Overlap of Fractional Cloud for Radiation Calculations in GCMs: A Global Analysis using CloudSat and CALIPSO Data

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The need to consider cloud overlap structure depends on the genre of the GCM:

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- conventional GCMs: *description of cloud overlap for unresolved cloud fields must be provided, via parametrization, to carry out, at least, radiative transfer calculations.*

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The need to consider cloud overlap structure depends on the genre of the GCM:

*- **conventional GCMs:** description of cloud overlap for unresolved cloud fields must be provided, via parametrization, to carry out, at least, radiative transfer calculations.*

*- **MMF-GCMs (global CSRMs):** cloud overlap ceases to be a parametrization issue and becomes a diagnostic variable*

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Objectives

- **make a global assessment of cloud overlap**

    - using CloudSat-CALIPSO data

- **estimate global-average radiative sensitivity for overlap**

    - from linear feedback analysis: $\left(\dfrac{\partial F}{\partial x_i} \dfrac{\partial x_i}{\partial T_s} \right)$

    where x_i is some measure of overlap

- **assess feasibility of a very simple overlap *parametrization***

Data

CloudSat-CALIPSO cloud-mask: Jan and Aug 2007

- http://cloudsat.cira.colostate.edu/data_dist/OrderData.php

- 2B-GEOPROF and 2B-GEOPROF-LIDAR (CWC?)

- *CPR_Cloud_mask* ; *Radar_Reflectivity* ; *CloudFraction*

    - cross-sections: 50, 100, 200, 500, and 1000 km

        - what best represents a GCM column (Astin + Di Girolamo 1999)?

        - ~37,000 columns/orbit... many thousands of samples

    - total cloud fractions $\in$ [0.05, 0.99]

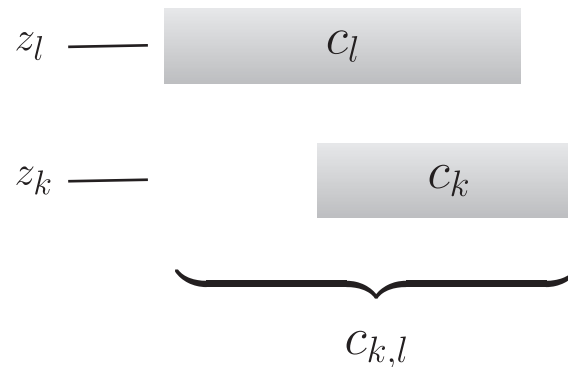   - CloudSat's radar reflectivity ~ r^6... precipitation-mask???

precipitation-mask

"cloud" in bins 3 and
4 above the surface?

remove up to max(R)
when lidar indicates
no cloud

Jan. 1, 2007 (47° 28' N ; 168° 22' E)
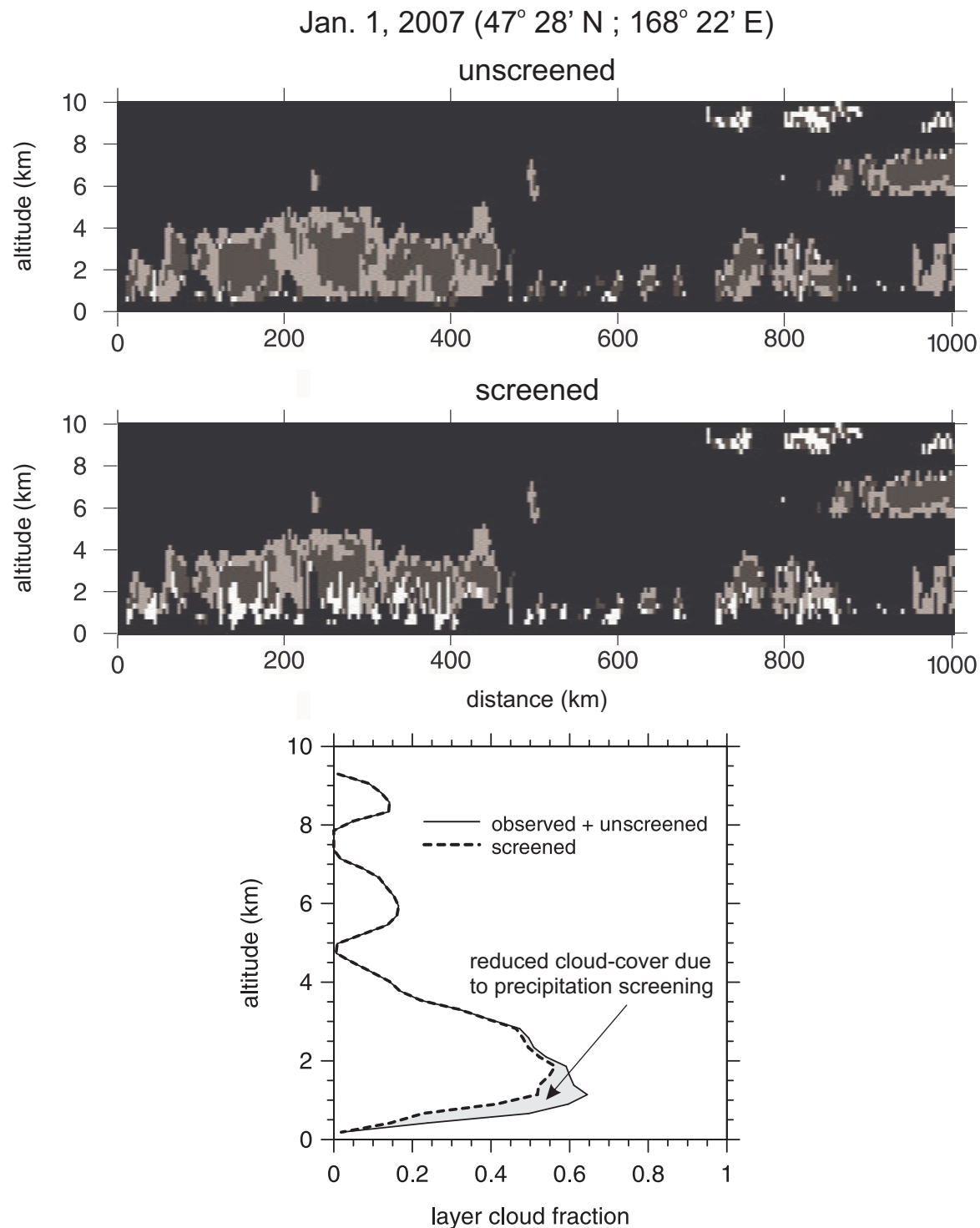
Methodology

Hogan and Illingworth (2000):

$$z_l \; \underline{} \; \boxed{c_l}$$

$$z_k \; \underline{} \; \boxed{c_k}$$

$$\underbrace{}_{c_{k,l}}$$

$$c_{k,l} \; = \; \alpha_{k,l} \underbrace{\max\left(c_k, c_l\right)}_{\substack{\text{maximum} \\ \text{overlap}}} \; + \; \left(1 - \alpha_{k,l}\right) \underbrace{\left(c_k + c_l - c_k c_l\right)}_{\substack{\text{random} \\ \text{overlap}}}$$

$$\alpha_{k,l} \equiv \exp\left[-\int_{z_k}^{z_l} \frac{dz}{\mathcal{L}_{cf}(z)}\right] \quad \Big| \quad \mathcal{L}_{cf}(z) \in [0, \infty) \; ; \; \alpha_{k,l} \in [0, 1)$$
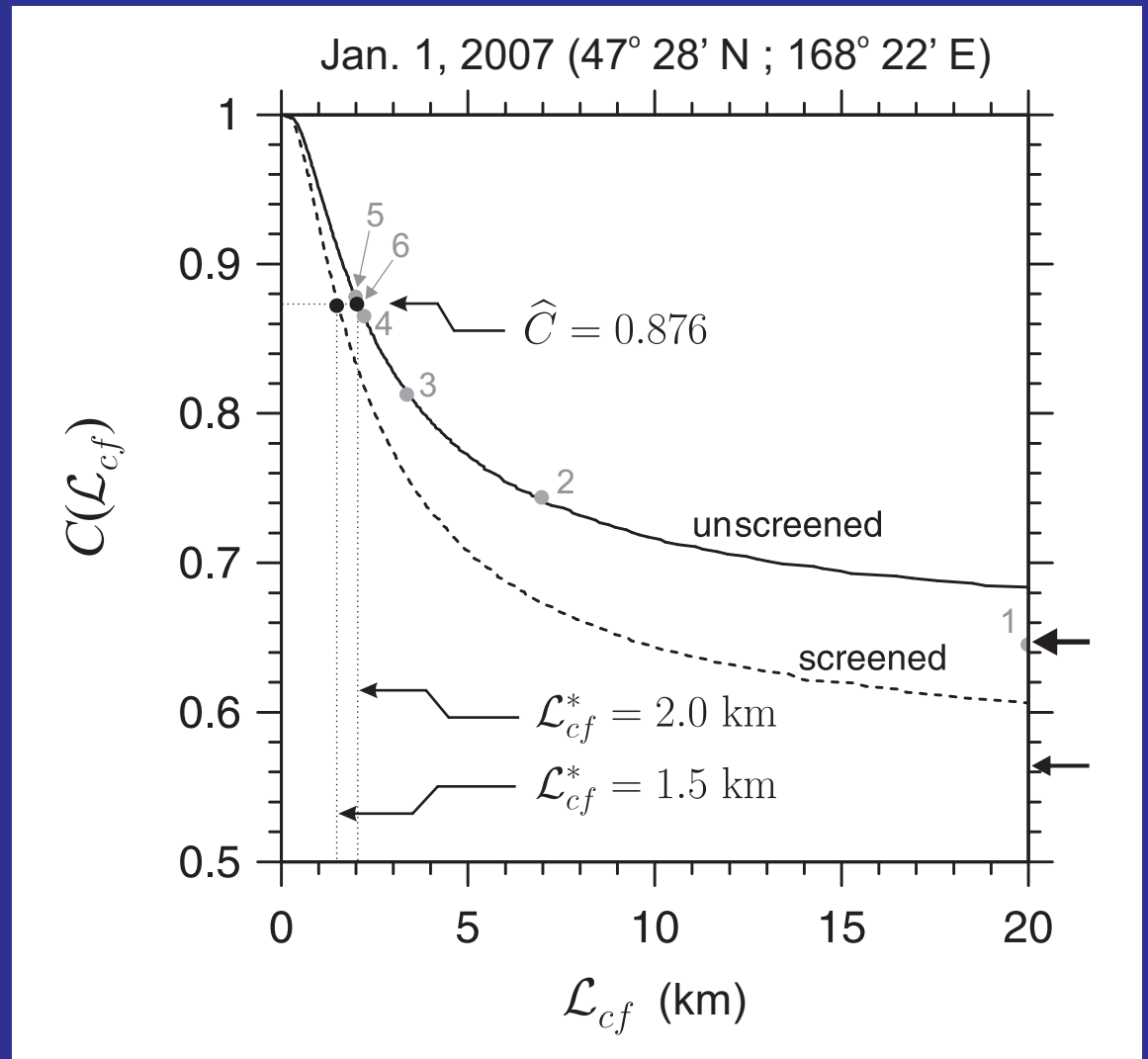
$$c_{k,l} \in \left(\max\left(c_k, c_l\right), c_k + c_l - c_k c_l\right]$$
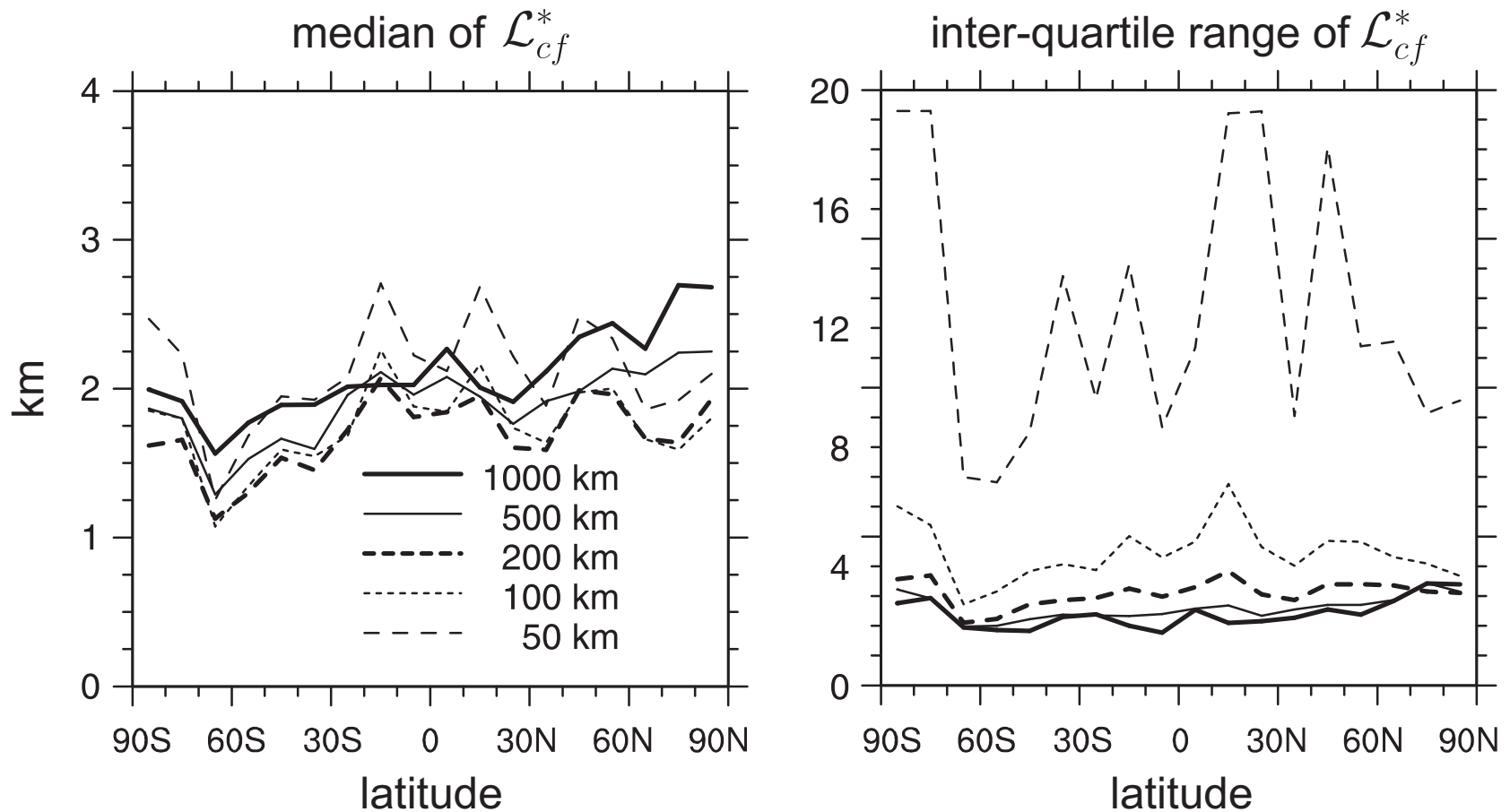
Effective Decorrelation Length

- assume that $\mathcal{L}_{cf}$ does not vary vertically...

  - unique $C(\mathcal{L}_{cf})$ given cloud fraction profile

- total cloud fraction $\widehat{C}$ from measurements

- using McICA's sub-grid cloud generator, solve:

$$C(\mathcal{L}_{cf}^*) = \widehat{C}$$
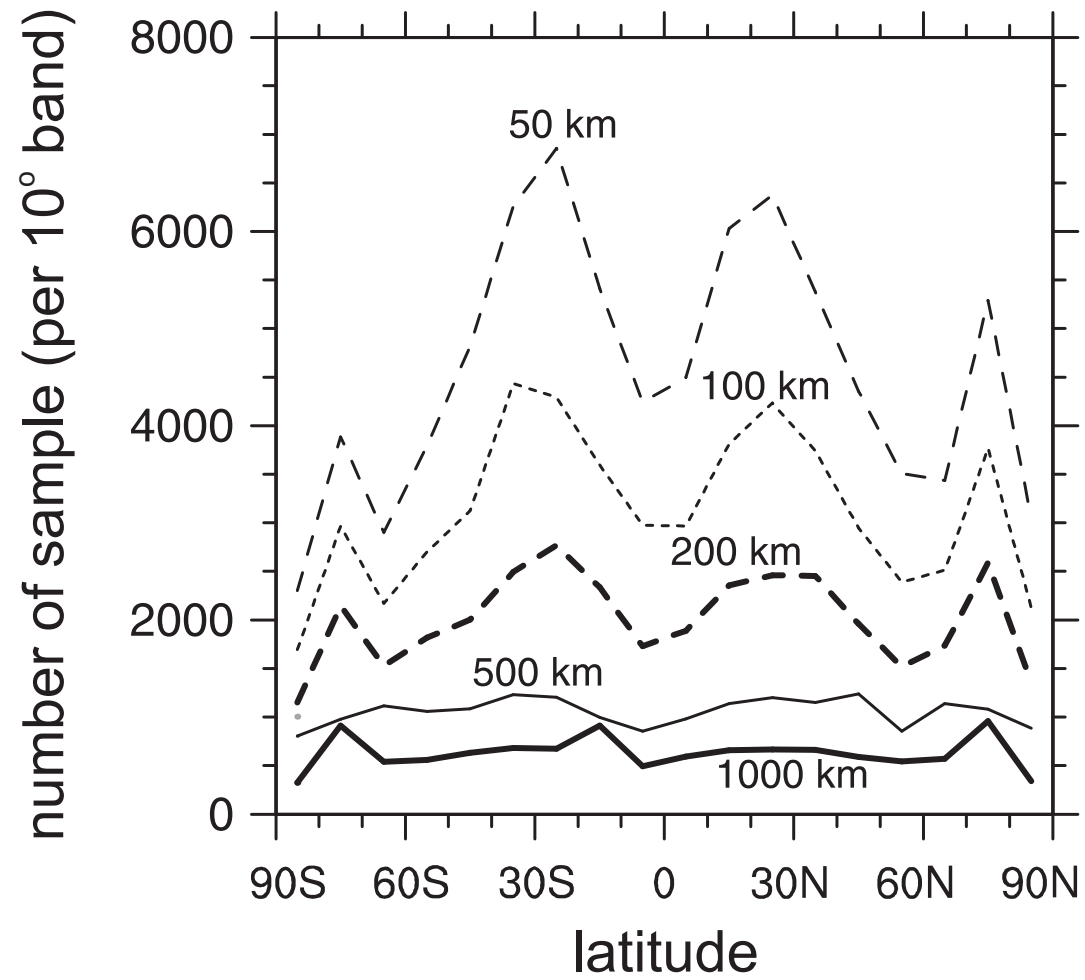

Jan. 1, 2007 (47° 28' N ; 168° 22' E)

$\widehat{C} = 0.876$

unscreened

screened

$\mathcal{L}_{cf}^* = 2.0$ km

$\mathcal{L}_{cf}^* = 1.5$ km

$C(\mathcal{L}_{cf})$

$\mathcal{L}_{cf}$ (km)

January 2007

median of $\mathcal{L}_{cf}^*$

km

latitude

- —— 1000 km
- —— 500 km
- - - - 200 km
- ⋯⋯ 100 km
- – – – 50 km

inter-quartile range of $\mathcal{L}_{cf}^*$
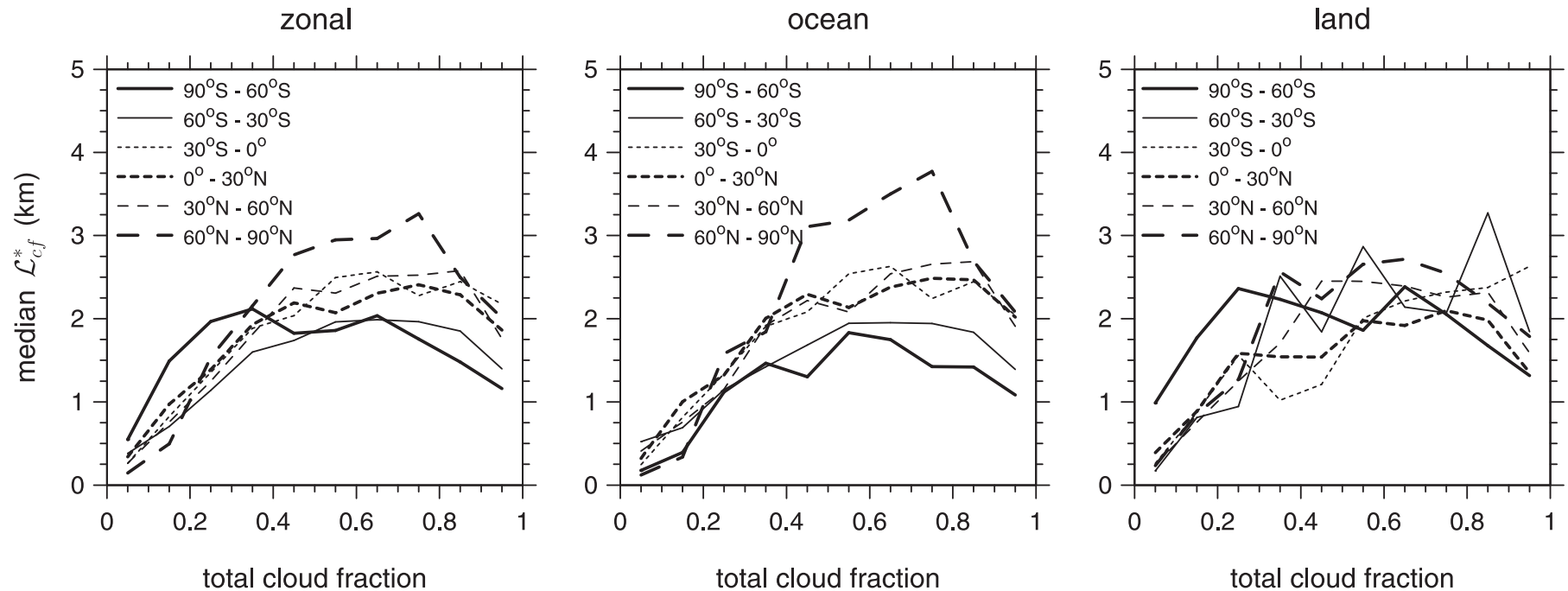

latitude

almost independent of cross-section length except for very small lengths

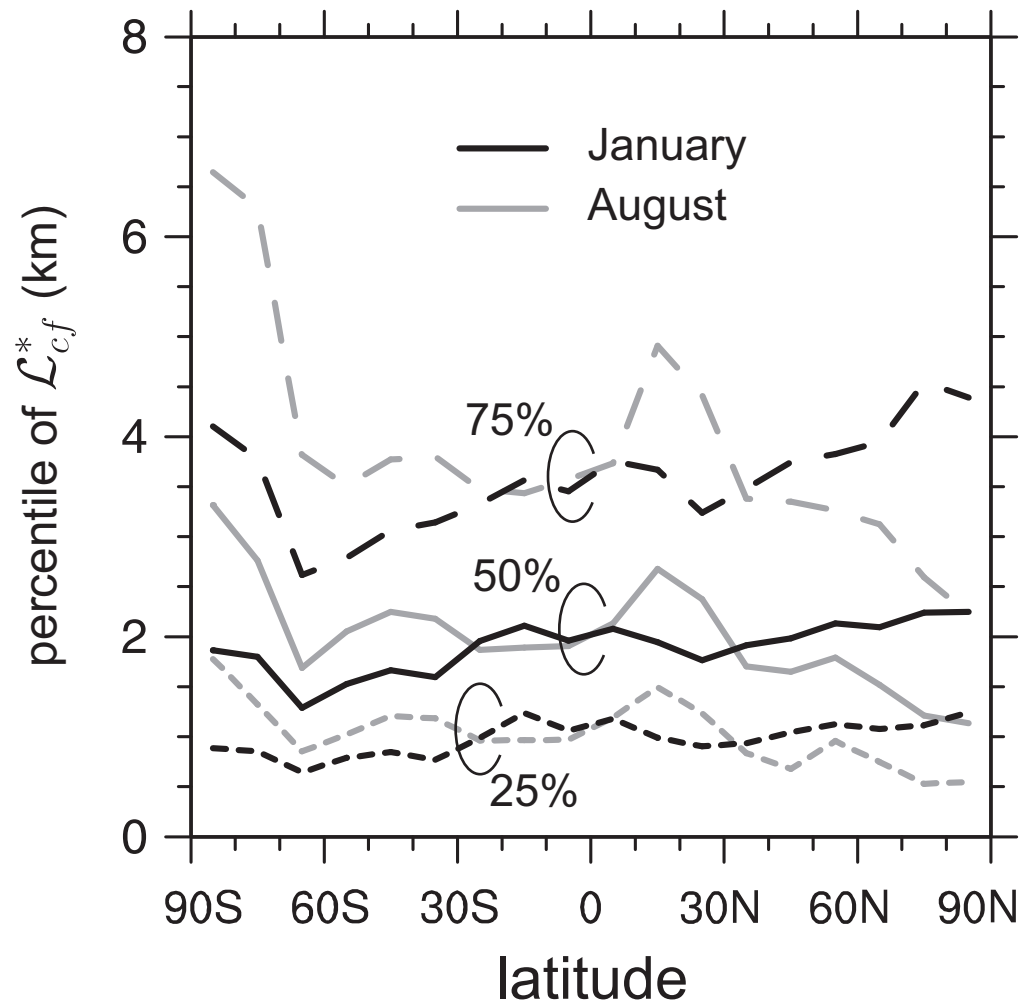(scale-independent parametrization?)

January 2007

January 2007

- little difference between land and ocean

- linear increase with C for small C
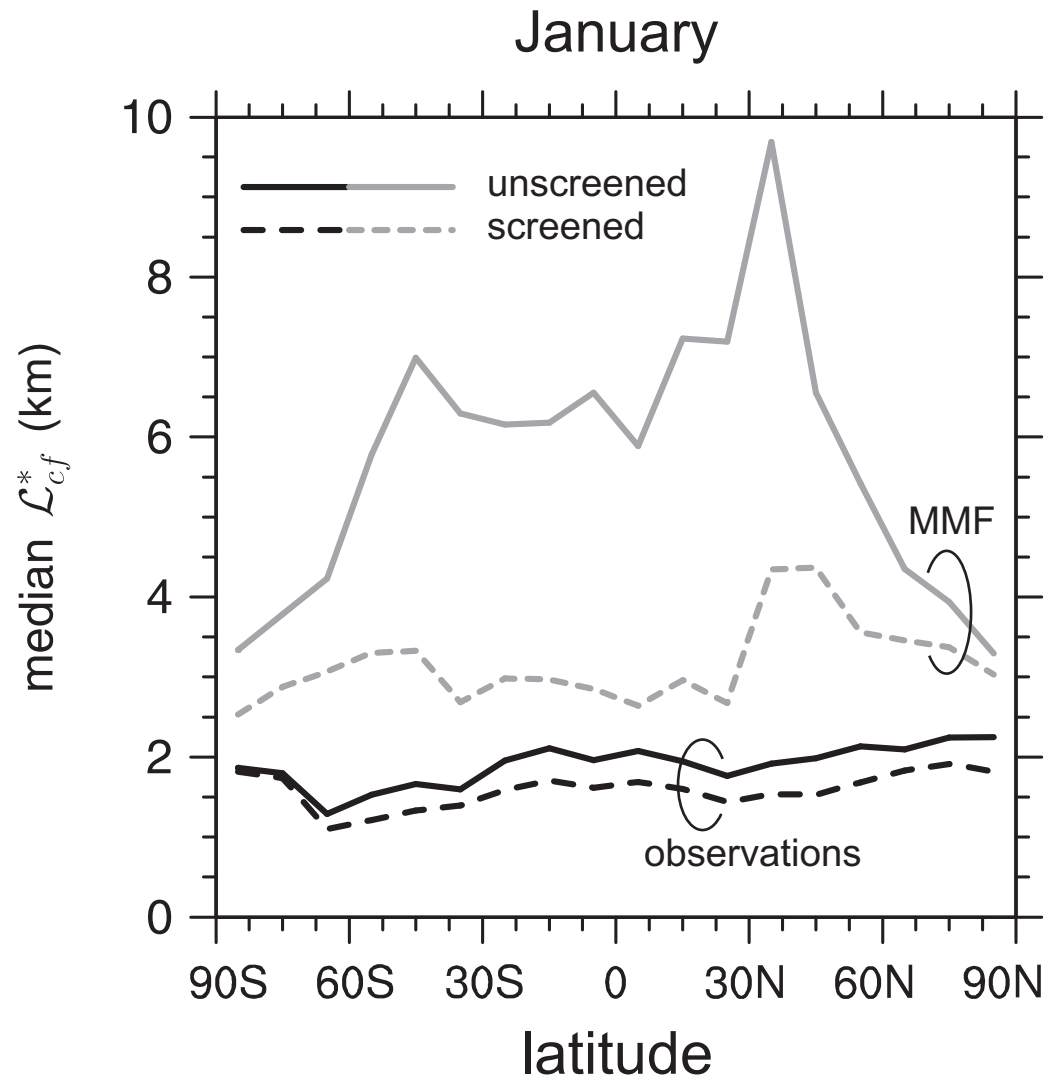
- peak medians of 2 to 3 km near $C = 0.7$

500 km cross-sections

largest values in Polar areas during winter and N. Tropics during boreal summer

- sedimentation of crystals and convection?

500 km cross-sections

January

- MMF values are very large (4 km grid-spacing vs. ~1.5 km?)

- screen for precip: minor for CloudSat, major for MMF

500 km cross-sections

On the use of $\mathcal{L}_{cf}^*$ in GCMs

- is vertically-constant sufficient?

- how to set it?... not from total cloud fraction...

- how complex need the parametrization be?

- is it something that changes with climate?...

On the use of $\mathcal{L}_{cf}^*$ in GCMs

- is vertically-constant sufficient?

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$$F_{\mathrm{ICA}} = \int_0^\infty p(\tau) F(\tau) \, d\tau$$

$$F_{\mathrm{ICA}} = (1 - \widehat{C}) F(0) + \widehat{C} \int_0^\infty \widehat{p}(\tau) F(\tau) \, d\tau$$
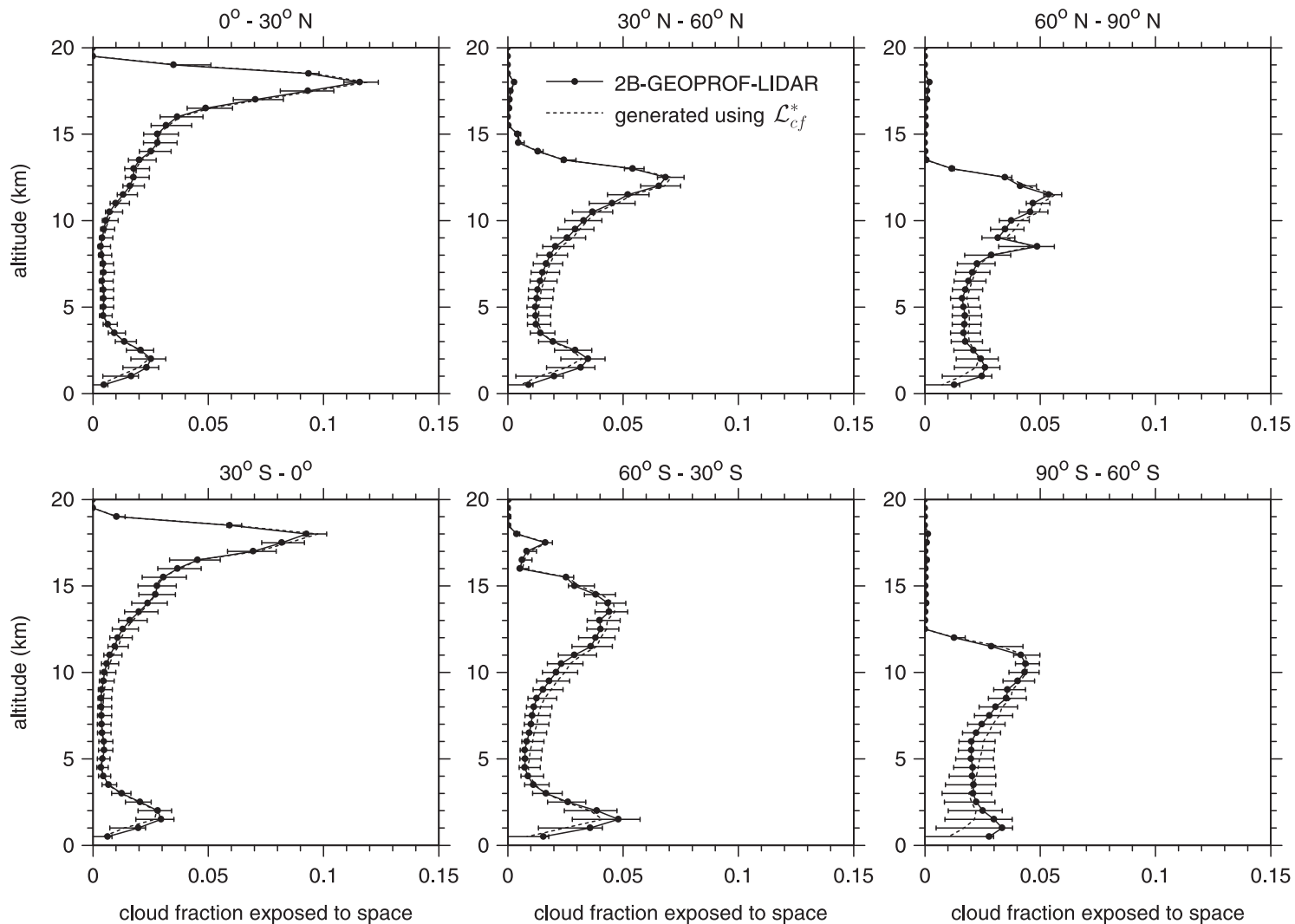
$$F_{\mathrm{ICA}} = (1 - \widehat{C}) F(0) + \sum_{m=1}^{M} \varepsilon_m \int_0^\infty \widehat{p}_m(\tau) F(\tau) \, d\tau$$

total cloud fraction

fraction of clouds in layer m with tops exposed to space

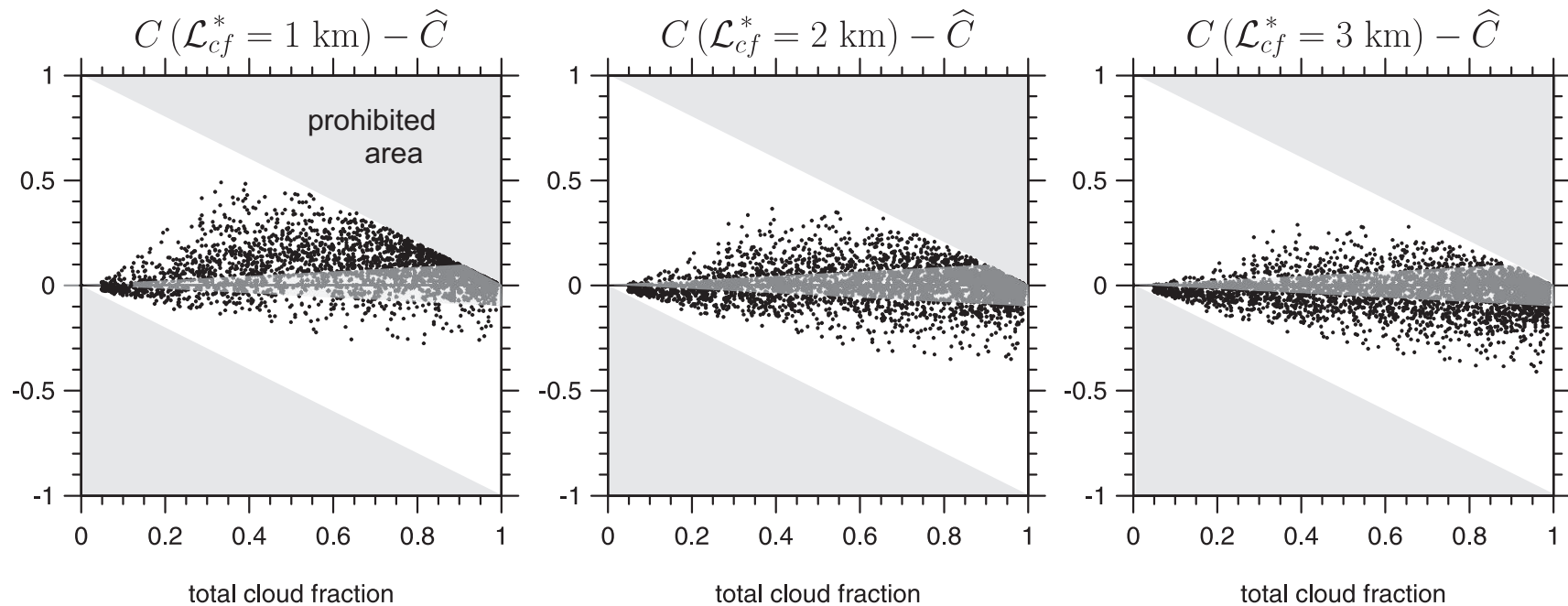distribution of τ for clouds in layer m with tops exposed to space

January 2007

- achieving an accurate distribution of cloudtops exposed to space appears doable

(given *correct* cloud fraction profiles and effective decorrelation lengths)

500 km cross-sections

January 2007

$C\left(\mathcal{L}_{cf}^* = 1 \text{ km}\right) - \widehat{C}$ $C\left(\mathcal{L}_{cf}^* = 2 \text{ km}\right) - \widehat{C}$ $C\left(\mathcal{L}_{cf}^* = 3 \text{ km}\right) - \widehat{C}$

prohibited area

total cloud fraction   total cloud fraction   total cloud fraction

- abundant (but significant?) random noise due to global setting

    - max-rand scheme has this *noise* too

- is it necessary to reduce variance?... cf. McICA

    - test with MMF (?)... forced realignment of CSRM fields for GCM RT

500 km cross-sections

Radiative Sensitivity for Overlap

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$$\frac{\partial F_{\mathrm{ICA}}}{\partial \mathcal{L}_{cf}} = -F(0)\frac{\partial \widehat{C}}{\partial \mathcal{L}_{cf}} + F_{\mathrm{cld}}\frac{\partial \widehat{C}}{\partial \mathcal{L}_{cf}} + \widehat{C}\frac{\partial F_{\mathrm{cld}}}{\partial \mathcal{L}_{cf}}$$

$$\frac{\partial F_{\mathrm{ICA}}}{\partial \mathcal{L}_{cf}} \simeq CRE\frac{\partial \ln \widehat{C}}{\partial \mathcal{L}_{cf}} + \widehat{C}\left[\underbrace{\frac{\partial F_{\mathrm{cld}}}{\partial \overline{\tau}}\frac{\partial \overline{\tau}}{\partial \mathcal{L}_{cf}}}_{< 0} + \underbrace{\frac{\partial F_{\mathrm{cld}}}{\partial \sigma_\tau}\frac{\partial \sigma_\tau}{\partial \mathcal{L}_{cf}}}_{\sim O(0)} + \cdots\right]$$

$$\left\langle \frac{\partial F_{\mathrm{ICA}}}{\partial \mathcal{L}_{cf}}\right\rangle \simeq \langle CRE \rangle \left\langle \frac{\partial \ln \widehat{C}}{\partial \mathcal{L}_{cf}}\right\rangle - O(\lesssim 1)$$

$$\simeq \left(-45 \text{ Wm}^{-2}\right)\left(-0.08 \text{ km}^{-1}\right) - O(\lesssim 1)$$

$$\simeq 3 \text{ Wm}^{-2} \text{ km}^{-1}$$

Radiative Sensitivity for Overlap

- to what extent is TOA radiation affected by overlap?...

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$$\left\langle\frac{\partial F_{\text{ICA}}}{\partial \mathcal{L}_{cf}}\right\rangle \simeq \langle CRE\rangle\left\langle\frac{\partial \ln \widehat{C}}{\partial \mathcal{L}_{cf}}\right\rangle - O(\lesssim 1)$$

$$\simeq \left(-45\ \text{Wm}^{-2}\right)\left(-0.08\ \text{km}^{-1}\right) - O(\lesssim 1)$$

$$\simeq 3\ \text{Wm}^{-2}\ \text{km}^{-1} \qquad \text{(LW is at least } \sim 3 \text{ times smaller)}$$

Conclusions + Recommendations

- 2 months of overlap analyses... more is needed

- bring in additional data (e.g., ECMWF)

- is $\mathcal{L}_{cf}^*$ sufficient?

    - can it be as simple as a few judicious settings based on local conditions?

- assess GCMs recognizing

$$F_{\mathrm{ICA}} = (1 - \widehat{C})F(0) + \sum_{m=1}^{M} \varepsilon_m \int_0^\infty \widehat{p}_m(\tau)F(\tau)\ d\tau$$

- if these are correct, so too is overlap, and your radiation budget