Polar Mesospheric Clouds and Cosmic Dust: Three years of SOFIE Measurements

SOFIE = the Solar Occultation For Ice Experiment, aboard *AIM*, NASA's Aeronomy of Ice in the Mesosphere mission

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Acknowledgements

- GATS
  - Mark Hervig, SOFIE instrument PI
  - Larry Gordley
  - Lance Deaver

- Hampton University
  - Jim Russell, AIM mission PI

Exploring Clouds at the Edge of Space

AIM

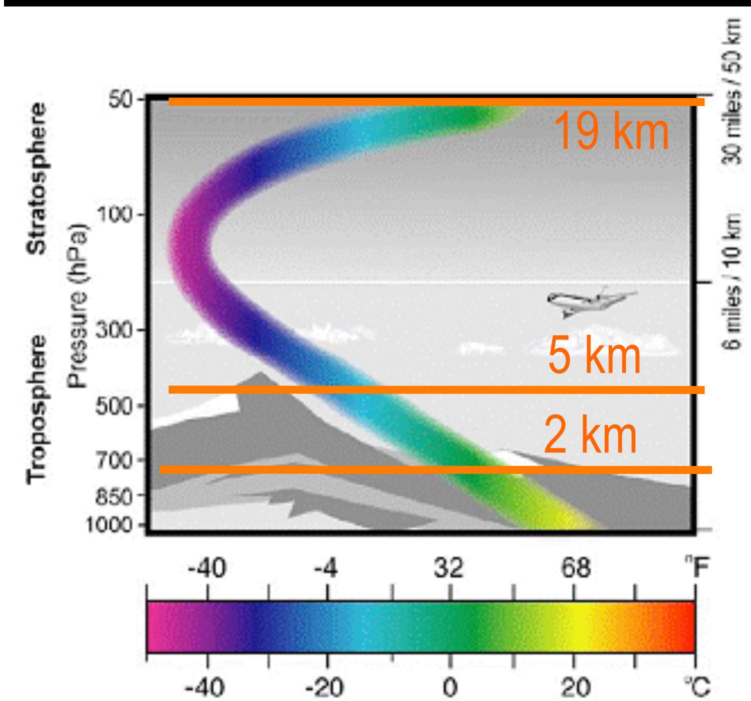
AIM overview

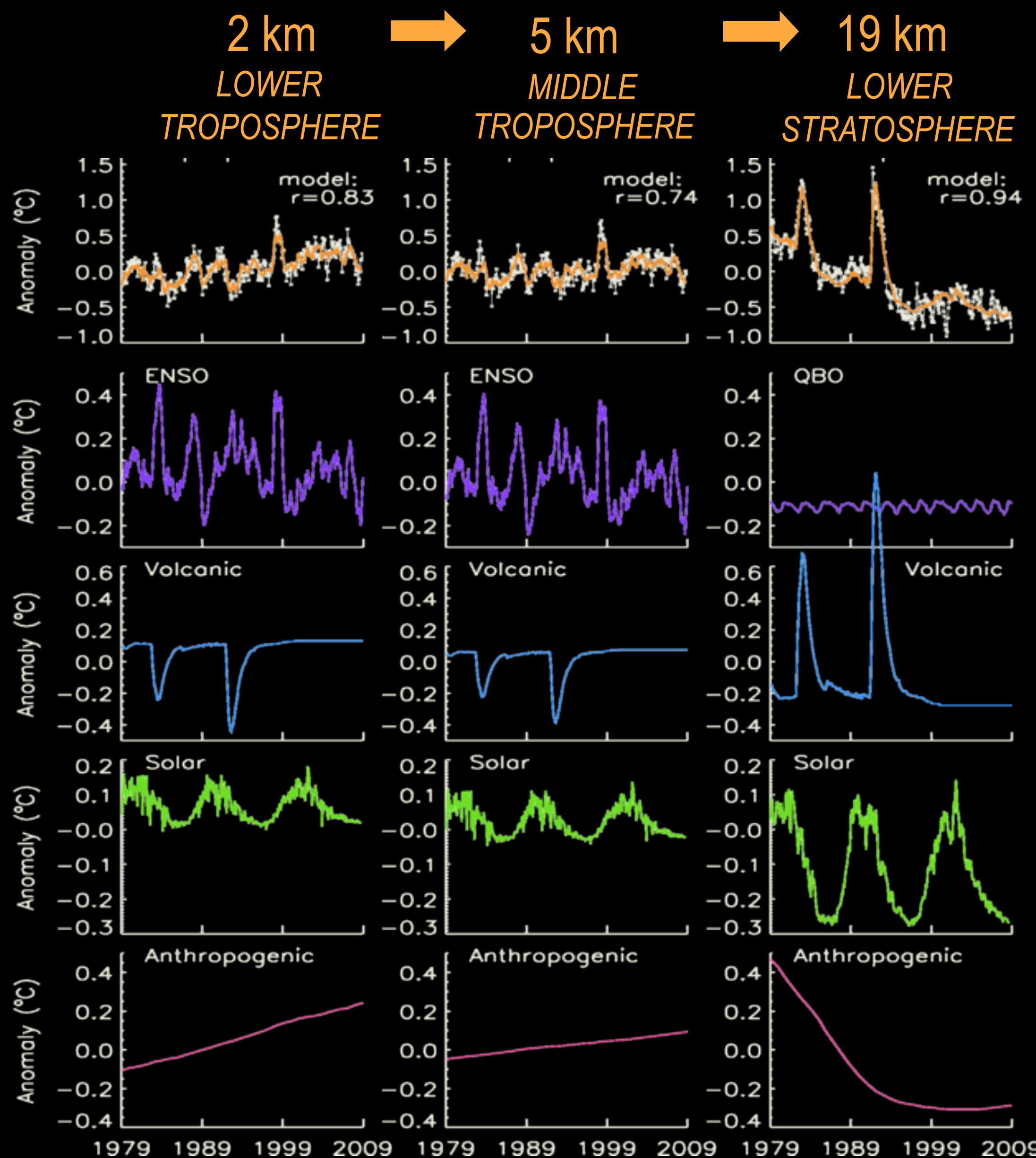
- NASA Small Explorer mission to study polar mesospheric clouds and their environment
  - launched 25-Apr-2007, into 600 km sun-synch orbit
  - prime mission complete, now in 3 year extended mission

- *three instruments*
  - **SOFIE** - Solar Occultation for Ice Experiment
  - CIPS - Cloud Imaging and Particle Size experiment
  - CDE - Cosmic Dust Experiment

Natural and Anthropogenic Change in Earth's Atmosphere

courtesy Judith Lean

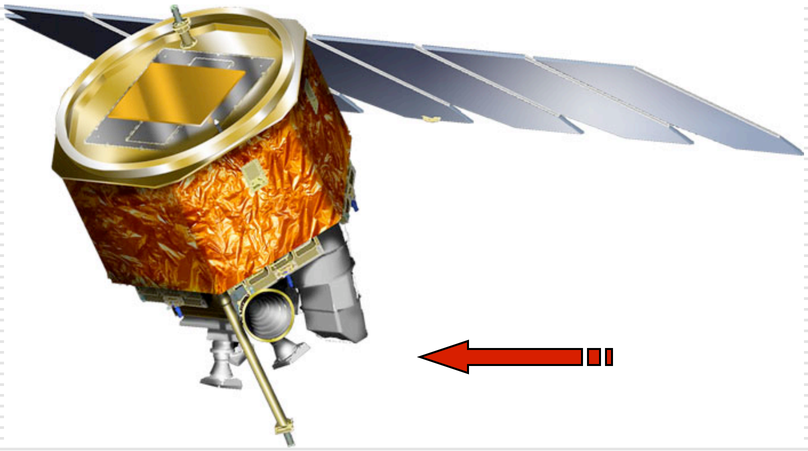


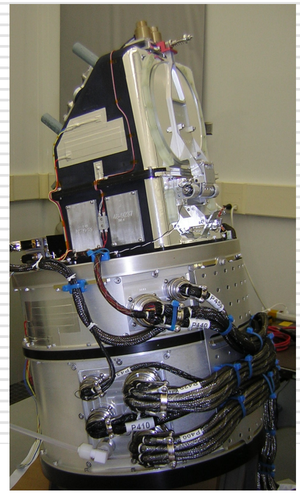


solar increase → warming
CO_2 increase → warming
volcanoes → cooling

solar increase → warming
CO_2 & CFC increase → cooling
volcanoes → warming

SOFIE overview



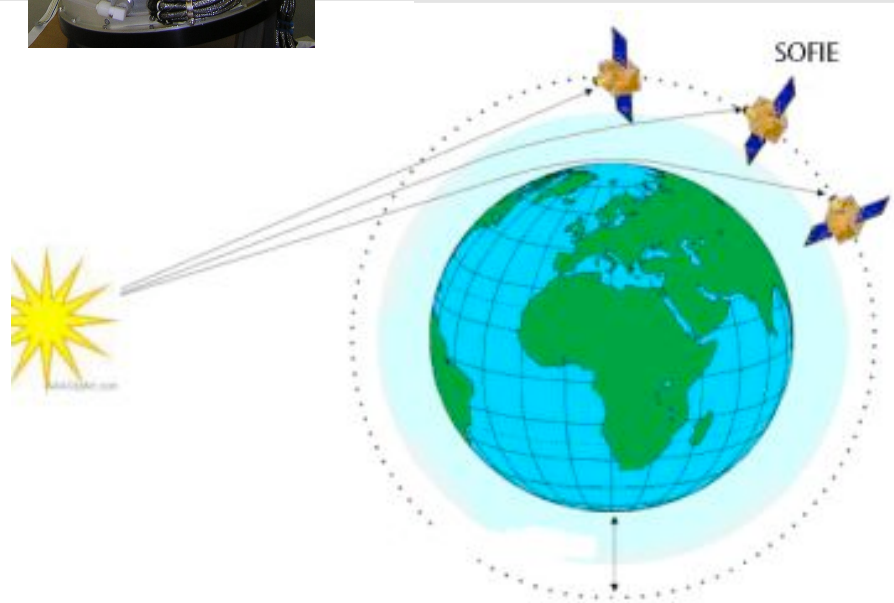


Vital Statistics

mass	38 kg
power	52 W
date rate	21 MB/day

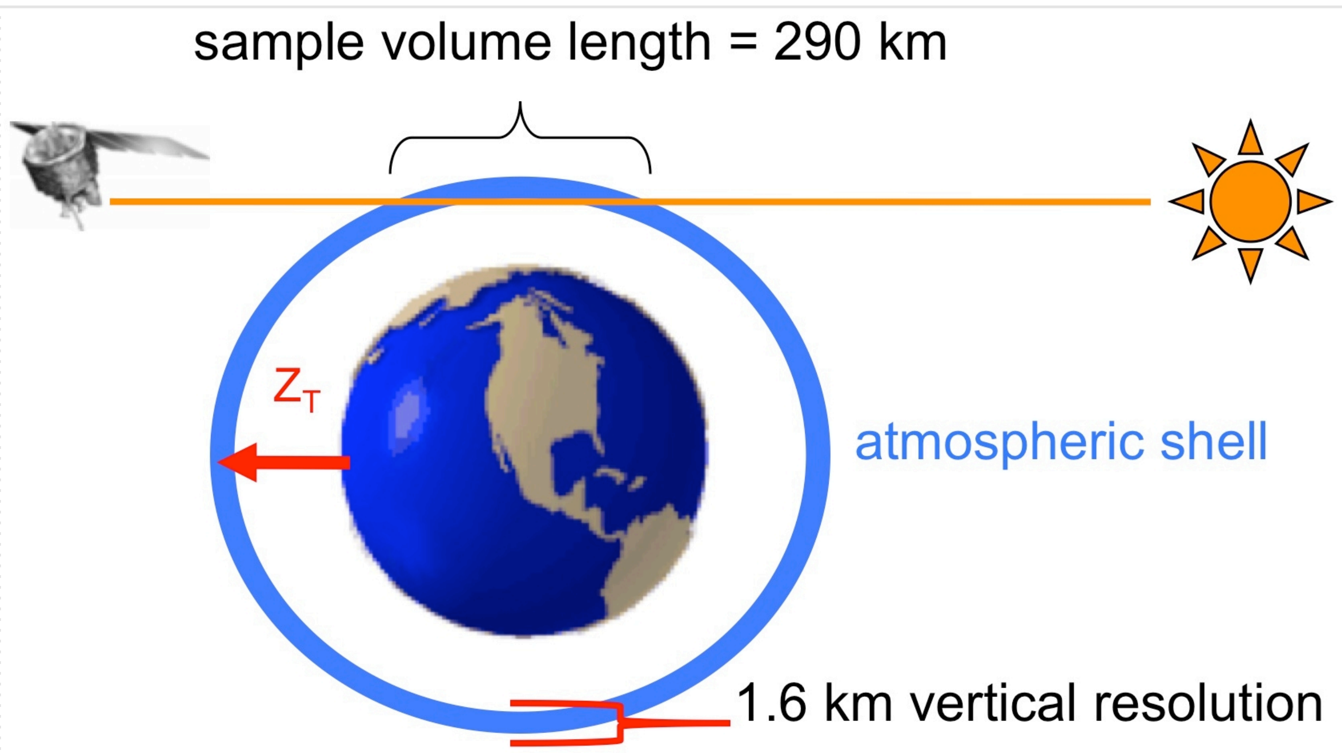
SOFIE Data Products

Product	***Altitude Range (km)***
temperature	1 – 100
carbon dioxide VMR	15 – 100
water vapor VMR	15 – 110
methane VMR	15 – 95
nitric oxide VMR	30 – 140
ozone VMR	15 – 100
particle extinction at 10 wavelengths from 0.328 to 4.98 μm	15 – 90

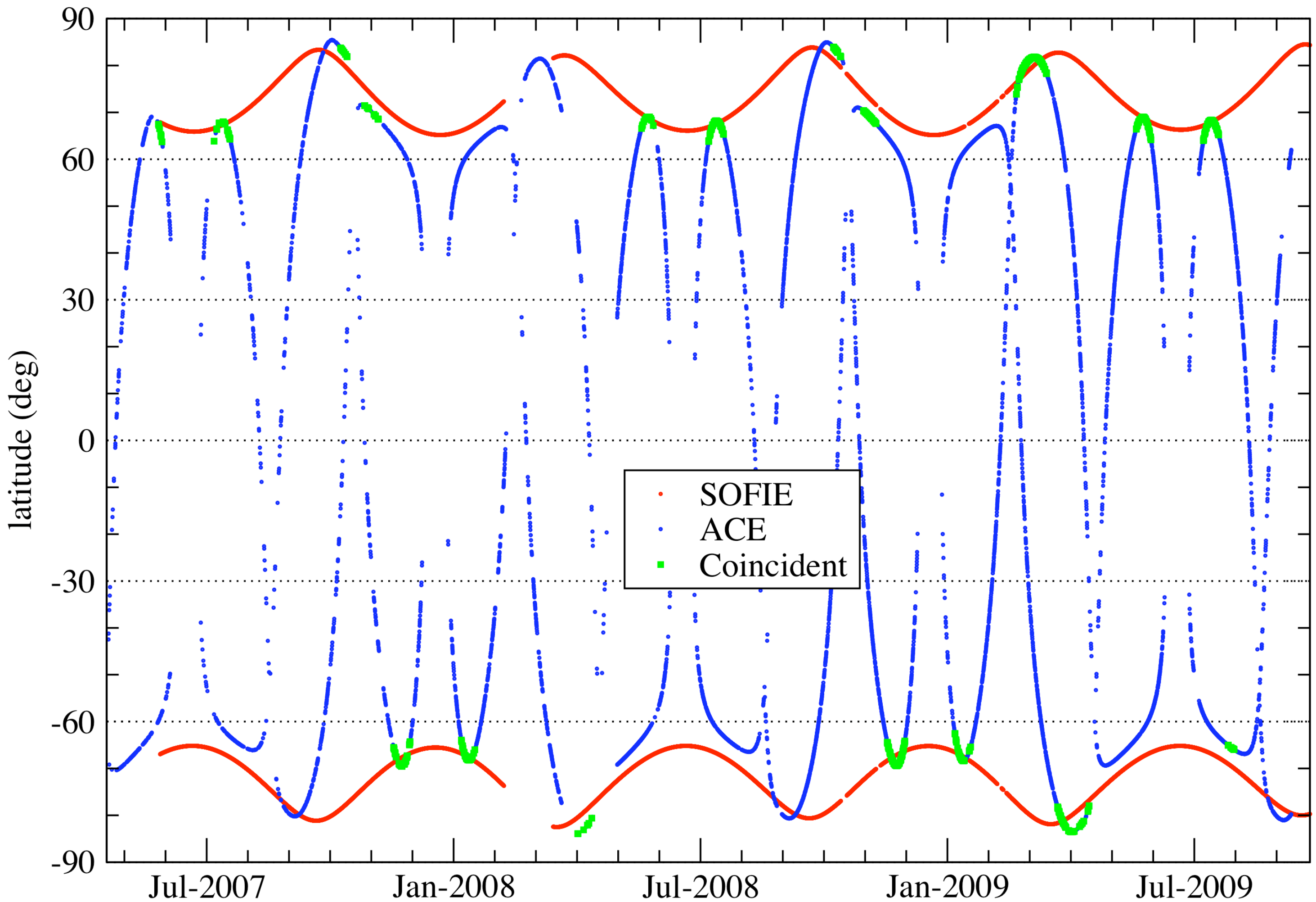


SOFIE overview

- Solar occultation measurements.
- Retrievals: Temperature, O_3, H_2O, CO_2, CH_4, NO, PMCs, meteoric smoke.
- Measurement latitudes: 65 – 82° (sunrise in North, sunset in South).

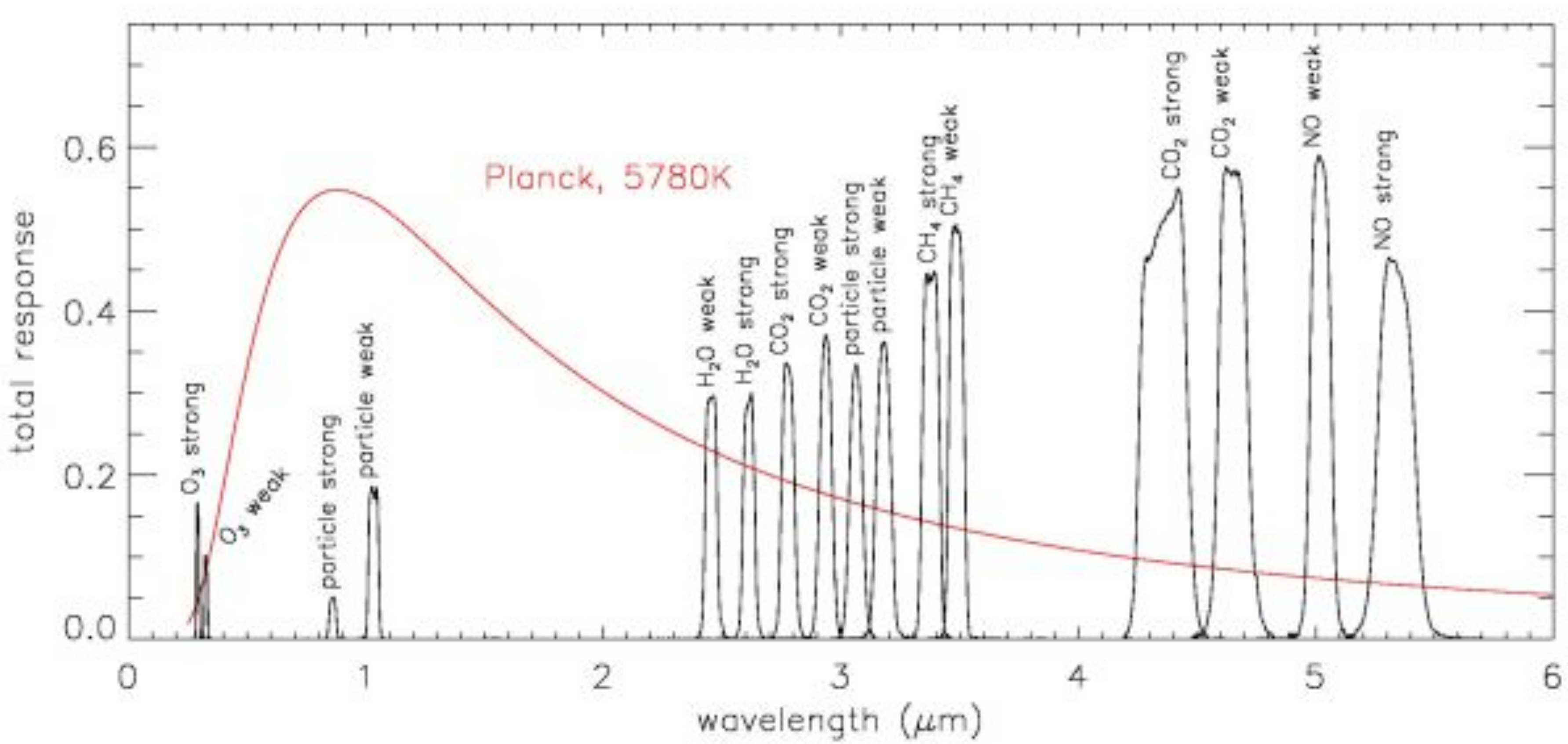


SOFIE latitude coverage



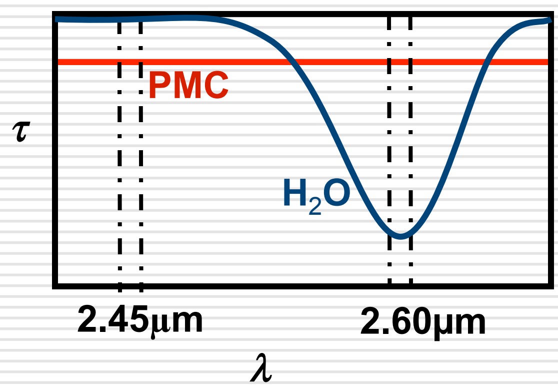
SOFIE Measurement Bands

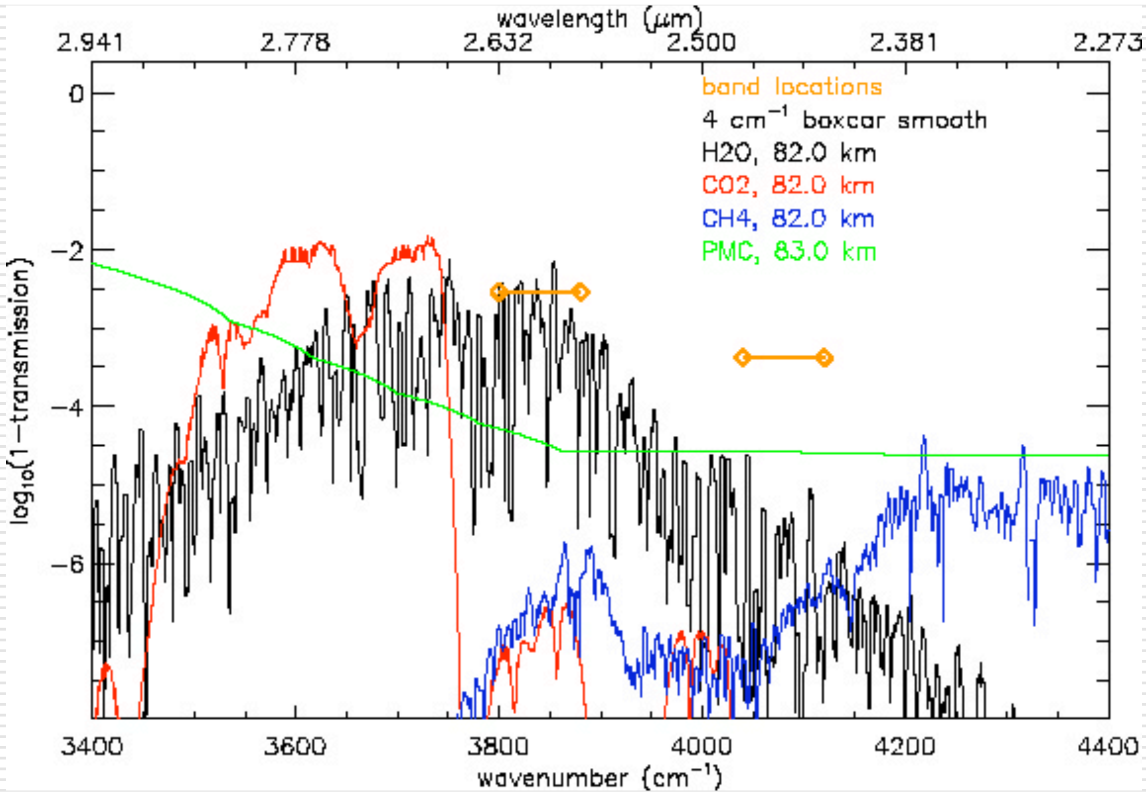
- 8 channels (16 wavelengths)
  - each channel pairs a strong and weak absorption region



differential radiometry

Measure the *normalized difference* in attenuation between spectral regions with weak and strong absorption by the target gas





SOFIE retrieval algorithm

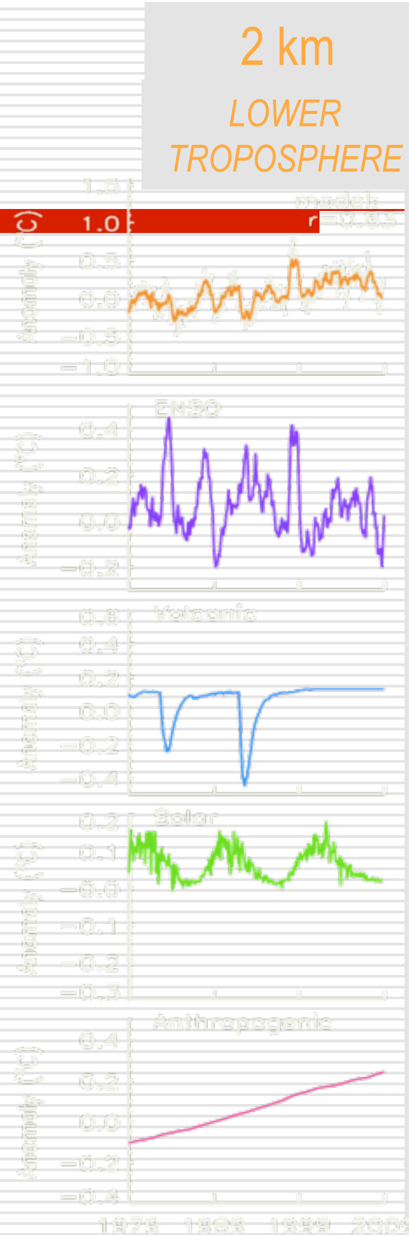
- **Level 0:**
  - Data quality checks
  - Time conversion
  - Combine science packets into occultation events
- **Level 1:**
  - Calibration (solar source, gain, background)
  - Signal conditioning (nonlinearity, drift)
  - Altitude registration
- **Level 2:**
  - Retrieval of geophysical parameters
- **Level 3:**
  - Time versus altitude cross section plots
- **Validation:**
  - Each retrieved profile is inspected for quality prior to release.

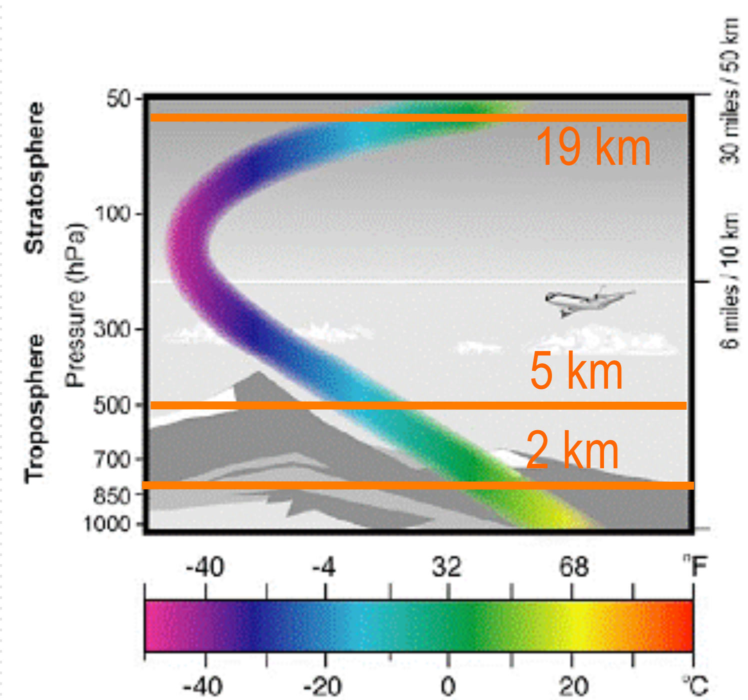
SOFIE data products

- **Level 2:**
  - Vertical profiles of Temperature, O_3, H_2O, CH_4, NO, PMC extinction
  - Grouped into daily data files (30 events)
- **Level 3:** Time versus height cross section plots for all parameters
- **Common Volume:**
  - Sample volume geometry, column O_3, derived PMC properties: Cloud top, peak, and base altitudes; Particle shape, eff.radius, size distribution; vertical column ice abundance
  - Each file contains data for an entire PMC season
- **Engineering/performance:** data can be viewed online

- **http://sofie.gats-inc.com**

Natural and Anthropogenic Change in Earth's Atmosphere





solar increase → warming
CO_2 increase → warming
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solar increase → warming
CO_2 & CFC increase → cooling
volcanoes → warming

Cambridge, MA

SOFIE data version history

V1.01, Feb 2008: Initial release

V1.02, Dec 2008

- Improved signal conditioning (higher altitudes obtained)
- Improved forward model (e.g., added O_3 interference in bands 3&4)

V1.022, Feb 2009

- Improved signal drift corrections
- Improved solar source corrections (i.e., pointing drift)
- Improved altitude registration
- Non-LTE temperature retrievals, 3 to 10 K colder, extended to 105 km

V1.03, processing underway, projected release Aug 2010

- Corrections to event timing
- Simultaneous temperature and CO_2 retrievals
- Off-axis FOV
- PMC corrections to ozone

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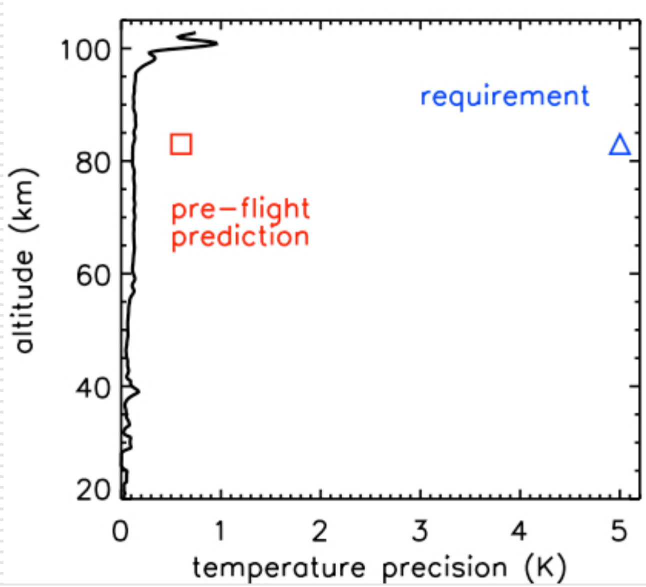
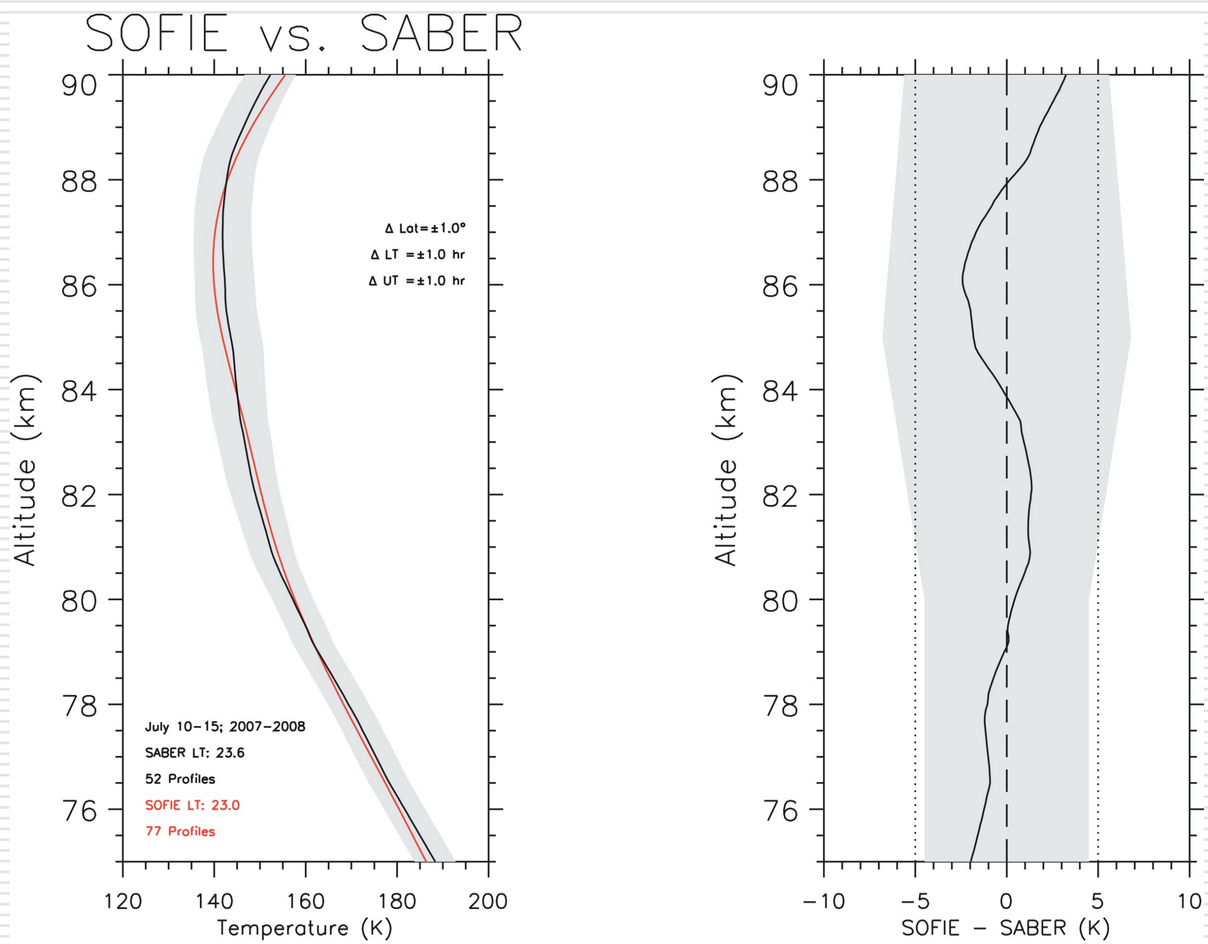
SOFIE performance summary

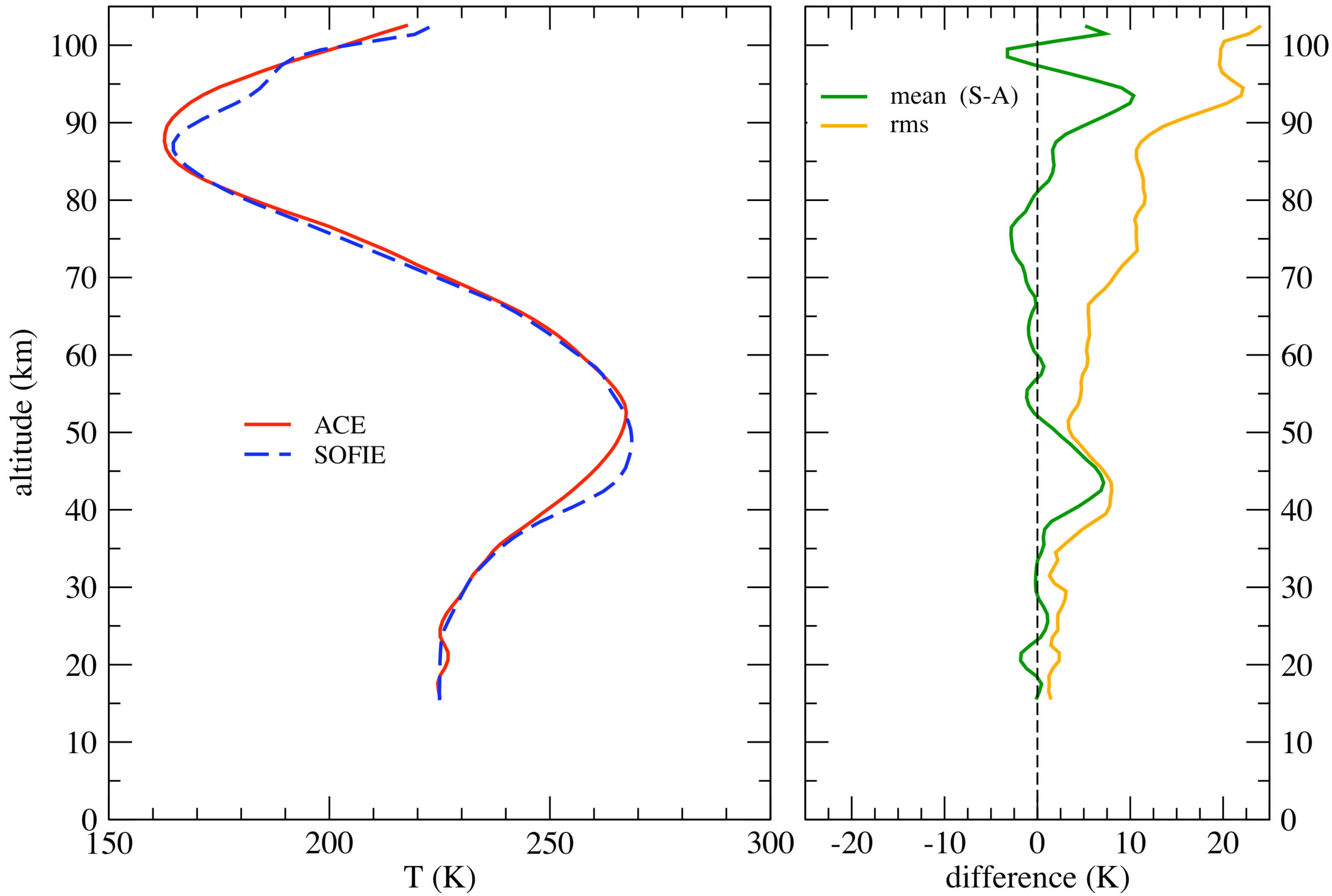
Geophysical Parameter	Precision (83 km altitude) Required / On-orbit	Altitude Range (km) Required / On-orbit	Vertical Resolution (km) Required / on-orbit
NIR cloud extinction	5×10^{-6} / 2×10^{-8} km^{-1}	78 – 85 / 75 – 90	3 / 1.8
IR cloud extinction	5×10^{-5} / 2×10^{-8} km^{-1}	78 – 85 / 75 – 90	3 / 1.8
Temperature	5 / 0.5 K	70 – 90 / 15 - 105	3 / 1.8
O_3 mixing ratio	100 / 10 ppbv	78 – 90 / 55 - 100	3 / 1.8
H_2O mixing ratio	0.6 / 0.1 ppmv	78 – 90 / 15 - 100	3 / 1.8
CO_2 mixing ratio	10 / ? ppmv	80 – 100 / 68 - 92	3 / 1.8
CH_4 mixing ratio	50 / 5 ppbv	30 – 90 / 15 - 75	3 / 1.8
NO mixing ratio	53 / 39 ppbv	80 – 95 / 30 - 140	5 / 1.8
Meteoric Smoke	NA / 2×10^{-8} km^{-1}	NA / 35 - 90	NA / 1.8

SOFIE temperature

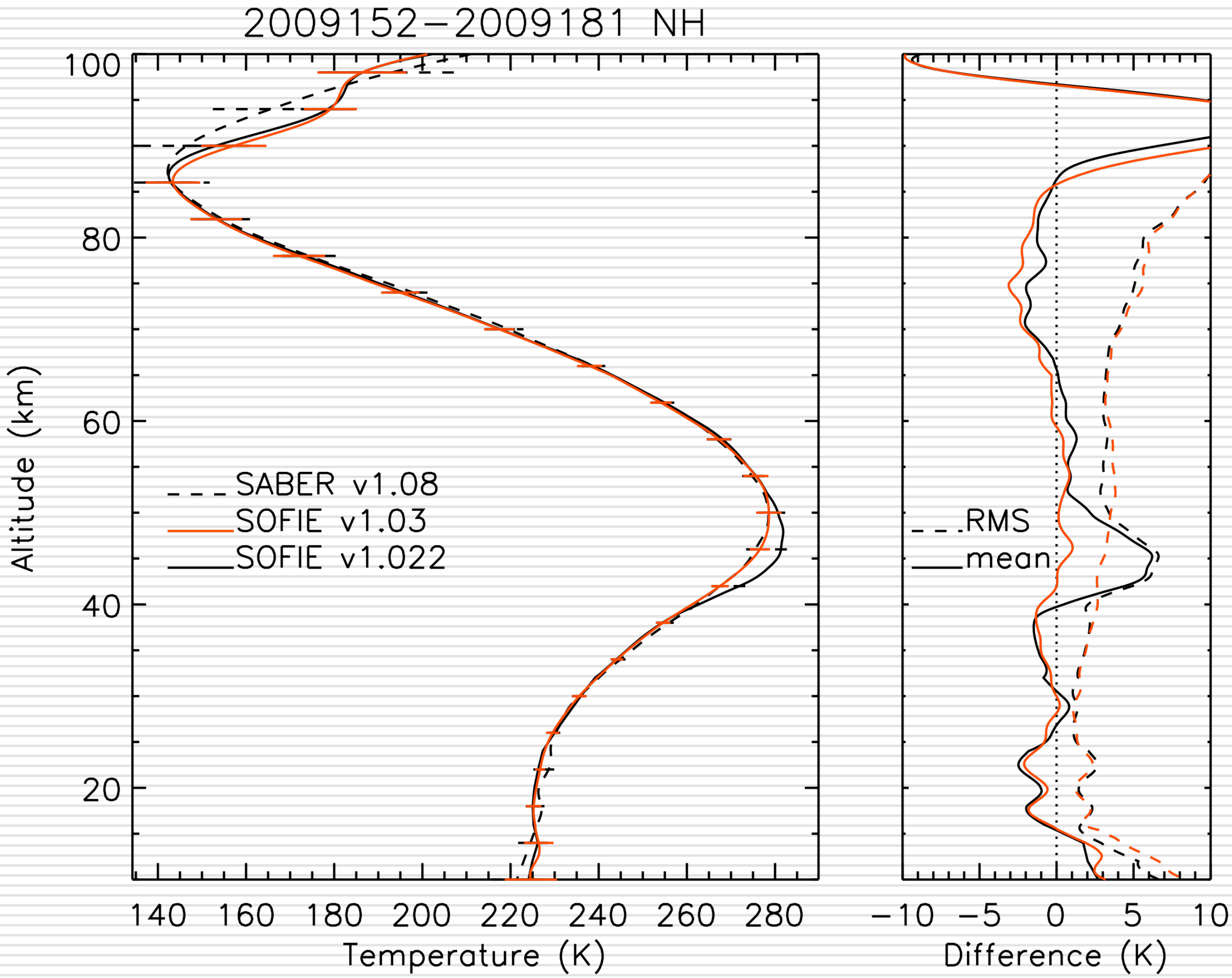




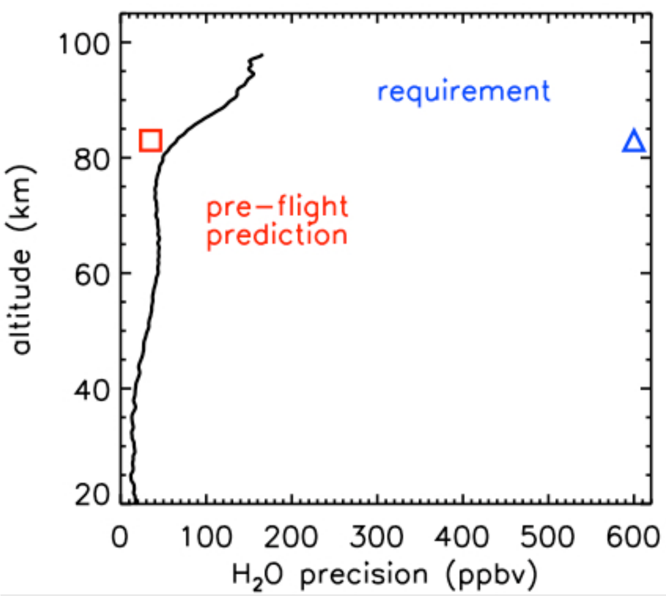
SOFIE temperature

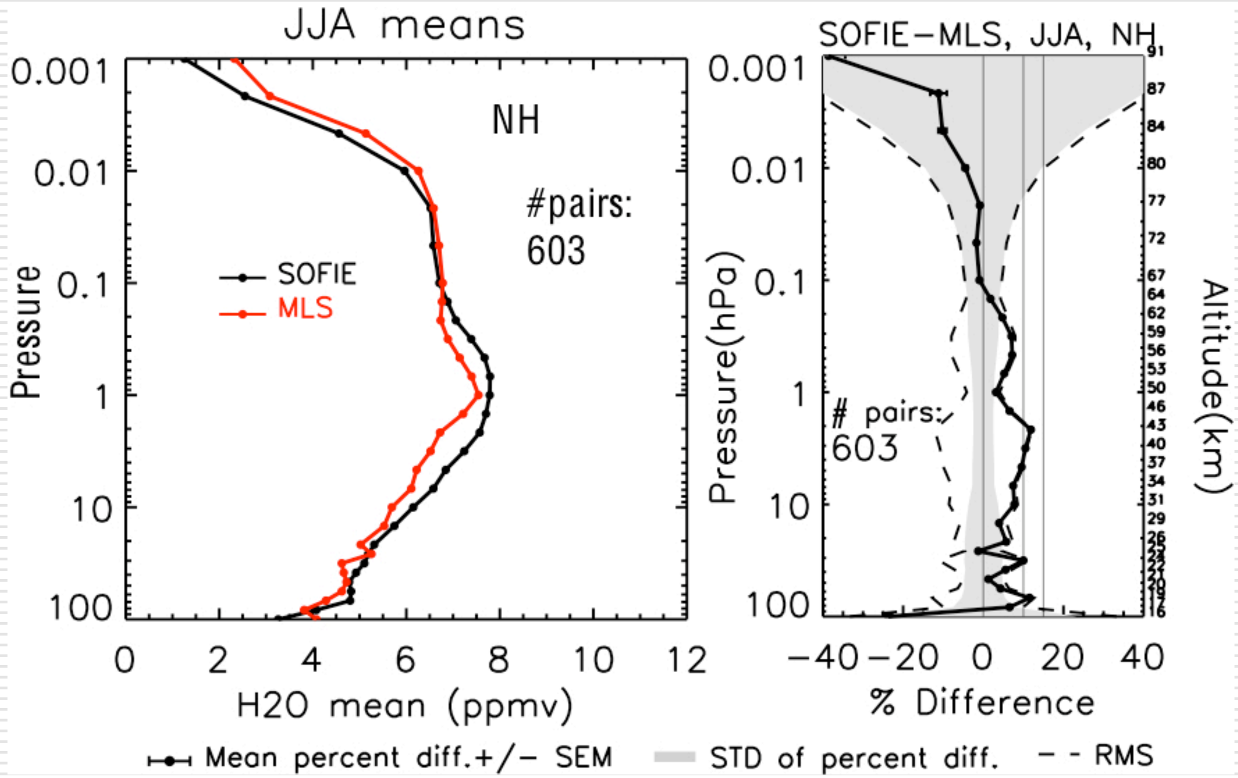


SOFIE temperature

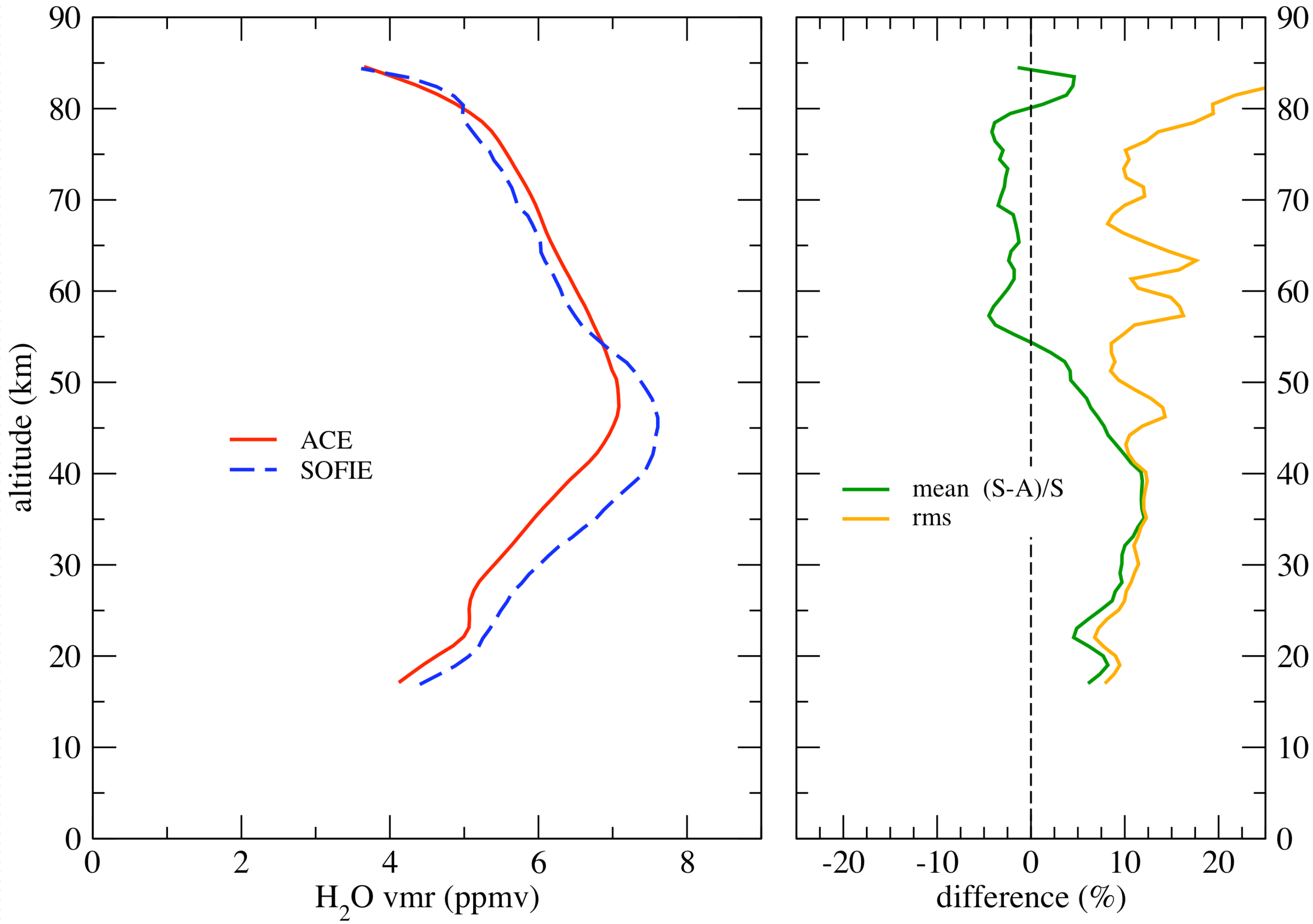


SOFIE water vapor

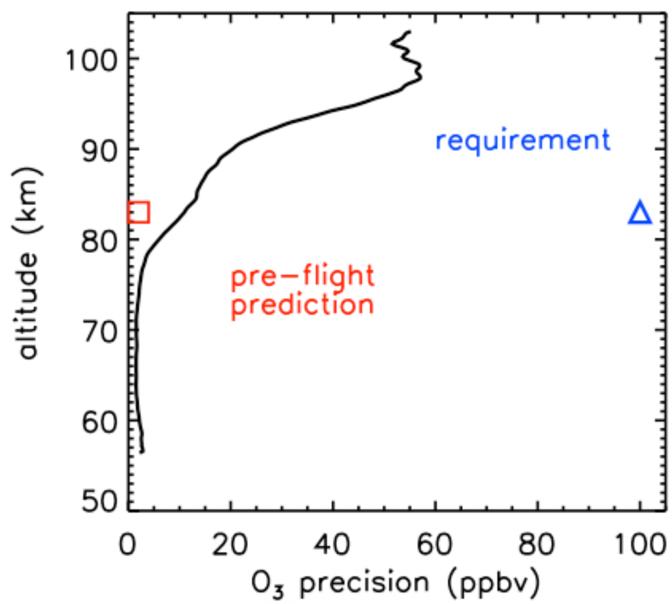


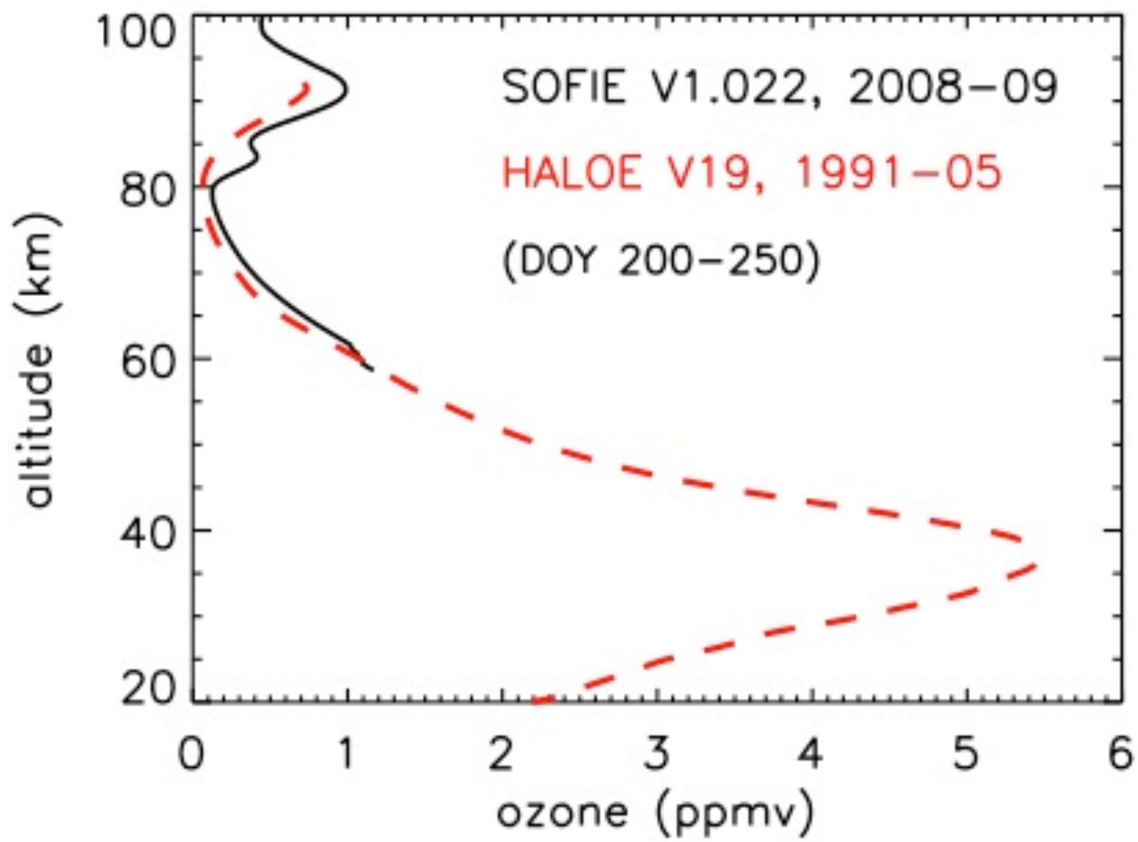


SOFIE water vapor

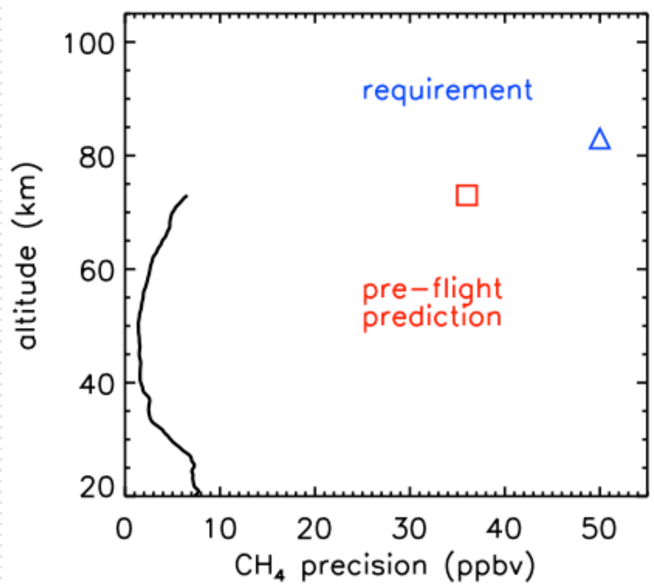


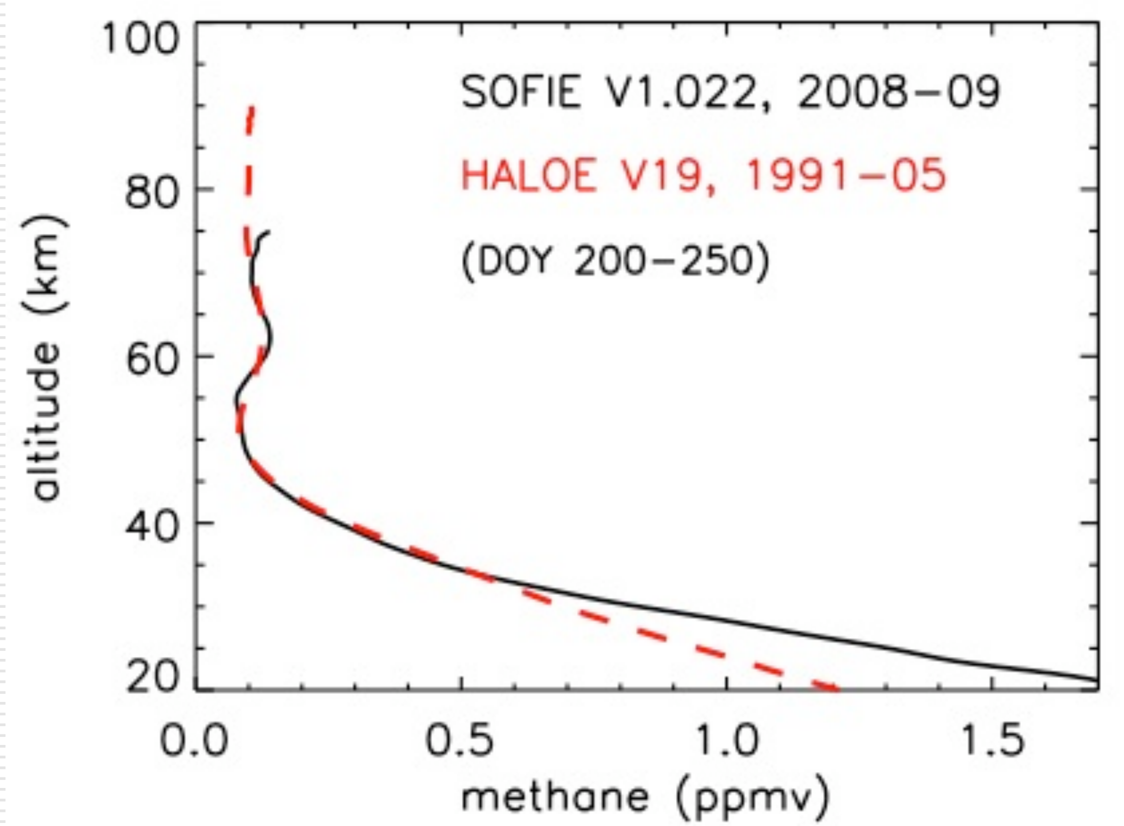
SOFIE ozone


100
90
80
70
60
50
altitude (km)
0
20
40
60
80
100
O3 precision (ppbv)
requirement
pre–flight
prediction

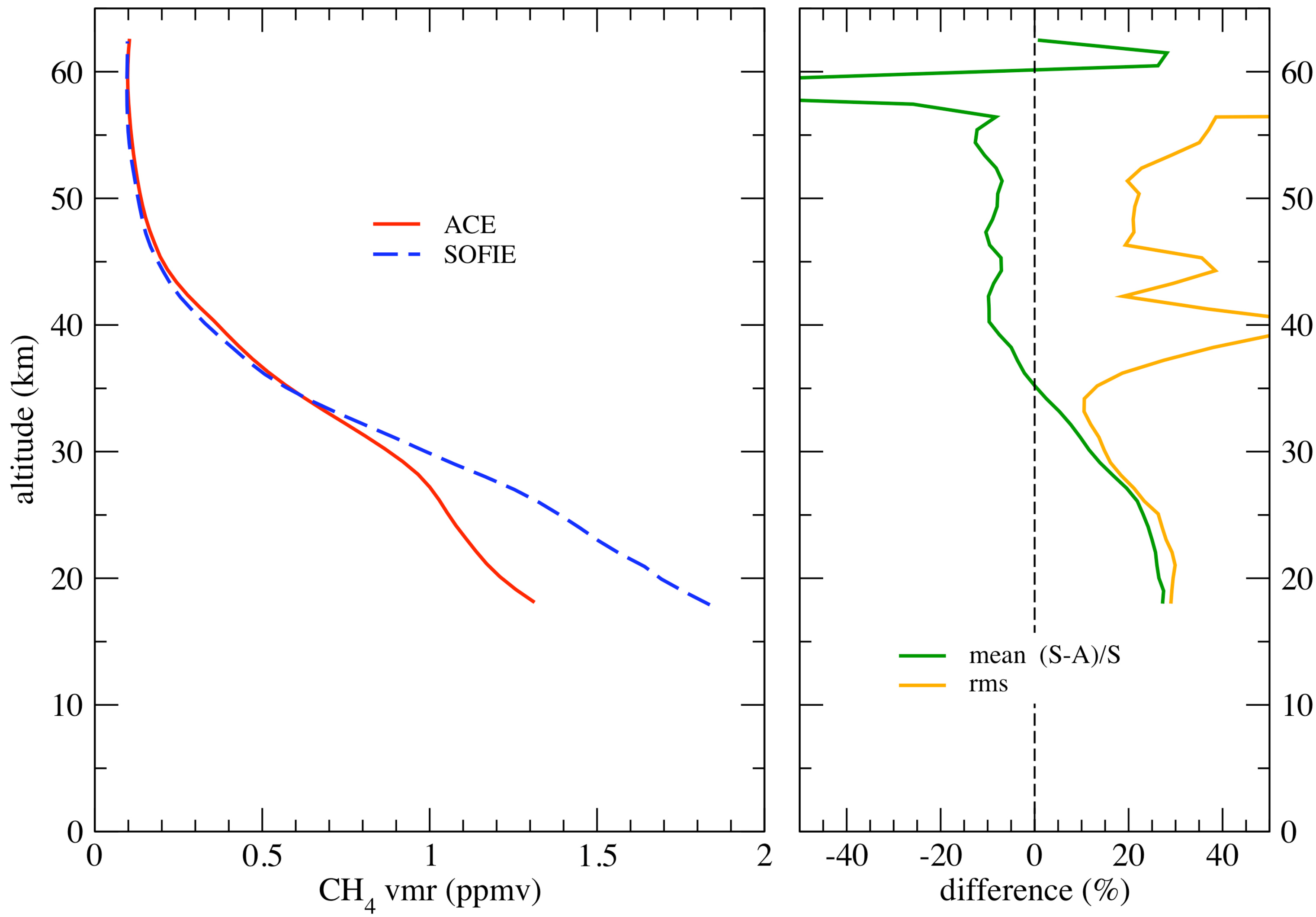

SOFIE V1.022, 2008–09
HALOE V19, 1991–05
(DOY 200–250)
100
80
60
40
20
altitude (km)
0
1
2
3
4
5
6
ozone (ppmv)

SOFIE methane

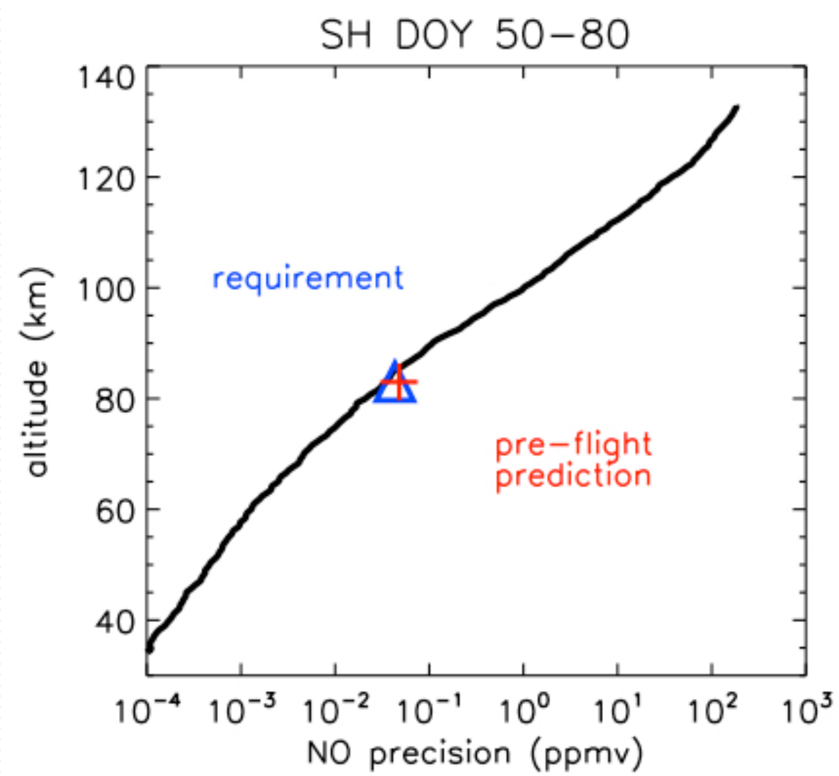


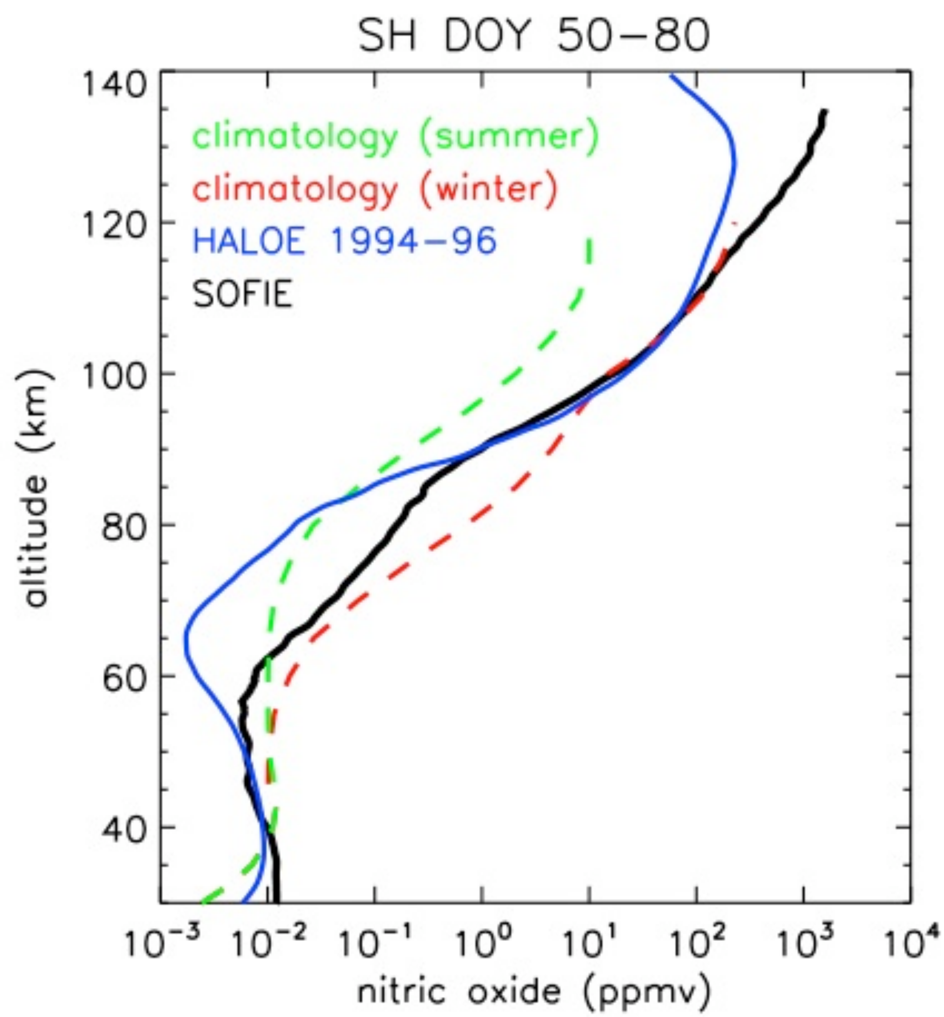


SOFIE methane

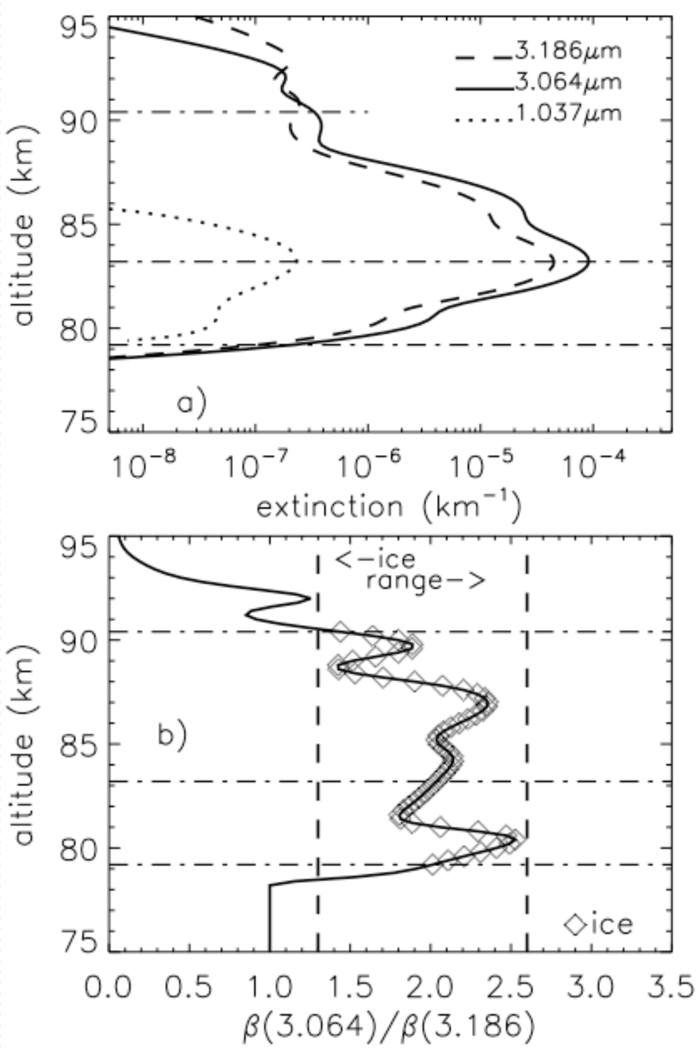


SOFIE nitric oxide

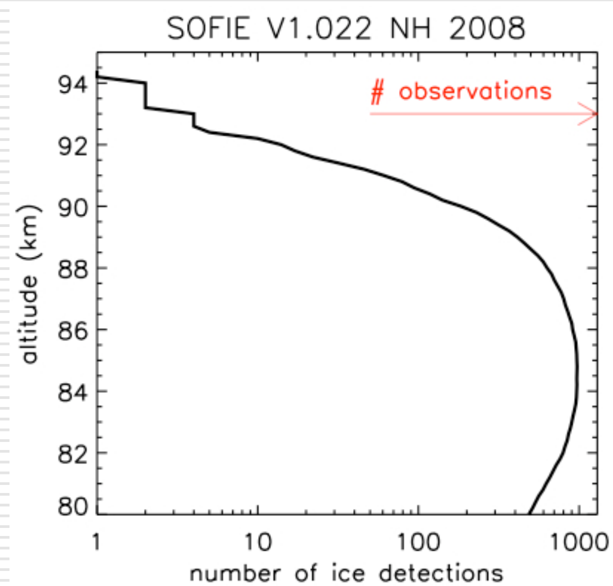




SOFIE ice sensitivity

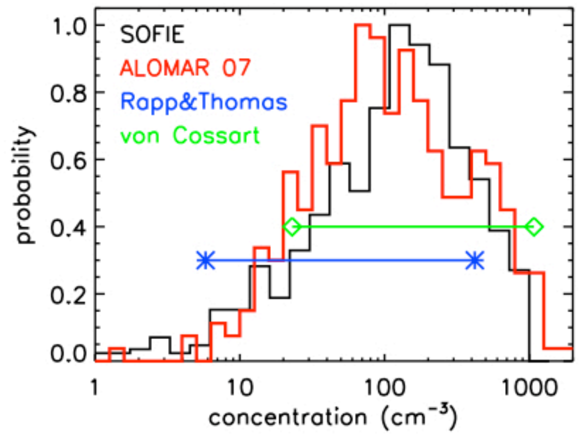


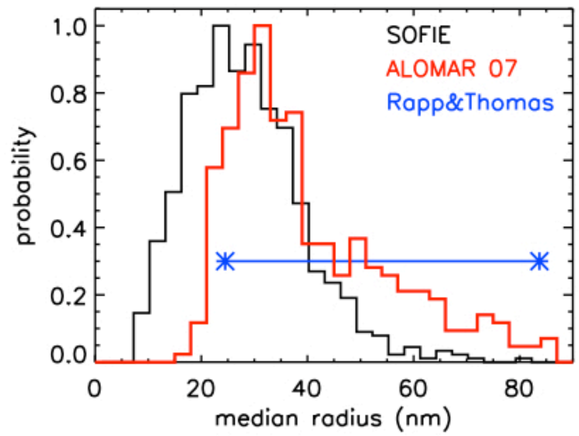
- 3.064 and 3.186 μm bands.
- detection threshold is 1×10^{-7} km^{-1}

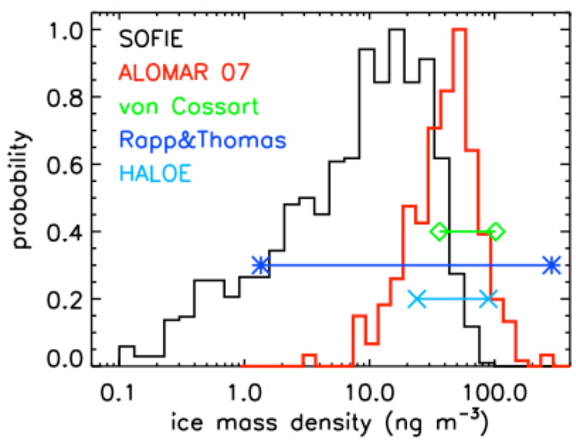


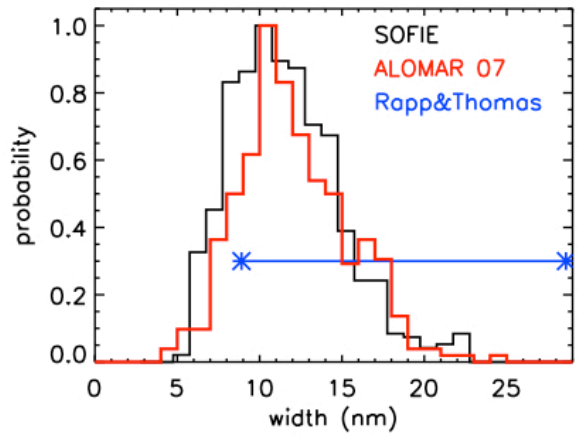
PMC properties

- mass density: uncertainty < 10%, sensitivity ~ 0.06 ng m^{-3}.
- shape: spheroid axial ratio, uncertainty < 20%.
- radius: uncertainty < 10%
- size distribution: (Gaussian N, r_m, σ) uncertainties <~ 35%









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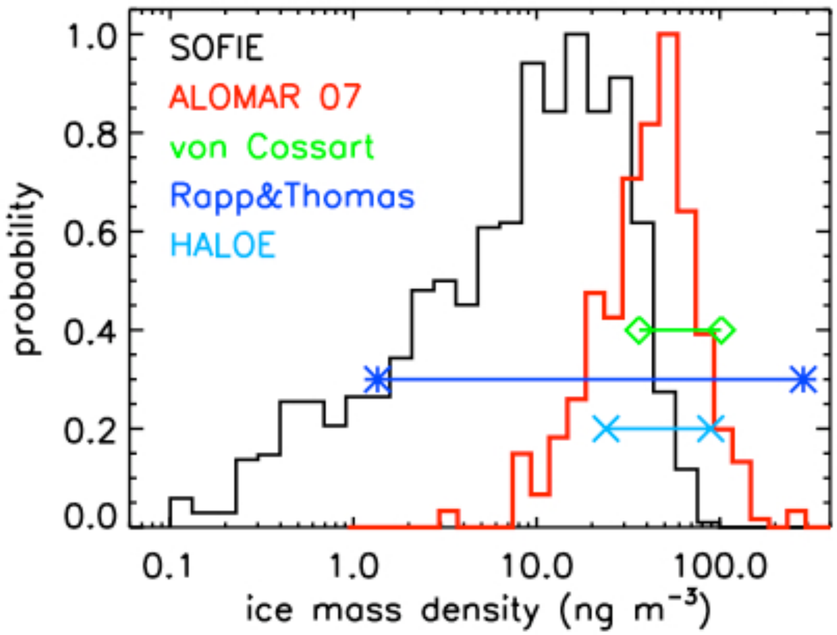
ice mass density



IR extinction is directly proportional to density.

slight dependence on particle shape

M_{ice} uncertainties are < 10%.

minimum detectable M_{ice} ~ 0.06 ng m^{-3}.

(smallest observed is 0.08 ng m^{-3})

HALOE: M_{ice} > 13 ng m^{-3}, LIDAR: M_{ice} > 2 ng m^{-3}.

NH 2007 averages

SOFIE: 14 ng m^{-3}

Lidar: 47 ng m^{-3}

ice effective radius

IR/NIR extinction ratios proportional to r_e (3V/S)

insensitive to particle shape.

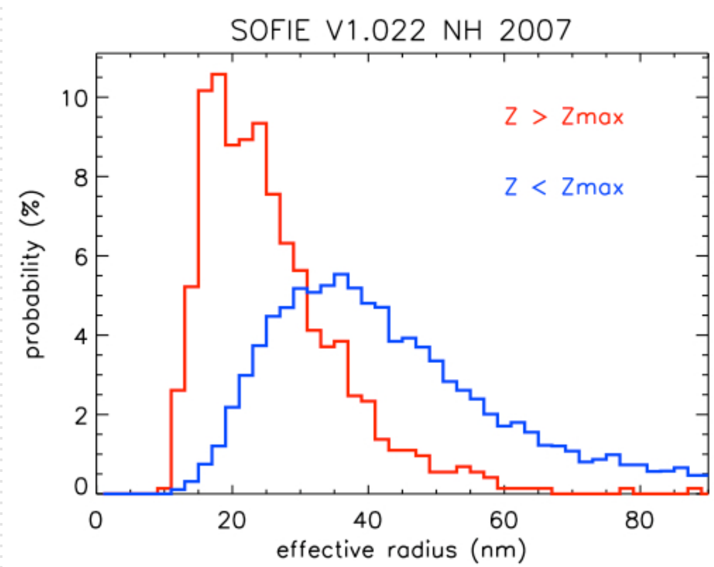
uncertainties < 10%

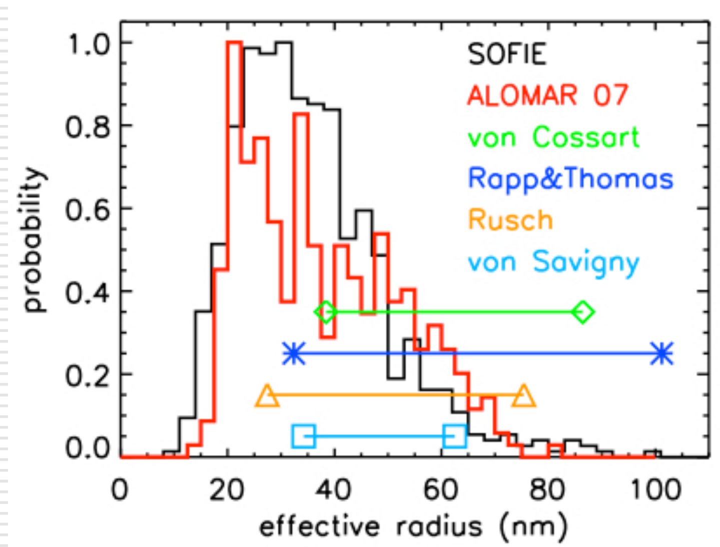
minimum detectable r_e appears to be ~9 nm.

NH 2007 averages

SOFIE: 35 nm

Lidar: 38 nm





ice particle shape

some IR extinction ratios are sensitive to particle shape but insensitive to size

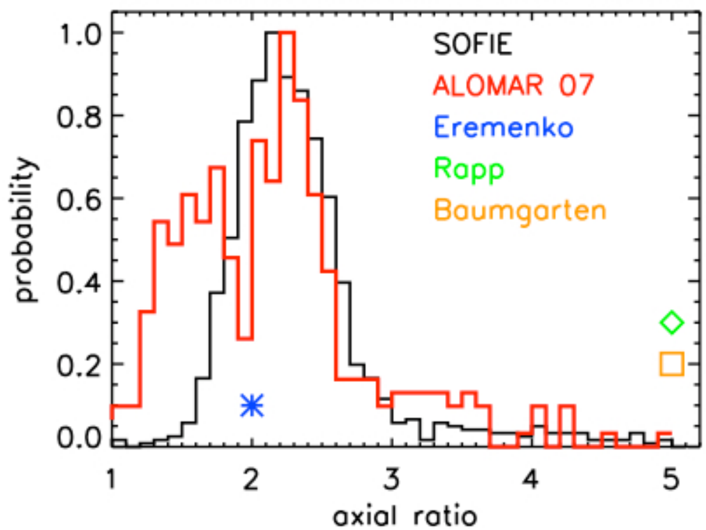
axial ratios are determined assuming oblate or prolate spheroids

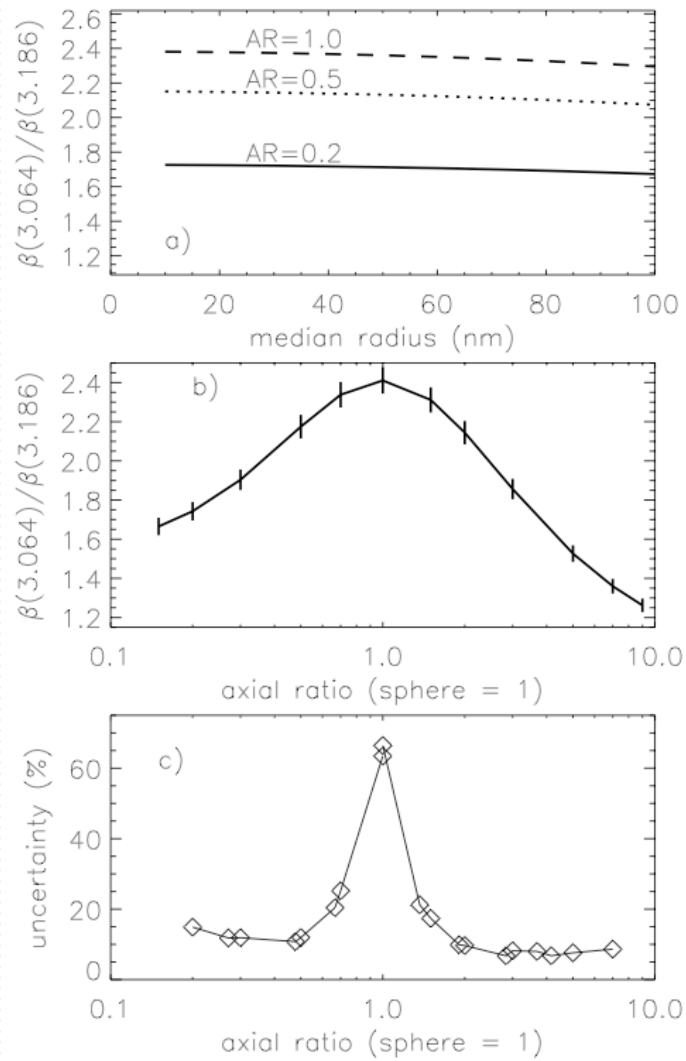
uncertainties are < 20% (except for AR ~ 1)

NH 2007 averages

SOFIE: 2.4

Lidar: 2.1

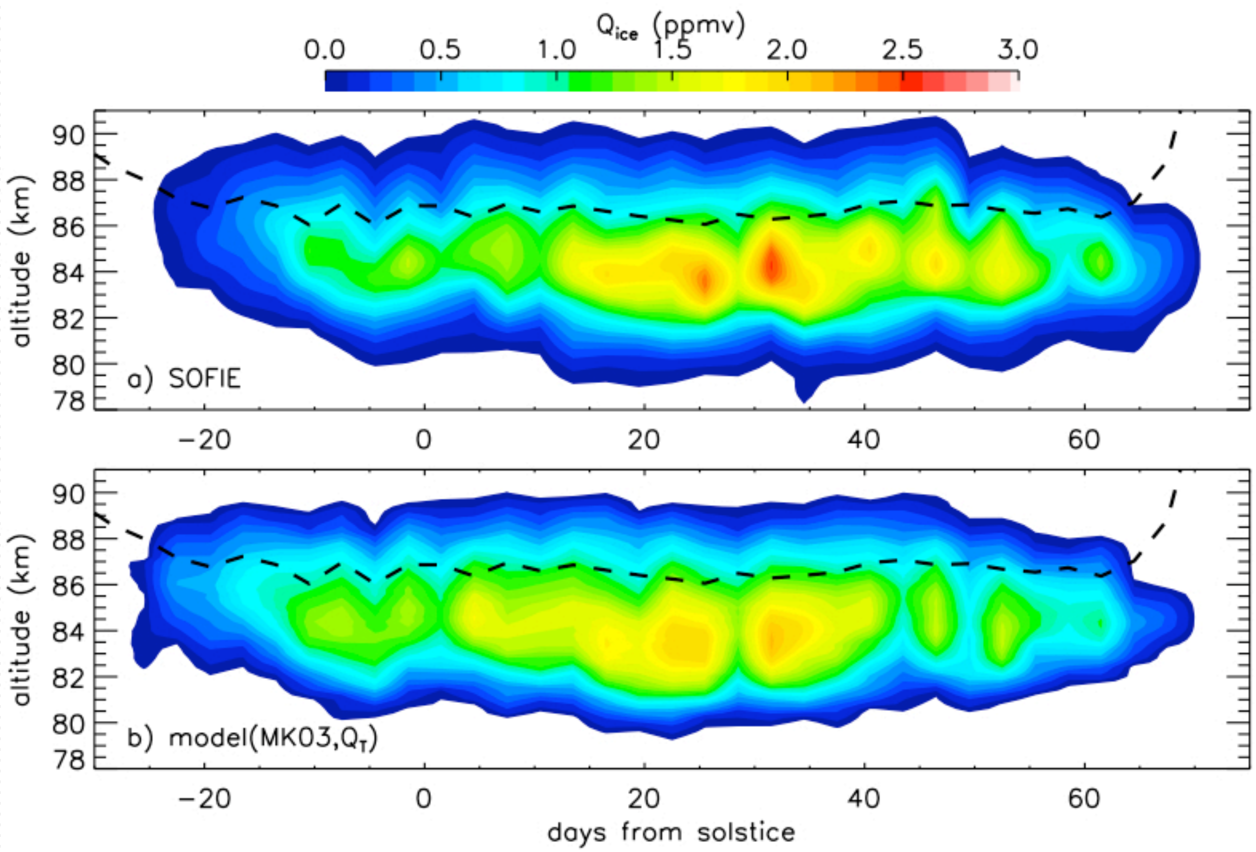




PMC measurement highlights

Before AIM, PMCs were considered sporadic layers 1 or 2 km thick.

SOFIE now shows a persistent ice layer up to ***10 km*** thick!



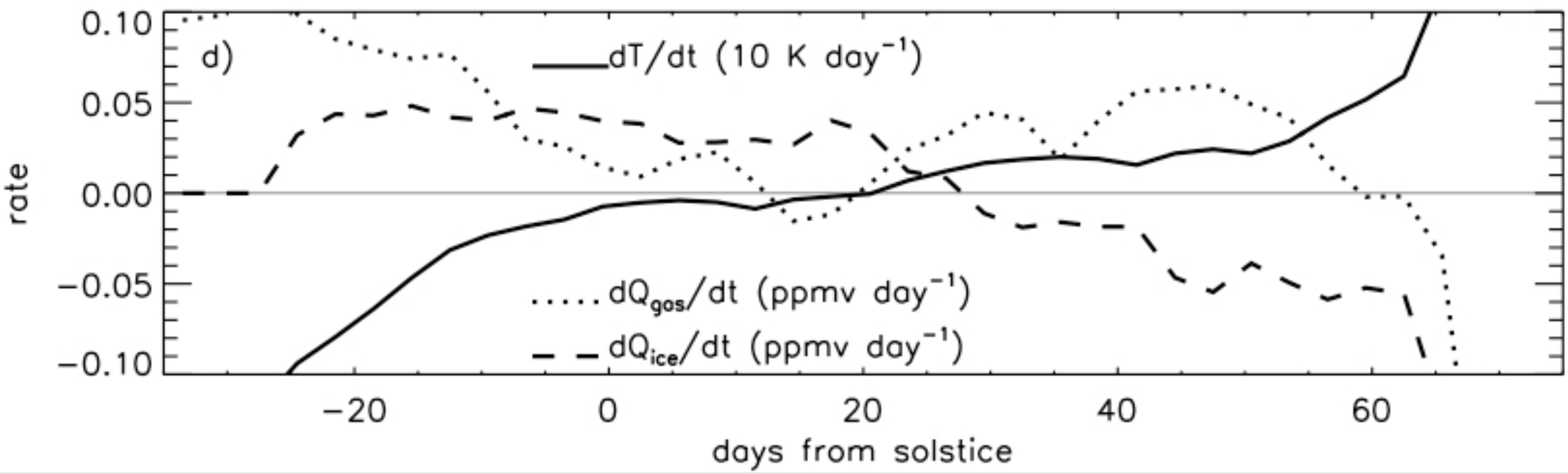
SOFIE ice mass densities are consistent with model predictions using SOFIE T and H_2O.

more PMC highlights

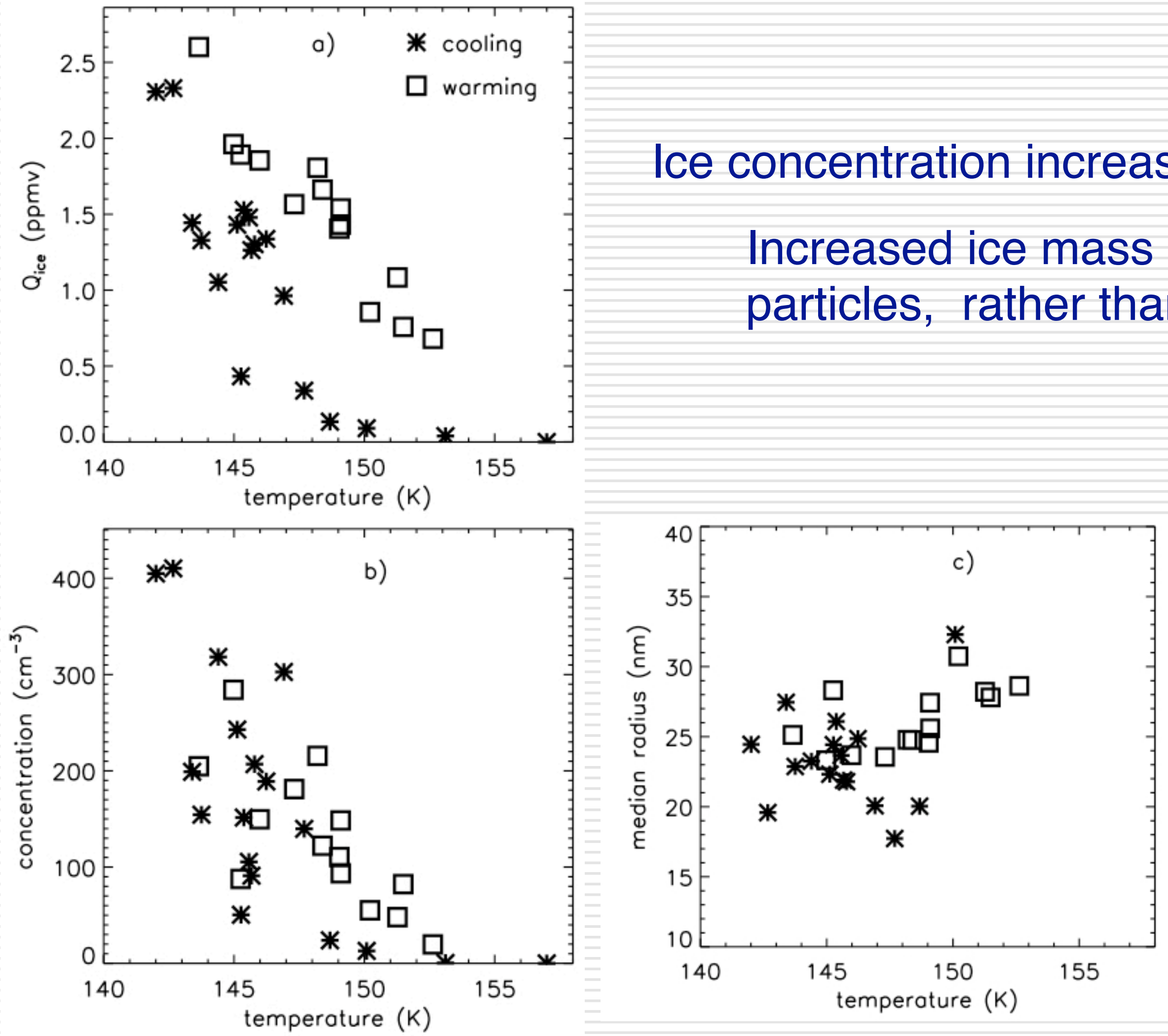
dependence of ice mass density on temperature varies:

Early season (cooling): steep dependence on T due to simultaneously increasing H2O.

Late season (warming): increasing H2O, sublimation buffers the effect of warming.



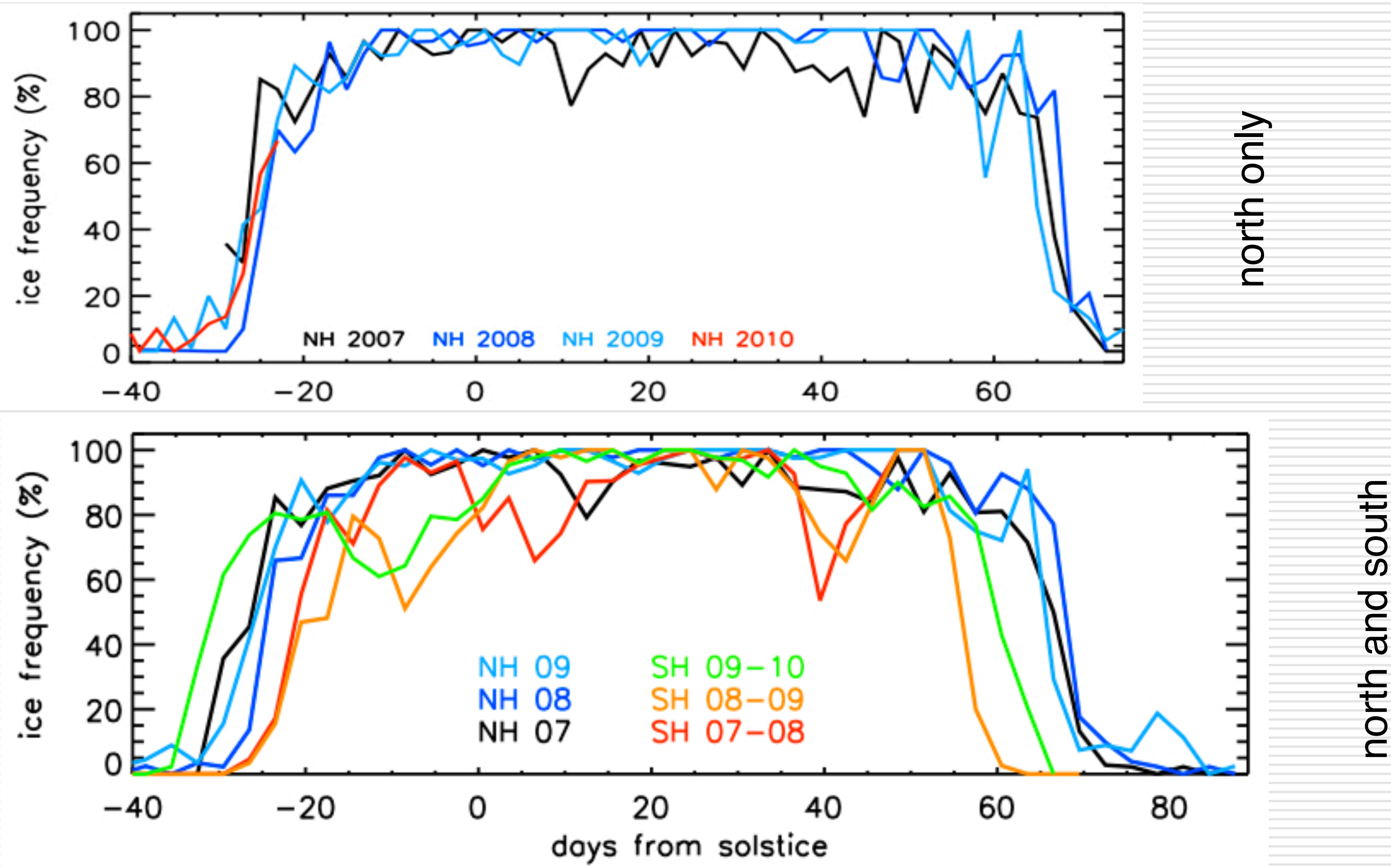
still more PMC highlights



Ice concentration increases at low temperatures:

Increased ice mass is due to nucleation of more particles, rather than growth of existing ice.

still more PMC highlights



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meteoric smoke

10 - 100 tons of meteoric material enter Earth’s atmosphere per day.

~70% of the incoming meteoroids ablate at ~70 - 110 km altitude, producing meteoric smoke particles (MSPs).

MSPs reside in the stratosphere & mesosphere, with radii of ~0.2 - 10 nm.

MSPs are important to understanding:

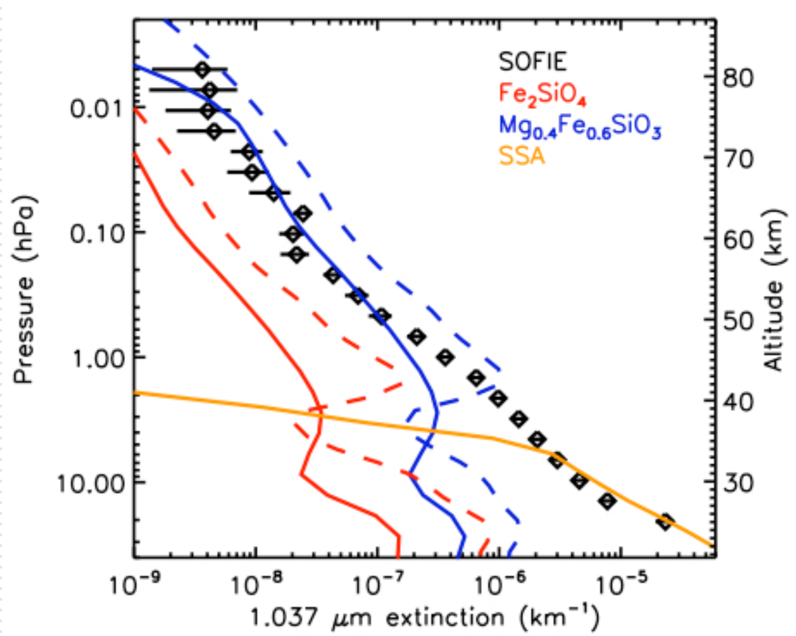
- Middle atmosphere neutral and ion chemistry.
- Stratospheric aerosol nucleation (sulfates & PSC).
- Mesospheric ice nucleation (PMC & PMSE).
- Long term accumulation of extraterrestrial material in polar ice.

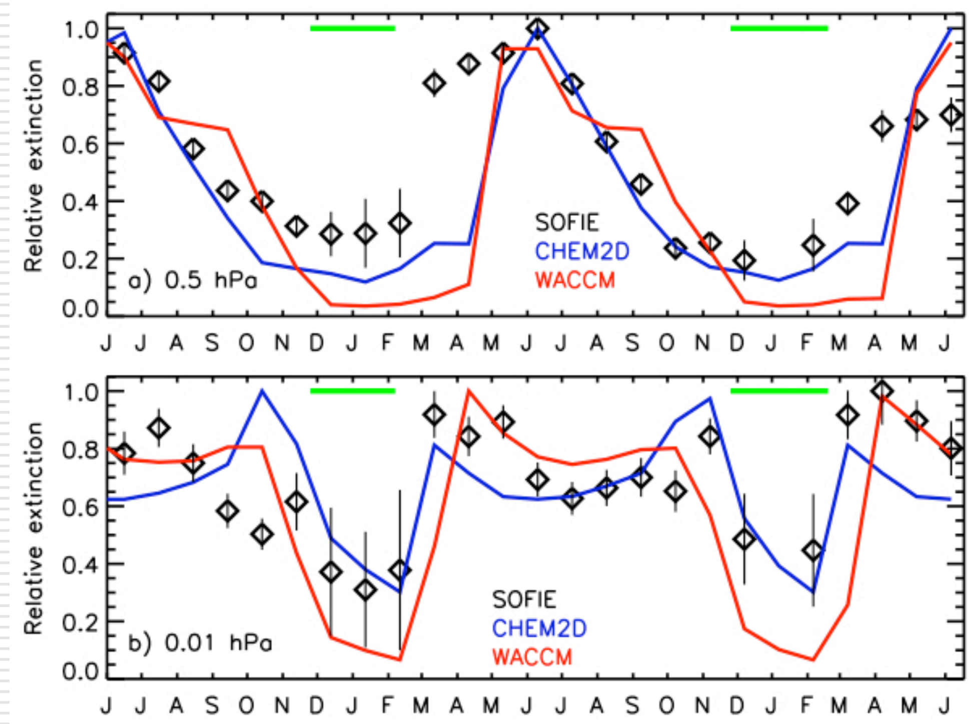
SOFIE meteoric smoke

first satellite observations of meteoric smoke.

35 - 90 km altitude

2×10^{-8} km^{-1} precision

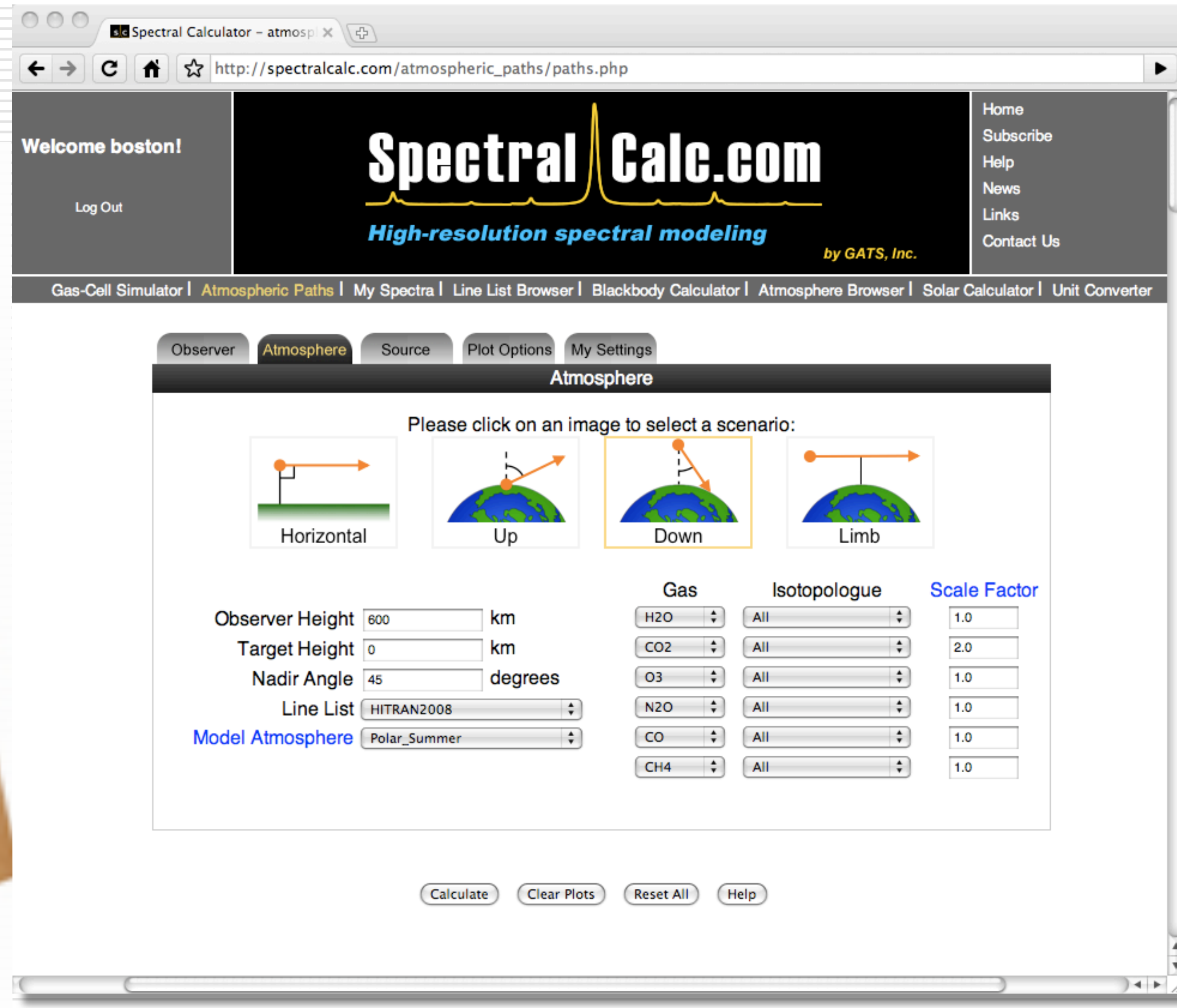


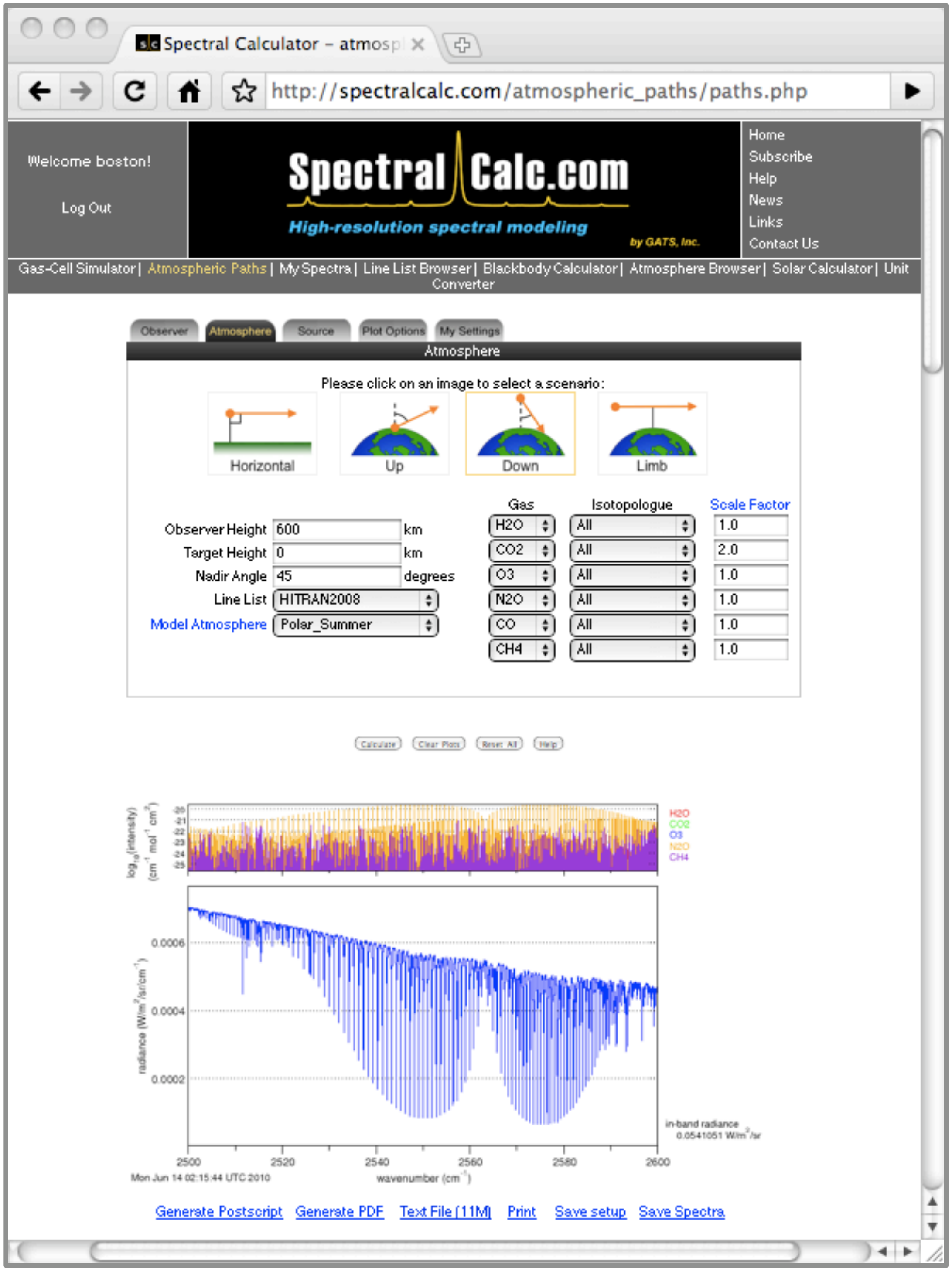


observes smoke ***in the atmosphere***, applies directly to the PMC environment.

may yield estimates of total meteoric influx, which was the CDE goal.

www.SpectralCalc.com

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Please click on an image to select a scenario:
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Up
Down
Limb
Observer Height 600 km
Target Height 0 km
Nadir Angle 45 degrees
Line List HITRAN2008
Model Atmosphere Polar_Summer
Gas
Isotopologue
Scale Factor
H2O All 1.0
CO2 All 2.0
O3 All 1.0
N2O All 1.0
CO All 1.0
CH4 All 1.0
Calculate
Clear Plots
Reset All
Help
H2O
CO2
O3
N2O
CH4
radiance (W/m²/sr/cm⁻¹)
0.0006
0.0004
0.0002
in-band radiance
0.0541051 W/m²/sr
2500
2520
2540
2560
2580
2600
wavenumber (cm⁻¹)
Mon Jun 14 02:15:44 UTC 2010
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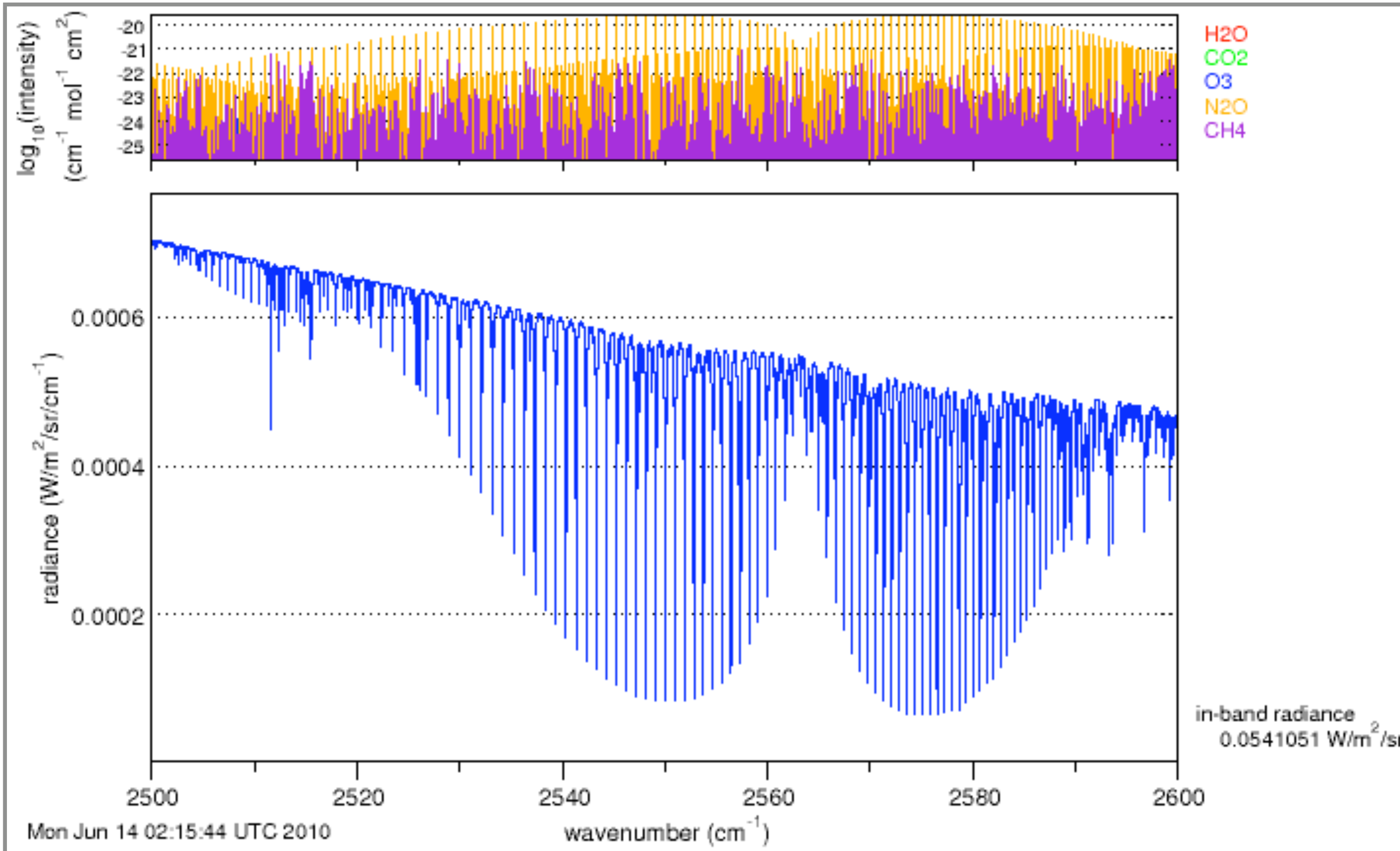
SpectralCalc.com

High-resolution spectral modeling

by GATS, Inc.

username: *boston*

password: *redsox*



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acknowledgements, again

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the end