Integrated Observing Strategies for Atmospheric Rivers: Major Field Studies and Future Directions

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Marty Ralph, Ruby Leung, Laura Iraci, Chris Barnet

9 August 2016

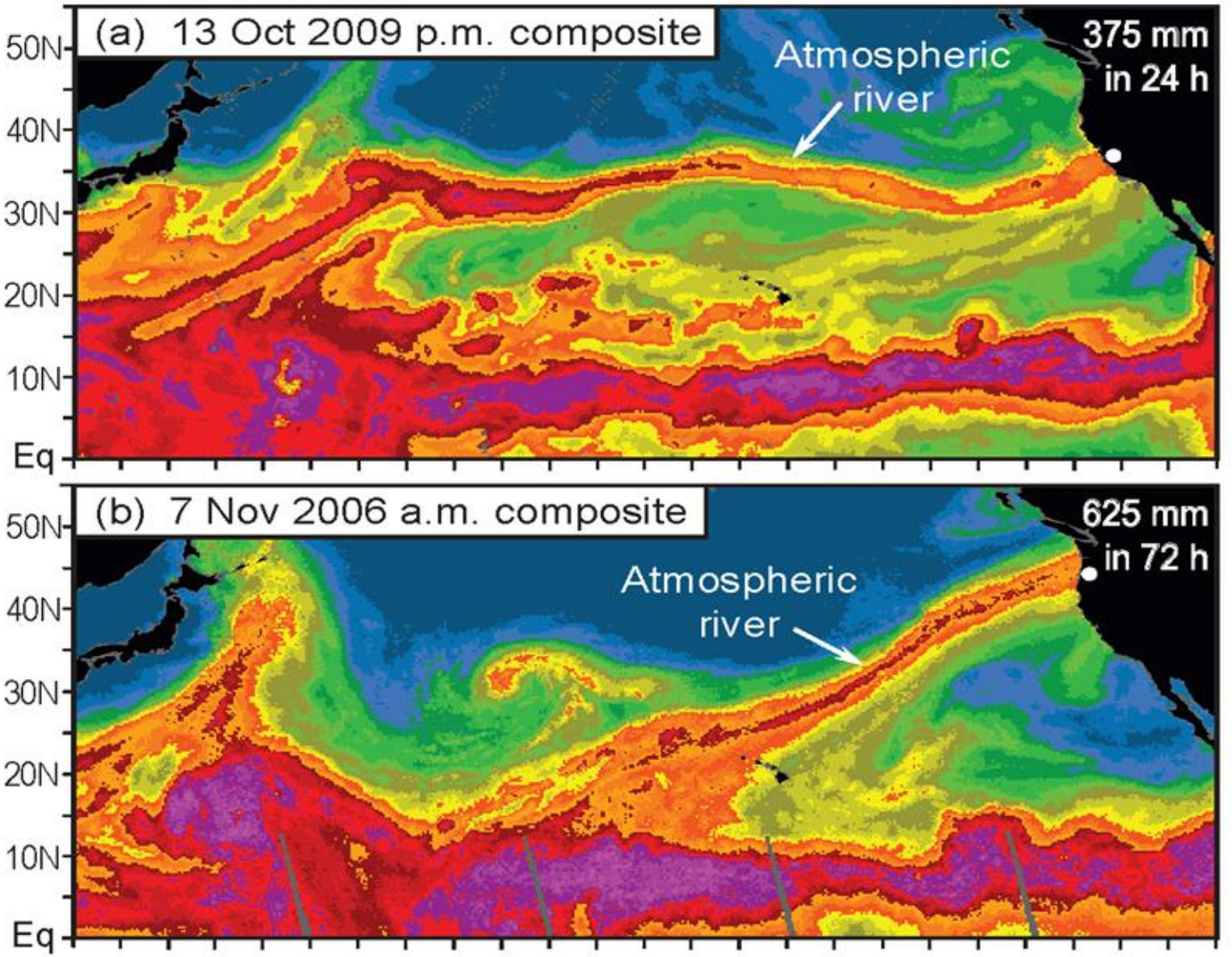
AR Science Drivers

Societal Relevance

- Variability of water supply
- Incidence of extreme precipitation events

Key Phenomena and Science Gaps

- Impact of atmospheric rivers (ARs) on flooding and drought relief
- Aerosol impacts on precipitation
- Effects of climate variability and change

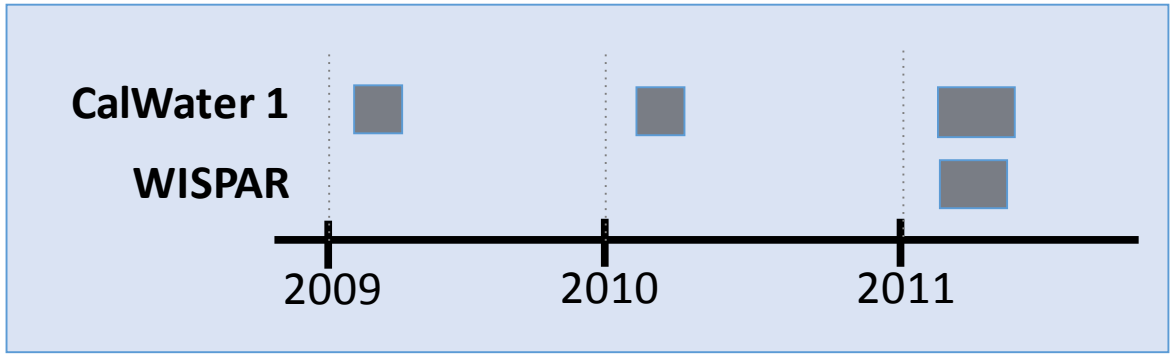


Above: Two examples of ARs that produced extreme rainfall and flooding

Recent Major AR Field Campaigns

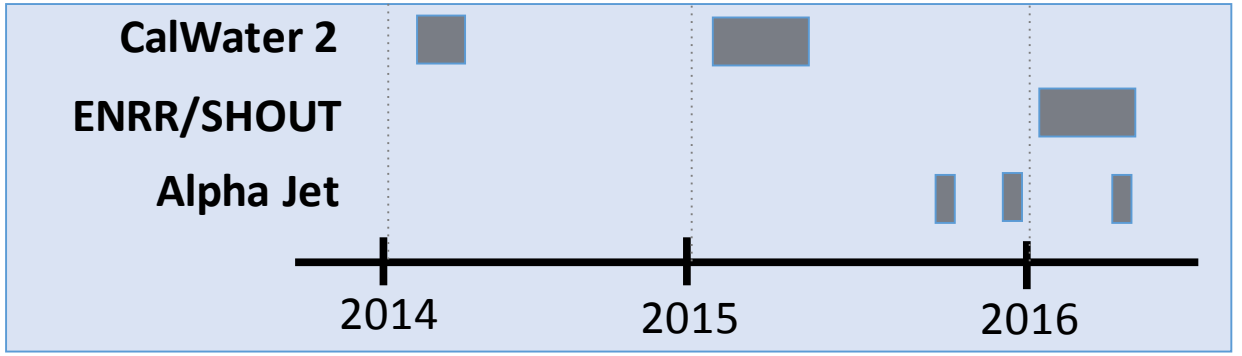
Pre- and Early CalWater Studies

- Early seminal field studies of ARs – CALJET (1998) and PACJET (2001)
- CalWater 1 studies in 2009-11 included cloud and aerosol payload on DOE G-1 to study AR landfall processes
- WISPAR: Winter Storms and Pacific Atmospheric Rivers with the NASA Global Hawk



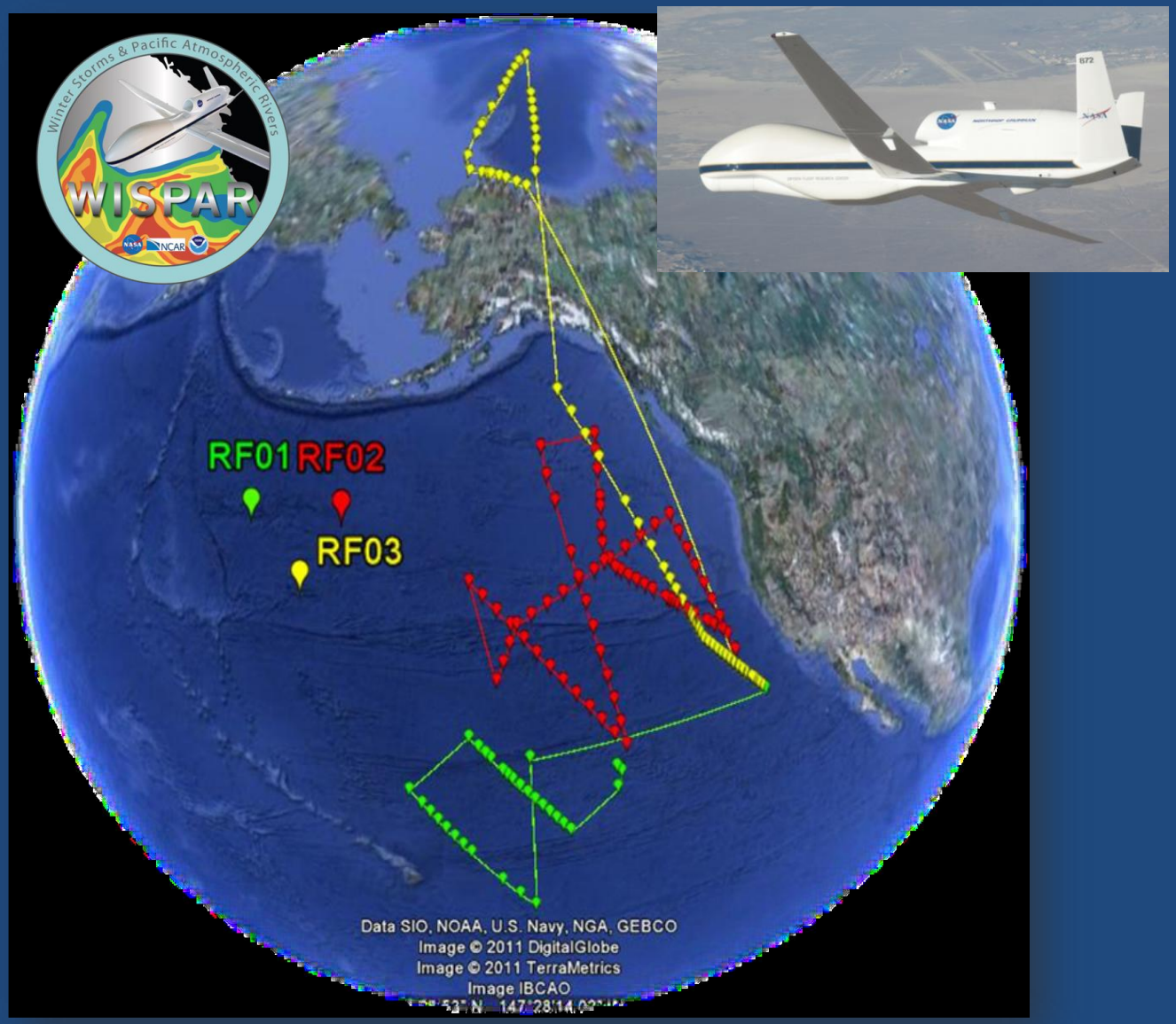
CalWater 2 Development and Campaigns

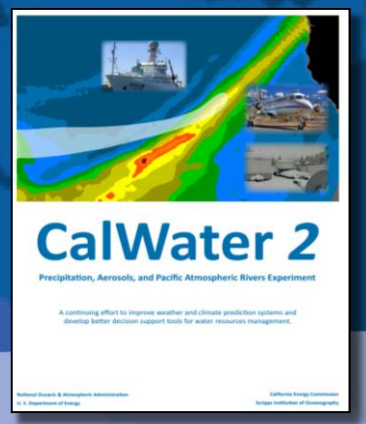
- CalWater 2014 with NOAA G-IV meteorology payload
- CalWater 2015 with NOAA G-IV, P-3, DOE G-!, NASA ER-2, NOAA Ron Brown, Bodega Bay studied ARs
- ENRR/SHOUT: NOAA El Niño Rapid Response Field Campaign with the NOAA G-IV, NASA GH, USAF C-130s, and NOAA Ron Brown examined tropical-extratropical linkages during the strong 2016 El Niño
- Alpha Jet flights targeting landfalling AR processes



Winter Storms and Pacific Atmospheric rivers

- WISPAR Feb-Mar 2011, NASA Dryden Flight Research Center, Edwards, CA
- Collaborative effort between NOAA-NASA-NCAR
- WISPAR flights were designed to:
  - Demonstrate the NOAA/NCAR GH dropsonde system for NOAA operations and research
  - Evaluate the capabilities of the GH for operational observations of atmospheric rivers (ARs), winter storms, and remote Arctic atmosphere





Ralph et al.,
BAMS, in press

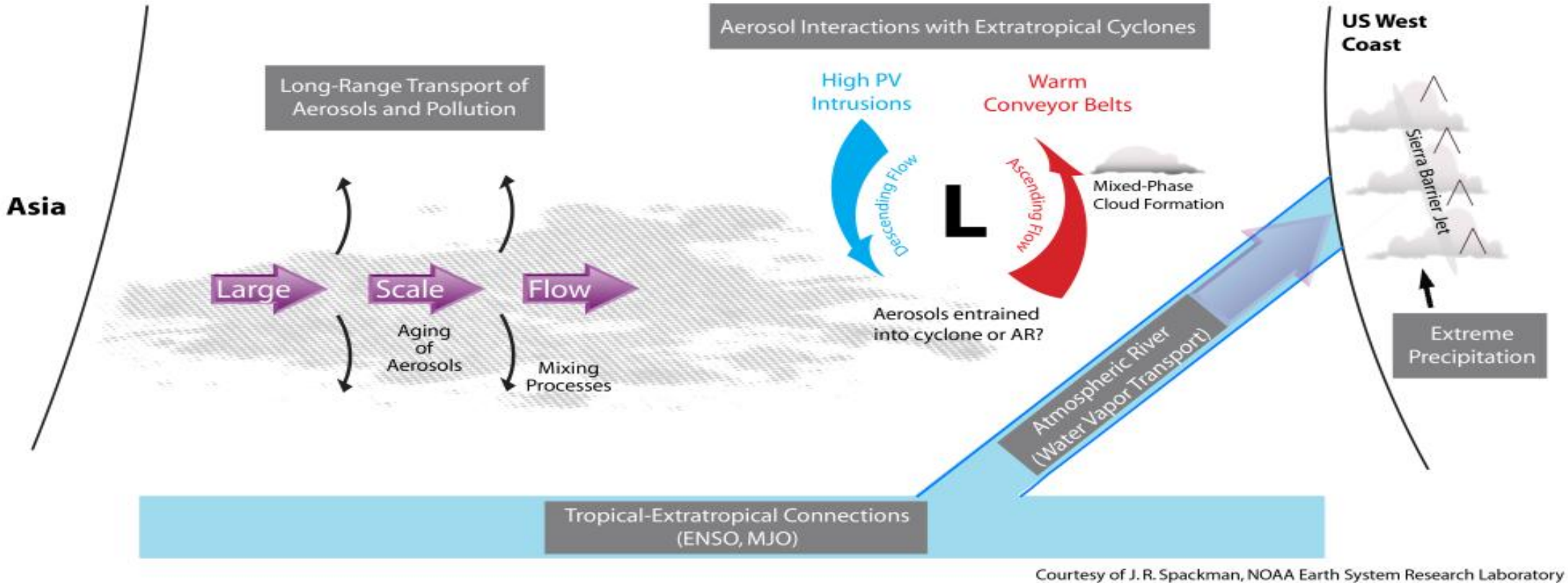
CalWater 2015

Precipitation, Aerosols, and Pacific Atmospheric Rivers Experiment

Marty Ralph, Kim Prather, Dan Cayan (Co-Leads)
Ryan Spackman (Flight Ops Scientist)
Scientific Steering Group: Paul DeMott, Mike Dettinger, Jim Doyle, Chris Fairall, Ruby Leung, Daniel Rosenfeld, Steven Rutledge, Duane Waliser, Allen White

CalWater 2015 Conceptual Framework

Challenge – Improve the predictive capability for extreme weather events by developing process understanding through the implementation of *integrated* observing strategies that include quantifying aerosol impacts on weather

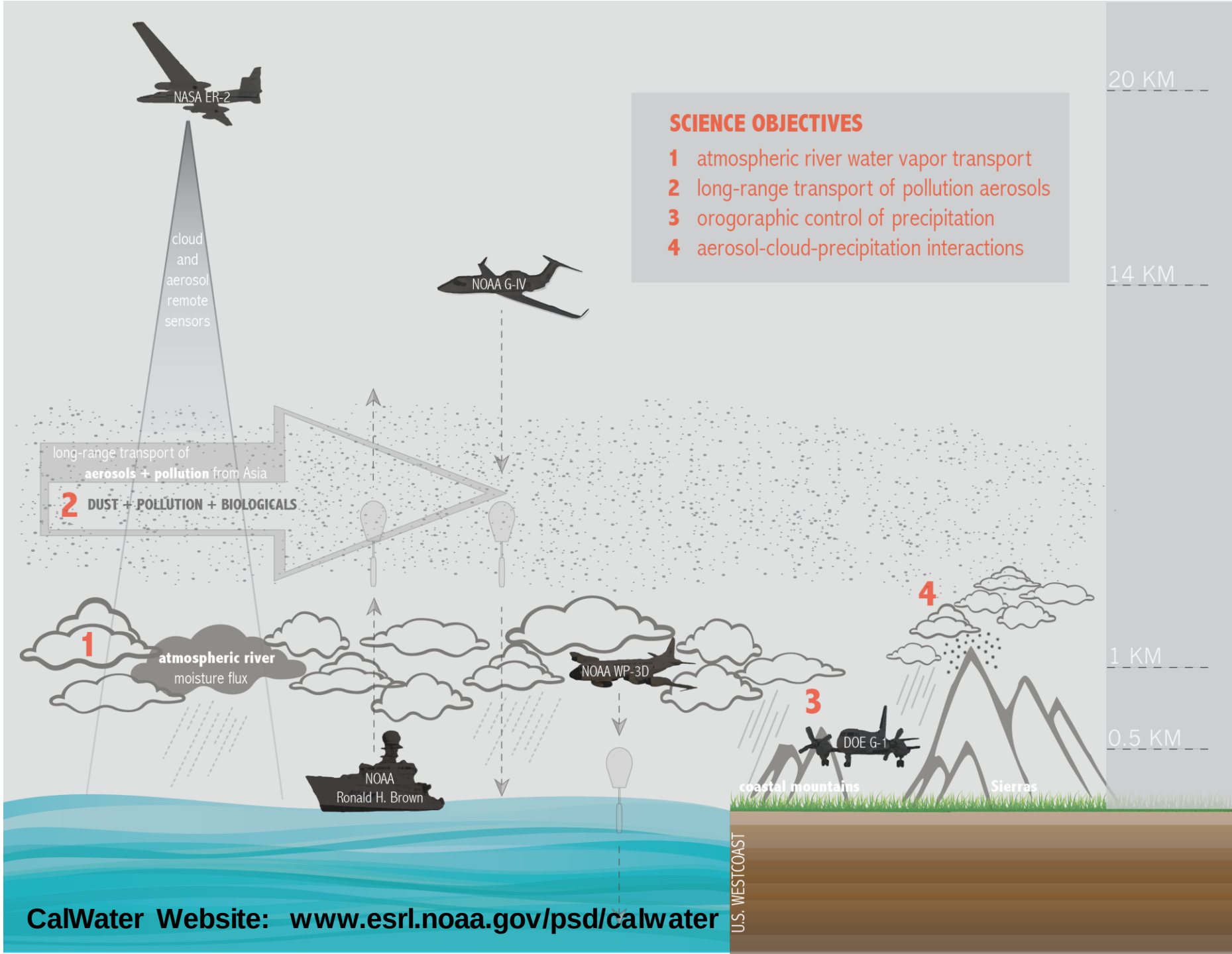


Courtesy of J. R. Spackman, NOAA Earth System Research Laboratory

CalWater Website: www.esrl.noaa.gov/psd/calwater

CalWater 2015/ACAPEX Implementation Strategy

- **Atmospheric Rivers** – Water vapor budgets offshore and orographic control of precipitation upon landfall
- **Aerosol impacts on precipitation** – Aerosol composition and microphysical conditions which facilitate nucleation and affect precipitation offshore and at landfall



CalWater 2014 Early Start Highlights

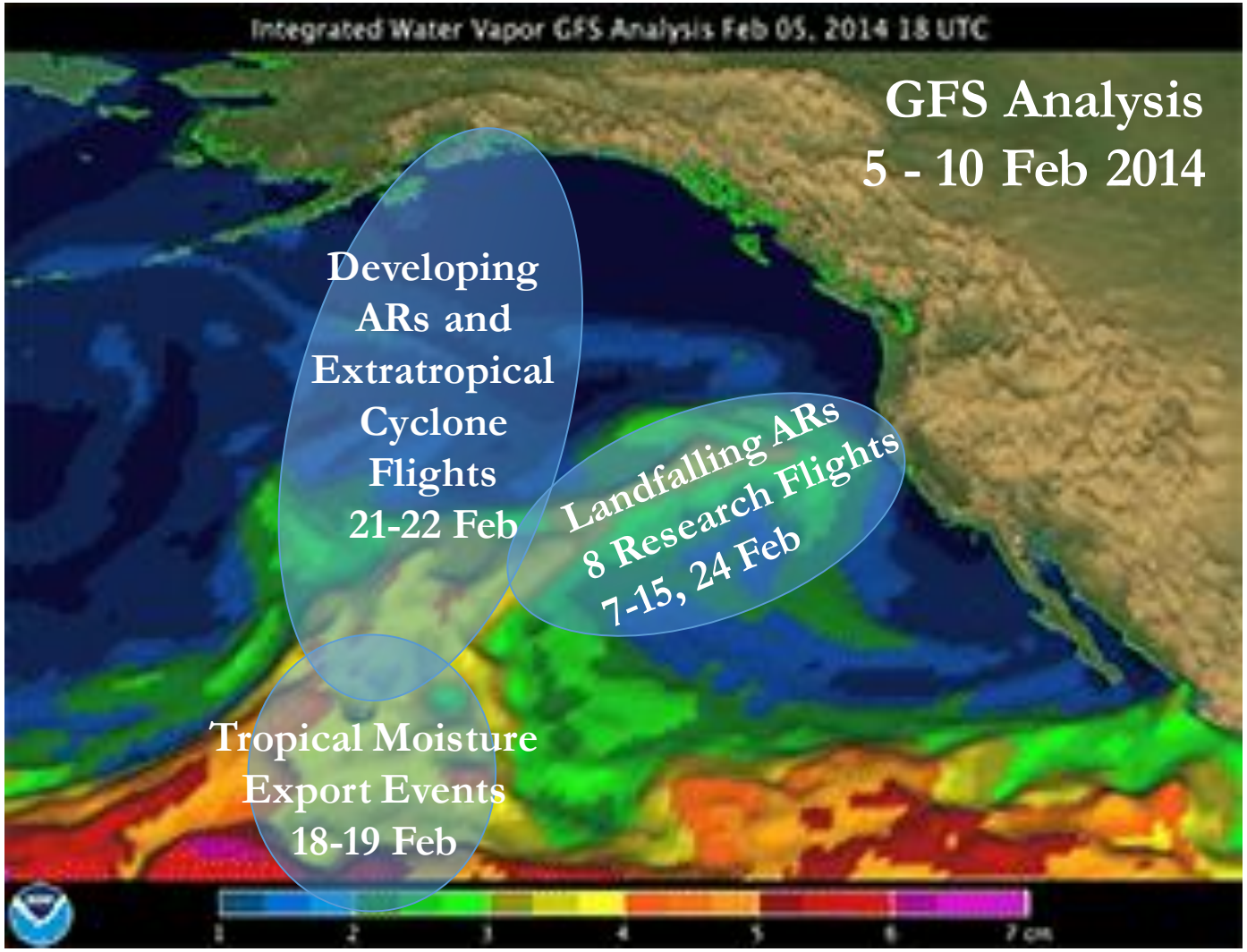
Science Priority – Evolution and structure of atmospheric rivers

Intensive Observations:

- **12 science flights** in 18 days along US West Coast in Feb 2014
- ~200 dropsondes deployed

High-Impact Weather Targets:

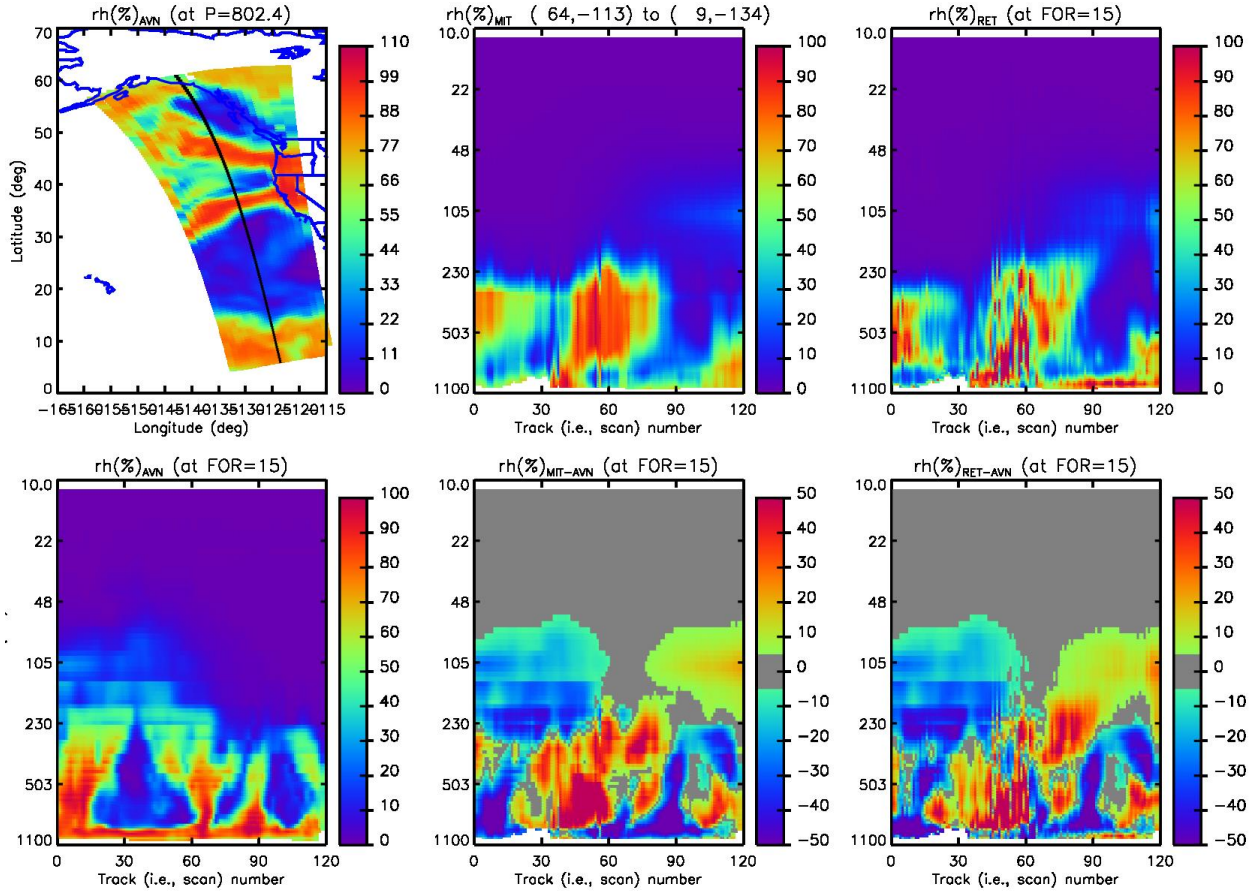
- 2 major landfalling AR events along West Coast
- Tropical Moisture Export (TMEs) events from Hawaii

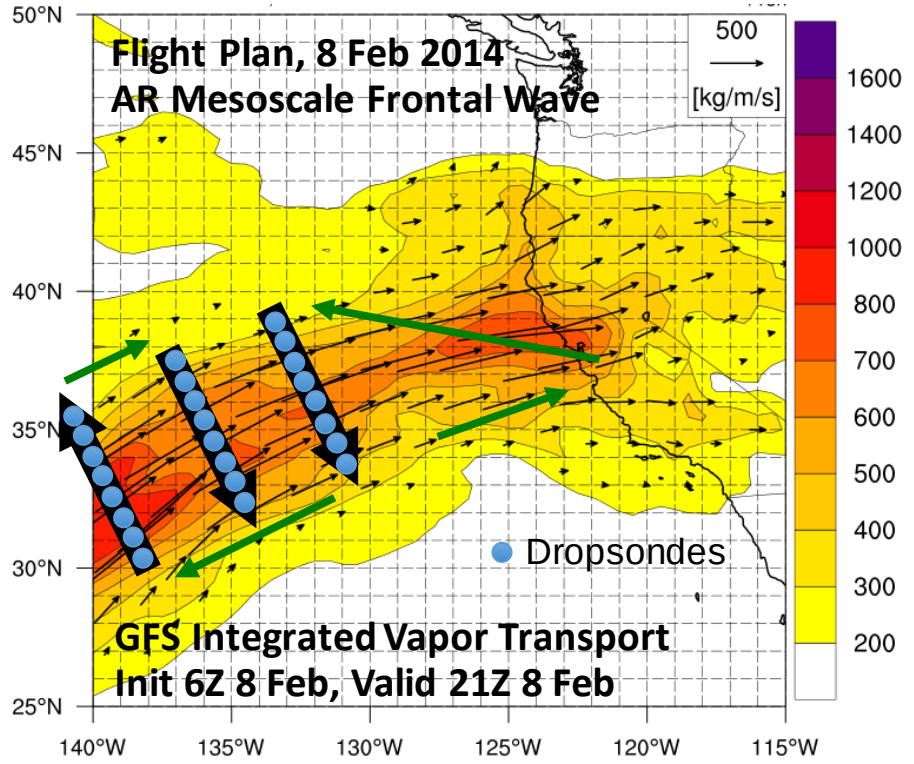


Forecast Improvements? – CrIS and ATMS

Item 1: AR landfalling forecast errors are large (500 km at 5 days, 200 km at 1 day from Wick et al. 2013)

➤ Preliminary analysis suggests retrievals from CrIS and ATMS could improve landfalling forecasts





Item 2: Vertical structure of water vapor in ARs is crucial to getting integrated vapor transport correct

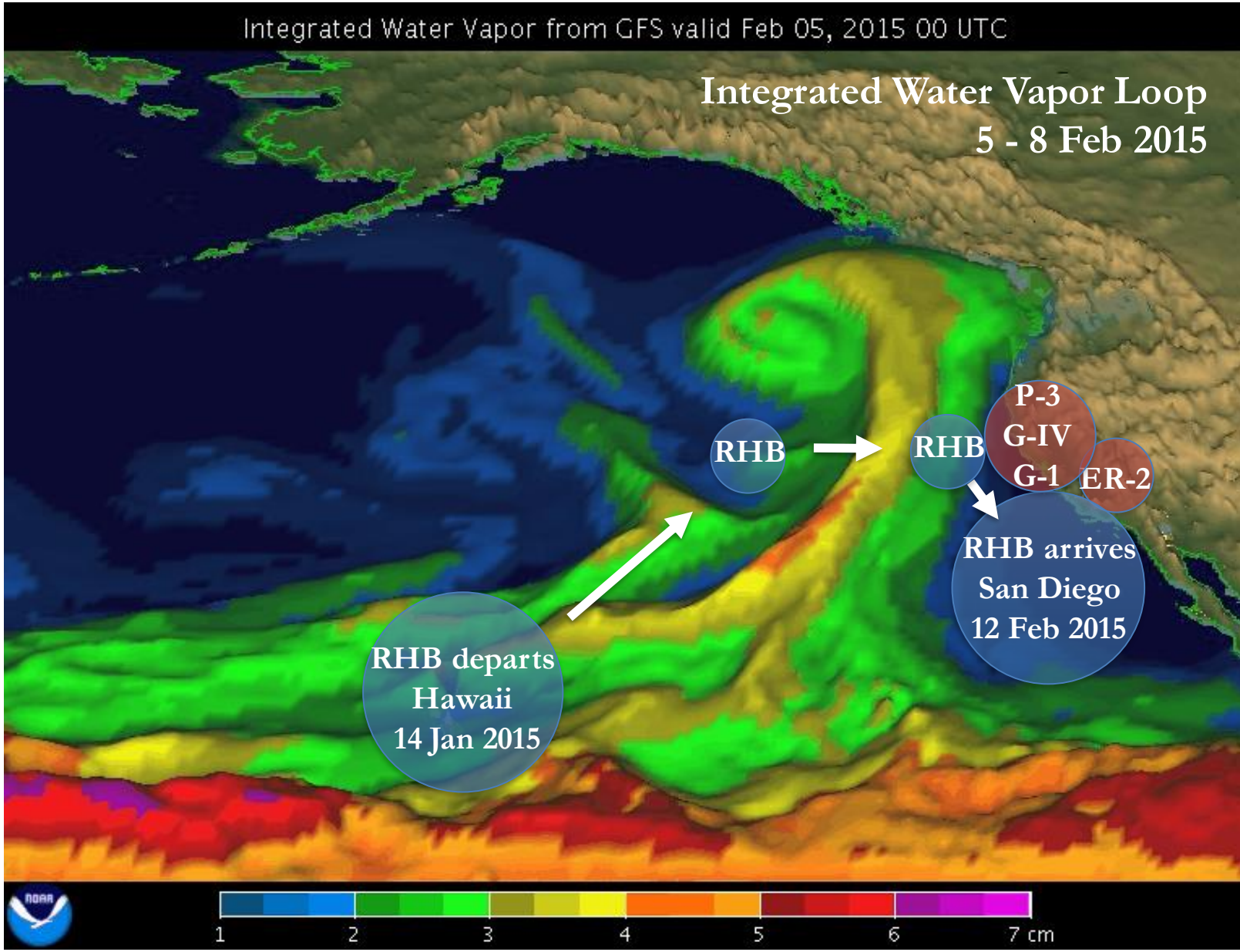
➤ Numerous discrepancies between model and dropsonde data were observed in vertical profiles of water vapor across ARs

For more info, please contact: Antonia Gambacorta, Chris Barnet
Science and Technology Corporation (STC) and NESDIS

CalWater 2015 Implementation

Intensive observations for 2 months in Jan-Feb 2015 with unprecedented interrogation of atmospheric rivers and related water vapor transport phenomena:

- 57 research flights
- 29 day research cruise
- 33 atmospheric river transects
- 444 dropsondes from P-3 and G-IV
- 300+ ship-based radiosonde launches
- Daily ship-based ozonesonde launches
- Coordination with NOAA HMT network and NSF-funded aerosol supersite observations

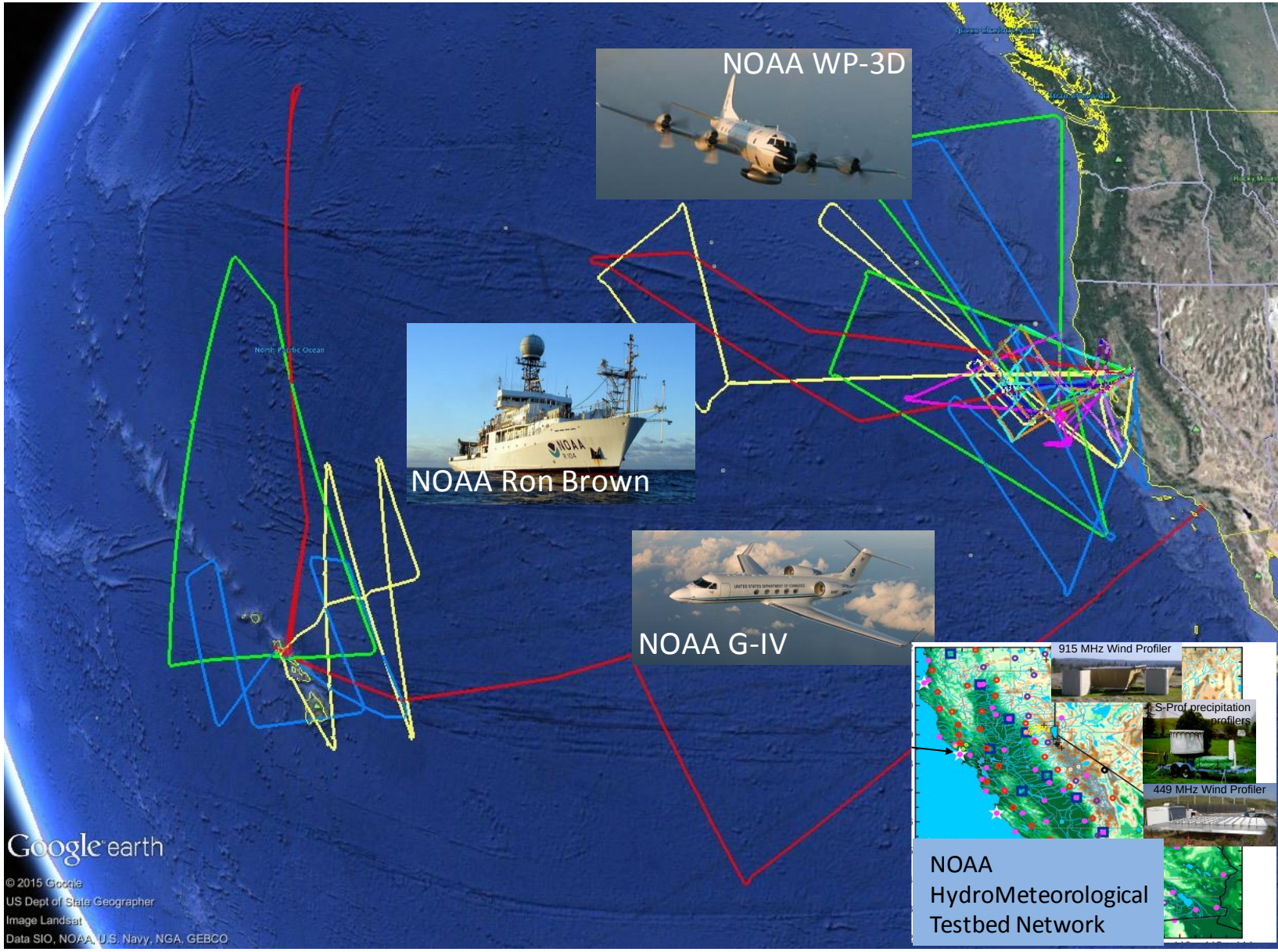


CalWater Website: www.esrl.noaa.gov/psd/calwater

Emerging CalWater 2015 Science Results

Several process studies are emerging from the intensive observations to address the CalWater 2015 science goals:

- Water vapor budget of ARs
- Air-sea flux interactions in ARs
- Aerosol-cloud interactions including role of direct and indirect aerosol impacts on precipitation
- Orographic control of precipitation and microphysical and barrier jet processes
- Tropical-extratropical connections
- Data denial/model integration studies with dropsonde observations



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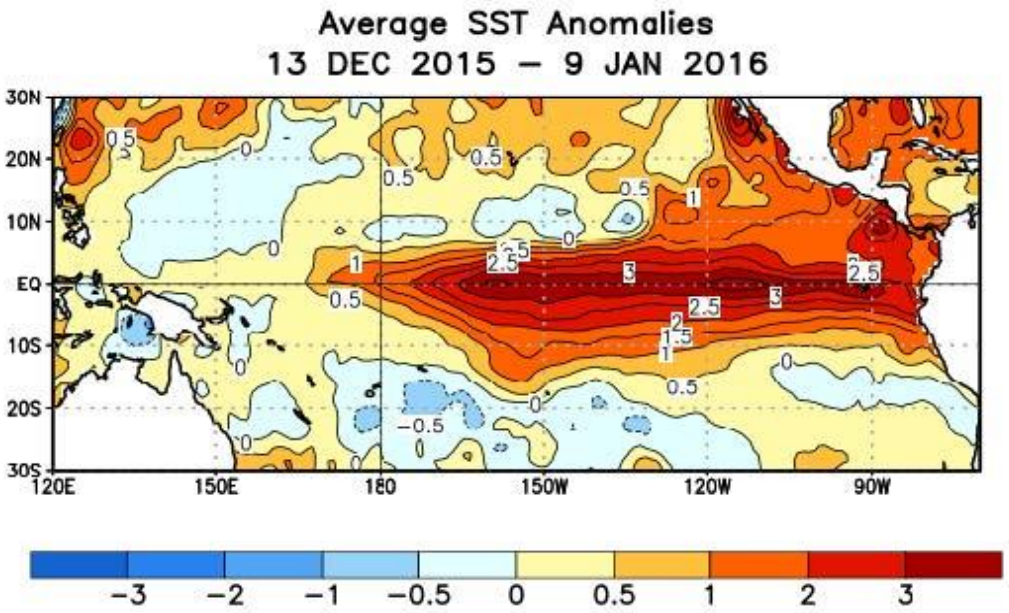
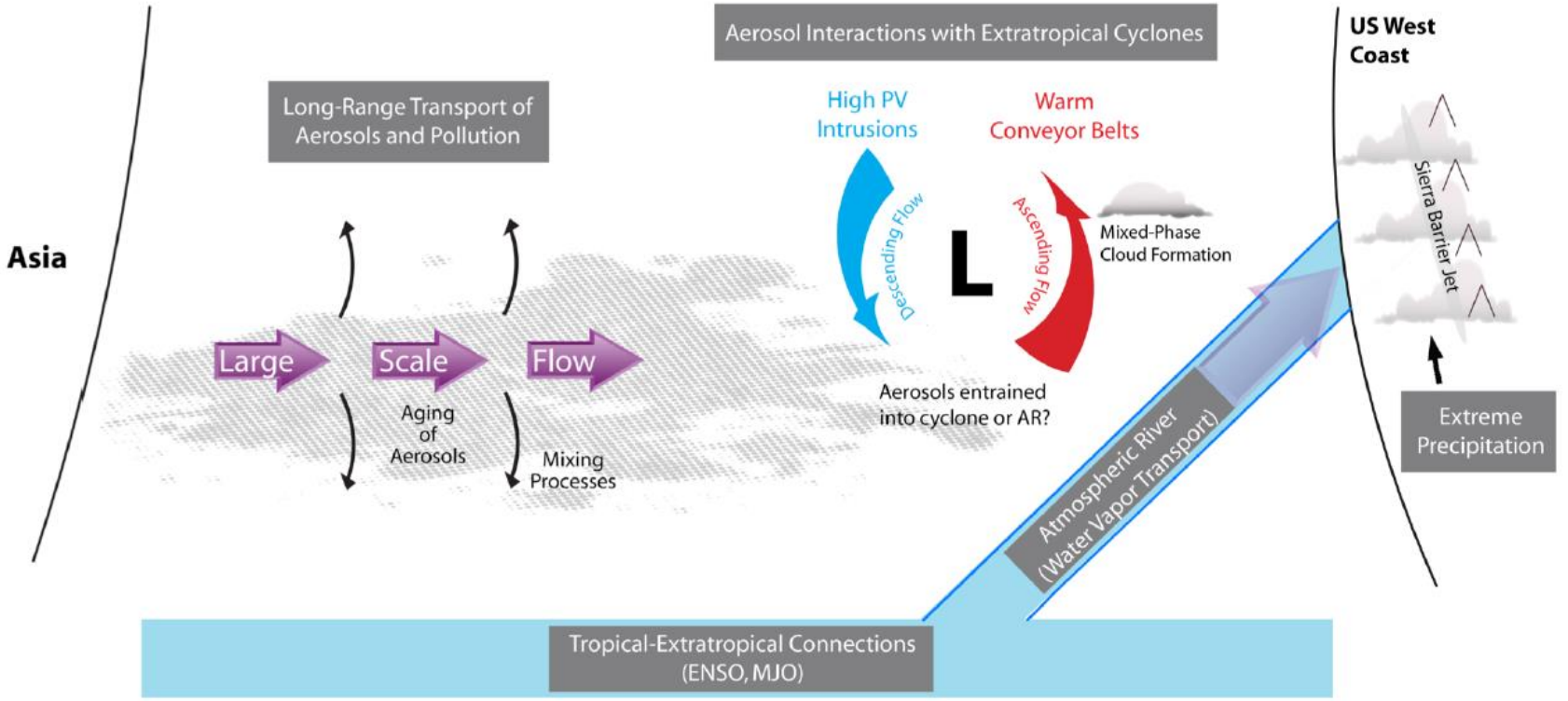
ENRR Science Drivers

- 2015-16 very strong El Niño is among top three on record
- Interesting differences from 1982-83 and 1997-98 with a more central Pacific focus in 2015-16 and variable downstream weather impacts in continental U.S.

ENRR Website: www.esrl.noaa.gov/psd/enso/rapid_response





Courtesy of J. R. Spackman, NOAA Earth System Research Laboratory

ENRR Focus:

- Initial atmospheric response to deep convection in central tropical Pacific during El Niño
- Linkages between outflow from convection across the subtropical jet to extratropical impacts along the U.S. West Coast

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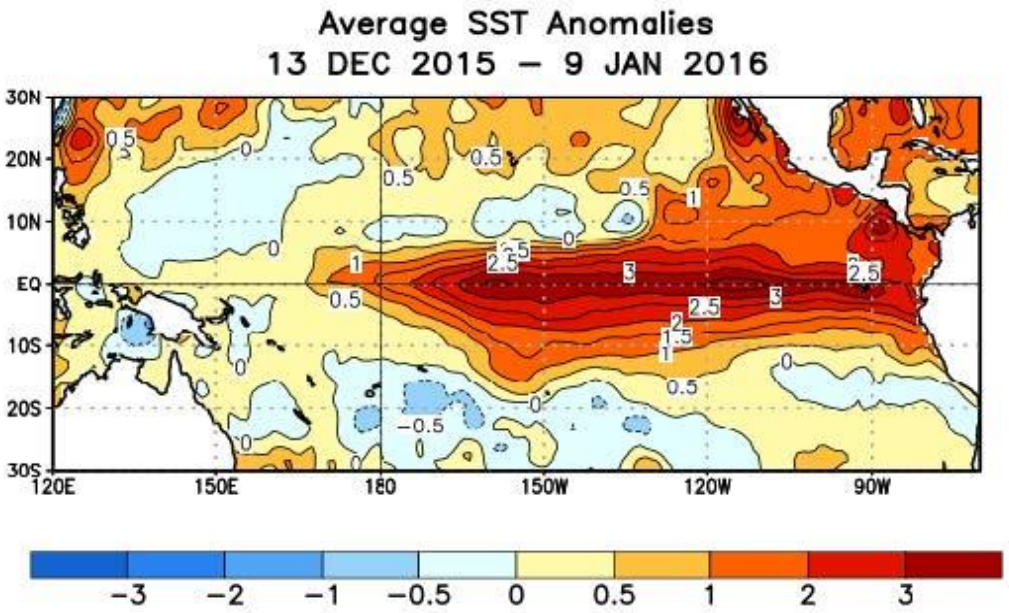

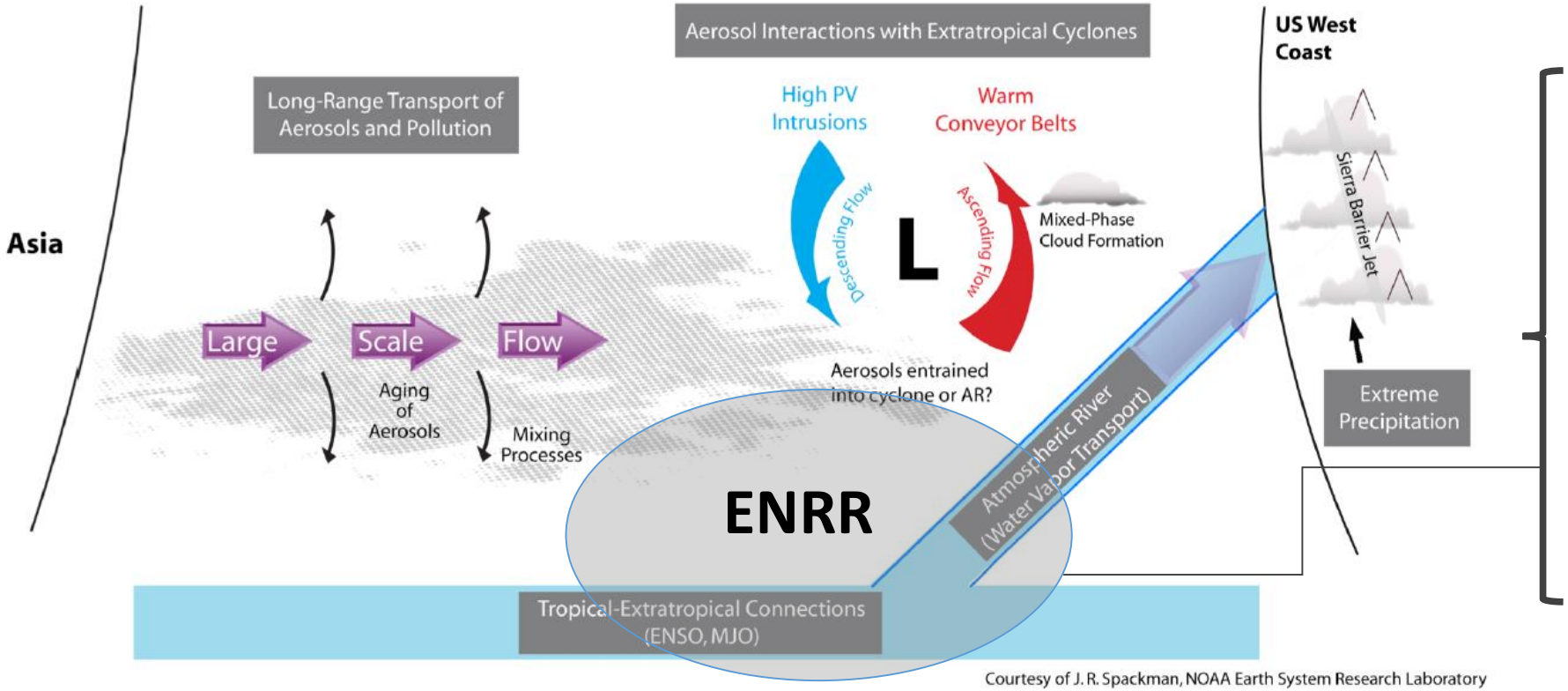

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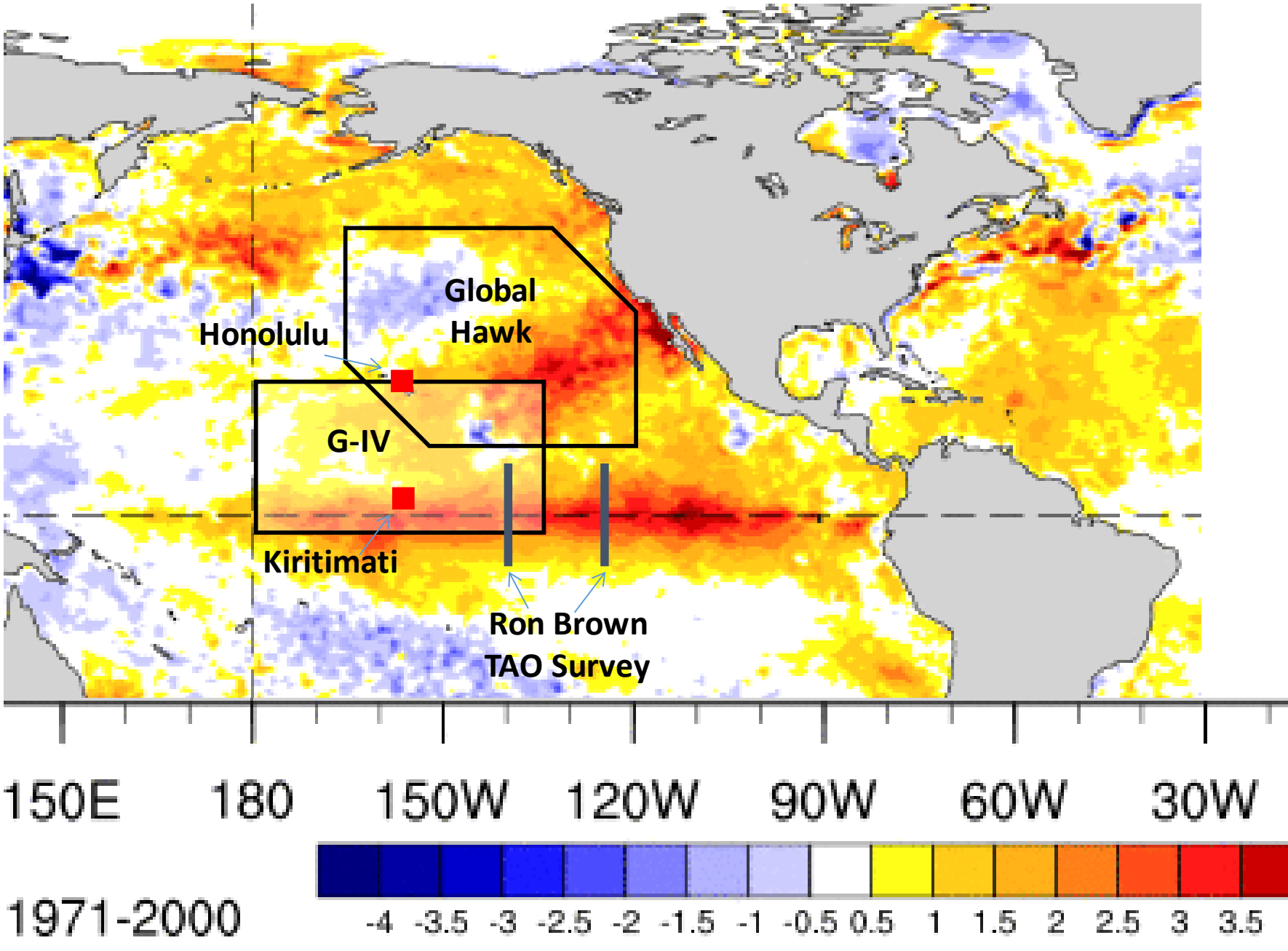
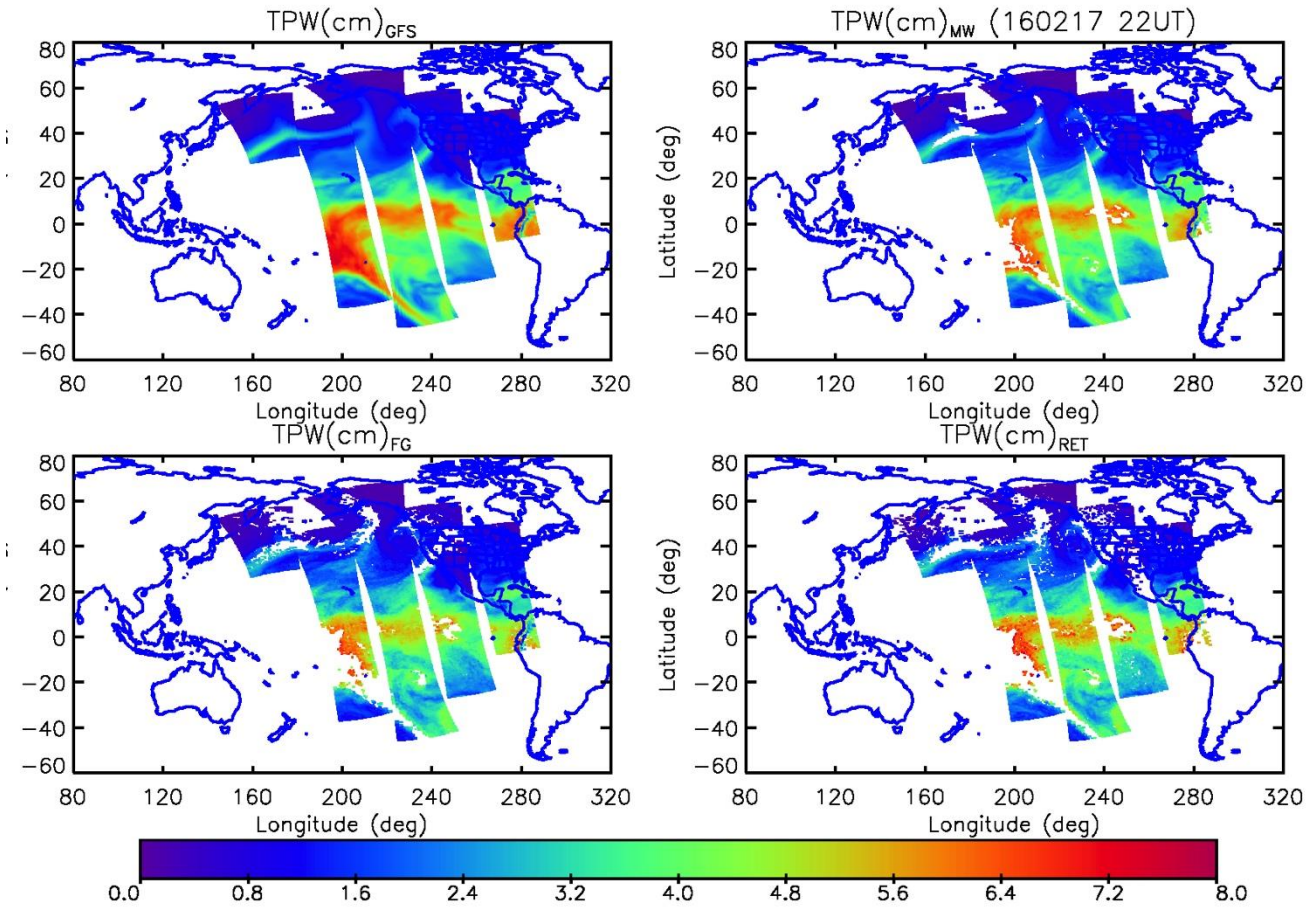
ENRR Implementation Strategy

- G-IV: Divergent outflow and jet extension processes in central and eastern tropical Pacific
- Global Hawk: Coupling to midlatitude weather with surveys in eastern Pacific midlatitudes to evaluate impacts on U.S. West Coast
- Kiritimati/Ron Brown: Survey of atmosphere and ocean conditions in eastern tropical Pacific

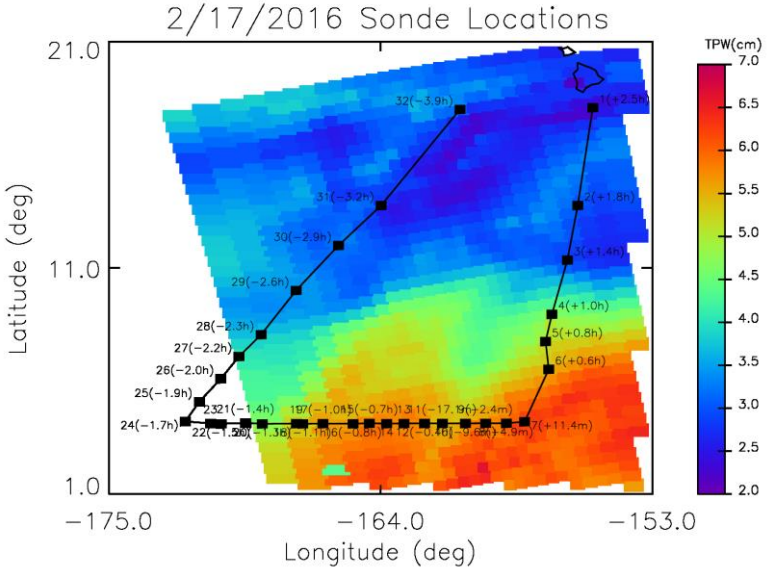
SST Daily Anomalies (°C), 25 Oct 2015



Using the NOAA Unique CrIS ATMS Processing System (NUCAPS) to assess hyper-spectral sounding capability during AR events: a test case from February 17, 2016



A snapshot of the full region



A close up figure over the flight path

➤Satellite data can provide near real time (~0.5 hour), 3D context to a high impact weather event

Courtesy of Antonia Gambacorta, Chris Barnet
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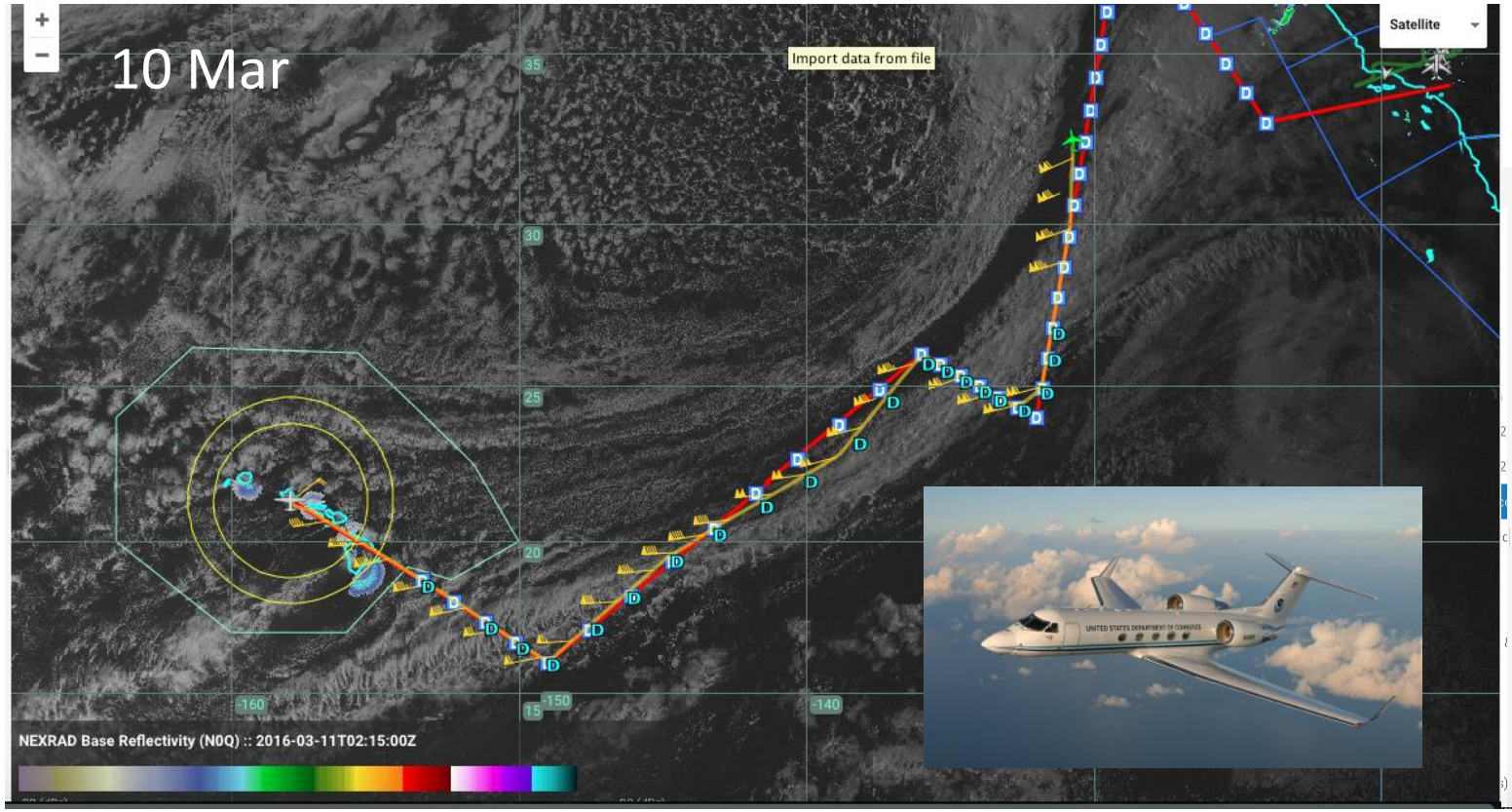
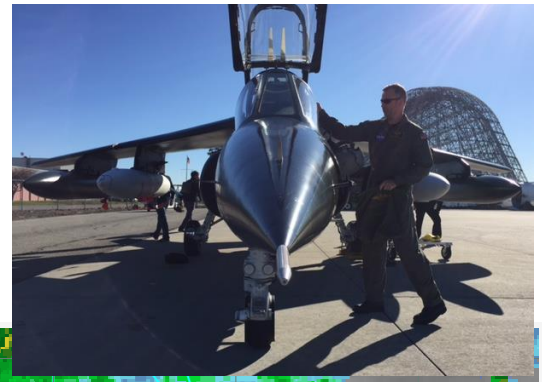
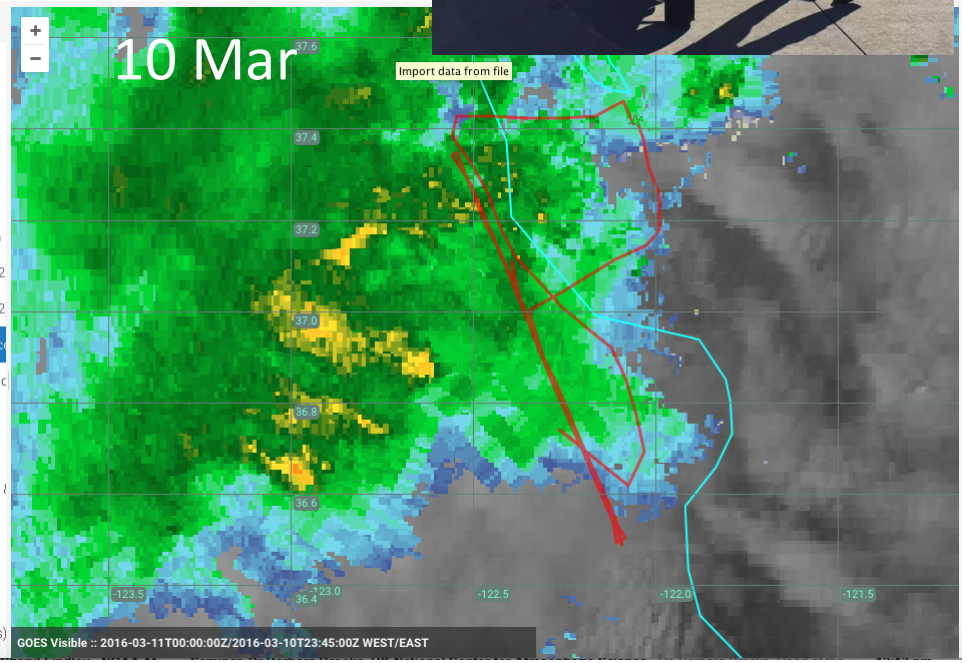
Tropical-Extratropical Linkages: G-IV Coordinated Flight with Alpha Jet

- G-IV flew multiple transects at cruise altitude (41-45 kft) across the mature atmospheric river NE of Hawaii making landfall along the northern CA coast
- Alpha Jet (based at Moffett Field) conducted a 1.5 hour stacked flight in the warm sector of the AR offshore SW of the Bay Area







Prospects for Future AR Field Studies

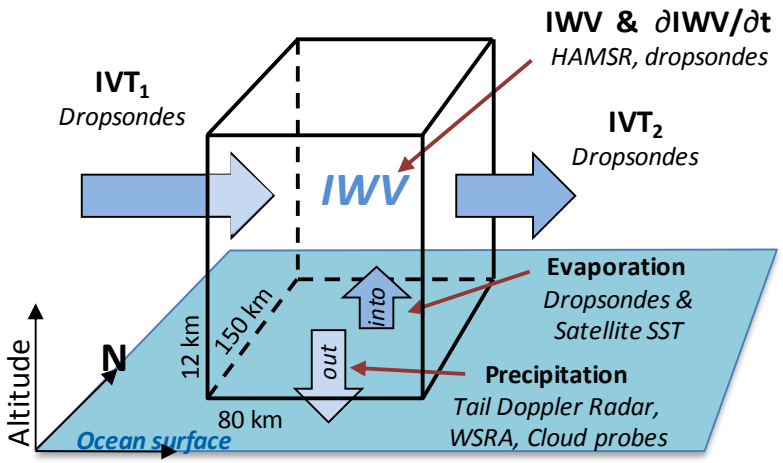
- Study tropical-extratropical linkages to improve our understanding of the processes linking outflow from convection in the tropics that enhances and extends the subtropical jet extension and can lead to AR activity along the U.S. West Coast
- Examine east Asian aerosol and dust outflow including aging and mixing processes that affect clouds, precipitation and large-scale dynamical processes over the remote Pacific that can modulate AR activity
- Alpha Jet/UAS opportunities: Examine barrier jet and pollution outflow processes associated with landfalling ARs

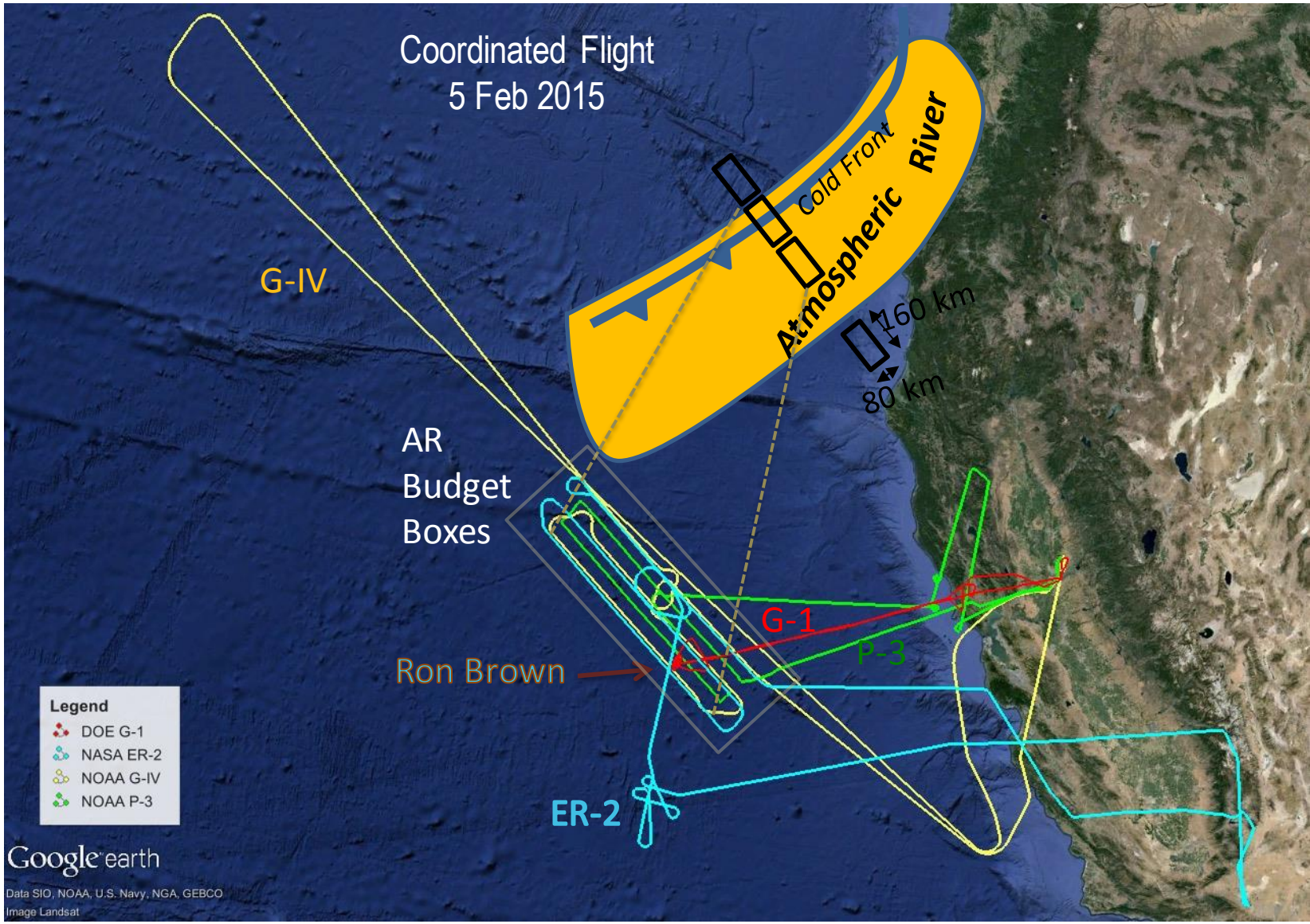
Supplementary Material

Emerging CalWater 2015 Science Results

Max Mission: Four research aircraft were coordinated with the NOAA Ron Brown during AR activity offshore of Northern California to address the science goal:

- Water vapor budget of ARs





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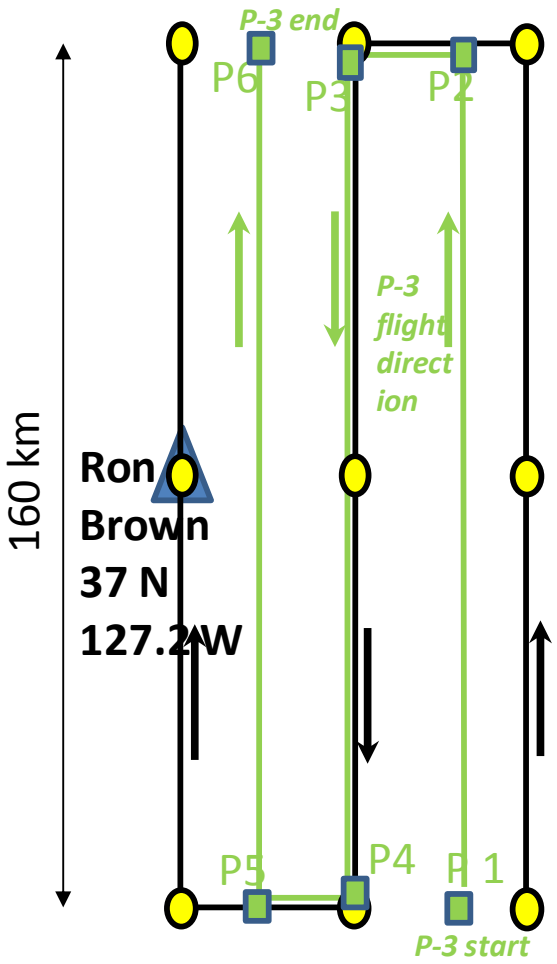
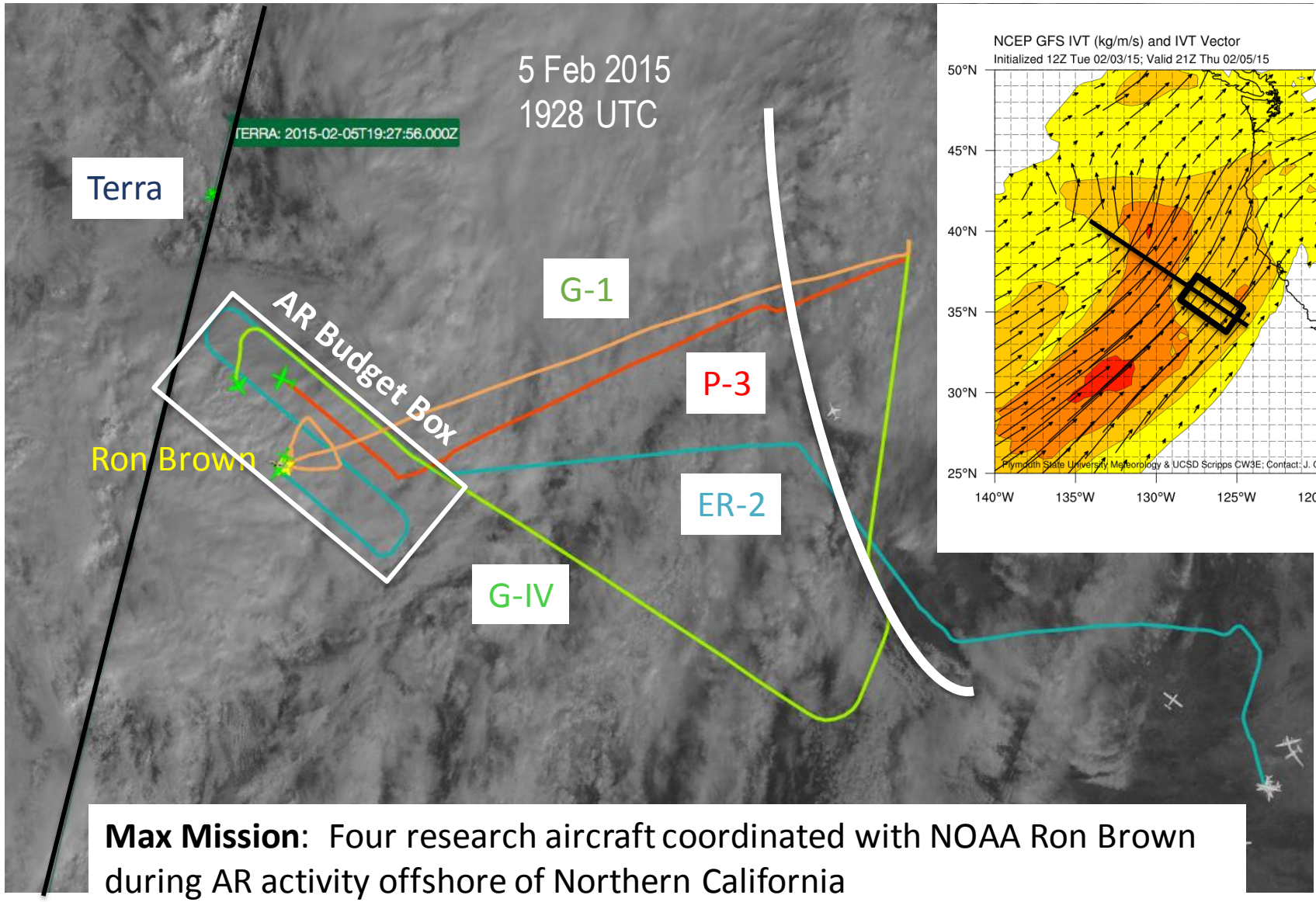
Coordinated Flight
5 Feb 2015





Max Mission: Four research aircraft coordinated with NOAA Ron Brown during AR activity offshore of Northern California

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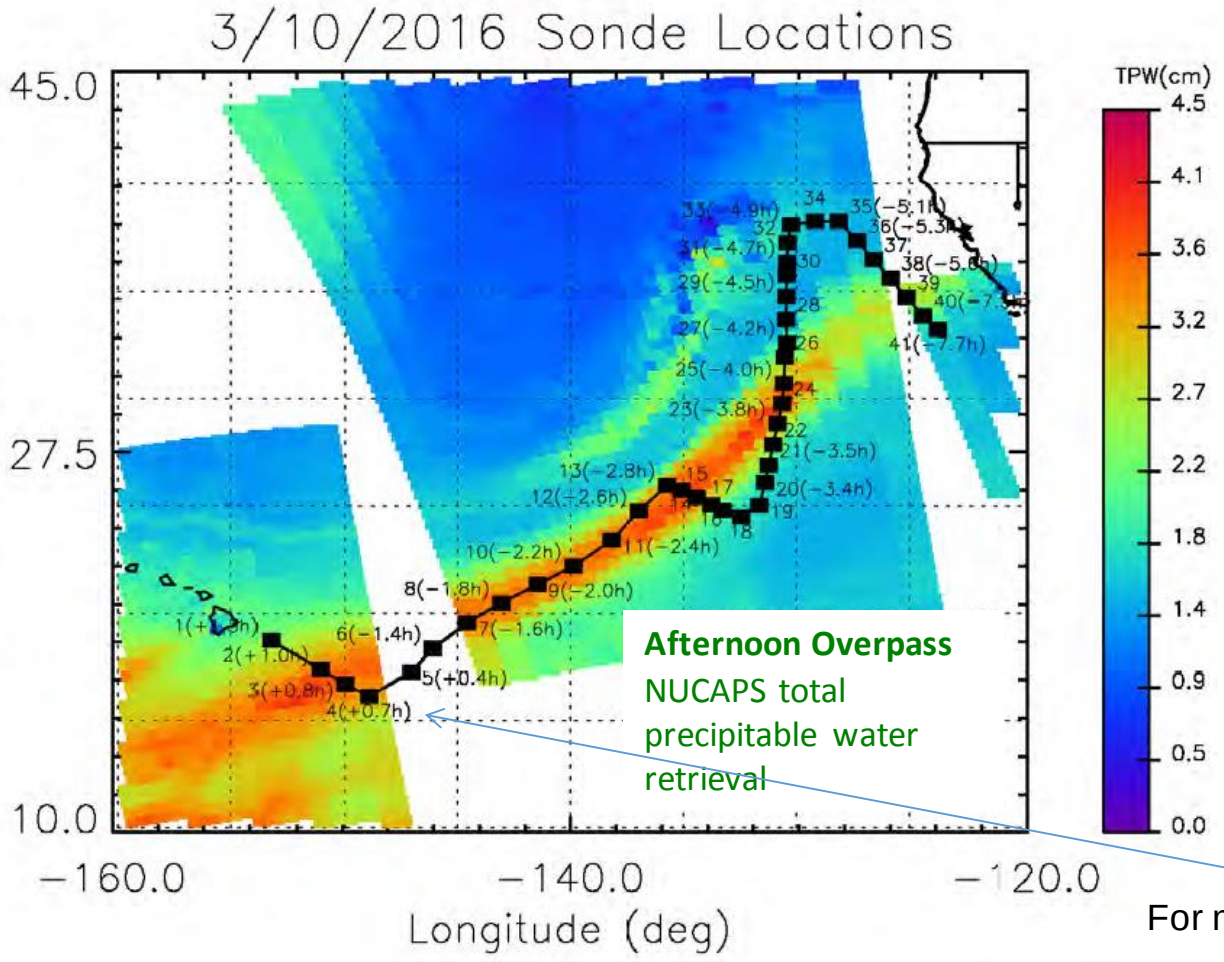
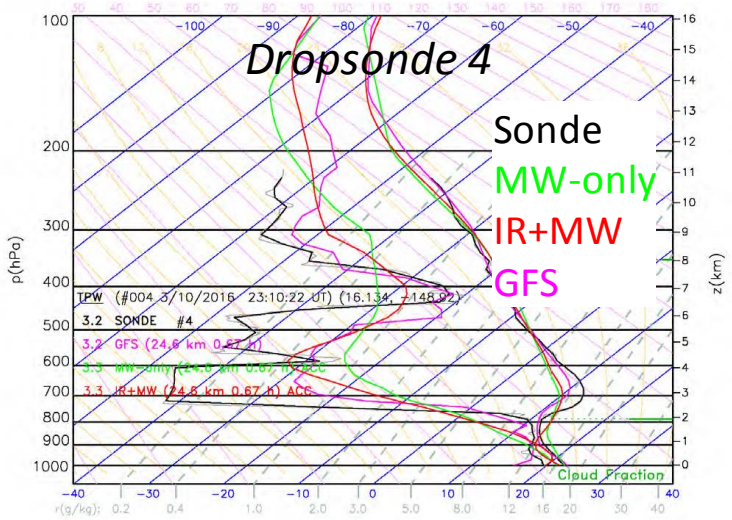
Satellite Remote Sensing Comparisons

Morning and afternoon retrievals were performed from overpasses of Suomi-NPP based on microwave-only (ATMS) and combined infrared and microwave (CrIS+ATMS) sounding retrievals and compared with G-IV dropsondes and NCEP's Global Forecast System 3-9 hour forecasts



Colors: Total precipitable water from NOAA S-NPP satellite sounding algorithm (NUCAPS)

Boxes: Location of dropsondes from NOAA G-IV (time offset from overpass)



For more info, please contact: Antonia Gambacorta, Chris Barnet
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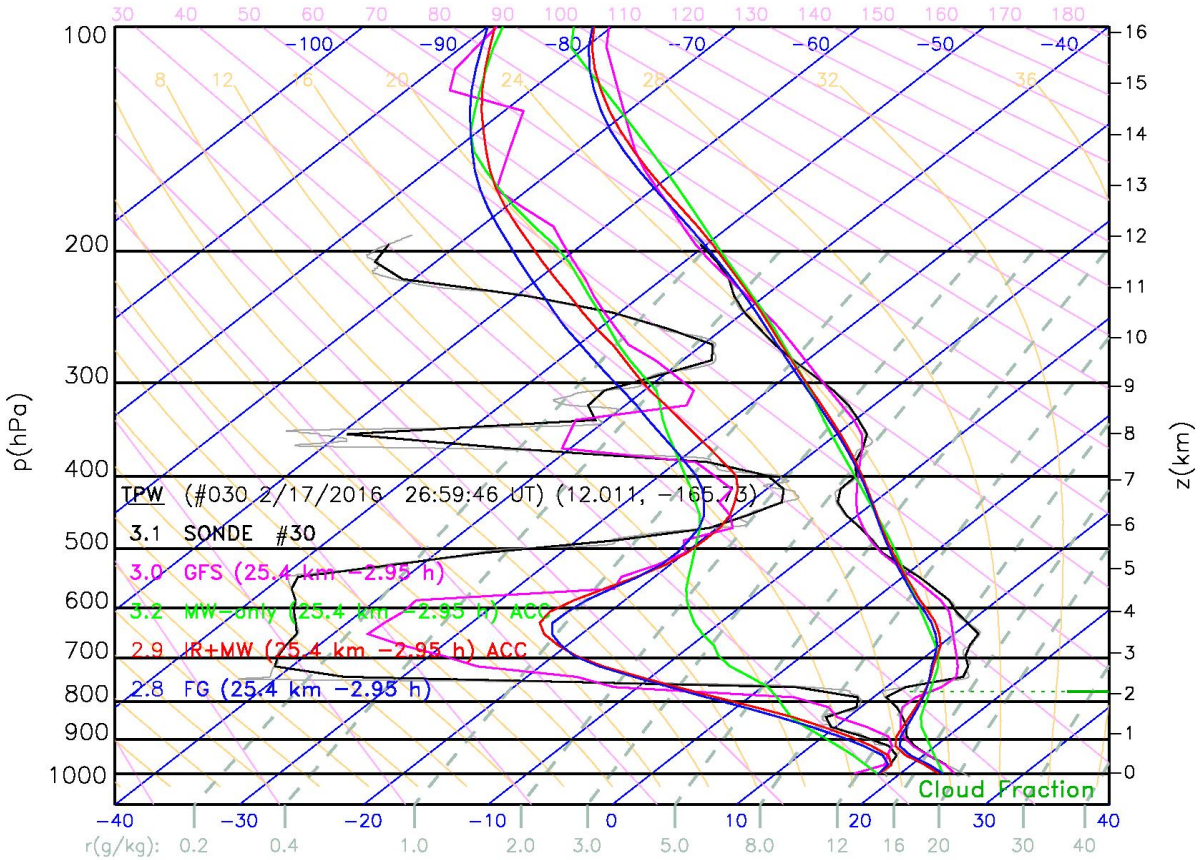
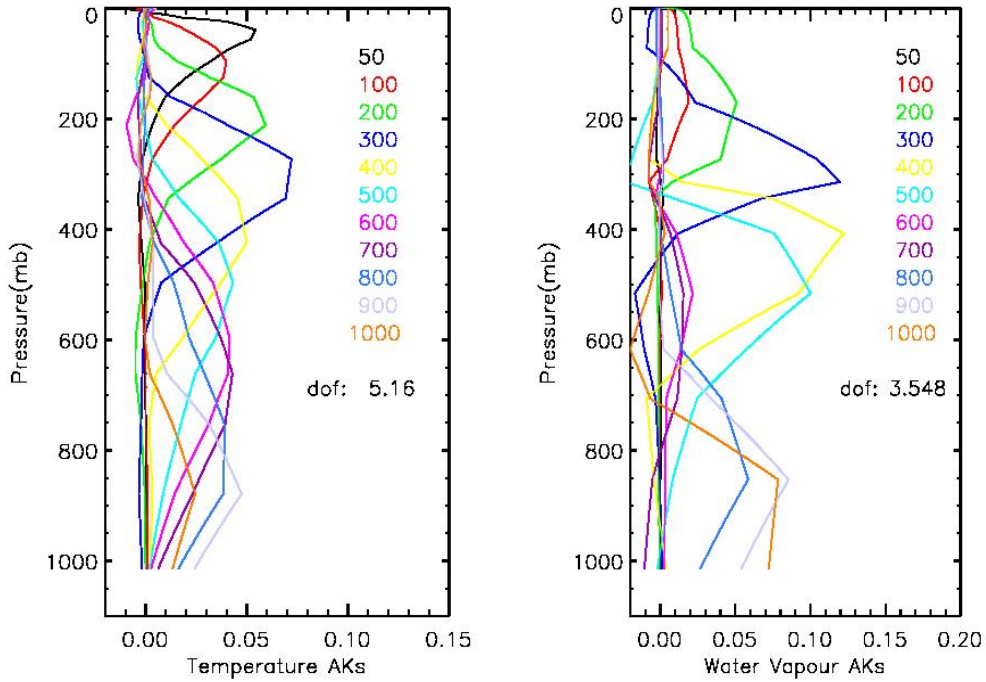
February 17, 2016:
a detailed comparison using dropsonde no. 30





➤Averaging Kernels provide insights on NUCAPS effective vertical resolution (broadness of the peaks) and information content (magnitude of the peaks)

➤ We are building a diagnostic capability to assess NUCAPS performance under high impact weather events. This will serve to make improvements on the algorithm and ultimately enable a more intelligent use of NUCAPS products.

Courtesy of Antonia Gambacorta, Chris Barnet
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