# Atmospheric Rivers in Reanalysis products:
# A six-event comparison with aircraft observations of water vapor transport


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## Motivation

Atmospheric water vapor transport is a critical component of the global water cycle and in precipitation formation and prediction. Atmospheric Rivers (ARs) are the primary mechanisms for transporting water vapor in the midlatitudes. ARs can generate extreme precipitation and flooding, and contribute greatly to the water supply of the Western U.S.. Reanalysis tools are used to study ARs, but relative performance of these tools in representing ARs has not been quantified. This study:

➙ Compares how observed water vapor transport in ARs relates to IWV signatures used in research and operational forecasting

➙ Quantifies the total amount of water vapor transport in ARs using observations by research aircraft Evaluate how well reanalysis products represent ARs

## Observing systems

### Research aircraft used in study

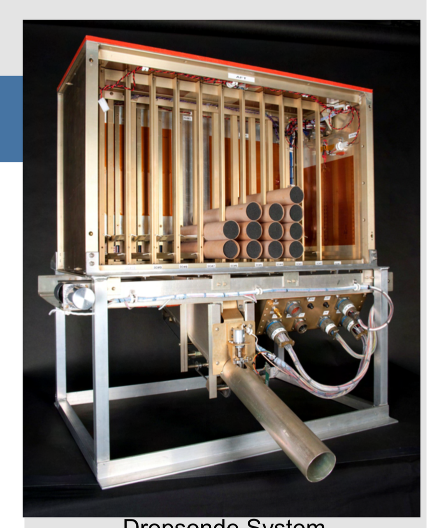
NOAA P3 aircraft (18 kft) – CALJET | NASA Global Hawk unmanned aircraft (60 kft) – WISPAR | NOAA G-IV aircraft (43 kft) – Ghost Nets/Hawaii–AR

### Summary table of the 6 flights

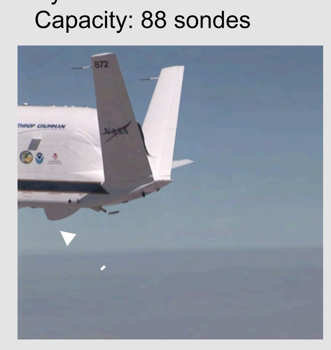
| Flight dates | Lat/Lon Range | Number of sondes | Experiment |
|---|---|---|---|
| 25-26 Jan 1998* | 33-37 N, 124-135 W | 10 | CALJET* |
| 25-26 Mar 2005** | 22-31 N, 151-161 W | 20 | Ghost Nets – HI/AR** |
| 11-12 Feb 2011 | 25-32 N, 142-151 W | 15 | WISPAR |
| 3-4 Mar 2011 | 17-29 N, 157-170 W | 17 | WISPAR |
| 3-4 Mar 2011 | 38-44 N, 128-139 W | 15 | WISPAR |
| 9-10 Mar 2011 | 35-45 N, 127-134 W | 19 | WISPAR |

*See case study by Ralph et al. (2004); California Landfalling Jets experiment (CALJET)

**See case study by Ralph et al. (2011); Ghost Nets – Hawaii Atmospheric River project



Dropsonde System designed and built by NCAR for NOAA to use on the NASA Global Hawk Unmanned Aircraft System.
Capacity: 88 sondes



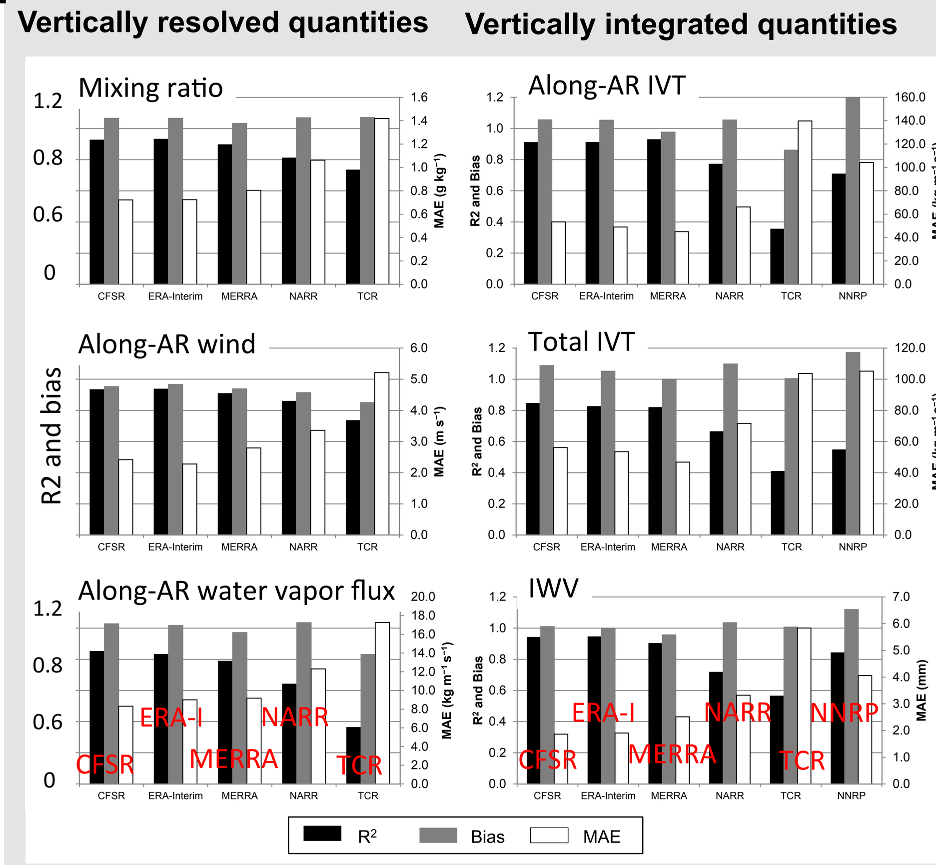
### Winter Storms and Pacific Atmospheric Rivers campaign

- The primary objective of the NOAA-led Winter Storms and Pacific Atmospheric Rivers (WISPAR) campaign was to demonstrate applications of the dropsonde system, developed for NOAA and NCAR for deployment on the NASA Global Hawk unmanned aircraft.
- The Global Hawk made 3 flights totaling ~70 h in Feb–Mar 2011 deploying a total of 177 dropsondes from ~60,000 ft altitude into ARs, winter storms, and the remote Arctic atmosphere.
- The AVAPS (Airborne Vertical Atmospheric Profiling System) dropsonde system provide high-resolution *in situ* thermodynamic & wind data (i.e., temperature, pressure, relative humidity, wind speed, and wind direction) from the lower stratosphere to the sea surface.

## Overarching results

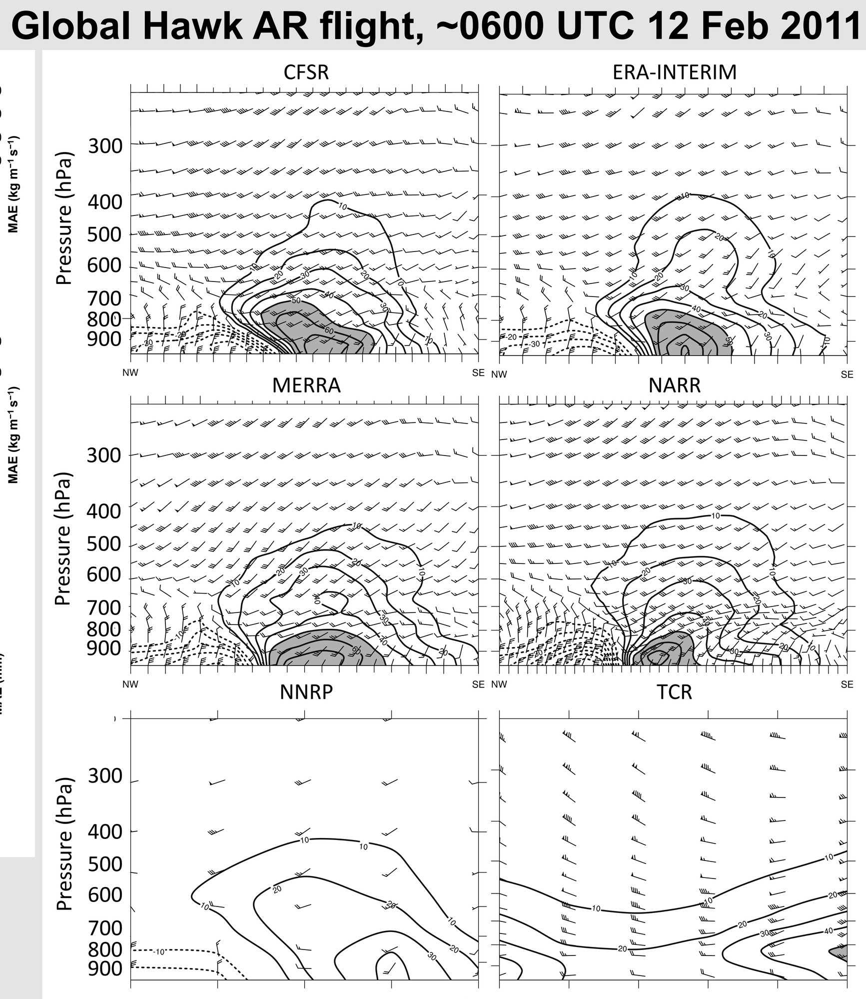
- **WISPAR demonstrated that the Global Hawk, using a dropsonde system for the first time, could uniquely sample Pacific ARs**
- **The width of 6 ARs averaged 670 km**
- **IVT-based widths are more robust than IWV-based**
- **Total water vapor transport in the 6 ARs averaged 284 x10⁶ kg s⁻¹**
    - Equivalent to 17 times the average discharge of the Mississippi River
- **CFSR, MERRA and ERA-Interim reanalysis are better suited to AR studies than NNRP, TCR, or NARR - based on several key AR characteristics**
    - Total water vapor transport in the best-three reanalyses were within +/- 7% of the observed transport, and within 5% of the observed width

## Evaluation of the reanalysis products




- State-of-the art reanalysis products, i.e., the CFSR, MERRA, and ERA-Interim, exhibited comparable performance in representing characteristics of ARs
- The CFSR, MERRA, and ERA-Interim performed somewhat better than NARR; significantly better than NNRP and TCR
- MAE for along-AR IVT ranged from 7 to 20%

### Global Hawk AR flight, ~0600 UTC 12 Feb 2011



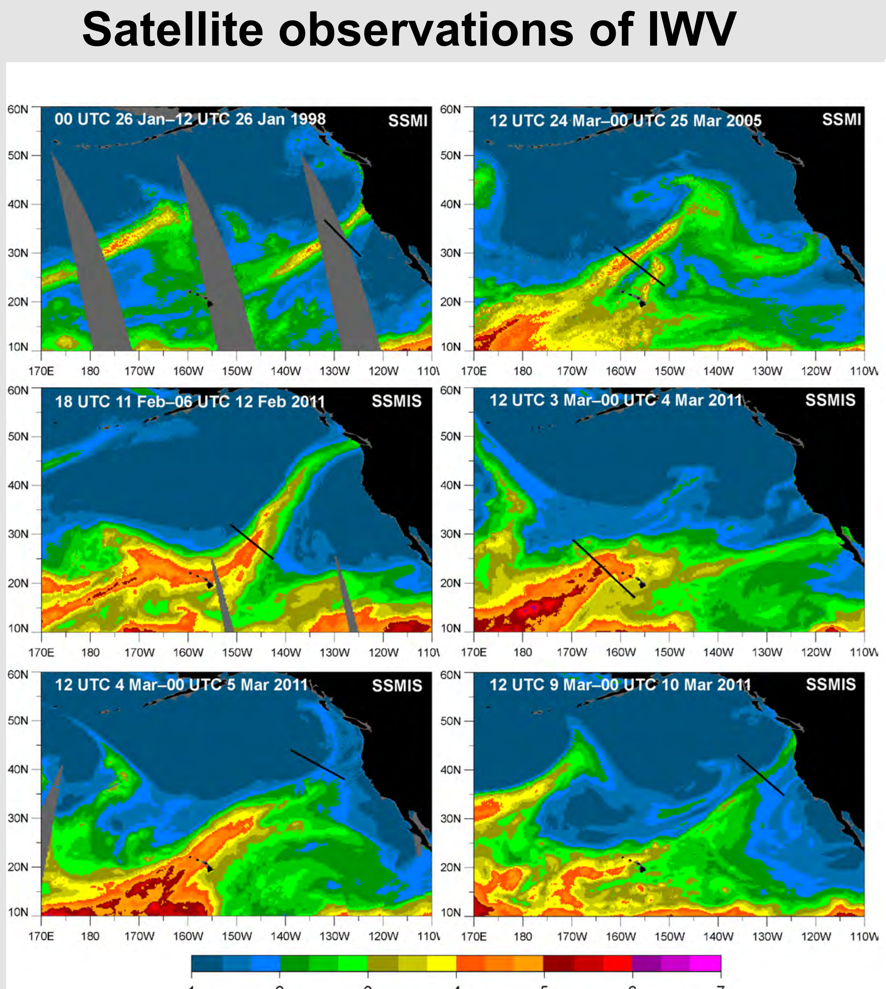

- Water vapor flux varies considerably with respect to both structure and magnitude between datasets
- CFSR displays best comparison with observations
- AR is displaced in both NARR and TCR

**Summary**:

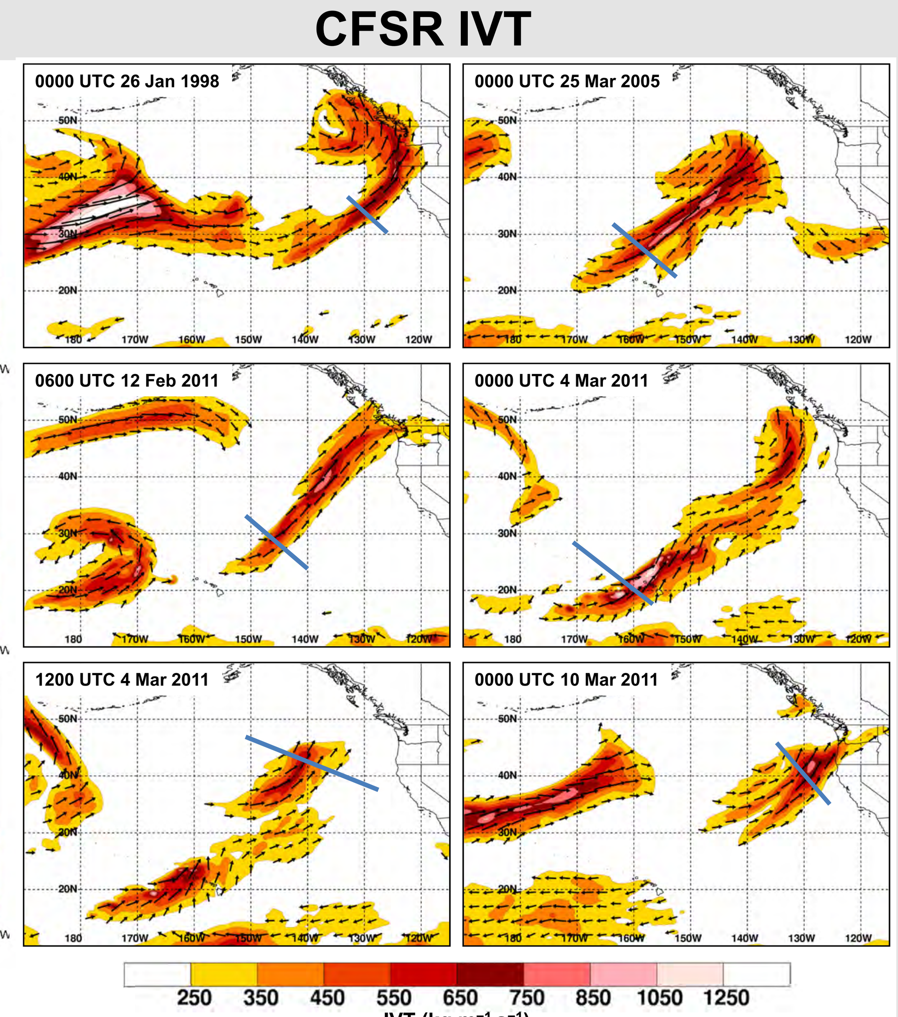
- For coarsest resolution reanalysis, i.e., the NNRP and TCR, AR width and total transport averaged 25% too large.
- Other reanalysis products were within +/- 7% for width & total transport, except for NARR, which was 10% too wide.

## Observations of the six atmospheric rivers

### Satellite observations of IWV



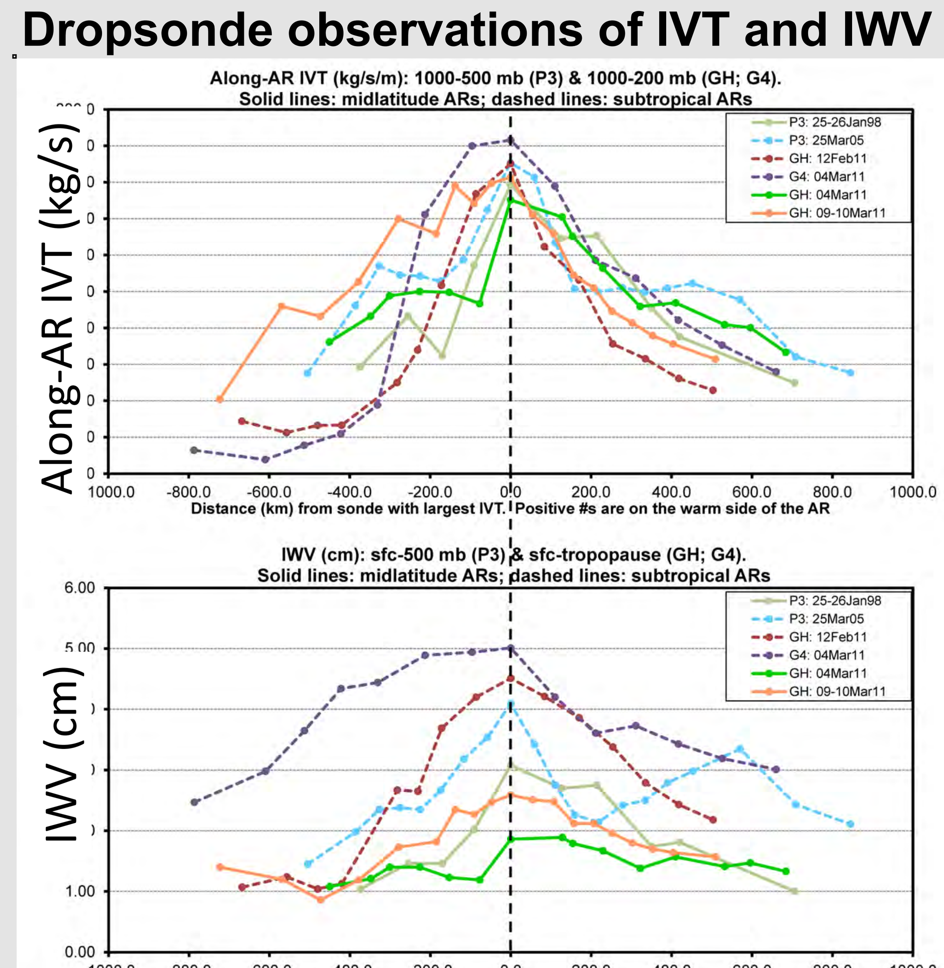

### CFSR IVT



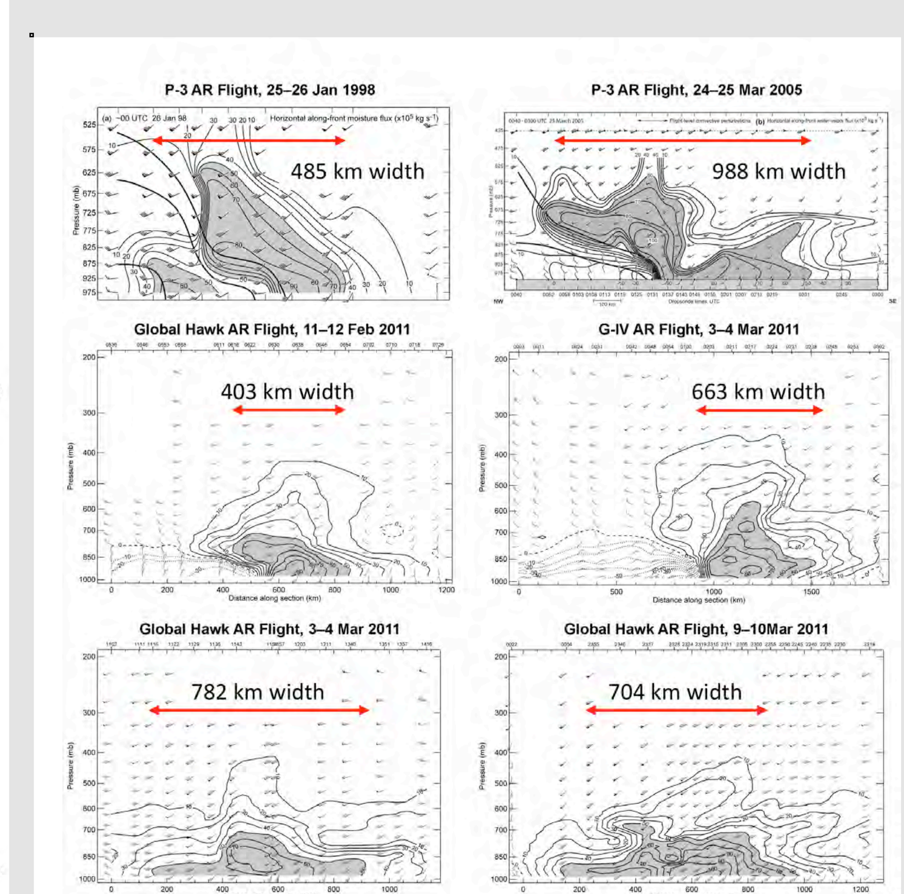

### Integrated water vapor (IWV) and integrated water vapor transport (IVT) characteristics of each transect

- IVT provides a more robust representation of ARs than does IWV.
- Midlatitude cases: IWV >2cm in long and narrow regions was a reasonable proxy for AR conditions based on IVT, although the IVT-based width was wider than the IWV-based width. Subtropical cases: IWV threshold did not suitably represent AR conditions because of large background values of IWV
- Threshold of IVT>250 kg m$^{-1}$ s$^{-1}$ was identified as useful in defining the boundaries of ARs.
- For IVT >250 kg m$^{-1}$ s$^{-1}$, observed AR widths ranged from roughly 400 to 1000 km
- Total water vapor transport: 186x10⁶ – 369x10⁶ kg s$^{-1}$ (~11–22 times the average discharge of the Mississippi River into Gulf of Mexico).
- **While availability of IWV from satellite observations has made IWV a valuable proxy for defining ARs, observations of IVT, e.g., using aircraft – as in this study, would be much more useful in clearly defining the size and strength of ARs as they approach the U.S. West Coast.**

### Dropsonde observations of IVT and IWV




### Cross sections from dropsonde observations




- The altitude of maximum along-front water vapor transport was primarily below 850 hPa
- Large values of along-front water vapor transport (i.e., >50 kg m$^{-1}$ s$^{-1}$) were primarily below 600 hPa
- Subtropical cross sections feature a prominent couplet of negative (southwestward) and positive (northeastward) along-front flux, with positive flux sloping poleward
- Uniformly positive along-front flux in midlatitude cross sections.
- Midlatitude cases: strong frontal dynamics and strong winds but scant water vapor content
- Subtropical cases: weak frontal dynamics and weak winds with large water vapor content
- Individual cases varied substantially in vertical structure

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