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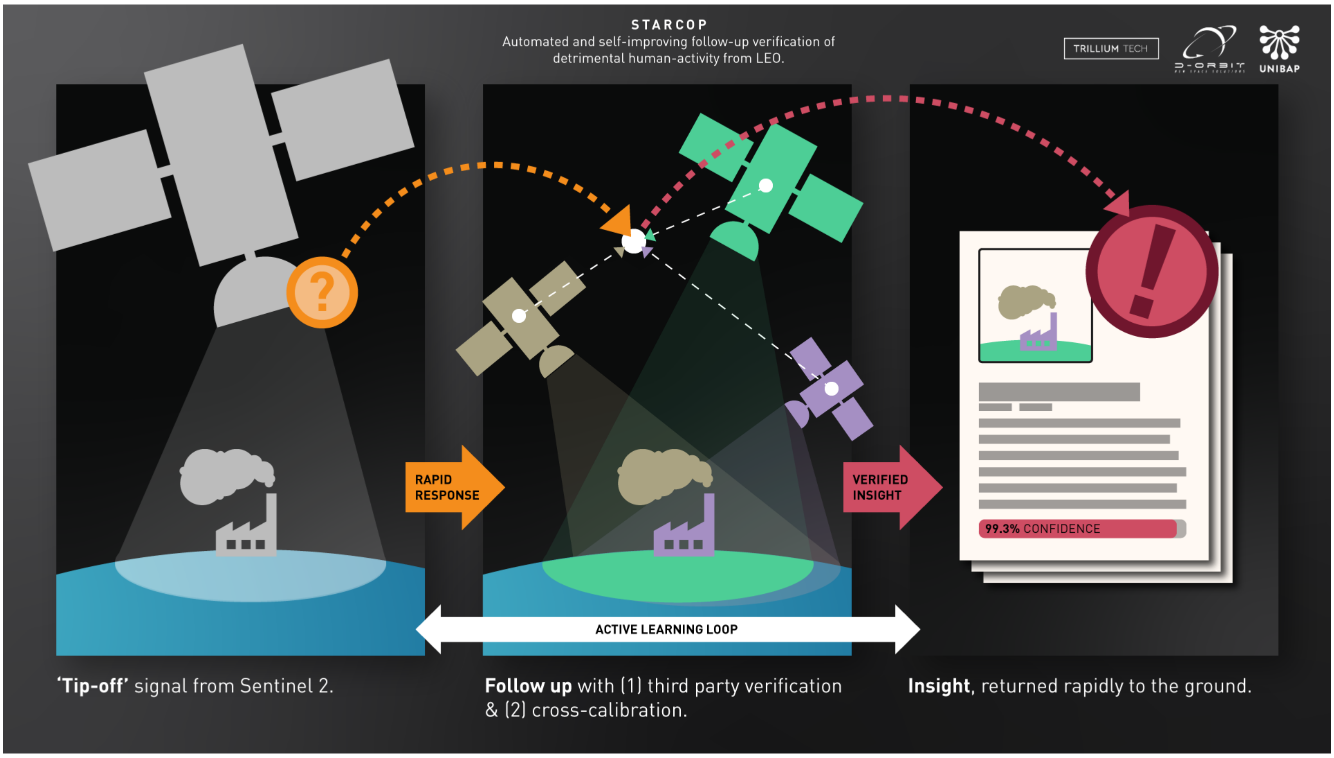

STARCOP: Automated and self-improving follow-up verification of detrimental human-activity from LEO

Executive summary

Activity type: Early Technology Development

ESA Cognitive Cloud Computing in Space Campaign

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Activity summary:

'STARCOP' is an initiative to use ML and multiple satellites of diverse detection capabilities to quickly detect methane leaks onboard and notify them in near-real-time. In this project we have developed ML models for automatic detection of methane in hyperspectral and multispectral

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imagery. Our hyperspectral model (HyperSTARCOP) is able to capture more than 90% of plumes in our test data while reducing the false positive rate by 39% when compared to state-of-the-art models. In addition, we show for the first time automatic multispectral approaches that are able to capture large plumes in Sentinel-2 data and WorldView-3 data.

Executive Summary

Methane leaks detection from anthropogenic sources has recently observed increased attention, as it has been selected as one of the most viable targets for preventing catastrophic scenarios in temperature increase due to climate change related effects (UN Global Methane Assessment). Given methane's short atmospheric lifetime, its removal from the atmosphere would have a very rapid effect in reducing global warming. Large leaks, the so-called super-emitters, have been shown to contribute disproportionately to the concentration of methane in the atmosphere: Lavaux et al **[1]** recently showed that 12% of all oil and gas (O&G) methane emissions are episodic ultra-emission events that in many cases are **caused by equipment failures in oil rigs, pipelines or well pads**. Additionally, those emissions are highly underestimated: for instance, Alvarez et al. **[2]** showed that **O&G supply chain emissions in 2015 were 60% higher** than bottom up estimates from the United States Environmental Protection Agency.

'STARCOP' is an initiative to use ML and multiple satellites of diverse detection capabilities to **quickly detect methane (CH4) leaks onboard and notify them in near-real-time**. The main objective of this study carried out in this project is to **assess the feasibility of an onboard methane detection system working on different types of instruments** to rapidly retrieve methane leaks.

The proposed 'tip and cue' system to be analysed will have two onboard models. The first model (tipping-off model) processes data from general purpose instruments with worse spatial/spectral resolution (such as Sentinel-2 or WorldView-3) to find potential methane leaks. Those detections will be used to task a high spectral resolution sensor on the receiving spacecraft –or other specialist spacecraft– to acquire additional insight over the area of interest. This hyper-spectral cueing signal will be processed by a second model (cueing model) that will (1) send the plume data back to Earth in case of positive detection for reporting and infringement of the COP26 agreements, and (2) use the signal as a feed for a continual-learning mechanism that improves the accuracy of the tipping-off model over time.

Deploying STARCOP will require multiple small steps to accomplish the vision. **In this project we focused on prototyping STARCOP to do automatic retrievals of methane**. In particular, we focus on developing AI models that can be run onboard to retrieve methane from multispectral and hyper-spectral cameras. It should be taken into account that m**ethane detection from space is still an open research problem:** current *state-of-the-art* models working on hyperspectral imagery still produce a high number of false positives whereas existing multispectral approaches are not even automatic and rely heavily on manual inspection. Additionally, accurate plume detection greatly depends on spatial and spectral resolution of the satellite imaging instrument and favourable surface conditions (e.g. it's easier to detect plumes over bright and homogeneous surfaces). ML has the potential to overcome these limitations but large annotated datasets are needed to train those models.

In this project, we have collected and curated two datasets with manually verified annotated methane plume masks: the **STARCOP-AVIRIS** dataset and the **STARCOP-SEN2** dataset.

The **STARCOP-AVIRIS dataset**, which was the initial proposal of the project, is a curated large (5.5TB) dataset of manually verified methane plumes from hyperspectral (AVIRIS-NG) aerial campaigns in the Permian basin. With this dataset we have developed models for hyperspectral sensors (see methodology section) and also models for multispectral sensors by simulating images using the spectral response function of known satellites. This allows us to develop ML models for existing and potential forthcoming satellites reusing the ground truth labels present in the original dataset. We show that the hyperspectral models (called **HyperSTARCOP**) have significantly better accuracy than other state-of-the-art models (mag1c from Foote et al.**[3]**). We also show for the first time automatic multispectral approaches that are able to automatically detect plumes. The model trained in simulated WV3 images from the STARCOP-AVIRIS dataset, **MultiSTARCOP-WV3,** is able to detect 50% of large (>1000kg/h) and 70% of very large (>3000kg/h) plumes using WorldView-3 SWIR bands (see Fig. 1).

Additionally, we show that using the **STARCOP-AVIRIS** dataset plumes are not visible in simulated Sentinel-2 images. This agrees with very recent studies **[13,14]** which have shown retrievals mainly in areas with favourable surface conditions (bright homogeneous surfaces) or for very strong emissions as shown very recently.

As segmentation of plumes in Sentinel-2 imagery is one of the project goals, we collected another dataset **STARCOP-SEN2** of real Sentinel-2 images with validated plumes over two areas with persistent emissions: Turkmenistan and Algeria. Plume locations in Turkmenistan were taken from the work of Irakulis-Loritxate et al. **[13]** while plume locations in Algeria are provided by personnel in the United Nations Environmental Program (UNEP). Using **STARCOP-SEN2**, we developed **MultiSTARCOP-SEN2,** the first automatic model that is able to detect plumes in Sentinel-2 images over these regions without requiring multi-temporal information.

Project achievements

1. We have collected and curated two datasets with manually verified and annotated methane plume masks: the **STARCOP-AVIRIS** dataset and the **STARCOP-SEN2** dataset.
2. Developed models for automatic methane plume segmentation of AVIRIS, WorldView-3 and Sentinel-2 images.
3. Developed automated models for hyperspectral sensors (**HyperSTARCOP**), that produce better results than previous *state-of-the-art*.
4. Developed automated models for multispectral sensors. We created models for WorldView-3 (**MultiSTARCOP-WV3**) using the STARCOP-AVIRIS dataset and for Sentinel-2 (**MultiSTARCOP-SEN2**) using the STARCOP-SEN2 dataset.
5. Compared multispectral models against hyperspectral ones in the same dataset (STARCOP-AVIRIS) providing consistent insights of sizes of plumes that can be retrieved.

References

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