



Evaluating Shortwave Observations from the CrIS Hyperspectral Infrared Instrument in the NOAA Global Data Assimilation System

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Objectives and Motivations



• Hyperspectral Infrared:

- Cubesat technology supports an alternative/cost effective/agile constellation of shortwave/midwave IR (SWIR/MWIR) sensors to provide temperature and water vapor profile information to numerical weather prediction (NWP)
- A SWIR constellation could compliment longwave (LWIR) sounders and add robustness to the global observation system

• The Problem:

 SWIR data (e.g. 4 μm CO₂ band) is not operationally assimilated in NOAA NWP models (LWIR and few MWIR channels are assimilated)

• The Question:

- To help shape future satellite global observing system architecture, can a SWIRonly solution achieve or exceed positive impact provided by LWIR radiances in medium-range, global NWP?
- Goals and Operational Outcomes:
 - Move towards the optimization of the NOAA GDAS for the assimilation of SWIR data (CrIS/IASI)
 - Assess whether the assimilation of SWIR can provide as much value as the assimilation of LWIR and advise on the potential use of future SWIR-only sensors
 - Improve radiance forward operator for SWIR (CRTM)



GMAO Ensemble Forecast Sensitivity to Observations Impact (EFSOI) showing reduction in 24-hour forecast errors per observation type. (Mahajan et al, 2017)



Current Status of SWIR in the NOAA GDAS





CrIS NPP 690 cm⁻¹ QC Flags

CrIS NPP 2380 cm⁻¹ QC Flags



Current GSI Quality Control flags for a Longwave IR channel (left) and Shortwave IR Channel (right)

GSI ingests the CrIS FSR 431 channel subset:

- 92 LWIR channels assimilated (642 1095 cm⁻¹), 8 MWIR (1227 1425 cm⁻¹)
- SWIR channels are monitored only, with strict QC
- Similar status for IASI and AIRS (using channel subsets)



Outlook on SWIR Assimilation







Data assimilation system enhancements needed for SWIR:

- Cloud detection scheme
 - SWIR channels in place of LWIR
- New SWIR observation errors
 - From fixed 1 K to scene-dependent
- Quality control modifications based on the above
- Activate 52 SWIR channels (2380 2507 cm⁻¹)
 - Disable 92 LWIR channels to isolate SWIR impact
- Forward operator, Community Radiative Transfer Model (CRTM)
 - Modeling of BRDF
 - NLTE correction
 - For more information, see Yingtao Ma's poster (#21)



SWIR-based Cloud Detection for Clear-Sky Radiances



- Cloud detection for IR in the GSI is based on Eyre and Menzel (1989)
- The scheme seeks to find cloud top pressure (*p*) and cloud fraction (*N*) that minimize

$$\sum_{j} \delta_j^2 = \sum_{j} \left[\left(R_j^m - R_j^{clr} \right) - N \left(R_j^{cld}(p) - R_j^{clr} \right) \right]^2$$
$$\delta_j = R_j^m - R_j$$

Where R_j^m is the measured radiance for channel *j*, and R_j^{clr} and R_j^{cld} are simulated clear and cloudy radiances

SWIR-based cloud detection allows more SWIR observations to pass cloud check – likely due to increased vertical resolution and increased sensitivity to cloud as a result of the non-linearity of the Planck Function in SWIR

Cloud Fraction using LWIR



Cloud Fraction using SWIR





Scene-Dependent Observation Error Specification



Fixed Err:

Obserrors in DA





 $\Delta T_b =$

690 cm⁻¹ GSI Obs Error



Impact of New Quality Control







Observation Minus Background/Analysis







Observing System Experiment Setup



Observation	Baseline (Ops)	LWIR (Control)	SWIR (Exp)
Conventional			
Sat-winds			
IASI			
AIRS			
CrIS LWIR			
CrIS SWIR			
ATMS			
AMSU/MHS			
GPSRO			

- FV3GFS 4DEnVar with 80 ensemble members at C384/C192 (~25 km GDAS/GFS, ~50 km ensemble)
- Experiments run 2018-12-01 to 2019-01-31
- Observations assimilated as in table to the left; AIRS/IASI turned off to enhance signal of CrIS LWIR and SWIR impact
- SWIR experiment uses updated SWIR quality control and observation errors
- Verified against ECMWF analysis
- Verification is using analyses/forecasts from 2018-12-07 to 2019-01-31



Temperature Analysis Differences/Forecast Impact (Preliminary)







Small global 200 hPa temperature analysis differences:

- SWIR degrades 200 hPa bias over the control in the temperature forecast
- SWIR improves RMSE of the temperature forecast, but not significantly



Temperature Analysis Differences/Forecast Impact (Preliminary)





850 hPa temperature analysis differences in the Southern Hemisphere:

- SWIR improves bias over the control in the 850 hPa Southern Hemisphere temperature mid-range forecast; bias degraded in short term
- Degraded (with respect to the control) Southern Hemisphere temperature RMSE with SWIR at earlier forecast times





Forecast Impact on Heights and Winds (Preliminary)



144

12



0.02

0.01

-0.01 -0.02

-0.03

-0.05

-0.06

-0.07

-0.06

-0.09

-0.1

-0.11

Difference w.r.t. CONTROL

Better scores

rms differences outside of outline are significant at the 95% confiden

Forecast Hour

Worse scores

144

0.006

-0.006

-0.012

-0.01

-0.024

-0.03

-0.042

-0.03

Difference w.r.t. CONTROL

Significance intervals

Forecast Hour

Tropical wind analysis differences:

- SWIR improves 200 hPa Tropical wind RMSE; improvements are significant at some forecast times
- SWIR generally improves 850 hPa Tropical wind RMSE, but not significantly for most forecast times



Forecast Impact on Global Relative Humidity (Preliminary)





Global relative humidity analysis differences:

- SWIR degrades RH RMSE performance over the control at 500 and 850 hPa in the short-term (e.g. 24-48 hours)
- SWIR improves RH RMSE scores at 200 and 500 hPa over the control at most forecast times



Background Fit to ATMS Sounding Channels







Conclusions and Future Work



Summing up:

- QC and obs error enhancements improve SWIR assimilation and increase number of SWIR observations used
- Preliminary results from initial experiments demonstrate that SWIR has potential to maintain skill of LWIR for parameters at several levels, forecast lead times, etc.

Next steps:

- Evaluate more forecast/analysis metrics, including cumulative metrics/statistics
- Run an experiment assimilating both LWIR and SWIR to test their skill together
- CRTM: Further improve NLTE to allow for the assimilation of the full 2211 CrIS channel set

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Summary Assessment Metric (SAM): LWIR Control + SWIR Exp, verif. ECMWF







Questions?

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Backup Slides

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Forward Operator Enhancements

370

2183.12

380

2385.0

390

2391.25

400

2397.5 Channel number / Wavenumber (cm-1)

410

2403.75





- NLTE impacts few channels in the CrIS 431 channel subset
- Pre-modification, the NLTE correction in CRTM was negatively affecting channels not impacted by NLTE

430

2527.5

BRDF On

BRDF Off

420

2410.0



LWIR / SWIR Channel Equivalence



	LWIR			SWIR	
Channel	431-subset channel	Wave No.	Channel	431-subset channel	Wave No.
65	30	690.00	1939	372	2380.00
69	34	692.50	1940	373	2380.62
73	38	695.00	1941	374	2381.25
67	32	691.25	1942	375	2381.88
75	40	696.25	1943	376	2382.50
44	12	676.50	1944	377	2383.12
83	48	701.25	1945	378	2383.75
85	50	702.50	1946	379	2384.38
89	54	705.00	1947	380	2385.00
91	56	706.25	1948	381	2385.62
95	60	708.75	1949	382	2386.25
99	64	711.25	1950	383	2386.88
103	68	713.50	1951	384	2387.50
107	72	716.25	1952	385	2388.12
109	74	717.50	1953	386	2388.75
127	92	728.75	1954	387	2389.38
131	96	731.25	1955	388	2390.00
125	90	727.50	1956	389	2390.62
121	86	725.00	1957	390	2391.25
123	88	726.25	1958	391	2391.88
153	118	745.00	1959	392	2392.50
			1960	393	2393.12
			1961	394	2393.75

SWIR R-branch