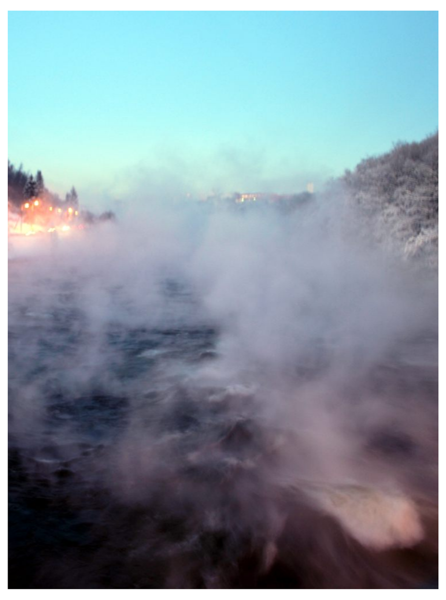
Stochastic Parametrisation of Fluxes in Cold-Air Outbreaks

Jan Chylík, J.Chylik@uea.ac.uk, Ian Renfrew, I.Renfrew@uea.ac.uk, — School of Environmental Sciences, University of East Anglia

Introduction

Unstable conditions in cold air outbreaks facilitate transport of heat and momentum [1]. High surface fluxes of heat and moisture lead to strong turbulent flows that supplement fluxes of sensible heat, latent heat and momentum higher into atmosphere, affecting the development of mesoscale and synoptic-scale weather systems.



Despite increasing complexity of NWP models, the majority of them have occasionally failed to predict serious weather events coming just in a few days. Recently popular approach has been to use ensemble forecasts, however on long runs their spread does not fit the reality.
In NWP models, parametrisations of the subgrid fluxes and variance does not capture effect of many convective-scale phenomena. One possible approach is deliberate introduction of uncertainty.[2]

Stochastic Approach

The atmosphere could be viewed as an infinite-dimension dynamical system. Using Palmer's notation [3], evolution of this system $\{\tilde{X}(t)\}_t$ is schematically described as

$$\dot{\tilde{X}} = \tilde{\mathbf{F}}[\tilde{X}], \qquad (1)$$

For the purpose of numerical weather prediction (NWP), Galerkin decomposition on a finite-dimension dynamical system described as

$$\dot{\mathbf{X}} = \mathbf{F}[\mathbf{X}] + \mathbf{P}[\mathbf{X}; \alpha], \qquad (2)$$

is performed, where parametrisation $\mathbf{P}$ represents the effect of truncated scales.

Instead of assigning each gridpoint j a constant function as in local enclosure methods, we model it as a Markov Chain,

$$(\mathbf{P}_j(t_{i+1}) - \mathbf{P}_j(t_i)) \mid \mathbf{P}_j(t_i) \sim Pr_{\mathbf{P}}, \qquad (3)$$

where Pr_P is a transitional probability.
Currently there are two main stochastic schemes used in mid-range forecasts

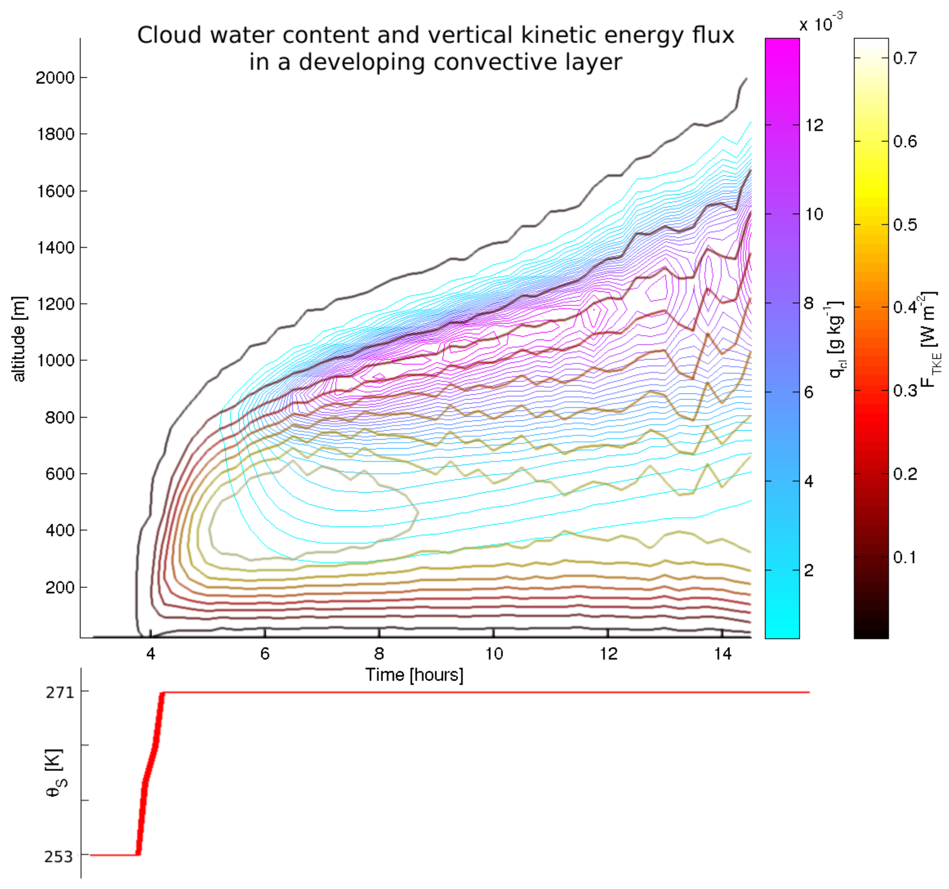
- the Stochastically Perturbed Parameterization Tendencies scheme (SPPT).[4]
- the Stochastic Kinetic Energy Backscatter scheme (SKEB).[5]

In this project, distribution of the probability is approximated by employing both the theory and fine large eddy simulations.

Large Eddy Model

Turbulent boundary layer can be numerically modelled in large eddy simulations such as Met Office *Large Eddy Model* (LEM). Simulations are run in small domains on fine resolution grids.

The run starts with a strongly stratified troposphere, where turbulent motion is initiated by a small horizontal velocity perturbations in lower model levels. Constant large scale forcing is applied and the model is advected over a warming sea-ice marginal zone. A shallow convective boundary layer soon forms and continues to grow.



Due to a relatively sparse system of AWS and often changing nature of sea ice, some properties of environment are relatively hard to determine in operational NWP forecasts.

- the surface roughness,
- the spatial heterogeneity in surface temperature,
- initial temperature profile in the atmospheric boundary layer.

With a goal to evaluate the impact of this variability on resulting development of the large scale weather, we have run few sets of simulations that differed in one of these parameters.

Model outputs were first qualitatively classified and then impact of boundary layer processes was assessed.

References

[1] Petersen, G. N. ; Renfrew, I. A.: *Aircraft-based observations of air–sea fluxes over Denmark Strait and the Irminger Sea during high wind speed conditions*, Quarterly Journal of the Royal Meteorological Society, 2009, **135**, pp.2030-2045

[2] Palmer, T.N., GJ Shutts, R Hagedorn, FJ Doblas-Reyes, T Jung and M. Leutbecher, 2005: *Representing model uncertainty in weather and climate prediction*, Annual Rev. Earth Planet. Sci, **33**, 163-93.

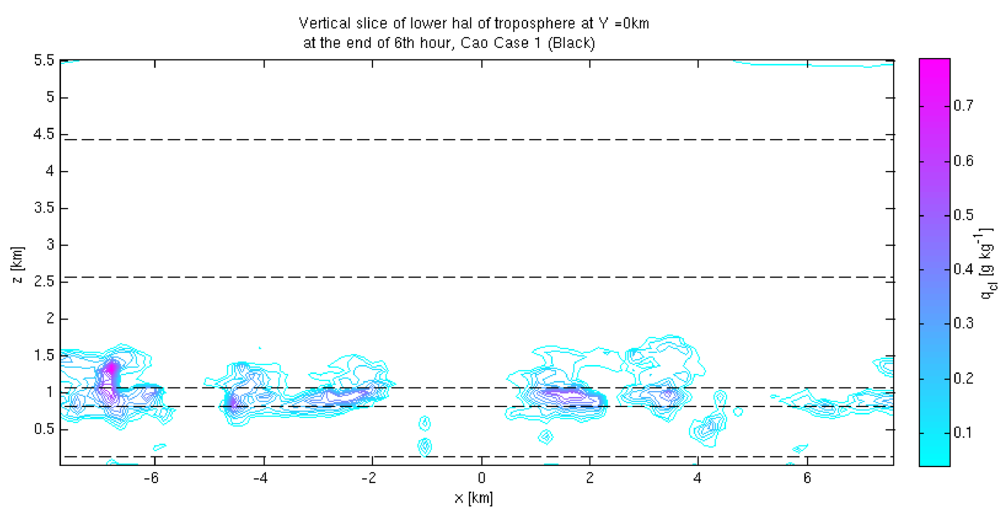
[3] Palmer, T. N. (2001), *A nonlinear dynamical perspective on model error: A proposal for non-local stochastic-dynamic parametrization in weather and climate prediction models*. Q.J.R. Meteorol. Soc., 127: pp. 279–304. Majda A. J., M. Branicki, Y. Frenkel *Improving Complex Models Through Stochastic Parameterization and Information Theory*, ECMWF-WCRP, Thorpex Workshop on Model Uncertainty, 2011

[4] Buizza, R., Milleer, M. and Palmer, T. N., (1999): *Stochastic representation of model uncertainties in the ECMWF ensemble prediction system*, Q.J.R. Meteorol. Soc., 125: 2887–2908. doi: 10.1002/qj.4971255600
239-252

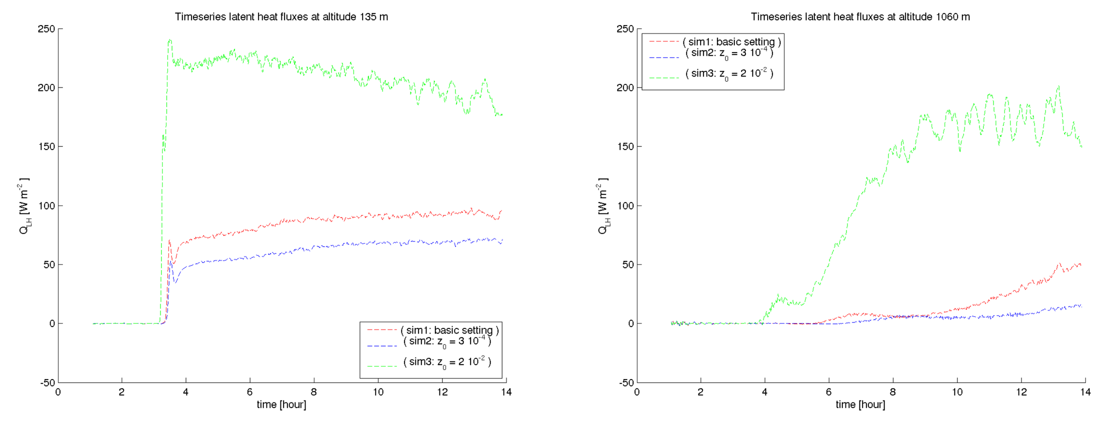
[5] Berner, J ; Shutts, GJ ; Leutbecher, M ; Palmer, TN (2009): *A Spectral Stochastic Kinetic Energy Backscatter Scheme and Its Impact on Flow-Dependent Predictability in the ECMWF Ensemble Prediction System*. Journal Of The Atmospheric Sciences, 2009, Vol.66(3), pp.603-626

Approximated Flux Distributions

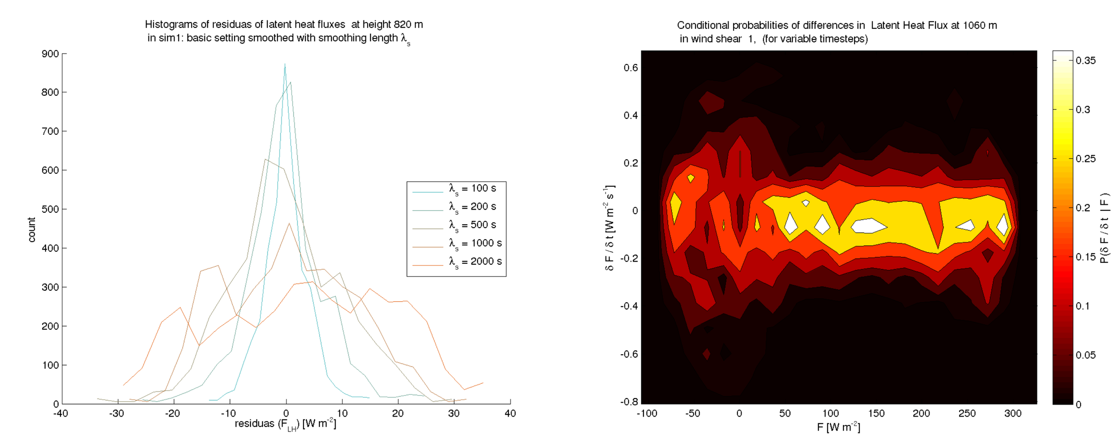
Vertical fluxes of the latent heat, the sensible heat and momentum are recorded at model levels chosen with respect to phenomena observed at these altitudes in field missions.



Recorded timeseries of fluxes are compared in each set of model runs.
A strong variability in resulting fluxes are observed in model runs with a differences in the surface roughness.

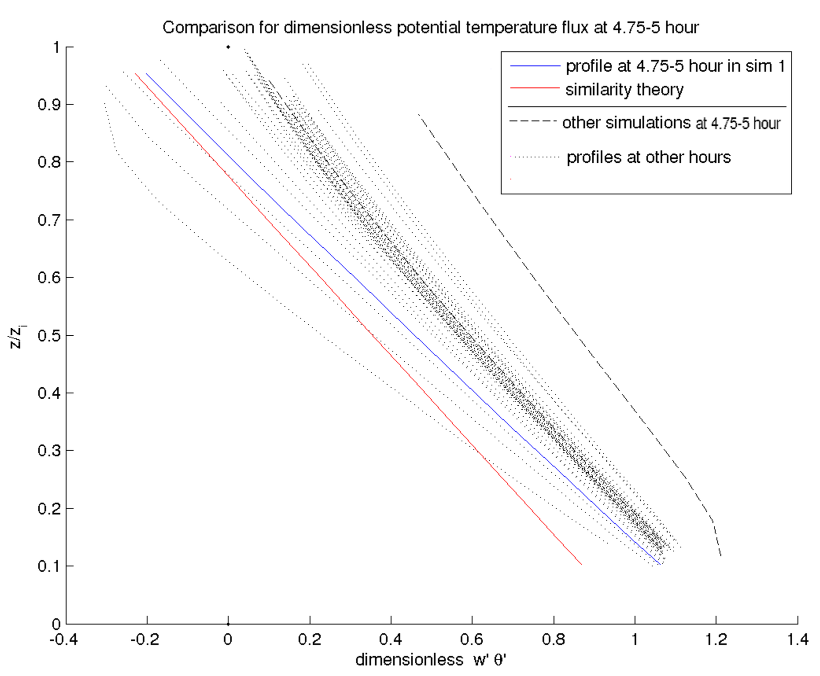


While timeseries show development of the vertical fluxes in detail, we can evaluate as well the temporal variability in measurement. Applying smoothing or sampling, residua are further analysed and their statistical distribution is estimated.



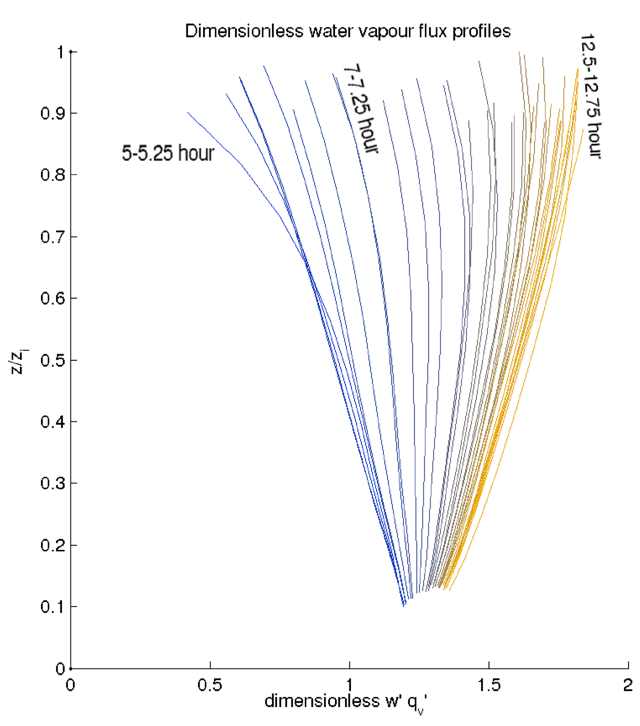
Output to Parametrisation Schemes

Profiles and series of fluxes are rendered dimensionless and compared against currently used parametrisations.
While similarity theory serves as a general approximation of the properties of the boundary layer, we continued with our analysis there before focusing on more advanced parametrisation techniques.



In a developing convective layer, the potential temperature flux mostly shows a higher values at the lower part of the boundary layer, followed generally by a steeper decline than what is suggested by similarity theory.

Profiles of water vapour flux are mostly linear, with positive incline later during the model development. This is likely related to active venting by cumulus cloud layer above and is suspected to further contribute to high spread of resulting fluxes at the top of the boundary layer.



Acknowledgements

Thanks to:

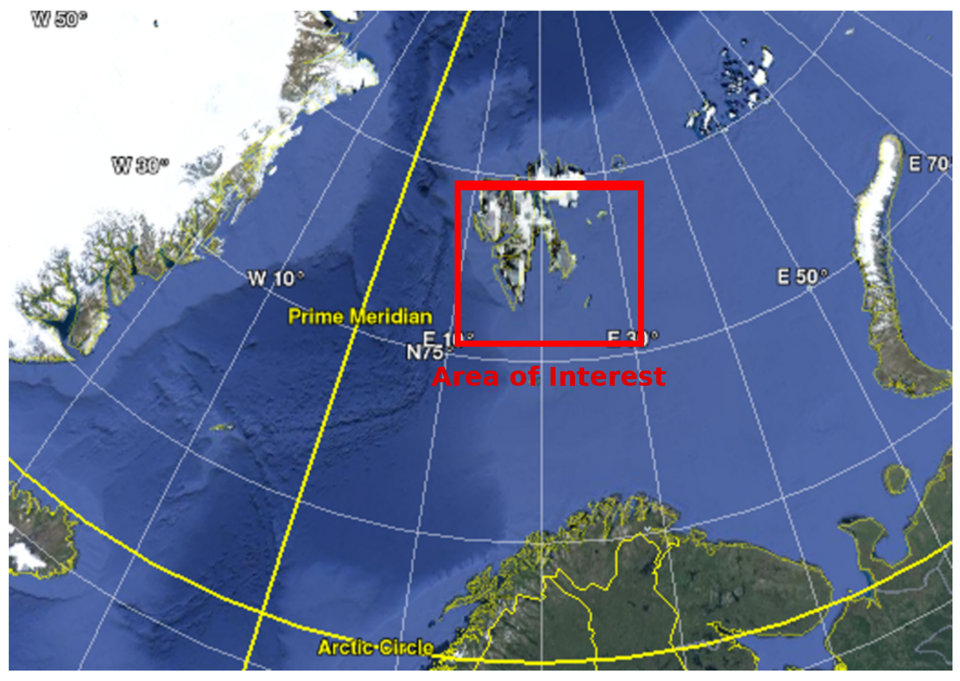
- Dr. Glenn Shutts (Met Office)
- Dr. Stefano Migliorini (ECMWF, University of Reading)

This project has been funded by **NCAS**.

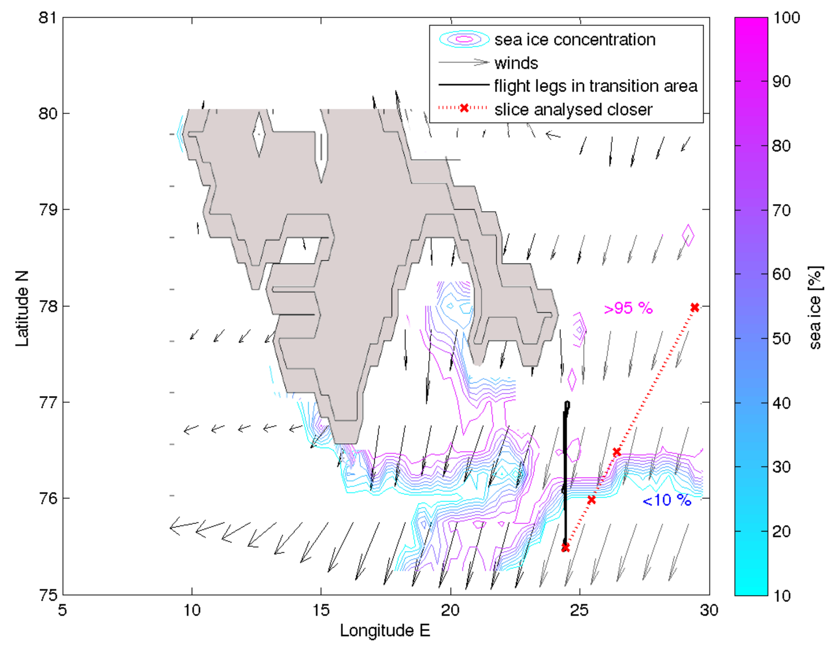
National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL
UEA University of East Anglia
COAS Centre for Ocean and Atmospheric Sciences

Data from ACCACIA flight B760

Cold-air outbreak on 21 March 2013 over marginal sea-ice zone east of Svalbard was closely observed by ACCACIA airborne mission B760 of FAAM.



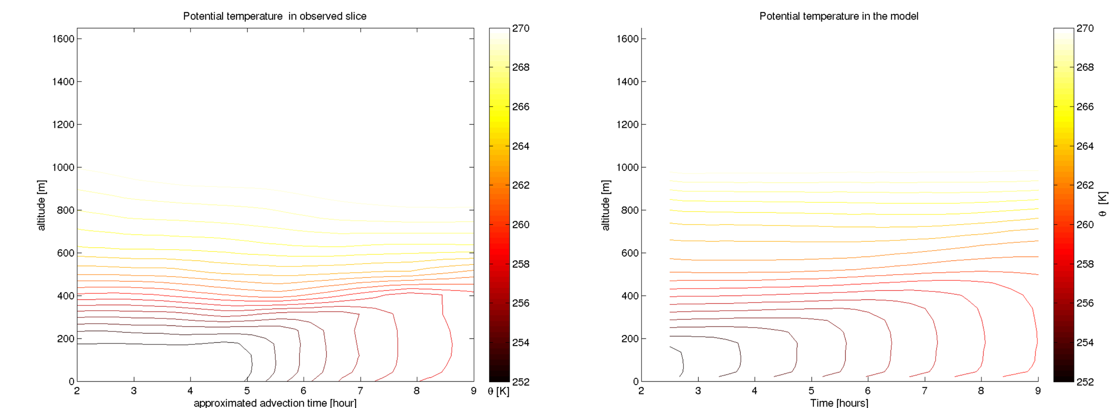
Transition from strongly stratified boundary layer do shallow convective layer was observed.



ECMWF global forecast served for initialisation of model runs and adding large scale forcing.

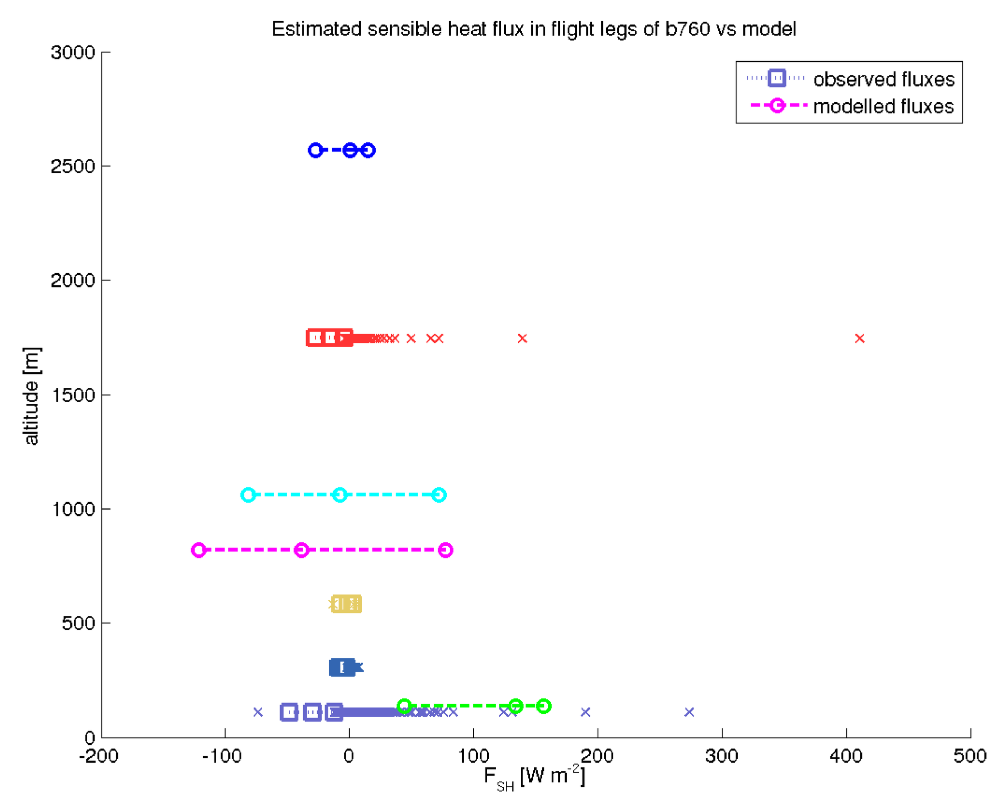
Case Simulation

Model shows a formation of a shallow convective layer capped with clouds in the initial hours of transition.
Early development of the convective boundary layer is generally more abrupt than in the ECMWF forecast.



Modelled fluxes of the sensible heat show a fair correspondence to processed turbulent measurements from the aircraft.

In general, the flux measurements in flight legs show less variability than in the model runs, however there are also number of positive outliers for some of the legs. That might amongst other indicate bias in observational data due to specific choice of the flight trajectory.



Conclusions and Further Aims

- Analysis of LEM model runs indicate that variability surface roughness and heterogeneity in surface temperature can have significant impact on resulting amount of heat and moisture transported higher into troposphere.

- ECMWF IFS parametrisation might be biased in the initial stages of development of convective boundary layers.

And some of the further aim follows

- More simulations based on observed Cold Outbreak cases. Comparison of fluxes in measurements and simulations.
- Fine simulations in LEM of cold outbreak case with a variability in surface roughness Aiming to estimate probability of resulting fluxes.
- Proposing stochastic parametrisation of fluxes for other parametrisations and stochastic schemes.
  - Fitting probability distributions in a parametric form.
  - Implementation of stochastic parametrisation in *ECMWF IFS* and Met Office *Unified Model* .