# Determining Biases in Hadley Circulation Reanalyses Using Independent Aircraft Observations

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## SUMMARY

We have developed an indirect technique to evaluate meridional circulation independent of analyses and reanalyses. We compare monthly means of analyses with integrals of high resolution aircraft wind observations. These wind observations are independent of existing Global Telecommunications System (GTS) data. They can be used to validate meridional circulations of different reanalyses. We conclude that ERA-40 Hadley circulation is about 9% low over 100˚ of longitude for June 2002. The technique allows us to distinguish among existing reanalyses which differ by about 30% in the peak values of their meridional stream functions.

## BACKGROUND

The following two figures show the Hadley circulation as zonally averaged stream functions and a 200 mb geographic map. Note the discrepancy between the in-situ and reanalysis stream function (arrows) in the following Fig. 1.

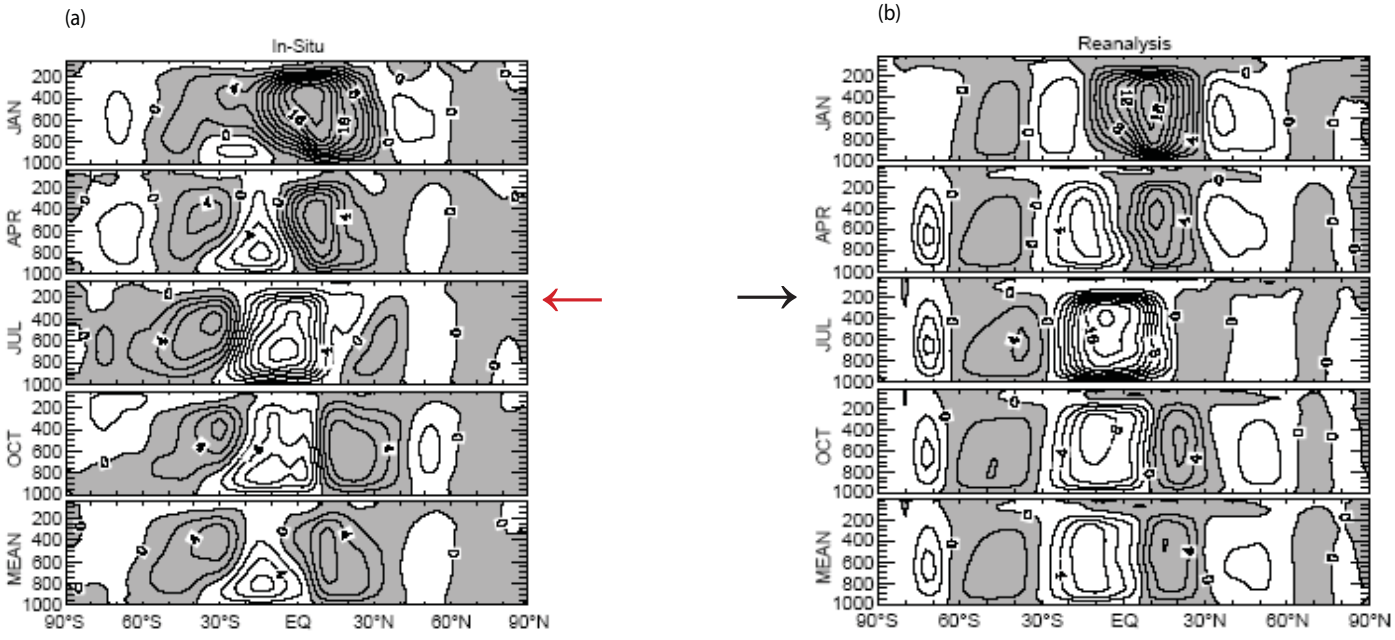


Fig. 1. Zonal-mean mass stream function derived from (a) in situ data sources and (b) for the NCEP/NCAR reanalysis mean January, April, July, and October conditions as well as the long-term mean for the period 1968-89. Units are $10^{10}$ kg $s^{-1}$ and the contour level is 2 x $10^{10}$ kg $s^{-1}$. [Adapted from Waliser et al. (1999)]

Fig. 2, adapted from Sadler (1975) shows the 200mb streamlines for July. Note that the traditional concept of the Hadley circulation as a predominantly meridional flow is true at only some longitudes and for these non-zero flows the basic behavior is that of a hairpin.

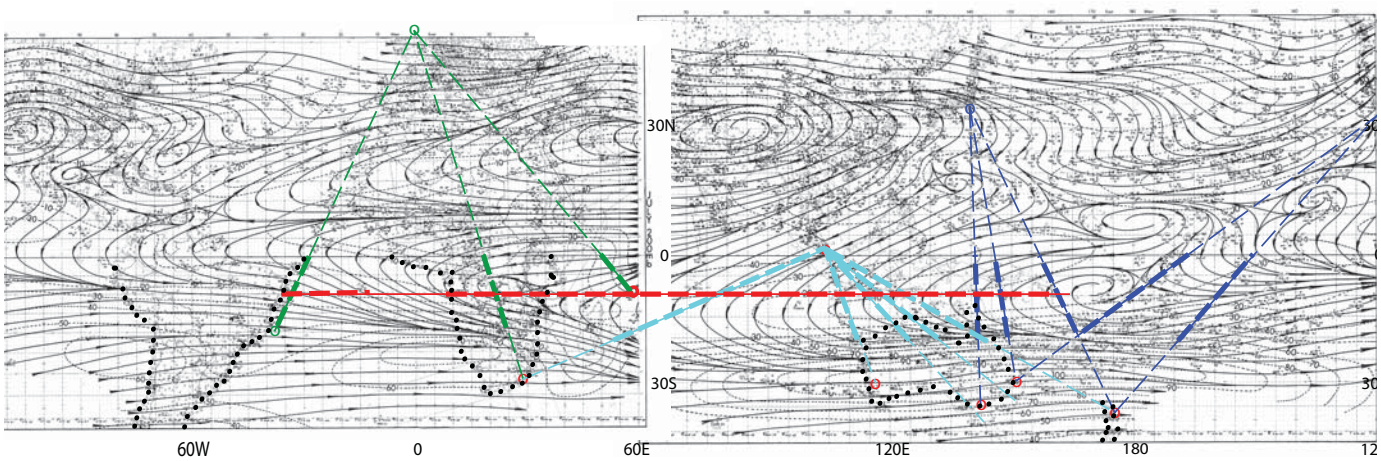


Fig. 2. Streamlines at 200 mb for July from Sadler (1975). Overlays represent tropical flights of British Airways (green), Singapore Airlines (turqoise), Qantas (blue) and the longitudes of substantial meridional flow (red) with thicker lines showing tropical longitudes covered. (Quality of the background contour map reflects, in part, that of the original report.)

## GLOBAL AIRCRAFT DATA SET (GADS) EXPERIMENT

This experiment (Cardinali et al., 2004) has collected and archived 57 Million high resolution aircraft wind observations since August 1996. The observation density is sufficient to permit evaluation of line integrals rather than just the checking of point measurements. We have flights for a substantial portion of the longitudes with non-neglibible meridional flow shown in Fig. 2. Fig. 3 gives an indication of the GADS observations from British Airways and Singapore Airlines.

Fig. 3. GADS routes for British Airways on 26 July 2007 as observed (solid red lines) and for Singapore Airlines on a typical day (dashed cyan lines).

**DETAILED TECHNIQUE AND ASSUMPTIONS**

Our primary technique is to work with monthly means of the flows and streamlines. We also assume that the flow is laminar and that there is no correlation of missing observation days, if any, with the flow.

The detailed technique is to evaluate the integral of aircraft winds between streamlines separated by 2.5˚ in latitude and extrapolate the difference with the analysis to the corresponding longitudes at 10˚S. The individual steps are as follows:

( a ) evaluate monthly mean wind speed and direction for as observed by GADS aircraft for one route every 2.5˚ in latitude
( b ) check date distribution
( c ) evaluate monthly mean analysis flow at midpoint of the two streamlines (slowly varying)
( d ) form projection of aircraft wind onto analysis wind, 2.0 * $|v_{acft}|$ |i| cos $\theta$, where $\theta$ is the angle between the aircraft and analysis monthly mean wind speed vectors
( e ) compare aircraft wind projection with analysis wind projection (cos $\theta$ = 1 for projection of $v_{anal}$ on itself by definition)
( f ) calculate percent error
( g ) propagate bounding streamlines back to 10˚S
( h ) correct analyzed meridional flow at 10˚S by the precent error from ( f )
( i ) form average to estimate Hadley circulation error for as many longitudes as GADS flights will permit

Fig. 4 shows the procedure in diagrammatic form.

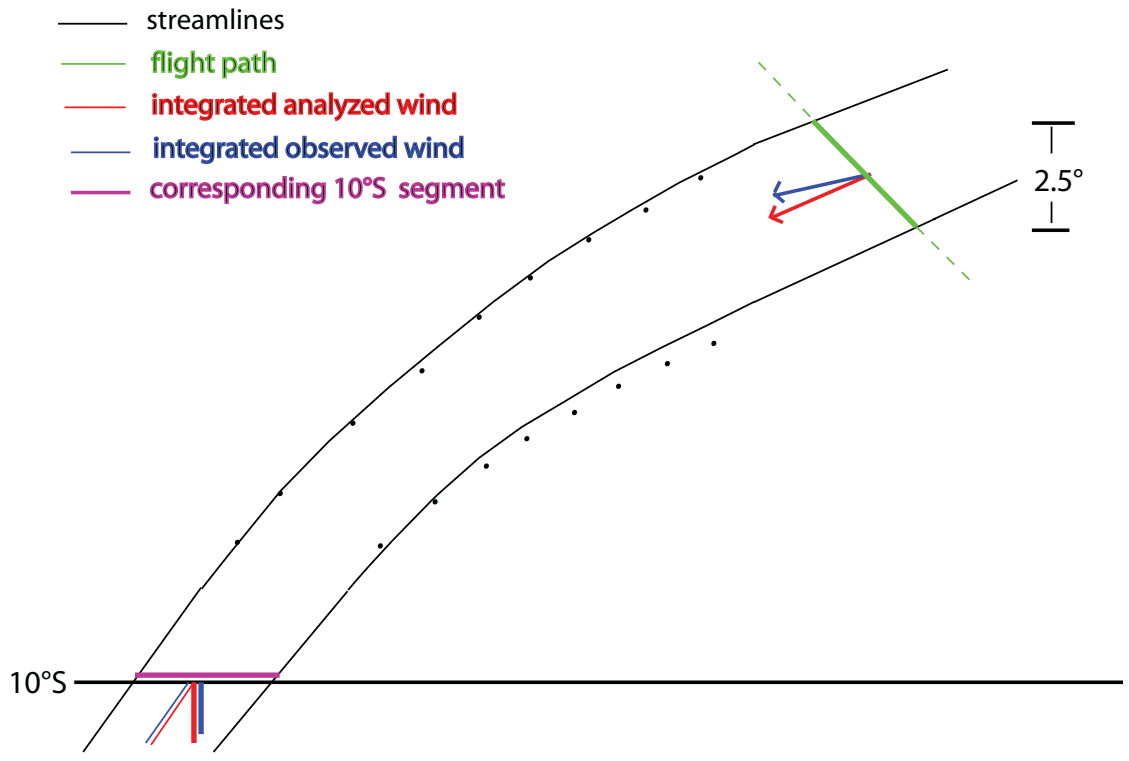


**Fig. 4. Schematic illustration of streamlines (black), aircraft flight path (green), analyzed wind (red), and observed wind (blue)., upper right. The projection of the two streamlines to 10°S is shown at the lower left along with analyzed (red) and observed (blue) meridional (Hadley) circulation. Longitudes covered at 10°S are shown in purple.**

## RESULTS

Our results for the ERA-40 analysis of June 2002 are given in Fig. 5 where the height of the colored ellipses indicates the percent error (reanalysis minus observations) and the width indicates the longitudinal coverage of that section of the flow between the streamlines separated by 2.5˚ in latitude.

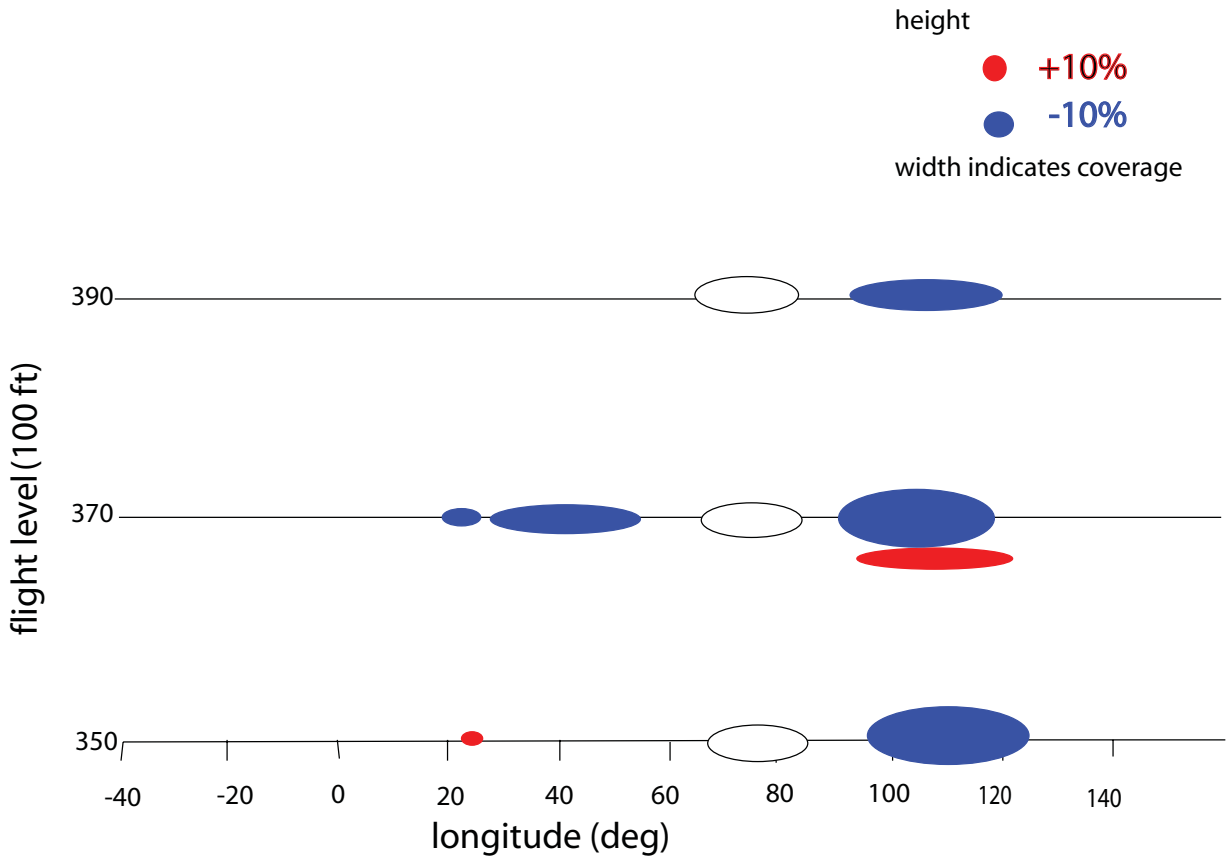


Fig. 5. Integrals of ERA-40 reanalysis minus GADS observations for June 2002 expressed as a percent error. Height of ovals indicates error with blue indicating negative and red indicating positive errors. Height of legend dots indicate 10% errors. Width of ovals indicates longitudes covered when projected to 10°S. Black open circles at 80°E indicate additional longitudes from Singapore Airlines.

## REFERENCES


GADS Web site: http://jet.purchase.edu/cmm

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