Warm Conveyor Belts and Cloud Radiative Forcing

WCB – WORKSHOP

ECMWF, March 12th 2020

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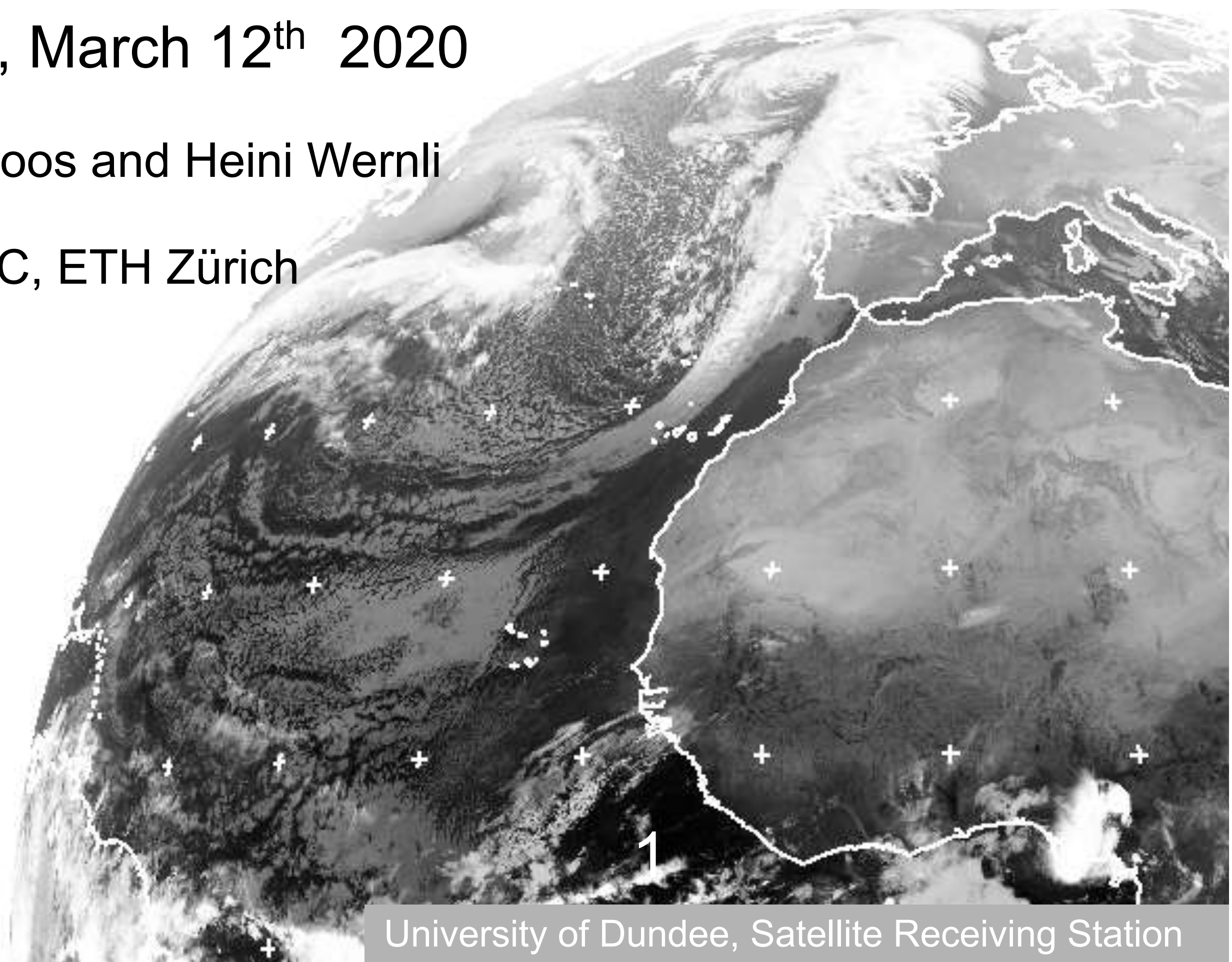
IAC, ETH Zürich



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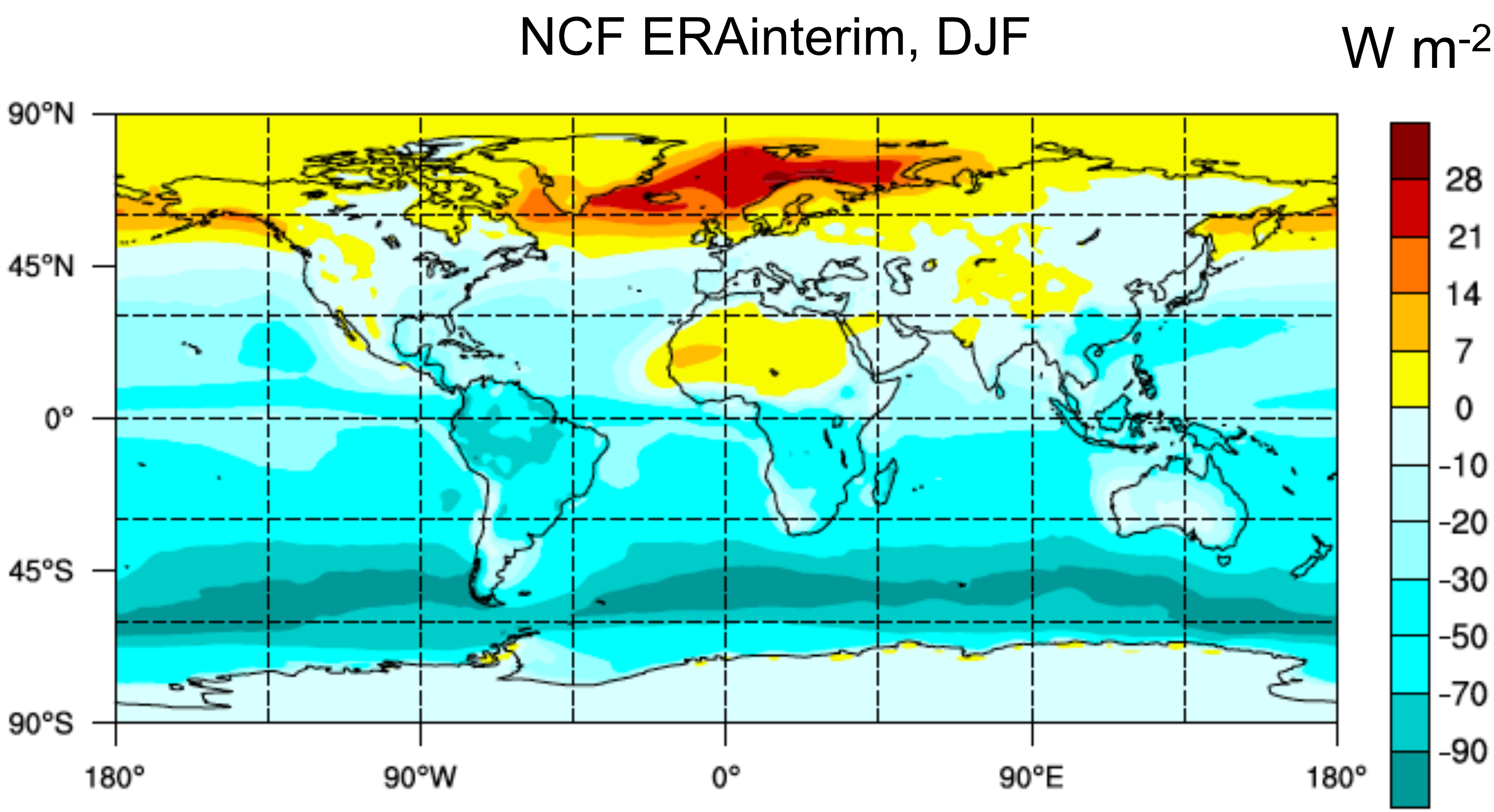
Introduction and Motivation

Clouds → strong impact on radiative budget

Definition of cloud forcing at TOA:

1. **Shortwave cloud forcing** $SCF = S_{clear} - S_{cloudy}$ → negative
2. **Longwave cloud forcing** $LCF = L_{clear} - L_{cloudy}$ → positive
3. **Net cloud forcing** $NCF = LCF + SCF$

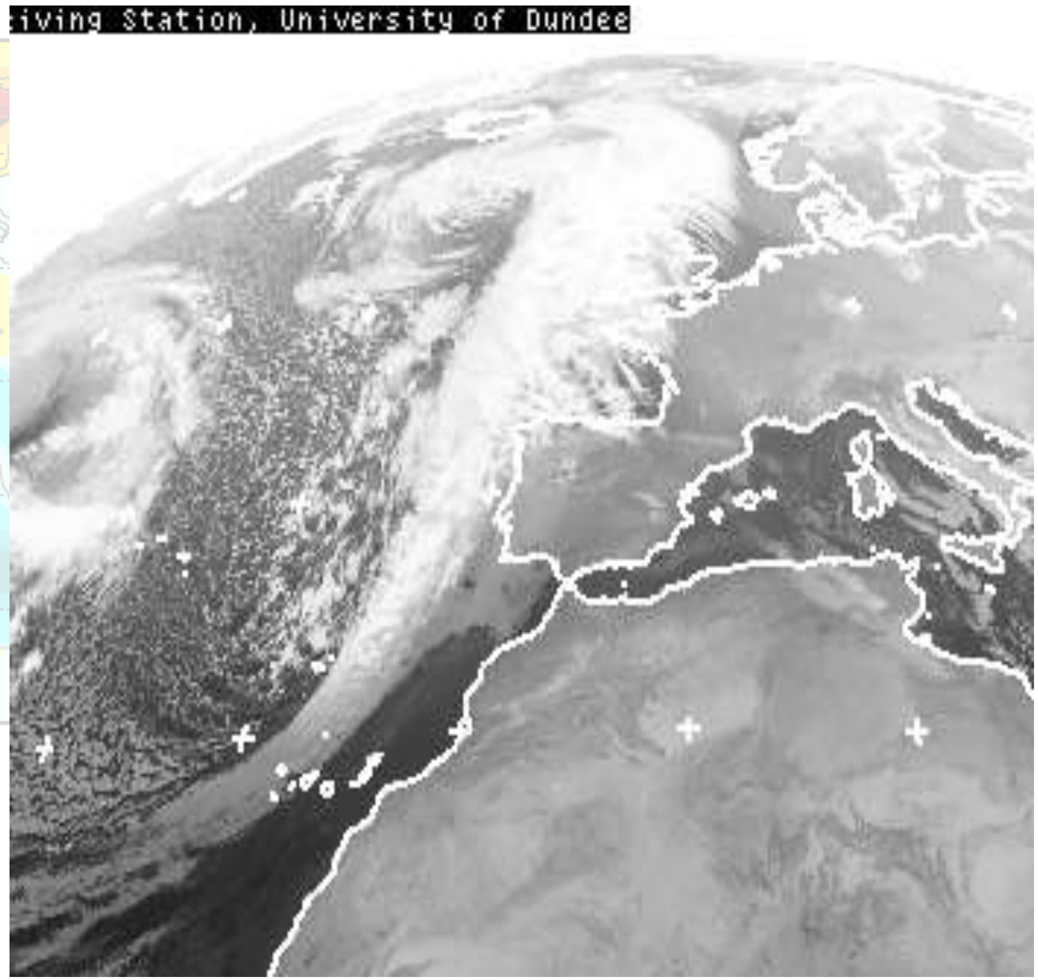


Introduction and Motivation

Clouds → strong impact on radiative budget

Clouds → are formed by different weather systems

in storm track mainly by **extra-tropical cyclones**



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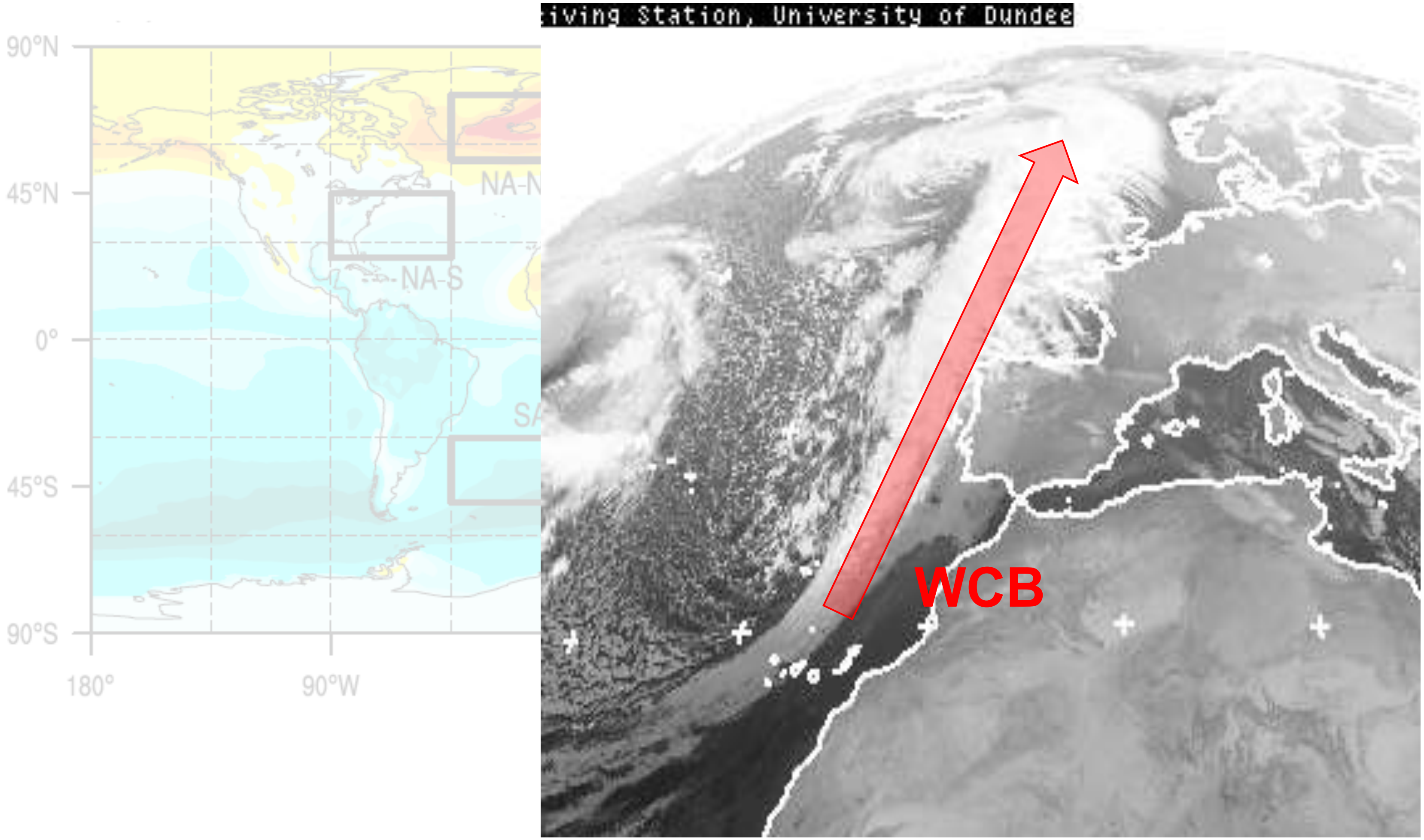

main cloud producing airstream = Warm Conveyor Belt

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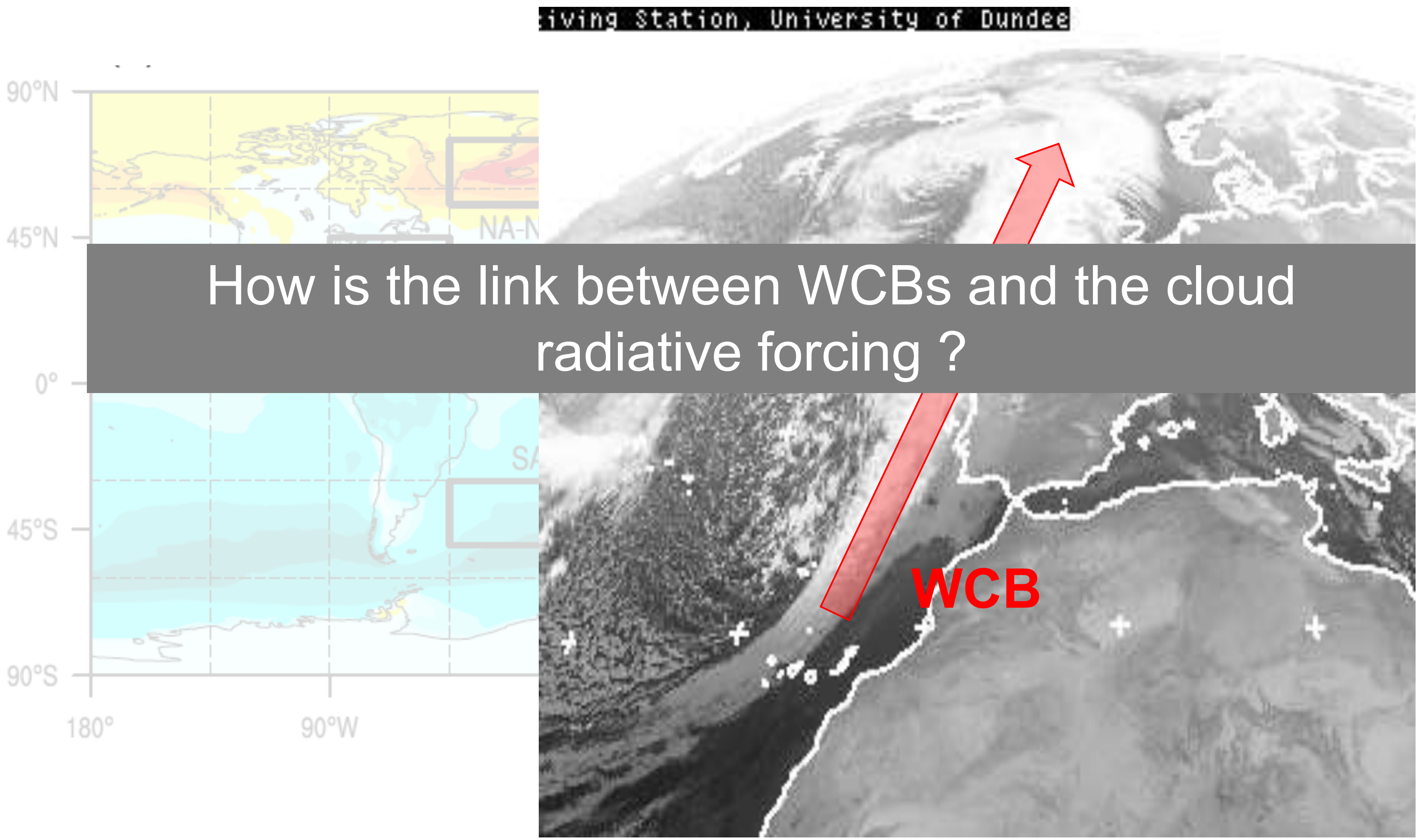


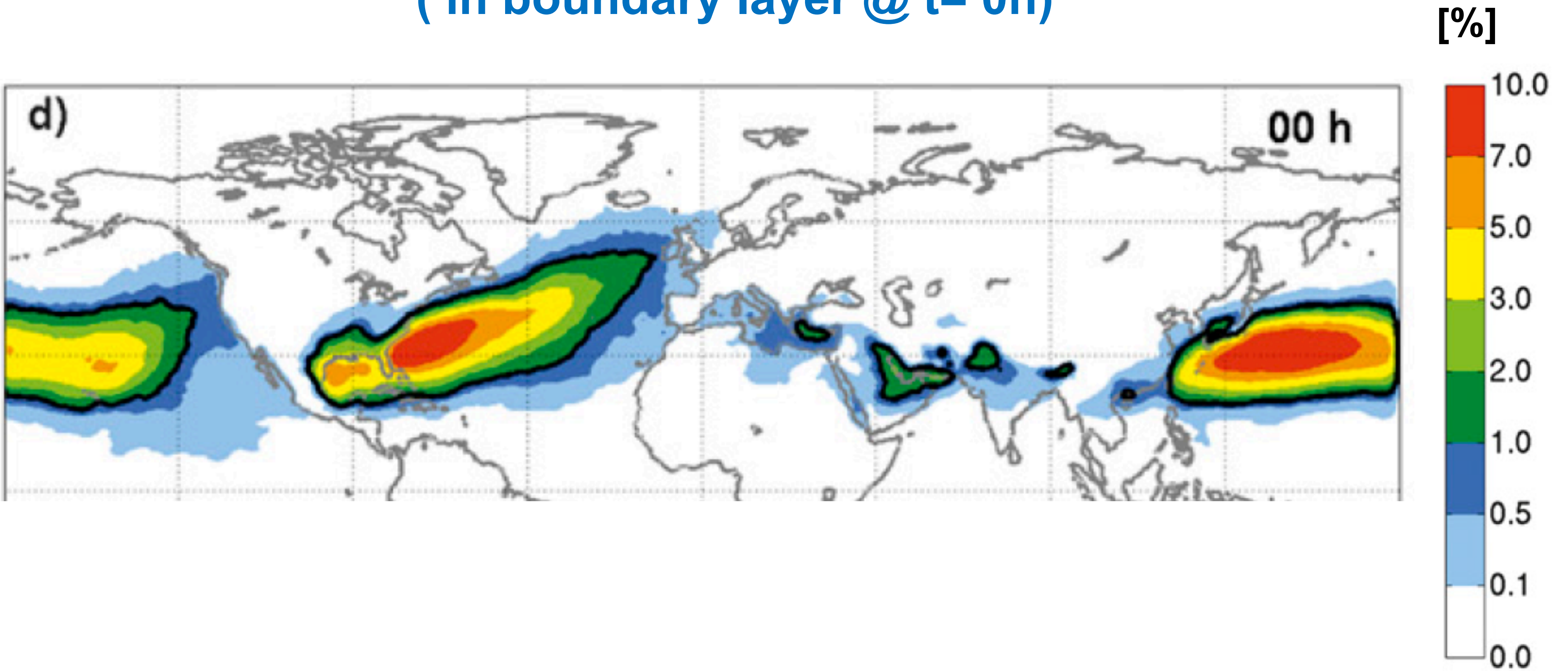
How is the link between WCBs and the cloud radiative forcing ?

main cloud producing airstream = Warm Conveyor Belt

WCB Climatology, 1979 – 2011, ERAInterim

WCB trajectory frequency, DJF

(in boundary layer @ t= 0h)

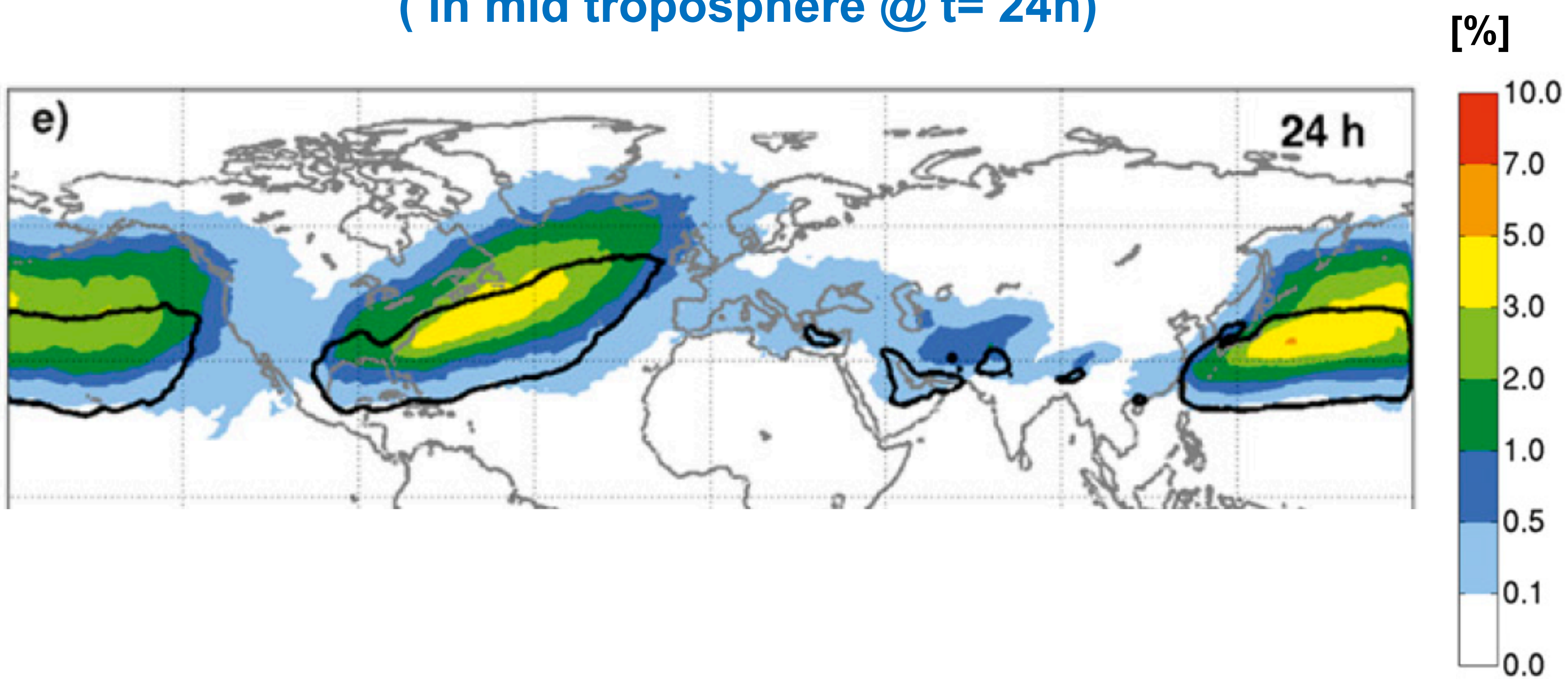


Madonna et al., 2014

WCB Climatology, 1979 – 2011, ERAInterim

WCB trajectory frequency, DJF

(in mid troposphere @ t= 24h)

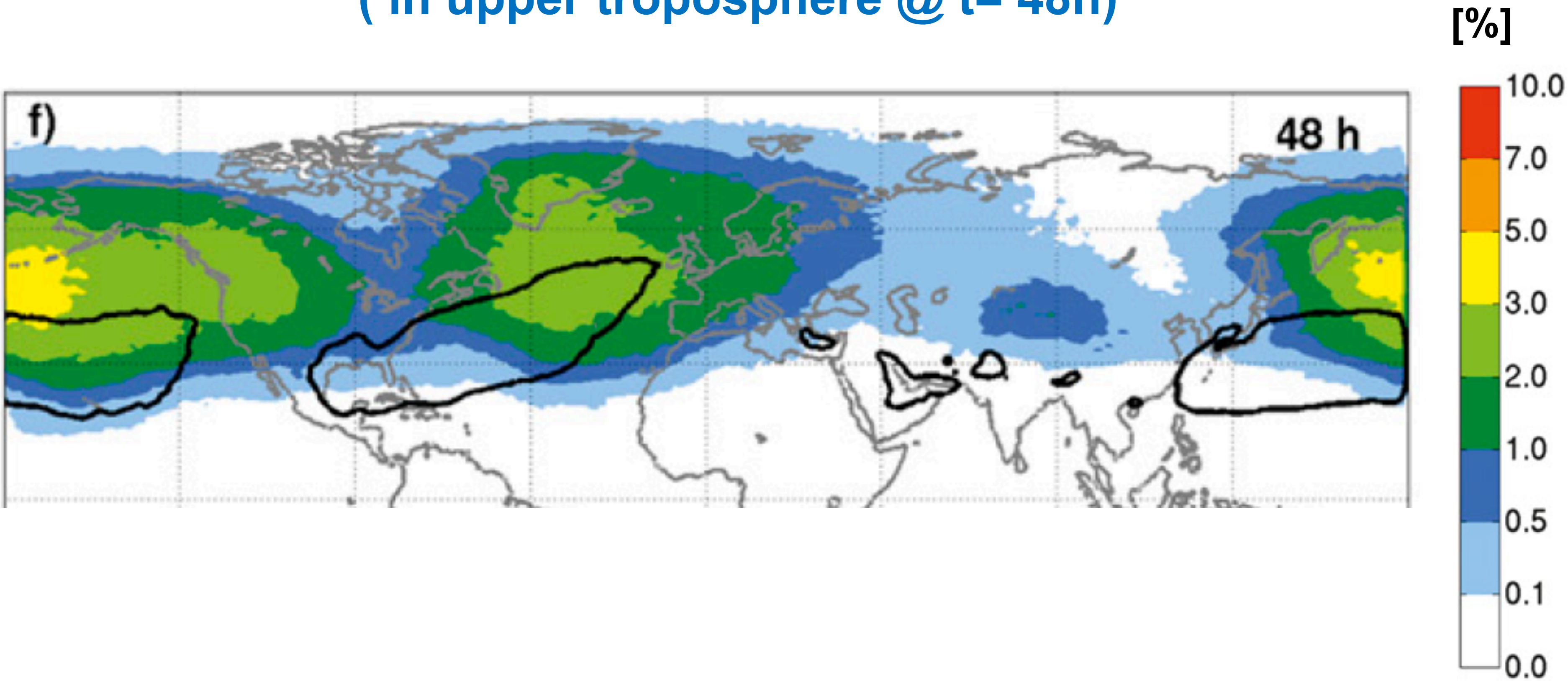


Madonna et al., 2014

WCB Climatology, 1979 – 2011, ERAInterim

WCB trajectory frequency, DJF

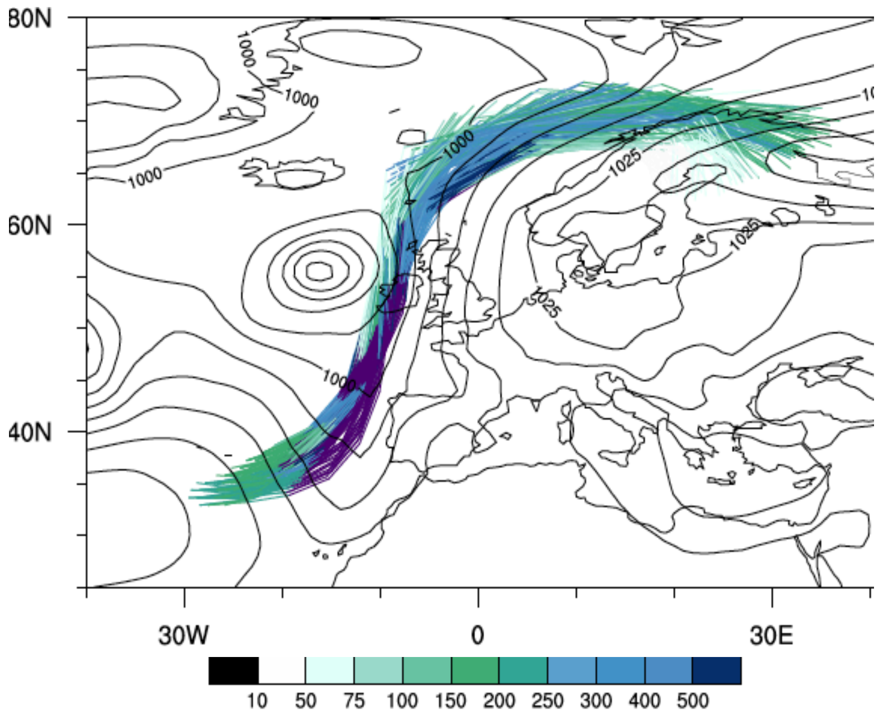
(in upper troposphere @ t= 48h)



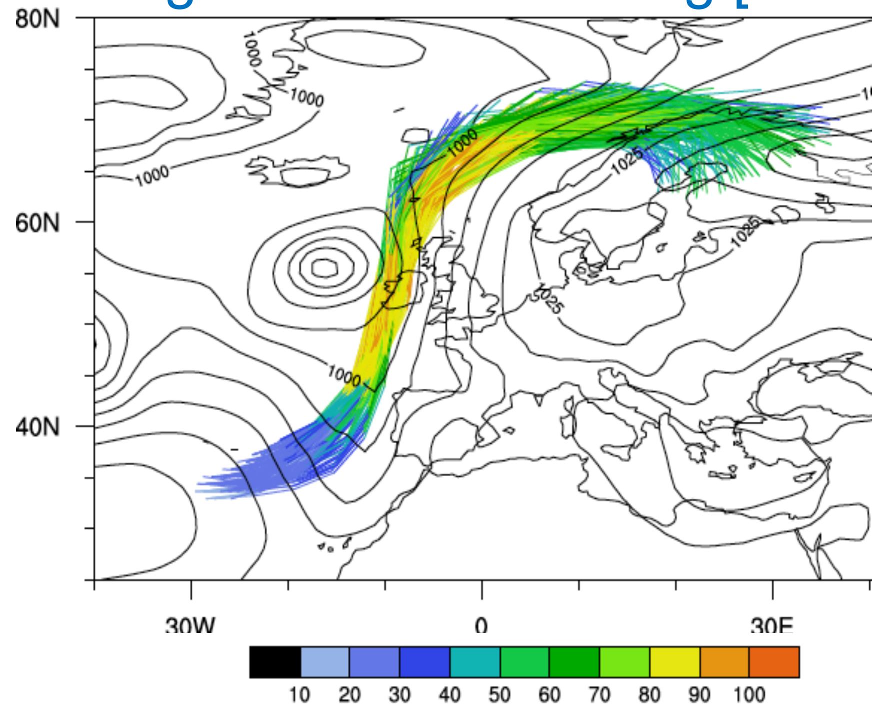
Madonna et al., 2014

Example of WCB and Cloud Radiative Forcing (CRF)

Total **L**iquid **W**ater [g m^{-2}]



Longwave **C**loud **F**orcing [W m^{-2}]



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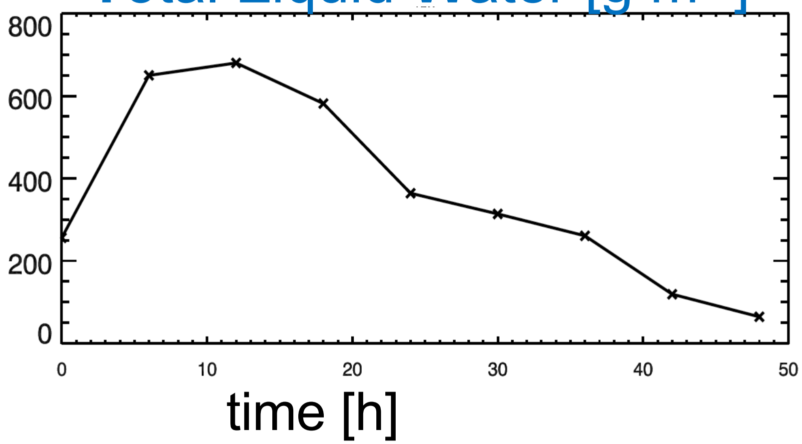

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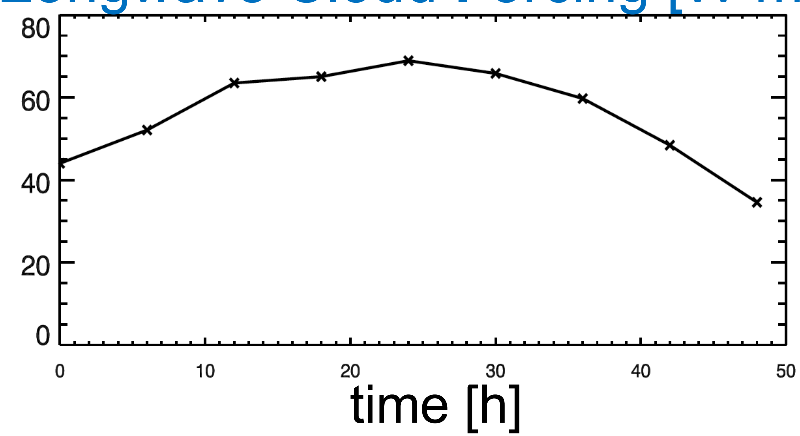

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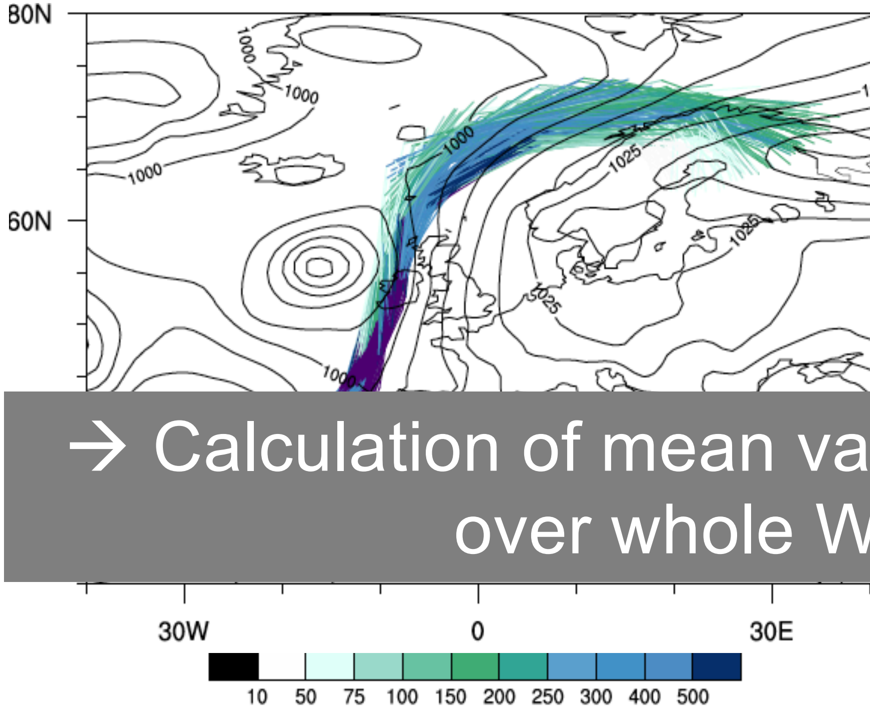

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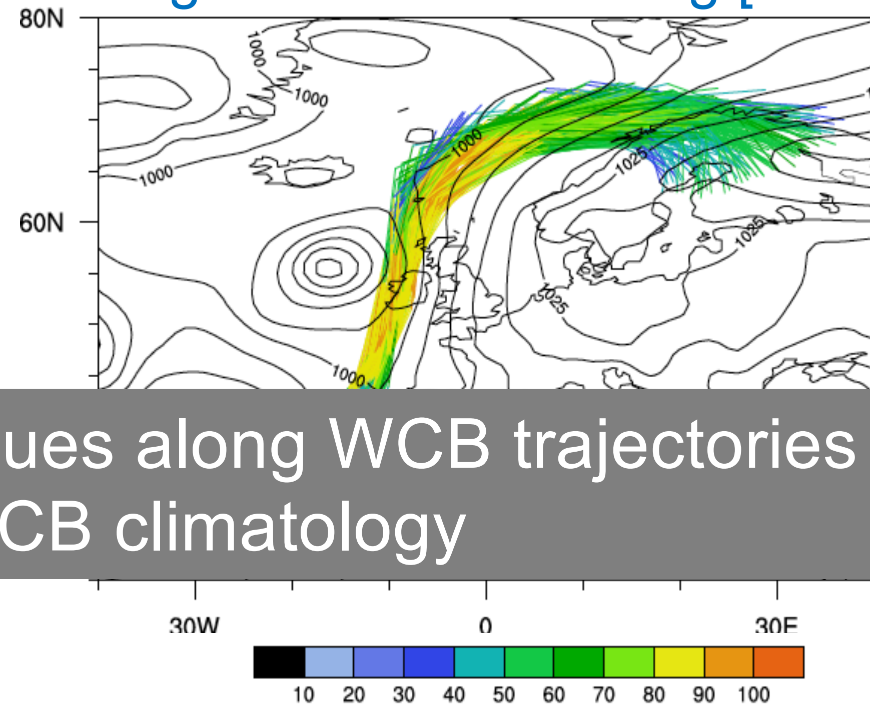

→ Calculation of mean values along WCB trajectories over whole WCB climatology

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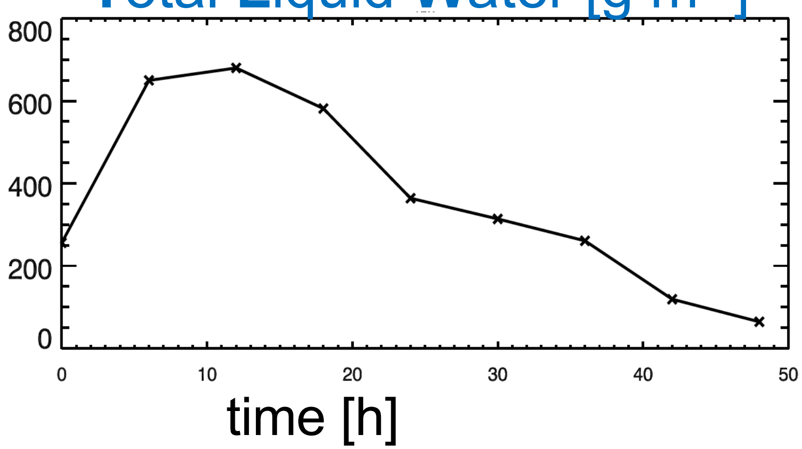
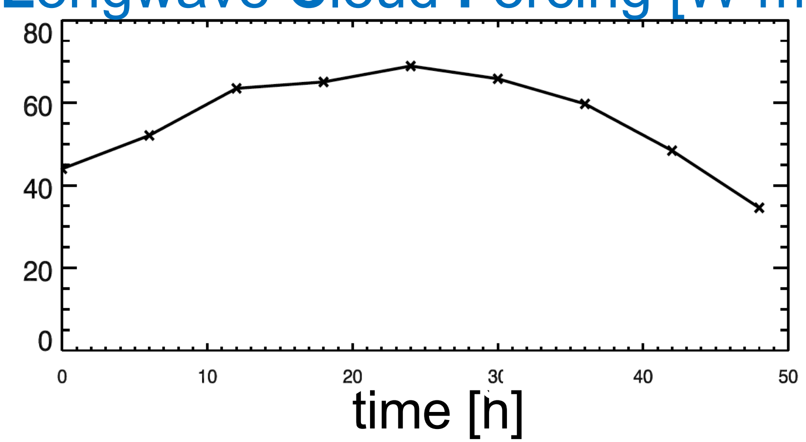
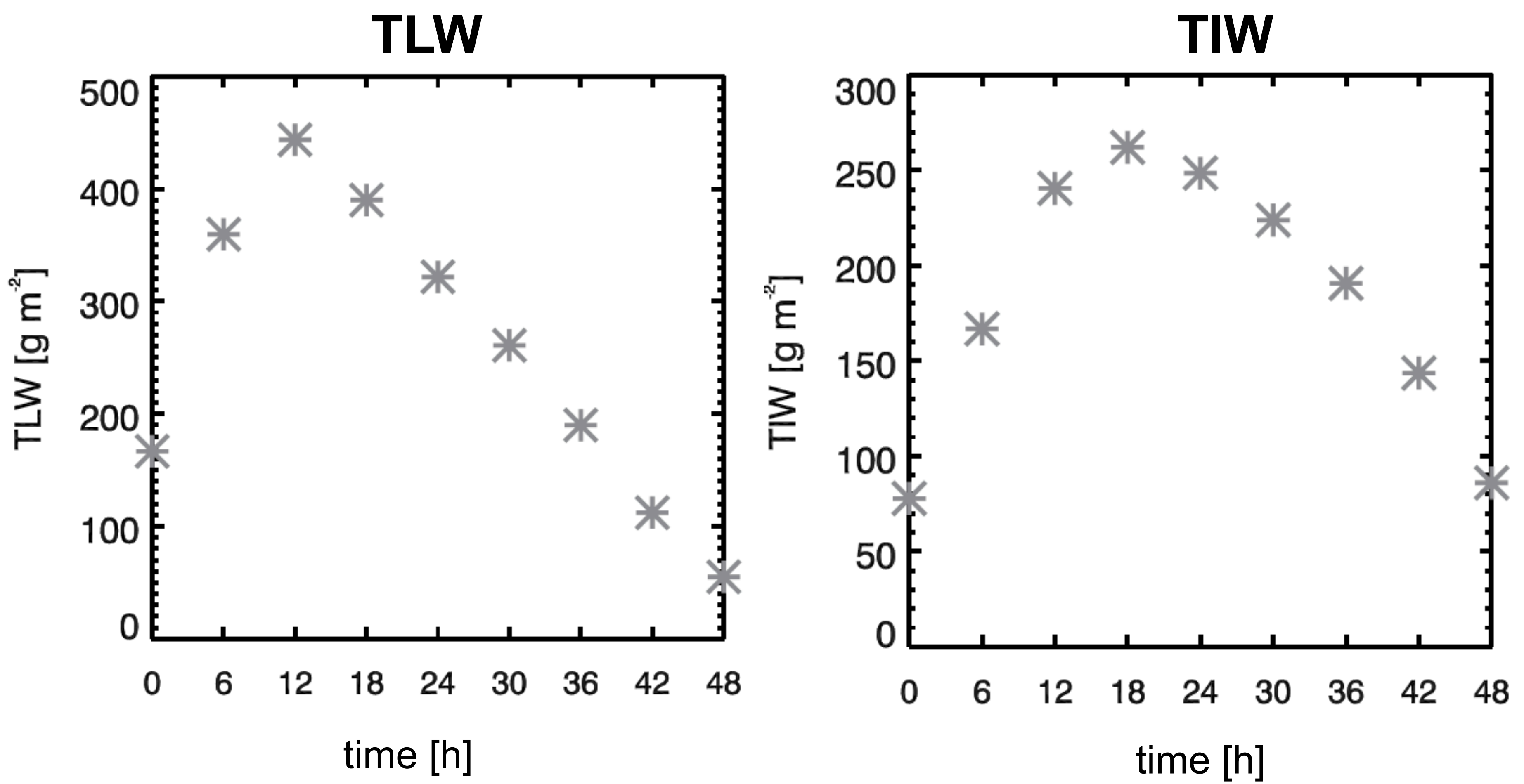


Longwave **C**loud **F**orcing [W m^{-2}]



Mean TLW, TIW along WCB trajectories

Northern Hemisphere winter (DJF)
whole climatology (1979 – 2011)



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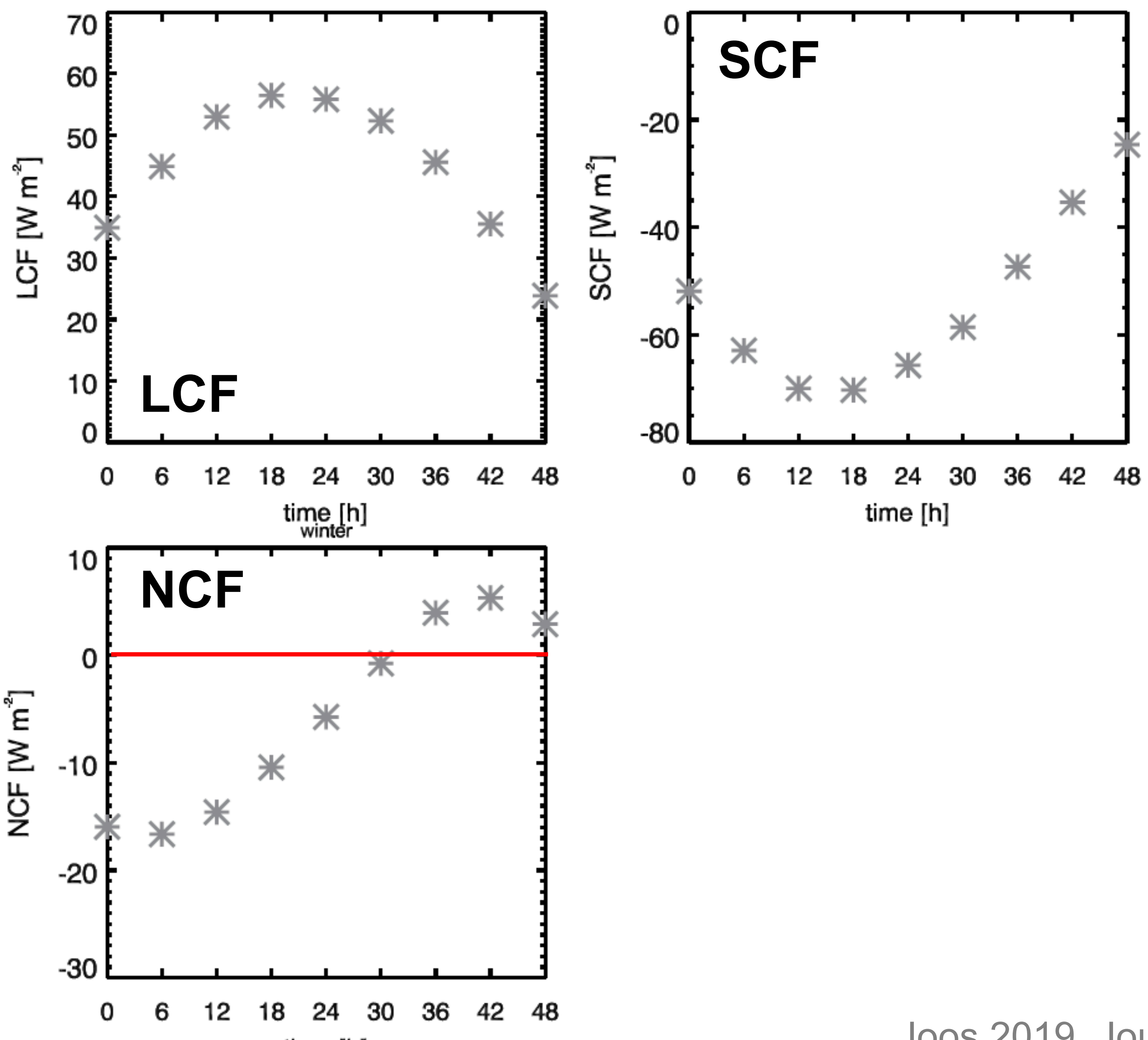
Mean Cloud Radiative Forcing along WCB trajectories



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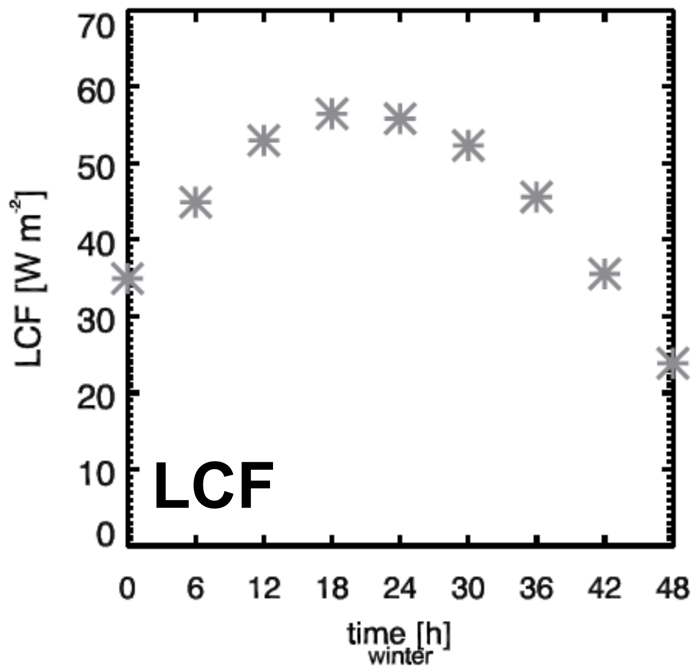

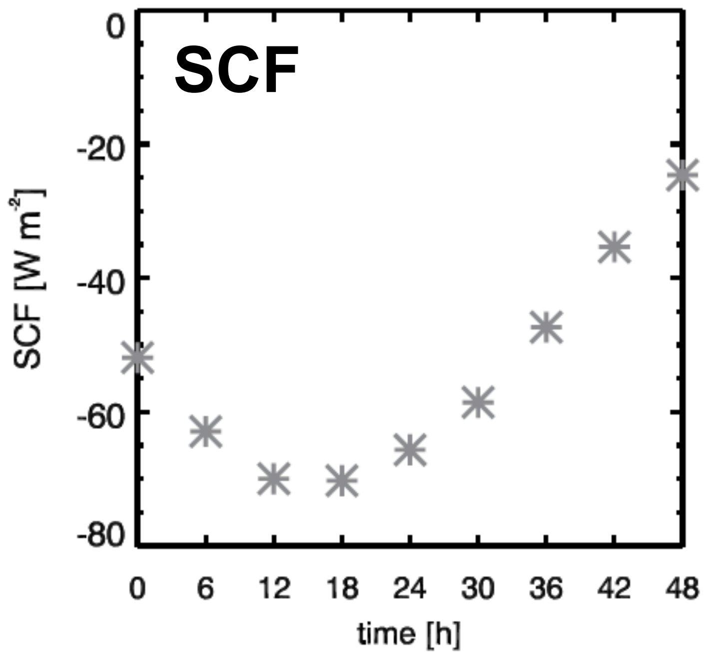

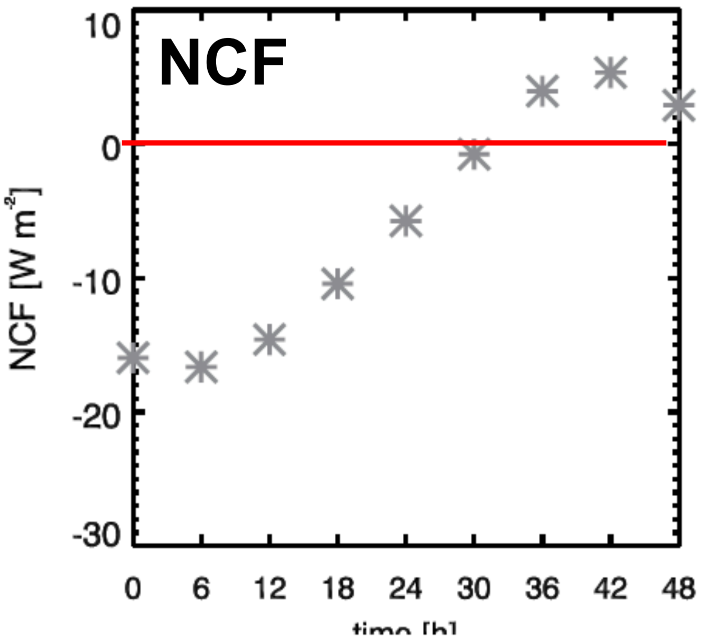

IN DJF

→ **Negative NCF** at start and ascent of WCBs

→ **Positive NCF** in WCB outflow

→ What causes this shift ?

→ Increase in cloud top height or poleward motion ?

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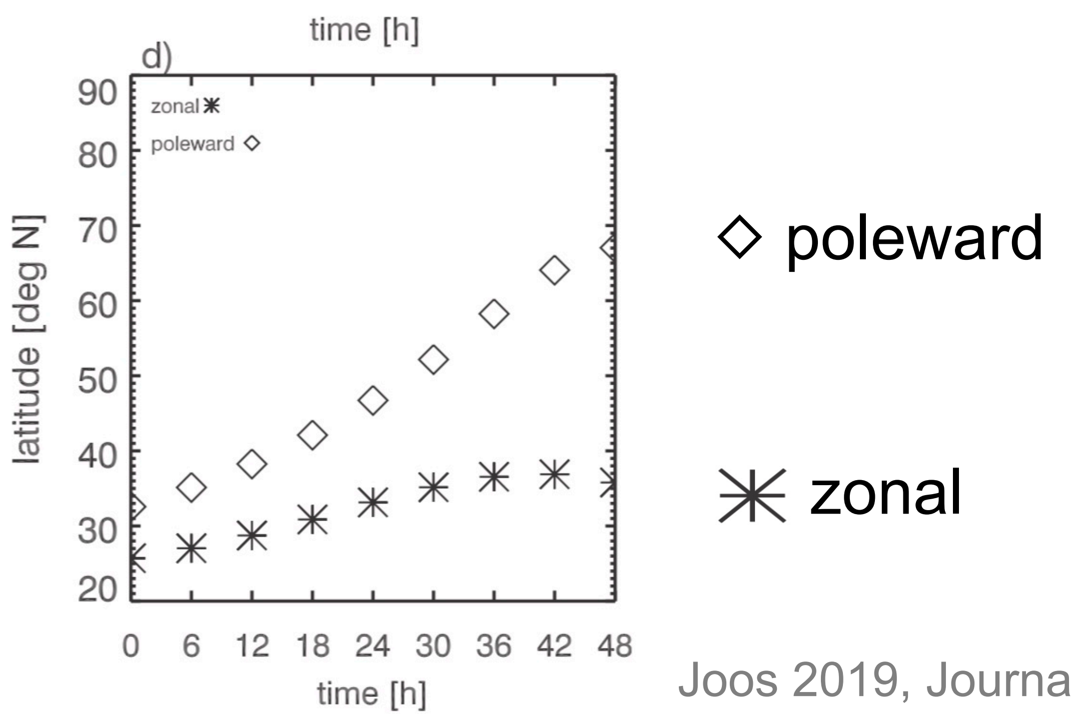
Zonal vs. poleward moving WCBs

zonal = lat < 50° at all times during ascent

poleward = ∆lat > 30 ° and lat@t=48h > 65°



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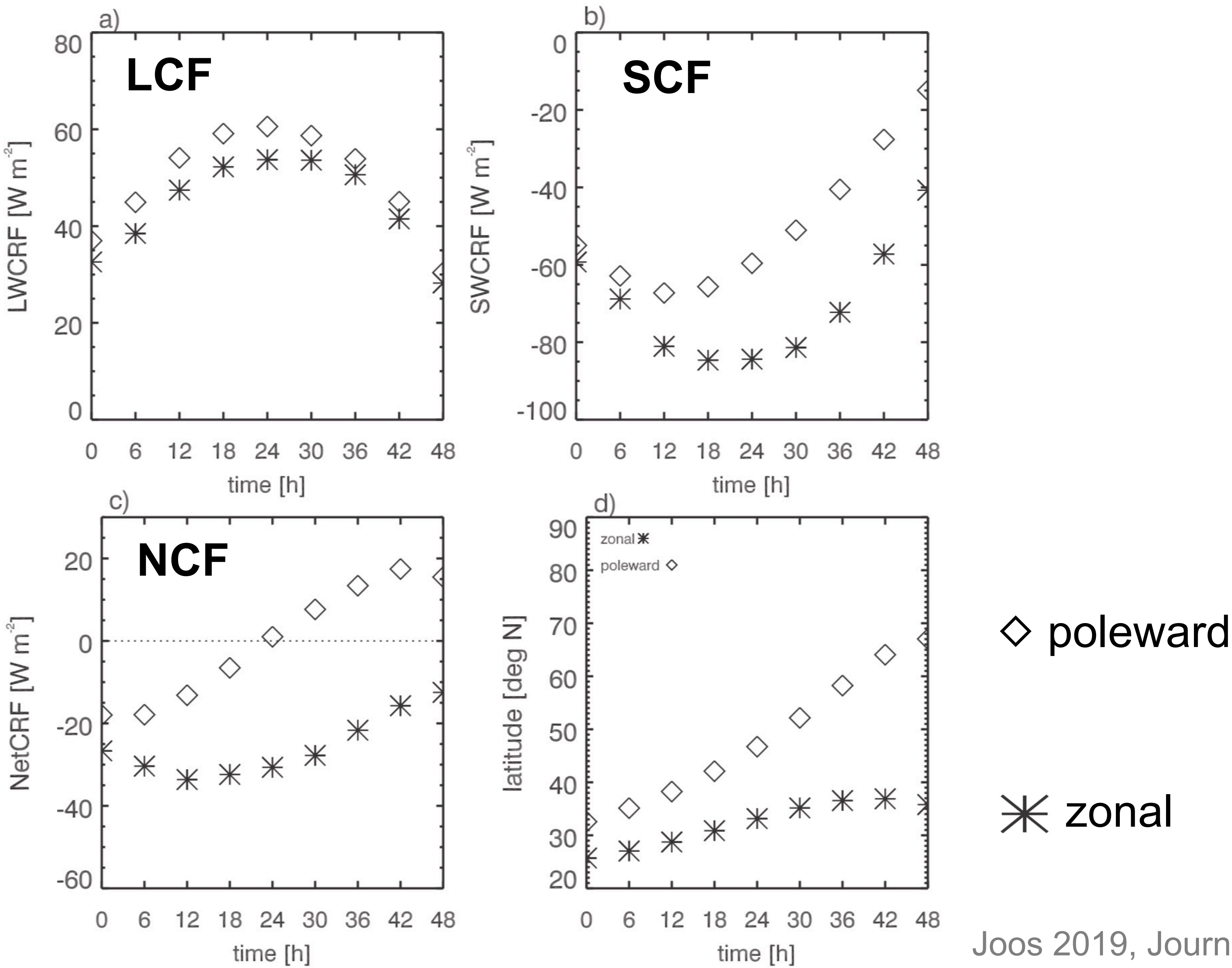
Zonal vs. poleward moving WCBs



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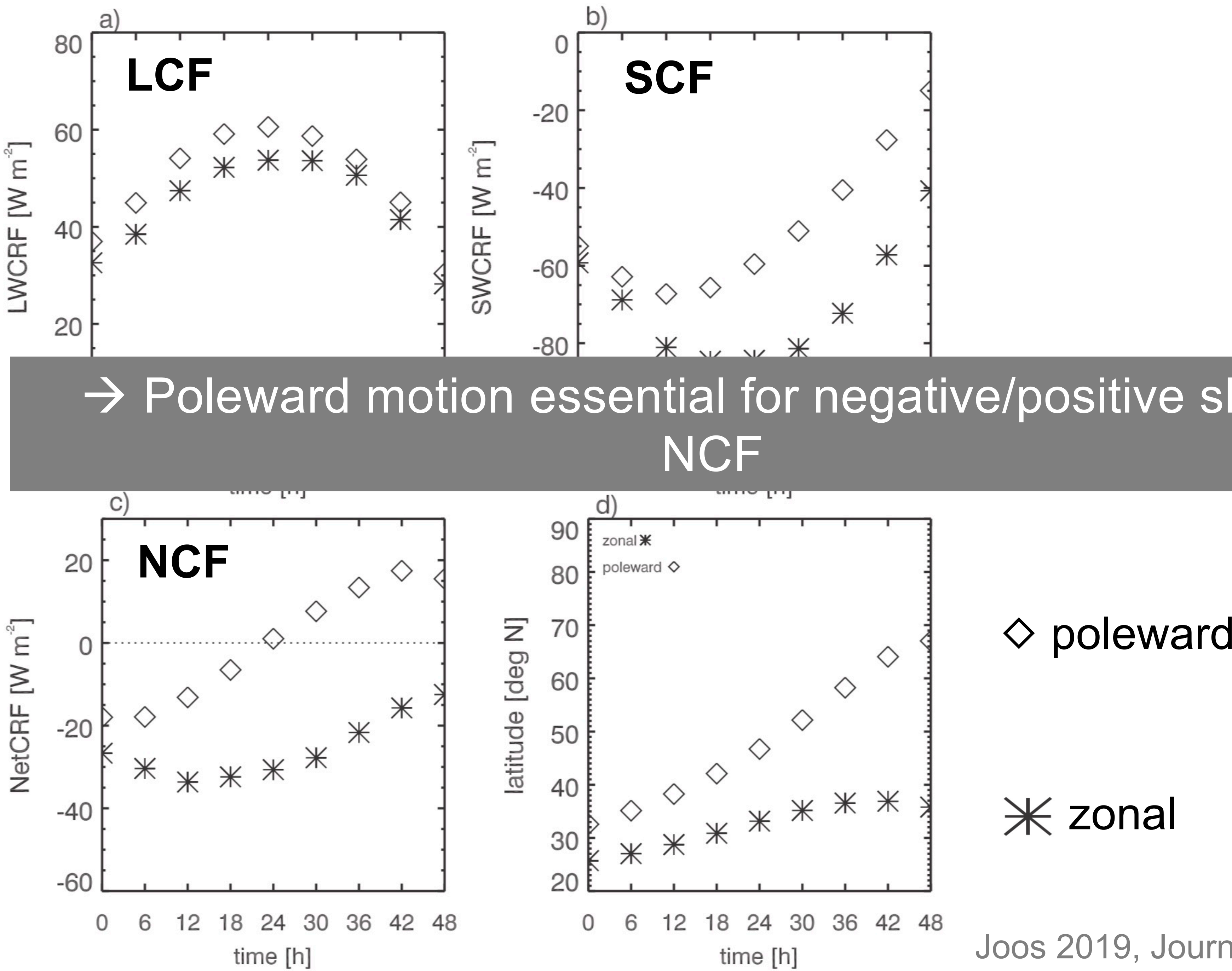

→ Poleward motion essential for negative/positive shift in NCF

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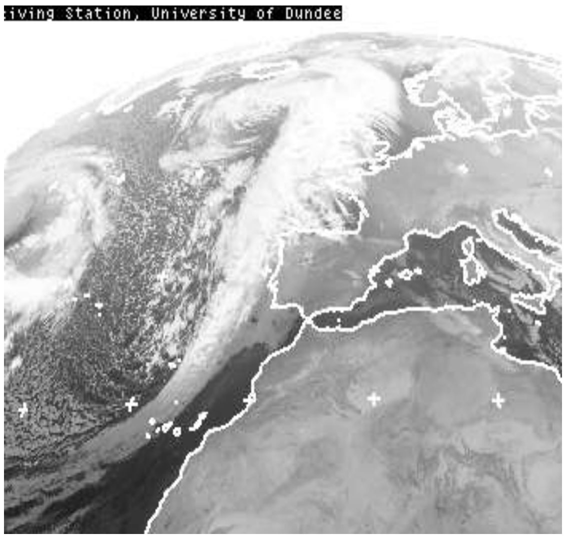
WCBs, clouds and CRF in an extratropical cyclone



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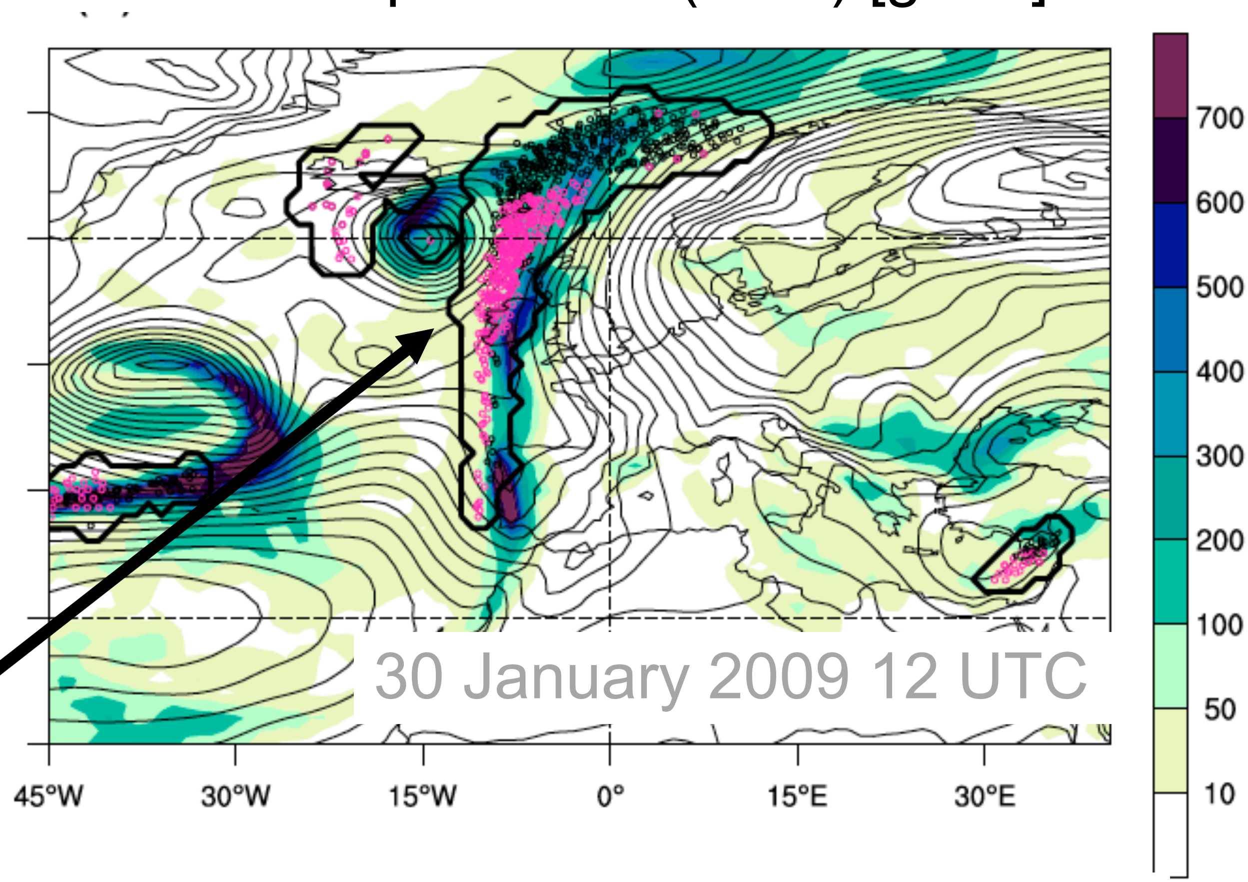
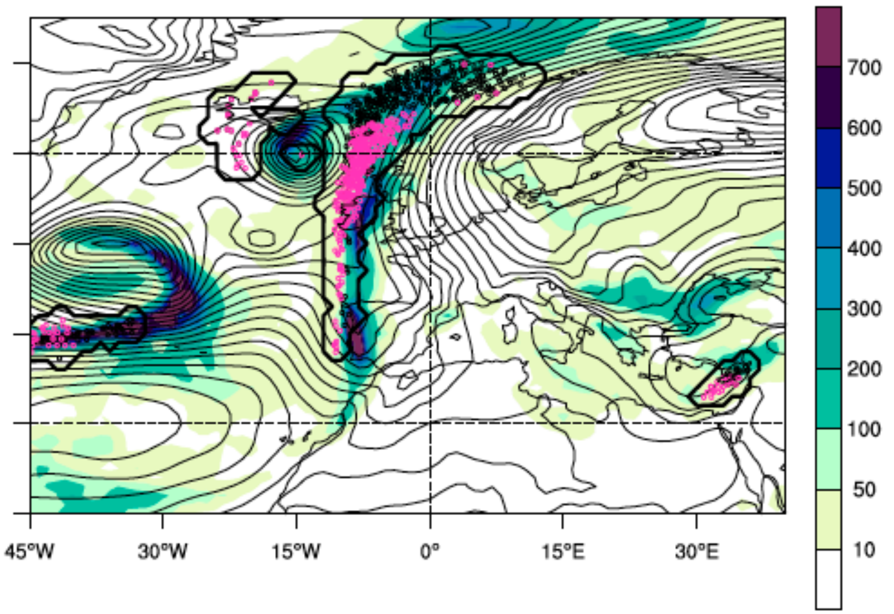
total liquid water (TLW) [g m^{-2}]



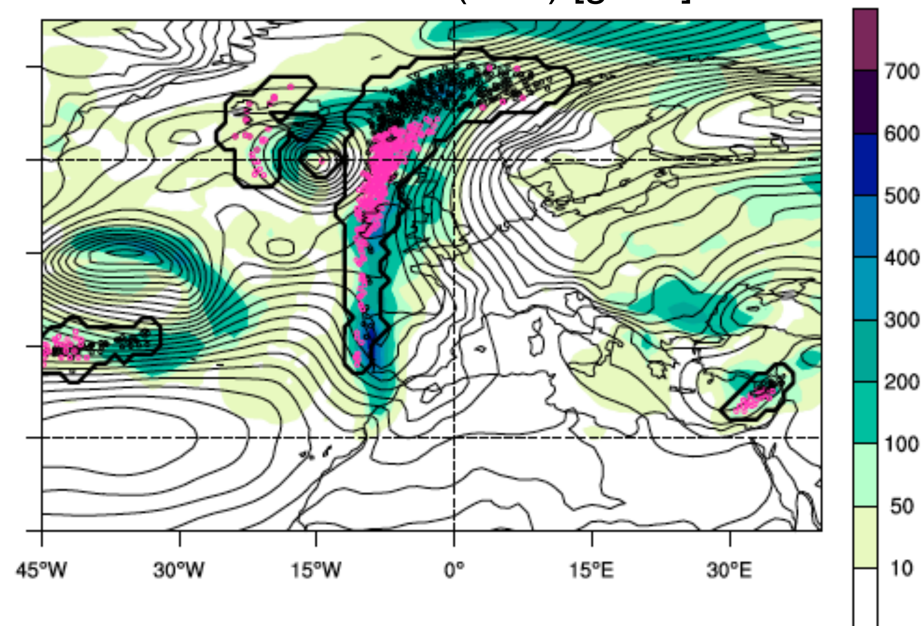
O / O = position of WCB at 30 January 2009, 12 / 18 UTC

WCBs, clouds and CRF in an extratropical cyclone

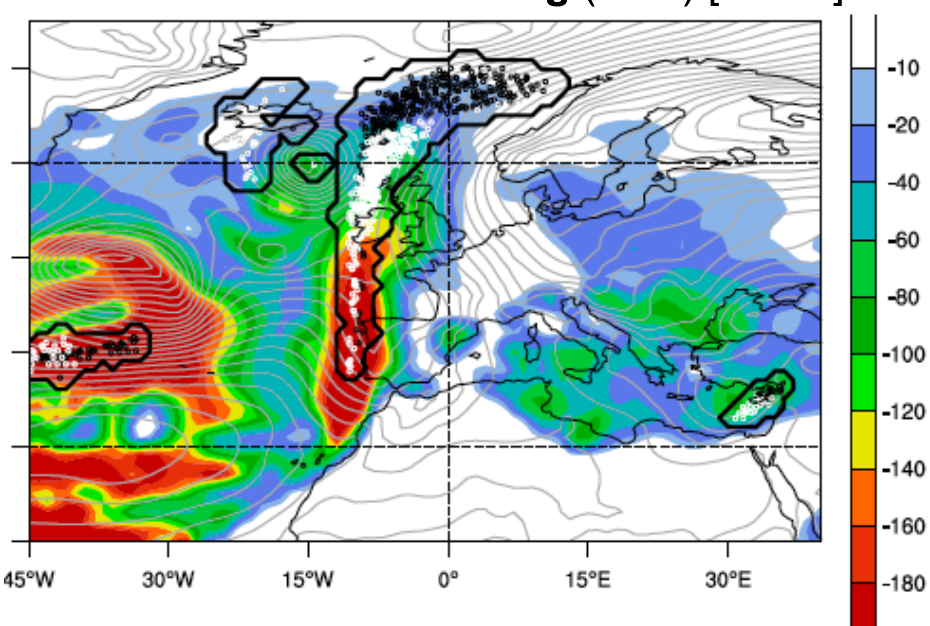
total liquid water (TLW) [g m^{-2}]



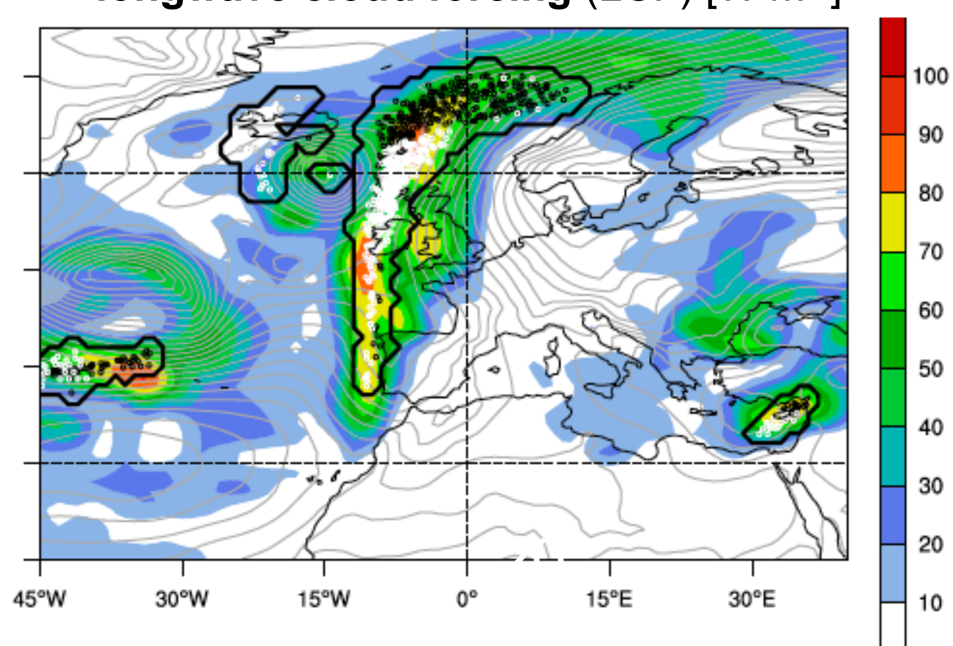
total ice water (TIW) [g m^{-2}]



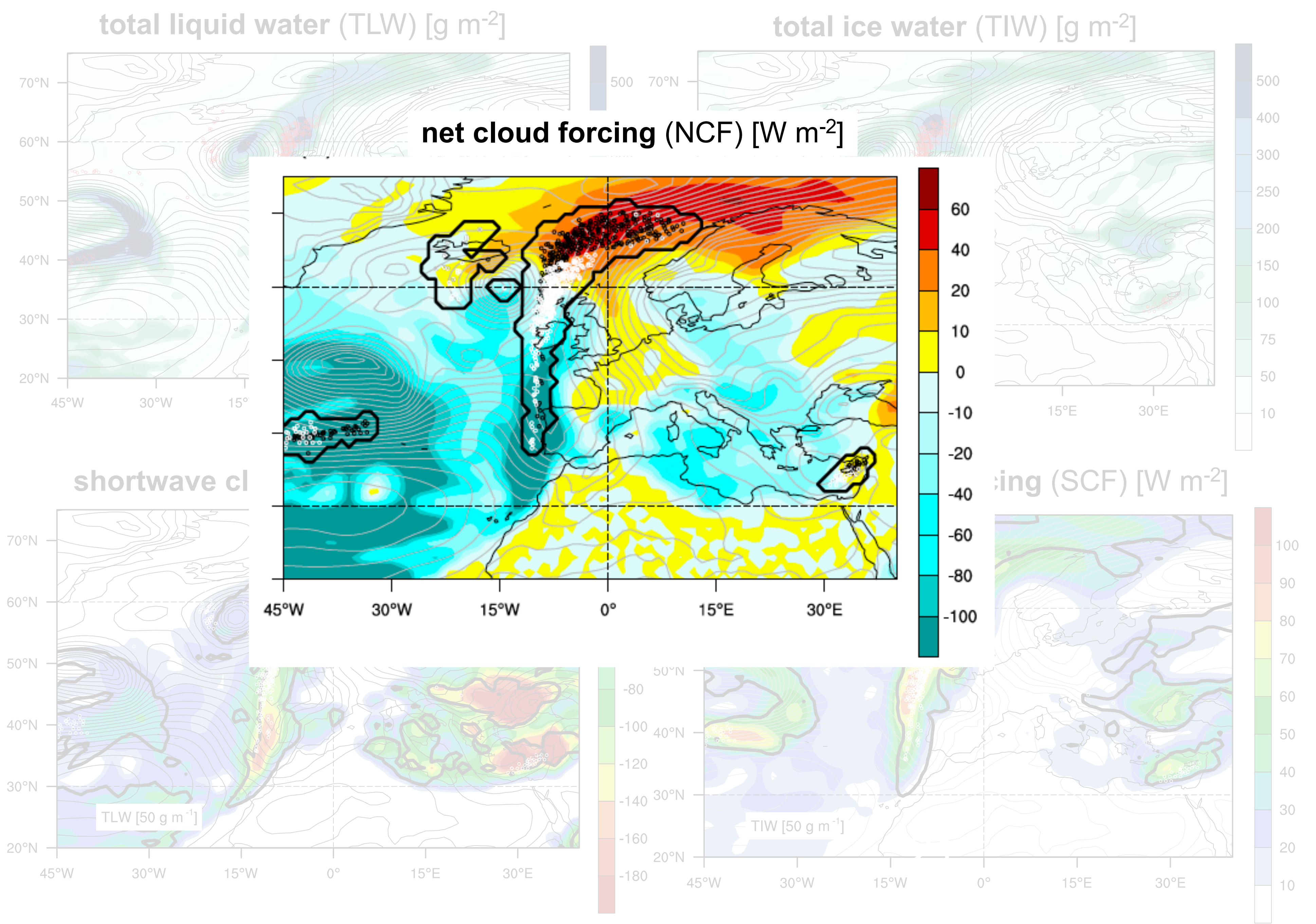
shortwave cloud forcing (SCF) [W m^{-2}]



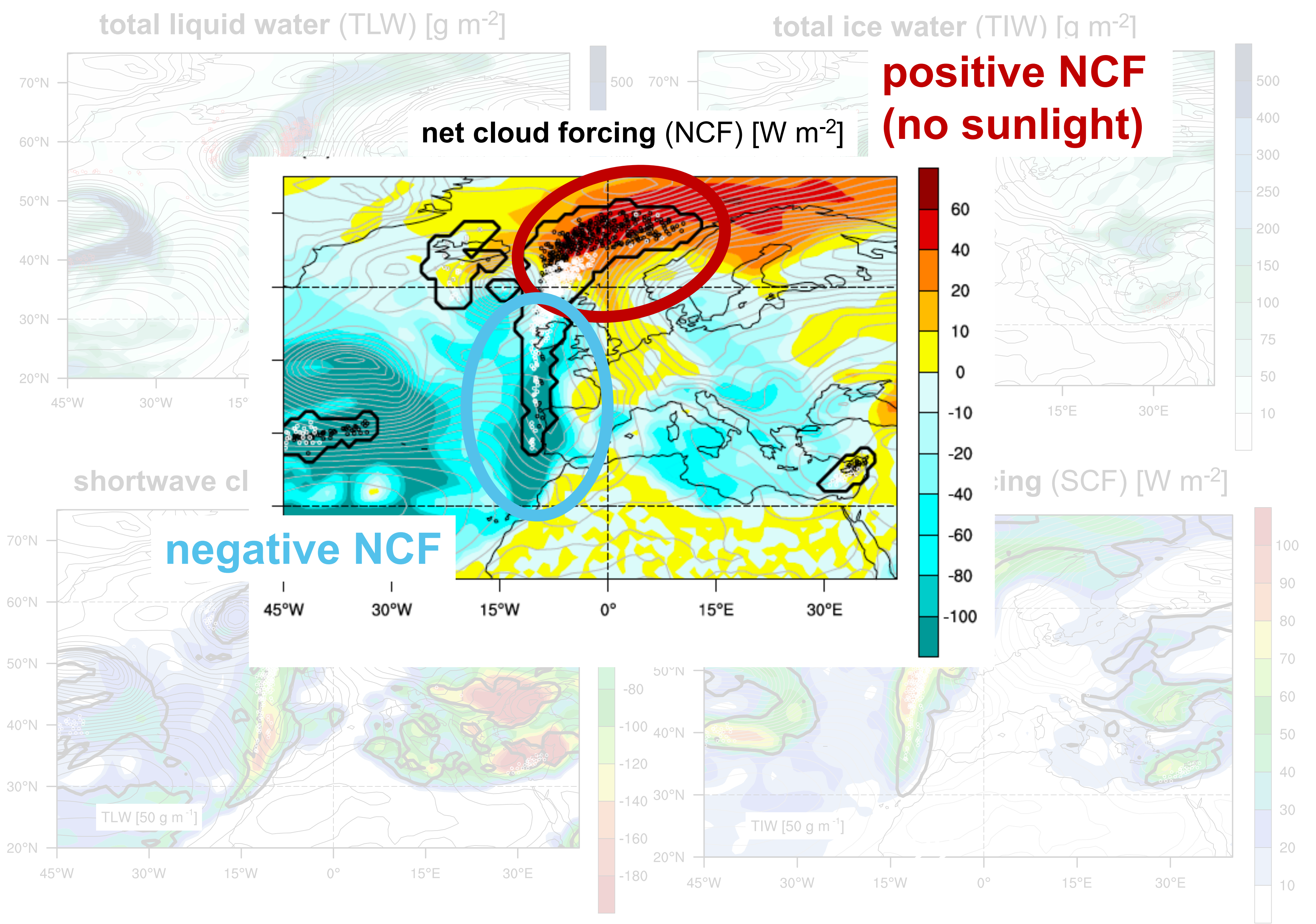
longwave cloud forcing (LCF) [W m^{-2}]



WCBs, clouds and CRF in an extratropical cyclone

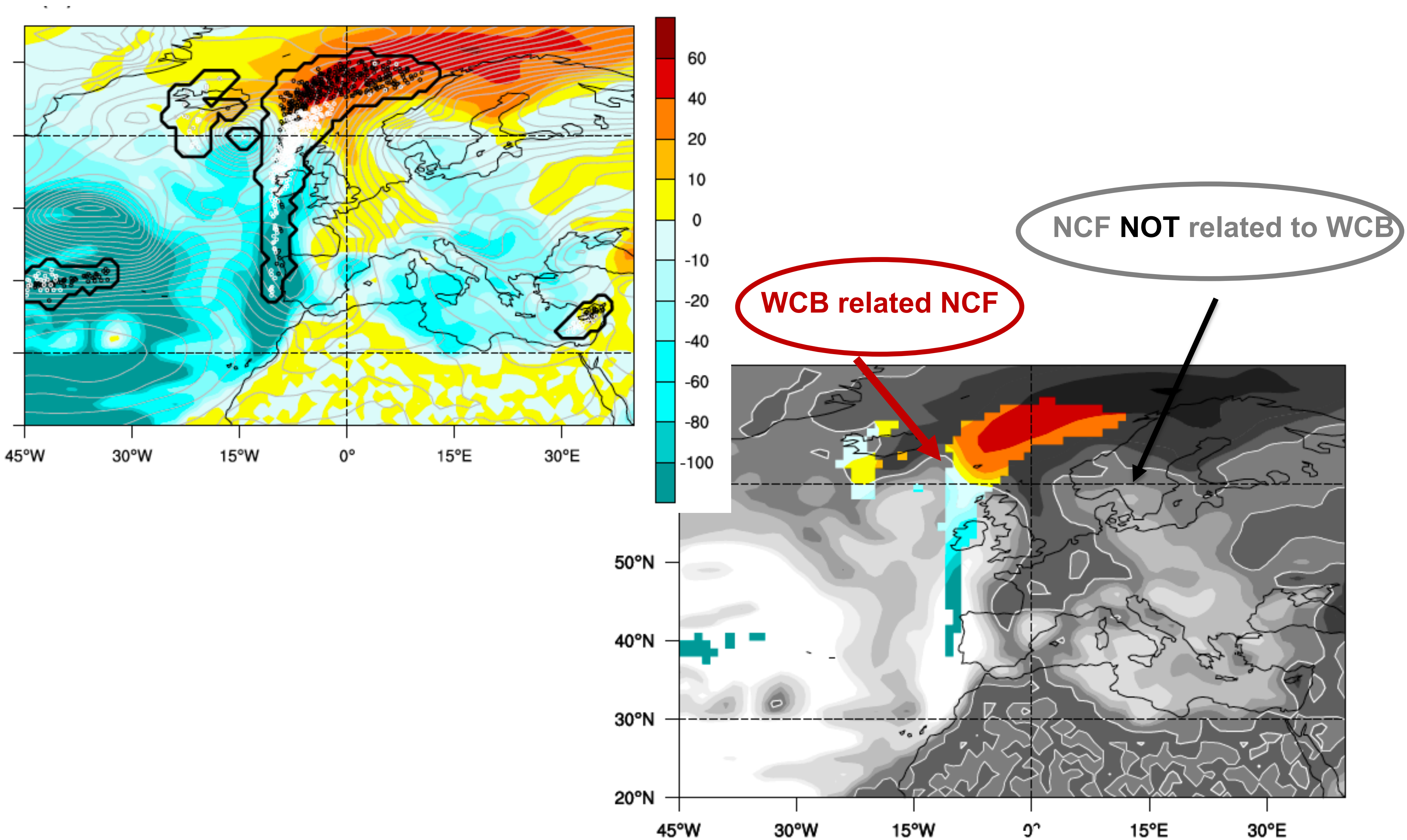


WCBs, clouds and CRF in an extratropical cyclone



WCBs, clouds and CRF in an extratropical cyclone

net cloud forcing (NCF) [W m^{-2}]



WCBs, clouds and CRF in an extratropical cyclone

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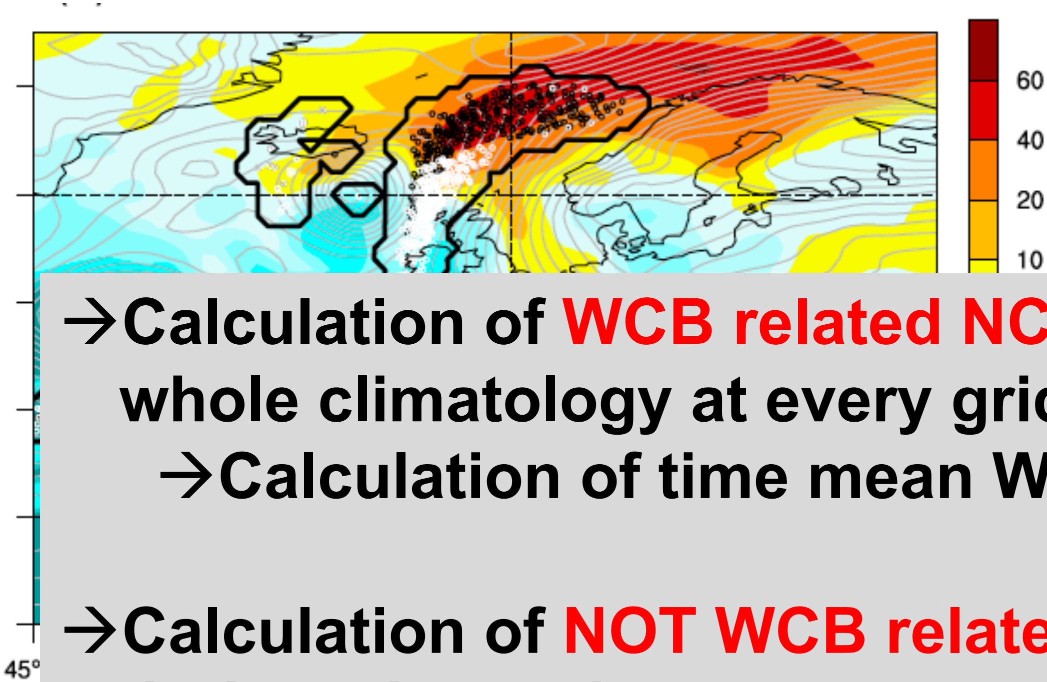
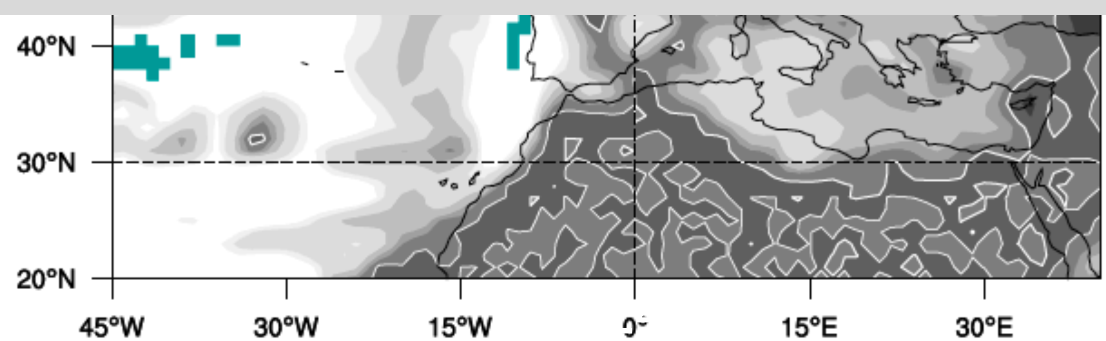


→Calculation of **WCB related NCF** at every 6h timestep during whole climatology at every gridpoint → (WCB)

→Calculation of time mean WCB related NCF (NCF_{WCB})

→Calculation of **NOT WCB related NCF** at every 6h timestep during whole climatology at every gridpoint

→Calculation of time mean NOT WCB related NCF (NCF_{NOWCB})



Decomposition of NCF climatology

Climatological mean value of NCF can be decomposed into:

$$NCF = NCF_{WCB} * f_{WCB} + NCF_{NOWCB} (1 - f_{WCB})$$

NCF_{WCB} = mean over all timesteps with WCB
NCF_{NOWCB} = mean over all timesteps without WCB
f_{WCB} = number of timesteps with WCB

} at every gridpoint

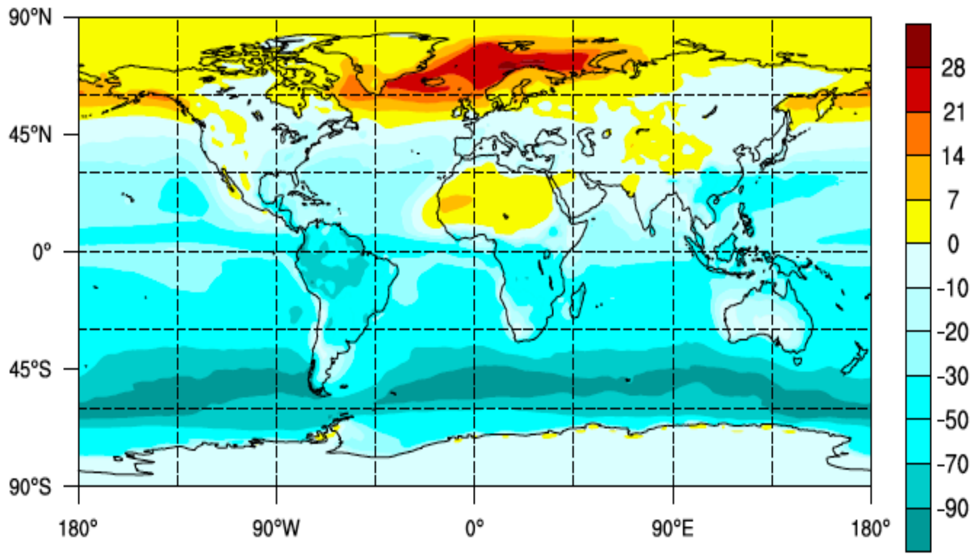
$$NCF = NCF_{NOWCB} + (NCF_{WCB} - NCF_{NOWCB}) * f_{WCB}$$

"world without WCBs" (NCF_{NOWCB})

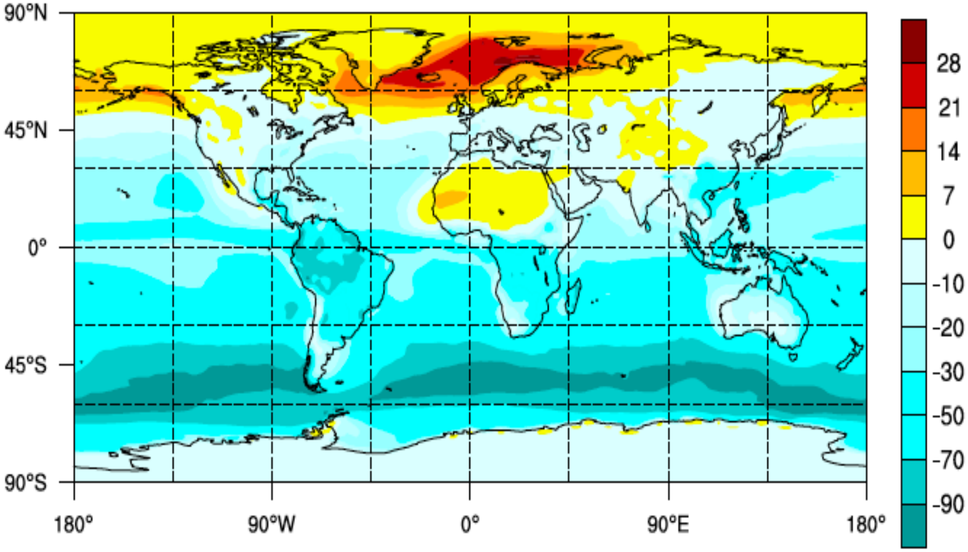
"Effect of WCBs" ($NCF_{WCB} - NCF_{NOWCB}$)

"frequency of WCBs" (f_{WCB})

Decomposition of NCF climatology (DJF)



Decomposition of NCF climatology (DJF)

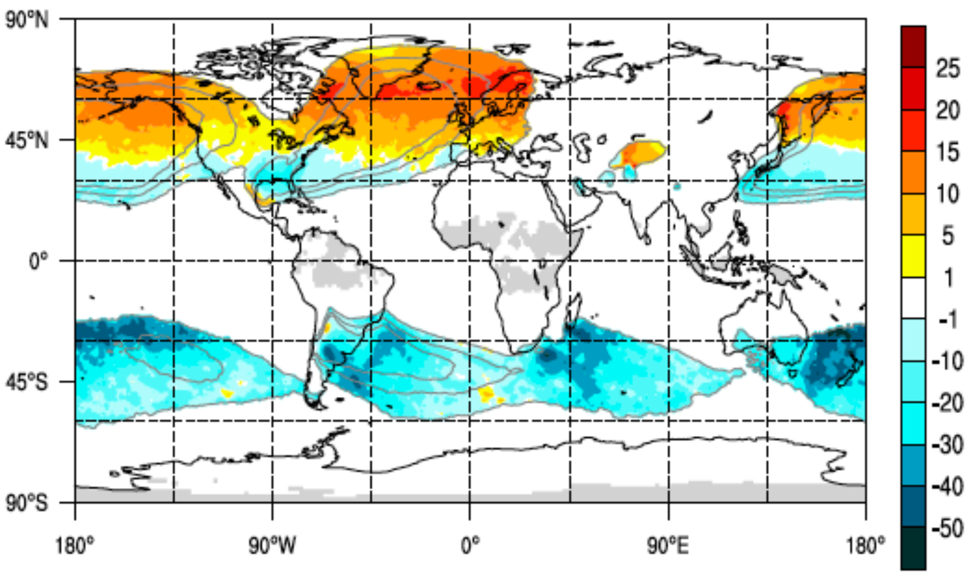


- "WCB – Effect" is to
  - decrease NCF in inflow regions
  - increase NCF in outflow regions

→ increase zonal NCF gradient in winter hemisphere

→ strongly decrease NCF in summer hemisphere

" WCB – Effect (**NCF_{WCB} – NCF_{NOWCB}**)"



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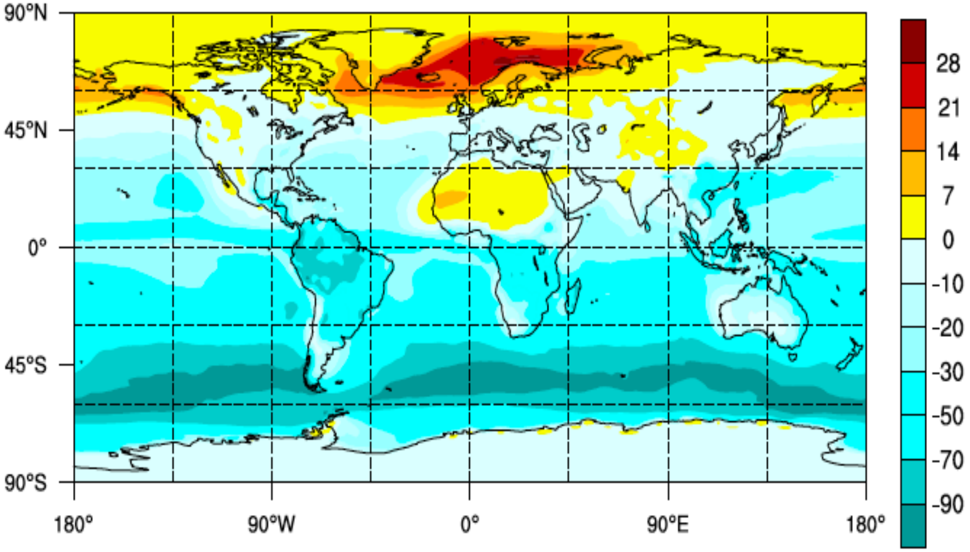
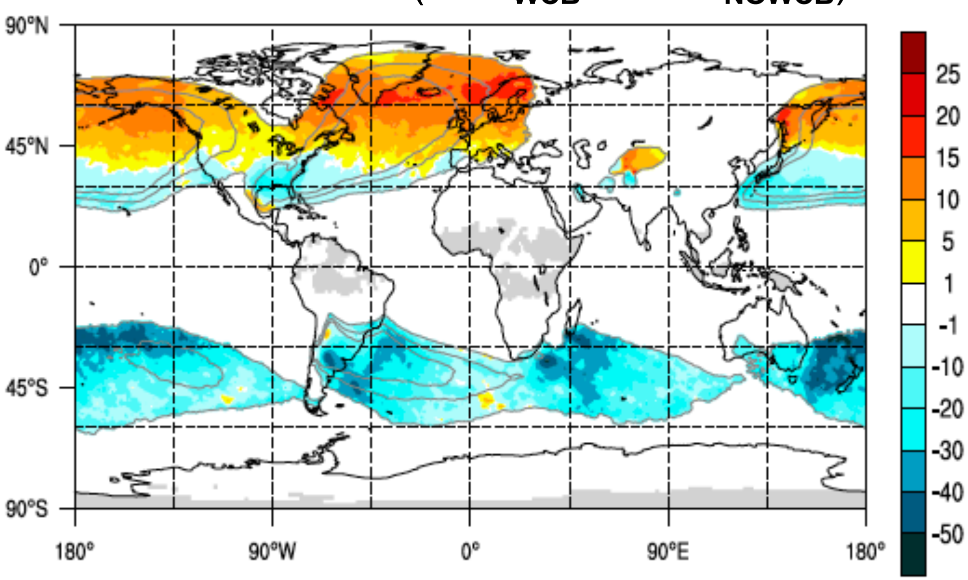
Decomposition of NCF climatology (DJF)

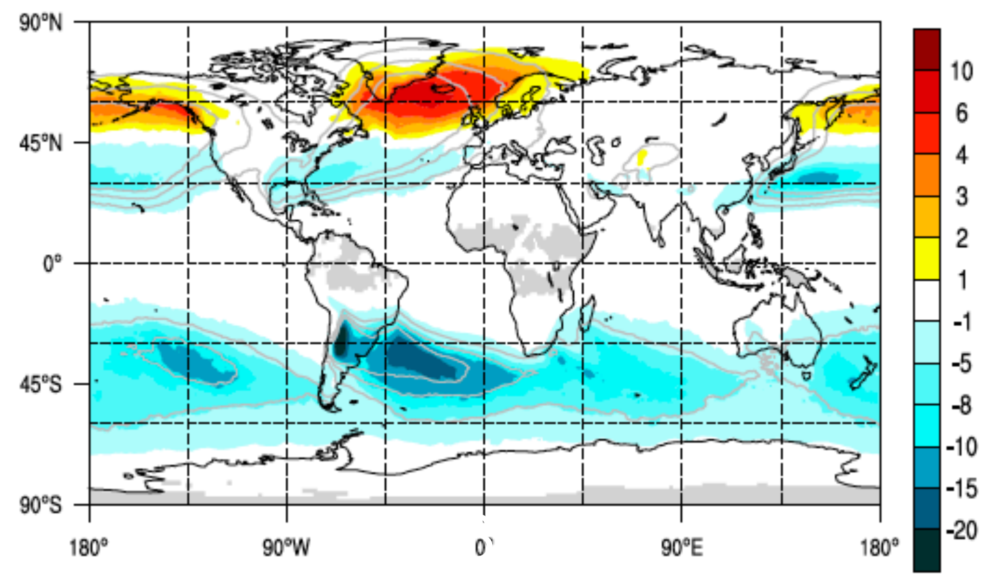


- WCBs contribution to NCF
  - > 6 W m^{-2} to the North Atlantic maximum
  - < -10 W m^{-2} in inflow regions
  - < -15 W m^{-2} in summer hemisphere

" WCB – Effect" (**NCF_{WCB} – NCF_{NOWCB}**)



" absolute WCB contribution"
NCF_{WCB} * f_{WCB}



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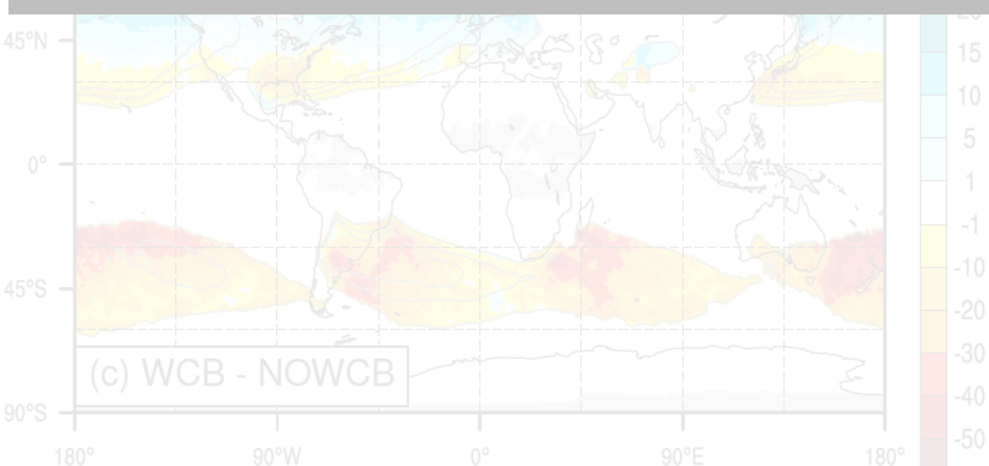
Decomposition of NCF climatology (DJF)

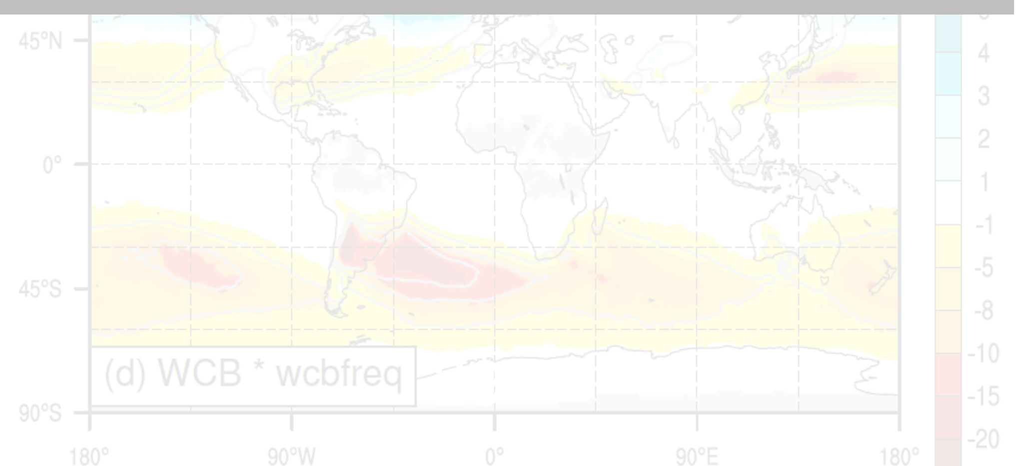
Decomposition of NCF climatology

Decomposing the climatological signal can help to disentangle the simulated changes in NCF in the extra-tropics in a future climate and to assign it to

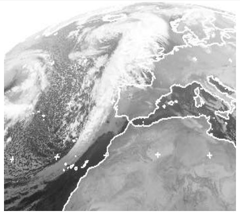
→ Dynamical changes (WCB ascent locations and frequency)

→ Microphysical changes, represented by the "WCB-effect" ($\mathbf{NCF_{WCB}}$ – $\mathbf{NCF_{NOWCB}}$)

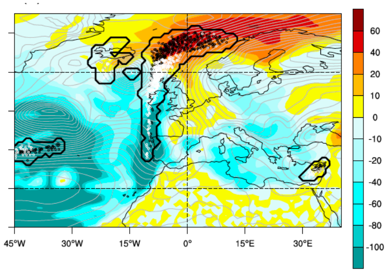




Summary and Conclusion



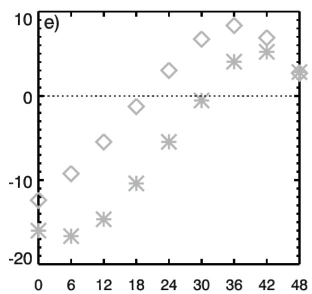
- WCBs are frequent flow features
- associated with elongated cloud bands



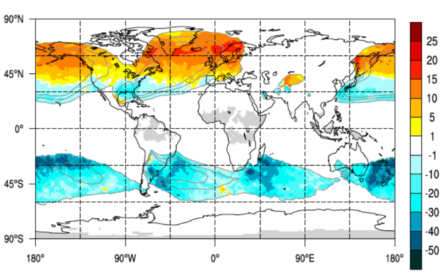
- associated with high values of

→ total condensate

→ cloud radiative forcing



- transition from neg. to pos. NCF from WCB start to outflow
- poleward motion essential



- WCB increase zonal NCF gradient in winter
- Decomposition allows investigating effect of changes in cloud properties vs. frequency of WCBs

→ Strong link highlights importance of correct representation of WCBs in climate models for the radiative budget

WCB as Lagrangian flow feature

Warm **C**onveyor **B**elts (**WCB**)

• strongly ascending airstreams in extratropical cyclones (e.g. Harrold, 1973; Carlson, 1980)

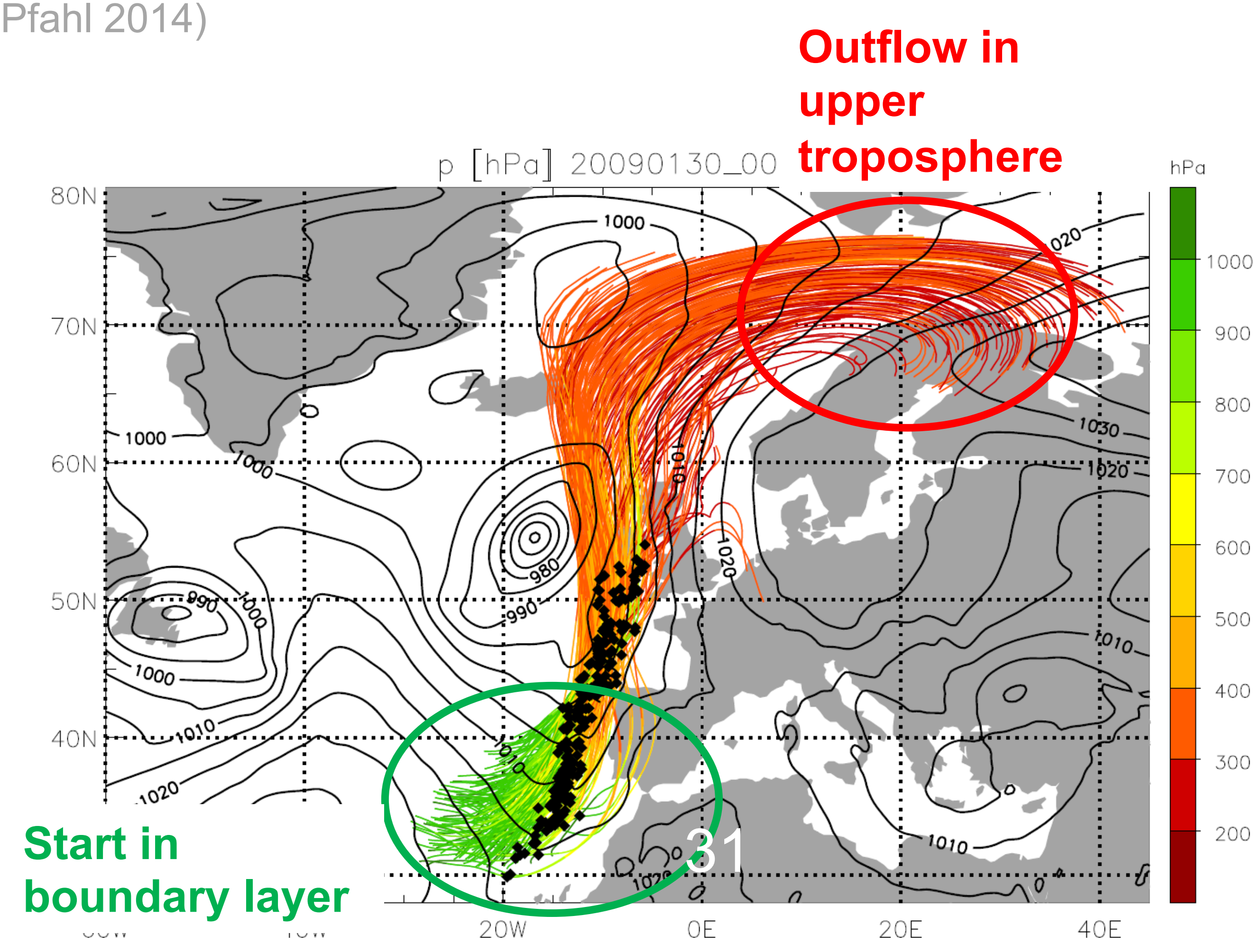
• formation of elongated cloud band with liquid, mixed-phase and ice clouds (e.g. Browning, 1986; Madonna, 2014; Joos and Wernli, 2012)

• produces most of the precipitation occurring in an extra- tropical cyclone (e.g. Browning, 1990; Wernli,1997; Pfahl 2014)

Definition of WCB:

Trajectories with ascent

> 600 hPa in 48 h



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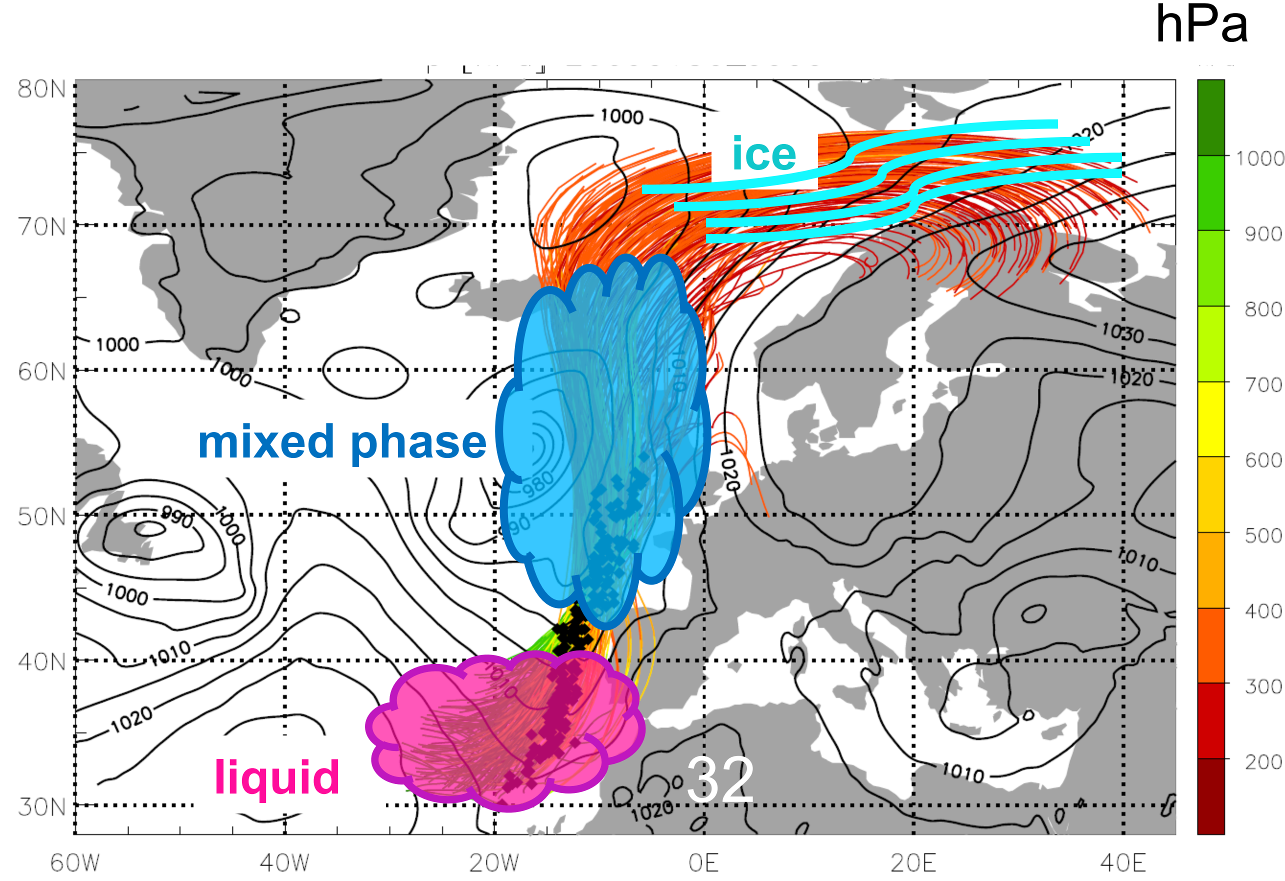

Introduction and Motivation

Clouds → strong impact on radiative budget

Net cloud forcing (TOA) DJF