**Summary**

Methane is the second most important greenhouse gas after CO2. Recent years have seen a huge increase in methane concentrations from anthropogenic sources which is an issue of concern. The aim of this project is to estimate the global methane concentrations by using existing methane products from satellite imagery and machine learning solutions. Below is a summary of the literature covered to:

* Understand geospatial imagery and satellites dealing with climate change.
* Understand the possible methods of obtaining emissions of methane from concentrations of methane.
* Visualize the data of existing methane products using Geo-Pandas in Python.
* Find the spatial, temporal and spectral gaps that might exist within the methane solutions offered by existing satellites.
* Do a brief discussion on possible ways of using machine learning solutions to fill the gaps.

Methane shows sensitivity to light in the Shortwave Infrared Region (SWIR), Near Infrared Region (NIR) and thermal infrared region (TIR). Spectrometers installed on the satellites measure reflected light in these regions of the electromagnetic spectrum through several bands. Depending on the number of bands, we can classify them as multi-spectral imagery (3 - 10 bands) or hyperspectral imagery (several hundred bands). TIR on the other hand uses the temperature difference between the earth and the atmosphere to quantify methane concentration in the upper-troposphere region.

Introduction:

Scanning imaging absorption Spectrometer for atmospheric cartography (SCIAMACHY) was the first multi-spectral instrument launched by the European Space Agency as a part of the Envisat-1 satellite in 2009 to measure methane concentration. While SCIAMACHY was the first satellite to estimate methane concentration in the SWIR and NIR region (using sunlight), Green House Gas Observing Satellite (GOSAT, GOSAT-2), TROPOMI were launched by space agencies around the world in the following years (from 2011 to 2017). These newer satellites made improvements in spatial resolution, temporal resolution (time to span observations across the entire earth), accounted for aerosols and cirrus particles along the optical path to make the measurements accurate, improved the spectrometers (better than grating spectrometers) and the technology of imaging (push broom sensors). Additionally, instruments such as Atmospheric InfraRed Sounder (AIRS) and [Infrared Atmospheric Sounding Interferometer](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/iasi) (IASI) make use of thermal infrared radiation (TIR) emitted by Earth's surface. This approach is less sensitive to clouds and aerosols and allows extension of the measurement coverage to nighttime conditions (including the polar night). Due to the limited transparency of the Earth's atmosphere to infrared radiation, these measurements are most sensitive to methane in the upper troposphere and lower stratosphere. Hyper-spectral imagery from satellites such as EnMap (Hyperion instrument) and airborne imagery are used to capture finer details and locate point sources of methane emissions.

Project Progress:

* A [satellite inventory](https://drive.google.com/open?id=1B9ACov1p8xUTPiEU4B8NBLhugWH2Ggo2) was made as a part of this project that lists the spatial, spectral and temporal specifics, advantages of satellites with applications in tackling climate change.
* Literature covered in the project first describes the physics methods used to estimate concentrations by understanding the phenomenon of scattering of light and accounting for clouds, aerosols through WFMD algorithm or the more recent SRFR algorithm (used with GOSAT and TROPOMI data). While fully understanding and implementing these methods is a substantially big task, a high-level discussion has been done to get a sense of how things work to make those estimates.
* Some of the [literature](https://www.youtube.com/watch?v=fNBkqOmdT4g) covered as part of the project talks about methods used to transition from concentrations to emissions. A “bottom up inventory” and a so-called inversion process is used to estimate emissions using concentration.
* A very common approach to validate the methane total column retrieval from SWIR region, is to compare the retrieval to co-located ground-based measurements of Total Carbon Column Observation Network (TCCON). Additionally, high resolution airborne imagery is used to make the validations.
* In order to visualize the trend in methane [data](https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-methane?tab=form) over several days (video of plots), or to observe potential gaps and patterns in a single plot, python Geo Pandas Library was used. The observations from GOSAT, SCIAMACHY and TROPOMI were plotted on the world map. A python file, along with the GOSAT dataset has also been added to the repository. Alternatively, Matplotlib’s Basemap tool can also be used for the same purpose.
* Gaps in methane observations are characterized not only by spatial and temporal gaps, but also due to clouds, as most satellites estimating methane in the SWIR rely on [cloud free conditions](https://www.youtube.com/watch?v=k0I-0ast4Uw) to make measurements. Satellites using TIR can be used to extend imagery to night time and over the ocean.
* A combination of imagery from more than one satellite is used to direct satellites like TROPOMI and GOSAT to traverse through cloud free regions in their path. Machine Learning solutions combined with geospatial imagery can be used to fill up these gaps. The possible gaps, the issues with existing satellites have been listed in the document containing all the literature.

Future Work:

* Locating point sources of methane emissions using available methane products and satellite imagery (high resolution / hyper-spectral) is a great potential application of machine learning tools.
* Estimating measurements for locations with cloud cover using TIR and machine learning is another scope of work.