Recent Validation and Science Results from the Atmospheric Chemistry Experiment (ACE)

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ACE on SCISAT

Atmospheric Chemistry Experiment (ACE) Satellite Mission

Mission to measure atmospheric composition: profiles of trace gas species, cloud and aerosol extinction and temperature/pressure

Focusing on investigating:

- Distribution of ozone in upper troposphere and stratosphere
- Effects of biomass burning on the troposphere
- Relationship between atmospheric chemistry and climate change

Size: 1.12 m dia. x 1 m; 152 kg
Total power: 70 W (from single solar panel)
Launch date: 12 August 2003
Orbit: 74º inclined circular orbit at 650 km

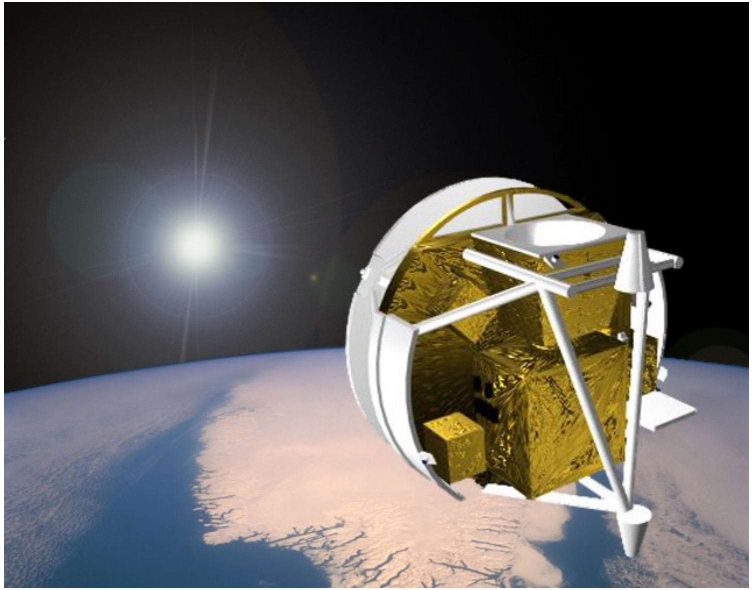


Image: T. Doherty.

ACE Solar Occultation Instruments

ACE-FTS (Fourier Transform Spectrometer):

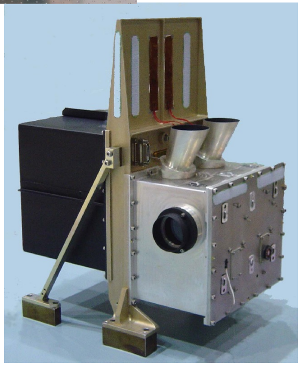
- Mid-infrared FTIR spectrometer – 2-13 microns at 0.02 cm^{-1} spectral resolution and two filtered imagers (Visible and NIR)

ACE-MAESTRO (Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation):

- dual UV/Visible/NIR spectrometer – 0.285 to 1.030 microns, with ~1-2 nm resolution

Time series: From late February 2004 and on-going

- Up to 30 sunrise and sunset measurements per day
- Designed for 2 year mission lifetime – in 19th year on orbit
  - Starting to see some degradation in ACE-FTS performance
  - ACE-MAESTRO continues to "age gracefully"



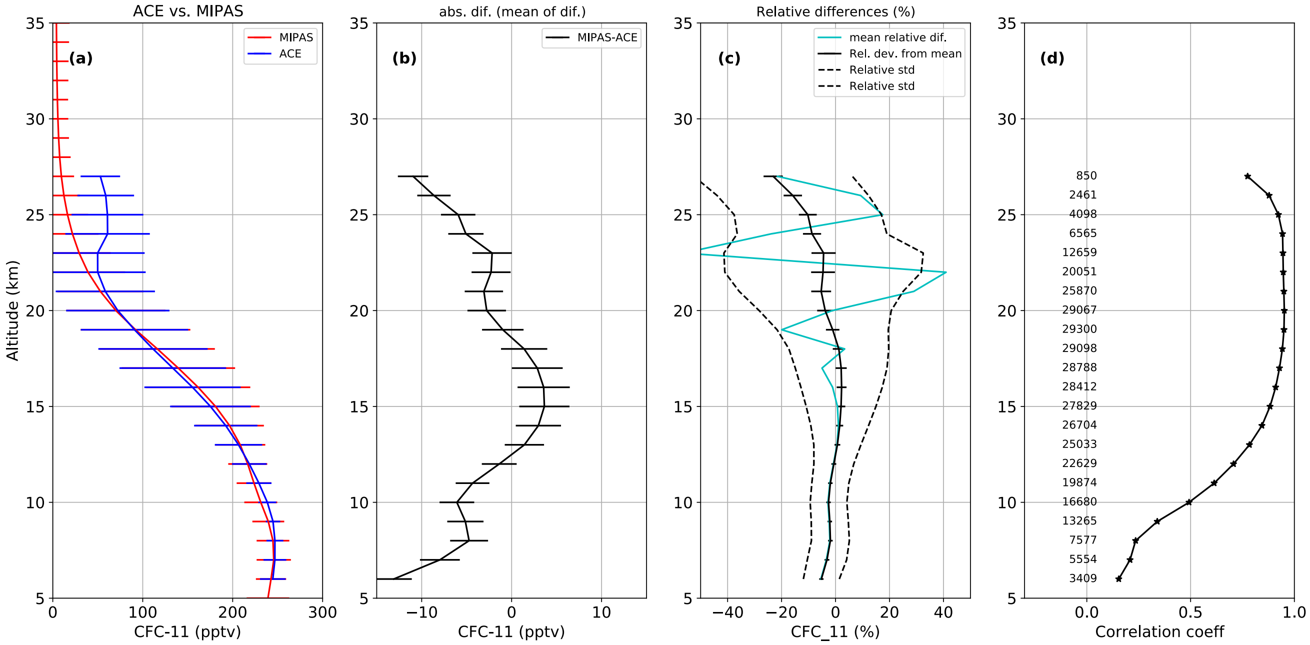
Images: ACE-FTS from ABB-Bomem; MAESTRO from T. McElroy *et al.*, Appl. Opt., 46, 4341-4356 (2007)

ACE Data Products

- ACE-FTS profiles (current version 4.1/4.2):
  - Tracers: H_2O, O_3, N_2O, NO, NO_2, HNO_3, N_2O_5, H_2O_2, HO_2NO_2, N_2, SO_2
  - Halogen-containing gases: HCl, HF, $ClONO_2$, CFC-11, CFC-12, CFC-113, COF_2, $COCl_2$, COFCl, ClO, CF_4, SF_6, CH_3Cl, CCl_4, HCFC-22, HCFC-141b, HCFC-142b, HFC134a, HFC-23
  - Carbon-containing gases: CO, CH_4, CH_3OH, H_2CO, HCOOH, C_2H_2, C_2H_4, C_2H_6, OCS, HCN acetone, CH_3CN, peroxyacetyl nitrate (PAN), CO_2 (5-18 km and >60 km), pressure / temperature from CO_2 lines
  - Isotopologues: Minor species of H_2O, CO_2, O_3, N_2O CO, CH_4, OCS, NO_2, HNO_3
- MAESTRO profiles (current version 3.13):
  - O_3, NO_2, optical depth, aerosol and water vapor (v31)
- IMAGERS profiles (current version 4.1/4.2):
  - Atmospheric extinction & aerosol extinction at 0.5 and 1.02 microns

MIPAS and ACE-FTS CFC Comparisons

- ACE-FTS v4.1 and new MIPAS IMK-IAA v8 retrievals between 2005 and 2012, global comparisons within 24 hours and 1000 km for CFC-11 and CFC-12
- Max. ACE-FTS retrieval altitude varies with lat. (~24-27 km from polar to tropics)
- Typical differences of less than 10 pptv and within 10%
- Improved agreement – previous comparison differences showed MIPAS ~10-20 pptv higher than ACE-FTS

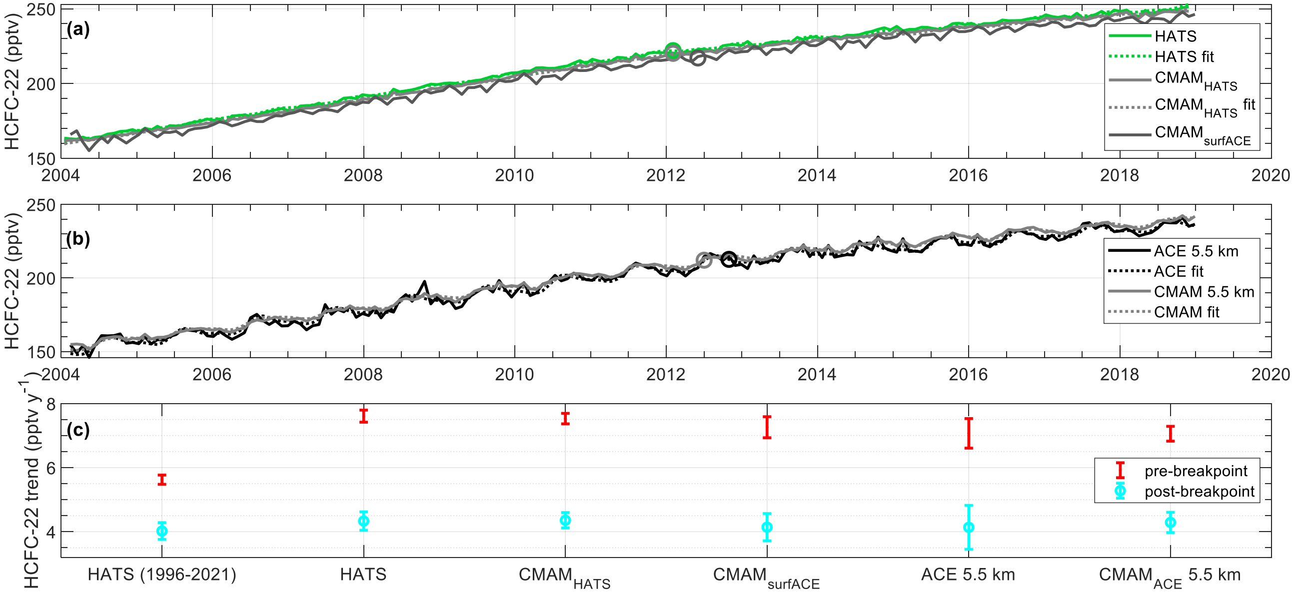


A. Jalali et al., in preparation.

Validation of ACE-FTS HCFC-22: Trend

In addition to comparisons with MIPAS, MkIV and BONBON balloon, and CARIBIC results

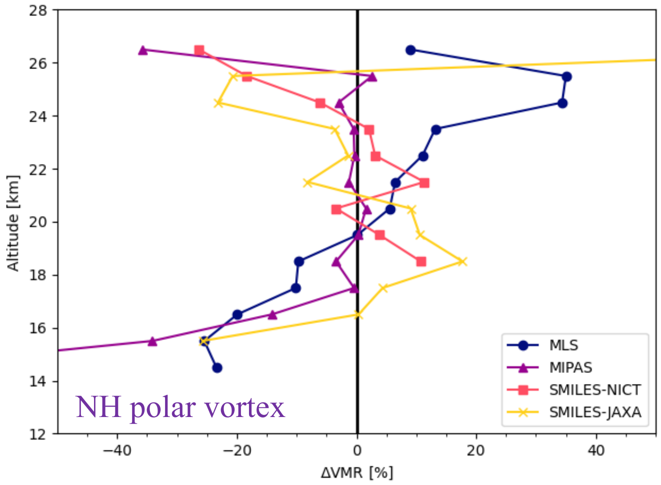
- Comparing trends in HCFC-22 from ACE-FTS at 5.5 km, NOAA HATS surface flask measurements and subsampled CMAM39-SD at ACE-FTS and HATS locations
- Fits of global monthly means using multiple linear regression
- Consistent change in trend at 2012 across datasets
- Significant decrease in trend at breakpoint
  Pre: 7.2±0.6 pptv/year;
  Post: 4.2±0.7 pptv/year

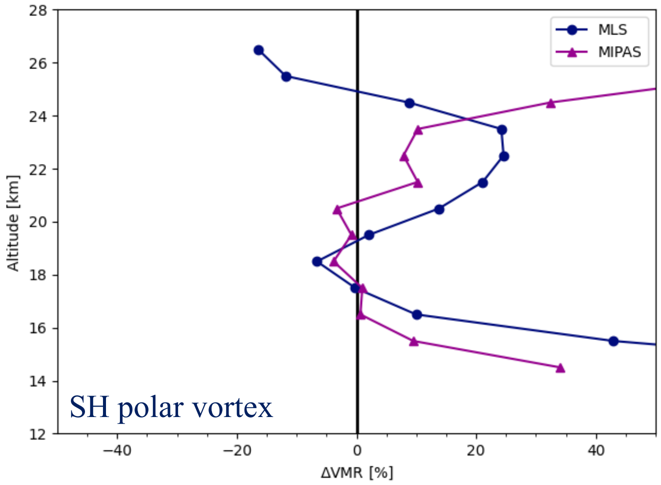


P. Sheese, F. Kolonjari, et al., in preparation.

v4.2 ClO versus MIPAS, Aura-MLS and SMILES

- Comparison of daytime profiles taken within 300 km of ACE-FTS, within polar vortex
- Used PRATMO chemical box model to scale comparison profiles to ACE local solar time
- Time periods for comparison vary; several months for SMILES to 2004-2020 for MLS
- Differences found from 17 - 24 km are within approx. ±10 - 20% for NH and between -10 and +25% for SH



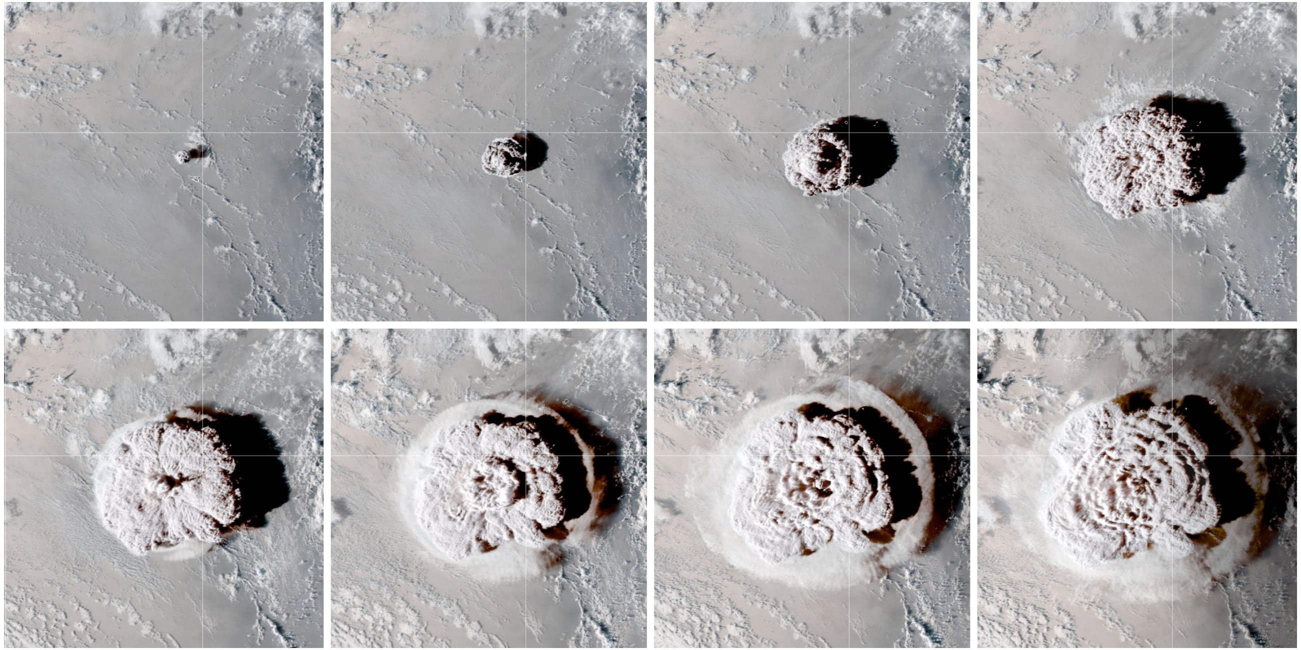


Medians of differences (ACE-FTS – comp.) shown for comparisons.

L. Saunders, N. Ryan et al., in preparation.

Hunga Tonga–Hunga Ha‘apai Eruption

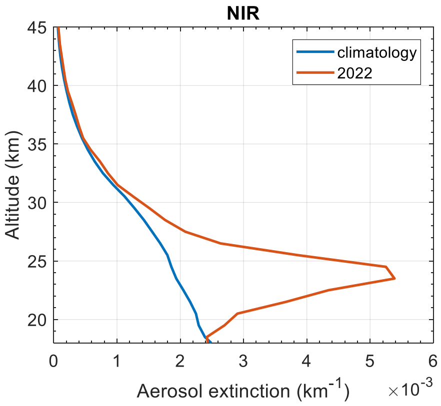
- 15 January 2022: Explosive eruption from submarine volcano (20.54º S, 175.38º W)
- Impact seen in tsunami alerts and ionospheric disturbances, and plume reached mesosphere
- Stereoscopic images from GOES-17 and Himawari-8 (10 min. interval for images)

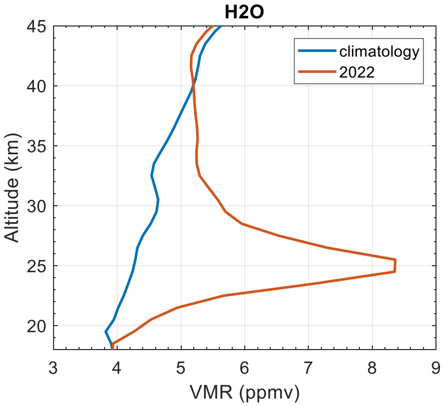


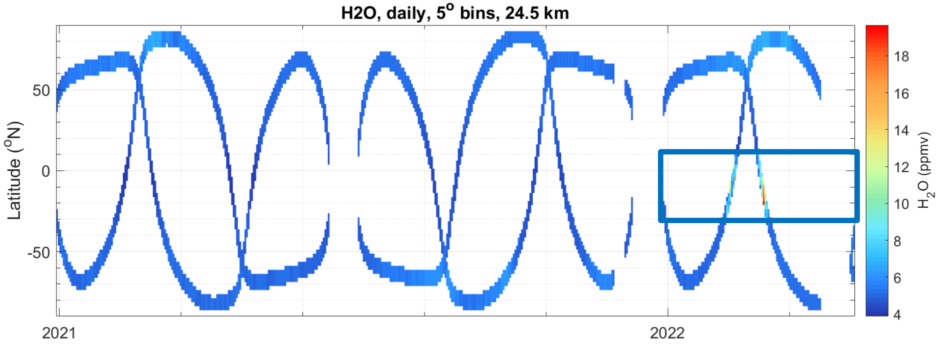
https://earthobservatory.nasa.gov/images/149474/tonga-volcano-plume-reached-the-mesosphere

Hunga Tonga–Hunga Ha‘apai Eruption

- ACE-FTS results from 30º S-10º N, comparing February 2022 to zonal mean from all of 2004-2021
- Aerosol extinction from ACE Imagers and SO_2 and H_2O from ACE-FTS all show strong enhancement at ~22-25 km
- Estimate that injection of water into stratosphere is equal to ~10% of total







Analysis by P. Sheese.

Timeseries analysis of mesospheric water vapour

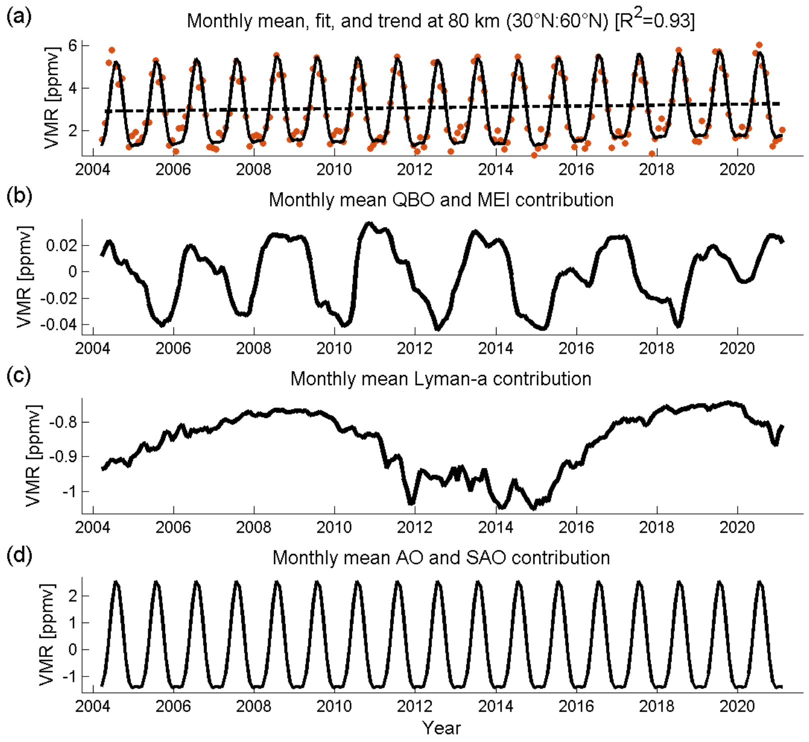
- Using 2004-2020 time series from ACE-FTS to examine behaviour of middle atmosphere water vapour over Solar Cycle 24 (2008-2019)
  - Monthly zonal means for 30 degree regions and all latitudes at each 1-km from 40 to 90 km

- Fitting using multi-variable linear regression:

$$H_2O(t) = a_0 + a_t t + a_{QBO} QBO(t) + a_{MEI} MEI(t) + a_{Ly\alpha} Ly\alpha(t) + \sum_1^2 \left(a_{1,n} \sin\left(\frac{2\pi t}{1/n}\right) + a_{2,n} \cos\left(\frac{2\pi t}{1/n}\right)\right)$$

$QBO(t)$: radiosonde winds at 30 hPa over Singapore - Free University of Berlin
$MEI(t)$: multivariate ENSO index - NOAA Physical Sciences Laboratory
$Ly\alpha(t)$: Lyman-α radiation using LISIRD composite of instrument and model time series from LASP U. Colorado

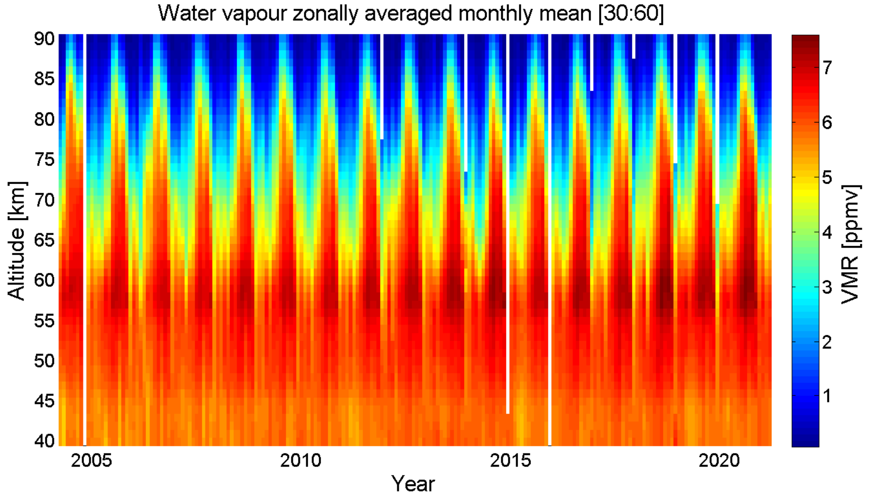
Results for 30º-60º N at 80 km

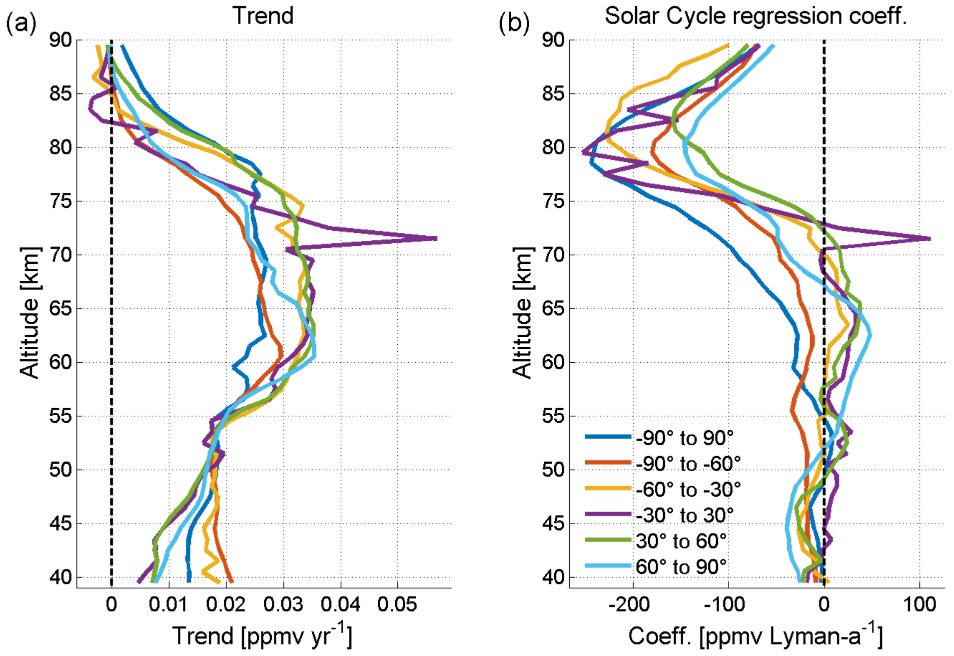


P. Jeffery et al., in preparation.

Linear Trend and Response to the Solar Cycle

- Examples of results – trend a_t and response to solar cycle $a_{Ly\alpha}$ terms
- Positive response to the solar cycle below 70 km is found in recent studies using Aura-MLS, HALOE, and SABER





P. Jeffery et al., in preparation.

Summary

- ACE has evolved from an ozone-focused mission to a climate-focused mission
  - Advantage of large number of species being measured simultaneously
  - Long time series with stability needed to meet climate data record requirements
- Data availability for ACE:
  - ACE-FTS and MAESTRO from https://databace.scisat.ca/level2 (registration required)
  - Data quality flags are being produced separately doi:10.5683/SP2/BC4ATC
  - Zonal mean climatologies available through SPARC Data Initiative or talk to me!

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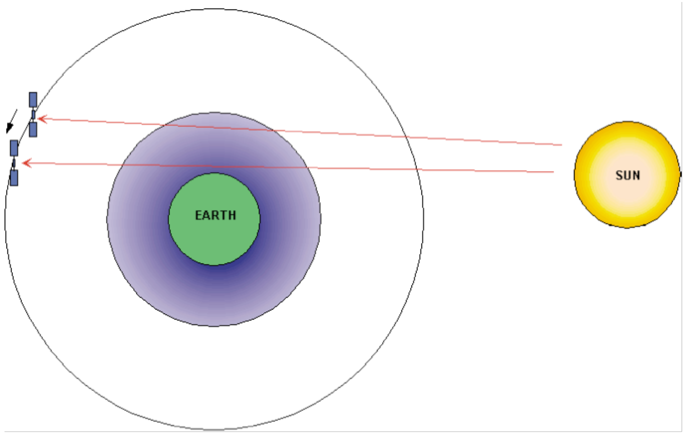
- SCISAT Science Operations Centre, Peter Bernath and Chris Boone
- MIPAS, MLS, SMILES teams: Gabriele Stiller, Thomas von Clarmann, Alexandra Laeng, Michelle Santee, Gloria Manney, Luis Milan, Makoto Suzuki, Masato Shiotani, Yasko Kasai
- CARABIC, HATS, MkIV teams: Andreas Engel, Tanja Schuck, Stephen A. Montzka, David E. Oram, Geoff Toon

Technique: Solar Occultation

Measure absorption spectra during sunrise and sunset

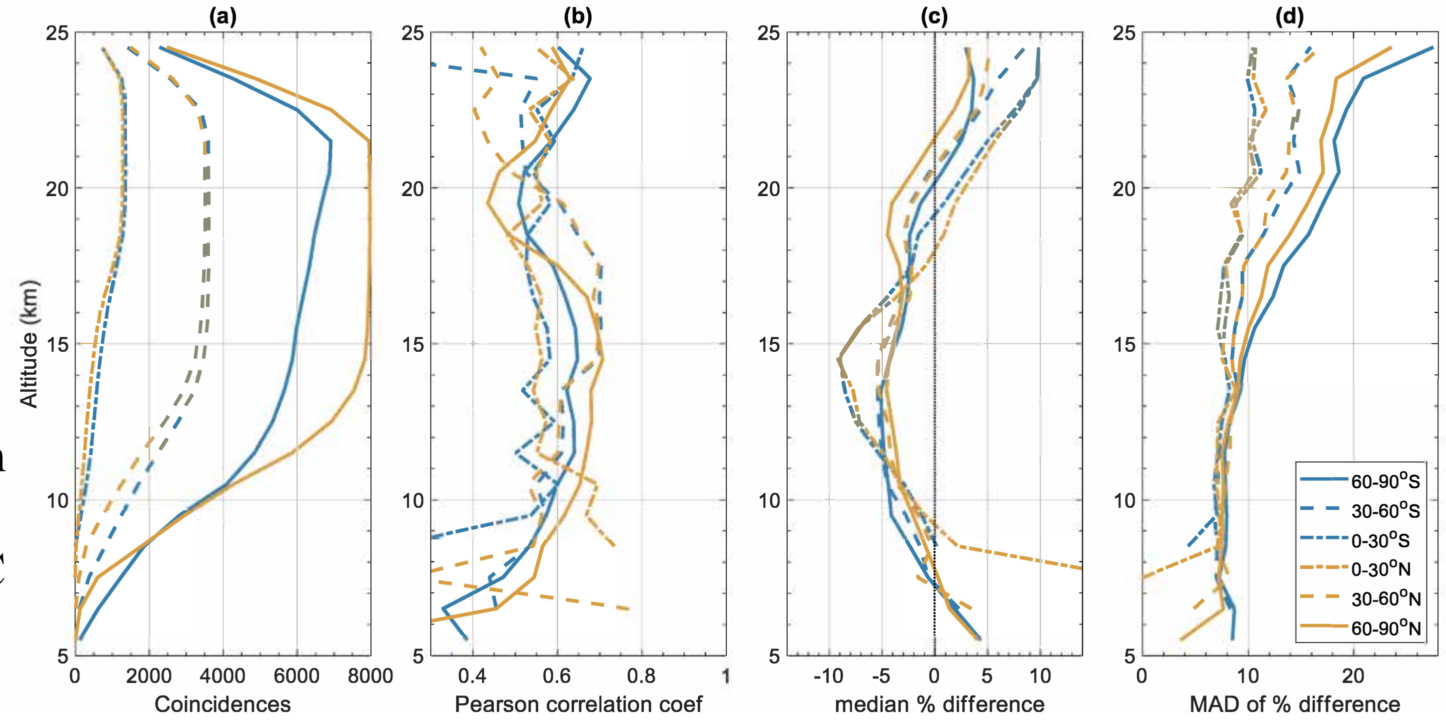
- Advantages:
  - High signal-to-noise ratio and long path to allow measurements of species with low concentrations as compared to limb emission or nadir
  - Simultaneous measurements of many species when using infrared "fingerprint" region
  - Less susceptible to changes in instrument sensitivity because of reference exo-atmospheric measurement
  - Produces very accurate and reliable time series

- Limitation of technique
  - Geographic coverage limited to 30 occultations per day
  - Samples only free troposphere



Validation of ACE-FTS HCFC-22

- Comparisons with ACE-FTS v4.2 with MIPAS IMK/IAA v8
- ACE-FTS biased low up to ~5-10% from 10-20 km
- Similar results with MkIV balloon FTIR and CARBIC aircraft in situ measurements



ACE-FTS – MIPAS for 2004-2012, within 12 hours, 10° latitude, 20° longitude, NH, SH

P. Sheese, F. Kolonjari, et al., in preparation.