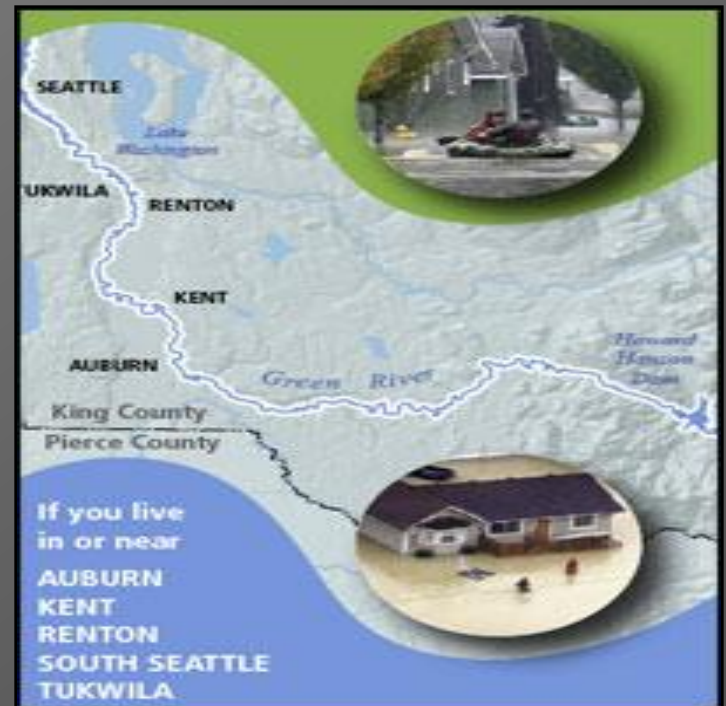
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Howard Hanson Dam Green River / Kent Valley

- Safety #1
- Flood Pool Restrictions
- Buy Flood Insurance



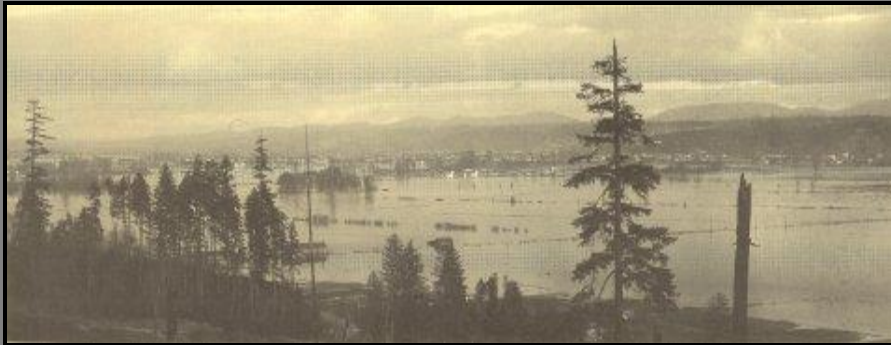
Courtesy of the Renton Historical Society, Renton



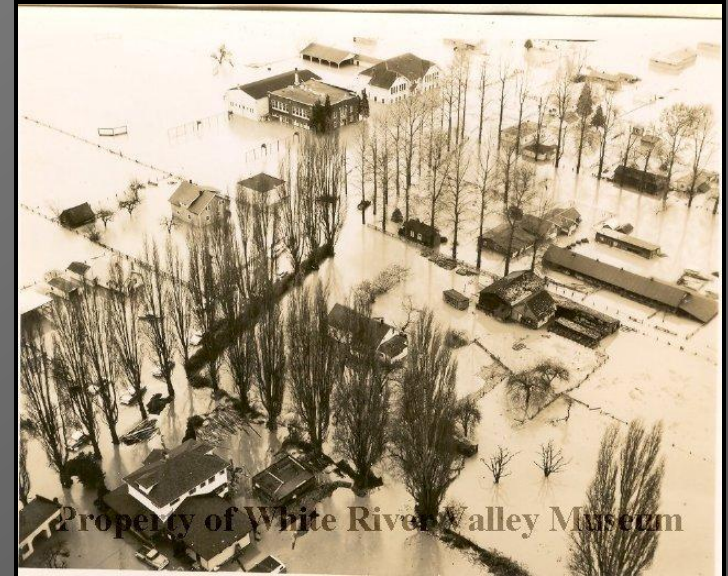


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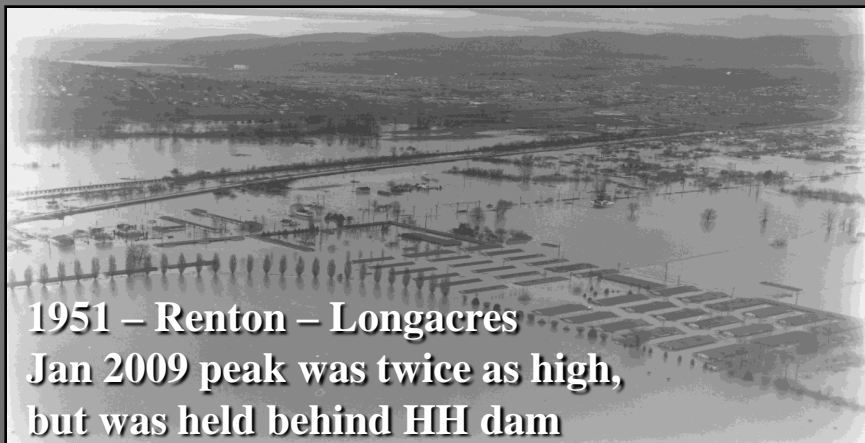
History of Flooding: Kent Valley



1933 - Near current HWY 18 looking NE toward north Auburn. People demanded action – a dam to control flooding



Nov 24, 1959 – Before Howard Hanson Dam near Longacres. Unregulated (no dam) 1959 flow: 27,000cfs



**1951 – Renton – Longacres
Jan 2009 peak was twice as high,
but was held behind HH dam**

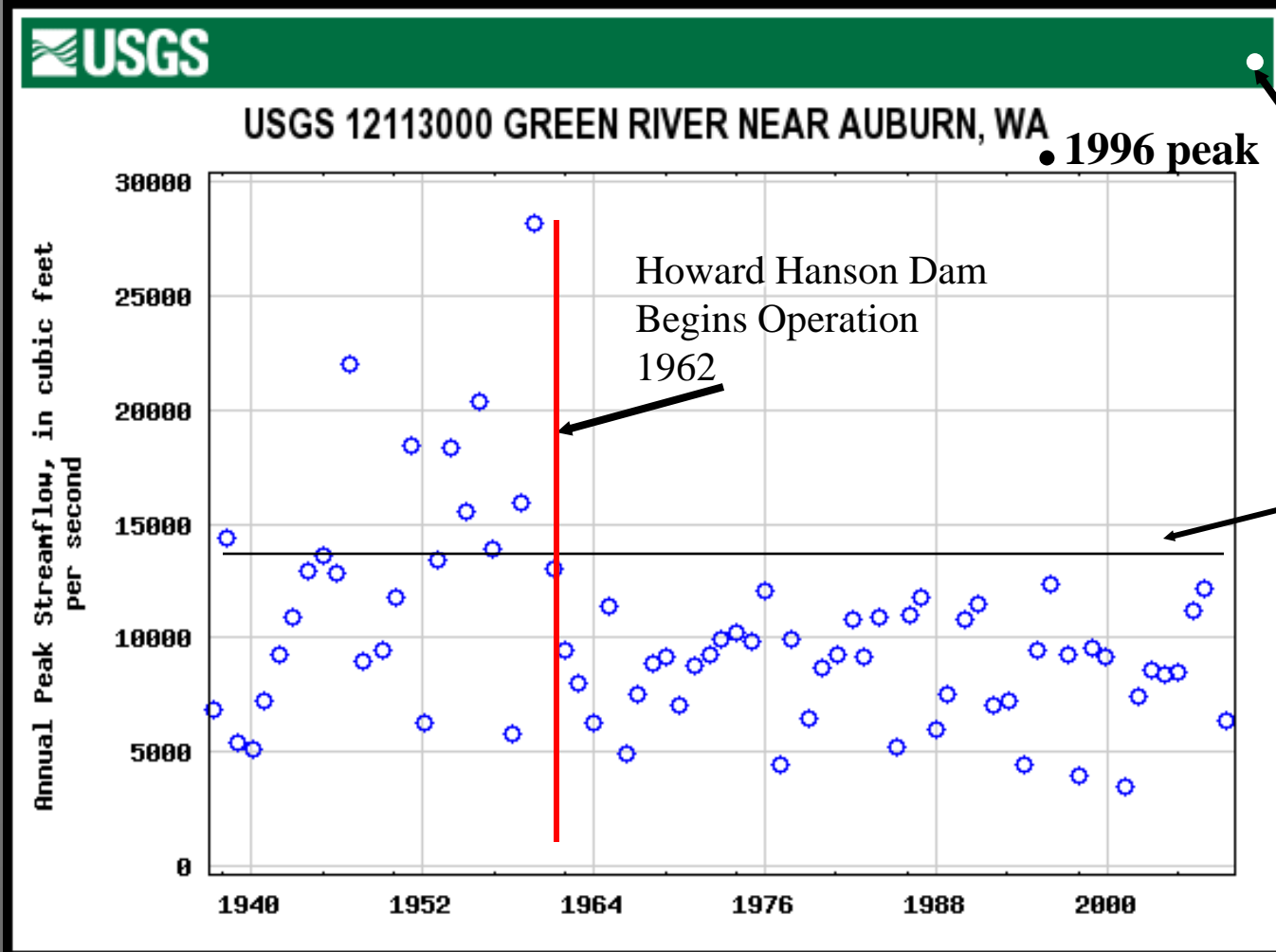
**Estimated unregulated flow 2009: 36,000cfs
Actual regulated flow 2009 ~ 12,000 cfs
In 2009 HH dam held back major flood**



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Annual Peak Flows

Stable peaks after dam built



Estimated peak
Jan 2009 -
without HH
dam:
36,000cfs

Levee capacity
12,800 cfs



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1959 Flood (before dam) & Now

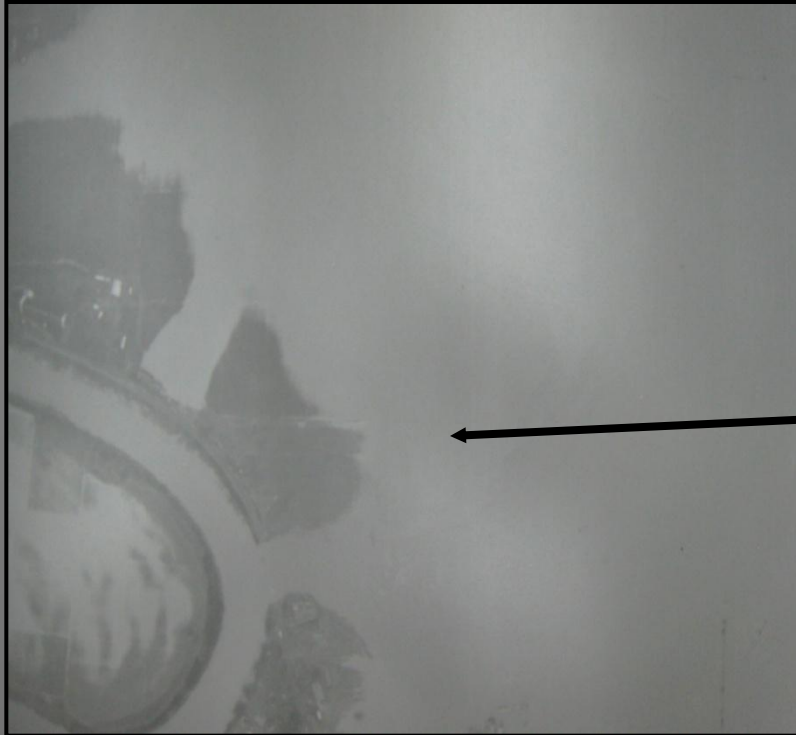
South Center





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1959 Flood (before dam) & Now



Lakeside Development





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Mud Mountain Dam White River

- Flooding at Pacific was caused by a decrease in White River channel capacity by 30% - probably occurred during storm



Pacific, Washington January 2009



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Never underestimate the power of water



Thank You

Impacts of Atmospheric Rivers on Flooding in
Western Washington

Larry Schick – U.S. Army Corps of Engineers -- Seattle



Winter of 1861 - 1862

- Several ARs move into West Coast, Nov - Jan.
- Major rain/flooding: Oregon, Northern and Southern California
- California major flood: Rainfall, LA-35”
SF-24” Central Valley floods
- Willamette River: Salem – 490,000 cfs
Flood of Record
- Frazier, Colombia, Willamette all freeze – Lake Union freezes 6”



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History

Northwest Native American History

Washington and Oregon are
Territories

Winter of 1861-1862 one of the
worst on
record for WA, BC, OR, CA

Major rains move from British Columbia to
California

From Nov –Feb Major floods, then bitter cold
in the NW





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The Overland Press Olympia
December 16, 1861
(Play 1800's harpsichord music)

“ the rain it raineth every day, and every night also –
week in
and week out, from the rising sun to the going
down of same, there is nothing but rain, rain, rain
'The windows of heaven are opened up.' Pluvius,
grieved
at some earth giving wrong, weeps as he would
never dry up.



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Pluvius

“sender of rain”





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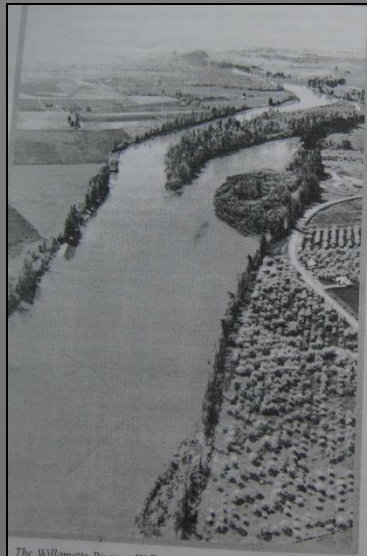
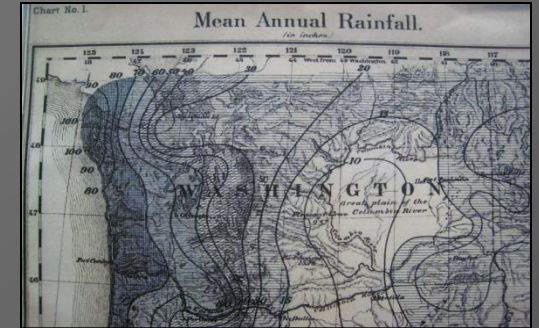
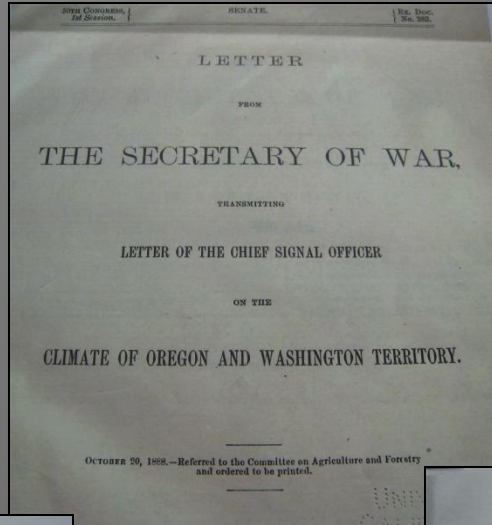
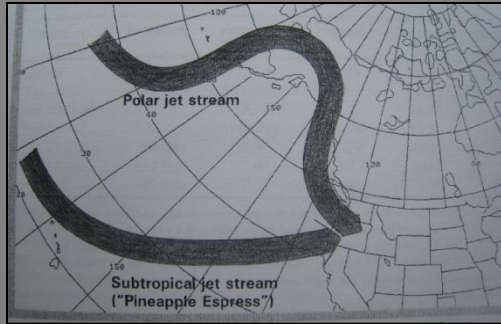
Longacres 1951(Looking North)





US Army Corps of Engineers

Winter of 1861-1862



The Great Willamette River Flood of 1861

by George R. Miller

GOVERNOR JOHN WHITEAKER, addressing the Oregon State Legislature on September 8, 1862, summed up the tragedy succinctly:

While our common country has been afflicted and still suffers from the greatest calamity a people can experience, our own state has been visited by a scourge which, though relieved from the horrors of civil war, has resulted in the loss of immense quantities of property, the depriving of many of our citizens of their homes or means of support, and seriously crippling, for the present, the agricultural interests of the state. Indeed, the high waters of December last did more than destroy property and desolate homes, many lives were lost while attempting to escape the floods or generously assisting to relieve others from their perils!

While a civil war engulfed the nation, a devastating flood had inundated a large part of the fertile Willamette River Valley in western Oregon. Often referred to as a "freshet," the "Great Flood" of December 1861 took several lives and destroyed property, livestock, bridges, and towns along the river and its tributaries from Eugene to Portland. At many locations in the valley, river heights have not been equaled since. At Salem, the flood reached an estimated gauge height of thirty-nine feet, almost a foot and a half higher than the flood of December 1964 and almost two feet higher than the flood of February 1880.

It was "the greatest flood known," hydrologist M. D. Brands reported in a summary of flood runoff in the Willamette Valley published in 1947. A 1949 U.S. Army Corps of Engineers report agreed: "The greatest flood ever experienced on [the] Willamette River, after

The Willamette River at Wells Island in about 1970, with the Buena Vista Ferry shown at upper right (courtesy of ODOT)

California Washed Away

The Great Flood of 1862

by Jan Null and Jocille Hulbert

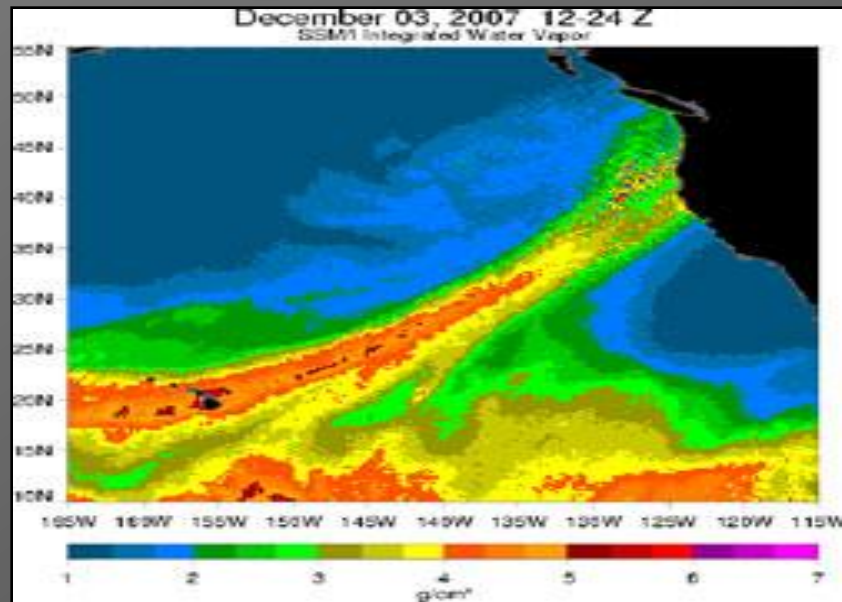
When the first storms of the winter season arrived in California in December 2005, they were initially a welcome sign that the state's long dry season was finally over. But as 2006 began, rivers were pushed over their banks as heavy rains prevailed across the northern



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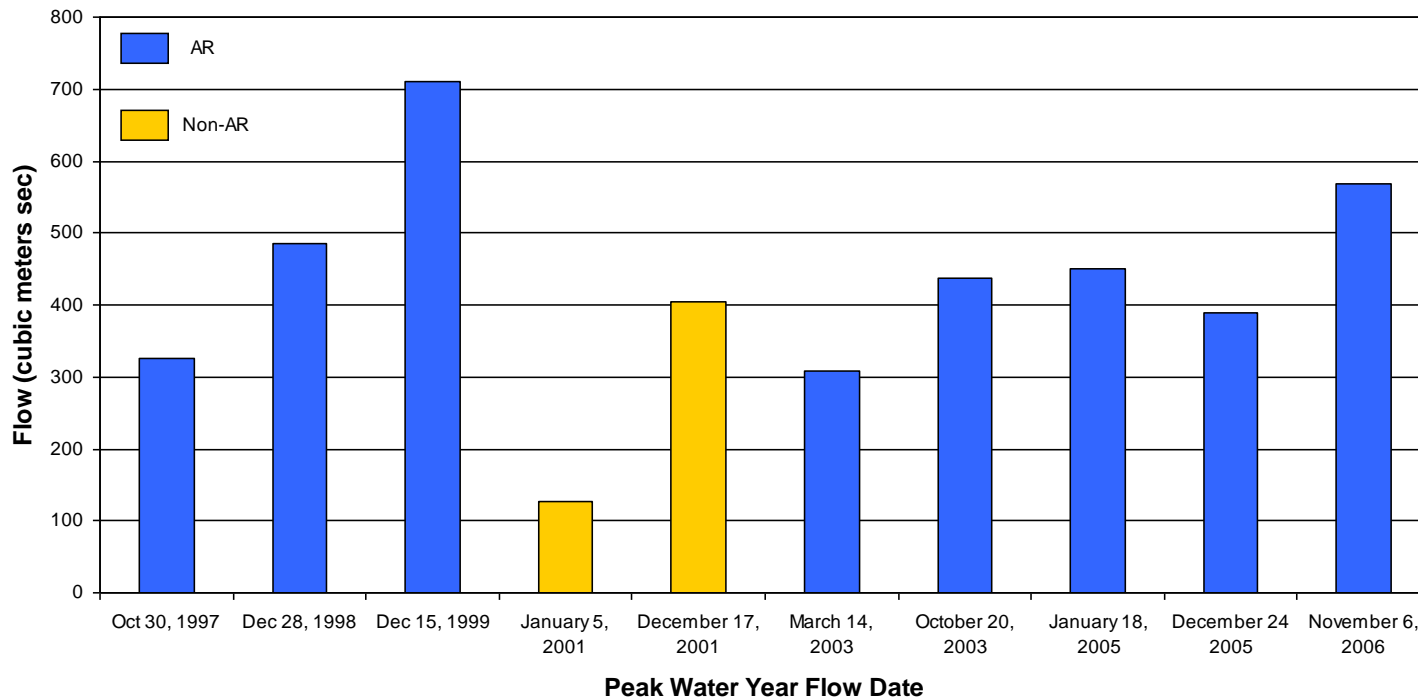
Sauk River: Water Year 1998- 2007

All the top 10 peak daily flows
were all the result of
Atmospheric Rivers



Peak Annual Flow and AR Events Wynoochee River

Wynoochee River, near Montesano peak flows and AR events

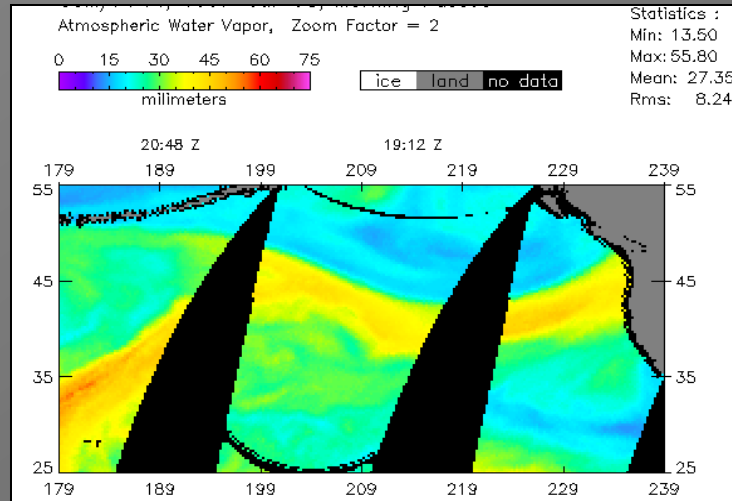


The major floods are all the result of atmospheric rivers



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Summer Atmospheric Rivers



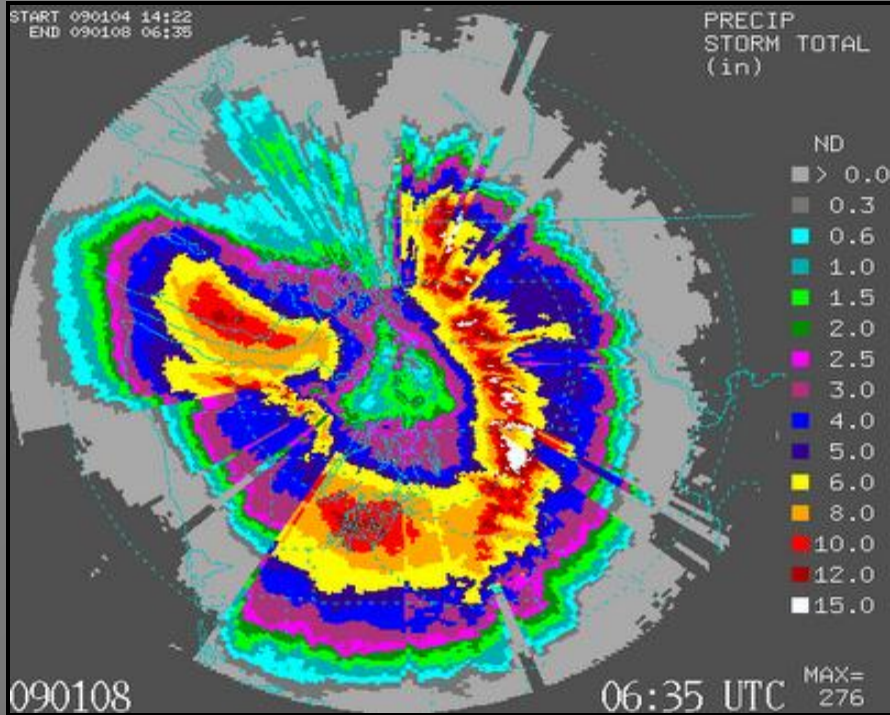
July 9th 1997 -- 91,400 regulated flow at Concrete,
Skagit River

Summer ARs have more water vapor, but weak low
level winds and dynamics, result in less efficient
precipitation.

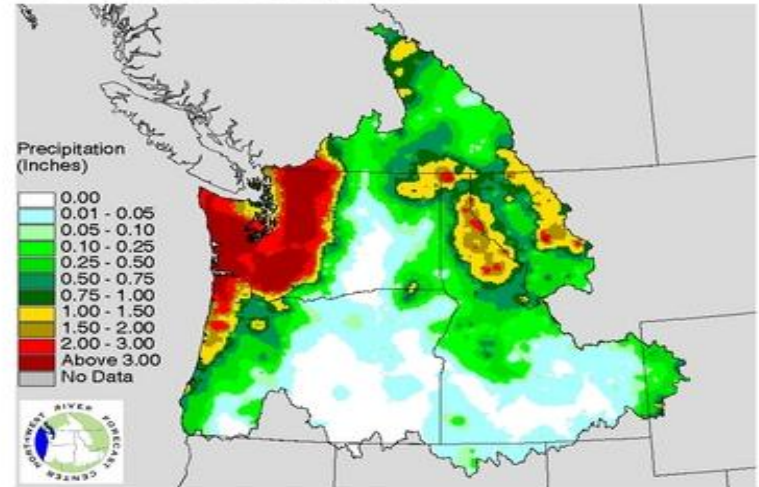


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January 2009 Flood

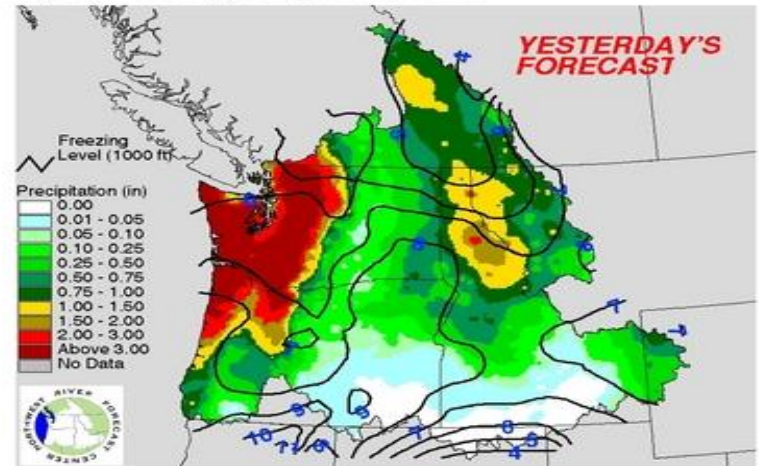


Yesterday's Observed Precipitation



Creation Time: Thu, Jan 08 2009 08:11:26

Day 1 (Wednesday) Precipitation Forecast



Creation Time: Wed, Jan 07 2009 09:35:41



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July 28, 2006 *Science Magazine*
Jonathan Martin, University of
Wisconsin

When an atmospheric river taps into
the tropics...

“ all hell can break loose”

Sound up: Heavy Metal music



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Urban Flooding



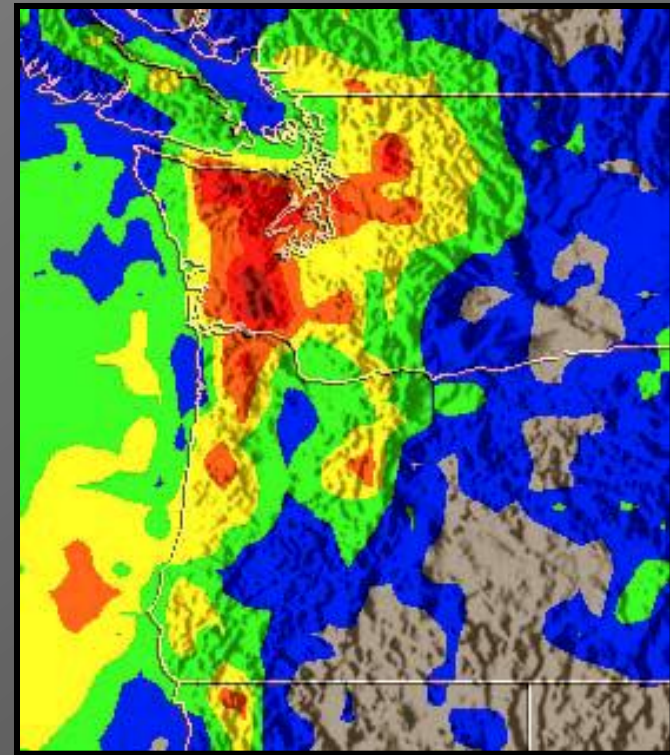
- **2006 Dec 14 Flash Flood City – wide, rainstorm of record intensity flooded low-lying areas of city during rush hour. Convection caused. Not an AR.**
- **2003 Oct Creek Flood / Watershed Thornton. Heavy rain in October flooded many basements. Watersheds heavily damaged. Major AR**
- **1996/7Creek Flood Thorton More basement flooding. Occurred in the same storm that caused many landslides. Rain on lowland snow. Major AR**
- **Dec 2007 – Major rain in city, West Seattle raging rivers, Shoreline, Magnolia, Sandpoint. Major AR**



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Seattle City 24 hr Rainfall Dec 3, 2007

NW Rainfall Nov 28 – Dec 4 2007



November 28 - December 4, 2007

Rainfall Totals (mm)

