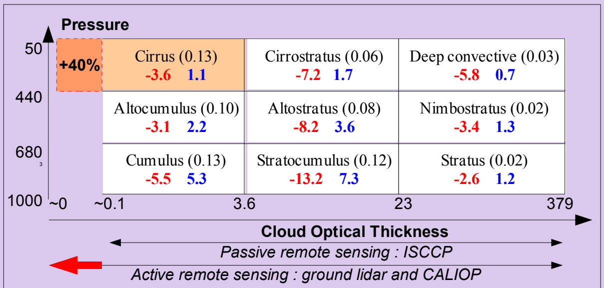
Observed cirrus cloud radiative forcing on surface-level shortwave and longwave irradiances

Jean-Charles Dupont*[1], Martial Haeffelin[2]

[1] Laboratoire de Météorologie Dynamique, Ecole Polytechnique, 91128 Palaiseau Cedex, France
[2] Institut Pierre et Simon Laplace, Ecole Polytechnique, 91128 Palaiseau Cedex, France

*Corresponding author : jean-charles.dupont@lmd.polytechnique.fr

1. Introduction

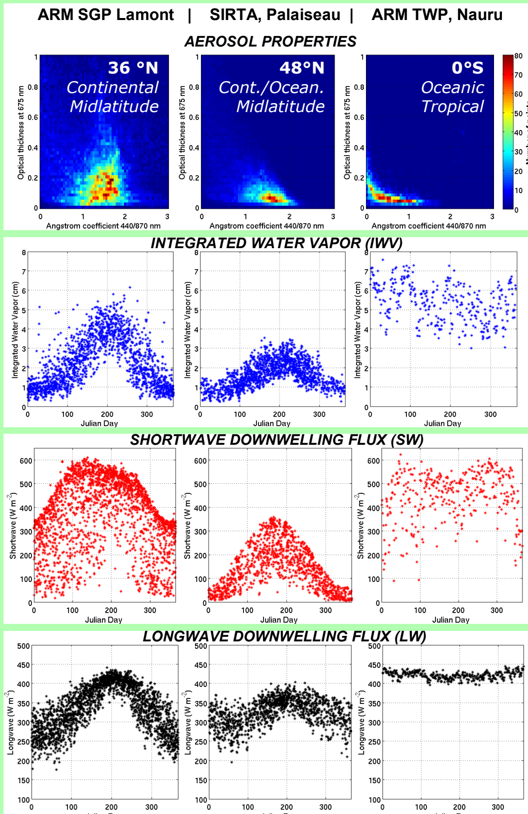


(Cloud amount), CRF_{SW} and CRF_{LW} (W m^{-2}). [Chen et al. 2000]

The radiative effects of high altitude clouds on the surface energy budget, in both the solar and infrared spectrum, are well known but not well quantified. In fact, satellite climatologies based on passive remote sensing measurements reveal high occurrence of cirrus clouds (13% average over the globe) but are not sensitive to the optically thin clouds, typically with cloud optical thickness smaller than 0.1. Long records of ground lidar measurements and recent CALIOP profiles however show that these optically thin clouds represent 50% or more of cirrus cloud population. Hence, the relatively small instantaneous radiative effect of these cirrus clouds can engender a significant cumulative Cloud Radiative Forcing (CRF) for shortwave (CRF_{SW}) and longwave (CRF_{LW}) irradiances. The quantification of this cirrus cloud radiative forcing requires precise reference, typically with RMS error < 10 W m^{-2}, of solar and infrared irradiance for the cloud free atmosphere determined here by a combined analysis of lidar and broadband flux measurements.

2. Climatologies of AOT, IWV, SW and LW fluxes

We analyze solar and infrared irradiance measurements, cloud and aerosol Lidar backscattering profiles, microwave radiometer brightness temperatures, radiosonde profiles, and sun-photometer extinctions located in midlatitude region (ARM SGP Lamont, SIRTA Palaiseau), in tropical region (ARM TWP Darwin, ARM TWP Nauru) and arctic region (ARM NSA Barrow).



3. Clear-sky period detection and clear-sky references

Clear-Sky = ***cloud free*** = sky without any liquid water or ice cloud (high or low altitude, high or low cloud fraction)

Clear-Sky periods detected by 3 thresholds

Lidar algorithm [Morille et al., 2007]	LongWave flux algorithm [Dürr and Philipona, 2004]	ShortWave flux algorithm [Long and Ackerman, 2000]
remove cirrus clouds from the dataset	detect low and middle level cloud	detect low and middle level cloud → hazy cases [Dupont et al., 2008]

=> Clear-sky parameterizations directly fit to observed data

ShortWave Clear-Sky Model

$$SWCSM = a \times \cos(SZA)^{b} \times c^{1/\cos(SZA)} + \Phi_{(AOT,\ IWV)}$$

[Dutton et al. 2001] — Corrective function

a : solar constant adjusted for the Earth-Sun distance for each site
b, **c** : constants adjusted on clear-sky atmosphere and correspond to average scattering of atmosphere for each site

AOT : Aerosol Optical Thickness at 675 nm ;
IWV : Integrated Water Vapor (cm)

Mean RMS error = 10 W/m²

LongWave Clear-Sky Model

$$LWCSM = \frac{\overbrace{\alpha \times (e/T)^{1/7}}^{\varepsilon_{Brutsaert}}}{\Gamma_{(e,\ T,\ IWV)}} \times \sigma \times \left[\frac{T}{\Pi_{(T)}}\right]^{4}$$

[Dupont et al., 2008]

T : 2m-height temperature (K)
e : water vapor pressure near the surface (hPa)
IWV : Integrated Water Vapor (cm)
σ : 5.67*10^{-8} W m^{-2} K^{-4}
α : constant adjusted on clear-sky periods
Γ : proxy for vertical distribution of humidity
Π : proxy for thermal inertia of atmosphere

Mean RMS error = 2 W/m²

RMS errors associated to these cloud-free reference (< 10 W m^{-2}) allow us to quantify very precisely cirrus cloud radiative forcing.

4. Shortwave high altitude cloud impact

Cloud Radiative Forcing (CRF) for shortwave (CRF_{SW}) and longwave (CRF_{LW}) irradiances are obtained by the difference between the measured surface downwelling irradiance and the cloud-free references.

Observed cirrus cloud radiative forcing for shortwave flux (W m^{-2})				
	SIRTA Palaiseau, 48°N	ARM SGP Lamont, 36°N	ARM TWP Nauru,0°S	NSA SGP Barrow,71°N
Cirrus occurrence (%)[1]	49,0	25,6	43,2	3,2
CRF_{SW}	-28 (-13,7)[2]	-32 (-8,2)[2]	-38 (-16,4)[2]	-25 (-0,8)[2]
Standard deviation	72,0	64,0	65,0	41,0
Standard error	10,0	11,0	6,6	7,3
Relationship between CRF_{SW} and COT (slope in W m^{-2} COT^{-1})				
All atmosphere	-130,7 ± 5.1	-122,8 ± 9,7	-123,2 ± 5	-201,5 ± 8,9
Turbid atmosphere	-121,1 ± 4 (-8 %)	-117,3 ± 5 (-5 %)	-114,8 ± 5 (-7 %)	-114,4 ± (-43 %)
Pristine atmosphere	-146,1 ± 4 (+11 %)	-137 ± 8 (+11 %)	-157,6 ± 4 (+28 %)	-237,4 ± (+17 %)

[1] Cirrus present in lidar observations
[2] mean impact multiplied by the cirrus occurrence

Average sensitivity of CRF_{SW} to COT is more important for Artic region (-200 W m^{-2} COT^{-1}) than for Midlatitude region (-130 W m^{-2} COT^{-1}) due to low IWV. The mask effect of atmosphere below the cloud ranges from -5 % to -40 % for Midlatitude and Arctic region respectively.

Note : At ARM TWP Darwin, we find a mean shortwave radiative impact of cirrus clouds of ~-24 ± 7 W m^{-2} and a slope of -440 ± 5 W m^{-2} COT^{-1} for the period between May and October 2005.

5. Longwave high altitude cloud impact

LW_{cirrus} corresponds to infrared flux emitted by cirrus cloud calculated by $LW_{cirrus} = \varepsilon_{cloud} \times \sigma \times T_{mean\ cloud}^{4}$ (ε_{cloud} is the infrared emissivity and $T_{mean\ cloud}$ is the average temperature inside cirrus cloud).

Observed cirrus cloud radiative forcing for longwave flux (W m^{-2})				
	SIRTA Palaiseau, 48°N	ARM SGP Lamont, 36°N	ARM TWP Nauru,0°S	NSA SGP Barrow,71°N
Cirrus occurrence (%)[1]	49,0	25,6	43,2	3,2
Mean impact	6,6 (3,2)[2]	8,9 (2,3)[2]	0,8 (0,3)[2]	5,5 (0,2)[2]
Standard deviation	9,9	7,7	6,5	7,0
Standard error	1,9	1,8	1,0	2,7
Relationship between CRF_{LW} and LW_{cirrus}				
CRF_{LW}/LW_{cirrus}	0,24	0,28	0,03	0,4
Mean IWV, *cm*	1,4	1,5	4,7	1,1

[1] Cirrus present in lidar observations
[2] mean impact multiplied by the cirrus occurrence

Instantaneous CRF_{LW} is more important in Artic and Midlatitude region (5-9 W m^{-2}) than in Tropical region (1 W m^{-2}). Sensitivity of CRF_{LW} to LW_{cirrus} ranges from 40%, 26% to 3%, for Artic, Midlatitude and Tropical sites respectively.

Note : At ARM TWP Darwin data, we find a mean longwave radiative impact of cirrus clouds of ~ +5 W m^{-2}.

6. Conclusions & Perspectives

Instantaneous radiative effect of high altitude clouds, both shortwave and longwave fluxes, is limited to near -30 and +7 W m^{-2} respectively. However, the significant coverage of cirrus clouds increases the contribution of these clouds to the total radiation budget compared to the other types of clouds [Chen et al., 2000]. Average sensitivity of CRF_{SW} to COT (-130 W m^{-2} COT^{-1}) ranges from -43 % to +28 % for turbid and pristine atmospheres respectively. Relationship between CRF_{LW} and infrared irradiance emitted by the cirrus clouds ranges from 3 to 40 % and strongly depends on the atmospheric humidity. Cirrus clouds detected by lidar but not by passive instruments (COT<0.1) have a mean impact near -5 and +1.1 W m^{-2} for SW and LW irradiances respectively. Future work consists in applying the relationships between cirrus cloud radiative forcing and macrophysical properties of these clouds at a global scale.

References

Chen, T., W. B. Rossow, and Y. Zhang (2000), Radiative effects of cloud-type variations. *J. Climate, 13*, 264–286.
Dupont J.C., M. Haeffelin, P. Drobinski and T. Besnard (2008), Parametric model to estimate clear-sky longwave irradiance at the surface based on vertical distribution of humidity and temperature, *JGR*
Dupont J.C., M. Haeffelin, C. N. Long (2008), Evaluation of cloudless-sky periods detected by shortwave and longwave algorithms using lidar measurements, *GRL*
Dürr B., R. Philipona (2004), Automatic cloud amount detection by surface longwave downward radiation measurements, *Journal of Geophysical Research*, *109*, D05201,
Long C. N., T. P. Ackerman, K. L. Gaustad and N. S. Cole (2006), Estimation of fractional sky cover from broadband shortwave radiometer measurements, *JGR*
Morille, Y., M. Haeffelin, P. Drobinski, J. Pelon (2007), STRAT : an automated algorithm to retrieve the vertical structure of the atmosphere from single channel lidar data, *JAOT*

Acknowledgements

The authors would like to thank the Centre National de la Recherche Scientifique (CNRS) and the Office National d'Etudes et de Recherches Aérospatiales (ONERA) for their support in this study and the Atmospheric Radiation Measurement (ARM) Program for the data.