Determining required signal-to-noise ratios for XCO_2 and XCH_4 precision targets: Application to AIM-North

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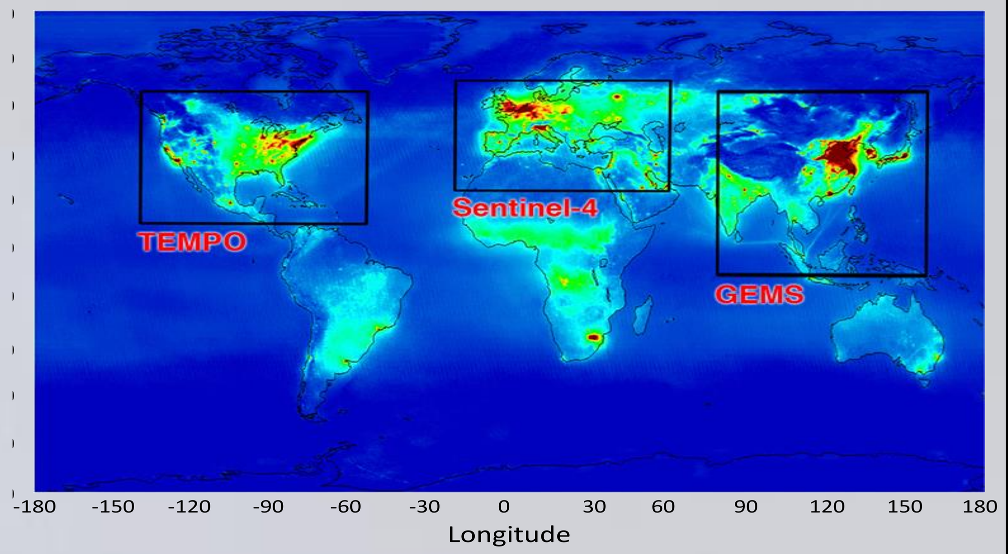
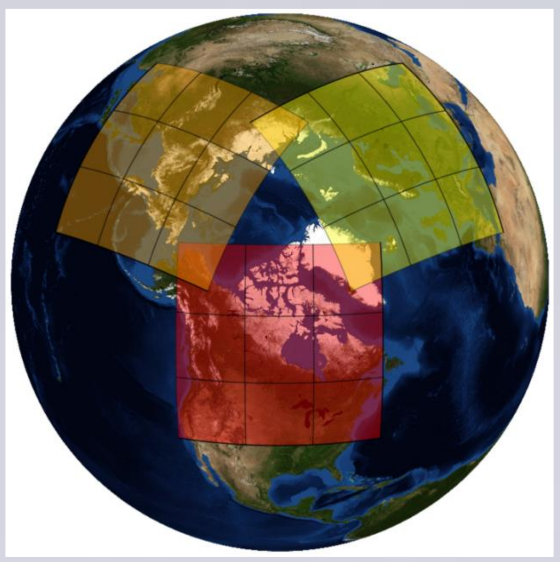
Background & Context

Introduction

There is a trend toward measuring climate-relevant trace gases from geostationary orbit to improve diurnal sampling relative to LEO. But geostationary satellites do not provide coverage at high latitudes. High latitudes are very sensitive to climate change.



Expected coverage from upcoming geostationary satellites



Satellite remote sensing from highly elliptical orbits such as Molniya provides quasi-geostationary observations at high latitudes to complement the coverage of geostationary observations.

Potential AIM-North imaging approach. Each colored region would be scanned every ~90 minutes during daylight. A three-apogee (TAP) orbit is assumed.

Instrument and spectral band selection

Satellite monitoring within the scientific focus of the climate research

- Imaging Michelson and pushbroom grating spectrometer are being considered
- Imaging Michelson covers larger area instantaneously
- Grating spectrometer has SNR advantage in the near-IR

	Band (nm)	Band (cm^{-1})	Spectral Sampling	Target Species
UV-vis grating	280-780	12820-35714	~0.4 nm	O_3, NO_2, aerosol, BrO, HCHO, SO_2, SIF and more
NIR & SWIR IFTS	758-762	13122-13186	0.25 cm^{-1}	O_2 *A* band: p_{surf}, aerosol, SIF
	1570-1587	6300-6370	0.25 cm^{-1}	CO_2 columns
	2042-2075	4810-4897	0.25 cm^{-1}	CO_2 columns
	2300-2385	4193-4348	0.25 cm^{-1}	CH_4 and CO columns

Radiative transfer simulations with MODTRAN 5.2

Determining SNR requirements

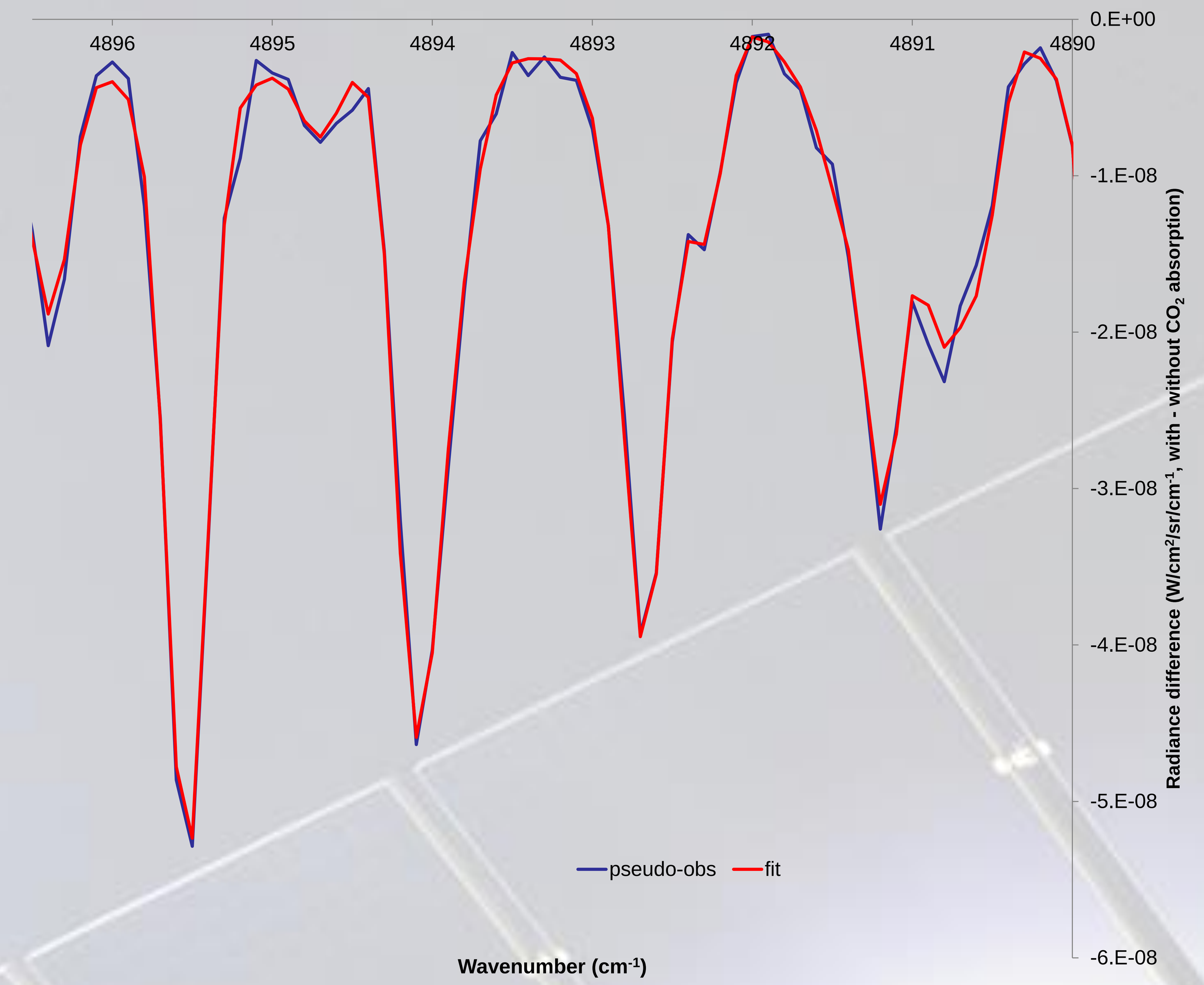
The following approach was used to determine SNR requirements:

1) Simulate noise-free instrument spectral signal using MODTRAN5.2 with absorption by gases, including target gas.
2) Add Gaussian-distributed random noise to obtain noisy pseudo-obs.
3) Simulate instrument signal without absorption by target gas.
4) Fit difference of step 2 and step 3 with difference between step 1 and 3. Relative standard error of spectral fit is used as "measurement" precision.
5) Change instrument throughput until desired measurement precision is achieved.

Species [typical value]	**Spatial Resolution**	**Precision (1 sigma)**
Primary		
CO_2 (X) [400 ppm]	4x4 km^2 (G), 7x7 km^2 (B), 10x10 km^2 (T)	0.25% (1 ppm) (G), 0.75% (3 ppm) (T)
CH_4 (X) [1800 ppb]	4x4 km^2 (G), 7x7 km^2 (B), 10x10 km^2 (T)	0.5% (9 ppb) (G), 1.5% (27 ppb) (T)
O_2 (C) [4×10^{24} cm^{-2}]	4x4 km^2 (G), 7x7 km^2 (B), 10x10 km^2 (T)	0.25%/srqt(2) (G)
CO (C) [2×10^{18} cm^{-2}]	4x4 km^2 (G), 10x10 km^2 (T)	5% (G) 15% (T)

Results

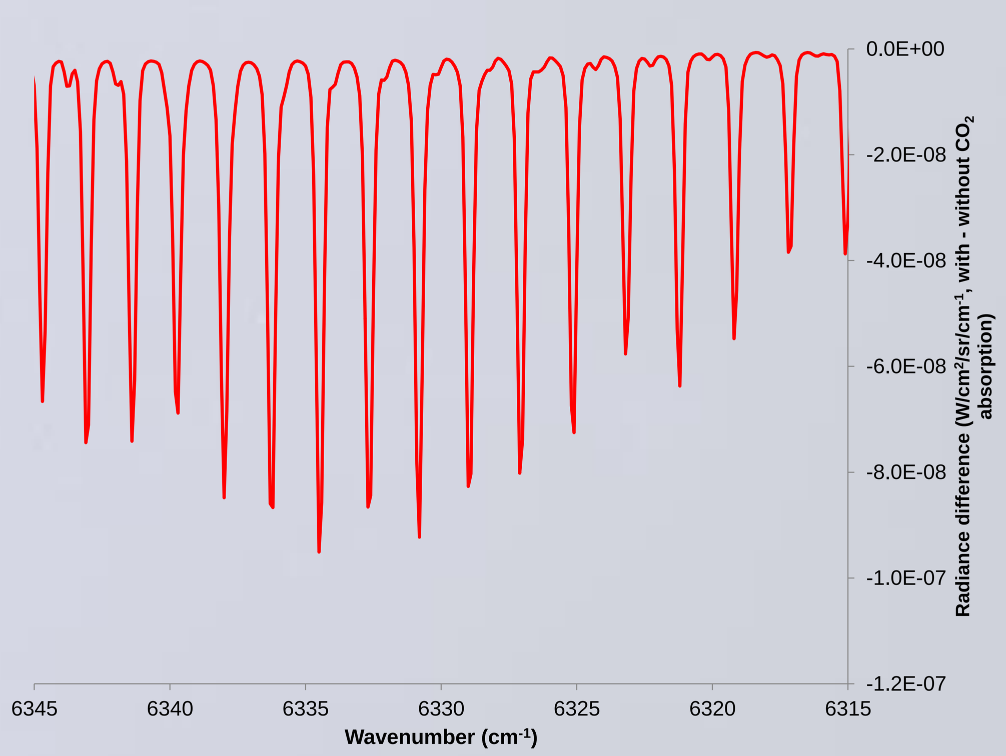
Sample spectral fit of noisy pseudo-observations



Zoom on several rotational lines within CO_2 strong band (2.0 μm band). SNR of 105.

SNR as a function of passband width

Instrument	spectral resolution	spectral sampling	SNR Goal	Target & Band	Band width cm^{-1}
FTS	0.3 cm^{-1}	0.3 cm^{-1}	215	xCO_2 (1.6 micron only: 6172.8-6369.4 cm^{-1})	196.6
FTS	0.3 cm^{-1}	0.3 cm^{-1}	290	xCO_2 (1.61 micron band only, 1593-1620 nm, 6172.8-6276.9 cm^{-1})	104.1
FTS	0.3 cm^{-1}	0.3 cm^{-1}	316	xCO_2 (1.57 micron band only, 6300-6369.4 cm^{-1})	69.4
FTS	0.3 cm^{-1}	0.3 cm^{-1}	464	xCO_2 (6315-6345 cm^{-1})	30

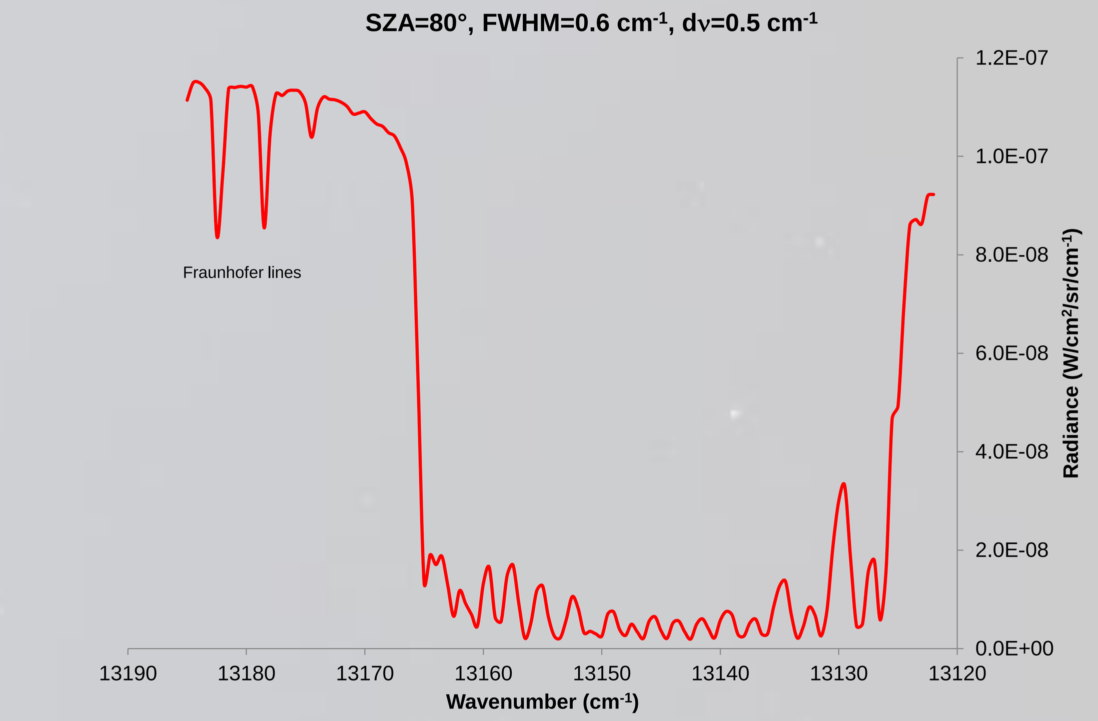


Plot of 6315-6345 cm^{-1} range within strong band of CO_2

SNR requirements

Instrument	spectral resolution	spectral sampling	SNR Goal	Target & Band
grating	0.3 cm^{-1}	0.3 cm^{-1}	106	xCO_2 (2 μm only: 4810-4897 cm^{-1})
grating	0.3 cm^{-1}	0.3 cm^{-1}	270	xCO_2 (1.61 μm only: 6173-6271 cm^{-1}, 1593-1620 nm)
grating	0.3 cm^{-1}	0.3 cm^{-1}	104 (2 μm)	xCO_2 (dual window: 4810-4897 cm^{-1} & 6300-6369 cm^{-1})
grating	0.3 cm^{-1}	0.3 cm^{-1}	122 (1.6 μm)	xCO_2 (dual window: 4810-4897 cm^{-1} & 6300-6369 cm^{-1})
FTS	0.3 cm^{-1}	0.3 cm^{-1}	143	xCO_2 (2 μm only: 4810-4897 cm^{-1})
FTS	0.3 cm^{-1}	0.3 cm^{-1}	315	xCO_2 (1.57 μm only: 6300-6369 cm^{-1})
FTS	0.3 cm^{-1}	0.3 cm^{-1}	290	xCO_2 (1.61 μm only: 6173-6271 cm^{-1}, 1593-1620 nm)
FTS	0.3 cm^{-1}	0.3 cm^{-1}	116 (2 μm)	xCO_2 (dual window: 4810-4897 cm^{-1} & 6300-6369 cm^{-1})
FTS	0.3 cm^{-1}	0.3 cm^{-1}	119 (1.6 μm)	xCO_2 (dual window: 4810-4897 cm^{-1} & 6300-6369 cm^{-1})
grating	0.3 cm^{-1}	0.3 cm^{-1}	116	CO (4192.8-4347.8 cm^{-1})
FTS	0.3 cm^{-1}	0.3 cm^{-1}	157	CO (4192.8-4347.8 cm^{-1})
grating	0.3 cm^{-1}	0.3 cm^{-1}	123	CH_4 (5988-6173 cm^{-1})
FTS	0.3 cm^{-1}	0.3 cm^{-1}	130	CH_4 (5988-6173 cm^{-1})
FTS	0.3 cm^{-1}	0.3 cm^{-1}	65	CH_4 in CO window (4192.8-4347.8 cm^{-1})
FTS	0.6 cm^{-1}	0.5 cm^{-1}	137	O_2 *A* (13000-13100 cm^{-1})
FTS	0.3 cm^{-1}	0.3 cm^{-1}	95	O_2 *A* (13000-13100 cm^{-1})
FTS	0.3 cm^{-1}	0.3 cm^{-1}	248	O_2 1Δ (7890-7990 cm^{-1})

O_2 *A* band window



The A band window was chosen to include isolated Fraunhofer lines, plus the R branch

Conclusions

- Although O_2 $^1\Delta$ has several advantages over the *A* band, the required SNR is much higher (248 vs. 131 for an FTS at 0.3 cm^{-1} resolution over 100 cm^{-1} windows, 7890-7990 cm^{-1} vs. 13000-13100 cm^{-1})
- Required SNR is much smaller for detecting CO_2 at 2.0 μm (2.042-2.075 μm) than at 1.6 μm (1.570-1.587 μm): 143 versus 315 for a 0.3 cm^{-1} FTS
- Similarly, SNR requirements are cut in half upon switching from 1.67 μm to 2.3 μm for CH_4

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