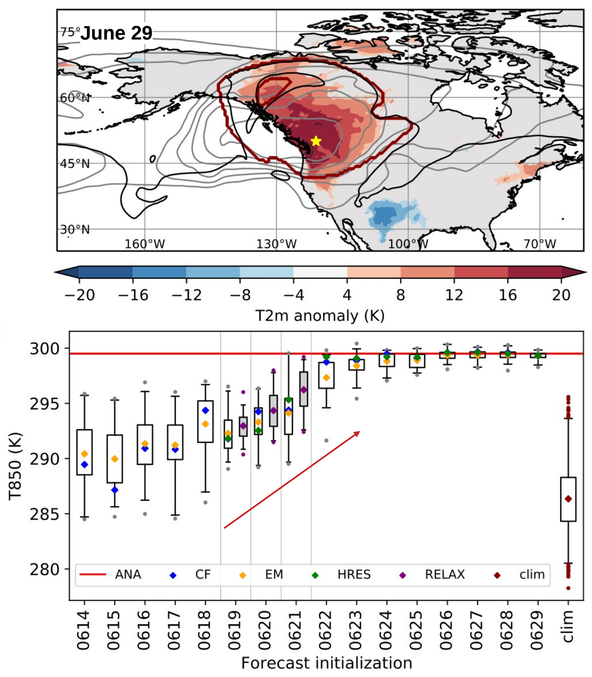
How warm conveyor belt activity across the North Pacific influenced the predictability of the North American heat wave

Pickl, M.[1], Oertel, A.[1], Quinting, J.F.[1], Hauser, S.[1], Wandel, J.[1], Magnusson, L[2], Balmaseda, M.[2], Vitart, F.[1], and Christian M. Grams[1]

[1]Institute of Meteorology and Climate Research, Department Troposphere Research (IMK-TRO), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
[2]European Centre for Medium-Range Weather Forecasts (ECMWF), Reading, United Kingdom

Introduction



- **Unprecedented heat wave** during end of June 2021 in western North America caused far-reaching socio-economic consequences
- **Low-probability event** even under consideration of the current state of climate change *(Philip et al., 2019)*
- Magnitude of the heat wave was not captured by numerical weather prediction models at forecast lead times **beyond seven days** *(e.g. Lin et al., 2022)*

Fig. 1: *ERA5 T2m anomaly (shading), upper-level negative PV-anomaly (red contour), position of the 2 PVU line at 335 K (black contour) and frequencies of upper-level negative PV-anomalies (gray contours in intervals of 2, 10, 20, 30, 40 and 50%) valid on June 29 2021 (top). Distributions of ensemble forecasts of 850 hPa temperature valid on 29 June 2021 averaged in a 20°x20° box around Lytton) initialised daily at 00 UTC between 14 and 29 June 2021. Boxes (whiskers) show the interquartile (1-99 interquantile) range of the ensemble. The gray boxes show the distributions of the relaxation experiments initialized on June 19, 20 and 21 (see Data & Methods).*

Data & Methods

- **Categorization of individual forecasts** as **"good"** and **"bad"** members based **on the representation of the upper-level ridge** (domain-average RMSE of θ at 2PVU in the region 145-95° W, 30-75° N) valid on June 29
- **10-day backward trajectories** using Lagranto from upper-level PV anomaly based on ERA5 *(Sprenger and Wernli 2015)*
- **Footprints of warm conveyor belts (WCBs)** using ELIAS2.0 (Quinting and Grams 2022) in operational ECMWF ensemble forecasts initialized between June 14 and 29 (n=765)
- **Relaxation experiments** that are nudged towards the analysed state of the atmosphere in the West Pacific, initialised on June 19, 20 and 21.

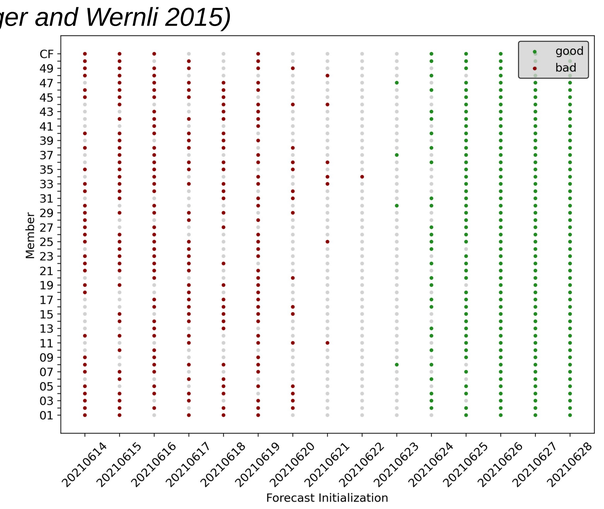


Fig. 2: *Initialisation dates of 'good' and 'bad' forecasts of ECMWF ensemble forecasts initialised daily between 14 and 29 June 2021.*

Linkage of upper-level ridge and heat wave

- **Good** forecasts that capture the upper-level ridge correctly represent the 850 hPa temperature anomaly
- **Bad** forecasts that do not correctly capture the upper-level ridge are characterised by a too zonal flow and **strongly underestimate the magnitude of the heat wave**

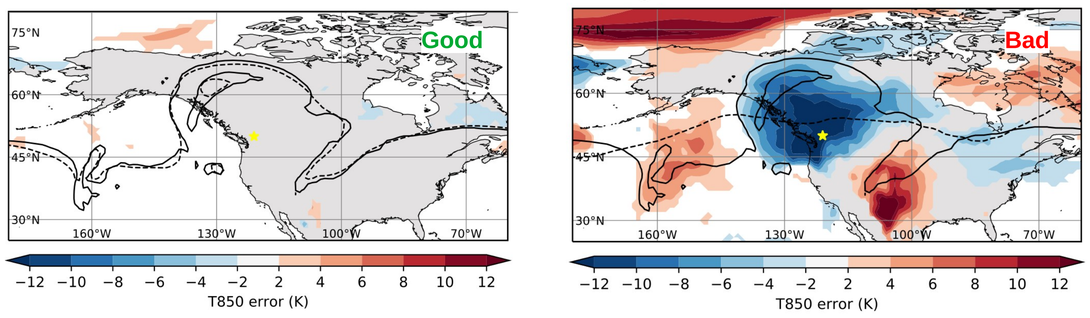


Fig. 3: *Composite-mean temperature at 850 hPa error (shading) and position of the 2 PVU contour at 335K (dashed line) of "good" (left) and "bad" (right) forecasts valid on June 29 2021. The black line shows the analyzed 2 PVU contour.*

Predictability limited by synoptic processes

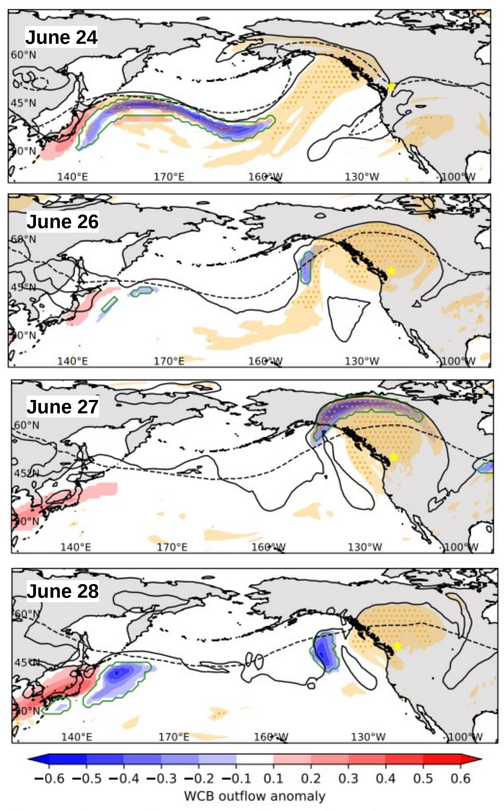


Fig. 5: *Composite-mean WCB outflow frequency errors (shading) and 2 PVU line on the 335 K isentrope (dashed line) of forecasts classified as 'bad'. The area enclosed by the green line shows WCB outflow in the analysis and the solid black line indicates the analyzed position of the 335 K 2 PVU line. The orange shading (hatching) highlights regions where the tropopause height (i.e. potential temperature on 2 PVU) exceeds the 95th (99th) percentile of the ERA5 dataset*

- WCB outflow in the West Pacific **pre-conditions the upper level flow** by ridge building and lifting the tropopause which favours downstream development
- Bad forecasts **mis-represent the WCB** activity in the West Pacific and therefore do not correctly capture the **complex chain of synoptic events**, including several WCB events
- **Relaxation experiments** nudged towards the truth in the West Pacific **improve the forecast of the heat wave,** but still underestimate its magnitude

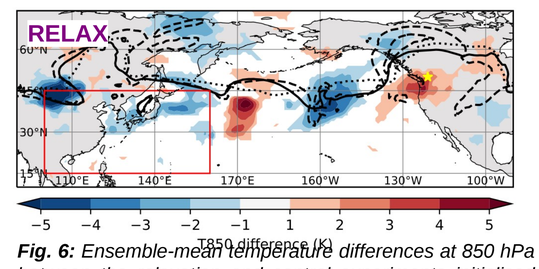
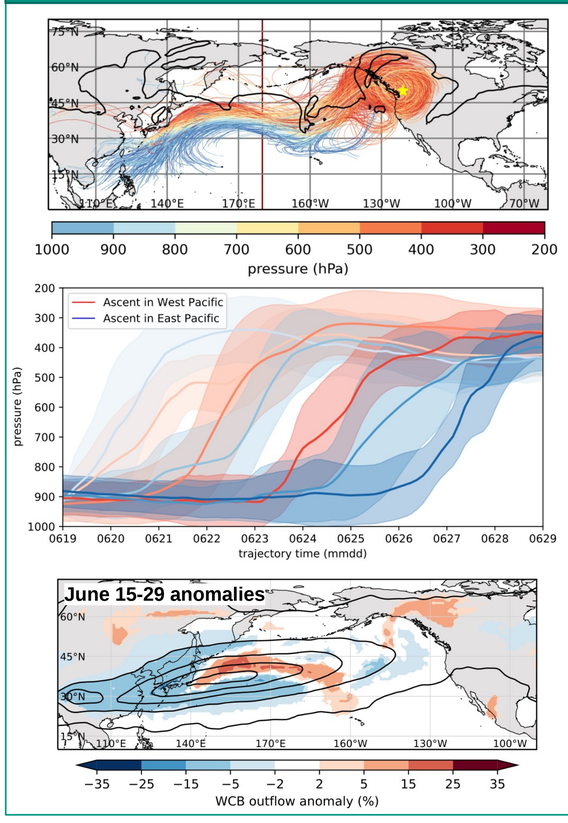


Fig. 6: *Ensemble-mean temperature differences at 850 hPa between the relaxation and control experiments initialised on 21 June 2021 (shading) and 2 PVU line on 335 K of the relaxation experiment (solid), the control experiment (dotted) and the analysis (dashed), valid on a 29 June*

Chain of synoptic events influences the upper-level ridge



- Upper-level ridge was continuously fed by **air masses that originate from the lower troposphere** (20% of all trajectories) and that are heated diabatically
- **Individual ascent events** take place at the Meiyu-Baiu-Front in the **West Pacific** and in the **East Pacific**
- **WCB activity** in the West Pacific is shifted north-eastwards and is **anomalously high** over the East Pacific

Fig. 4: *10-day backward trajectories started from the upper-level negative PV-anomaly on June 29 2021 (top). Average pressure evolution of coherent trajectory bundles that originate from the lower troposphere (p > 800 hPa) clustered by the location of the ascent (red: West Pacific, blue: East Pacific) and time interval when the ascent occurred (middle). Absolute WCB outflow anomalies from June 15-29 (shading) with respect to the 40-year June ERA5 climatology (contours; intervals at 0.5, 5, 10 and 20%; bottom).*

Conclusions

- **WCB activity in the West Pacific** related to the Meiyu-Baiu-Front and its interaction with the upper-level jet acts as **predictability barrier** for the North American heat wave
- **Complex chain of synoptic events** has to be considered to understand the dynamics and predictability of rare extreme events

References

Philip et al., 2021: Rapid attribution analysis of the extraordinary heatwave on the Pacific Coast of the US and Canada June 2021. World Weather Attribution. DOI: 10.5194/esd-2021-90

Quinting and Grams, 2022: EuLerian Identification of ascending Air Streams (ELIAS 2.0) in Numerical Weather Prediction and Climate Models. Part I: Development of deep learning model. *Geosci. Mod. Dev. DOI: 10.5194/gmd-2021-276*

Oertel et al., 2022: Everything hits at once - how remote rainfall matters for the prediction of the Canadian heat 2021. In review for Geophys. Res. Lett. DOI: 10.1002/essoar.10512269.1