

# Impactos económicos de los ríos atmosféricos en el oeste de Estados Unidos



Center for Western Weather  
and Water Extremes

Tom Corringham, Marty Ralph, Sasha Gershunov, Dan Cayan,  
Luca Delle Monache, John Helly, Tamara Shulgina



UC San Diego



TOM CORRINGHAM → [TOMC@UCSD.EDU](mailto:TOMC@UCSD.EDU)

# Esquema

- Ríos atmosféricos (RAs)
- Escala de categorización
- RAs y daños por inundaciones en el oeste de Estados Unidos
- RAs, daños por inundaciones, y proyecciones del clima
- RAs y costos de transporte
- RAs y sequía
- Forecast-Informed Reservoir Operations (FIRO)
- ¿Operaciones de embalse informadas por pronósticos meteorológicos?

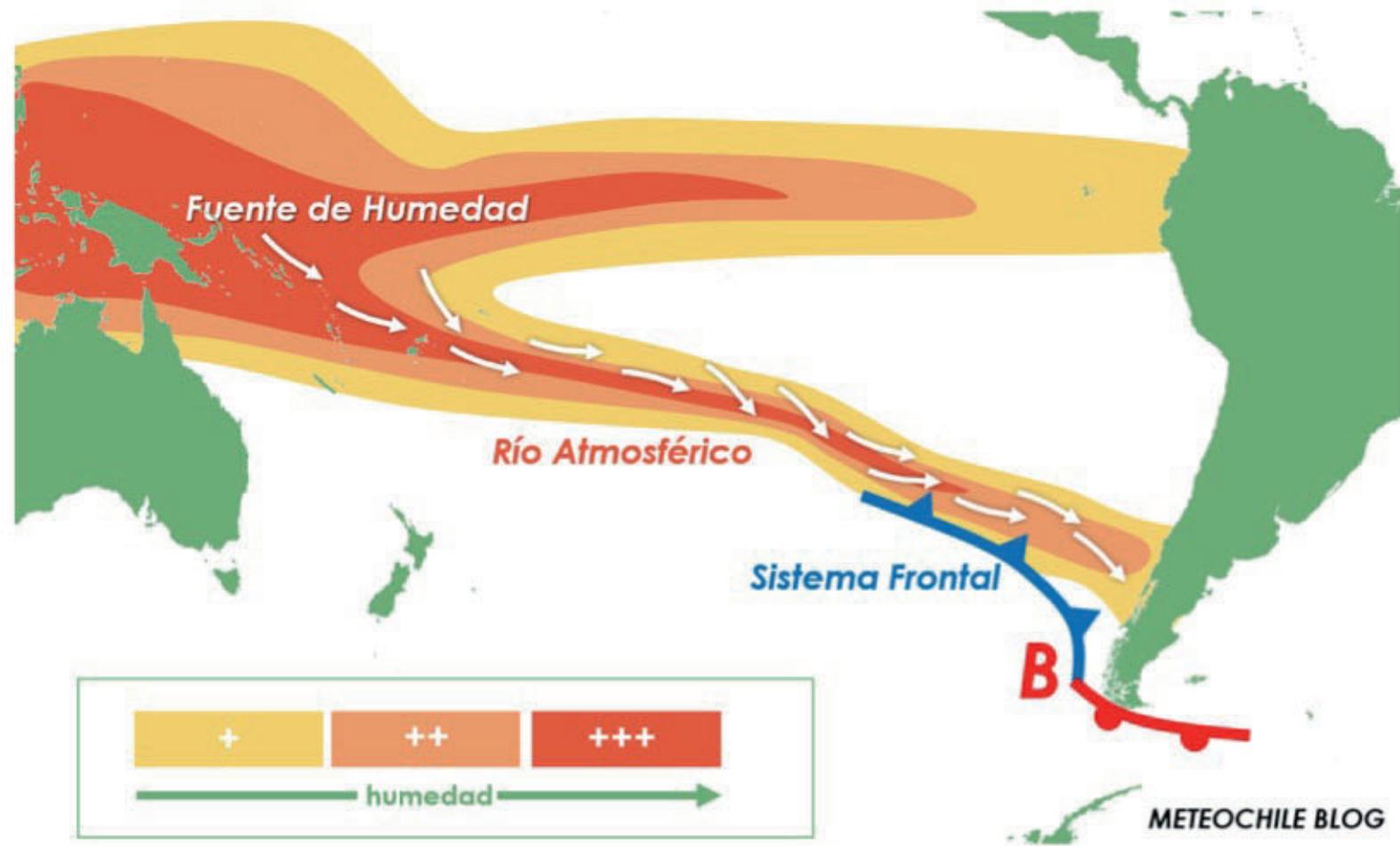


# ¿Qué son los ríos atmosféricos (RAs)?

Los ríos atmosféricos son **zonas largas y angostas en la atmósfera** que trasladan el vapor de agua desde los trópicos a las latitudes medias.

Son miles de kilómetros de largo y cientos de kilómetros de ancho que **transportan más humedad que el río Amazonas**.

Acompañan normalmente a los frentes fríos o ciclones extratropicales. Afectan a las **costas occidentales** de las masas terrestres.



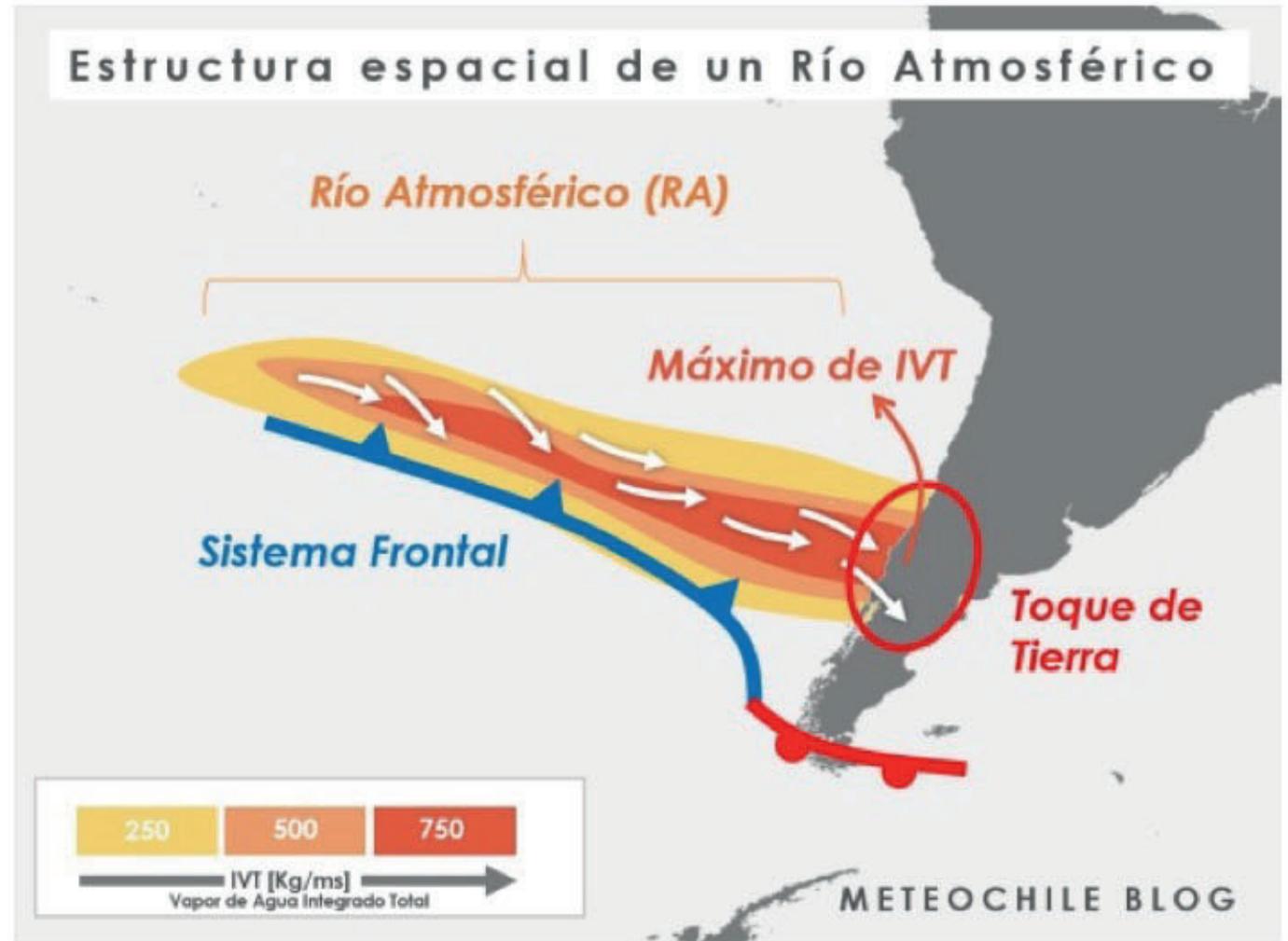
# Vapor de agua integrado total (IVT)

Vapor de agua integrado total

$$IVT = \int_{Sfc}^{Trop} q \bar{V}_h dz = \frac{1}{\rho} \int_{Sfc}^{300mb} q \bar{V}_h dp$$

IVT mide la cantidad de humedad transportada en un lugar determinado en Kg / m s.

Un IVT de 400 se considera alto, pero a veces se observan valores superiores a 1200.



# Ríos atmosféricos y precipitaciones extremas

La nube orográfica genera precipitaciones en forma de lluvia y nieve y a veces inundaciones.



METEOCHILE BLOG



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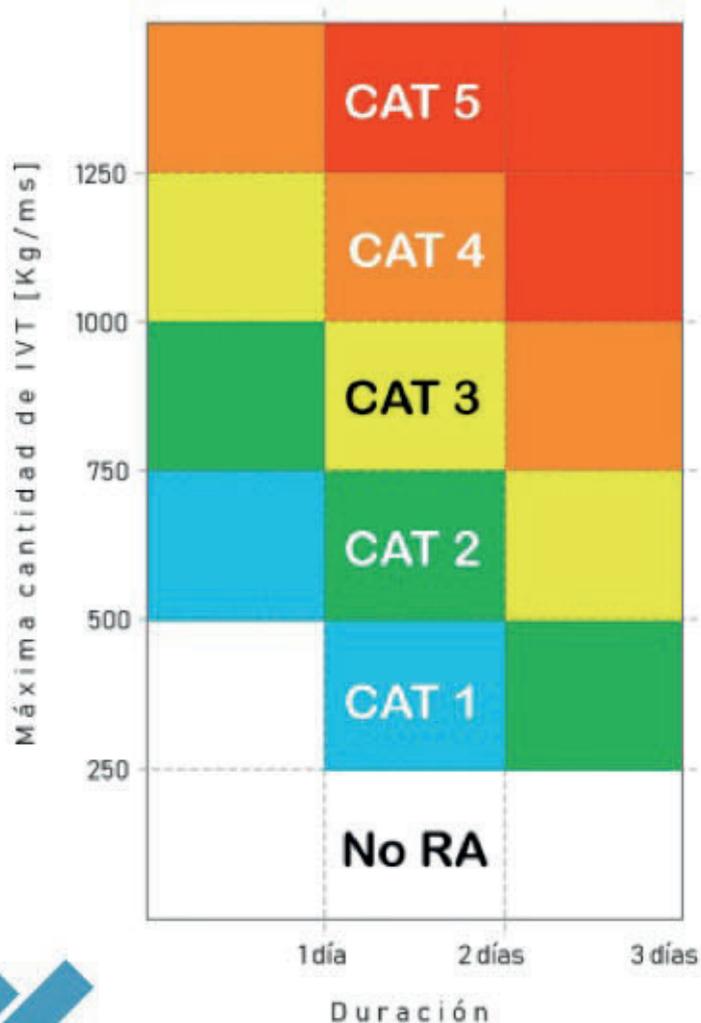
SCRIPPS INSTITUTION OF  
OCEANOGRAPHY



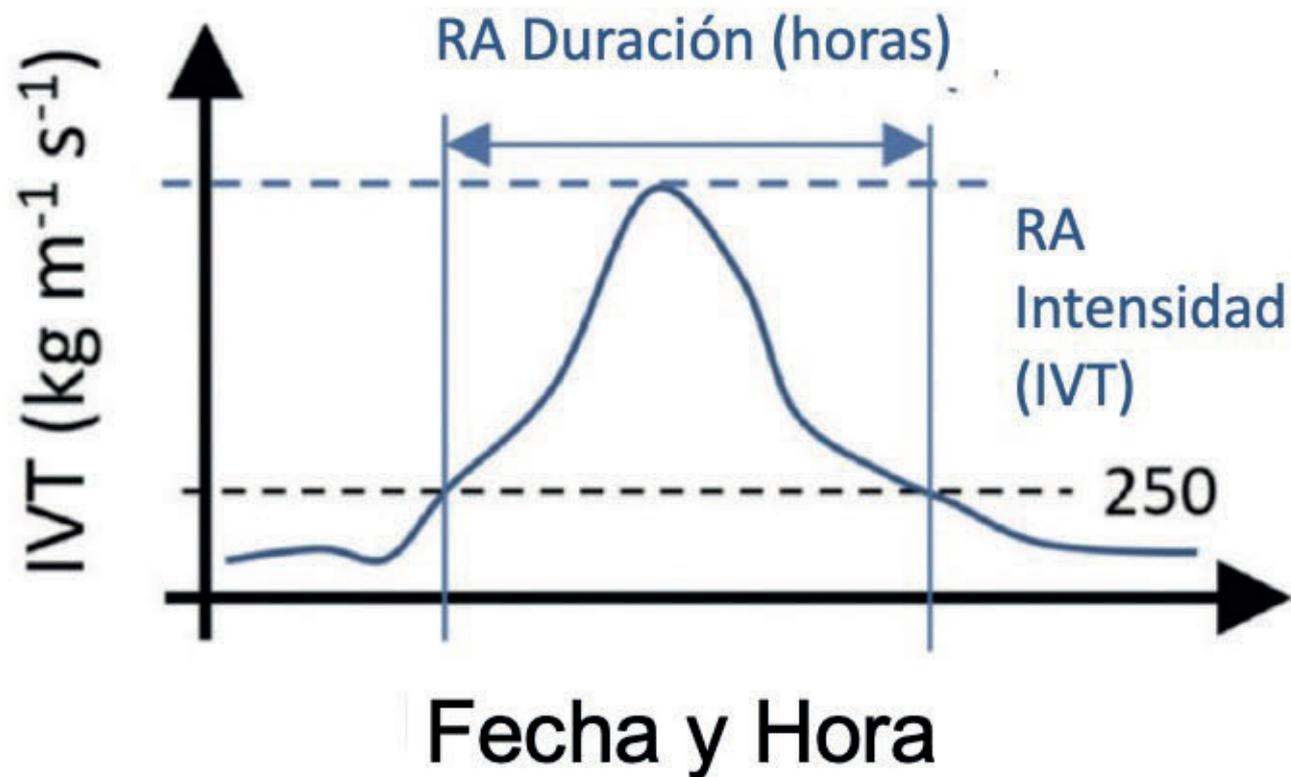
Center for Western Weather  
and Water Extremes

# Escala de categorización (Ralph et al. 2019)

Escala de Categorización de Ralph et al. (2019)



Efectos sobre Tierra



# RA2 "moderado" – mayormente beneficioso, algunos peligros

## RA2

Región de Valparaíso a  
Región del Biobío 25 Junio  
2017

Precipitación intensa  
durante 3 días, pero que no  
produjo mayores daños,  
aliviando parcialmente  
déficit de lluvias en la zona.



# RA4 "extremo" – mayormente peligro, algunos beneficiosos

## RA4

Villa Santa Lucia, Región de Los Lagos 16 Diciembre 2017

Intensas lluvias, en combinación con altas temperaturas provocaron un proceso de remoción en masa (aluvión)



# RA2 "moderado" – mayormente beneficioso, algunos peligros

## RA2

Montecito California  
9 de enero de 2018

Intensas lluvias (narrow cold-frontal rainband, NCFR) después del incendio Thomas provocaron un proceso de remoción en masa que causó 22 muertes y daños de más de 250 millones de dólares.



# RA4 "extremo" – **mayormente peligro**, algunos beneficiosos

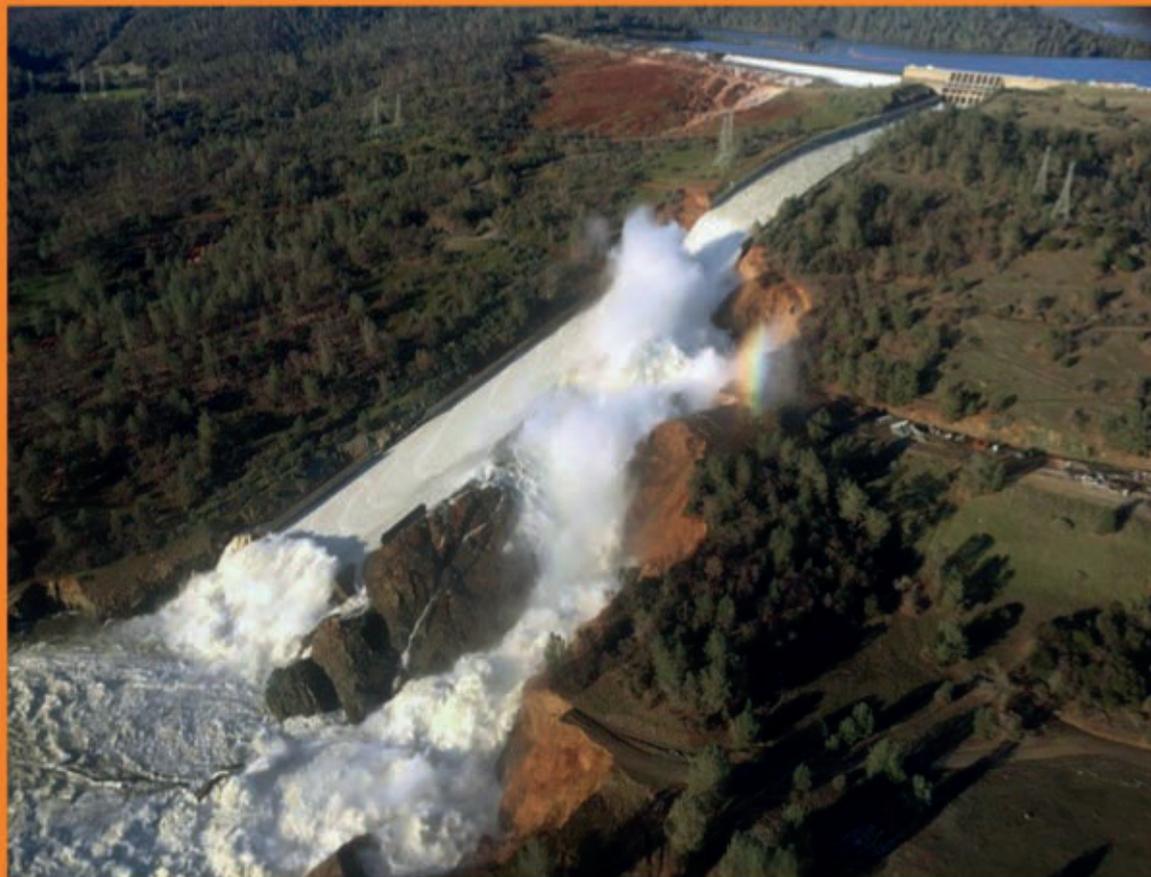
## RA 4/5

Crisis de la presa de Oroville  
7 de febrero de 2017

188.000 personas  
evacuadas

23.000 miembros de la  
Guardia Nacional  
desplegados

Los daños económicos  
directos superaron los mil  
millones de dólares



# 2017 Crisis de la Presa de Oroville



Los Angeles Times

CALIFORNIA

## Oroville Dam repair costs soar past \$1 billion



Construction crews work on the main spillway of the Oroville Dam on Oct. 19, 2017. (Luis Sinco / Los Angeles Times)

By RALPH VARTABEDIAN

SEP. 5, 2018 9:35 PM PT

Vano et al. (2019) Hydroclimatic Extremes as Challenges for the Water Management Community: Lessons from Oroville Dam and Hurricane Harvey. *BAMS*, 100(1), S9-S14.

# Ríos atmosféricos y daños por inundaciones

SCIENCE ADVANCES | RESEARCH ARTICLE

ATMOSPHERIC SCIENCE

## Atmospheric rivers drive flood damages in the western United States

Thomas W. Corringham<sup>1\*</sup>, F. Martin Ralph<sup>1</sup>, Alexander Gershunov<sup>1</sup>, Daniel R. Cayan<sup>1</sup>, Cary A. Talbot<sup>2</sup>

Atmospheric rivers (ARs) are extratropical storms that produce extreme precipitation on the west coasts of the world's major landmasses. In the United States, ARs cause significant flooding, yet their economic impacts have not been quantified. Here, using 40 years of data from the National Flood Insurance Program, we show that ARs are the primary drivers of flood damages in the western United States. Using a recently developed AR scale, which varies from category 1 to 5, we find that flood damages increase exponentially with AR intensity and duration: Each increase in category corresponds to a roughly 10-fold increase in damages. Category 4 and 5 ARs cause median damages in the tens and hundreds of millions of dollars, respectively. Rising population, increased development, and climate change are expected to worsen the risk of AR-driven flood damage in future decades.

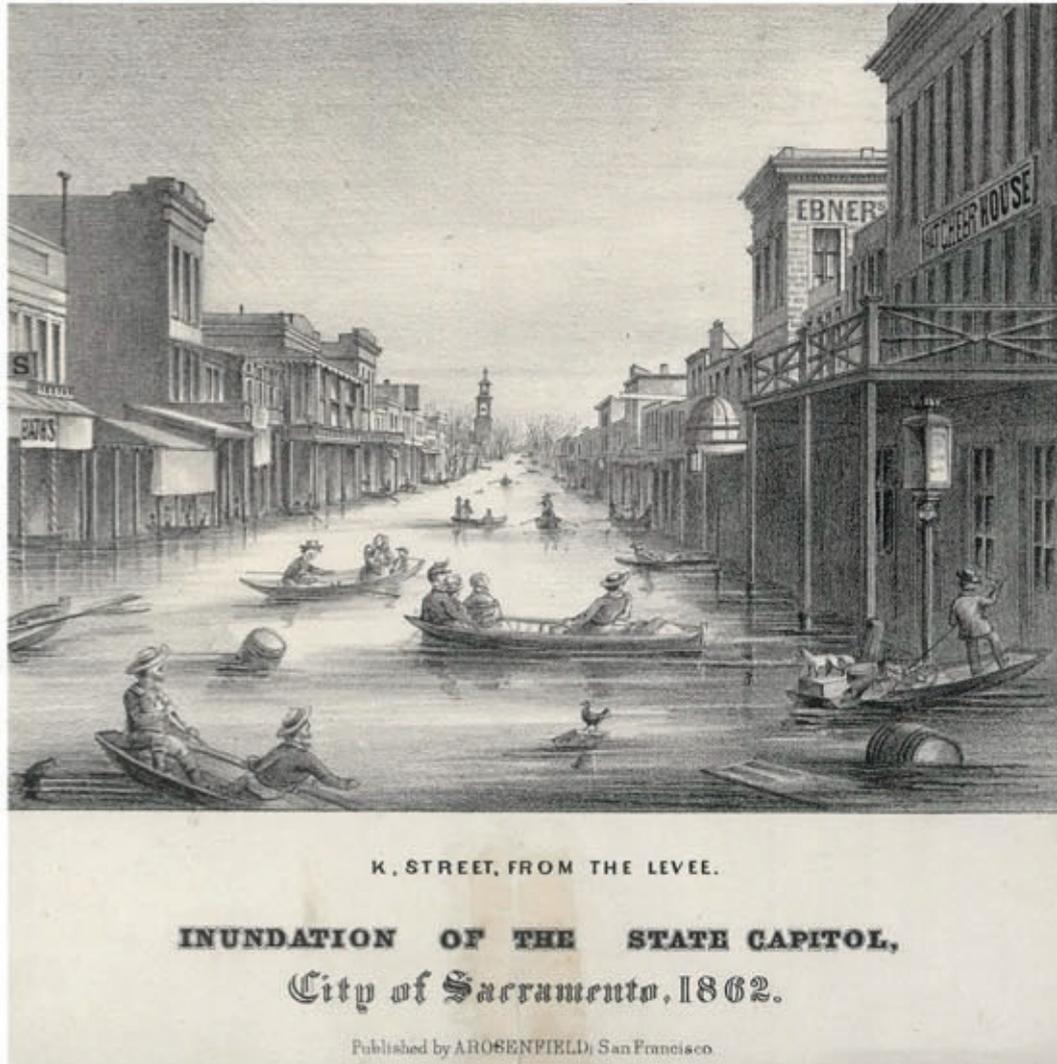
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# Ríos atmosféricos y daños por inundaciones

- ARkStorm estimó los costos de una serie de eventos de 1/1000 años **860 mil millones de dólares** (2020 dólares) Porter, et al. 2011
- Estimaciones de costos de tormentas específicas
  - California: enero–feb. 1995 **\$5b**; enero 1997 **\$2.6b** serie de eventos (Perry 2005)
  - California: al menos 7 eventos **> \$1b** de 1812 a 2011 (CA DWR 2013)
  - Chehalis: dic. 2007, **\$902m** estimado, **> \$1b** declarado (Dominguez et al. 2018)
- Pero: *no habían medidas consistentes de daños a lo largo del tiempo*



# La Gran Inundación de California de 1862



- Noviembre 1861 a enero 1862
- Serie de ríos atmosféricos
- 3 metros de lluvia en un período de 43 días
- El evento consistió en lluvia cálida sobre nieve
- Daños extensos a Sacramento
- Las inundaciones se extendieron al sur de California
- Período de retorno estimado: 100-200 años



# Fuentes de información

- National Flood Insurance Program (NFIP)  
Pérdidas aseguradas diarias, por comunidad, 1978 – 2017
- National Weather Service (NWS) (Downton et al. 2005 *ASCE*)  
Daños anuales, por Estado, 1983 – 2003
- Gershunov et al. 2017 *GRL* catálogo de eventos de RA  
Integrated Vapor Transport (IVT)  $\text{kg m}^{-1} \text{s}^{-1}$ , 2.5° cuadrado
- Ralph et al. 2019 *BAMS* escala de RA



# Ríos atmosféricos y daños por inundaciones

Date	Initial Landfall Region	Initial Landfall Latitude	n Days	Max IVT	Claims	Insured Losses (\$m)	Total Damages (\$b)
1/4/1995	S. CA	32.5	11	922	4725	125.8	3.7
12/29/2005	N. CA	40	5	781	2554	117.6	3.5
12/29/1996	C. CA	35	8	1216	3407	104.6	3.1
2/5/1996	N. OR	45	4	685	2695	99.3	3.0
12/2/2007	N. OR	45	3	1214	1447	83.9	2.5
2/15/1986	WA	47.5	5	826	2048	66.6	2.0
3/7/1995	S. OR	42.5	5	884	2343	58.7	1.8
1/5/2009	S. OR	42.5	4	787	1636	53.9	1.6
2/1/1998	Bay Area	37.5	3	751	2417	46.8	1.4
11/1/2006	N. CA	40	7	997	1184	38.7	1.2
1/25/1983	Bay Area	37.5	5	969	1545	34.9	1.0

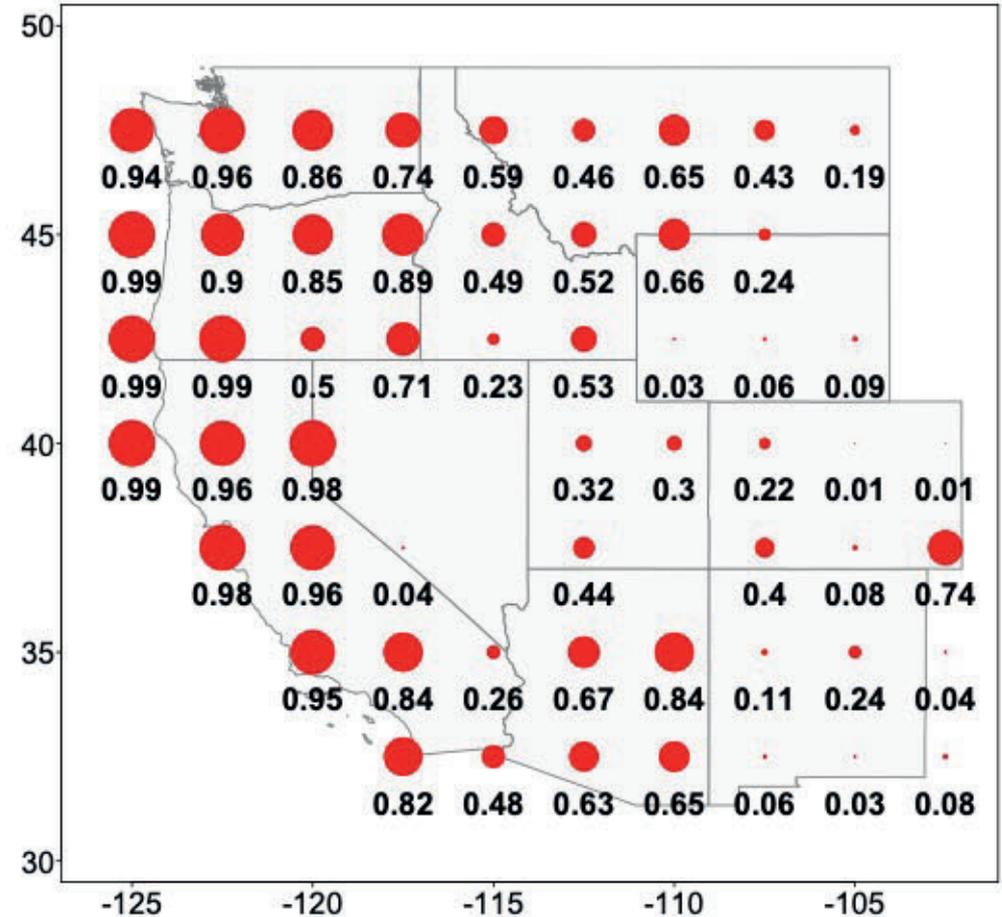
- Costo medio: **\$28 millones** (mediana: **\$0**)  
El 53% no causó pérdidas aseguradas
- Condicionado a la pérdida asegurada > 0
- Costo medio **\$60 millones** (mediana **\$1.8 millones**)
- Costo máximo estimado > **\$1 mil millones** cada 3 a 7 años
- **28** días representaron el **50%** de las pérdidas más de 40 años – **26** eran RAs



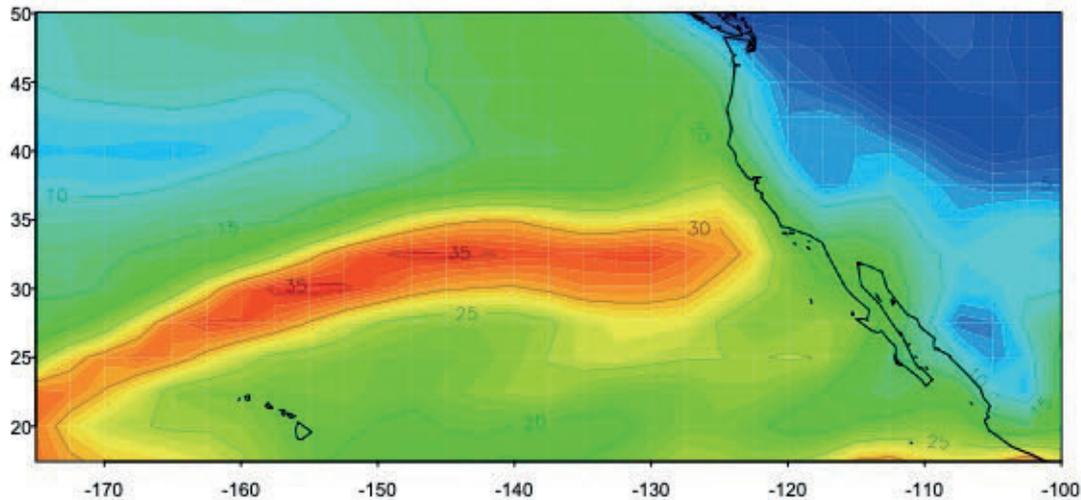
# Ríos atmosféricos impulsan los daños

- El **84%** de las pérdidas aseguradas en los 11 estados occidentales fueron causadas por RAs.
- Más del **99%** de las pérdidas aseguradas fueron causadas por RAs en muchas de las zonas más afectadas.
- Proporciones menores pero aún significativas de pérdidas aseguradas en el sur de California y Arizona fueron causadas por RAs.

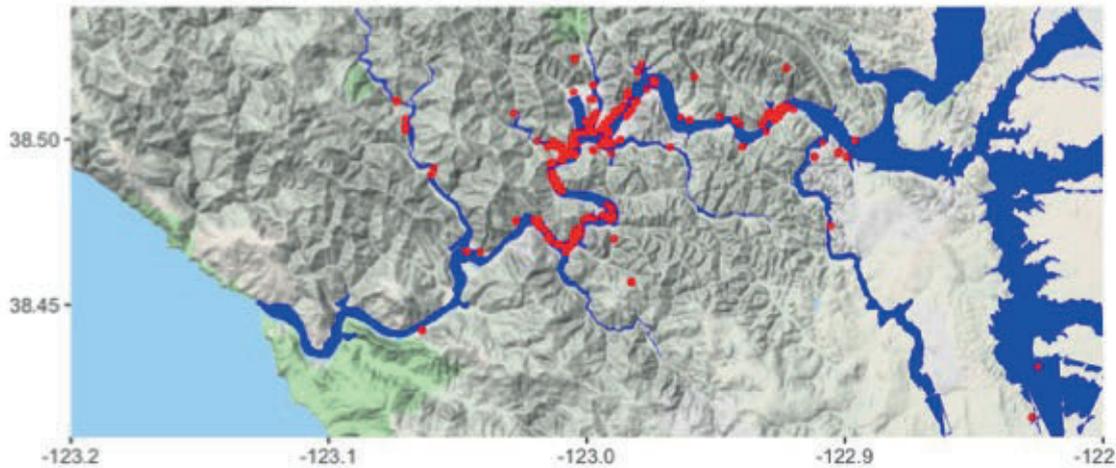
## Proporción de las pérdidas aseguradas debidas a ríos atmosféricos



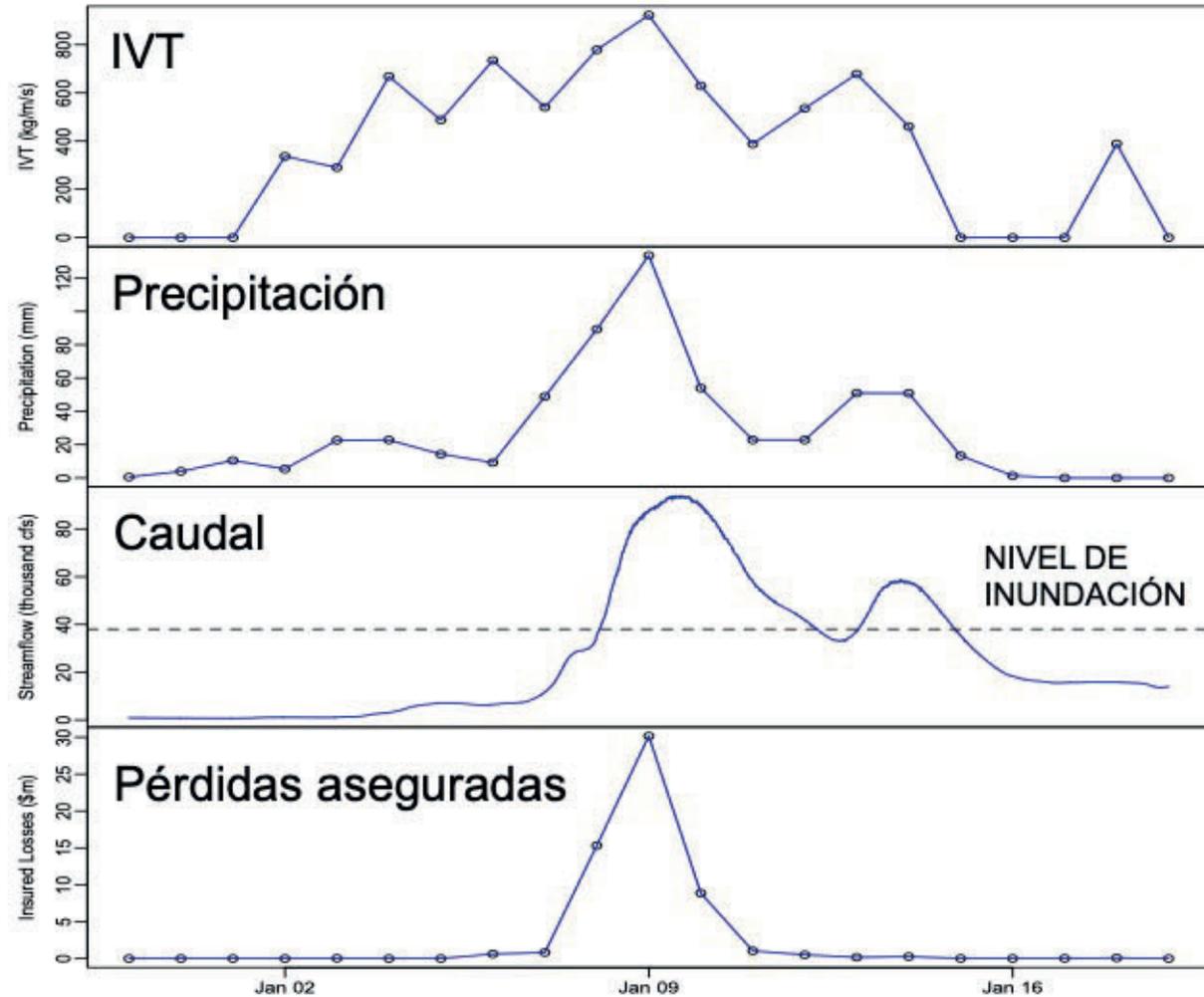
# Condado de Sonoma, 9 de enero de 1995



Russian River at Guerneville



## Sonoma County



# Ríos atmosféricos dañinas y contadas afectadas

## Damage from atmospheric rivers / 1978-2017

### Most damaging events

Storm	Landfall	Category	Damage
Jan. 4, 1995	So. Calif.	4	\$3.7 billion
Dec. 29, 2005	No. Calif.	4	\$3.5 billion
Dec. 29, 1996	Central Calif.	5	\$3.1 billion
Feb. 5, 1996	No. Oregon	3	\$ 3 billion
Dec. 2, 2007	No. Oregon	5	\$2.5 billion
Feb. 15, 1996	Washington	4	\$2 billion
March 7, 1995	So. Oregon	4	\$1.8 billion
Jan. 5, 2009	So. Oregon	4	\$1.6 billion
Feb. 1, 1998	Bay Area	4	\$1.4 billion
Nov. 1, 2006	No. Calif.	5	\$1.2 billion
Jan. 25, 1983	Bay Area	5	\$1 billion
Feb. 25, 1983	Bay Area	3	\$900 million
Feb. 12, 1980	Baja Calif.	3	\$900 million
Jan. 3, 1982	No. Calif.	3	\$800 million
Feb. 11, 1986	No. Calif.	4	\$700 million
Nov. 21, 1990	Washington	4	\$700 million

**Category 1**  
Weak, primarily beneficial.

**Category 2**  
Moderate, mostly beneficial.

**Category 3**  
Strong, beneficial and hazardous.

**Category 4**  
Extreme, hazardous, but also beneficial.

**Category 5**  
Exceptional, primarily hazardous.

Sources: Scripps Institution of Oceanography

John Blanchard / The Chronicle

## Damage from atmospheric rivers / 1978-2017



Sources: Scripps Institution of Oceanography

John Blanchard / The Chronicle

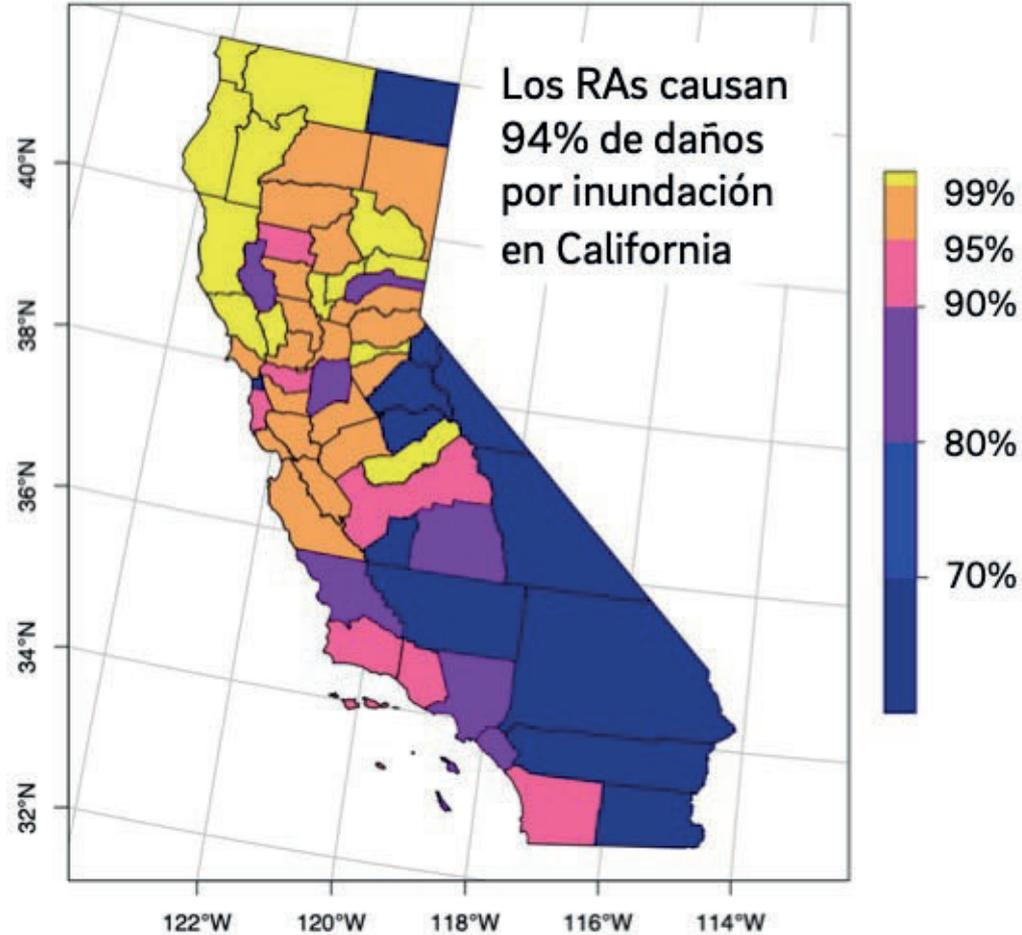
County	Insurance claims	Total damages (\$b)	AR damages (\$b)
Sonoma County, Calif.	6,650	\$5	\$5
Los Angeles County, Calif.	8,280	\$3	\$3
Lewis County, Wash.	1,979	\$3	\$3
Marin County, Calif.	3,152	\$2	\$2
King County, Wash.	2,915	\$2	\$2
Sacramento County, Calif.	3,609	\$2	\$2
Snohomish County, Wash.	1,818	\$1	\$1
Monterey County, Calif.	1,253	\$1	\$1
Napa County, Calif.	1,331	\$1	\$1
Washoe County, Nev.	720	\$1	\$1
Maricopa County, Ariz.	2,368	\$1	\$1
Santa Clara County, Calif.	1,557	\$1	\$1
Clackamas County, Ore.	730	\$1	\$1
San Diego County, Calif.	1,945	\$1	\$1
Orange County, Calif.	3,619	\$1	\$1
Pierce County, Wash.	934	\$1	\$1
Riverside County, Calif.	1,619	\$1	\$1
Cowlitz County, Wash.	709	\$1	\$1
Placer County, Calif.	598	\$1	\$1
Columbia County, Ore.	414	\$1	\$1

Source: Thomas Corringham, et al (Science Advances) • [Get the data](#)

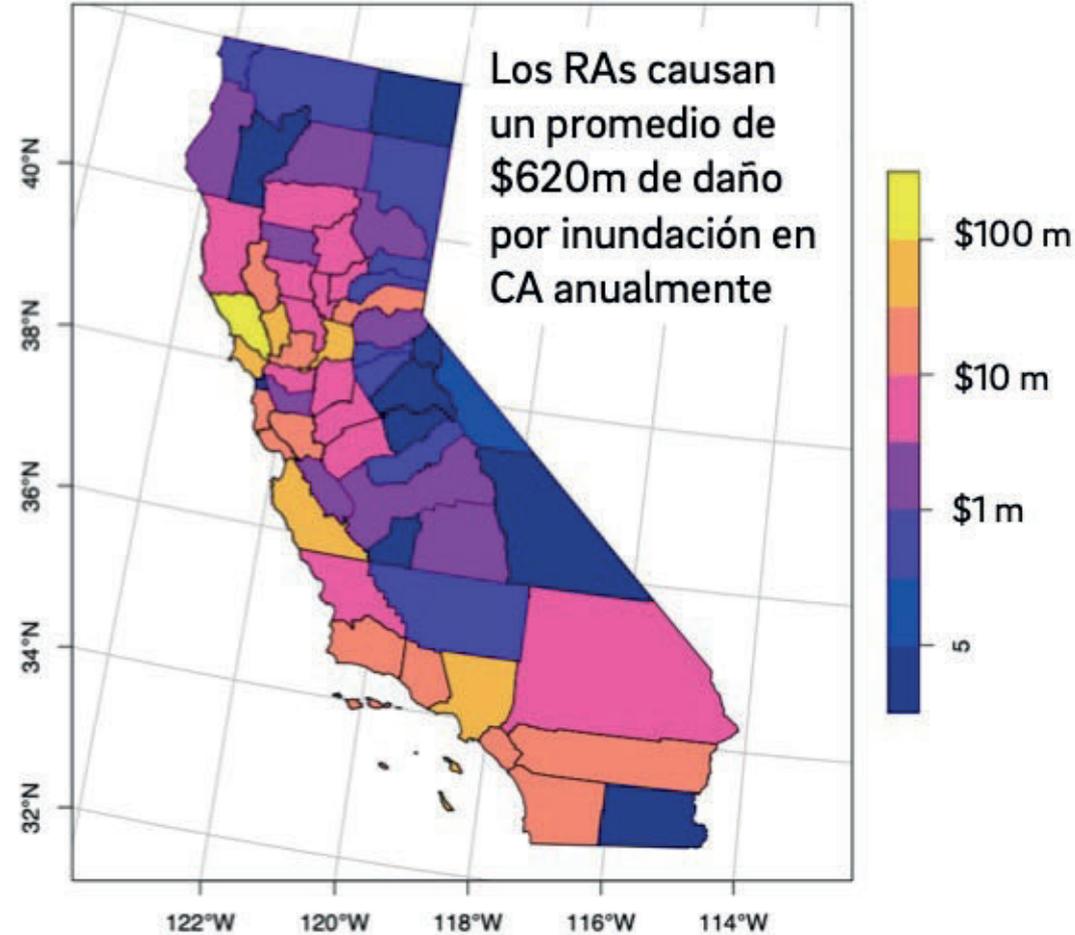
Michael Finch, Sacramento Bee

# Distribución espacial de los daños por RA en California

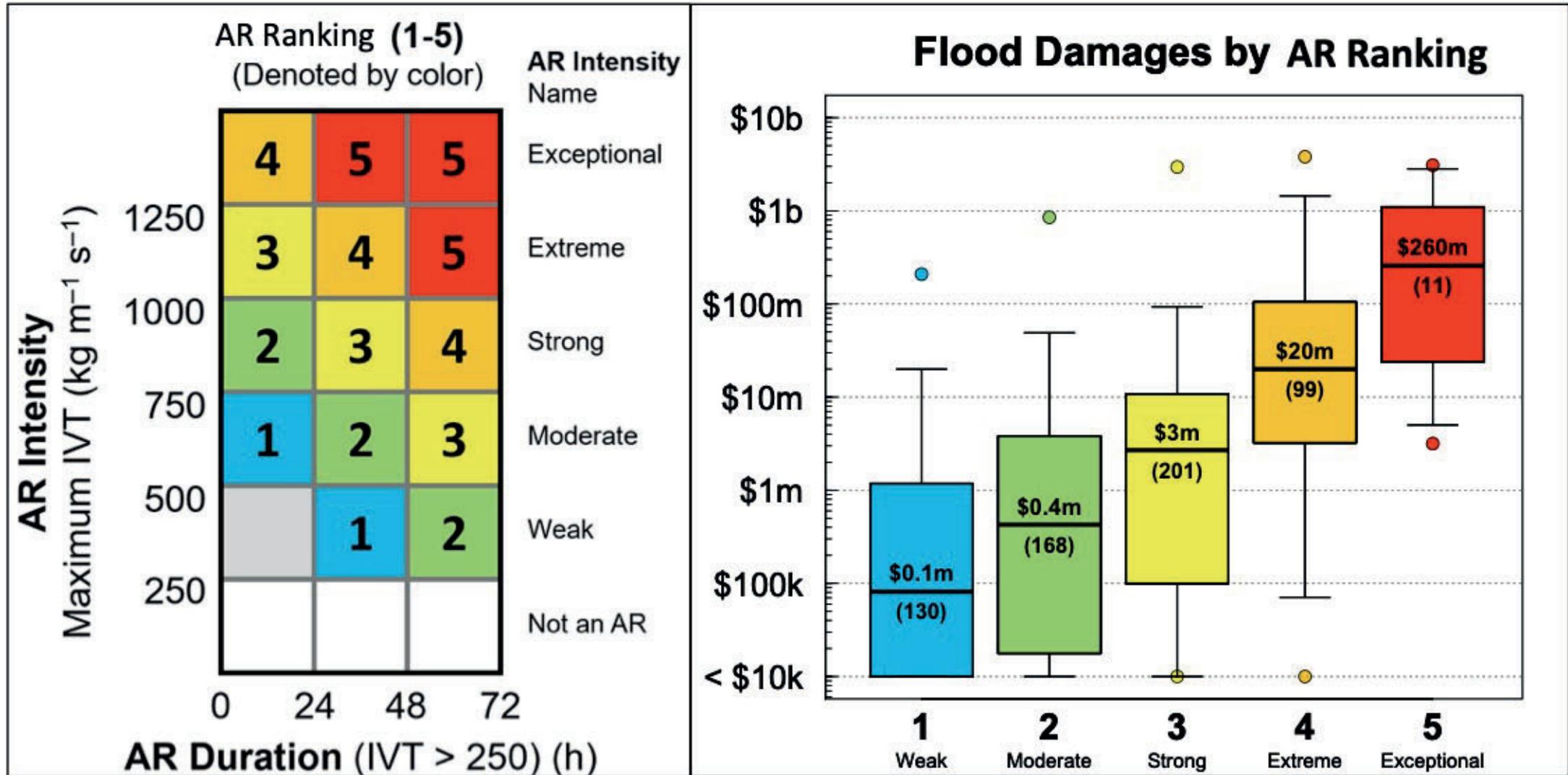
Porcentaje de daños por inundación debido a ARs



Promedio anual de daños por inundaciones AR

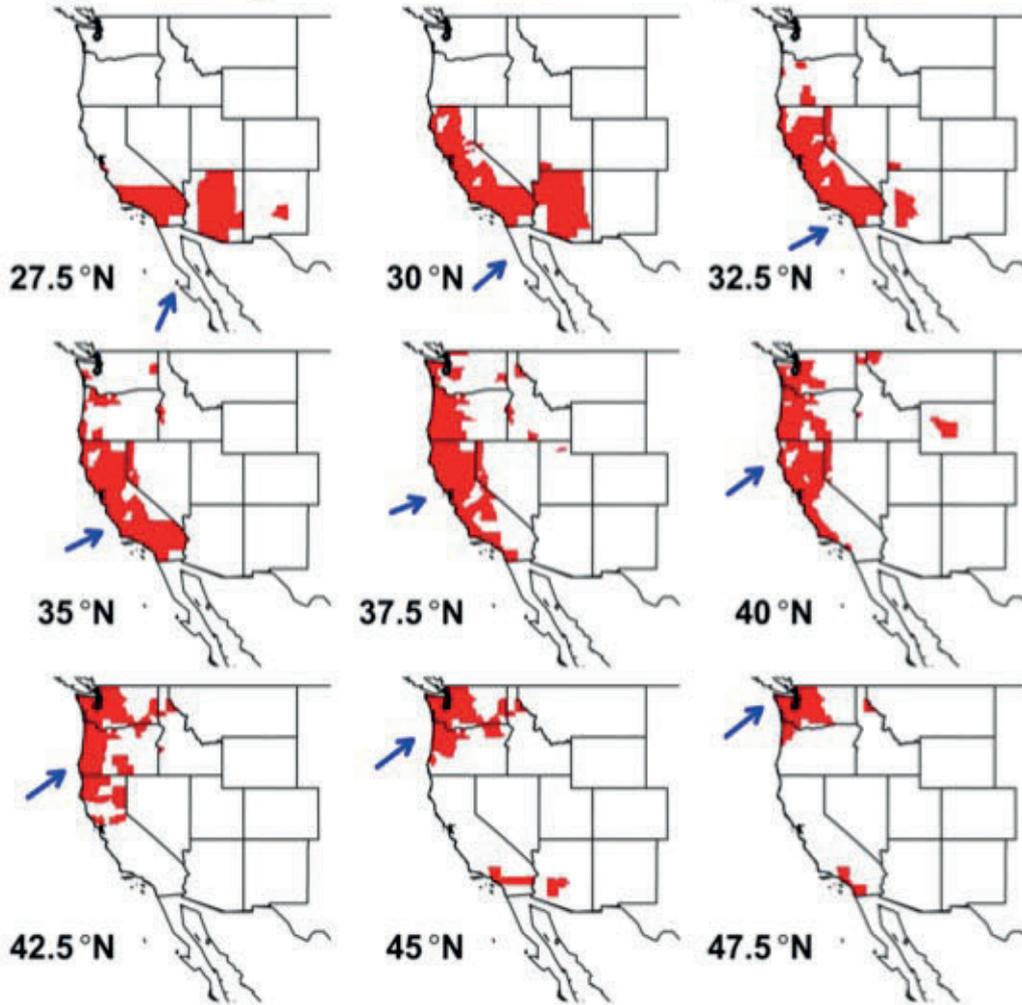


# Escala de RA y daños por inundaciones

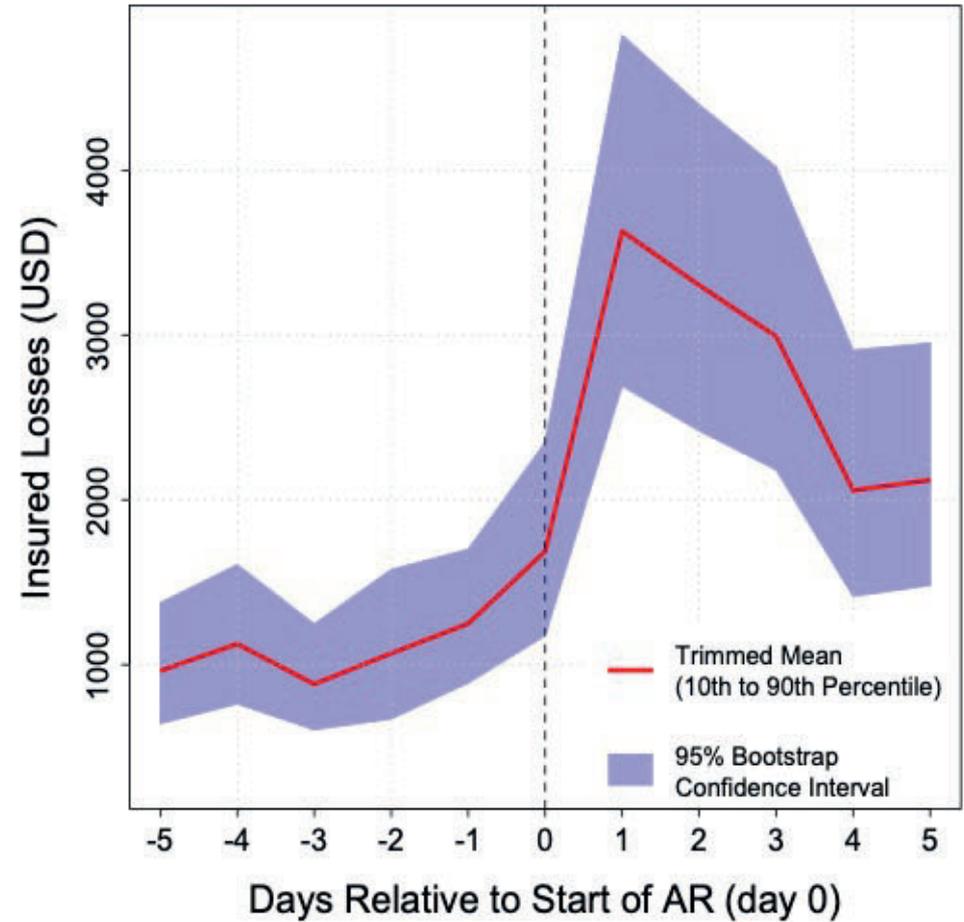


# Penetración interior y temporalidad de los daños

## Significantly Affected Counties by AR Latitude

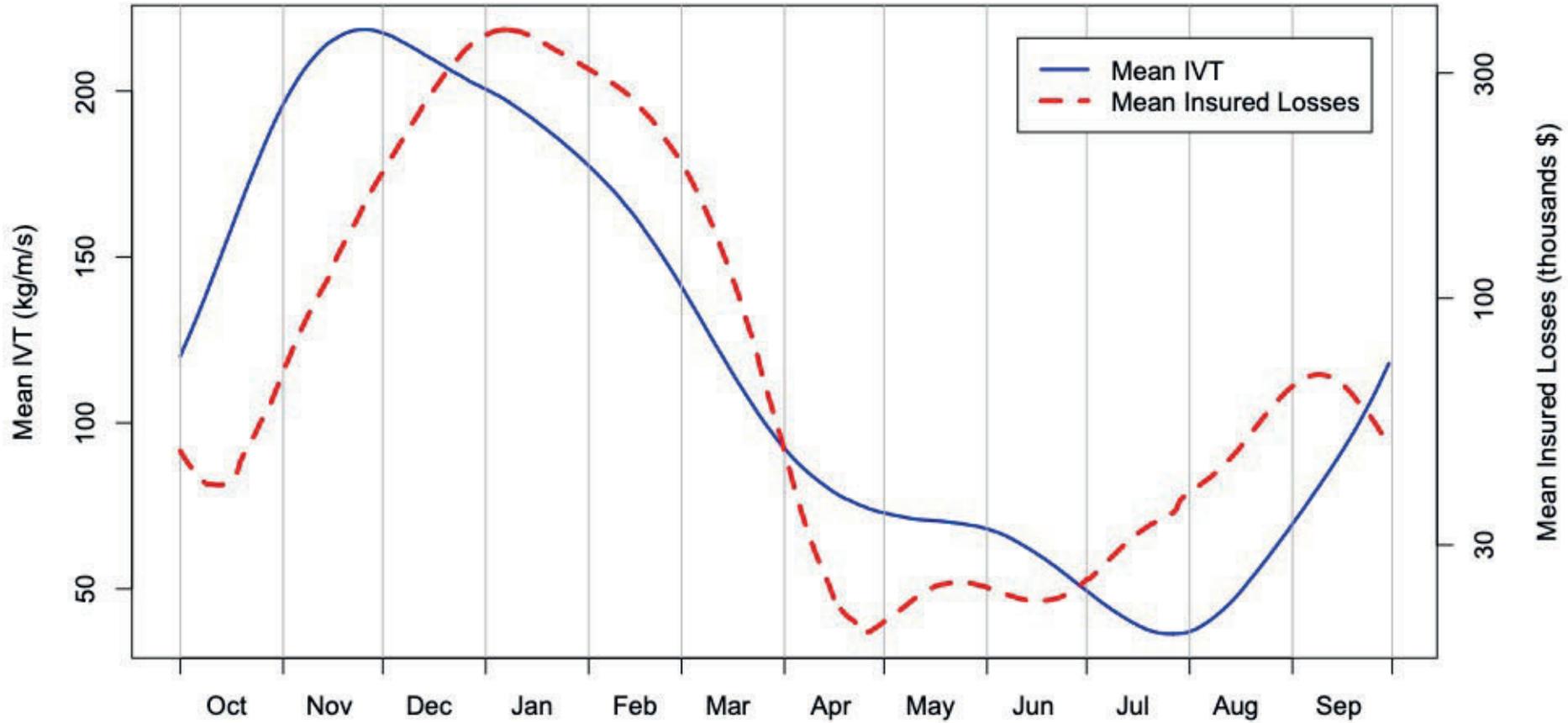


## Time Course of Insured Losses



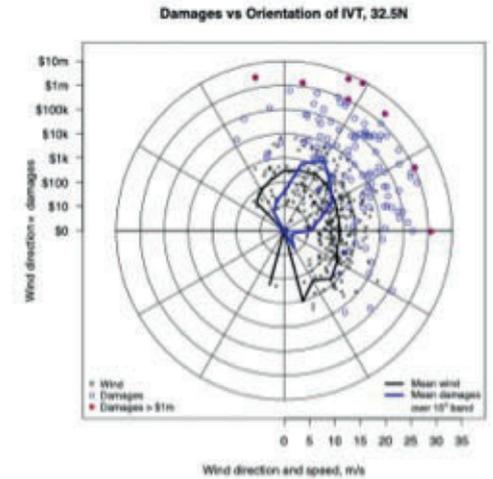
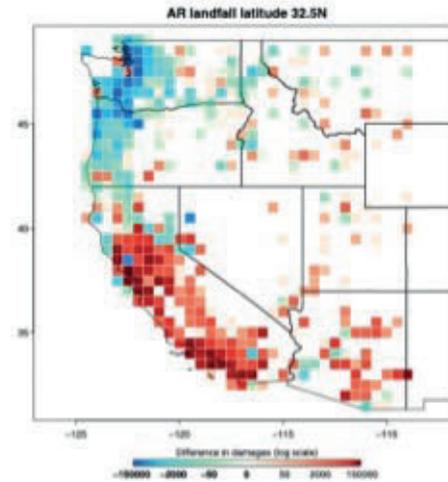
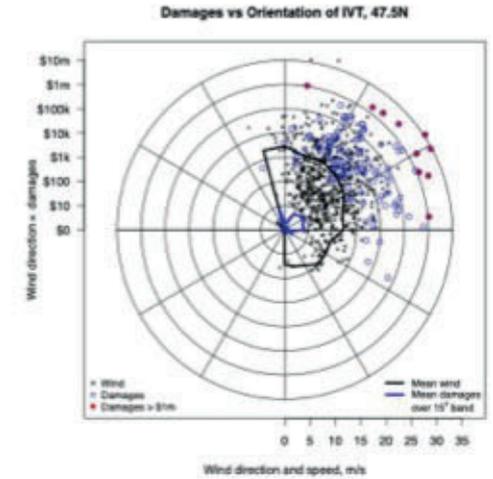
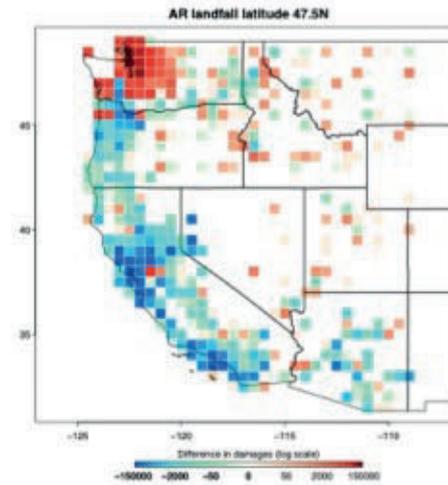
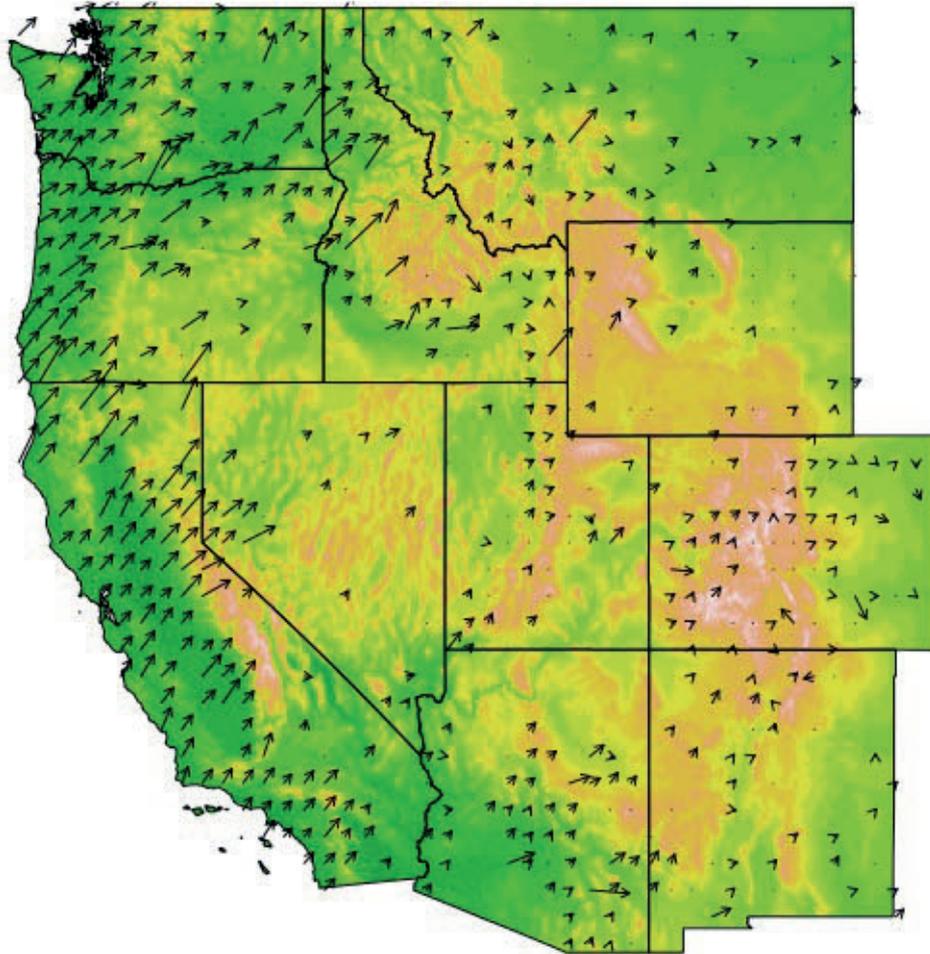
# Retraso en daños y papel de la humedad antecedente

Seasonality of IVT and Insured Losses



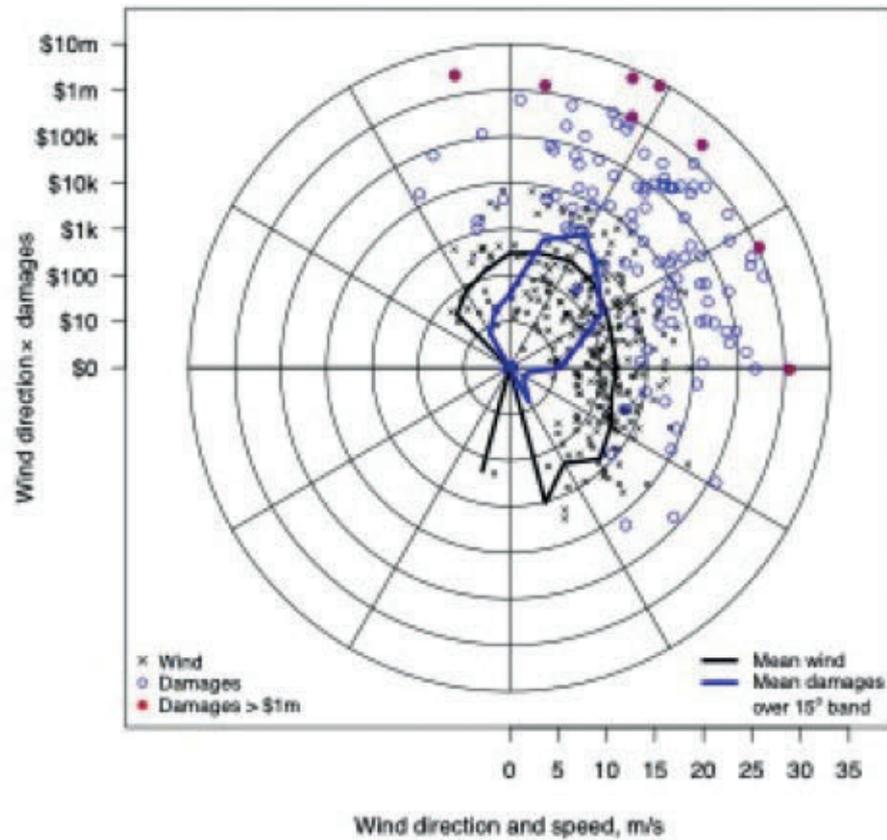
# Papel de la orientación de la RA

## Mean IVT intensity and direction on days with claims

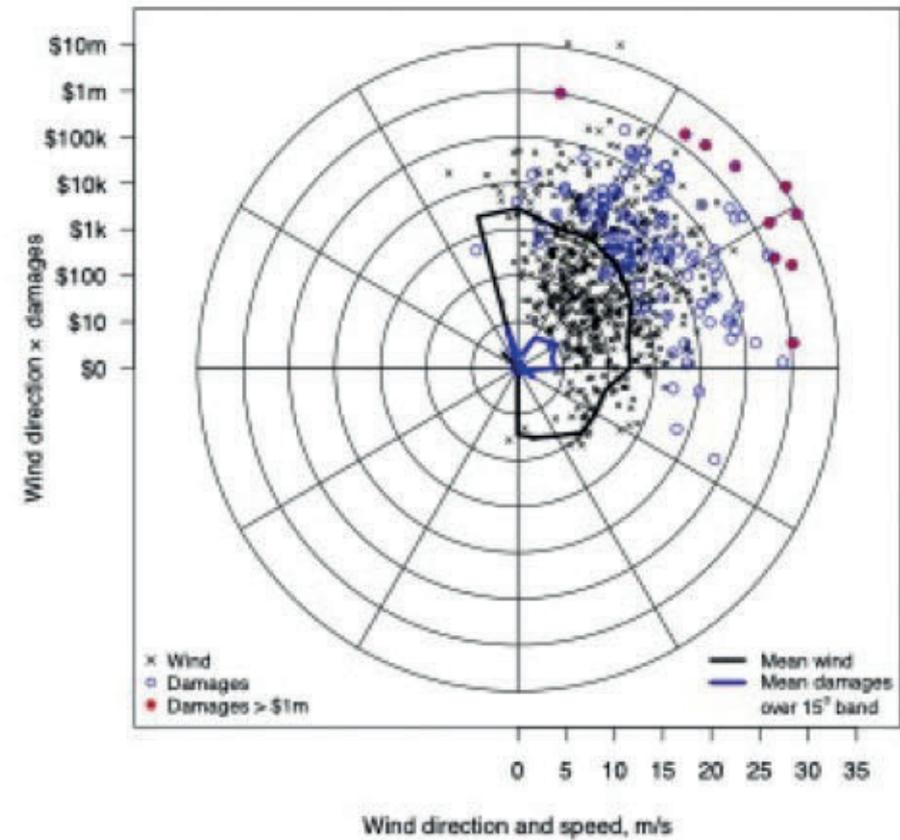


# Papel de la orientación de la RA

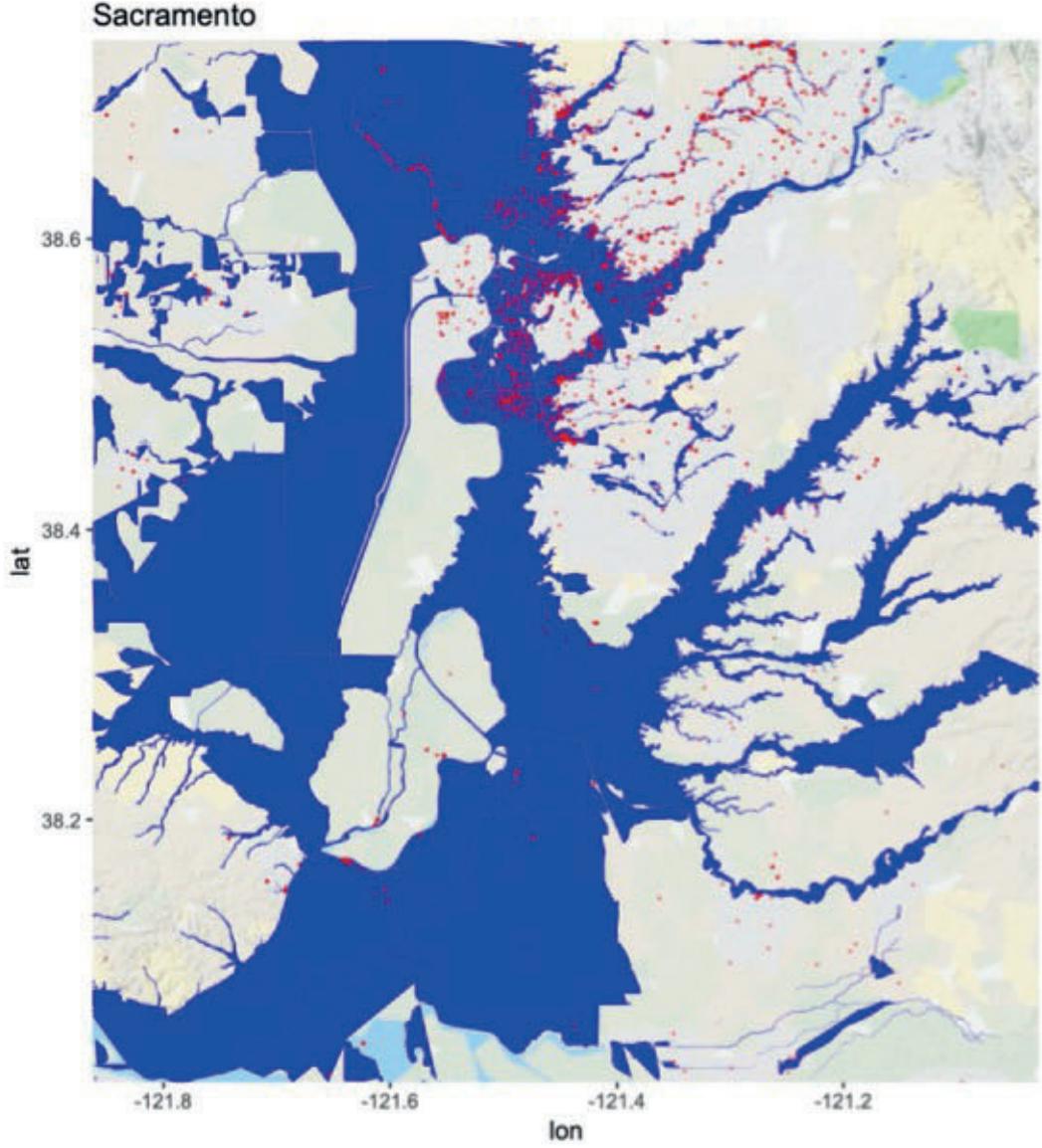
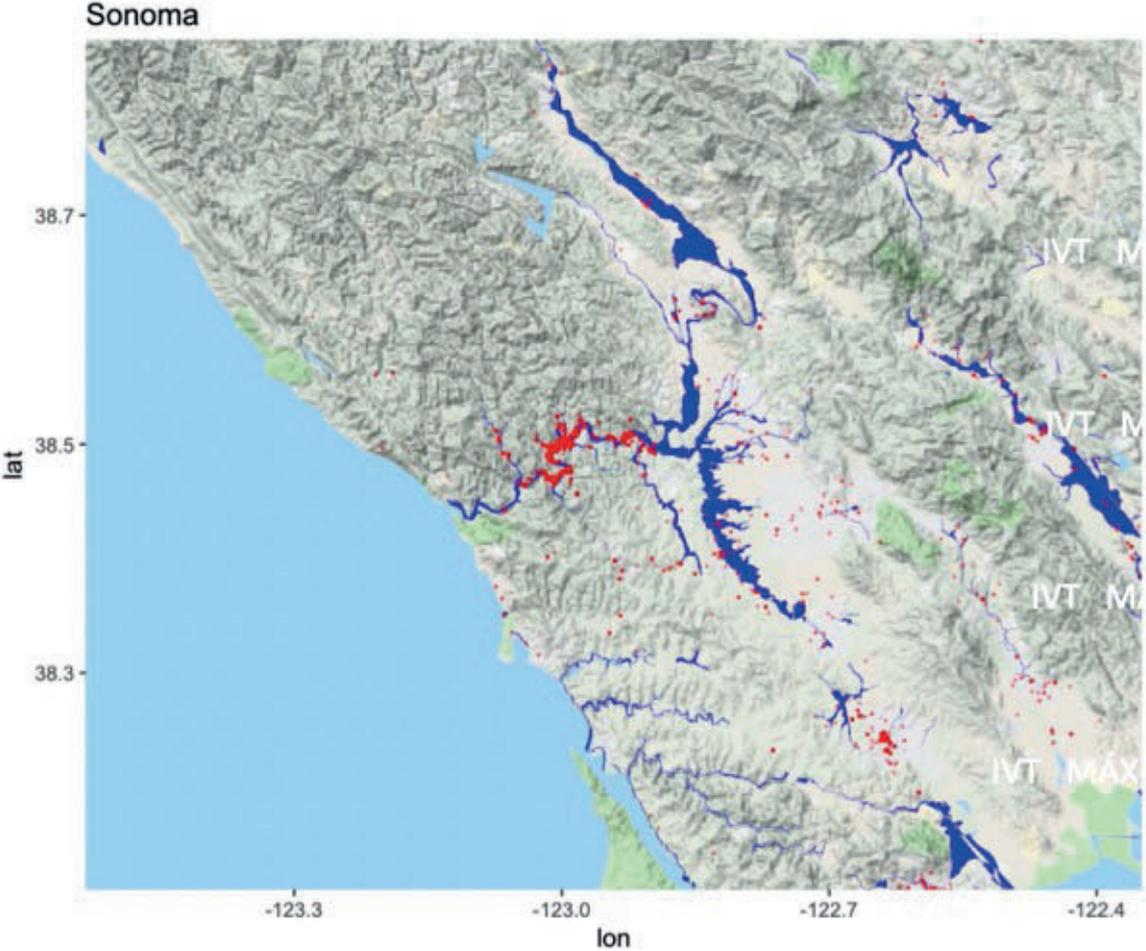
Damages vs Orientation of IVT, 32.5N



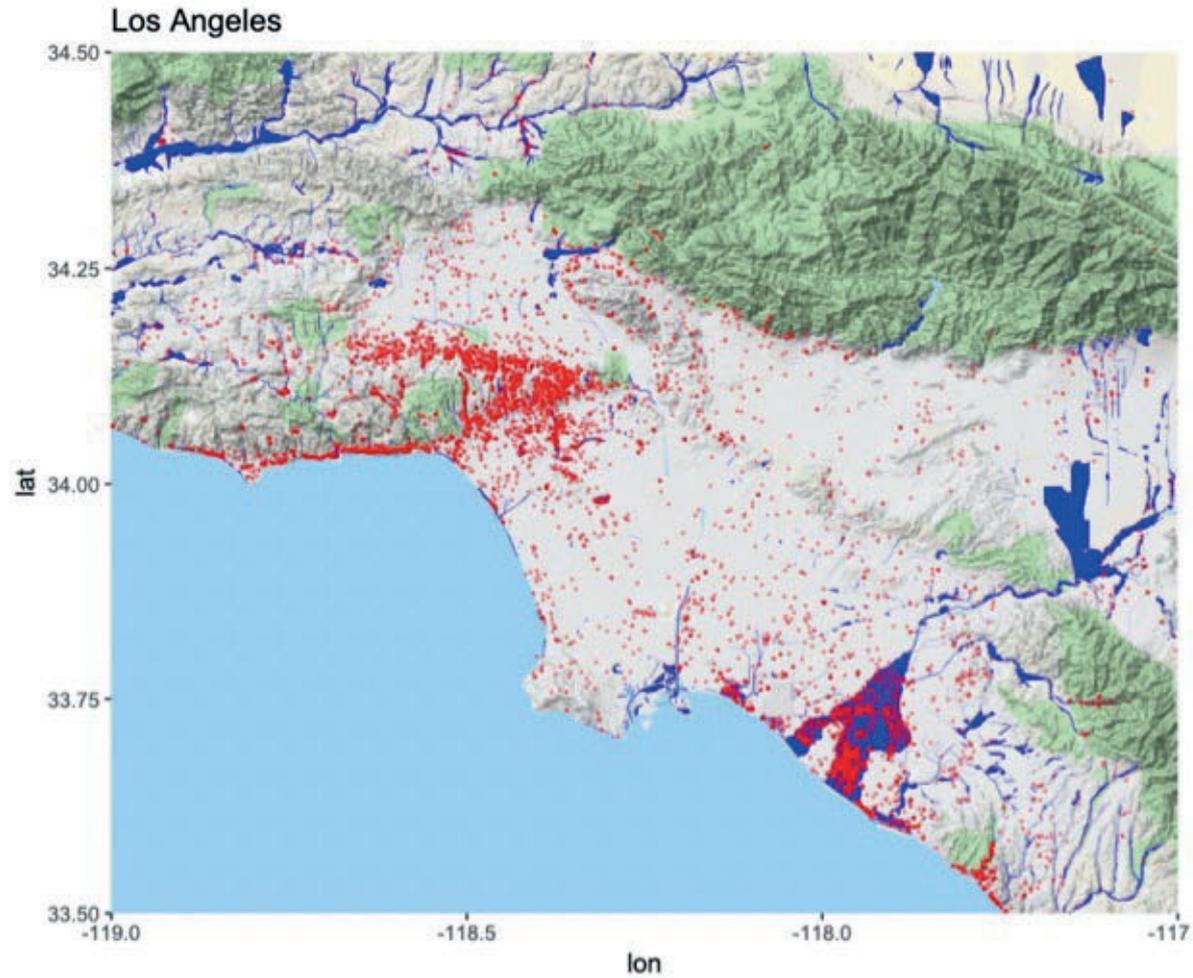
Damages vs Orientation of IVT, 47.5N



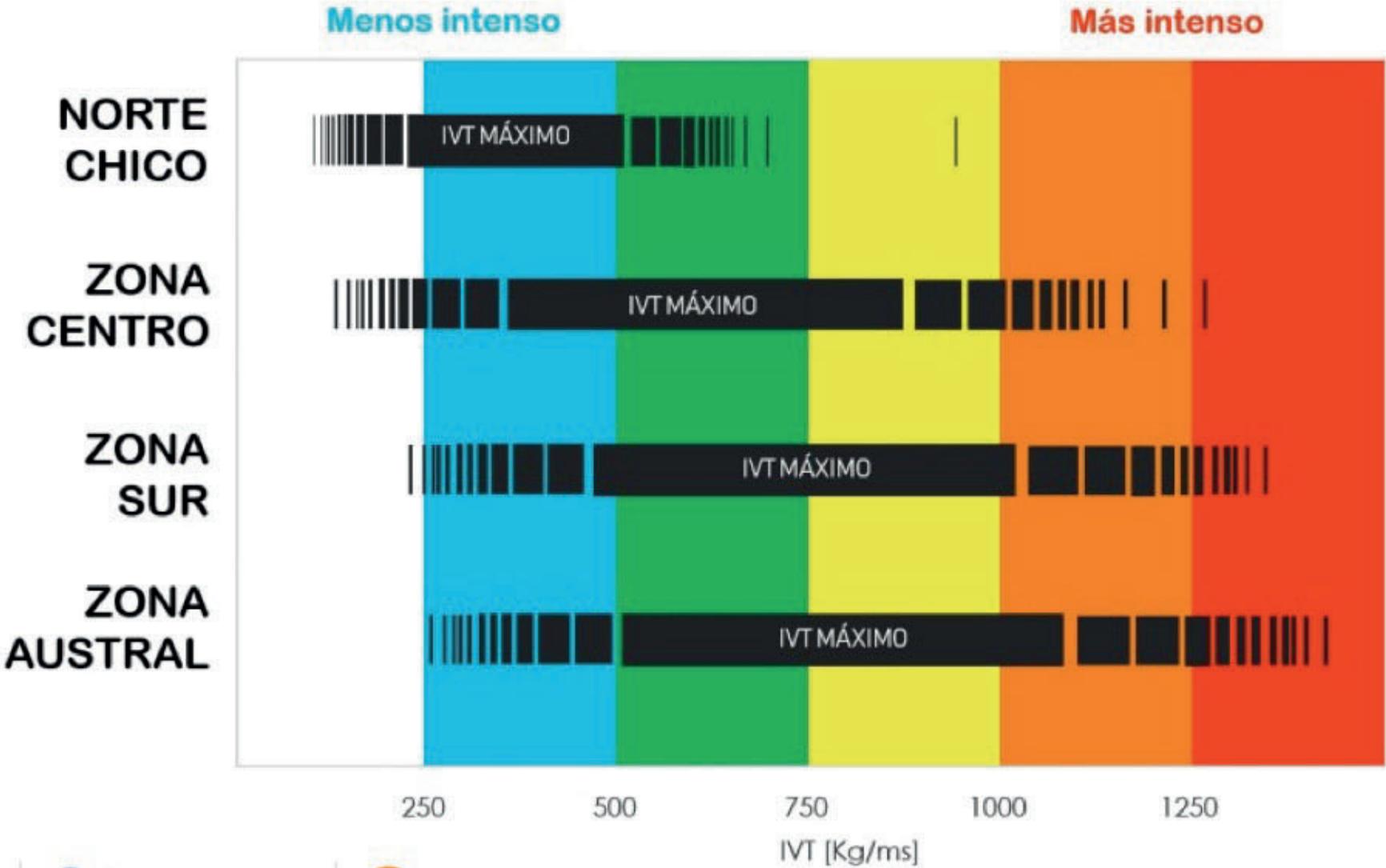
# Efectos de la topografía local



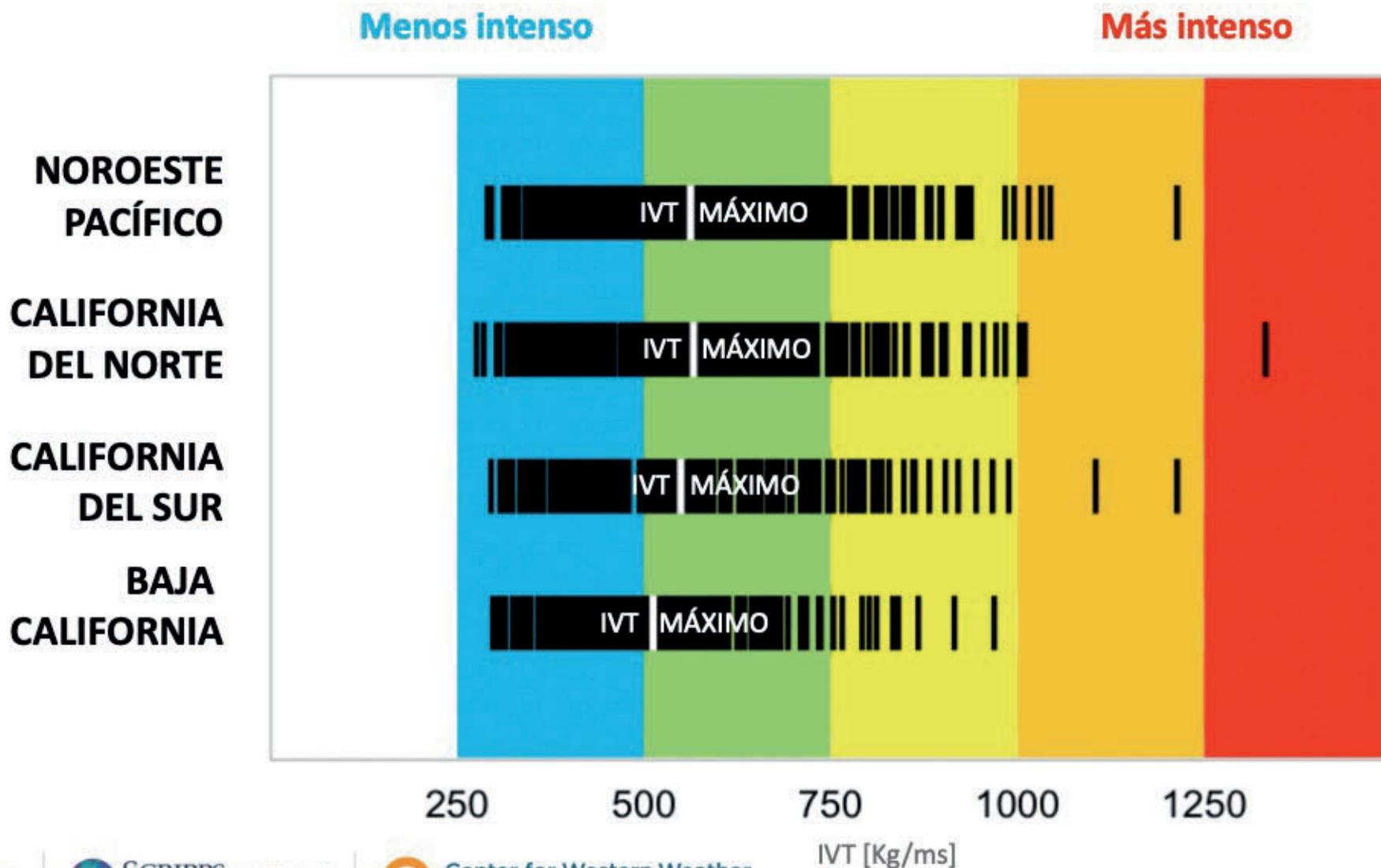
# Efectos de la topografía local



# Intensidad del RA según Zona



# Intensidad del RA según la región de la costa oeste de EEUU



# SCIENTIFIC REPORTS

OPEN

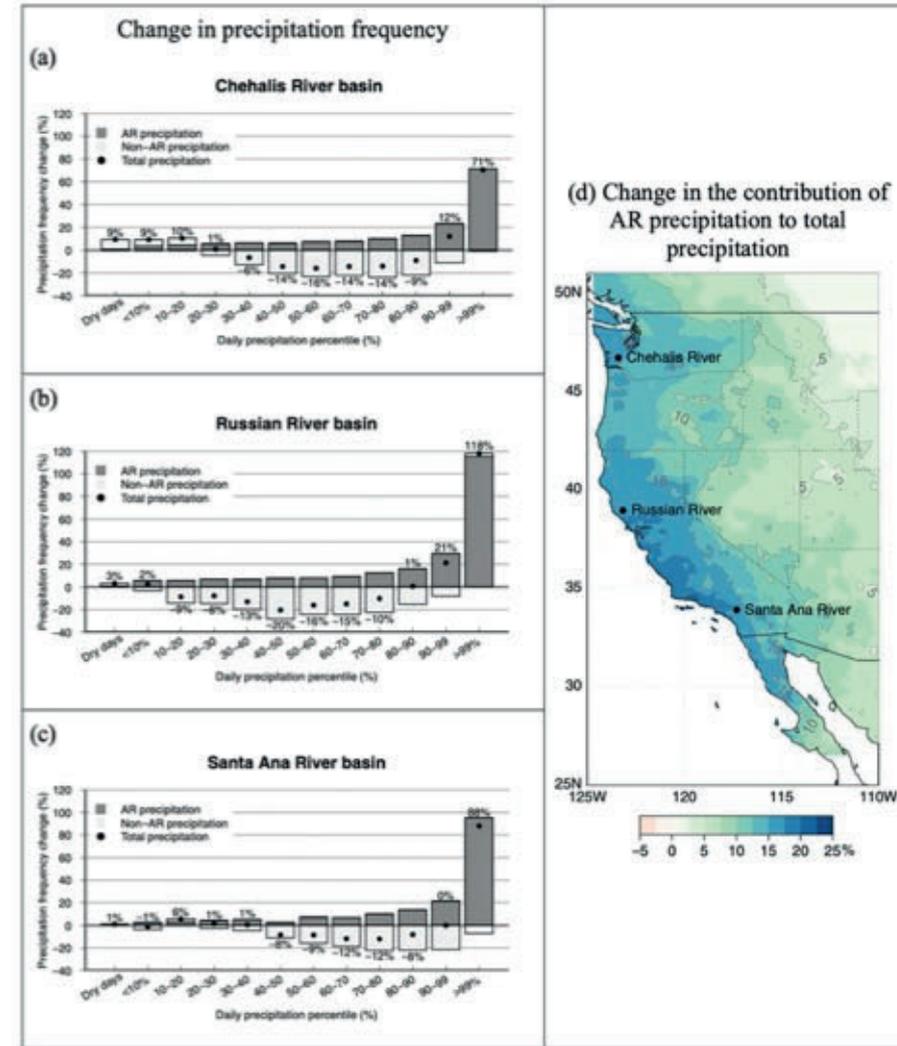
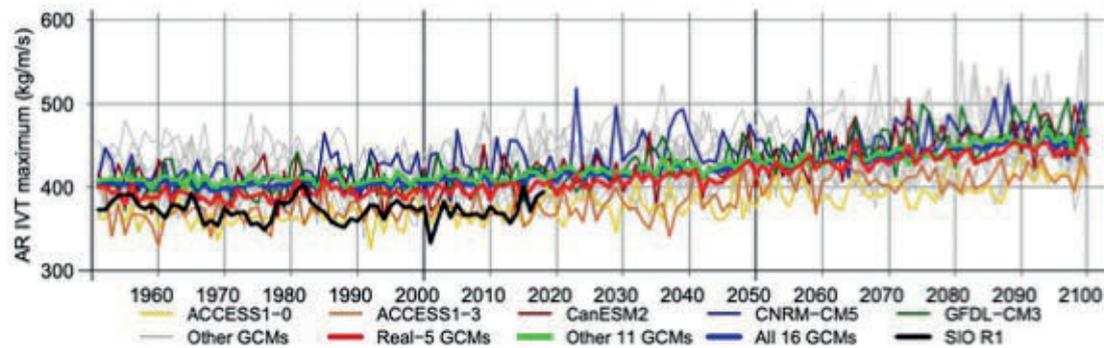
## Precipitation regime change in Western North America: The role of Atmospheric Rivers

Alexander Gershunov<sup>1,2</sup>, Tamara Shulgina<sup>1,2</sup>, Rachel E. S. Clemesha<sup>2</sup>, Kristen Guirguis<sup>1,2</sup>, David W. Pierce<sup>2</sup>, Michael D. Dettinger<sup>3</sup>, David A. Lavers<sup>4</sup>, Daniel R. Cayan<sup>2</sup>, Suraj D. Polade<sup>5</sup>, Julie Kalansky<sup>1,2</sup> & F. Martin Ralph<sup>1,2</sup>

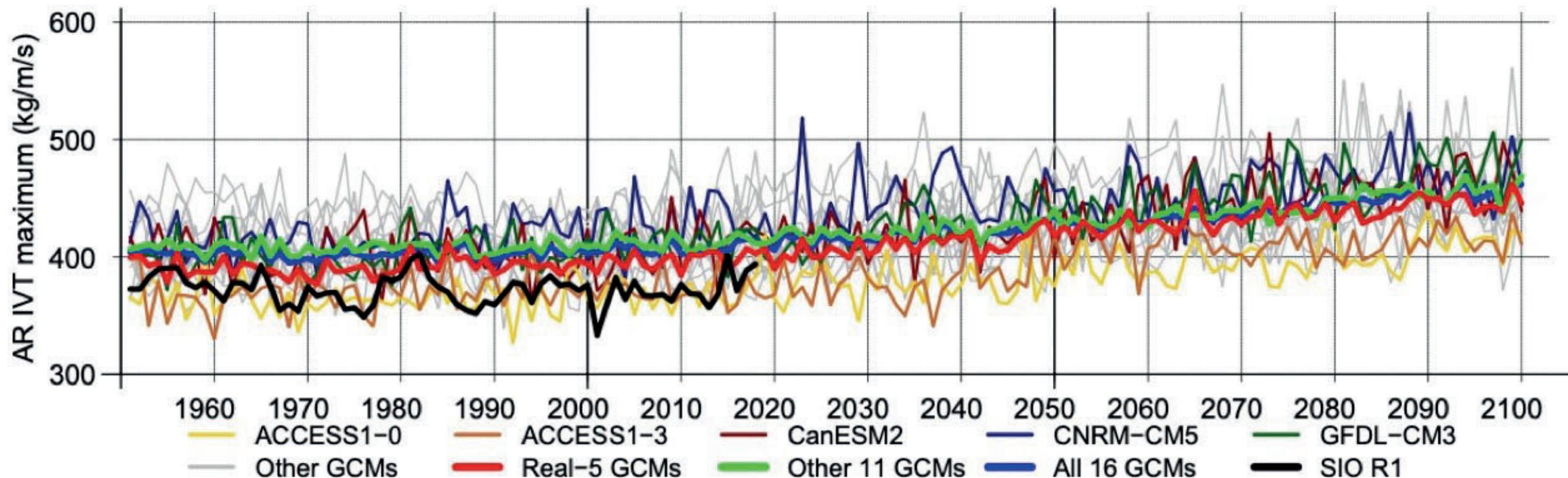
Received: 19 March 2019

Accepted: 20 June 2019

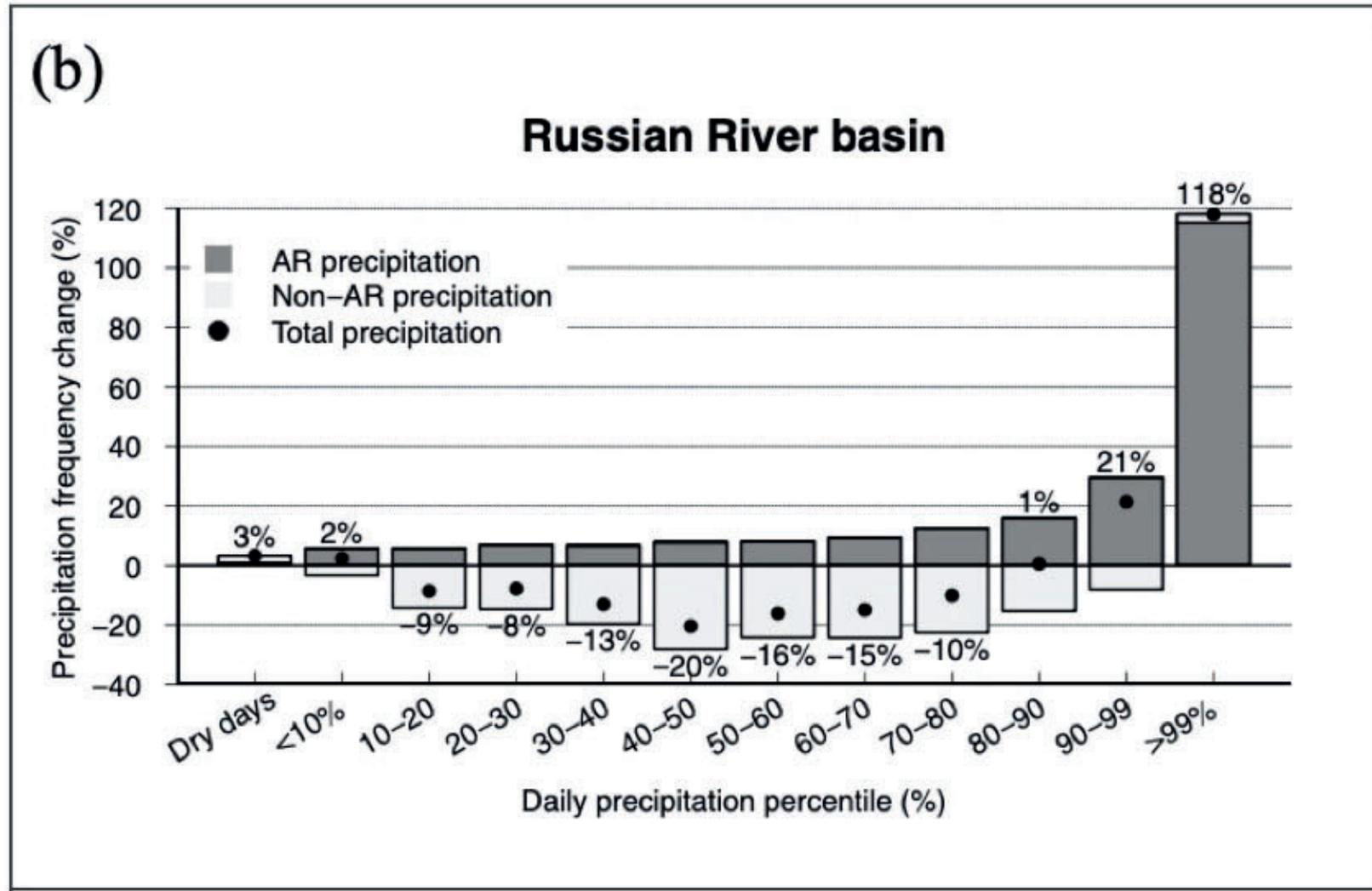
Published online: 09 July 2019



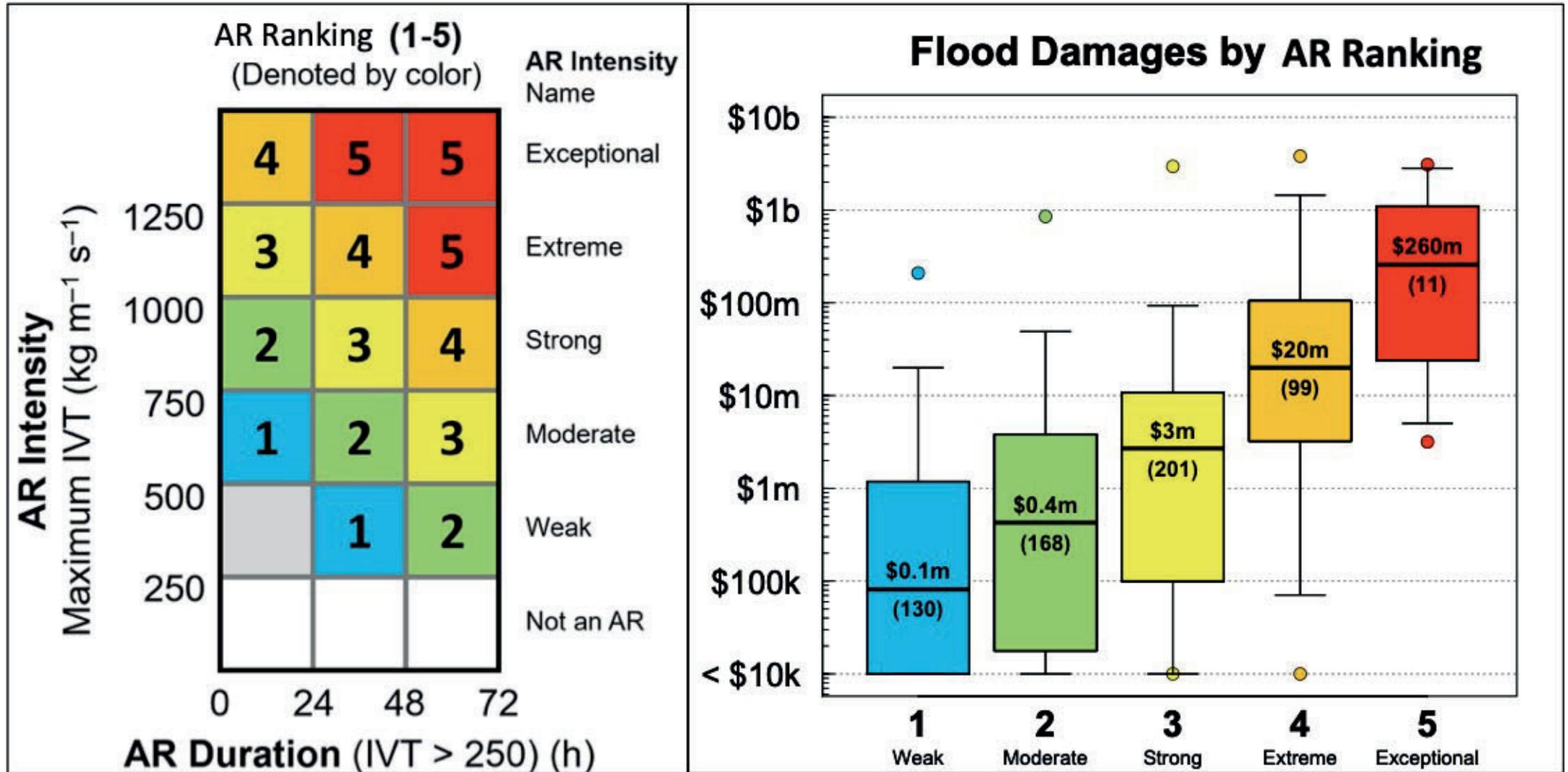
# El cambio climático: aumento del IVT a lo largo del tiempo



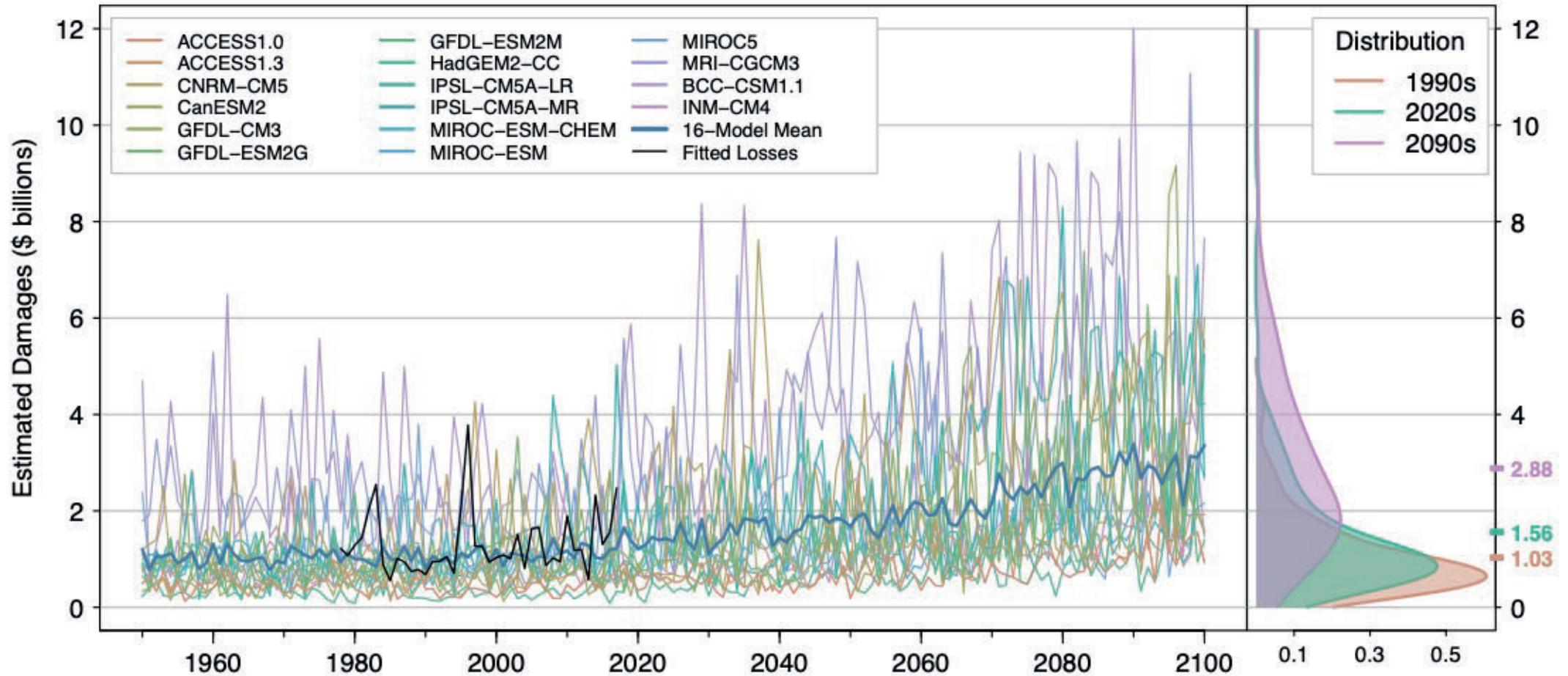
# El cambio climático: aumento de eventos de alta intensidad



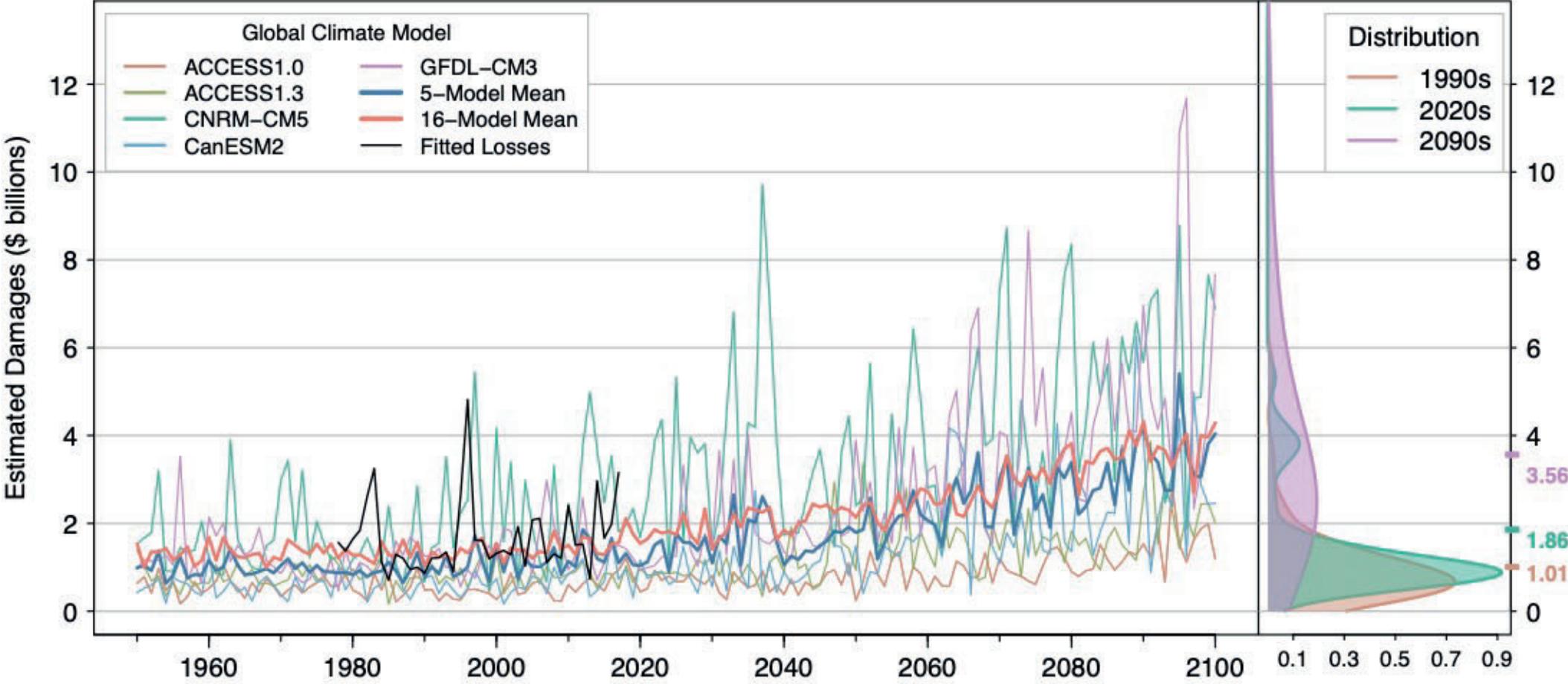
# Los daños aumentan exponencialmente con la intensidad



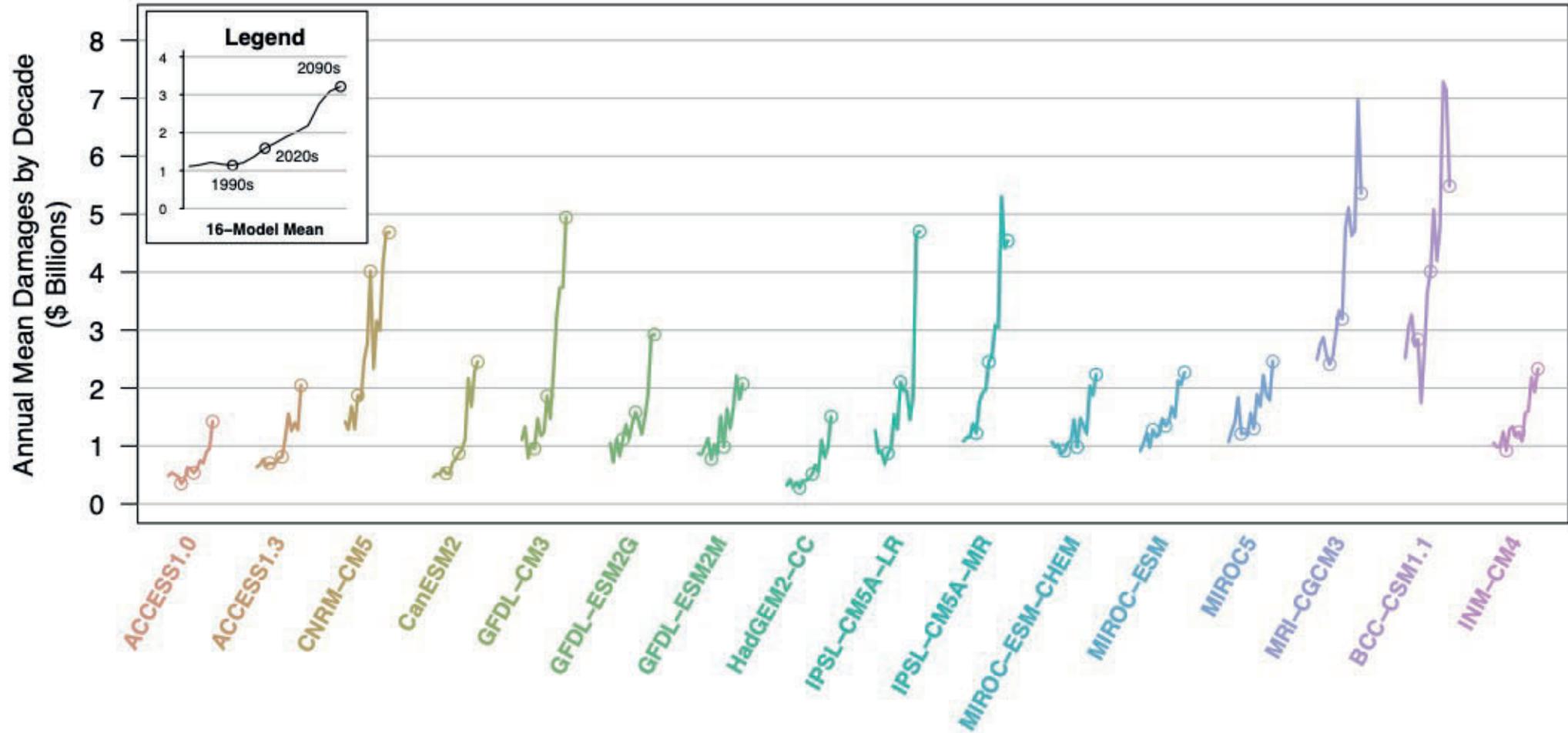
# Proyecciones de daños relacionados con los RA



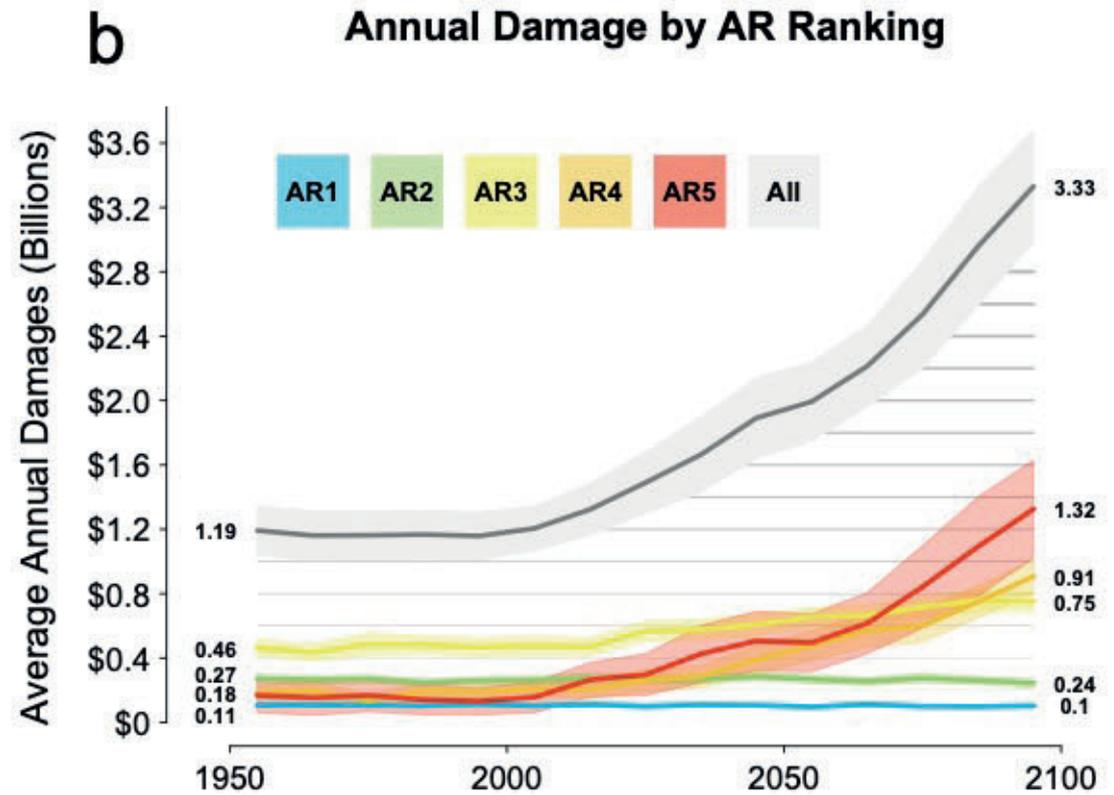
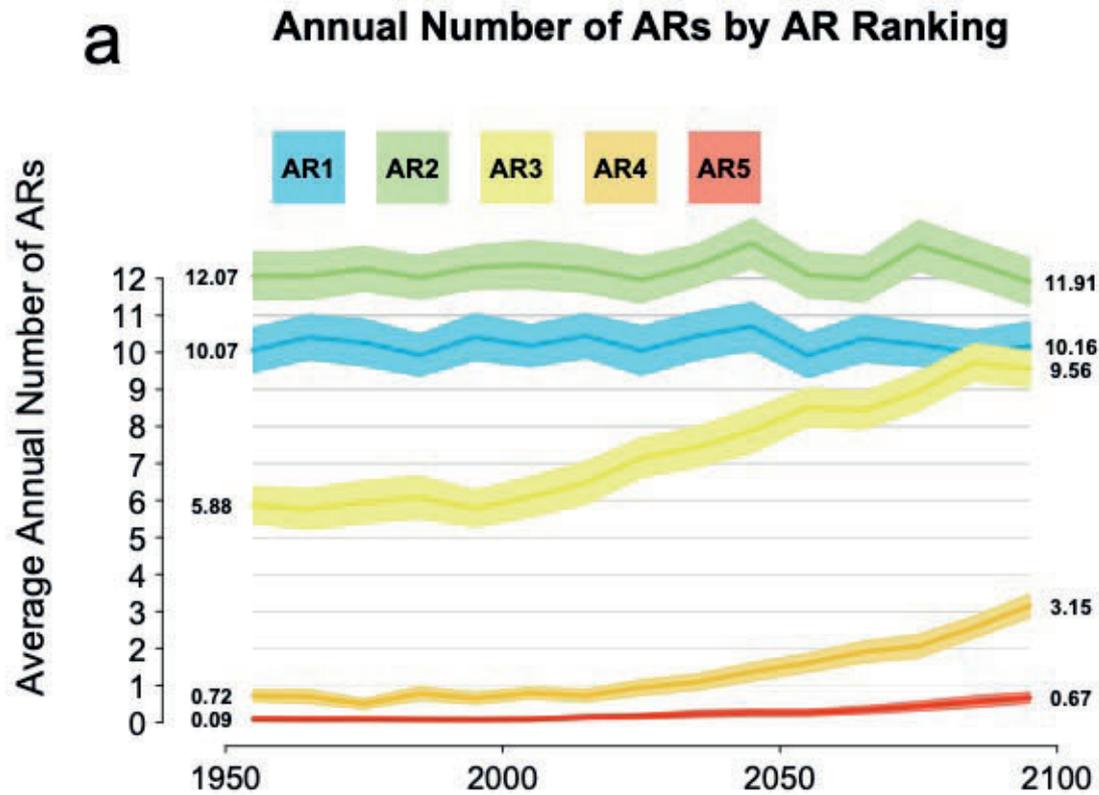
# Los 5 mejores GCMs de Gershunov et al. 2019



# Patrón uniforme en 16 modelos climáticos mundiales

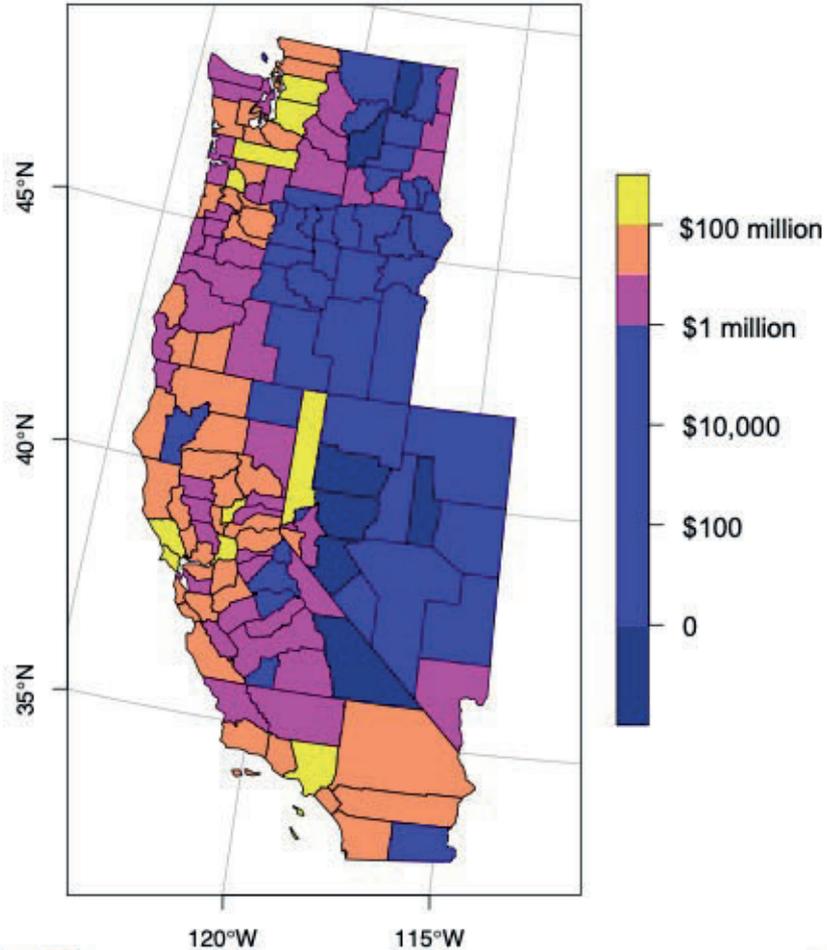


# Cambios por clasificación RA

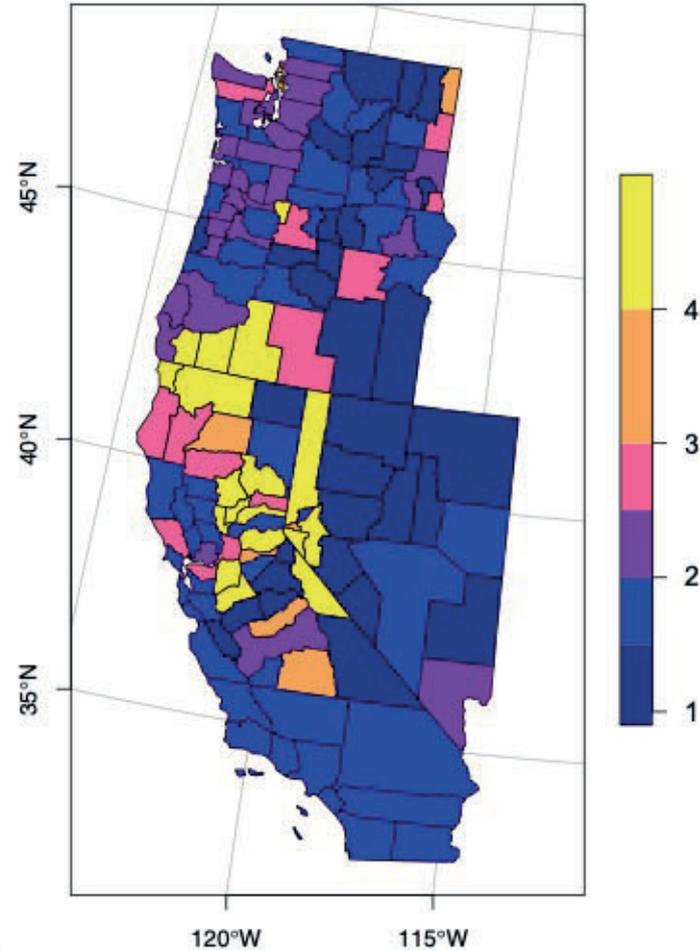


# Distribución espacial de los cambios en los daños

Difference in Annual Damages  
2090s vs 1990s



Ratio of Annual Damages  
2090s to 1990s



	County	State	Difference (Millions \$)	Ratio
1	Sonoma	California	283.2	2.53
2	Washoe	Nevada	275.5	4.47
3	Lewis	Washington	168.7	2.05
4	Sacramento	California	111.3	2.80
5	Yuba	California	103.7	4.89
6	Los Angeles	California	71.5	1.91
7	King	Washington	70.7	2.02
8	Marin	California	63.6	1.85
9	Columbia	Oregon	59.4	2.26
10	Snohomish	Washington	58.7	2.26
11	Pierce	Washington	49.7	2.47
12	Stanislaus	California	43.8	4.55
13	Douglas	Nevada	41.3	4.81
14	Napa	California	40.5	1.95
15	Placer	California	37.7	1.91
16	Sutter	California	33.1	4.80
17	Clackamas	Oregon	30.2	1.76
18	Skagit	Washington	28.8	2.09
19	Monterey	California	27.3	1.58
20	San Joaquin	California	27.2	4.02



# Cambios a corto plazo de los daños

## Losses and Damages 2020 to 2050 relative to 2020

Year	Insured Loss (\$M)	Estimated Damage (\$B)	Percent Change	K.S. p-Value
2020	44.13	1.32	0	1
2025	47.59	1.43	7.8	0.91
2030	48.55	1.46	10.0	0.57
2035	52.02	1.56	17.8	0.20
2040	54.79	1.64	24.1	0.02
2045	56.91	1.71	28.9	0.0072
2050	59.01	1.77	33.7	0.0014



# Costos futuros de los ríos atmosféricos

- Los RAs se están volviendo "más largos, más anchos y más húmedos"
- Espinoza et al. 2018 *GRL*, Gershunov et al. 2019 *Sci. Rep.*
- Aumentos modestos de la intensidad → aumentos significativos de los daños
- Se espera que los daños anuales aumenten de \$1b a \$3b en un siglo
- Aumento del 10% de los daños esperados por década hasta 2050
- Necesidad de mejorar la predicción de AR para mitigar los daños
- Inversiones destinadas a las zonas de mayor riesgo para prevenir los daños de inundaciones futuras



# Costos futuros de los ríos atmosféricos

Weather and Climate Extremes 32 (2021) 100326



Contents lists available at ScienceDirect  
Weather and Climate Extremes

journal homepage: [www.elsevier.com/locate/wace](http://www.elsevier.com/locate/wace)



## Implications of warming on western United States landfalling atmospheric rivers and their flood damages

Alan M. Rhoades<sup>a,\*</sup>, Mark D. Risser<sup>b</sup>, Dáithí A. Stone<sup>b</sup>, Michael F. Wehner<sup>c</sup>, Andrew D. Jones<sup>b</sup>

<sup>a</sup> Climate and Ecosystem Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

<sup>b</sup> National Institute of Water and Atmospheric Research, Wellington, New Zealand

<sup>c</sup> Computational Research Division, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

### ARTICLE INFO

#### Keywords:

Atmospheric rivers  
Western United States  
Climate change  
Societal impacts  
Detection and attribution  
Stabilized warming scenarios

### ABSTRACT

Atmospheric rivers (ARs) are critical to the hydrological cycle of the western United States with both favorable and formidable impacts to society based on their landfalling characteristics. In this study, we provide a first-of-its-kind evaluation of how landfalling ARs may respond to several stabilized warming scenarios. To do this we combine a recently developed AR detection workflow with an ensemble of uniform high-resolution (0.25°) Community Earth System Model simulations designed to facilitate detection and attribution of extreme events with global warming. These simulations include a world that might have been in the absence of anthropogenic warming (+0 °C), a world that corresponds to present day warming (+0.85 °C), and several future worlds corresponding to +1.5 °C, +2 °C and +3 °C global warming. We show that warming increases the number of water management relevant landfalling ARs from 19.1 ARs per year at +0 °C to 23.6 ARs per year at +3 °C. Additionally, this warming intensifies the amount of water transported by landfalling ARs resulting in a decrease in the fraction of ARs that are “mostly to primarily beneficial” to water resource management (i.e., 91% of ARs at +0 °C to 78% at +3 °C) and an increase in the fraction of ARs that are “mostly or primarily hazardous” to water resource management (i.e., 2% of ARs at +0 °C to 8% at +3 °C). Shifts in AR character also have important ramifications on flood damages, whereby for every +1 °C of additional warming from present conditions annual average flood damages increase by ~\$1 billion. These findings highlight the pragmatic implications of climate mitigation aimed at limiting global warming to under +2 °C.

A.M. Rhoades et al.

Weather and Climate Extremes 32 (2021) 100326

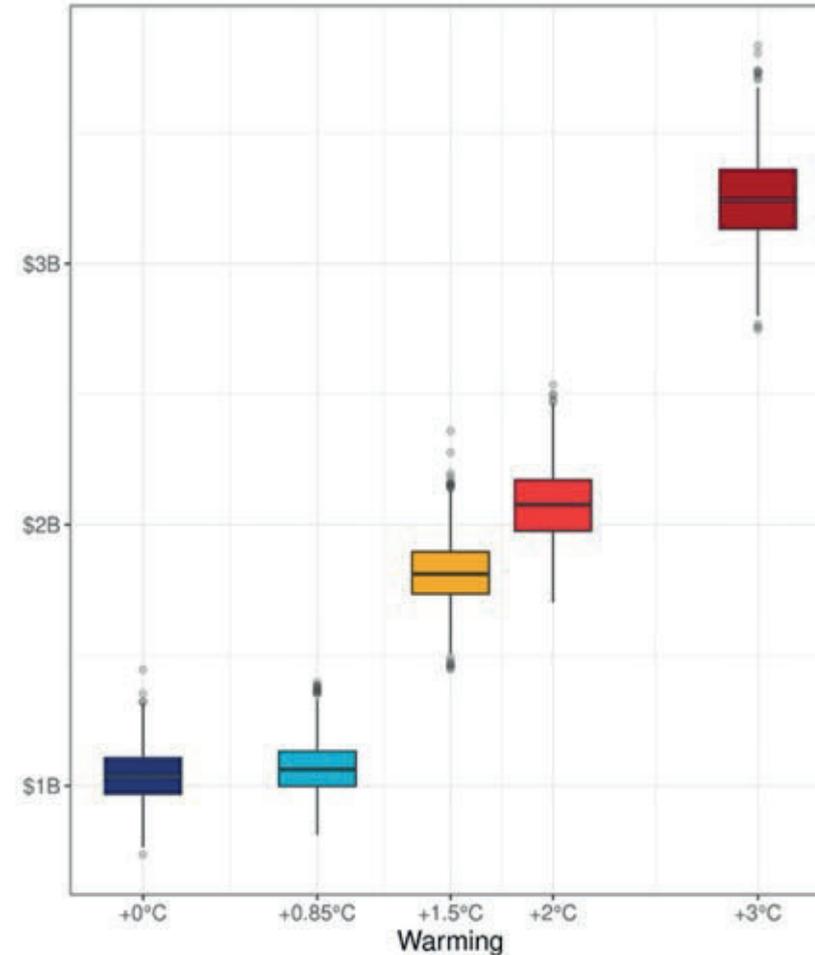


Fig. 4. Annual AR flood damage estimates based on Markov chain Monte Carlo sampling of the C20C+ D&A and HAPPI experiments. Box-and-whisker plots are labeled on the x-axis according to each C20C+ D&A and HAPPI experiment's average global temperature delta from the Nat-Hist experiment. Box-and-whiskers indicate the 5th to 95th percentiles with the 25th percentile, median, and 75th percentile demarcating the box region. Flood damage outliers outside of the 5th and 95th percentiles are shown via dots.

# Más allá de las inundaciones

Agua y Extremos

## Análisis: ¿Una tormenta de invierno en pleno verano? Entendiendo el extraordinario evento de finales de enero de 2021 en Chile central | (CR)2

19 marzo, 2021

3233

René D. Garreaud, Departamento de Geofísica de la Universidad de Chile, y Centro de Ciencia del Clima y la Resiliencia (CR)2; Iván Vergara, Instituto Andino Patagónico de Tecnologías Geoambientales – CONICET, Bariloche, Argentina; y Maximiliano Viale, Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales – CONICET, Mendoza, Argentina

<http://www.cr2.cl/analisis-una-tormenta-de-invierno-en-pleno-verano-entendiendo-el-extraordinario-evento-de-finales-de-enero-de-2021-en-chile-central-cr2/>

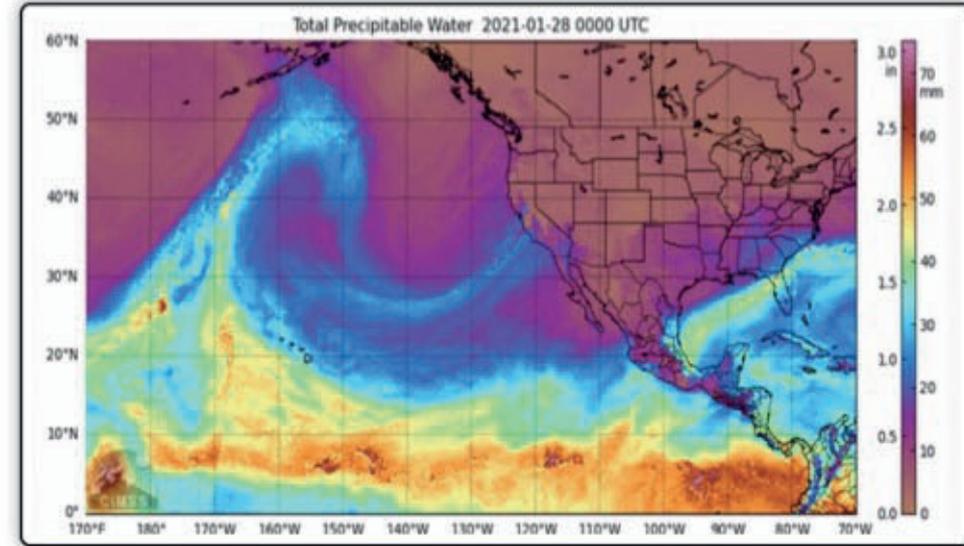


## Principales afectaciones tormenta 28-31 Enero 2021





# Efectos de los RAs en el transporte



Satellite loop showing the evolution of the Atmospheric River impacting the Bay Area and Central Coast.

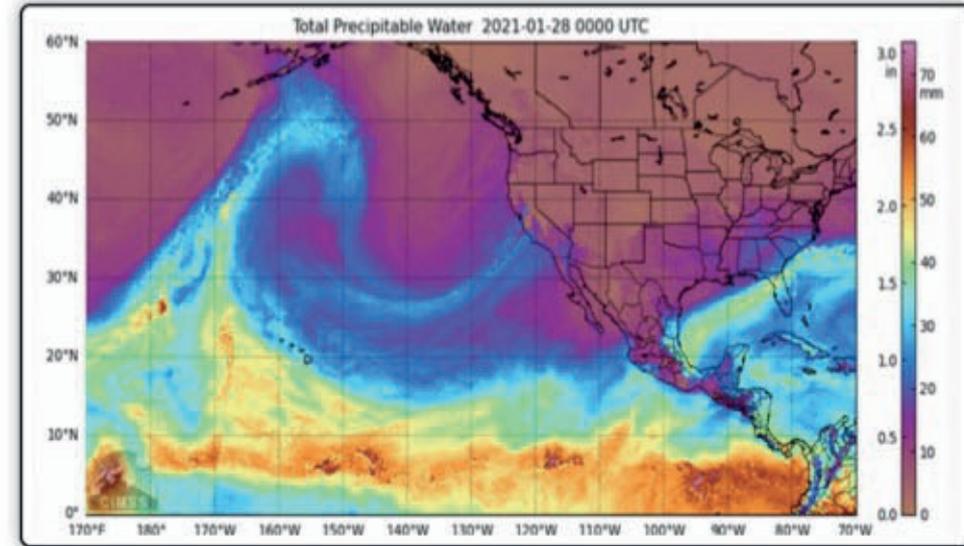




# Efectos de los RAs en el transporte



Winter landslides seemed likely after the Dolan Fire burned 128,000 acres of forest last fall.

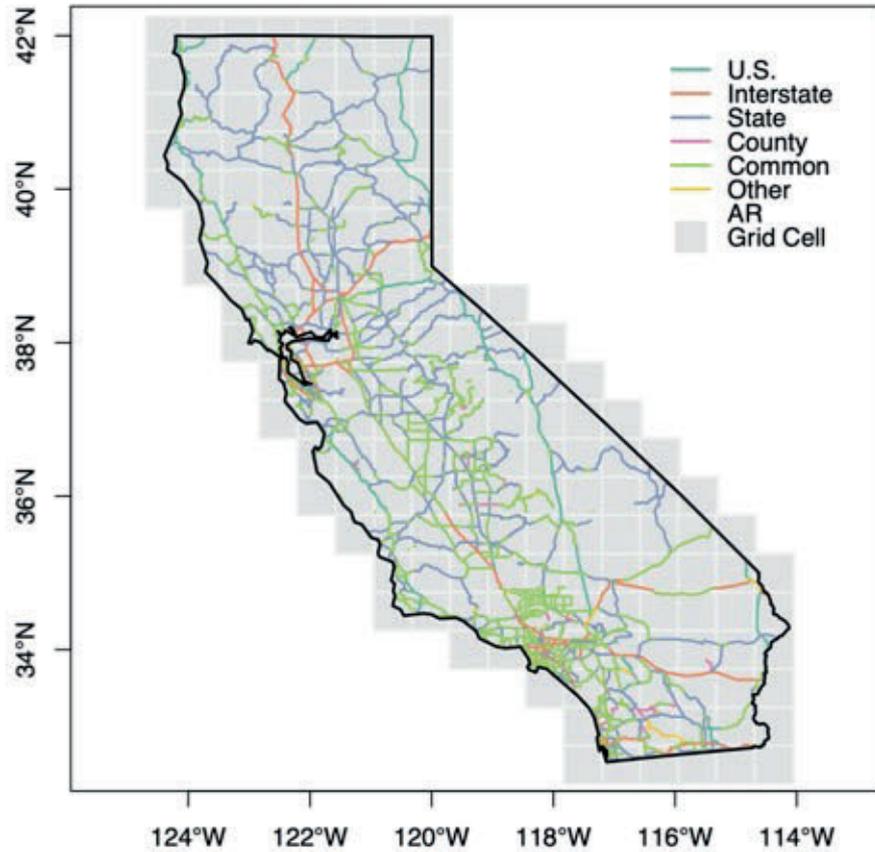


Satellite loop showing the evolution of the Atmospheric River impacting the Bay Area and Central Coast.

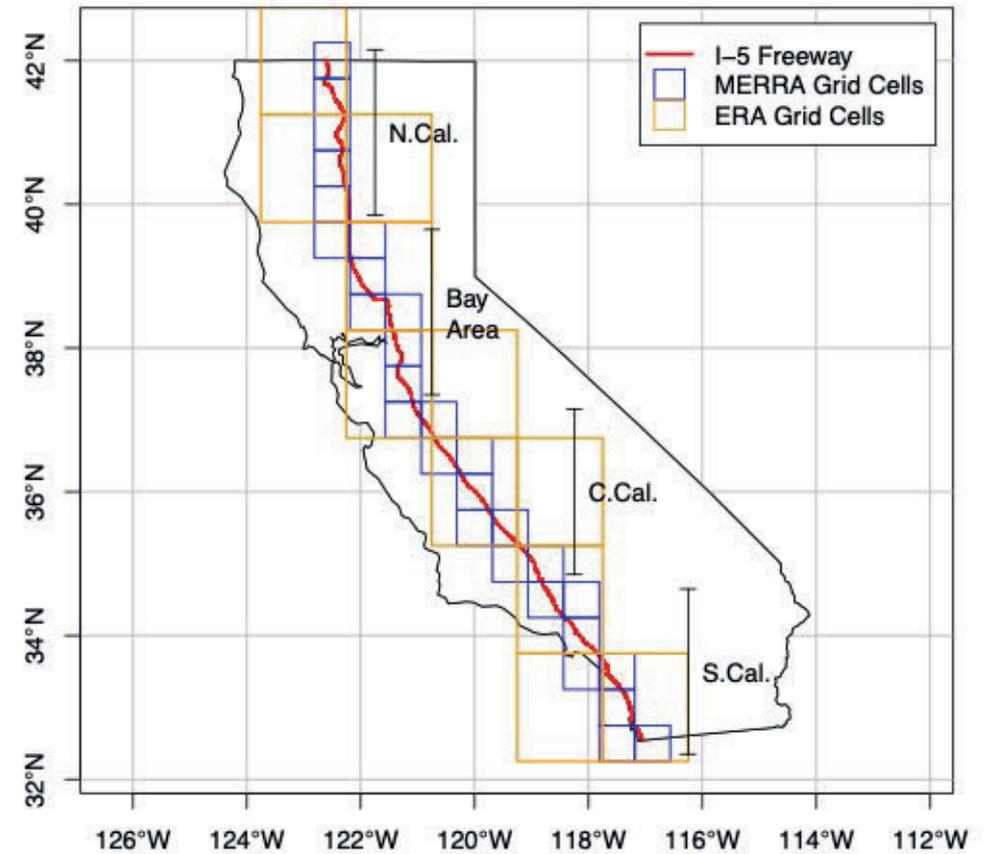


# Impactos de RAs en la autopista I-5 de California

California Highways and AR Grid

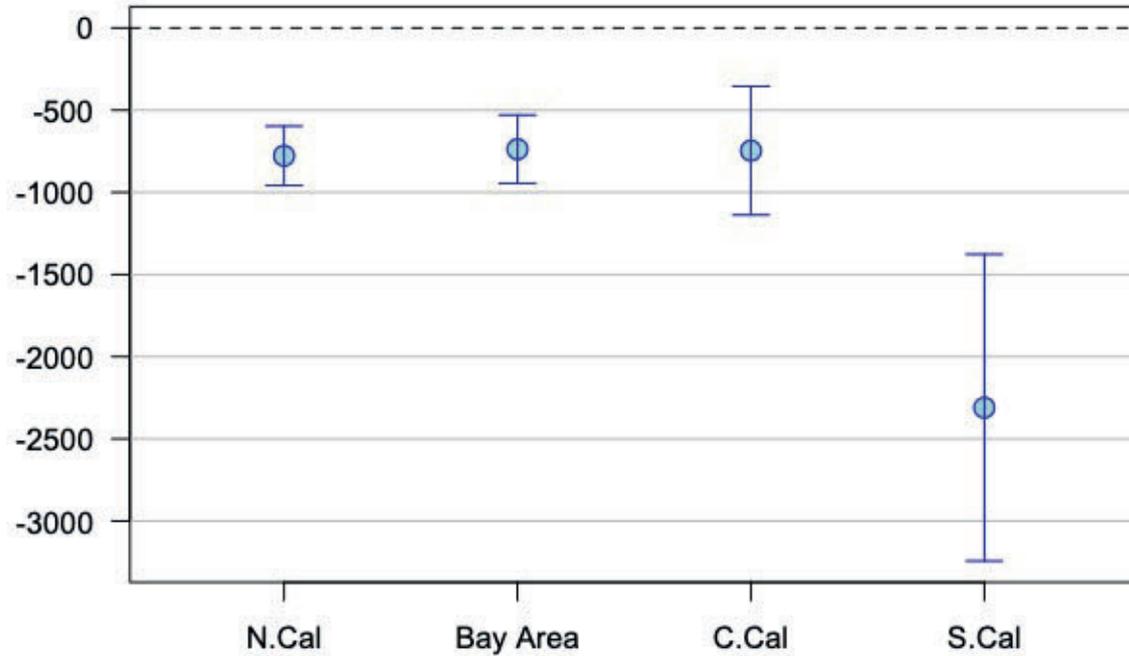


California I-5 Extents

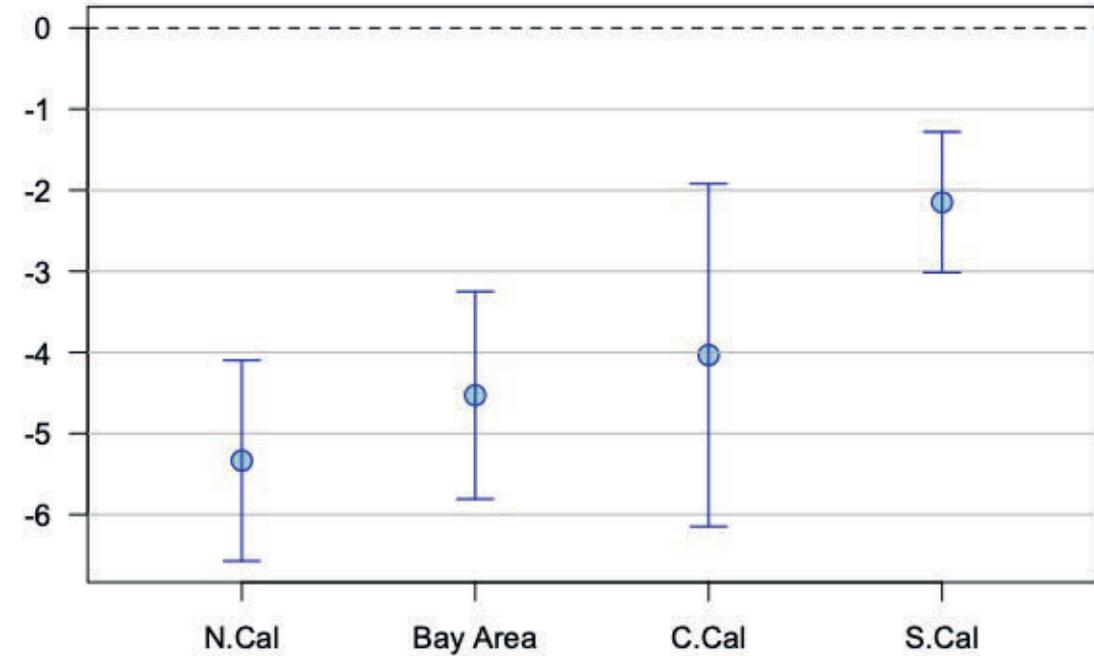


# Efectos de los RAs en la fluidez del tráfico

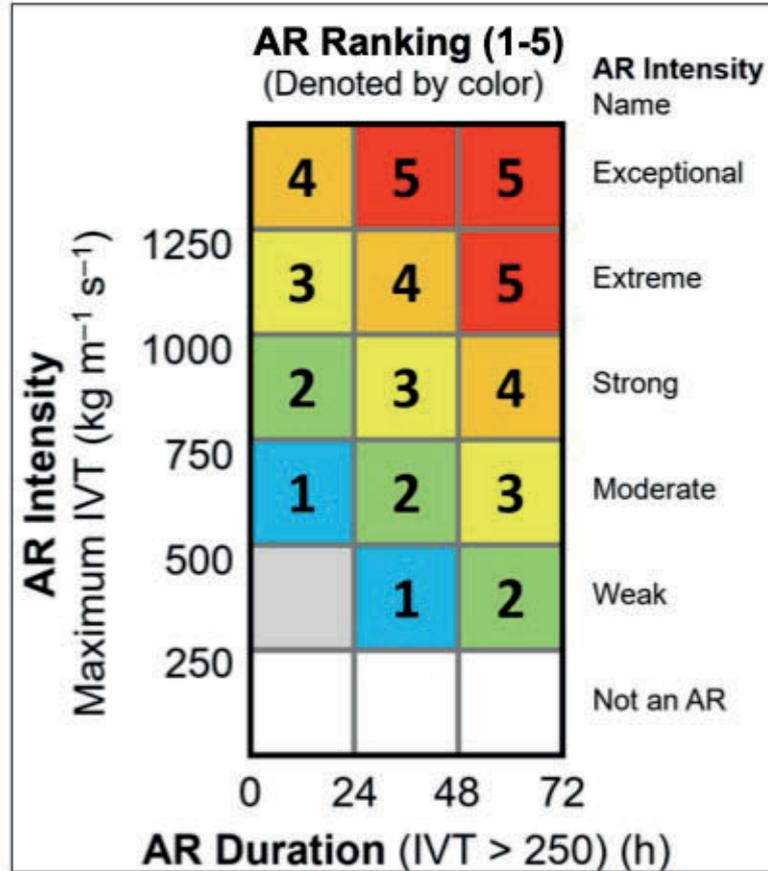
AR Effect on V-Class Total Flow



AR Percent Effect on V-Class Total Flow



# Efectos en la fluidez del tráfico por clasificación RA



Northern California

AR1  
AR2  
AR3  
AR4  
AR5

Bay Area

AR1  
AR2  
AR3  
AR4  
AR5

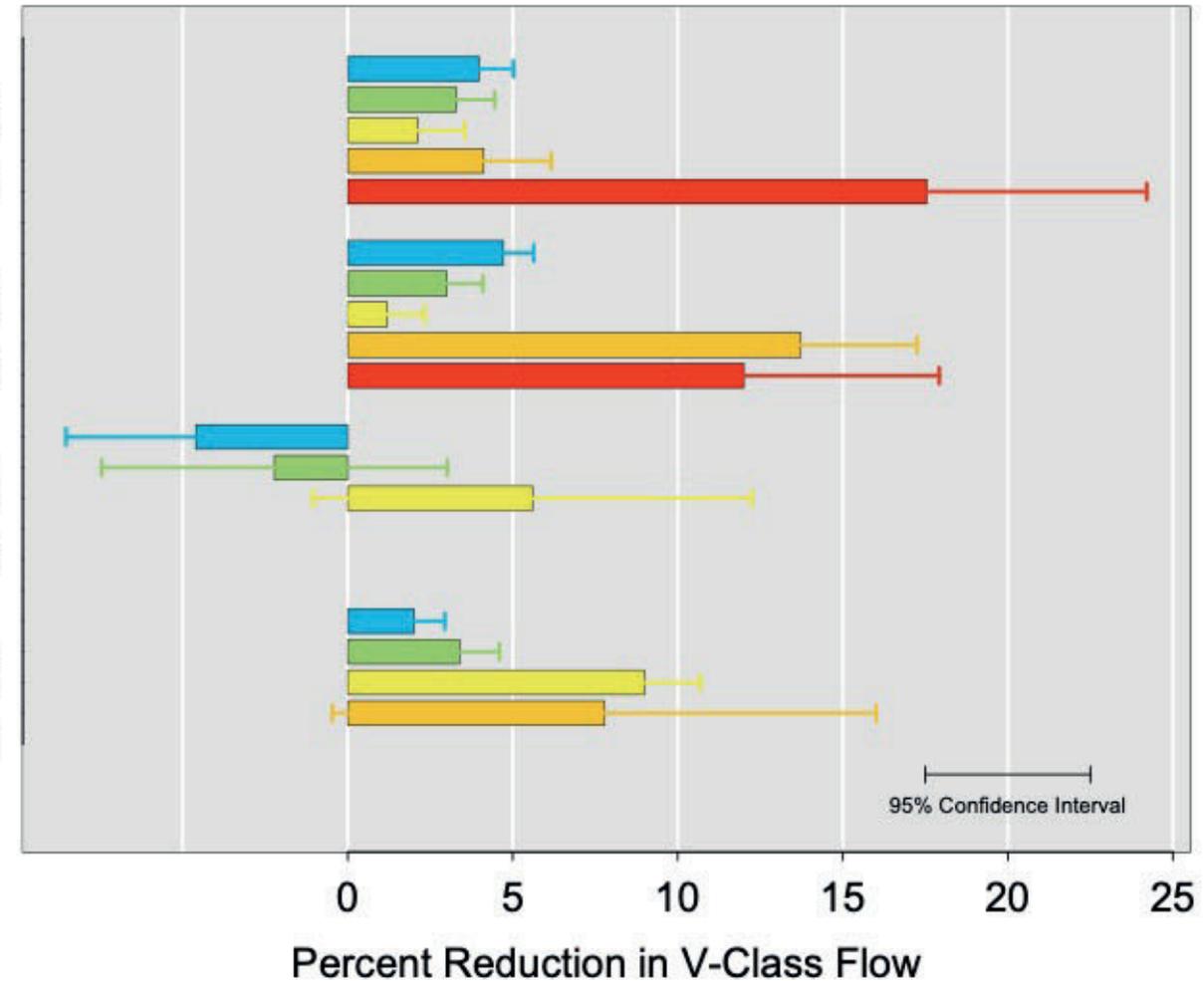
Central California

AR1  
AR2  
AR3  
AR4  
AR5

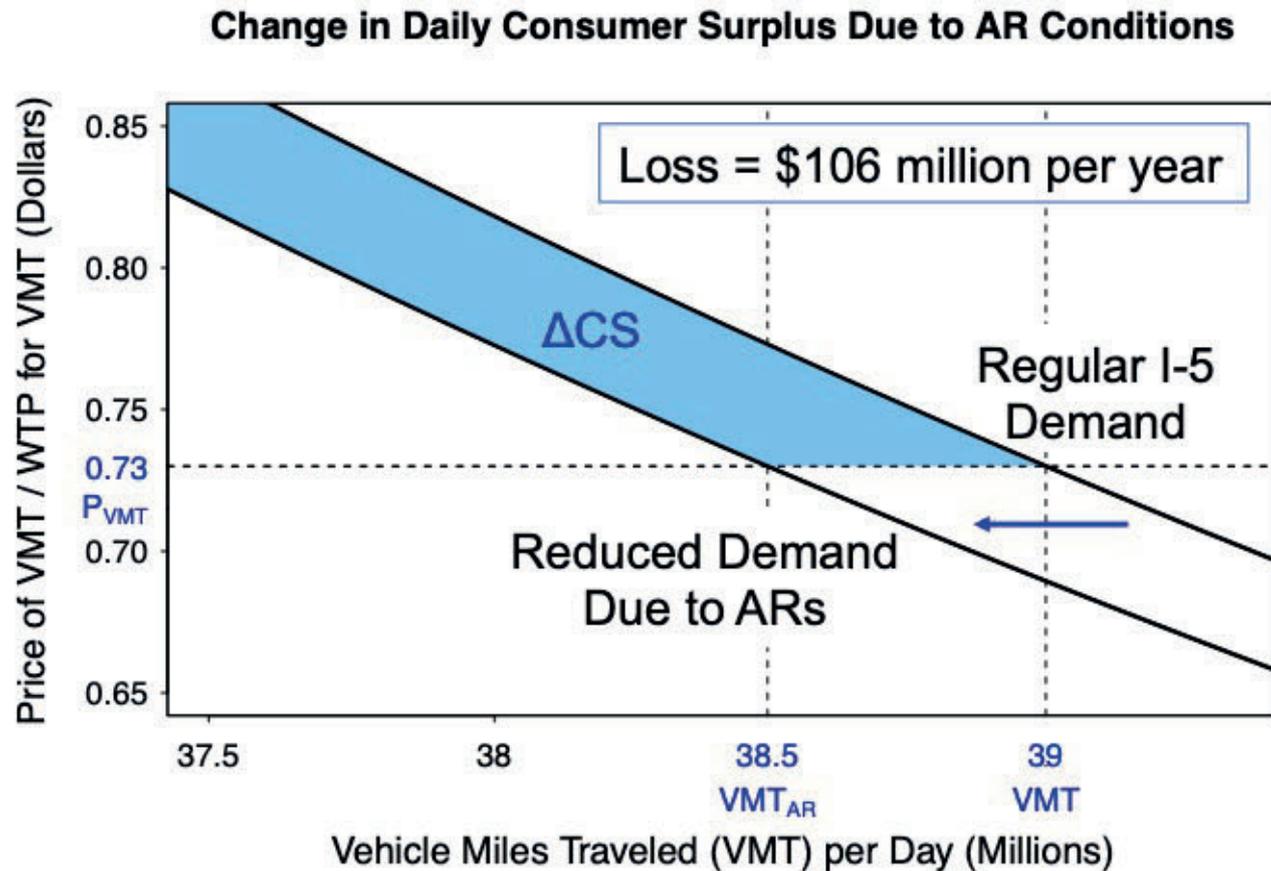
Southern California

AR1  
AR2  
AR3  
AR4  
AR5

## AR Traffic Flow Reductions



# Coste económico de la movilidad reducida

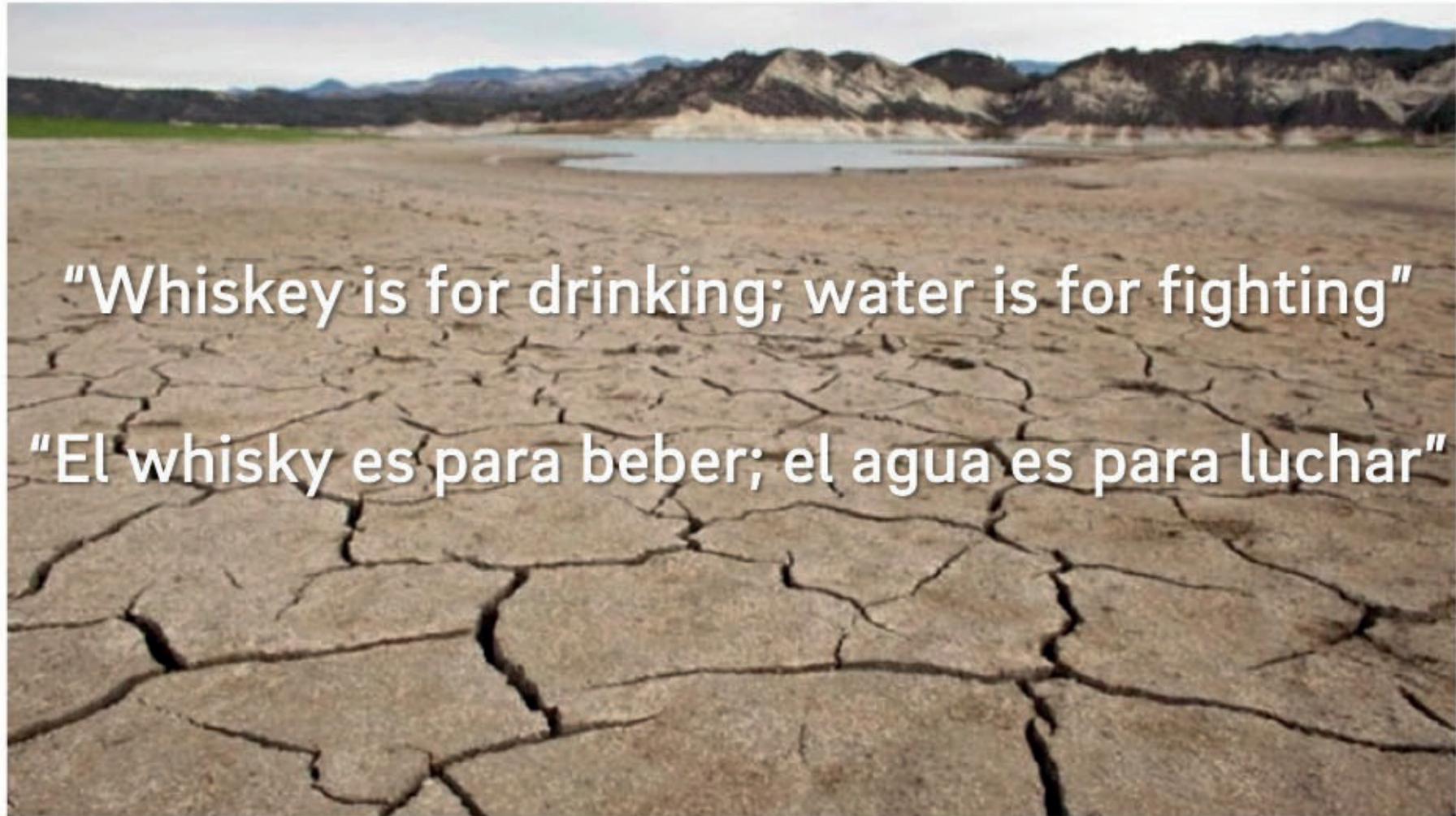


El costo estimado de los viajes cancelados o aplazados varía de **78 a 233 millones de dólares** por año, según las hipótesis sobre la demanda del uso de carreteras.

Las estimaciones de pérdidas son más elevadas si se supone que los conductores de vehículos modifican menos su comportamiento antes las condiciones adversas.



# Escasez de agua en California



"Whiskey is for drinking; water is for fighting"

"El whisky es para beber; el agua es para luchar"

The remains of Cachuma Lake, the main water source for 200,000 people in southern Santa Barbara County. **Ruaridh Stewart/ZUMA**

# Escasez de agua en California



WATER

BY 2100  
WATER SUPPLY FROM SNOWPACK  
IS PROJECTED TO  
**DECLINE BY  
TWO-THIRDS**



Water management practices in California face growing challenges from continued climate change and extreme weather. Promising technical adaptation options to reduce these negative water supply impacts include the use of probabilistic hydrological forecasts, groundwater storage, and better measurements of the snowpack.



<http://climateassessment.ca.gov/state/docs/20190116-StatewideSummary.pdf>

# Escasez de agua en California

## IMPACTS TO AGRICULTURE

By 2050, under certain precipitation conditions, a study estimates California's agricultural production could face climate-related

**water shortages of up to 16 percent in certain regions.**

Hotter conditions due to climate change could lead to loss of soil moisture.

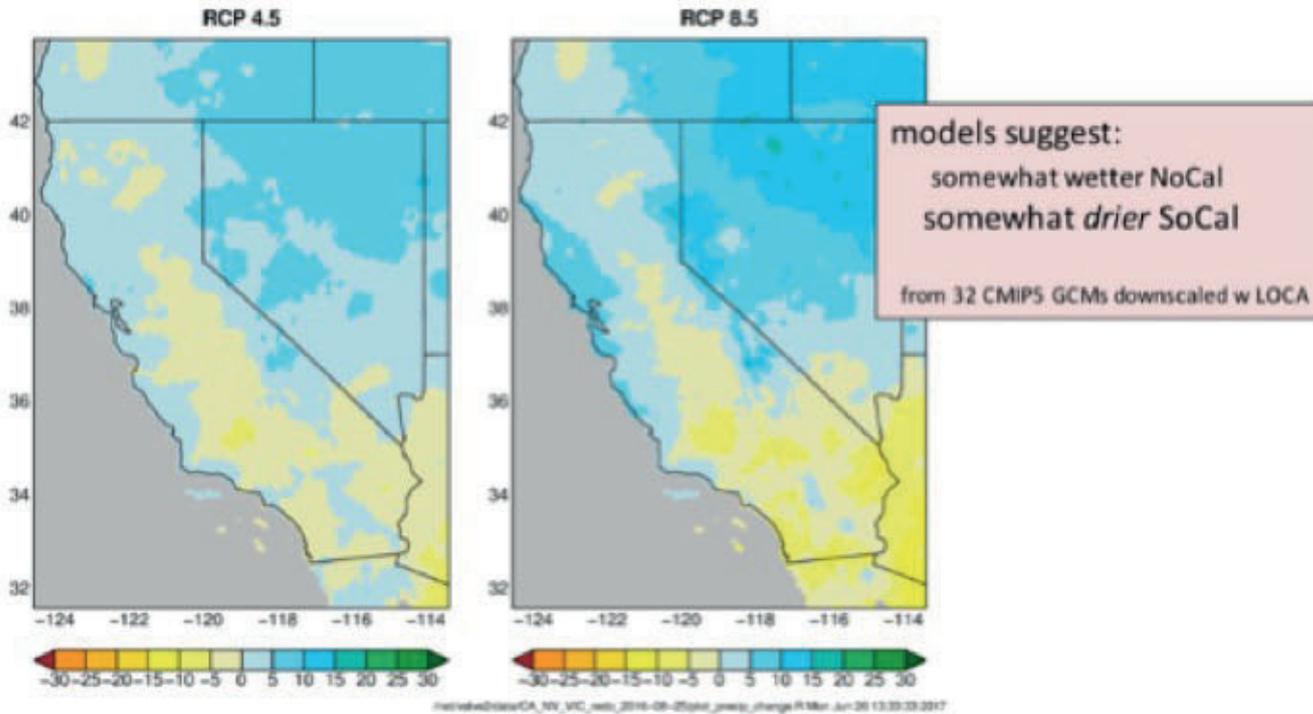
Models show that increasing soil organic matter increases the soil water holding capacity, demonstrating one adaptation option.



<http://climateassessment.ca.gov/state/docs/20190116-StatewideSummary.pdf>

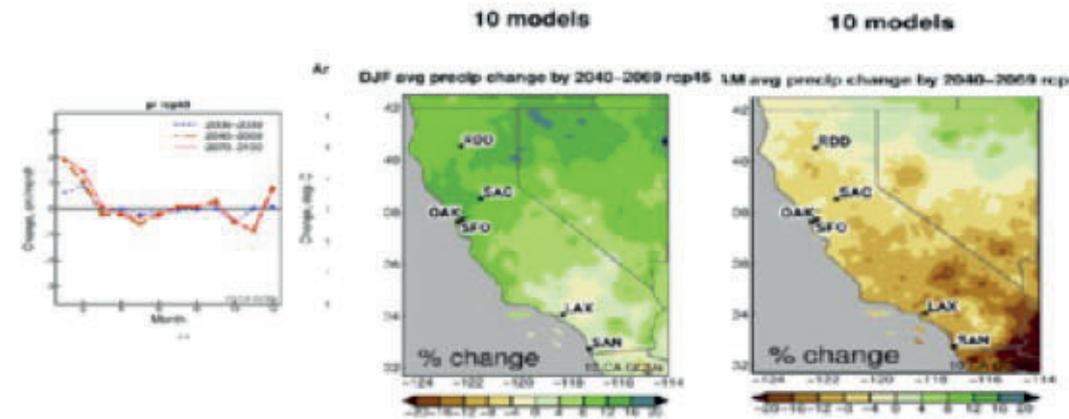
# Impactos del cambio climático en California

Change in annual precip [%], 2070–2100 w.r.t. 1950–2005



## Wetter Winter but Drier Springs – A Shorter Wet Season

- Projected Precipitation Increase in Dec-Feb, Decrease in Mar-Apr (MAM) 10 LOCA downscaled RCP4.5 GCMs mid-21st century



La temperatura aumenta en California, pero ¿se vuelve más húmeda o más seca?

# Wetter, Drier, or Both?

## INCREASING PRECIPITATION EXTREMES IN CALIFORNIA

California's climate has always featured wide swings between drought and flood. But in a warming world, precipitation will likely become even more volatile — with large increases in the frequency of extreme wet events, extreme dry events, and rapid transitions between them. These changes will pose major challenges for water, fire, and emergency management in 21st-century California.

### Extreme Dry Years

Low November–March precipitation totals for these years resemble 2013–14 or 1976–77, the driest year in modern California history.

FREQUENCY 1895–2017  $1/100$  YEARS

FUTURE RISK BY 2100



#### KEY IMPACT WATER SCARCITY

Available surface water may not meet human demands, leading to water shortages or unsustainable use of groundwater. Ecosystems also suffer, as low river flows can harm fish and drought-stressed vegetation can fuel wildfires.

### Extreme Wet Years

In these years, the November–March period is as wet as in 2016–17, when statewide precipitation was 54% greater than average.

FREQUENCY 1895–2017  $4/100$  YEARS

FUTURE RISK BY 2100



#### KEY IMPACT INFRASTRUCTURE STRESS

Runoff from heavy rains can stress levees, dams, and other flood control structures. Warmer temperatures amplify this effect by causing more precipitation to fall as rain, which immediately flows into rivers and streams, instead of snow.

### Dry-to-Wet Whiplash

This scenario represents the transition from a very dry year to a very wet one, as occurred between 2015–16 and 2016–17.

FREQUENCY 1895–2017  $4/100$  YEARS

FUTURE RISK BY 2100



#### KEY IMPACT MUDSLIDES

Although a very wet year following a drought can boost water supplies, a sudden transition from dry to wet conditions can cause its own problems. For example, heavy rains can result in mudslides and debris flows, especially near recent wildfire burn scars.

### Severe Storm Sequence

In this scenario, 40-day precipitation totals are similar to those during California's "Great Flood of 1862."

FREQUENCY 1895–2017  $1/200$  YEARS

FUTURE RISK BY 2100



#### KEY IMPACT CATASTROPHIC FLOODING

Such an event would cause inundation of a magnitude not experienced in modern California. The Great Flood of 1862 flooded much of the Central Valley and swaths of Los Angeles and Orange Counties now home to millions of people.

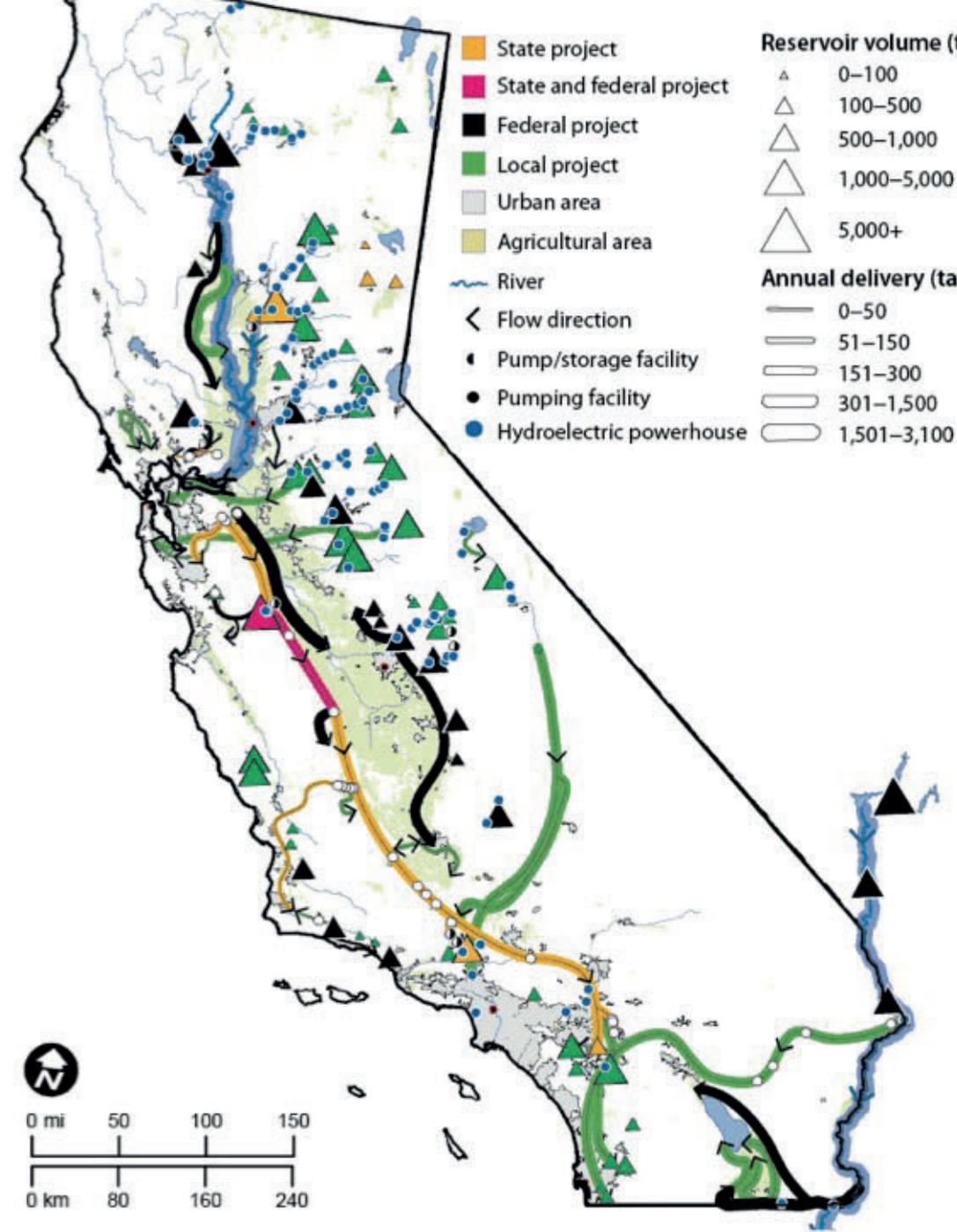
# Impactos del cambio climático en California

- **California espera perder 2/3 de su capa de nieve para 2100**
- Más precipitación como lluvia, menos como nieve
- Precipitaciones más intermitentes pero más extremas en forma de ríos atmosféricos
- Menos precipitaciones en las estaciones intermedias de primavera y otoño
- Las aguas superficiales serán más difíciles de capturar y almacenar

# Infraestructura hidráulica

- Aguas superficiales: embalses, infraestructura de transporte
- Aguas subterráneas: pozos, instalaciones de tratamiento, recarga
- Mercados de agua y derechos sobre el agua
  - Oferta y demanda de agua para la agricultura
  - Oferta y demanda de agua municipal
  - Agua para los servicios de los ecosistemas

[www.ppic.org/publication/californias-water-grid/](http://www.ppic.org/publication/californias-water-grid/)



# Envejecimiento de la infraestructura hidráulica

## Largest reservoirs in California

The water bond on November's ballot contains \$2.7 billion for two huge new dams — the first major dams built in California in three decades. Here are the state's 10 largest reservoirs, which were built between 1927 and 1979.



Reservoir	Year opened	Acre feet of water in millions	Dam height	Location
1 Almanor	1927	1.3	130 feet	Plumas County
2 Shasta	1945	4.5	521	Shasta County
3 Folsom	1956	1	275	Sacramento County
4 Berryessa	1957	1.6	255	Napa County
5 Trinity	1962	2.4	458	Trinity County
6 New Exchequer	1967	1	479	Mariposa County
7 San Luis	1967	2	305	Merced County
8 Oroville	1968	3.5	742	Butte County
9 Don Pedro	1971	2	568	Tuolumne County
10 New Melones	1979	2.4	578	Calaveras County

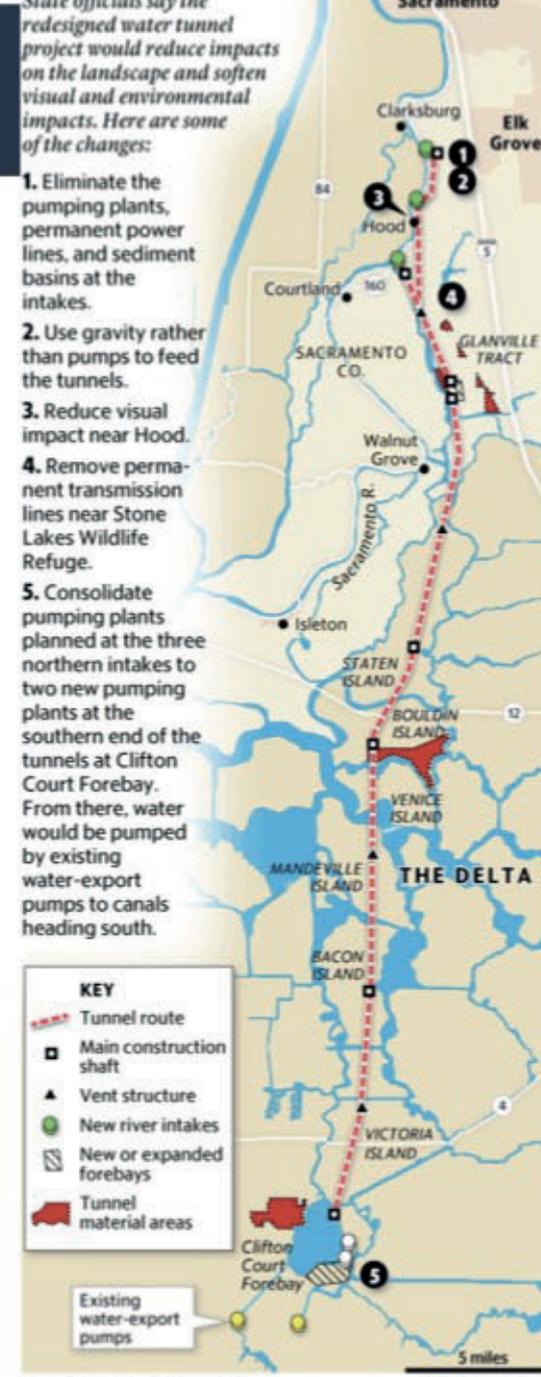
BAY AREA NEWS GROUP

[www.mercurynews.com/2014/08/31/california-drought-why-doesnt-california-build-big-dams-any-more/](http://www.mercurynews.com/2014/08/31/california-drought-why-doesnt-california-build-big-dams-any-more/)

# Soluciones posibles

- Construir nuevas presas, aumentar los embalses existentes
- Nueva infraestructura de transporte (California Water Fix)
- Sustainable Groundwater Management Act (SGMA)
- Flood MAR (recarga controlada de los acuíferos por inundaciones)
- Conservación y agua reciclada
- Restaurar las llanuras aluviales naturales
- Nuevas tecnologías: estanqueidad selectiva con diques de caucho, desalinización

<https://www.sacbee.com/news/california/water-and-drought/article26872906.html>



# Soluciones posibles

## California WaterFix is Supported by LAEDC



[laedc.org/2018/04/09/laedc-supports-california-waterfix/](http://laedc.org/2018/04/09/laedc-supports-california-waterfix/)

## JUST SAY NO TO THE CALIFORNIA WATER FIX

Posted on 6 July 2017

By Charming Evelyn, Angeles Chapter Water Committee Chair

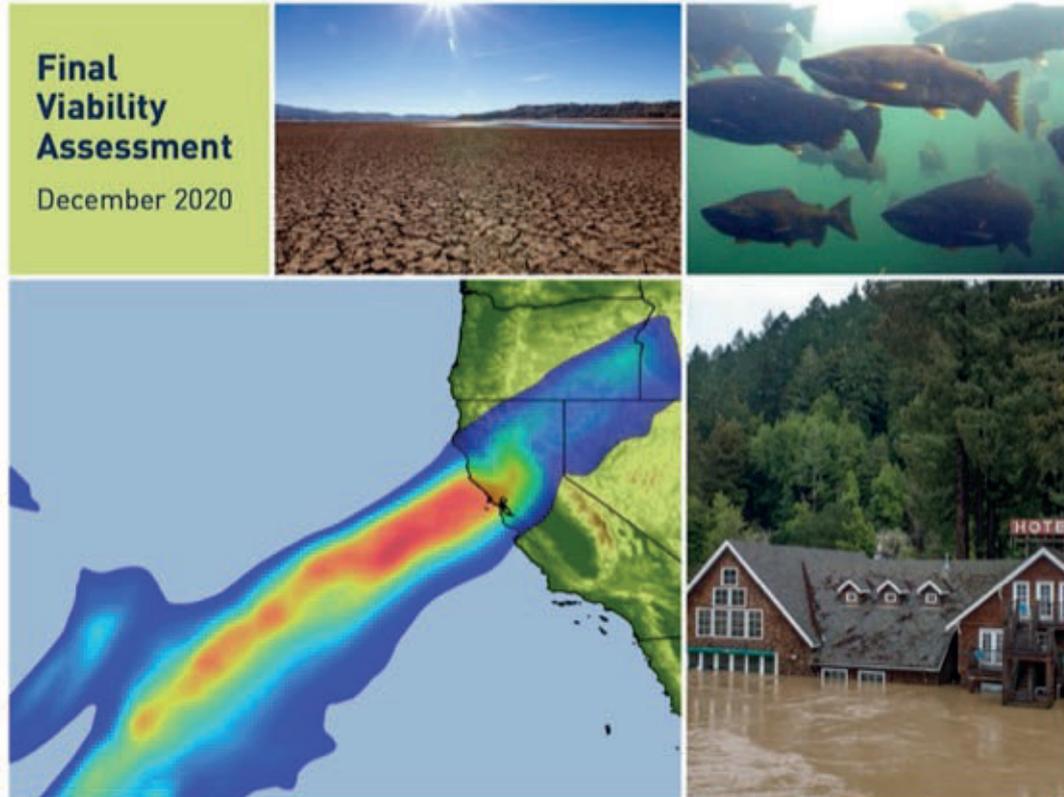


[angeles.sierraclub.org/news/blog/2017/07/just\\_say\\_no\\_california\\_water\\_f](http://angeles.sierraclub.org/news/blog/2017/07/just_say_no_california_water_f)

# Forecast Informed Reservoir Operations (FIRO)

Lake Mendocino

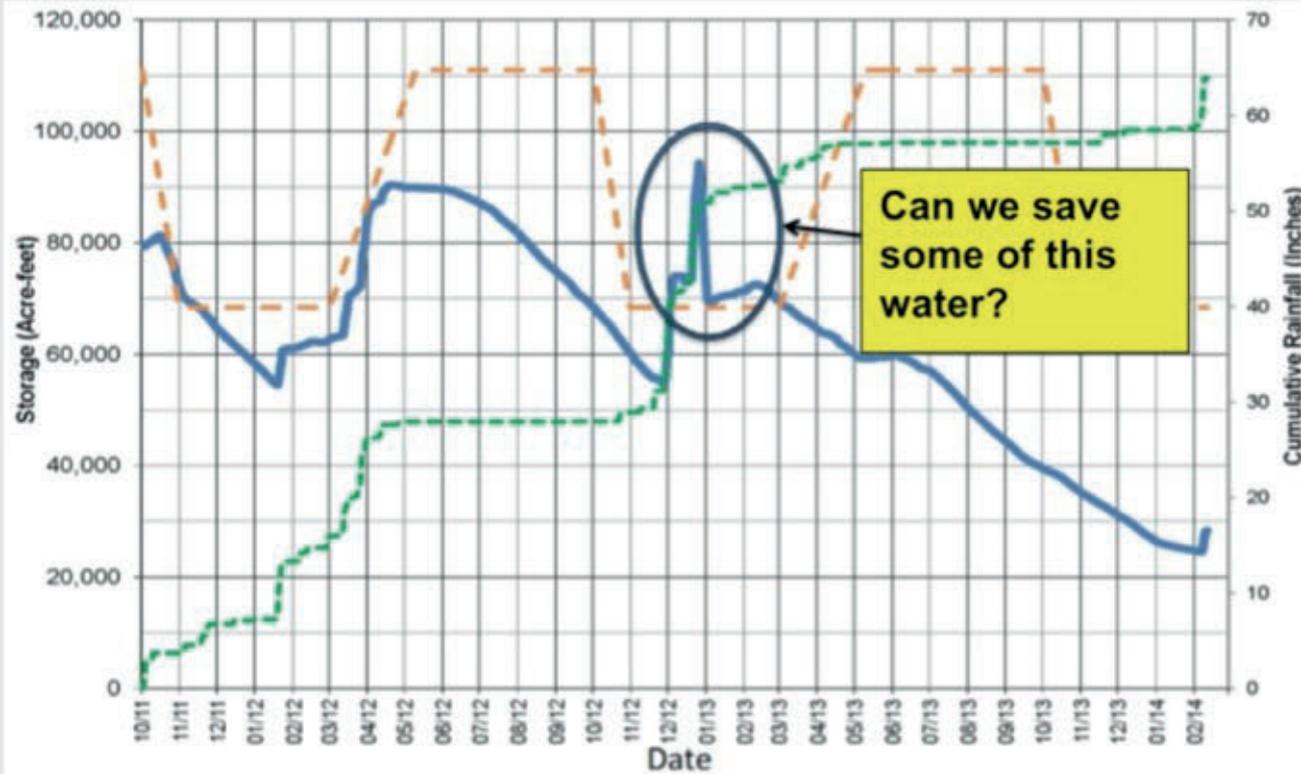
## FORECAST INFORMED RESERVOIR OPERATIONS



### Cómo funciona

- Las "rule curves" del depósito se ajustan para permitir un mayor almacenamiento de agua durante los meses húmedos
- Cuando se pronostican grandes tormentas, el agua se libera antes de la tormenta para permitir un mayor almacenamiento
- Al final de la temporada si se pronostican condiciones secas, se almacena más agua

# Forecast Informed Reservoir Operations (FIRO)

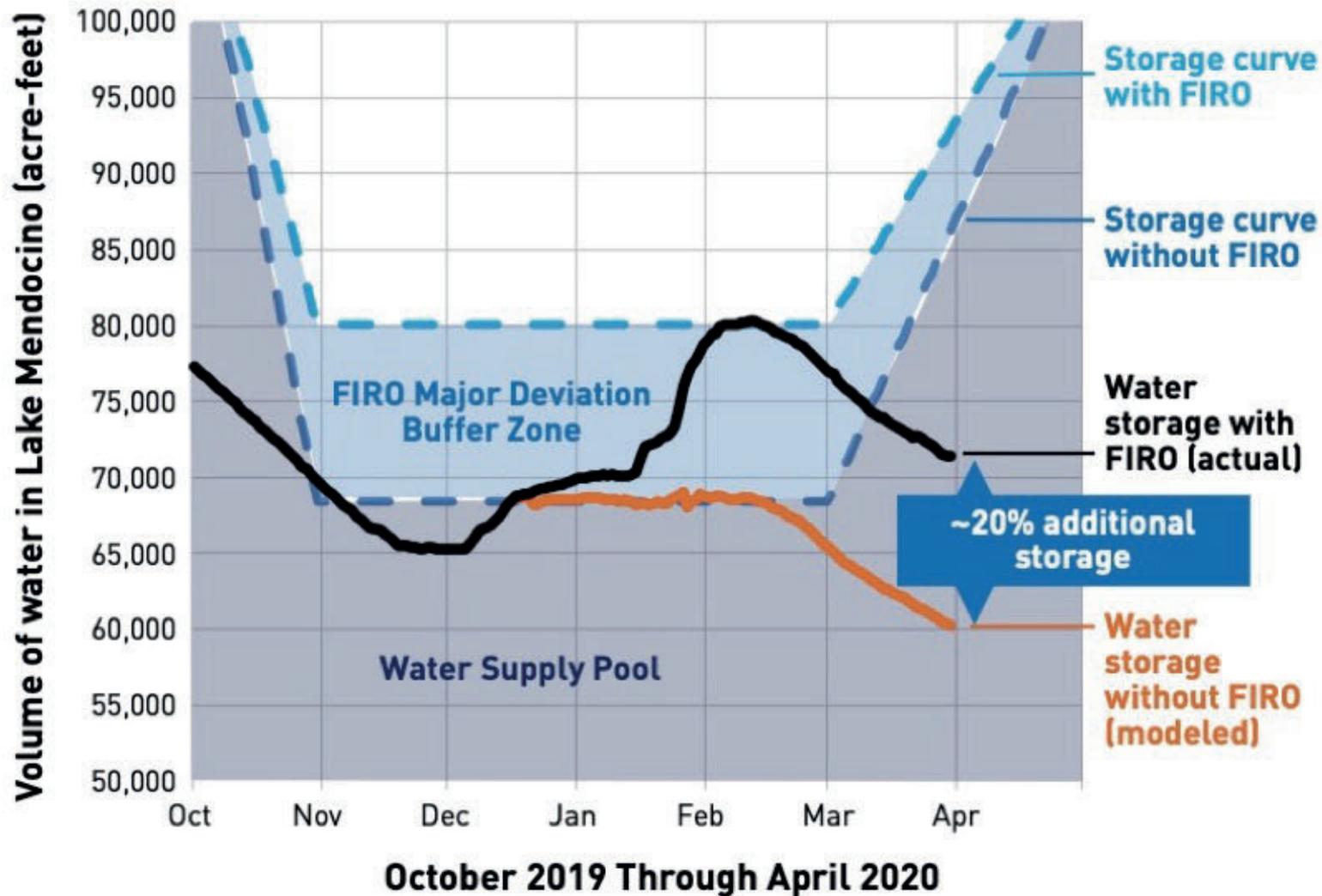


*Figure 2. In late December 2013 an Atmospheric River storm greatly increased the amount of water in Lake Mendocino (thick blue line shows reservoir storage; green dashed line shows cumulative rainfall). The “rule curve” (dashed orange line) led to the release of this water. The lack of later rains (to February 2014) led to drought conditions and extremely low lake levels. Figure courtesy of F. M. Ralph (UC San Diego/ Scripps /CW3E; mralph@ucsd.edu) and J. Jasperse (Sonoma Water) – FIRO Steering Committee Co-Chairs*

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# Forecast Informed Reservoir Operations (FIRO)

## Lake Mendocino Storage



**Figure 2.** Lake Mendocino storage increased by about 20 percent during major deviation operations in WY 2020, compared with modeled storage without FIRO, during a year when precipitation was 38 percent of average.

[https://cw3e.ucsd.edu/FIRO\\_docs/LakeMendocino\\_FIRO\\_FVA\\_ExecutiveSummary.pdf](https://cw3e.ucsd.edu/FIRO_docs/LakeMendocino_FIRO_FVA_ExecutiveSummary.pdf)

# Los beneficios económicos de FIRO



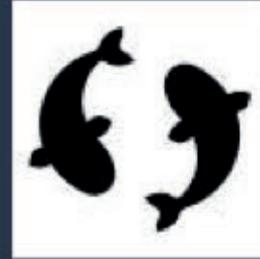
# FIRO en el lago Mendocino



# Beneficios económicos de FIRO en Lago Mendocino



Abastecimiento  
de agua agrícola



Pesca



Abastecimiento de  
agua Municipal e  
Industrial (M&I)



Recreación



Energía  
hidroeléctrica



Costos reducidos de  
operaciones, mantenimiento  
y reemplazo (OM&R)

# Abastecimiento de agua agrícola



La FIRO puede mejorar la calidad y la cantidad de la agricultura.

Usamos el método de imputación residual para atribuir el "precio sombra" del agua.

- Calcular los rendimientos netos (ingresos - costes).
- Calcular el valor de una unidad de agua dividiendo los rendimientos netos por el uso del agua.
- Estimar el posible aumento del suministro de agua.
- Multiplicar el valor de una unidad de agua por el aumento en el suministro de agua.

Centrado en uvas de vino y extrapolado a otros cultivos. Dependiendo de la cosecha, el valor de un acre-pie de agua es de hasta \$ 634. (...)

Los beneficios anuales medios son 114.079 dólares.

# Abastecimiento de agua Municipal e Industrial (M&I)



FIRO puede mejorar la fiabilidad del suministro de agua.

Este beneficio se cuantificó de dos maneras basadas en si se espera que cambie el precio del agua.

**\$2.7  
million**

Estimate the price elasticity of demand (-0.4)

Estimate increase in water supply reliability

Estimate demand curve and average change in price

Estimate change in consumer surplus

**\$1.0  
million**

Estimate the increase in water supply reliability

Obtain price

Calculate product

# Pesca



Salmón Coho



Salmón Chinook



Trucha Steelhead

FIRO puede mejorar el flujo de la corriente y reducir la temperatura del agua, beneficiando a los peces.

Se realizó un análisis de alternativa menor-coste para estimar los beneficios.

- Consideramos proyectos alternativos que tendrían el mismo impacto que FIRO.
- En lugar de evaluar todas las alternativas, elegimos una alternativa que sea factible, que se haya considerado previamente, que tenga algunos datos disponibles y que sea plausiblemente la de menor costo.
- Estimamos el costo de esta alternativa.
- Este costo evitado representa el beneficio.

# Pesca



Salmón Coho



Salmón Chinook

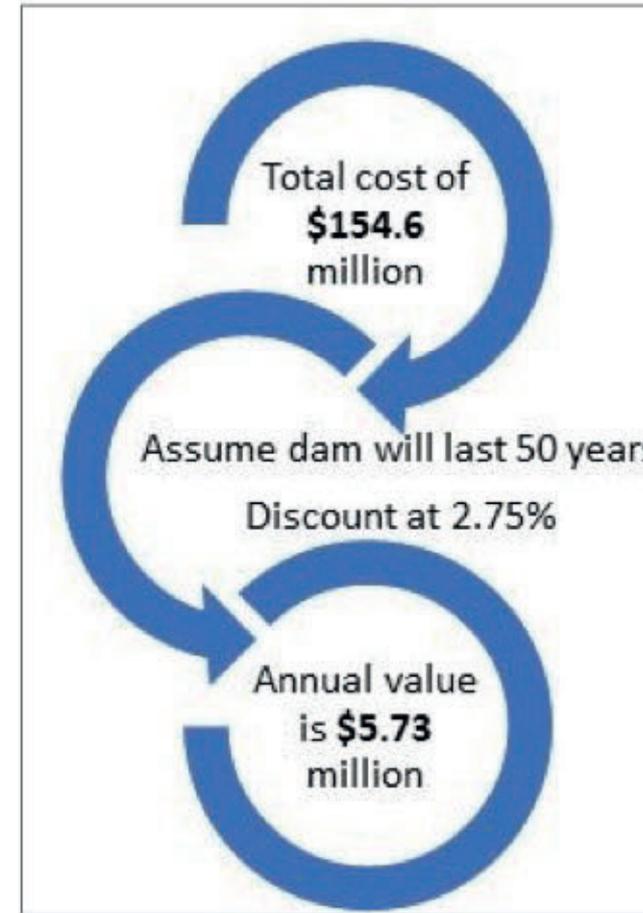


Trucha Steelhead

La alternativa elegida es aumentar la capacidad de la presa.

Asumimos que elevar la presa 2 metros resultaría beneficioso para el caudal y la temperatura, y que los beneficios son equivalentes a los de FIRO.

Usamos un costo estimado existente para elevar la presa en 10 metros y aplicamos ciertas suposiciones para aproximar el costo de un aumento de 2 metros.



## Beneficios anuales estimados de la FIRO

Benefit Type	Modified Hybrid
Agricultural water supply	\$114,100
M&I water supply	\$2,674,600
Hydropower	-\$1,900
Fisheries	\$5,726,400
Recreation	\$802,700
Reduced OM&R costs	\$45,500
<b>Total</b>	<b>\$9,361,400</b>

(Resultados provisionales)



# Lake Mendocino FORECAST INFORMED RESERVOIR OPERATIONS

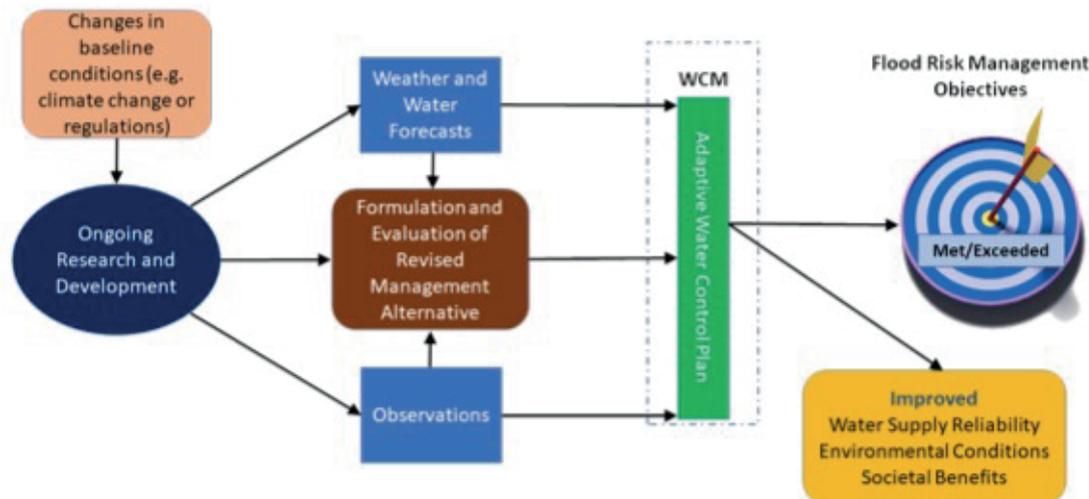
Final  
Viability  
Assessment

December 2020



[https://cw3e.ucsd.edu/FIRO\\_docs/LakeMendocino\\_FIRO\\_FVA.pdf](https://cw3e.ucsd.edu/FIRO_docs/LakeMendocino_FIRO_FVA.pdf)

## FIRO Model for Adaptive Water Control Manuals



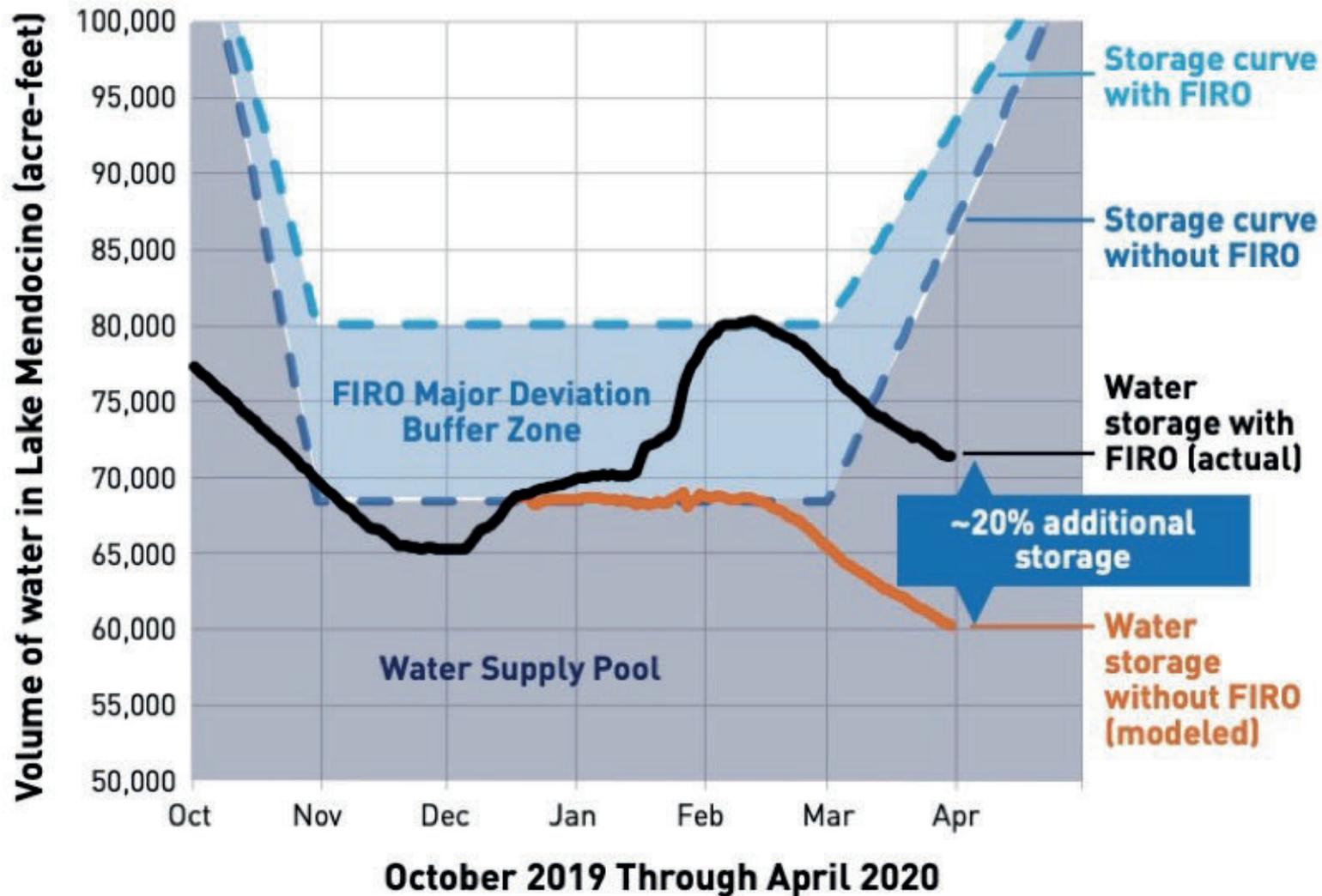
Lake Mendocino Storage



Figure 2. Lake Mendocino storage increased by about 20 percent during major deviation operations in WY 2020, compared with modeled storage without FIRO, during a year when precipitation was 38 percent of average.

# Forecast Informed Reservoir Operations (FIRO)

## Lake Mendocino Storage



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Tom Corringham → [tomc@ucsd.edu](mailto:tomc@ucsd.edu)

¡Gracias por su atención!

[http://www.cr2.cl/  
evaluacion-economica-de-la-megasequia/](http://www.cr2.cl/evaluacion-economica-de-la-megasequia/)

[cw3e.ucsd.edu](http://cw3e.ucsd.edu)



UC San Diego



(CR)<sup>2</sup> – 29 junio 2021