Magnitude of the Shortwave Aerosol Indirect Effect in Springtime Arctic Liquid-Water Clouds

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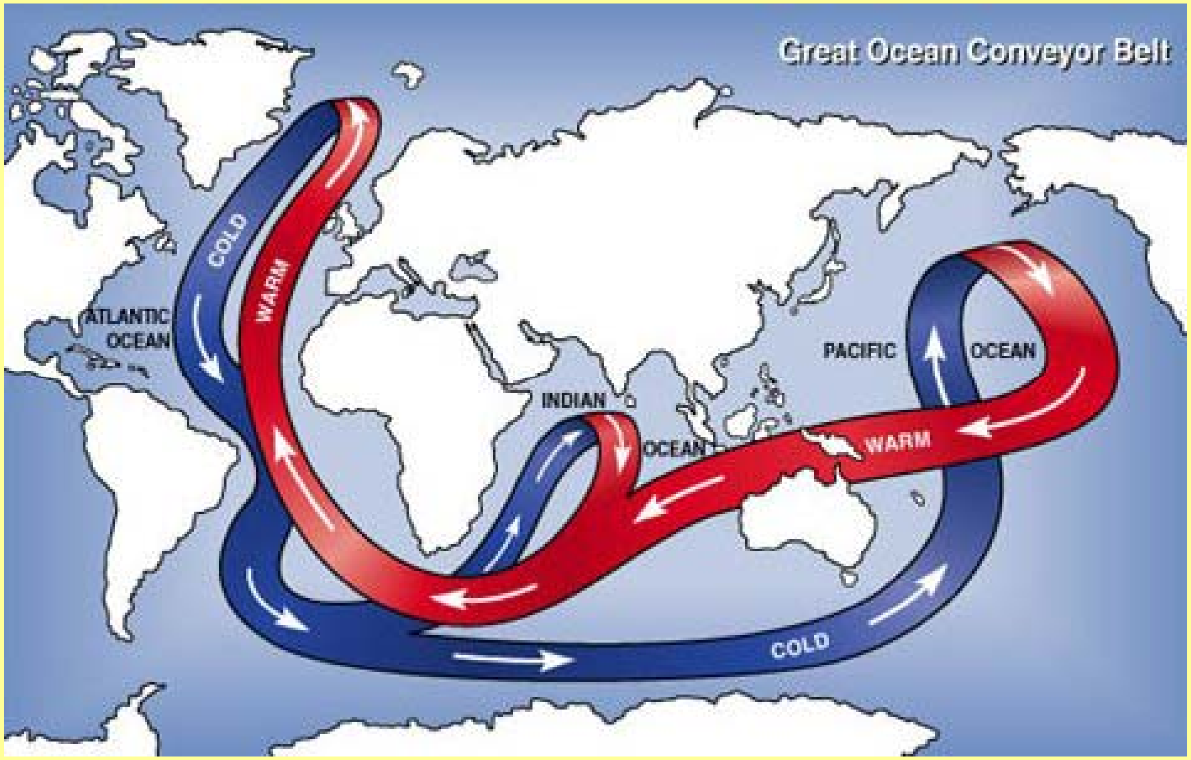
28 March 2007
ARM Science Team Meeting
Monterey, CA

Why the Arctic?

1. The great “bellwether” for global climate warming
2. Well known potential impacts on global ocean circulation



Why the Arctic?

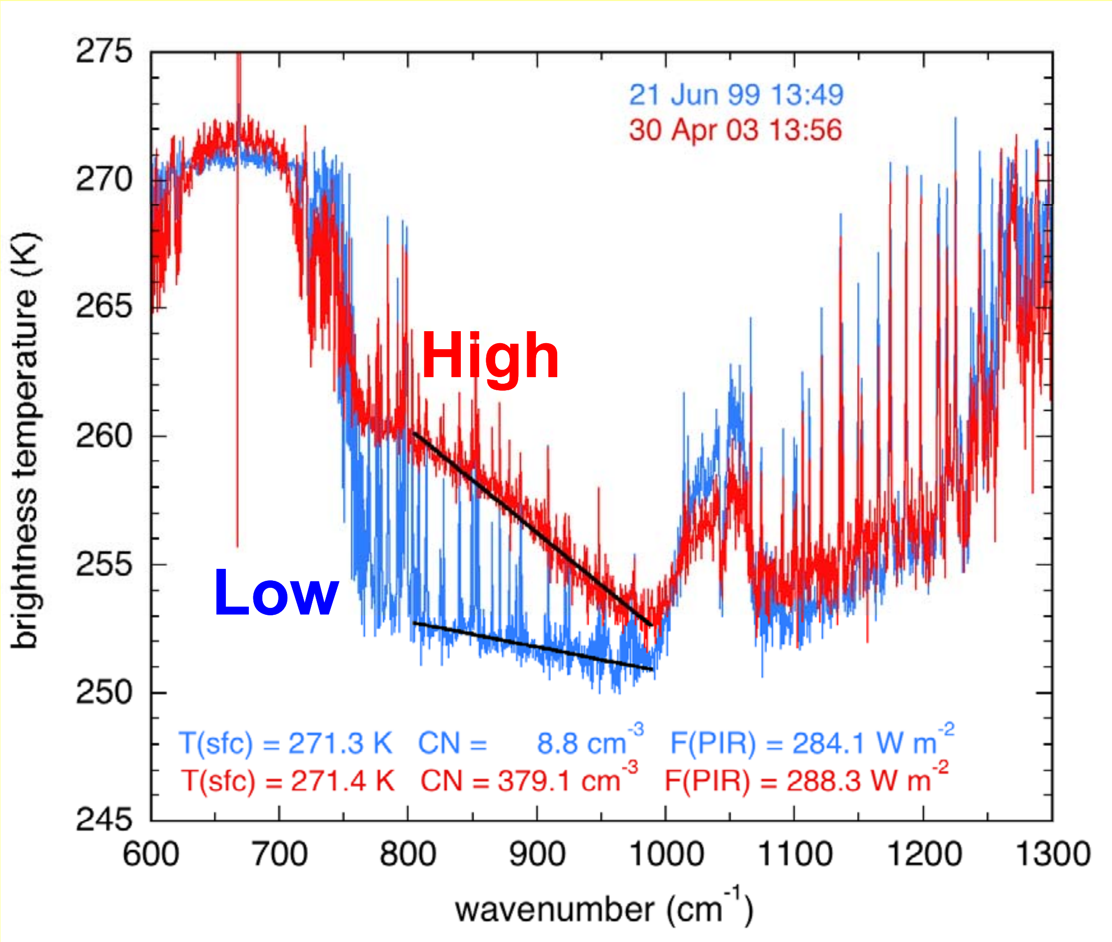
3. Unique modes of human habitation

- Indigenous populations at least 15,000 years old, possibly 30,000 in Siberia.
- Fragile big game hunter societies closely dependent on environment.
- Inuit and other societies already strained by social & economic contact with the modern world.

Motivation

- **Liquid water cloud is the most prevalent meteorological condition in the high Arctic (e.g., Shupe and Intrieri, 2004).**
- **Previous work with ARM NSA data**
  - **Revealed a longwave manifestation of the aerosol first indirect (Lubin and Vogelmann, 2006; Garrett and Zhao, 2006)**
  - **Springtime liquid water clouds**
  - **Surface warming comparable to that of trace gas forcing**
- **What is the corresponding shortwave (SW) manifestation of the indirect effect?**

LW Indirect Effect from AERI



Similar clouds - but low versus high aerosol - shows consistency with theory

Detection Method:

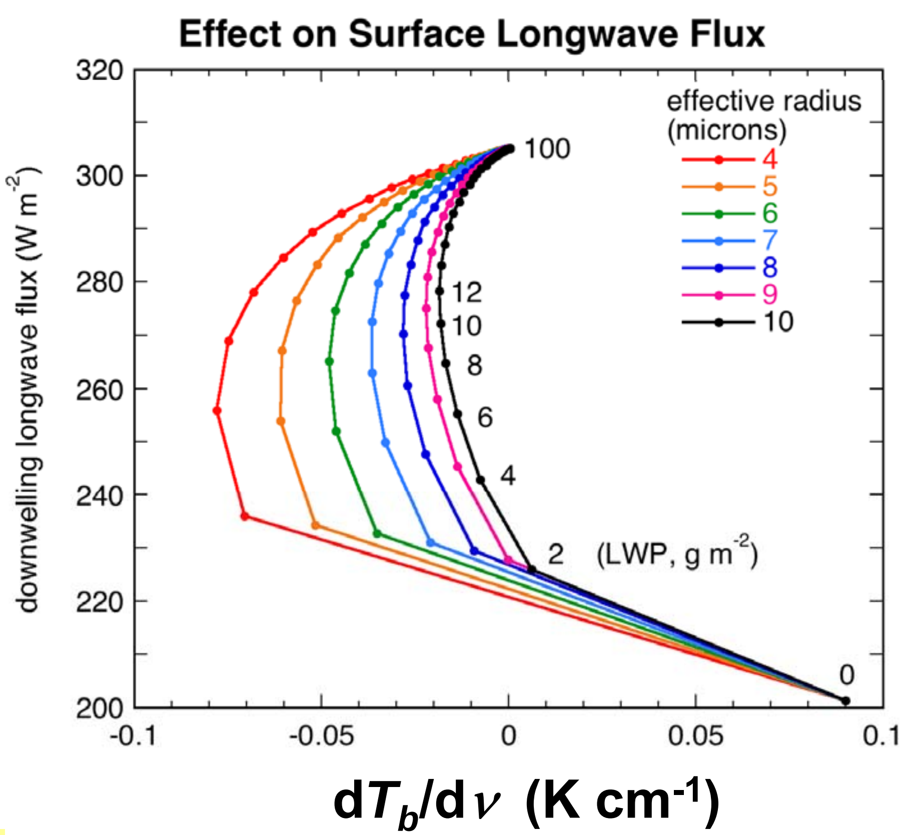
Slope of Mid-IR Window

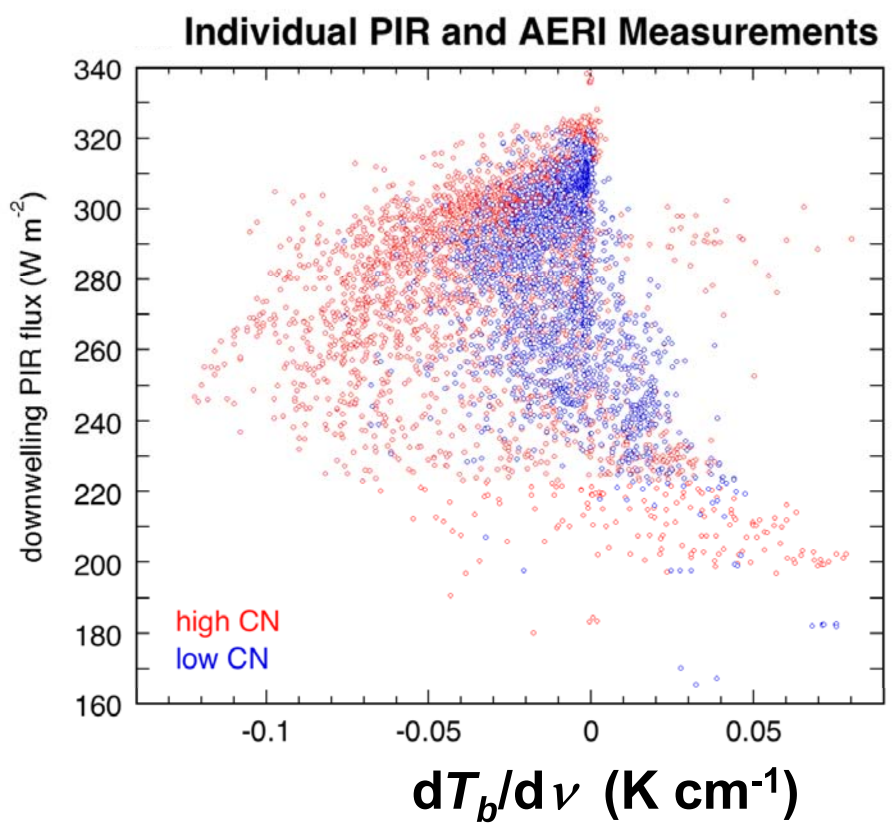
$dT_b/d\nu$

Lubin and Vogelmann, *Nature* (2006)

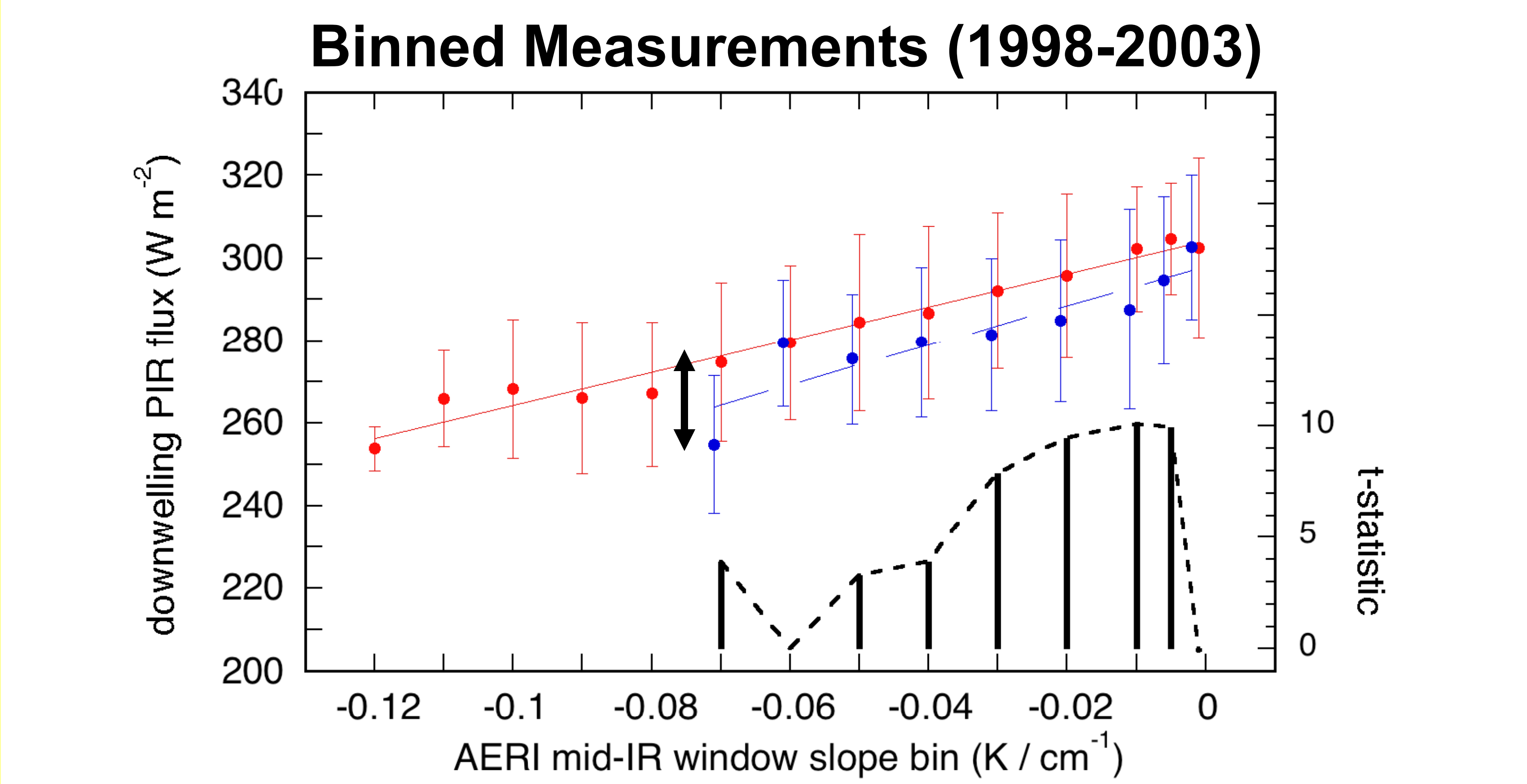
LW Indirect Effect: AERI Detection

- **Slopes dT_b/dν for six years of AERI data (1998-2003)**
- **Single layer clouds detected by ARSCL, base and thickness < 1000 m**
- **Low CN: < 50 cm^{-3}, High CN: > 175 cm^{-3}**





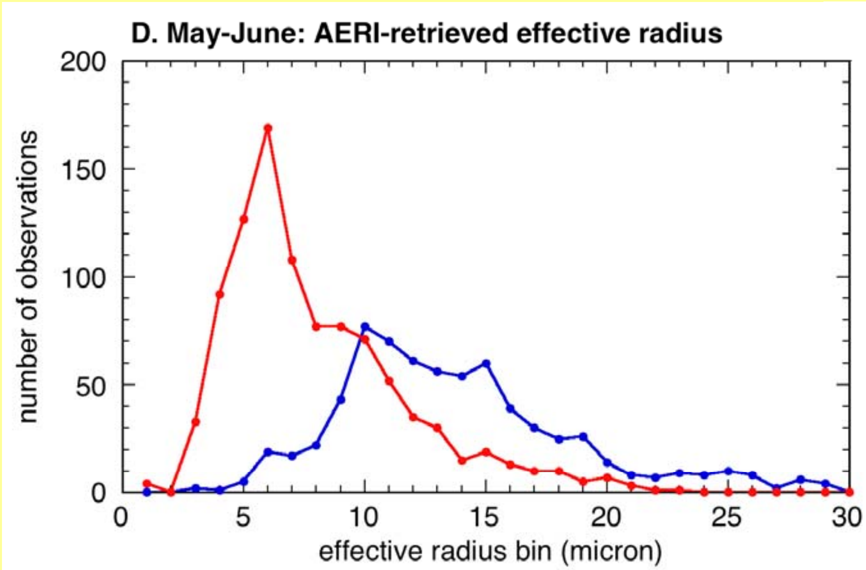
LW Indirect Effect

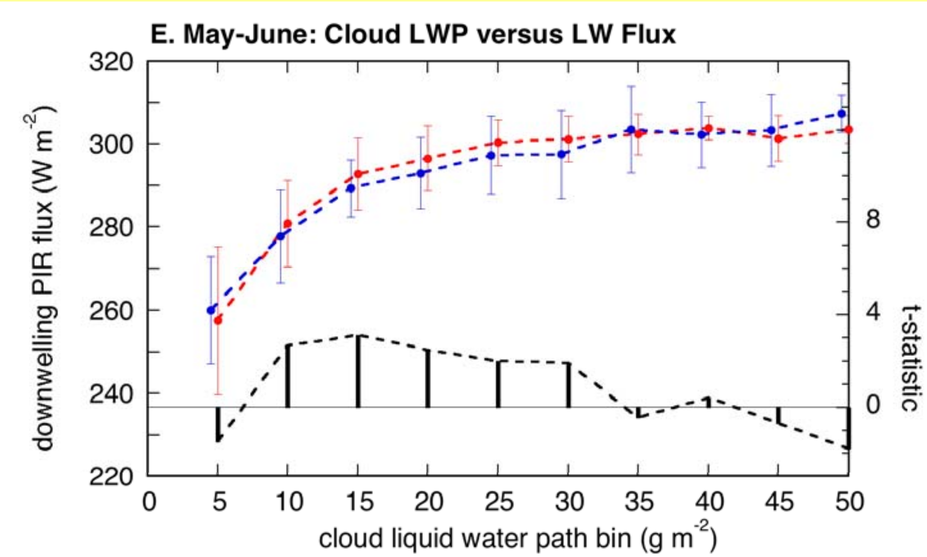


Consistent difference of 8.2 W m^{-2}

LW Indirect Effect: Attribution

- **Retrieve r_e and *LWP* from mid-IR window slope & intercept**





- **Sorting on LWP, we find that of the 8.2 W m^{-2}:**
  - **An ave. of 3.4 W m^{-2} is readily attributable to the 1st indirect effect**
  - **The rest cannot be conclusively explained by existing ARM data.**

This effect exists only for optically thin cloud (τ < ~8-10)

How Does this LW 1st Indirect Effect Compare with Other Arctic Aerosol-Radiative Effects?

Approaches

1. Shortwave Direct Effect (Observation)

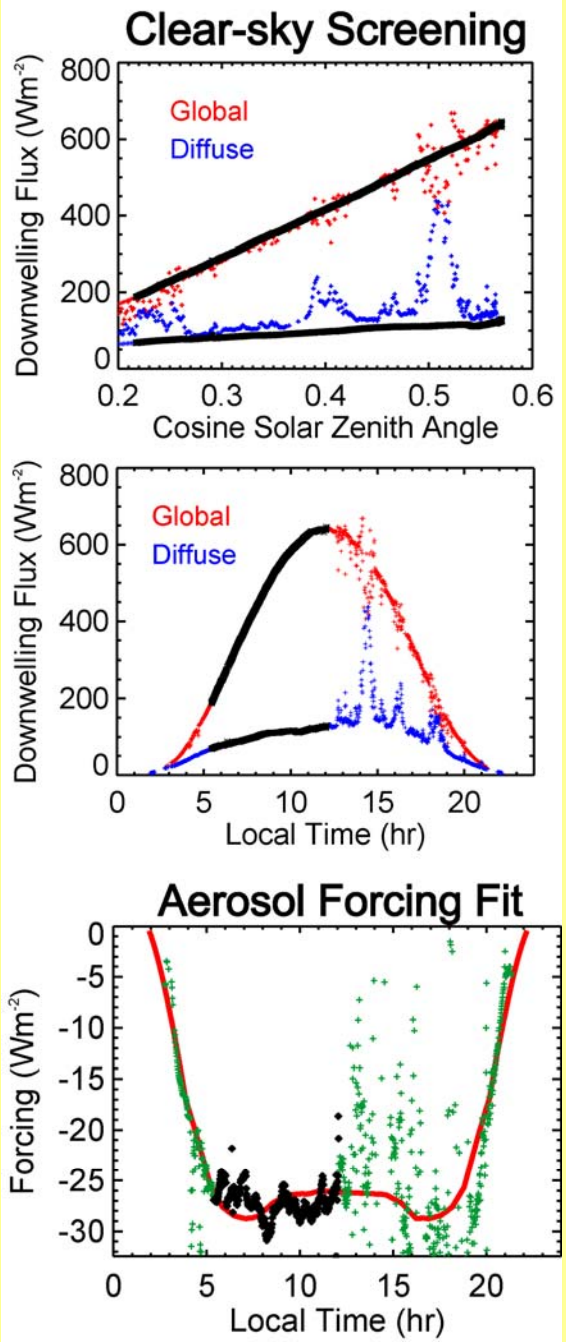
- Determine SW direct aerosol forcing from ARM MFRSR and pyranometer data

2. Shortwave Indirect Effect (Modeling)

- Estimate from radiative transfer simulations Lubin and Vogelmann, *GRL* (2007, in review)

3. Shortwave Indirect Effect (Observation)

- Determine SW indirect effect from pyranometer data, analogous to Lubin and Vogelmann (2006)
  - Work nearly done, will have some useful results in ~ 1 month
  - Finishing up "forensic" work with multiyear pyranometer data set



Shortwave Direct Effect

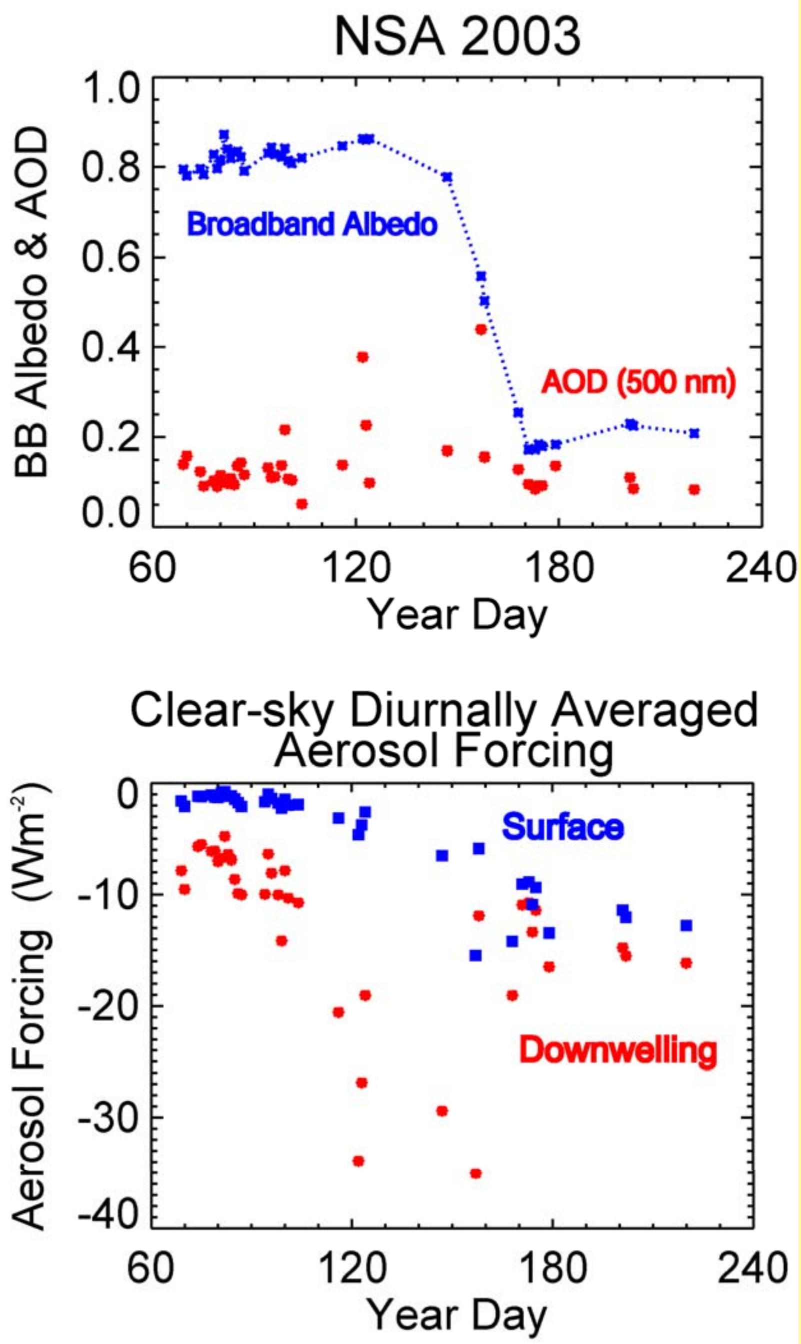
Obtained from ARM NSA Observations

- Pyranometer, MFRSR
- Tower radiometers
- MWR, Sondes
- Method similar to Conant (2000)

1. Cloud screening tests direct and diffuse fluxes for piece-wise linearity with $\cos(\theta_o)$.

- Aerosol-free downwelling fluxes are modeled using MWR water vapor, spectral surface albedos for snow and vegetation Aerosol forcing is the observed clear-sky fluxes minus the modeled aerosol-free fluxes.

- The 'observed' aerosol forcing estimates constrain a fit over the diurnal cycle to get the diurnally averaged aerosol forcing.



Shortwave Direct Effect

Top Panel:

- Broadband surface albedo deduced from the tower and upward looking radiometers.
- Diurnally averaged AOD which is obtained from the MFRSR and averaged for only the 'good' points.
- The two large values are consistent with aerosol:

  Angstroms are large, hence small particles, not likely to be a cloud.

  CMDL observations of CN among the largest for those points.

Lower Panel: Forcing versus Time

- All forcings reported are diurnally averaged and for a 100% clear sky.
- The 'downwelling' points are the aerosol effect on the downwelling flux incident at the surface.
- The 'surface' fluxes are the net surface aerosol forcing, given by the downwelling fluxes times the surface co-albedo.

Shortwave Indirect Effect Simulation

Approach

- Estimate using diurnally averaged calcs for Surface and TOA
- “Low” and “high” aerosol effects/amounts
- Difference yields an estimate of the shortwave indirect effect

Radiative Transfer Model

179-band, Discrete-Ordinates (Stamnes et al., 1988; Lubin et al., 2006)

Surface Albedo from SHEBA

- Perovich et al. (2000)
  - Snow covered ice March-May
  - Bare sea ice June (onset of melt season)

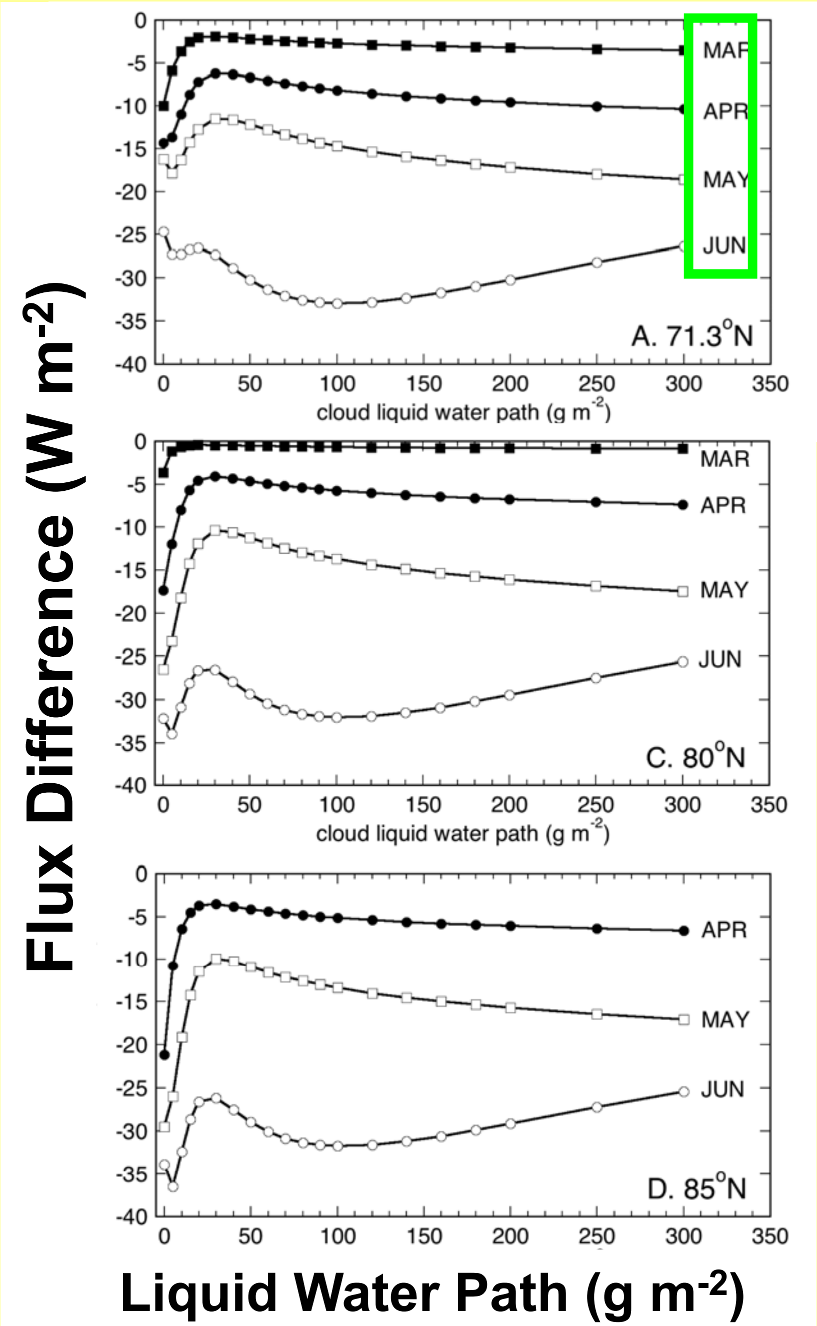
Aerosol loading (Optical depth at 500 nm)

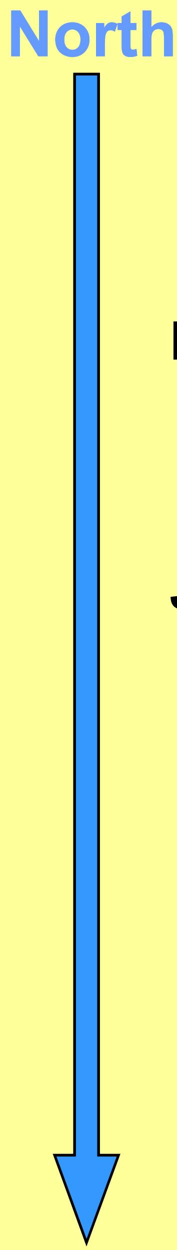
- Background $\tau_a = 0.1$
- Polluted $\tau_a = 0.5$

Cloud effective droplet radii

Estimated based on Lubin and Vogelmann (2006), Garrett and Zhao(2006)

- 11 μm – Clean air, background aerosol
- 8 μm – Arctic haze condition; high aerosol





Indirect Effect: Surface Forcing

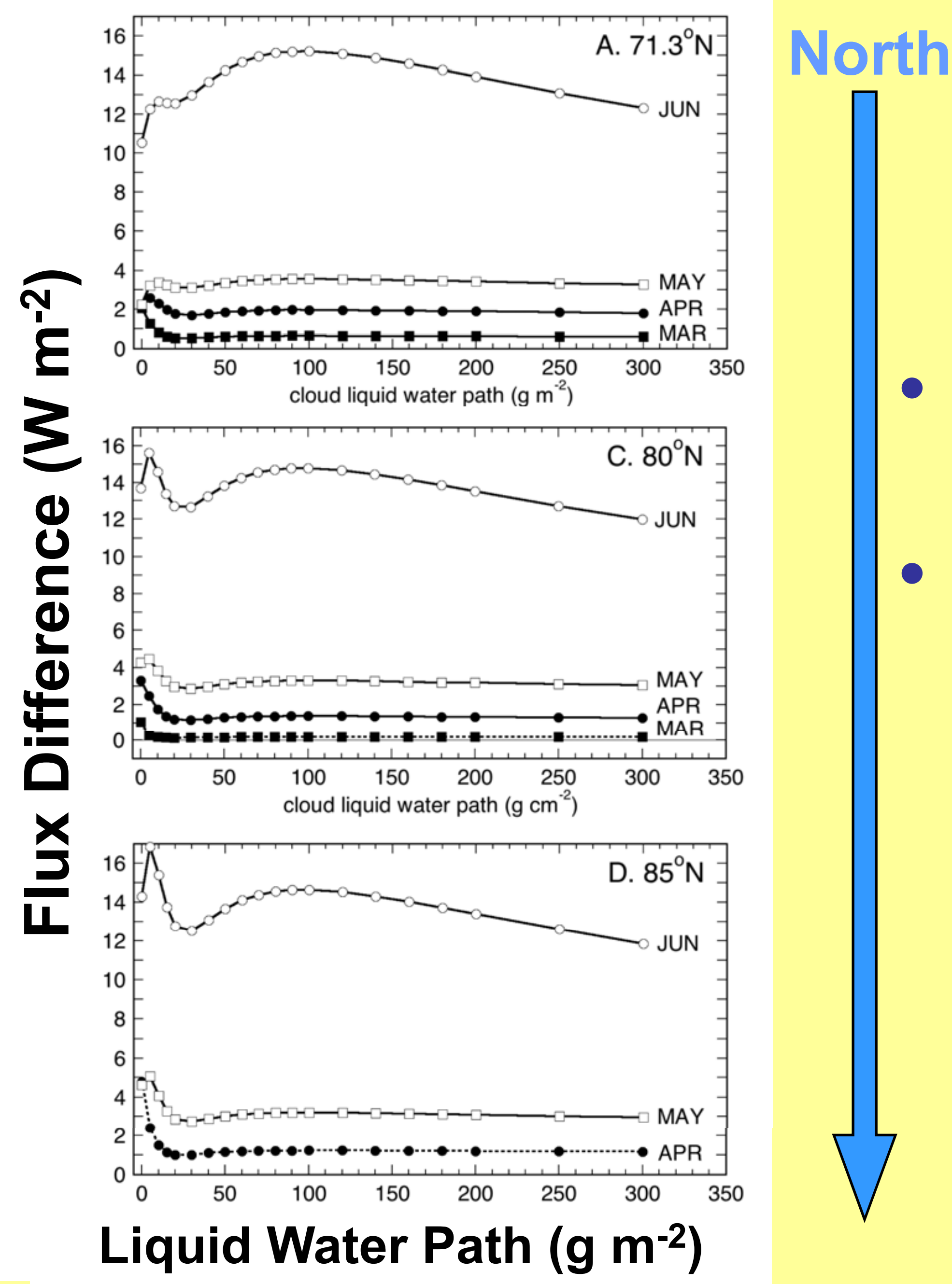
March through May

- Flux difference increases
- Increasing solar elevation and day length

June

- Differences **<u>enhanced</u>**
- Onset of sea ice melt
  - ➔ Lower surface albedo
  - ➔ Fewer multiple reflections

Indirect Effect: TOA Forcing

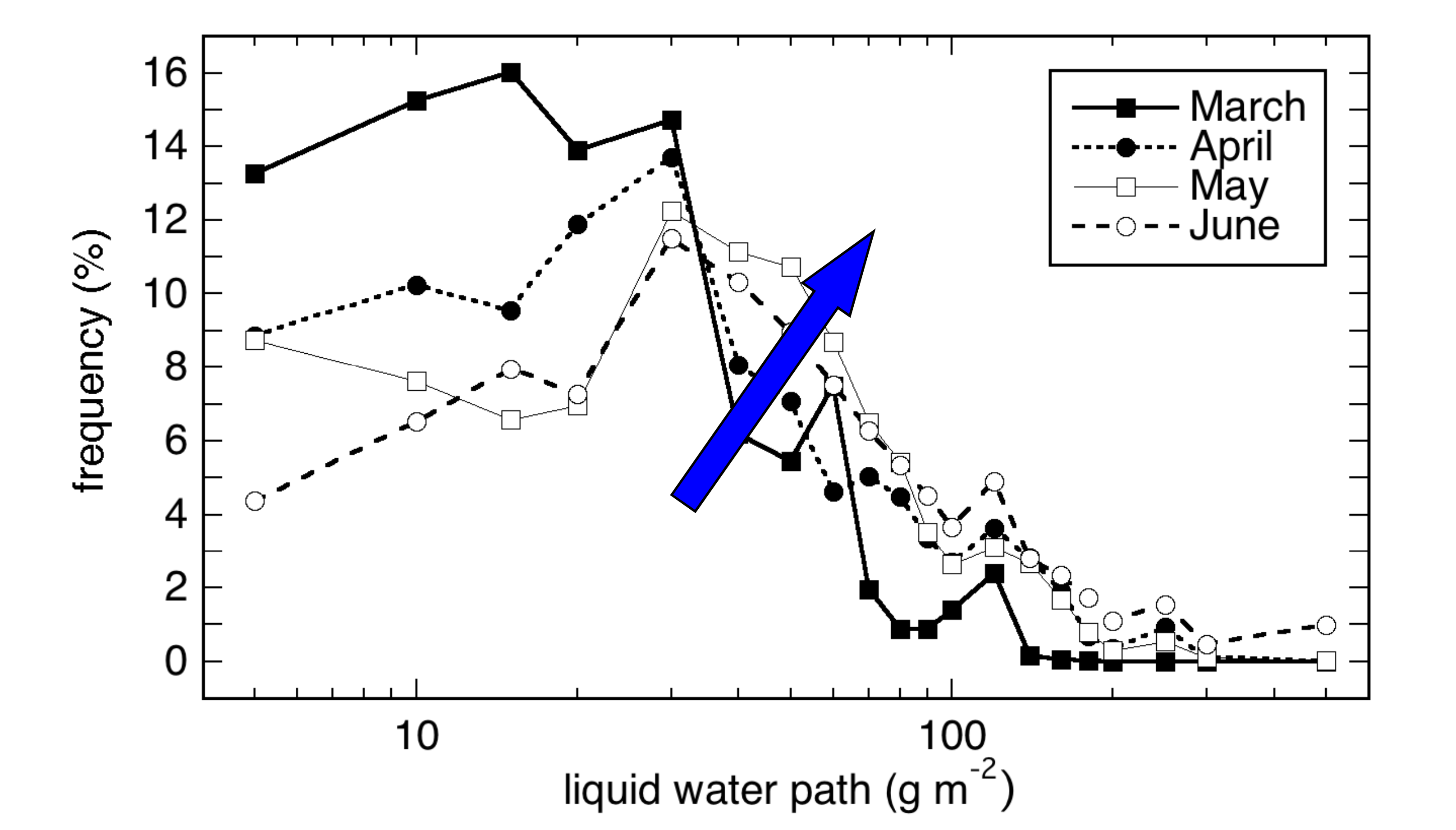


- TOA effect is ~1/2 of the Surface (opposite sign)
- Difficult to detect from space during early spring (snow surface)

Monthly Cloud-Liquid Water Paths

Five years of NSA data

- **MWR**
- **ARSCL identifies low, single-layer clouds**



Simulated Flux Differences

- LWP from MWR distributions
- High minus Low Aerosol (R_{eff}, τ_a)
- Cloudy skies are overcast

		March		April		May		June	
		clear	**cloudy**	clear	**cloudy**	clear	**cloudy**	clear	**cloudy**
Surface	85 N			-21.2	**-7.2**	-29.5	**-15.2**	-33.9	**-29.4**
	80 N	-3.7	**-0.7**	-17.4	**-7.4**	-26.5	**-14.9**	-32.2	**-29.4**
	75 N	-7.5	**-2.0**	-16.4	**-8.6**	-19.9	**-14.1**	-28.9	**-29.3**
	71.3 N	-10.0	**-3.2**	-14.3	**-9.1**	-16.2	**-14.0**	-24.7	**-29.2**
TOA	85 N			4.8	**1.7**	4.6	**3.4**	14.3	**13.8**
	80 N	1.0	**0.2**	3.3	**1.7**	4.3	**3.4**	13.7	**13.7**
	75 N	1.7	**0.5**	2.9	**1.9**	3.0	**3.2**	12.4	**13.7**
	71.3 N	2.1	**0.8**	2.2	**2.0**	2.2	**3.2**	10.5	**13.6**

2X

North

Conclusions

Aerosol Direct Effects

- LW direct: Barely detectable in the Arctic.
- SW direct: Measured - Small in spring, larger in summer

Aerosol Indirect Effects

- LW Indirect Effect: Measured with AERI data
  - In all liquid-water cloud data for high vs. low CN
    - Consistent 8.2 W m^{-2} difference
    - 3.4 W m^{-2} is identifiable with first indirect effect
  - Applies only to optically thin cloud (τ < ~8-10)
- SW Indirect Effect:
  - Theoretically comparable to LW effect Mar-Apr, larger May-Jun
  - Possibly difficult to detect at TOA
  - More detailed empirical analysis underway with ARM NSA data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