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Estimates of in-canopy ammonia sources and sinks using measured profiles and turbulence closure models

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Topics to be Discussed

1. Overview
   - Description of the problem
2. Measurement and Site Description
   - Brief description of the site, instrumentation and measurements taken
3. Closure Model Evaluation
   - Model description and evaluation with a historical data set and sensible heat measurements
4. In-Canopy Ammonia Fluxes
   - Closure model estimates vs. modified Bowen ratio measurements
   - In-canopy sources and sinks
5. Conclusions and Future Directions of Research

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Why measure in-canopy exchange?

- The largest sources of atmospheric ammonia are evasion from fertilized fields and livestock operations
- Cropland dedicated to fertilizer intensive crops has increased dramatically
- The air-surface exchange of ammonia is bidirectional
  - The relative contributions of vegetation and soil process needed for model development are not captured in above canopy measurements
- Can we measure/model the ammonia evasion processes in a fertilized agricultural field?
  - Specifically the soil evasion and canopy interception processes

Site Description

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Site Description

- 300 Acre corn field in Lillington NC
- Manual denuder and automated ammonia concentration measurements
- 3-D sonic anemometers mounted at 10, 3.5, 2.5 and in the corn canopy ~ 0.5 meters
- Manual denuders at 10, 4.4, 2.25, 1.5, 0.95, 0.45, 0.1 meters
- Temperature measurements collocated with each ammonia concentration measurement
- Leaf, dew, and soil chemistry measurements collected

In-Canopy Flux Estimates

- Modified Bowen Ratio (MBR)
  - ➢ Works in homogeneous well-mixed conditions (above the canopy)
- Canopy sublayer wind field is complex but concentration gradients are typically stronger than above the canopy
- In-canopy fluxes are estimated by simplified K- ε and an analytical ½ order closure models
  - ➢ Simpler parameterization of in-canopy variables and stability effects than Lagrangian near field (LNF) dispersion methods used in previous studies
    - ▪ Difficult to derive Lagrangian statistics from Eulerian-based measurements
  - ➢ Canopy parameters can be manipulated in a meaningful way in a simple model

K-ε and Analytical Model

- Continuous scalar concentration profiles are estimated by fitting a cubic spline to the data
- One equation K-ε model of Katul *et al* (2004)
  - Drag coefficient estimated from wind profile and measured in canopy momentum flux rather than estimated *a priori*
- Analytical model described below

$$\frac{\partial \overline{C}}{\partial t} = -\frac{\partial \overline{w'C'}}{\partial z} + s$$

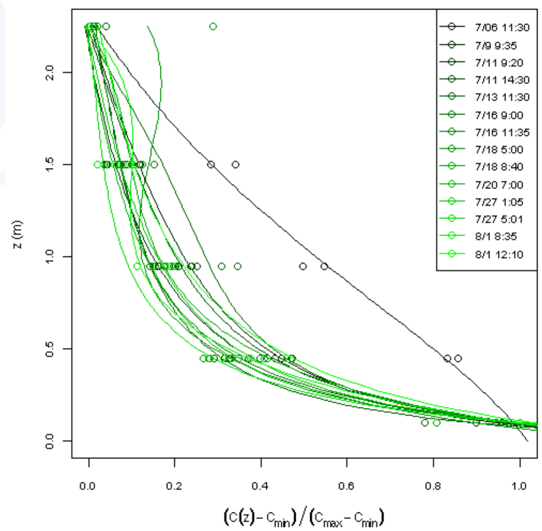
$$\overline{w'C'} = K_t \frac{\partial \overline{C}}{\partial z}$$

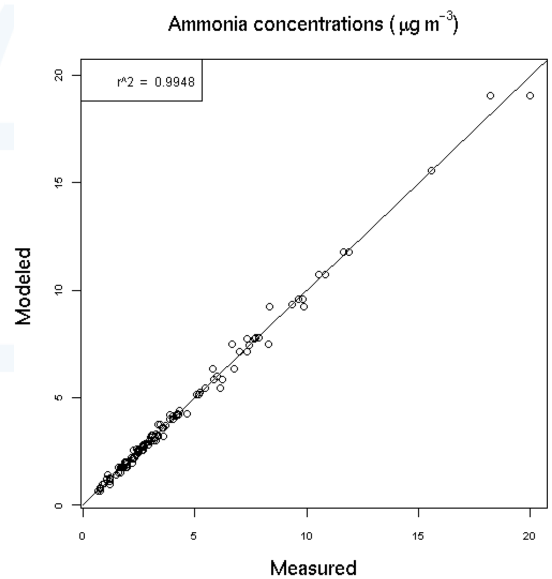
$$\overline{U}(z) = \begin{cases} \dfrac{u^*}{\beta} e^{\frac{\beta}{L_m(\zeta, C_d)}(z-h_c)} & z \le h_c \\ \dfrac{u^*}{k}\left(\ln\left[\dfrac{z-d}{z_0}\right] + \psi_m(\zeta)\right) & z > h_c \end{cases}$$

Concentration Profiles

- Soil boundary conditions
  - Sensible heat flux BC - Soil heat flux
  - Ammonia flux BC - concentration at the soil surface
- Ammonia concentration at 0 m was estimated by finding a relationship between measured concentration and measurement height
  - Extrapolated to 0 m

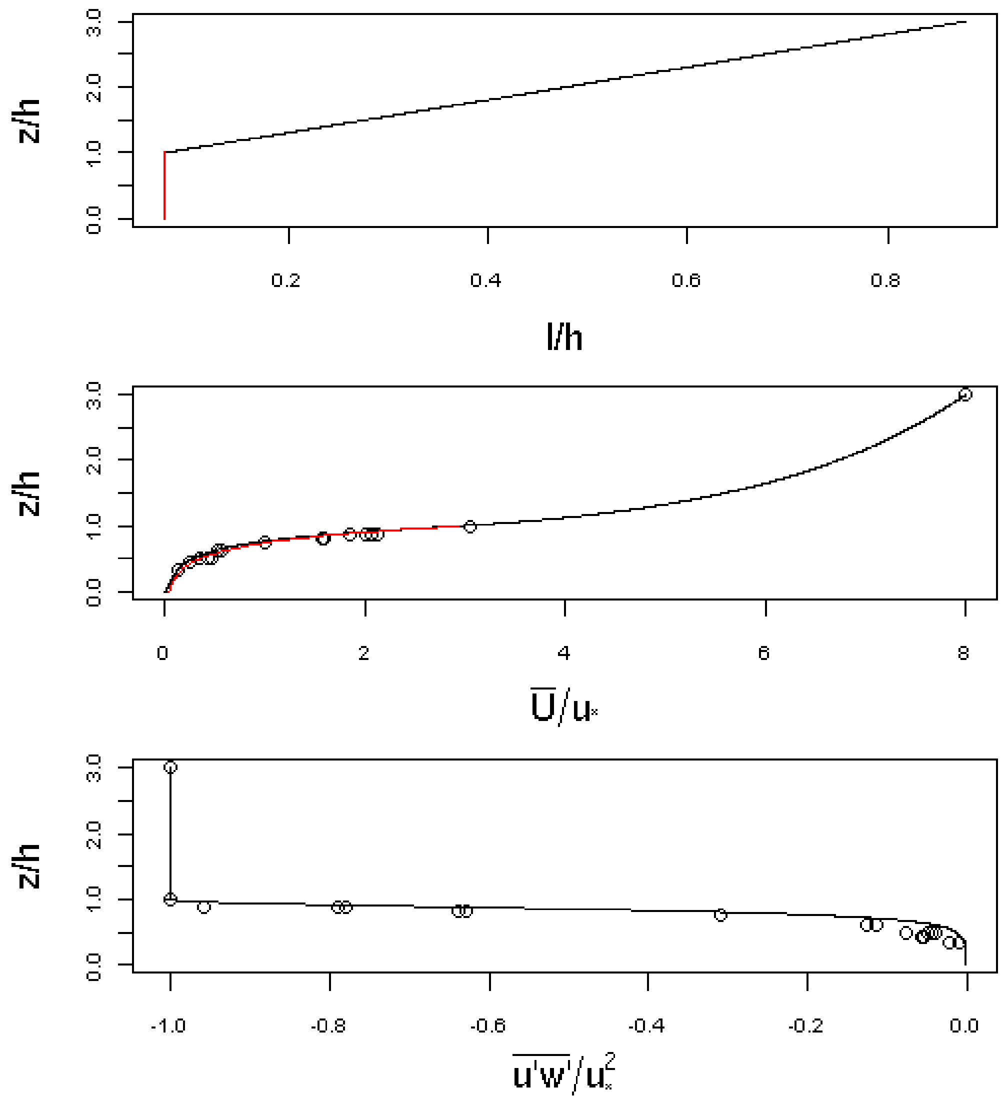
$$\overline{C}(z) = \frac{1}{a z^2 + b z + c}$$



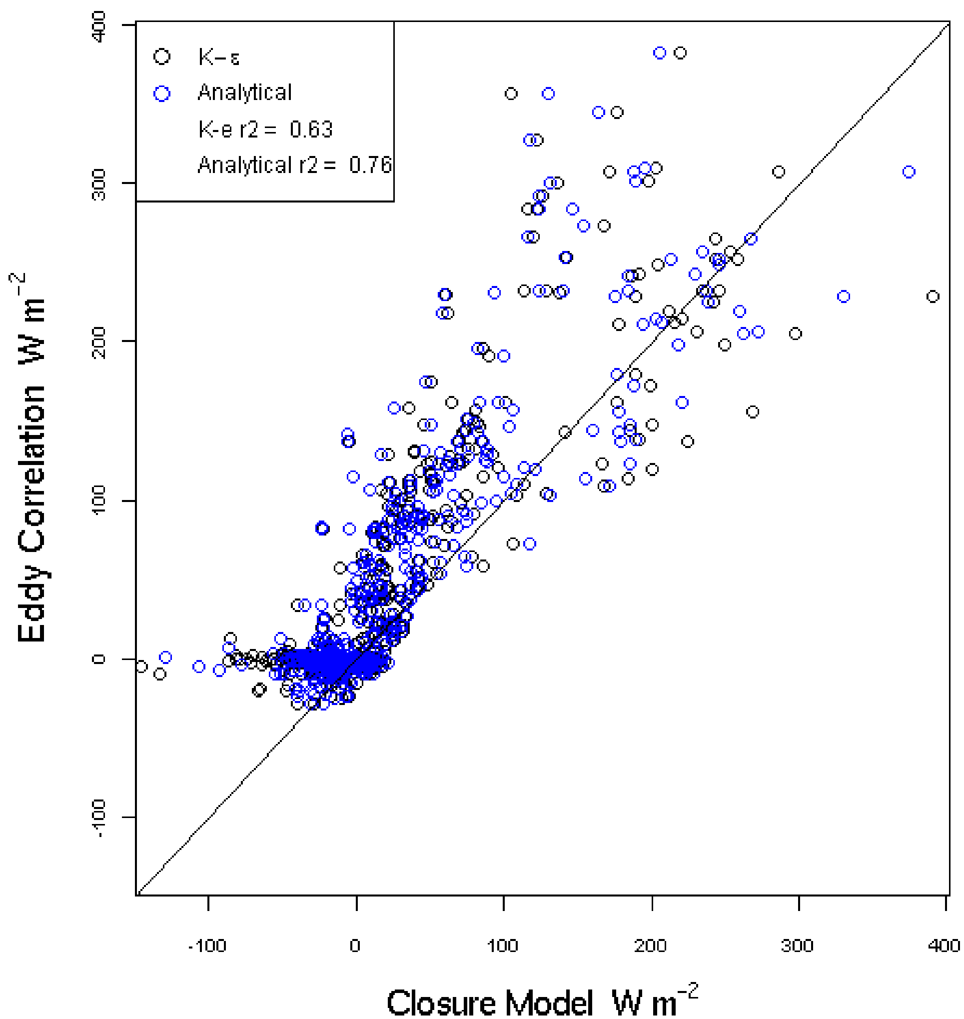


Wilson *et al.* 1988 Dataset

- *A priori* specified C_d = 0.3 by Wilson *et al* (1988)
- Estimated C_d = 0.335 from in canopy wind profiles
- Predicted wind speeds correlate well with both methods
  - *A priori* C_d
    R^2 = 0.989
  - Estimated C_d
    R^2 = 0.987



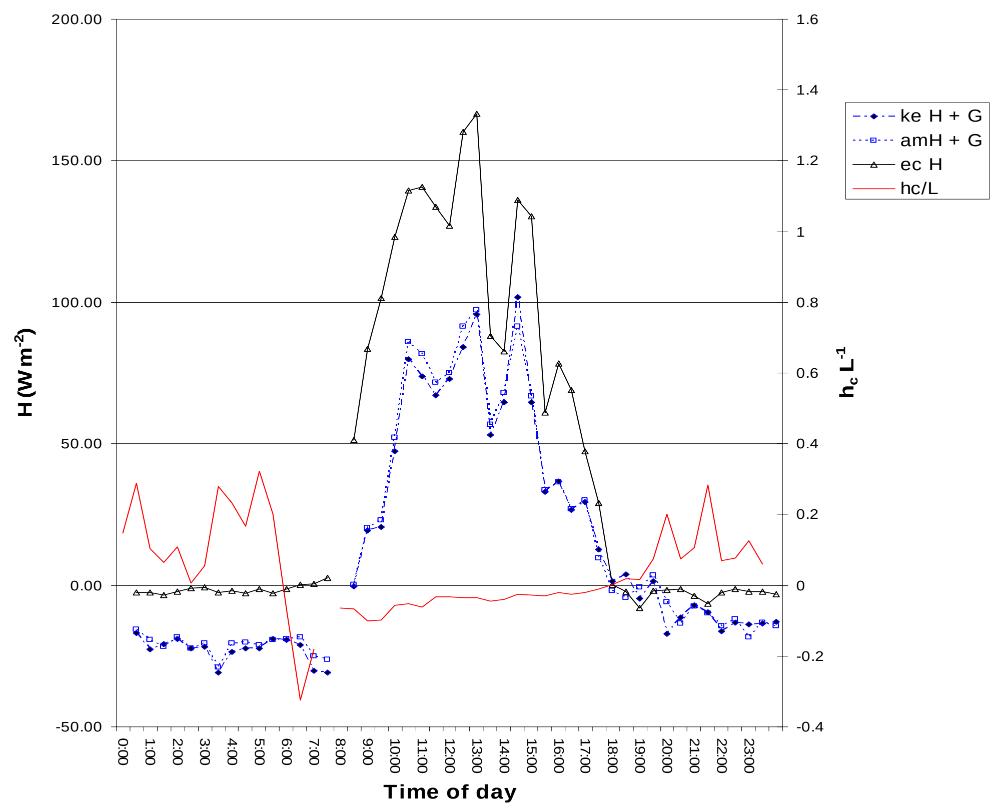
Lillington, NC Sensible Heat Flux



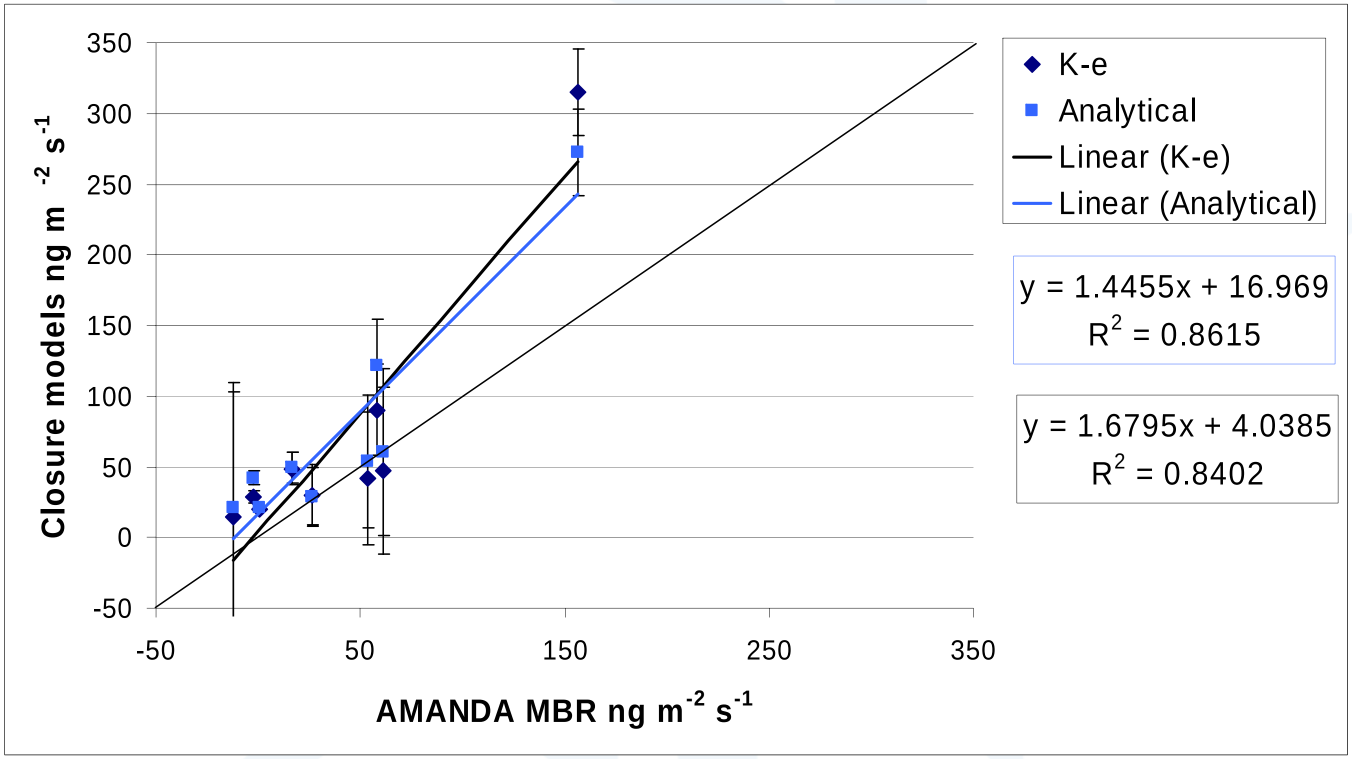
- Both closure models predicted sensible heat flux well (N=572)
- Estimated C_d parameterization predicted sensible heat flux over a variety of stability regimes better than the constant parameterization (C_d = 0.3)
- Slope of 1.01 and 0.81 and intercept of 25.1 and 31.5 W m^{-2} for analytical and K- ε model respectively
  - Slope and intercept significant at $p < 0.001$

Lillington, NC Sensible Heat Flux

- Peak daytime sensible heat fluxes under predicted by approximately 30% for both closure models
- In-canopy sensible heat flux under predicted from 20:00 to 8:30
- Canopy sublayer may become decoupled from the stable boundary layer during those times



Lillington, NC Ammonia Flux



- Compares reasonably well with MBR flux estimates
  - Slope is significant at $p < 0.001$
  - Spearman rank correlation coefficient of 0.85

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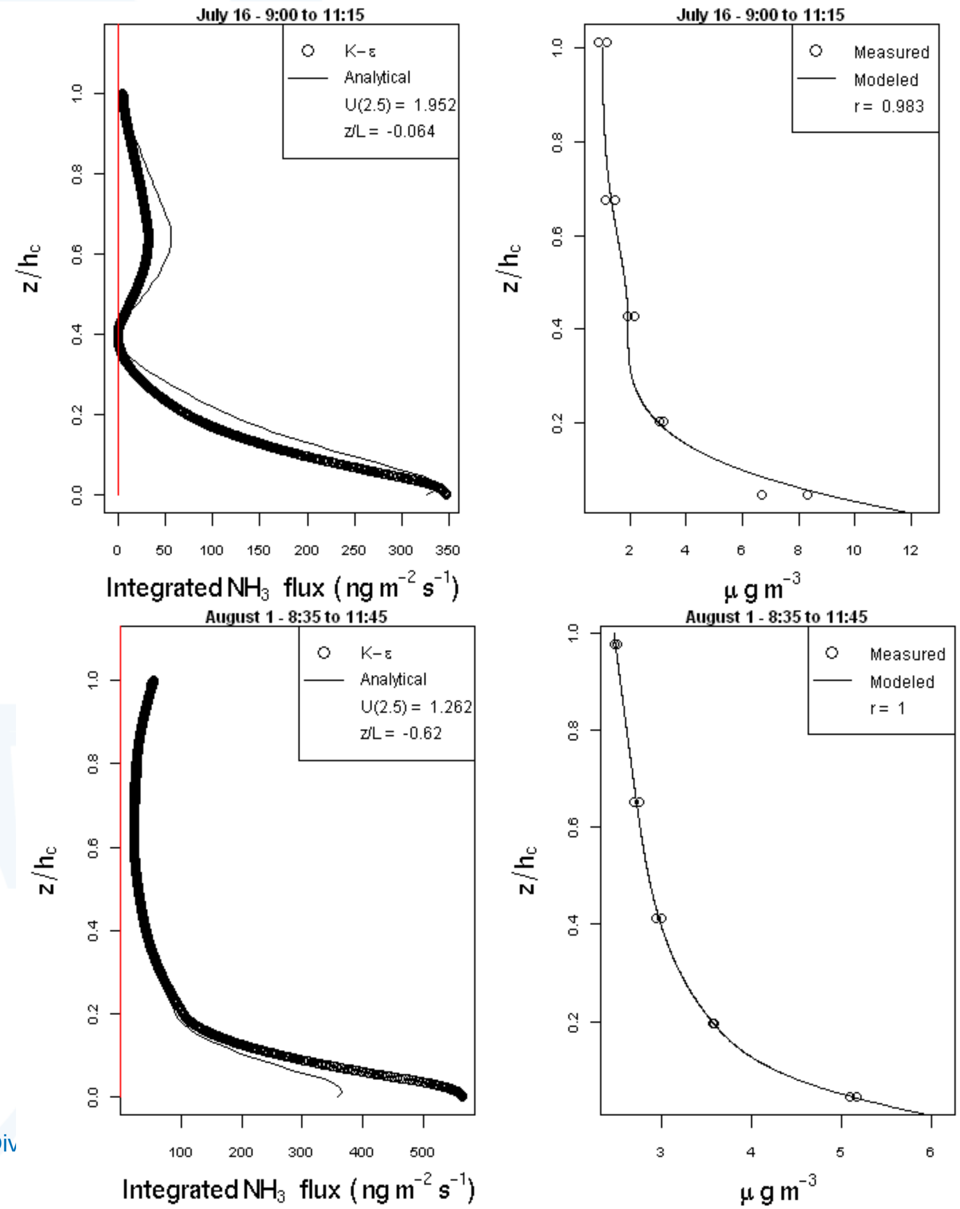
In Canopy Flux Profiles

- Closure models predict in-canopy flux and a source/sink profile
- In-canopy flux is variable with height
- Estimates soil emissions and canopy uptake
- Compensation point can be estimated from the profile
  - 1.94 μg m^{-3} at 0.9 m in the July 16th example



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Conclusions

- Both the K-ε and analytical model perform well when compared to momentum, energy and MBR ammonia fluxes
- Closure models can be used to separate soil from canopy level processes
- Eulerian based in canopy flux estimates are more analogous to the frame-work of air quality models
  - There is greater similarity than with LNF estimates
- Canopy compensation points are variable throughout the measurement campaign

Conclusions

- Measurements required for closure models flux estimates are labor intensive
- A strong concentration gradient is needed like other flux measurements
  - Concentration gradients in the canopy sublayer are often stronger than the atmospheric boundary layer
- The closure models presented are sensitive to changes in the drag coefficient and shape of the concentration profile

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Future research

- Evaluation of soil chemistry-based compensation points
  - Can the differences between concentration measurements and model estimates be rectified by soil resistance parameterizations?
- Evaluation of leaf chemistry-based compensation points
  - Leaf chemistry based estimates vs. concentration measurements, above canopy flux measurements and in canopy flux estimates
- Evaluation of regional air quality model (CMAQ) estimates of bidirectional exchange
  - How do fluxes from a simpler canopy model compare?

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***** Although this work was reviewed by EPA and approved for publication, it may not necessarily reflect official Agency policy***

Thank you
Questions?

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