An Assessment of AGCM Skill in Predicting Horizontal Vapor Transport in Pacific Ocean Atmosperic Rivers

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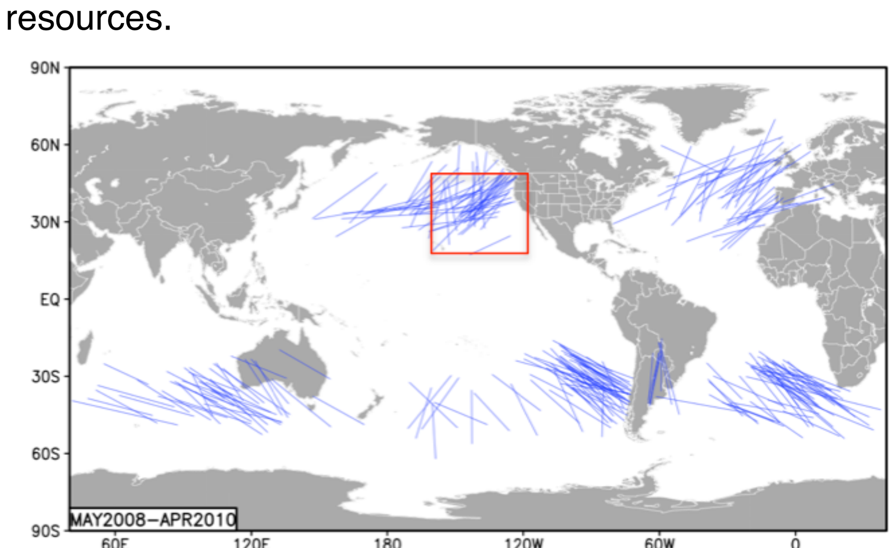
Abstract

Atmospheric rivers (AR) play a crucial role in the horizontal transport of water vapor and moist static energy in the midlatitudes and in delivering water to a variety of continental climate zones. In California, up to 60% of the annual precipitation depends on the arrival of a small number of AR. Despite their importance, state-of-the-art atmospheric circulation models are consistently poor in predicting AR location and timing. We will demonstrate that model predictions can also contain large errors in the magnitude of AR horizontal vapor transport. In this study we verify the prediction skill in horizontal water vapor transport from the Global Forecast System (GFS) and examine AR structural details in both the GFS and the ERA-Interim reanalysis. We verify model skill using dropsonde observations taken from the CalWater 2014 - 2015 field campaigns. We compare model predictions to observations across number of lead times ranging from 12 to 132 hours. Our preliminary results suggest that the Integrated Vapor Transport (IVT) and total vapor flux are often underforecast. Furthermore, the low bias in GFS forecast IVT is located consistently below the 700 hPa level. Companion investigation of thermal and moisture fields suggest that low forecasts in vapor transport arise primarily due to errors in wind speed rather than low moisture content or poor vertical moisture structures. Examination of forecast skill in mid-level geopotential height suggests that the issue of low wind speeds may be related to erros in the AR mass balance.

Atmospheric Rivers (AR)

ARs are a dynamic confluence of atmospheric moisture prevalent in the midlatitudes and can lead to extreme precipitation totals when they make landfall. They can both produce hydrological hazards and supply valuable water resources.



Above: Global plot of 259 AR identified between May 2008-April 2010. The red box denotes the theater of operations for CalWater 2. Image courtesy of Waliser et. al 2012 *Bull. Amer. Meteor. Soc.*

Some Active AR Research topics:

- Climate variability in AR Frequency and location
- **AR water vapor flux and moist stability structures**
- **AR predictability and skill in AGCM**
- Interaction between AR, MJO, TME, WCBs
- AR behavior near rapid ET cyclogenesis
- Non-warm sector AR
- Ageostrophic flows in landfalling AR

Calwater-2

NOAA-ESRL, UCSD-SIO, NASA-JPL, DOE PNNL, NRL and UC Davis have been collaborating on a multiple agency, multiple year (2014 - 2017), multiple funding source project known as CalWater 2. The participating agencies have focused air, sea and land-based in-situ measurements, along with special remote sensing and modeling capabilities on:

(1) **Atmospheric rivers** (ARs) in delivering much of the precipitation associated with major storms along the U.S. West Coast, and

(2) **Aerosols**—from local sources as well as those transported from remote continents—and their modulating effects on western U.S. precipitation.

The suite of measurements taken are designed to lend insight into physical processes and validate the simulation of these processes in weather and climate models.

Measurements and Data Sources

Airborne Facilities:

Platform	Theater of Operations	Measurements	# Sondes Released
NOAA WP-3D *Altitude < 22 kft* 	Offshore CA	**Dropsondes (P, Z, T, RH, wind)** Tail Doppler radar Microphysics (CCN, IN, cloud water/ice, precipitation spectra) Aerosols and chemical tracers	2015 (P-3 and G-IV): 444 / 18 flights
NOAA G-IV *Altitude < 45 kft* 	HI to CA	**Dropsondes (P, Z, T, RH, wind)** Tail Doppler radar Chemical tracer (ozone)	2014 (G-IV Only): 200 / 12 flights

AR Transects:

A series of dropsondes comprised a "complete" AR core transect if:

- The drops cross the narrow dimension of the AR (nearly IVT perpendicular) in one or two legs of the flight path
- The most equatorward and most poleward sonde measure IVT less than 500 kg m^{-1} s^{-1}
- The soundings between the most equatorward and most poleward sondes contain one or more IVT maxima whose value is greater than 500 kg m^{-1} s^{-1}.

15 complete transects were built from 191 Calwater 2014 and 2015 sondes using these criteria.

GFS and Reanalysis:

- GFS reforecast version 2 acquired from NOAA-ESRL (DOE) archive on 6 significant pressure levels (every 25 hPa) for 0-132 hrs forecast and u, v, T, z, specific humidity for use in skill (cross-section) analyses.
- ERA-Interim acquired from NCAR DSS on pressure levels ~ every 25 / 50 hPa
- Both were acquired for closest "valid time" to transect midpoint and interpolated to the average GPS location of each sonde using latitude-weighted bilinear interpolation.
- GFS was acquired for a range of lead times (init times vary) from 12 to 132 hours.

Analysis Methods

Dropsondes, model and reanalysis:

- QC performed in *Aspen* according to data quality flags

Dropsonde Composites:

- Seven AR Core transects were used to create composite moisture flux and horizontal wind analyses. The dropsonde with maximum IVT was used for the center location in each. Sondes were binned every 100 km poleward (equatorward) of the center thereafter. Maximum (minimum) sondes composited: 8 (3)

Displacement required for Saturation:

- Found as the vertical distance (in km) needed to lift a parcel from each GFS significant pressure level to the analyzed LCL

IWV, IVT, BSS and dIVT:

$$dIVT = -\frac{1}{g}\int_{p_0}^{p_0+\delta p} \vec{u} q_v \, dp$$

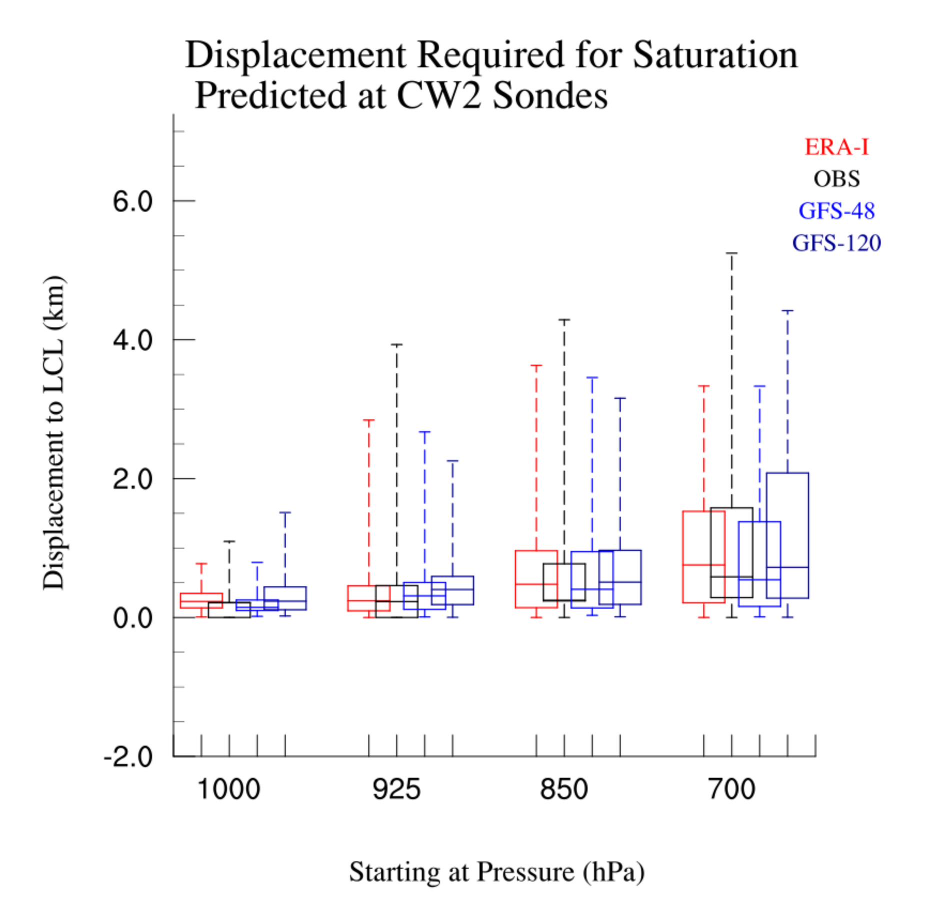
$$IVT = -\frac{1}{g}\int_{1000hPa}^{300hpa} \vec{u} q_v \, dp \qquad IWV = -\frac{1}{g}\int_{1000h}^{300hpa} q_v \, dp$$

$$BSS = \begin{cases} 1 - MSE_F MSE_R^{-1}, & MSE_F \le MSE_R \\ MSE_R MSE_F^{-1} - 1, & MSE_F > MSE_R \end{cases}$$

BSS Reference forecasts:

GFS v2 reforecast climatology 1990 - 2015 for the day of transect was used as the BSS reference forecast unless noted.

AR Core Stability and Saturation

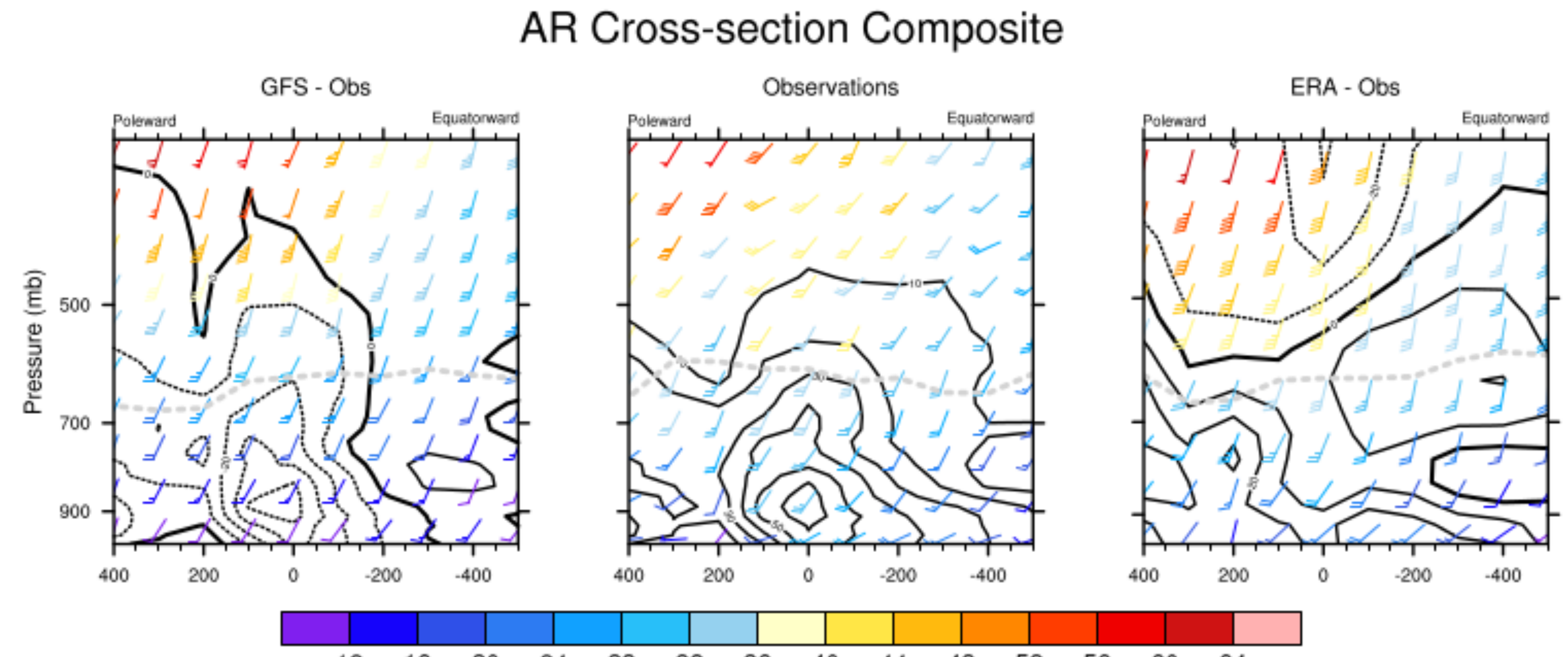


Above: Displacement needed to reach saturation (km) if vertically lifted from the given layer for: ERA-I (red-right), Sonde observations (black - second from right), GFS 48 hr forecast

Structure of AR wv Flux and Model Biases

Below center: Composite dIVT (kg m^{-1} s^{-1} - black contours), horizontal wind barbs (m-1 s-1) and level of 75% IVT (gray dashed) from 7 Calwater 2 transects. Ordinate displays distance from "AR Core". Below right: As in center, except departure of GFS 48 hr forecast dIVT from dropsondes (negative contours dashed, zero contour bold). Below left: As in right, except for ERA-I departure.

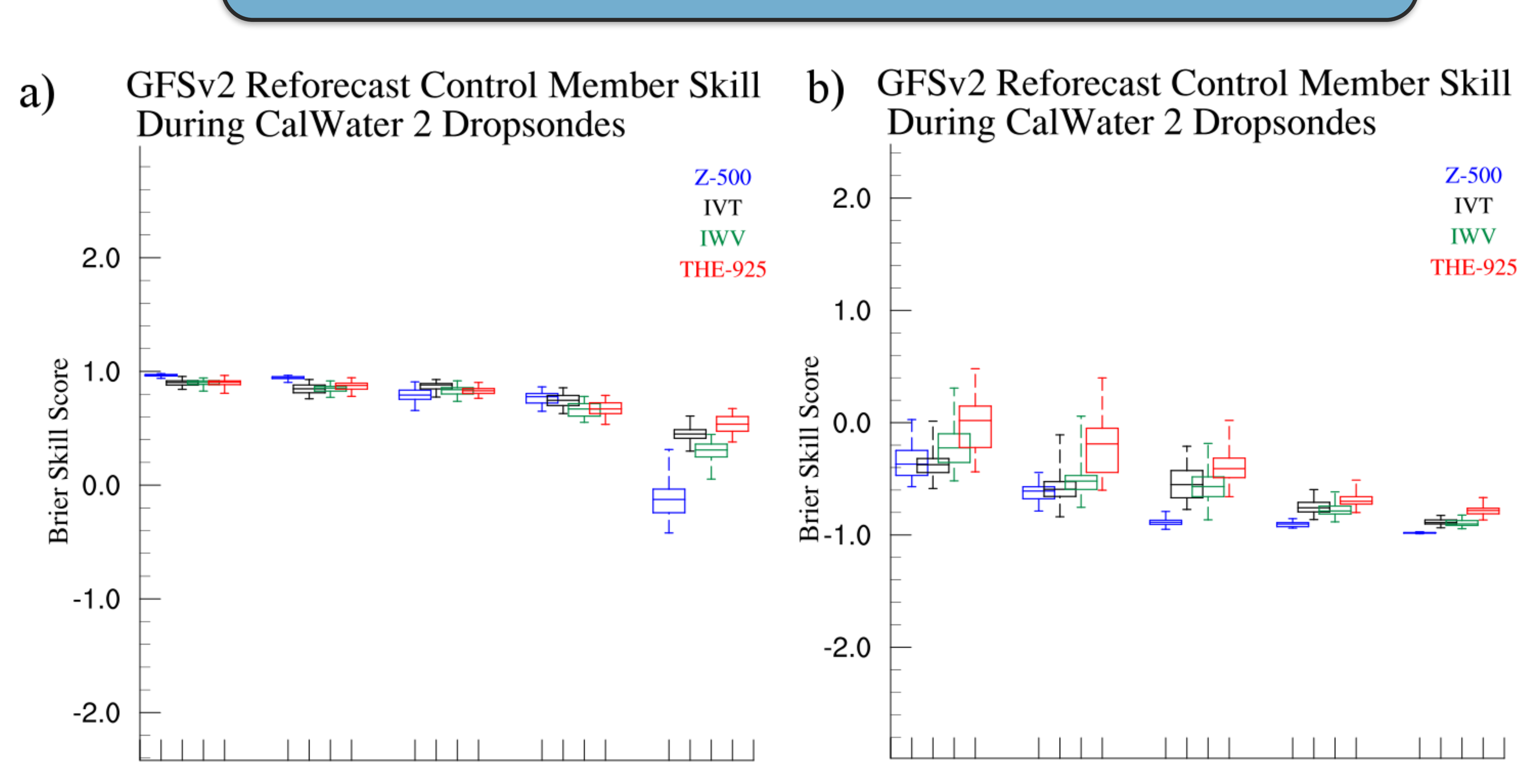
AR Cross-section Composite



Relative Errors in Cross-Transect Vapor Flux

	All Lead Times 48hr +
Mean Error Relative to Sondes	-22.7%

Assessment of GFS Skill vs. Lead Time



Above left: Brier Skill Score computed from climatology reference vs. GFS forecast lead time (ordinate) ~ 1 day to ~ 5 days for: 500 hPa geopotential (blue - right), sounding IVT (black - second from right), IWV (green - second from left) and 925 hPa equiv. potential temperature (red - left). Above right: as in above left, except ERA-I serves as reference forecast.

Initial Results Summary

- GFS underforecasts IVT, low level dIVT and wind speed near 48 hour lead time. Level of 75% IVT does not depart greatly from Obs.
- ERA-I reanalyses identify a much broader core of wv flux in the transects than do the sondes.
- Both GFS and ERA-I fail to extend the upper level composite jet above the AR IVT maxima. Both also have much more southerly winds at upper levels.
- GFS skill against climatology remains high to 5 days forecast for IVT, IWV and 925 equivalent pot. temp. 500 hPa Z forecast skill disappears after 4 days lead time - suggesting GFS errors may appear in mid-level mass balance first.
- GFS Relative errors in total through-transect water vapor flux become fairly large after 48 hours.

- The rapid decrease in skill when compared to a reanalysis reference forecast reinforces the large vapor flux error after 48 hours.
- 925 hPa equivalent pot. temp. skill remains high longest, and errors in displacement needed for saturation remain low compared to observations

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