ccast calibration equations

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introduction

An overview of the UMBC CCAST calibration equations, parameters, filters, and ILS. Topics include

- CCAST and NOAA calibration equations
- calibration equation parameters
- CCAST CrIS resolution modes
- raised cosine and ATBD processing filters
- processing, FIR filter, and responsivity plots
- CCAST ILS with sample plots
- extended resolution apodization

ccast calibration equations

CCAST reference equation

$$r_{\text{ES}}^{\text{user}} = F \cdot r_{\text{ICT}}^{\text{sensor}} \cdot f_{\text{cos}} \cdot \text{SA}^{-1} \cdot f_{\text{cos}} \cdot \frac{\Delta\text{ES}}{\Delta\text{IT}} \tag{1}$$

$$r_{\text{ES}}^{\text{user}} = F \cdot f_{\text{cos}} \cdot \text{SA}^{-1} \cdot f_{\text{cos}} \cdot r_{\text{ICT}}^{\text{fov}} \cdot \frac{\Delta\text{ES}}{\Delta\text{IT}} \tag{2}$$

NOAA algorithm 4

$$r_{\text{ES}}^{\text{user}} = r_{\text{ICT}}^{\text{user}} \cdot \frac{F \cdot f_{\text{ATBD}} \cdot \text{SA}^{-1} \cdot f_{\text{ATBD}} \cdot (\frac{\Delta\text{ES}}{\Delta\text{IT}}) \cdot |\Delta\text{IT}|}{F \cdot f_{\text{ATBD}} \cdot \text{SA}^{-1} \cdot f_{\text{ATBD}} \cdot |\Delta\text{IT}|} \tag{3}$$

$$\Delta\text{ES} = \text{ES} - \langle\text{SP}\rangle, \quad \Delta\text{IT} = \langle\text{IT}\rangle - \langle\text{SP}\rangle$$

calibration equation parameters

$$
\begin{aligned}
\mathrm{ES} &= \mathrm{NLC}(\mathrm{FIR}^{-1}(\mathrm{ES}_0)) \\
\langle \mathrm{IT} \rangle &= \mathrm{NLC}(\mathrm{FIR}^{-1}(\langle \mathrm{IT}_0 \rangle)) \\
\langle \mathrm{SP} \rangle &= \mathrm{NLC}(\mathrm{FIR}^{-1}(\langle \mathrm{SP}_0 \rangle))
\end{aligned}
$$

NLC is the ATBD non-linearity correction and ES_0, IT_0, and SP_0 are uncorrected earth-scene, ICT, and space spectra. $\langle \mathrm{IT}_0 \rangle$ and $\langle \mathrm{SP}_0 \rangle$ are moving averages, by default over 9 scans. FIR^{-1} is pointwise division by the spectral form of the numeric filter

- $r_{\mathrm{ICT}}^{\mathrm{user}}$ is expected ICT radiance at the user grid
- $r_{\mathrm{ICT}}^{\mathrm{sensor}}$ is expected ICT radiance at the sensor grid
- $r_{\mathrm{ICT}}^{\mathrm{fov}} = \mathrm{SA} \cdot r_{\mathrm{ICT}}^{\mathrm{sensor}}$, expected uncorrected ICT radiance

calibration equation parameters

expected ICT radiance is calculated as per the ATBD, using engineering packet parameters and a scan baffle temperature orbit profile correction

- $r_{\mathrm{ES}}^{\text{user}}$ is calibrated earth-scene radiance at the user grid
- F is double Fourier interpolation from sensor to user grid
- f_{cos} is a raised-cosine bandpass filter with wings at or just inside instrument responsivity
- f_{ATBD} is the NOAA version of the CrIS ATBD expontial bandpass filter
- the columns of SA are the periodic sinc ILS wrapping at the sensor grid, without extension or trimming

CCAST resolution modes

- UMBC CCAST sensor-grid resolution modes include

mode	LW	MW	SW	comment
lowres	866	530	202	low res
hires1	866	1039	799	old high res
hires2	866	1052	799	2014 high res
hi3to2	866	1052	800	truncation test
hires3	874	1052	808	new extended res

- CCAST user grid resolution modes include the original 0.8/0.4/0.2 cm^{-1} OPD low res mode and the 0.8 cm^{-1} OPD high res mode
- double Fourier interpolation from the sensor to user grid allows for any combination of sensor and user resolutions
- interferogram centers are at decimated points $n/2+1$ for even point sets. The center is at $n/2+1$ for the 799 point set as well, but in that case is not an integer

raised cosine processing filter

CCAST processing filter weight as a function of frequency is

$$f_{\cos}(v) = \begin{cases} 0 & v < v_L \\ (1 + \cos(-\pi(p_L - v)/(p_L - v_L)))/2 & v_L \leq v < p_L \\ 1 & p_L \leq v < p_H \\ (1 + \cos(\pi(p_H - v)/(p_L - v_H)))/2 & p_H \leq v < v_H \\ 0 & v_H \leq v \end{cases}$$

CCAST high res filter parameters are

band	p_L	p_H	r_L	r_H
LW	650	1100	15	20
MW	1200	1760	30	30
SW	2145	2560	30	30

with $v_L = p_L - r_L$ and $v_H = p_H + r_H$

ATBD processing filter

ATBD processing filter weights as a function of index are

$$f_{\mathrm{ATBD}}(k) = \frac{1}{e^{a_2(k_0 - a_1 - k)} + 1} \cdot \frac{1}{e^{a_4(k - k_1 - a_3)} + 1}$$

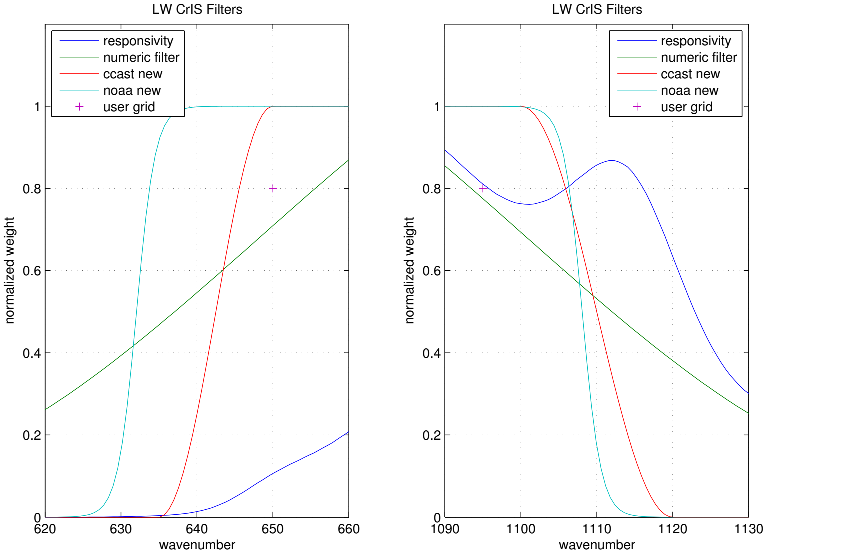
NOAA high res ATBD filter parameters

band	size	k_0	k_1	a_1	a_2	a_3	a_4
LW	866	78	790	30	0.5	30	0.5
MW	1052	95	959	59	0.5	59	0.5
SW	799	84	716	41	0.5	41	0.5

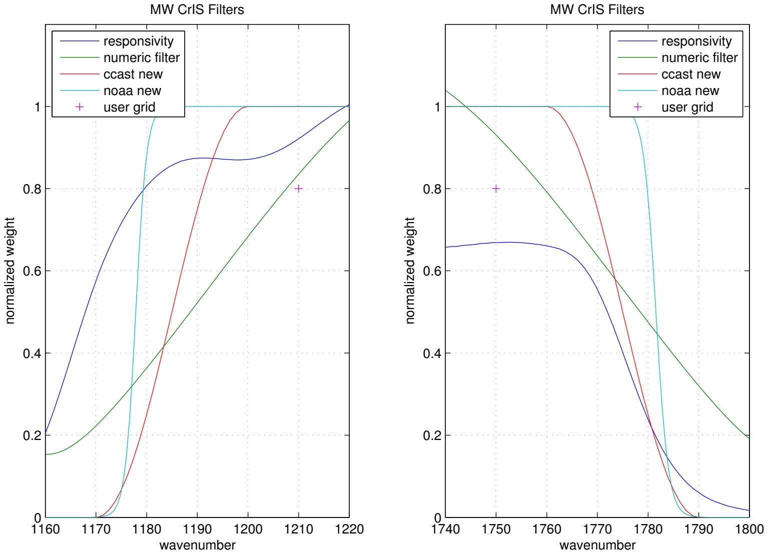
UMBC extended res ATBD filter parameters

band	size	k_0	k_1	a_1	a_2	a_3	a_4
LW	874	79	797	30	0.5	30	0.5
MW	1052	95	959	59	0.5	59	0.5
SW	808	85	724	41	0.5	41	0.5

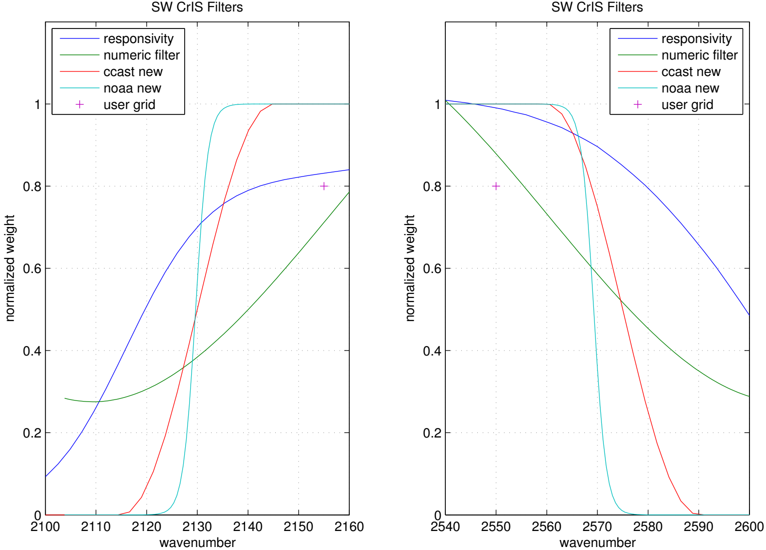
ccast and noaa LW filters



ccast and noaa MW filters



ccast and noaa SW filters



CCAST ILS function

the CCAST ILS for FOV_i can be represented as

$$\int_{\mathrm{FOV}_i} w_i(\theta)\,\mathrm{psinc}(2\pi d(v - v_0 \cos\theta))\,d\theta$$

- d is max OPD
- v is frequency
- v_0 is reference or channel frequency
- $\mathrm{psinc}(x) = sin(x)/(n \sin(x/n))$ for $x \neq 0$, 1 for $x = 0$, where n is the number of points in the sensor grid
- $\mathrm{psinc}(2\pi d(v - v_0 \cos\theta))$ gives the ILS for a single ray at off-axis angle θ
- integration is over the intersection of on-axis arcs with FOV_i, with $w_i(\theta)$ the length of an intersecting arc at off-axis angle θ

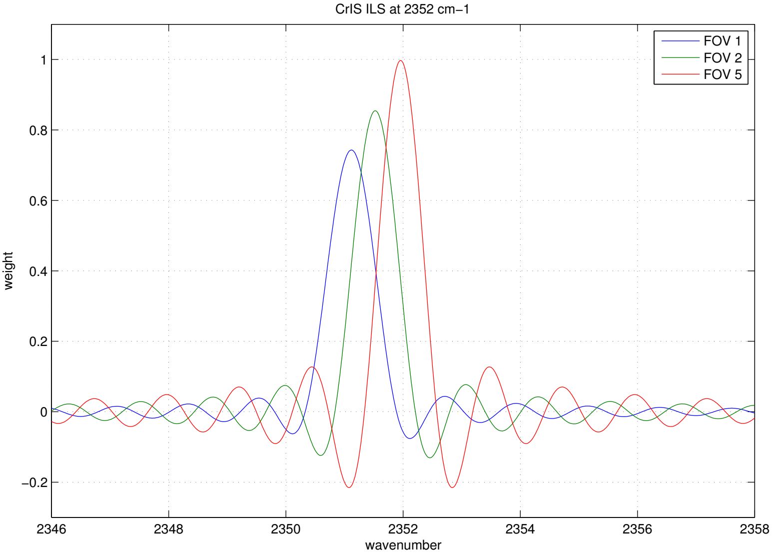
CCAST SA matrix

the CCAST SA matrix for FOV_k is

$$\text{SA}(i,j) = \int_{\text{FOV}_k} w_k(\theta)\,\text{psinc}(2\pi\delta(v_i - v_j\cos\theta))\,d\theta$$

- $1 \le i,j \le n$, for n the number of points in the sensor grid
- v_i is frequency for channel i, and δ is max OPD
- $\text{psinc}(x) = sin(x)/(n\sin(x/n))$ for $x \ne 0$, 1 for $x = 0$
- $\text{psinc}(2\pi\delta(v - v_0\cos\theta))$ gives the ILS for a single ray at off-axis angle θ and reference or channel frequency v_0
- integration is over the intersection of on-axis arcs with FOV_k, with $w_k(\theta)$ the length of an intersecting arc at off-axis angle θ

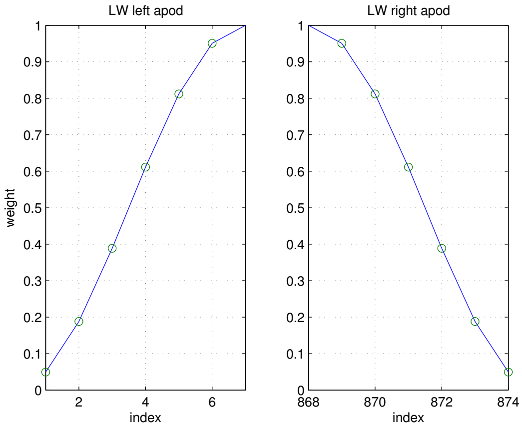
sample CCAST ILS



extended interferogram apodization

- we can drop 6 points on each side of the extended resolution interferograms and stay very close to the OPD spec
- $(n-12) \cdot dx = 1.5995$ for the LW, 1.6081 for the MW, and 1.6001 for the SW bands, for typical metrology laser values
- this includes the MW band, even though that was not extended in the recent update
- apodizing (rather than dropping) these points leaves effective resolution within specs
- note that the apodized extension discussed here is distinct from any downstream apodization (such as Hamming) that is applied to user-grid radiances

extended interferogram apodization



edge of band details for the LW extended resolution apodization. The apodization is symmetrical and all the weights are non-zero.

calibration equation notes

- most CCAST validation tests were done with calibration equations (1) and (3), but Yong and Larrabee have suggested moving to (2) instead of (1) for the "ratio first" approach
- the second processing filter applications gave a significant reduction in residuals in earlier tests, but may no longer be necessary
- runtime for the equations is similar. The NOAA equation is more complex but the denominator needs to be calcluated only once per scan
- equation (1) is CCAST calibration option "e5", (2) is "e6", and (3) is "d4". The CCAST option names were set in earlier test rounds
- parameters for the UMBC extended res ATBD filter are chosen to match the NOAA high res filter as a function of frequency