Assessing the Effects of Uncertainty in the IR Measurements on Derivation of Spectral Fingerprints Temperatures

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Agenda

- Background/Objectives
- Preliminary Framework
- Detail Analysis
  - Input, Method, Output definitions
  - Perfect vs. CLARREO instruments
  - Outstanding Questions
- Instrument Bias Exploration
- Conclusion/Next Steps

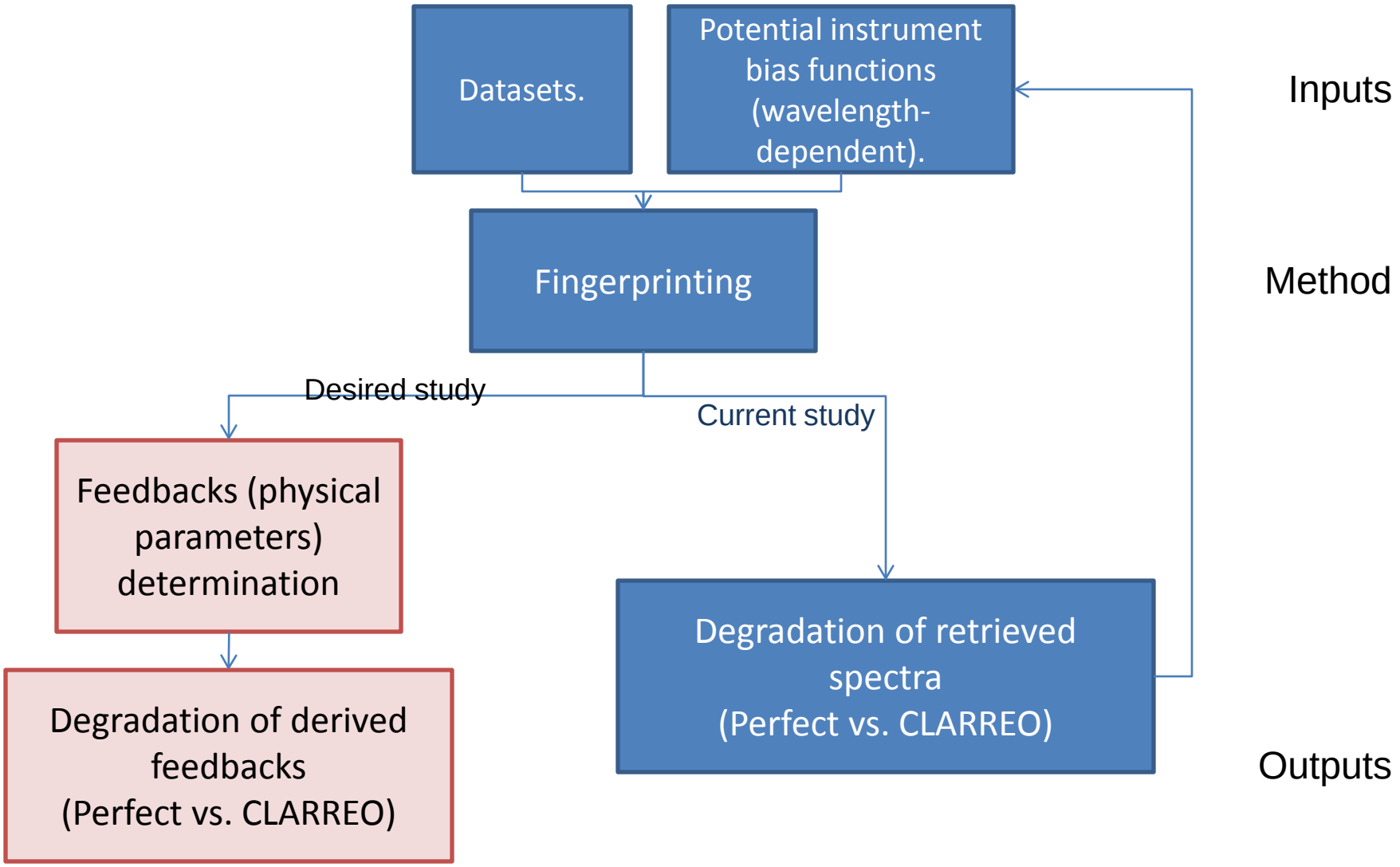
Background

- Current IR systematic error requirement is 0.1K (3-k) across wavenumbers of 200-2000 cm-1 for all scene temperatures of 200-300K.

Objectives

- To determine an allowable IR systematic error distribution across the specified wavenumbers and scene temperatures that will still enable the derivation of physical parameters (e.g., water vapor feedback, etc.)
- To help defining IR requirement.

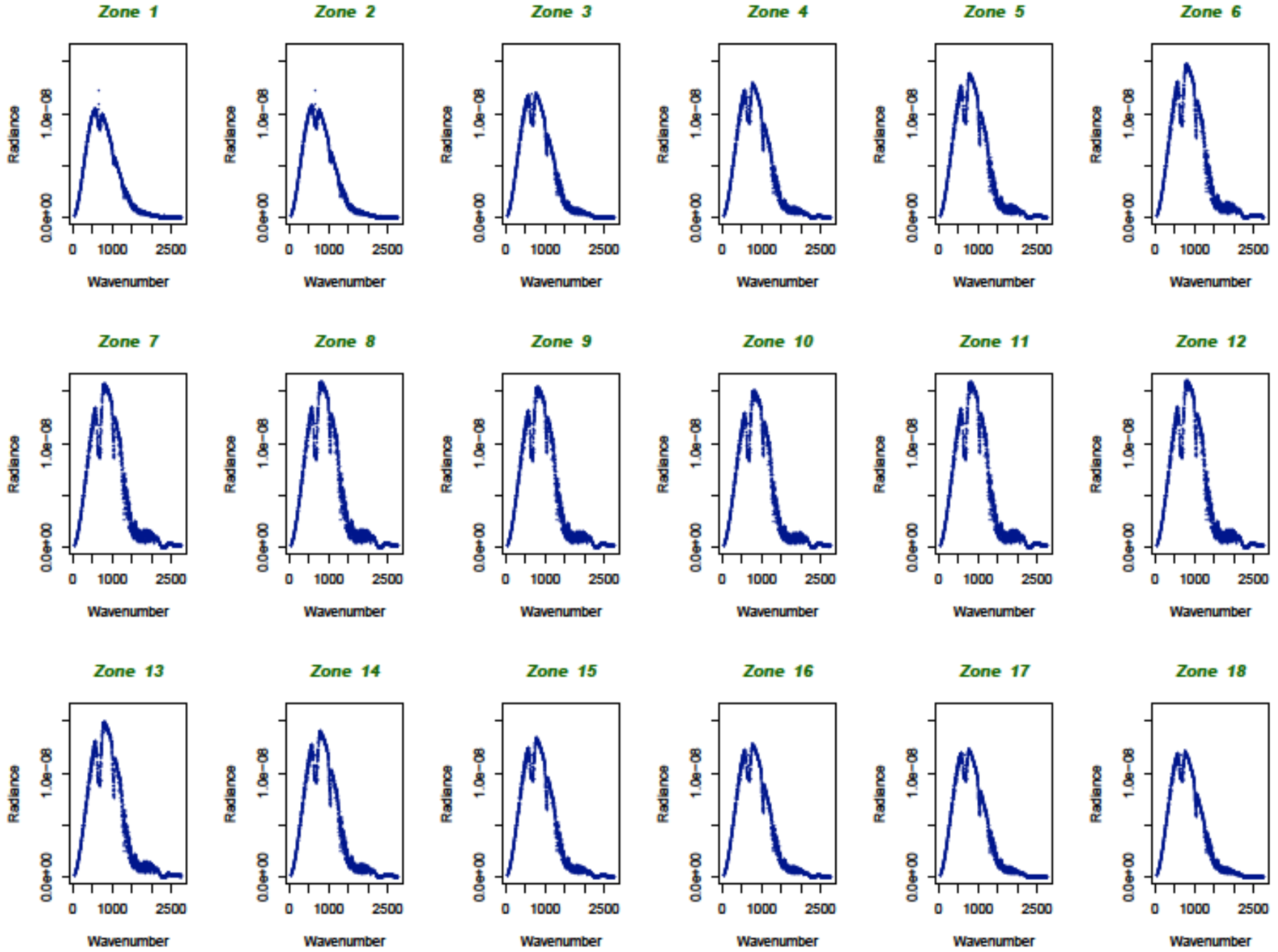
Preliminary Framework



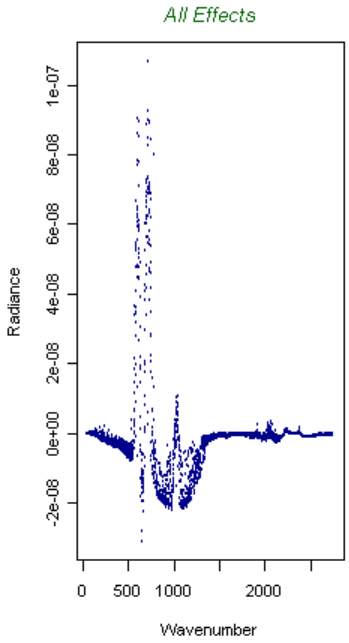
Current Study

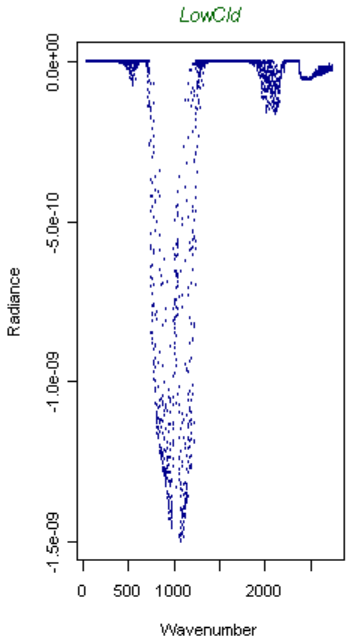
- Inputs
  - Datasets: the radiance differences of all-sky CCCMA from Huang et al. [2010].
  - Instrument bias function: 0.1K every wavenumbers (using scene temperatures from Seiji's TB zonal annual averages)
  - Perfect instrument
    - To study a 20-year expected change, the radiance difference is decreased by a factor of 10.
  - CLARREO instrument
    - Add 0.2K bias to the perfect instrument's data
- Method
  - Huang et al. [2010]
- Outputs
  - Performance measures of retrieval degradation.

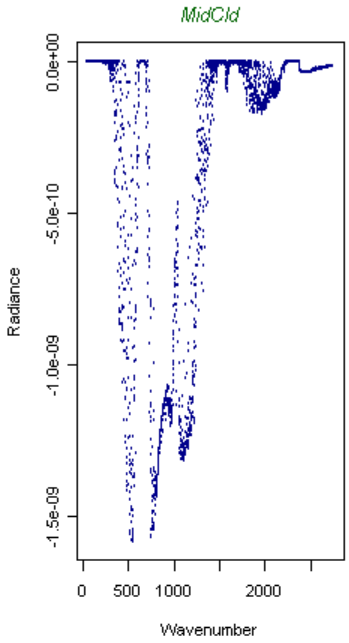
Instrument Bias of 0.1K everywhere

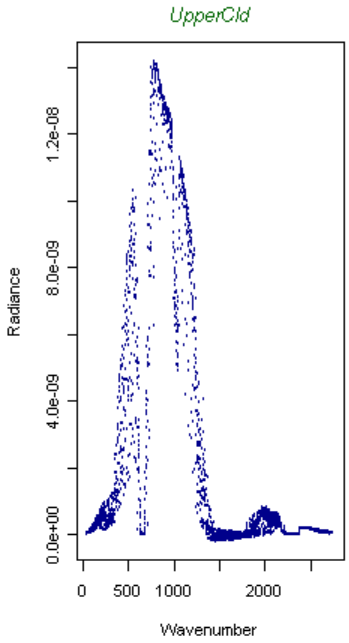


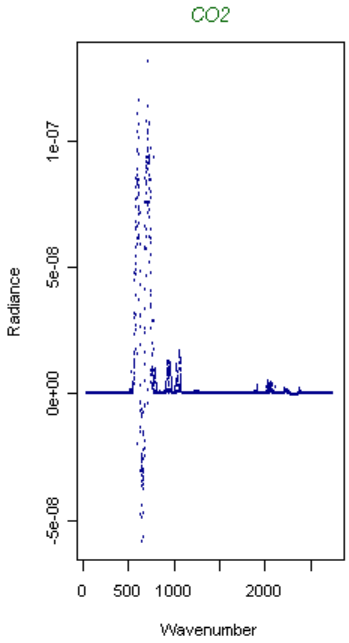
Signal Signatures

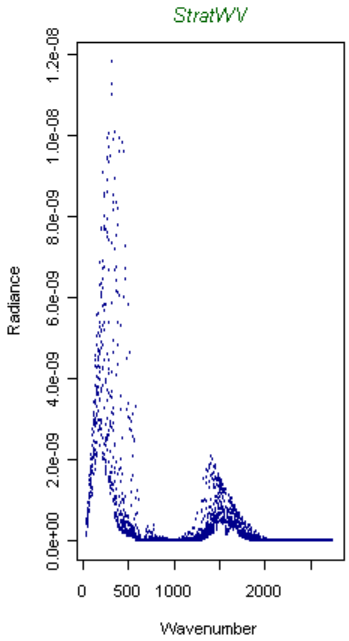


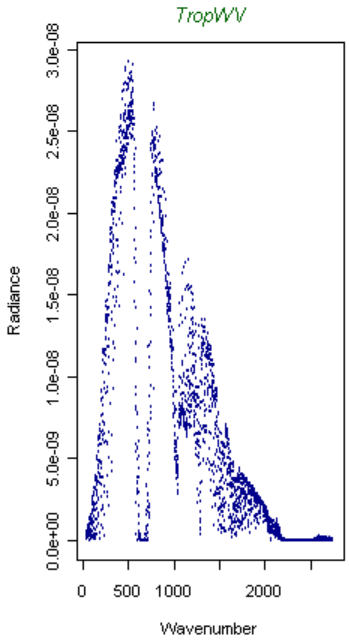


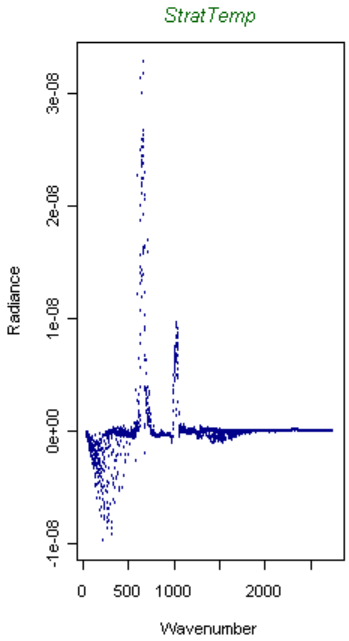


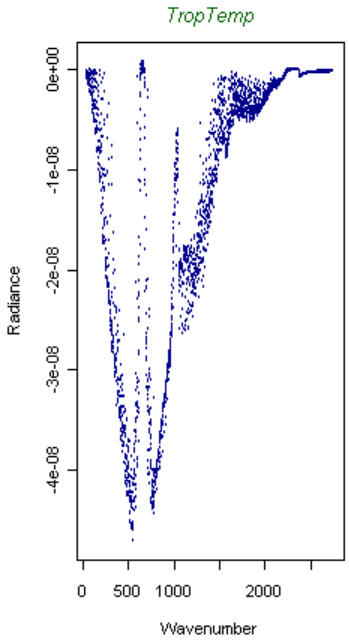


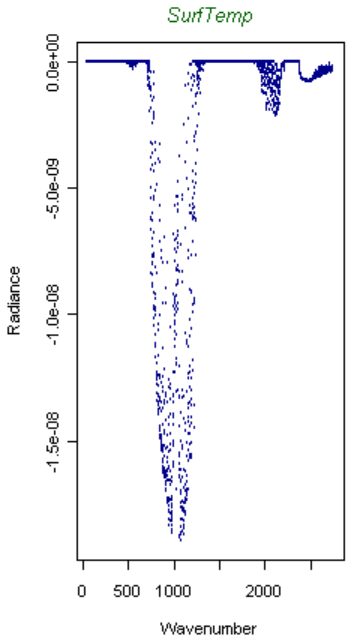






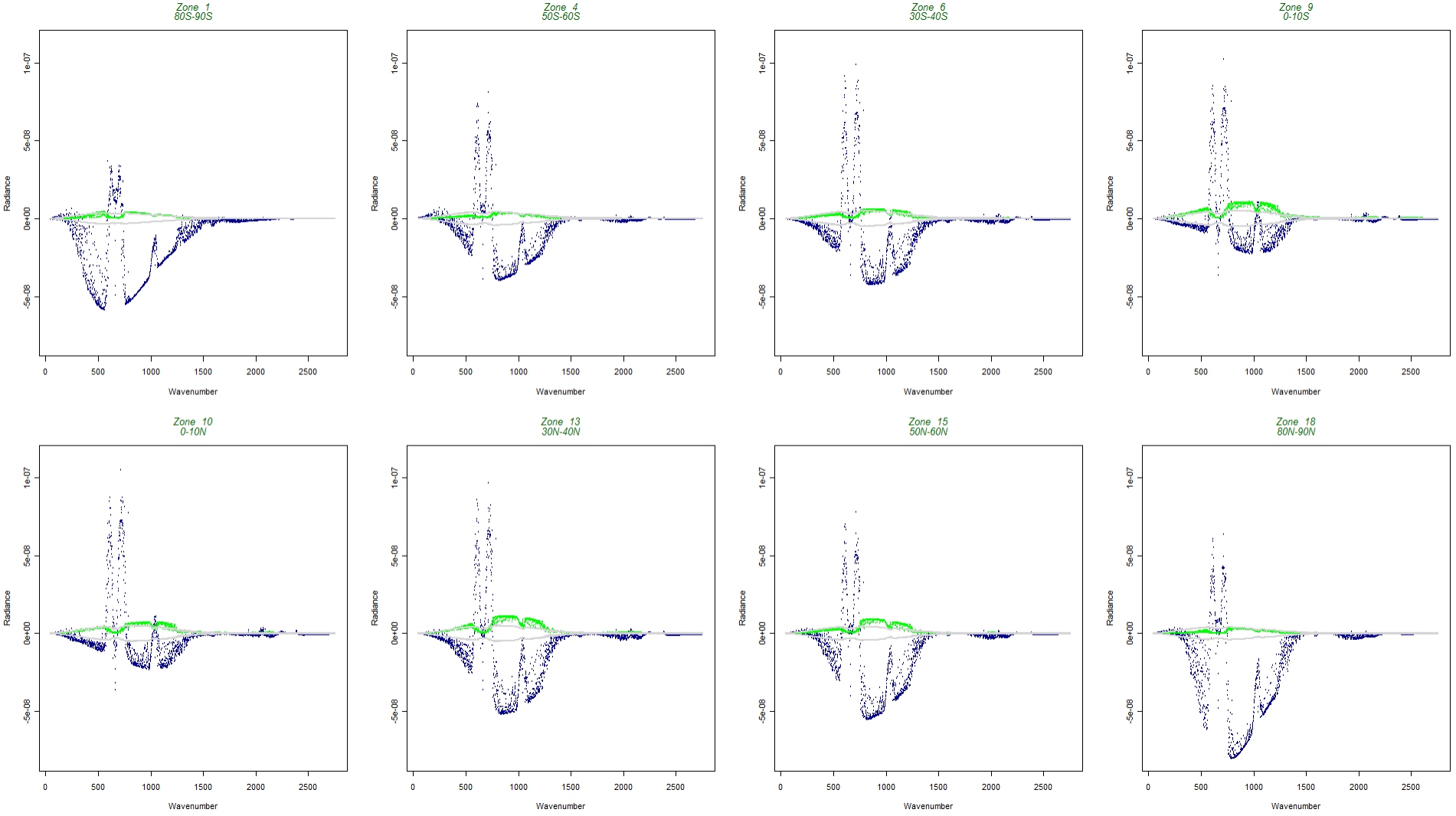






Perturbed all effects - Perfect

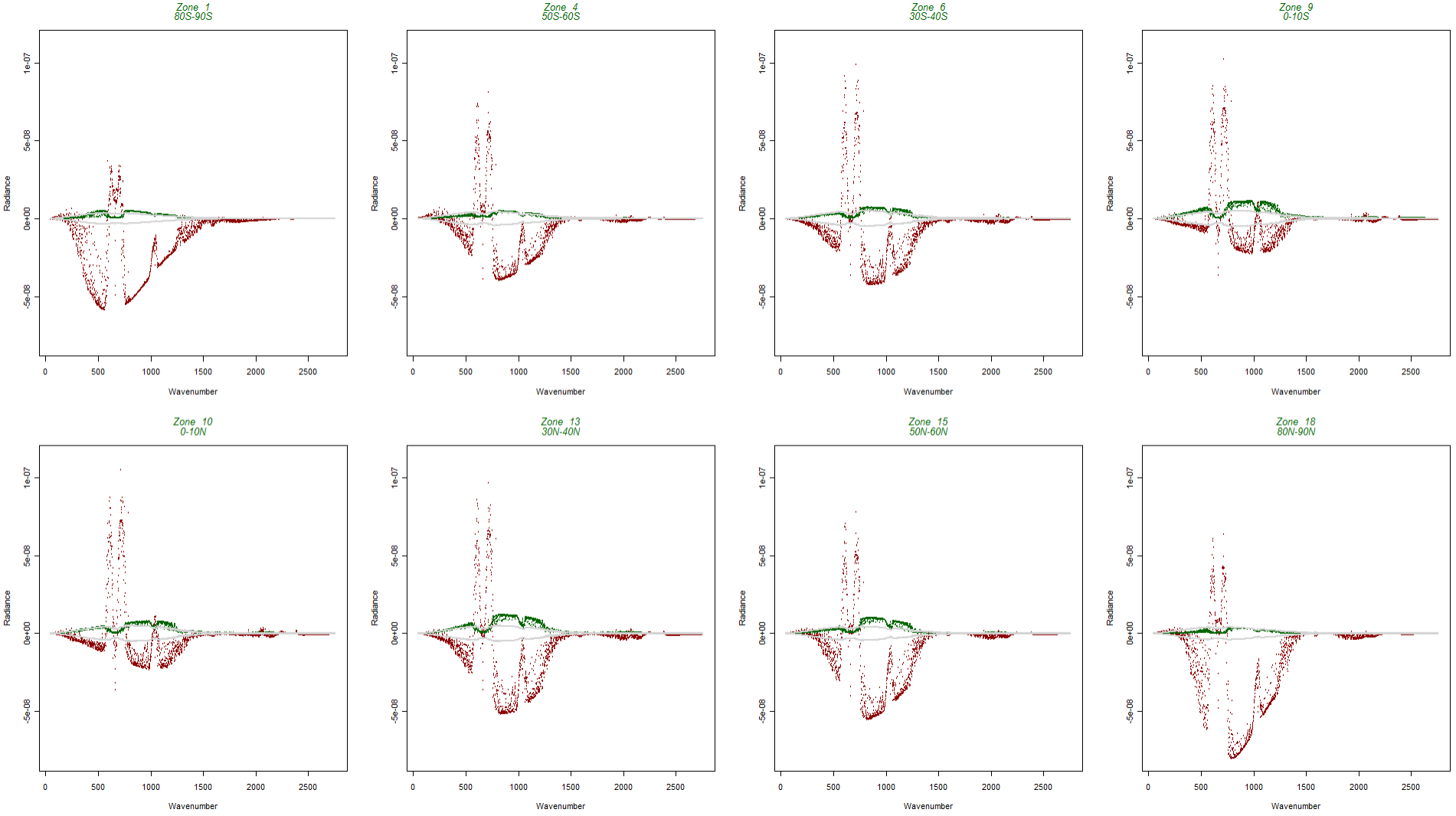
(Blue = Retrieval Mean of Perfect, Green = Retrieval Uncertainty, Gray = 0.03K (1-k) accuracy)



Define: SNR(Perfect) = Retrieval Mean of Perfect / Retrieval Uncertainty of Perfect

Perturbed all effects - CLARREO

(Red = Retrieval Mean of CLARREO, Dark Green = Retrieval Uncertainty, Gray = 0.03K (1-k) accuracy)

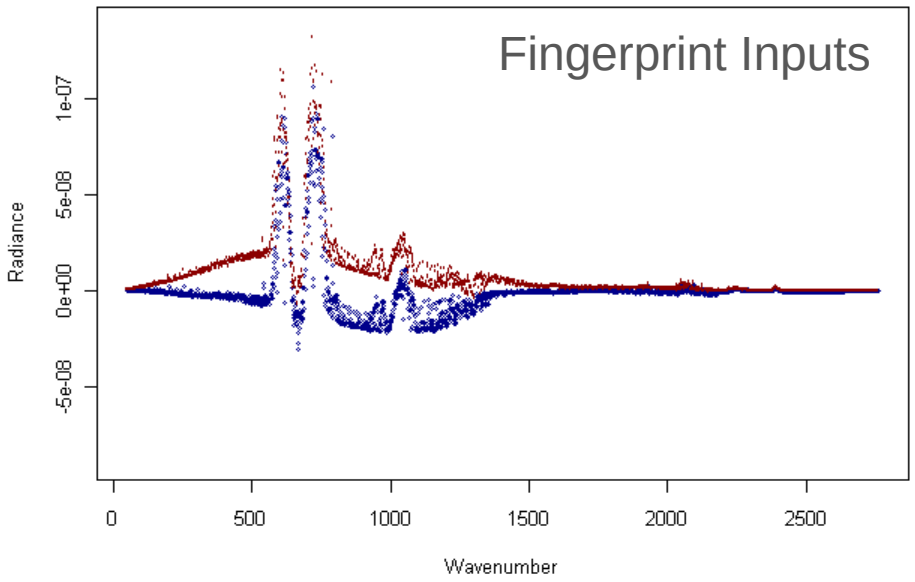


Define: SNR(CLARREO) = Retrieval Mean of CLARREO / Retrieval Uncertainty of CLARREO

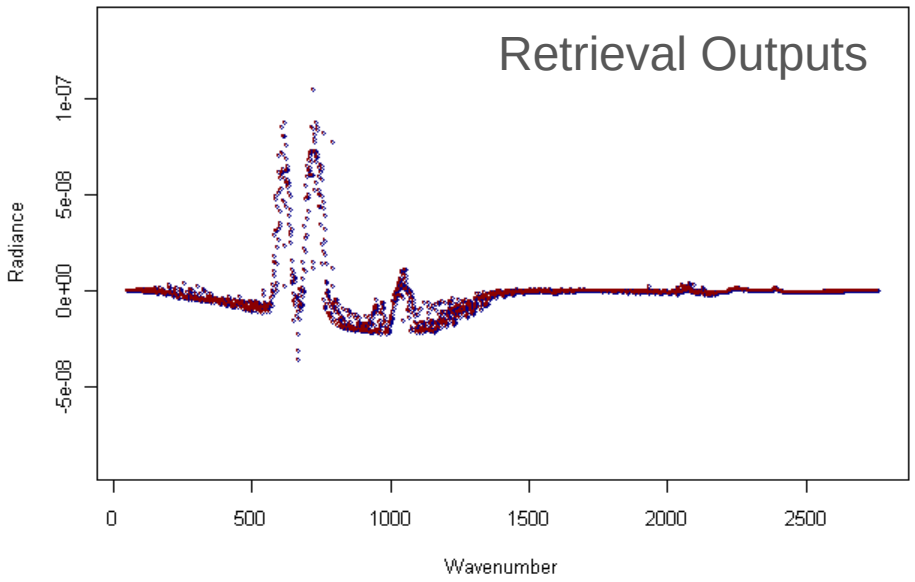
Example: All effects of Zone 10

(Blue = Perfect, Red = CLARREO, Gray = R(0.2K))

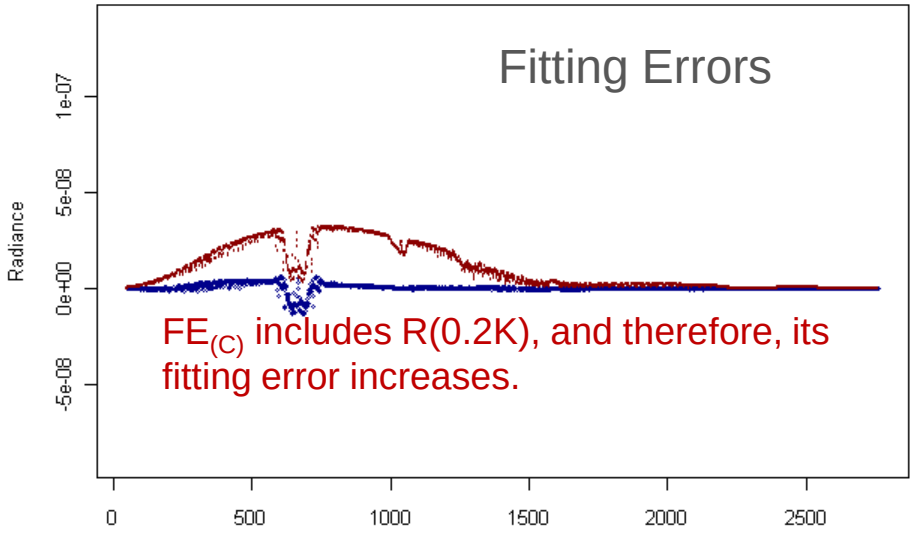
Yp vs. Yc



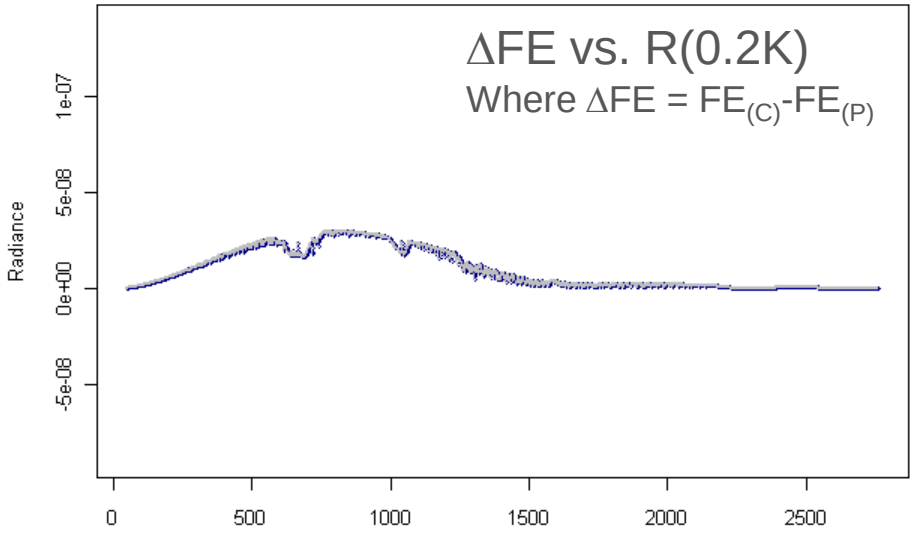
Yp(hat) vs. Yc(hat)



FEp vs. FEc

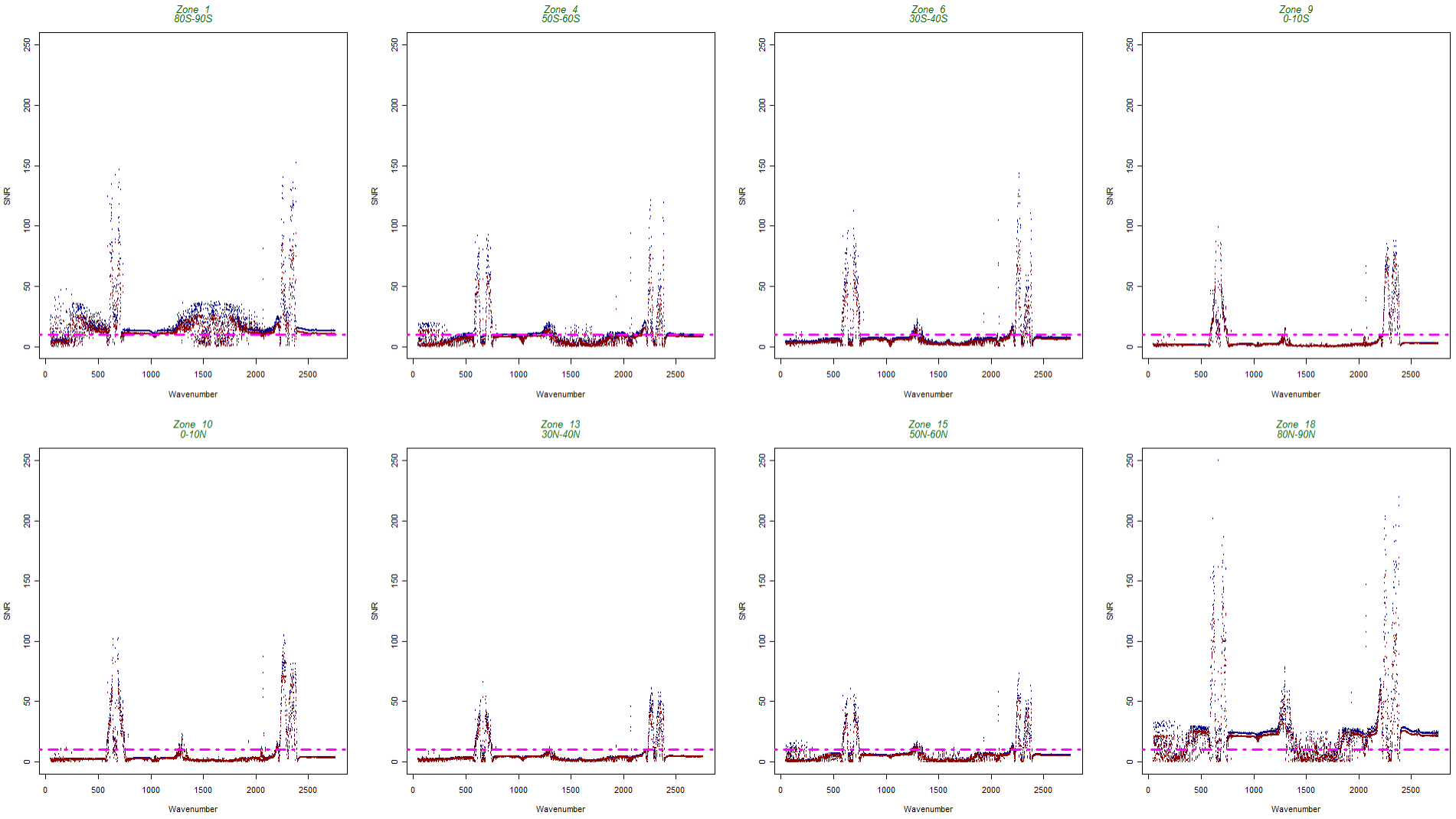


Delta FE vs. 0.2K



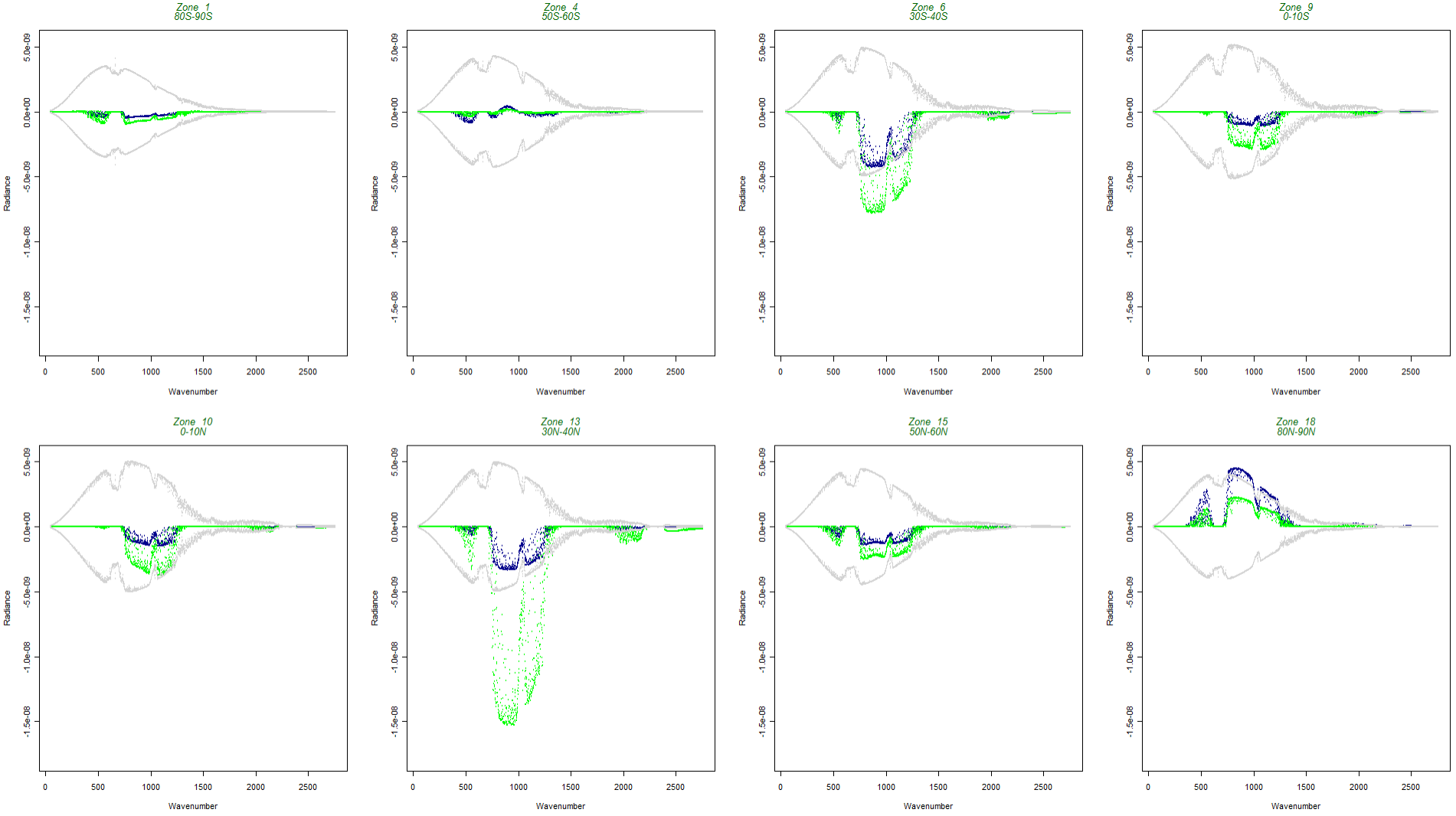
SNR: Perturbed all effects - All zones have SNR(CLARREO) < SNR(Perfect).

Blue = Perfect, Red = CLARREO, Magenta = 10:1 SNR



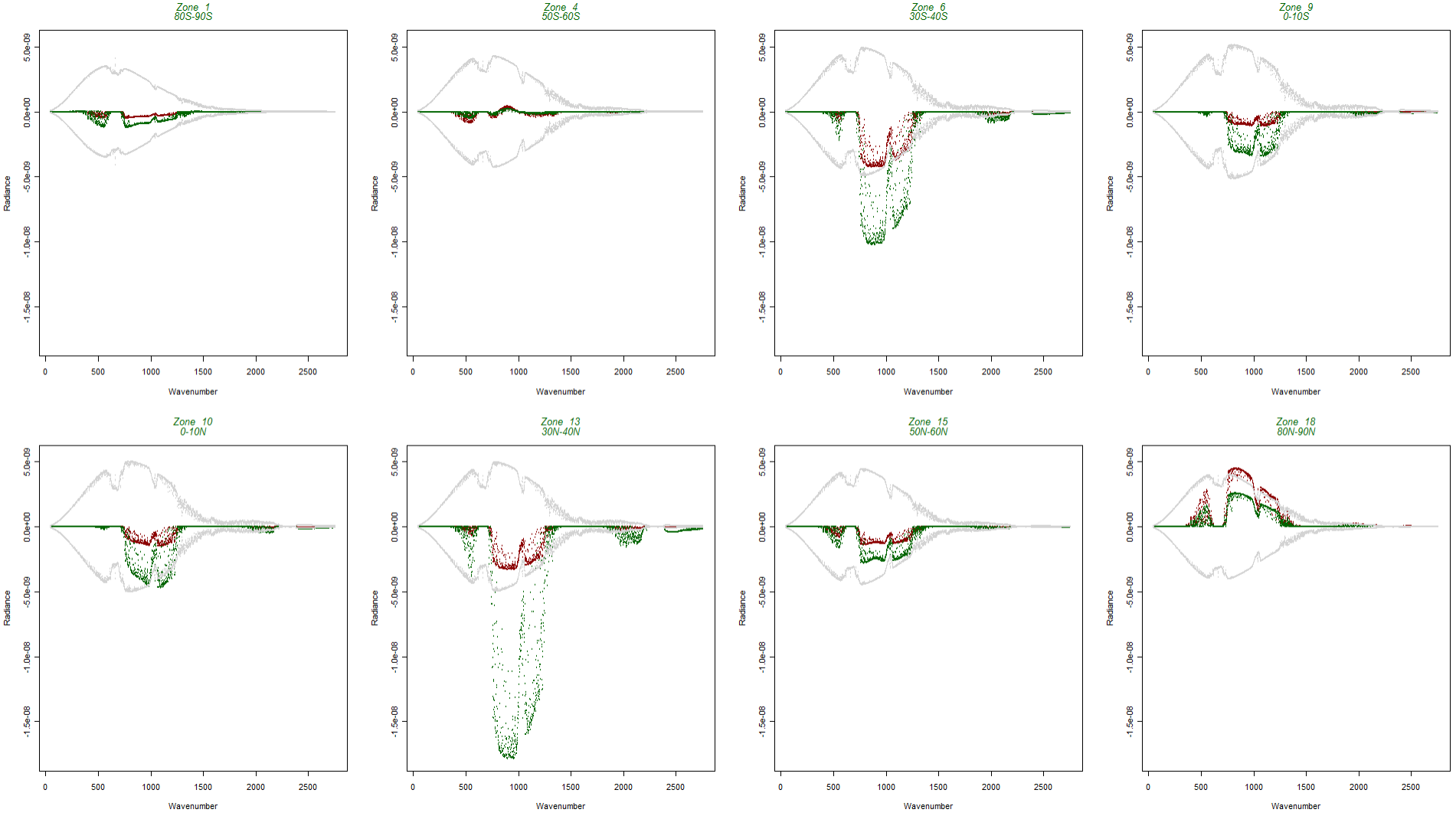
Lower Trop Cloud - Perfect

(Blue = Retrieval Mean of Perfect, Green = Retrieval Uncertainty, Gray = 0.03K (1-k))



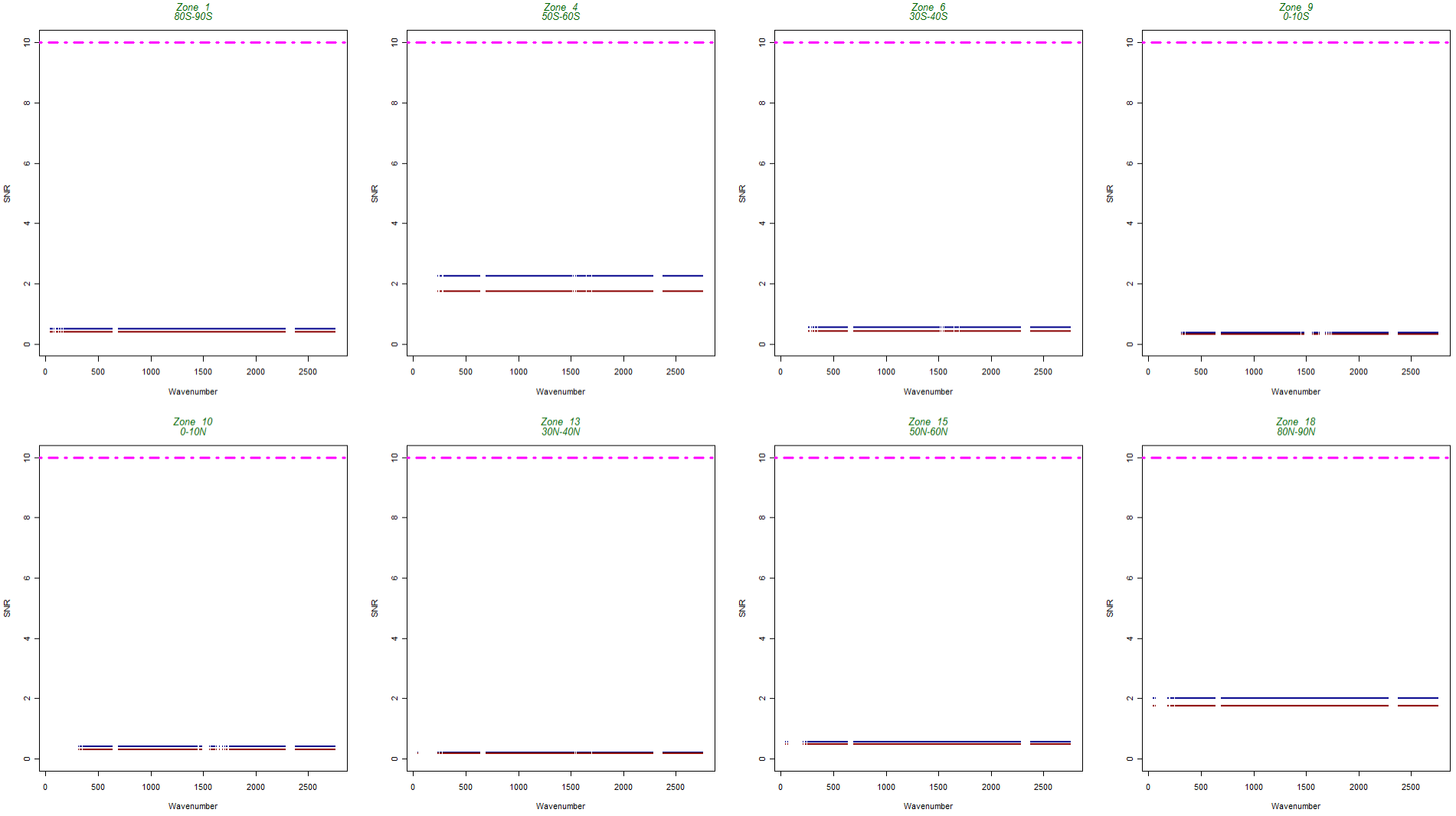
Lower Trop Cloud - CLARREO

(Red = Retrieval Mean of CLARREO, Dark Green = Retrieval Uncertainty, Gray = 0.03K (1-k))



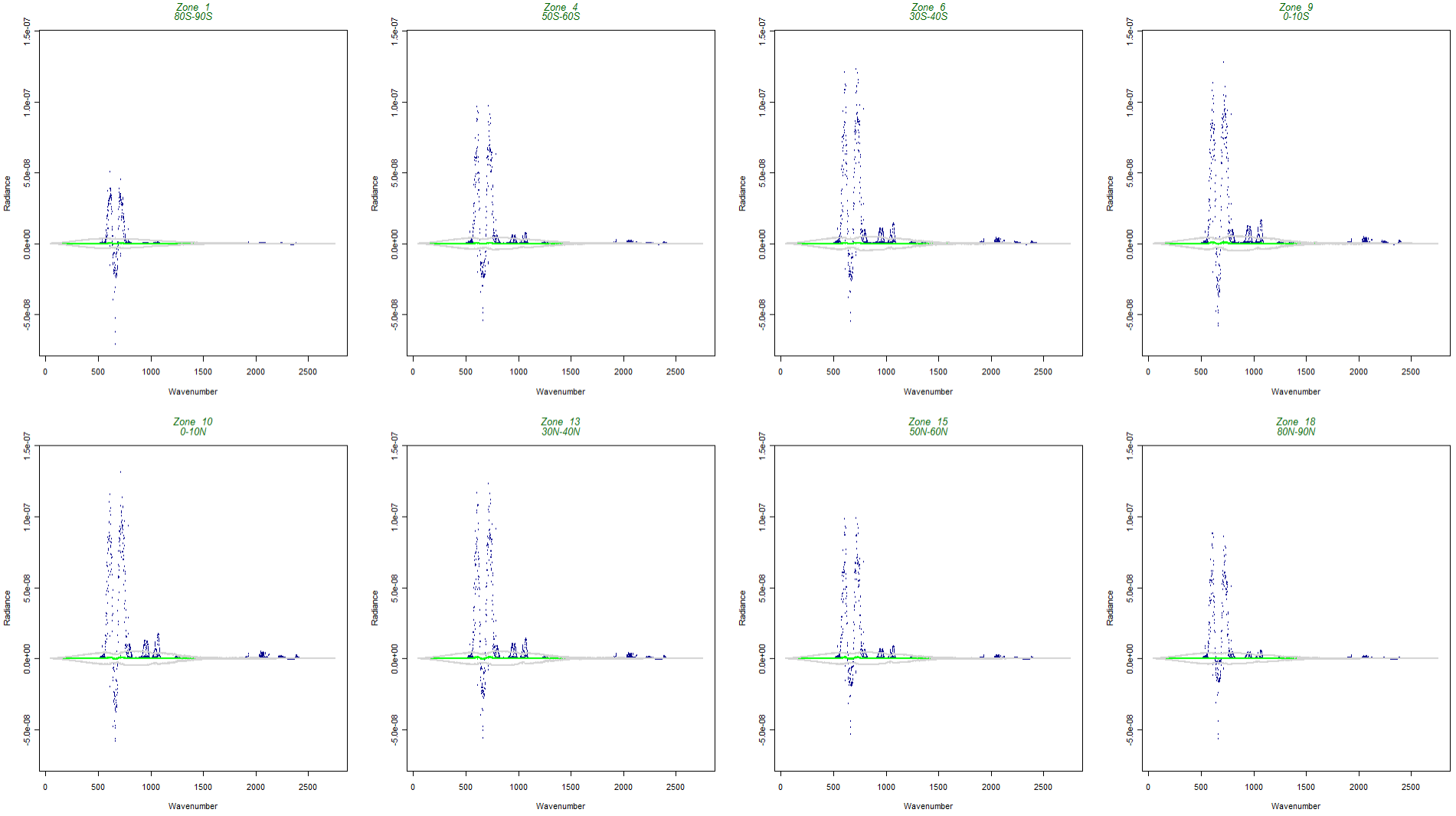
SNR: Lower Trop Cloud

Blue = Perfect, Red = CLARREO, Magenta = 10:1 SNR



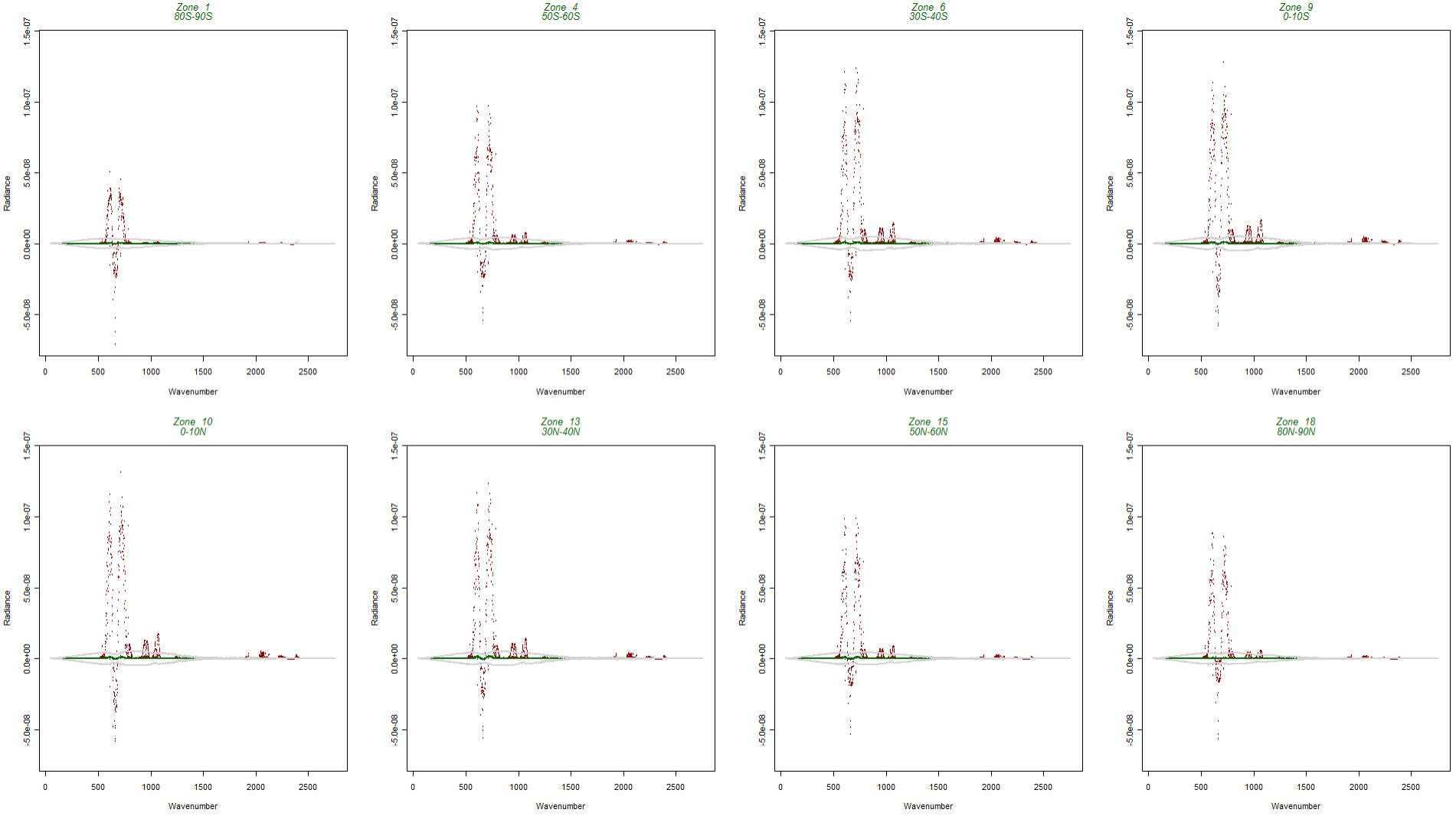
CO_2 - Perfect

(Blue = Retrieval Mean of Perfect, Green = Retrieval Uncertainty, Gray = 0.03K (1-k))



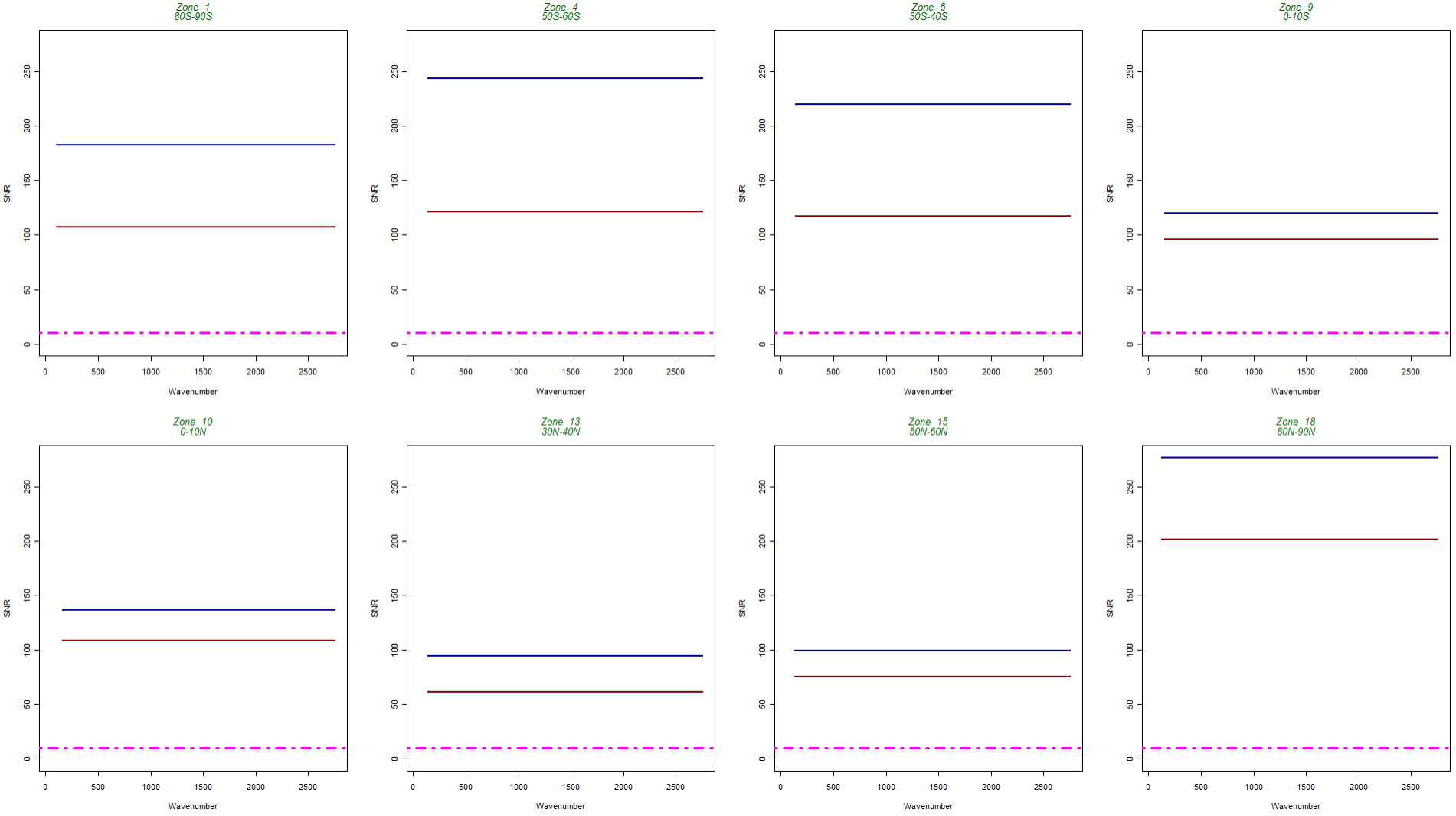
CO_2 - CLARREO

(Red = Retrieval Mean of CLARREO, Dark Green = Retrieval Uncertainty, Gray = 0.03K (1-k))



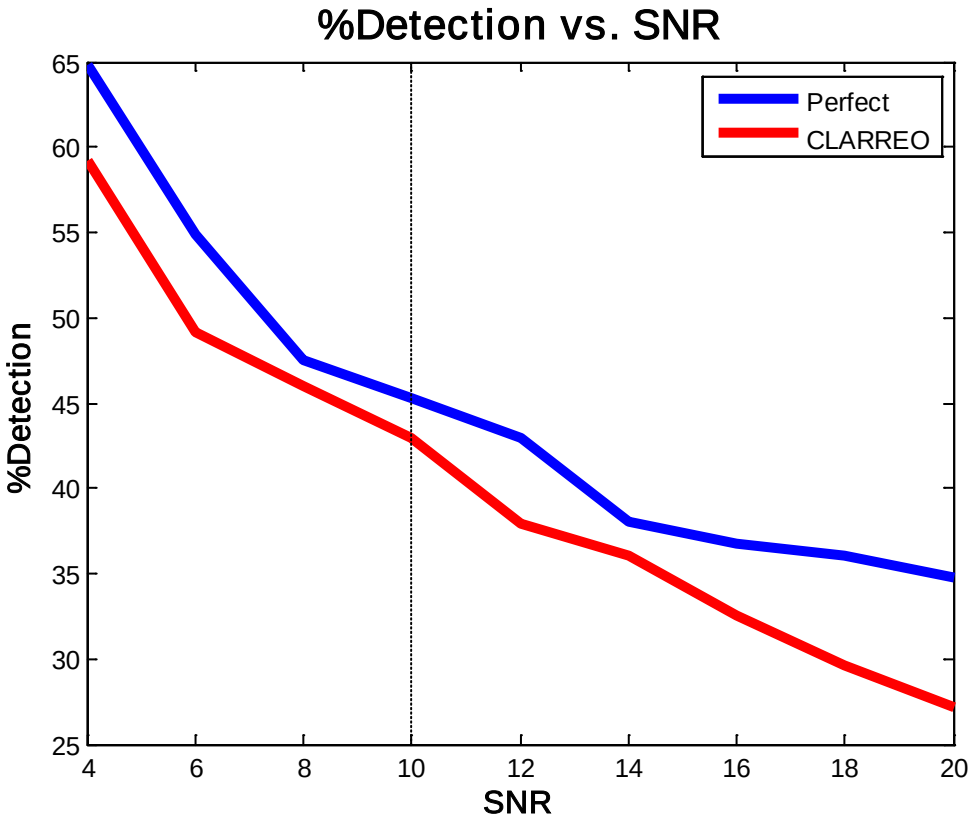
SNR: CO_2

Blue = Perfect, Red = CLARREO, Magenta = 10:1 SNR



%Detection of Perfect and CLARREO

- %Detection = Data with SNR ≥ threshold / Total data
- Total data = Number of data in all wavenumbers, all zones, and all effects that its radiance ≥ 0



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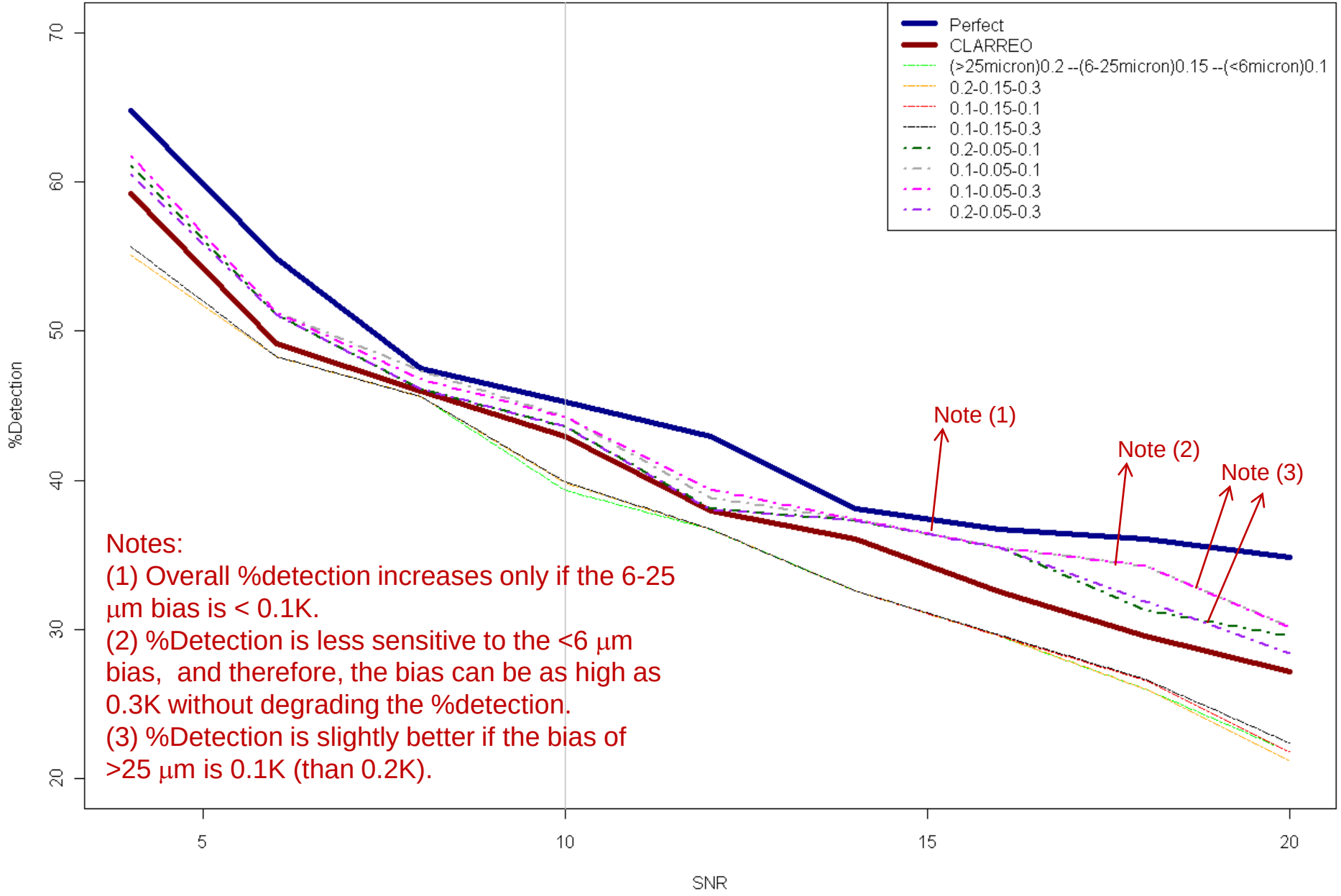
Outstanding questions

- Fingerprinting retrieval degradation measures
  - What are the right measures to achieve the objectives?
    - %Detection based on SNR
    - Time to detect trend
    - Others?
  - How do we know we achieve them?
    - Degradation (from Perfect) of %Detection $\leq X$
    - Degradation of time to detect trend $\leq Y$
    - Others?
- Counter-intuitive on no degradation on the retrieval spectra when instrument is not perfect.
- Signal shapes do not evolve over time?

Instrument Bias Exploration

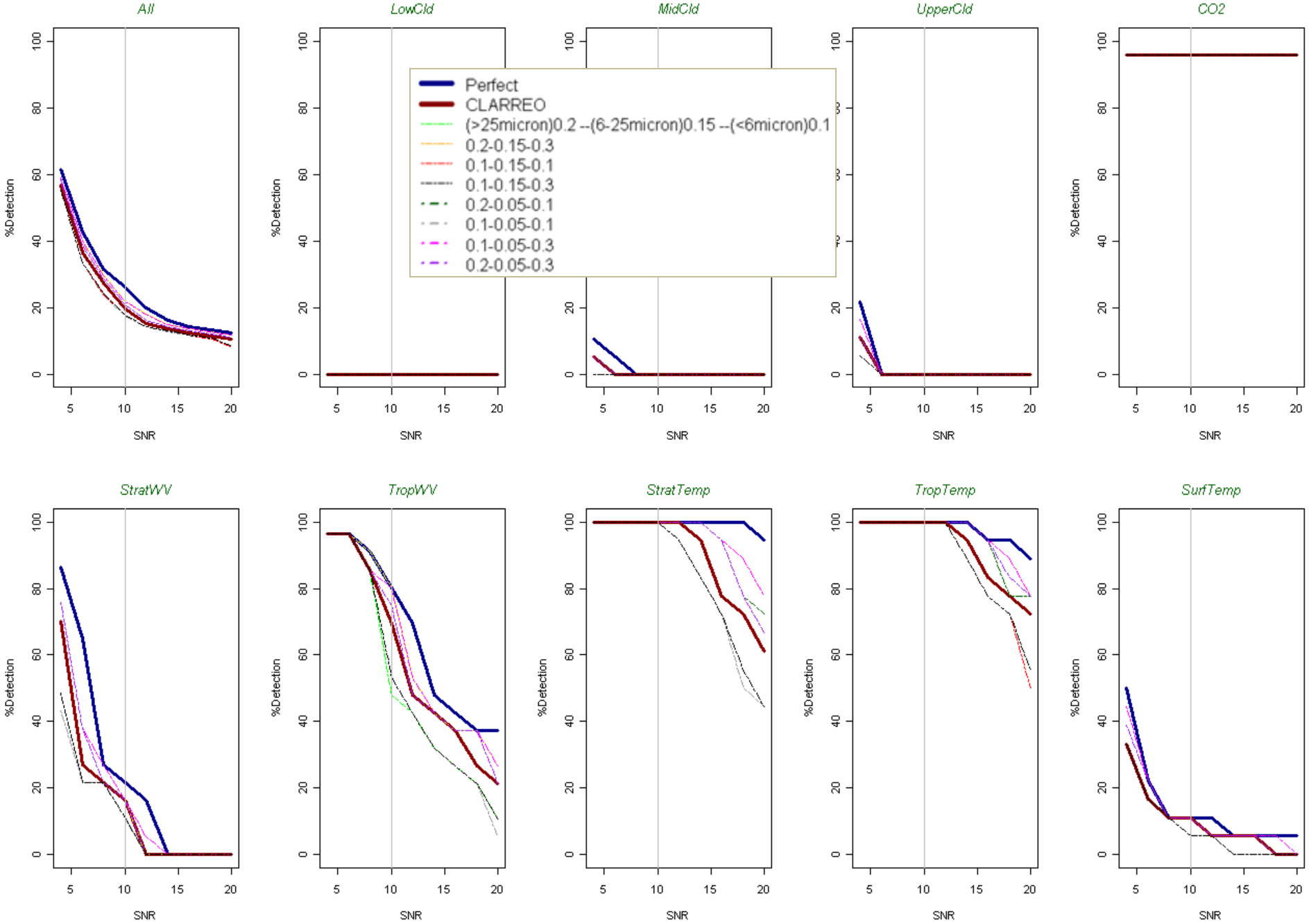
- Exploring the bias distributions of three ranges:
  - ❖ < 6 μm (1667-2760 cm^{-1}) = {0.1K, 0.3K}
  - ❖ 6 – 25 μm (400-1666 cm^{-1}) = {0.05K, 0.15K}
  - ❖ > 25 μm (50-399 cm^{-1}) = {0.1K, 0.2K}
    - ➢ For example, the bias distribution of (0.1K, 0.05K, 0.1K) for (< 6 μm, 6-25 μm, >25 μm), respectively.
    - ➢ Total of 8 distributions (2*2*2) are explored.

CCCMA - Percent Detection vs. SNR



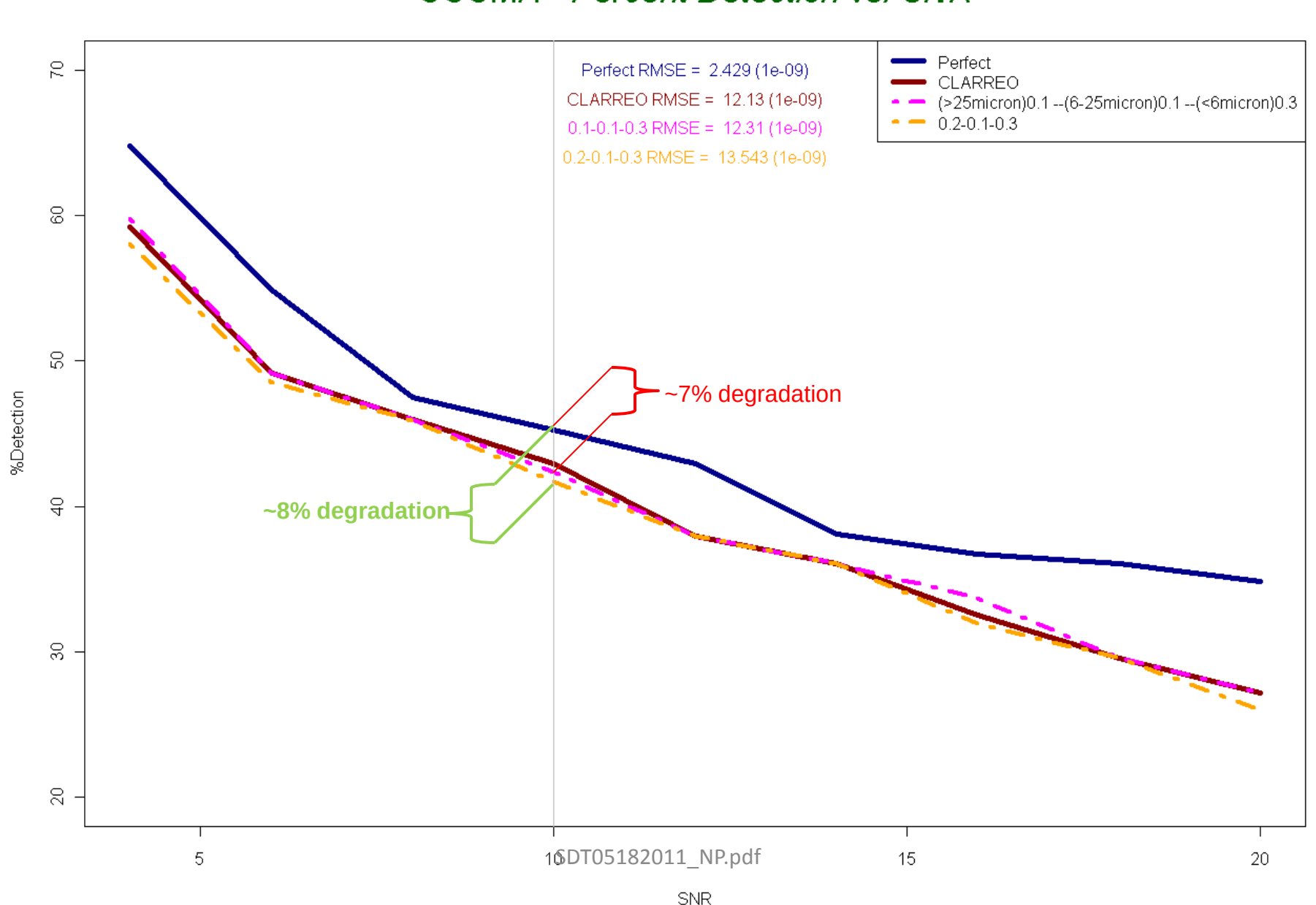
Notes:
(1) Overall %detection increases only if the 6-25 μm bias is < 0.1K.
(2) %Detection is less sensitive to the <6 μm bias, and therefore, the bias can be as high as 0.3K without degrading the %detection.
(3) %Detection is slightly better if the bias of >25 μm is 0.1K (than 0.2K).

%Detection by Effects (all zones combined)



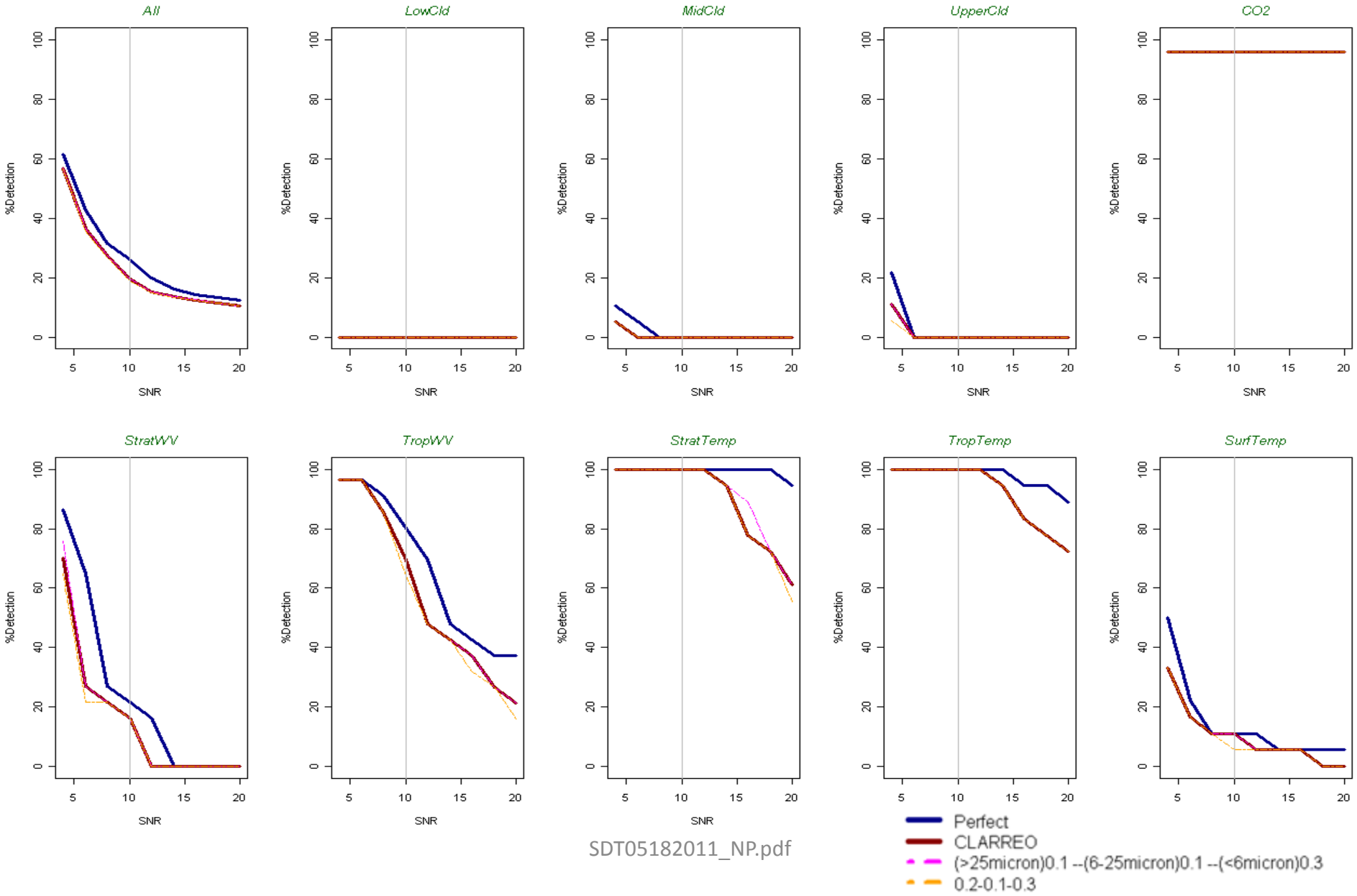
Run 2 additional bias distributions:

(>25, 6-25, <6μm) = (0.1, 0.1, 0.3) and (0.2, 0.1, 0.3)



%Detection by Effects (all zones combined)

%Detection of TropWV and SurfTemp effects can be degraded if >25 μm is 0.2K.



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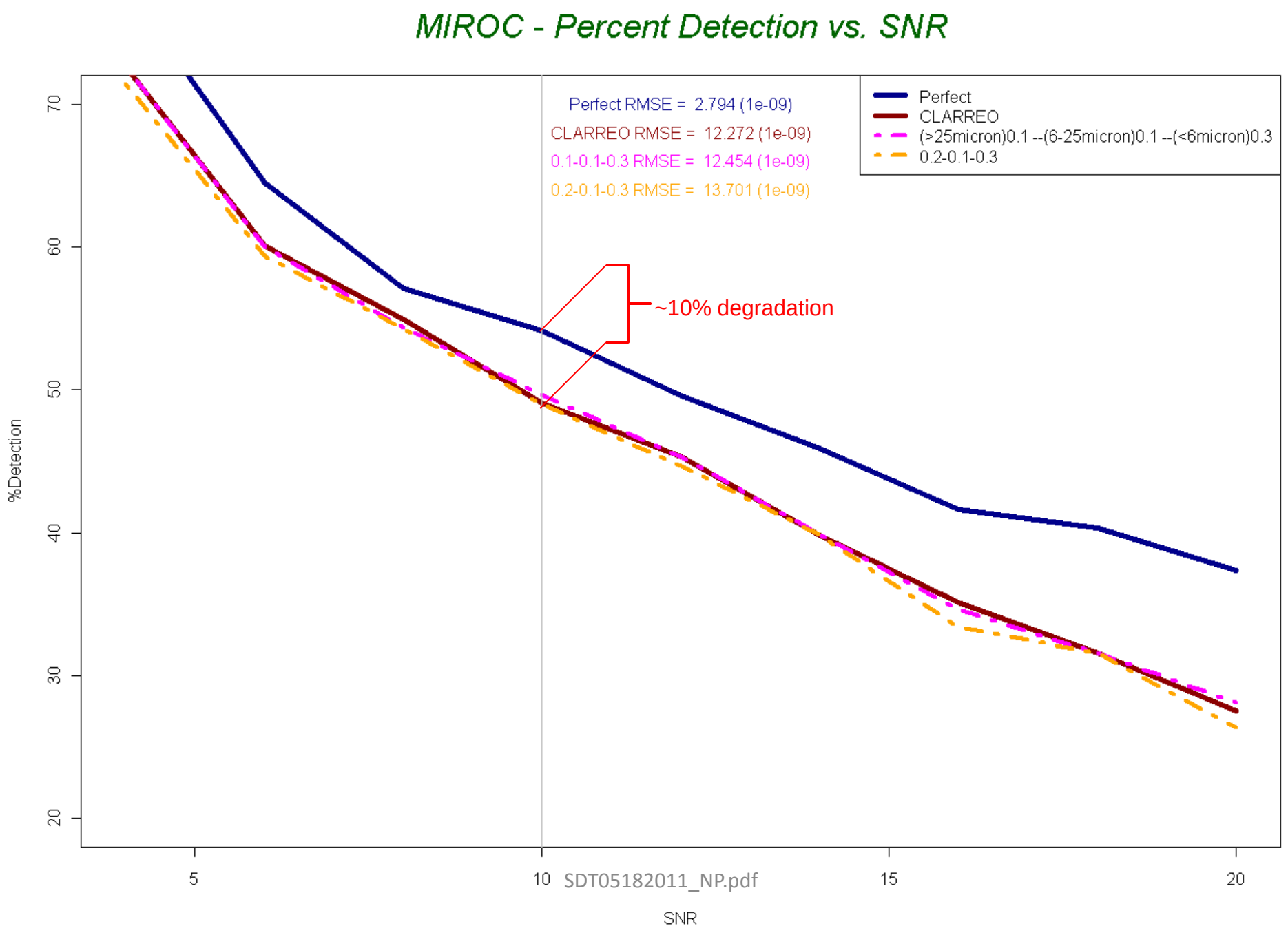
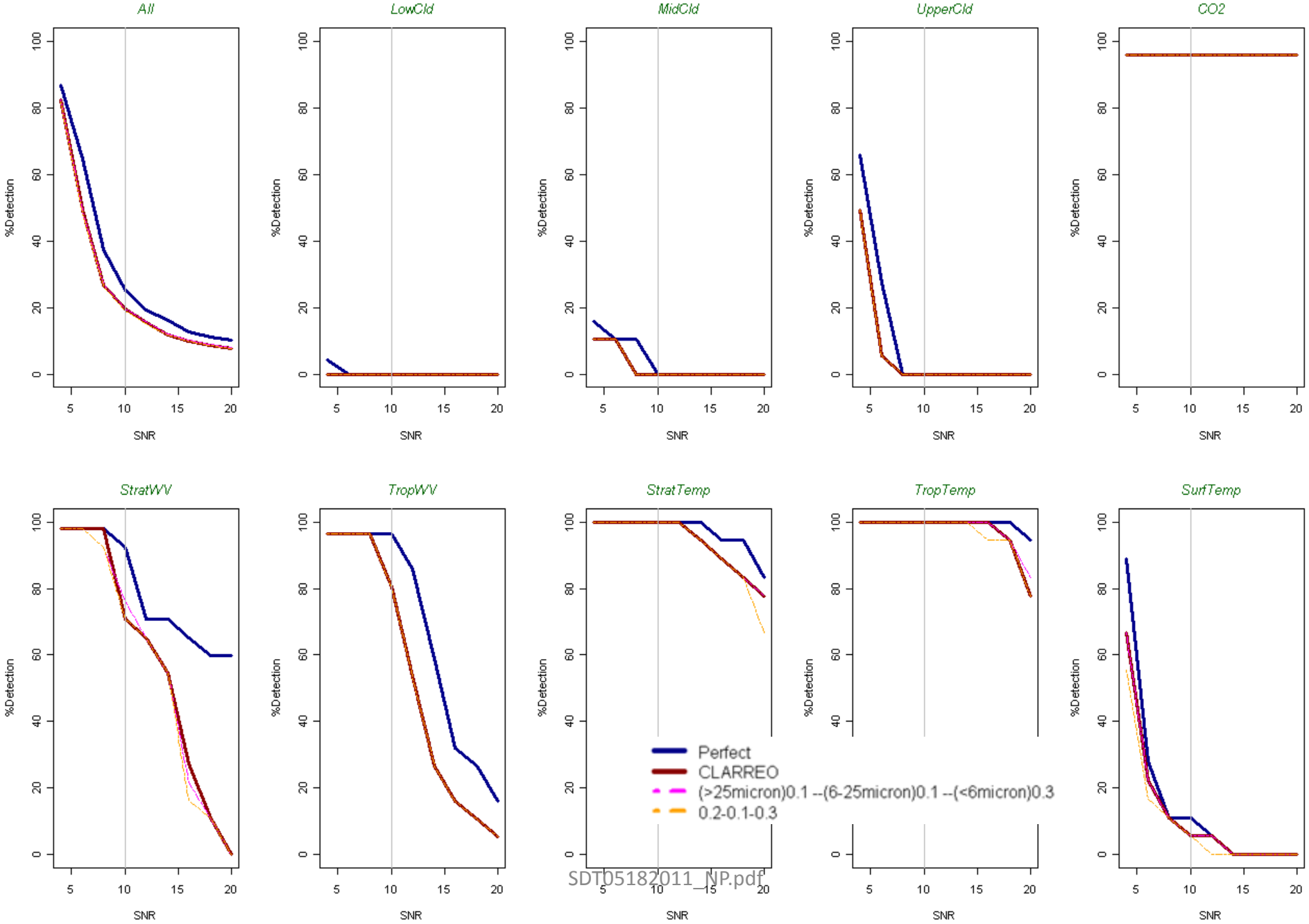
Repeat the analysis with MIROC dataset



MIROC - %Detection by Effects (all zones combined)



Conclusion/Next Steps

We have demonstrated a framework of applying fingerprinting (based on Huang et al. [2010]) to help defining IR systematic error distribution across the specified wavenumbers and scene temperatures that will still enable the retrieval of atmospheric spectra.

Next Steps

- Performance metrics definition.
- Counter-intuitive on no degradation on the retrieval spectra when instrument is not perfect.
- Signal shapes do not evolve over time?

BACK-UP

Datafiles (Huang et al. 2010)

Experiment name	Variable suppressed	Spectral radiance change	
co2	*CO2 (fixed at 280ppmv), r_{co2}*	$\delta R_{co2} = R(r_{co2},...) - R(\bar{r}_{co2},...)$	→ S_4
ts	*Surface temperature, T_S*	$\delta R_{T_S} = R(...,T_S,...) - R(...,\bar{T}_S,...)$	→ S_9
ta-trop	*Tropospheric temperature, T_{trop}*	$\delta R_{Ttrop} = R(...,T_{trop},...) - R(...,\bar{T}_{trop},...)$	→ S_8
ta-strat	*Stratospheric temperature, T_{strat}*	$\delta R_{Tstrat} = R(...,T_{strat},...) - R(...,\bar{T}_{strat},...)$	→ S_7
hus-trop	*Tropospheric water vapor; q_{trop}*	$\delta R_{qtrop} = R(...,q_{trop},...) - R(...,\bar{q}_{trop},...)$	→ S_6
hus-strat	*Stratospheric water vapor; q_{strat}*	$\delta R_{qstrat} = R(...,q_{strat},...) - R(...,\bar{q}_{strat},...)$	→ S_5
cld-lowertrop	*Lower tropospheric cloud, C_{low}*	$\delta R_{Clow} = R(...,C_{low},...) - R(...,\bar{C}_{low},...)$	→ S_1
cld-midtrop	*Middle tropospheric cloud, C_{mid}*	$\delta R_{Cmid} = R(...,C_{mid},...) - R(...,\bar{C}_{mid},...)$	→ S_2
cld-uppertrop	*Upper tropospheric cloud, C_{hgh}*	$\delta R_{Chgh} = R(...,C_{hgh}) - R(...,\bar{C}_{hgh})$	→ S_3
all	*All variables – total signal*	$\delta R_{total} = R(r_{co2},T_S,T_{trop},T_{strat},q_{trop},q_{strat},C_{low},C_{mid},C_{hgh}) -$ $R(\bar{r}_{co2},\bar{T}_S,\bar{T}_{trop},\bar{T}_{strat},\bar{q}_{trop},\bar{q}_{strat},\bar{C}_{low},\bar{C}_{mid},\bar{C}_{hgh})$	→ y

$$\delta OLR_x = \pi \int \delta R_x \, d\upsilon$$

$$\delta R_x = S_x$$

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Perfect instrument

y

Known
S1 – S9

Fingerprint

$y = Sa + \varepsilon$

$a = (S^T \Sigma^{-1} S)^{-1} S^T \Sigma^{-1} y$

$\Sigma = \Sigma_{nat} + \Sigma_{shape} + \Sigma_{nl}$

$\varepsilon \sim N(0, \Sigma)$

$\hat{y},\ S_1\hat{a}_1,\ \ldots,\ S_9\hat{a}_9,\ \mathrm{FE}$

$y = S_1 a_1 + \ldots + S_9 a_9 + \varepsilon$

Estimated by

$\hat{y} = S_1\hat{a}_1 + \ldots + S_9\hat{a}_9$

Fitting Error (FE) = y-$\hat{y}$

CLARREO instrument

$y_{(CLARREO)}$ = y + R(0.2K)

Known
S1 – S9

Fingerprint

$y_c = Sa_c + \varepsilon_c$

$a_c = (S^T \Sigma_c^{-1} S)^{-1} S^T \Sigma_c^{-1} y_c$

$\Sigma_c = \Sigma'_{nat} + \Sigma_{shape} + \Sigma'_{nl}$

$\varepsilon_c \sim N(0, \Sigma_c)$

$\hat{y}_{(CLARREO)},\ S_1\hat{a}_{1(C)},\ \ldots,\ S_9\hat{a}_{9(C)},\ \mathrm{FE}_{(C)}$

$y_{(CLARREO)} = S_1 a_{1(C)} + \ldots + S_9 a_{9(C)} + \varepsilon_{(C)}$

Estimated by

$\hat{y}_{(CLARREO)} = S_1\hat{a}_{1(C)} + \ldots + S_9\hat{a}_{9(C)}$

$\mathrm{FE}_{(C)} = y_{(CLARREO)} - \hat{y}_{(CLARREO)}$

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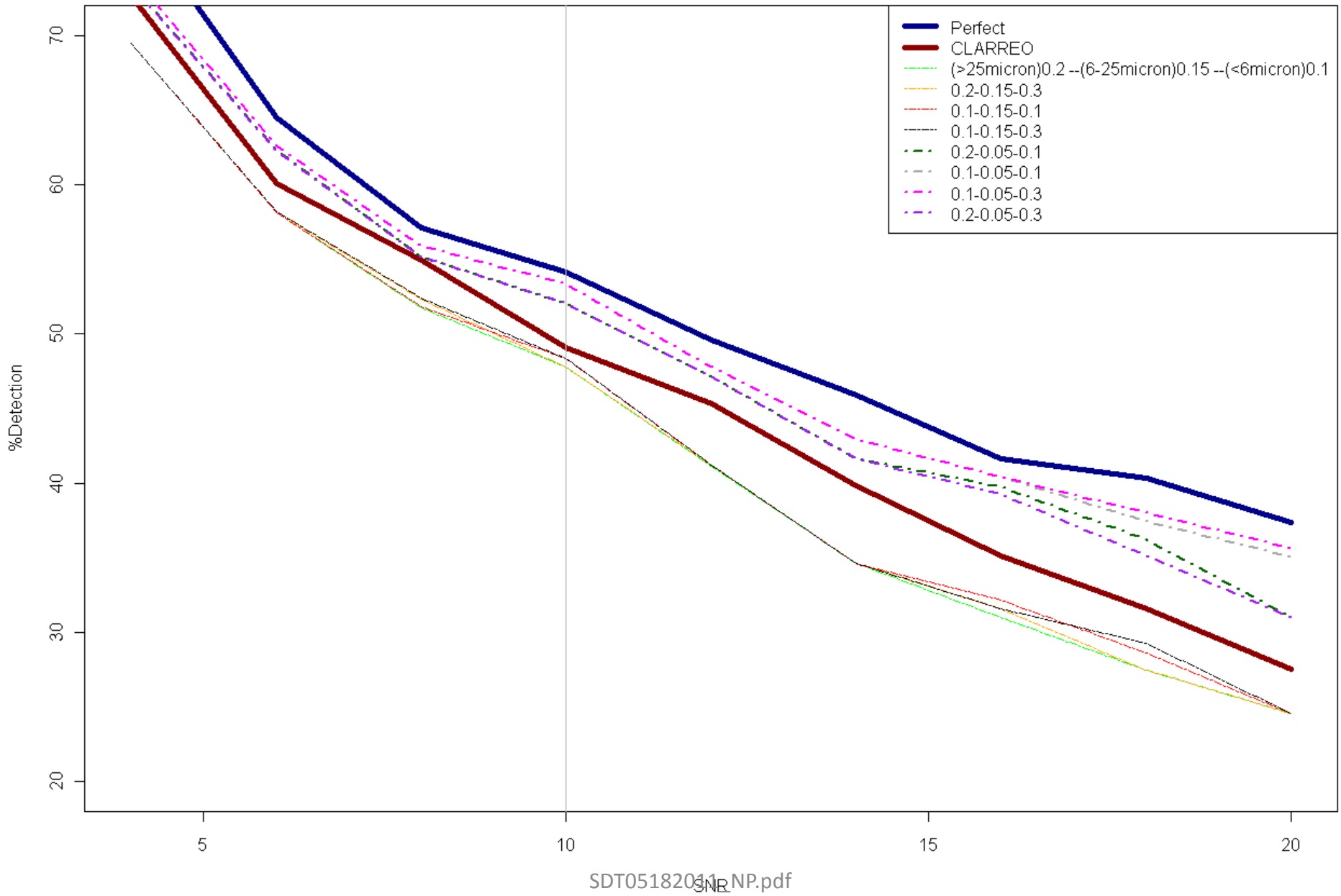
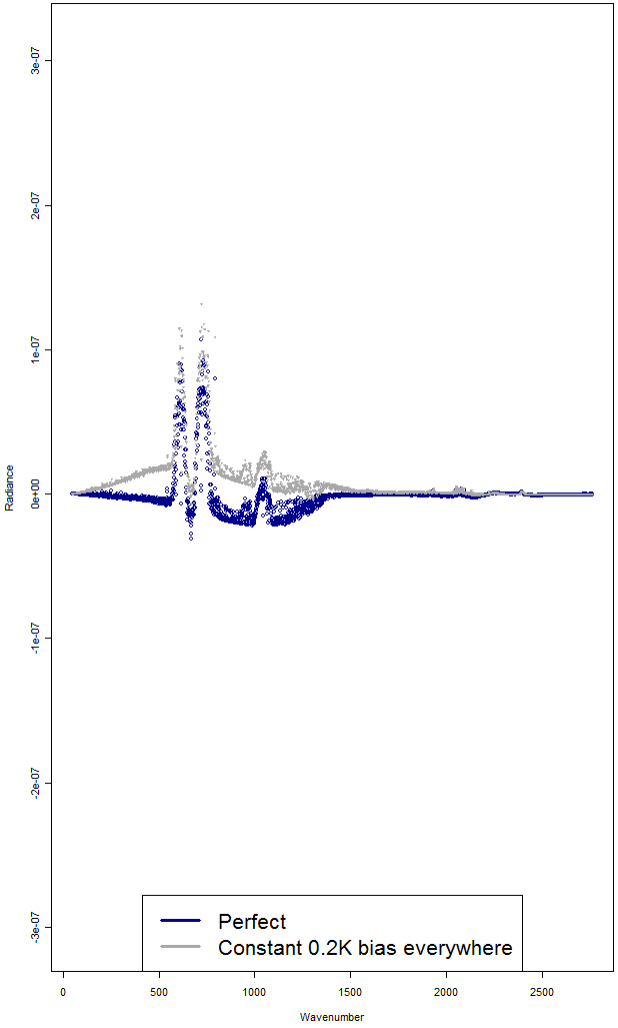
Let $\Delta\mathrm{FE} = \mathrm{FE}_{(C)} - \mathrm{FE} = y_{(CLARREO)} - \hat{y}_{(CLARREO)} - y + \hat{y} \approx y_{(CLARREO)} - y \approx R(0.2K)$

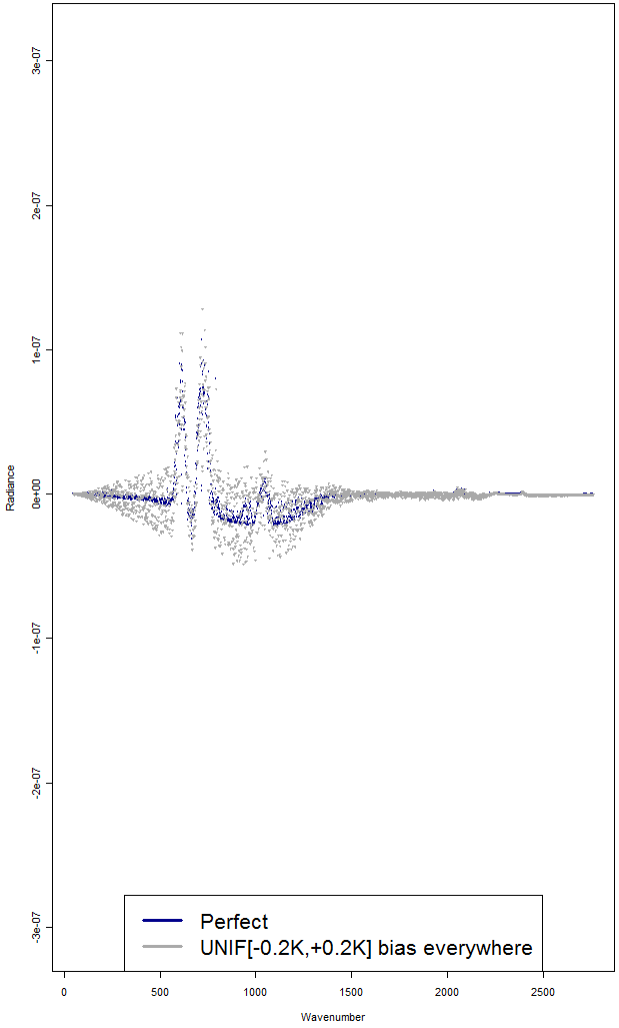
MIROC - Percent Detection vs. SNR



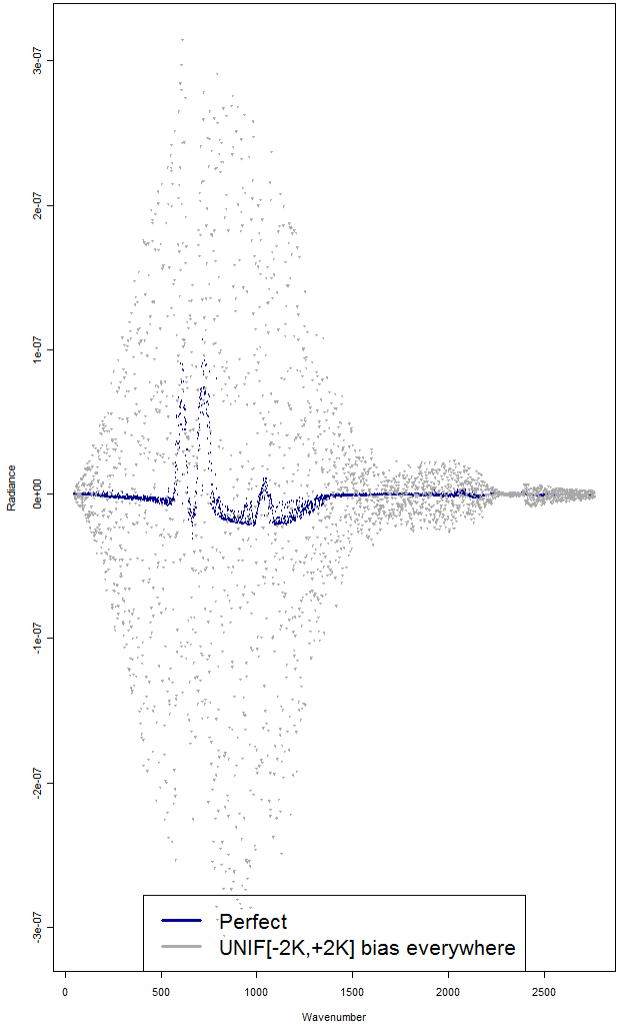
Measurement Data - Zone 10



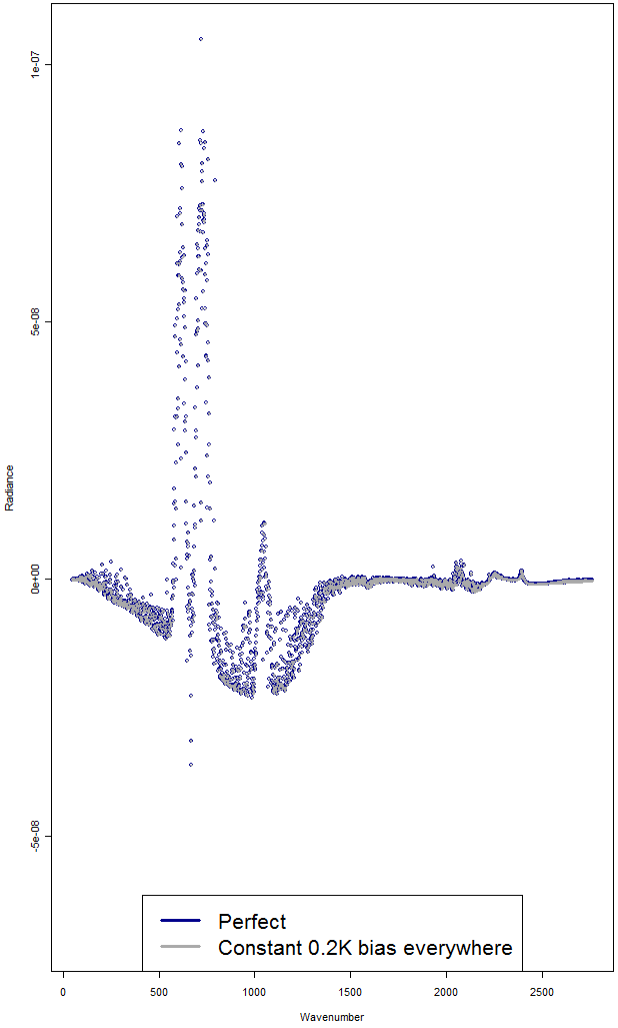
Measurement Data - Zone 10



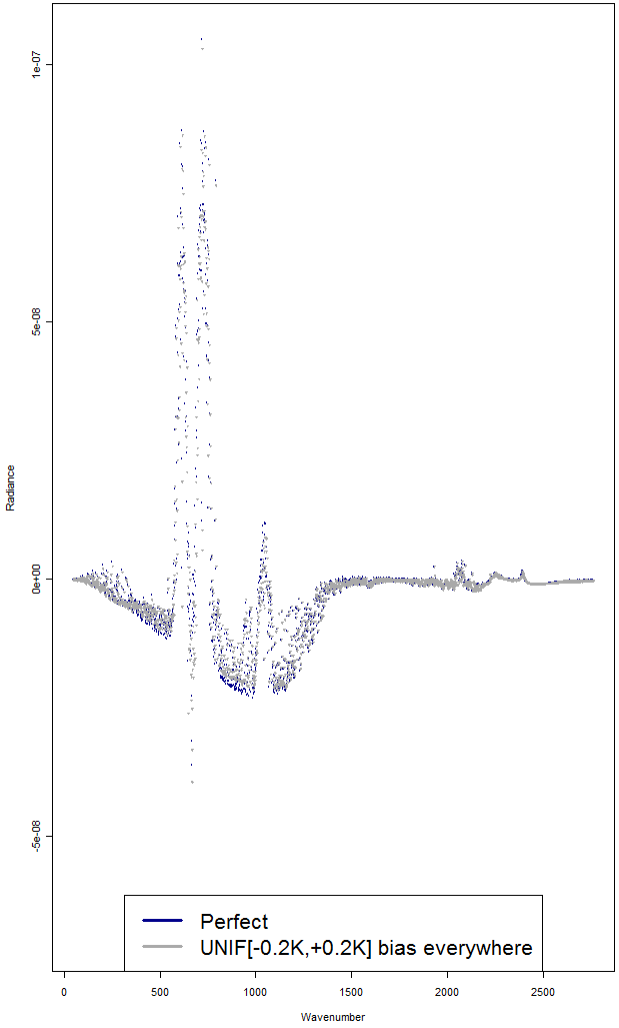
Measurement Data - Zone 10



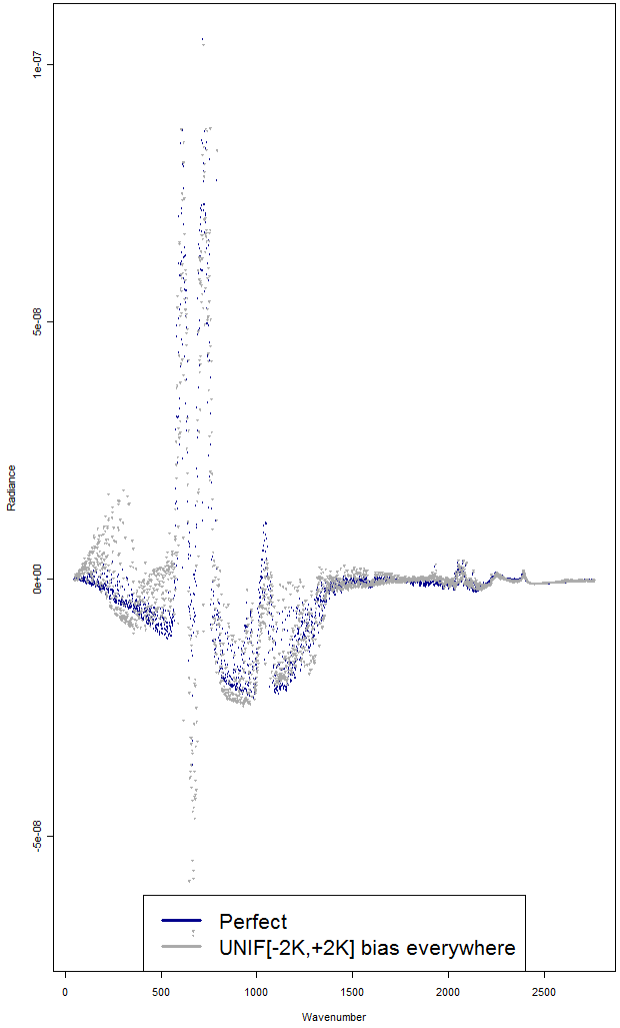
Perturbed All Retrieval - Zone 10

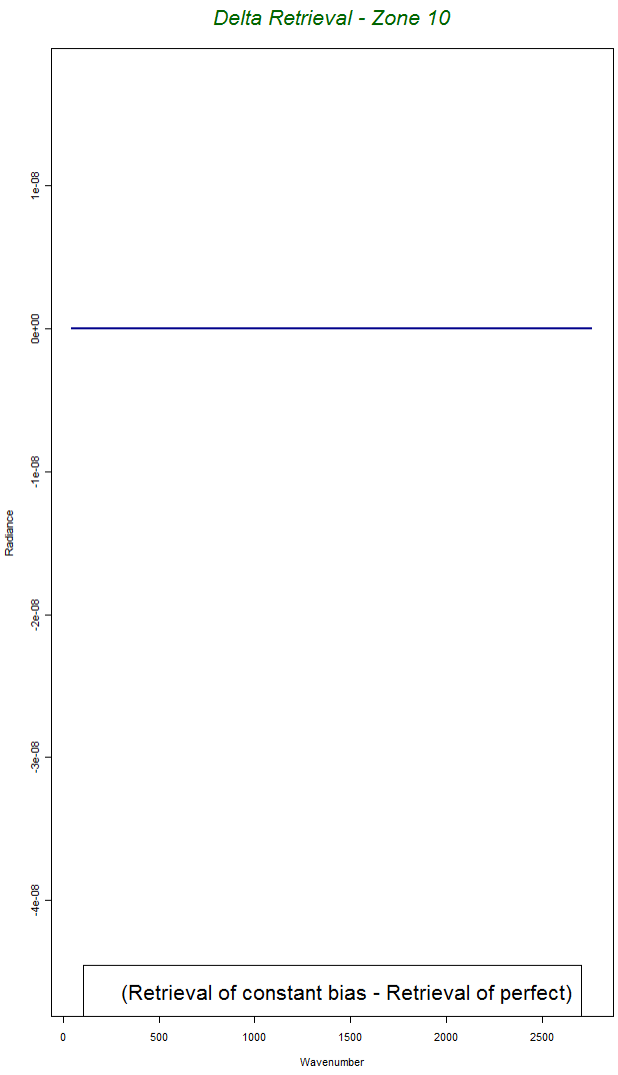


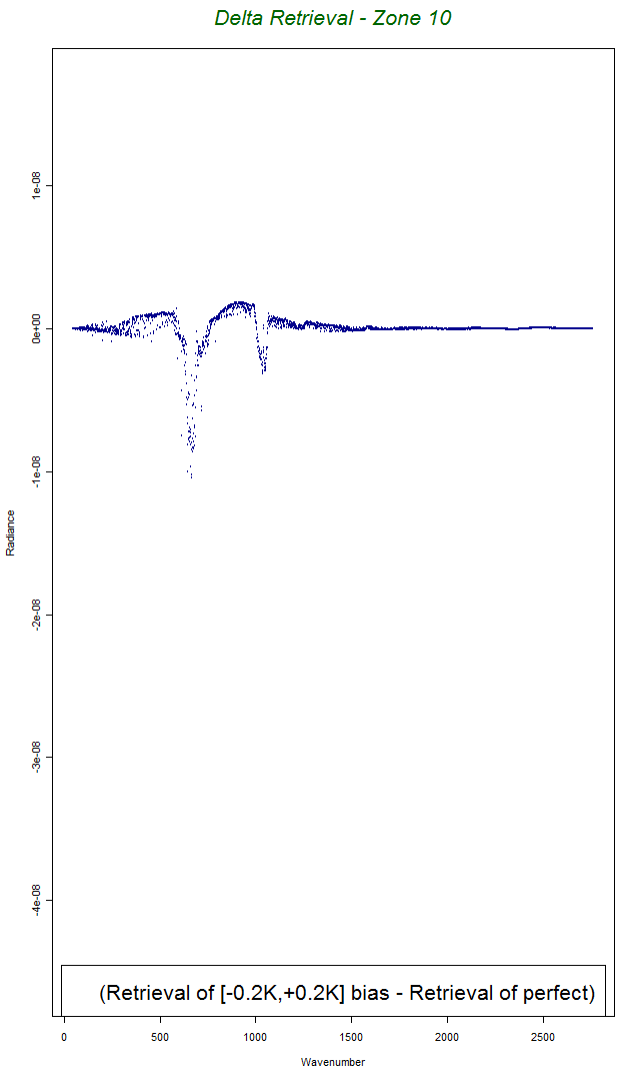
Perturbed All Retrieval - Zone 10

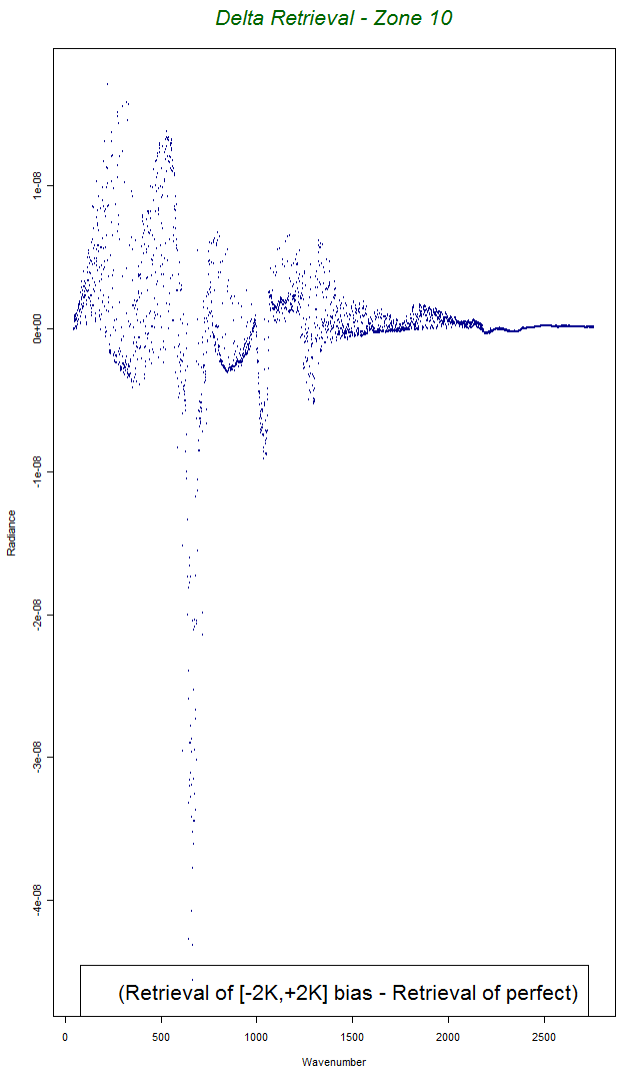


Perturbed All Retrieval - Zone 10




Delta Retrieval - Zone 10
Radiance
1e-08
0e+00
-1e-08
-2e-08
-3e-08
-4e-08
0
500
1000
1500
2000
2500
Wavenumber
(Retrieval of constant bias - Retrieval of perfect)


Delta Retrieval - Zone 10
Radiance
1e-08
0e+00
-1e-08
-2e-08
-3e-08
-4e-08
0
500
1000
1500
2000
2500
Wavenumber
(Retrieval of [-0.2K,+0.2K] bias - Retrieval of perfect)


Delta Retrieval - Zone 10
Radiance
1e-08
0e+00
-1e-08
-2e-08
-3e-08
-4e-08
0
500
1000
1500
2000
2500
Wavenumber
(Retrieval of [-2K,+2K] bias - Retrieval of perfect)