LES subgrid modelling using neural networks

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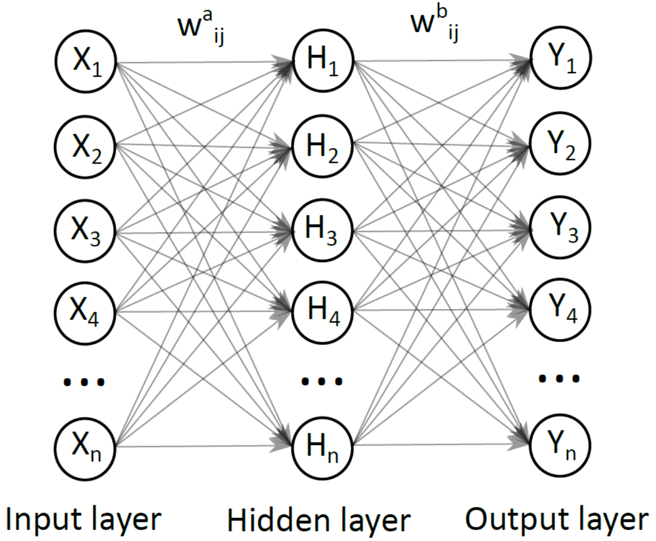
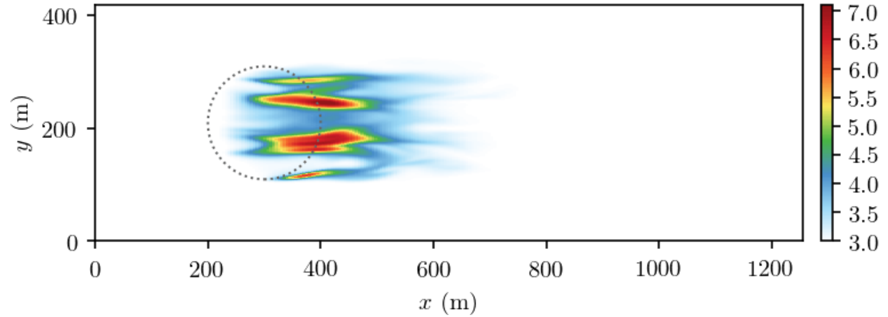


EGU general assembly, 6th May 2020

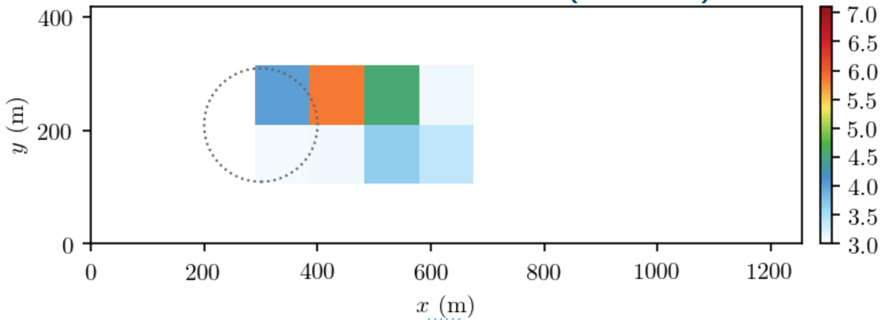
Large eddy simulation (LES) misses many details of small-scale turbulent transport: example of simulated moisture content (g/kg) with horizontal advection over circular irrigated field in desert

Computationally expensive high-resolution direct numerical simulation (DNS)



g/kg

Lower-resolution LES (~100m)



g/kg

Picture: George Steinmetz, 2016

Subgrid models required to account for the net effects of small-scale turbulent motions on the resolved flow

Problem:
Traditional LES subgrid models (e.g Smagorinsky) need strong assumptions about their functional form that are hard to meet in practice

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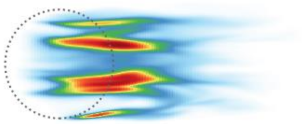
Research question: Can traditional LES subgrid models be replaced with neural networks learning from high-resolution DNS simulations for a turbulent channel flow test case?

Input

Large eddy simulation (LES)
(~100m)

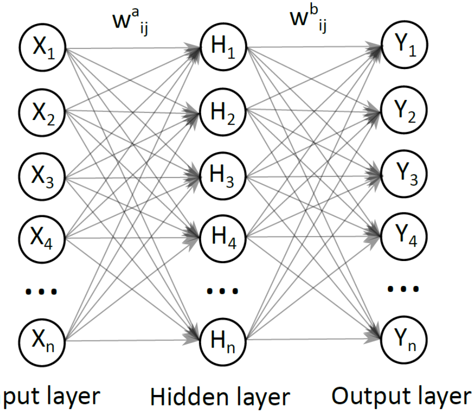
Training

Direct numerical simulation (DNS)



Output

Unresolved
Turbulent transport
momentum



During training, corresponding input-output pairs are generated from DNS that serve as the ground truth

The neural networks are very flexible regarding their functional form and require few assumptions

After training, the neural network predict the unresolved transport based only on the *locally* resolved flow fields

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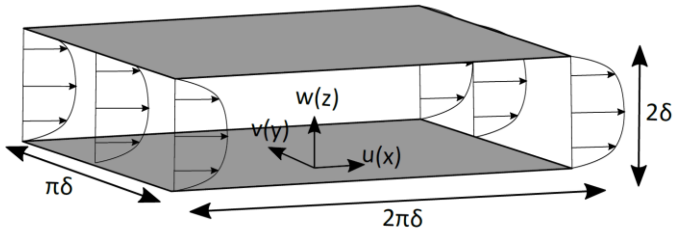
Test case: turbulent channel flow simulated with CFD-code MicroHH

- Turbulent channel flow (Moser et al., 1999):
  - Horizontal flow bounded by walls
  - No temperature/humidity effects
  - Represents simplified neutral atmospheric boundary layer
  - Friction Reynolds number: 590

Vertical cross-section turbulent channel flow



- MicroHH: an open-source flow simulation model for the near-surface atmosphere (Van Heerwaarden et al., 2017)
  - Is able to run both on high- (DNS) and lower-resolutions (LES)

LES subgrid model validation: *a priori* and *a posteriori* testing

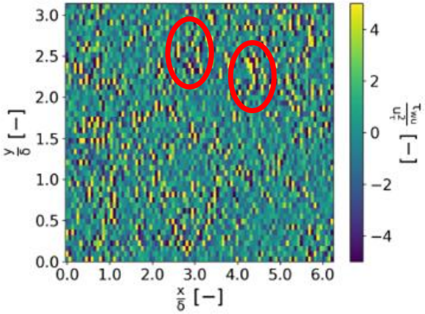
- A priori testing (offline):
  - Assesses whether NN produces **accurate subgrid transports**
  - In general good agreement (see next slide)
- A posteriori testing (online):
  - Assesses whether NN improves **accuracy of the simulation as a whole**

→ NN makes simulations numerically unstable after a few time steps, with continuous increase in TKE

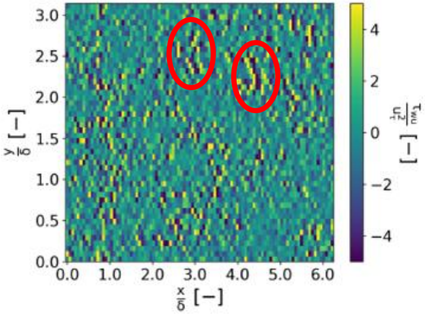
→ Our current hypotheses:

1. The NN ends up in a positive feedback loop because of its own errors, causing divergence
2. The NN is under-dissipative

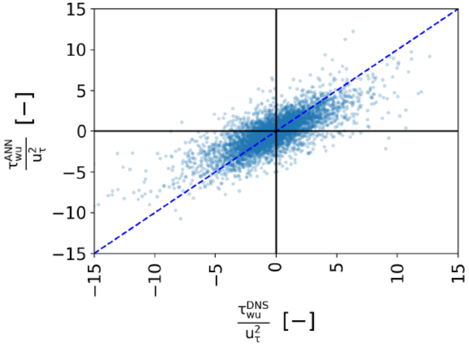
a priori test example: good agreement between NN-predicted and DNS-derived subgrid vertical transport (τ_{wu}) in log-layer ($z^+ = 55.3$) for validation set

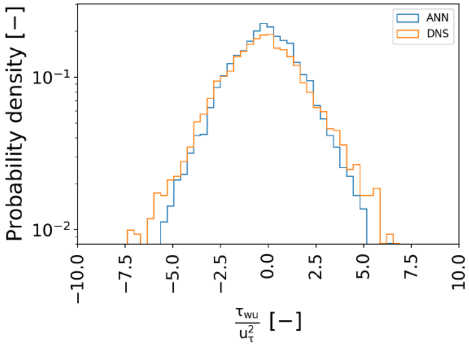


a) DNS



b) NN ($n_{hidden} = 512$)





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