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Supplement of

A first global height-resolved cloud condensation nuclei data set derived from spaceborne lidar measurements

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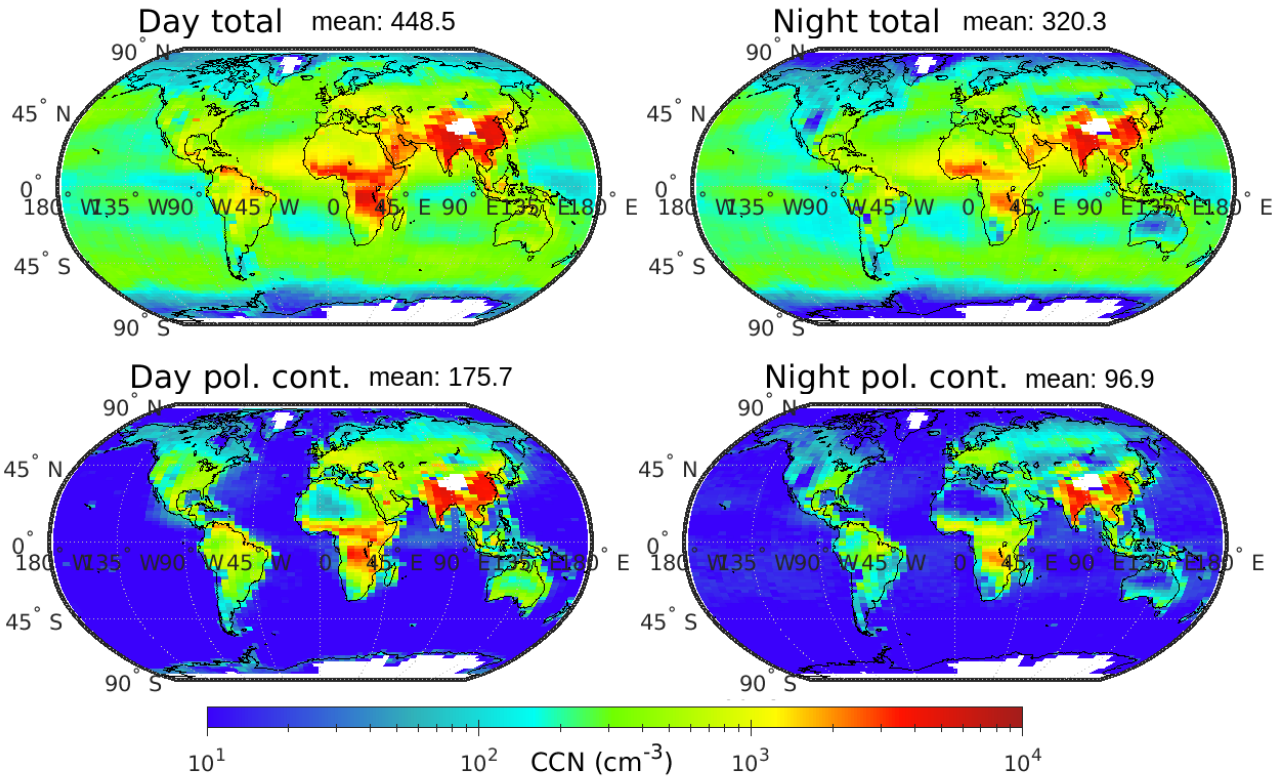

Figure S1: CCN daytime (left column) and nighttime (right column) climatology estimated using more than 15 years of CALIPSO level 2 aerosol profile product (June 2006 to December 2021). The top and bottom row represents the total CCN and polluted continental CCN concentrations, respectively.

S1 MATLAB plotting routines

S1.1 Codes for re-producing Figure 2

```
%% Figure 2
clc,clear,close all
% model data
model_path = 'surface_global_models_year2011.hdf';
mlat = double(hdfread(model_path, '/lat'));
mlon = double(hdfread(model_path, '/lon'));
mCCN = read_ccn_model(model_path);
mCCN_med = nanmedian(mCCN,3);
mCCN_max = nanmax(mCCN,[],3);
mCCN_min = nanmin(mCCN,[],3);

% CALIOP data
caliop_path = 'CCN_monthly_cloudfree_2011_8km.nc';
clat = double(ncread(caliop_path,'lat'));
clon = double(ncread(caliop_path,'lon'));
calt = double(ncread(caliop_path,'altitude'));
cCCN = double(ncread(caliop_path,'CCN'));
cN = double(ncread(caliop_path,'N'));
% annual average
cCCN1 = nansum(cCCN.*cN,4)./nansum(cN,4); % yearly average
% average CCN between altitudes of 0.5 and 1 km
```

```
cCCN1 = squeeze(nanmean(cCCN1(:,:,calt<1 & calt>0.5),3))';

% Regrid model data to CALIOP grid
[mlong,mlatg]=meshgrid(mlon,mlat);
[clong,clatg]=meshgrid(clon,clat);
mCCN_medc = interp2(mlong,mlatg,mCCN_med,clong,clatg);
mCCN_maxc = interp2(mlong,mlatg,mCCN_max,clong,clatg);
mCCN_minc = interp2(mlong,mlatg,mCCN_min,clong,clatg);
%%
close all
cm = customcolormap([0,0.15,0.3,0.5,0.65,0.85,1],
{'#a31d1b','#ff1300','#fffb02','#70ff00','#00fff3','#31b1b9','#3a01fb'});
clims = [10,1e4];
load coastlines.mat
%define size of subplots
xx = 11; yy=6.5;
f1 = figure('units','centimeters','position',[1,1,28.5,14.5]);
ax1 = axes('units','centimeters','position',[1,7,xx,yy]);
axis tight
% axesm('MapProjection','robinson');
worldmap('world')
pcolorm(clat,clon,cCCN1,'LineStyle','none')
plotm(coastlat,coastlon,'k');
set(gca,'ColorScale','log')
colormap(cm);
colorbar('off');
% cb.TickDirection= 'both'; cb.Ticks = [100,300,1000,3000,10000];
clim(clims)
text(0.01,1.1,'(a) CALIOP','FontSize',15,'units','normalized')
box off
ax2 = axes('units','centimeters','position',[13.5,7,xx,yy]);
axis tight
worldmap('world')
pcolorm(clat,clon,mCCN_medc,'LineStyle','none')
plotm(coastlat,coastlon,'k');
set(gca,'ColorScale','log')
colormap(cm);
colorbar('off');
clim(clims)
text(0.01,1.1,'(b) Models median','FontSize',15,'units','normalized')

ax3 = axes('units','centimeters','position',[1,0,xx,yy]);
axis tight
worldmap('world')
pcolorm(clat,clon,mCCN_maxc,'LineStyle','none')
plotm(coastlat,coastlon,'k');
set(gca,'ColorScale','log')
colormap(cm);
colorbar('off')
clim(clims)
text(0.01,1.1,'(c) Models maximum','FontSize',15,'units','normalized')

ax4 = axes('units','centimeters','position',[13.5,0,xx,yy]);
axis tight
worldmap('world')
pcolorm(clat,clon,mCCN_minc,'LineStyle','none')
plotm(coastlat,coastlon,'k');
```

```
set(gca,'ColorScale','log')
colormap(cm);
clim(clims)
% colorbar(ax4a,'off')
text(0.01,1.1,'(d) Models minimum','FontSize',15,'units','normalized')
%%%%%%%%%%%%%%% colorbar %%%%%%%%%%%%%%%%%%
cb = colorbar(ax4);
ylabel(cb,'n_{CCN} (cm^{-3}) ss=0.2 %','FontSize',16)
cb.TickDirection= 'both'; cb.Ticks = [10,30,100,300,1000,3000,10000];
cb.Position = cb.Position+[0.065,0.2,0,0.2];
saveas(f1,'fig02.png')
```

S1.2 Codes for re-producing Figure 3

```
% Figure 3
clc,clear,close all
% load the climatology data
file_path = 'CCN_climatology_cloudfree_8km.nc';
lat = double(ncread(file_path,'lat'));
lon = double(ncread(file_path,'lon'));
altitude = double(ncread(file_path,'altitude'));
CCN = double(ncread(file_path,'CCN_cl'));
CCN_d = double(ncread(file_path,'CCN_cl_d'));
CCN_m = double(ncread(file_path,'CCN_cl_m'));
CCN_es = double(ncread(file_path,'CCN_cl_es'));
CCN_pc = double(ncread(file_path,'CCN_cl_pc'));

% altitude < 2
altid = altitude>0 & altitude<2;
% average for a altitude < 2 km
aCCN= nanmean(CCN(:,:,altid),3);
aCCN_d = nanmean(CCN_d(:,:,altid),3);
aCCN_m = nanmean(CCN_m(:,:,altid),3);
aCCN_es = nanmean(CCN_es(:,:,altid),3);
aCCN_pc = nanmean(CCN_pc(:,:,altid),3);

% land ocean separate
load coastlines.mat
[latgr,longr] = meshgrid(lat,lon);
[land_id] = inpolygon(longr(:),latgr(:),coastlon,coastlat);
land_id = reshape(land_id,size(latgr));
cal_land_id = repmat(land_id,1,1,size(CCN,3));
%%
close all

cm = customcolormap([0,0.15,0.3,0.5,0.65,0.85,1],
{'#a31d1b','#ff1300','#fffb02','#70ff00','#00fff3','#31b1b9','#3a01fb'});
clims = [10,1e4];
xx = 9; yy=5; x0 = 11; y0 = 13;
x1 = [6,16.5]; y1 = [6.5,0.8];
f2 = figure('units','centimeters','position',[1,1,31.5,19]);
ax0 = axes('units','centimeters','position',[x0,y0,xx,yy]);
axis tight
worldmap('world')
pcolorm(lat,lon,aCCN','LineStyle','none')
plotm(coastlat,coastlon,'k');
```

```
set(gca,'ColorScale','log')
colormap(cm);
colorbar('off');
% cb.TickDirection= 'both'; cb.Ticks = [100,300,1000,3000,10000];
caxis(clims)
text(0.01,1.1,'(a) Total CCN','FontSize',15,'units','normalized')
%%%%%%%%%%
ax1 = axes('units','centimeters','position',[x1(1),y1(1),xx,yy]);
axis tight
worldmap('world')
pcolorm(lat,lon,aCCN_d','LineStyle','none')
plotm(coastlat,coastlon,'k');
set(gca,'ColorScale','log')
colormap(cm);
colorbar('off');
% cb.TickDirection= 'both'; cb.Ticks = [100,300,1000,3000,10000];
caxis(clims)
text(0.01,1.1,'(b) Dust CCN','FontSize',15,'units','normalized')

ax2 = axes('units','centimeters','position',[x1(2),y1(1),xx,yy]);
axis tight
worldmap('world')
pcolorm(lat,lon,aCCN_pc','LineStyle','none')
plotm(coastlat,coastlon,'k');
set(gca,'ColorScale','log')
colormap(cm);
colorbar('off');
caxis(clims)
text(0.01,1.1,'(c) Polluted continental CCN','FontSize',15,'units','normalized')

ax3 = axes('units','centimeters','position',[x1(1),y1(2),xx,yy]);
axis tight
worldmap('world')
pcolorm(lat,lon,aCCN_m','LineStyle','none')
plotm(coastlat,coastlon,'k');
set(gca,'ColorScale','log')
colormap(cm);
colorbar('off')
caxis(clims)
text(0.01,1.1,'(d) Marine CCN','FontSize',15,'units','normalized')

ax4 = axes('units','centimeters','position',[x1(2),y1(2),xx,yy]);
axis tight
worldmap('world')
pcolorm(lat,lon,aCCN_es','LineStyle','none')
plotm(coastlat,coastlon,'k');
set(gca,'ColorScale','log')
colormap(cm);
caxis(clims)
% colorbar(ax4a,'off')
text(0.01,1.1,'(e) Elevated smoke CCN','FontSize',15,'units','normalized')
%%%%%%%%%%%%%%%% colorbar %%%%%%%%%%%%%%%%%%
cb = colorbar(ax0);
ylabel(cb,'n_{CCN} (cm^{-3}) ss=0.2 %','FontSize',13)
cb.TickDirection= 'both'; cb.Ticks = [10,30,100,300,1000,3000,10000];
cb.Position = cb.Position+[0.065,0.0,0,0.0];
```

```
%%%%%%%%%%%%%%%%%%%%%% Add profiles %%%%%%%%%%%%%%%%%%%%%%%%
xx1 = 4; yy1=5; dy = 0.3;
ax11 = axes('units','centimeters','position',[x0-xx1-1,y0+dy,xx1,yy1-0.5]);
pp = plot_cal_profile(CCN,altitude,cal_land_id);
legend(pp,{'Globe','Land','Ocean'},'FontSize',10)
text(0.02,0.93,'(a1)','FontSize',10,'units','normalized')
axes('units','centimeters','position',[x1(1)-xx1-1,y1(1)+dy,xx1,yy1-0.5]);
plot_cal_profile(CCN_d,altitude,cal_land_id);
xlabel('')
text(0.02,0.93,'(b1)','FontSize',10,'units','normalized')
axes('units','centimeters','position',[x1(2)+xx+1,y1(1)+dy,xx1,yy1-0.5]);
plot_cal_profile(CCN_pc,altitude,cal_land_id);
ylabel(''); xlabel('')
text(0.02,0.93,'(c1)','FontSize',10,'units','normalized')

axes('units','centimeters','position',[x1(1)-xx1-1,y1(2)+dy,xx1,yy1-0.5]);
plot_cal_profile(CCN_m,altitude,cal_land_id);
text(0.02,0.93,'(d1)','FontSize',10,'units','normalized')

axes('units','centimeters','position',[x1(2)+xx+1,y1(2)+dy,xx1,yy1-0.5]);
plot_cal_profile(CCN_es,altitude,cal_land_id);
ylabel('')
text(0.02,0.93,'(e1)','FontSize',10,'units','normalized')
saveas(f2,'fig03.png')
```

S1.3 Codes for re-producing Figure 4

```
clc,clear,close all
% load the climatology data
file_path = 'CCN_climatology_cloudfree_8km.nc';
lat = double(ncread(file_path,'lat'));
lon = double(ncread(file_path,'lon'));
altitude = double(ncread(file_path,'altitude'));
CCN.tot = double(ncread(file_path,'CCN_cl_sn'));
CCN.d = double(ncread(file_path,'CCN_cl_sn_d'));
CCN.es = double(ncread(file_path,'CCN_cl_sn_es'));
CCN.m = double(ncread(file_path,'CCN_cl_sn_m'));
CCN.pc = double(ncread(file_path,'CCN_cl_sn_pc'));
% separate the seasons for each aerosol type
type = {'tot','d','pc','m','es'};
for i=1:numel(type) % 4 seasons
    winter.(type{i}) = CCN.(type{i})(:,:,:,1);
    spring.(type{i}) = CCN.(type{i})(:,:,:,2);
    summer.(type{i}) = CCN.(type{i})(:,:,:,3);
    autumn.(type{i}) = CCN.(type{i})(:,:,:,4);
end

% crop w.r.t altitude
nCCN_cl_sn_a = squeeze(nanmean(CCN.tot(:,:,altitude>0 & altitude<2,:),3));
%%
close all
cm = customcolormap([0,0.15,0.3,0.5,0.65,0.85,1],
{'#a31d1b','#ff1300','#fffb02','#70ff00','#00fff3','#31b1b9','#3a01fb'});
clims = [10,1e4];
xx = 9; yy=5;
```

```
x1 = [6,16.5]; y1 = [7.5,1.5];
f3 = figure('units','centimeters','position',[1,1,31.5,14]);
ax1 = axes('units','centimeters','position',[x1(1),y1(1),xx,yy]);
axis tight
worldmap('world')
pcolorm(lat,lon,squeeze(nCCN_cl_sn_a(:,:,1))','LineStyle','none')
plotm(coastlat,coastlon,'k');
set(gca,'ColorScale','log')
colormap(cm);
colorbar('off');
% cb.TickDirection= 'both'; cb.Ticks = [100,300,1000,3000,10000];
clim(clims)
text(0.01,1.1,'(a) Winter (DJF)','FontSize',15,'units','normalized')

ax2 = axes('units','centimeters','position',[x1(2),y1(1),xx,yy]);
axis tight
worldmap('world')
pcolorm(lat,lon,squeeze(nCCN_cl_sn_a(:,:,2))','LineStyle','none')
plotm(coastlat,coastlon,'k');
set(gca,'ColorScale','log')
colormap(cm);
colorbar('off');
caxis(clims)
text(0.01,1.1,'(b) Spring (MAM)','FontSize',15,'units','normalized')

ax3 = axes('units','centimeters','position',[x1(1),y1(2),xx,yy]);
axis tight
worldmap('world')
pcolorm(lat,lon,squeeze(nCCN_cl_sn_a(:,:,3))','LineStyle','none')
plotm(coastlat,coastlon,'k');
set(gca,'ColorScale','log')
colormap(cm);
colorbar('off')
caxis(clims)
text(0.01,1.1,'(c) Summer (JJA)','FontSize',15,'units','normalized')

ax4 = axes('units','centimeters','position',[x1(2),y1(2),xx,yy]);
axis tight
worldmap('world')
pcolorm(lat,lon,squeeze(nCCN_cl_sn_a(:,:,4))','LineStyle','none')
plotm(coastlat,coastlon,'k');
set(gca,'ColorScale','log')
colormap(cm);
caxis(clims)
text(0.01,1.1,'(d) Autumn (SON)','FontSize',15,'units','normalized')
%%%%%%%%%%%%%%%% colorbar %%%%%%%%%%%%%%%%%%%
cb = colorbar(ax4,'southoutside');
text(-0.21,-0.07,'n_{CCN} (cm^{-3})','FontSize',12,'Units','normalized')
cb.TickDirection= 'both'; cb.Ticks = [10,30,100,300,1000,3000,10000];
cb.Position = cb.Position+[-0.27,-0.12,0.2,0];

%%%%%%%%%%%%%%%%%%%%%%%%%% ADD profiles %%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%
xx1 = 4; yy1=5; dy = 0.3;
clear pp
axes('units','centimeters','position',[x1(1)-xx1-1,y1(1)+dy,xx1,yy1-0.5]);
pp = plot_cal_profile_type(winter,altitude);
```

```
legend(pp,{'Total','Dust','Poll. Cont.','Marine','Smoke'},'FontSize',10)
xlabel('')
text(0.02,0.93,'(a1)','FontSize',10,'units','normalized')
axes('units','centimeters','position',[x1(2)+xx+1,y1(1)+dy,xx1,yy1-0.5]);
plot_cal_profile_type(spring,altitude);
ylabel(''); xlabel('')
text(0.02,0.93,'(b1)','FontSize',10,'units','normalized')

axes('units','centimeters','position',[x1(1)-xx1-1,y1(2)+dy,xx1,yy1-0.5]);
plot_cal_profile_type(summer, altitude);
text(0.02,0.93,'(c1)','FontSize',10,'units','normalized')

axes('units','centimeters','position',[x1(2)+xx+1,y1(2)+dy,xx1,yy1-0.5]);
plot_cal_profile_type(autumn,altitude);
ylabel('')
text(0.02,0.93,'(d1)','FontSize',10,'units','normalized')
saveas(f3,'fig04.png')
```

S1.4 Supporting functions

```
function [pp] = plot_cal_profile(CCN,altitude,land_id)
%
ccn_p = squeeze(mean(CCN,[1,2],'omitmissing'));
ccn_p_std = squeeze(std(CCN,0,[1,2],'omitmissing'));

ccn_land = CCN; ccn_land(~land_id)=nan;
ccn_ocean = CCN; ccn_ocean(land_id)=nan;

ccnl_p = squeeze(mean(ccn_land,[1,2],'omitmissing'));
ccno_p = squeeze(mean(ccn_ocean,[1,2],'omitmissing'));
hold on
pp(1) = plot(ccn_p,altitude,'k','LineWidth',2);
fill_line_y([ccn_p-ccn_p_std/4;flip(ccn_p+ccn_p_std/4)]',...
    [altitude;flip(altitude)]','k',0.2);

pp(2) = plot(ccnl_p,altitude,'--r','LineWidth',2);
pp(3) = plot(ccno_p,altitude,'--b','LineWidth',2);
ylim([0.25,8])
xlabel('CCN (cm^{-3})')
ylabel('Height (km)')
grid on
box on

end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [pp] = plot_cal_profile_type(ssn,altitude)

type = {'tot','d','pc','m','es'};
cc=[255,0,255;255,128,0;0,204,102;0,0,255;64,64,64]/255;
hold on
for i=1:5
    ccn_p = squeeze(mean(ssn.(type{i}),[1,2],'omitmissing'));
    pp(i) = plot(ccn_p,altitude,'color',cc(i,:),'LineWidth',2);
    if i==1
        ccn_p_std = squeeze(std(ssn.(type{i}),0,[1,2],'omitmissing'));
        fill_line_y([ccn_p-ccn_p_std/4;flip(ccn_p+ccn_p_std/4)]',...
```

```
            [altitude;flip(altitude)]',cc(i,:),0.2);
    end
end
ylim([0.25,8])
xlim([0,600])
xlabel('CCN (cm^{-3})')
ylabel('Height (km)')
grid on
box on
end
```