How many flux towers are enough?

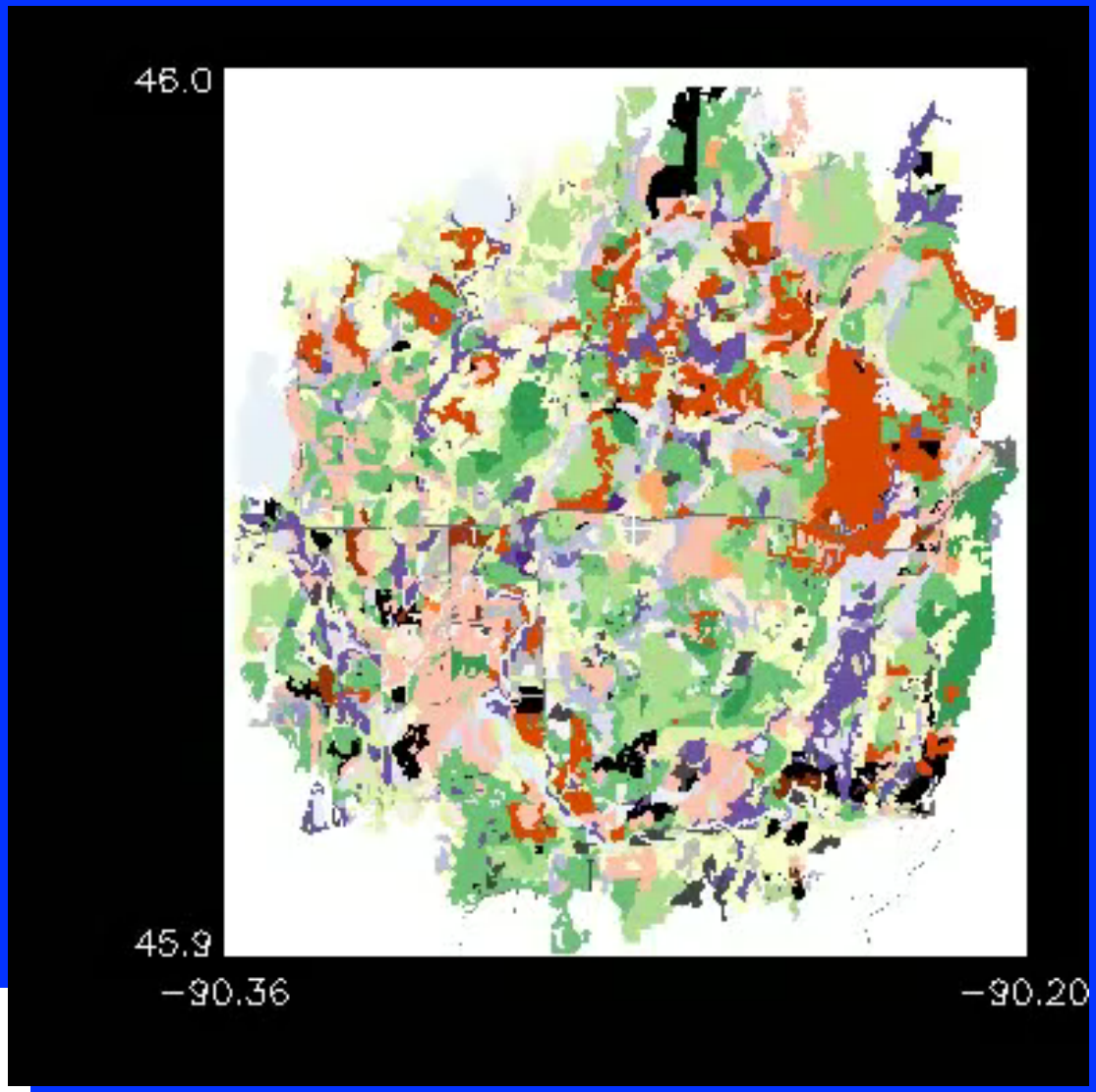
Energy balance closure and large eddy simulation (LES) as diagnostic tools for secondary circulations

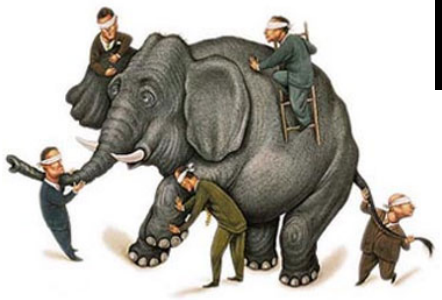
A.R. Desai, Z. Hansen, K. Xu, University of Wisconsin-Madison
M. Mauder, F. Deroo, KIT IMK-IFU Garmisch-Partenkirchen
S. Metzger, NEON, Inc.

J2.1
AMS BLT-22
AFM-32 Biogeo-3
TUE Jun 21 2016
1:30pm CANYONS


Is this a homogenous landscape?

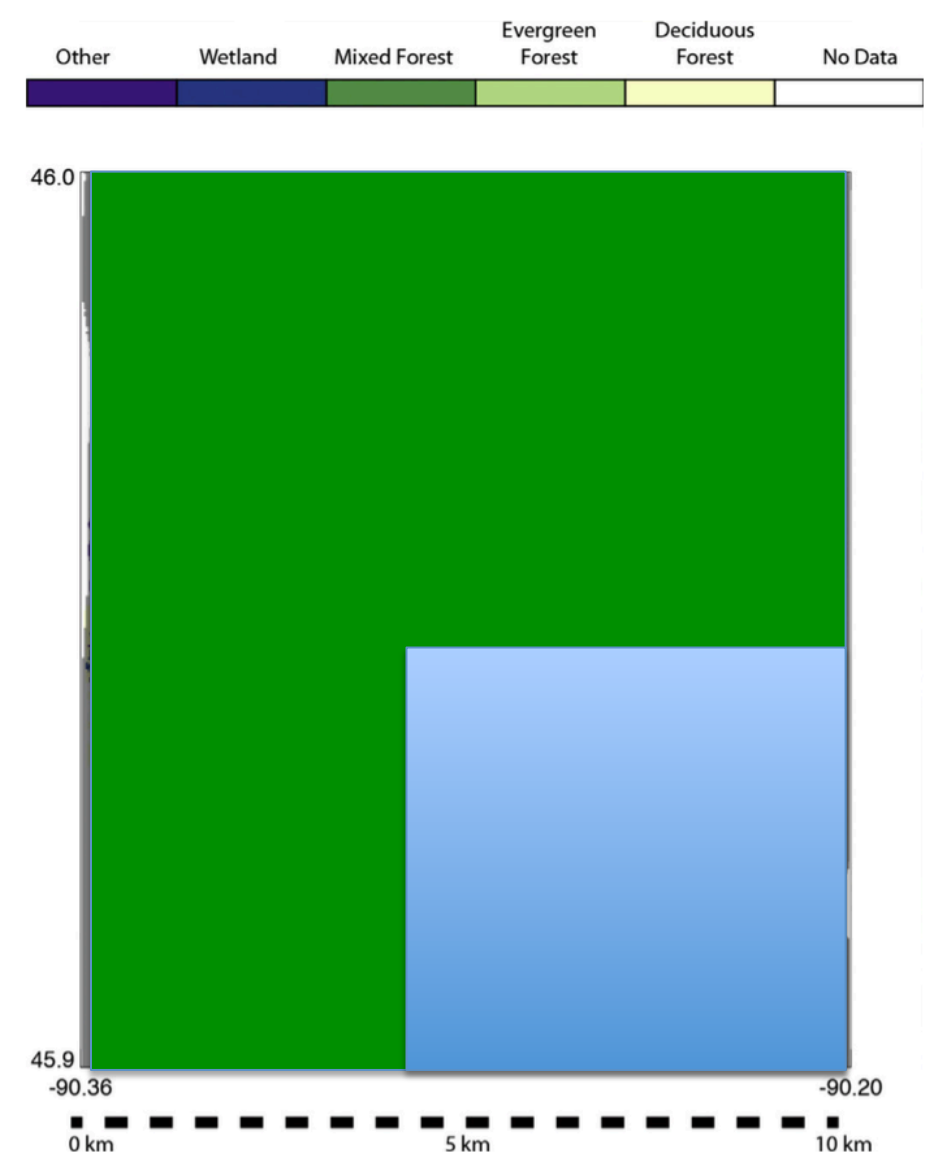
Flux towers see the trees for the forest…





Adopted from a version by HaPE Schmid (KIT)

Earth system models see green slime

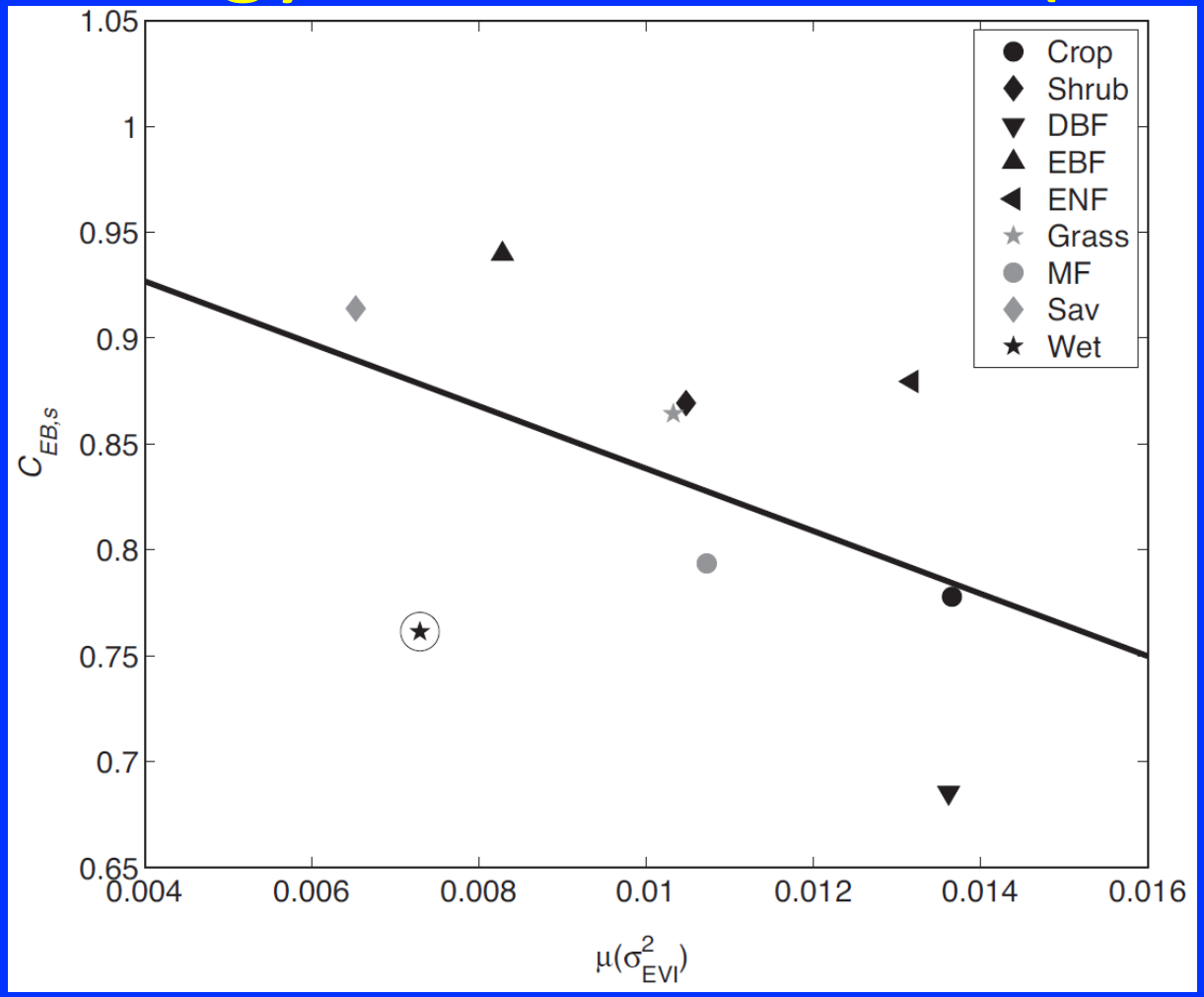


Desai et al., 2015, AFM

Heterogeneous sites have worse energy balance closure (EBC)

EBC=
H+Le

Rnet-G



Greenness spatial variance

Stoy et al., 2013, AFM

Landscape variance potentially drives stationary eddies

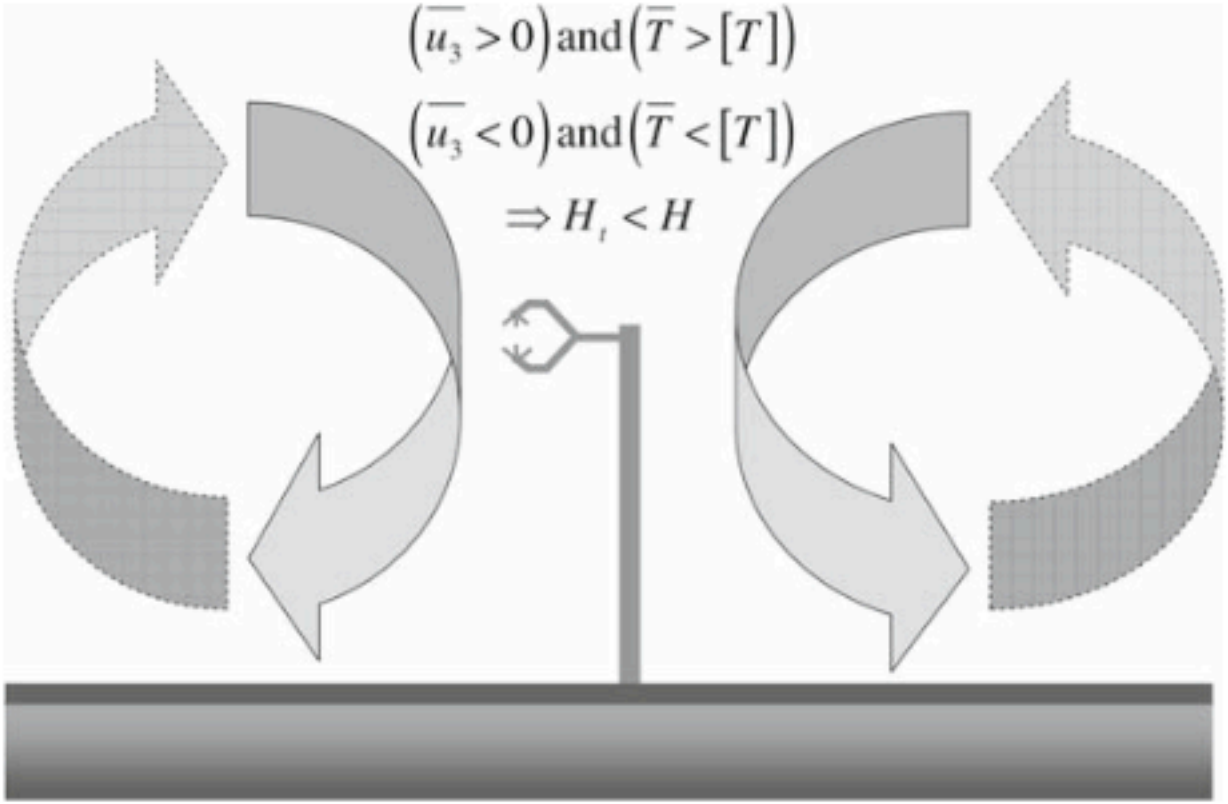


Fig. 1 Schematic showing how quasi-stationary eddies cause an underestimation of the total sensible heat flux H when using the temporal EC method to calculate H_t. The single-point sonic measurement in the centre is not able to resolve quasi-stationary eddies

Mauder et al., 2008, BLM

What to Do?

- 1) Assume what tower sees is representative of whole, maybe screen for poor energy balance
- 2) Build more towers and fuse them someway
- 3) Make a taller tower
- 4) Use a scaling function based on differences of sample area and region of interest: sampling tower like model or model like tower

What to Do?

- 1) Assume what tower sees is representative of whole, maybe screen for poor energy balance
- 2) Build more towers and fuse them someway

QUESTIONS

- How homogenous is homogenous enough?
  - How well does a single eddy flux tower represent a typical earth system model domain (10x10 km) mean surface energy fluxes and how does mean flux and energy balance closure vary with surface flux heterogeneity?
- How many flux towers are towers enough?
  - If you had multiple towers, how many would you need before sufficiently sampling domain mean flux? Are there smarter ways to compute the mean flux when you have multiple towers?

How Long Is Long Enough When Measuring Fluxes and Other Turbulence Statistics?

D. H. LENSCHOW, J. MANN,* AND L. KRISTENSEN*

National Center for Atmospheric Research,† Boulder, Colorado

(Manuscript received 2 November 1992, in final form 16 August 1993)

How Close is Close Enough When Measuring Scalar Fluxes with Displaced Sensors?

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National Center for Atmospheric Research, Boulder, Colorado*

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The Pennsylvania State University, University Park, Pennsylvania

(Manuscript received 19 September 1996, in final form 4 December 1996)

Large-Eddy Simulation: How Large is Large Enough?

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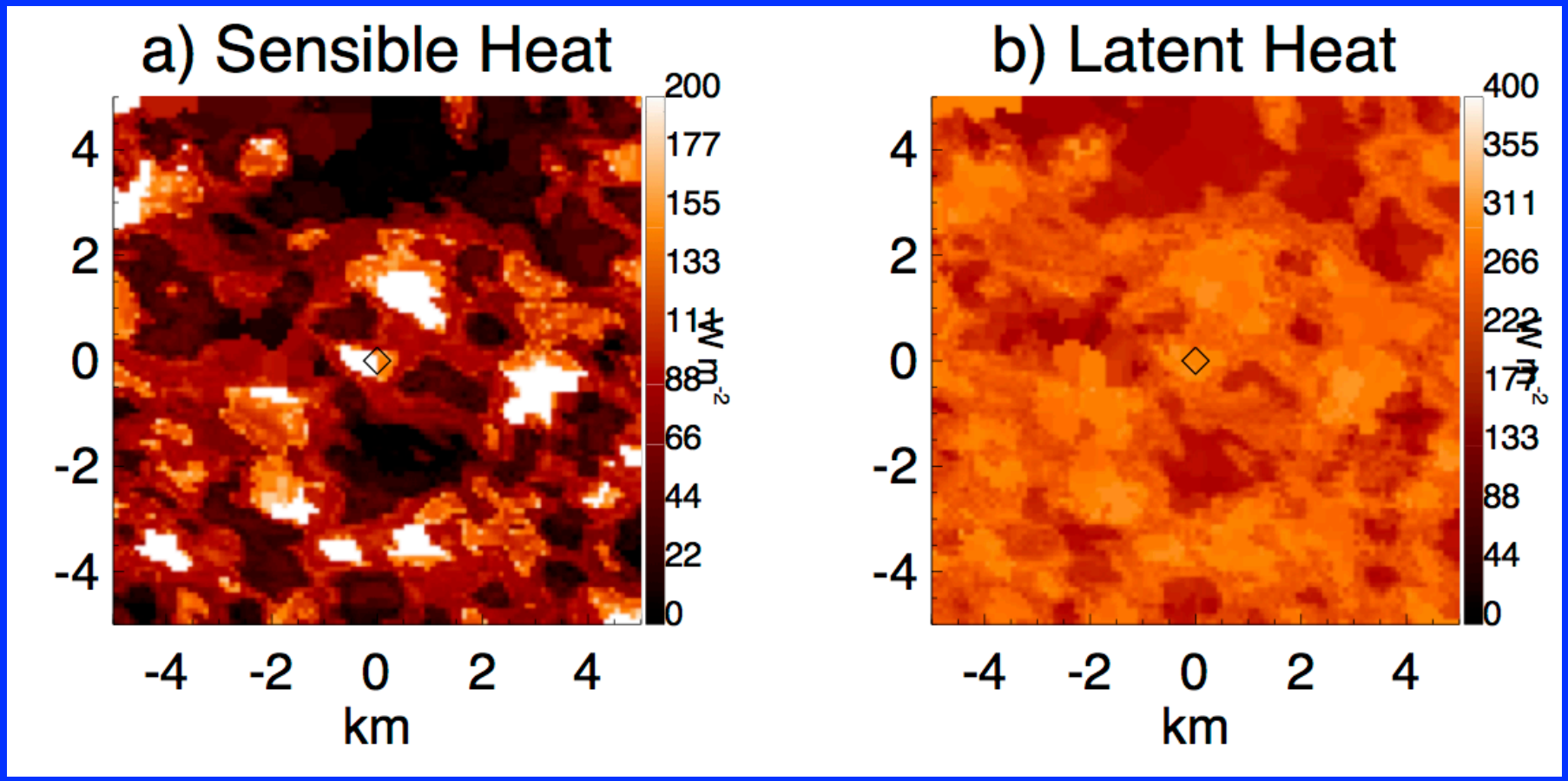
HARM J. J. JONKER

Thermofluids Section, Department of Applied Physics, Delft University of Technology, Delft, Netherlands

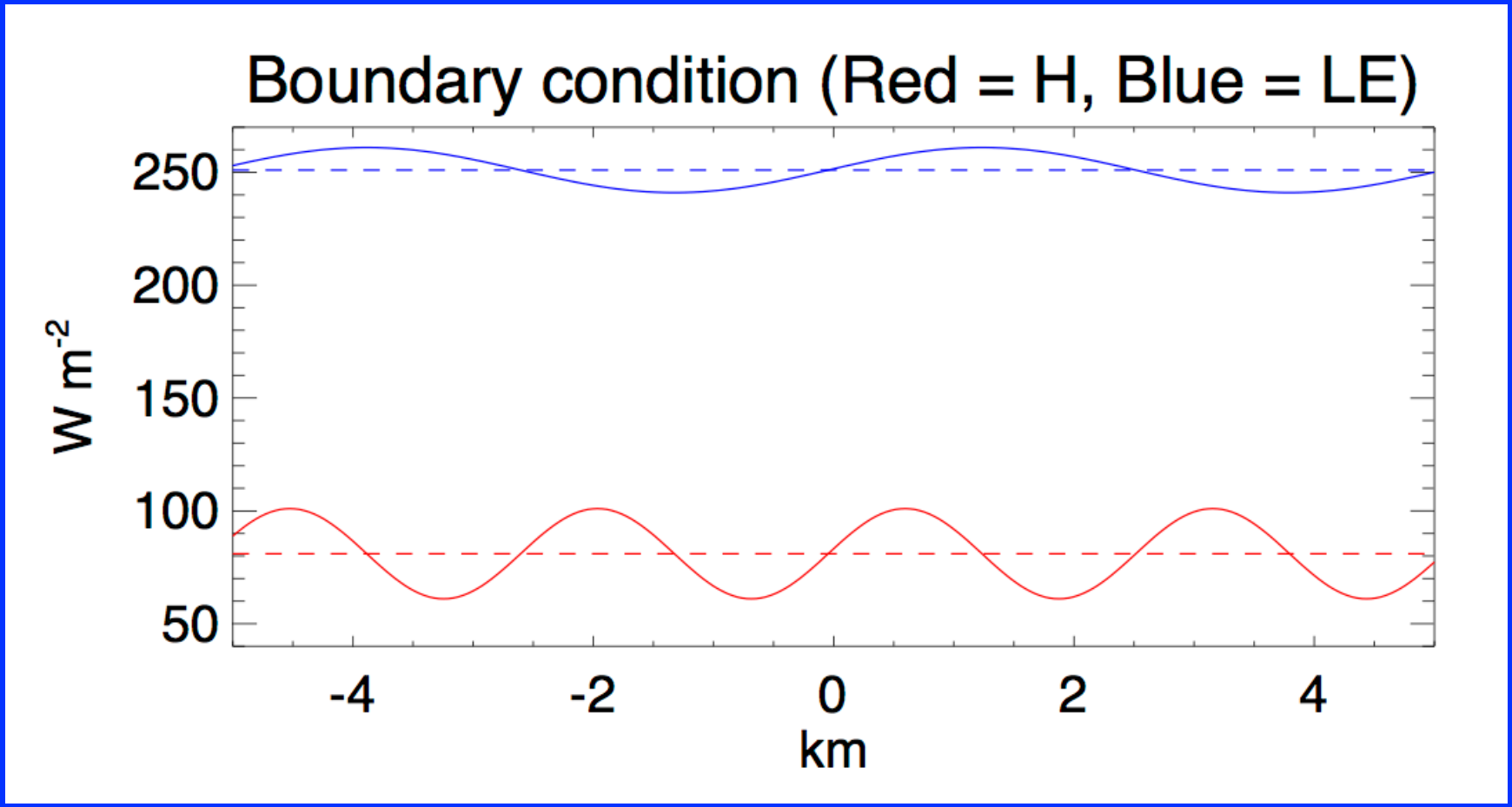
Meet SAM

- SAM: System for Atmospheric Modeling LES
  - Khairoutdinov and Randall (2003)
  - 256x256x128 grid points, 0.4 s temporal
  - 10x10 km domain intended to represent Park Falls, WI US-PFa Very Tall Tower in Northern Wisconsin
  - 40x40m horizontal, ~10m in vertical near surface
  - Periodic horizontal boundary conditions, mid-summer initial profile
  - 1.5 order sub-grid closure
  - Analysis of single 30 minute period after spin up with flux tower based surface energy forcing (1-D variation only)
  - Flux towers (w,q,t,p) sampled at 75m vertical level

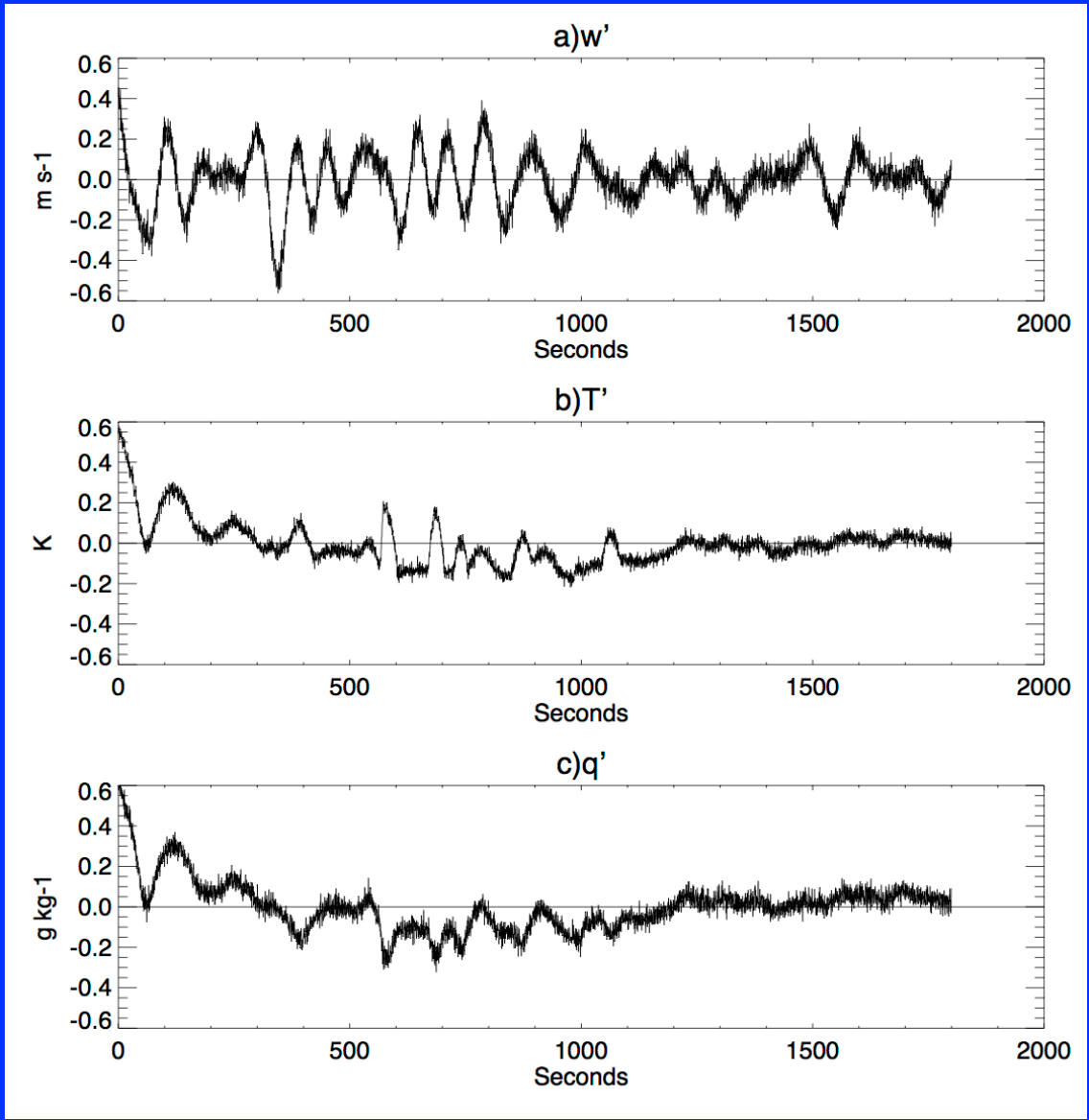
Forcing from tower-based observational scaling



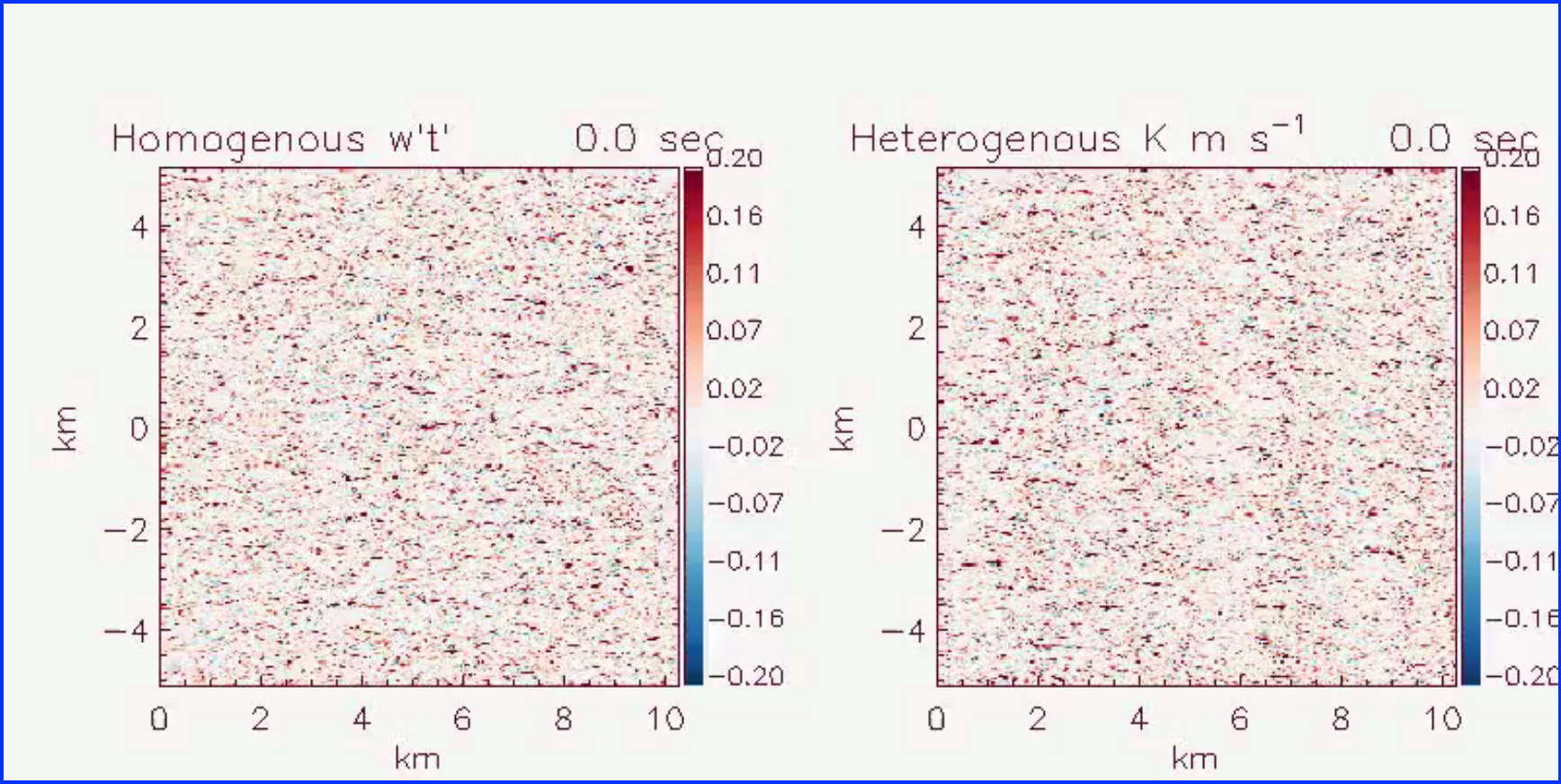
LES cases have to be simplified



Sample LES like a flux tower

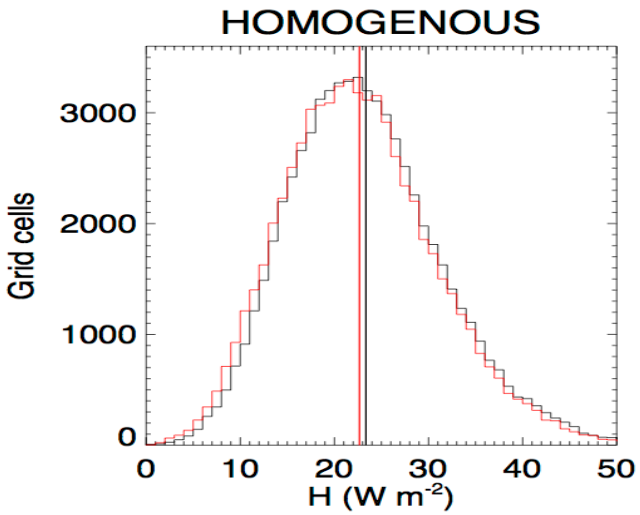


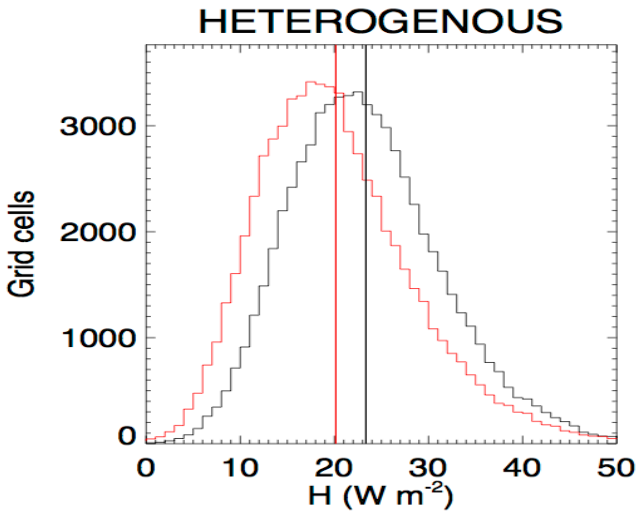
Where would you put your tower?



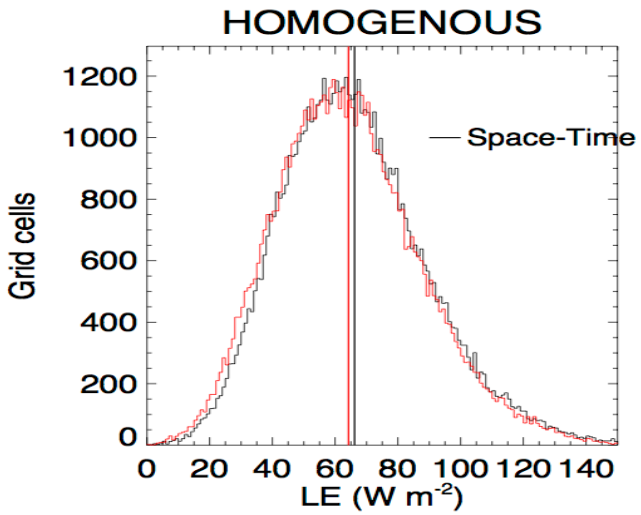
Sampling LES fluxes like a tower (RED) leads to greater biases in heterogeneous simulation when compared to space-time average (BLACK)

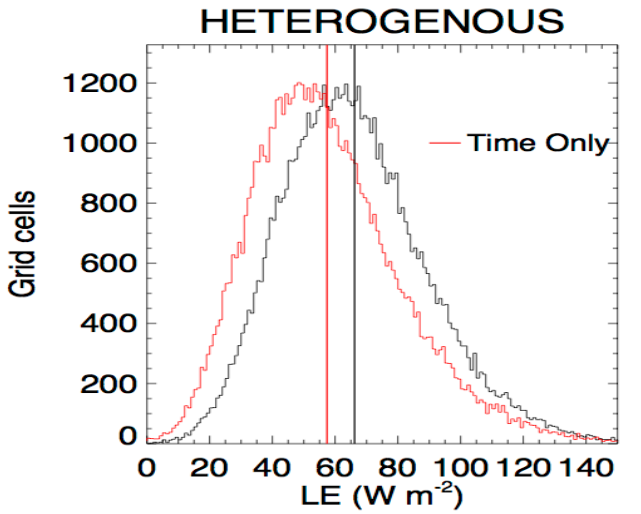
SENSIBLE HEAT (H)





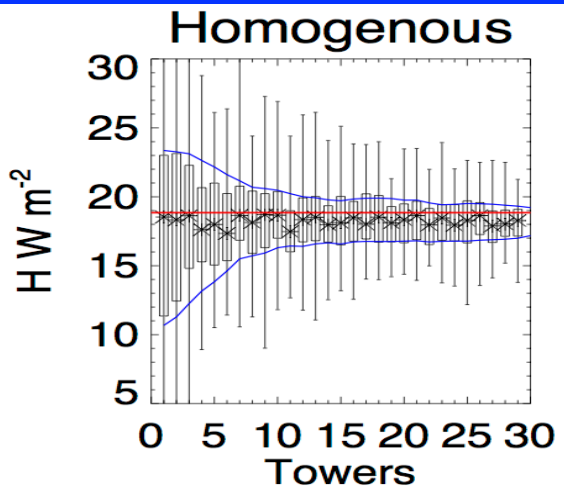
LATENT HEAT (LE)

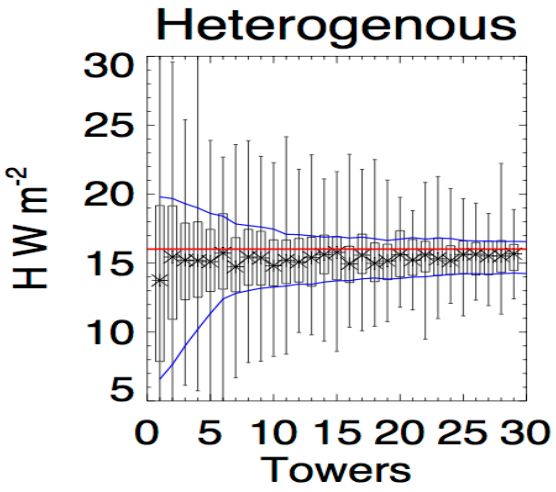




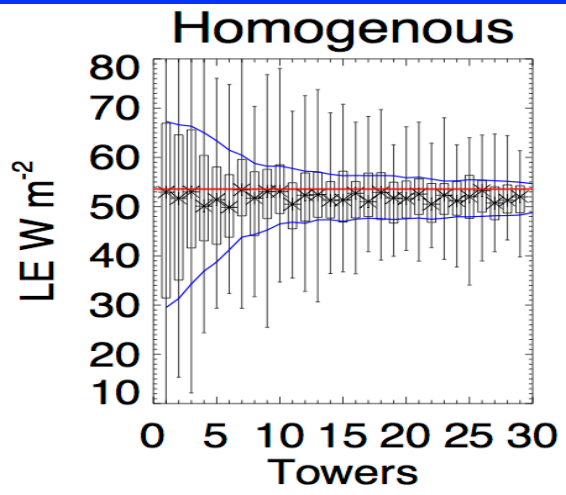
In both cases, a single random tower could vary by ~60% of mean domain flux, and heterogeneous simulation more consistently low biased

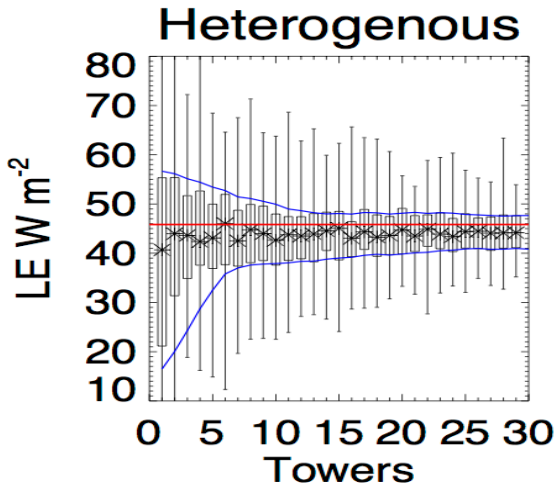
SENSIBLE HEAT (H)

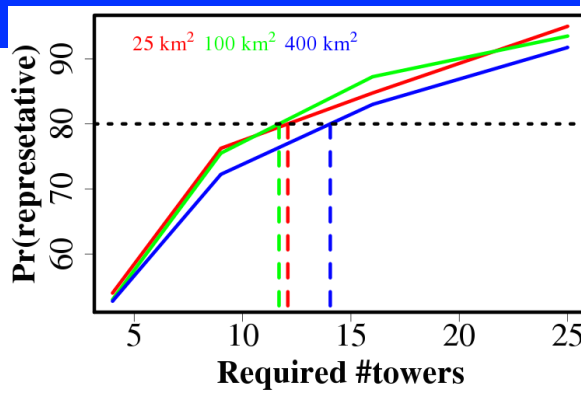




LATENT HEAT (LE)







Interestingly, convergence on domain mean flux (<10% error) with multiple towers in LES happens around ~10 towers, about sample as number of towers needed to sample land cover variance in actual domain

Could we take advantage of multiple towers in a better way?

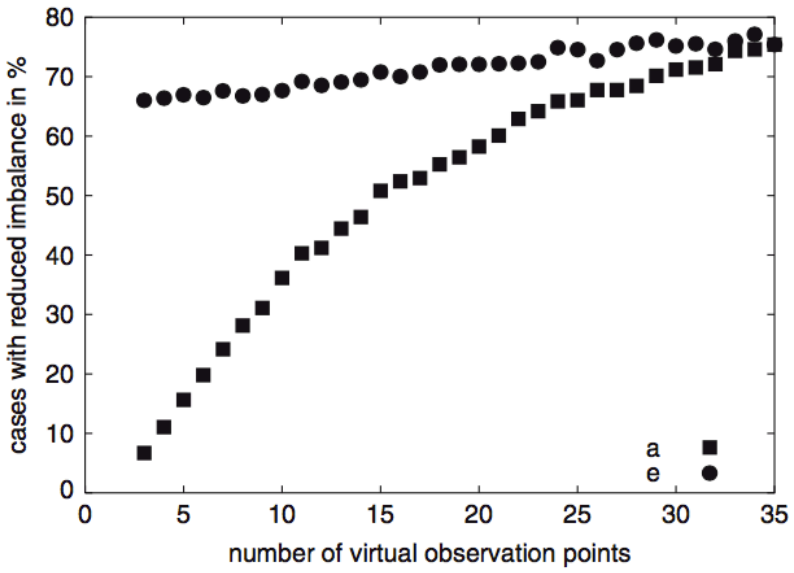
Boundary-Layer Meteorol (2007) 123:77–98
DOI 10.1007/s10546-006-9133-x

ORIGINAL PAPER

Spatial representativeness of single tower measurements and the imbalance problem with eddy-covariance fluxes: results of a large-eddy simulation study

Gerald Steinfeld · Marcus Oliver Letzel · Siegfried Raasch · Manabu Kanda · Atsushi Inagaki

$$\left[\overline{F}\right] = \overline{\left[w\,\langle\Theta\rangle\right]} + \overline{\left[w\Theta'_{\text{filter}}\right]} + \left[\overline{w\Theta_b}\right]$$



Boundary-Layer Meteorol
DOI 10.1007/s10546-016-0161-x

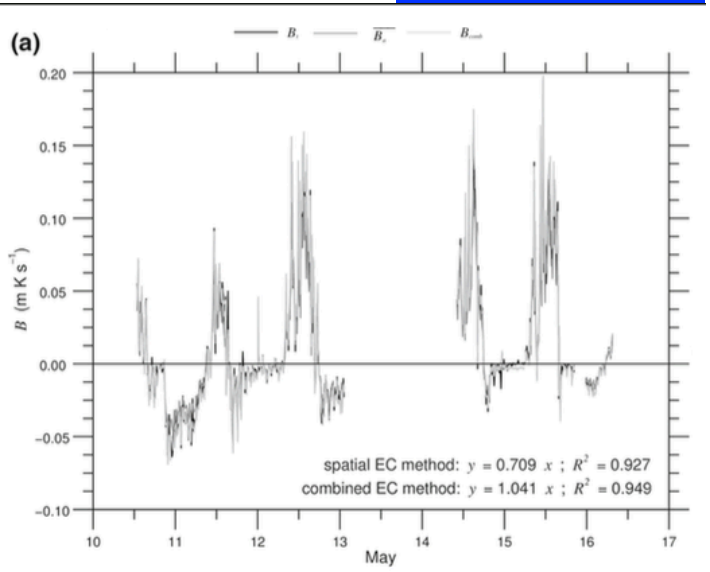
RESEARCH ARTICLE

Exploring Eddy-Covariance Measurements Using a Spatial Approach: The Eddy Matrix

Christian Engelmann[1,2] · **Christian Bernhofer**[1]

$$B_{\mathrm{comb}} = \overline{\langle w''\theta'' \rangle} + \overline{\langle w \rangle' \langle \theta \rangle'} \tag{3a}$$

$$= \overline{B_a} + \left(\frac{1}{M-1} \right) \sum_{i=1}^{M} \left(\left(\langle w \rangle_i - \overline{\langle w \rangle} \right) \left(\langle \theta \rangle_i - \overline{\langle \theta \rangle} \right) \right), \tag{3b}$$



Boundary-Layer Meteorol (2008) 128:151–172
DOI 10.1007/s10546-008-9279-9

ORIGINAL PAPER

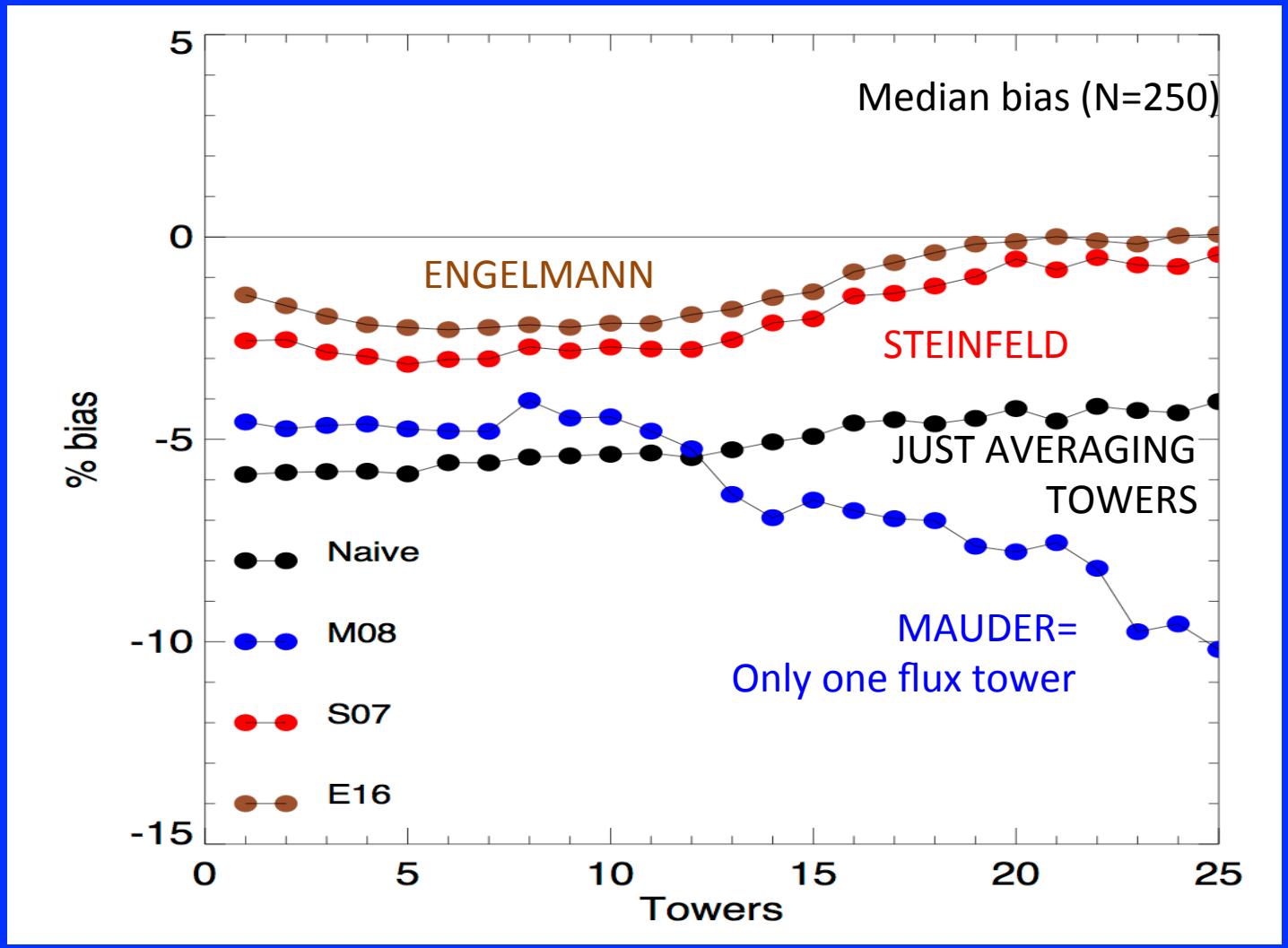
Measurement of the Sensible Eddy Heat Flux Based on Spatial Averaging of Continuous Ground-Based Observations

M. Mauder · R. L. Desjardins · E. Pattey · Z. Gao · R. van Haarlem

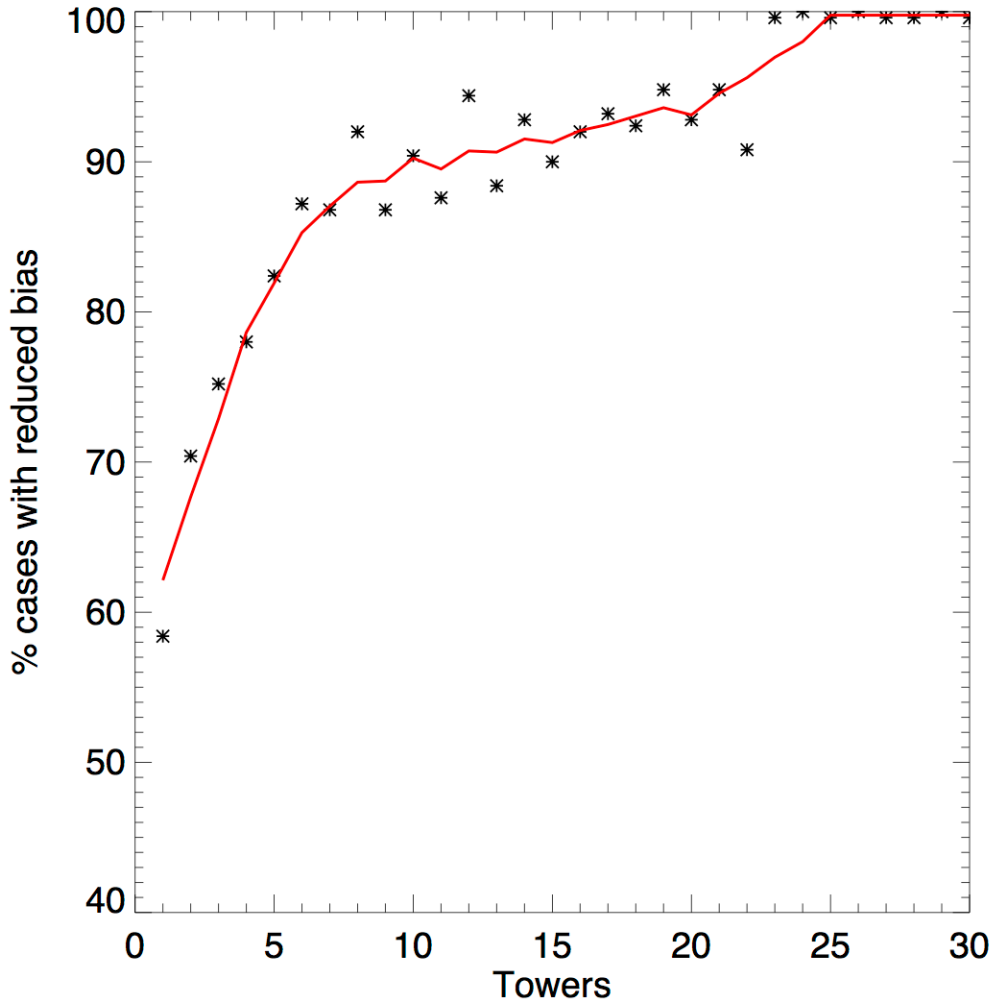
NOTE: In this scenario, only one of the towers is high-frequency, rest are T/Q only

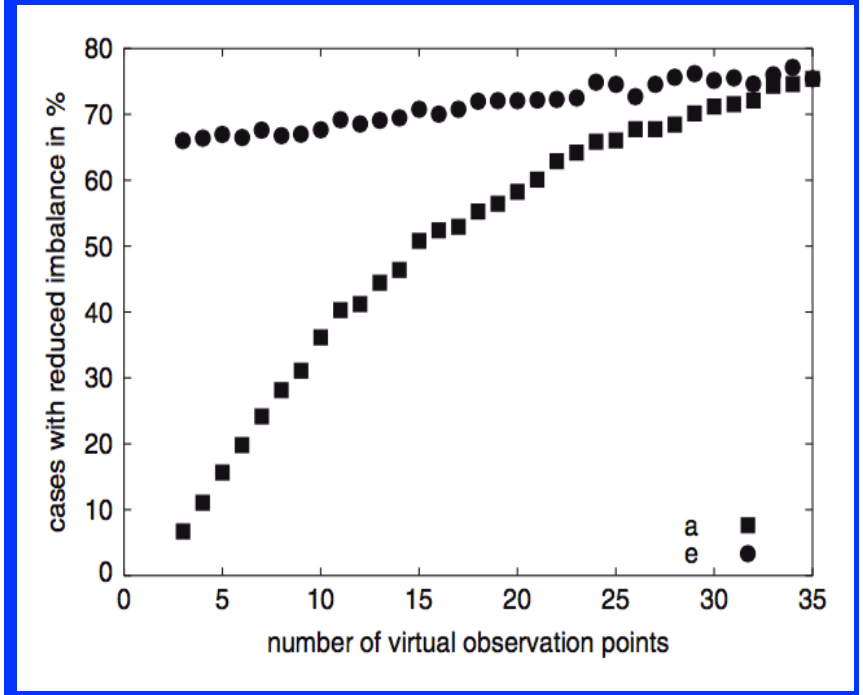
$$H = \overline{u_3}\left(\overline{T} - T_0\right) + \overline{u_3'T'} \approx \overline{u_3}\left(\overline{T} - [T]\right) + \overline{u_3'T'} = \overline{u_3}\left(\overline{T} - [T]\right) + H_t$$

Spatial covariance approaches do improve the flux relative to domain mean, but in different ways



Our results on S07 method consistent with their paper and suggests energy balance may be addressed with density of ~10-20 towers per 100 square kilometers



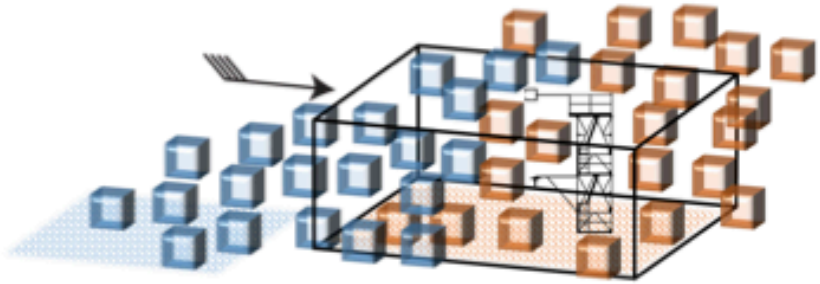


So we only need 70 million towers?

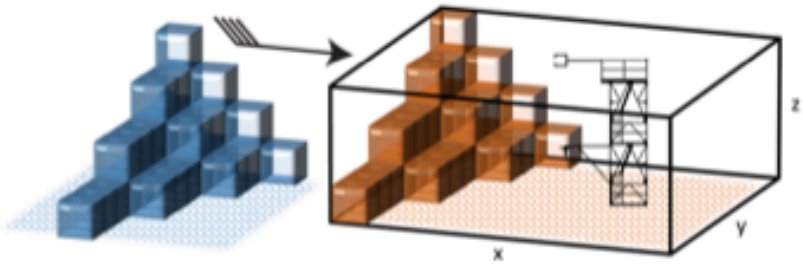
WED 6.1 8:00 am Arches

Surface-atmosphere exchange in a box:
Making it a suitable representation for in-situ observations

flux observations



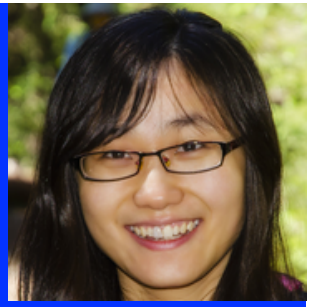
environmental response function
virtual control volume



Stefan Metzger[1,2]

[1]National Ecological Observatory Network, Boulder, Colorado, USA
[2]University of Colorado, Boulder, Colorado, USA

WED 6.2 8:15 am Arches



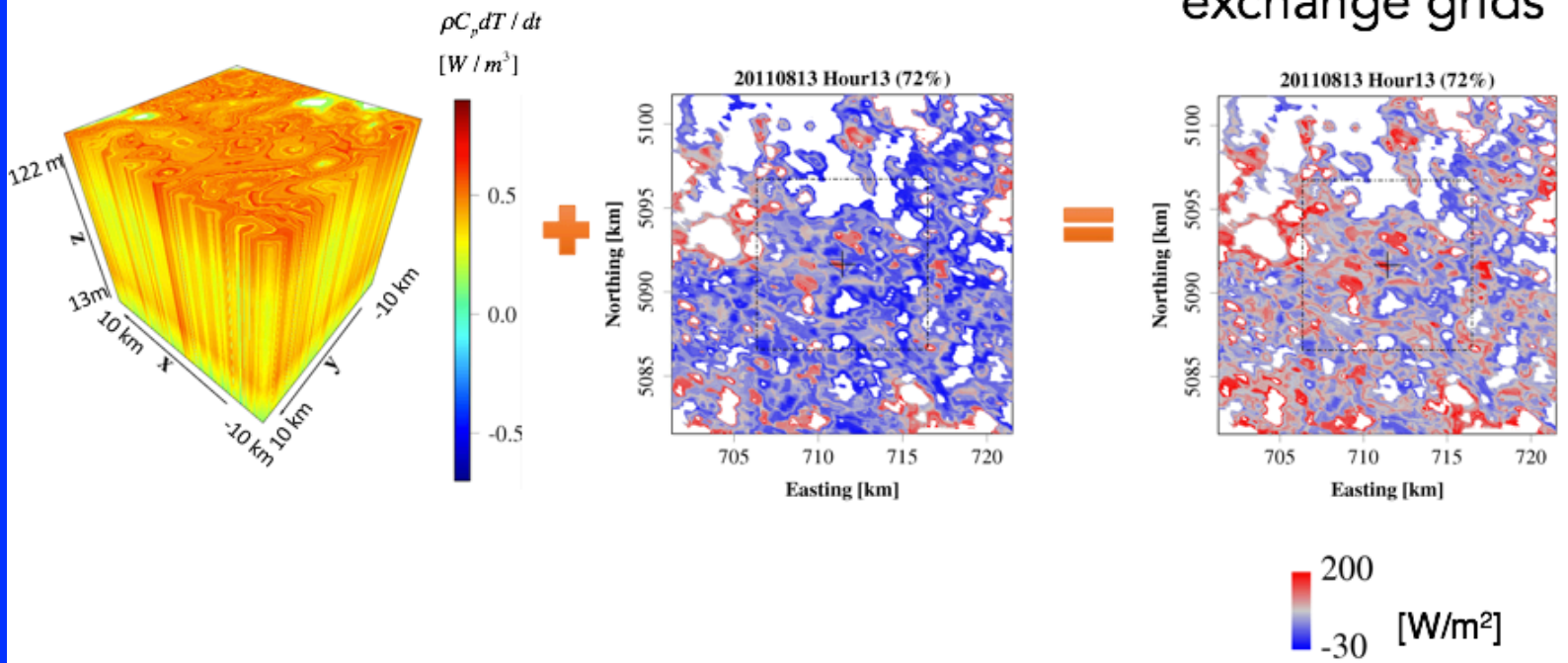
Surface-atmosphere exchange in a box II: A practical realization with single tower eddy covariance observations

Ke Xu[1], Stefan Metzger[2,3], Ankur R. Desai[1]

Storage flux

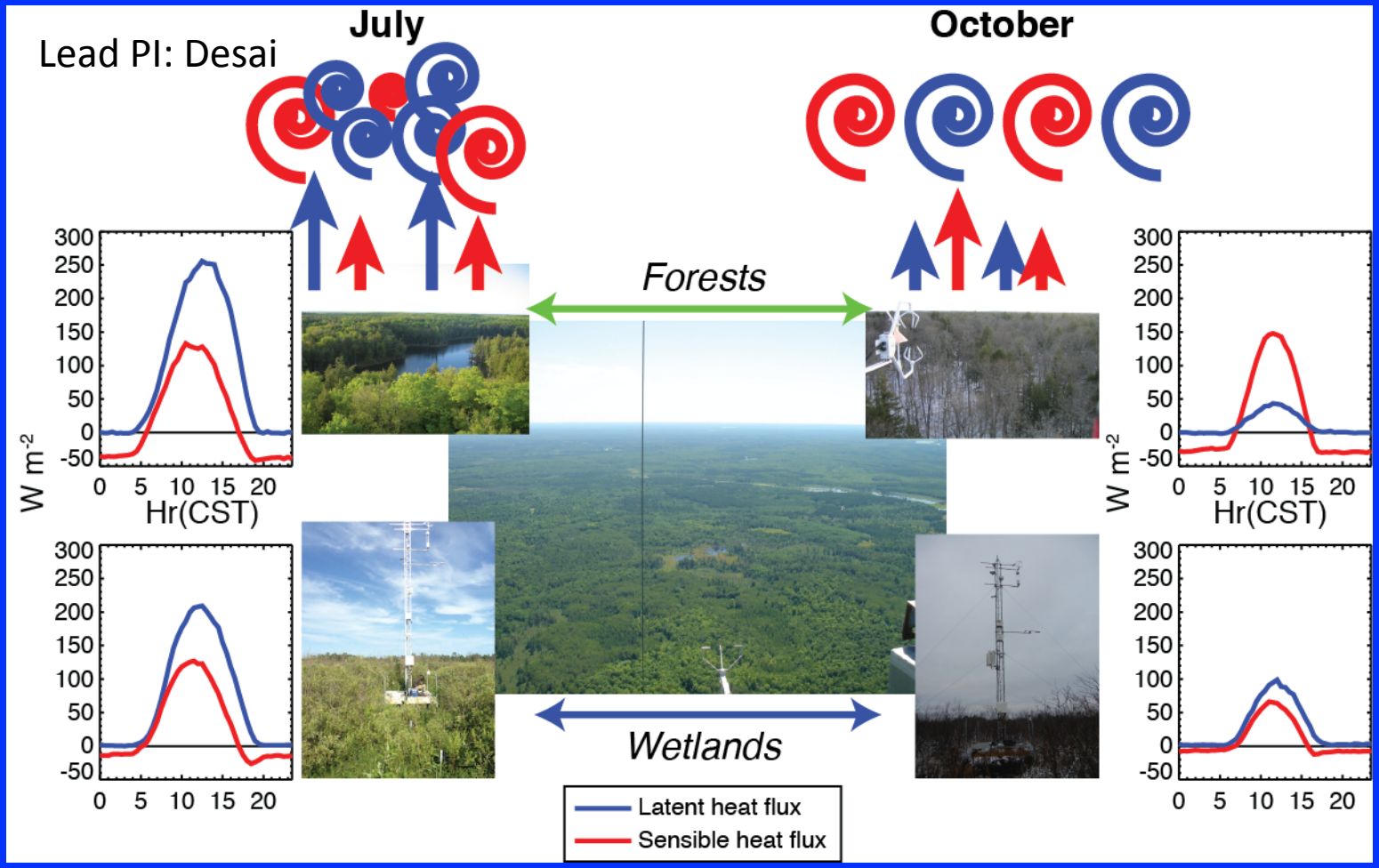
Turbulent flux grids

Surface-atmosphere exchange grids



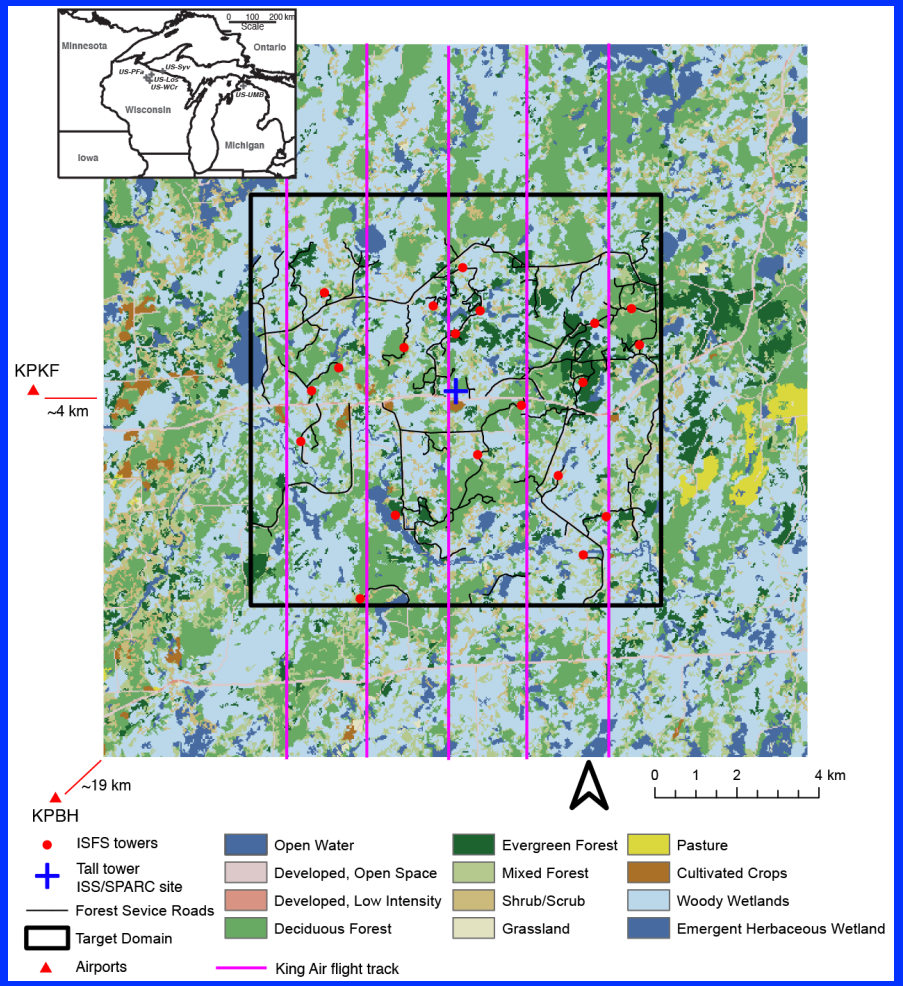
Chequamegon Heterogeneous Ecosystem Energy-balance Study Enabled by a High-density Extensive Array of Detectors **(CHEESEHEAD)**

NSF: U Wisc Madison-U Wisc Milwaukee-NASA GSFC-NCAR-U Wyoming-KIT IFU-Montana State



Experimental Design

- Distribute 20+ eddy covariance flux towers (red dots) within 10x10 km box (black box, right) around WLEF tall tower (blue cross). Run continuously July-Oct, top of canopy fluxes + micromet profiles
  - Ecology and phenology bi-weekly sampling at all towers
- Place in-situ and remote profiling instruments in 100 m clearing.
- 3 IOPs in late Jul, late Aug, late Sep with airborne legs in 2 km spacing at 500 and 1000 ft AGL (purple lines).
  - Upward pointing LiDAR to map PBL dept. Raman LiDAR for profiles of temperature and water vapor, if possible
  - Single hyperspectral visible-IR and canopy LiDAR mapping mission from NASA G-LiHT, potentially integrated with UWKA
- LES simulations for each IOP and select cases across study period



Thank you

- How many flux towers do you need?
  - Depends on how you use them and your site spatial heterogeneity!

- DOE LBL Ameriflux Network Management Project subaward to ChEAS Core Site Cluster
- NEON, Inc.