# Wet Removal without (much) surface precipitation:

## The importance of weakly-drizzling clouds in controlling aerosol number

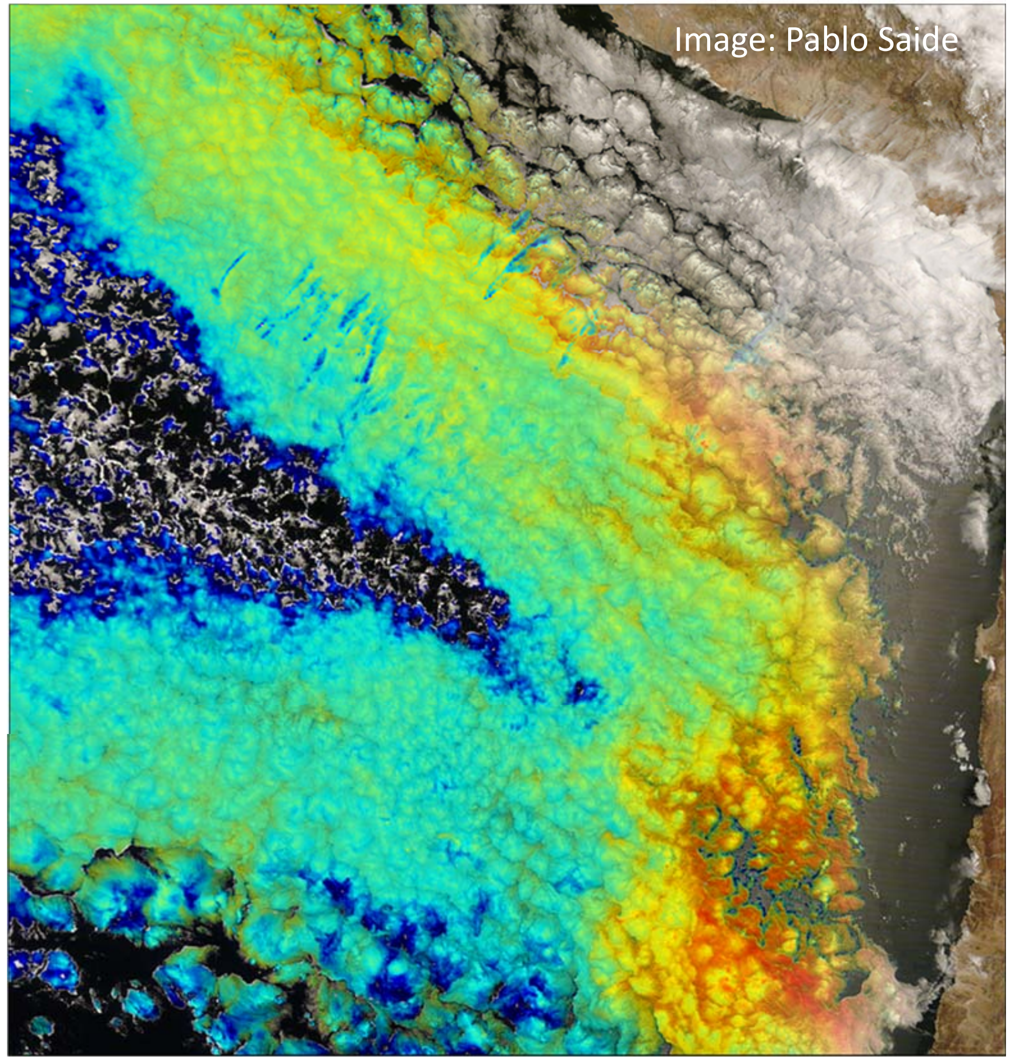
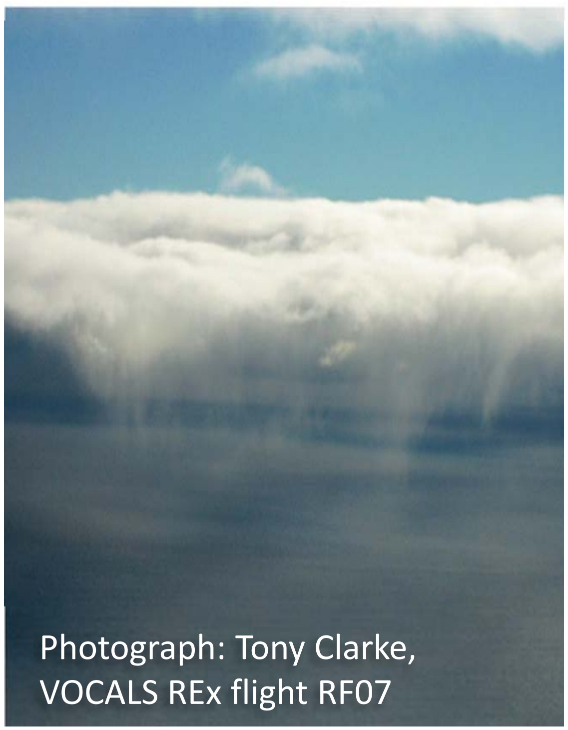


Image: Pablo Saide



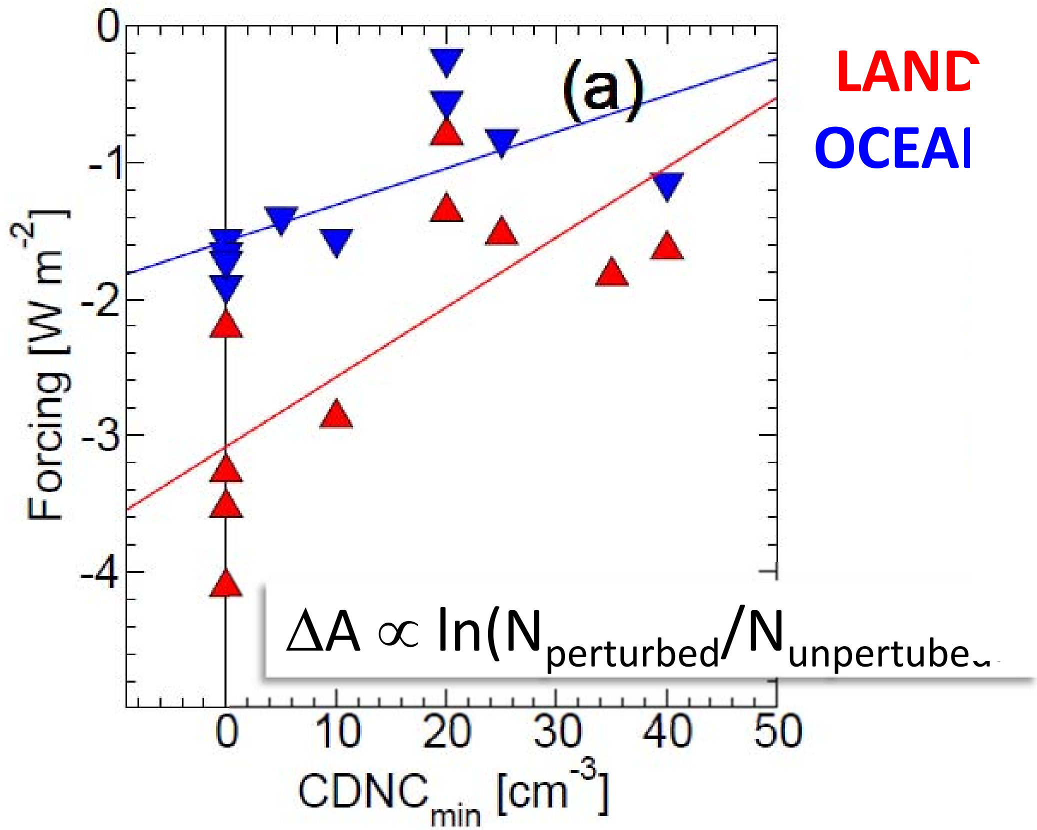
Photograph: Tony Clarke, VOCALS REx flight RF07

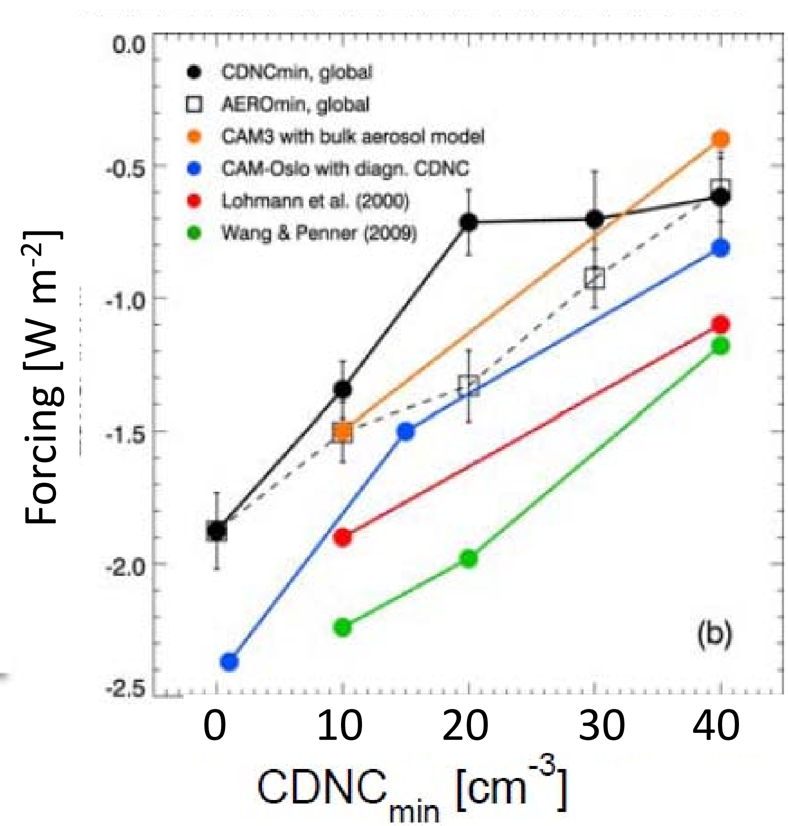
**Robert Wood**

*University of Washington*

with help/data from Dan Grosvenor, Daniel McCoy, Chris Terai, Matt Lebsock, Dave Leon, Jeff Snider, Tony Clarke

# "Background" (minimum imposed) cloud droplet concentration influences aerosol indirect effects



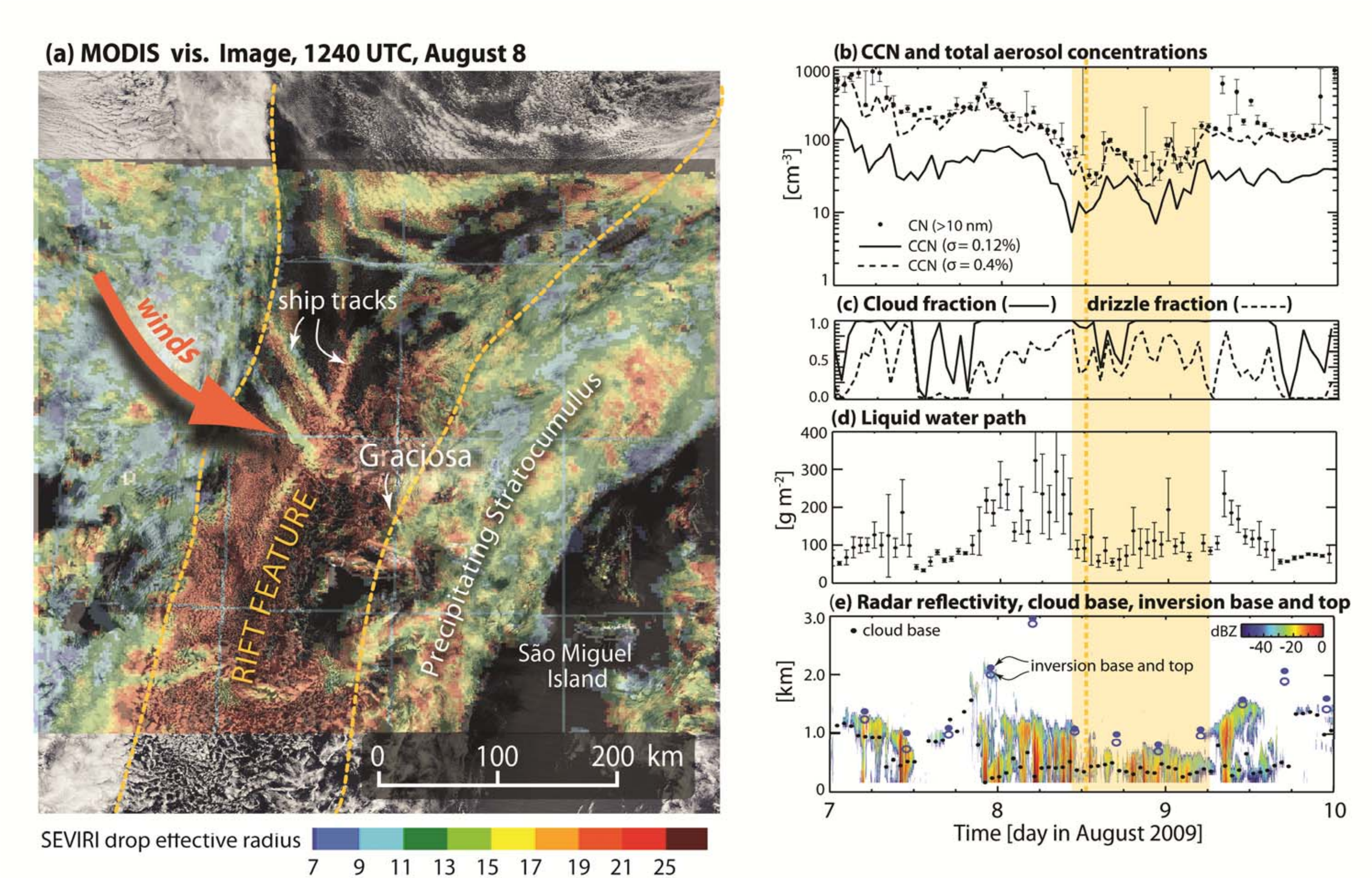




Low $N_d$ background $\Rightarrow$ strong Twomey effect

High $N_d$ background $\Rightarrow$ weaker Twomey effect

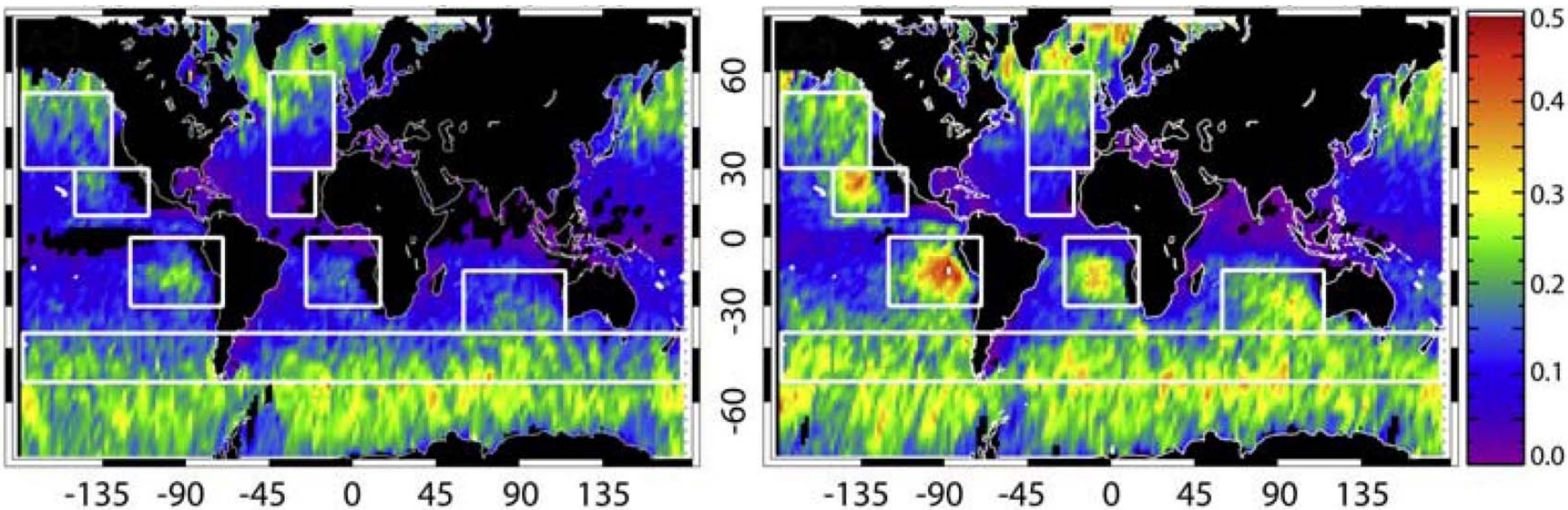
Quaas et al., AEROCOM (Atmos. Chem. Phys., 2009) Hoose et al. (GRL, 2009)

# Extreme coupling between drizzle and CCN



# Prevalence of drizzle from low clouds

**DAY** **NIGHT**




Drizzle occurrence = fraction of low clouds (1-4 km tops) for which $Z_{max}$> -15 dBZ

Leon et al., *J. Geophys. Res.* (2008)

Half of all clouds precipitate at Graciosa (Rémillard et al. 2012)

# Simple CCN budget in the MBL

$$\dot{N} = \left[\dot{N}\right]_{ent} + \left[\dot{N}\right]_{sfc} + \left[\dot{N}\right]_{coal} + \left[\dot{N}\right]_{dry\,dep}$$

**Model accounts for:**

- Entrainment
- Surface production (sea-salt)
- Coalescence scavenging
- Dry deposition

**Model does not account for:**

- New particle formation – significance still too uncertain to include
- Advection

# Production terms in CCN budget

Entrainment rate

FT Aerosol concentration

$$[\dot{N}]_{ent} = \frac{w_e(N_{FT} - N)}{z_i}$$

MBL depth

Sea-salt parameterization-dependent constant

Wind speed at 10 m

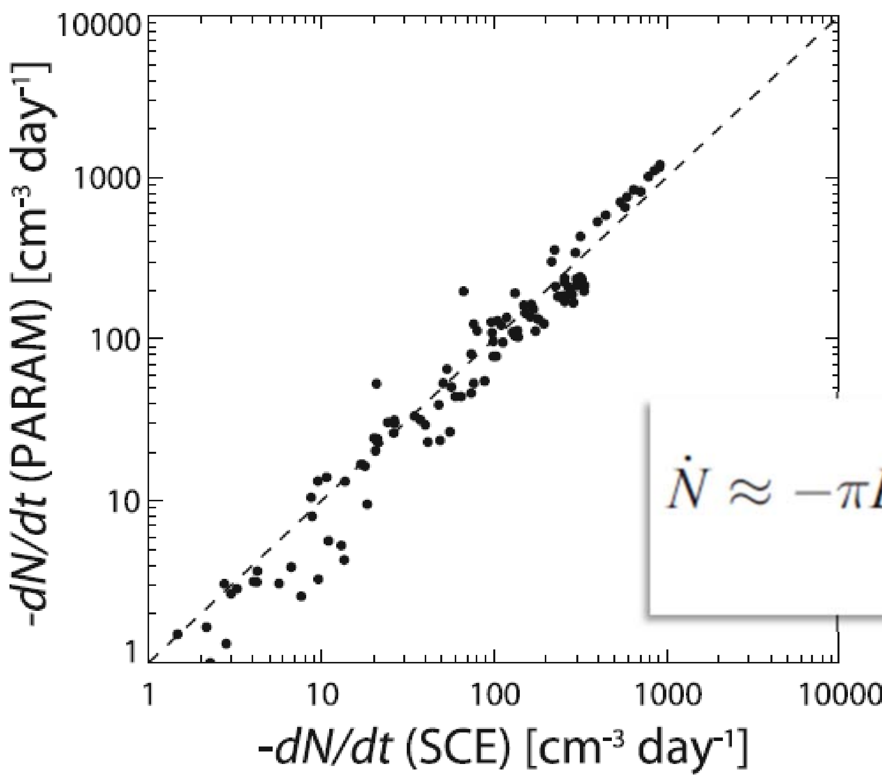
$$[\dot{N}]_{sfc} = \frac{\beta U_{10}^{3.41}}{z_i}$$

We use Clarke et al. (*J. Geophys. Res.*, 2007) at 0.4% supersaturation to represent an upper limit

# Loss terms in CCN budget: (1) Coalescence scavenging

$$[\dot{N}]_{coal} = -KNP_{CB}\frac{h}{z_i}$$

- Constant: $K$
- Precip. rate at cloud base: $P_{CB}$
- cloud thickness: $h$
- MBL depth: $z_i$



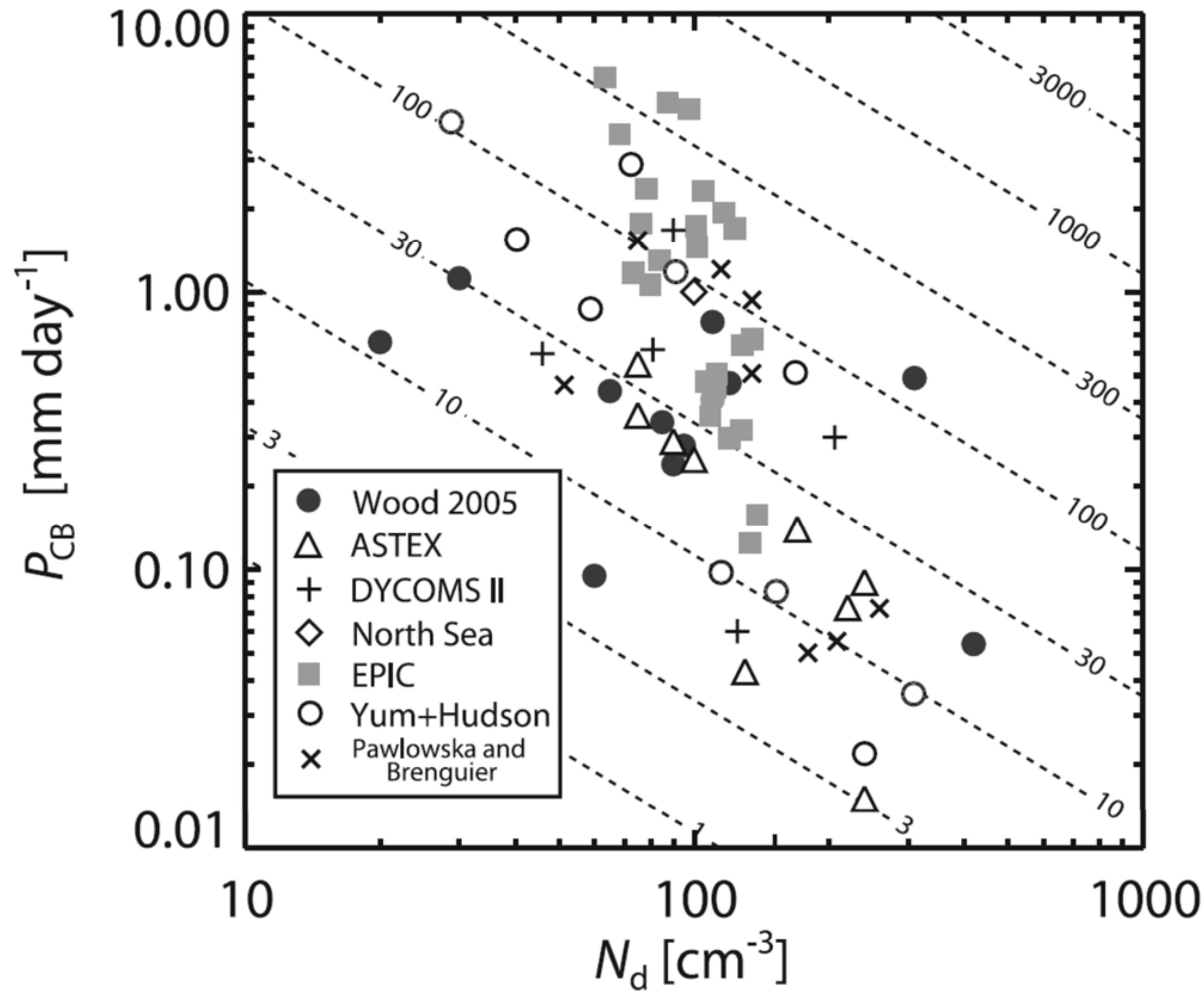

Comparison against results from stochastic collection equation (SCE) applied to observed size distribution

$$\dot{N} \approx -\pi E_0 N \int_0^\infty r^3 w_T n(r)dr = -\frac{3}{4\rho_w}E_0 NP$$

Wood, *J. Geophys. Res.*, 2006

# MBL mean CCN loss rates

Contours are loss rates in $cm^{-3}$ $day^{-1}$




Wood, *J. Geophys. Res.*, 2006

# Loss terms in CCN budget: (2) Dry deposition

$$[\dot{N}]_{dry\ dep.} = -N\frac{w_{dep}}{z_i}$$

Deposition velocity

$$\frac{[\dot{N}]_{coal}}{[\dot{N}]_{dry\ dep.}} = \frac{KP_{CB}h}{w_{dep}}$$

$w_{dep}$ = 0.002 to 0.03 cm $s^{-1}$ (Georgi 1988)

$K$ = 2.25 $m^2$ $kg^{-1}$ (Wood 2006)

For $P_{CB}$ = > 0.1 mm $day^{-1}$ and $h$ = 300 m

$$\frac{[\dot{N}]_{coal}}{[\dot{N}]_{dry\ dep.}} = 3 \text{ to } 30$$

For precip rates > 0.1 mm $day^{-1}$, coalescence scavenging dominates

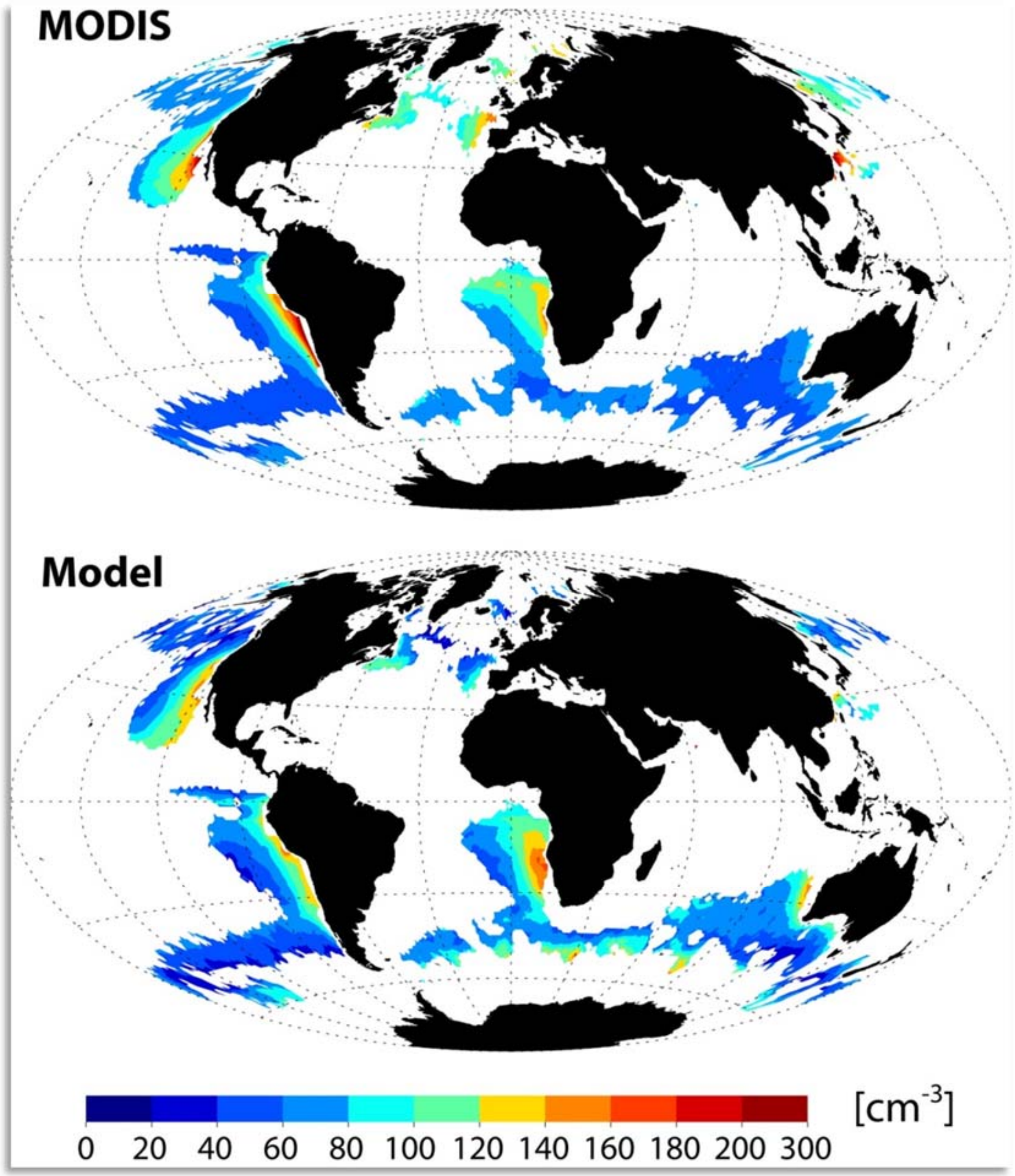
# What controls $N_d$?

- **<u>Simple</u>** budget model for CCN/$N_d$ in the MBL:

$$\dot{N} = [\dot{N}]_{ent} + [\dot{N}]_{sfc} + [\dot{N}]_{coal}$$

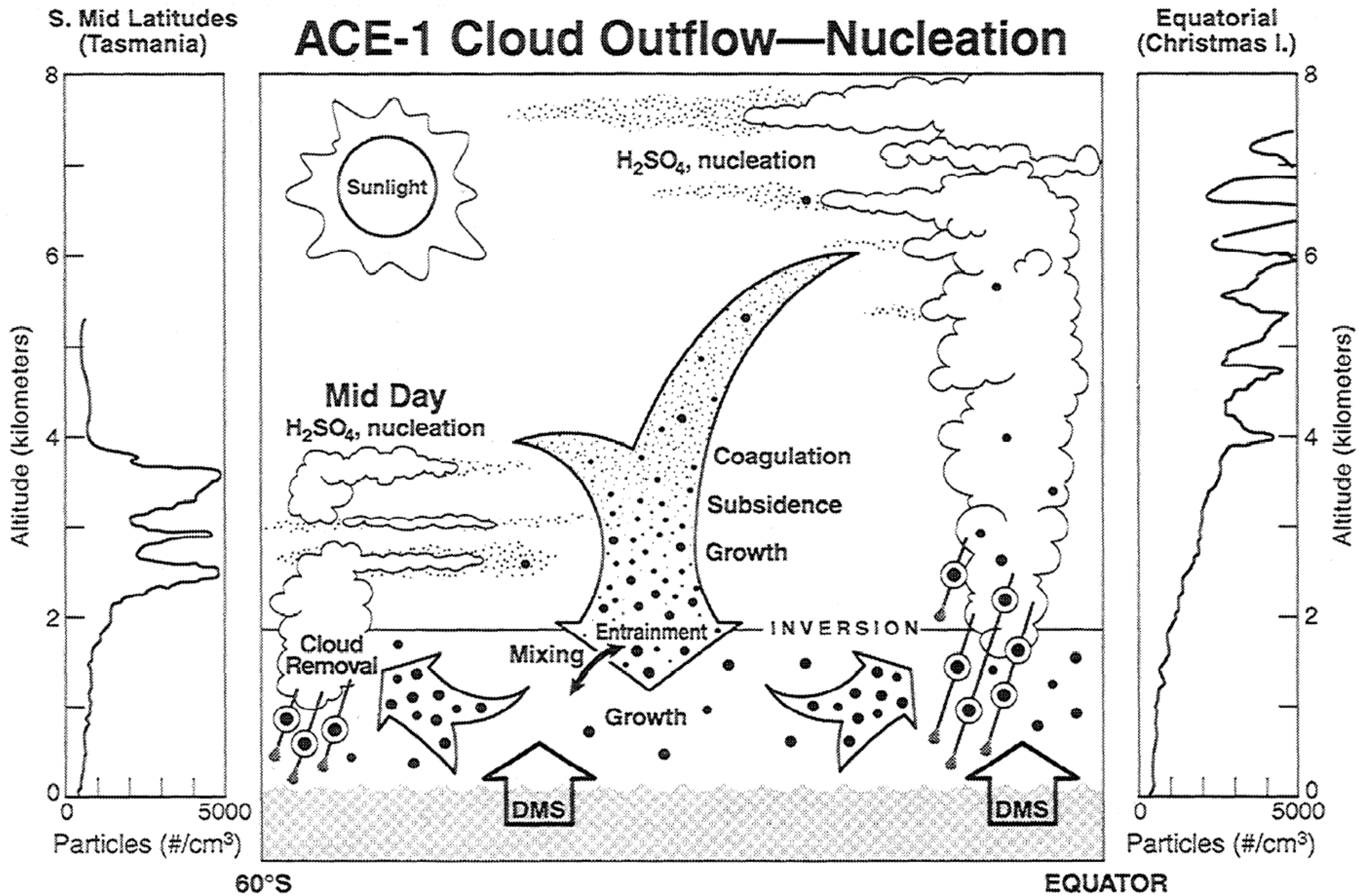
$$N_{eq} = \frac{\left(N_{FT} + \frac{\beta U_{10}^{3.41}}{D z_i}\right)}{\left(1 + \frac{hkP_{CB}}{D z_i}\right)}$$

- Assume aerosol sources constant (here represented by FT concentration "buffer")
- **Model pattern almost entirely driven by precipitation sinks**
- Can reproduce significant amount of variance in $N_d$ over oceans $\Rightarrow$ implications for significance of AOD vs $r_e$ relation ships




Wood (2011)

# Conceptual model of background FT aerosol



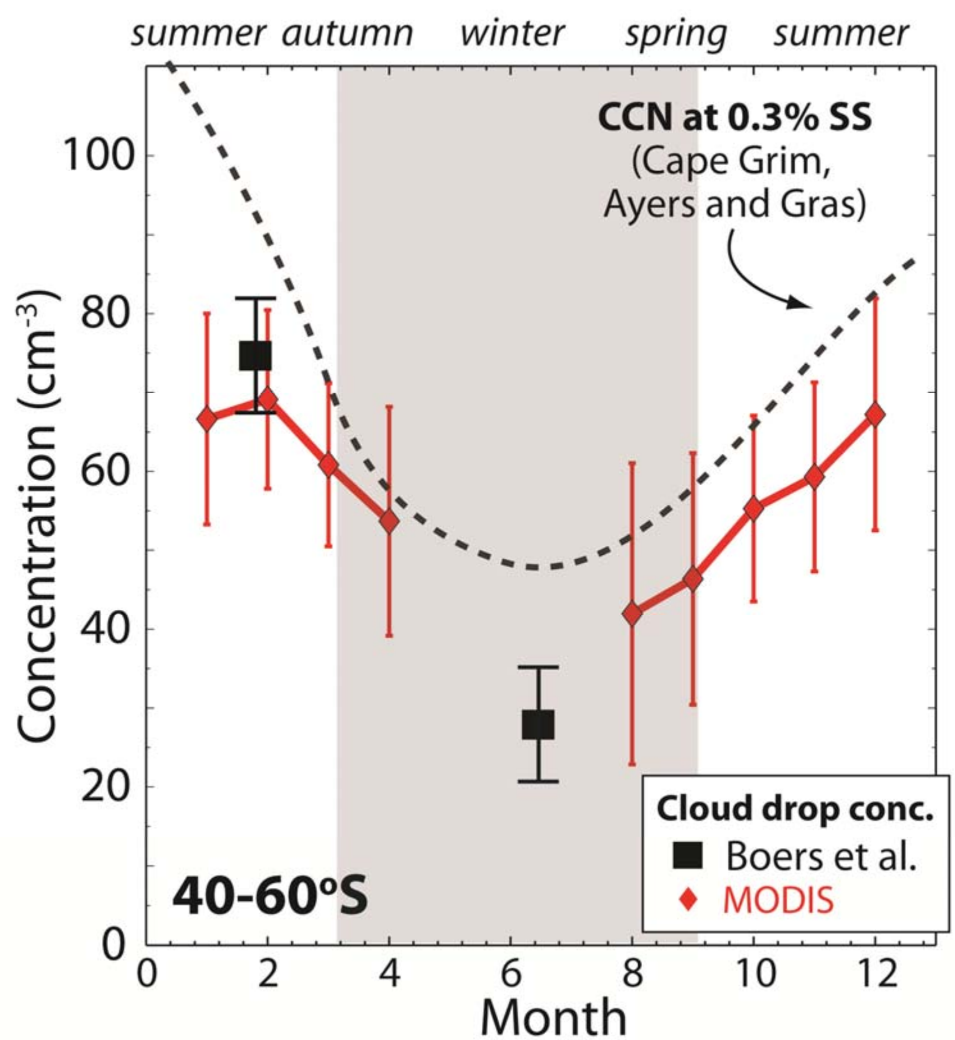

Clarke et al. (*J. Geophys. Res*. 1998)

# Conclusions

- Aerosol loss rates to coalescence scavenging in weakly-precipitating clouds are significant and are a dominant control on CCN in regions of marine low clouds
- Simple CCN budget model predicts cloud droplet concentrations in regions of persistent low level clouds with some skill, demonstrating importance of light precipitation for setting "background" Nd in the remote marine PBL
- Entrainment aerosols from FT (and sea-salt in regions of stronger mean winds) can provide sufficient CCN to supply MBL. Need to understand factors controlling entrainment, but most importantly need measurements of FT CCN concentrations.
- Significant fraction of the variability in $N_d$ across regions of extensive low clouds is likely related to drizzle sinks rather than source variability. Rates can be quantified with sensitive ARM radars.

# Southern Ocean Annual Cycle

- Marked annual cycle of $N_d$ in low clouds over Southern Ocean
- Summer maximum likely biogenic (DMS?)
- In-situ and satellite observations consistent
- Summer maximum (70 $cm^{-3}$); Winter minimum (35 $cm^{-3}$)
- Twomey effect 25%?
- Not well captured in models (e.g. CAM5)




Wood et al. (2013)