In situ verification of MFRSR's and RSS cosine responses via collocated NIMFR - Can we do it?

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Calibrating MFRSR via Langley regression: angular response effects

Signal form MFRSR

$$S = R \cdot \cos(\theta) \cdot A(m,\phi) \frac{I_0}{r^2} \exp(-\tau \cdot m) \qquad \frac{S}{\cos(\theta)} r^2 = V = V_0 \cdot A(m,\phi) \exp(-\tau \cdot m)$$

$$\ln\left(\frac{V}{A(m,\phi)}\right) \overset{def}{=} \ln\left(V_0\right) - \tau \cdot m$$

Calibration via Langley

$$\ln\left(\frac{V}{\hat{A}(m,\phi)}\right) \overset{fit}{=} \ln\left(\hat{V}_0\right) - \hat{\tau} \cdot m \qquad A(m,\phi) \neq \hat{A}(m,\phi) \quad \Rightarrow \quad \hat{V}_0 = V_0 + \Delta V_0$$

Optical depth retrieval

$$\bar{\tau} = -\frac{1}{m} \ln\left(\frac{V}{\hat{V}_0 \cdot \hat{A}(m,\phi)}\right) = \tau + \Delta\tau$$

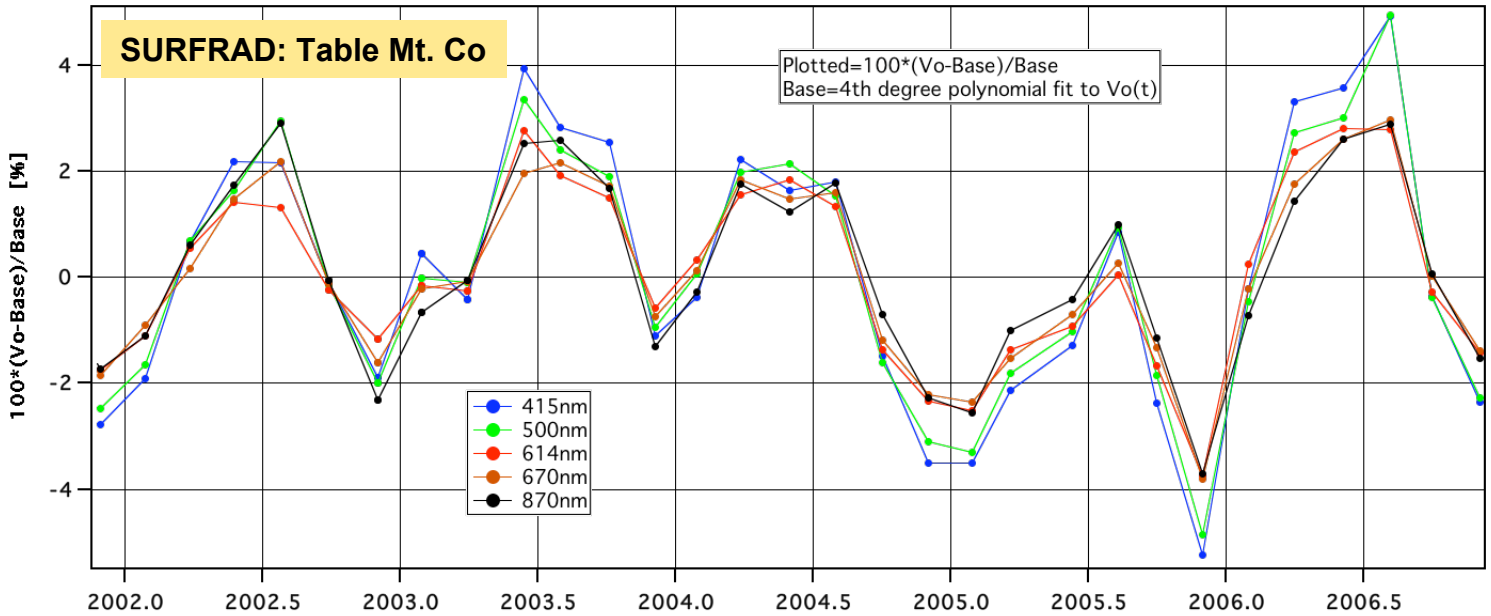
$$(1) \qquad \Delta V_0 \propto \Delta R \quad \Rightarrow \quad \Delta\tau = 0$$

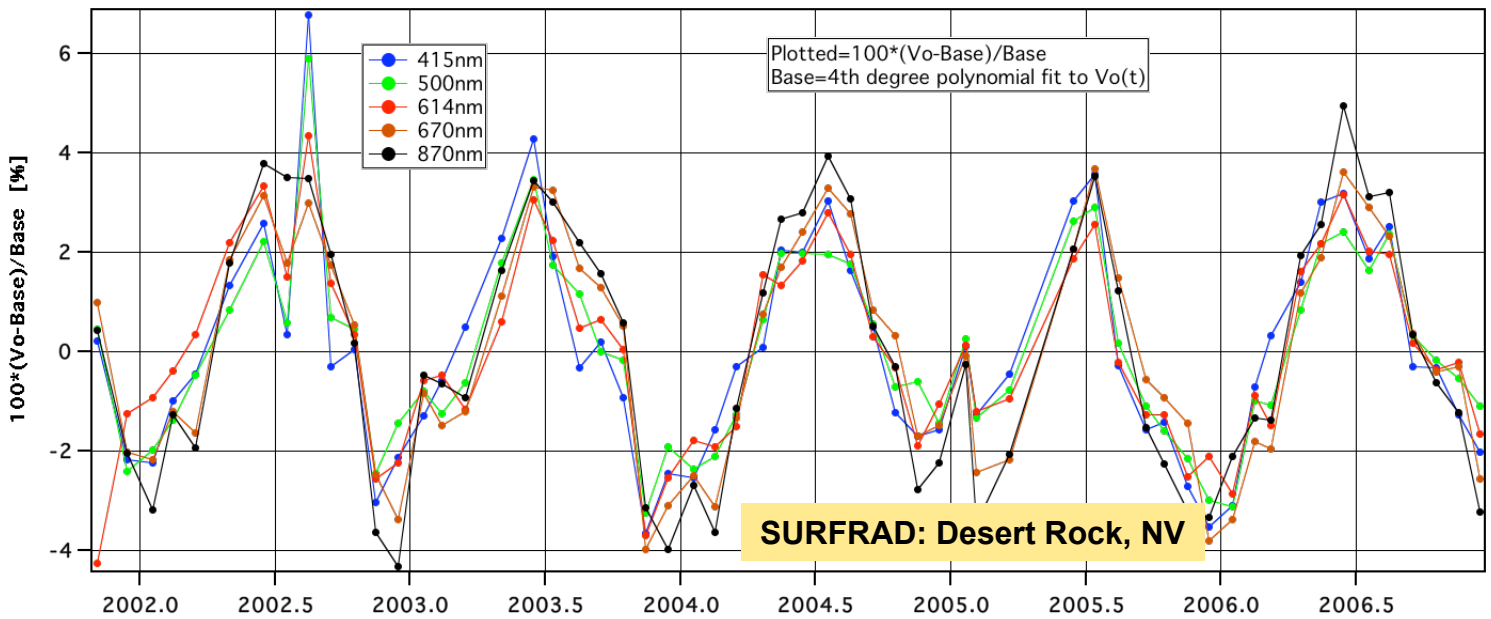
$$(2) \qquad \Delta V_0 \Leftarrow \{A(m,\phi) \neq \hat{A}(m,\phi)\} \quad \Rightarrow \quad \Delta\tau \neq 0$$

The problem

How can we detect and separate cases (1) and (2) ?
And when it does and when it does not matter?

Seasonal Variation of Vo's in MFRSR's





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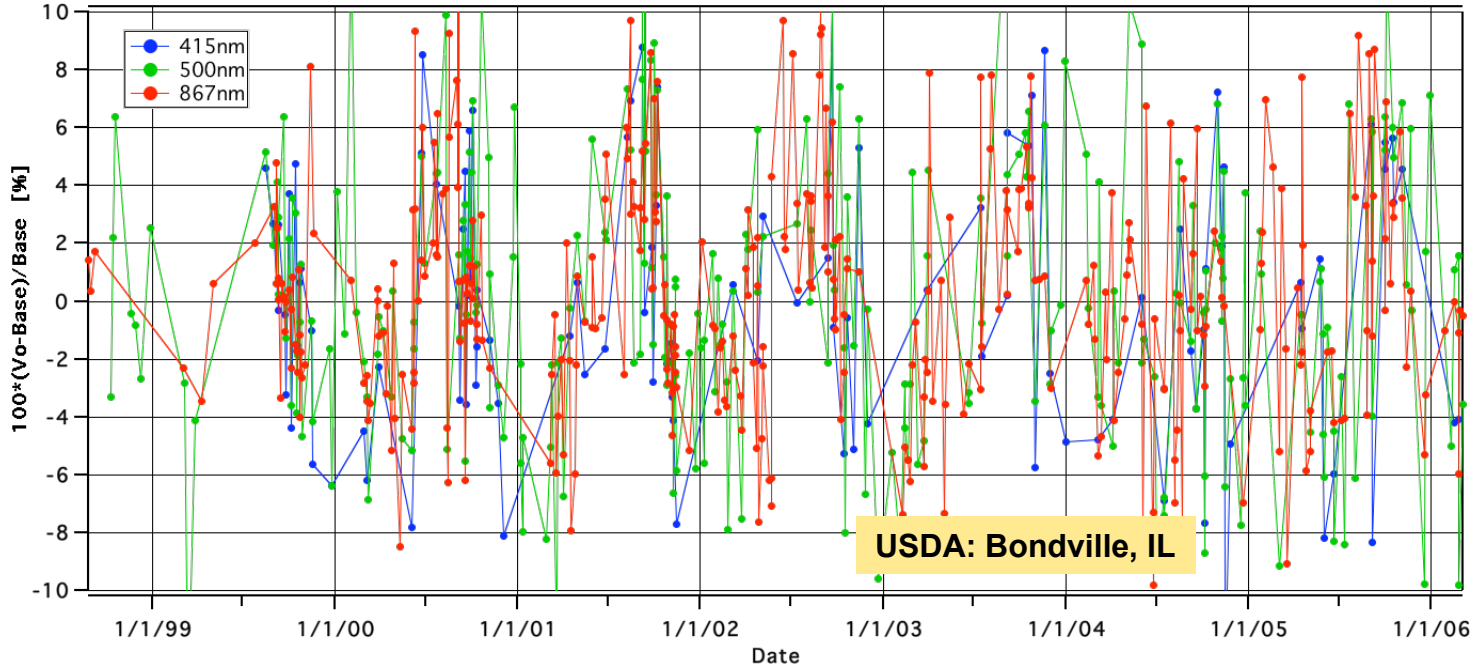
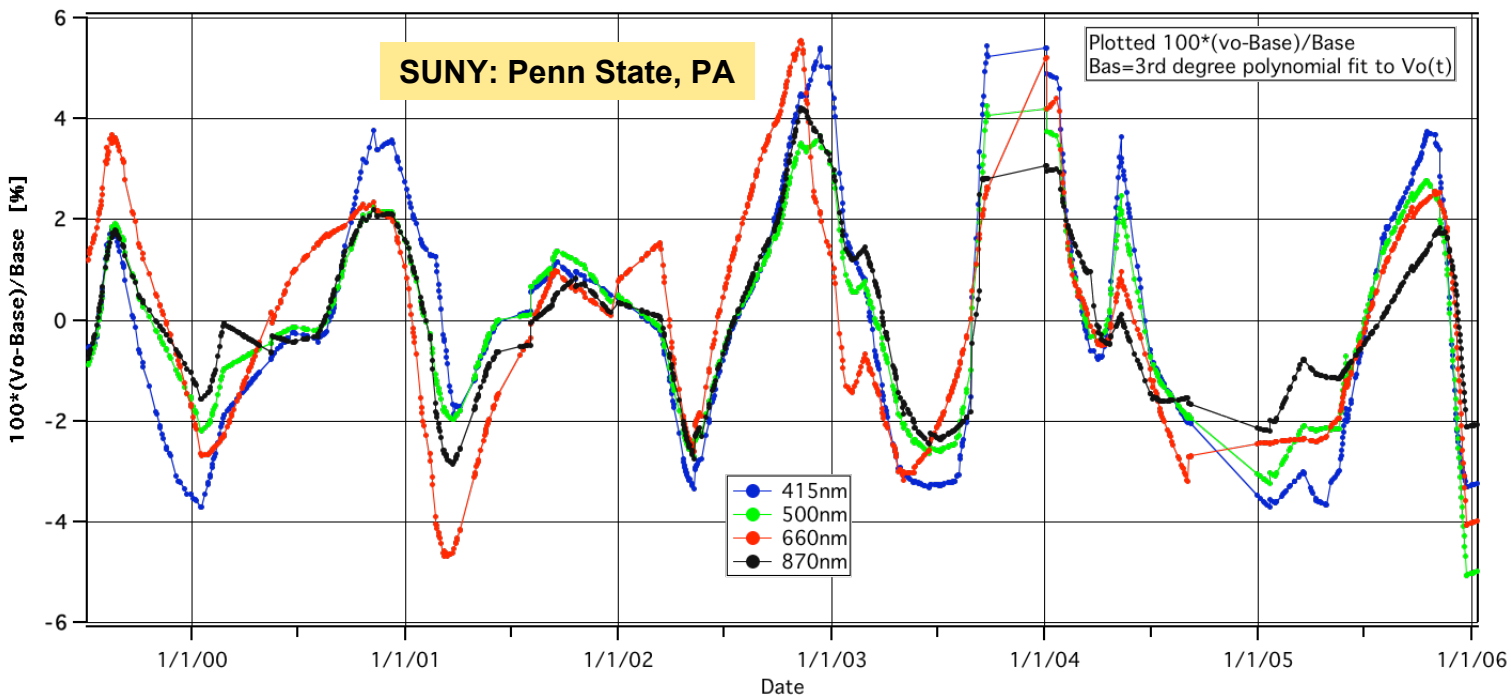
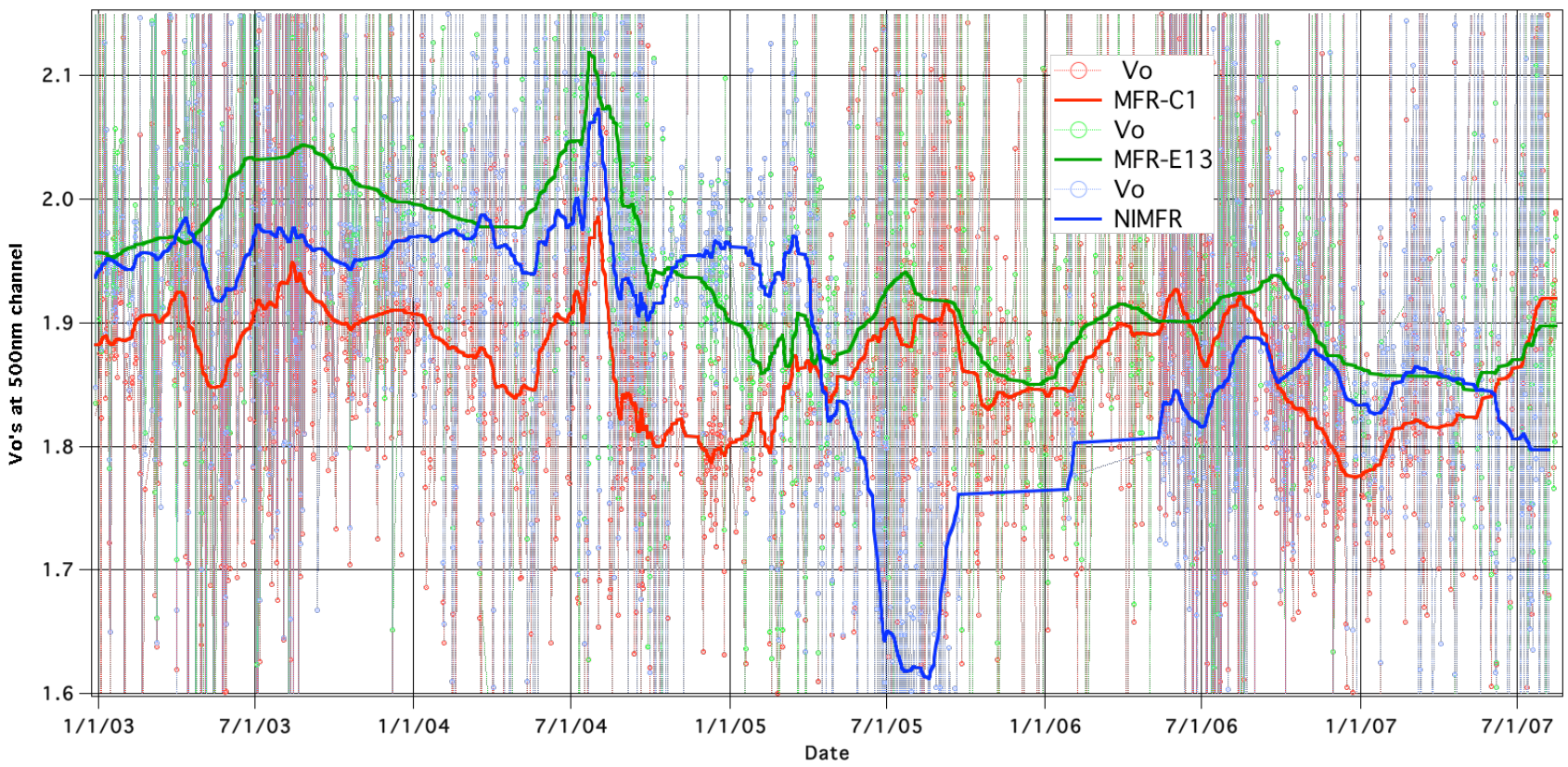
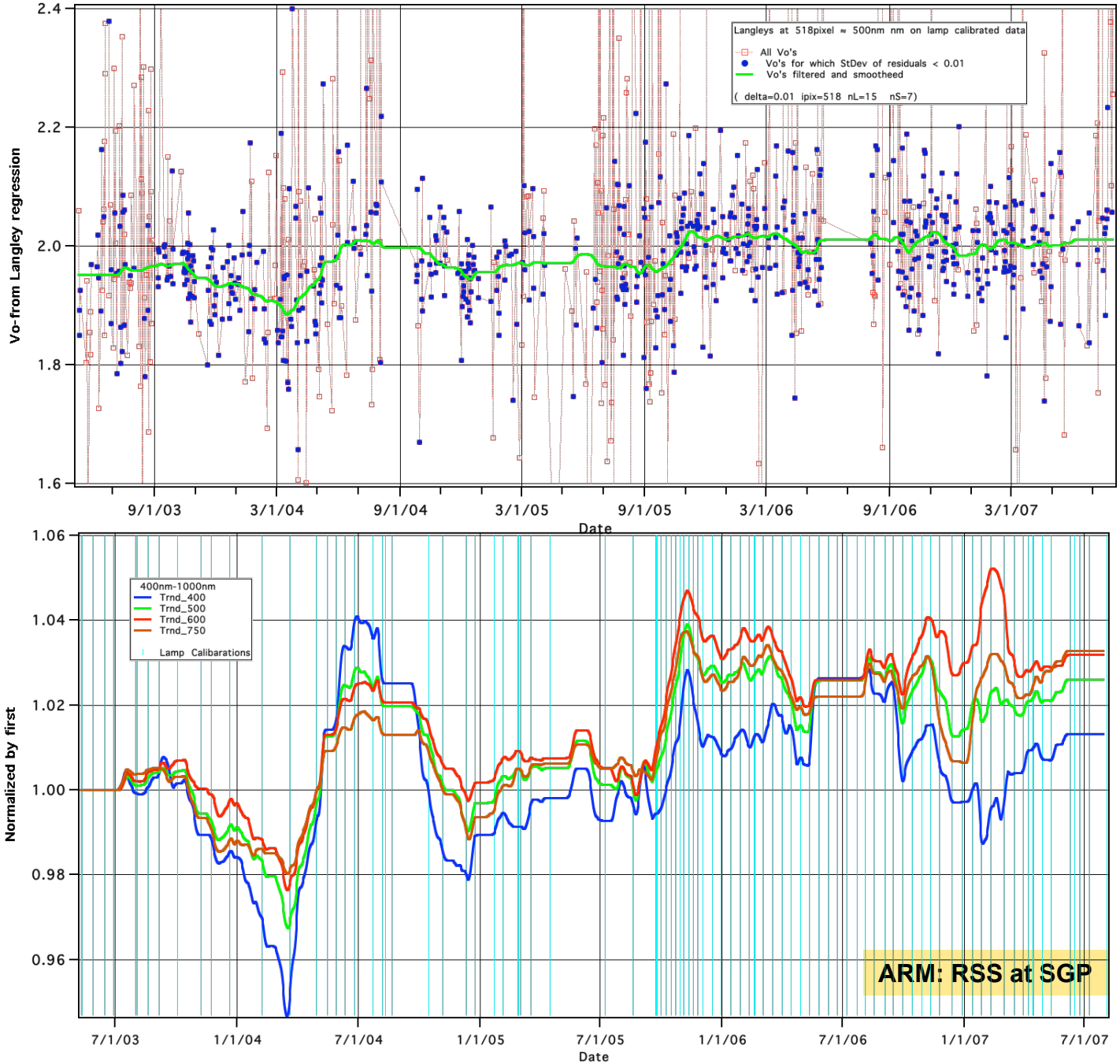




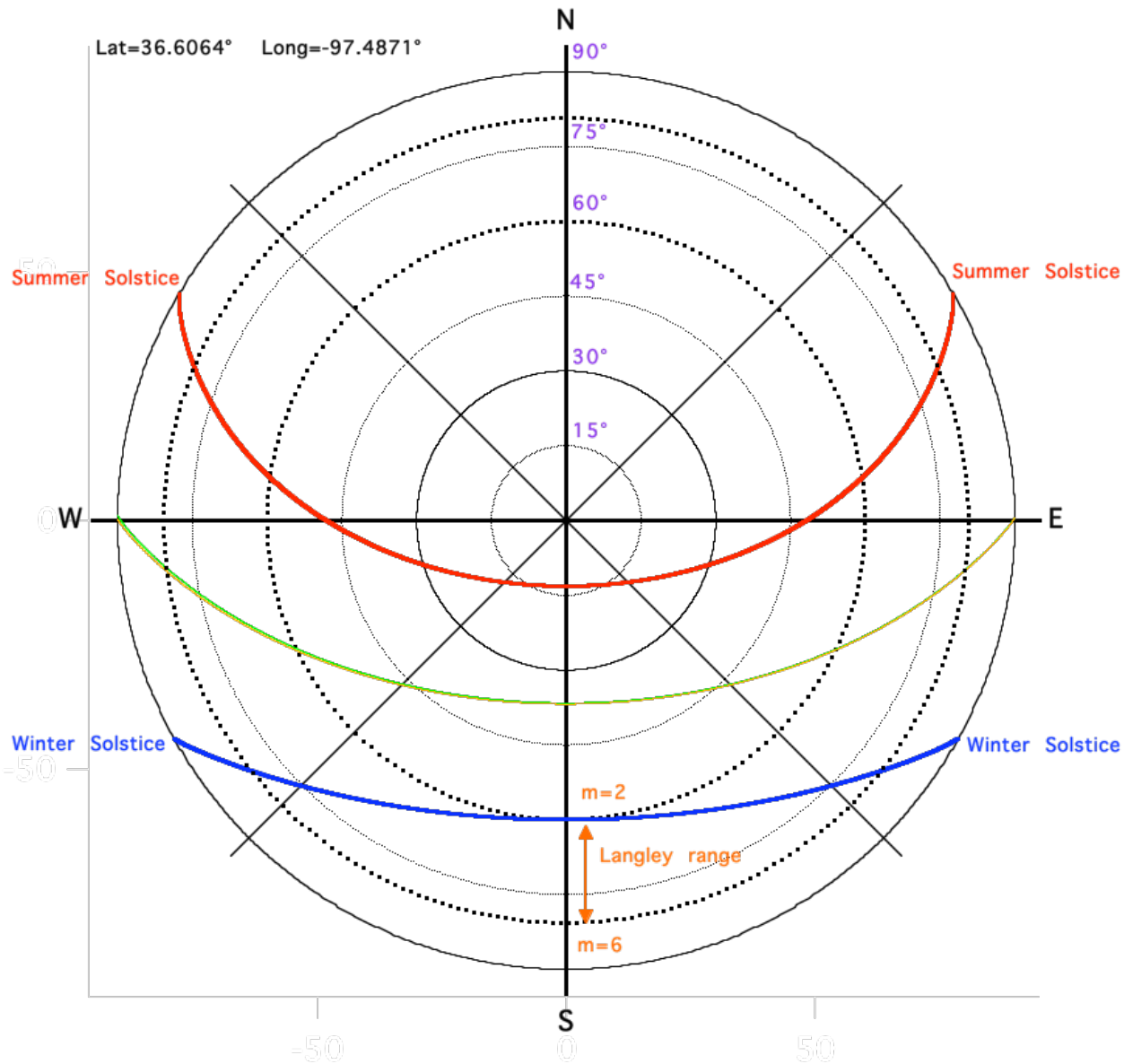
Seasonal Variation of Vo's at SGP



RSS: Seasonal Variation of Vo's at SGP



Winter and Summer Sun trajectories at SGP



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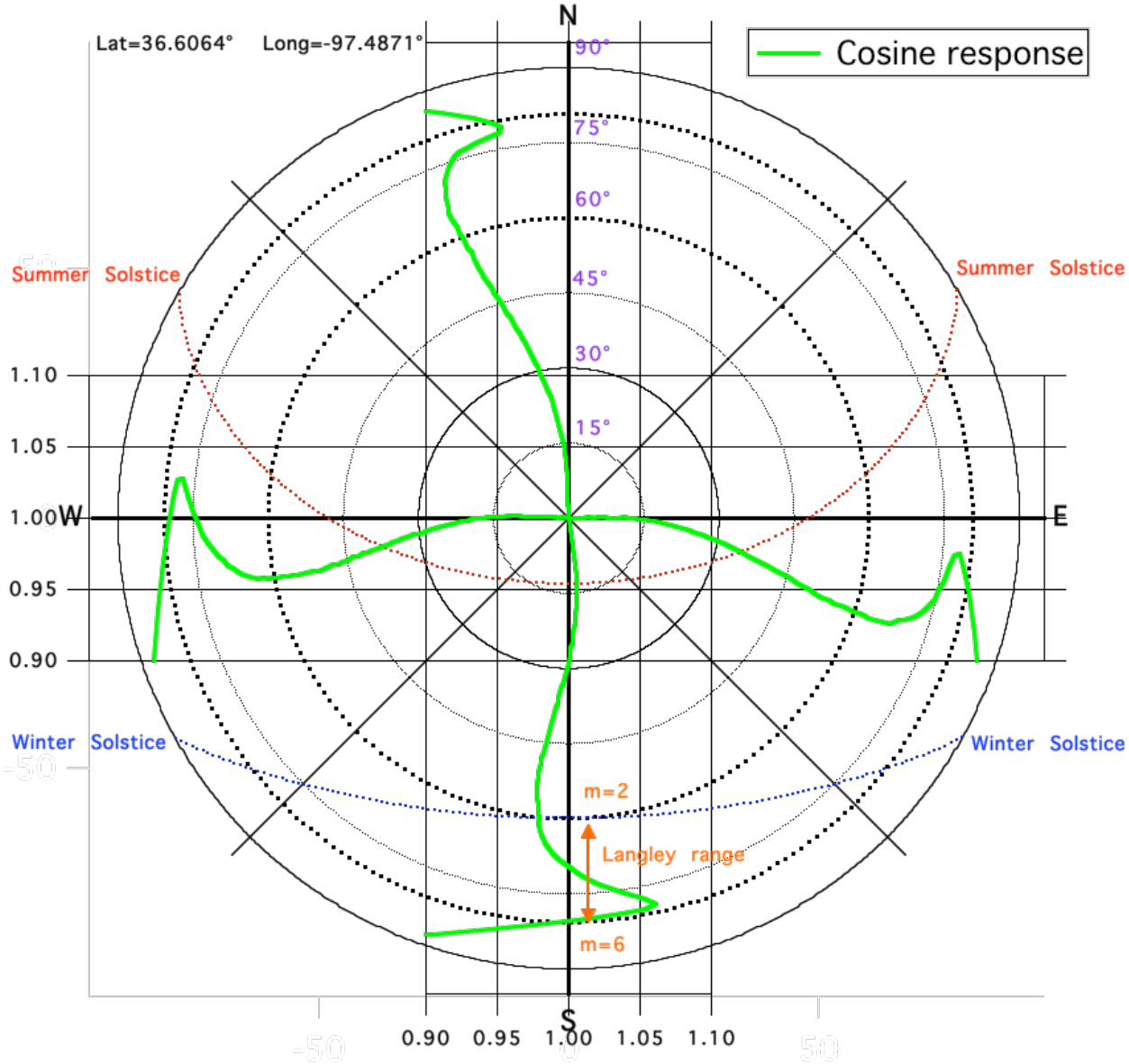
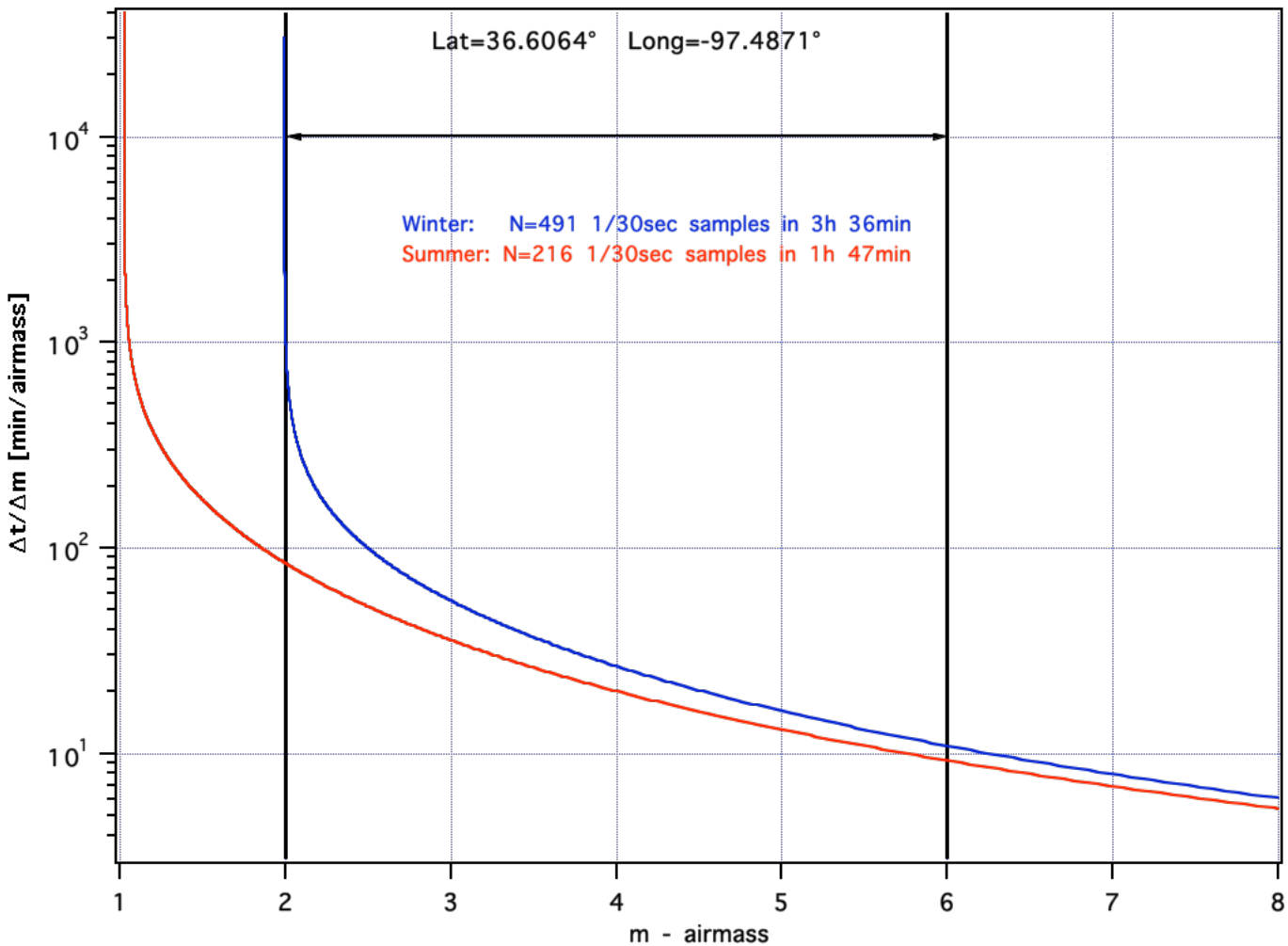
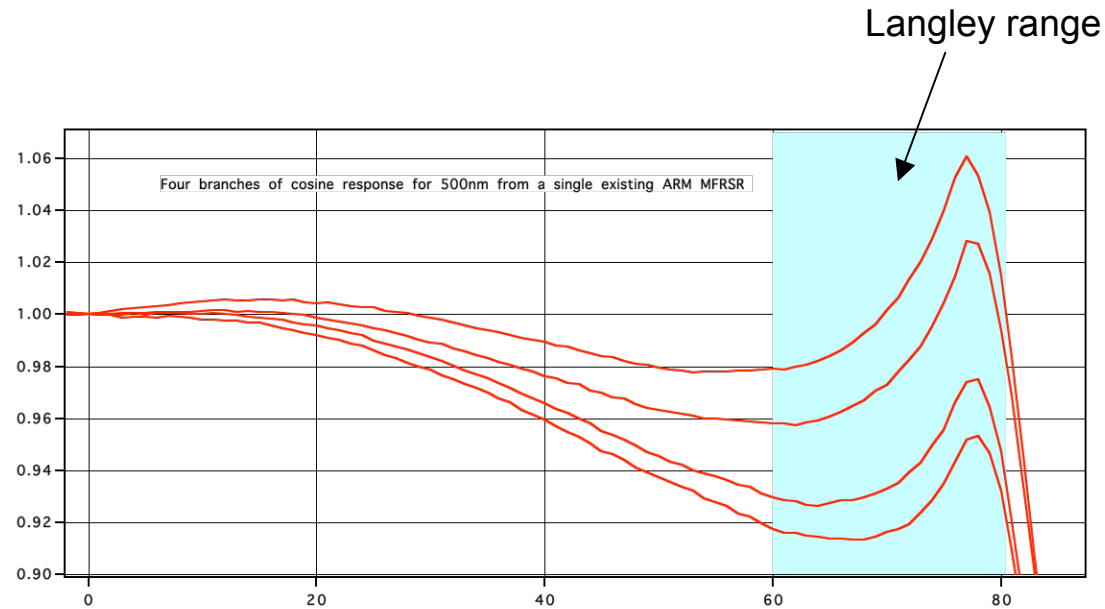


Duration and number of samples in Langley plot in Winter and Summer

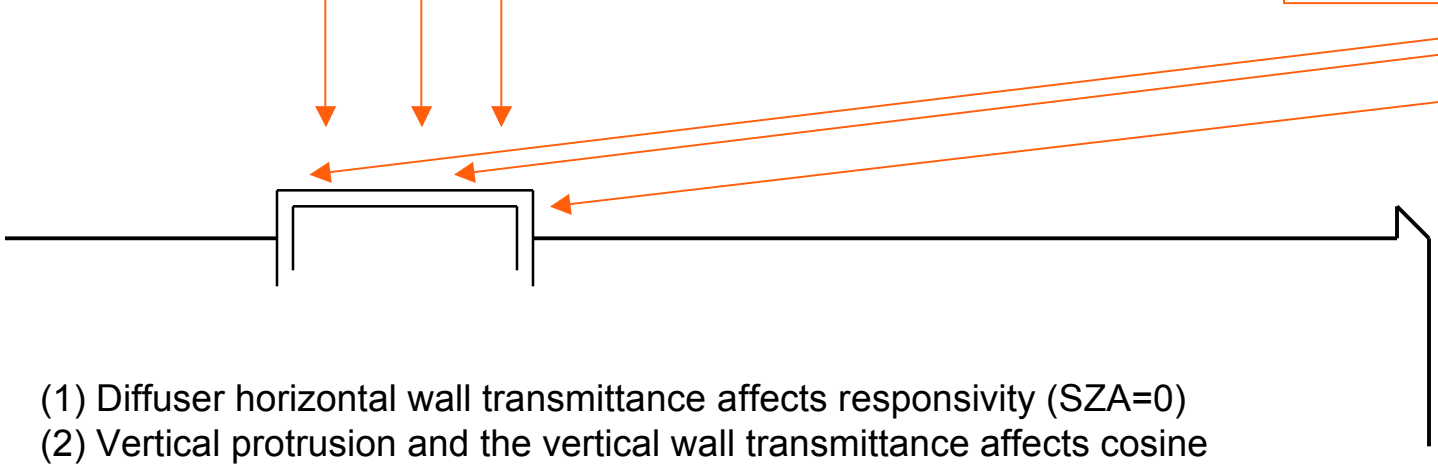


What makes a cosine response?



R^{mfr} *for* $SZA = 0$
Vo *from* $Langley$

$A(m,\phi)$ *when* $SZA \rightarrow 70°$



(1) Diffuser horizontal wall transmittance affects responsivity (SZA=0)
(2) Vertical protrusion and the vertical wall transmittance affects cosine response for large SZA

Angular response change that does not affect Langley plot

Case of perfect Langley plot

$$\ln\left(\frac{V}{\hat{A}(m)}\right) \overset{fit}{=} \ln\left(\hat{V}_0\right) - \hat{\tau}\cdot m \quad \Rightarrow \quad \ln\left(V_0\right) + \ln\left(\frac{A(m)}{\hat{A}(m)}\right) \overset{fit}{=} \ln\left(\hat{V}_0\right) - (\hat{\tau} - \tau)\cdot m$$

$$\ln\left(\frac{A(m)}{\hat{A}(m)}\right) = a(m) = \varepsilon + \delta\cdot m \quad \Rightarrow \quad \ln\left(V_0\right) + \varepsilon \overset{fit}{=} \ln\left(\hat{V}_0\right) - (\hat{\tau} - \tau + \delta)\cdot m \quad \Rightarrow \quad \hat{V}_0 = V_0\cdot\exp(\varepsilon)$$

$$\bar{\tau} = -\frac{1}{m}\ln\left(\frac{V}{\hat{V}_0\cdot\hat{A}(m)}\right) = \tau - \frac{1}{m}\ln\left(\frac{V_0\cdot A(m)}{\hat{V}_0\cdot\hat{A}(m)}\right) = \tau - \frac{1}{m}(-\varepsilon + \varepsilon + \delta\cdot m) = \tau - \delta$$

Two notes

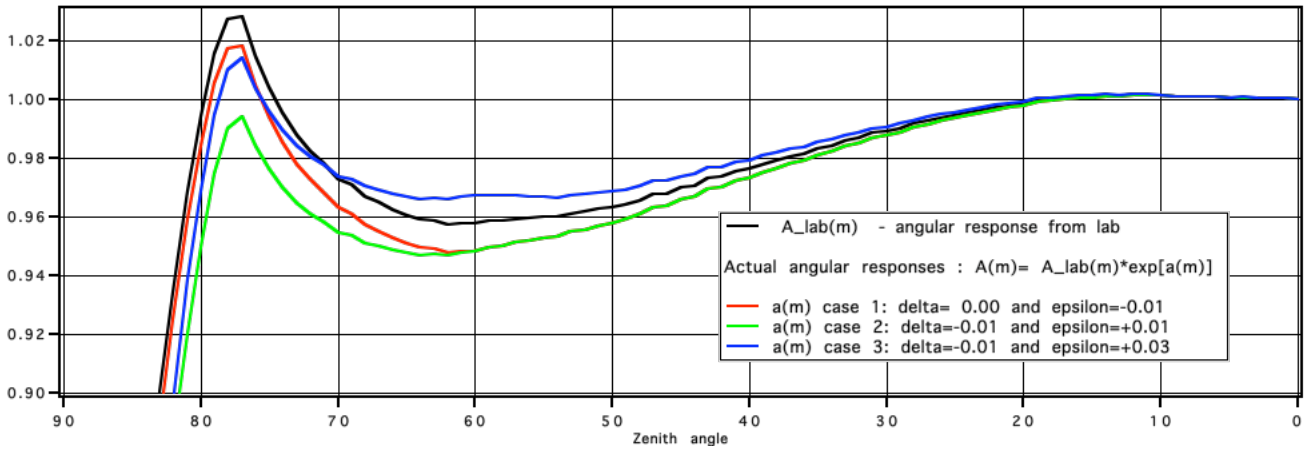
$(a)\quad \varepsilon = 0 \quad \Rightarrow \quad \hat{V}_0 = V_0$

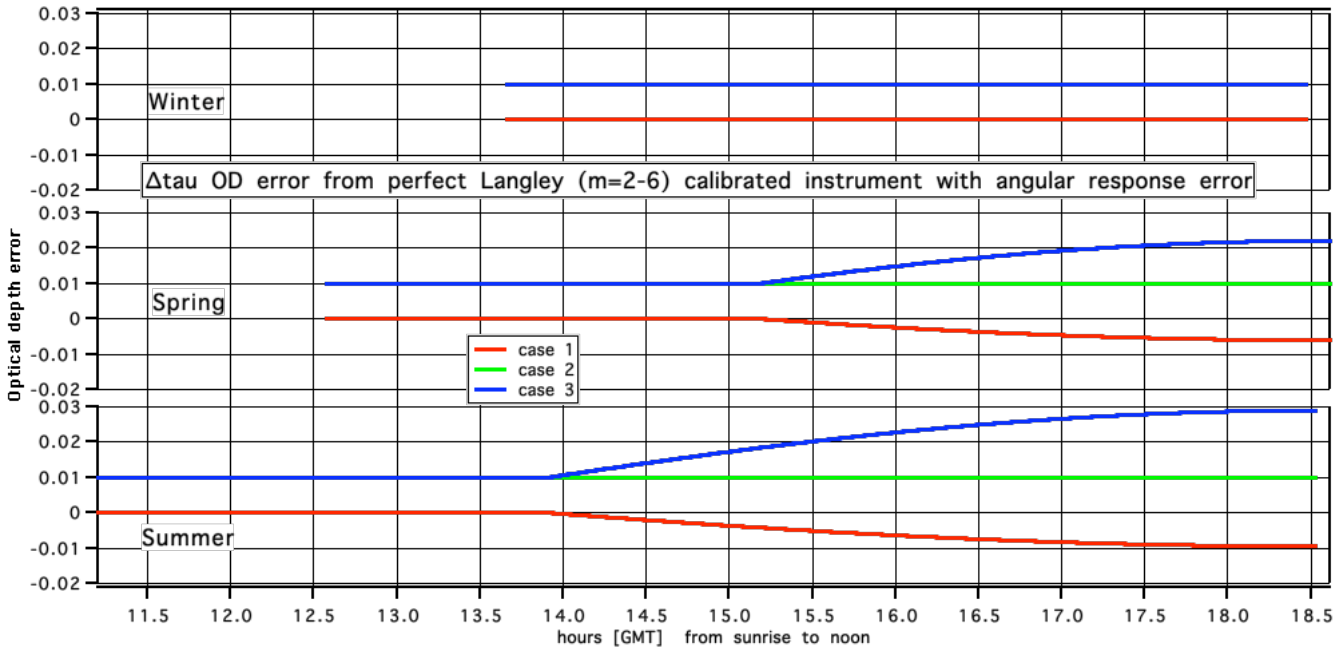
$(b)\quad A(1) = \hat{A}(1) \overset{def}{=} 1 \quad \Rightarrow \quad a(1) = 0 \quad \Rightarrow \quad \varepsilon + \delta = 0$

Physically correct case

$$a(m) = \begin{cases} \varepsilon + \delta\cdot m & 2 \le m \le 6 \quad \Rightarrow \quad \hat{V}_0 = V_0\cdot\exp(\varepsilon) \quad \Rightarrow \quad \Delta\tau = -\delta \\ (\varepsilon + 2\delta)(m-1) & 1 \le m < 2 \quad \hat{V}_0 = V_0\cdot\exp(\varepsilon) \quad \Rightarrow \quad \Delta\tau = -(\varepsilon + 2\delta) + 2(\varepsilon + \delta)/m \end{cases}$$

Examples of angular response (Perfect Langley) change and optical depth error





Checking angular response using NIMFR

MFRSR

$$V^{mfr} = R^{mfr} \cdot A(m,\phi)\frac{I_0}{r^2}\exp(-\tau_{mfr} \cdot m)$$

NIMFR

$$V^{mfr} = R^{nfr}\frac{I_0}{r^2}\exp(-\tau_{nfr} \cdot m)$$

$$(FOV^{mfr} \approx FOV^{nfr}) \wedge (\lambda^{mfr} \approx \lambda^{nfr}) \wedge (fwhm^{mfr} \approx fwhm^{nfr}) \quad \Rightarrow \quad \tau^{mfr} \approx \tau^{nfr} \quad \Rightarrow \quad A(m,\phi) = k\frac{V^{mfr}}{V^{nfr}} \quad \Leftarrow \quad k = \frac{R^{nfr}}{R^{mfr}}$$

Angular response short term check using raw signals

$A(m,\phi)$ *actual*

$\hat{A}(m,\phi)$ *lab*

$$\min_k \sum_i \left(\frac{\hat{A}(m_i,\phi_i) - k\frac{V_i^{mfr}}{V_i^{nfr}}}{\hat{A}(m_i,\phi_i)} \right)^2 \quad \Rightarrow \quad k \quad \& \quad rms$$

Angular response short term check using optical depth

$$\Delta\tau = \hat{\tau}_{mfr} - \hat{\tau}_{nfr} \cong \hat{\tau}_{mfr} - \tau = -\frac{1}{m}\ln\left(\frac{V_o \cdot A(m,\phi)}{\hat{V}_o \cdot \hat{A}(m,\phi)}\right)$$

$$\frac{V_o \cdot A(m,\phi)}{\hat{V}_o \cdot \hat{A}(m,\phi)} = \exp(-\Delta\tau \cdot m)$$