SCISAT Status & Atmospheric Data Continuity and Improvement (ADCI)

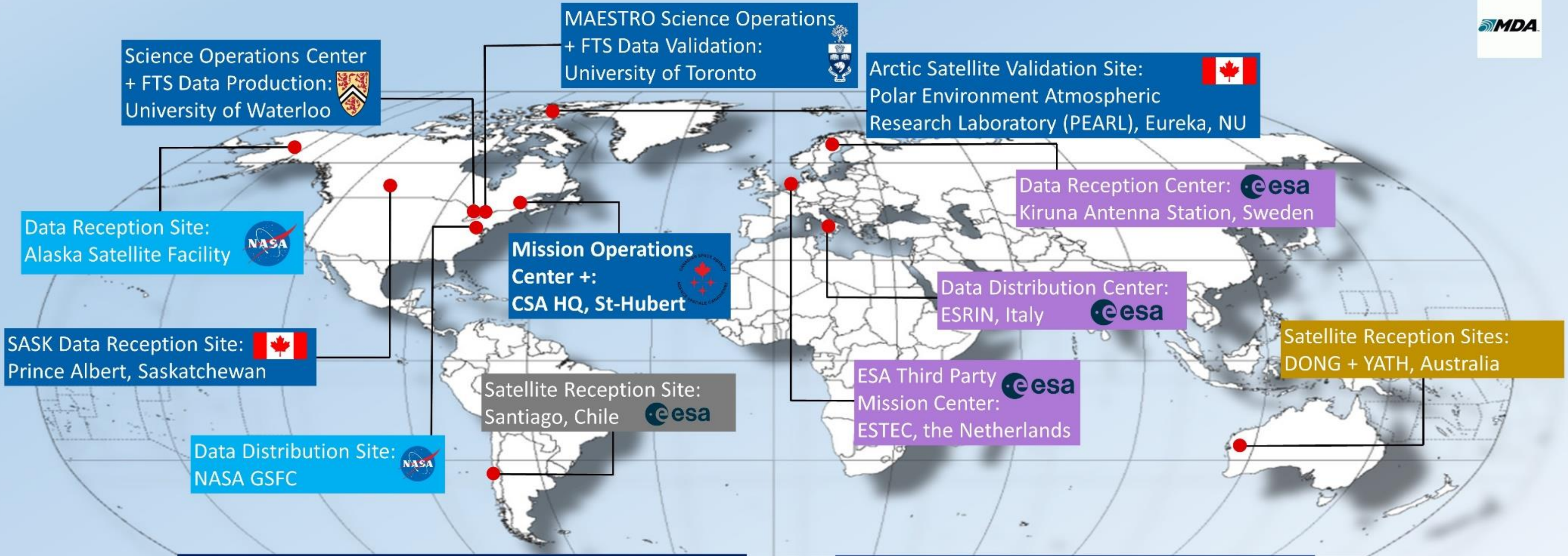
CEOS AC-VC-19 Meeting

Brussels, BE.

Date: 25 Oct. 2023

DR. M. DEJMEK
SUN-EARTH SYSTEM SCIENCES
SPACE UTILIZATION

SCISAT Global Mission Team



UNIVERSITY OF WATERLOO: SCISAT ACE-FTS TEAM


Peter Bernath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Johnny Steffen


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UNIVERSITY OF TORONTO: MAESTRO + VALIDATION


Kaley Walker


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20 YEARS OF ACE-FTS SCISAT DATA PRODUCTS

CANADIAN SPACE AGENCY · AGENCE SPATIALE CANADIENNE

LAUNCH

2003

2004

The V 1.0 Dataset Release

This version measures the profiles of 18 molecules: H_2O, O_3, N_2O, CO, CH_4, NO, NO_2, HNO_3, HF, HCl, N_2O_5, $ClONO_2$, CCl_2F_2, CCl_3F, COF_2, CHF_2Cl, HDO, SF_6, plus p-T.

2005

The V 2.0 and 2.1 Dataset Releases

Version 2.0 improved on the p-T retrieval approach. The following molecules were added: HCN, CH_3Cl, CF_4, C_2H_2, C_2H_6, and N_2. With v2.1, the problem of unphysical oscillations was addressed and the retrievals of ClO were added.

2005

The V 2.2 Dataset Release

This version added the retrieval of the following weak absorbers: HOCl, H_2O_2, and HO_2NO_2. The retrieval of subsidiary isotopes also began with this version, including $^{13}CH_4$, CH_3D, $H_2{}^{18}O$, $H_2{}^{17}O$, and HDO. More than 30 trace gases are retrieved.

2010

The V 3.0 Dataset Release

This version provides profiles of temperature and VMRs of more than 30 atmospheric trace gas species, as well as 20 subsidiary isotopologues of the most abundant trace atmospheric constituents over a latitude range of ~85°N to ~85°S. This update provides a dataset that is more appropriate for studying longer-term changes and investigating trends.

2014/16

The V 3.5 and 3.6 Dataset Releases

Version 3.5 fixes data issues with v3.0 from 2010 onward, and incorporates research products from v3.0. The microwindow sets for C_2H_6 and HCFC-22 have been adjusted, and the shape of the CO VMR profile for altitudes above ~120 km has been changed. Version 3.6 data cover November 2012 onward.

2019/20/21

The V 4.0, 4.1, and 4.2 Dataset Releases

Version 4.0 provides ten atmospheric constituents that were not included in v3.0 (acetone, PAN, HFC-23, CH_3CN, HFC-134a, ClO, SO_2, $^{15}NO_2$, ^{17}OOO, $H^{15}NO_3$, and), as well as CO_2 below 18 km. This creates a total of 44 molecules and 24 isotopologues. The primary purpose of v4.1 was to improve on the N_2 continuum analysis. v4.2 was produced on a different computing environment.

2022/23

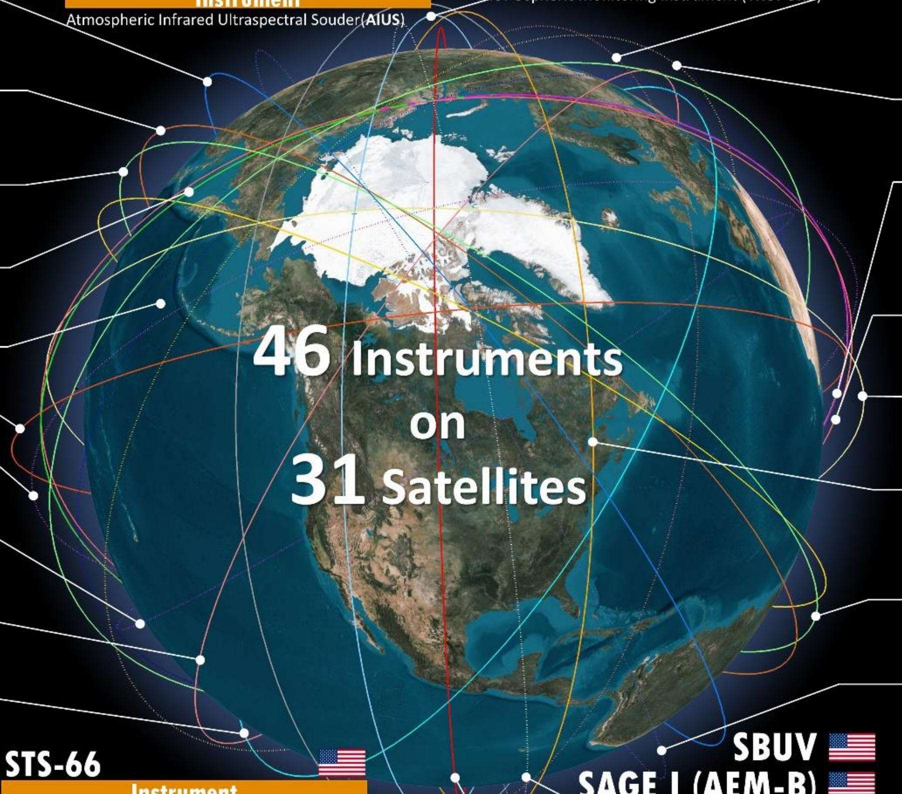
The V 5.0, 5.1, and 5.2 Dataset Releases

Version 5.0 adds HOCl and HFC-32, plus line of sight winds as new data products. It raises the upper altitude limits for SO_2 (from 24 km to 40 km) and ClO (from 30 km to 40 km). It also updates the spectroscopy to the most recent information, implements improvements in the Level 1 data (the atmospheric transmittances), and models the contribution of the ACE-FTS field of view in the analysis. v5.1 addressed software issues encountered during v5.0 processing. For v5.2, problem occultations were identified and filtered.

2023

20^{th} ANNIVERSARY

SPACE-BASED INSTRUMENTS VALIDATED, COMPARED OR CALIBRATED WITH SCISAT DATA



METEOP-A
Instruments
Infrared Atmospheric Sounding Interferometer (**IASI**)
Global Ozone Monitoring Experiment 2 (**GOME-2**)

TERRA
Instruments
Measurement of Pollution in the Troposphere (**MOPITT**)
Moderate Resolution Imaging Spectroradiometer (**MODIS**)

SPOT-3
Instrument
Polar Ozone and Aerosol Measurement II (**POAM II**)

CALIPSO
Instrument
Cloud-Aerosol Lidar with Orthogonal Polarization (**CALIOP**)

ERS-2
Instrument
Global Ozone Monitoring Experiment (**GOME**)

TSX

NIMBUS-7
Instrument
Limb Infrared Monitor (**LIMS**)

ERBS
Instrument
Stratospheric Aerosol and Gas Experiment II (**SAGE** II)

AIM
Instrument
Solar Occultation for Ice Experiment (**SOFIE**)

ISS
Instruments
Stratospheric Aerosol and Gas Experiment III (**SAGE III**)
Superconducting Submillimeter-Wave Limb Emission Sounder (**SMILES**)
Solar Spectral irradiance measurements (**SOLSPEC**)

ExoMars TGO
Instrument
Nadir and Occultation for Mars Discovery (**NOMAD**)
Atmospheric Chemistry Suite (**ACS**)

GaoFen-5
Instrument
Atmospheric Infrared Ultraspectral Souder(**AIUS**)

STS-66
Instrument
Atmospheric Trace Molecule Spectroscopy (**ATMOS**)

COSMIC (FORMOSAT-3)

GRACE

ICON
Instruments
Michelson Interferometer for Global High-Resolution Thermospheric Imaging (**MIGHTI**)

Sentinel-5P
Instruments
TROPOspheric Monitoring Instrument (**TROPOMI**)

SBUV

SAGE I (AEM-B)

SNOE

CHAMP

Odin
Instruments
Optical Spectrograph and InfraRed Imager System (**OSIRIS**)
Sub-millimeter Radiometer (**SMR**)

UARS
Instruments
Halogen Occultation Experiment (**HALOE**)
High Resolution Doppler Imager (**HRDI**)
Microwave Limb Sounder (**MLS**)
Wind Imaging Interferometer (**WINDII**)

ADEOS-II
Instrument
Improved Limb Atmospheric Spectrometer-II (**ILAS-II**)

AURA
Instruments
High Resolution Dynamics Limb Sounder (**HIRDLS**)
Microwave Limb Sounder (**MLS**)
Ozone Monitoring Instrument (**OMI**)
Tropospheric Emission Spectrometer (**TES**)

AQUA
Instrument
Atmospheric Infrared Sounder (**AIRS**)

GOSAT
Instrument
Thermal And Near-infrared Sensor for carbon Observation Fourier Transform Spectrometer (**TANSO-FTS**)

TIMED
Instrument
Sounding of the Atmosphere using Broadband Emission Radiometry (**SABER**)
TIMED Doppler Interferometer (**TIDI**)

SPOT-4
Instrument
Polar Ozone and Aerosol Measurement III (**POAM III**)

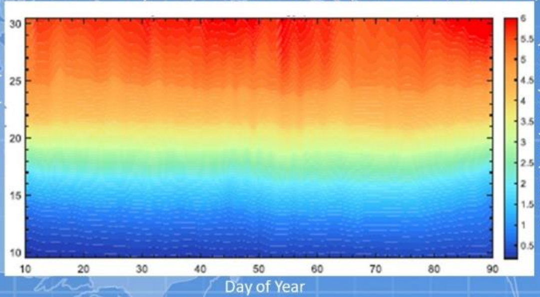
ENVISAT
Instruments
Global Ozone Monitoring by Occultation of Stars (**GOMOS**)
Michelson Interferometer for Passive Atmospheric Sounding (**MIPAS**)
SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (**SCIAMACHY**)

SNPP
Instrument
Ozone Mapping and Profiler Suite (**OMPS**)

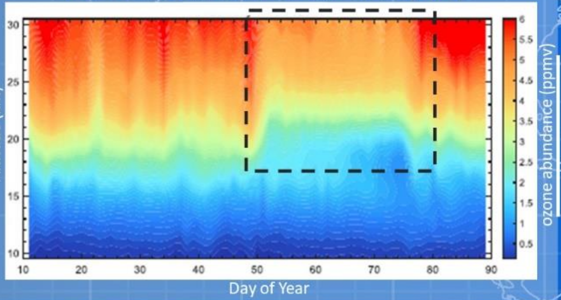
SCISAT Ozone Measurements

This image shows multi-year measurements of ozone over the Arctic taken by Canada's SCISAT satellite. These baseline concentrations for our planet are shown as a function of altitude and day of year (Jan-Mar). Ozone levels are consistently lower in the troposphere (blue), increase starting at 17 km (green), and reach a maximum in the stratosphere (red).

Arctic Ozone Daily-Mean Measurements (2004-2019, not 2011)



Arctic Ozone Daily-Mean Measurements (2020)



This image shows measurements of Arctic ozone as a function of altitude from Jan-Mar 2020. Lower ozone values are seen over a 30 day period in Feb and Mar as compared to other days. This shows the record levels of Arctic ozone depletion in 2020.

Ozone depletion occurs over the Antarctic and Arctic in the springtime due to ozone depleting reactions. These occur due to a combination of UV radiation, cold stratospheric temperature, and chlorine (and bromine) from halogen source gases (CFCs, HCFCs, etc.).

Ozone and its Impact

"…Earth's protective ozone layer in the stratosphere…"

- Salawitch and McBride, Science 378, 6622, 2022

"The Montreal Protocol….was established…for protection of the environment and human health against excessive amounts of harmful ultraviolet-B…radiation reaching the Earth's surface due to a reduced UV-B-absorbing ozone layer."

"Increasing concentrations of greenhouse gases are partly responsible for enhanced atmospheric circulation resulting in a downward transport of additional ozone ('good' UV-B-absorbing ozone) from the stratosphere to the troposphere ('bad' ozone, part of smog)."

"…the ozone layer will be increasingly influenced by emissions of GHGs…These trends are highly likely to modify the amount of UV radiation reaching the Earth's surface with implications for the effects on ecosystems and human health."

- UNEP "Environmental Effects Assessment Panel: 2022"

Ozone Depletion

"Recovery of ozone in the upper stratosphere is progressing. Total column ozone (TCO) in the Antarctic continues to recover, notwithstanding substantial interannual variability in the size, strength, and longevity of the ozone hole."

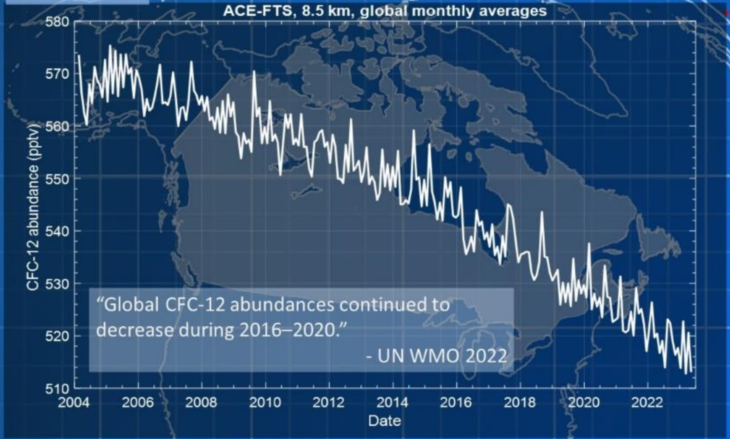
"New results since the 2018 Assessment support the findings reported at that time that the Antarctic ozone hole has generally diminished in size and depth since the year 2000… September is the period when stratospheric ozone over Antarctica shows the largest sensitivity to decreasing ODSs, and when Antarctic ozone recovery rates are the strongest and the most statistically significant."

"In the Arctic, observed trends in ozone remain small compared to the large year-to-year variability…Arctic total ozone reached exceptionally low values in spring 2020."

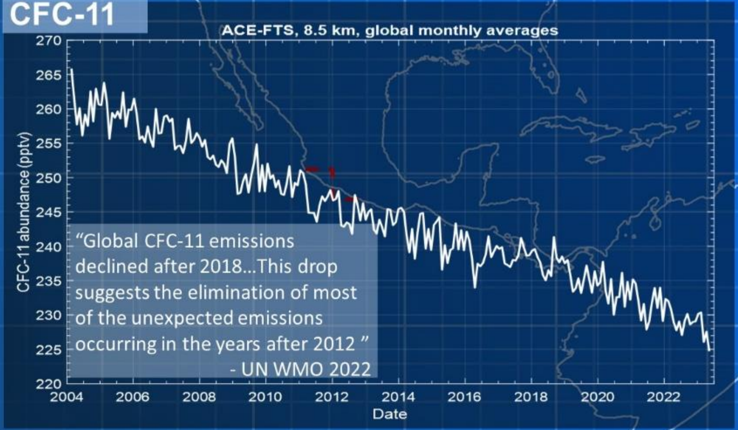
- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

SCISAT CFC Measurements

CFC-12



CFC-11



What are CFCs (chlorofluorocarbons)?

"Ozone depletion is caused by human-related emissions of ozone-depleting substances (ODSs) and the subsequent release of reactive halogen gases, especially chlorine and bromine, in the stratosphere. ODSs include chlorofluorocarbons (CFCs) ..."

"These ODSs are long-lived (e.g., CFC-12 has a lifetime greater than 100 years) and are also powerful greenhouse gases (GHGs)."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

Impact on Atmosphere

"The unreported production of CFC-11 over 2012–2019 is estimated to delay polar ozone return to 1980 values by up to 3 years. For global total column ozone, the delay is about 1 year."

"The CFC-11 production that led to these observed unexpected emissions has most likely increased global banks."

"The total direct radiative forcing of CFCs continues to be distinctly higher than that of HCFCs, with CFCs contributing around 68% of the total forcing from ODSs."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

The decline of these ozone depleting substances is one of the success stories of the UN Montreal Protocol.

Decreasing Concentrations

"As a consequence of Montreal Protocol controls, the stratospheric concentrations of anthropogenic chlorine and bromine are declining."

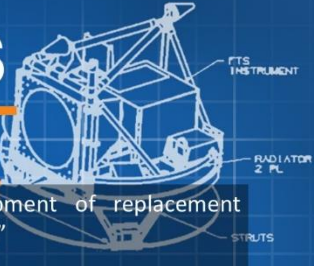
"Total chlorine entering the stratosphere from controlled and uncontrolled ODSs declined by 11.5% between the 1993 peak and 2020... This long-term decrease was largely driven by decreasing abundances of... CFCs."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

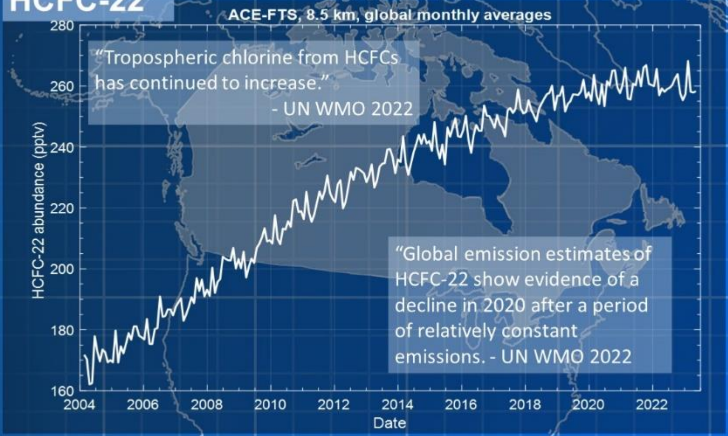
"SCISAT is currently the only satellite in the world to measure CFC profiles from space."

- SCISAT Science Team, 2020

SCISAT HCFC MEASUREMENTS



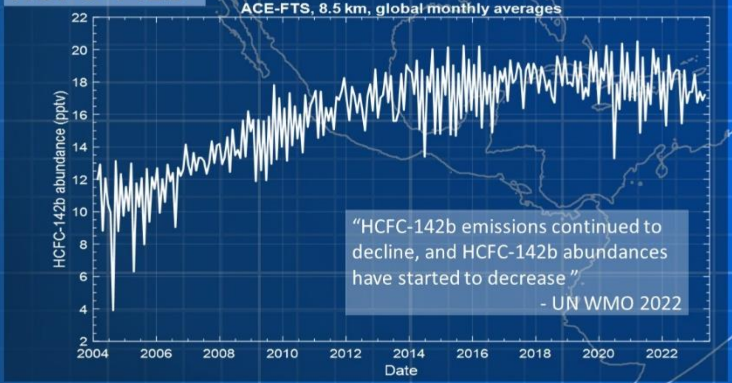
HCFC-22



"Tropospheric chlorine from HCFCs has continued to increase."
- UN WMO 2022

"Global emission estimates of HCFC-22 show evidence of a decline in 2020 after a period of relatively constant emissions. - UN WMO 2022

HCFC-142b



"HCFC-142b emissions continued to decline, and HCFC-142b abundances have started to decrease."
- UN WMO 2022

WHAT ARE HCFCS (HYDROCHLOROFLUOROCARBONS)?

"The Montreal Protocol's control of ODSs stimulated the development of replacement substances, firstly HCFCs and then HFCs, in a number of industrial sectors."

"Hydrofluorocarbons (HFCs), widely used in the air conditioning and refrigeration sectors, are now controlled under the Kigali Amendment of the Montreal Protocol."

"ODSs include…hydrochlorofluorocarbons (HCFCs)…"

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

"SCISAT is currently the only satellite in the world measuring HCFCs."
- SCISAT Science Team, 2020

IMPACT ON ATMOSPHERE

"TFA, a breakdown product of some HFCs, HCFCs, HFOs and HCFOs, is a persistent chemical with potential harmful effects on animals, plants, and humans."

"The current combined GWP-weighted emissions of CFCs plus HCFCs are comparable to those of HFCs."
- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

LEVELLING OFF CONCENTRATIONS

"During the period 2016–2020, the observed rate of decline in tropospheric chlorine due to controlled substances was 15.1 ± 2.45 ppt chlorine/year, which is larger than during the 2012–2016 period."

"Combined emissions of the major HCFCs have declined since the previous Assessment. Emissions of HCFC-22 and HCFC-142b likely declined between 2016 and 2020."

"The calculated total direct radiative forcing due to CFCs, HCFCs…decreased by 0.006 W/m² since 2016 … This forcing is approximately 16% of the radiative forcing of CO_2.
- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

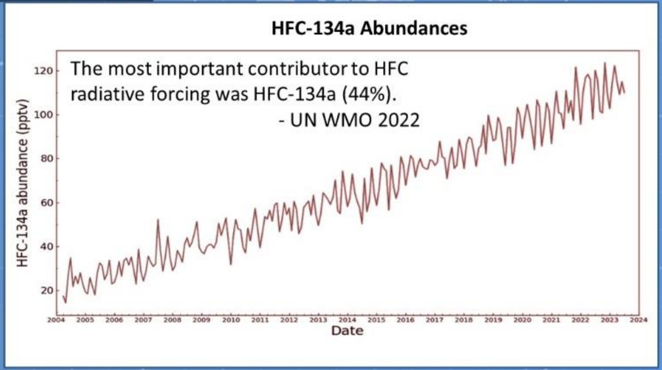
Canadian Space Agency / Agence spatiale canadienne

***radiative forcing:** measure of the warming of the Earth's atmosphere and surface due to greenhouse gases emitted from human activities.

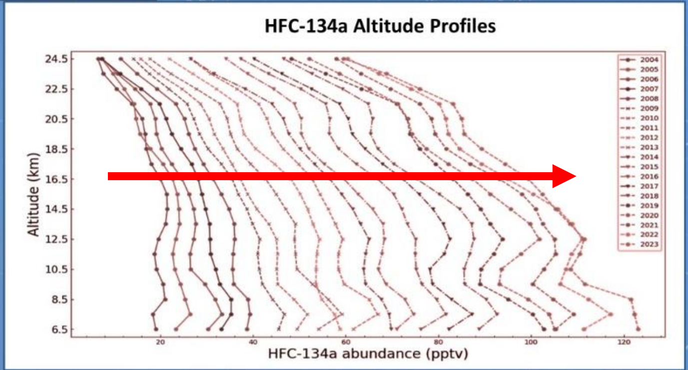
Canada

SCISAT HFC MEASUREMENTS

HFC-134a



HFC-134a



WHAT ARE HFCS (HYDROFLUOROCARBONS)?

"Hydrofluorocarbons (HFCs) have been increasingly produced and used in applications such as refrigeration, air-conditioning, and foam blowing following the phasedown of ozone-depleting substances (ODSs)."

"Hydrofluorocarbons (HFCs) do not contain ozone-depleting chlorine or bromine. Similar to long-lived CFCs and HCFCs, some HFCs have high global warming potentials."

"Compliance with the 2016 Kigali Amendment to the Montreal Protocol, which requires phase down of production and consumption of some hydrofluorocarbons (HFCs), is estimated to avoid 0.3–0.5°C of warming by 2100. This estimate does not include contributions from HFC-23 emissions."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

"SCISAT is the only satellite in the world to measure HFCs from space. Furthermore, no satellite currently under development is capable of measuring HFCs."

- SCISAT Science Team, 2020

INCREASING CONCENTRATIONS

"The radiative forcing due to HFCs is currently small, and the Kigali Amendment was designed to avoid uncontrolled radiative forcing growth in coming decades."

"Global atmospheric abundances and emissions of most HFCs are increasing."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

IMPACT OF HFC-134a

"HFC-134a is the most abundant HFC and contributes the most to total HFC radiative forcing. Its lifetime in the atmosphere is approximately 14 years, and its 100-year Global Warming Potential (GWP) is approximately 1470."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

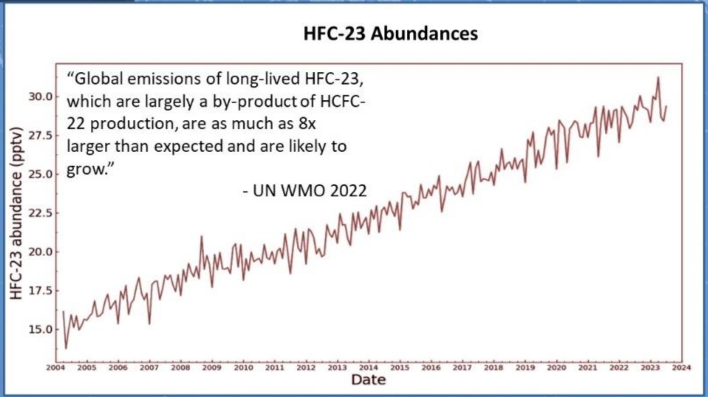
Canadian Space Agency · Agence spatiale canadienne

***radiative forcing:** measure of the warming of the Earth's atmosphere and surface due to greenhouse gases emitted from human activities.

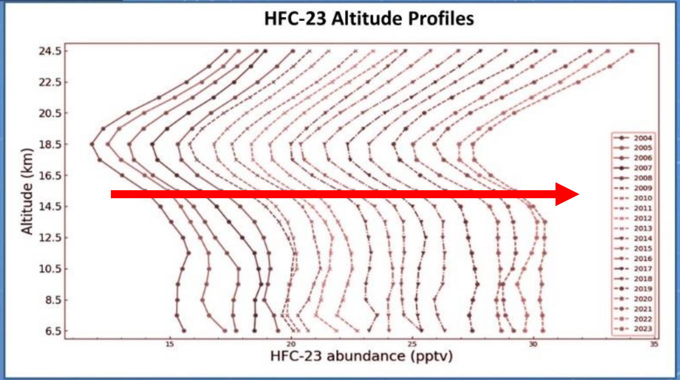
Canada

SCISAT HFC Measurements

HFC-23



HFC-23



What are HFCs (hydrofluorocarbons)?

""Hydrofluorocarbons (HFCs) have been increasingly produced and used in applications such as refrigeration, air-conditioning, and foam blowing following the phasedown of ozone-depleting substances (ODSs)."

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- UN WMO "Scientific Assessment of Ozone Depletion: 2022

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"SCISAT is the only satellite in the world to measure HFCs from space. Furthermore, no satellite currently under development is capable of measuring HFCs."

- SCISAT Science Team, 2020

Increasing Concentrations

"The radiative forcing due to HFCs is currently small, and the Kigali Amendment was designed to avoid uncontrolled radiative forcing growth in coming decades."

"Global atmospheric abundances and emissions of most HFCs are increasing."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

UN Montreal Protocol: Kigali Amendment

"The Kigali Amendment, which came into force in January 2019 for parties who ratified the Amendment, seeks to limit the production and consumption of a selection of HFCs. For HFC-23, the Kigali Amendment seeks to limit emissions formed as a by-product of HCFC (hydrochlorofluorocarbon) and HFC production to the extent practicable using approved technologies."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

*GWP: a metric for determining contribution of a substance to climate warming relative to CO_2 (CO_2 has a GWP equal to 1).

SCISAT Monitoring of Essential Climate Variables

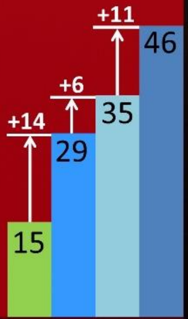
The Paris Climate Agreement is expected to reduce these Greenhouse gases (GHGs)

"Parties shall account for their nationally determined contributions. In accounting for anthropogenic emissions and removals… Parties shall promote environmental integrity, transparency, accuracy, completeness, comparability, and consistency…"
[Art. 4.13, UN Paris Agreement, 2016]

Carbon Dioxide CO2

"Carbon observations deserve very special attention because the increasing concentrations of CO_2… play a central role in driving global climate change."

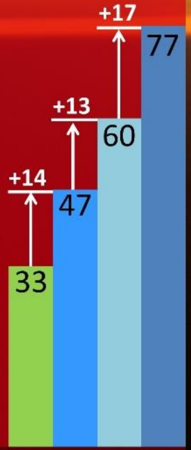
90 (authors)
48 (affiliations)
14 (countries)



Methane CH4

"Methane is the second most important anthropogenic greenhouse gas…"

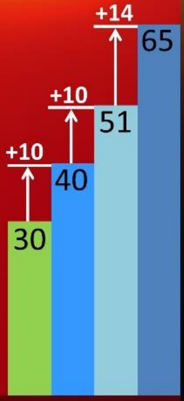
203 (authors)
82 (affiliations)
21 (countries)



Nitrous Oxide N2O

"N_2O is currently the third most important long-lived greenhouse gas contributing to radiative forcing…"

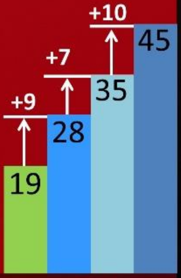
152 (authors)
64 (affiliations)
15 (countries)



Chlorofluorocarbons CFCs

"The ozone depletion over Antarctica results from… ozone depleting chemicals… in particular chlorofluoro-carbons (CFCs)."

60 (authors)
27 (affiliations)
12 (countries)



Ozone O3

"…[Stratospheric] ozone is vital for life on Earth: it shields humans, flora and fauna from harmful UV light from the Sun…"

384 (authors)
132 (affiliations)
24 (countries)

LEGEND: The # of SCISAT-related publications from 2003-14 (Mar); # of publications from 2003-17 (Aug); # of publications from 2003-20 (Aug); # of publications from 2003-23 (Mar); # Authors involved in SCISAT-related studies for the period 2020-23; # Affiliations for the period of 2020-23; # Countries for the period of 2020-23.

SCISAT CO_2 MEASUREMENTS

IMPACT OF CO_2 ON OZONE

"Increasing concentrations of the GHGs carbon dioxide (CO_2) and methane (CH_4) during this century will cause global ozone levels to increase beyond the natural level of ozone observed in the 1960s, primarily because of the cooling of the upper stratosphere and a change of the stratospheric circulation."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

WHAT IS CO_2?

"Greenhouse gases are gases in the atmosphere such as water vapour, carbon dioxide, methane and nitrous oxide that can absorb infrared radiation, trapping heat in the atmosphere."

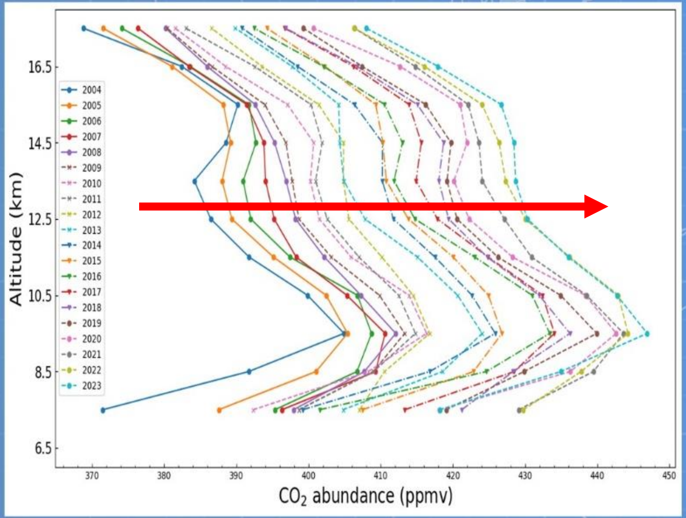
- IPCC Updates Methodology for Greenhouse Gas Inventories, 2019

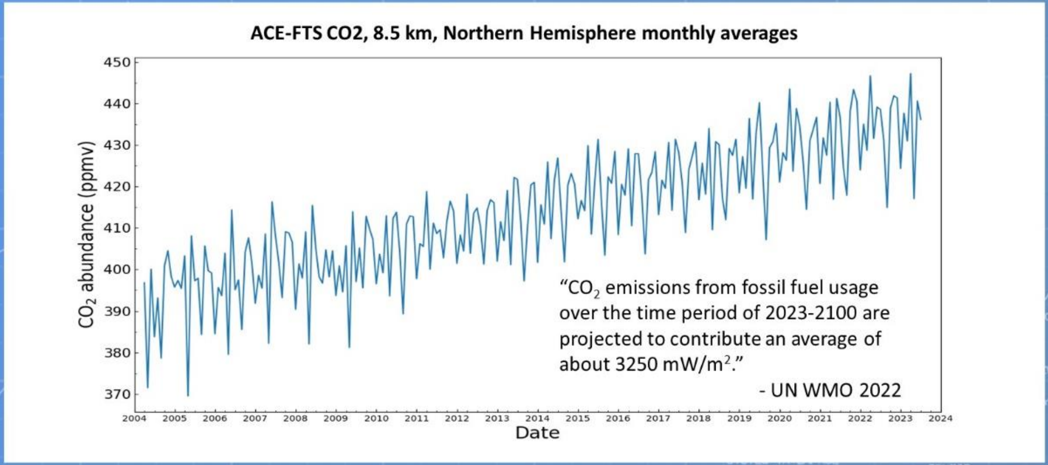
"Three major greenhouse gases—CO_2, CH_4, and N_2O—cause changes in stratospheric chemistry and dynamics that can affect O_3... Increases in CO_2 tend to increase global stratospheric column ozone. These gases have increased over the industrial era and continue to increase."

"Preindustrial (in 1750) mole fractions are assumed to be zero for most gases... For comparison, the radiative forcing due to CO_2 was approximately 2111 mW/m^2 in 2020."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

CO_2 profiles for May, 2004-2023, region 45N-70N (Over Canada)





SCISAT CH_4 MEASUREMENTS

IMPACT OF CH_4 ON OZONE

"CH_4 and N_2O cause the release of chemicals into the stratosphere that catalytically produce and destroy ozone."

"Our ability to accurately predict future changes in the ozone layer continues to be limited more by uncertainties in the future levels of CH_4, CO_2, and N_2O than by uncertainties in the levels of ODSs."

"Increasing concentrations of the GHGs...methane (CH_4) during this century will cause global ozone levels to increase beyond the natural level of ozone observed in the 1960s, primarily because of the cooling of the upper stratosphere and a change of the stratospheric circulation."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

WHAT IS CH_4?

"Greenhouse gases are gases in the atmosphere such as water vapour, carbon dioxide, methane and nitrous oxide that can absorb infrared radiation, trapping heat in the atmosphere."

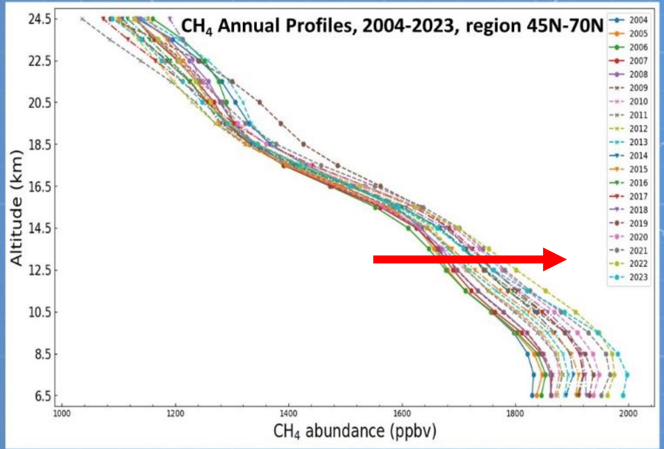
- IPCC Updates Methodology for Greenhouse Gas Inventories, 2019

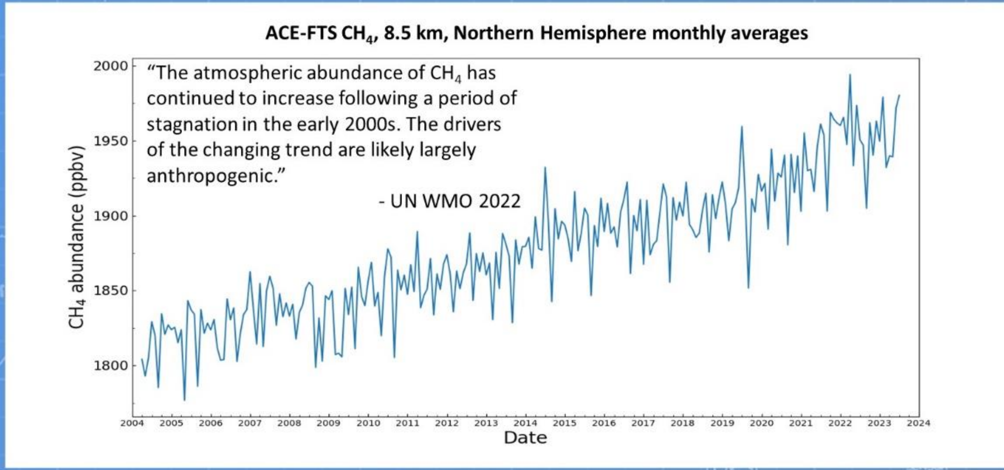
"Increases in CH_4 tend to increase global stratospheric column ozone. These gases have increased over the industrial era and continue to increase."

"The influences of CH_4 and N_2O occur primarily through their roles as chemical reagents in the atmosphere."

"CH_4 increased, on average, by 9.3 ± 2.4 ppb/year between 2014 and 2019."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"





SCISAT N_2O MEASUREMENTS

WHAT IS N_2O (NITROUS OXIDE)?

"The influences of CH_4 and N_2O occur primarily through their roles as chemical reagents in the atmosphere."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"

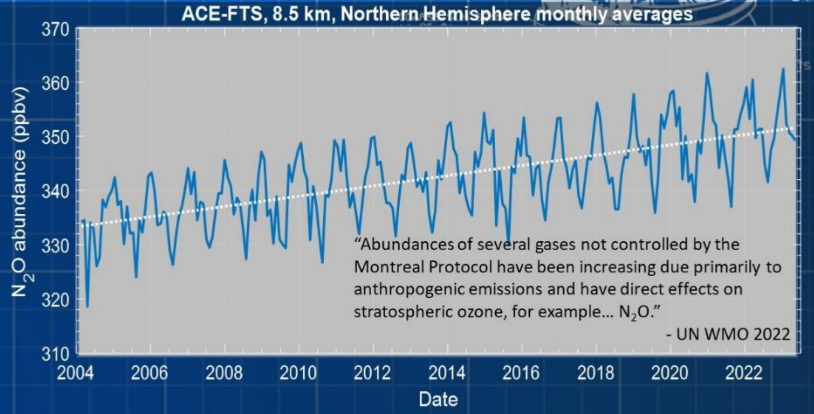
"Greenhouse gases are gases in the atmosphere such as water vapour, carbon dioxide, methane and nitrous oxide that can absorb infrared radiation, trapping heat in the atmosphere."

- IPCC Updates Methodology for Greenhouse Gas Inventories, 2019

"…two-thirds of … [N_2O's] anthropogenic flux comes from agriculture…"

"Governments have been unwilling to tackle N_2O … [as] some believe that the cost of mitigating N_2O will translate into higher food costs."

- Solomon et al, Nature Com 11, 4272, 2020



IMPACT OF N_2O ON OZONE

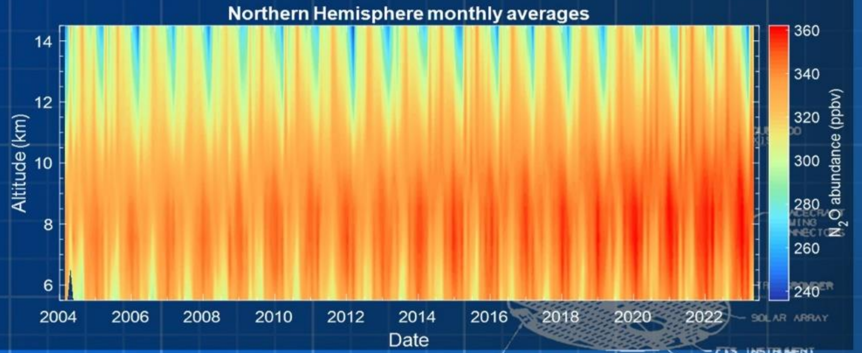
"The chemical effect of increasing concentrations of nitrous oxide (N_2O), another GHG, is to deplete stratospheric ozone…"

"Heightened concerns about influences on 21st century ozone include impacts of: further increases in nitrous oxide (N_2O)."

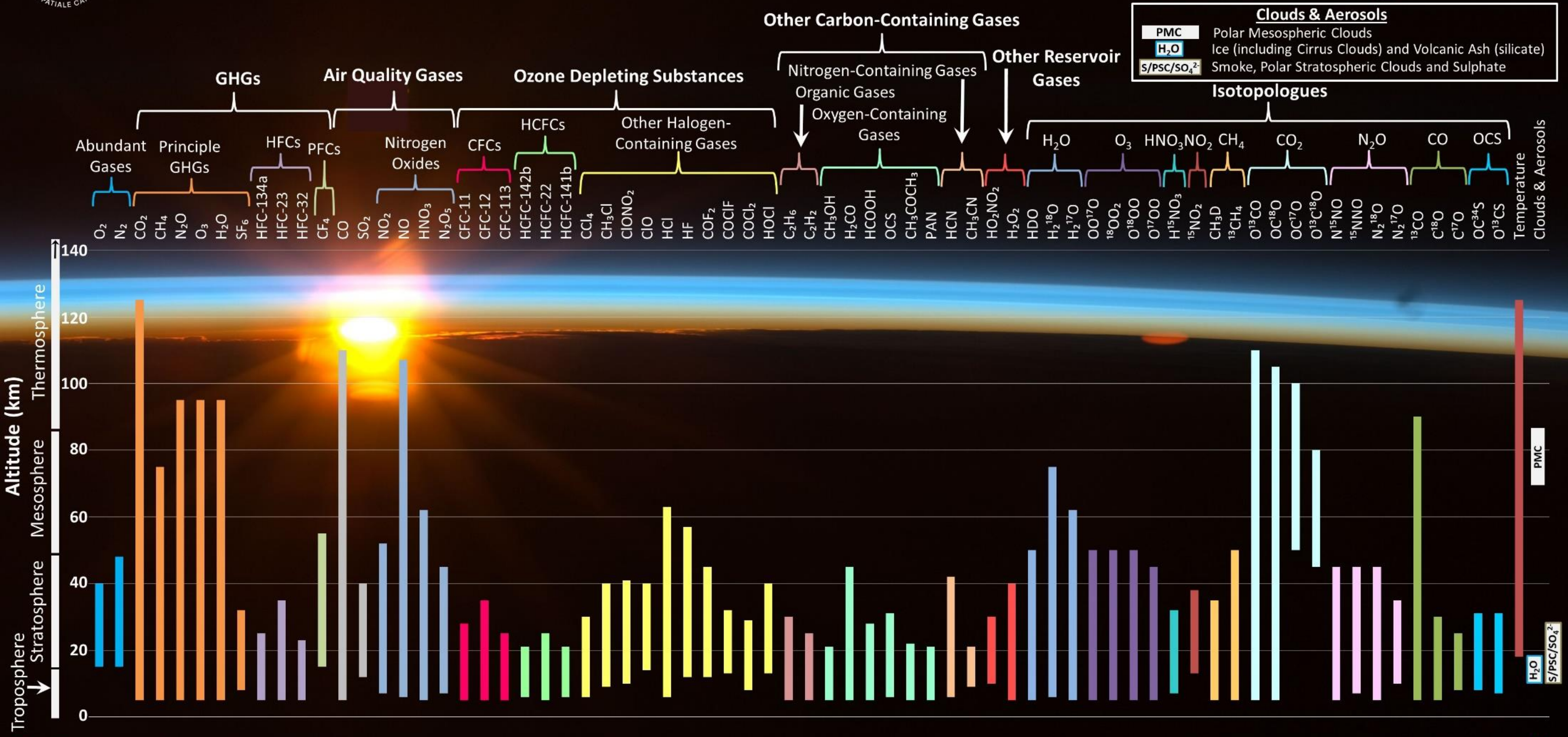
"Anthropogenic N_2O emissions in 2020, when expressed as a CFC-11-equivalent, were more than two times the ODP-weighted emissions from all CFCs in that year, and more than 20% of the CFC emissions in 1987, when the latter were at their peak."

"Mole fractions of N_2O, which is an ODS, continue to grow in the atmosphere, with growth rates exceeding some of the highest projections."

- UN WMO "Scientific Assessment of Ozone Depletion: 2022"



Atmospheric Profiles Measured by SCISAT



Canadian Space Agency Agence spatiale canadienne

SOURCE ► SCISAT Science Operation Centre, UofW, UofT, ACE-FTS Spectroscopy – Version 5.0, January 2022

Canada

Atmospheric Data Continuity Initiative

- The next few slides attempt to provide a summary of the work conducted from a CSA-led Phase 0 for the CASS/SCISAT2.0 mission ~10yrs ago, in cooperation with ECCC researchers.
- The scientific user needs and mission objectives were developed as part of a possible single-satellite mission concept to replace the existing SCISAT satellite.
- Update: over the past 10yrs, national and worldwide data users have compiled measurement needs through multiple efforts which require additional measurement capabilities beyond the single satellite, solar occultation measurement technique.

CASS Mission Science Objectives

To further establish collaborations between academic and federal researchers and programs.

1 Climate and Ozone Balance Monitoring

Continuation of the ACE-FTS and OSIRIS records

2 Atmospheric Climate Drivers

Advance knowledge of processes driving climate and its change

Five Focus Areas

Climate and Ozone Balance

Study the impact of natural and man-made climate change on atmospheric chemistry and the coupling between climate change and stratospheric ozone.

Role of the Upper Troposphere Lower Stratosphere (UTLS) in Atmosphere-Surface Coupling

Spatial structure and temporal dependence of trace gases will be characterized, along with transport processes, exchanges between the troposphere and stratosphere, and UTLS radiative and dynamical properties.

Improving the Estimates of CO_2 Sources and Sinks

Measurements will help precisely quantify CO_2 fluxes, which are essential to predict future atmospheric abundances of CO_2.

Mesosphere and Lower Thermosphere

Measurements in the mesosphere and lower thermosphere will allow to study mixing and transport processes in this region, and provide dynamical constraints on chemistry-climate models.

Understanding the Role of Aerosols

Measurements will allow to quantify upper tropospheric and stratospheric aerosols variability, their impact on climate and their role in stratospheric ozone chemistry.

CASS Mission Science Requirements

Responding to the Canadian and international space climate science communities – primarily academic researchers.

1 Vertical Resolution

Requirements:

All species < 2 km

O_3, NO_2, aerosols < 0.5 km

2 Altitude Coverage

Requirements:

As low as 5 km, up to 100 km, depending on species.

5 Duration of Mission

Minimum: 3 years

Goal: ten-year extended mission lifetime.

3 Target Species

CASS-FTS:

- **For climate change**: CO_2, N_2O, CH_4, H_2O, O_3, halocarbons (CFC-11, CFC-12, CH_3Cl, CCl_4, CFC-113, HCFC-142b, HCFC-22, and HFC-134a), CF_4 , SF_6
- **For ozone recovery**: O_3, chorine reservoirs (HCl, $ClONO_2$), halocarbons (CFC-11, CFC-12, CH_3Cl, CCl_4, CFC-113, HCCFC-142b, HCFC-22 and HFC-134a), Cl breakdown products (COClF and $COCl_2$), nitrogen oxides (NO_y: NO, NO_2, N_2O_5, HNO_3, and HNO_4), atmospheric tracers (HF, CH_4, N_2O and H_2O)
- **For UTLS**: Complementary constituent profiles: H_2O, water isotopologues (HDO, $H_2{}^{18}O$), CO, HNO_3, HCl, CH_4, N_2O, NO, NO_2, HCN

CASS-CATS:

- **For climate change**: O_3, sulphate aerosols
- **For ozone recovery**: O_3, NO_2, BrO and sulphate aerosols
- **For UTLS**: Primary constituent profiles: O_3 and sulphate aerosols

CASS-IMAGER:

- **For climate change**: aerosol, cloud
- **For ozone recovery**: aerosol, cloud
- **For UTLS**: aerosol extinction

4 Temporal Sampling

Yearly repeating observations at the same latitude locations.

The **CASS-FTS** shall generate spectra at a rate of approximately **0.75 per second**.

The **CASS Pointing Imager** shall produce images at a frequency of at least **100 per second**.

The **CASS Aerosol Imager** shall produce images at a frequency of at least **4 per second**.

The **CASS CATS** shall measure all spectra within the tangent altitude range from 5 km to 60 km in a time that is no greater than **12 seconds**.

Requires further input from the Canadian federal government community.

Satellite Concept for the CASS Mission

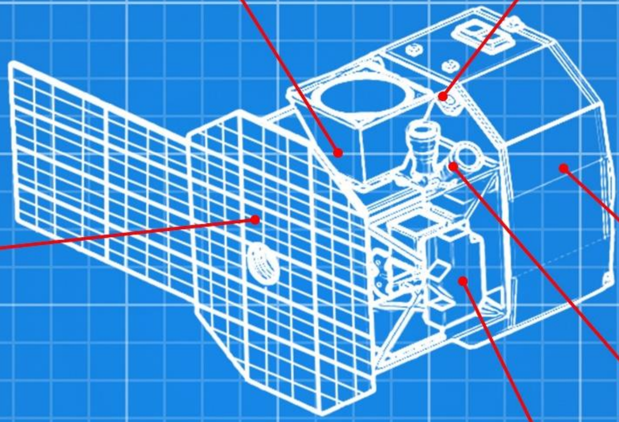
One satellite will combine two Canadian signature technologies to produce new data products.
A constellation of FTS instruments would respond to more government priority needs.

CASS-FTS Instrument

The FTS instrument provides profile measurements of ~70 different atmospheric species including ozone, ozone depleting substances, all major greenhouse gases, and isotopologues. These measurements are made at a rate of ~0.75/sec. The CASS-Imager measures aerosol, cloud and temperature profiles at a frequency of at least 100/sec.

Solar Panels

Power for the spacecraft will be provided by a fixed solar array of area 2.32 m^2. Preliminary sizing indicates that 35 strings of 21 cells are required. A deployable side panel will supplement the static array. The side panel has an area of 0.56 m^2. A peak power consumption of 588W is estimated.



Orbit

The spacecraft will be in a circular orbit with an altitude in the 550-650 km range and inclination in the 65° range for global coverage from 80°N to 80°S latitude, with specific focus on providing Northern polar springtime data acquisitions. CASS will provide data throughout the orbit when the sun illuminates the limb.

CASS-CATS Instrument

Provides spectral measurements of ozone, nitrogen dioxide, bromine oxide and sulphate aerosols through sunlight scattered from Earth's limb.

Communication Antennas

Spectral measurements and engineering data stored in the spacecraft are converted to radio waves and then transmitted through one of the spacecraft's high-gain antennas which relays them to the ground.

The spacecraft command and control will use a S-band TT&C subsystem which accesses the Saskatoon and St. Hubert ground stations. Science data downloads will be done using X-band at Prince Albert.

Support Systems

Essential support systems such as electronics, command and control software, propulsion modules, batteries, power control units, and telemetry, command and data handling subsystems are contained in these areas.

Attitude Knowledge & Control

In the middle of the spacecraft, near the center of gravity, are three reaction wheels to orient the satellite. To minimize the attitude knowledge uncertainty, high accuracy star trackers are required. Tangent altitude knowledge of ±100m is required, with ±50m as the goal.

SOURCE ► CASS MCARR, Magellan Aerospace, 2012. Note that the satellite illustration is notional.

FTS Instrument Concept for CASS

The successor to the FTS instrument on SCISAT would be a product of 15 years of Canadian industry innovation.

Fourier Transform Spectrometer

Canada's FTS instrument technology uses the solar occultation technique (collect spectra of the atmosphere by using the Sun as background illumination) to measure ~70 atmospheric trace gases including ozone, ozone depleting substances, all major greenhouse gases, aerosols, and isotopologues.

Passive Cooler

The infrared (IR) science detectors are passively cooled and the cooler must be directed to deep space. The payload is equipped with its own Earth-shield and Sun-shield to protect the passive cooler.

Instrument Structure

The instrument will carry two aerosol imagers which provide altitude profiles of aerosol extinction and cloud detection. The imagers are embedded into the optomechanical and electrical design, and are considered an integral part of the FTS instrument.

Radiator Side

Heat from the instrument electronics is evacuated through a panel on the backside of the instrument structure. The instrument is designed for operating temperatures between 10°C and 40°C, and has its own heaters to keep itself within survival limits.

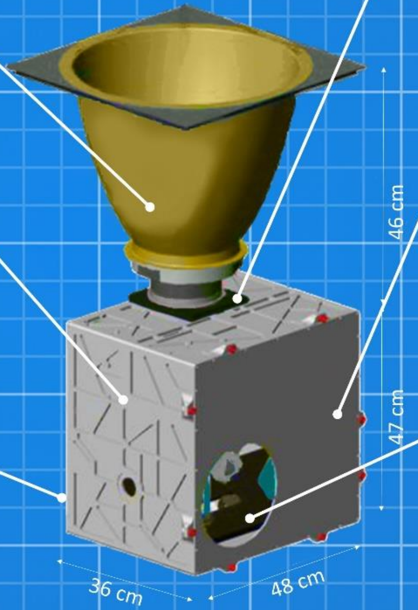


Photo-Detectors

The detectors capture the spectral signal as a function of time and transform the spectral radiant power into an electrical signal. The photo-detectors must be cooled to achieve the sensitivity required for high-quality measurements.

Instrument Electronics

Onboard electronics manage all sub-systems, collecting the telemetry and science signals and exchanging data, power, and commands with the spacecraft bus. The raw data is received by ground antennae where it is decoded and validated before being transformed to measurements of vertical concentrations of trace gases.

Optical Input Port

The spectral radiance from the Sun transmitted through the atmosphere is captured and collected here. The port must face within ±1° of the Sun center during measurements. The diameter of the aperture is 22cm.

SOURCE ► CASS MCARR, Magellan Aerospace, 2012.

CATS Instrument Concept for CASS

The successor to OSIRIS has been funded by CSA through multiple technology development studies over the past 15 years.

Canadian Atmospheric Tomography System

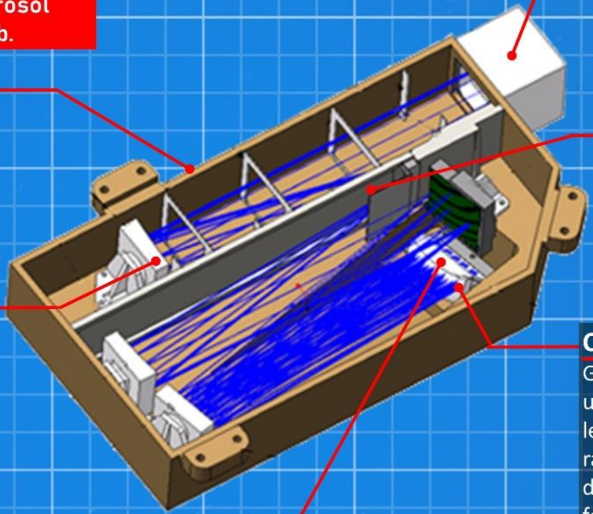
CATS is an improved version of the OSIRIS ultraviolet/visible imaging spectrometer. It will provide complementary trace gas and aerosol measurements by imaging sunlight scattered from Earth's limb.

Instrument Layout

To improve on stray light rejection, the optical cavity between mirrors is increased in depth and height. The light is focused onto a slit plate and then collimated by a parabolic mirror. Further analysis is planned to optimize the off-axis section with parabolic mirror focal length, slit plate location, and slit design.

Scanning Mirror

The instrument must provide its own altitude scanning, achieved using the mirror at the back end of the baffle. The actuator moves the mirror to provide a wide altitude coverage. The scanning mirror will continuously scan over an 8 arc-minute range at a speed of 0.6 to 2.4 arc-minutes per second. Surface quality and cleanliness are key.



Input Baffle

Baffles and vanes form part of the optics, and are used to reduce both internal and external stray light. A standard black anodize coating treatment is assumed on the baffle, vanes and internal surfaces. The anti-reflective and mirror coatings will be designed to minimize scatter in the 300-425 nm region with enhanced transmission relative to the longer wavelengths.

Slit Plate

The slit plate has a maximum of eleven staggered slits of various widths and heights. The dimensions will be selected as part of an optical and science requirement analysis. Both sides of the slit plate will be treated with a low-out gassing, low reflectivity coating.

Charged Coupled Device

Greater spectral coverage with higher resolution is achieved using a CCD with more pixels in the spectral dimension. At least 2400 pixels are required to sample the CATS spectral range, corresponding to 36 mm of dispersion at the CCD. It is desirable to increase the spectral dispersion by increasing the focal length of the spectrometer.

Design Concept

Three modules would be created (see image on left) to form the full CATS instrument, each with a similar design. Each module has a limited wavelength range and a multi slit design that measures simultaneously along 7 look directions. The instrument would be pointed at the Earth's limb using a coarse pointing limb-tracking mechanism and a fine-pointing mirror mechanism would be used to scan over the required altitude range.

The FOP

Light is captured by the CCD image plane with a spherical camera mirror and a combination field flattener, order sorter and prism element, called the FOP. It is a combination of four elements: two Plano-spherical lenses, one order sorter, and a right angle, total internal reflection prism. it is desired to increase the spatial sampling rate to address the increased spectral resolution required for CATS.

SOURCE ► CASS MCARR, Magellan Aerospace, 2012, Canada-Europe Copernicus Workshop Presentation, K. Walker and the CASS Consortium Team , 2019.

Possible Mission Architectures

- User Needs for a Single Platform
  - A Phase 0 was completed 10yrs ago for the CASS mission. It had multiple iterations, including the final two-instrument, single science satellite mission concept. It was also proposed as a joint NASA-CSA mission during that time, to meet objectives in atmospheric composition monitoring for both nations.
- User Needs for Two Platforms
  - Since 2013, other mission architectures were studied in partnership with ECCC, including smaller science monitoring satellites on individual platforms (CATS microsat) or a hosted payload on a partner-led satellite (ALISS). The FTS instrument would have been proposed on a separate satellite.
- User Needs for a Constellation of Satellites/Instruments
  - In parallel over the past 10 years, the international scientific and government monitoring community, including ECCC, have developed atmospheric composition measurement needs, including those efficiently covered by space assets.
  - In order to meet various immediate Canadian commitments identified by national laws and multiple international treaties, a constellation mission architecture may be proposed.
  - Such an architecture needs to be studied as part of an update to the Phase 0 to address ECCC operational and scientific needs, geographical and temporal coverage, diurnal effects, and enhancement of multiple space instrument datasets with future space missions now being defined by our partners.

Oct. 16-18, 2023:
SCISAT
20th ANNIVERSARY

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