Motivation

All ground based ozone data are measured at one point and thus the number of ground-based measurements of ozone is insufficient for global coverage, especially in the Southern Hemisphere. Satellite ozone data have broader coverage, and these data are widely used in trend analysis in ozone research. But in some areas, it is impossible to measure ozone (polar night, below dense clouds) by satellite.

On the other hand, the ozone data from reanalysis are temporally and spatially homogeneous, but there is a big question of the suitability of these data for trend analysis due to the occurrence of discontinuities in them. They can be caused by satellite or instrument replacement or by assimilation of not homogenous basic parameters. The aim of this contribution is to find discontinuity in reanalyse data with the help of Pettitt test.

Data and method

In this paper, we used the ozone monthly mean from MERRA 2, ERA 5 and JRA 55 from 500 hPa up to 1 hPa in the period 1980–2017. From table 1 we see the top layer in the reanalyses is not the same MERRA 2 has top layer at 0.1 hPa, while ERA 5 and JRA have their top layer at 1 hPa. Also the layers 4 hPa and 40 hPa is present only in MERRA 2 and the data from 125 hPa, 175 hPa and 225 hPa are given only in ERA 5 and JRA 55, not in MERRA 2. Reanalyses used in this paper cover the whole satellite era.

In each grid and each layer, we used the time series of the ozone concentration and applied the Pettitt homogeneity test [19] to look for discontinuity in it. In each grid, the Pettitt test estimates only one main discontinuity, so this procedure is not able to detect multiple discontinuities. This test is widely used in the climatological research especially for precipitation and temperature analysis We are interested only in the spatial distribution of the discontinuities. The Pettitt test tells us the year in which the discontinuity in time series occurs. But it does not say how big the discontinuity is or how it can affect trends. Small discontinuities have little impact on trend analyses. On the other hand, the large one can have a strong trend impact, so we must divide the discontinuities according to their size. We tried to identify which ones were significant (in our case big enough to impact the trend) or insignificant according to this rule: Suppose we have a time series with the length L, and in year x, we observe the discontinuity. We compute the difference between the average before the year x and after this year. If this difference is larger than the variance of time series, we can say that the discontinuity is significant and will have some impact on trends, and we should be careful using this grid point in a trend analysis. This rule should be used mainly in areas with big variance because if the variance is very small, even the small discontinuities can be identified as significant.

	0,1	0,3	0,4	0,5	0,7	1	2	3	4	5	7	10	20	30	40	50
MERRA -2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
ERA -5						*	*	*		*	*	*	*	*		*
JRA -55						*	*	*		*	*	*	*	*		*

	70	100	125	150	175	200	225	250	300	350	400	450	500
MERRA -2	*	*		*		*		*	*	*	*	*	*
ERA -5	*	*	*	*	*	*	*	*	*	*	*	*	*
JRA -55	*	*	*	*	*	*	*	*		*	*	*	*

Table 1: Layers in reanalyse used in this contribution.

3. Results

In fig. 1 (2) there is a vertical profile of discontinuity occurrence (DO) in each month for MERRA 2 (upper panel), ERA 5 (middle panel) and JRA 55 (lower panel) for all (significant) discontinuities. We see the behaviour of profiles is similar for every month within the same reanalyse. This statement is true both for all and the significant discontinuities. Thus we can compare DO among the reanalyses. We see also there are layers where the discontinuities are present more or less frequent. These layers are the same in each month within one reanalyse.

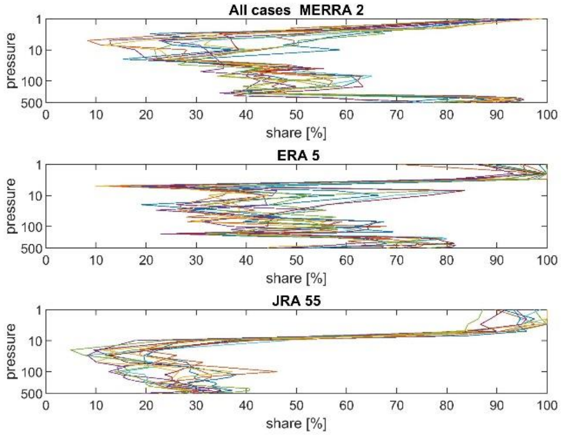
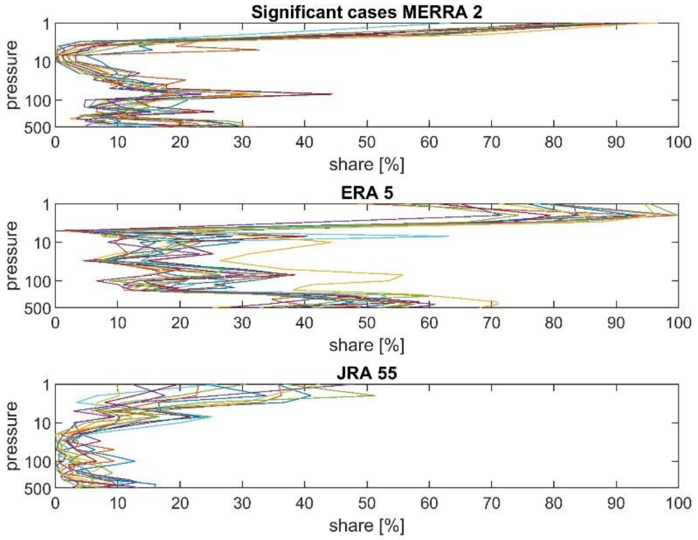


Figure 1: Vertical profile of discontinuity occurrence for MERRA 2 (upper panel), ERA 5 (middle panel) and JRA 55 (lower panel) for all discontinuities.


Significant cases MERRA 2

ERA 5

JRA 55

Figure 2: The same as Fig.1, but for the significant discontinuities

3.1. Comparison of discontinuity occurrence between MERRA 2 and ERA 5

3.1.1. All cases

In fig. 3 we see the average DO from each month and each common layer for MERRA 2 and ERA 5 for all discontinuities (upper panel). The sign S in the graph means the difference between the average DO from MERRA 2 and ERA5 is statistical significant at the 95 % level. We see in the case of MERRA 2 the maximal DO at 1 hPa (93,4 %) and minimal at 20 hPa (24,9 %). The other area of high DO is the troposphere with maximum (85,2 %) at 400 hPa. ERA 5 average DO has got maximal value in the upper stratosphere (98,5 %) at 2 hPa, sharp minimum at 5 hPa (25,0 %) and we observe high DO in the troposphere with maximum (70,4 %) at 350 hPa. Above 350 hPa the average DO is higher at the majority of layers for ERA -5. The only significant differences between the average DO is seen at 2, 3 and 250 hPa. On the contrary below 350 hPa we observe high average DO for MERRA 2, but these differences are not significant.

We can look at the differences in the geographical distribution of discontinuities for areas where the DO differences are significant for all discontinuities. From fig.3 (upper panel) we see the two main areas of significant DO differences: upper stratosphere and 250 hPa. We look at the geographical distribution of discontinuities at 3 hPa for September (difference -67,9 %) for MERRA 2 (upper panel of fig. 4) and for ERA -5 (lower panel). The yellow colour means there is so discontinuity in a certain grid and the red one shows the discontinuity in a certain grid. In the case of MERRA 2 we see at the majority of grids there is no discontinuity, while for ERA -5 we observe discontinuities at the large number of grids. In the 250 hPa. (fig.5) the geographical distribution is similar (difference is smaller -41,5 %).

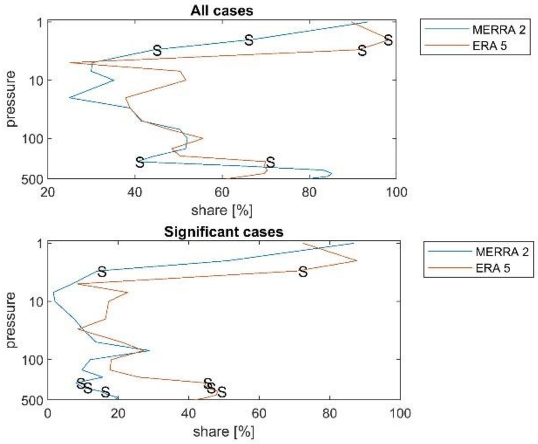


Figure 3: The average vertical profile of DO for MERRA 2 and ERA 5 for all (upper panel) and the significant discontinuities (lower panel)

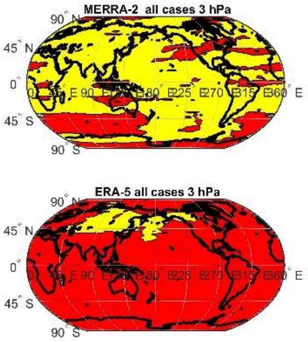


Figure 4: Geographical distribution of all discontinuities (yellow –no discontinuity, red – discontinuity) for MERRA 2 (upper panel) and ERA 5 (lower panel) at 3hPa.

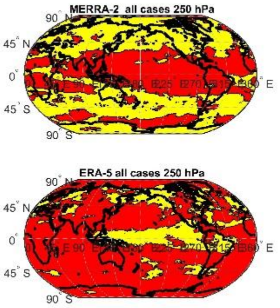


Figure 5: The same as fig. 4, but for 250 hPa

3.1.2. Significant cases

In fig. 3 there is the average DO from each month and each common layer for significant discontinuities (lower panel). The vertical profile of DO is similar as in the case of all discontinuities. MERRA 2 has maximal DO at 1 hPa (86,9 %) and minimal at 7 hPa (1,5 %). ERA 5 average DO has got maximum in the upper stratosphere (87,7 %) at 2 hPa and sharp minimum at 5 hPa (8,4 %). The average DO in the troposphere is much higher for ERA 5 than for MERRA 2 with maximum (48,1 %) at 350 hPa. In the case of significant discontinuities at the majority of layers we observe higher average DO for ERA -5 than for MERRA -2. The greatest differences in the vertical profile pattern between all and significant discontinuities is seen in the troposphere, where in the case of all discontinuities we see higher DO for MERRA2 then ERA5. The opposite is true for significant discontinuities. The DO differences between MERRA2 and ERA5 are significant in the upper stratosphere at 3 hPa and in the troposphere at 250, 300 and 350 hPa.

We can look at the differences in the geographical distribution of discontinuities at the selected cases where the DO differences are significant. From fig.3 (lower panel) we see two main areas of significant DO differences: the upper stratosphere and the troposphere. We look at the geographical distribution of the significant discontinuities at 3 hPa for June (difference -74,8 %) for MERRA 2 (upper panel of fig. 6) and for ERA -5 (lower panel). In the case of MERRA 2 we see at the majority of grids there is no discontinuity, while for ERA -5 we observe discontinuities at the large number of grids. In the 250 hPa. (fig.7) the geographical distribution is similar (difference is smaller -49,1 %).

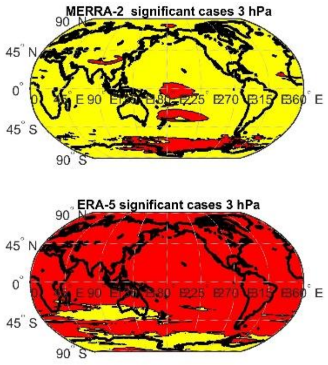


Figure 6: Geographical distribution of the significant discontinuities for MERRA 2 (upper panel) and ERA 5 (lower panel) at 3hPa.

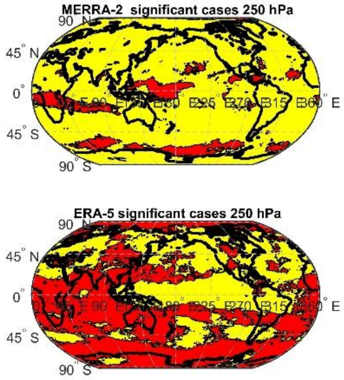


Figure 7: The same as fig. 4, but for 250 hPa

3.2. Comparison of discontinuity occurrence between MERRA 2 and JRA 55

3.2.1. All cases

We see the vertical profile of DO for MERRA 2 and JRA 55 in fig. 8 (upper panel). Above 10 hPa DO is higher for JRA-55 than for MERRA2 with significant differences at 3 and 5 hPa. Below 10 hPa at all layers DO of JRA 55 is smaller than that of MERRA 2. Significant differences are also seen at 30 hPa and in the troposphere below 300 hPa, where difference in each layer is significant.

The geographical distribution of DO for September at 5 hPa (difference -67,5 %) is shown in fig.9 for MERRA 2 (upper panel) and for JRA 55 (lower panel). At the majority of grids there is no discontinuities in the case of MERRA 2. The opposite is true for JRA 55. In the troposphere the situation is very different. Fig. 10 displays the geographical distribution of DO for 400 hPa in March (difference 64,8 %), Nearly at all grids the is a discontinuity in the case MERRA 2 (upper panel). DO is substantially lower for JRA 55 (lower panel).

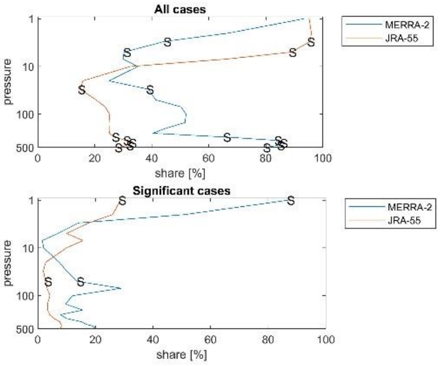


Figure 8: The average vertical profile of DO for MERRA 2 and JRA 55 for all (upper panel) and the significant discontinuities (lower panel)

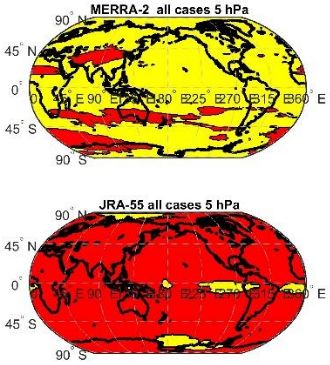


Figure 9: Geographical distribution of all discontinuities for MERRA 2 (upper panel) and JRA 55 (lower panel) at 5hPa.

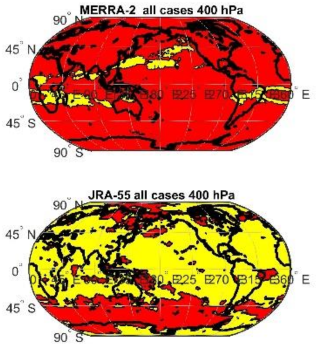


Figure 10: The same as fig. 9, but for 400 hPa

3.2.2. Significant cases

In the case of significant discontinuities (fig 8, lower panel) we can observe that at the majority of layers DO obtained from JRA 55 is smaller. There are huge differences in behaviour of DO in the case of the significant and all discontinuities in the uppermost layers (1,2 hPa). DO of all discontinuities is larger for JRA 55, the opposite is true for the significant discontinuities, where at 1 hPa the MERRA 2 and JRA 55 differences are significant. From 3 hPa down to 10 hPa we observe insignificant differences with higher DO values for JRA 55. Below 10 hPa DO is higher for MERRA 2 at all layers, but these differences are insignificant except 50 hPa. In fig.11 the geographical distribution of significant discontinuities at 1 hPa for October (difference 84,9 %) is seen. In MERRA 2 there are discontinuities at the vast majority of grids, while for JRA 55 the occurrence of discontinuities is strongly reduced.

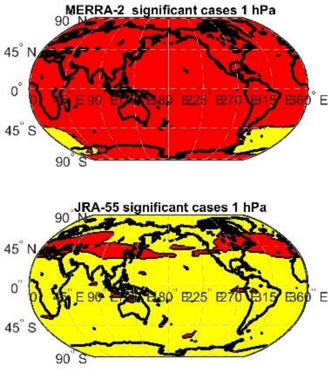


Figure 11: Geographical distribution of the significant discontinuities for MERRA 2 (upper panel) and JRA 55 (lower panel) at 1hPa.

3.3. Comparison of discontinuity occurrence between ERA 5 and JRA 55

3.3.1. All cases

In fig. 12 (upper panel) there is a vertical profile of the average DO between ERA 5 and JRA 55 for all discontinuities. The profile patterns are similar as for MERRA 2 and JRA 55 differences. Above 5 hPa the DO for ERA 5 is comparable or slightly higher than for JRA 55. At 5 hPa there is a sharp minimum in DO in the case of ERA 5, so this difference is significant. Below 7 hPa DO for JRA 55 is smaller at all layers. These differences are significant from the lower stratosphere (below 225 hPa) down to upper troposphere (above 500 hPa). The geographical distribution of all discontinuities at 5 hPa for August (difference -83,3 %) is seen in fig.13 for ERA 5 (upper panel) and for JRA 55 (lower panel). For JRA 55 the discontinuities occur at vast majority of grids, while at ERA 5 the number of discontinuities is substantially lower. In the troposphere (fig. 14) the situation is opposite. At 250 hPa in June (difference 58,7 %) the occurrence of discontinuities is higher for ERA 5 than JRA 55.

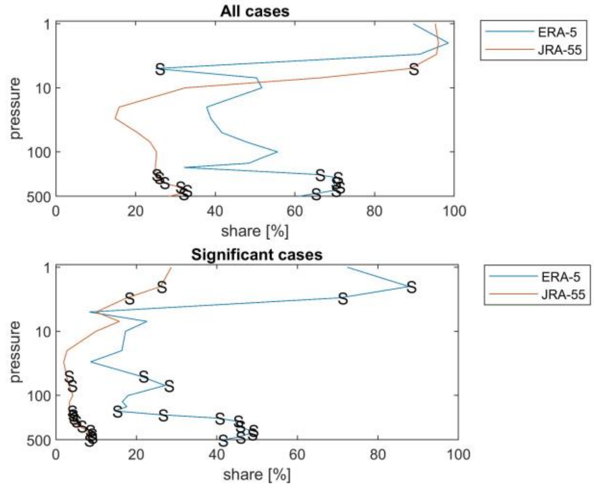


Figure 12: The average vertical profile of DO for ERA 5 and JRA 55 for all (upper panel) and the significant discontinuities (lower panel)

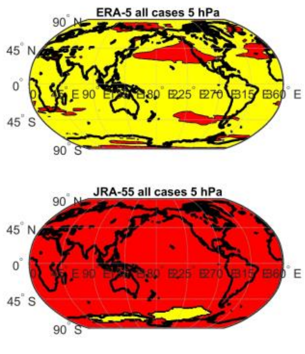


Figure 13: Geographical distribution of the all discontinuities for ERA 5 (upper panel) and JRA 55 (lower panel) at 5hPa.

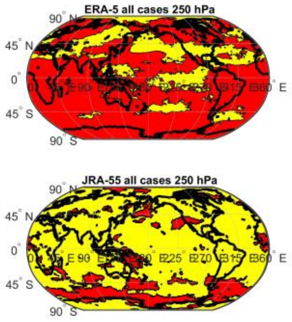


Figure 14: The same as fig.13, but for 250 hPa.

3.3.2. Significant cases

We see the average vertical profile of differences between ERA 5 and JRA 55 for the significant discontinuities in fig. 12 (lower panel). Again these differences are similar to that of MERRA 2 and ERA 5. At all layers except 5 hPa the discontinuity occurrence is higher for ERA 5 than JRA 55. These differences are significant above 3 hPa, at 50 and 70 hPa and at all layers below 225 hPa. The figure 15 (2 hPa, June difference 91,6 %) and figure 16 (400 hPa, December, difference 54,7 %) also support these conclusions.

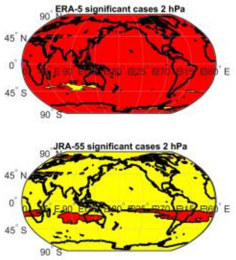


Figure 15: Geographical distribution of the significant discontinuities for ERA 5 (upper panel) and JRA 55 (lower panel) at 2hPa.

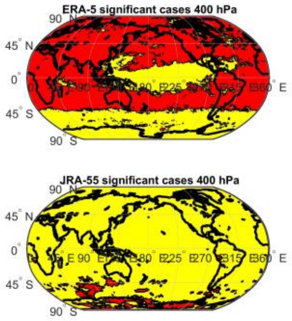


Figure 16: The same as fig.13, but for 400 hPa.

5. Conclusions

The main results of these paper are the following:

- There are differences in the DO occurrence among reanalyses.
- In the upper layers we observe the tendency toward the higher occurrence of DO in all reanalyses
- Another area of higher discontinuity occurrence is the troposphere
- DO in JRA 55 is on average the lowest from all reanalyses below 10 hPa especially for the significant discontinuity.
- According our results, the JRA 55 is the most suitable for reanalyse trend studies due to low discontinuity occurrence.