NOAA Unique CrIS ATMS Processing System (NUCAPS)

Phase 3 Delivery

Critical Design Review

December 2, 2013

Prepared By: Antonia Gambacorta[1], Letitia Soulliard[1], Haibing Sun[1],
Kexin Zhang[1], Tom King[1] and Walter Wolf[2]

[1] IMSG
[2] NOAA/NESDIS/STAR

Review Agenda

Section	Time	Presenter
Introduction	8:30 – 8:40	Tom King
ARR Phase 2 Report	8:40 – 8:50	Tom King
Phase 3 Requirements	8:50 – 9:15	Tom King
Concept of Operations	9:15 – 9:30	Tom King
Algorithm Theoretical Basis: OLR	9:30 – 10:00	Kexin Zhang
Algorithm Theoretical Basis: ILS	10:00 – 10:30	Antonia Gambacorta
Algorithm Theoretical Basis: Collocation	10:30 – 11:00	Haibing Sun
Phase 3 Software Architecture	11:00 – 11:20	Letitia Soulliard
Quality Assurance	11:20 – 11:40	Tom King
Risk Summary	11:40 – 11:50	Tom King
Summary and Conclusions	11:50 – 12:00	Tom King

Review Outline

- Introduction
- ARR Phase 2 Report
- Phase 3 Requirements
- Concept of Operations
- Algorithm Theoretical Basis: OLR
- Algorithm Theoretical Basis: ILS
- Algorithm Theoretical Basis: Collocation
- Phase 3 Software Architecture
- Quality Assurance
- Risk Summary
- Summary and Conclusions

Section 1 – Introduction

Presented by

Tom King

S-NPP/JPSS

- S-NPP and JPSS, a joint NOAA/NASA effort, is the next series of polar-orbiting satellites dedicated to among other things, operational meteorology. The objective of the JPSS mission is to ensure continuity, improvement and availability of operational observations from an afternoon polar orbit (13:30 pm).

- Meteorological/Climatological Instrument packages on NPP/JPSS:
  - CrIS, ATMS, VIIRS, OMPS, CERES

- NPP launched October 28, 2011 and is the first of 3 satellites.

NUCAPS Objectives
Phase 1

- Phase 1 Objectives:
  - » Apodize and subset the CrIS SDR's both spatially and spectrally to produce thinned radiance datasets for use by NWP and DOD centers within 3 three hours of observation (or 30 minutes of data receipt from IDPS) to NWS and DOD.
  - » SDR Validation Products: Global Grids, Matchups, and Binaries

NUCAPS Objectives
Phase 2

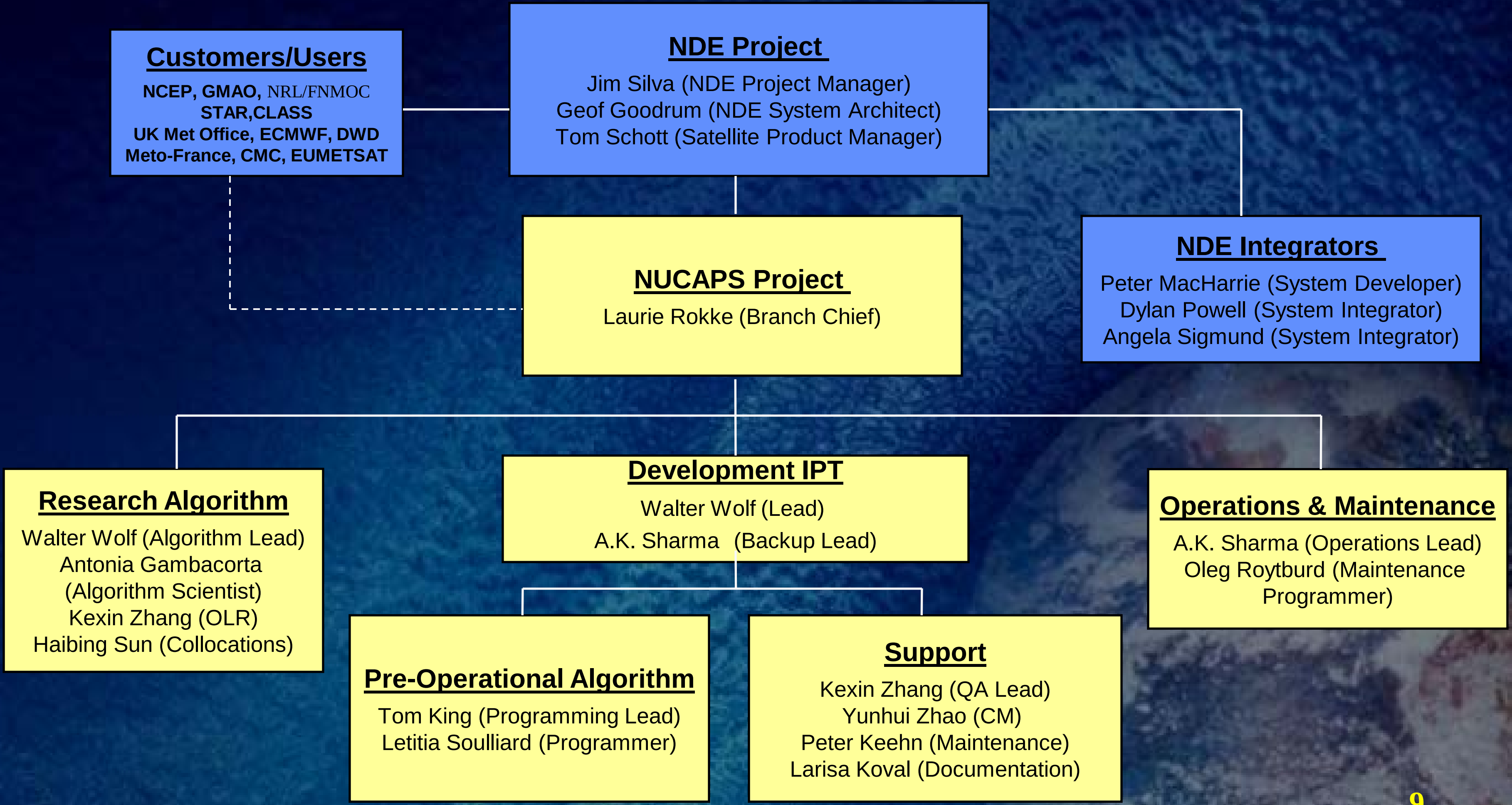
- Phase 2 Objectives:
  - » Provide CrIS/ATMS NOAA Unique products within three hours of observation (or 30 minutes of data receipt from IDPS) to NWS and DOD.
    - – Temperature, moisture, pressure profiles
    - – Cloud cleared radiances
    - – NOAA Unique trace gas products
    - – Principal components
    - – Science QC products for OSPO
  - » Provide NOAA Unique CrIS/ATMS Products with metadata to CLASS.
  - » EDR Validation Products: Global Grids, Matchups, and Binaries.

NUCAPS Objectives
Phases 3 and 4

- Phase 3 Objectives:
  - Collocated CrIS/VIIRS-cloud datasets
  - CrIS OLR
  - ILS Shift
  - Retrieval updates (regression update, bug fixes)

- Phase 4 Objectives:
  - Retrieval updates (regression update, bug fixes)
  - Updates to accommodate increased CrIS spectral resolution?

NUCAPS Project: Organization Chart



Customers/Users

NCEP, GMAO, NRL/FNMOC
STAR,CLASS
UK Met Office, ECMWF, DWD
Meto-France, CMC, EUMETSAT

NDE Project

Jim Silva (NDE Project Manager)
Geof Goodrum (NDE System Architect)
Tom Schott (Satellite Product Manager)

NUCAPS Project

Laurie Rokke (Branch Chief)

NDE Integrators

Peter MacHarrie (System Developer)
Dylan Powell (System Integrator)
Angela Sigmund (System Integrator)

Research Algorithm

Walter Wolf (Algorithm Lead)
Antonia Gambacorta
(Algorithm Scientist)
Kexin Zhang (OLR)
Haibing Sun (Collocations)

Development IPT

Walter Wolf (Lead)
A.K. Sharma (Backup Lead)

Operations & Maintenance

A.K. Sharma (Operations Lead)
Oleg Roytburd (Maintenance Programmer)

Pre-Operational Algorithm

Tom King (Programming Lead)
Letitia Soulliard (Programmer)

Support

Kexin Zhang (QA Lead)
Yunhui Zhao (CM)
Peter Keehn (Maintenance)
Larisa Koval (Documentation)

Project Stakeholders – Development Team

- STAR (Walter Wolf-P.I., Thomas King, Antonia Gambacorta, Letitia Soulliard, Larisa Koval, Haibing Sun, Kexin Zhang, Yunhui Zhao, Peter Keehn)
  - » Develop the NUCAPS algorithms
  - » Integrate algorithm code into a package designed to interface with NDE system
  - » Conduct testing and validation
  - » Develop documentation
  - » Work with data users to obtain detailed product requirements

Project Stakeholders – Operations and Maintenance

- NDE – NPOESS Data Exploitation (Geoff Goodrum, Peter MacHarrie)
  - Develop the NDE system
  - Integrate science algorithm packages received from STAR
- OSPO (A.K. Sharma – NUCAPS PAL)
  - Run and maintain the NDE system on the operation side
  - Distribute the data and products to users

Project Stakeholders – Customers and Users

- U.S. Users:
  - NCEP (John Deber, Andrew Collard, Dennis Keyser)
  - GMAO (Emily Liu)
  - AWIPS (Jim Heil)
  - STAR (Tony Reale, Murty Divakarla, Kexin Zhang)
  - NCDC/CLASS (Phil Jones, Brian Merandi)
- International Users:
  - EUMETSAT (Simon Elliott)
    - UK Met Office (Nigel Atkinson)
    - ECMWF (Tony McNally)
    - DWD (Reinhold Hess)
    - Meteo-France (Lydie Lavanant)
    - Plus other EUMETSAT members states
  - CMC (Louis Garand)
  - EC (Sylvain Heilliette)
  - JMA (Hidehiko Murata)
  - BOM (John Le Marshall)

Project Plan:
Task and Schedules

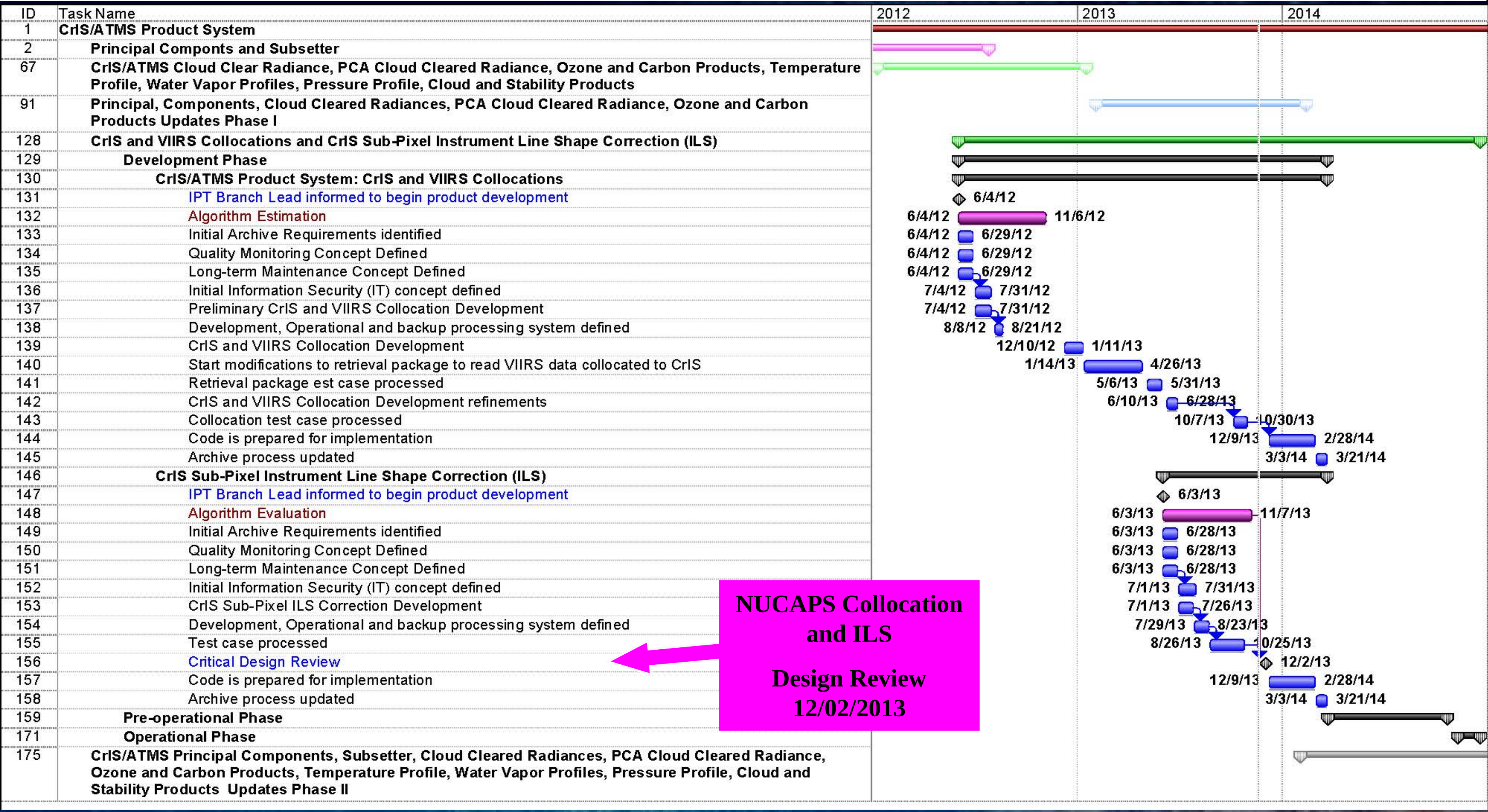
- Tasks defined in the PSDI project plan:
  - FY14_Polar_CrIS-ATMS_V2.0.ppt
  - FY14_Polar_CrIS_OLR_V2.0.ppt

- Schedule (key milestones):
  - Preliminary Design Review – May 9, 2007
  - Critical Design Review – Sep. 29, 2008
  - Test Readiness Review – Sep. 29, 2010
  - Code Unit Test Review – Oct. 20, 2010
  - Phase 1 Algorithm Readiness Review – Mar. 14, 2012
  - NUCAPS Phase 1 Delivery – Mar. 19, 2012
  - NUCAPS Phase 2 Delivery – Dec. 3, 2012
  - Phase 2 Algorithm Readiness Review – Jan. 14, 2013
  - SPSRB Briefing for Phase 1 – Jul. 17, 2013 (May 2013) (Jun. 2012) (Jan. 2012)

Project Plan: Task and Schedules

- Schedule (key milestones) continued:
  - NUCAPS Phase 1 Operations Commence – Sep. 19, 2013 (Jun. 2013) (Jul. 2012) (Feb. 2012)
  - SPSRB Briefing for Phase 2 – Sep. 18, 2013 (May. 2013) (Jun. 2012) (Jan. 2012)
  - NUCAPS Phase 2 Operations Commence – Oct 2013 (Jun. 2013) (Jul. 2012) (Feb. 2012)
  - NUCAPS Phase 3 Critical Design Review – Dec. 2, 2013 (Nov. 2013)
  - NUCAPS Phase 3 Algorithm Readiness Review – Sep 2014
  - NUCAPS Phase 3 DAP Delivery – Sep 2014
  - SPSRB Phase 3 briefing – Nov. 2014
  - NUCAPS Phase 3 Operations Commence – Nov. 2014

NUCAPS Project Timeline

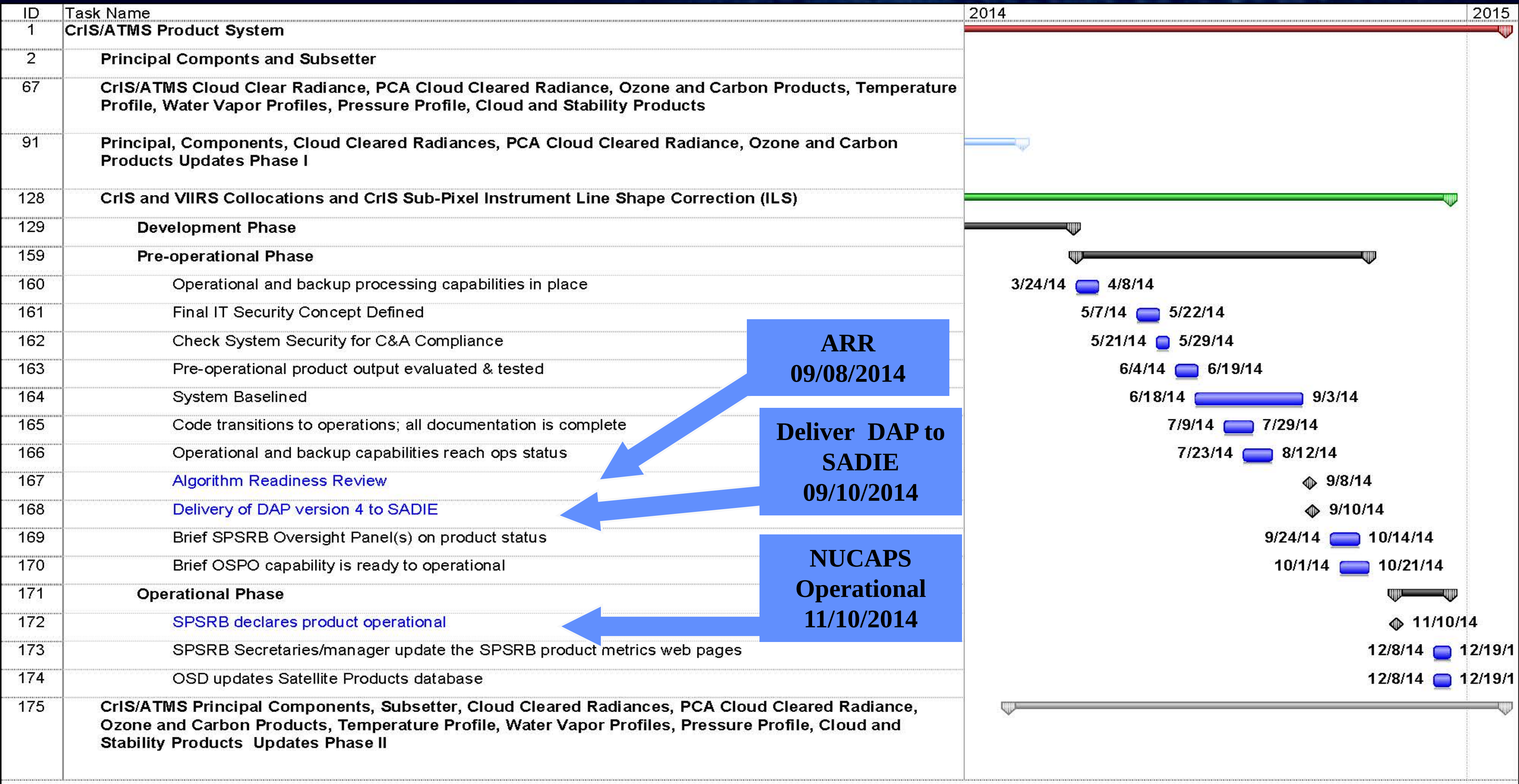


ID	Task Name	2012 2013 2014
1	CrIS/ATMS Product System	
2	Principal Componts and Subsetter	
67	CrIS/ATMS Cloud Clear Radiance, PCA Cloud Cleared Radiance, Ozone and Carbon Products, Temperature Profile, Water Vapor Profiles, Pressure Profile, Cloud and Stability Products	
91	Principal, Components, Cloud Cleared Radiances, PCA Cloud Cleared Radiance, Ozone and Carbon Products Updates Phase I	
128	CrIS and VIIRS Collocations and CrIS Sub-Pixel Instrument Line Shape Correction (ILS)	
129	Development Phase	
130	CrIS/ATMS Product System: CrIS and VIIRS Collocations	
131	IPT Branch Lead informed to begin product development	6/4/12
132	Algorithm Estimation	6/4/12 11/6/12
133	Initial Archive Requirements identified	6/4/12 6/29/12
134	Quality Monitoring Concept Defined	6/4/12 6/29/12
135	Long-term Maintenance Concept Defined	6/4/12 6/29/12
136	Initial Information Security (IT) concept defined	7/4/12 7/31/12
137	Preliminary CrIS and VIIRS Collocation Development	7/4/12 7/31/12
138	Development, Operational and backup processing system defined	8/8/12 8/21/12
139	CrIS and VIIRS Collocation Development	12/10/12 1/11/13
140	Start modifications to retrieval package to read VIIRS data collocated to CrIS	1/14/13 4/26/13
141	Retrieval package est case processed	5/6/13 5/31/13
142	CrIS and VIIRS Collocation Development refinements	6/10/13 6/28/13
143	Collocation test case processed	10/7/13 10/30/13
144	Code is prepared for implementation	12/9/13 2/28/14
145	Archive process updated	3/3/14 3/21/14
146	CrIS Sub-Pixel Instrument Line Shape Correction (ILS)	
147	IPT Branch Lead informed to begin product development	6/3/13
148	Algorithm Evaluation	6/3/13 11/7/13
149	Initial Archive Requirements identified	6/3/13 6/28/13
150	Quality Monitoring Concept Defined	6/3/13 6/28/13
151	Long-term Maintenance Concept Defined	6/3/13 6/28/13
152	Initial Information Security (IT) concept defined	7/1/13 7/31/13
153	CrIS Sub-Pixel ILS Correction Development	7/1/13 7/26/13
154	Development, Operational and backup processing system defined	7/29/13 8/23/13
155	Test case processed	8/26/13 10/25/13
156	Critical Design Review	12/2/13
157	Code is prepared for implementation	12/9/13 2/28/14
158	Archive process updated	3/3/14 3/21/14
159	Pre-operational Phase	
171	Operational Phase	
175	CrIS/ATMS Principal Components, Subsetter, Cloud Cleared Radiances, PCA Cloud Cleared Radiance, Ozone and Carbon Products, Temperature Profile, Water Vapor Profiles, Pressure Profile, Cloud and Stability Products Updates Phase II	

NUCAPS Collocation and ILS

Design Review 12/02/2013

NUCAPS Project Timeline



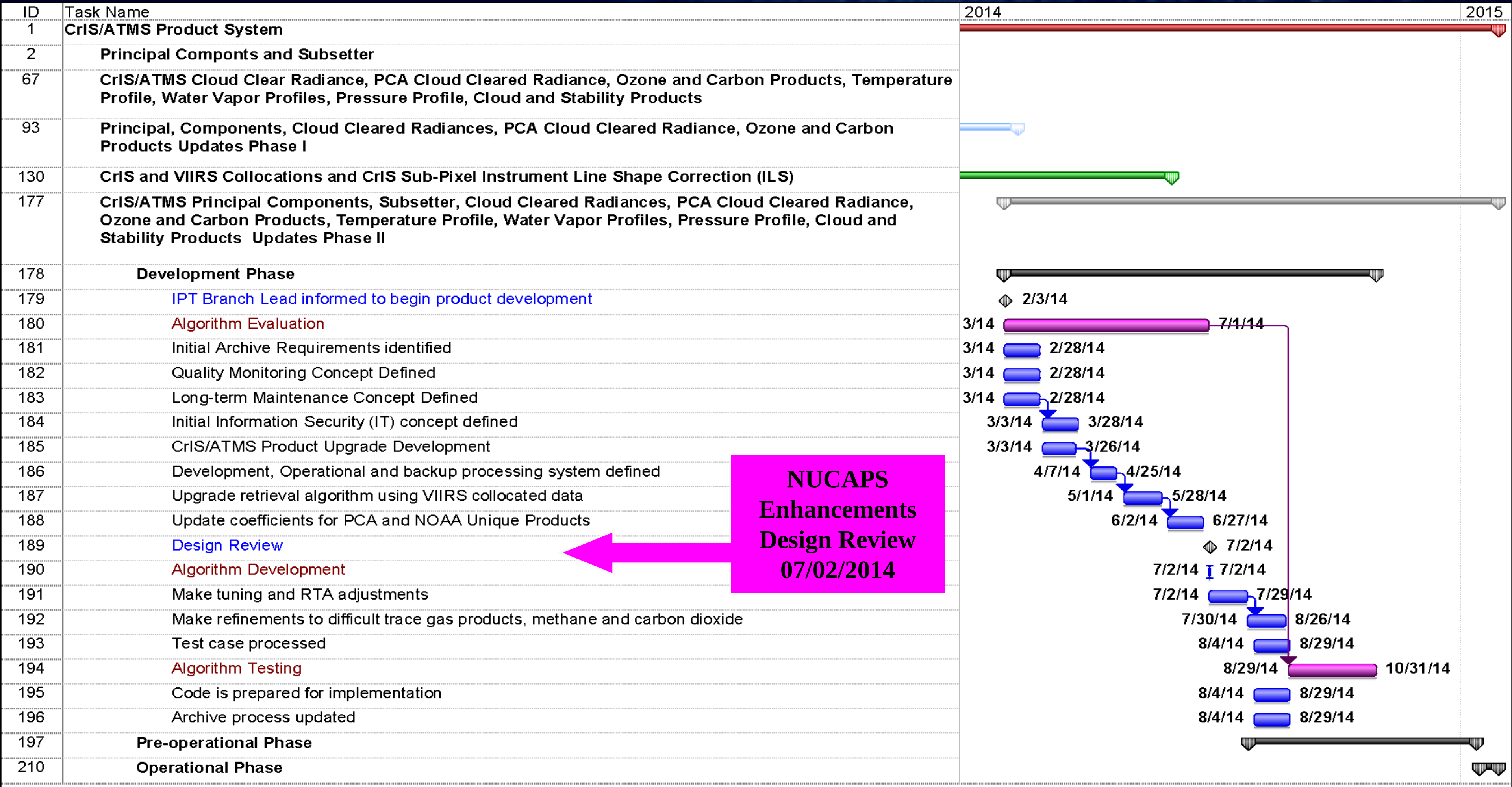
ID	Task Name	2014	2015
1	**CrIS/ATMS Product System**		
2	**Principal Componts and Subsetter**		
67	**CrIS/ATMS Cloud Clear Radiance, PCA Cloud Cleared Radiance, Ozone and Carbon Products, Temperature Profile, Water Vapor Profiles, Pressure Profile, Cloud and Stability Products**		
91	**Principal, Components, Cloud Cleared Radiances, PCA Cloud Cleared Radiance, Ozone and Carbon Products Updates Phase I**		
128	**CrIS and VIIRS Collocations and CrIS Sub-Pixel Instrument Line Shape Correction (ILS)**		
129	**Development Phase**		
159	**Pre-operational Phase**		
160	Operational and backup processing capabilities in place	3/24/14 4/8/14	
161	Final IT Security Concept Defined	5/7/14 5/22/14	
162	Check System Security for C&A Compliance	5/21/14 5/29/14	
163	Pre-operational product output evaluated & tested	6/4/14 6/19/14	
164	System Baselined	6/18/14 9/3/14	
165	Code transitions to operations; all documentation is complete	7/9/14 7/29/14	
166	Operational and backup capabilities reach ops status	7/23/14 8/12/14	
167	Algorithm Readiness Review	9/8/14	
168	Delivery of DAP version 4 to SADIE	9/10/14	
169	Brief SPSRB Oversight Panel(s) on product status	9/24/14 10/14/14	
170	Brief OSPO capability is ready to operational	10/1/14 10/21/14	
171	**Operational Phase**		
172	SPSRB declares product operational	11/10/14	
173	SPSRB Secretaries/manager update the SPSRB product metrics web pages	12/8/14 12/19/1	
174	OSD updates Satellite Products database	12/8/14 12/19/1	
175	**CrIS/ATMS Principal Components, Subsetter, Cloud Cleared Radiances, PCA Cloud Cleared Radiance, Ozone and Carbon Products, Temperature Profile, Water Vapor Profiles, Pressure Profile, Cloud and Stability Products Updates Phase II**		

ARR
09/08/2014

Deliver DAP to SADIE
09/10/2014

NUCAPS Operational
11/10/2014

NUCAPS Project Timeline



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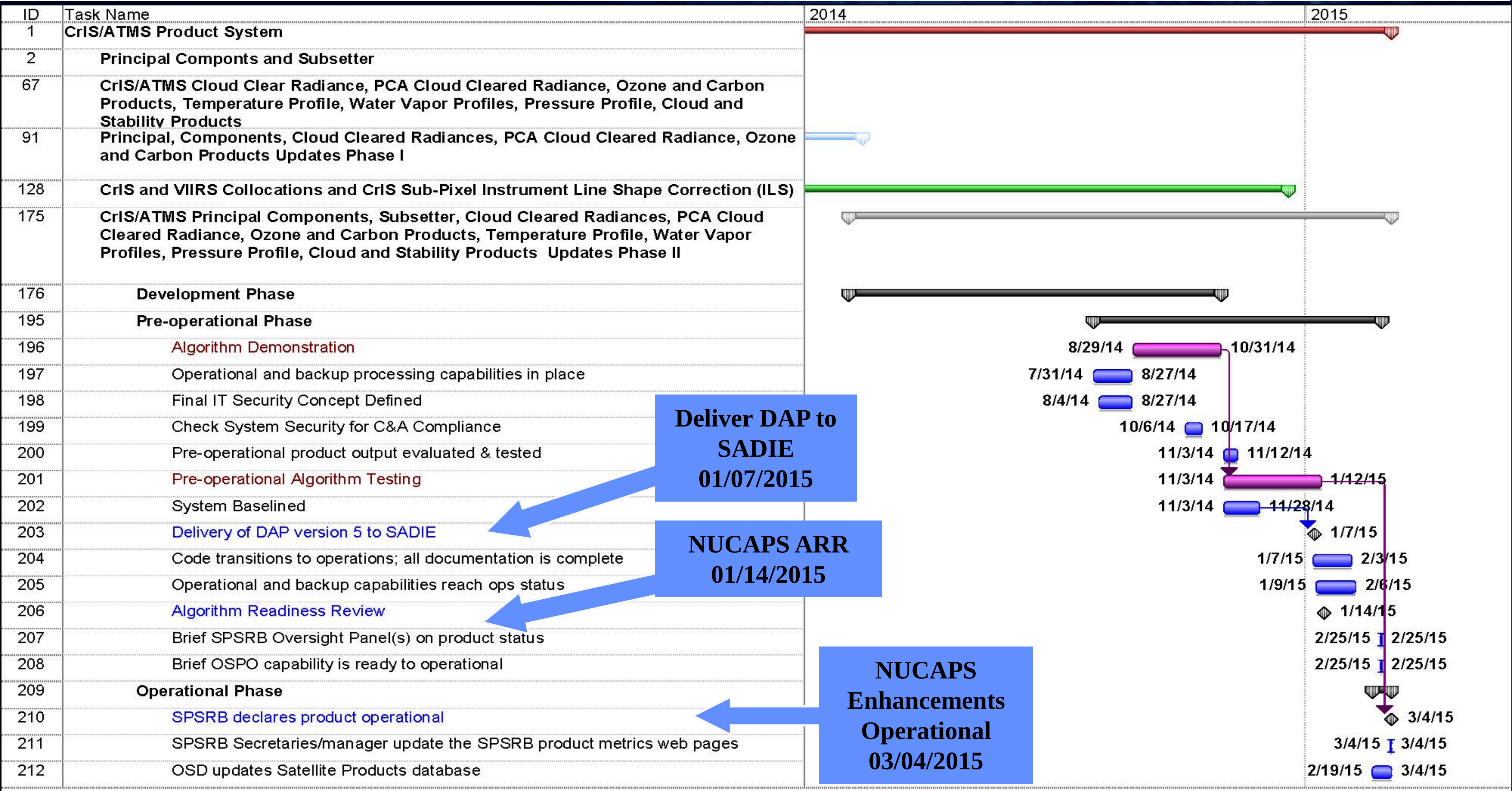
177	**CrIS/ATMS Principal Components, Subsetter, Cloud Cleared Radiances, PCA Cloud Cleared Radiance, Ozone and Carbon Products, Temperature Profile, Water Vapor Profiles, Pressure Profile, Cloud and Stability Products Updates Phase II**
178	**Development Phase**
179	IPT Branch Lead informed to begin product development
180	Algorithm Evaluation
181	Initial Archive Requirements identified
182	Quality Monitoring Concept Defined
183	Long-term Maintenance Concept Defined
184	Initial Information Security (IT) concept defined
185	CrIS/ATMS Product Upgrade Development
186	Development, Operational and backup processing system defined
187	Upgrade retrieval algorithm using VIIRS collocated data
188	Update coefficients for PCA and NOAA Unique Products
189	Design Review
190	Algorithm Development
191	Make tuning and RTA adjustments
192	Make refinements to difficult trace gas products, methane and carbon dioxide
193	Test case processed
194	Algorithm Testing
195	Code is prepared for implementation
196	Archive process updated
197	**Pre-operational Phase**
210	**Operational Phase**

NUCAPS Enhancements Design Review 07/02/2014

NUCAPS Project Timeline



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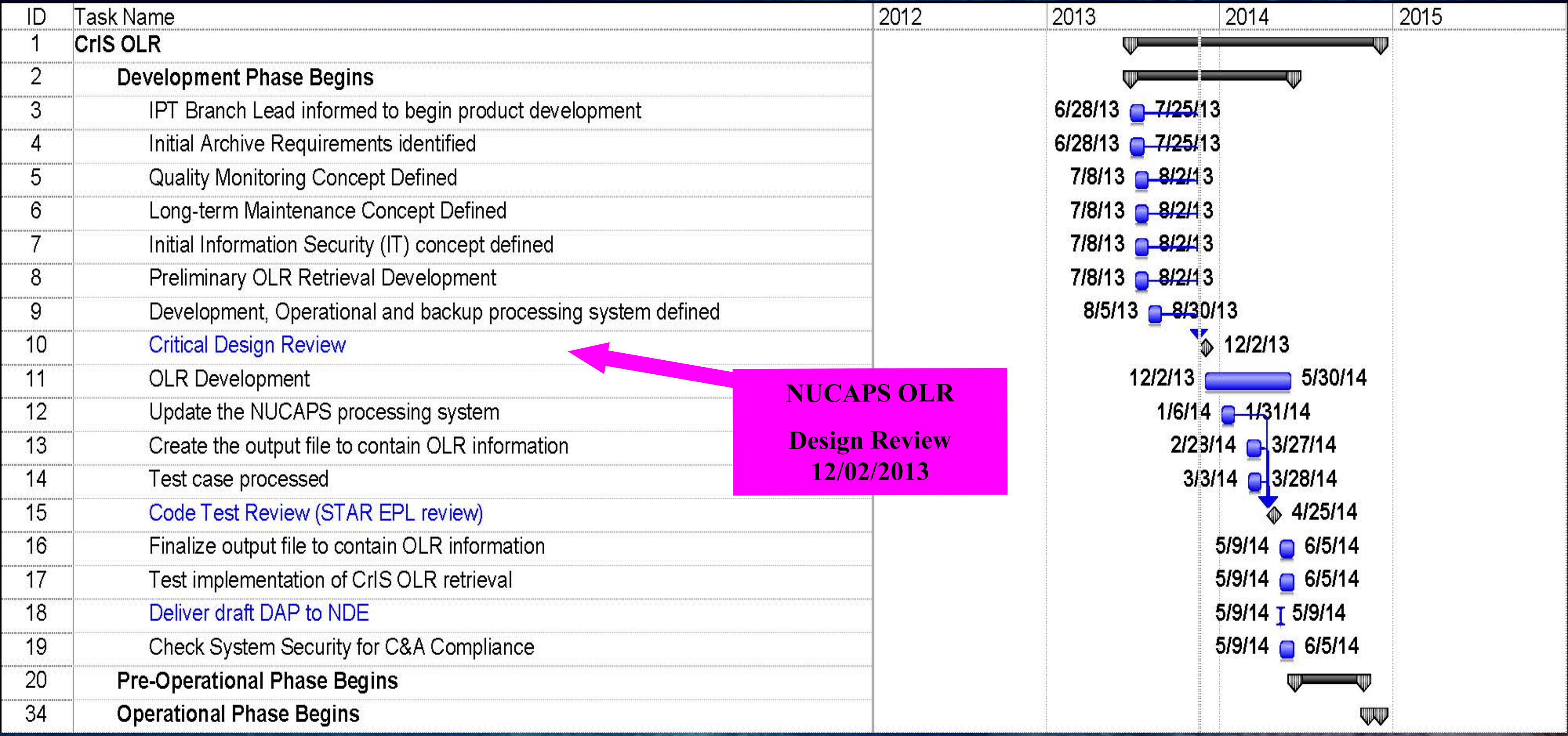
176	Development Phase
195	Pre-operational Phase
196	Algorithm Demonstration
197	Operational and backup processing capabilities in place
198	Final IT Security Concept Defined
199	Check System Security for C&A Compliance
200	Pre-operational product output evaluated & tested
201	Pre-operational Algorithm Testing
202	System Baselined
203	Delivery of DAP version 5 to SADIE
204	Code transitions to operations; all documentation is complete
205	Operational and backup capabilities reach ops status
206	Algorithm Readiness Review
207	Brief SPSRB Oversight Panel(s) on product status
208	Brief OSPO capability is ready to operational
209	Operational Phase
210	SPSRB declares product operational
211	SPSRB Secretaries/manager update the SPSRB product metrics web pages
212	OSD updates Satellite Products database

Deliver DAP to SADIE 01/07/2015

NUCAPS ARR 01/14/2015

NUCAPS Enhancements Operational 03/04/2015

OLR Project Timeline

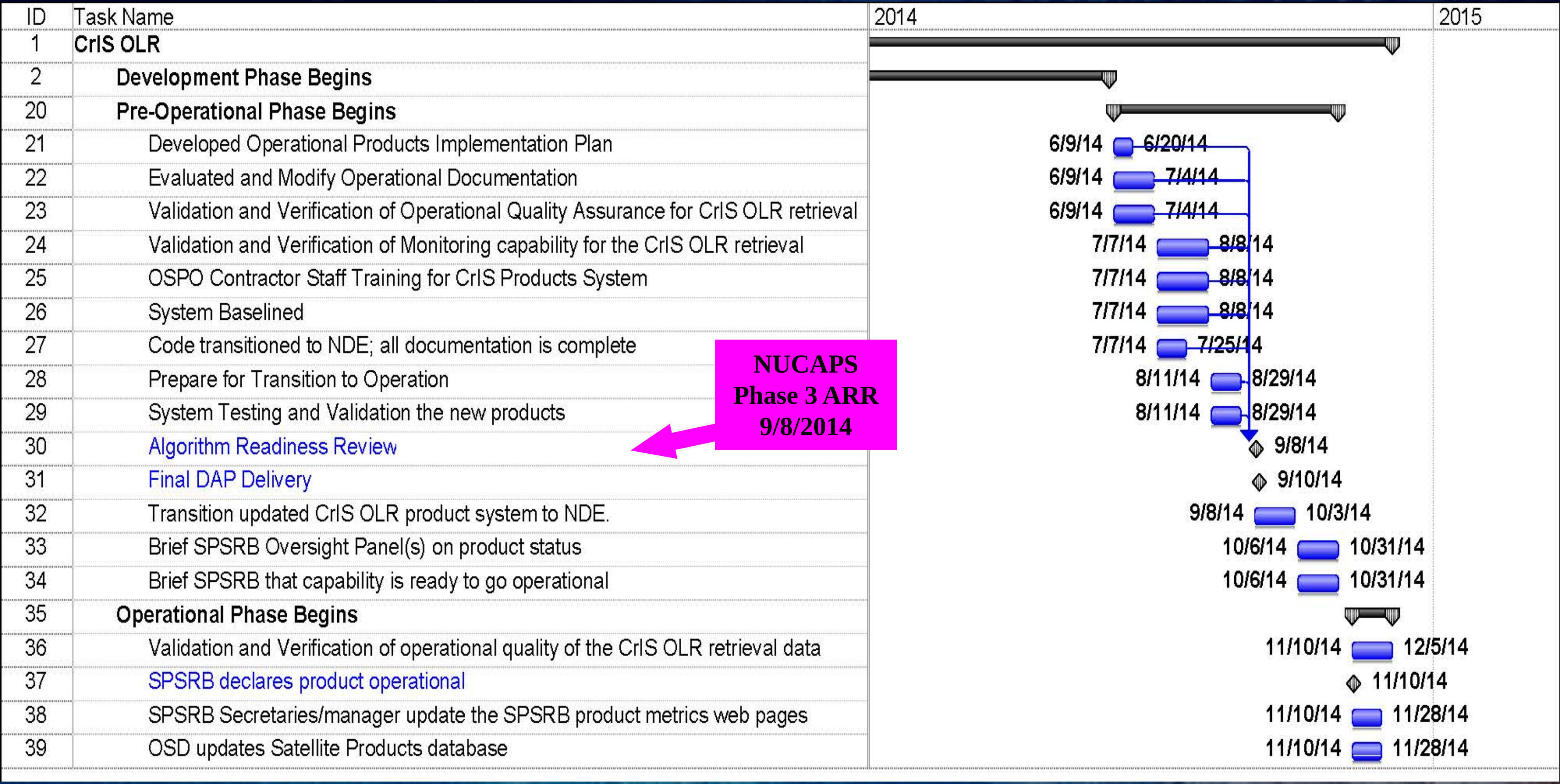


ID	Task Name	2012	2013	2014	2015
1	**CrIS OLR**				
2	**Development Phase Begins**				
3	IPT Branch Lead informed to begin product development		6/28/13 7/25/13		
4	Initial Archive Requirements identified		6/28/13 7/25/13		
5	Quality Monitoring Concept Defined		7/8/13 8/2/13		
6	Long-term Maintenance Concept Defined		7/8/13 8/2/13		
7	Initial Information Security (IT) concept defined		7/8/13 8/2/13		
8	Preliminary OLR Retrieval Development		7/8/13 8/2/13		
9	Development, Operational and backup processing system defined		8/5/13 8/30/13		
10	Critical Design Review			12/2/13	
11	OLR Development		12/2/13	5/30/14	
12	Update the NUCAPS processing system		1/6/14	1/31/14	
13	Create the output file to contain OLR information		2/23/14	3/27/14	
14	Test case processed		3/3/14	3/28/14	
15	Code Test Review (STAR EPL review)			4/25/14	
16	Finalize output file to contain OLR information			5/9/14 6/5/14	
17	Test implementation of CrIS OLR retrieval			5/9/14 6/5/14	
18	Deliver draft DAP to NDE			5/9/14 5/9/14	
19	Check System Security for C&A Compliance			5/9/14 6/5/14	
20	**Pre-Operational Phase Begins**				
34	**Operational Phase Begins**				

NUCAPS OLR

Design Review 12/02/2013

OLR Project Timeline



ID	Task Name	2014	2015
1	**CrIS OLR**		
2	**Development Phase Begins**		
20	**Pre-Operational Phase Begins**		
21	Developed Operational Products Implementation Plan	6/9/14 6/20/14	
22	Evaluated and Modify Operational Documentation	6/9/14 7/4/14	
23	Validation and Verification of Operational Quality Assurance for CrIS OLR retrieval	6/9/14 7/4/14	
24	Validation and Verification of Monitoring capability for the CrIS OLR retrieval	7/7/14 8/8/14	
25	OSPO Contractor Staff Training for CrIS Products System	7/7/14 8/8/14	
26	System Baselined	7/7/14 8/8/14	
27	Code transitioned to NDE; all documentation is complete	7/7/14 7/25/14	
28	Prepare for Transition to Operation	8/11/14 8/29/14	
29	System Testing and Validation the new products	8/11/14 8/29/14	
30	Algorithm Readiness Review	9/8/14	
31	Final DAP Delivery	9/10/14	
32	Transition updated CrIS OLR product system to NDE.	9/8/14 10/3/14	
33	Brief SPSRB Oversight Panel(s) on product status	10/6/14 10/31/14	
34	Brief SPSRB that capability is ready to go operational	10/6/14 10/31/14	
35	**Operational Phase Begins**		
36	Validation and Verification of operational quality of the CrIS OLR retrieval data	11/10/14 12/5/14	
37	SPSRB declares product operational	11/10/14	
38	SPSRB Secretaries/manager update the SPSRB product metrics web pages	11/10/14 11/28/14	
39	OSD updates Satellite Products database	11/10/14 11/28/14	

NUCAPS Phase 3 ARR 9/8/2014

NUCAPS Phase 3 CDR Entry Criteria

- Phase 2 ARR Report (Review Item Disposition)
  - » PDR Risks and Actions
  - » CDR Risks and Actions
  - » TRR Risks and Actions
  - » Phase 1 ARR Risks and Actions
  - » Phase 2 ARR Risks and Actions

- Updated Phase 2 Algorithm Readiness Document

- Updated Requirements Allocation Document

NUCAPS Phase 3 CDR Entry Criteria

- Phase 3 Critical Design Review Document containing:
    - Project schedule
    - Requirements
    - Algorithm description
        - Background
        - Theoretical basis of chosen algorithm
        - Validation and verification plans
    - QA plans
    - Software Architecture
    - Risks and actions

NUCAPS Phase 3 CDR
Exit Criteria

- Updated Phase 3 RID
- Updated Phase 3 CDR presentation package
- Updated Phase 3 RAD

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Section 2 –
Phase 2 ARR Report

Presented by

Tom King

Phase 2 ARR Report

- The NUCAPS Phase Review Item Disposition (RID) spreadsheet (Shared on Google Docs)

- The RID covers the following:
  - Open PDR Risks and Actions at CDR
  - Open CDR Risks and Actions
  - Open TRR Risks and Actions
  - Phase 1 AAR Risks and Actions
  - Phase 2 AAR Risks and Actions

- Risks closed in previous reviews are not shown here, but are located in the RID.

- Risks shown here that are marked as “closed” will be closed with the approval of this review.

PDR Risks and Actions

- **Risk #9:** Project metadata do not meet user requirements
- **Risk Assessment:** Medium
  - » Granule-level metadata have been created, but still needs to be reviewed by CLASS. That effort and the SA development haven't moved forward because of a lack of funding on the CLASS side. CLASS wants to begin archiving NUPs in Spring 2013. However, NUCAPS EDR capability needs to be delivered now for AWIPS to receive EDRs in January 2013. Therefore, CLASS will receive the EDRs and metadata in Spring 2013, but if they don't approve of the metadata, they will have to wait for the next NUCAPS DAP (version 3 to be delivered 09/25/2013) for any modifications.
- **Impact:** Medium
- **Likelihood:** Medium
- **Risk Mitigation:**
  - » Work with CLASS on the SA and making metadata available to them for approval.
  - » Work with Jay Morris at CLASS via the STAR CSWG to update and formalize the metadata methodology.
- **Status:** Closed

CDR Risks and Actions

- **Risk #30:** The current CrIS instrument's spectral resolution in the short-wave band is too low for retrieval of carbon monoxide within requirements.
- **Risk Assessment:** Low
  - New risk at CDR. The NPP CrIS will not be able to maintain continuity on this product.
  - Even though the likelihood is high, we’ve assessed this issue as low because our one user (AWIPS) has not requested CO.
- **Impact:** Low
- **Likelihood:** High
- **Risk Mitigation:**
  - JPSS Project Office has been investigating bringing down full resolution data in the CrIS RDR, but there is not yet a plan to put it into the SDR.
  - NUCAPS science development team will continue to work with the Project Office to have these data available in the SDR.
- **Status:** Open

TRR Risks and Actions

- **Risk #38:** NDE may have to deliver the system to operations without the completed documentation. SPSRB may or may not find this acceptable.
- **Risk Assessment:** High
  - New risk added after TRR. This was a risk for the BUFR toolkit, but it also applies to this project as well.
- **Impact:** High
- **Likelihood:** Medium
- **Risk Mitigation:**
  - NDE will work with STAR and OSPO PALs to complete the required sections of the SPSRB documents.
- **Status:** Closed

ARR Phase 1 Risks and Actions

- **Risk #39:** The review team would like to have a Software Code Review prior to operational implementation.
- **Risk Assessment:** Low
  - » The code was prepared and delivered to OSPO in June 2012, but OSPO could not review it because they had not received funding to make NPP operational. This is still true as of today.
- **Impact:** Low
- **Likelihood:** Low
- **Risk Mitigation:**
  - » After IASI code review, we cleaned up NUCAPS code on our side so it would meet operational requirements.
  - » We could do an SCR after delivery to NDE, once OSPO gets funding. Then, do a delta delivery.
- **Status:** Closed (SCR held on 2/20/2013)

ARR Phase 2 Risks and Actions

- **Risk #40:** NUCAPS ATBD is not finished.
- **Risk Assessment:** Low
  - The risk should be low given that an ATBD does exist for AIRS and IASI, but it is not in a document following the SPSRB ATBD template.
- **Impact:** Low
- **Likelihood:** Low
- **Risk Mitigation:**
  - Complete the ATBD
- Status: Closed

ARR Phase 2 Risks and Actions

- **Risk #41:** NUCAPS EDR and CCR files will initially fail to be archived because CLASS does not currently have funding.
- **Risk Assessment:** High
  - » NUCAPS EDR and CCR files will initially fail to be archived because CLASS does not currently have funding.
- **Impact:** High
- **Likelihood:** High
- **Risk Mitigation:**
  - » Expedite work on the Submission Agreement as soon as CLASS has its funding to minimize the amount of data lost to the archive.
- **Status:** Closed

ARR Phase 2 Risks and Actions

- **Risk #42:** PAL and his team need to complete assigned sections of the SPSRB documents as they are already funded to do so.
- **Risk Assessment:** Low
  - » OSPO will not have completed documentation at the time of operational implementation.
- **Impact:** Low
- **Likelihood:** Low
- **Risk Mitigation:**
  - » NUCAPS team will deliver the DAP or at least the document part to OSPO so they can finish their sections.
- **Status:** Closed

ARR Phase 2 Risks and Actions

- **Risk #43:** PAL needs to identify the trace gas community users.
- **Risk Assessment:** Low
  - » This needs to be done prior to the operational briefing of the SPSRB to ensure operational approval for the project.
- **Impact:** Low
- **Likelihood:** Low
- **Risk Mitigation:**
  - » AK Sharma will work with Donna McNamara and others to identify who the trace gas users are for NUCAPS.
- **Status:** Open

ARR Phase 2 Review Report

- 8 Risks Total
  - » 1 PDR Risk
  - » 1 CDR (Phase 1) Risks
  - » 1 TRR Risks
  - » 1 ARR Phase 1
  - » 4 ARR Phase 2

- 6 risks can be closed

- 2 risks remain open
  - » 1 ARR Phase 1
  - » 1 CDR

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- Quality Assurance
- Risk Summary
- Summary and Conclusions

Section 3 –
Phase 3 Requirements

Presented by

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Requirements

- This section is broken into 2 parts
  - NUCAPS Phases 1-3
  - NUCAPS OLR requirements
- All requirements for Phases 1-3 are presented in this section, but we'll only cover new or updated requirements since Phase 2 ARR.
  - Note that VIIRS collocation requirements were originally present at Phase 1 of this project.
  - OLR requirements were made available to the review team on 9/30/2013 so these will not be covered in detail.
- The following color coding is used:
  - Yellow - Basic requirements
  - Green - New or updated requirements since Phase 2 ARR
  - Gray - Removed requirements
- The revised Requirements Allocation Documents (RAD) are available (Shared on Google Docs)

NUCAPS Requirements – Basic Requirement 0.0

- **Requirement 0.0:** *The NUCAPS project shall adopt the standard practices of the STAR Enterprise Product Lifecycle (EPL), as established in the STAR EPL process assets v2.0, except as specified in requirement 0.1* (process)

- **Requirement 0.1:** The checklist items for the NUCAPS reviews shall be tailored. The tailored checklist items shall be established in the NUCAPS project file “NUCAPS Review Checklists v1r0.xls”. (process).

- **Requirement 0.1.1:** The NUCAPS project file “NUCAPS Review Checklists v1r0.xls” shall be established and maintained under CM in the NUCAPS project artifact repository. (process)

- **Requirement 0.1.2:** The review artifacts specified in the file "NUCAPS Review Checklists v1r0.xls" shall be available to reviewers in advance of each review. (process)

NUCAPS Requirements – Basic Requirement 1.0

- **Requirement 1.0**: *The NUCAPS shall generate CrIS thinned radiance products for NWP center users.* (product, functional)

- **Requirement 1.1**: *For NCEP, NUCAPS shall generate CrIS full spatial resolution granule files containing 399 CrIS channels.* (system, functional)

- **Requirement 1.1.1**: *The CrIS radiances for shall be apodized.* (product)

- **Requirement 1.1.1.1**: *The type of apodization shall be specified in the delivered system documentation.* (delivery, product)

- **Requirement 1.1.2**: *The NUCAPS shall develop the BUFR table for the CrIS radiances.* (system, functional)

- **Requirement 1.1.2.1**: *The CrIS radiance data for shall be represented as scaled radiances in the BUFR (instead of brightness temperatures).* (system, functional)

NUCAPS Requirements – Basic Requirement 1.0

- **Requirement 1.1.2.1.1**: *The BUFR radiance scaling shall allow for the storage of negative radiances.* (product)
- **Requirement 1.1.2.2**: *The radiance data shall be represented by 16 bit words in the BUFR format.* (system, functional)
- **Requirement 1.1.2.3**: *The NUCAPS shall supply the NDE System Development Team (SDT) with BUFR table as well as the frequency list.* (product, operational)
- **Requirement 1.1.2.4**: *The BUFR table shall contain a table 8 descriptor to allow users to differentiate between (a) CrIS radiances, (b) CrIS cloud-cleared radiances, and (c) CrIS principal component reconstructed radiances.* (product)
- **Requirement 1.1.2.5**: *The BUFR table shall use delayed replication for writing subsets of channels.* (product)
- **Requirement 1.1.2.6**: *The BUFR must contain the VIIRS derived cloud fraction and cloud height.* (performance)
- **Requirement 1.1.2.6.1**: *The VIIRS fields of view must be collocated to those of CrIS.* (performance)

NUCAPS Requirements – Basic Requirement 1.0

- **Requirement 1.1.2.7:** *The BUFR table shall contain the following variables. Variables with parentheses indicate dimensionality.* (product)

Satellite ID
ID of originating center
Satellite instrument
Satellite classification
Year
Month
Day
Hour
Minute
Second
Subsattellite Latitude
Subsattellite Longitude
Latitude
Longitude
Satellite Height
Satellite Zenith
Satellite Azimuth
Solar Zenith
Solar Azimuth

Orbit Number
Granule Number
Scan Line
CrIS FOR
CrIS FOV
Land Fraction
Land-Sea-Coast-Flag
Cloud Fraction
Cloud Height
CrIS Channels(1305)
CrIS Radiances(1305)
CrIS Quality Flag 1
CrIS Quality Flag 2(3)
CrIS Quality Flag 3(3)
CrIS Quality Flag 4(3)
CrIS Quality Flag 5
CrIS Quality Flag 6

NUCAPS Requirements – Basic Requirement 1.0

- **Requirement 1.1.3**: *The product for shall be available within three hours of observation.* (performance)

- **Requirement 1.1.4**: *The NUCAPS shall write CrIS radiance data for NCEP into netCDF4 format so they can be reformatted downstream into BUFR by the N4RT toolkit. Therefore, the contents of the BUFR table defined in section 1.1.2 are, at least, a subset of the netCDF4 output files.* (system, functional)

- **Requirement 1.1.4.1:** *The contents of the BUFR table defined in Requirement 1.1.2 are, at least, a subset of the netCDF4 output files. (system functional)*

- **Requirement 1.5:** *For EUMETSAT, NUCAPS shall generate CrIS full spatial resolution granule files containing all CrIS FOVs and FORs for all 1305 channels. All the other derived requirements for the NCEP product in section 1.1 also apply to this requirement.*

NUCAPS Requirements – Basic Requirement 1.0

- **Requirement 1.2 - Removed**: *For NRL and FNMOC, NUCAPS shall generate CrIS spatially thinned radiance granule files containing the warmest CrIS FOV per FOR for approximately 399 channels.* (system, functional)

  REMOVED: NRL and FNMOC will use the CrIS full channel set from the AirForce (email from Ben Ruston 5/19/2011)

- **Requirement 1.2.1 - Removed**: *The NUCAPS shall write CrIS thinned radiances for NRL and FNMOC into netCDF4 format so the NDE tailoring can convert it into BUFR format.* (system, functional)

- **Requirement 1.2.1.1 - Removed**: *In addition to the variables listed in 1.1.2.7, the BUFR table shall include "ascending and descending flag" variable.* (product)

- **Requirement 1.3:** *For GMAO, NUCAPS shall generate full spatial resolution CrIS radiance granule files for approximately 399 channels.* (system, functional)

- **Requirement 1.3.1:** *The NUCAPS shall write CrIS thinned radiances for GMAO into netCDF4 format so the NDE tailoring tool can convert it into_BUFR format.* (system, functional)

NUCAPS Requirements – Basic Requirement 2.0

- **Requirement 1.4**: *The NUCAPS Integrated Product Team (IPT) shall perform validation and verification of CrIS thinned radiances.* (system, operational)

- **Requirement 1.4.1**: *The NUCAPS IPT shall verify that the thinned radiances in the output netCDF4 files are generated correctly and document this in the Validation and Verification Report (VVR).* (system, operational)

NUCAPS Requirements – Basic Requirement 2.0

- **Basic Requirement 2.0 - Removed**: *The NUCAPS shall generate granule files of Principal Components for NRL and FNMOC.* (product, functional)

  NRL and FNMOC will use the full 1305 channel set from the AirForce (email from Ben Ruston 5/19/2011)

- **Requirement 2.1 - Removed**: *The NUCAPS shall generate the eigenvector files that are needed to generate the principal components.* (product, functional)

- **Requirement 2.1.1 - Removed**: *The NUCAPS shall generate the global coverage input datasets used for generating eigenvector files.* (product, functional)

- **Requirement 2.1.2 - Removed**: *The NUCAPS shall supply NDE with the eigenvector files, to give to the customer, during delivery of the DAP.* (product, operational)

NUCAPS Requirements – Basic Requirement 2.0

- **Requirement 2.2 - Removed:** *The NUCAPS shall generate the Principal Component granule files for NRL and FNMOC from the CrIS warmest FOV per FOR.* (product, functional)

- **Requirement 2.2.1 - Removed:** *The NUCAPS shall write principal components into NetCDF4 format.* (system, functional)

- **Requirement 2.2.1 - Removed:** *The NUCAPS shall write principal components into NetCDF4 format.* (system, functional)

- **Requirement 2.2.2 - Removed:** *The NUCAPS IPT shall perform validation and verification of principal components products for NRL and FNMOC.* (system, functional)

- **Requirement 2.2.2.1 - Removed:** *The NUCAPS IPT shall verify that the principal components are being generated correctly and document these results in the VVR.* (system, operational)

NUCAPS Requirements – Basic Requirement 2.0

- **Requirement 2.3 - Removed:** *The NUCAPS shall generate the Principal Component granule files for NRL and FNMOC meeting the following temporal specifications.* (product, functional)

- **Requirement 2.4 - Removed**: *The NUCAPS shall generate the Principal Component files meeting the following spatial specifications:*

  Global coverage.

  Horizontal resolution of ≈50 km (Set of 9 CrIS FOV's collocated with ATMS FOR).

- **Requirement 2.5 - Removed**: *The NUCAPS shall generate approximately 85 principal components from the original 1305 CrIS channel set.*

NUCAPS Requirements – Basic Requirement 3.0

- **Basic Requirement 3.0:** *The NUCAPS shall generate trace gas profile products for U.S users.* (product, functional)

- **Requirement 3.1:** *The NUCAPS shall generate profiles of following trace gases for NRL and FNMOC, derived from a retrieval of CrIS/ATMS radiances:* (product, functional)

  Ozone
  Carbon Monoxide
  Carbon Dioxide
  Methane
  Volcanic Sulfur Dioxide Product
  Nitric Acid
  Nitrous Oxide

NUCAPS Requirements – Basic Requirement 3.0

- **Requirement 3.1.1**: *The NUCAPS trace gas profiles for NRL and FNMOC shall consist of at 100 levels.* (product, functional)

- **Requirement 3.1.2**: *The NUCAPS trace gas profiles for NRL and FNMOC shall meet performance specifications*. (product, functional)

- **Requirement 3.1.2.1**: *Trace gas profiles for FNMOC and NRL shall have the following accuracy*

  O3: 20%/5-km near tropopause
  O3: 10% total column
  CO: 40% mid-trop column (w/ 0.2 cm OPD SW band)
  CH4: 1% mid-trop column
  CO2: 1% mid-trop column
  HNO3: 50% mid-trop column. (product, performance)

- **Requirement 3.1.2.2**: *Trace gas profiles for FNMOC and NRL shall meet the following temporal specifications:*

  Timeliness of less than 3 hours after observation.
  Latency of no more the 15 minutes after granule data are available.

NUCAPS Requirements – Basic Requirement 3.0

- **Requirement 3.1.2.3**: *Trace gas profiles for FNMOC and NRL shall meet the following spatial specifications:*
    - *Global coverage.*
    - *Horizontal resolution of* ≈50 km (Set of 9 CrIS FOV's collocated with ATMS FOR).
- **Requirement 3.1.2.4**: *Trace gas profiles for FNMOC and NRL shall include the vertical weighting functions.*
- **Requirement 3.1.3**: *The NUCAPS shall produce the trace gas products in netCDF4 format for NRL and FNMOC.* (system, functional)
- **Requirement 3.2:** *The NUCAPS shall generate trace gas profile products for CLASS derived from CrIS/ATMS radiances.* (system, functional)
- **Requirement 3.2.1:** *The NUCAPS shall write the trace gas profile products for CLASS in netCDF4 format.* (system, functional)

NUCAPS Requirements – Basic Requirement 3.0

- **Requirement 3.2.2:** *The EDR product for CLASS shall contain the following trace gas profiles and surface and cloud properties calculated on each CrIS FOR:*

Time
Latitude
Longitude
View Angle
Satellite Height
Mean CO2
Solar Zenith
Ascending/Descending Status
Topography
Land-Sea-Coast Flag
Surface Pressure
Skin Temperature
MIT Skin Temperature
First Guess Skin Temperature
Microwave Surface Class
Microwave Surface Emissivity
Number of Cloud Layers
Retrieval Quality Flag

Cloud Top Pressure
Cloud Top Fraction
Pressure (at 100 levels)
Effective Pressure (at 100 levels)
Temperature (at 100 levels)
MIT Temperature (at 100 levels)
First Guess Temperature (at 100 levels)
H2O layer column density (at 100 levels)
H2O mixing ratio (at 100 levels)
First Guess H2O layer column density (at 100 levels)
First Guess H2O mixing ratio (at 100 levels)
MIT H2O layer column density (at 100 levels)
MIT H2O mixing ratio (at 100 levels)
O3 layer column density (at 100 levels)
O3 mixing ratio (at 100 levels)
First Guess O3 layer column density (at 100 levels)
First Guess O3 mixing ratio (at 100 levels)
Liquid H2O layer column density (at 100 levels)
Liquid H2O mixing ratio (at 100 levels)

NUCAPS Requirements – Basic Requirement 3.0

Ice/liquid flag (at 100 levels)
CH_4 layer column density (at 100 levels)
CH_4 mixing ratio (at 100 levels)
CO_2 mixing ratio (at 100 levels)
HNO_3 layer column density (at 100 levels)
HNO_3 mixing ratio (at 100 levels)
N_2O layer column density (at 100 levels)
N_2O mixing ratio (at 100 levels)
SO_2 layer column density (at 100 levels)
SO_2 mixing ratio (at 100 levels)
Microwave emissivity
MIT microwave emissivity
Infrared emissivity
MIT infrared emissivity
Infrared surface emissivity
First Guess infrared surface emissivity
Infrared surface reflectance
Atmospheric Stability
Cloud infrared emissivity
Cloud reflectivity

NUCAPS Requirements – Basic Requirement 3.0

- **Requirement 3.2.3**: *The NUCAPS shall generate granule-level ISO-compliant metadata for CLASS.* (product, quality)

- **Requirement 3.2.4**: *The NUCAPS IPT shall create a Submission Agreement (SA) with CLASS. The SA shall include all information regarding the archival of EDR product granule files.* (product, quality)

- **Requirement 3.3**: *The NUCAPS shall generate trace gas profiles for GMAO, derived from CrIS/ATMS radiances.* (system, functional)

- **Requirement 3.3.1**: *The NUCAPS trace gas profiles for GMAO shall meet performance specifications.* (system, functional)

NUCAPS Requirements – Basic Requirement 3.0

- **Requirement 3.3.1.1**: *Trace gas profiles for GMAO shall have the following accuracy*
  O3: 20%/5-km near tropopause
  O3: 10% total column
  CO: 40% mid-trop column (w/ 0.2 cm OPD SW band)
  CH4: 1% mid-trop column
  CO2: 1% mid-trop column
  HNO3: 50% mid-trop column. (product, performance)

- **Requirement 3.3.1.2**: *Trace gas profiles for GMAO shall meet the following temporal specifications:*
  Timeliness of less than 3 hours after observation.
  Latency of no more the 15 minutes after granule data are available.

- **Requirement 3.3.1.3**: *Trace gas profiles for GMAO shall meet the following spatial specifications:*
  Global coverage.
  *Horizontal resolution of ≈*50 km (Set of 9 CrIS FOV's collocated with ATMS FOR).

NUCAPS Requirements – Basic Requirement 3.0

- **Requirement 3.3.1.4**: *Trace gas profiles for GMAO shall include the vertical weighting functions.*
- **Requirement 3.4**: *The NUCAPS IPT shall perform tests to demonstrate that all trace gas profile products are being produced correctly and to user specification.* (system, operational)
- **Requirement 3.4.1**: *The results of the tests on the trace gas profile products shall be documented in the VVR.* (system, operational)
- **Requirement 3.5**: *The NUCAPS software shall perform a local angle correction to the CrIS radiances to generate retrievals.* (system, functional)
- **Requirement 3.6**: *The NUCAPS software will need to extract topography and land mask information from a Digital Elevation Model (DEM).* (system, functional)
- **Requirement 3.7**: *The NUCAPS software will need to resample the ATMS FOV to the resolution of the CrIS field of regard.*

NUCAPS Requirements – Basic Requirement 3.0

- **Requirement 3.8**: *The NUCAPS software will produce an SO_2 alert file if an SO_2 anomaly is detected by the retrieval preprocessing.*
- **Requirement 3.9:** *The NUCAPS software shall generate NOAA-Unique profiles for AWIPS derived from CrIS/ATMS radiances.*
- **Requirement 3.9.1:** *The NUCAPS shall write the retrieval products for AWIPS in netCDF4 format.*

NUCAPS Requirements – Basic Requirement 3.0

- **Requirement 3.9.2:** *The retrieval product for AWIPS shall contain the following variables.*

- *Note: This is a subset of the existing set of variables produced by the retrieval. It is our understanding that NDE will extract this subset of variables.*

CrIS FOR
Latitude
View Angle
Topography
Skin Temperature
Pressure (at 100 levels)
Temperature (Kelvin at 100 levels)
O3 (ppb at 100 levels)
Ice/Liquid Flag (at 100 levels)
Stability parameters

Time
Longitude
Ascending/Descending Status
Surface Pressure
Quality Flag
Effective Pressure (at 100 levels)
H2O (g/g at 100 levels)
Liquid H2O (g/g at 100 levels)
SO2 (g/g at 100 levels)

NUCAPS Requirements – Basic Requirement 4.0

- **Basic Requirement 4.0**: *The NUCAPS shall generate CrIS Cloud-clear Radiance (CCR) products for NWP centers and CLASS.* (product, operational)

- **Requirement 4.1**: *The NUCAPS shall generate CrIS CCR products for GMAO.* (system, operational)

- **Requirement 4.1.1**: *CCR products for GMAO shall have an accuracy of less then 1 Kelvin.* (system, functional)

- **Requirement 4.1.2**: *CCR products for GMAO shall meet the following temporal specifications. (system, functional):*

  Timeliness of less than 3 hours after observation.

  Latency of no more the 15 minutes after granule data are available.

NUCAPS Requirements – Basic Requirement 4.0

- **Requirement 4.1.3**: *CCR products for GMAO shall meet the following spatial specifications:*

  Global coverage.

  Horizontal resolution of ≈50 km (Set of 9 CrIS FOV's collocated with ATMS FOR).

- **Requirement 4.2**: *The NUCAPS shall generate CrIS CCR products for CLASS.* (system, operational)

- **Requirement 4.2.1**: *The NUCAPS shall write the CrIS CCR products for CLASS in netCDF4 format.* (system, functional)

- **Requirement 4.2.2**: *The product shall contain CrIS cloud-cleared radiances from all channels.* (product, quality)

- **Requirement 4.2.3**: *The NUCAPS shall generate for CLASS ISO-compliant granule-level metadata for the CCR product.* (product, quality)

NUCAPS Requirements – Basic Requirement 4.0

- **Requirement 4.2.4**: *The NUCAPS IPT shall create a Data Submission Agreement (DSA) with CLASS. The DSA shall include all information regarding the archival of CrIS CCR granule files.* (product, quality)

NUCAPS Requirements – Basic Requirement 5.0

- **Basic Requirement 5.0**: *The NUCAPS shall generate daily global products for system validation, maintenance, and development.* (product, operational)

- **Requirement 5.1**: *The NUCAPS shall generate matchup datasets between satellite measurements and other existing correlated instruments. These products are for STAR.* (system, operational)

- **Requirement 5.1.1**: *The NUCAPS shall generate daily matchups for CrIS and ATMS radiances.* (system, operational)

- **Requirement 5.1.1.1**: *The NUCAPS radiance matchups file shall be a direct access binary file.* (system, operational)

- **Requirement 5.1.1.1.1**: *The NUCAPS shall have code that can write radiance matchup files in direct access binary format.* (product, functional)

- **Requirement 5.1.1.2**: *The NUCAPS radiance matchups file shall be available one day after observation.* (system, operational)

NUCAPS Requirements – Basic Requirement 5.0

- **Requirement 5.1.2**: *The NUCAPS shall generate daily matchups for the CrIS/ATMS retrievals.* (system, operational)

- **Requirement 5.1.2.1**: *The NUCAPS daily matchups file shall be a direct access binary file.* (system, operational)

- **Requirement 5.1.2.1.1**: *The NUCAPS shall have code that can write the retrieval matchup files in direct access binary format.* (product, functional)

- **Requirement 5.1.2.2**: *The NUCAPS daily matchups file shall be available one day after observation.* (system, operational)

- **Requirement 5.2**: *The NUCAPS shall generate gridded products for STAR.* (system, operational)

- **Requirement 5.2.1**: *The NUCAPS shall generate daily Principal Component and reconstructed radiance gridded product files at 0.5X2.0 and 3.0X3.0 degree resolution for STAR.* (product, functional)

NUCAPS Requirements – Basic Requirement 5.0

- **Requirement 5.2.1.1**: *The NUCAPS principal component and reconstructed radiance gridded files shall be in direct access binary format.* (product, functional)
- **Requirement 5.2.1.1.1**: *The NUCAPS shall have code that can write principal component gridded files in direct access binary format.* (product, functional)
- **Requirement 5.2.1.2**: *The NUCAPS principal component and reconstructed radiance gridded files shall be available one day after observation.* (system, operational)
- **Requirement 5.2.1.3:** *The NUCAPS shall generate the eigenvector files that are needed to generate the principal components.*
- **Requirement 5.2.1.3.1:** *The NUCAPS shall generate the global coverage input datasets used for generating eigenvector files.*
- **Requirement 5.2.1.4:** *The NUCAPS shall generate the Principal Component files meeting the following spatial specifications:*

    Global coverage.

    Horizontal resolution of ≈50 km (Set of 9 CrIS FOV's collocated with ATMS FOR).

NUCAPS Requirements – Basic Requirement 5.0

- **Requirement 5.2.1.5:** *The NUCAPS shall generate approximately 85 principal components from the original 1305 CrIS channel set.*

- **Requirement 5.2.2**: *The NUCAPS shall generate daily CrIS/ATMS radiance gridded product files at 0.5X2.0 and 3.0X3.0 degree resolutions for STAR.* (product, functional)

- **Requirement 5.2.2.1**: *The NUCAPS CrIS/ATMS radiance gridded files shall be in direct access binary format.* (product, functional)

- **Requirement 5.2.2.1.1**: *The NUCAPS shall have code that can write radiance gridded files in direct access binary format.* (product, functional)

- **Requirement 5.2.2.2**: *The NUCAPS CrIS/ATMS radiance gridded files shall be available one day after observation.* (system, operational)

- **Requirement 5.2.3**: *The NUCAPS shall generate daily CrIS/ATMS EDR gridded product files at 0.5X2.0 and 3.0X3.0 degree resolutions for STAR.* (product, functional)

NUCAPS Requirements – Basic Requirement 5.0

- **Requirement 5.2.3.1**: *The CrIS/ATMS EDR gridded files shall be in direct access binary format.* (product, functional)
- **Requirement 5.2.3.1.1**: *The NUCAPS shall have code that can write the EDR gridded files in direct access binary format.* (product, functional)
- **Requirement 5.2.3.2**: *The NUCAPS CrIS/ATMS EDR gridded files shall be available one day after observation.* (system, operational)
- **Requirement 5.2.4**: *The NUCAPS shall generate daily CrIS CCR gridded product files at 0.5X2.0 and 3.0X3.0 degree resolution for STAR.* (product, functional)
- **Requirement 5.2.4.1**: *The NUCAPS daily CrIS CCR gridded files shall be in direct access binary format.* (product, functional)
- **Requirement 5.2.4.1.1**: *The NUCAPS shall have code that can write the CCR gridded files in direct access binary format.* (product, functional)

NUCAPS Requirements – Basic Requirement 5.0

- **Requirement 5.2.4.2**: *The NUCAPS daily CrIS CCR gridded files shall be available one day after observation.* (system, operational)

NUCAPS Requirements – Basic Requirement 6.0

- **Basic Requirement 6.0**: *The NUCAPS package shall be delivered to NDE for integration into the NDE Data Handling System (DHS). The following is required as part of this delivery.* (system, operational)

- **Requirement 6.1**: *NUCAPS shall be delivered in the form of a Delivered Algorithm Package (DAP) whose name and contents are defined in the NDE document entitled "Algorithm Delivery Standards, Integration, and Test V1.3". (system, delivery)*

- **Requirement 6.2**: *The NUCAPS shall be able to run on the NDE SADIE platform.* (system, functional)

- **Requirement 6.3**: *The NUCAPS unit driver scripts shall be able to read and handle the content from a Process Control File (PCF) passed to them from the NDE Product Generation Manager (PGM) for each run of the script.* (system, functional)

- **Requirement 6.4**: *The NUCAPS unit driver scripts shall each produce a Process Status File (PSF) after each run of the script in the format required by the NDE Data Handling System (DHS).* (system, functional)

NUCAPS Requirements – Basic Requirement 6.0

- **Requirement 6.5**: *The NUCAPS code shall adhere to the STAR/NDE coding and ESPC security standards.* (system, functional)

- **Requirement 6.6**: *The NUCAPS software shall be able to write all output product into CF-compliant netCDF4 format.* (system, functional)

- **Requirement 6.7:** *The NUCAPS IPT shall deliver an System Maintenance Manual. (product, operational). This is an SPSRB required document.*

- **Requirement 6.8:** *The NUCAPS IPT shall deliver a External Users Manual for NUCAPS products. (product, operational). This is an SPSRB required document.*

- **Requirement 6.9**: *Delivered code within the DAP must compile without errors or unexpected warnings using one or more of the following compilers:*

  xlC version 9.0 or greater (C/C++); gcc version 3.4.6 or greater (C/C++)

  xlf version 11.1 or greater (Fortran 77/90/95)

  java version 1.4.2 or greater. (system, functional)

NUCAPS Requirements – Basic Requirement 6.0

- **Requirement 6.10**: *Delivered Perl scripts must be compatible with version 5.8.2 or greater.* (system, functional)

- **Requirement 6.11:** *Delivered DAP must be compressed using gzip and follow the following naming convention:*

  Project-name_algorithm-identifier_Vnumber_date.tar.gz

- **Requirement 6.12:** *All NUCAPS output product files shall adhere to the naming convention specified in the NDE DAP Content Standards document.*

NUCAPS Requirements – Basic Requirement 7.0

- **Basic Requirement 7.0**: *The delivered NUCAPS system shall be able to read and check NDE input data.*

- **Requirement 7.1**: *All NUCAPS software units shall be able to perform data range checks on the input HDF5 files provided by the NDE DHS.* (system, functional)

- **Requirement 7.2**: *The NUCAPS software shall be able to read the CrIS, ATMS and VIIRS HDF5 input data supplied by NDE.* (system, functional)

- **Requirement 7.2.1**: *The NUCAPS software shall be able to read the VIIRS Cloud Mask and Cloud Top Height produced by IDPS.* (system, functional)

- **Requirement 7.3**: *The NUCAPS software shall not process any instrument data if the input file ATMS or CrIS metadata indicates the platform is undergoing a maneuver. If the CrIS instrument is being calibrated, no data will be processed as well.*

NUCAPS Requirements – Basic Requirement 8.0

- **Basic Requirement 8.0:** *The NUCAPS software shall comply with OSPO coding standards identified in the OSPO security checklist.*

NUCAPS Requirements – Basic Requirement 9.0

- **Basic Requirement 9.0:** *The NUCAPS software shall produce data files for science quality monitoring of SDR and EDR data.*

- **Requirement 9.1:** *The NUCAPS software shall produce retrieval output statistics files from each retrieval run to monitor the CrIS EDR quality.*

- **Requirement 9.2:** *The NUCAPS software shall produce principal component score statistics files for each granule to monitor the CrIS SDR quality.*

Note: These files are produced in support of OSPO science quality monitoring efforts.

NUCAPS Requirements – Basic Requirement 10.0

- **Basic Requirement 10.0:** *The NUCAPS science team shall evaluate the need for an Instrument Line Shape (ILS) correction. If necessary, this correction will be implemented in the NUCAPS retrieval algorithm. If not, scientific justification must be provided for why it is not necessary.*

CrIS OLR
Project Requirements

- CrIS OLR Project requirements are present in this section.

- These were are shown in a separate section because these money to fund this portion of the project is separate from the regular NUCAPS funding.

- We will not cover these requirements as they were sent out for review on 9/30/2013.

Basic Requirement 0.0

- **CrIS-OLR-R 0.0:** *The CrIS OLR development project shall adopt the standard practices of the Satellite Product and Services Review Board (SPRB).*
  - **Driver:** *STAR Enterprise Product Lifecycle (EPL)*. The SPSRB process has been updated by incorporating aspects of the STAR EPL Process.

Basic Requirement 0.0

- **CrIS-OLR-R 0.1:** *The CrIS OLR development project practices shall be tailored from the SPSRB process.*

    - » This requirement should be met by following the SPSRB process, as long as the tailoring does not introduce an incompatibility.

Basic Requirement 1.0

- **CrIS-OLR-R 1.0:** *The CrIS OLR package shall contains software to generate an Outgoing Longwave Radiation (OLR) product.*

- **Driver:** This basic requirement is traced to user needs as stated in SPSRB User Request #0907-0015 for NCEP/CPC.

Basic Requirement 1.0

- **CrIS-OLR-R 1.1:** *The OLR shall have horizontal resolution of each CrIS FOV.*
  - » User Request from NCEP/CPC.
- **CrIS-OLR-R 1.2:** *The OLR shall have a measurement accuracy < 0.2 W/m^2.*
  - » User Request from NCEP/CPC. Specifications are based on CERES OLR.
  - » Note: these specs are better than those assigned in the L1RD sup. V 2.9.

Basic Requirement 1.0

- **CrIS-OLR-R 1.3:** *The OLR shall have a measurement precision < 3 W/m^2*
  - » User Request from NCEP CPC. Specifications are based on CERES OLR.
  - » Note: these specs are better than those assigned in the L1RD sup. V 2.9.
- **CrIS-OLR-R 1.4:** *The OLR shall be produced within three hours of observation.*
  - » User Request from NCEP CPC. The data should reach the users prior to forecast cycles.

Basic Requirement 1.0

- **CrIS-OLR-R 1.5:** *The OLR product shall be written in netCDF4 format.*

User Request from NCEP CPC. Current QC monitoring tools operate on netCDF3 files.

Basic Requirement 1.0

- **CrIS-OLR-R 1.6:** *The CrIS OLR product shall be validated.*

- **CrIS-OLR-R 1.6.1:** *Routine data range checks in near real time to flag anomalous OLR values shall be performed.*
  - The OLR software will contain range checks to ensure that the OLR data will flag data outside of the range.

Basic Requirement 1.0

- **CrIS-OLR-R 1.6.2:** *The Matchup datasets between satellite measurements and other existing correlated instruments shall be generated.*

The CrIS OLR product will be compared with that of the CERES and IASI OLR.

- **CrIS-OLR-R 1.6.3:** *Test OLR product files shall be sent to the customers in near real-time mode to ensure the product meets customer's needs and to allow them to test their product ingestion.*

  - » Sample CrIS OLR product files will be made available to CPC on an ftp server for evaluation prior to delivery of the capability to operations. This will ensure that the product file meet user needs and expectations and facilitate user readiness.

Basic Requirement 1.0

- **CrIS-OLR-R 1.7:** *The CrIS OLR algorithm shall be implemented to generate the product to the required specifications.*

This is a requirement allocated to the code that generates OLR.

Basic Requirement 1.0

- **CrIS-OLR-R 1.7.1:** *The CrIS OLR code shall generate Outgoing Longwave Radiation from the CrIS SDR input.*
    - » This is allocated to the OLR code.
- **CrIS-OLR-R 1.7.2:** *The CrIS OLR code shall use static regression coefficients to generate the OLR product.*
    - » This regression file will be generated by the science development team and will be read at run time by the OLR code.

Basic Requirement 1.0

- **CrIS-OLR-R 1.8:** *The CrIS OLR algorithm shall be implemented within NUCAPS system.*

- *See the NUCAPS RAD Version 1.4 for details about the NUCAPS requirements.*

- **CrIS-OLR-R 1.9:** *The CrIS OLR data files shall be archived at CLASS.*

Basic Requirement 1.0

- **CrIS-OLR-R 1.9.1:** *The CrIS Submission Agreement shall be developed and CrIS OLR netCDF4 granule files shall be added.*
- **CrIS-OLR-R 1.9.2:** *Metadata for the CrIS OLR netCDF files shall be generated for CLASS.*
  - Metadata will be included at the header of the netCDF4 files.

Basic Requirement 2.0

- **CrIS-OLR-R 2.0:** *The CrIS OLR package shall have the QC monitoring capability.*

Driver: This basic requirement is traced to an OSPO need for QC monitoring.

Basic Requirement 2.0

- **CrIS-OLR-R 2.1:** *The CrIS OLR package output shall include overall quality control flags.*
    - Needed for distribution, archive, quality control and post-processing in the products files.

Basic Requirement 3.0

- **CrIS-OLR-R 3.0:** *A fully functional pre-operational package shall be created in the Development Environment at STAR.*

- **Driver:** This basic requirement is traced to a STAR need for a fully functional package ready for integration and system testing.

Basic Requirement 3.0

- **CrIS-OLR-R 3.1:** *The Development Environment shall use IBM P570 hardware.*
  - The orbit001b machine at STAR will be used.

- **CrIS-OLR-R 3.1.1:** *The Development Environment shall include a C/C++ compiler.*
  - » Needed for the C code. The orbit001b machine at STAR has this (IBM XL version 7.0 C/C++ compiler).
- **CrIS-OLR-R 3.1.2:***The Development Environment shall include Fortran compilers.*
  - » Needed for the Fortran 77 code and Fortran 90 code. The orbit001b machine at STAR has this (IBM version 10.01 Fortran 90 and 77 compilers).

Basic Requirement 3.0

- **CrIS-OLR-R 3.1.3:***The Development Environment shall have 32 GB of memory.*
  - » The orbit001b machine at STAR has this (16 CPUs with 2GB memory/CPU).

- **CrIS-OLR-R 3.1.4:** *The Development Environment shall have 3 TB of data storage.*
  - The orbit001b machine at STAR has this (5.5 TB SAN disk space).

Basic Requirement 3.0

- **CrIS-OLR-R 3.2:** *The Development Environment shall be capable of hosting unit tests.*

- **CrIS-OLR-R 3.2.1:** *The Development Environment shall have access to CrIS SDR data.*
  - The orbit001b machine at STAR has access to these data through the STAR Collaborative Data Repository (SCDR). The NUCAPS system will preprocess the data used by the CrIS OLR package.

Basic Requirement 3.0

- **CrIS-OLR-R 3.3:** *The Development Environment shall host the CrIS OLR pre-operational package.*
  - » Complete test of the pre-operational code is expected before delivery to NDE.

- **CrIS-OLR-R 3.3.1:** *The CrIS OLR package will be integrated, run, and tested within NUCAPS.*
  - » The CrIS OLR development environment (orbit001b at STAR) will be the same machine as that used for NUCAPS. The updated version of NUCAPS will be delivered to NDE.

Basic Requirement 4.0

- **CrIS-OLR-R 4.0:** *The CrIS OLR integrated pre-operational code shall be transitioned from the CrIS OLR Development Environment to the NDE Test Environment.*

  » **Driver:** NDE needs for a fully functional CrIS OLR package in its Test Environment.

Basic Requirement 4.0

- **CrIS-OLR-R 4.1:** *The integrated pre-operational package shall include all processing code and ancillary files needed to reproduce the unit test.*
  - » Specific items will be documented in the Code Test Review (CTR) package.

- **CrIS-OLR-R 4.2:** *The integrated pre-operational package shall include all input test data needed to reproduce the unit test.*
  - » Specific items will be documented in the Code Test Review (CTR) package.

Basic Requirement 4.0

- **CrIS-OLR-R 4.3:** *The integrated pre-operational package shall include all output data produced by the unit test.*
  - » Specific items will be documented in the Code Test Review (CTR) package.

- **CrIS-OLR-R 4.4:** *The integrated pre-operational CrIS OLR package shall be delivered to NDE within the NUCAPS Delivered Algorithm Package (DAP).*
  - » Code, test data, and documentation will be placed in a DAP whose contents are defined by the NDE DAP document: *Algorithm Delivery Standards, Integration, and Test V1.4*.

Basic Requirement 4.0

- **CrIS-OLR-R 4.4.1:** *The CrIS OLR algorithm theoretical basis shall be added to the NUCAPS Algorithm Theoretical Basis Document (ATBD) and delivered in an updated NUCAPS DAP.*
  - » The NUCAPS ATBD follows the SPSRB Version 2 document standards.
- **CrIS-OLR-R 4.4.2:** *The CrIS OLR software shall be documented within the NUCAPS System Maintenance Manual (SMM) and delivered in an updated NUCAPS DAP.*
  - » The NUCAPS SMM follows SPSRB Version 2 document standards.

Basic Requirement 4.0

- **CrIS-OLR-R 4.4.3:** *The CrIS OLR product user information shall be included in the NUCAPS External Users Manual (EUM) and delivered in an updated NUCAPS DAP.*
    - » The NUCAPS EUM follows SPSRB Version 2 document standards.

Basic Requirement 5.0

- **CrIS-OLR-R 5.0:** *The CrIS OLR software shall comply with OSPO Code Review Security check lists.*
    - » **Driver:** OSPO need for compliance with code and security standards.

Basic Requirement 5.0

- **CrIS-OLR-R 5.1:** *The CrIS OLR software shall comply with OSPO data integrity check list.*
  - OSPO data integrity check list is part of the OSPO Code Review Security check lists.
- **CrIS-OLR-R 5.2:** *The CrIS OLR software shall comply with OSPO development security check list.*
  - OSPO development security check list is part of the OSPO Code Review Security check lists.

Basic Requirement 5.0

- **CrIS-OLR-R 5.3:** *The CrIS OLR software shall comply with OSPO code check list.*

  - » OSPO code check list is part of the OSPO Code Review Security check lists.

CrIS OLR Project Requirements – Summary

- The CrIS OLR Package Requirements have been established.
- The Requirements have been documented in the Requirements Allocation Document (RAD).
- The Requirements are traceable to drivers (customer needs or expectations) and other requirements.

NUCAPS Requirements – Summary

- The NUCAPS Requirements have been established.
- The NUCAPS Requirements have been documented in the Requirements Allocation Documents (RAD).
- The NUCAPS Requirements are traceable to drivers (customer needs or expectations) and other requirements.

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- Phase 3 Requirements
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Section 4 –
Concept of Operations

Presented by

Tom King

Operations Concept - Overview

- Before requirements are developed for a product and product system, the developers should know the intentions of the customers and/or users of the product. They must have the answers to the following questions:
  - » What is the product?
  - » Why is this product being produced?
  - » How will this product be used?
  - » How should this product be produced?

- The answers to the preceding questions should be derived from customer/user needs and expectations and production constraints

What is the Product?

- CrIS BUFR
  - These files are currently produced in the NDE system running in OSPO.
  - They produced as thinned (399 channel) and full resolution (1305 channel) files.
  - The CrIS data are preprocessed and thinned by NUCAPS and then converted into BUFR by the BUFR/GRIB2 Tailoring Toolkit.
  - The existing product will be updated to add collocated VIIRS cloud fraction and cloud top height. The current CrIS BUFR table already contains these descriptors.
  - The current input files made available to the Toolkit already contain the VIIRS cloud variables and the BUFR code will not need to change to accommodate the update to NUCAPS.

- CrIS OLR
  - This will be a new product.
  - It will be produced for each CrIS FOV as a granule product.
  - This will match the quality of the current IASI OLR product.

Why is the Product Being Produced?

- SPSRB requirement 0907-0015, CERES-Like OLR from IASI and CrIS
  - NESDIS STAR has shown success with generating a CERES-Like OLR product from AIRS on Aqua. For validation efforts and monitoring needs CPC would like a CERES-Like product from the IASI instrument on MetOP. CPC would also like a similar product from NPP and NPOESS CrIS.
  - OLR with CERES like quality in the Metop orbit will provide important information on diurnal signal for model verification and monitoring and will also provide a backup capability in case of a problem with CERES. The verification is fundamental because it provide us with important guidance for predicting tropical influences on mid latitude weather patterns. CERES like OLR from CrIS will also be very beneficial for monitoring CERES performance and also provide a backup
- User community: NWS/CPC, JCSDA, Climate Users
- Benefit To User:
  - Blending of sensor data for maximum product accuracy and yield addresses GEOSS goals.
  - CrIS OLR tied to CERES will extend climate quality OLR to NPP orbital plane. Contributes to better OLR temporal coverage.
- NOAA Mission Goal supported: Climate, Weather & Water, Polar Satellites Acquisitions
- Mission priority: Mission Critical, distribution of the CrIS data to the NWP centers is a top priority.

Why is the Product Being Produced?

- SPSRB requirement 0403-1, CrIS/ATMS Products for NWS
  - This includes the thinning and preparation (apodization) of CrIS radiances.
- Other requirement documentation: NPOESS IORD II.
- User community: NWS/NCEP/EMC, NWS/NCEP/NCO, JCSDA, ECMWF, International NWP users, NWP FOs, Climate Users.
  - Simon Elliott at EUMETSAT has stated that they are currently doing their own VIIRS/CrIS collocation. However, they intend to switch to using our collocated BUFR once it becomes available.
- NOAA Mission Goal supported: Climate, Weather & Water, Polar Satellites Acquisitions.
- Mission priority: Mission Critical, distribution of the CrIS/ATMS data to the NWP centers is a top priority.

How Will the Products Be Used?

- CrIS BUFR are used for data assimilation:
  - NCEP
  - EUMETSAT (ECMWF, UK Met, Meteo France, etc…)
  - Global NWP community - EUMETSAT makes these data on the GTS.

- CrIS OLR will be used by for climate prediction modeling.
  - CPC
  - CLASS (non-operational science user community)

How Should The Products Be Produced?

- The development, test, and production environments are described later in the software architecture section.
  - » Development: STAR
  - » Integration: OSD/NDE
  - » Production: OSPO
- Distribution will conducted by the NDE system running at OSPO through existing distribution pathways to NCEP and EUMETSAT. Eventually, PDA will be the distribution mechanism for all NDE and OSPO data.

How Should The Products Be Produced?

- Production and data quality monitoring will be conducted in OSPO.
  - CrIS radiances will monitored OSPO quality monitoring, IDPS data quality technicians, and STAR CrIS SDR cal/val team.
  - VIIRS cloud mask and cloud top products are monitored by IDPS data quality technicians and STAR VIIRS cloud product cal/val team.
  - CrIS OLR will be monitored as part of the ongoing OSPO science quality monitoring efforts.

How Should The Products Be Produced?

- CrIS OLR will use as input, the apodized CrIS SDR data.

- The CrIS/VIIRS collocated product will use as input the VIIRS Cloud Mask (CM) and Cloud Top Height (CTH) from the IDPS.
  - » The original plan was to use the output moderate-resolution (750m) VIIRS cloud top products from the JPSS Risk Reduction (JPRR) project. However, this will not be available until sometime in 2015.
  - » The approach proposed here will use the existing IDPS output and would make the product available to users earlier. However:
    - VIIRS CM is 750 m resolution and VIIRS CTH is ~6 km resolution. This is lower resolution, adds complexity to the design because 2 collocations are required for the data at each resolution.
    - If later on the higher resolution cloud top height from JPSS Risk Reduction is to be added, this will require an additional update and testing.

CrIS/VIIRS Operations Sequences

- The VIIRS collocation will be performed within the existing NUCAPS Processor Unit (NUCAPS_Preproc.pl). This is the front end unit for the NUCAPS system. Additional details will be provided later in the Software Architecture section.

- The current production rules specify the unit will execute when the following IDPS output data are made available to NUCAPS from the NDE DHS:
  - 1 CrIS SDR granule file (this is the “target” file)
  - 3 ATMS TDR granules that surround the 1 CrIS target granule

CrIS/VIIRS Operations Sequences

- Phase 3 updated production rules will also require the availability of the following:
  - 1 or 2 overlapping VIIRS Cloud Top Height granules
  - 1 or 2 overlapping VIIRS Cloud Mask granules

- The VIIRS CM and CTH data arrive ~3-6 minutes after CrIS on average so production would be initiated then.
  - Risk: Users such as Andrew Collard (NCEP) and Simon Elliott (EUMETSAT) have indicated that they would not want to delay the production of CrIS BUFR. The question is, is this short delay acceptable to the users?

CrIS/VIIRS Operations Sequences

- First, the existing preprocessing executable (main_nucaps_preproc.f90) will run doing the following:
  - » Reads in the CrIS and ATMS data
  - » Footpring resampling
  - » Applies DEM (for topography and land fraction)
  - » Performs apodization
  - » Performs scan misalignment correction
  - » Write output to the NUCAPS ALL netCDF4 output file

CrIS/VIIRS Operations Sequences

- Next, a new set of executables running within the NUCAPS Preprocessor Unit will run. They will:
  - » Combine the 1-2 VIIRS granules into 1 larger overlapping granule that fully covers the target CrIS granule
  - » Reformat CrIS and VIIRS geo data into the collocation codes required input file.
  - » Execute the collocation algorithm code
  - » Take the output and compute the average weighted cloud fraction and select the highest cloud top height.
  - » Write (add to) the output into the existing NUCAPS ALL file created upstream by main_nucaps_preproc.f90.

CrIS/VIIRS Operations Sequences

- Third, the existing downstream Subsetter unit (within NUCAPS) and the BUFR Toolkit (N4RT) will direct the cloud information to the BUFR file.

- Note: Cloud fraction and height fields are already present in the currently produced “NUCAPS ALL” netCDF4 output file, but are set to missing.

- Note, again, the BUFR/GRIB2 Toolkit code and the CrIS BUFR table already contain these fields so no changes are required to the existing downstream code.

CrIS OLR Operations Sequences

- The CrIS OLR generation will be performed within the existing NUCAPS Processor Unit (NUCAPS_Preproc.pl). This is the front end unit for the NUCAPS system. Additional details will be provided later in the Software Architecture section.
- The current production rules (input file requirements) do not need to change because only the CrIS SDR is required.
- The OLR will use as input the “NUCAPS all” file (full resolution).

CrIS OLR
Operations Sequences

- The OLR will be generated by a single executable running immediately downstream of the main_nucaps_preproc Fortran executable (which generates the “NUCAPS all” file).

- Static ancillary inputs will be:
  - » Regression coefficient file
  - » Input radiation correction file.

- This production scenario is identical to that of the IASI OLR.

- The output CrIS OLR will be in netCDF4 will CLASS compliant metadata.

CrIS OLR Operations Sequences

- Metadata will be made available by the driver script and written into the header of the output file as global attributes by the OLR executable.

- NDE will distribute this file as is. No additional tailoring will be required.

Monitoring and Maintenance

- OSPO will run and monitor the production of NUCAPS products generated within the NDE system.

- STAR will work this OSPO to develop and deliver tools to monitor the science quality of the CrIS OLR product.

- STAR will assist NDE and OSPO with integration and troubleshooting.

Distribution Scenarios – Product Files

- All NUCAPS Phase 3 products will distributed through the NDE distribution server (and eventually PDA).
  - » NCEP, EUMETSAT
  - » CPC
- System and user documentation will be provided to NDE as part of the DAP. The PAL will make relevant documentation available to users as needed.
  - » SMM
  - » EUM
  - » ATBD

User Interaction

- The ESPC help desk will serve as the operational point of contact to provide 24/7 service support for users.
  - Provides information about the data products to the user community.
  - Resolves user issues through coordination with the Soundings PAL (Product Area Lead).

- The Soundings PAL will coordinate with the STAR scientists to identify and resolve any product quality issues and will report these to the users.

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Section 5 –

Algorithm Theoretical Basis: OLR

Presented by

Kexin Zhang

S-NPP CrIS OLR Algorithm Theoretical Basis

- Purpose: Provide a physical and mathematical description of the S-NPP CrIS OLR algorithms for product developers, reviewers and users.
- Details will be available in the NUCAPS Algorithm and Theoretical Basis Document (ATBD).

OLR Algorithm Objectives

- Meet the requirement specified for the LW Radiation Budget products.
- Maintain heritage with AIRS, IASI and CrIS to ensure continuity and consistency of LW radiation budget products from hyperspectral IR sounders.
- Modular in design to support enhancements.
- Simple to implement, robust and fast for operational use.

Requirements

Name	Outgoing Longwave Radiation at TOA
User	NOAA CPC
Geographic Coverage	Nearly global
Vertical Resolution	N/A
Horizontal Resolution	20 km
Product Refresh Rate/Coverage Time	3 minutes
Measurement Range	0–500 Wm^{-2}
Measurement Accuracy	0.2 Wm^{-2}
Measurement Precision	3 Wm^{-2}

AIRS OLR Algorithm

- AIRS PC regression OLR algorithm
  - least-squares regression between CERES OLR and AIRS radiance principal component scores
  - The first 35 PCs of 1707 pristine channels as predictors
  - Eight sets of regression coefficients to account for view angle dependence

IASI OLR Algorithm

IASI has no simultaneous broadband measurements.

- Least-squares regression Algorithm:
  - » Use of Pseudo channels
  - » OLR is estimated directly as the weighted sum of pseudo channel radiances calculated from IASI radiances
  - » Least-squares regression between CERES OLR and pseudo channel radiances calculated from AIRS radiances
  - » Correct IASI to AIRS-like pseudo channel radiances based on radiative transfer model calculations

CrIS OLR Algorithm

CrIS has simultaneous broadband CERES measurements, but we will use it as "truth", and AIRS as the third transfer instrument.

- Least-squares regression Algorithm:
    - » Use of Pseudo channels
    - » Correct CrIS to AIRS-like pseudo channel radiances based on radiative transfer model calculations.
    - » Least-squares regression between CERES OLR on Aqua and pseudo channel radiances calculated from AIRS-like radiances.
- Advantages
    - » Make OLR algorithm consistent with AIRS, IASI and CrIS.
    - » Validated using simultaneous S-NPP CERES measurements.
    - » Simplicity with accuracy
        - – Understandable, repeatable, with high confidence
- Disadvantages
    - » Limited by accuracy and precision of CERES OLR
    - » Uncertainties in AIRS and CrIS RTAs

OLR Retrieval Strategy

- **Least-squares regression Algorithm**
  - Broadband radiometer CERES OLR as ‘truth’. AIRS is used as the third transfer instrument.
  - Radiance correction regression database is derived with theoretical radiative transfer model simulations given ‘noaa88’ and ‘noaa89’ sounding collections for both clear and cloudy conditions. Cloud conditions were simulated by ATOV derived cloud properties. Cloud is black except for cirrus which has spectral-dependent emissivity.
  - Collocation of AIRS and CERES measurements in big box.
  - Eight sets of regression coefficients are trained to account for view angle dependence of CrIS radiances.
  - OLR is expressed as weighted linear combination of pseudo channel radiances.

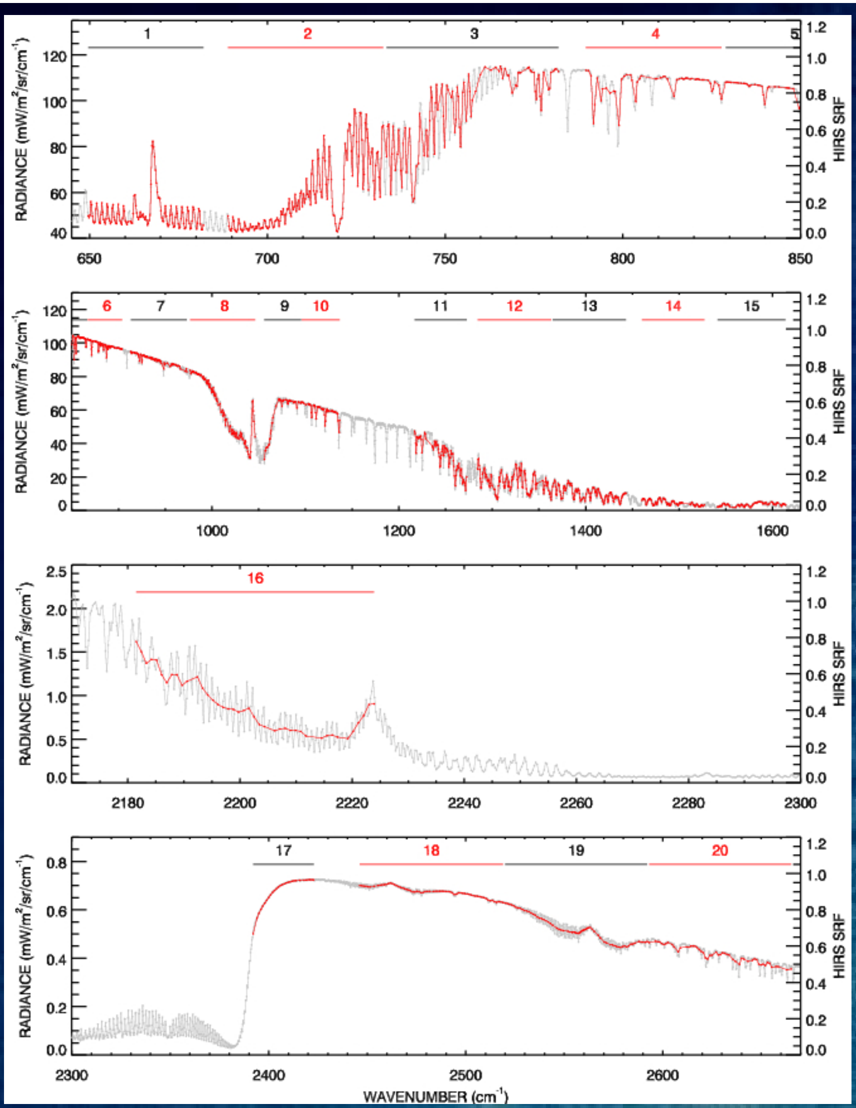
OLR Retrieval: Physical Basis

- The LW radiation spectrum is determined by the surface thermal emission and the atmospheric absorption & thermal emission.
- Radiances are spectrally correlated. The variance of the spectrum could, to certain degree, be estimated with radiances sampled at several key frequencies. This forms the basis for narrow to broadband conversion.

OLR Retrieval: Methodology Steps

- Degrade AIRS, CrIS radiance spectra
- Calculation of AIRS and CrIS pseudo channel radiance
- Correction of CrIS pseudo channel radiance to AIRS-like pseudo channel radiance
  - Simulation of AIRS and CrIS radiance
  - Radiance corrected
  - OLR corrected
- Estimation of CrIS OLR
  - Training and test ensemble
  - Pseudo channels excluded by AIC stepwise regression analysis

OLR Retrieval: Methodology
Degrade AIRS and CrIS Radiance Spectra



- IASI (grey) and AIRS (red) radiance spectra calculated from LBLRTM simulated radiance spectrum of the US standard atmospheric profile.
- Minimize the brightness temperature difference (ΔBT ≤ 1K) between AIRS and CrIS pseudo channel radiance.
- Avoid AIRS spectral gaps and "bad" channels at the end of the pseudo channels.
- 20 pseudo channels. Mean and standard deviation of pseudo channel width are 54.4 cm^{-1} and 16.58 cm^{-1}.

OLR Retrieval: Methodology (2) Calculation of AIRS and CrIS Pseudo Channel Radiance

For each pseudo channel, AIRS and CrIS spectrally convolved radiance (R) is defined as,

$$R = \frac{1}{v_2 - v_1} \int_{v_1}^{v_2} I(v)dv$$

Where, $[v_1, v_2]$ is the spectral range of a pseudo channel. $I(v)$ is AIRS or CrIS observed radiances within the pseudo channel.

OLR Retrieval: Methodology (3)
Correction of CrIS Pseudo Channel Radiance to AIRS-like Pseudo Channel Radiance

For each pseudo channel, radiance difference (ΔR) between AIRS and CrIS pseudo channel radiance is corrected by,

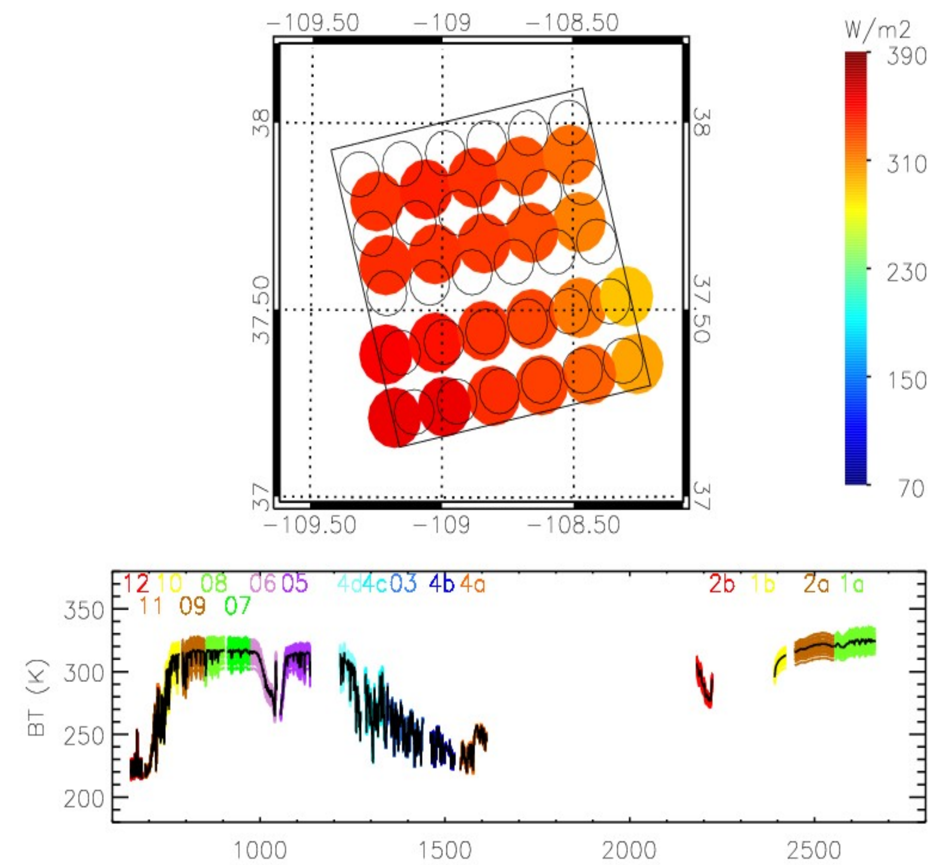
$$\Delta R = A_0 + \sum_{k=1}^{K} A(k) I_{CrIS}(k)$$

Where, K is the number of CrIS channels in the pseudo channel. The regression coefficients are trained by AIRS and CrIS simulated radiance using AIRS and CrIS fast forward radiative transfer model (RTA) based on 'noaa89' training dataset that has 7622 sounding profiles.

OLR Retrieval: Methodology (4)
Simulation of AIRS and CrIS Radiance

- NOAA training dataset of “noaa88b” (nprof=7547) and “noaa89b” (nprof=7622).
- AIRS version 10ab RTA. Add noise: L2.chan_prop.2005.03.01.v9.5.1.ans.
- CrIS version 10a RTA. Add noise: tobin120120.dat.
- All-sky.
- 90 CrIS view angles. No. of samples=90*nprof.

OLR Retrieval: Methodology (5)
Collocation of AIRS and CERES measurements



AIRS and CERES are collocated in the 6 x 5 array of BIG BOX (6 FOVs in the scan direction and 5 FOVs along the track)

OLR Retrieval: Methodology (6)
Estimation of CrIS OLR

CrIS OLR is a liner combination of the pseudo channel radiances,

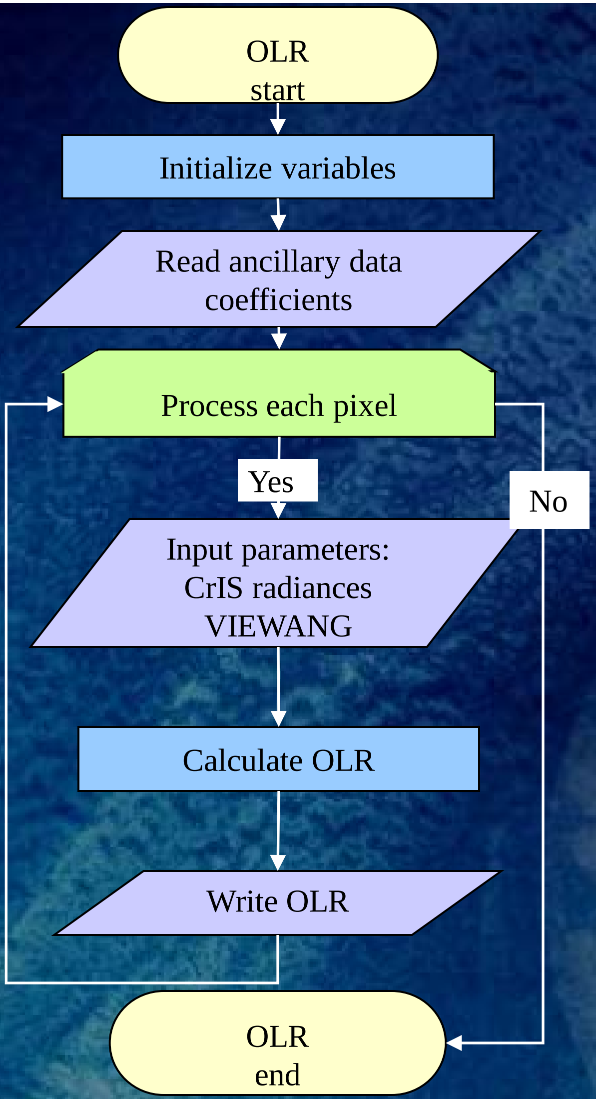
$$OLR = A_0 + \sum_{k=1}^{K} A(k) \bullet R(k)$$

Where, K is the number of the pseudo channels that are not excluded by **AIC Stepwise Regression Analysis**. A's are trained by the collocated Aqua CERES FM3 TOA OLR and AIRS pseudo channel radiances. CrIS pseudo channel radiances are corrected to AIRS-like pseudo channel radiances before applying regression coefficients. Eight sets of regression coefficients are trained to account for view angle dependence.

Summary of OLR Retrieval

- The least-square regression algorithm uses the weighted linear combination of pseudo channel radiances to estimate OLR directly with CrIS radiance observations
  - Regression equations for OLR estimation and radiance correction.
  - AIC stepwise analysis will be used to determine the pseudo channels that passed significant statistical test (in R).

OLR Algorithm Processing Outline



OLR start

Initialize variables

Read ancillary data coefficients

Process each pixel

Yes

No

Input parameters:
CrIS radiances
VIEWANG

Calculate OLR

Write OLR

OLR end

OLR Algorithm Input
Sensor Input

- IASI level-1c radiances in 4418 out of IASI 8461 channels

Pseudo Channel	Center Wavenumber (cm^{-1})	Width (cm^{-1})	No. of IASI Channels
1	665.81	32.62	130
2	710.79	43.96	176
3	757.81	48.85	195
4	808.60	38.68	154
5	847.68	37.93	152
6	885.54	37.16	149
7	943.06	60.44	242
8	1011.58	70.64	282
9	1075.66	40.13	160
10	1116.32	41.18	165
11	1244.93	55.42	226
12	1323.67	79.21	317
13	1403.72	79.30	317
14	1493.81	67.71	271
15	1577.49	73.47	293
16	2202.72	43.37	173
17	2407.22	32.26	129
18	2482.56	73.76	295
19	2556.04	73.19	293
20	2628.97	74.77	299

OLR Algorithm Input
Sensor Input Details

- For each pixel
  - CrIS radiance (mWm^{-2} (cm^{-1} sr)$^{-1}$)
  - view angles (deg)
  - sensor quality flags

Type	Description	Dimension
input	Calibrated CrIS level-1c radiances	grid (xsize, ysize, nchannel)
input	view angle	grid (xsize, ysize)
input	quality control flags with level -1c data	grid (xsize, ysize)

OLR Algorithm Input Ancillary Data

- Three types of ancillary data needed:
  - **Static Non-CrIS Data**: Parameters of 17 pseudo channels, OLR regression Coefficients, radiance correction coefficients.
  - **Dynamic Non-CrIS Data**: N/A
  - **CrIS Derived Data**: N/A

OLR Algorithm Input Ancillary Data Details (1)

- **Static Non-CrIS Data:** Parameters of 17 pseudo channels

Name	Type	Description	Dimension
Parameters of Pseudo Channel	input	Start, end and center wavenumber	Floating number Array (17, 3)
		List of CrIS channels	integer number (17, nchannel)
		Weights	Floating number (17, nchannel)

OLR Algorithm Input Ancillary Data Details (2)

- **Static Non-CrIS Data:** OLR Regression Coefficients

Name	Type	Description	Dimension
OLR Regression Coefficients	input	CrIS OLR regression coefficients	Floating number Array (18, 8)

OLR Algorithm Input Ancillary Data Details (3)

- **Static Non-CrIS Data:** Radiance Correction Coefficients

Name	Type	Description	Dimension
Radiance Correction Coefficients	input	CrIS to AIRS pseudo channel radiance correction regression coefficients	Floating number Array (18, nchannels)

OLR Algorithm Output

- Metadata
  - Processing date stamp & Others
- Scientific Datasets

Name	Type	Description	Dimension
OLR	output	Retrieved Upward Longwave Radiation at TOA	grid (xsize, ysize)
QC Flags	output	QC flags for OLR retrievals	grid (xsize, ysize)

OLR Algorithm Validation Data

Validation strategy:

- Compare CrIS OLR to simultaneous CERES OLR measurements directly.

OR

- Compare CERES OLR to AIRS Data
- Compare AIRS and CrIS radiances of Aqua and S-NPP simultaneous nadir overpass (SNO) observations.

OLR Algorithm Validation (1)
(AIRS OLR vs. CERES OLR)

AIRS vs. CERES

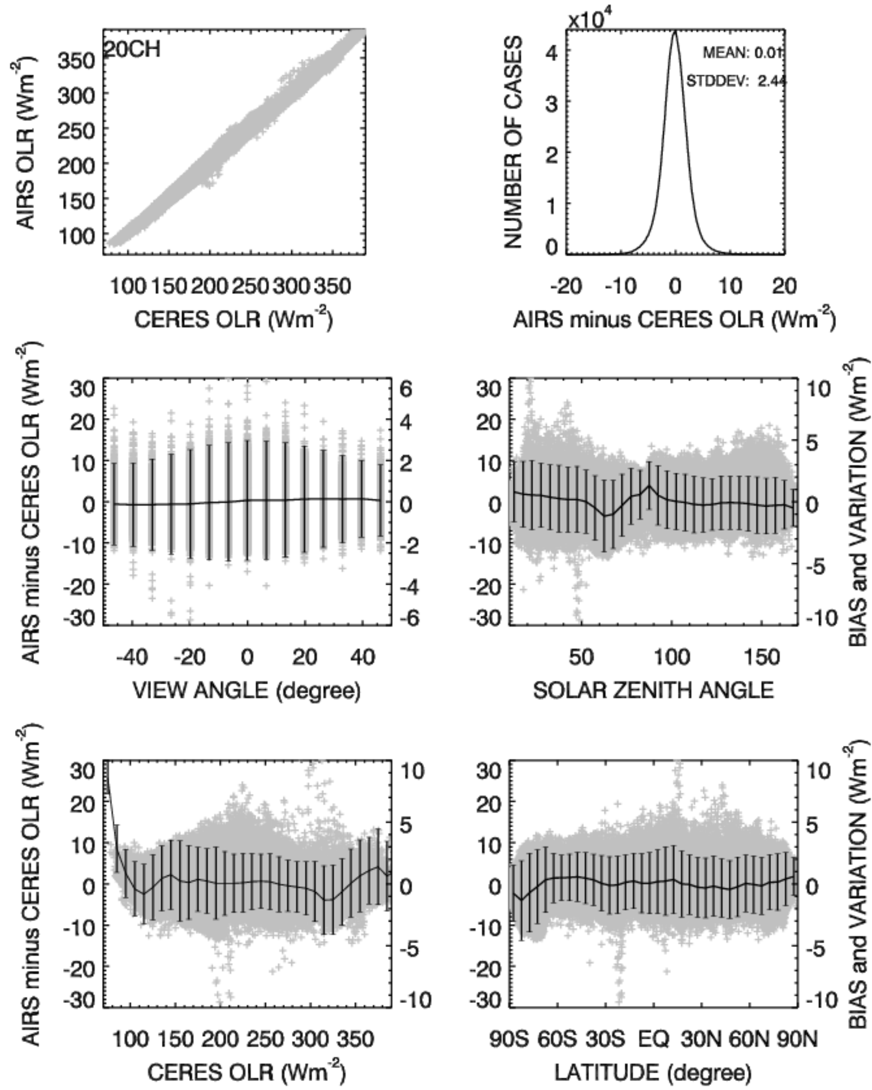
OLR Difference

AIRS View Angle

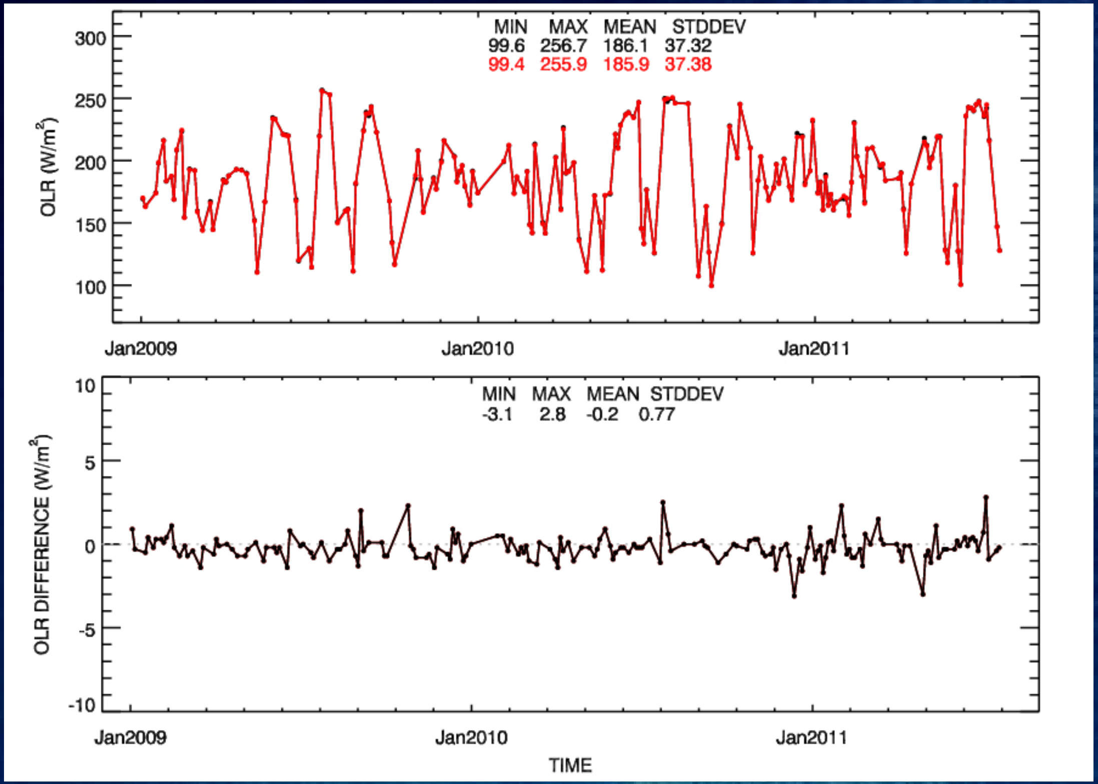
Solar Zenith Angle

CERES OLR

Latitude



OLR Algorithm Validation (2) Compare IASI and AIRS OLR through SNO Observations



- Temporal range: Jan. 1, 2009 to July 31, 2011.
- Threshold:
  - Time difference < 60 s
  - Space difference < 30 km
- 180 cases where coefficient variation of AIRS OLR < 1.5 %.

Assumptions and Limitations

- **Assumptions:**
  - » The CrIS OLR algorithm will be evaluated by simultaneous S-NPP CERES OLR directly.
- **Limitations:**
  - » The accuracy of CrIS OLR is limited by that of CERES OLR.

Summary of OLR Algorithm Development

- Adaptation of AIRS experimental regression OLR algorithm to CrIS as a surrogate instrument of CERES.
- Integral CrIS and AIRS observed radiance in pseudo channel to reduce the uncertainties in correction of CrIS pseudo channel radiances to AIRS.
- CrIS OLR algorithms will be validated using simultaneous S-NPP CERES OLR.
- Regression coefficients for correction of CrIS pseudo channel radiances to AIRS will be generated.
- Collocation of AIRS and CERES will be implemented spatially.
- OLR regression coefficients will be calculated.

Review Outline

- Introduction
- ARR Phase 2 Report
- Phase 3 Requirements
- Concept of Operations
- Algorithm Theoretical Basis: OLR
- Algorithm Theoretical Basis: ILS
- Algorithm Theoretical Basis: Collocation
- Phase 3 Software Architecture
- Quality Assurance
- Risk Summary
- Summary and Conclusions

Section 6 –

Algorithm Theoretical Basis: Instrument Line Shape (ILS) Distortion Effects in Presence of Scene Inhomogeneities

Presented by

Antonia Gambacorta

Introduction

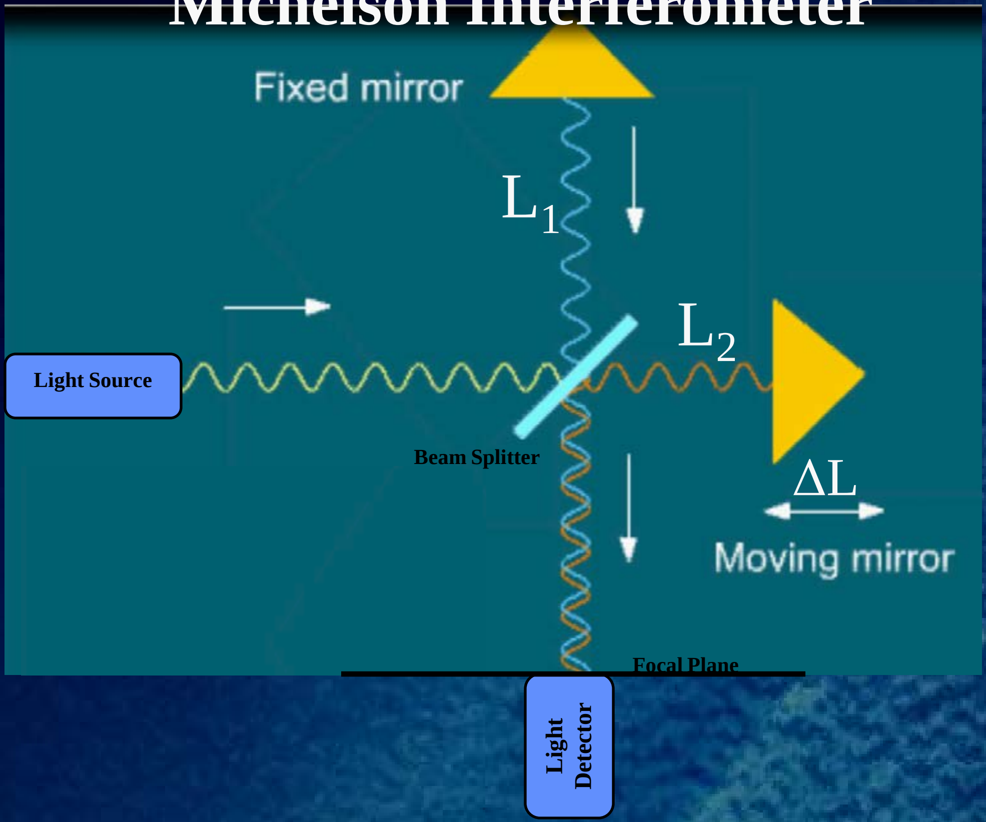
- **The precise knowledge of the Instrument Line Shape (ILS) of an interferometer is critical for any application of the radiance measurement: any error in the knowledge of the ILS will introduce a signal attribution error *δR* in the radiance spectrum.**

- **Scene in-homogeneities (clouds, surface in-homogeneities over the field of view) are responsible for a distortion of the theoretical ILS, which is mainly a peak frequency shift effect, *δv*, hence the definition of "ILS shift".**

- ***1) What is the magnitude of the radiance error introduced by the ILS distortion?***
- ***2) What is the impact on the retrieval accuracy?***

Basic Concept of Interferometry

Michelson Interferometer



The detector measures the variation of intensity as the mirror is displaced:

$$G(x) = g(\nu)[1 + \cos(2\pi\nu \cdot x)]$$

g(ν) = Input radiant power at frequency ν

x = Optical Path Difference = 2(L1-L2)

Constructive Interference: x = nλ

Destructive Interference: x = (2n+1) λ/2

Polychromatic source:

$$G(x) = \int_0^\infty g(\nu)[1 + \cos(2\pi\nu \cdot x)]d\nu$$

Interferogram = oscillating part of G(x)

$$I(x) = \int_0^\infty g(\nu)\cos(2\pi\nu \cdot x)d\nu$$

The spectrum of the Source is Given by the Fourier Transform of the Interferogram

In practice the first term is lost due to AC coupling of the detectors.
Interferogram = oscillating part of G(x)

$$I(x) = KY\mathrm{H}\int_{0}^{\infty} g(\nu)\cos(2\pi\nu\cdot x)d\nu$$

(cm^2 sr) (Volts/Watts) (Watts/cm^2 /sr/cm^{-1}) cm^{-1}= Volts

→ Detector response (Volts/Watts)
→ Optical acceptance (cm^2 sr)
→ Amplifier gain or optical losses

$$I(x) = C\int_{-\infty}^{\infty} g'(\nu)\cos(2\pi\nu x)d\nu = C\int_{-\infty}^{\infty} g'(\nu)\exp(j2\pi\nu x)d\nu$$

$$g'(\nu) = \begin{cases} \dfrac{g(\nu)}{2} & for\,\nu \geq 0 \\ \dfrac{g(\nu)}{2} & for\,\nu < 0 \end{cases}$$

I(x) is the Fourier transform of the source, g(ν).
The spectrum of the source is given back by the Inverse Fourier transform of I(x):

$$g(\nu) = \mathrm{F}^{-1}[I(x)] = \frac{2}{C}\int_{-\infty}^{+\infty} I(x)\exp(j2\pi\nu x)dx$$

Can’t measure x over [-∞, ∞]
The interferogram is truncated at L_{max}

Truncation of the Interferogram

The measurement limit is a truncation of the interferogram between ±L_{max} :

$$g_{meas}(v) = \frac{2}{C}\int_{-\infty}^{+\infty} A(x)I(x)\exp(j2\pi vx)dx$$

$$A(x) = \begin{cases} 1; |x| \le L_{max} \\ 0; |x| > L_{max} \end{cases}$$

$$g_{meas}(v) = \frac{2}{C}\mathrm{F}[A(x)I(x)] = \frac{2}{C}\mathrm{F}[A(x)] \otimes \mathrm{F}[I(x)] = \mathrm{ILS} \otimes \mathrm{g}(v)$$

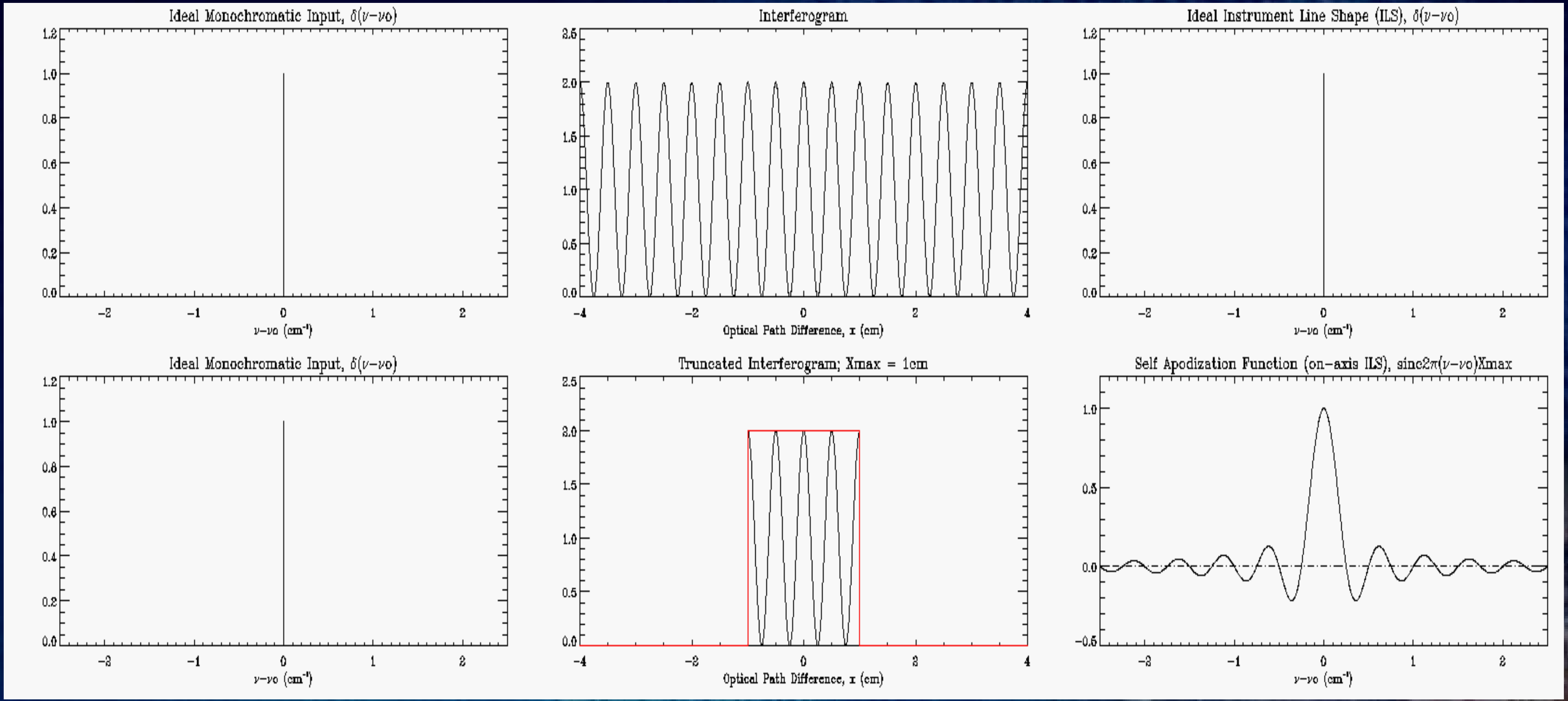
The instrument effect is a loss in accuracy where the original spectrum is “broaden” by the convolution with the instrument line shape function:

$$g_{meas}(v) = \int_{-\infty}^{+\infty} ILS(v - v')g(v')dv'$$

In the case of the box car function, A(x):

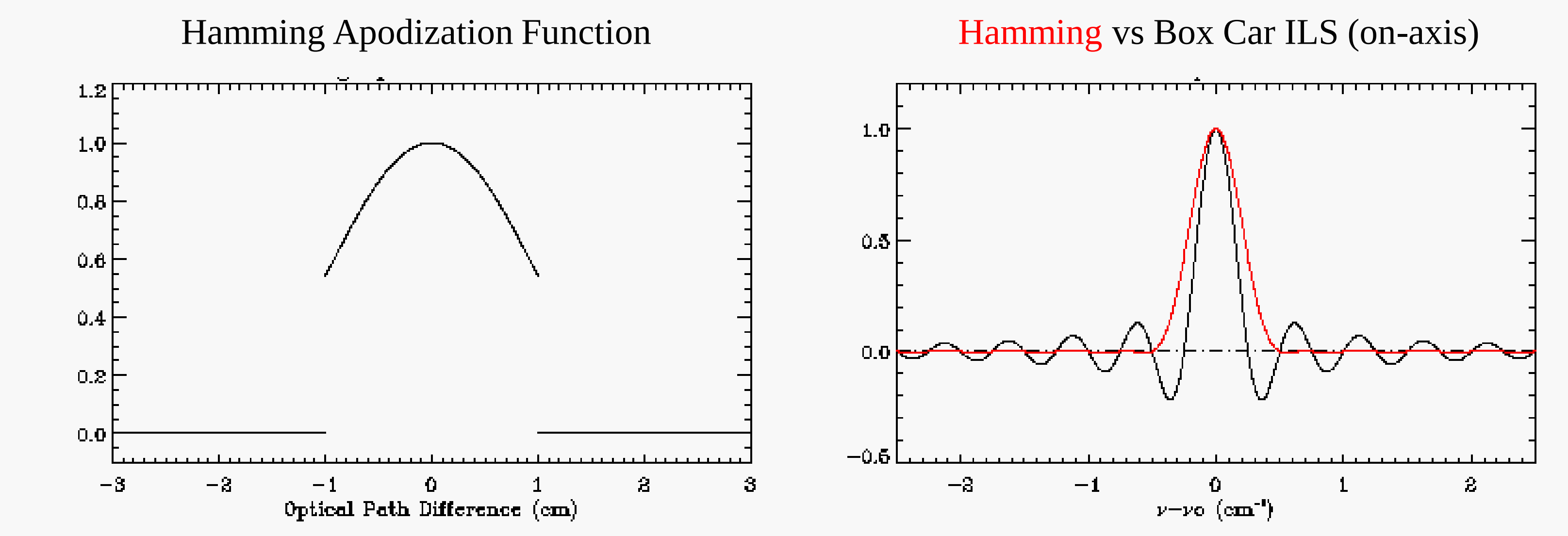
$$ILS = \mathrm{F}[A(x)] = 2L_{max}\frac{\sin(2\pi vL_{max})}{2\pi vL_{max}} = 2L_{max}\,\mathrm{sinc}(2\pi vL_{max})$$

Truncation of the Interferogram & Resulting Instrument Line Shape



The Instrument Line Shape resulting from the box-car truncation is a sinc function with pronounced side lobe effects.

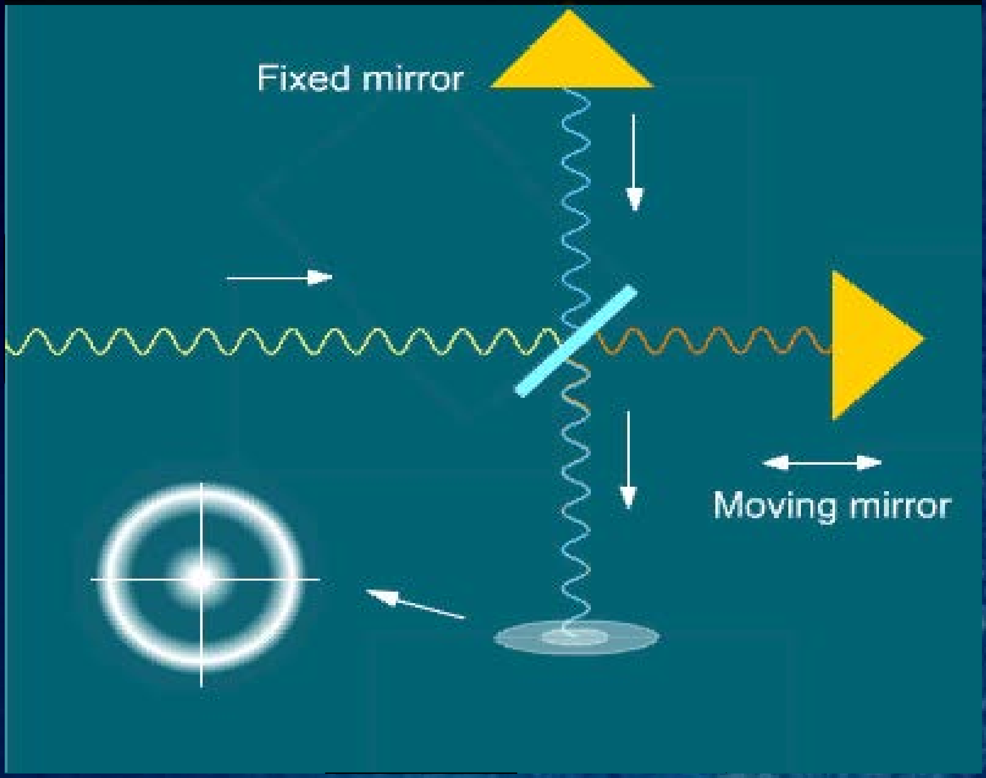
Hamming Apodization Function (on-axis monochromatic input)



The Instrument Line Shape resulting from the Hamming truncation function is a more smoothed function that gets rid of side lobe effects with the penalty of lower spectral resolution and correlated adjacent channels.

Basic Concept of Interferometry

Michelson Interferometer



A natural source of light has off-axis propagating beams which will intercept the focal plane at different angles, α.

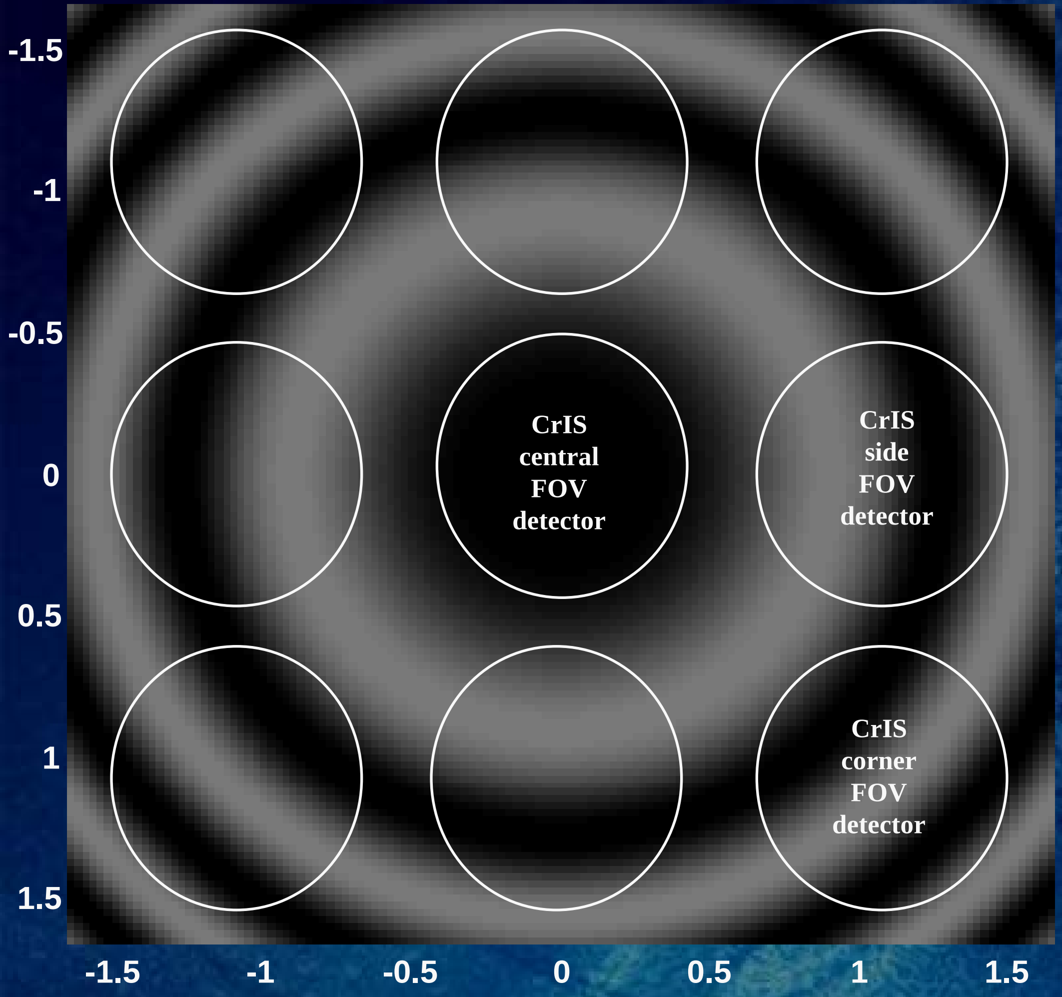
Off-axis optical path difference:

$X_{off\text{-}axis} = X_{on\text{-}axis}\cos\alpha$

The off-axis measurement on the screen is a α-dependent interference pattern consisting of a bright center and alternating dark and bright fringes given by:

$$G(x) = g(\nu)[1 + \cos(2\pi\nu \cdot x\cos\alpha)]$$

Self Apodization Effect & CrIS FOV Geometry

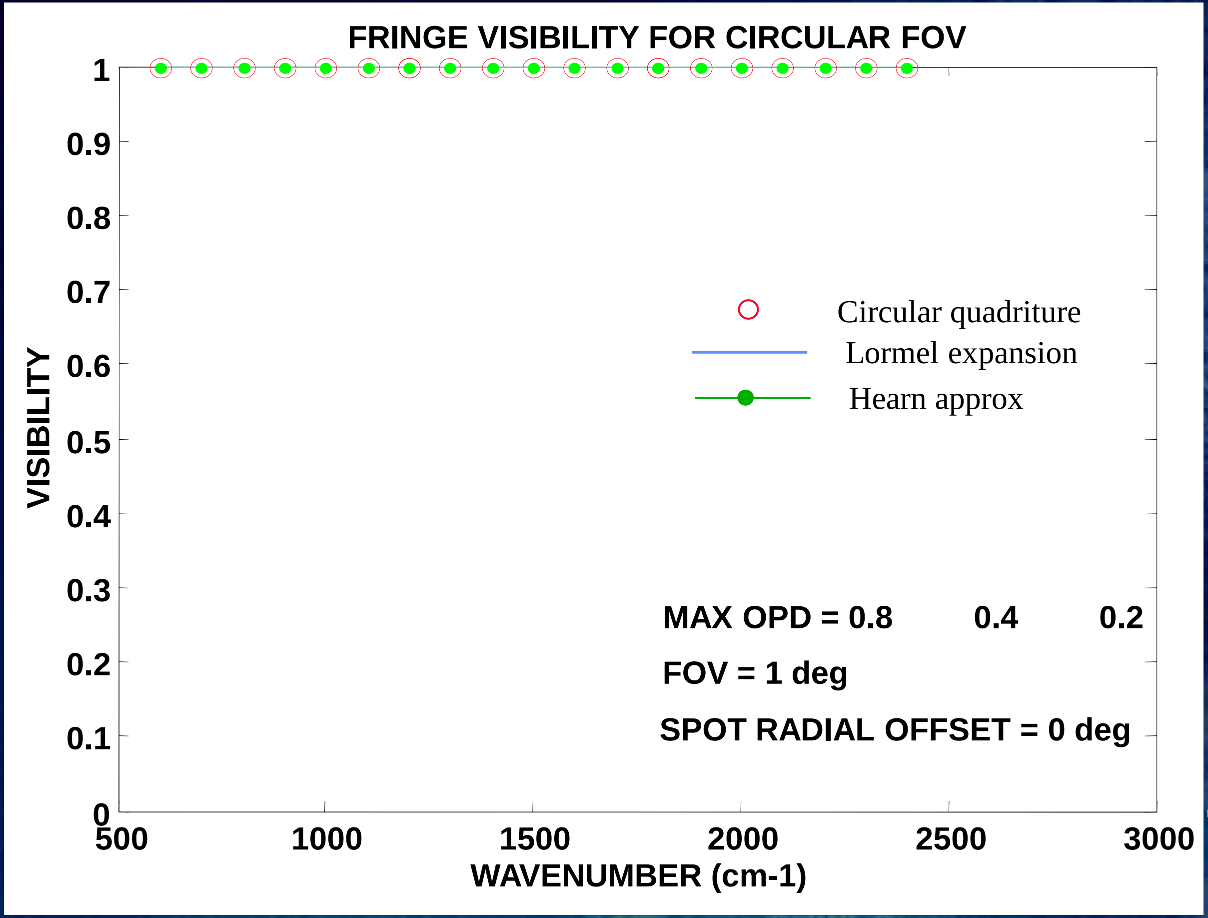


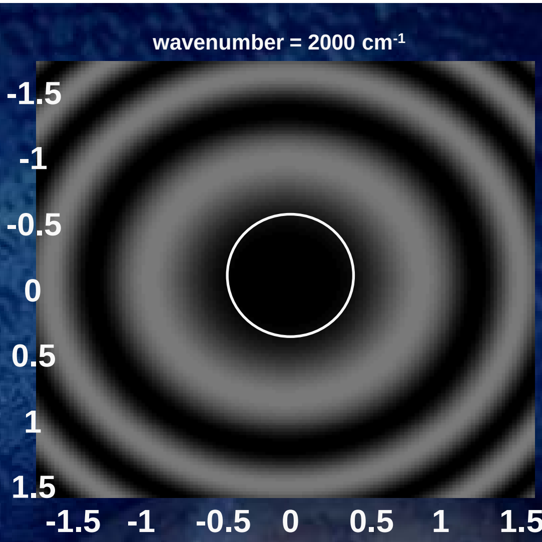
What the detector measures is the integration over the solid angle subtended by the detector at the exit pupil:

$$G(x) = \int_{0}^{\Omega_{\max}} G(x,\Omega)\, d\Omega$$

If the detector FOV falls beyond the central bright spot, it will integrate over bright and dark fringes, hence a signal loss corresponding to a reduction in signal to noise ratio ("Self Apodization Effect")

Visibility for CrIS Central FOV





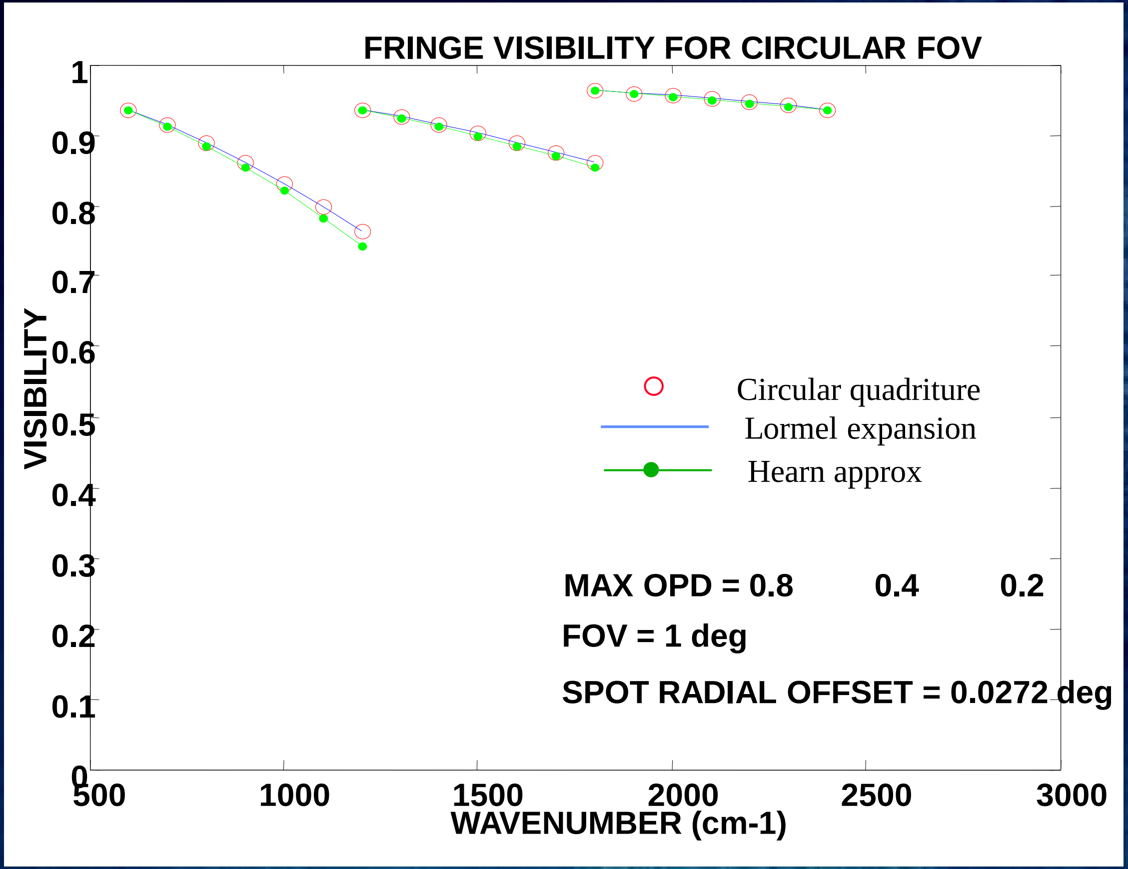
Picture courtesy of D. Mooney

Define visibility V(x):

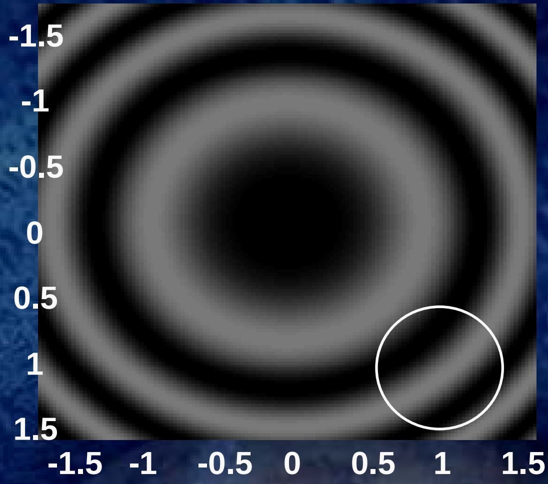
$$V(X) = \frac{G_{\max}(x) - G_{\min}(x)}{G_{\max}(x) + G_{\min}(x)}$$

The central detector falls inside the central bright spot. There is no loss in signal, V(x) =1

Visibility for CrIS Corner FOV



Picture courtesy of D. Mooney

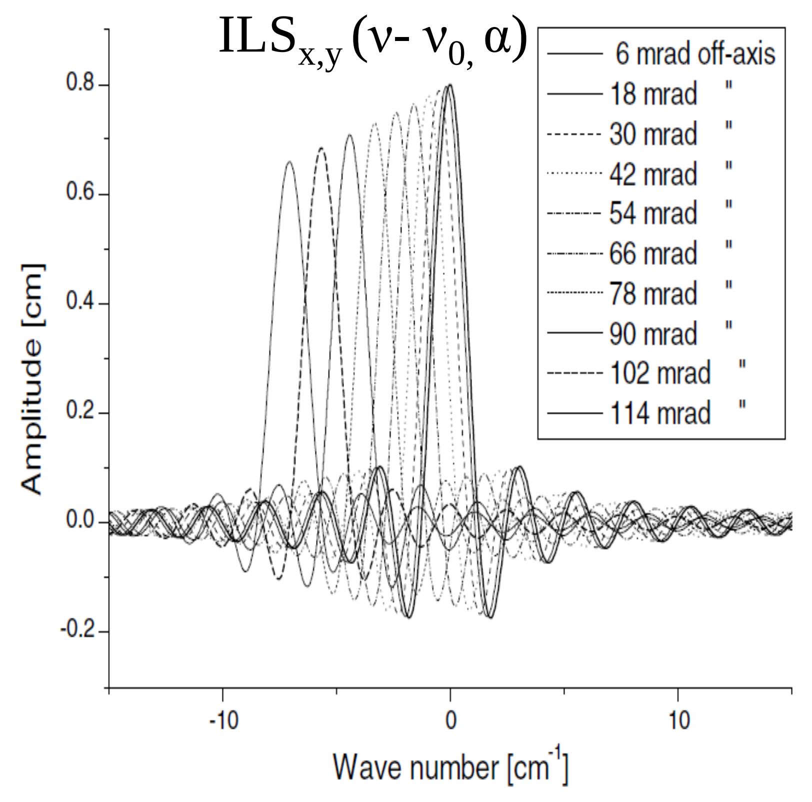


Define visibility V(x):

$$V(X)=\frac{G_{\max}(x)-G_{\min}(x)}{G_{\max}(x)+G_{\min}(x)}$$

The corner detector falls outside the central bright spot. There is a loss in signal, V(x) <1.

Off-Axis ILS



The off-axis ILS is shifted, asymmetric and attenuated. The frequency shift of the peak is the dominating effect and is related to the angular offset of the light beam as:

$$\frac{\delta\upsilon}{\upsilon} \sim \alpha\delta\alpha$$

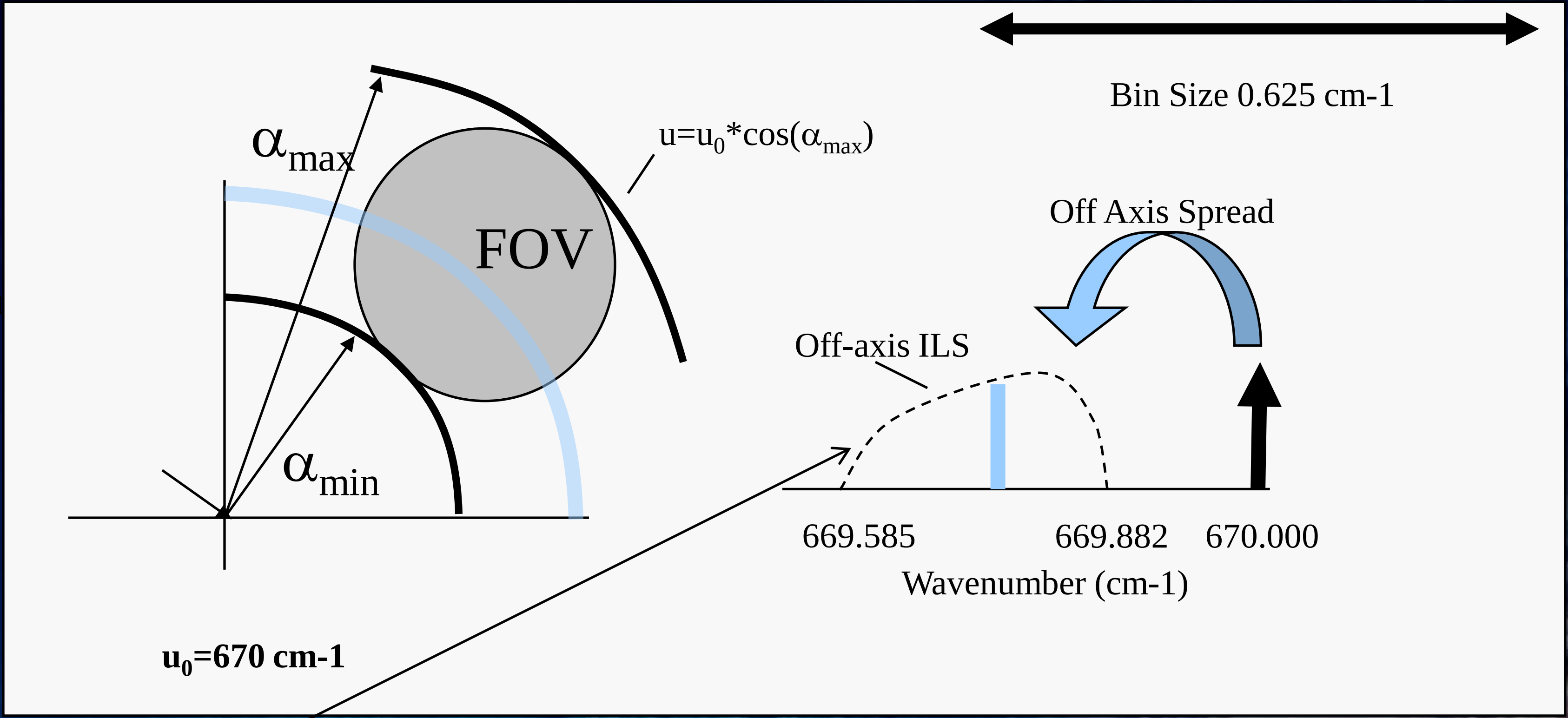
<u>**Homogeneous source (and monochromatic):**</u>

$$\mathrm{ILS}^{\alpha}{}_{x,y}\left(\nu-\nu_0\right)=\mathrm{ILS}^{\alpha}{}_{x',y'}\left(\nu-\nu_0\right)$$

We can express the resulting output spectrum at each frequency as:

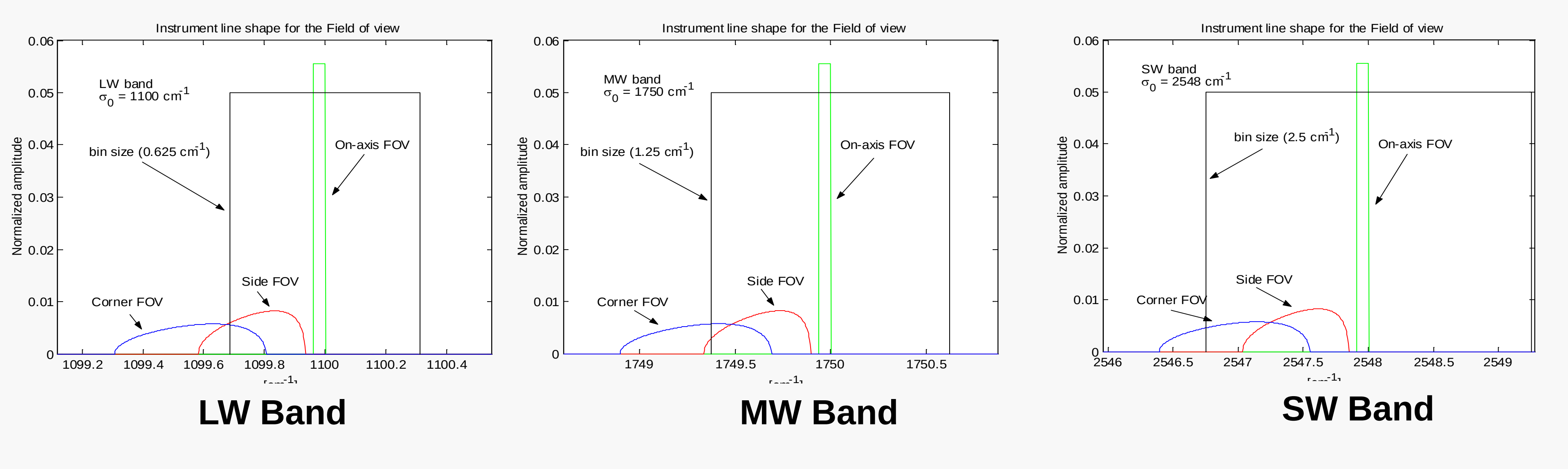
$$g_{meas}(\nu)=\sum_{FOV} ILS_{x,y}(\nu-\nu_0)\otimes g(\nu_0)$$

Smear & Shift Effect in an OFF-Axis FOV ILS



$$\mathrm{ILS}_{\mathrm{FOV}}(v-v_0)=\sum_{FOV} ILS_{x,y}(v-v_0)$$

Smear & Shift Effect of Each FOV ILS in the 3 Bands (one example for each band)



LW Band **MW Band** **SW Band**

Picture courtesy of D. Mooney

- Shifts of the ILS by half a bin width are typical for corner FOVs

Self Apodization Matrix

Polychromatic, homogeneous source:

$$g_{meas}(v) = \sum_{FOV} ILS_{x,y}(v - v_0) \otimes g(v_0) + \sum_{FOV} ILS_{x,y}(v - v_1) \otimes g(v_1) + \ldots + \sum_{FOV} ILS_{x,y}(v - v_n) \otimes g(v_n)$$

$$g_{meas}(v) = \mathrm{ILS}_{FOV}(v - v_0) \otimes g(v_0) + \mathrm{ILS}_{FOV}(v - v_1) \otimes g(v_1) + \ldots$$

In matrix form (“Self Apodization Matrix”):

$$\begin{bmatrix} g_{\mathrm{meas}}(\nu_0) \\ g_{\mathrm{meas}}(\nu_1) \\ \ldots \\ \ldots \\ \ldots \\ g_{\mathrm{meas}}(\nu_n) \end{bmatrix} = \begin{bmatrix} \mathrm{ILS}_{\mathrm{FOV}}(\nu_0 - \nu_0) & \mathrm{ILS}_{\mathrm{FOV}}(\nu_0 - \nu_1) & \ldots & \mathrm{ILS}_{\mathrm{FOV}}(\nu_0 - \nu_n) \\ \mathrm{ILS}_{\mathrm{FOV}}(\nu_1 - \nu_0) & \mathrm{ILS}_{\mathrm{FOV}}(\nu_1 - \nu_1) & \ldots & \mathrm{ILS}_{\mathrm{FOV}}(\nu_1 - \nu_n) \\ & \ldots & & \\ & \ldots & & \\ & & & \\ \mathrm{ILS}_{\mathrm{FOV}}(\nu_n - \nu_0) & \mathrm{ILS}_{\mathrm{FOV}}(\nu_n - \nu_1) & \ldots & \mathrm{ILS}_{\mathrm{FOV}}(\nu_n - \nu_n) \end{bmatrix} \begin{bmatrix} g_{\alpha=0}(\nu_0) \\ g_{\alpha=0}(\nu_1) \\ \ldots \\ \ldots \\ \\ g_{\alpha=0}(\nu_n) \end{bmatrix}$$

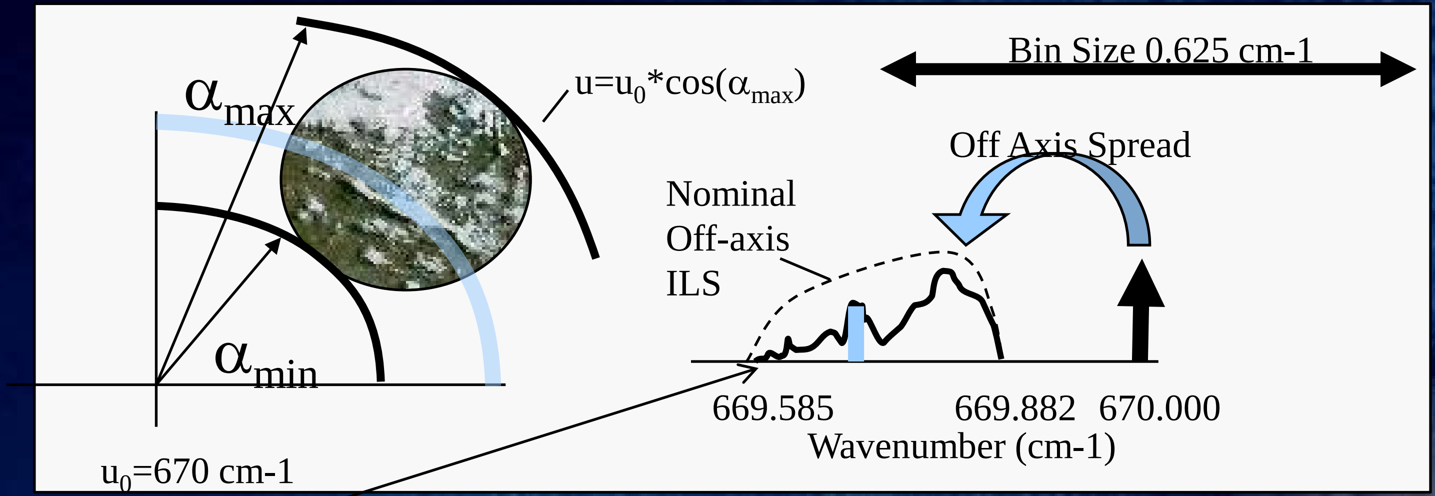
IMPORTANT: The inversion of the self apodization matrix allows for off-axis correction and removes the self-apodization effect of the 9 FOVs.

The self apodization removal requires accurate knowledge of each $\mathrm{ILS}_{\mathrm{FOV}}$ (“Nominal ILS)”

FOV ILS Distortion in Presence of Scene Inhomogeneities

In-homogeneous scene:

$$\mathrm{ILS}^{\alpha}{}_{x,y}\left(\nu-\nu_0\right)\neq \mathrm{ILS}^{\alpha}{}_{x',y'}\left(\nu-\nu_0\right)$$



$$\mathrm{ILS}_{\mathrm{FOV}}(\nu-\nu_0)=\sum_{FOV} ILS_{x,y}(\nu-\nu_0)$$

- Scene in-homogeneities (clouds, surface variability, et.) are responsible for an *angular* shift of the radiometric center of the FOV (towards the location in the FOV where the warmer scenes are distributed) and an associated distortion of the nominal FOV ILS. This introduces an error in the nominal self apodization matrix which mainly consists in a spectral shift of the FOV ILS peak frequency.
- This error is propagated through the off-axis correction (inversion of the self apodization matrix) introducing a signal attribution error in the radiance spectrum.

Why is it important to assess the magnitude of the radiance error introduced by the ILS distortion?

- Scene in-homogeneities (clouds, surface variability, et.) are responsible for an *angular* shift of the radiometric center of the FOV (towards the location in the FOV where the warmer scenes are distributed) and an associated distortion of the nominal FOV ILS. This introduces an error in the nominal self apodization matrix which mainly consists in a spectral shift of the FOV ILS peak frequency.
- This error is propagated through the off-axis correction (inversion of the self apodization matrix) introducing a signal attribution error in the radiance spectrum.

- Assessing the magnitude of the radiance error introduced by the ILS distortion is important for remote sensing applications.
- Example: Forcings/Feedbacks studies
    - CO2 growth rate is 2 ppm/year and introduces a forcing of 0.06K/year at 2388 cm^{-1}
    - AIRS stability < 0.01K/year (radiometric and frequency)allows CO2trends/variability to <0.5 ppm.
    - CrIS frequency errors of 1 ppm = 0.015K at 2388 cm^{-1}
    - Need frequency errors on CrIS <1 ppm to reach AIRS stability and measure 0.5 ppm CO2 forcing.
- Example: atmospheric retrieval from data assimilation
    - Any radiance signal attribution error δR will propagate into a retrieval error δX

- **What's the magnitude of the radiance error introduced by the ILS distortion?**
- **What is the impact on the NUCAPS retrievals accuracy?**

What's the magnitude of the radiance error introduced by the ILS distortion due to scene inhomogeneities?

Two possible approaches:

1) By simulation, we can create an ensemble of in-homogeneuos scenes, parameterize the radiative properties of the scene in-homogeneities and correct the self apodization matrix. Compute corrected radiances and calculate δR. Computationally intense, need a correct parameterization of radiative properties of all possible scene in-homogeneities.
2) Use a sub-pixel imager to measure the actual angular shift δα of the FOV radiometric centroid. Determine the corresponding spectral shift δν of the FOV ILS:

$$\frac{\delta\upsilon}{\upsilon} \sim \alpha\delta\alpha$$

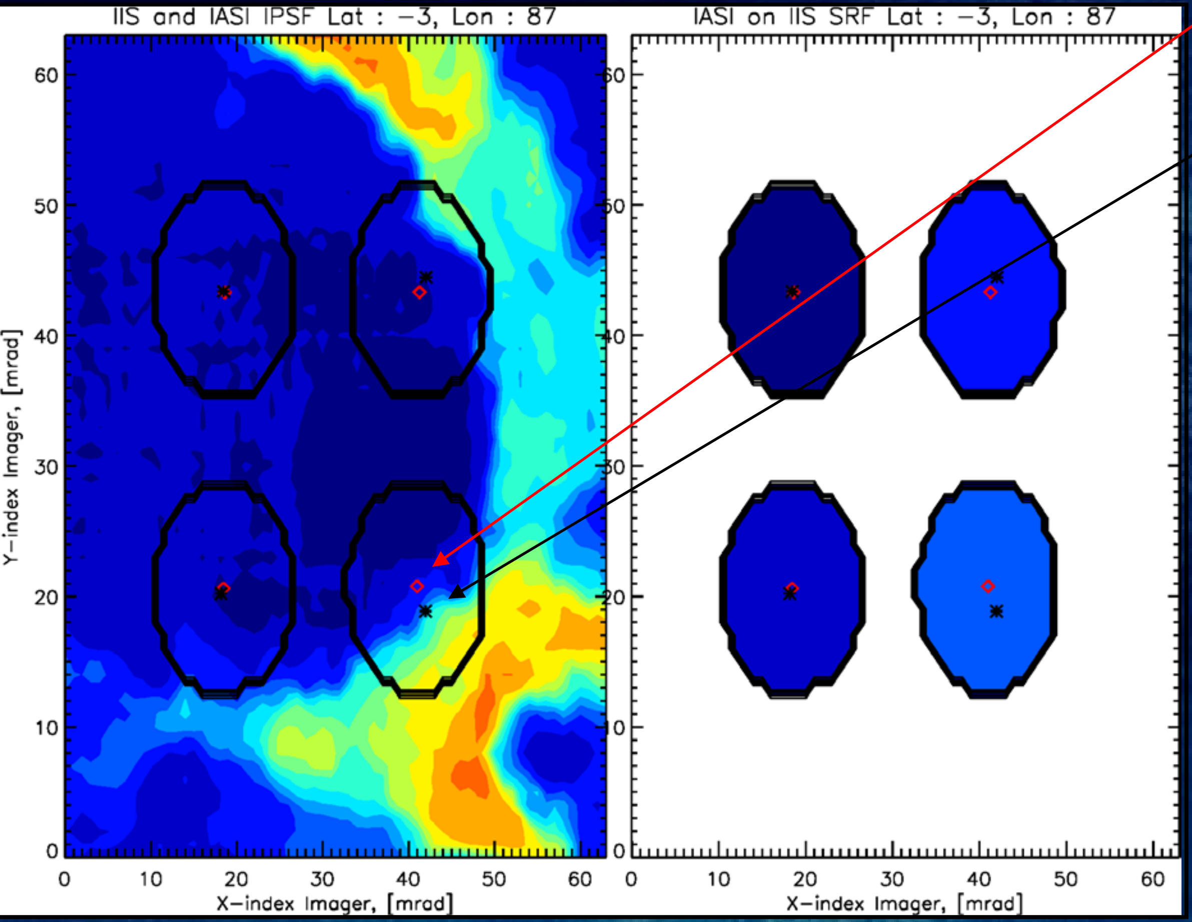
Re-sample the measured radiance spectrum via Fourier inversion and zero-filling technique and re-compute the corrected radiance spectrum. Compute δR.

Computationally intense but easier, need an accurately collocated sub-pixel imager.

- The onboard imager VIIRS is not perfectly collocated to CrIS to ensure the level of precision required to compute the angular radiometric offset.
- We run an experiment using the IASI (2x2 FOV geometry) and the associated Integrated Imaging Subsystem (IIS) instrument . The IIS lays on the same focal plane of IASI and offers a highly accurate collocation.
- We will leverage on the lessons learned from IASI+IIS to make appropriate conclusions on the ILS shift problem for the CrIS instrument (same instrument concept, different geometry).

IASI Nominal Geometric Centroids (◊) versus *Radiometric* Centroids (*) :

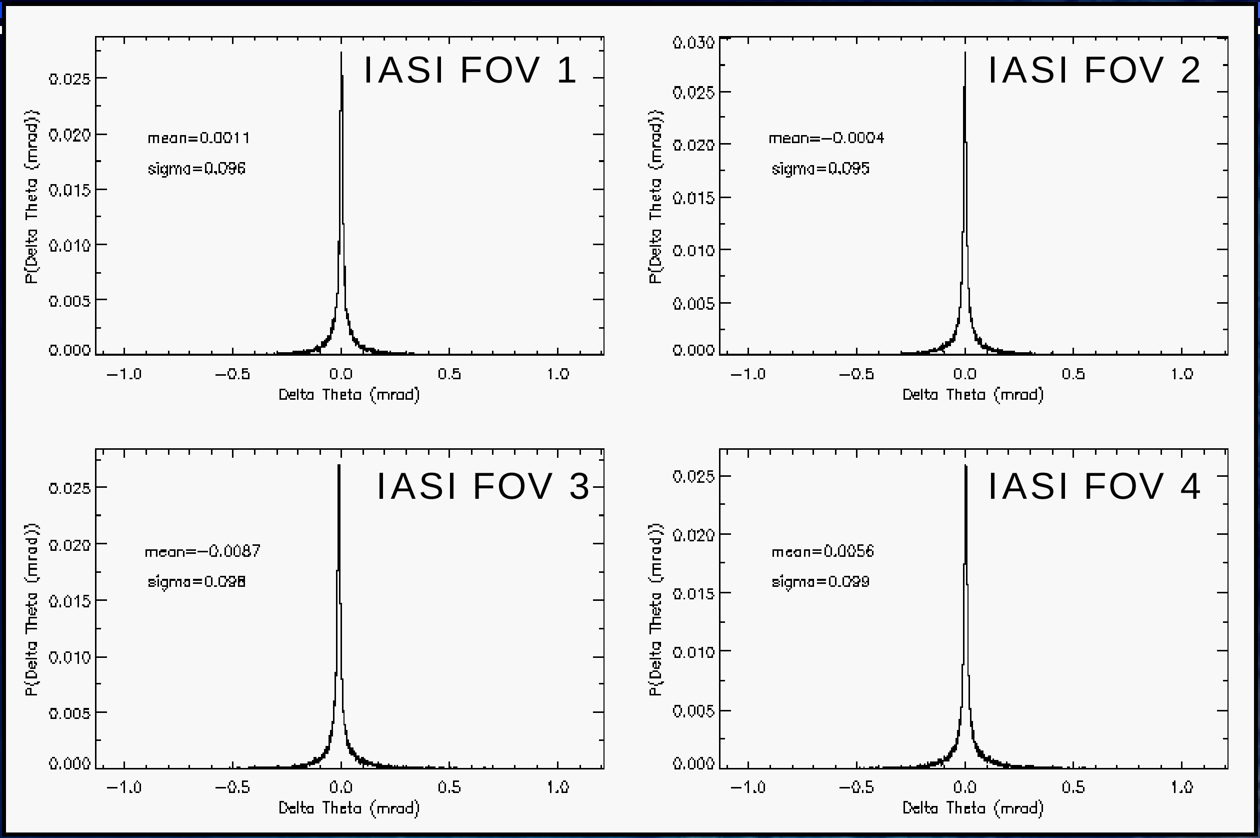
IIS Imager (64x64 pixels) and IASI FOVs (black contour)



- Nominal Geometric Centroids obtained from the IASI Instrument Point Source Function (IPSF)
- Radiometric Centroids obtained from integrating the IIS subpixel measurements (IIS LW frequency)
- Spatial inhomogeneities introduce a shift δα between the geometric and radiometric centroids .
- The higher the spatial inhomogeneity, the largest the radiometric centroid shift, δα.
- IASI’s detector (right panel) does not know anything about the sub-pixel in-homogeneities. The off-axis correction assumes uniform scenes and uses the nominal FOV ILS.
- The radiometric angular offset δα corresponds to a spectral shift δν in the FOV ILS introducing an error δR that we want to quantify.

IASI Centroid Angular Shift (δα, mrad) Distributions

(clear & cloudy scenes, October 19th, 2007)

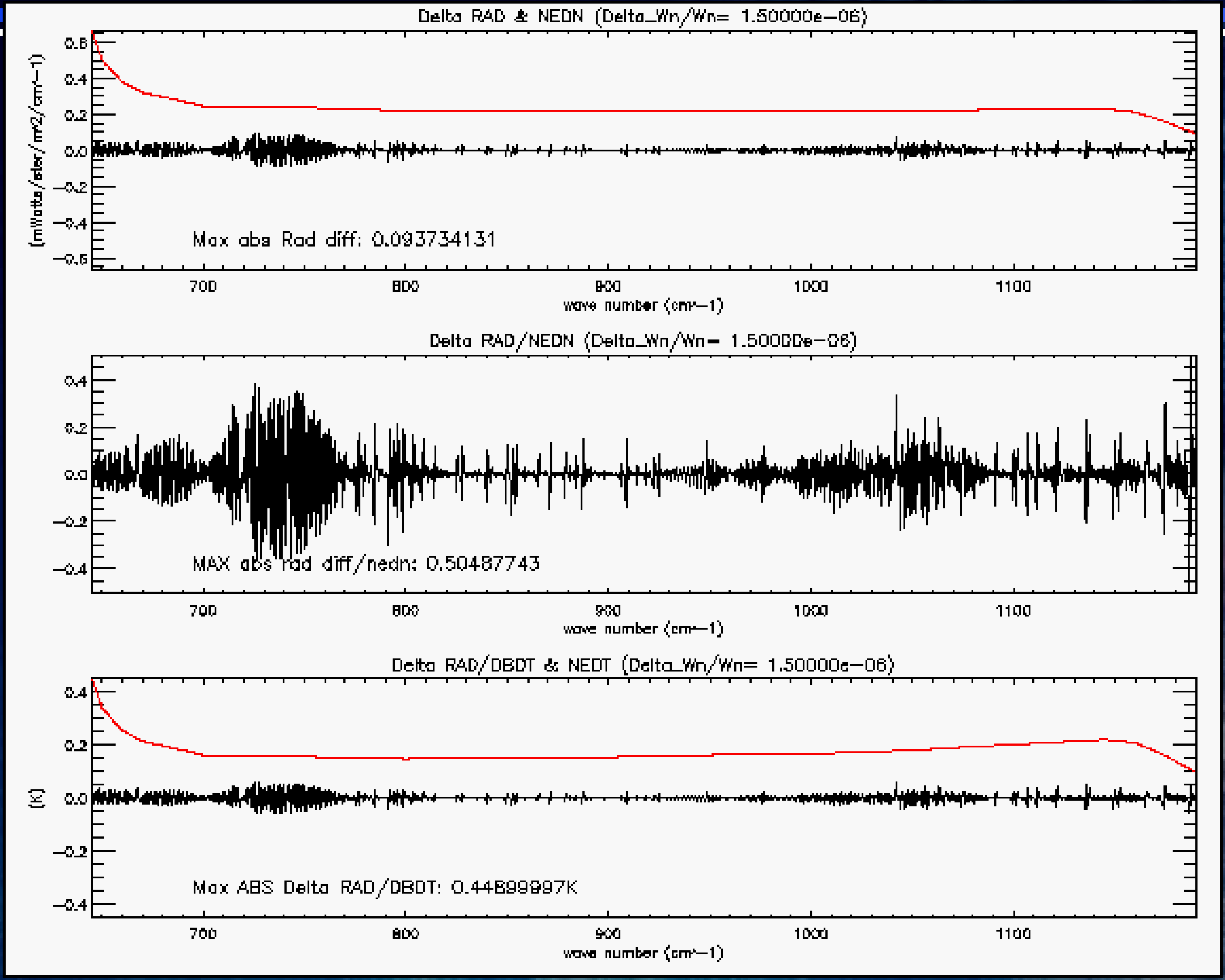


The angular offset distribution is similar across the 4 FOVs. The average offset is ~0.004 mrad, the 1sigma ~0.1mrad

$$\frac{\delta\nu}{\nu} \sim \alpha\delta\alpha = \begin{cases} 1.5\text{e-}06 \;\; (\;\delta\alpha = 1sigma \sim 0.1mrad\;) \\ 3.0\text{e-}06 \;\; (\;\delta\alpha = 2sigmas \sim 0.2mrad\;) \\ 4.5\text{e-}06 \;\; (\;\delta\alpha = 3sigmas \sim 0.3mrad\;) \end{cases}$$

In the next slides we compute the radiance error derived from the computed spectral shifts at δα=1, 2, 3 sigma

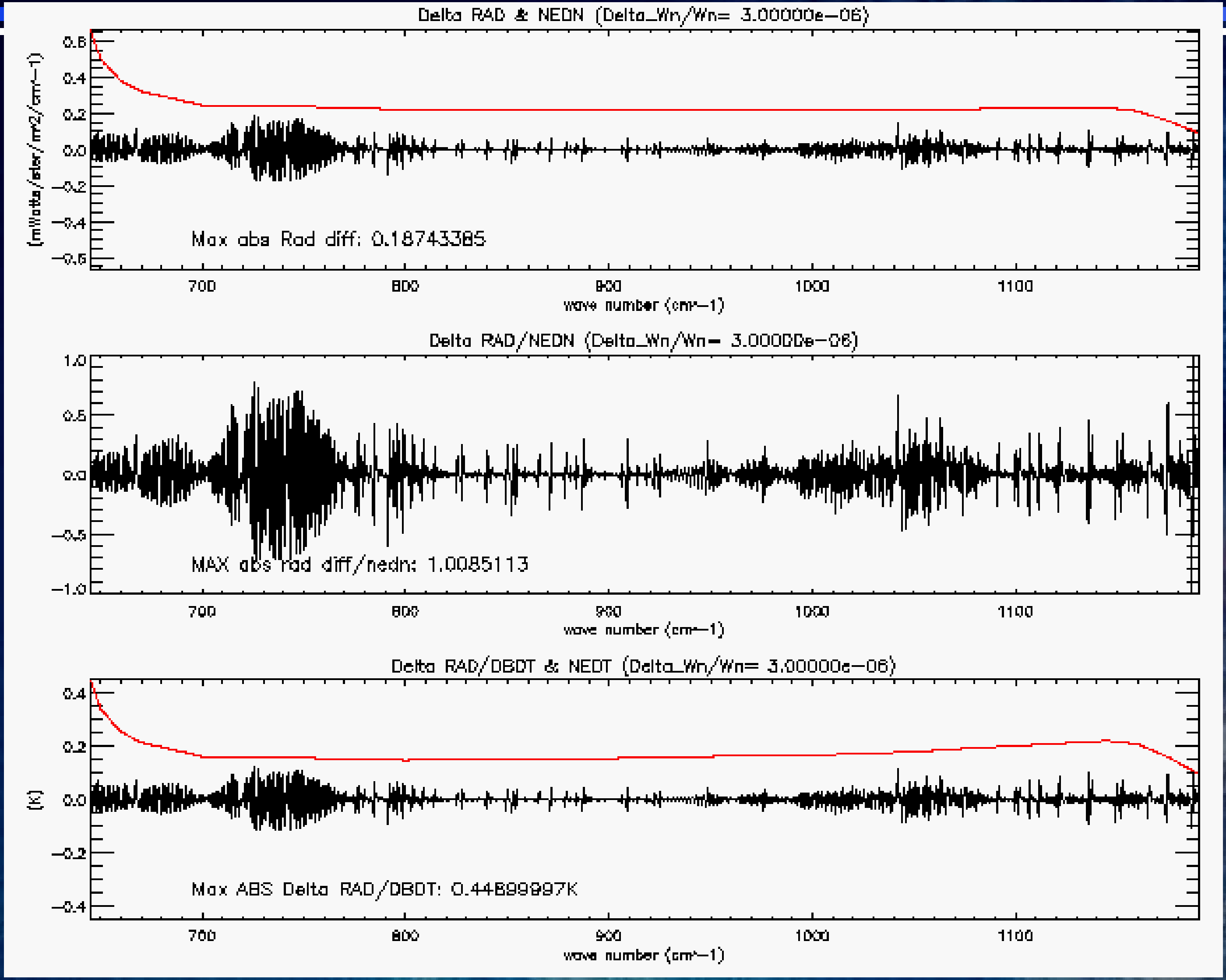
Radiance Error - BAND 1 (Gran # 393)
<u>dα=1 sigma</u> (0.1mrad): dν/ν~1.5e-06



<u>dα=0.1mrad</u>
(dν/ν~1.5e-06)

<u>BAND 1:</u>
The radiance error introduced by the ILS shift is much lower than the instrument noise

Radiance Error - BAND 1 (Gran # 393)
dα = 2 sigma (0.2mrad): dv/v~3e-06



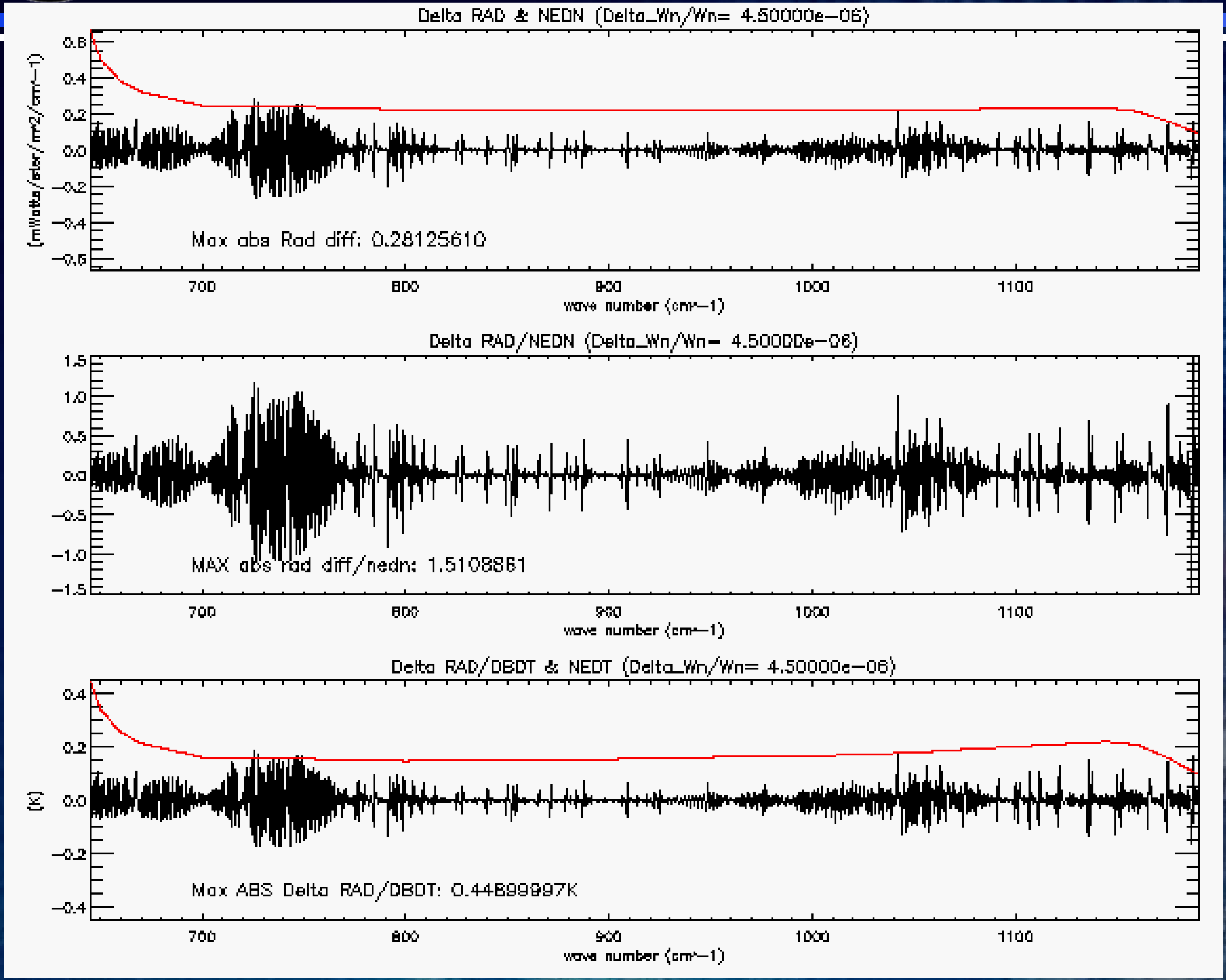
dα=0.2mrad
(dv/v~3e-06)

BAND 1:

The radiance error introduced by the ILS shift is much lower than the instrument noise

Radiance Error - BAND 1 (Gran # 393)

dα = 3 sigma (0.3mrad): dv/v~4.5e-06



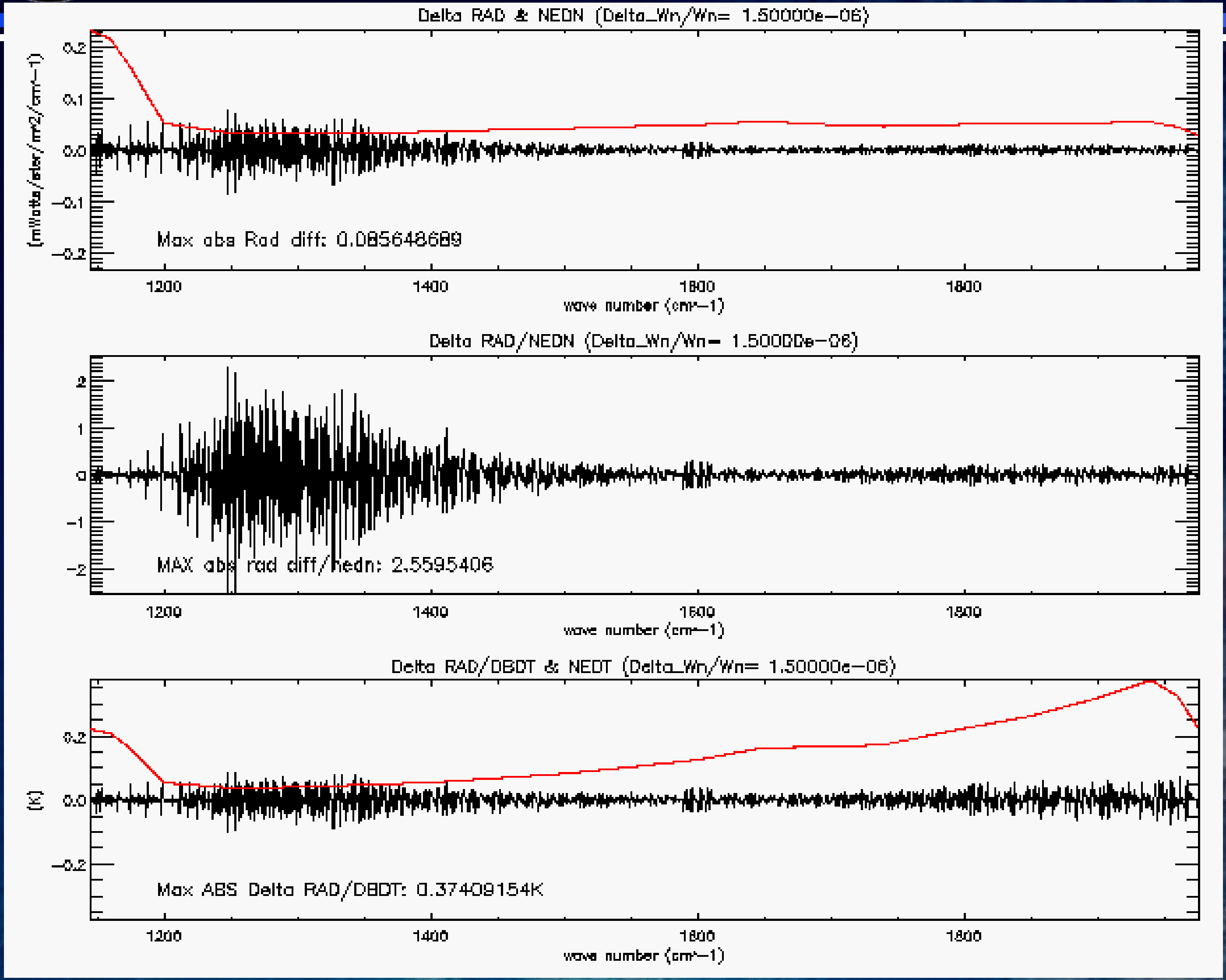
dα=0.3mrad

(dv/v~4.5e-06)

BAND 1:

The radiance error introduced by the ILS shift becomes comparable to the instrument noise

Radiance Error - BAND 2 (Gran # 393)
$d\alpha=1$ sigma (0.1mrad): dv/v~1.5e-06



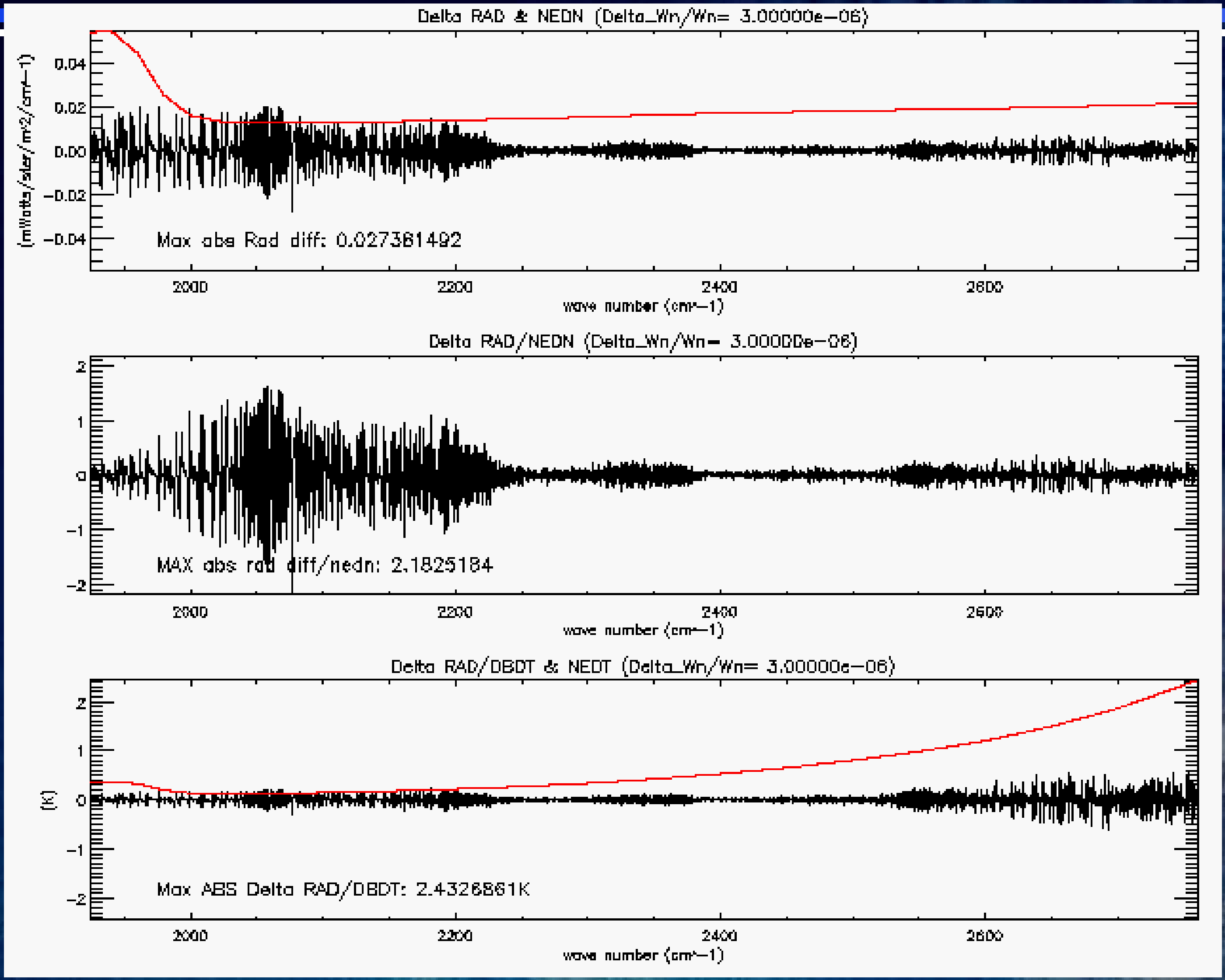
$d\alpha=0.1$mrad

(dv/v~1.5e-06)

BAND 2:

The radiance error introduced by the ILS shift is comparable to the instrument noise

Radiance Error - BAND 3 (Gran # 393)
dα =2 sigma (0.2mrad): dv/v~3e-06



dα=0.2mrad

(dv/v~3e-06)

BAND 3:

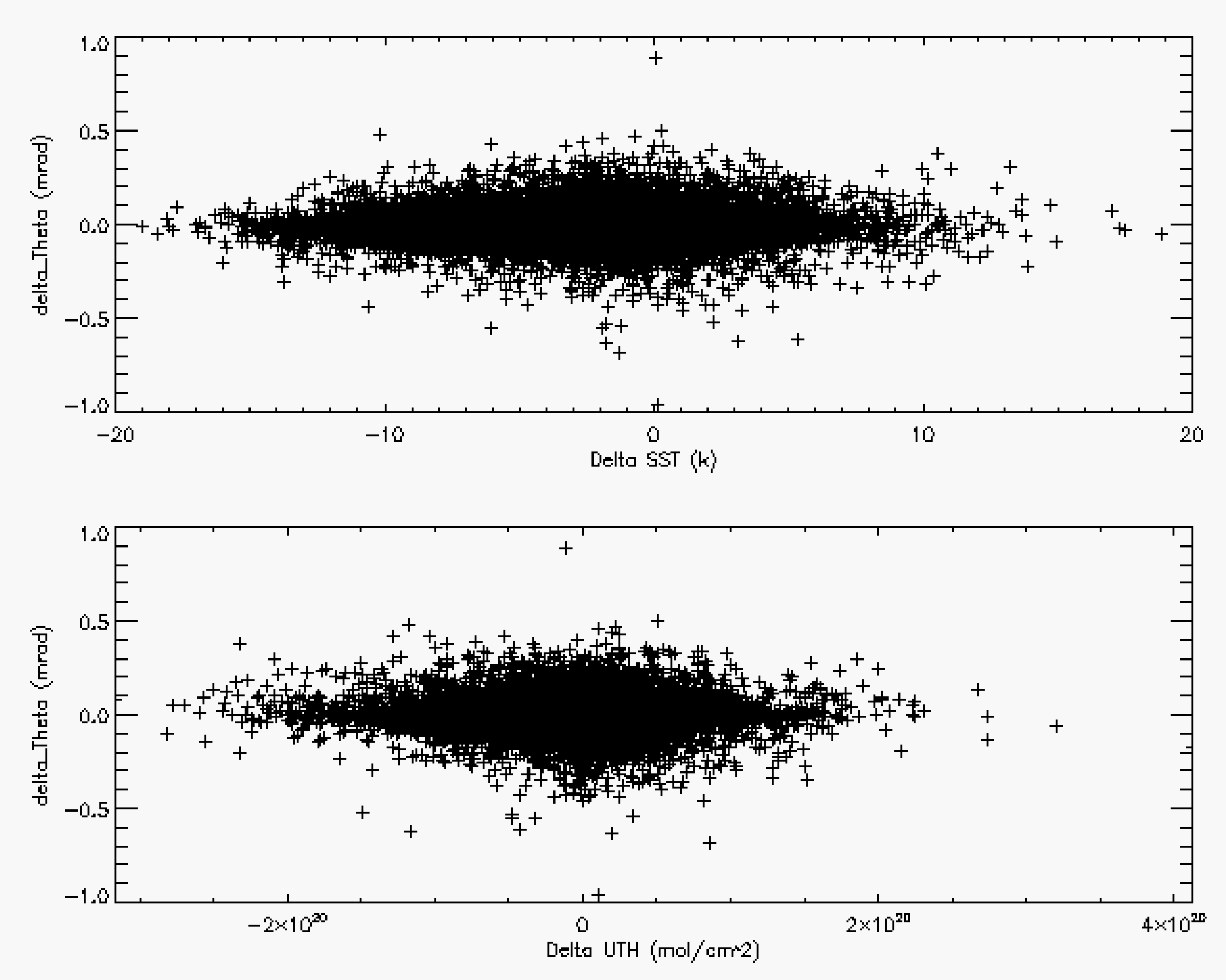
The radiance error introduced by the ILS shift is comparable to the instrument noise

Radiance Error Assessment

- The radiance error of the IASI spectra introduced by the ILS shift is generally negligible wrt the IASI instrument noise.
- Only 5% of the full day ensemble is seen to undergo an angular shift of ~1 sigma or higher.

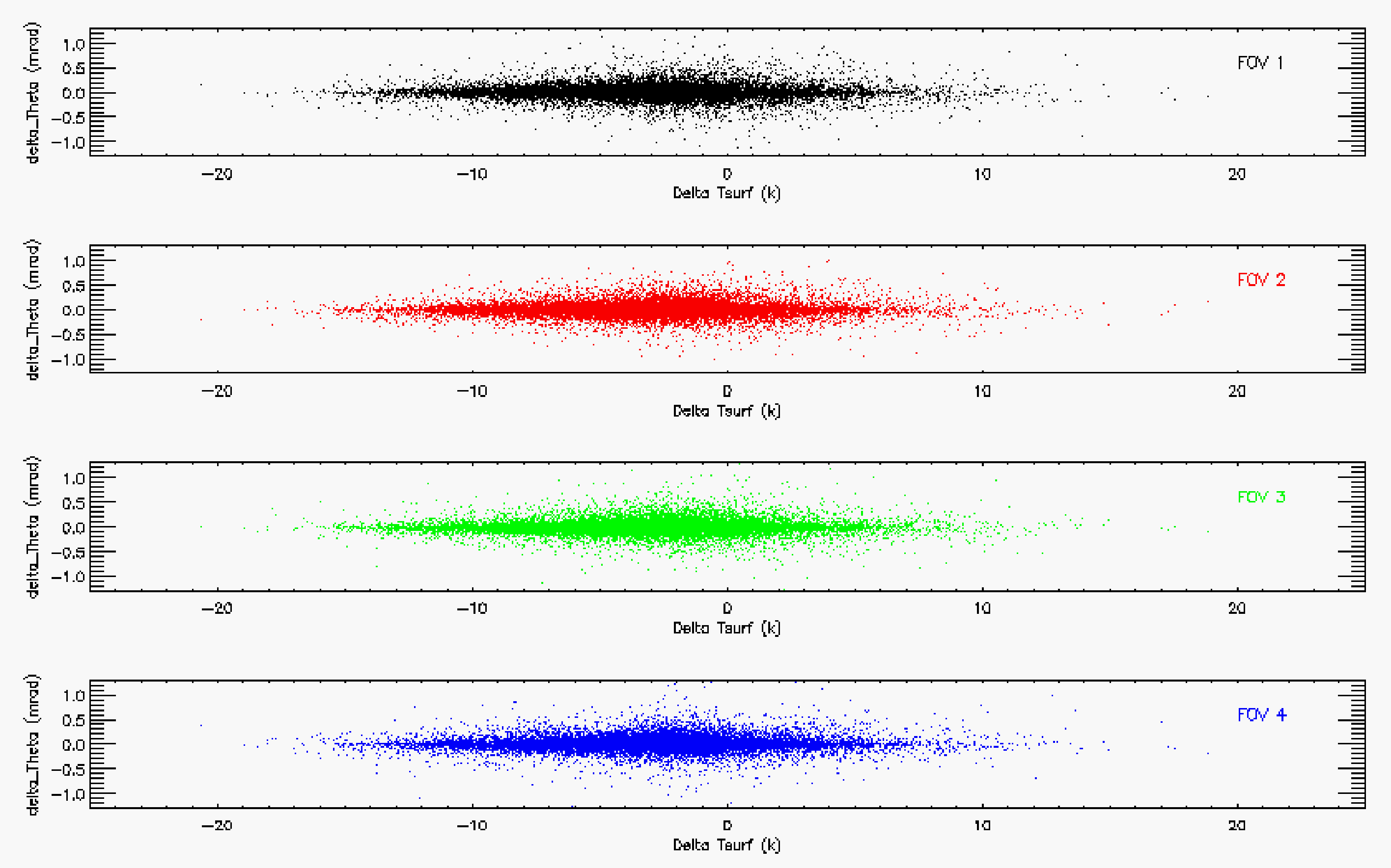
- Next slide: we investigate the effect of the ILS shift on the retrieval accuracy

4 FOV MEAN Centroid Shift vs SST & UTH bias (Oct 19 2007)



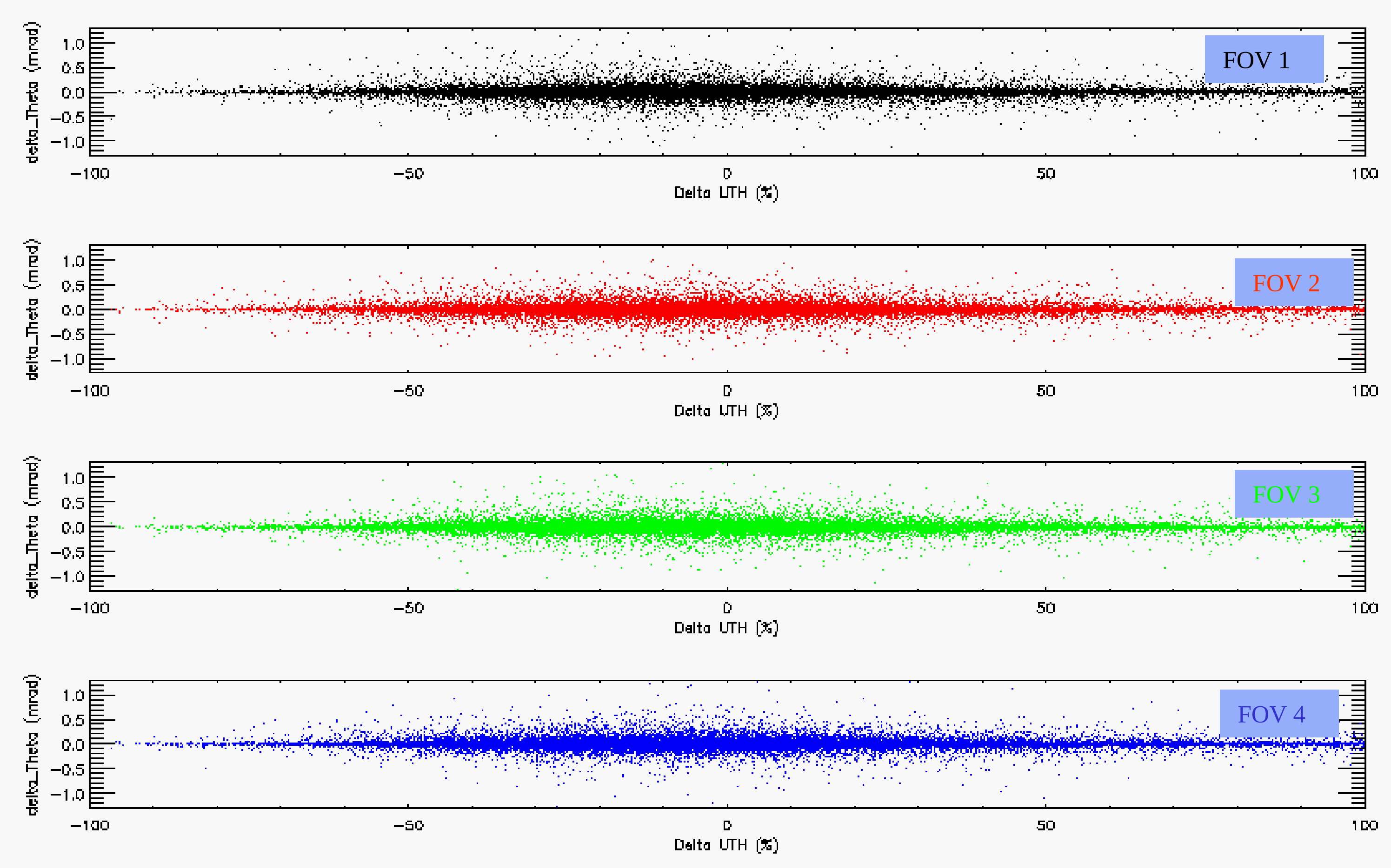
No significant correlation is seen to stand out between the averaged radiometric angular shift and the retrieved SST or UTH bias

Centroid Shift vs Tsurf bias (ret- ecmwf) (Oct 19 2007)



No significant correlation is seen to stand out between each FOV radiometric angular shift and the retrieved SST bias

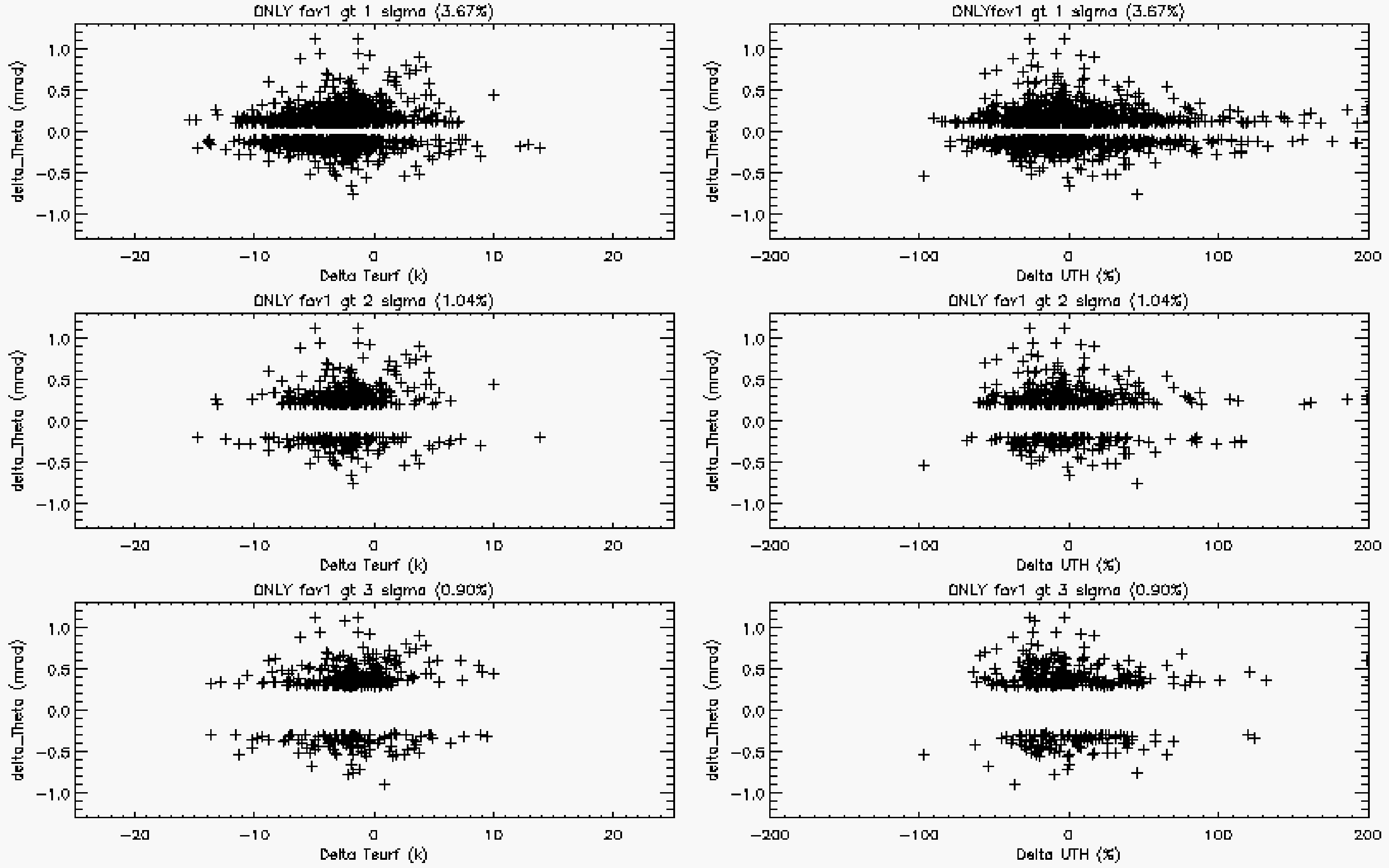
Centroid Shift vs UTH bias (ret- ecmwf) (Oct 19 2007)



No significant correlation is seen to stand out between each FOV radiometric angular shift and the retrieved UTH bias

Examples of cases that are likely to pass Radiance Cloud Clearing QAs (high cloud contrast)

1) ONLY FOV 1 has dα gt 1, all others lt 1 sigma
2) ONLY FOV 1 has dα gt 2, all others lt 1 sigma
3) ONLY FOV 1 has dα gt 3, all others lt 3 sigma

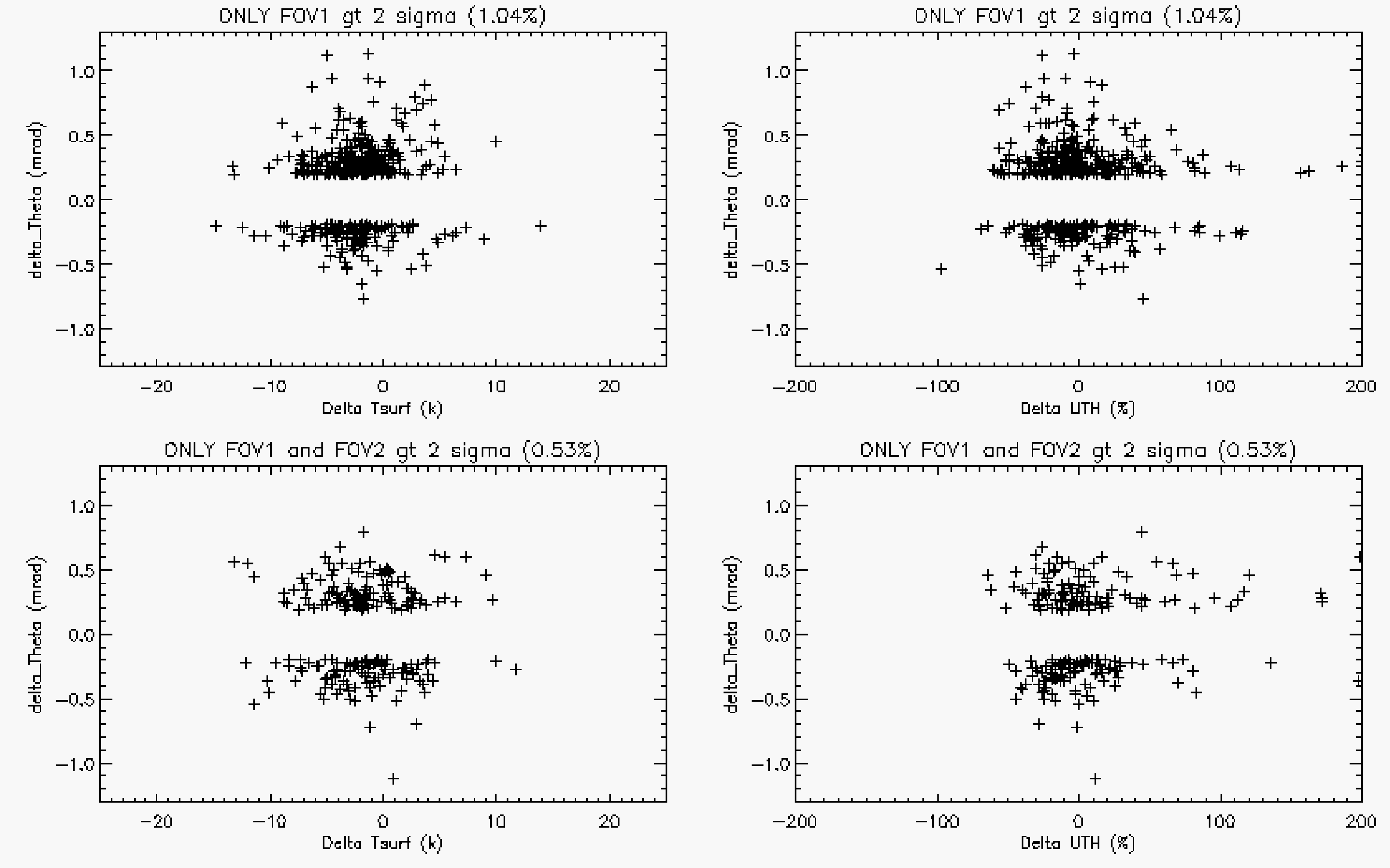


No significant correlation is seen to stand out between the radiometric angular shift and the retrieved SST or UTH bias

Examples of cases that are likely to pass Radiance Cloud Clearing QAs (high cloud contrast)

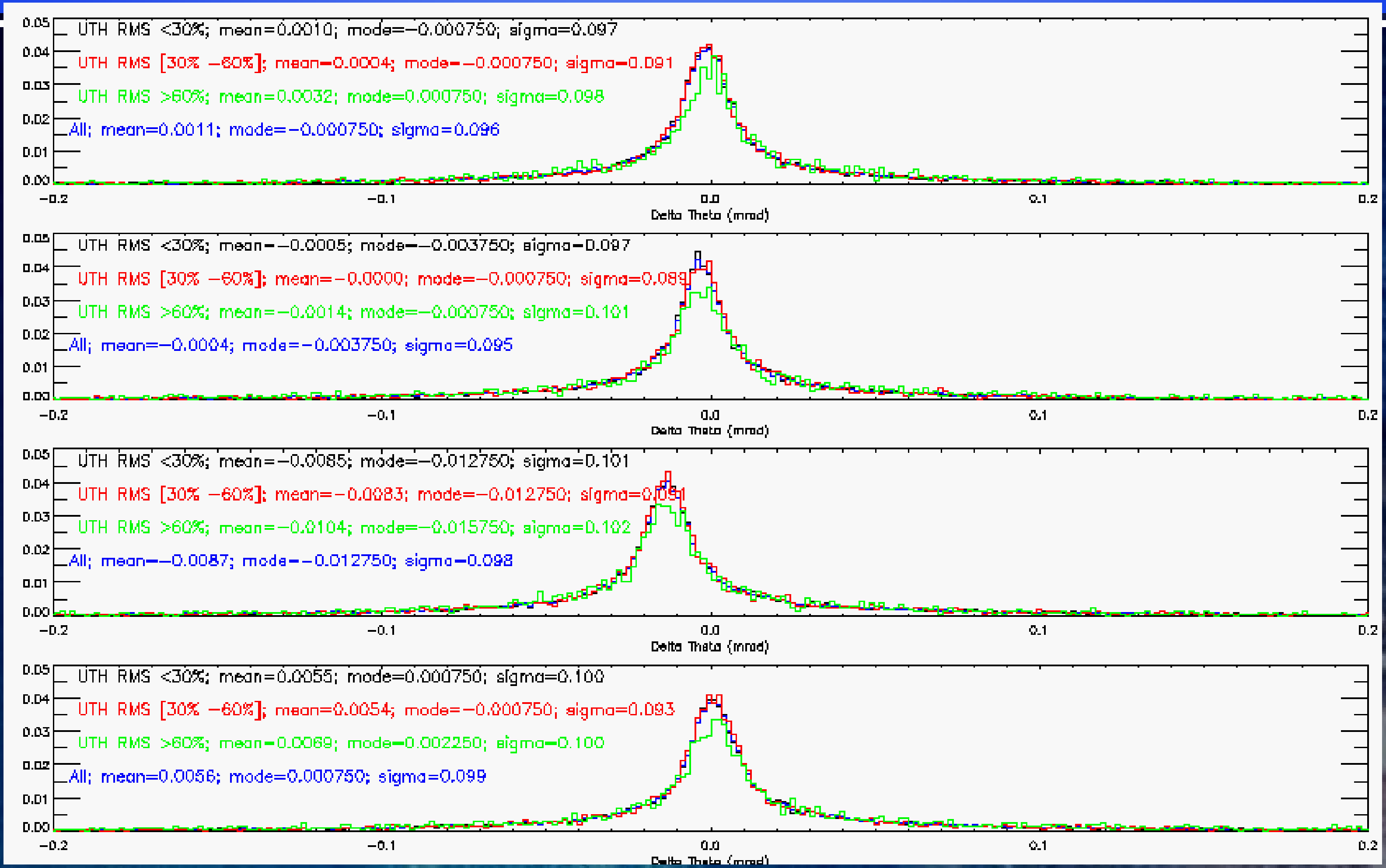
1) ONLY FOV 1 dθ gt 2, all others lt 1 sigma

2) ONLY FOV1 and FOV2 gt 2 sigma, all others lt 1 sigma



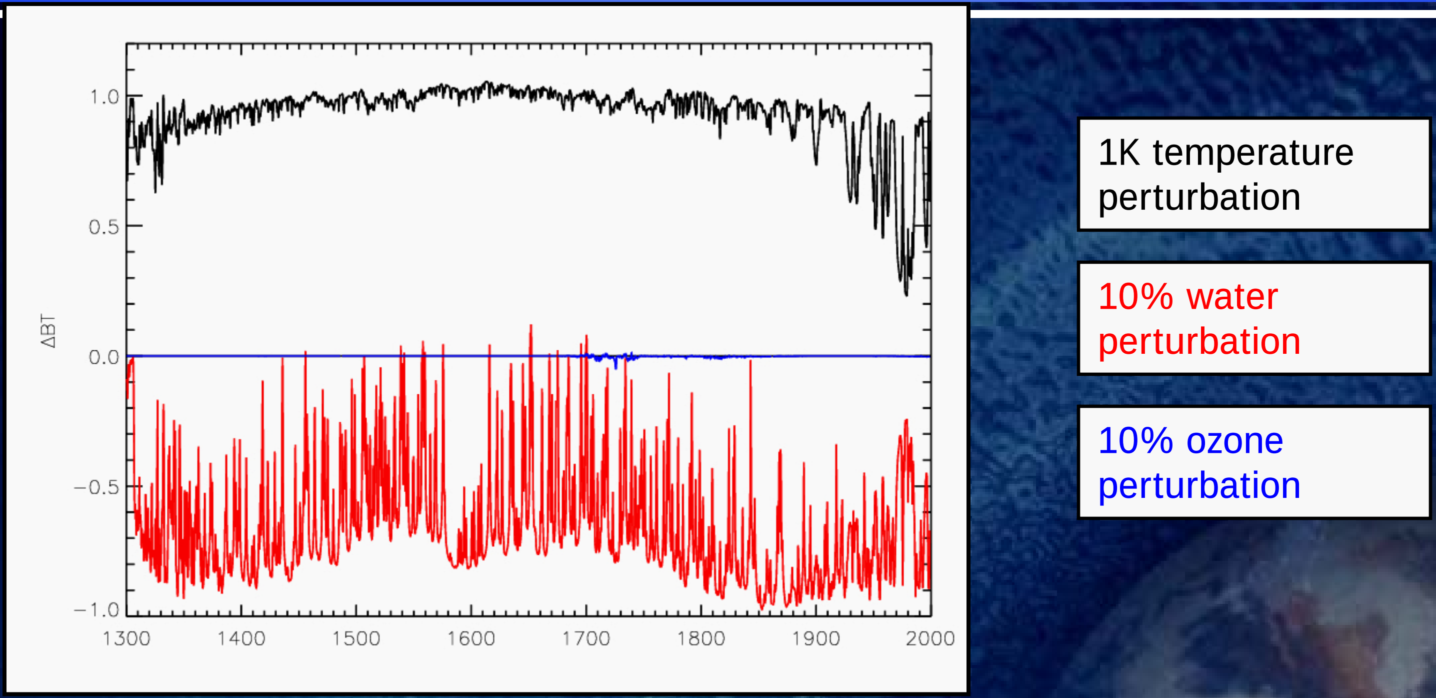
No significant correlation is seen to stand out between the radiometric angular shift and the retrieved SST or UTH bias.

Centroid Distribution Conditioned by UTH statistics



No significant correlation is seen to stand out between the radiometric angular shift and the retrieved UTH rms

Comparison with the Sensitivity to Temperature and Water Vapor Perturbations in 6.7 μm Band



- The retrieval uncertainty appears to be dominated by other sources of error
- The main assumption of the cloud clearing algorithm is that besides clouds, everything in the FOR scene is homogeneous. This is a much broader assumption than the unperturbed ILS one; i.e. water vapor in the FOR can vary up to 10% and more. The radiance error introduced by this assumption can go up to 1K.

Radiance Error Assessment & Impact on the Retrieval Accuracy: Lessons Learned from IASI

- The analysis above indicates that the IASI radiance error induced by the ILS shift in presence of clouds is negligible:
  - The radiance error is by far smaller than the instrument noise for radiometric center offset values up to 3 sigma (band 1), 2 sigma (band 3) and 1 sigma (band2) of the overall offsets distributions.
  - In retrieval space, there does not appear to exist any correlation among angular offsets and retrieval biases of SST, UTH, CH4, etc (not shown) wrt ECMWF or climatology. This is possibly due to:
    - the presence of other factors dominating the uncertainty in the retrievals
    - no preferential distribution in angular offsets across the 4 FOVs (all 4 are centered around zero angular offset) such that the effect is likely to be averaged to zero during cloud clearing.
  - Angular offsets can still be monitored in order to build an ad hoc rejection flag (under study).

Lessons Learned from IASI and Considerations on the ILS Shift Effect on CrIS

•CrIS has lower instrument noise than IASI (the lower the max optical path, the lower the fringe effect, the higher the signal to noise), but a lower spectral resolution (the lower the max optical path, the lower the spectral resolution) which makes it less sensitive to the spectral shift.

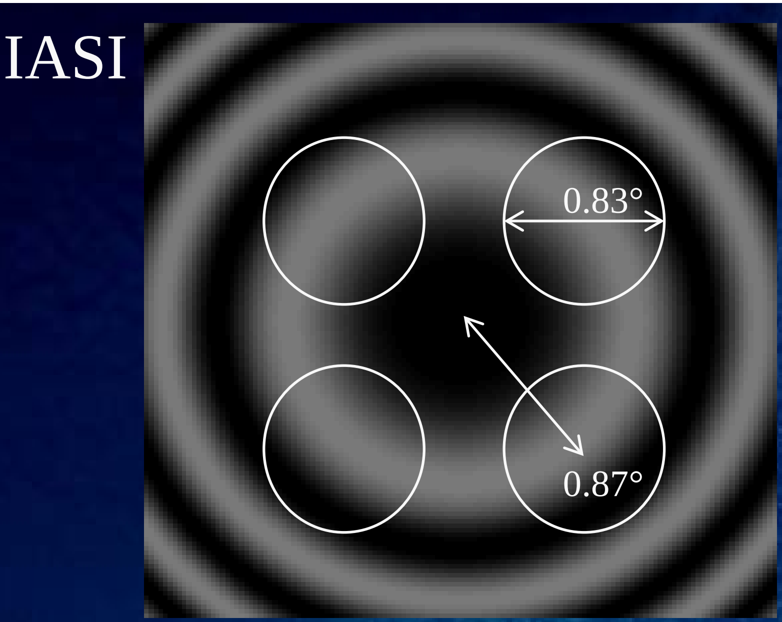
• CrIS central FOV falls in within the central bright spot at all frequencies. Self apodization is more severe in IASI which makes it more sensitive to the ILS shift than CrIS.

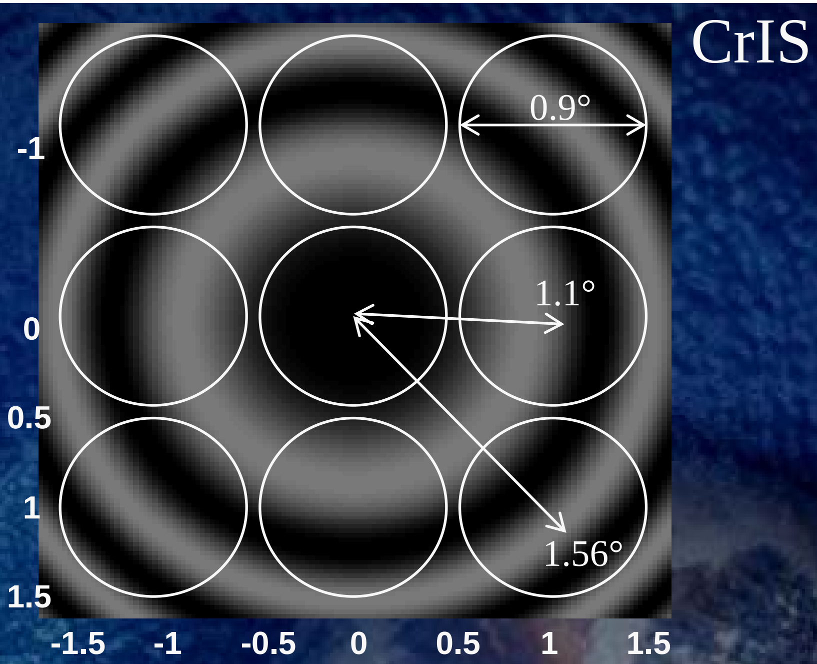
• IASI is a 9:am/9:30pm equatorial crossing orbit; CrIS is a 1:30am/1:30pm equatorial crossing orbit. The climatology of clouds observed is quite different. 1:30pm is the onset of convection leading to overcast scenes, normally rejected by any retrieval or assimilation scheme. 9:30pm is likely the time for convective cloud detrainment leading to the formation of cirrus anvils. Broken cloud scenes, which are likely to introduce significant scene in-homogeneities, can likely pass the retrival rejection criteria.

• Based on the above consideration we can estimate the effect of the ILS shift to be less important for CrIS than for IASI.

•The only remaining issue to be investigated, though, is CrIS’s acquisition geometry. See next slide.

IASI vs CrIS FOV geometry





- IASI FOVs are arranged in a 2x2 grid on a α=0.87° radius circle from the optical axis.
- CrIS FOVs are arranged on a 3x3 grid on a α=0 °, 1.1 ° and 1.56 ° radius circle from the optical axis.
- For both off-axis CrIS FOVs we should expect a larger frequency shift: $\delta\nu \sim \nu\alpha\delta\alpha$
- Applying IASI's 1sigma angular offset ($\delta\alpha$ =0.1mrad), we should expect, for CrIS, a frequency shift of:
  - CrIS Side Cube (α=1.1°=0.019rad): $\delta\nu/\nu \sim \alpha\delta\alpha = 1.91e\text{-}6$
  - CrIS Corner Cube (α=1.56°=0.027rad): $\delta\nu/\nu \sim \alpha\delta\alpha = 2.72e\text{-}6$
- CrIS ILS frequency shift is of the same order of IASI.
- CrIS ILS frequency shift (1ppm) stable enough to study climate forcings.

Ongoing and Future Work

- Repeat the same analysis done for IASI: perturb CrIS radiance spectrum based on the computed frequency shift and obtain the radiance error in CrIS spectra due to the ILS shift. Assess the impact on retrieval space (Ongoing work).

- What if we find the radiance error to be significant (greater than the instrumental noise)?
- Four approaches:
  - » 1) Correct for the ILS shift:
    - – Use VIIRS to compute angular offset and correct the self apodization matrix. Computationally very expensive, not feasible for operations.
    - – Identify (if it exists) the one eigenvector of the radiance ensemble that correlates the most with the radiance shift. Reconstruct the radiances without that eigenvector. Computationally expensive, high risk methodology (different ensemble have proven to have different highest correlated eigenvector).
  - » 2) Identify the cases of significant ILS shift and flag them out.
    - – Use PC score analysis to flag anomalous cases. Requires training, might effect the yield considerably.
  - » 3) Make the retrieval insensitive to the problem.
    - – Incorporate radiance shift signal into the retrieval error covariance matrix to make the retrieval insensitive to this error. Requires training and significant changes to the overall optimization scheme of the retrieval code.
  - » 4) Use only the central FOV.
    - – Adopt a VIIRS integrated cloud-clearing scheme instead of the 3x3 scheme to perform retrievals. Code already in use for IASI, VIIRS is already collocated to CrIS. Requires testing, limits the spatial resolution of the data.

Review Outline

- Introduction
- ARR Phase 2 Report
- Phase 3 Requirements
- Concept of Operations
- Algorithm Theoretical Basis: OLR
- Algorithm Theoretical Basis: ILS
- Algorithm Theoretical Basis: Collocation
- Phase 3 Software Architecture
- Quality Assurance
- Risk Summary
- Summary and Conclusions

Section 7 –

Algorithm Theoretical Basis: VIIRS/CrIS Physical Collocation

Presented by

Haibing Sun

Outline: Algorithm Theoretical Basis

Objective:

Provide sub-pixel level VIIRS cloud information to the CrIS SDR data so it can be output into the CrIS SDR BUFR.

- CrIS / VIIRS product collocation processing.
- Physical collocation method.
- CrIS observation spatial response.
- VIIRS product spatial response.
- Processing system design and installation.
- Algorithms/System Validation
- Conclusion.

CrIS/VIIRS Collocation Processing

A physical collocation method based on that used for AIRS/MODIS and IASI/AVHRR will collocate high spatial resolution VIIRS cloud products to the CrIS observation Fields Of View (FOVs).

Collocate “pixel”-level intermediate VIIRS cloud fraction product within CrIS FOVs.

CrIS granule: 4 scan line, 30 FOR, 9 FOV

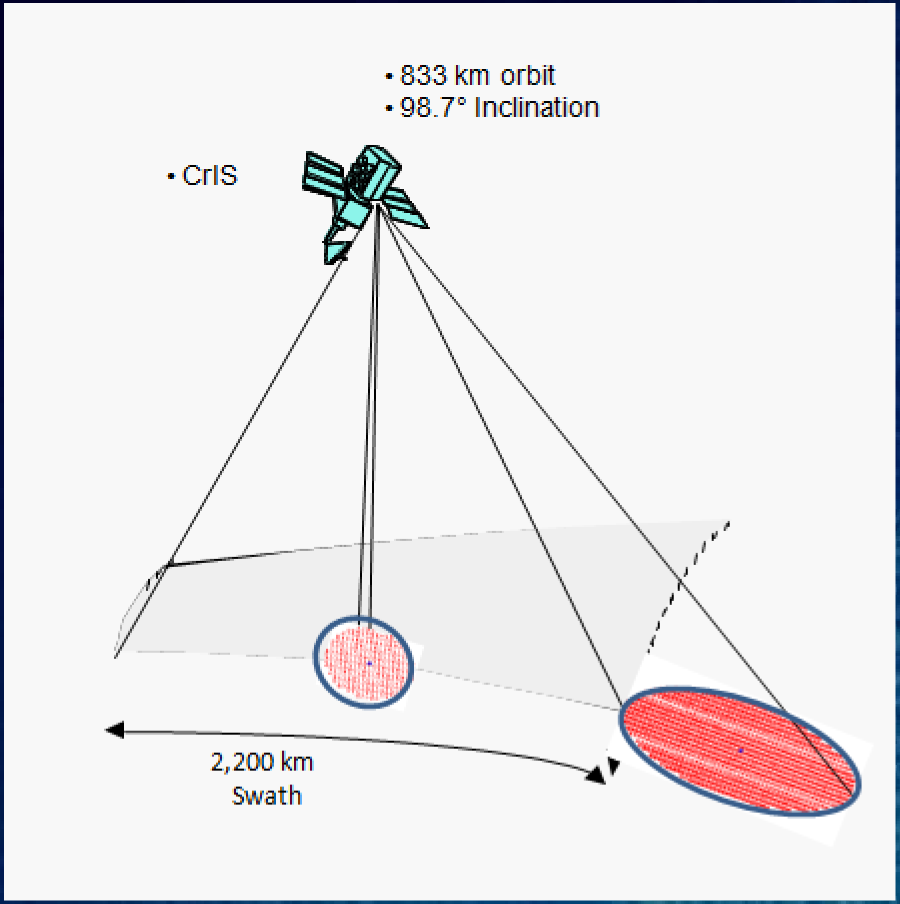
VIIRS granule: 786*3200 Aggregated /Trimmed “M” band Pixel Geo-location.

Collocate product cell-level VIIRS EDR cloud height product within CrIS FOVs

CrIS granule : 4 scan line, 30 FOR, 9 FOV

VIIRS granule: 96* 508 Aggregated /Trimmed-> Aggregated product cell Geo-location.

Physical Collocation Method



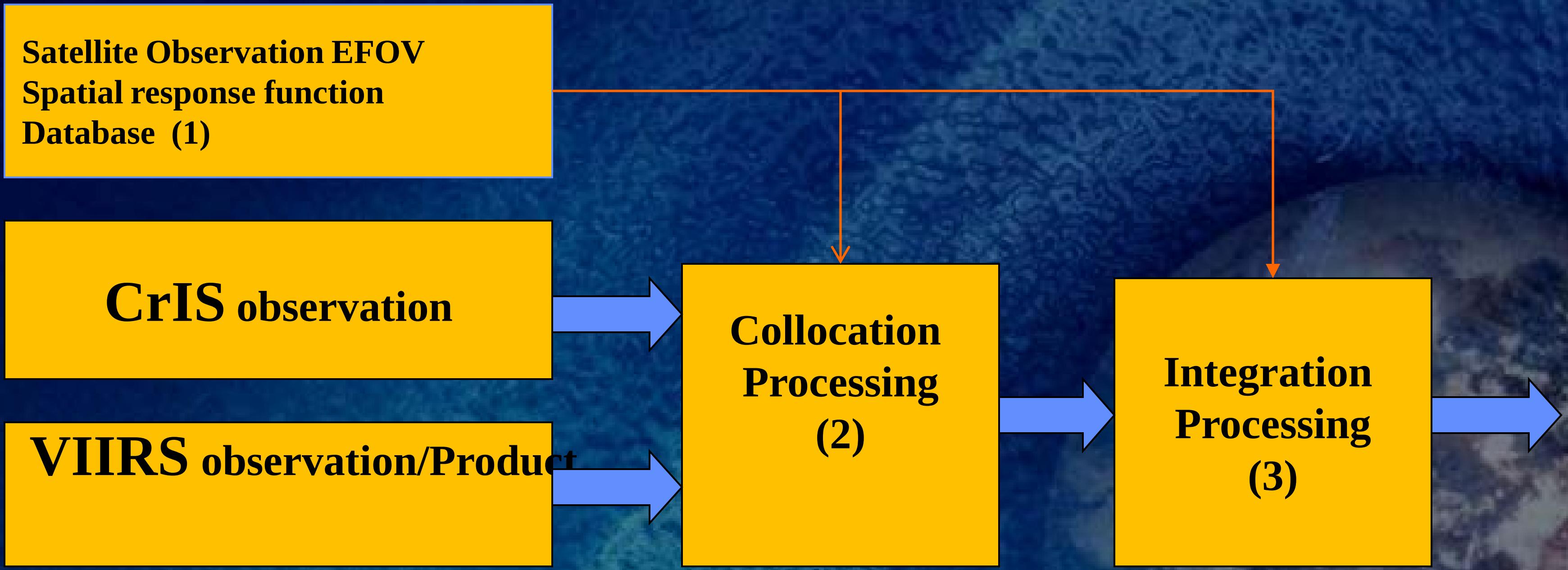
CrIS observation/VIIRS product:

- Same physical target. (Center geo-location)
- Same physical coverage. EFOV (Effective field of View)
- Same spatial response.

A set of physical collocation algorithms and software package have been developed to collocated LEO-LEO,GEO-LEO observation /product.[1] [2] [3] [4]

CrIS/VIIRS Collocation System Diagram

CrIS-VIIRS Integration System



Satellite Observation EFOV
Spatial response function
Database (1)

CrIS observation

VIIRS observation/Product

Collocation Processing (2)

Integration Processing (3)

CrIS-VIIRS Collocation Algorithm: Collocation Processing

Requirement: Fast and robust

1. Group the VIIRS granule data to match the CrIS granule data based on the observation time.

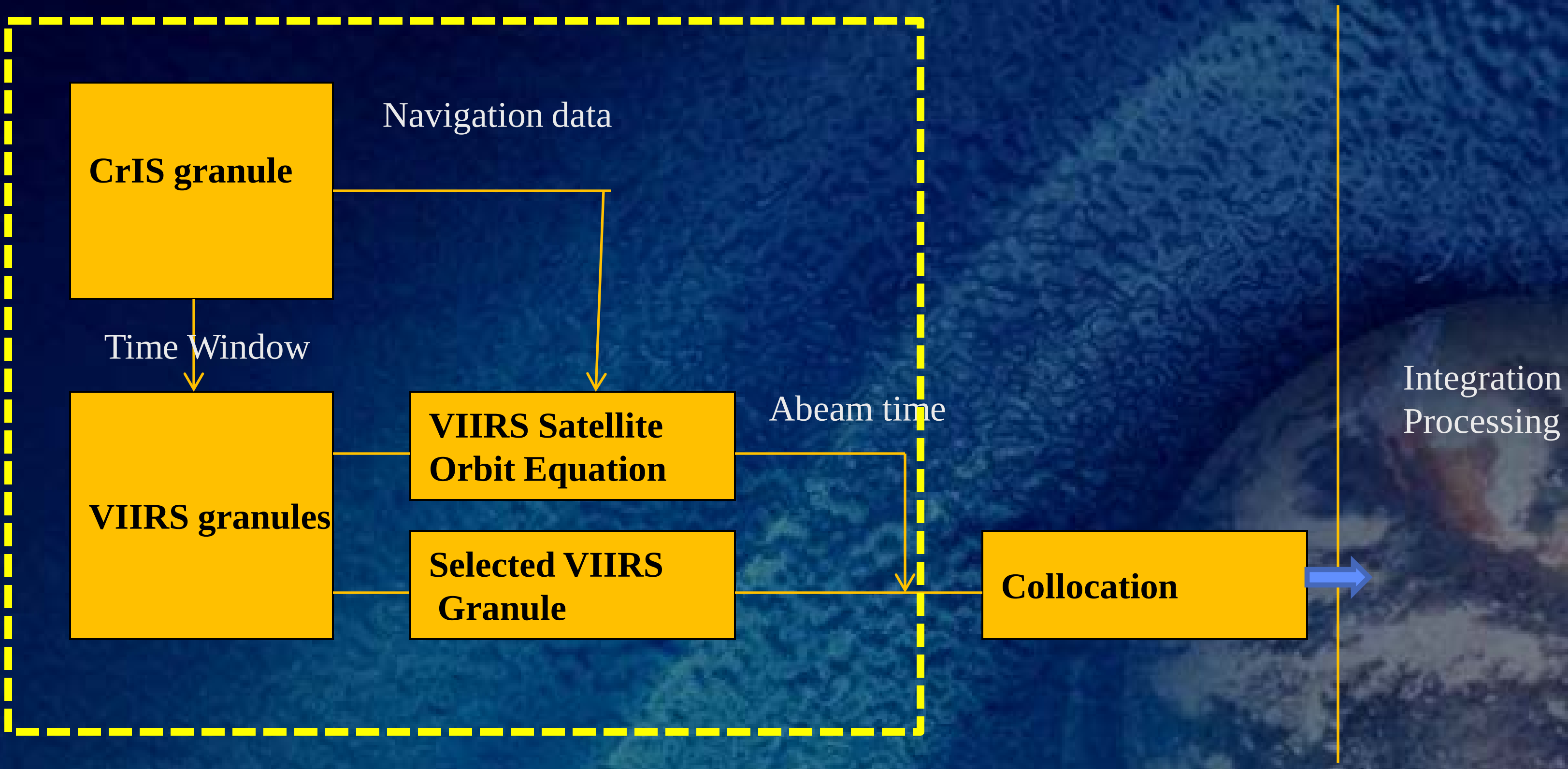
2. Reconstruct the VIIRS satellite platform orbit equations.

3. Using the VIIRS orbit equation, collocate/acquire the beam time of the VIIRS measurement closest to the center of the CrIS observation.

LUT (Look up table algorithms is built for CrIS/VIIRS)

CrIS-VIIRS Collocation Algorithm Diagram

Objective: Same physical target. (Center geo-location)



LUT(CrIS/VIIRS)

Physical Collocation Methodology

Requirement: CrIS observation and VIIRS cloud products must have spatial and physical consistency

Procedure:

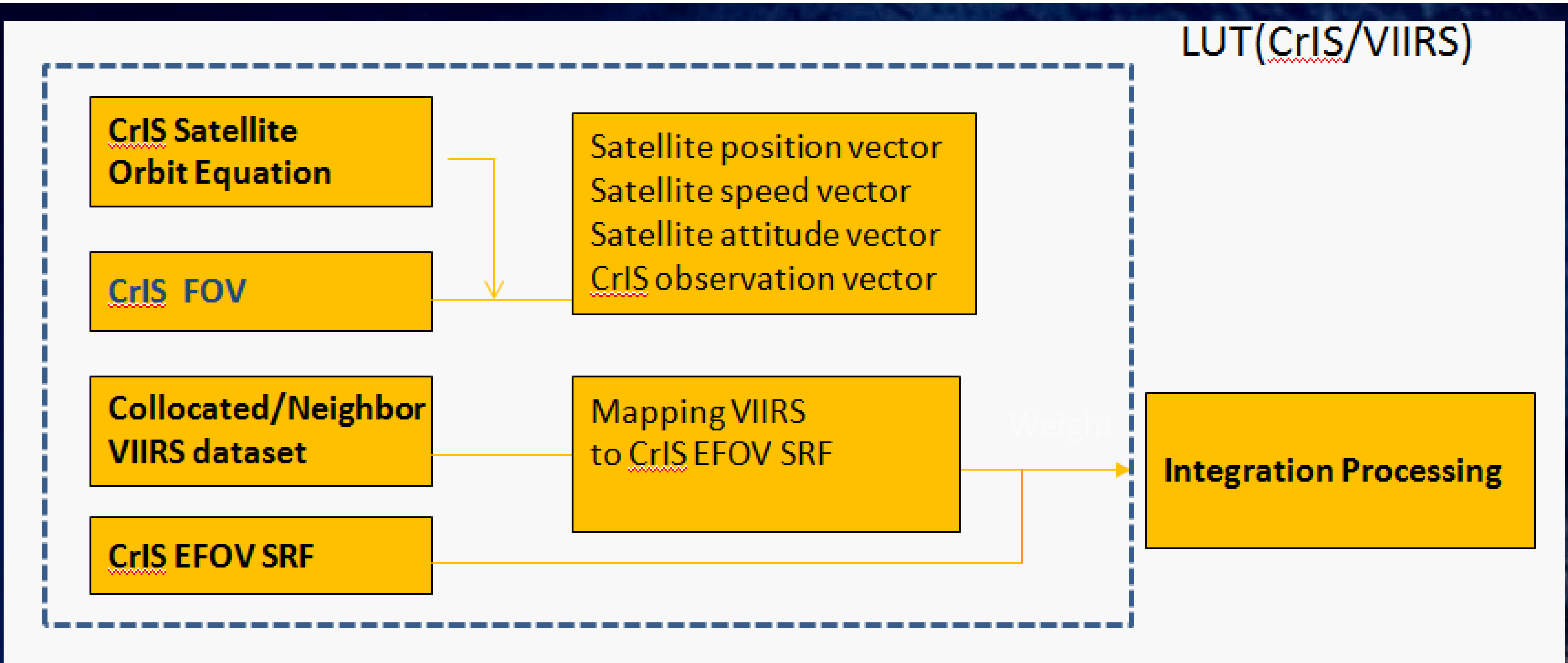
1. Map the collocated VIIRS product pixels to the CrIS EFOV Spectral Response Function (SRF) to get the contribution weight.

2. Select the VIIRS point with contribution weight criteria to build the collocated VIIRS dataset for the CrIS observation.

3. Calculate a weighted average of the VIIRS products with the contribution weight to integrate the VIIRS data to CrIS field-of-view.

$$R_{col} = \sum_{l=1}^{N} R_{A_i} w_l$$

Mapping VIIRS to the CrIS EFOV SRF



LUT(CrIS/VIIRS)

CrIS Satellite Orbit Equation

CrIS FOV

Satellite position vector
Satellite speed vector
Satellite attitude vector
CrIS observation vector

Collocated/Neighbor VIIRS dataset

Mapping VIIRS
to CrIS EFOV SRF

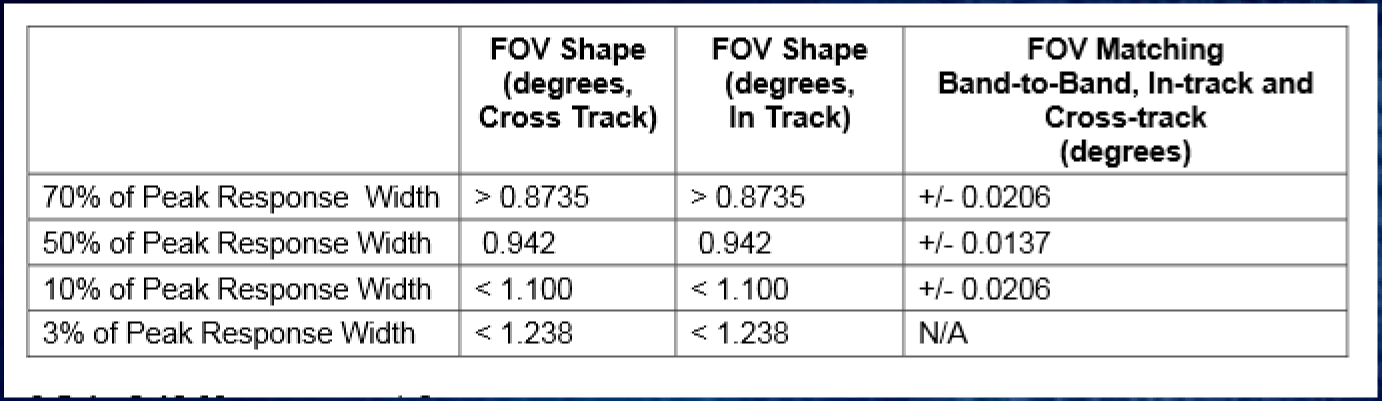
Weight

Integration Processing

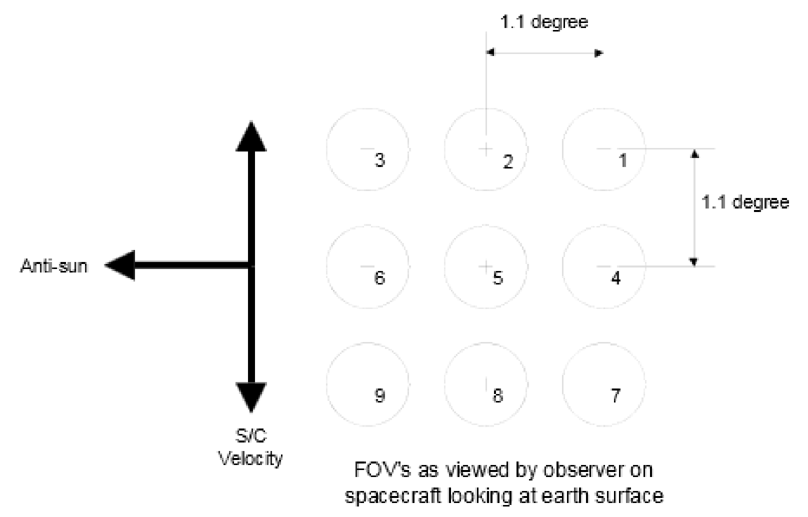
CrIS EFOV SRF

1. Calculate CrIS satellite position/speed/attitude vector from the CrIS orbit equation.
2. Calculate CrIS observation vector.
3. Calculate the VIIRS observation vector from CrIS satellite platform.
4. Map the VIIRS point to CrIS SRF.

CrIS Spatial Response Characteristics



	FOV Shape (degrees, Cross Track)	FOV Shape (degrees, In Track)	FOV Matching Band-to-Band, In-track and Cross-track (degrees)
70% of Peak Response Width	> 0.8735	> 0.8735	+/- 0.0206
50% of Peak Response Width	0.942	0.942	+/- 0.0137
10% of Peak Response Width	< 1.100	< 1.100	+/- 0.0206
3% of Peak Response Width	< 1.238	< 1.238	N/A



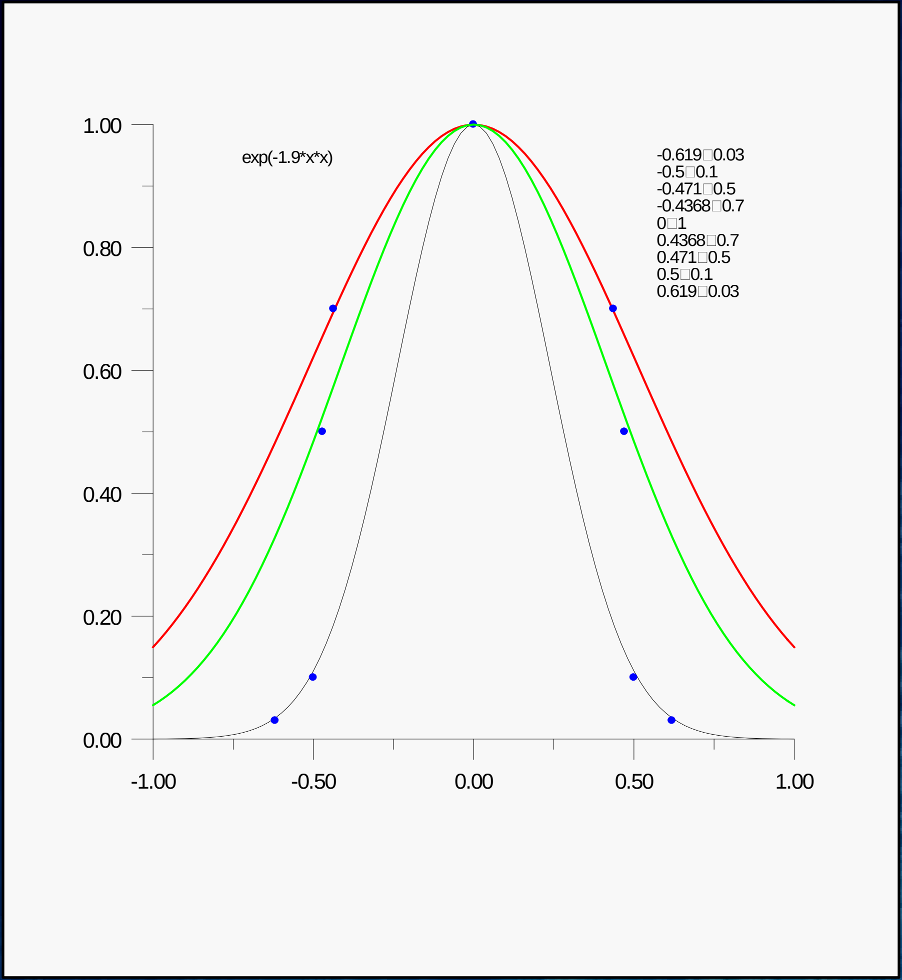
FOV's as viewed by observer on spacecraft looking at earth surface

No “real” on-orbit CrIS effective field of view SRF is available now.

Conceptual model based on instrument FOV shape is applied.

The instrument FOV shape is defined on instrument coordinate frame.

CrIS Spatial Response Characteristics



Circularly symmetric Gaussian function is applied to represent the CrIS observation spatial response. The parameter of the Gaussian function is selected based on the FOV shape requirement.

A “on-orbit” CrIS EFOV SRF retrieval algorithms is being developed and a “better” SRF will applied in the future.

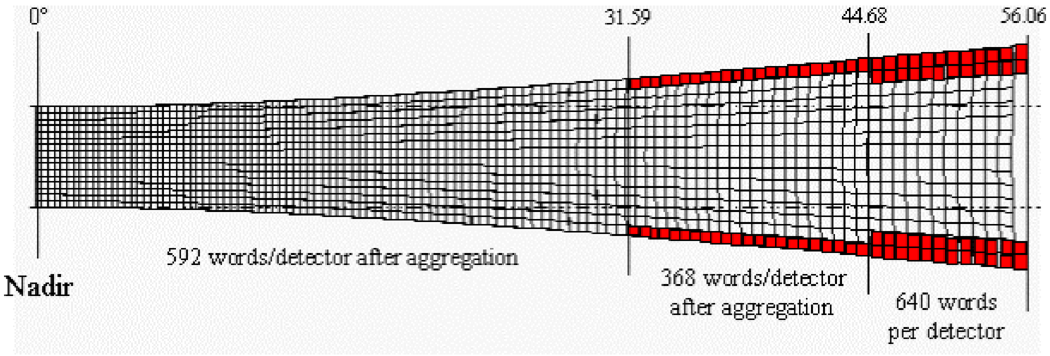
VIIRS Product Spatial Response Characteristics Discussion

- VIIRS Cloud Fraction spatial response characteristics
- VIIRS Cloud Height spatial response characteristics
- At present, the VIIRS product is applied as a point product in collocation

VIIRS Cloud Fraction Spatial Response Characteristics

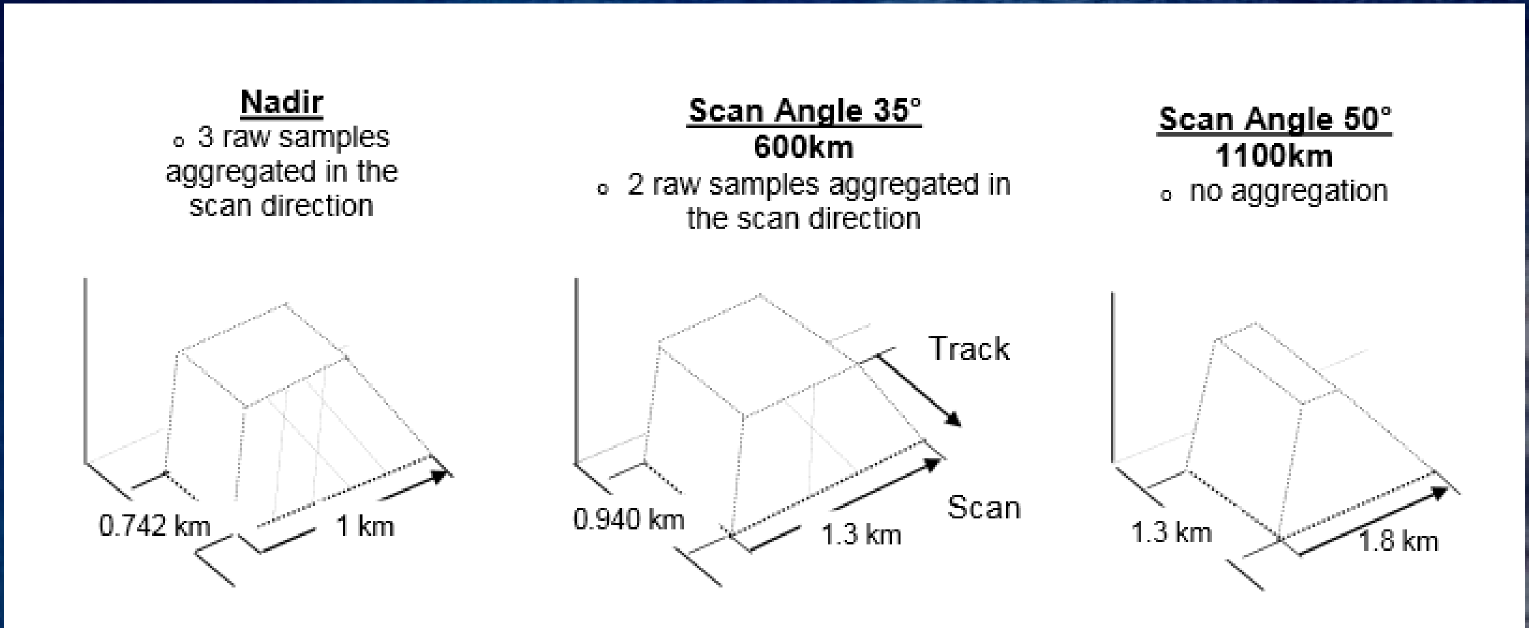
VIIRS cloud fraction product spatial response is defined by ‘M’ band SDR data.

- The VIIRS instrument ‘M’ band has detectors that are rectangular in shape and receive a signal at any particular instant of time from an area of the Earth's surface that is approximately 742 m along-track by 259 m across-track (nadir pixels).
- For SDR ‘M’ band, to optimize both spatial resolution and signal-to-noise ratio (SNR) across the scan, the aggregation scheme is applied on the VIIRS observations. At 31.6 degrees in scan angle, the aggregation scheme is changed from 3x1 to 2x1. A similar switch from 2x1 to 1x1 aggregation occurs at 44.7 degrees.
- The “bow-tie deletion” processing is applied to trim the data to remove the overlap at scan angles greater than approximately 19 degrees. This will result in some of the samples in the overlap area to be excluded from the data that are delivered to the ground.



VIIRS Cloud Fraction Spatial Response Characteristics

The VIIRS ‘M’ band SDR data spatial response function is defined by the detector spatial response, instrument sampling characteristic and along track pixel aggregation processing. A simple nominal VIIRS spatial response is used in the algorithm development.



VIIRS Cloud Height Spatial Response Characteristics

VIIRS cloud height product spatial response is defined by the EDR product cell spatial response.

- The VIIRS Moderate Resolution SDR geo-location (non terrain corrected) pixel positions are aggregated to produce the Cloud Height aggregated geo-location. The geo-location indicates the location of a cell where the cloud resides.
- The product cell size for the VIIRS Cloud Height aggregated output is approximately 6 km from nadir to end-of-scan (EOS). At nadir, the product cell size is 8 by 8 pixels. At EOS, the product cell is 4 by 4 pixels.
- A pre-computed look-up table (LUT) provides a map of all pixels into a set of product and clustering cells. This LUT is computed off-line and read in once when the program is loaded.

Algorithm Implementation

- CrIS and VIIRS are on the same platform. Therefore satellite position, satellite speed vector and satellite attitude are the same.

- CrIS/VIIRS scan on the "const sampling pattern" independently:

  CrIS :8 second. VIIRS: 1.784612 second.

Two collocation methods can be implemented:

- 1: Collocation processing based on real time CrIS/VIIRS navigation data. Precise and flexible, but time consuming.

- 2: Collocation processing basing on Look up table. Fast and robust, but have limited accuracy .

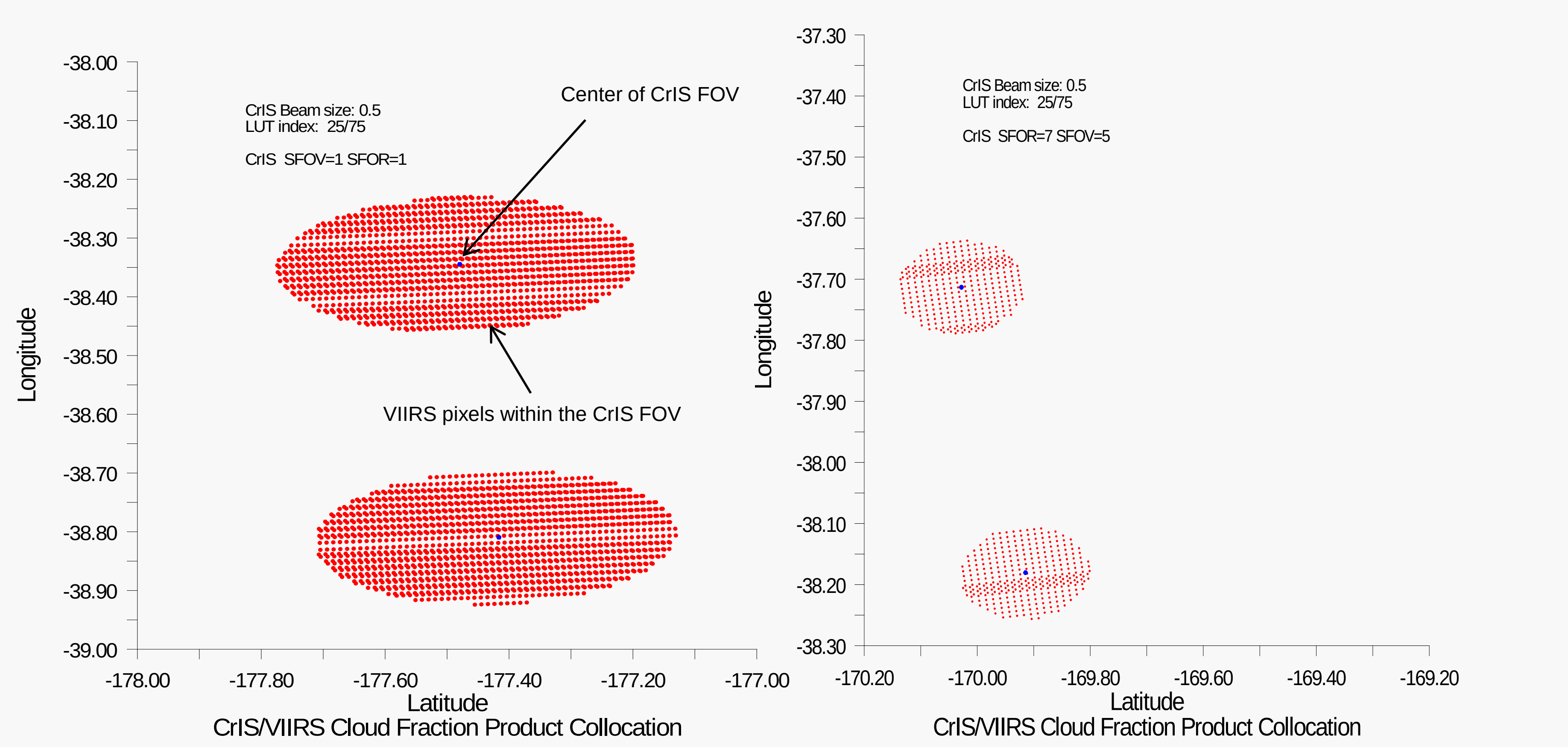
Algorithm Implementation

- Due to the fact that the CrIS/VIIRS observation (product) relative position will change because of their different scan periods (8 seconds/scan vs 1.78412 second/scan), a set of LUTs are calculated off-line for discrete relative positions. The relative position of CrIS and VIIRS can be defined by the center time difference between the two closest scan lines.

Relative position: The Colocated VIIRS position relative to the center of CrIS.

- The LUTs provide the VIIRS scan line/foot print index and contribution weight for each collocated CrIS FOV (30*9 for each scan line).

Algorithm Implementation: Cloud Fraction

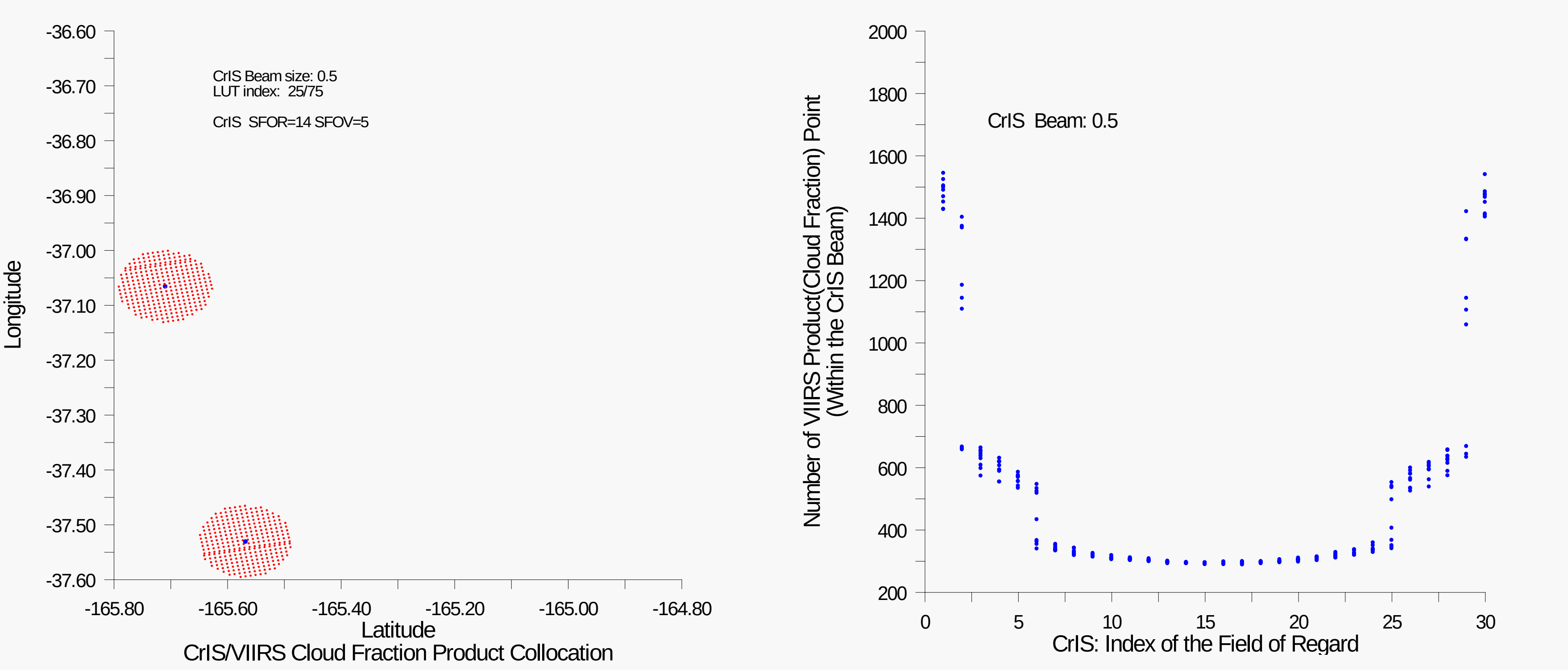


CrIS/VIIRS Cloud Fraction Product Collocation

CrIS/VIIRS Cloud Fraction Product Collocation

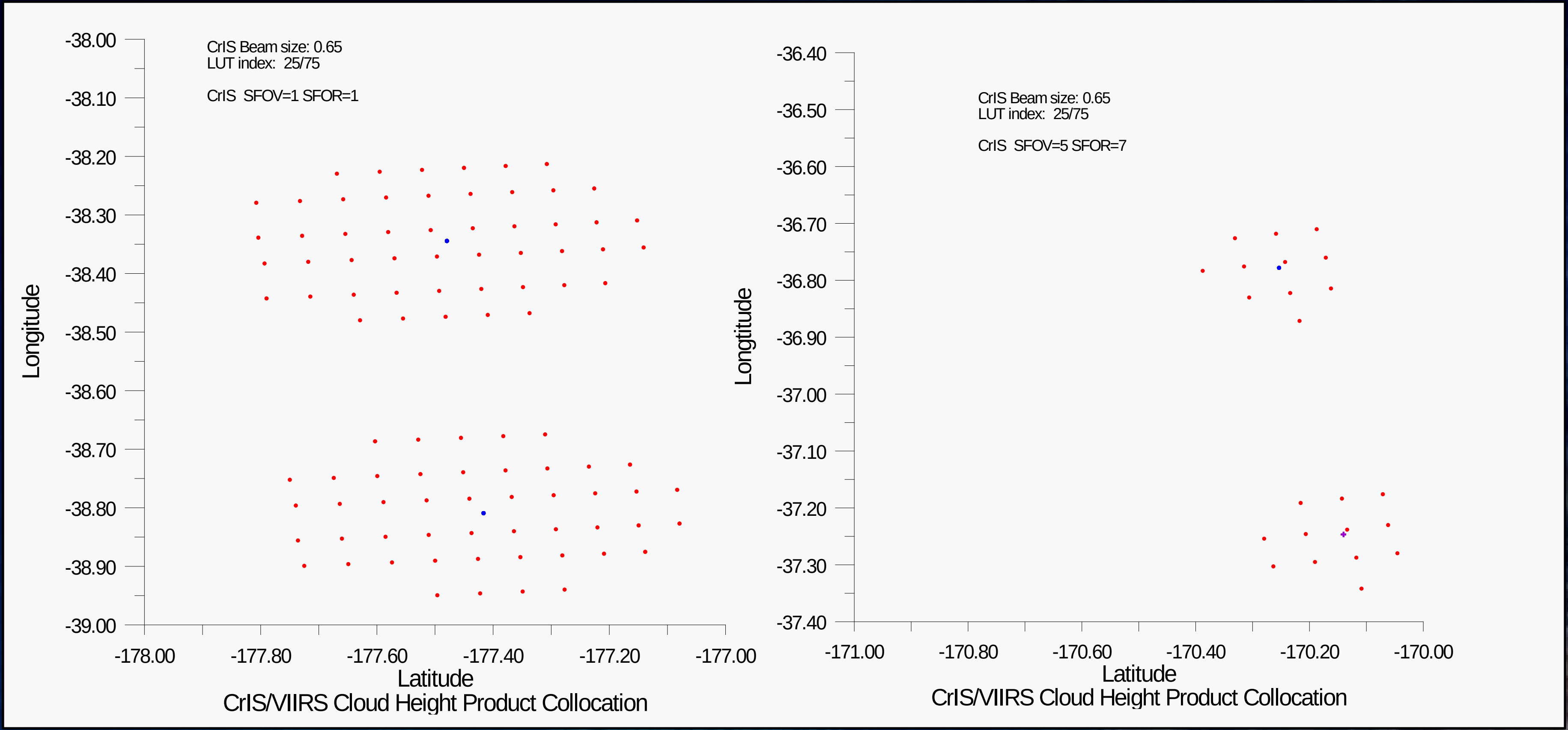
The LUT for CrIS/VIIRS Cloud Fraction give all the collocated VIIRS product positions, pixel weights, and the total number within the CrIS EFOV.

Algorithm Implementation: Cloud Fraction



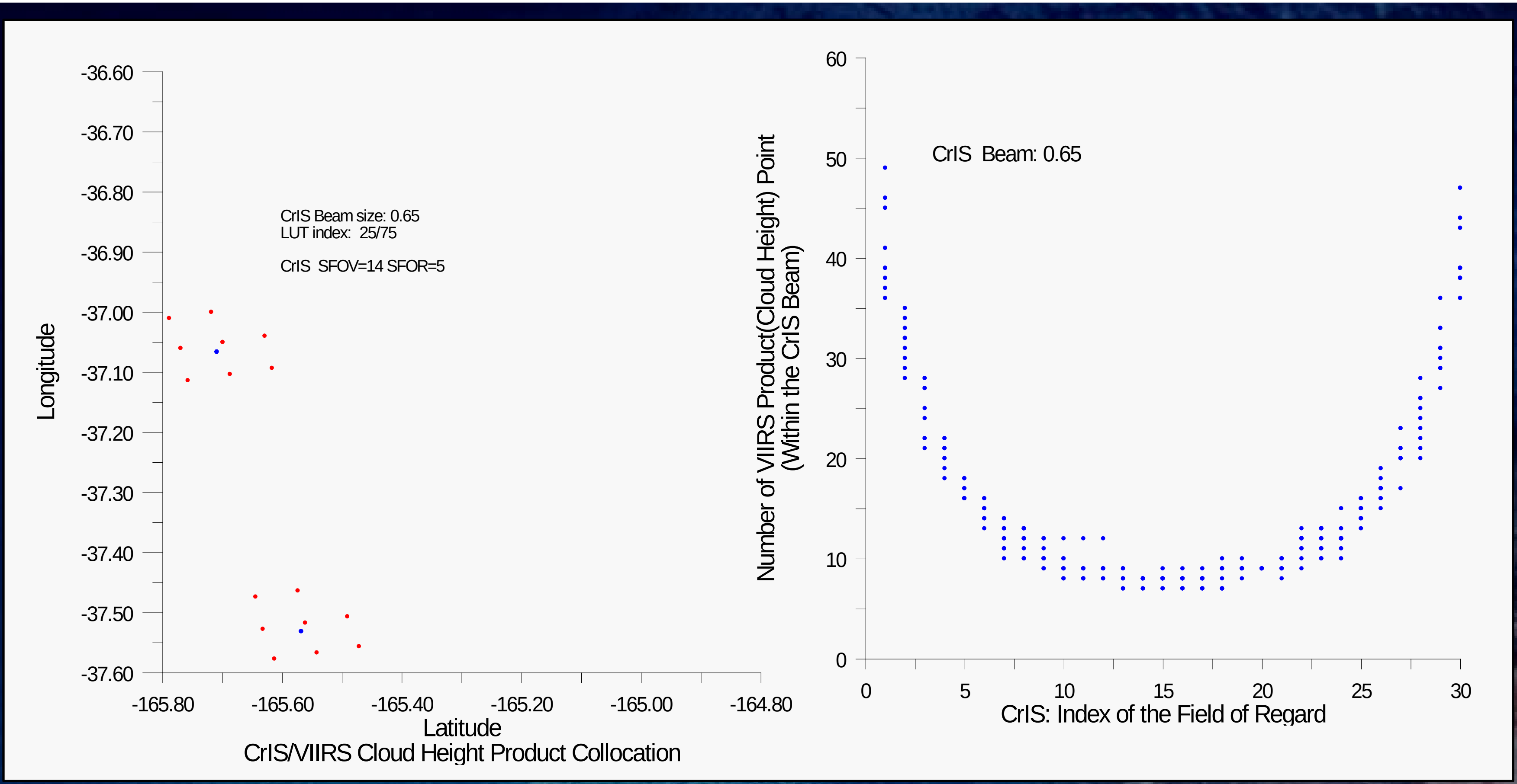
The number of collocated VIIRS cloud fraction product points for 0.5 degree CrIS beam will change from ~250-1500 (From nadir point to scan of end).

Algorithm Implementation: VIIRS Cloud Height



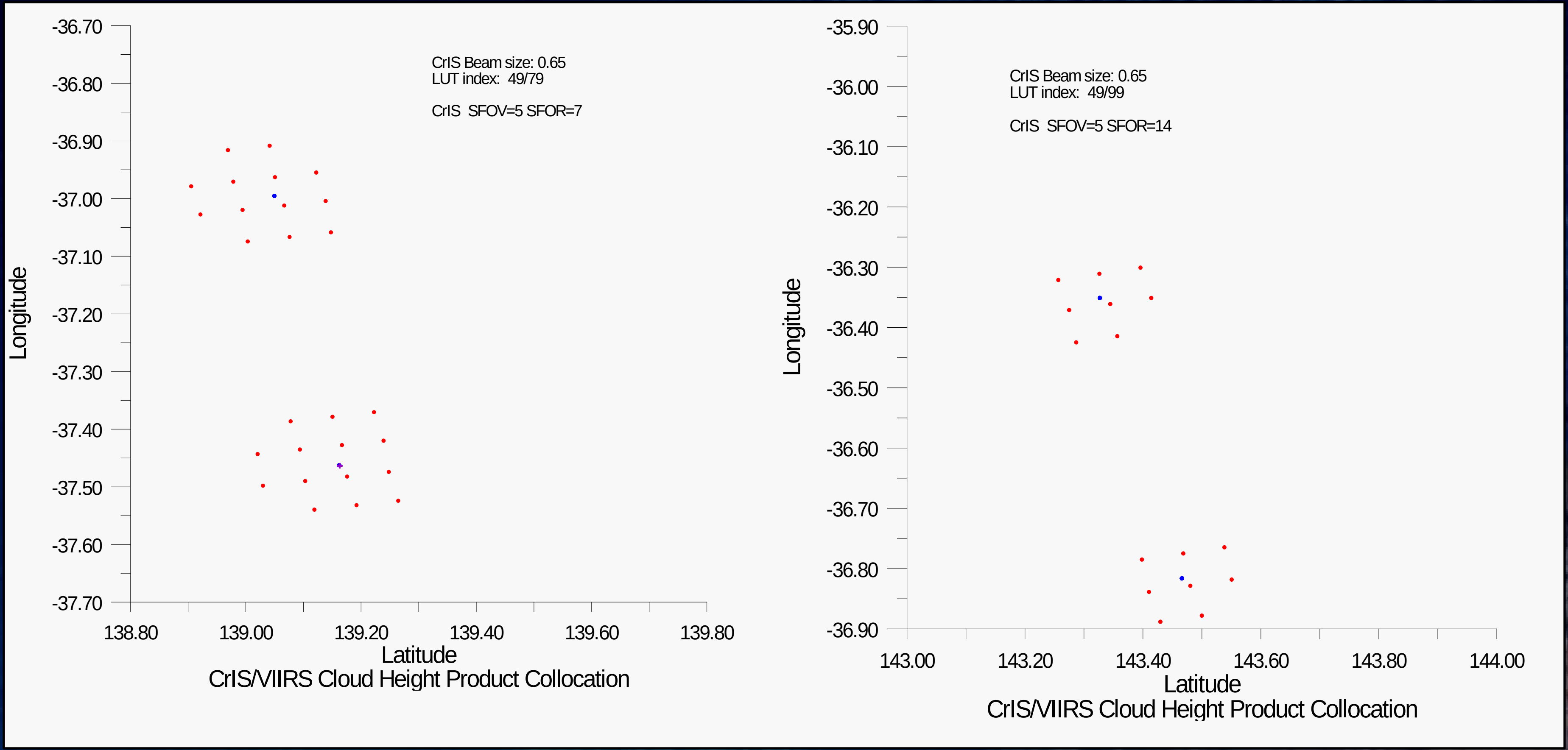
The LUT for CrIS/VIIRS Cloud Height give all the collocated VIIRS product positions, weights, and total number within the CrIS EFOV.

Algorithm Implementation: VIIRS Cloud Height



The number of collocated VIIRS cloud height product points for 0.65 degree CrIS beam will change from ~6-50 (From nadir point to scan of end).

Algorithm Implementation: VIIRS Cloud Height

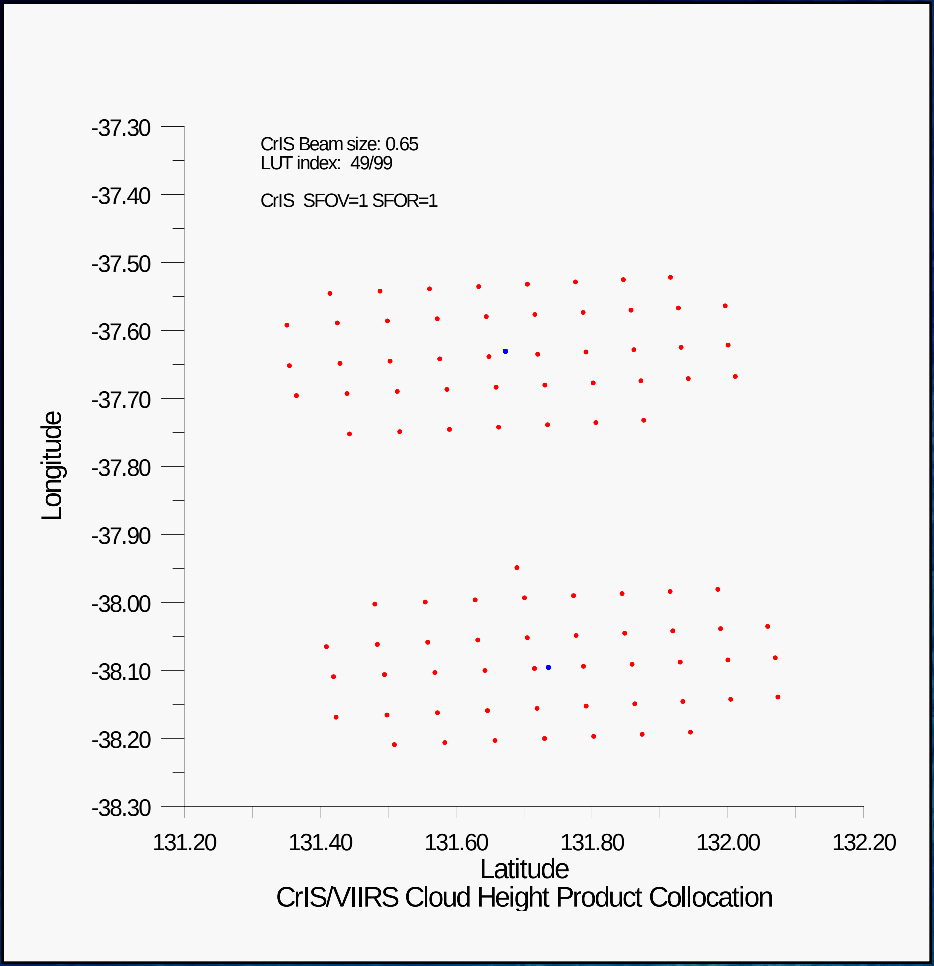


CrIS/VIIRS Cloud Height Product Collocation

CrIS/VIIRS Cloud Height Product Collocation

The relative position is changing and will repeat (8 seconds/scan vs 1.78412 seconds/scan). At present time, a set of LUTs is generated. The time resolution is 0.018 second.

Algorithm Implementation: VIIRS Cloud Height



CrIS/VIIRS Cloud Height Product Collocation

The relative position changing is shown in two cases.

To improve the temporal resolution of the LUT, it can be calculated using more points.

Algorithms and Processing Validation

- Purpose:
  - Validate the observation’s geo-physical collocation
  - Validate the projection (VIIRS points to CrIS EFOV SRF frame)
  - Validate the VIIRS point contribution weight calculation
  - Evaluate the algorithms implementation
    - Real time computation vs processing with LUT(off line look up table)

- Preliminary validation has already been done and will be shown here. Once the algorithm has been implemented in the NUCAPS code, the same validation can be done to verify that the algorithm is working and was integrated correctly.

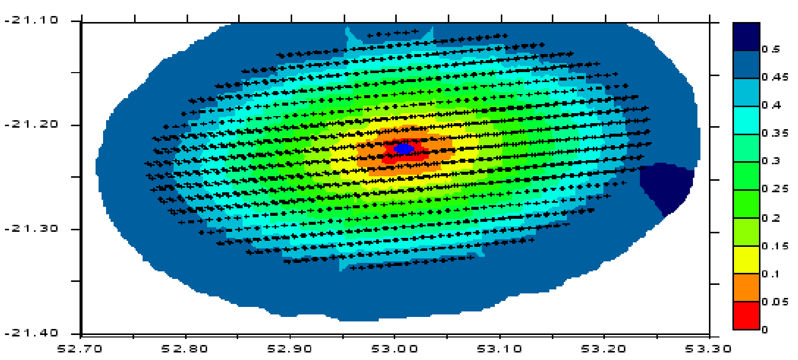
Test data date: 09/23/2013

Method: Case study and statistics

- An individual granule is processed to check the effective and correctness of the algorithms.

- Statistics were generated using over 120 collocated CrIS/VIIRS granules result is used to compare the difference between “real time computation” and “processing with LUT”.

CrIS/VIIRS Collocation Validation



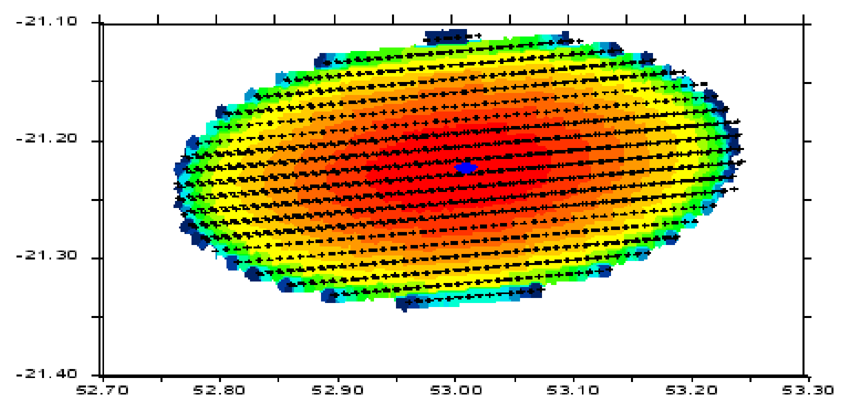
VIIRS product point projection (Cloud Fraction) : Angle between CrIS observation vector and VIIRS point observation vector. CrIS : SFOR=1 SFOV=1
1 : Projection basing on calculation with navigation data

Testing granule: 09/23/2013
CrIS observation: FOR=1 FOV=1

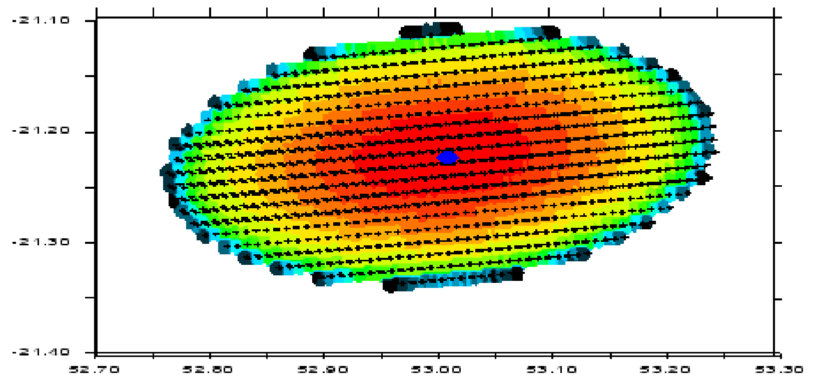
A: VIIRS Point is collocated and projected into CrIS EFOV SRF.

B: VIIRS Point contribution weight is calculated basing on CrIS SRF.

C: Same result with LUT installation scheme.

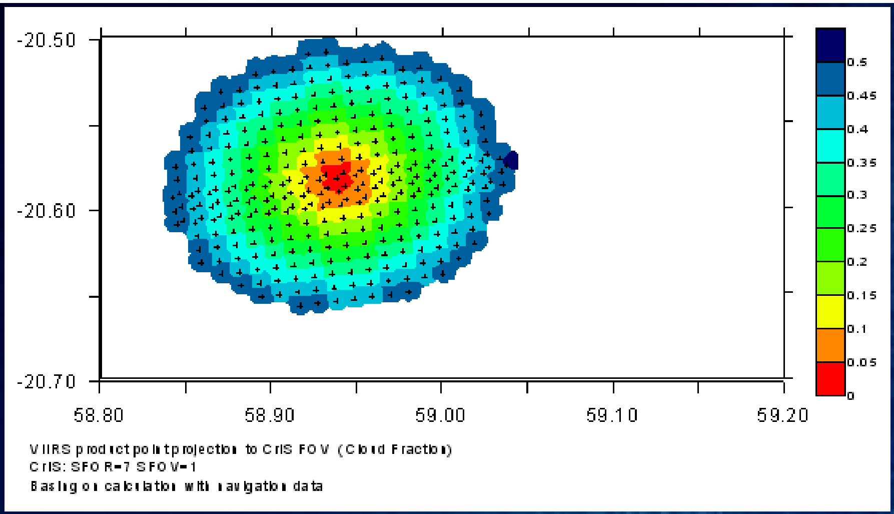


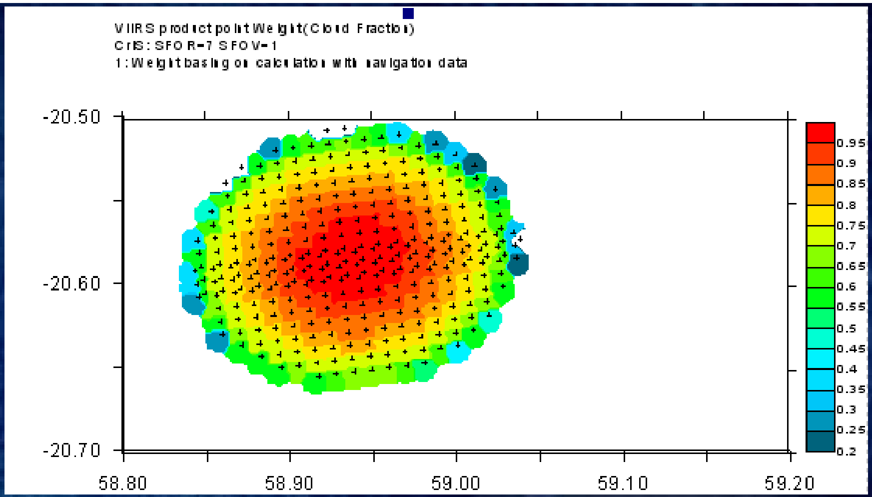
VIIRS product point Weight(Cloud Fraction)
CrIS : SFOR=1 SFOV=1
1 : Weight basing on calculation with navigation data

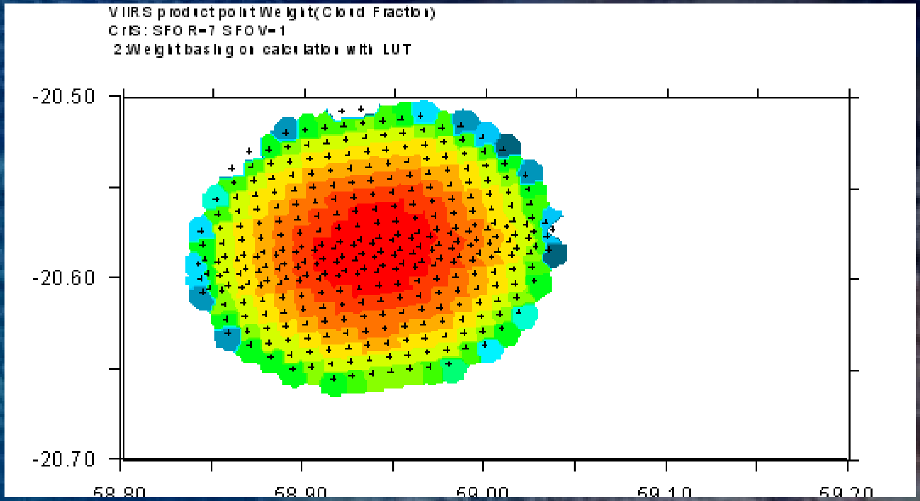


VIIRS product point Weight(Cloud Fraction)
CrIS : SFOR=1 SFOV=1
2:Weight basing on calculation with LUT

CrIS/VIIRS Collocation Validation







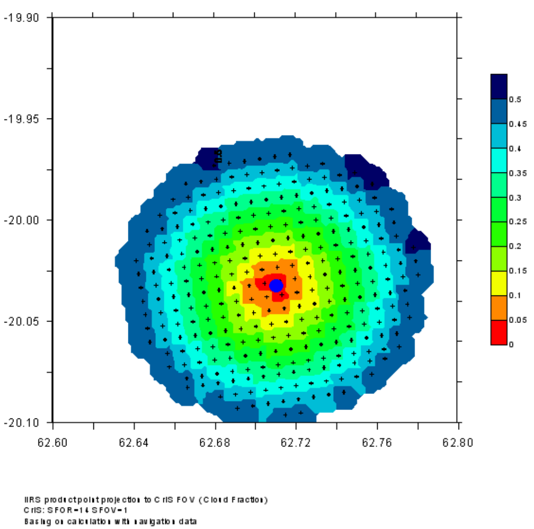
Testing granule: 09/23/2013
CrIS observation: FOR=7 FOV=1

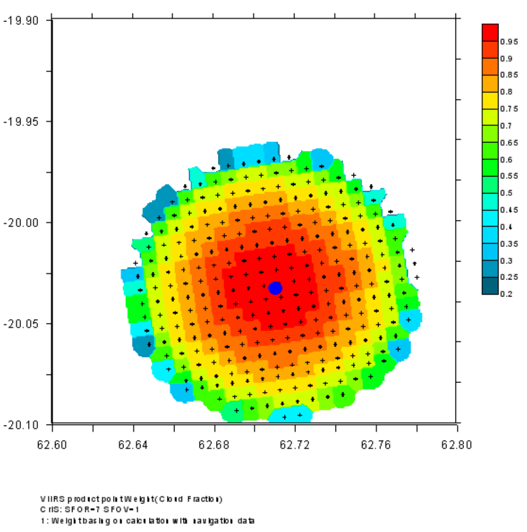
A: VIIRS Point is collocated and projected into CrIS EFOV SRF.

B: VIIRS Point contribution weight is calculated basing on CrIS SRF.

C: Same result with LUT installation scheme.

CrIS/VIIRS Collocation Validation



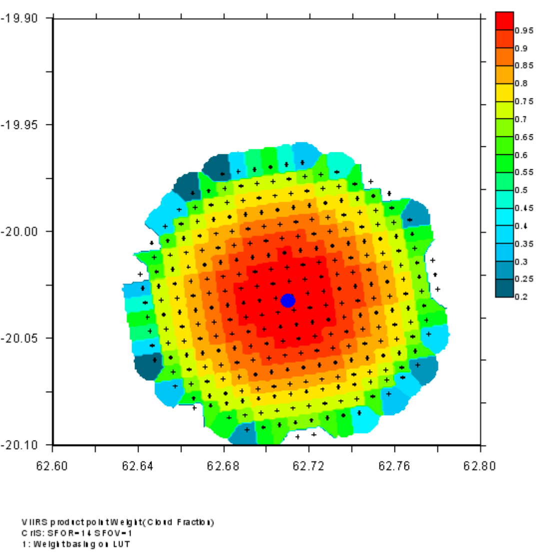


Testing granule: 09/23/2013
CrIS observation: FOR=14 FOV=1

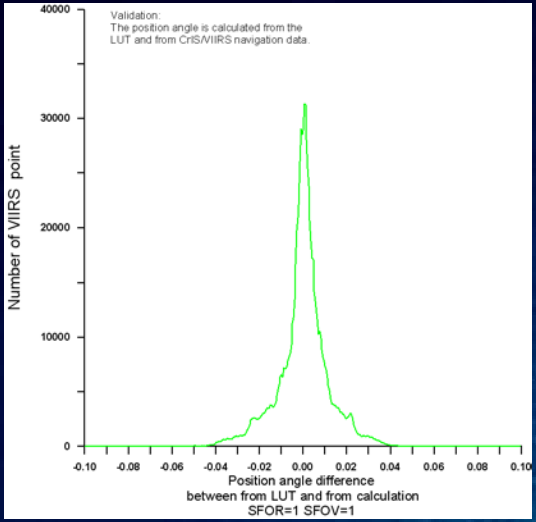
A: VIIRS Point is collocated and projected into CrIS EFOV SRF.

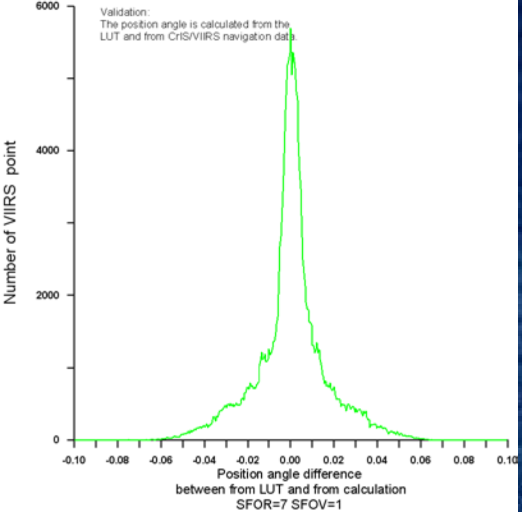
B: VIIRS Point contribution weight is calculated basing on CrIS SRF.

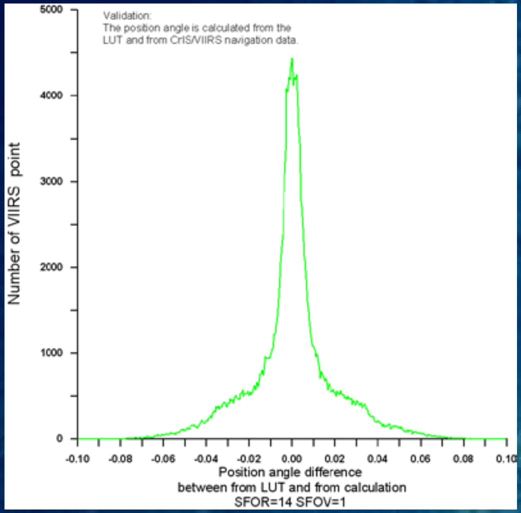
C: Same result with LUT installation scheme.

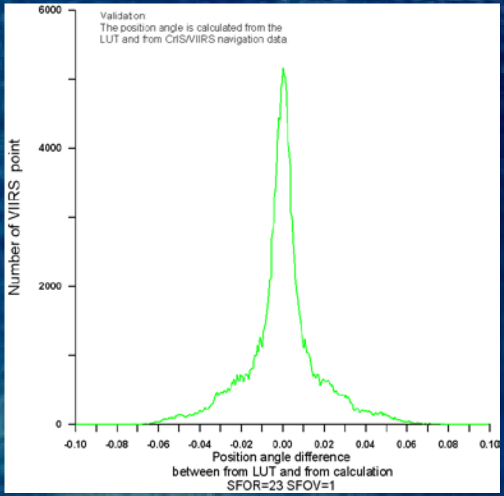


CrIS/VIIRS Collocation Validation: LUT vs Calculation









The angle between the CrIS fov center observation vector and collocated VIIRS observation vector from CrIS position define the effective VIIRS position within CrIS EFOV SRF.

The statistical result of calculation bias between from the real time computation and from LUT is from 120 granules.

Most of the calculation bias is within [-0.035 ,0.035]

Algorithms and Processing Validation: Summary

Summary:

- Present algorithms/system can provide valid geo-physical collocation.
- Present algorithms/system can provide valid projection.
- Present algorithms/system can provide valid contribution weight calculation.
- Based on the statistic result, both “real time computation” installation scheme and the LUT installation scheme can provide acceptable accuracy. However, the LUT scheme can provide faster processing.

Summary

Satellite observation collocation and integration algorithms package developed for AIRS/MODIS and IASI/AVHRR will be extended to provide CrIS/VIIRS cloud product collocation processing.

The VIIRS intermediate cloud fraction and VIIRS EDR cloud height product will be collocated to the CrIS observations to provide sub-pixel level cloud information for the CrIS SDR BUFR output.

The collocation LUTs will be generated and will provide a fast and robust implementation. At the same time, the LUT scheme will provide limited time resolution for collocation processing. The quality of this methodology will be evaluated in the future.

An “on-orbit” CrIS spatial response function retrieval algorithm is being developed. The result may be applied in future to improve precision of the CrIS SRF model.

Review Outline

- Introduction
- ARR Phase 2 Report
- Phase 3 Requirements
- Concept of Operations
- Algorithm Theoretical Basis: OLR
- Algorithm Theoretical Basis: ILS
- Algorithm Theoretical Basis: Collocation
- Phase 3 Software Architecture
- Quality Assurance
- Risk Summary
- Summary and Conclusions

Section 8 –
NUCAPS Phase 3
Software Architecture

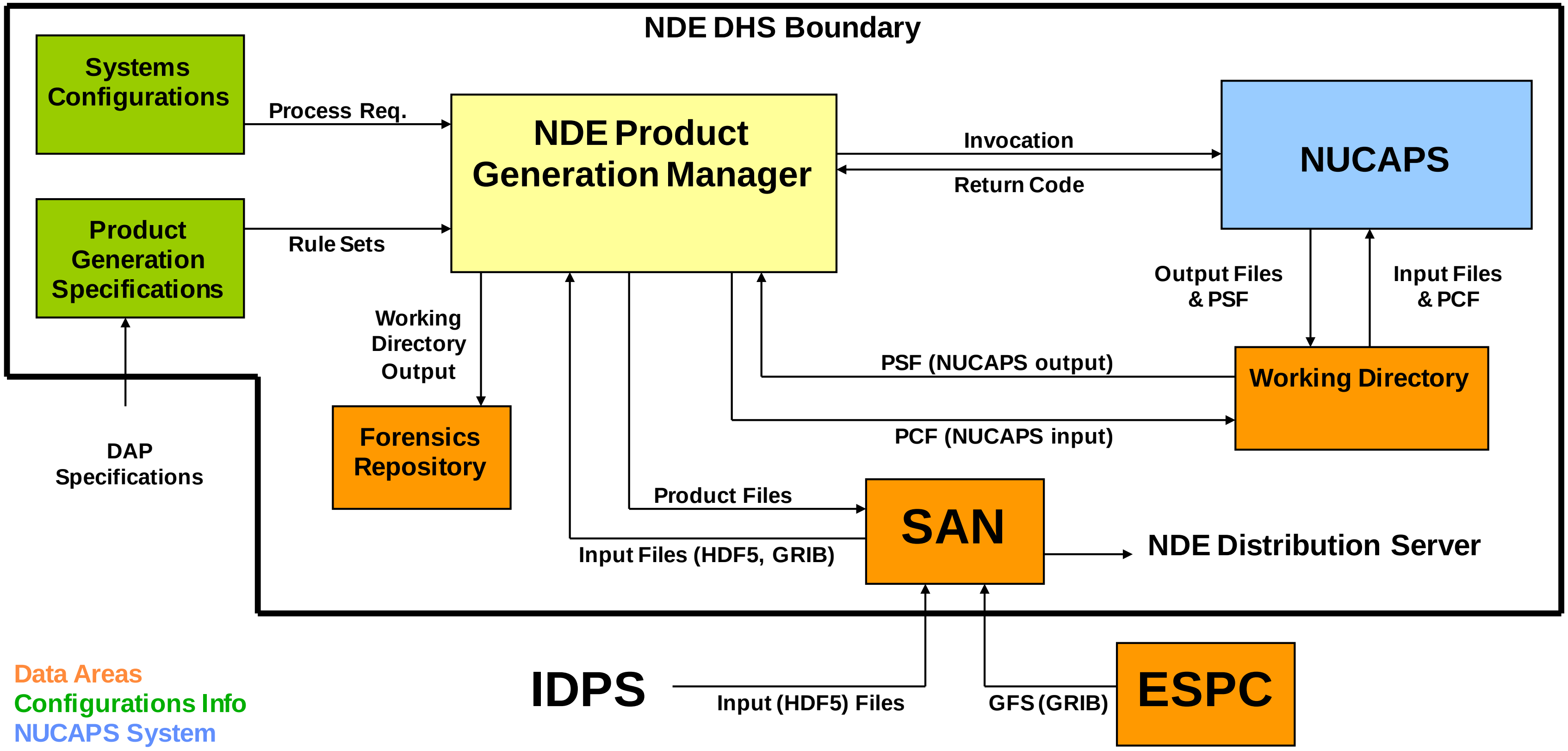
Presented by

Letitia Soulliard

NUCAPS Phase 3 Software Architecture

- This section shows the architecture for the entire NUCAPS package (Phases 1-3).
- The phase 3 delivery will be a redelivery of the entire package as opposed to an incremental delivery (only updated components) because the phase 3 components will be integrated into the existing software.
- The added phase 3 inputs are identified in the tables and the software flow diagrams.
- 3 Layers of design will be presented.
    - » External Interfaces
    - » System Layer
    - » Unit Layer

NUCAPS Phase 3 External Interfaces



NUCAPS External Interfaces

NDE DHS Boundary

Systems Configurations

Process Req.

Product Generation Specifications

Rule Sets

NDE Product Generation Manager

Invocation

Return Code

NUCAPS

Output Files & PSF

Input Files & PCF

Working Directory Output

PSF (NUCAPS output)

Working Directory

PCF (NUCAPS input)

Forensics Repository

DAP Specifications

Product Files

SAN

NDE Distribution Server

Input Files (HDF5, GRIB)

IDPS

Input (HDF5) Files

GFS (GRIB)

ESPC

Data Areas
Configurations Info
NUCAPS System
NDE Production Manager

NUCAPS
External Interfaces

- The following tables identifies the input files and output files for the entire NUCAPS package.

- The following new and modified items will be present in Phase 3:
  - Inputs
    - VIIRS CM + geo
    - VIIRS CTH + geo
  - Outputs
    - NUCAPS OLR files (containing metadata in header)
    - NUCAPS OLR global grids (for OSPO science quality monitoring efforts)
    - CrIS SDR netCDF4 (updated to contain VIIRS cloud information for the BUFR generated downstream)

NUCAPS Phase 3
External System Inputs

File	Input/ Output	Source	Description	State
CrIS SDR HDF5	Input	IDPS	CrIS granule files containing science data (radiances).	Dynamic
CrIS SDR Geo HDF5	Input	IDPS	CrIS granule files containing geolocation information for the science data.	Dynamic
ATMS TDR HDF5	Input	IDPS	ATMS granule files of ATMS antenna temperatures. 3 files are needed: the granule matching that of the CrIS granule and the 2 neighboring ATMS granules. The neighboring granules are needed for the FOV resampling.	Dynamic
ATMS TDR Geo HDF5	Input	IDPS	ATMS granule files containing geolocation information for the TDR.	Dynamic
GFS Forecast	Input	NCEP	The GFS 6-hour forecast file in GRIB2 format	Dynamic
VIIRS Cloud Mask IP HDF5	Input	IDPS	VIIRS Intermediate Product (IP) Cloud Mask	Dynamic
VIIRS Cloud Top Height HDF5	Input	IDPS	VIIRS Cloud Top Height EDR	Dynamic
VIIRS Cloud Mask IP Geo HDF5	Input	IDPS	VIIRS Moderate Bands Ellipsoid Geolocation Data (Not Terrain Corrected) for Cloud Mask.	Dynamic
VIIRS Cloud Top Height Geo HDF5	Input	IDPS	VIIRS Cloud Aggregated Ellipsoid Geolocation Data (Not Terrain Corrected) for Cloud Top Height	Dynamic

NUCAPS Phase 3
External System Outputs (1)

File	Input/ Output	Source	Description	State
CrIS/ATMS + VIIRS Cloud (all CrIs FOVs 399 channels)	Output	NUCAPS	The CrIS/ATMS netCDF4 granule file for 399 channels on all CrIS FOVs for all FORs. This will also contain the collocated VIIRS cloud information. This file will be converted to BUFR outside of NUCAPS.	Dynamic
CrIS/ATMS + VIIRS Cloud (all CrIs FOVs 1305 channels)	Output	NUCAPS	The CrIS/ATMS netCDF4 granule file for 1305 channels on all CrIS FOVs for all FORs. This will also contain the collocated VIIRS cloud information. This file will be converted to BUFR outside of NUCAPS. It is also used for quality monitoring at OSPO.	Dynamic
NUCAPS EDR netCDF4	Output	NUCAPS	This is the netCDF4 granule output file containing the EDR product.	Dynamic
NUCAPS CCR netCDF4	Output	NUCAPS	This is the netCDF4 granule output file containing all the CCR product data.	Dynamic
NUCAPS EDR Monitoring	Output	NUCAPS	This is a small text file output from the NUCAPS retrieval that is to be made available to OSPO for EDR QC monitoring.	Dynamic
NUCAPS PCS Monitoring	Output	NUCAPS	This is a small text file output from the NUCAPS PCS processing that is to be made available to OSPO for SDR QC monitoring.	Dynamic
NUCAPS OLR	Output	NUCAPS	The CrIS OLR granule product file in netCDF4 with metadata.	Dynamic

NUCAPS Phase 3
External System Outputs (2)

File	Input/ Output	Source	Description	State
CrIS/ATMS 0.5X2 Global Grids	Output	NUCAPS	CrIS/ATMS daily global grids at 0.5X2 degree grid resolution.	Dynamic
CrIS/ATMS 3X3 Global Grids	Output	NUCAPS	CrIS/ATMSdaily global grids at 3X3 degree grid resolution.	Dynamic
CrIS 3X3 PCS Global Grids (3-band)	Output	NUCAPS	CrIS 3-band principal component daily global grids at 3X3 degree resolution.	Dynamic
CrIS 0.5X2 PCS Global Grids (1-band)	Output	NUCAPS	CrIS 1-band principal component daily global grids at 0.5X2 degree resolution.	Dynamic
CrIS 3X3 PCS Global Grids (1-band)	Output	NUCAPS	CrIS 1-band principal component daily global grids at 3X3 degree resolution.	Dynamic
CrIS/ATMS 0.5X2 EDR global grids	Output	NUCAPS	CrIS/ATMS EDRs on a daily global grid at 0.5X2 degree resolution.	Dynamic
CrIS CCR 0.5X2 global grids	Output	NUCAPS	Cloud-cleared CrIS radiances on a daily global grid at 0.5X2 degree resolution.	Dynamic
CrIS OLR 0.5X2 global grids	Output	NUCAPS	CrIS OLR daily global grid at 0.5X2 degree resolution.	Dynamic

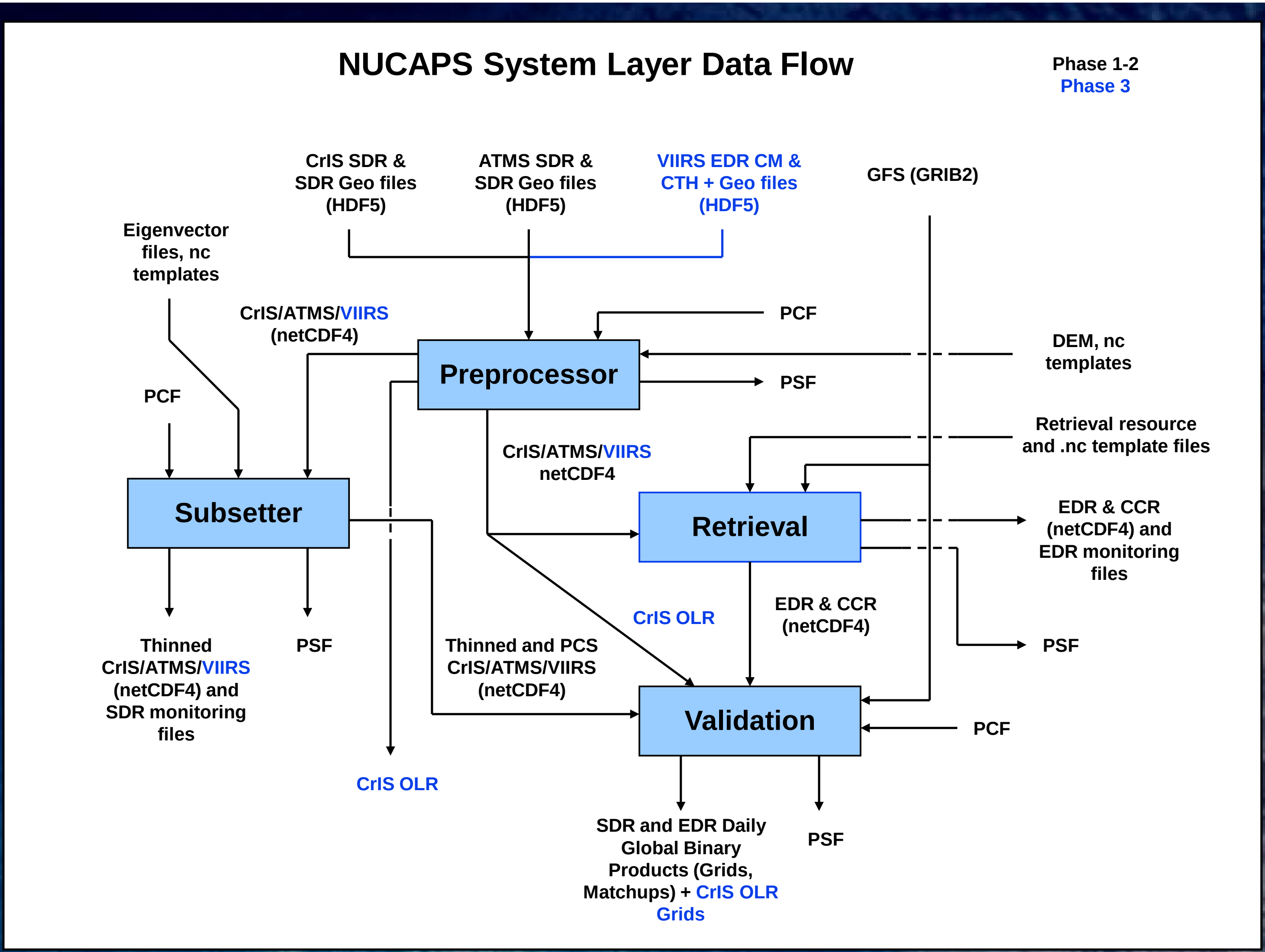
NUCAPS Phase 3 External System Outputs (3)

File	Input/ Output	Source	Description	State
GFS 0.5X2 global grids	Output	NUCAPS	A daily global coverage file of selected GFS forecast fields collocated to the same 0.5X2.0 degree grid as the CrIS/ATMS/VIIRS global grids.	Dynamic
CrIS 1-scan global binary	Output	NUCAPS	This file is a CrIS global binary used solely for off-line eigenvector generation at STAR	Dynamic
NUCAPS SDR matchups	Output	NUCAPS	This is a binary file containing all the NUCAPS SDR output matched to radiosonde locations.	Dynamic
NUCAPS SDR matchups list	Output	NUCAPS	This is a text file listing all the possible radiosonde matchup locations/times	Dynamic
NUCAPS EDR matchups	Output	NUCAPS	This is a binary file containing all the NUCAPS EDR output matched to radiosonde locations.	Dynamic
NUCAPS EDR matchups list	Output	NUCAPS	This is a text file listing all the possible radiosonde matchup locations/times	Dynamic

NUCAPS Phase 3
System-Layer Data Flow

- The next figure shows the NUCAPS Phase 3 “system layer” once it is configured within NDE.
- The text and figure elements labeled in blue also identify those components that are added to the Phase 1-2 configuration for Phase 3.

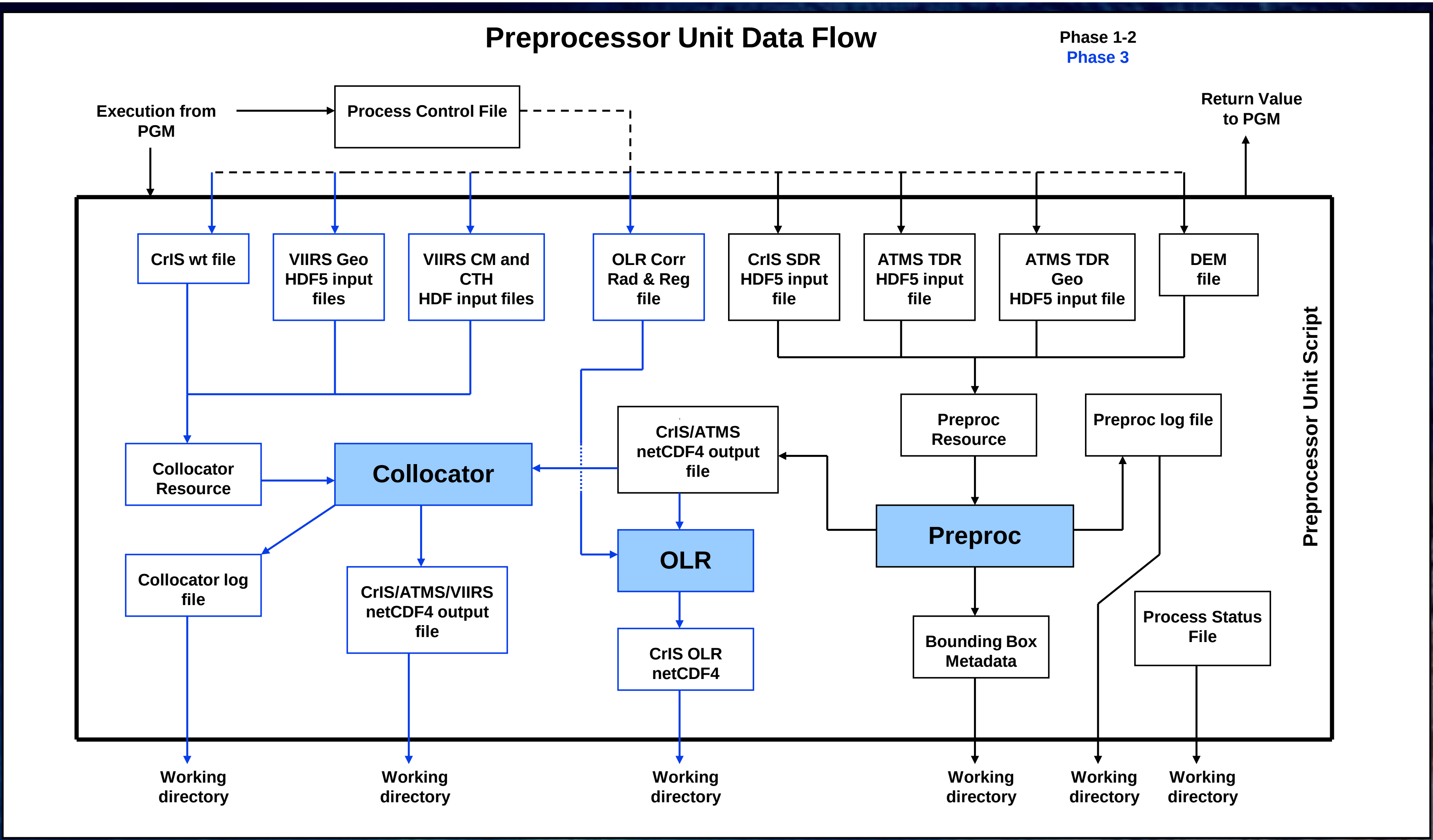
NUCAPS Phase 3
System-Layer Data Flow



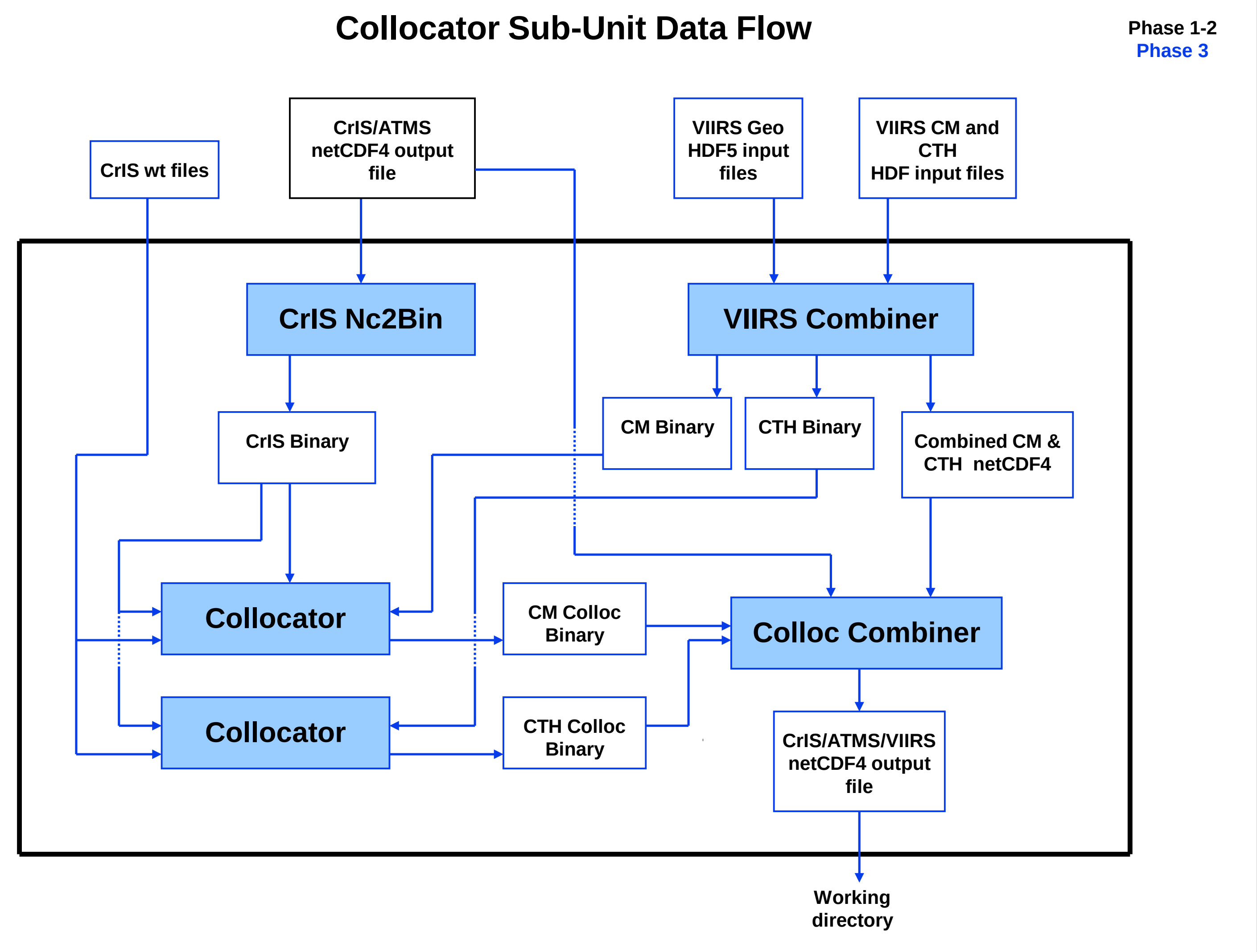
Preprocessor Unit

- The following figure and tables shows the Phase 3 Preprocessor unit data flows.
- The tables that follow identify the input, intermediate, and output files.
- Noteworthy items:
  - » VIIRS collocation added
    - – This is run inside a collocation sub-unit
  - » CrIS OLR added

Preprocessor Unit



Collocator Sub-Unit



Preprocessor Unit Interfaces (1)

File	Input/ Output	Source	Description	State
PCF	Input	NDE	The Process Control File supplied by the NDE PGM.	Dynamic
CrIS SDR HDF5	Input	NDE	CrIS granule files containing science data (radiances).	Dynamic
CrIS SDR Geo HDF5	Input	NDE	CrIS granule files containing geolocation information for the science data.	Dynamic
ATMS TDR HDF5	Input	NDE	ATMS granule files of ATMS antenna temperatures at native ATMS resolution.	Dynamic
ATMS TDR Geo HDF5	Input	NDE	ATMS granule files containing geolocation information for the TDR.	Dynamic
VIIRS Cloud Mask IP HDF5	Input	IDPS	VIIRS Intermediate Product (IP) Cloud Mask	Dynamic
VIIRS Cloud Top Height HDF5	Input	IDPS	VIIRS Cloud Top Height EDR	Dynamic
VIIRS Cloud Mask IP Geo HDF5	Input	IDPS	VIIRS Moderate Bands Ellipsoid Geolocation Data (Not Terrain Corrected) for Cloud Mask.	Dynamic
VIIRS Cloud Top Height Geo HDF5	Input	IDPS	VIIRS Cloud Aggregated Ellipsoid Geolocation Data (Not Terrain Corrected) for Cloud Top Height	Dynamic
DEM binary	Input	NUCAPS	Digital Elevation Model file containing surface elevation and land-sea-coast coverage for the globe at 1km.	Static
CrIS/ATMS/VIIRS CDL template	Input	NUCAPS	The netCDF4 CDL template used to create the output file.	Static

Preprocessor Unit Interfaces (2)

File	Input/ Output	Source	Description	State
CrIS wt file (750m)	Input	NUCAPS	The CrIS weighting function coefficients which determine how averaging to be performed on the 750 m VIIRS data collocated to CrIS	Static
CrIS wt file (6km)	Input	NUCAPS	The CrIS weighting function coefficients which determine how averaging to be performed on the 6 km VIIRS data collocated to CrIS	Static
CrIS Corr Rad	Input	NUCAPS	The CrIS OLR input radiation correction coefficient file.	Static
CrIS Pseudo Chan	Input	NUCAPS	The CrIS OLR input pseudo 20 channel parameter file.	Static
CrIS OLR Regression	Input	NUCAPS	The CrIS OLR regression coefficient file.	Static
Collocator Resource	Intermediate	NUCAPS	This is the resource text file containing the input file names and input parameters for the collocator program.	Dynamic
Combiner Resource	Intermediate	NUCAPS	This is the resource text file containing the input file names and input parameters for the combiner program.	Dynamic
CrIS/ATMS/VIIRS netCDF4	Output	NUCAPS	The output spatially and temporally collocated CrIS, ATMS, and VIIRS data. The CrIS and ATMS data file consist of radiances and the VIIRS data will consist of the cloud fraction and height averaged onto the CrIS FOVs. CrIS radiances have also been apodized and corrected for local angle viewing. The surface information has been added in from the DEM as well.	Dynamic

Preprocessor Unit Interfaces (2)

File	Input/ Output	Source	Description	State
Bounding Box metadata	Output	NUCAPS	This is a small text file containing NUCAPS internal metadata about the bounding box of the granule and ascending/descending status. This file is required as input to the Retrieval Unit.	Dynamic
NUCAPS OLR	Output	NUCAPS	The CrIS OLR granule product file in netCDF4 with metadata.	Dynamic
Collocator Run log	Output	NUCAPS	This is the run log containing the standard output and return status of Collocator sub-unit.	Dynamic
Combiner Run log	Output	NUCAPS	This is the run log containing the standard output and return status of Combiner sub-unit.	Dynamic
PSF	Output	NUCAPS	This is the Process Status File which is the formatted output status for the entire Preprocessor unit	Dynamic

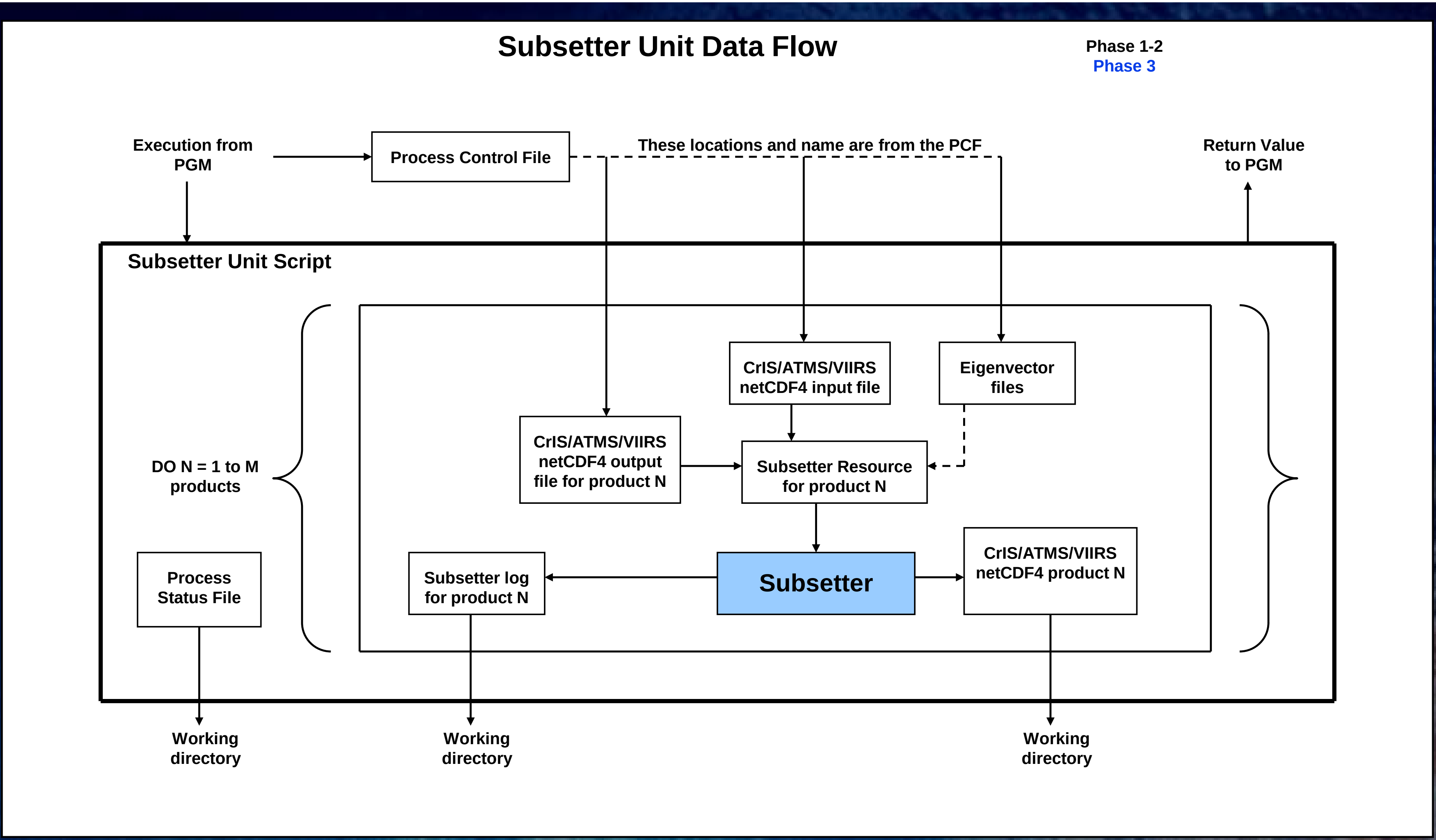
Subsetter Unit

- The following figure and tables shows the Phase 3 Subsetter unit data flows.

- The tables identify the input, intermediate, and output files.

- Noteworthy items:
  - » Nothing has changed in the Subsetter Unit for Phase 3

Subsetter Unit



Subsetter Unit Interfaces (1)

File	Input/ Output	Source	Description	State
PCF	Input	NDE	The Process Control File supplied by the NDE PGM.	Dynamic
CrIS/ATMS/VIIRS netCDF4	Input	NUCAPS (Preprocessor unit)	The full spectral and spatial resolution netCDF4 files of spatially and temporally collocated CrIS, ATMS, and VIIRS granule files. CrIS radiances have been apodized and corrected for local angle viewing.	Dynamic
Full-band eigenvector File	Input	STAR	The full-band (for 1305 channels) eigenvector file used to generate the principal components.	Static
Band-1 eigenvector file	Input	STAR	The band-1 eigenvector file used to generate the principal components.	Static
Band-2 eigenvector file	Input	STAR	The band-2 eigenvector file used to generate the principal components.	Static
Band-3 eigenvector file	Input	STAR	The band-3 eigenvector file used to generate the principal components.	Static
CrIS/VIIRS template, all FOVs 399 channels	Input	STAR	The thinned radiance netCDF4 template used to make all FOVs on all FORs, 399 channel file.	Static
CrIS/VIIRS template, center FOVs 399 channels	Input	STAR	The thinned radiance netCDF4 template used to make center FOVs on all FORs, 399 channel file.	Static

Subsetter Unit Interfaces (2)

File	Input/ Output	Source	Description	State
PCS CrIS/VIIRS template 1-scan	Input	STAR	This is a thinned radiance netCDF4 template file for generating subsets with full resolution CrIS data on only 1 scans per granule.	Static
PCS CrIS/VIIRS template (3-band) All FOVs	Input	STAR	The principal component netCDF4 template file used to make the 3-band, 300 PCS file, for all FOVs.	Static
PCS CrIS/VIIRS template (1-band) All FOVs	Input	STAR	The principal component netCDF4 template file used to make the 3-band, 100 PCS file, for all FOVs.	Static
PCS CrIS/VIIRS template (3-band) Center FOV	Input	STAR	The principal component netCDF4 template file used to make the 3-band, 300 PCS file, for the center FOV.	Static
PCS CrIS/VIIRS template (1-band) Center FOV	Input	STAR	The principal component netCDF4 template file used to make the 3-band, 100 PCS file, for the center FOV.	Static
CrIS/ATMS/VIIRS all FOVs 399 resource	Intermediate	NUCAPS	This is the resource file needed to generate the CrIS/ATMS/VIIRS all FOVs 399 channel file.	Dynamic
CrIS/ATMS/VIIRS center FOV 399 resource	Intermediate	NUCAPS	This is the resource file needed to generate the CrIS/ATMS/VIIRS center FOV 399 channel file.	Dynamic

Subsetter Unit Interface (3)

File	Input/ Output	Source	Description	State
CrIS/ATMS/VIIRS 1-scan resource	Intermediate	NUCAPS	This is the resource file needed to generate the CrIS/ATMS/VIIRS 1-scan file.	Dynamic
PCS CrIS/ATMS/VIIRS 3-band resource (All FOVs)	Intermediate	NUCAPS	This is the resource file needed to generate the PCS CrIS/ATMS/VIIRS 3-band file (for all FOVs).	Dynamic
PCS CrIS/ATMS/VIIRS 1-band resource (All FOVs)	Intermediate	NUCAPS	This is the resource file needed to generate the PCS CrIS/ATMS/VIIRS 1-band file (for all FOVs).	Dynamic
PCS CrIS/ATMS/VIIRS 3-band resource (Center FOV)	Intermediate	NUCAPS	This is the resource file needed to generate the PCS CrIS/ATMS/VIIRS 3-band file (for the center FOV).	Dynamic
PCS CrIS/ATMS/VIIRS 1-band resource (Center FOV)	Intermediate	NUCAPS	This is the resource file needed to generate the PCS CrIS/ATMS/VIIRS 1-band file (for the center FOV).	Dynamic
CrIS/ATMS/VIIRS all FOVs 399 run log	Output	NUCAPS	This is the run log for the CrIS/ATMS/VIIRS all FOVs 399 channel file.	Dynamic
CrIS/ATMS/VIIRS center FOV 399 run log	Output	NUCAPS	This is the run log for the CrIS/ATMS/VIIRS center FOV 399 channel file.	Dynamic
CrIS/ATMS/VIIRS 1-scan run log	Output	NUCAPS	This is the run log for the CrIS/ATMS/VIIRS 1-scan run log file.	Dynamic
PCS CrIS/ATMS/VIIRS 3-band run log (all FOVs)	Output	NUCAPS	This is the run log for the CrIS/ATMS/VIIRS 3-band file (all FOVs).	Dynamic

Subsetter Unit Interface (4)

File	Input/ Output	Source	Description	State
PCS CrIS/ATMS/VIIRS 1-band run log (all FOVs)	Output	NUCAPS	This is the run log for the CrIS/ATMS/VIIRS 1-band file (all FOVs).	Dynamic
PCS CrIS/ATMS/VIIRS 3-band run log (center FOVs)	Output	NUCAPS	This is the run log for the CrIS/ATMS/VIIRS 3-band file (center FOVs).	Dynamic
PCS CrIS/ATMS/VIIRS 1-band run log (center FOVs)	Output	NUCAPS	This is the run log for the CrIS/ATMS/VIIRS 1-band file (center FOVs).	Dynamic
CrIS/ATMS/VIIRS, all FOVs 399	Output	NUCAPS	The CrIS/ATMS/VIIRS netCDF4 granule file for 399 channels on all CrIS FOVs for all FORs. This is will be converted to BUFR outside of NUCAPS	Dynamic
CrIS/ATMS/VIIRS, center FOV 399	Output	NUCAPS	The CrIS/ATMS/VIIRS netCDF4 granule file for 399 channels on the center CrIS FOV for all FORs. This file is used as input to the 05.X2.0 degree global grids.	Dynamic
CrIS/ATMS/VIIRS 1-scan product	Output	NUCAPS	The CrIS/ATMS/VIIRS netCDF4 granule file with only 1 full resolution scans of CrIS FOVs for all 1305 channels. This file is used in the validation unit to generate a thinned coverage daily global file.	Dynamic
PCS CrIS/ATMS/VIIRS 3-band (all FOVs)	Output	NUCAPS	The CrIS PCS full spatial resolution netCDF4 granule file for 3-bands of 300 PCS (all FOVs)	Dynamic
PCS CrIS/ATMS/VIIRS 1-band (all (FOVs)	Output	NUCAPS	The CrIS PCS full spatial resolution netCDF4 granule file for 1-band of 100 PCS (all FOVs)	Dynamic

Subsetter Unit Interfaces (5)

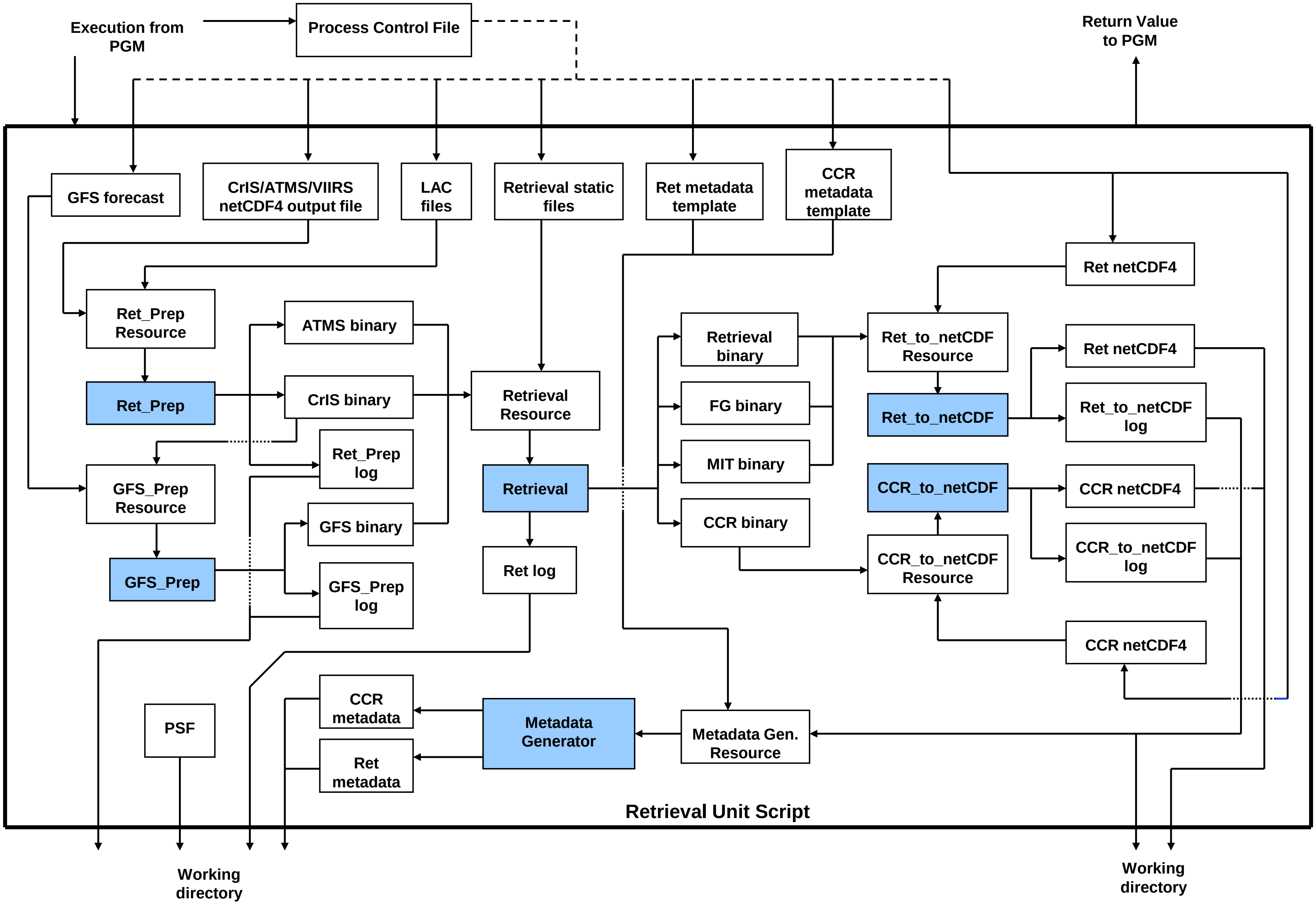
File	Input/ Output	Source	Description	State
PCS CrIS/ATMS/VIIRS 3-band (center FOVs)	Output	NUCAPS	The CrIS PCS full spatial resolution netCDF4 granule file for 3-bands of 300 PCS (center FOVs)	Dynamic
PCS CrIS/ATMS/VIIRS 1-band (center (FOVs)	Output	NUCAPS	The CrIS PCS full spatial resolution netCDF4 granule file for 1-band of 100 PCS (center FOVs)	Dynamic
PCS SDR monitoring file	Output	NUCAPS	This is the PC Score statistics monitoring file which is used for SDR monitoring by OSPO	Dynamic
PSF	Output	NUCAPS	This is the Process Status File containing the formatted status output for the entire Subsetter unit	Dynamic

Retrieval Unit

- The following figure and tables shows the Retrieval unit data flows.
- The tables identify the input, intermediate, and output files.
- Noteworthy items:
  - » Nothing has changed in the Retrieval Unit for Phase 3.

Retrieval Unit Data Flow

Phase 1-2
Phase 3



Execution from PGM
Process Control File
Return Value to PGM
GFS forecast
CrIS/ATMS/VIIRS netCDF4 output file
LAC files
Retrieval static files
Ret metadata template
CCR metadata template
Ret netCDF4
Ret_Prep Resource
ATMS binary
Retrieval binary
Ret_to_netCDF Resource
Ret netCDF4
Ret_Prep
CrIS binary
Retrieval Resource
FG binary
Ret_to_netCDF
Ret_to_netCDF log
Ret_Prep log
MIT binary
GFS_Prep Resource
Retrieval
CCR_to_netCDF
CCR netCDF4
GFS binary
CCR binary
CCR_to_netCDF log
GFS_Prep
GFS_Prep log
Ret log
CCR_to_netCDF Resource
CCR netCDF4
CCR metadata
PSF
Metadata Generator
Metadata Gen. Resource
Ret metadata
Retrieval Unit Script
Working directory
Working directory

Retrieval Unit Interfaces (1)

File	Input/ Output	Source	Description	State
PCF	Input	NDE	The Process Control File supplied by the NDE PGM.	Dynamic
CrIS/ATMS/VIIRS netCDF4	Input	NUCAPS (Preprocessor unit)	The spatially and temporally collocated CrIS, ATMS, and VIIRS granule data files. CrIS radiances have been apodized and corrected for local angle viewing.	Dynamic
GFS Forecast	Input	NCEP	The GFS 6-hour forecast file in GRIB format	Dynamic
NUCAPS Bounding Box	Input	NUCAPS (Preprocessor Unit)	This is an internal metadata file for NUCAPS. It is produced by the Preprocessor Unit and contains the bounding box and ascending/descending status.	Dynamic
NUCAPS EDR template	Input	STAR	This is the netCDF4 template file needed to create the EDR output file.	Static
CrIS CCR template	Input	STAR	This is the netCDF4 template file needed to create the CCR output file.	Static
CrIS AR CCR template	Input	STAR	This is the netCDF4 template file needed to create the CCR output file specifically for the CLASS (“AR” = Archive).	Static

Retrieval Unit Interfaces (2)

File	Input/ Output	Source	Description	State
Cloud namelist	Input	STAR	Cloud files name list	Static
IO namelist	Input	STAR	Input/Output name list	Static
Microwave namelist	Input	STAR	Microwave file name list	Static
Ozone namelist	Input	STAR	Ozone file name list	Static
Pro namelist	Input	STAR	Profile file name list	Static
Temp namelist	Input	STAR	Temperature file name list	Static
Water namelist	Input	STAR	Water vapor file name list	Static
CC_DAY_FILENAME			This is the name and location (if not in the local working directory) of the clear flag day time file needed by the retrieval.	Static
CC_NIGHT_FILENAME	Input	STAR	This is the name and location (if not in the local working directory) of the clear flag night time file needed by the retrieval.	Static
OLRCOEFFILE	Input	STAR	This is contains the rapid transmittance coefficients to compute outgoing longwave radiation.	Static
TUNINGCOEFFILE	Input	STAR	The tuning coefficient file.	Static
TUNINGMASKFILE	Input	STAR	The tuning mask file.	Static
RTAERRFILE	Input	STAR	The error coefficient file for the radiative transfer model.	Static
MWNOISEFILE	Input	STAR	This is microwave noise file.	Static
TC_AMSU	Input	STAR	This is the ATMS transmittance coefficient file.	Static
TC_AIRS	Input	STAR	This is the post-flight CrIS RTA coefficient file.	Static

Retrieval Unit Interfaces (3)

File	Input/ Output	Source	Description	State
IRNOISEFILE	Input	STAR	This is post-flight CrIS RTA coefficients file.	Static
SOLARFILE	Input	STAR	This is the CrIS solar irradiance file for the radiance calculation.	Static
NOAAEIGFILE	Input	STAR	This is the NOAA IR regression radiance eigenvector file.	Static
NOAAFRQFILE	Input	STAR	This is the NOAA IR regression frequency file.	Static
NOAAANGFILE	Input	STAR	This is the NOAA angle depended regression coefficient file.	Static
NOAAREGFILE	Input	STAR	This is the NOAA IR regression coefficient file.	Static
CLDAVGFILE	Input	STAR	This is the cloud averaging table.	Static
L2ERROR_IN	Input	STAR	This is a file containing the ensemble error estimate of climatology.	Static
MASUDAFILE	Input	STAR	This is coefficients file for the Masuda surface emissivity model for ocean.	Static
MWCOVFILE	Input	STAR	This is a microwave retrieval covariance file.	Static
ECOFFILE	Input	STAR	This is a microwave retrieval error covariance file.	Static
HSBWEIGHTFILE	Input	STAR	This is a microwave weighting file.	Static
UARSCLIMFILE	Input	STAR	This is the UARS climatology file for upper atmosphere.	Static
NCEPCLIMFILE	Input	STAR	This is the NCEP climatology file for Temperature and water vapor.	Static

Retrieval Unit Interfaces (4)

File	Input/ Output	Source	Description	State
CrIS ret binary	Intermediate	NUCAPS	The CrIS retrieval input format binary file.	Dynamic
ATMS ret binary	Intermediate	NUCAPS	The ATMS retrieval input format binary.	Dynamic
GFS ret binary	Intermediate	NUCAPS	The GFS retrieval input format binary.	Dynamic
Retrieval binary	Intermediate	NUCAPS	The retrieval output binary.	Dynamic
FG binary	Intermediate	NUCAPS	The first guess output binary.	Dynamic
MIT binary	Intermediate	NUCAPS	The MIT retrieval output binary.	Dynamic
CCR binary	Intermediate	NUCAPS	The CCR output binary.	Dynamic
TRU binary	Intermediate	NUCAPS	The TRU (Truth file) output binary.	Dynamic
F61 binary	Intermediate	NUCAPS	The f61 output binary.	Dynamic
F69 binary	Intermediate	NUCAPS	The f69 output binary.	Dynamic
F70binary	Intermediate	NUCAPS	The f75 diagnostic output binary.	Dynamic
F95 binary	Intermediate	NUCAPS	The f95 diagnostic output binary.	Dynamic
BIN binary	Intermediate	NUCAPS	The BIN diagnostic output binary.	Dynamic
Ret_Prep resource	Intermediate	NUCAPS	The Ret_Prep resource file required to reformat the satellite data into the retrieval input format.	Dynamic

Retrieval Unit Interfaces (5)

File	Input/ Output	Source	Description	State
GFS_Prep resource	Intermediate	NUCAPS	The GFS_Prep resource file required to reformat the GFS surface pressure data into the retrieval input format.	Dynamic
Retrieval resource	Intermediate	NUCAPS	The resource file required to run the retrieval.	Dynamic
Ret_to_netCDF resource	Intermediate	NUCAPS	The resource file required to reformat the retrieval, FG, and MIT output into netCDF4.	Dynamic
CCR_to_netCDF resource	Intermediate	NUCAPS	The resource file required to reformat the CCR output into netCDF4 format.	Dynamic
Ret_Prep run log	Output	NUCAPS	The Ret_Prep run log file.	Dynamic
GFS_Prep run log	Output	NUCAPS	The GFS_Prep run log file.	Dynamic
NUCAPS Retrieval run log	Output	NUCAPS	The Retrieval run log file.	Dynamic
Ret_to_netCDF run log	Output	NUCAPS	The Ret_to_netCDF run log file.	Dynamic
CCR_to_netCDF run log	Output	NUCAPS	The CCR_to_netCDF run log file.	Dynamic
NUCAPS EDR netCDF4	Output	NUCAPS	This is the netCDF4 granule output file containing the EDR.	Dynamic

Retrieval Unit Interfaces (6)

File	Input/ Output	Source	Description	State
CrIS CCR netCDF4	Output	NUCAPS	This is the netCDF4 granule output file containing all the CCR product data.	Dynamic
NUCAPS EDR monitoring file	Output	NUCAPS	This is the retrieval.out EDR statistics monitoring file for OSPO.	Dynamic
Retrieval log	Output	NUCAPS	This is the run log containing the standard output and return status of retrieval sub-unit processes.	Dynamic
PSF	Output	NUCAPS	This is the Process Status File containing the formatted status output for the entire Retrieval unit	Dynamic

Validation Unit

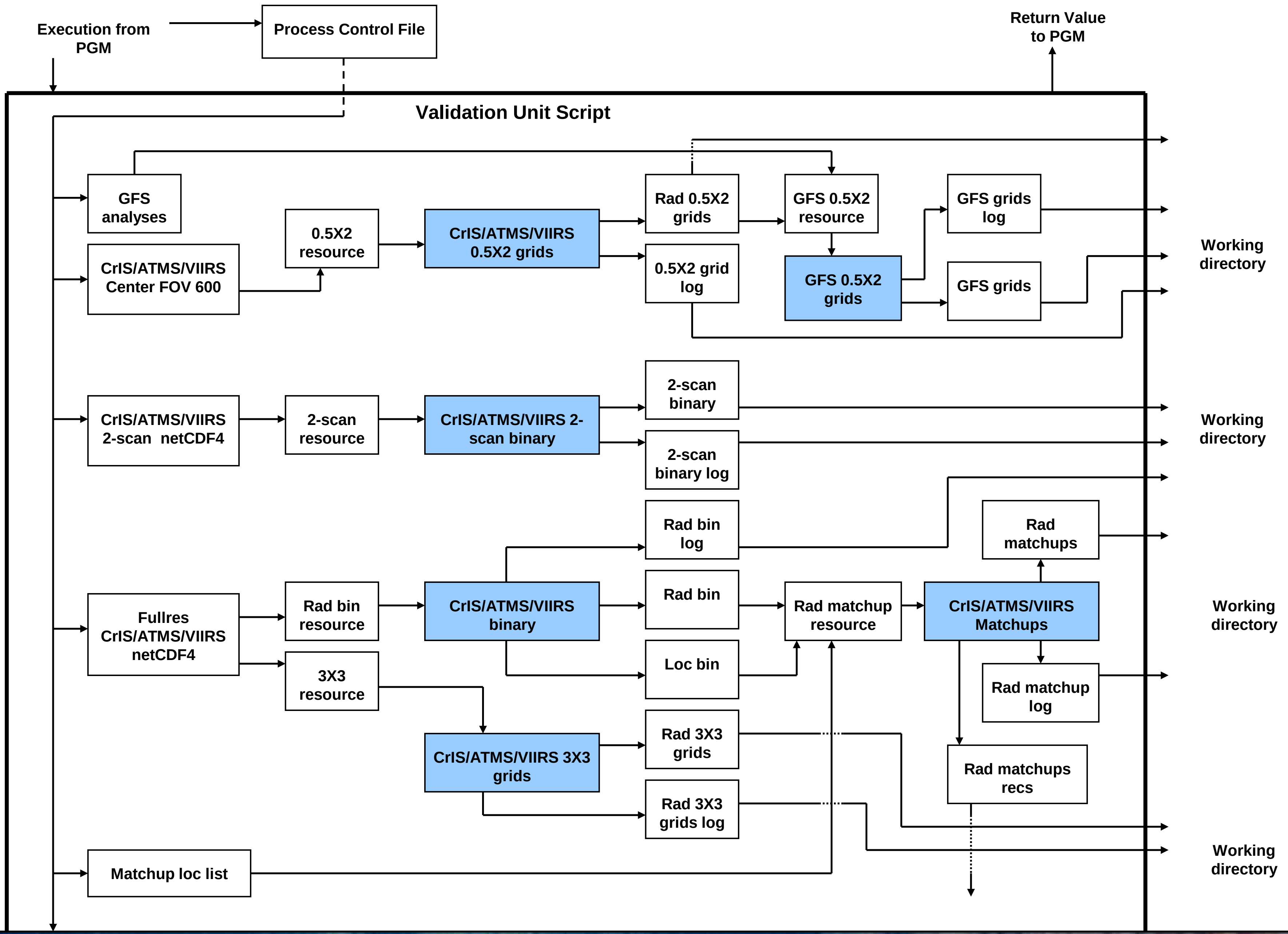
- The following figure and tables shows the Phase 3 Validation unit data flows. All new items are identified in blue

- The tables identify the input, intermediate, and output files.

- Noteworthy items:
  - » OLR Grids

Validation Unit Data Flow – Part 1

Phase 1-2
Phase 3



Execution from PGM

Process Control File

Return Value to PGM

Validation Unit Script

GFS analyses

CrIS/ATMS/VIIRS Center FOV 600

0.5X2 resource

CrIS/ATMS/VIIRS 0.5X2 grids

Rad 0.5X2 grids

0.5X2 grid log

GFS 0.5X2 resource

GFS 0.5X2 grids

GFS grids log

GFS grids

Working directory

CrIS/ATMS/VIIRS 2-scan netCDF4

2-scan resource

CrIS/ATMS/VIIRS 2-scan binary

2-scan binary

2-scan binary log

Working directory

Fullres CrIS/ATMS/VIIRS netCDF4

Rad bin resource

3X3 resource

CrIS/ATMS/VIIRS binary

Rad bin log

Rad bin

Loc bin

Rad matchup resource

CrIS/ATMS/VIIRS Matchups

Rad matchups

Rad matchup log

Rad matchups recs

CrIS/ATMS/VIIRS 3X3 grids

Rad 3X3 grids

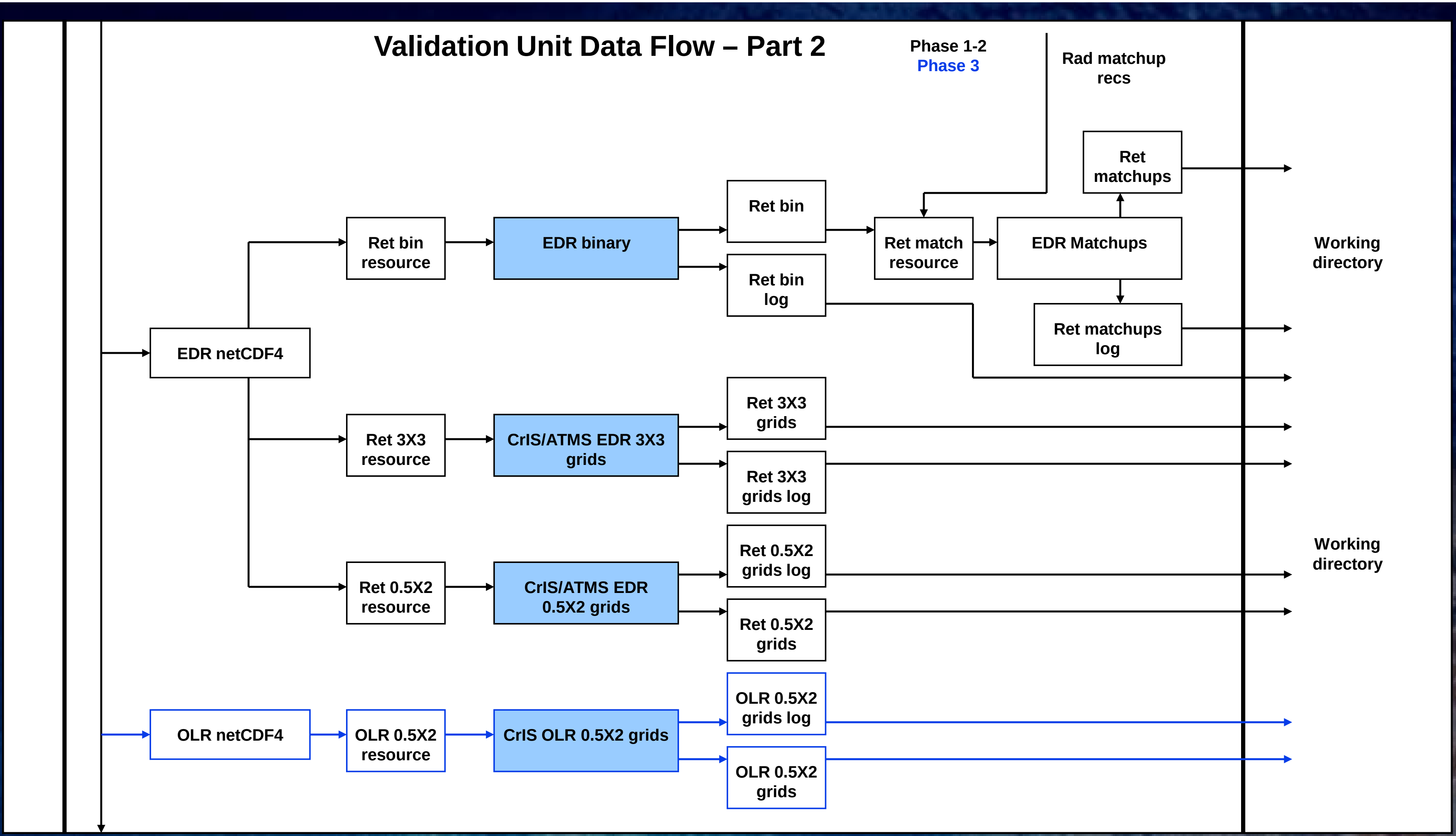
Rad 3X3 grids log

Working directory

Matchup loc list

Working directory

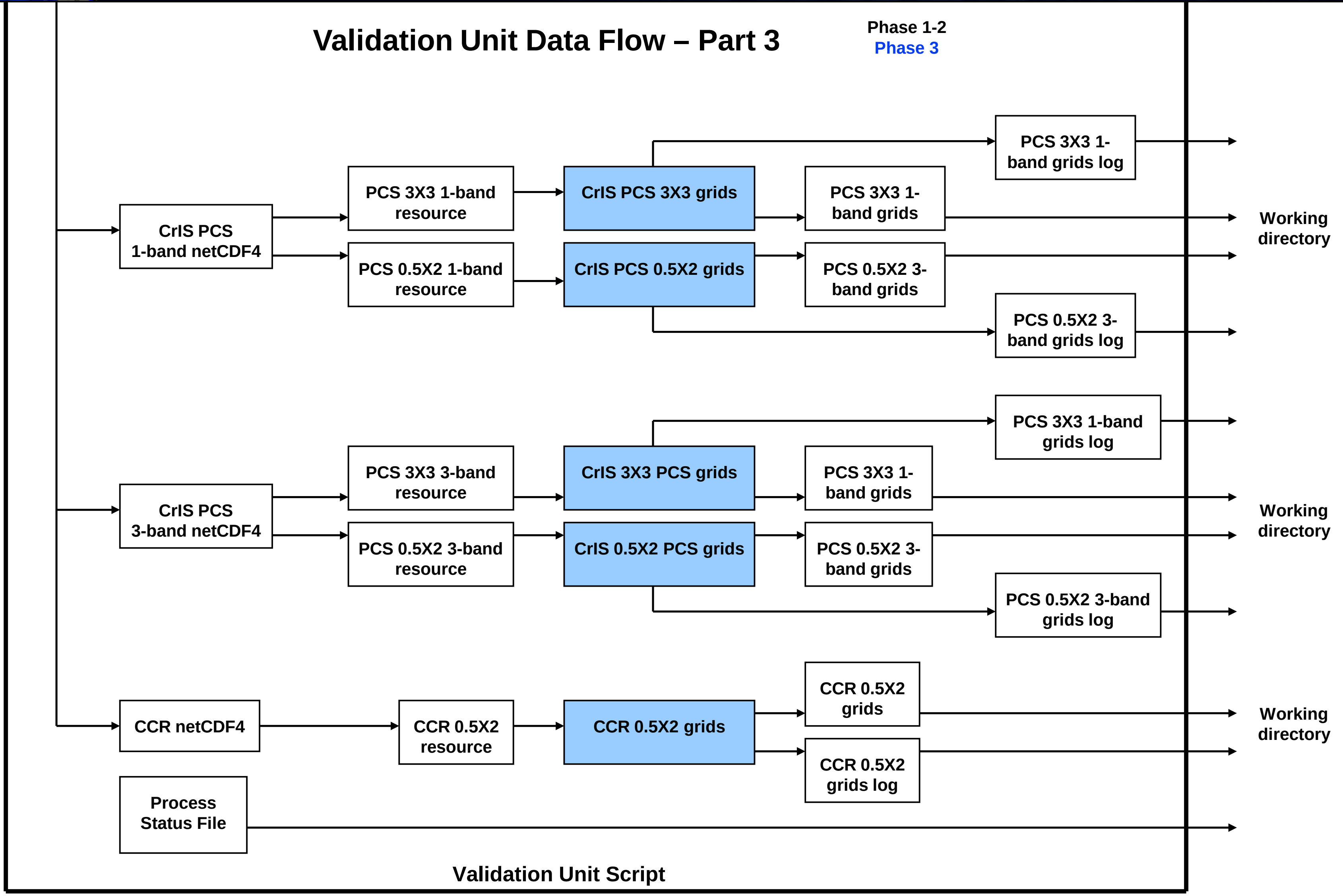
Validation Unit (2)



Validation Unit Data Flow – Part 2

Phase 1-2
Phase 3

Validation Unit (3)



Validation Unit Data Flow – Part 3

Phase 1-2
Phase 3

CrIS PCS
1-band netCDF4

PCS 3X3 1-band resource

PCS 0.5X2 1-band resource

CrIS PCS 3X3 grids

CrIS PCS 0.5X2 grids

PCS 3X3 1-band grids log

PCS 3X3 1-band grids

PCS 0.5X2 3-band grids

PCS 0.5X2 3-band grids log

Working directory

CrIS PCS
3-band netCDF4

PCS 3X3 3-band resource

PCS 0.5X2 3-band resource

CrIS 3X3 PCS grids

CrIS 0.5X2 PCS grids

PCS 3X3 1-band grids log

PCS 3X3 1-band grids

PCS 0.5X2 3-band grids

PCS 0.5X2 3-band grids log

Working directory

CCR netCDF4

CCR 0.5X2 resource

CCR 0.5X2 grids

CCR 0.5X2 grids

CCR 0.5X2 grids log

Working directory

Process Status File

Validation Unit Script

Validation Unit Interfaces (1)

File	Input/ Output	Source	Description	State
PCF	Input	NDE	The Process Control File supplied by the NDE PGM.	Dynamic
CrIS/ATMS/VIIRS netCDF4	Input	NUCAPS (Preprocessor)	The spatially and temporally collocated CrIS, ATMS, and VIIRS granule data files (all CrIS FOVs and channels) CrIS radiances have been apodized.	Dynamic
Thinned CrIS/ATMS/VIIRS netCDF4 file for a center FOV, 399 channels	Input	NUCAPS (Subsetter)	The CrIS/ATMS/VIIRS netCDF4 files for the center FOV.	Dynamic
Thinned CrIS/ATMS/VIIRS netCDF4 1-scan file.	Input	NUCAPS (Subsetter)	The CrIS/ATMS/VIIRS netCDF4 files containing only 1 scans of CrIS FOVs per granule.	Dynamic
PCS CrIS/ATMS/VIIRS 1-band (all (FOVs)	Input	NUCAPS (Subsetter)	The CrIS PCS full spatial resolution netCDF4 granule file for 1-band of 100 PCS (all FOVs)	Dynamic
PCS CrIS/ATMS/VIIRS 3-band (center FOVs)	Input	NUCAPS (Subsetter)	The CrIS PCS full spatial resolution netCDF4 granule file for 3-bands of 300 PCS (center FOVs)	Dynamic
PCS CrIS/ATMS/VIIRS 1-band (center (FOVs)	Input	NUCAPS (Subsetter)	The CrIS PCS full spatial resolution netCDF4 granule file for 1-band of 100 PCS (center FOVs)	Dynamic
EDR netCDF4	Input	NUCAPS (Retrieval)	This is the netCDF4 granule file containing the EDR product.	Dynamic
CrIS CCR netCDF4	Input	NUCAPS (Retrieval)	This is the netCDF4 granule file containing all the CCR product data.	Dynamic
GFS analyses	Input	NCEP	These are the GFS analysis files generated at 00, 06, 12, and 18Z.	Dynamic

Validation Unit Interfaces (2)

File	**Input/ Output**	**Source**	**Description**	**State**
Matchup loc list	Input	NUCAPS	This is a static ASCII text file containing a list of in-situ measurement locations and observations times. These are mostly radiosonde observations, but could include aircraft or dropsondes as well.	Static
NUCAPS OLR	Input	NUCAPS	The CrIS OLR granule product file in netCDF4 with metadata.	Dynamic
Rad bin	Intermediate	NUCAPS	The CrIS/ATMS/VIIRS global binary used as the input to the CrIS/ATMS/VIIRS matchups.	Dynamic
Ret bin	Intermediate	NUCAPS	The EDR global binary used as the input to the EDR matchups.	Dynamic
Rad matchups recs	Intermediate	NUCAPS	The matchup direct access record list produced by the CrIS/ATMS/VIIRS matchups and used by the NUCAPS EDR matchups.	Dynamic
CrIS/ATMS/VIIRS 0.5X2 grids resource	Intermediate	NUCAPS	The resource file required to generate the CrIS/ATMS/VIIRS 0.5X2 grids.	Dynamic
CrIS/ATMS/VIIRS 3X3 grids resource	Intermediate	NUCAPS	The resource file required to generate the CrIS/ATMS/VIIRS 3X3 grids	Dynamic
1-scan resource	Intermediate	NUCAPS	The resource file required to generate the CrIS/ATMS/VIIRS 1-scan binary.	Dynamic

Validation Unit Interfaces (3)

File	Input/ Output	Source	Description	State
CrIS/ATMS/VIIRS binary resource	Intermediate	NUCAPS	The resource file required to generate the CrIS/ATMS/VIIRS global binary which is needed for the matchups.	Dynamic
GFS forecast grids resource	Intermediate	NUCAPS	The resource file required to generate the 0.5X2 GFS global grids.	Dynamic
Rad matchup resource	Intermediate	NUCAPS	The resource file required to generate the CrIS/ATMS/VIIRS matchups.	Dynamic
Ret bin resource	Intermediate	NUCAPS	The resource file required to generate the EDR global binary which is needed for the retrieval matchups.	Dynamic
Ret match resource	Intermediate	NUCAPS	The resource file required to generate the EDR matchups.	Dynamic
Ret 3X3 resource	Intermediate	NUCAPS	The resource file required to generate the NUCAPS EDR 3X3 grids	Dynamic
Ret 0.5X2 resource	Intermediate	NUCAPS	The resource file required to generate the NUCAPS EDR 0.5X2 grids	Dynamic
PCS 3X3 1-band resource	Intermediate	NUCAPS	The resource file required to generate the 1-band PCS CrIS/ATMS/VIIRS 3X3 grids.	Dynamic
PCS 0.5X2 1-band resource	Intermediate	NUCAPS	The resource file required to generate the 1-band PCS CrIS/ATMS/VIIRS 0.5X2 grids.	Dynamic

Validation Unit Interfaces (4)

File	Input/ Output	Source	Description	State
PCS 0.5X2 3-band resource	Intermediate	NUCAPS	The resource file required to generate the 3-band PCS CrIS/ATMS/VIIRS 0.5X2 grids.	Dynamic
CCR 0.5X2 resource	Intermediate	NUCAPS	The resource file required to generate the CCR 0.5X2 grids.	Dynamic
CrIS/ATMS/VIIRS 0.5X2 grids run log	Output	NUCAPS	The run log generated by the running of the CrIS/ATMS/VIIRS 0.5X2 grids program.	Dynamic
CrIS/ATMS/VIIRS 3X3 grids run log	Output	NUCAPS	The run log generated by the running of the CrIS/ATMS/VIIRS 3X3 grids program.	Dynamic
1-scan run log	Output	NUCAPS	The run log generated by the running of the CrIS/ATMS/VIIRS 1-scan binary program.	Dynamic
CrIS/ATMS/VIIRS binary resource	Output	NUCAPS	The run log generated by the running of the CrIS/ATMS/VIIRS global binary program.	Dynamic
GFS forecast grids run log	Output	NUCAPS	The run log generated by the running of the GFS 0.5X2 grids program.	Dynamic

Validation Unit Interfaces (5)

File	Input/ Output	Source	Description	State
Rad matchup run log	Output	NUCAPS	The run log generated by the running of the CrIS/ATMS/VIIRS radiance matchups program.	Dynamic
Ret bin run log	Output	NUCAPS	The run log generated by the running of the EDR binary program.	Dynamic
Ret match run log	Output	NUCAPS	The run log generated by the running of the EDR matchups program.	Dynamic
Ret 3X3 run log	Output	NUCAPS	The run log generated by the running of the EDR 3X3 grids program.	Dynamic
Ret 0.5X2 run log	Output	NUCAPS	The run log generated by the running of the EDR 0.5X2 grids program.	Dynamic
PCS 3X3 1-band run log	Output	NUCAPS	The run log generated by the running of the 1-band PCS CrIS/ATMS/VIIRS 3X3 grids program.	Dynamic
PCS 0.5X2 1-band run log	Output	NUCAPS	The run log generated by the running of the 1-band PCS CrIS/ATMS/VIIRS 0.5X2 grids program.	Dynamic
PCS 0.5X2 3-band run log	Output	NUCAPS	The run log generated by the running of the 3-band PCS CrIS/ATMS/VIIRS 0.5X2 grids program.	Dynamic

Validation Unit Interfaces (6)

File	Input/ Output	Source	Description	State
CCR 0.5X2 run log	Output	NUCAPS	The run log generated by the running of the CCR 0.5X2 grids program.	Dynamic
OLR 0.5X2 run log	Output	NUCAPS	The run log generated by the running of the CrIS OLR 0.5X2 grids program.	Dynamic
CrIS/ATMS/VIIRS 0.5X2 Global Grids	Output	NUCAPS	CrIS/ATMS/VIIRS daily global grids at 0.5X2 degree grid resolution.	Dynamic
CrIS/ATMS/VIIRS 3X3 Global Grids	Output	NUCAPS	CrIS/ATMS/VIIRS daily global grids at 3X3 degree grid resolution.	Dynamic
CrIS 0.5X2.0 PCS Global Grids (3-band)	Output	NUCAPS	CrIS 3-band principal component daily global grids at 0.5X2 degree resolution.	Dynamic
CrIS 0.5X2 PCS Global Grids (1-band)	Output	NUCAPS	CrIS 1-band principal component daily global grids at 0.5X2 degree resolution.	Dynamic
CrIS 3X3 PCS Global Grids (1-band)	Output	NUCAPS	CrIS 1-band principal component daily global grids at 3X3 degree resolution.	Dynamic
CrIS/ATMS 0.5X2 EDR global grids	Output	NUCAPS	CrIS/ATMS EDRs on a daily global grid at 0.5X2 degree resolution.	Dynamic
CrIS CCR 0.5X2 global grids	Output	NUCAPS	Cloud-cleared CrIS radiances on a daily global grid at 0.5X2 degree resolution.	Dynamic
CrIS OLR 0.5X2 global grids	Output	NUCAPS	CrIS OLR on a daily global grid at 0.5X2 degree resolution.	Dynamic

Validation Unit Interfaces (7)

File	Input/ Output	Source	Description	State
GFS forecast global grids	Output	NUCAPS	A daily global coverage file of selected GFS forecast fields collocated to the same 0.5X2.0 degree grid as the CrIS/ATMS/VIIRS global grids.	Dynamic
CrIS 1-scan global coverage binary	Output	NUCAPS	This file is a CrIS global binary used solely for off-line eigenvector generation at STAR	Dynamic
NUCAPS SDR matchups	Output	NUCAPS	This is a file with matches between CrIS/ATMS/VIIRS FORs and radiosonde (or other instrument) locations.	Dynamic
NUCAPS EDR matchups	Output	NUCAPS	This is NUCAPS EDR output matched to radiosonde locations.	Dynamic
Run log	Output	NUCAPS	This is the run log containing the standard output and return status of Validation unit sub-unit processes.	Dynamic
PSF	Output	NUCAPS	This is the Process Status File containing the formatted status output for the entire Validation unit	Dynamic

Updates to PCF Files

- NUCAPS_Preproc.pl.PCF
  - VIIRS CM
  - VIIRS CTH
  - VIIRS Moderate Bands Ellipsoid Geolocation Data (Not Terrain Corrected)
  - VIIRS Cloud Aggregated Ellipsoid Geolocation Data (Not Terrain Corrected)
  - VIIRS file count
  - VIIRS netCDF template file
  - CrIS FOV 750 m weighting function file
  - CrIS FOV 6 km weighting function file
  - CrIS OLR input radiation correction coefficient file
  - CrIS OLR regression coefficient file
  - Flag to turn on or off the VIIRS/CrIS collocation
  - Flag to turn on or off the OLR
- NUCAPS_Validation.pl.PCF has some updates
  - CrIS OLR input files for the 0.5X2.0 grids
  - Flag to turn on or off this product

Updates to PSF Files

- NUCAPS_Preproc.pl.PSF
  - NUCAPS OLR netCDF4
- NUCAPS_Validation.pl.PSF
  - NUCAPS OLR 0.5X2.0 Global Grid

NUCAPS Phase 3 Software Architecture Summary

- NUCAPS Phase 3 delivery will be a redelivery of the entire code package (all 4 original software units).
- Updates will be to the following:
  - » The Preprocessor and Validation Units (driver scripts and Fortran code)
  - » Updates to PCF and PSF files for both units
  - » Updates to production rules to both units
  - » Updates to ATBD, SMM, and EUM
- The subsetter unit will not need to change to handle processing the CrIS thinned radiances.
- N4RT will not need to change to produce the CrIS BUFR.

Review Outline

- Introduction
- ARR Phase 2 Report
- Phase 3 Requirements
- Concept of Operations
- Algorithm Theoretical Basis: OLR
- Algorithm Theoretical Basis: ILS
- Algorithm Theoretical Basis: Collocation
- Phase 3 Software Architecture
- Quality Assurance
- Risk Summary
- Summary and Conclusions

Section 9 –
Quality Assurance

Presented by

Tom King

Quality Assurance

- Quality assurance consists of PROCESS QA and PRODUCT QA.
- PROCESS QA is concerned with assuring that the SPSRB process standards are met during the planning, development, operations, and distribution phases of the project.
  - » Process QA is achieved through the standard reviews. Each review check list and entry/exit criteria are designed to ensure that the relevant process standards are met by the implementation of standard practices during the steps leading up to the review.
- PRODUCT QA is concerned with assuring that the work products created during the project’s lifecycle meet their requirements.
  - » Product QA is achieved by verification of the project’s work products and validation of the products, operator needs, and user needs. This work is done in the unit testing phases and assisting with user readiness. At this stage, it’s covered under the validation sections of the ATBDs.

Quality Assurance Methodology

- STAR has used the Capability Maturity Model Integrated (CMMI) to improve processes and practices for development and the transfer of research to operations.

- The STAR Enterprise Life Cycle (EPL) is a CMMI Level 3 process.

- The NUCAPS Phase 3 project will follow the updated SPSRB process that has been influenced by the STAR EPL process.

Reviews

- Requirements Review for OLR (9/30-10/17)
- Preliminary Design Review (None)
  - » Waived for this project
- Critical Design Review (12/2/2013)
  - » To finalize requirements and to verify that the chosen design is able to meet those requirements.
- Software Code Review (4/23/2014)
  - » Check that code meets all OSPO coding and security standards.
- Algorithm Readiness Review (9/8/2014)
  - » Will demonstrate that all products are meeting requirements.

Configuration Management

- STAR CM Tool (IBM Rational ClearCase, Version 7.0)
  - » Has been implemented in the Collaborative Environment.
- OSPO CM Tool – Subversion
  - » Open source
- STAR CM personnel have been identified.
- STAR CM training:
  - » Administrator training completed.
  - » If required, developers will be trained by the CM administrator.

SPSRB Coding Standards

- Coding standards and security guidelines are available to developers.
- Developers must adhere to the standards throughout the development life cycle.
- Code is checked for compliance during the software review and then, based on recommendations, is subsequently updated and redelivered to the review team.

Quality Assurance – Software

- At STAR all code is developed and tested on a platform that is nearly identical to the test and production target platforms using nearly identical compilers and operating system. STAR development is done on Linux and IBM P5 hardware in STAR.

- STAR code checking tools and Valgrind will be used to minimize coding bugs and to ensure that software meets the coding standards.

- Common checks are:
  - » The status of all system calls and intrinsic functions are checked for error trapping.
  - » Memory leaks.
  - » No hardcoding of paths.
  - » No goto statements
  - » Proper use of headers, indentation, and use of comments.

Quality Assurance – Software

- The software and its output products will be unit tested and validated at STAR.
- Prior to delivery, the code will also be compiled and run on the NDE SADIE platform to ensure compatibility with NDE.
- Preoperational sample data will be made available to end users to assist with product validation and user readiness.
- System testing of the code will be performed within NDE.
- As in the past, STAR developers will work with NDE to assist with integration and system validation.

Delivered Algorithm Package

- An official NDE-compliant DAP will be delivered:
  - Test plans and test data
  - SPSRB documentation (ATBD, SMM, EUM)
  - Source Code
  - All scripts, static data files, and configuration files
  - Production rules
  - Description of PCF and PSF specifications
  - Delivery memo and README

Quality Assurance – Products

- The NUCAPS developers and science team will work with OSPO to assist with product quality monitoring.
- OLR grids will be made available to OSPO monitoring efforts (similar to IASI).
- Will work with the VIIRS Cal/Val teams and JPSS algorithm manager and IDPS quality monitors to assess operational product quality of the input CM and CTH.

Quality Assurance – Archive and Maintenance

- Archive Plan
  - » STAR developers will work with CLASS and the NDE liaison to update the existing data archiving agreement.
  - » STAR developers will work with CLASS to define the product metadata. Metadata will adhere to the current NDE/CLASS guidelines.

- Long Term Maintenance Plan
  - » The NUCAPS Phase 3 system will officially be operated and maintained by the OSPO staff
  - » STAR system developers will be available

Quality Assurance – Documentation

- Documentation Plan
  - The Documentation will include the SPRSB documents for OSPO and NDE needs:
    - SMM
    - ATBD
    - EUM
  - Additional project documentation will consist of:
    - Additional DAP contents (README, Delivery memo, production rules, PCF/PSF specifications)
    - RAD
    - RID
    - Project Reviews (CDR, CTR, ARR)
    - Data Access Request Forms
    - Updated Product/User spreadsheet

Quality Assurance Summary

- Quality assurance plan will consist of:
  - Project reviews at which stakeholders are encouraged to participate.
  - Ongoing interaction with algorithm developers, product users, NDE, the PAL, and OSPO quality monitoring and operators.
  - Adhering to SPSRB software standards and use of standard libraries only.
  - Software unit tests shall be conducted and presented at a readiness review.
  - Documentation of the code operation, production rules, and software tests will be in the algorithm package.
  - Documentation of requirements will be in the RAD.

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Section 10 –
Risks Summary

Presented by

Tom King

Open Risks and Actions

- **Risk #30:** The current CrIS instrument's spectral resolution in the short-wave band is too low for retrieval of carbon monoxide within requirements.
  - » **Risk Mitigation:**
  - » JPSS Project Office has been investigating bringing down full resolution data in the CrIS RDR, but there is not yet a plan to put it into the SDR.
  - » NUCAPS science development team will continue to work with the Project Office to have these data available in the SDR.
- **Closure Date:** TBD

ARR Phase 2 Risks and Actions

- **Risk #43:** PAL needs to identify the trace gas community users.
  - **Risk Mitigation:**
  - AK Sharma will work with Donna McNamara and others to identify who the trace gas users are for NUCAPS.
- **Closure Date:** Jan 2014

New Risks and Actions

- **Risk #44:** To expedite the release of this product, the lower resolution cloud top height from IDPS will be used for now. This will be a lower quality product than what we will get using the JPRR cloud top height.
- **Status:** TBD
  - » **Risk Mitigation:**
    - TBD. We have some options here, but it depends on schedules and funding. Mitigation on Risk #45 is relevant here as it will involve meeting with the users:
    - (1) Do we want to do this (using IDPS data) and be done? The problem is that EUMETSAT is already doing this on their own so they would not benefit from this.
    - (2) Wait for JPRR cloud height and mask to be produced and use that instead of IDPS products. That means we delay.
    - (3) Do we want to do option 1 now and then add in the higher resolution JPRR cloud top height later? This will require more work later?
- **Closure Date:** Jan 2014

New Risks and Actions

- **Risk #45:** Latency of the VIIRS CM and CTH with respect to the associated CrIS SDRs is 3-6 minutes (according to Dylan Powell). Prior to receiving these latency numbers, Andrew Collard and Simon Elliott stated that no delay was acceptable.
- **Status:** High
  - **Risk Mitigation:**
    - Walter has been given an action to set up a meeting with the users (Collard, Jung). We need to know that the users actually want this product and, if so, if a 3-6 minute delay (on average) would be acceptable. It depends on how much the users want this updated feature versus how long they're willing to wait.
- **Closure Date:** Jan 2014

Review Items Summary

- 2 open risks
  - » 1 risk from Phase 1 CDR
    - – Low
  - » 1 risk from Phase 1 ARR
    - – Low
  - » 2 new risks
    - – 1 High
    - – 1 TBD

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Section 11 –
Summary and Conclusions

Presented by

Tom King

Review Objectives Have Been Addressed

- The following have been reviewed
  - Production schedule
  - Phase 2 ARR Risks and Actions
  - Updated Requirement Allocation
  - Concept of Operations
  - NUCAPS Phase 3 Algorithm Theoretical Basis
  - NUCAPS Phase 3 Software Architecture
  - Quality Assurance
  - Risks and Actions Summary

Next Steps for NUCAPS

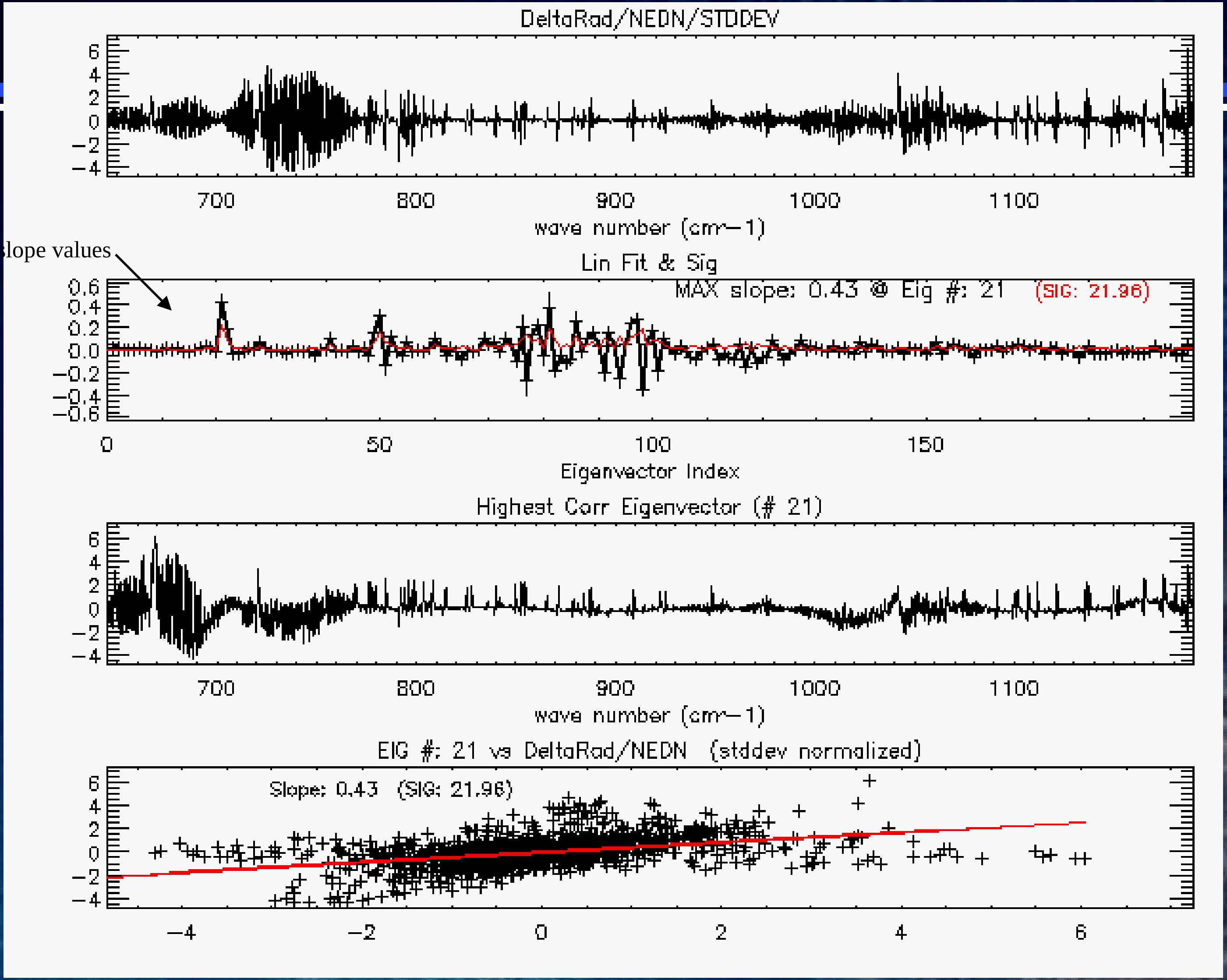
- Update project materials and post them for the review team.
- Commence algorithm development.
- Continue to monitor and mitigate risks.
- Continue to engage users to update requirements and assist user readiness.

Open Discussion

- The review is now open for free discussion

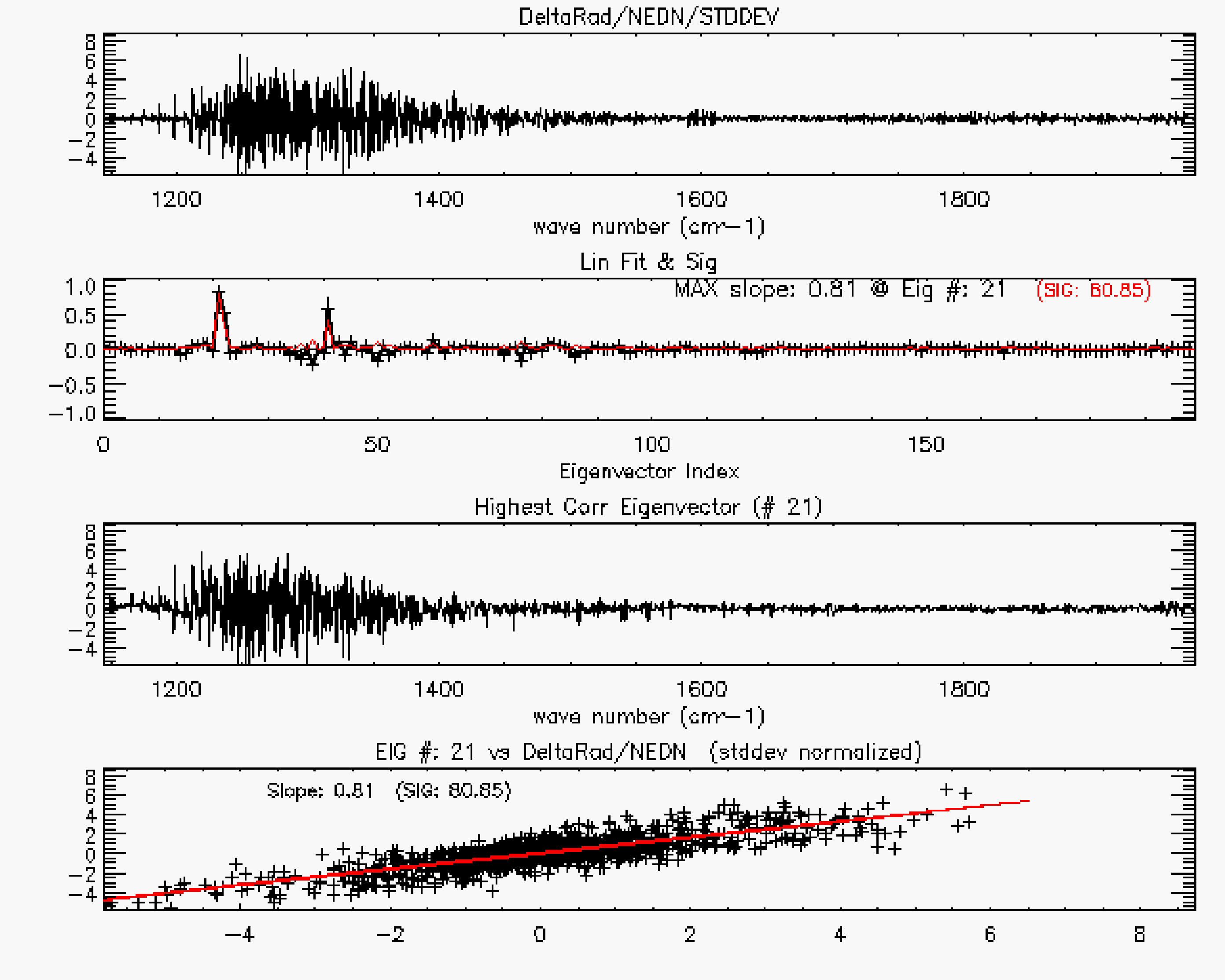
BACK UP SLIDES

Band 1, Gran # 393

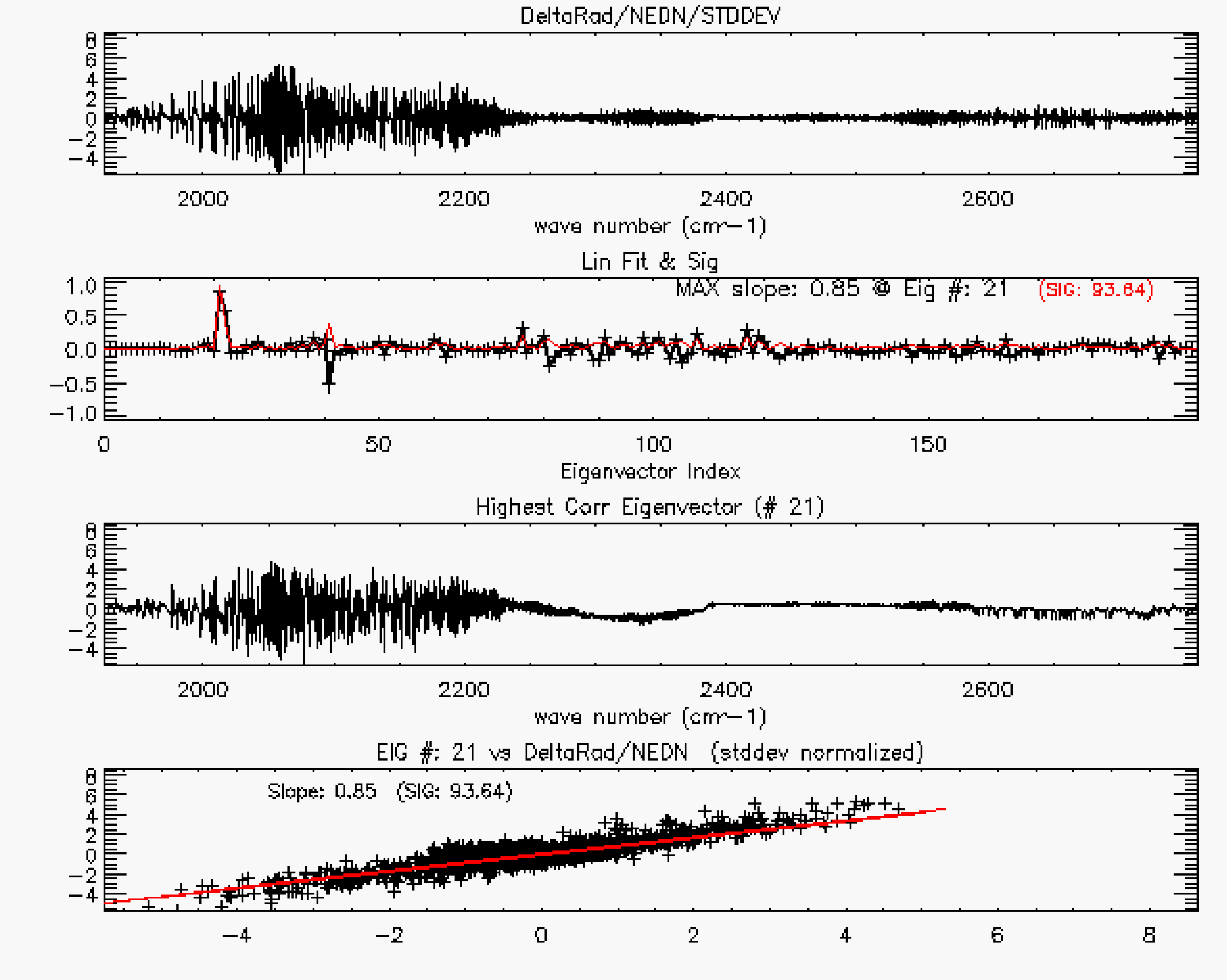


Each black point is a slope values

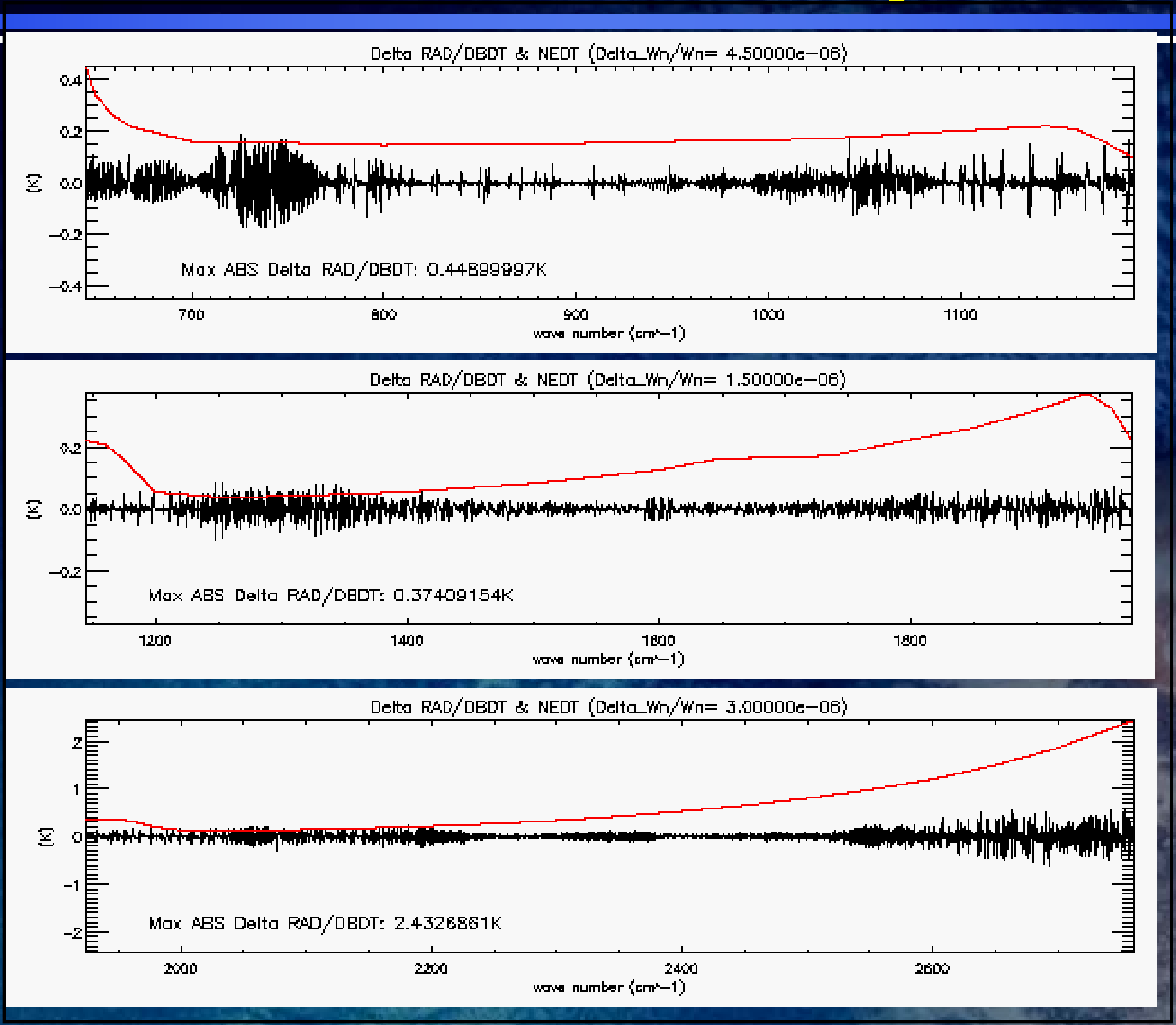
Band 2, Gran # 393



Band 3, Gran # 393



Band 1, 2, and 3 BT Error Summary



Delta RAD/DBDT & NEDT (Delta_Wn/Wn= 4.50000e−06)

Max ABS Delta RAD/DBDT: 0.44899997K

Delta RAD/DBDT & NEDT (Delta_Wn/Wn= 1.50000e−06)

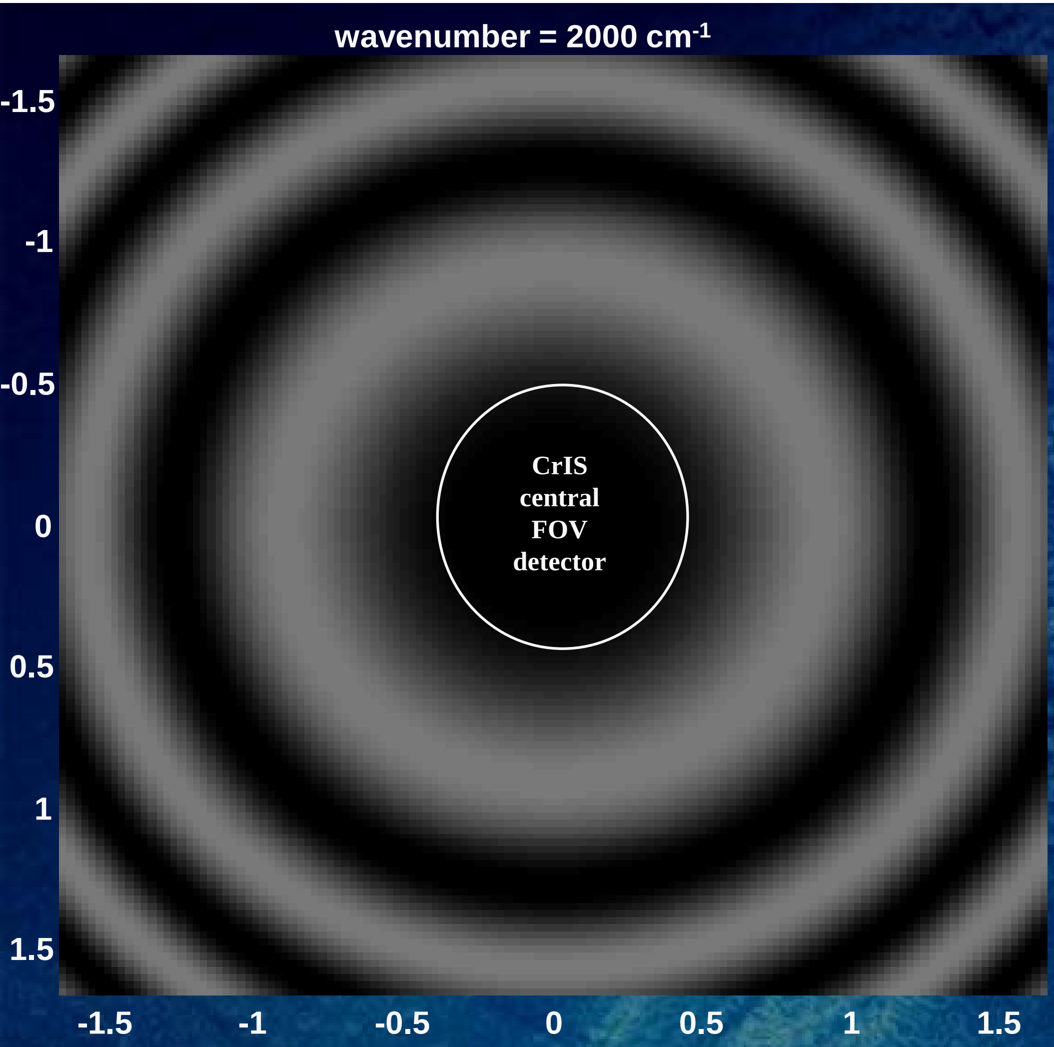
Max ABS Delta RAD/DBDT: 0.37409154K

Delta RAD/DBDT & NEDT (Delta_Wn/Wn= 3.00000e−06)

Max ABS Delta RAD/DBDT: 2.4326861K

Self Apodization Effect & CrIS FOV Geometry

$$\frac{\nu}{\Delta\nu} = 2x_{\max}\nu$$



What the detector measures is the integration over the solid angle subtended by the detector at the exit pupil:

$$G(x) = \frac{g(\nu)}{\Omega_{\max}} \int_0^{\Omega_{\max}} [1 + \cos 2\pi\nu x(1 - \frac{\Omega'}{2\pi})] d\Omega'$$

$$ILS(\nu) = \mathrm{F}[\mathrm{G(x)}] \propto \mathrm{sinc}(2\pi\nu x_{\max})$$

Spectral Resolution: (RSR): $\Delta\nu = \frac{1}{2x_{\max}}$

Visibility: $V(X) = \frac{G_{\max}(x) - G_{\min}(x)}{G_{\max}(x) + G_{\min}(x)}$

Spectral Resolution – Visibility Trade off

X ↑ SR ↑ V ↓