Use of Airborne GPS RO observations to Investigate the Dynamics of an Extra-tropical Cyclone in a Data Assimilation study of an Atmospheric River

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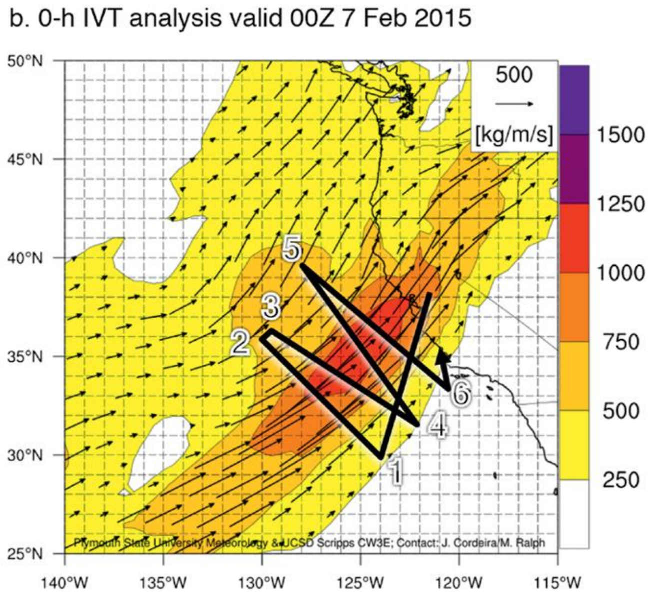
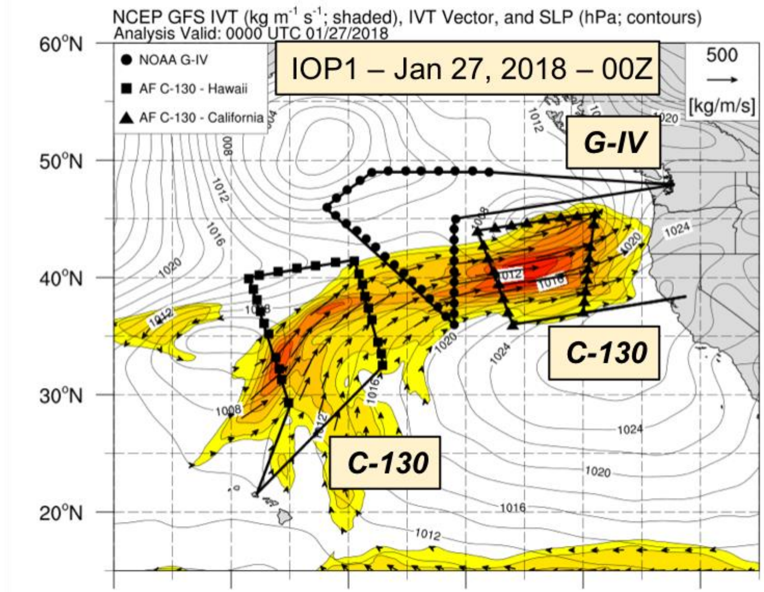
SCRIPPS INSTITUTION OF OCEANOGRAPHY

UC San Diego

NSF NOAA CW3E

Data assimilation / Upper level dynamics

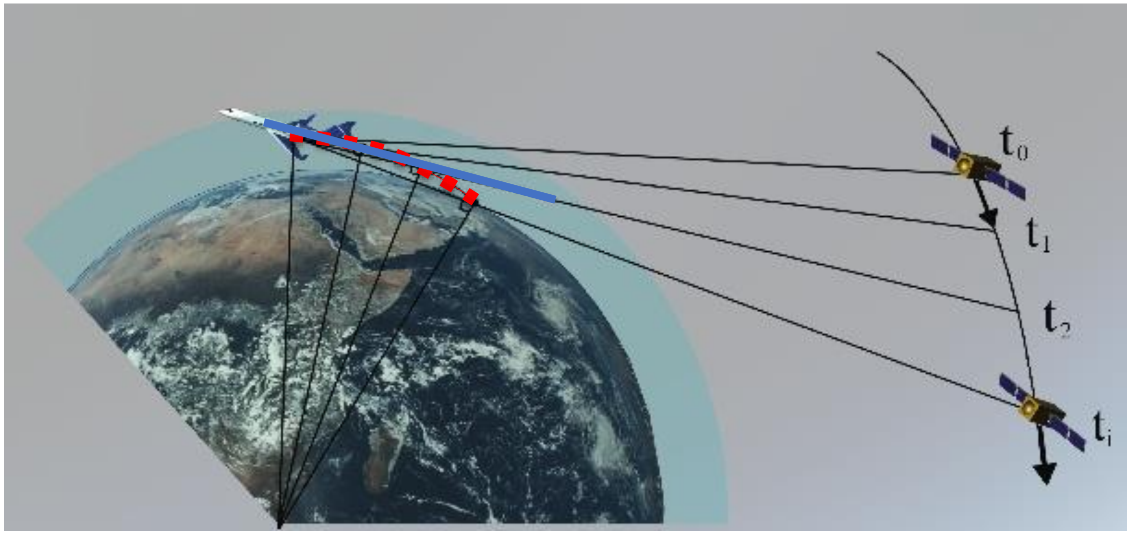




- Calwater 2015: Improve upstream vertical distribution of water vapor
  - Sampled the mid/low level moisture with high vertical resolution prior to landfall
  - uses GISMOS receiver – high sample rate signal recorder samples lower in the atmosphere
- Development and testing of data assimilation method for radio occultation
- Experiments compared spaceborne GPS RO, dropsondes, conventional observations

- AR 2018: Improve the upper level temperature structure in the cold sector
  - Targeted sampling based on sensitivity of precipitation to potential vorticity
  - Uses ROC2 receiver – simpler to operate, uses phase tracking, does not penetrate as low
- Improve ARO data analysis and verification
- Comparison with distribution and resolution of dropsonde observations

Airborne radio occultation (ARO)



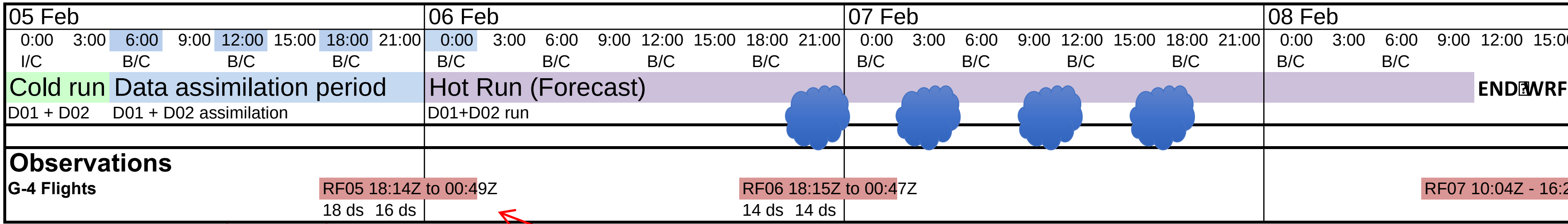
- The delay of the GPS signal from a setting GPS satellite is observed through a Doppler shift in the carrier phase and refractive bending angle.
- Airborne Radio Occultation (ARO) provides a limb-sounding profile of refractivity, *N*, using the same technique as COSMIC satellites

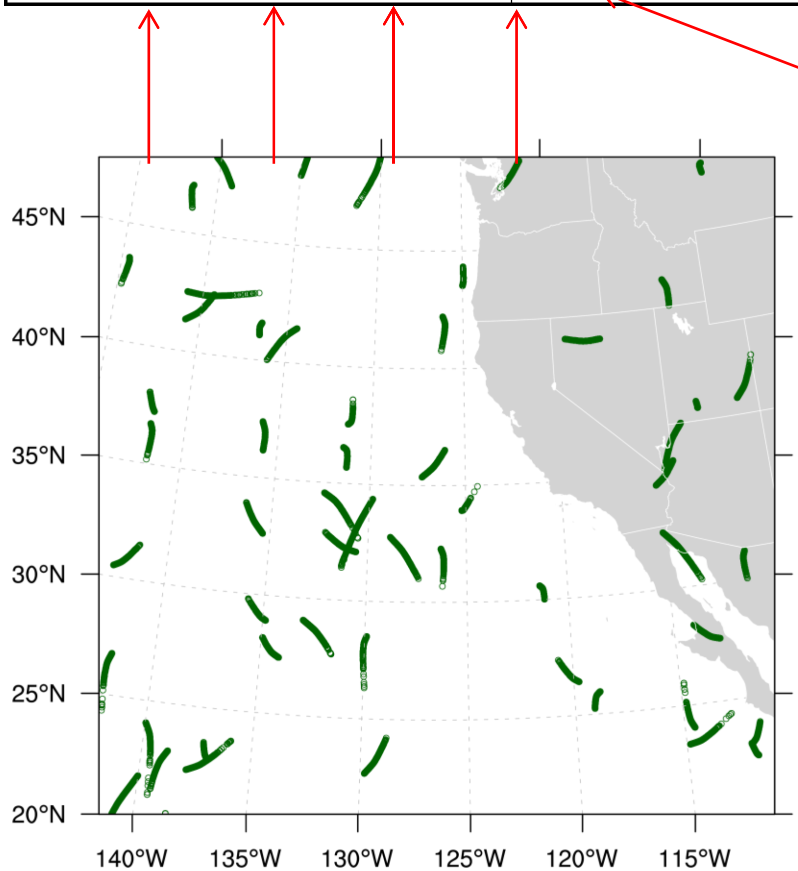
$$N = (n - 1) \times 10^6 = k_1 \frac{P}{T} + k_2' \frac{e}{T^2}$$

Haase et al, 2014, GRL

Data assimilation experiments with COSMIC and field obs

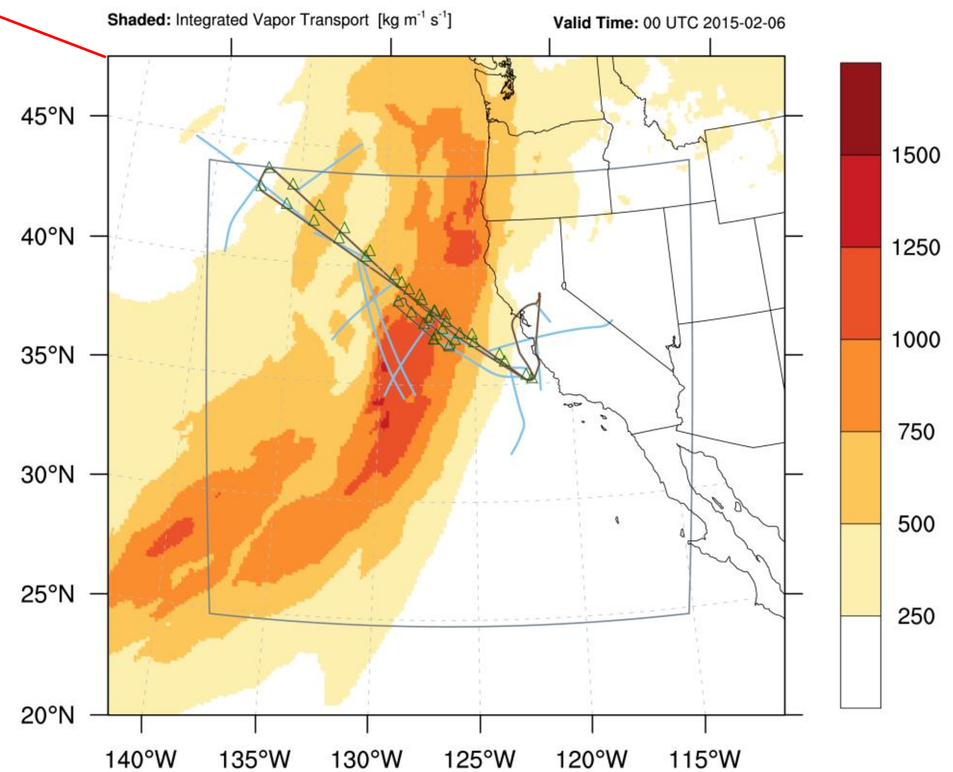
WRF-ARW WRFDA 3.7.1.1 3DVAR





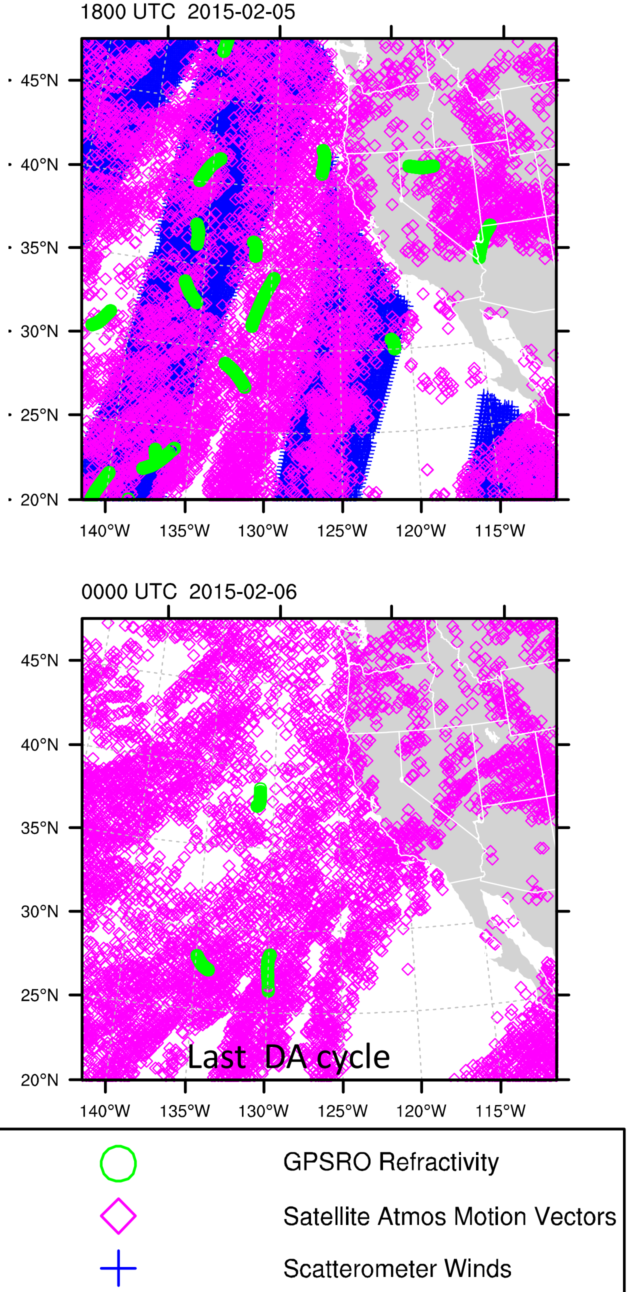
COSMIC

Calwater 2015 Research Flight 05 Feb 2015

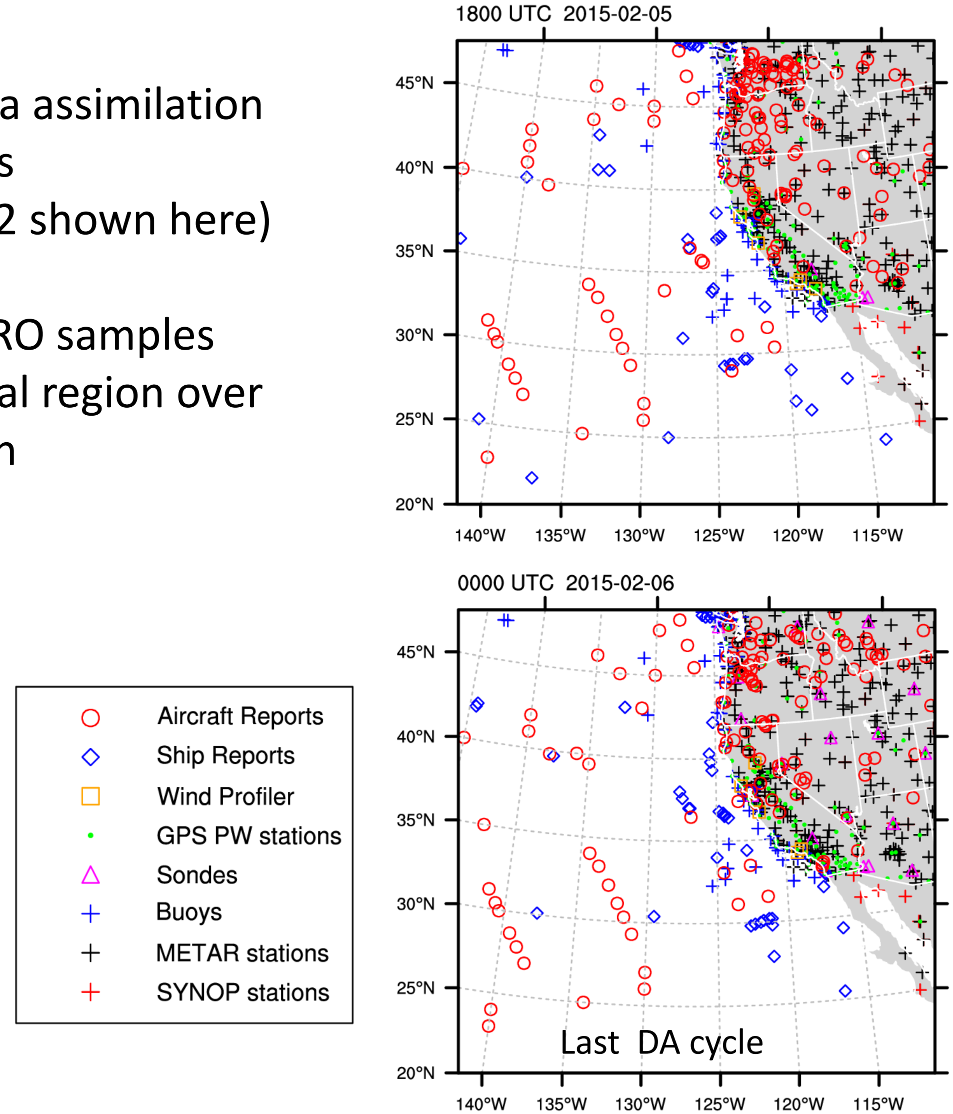


Dropsondes

Satellite Obs and GPS RO



Conventional Obs

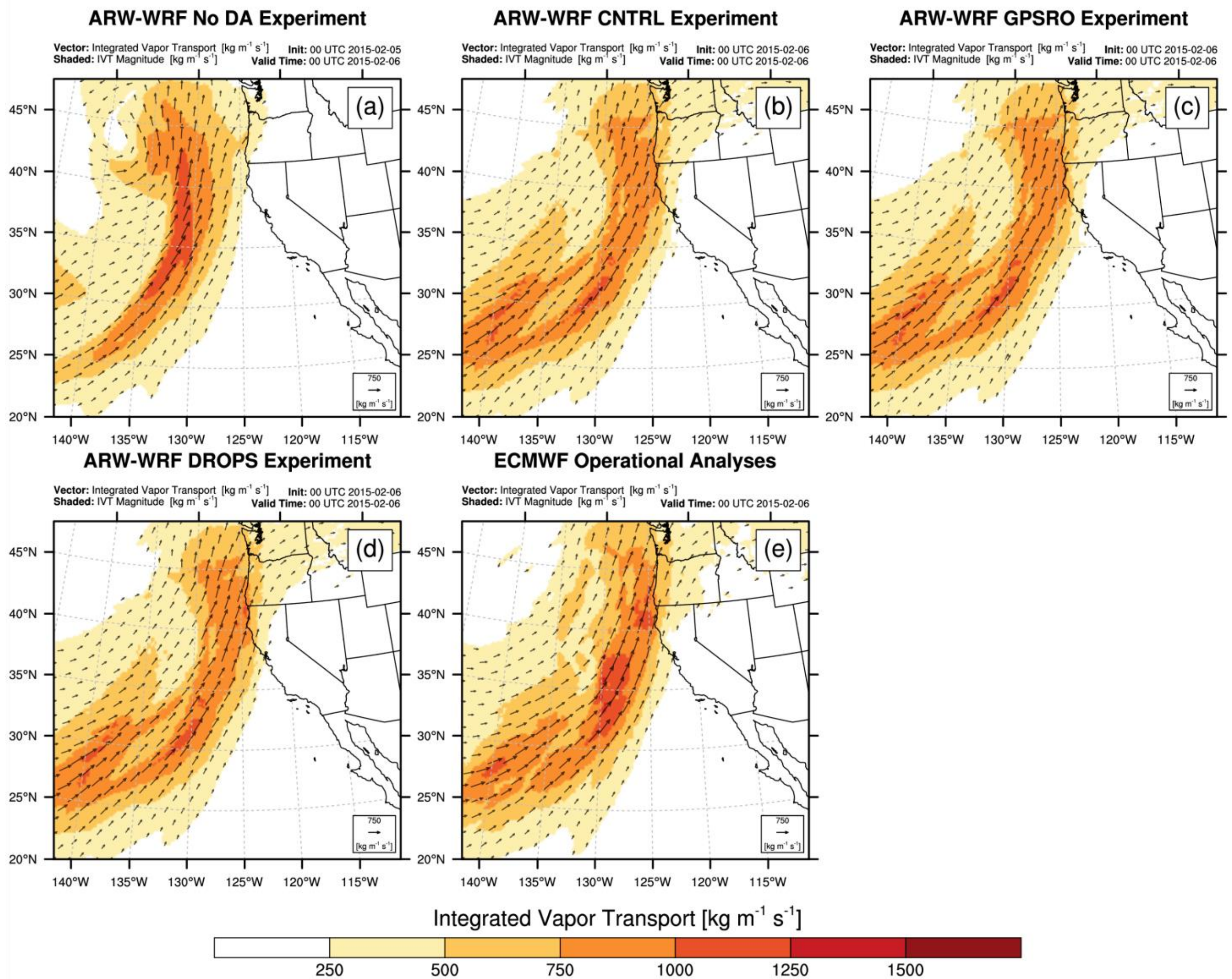


4 data assimilation cycles
(last 2 shown here)

GPS RO samples frontal region over ocean

No Satellite Radiance Assimilated

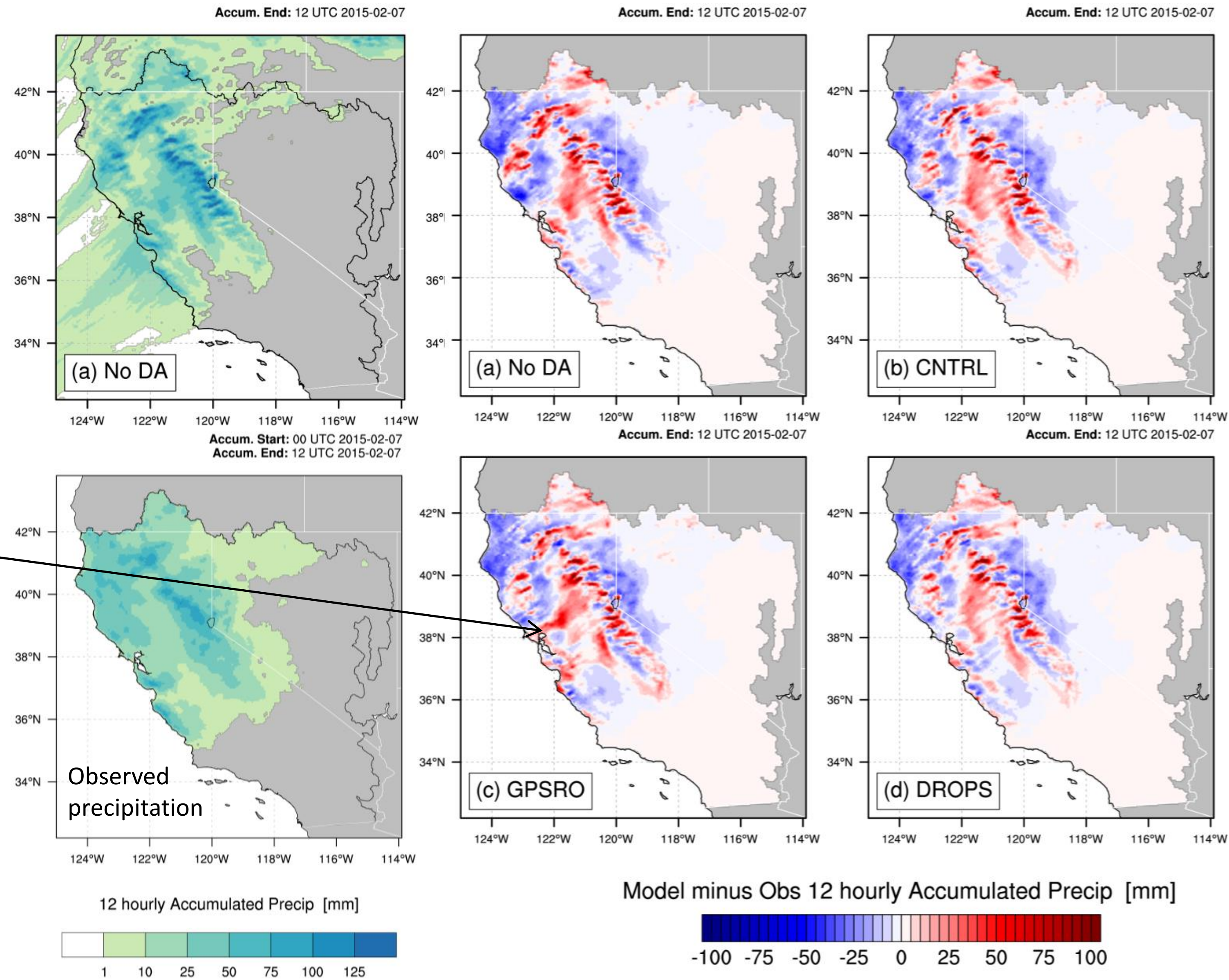
Analysis of Integrated Vapor Transport



Difference in Accumulated Precip

Accumulations from 00-12 UTC on 07 Feb 2015

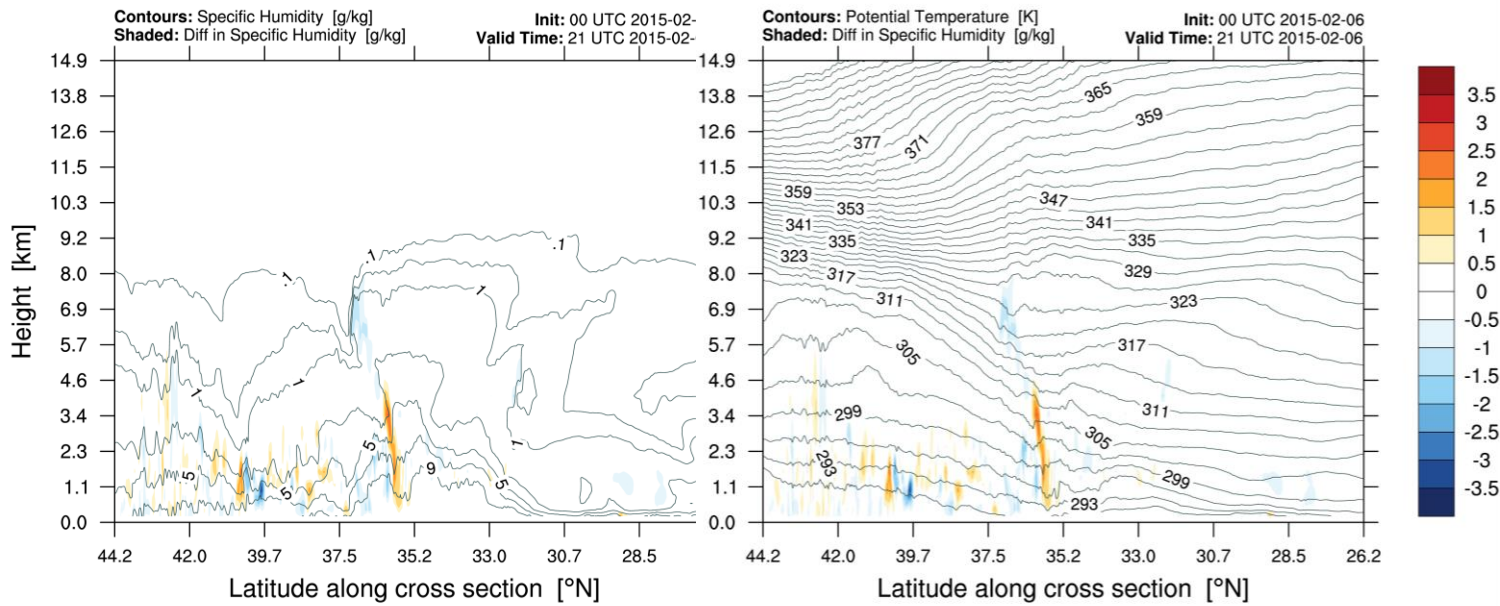
GPSRO and DROP experiments had small but noticeably different effects on the precipitation in the Central Valley / Petaluma gap



q differences at the front before landfall

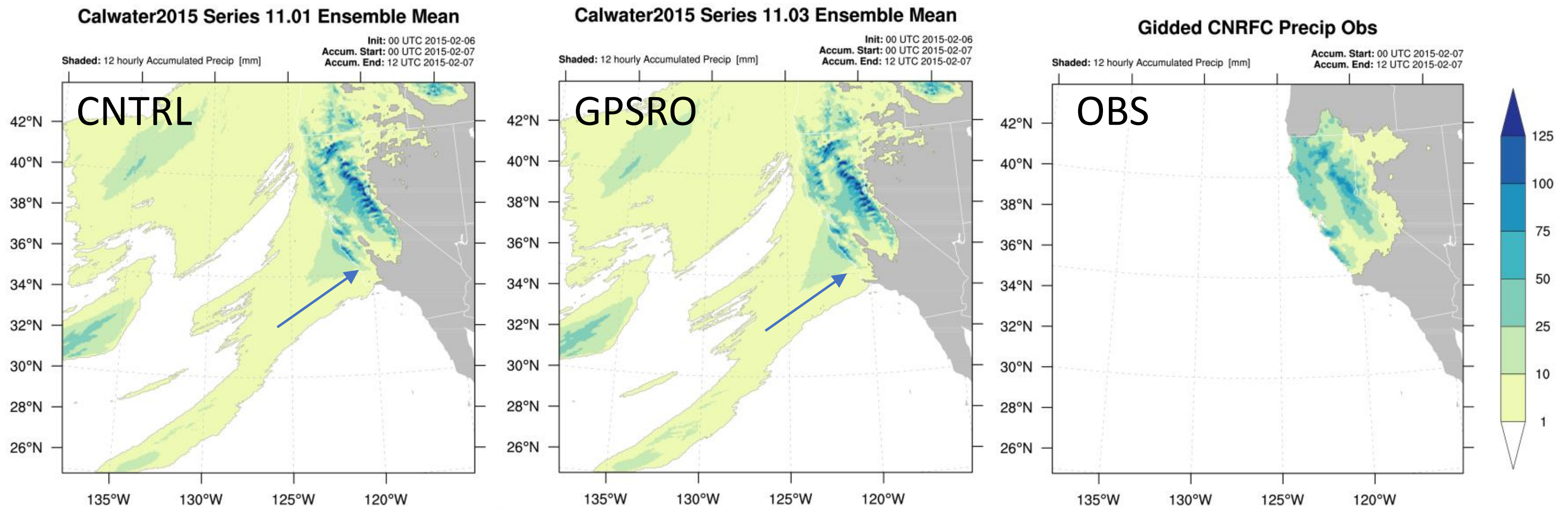
GPSRO Exp
minus
CNTRL Exp

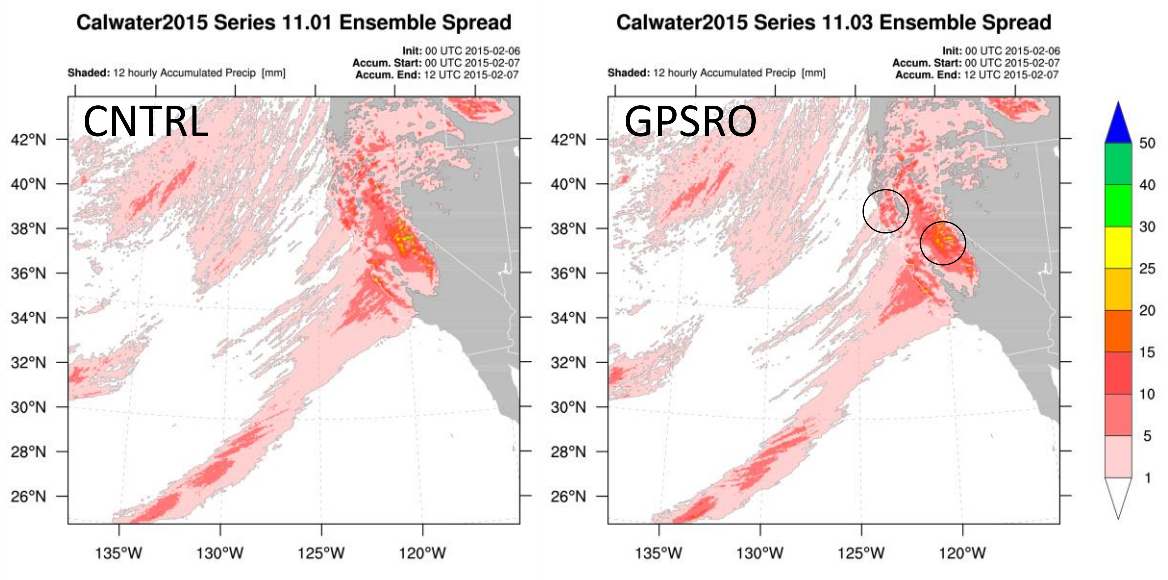
Specific humidity contours | Potential temperature contours



- Current DA experiments were conducted with local point refractivity assimilation
- Data assimilation is stable and did not produce negative impact => background fields are reliable, and high resolution provides benefit.
- Differences are concentrated at the front.
- Differences extend up to significant heights.
- The non-local refractivity assimilation has been developed which is critical for the airborne radio occultation data assimilation In strong horizontal gradients, .

Ensemble Experiments

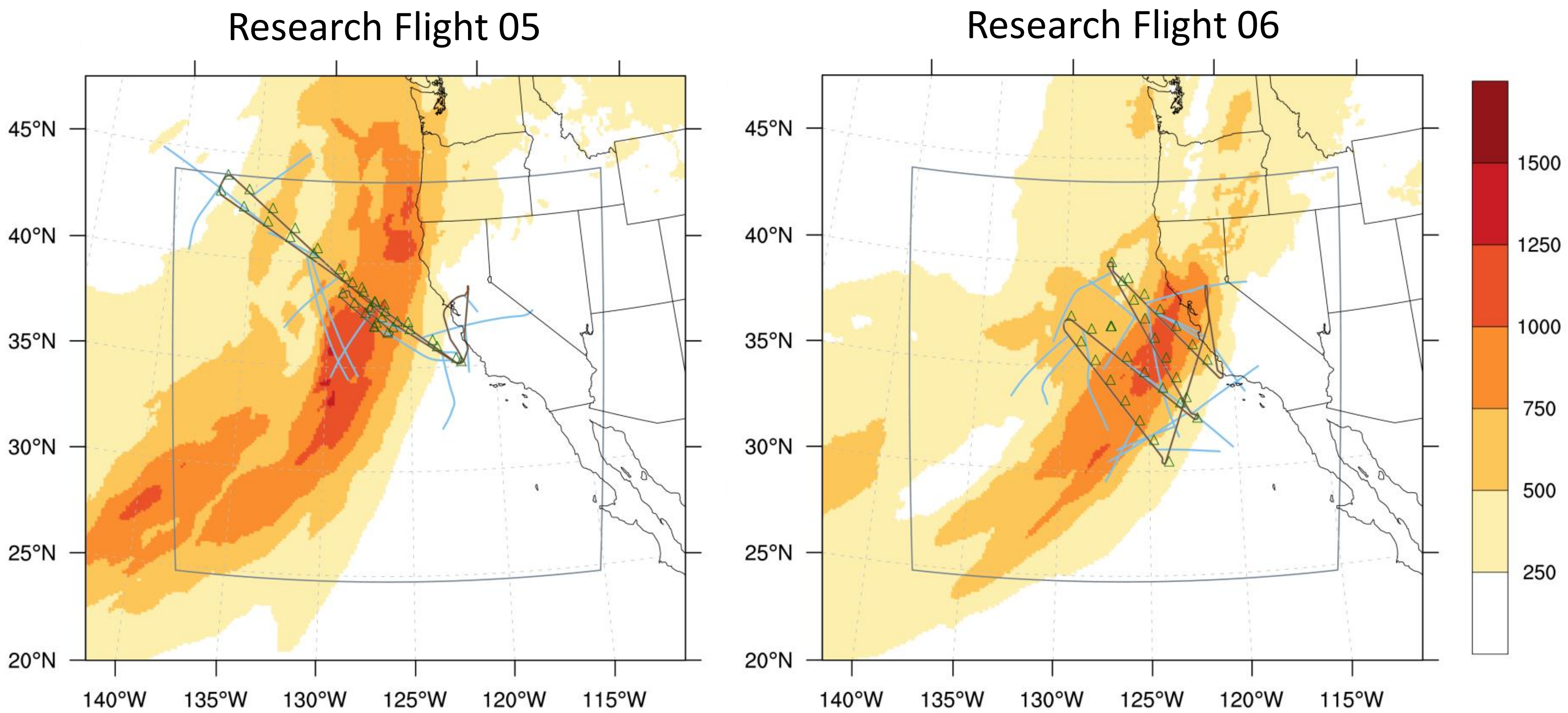




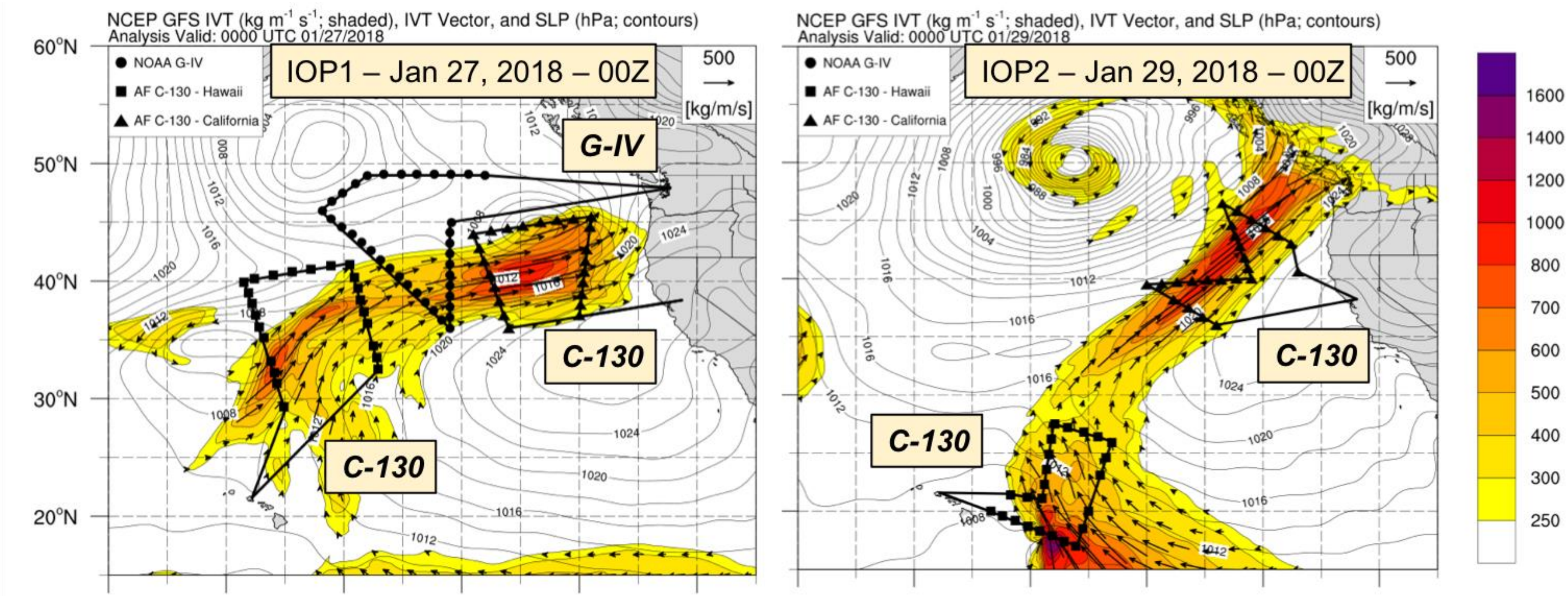
CNTRL forecast is already quite close to observed spatial distribution.
GPSRO Ensemble mean shifts southern limit of precip further south.
Ensemble spread is slightly smaller in GPSRO experiment, ie in circled areas.

Perspectives for Calwater 2015 dataset

- Excess phase DA was implemented to accommodate horizontal variability of the atmosphere in the RO observations
- We found DA of radio occultation observations produced the most significant water vapor impact in the frontal zone up to 7 km
- Denser airborne RO within the AR will have significantly greater impact, and provide additional forecast validation observations.



ARO observations focused on AR Recon IOP-1



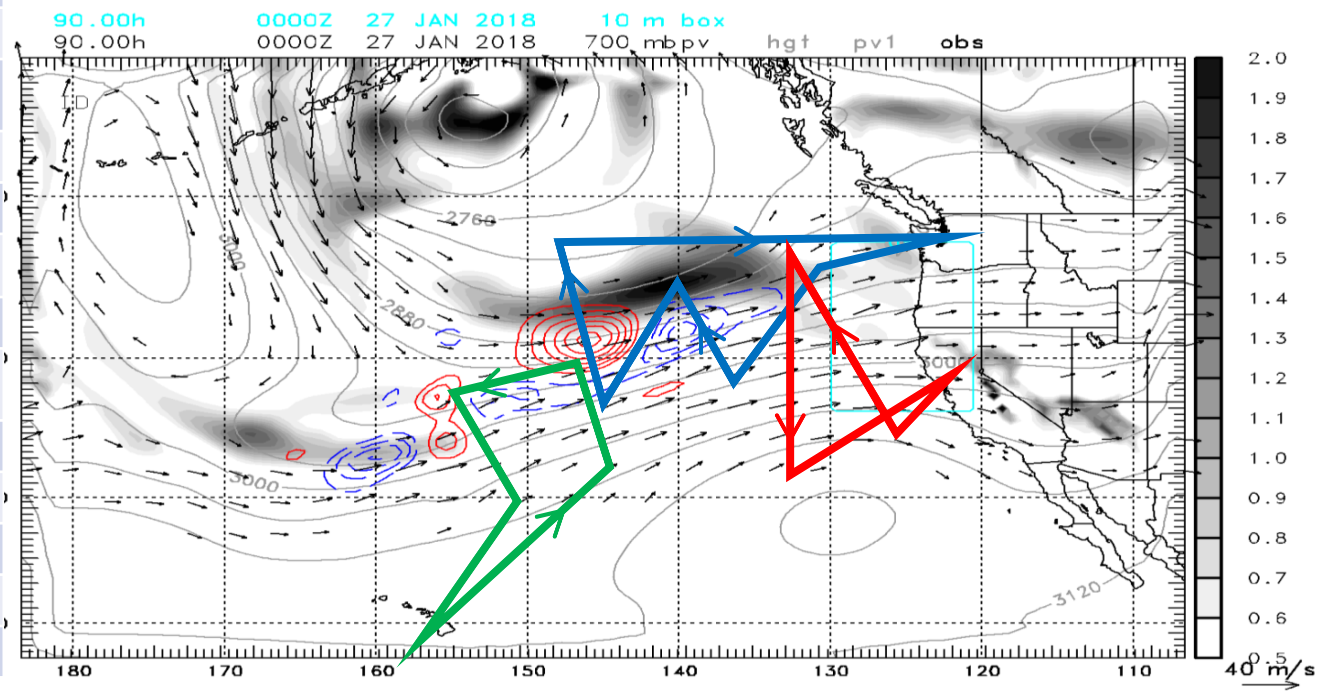
G-IV with upper level ARO observations during IOP1

No G-IV flight on IOP2, however C-130 dropsondes available for verification

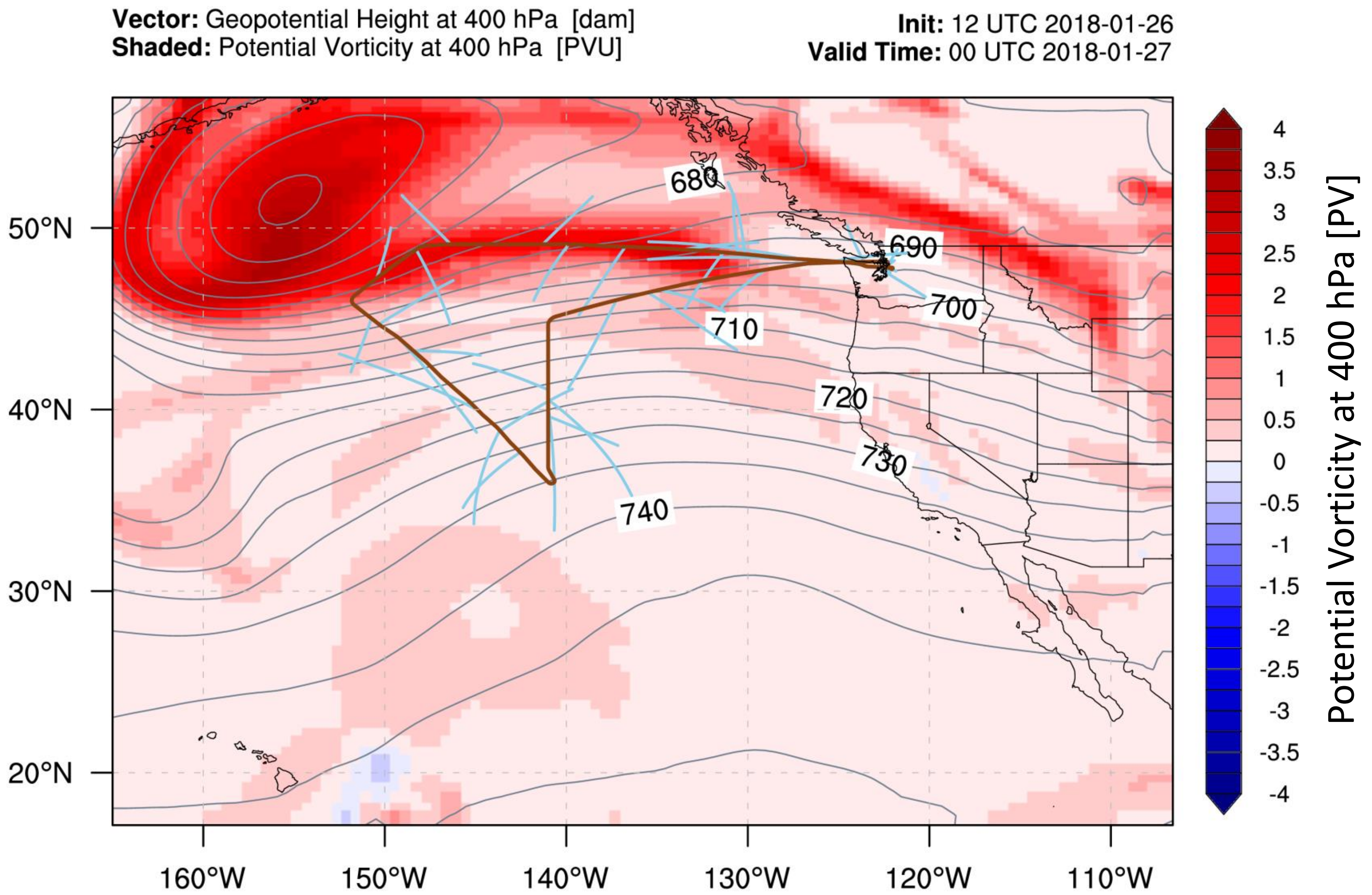
GIV flights targeted sensitive potential vorticity regions for coastal rainfall

Base	Waypoint	Lat (∘N)	Long (∘W)
C-130: Travis AFB CA	**TO: 1800**	**38.22**	**121.94**
	1A	35.0	125.5
	1B	47.0	133.0
	1C	32.5	132.5
C-130: Hickam AFB HI	**TO: 1715**	**21.34**	**157.95**
	2A	30.5	150.5
	2B	37.5	155.0
	2C	39.5	146.5
	2D	32.5	144.5
G-IV: Everett WA	**TO: 1800**	**47.91**	**-122.28**
	3A	46	-135
	3B	39	-137
	3C	45	-142
	3D	39	-145
	3E	48	-147

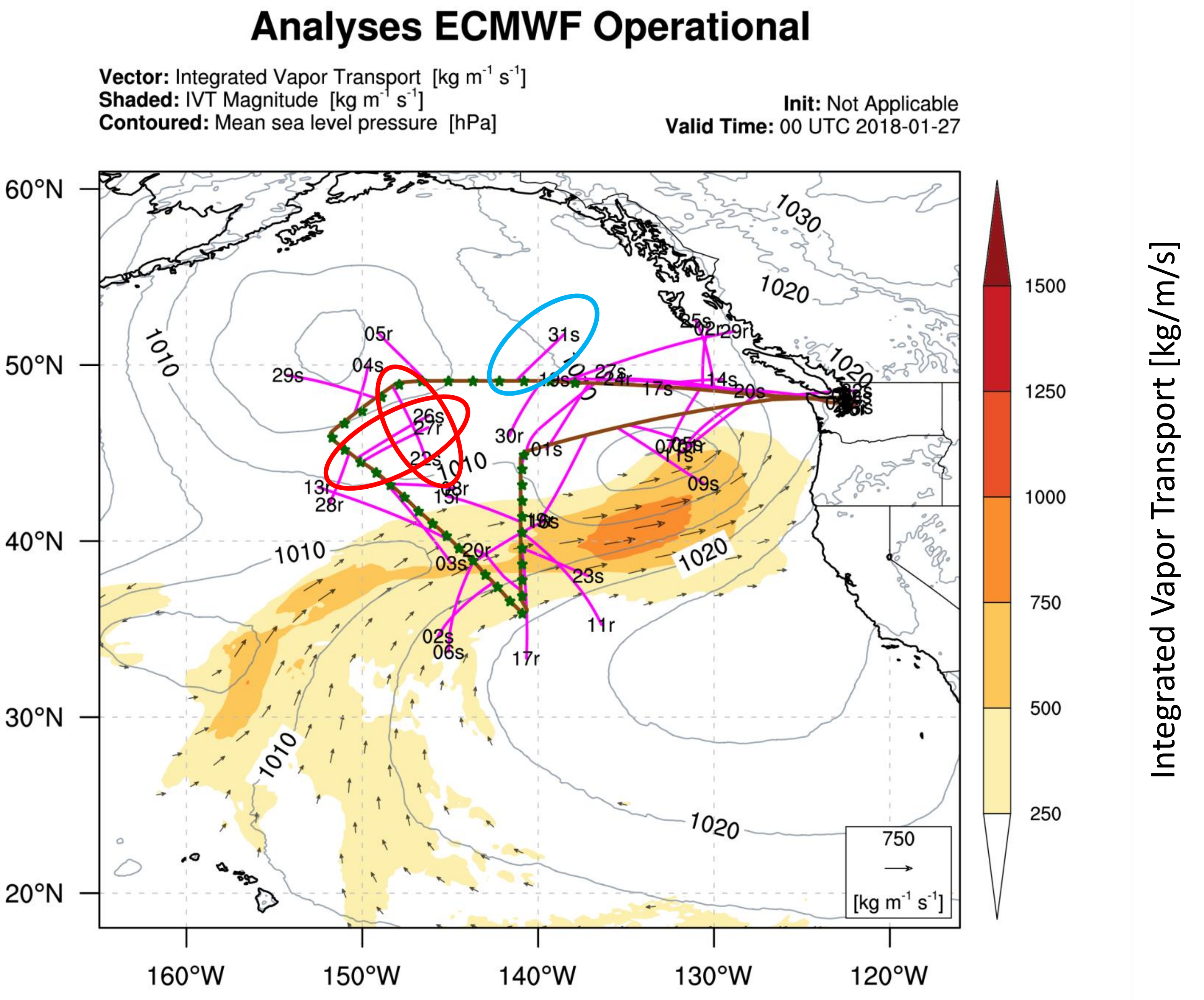
COAMPS Adjoint Sensitivity
Valid at 00Z 27 January (90h)
700 hPa PV (gray)
700 hPa Heights (gray contour) and Winds (vectors)
700 hPa PV Sensitivity (blue/red)

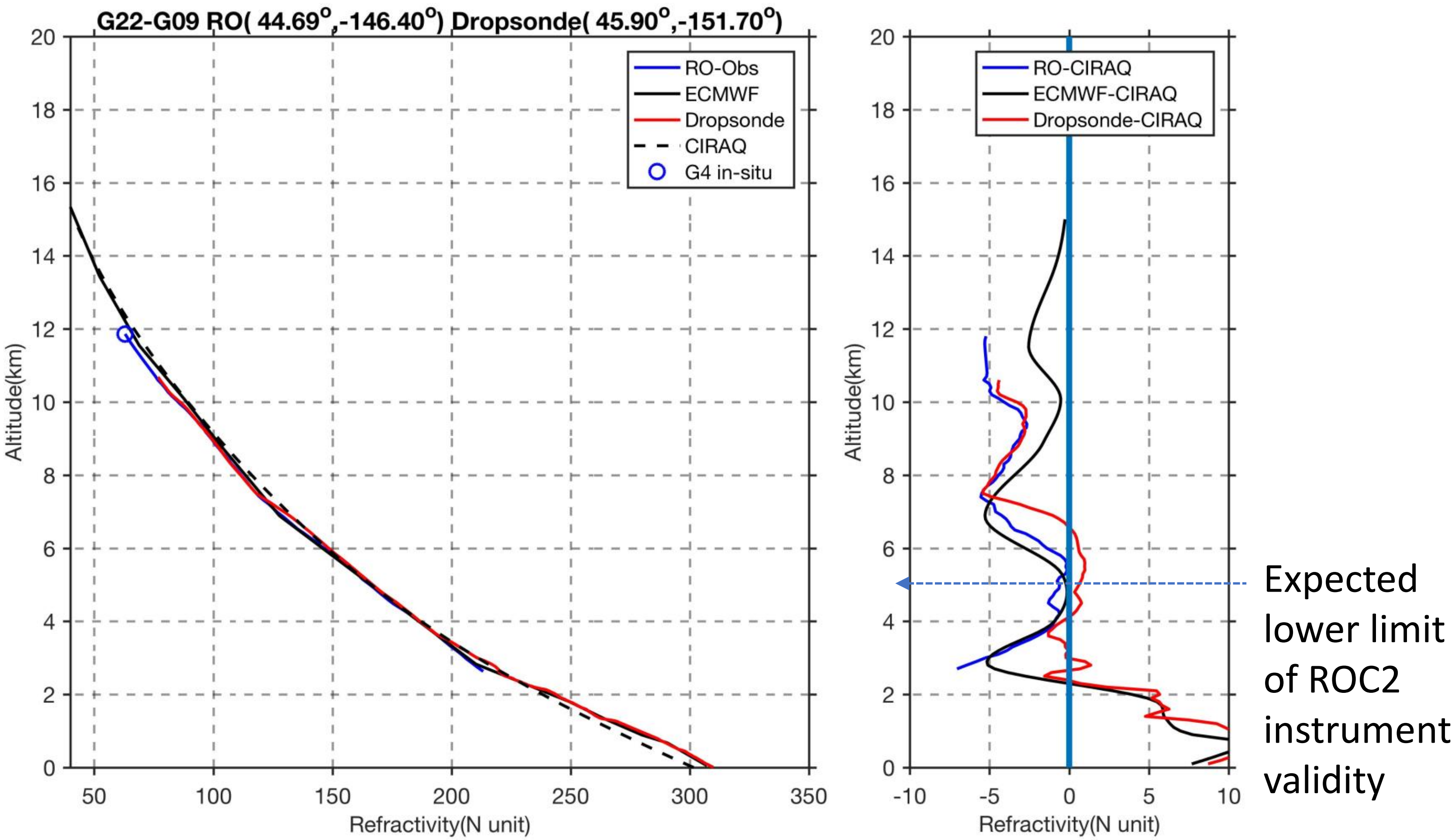


The sensitivity of the forecast 12h accumulated precipitation in the cyan box 24-36h after flight time (in this case, 00Z to 12Z 28 January) to the state of the atmosphere (PV at 700 hPa) at flight time 00Z 27 Jan based on a forecast initialized at 06Z 23 Jan.

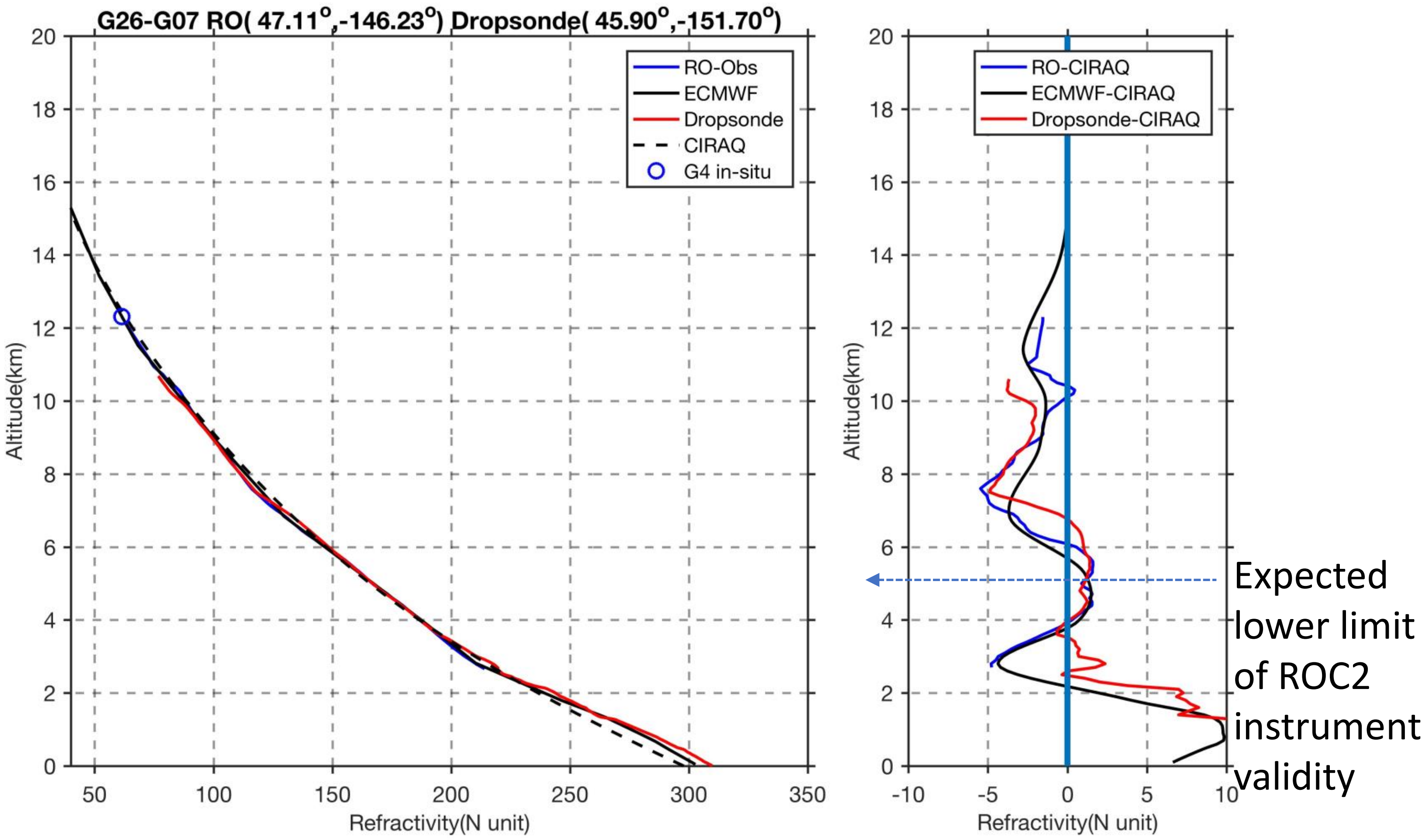


Vector: Geopotential Height at 400 hPa [dam]
Shaded: Potential Vorticity at 400 hPa [PVU]
Init: 12 UTC 2018-01-26
Valid Time: 00 UTC 2018-01-27
680
690
700
710
720
730
740
50°N
40°N
30°N
20°N
160°W
150°W
140°W
130°W
120°W
110°W
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
Potential Vorticity at 400 hPa [PV]


Analyses ECMWF Operational
Vector: Integrated Vapor Transport [kg m-1 s-1]
Shaded: IVT Magnitude [kg m-1 s-1]
Contoured: Mean sea level pressure [hPa]
Init: Not Applicable
Valid Time: 00 UTC 2018-01-27
60°N
50°N
40°N
30°N
20°N
160°W
150°W
140°W
130°W
120°W
1030
1020
1010
750
[kg m-1 s-1]
1500
1250
1000
750
500
250
Integrated Vapor Transport [kg/m/s]



- *There will be some differences due to slanting vs vertical profiles*
- ARO, ECMWF, dropsonde relative to CIRQ (Reference climatology)
- Warm sector profile comparison ARO mimics vertical structure of DS above 7 km.

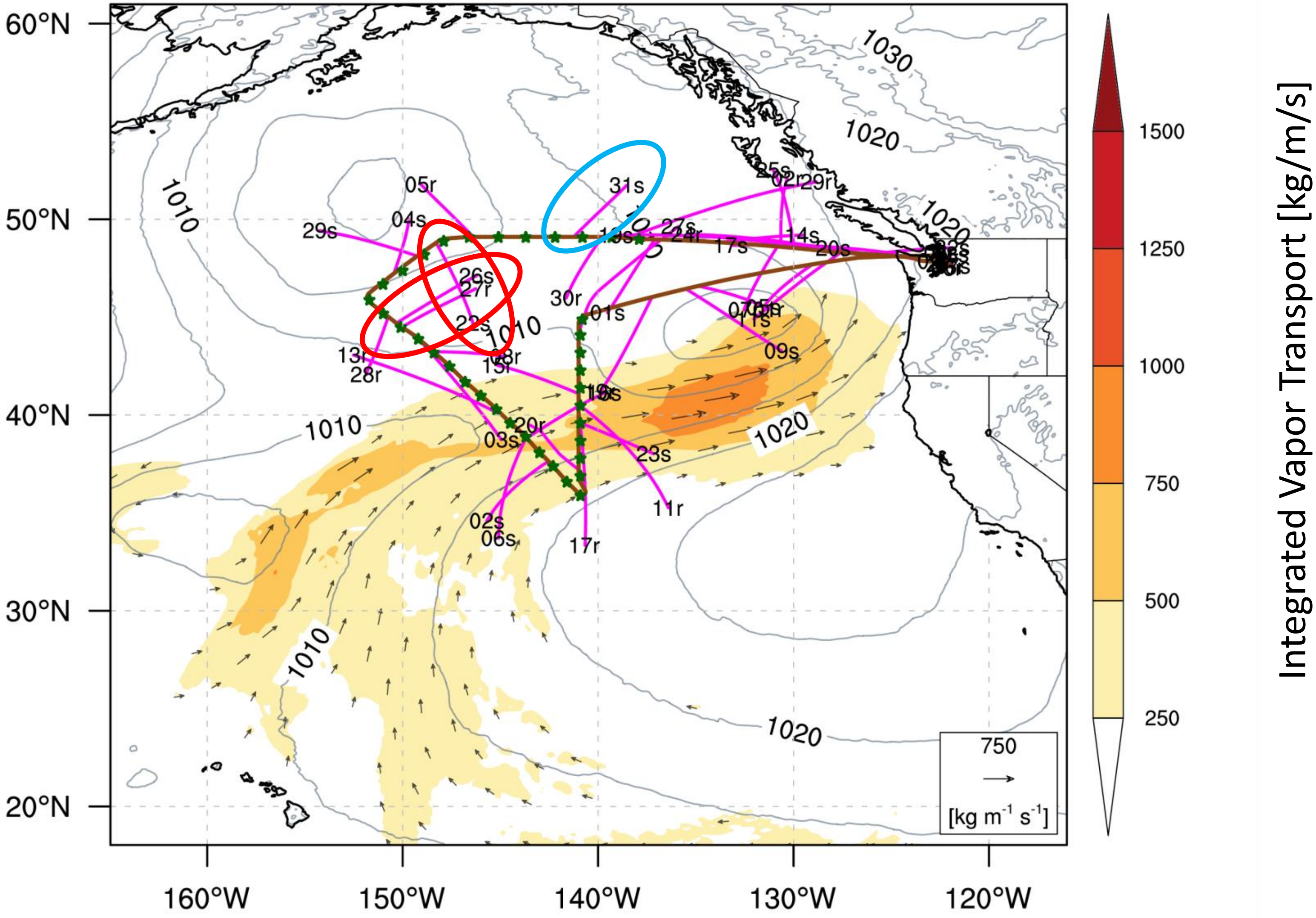


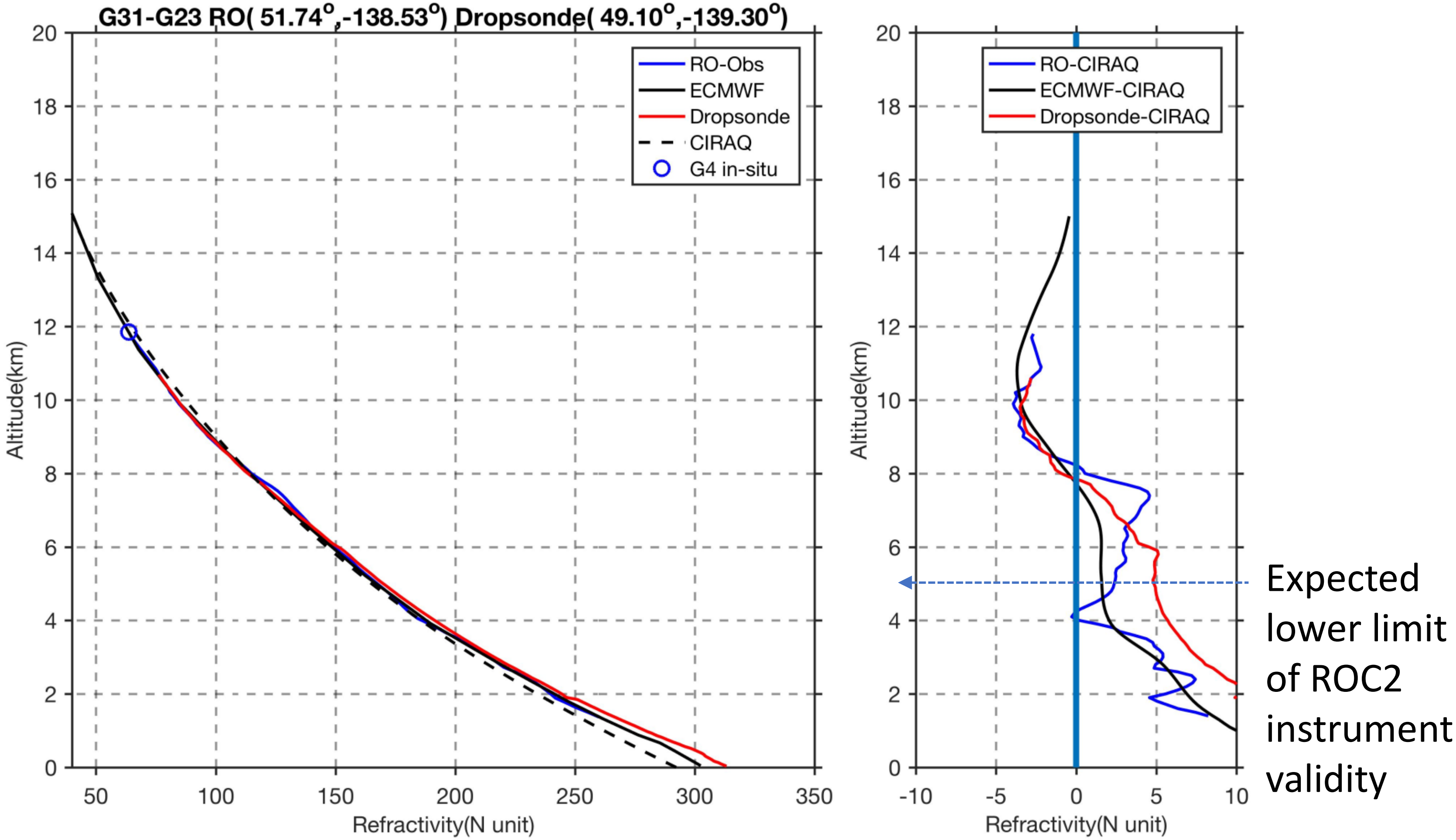
- *There will be some differences due to slanting vs vertical profiles*
- ARO, ECMWF, dropsonde relative to CIRQ (Reference climatology)
- Warm sector profile comparison ARO closer to EC in mid-levels 5-7 km

Analyses ECMWF Operational

Vector: Integrated Vapor Transport [kg m^{-1} s^{-1}]
Shaded: IVT Magnitude [kg m^{-1} s^{-1}]
Contoured: Mean sea level pressure [hPa]

Init: Not Applicable
Valid Time: 00 UTC 2018-01-27





- *There will be some differences due to slanting vs vertical profiles*
- ARO, ECMWF, dropsonde relative to CIRQ (Reference climatology)
- Cold sector ARO profile vertical structure deviates significantly from DS

Perspectives for AR2018

- ARO recordings are exceptionally good for lightweight phase tracking ROC2 receiver
- Sampling is 16 GPS occultations over 7.5 hrs (as many as 9 additional European Galileo occultations)
- The lowest point on some profiles is ~1.5 km above the surface
- Unexpectedly good penetration to low levels even in the warm sector

- Further analysis must incorporate 3D geometry to understand differences in vertical structure
- Next step is incorporating ARO observations into the WRF data assimilation runs