Warm Conveyor Belts and Cloud Radiative Forcing

WCB – WORKSHOP

ECMWF, March 12th 2020

Hanna Joos and Heini Wernli

IAC, ETH Zürich
Introduction and Motivation

Clouds \( \rightarrow \) strong impact on radiative budget

Definition of cloud forcing at TOA:

1. Shortwave cloud forcing \( \text{SCF} = S_{\text{clear}} - S_{\text{cloudy}} \) \( \rightarrow \) negative
2. Longwave cloud forcing \( \text{LCF} = L_{\text{clear}} - L_{\text{cloudy}} \) \( \rightarrow \) positive
3. Net cloud forcing \( \text{NCF} = \text{LCF} + \text{SCF} \)

NCF ERAinterim, DJF \( \text{W m}^{-2} \)
Clouds $\rightarrow$ strong impact on radiative budget

Clouds $\rightarrow$ are formed by different weather systems in storm track mainly by extra-tropical cyclones
Clouds $\rightarrow$ strong impact on radiative budget

Clouds $\rightarrow$ are formed by different weather systems in storm track mainly by **extra-tropical cyclones**

**Introduction and Motivation**

main cloud producing airstream = **Warm Conveyor Belt**
Clouds → strong impact on radiative budget

Clouds → are formed by different weather systems in storm track mainly by extra-tropical cyclones

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

main cloud producing airstream = Warm Conveyor Belt
WCB trajectory frequency, DJF
(in boundary layer @ t= 0h)

Madonna et al., 2014
WCB trajectory frequency, DJF
(in mid troposphere @ t= 24h)

Madonna et al., 2014
WCB trajectory frequency, DJF
(in upper troposphere @ t= 48h)

Madonna et al., 2014
Example of WCB and Cloud Radiative Forcing (CRF)

**Total Liquid Water [g m\(^{-2}\)]**

**Longwave Cloud Forcing [W m\(^{-2}\)]**
Example of WCB and Cloud Radiative Forcing (CRF)

→ Calculation of mean values along WCB trajectories over whole WCB climatology
Mean TLW, TIW along WCB trajectories

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

Joos 2019, Journal of Climate
Mean Cloud Radiative Forcing along WCB trajectories

Joos 2019, Journal of Climate
Mean Cloud Radiative Forcing along WCB trajectories

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?

Joos 2019, Journal of Climate
Zonal vs. poleward moving WCBs

zonal = \( \text{lat} < 50^\circ \) at all times during ascent

poleward = \( \Delta \text{lat} > 30^\circ \) and \( \text{lat}@t=48h > 65^\circ \)
Zonal vs. poleward moving WCBs

Joos 2019, Journal of Climate
Zonal vs. poleward moving WCBs

→ Poleward motion essential for negative/positive shift in NCF

Joos 2019, Journal of Climate
WCBs, clouds and CRF in an extratropical cyclone

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$^{-2}$]

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

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

longwave cloud forcing (LCF) [W m$^{-2}$]
WCBs, clouds and CRF in an extratropical cyclone

**Total Liquid Water (TLW)** \[g m^{-2}\]

**Total Ice Water (TIW)** \[g m^{-2}\]

**Net Cloud Forcing (NCF)** \[W m^{-2}\]

**Shortwave Cloud Forcing (SCF)** \[W m^{-2}\]

**Longwave Cloud Forcing (LCF)** \[W m^{-2}\]

**Net Cloud Forcing (NCF)** \[W m^{-2}\]
WCBs, clouds and CRF in an extratropical cyclone

- **Total liquid water (TLW) [g m$^{-2}$]**
- **Total ice water (TIW) [g m$^{-2}$]**
- **Net cloud forcing (NCF) [W m$^{-2}$]**

**Positive NCF** (no sunlight)

**Negative NCF**

**Shortwave cloud forcing (SCF) [W m$^{-2}$]**

**Longwave cloud forcing (LCF) [W m$^{-2}$]**
WCBs, clouds and CRF in an extratropical cyclone

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

WCB related NCF

NCF NOT related to WCB
WCBs, clouds and CRF in an extratropical cyclone

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

→ Calculation of **WCB related NCF** at every 6h timestep during whole climatology at every gridpoint \(\rightarrow (\text{WCB})\)
→ Calculation of time mean WCB related NCF \(\left(\text{NCF}\_\text{WCB}\right)\)

→ Calculation of **NOT WCB related NCF** at every 6h timestep during whole climatology at every gridpoint
→ Calculation of time mean NOT WCB related NCF \(\left(\text{NCF}\_\text{NOWCB}\right)\)
Climatological mean value of NCF can be decomposed into:

\[
NCF = NCF_{WCB} \times f_{WCB} + NCF_{NOWCB} (1 - f_{WCB})
\]

- \( NCF_{WCB} \) = mean over all timesteps with WCB
- \( NCF_{NOWCB} \) = mean over all timesteps without WCB
- \( f_{WCB} \) = number of timesteps with WCB at every gridpoint
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
Decomposition of NCF climatology (DJF)

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

“WCB – Effect” ($\text{NCF}_{\text{WCB}} - \text{NCF}_{\text{NOWCB}}$)

“absolute WCB contribution”

$\text{NCF}_{\text{WCB}} \times f_{\text{WCB}}$

Joos 2019, Journal of Climate
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” \( \Delta \text{NCF}_{\text{WCB}} = \text{NCF}_{\text{WCB}} - \text{NCF}_{\text{NOWCB}} \)
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 Conveyor Belts (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 extratropical cyclone (e.g. Browning, 1990; Wernli, 1997; Pfahl, 2014)

**Definition of WCB:**

Trajectories with ascent

> 600 hPa in 48 h
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Net cloud forcing (TOA) DJF

(CERES, 2000 - 2010)

(ERAinterim, 1979 - 2011)