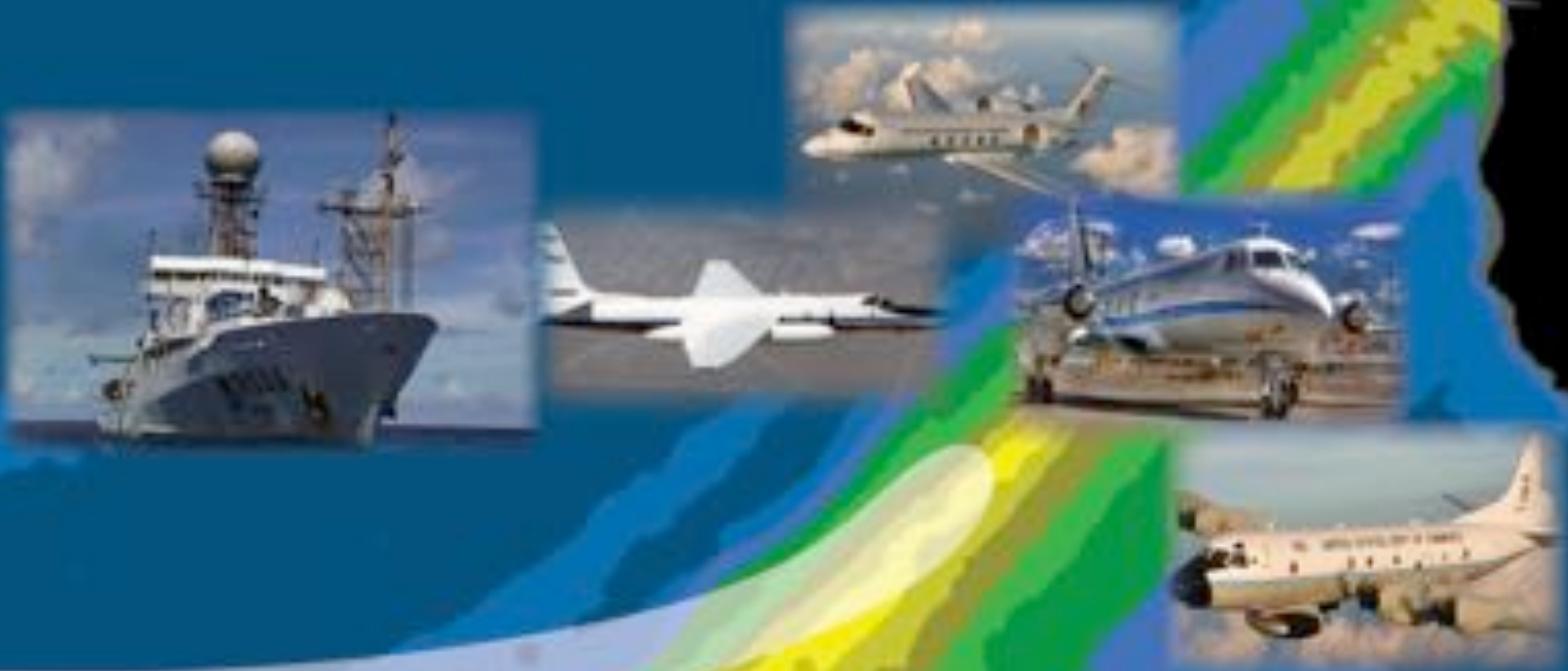


CalWater 2

Precipitation, Aerosols, and Pacific Atmospheric Rivers Experiment

F. Martin Ralph
UC San Diego/Scripps Institution of Oceanography
Center for Western Weather and Water Extremes (CW3E)

Science Steering Committee

Marty Ralph, Kim Prather, Dan Cayan, Ryan Spackman, Paul DeMott, Mike Dettinger, Chris Fairall, Ruby Leung, Daniel Rosenfeld, Steven Rutledge, Duane Waliser, Allen White

Translating Process Understanding to Improve Climate Modeling
CLIVAR Workshop, Princeton NJ – 16 Oct 2015

CalWater Timeline

CalWater Major Planning Milestones/Calendar year	2008	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18
Initial Planning workshop at Scripps	X										
Aerosol-Precip and Atmospheric River foci chosen		X									
Early Start joint Sierra HMT/Aerosol site – Sugar Pine		X	X	X	X						
2nd field season; more profiler, snow and Sierra sites			X	X							
3rd field season w/G-1 aircraft, scanning radar....				X							
Analysis underway		X	X	X	X	X	X				
Decision to pursue CalWater 2					X						
CalWater 2 Science Steering Group formed					X						
CalWater 2 Science white paper completed						X					
CalWater 2 Interagency briefings DC						X					
CA EFREP/HMT AR mesonetwork >90% complete							X	X	X	X	X
Early start: NOAA G-IV (AR)+Bodega Bay (aerosols)							X				
Scripps CW-2 planning workshop							X				
CW-2015 with ACAPEX (ship, G-I, G-IV, P-3, ER-2)								X			
NOAA G-IV proposed									X	X	X
Potential for international CW field campaign										X	X

CalWater 1

CalWater 2 Planning

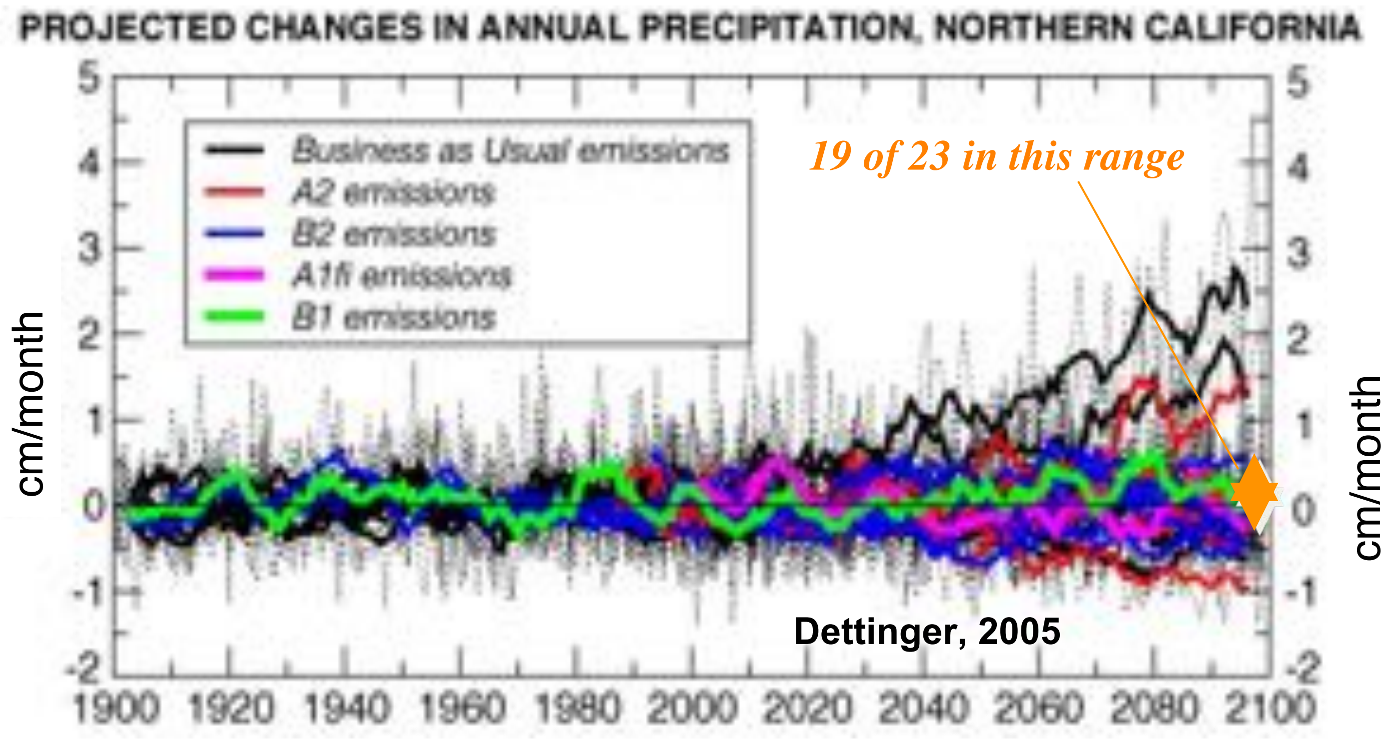
CalWater 2

$17 M total

NOAA*
DOE*
CEC*
NSF*
DWR
ONR
NASA

*Primary Sponsors

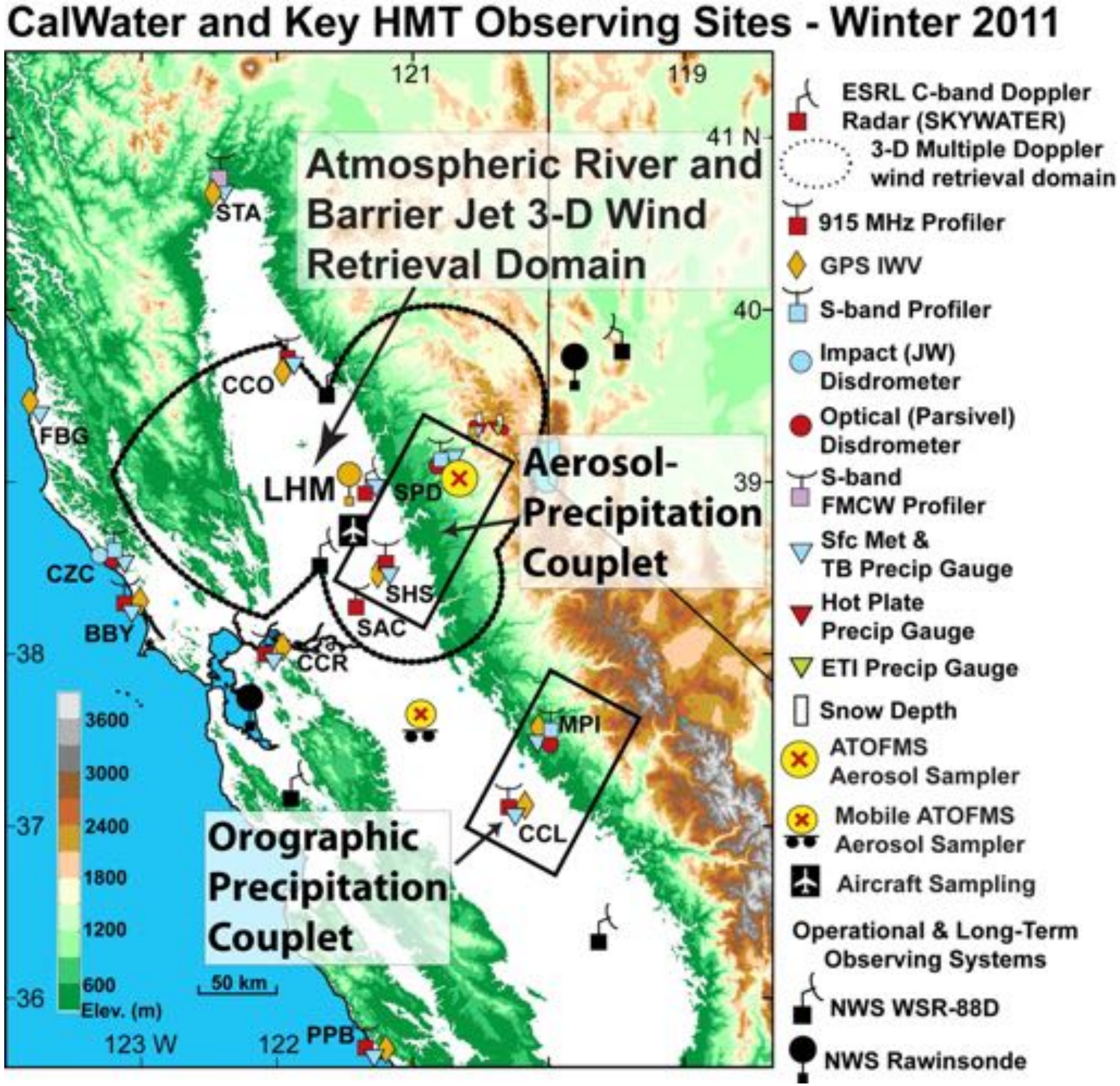
A Key Challenge: Changing Climate

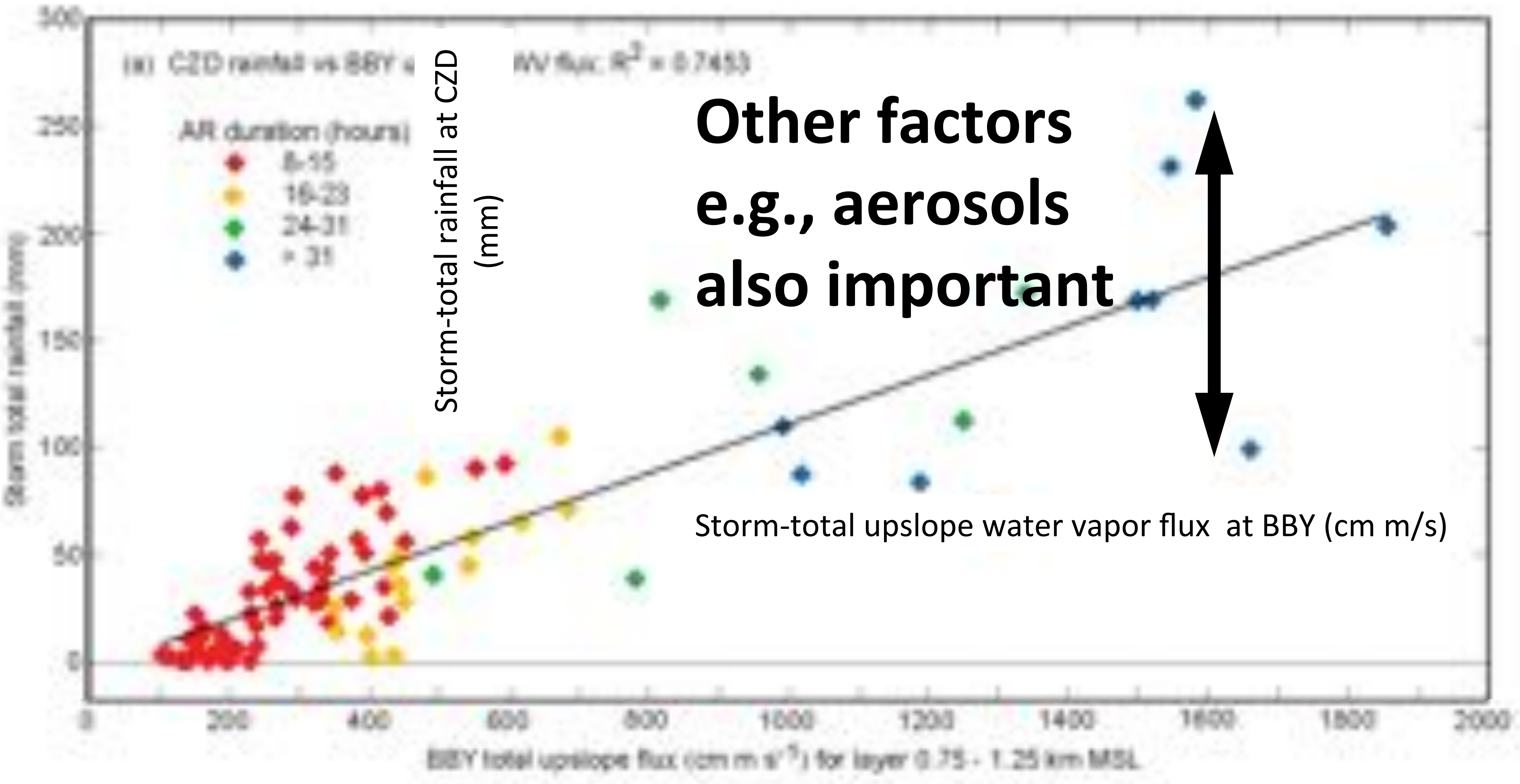


Annual precipitation projections vary mostly due to how extreme precipitation events are handled (in CA this means ARs).

Pierce et al 2013 (J. Clim.): Model disagreements in the projected change in occurrence of the heaviest precipitation days (>60 mm day^{-1}) account for the majority of disagreement in the projected change in annual precipitation, and occur preferentially over the Sierra Nevada and Northern California.

CalWater 1
2009-2011



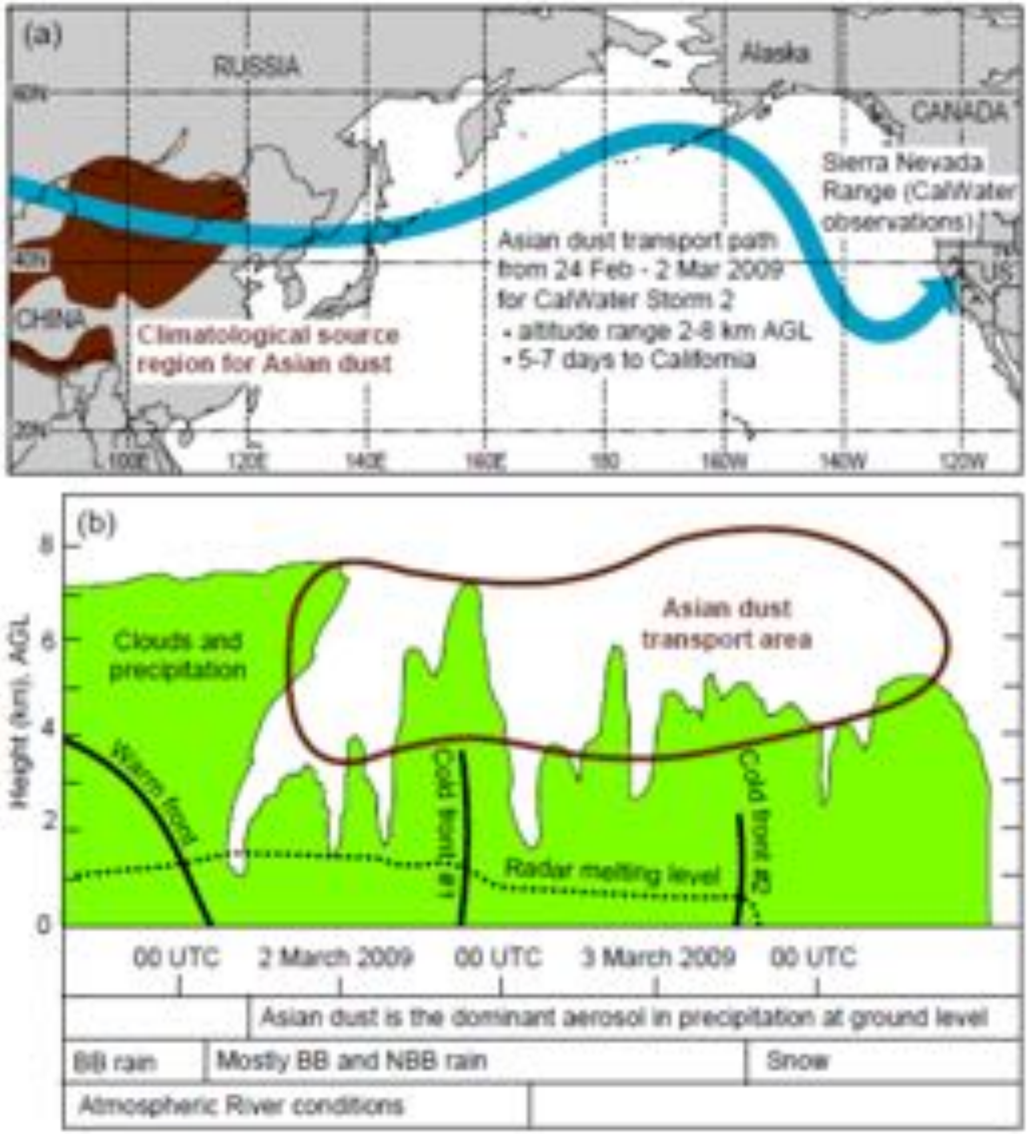


The greater the precipitation

The greater the AR strength and duration

From Ralph et al. 2013, *J. Hydrometeorology*

Potential Impacts of Aerosols on California Precipitation and Water Supply



- **CalWater** field experiment has documented a potentially important role of Asian dust and related aerosols on Sierra Nevada precipitation
- CalWater involves CEC, NOAA, SIO, DOE, NASA, and other partners
- Initial results published in JGR Sept 2011 (Ault et al.)
- 40% greater precipitation in a storm with Asian dust and aerosols versus a very similar storm without them
- **Creamean et al. 2013 (Science) used aircraft data to confirm Ault et al. 2011**

CalWater-2015

DOE G-1 aircraft: measuring cloud, rain and snow particles, as well as aerosols such as dust and smoke from sources near and far

NOAA G-IV aircraft: measuring atmospheric river strength and structure offshore using dropsondes and precipitation radar

NOAA P-3 aircraft: measuring ocean and atmosphere with radars for precipitation, cloud & ocean waves, and air & ocean sondes

NOAA Ron Brown Ship: measuring aerosols, clouds, atmospheric rivers, ocean surface and subsurface conditions

DOE AMF2: many sensors mounted on the NOAA ship; measuring aerosols, precipitation, clouds & winds aloft and at the surface

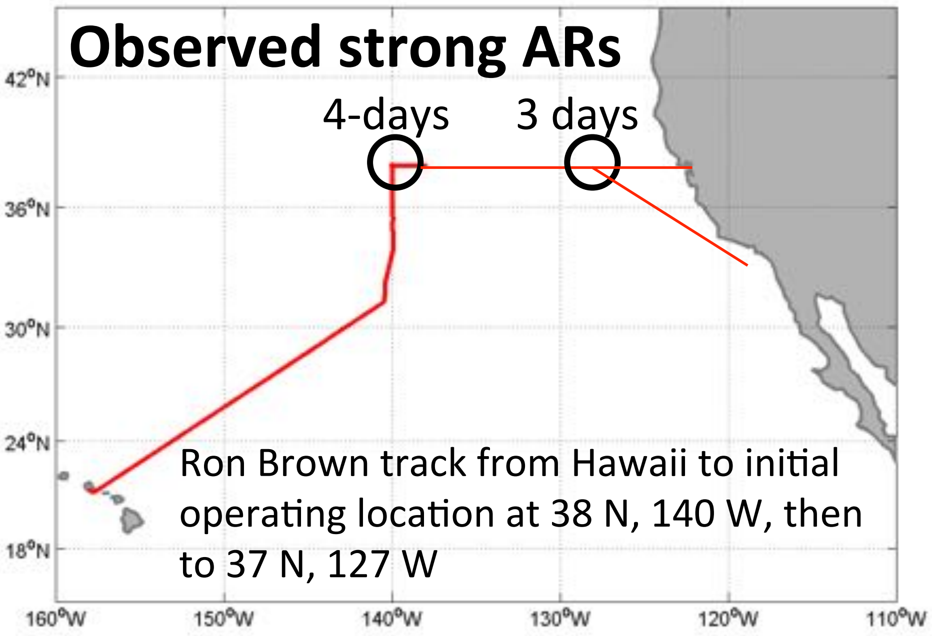
CA Dept. of Water Resources extreme precipitation network: measuring atmospheric rivers, snow level and soil across California

NSF - sponsored aerosol and rain measurements at the coast

NASA ER-2 aircraft: measuring aerosols, clouds and water vapor with radar, lidar and radiometer

CALWATER-2015: Ship-based Sensors

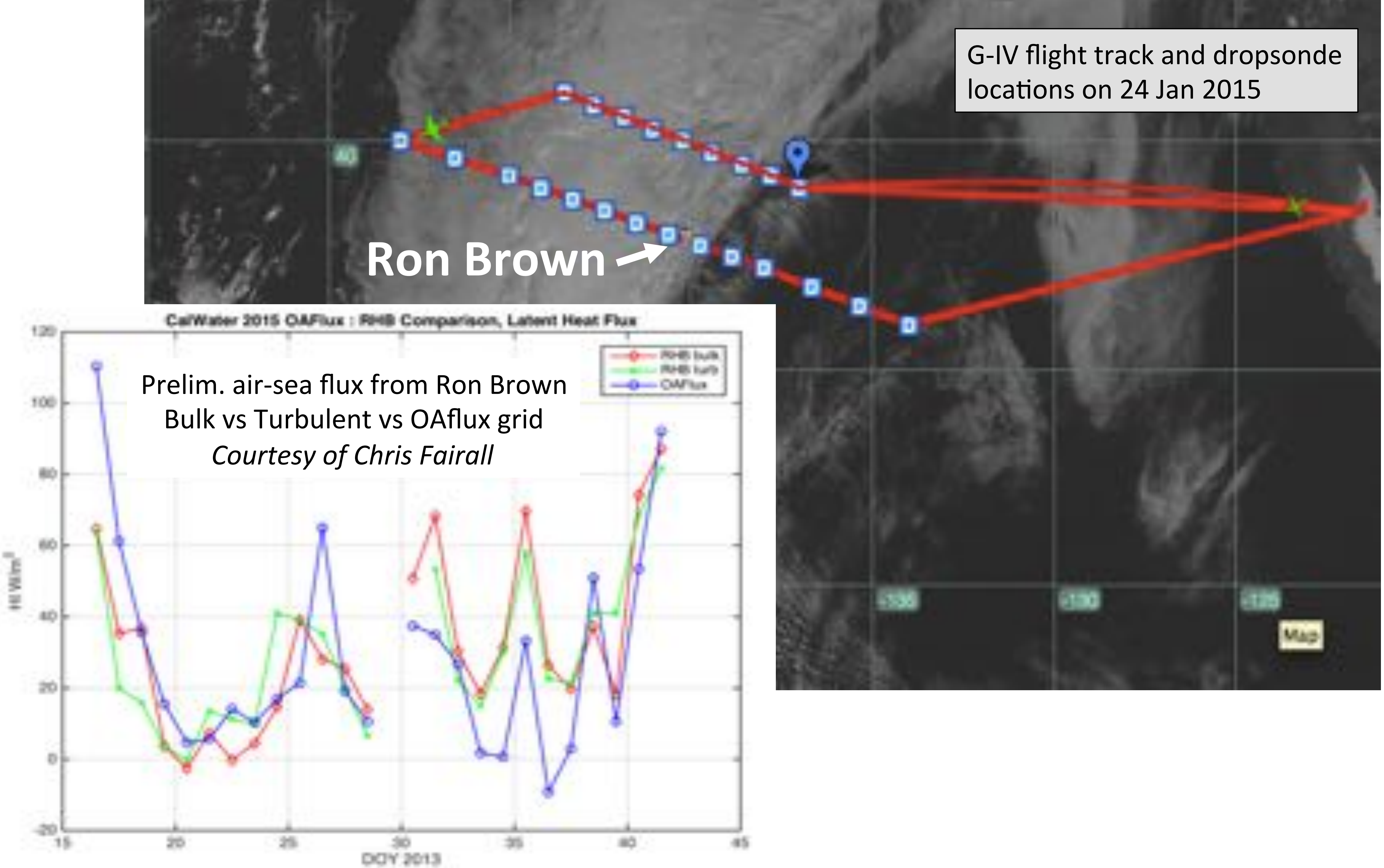
- DOE AMF2 - PNNL (Leung) (Aerosols, radars, lidars, wind profiler, …)
- Fluxes and Near-Surface Meteorology-ESRL/PSD (Fairall)
- Balloon soundings - NOAA/NESDIS (Nalli)
- Wave dissipation (SWIFT buoys) –UW/APL (Thompson)
- GPS water vapor - U Hawaii (Almanza , Businger)



NSF-supported aerosol and precipitation measurements at **Bodega Bay**: UCSD, Colorado State University, North Carolina State University

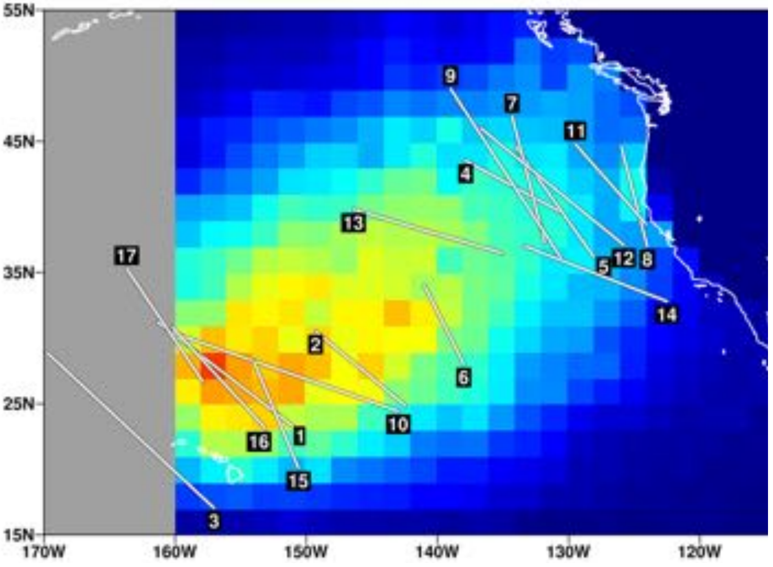
PIs: Kim Prather (UCSD/Scripps), Sonia Kreidenweiss (CSU), Marcus Petters (NCSU)
Also Paul Demott (CSU) and Andrew Martin (UCSD/Scripps)

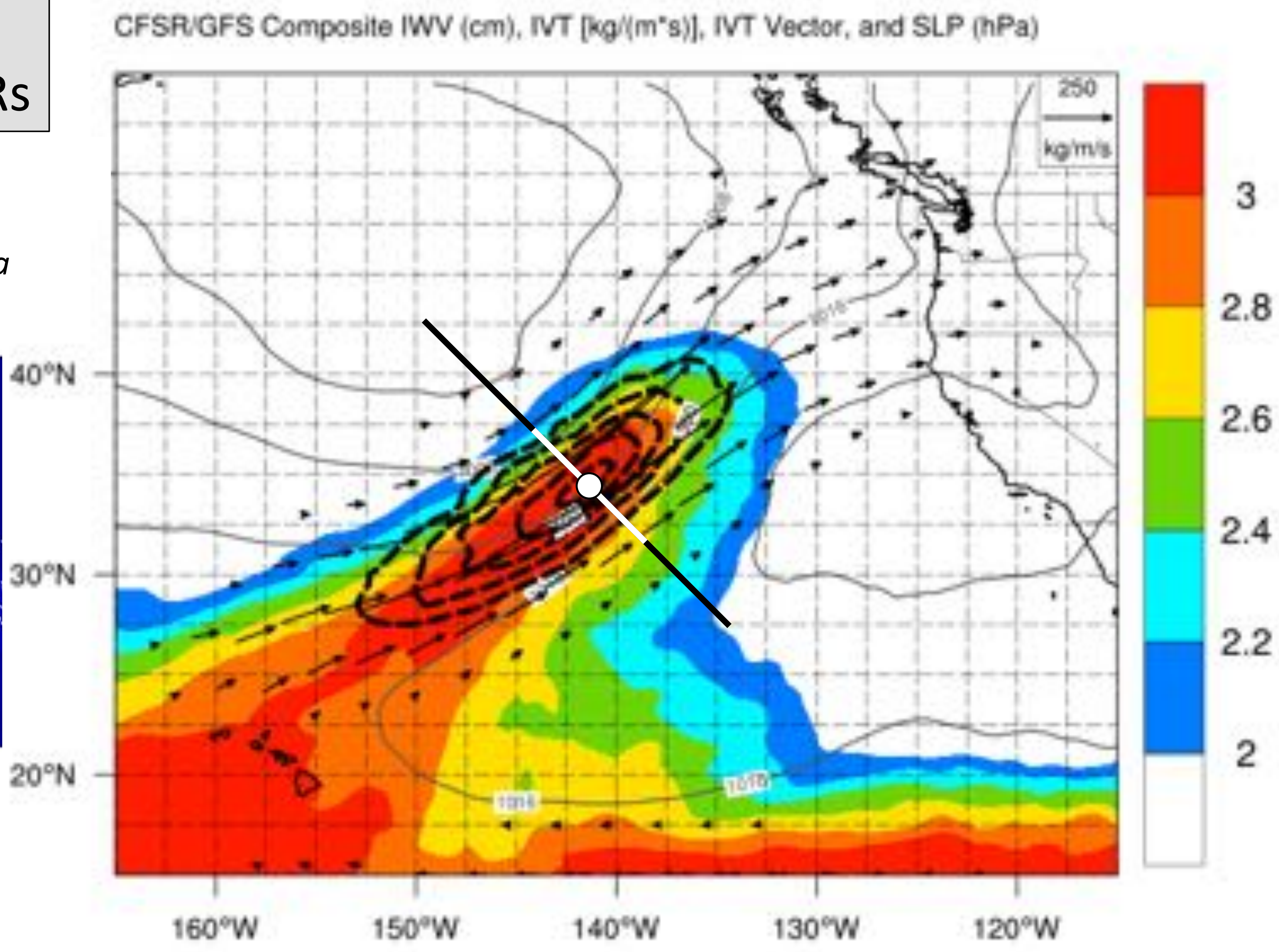
- Precipitation collections for residue chemical, biological and ice nucleation
- Aerosols
  - Single particle aerosol mass spectrometry
  - IMPROVE chemically-speciated PM2.5 and PM10
  - WIBS-4A bioaerosols and fluorescence microscopy collections
  - Continuous aerosol size distribution
- Cloud-active aerosols
  - Ice nucleation filter samples (integrated periods for offline analysis)
  - Selected periods of single particle ice nuclei mass spectral composition
  - Real-time ice nucleation measurements 4-8 hours daily
  - Continuous scanning CCN
- Meteorology (NOAA and CA DWR)

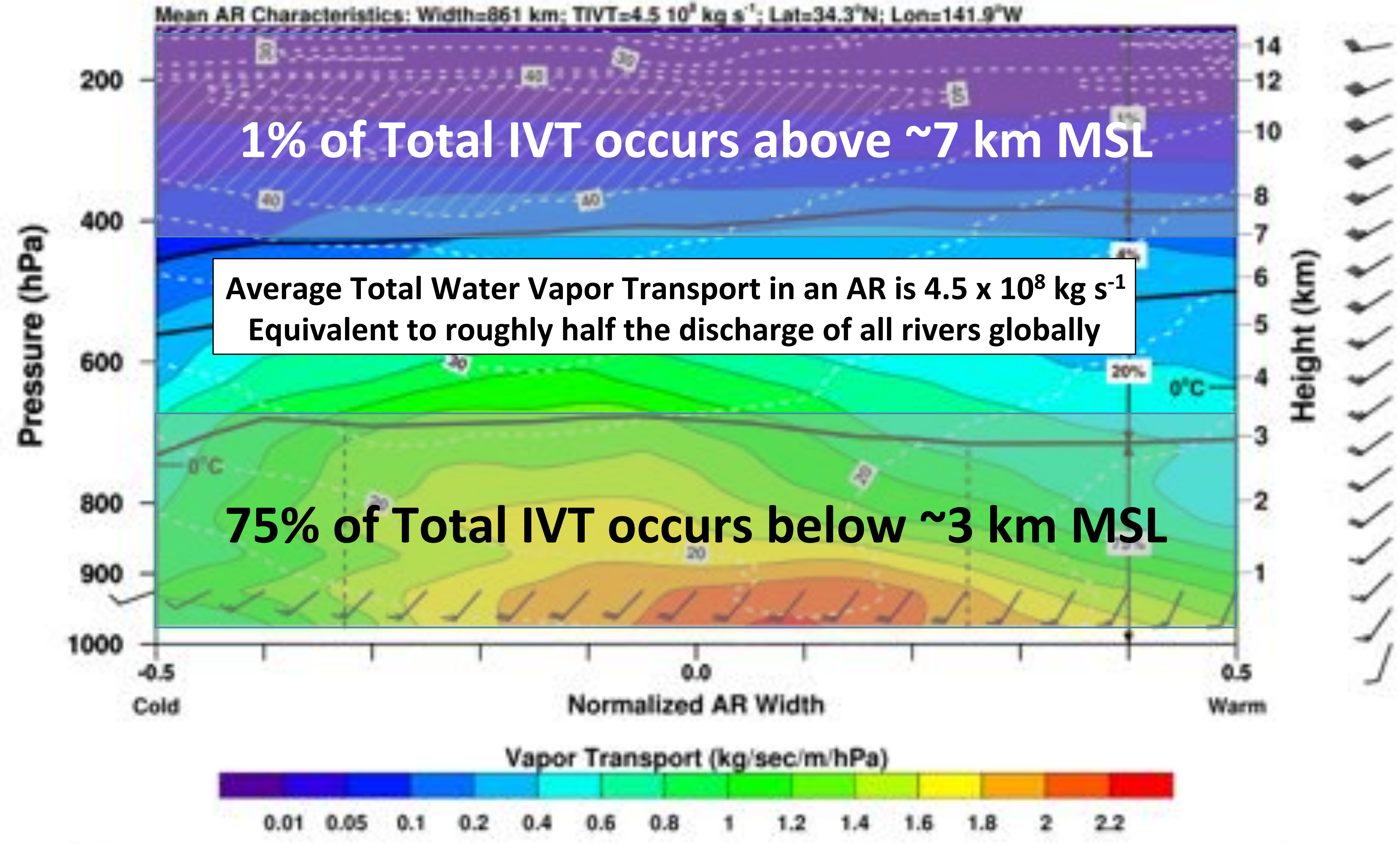

G-IV flight track and dropsonde locations on 24 Jan 2015
Ron Brown
40
-135
-130
-125
Map
CalWater 2015 OAFlux : RHB Comparison, Latent Heat Flux
RHB bulk
RHB turb
OAFlux
Prelim. air-sea flux from Ron Brown
Bulk vs Turbulent vs OAflux grid
Courtesy of Chris Fairall
120
100
80
60
40
20
0
-20
15
20
25
30
35
40
45

Composite
17 aircraft-observed ARs

Preliminary analysis from
F.M. Ralph, S. Iacobellus, J. Cordeira



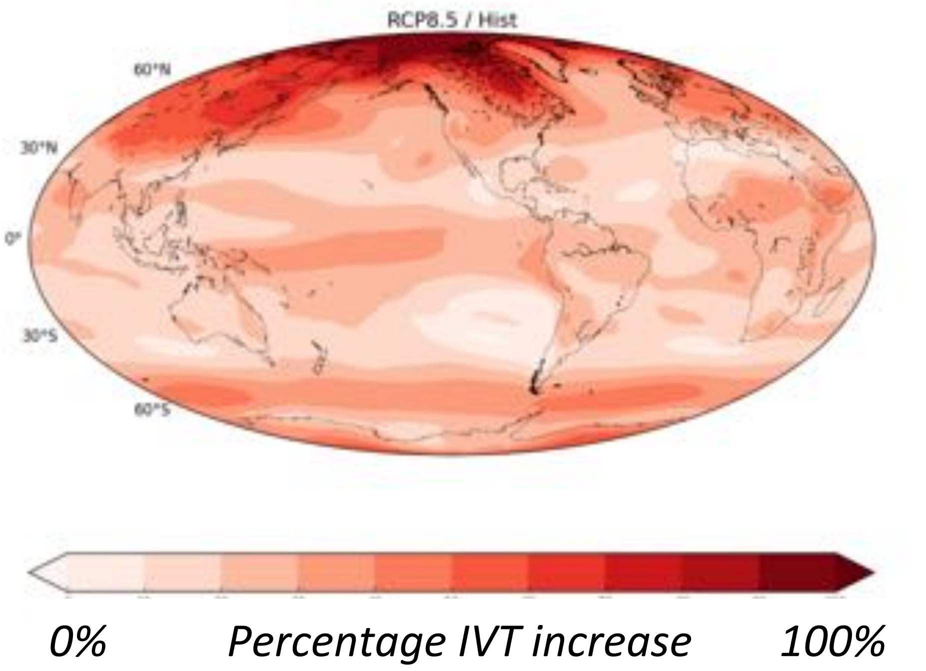




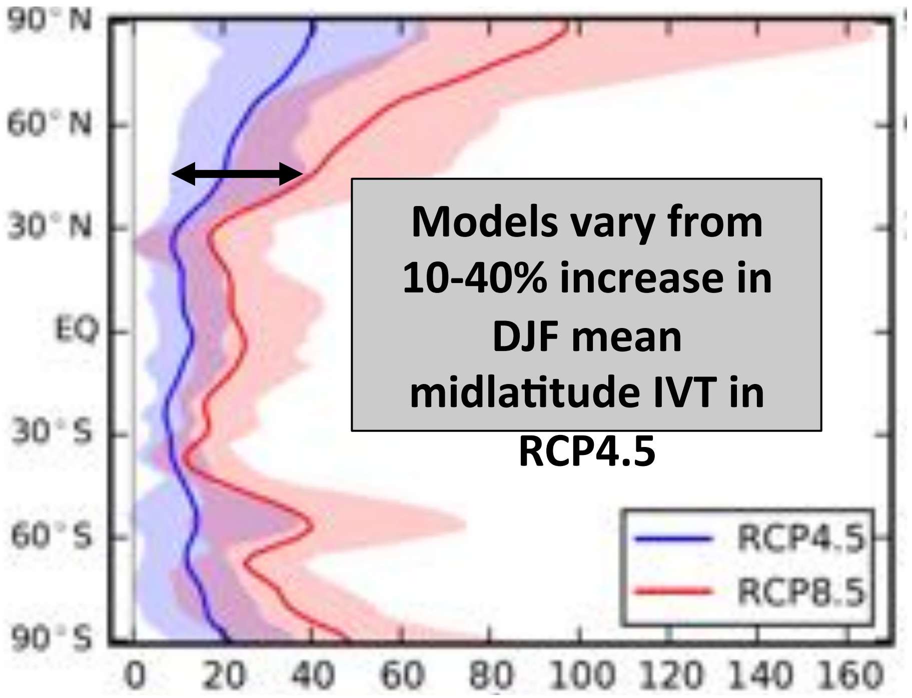
Mean AR Characteristics: Width=861 km; TIVT=4.5 10⁸ kg s⁻¹; Lat=34.3°N; Lon=141.9°W
1% of Total IVT occurs above ~7 km MSL
Average Total Water Vapor Transport in an AR is 4.5 x 10⁸ kg s⁻¹
Equivalent to roughly half the discharge of all rivers globally
75% of Total IVT occurs below ~3 km MSL
Pressure (hPa)
Height (km)
Normalized AR Width
Cold
Warm
0°C
Vapor Transport (kg/sec/m/hPa)

Climate change intensification of horizontal water vapor transport in CMIP5

D.A. Lavers, F.M. Ralph, D.E. Waliser, A. Gershunov, and M.D. Dettinger
Geophysical Research Letters (2015)



Percentage mean IVT increase (RCP8.5 / HIST) in DJF. 20-30% increases near California.



Percentage zonal-averaged mean IVT change in DJF.

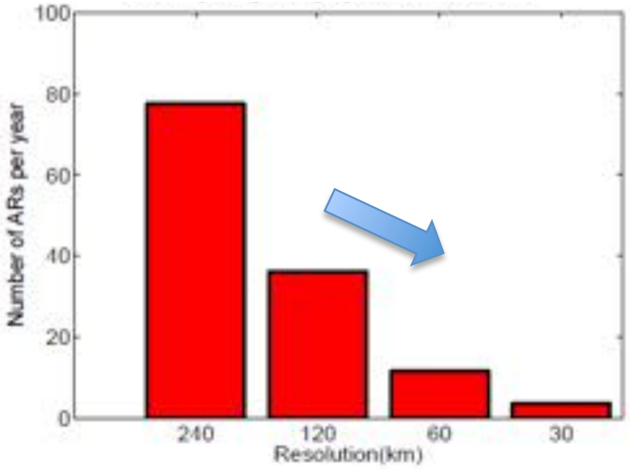
Main conclusions

1. The mean & variance of atmospheric water vapor flux will intensify under projected climate change.

2. The high-latitude (Arctic) water vapor flux exhibits the largest percentage increases.

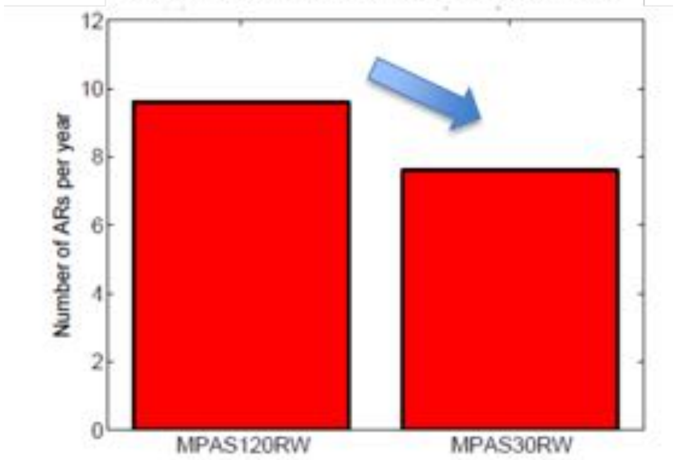
3. The increased water vapor flux is almost exclusively due to increased low-level specific humidity.

AR frequency in aquaplanet simulations

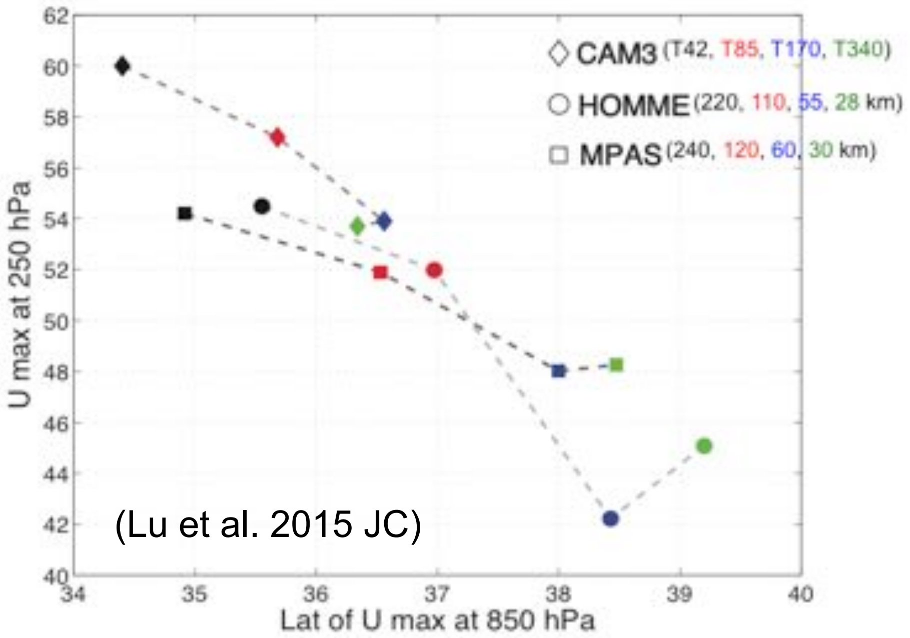


(Hagos et al. 2015 JC)

Southeast Pacific AR frequency in AMIP simulations



Eddy-driven jet shifts poleward and weakens with increasing resolution



- AR frequency consistently decreases with increasing model resolution
- This sensitivity is traced to the poleward shift of subtropical jet with increasing model resolution
- Uncertainty in projecting changes in AR frequency in the future is partly related to uncertainty in projecting the jet shift

Slide courtesy of Roby Leung

For a CalWater overview, see
Ralph et al. 2015 BAMS Early Online Release

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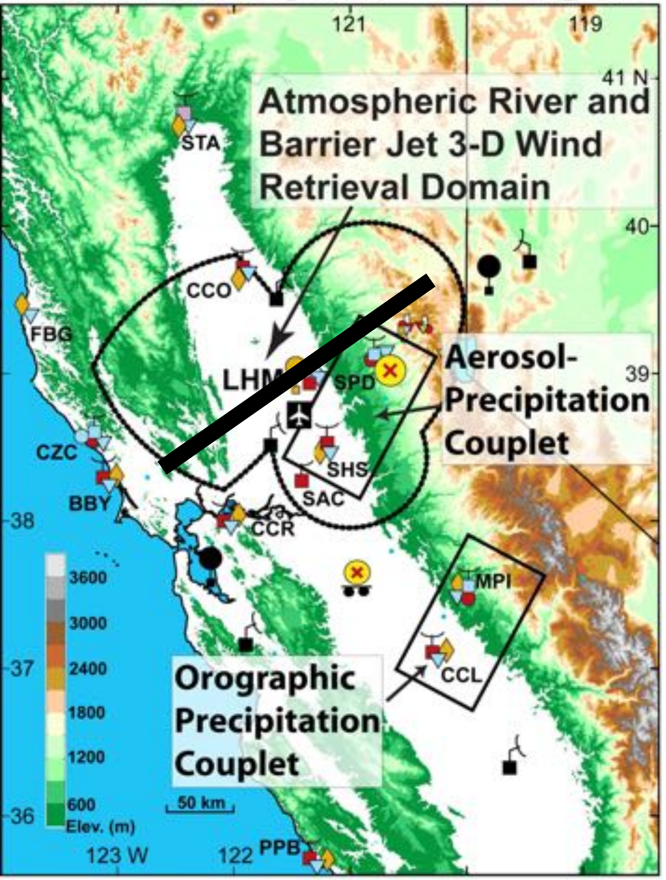
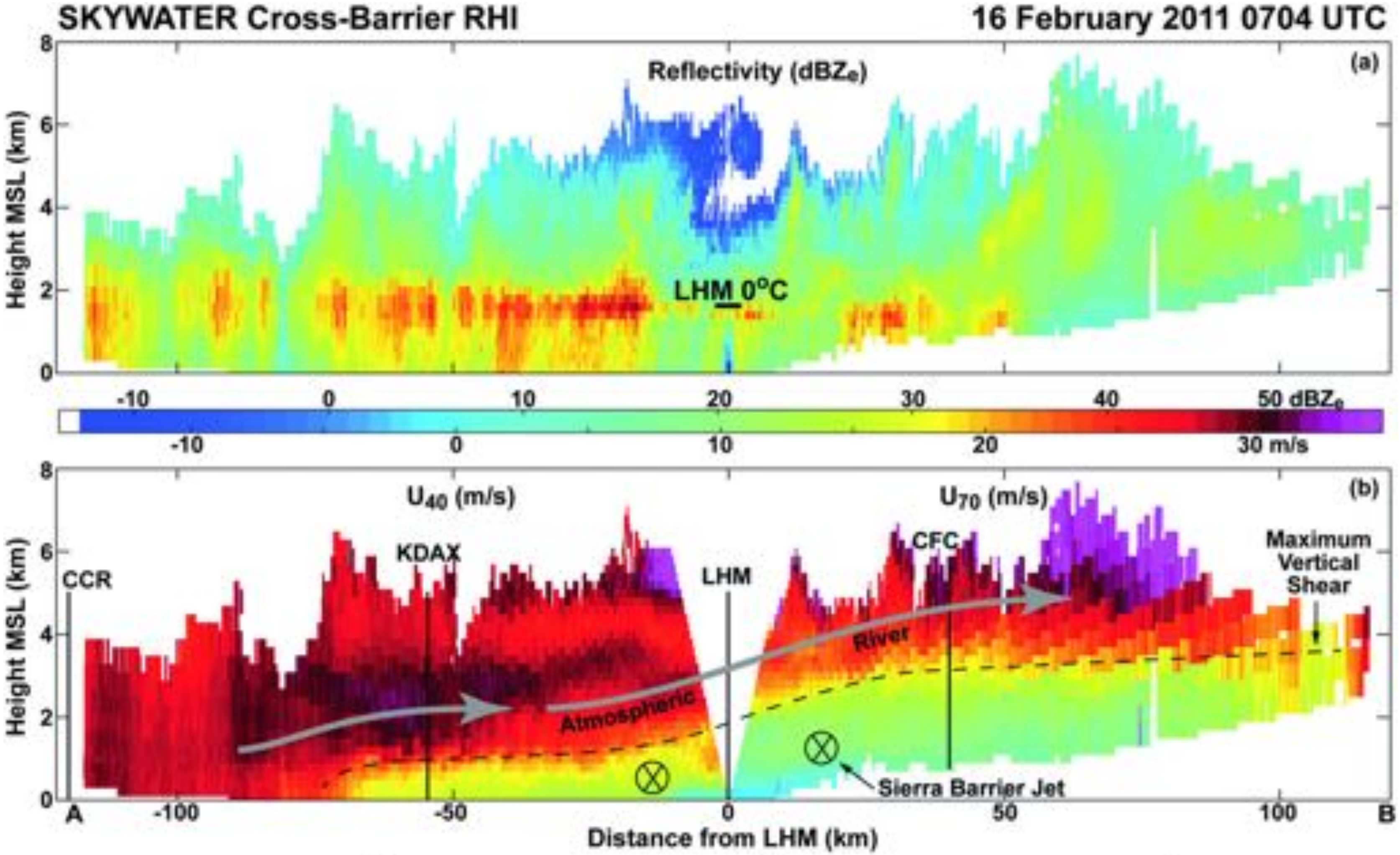
Center for Western Weather
and Water Extremes


Atmospheric River and Barrier Jet 3-D Wind Retrieval Domain
Aerosol-Precipitation Couplet
Orographic Precipitation Couplet
121
119
41 N
40
39
38
37
36
123 W
122
STA
CCO
FBG
LHM
SPD
SHS
SAC
CZC
BBY
CCR
MPI
CCL
PPB
3600
3000
2400
1800
1200
600
Elev. (m)
50 km


SKYWATER Cross-Barrier RHI
16 February 2011 0704 UTC
Reflectivity (dBZe)
(a)
LHM 0°C
Height MSL (km)
-10
0
10
20
30
40
50 dBZe
30 m/s
U40 (m/s)
U70 (m/s)
(b)
CCR
KDAX
LHM
CFC
Maximum Vertical Shear
Atmospheric
River
Sierra Barrier Jet
A
B
-100
-50
0
50
100
Distance from LHM (km)

Key Science Gaps

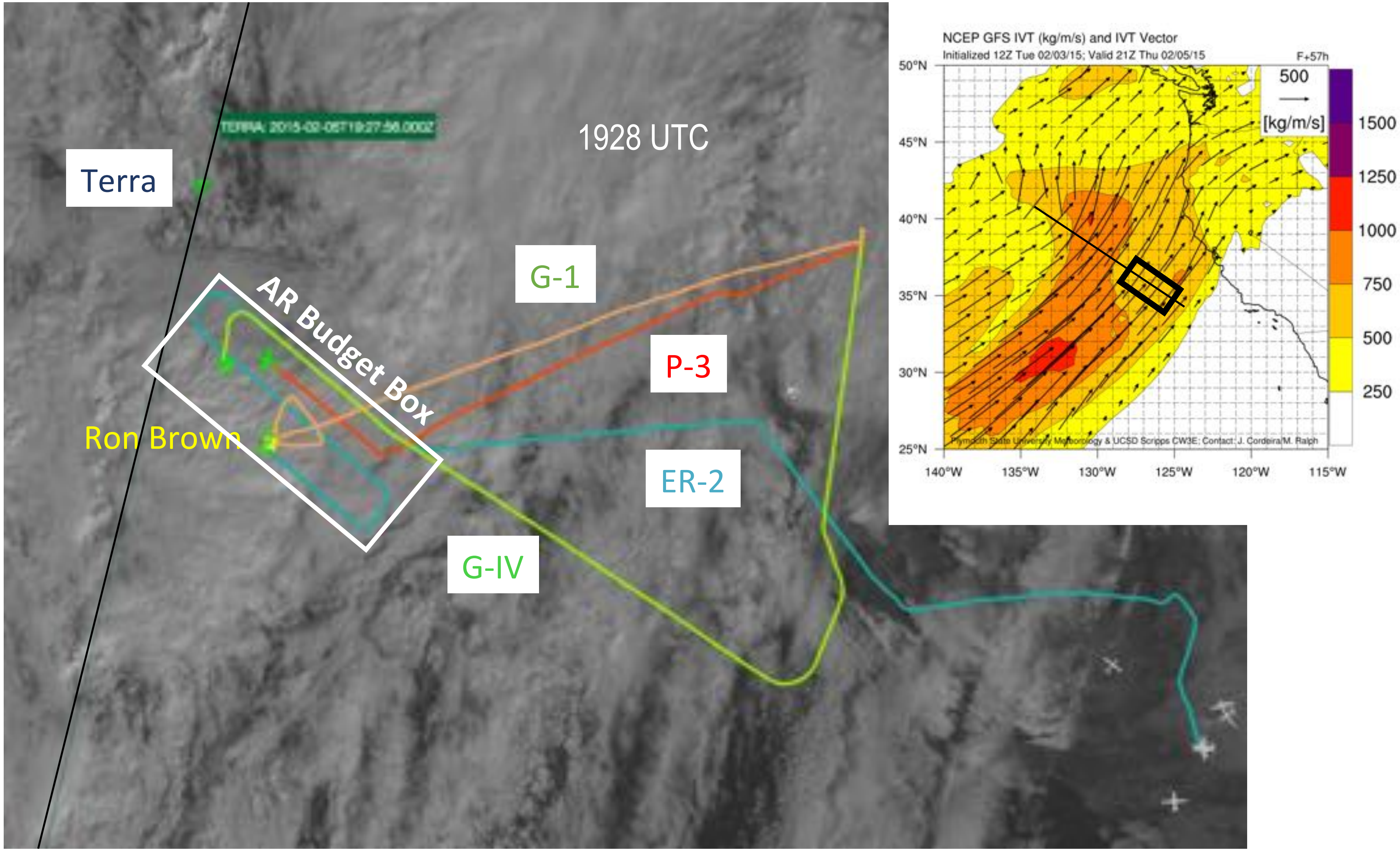
Major goal: Measure influx of moisture to California from landfalling atmospheric rivers and study the influence of transported (cross Pacific) or local (Central Valley) aerosols on precipitation from the coast to Sierra.

- **Evolution and structure of ARs**, including quantifying terms in the water vapor transport budget (air-sea flux, rainout, frontal convergence, entrainment from tropics)

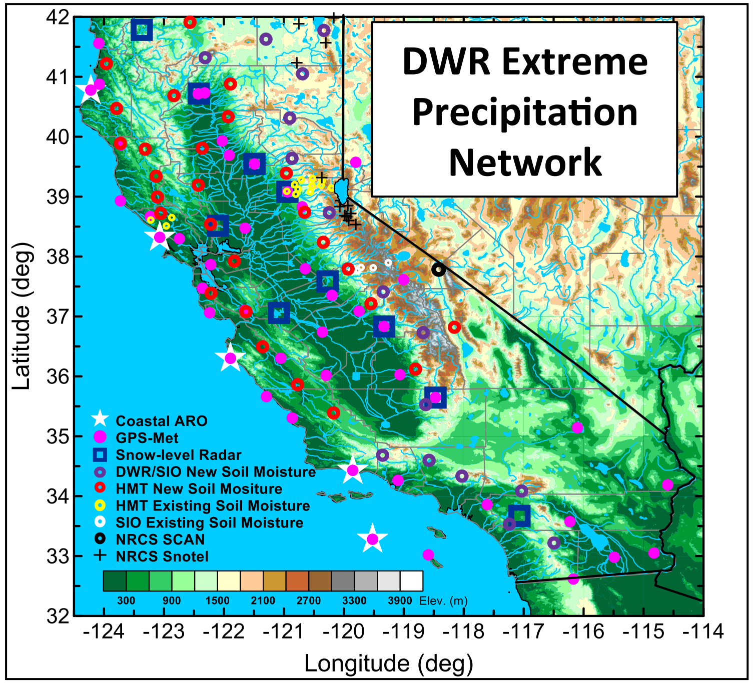
- **Prediction of aerosol burdens and properties** during intercontinental transport from remote source regions to the U.S. West Coast, including dust, biological and ice nuclei

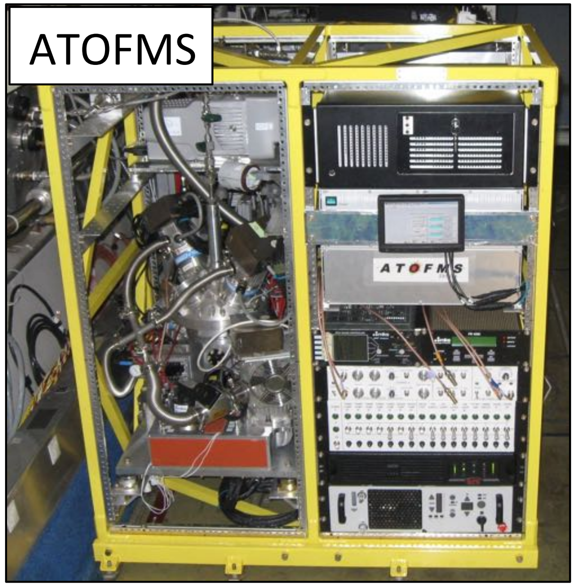
- **Effects of climate variability and change on these phenomena**

Coordinated flights, February 5, 2015



CalWater - 2015





Highlights about 60% through 2015 campaign

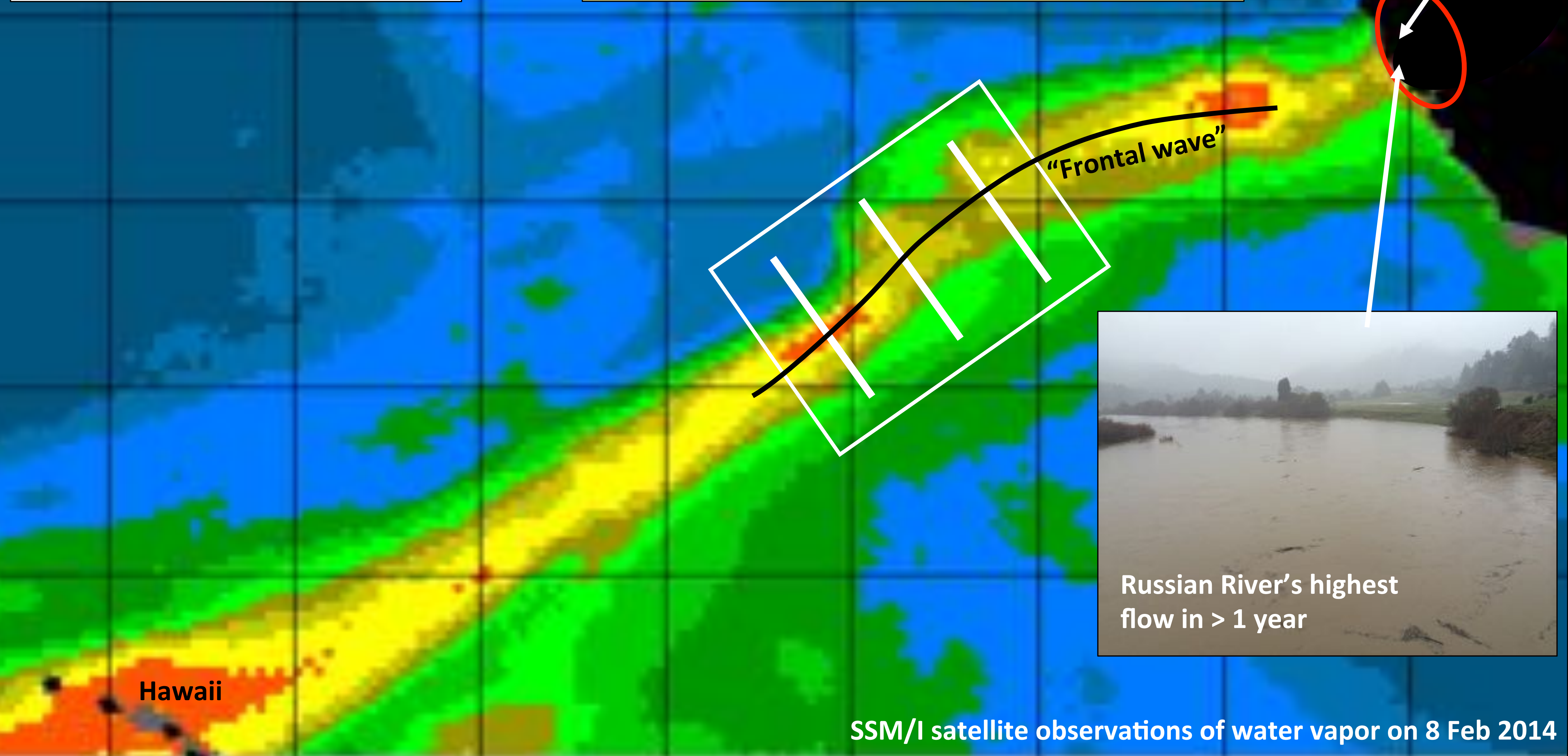
- Many ARs and a wide variety of aerosol/cloud conditions observed
- 35 research aircraft flights conducted (through 12 Feb)
- 270 dropsondes and 150 AXBTs deployed by aircraft
- 30 day cruise by the Ron Brown completed (finished 12 Feb)
- 30 days of ground operations at Bodega Bay plus 25 more planned
- 2 fully coordinated IOPs with all assets participating
- 20+ additional research flights anticipated (180 more dropsondes)

- Total cost: ~$11 M (NOAA $4M, DOE $4M, NSF $2M + ONR, NASA)

CalWater-2014

Ralph et al 2015 (BAMS in press)

This AR increased precipitation-to-date from 16% to 40% of normal in < 4 days in key Northern California watersheds, but runoff was muted due to dry soils.



SSM/I satellite observations of water vapor on 8 Feb 2014