

The GFCR (Gas Filter Correlation Radiometer) for Limb Occultation demo for upper atmosphere Temperature (GLOTemp)

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GLO (GFCR for Limb Occultation)

GLO is a solar occultation instrument that provides vertical profiles of these traces gases and aerosols. It primarily focuses on the Upper Troposphere and Lower Stratosphere

- The UTLS plays a key role in controlling the Earth's outgoing long-wave radiation flux and surface climate.
- Transport of constituents into and out of the UTLS is not well understood, with potentially important relevance to radiative forcing and climate modeling.





GLO- Major driving instrument requirements and solutions

- Requires high SNR and sensitivity to measure trace gases ranging from the stratosphere to deep into the optically thick troposphere in the presence of multiple species
 - Multiple measurements or multiple detectors => focal plane arrays
 - GFCR (Gas filter correlation radiometry)
- Sufficient global coverage
 - Multiple SmallSats or CubeSats => small SWaP
 - On-board processing to lower the data rate and autonomous operation
- Extended wavelength range from VIS to MWIR
 - nBn focal plane arrays
- Accurate pointing knowledge
 - Image full sun ~5m accuracy





GLOTemp | 4



GLO Instrument Overview

- 23 filtered solar images onto 4 focal plane arrays
- 9 GFCR on/off channels (2 images each) equivalent spectrally and optically
 - On contains gas cell, off no gas cell
- 6 "broadband" channels
- Wavelengths from 0.45 to 3.9 microns
- GLO design used one cryocooler for two fpa's

9 GFCR Channels				
Channel	λ_0 (µm)	Δλ		
CH ₄	2.315	0.046		
CO	2.361	0.054		
HF	2.451	0.049		
03	2.474	0.037		
H ₂ O	2.506	0.063		
HCN	3.005	0.060		
HCI	3.515	0.070		
HDO	3.759	0.101		
N ₂ O	3.905	0.098		

5 Single (broadband)
Radiometer Channels

Channel	$\lambda_0 (\mu m)$	Δλ
aerosol	0.450	0.005
aerosol	1.020	0.010
aerosol	1.556	0.016
H ₂ O	2.600	0.052
CO ₂	2.801	0.056



Optical Channels Layout



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GLOTemp and history

GLOTemp will act as a pathfinder for GLO

Navy needs

- Accurate ionospheric prediction requires operational T observations in the upper atmosphere for NWP data assimilation.
- Waves propagating up from the lower atmosphere produce lonospheric ion density variations of up to ~30% (in geomagnetically undisturbed conditions) [e.g., *Liu et al., JGR 2010*].
- UA NWP important for long-range (~30 days) and seasonal tropospheric forecasting.
- Only remaining DMSP SSMI/S with operational UA T is 6 years beyond design life, no replacement planned: As Navy interest in UA NWP is growing, source of data is going away.

2015	SOCRATES NASA Earth Venture Mission Proposal
2020	NASA Instrument Incubator Program
2021	CUE NASA Earth Venture Mission Proposal Submitted
2021	GLOTemp STPSat-7 ride 2023. ESPA class AEGIS M-1 bus
2022	NASA funds GLOTemp development
2025	Launch STPSat-7

GLOTemp

4 G	FCR Chanı	nels	4 Singl Radion	e (broadl neter Cha	oand) annels
			Channel	λ_{0} (um)	<u>Λλ</u> .
Channel	$\lambda_0(\mu m)$	Λλ	Channel	/ (part)	
			aerosol	0.450	0.005
CH_4	2.315	0.046	aerosol	1.020	0.010
0)	2,361	0.054		1.020	0.010
	2.501	0.031	H2O	1.556	0.016
HCI	3.515	0.070	H.O	2 600	0.052
N ₂ O	3,905	0.098	1120	2.000	0.052
	0.000	0.000	CO ₂	2.801	0.056

GLO

9 G	FCR Chanr	nels	5 9	Singl	e (broadł	band)
Channel	λ_0 (μ m)	Δλ	Ra	dion	neter Cha	annels
CH ₄	2.315	0.046	Char	nnel	λ_0 (µm)	Δλ
CO	2.361	0.054	aero	sol	0 450	0.005
HF	2.451	0.049	acre		1 020	0.010
03	2.474	0.037	aero		1.020	0.010
H ₂ O	2.506	0.063	aerc	osol	1.556	0.016
HCN	3 005	0.060	H ₂	0	2.600	0.052
HCI	3.515	0.070	CC)2	2.801	0.056
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Mechanical Overview

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Stratosphere-troposphere exchange



Fig. D-3: Principal phenomena that control UTLS composition. The BDC (1) causes STE via large-scale transport. Air injected into the UTLS by monsoons (3) and episodic events (4-7; Box D-3) is transported and mixed by QIE (2). Variability in the tropopause height is shown by thickness of blue line. The Tropical Tropopause Layer (TTL) spans the upper troposphere to tropopause in the tropics. CUE is focused on transport pathways 2-7.

- Brewer-Dobson circulation- upward at equator and downward at poles
- Quasi-isentropic exchange- primarily planetary waves breaking along constant potential temperature surfaces leading to transport and exchange
 - Largest source of exchange
 - Predicted to increase with increasing green house gases
 - Enhanced in monsoon regions
- Episodic events
 - Baroclinic cyclones
 - Volcanoes
 - Pyrocumulonimbus "fire-breathing dragon of clouds"
 - Convective overshoot



CUE will challenge and constrain Earth system models and enable the improvements needed for reliable climate prediction.

The GLO suite of tracers will provide crucial constraints on model representations of key UTLS transport processes.

GLO Provides the Measurement Suite Needed to Quantify the Drivers of UTLS Variations					
Aerosol Extinction	0.450 µm 1.020 µm 1.556 µm 2.451 µm 3.005 µm 3.759 µm	Unprecedented wavelength coverage suitable for inferring aerosol composition.			
Tracer Species	$\begin{array}{c} CH_4 \ CO \ H_2O \ HCI \\ HCN \ HDO \ HF \ N_2O \ O_3 \end{array}$	Required altitude range 8-30 km Meet with margin to			
Greenhouse Gases	$CH_4 H_2 O N_2 O O_3$	50+ km <1km vertical			
Temperature		resolution for all measurements.			

GLOTemp channels



- Extinction ratios trend differently for different aerosols (left)
- Simulations compared to model results (right)





GLO wavelength range will give unprecedented view of aerosol composition and radiative properties

Aerosol Type	Composition, Refractive index [reference]		Particle Sizes ¹ (mm)	Positive ID ²
sulfate	H ₂ SO ₄ - H ₂ O (25 - 95% H ₂ SO ₄)	[Palmer and Williams, 1975]	background: 0.02 - 0.3 mm volcanic: 0.02 - 0.6 mm	r _e < 0.3 mm
cirrus	H ₂ O ice	[Warren and Brandt, 2008]	0.7 - 15 mm	r _e < 7 mm
fire smoke	black carbon - sulfate mixture (1 - 12% BC),	Effective medium mixture [Hess et al., 1998; Palmer and Williams, 1975]	0.02 - 0.6 mm	r _e < 0.6 mm
organic	methanesulfonic acid (MSA) CH ₃ SO ₂ OH – H ₂ O (1 – 20% CH ₃ SO ₂ OH)	[Myhre et al., 2004]	0.1 - 2 mm	r _e < 2 mm
organic	brown carbon (BrC) (NH ₄) ₂ SO ₄ – CH ₃ C(O)CHO mix	Optically similar to (NH ₄) ₂ SO ₄ [Toon et al., 1976]	0.1 - 2 mm	looks like MSA
desert dust	quartz - clay mixture	[Hess et al., 1998]	0.1 - 5.7 mm	r _e < 1 mm

Backup

Data collection and processing for high SNR and Pointing



High SNR from frame stacking and pixel summing

US ΝΑΛΔΙ





High SNR from frame stacking and pixel summing

- Solar sink rate is 1.09 mrad/s
- 0.5 km takes 0.16 seconds
- At 99 Hz frame rate, 16 frames collected per 0.5 km

LS ΝΔVΔΙ

Data collection and processing



High SNR from frame stacking and pixel summing

- Solar sink rate is 1.09 mrad/s
- 0.5 km takes 0.16 seconds
- At 99 Hz frame rate, 16 frames collected per 0.5 km
- Additionally each pixel in the ROI sees same tangent altitude



ΝΔ\/Δ





Performed on board instrument to save memory/downlink BW

U.S.NAVAL

Lockheed Martin SBF207 ROIC nBn detector array

Size	1280 x 1024 pixels	
Pixel pitch	12 microns	
Wavelength	0.45-5.2 microns	
A/D	13 or 14 bit	
Frame Rate	99 Hz full frame and 14 bit	
Well Depth	2.05 million electrons	
ROIC noise	200 electrons	
Responsivity	125 electrons/bit	
Power	160 mWatts	
Integration modes	Snapshot- integrate while or then read	
Windowing	608 x 8 in 1 x 4 increments	
QE	>80%	
Operability	>99.5%	
Readout	Direct injection	
AR coating	1-5 microns	





SNR Models

• SNR models updated for measured filter curves and fpa parameters including dark noise, read noise, and QE

	Original Model	Ν	Measur	ed			
Dark noise at 1ms int. time (e-)	79		62			Each mea	asurement SNR 1150:
Read noise (e-)	300		180			Iotal Sinf	460,000:1
QE	0.75		0.84				
		Channel =	0.448	2.446	3.500	2.589	3.905
		image size =	211	211	211	211	211 pixels
		resolution =	0.5	0.5	0.5	0.5	0.5 km
6.00E+05		focal length =	272.0	272.0	272.0	272.0	272.0 mm
		ROI size =	100	100	100	100	100 pixels
5.00E+05		frame rate =	99	99	99	99	99 Hz
• 4.00E+05	S	tacked frames =	16.2	16.2	16.2	16.2	16.2 frames
te esta esta esta esta esta esta esta es		int. time =	1.000	1.000	1.000	1.000	1.000 ms
0 3.00E+05		well fill =	64.9	64.9	65.0	65.0	65.0 %
2.00E+05	on	read noise =	180	180	180	180	180 electrons
		shot noise =	1151	1152	1152	1153	1152 electrons
4 1.00E+05	digi	tization noise =	36.1	36.1	36.1	36.1	36.1 electrons
0.00E+00		dark noise =	61.44	61.44	61.44	61.44	61.44 electrons
0.00 1.00 2.00	3.00 4.00 F	oarasitic noise =	0.00	0.00	0.00	0.00	0.00 electrons
Mayelengt	·b (um)	ed stop noise =	0.00	0.00	0.00	0.00	0.00 electrons
Wavelenge	(miii)	OOB noise =	0.00	0.00	0.00	0.00	0.00 electrons

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Gas Cell Designs

Copper gas cell with Soldered sapphire windows

	GLO	
Species	Wavelength (µm)	Gas
Aerosol	0.45	N/A
Aerosol	1.02	N/A
Aerosol	1.556	N/A
CH4	2.315	CH4
CO	2.361	CO
HF	2.451	HF
03	2.474	HF
H2O	2.506	HF
H2O	2.6	N/A
CO2	2.801	N/A
HCN	3.005	HCN
HCI	3.515	HCI
HDO	3.759	HDO
N2O	3.905	N2O





Optomechanics: Design



Modular Optical Bench (OB) design

- Each OB has 5-6 channels and is associated with single FPA
- OBs are mounted on opposite sides of a single structure, which is associated with a separable half of the QuIDCA Current design:
- Increased dimensions to accommodate kinematic mounts and COTS components:
 - Kinematic mounts for mirrors
 - Kinematic mounts for beam splitter cubes
- Open design for alignment
- OB support structures machined from a single piece



Solar Measurements with GLO IIP

August 26, and December 29, 2020

- Measure solar signal as sun rises and sets
- Perform Langley plots on aerosol channels and compare to AERONET at NASA Goddard (2 miles north)
- Compare non-gas cell channels to a standard model, normalized to zenith
- ND filters not in place for these.



