

# UNDERSTANDING SEASONAL VARIABILITY IN THIN CIRRUS CLOUDS FROM CONTINUOUS MPLNET OBSERVATIONS AT GSFC IN 2012

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## ABSTRACT

Optically thin cirrus cloud (optical depth  $< 0.3$ ) net radiative forcing represents one of the primary uncertainties in climate feedback, as sub-visible clouds play a fundamental role in atmospheric radiation balance and climate change. A lidar is a very sensitive optical device to detect clouds with an optical depth as low as  $10^{-4}$ . In this paper we assess the daytime net radiative forcing of sub-visible cirrus clouds detected at Goddard Space Flight Center, a permanent observational site of the NASA Micro Pulse Lidar Network in 2012. Depending on their height, season and hour of the day, the solar albedo effect can outweigh the infrared greenhouse effect, cooling the earth-atmosphere system rather than warming it exclusively. As result, based on latitude, the net forcing of sub-visible cirrus clouds can be more accurately parameterized in climate models.

## 1. INTRODUCTION

Cirrus clouds, and especially optically thin ice crystal clouds with an optical depth below 0.03 exist globally [1], but are mostly found in the tropical upper troposphere, where the temperature is very low [2]. These sub-visible cirrus clouds (SVC) have been investigated over several decades both from in-situ measurements through airborne probes [15] and through ground-based lidar profiling [1]. SVC clouds are responsible for a large proportion of the uncertainties of climate change projections by General Circulation Models (GCM). This comes from poorly understood and represented interactions and feedbacks between dynamic, microphysical and radiative processes affecting cirrus clouds ([3], [4]). A recent IPCC report (AR4) shows that different climate models parameterize ice formation in a very simplified

way, leading to a factor of ten in difference between zonally averaged Ice Water Content (IWC; [5]). As a consequence, climate modeling is very sensitive to small changes in cirrus coverage or ice microphysics. Large uncertainties in climate prediction caused by processes involving cirrus clouds highlight the importance of more quantitative information by observation, especially on SVC.

SVC are primary regulators of water vapor concentrations in the upper troposphere-lower stratosphere region, which plays a fundamental role in atmospheric radiation balance [15] and then climate change effects seen at the surface. Lidars are ideally sensitive to detecting clouds with an optical depth (COD) as low as  $10^{-4}$ . The main purpose of this study is to assess properties and the seasonal variability of SVC net radiative effect and statistical properties, detected at Goddard Space Flight Center (GSFC), a permanent observational site of the NASA Micro Pulse Lidar NETWORK (MPLNET) in 2012.

## 2. METHODOLOGY

MPLNET [6], [7], [12], [13] is a global federated lidar network, begun in 1999, which counts more than twenty stations (deployed worldwide, from tropics, mid-latitudes, equator, Arctic and Antarctic regions) equipped with homogenous single wavelength elastic commercially available lidars. Project instruments sample the atmosphere continuously with a spatial resolution of 75m and a temporal resolution of 1 min in all different meteorological conditions. Measurements are centrally processed in near-real time at GSFC, and are made publicly available online to the scientific community (<http://mplnet.gsfc.nasa.gov>).

The new Version 3 (V3) MPLNET cloud algorithm (Lewis et al., 2015, *in progress*) is applied in this study to detect single-layer optically-thin clouds profiled at the GSFC site in 2012. The cloud extinction profile is retrieved simultaneously at 20 and 30 sr, respectively, to replicate the potential variance within this applied solution. All cloud samples are included, depending on the temporal sampling resolution used to resolve them in the V3 product (1, 5 or 20 min averaging). SVC microphysical properties are retrieved using [8] parameterization. *IWC* and average ice crystal dimensions (*D<sub>ge</sub>*) profiles are retrieved by integrating lidar cloud extinction at both 20/30 sr settings with WMO radiosonde temperature and pressure measurements from nearby Sterling, Virginia (~ 50 km).

Radiative forcing parameters are calculated with the Fu-Liou-Gu (FLG) radiative transfer code [9], [10]. FLG is a  $\delta$ -four stream transfer scheme for flux calculations in both solar and infrared spectra, which are divided into six and twelve bands, respectively. The K-distribution method is used to parameterize non-gray gaseous absorption by CH<sub>4</sub>, O<sub>3</sub>, CO<sub>2</sub> and H<sub>2</sub>O. Parameterization of cirrus clouds assumes hexagonal ice crystals, randomly-oriented, and combines the extinction coefficient  $\alpha$  with *D<sub>ge</sub>* and *IWC* at each range bin *r* as:

$$\alpha(r) = \frac{4(3)^{1/3}}{3\rho_i} \frac{IWC(r)}{D_{ge}(r)} \quad (1)$$

where  $\rho_i$  is the ice density. The vertically resolved ice crystal mean effective size *D<sub>ge</sub>* (in  $\mu\text{m}$ ) is calculated with an empirical formula that links crystal size and cloud top temperature [8].

### 3. RESULTS

At GSFC in 2012, more than 1e4 SVC cases were profiled. Each cloud is characterized by several parameters, including radiative forcing, cloud optical depth, cloud thickness, cloud position, etc., making a visualization of n-dimensional space impossible.

Principal Component Analysis (PCA) is a common multivariate statistical technique that reveals what variables in a given dataset form a coherent subset that is relatively independent of one another. PCA extracts the maximum variance from a data set with each component. The first

principal component is the linear combination of observed variables that efficiently separate subjects by maximizing the variance of their component scores. The second component is computed from the residual correlation. It is the linear combination of observed variables that extracts maximum variability. This variability is uncorrelated with the first component. The subsequent components also extract maximum variability from the residual correlations and are independent from all the other components. The extracted components represent most of the variance of the original data set and can be used in further analysis, like for characterizing the most common cirrus cloud features and how they change with season. PCA is applied here in this analysis seasonally. Each cirrus cloud is represented as a point the 10-dimensional space with parameters reported in Table 1.

PCA parameters	Units/Values
Net cloud forcing (TOA)	W/m <sup>2</sup>
COD	--
Day/Night	1 Day – 0 Night
Cloud Top	Km
Dge	$\mu\text{m}$
pIWC	g/m <sup>2</sup>
Ground-Cloud Top Diff.	K
SZA	Deg
Cloud Top Temp	K
DOY	--

Table 1 Cirrus cloud retrieved and measured parameters.

Figure 1 shows how SVC cluster together. The two primary clusters represent daytime (upper strip) and nighttime clouds (lower strip). The first component (PC1) is related to cloud top temperature, cloud top altitude, crystal average size and the temperature difference between the ground and cloud top (higher factor loading). This component is characterized as the thermodynamic properties of SVC.

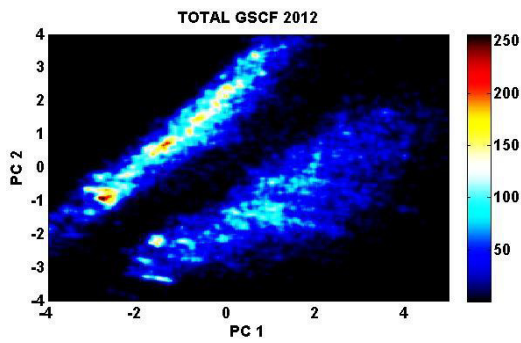


Figure 1 SVC PCA analysis at Goddard in 2012. The two distinct patterns represent day(up) and night (down) clouds. PC 1 and PC2 are the scores related to the first and second component, linear combination of parameters in Table 1.

SVC with higher values on PC1 are those clouds with warmer cloud tops, lower in altitude, with bigger crystals and IWC but with a smaller difference between ground temperature and cloud top.

The second component (PC2) relates to net TOA cloud radiative forcing (CRF), day/night flag and solar zenith angle. PC2 is thus characterized by the radiative properties of the cloud, and higher PC2 scores in Fig. 1 represent SVC with lesser CRF (in absolute value) and lower SZA. While nighttime clouds are always warming clouds, daytime SVC can both cool and warm the earth-atmosphere system depending on SZA and cloud top altitude (the former is related to the IWC and the latter to the crystal average size; [11]). The main daytime cluster (case density > 100) shows that SVC are cooling the atmosphere when cloud top is generally lower than 11.5 km.

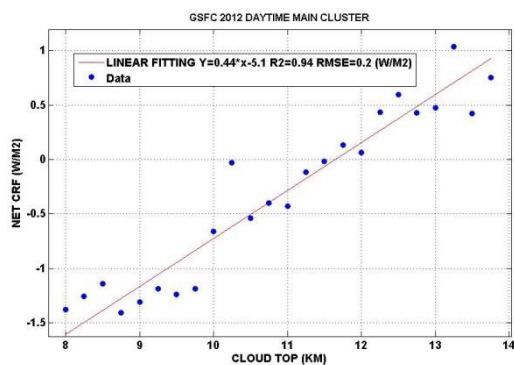


Figure 2 Daytime main cluster (density>100) showing Net Cloud Radiative Forcing (CRF) vs. cloud top altitude (Km). 11.5Km cut-off point from cooling to warming

Conversely, SVC warm the atmosphere when the SZA is generally less than 54 degrees.

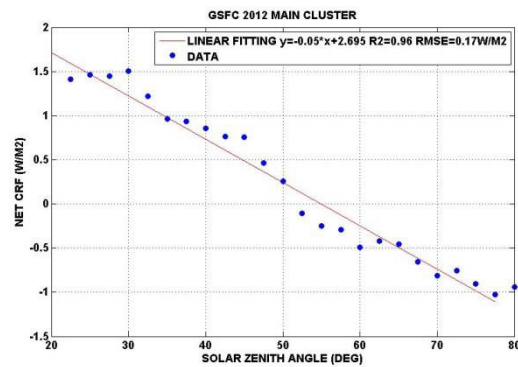


Figure 3 Daytime main cluster (density>100) showing Net Cloud Radiative Forcing (CRF) vs. SZA (deg). For SZA= 54 deg transition from warming to cooling.

By performing this same analysis seasonally, we derive approximate threshold SZA and SVC separating daytime cooling and warming (Table 2)

	CLOUD TOP	SZA
DJF	12.25 KM	37.5
MAM	11.1 KM	61
JJA	10.8 KM	64
SON	11.4 KM	58

Table 2 Seasonal variability of transition point between cooling and warming (Cloud Top) and warming and cooling (SZA).

During winter, daytime SVC are more prone to cool the atmosphere, as threshold points are 12.25 km for cloud top height and 37.5 degrees for SZA. Summer SVC are more keen to warm the earth-atmosphere, as threshold top is 10.8 Km and SZA 64 deg. Keep in mind that this analysis relates both to common seasonal distributions of SVC heights and the duration of the solar day relative to SZA.

#### 4. CONCLUSIONS

From new Version 3 Micro Pulse Lidar cloud products, 1e4 optically thin cirrus clouds (COD <0.03, or sub-visual cirrus; SVC) were profiled in 2012 at NASA GSFC permanent MPLNET observation site. For each cloud, net radiative forcing was calculated with Fu-Liou-Gu code, where retrieved cloud extinction is related to both IWC and the average crystal size (Dge) after integrating local radiosonde temperature profiles. Principal components analysis (PCA) is used to

reduce dimensions and visualize the main cloud clusters by their thermodynamic and radiative properties. Daytime PCA clusters are evaluated to determine when the solar albedo effect is outweighing the infrared greenhouse effect, producing a net cooling effect.

Surprisingly, thin cirrus clouds, depending on position and hour of the day, are primarily atmospheric coolers, contradicting previous results in literature. Seasonally, the variability of threshold cloud top and solar zenith angle (SZA) values indicate that SVC during winter are more prone to cool the atmosphere.

This study is a first step toward reducing the uncertainty in parameterization of the net radiative forcing of thin cirrus cloud in global climate models. Further analysis will be performed on other years and MPLNET sites.

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