Overview of the Suomi-NPP Science Team Activities

Presented by: Chris Barnet

With contributions from: Antonia Gambacorta

AIRS Science Team Meeting

Wednesday, Sep. 14, 2016 (Session 03, 10:40 am)

The S-NPP Science Team

PI	Affiliation	Area of study
Aumann, Hartmut	NASA/JPL	Analysis of AIRS and CrIS cloudy radiances and propagation of errors into products
Barnet, Chris	STC	**ST lead**, Develop sequential O-E approach based on NUCAPS algorithm, called CLIMCAPS
Cady-Pereria, Karen & Helen Worden	AER & UCAR	Develop NH3 & CO retrieval algorithms
Lambrigtsen, Bjorn	NASA/JPL	ATMS-only level-1 and level-2 products
Moncet, Jean-Luc	AER	Develop simultaneous O-E approach based on CrIMSS-EDR algorithm for CCR, T/q/O3
Susskind, Joel	NASA/GSFC	Apply AIRS v6 algorithm to CrIS/ATMS

Sounder Lead Activities

- We hold monthly telecons, usually last Monday of the month
  - All presentations and discussion are archived
  - Contact barnet@stcnet.com to get on the invite list
- Encourage open discussion on objective evaluation methodology for climate products and sounding topics
- Coordinate with both the NASA-funded CrIS Calibration Team (Hank Revercomb, Larrabee Strow, Dave Tobin) and NOAA-funded CrIS Cal/Val Team (Yong Han's team)
- Attend EDOS/SIPS meetings (includes all NPP disciplines)
- I am also the co-lead for NOAA JPSS *Sounding Initiatives* and an SME for operational NUCAPS algorithm
  - Allows synergy between NASA and NOAA S-NPP activities
  - Acquiring datasets of extreme events (*e.g.*, 2016 El Nino)

We provided guidance on a number of flight topics

- CrIS full spectral resolution: justification and implementation
  - Select channels (see Jonathan Smith's talk, 3:20 pm today)
  - Evaluation of carbon monoxide retrieval (see Nadia Smith, 9:20 am Thursday)
  - Receipt and packaging of UMBC SARTA
- ATMS Scan Motor reversal guidance
  - Keep ATMS alive as long as possible (now 2 reversals/orbit)
  - Prepare for loss of ATMS (NUCAPS CrIS-only mode)
- Discussion on improvements to CrIS on future satellites
  - Spectral gap filling (allows intercal and other trace gases)
  - Smaller FOV's (smaller 3x3 or NxN approaches)
- ATMS and CrIS co-alignment on JPSS-2 satellite
  - Decision to rotate ATMS to improve alignment across scan set
- Investigating and justifying the need for level-1a product
  - We are doing a cost-benefit analysis of archiving L1A

Team Activities (#1/3)

- Sounder SIPS has produced sample NASA level.1 for both ATMS and CrIS radiances with the latest calibration
  - Co-located in a 45 scanset NETCDF format
    - data have the “look and feel” of AIRS products
    - files were evaluated and will be ready for production in the near future
    - (next 2 talks by Steve Friedman's and Evan Manning's)
- GSFC has delivered their v6.29 algorithm that can run both AIRS/AMSU and CrIS/ATMS (see Joel Susskind's talk at 2:00 today)
- STC has delivered a CrIS/ATMS pre-processor code
  - ability to prepare data for both the GSFC and STC retrieval codes
  - creates co-located granule files for both ECMWF (spatial co-location), GFS (spatial and temporal co-location), and Merra-2 reanalysis (spatial and temporal co-location) to support algorithm comparisons
  - delivered NUCAPS retrieval output for a focus day along with GFS forecast and Merra-2 reanalysis co-located in space and time to CrIS
  - STC has recently installed NUCAPS/CLIMCAPS on the Sounder SIPS

Team Activities (#2/3)

- The JPL/SIPS has done a comparison between the GSFC retrieval for both AIRS and CrIS, the NUCAPS retrieval for CrIS, ECMWF, GFS, and Merra-2. Provides a foundation for objective inter-comparisons. (Van Dang's talk at 4:00 pm)
- STC is working on the CLIMCAPS algorithm (Antonia Gambacorta's talk at 2:30 pm)
  - Formally CHIMERA – had to change the name
- AER is preparing an algorithm inter-comparison testbed (Alan Lipton talk at 2:20 pm) that includes the CrIMSS IDPS retrieval
- AER is also providing ammonia and carbon monoxide retrievals. (part of Vivienne Payne's talk 11:40 am Thursday)
- We have made progress on defining the ATMS-only retrieval module (see Bjorn Lambrigtsen, Evan Fishbein, Mathias Schreier, Antonia Gambacorta talks today at 4:40-6:00 pm)
- George Aumann has been making radiometric comparisons (see talks at 1:40 pm today, 3:00 pm Thursday)

Team Activities (#3/3) (Externally Funded Items)

- (NASA Terra/Aqua) I have invited Bill Irion to participate in S-NPP algorithm discussions and evaluations of cloud clearing and *a-priori* choices (see Thursday 2:20 pm talk)
- (NOAA/NASA funding) Larrabee Strow is close to delivery of the high spectral SARTA forward model for CrIS
- (NASA) Employ/evaluate the MEASURES CAMEL product (Eva Borbas talk, 3:00 pm today)
- (NOAA) Characterization of NUCAPS methane and carbon monoxide trace gas products for operational applications (Nadia Smith talk 9:20 am, Thursday)
- (NOAA) Participated in Pacific field campaigns (Atmospheric River and El Nino Rapid Response). Over 1500 dropsondes have been acquired in extreme weather & climate events.

Let's define a few terms

- The O-E solution can be written as:

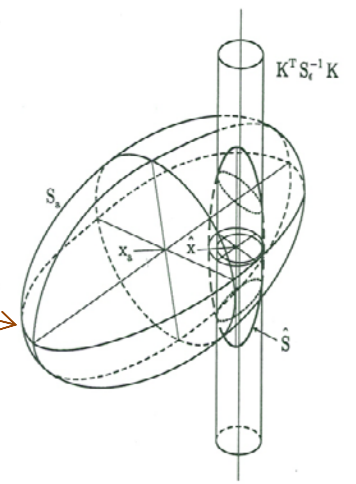
Measurement (O-C) covariance

A-priori covariance defines amount of regularization

$$X_j^i = X_j^A + \left[K_{j,n}^T \cdot N_{n,n}^{-1} \cdot K_{n,j} + C_{j,j}^{-1}\right]^{-1} \cdot K_{j,n}^T \cdot N_{n,n}^{-1} \cdot \left[R_n^{obs} - R_n(X^{i-1}) + K_{n,j} \cdot \left(X_j^{i-1} - X_j^A\right)\right]$$

A-priori is "pivot point" and immediately replaces the 1st guess

Solution "blends" measurements and a-priori knowledge



f/ Rodgers 1977

$$K_{n,j}^{i-1} = \frac{\partial R_n\left(\vec{X}^{i-1}\right)}{\partial X_j}$$

1st guess can only affect Jacobian and the rate of convergence

Summary of algorithms to characterize

	Susskind	AER	CLIMCAPS	Irion
Regularization	SVD	O-E	O-E	O-E
Alg. type	sequential	Simultaneous/ sequential	sequential	simultaneous
Clouds	Cloud clearing	Cloud clearing	Cloud clearing	Solve f/cloud
A-priori for T(p), q(p)	Neural Net	Climatology f/ multiple sources	Climatology & MERRA-2	ECMWF
A-priori for emissivity	Borbas	Fit to Zhou database ?	MEASURES CAMEL	Borbas
A-priori for trace gases	Climatology, No covariance	Climatology w/ covariance	Climatology w/ covariance	Climatology w/ covariance
Error Propagation	Diagonal	T/q, Ts/ε, NH3, CO steps	3-6 eigenvector	n/a
Error estimates	Parametric fit to ECMWF	O-E	Propagated O-E	O-E

More Algorithm Details (included for completeness)

	Table 1: Summary of Level.2 Algorithms to be studied as part of NPP Science Team Activities					
PI	Lambrigtsen	Susskind	Barnet	Moncet	Cady-Pereira	Irion
affiliation	JPL	GSFC	STC	AER	AER	JPL
funding	NPP	NPP	NPP	NPP	NPP	Terra-Aqua
ATMS	ATMS FOV	CrIS FOR	CrIS FOR	CrIS FOR	n/a	n/a
CrIS	n/a	CrIS FOR	CrIS FOR	CrIS FOR	CrIS FOV	CrIS FOV
Regularization	O-E	SVD	O-E	O-E	O-E	O-E
Alg. Type	Sequential	Sequential	Sequential	Simultaneous	Sequential	Simultaneous
Alg. Heritage	AIRS ST	AIRS ST v6+	AIRS ST v5.9, NUCAPS-IASI	CrIMSS EDR	TES	TES
Cloud Clearing	n/a	Yes	Yes	Yes	No	No
T/q a-priori	NCEP Climatology	Neural Net	Climatology and Merra-2	Climatology	AER product	ECMWF
Trace gas a-priori	n/a	Climatology	Climatology	Climatology for O3	Climatology	Climatology
Error estimate	O-E	ECMWF regression	O-E	O-E	O-E	O-E
Averaging Kernels	No	No	Yes	No	Yes	Yes
Execution Time (per FOR)	~5 ms/FOR (MIT)	~150 ms/FOR	~200 ms/FOR	?	?	~15 sec/FOV
Delivered to SIPS	12/2016	9/2015	1/2017 (T,q,ε) 3/2017 (trace gases)	11/2016 1/2018 (final)	NH3: 1/2017 CO: TBD (need FSR)	?
	Abbreviations: SVD=Singular Value Decomposition, O-E=Optimal Estimation, FOV=field of view, FOR=field of regard (CrIS set of 3x3 FOVs)					

Simultaneous versus sequential retrieval trade-offs

Simultaneous OE	Sequential OE
Solve all parameters simultaneously.	Solve each state variable (*e.g.*, T(p)), separately.
O-C error covariance can be simpler (does not require propagation from one step to another)	O-C error covariance is computed for all *relevant* state variables that are held fixed in a given step. Retrieval error covariance *must be* propagated between steps.
Each parameter is derived from <u>all</u> channels used (*e.g.*, can derive T(p) from CO_2, H_2O, O_3, CO, … lines).	Each parameter is derived from the best channels for that parameter (*e.g.,* derive T(p) from CO_2 lines, q(p) from H_2O lines, etc.). More linear.
A-priori must be rather close to solution, since state variable interactions can de-stabilize the solution. Covariance must contain cross-terms (e.g., dT/dq, dT.dO_3)	*A-priori* can be simple for hyperspectral and, therefore, covariance can be large, more signal can be derived from the radiances
Has larger state matrices (all parameters solved) and O-C covariance matrices (all channels used). Inversion of large matrices is computationally expensive.	State matrices are small (largest is 25 T(p) parameters) and O-C covariance matrices of the channel subsets are quite small. Very fast algorithm. Encourages using more channels.

As we move from SVD to O-E we need to decide on a-prior

Type of a-priori	regression	Static climatology	forecast	reanalysis
Vertical structure	High, derived from radiances	Low, Smooth	High, derived from model and all obs	High, derived from model and all obs
Spatial & temporal structure	high	Smooth	Very high	Very high
Error co-variance	small	large	small	medium
Relative impact of Radiances	Low, IC is conflated (a tautological error – R's used 2x)	Very high, all structure comes from instrument	Very low, fine structure from forecast, tautological error is f(t)	Relatively low, fine structure from reanalysis, weak tautological error

NOTE: When relative impact of radiances is low, you cannot remove errant structures

<u>Choice</u> of *a-priori* is application dependent

- My goal for S-NPP ST is to inter-compare sounding concepts
  - Impact of *a-priori* assumptions on hyperspectral retrievals
  - Test our ability to <u>quantify</u> retrieval information content and error
- Discussion of *a-priori* has been a topic in our community for over 40 years (see discussion at the end of Rodger's 1977 – 1pg shown on right)
- Choice of the relative weight of the a-priori is important to characterize and communicate to our users

DISCUSSION

Susskind: I just wanted to ask something quickly about what you have just done. These radiances--are these the observed radiances, or the radiances taking out the effects of clouds, or what? I mean, if you have clouds coming into the picture, it is certainly going to foul up.

Rodgers: These are actually stratospheric radiances.

Susskind: Okay, so you're not worrying about that.

Rodgers: This isn't the Nimbus 5 selective chopper. It's about 45 kilometers.

Green: On your first slide, you said "given some knowledge of a function." Should you have replaced the word "function" by "functional"?

Rodgers: Sorry, yes, it is functional.

Green: Thus, the problem is how to get a function from a functional.

Rodgers: I was just not being quite rigorous.

Chahine: Clive, you made a statement that we should pay just as much attention to our actual measurement as we do to virtual measurements. I know how to improve my actual measurements. I have the physics. How can I improve my virtual measurements and be sure of that?

Rodgers: By the same sort of techniques as your actual measurements. If you have no virtual measurements, you just can't solve the problem. You just have to go into some other problem. The only way of producing a profile is by having enough virtual measurements from somewhere. It may be physics. I can produce a virtual measurement off the top of my head immediately. I can say the temperature in the atmosphere anywhere is going to lie between zero and 500°. I know it's not going to help you very much; it reduces the variance a bit. It just makes it noninfinite at least. But it still means the errors on all the points are going to be 250°.

Chahine: For the nonlinear method, I assume the temperature to be positive and real. But in your case, you are using *a priori* statistics.

Rodgers: This isn't only statistics. This applies to any kind of virtual measurement.

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p.135 from Rodgers, C.D. 1977. Statistical principles of inversion theory. in "Inversion Methods in Atmospheric Remote Sounding" (ed. A. Deepak) p.117- 138.

QUESTIONS?

Algorithm Philosophy

- Algorithm and code should be open source
- Algorithm should function on all operational modern hyperspectral and advance microwave sounder space-borne instruments
  - Minimize instrument dependent features
  - Exploit the full information content of the measurements
    - Ability to discriminate between physical correlations (e.g., climate sensitivity of dq/dT) and spectral correlations induced by measurements (e.g., dq/dT induced by spectroscopy)

Philosophy 2/3

- Minimize dependence of things we don't know
  - Minimize sensitivity to clouds
    - Exploit microwave information
    - IR cloud forward models are not robust (in my opinion, but some day soon this will be false)
    - Sensitivity of radiances to cloud parameters (particle sizes and shapes, vertical density) are highly non-linear
    - cloud parameters are not well constrained by infrared or microwave sounder measurements alone
  - Minimize Sensitivity of products to interfering signals
    - dT, dq, dTskin co-varies with cloud signals
    - dT co-varies w/ dq, dO3, ... for IR, dT co-varies with O2 for MW
    - dq co-varies w/ dT, dCH4, dSO2, ... for IR
      - dq is significantly more linear for MW
    - If ignored, this “spectral” covariance can confound measurement of natural correlations (*i.e.*, Earth physical correlations)

Philosophy 3/3

- Desire a global, all season, all sky, all regions, retrieval
  - avoid regional or highly tailored a-priori terms
  - avoid datasets that are not available or not skillful in remote regions
- Derive formal and traceable error estimates
  - have either averaging kernels or error covariance output for each product
  - algorithm should fully characterize inter-correlation of products induced by retrieval
- Desire a real time (weather) and re-processing (climate) capability
  - avoid algorithms that are computationally intensive (either in CPU or memory requirements) if they do not add sufficient skill
  - avoid datasets with high latency (weather)