AIRS SRFs and Forward Model

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Overview

- V1.5 Forward Model Delivery and Associated SRF Model
- Ground and In-Orbit Determination of the AIRS SRFs

Although the SRFs are not a deliverable, they are embedded in the forward model, and must be extremely well-characterized since they are used indirectly in every single retrieval.

The AIRS Level 1B product is quite useless without the associated SRFs.

Changes in the New Fast Forward Model

- SRFs based on actual test data
- Expanded coverage of methane
- New high spectral resolution solar radiance routine
- Corrections to reflected thermal
- Speed, accuracy, size similar to previous Forward Model
- (No new spectroscopy)
- On schedule for late October/early November delivery

SRF Model for V1.5 Software Delivery

- This method will *not* be used for the final FM software
- Wanted to faithfully represent actual SRFs as well as possible with as little work as possible (time limits)
- Based on Tests 261/266
- Use raw SRF data where S/N is good, used a model elsewhere
- Blen raw SRF data with model in wings
- No explicit treatment of channeling, so longwave SRFs not well characterized due to S/N limitations in raw SRF data

SRF Analytic Model

We are using an analytic model the the SRFs that was suggest by H. Aumann with some small modifications. For the V1.5 software delivery, this model is primarily used to estimate the SRF wings.

$$SRF(x) = g_f \left(e^{-log(2)x^{(2+g_s x)}} \right) + (1 - g_f) \left(\frac{1}{(1 + x^{L_e})} \right)$$

where

$$x = \frac{|\nu - \nu_i|}{(0.5 * \gamma_i)}$$

and γ_i is the 50% full width of the SRF. Typically,

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g_s \approx 0.5, \ g_f \approx 0.95, \ L_e \approx 1.8.
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At x = 1, SRF = 0.5 regardless of the values of the other variables.

The Gaussian term dies off quickly past ~ 1 full width away from v_i so the model is essentially a pure Lorentzian in the wing.

Note: g_f stands for "Gaussian fraction", and g_s stands for "Gaussian slope".

Details on Construction of V1.5 SRFs

- Estimate the minimum value for trustworthy data in the individual measured SRFs
- Fit array-averaged SRF to analytic model in order to determine far-wing model parameters.
- Fit the measured SRF data around blend point with a low-order polynomial.
- Cross-fade this polynomial fit with the model (basically tack the array-averaged wings onto the individual SRFs).
- The test data for the longwave modules has too low signal-to-noise to measure the SRF wings to required levels.
 For now we used the M4a wings for the longwave modules.
 Evaluate non-IS data more carefully for longwave wings.

Forward Model RMS Fitting Errors







Next Forward Model Delivery

- Improved spectroscopy
- Final (as final as possible) SRFs
- If it makes sense, deliver ~ 5 sets of coefficients for a range of channel centers based on possible uncertainties in the grating model.
- Next: What does it take to account for channeling in the entrance filters?

M4a Sample SRF with Fringes



M4a OCLI Low-Res τ with Simulated Fringes



Estimated B(T) Errors if Channeling Not Modeled



Sample B(T) Errors if Fringe Phase Unknown



In-Orbit AIRS SRFs, Basic Approach

- Channel centers and fringe positions have different sensitivities to temperature, consequently we cannot determine the AIRS SRFs until we are in orbit!
- Ground calibration
 - Model the observed SRFs, include
 - * "Pure" SRF parameterization (Gaussian + Lorentz)
 - * Bruker effects
 - * Fringe period, phase, finesse parameterization
- In orbit calibration
 - Use SRF model from ground calibration to compute in-orbit SRFs once we know? the fringe period/phase/finesse and channel center frequencies.
- Repeat this procedure for each operating temperature (new forward model) and communicate to all end users

SRF Model with Channel Spectra

- We have developed a model to represent the SRFs for a given module with a relatively small number of parameters
- Inputs to the model include
 - Channel widths and centers, typically taken from a grating model fit to measured SRFs
 - The SRF shape parameters for H. Aumann's parameterized response function (g_s, g_f, L_e)
 - Low resolution measured filter data (substitute high-resolution data when available, at least for finesse)
 - Filter fringe phase and period, for simulated filter fringes
 - For simulation purposes we also need the Bruker parameters; including the OPD, self-apodization, and an estimate of interferometric noise. (We hope to avoid off-axis model of Bruker.)

Simulations of Ground Calibration of SRFs: I

Generate Simulated SRFs

- Using analytic SRF model and nominal grating model, generate reasonable SRFs
- Multiply SRFs by simulated high-resolution filter transmittances (fringe finesse derived from filter transmission using low-resolution OCLI filter curves)
- Apply inverse FFT to "true" simulated SRFs, add simluated noise, truncate FFT, apply self-apodization
- Apply forward FFT to generate simulated Bruker SRF observations

Simulations of Ground Calibration of SRFs: II

Retrieve SRFs from Simulated Spectral Data

- Determine apparent SRF widths, centroids from simulated data
- Fit the widths and centroids to the AIRS grating model
- Fit our our SRF parametized model to the raw SRF data, one array at a time, varying the following parameters (one per array)
 - Width scale factor
 - Centroid offset
 - SRF model parameters (g_s, g_f, L_e)
 - Fringe phase or fringe period or remaining parameters
- Each step in this non-linear optimization includes application of Bruker effects on the SRFs.
- The process is computationally intensive but not intractible, with a fit for one module taking on the order of a couple of hours

Simulation Results for Ground Calibration: Preliminary

- Fringe period and phase are perhaps the most difficult to retrieve
- A staged search appears to work in simulation
 - 1. Let fringe phase and period vary
 - 2. Fix fringe period obtained in previous step, retrieve fringe phase
 - 3. Fix fringe phase and period, retrieve remaining parameters
- Cannot reliably retrieve fringe phase with single test noise in the longwave (M11/M12)
- With 4X lower noise we can retrieve phase (in simulation)
- This process only simulates the ground portion of the SRF determination, still need to determine fringe phase in orbit.

Preliminary Fits to Real SRF Data

- We have performed some limited fits to real SRF data (Tests 2xx)
- Knowledge of fringe period essential. 1% error in fringe period implies up to 2 π error in phase.
- Insufficient S/N to evaluate if fits are successful for longwave arrays.
- Single array fit takes several hours to converge



M4a Sample Observed, Modeled SRFs

How Determine Fringe Phase In-Orbit?

- Fringe phase moves faster than spectrometer with T, $8 \times 10^{-5} \times v$ cm⁻¹/K for fringe phase vs $2.5 \times 10^{-5} \times v$ cm⁻¹/K for grating.
- Use detector responsivity as a function of temperature to get fringe period/phase (both in orbit and during ground calibration)? Untested so far (by us), but promising. Can we get big enough $\Delta T's$ to get finesse?
- Determine absolute position (in wavenumber) of fringe phase during ground calibration for given filter temperature (possible, not proven yet). Then using in-orbit filter temperature, compute relative movement of fringe phase. Assumes filters are stable to interferometric standards during launch. Very risky.
- If the filter temperatures drift (or SRF centroids) we will be faced with a very difficult scenario. Drift of the fringe phase is 0.06 cm⁻¹/K at 700 cm⁻¹.
- Is there sufficient signal in the shortwave radiometric signal to see fringe phase?

Other Unresolved SRF Issues

- Fringes and large Bruker mis-alignments have prevented us from looking into more subtle effects (see next vu-graph)
- Remaining asymmetries once remove Bruker effects? Probably can fit since they will vary slowly across an array.
- S/N insufficient in longwave to get wings to 3×10^{-4} . Use non-IS data, or use wings from other arrays?
- Strong H₂O lines present in some test data (Test 261, for example)



CO Lineshape Showing Bruker Mis-alignment

Summary of SRF Fringe Problem

- We do not yet have a comprehensive plan to deal with the effect of channeling on the AIRS forward model
- A foolproof method for the measurement of the fringe phase in orbit, for each potential set operating conditions, has not yet been developed. Radiometric technique promising for longwave, but uncertain for shortwave.
- We cannot assume we can compute fringe phase solely from filter temperatures, (a) requires very good absolute calibration on ground (S/N issues and wavenumber calibration uncertainties) and (b) stress/vibration could move filters and affect fringe phase
- If, for some reason, the filter temperatures or the channel centers are not stable, it will be *very* difficult to track in software, especially for external users.
- Error budget creep: S/N in longwave test data already limits centroid/width errors in the 1-2% range. Bruker SRF knowledge still an issue in error budget?

Are These SRF Uncertainties Important?

- AIRS radiometric accuracy looks very good (0.1K or better)
- AIRS NE Δ T is extremely low
- Accuracy of our final forward model may approach the \sim 0.1K level!
- AIRS 1K/1km may be compromised with 0.3-0.5K B(T) uncertainties
- AIRS H₂O retrievals cannot be bias-corrected, especially in the mid- to upper-tropospheric; This is a major global climate change issue.
- We will never be certain if remaining obs-calcs are due to spectroscopy or the instrument if the channeling is not fixed
- Although we have ideas on how to cope with the fringes, significant risk remains. Data will be difficult for end-users.
- We have an extremely good instrument, all of the difficult problems have been overcome.
- We need to replace the entrance filters with wedged filters so that the full potential of AIRS can be realized.

RAL Laboratory Comparisons, P/R Mixing



Wintex (NAST), CAMEX (HIS), P/R Mixing



Wintex (NAST) P/R Mixing, 15 μm



ARIES P/R Mixing, 15 μm (Acknowledgement to Dr. J. Taylor of UK Met Office)

