A. How to generate the layer of annual mean tropospheric NO_2 vertical columns from the raw data of Sentinel-5p?

A. 1) Go to Sentinel-5P Pre-Operations Data Hub https://s5phub.copernicus.eu/dhus/#/home (Accessed on 16 November, 2021)

A. 2) Under *Advanced Search*, choose to sort the data by *sensing date* and input *2018/10/25* and *2019/10/2*4 as the start and the end date of the sensing period. Check *Mission: Sentinel-5P*. For *Product Type*, choose *L2__NO2__*. For *Processing Level*, choose *L2*. For *Timeliness*, choose *Offline*. We recommend to save the data of the same date in the same folder.

A. 3) Download and open ESA SNAP (we use version 6.0.0).

A. 4) EXTRACT DAILY TROPOSPHERIC COLUMNS: On the menu bar of the SNAP, choose *Raster* → *Geometric Operations* → *Mosaicing*. Then click + under the tab of *I/O Parameters* to load the data of a certain day (e.g. 25 October 2018) and set the parameters of the tabs of *I/O Parameters*, *Map Projection Definition*, and *Variable & Conditions* successively.
Under tab *I/O Parameters*: Uncheck *Update target product*, define *Name:* (e.g. *MoscaisCL181025*), choose (save as) *GeoTIFF*, define the target *Directory:* (e.g. *M:\veriColu181025*), check *Open in SNAP*.
Under tab *Map Projection Definition*: Click *Custom CRS*, choose *UTM/WGS 84 (Automatic)*, for *Mosaic Bands*, set *-30.0°* for west, *45.0°* for east, *72.0°* for North, and *27.0°* for South. Use *7000.0m* for pixel size X and Y. Keep others unchanged.
Under tab *Variable & Conditions*, click  and select *nitrogendioxide_tropospheric_column*, and click *OK*.
Click *Run* at the lower right corner of the window. Repeat this step to extract the daily tropospheric columns of 365 days.
NB: You may receive an error saying that SNAP cannot display source products and the value for 'North bound' is out of range [-90,90]. Click *OK* and neglect it.

A. 5) EXTRACT DAILY DATA QUALITY RASTER LAYERS: On the menu bar of the SNAP, choose *Raster* → *Geometric Operations* → *Mosaicing*. Then click + under the tab of *I/O Parameters* to load the data of a certain day (e.g. 25 October 2018) and set the parameters of the tabs of *I/O Parameters*, *Map Projection Definition*, and *Variable & Conditions* successively.
Under tab *I/O Parameters*: Uncheck *Update target product*, define *Name:* (e.g. *MoscaisQA181025*), choose (save as) *GeoTIFF*, define the target *Directory:* (e.g. *M:\veriQA181025*), check *Open in SNAP*.
Under tab *Map Projection Definition*: Click *Custom CRS*, choose *UTM/WGS 84 (Automatic)*, for *Mosaic Bands*, set *-30.0°* for west, *45.0°* for east, *72.0°* for North, and *27.0°* for South. Use *7000.0m* for pixel size X and Y. Keep others unchanged.
Under tab *Variable & Conditions*, click  and select *qa_value*, and click *OK*.
Click *Run* at the lower right corner of the window. Repeat this step to extract the daily data quality raster layers of 365 days.
NB: You may receive an error saying that SNAP cannot display source products and the value for 'North bound' is out of range [-90,90]. Click *OK* and neglect it.

A. 6) Close SNAP and open ArcMap 10.6.

A. 7) RECLASSIFY DAILY DATA QUALITY RASTER LAYERS: Load a certain daily data quality raster layer (*MoscaisQA181025.tif*) and open *Reclassify (Spatial Analyst)* tool. Reclassify *MoscaisQA181025.tif*, from *0-0.75* (Old Values) to *NoData* (New Values), and from *0.75-1* (Old Values) to *1* (New Values), and from *NoData* (Old Values) to *NoData* (New Values). No need to change missing values to NoData. Repeat this step to reclassify daily data quality raster layers of 365 days.

A. 8) CLIP DAILY TROPOSPHERIC COLUMNS ACCORDING TO THE DAILY DATA QUALITY: Open *Extract by Mask* tool and use classified daily data quality layer of a certain day (gained from A. 7)) to clip daily tropospheric columns of that date (gained from 4)) one by one. Repeat this step to clip columns of 365 days.

A. 9) Open *Raster Calculator* tool, use *SetNull ("rasterName"<0, "rasterName")* to filter daily NO_2 columns, replace "rasterName" with the results of A. 8) of each day. Repeat this step of 365 days.

A. 10) Open *Cell Statistics*, for *Input rasters or constant values*, select all the results generated from A. 9), for *Overlay statistic*, select *MEAN*, check *Ignore NoData in calculations*.

A. 11) Use *Project Raster* to convert the projection of A. 10) to WGS_1984_Web_Mercator_Auxiliary_Sphere (the projection of FUA data from GHSL were checked and adjusted (if necessary) to have the same projection).

A. 12) Use *Raster Calculator* to multiply the raster gained from A. 11) by 10^6. The unit of each cell becomes $\mu mol/m^2$.

A. 13) Create a buffer of 20km around the FUA (Dissolve Type: all) to act as mask and clip the results of A. 12) by *Extract by Mask*. This step is to accelerate the efficiency of geo-processing. The following operations will be based on this clipped raster.

A. 14) Use *Raster to Point* to convert the raster to point to get a point set, add 2 fields (Type: Double, Precision:10 Scale:10) to calculate the X & Y (PoiX, PoiY) coordinates of the data points.

A. 15) Use *Buffer (Analysis)* and *Feature Envelope to Polygon (Data Management)* to generate a shapefile of squares using the results of A. 14), where the location of the points are the centroids of the squares. Set the radius to 3500 meters when performing buffering.

A. 16) *Intersect* the results of A. 15) with the FUA shapefile containing the information of city centers (e.g. X & Y coordinates (CBDX,CBDY), names, etc.). And open the attribute table of this result, calculate the Euclidean distance between the XYs ($Sqr((PointX-CBDX)^2+(PointY-CBDY)^2)$). Then convert this layer to an Excel file for the regression analysis of annual mean tropospheric NO_2 columns.

A. 17) To visualize the annual mean tropospheric NO_2 columns over the FUAs, join the results from A. 15) with the FUA shapefile containing the information of city centers (e.g. X & Y coordinates, names, etc.) using *Joins and Relates* → *Join Data*, and check *Sum* under *How do you want the attributes to be summarized?*

A. 18) Open the attribute table of the results form A. 17) and examine the column *Sum_Count_*, select all the rows having a *Sum_Count_* value higher than 0, and export them to a separate vector layer.

A. 19) Use the result of A. 18) as mask and clip the results of A. 13) by *Extract by Mask*. You will get the annual mean tropospheric NO_2 columns over the FUAs.