TEMPO

Tropospheric Emissions:
Monitoring of Pollution

National Aeronautics and Space Administration

Smithsonian Astrophysical Observatory

The TEMPO concept for geostationary monitoring of Greater North American atmospheric pollution

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and the TEMPO team

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Footprint, GSD and FOR

Each 2 km × 4.5 km pixel is a 2K element spectrum from 290-690 nm!

UV/Vis satellite background

A full, minimally-redundant, set of polluting gases, plus aerosols and clouds is currently measured to very high precision from satellites. This includes O_3 (with profiles and tropospheric O_3), NO_2 (for NO_x), H_2CO and $C_2H_2O_2$ (for VOCs), SO_2, H_2O, O_2-O_2, N_2 and O_2 Raman scattering, and halogen oxides (BrO, ClO, IO, OClO). Spectrometers planned since 1985 began making these measurements in 1995.

- Measurements of the critical set of gases are fitted to 2-5×10^{-4} of the full-scale measured radiances.
- Scaling from LEO implies successful geostationary pollution monitoring.

SCIAMACHY original sensitivity study – K. Chance, W. Schneider, J. Burrows, 1986-1987

Appendix on Sensitivity Studies for Constituent Measurements

Summary

SCIAMACHY sensitivity studies include the three measurement geometries: nadir observing, viewing the earth's limb in scattered light, and solar and lunar occultations. In nadir observation alone, profile information is determinable in some cases by differential penetration of backscattered light at different wavelengths (as in TOMS/SBUV), and by the variable temperature structure of some molecular absorptions. Height resolution from nadir measurements is limited to 8-10 km from differential penetration and 3 km in favorable cases using temperature structure. Height resolution in limb viewing is 3 km, limited by the weighting functions for limb scattering and by the spacecraft stability. Height resolution is also 3 km for occultations, limited primarily by the telemetry data rate - 1 km resolution would otherwise be possible. The quantities retrieved from SCIAMACHY measurements include:

- Nadir observations: Total column amounts of O_3, O_4, O_2, CO, H_2O, CH_4, CO_2, NO_2, N_2O, HCHO, SO_2, ClO, OClO, and BrO; stratospheric profiles of O_3, CO, H_2O, CH_4, CO_2, N_2O; the column of NO above the ozone layer; tropospheric profiles or columns of O_3, CO, H_2O, CH_4, CO_2, N_2O. Stratospheric profile information, discrimination between stratospheric and tropospheric columns, and, in some cases, tropospheric profile information is derived from the temperature dependences of the absorption features.

eXceL O_3!

- Limb viewing observations: Stratospheric profiles of O_3 (20-50 km), $O_2(^1\Delta)$ (50 km-90 km), O_2 (20-50+ km), CO (20-35 km), H_2O (20-53 km), CH_4 (20-40 km),

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SPIE 1991

Retrieval and Molecule Sensitivity Studies for the Global Ozone Monitoring Experiment and the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY

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All geostationary molecules except $C_2H_2O_2$ analyzed

ABSTRACT

The Global Ozone Monitoring Experiment (GOME) and the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) are diode array-based spectrometers that will make atmospheric constituent and aerosol measurements from European satellite platforms beginning in the mid 1990's. GOME measures the atmosphere in the UV and visible in nadir scanning, while SCIAMACHY performs a combination of nadir, limb, and occultation measurements in the UV, visible and infrared. We present a summary of the sensitivity studies that have been performed for SCIAMACHY measurements. As the GOME measurement capability is a subset of the SCIAMACHY measurement capability, the nadir, UV and visible portion of the studies shown here apply to GOME as well.

Sun-synchronous heritage GOME/SCIAMACHY/OMI/GOME-2/OMPS nadir

Instrument	Detectors	Spectral Coverage [nm]	Spectral Resolution [nm]	Ground Pixel Size [km^2]	Global Coverage
GOME (1995-2011)	Linear Arrays	240-790	0.2-0.4	40 × 320 (40 × 80 zoom)	3 days
SCIAMACHY (2002-2012)	Linear Arrays	240-2380	0.2-1.5	30 × 30/60/90 30 × 120/240 (depending on product)	6 days
OMI (2004)	2-D CCD	270-500	0.42-0.63	15 × 30 - 42 × 162 (depending on swath position)	daily
GOME-2 (2006, 2012)	Linear Arrays	240-790	0.24-0.53	40 × 40 (40 × 80 wide swath; 40 × 10 zoom)	near-daily
OMPS-1 (2011)	2-D CCDs	250-380	0.42-1.0	50 × 50 250 × 250 (depending on product)	daily

Previous experience (since 1985 at SAO)

Scientific and operational measurements of pollutants O_3, NO_2, SO_2, H_2CO, and $C_2H_2O_2$ (and BrO, OClO, ClO, IO, H_2O, O_2-O_2, Raman, ….)

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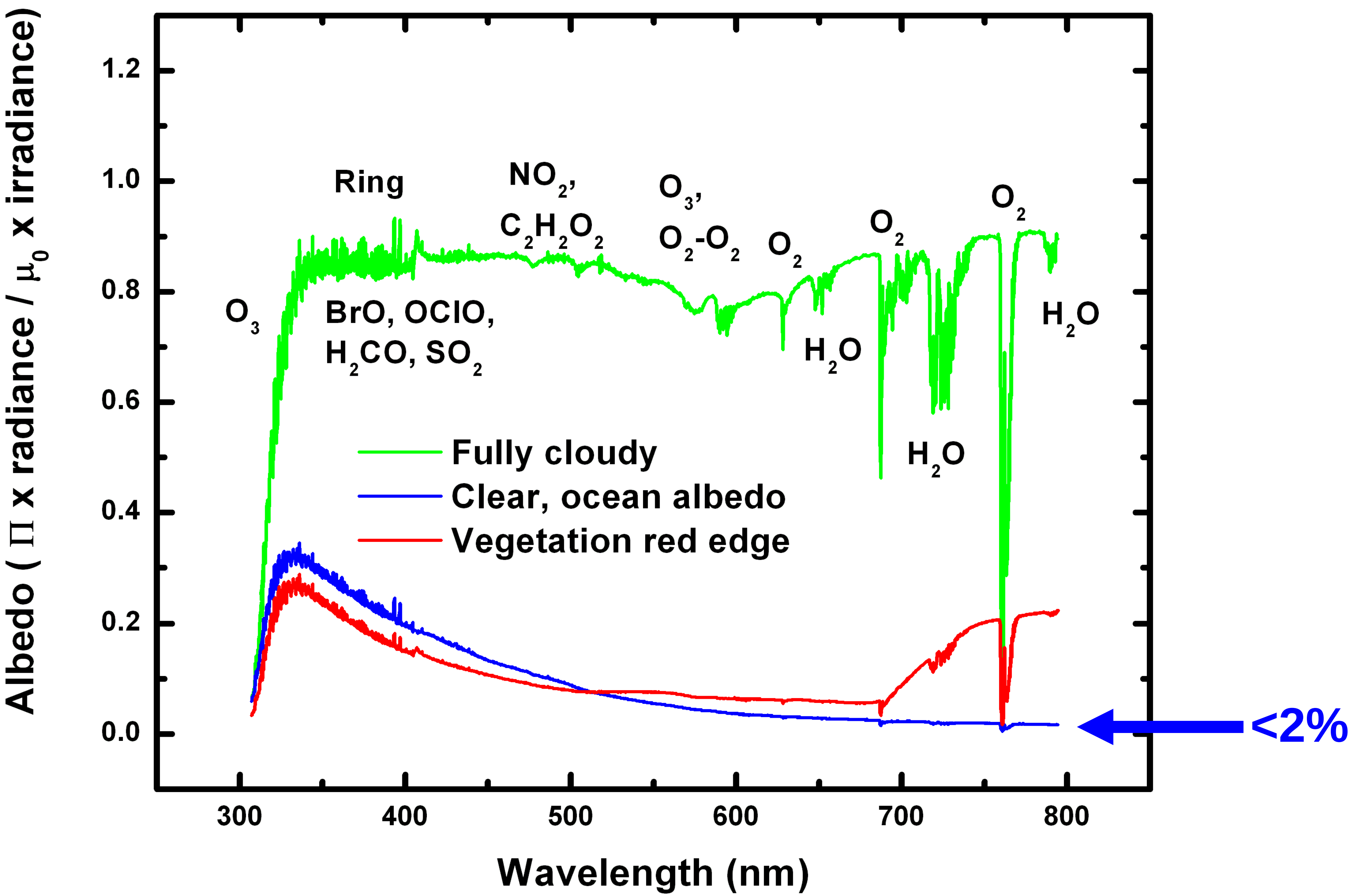
GOME Earth albedo spectra, clear and cloudy



SAO-developed the algorithm physics for UV/vis atmospheric measurements:

- Precise dynamic wavelength and slit function calibration
- Quantum-mechanically correct Raman scattering (Ring effect) correction
- Spectral undersampling correction for insufficient Nyquist sampling
- Spectral common-mode correction
- Configuration-controlled choices of reference spectra (HITRAN! http://www.cfa.harvard.edu/hitran)

Vertical Column Retrievals

Trace gas column fitting results (NO_2, SO_2, H_2CO, $C_2H_2O_2$, H_2O, BrO, OClO, IO) come from directly fitting radiances

- **Simple Ring effect formulation (no induced Fraunhofer structure or induced wavelength mismatch**
- **No distortion of measured data due to high-pass filtering: Full dynamic range of measurements used**
- **THEN: Division by air-mass factor (AMF) using LIDORT/ VLIDORT radiative transfer model and GEOS-CHEM 3-D tropospheric chemistry and transport model**
- **NOW: Pre-division of reference spectra by λ-dependent AMF – Current tabulation G. Gonzalez Abad *et al.***

OMI O_3 Profile Algorithm Description (eXceL)

- **Spectral fitting with full radiative transfer model simulation (VLIDORT) (Spurr *et al*., 2001; 2002, 2004, 2006, 2008).**
- **Fitting windows: 290-307, 325-340 nm (GOME), 270-330 nm (OMI)**
- **Retrieve O_3 partial columns at 24 layers from surface to above 60 km**
- **Ill-posed problem: non-linear optimal estimation (Rodgers, 2000) with ozone profile climatology (McPeters *et al*., 2007) to constrain retrievals**

$$c^2 = \left\| \mathbf{S}_y^{-\frac{1}{2}} \{\mathbf{K}_i(\mathbf{X}_{i+1} - \mathbf{X}_i) - [\mathbf{Y} - \mathbf{R}(\mathbf{X}_i)]\} \right\|_2^2 + \left\| \mathbf{S}_a^{-\frac{1}{2}} (\mathbf{X}_{i+1} - \mathbf{X}_a) \right\|_2^2$$

$$\mathbf{X}_{i+1} = \mathbf{X}_i + (\mathbf{K}_i^T \mathbf{S}_y^{-1} \mathbf{K}_i + \mathbf{S}_a^{-1})^{-1} \{\mathbf{K}_i^T \mathbf{S}_y^{-1} [\mathbf{Y} - \mathbf{R}(\mathbf{X}_i)] - \mathbf{S}_a^{-1} (\mathbf{X}_i - \mathbf{X}_a)\}$$

Y: Measurement vector (*e.g*., radiances)
X, X_i, X_{i+1}: State vector (*e.g*. ozone profile)
X_a: *a priori* state vector
K : Weighting function matrix, sensitivity of radiances to ozone
S_a: *A priori* covariance matrix
S_y: Measurement error covariance matrix

Liu *et al*., 2005, JGR, Liu *et al*., 2010

OMI eXceL O_3 profile product

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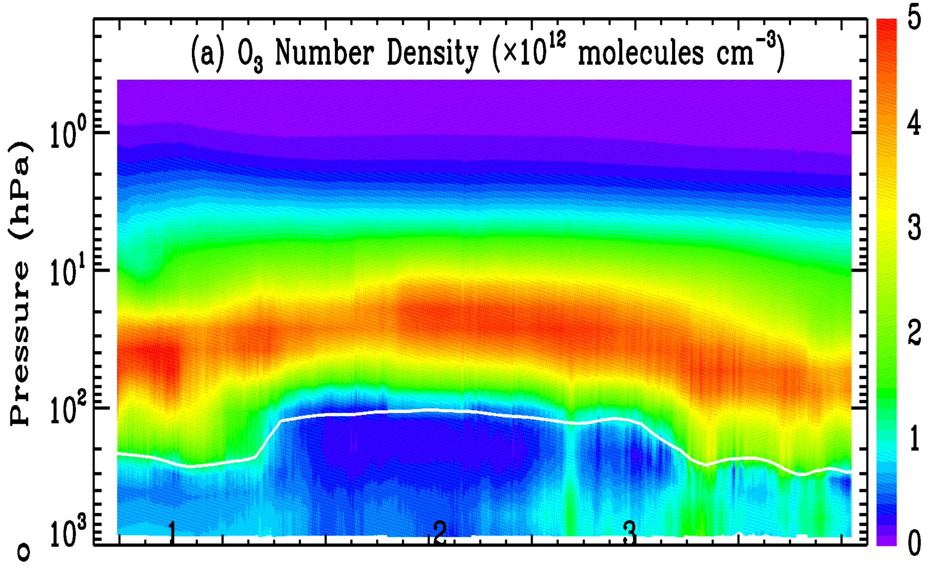
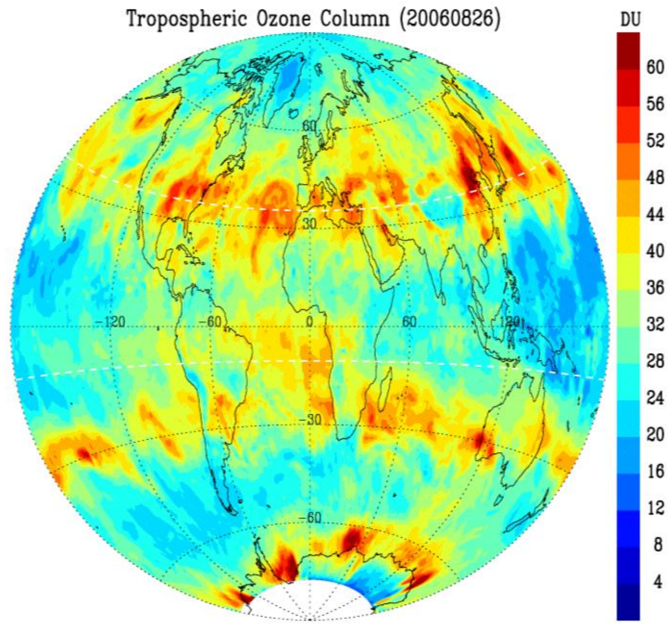
O_3 Profile APP: PROFOZ (V1.0) at OMI SIPS (Liu *et al*., 2010a,b)

- **O_3 at 24 layers up to ~60 km from 270-330 nm OMI radiances**
- **Soft radiometric correction (independent of time & space)**
- **Optimal estimation with LLM climatology (McPeters *et al*., 2007)**
- **NCEP tropopause, derive TOZ, SCO, TCO to within a few DU**
- **Data availability: Oct. 2004-May 2009**
- **Improvements will include tropopause-based O_3 climatology (Pusan U. & SAO, publication in progress)**



July 11, 2006



Aug. 26, 2006

TEMPO works from the GEO-CAPE Science Traceability Matrix to define measurement requirements and then instrument requirements

11-28-2011 DRAFT GEO-CAPE aerosol-atmospheres Science Traceability Matrix BASELINE and THRESHOLD

Science Questions

1. What are the temporal and spatial variations of emissions of gases and aerosols important for air quality and climate?
2. How do physical, chemical, and dynamical processes determine tropospheric composition and air quality over scales ranging from urban to continental, diurnally to seasonally?
3. How does air pollution drive climate forcing and how does climate change affect air quality on a continental scale?
4. How can observations from space improve air quality forecasts and assessments for societal benefit?
5. How does intercontinental transport affect air quality?
6. How do episodic events, such as wild fires, dust outbreaks, and volcanic eruptions, affect atmospheric composition and air quality?

Measurement Objectives (color flag maps to Science Questions)

Baseline measurements[1]:

O3, NO2, CO, SO2, HCHO, CH4, NH3, CHOCHO, different temporal sampling frequencies, 4 km x 4 km product horizontal spatial resolution at the center of the domain; and AOD, AAOD, AI, aerosol optical centroid height (AOCH), hourly for SZA<70 and 8 km x 8 km product horizontal spatial resolution at the center of the domain.

Threshold measurements[1]:

CO hourly day and night; O3, NO2 hourly when SZA<70; AOD hourly (SZA<50) ; at 8 km x 8 km product horizontal spatial resolution at the center of the domain.

A. Measure the threshold or baseline species or properties with the temporal and spatial resolution specified (see next column) to quantify the underlying emissions, understand emission processes, and track transport and chemical evolution of air pollutants [1, 2, 3, 4, 5, 6]

B. Measure AOD, AAOD, and NH3 to quantify aerosol and nitrogen deposition to land and coastal regions [2, 4]

C. Measure AOD, AAOD, and AOCH to relate surface PM concentration, UV-B level and visibility to aerosol column loading [1, 2, 3, 4, 5, 6]

D. Determine the instantaneous radiative forcings associated with ozone and aerosols on the continental scale and relate them quantitatively to natural and anthropogenic emissions [3, 5, 6]

E. Observe pulses of CH4 emission from biogenic and anthropogenic releases; CO anthropogenic and wildfire emissions; AOD, AAOD, and AI from fires; AOD, AAOD, and AI from dust storms; SO2 and AOD from volcanic eruptions [1, 4, 6]

F. Quantify the inflows and outflows of O3, CO, SO2, and aerosols across continental boundaries to determine their impacts on surface air quality and on climate [2, 3, 5]

G. Characterize aerosol particle size and type from spectral dependence measurements of AOD and AAOD [1, 2, 3, 4, 5, 6]

H. Acquire measurements to improve representation of processes in air quality models and improve data assimilation in forecast and assessment models [4]

I. Synthesize the GEO-CAPE measurements with information from in-situ and ground-based remote sensing networks to construct an enhanced observing system [1, 2, 3, 4, 5, 6]

J. Leverage GEO-CAPE observations into an integrated observing system including geostationary satellites over Europe and Asia together with LEO satellites and suborbital platforms for assessing the hemispheric transport [1, 2, 3, 4, 5, 6]

K. Integrate observations from GEO-CAPE and other platforms into models to improve representation of processes in the models and to link the observed composition, deposition, and radiative forcing to the emissions from anthropogenic and natural sources [1, 2, 3, 4, 5, 6]

Measurement Requirements (mapped to Measurement Objectives) / Measurement Rationale

Measurement Requirements		Measurement Rationale
Geostationary Observing Location: 100 W +/-10		Provides optimal view of North America.
***Column measurements:* A to K** All the baseline and threshold species		Continue the current state of practice in vertical; add temporal resolution.
Cloud Camera *1 km x 1km horizontal spatial resolution, two spectral bands, baseline only*		Improve retrieval accuracy, provide diagnostics for gases and aerosol
***Vertical information:* A to K**		
Two pieces of information in the troposphere in daylight with sensitivity to the lowest 2 km	O3, CO (Baseline and Threshold)	Separate the lower-most troposphere from the free troposphere for O3, CO.
Altitude (+/- 1km)	AOCH (baseline only)	Detect aerosol plume height; improve retrieval accuracy.
Product horizontal spatial resolution at the center of the domain, (nominally 100W, 35 N ***)*: A to H**		
4 km x 4 km (baseline), 8 km x 8 km (threshold)	Gases	Capture spatial/temporal variability; obtain better yields of products.
8 km x 8 km (baseline, threshold)	Aerosol properties	
16 km x 16 km (baseline only)	Over open ocean	Inherently larger spatial scales, sufficient to link to LEO observations
***Spectral region* : A to H**		Typical use
UV-Vis or UV-TIR	O3	Provide multispectral retrieval information in daylight
SWIR, MWIR	CO	
UV	SO2, HCHO	Retrieve gas species from their atmospheric spectral signatures (typical)
SWIR	CH4	
TIR	NH3	
Vis	AOD, NO2, CHOCHO	Obtain spectral-dependence of AOD for particle size and type information
UV-deep blue	AAOD	Obtain spectral-dependence of AAOD for aerosol type information
UV-deep blue	AI	Provide absorbing aerosol information
Vis-NIR	AOCH	Retrieve aerosol height [3]

***Atmospheric measurements over Land/Coastal areas, baseline and threshold:* A to K**

Species	*Time resolution*	*Typical value* [2]	*Precision* [2]	Description
O3	Hourly, SZA<70	9×10^{18}	0-2 km: 10 ppbv 2km–tropopause: 15 ppbv Stratosphere: 5%	Observe O3 with two pieces of information in the troposphere with sensitivity to the lowest 2 km for surface AQ; also transport, climate forcing
CO	Hourly, day and night	2×10^{18}	0-2 km: 20ppbv 2km–tropopause: 20 ppbv	Track anthropogenic and biomass burning plumes; observe CO with two pieces of information in the vertical with sensitivity to the lowest 2 km in daylight
AOD	Hourly, SZA<70	0.1 – 1	0.05	Observe total aerosol; aerosol sources and transport; climate forcing
NO2	Hourly, SZA<70	6×10^{15}	1×10^{15}	Distinguish background from enhanced/ polluted scenes; atmospheric chemistry

***Additional atmospheric measurements over Land/Coastal areas, baseline only:* A to K**

Species	*Time resolution*	*Typical value* [2]	*Precision* [2]	Description
HCHO*	3/day, SZA<50	1.0×10^{16}	1×10^{16}	Observe biogenic VOC emissions, expected to peak at midday; chemistry
SO2*	3/day, SZA<50	1×10^{16}	1×10^{16}	Identify major pollution and volcanic emissions; atmospheric chemistry
CH4	2/day	4×10^{19}	20 ppbv	Observe anthropogenic and natural emissions sources
NH3	2/day	2×10^{16}	0-2 km: 2ppbv	Observe agricultural emissions
CHOCHO*	2/day	2×10^{14}	4×10^{14}	Detect VOC emissions, aerosol formation, atmospheric chemistry
AAOD	Hourly, SZA<70	0 – 0.05	0.02	Distinguish smoke and dust from non-UV absorbing aerosols; climate forcing
AI	Hourly, SZA<70	-1 – +5	0.1	Detect aerosols near/above clouds and over snow/ice; aerosol events
AOCH	Hourly, SZA<70	Variable	1 km	Determine plume height; large scale transport, conversions from AOD to PM

Open ocean measurements:* F H, I, J, K *baseline only, *16 km x 16 km*

O3	1/day	Over open oceans, capture long-range transport of pollution, dust, and smoke into/out of North America; establish boundary conditions for North America
CO	1/day	
AOD, AAOD, AI	1/day	

AOD=Aerosol optical depth, AAOD=Aerosol absorption optical depth, AI=Aerosol index. See next page for footnotes.

Required Concentration Precisions for GEO-CAPE/TEMPO Air Quality Gas Measurements*

Molecule	Vertical Column [mol cm^{-2}]	Sensitivity Driver
O_3	2.4×10^{16}	Hourly for SZA $\leq 70^o$ ~10 ppbv in PBL; reality (profiling) is more complicated
NO_2	1.0×10^{15}	Hourly for SZA $\leq 70^o$ Distinguish background from enhanced/polluted scenes
SO_2	1.0×10^{16}	3/day for SZA $\leq 50^o$ Identify major pollution and volcanic emissions
H_2CO	1.0×10^{16}	3/day for SZA $\leq 50^o$ Observe biogenic VOC emissions, expected to peak at midday
$C_2H_2O_2$	4.0×10^{14}	2/day for SZA $\leq 50^o$ Track urban and fire emissions

*Sensitivities for lowest 1 km. Clouds and aerosol products not discussed here.

BrO, and H_2O will also be measured well!

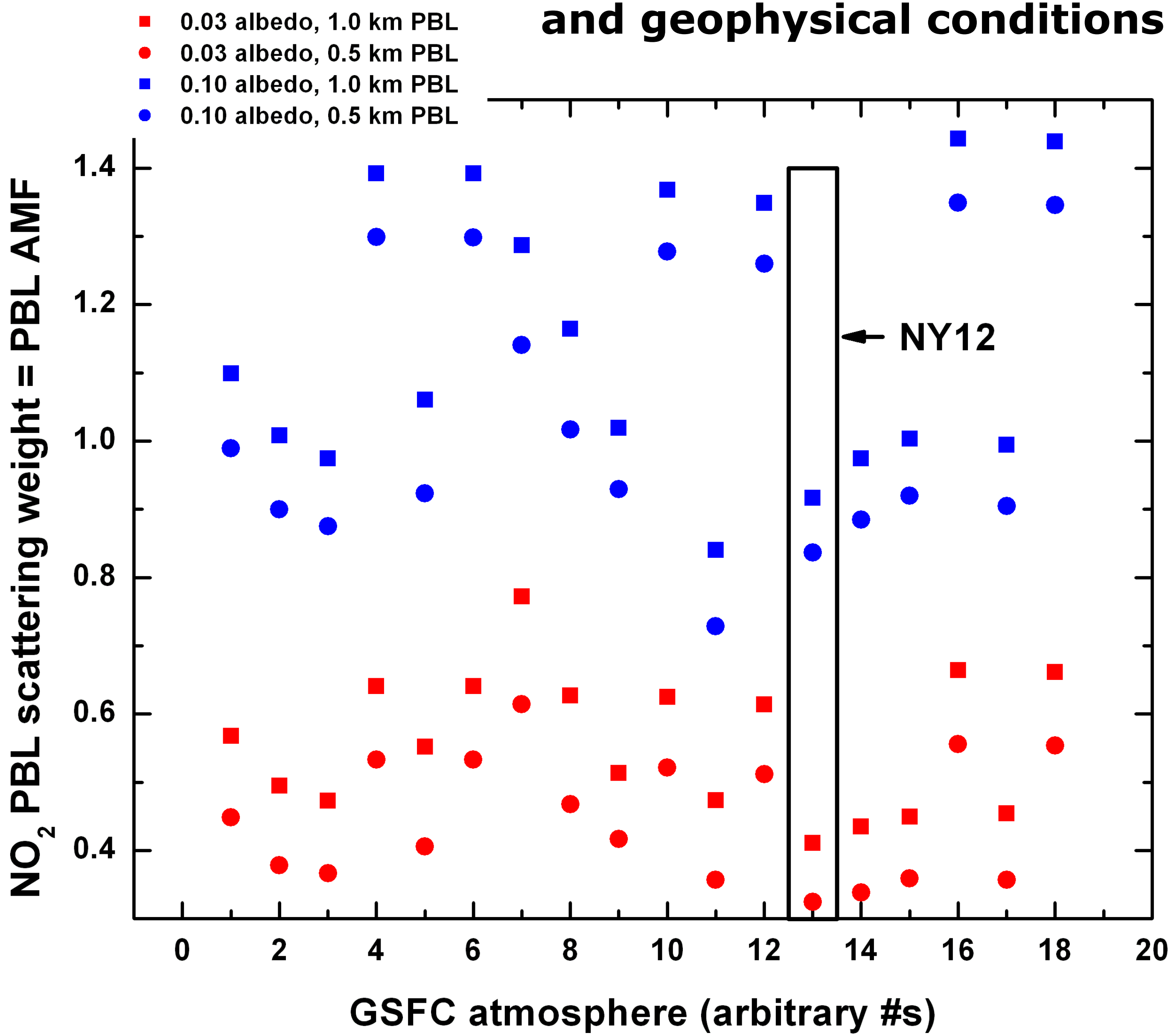
TEMPO O_3 and trace gas retrieval and sensitivity study tools

- **Radiative transfer tool to calculate scattering weights, Jacobians, AMFs, and radiances from synthetic atmospheres using the VLIDORT RTM**
  - **18 GSFC atmospheres studied for O_3 and trace gases (HCHO, NO_2, SO_2, CHOCHO).**

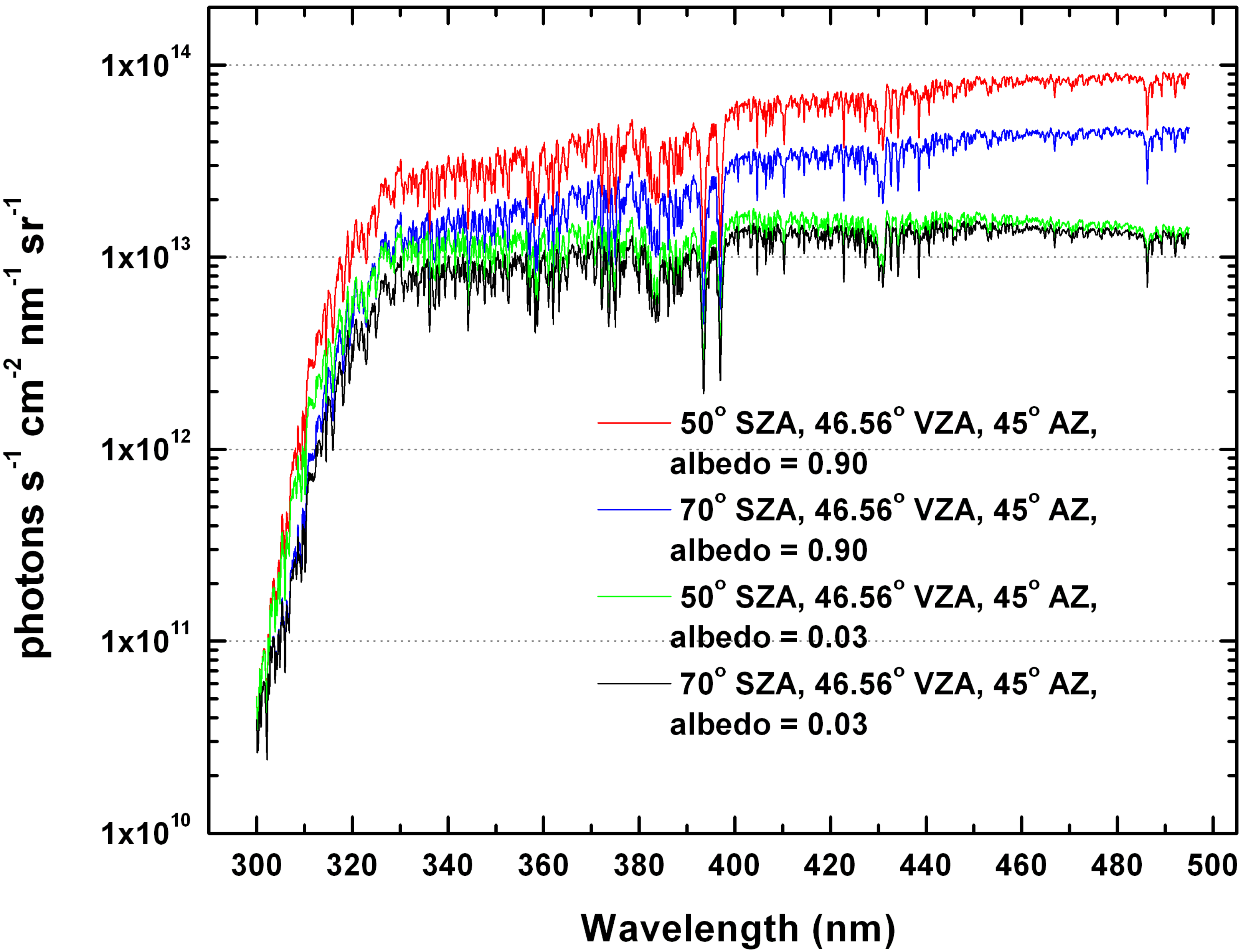
- **For trace gases:**
  - **Albedos 0-1, SZA 0-90º, wavelengths 280-900 nm.**
  - **Finalize measurement requirements from STM species, sensitivities, footprint, and temporal, geographic, and SZA coverage.**

- **Fitting studies address tradeoffs between S/N and spectral resolution.**
  - ***improved noise model, S/N proportional to $[radiance]^{1/2}$; window averages of S/N given in plots and requirements***
  - ***cross sections normalized to AMF for direct vertical column retrieval***

Choice of worst case model and geophysical conditions



Radiances from GSFC NY-12 model and SAO2010 irradiance



Measurement Requirements

Molecule	SO_2	NO_2	H_2CO	$C_2H_2O_2$
Fitting Window (nm)	305-330	423-451	327-356	433-465

Measurement requirements come from full multiple scattering calculations with VLIDORT, including gas loading & aerosols (GSFC NY12 atmosphere), an 0.03 albedo, and are for fitting to concentrations in the lowest 2 km.

Full-up fitting studies comparing spectral resolution and signal-to-noise ratio then give:

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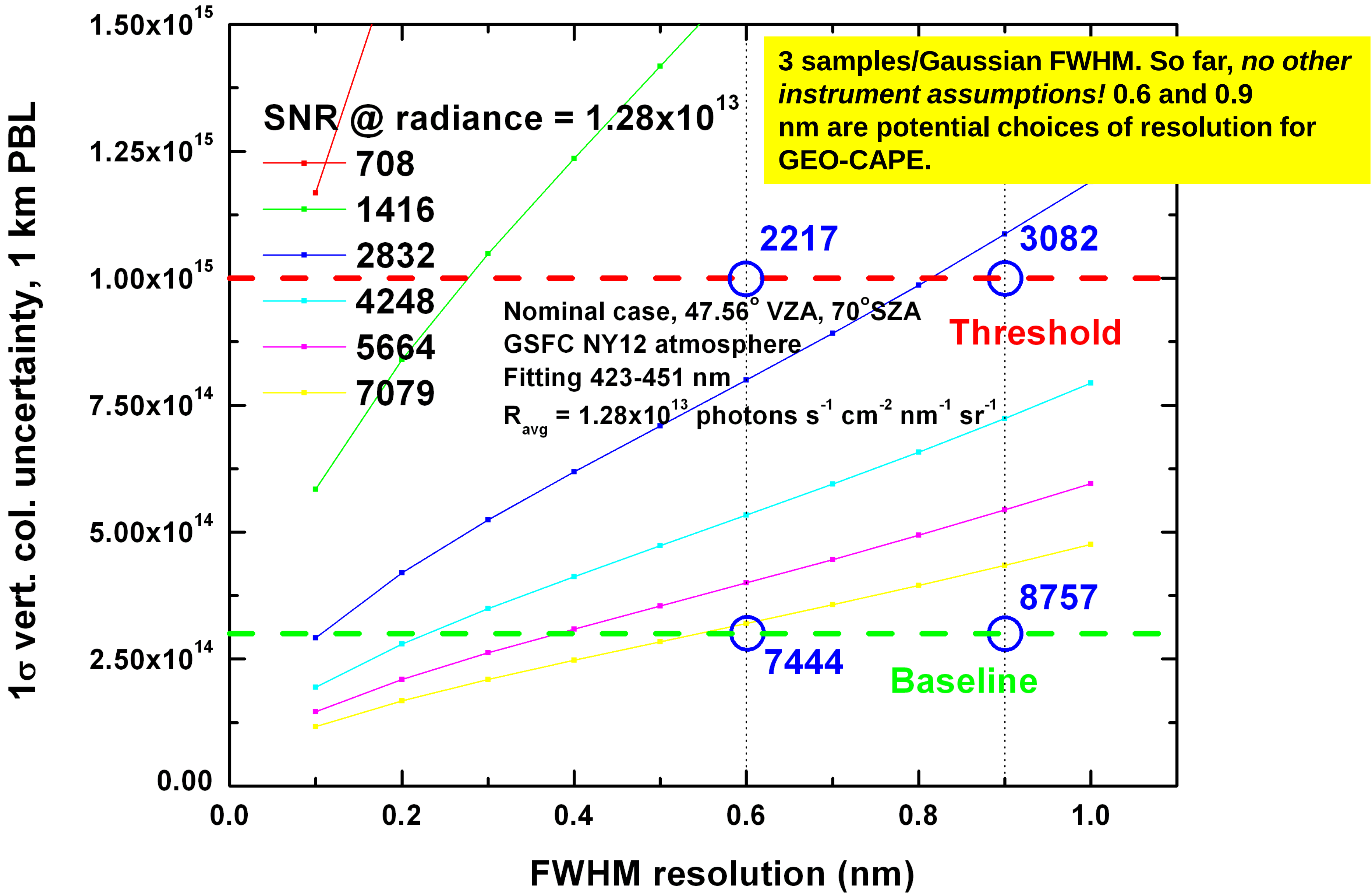
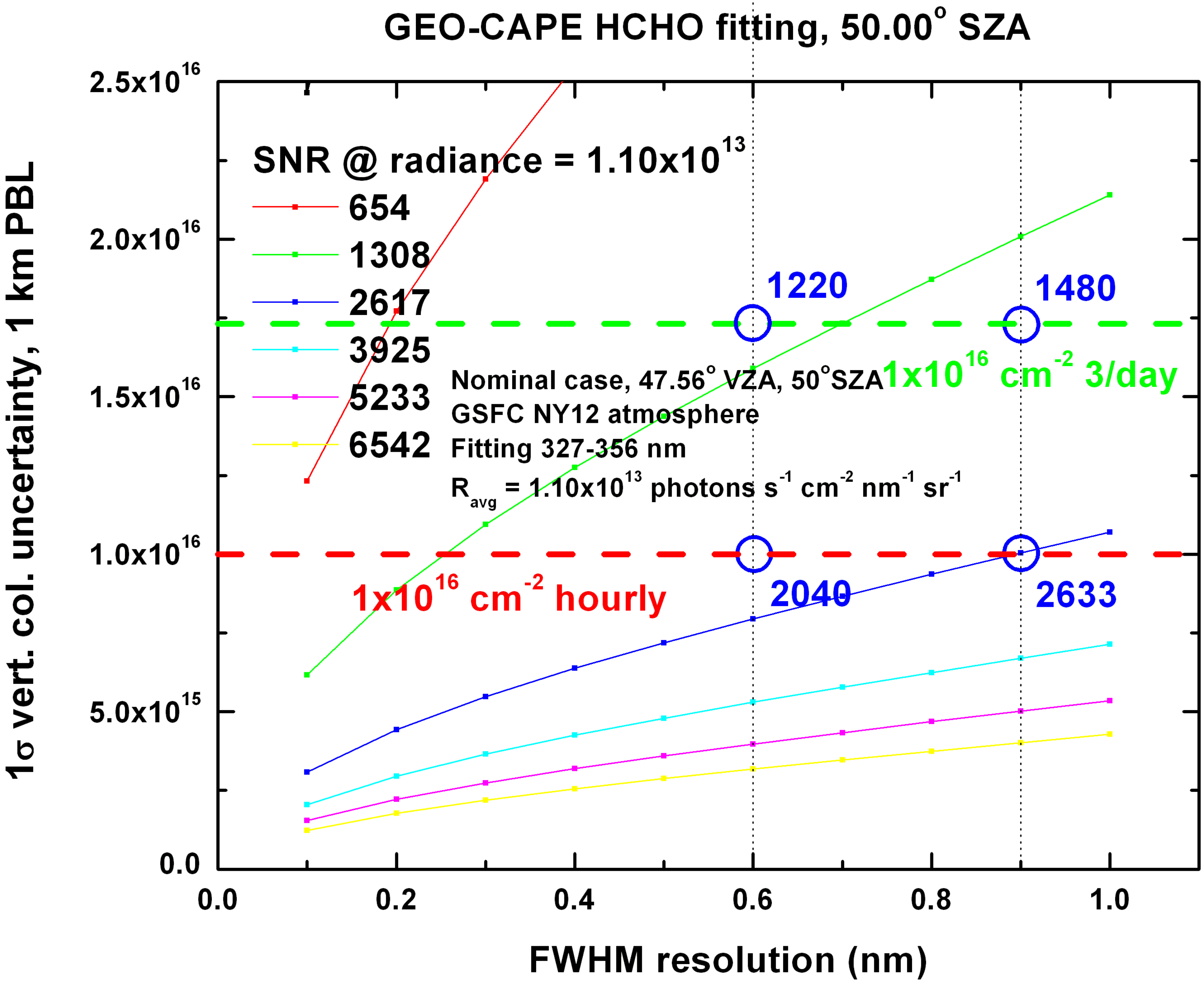
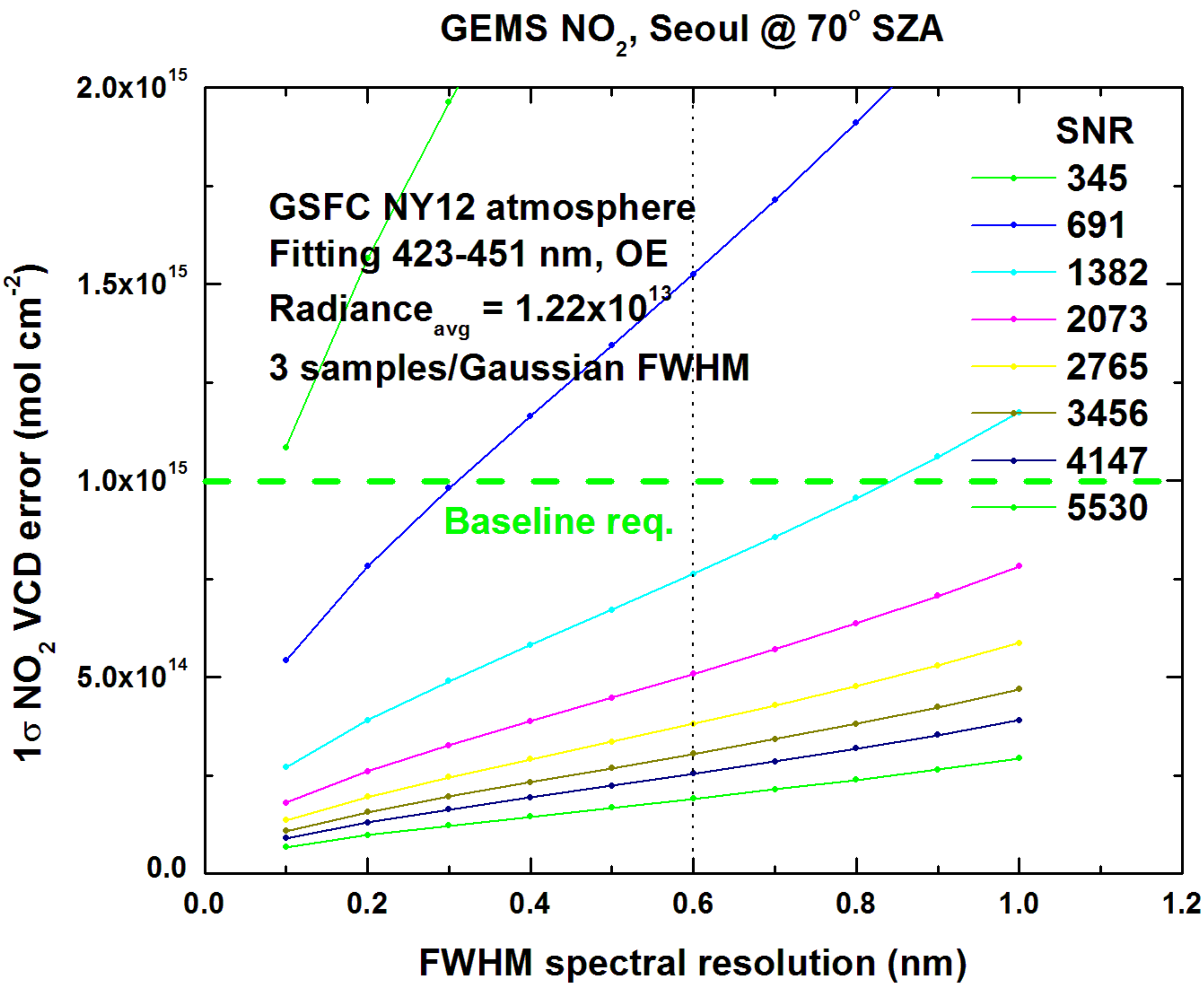
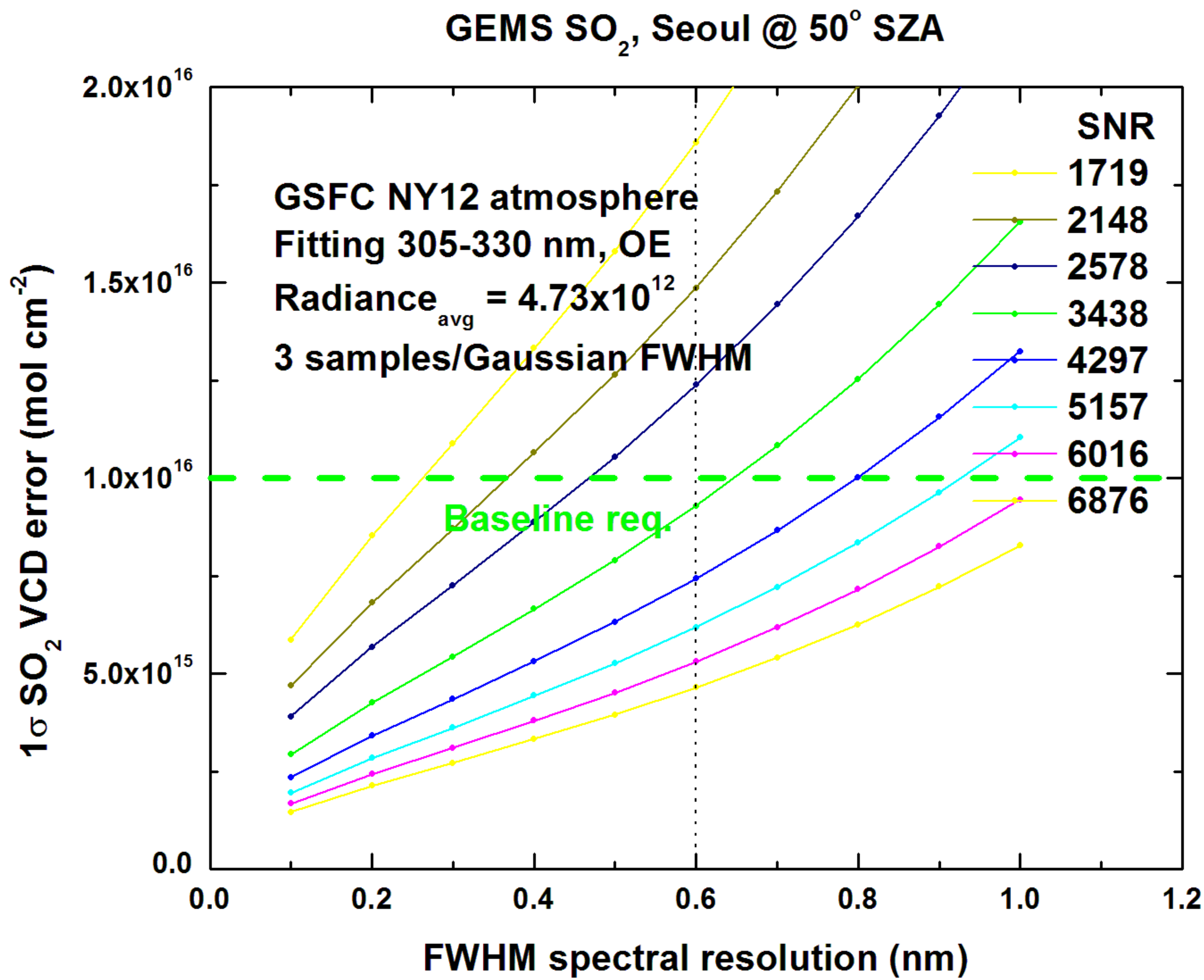
GEO-CAPE NO_2 fitting, 70.00° SZA

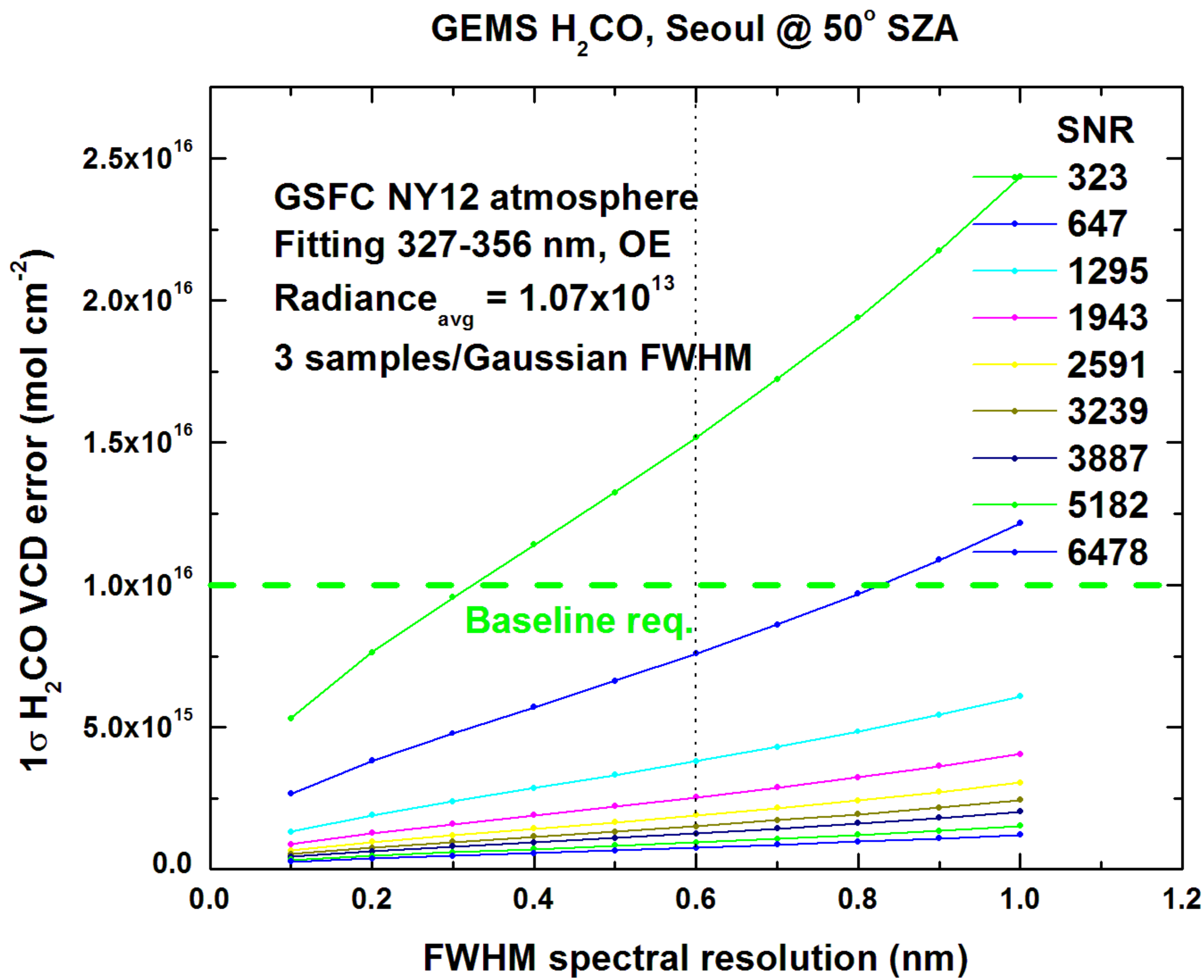


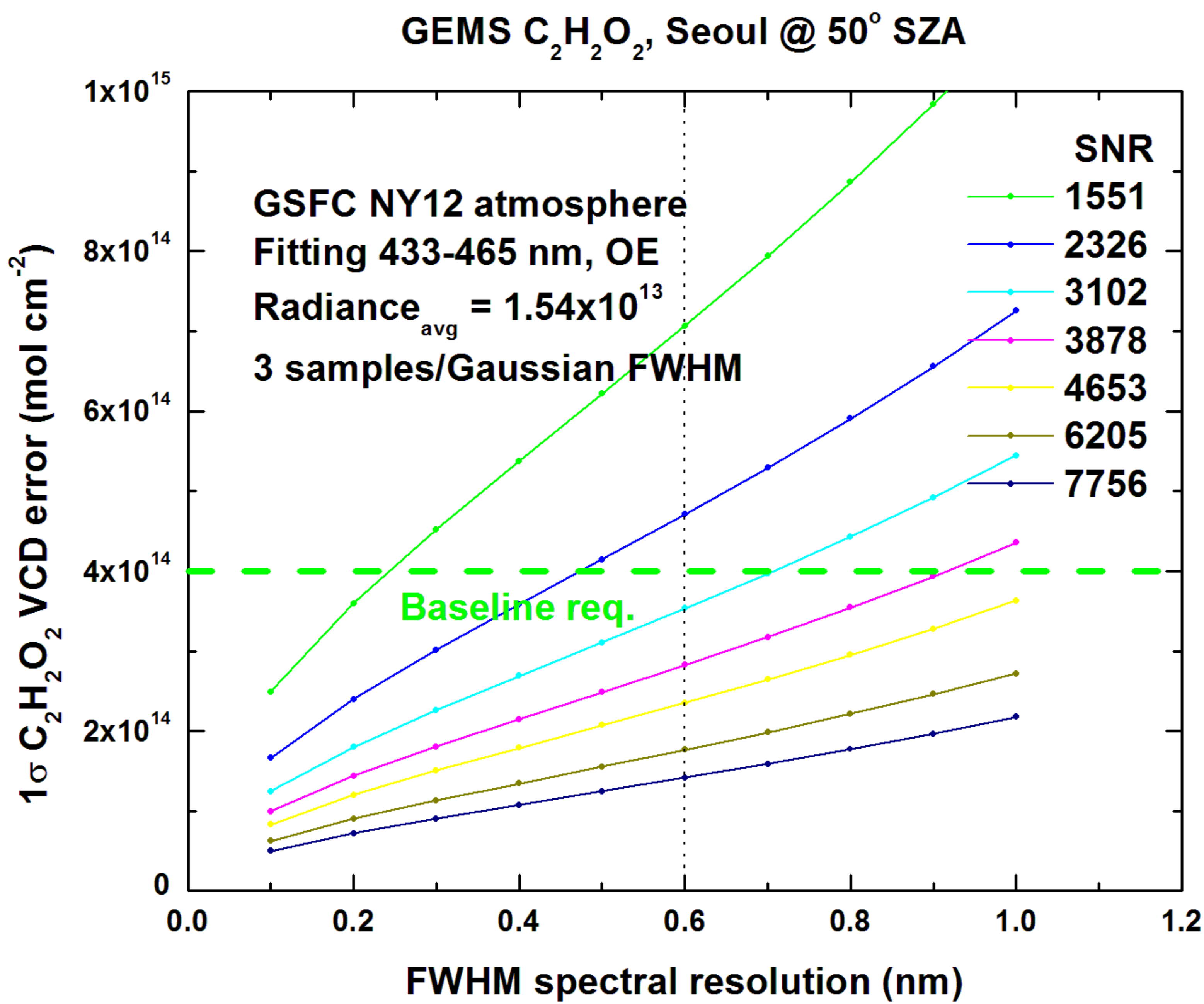

GEO-CAPE HCHO fitting, 50.00° SZA
SNR @ radiance = 1.10x10^13
654
1308
2617
3925
5233
6542
Nominal case, 47.56° VZA, 50°SZA
GSFC NY12 atmosphere
Fitting 327-356 nm
R_avg = 1.10x10^13 photons s^-1 cm^-2 nm^-1 sr^-1
1220
1480
1x10^16 cm^-2 3/day
2040
2633
1x10^16 cm^-2 hourly
1σ vert. col. uncertainty, 1 km PBL
FWHM resolution (nm)
0.0
5.0x10^15
1.0x10^16
1.5x10^16
2.0x10^16
2.5x10^16
0.2
0.4
0.6
0.8
1.0


GEMS NO2, Seoul @ 70° SZA
GSFC NY12 atmosphere
Fitting 423-451 nm, OE
Radiance avg = 1.22x10^13
3 samples/Gaussian FWHM
Baseline req.
SNR
345
691
1382
2073
2765
3456
4147
5530
1σ NO2 VCD error (mol cm^-2)
2.0x10^15
1.5x10^15
1.0x10^15
5.0x10^14
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
FWHM spectral resolution (nm)



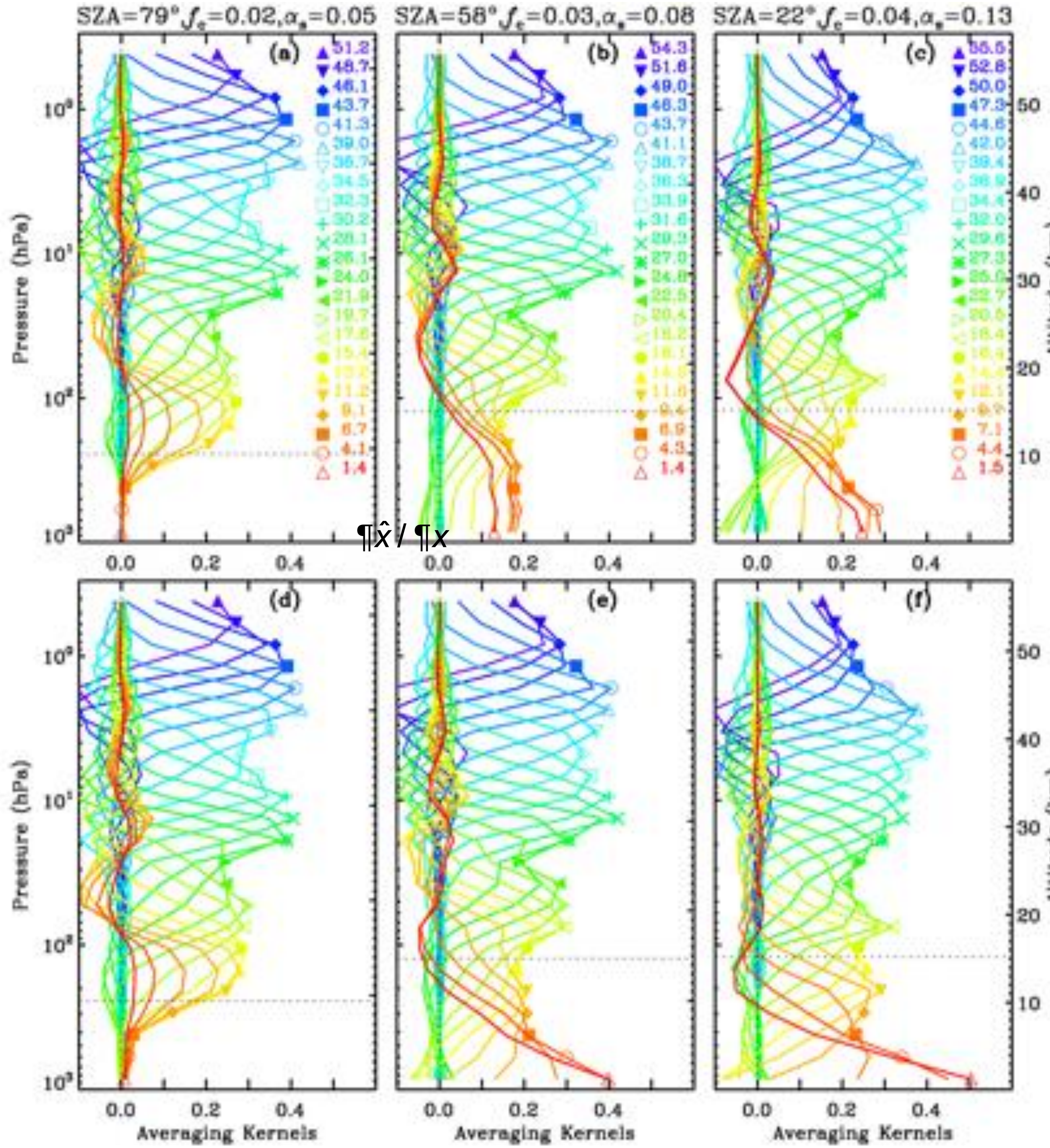
GEMS SO2, Seoul @ 50° SZA
1σ SO2 VCD error (mol cm-2)
FWHM spectral resolution (nm)
GSFC NY12 atmosphere
Fitting 305-330 nm, OE
Radiance avg = 4.73x10^12
3 samples/Gaussian FWHM
Baseline req.
SNR
1719
2148
2578
3438
4297
5157
6016
6876
2.0x10^16
1.5x10^16
1.0x10^16
5.0x10^15
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2


GEMS H_2CO, Seoul @ 50° SZA
GSFC NY12 atmosphere
Fitting 327-356 nm, OE
$Radiance_{avg} = 1.07 \times 10^{13}$
3 samples/Gaussian FWHM
SNR
323
647
1295
1943
2591
3239
3887
5182
6478
Baseline req.
1σ H_2CO VCD error (mol cm^{-2})
FWHM spectral resolution (nm)
0.0
5.0×10^{15}
1.0×10^{16}
1.5×10^{16}
2.0×10^{16}
2.5×10^{16}
0.0
0.2
0.4
0.6
0.8
1.0
1.2



GEMS C2H2O2, Seoul @ 50° SZA
GSFC NY12 atmosphere
Fitting 433-465 nm, OE
Radiance avg = 1.54x10^13
3 samples/Gaussian FWHM
SNR
1551
2326
3102
3878
4653
6205
7756
Baseline req.
1σ C2H2O2 VCD error (mol cm^-2)
FWHM spectral resolution (nm)
0
2x10^14
4x10^14
6x10^14
8x10^14
1x10^15
0.0
0.2
0.4
0.6
0.8
1.0
1.2

Three examples of nearly clear-sky retrieval averaging kernels (sensitivities of retrievals to the true state), for pixels (1)-(3) indicated on previous figures. (d)-(e) are the same as (a)-(c) but under ideal conditions (i.e., without interferences from other parameters). These AKs have been normalized by the actual ozone variability (*i.e.*, *a priori* error). The symbols indicate the altitude of the averaging kernels. The dotted black horizontal lines indicate the tropopause. The caption on top of each of panel shows solar zenith angle, cloud fraction, and surface albedo



TEMPO Instrument Concept

- **Spatial resolution:** 2 km N/S × 4.5 km E/W native resolution (9 km^2)
  - Co-add/cloud clear for some products
- **Band pass and spectral resolution:** 290-690 nm @ 0.6 nm FWHM, 0.2 nm sampling
- **Field of regard**: **Mexico City to the Canadian tar ("oil") sands**, Atlantic to Pacific
- **Data products and sampling rates:** NO_2 sampled hourly; O_3, H_2CO and $C_2H_2O_2$ 3 times/day (hourly samples averaged to get required S/N), except that eXceLO_3 for selected target areas may be sampled hourly; SO_2 2 times/day. Aerosol and cloud products are sampled hourly.
- **Signal-to-noise ratio (S/N) values** from standard radiances that have been delivered from SAO to BATC and GSFC.
  - 70^o SZA for NO_2, 50^o for other standard products.
  - Address beginning of life versus end of life S/N values

TEMPO Mission Concept

- **Geostationary orbit,** 90-110º W preferred, 80-120º W acceptable
  BATC is currently surveying COMSAT companies for specifications on the satellite environment and launch manifests to see what platforms will become available.
- **Full measurement and telemetry duty cycle for ≤70º SZA**
- **Standard products:** NASA TOMS-type O_3; SO_2, NO_2, H_2CO from AMF-normalized cross sections; AAI; RRS cloud. SAO eXceLO_3 included for selected geographic targets.
  - Non-O_3 gas algorithm model is SAO operational OMI code currently running @ GSFC DISC; TOMS-type O_3, AAI and RRS cloud are also from OMI operational model.
- **Secondary products:** eXceL O_3 for broader regions; BrO and $C_2H_2O_2$ from AMF-normalized cross sections; H_2O, height-resolved SO_2; additional aerosols (TBC; this is currently the largest unknown); alternate cloud products.
- **Higher-level products:** pollution/AQ indices from standard products, possibly including city light maps, distributed broadly in near-real-time.
- ***All proposed TEMPO measurements have been made from existing LEO satellite instruments to the required precisions***
- ***All TEMPO launch algorithms are implementations of currently operational satellite algorithms***

Default Launch Data Products

Product	Algorithm	Hourly Coverage @ $\leq 4.5 \times 8$ km^2
O_3	TOMS-Vn	15 - 50.25ºN, 60 - 130ºW
O_3	XL optimal estimation	Selected urban areas and burning regions
NO_2	Direct fitting, AMF (λ)	15 - 50.25ºN, 60 - 130ºW
SO_2	Direct fitting, AMF (λ)	15 - 50.25ºN, 60 - 130ºW
H_2CO	Direct fitting, AMF (λ)	15 - 50.25ºN, 60 - 130ºW
$C_2H_2O_2$	Direct fitting, AMF (λ)	15 - 50.25ºN, 60 - 130ºW
Aerosol OD and SSA	AERUV	15 - 50.25ºN, 60 - 130ºW
Cloud pressure and fraction	CLDRR	15 - 50.25ºN, 60 - 130ºW
UBV and Eryth. dose	UVB (?)	15 - 50.25ºN, 60 - 130ºW
AQ indices	L3-L4 based	15 - 50.25ºN, 60 - 130ºW

Secondary and Improved Data Products

Product	Algorithm	Hourly Coverage @ ≤ 4.5 × 8 km^2
O_3	XL optimal estimation	15 - 50.25°N, 60 - 130°W (or, extended regions)
BrO	Direct fitting, AMF (λ)	15 - 50.25°N, 60 - 130°W
H_2O	Direct fitting, AMF (λ)	15 - 50.25°N, 60 - 130°W
$C_2H_2O_2$	Direct fitting, AMF (λ)	15 - 50.25°N, 60 - 130°W
Aerosols	AERUV	15 - 50.25°N, 60 - 130°W
Clouds	CLDRR	15 - 50.25°N, 60 - 130°W
SO_2	Height-resolved	15 - 50.25°N, 60 - 130°W
NO_2	Improved	15 - 50.25°N, 60 - 130°W

The End!

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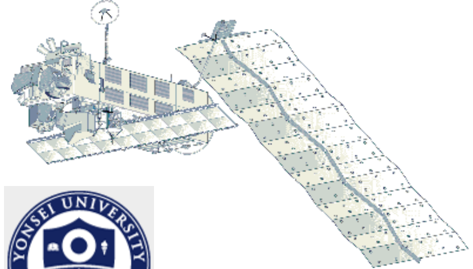

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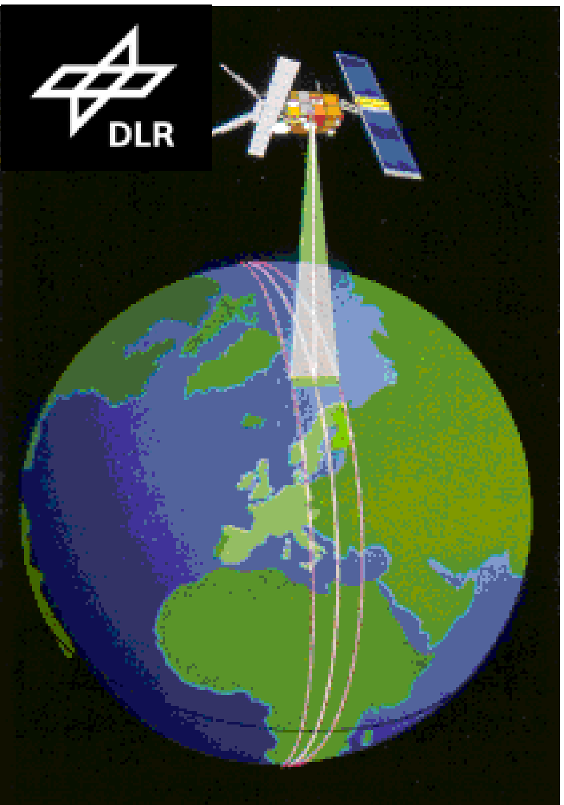

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