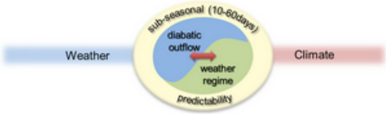
Young Investigator Group VH-NG-1243: *"**S**ub-seasonal **PRE**dict**A**bility: understanding the role of **D**iabatic **OUT**flow" (SPREADOUT)*

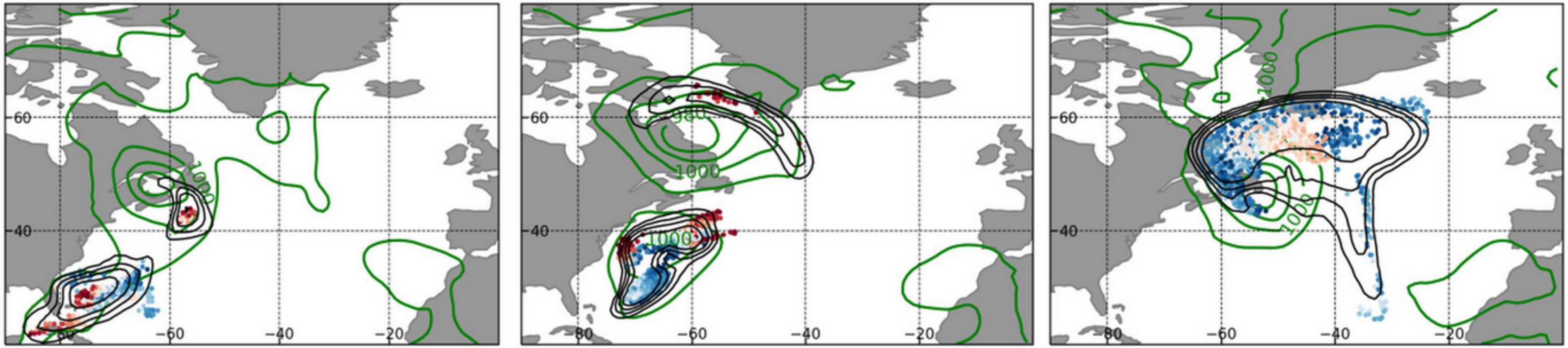


HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Deep Learning for the Verification of Synoptic-scale Processes in NWP and Climate Models

Julian Quinting, Karlsruhe Institute of Technology

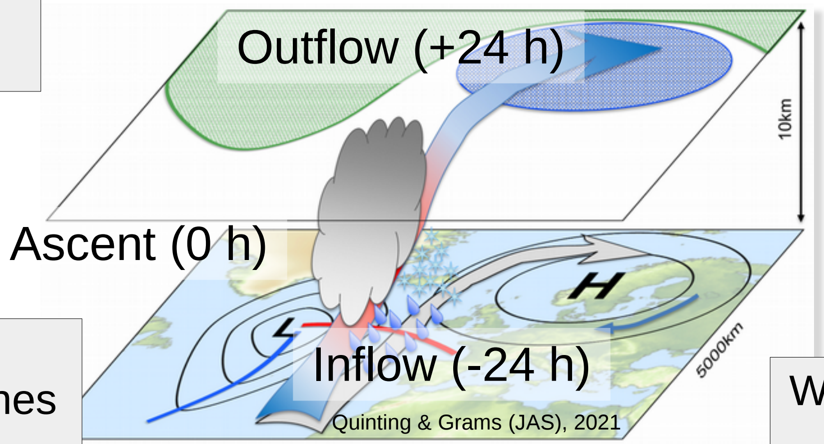
Christian M. Grams, Annika Oertel, Jan Wandel



Representative of synoptic processes: warm conveyor belt

WCBs are associated with precipitation extremes
(e.g., Pfahl et al. 2014)

WCBs affect lifecycle of blocking anticyclones
(e.g., Steinfeld&Pfahl 2019)



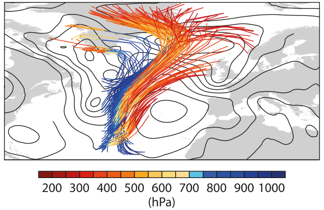
WCBs contribute to intensification of cyclones
(e.g., Binder et al. 2016)

WCBs are source/magnifier of forecast uncertainty
(e.g., Grams et al. 2018)

Accurate representation of WCBs in weather and climate models desirable

Why deep learning to identify WCBs?

Data	ERA-INTERIM *(Dee et al. 2010)*	Forecasts/climate projections
amount	~ 58,400 time steps	~10^6 to 10^7 time steps
availability	Grid: 1° at 61 vertical model levels Temporal availability: 6-hourly	Grid: 1.5° at 10 pressure levels Temporal availability: 24-hourly



Trajectory calculation ✅

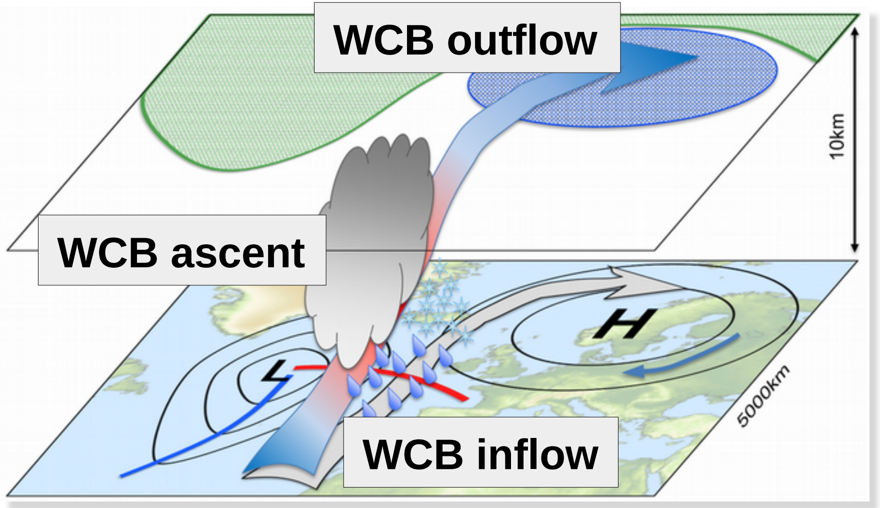
Trajectory calculation ❌

Train CNNs to identify WCB objects from routinely available fields!

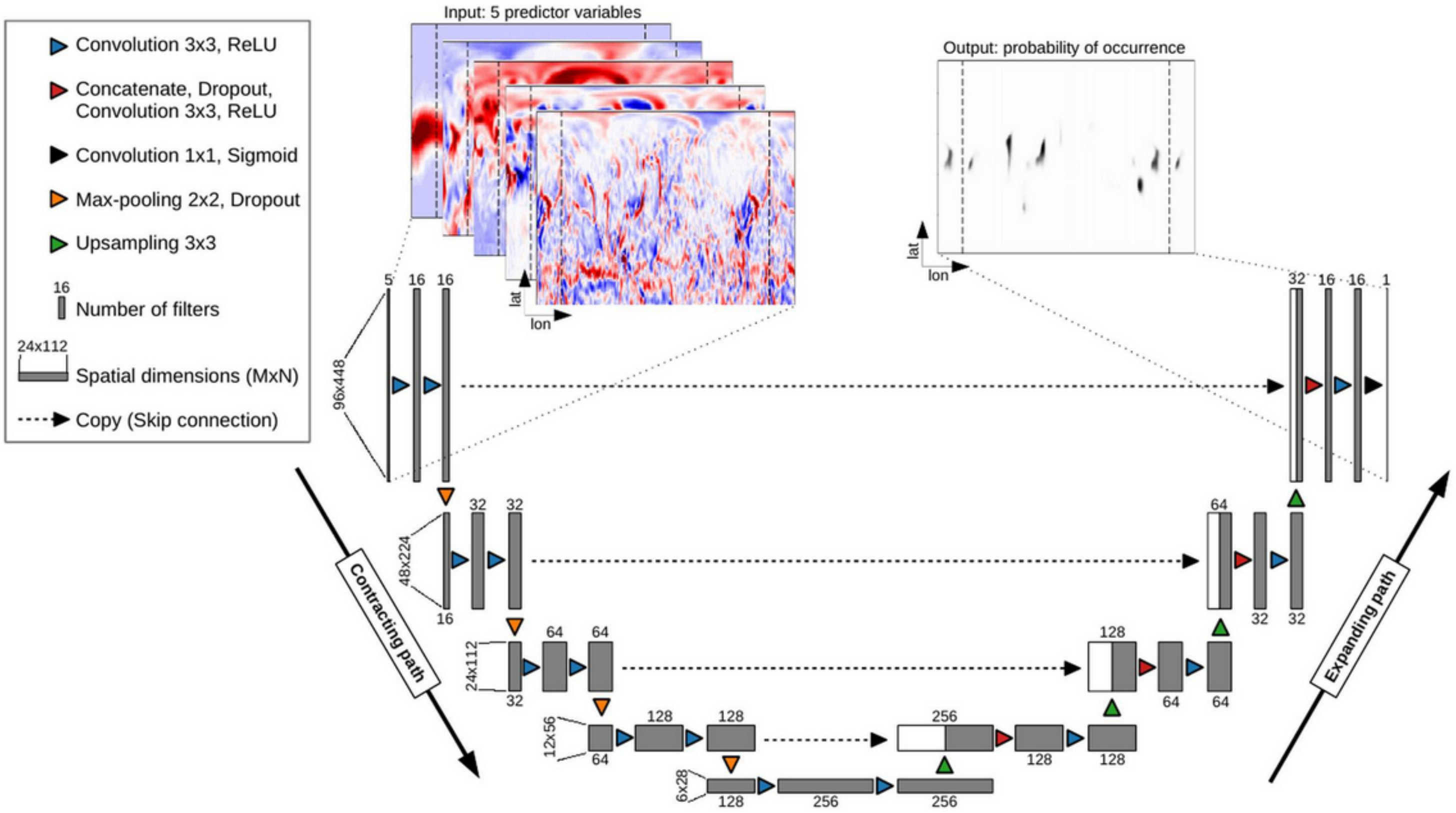
Model development

- Predictand: binary fields (0/1 flag) of WCB inflow, ascent and outflow based on ERA-I
  (Madonna et al. 2014; Thanks to ETH Zurich Atmospheric Dynamics group for sharing the data.)

- Predictors: initial set based on ERA-I of U, V, T, Z, Q at pressure levels determined via stepwise forward predictor selection *(Quinting and Grams 2021; JAS)*



Model development



adapted from Ronneberger et al. 2015

Model development

Dataset	Time period
Training	1 Jan 1980 – 31 Dec 1999
Validation	1 Jan 2000 – 31 Jan 2004
Testing	1 Jan 2005 – 31 Dec 2016


scc.kit.edu

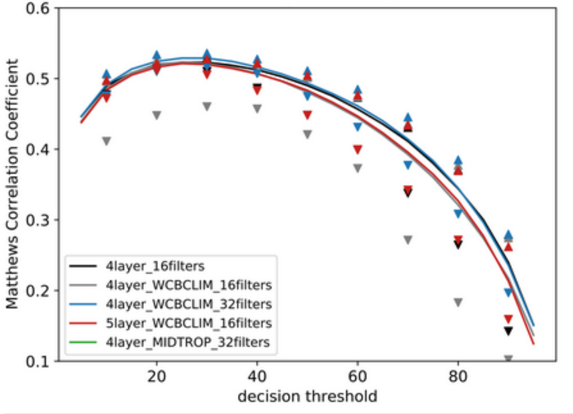
- Development of one model per WCB stage (inflow, ascent, outflow)
- Testing of 72 hyperparameter combinations concerning choice of number of filters, batch size, and dropout fraction to find the „best“ CNN model

Model development – hyperparameters

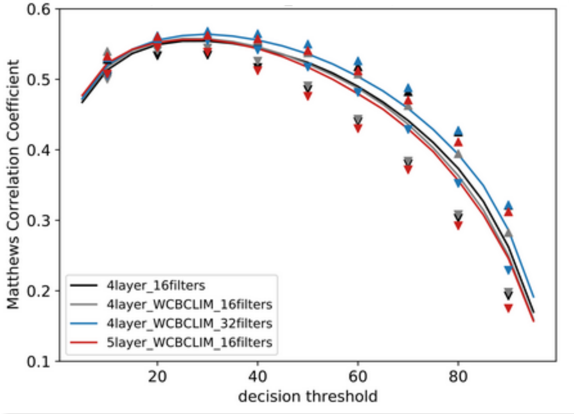
$$MCC = \frac{TP \times TN - FP \times FN}{\sqrt{(TP+FP)(TP+FN)(TN+FP)(TN+FN)}}$$

- MCC=+1 → perfect forecast
- MCC=-1 → total disagreement

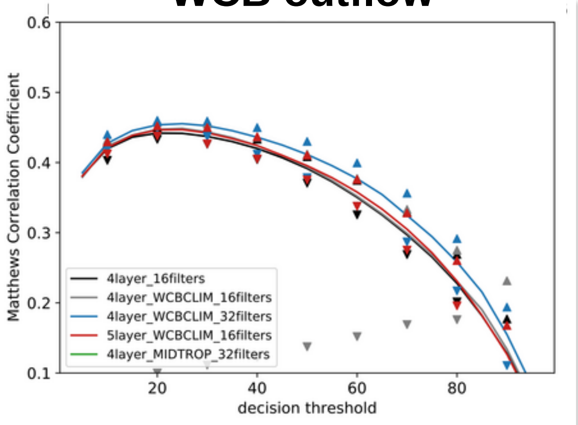
WCB inflow



WCB ascent



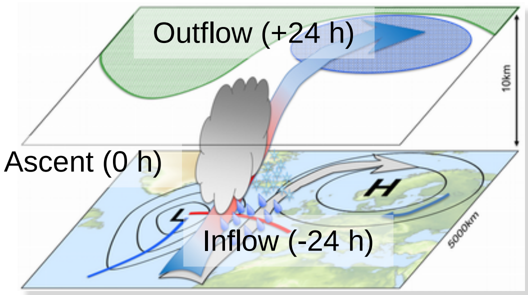
WCB outflow



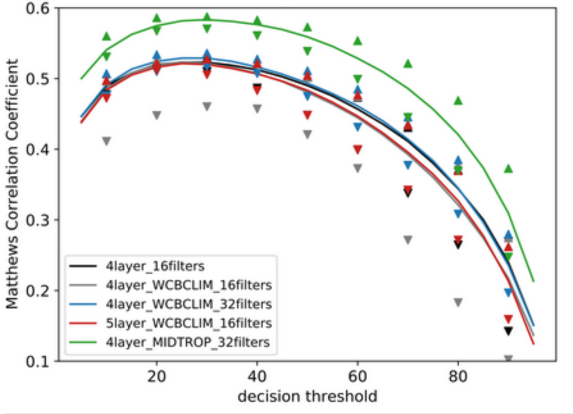
Model for WCB ascent is best performing

Small sensitivity to hyperparameters

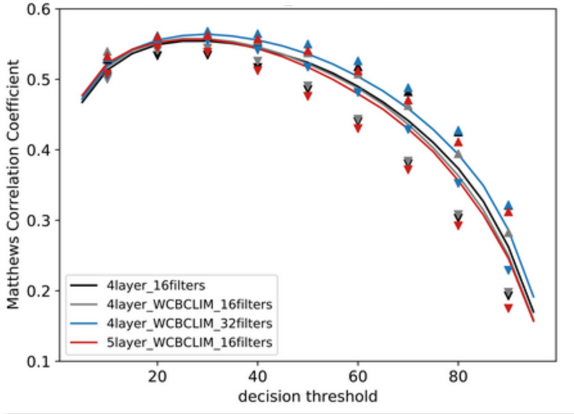
Model development – hyperparameters



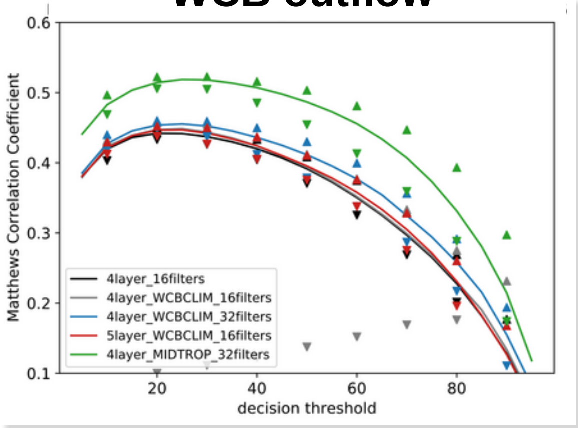
WCB inflow



WCB ascent



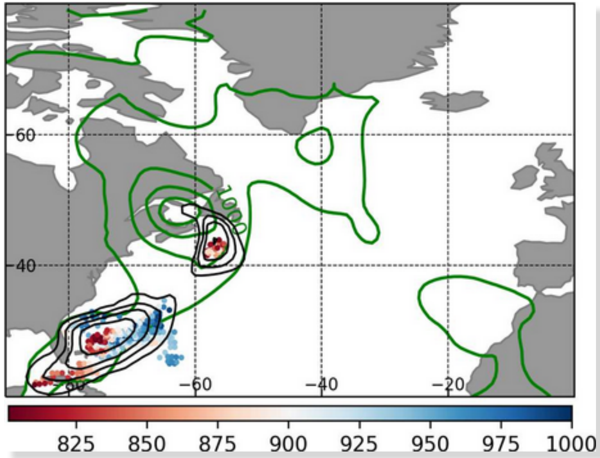
WCB outflow



Models for inflow and outflow greatly improved with time-lagged information on WCB ascent probability

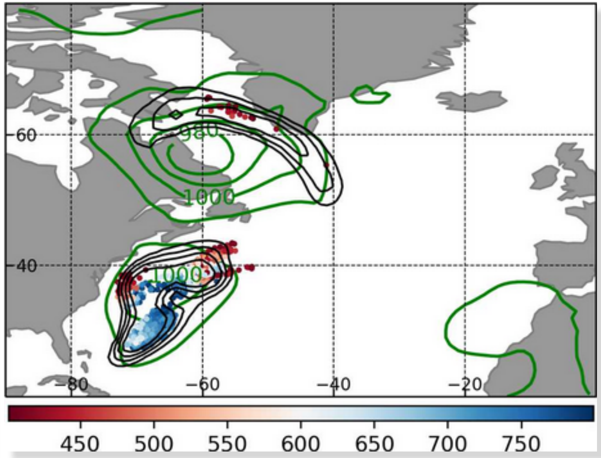
Model evaluation – case study

WCB inflow



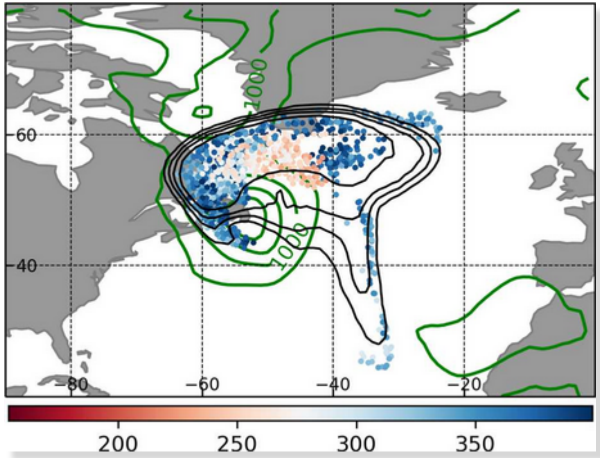
22 January 2011 06 UTC

WCB ascent



23 January 2011 06 UTC

WCB outflow



24 January 2011 06 UTC

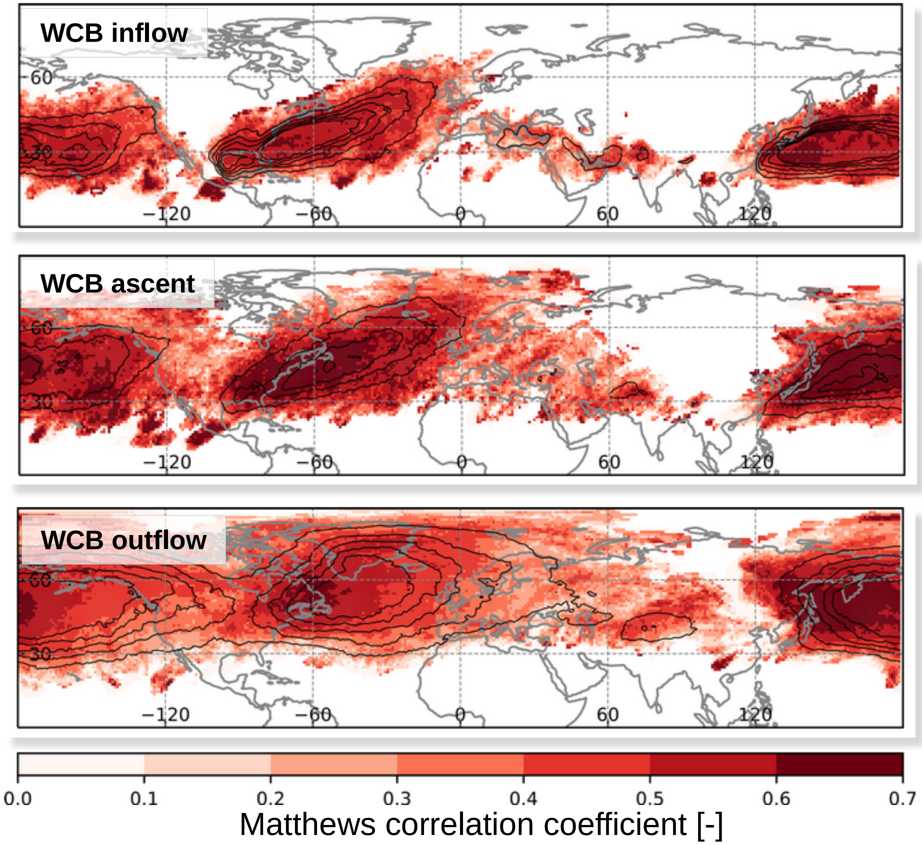
Sea level pressure [hPa]

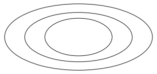
WCB probability predicted by CNN

WCB air parcel locations colored by height [hPa]

Model evaluation – Skill and Biases

Model skillfully identifies WCB footprints



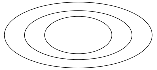

Lagrangian DJF WCB climatology

Model evaluation – Skill and Biases

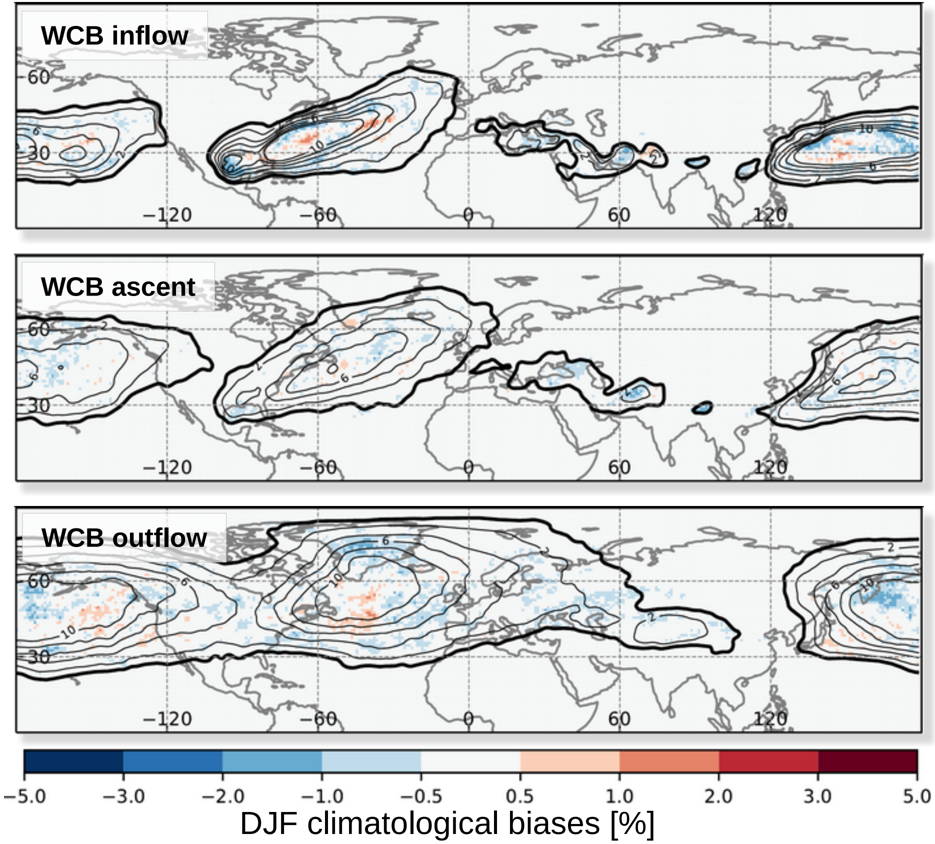
Model skillfully identifies WCB footprints

Model replicates Lagrangian climatology

Computing time reduces
by a factor of ~30



Lagrangian DJF WCB climatology

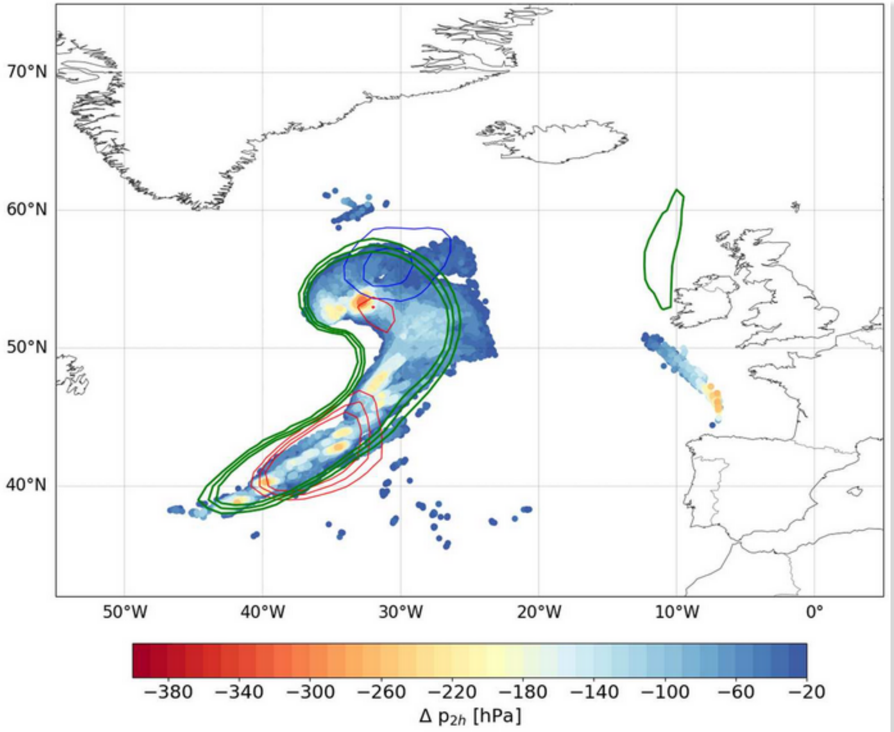


Model applications – WCB in convection-permitting NWP simulation

- trajectory calculation based on NWP data at 6.5 km
- CNN applied to data at 1°

CNN captures WCB ascent structure incl. bent-back warm front

Ongoin work: test sensitivities of WCB to cloud microphysics



inflow prob. ascent probability outflow prob.

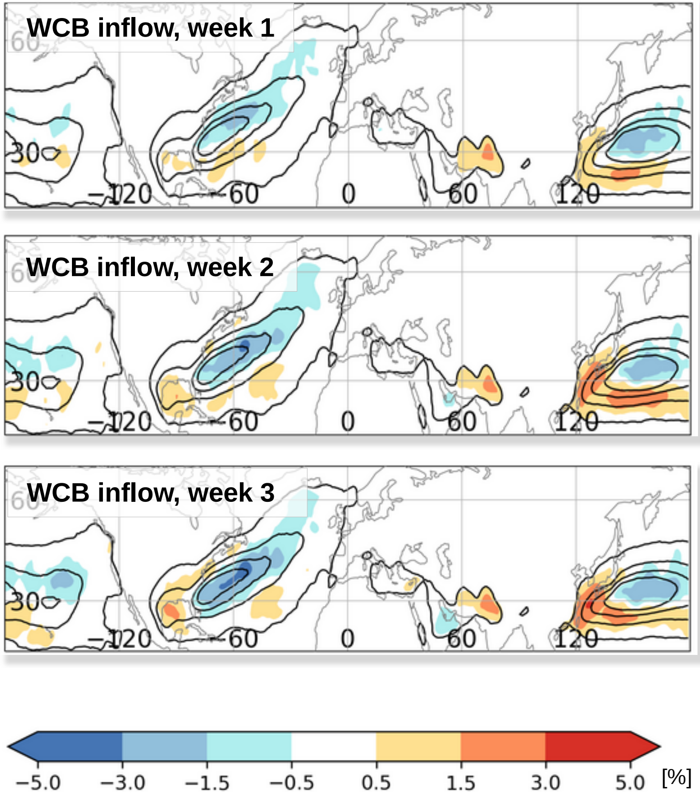
WCB air parcels colored by 2-h pressure change [hPa]

Model applications – Verification of WCBs in S2S reforecasts

- Identification of WCBs in 920 ECMWF IFS reforecast (NDJFM; 1997-2017) from Subseasonal-to-seasonal (S2S) database (Vitart et al. 2017)
- Verification against ERA-Interim reanalysis (Dee et al. 2011)

PhD of Jan Wandel

Model applications – Verification of WCBs in S2S reforecasts



CNN model newly allows the **systematic identification** of WCBs in sub-seasonal reforecasts

WCB frequency biases saturate at **forecast day 15**

Biases in WCB inflow correlate well with **biases** in **moisture flux** at 850 hPa

Wandel, J. et al. (2021): Toward a Systematic Evaluation of Warm Conveyor Belts in Numerical Weather Prediction and Climate Models. Part II: Verification of operational reforecasts, *JAS*

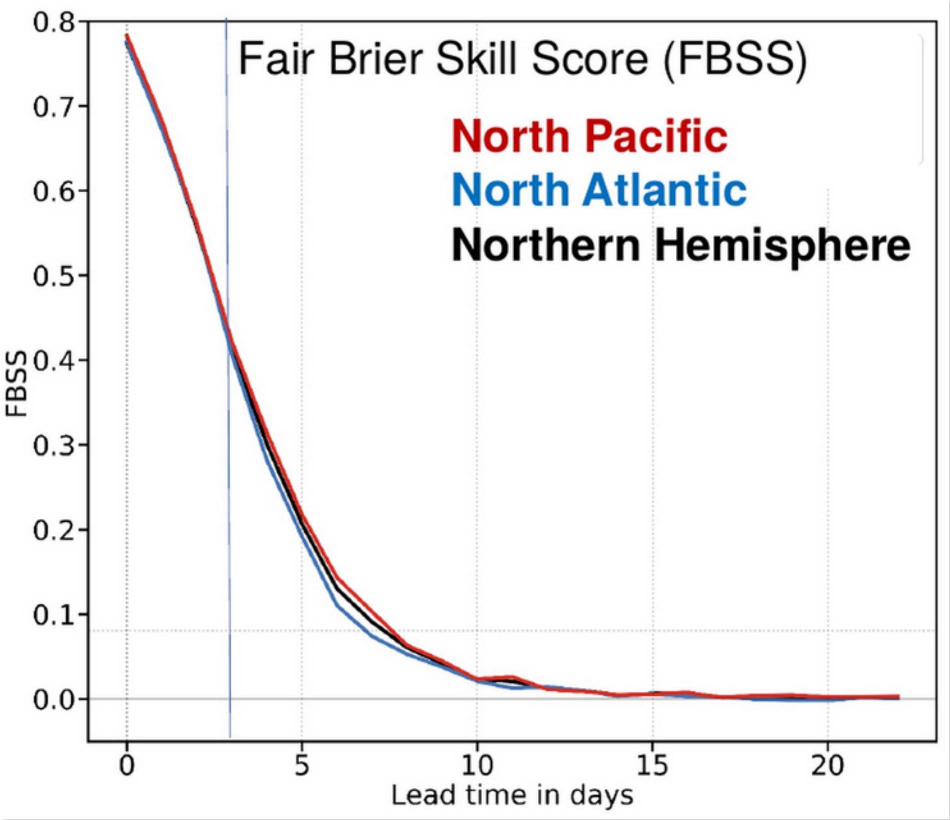
Model applications – Verification of WCBs in S2S reforecasts

WCB forecast **skill horizon** limited to **8-10 days**

Skill over **North Pacific higher** than over the **North Atlantic**

↓

Influence of modes of tropical convection (e.g., MJO)?



Take-home messages

- Deep learning models skillfully identify footprints of Lagrangian airstreams at significantly reduced costs and from data at coarse resolution
- Models newly allow to systematically evaluate representation of WCBs in ensemble reforecasts and climate projections
- Time-lagged predictor selection greatly improves models
- The CNN models useful to unveil processes leading to WCB biases in forecast models

Success of CNNs to identify different weather systems (fronts, atmospheric rivers, tropical cyclones, dry intrusions) proven in numerous studies
(e.g., Lagerquist et al. 2019; Kumler-Bonfanti et al. 2020; Prabhat et al. 2021; Silverman et al. 2021 and many more)

Time for a community effort to publish benchmark data sets and repository?

Model documentation

Description of model development and evaluation:

https://doi.org/10.5194/gmd-2021-276
Preprint. Discussion started: 22 September 2021

Geoscientific Model Development Discussions
Open Access
EGU

EuLerian Identification of ascending Air Streams (ELIAS 2.0) in Numerical Weather Prediction and Climate Models. Part I: Development of deep learning model

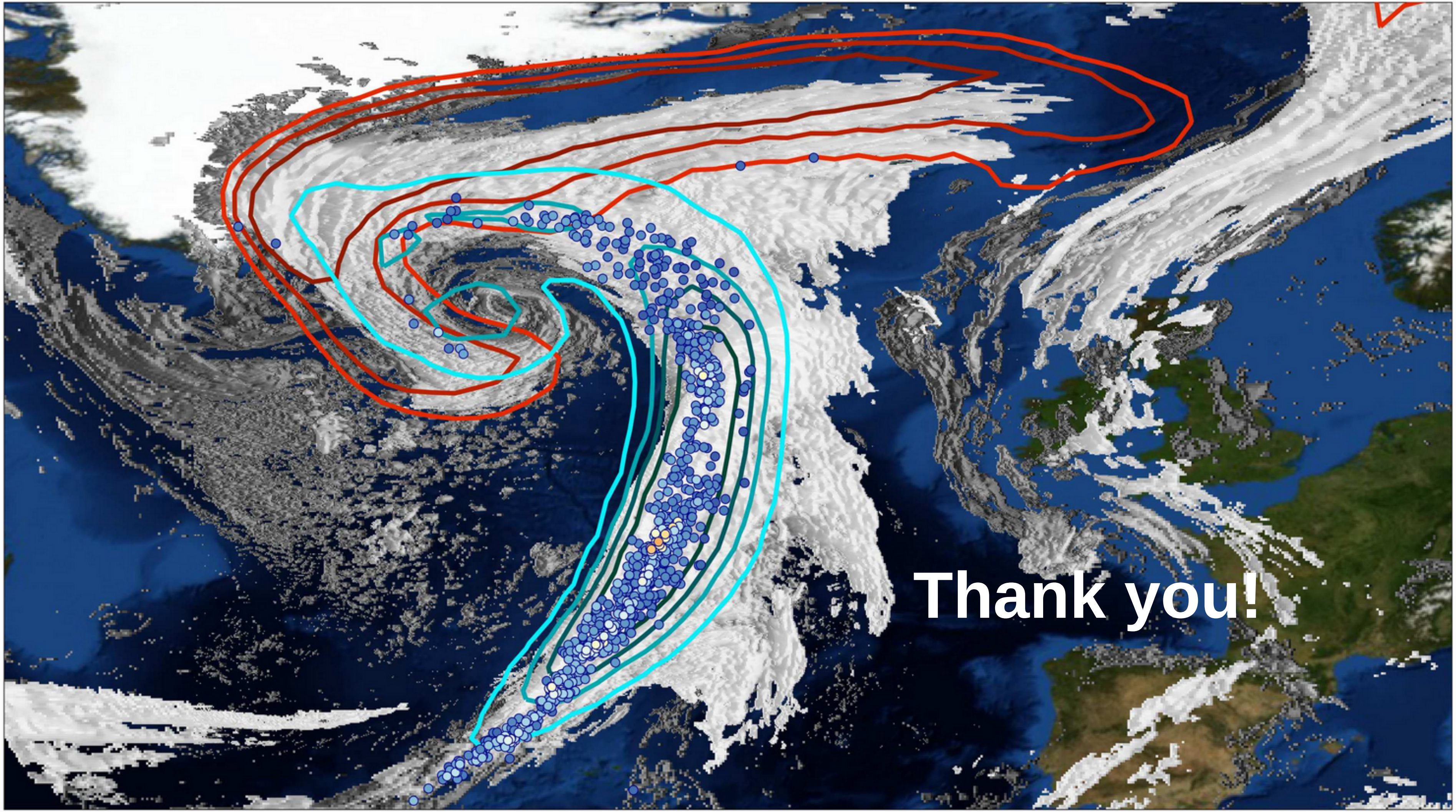
Application examples:

https://doi.org/10.5194/gmd-2021-278
Preprint. Discussion started: 28 September 2021

Geoscientific Model Development Discussions
Open Access
EGU

EuLerian Identification of Ascending air Streams (ELIAS 2.0) in Numerical Weather Prediction and Climate Models. Part II: Model application to different data sets

Trained-models and example scripts available on Gitlab!


Thank you!