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Near-surface radiative and turbulent heat exchange processes observed during coastal fog events

Sebastian W. Hoch, Fabien M. Margairaz, and Eric R. Pardyjak
University of Utah, Salt Lake City, UT

Introduction

On of the goals of the CFOG field campaign conducted between August and October 2018 in Newfoundland, Canada, was to measure the vertical distribution of the terms of the temperature tendency equations (Fig 1) – or, in other words - evaluating the role of different cooling contributions during the life cycle of coastal fog.

$$\underbrace{\frac{\partial\bar\theta}{\partial t}}_{I}+\underbrace{\bar{u}_i\frac{\partial\bar\theta}{\partial x_i}}_{II}+\underbrace{\frac{\partial\overline{u_i'\theta'}}{\partial x_i}}_{III}=\underbrace{\alpha\frac{\partial^2\bar\theta}{\partial x_i^2}}_{IV}-\underbrace{\frac{1}{\rho c_p}\frac{\partial \bar R_{ni}}{\partial x_i}}_{V}-\underbrace{\frac{L_v}{c_p}\frac{\partial\overline{u_i'q'}}{\partial x_i}}_{VI}$$

Fig 1: Temperature tendency equation.

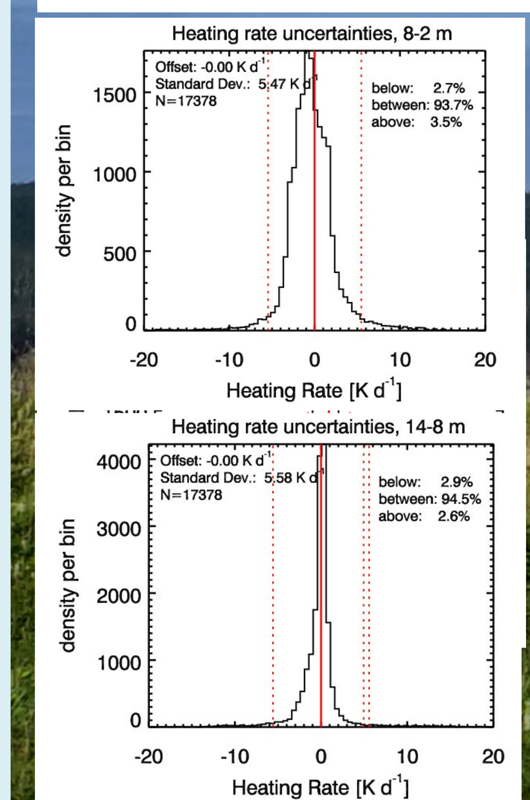
At the Ferryland "Battery" site (Fig 2), observations of radiative (longwave), sensible, and latent heat fluxes were taken at different heights of a 15-m meteorological tower (background Figure). These measurements allowed a direct evaluation of the divergence (cooling) or convergence (heating) of these fluxes.

Fig 2.: The Ferryland study area during CFOG (Google Earth).

Fig 3.: Relative calibration of pyrgeometers.

Relative calibration

Kipp and Zonen CGR4 pyrgeometers were carefully calibrated at the CFOG field site prior to deployment on the meteorological mast. The relative calibration (Fig. 3) involves a regression allowing the calibration coefficient of the instruments and the thermistor coefficients to vary within their uncertainty ranges. The uncertainties (STDEV) in the radiative heating rates determined for the bulk layer between the two measurement levels were below 6 K day^{-1} or 0.25 K hr^{-1}.



Here, we evaluate the contributions of radiative (RFD), sensible (SHDF), and latent heat flux divergence (LHFD) during a clear (23 October 2018) and a foggy (29 October 2018) day.

Fig 4 a

Fig 4 b

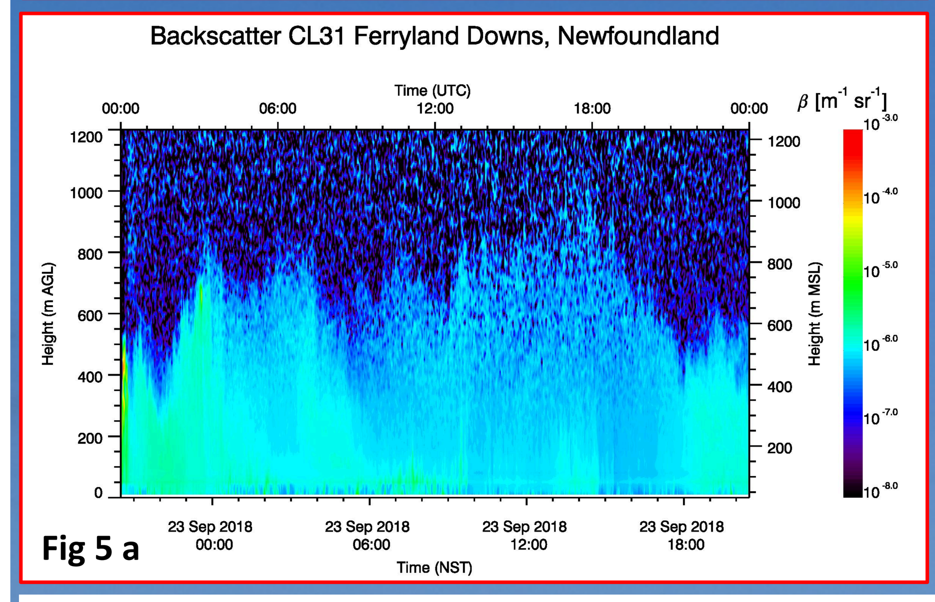


Fig 5 a

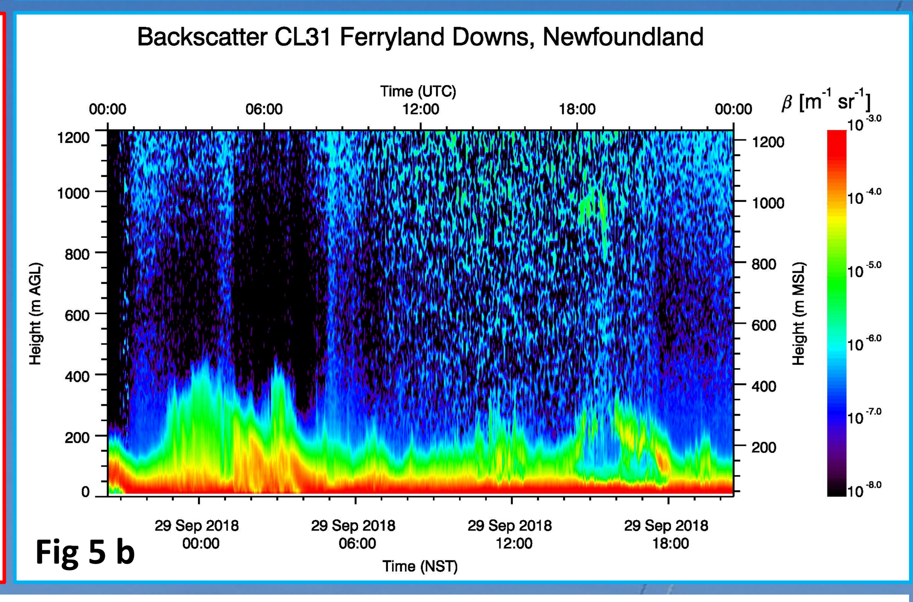


Fig 5 b

Representative webcam photos (Fig 4) and the time-height cross sections of backscatter from a ceilometer (Fig 5) illustrate the conditions. Time series from different height of the 15-m meteorological tower of radiative short and longwave fluxes, turbulent sensible (H) and latent (L) fluxes, temperature and humidity, wind speed and direction, turbulence kinetic energy (TKE), and visibility show the detailed evolution of the two example days in Figs 6 and 7. Fig 8 and 9 show the time series of heating rates due to radiative (RFD) sensible (SHFD) and latent (LHFD) heat flux divergence. Figures 10 and 11 show selected vertical profiles of these heating rates and their relation to the wind direction and TKE profiles.

Fig 6:

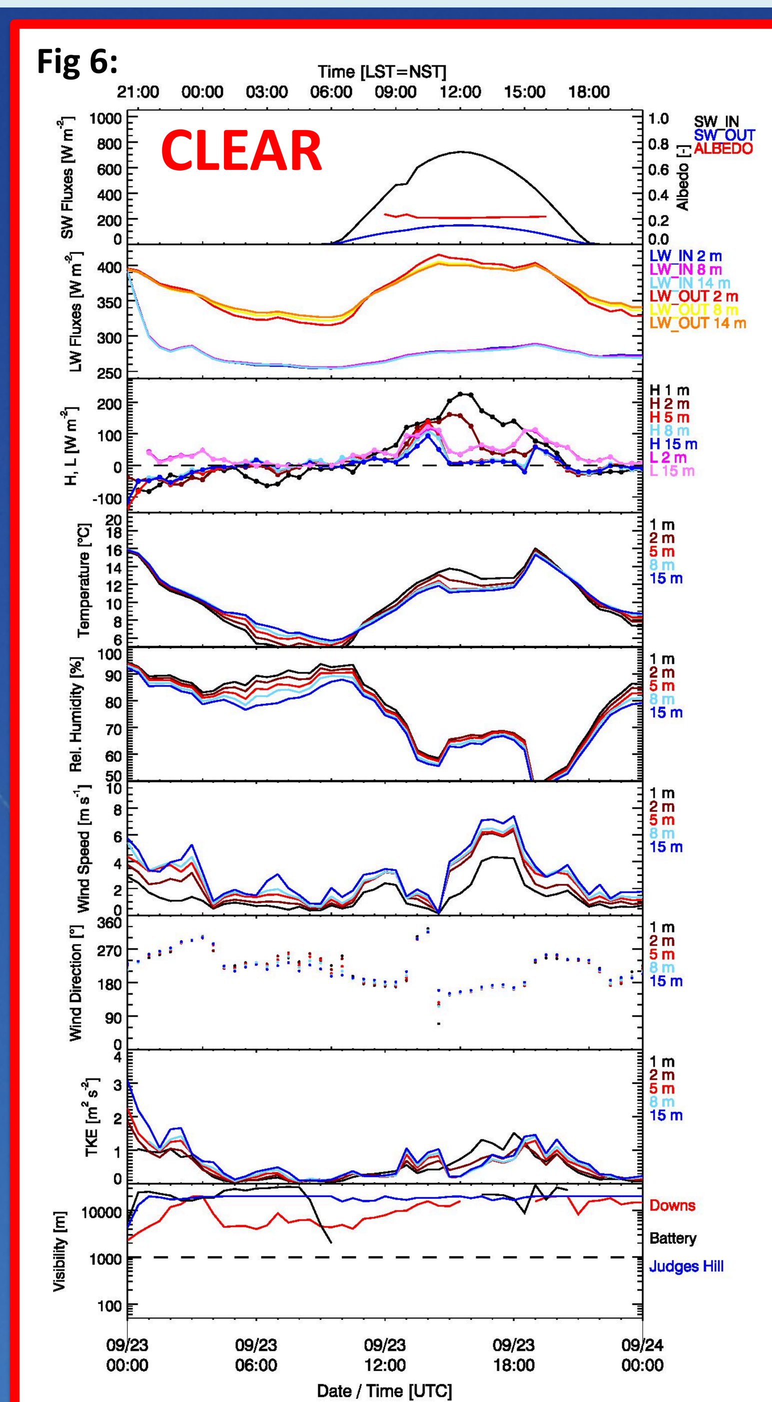


Fig 8:

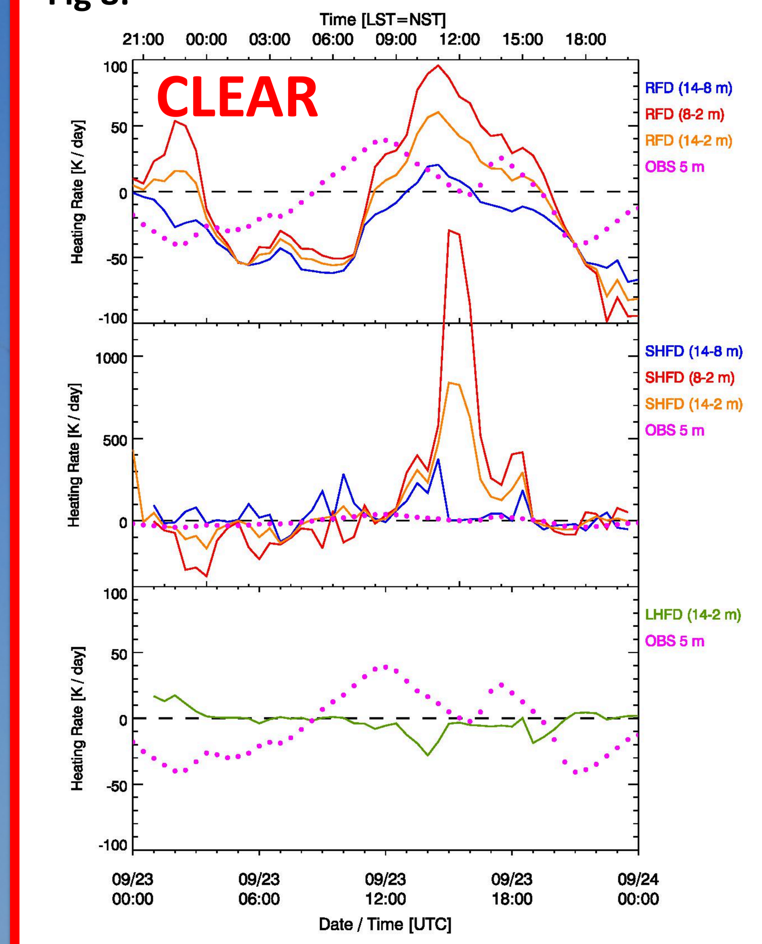


Fig 7:

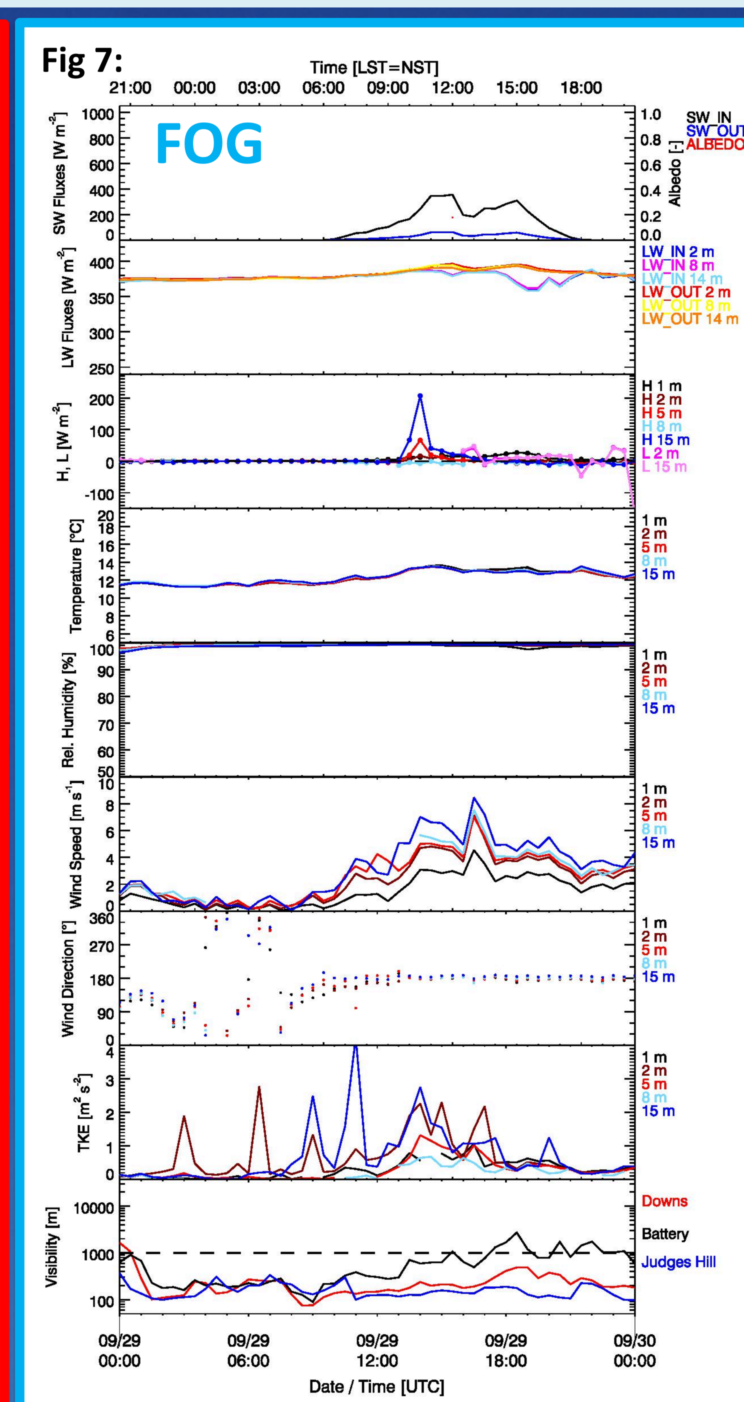


Fig 9:

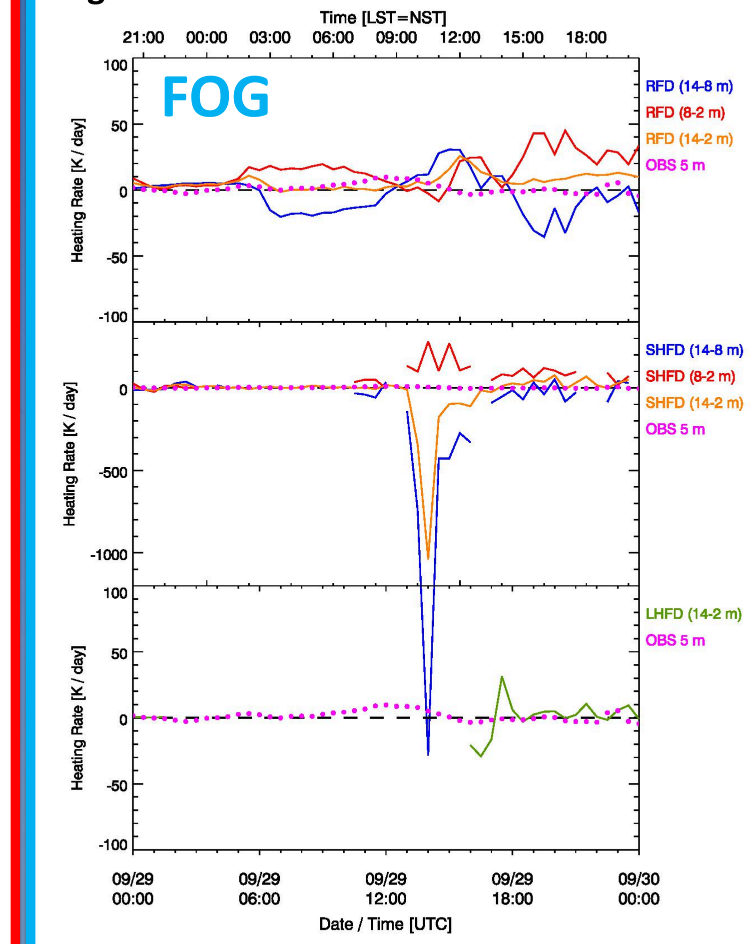


Fig 10:

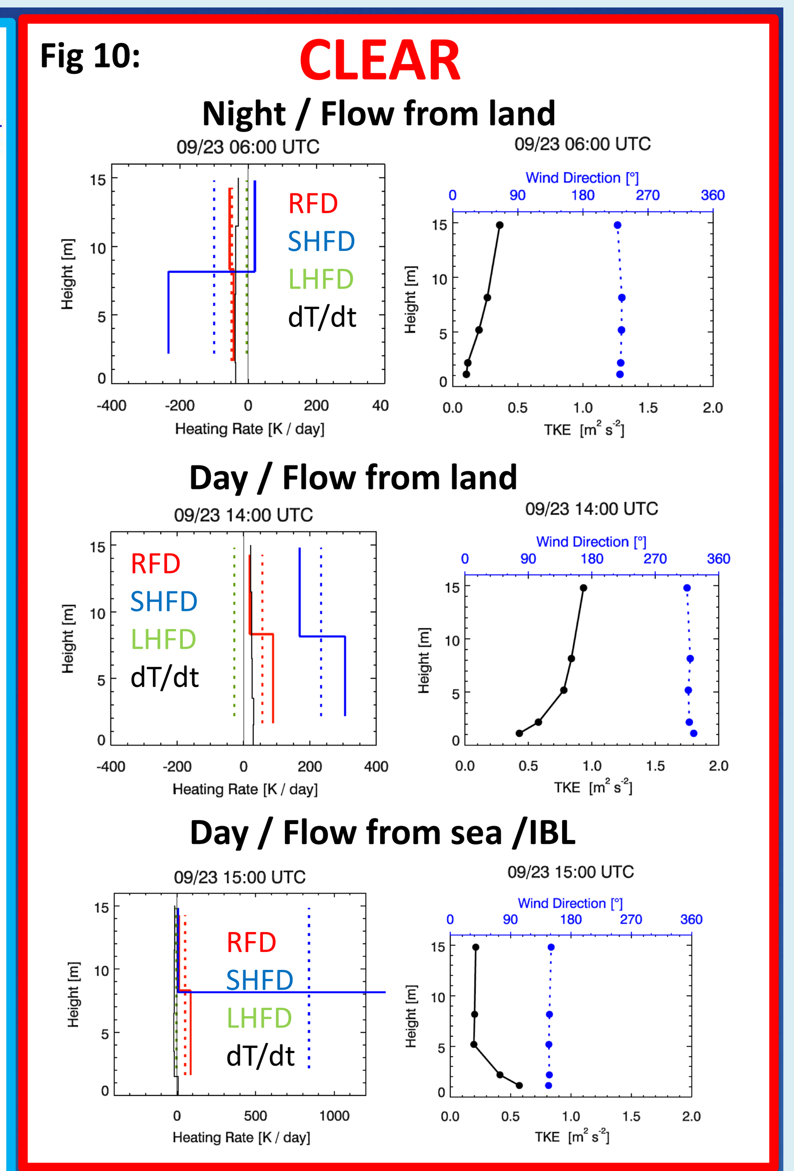
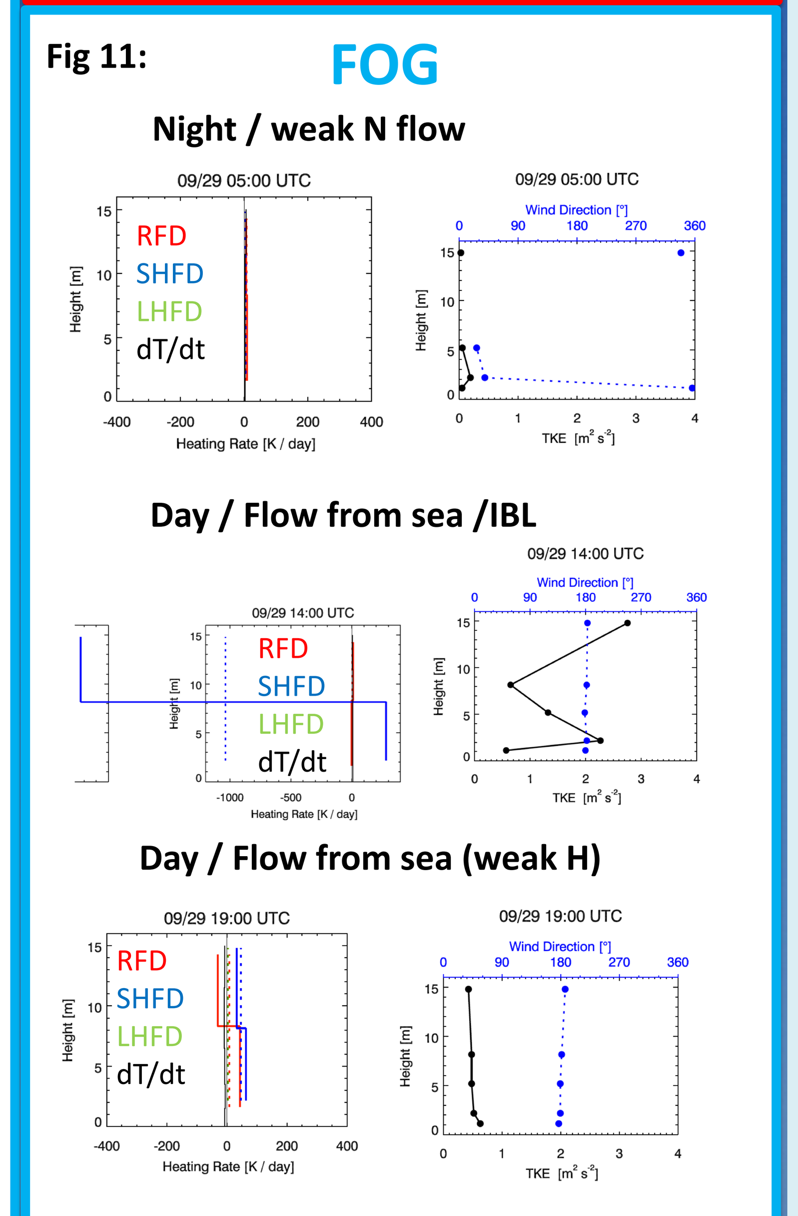


Fig 11:



Key findings: (NEEDS WORK)

- The development of internal boundary layers plays in important role and can triggers very large SHFD values of both signs.
- Advection is important !
- Latent heat flux divergence contribution is small but measurable during clear skies.
- TKE profiles can change with wind direction.

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