

Answers to the reviewer

The authors gratefully acknowledge the further suggestions of peer reviewer#2 assigned to this manuscript. We made all the proposed changes, improving the overall manuscript clarity.

Reviewer Comments in red

Author Responses in black

1.) Lines 17-18: “Specifically, CP simplifies...LW...”

You don't mention the simplification of the SW CRE calculation here, despite referring to the parameter y^* (related to simplifications of SW flux calculations in CP model) further in the text?

The reviewer is completely right. We simply forgot to mention it into the abstract. Now it is expressly specified that CP simplifications apply both to SW and LW.

2.) You might want to mention the Greenbelt site in the abstract.

Done

3.) Chapter 3.1 – model sensitivities for -> daytime only? Please specify!

It would be also valuable to include information on LW and SW CRE component, not only NET.

I think that should be done already in this study (considering its simplicity), and not simply left as an outlook (which you state in lines 310-313).

We agree that the manuscript will be more complete adding SW and LW components to the study. Now, for each changed parameter in the sensitivity study, there is also how much is changed LW and SW CRE. Values have been added in Table 1.

4.) Chapters 3.2 and 3.3

I don't see what is the advantage of having both years separately, and not clustering the results together. If you keep them separately, you need to understand what caused a different value of the CP model bias (suggestion: Does it correlate with the surface temperature?)

And – if you keep two separate panels - Were the 2 years, meteorologically significantly different? Different ENSO phase, etc.?

Now we are persuaded that there is not variability for 2010 and 2011, so there is no reason to treat them separately. Now the analysis is performed on cirrus clouds of the whole period (2010-2011). We checked the mean, median and corresponding std without founding any difference in temperature patterns among the two years.

5.) Lines 205 – 214 :

I would suggest first stating the general conclusion (CP larger values for 40-60%) , followed by an example (1 W m⁻² vs. 1.4-1.6 W m⁻²) .

Done

“..shows higher variability depending on the year...”

Yes, but year isn't the root cause of the change. What was different between 2010 and 2011? Maybe surface temperature?

Surface temperature is on average and std practically the same. For this reason we grouped both years together

6.) Lines 235-236:

I don't see any significant differences in the error between the 2 sites.

The sentence has been modified accordingly.

7.) Mention why CP2009 used σ^* and k^* and not simply k and σ .

Text has been modified accordingly. Now there is a description about the CP used parameters

8.) Lines 247-250:

Making a step further and trying to understand better what exactly is causing the error is something one could quickly look at. For instance, based on the Fig. 1 in CP2009 and your text lines 261-265, one would expect the error to be related to temperature, at least in the tropics. Your current conclusions of Chapter 3.4 do not add much to what already stated in CP2009. Therefore I would suggest (at least) one new sensitivity test in which you would if that leads to a better agreement with FLG model. (or select measurements at warmest/coldest surface temperature conditions for both Singapore and Greenfield). This sensitivity test would be useful in better determining the conditions at which the CP model's bias is still at acceptably low levels (maybe those stated in CP2009 paper?).

That's a great suggestion that helps the manuscript to nail the main point. We perform net CRE calculation for Greenbelt for land surface temperature lower or equal to 288K and we found out that the two models are in a great agreement. We added a plot of this analysis. Definitely problems arise when temperatures are higher and more humidity is then in the atmosphere. We used 288K as lower limit and for this reason we picked up Greenbelt because in Singapore not so many points are available.

9.)

Figures 1-6:

I still don't see why not making a technical effort with Matlab to cluster the years 2010 and 2011. Couldn't you just make a sum of the two histograms/bar plots, as the x-axis values do not change?

This would sharpen the main points of the paper.

Now, for Singapore, years 2010 and 2011 are grouped together. Also plots are reduced, as for Singapore analysis there is only analysis over ocean and over land for the whole dataset

Minor comments

-be consistent with units – you use both $W\ m^{-2}$ and W/m
changed accordingly

-line 53: delete the dot (.)
changed as suggested

-line 98: Polar Regions => polar regions
changed as suggested

-lines 99-100:
Why Singapore more digits than the mid-latitude site?
changed accordingly

-line 104 – What do you mean by:
“...polar clouds that should be net cooling elements”

-line 140: 39m => 39 m
changed as suggested

-line 273: ...value for theses parameterizations (?)
now read:” value for these parameterizations

-line 285-287:

-Why are the COD ranges different in Greenbelt and Singapore? Can that lead to differences in CRE?

Greenbelt is using only 30sr, that has a COD going from 0 to 3, with 0.03 increment step. Also Singapore has the same for 30sr, while for 20sr the incremental step is 0.01 and COD is going from 0 to 1

-Why are the net CRE so different when comparing 20 sr with 30 sr results?
Could you briefly mention that in the text?

Supplementary rows have been added to explain why CRE is different at two LR

Abstract

We compare, for the first time, the performance of a simplified atmospheric radiative transfer algorithm package, the Corti-Peter (CP) model, versus the more complex Fu-Liou-Gu (FLG) model, for resolving top-of-the-atmosphere radiative forcing characteristics from single layer cirrus clouds obtained from the NASA Micro Pulse Lidar Network database in 2010 and 2011 at Singapore **and in Greenbelt, Maryland, USA in 2012**. Specifically, CP simplifies calculation of both clear-sky longwave and shortwave radiation through regression analysis **applied to radiative calculations**, which contributes significantly to differences between the two. The results of the intercomparison show that differences in annual net TOA cloud radiative forcing can reach 65%. **This is particularly true when land surface temperatures are warmer than 288 K, where the CP regression analysis becomes less accurate**. CP proves useful for first-order estimates of TOA cirrus cloud forcing, but may not be suitable for quantitative accuracy, including the absolute sign of cirrus cloud daytime TOA forcing that can readily oscillate around zero globally.

1. Introduction

Cirrus clouds play a fundamental role in atmospheric radiation balance and their net radiative effect remains unclear (IPCC 2013; Berry and Mace 2014; Campbell et al. 2016; Lolli et al. 2017). Feedbacks between cirrus dynamic, microphysical and radiative processes are poorly understood, with ramifications across a host of modeling interests and temporal/spatial scales (Liou 1985; Khvorostyanov and Sassen 1998). Simply put, different models parameterize ice formation in varied, yet relatively simplified, ways that impact how cirrus are resolved, and how their macro/microphysical and radiative properties are coupled with other atmospheric processes (e.g., Comstock et al. 2001; Immler et al. 2008). Consequently, models are very sensitive to small changes in cirrus parameterization (Soden and Donner 1994; Min et al. 2010; Dionisi et al., 2013).

Cirrus clouds are the only tropospheric cloud genus that either exerts a positive or negative top-of-the-atmosphere (TOA) cloud radiative forcing effect (CRE) during daytime. All other clouds exert a negative daytime TOA CRE. Cirrus clouds exerting negative net TOA CRE cool the earth-atmosphere system and surface below them. This occurs as the solar albedo term is greater than the infrared absorption and re-emission term. Positive forcing occurs when the two are reversed and infrared warming and re-emission exceed scattering back to space. In contrast, all clouds cause a positive nighttime TOA value, with an infrared term alone and no compensating solar albedo term. This dual property makes cirrus distinct, and why it's crucial to understand how well radiative transfer models are resolving their TOA CRE properties.

The burgeoning satellite and ground-based era of atmospheric monitoring (Sassen and Campbell 2001; Campbell et al. 2002; Welton et al. 2002; Nazaryan, et al. 2008; Sassen et al. 2008) has led to a wealth of new data for looking at global cirrus cloud properties. In particular, TOA CRE, or at the surface (SFC), are evaluated by means of radiative transfer modeling, designed with different degrees of complexity. What is not yet known is how the relative simplicity of some models translates to a relative retrieval uncertainty, given that the CRE effect of cirrus clouds, at both the ground and TOA, are typically on the order of 1 W m^{-2} (e.g., Campbell et al. 2016; Lolli et al. 2017). Whereas some studies show the relative uncertainty of such models as static percentages (Corti and Peter, 2009), the absolute magnitude of uncertainty with respect to cirrus CRE is necessary to understand whether or not they fit within acceptable tolerance thresholds sufficient for quantitative use. Further, given the sensitivity in the sign of net annual cirrus cloud daytime TOA CRE specifically (Campbell et al. 2016), it's plausible that some simpler models are routinely aliasing positive versus negative TOA CRE.

Corti and Peter (2009; CP) describe a simplified radiative transfer model that relies upon a constrained number of input parameters, including surface temperature, cloud top temperature, surface albedo, layer cloud optical depth, and the solar zenith angle. CP simplifies drastically the framework of the Fu-Liou-Gu radiative transfer model (Fu and Liou 1992; Gu et al. 2003; Gu et al., 2011; FLG), for instance, through a parameterization of the longwave and shortwave fluxes derived from the FLG model calculations for realistic atmospheric conditions. Moreover, CP does not directly consider gaseous absorption. The model has increasingly been

used to assess cirrus cloud radiative effects (Kothe et al. 2011; Kienast-Sjögren et al. 2016; Burgeois et al. 2016) from lidar measurements, owing to its relative simplicity and lower computational burden compared with a model like FLG.

To date, CP model performance vs. FLG model has been evaluated for sensitivities only to simulated synthetic clouds and never on real measurements, especially those collected over long periods (Corti and Peter 2009). Such evaluation, however, can readily be conducted using the unique NASA Micro Pulse Lidar Network (MPLNET; Welton et al. 2002; Campbell et al. 2002; Lolli et al. 2013; Lolli et al., 2014), **established in 1999 to continuously monitor cloud and aerosol physical properties (Wang et al., 2012, Pani et al., 2016).**

The objective of this technical note is to then assess differences between CP and FLG in terms of net annual daytime TOA CRE. CP and FLG model performance are evaluated using MPLNET datasets collected from Singapore in 2010 and 2011, a permanent tropical MPLNET observational site, and at Greenbelt, Maryland in 2012, a midlatitude site. Our goal is to more appropriately characterize the sensitivities of CP relative to what is generally considered a more complex, and presumably more accurate, model, with the hopes of better understanding relative uncertainties, and thus interpreting whether such uncertainties are appropriate for long-term global cirrus cloud analysis.

2. Method

FLG is a combination of the delta four-stream approximation for solar flux calculations (Liou et al. 1988) and a delta-two-four-stream approximation for IR

flux calculations (Fu et al. 1997), divided into 6 and 12 bands, respectively. It has been extensively used to assess net cirrus cloud daytime radiative effects, most recently for daytime TOA forcing characteristics within MPLNET datasets at both Greenbelt, Maryland and Singapore, respectively (Campbell et al. 2016; Lolli et al. 2017). The results from these studies have led to the hypothesis of a meridional gradient in cirrus cloud daytime TOA radiative forcing existing, with daytime cirrus clouds producing a positive daytime TOA CRE at lower latitudes that reverses to a net negative daytime TOA CRE approaching the non-snow and ice-covered polar regions. They estimate absolute net cirrus daytime TOA forcing term between 0.03 and 0.27 W m⁻² over land at the mid-latitude site, which ranges annually between 2.20 - 2.59 W m⁻² at Singapore. The key here to this phenomenon is the possible oscillation of the net daytime TOA CRE term about zero, which is believed to vary by a maximum +/- 2 W m⁻² in absolute terms (i.e. normalized for relative cirrus cloud occurrence rate **and total daytime percentage locally**), after accounting for polar clouds that should be net cooling elements and varying surface albedos over land and water exclusively (i.e., not ice). Resolving such processes thus requires relatively high accuracy in radiative transfer simulations.

To calculate daytime cirrus cloud radiative effects from MPLNET datasets, the lidar-retrieved single layer cirrus cloud extinction profile (Campbell et al. 2016; Lewis et al., 2016, Lolli et al., 2016, Lolli et al., 2017) is transformed into crystal size diameter (using the atmospheric temperature profile) and ice water content (*IWC*) profiles using the parameterization proposed by Heymsfield et al. (2014). Those parameters, at each range bin, are input into FLG. The thermodynamic atmospheric

profiles, together with ozone concentrations are obtained with a temporal resolution of +/- 3 hr, from a meteorological reanalysis of the NASA Goddard Earth Observing System Model Version 5.9.12 (GEOS-5). In contrast, for a given cloud case, the corresponding cloud and atmospheric CP input parameters are explicitly the land/ocean surface temperature, the cloud top temperature, the surface albedo, the cloud optical depth for the specific layer and the solar zenith angle.

Calculations here are performed for the same MPLNET observational sites, Singapore and Greenbelt, Maryland (i.e., NASA Goddard Space Flight Center; GSFC). For the former site, two different values of the surface albedo, which is a common input parameter in both models, are fixed at 0.12 and 0.05, respectively, as Singapore is a metropolitan area completely surrounded by sea. This allows us to more reasonably characterize forcing over the broader archipelago of Southeast Asia, and follows the experiments described by Lolli et al. (2017). . At NASA GSFC, only a single over-land albedo is used, though one that varies monthly between 0.12-0.15 based on climatology.

Here, we reconsider these results by first intercomparing those solved with FLG and CP for net daytime TOA CRE over a practical range of cloud optical depth (COD). As described in both Campbell et al. (2016) and Lolli et al. (2017), daytime is specifically defined in these experiments as those hours where incoming net solar energy exceeds that outgoing. Only under such circumstances can the net TOA CRE term become negative. Otherwise, it is effectively nighttime, as the term is positive and all clouds induce a warming TOA term. Nighttime results will instead be

considered as context to understanding net diurnal differences between the models when examining the GSFC dataset.

3. Intercomparisons

The daytime cirrus net TOA CRE, normalized by corresponding occurrence frequency, in this case as a function of COD, was evaluated at Singapore (1.3 N, 103.8 E, 20 m above mean sea level) and GSFC (38.9 N, 76.8 W, 39 m above mean sea level) for both FLG and CP. The method to estimate MPLNET cirrus cloud optical properties is described in Lewis et al. (2015) and Campbell et al. (2016), for both 20 and 30 sr solutions from the unconstrained single-wavelength elastic lidar equation at 532 nm (Campbell et al. 2016). The latter constraint provides “bookend” estimates for TOA CRE designed to approximate system variance. For both models, the daytime cirrus cloud net TOA CRE is calculated as the difference of two model computations using different assumed states (cloudy sky minus cloud and aerosol particulate-free conditions) to isolate the distinct cirrus cloud impact alone (in $W m^{-2}$).

3.1 Model sensitivities

An initial sensitivity study was carried out to evaluate how the input parameters, and eventually their uncertainties, influence the net TOA CRE calculations. Results are summarized in Table 1. Model input parameter sensitivities were investigated for surface albedo, COD, land/ocean surface temperature and cloud top temperature. Table 1 shows how much net, SW and LW fluxes change by varying each individual parameter alone. For instance, changing

the surface albedo from 0.12 to 0.14 and keeping the other three parameters fixed produces similar changes in both models (26% for CP model and 25% for FLG model). Changing COD from 1 to 1.1 produces a change of 16% for CP and 21% for FLG. Changing surface temperature and cloud top temperature of 1K produces respective changes of 10% and 7% for CP and 7% and 6% for FLG. Though subtle, the models exhibit some differences in variance relative to the input parameters required to initialize them.

3.2 Singapore (2010-2011)

FLG and CP were compared over a total of 33072 total daytime single layer cirrus clouds at Singapore from 2010 to 2011. Figures 1, 2, 3 and 4 reflect histograms of cirrus cloud relative frequency and net annual daytime TOA CRE normalized by corresponding frequency, for both surface albedo values of 0.05 (Fig. 3 and 4; i.e., over sea) and 0.12 (Fig. 1 and 2; i.e. over land) at 0.03 COD resolution from 0 to 3. This latter range was chosen as consistent with Sassen and Cho (1992), and the nominal effective COD range corresponding with cirrus cloud occurrence. Note, since a common cloud sample is used, the 20 sr samples vary in COD between only 0 and approximately 1 in contrast to the 30 sr sample topping out at 3. **The observed differences in net radiative effect can be ascribed to the different lidar ratio. The results here mirror the work of Berry and Mace (2014) who first recognized the significance of optically-thin cirrus influencing the net normalized term so greatly.**

Intercomparison of net daytime TOA CRE vs. COD over the ocean at 20 sr shows an overall forcing of 1.34 W m^{-2} for CP and 0.48 W m^{-2} for FLG. At 30 sr, we obtain -0.89 W m^{-2} from CP and -0.37 W m^{-2} for FLG. The overall CP net TOA CRE is greater in absolute magnitude than FLG by a maximum difference of 65%. This value is obtained by taking the ratio between yearly CRE from FLG over CP and then the percentage difference. Over land (urban environment), CP net daytime TOA CRE are higher than the FLG model by 30% (CP = 4.20 W m^{-2} , FLG= 2.98 W m^{-2} at 20 sr; CP= 4.43 W m^{-2} and FLG= 3.35 W m^{-2} at 30 sr). The COD value at which cirrus begin cooling the earth-atmosphere system, moving toward higher COD, is systematically shifted towards higher values for CP with respect to FLG. This is particularly evident over ocean at 20 sr where there is a shift of 0.2 in COD (0.6 for CP and 0.4 for FLG; Fig. 3).

To better understand the different outputs between the two models, a scatter plot between from FLG barplot entries is shown in Figs. 2 and 4 (30 sr solution), and the corresponding CP barplot values are plotted for each year, over land and over ocean, in Figs. 5 and 6. The red line represents the actual linear data regression, while the blue line represents an ideal case (i.e., slope=1, intercept=0). If the two radiative transfer models show identical results regarding CRE, all the points should lie on the blue line. The red line instead represents the actual regression line, or a relative measure of how much the two models differ.

From Figs. 5 and 6, the FLG-derived net daytime **CP TOA CRE values are systematically greater in absolute value than the corresponding FLG values by 60%. More in detail CP TOA CRE of 1 Wm^{-2} corresponds with FLG values ranging from**

0.57 Wm^{-2} to 0.59 Wm^{-2} . On the contrary, the bias (or the intercept from the linear regression) shows higher variability depending on the surface type underlying the cirrus cloud (land versus ocean). This indicates that when a cirrus cloud shows a neutral effect (0 Wm^{-2}) for CP model, FLG model solutions range from -0.05 (land) to -1.1 Wm^{-2} (ocean). This implies that characterization of cirrus cloud warming or cooling effects depend on the model.

3.4 Greenbelt, Maryland 2012

To limit potential assessment ambiguity based on a single-site analysis, we performed a second model comparison using the 2012 NASA GSFC dataset. A summary of this dataset and net daytime TOA CRE results can be found in Campbell et al. (2016). As this site is land-locked, only the single albedo was, again, used, though varied monthly based on climatological passive satellite estimates. 21107 daytime cirrus cloud profiles were considered. Shown in Figure 6 (upper panel) are the total net TOA CRE vs. COD at 30 sr, for CP (-2.59 Wm^{-2}) against FLG (0.05 Wm^{-2}). A relative differencing here is impractical. Suffice however, this is a significant difference, and the sign of the net daytime forcing term is in direct question between the two.

With this NASA GSFC dataset, we further consider an additional 32185 nighttime cirrus cloud cases within the analysis (Fig. 6, lower panel). The thought here is that, relative to prior estimates of CP uncertainty compared with more complex models, a diurnal average would be likely to produce a different, and plausibly closer, relative agreement consistent with prior studies. That is, since during for most of the period we define here as night there is no solar input, a

simplification of the infrared forcing terms and parameterizations alone would potentially yield a closer comparison between the two models. For the NASA GSFC dataset, we solved a relative net nighttime TOA CRE of 29.1 Wm^{-2} with FLG compared with 21.0 Wm^{-2} with CP, or a relative difference approaching 50%. Summarized in Table 2 are the discrepancies in terms of CRE at both observational sites.

It is useful at this point to discuss some of the potential elements driving these differences. The larger discrepancies between the two models are likeliest ascribed to the parameterization of three specific parameters in the CP model: the first two, σ^* and k^* (Eq. 2 of Corti and Peter, 2009) are two approximated parameters for the Stefan-Boltzmann constant and the surface temperature exponent estimated from radiative calculations and used to calculate the outgoing longwave earth radiation. The last parameter, γ^* (again obtained from a regression analysis), is related to the asymmetry factor of cloud droplets and used to calculate the cloud reflectance of shortwave radiation (Eq. 11 in Corti and Peter; 2009). We speculate that, though the analysis is left to a future study on broader uncertainties in modeling ice radiative properties inherently with any model, these parameters are not the constants ascribed by CP, but that their values instead change with respect to season and latitude.

The 20% relative model accuracy claimed in Corti and Peter (2009) may be verified for special conditions in tropical latitudes, where the three parameters discussed above are well optimized. But, that is clearly not found from our study. Corti and Peters (2009) expressly stated that they used fixed values for those three

parameters (i.e., σ^* and k^* in Eq. 2 and γ^* in Eq. 11 in Corti e Peter, 2009) again using regression analysis, but this shouldn't be the case, as net TOA CRF is very sensitive to those parameters. For example, varying water vapor concentrations in the atmosphere can be the responsible of a difference up to 25 Wm^{-2} (for temperatures at the surface higher than 288K) in clear-sky earth longwave radiation at Singapore, as stated in Corti and Peter (2009; Fig. 1). In our analysis we verified that, over one year, the land surface temperature is higher than 288K 66% of the time. For this reason, to assess if land surface temperature is responsible for these larger discrepancies, we reproduced Fig. 6 (upper panel) masking out all cases corresponding with land surface temperatures higher than 288 K at Greenbelt (in Singapore those temperatures are mostly during nighttime). Shown in Figure 7 are the results of the analysis. CP and FLG radiative transfer models in this range of temperature are in much better agreement (NET CP = -8.06 Wm^{-2} ; NET FLG -8.65 Wm^{-2}), within 6%.

We advise that those looking to apply CP to long-term climate/cirrus cloud study should carefully analyze the relevance of these settings to their given experiment before directly applying the model, especially when land surface temperatures are warmer than 288K.

4. Conclusions

Annual single-layer cirrus cloud top-of-the-atmosphere (TOA) radiative effects (CRE) calculated from the Corti and Peter (2009) radiative transfer model

(CP) are compared with similar results from the more complex, and presumably more accurate, Fu-Liou-Gu (FLG) radiative transfer model. The CP model calculates CRE using a parameterization of longwave and shortwave fluxes that are derived from real measurements optimized for a tropical environment through a regression analysis to simplify the radiative calculations. Values for these parameterizations, as suggested in Corti and Peter (2009), lead to relative differences in TOA CRE that far exceed the stated 20% in the original manuscript. This includes parsing results out for daytime, nighttime or diurnal averages. It is believed that specific parameterizations with the simplified model cannot be considered global constants, as originally defined for CP, but that they should be carefully evaluated on single case basis for each experiment. **Moreover we find that the land surface temperature is responsible for significant discrepancies when larger than 288K, because the original CP regression analysis is less accurate for larger temperatures.** However, CP uses less input parameters compared with FLG, making it practically and computationally more efficient, particularly for large climate datasets. This is the first time, however, that the two models are compared using long-term cirrus clouds datasets, as opposed to synthetic datasets, with experiments conducted using NASA Micro Pulse Lidar datasets collected at Singapore in 2010 and 2011 (Lolli et al. 2017) and Greenbelt, Maryland in 2012.

Net daytime TOA CRE was evaluated versus cloud optical depth (COD) for steps of 0.03 (COD range: 0-1) at 20 sr and for steps of 0.1 at 30 sr (COD range: 0-3) for both the Singapore and Greenbelt, Maryland datasets. Our findings suggest that the difference in annual net TOA CRE between the two models approaches 65% in

one experiment at Singapore. At Greenbelt, Maryland, the sign of the net annual daytime TOA CRE term differs, and the absolute difference varies between by nearly 2.5 Wm^{-2} . Differences in the sign of the net TOA forcing term, however, are most worrying. Since cirrus clouds are the only cloud that can exhibit daytime positive or negative net TOA CRE, subtle differences in absolute magnitude are less important than whether or not the clouds are inducing a cooling or forcing term in the TOA radiation budget.

In spite of this comparison, even if we reasonably speculate that FLG is the more accurate model overall, because of its relative complexity compared with CP, we are still missing regular comparisons of FLG with real observational data. Thus, the practical gains to long-term application of a simplified model like CP cannot be overstated, given lower computational demands. However, we believe that the results from this study are noteworthy because they show that the differences between the two models are significant. With respect to cirrus annual net daytime TOA CRE, and given the perspective on their global distribution described by Campbell et al. (2016) and Lolli et al. (2017), these sensitivities can lead to completely different conclusions about global cirrus TOA forcing effects. Therefore, in future work, it is imperative on the community to continue understanding and refining the global parameterizations used in all radiative transfer models regarding cirrus. Continued intercomparisons between models with real observation both at ground (using flux measurements), in situ (aircraft measurements) and at TOA (using satellite-based measurements,) remain critical interests.

Acknowledgements

This study and the NASA Micro Pulse Lidar Network (MPLNET) are supported by the NASA Radiation Sciences Program (H. Maring). Author JRC acknowledges the Naval Research Laboratory Base Program (BE033-03-45-T008-17) and support of NASA Interagency Agreement NNG15JA17P on behalf of MPLNET.

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FIGURES

FIGURE 1 Analysis over land (Albedo=0.12) for 20sr solution. Top Panel: CRE vs. COD weighted by occurrence frequency for Corti and Peter(red) and FLG (blue) models on 2011. Bottom Panel: CRE vs. COD weighted by occurrence frequency for Corti and Peter(red) and FLG (blue) models on 2010

FIGURE 2 Analysis over land (Albedo=0.12) for 30sr solution. Top Panel: CRE vs. COD weighted by occurrence frequency for Corti and Peter(red) and FLG (blue) models on 2011. Bottom Panel: CRE vs. COD weighted by occurrence frequency for Corti and Peter(red) and FLG (blue) models on 2010

FIGURE 3 Same as Figure 1, but over the ocean (Albedo=0.05)

FIGURE 4 Same as Figure 2, but over the ocean (Albedo=0.05)

FIGURE 5 Scatter plot and linear regression for 30sr solution for FLG and CP CRE in 2010-2011 over land (upper panel) and ocean (lower panel)

FIGURE 6 Analysis on 2010 dataset from MPLNET GSFC observational site for 30sr solution daytime (upper panel) and nighttime (lower panel).

FIGURE 7 Same as Figure 6, taking out those measurements with a land surface temperature $T_{\text{surf}} > 288\text{K}$

Tables

NET CP	NET FLG	LW TOA FLG	SW TOA FLG	LW TOA CP	SW TOA CP	
-12.6	-9.4	67.8	-77.2	69	-81.6	Ref
9.3 (26%)	-7 (25%)	67.8	-74.8	69	-78.3	Albedo
-14.7 (16%)	-11.4 (21%)	71.8	-83.2	73.5	-88.2	Cod
-11.3(10%)	-8.7(7%)	68.5	-77.2	70.3	-81.6	Surf Temp
-13.5(6%)	-10(5%)	67.2	-77.2	68.1	-81.6	Cl Top Temp

Table 1 Total NET, SW and LW fluxes (W/m^2) at TOA. Sensitivities of CP and FLG radiative transfer models with respect to the surface albedo, cloud optical depth Unperturbed parameters are COD=1, Surface albedo=0.12, $T_{surf}=294K$ Cloud top $T_{top}=229K$. The variation in net radiative forcing expressed in percentage for each parameter are calculated changing the surface albedo from 0.12 to 0.14, the COD from 1 to 1.1, and augmenting the temperatures of 1K.

CRE vs. COD	Land	Ocean
SING 2010-2011	20sr CP=4.20 FLG=2.98 (41%)	20sr CP=1.34 FLG=0.48 (68%)
	30sr CP=4.43 FLG=3.35 (32%)	30sr CP=-0.89 FLG=-0.37 (40%)
GSFC 2012	30sr CP=-2.59 FLG=0.07	

Table 2 Summary of principal CRE (Wm^{-2}) differences between FLG and CP radiative transfer model depending on year and on land/ocean.

Figures

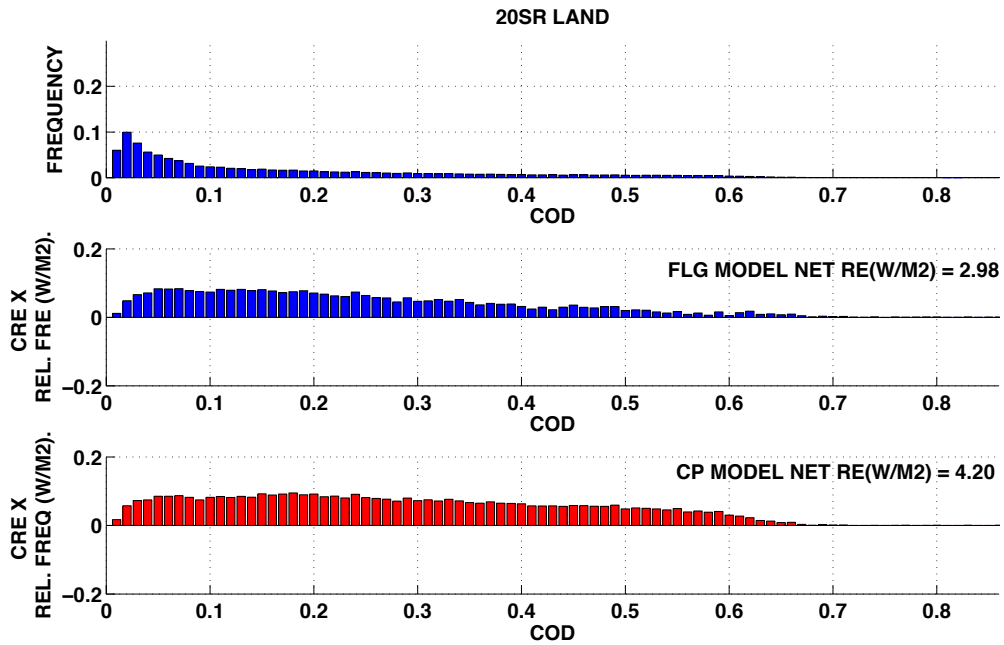


Figure 1 Analysis over land (Albedo=0.12) for 20sr solution. CRE vs. COD is weighted by occurrence frequency for Corti and Peter(red) and FLG (blue) models over 2010-2011

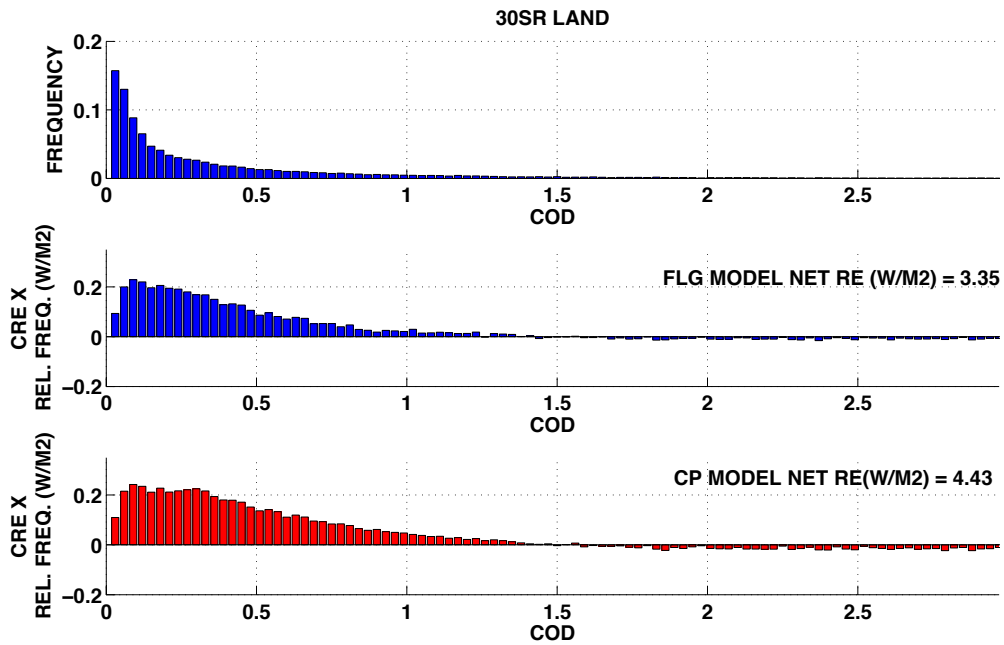


Figure 2 Analysis over land (Albedo=0.12) for 30sr solution. CRE vs. COD is weighted by occurrence frequency for Corti and Peter(red) and FLG (blue) models on 2010-2011.

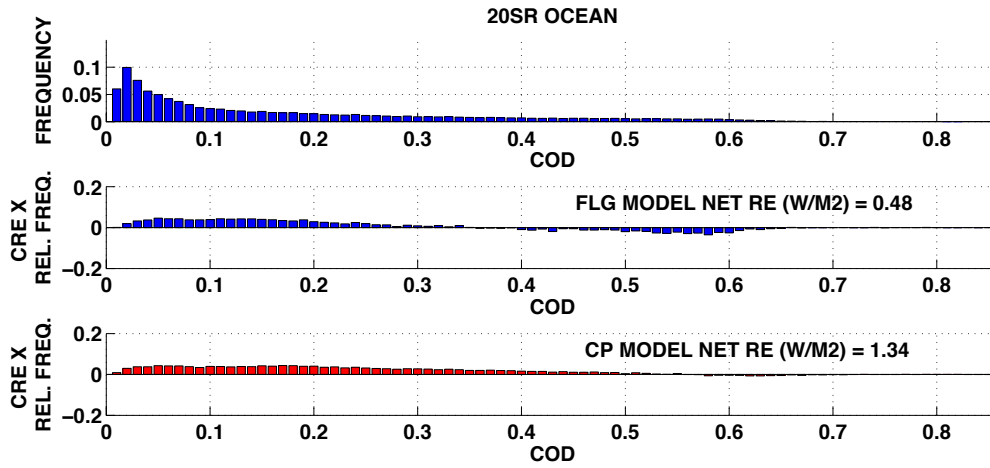


Figure 3 Same as Figure 1, but over the ocean (Albedo=0.05)

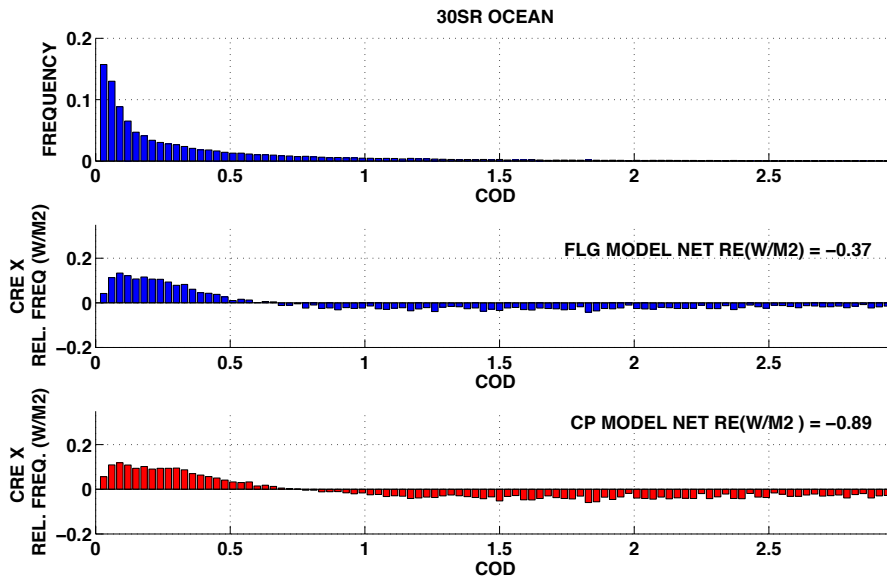


Figure 4 Same as Figure 2, but over the ocean (Albedo=0.05)

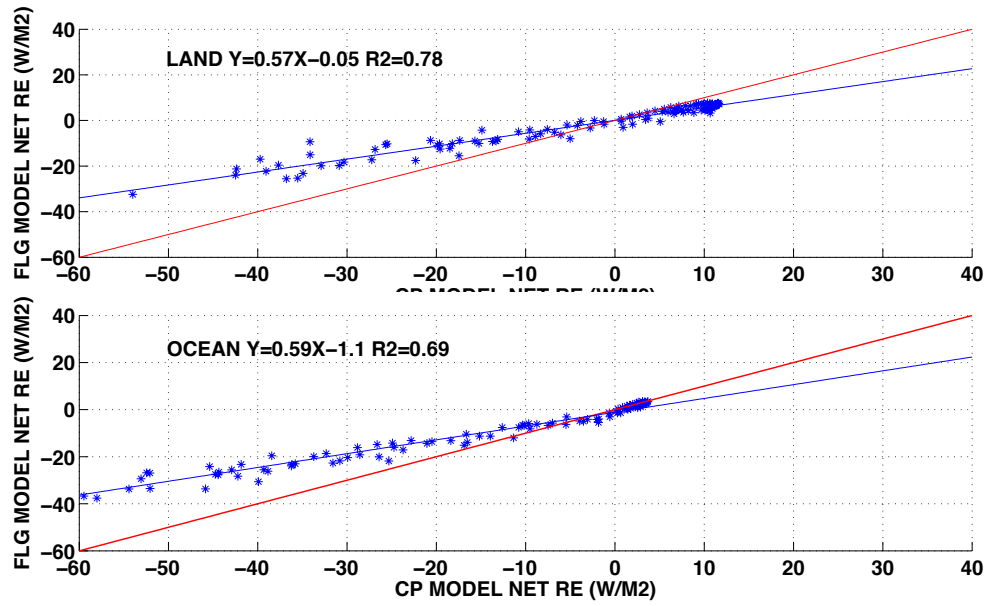


Figure 5 Scatter plot and linear regression for 30sr solution for FLG and CP CRE in 2010-2011 over land (upper panel) and ocean (lower panel)

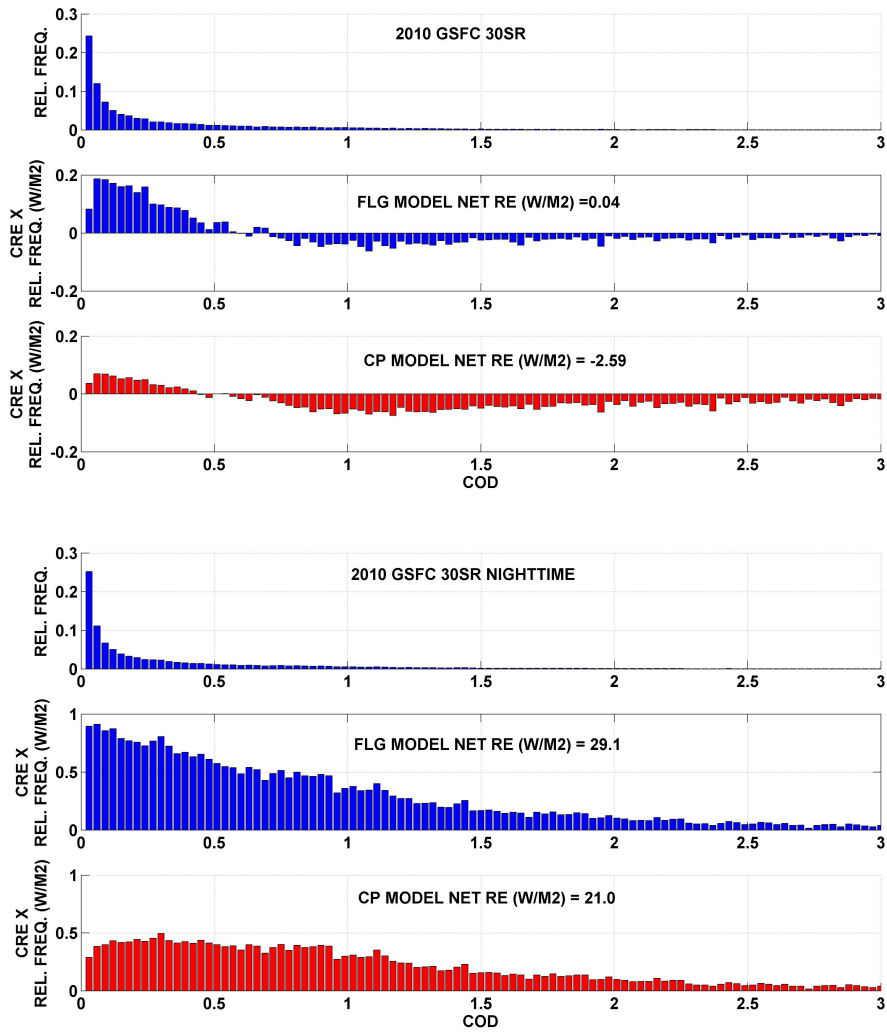


Figure 6 Analysis on 2010 dataset from MPLNET GSFC observational site for 30sr solution daytime (upper panel) and nighttime (lower panel).

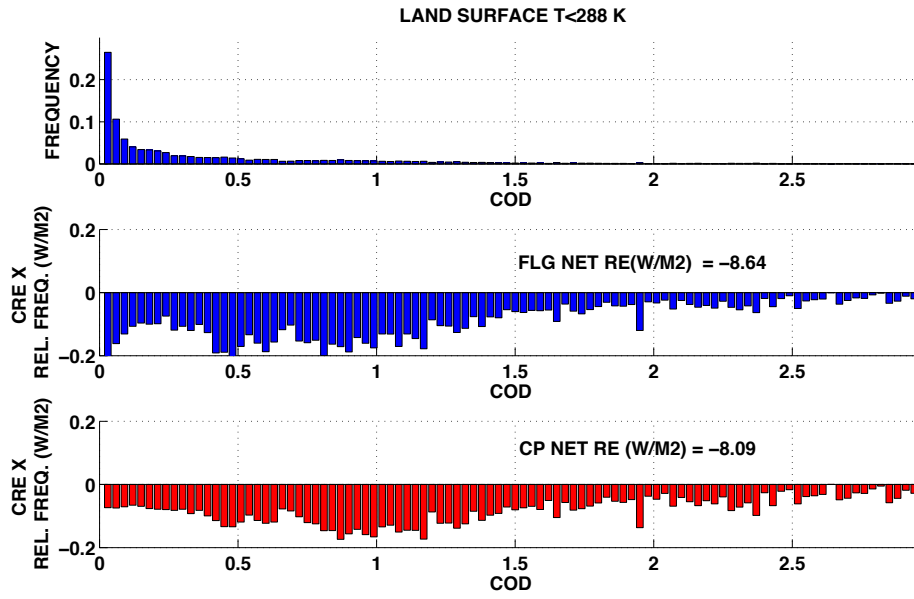


Figure 7 Same as Figure 6, taking out those measurements with a land surface temperature $T_{\text{surf}} > 288\text{K}$