Supplementary Figure 1. The IAV amplitude map, with different resolution from (a) 2.5° longitude by 2.5° latitude, to (b) 5° longitude by 5° latitude, to (c) 10° longitude by 10° latitude, to (d) 5° longitude by 10° latitude and (e) 5° longitude by 15° latitude.
Supplementary Figure 2. The IAV amplitude difference for different resolution. (a) between 5° longitude by 5° latitude and 2.5° longitude by 2.5° latitude, (b) between 10° longitude by 10° latitude and 5° longitude by 5° latitude, (c) between 10° longitude by 5° latitude and 5° longitude by 5° latitude, (d) between 15° longitude by 5° latitude and 10° longitude by 5° latitude.
Supplementary Figure 3. The IAV amplitude map, use different sounding numbers as the benchmark to filter and get the aggregated OCO-2 detected XCO₂.
Supplementary Figure 4. The IAV amplitude difference between OCO-2 detected XCO₂ IAV based on different sounding numbers.
**Supplementary Figure 5.** The Log of Mean sounding numbers for 12 months for each 5 by 5 ° gridcell all over the world. The colorbar range is set to log -1 to 10 which is equivalent absolute soundings of 0 to 20000.
Supplementary Figure 6. The number of valid records (X out of 6 for JAN~JULY, 5 for AUG or 7 for SEP~DEC) for each month (JAN, FEB, etc...) for each 5 by 5 degree gridcell.
Supplementary Figure 7. The number of months out of 12 months in the year of 2014~2020 (JAN, FEB, MAR…) are available for each grid cell. It shows the OCO-2 XCO₂'s capability of detecting, which is related to the validity of our calculated IAV.
Supplementary Figure 8. Monthly Mean of OCO-2 XCO₂ observation.
Supplementary Figure 9. Monthly STD of OCO-2 XCO₂ observation.
Supplementary Figure 10. Bootstrapping Linear Regression fit between TCCON and OCO-2 monthly averaged XCO₂ IAV over 26 TCCON sites which have records between 2014.09 to 2018.12.

Light-blue regression lines in each plot are based on 1000 times ‘resampling’ of the original OCO-2 vs. TCCON IAV data points. The Steelblue line in each plot is just a simple polynomial fit between y and x.

The 95% significant level for regression slope is calculated based on the distribution of the possible 1000 slopes during the bootstrapping. The last figure, which is the histogram of the 1000 slopes for Lauder, gives an example of how I obtain the range of k-slope.
Supplementary Figure 11. Timeseries comparison between the OCO-2 XCO₂ and TCCON IAV, blue shading shows the uncertainty range of TCCON, green for OCO-2.
NH Tropical MBL sites

KUM

GMI

RPB

CHR

CO₂ AV [ppm]

Year
Supplementary Figure 12. Timeseries comparison between surface CO$_2$ MBL IAV and the co-located OCO-2 XCO$_2$ and. Orange lines based on OCO-2 observations while blue lines based on MBL sites.
Supplementary Figure 13. Timeseries comparison between the zonal mean OCO-2 XCO$_2$ and zonal mean MBL surface CO$_2$ IAV.
<table>
<thead>
<tr>
<th></th>
<th>Temperate Northern Hemisphere (20-60°N)</th>
<th>Northern hemisphere tropical (0 - 20°S)</th>
<th>Southern hemisphere tropical (0 - 20°S)</th>
<th>Temperate Southern Hemisphere (20-60°S)</th>
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<tr>
<td>Averaged R in a zonal band</td>
<td>0.280</td>
<td>0.173</td>
<td>0.501</td>
<td>0.423</td>
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<td>R of the averaged zonal mean IAV timeseries</td>
<td>0.546</td>
<td>0.335</td>
<td>0.711</td>
<td>0.509</td>
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</tbody>
</table>

**Supplementary Table 1.** Comparison between the averaged R value for all TCCON sites IAV timeseries in a latitude band and the R value of the averaged TCCON IAV timeseries within the zonal band.