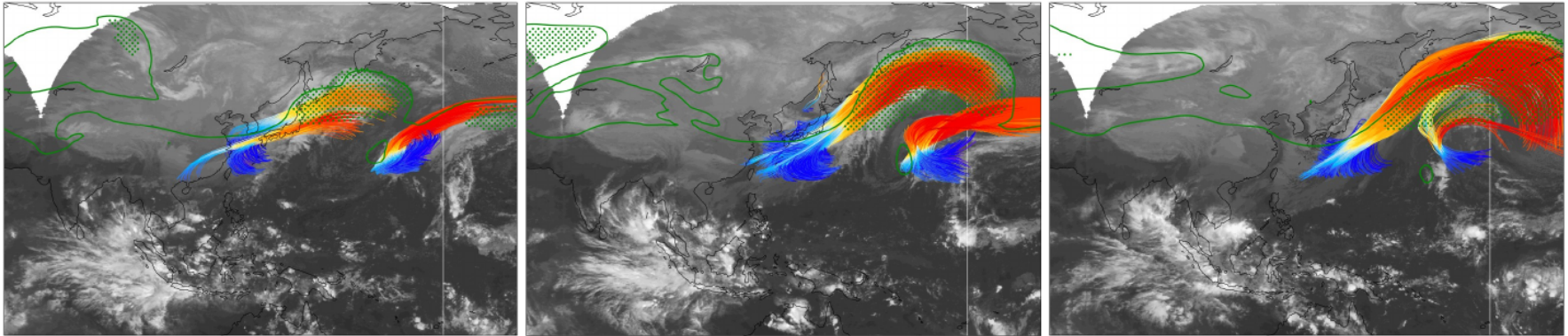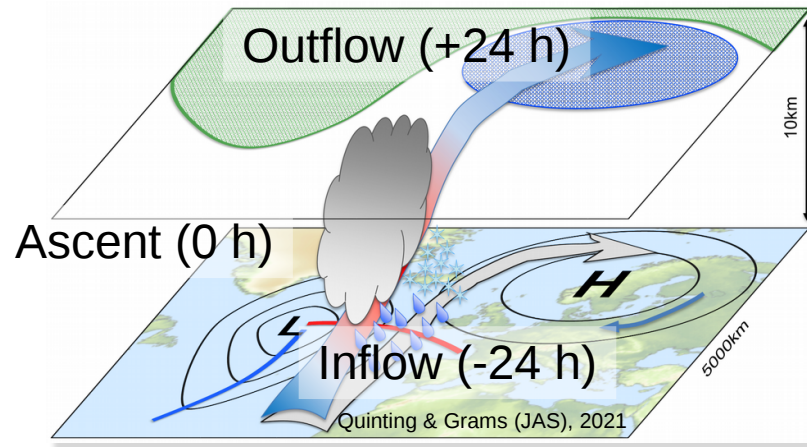**HELMHOLTZ**
RESEARCH FOR GRAND CHALLENGES

Importance of the representation of warm conveyor belts for the predictability of the large-scale flow on sub-seasonal time scales

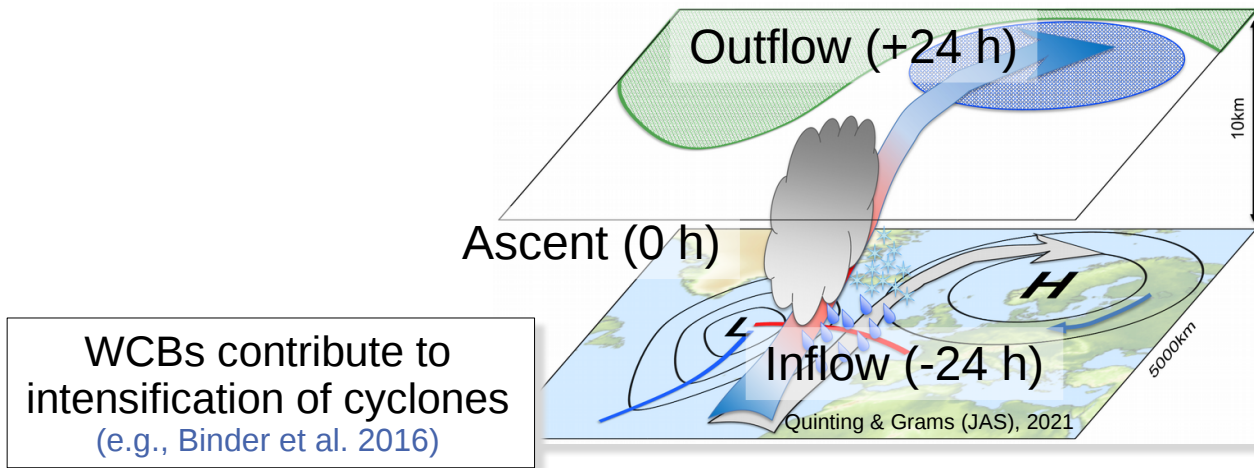**Julian Quinting, Karlsruhe Institute of Technology**
with contributions from Christian M. Grams, Jan Wandel, Peter Knippertz, Stephan Pfahl, and Heini Wernli

www.kit.edu

Role of WCBs for large-scale dynamics and predictability

Outflow (+24 h)

Ascent (0 h)

Inflow (-24 h)

10km

5000km

Quinting & Grams (JAS), 2021

6th WGNE Workshop on systematic errors in weather and climate models
ECMWF, Reading

Institute of Meteorology and Climate Research (IMK-TRO)

Role of WCBs for large-scale dynamics and predictability

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

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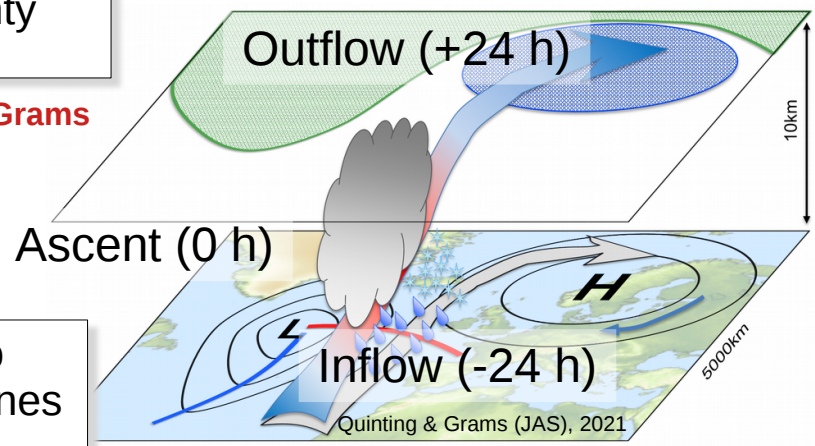Quinting & Grams (JAS), 2021

Role of WCBs for large-scale dynamics and predictability

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

see Poster presented by C. Grams in poster session 2

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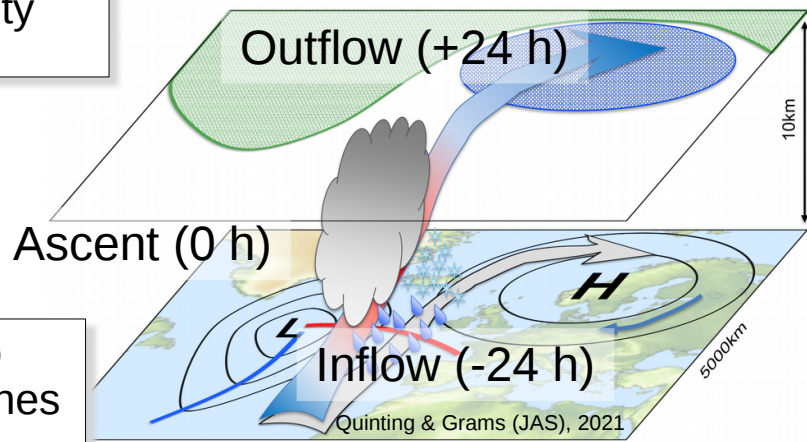(e.g., Binder et al. 2016)

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H

Quinting & Grams (JAS), 2021

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Role of WCBs for large-scale dynamics and predictability

WCBs affect lifecycle of blocking anticyclones
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Quinting & Grams (JAS), 2021

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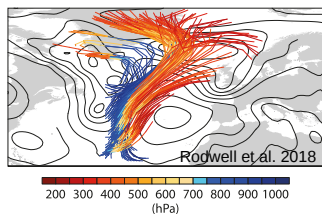Inflow (-24 h)

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Quinting & Grams (JAS), 2021

WCBs contribute to intensification of cyclones
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WCBs are associated with precipitation extremes
(e.g., Pfahl et al. 2014)

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Role of WCBs for large-scale dynamics and predictability

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Quinting & Grams (JAS), 2021

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Accurate representation of WCBs in weather and climate models desirable

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An Eulerian WCB Metric (ELIAS 2.0)

Data	**ERA-INTERIM** *(Dee et al. 2010)*
amount	~ 58,400 time steps
availability	Grid: 1° at 61 vertical model levels Temporal availability: 6-hourly

Rodwell et al. 2018

200 300 400 500 600 700 800 900 1000
(hPa)

Trajectory calculation ✅

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An Eulerian WCB Metric (ELIAS 2.0)

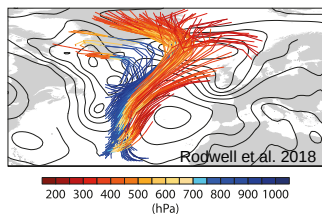| Data	ERA-INTERIM *(Dee et al. 2010)*	S2S ensemble reforecasts
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Trajectory calculation ❌

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Trajectory calculation ✅

Trajectory calculation ❌

Eulerian metric to identify signature of WCB stages based on Unet-type convolutional neural network

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An Eulerian WCB Metric (ELIAS 2.0)

Predictor selection

- Predictors based on standard
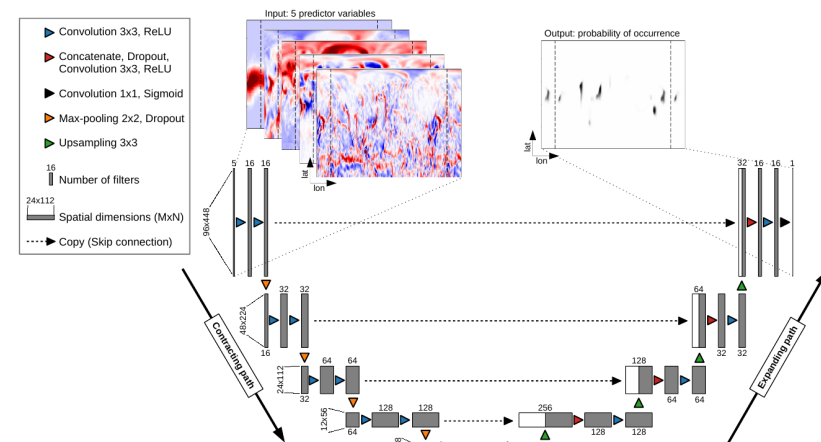 input fields at pressure levels: T, q_v, Z, u, v

P	WCB inflow	WCB ascent	WCB outflow
1	700-hPa thickness advection	850-hPa relative vorticity	300-hPa relative humidity
2	850-hPa meridional moisture flux	700-hPa relative humidity	300-hPa irrotational wind speed
3	1000-hPa moisture flux convergence	300-hPa thickness advection	500-hPa static stability
4	500-hPa moist potential vorticity	500-hPa meridional moisture flux	300-hPa relative vorticity
5	conditional probability of ascent (+24 h)*	30-d WCB ascent climatology**	conditional probability of ascent (-24 h)*

Quinting and Grams (2021), *JAS*
doi:10.1175/JAS-D-20-0139.1

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Quinting and Grams (2021), *JAS*
doi:10.1175/JAS-D-20-0139.1

Unet-type convolutional neural network

- Trained on global ERA-Interim
  at 1° grid spacing

Quinting and Grams (2022), doi:10.5194/gmd-15-715-2022
https://git.scc.kit.edu/nk2448/wcbmetric_v2

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WCB frequency biases in S2S IFS reforecasts (PhD Jan Wandel)

WCB biases 1997-2017 (DJF)
(CY43R1, CY43R3, CY43R5)

Systematic **underestimation of WCB activity** in northern North Atlantic

WCB frequency biases saturate in **week 2**

WCB outflow biases coincide with biases in geopotential

(a) Inflow Week 1 (b) Ascent Week 1 (c) Outflow Week 1
(d) Inflow Week 2 (e) Ascent Week 2 (f) Outflow Week 2
(g) Inflow Week 3 (h) Ascent Week 3 (i) Outflow Week 3
(j) Inflow Week 4 (k) Ascent Week 4 (l) Outflow Week 4
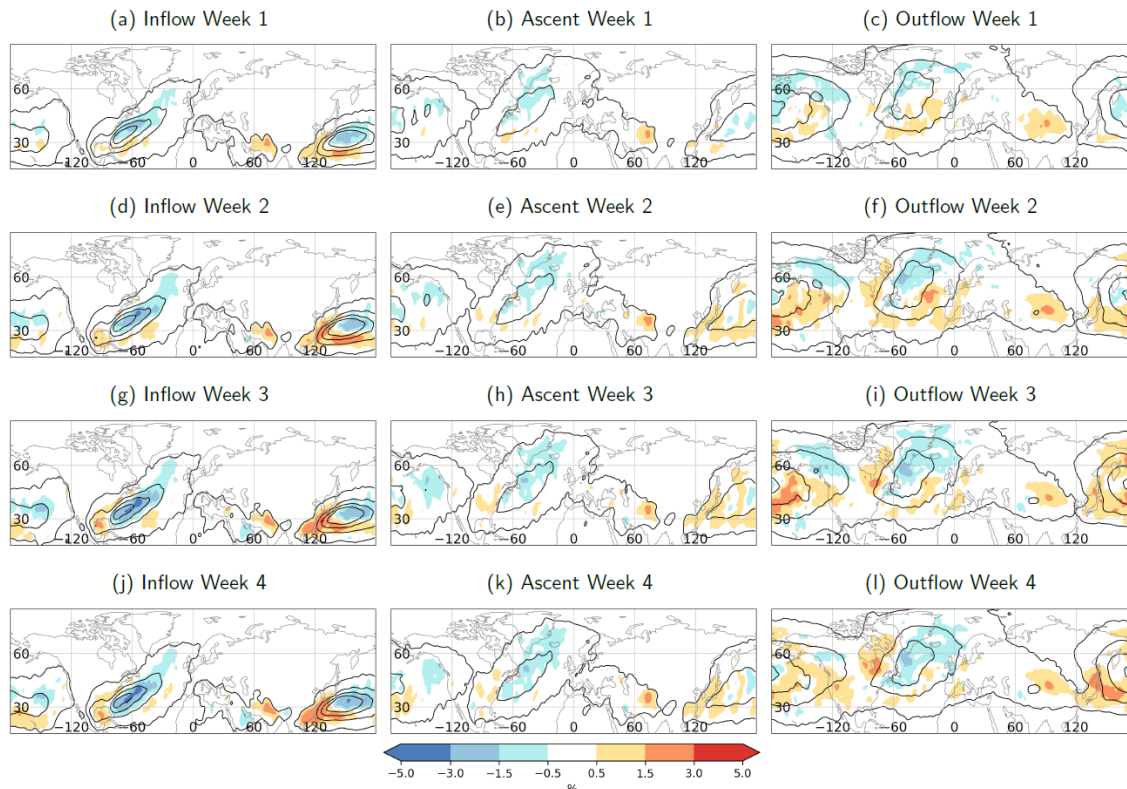
DJF WCB climatology at 1, 5, 10, 15%

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WCB outflow skill in S2S IFS reforecasts (PhD Jan Wandel)

WCB skill 1997-2017 (DJF)
(CY43R1, CY43R3, CY43R5)

Daily forecast skill horizon
limited to about 7-9 days

Skill up to week 2 for weekly
mean

Skill over North Pacific higher
than over North Atlantic

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

WCB outflow skill
(daily)
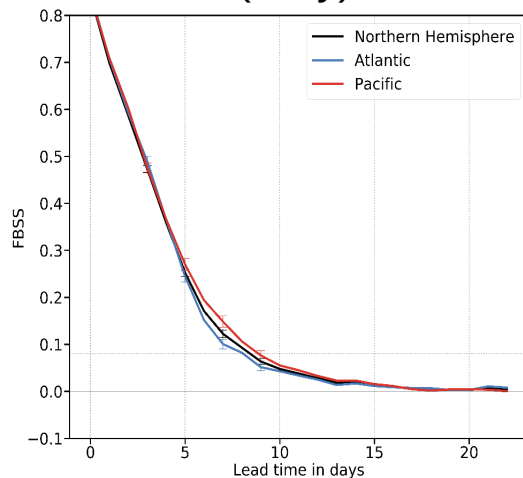
WCB outflow skill
(weekly)
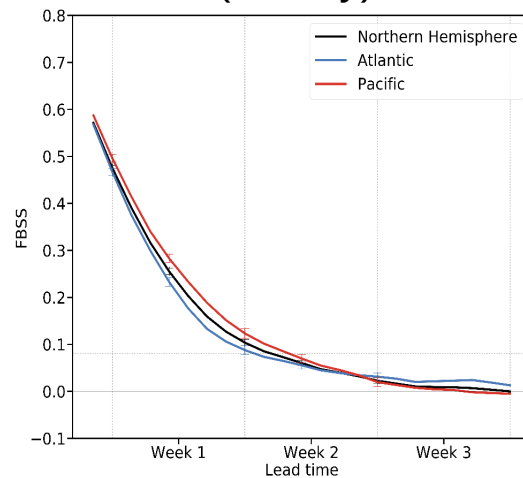
Wandel et al. 2021, JAS, doi: 10.1175/JAS-D-20-0385.1
here shown for ELIAS 2.0 PhD Dissertation Jan Wandel (2022)
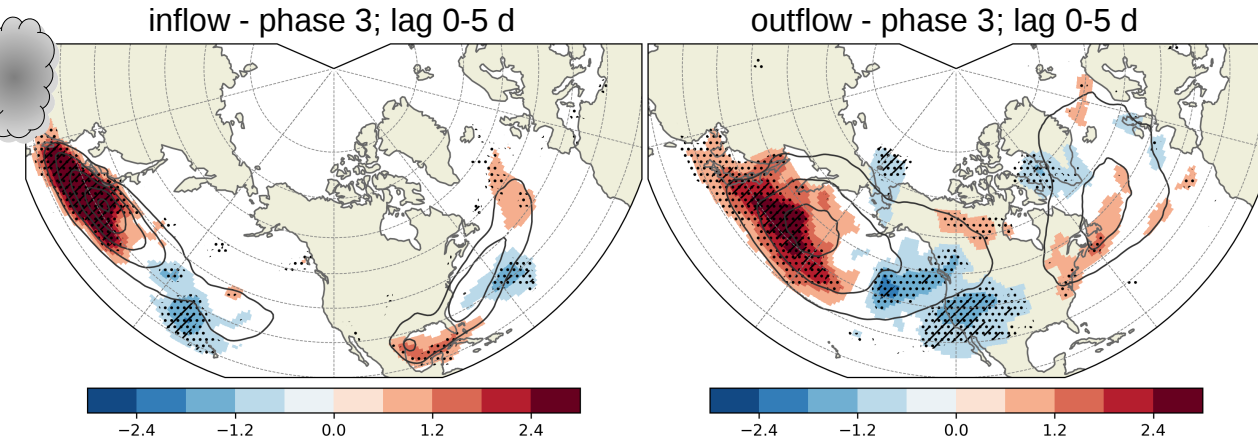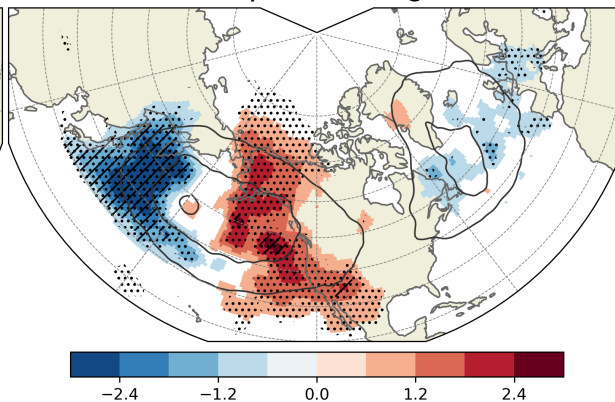
Institute of Meteorology and Climate Research (IMK-TRO)
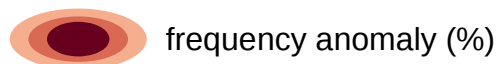
MJO modulates WCB activity

inflow - phase 3; lag 0-5 d   outflow - phase 3; lag 0-5 d

WCB activity increases significantly over the western North Pacific during/after MJO phase 3 (cf. Guo et al. 2017)

climatological frequency   frequency anomaly (%)

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MJO modulates WCB activity

inflow - phase 3; lag 0-5 d

outflow - phase 3; lag 0-5 d

Z500 - phase 3; lag 0-5 d
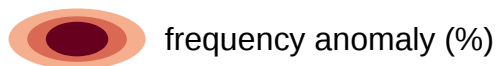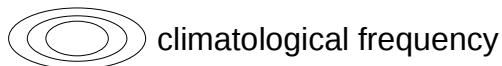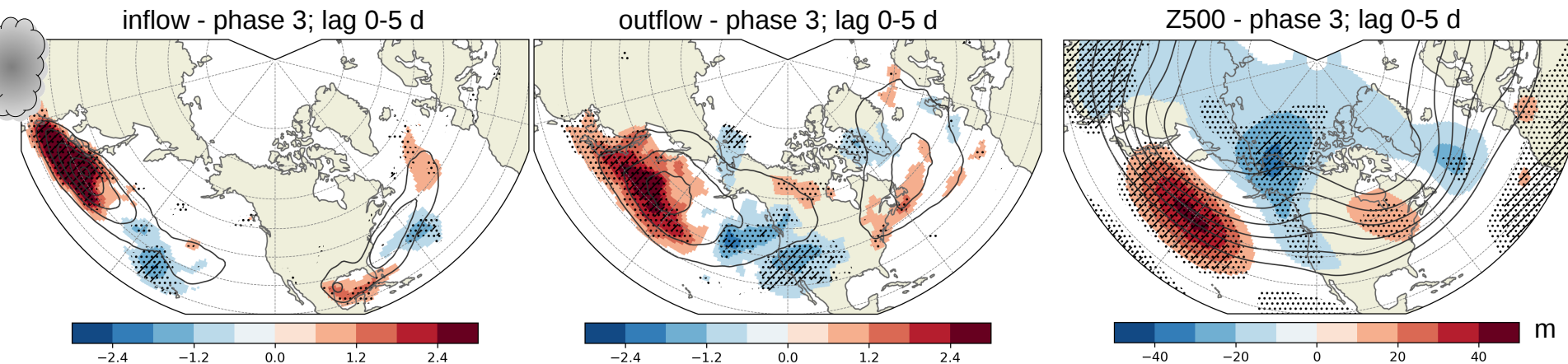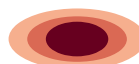
WCB activity increases significantly over the western North Pacific during/after MJO phase 3 (cf. Guo et al. 2017)

Anomalous ridging over Pacific (e.g., Moore et al. 2010)

climatological frequency   frequency anomaly (%)

MJO modulates WCB activity
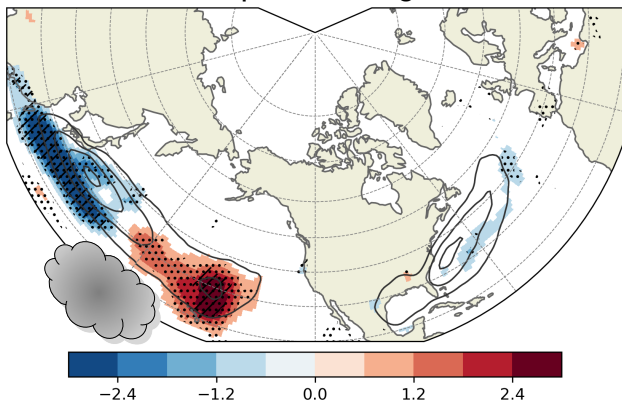
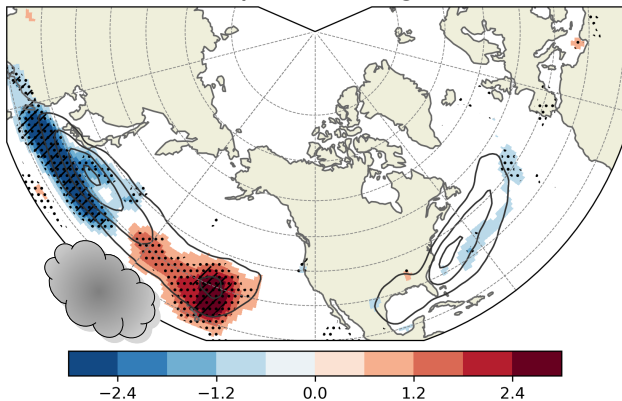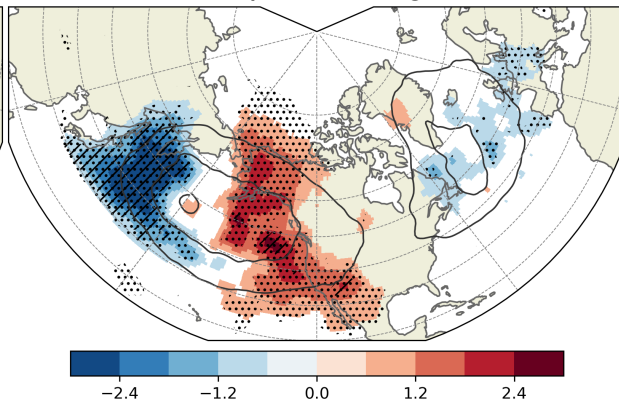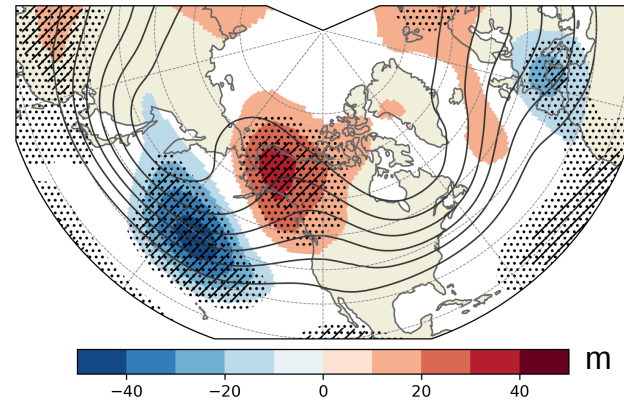inflow - phase 7; lag 0-5 d

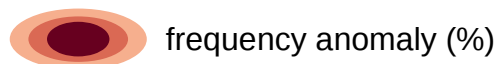outflow - phase 7; lag 0-5 d

WCB activity increases significantly over the eastern
North Pacific during/after MJO phase 7

climatological frequency   frequency anomaly (%)

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MJO modulates WCB activity

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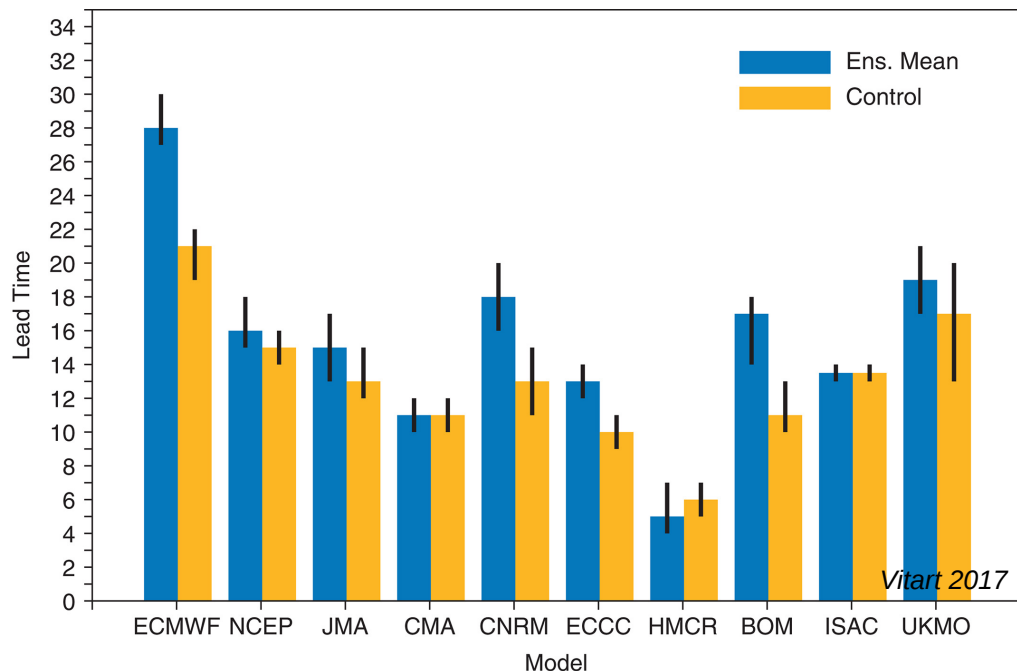
WCB activity increases significantly over the eastern North Pacific during/after MJO phase 7

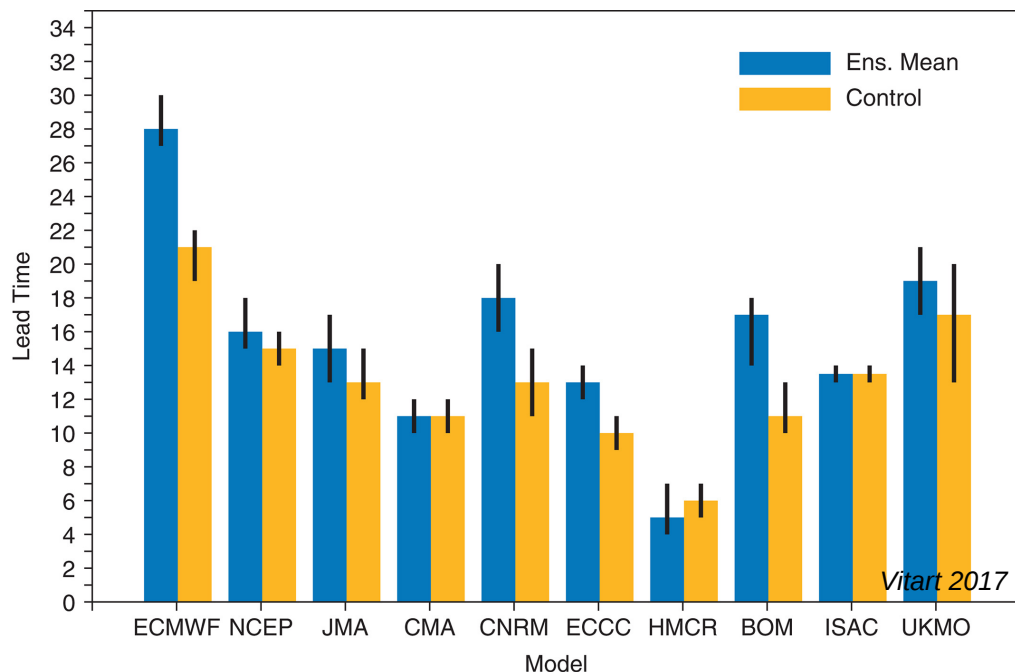Anomalous ridging over Alaska (e.g., Henderson et al. 2016)

climatological frequency   frequency anomaly (%)

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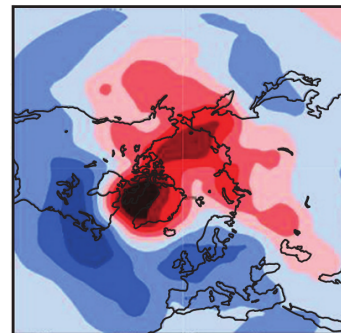Institute of Meteorology and Climate Research (IMK-TRO)

How is this modulation represented in S2S IFS reforecasts?

Vitart 2017

Current NWP models skillfully predict
the MJO out to 28 days

(Vitart 2017)

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Institute of Meteorology and Climate Research (IMK-TRO)

How is this modulation represented in S2S IFS reforecasts?

Vitart 2017

ERAI

Z500 anomaly 11-15 days after phase 7
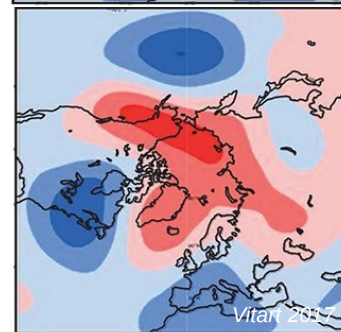
Vitart 2017

S2S IFS reforecast

Z500 anomaly 11-15 days after phase 7

Current NWP models skillfully predict the MJO out to 28 days

(Vitart 2017)

Teleconnection signals are weakening with forecast lead time

(Vitart 2017)

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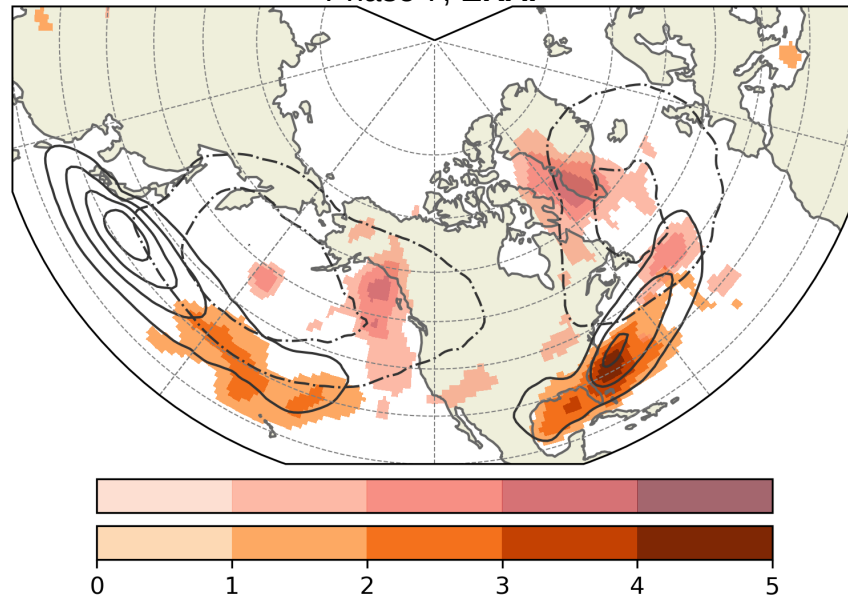
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How is this modulation represented in S2S IFS reforecasts?

Phase 7; **IFS** 0-5 days after initialization
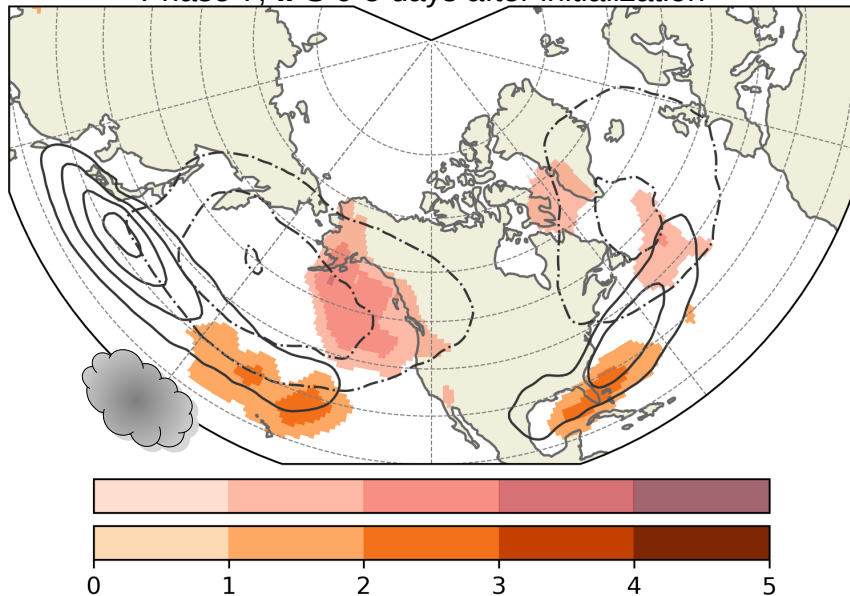
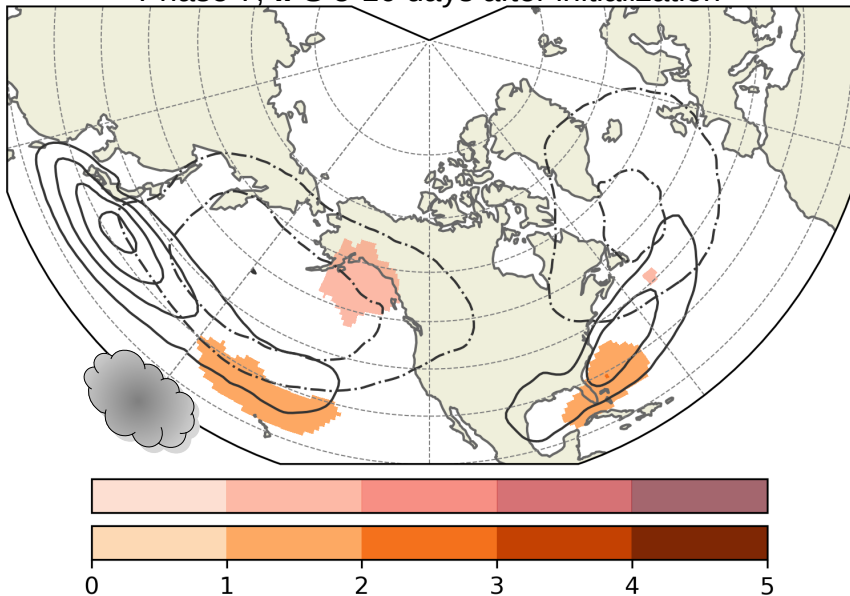Phase 7; **ERAI**

At early leadtimes ECMWF's S2S forecast represent WCB increase over eastern Pacific after phase 7.
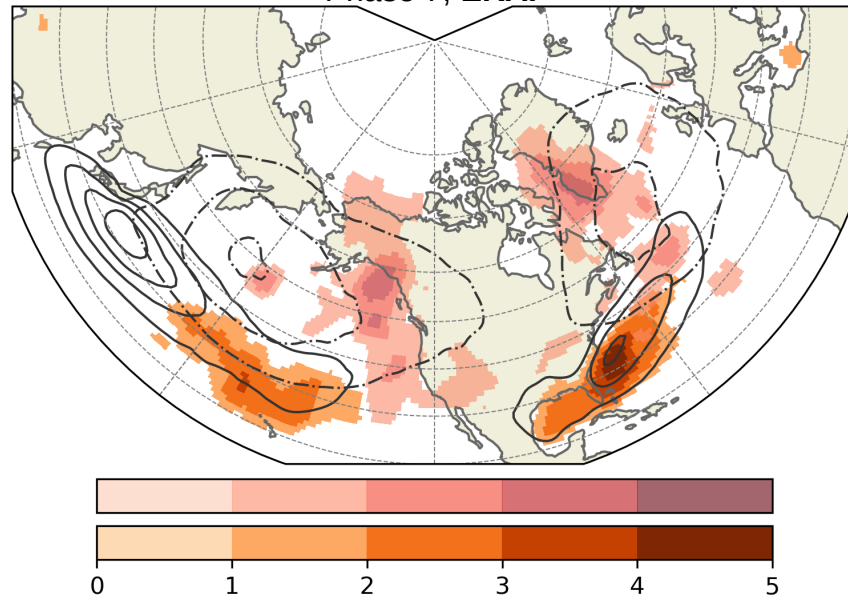
pos. inflow frequency anomaly   pos. outflow frequency anomaly

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How is this modulation represented in S2S IFS reforecasts?

Phase 7; **IFS** 5-10 days after initialization

Phase 7; **ERAI**

Anomalous WCB activity ceases in reforecasts
after 5-10 days forecast lead time

pos. inflow frequency anomaly

pos. outflow frequency anomaly

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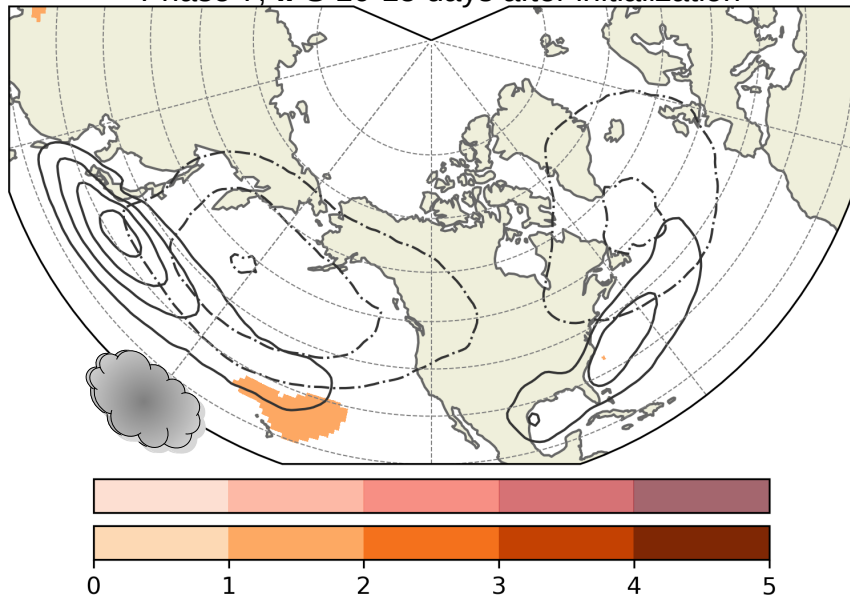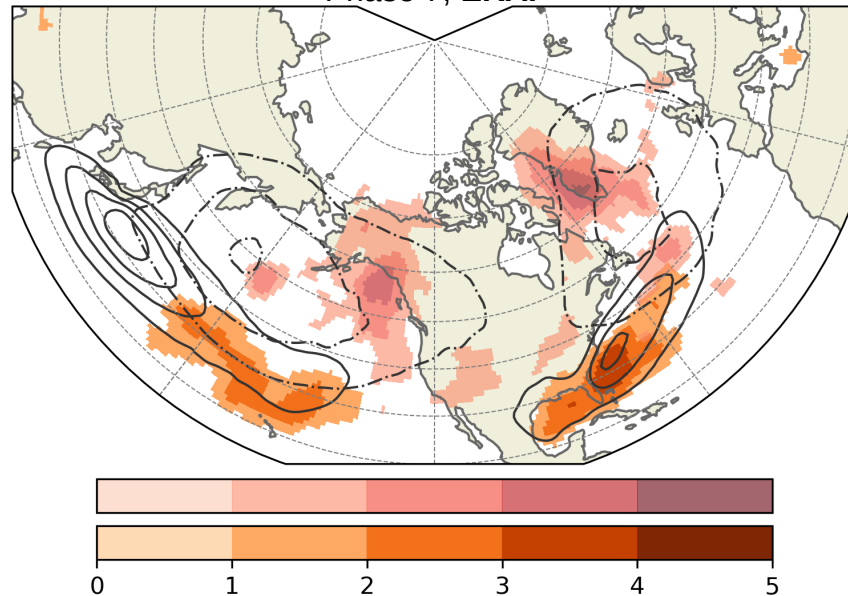# How is this modulation represented in S2S IFS reforecasts?

Anomalous WCB activity ceases in reforecasts
after 5-10 days forecast lead time

pos. inflow frequency anomaly   pos. outflow frequency anomaly

Institute of Meteorology and Climate Research (IMK-TRO)
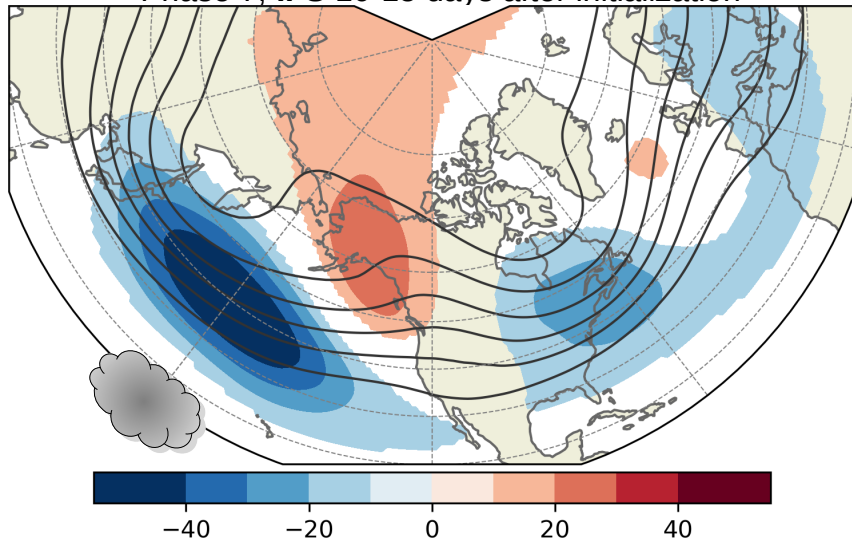
How is this modulation represented in S2S IFS reforecasts?

Phase 7; **IFS** 10-15 days after initialization

Phase 7; **ERAI**
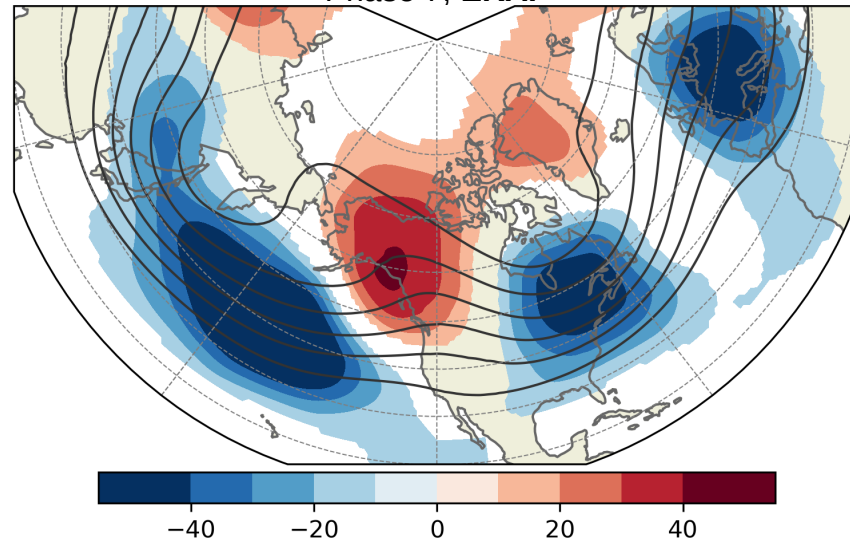
Anomalous outflow frequency and ridge over western North America are underestimated. Coincidence or causality?

500-hPa geopotential height anomaly

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Implications for MJO phase 7 with unusually high WCB activity

Consider all forecasts that were
initialized 5 days before observed
phase 7 with pentad of abnormally
high/low WCB activity

Phase 7; **ERAI**
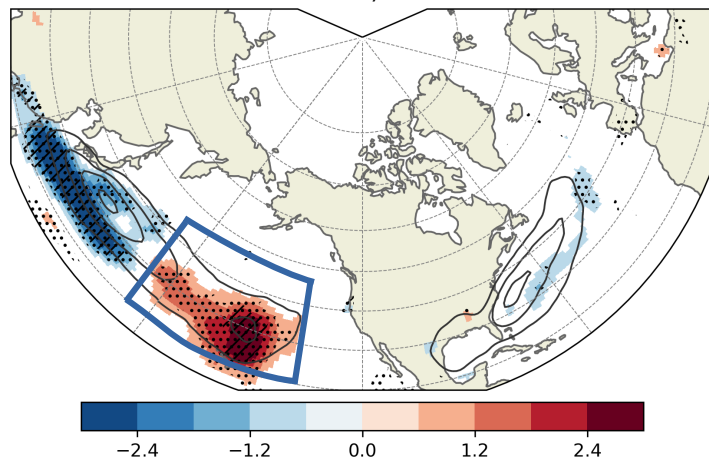
climatological frequency   Inflow frequency anomaly (%)

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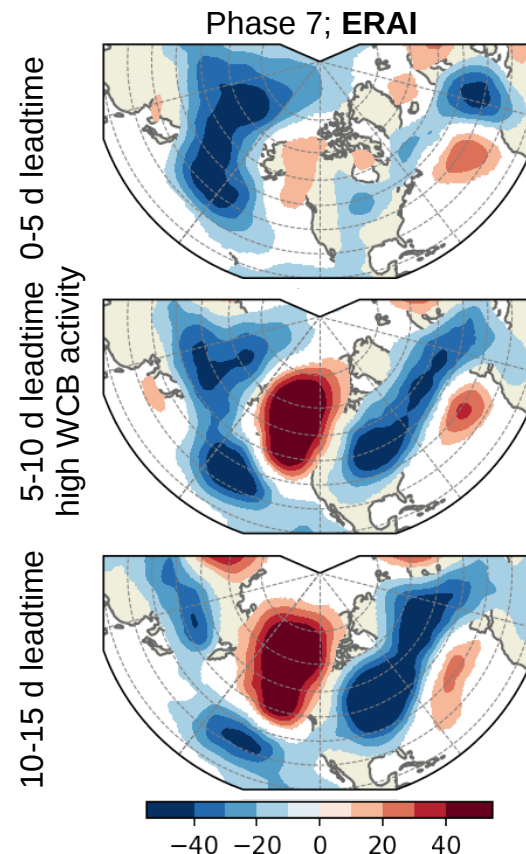# Implications for MJO phase 7 with unusually high WCB activity

High amplitude ridge/blocking develops over western North America

Canonical teleconnection pattern towards NAO- does not establish

300-hPa geopotential height anomaly

Phase 7; **ERAI**

0-5 d leadtime

5-10 d leadtime high WCB activity

10-15 d leadtime

−40 −20   0   20   40

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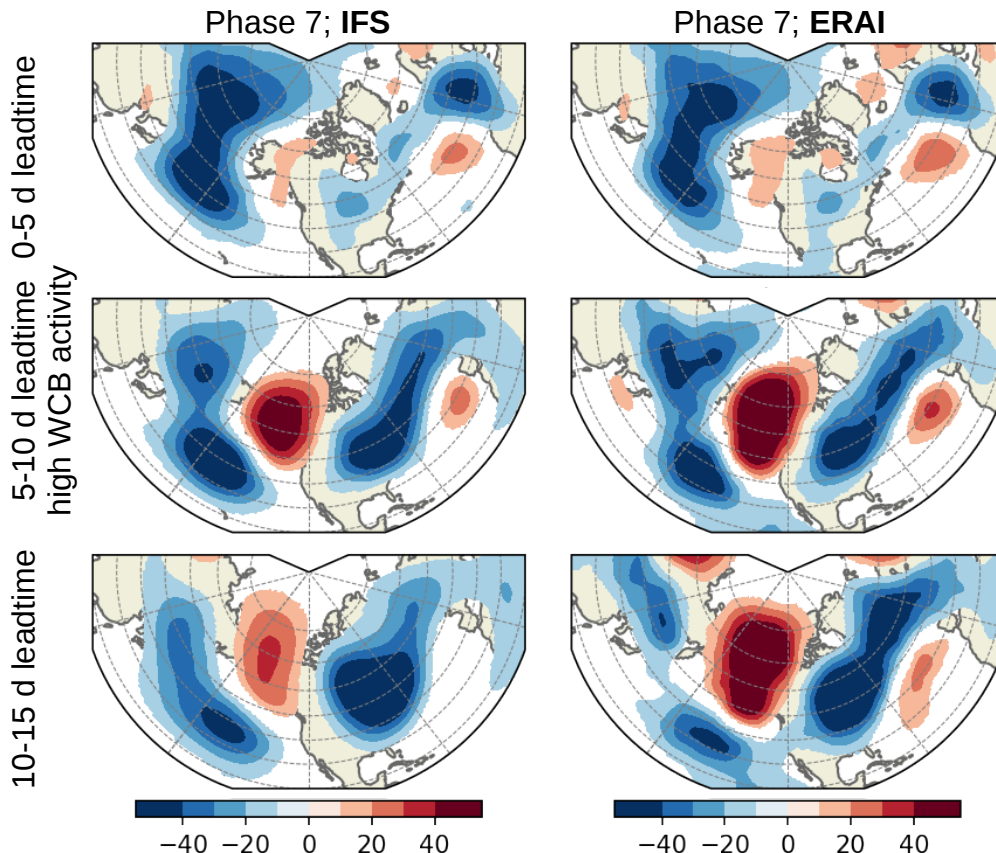Institute of Meteorology and Climate Research (IMK-TRO)

Implications for MJO phase 7 with unusually high WCB activity

High amplitude ridge/blocking develops over western North America

Canonical teleconnection pattern towards NAO- does not establish

High amplitude ridge in IFS S2S reforecasts weakens more rapidly than in ERAI

Phase 7; **IFS**   Phase 7; **ERAI**

0-5 d leadtime

5-10 d leadtime
high WCB activity

10-15 d leadtime

300-hPa geopotential height anomaly

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Take-home messages

- Deep learning models skillfully identify footprints of Lagrangian airstreams at **significantly reduced costs** and from data at coarse resolution

- systematic biases in WCB occurrence in S2S reforecasts affect Rossby wave pattern

- weekly **WCB skill up to 2 weeks**

- WCB activity is modulated by MJO
  → in line with studies on ECs and ARs (Moore et al. 2010; Mundhenk et al. 2016; Guo et al. 2017)

- modulation of **WCB activity weakens beyond 10 days** lead time

- underestimation of ridge building over western North America after phase 7 correlates with too low WCB outflow activity
  → cause of a long-standing problem in extended-range forecasts? (e.g., Vitart 2017)

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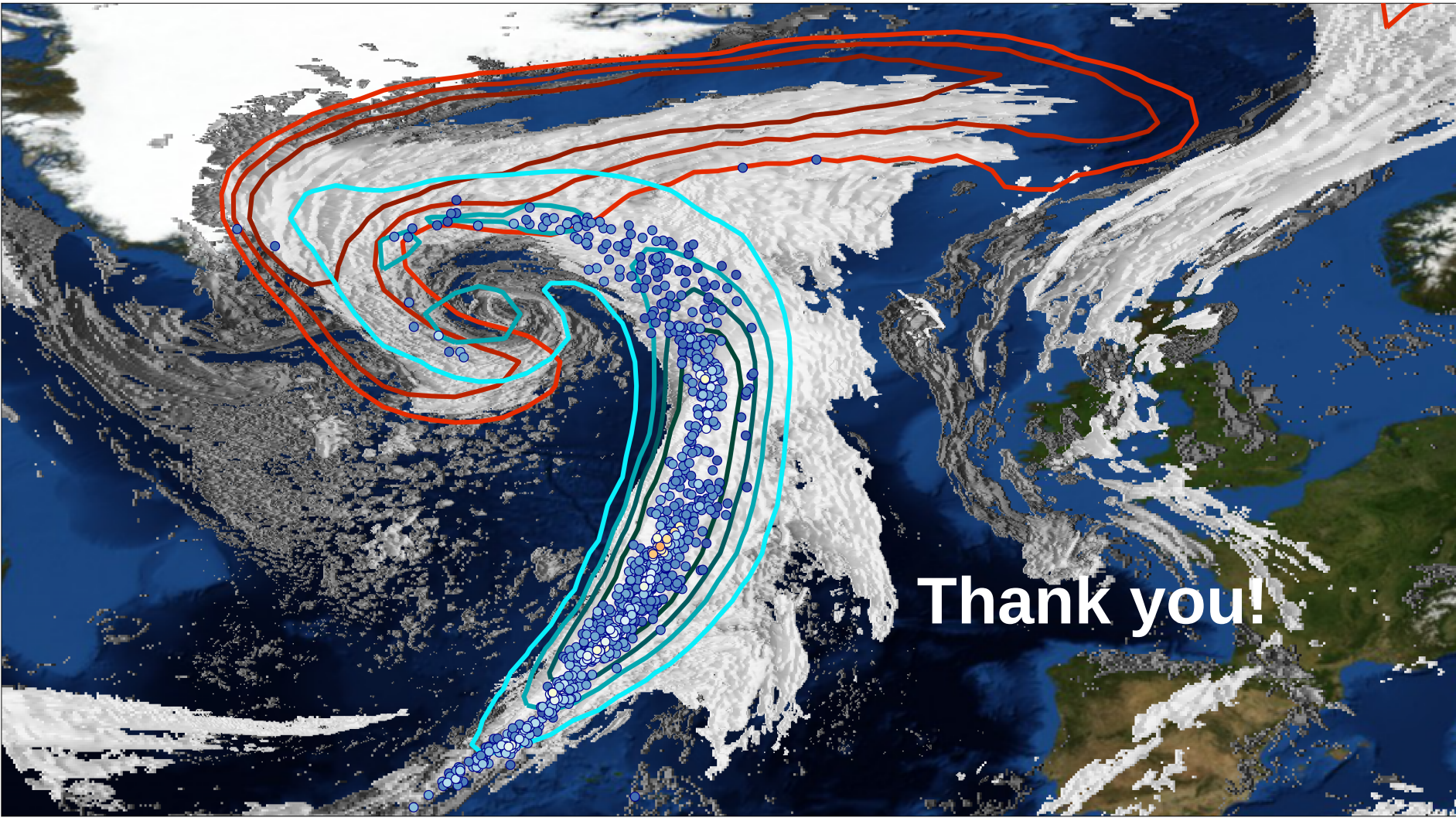
Model documentation

Description of model development and evaluation:

Geoscientific
Model Development
Discussions

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:

Geoscientific
Model Development
Discussions

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!

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