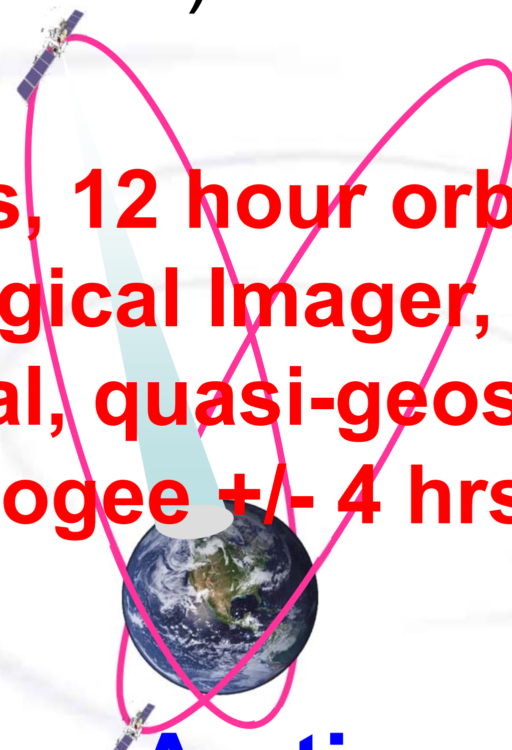
PCW/ PHEMOS Weather, Climate and Air quality Mission Focus on FTS

Jack McConnell on behalf of the PHEMOS Team

Polar Communications & Weather (PCW) Mission



2 satellites, 12 hour orbits, Meteorological Imager, operational, quasi-geostationary around apogee +/- 4 hrs

Focus on Arctic

PCW Imager Specifications

Band No.	subgroup	Wavelength (microns)	Heritage	Priority	GSD (km) Goal Max	Main applications
1	VNIR	0.45-0.49	ABI, FDHSI	1	0.5 1.5	Surface, clouds, aerosols
2		0.59-0.69	ABI, FDHSI	1	0.5 1.5	Wind, clouds, ice mapping
3		0.704-0.714	MERIS-09	2	0.5 1.5	Water quality, chlorophyll
4		0.85-0.89	ABI, FDHSI	1	0.5 1.5	Wind, aerosols, vegetation
5	SWIR	1.04 – 1.06	SGLI SW1	2	1.0 3.0	Snow grain and clouds
6		1.37-1.39	ABI, FDHSI	2	1.0 3.0	Cirrus detection
7		1.58-1.64	ABI, FDHSI	1	0.5 1.5	Snow-cloud distinction, ice cover
8		2.22-2.28	ABI, FDHSI	1	1.0 3.0	Aerosol, smoke, cloud phase
9	MWIR	3.80-4.00	ABI, FDHSI	1	2.0 3.0	Fog, fires, ice/cloud separation, wind, cld.phase
10		5.77-6.60	ABI, FDHSI	1	2.0 3.0	Wind, high level humidity
11		6.75-7.15	ABI, MTSAT	2	2.0 3.0	Wind, mid level humidity
12		7.24-7.44	ABI, FDHSI	1	2.0 3.0	Wind, low level humidity
13	LWIR	8.30-8.70	ABI, FDHSI	1	2.0 3.0	Total water, cloud phase
14		9.42-9.80	ABI, FDHSI	2	2.0 3.0	Total ozone
15		10.1-10.6	ABI, FDHSI	2	2.0 3.0	Cloud, surface, cirrus
16		10.8-11.6	ABI, HIRS	1	2.0 3.0	Cloud, SST, ash
17		11.8-12.8	ABI, FDHSI	1	2.0 3.0	Ash, SST
18	LIRCO2	13.0-13.6	ABI, FDHSI	1	2.0 3.0	Cloud height
19		13.5-13.8	MODIS,HIRS	2	2.0 6.0	Cloud height, low level temperature
20		13.8-14.1	MODIS,HIRS	2	2.0 6.0	Cloud height, mid level temperature
21		14.1-14.4	MODIS,HIRS	2	2.0 6.0	Cloud height, high level temperature

Other Minimum Requirements

- Imagery refresh rate: (T) 20 min (G) 15 min
- Solar bands pixel resolution: (T) 1.5 km (G) 0.5-1.0 km
- Infrared pixel resolution: (T) 3 km (G) 2 km

PHEMOS

- **P**olar **H**ighly **E**lliptical **M**olinya **O**rbital **S**cience for PCW
- Science instrument suite (N-O)
- Weather, Air quality, & Climate,

Strategic Scientific Objectives - Primary

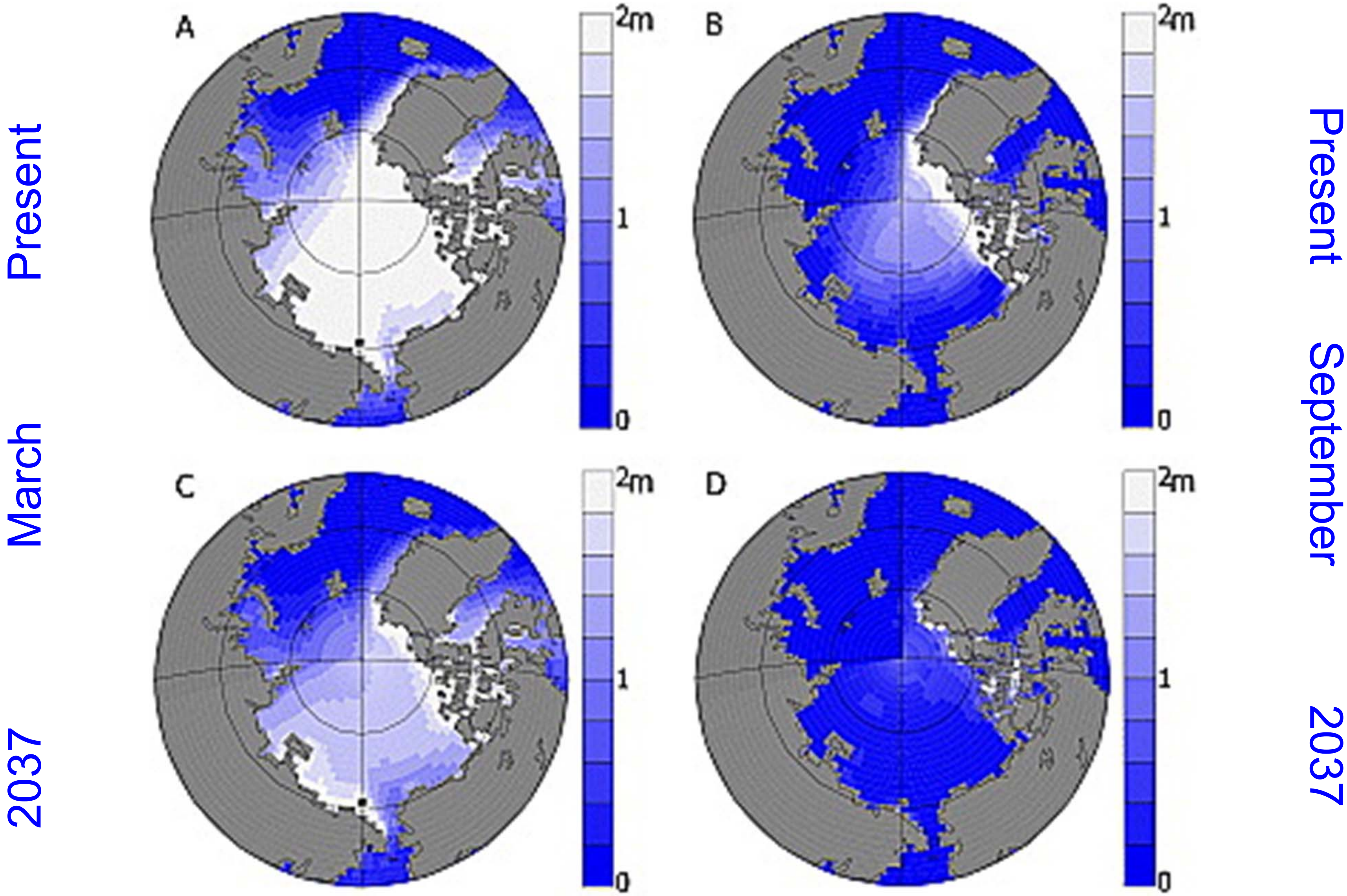
– Improve climate process modeling and weather forecasting, using the provision of basic weather information, including vertical temperature and water vapour profiles

– Better understand the impact of industrial and agricultural pollution and Boreal forest burning on the Arctic as well as the putative impact of expected increases in shipping in the Arctic resulting from the dramatic decrease in multi-year ice using the collection of synoptic-scale air quality (gas and aerosol) measurements over the Arctic.

– Assess perturbations due to the increasing release of methane from the permafrost and from shallowly buried clathrates using the acquisition of column abundance data on methane over the Arctic.

Strategic Scientific Objectives
Secondary

- provide measurements of column abundances for stratospheric ozone and a number of other species.
- provide, with modelling, a measure of the solar-terrestrial impact on the stratosphere via auroral deposition of NOx in the mesosphere.



Arctic sea ice thickness in metres Future sea ice cover is based on an average of the 6 IPCC models. 2037 is determined as the most probable year for which Arctic Sea ice cover declines to < 1 million km^2 (Wang and Overland, 2009).

Science Objectives

- Provide Arctic data
- To improve meteorological data
  - T, P, H2O, ice clouds
- To improve understanding of impact of northern nations on air quality
  - Measuring gaseous species data
  - Aerosols
- To improve estimates of GHG gases sources

EC Operational Objectives

- Improve accuracy of short and middle range weather forecasts
- Improve understanding and prediction of AQ from assimilation of column
- To improve modelling of physical processes characterizing Arctic climate and monitoring
- To improve estimates of GHG gases sources (EC/Carbon Assimilation System)

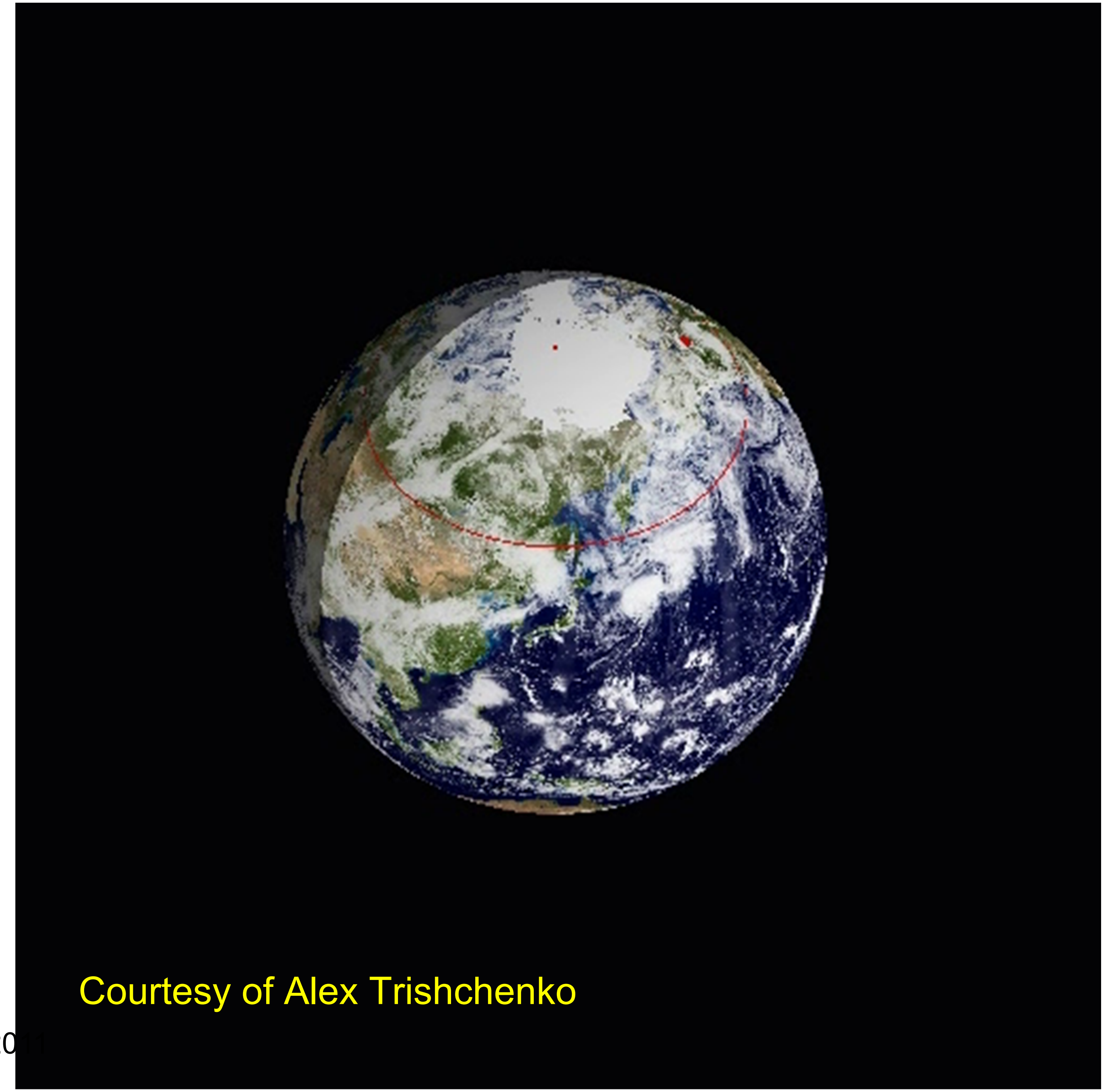
Institutions

- ABB Bomen
- COM DEV
- York University
- University of Toronto
- Dalhousie University
- University of Sherbrooke
- Université de Quèbec a Montréal
- Carleton University
- University of Saskatchewan
- University of Waterloo
- Environment Canada

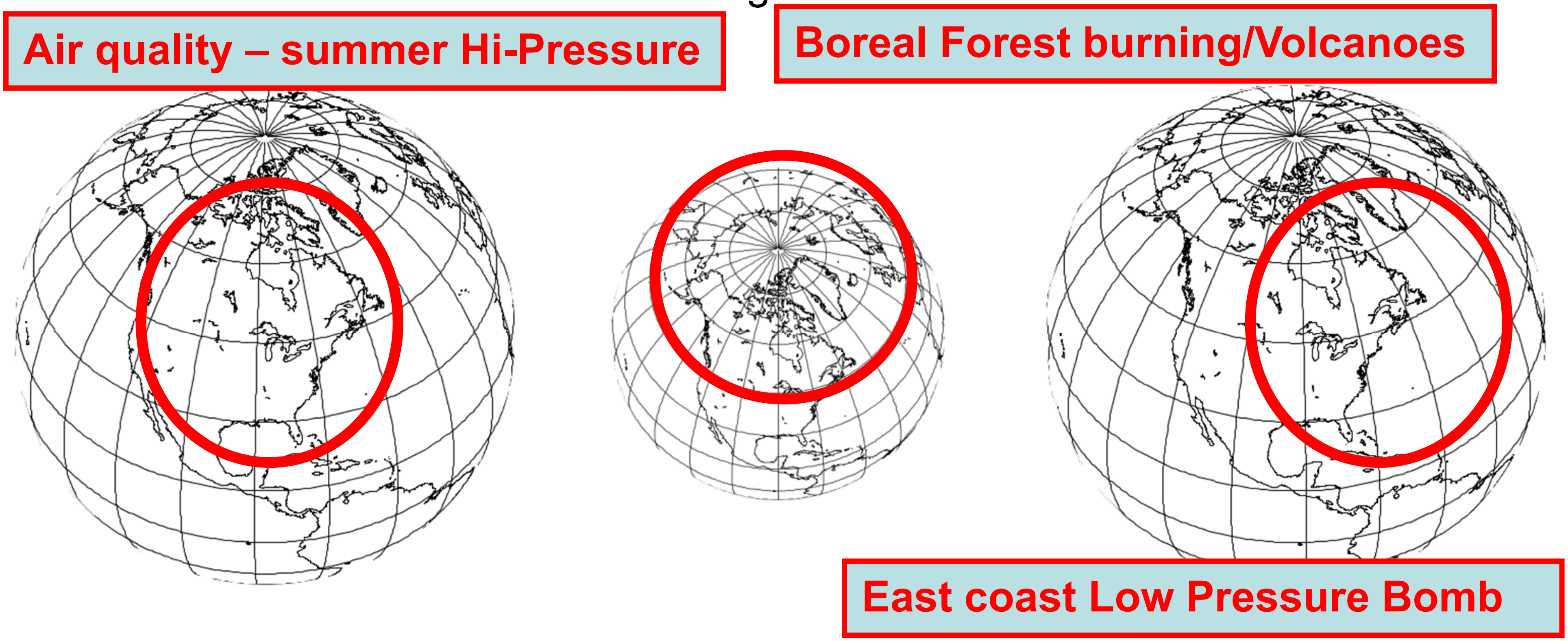
Instrument and viewing considerations

How to achieve objectives

Viewing Earth from UV to Mid-IR


Courtesy of Alex Trishchenko

Viewing geometry from Molnyia orbit locations. The 3 views are for an apogee at 90°W longitude. Images have been scaled to show approximate angular size difference due to altitude change over the 8 hr period they span. Note that rotation of the Earth almost exactly compensates for satellite motion in longitude.



Apogee – 4 hours   Apogee   Apogee + 4 hours

Viewing geometry from Molnyia orbit locations. The 3 views would be for the alternate apogees which would occur at 90^{o}E. Images have been scaled to show approximate angular size difference due to altitude change over the 8 hr period they span. Note that rotation of the Earth almost ... for satellite motion in longitude.

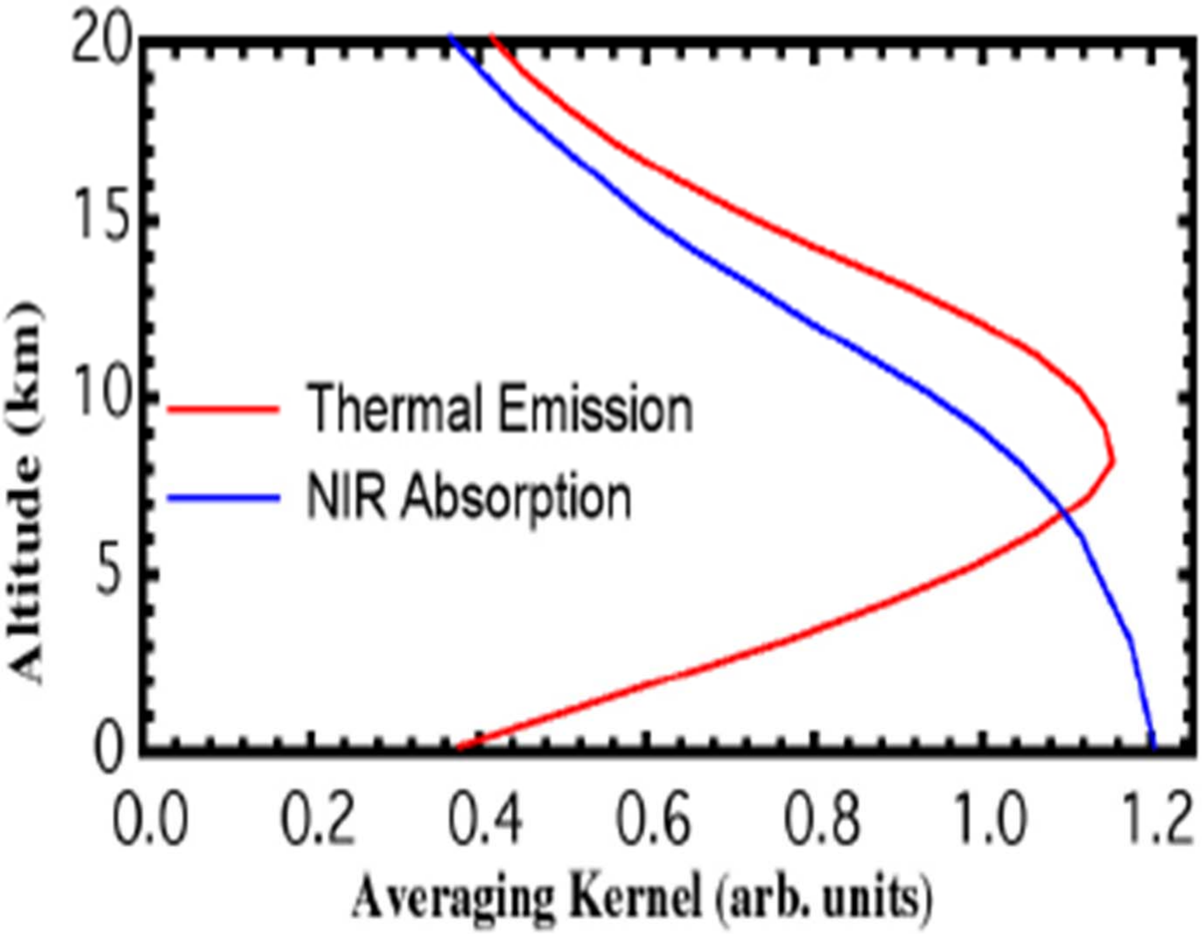
Apogee – 4 hours   Apogee   Apogee + 4 hours

Spectral Regions

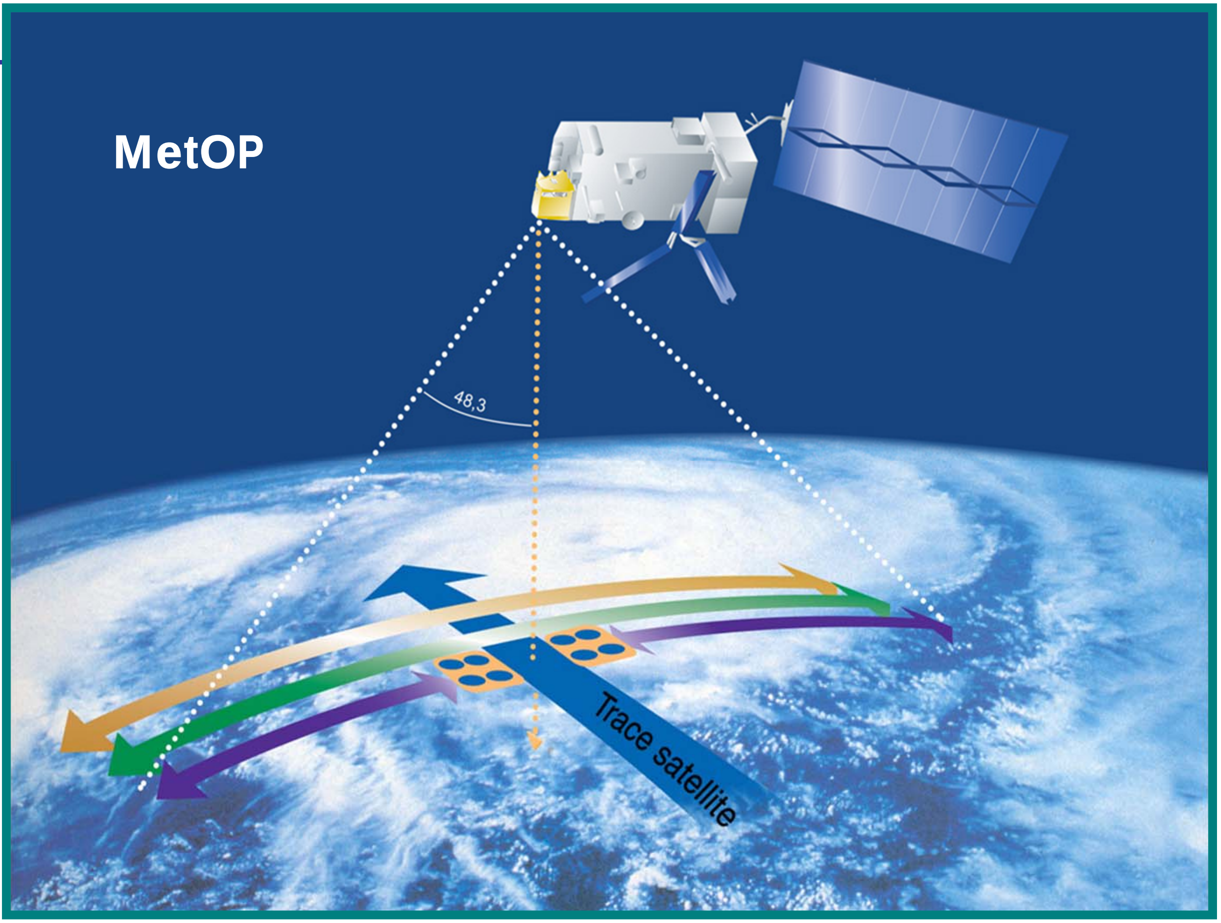
- Mid-IR
  - Vertical profiles of T and H2O (only)
  - Kernal is generally of low sensitivity near surface
  - Using IASI or AIRS as a guide range of potential species is large (next slide)
  - Will include limited/partial column information on AQ species, GHG species

Spectral Regions

- UVS
  - Kernal is generally uniform sensitivity with height
- UV-Vis
  - Resolution ~ 1nm
  - Total column (tro
    - O3, NO_2, SO_2, C
    - O2-A band < 0.5
- NIR
  - Could include col
  - CO_2, CH_4, CO
  - Resolution ~ 0.2

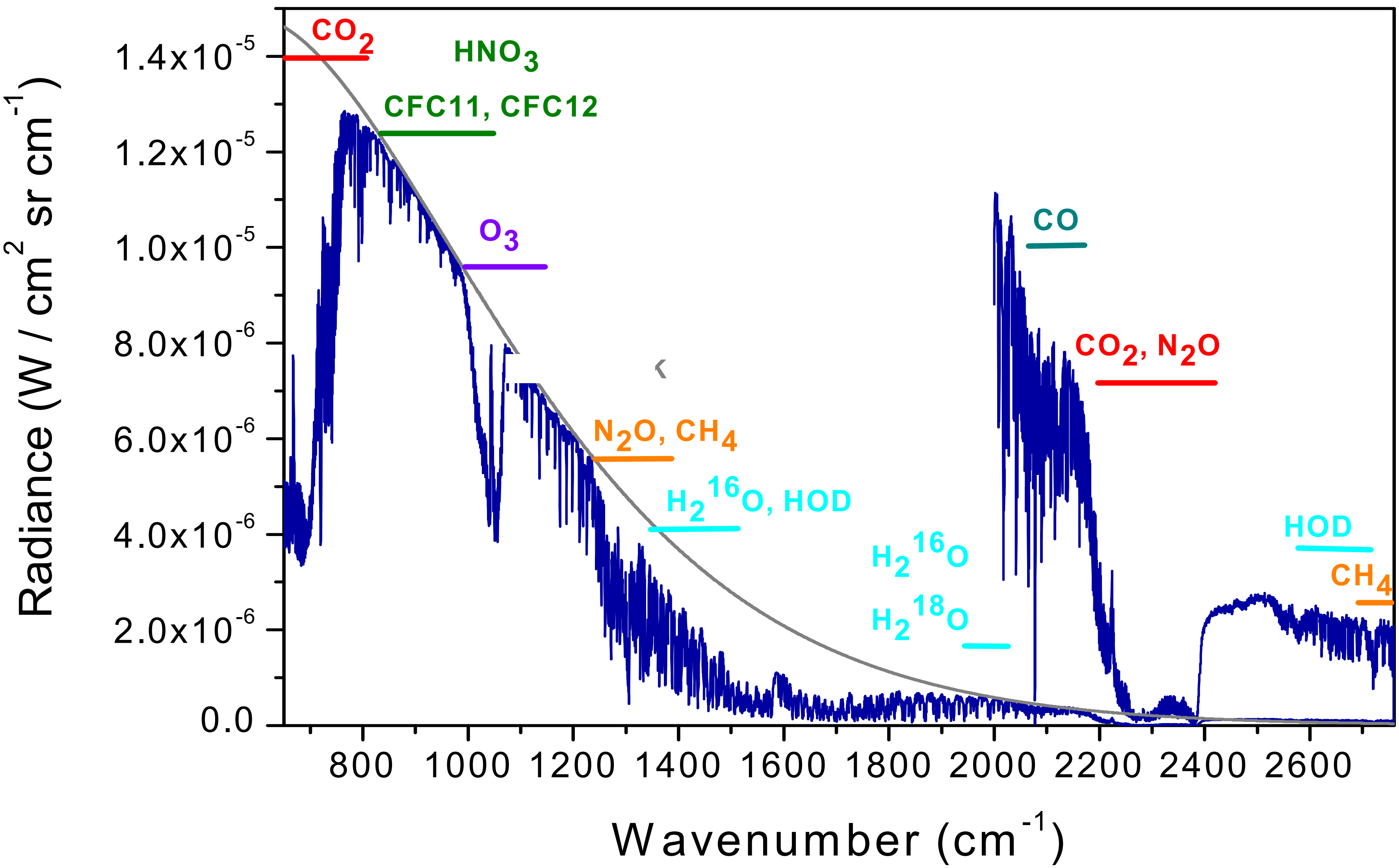


A. Trishchenko, L. Garand, and L.Trischtchenko, Submitted to *J. Atmos. Ocean.Tech.*, March, 2011



IASI instrument

Nadir looking FTS, 12 km pixel x 4 @ nadir, + scanning = +/- 48.3°
Spectral coverage = 645-2760 cm-1, Spectral resolution = 0.5 cm-1
Radiometric noise ~ 0.25-0.5 K
Priorities:
NWP: Temperature and humidity profiles each kilometer in the troposphere, (1 K, 10 % accuracy)
Tropospheric chemistry and climate
Integrated concentrations or vertical profiles for a series of target trace gases
Courtesy of Cathy Clerbaux, 2010

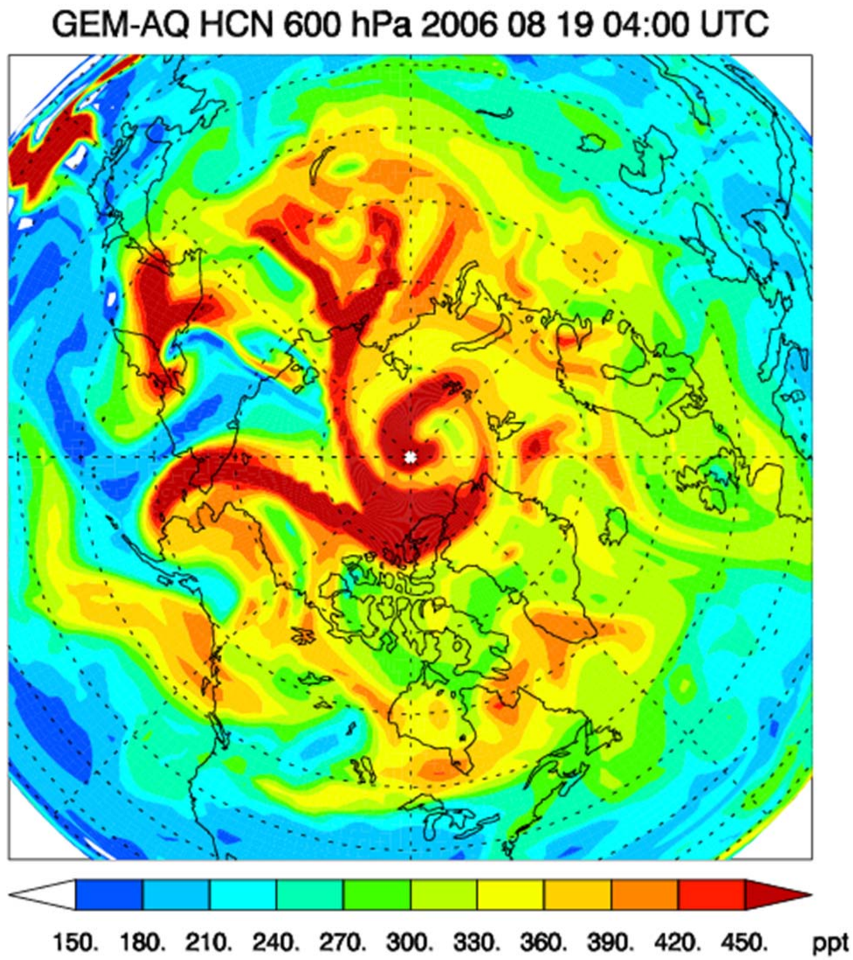


120 spectra along the swath (2400 km)
Each 50 km along the trace

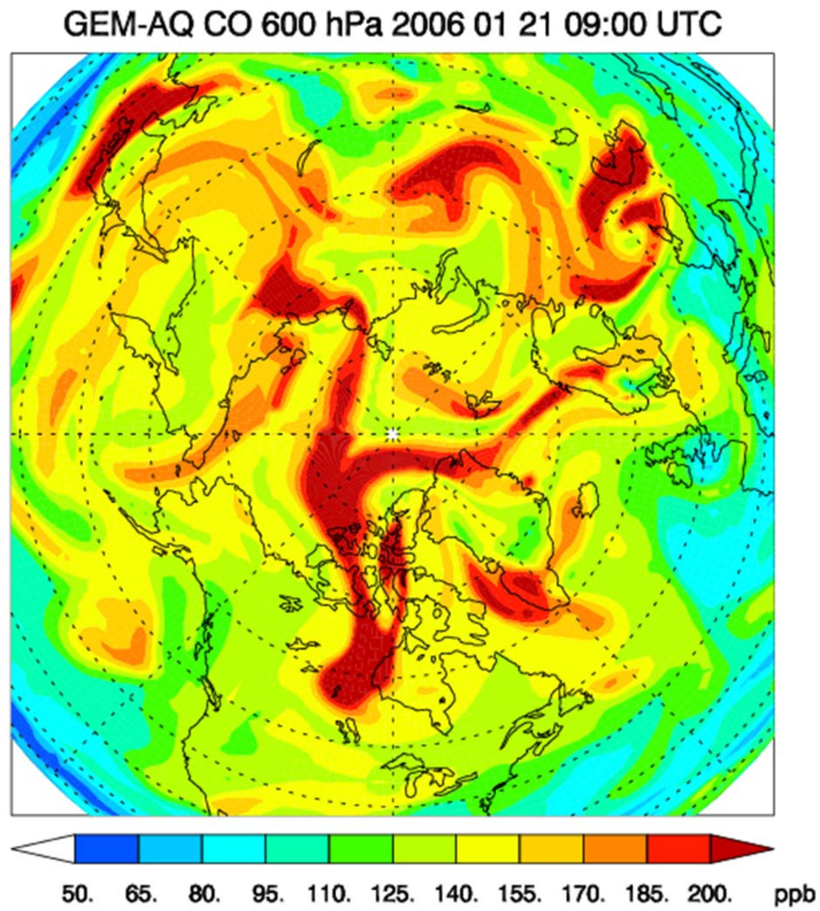
Courtesy of Cathy Clerbaux, 2010

Spatial Goals and Temporal Goals

- Require highest spatial resolution compatible with mass, technology and financial
- Cloud clearing
- Resolution of features: plumes
- Watch the Earth breath (emissions: AQ and GHGs)



GEM-AQ HCN volume mixing ratio at 600 hPa over the Arctic on 19 August 2006 at 0400 UTC. The HCN plume swirling around the North Pole originated from forest fires in Siberia. (Courtesy of Alex Lupu, 2010).

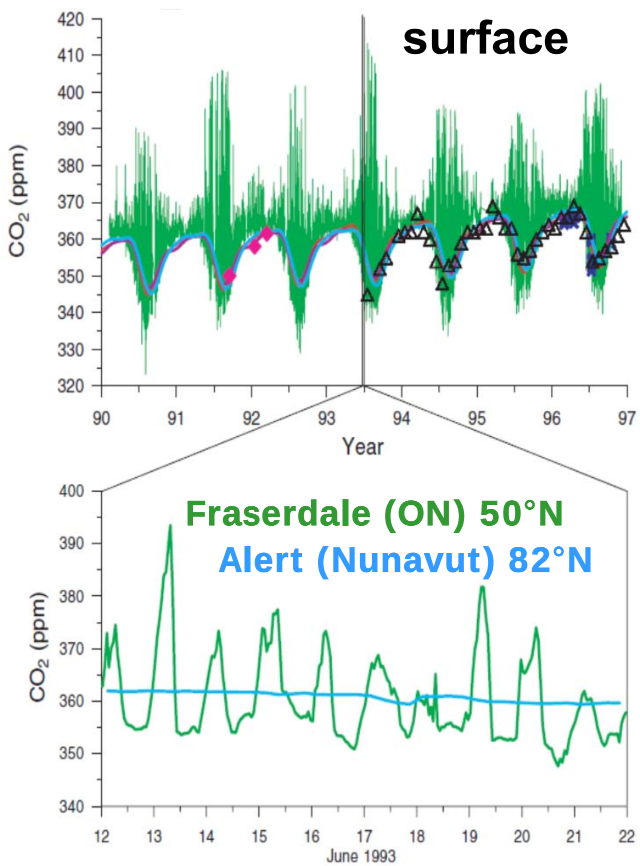


GEM-AQ CO volume mixing ratio at 600 hPa on 21 January 2006 at 0900 UTC illustrating wintertime transport of mid-latitude pollution into the Arctic troposphere.

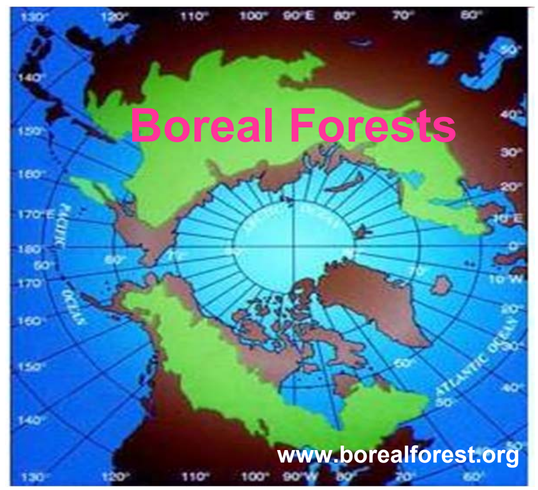
(Courtesy of Alex Lupu, 2010).

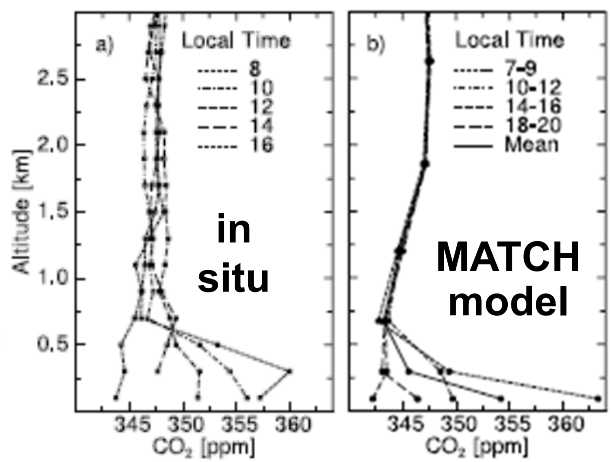
Observing the CO_2 Diurnal Cycle

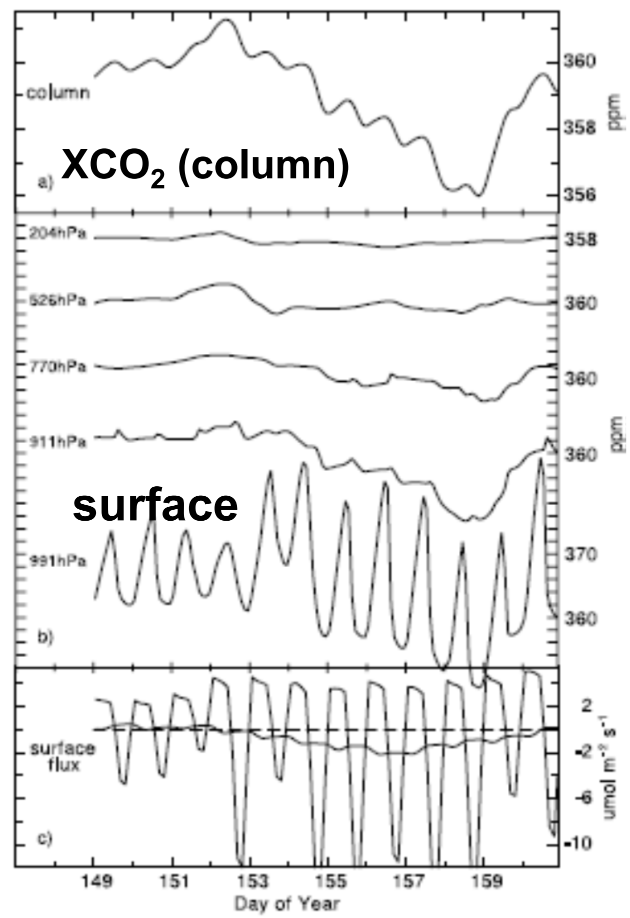
- Strong diurnal cycle of near-surface CO_2 over Boreal Forests, but not north of tree line
- **XCO_2 diurnal amplitude < 1 ppm over forests, not observable in sun-sync LEO**



Higuchi et al. (2003),
Tellus 55B, 115-125





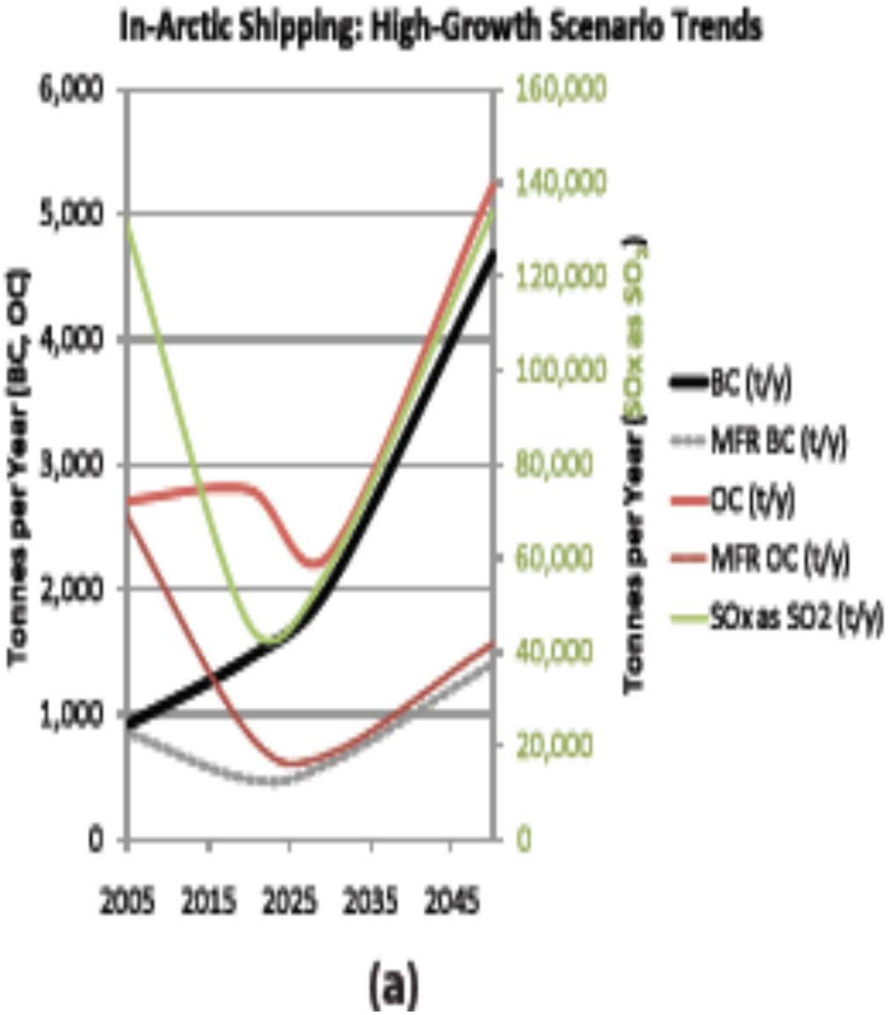


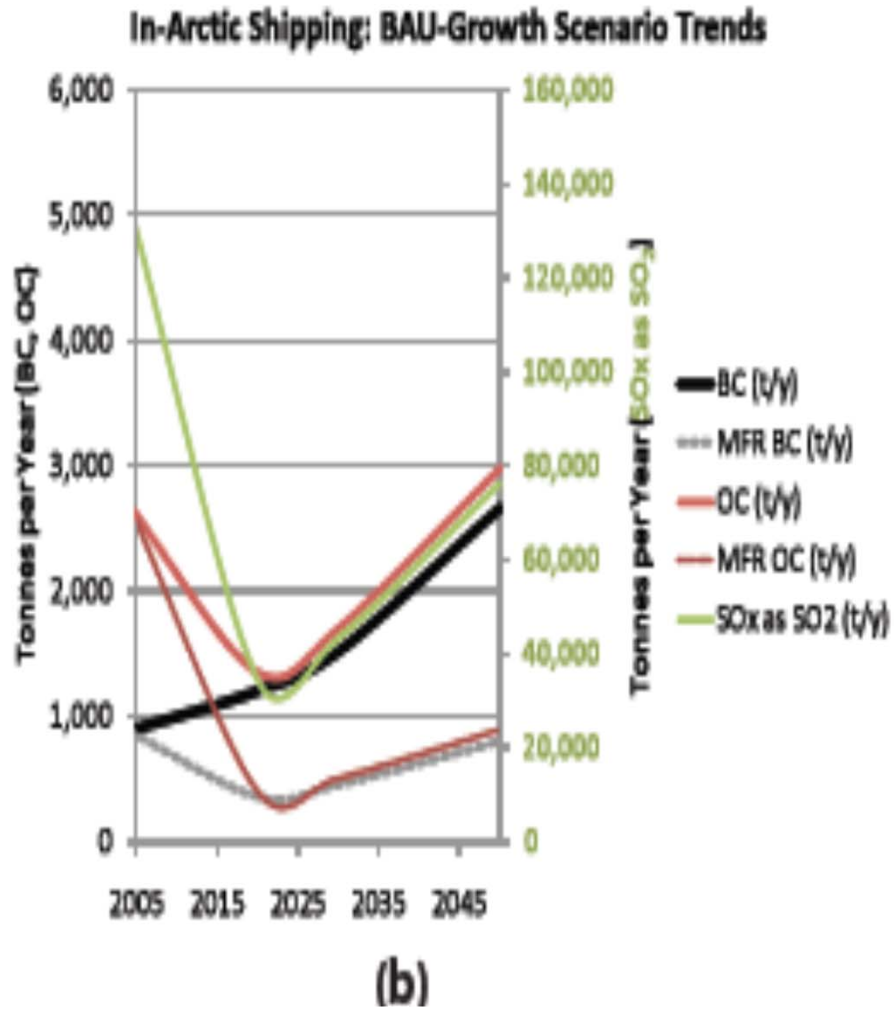
Olsen & Randerson (2004), JGR 109, D02301

Air Quality

- Goals:
  - Human and biosphere exposures, gaseous, PM
  - source estimates
- Low(er) latitude urban areas
  - Natural sources
    - Trees
    - Boreal forest burning
- High latitude industrial sources
  - Current Northern Industry
  - New oil, gas, mineral exploration
  - Ship traffic increasing
- Volcanoes
- Aircraft

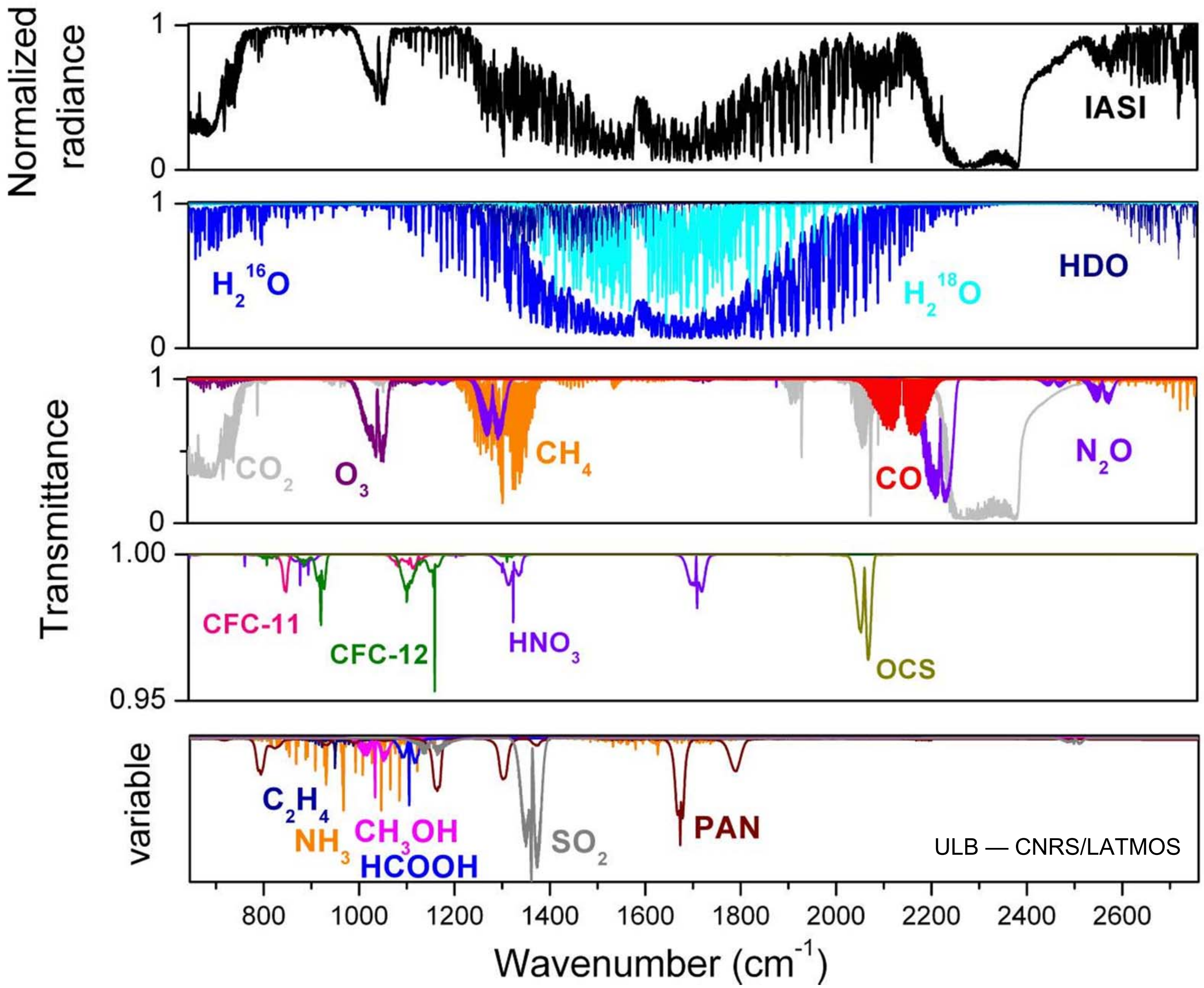
ACIA, 2004





Comparison of in-Arctic trends for black carbon, organic carbon, and SOx emissions under
(a) high growth and
(b) BAU (business as usual) scenarios.. (Corbette al, 2010)

IASI processing at CNRS-ULB



IASI chemistry products

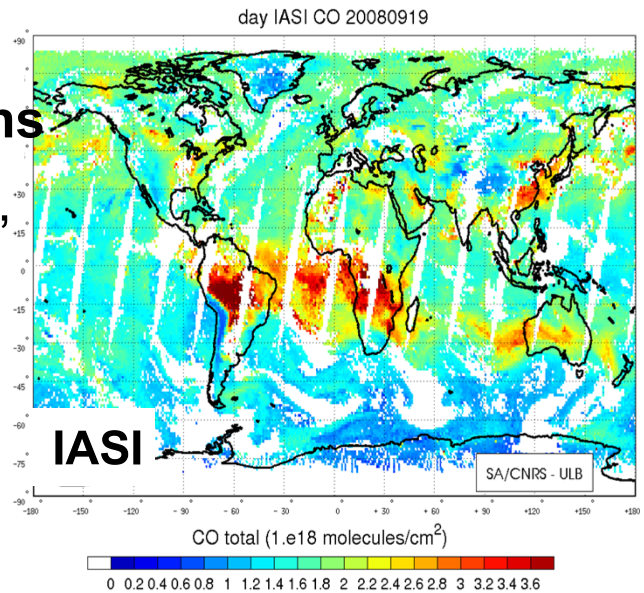
NRT	Research
	H_2O, HDO, $H_2{}^{18}O$; δD, $\delta^{18}O$ profiles
CO profiles O_3 Pcolumns	CH_4 profiles O_3 profiles
HNO_3 columns	
SO_2 (BTDs to columns)	
NH_3 BTDs	

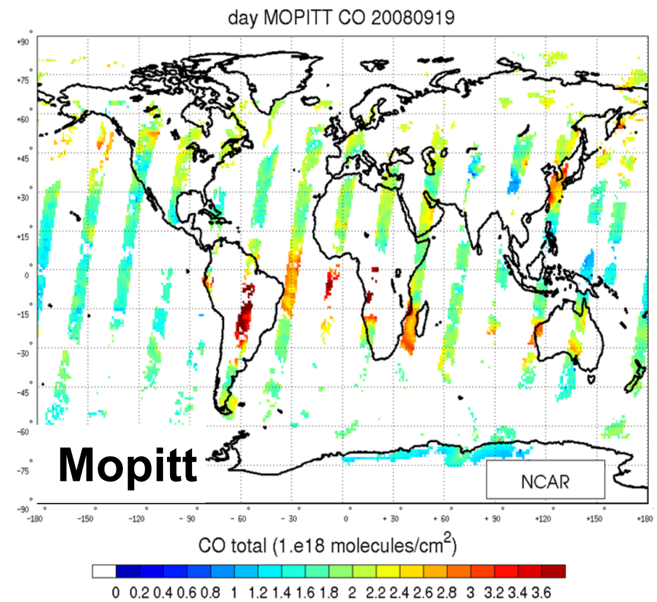
Courtesy of Cathy Clerbaux, 2010

IASI carbon monoxide

Global distributions

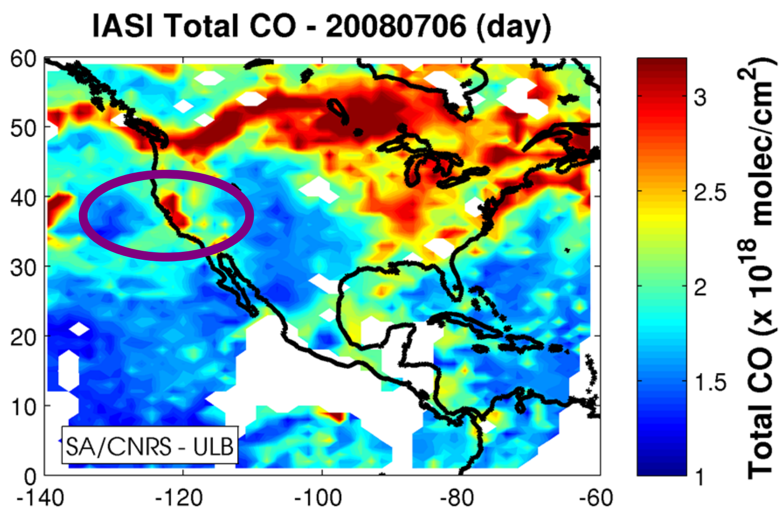
Daily observation, morning orbit





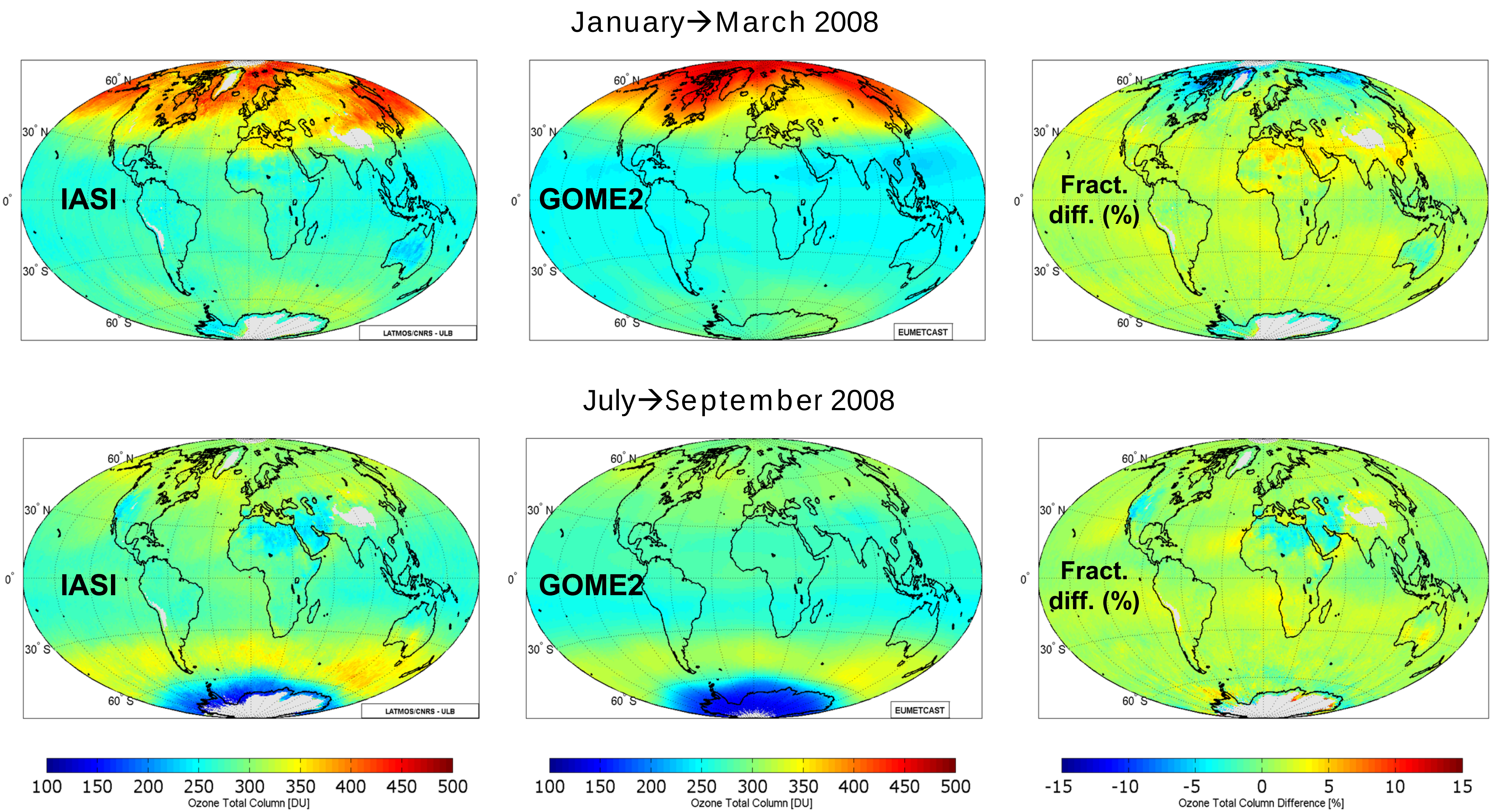
Sources and LRT

California fires
July 2008



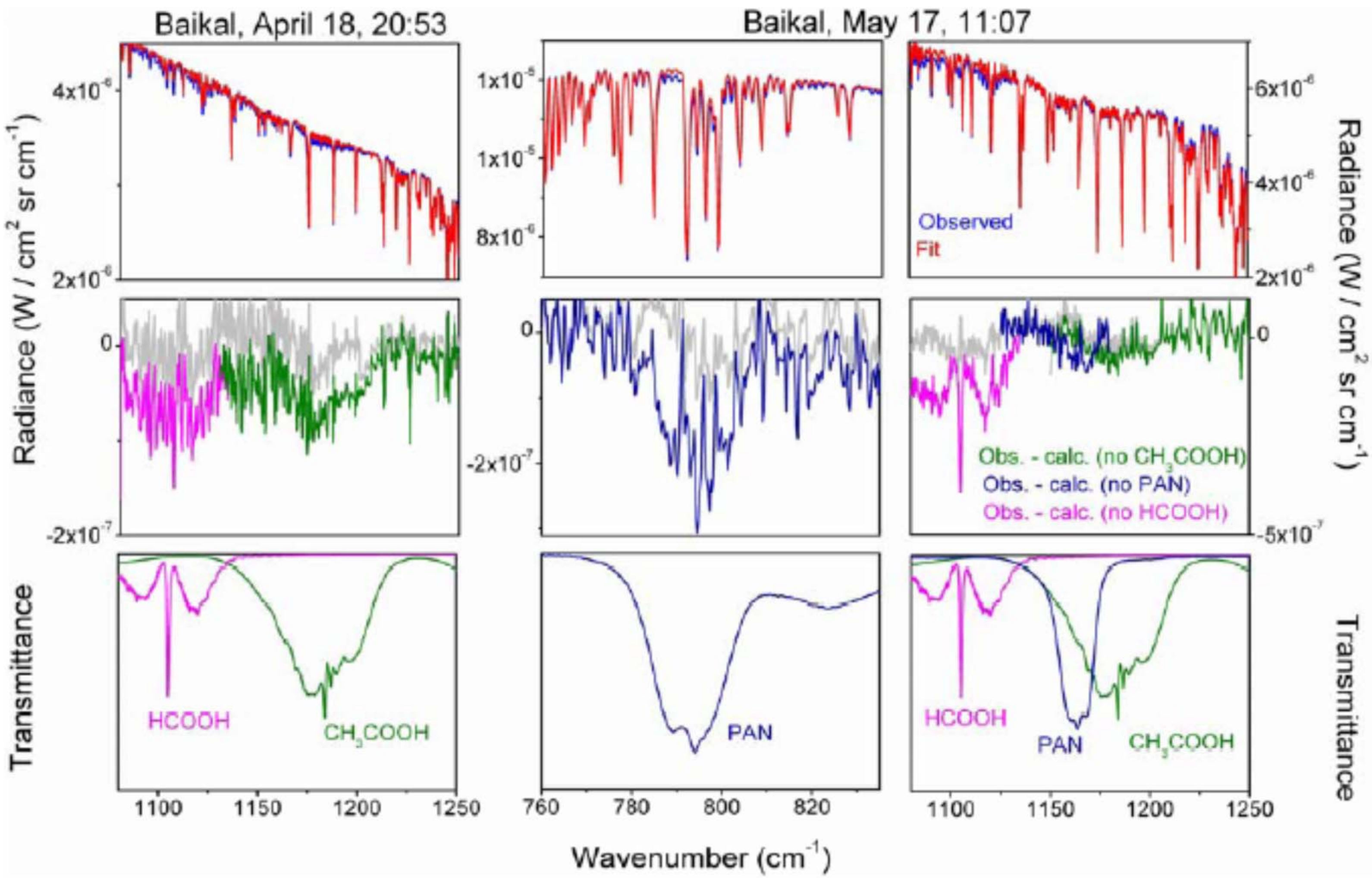
George et al., in preparation for ACP
Turquety et al., in preparation for ACP

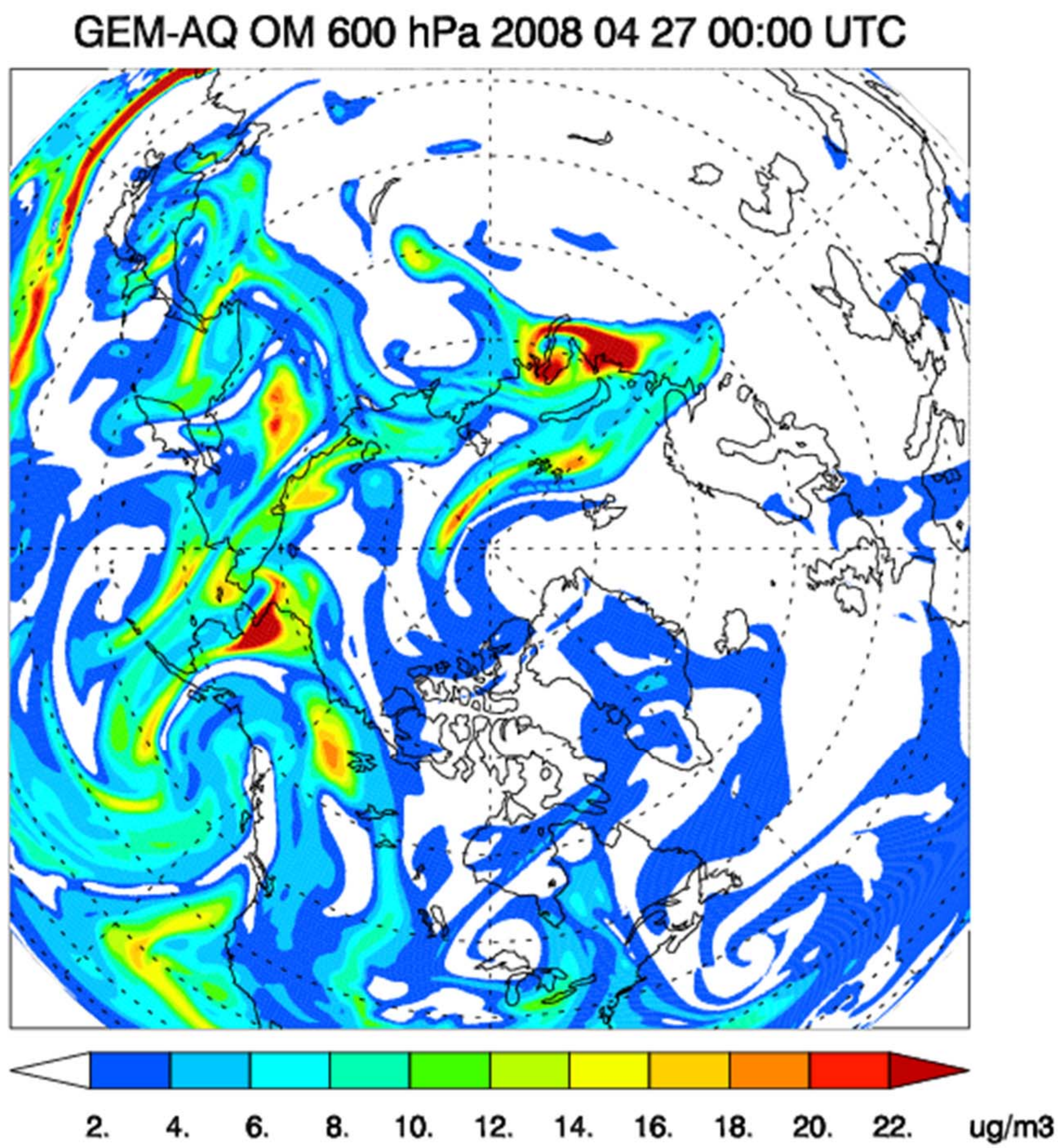
Ozone: IASI (SA-NN) vs GOME-2 Stratospheric O3 columns



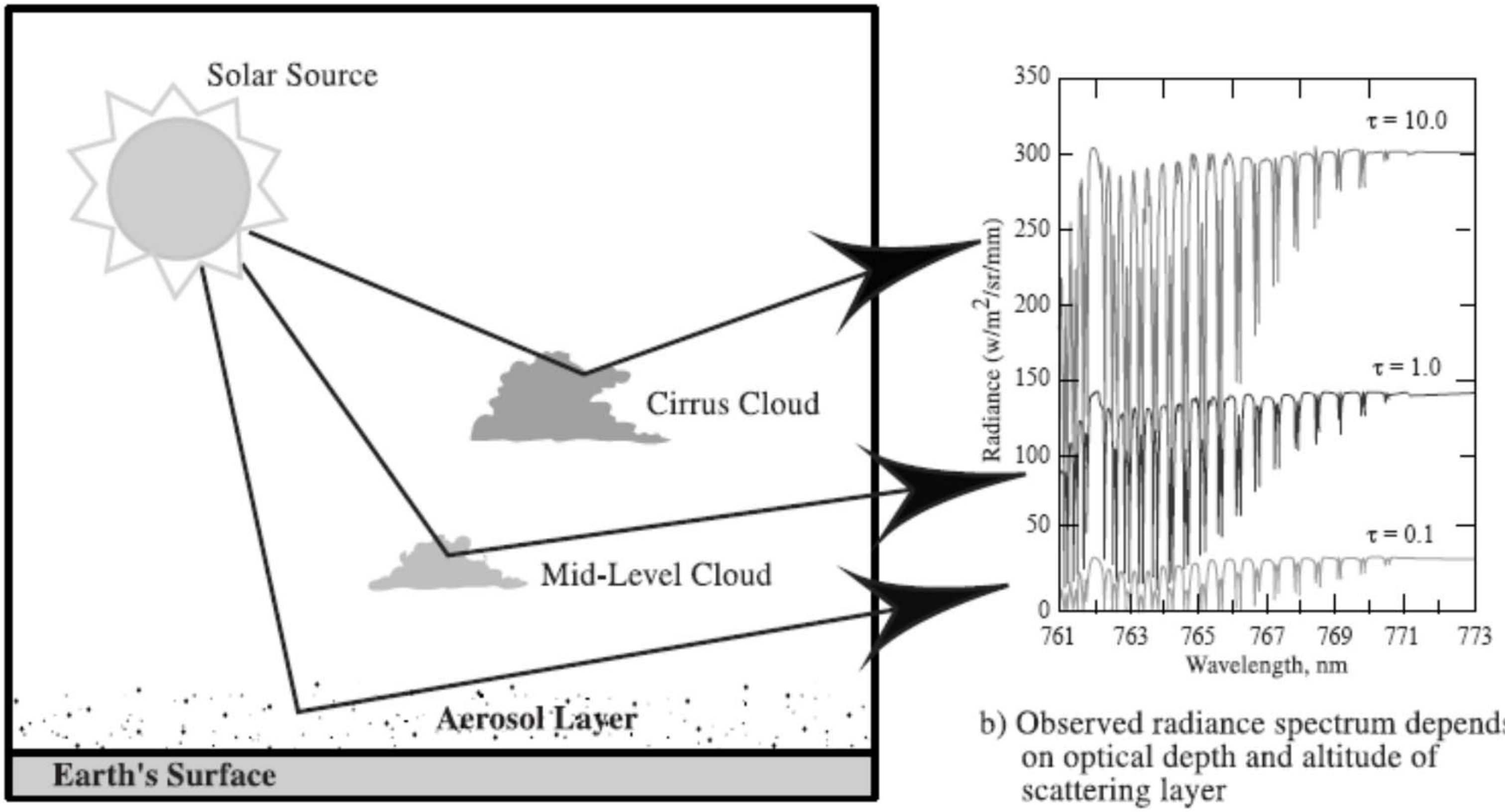
Boynard et al., in preparation for ACP

A spectrum measured on 17 May in Eastern Siberia (46.09 N, 118.99 E, 11:07 local time, middle and right vertical panels). The focus is given here to the region 1075–1250 cm−1, with contributions from HCOOH, CH3COOH and PAN (CO stretching modes) and to the region from 760 to 835 cm−1 with contribution from PAN (NO2 bending mode). In the middle panels, the light gray lines are the spectral residuals with all species accounted for in the retrieval, indicative of the best achievable RMS (Coheur et al., 2009)





GEM-AQ organic matter concentration at 600 hPa over the Arctic on 27 April 2008 at 0000 UTC. Year 2008 was characterized by an unusually early start of the fire season in northern Asia that resulted in large amounts of pyrogenic emissions being transported into the Arctic troposphere. courtesy of Alex Lupu, 2010



a) A high spectral resolution A-band spectrometer observes reflected sunlight within the oxygen A-band.

b) Observed radiance spectrum depends on optical depth and altitude of scattering layer

Concept for remote sensing of aerosol and cloud optical properties with a **high resolution A-band spectrometer** (Pitt et al., 2000)

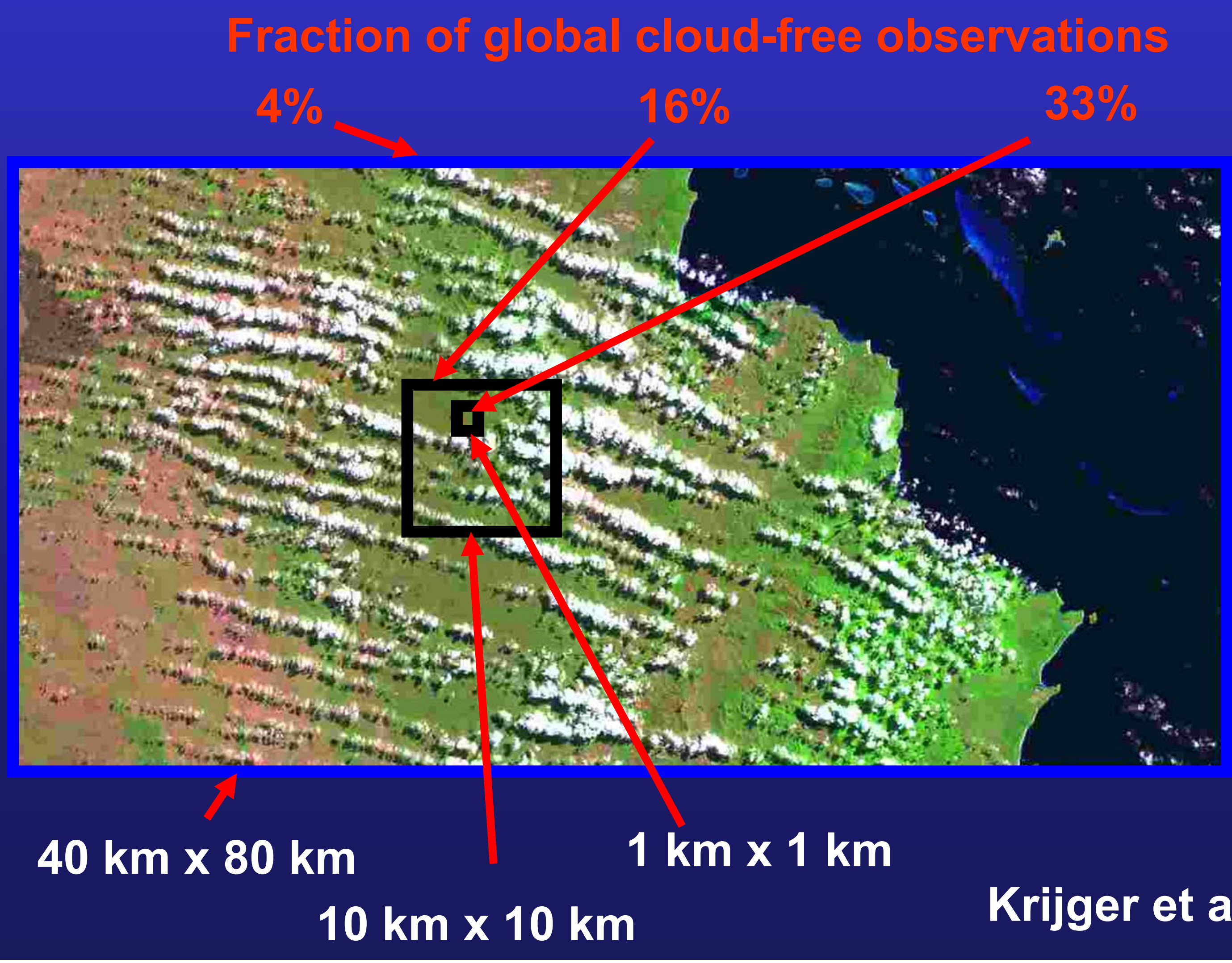
Cloud Clearing

- Problem for all instruments
- Cloudiness and pixel size
- Critical for temperature
- Critical for GHGs
- Important for AQ

Higher Spatial Resolution UVNS for NO_2?

Cloud Error Reduced with Increasing Resolution

Study by K. Chance for GEOCAPE: Sufficient S/N for NO_2 Down to 2-4km



Krijger et al., ACP, 2007

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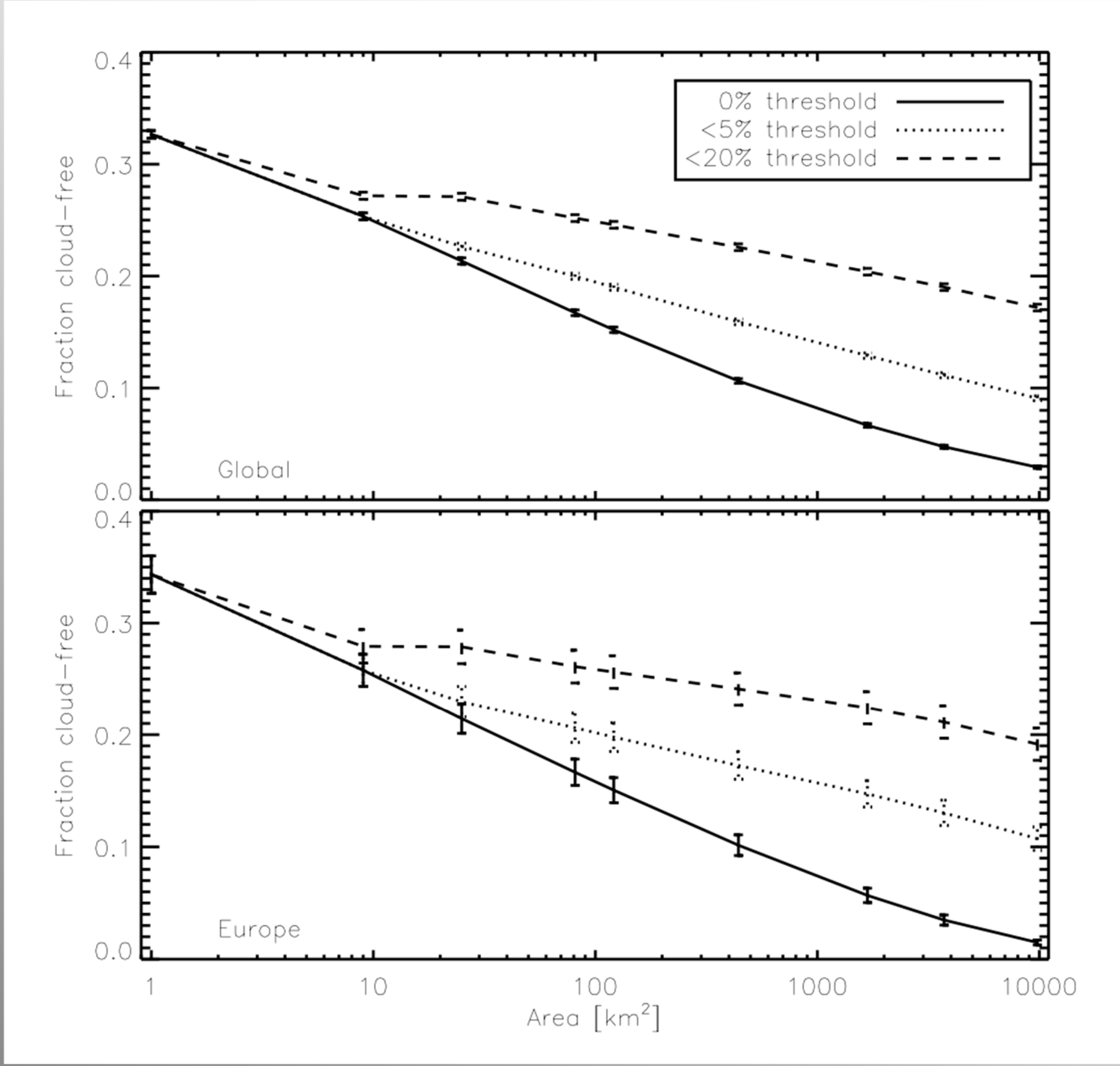

The fraction of cloud-free observations as a function of sensor resolution (footprint area) for 3 different threshold levels for cloud cover within the field of view. This is a copy of Figure 1 from Krijger et al., 2007.

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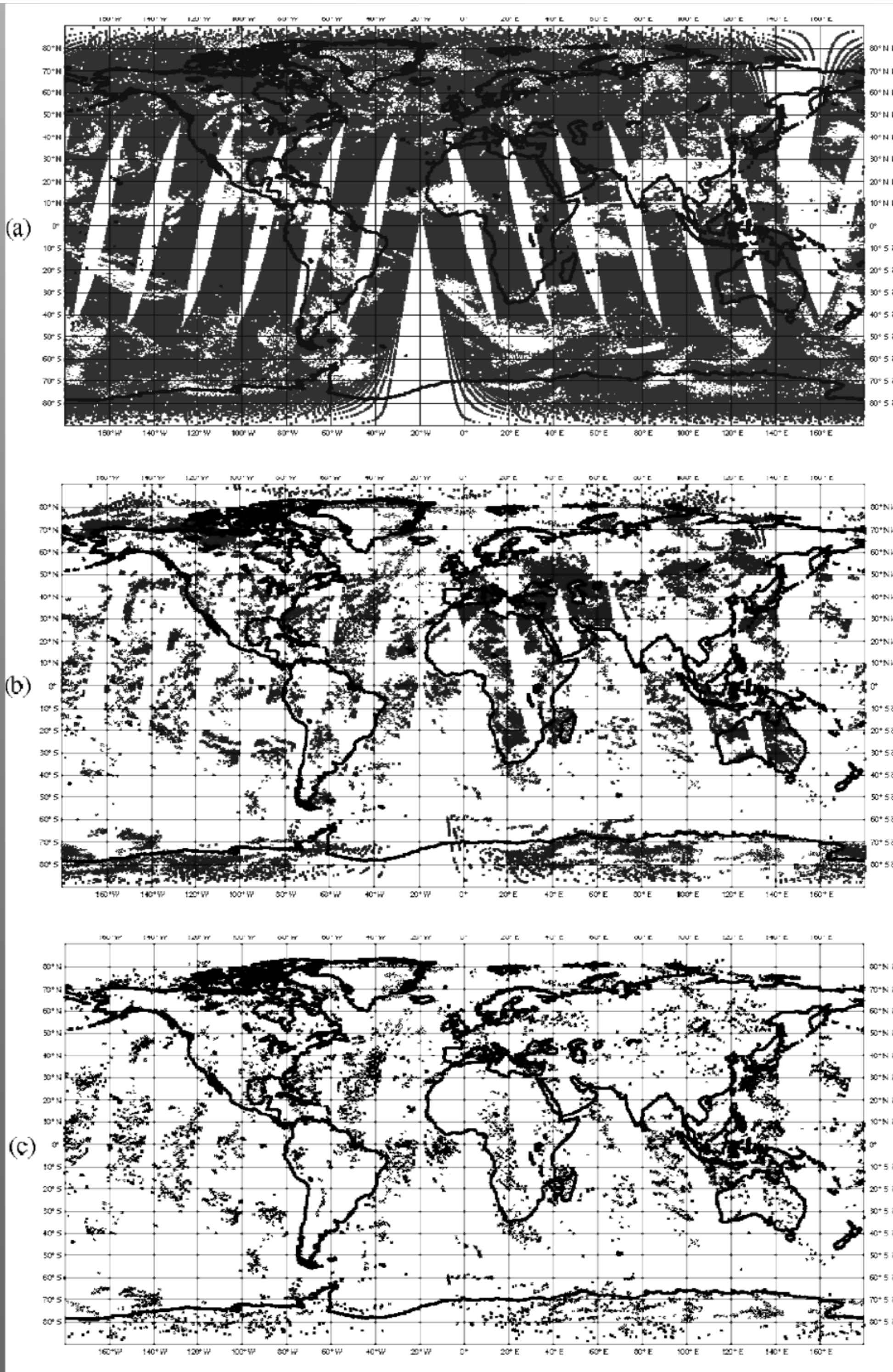


Distribution of clear locations for three AIRS channels:

A. channel 145 (at 14.5 µm and a weighting function peak around 100 hPa),

B. channel 226 (at 13.5 µm and a weighting function peak around 600 hPa),

C. channel 787 (at 11.0 µm and a weighting function peak at the surface). (McNally and Watts, 2003).

Table 2 Instrument Characteristics Table 2A				
Instrument	**Spectral Range**	**Spectral Resolution**	**Sensitivity Goal (G), Threshold (T)**	**Ground IFOV**
FTS – Band 1	700 - 1500 cm^{-1} 14.2 to 6.7 µm	0.25 cm^{-1} ±2 cm OPD	NEdT cm^{-1} = 0.33K (T) 700-1500 = 0.075K (G) 700-1000 = 0.1K (G) 1000-1200 = 0.2K (G) 1200-1500	10x10 km^2 IFOV Contiguous
Table 2B				
FTS – Band 2	1800 - 2700 cm^{-1} 5.6 to 3.7 µm	0.25 cm^{-1} ±2 cm OPD	NEdT cm^{-1} = 0.6(T), 0.3(G)K 1800-2000 = 1.0(T), 0.5(G)K 2000-2200 = 2.0(T), 1.0(G)K 2200-2700	10x10 km^2 IFOV Contiguous
Table 2 C				
FTS - Band 3 CH_4	5990 - 6010 cm^{-1}	0.25 cm^{-1}	> 500:1 for 0.4 albedo at 60° SZA SNR(T)=80, (G)=240	10x10 km^2 contiguous
UVS	280 - 540 nm	1.0 nm	200 to 4,000 (0.1 s) 8x8 km IFOV SNR(T)=1250, (G)=2000, 400 nm SNR(T)=300, (G) = 600, 350 nm	1-D scan 6.8x8.5 km^2

Table 2D – additional options to Table 2A above				
FTS – Band 3 $CH_4 + CO_2$	5990 - 6450 cm^{-1}	0.25 cm^{-1}	> 130:1 for 0.4 albedo at 60° SZA	10x10 km^2 contiguous
FTS – Band 4 O_2 (A-band)	13060-13160 cm^{-1}	0.5 cm^{-1}	> 100:1 for 0.4 albedo at 60° SZA	10x10 km^2 contiguous
Table 2E – option for heavier mass				
SHS – CH_4	1663-1668 nm	0.1 cm^{-1}	$3x10^{-9}$ Wm^{-2}	3x3 km^2 IFOV 2-D scan
SHS – CO_2	1993-1998 nm	0.1 cm^{-1}	$3x10^{-9}$ Wm^{-2}	3x3 km^2 IFOV 2-D scan
SHS - O_2	13000-13100 cm^{-1} TBC	0.1cm^{-1} TBC	TBC	3x3 km^2 IFOV 2-D scan

Note: UVS numbers are for a bright scene (high albedo)

IR-Sounder description
High level requirements - Baseline

Instrument	Spectral Range	Spectral Resolution	Sensitivity Goal (G), Threshold (T)	Ground IFOV
FTS – Band 1	700 - 1500 cm^{-1} 14.2 to 6.7 μm	0.25 cm^{-1} ±2 cm OPD	NEdT < 0.33 K (T) 700-1500 cm^{-1} < 0.075 K (G) 700 -1000 cm^{-1} < 0.1 K (G) 1000 -1200 cm^{-1} < 0.2 K(G) 1200-1500 cm^{-1}	10×10 km^2 IFOV contiguous
FTS – Band 2	1800 - 2700 cm^{-1} 5.6 to 3.7 μm	0.25 cm^{-1} ±2 cm OPD	NEdT < 0.6 K(T), 0.3 K (G) 1800-2000 cm^{-1} < 1.0 K (T), 0.5 K (G) 2000-2200 cm^{-1} < 2.0 K (T), 1.0 K (G) 2200-2700 cm^{-1}	10×10 km^2 IFOV contiguous
FTS - Band 3 CH_4	5990 - 6010 cm^{-1}	0.25 cm^{-1}	SNR > 80 (T), 240 (G) for 0.4 albedo at 60° SZA	10×10 km^2 contiguous
FTS – Band 3b $CH_4 + CO_2$	5990 - 6450 cm^{-1}	0.25 cm^{-1}	SNR > 130 for 0.4 albedo at 60° SZA	10×10 km^2 contiguous
FTS – Band 4 O_2 (A-band)	13060-13160 cm^{-1}	0.5 cm^{-1}	SNR > 100 for 0.4 albedo at 60° SZA	10×10 km^2 contiguous

Interfaces
Main resources required

	IR-Sounder	UVNS	Resources
Mass	38.7 kg + 11 kg contingency	Optical head: 6 kg Electronics: 5 kg Structure: 9 kg Contingency: 6 kg	50 kg
Volume	32 cm x 30 cm x 22 cm	Optical head: 35 cm x 30 cm x 25 cm Structure: 46 cm × 35 cm × 20 cm	30 cm x 30 cm x 30 cm
Power	106 W + 25 W contingency	25 W	100 W
Data rate	< 16.4 Mb/s	5 Mb/s	5 Mb/s

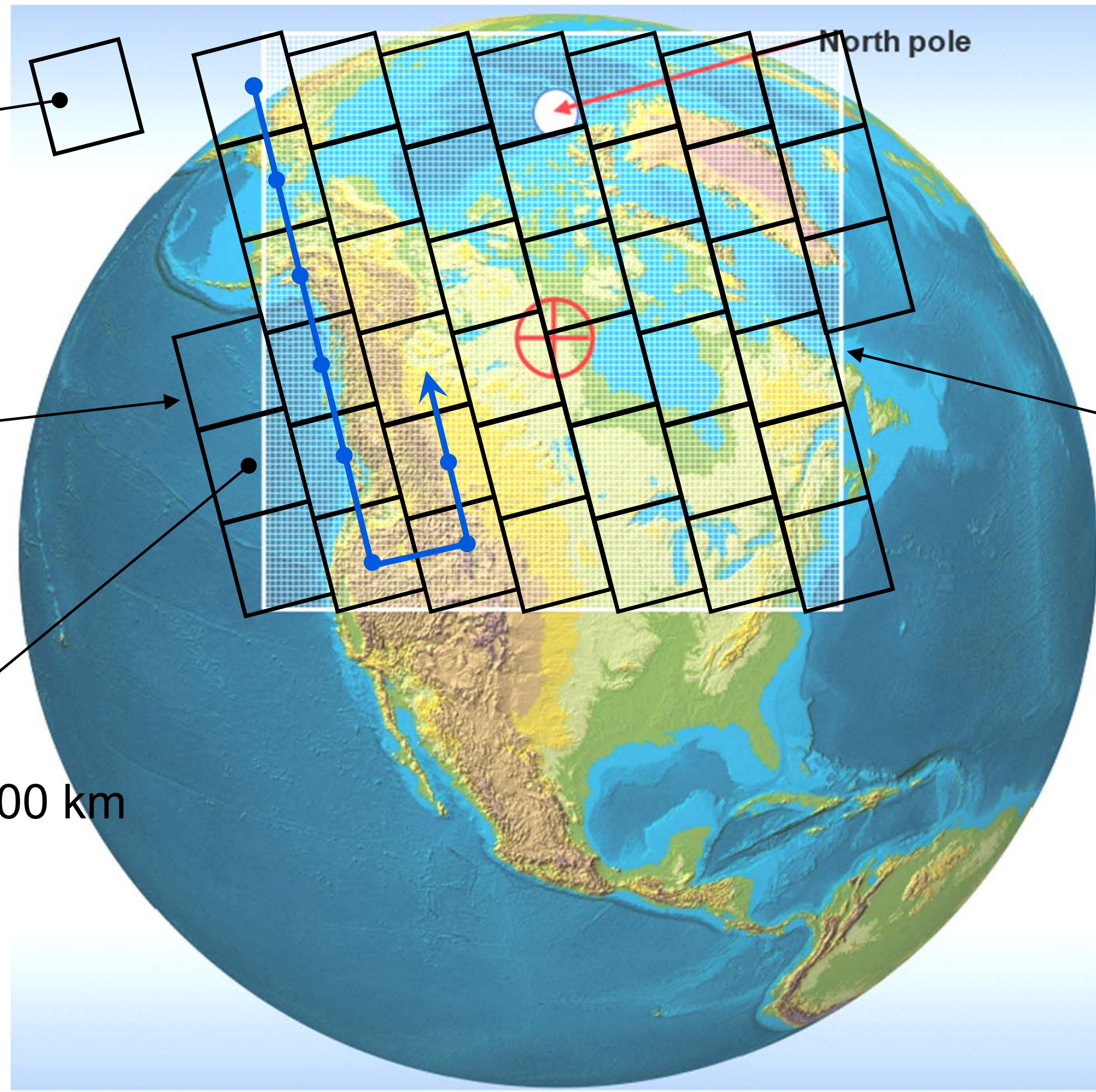
Nominal parameters of PHEMOS FTS

- 10 x 10 km GIFOV at nominal 37600 km altitude and nadir
  - For all bands
- Measurement time per GIFOV ~100s.
  - For contiguous coverage measure ~100,000 IFOVs in ~60 min.
    - Require at least 2800 parallel detectors
    - Focal plane array detectors with ~60 x 60 pixels
- With mirror can stare/point to mesoscale event (fire, storm, volcano)
  - Reduce FOR
  - Reduce repeat time

IR-Sounder description
Observation scenario

- Field of regard is approximately 3020 km x 3530 km (± 1.5 h from apogee)
- Field of regard is scanned in 2-D
  - Step & stare
  - 6 x 7 stares
  - 10% overlap (contingency for pointing error)
- Each stare:
  - Has 56 x 56 pixels
- Each pixel is 10 km x 10 km (± 1.5 h from apogee)
- The FOR is imaged in 1 h 11 min (FOV 100s)
- Imaging time is kept constant over the orbit
  - FOR dimension will vary with altitude

IR-Sounder description
Scan pattern



GIFOV at nadir at 37600 km

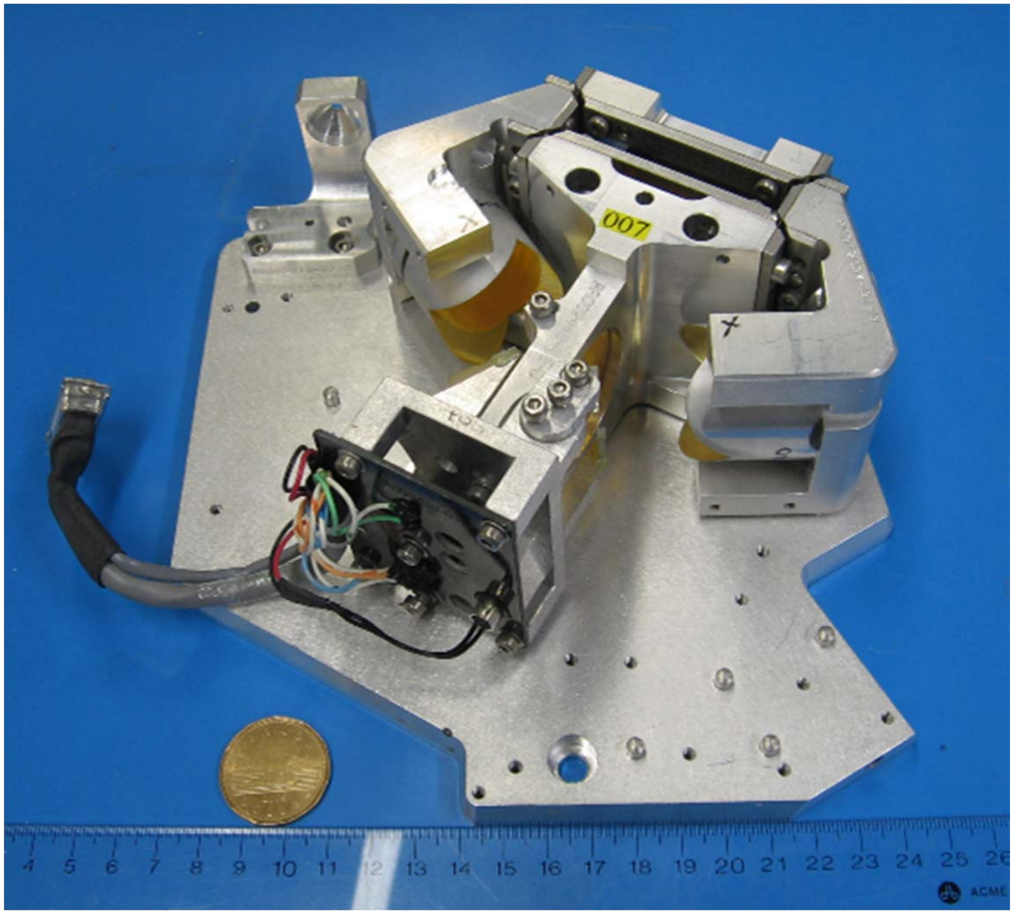
10 x 10 km all bands

Nominally 1 hr repeat

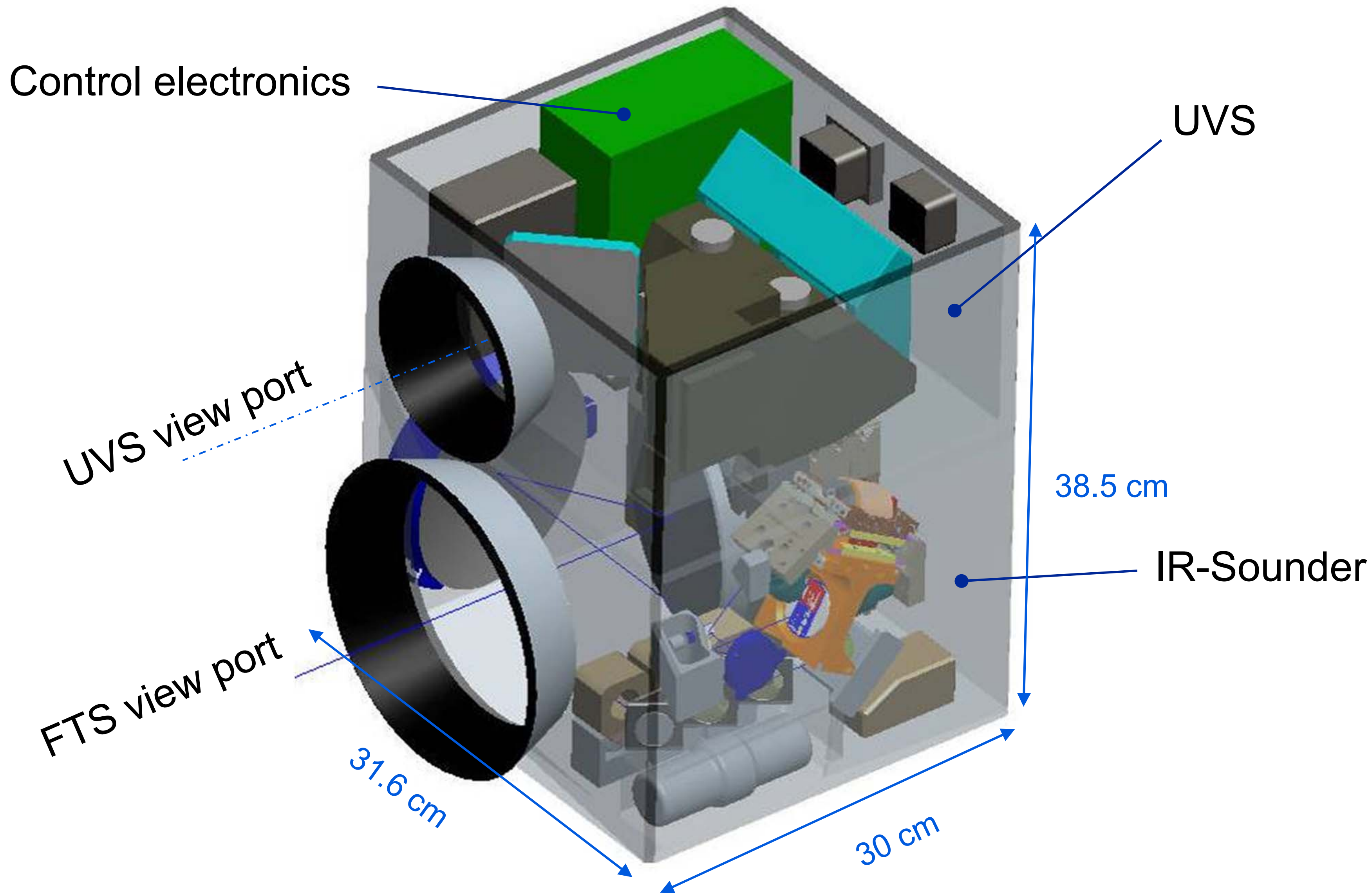
IR-Sounder description
Interferometer

- Based on MINT interferometer (CSA STDP)

- Mass: 1 kg
- MPD: 2 cm
- Fibre-coupled laser metrology
- Spectral range: 0.7 to 25 µm
- Beam size: 30 mm
- Modulation efficiency: 80% at 1.6 µm

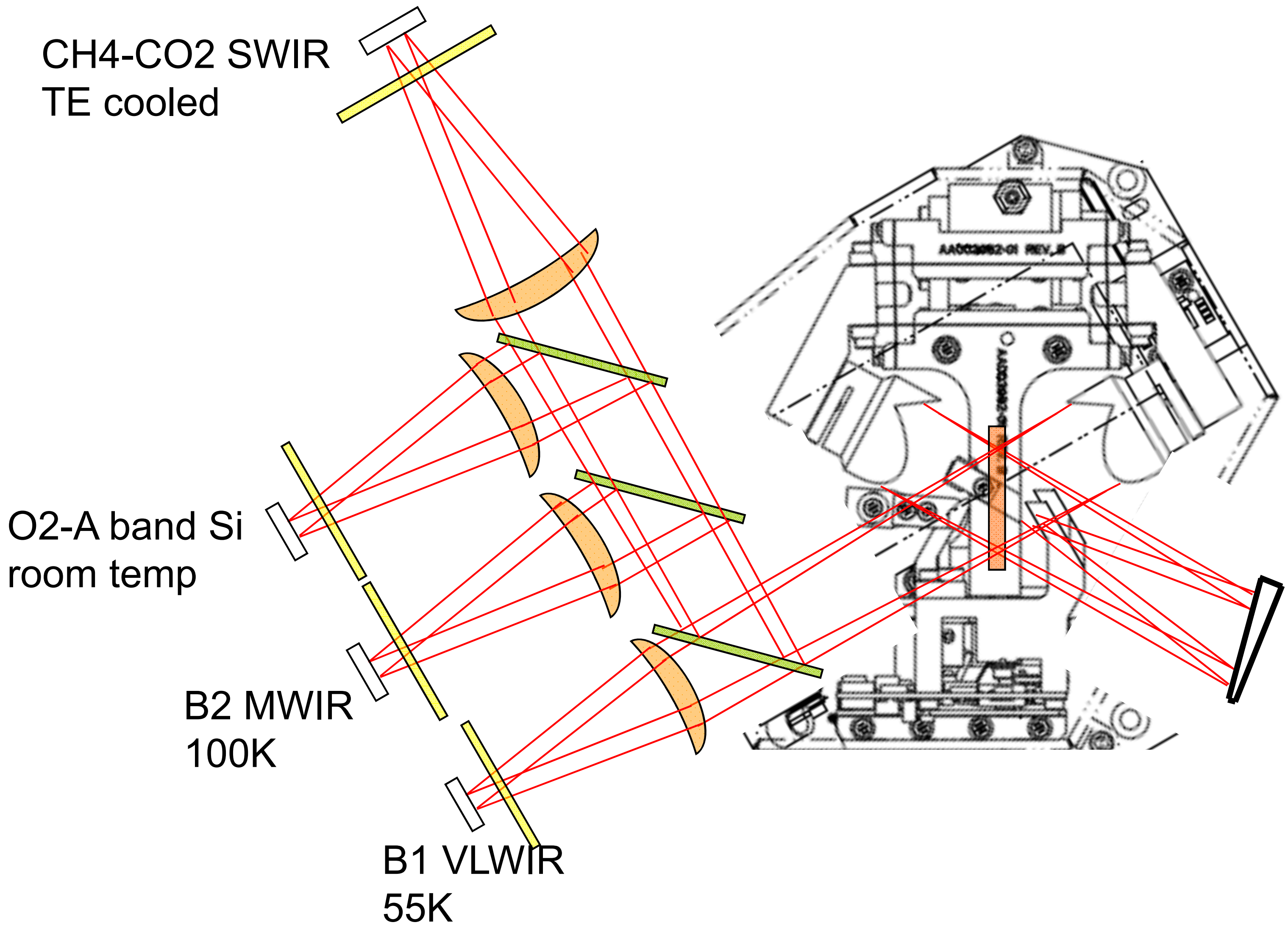


Baseline
3-D view



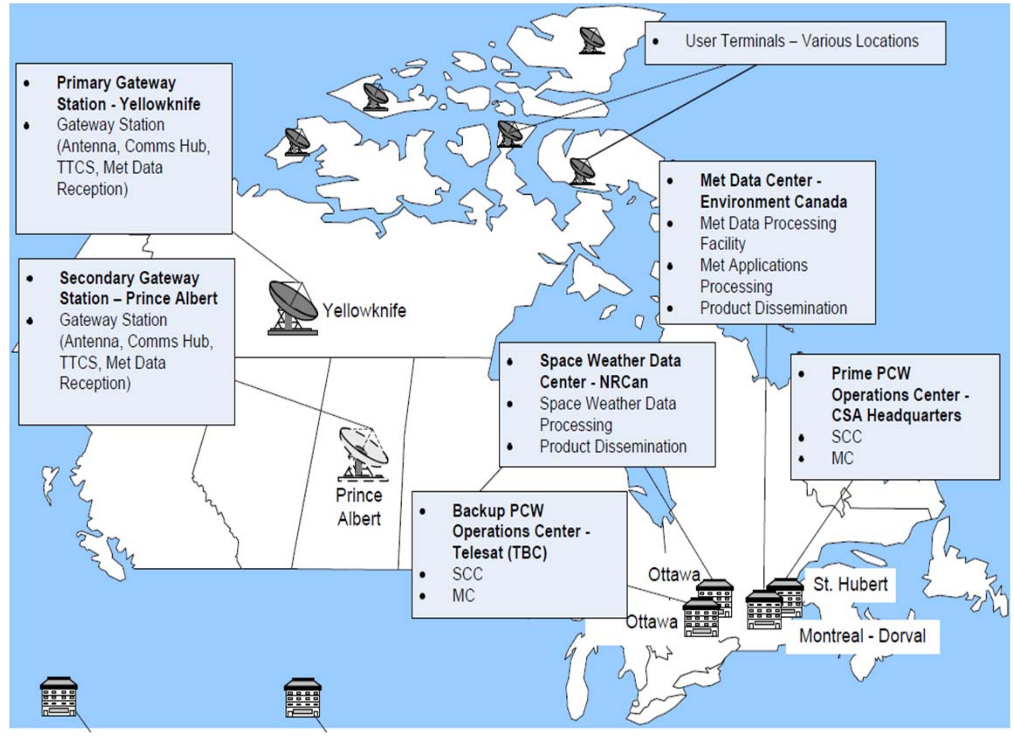
MINT interferometer

Option CH_4 +CO_2 imaging with O_2-A band



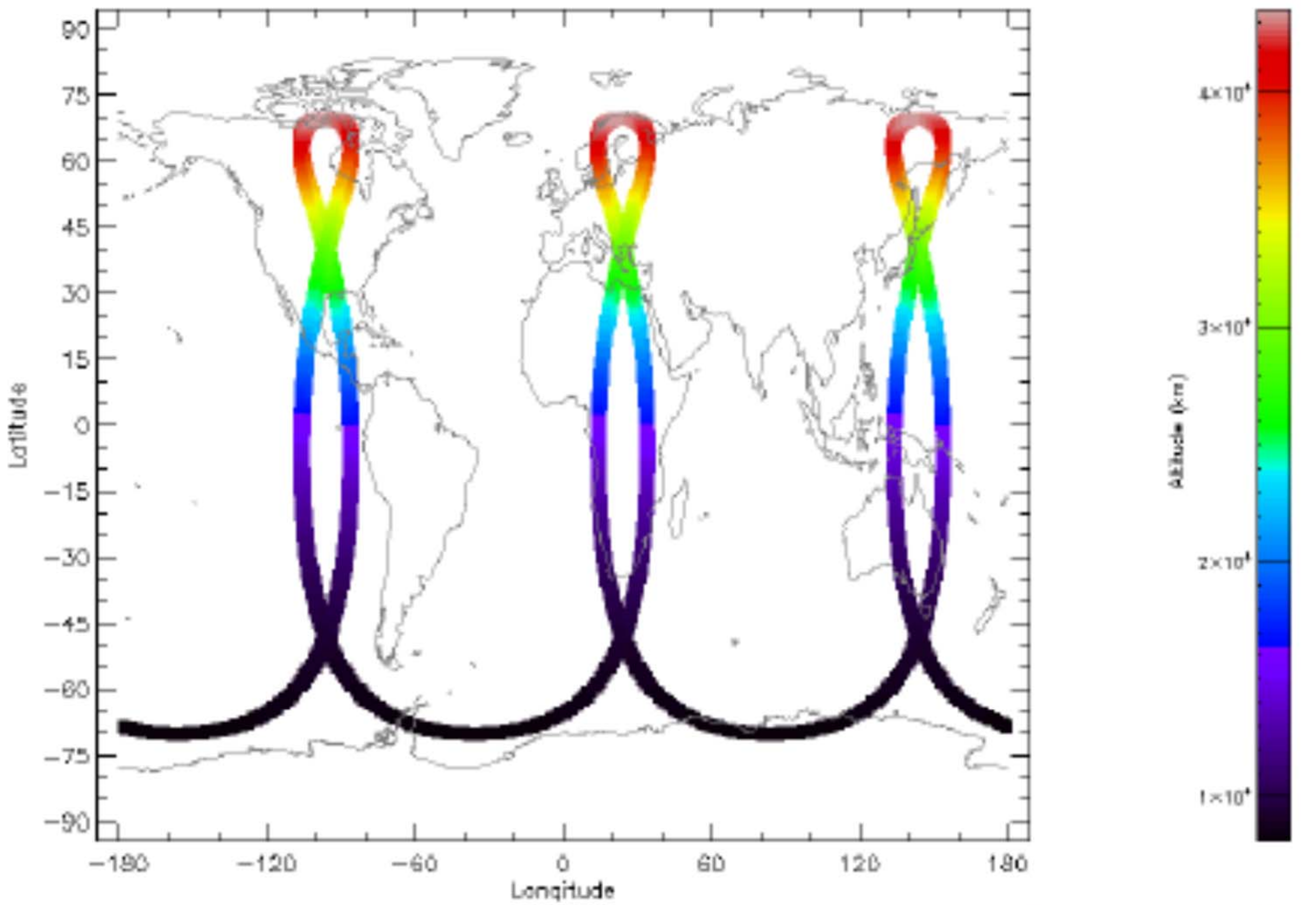
Ground Segment
Overall Principles

- Three main data streams:
  - DS1: operational meteorological and air quality
    - Complement to PCW MP
  - DS2: special events (volcanic eruption, etc.)
  - DS3: research products
- Same data products level as PCW MP



- Use the PCW Ground Segment for DS1 and DS2
- Use the PHEMOS Ground Segment for DS3
- PHEMOS Ground Segment has no direct access to the PCW satellite, the PCW payloads and the PHEMOS payloads.

16hrs orbit is very good alternative candidate for PCW

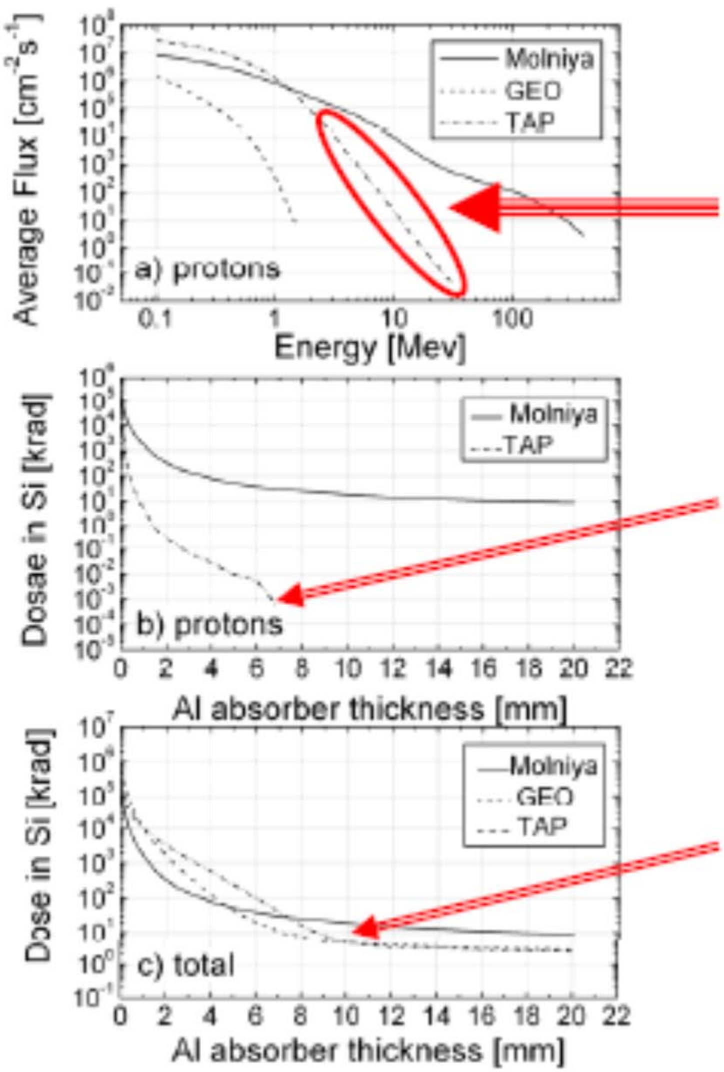


Three APogee (TAP) orbit

Suggested apogees: 95^{0}W; 25^{0}E, 145^{0}E

A. Trishchenko, L. Garand, and L.Trischtchenko, Submitted to *J. Atmos. Ocean.Tech.*, March, 2011

Comparison of radiation conditions between Molniya, GEO and TAP orbits



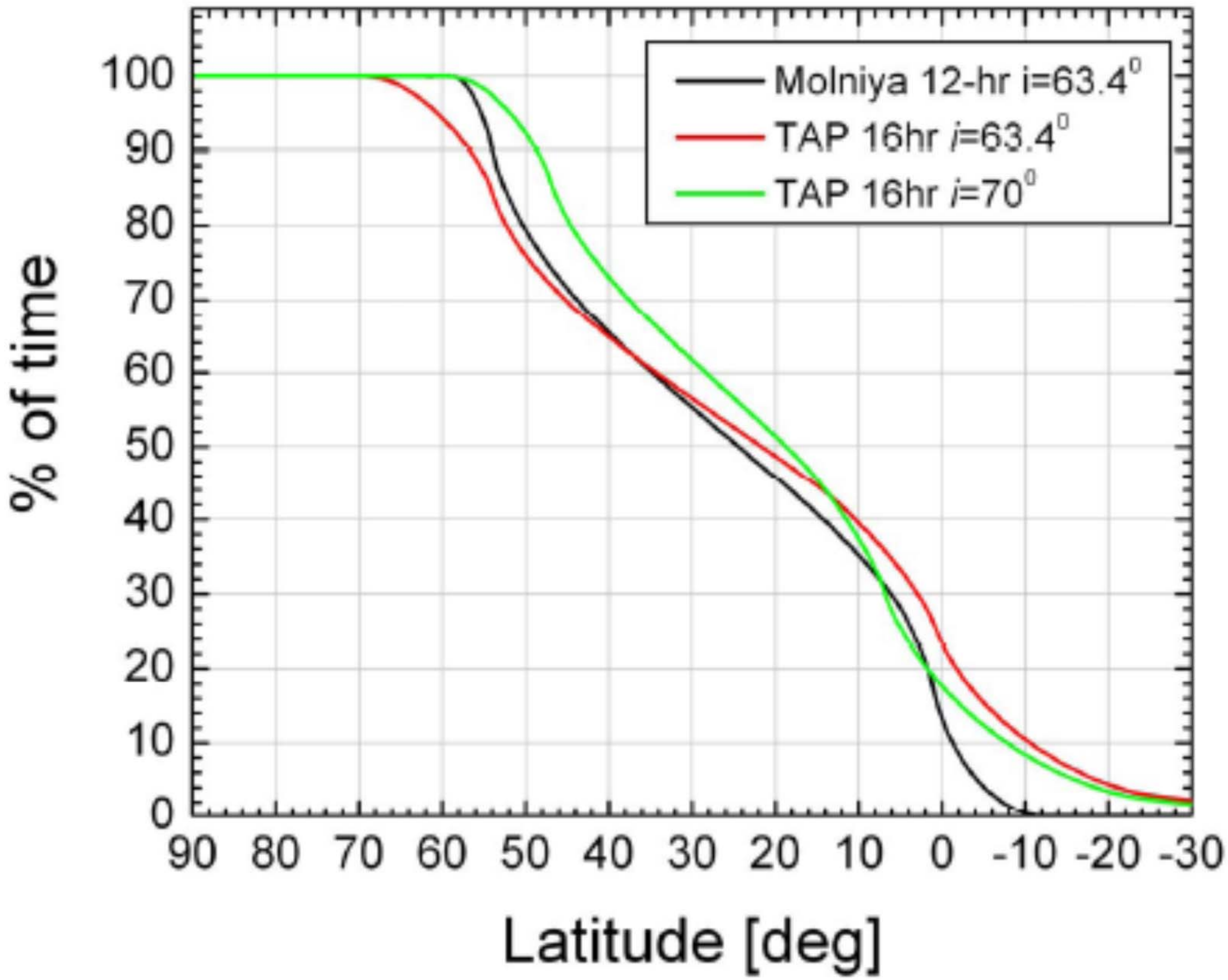
3-4 order of magnitude smaller flux of high energy trapped protons

trapped protons flux essentially vanishes after ≈7mm AL shielding

after ≈9mm AL shielding TAP orbit becomes similar to GEO

A. Trishchenko, L. Garand, and L.Trischtchenko, Submitted to *J. Atmos. Ocean.Tech.*, March, 2011

Zonal mean coverage: 12-hr vs 16-hr orbit



A. Trishchenko, L. Garand, and L.Trischtchenko,
Submitted to *J. Atmos. Ocean.Tech.*, March, 2011

Summary from Phase 0

- Application of FTS in Thermal and NIR spectral range
- UV instrument also possible
- For Highly Elliptical Orbits (Molinya and TAP)
  - 24x7 coverage above ~ 60N
  - 2 satellites
  - Possibility of stereo viewing
  - Footprint better or equal to 10x10 km2
- Compact
- Science (N-O)
  - Weather forecasting – T, water profiles
  - Air quality, total/partial columns
  - Climate Gases/total partial columns

Thank You