UNDERSTANDING THE ROLE OF TURBULENCE ON IN-CANOPY CHEMISTRY AT THE PROPHET SITE

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September 13th, 2017
6th Annual IACPES Symposium on Atmospheric Chemistry and Physics

ACKNOWLEDGEMENTS

- **Jennifer Murphy**
- **Allison Steiner**
- **Dylan Millet**
- **Hari Alwe**
- **Phil Stevens**
- **Steve Bertman** • **Chris Vogel** (AmeriFlux)
- The Murphy and Steiner groups
- The PROPHET-AMOS team

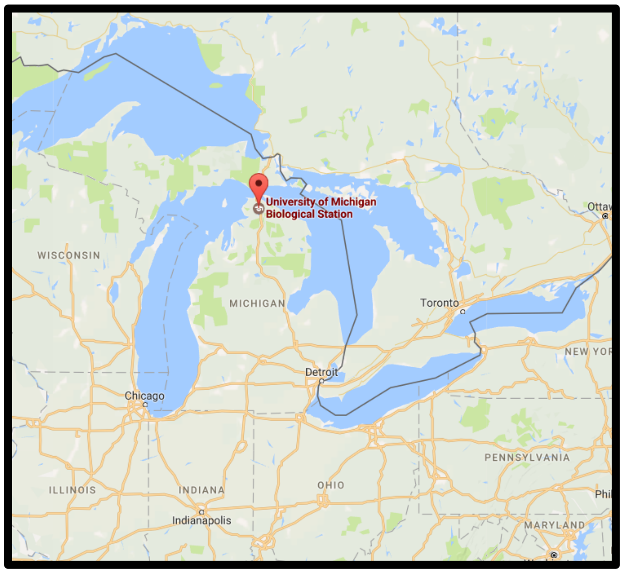
AN NSERC CREATE PROGRAM
IACPES
INTEGRATING ATMOSPHERIC CHEMISTRY AND PHYSICS FROM EARTH TO SPACE

UNIVERSITY of TORONTO
THE CENTRE FOR GLOBAL CHANGE SCIENCE

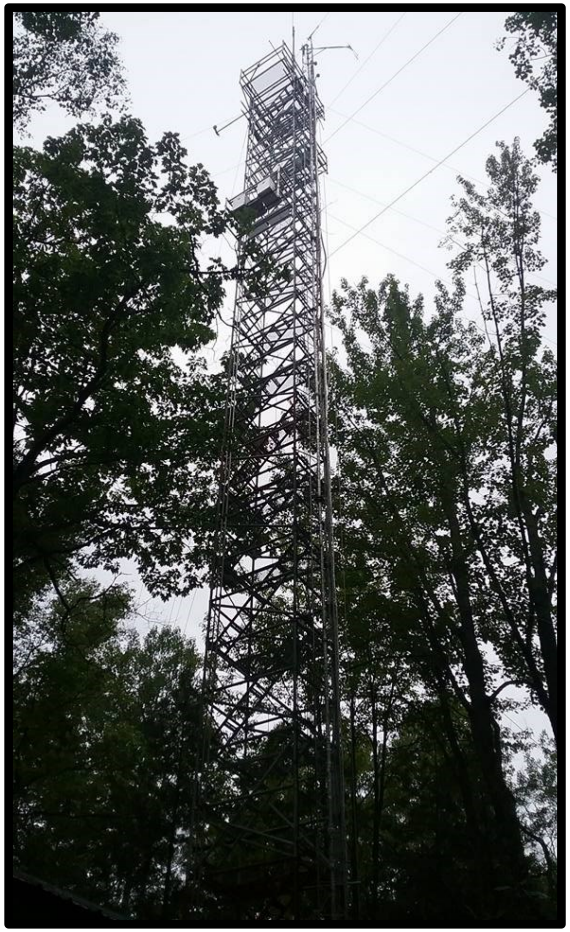
PROPHET-AMOS CAMPAIGN

July 1st – 31st, 2016

University of Michigan Biological Station



- 22-institute collaboration
- Temperate-Boreal transition forest (mixed wood)
- Average LAI 3.3 m^2/m^2
- Site houses two flux towers (PROPHET 34m, AmeriFlux 46m) and one lab



Campaign Goal: **Improve our understanding of radical chemistry in forested environments**

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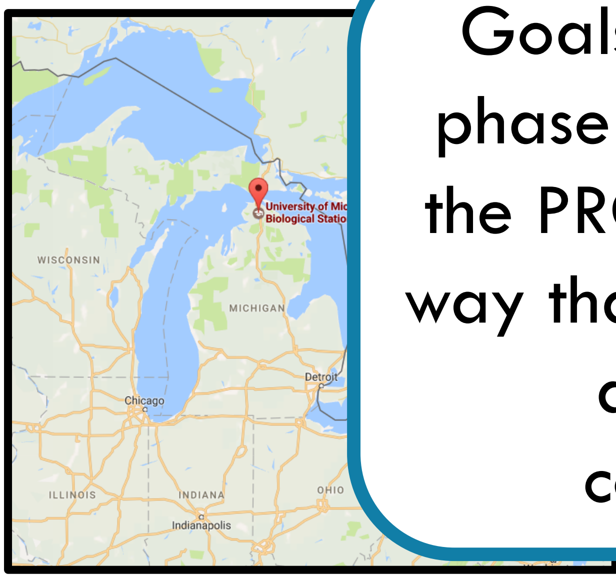
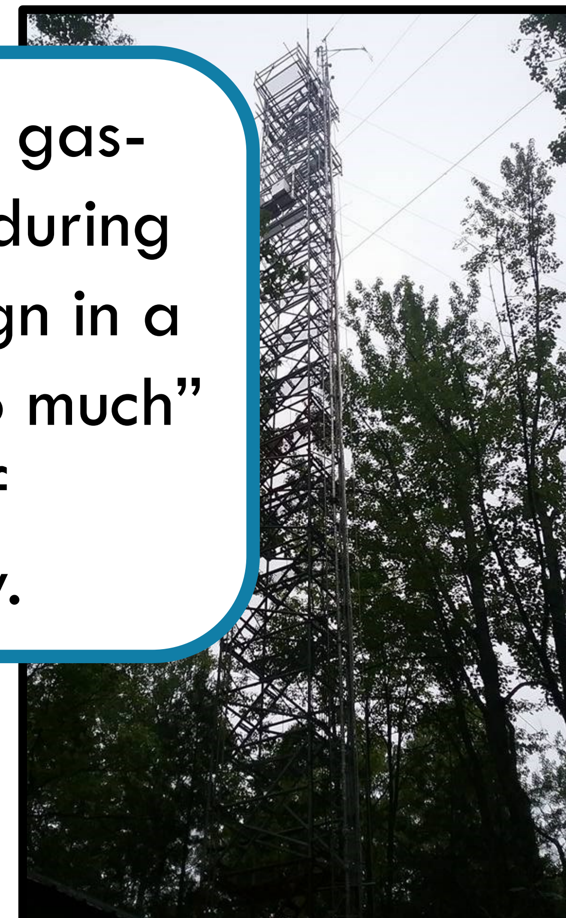


Goals of this project: Model gas-phase chemistry and mixing during the PROPHET-AMOS campaign in a way that doesn't sacrifice "too much" accuracy in the name of computational efficiency.



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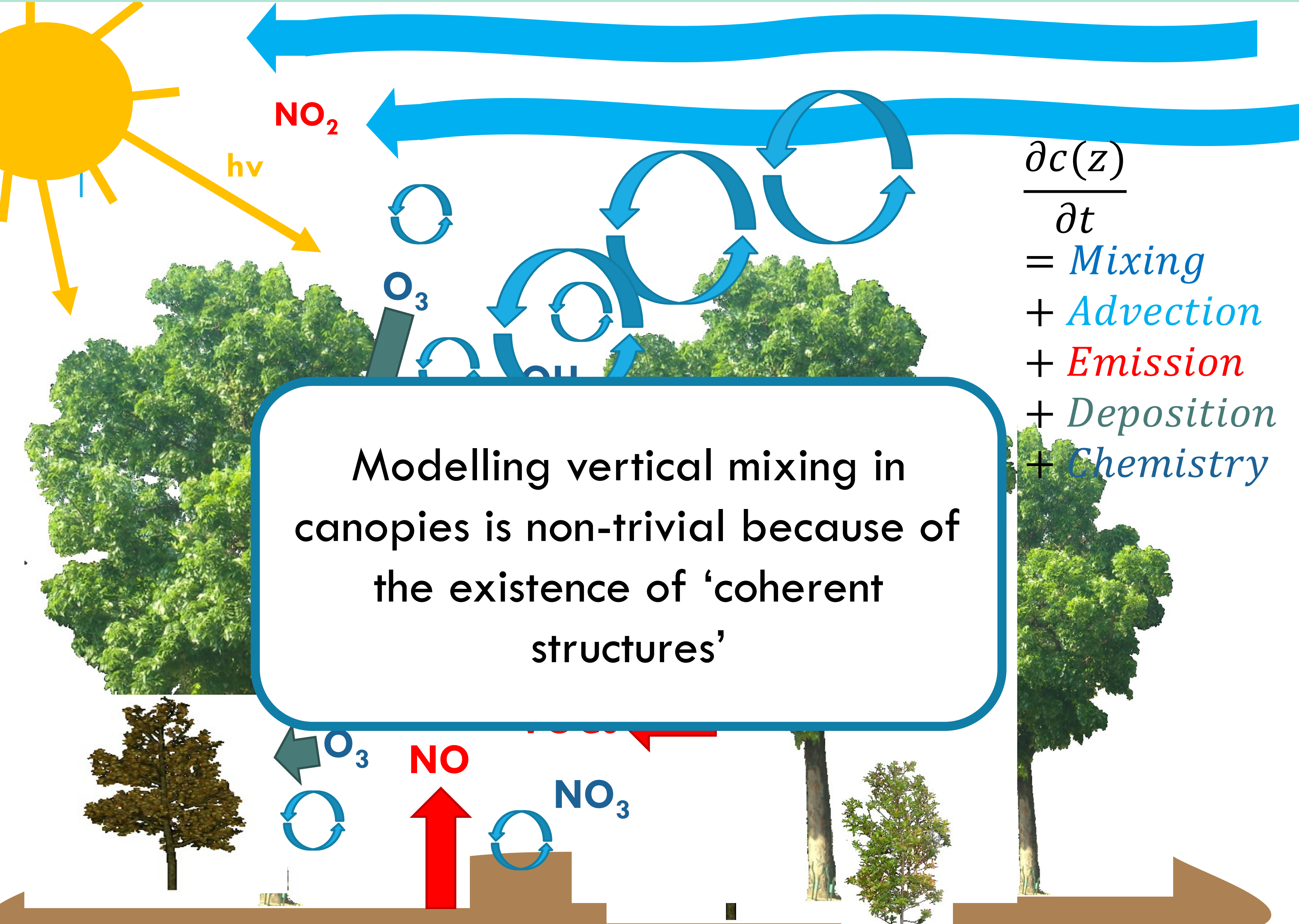
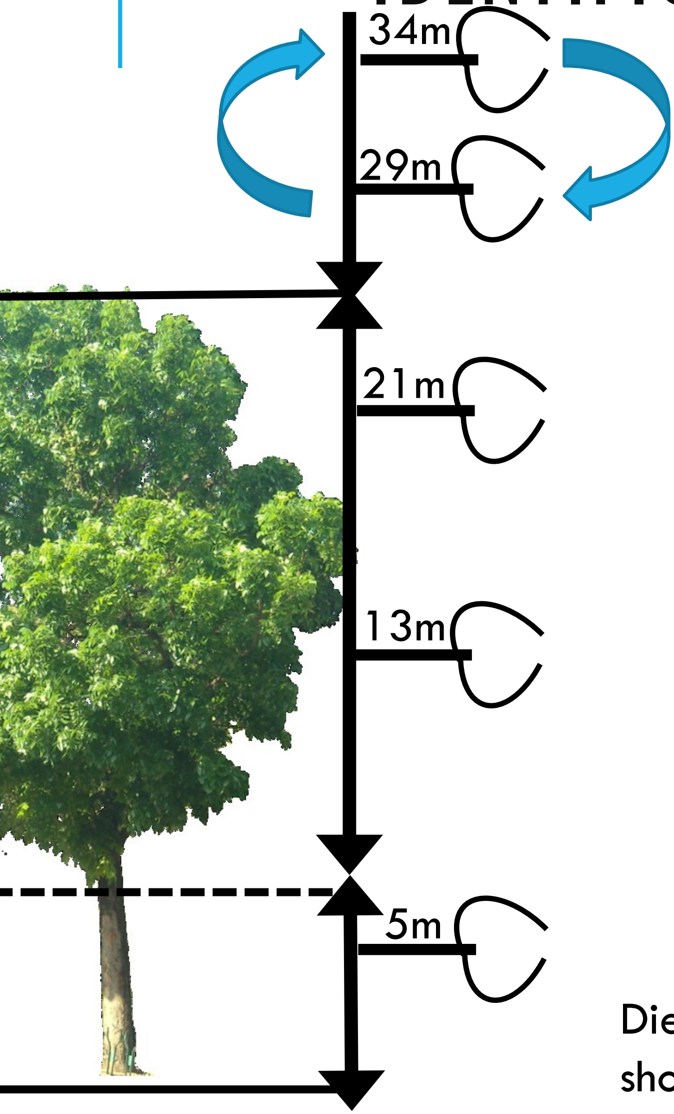
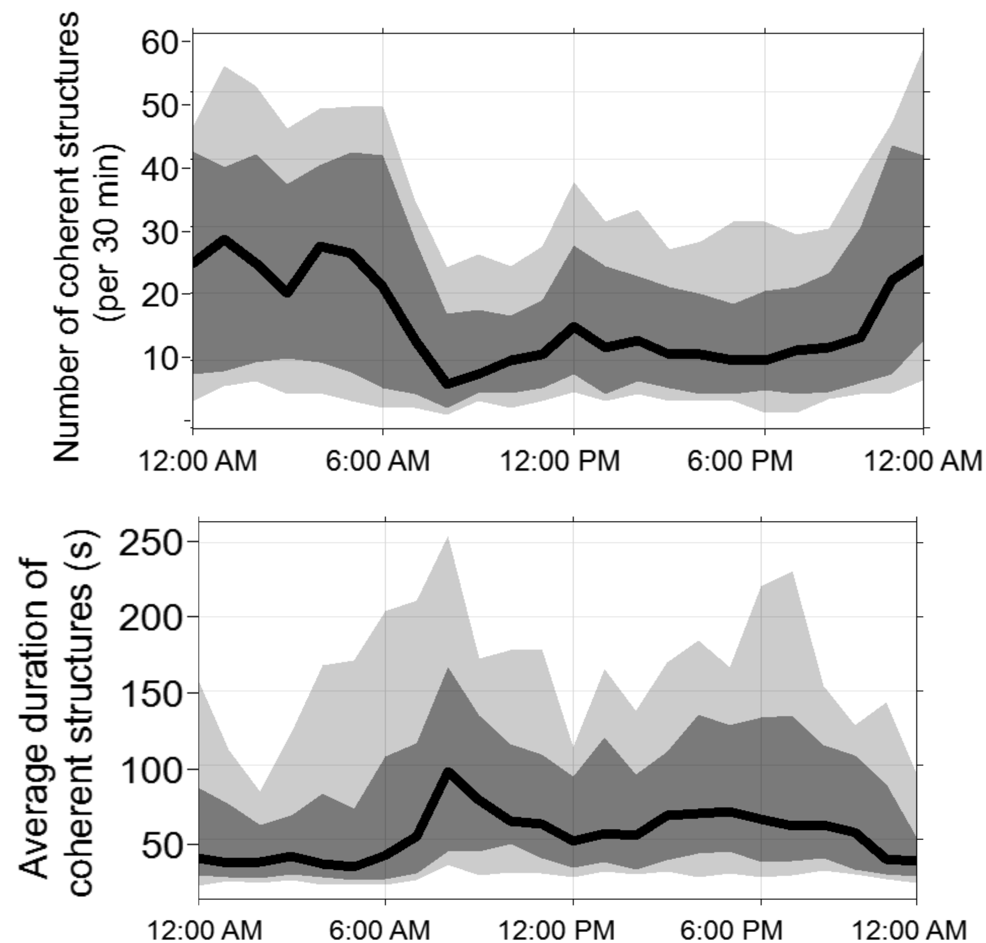


$$\frac{\partial c(z)}{\partial t} = \mathit{Mixing} + \mathit{Advection} + \mathit{Emission} + \mathit{Deposition} + \mathit{Chemistry}$$

Modelling vertical mixing in canopies is non-trivial because of the existence of ‘coherent structures’

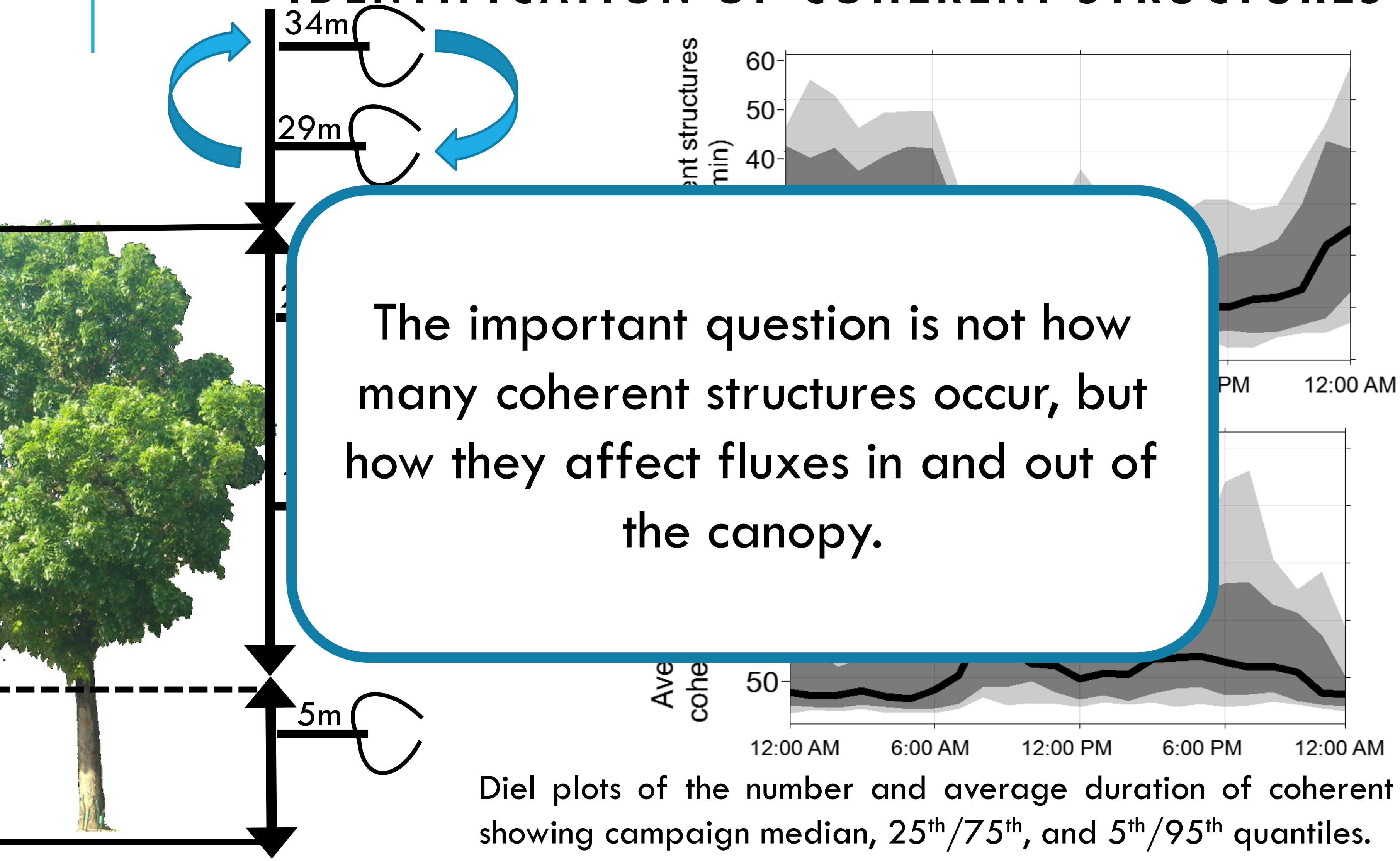
IDENTIFICATION OF COHERENT STRUCTURES





Diel plots of the number and average duration of coherent (s) showing campaign median, 25th/75th, and 5th/95th quantiles.

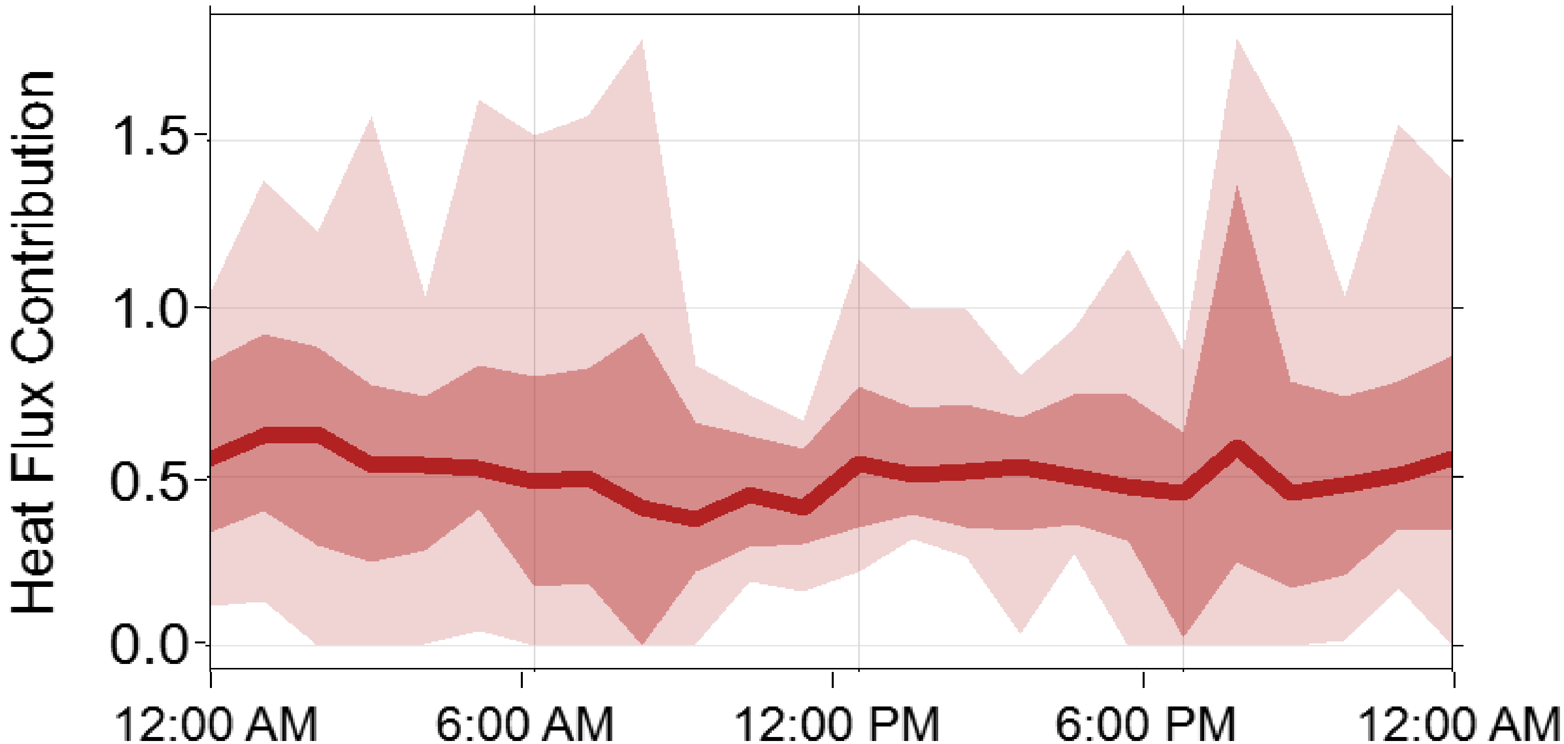
IDENTIFICATION OF COHERENT STRUCTURES



The important question is not how many coherent structures occur, but how they affect fluxes in and out of the canopy.

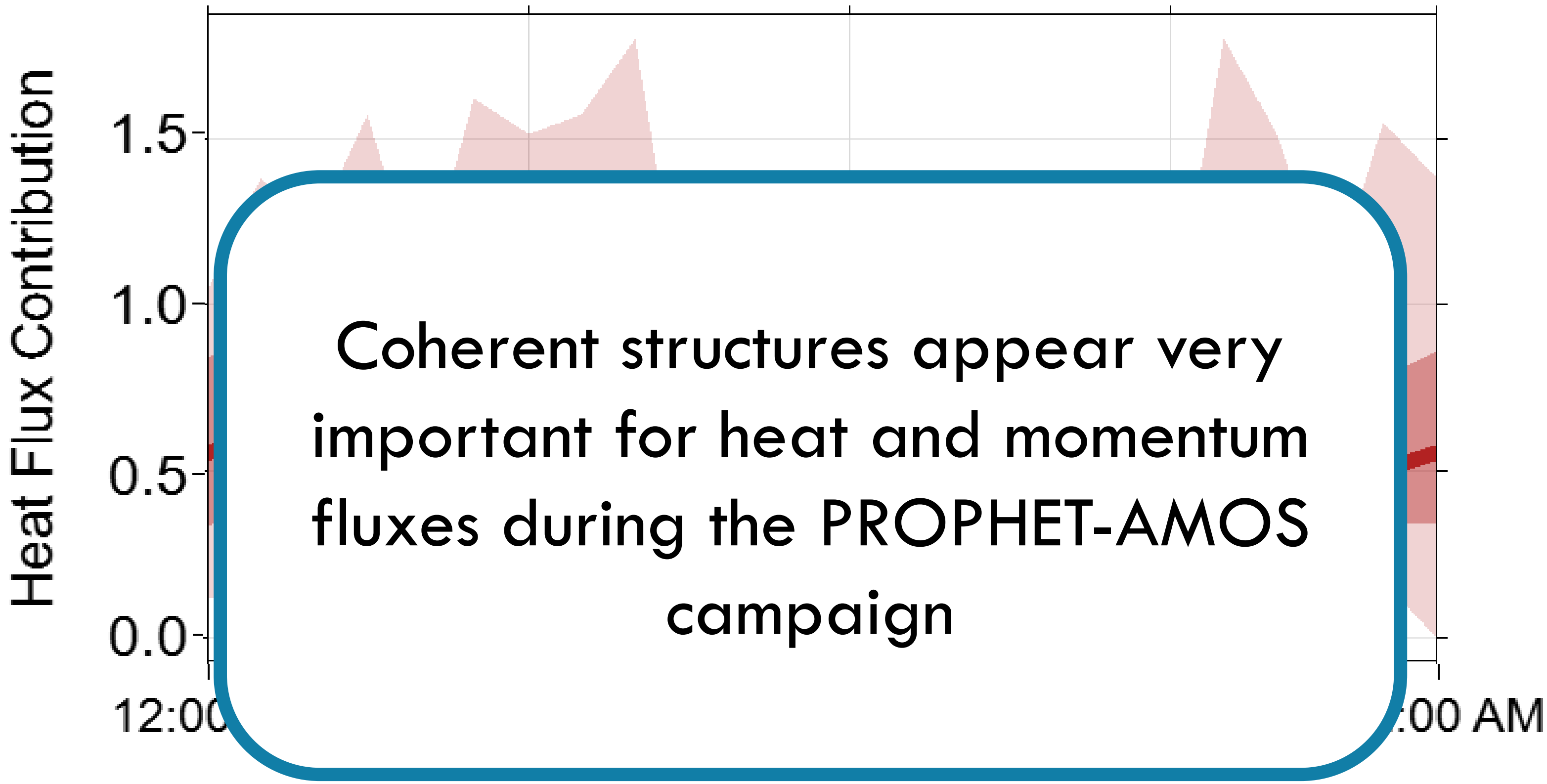
Diel plots of the number and average duration of coherent (s) showing campaign median, 25th/75th, and 5th/95th quantiles.

IMPORTANCE OF COHERENT STRUCTURES



Diel plot of the fractional contribution of coherent structures to kinematic heat flux showing campaign median, $25^{th}/75^{th}$, and $5^{th}/95^{th}$ quantiles.

IMPORTANCE OF COHERENT STRUCTURES

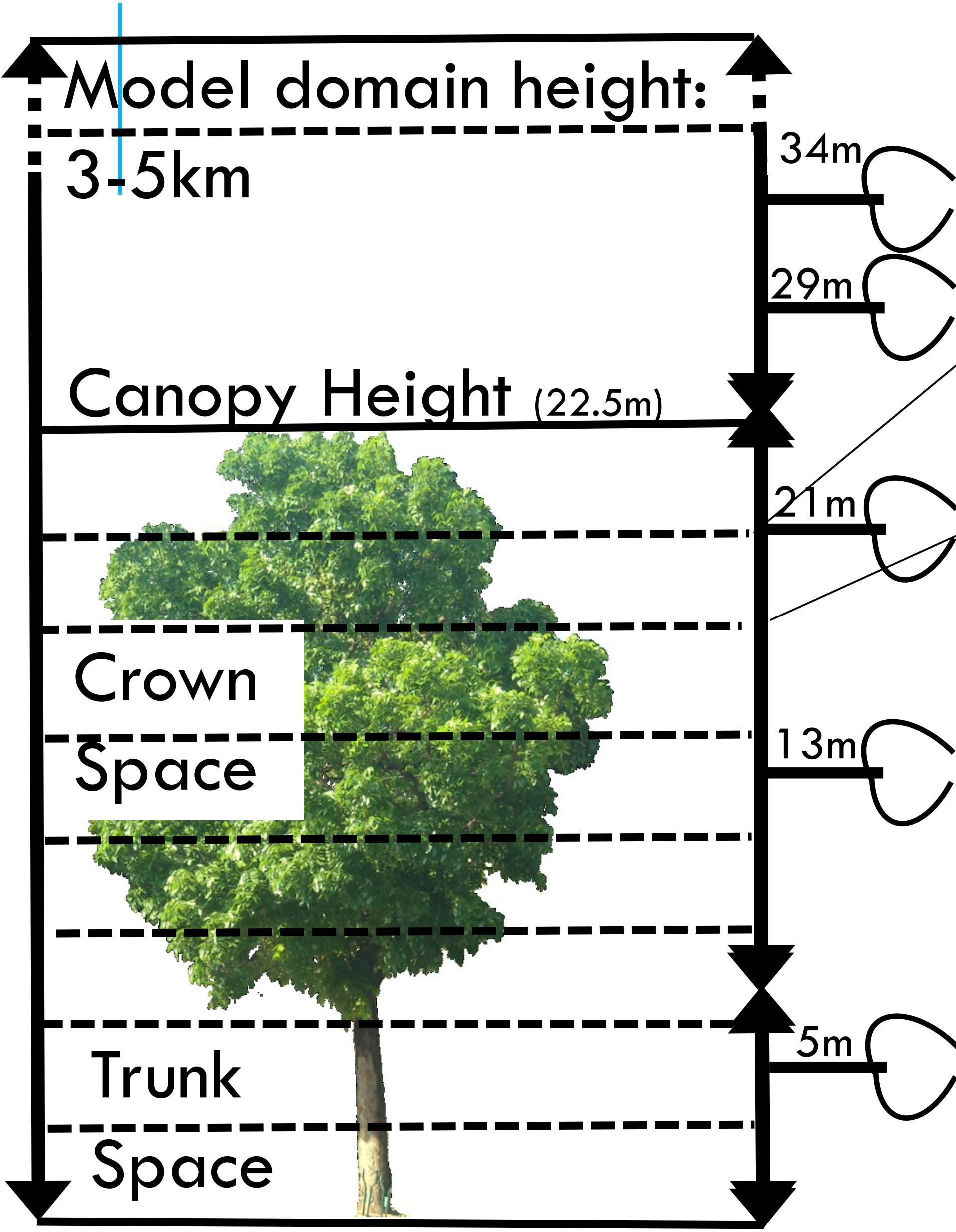


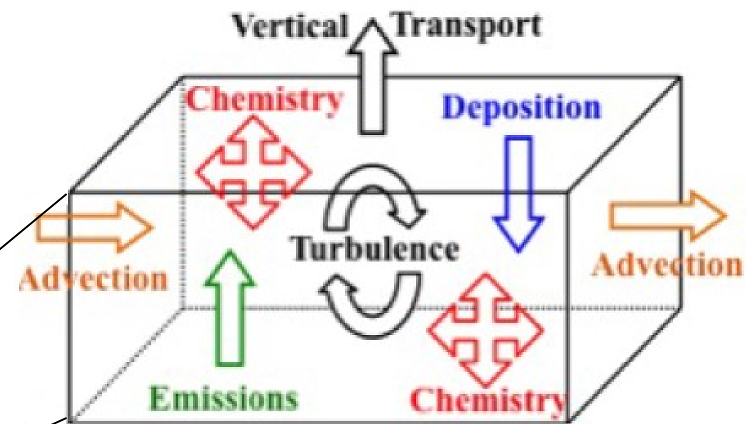
Coherent structures appear very important for heat and momentum fluxes during the PROPHET-AMOS campaign

Diel plot of the fractional contribution of coherent structures to kinematic heat flux showing campaign median, 25th/75th, and 5th/95th quantiles.

THE FORCAST MODEL

Forkel et al., 2006.
Bryan et al., 2012.
Ashworth et al., 2015.





FORCAsT (Ashworth et al., 2015) was constrained by PROPHET-AMOS observations and used to model the campaign chemistry. In FORCAsT, mass fluxes are calculated by solving the continuity equation:

$$\frac{\partial c}{\partial t} = \frac{\partial}{z}\left(K_H \frac{\partial c}{\partial z}\right) + S_c + C$$

Where c is the mixing ratio of the species of interest, K_H is the turbulence exchange coefficient, S_C includes contributions from emissions, deposition, and advection, and C represents chemical production and loss.

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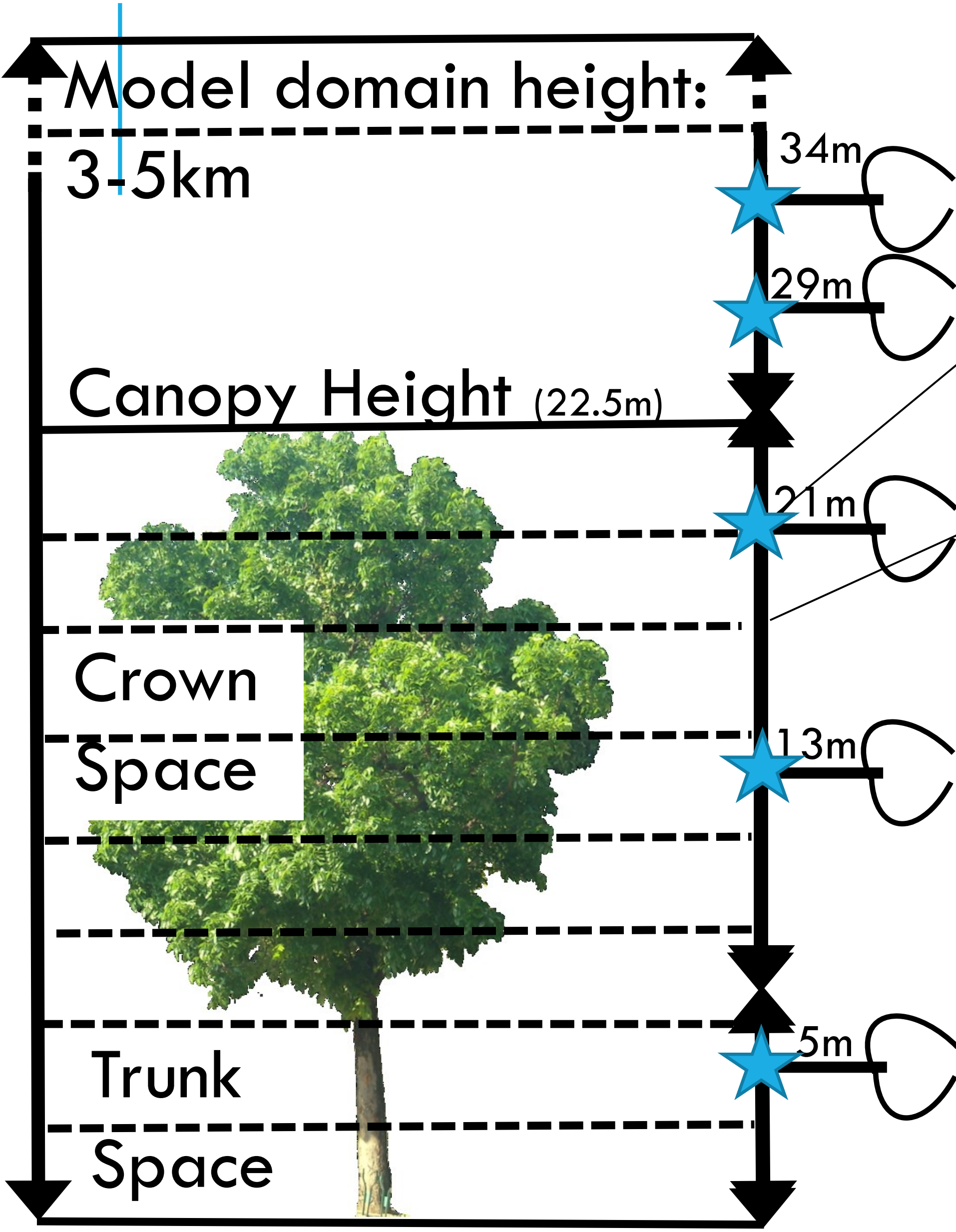
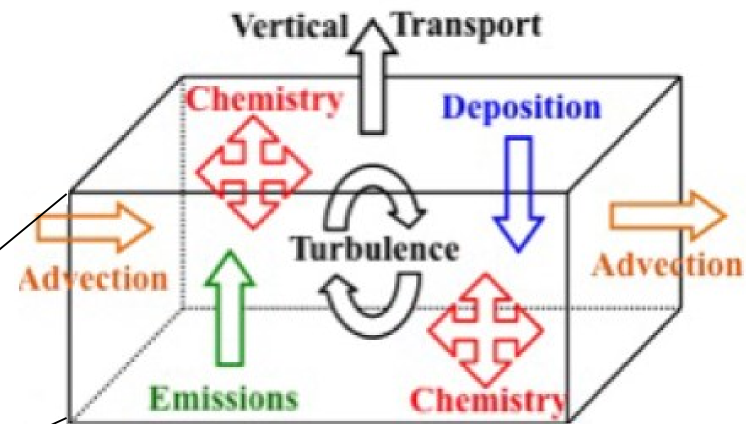




We define and observed K_H following Makar et al. (1999)

$$K_{H,obs} = \sigma_w^2 \frac{0.3h}{u_*}$$

Where h is the height, u_* is the friction velocity, and σ_w is the standard deviation of the vertical velocity.

TWO MAJOR QUESTIONS

1) How much faith should we put into a 1D canopy model that does not explicitly represent coherent structures?

2) How important are sub-canopy constraints on our mixing scheme for modelling chemical mixing ratios?

HOW WELL CAN WE MODEL CANOPY EXCHANGE WITHOUT EXPLICIT COHERENT STRUCTURES?

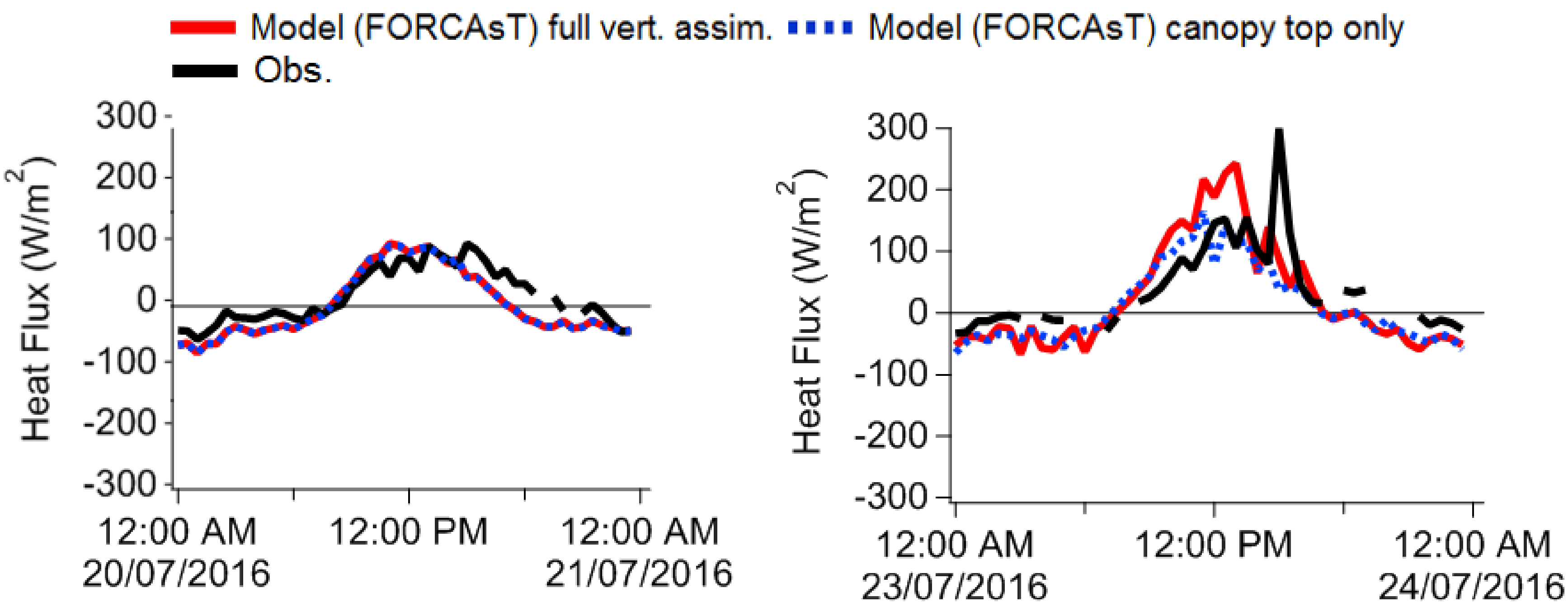
July 20th, 2016

Fraction of heat flux attributable to coherent structures = **0.45**

Campaign average 0.52±0.07

July 23rd, 2016

Fraction of heat flux attributable to coherent structures = **0.62**



36m (12m above canopy height)

HOW WELL CAN WE MODEL CANOPY EXCHANGE WITHOUT EXPLICIT COHERENT STRUCTURES?

July 20th, 2016

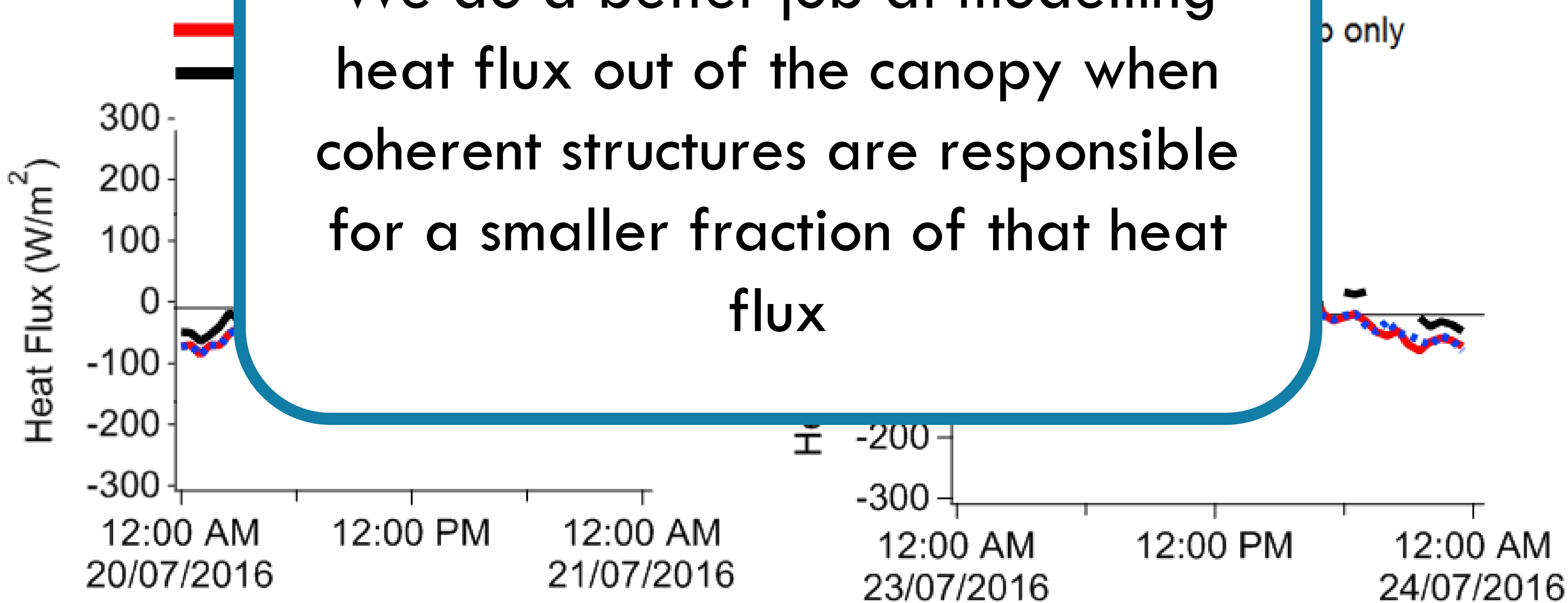
July 23rd, 2016

Fraction of heat flux attribut… struct…

Campaign

Fraction of heat flux … o coherent … **2**

… o only



We do a better job at modelling heat flux out of the canopy when coherent structures are responsible for a smaller fraction of that heat flux

36m (12m above canopy height)

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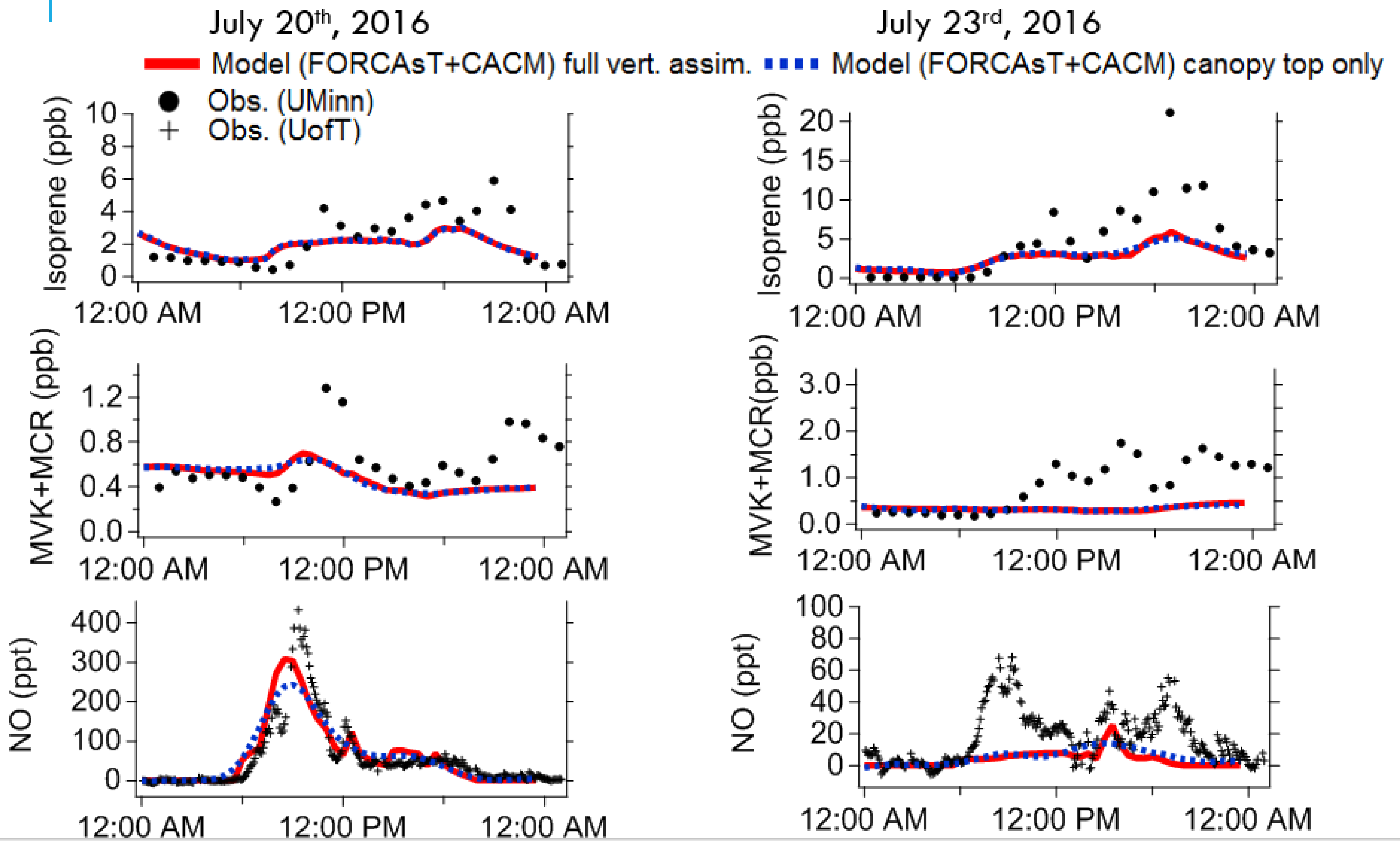
MODELLING CHEMISTRY DURING PROPHET-AMOS



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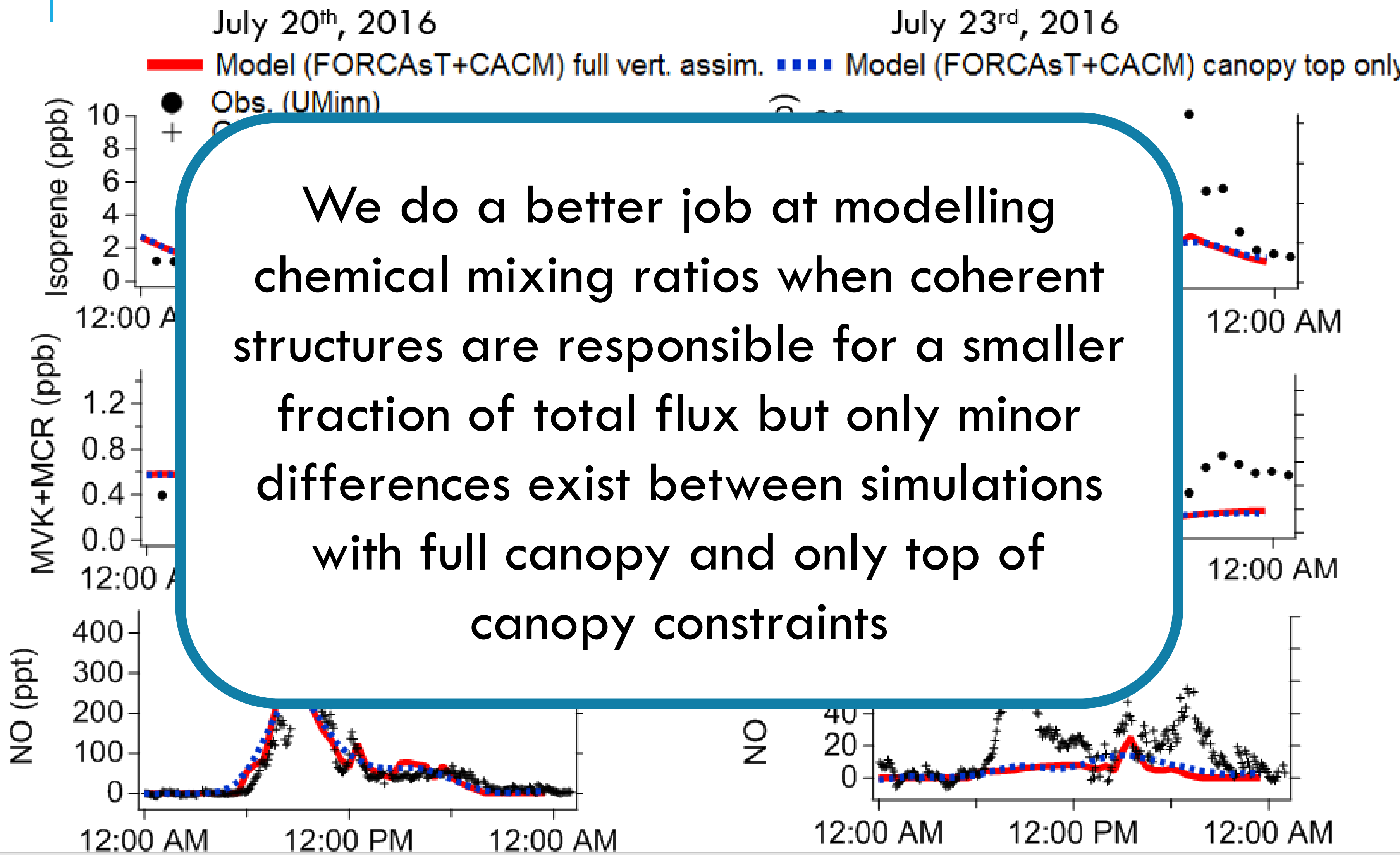
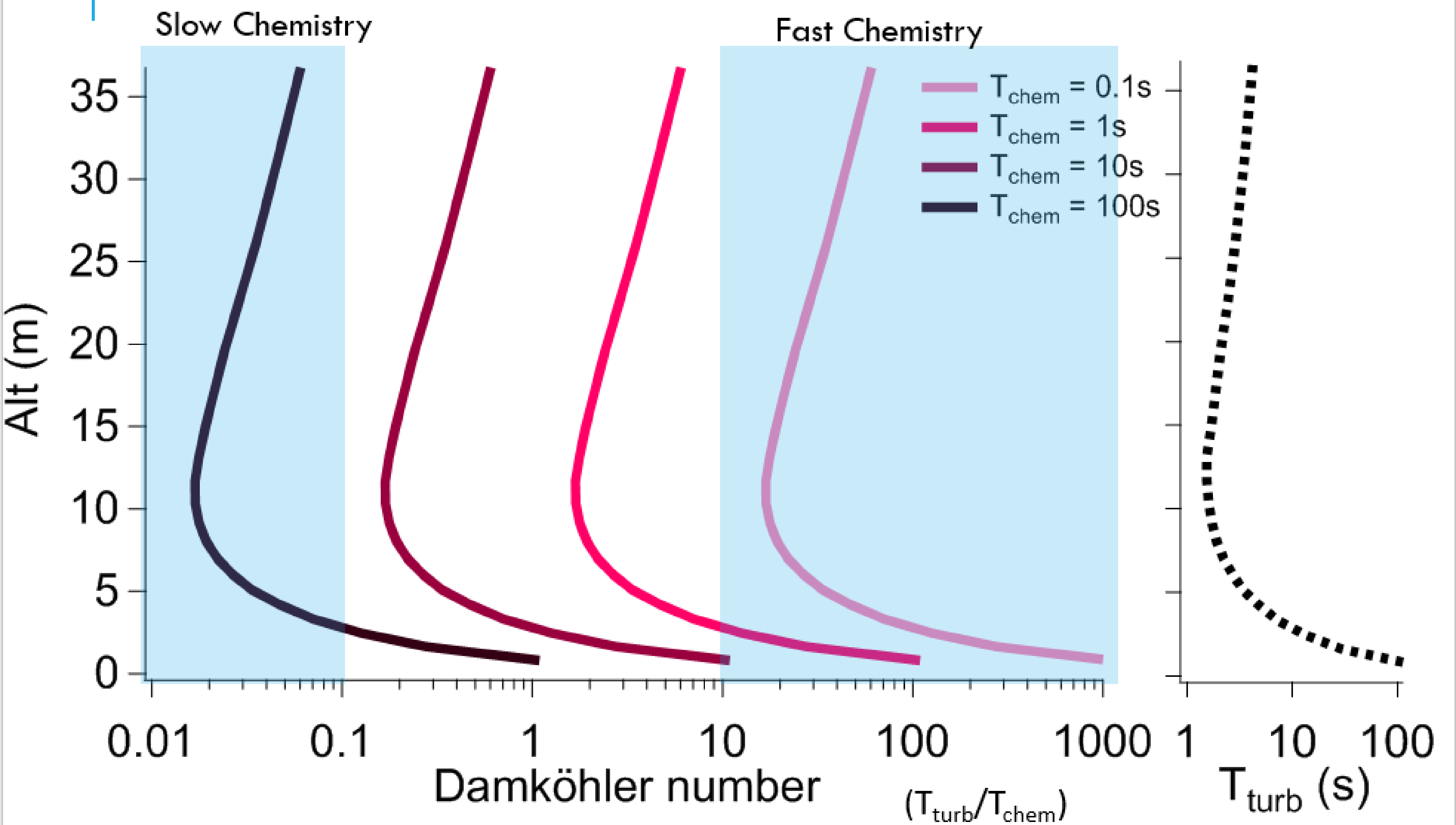
MODELLING CHEMISTRY DURING PROPHET-AMOS



We do a better job at modelling chemical mixing ratios when coherent structures are responsible for a smaller fraction of total flux but only minor differences exist between simulations with full canopy and only top of canopy constraints

IMPACT OF TURBULENCE ON CHEMISTRY

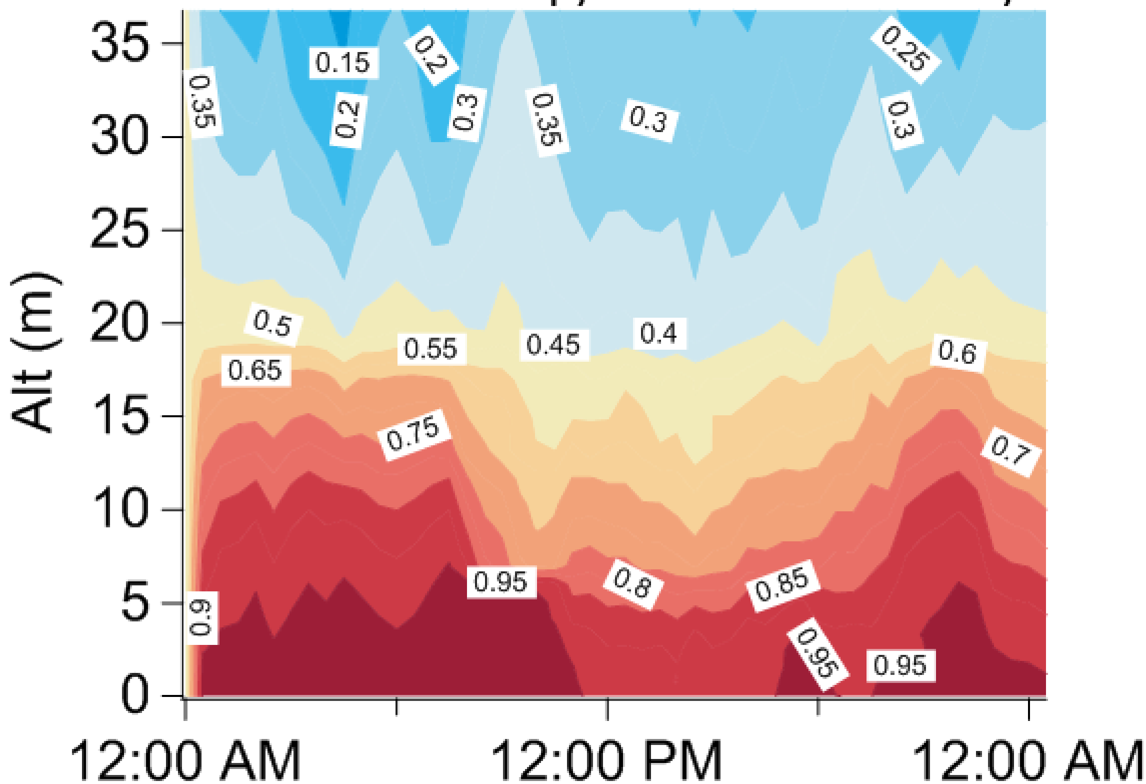


IMPACT OF TURBULENCE ON CHEMISTRY

A → C

A → B

Ratio of B to B+C, $T_{chem,\,A}$ = 0.1s
Above canopy sonic assimilation only



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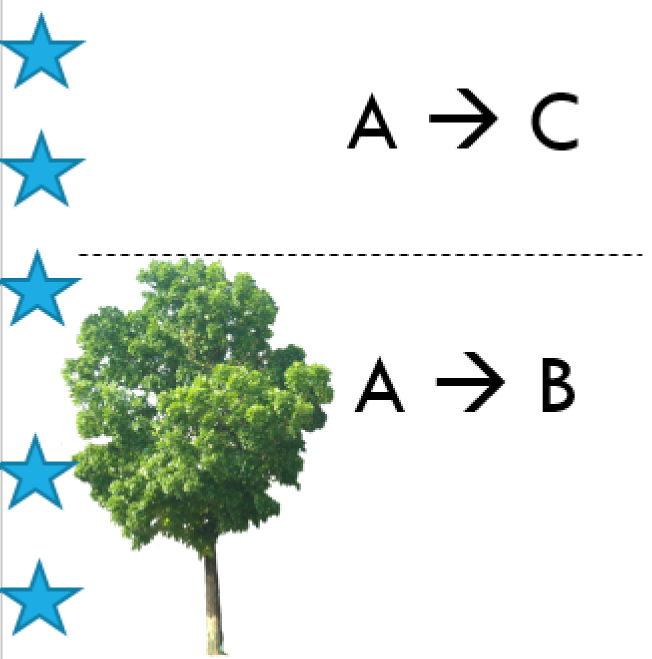
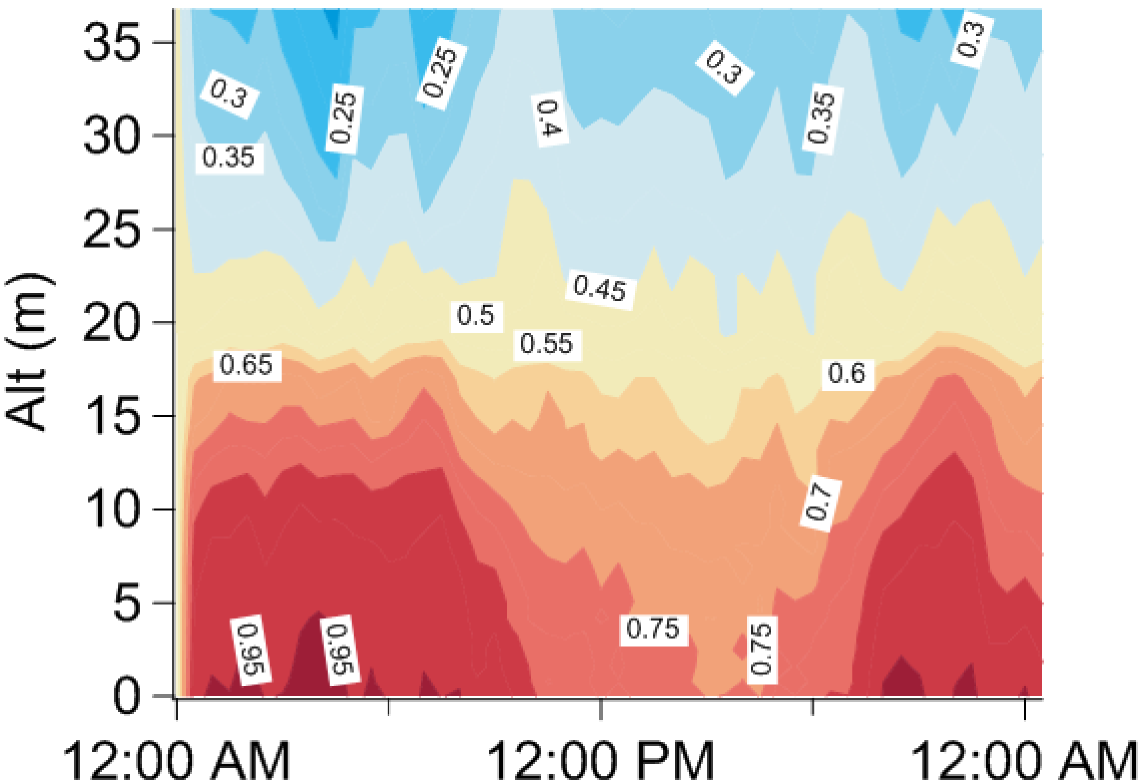
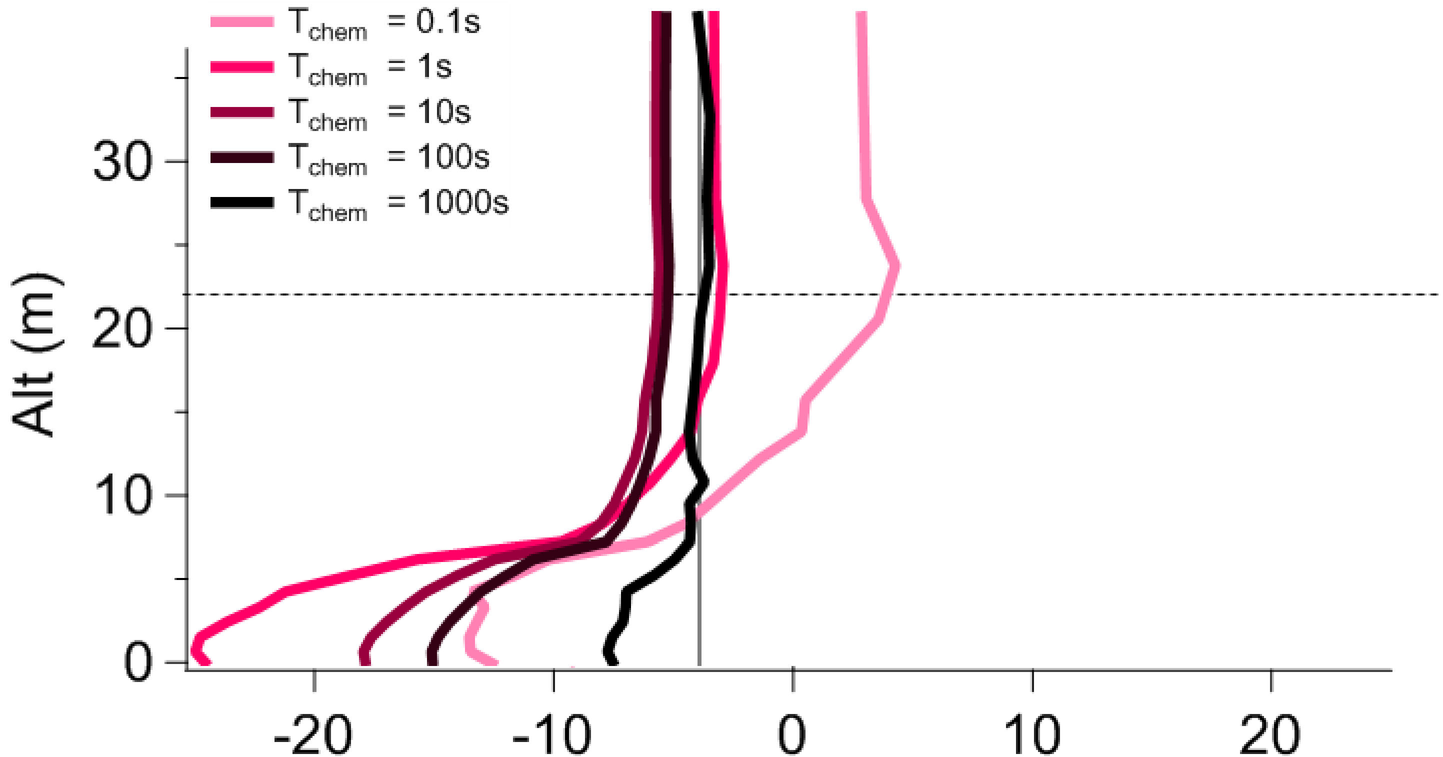


Ratio of B to B+C, $T_{chem,\,A} = 0.1s$
Full vertical sonic assimilation



SIGNIFICANCE OF SUBCANOPY CONSTRAINTS ON MIXING



Percent change in $\frac{B}{B+C}$ ratio going from only top of canopy mixing constraints to full vertical mixing constraints

CONCLUSIONS AND ON-GOING WORK

- We can model heat flux and chemical mixing ratios with reasonable accuracy in a 1D column model without explicit coherent structure representation (despite the large contribution coherent structures make to fluxes) so long as we fix K_H by observations
- Model preference is best when the fractional contribution of coherent structures to fluxes is the lowest
- Constraining the subcanopy mixing in our model is important for chemical compounds with Damköhler numbers near 1
- By knowing the conditions in which our model recreates vertical exchange the most accurately, we can begin to probe other aspects of the model (like choice of chemical mechanism and dry deposition parametrization)