Organic (OC) and Elemental (EC) Carbon in Central Greenland Air and Snow: Towards a Better Understanding of Sources, Source Regions and Radiative Forcing

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Important Questions

- **What are the concentrations, sources, and source regions of particulate carbon in the air and snow at Summit, Greenland?**
- **Do post-depositional processes, in particular photochemistry, influence the concentrations of particulate carbon within the snowpack?**
- **To what extent are light absorbing aerosols, including OC/EC, and dust, impacting the radiation balance of the Greenland Ice Sheet?**
- **How does the variability in surface snow albedo influence direct aerosol radiative forcing?**

Sampling overview

- Timeline: May through July, 2006
- Avoidance of camp impact: measurements at Satellite Camp (~1 km from main camp), sector-control in place to flag/shut-off sampling

Near-real-time samples:

$PM_{0.1\text{-}1.0}$, σ_{ap}, gas/particle OC

Filter samples: 80-160 hrs

Particle OC/EC/WSOC, trace organics

Sampling overview

Surface snow:

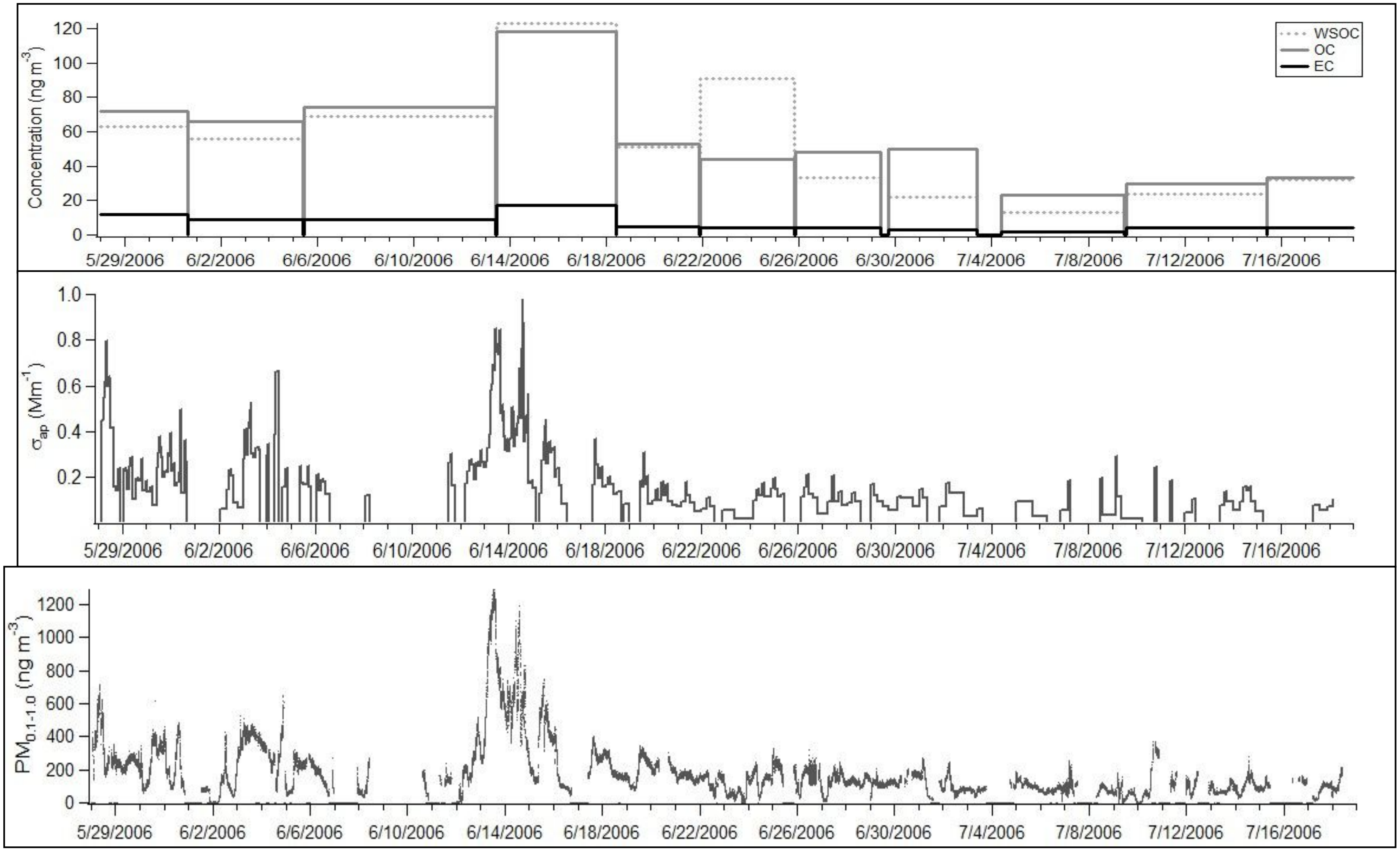
- Daily: for EC and OC
- 4-6 hours: water-soluble OC
- 3 Day exposure of isotopically labeled specific organics

Snow pits

3 meter pit:

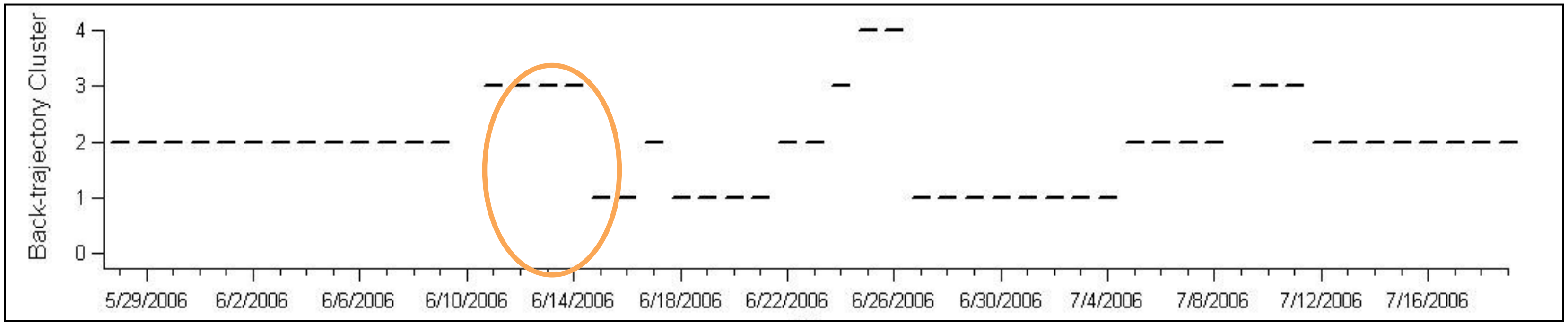
- OC, EC, WSOC, ions, deuterium ratio, elements
- Speciated Organics, LCW absorption
- *1 meter pits (6):*
- At Summit Camp and up to 20 km N and S of camp
- Sampled for OC, EC, absorption

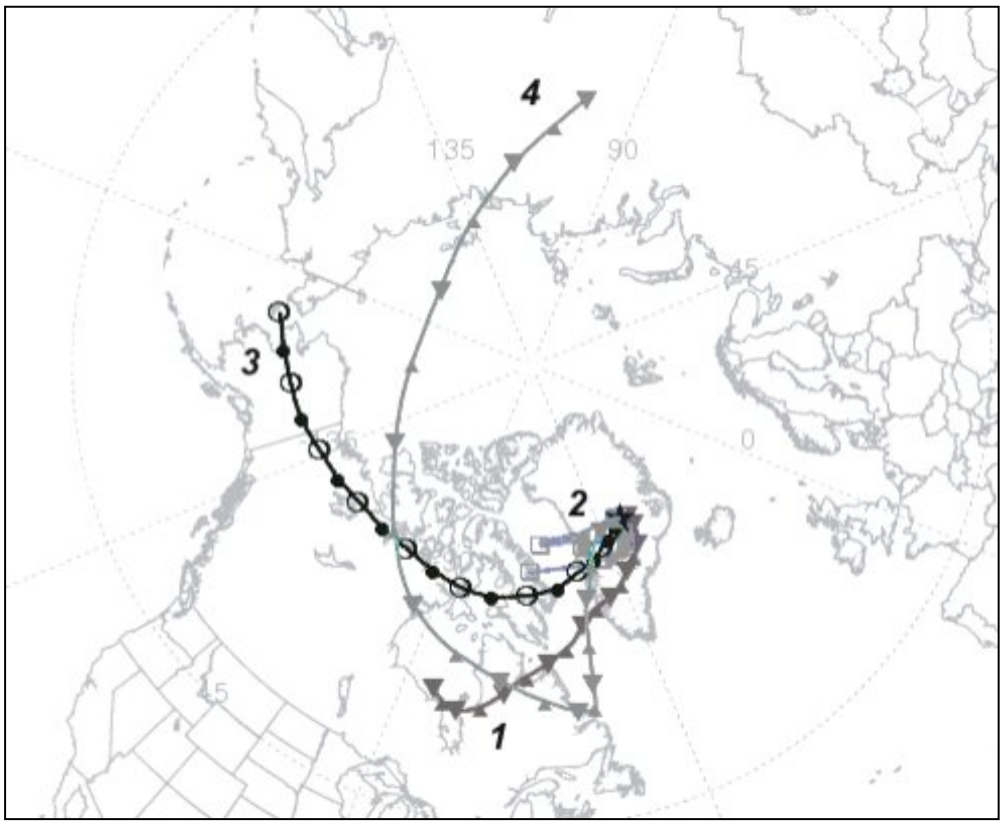
Results: Air



- Concentrations during June 13-14 > 197% higher than rest of the summer
- WSOC is ~90% of OC suggesting most is secondary in nature (SOA)
- OM accounts for a large fraction (40-90%) of the total particulate mass

Results: Airmass Back Trajectories

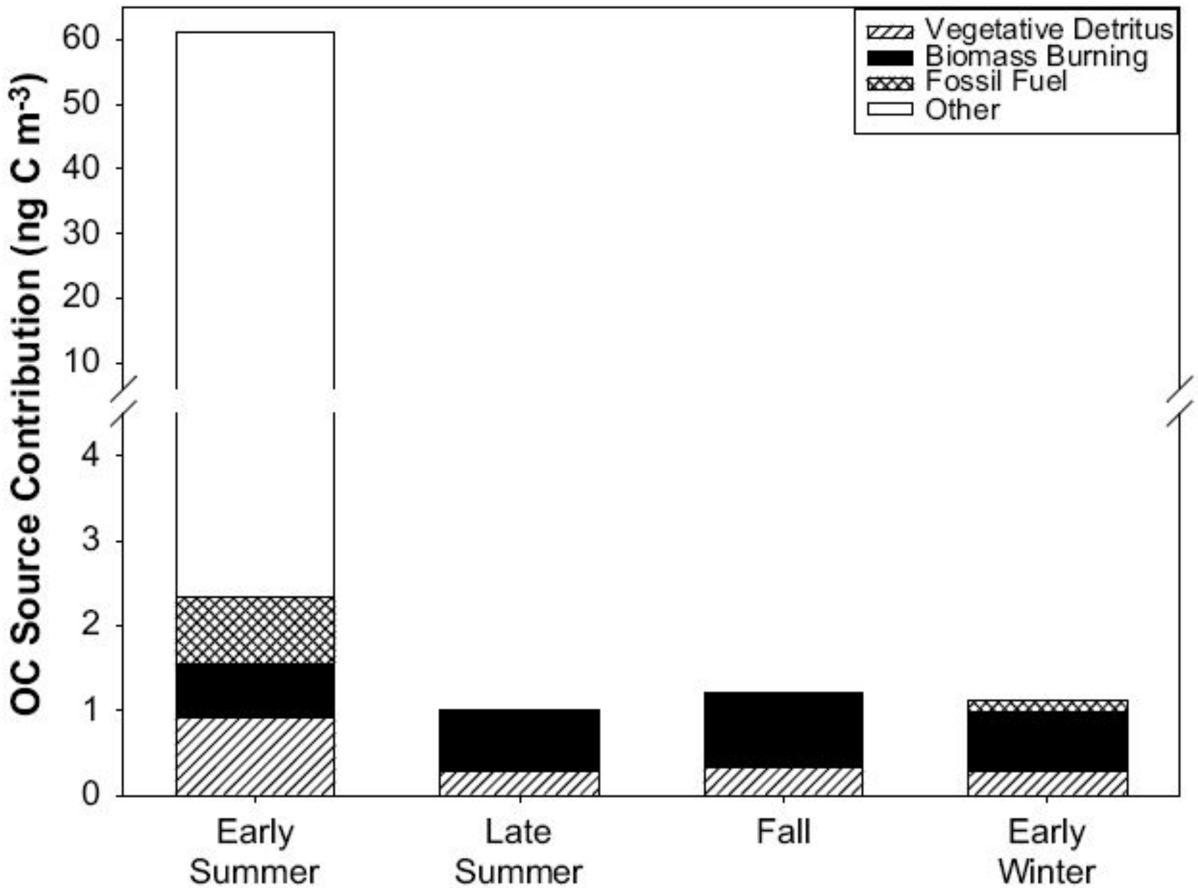




High aerosol concentrations on June 13-14 associated with long range transport over Alaska/ Northern Canada likely associated with forest fires

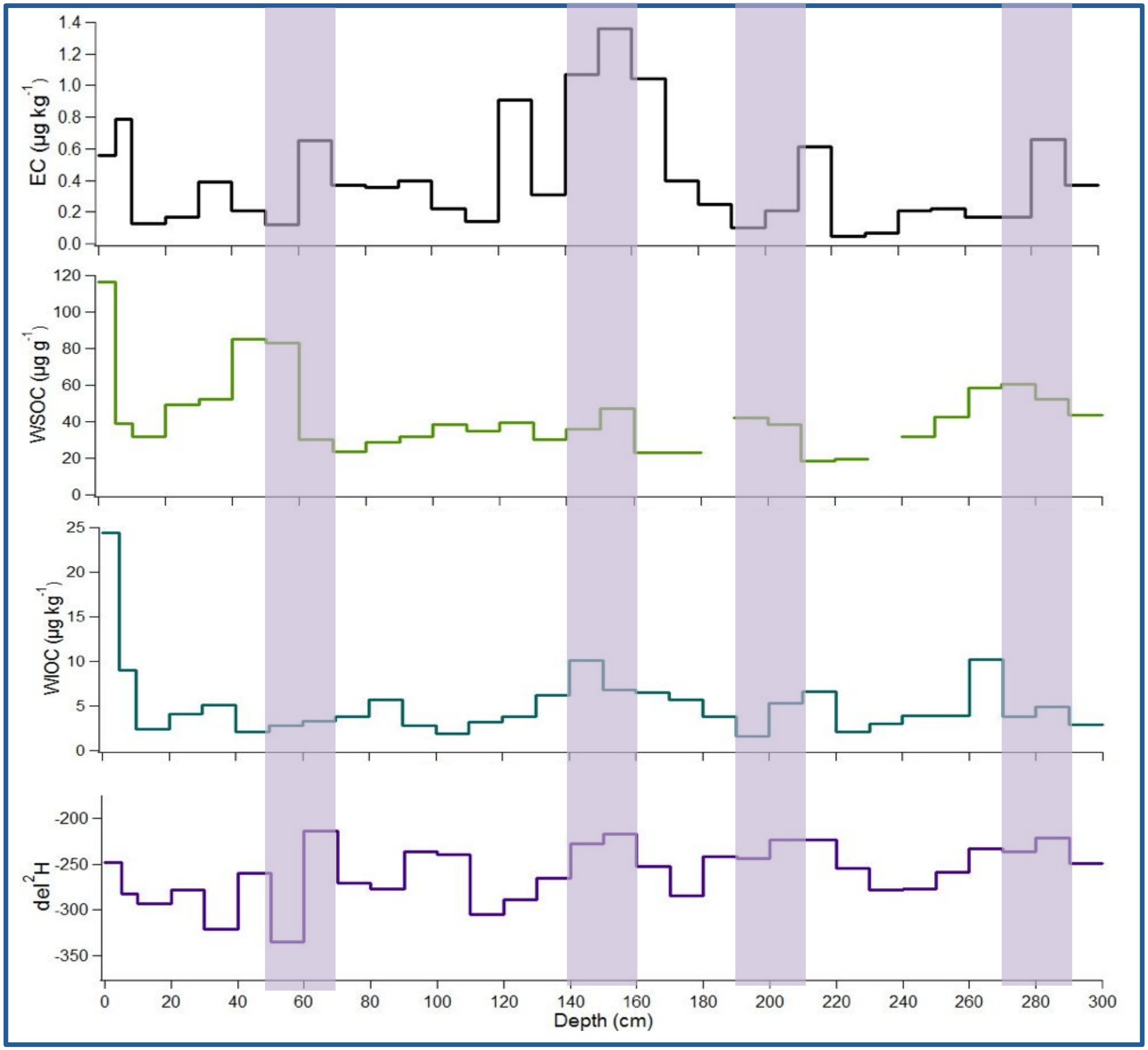
(Hagler et al., 2007)

Results: Source Apportionment of Primary OC



- Primary fossil fuel and biomass burning OC particulates reach Summit but majority of OC (~95%) has undergone chemical processing and is secondary in nature (SOA)

Results: Surface vs. aged snow layers

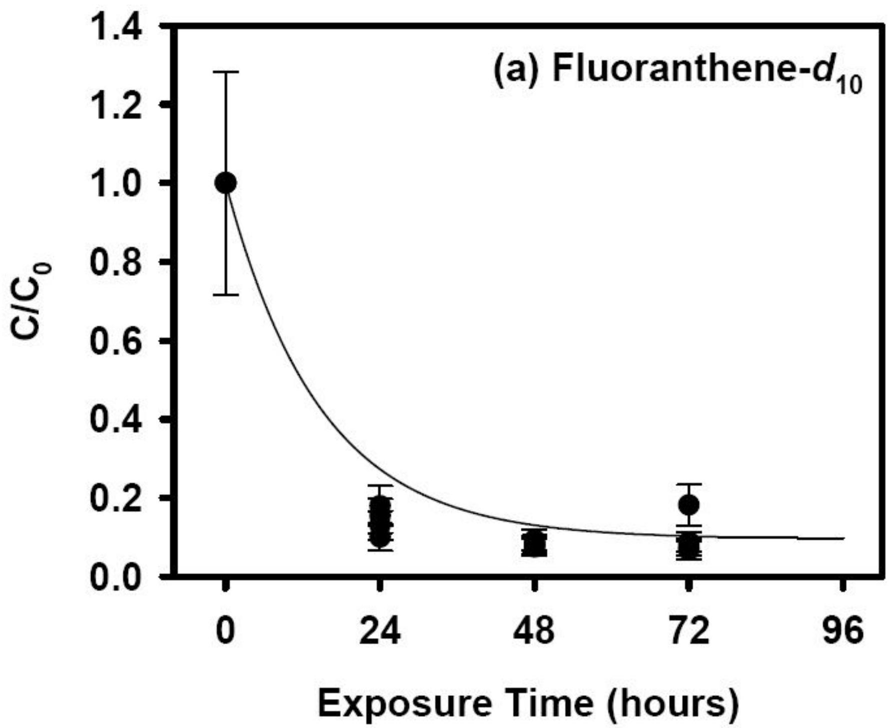


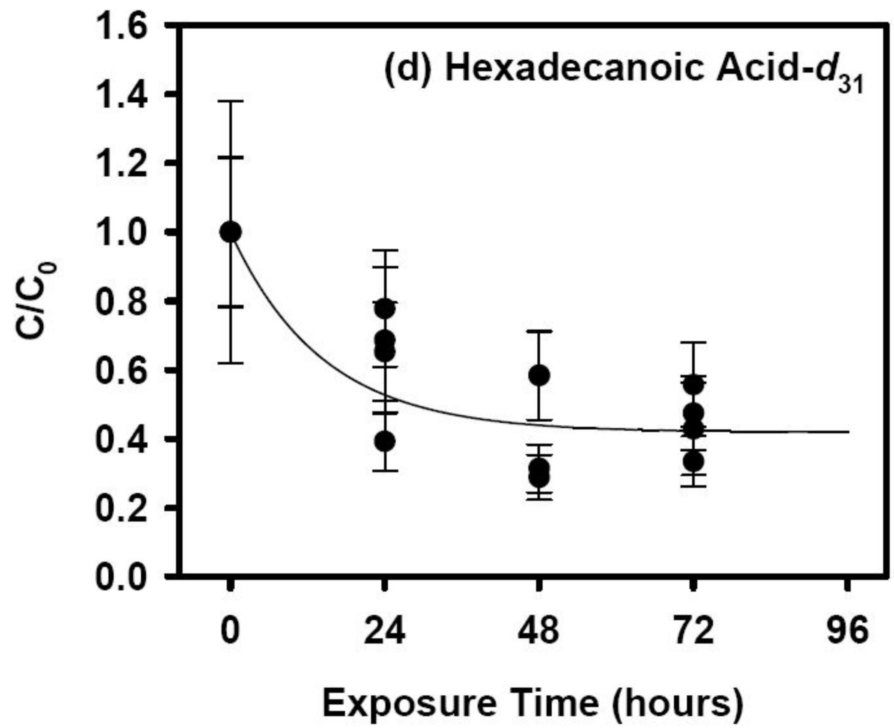
Observed evidence of 2004 major forest fire event (Stohl et al., 2006)

Nearly 2-fold decrease in both WSOC and WIOC between surface and buried snow clearly indicating loss of OC post-deposition

(Hagler et al., 2007)

Results: Degradation of isotopically labeled compounds in surface snow





- Compounds degrade on timescales of ~ 1 day, further evidence that post-depositional change plays an important role in the storage of OC in snow

(von Schneidemesser et al., 2010)

Results: Aerosol Climate impact via Snow Albedo Modification

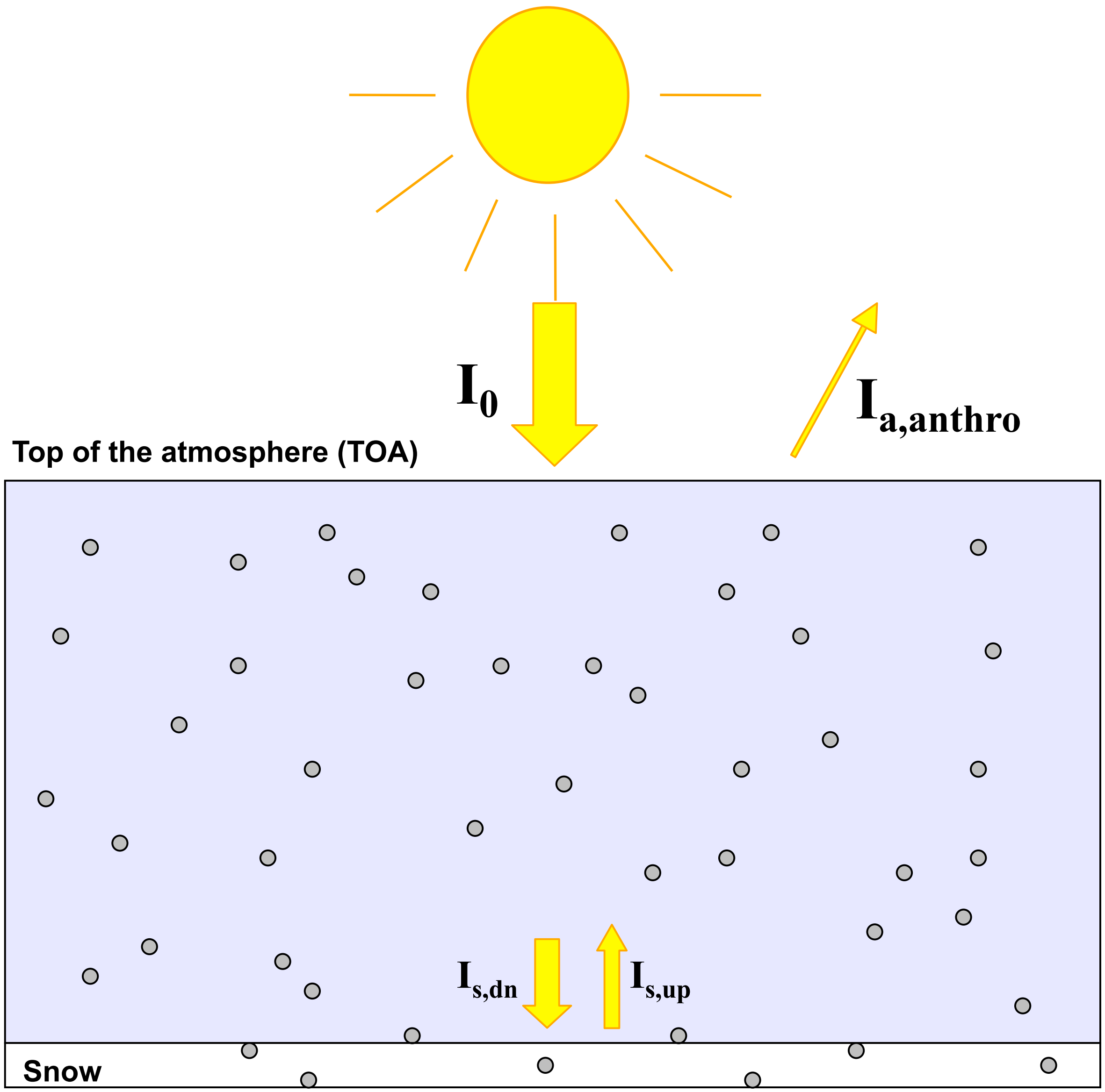
...."[Shackleton] ordered the men to shift camp because their floe was melting at a dangerous rate. The soot from the blubber stove had been tracked all over the surface of the ice, and it was holding the heat of the sun." (1915)

"Endurance: Shackleton's Incredible Voyage", by Alfred Lansing

Relatively old idea: Warren and Wiscombe (1980), Chylek et al. (1983), Cess (1983)

Estimates by McConnell (2007) using SNICAR model suggest BC albedo effect resulting in ~0.5 Wm^{-2}

Results: Direct Aerosol Radiative Forcing at TOA



$\Delta F_{toa} = I_{a,anthro} - I_{a,back}$
$= f(\tau_a, \omega_0, \beta, R_s)$

where:

τ_a = Aerosol Optical Depth

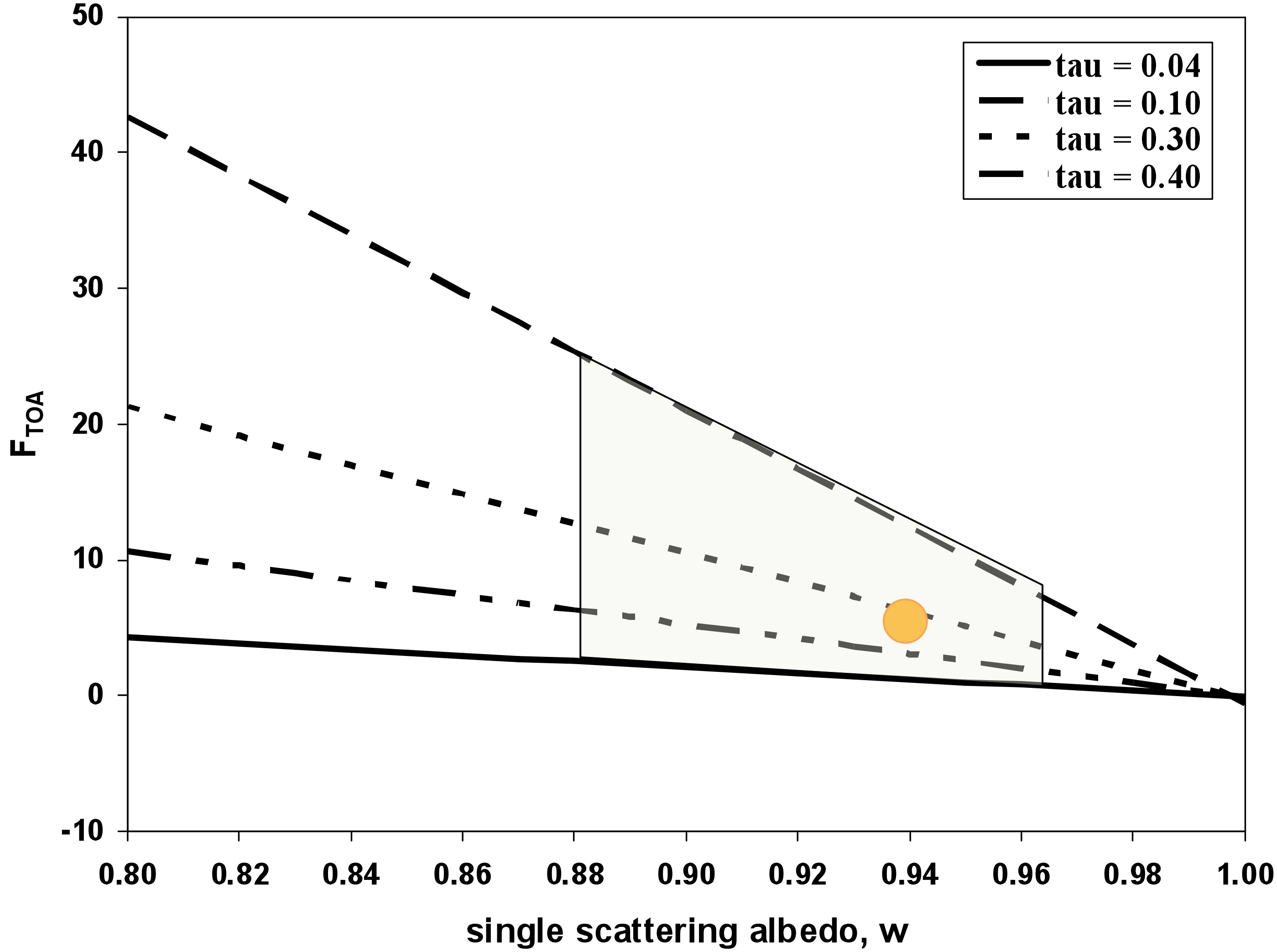
ω_0 = Single Scattering Albedo

β = Upscatter Fraction

R_s = Surface Albedo

ΔF_s = (snow physical and optical properties, absorbing compounds)

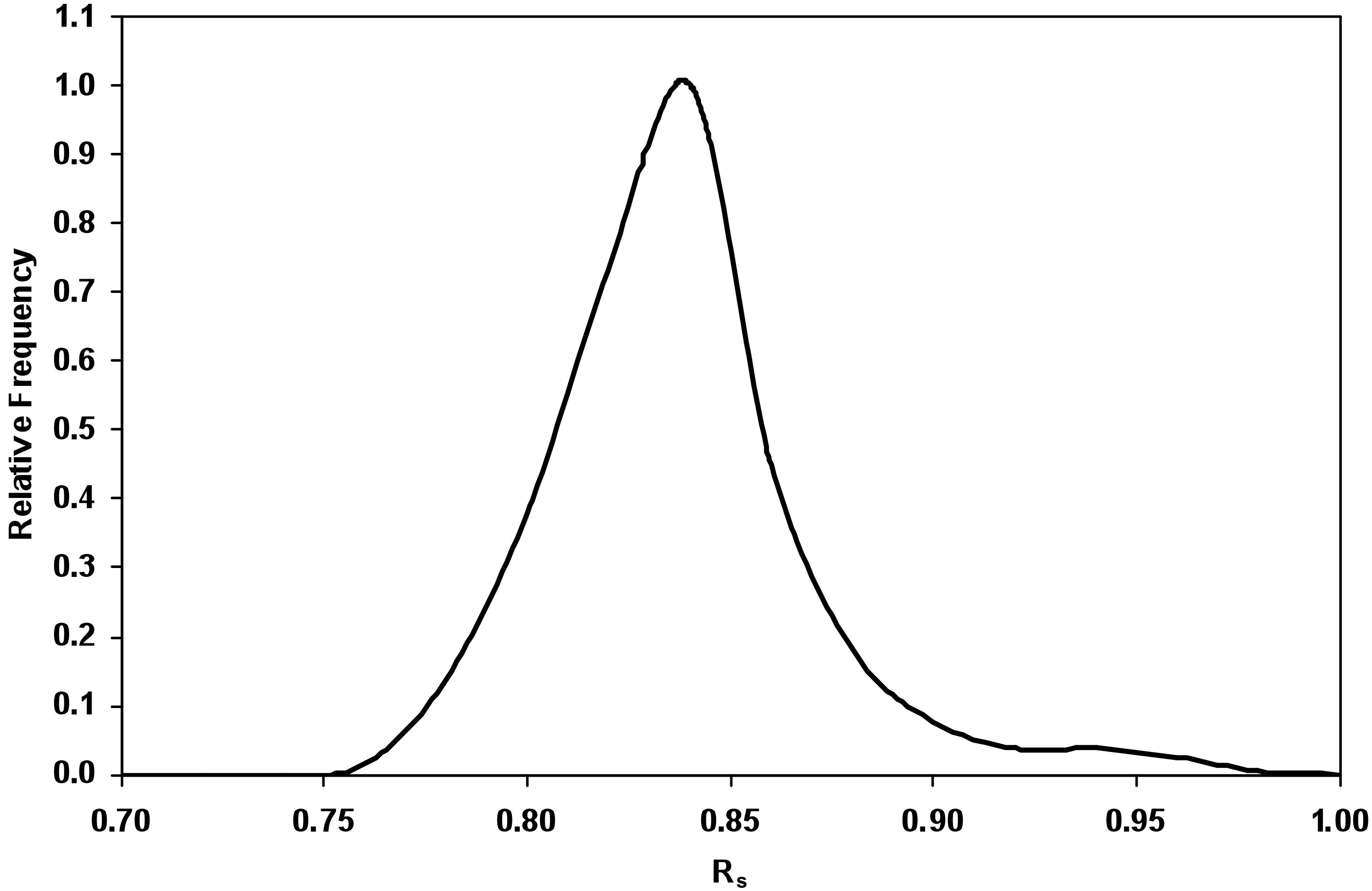
Results: Direct TOA Aerosol Radiative Forcing Rough Estimate (Constant R_s)



- **Based on Stohl et al. (2006) τ_a measurements at Summit broad range of forcing with likely mean value of ~10 Wm^{-2}? (NOTE: THAT'S A LOT OF FORCING!)**
- **Still difficult to estimate since we don't explicitly know *w***

(Haywood and Shine, 1995)

Results: Snow albedo varies greatly at Summit During Summer



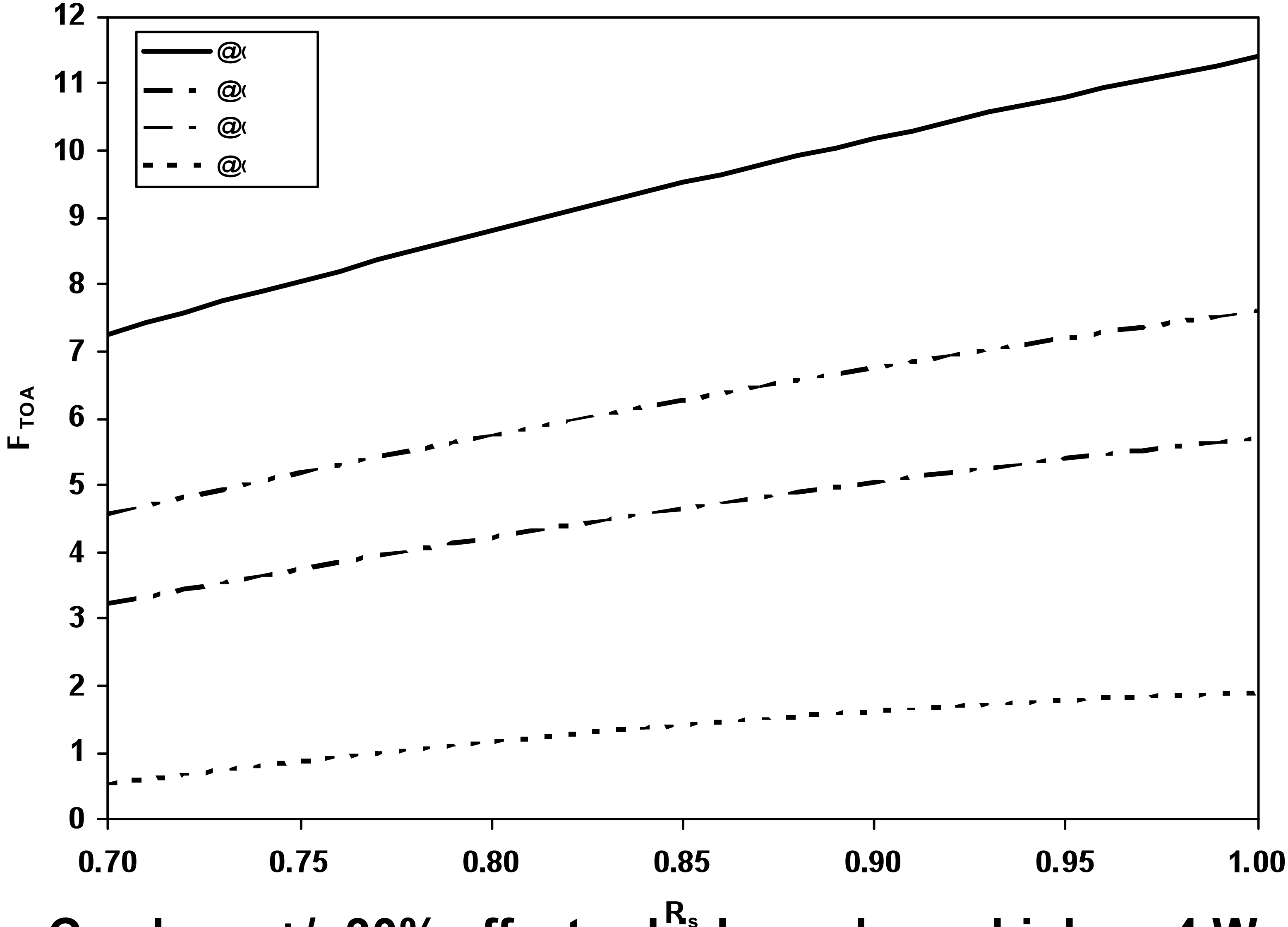
- Variability most likely linked with changes in snow physical properties (i.e. grain size and characteristic)

(Data from K. Steffen)

Results: Surface hoar and rime (large crystals)

Results: Relatively fresh snow (small crystals)

Results: Direct radiative forcing sensitivity to surface snow albedo variability (τ_a = 0.15)



- Can have +/- 30% effect, which can be as high as 4 W m^{-2}

(Haywood and Shine, 1995)

Summary

- **Particulate organic carbon reaching central Greenland makes up a significant fraction of the total aerosol mass**
- **Most of the particulate carbon at Summit is secondary (SOA) in nature making source attribution of OC mass difficult**
- **Significant loss of both water soluble and insoluble organic carbon is observed in surface snow, highlighting the importance of post-depositional processes in the archival of organic compounds in snow**
- **Direct toa radiative forcing by light absorbing aerosols may at times be as high as 30 Wm^{-2} with typical values of 10 Wm^{-2} over central Greenland**
- **Variability in snow albedo may play an important role in direct radiative forcing by aerosols**

Future Work

- **In-situ measurements of key aerosol parameters needed to estimate direct radiative forcing over central Greenland (τ, *w*, B, R_s)**
- **In-situ measurements of surface snow chemical, physical and optical properties (D_{eff}, SSA, R_s, black carbon and trace elements)**
- **Radiative transfer modeling to estimate the direct aerosol forcing at the surface and top of the atmosphere**
- **Field studies addressing the aerosol indirect effect**

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