# Monitoring Carbon Dioxide from Space: Retrieval Algorithm, Cal/Val and Application

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Carbon dioxide ($CO_2$) is the major anthropogenic greenhouse gas, but substantial uncertainties remain about the magnitude, location, and durability of natural fluxes. Atmospheric $CO_2$ has increased from a pre-industrial value of about 280 parts per million (ppm) to more than 380 ppm today. Our current understanding of the temporal and spatial distribution of atmosphere $CO_2$ is largely informed by a sparse network of in situ high precision/accuracy measurements of $CO_2$ concentration at the surface. The sparseness of this network compromises our ability to quantify regional fluxes of $CO_2$, particularly at low latitudes and high northern latitudes where there are only a few measurement sites. Detailed computer model studies indicate that uncertainties in the atmospheric $CO_2$ balance could be significantly reduced with global, unbiased space-borne measurements of column-average $CO_2$ dry-air mixing ratio ($XCO_2$) that had a single measurement precision of 1%.

Thermal infrared wavelengths (e.g., already available from AIRS, TES, and IASI) are most sensitive to $CO_2$ changes in the middle and upper troposphere, with far less sensitivity to near surface $CO_2$. Short-wave infrared (SWIR) wavelengths are more sensitive to $CO_2$ changes in the lower troposphere and are therefore more suitable for estimating the magnitude and geographical distribution of surface source/sinks.

The ESA SCIAMACHY/ENVISAT, launched in 2002, was the first space-based instrument to measure $CO_2$ SWIR bands but due to its low spectral resolution the precision and accuracy of the resulting $XCO_2$ data is limited and thus do not improve upon the surface data. TANSO/GOSAT is the first high spectra resolution Fourier Transform Spectrometer (FTS) which was successful launched after the NASA OCO launch failure. Calibration problems currently limit the full science exploitation of the TANSO spectral data.

The Chinese Carbon Satellite (TanSat, Tan - carbon in Chinese) Mission has been proposed by MOST and CAS. TanSat will be launched in the 2015 time frame with a hyper-spectral $CO_2$ sounder and a Clouds and Aerosols Polarization Imager (CAPI) on board. The $CO_2$ sounder incorporates three high resolution grating spectrometer to make coincident measurements in the $O_2$ A-band (0.76 0700m) and SWIR $CO_2$ absorption bands (1.61 and 2.06 0700m) from reflected sunlight. CAPI is a wide field of view moderate resolution imaging spectrometer. It covers ultraviolet, visible, and near infrared bands (0.38, 0.67, 0.87, 1.38 and 1.610700m) and two polarization channels at 0.67, 1.64 0700m.

In this proposal we will compare and interpret retrieval and forward model results from simulations for different geophysical scenarios. We will carry out retrieval experiments using GOSAT data, compare and interpret retrieval results from subsequent validation with TCCON and Chinese ground-based measurements. Additional error estimation and analysis will be carried out during the program. The sources and sink inventory of $CO_2$ will be investigated by using Observing System Simulation Experiment (OSSE) and data assimilation tools. This project is a joint project of Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences (CAS) and Earth Observation Science, Space Research Centre, Department of Physics & Astronomy University of Leicester and the School of GeoSciences at University of Edinburgh. No extra funding for this project is presently available. Work by both teams will be part of the normal scientific research. Chinese team is funded by MOST and CAS, from which a limited amount of funding could be used to support international cooperation research. University of Leicester and University of Edinburgh will

carry out the work using existing University resources and whenever possible by synergies with on-going research projects funded by NERC, ESA and the EU.

# 利用卫星监测二氧化碳：反演算法，验证和应用

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CO2（二氧化碳）是主要的人为排放温室气体。在自然界中，人类活动对CO2源汇的大小、位置和持续时间的估计仍存在较大不确定性。大气中的CO2含量（干空气混合比）从工业革命前280 ppm持续增涨至今天380 ppm。目前，大气CO2时空分布的研究主要依赖于分布稀疏的地基观测网的观测数据。虽然地基观测网能够提供高精度的近地面CO2浓度数据，但是全球站点分布稀疏的性质限制了区域CO2源和汇的定量评估，特别是在站点极少的低纬和高纬地区，这一劣势更为明显。数值模拟的研究结果表明：利用卫星观测，获取精度在1%以内的全球无偏差大气CO2干空气混合比（Xco2）将能够显著降低CO2源和汇评估的不确定性。

热红外波段（如：AIRS，TES和IASI等仪器）对对流层中层和上层CO2的变化最为敏感，且远高于对对流层低层CO2的敏感性；而短波红外波段对对流层低层CO2的变化极为敏感，因此基于短波红外的遥感反演产品更适用于估算地面CO2源和汇的强度及分布。欧洲空间局（ESA）于2002年发射SCIAMACHY/Envisat，是第一个基于卫星平台的短波红外CO2观测仪，但是由于其光谱分辨率较低，所获得的Xco2数据在准确度和精度方面不足以改进科学界对地面CO2源和汇的认知情况。日本于2009年成功发射TANSO/GOSAT, 是第一个基于卫星的短波红外高光谱分辨率傅里叶变换光谱仪。

中国碳卫星计划（TanSat）获得了科技部和中国科学院资助。TanSat将搭载高光谱分辨率CO2监测仪以及云和气溶胶偏振成像仪（CAPI），其中，CO2探测仪包含三个高光谱分辨率光栅光谱仪，可以综合利用 O2-A波段（0.76 μm）和CO2短波吸收波段（1.61和2.06μm）的大气后向散射的太阳辐射，对大气CO2含量进行定量监测；CAPI是一台中分辨率广角成像光谱仪，其波段覆盖了紫外、可见光和短波红外等光谱区间，其中包括了两个偏振波段。

该项目的合作双方，将致力于研究、比较在不同的观测条件下的正演和反演模拟计算结果；使用GOSAT数据进行反演试验，并利用TCCON和中国地基观测站的数据对反演结果进行验证，分析并解释验证结果；进行反演误差的估计和分析研究；利用观测模拟分析实验系统（Observing System Simulation Experiment, OSSE）和数据同化技术对大气CO2的源和汇进行研究。该项目将由中方的中国科学院大气物理研究所以及英方的Earth Observation Science, Space Research Centre, Department of Physics & Astronomy University of Leicester（来彻斯特大学物理与天文系空间研究中心地球观测科学组）和School of GeoSciences at University of Edinburgh（爱丁堡大学地球科学院）共同参与。该项目是常规科研项目，目前没有得到额外的项目经费支持，中方目前得到中国科学技术部863重大项目"全球二氧化碳监测科学实验卫星与应用示范"和中科院战略性先导专项"应对气候变化的碳收支认证及相关问题"提供的项目经费支持，但是其中只有有限的经费可以提供于本项目进行国际学术合作和交流；英方（University of Leicester 和 University of Edinburgh）将会利用已有的资源或者由NERC，ESA和EU等机构提供的科研经费支持本项目的执行。