Variational Assimilation of Specific Humidity and Air Temperature and the Estimation of Turbulent Heat Fluxes

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Introduction

- The heat fluxes between the land surface and overlying atmosphere strongly influence the characteristics of the planetary boundary layer, playing a significant role in the land-atmosphere interaction.
- Previous Variational Data Assimilation (VDA) methods assimilated land surface temperature (LST) into the heat diffusion equation and ignored the implicit information in micrometeorological data. This can yield errors in turbulent fluxes estimates, specifically if they are controlled by atmospheric conditions rather than the land surface properties.
- In this study, screen-level air temperature and specific humidity measurements were assimilated into a coupled land surface-atmospheric boundary layer (ABL) model within a VDA framework.
- The two main unknown parameters of the VDA are the neutral bulk heat transfer coefficient (C_{HN}) and evaporative fraction (*EF*).
- C_{HN} scales the sum of turbulent heat fluxes and EF scales their partitioning.
- The new model takes advantage of information in the sequences of reference-level air temperature and specific humidity to partition available energy between the turbulent heat fluxes by estimating C_{HN} and *EF*.
- The new approach is tested over the Cabauw site in the west of the Netherlands where surface heat fluxes and meteorological data are available.

Atmospheric Boundary Layer (ABL) Model and surface Heat Fluxes

The potential temperature and moisture in the mixed layer are described by,

$$\rho c_p h \frac{d\theta}{dt} = \left[R_{ad} + R_{gu} + (R_{ad}(1-\epsilon_a) + R_{Ad})(1-\epsilon_s)\right]\epsilon_a - R_{Ad} - R_{Au} + H - H_{top}$$

$$\rho h \frac{dq}{dt} = E - E_{top}$$

The sensible heat flux is given by,

$$H = \rho c_p C_{HN} f(Ri) U (T - T_a)$$

EF is defined as the ratio of latent heat flux to the sum of turbulent heat fluxes,

$$EF = \frac{LE}{LE + H} \longrightarrow LE = \frac{EF}{1 - EF} H$$

The daytime growth of the ABL height is given by,

$$\frac{dh}{dt} = \frac{2\theta G_* e^{-\varepsilon h}}{g h \delta_\theta} + 0.4 \frac{H_v}{\rho c_p \delta_\theta}$$

ABL Profile

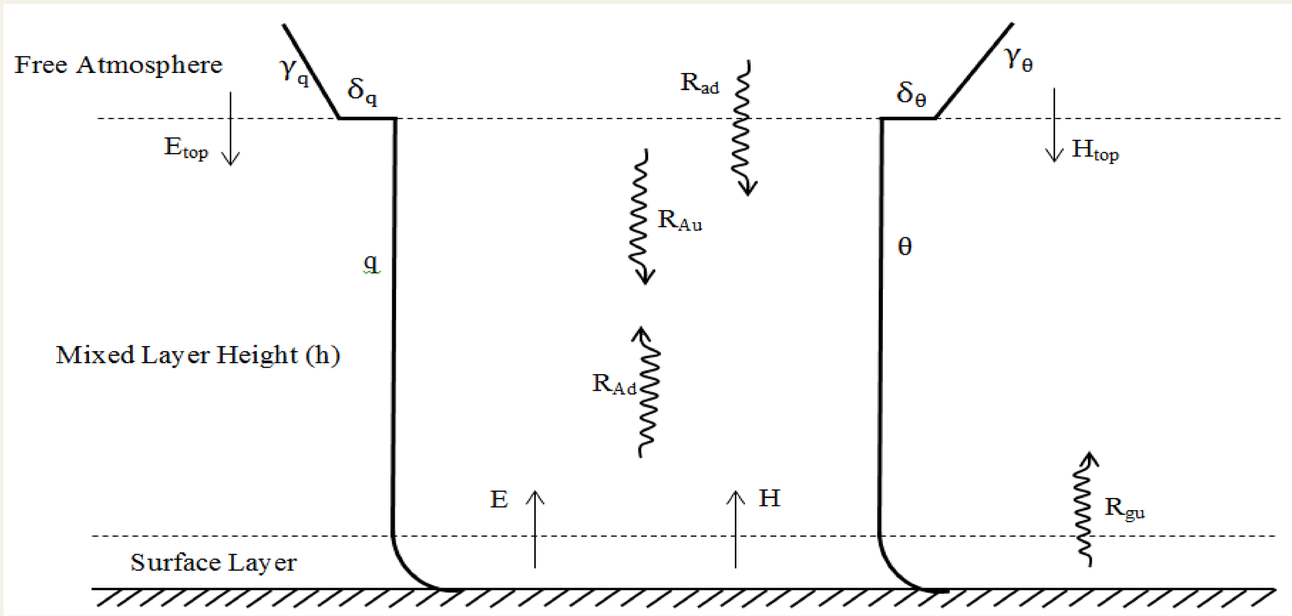

Figure 1. Idealized profiles of ABL states and corresponding fluxes between the mixed layer and overlying atmosphere.

Variational Data Assimilation Scheme

- To minimize the cost function (J), its variation (δJ) with respect to the independent variables (i.e., θ, q, C_{HN} and EF) should be set to zero.
- The data assimilation scheme iteratively improves estimates of EF and C_{HN} starting from the initial guesses EF' and C_{HN}', and finally estimates optimum values of daily EF and monthly C_{HN}.

Cost function

$$J(\theta, q, \lambda_1, \lambda_2, C_{HN}, EF) =$$

$$K_\theta \sum_{i=1}^{N\,Days} \int_{t_o}^{t_1} (\theta_{obs}(t) - \theta_{est}(t))^2 \, dt + K_q \sum_{i=1}^{N\,Days} \int_{t_o}^{t_1} (q_{obs}(t) - q_{est}(t))^2 \, dt + C_{kk}(C_{HN} - C_{HN}')^2 + C_{\mu\mu} \sum_{i=1}^{N\,Days} (EF_i - EF_i')^2 +$$

$$\sum_{i=1}^{N\,Days} \int_{t_o}^{t_1} \lambda_{1i}(t) \left[\rho c_p h_i(t) \frac{d\theta_i(t)}{dt} - [R_{ad} + R_{gu} + (R_{ad}(1-\epsilon_a) + R_{Ad})(1-\epsilon_s)]\epsilon_a + R_{Ad} + R_{Au} - H + H_{top}\right] dt + \sum_{i=1}^{N\,Days} \int_{t_o}^{t_1} \lambda_{2i}(t) \left[\rho h_i(t) \frac{dq_i(t)}{dt} - E + E_{top}\right] dt$$

Results

Table 1. Neutral bulk heat transfer coefficient (C_{HN}) for Cabauw 2015 estimated by the VDA model.

Cabauw 2015		
Julian days	C_{HN}	*LAI*
181 - 211	0.0030	2.50
212 - 248	0.0018	2.50
249 - 278	0.0025	2.50

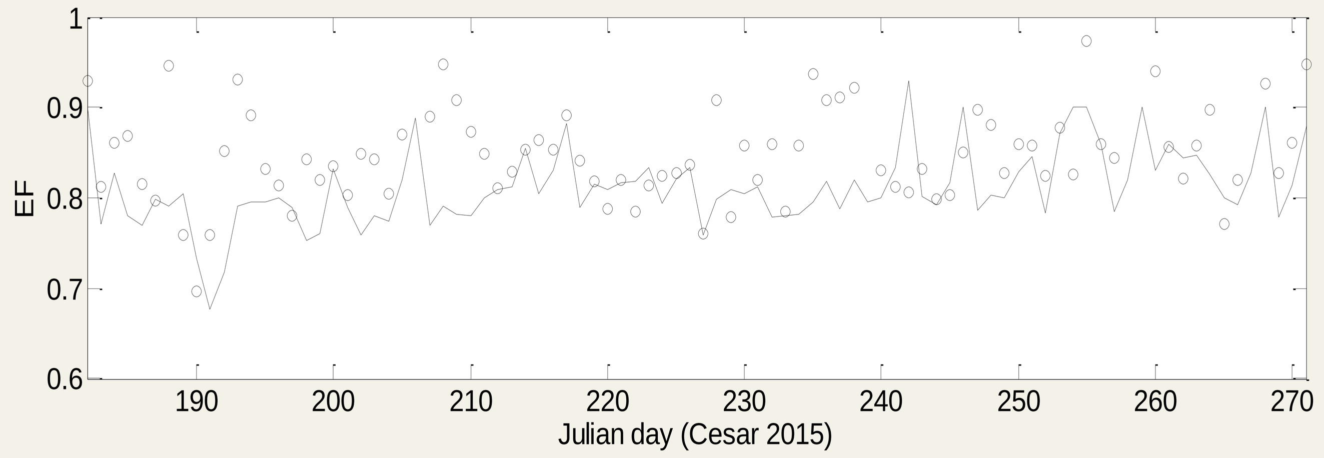

Figure 2. Time series of evaporative fraction for Cabauw 2015. [Estimated evaporative fraction from measured heat fluxes (circles), VDA model (solid lines)].

Results

Figure 3. Time series of observed daily turbulent heat fluxes (circles) and predicted values from VDA model (solid lines) sensible (top), and latent heat flux (bottom).

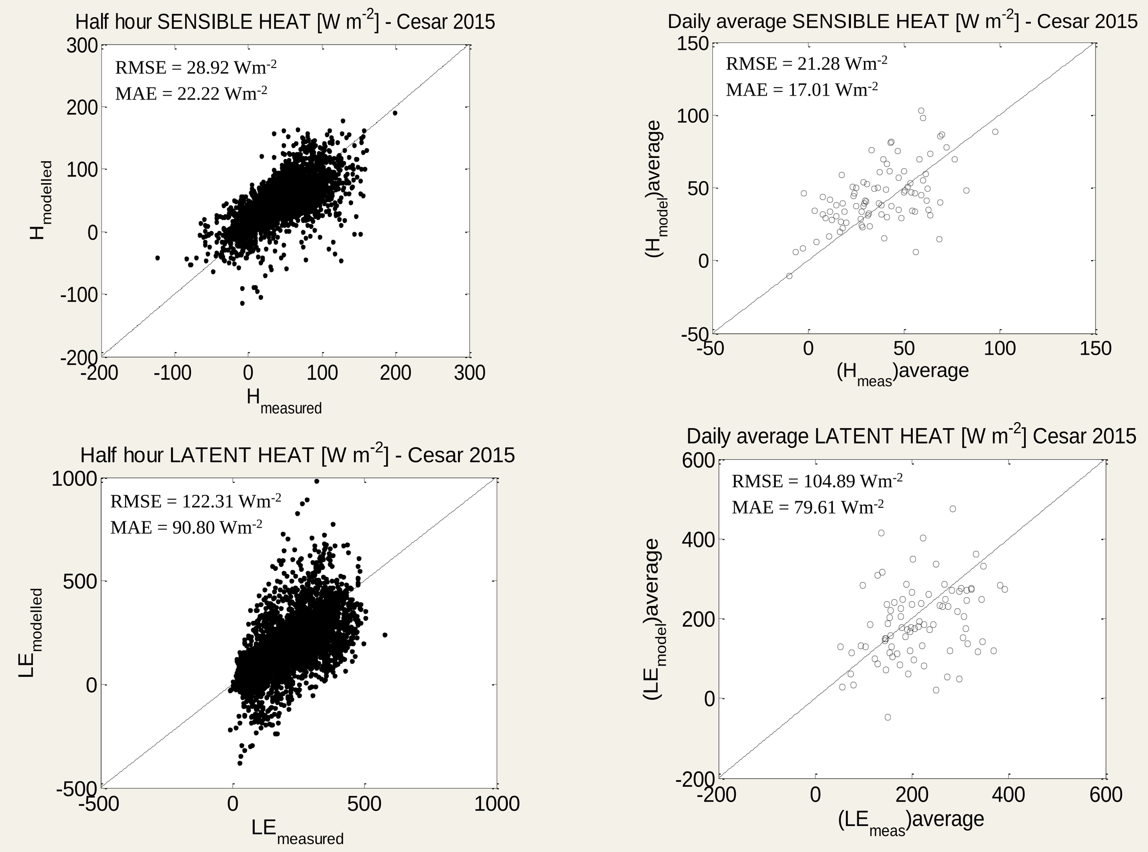

Figure 4. Scatterplot of (right) half-hourly modeled and (left) average versus measured (top) sensible and (bottom) latent heat fluxes.

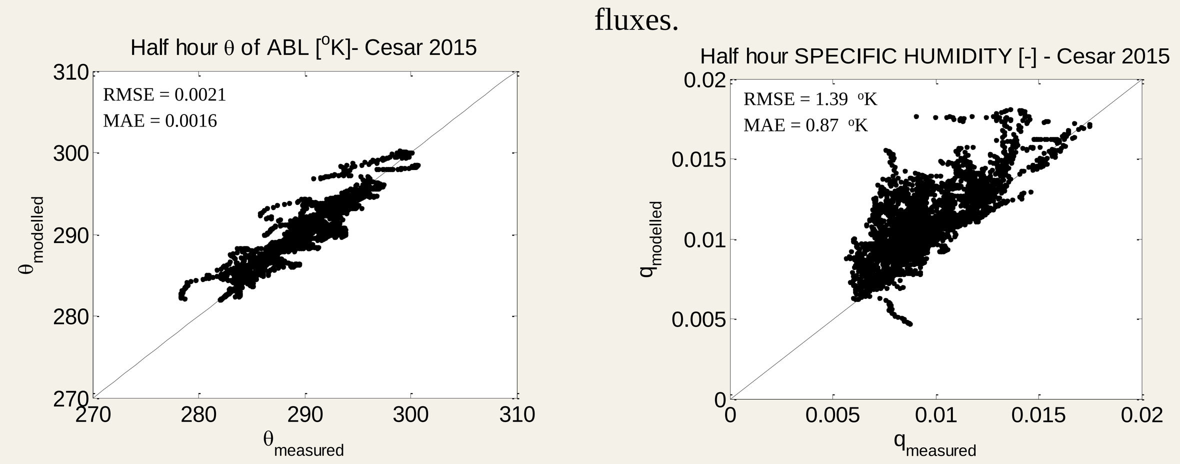

Figure 5. Scatterplot of half-hourly modeled versus measured (right) specific humidity, and (left) potential temperature.

Conclusions

- A new variational data assimilation approach is introduced to estimate surface heat fluxes by assimilating the state variables of atmosphere (i.e., air temperature and humidity).
- The changes in the estimated neutral bulk heat transfer coefficient (C_{HN}) are consistent with variations in vegetation phenology.
- The day-to-day variations in the estimated daily *EF* are incredibly consistent with observations.
- Comparing the estimated surface heat fluxes with measurements over the Cabauw site shows that new VDA model can partition the existing energy among the turbulent heat fluxes reasonably well and is able to efficiently capture their temporal variability.

References

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- Gentine, P., Chhang, A., Rigden, A., and Salvucci, G. (2016). Evaporation estimates using weather station data and boundary layer theory. Geophysical Research Letters, 43, doi: 10.1002/2016GL070819.