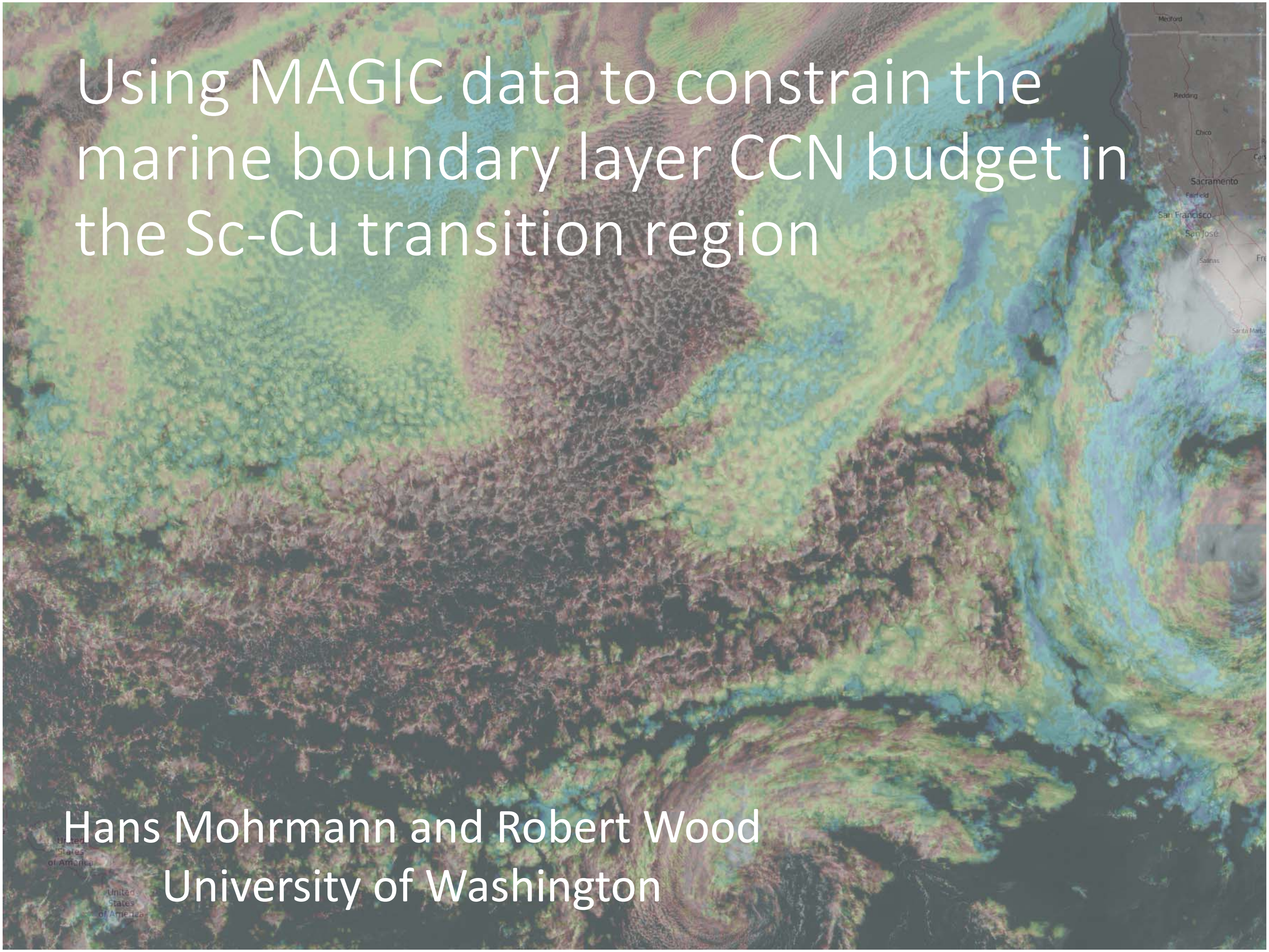
Using MAGIC data to constrain the marine boundary layer CCN budget in the Sc-Cu transition region



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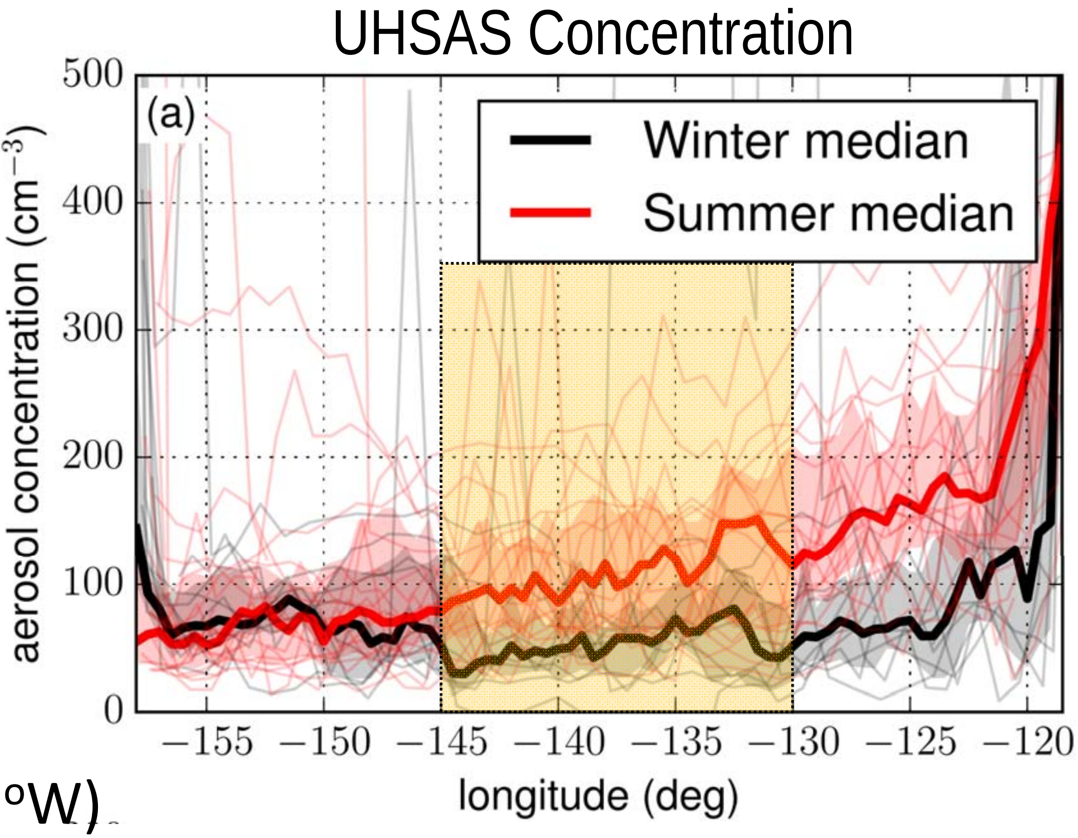
University of Washington

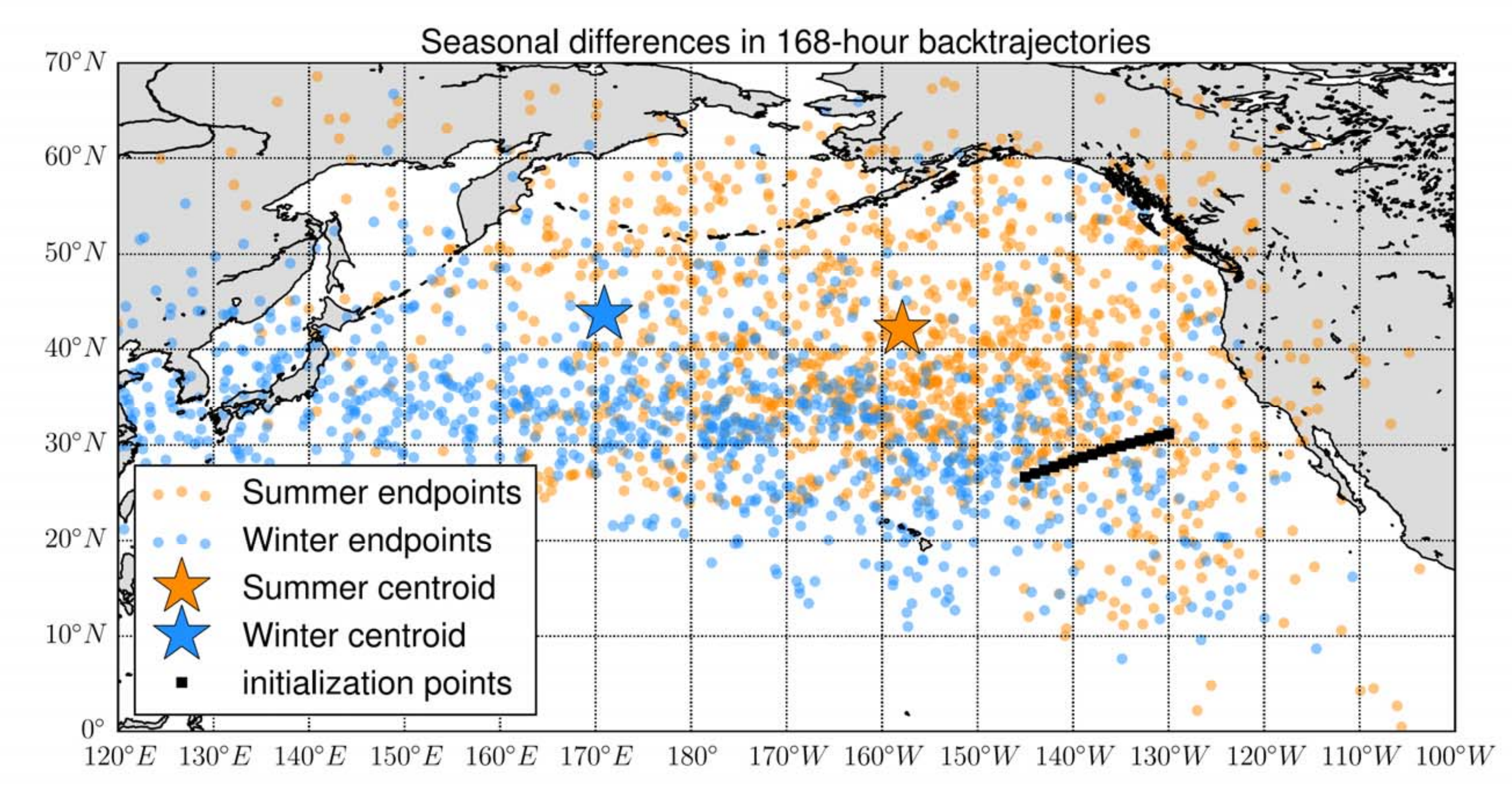
MAGIC: Seasonality of accumulation mode aerosol concentration

- **Winter**: Legs 02A-08B (Sep 2012-Jan 2013)
- **Summer**: Legs 10A-19B (May-Sep 2013)



- Here, focus is on understanding the remote region (130-145°W)
- Coastal region variability explored in Painemal et al. (2015)

Back-trajectory source locations



Simple CCN budget in the MBL

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

Model accounts for:

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

Model does not account for:

- New particle formation – significance still too uncertain to include
- Advection
- Dry deposition (typically <10% of coalescence scavenging)
- Interstitial aerosol scavenging in-cloud, or subcloud precip scavenging

Production terms in CCN budget

Entrainment rate

FT Aerosol concentration

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

MBL depth

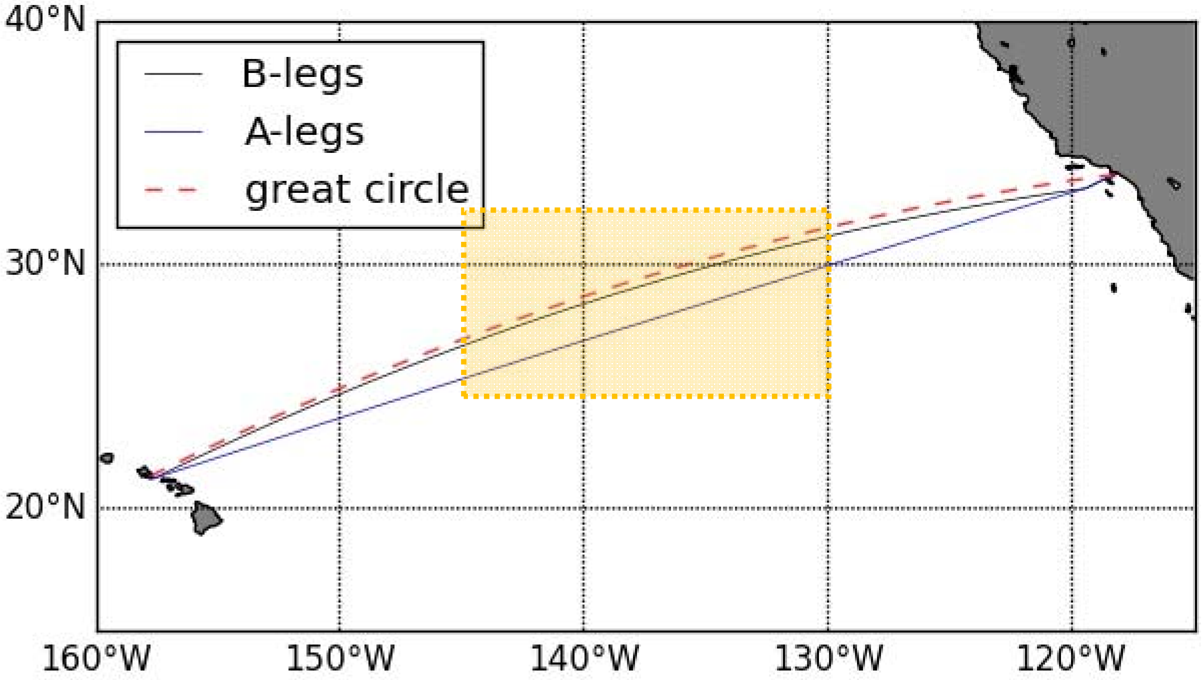
Sea-salt
parameterization-dependent
constant

Wind speed at 10 m

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

We use Clarke et al. (*J. Geophys. Res.*, 2006) at 0.2% supersaturation to represent an upper limit

MAGIC Data used



- Focus on Sc-Cu transition region (130-145^{o}W)
- Split data into summer and winter

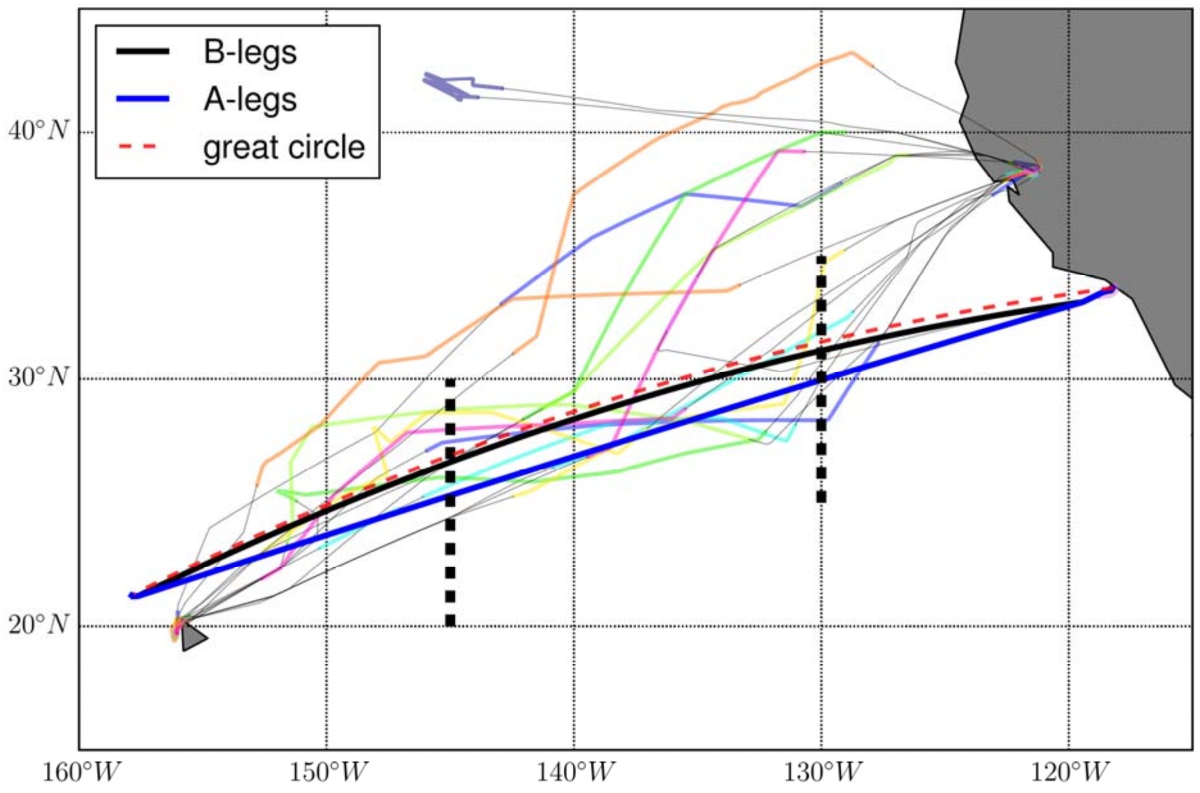
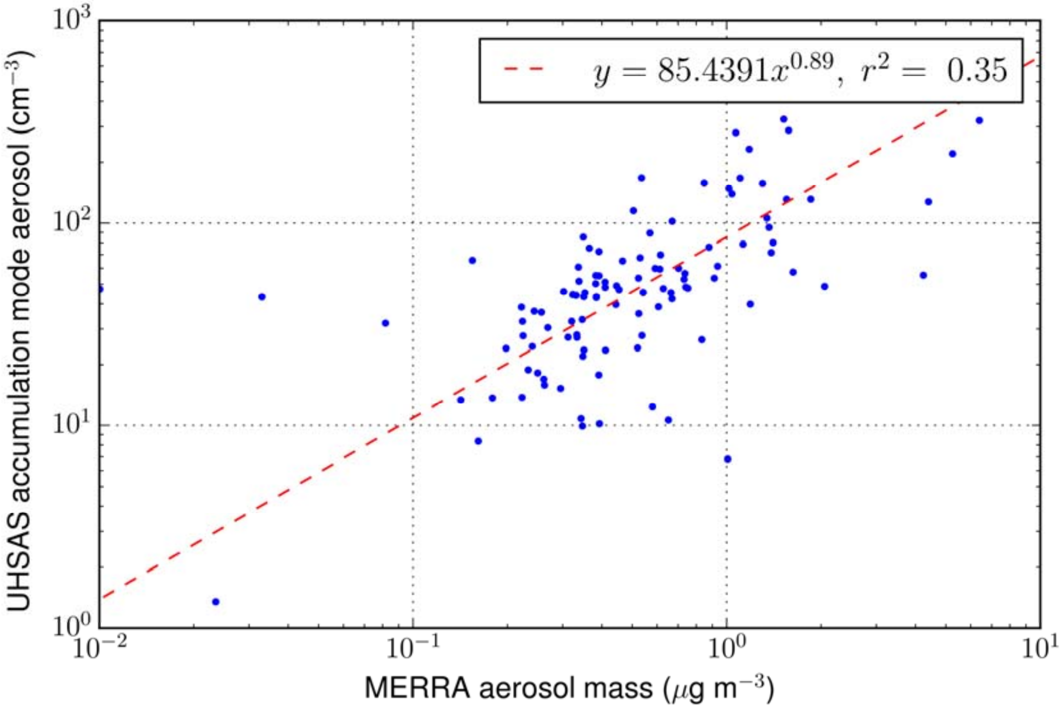


Figure 2.1: (Thick black and blue lines) MAGIC ship path from Leg 15; the *Spirit* followed a fixed path for all legs with minor deviation. Thick dashes show boundaries of west/central/east regions of analysis. (Thin colored lines) CSET flghts; colored section corresponds to boundary-layer and lower free-tropospheric profiling. Note that the bulk of the CSET flights took place within the central region.

Free tropospheric aerosol (N_{FT})

Data from NSF Cloud System Evolution in the Trades (CSET) aircraft campaign (G-V HIAPER, Jul-Aug 2015)

- Correlate lower free-tropospheric concentration from UHSAS on G-V with MERRA-2 submicron aerosol mass
- Use MERRA-2 seasonally-varying aerosol mass to estimate seasonal cycle in FT accumulation mode aerosol concentration
- Not great, but it is probably the best we can do



Cloud top entrainment rate

- Use Wood and Bretherton (2004) mass budget approach. For seasonal means, there is no storage term ($\partial z_i/\partial t=0$), so:

$$w_e = w_s + \mathbf{U} \cdot \nabla z_i$$

entrainment rate

subsidence rate (ERA-I)

advection of MBL depth (ERA-I)

Winter: w_e = 3.4 mm s^{-1}

Summer: w_e = 5.5 mm s^{-1}

Loss term in CCN budget: Coalescence scavenging

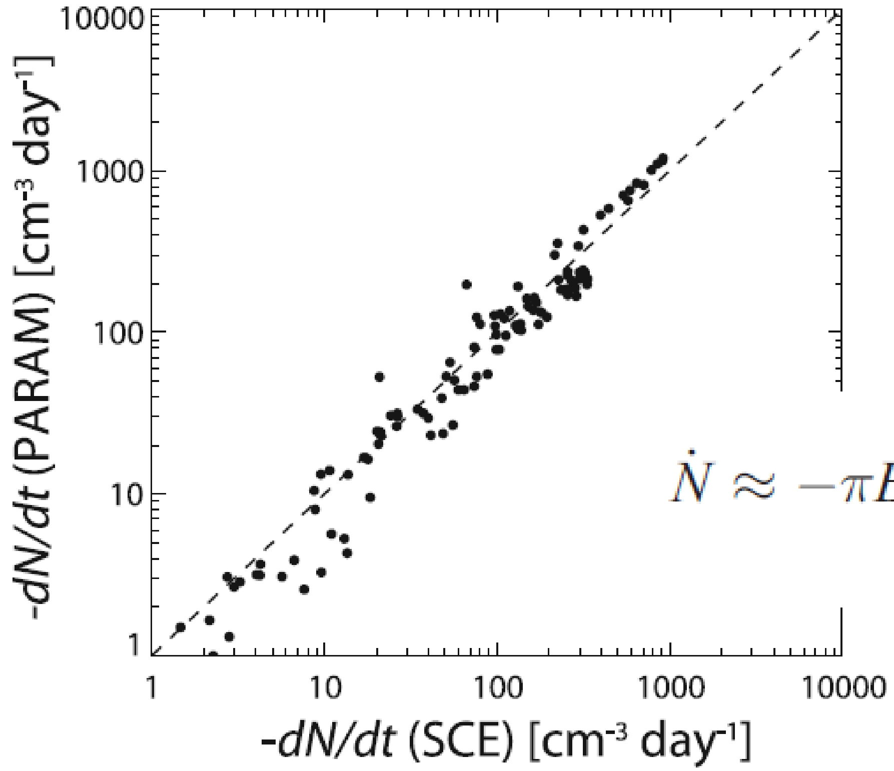
Constant

Precip. rate at cloud base

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

cloud thickness

MBL depth



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

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

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

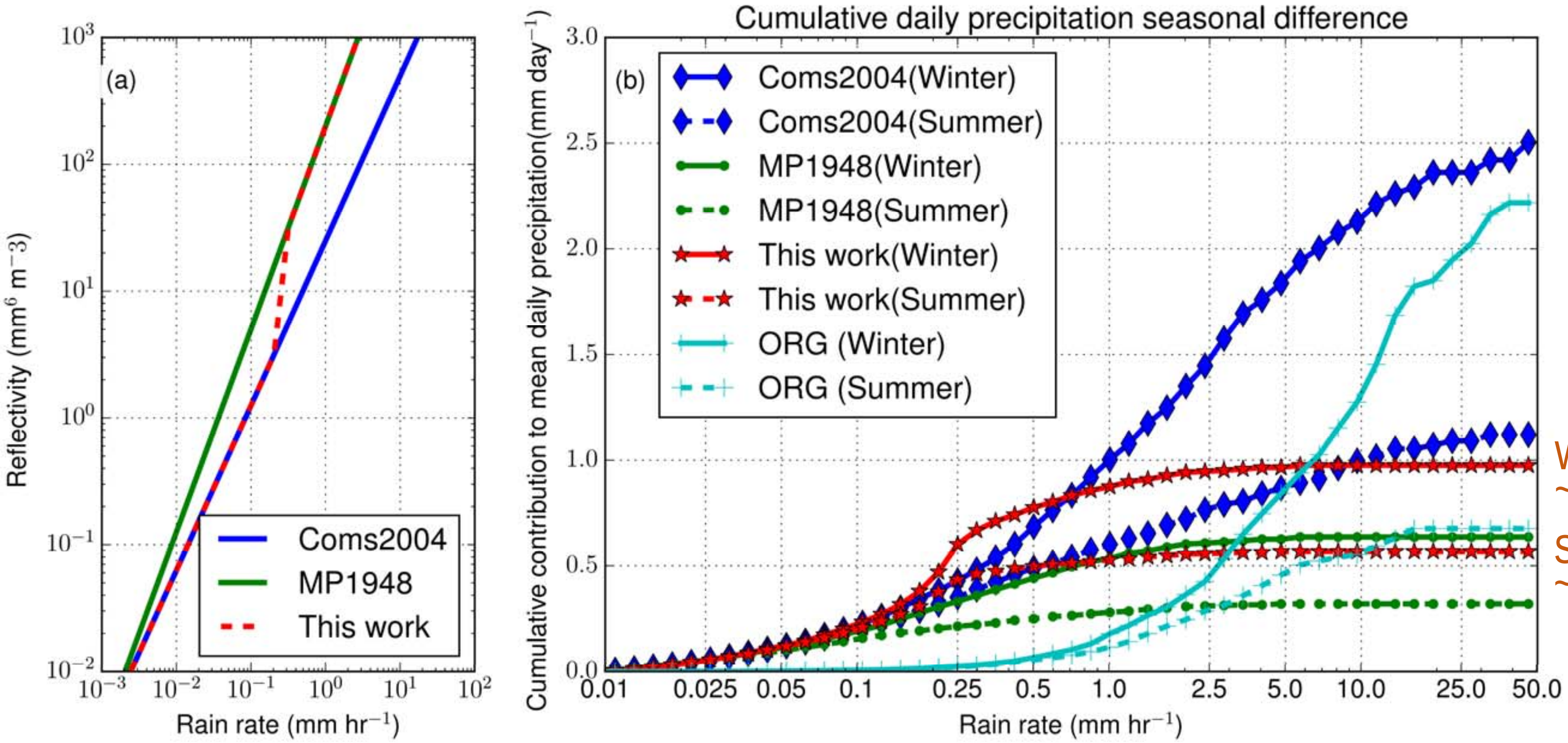
Steady state (equilibrium) CCN concentration

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

$w_e/z_i = D$ = surface divergence

Precipitation estimates

- Z-R based estimates from WACR
- Z-R relationship for cloud base from Comstock et al. (2004) for light rain rates, with Marshall-Palmer Z-R for heavier rates, to generate a “hybrid” cloud base precipitation rate
- Winter mean precipitation <u>rate</u> exceeds summer by ~70%



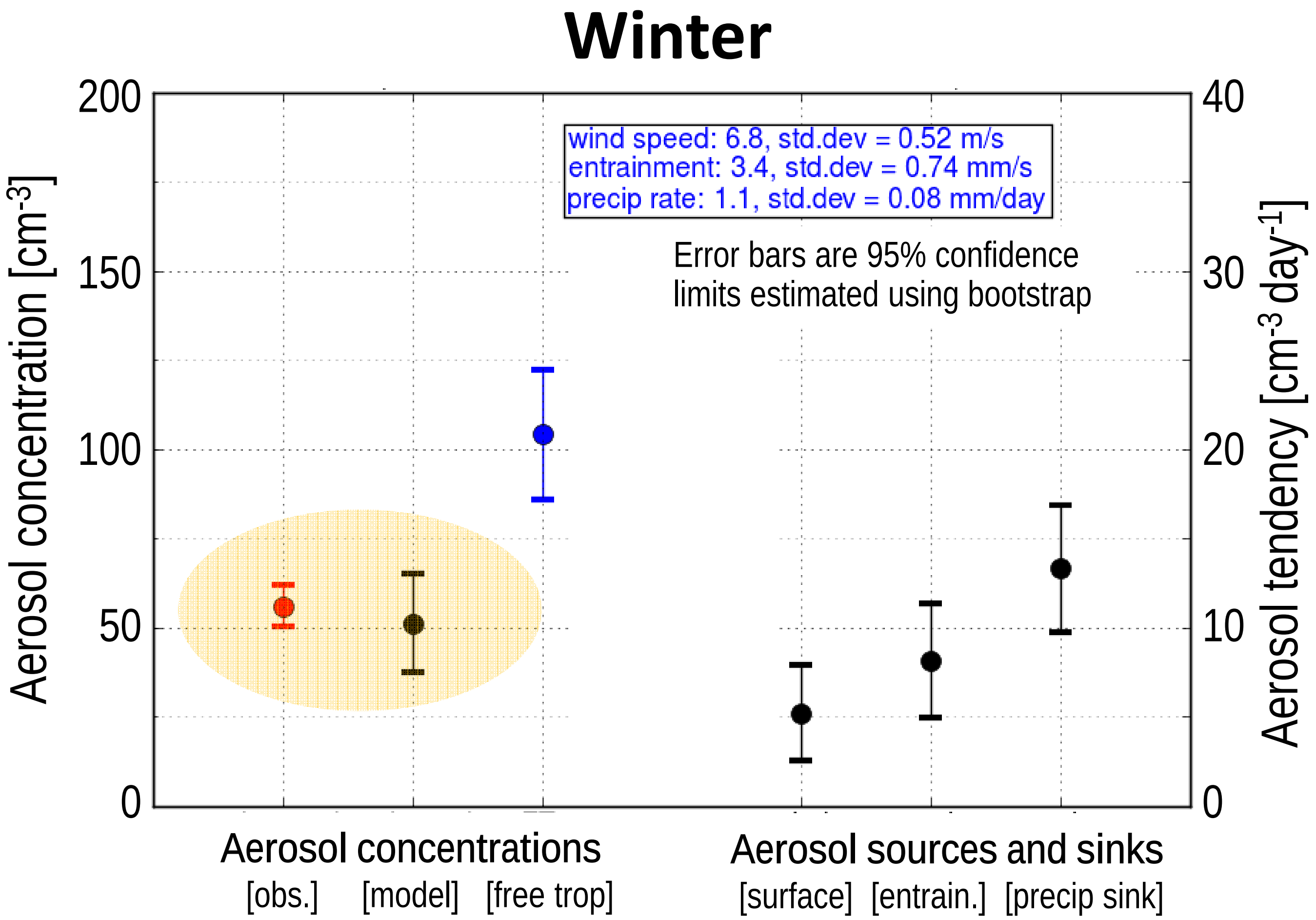
Winter
~1 mm d^{-1}

Summer
~0.6 mm d^{-1}

0.24 0.6 1.2 2.4 6.0 12 24 60 120 240 600 1200
Rain rate [mm d^{-1}]

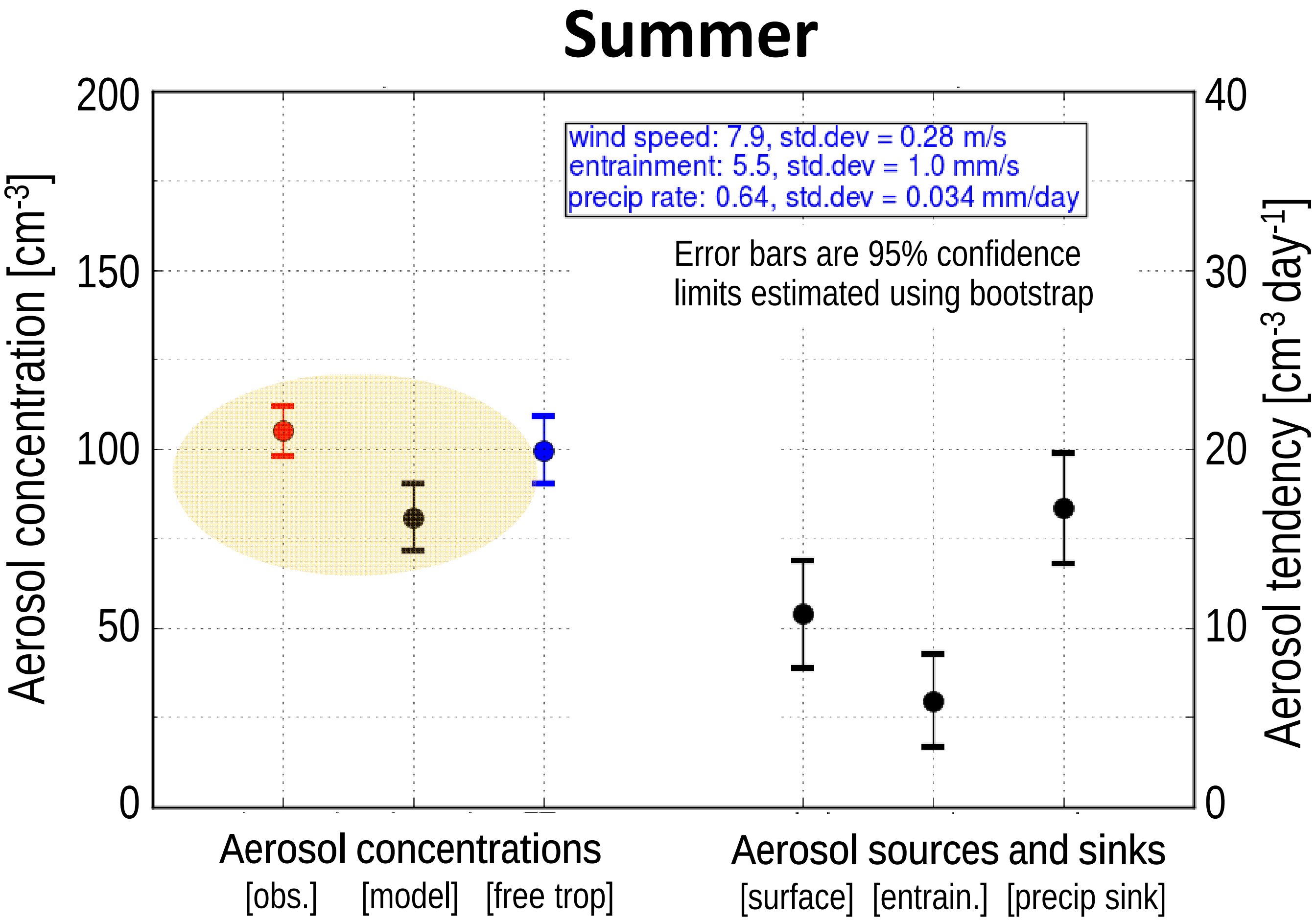
How well do we estimate the accumulation mode aerosol concentration?

- Good agreement between observed and modeled aerosol concentration
- Free troposphere serves as a source and exceeds surface source



How well do we estimate the accumulation mode aerosol concentration?

- Concentrations roughly factor of two higher during summer; model captures quite well
- Precipitation explains 50% of seasonal difference
- Free troposphere is a weaker source than during winter owing to weaker FT-MBL differential
- Surface source more important

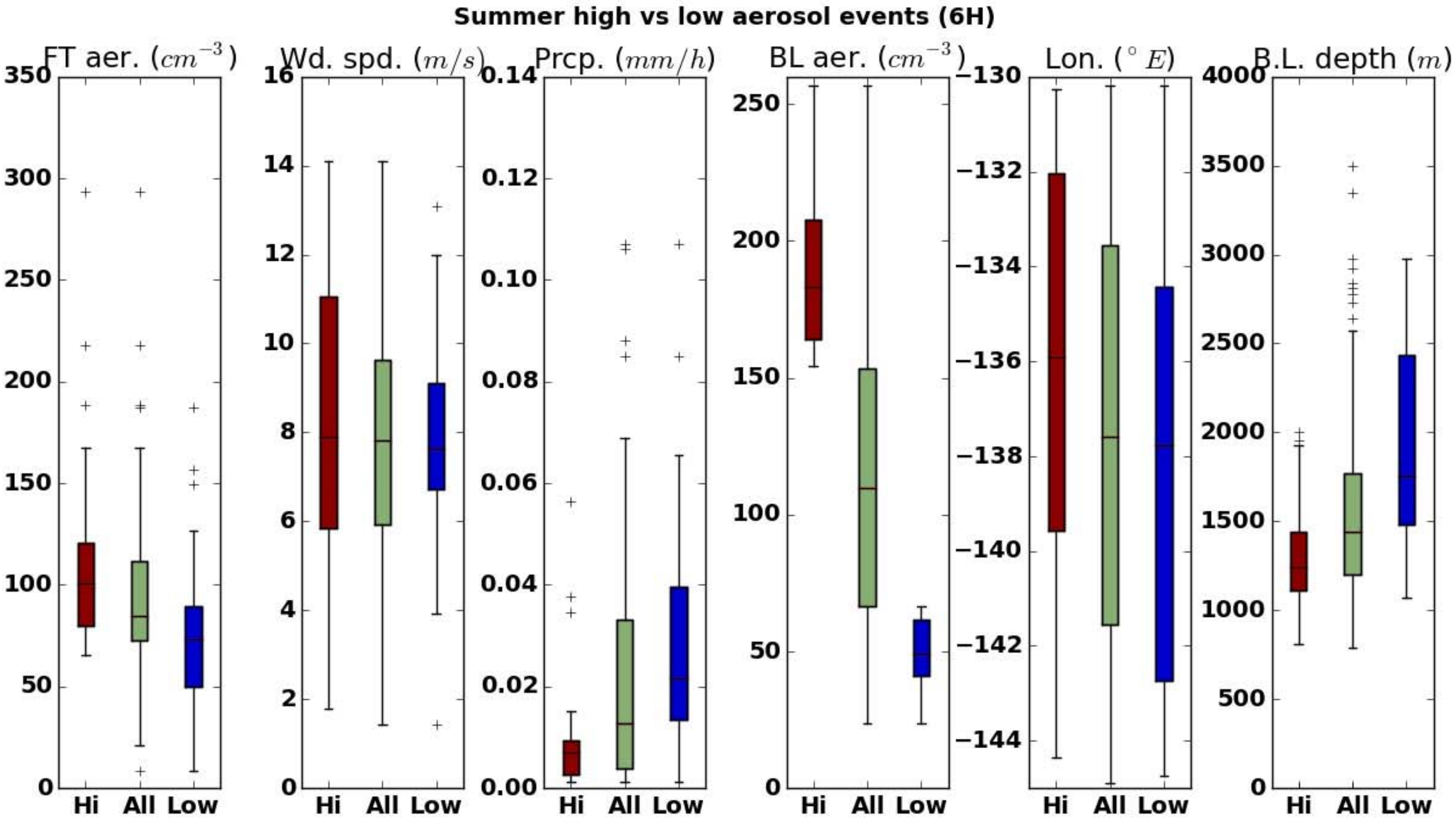


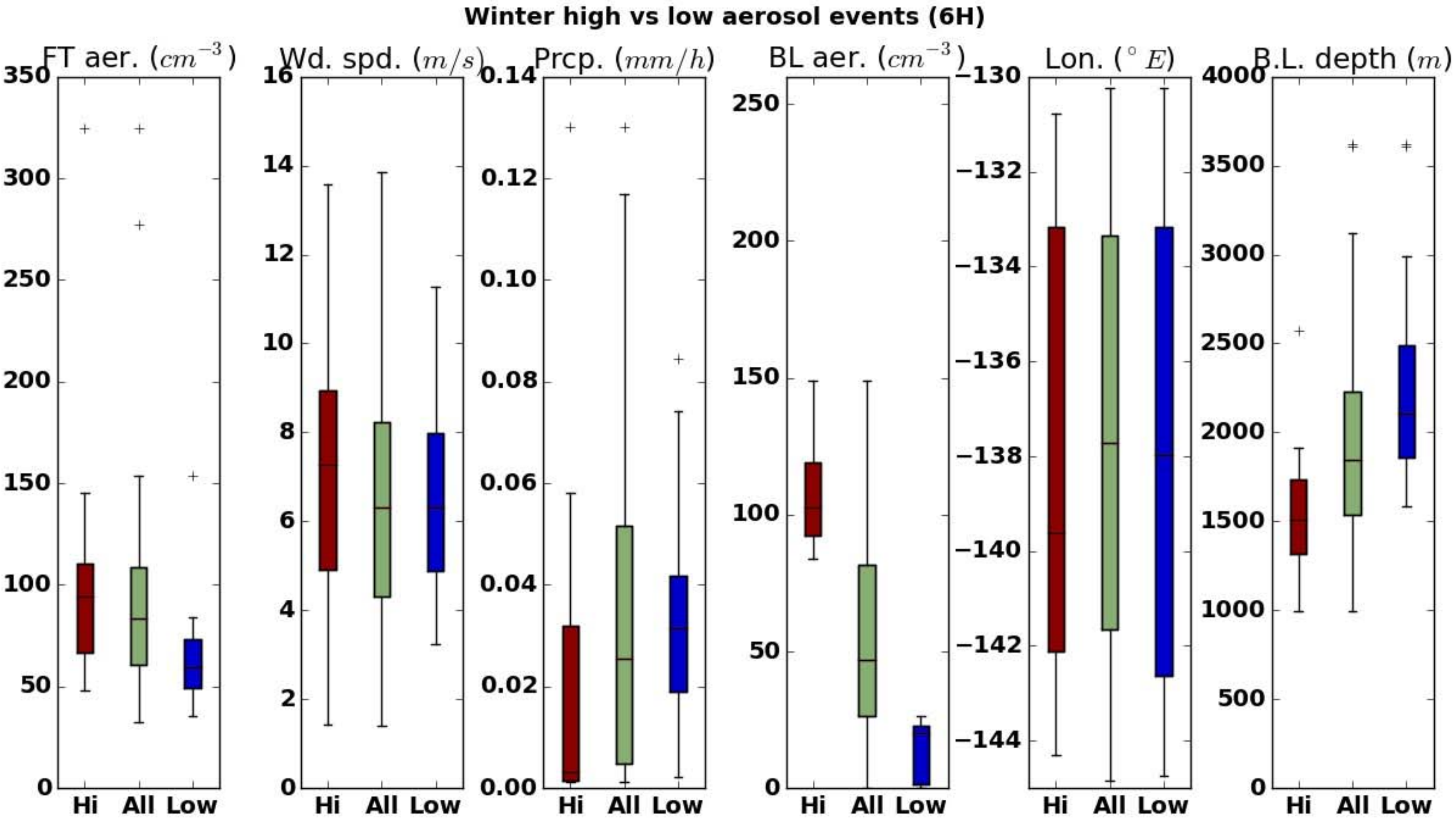
Summary

- In the Sc-Cu transiton region away from the coast, the mean summer accumulation mode aerosol concentration (N_a) in the MBL is roughly twice that during winter (100 cm^{-3} vs 50 cm^{-3})
- The summer-winter difference in N_a is captured reasonably well by simple CCN budget model driven by observationally-constrained surface sources, FT entrainment and precipitation sinks
- Seasonal cycle driven mostly (50%) by higher precipitation sink during winter
- There is plenty of uncertainty in these estimates

Additional slides

Subseasonal variability

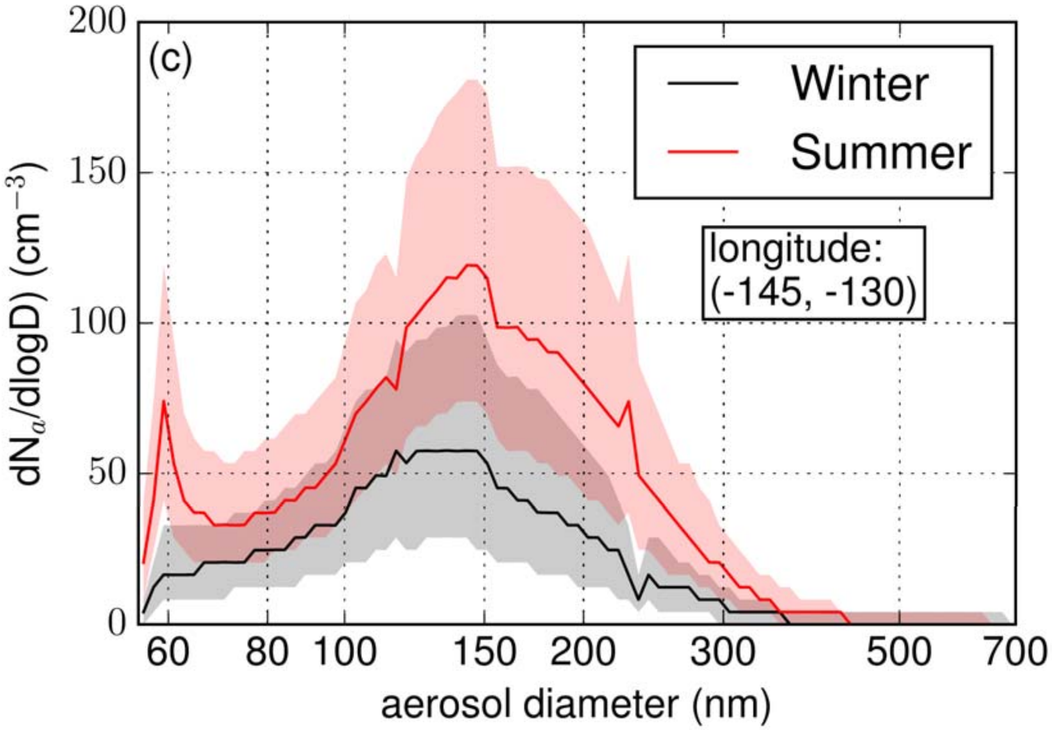




Winter high vs low aerosol events (6H)
FT aer. (cm^{-3})
Wd. spd. (m/s)
Prcp. (mm/h)
BL aer. (cm^{-3})
Lon. ($^\circ E$)
B.L. depth (m)
350
300
250
200
150
100
50
0
16
14
12
10
8
6
4
2
0
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
250
200
150
100
50
0
−130
−132
−134
−136
−138
−140
−142
−144
4000
3500
3000
2500
2000
1500
1000
500
0
Hi
All
Low

UHSAS Size Distribution

- Seasonal concentration differences largely explained by changes in all size categories



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

CCN budget with all processes

Sea spray

Growth to CCN size

Precipitation loss

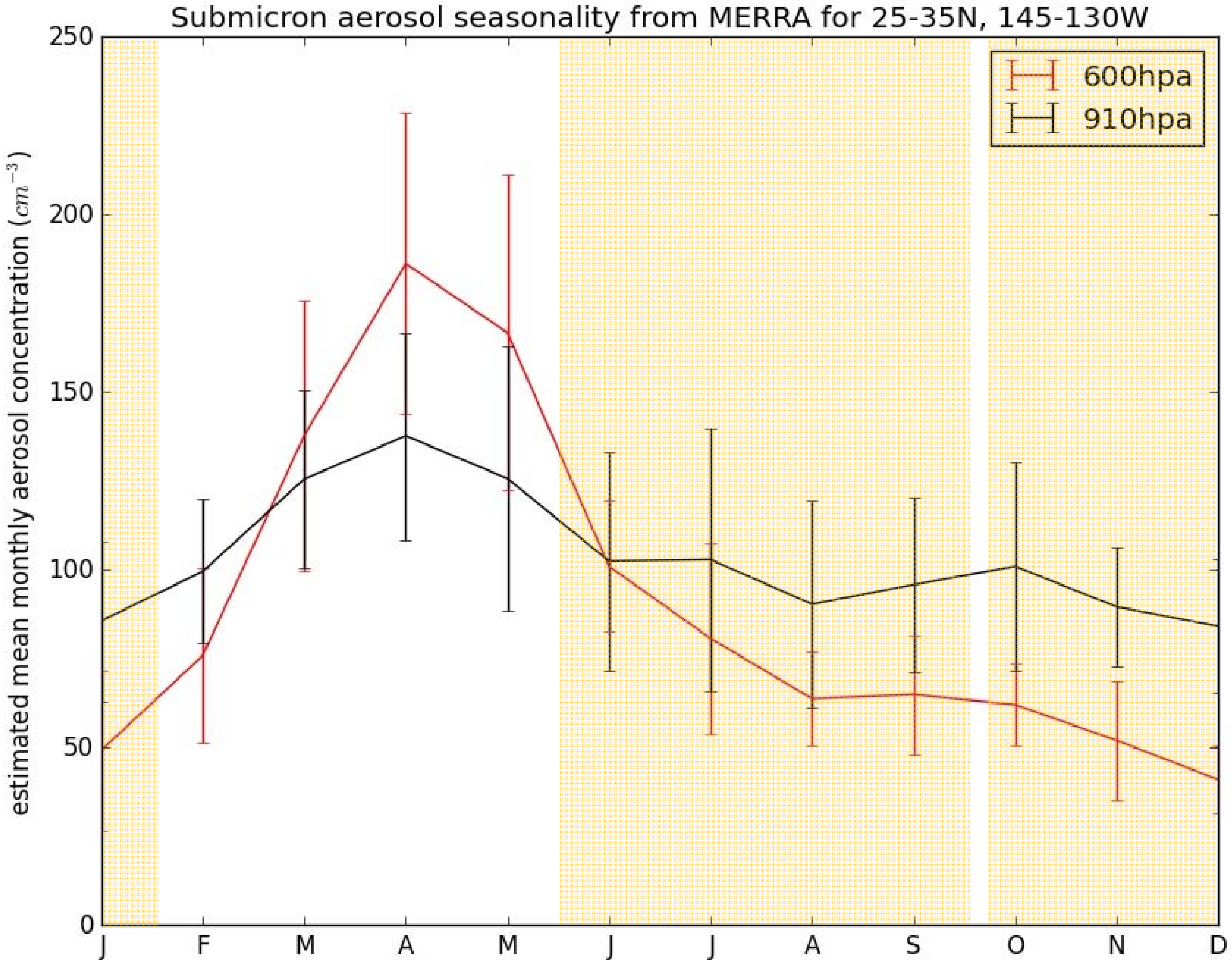
Advection

Entrainment

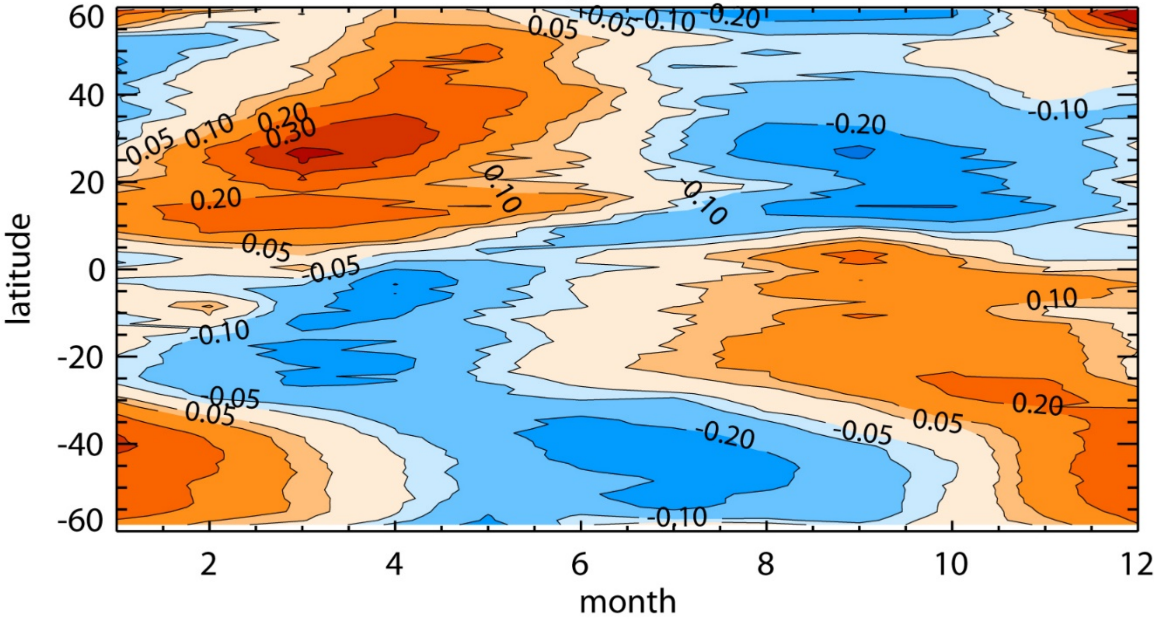
Dry Deposition

Secondary formation

$$\frac{\mathrm{d}N_a}{\mathrm{d}t} = \left.\frac{\partial N_a}{\partial t}\right|_{adv} + \left.\frac{\partial N_a}{\partial t}\right|_{sfc} + \left.\frac{\partial N_a}{\partial t}\right|_{ent} + \left.\frac{\partial N_a}{\partial t}\right|_{grth} + \left.\frac{\partial N_a}{\partial t}\right|_{dry} + \left.\frac{\partial N_a}{\partial t}\right|_{prcp} + \left.\frac{\partial N_a}{\partial t}\right|_{scnd}$$


Submicron aerosol seasonality from MERRA for 25-35N, 145-130W
estimated mean monthly aerosol concentration (cm^{-3})
0
50
100
150
200
250
J
F
M
A
M
J
J
A
S
O
N
D
600hpa
910hpa

Fractional N_d anomaly [ocean]



Fractional AOD anomaly [ocean]