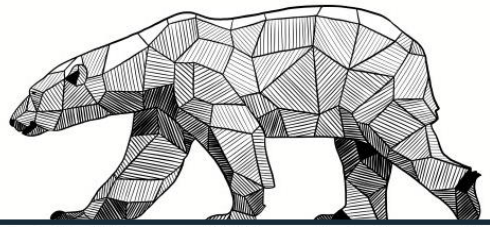
A spatial model for warm extremes in the High Arctic



Gabriele Messori
Dept. of Earth Sciences, Uppsala University, Sweden

R. Caballero, C. Woods, Stockholm University, Sweden
R. Wada, University of Tokyo, Japan

UPPSALA UNIVERSITET

The Physical Basis

- Warm spells: driven by mid-latitude moisture intrusions.
- Clear spatial footprint and underlying physical mechanism.

The Physical Basis

- Warm spells: driven by mid-latitude moisture intrusions.
- Clear spatial footprint and underlying physical mechanism.

A Spatial Model for Extreme Events

- Extremes with a narrow spatial footprint are problematic.
- Need to include information on spatial exposure in model.

The Physical Basis

- Warm spells: driven by mid-latitude moisture intrusions.
- Clear spatial footprint and underlying physical mechanism.

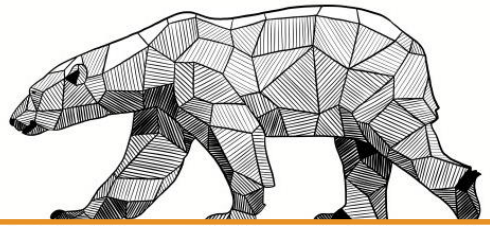
A Spatial Model for Extreme Events

- Extremes with a narrow spatial footprint are problematic.
- Need to include information on spatial exposure in model.

An Application to Warm Extremes

- A conventional EVT approach provides unphysical estimates.
- The spatial model improves over conventional EVT.

The Physical Basis of Warm Extremes in the High Arctic



Based on Messori *et al.*, *J. Clim.* (2018)

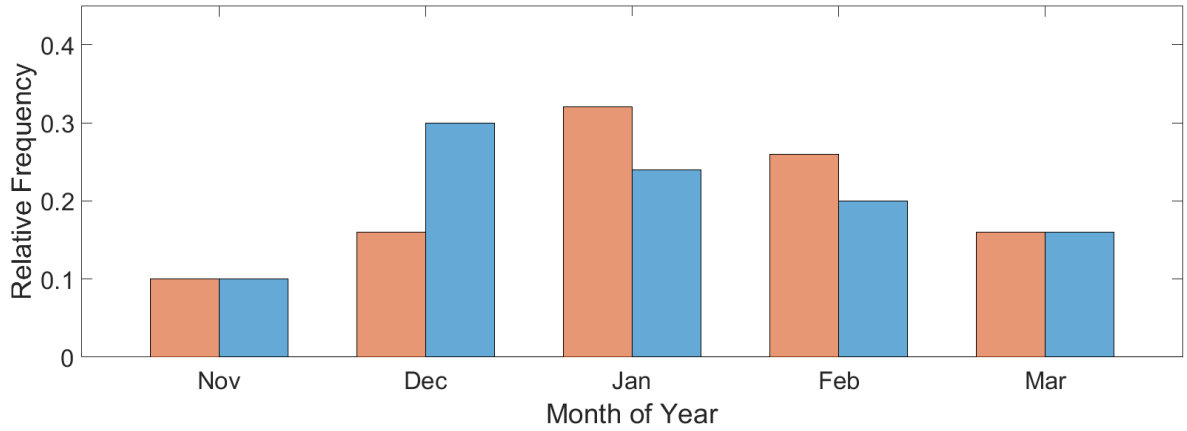
The Physical Basis

Warm spells: based on **domain-averaged T_{2m} anomalies** above 80˚ N in ERA-Interim.

The Physical Basis

Warm spells: based on **domain-averaged T_{2m} anomalies** above 80˚ N in ERA-Interim.

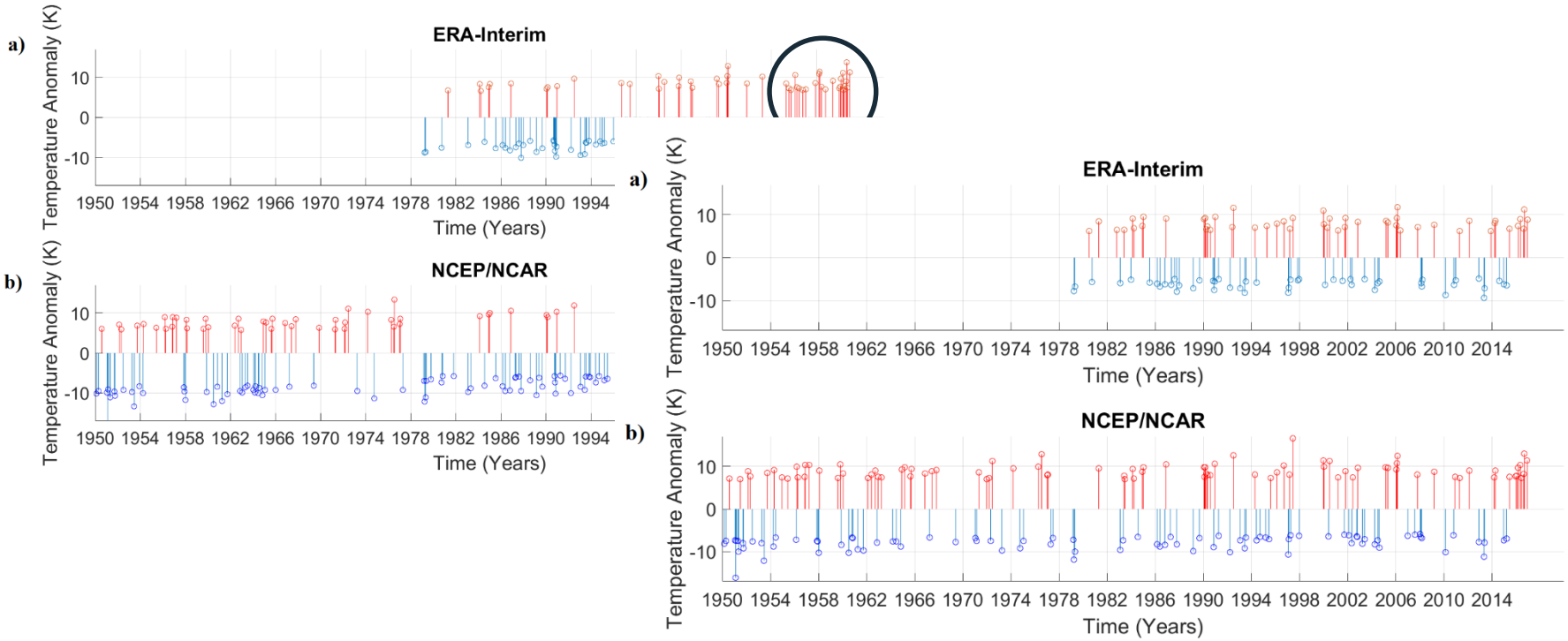
Select extreme events (~50) over 1979-2016.



Warm/cold spell frequency over NDJFM

The Physical Basis

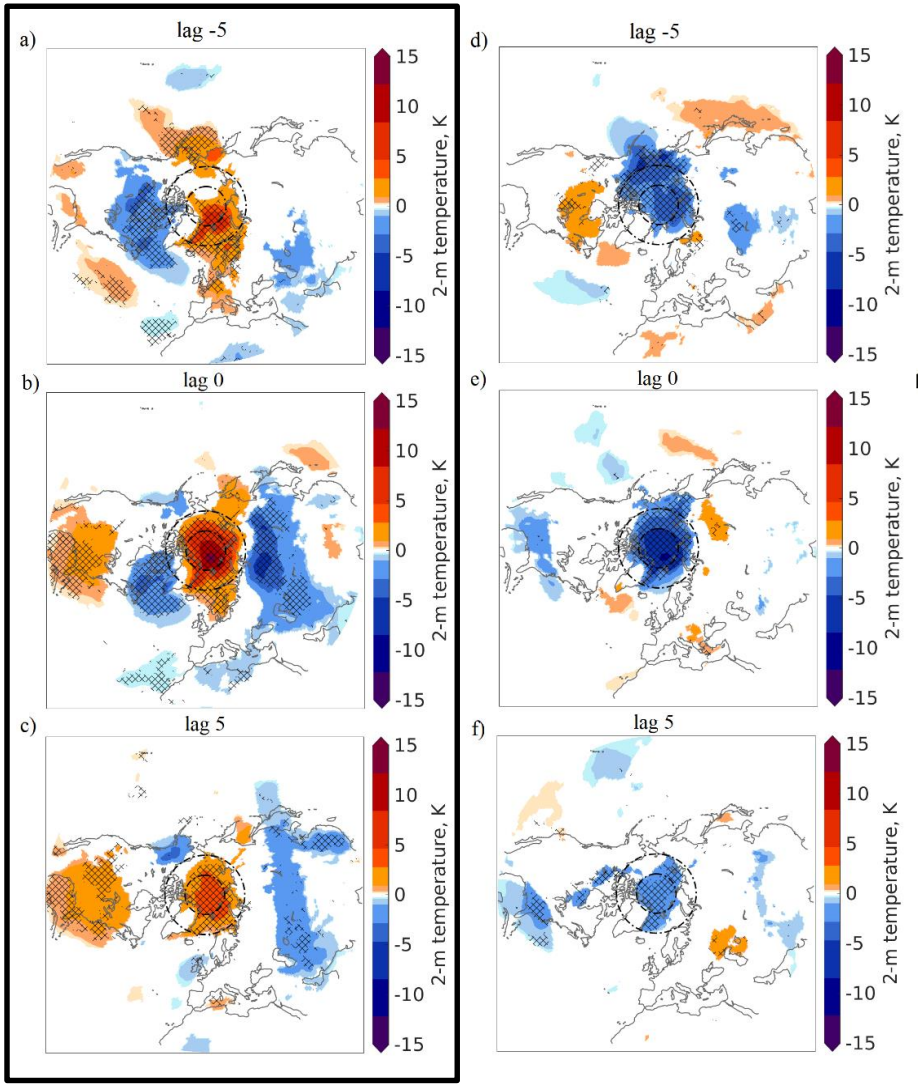
Removing the trend: moving average climatology.



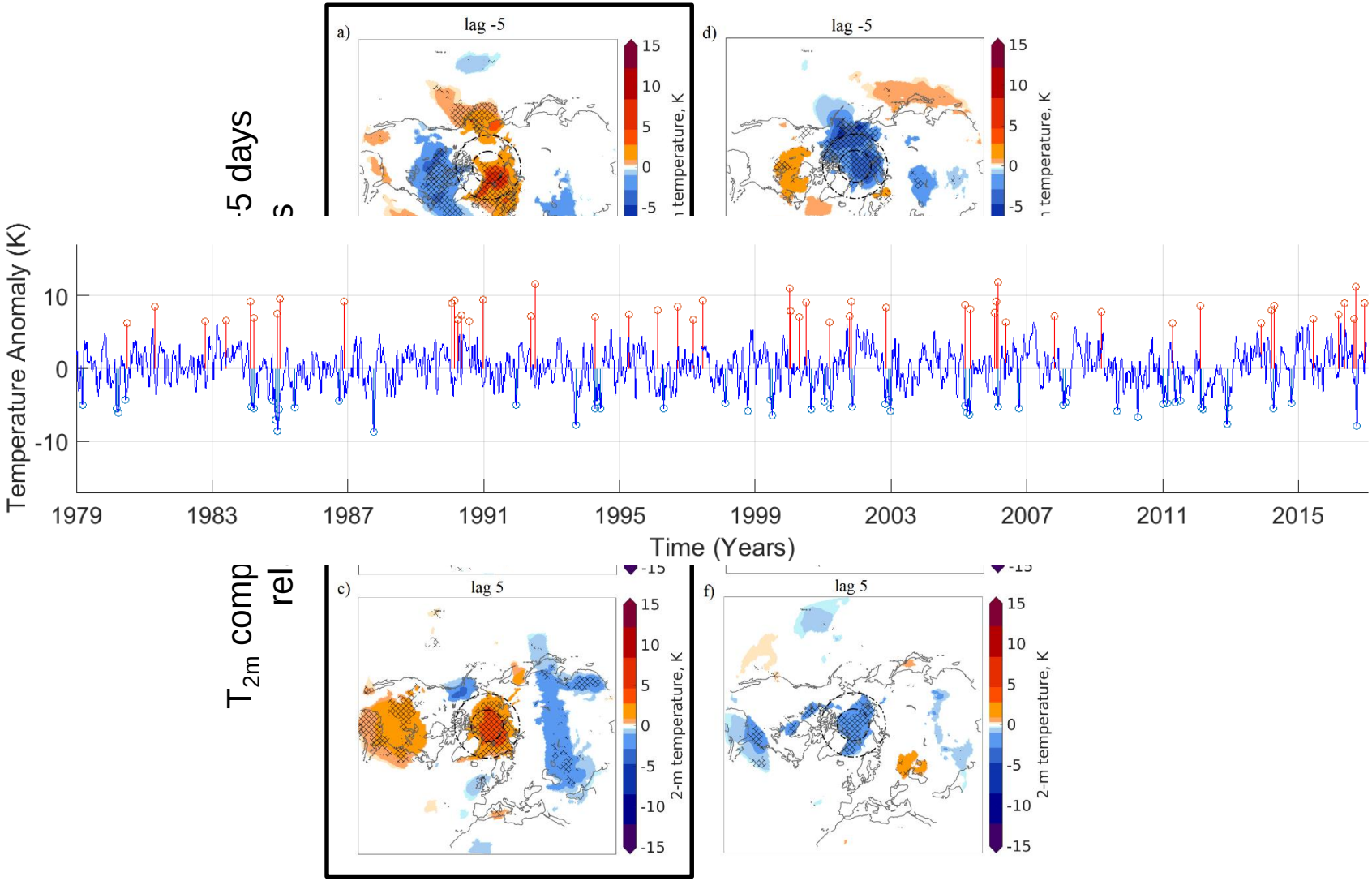
Warm/cold spell occurrences

THE PHYSICAL BASIS

T_{2m} composites at lags of -5 to +5 days relative to peak anomalies

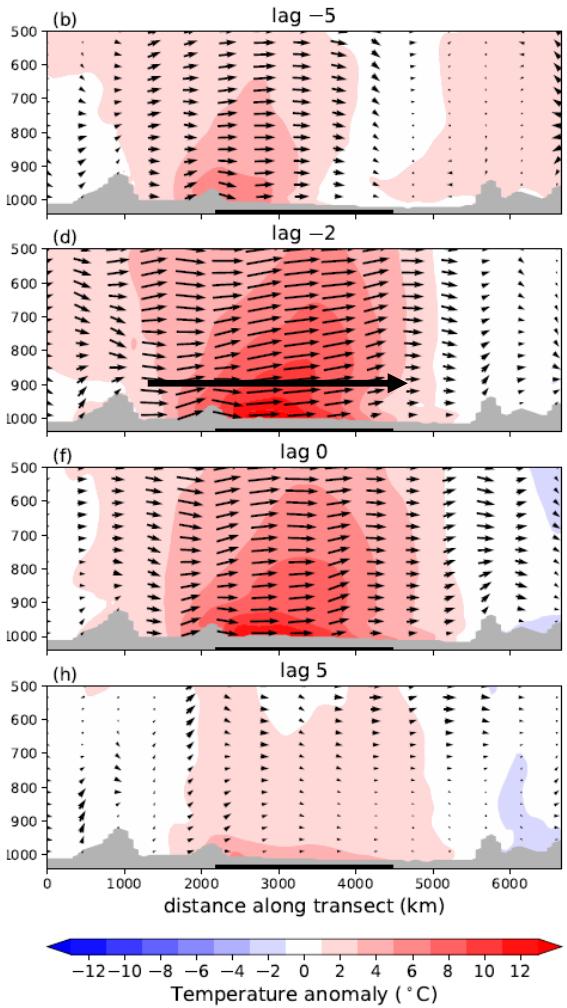


The Physical Basis



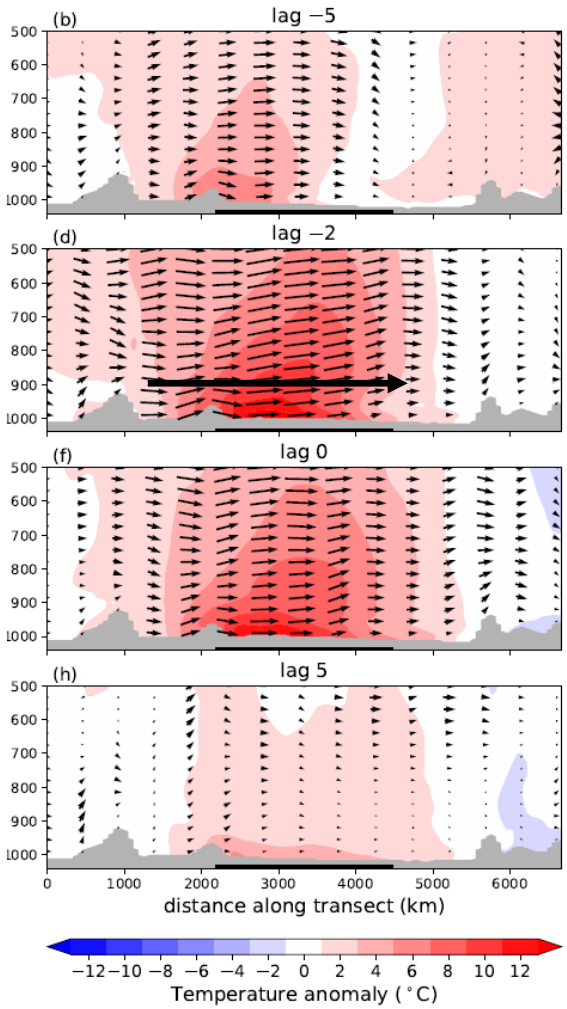
The Physical Basis

Wind and temperature composites at lags of -5 to +5 days relative to peak anomalies

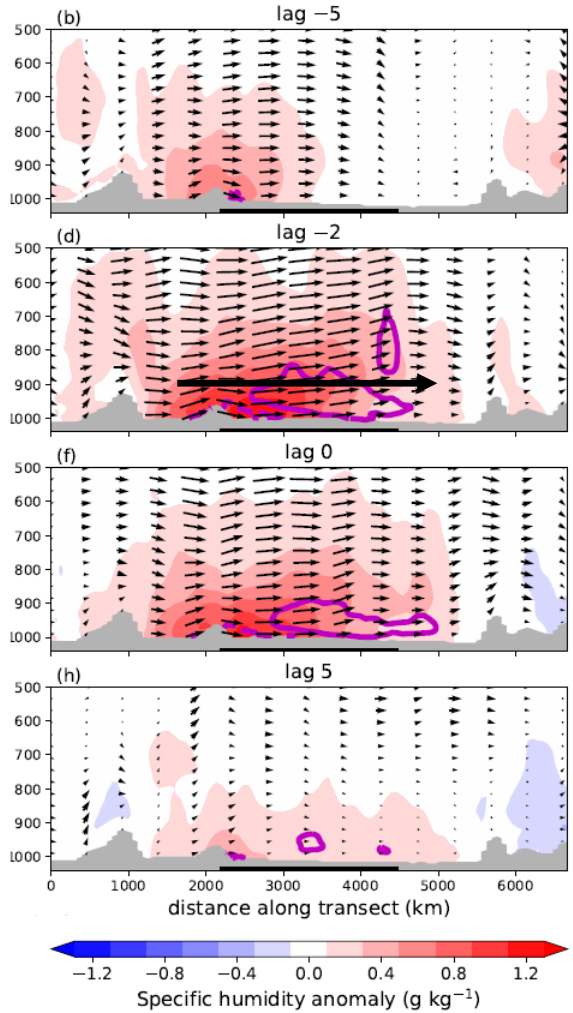


The Physical Basis

Wind and temperature composites at lags of -5 to +5 days relative to peak anomalies



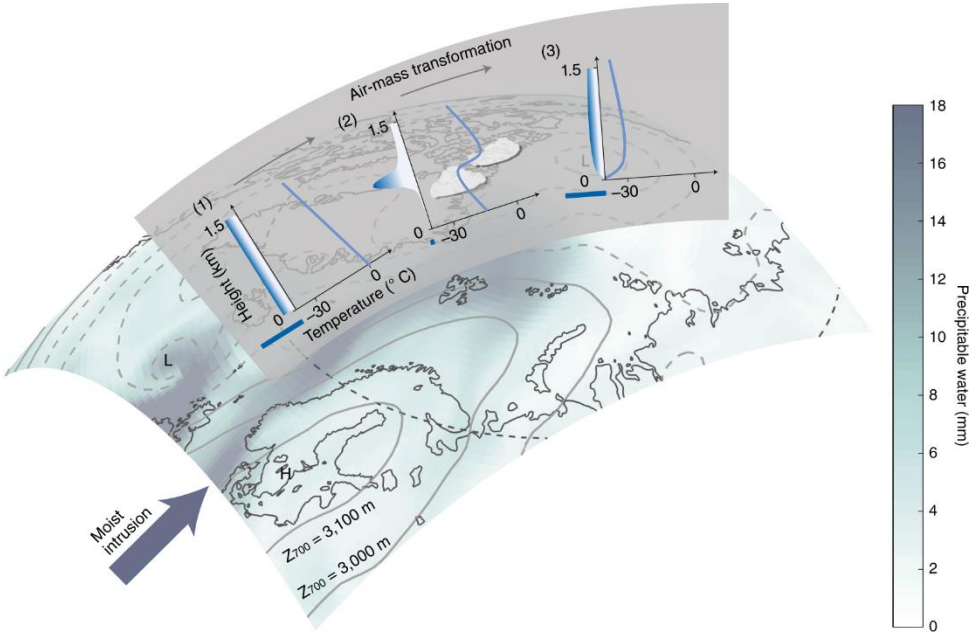
Wind and humidity composites at lags of -5 to +5 days relative to peak anomalies



The Physical Basis

Moisture intrusions: **intense, persistent and zonally extended** moisture flux across 70 °N.

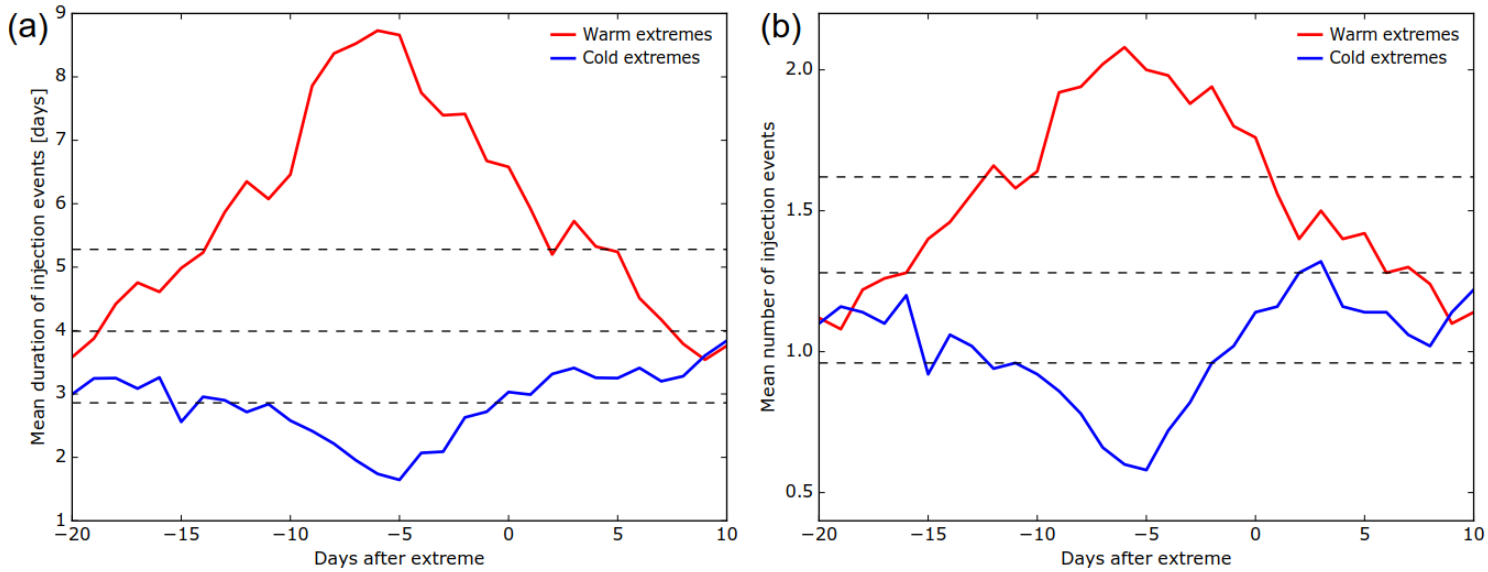
Basically mid-latitude airmass intrusion extremes.



Pithan *et al.*, *Nature Geosci.* (2018)

The Physical Basis

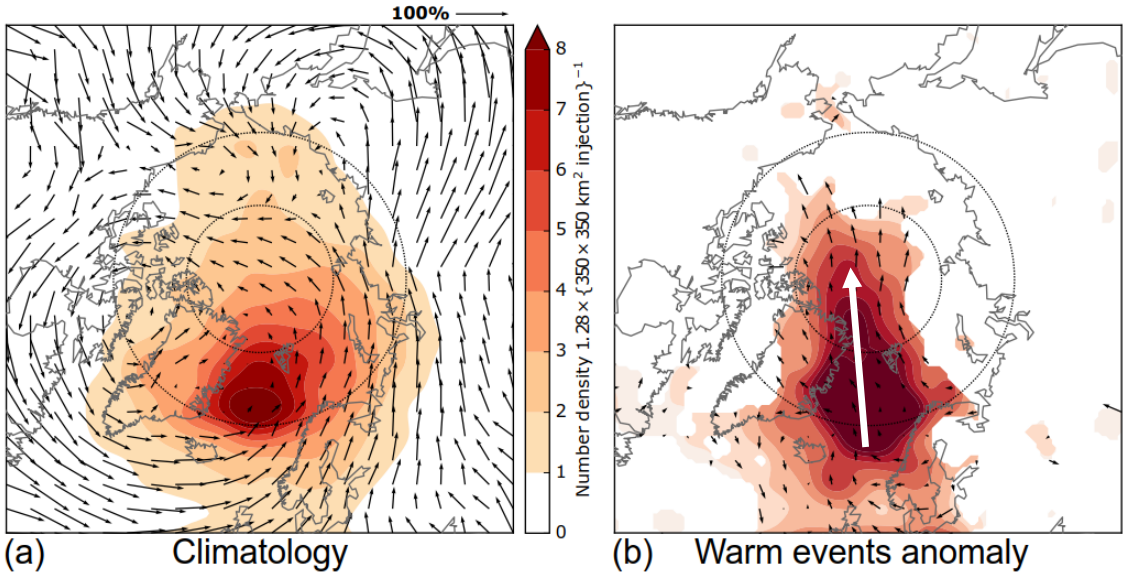
Moisture intrusions: **clear link** with warm spells:



Mean intrusion duration and number relative to peak temperature anomalies

The Physical Basis

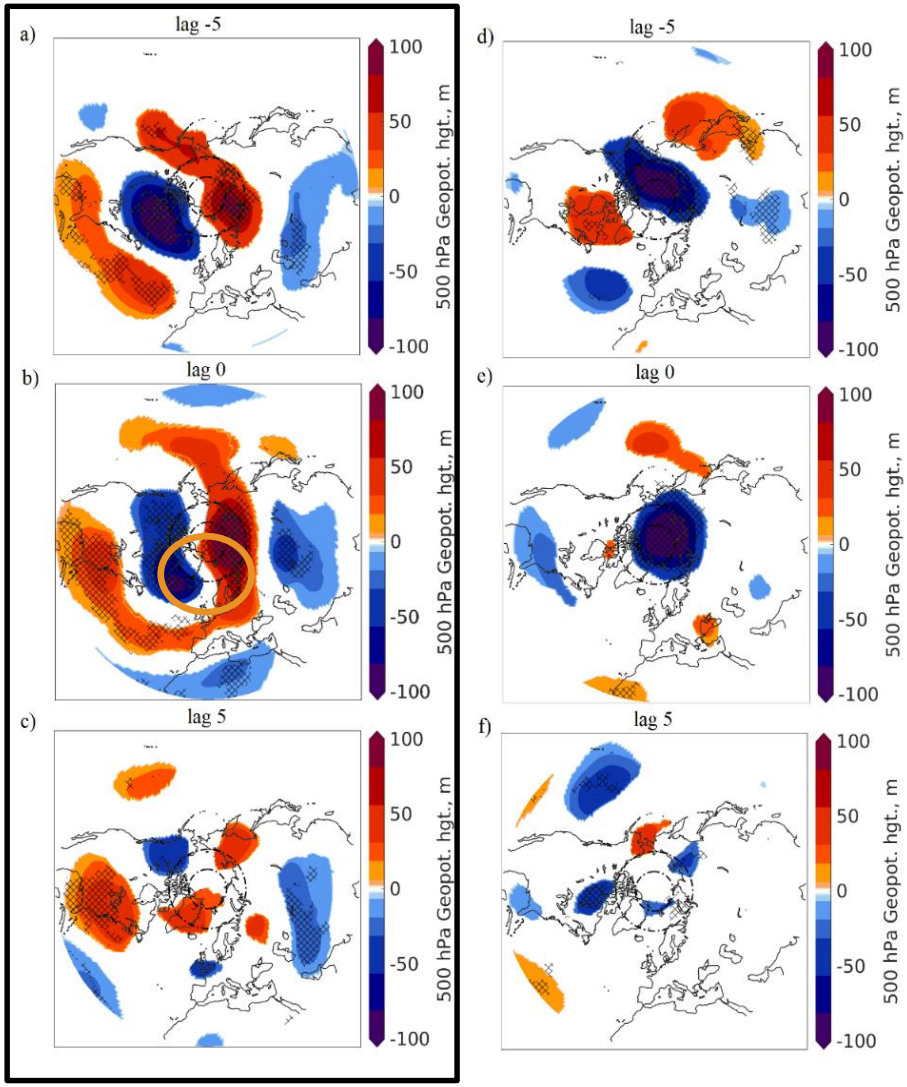
Moisture intrusions: **clear link** with warm spells:



Intrusion trajectories lags -8 to -2 days relative to peak temperature anomaly

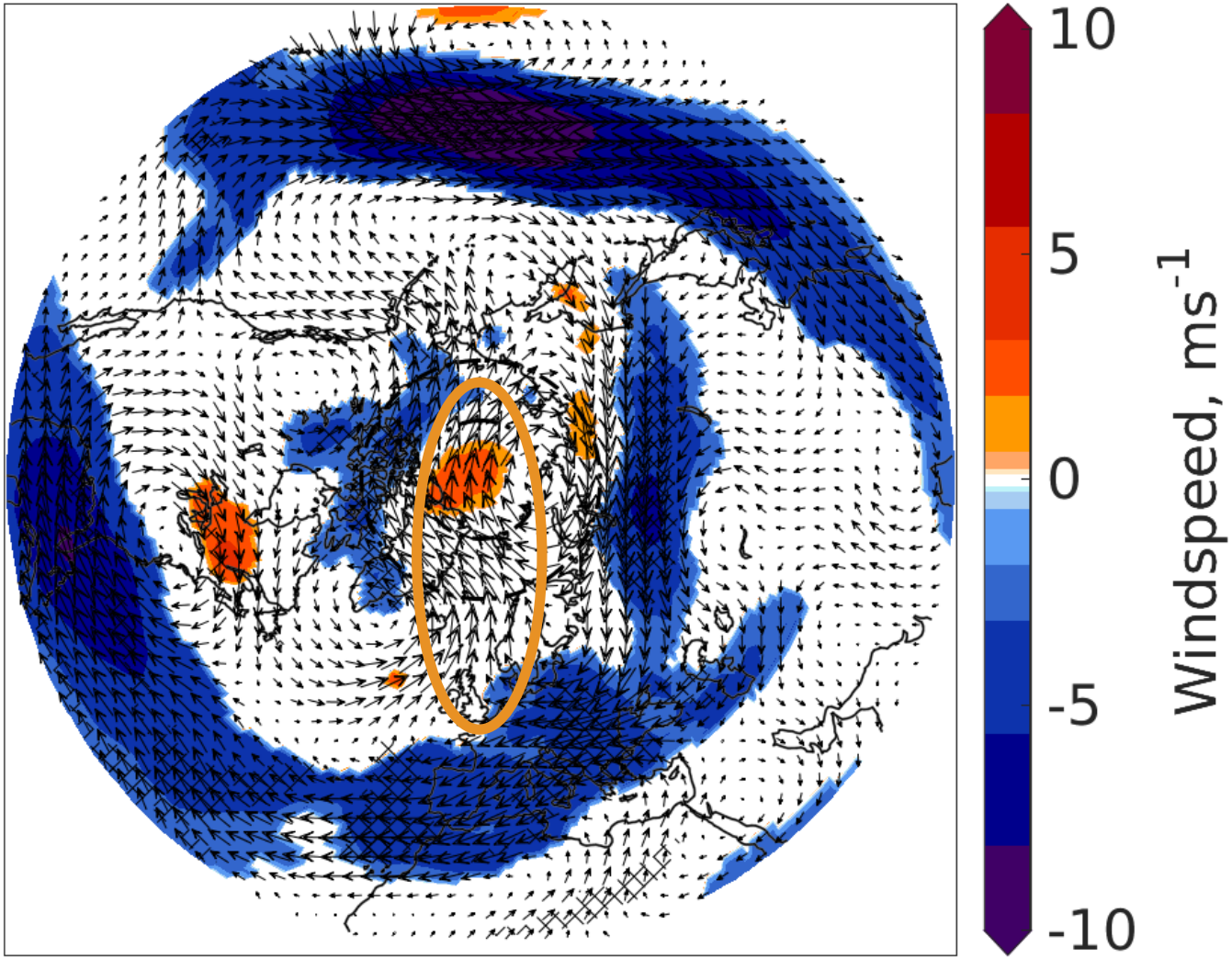
The Physical Basis

Z_{500} composites at lags of -5 to +5 days relative to peak anomalies



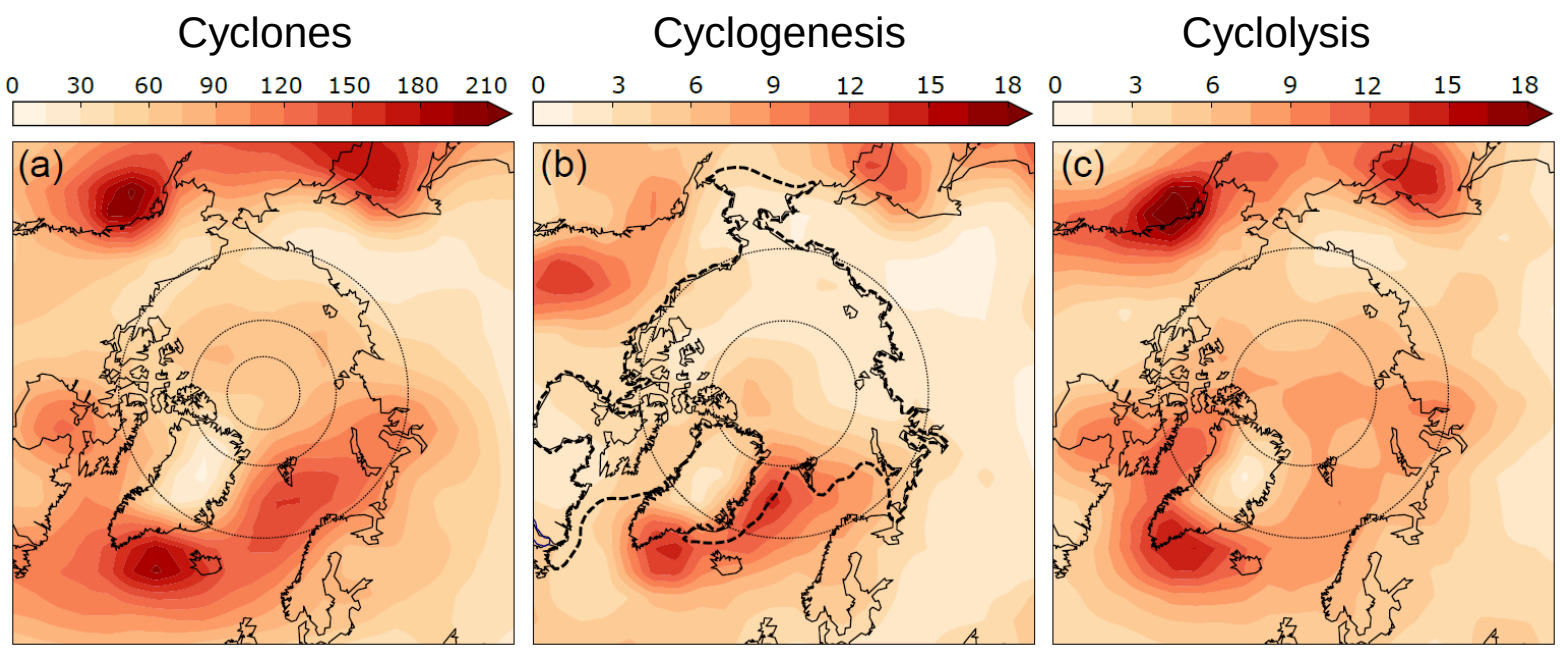
The Physical Basis

300 hPa wind and windspeed composite
on day of peak anomalies



The Physical Basis

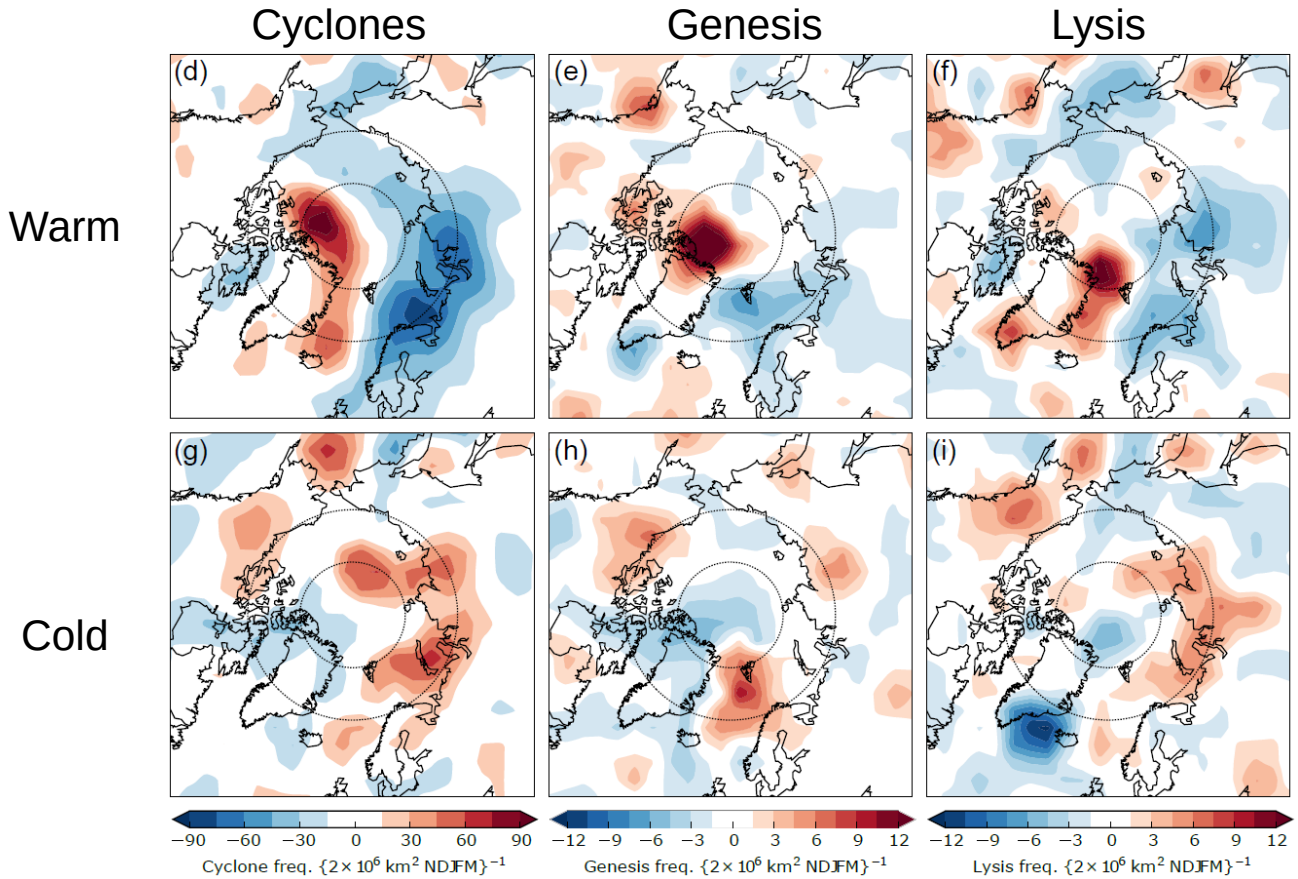
Cyclone Climatology:



Hanley and Caballero, *GRL* (2012)

The Physical Basis

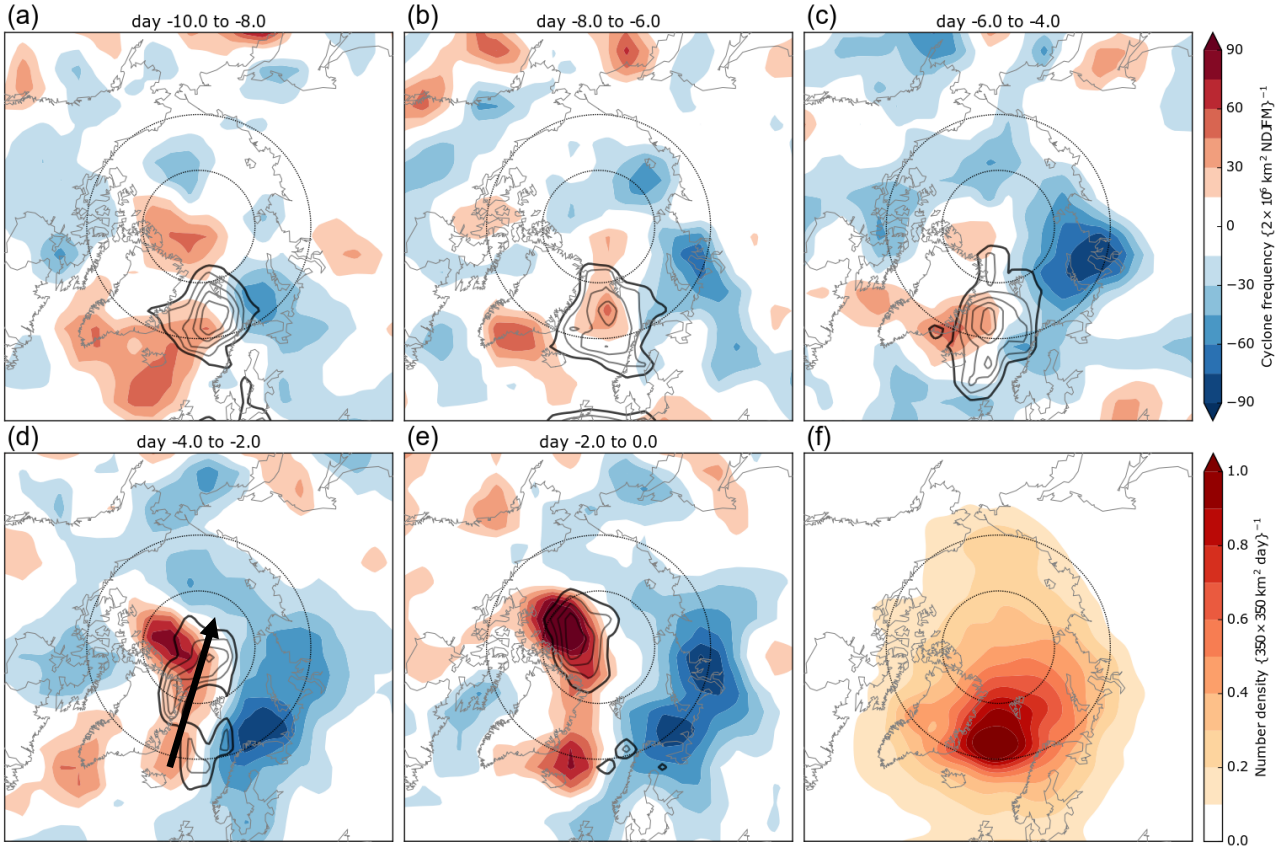
Cyclone Climatology:



Frequency anomaly of cyclones, genesis and lysis for 4 days prior to warm and cold spells.

The Physical Basis

Cyclone Climatology:



Frequency anomaly of cyclones prior to warm spells.

The Physical Basis of Warm Extremes in the High Arctic

- Mid-lat airmasses/moisture intrusions with clear spatial footprint → warm Arctic extremes.
- Large-scale configurations favour the intrusions/ extremes, chiefly in the Atlantic sector.
- Important role of cyclones on synoptic scales.

A Spatial Model for Extreme Events

Based on Wada *et al.*, *Ocean Eng.* (2018)

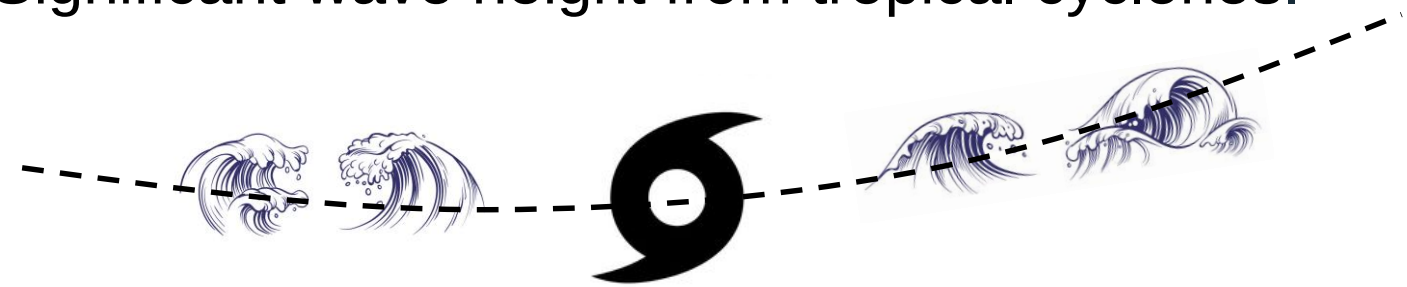
A Spatial Model for Extreme Events

The problem:

Estimate severity over long return times from short observational data series, for geophysical extremes with a narrow spatial footprint.

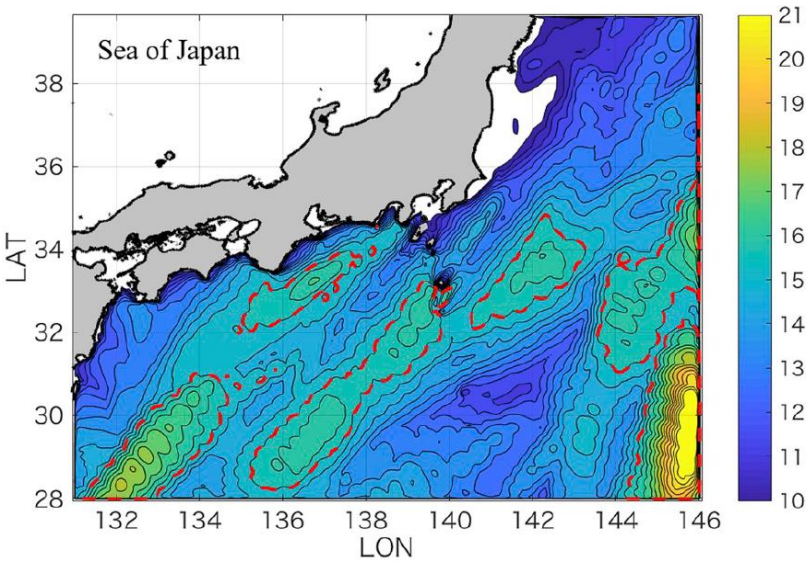
A good example:

Significant wave height from tropical cyclones.

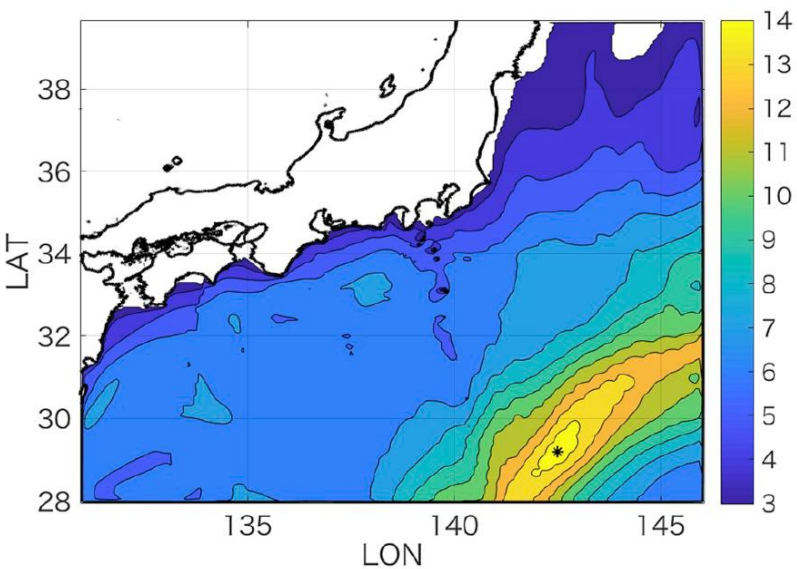


A Spatial Model for Extreme Events

A naïve attempt with classical EVT:



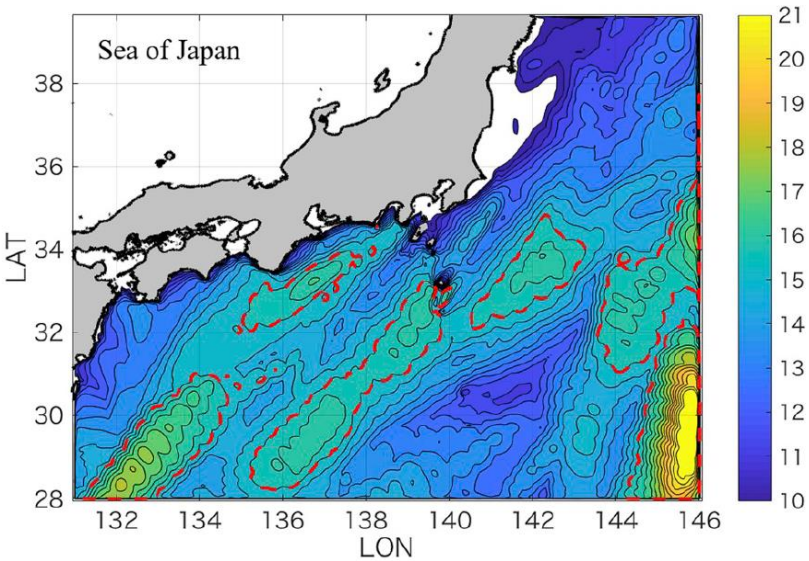
Max. significant Wave Height (m) in Todai hindcast dataset



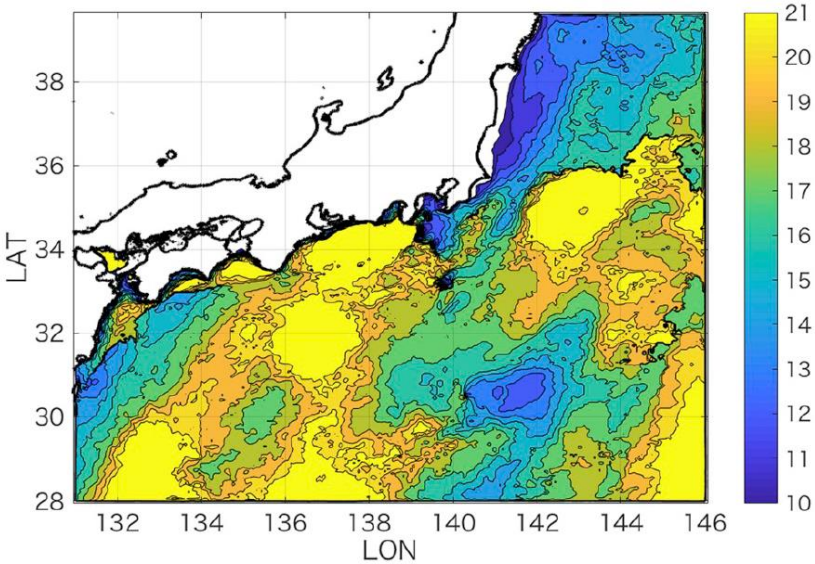
Max. significant Wave Height (m) for an individual cyclone

A Spatial Model for Extreme Events

A naïve attempt with classical EVT:



Max. significant Wave Height (m) in Todai hindcast dataset



100-year return value estimates for max. significant Wave Height (m)

A Spatial Model for Extreme Events

STM-E Model:

Two-part model: Space-Time Maxima (STM) and Exposure (E)

STM: extract the locations of the maximum values during each extreme event.

E: a value normalized in [0, 1] for each event, in the form of a geographical map.

Assuming that the distributions of STM and E are independent, the two may be multiplied to derive the STM-E extreme behavior estimate at each location.

A Spatial Model for Extreme Events

Define STMs:

Select maximum for each physical event (e.g. cyclone)

$\{s\}_{i=1}^{n}$, n being the number of events

Can then use standard EVT (e.g. GPD to compute conditional distribution of threshold exceedances).

Define Es (N.B. sloppy notation for conciseness):

$e_{i,j} = \max\left(\frac{h(j,t)}{s_i}\right)$, *j* being an index over spatial locations, and t being an index over timesteps for which the event lasts.

A Spatial Model for Extreme Events

Combine to obtain STM-E:

Event severity at a location *j* is $H_j = E \times S$, *E* and *S* random variables for STM and Exposure.

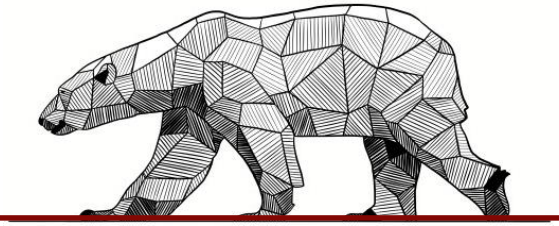
Can then obtain the cumulative distribution of H_j.

N.B. We have thus «pooled» STMs so that all physical events contribute to the set $\{s_i\}$.

A Spatial Model for Extreme Events

- Some geophysical extremes pose a challenge to conventional EVT estimates.
- STM-E approach presents a possible solution, taking into account spatial exposure and “pooling” space-time maxima.
- Subject to some assumption on independence of distributions.

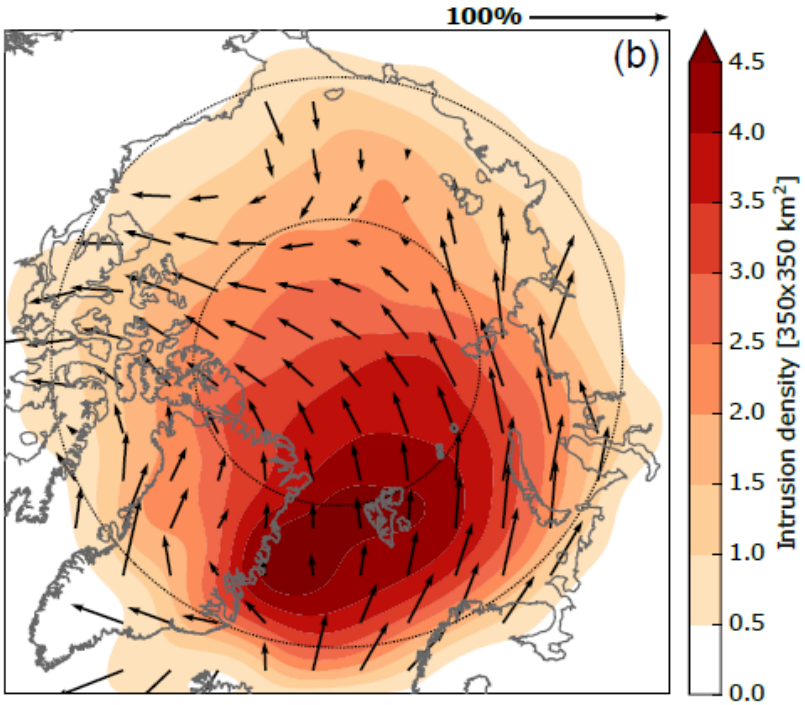
An Application to Warm Extremes in the High Arctic



Based on Messori *et al.*, *Q. J. Roy. Met. Soc., in review.*

An Application to Warm Extremes

Focus on **warm extremes driven by mid-latitude airmass intrusions:**



Intrusion density and trajectories, NDJFM

An Application to Warm Extremes

Process:

(i) Extract 2-metre air temperature anomalies for each intrusion. N.B. Can last for multiple days.

(ii) Compute STM and retain events with STM > 22.5K (we tested sensitivity).

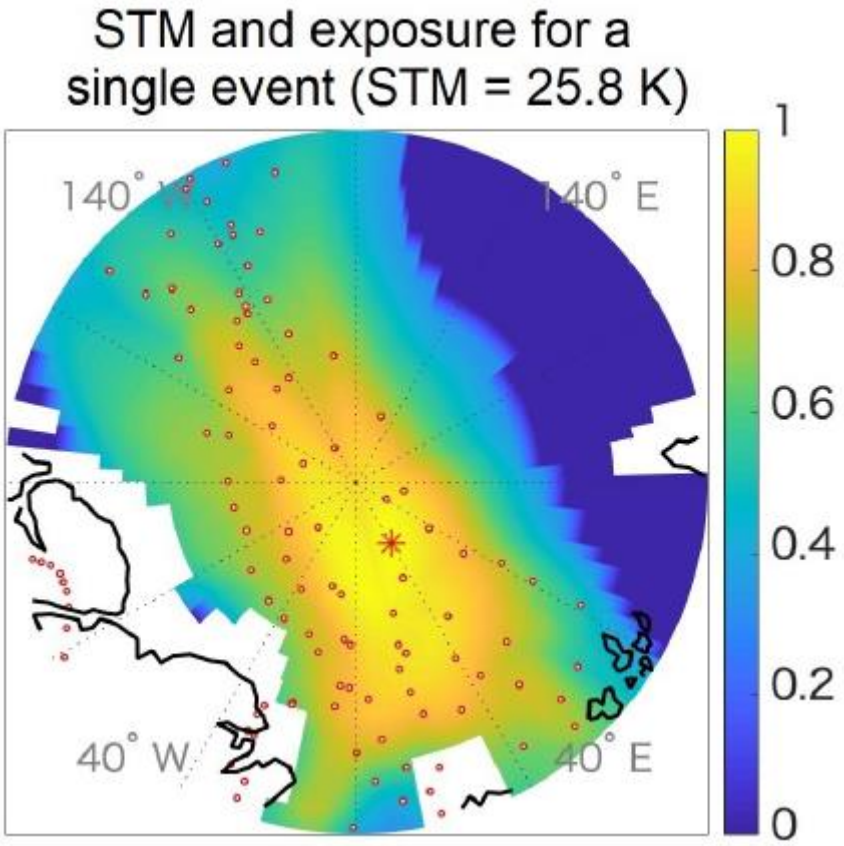
(iii) Set a threshold of 8 K (we tested sensitivity).

(iv) Identify contiguous geographical exceedance regions matching the intrusions and compute E.

(v) Apply STM-E!

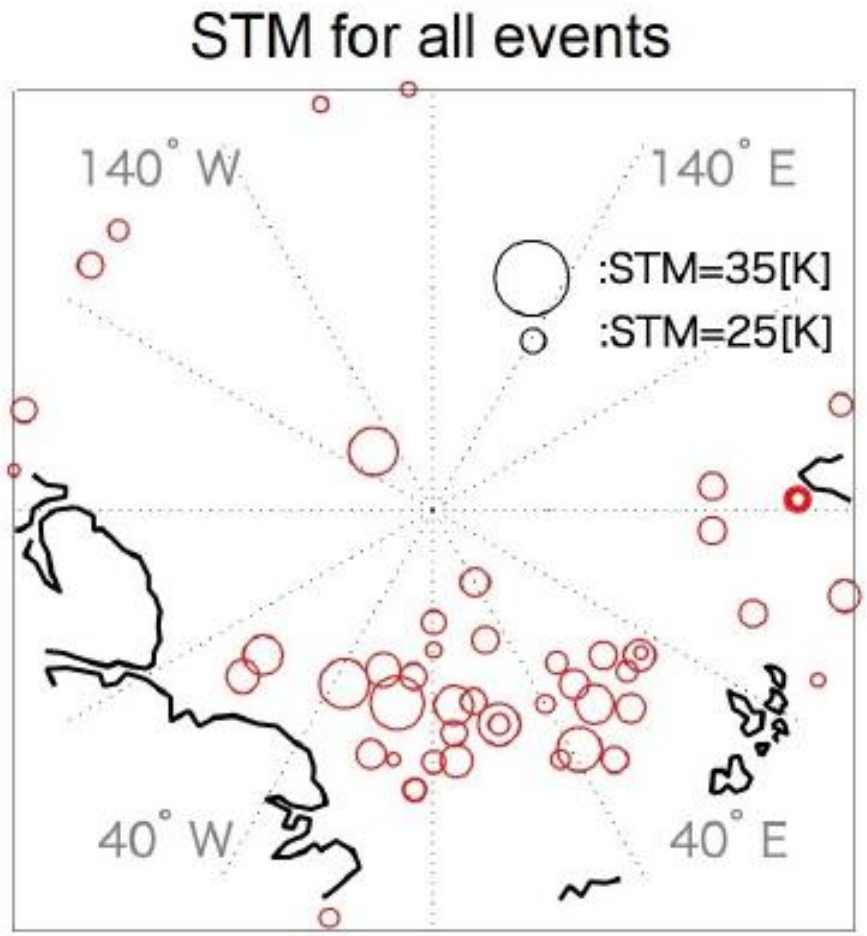
An Application to Warm Extremes

Example for one event:



An Application to Warm Extremes

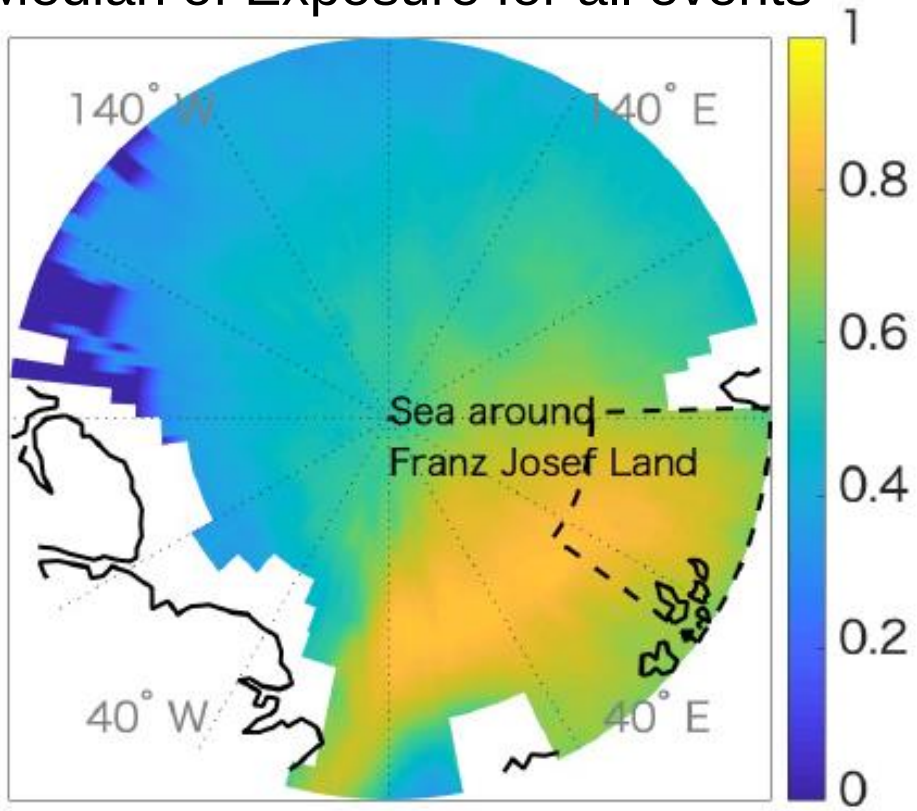
STMs:



An Application to Warm Extremes

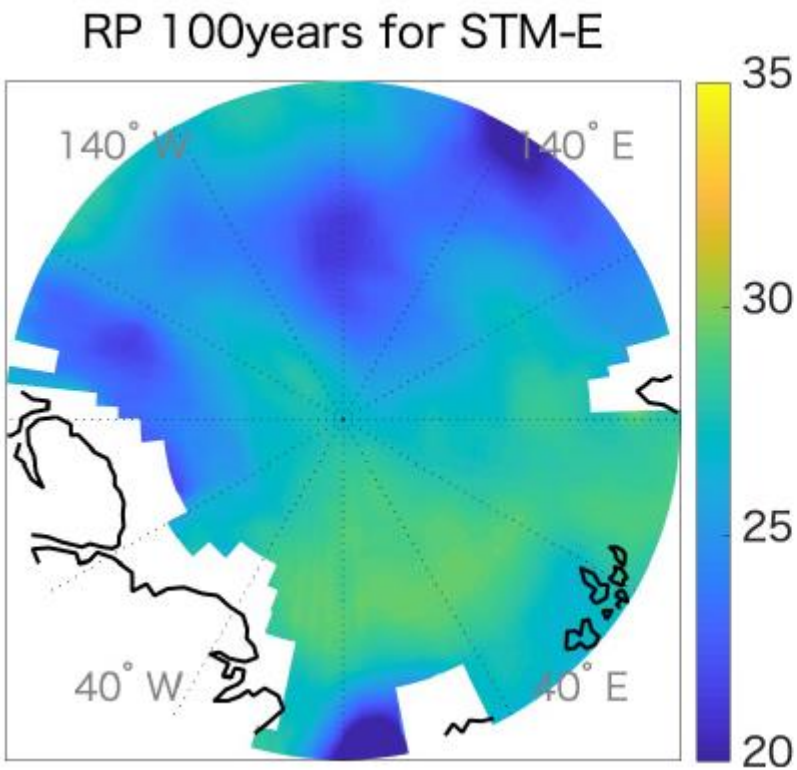
Exposure:

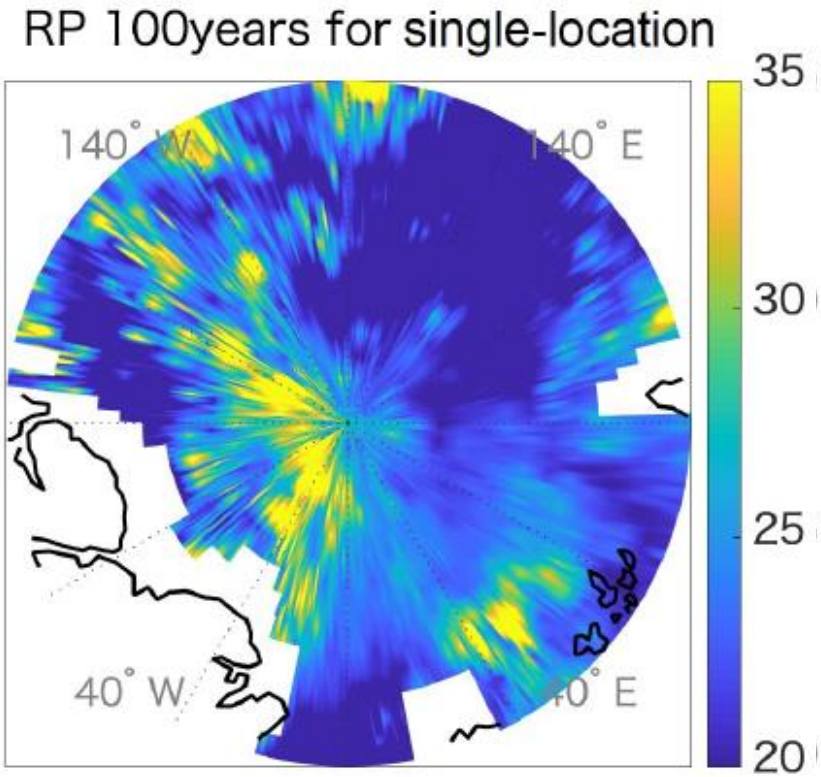
Median of Exposure for all events



An Application to Warm Extremes

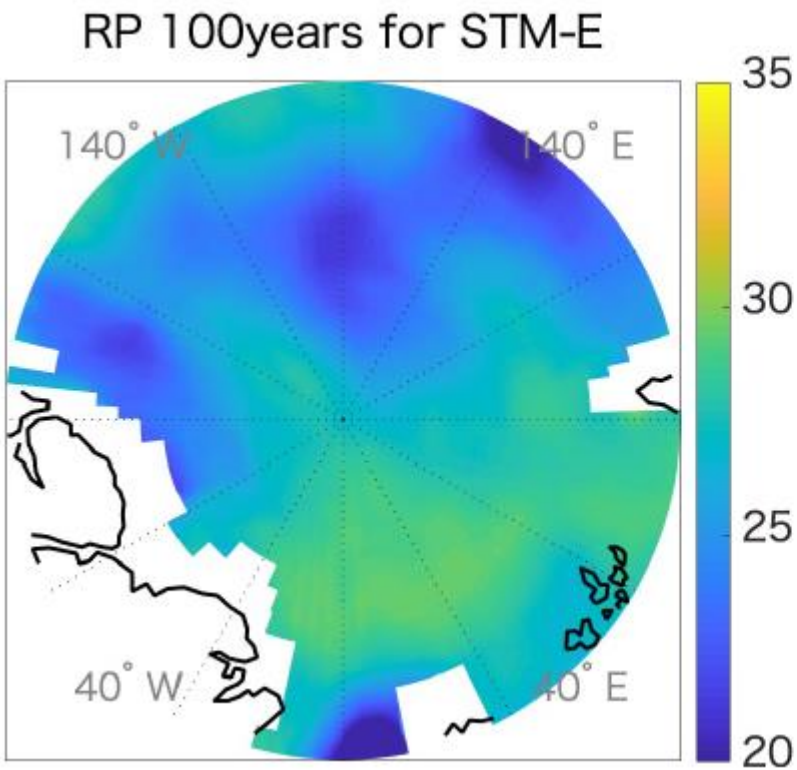
100-yr return values:

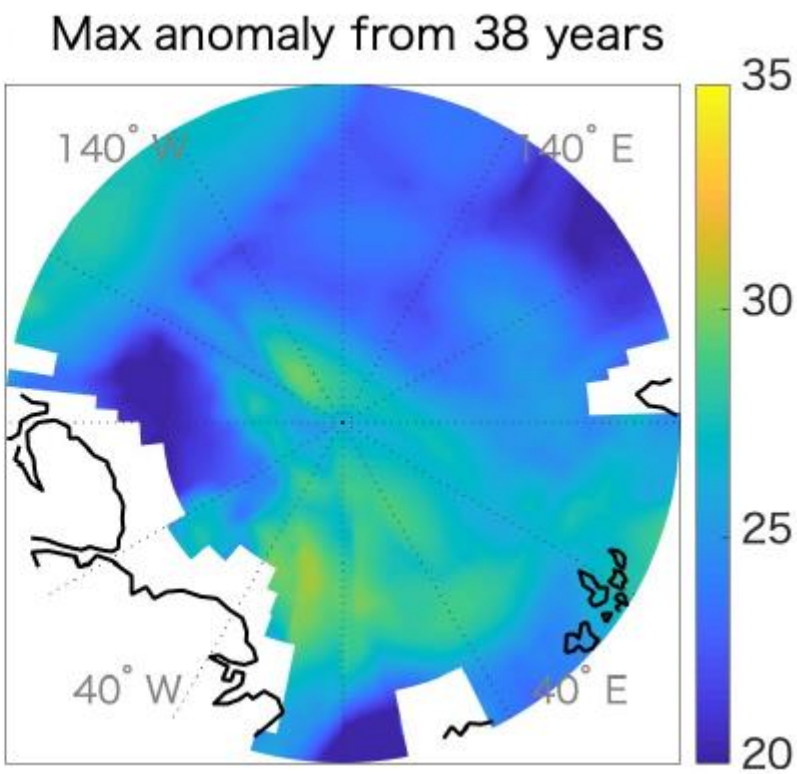




An Application to Warm Extremes

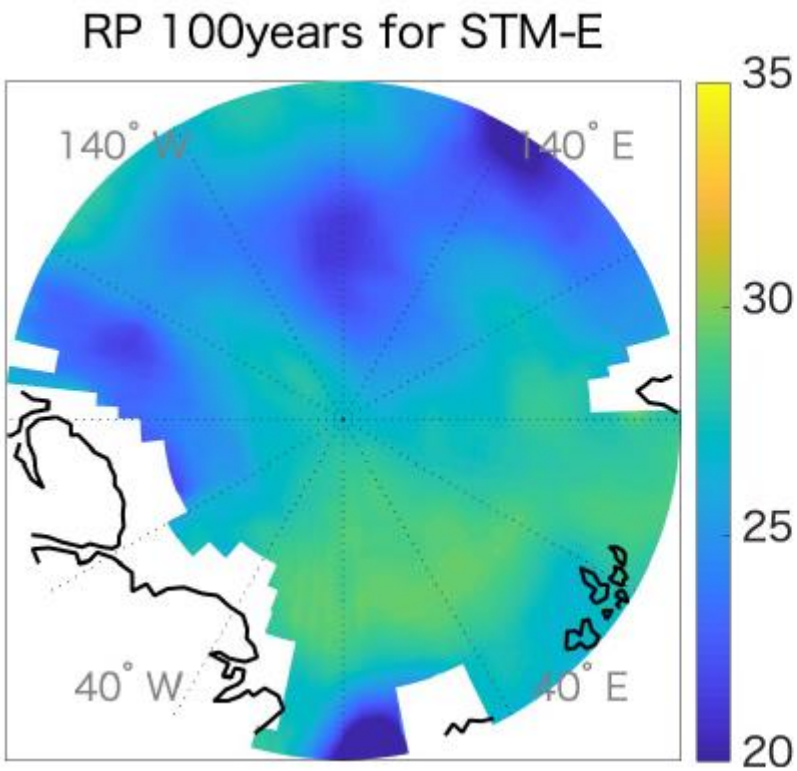
100-yr return values:

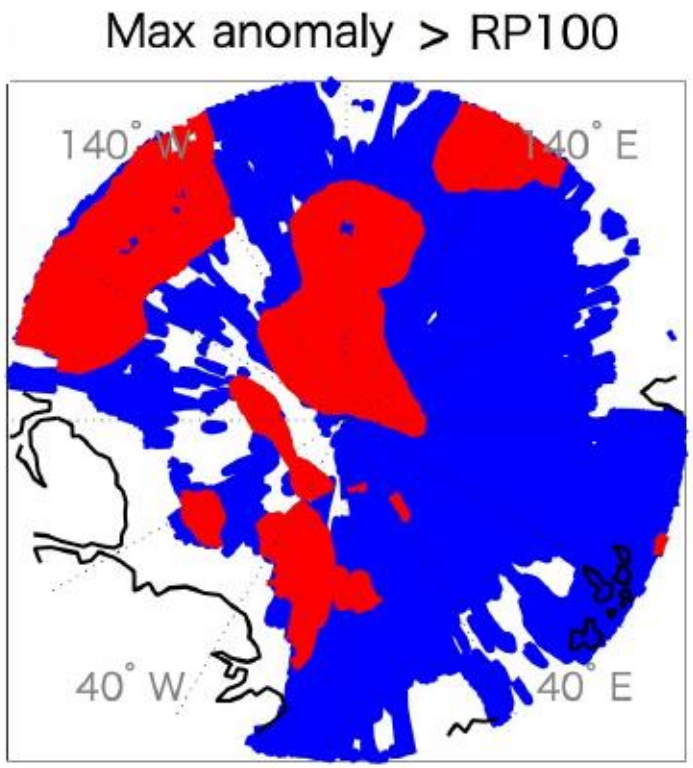




An Application to Warm Extremes

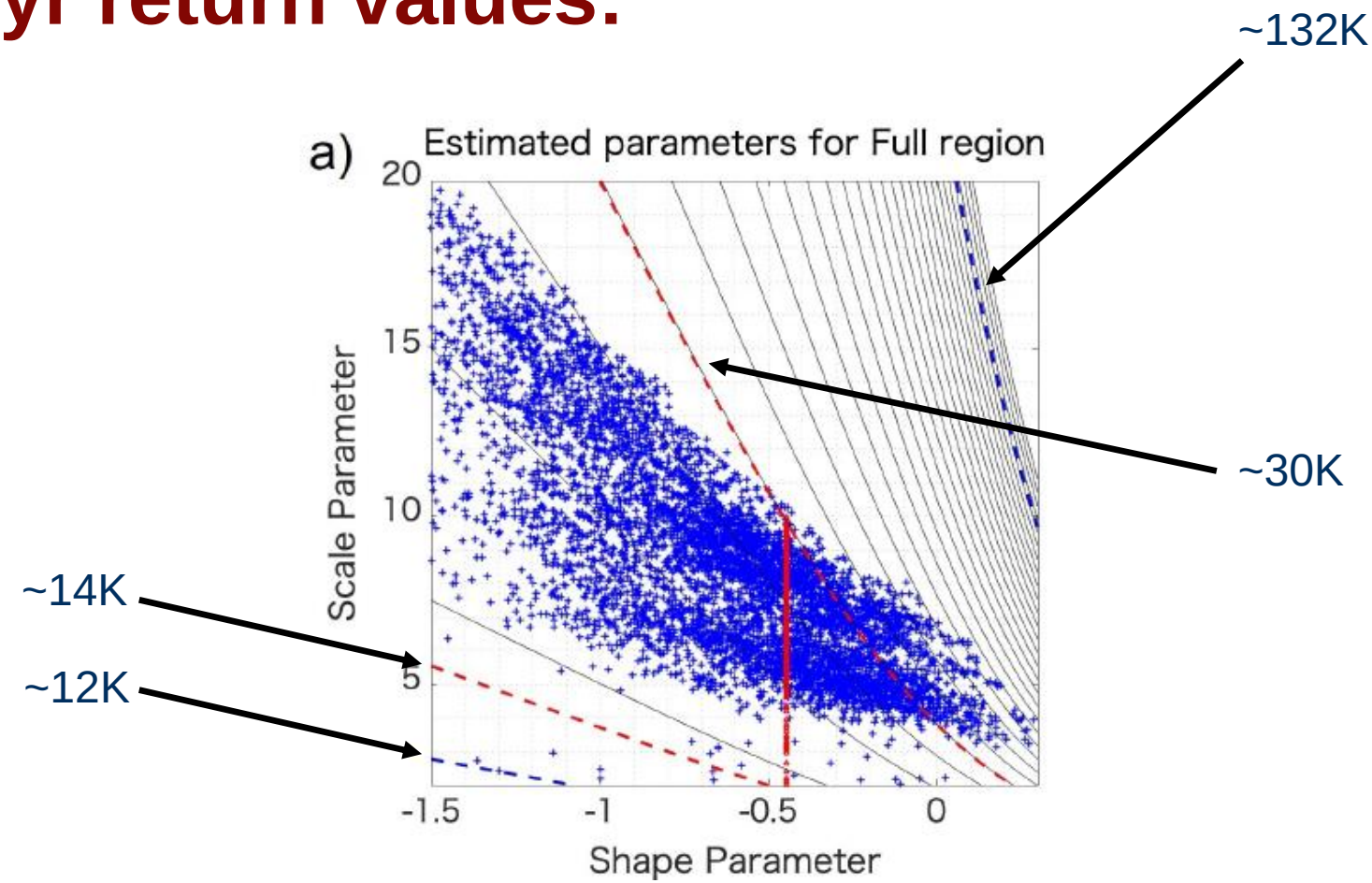
100-yr return values:





An Application to Warm Extremes

100-yr return values:



An Application to Warm Extremes in the High Arctic

- Arctic warm extremes are an example of geophysical extreme where a naïve EVT approach fails.
- The STM-E model seems to provide sensible estimates.
- Possible in the future to include non-stationarity in the framework?

Thank You!

Messori, G.*, Ryota, W.*, (equal contribution) Woods, C. A spatial model for warm temperature extremes in the High Arctic. *Q. J. Roy. Met. Soc., in review.*

Wada, R., Waseda, T., Jonathan, P. (2018). A simple spatial model for extreme tropical cyclone seas. *Ocean Eng*.

Messori G., Woods C., Caballero R. (2018) On the drivers of wintertime temperature extremes in the High Arctic. *J. Clim*.

Woods, C., Caballero, R. (2016). The role of moist intrusions in winter Arctic warming and sea ice decline. *J. Clim*.