Stochastic Parametrisation of Fluxes in Cold-Air Outbreaks

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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 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 severe weather events coming just a few days. Recently, popular approach has been to use ensemble forecasts, however on long rates 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.

Stochastic Approach

The atmosphere could be viewed as an infinite-dimension dynamical system. Using Palter’s notation [3], evolution of this system $X(t)$, is schematically described as

\[ \dot{X} = F(X) \]  

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

\[ \dot{X} = F(X) + P(X) \xi(t) \]

is performed, where parametrisation $P$ represents the effect of truncated scales. Instead of assigning such gridpoint $i$ a constant function as in local closure methods, we model it as a Markov Chain, $P(X(t), i) = \tilde{P}_{ij}$, where $\tilde{P}_{ij}$ is a transitional probability.

Currently there are two main stochastic schemes used in mid-range forecasts

- 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 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.

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References

[4] The Stochastically Perturbed Parameterization Tendencies scheme (SPPt) has been developed by NCAS, with the help of I. Renfrew. The work was carried out as part of the Monsoon Microphysics project (MON) (EC4-CT2004-005476).
[5] The Stochastic Kinetic Energy Backscatter scheme (SKEB) has been developed by NCAS and A. Sutcliffe as part of the ACCACIA project (EC4-CT2004-005299). This work was supported by the European Union’s Seventh Framework Program (FP7/2007-2013) under grant agreement no. 212078.

Approximated Flux Distributions

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

While timeseries show development of the vertical fluxes in detail, we can evaluate as well the temporal variability in measurement. Applying smoothing or sampling, residuals 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.

Data from ACCACIA flight B50

Cold-air outbreak on 20 March 2013 over marginal sea-ice zone east of Svalbard was closely observed by ACCACIA airborne mission B50 at FAAM.

Vertical timeseries of fluxes are compared in each set of runs.

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

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.
- Some of the further aims 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.

Appendix:

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Implementing stochastic parametrisation in LEM would be an important step towards more realistic simulations of cold-air outbreaks.

Conclusion

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