# New Understanding on Measure of the 1st Aerosol Indirect Effect

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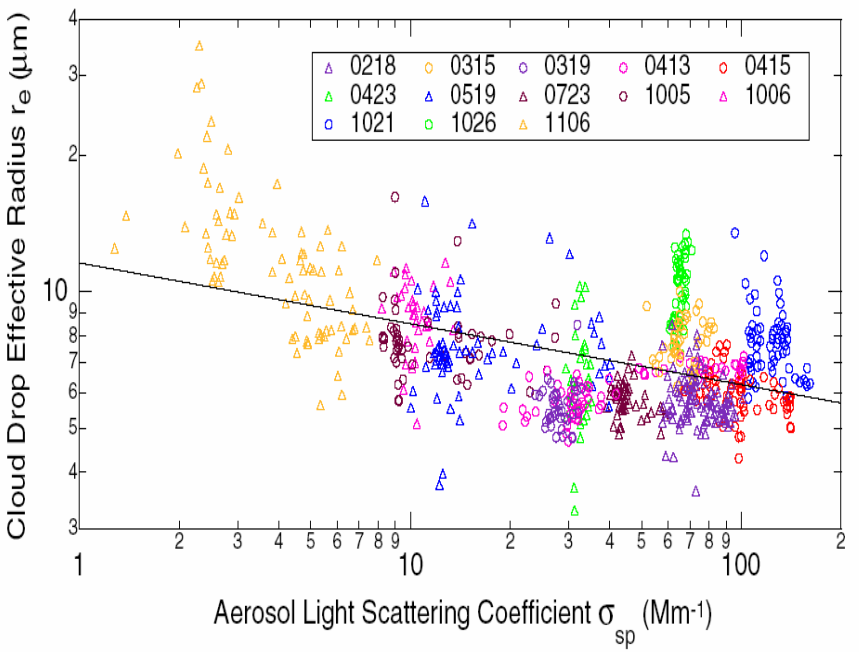
# Relative Measure of the First Indirect Aerosol Effect

$$I \equiv -\frac{d\ln r_e}{d\ln N_a} = -\frac{N_a}{r_e}\frac{dr_e}{dN_a}$$




*Kim, Schwartz, Miller, and Min, JGR, 2003*

**(Courtesy of Dr. S. E. Schwartz)**

**I = Relative measure of 1st AIE**

**$r_e$ = effective radius**

**$N_a$ = aerosol concentration**

**(Aerosol optical properties such as light scattering coefficient are often used as surrogates for $N_a$ in practice)**

**<u>References</u>**


**Nakajima et al. 2001, JGR**
**Breon et al. 2002, Science Shao & Liu 2005, 2006, GRL.**
**Feingold et al. 2003, GRL, 2006 JGR. Kim et al. 2003, GRL; Garrett et al. 2004, GRL.**

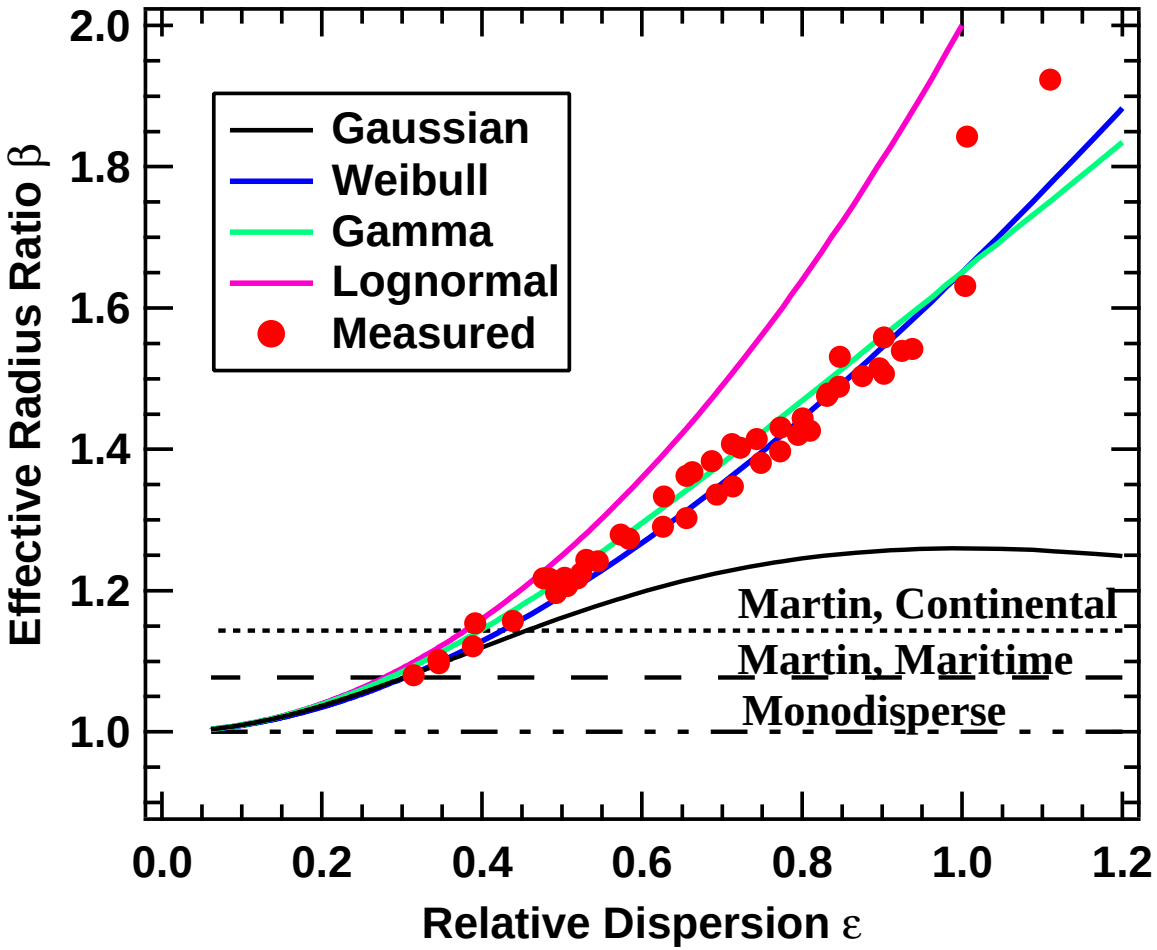
# Primary Revelation

**Relative measure** $$I \equiv -\frac{d\ln r_e}{d\ln N_a}$$

**reflects two dispersion effects:**
**one is from aerosol relative dispersion,**
**and the other from the droplet relative dispersion.**

**(Relative dispersion is a relative measure of spectral width of particle size distribution defined as the ratio of standard deviation to mean radius.)**

# Effective Radius and Effect of Relative Dispersion



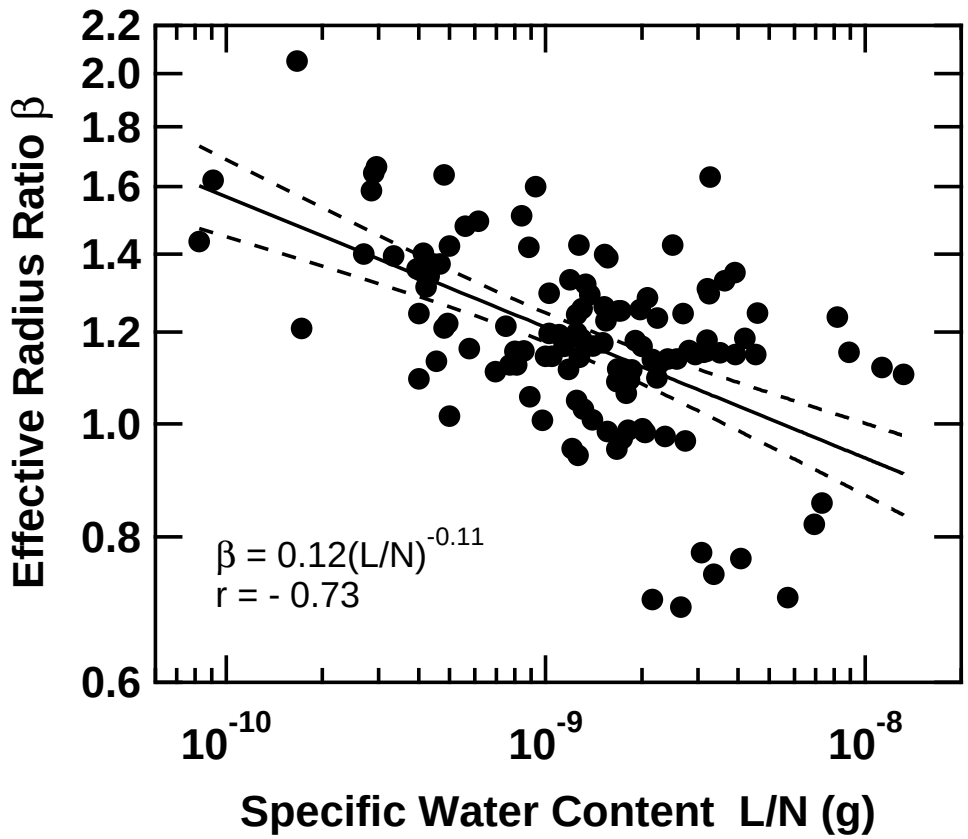

$$r_e = \beta \left( \frac{3}{4\pi\rho_w} \right)^{1/3} \left( \frac{L}{N} \right)^{1/3} \quad (1)$$

$$\beta = \frac{\left(1 + 2\varepsilon^2\right)^{2/3}}{\left(1 + \varepsilon^2\right)^{1/3}} \quad (2)$$

ε = Standard deviation/mean

**This figure shows that β is an increasing function of the relative dispersion, which is well described by Eq. (2).**

# Dependence of β on Specific Liquid Water Content




$$\beta = a_\beta \left(\frac{L}{N}\right)^{-b_\beta}$$

$$r_e = a_e \left(\frac{L}{N}\right)^{b_e}$$

$$b_e = \frac{1}{3} - b_\beta$$

**Dispersion effect (β) is represented using "L/N" better than N alone as previously used (Liu & Daum 2002, Nature; Rotstayn & Liu 2003, J. Climate; Peng & Lohmann 2003, GRL ) .**

# Partition of Relative Measure I

$$I \equiv -\frac{d\ln r_e}{d\ln N_a} \qquad r_e = a_e\left(\frac{L}{N}\right)^{b_e} \qquad b_e = \frac{1}{3} - b_\beta$$

$$I = I_N + I_\varepsilon$$

$$I_\varepsilon = -3b_\beta I_N$$

$I$ = 1st indirect effect

$I_N$ = Number effect

$I_\varepsilon$ = Dispersion effect

**what does $I_N$ really measure ?**

# Essence of Number Effect $I_N$

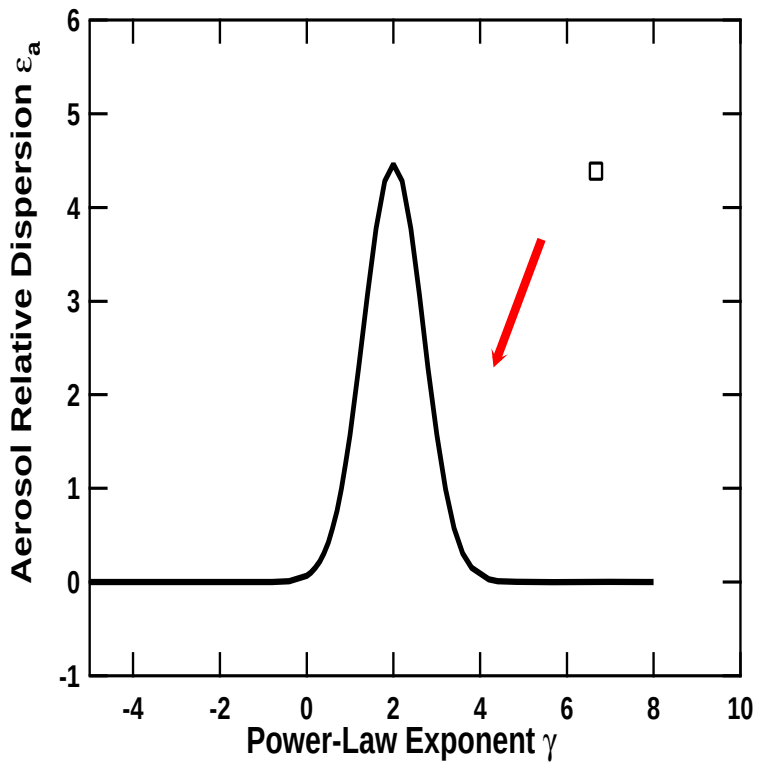
Kohler theory + $n(r_d) = \delta r_d^{-\gamma}$

$$N_{CCN} = CS^k;\ k = \frac{2(\gamma - 1)}{3}$$

**Droplet activation (Twomey 1959)**

$$N \propto N_a^{3/(\gamma+2)}$$

$$\boxed{I_N = \frac{1}{3}\frac{d\ln N}{d\ln N_a} = \frac{1}{\gamma + 2}}$$




**$I_N$ reflects the effect on droplet concentration of relative dispersion ($\varepsilon_a$) of aerosol size distribution, not aerosol concentration!**

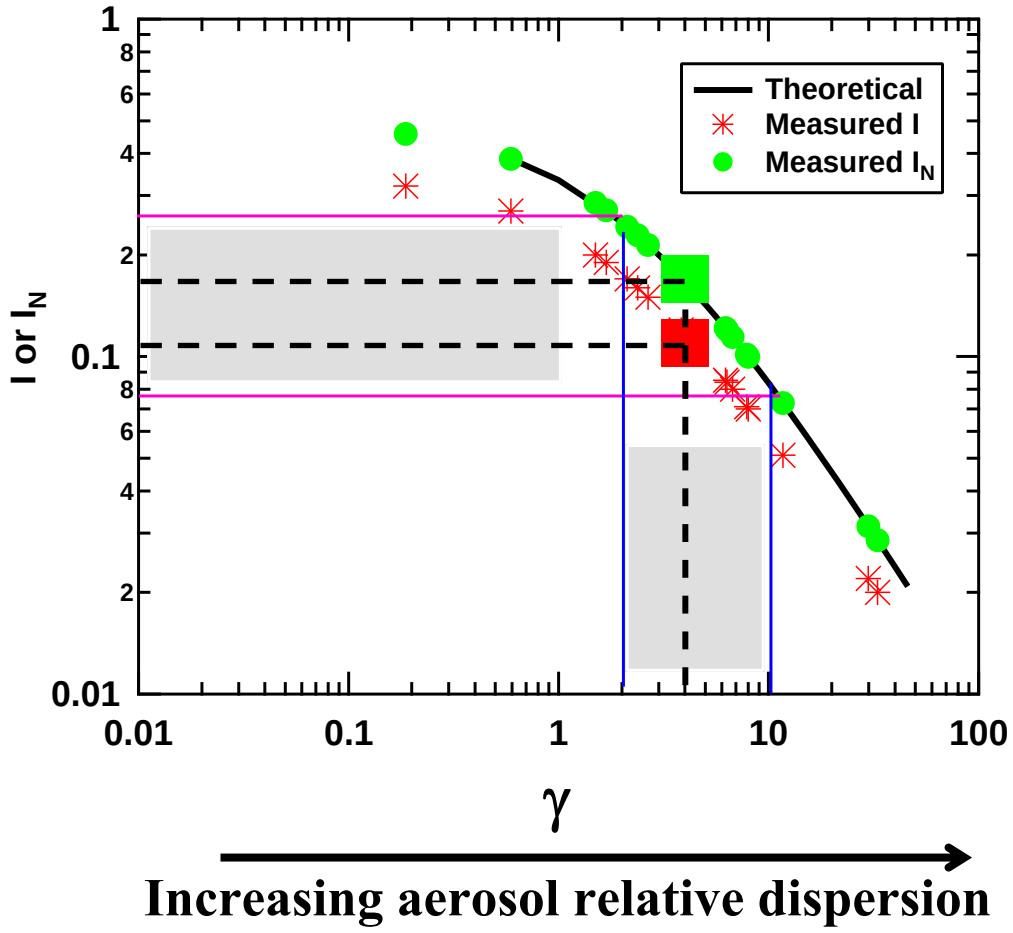
# What does relative measure I really tell us?

**Relative measure (I) reflects two dispersion effects:**

$$I = \frac{1}{\gamma + 2} - \frac{3b_\beta}{\gamma + 2}$$

$$\downarrow \qquad \downarrow$$

$$I_N \qquad I_\varepsilon$$




**Typical values of $\gamma = 4$ and $b_\beta = 0.11$ yield typical values of $I_N$ and I: $I_N = 0.17$ and $I = 0.11$.**

# Take-Home Message

**The relative measure** $I \equiv -\dfrac{d\ln r_e}{d\ln N_a}$

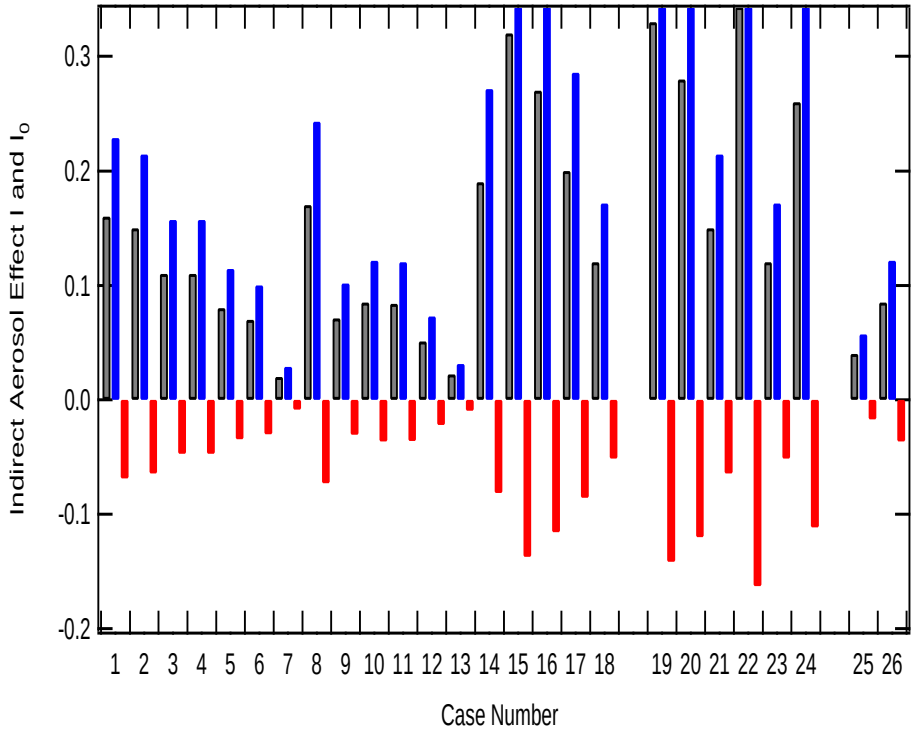
**reflects two dispersion effects:**
**one is from aerosol relative dispersion,**
**and the other from the droplet relative dispersion.**

**Pros and Cons ….**

# Relative Measure of the First Indirect Aerosol Effect

$$I \equiv -\frac{d\ln r_e}{d\ln N_a}$$

(Satellite: Nakajima et al. 2001, JGR; Breon et al. 2002, Science; Shao & Liu 2005, 2006, GRL. Surface-Based: Feingold et al. 2003, GRL; Kim et al. 2003, GRL; Garrett et al. 2004; Feingold et al. 2006, JGR)




**Advantage: relative measure reduces uncertainties associated remote sensing techniques.**

**What else ?**