A Study to Better Understand the Diurnal Cycle of Turbulent Fluctuations of Heat with Emphasis on Transition Periods in the Surface Layer

Chaoxun Hang[1], Daniel Nadeau[2], Derek Jensen[1], Eric Pardyjak[1]

[1] Department Of Mechanical Engineering, University Of Utah

[2] Department Of Civil And Water Engineering, Université Laval, Quebec City, Canada

0. PREVIOUS WORK SUMMARY

Playa soil moisture and evaporation dynamics during the MATERHORN field Program

Hang, Chaoxun, Daniel F. Nadeau, Derek D. Jensen, Sebastian W. Hoch, Eric R. Pa

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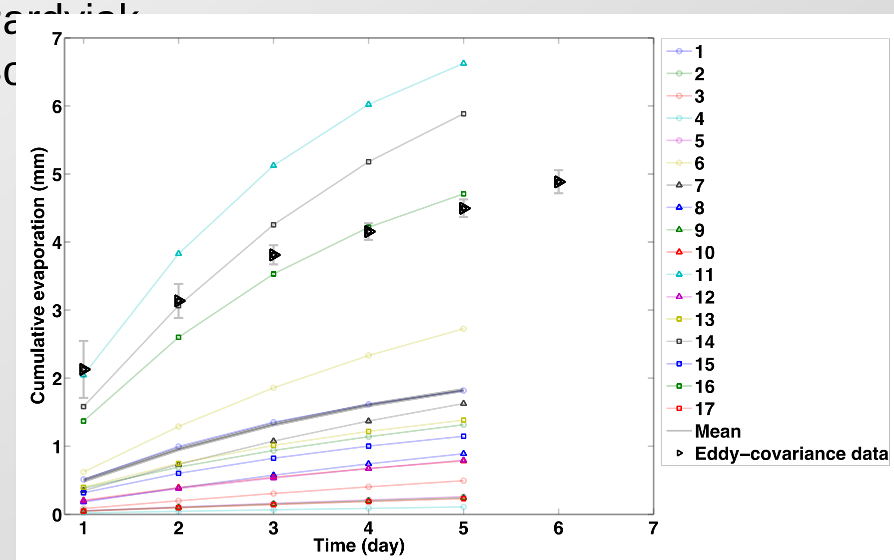

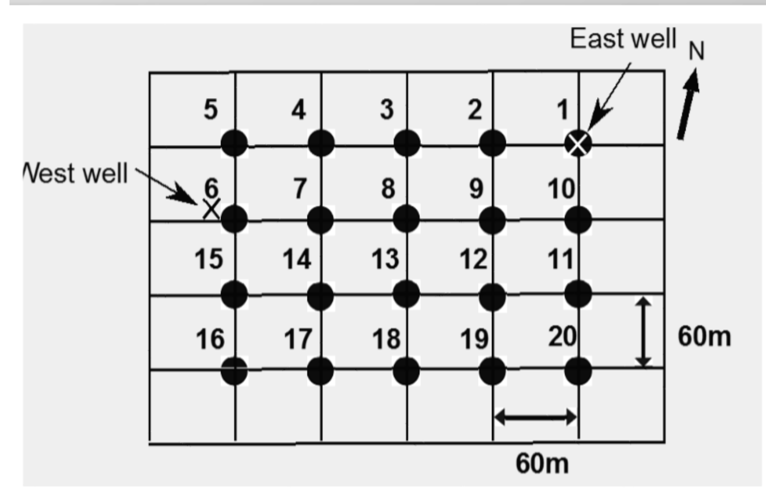

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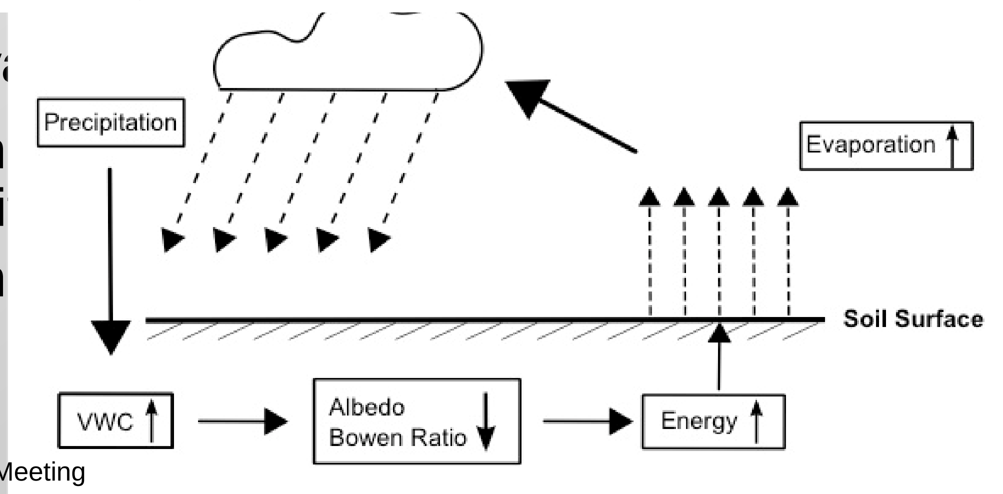


1. MOTIVATION

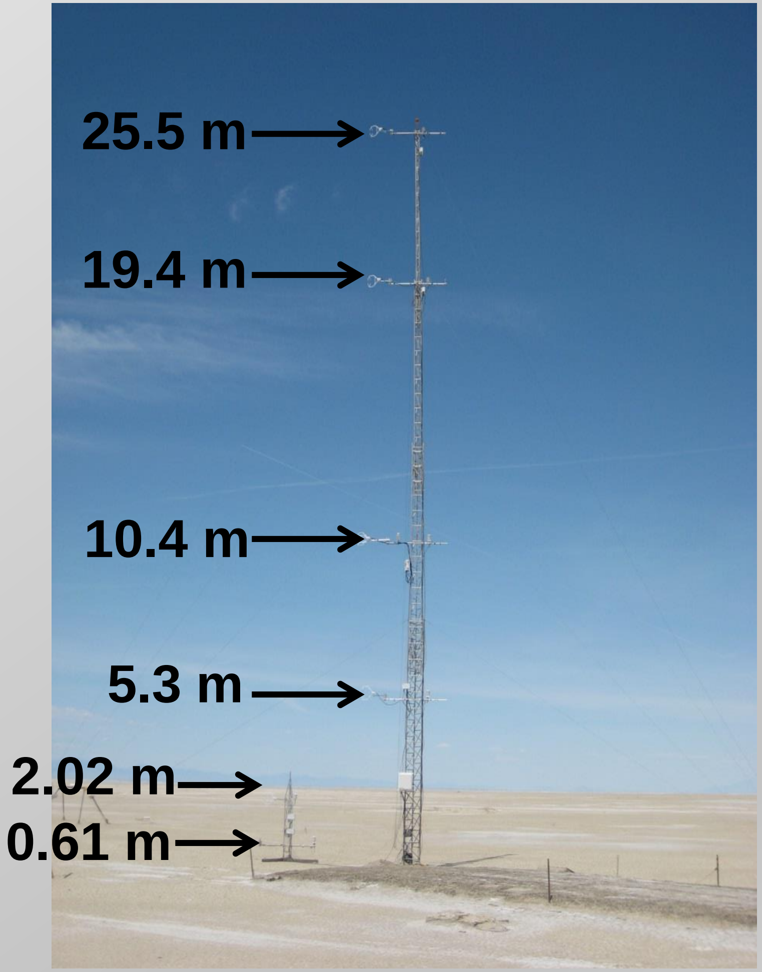
- It is important to understand the physical processes of turbulent fluctuations of scalar quantities in the atmospheric boundary layer
- Turbulent fluctuations of heat (i.e. potential temperature variance) is a key factor to improve the second-order turbulence closure models (or Level 2), which is widely used in numerical weather predictions

2. OBJECTIVES

- To analyze the potential temperature variance budget during the transition periods in the surface layer
- To develop a simple model of potential temperature variance budget and to validate it with MATERHORN experimental data

3. METHODS

- **Site**: Desert playa
- **Time**: May 1 to May 31, 2013
- **Instrument**:
  - Sonic anemometers at 6 levels
  - Open-path gas analyzer at 10.4 m
  - Temperature/relative humidity sensors at 6 levels
  - Hot-wire



4. BACKGROUND

Potential temperature variance budget equation (Antonia et al. BLM, 1980):

$$\underbrace{\frac{\partial \overline{\theta'^2}}{\partial t}}_{\text{I}} + \underbrace{\overline{U_j}\frac{\partial \overline{\theta'^2}}{\partial x_j}}_{\text{II}} = \underbrace{-2\overline{\theta' u'_j}\frac{\partial \overline{\Theta}}{\partial x_j}}_{\text{III}} - \underbrace{\frac{\partial \overline{u'_j \theta'^2}}{\partial x_j}}_{\text{IV}} - \underbrace{2\epsilon_\theta}_{\text{V}} - \underbrace{2R_\theta}_{\text{VI}}$$

I	Storage
II	Advection by the mean wind
III	Production
IV	Turbulent transport
V	Dissipation
VI	Radiation destruction

θ'	potential temperature fluctuation
t	time
U_j	mean wind speed in the j-direction
$u_j{}'$	wind speed fluctuation
Θ	mean potential temperature

4. BACKGROUND

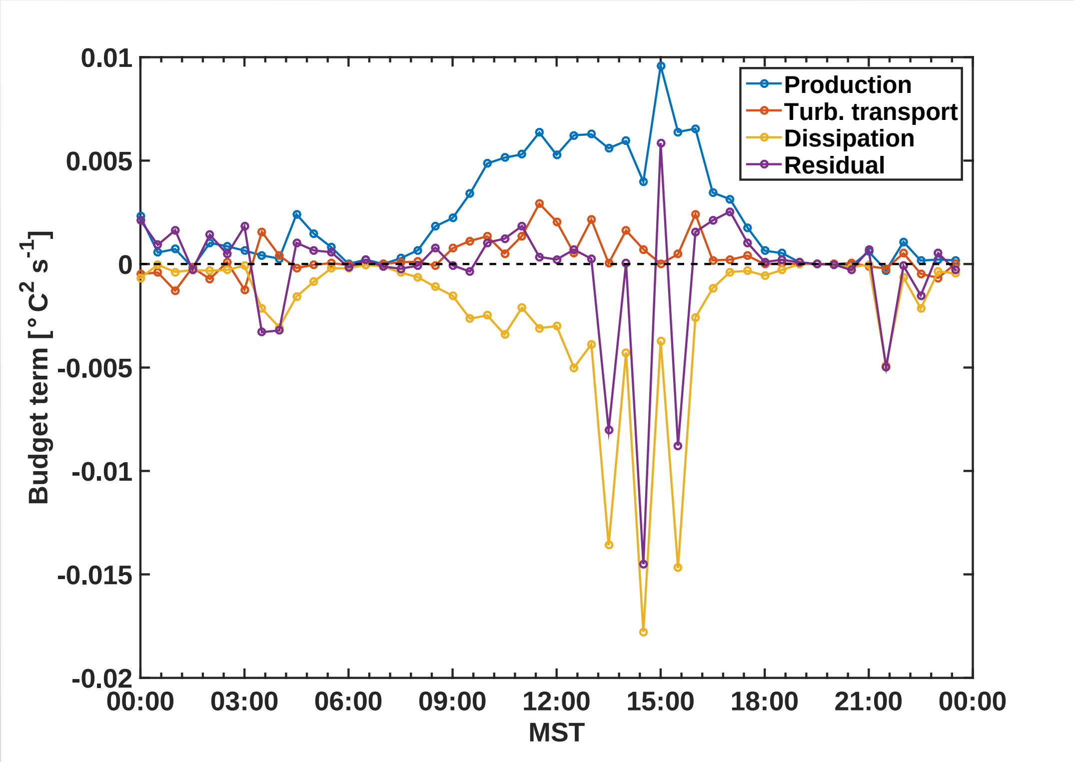
Assumptions:

- Steady state flow
- Horizontal homogeneity
- Negligible subsidence
- Negligible radiation destruction

$$0 = \underbrace{-2\overline{\theta' w'}\frac{\partial\overline{\theta}}{\partial z}}_{\text{III}} - \underbrace{\frac{\partial\overline{w'\theta'^2}}{\partial z}}_{\text{IV}} - \underbrace{2\epsilon_\theta}_{\text{V}}$$

5. PRELIMINARY RESULTS

diurnal cycle of the $\overline{q'^2}$ budget terms

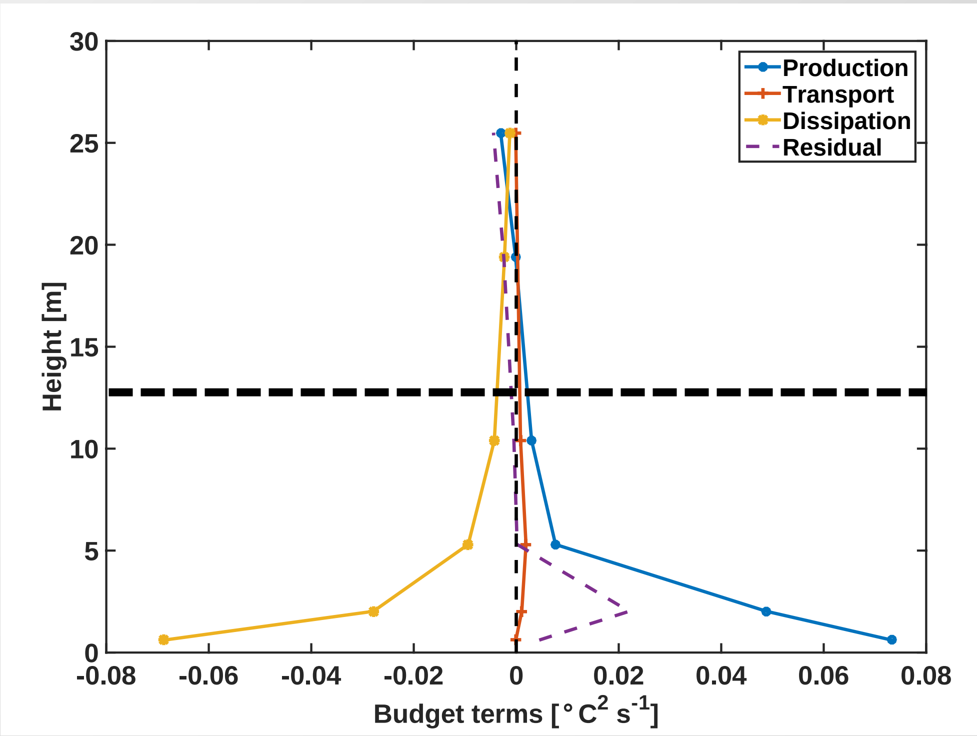


May 13, 2013 at 10-m level

- Dissipation rate is calculated by second-order structure function (Kiely et al. BLM, 1996).
- 30-min averaged data
- Reasonable balance between production and dissipation

5. PRELIMINARY RESULTS

Medians of the $\overline{q'^2}$ budgets at six levels



Daytime (1000 to 1600 MST) during the spring field campaign 2013

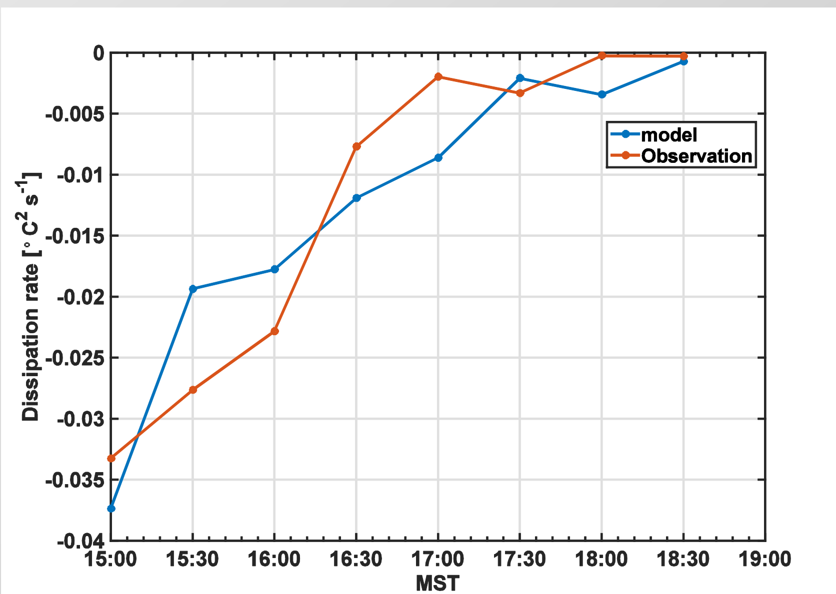
- General balance between production and dissipation through all levels
- Statistically negligible turbulent transport term
- A thin layer at 10 – 15m (dashed line)
- Unknown big residual at 2-m level
  - Radiation destruction?

5. PRELIMINARY RESULTS

Model the $\overline{q'^2}$ budget during late-afternoon transition period

- Steady state assumption is not valid during the transition periods(Foken & Wichura, AFM, 1996);
- The storage term is no longer negligible;
- Potential temperature variance budget can be written as:

$$\frac{\partial \overline{\theta'^2}}{\partial t} = -2\overline{w'\theta'}\frac{\partial \Theta}{\partial z} - 2\varepsilon_\theta$$



Afternoon transition period on May 13, 2013

- Dissipation model:

$$e_q = \frac{q\overline{q'^2}}{L}$$

q	U^* at 10m
L	10 m

- Observation is calculated by second-order structure function

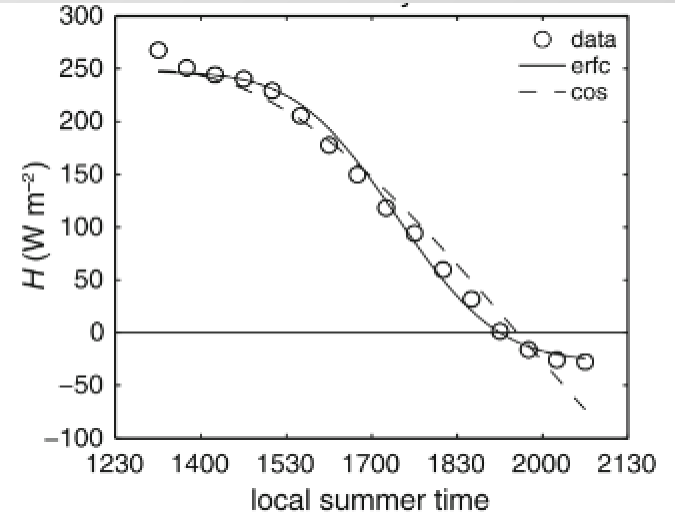
5. PRELIMINARY RESULTS

Model the $\overline{q'^2}$ budget during late-afternoon transition period

$$\frac{\partial \overline{\theta'^2}}{\partial t} = -2\overline{w'\theta'}\frac{\partial \Theta}{\partial z} - 2\varepsilon_\theta$$

Vertical heat flux:
- Erfc function
- Cosine function

(Nadeau et al. BLM 2011)



Nadeau et al., BLM, 2011

Vertical temperature gradient:
- $\frac{\partial \Theta}{\partial z} \sim \frac{\sqrt{\overline{\theta'^2}}}{\Lambda}$
- $\frac{\partial \Theta}{\partial z} \sim \frac{T^*}{\Lambda} \sim \frac{-\overline{w'\theta'}}{u^*\Lambda}$

6. FUTURE PLAN

- Model the vertical mean potential temperature gradient as a function of time during the transition periods
- Validate dissipation rates by hot-wire data
- Solve the simplified potential temperature variance budget equation numerically
- Evaluate the new model and compare it with the existing ones (e.g. Monin-Obukhov Similarity Theory)

7. OUTLOOK - FOG STUDY

- Task
  - To conduct a case study of turbulence effects on fog processes in a small high-altitude valley

- Objectives
  - To better understand the role of turbulent mixing on fog events under different conditions
  - To improve the parameterizations of numerical weather forecasting models for fog

- Future work
  - Thoroughly analyze the entire fog processes
    1. To determine the fog formation by looking at the visibility and downwelling longwave radiative flux (DWLW)
    2. To describe the fog developing processes by the vertical atmospheric profiles (i.e. from tethered balloon)
    3. To discuss the decay of fog as functions of solar radiation, turbulent mixing, moisture, etc.
  - Study the mechanisms of fog formation under light stable boundary condition

Thank you!