Channel Selection and Apodization Considerations for Hyperspectral Infrared Sounder Data

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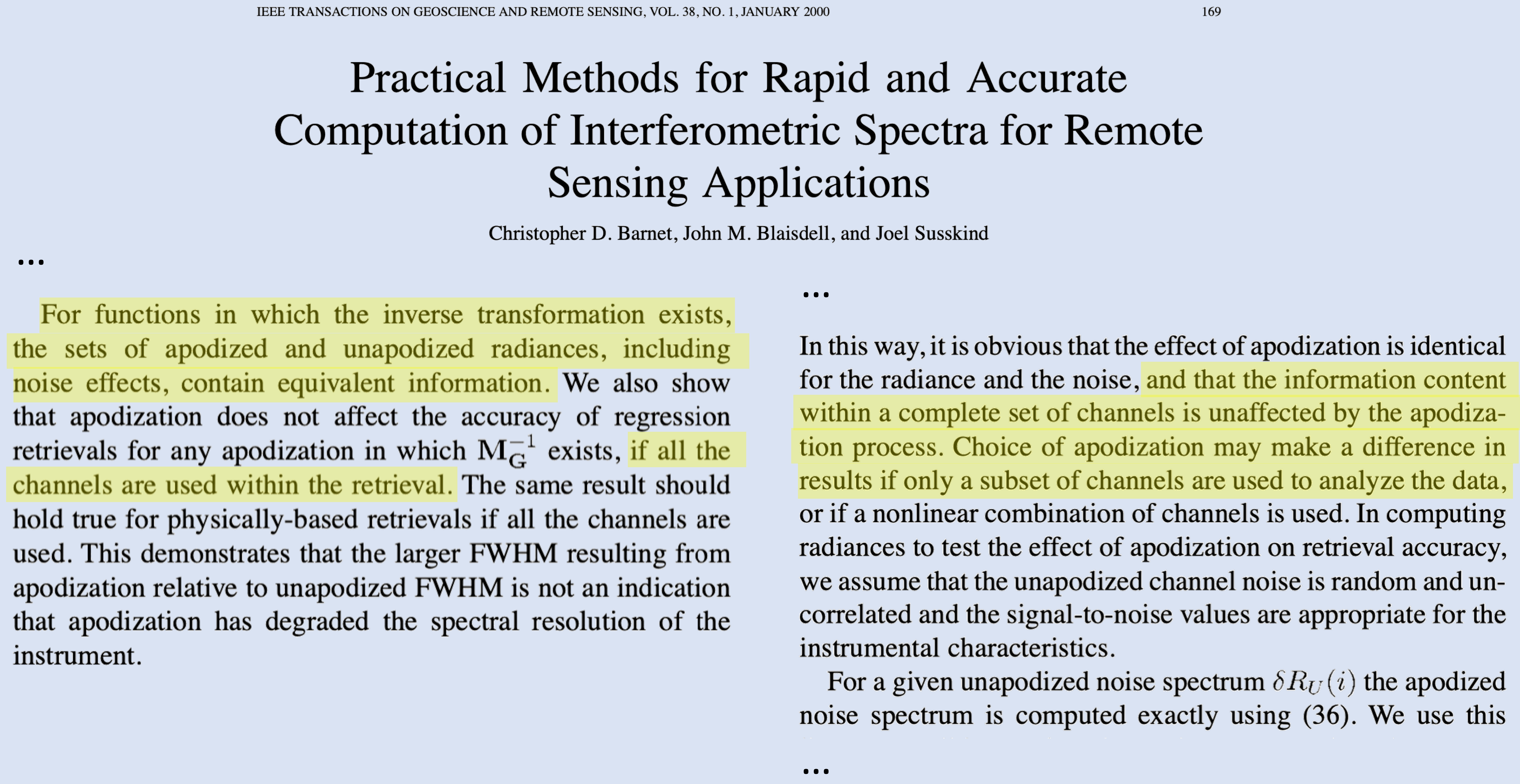

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 38, NO. 1, JANUARY 2000 169

Practical Methods for Rapid and Accurate Computation of Interferometric Spectra for Remote Sensing Applications

Christopher D. Barnet, John M. Blaisdell, and Joel Susskind

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For functions in which the inverse transformation exists, the sets of apodized and unapodized radiances, including noise effects, contain equivalent information. We also show that apodization does not affect the accuracy of regression retrievals for any apodization in which $\mathrm{M}_{\mathbf{G}}^{-1}$ exists, if all the channels are used within the retrieval. The same result should hold true for physically-based retrievals if all the channels are used. This demonstrates that the larger FWHM resulting from apodization relative to unapodized FWHM is not an indication that apodization has degraded the spectral resolution of the instrument.

…

In this way, it is obvious that the effect of apodization is identical for the radiance and the noise, and that the information content within a complete set of channels is unaffected by the apodization process. Choice of apodization may make a difference in results if only a subset of channels are used to analyze the data, or if a nonlinear combination of channels is used. In computing radiances to test the effect of apodization on retrieval accuracy, we assume that the unapodized channel noise is random and uncorrelated and the signal-to-noise values are appropriate for the instrumental characteristics.

For a given unapodized noise spectrum $\delta R_U(i)$ the apodized noise spectrum is computed exactly using (36). We use this

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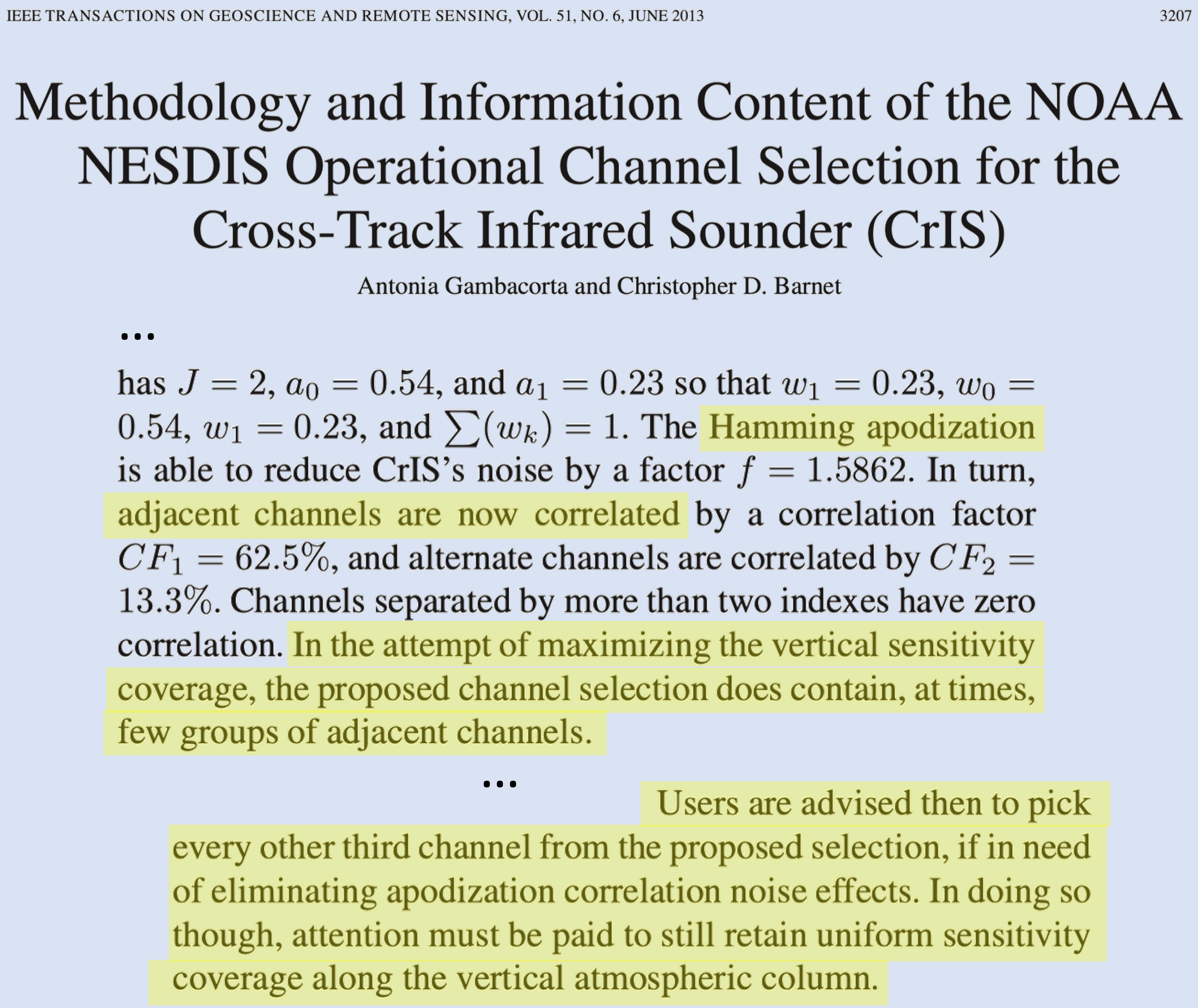
Barnet et al., TGRS, 2000



IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 51, NO. 6, JUNE 2013 3207

Methodology and Information Content of the NOAA NESDIS Operational Channel Selection for the Cross-Track Infrared Sounder (CrIS)

Antonia Gambacorta and Christopher D. Barnet

…

has $J = 2$, $a_0 = 0.54$, and $a_1 = 0.23$ so that $w_1 = 0.23$, $w_0 = 0.54$, $w_1 = 0.23$, and $\sum(w_k) = 1$. The Hamming apodization is able to reduce CrIS's noise by a factor $f = 1.5862$. In turn, adjacent channels are now correlated by a correlation factor $CF_1 = 62.5\%$, and alternate channels are correlated by $CF_2 = 13.3\%$. Channels separated by more than two indexes have zero correlation. In the attempt of maximizing the vertical sensitivity coverage, the proposed channel selection does contain, at times, few groups of adjacent channels.

…

Users are advised then to pick every other third channel from the proposed selection, if in need of eliminating apodization correlation noise effects. In doing so though, attention must be paid to still retain uniform sensitivity coverage along the vertical atmospheric column.

Gambacorta and Barnet., TGRS, 2013

A critical issue …

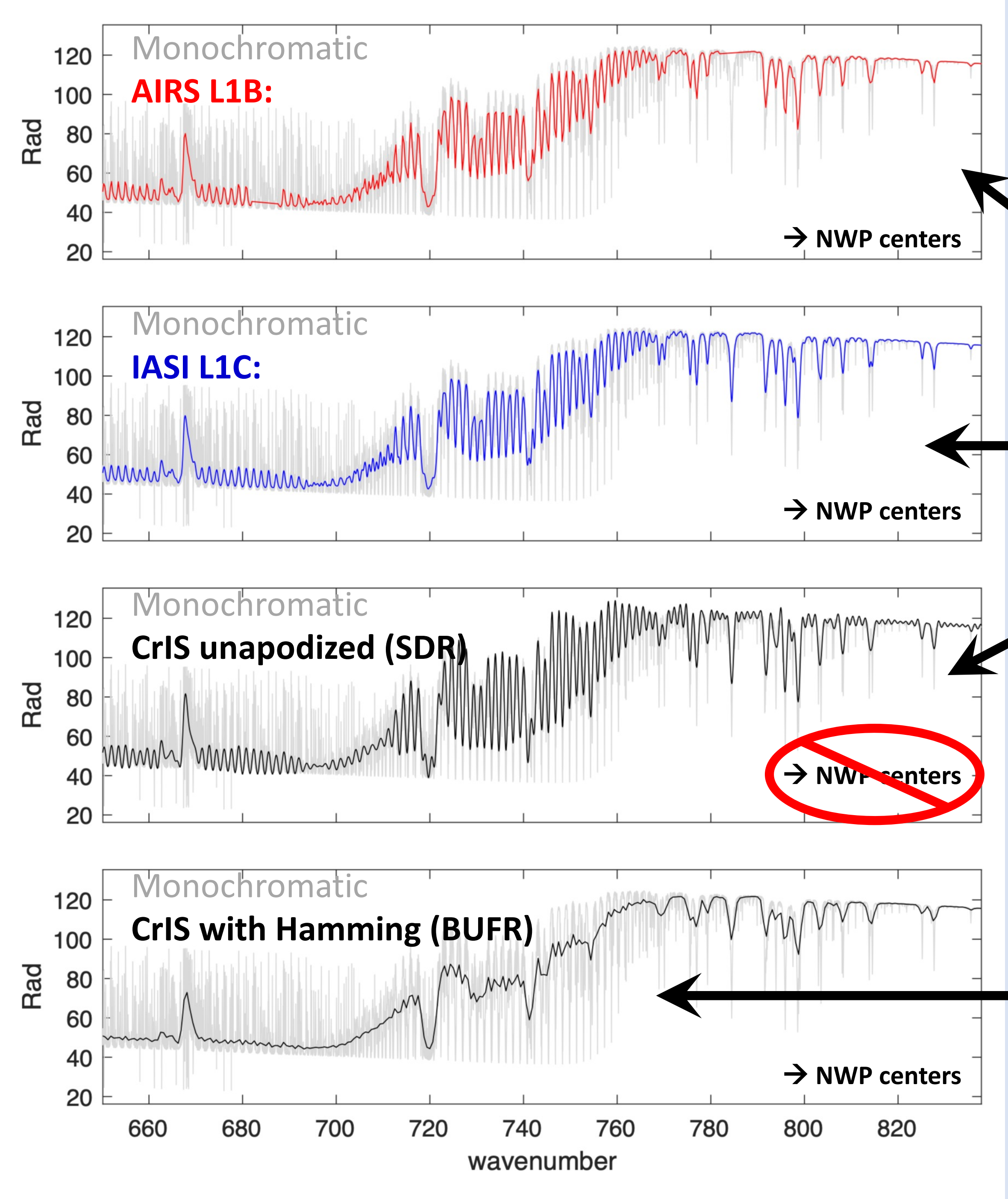
CrIS data used at NWP centers is Hamming apodized, which is a heavy spectral smoothing.

When combined with non-continuous channel sets, this can reduce CrIS information content to that of a broadband sensor.

This same issue applies to HIRAS, GIIRS, MTG-IRS, and GXS

(all with MaxOPD of ~0.8cm)

Example Clear Sky Longwave Spectra



AIRS L1B, IASI L1C, and unapodized CrIS spectra have similar T/q information content for sounding and NWP applications

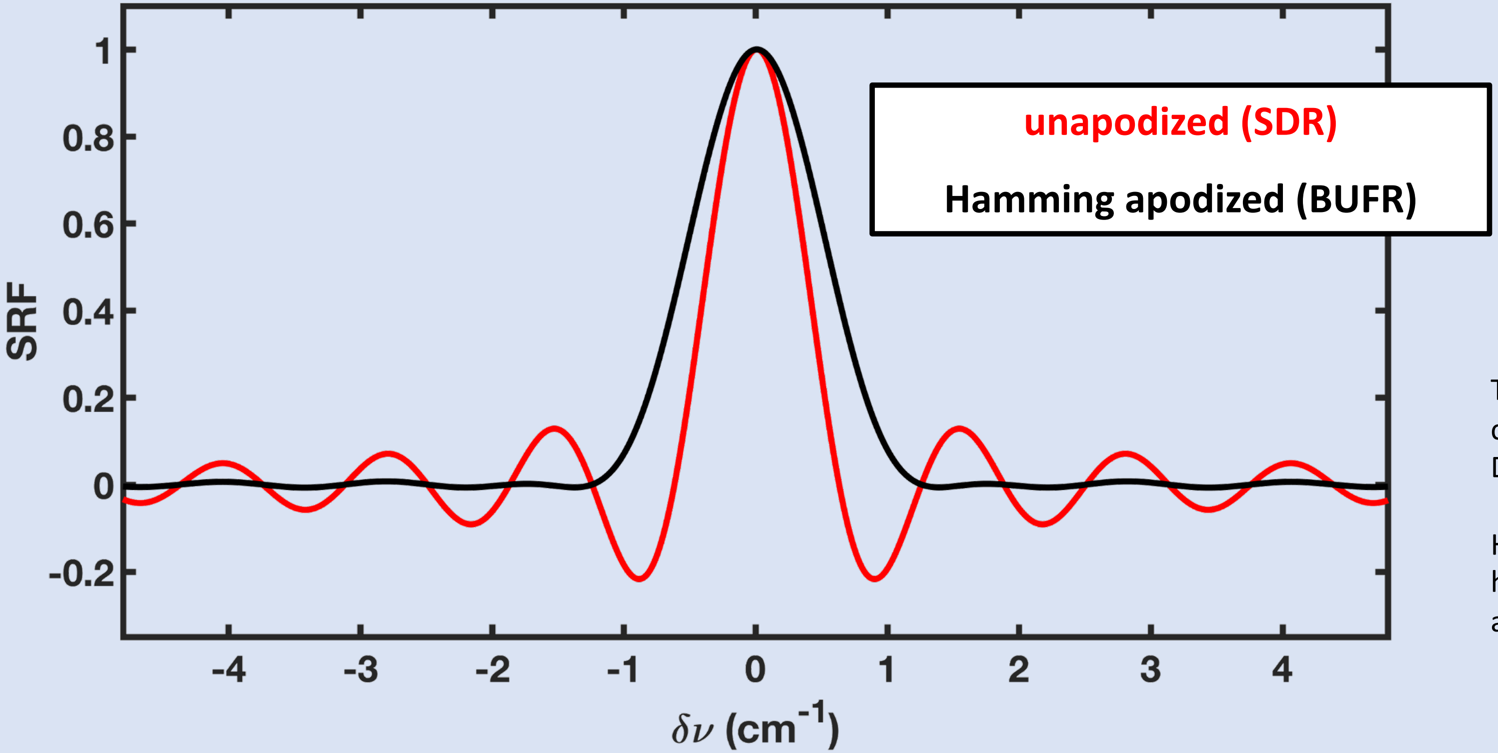
But NWP centers do not receive the unapodized spectra. They receive Hamming apodized CrIS spectra.

And unlike the other data, CrIS with Hamming does not resolve the crucial 15 micron CO_2 lines.

Hamming Apodization for CrIS

- **Hamming apodization is a simple linear combination of 3 adjacent unapodized channels [0.23, 0.54, 0.23]**
- **It is applied because Polychromatic fast RT models (e.g. CRTM, RTTOV, SARTA) typically require SRF ≥ 0**
- **It heavily damps the unapodized SRF (sinc) side lobes, increases the FWHM, and creates large noise correlation in adjacent spectral channels**
- **It is exactly reversible with no information loss if adjacent channels are retained and utilized**

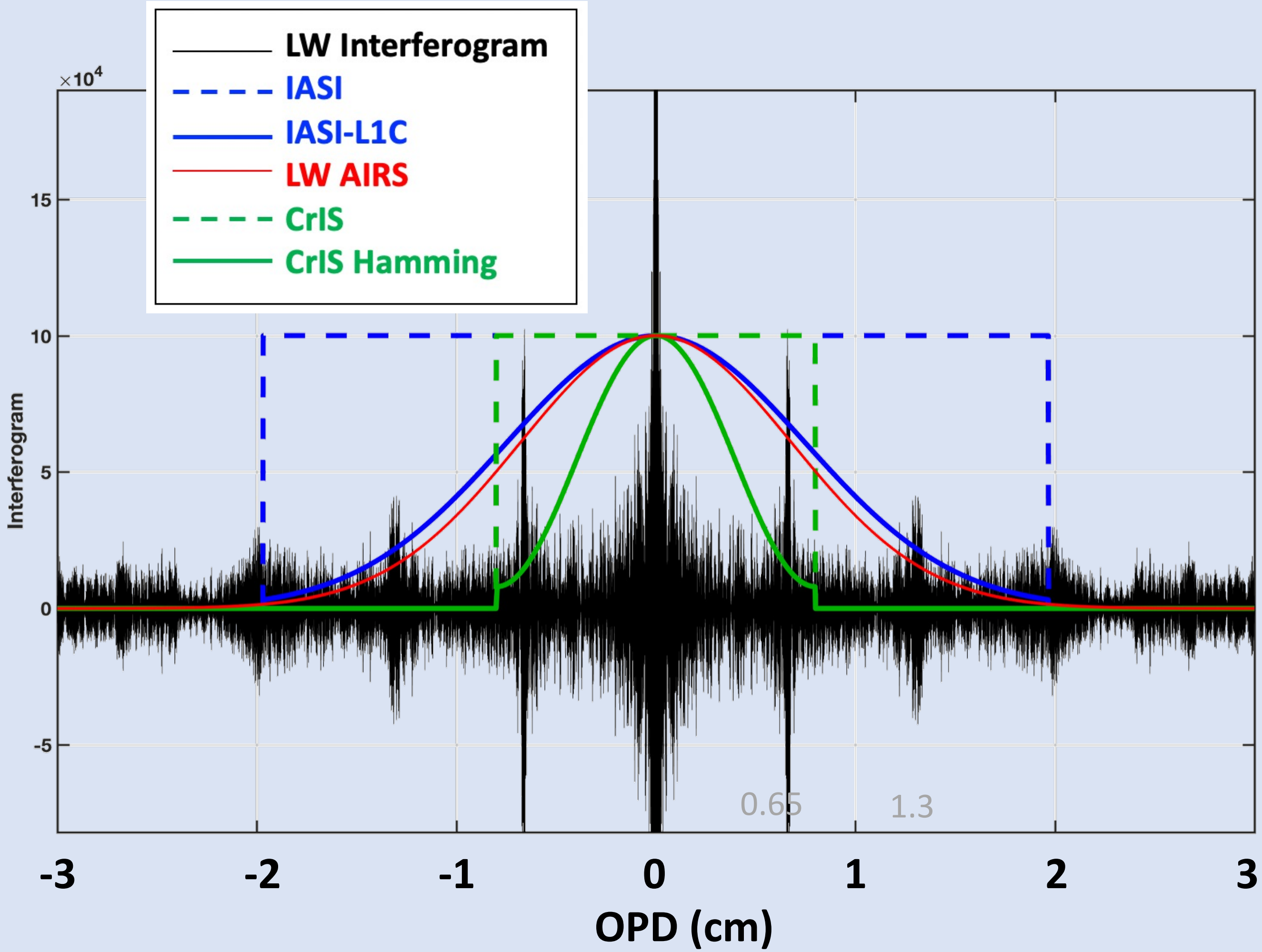
CrIS Spectral Response Functions



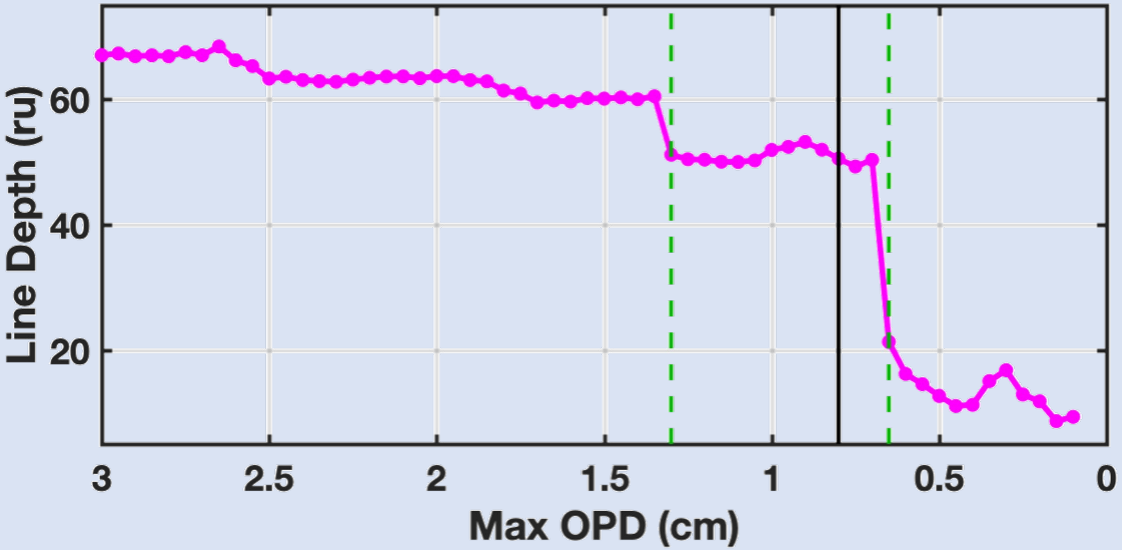
The unapodized CrIS SRF (a sinc function) corresponds to a Maximum Optical Path Difference of 0.8 cm.

HIRAS, GIIRS, MTG-IRS, and GXS all also have MOPD of ~0.8cm, so this issue is also directly relevant to them.

Response in the Interferogam (Optical Path Difference) domain

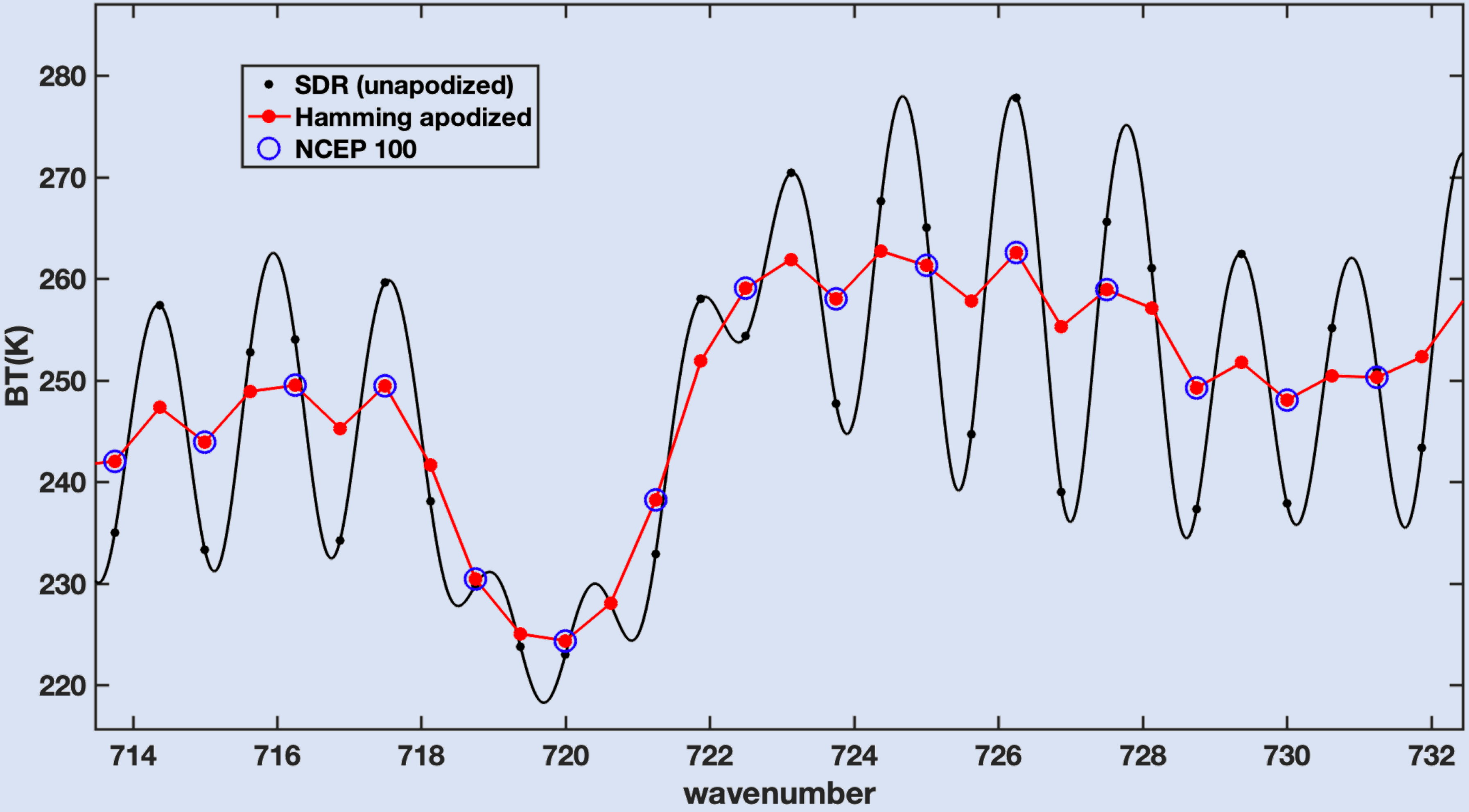


15 μm line depth vs MaxOPD



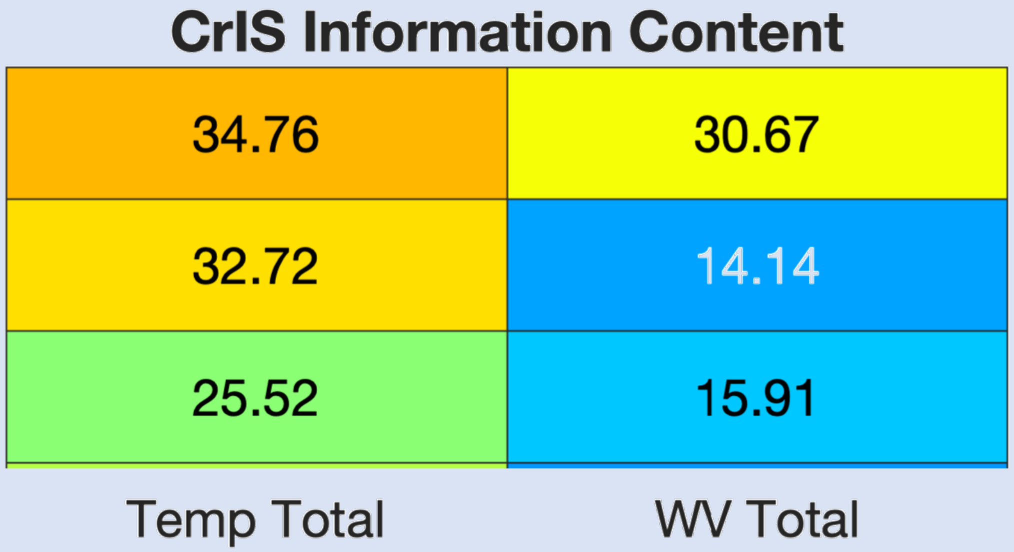
- Hamming damps the 0.65 cm resonance by 85%, greatly smoothing out the 15 μm CO_2 lines

Hamming Apodization combined with Channel Selection



- Adjacent channels are not included in the NCEP channel set, to mostly avoid the spectral correlation introduced by Hamming
- But also making it impossible to recover the high spectral resolution signals
- Thus, reducing CrIS to a broadband sensor (with very good calibration and low noise)

Impact on Temperature and Water Vapor Information Content



CrIS Information Content

	Temp Total	WV Total
All Channels, Unapodized	34.76	30.67
All LW Channels, Unapodized	32.72	14.14
NCEP 100 Channels, Hamming Apodized	25.52	15.91

Significant loss of T and WV Information content

Information Content calculations performed by Elisabeth Weisz and Paul Menzel, and very similar to Smith et al. 2021

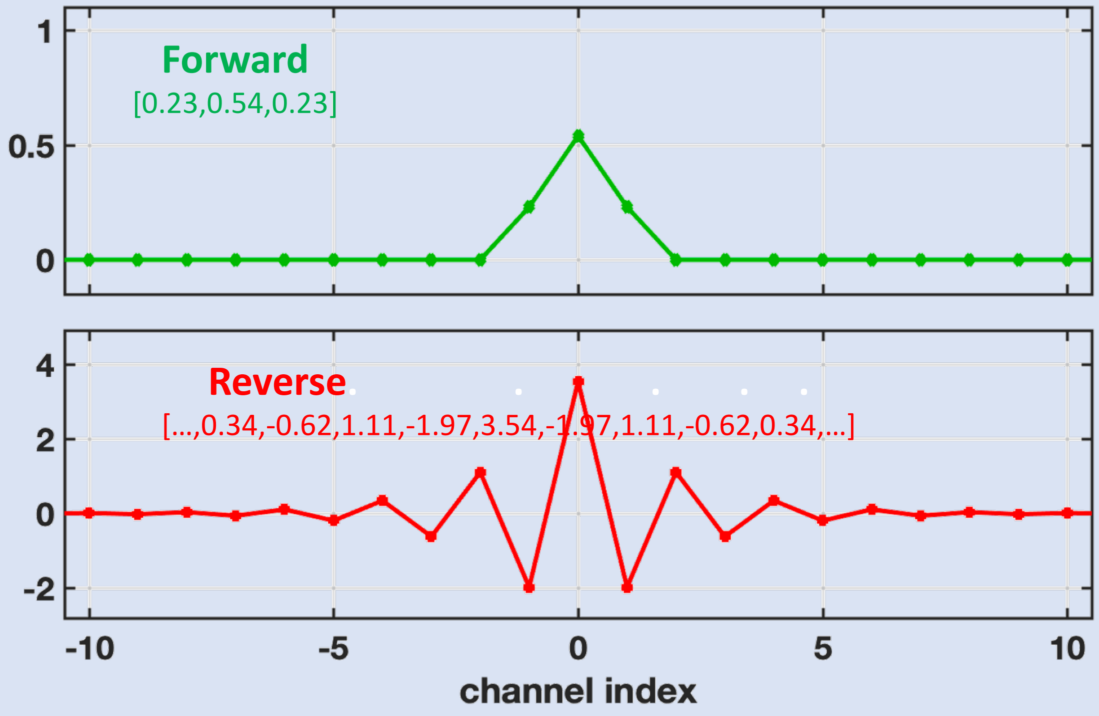
There are several solution paths:

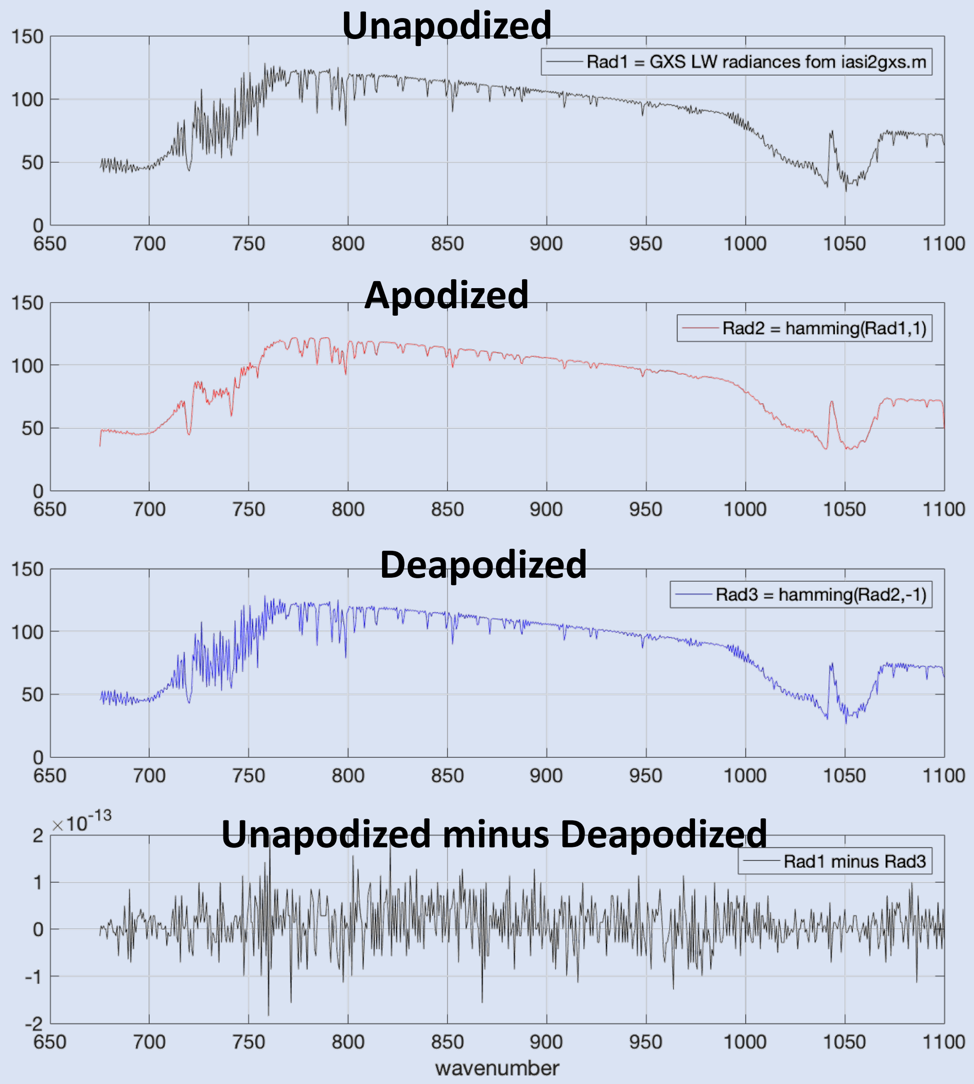
- ➢ Use the apodized spectra and continuous channels in important spectral regions along with an off-diagonal covariance matrix which is capable of reversing the apodization (e.g. ECMWF)
- Use the unapodized spectra and an appropriate (unapodized) forward RT model (e.g. Smith and Weisz et al., Zhou et al., Lui et al.)
- A different approach, also, is the assimilation of retrieval products (e.g. Smith et.al., McNally et.al., …)

Hamming is a simple three point (reversible) smoothing of the unapodized spectra.

The Hamming coefficients are [a b a] with a=0.23 and b=0.54.

Hamming coefficients in the spectral domain





It should be noted that:

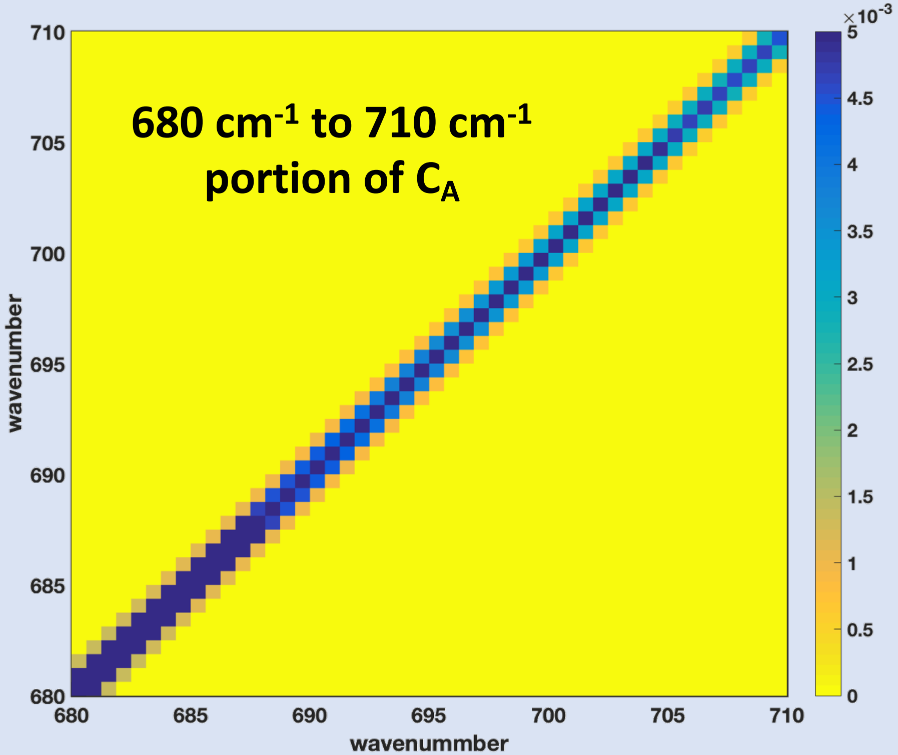
1. **Application of Hamming takes three adjacent unapodized spectral channels, and**
2. **Accurate removal of Hamming takes approximately 11 to 13 adjacent apodized channels.**

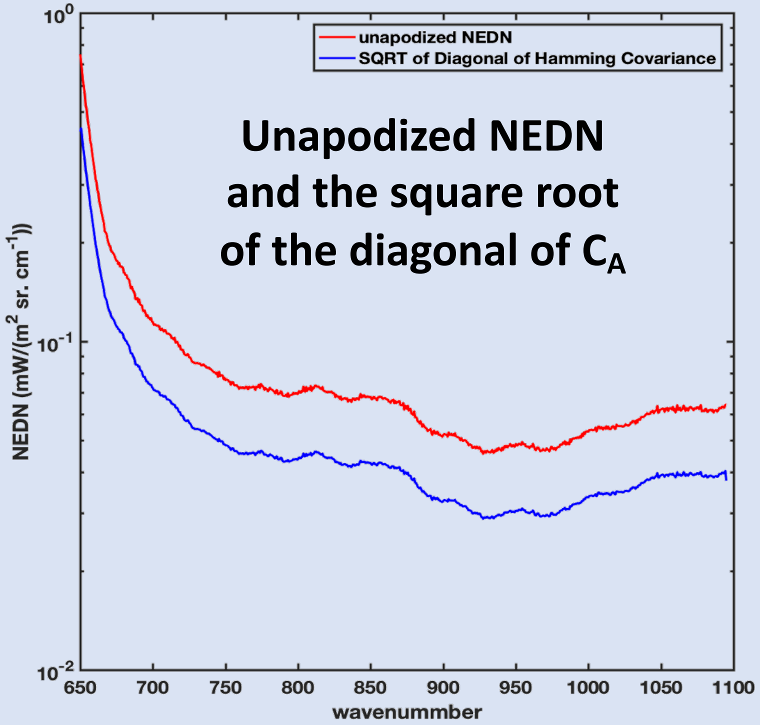
With the unapodized (diagonal NEDN) covariance matrix C_U and the Hamming matrix A, the covariance for Hamming apodized spectra is:

$$C_A = A\, C_U\, A^T$$

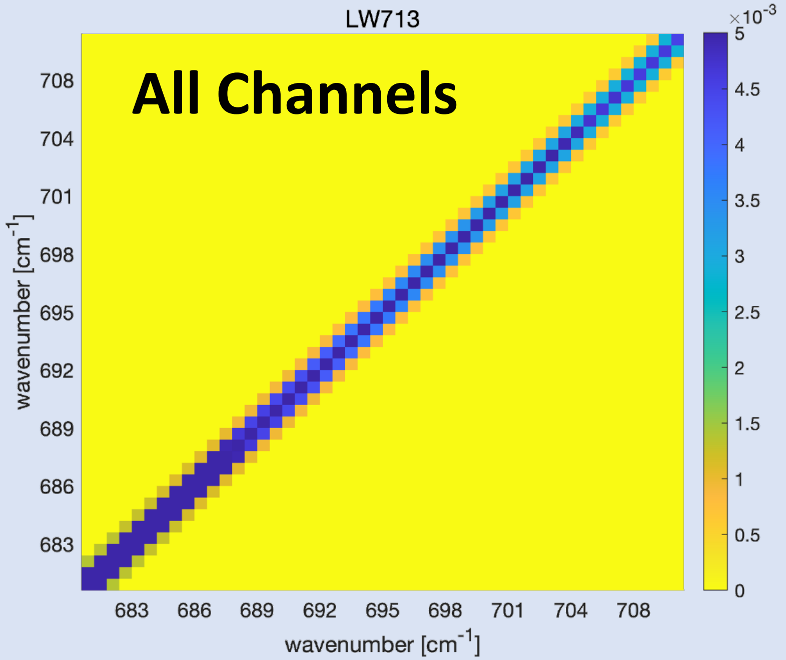
So, this covariance is computed directly from the unapodized NEDN (for any given CrIS sensor or FOV) and the Hamming coefficients.

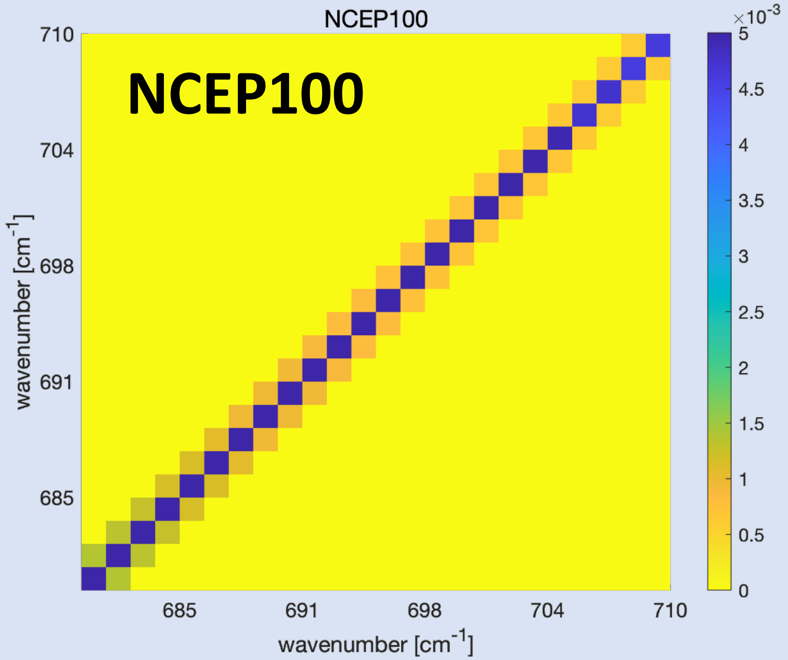
C_A for the LW band example (using JPSS-2 CrIS FSR NEDN) and the diagonal terms are:

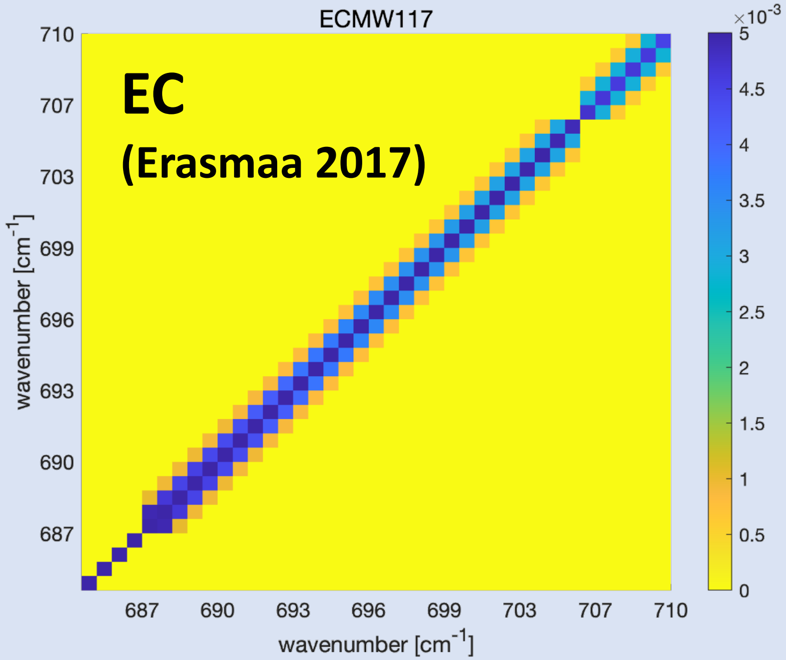




Hamming Covariance matrices for 3 channel sets (680 to 710 cm^{-1} portions shown)


All Channels


NCEP100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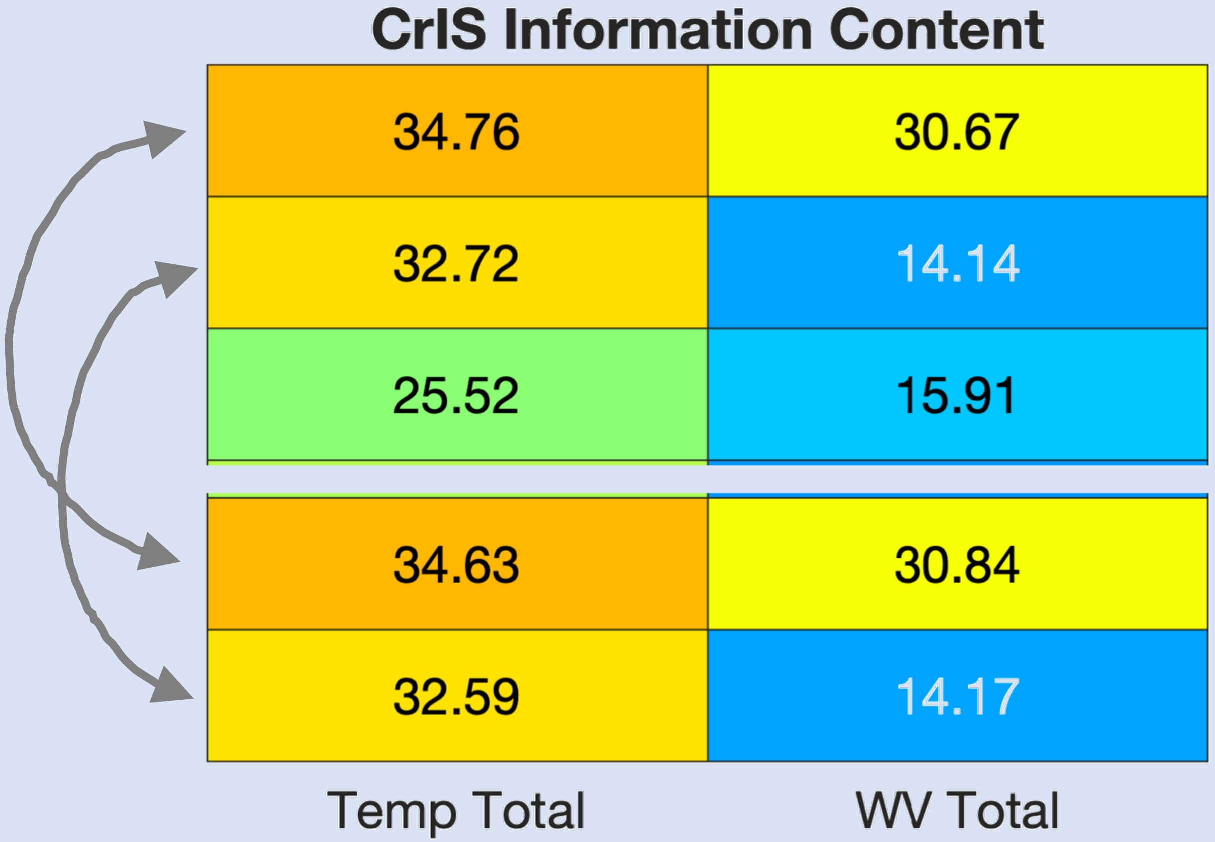
(Erasmaa 2017)

- **This is what the ”Obs” contribution to the O-minus-B Covariance matrix should look like if using Hamming apodized radiances. Very important non-zero values within +/- 2 elements of the diagonal.**

Impact on Temperature and Water Vapor Information Content



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NCEP 100 Channels, Hamming Apodized	25.52	15.91
All Channels, Apodized, with Hamming covariance	34.63	30.84
All LW Channels, Apodized, with Hamming covariance	32.59	14.17

Information is retained if (1) the Hamming covariance is specified and (2) enough adjacent channels are used

(Same basic conclusions as Amato et al. 1998 and Barnet et al 2000)

Information Content calculations performed by Elisabeth Weisz and Paul Menzel, and very similar to Smith et al. 2021

The assimilation of Cross-track Infrared Sounder radiances at ECMWF

Eresmaa et al. (2017) Quart J Royal Meteoro Soc, Volume: 143, Issue: 709, Pages: 3177-3188

"Apart from a few channels with considerable humidity sensitivity, **every single channel is used in wavenumber ranges 687–710 cm^{-1} and 720–740 cm^{-1}, so that the observing resolution in the vertical dimension is as high as practically possible** in the layer extending from lower stratosphere to mid-troposphere."

"Impact on the forecast examined on a channel-by-channel basis shows that **the subset of CrIS stratospheric-sensitive sounding channels (wavenumber range 690–710 cm^{-1}) give the greatest impact, followed by the subset of tropospheric-sensitive sounding channels (wavenumber range 720–760 cm^{-1}).** "

"The relative impact of various observation types is significantly influenced by the volume of each data type. Also contributing to the impact are changes in the data assimilation system, in particular the recent updates to CrIS and IASI observation-error covariance matrices. In terms of FSOI, **CrIS improves the forecast in the ECMWF system and consistently provides a total impact similar to IASI carried on either of the two MetOp satellites**."

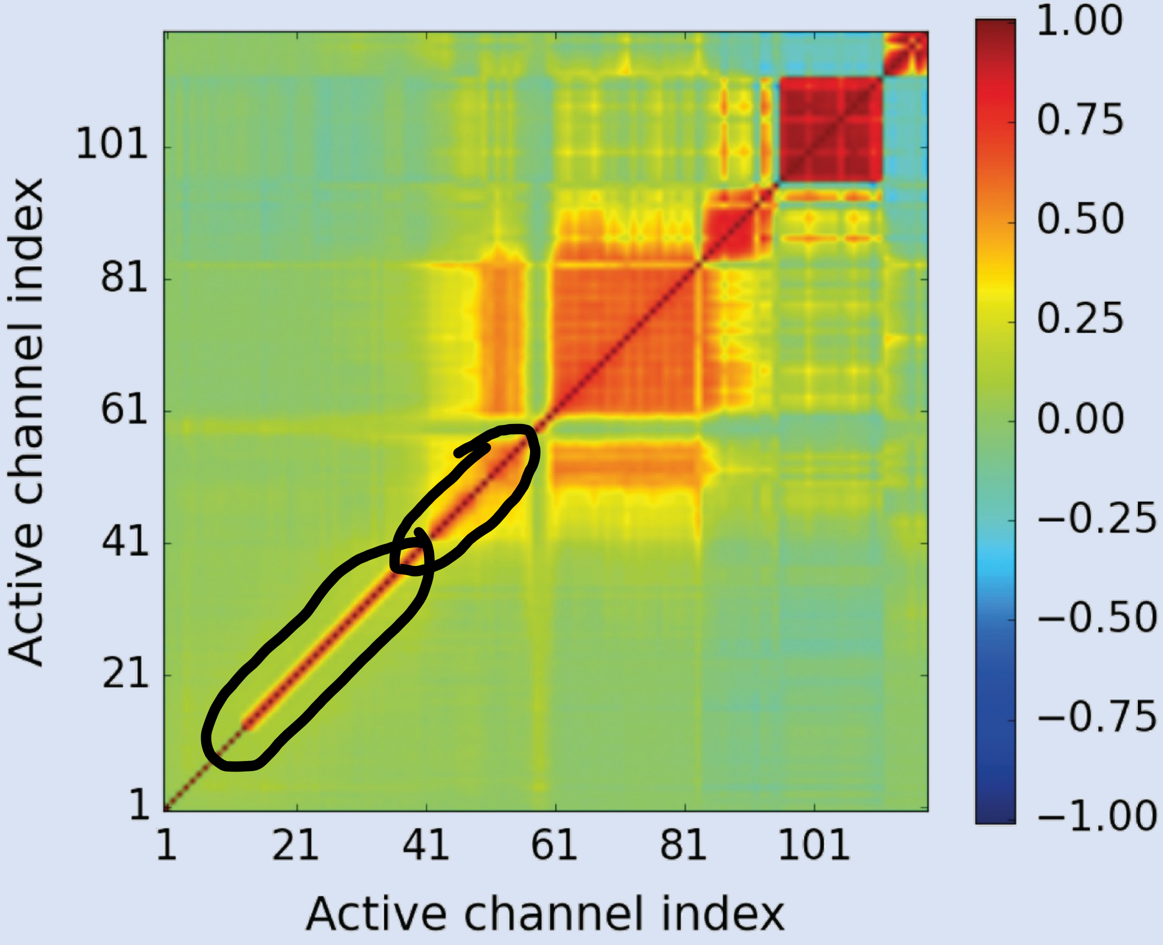

Figure 6. CrIS inter-channel observation-error correlation matrix.

Eresmaa et al. QJRMS, 2017

Summary

Hamming apodization, combined with certain spectral channel selection schemes, has the potential to reduce the information content of today's advanced IR sounders to that of previous era broadband sensors.

In some cases this is having a negative impact on the use of today's operational data, as well as on the perceived impact of future sensors.

One solution is to use the Hamming apodized radiances, but use continuous channels in important spectral regions combined with a covariance matrix which captures the Hamming effects, as demonstrated for example by ECMWF.

This is important not only for CrIS but also HIRAS, GIIRS, MTG-IRS, and GXS.

A few comments about unapodized RT models

- When Hamming is implicitly undone in an NWP system, the RT model then needs to be accurate for unapodized radiances.
- Various unapodized models exist now (OSS, PCRTM, HT-FRTC, …)
- Can test CRTM and RTTOV polychromatic models for producing unapodized CrIS radiances. Perhaps re-train such that de-apodized radiances have the desirable accuracy.
- A possible (and simple) CRTM and/or RRTOV based option: Use the existing polychromatic models to produce IASI L1C, and then add a module to exactly transform to unapodized CrIS.