Comparison of Parameterizations of the Aerodynamic Resistance and Implications for Dry Deposition Modeling

John T. Walker, Donna Schwede, Jesse Bash

U.S. EPA

Office of Research and Development

Research Triangle Park, NC

Chris Oishi

U.S. Forest Service

Southern Research Station

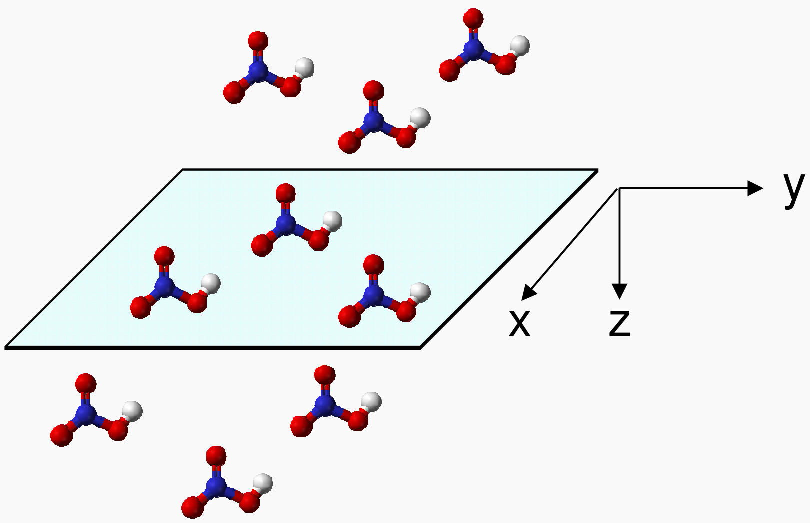
Otto, NC

Conceptual framework

Flux (Deposition Rate) = Deposition Velocity * Concentration

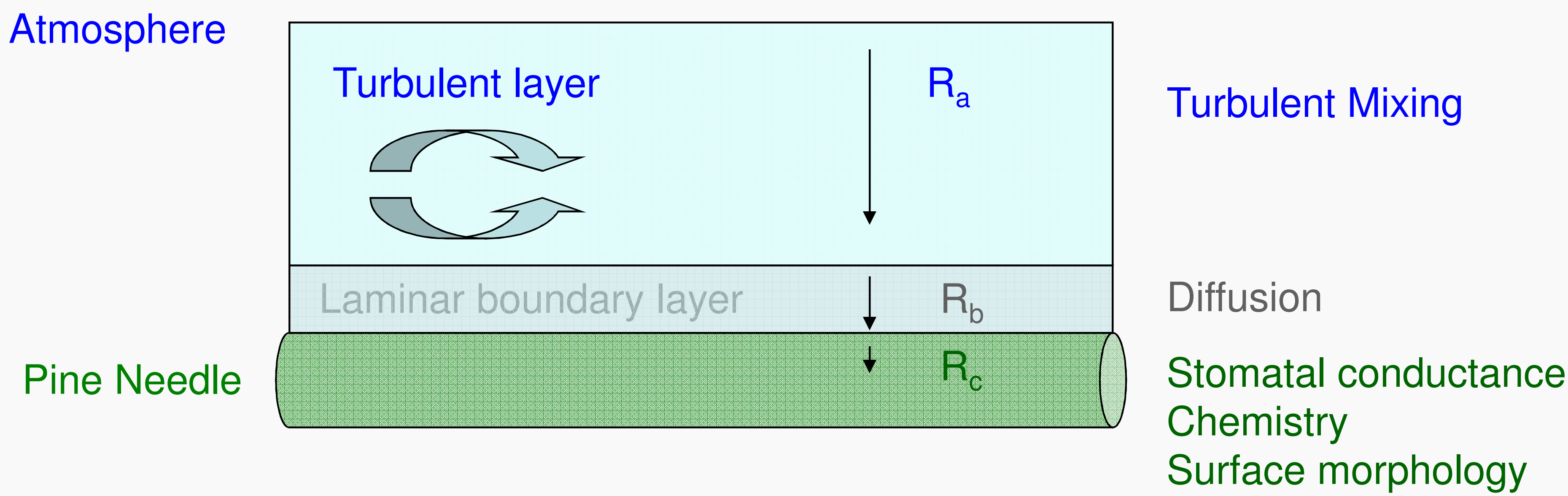
$$F = -v_d * c$$

units $$\frac{\mu g}{m^2 s} = \frac{m}{s} * \frac{\mu g}{m^3}$$

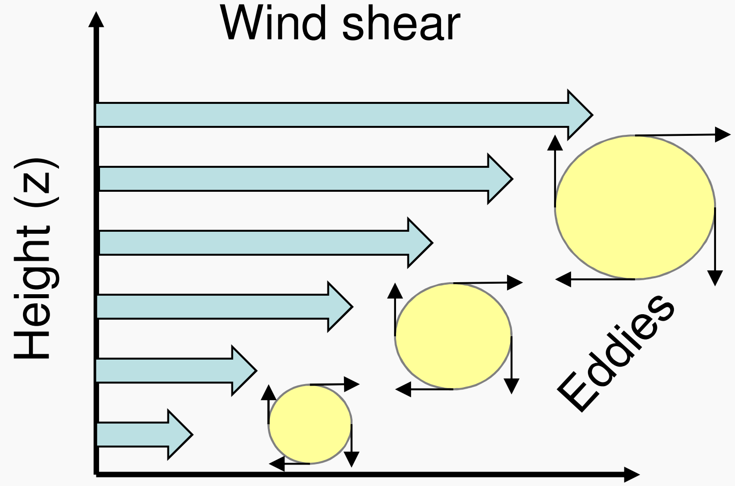


$$v_d = \frac{1}{R_a + R_b + R_c}$$

- R_a - aerodynamic resistance
- R_b – boundary layer resistance
- R_c – canopy resistance



R_a is a function of wind speed and turbulence

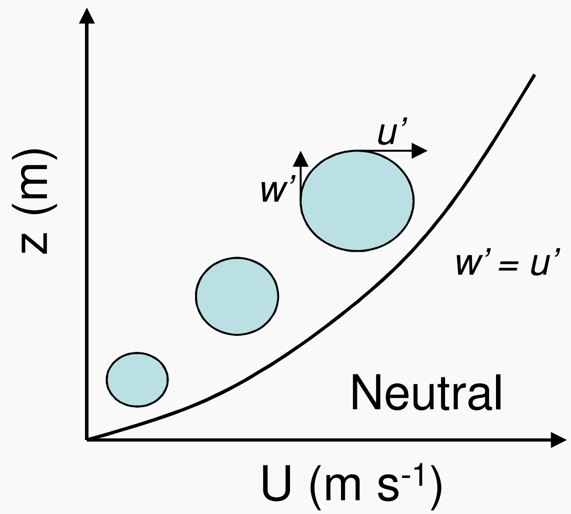


$$\frac{\partial u}{\partial z} = f(z, \rho, \tau) = f(z, u_*)$$

- Wind speed increases with height.
- Momentum is directed from higher to lower wind speed
- Some of the horizontal momentum is directed into the vertical plane
- The vertical flux of horizontal momentum is $\tau = \rho u_*$. Has units of force/unit ground area
- Friction velocity (u_*) is the tangential velocity of the eddies (indicates degree of turbulent mixing).

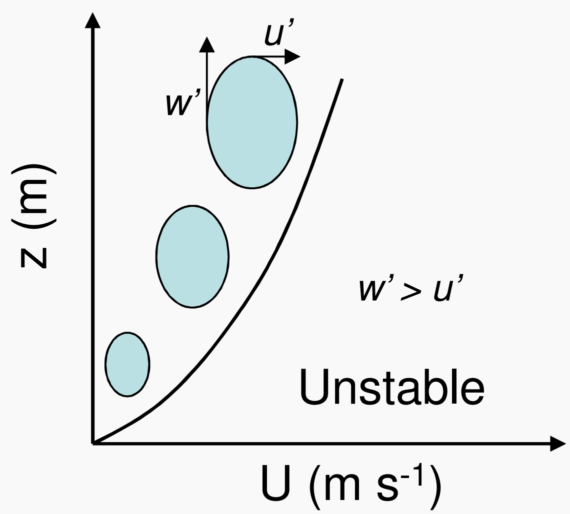
Dimensional analysis $$\frac{\partial u}{\partial z} = \frac{z}{u_*} \longrightarrow \left(\frac{\partial u}{\partial z}\right)\frac{u_*}{z} = \text{constant} = \frac{1}{k}$$ von Karman's constant $k = 0.4$

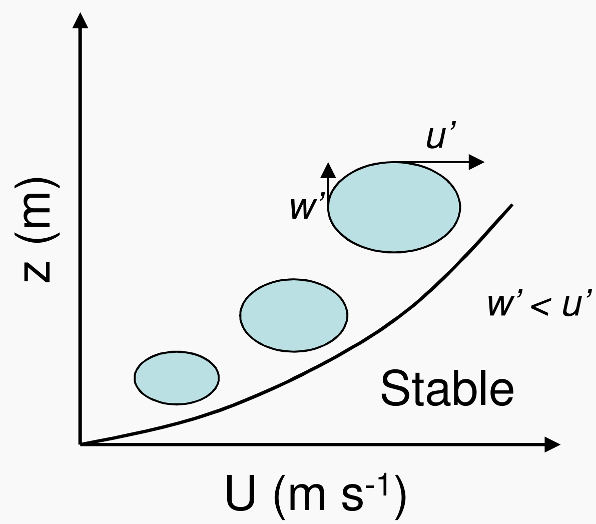
$$\frac{\partial u}{\partial z} = \frac{z}{ku_*} \longrightarrow \text{Integrate w.r.t. } z \longrightarrow u(z) = \frac{u_*}{k}\ln\left(\frac{z}{z_0}\right)$$



- The basic form of the logarithmic wind profile is valid under neutral atmospheric stability.
- For unstable (daytime, surface heating) and stable (nighttime, surface cooling) conditions, a stability correction must be applied to yield the correct vertical profile of wind speed.

$$u(z) = \frac{u_*}{k}\left[\ln\left(\frac{z}{z_0}\right) - \psi_m\left(\frac{z}{L}\right) + \psi_m\left(\frac{z_0}{L}\right)\right]$$





Ψ_m = integrated stability function for momentum

L = Obukhov length scale (measure of stability)

- The aerodynamic resistance to transfer of momentum (R_a) between height *z* and the height at which wind speed goes to zero (surface) is described as:

$$\tau = \frac{\rho u(z)}{R_a} \quad \longrightarrow \quad \tau = \rho u_*^2 \quad \longrightarrow \quad R_a = \frac{u(z)}{u_*^2}$$

- Because R_a is a function of wind speed, it is also subject to correction for stability effects.

- Parameterizations for R_a differ with respect to functional dependence on surface layer characteristics, application of stability corrections, and form of stability corrections.

$$R_a = \frac{u(z)}{u_*^2} \qquad R_a = \frac{\ln\{(z-d)/z_0\}}{ku_*} \qquad R_a = \frac{\ln\{(z-d)/z_0\}^2}{k^2 u(z)}$$

Neutral conditions – mechanical turbulence only

$$R_a = \frac{1}{k^2 u(z)}\left[\ln\left(\frac{z-d}{z_{0m}}\right) - \psi_m(\varsigma)\right]\left[\ln\left(\frac{z-d}{z_h}\right) - \psi_h(\varsigma)\right]$$

Mechanical and buoyancy generated turbulence. Thom, 1975

The purpose of this study is to quantify the degree to which differences in model-derived dry deposition fluxes are related to use of different R_a parameterizations.

The following models are compared:

CMAQ-WRF
CMAQ-MM5
CAMx
CAPMoN
MLM

All are based a version of Thom's method but differ in application of stability correction and assumptions regarding similarity between heat and momentum flux.

The MLM approach assumes that R_a is function of wind speed and the standard deviation of wind direction (σ_θ), which is related to the vertical momentum flux.

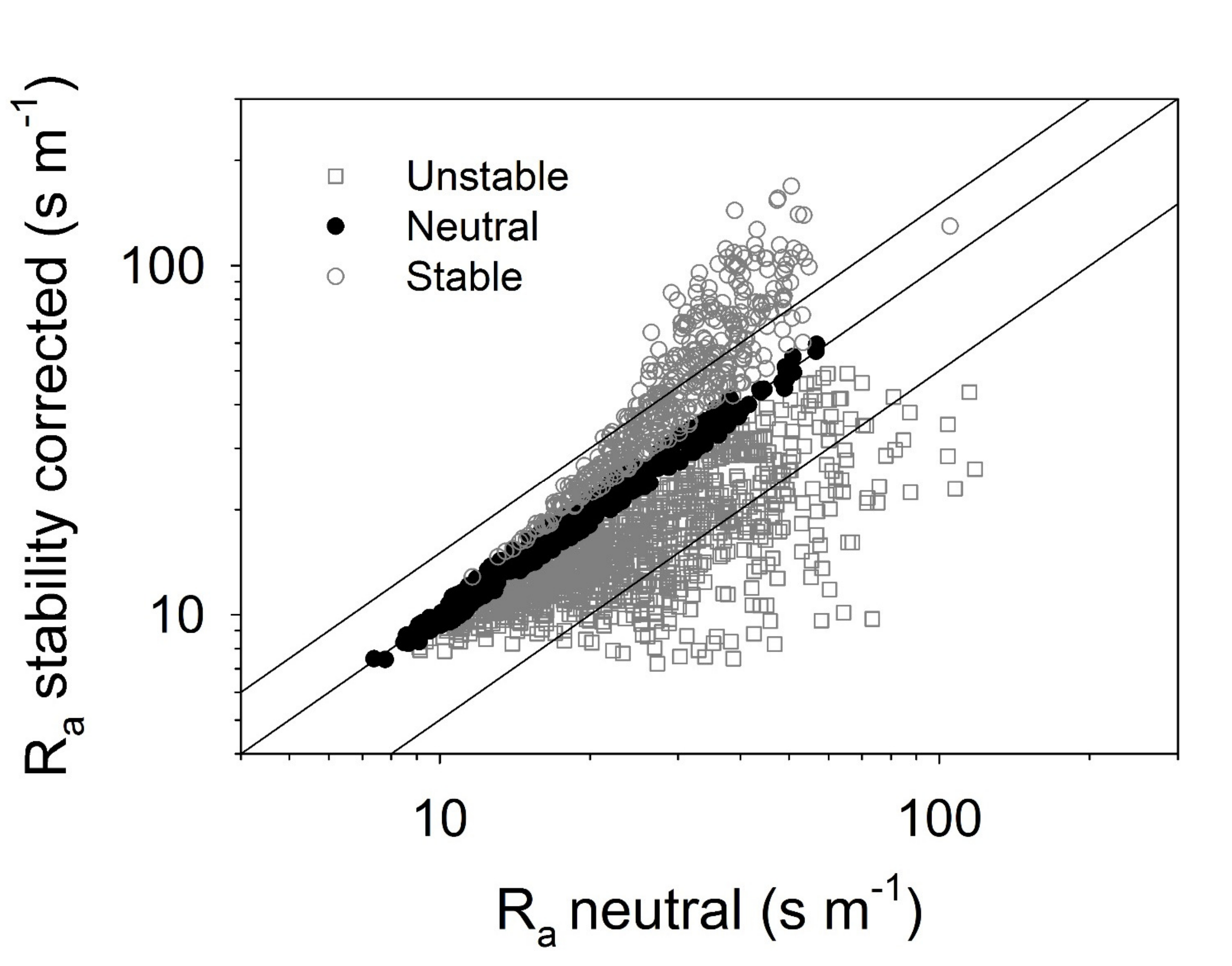
$$R_a = \frac{C}{u(z)\sigma_\theta^2}$$

C = 4 for neutral and stable conditions and C = 9 for unstable conditions as determined by global radiation.

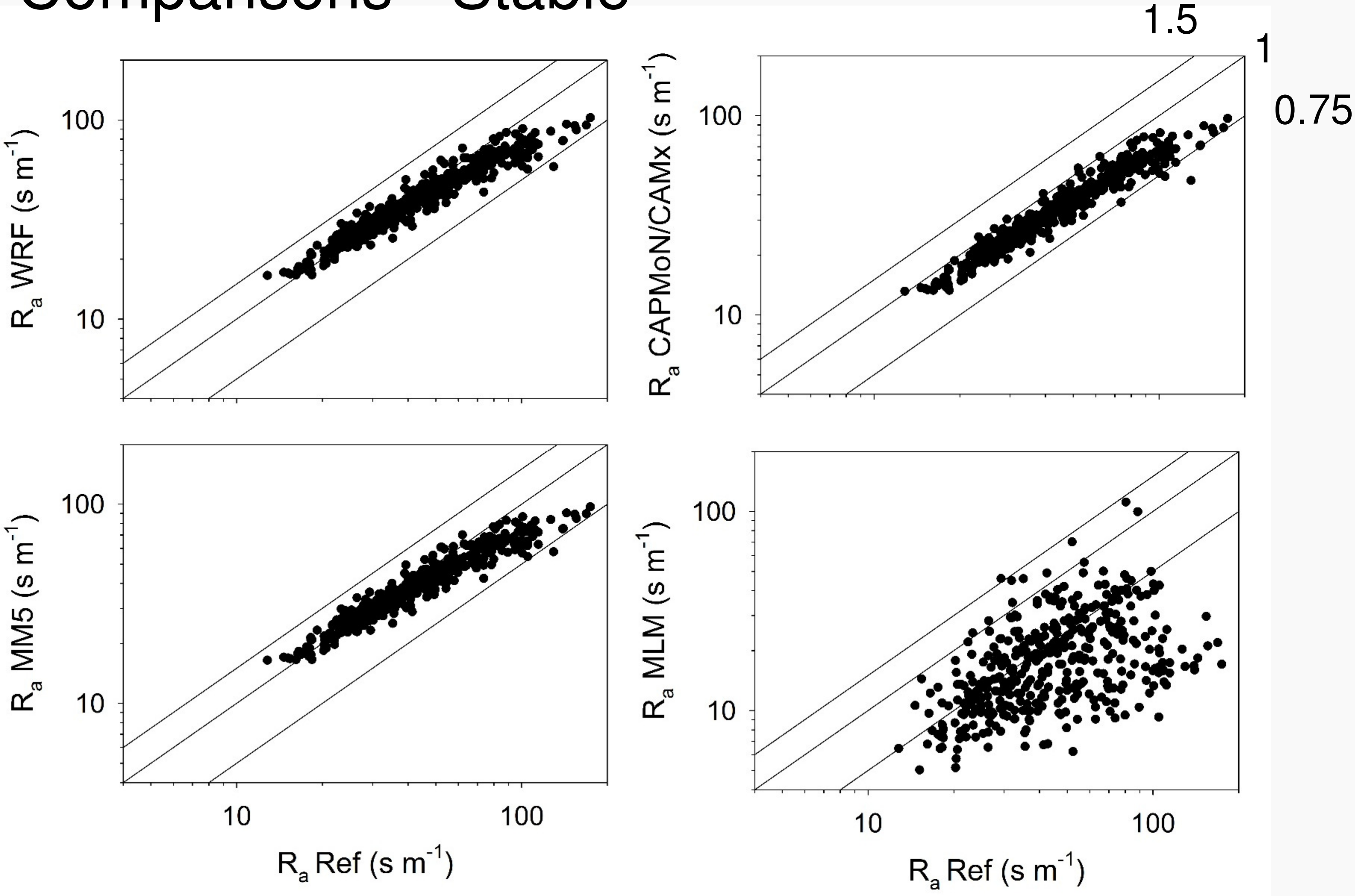
Comparison details

- Grass field h_c = 1.2m
- U(z), u_*, Obukhov stability parameter (z/L), measured by sonic anemometer
- Data from September – October, 2012 and February – March, 2013
- Models use common set of meteorological inputs

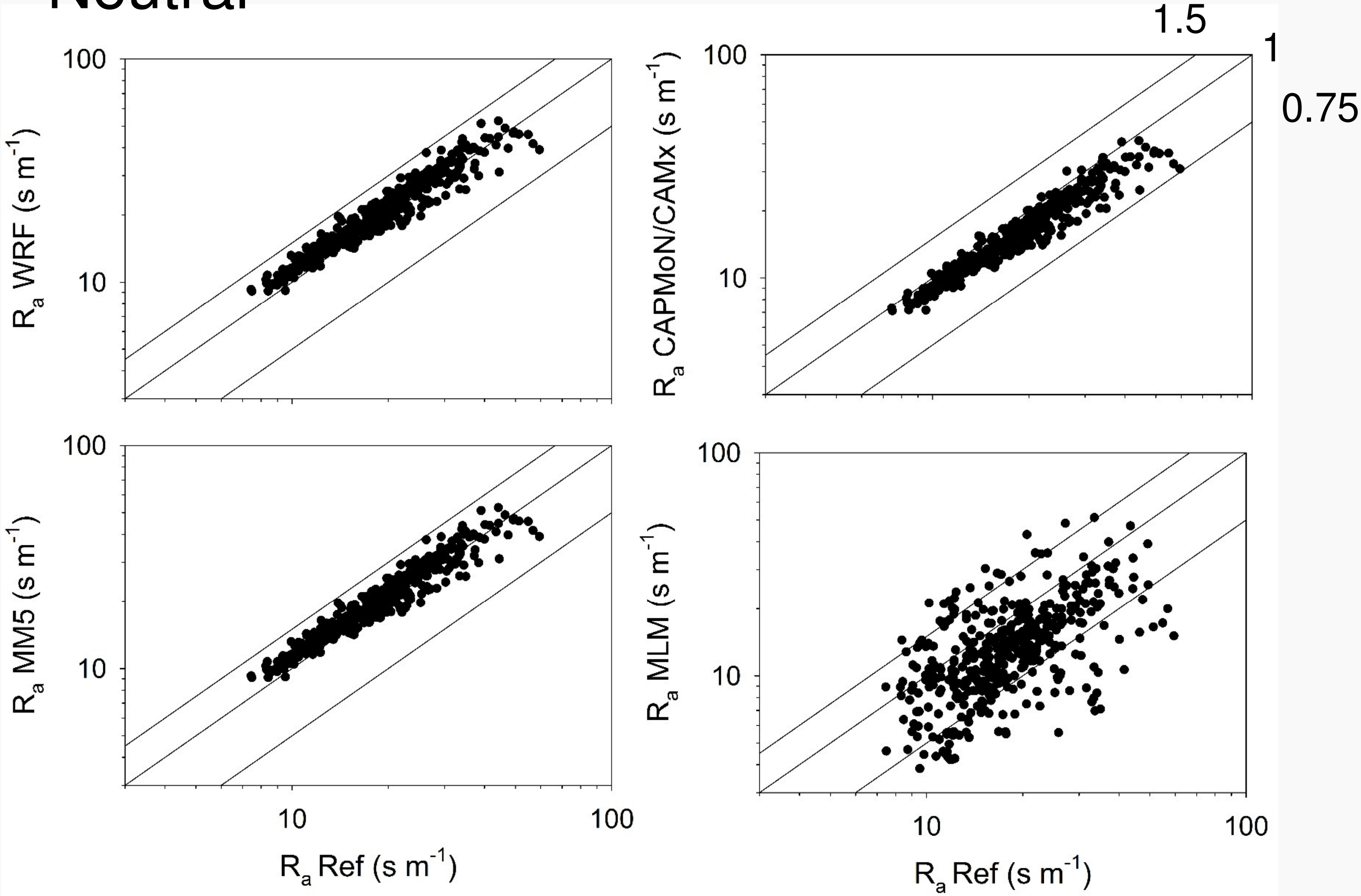
How important is the stability correction?



Comparisons - Stable

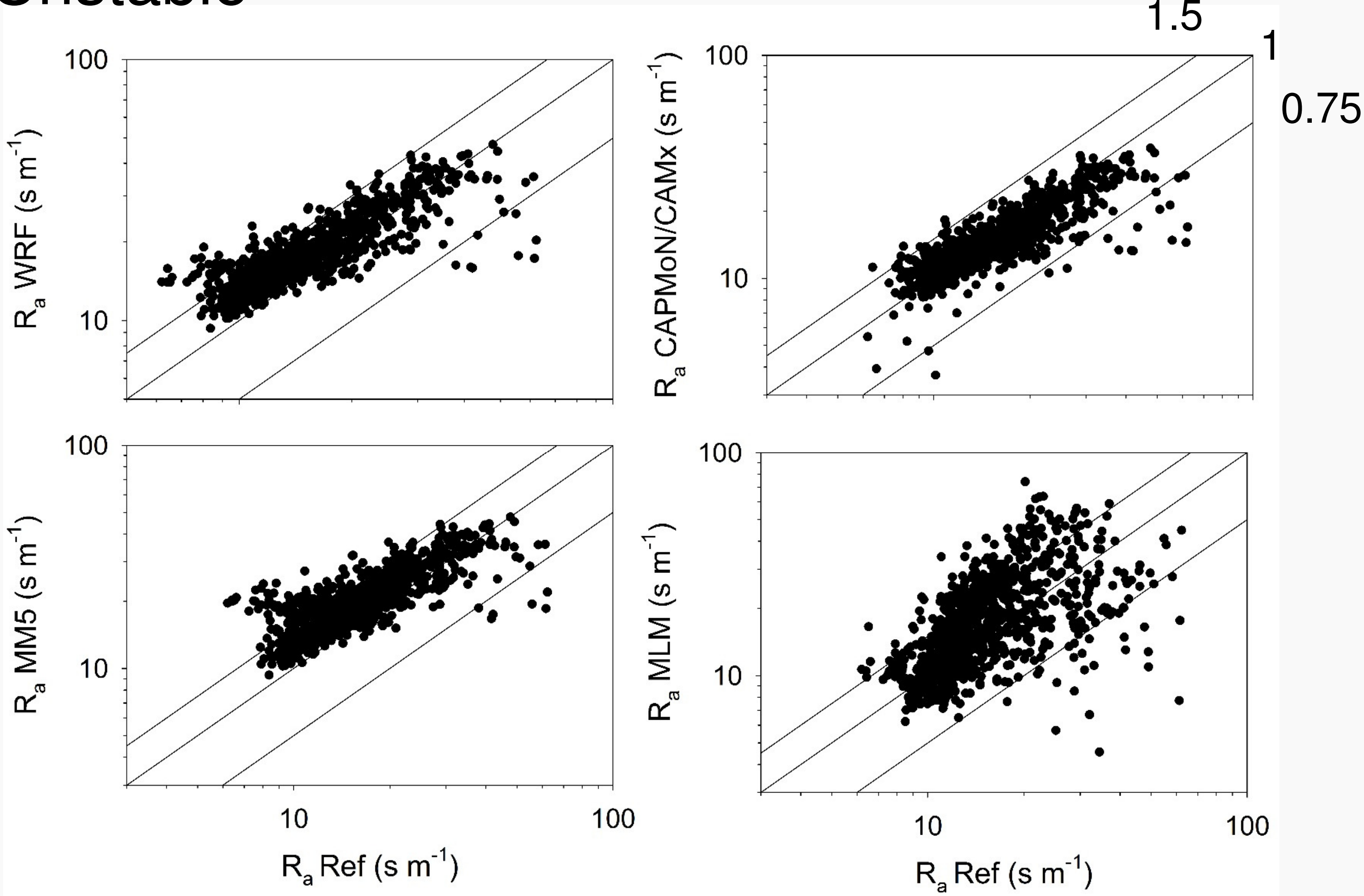


Neutral



1.5
1
0.75
100
10
R_a WRF (s m^{-1})
R_a CAPMoN/CAMx (s m^{-1})
R_a MM5 (s m^{-1})
R_a MLM (s m^{-1})
R_a Ref (s m^{-1})

Unstable



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R_a WRF (s m^{-1})
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R_a MM5 (s m^{-1})
R_a MLM (s m^{-1})
10
100
R_a Ref (s m^{-1})
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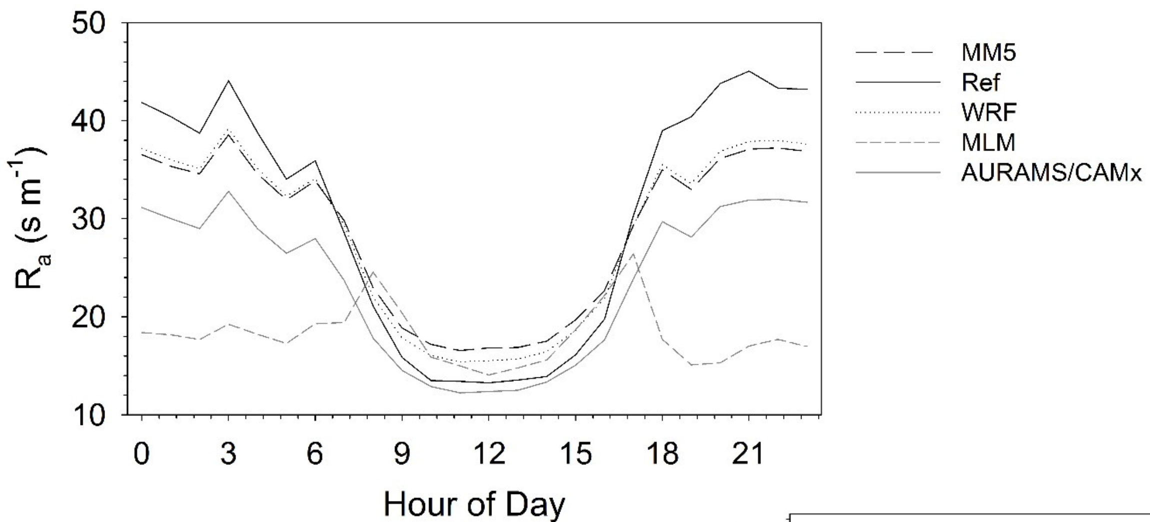
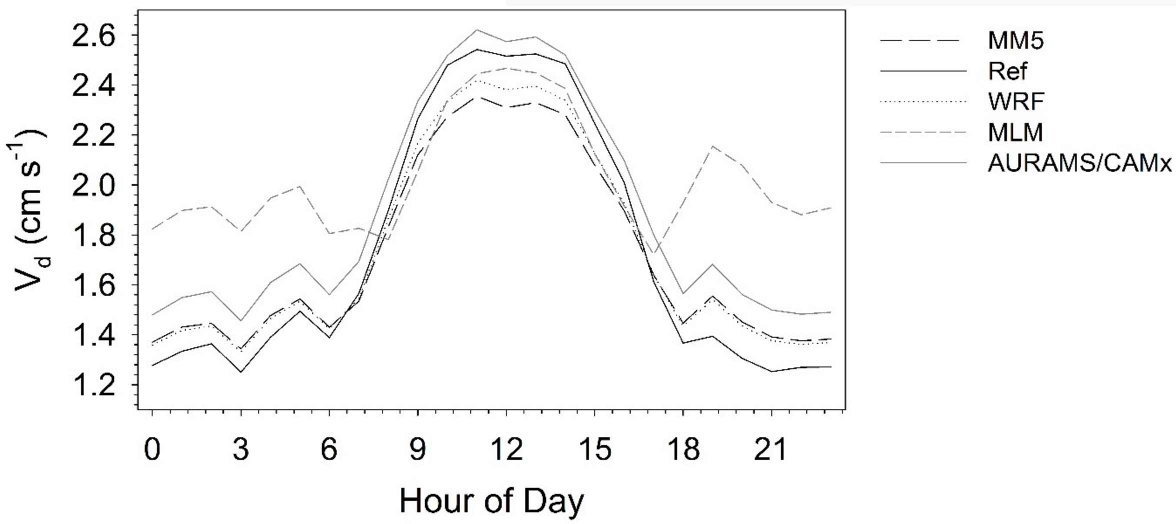
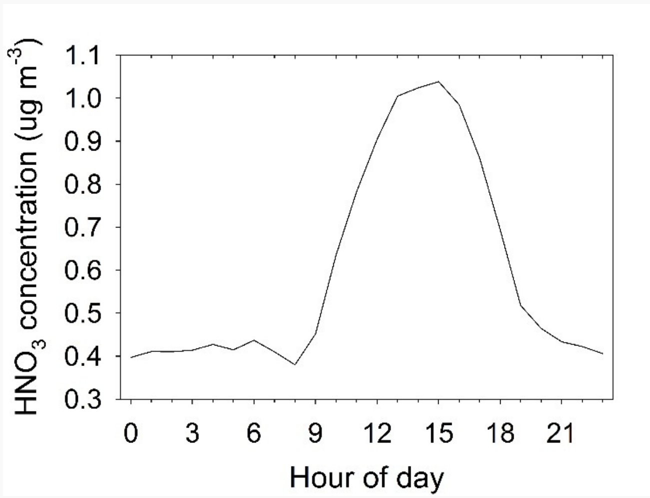
Diurnal R_a and V_d for HNO_3

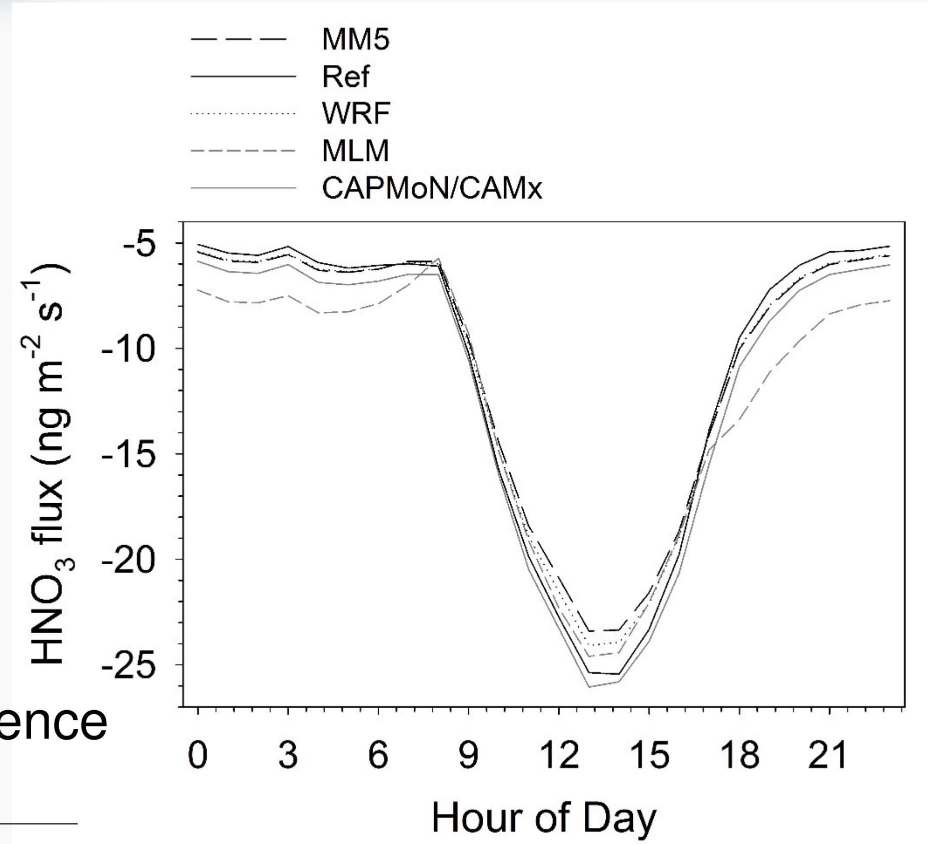


Largest differences in R_a and V_d observed under stable conditions at night.



Diurnal flux of HNO_3

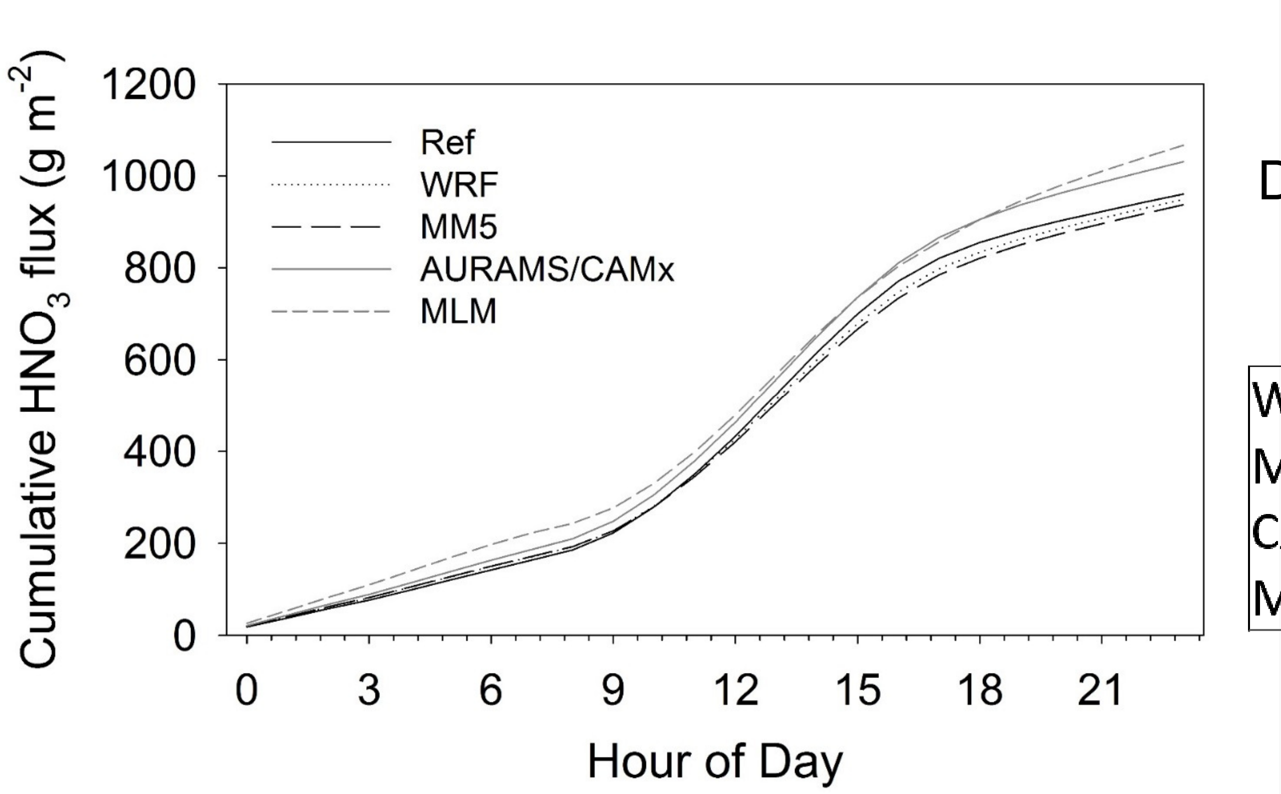




Flux differences (%) relative to reference method

	Night	Mid-day
WRF	6.6	-5.1
MM5	7.6	-7.5
CAPMoM/CAMx	16.4	2.7
MLM	45.4	-3.8

Daily cumulative HNO_3 flux



Difference (%) in daily total flux relative to reference method

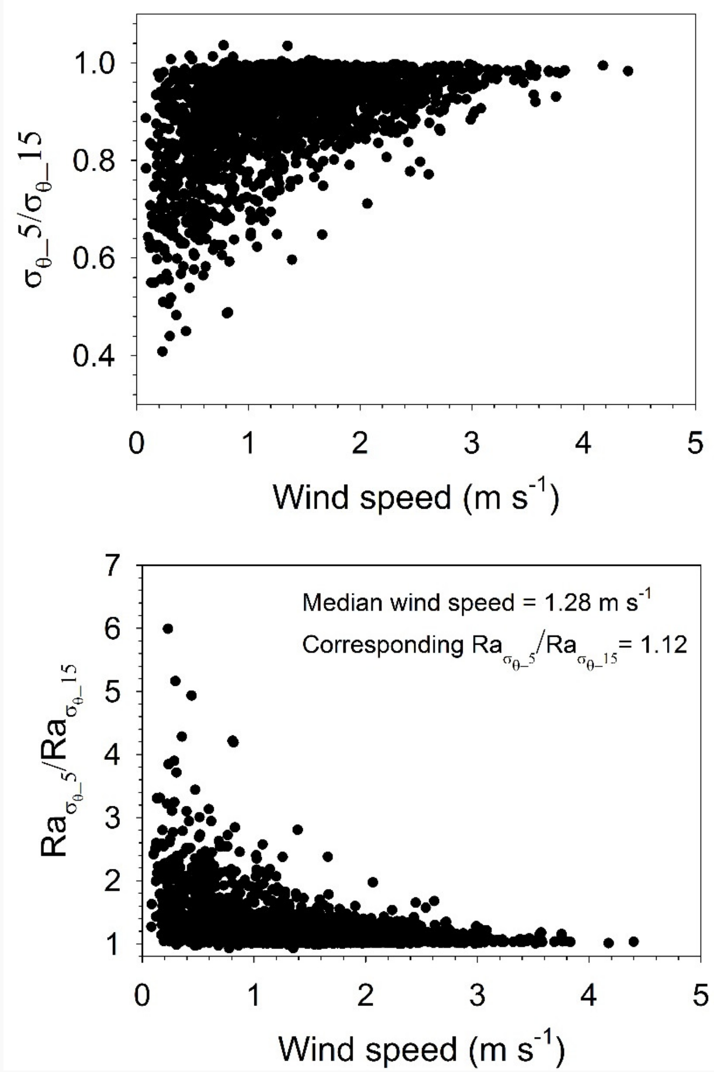
WRF	-1.2
MM5	-2.4
CAPMoM/CAMx	7.3
MLM	11.0

MLM approach

At low wind speeds typically encountered at night, intermittent turbulence can cause the standard deviation of wind direction (σ_θ) to become very large.

To minimize this effect, (σ_θ) is calculated for subintervals (15 minutes) during each hour.

At Duke Forest, reducing the subinterval to 5 minutes would be sufficient to remove the bias between MLM and the reference method.



Next steps

- Conduct analysis at additional sites with different meteorology, surface characteristics, and HNO_3 concentration.
  - Howland Forest (evergreen forest),
  - Coweeta Hydrologic laboratory (deciduous forest)

- Extend analysis to compare grid model R_a to point estimates of R_a.