

## ***Interactive comment on “Climatology and trends in the forcing of the stratospheric zonal-mean flow” by E. Monier and B. C. Weare***

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We appreciate the comments by the referee 2. We respond point by point to the comments.

**Major Revisions: (1) In the reanalysis data how reliable is it that the residual term in the TEM budget is predominantly gravity waves and does not include a significant contribution from any Analysis Error? If there is a bias between the model and observations this will result in a forcing in the assimilation and will appear in the residual term.**

In the revised manuscript, we have attempted to address the uncertainty in the residual term and its attribution to a gravity wave drag by analyzing the residual term in a

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different independent re-analysis dataset, the NCEP re-analysis 2. We found several consistent features between the ERA40 residual term and that calculated using the NCEP re-analysis 2. In particular, the vertical profile and seasonality of both residual terms broadly agree outside of the polar region, although the ERA40 is noisier than the NCEP re-analysis 2 (see Fig. 1). The correlation analysis was redone using the NCEP re-analysis 2 (see Fig. 2 and Fig. 3), showing that the high spatial correlation between the Coriolis term and the residual term agree are nearly identical between the two independent re-analyses. This suggests that the contribution of noise or bias to the high (negative) correlation between the residual term and the Coriolis in the ERA40 re-analysis is small. This result strengthens the attribution of the residual term to a gravity wave drag, and the considerable role of the residual term in driving the Brewer-Dobson circulation, which is in agreement with previous studies that are cited in this manuscript.

**(2) In the reanalysis when data from a new instrument becomes available and is assimilated this could potentially cause erroneous trends in the data. Has this been considered? See for instance: (a) ‘Erroneous Arctic Temperature Trends in the ERA-40 Reanalysis: A Closer Look’, Screen and Simmonds, J. Clim., 2011. (b) ‘Arctic tropospheric warming amplification?’, Thorne, Nature, 2008.**

We also redid the trend analysis of the various forcing terms based on the NCEP re-analyses 2 and added that analysis to the revised manuscript (see Fig. 4). There are clear similarities with the trend analysis based on the ERA-40 re-analysis: - the trend in  $du/dt$  and its seasonality are nearly identical; - the trends in the EP flux divergence and its seasonality agree well; - the trends in the Coriolis term and in the residual term mirror each other well, especially when the trends in the EP flux divergence are small. Nonetheless, the signs of the trends in the Coriolis term and in the residual term do not agree well. As a result we have underlined the fact that while the trends in both terms mirror each other well in both re-analyses, there is a large uncertainty in the sign of the trends. As a result, we included a discussion on the potential causes for

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the discrepancy in the trend analysis between the two datasets, including biases in the data assimilation.

#### **Minor Revisions and Typos:**

The authors appreciate the care with which this reviewer has reviewed the article, in particular the small but important mistakes that this reviewer found.

**(1) 11650L5-7: 'A trend analysis, from 1980 to 2001...' This sentence could be clarified to specifying later in the season in recent years.**

This sentence was changed accordingly.

**(2) 11651L17: '...stronger westerly winds in the summer-fall season...' Is fall too late?**

The authors are confused by the question.

**(3) 11652L23-26: Be consistent with use of section and Sect.**

This is corrected in the revised manuscript.

**(4) 11653L13-15: 'In addition, Knudsen...' This sentence is a little unwieldy to read with so many sub clauses.**

That sentence was changed to: "In addition, Knudsen et al. (2004) show that the ERA-40 winter-averaged polar stratospheric cloud (PSC) areas agree well in most years with the Free University of Berlin (FUB) analysis, which is largely independent of satellite data."

**(5) 11654 Equation (1) and (2): These are identical, remove one.**

This is an unfortunate formatting mistake that is corrected in the revised manuscript.

**(6) 11654 Equation (2) and throughout manuscript. curl F should be replaced by div F (as in Andrews et al 1987). Mathematically these have difference meanings.**

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This is also corrected in the revised manuscript.

**(7) 11654L12: '...the horizontal and vertical components of the residual mean meridional circulation...' change to '...the meridional and vertical components of the residual mean circulation...'**

This is corrected in the revised manuscript.

**(8) 11655L16: 'diagnostics' should be 'diagnostic'**

This is corrected in the revised manuscript.

**(9) 11659L7: 'lower-troposphere drag' should this be 'lower-tropospheric drag'?**

This is corrected in the revised manuscript.

**(10) 11660L15: 'Finally, and analysis of the seasonal cycle of the tropical residual term (not shown)...' Can this be included as supplementary material?**

This analysis can be included as supplementary material.

**(11) 11662L7: 'while considerable..., it is unclear why it is not removed from the climatology mean'. Needs clarification as I am unclear as to the meaning of this sentence.**

This sentence was removed from the revised manuscript.

**(12) 11662L15: In figure 5 rather than doing overplotted contours of the EP Flux components (bottom row) can you do a vector plot?**

We can change these plots to vector plots.

**(13) 11663L25: 'Also, the Coriolis and advective terms..., reflecting the fact that the wave drag exerted by  $\text{div}F_z$  is consumed by driving the B-D circulation'. Perhaps I have misunderstood, but you seem to be linking tropospheric correlations with a stratospheric feature in the B-D circulation?**

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The author is right that the author should refer to the residual circulation and not the B-D circulation. This is corrected in the revised manuscript.

**(14) 11664L11-13: 'Furthermore, the uncertainties ....'. I am not sure whether a bias will affect a correlation and how all these correlations fit together. The correlation between  $du/dt$  vs  $Cor+Adv$  is positive in the summer stratosphere,  $du/dt$  vs  $X$  is positive but small in the summer stratosphere but  $Cor+Adv$  vs  $X$  shows a strong negative correlation in summer. i.e. If  $A$  is positively correlated with  $B$  and  $A$  is positively correlated with  $C$  can  $B$  be negatively correlated with  $C$ ? Perhaps it is worth considering doing a regression which will give some idea of the importance of the term instead of a correlation.**

The correlation analysis presented here is used to identify how the various forcing terms relate to one another. Pfeffer, 1992 showed a similar correlation analysis for the troposphere that highlights striking relations between the various terms. We simply aim at extending this analysis to the stratosphere. One of the striking features we find is the high correlation between the Coriolis term and the residual term in the stratosphere, in both the ERA-40 re-analysis and the NCEP re-analysis 2 (see Fig. 2 and Fig. 3).

**(15) 11665L3: 'Since the period of the QBO is variable...' I am not sure I follow the reasoning in this sentence.**

This sentence was removed from the revised manuscript.

**(16) 11667L25-26: 'Overall, Fig 8 ....., in driving long-term changes in the B-D circulation during seasons when the planetary wave activity is weak.' From Fig 8 it shows that the residual term mainly balances changes in the  $cor+adv$  (or B-D circulation). Looking at when  $du/dt$  is non zero this corresponds to when the eddy forcing is non zero. I can't see 'driving' only balancing. If anything looking at  $du/dt$  when the eddy forcing is zero it would appear that the B-D circulation is stronger than the balancing residual term.**

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In the revised manuscript, we have made a strong effort to identify the residual term to a gravity wave drag by including an analysis of the NCEP re-analysis 2 (see Fig. 4). We have made clear the relationship between the residual term and the Coriolis force (B-D circulation) in both re-analyses, in both the climatology and trends. Several studies cited in this manuscript suggest that gravity wave drag plays a significant role in driving the B-D circulation, along with its long-term changes. The results of this study provide more evidence of the relationship between the two terms.

**(17) 11672L24: 'various re-analysis dataset...' should be 'various re-analysis datasets'**

That is corrected in the revised manuscript.

**(18) 11686 Fig 6: It is slightly confusing that the y axis ranges changes. I would suggest either using a fixed range (-1 to 1) for all plots or alert the reader in the caption that the range changes.**

This issue is addressed in the revised manuscript (see Fig. 2 and Fig. 3).

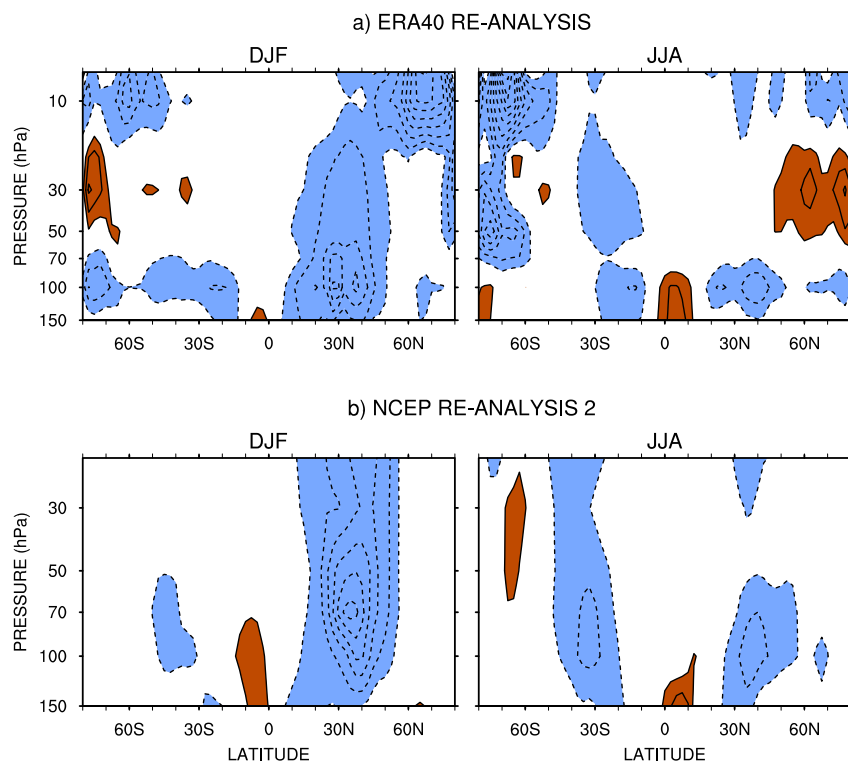
**(19) 11688 Fig 8: The legend lines are not clearly indicative of the line styles used in the plots.**

The legend lines are improved in the revised manuscript.

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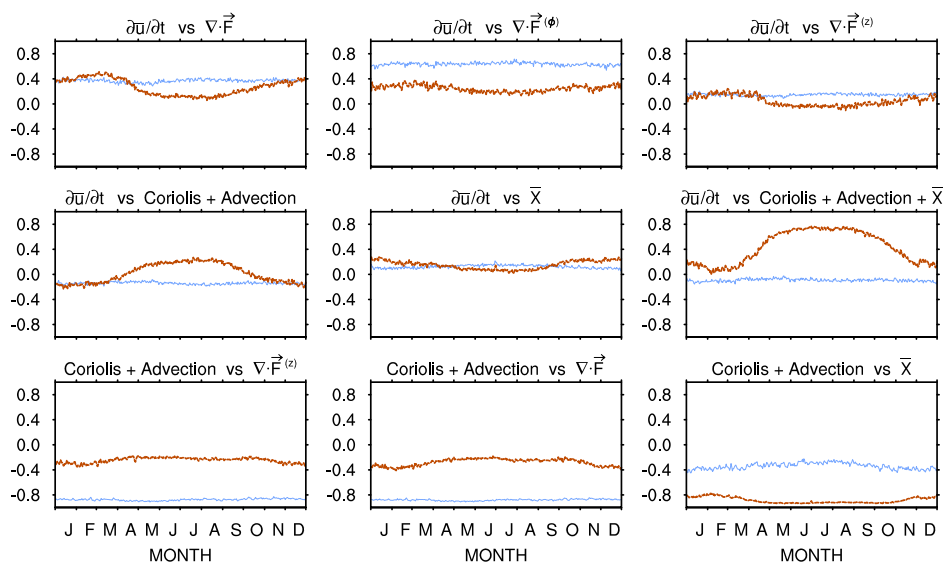
Interactive comment on Atmos. Chem. Phys. Discuss., 11, 11649, 2011.

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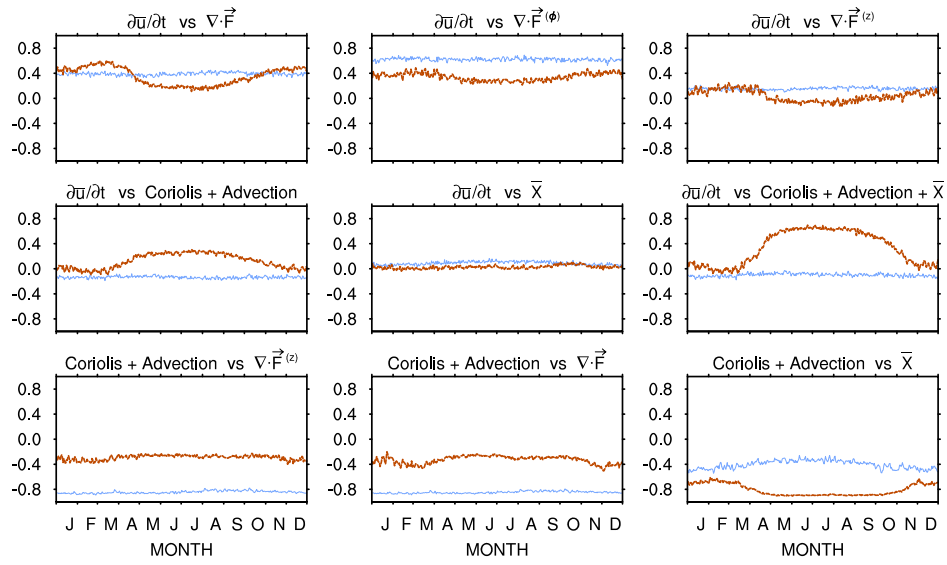
**Fig. 1.** Latitude-height cross-section of the residual term in the TEM momentum equation averaged of DJF and JJA for both ERA-40 re-analysis and NCEP re-analysis 2.

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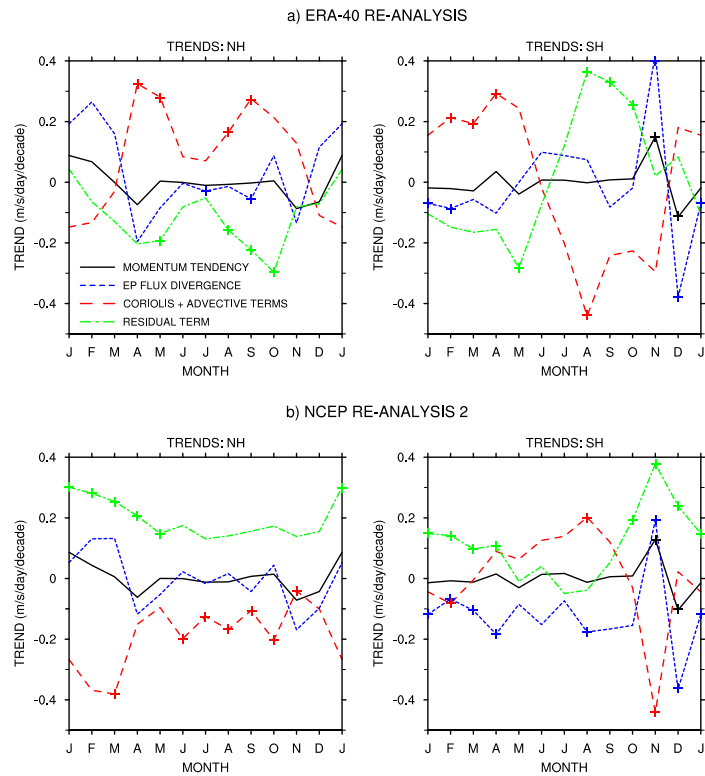
**Fig. 2.** Time variations of spatial correlations over the Northern Hemisphere in the troposphere (blue lines), and in the stratosphere (brown lines), for the ERA-40 re-analysis.

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**Fig. 3.** Same as Fig. 2 but for the NCEP re-analysis 2.

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**Fig. 4.** Annual cycle of the trends in the momentum tendency and its forcing terms, for the (left) NH and the (right) SH, for both the ERA-40 re-analysis and the NCEP re-analysis 2.

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