Embedded Convection in Warm Conveyor Belts

Online trajectories in convection-permitting COSMO simulations

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Annika Oertel
Maxi Böttcher
Hanna Joos
Heini Wernli

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Warm conveyor belts (WCBs)

- Strongly ascending airstreams along the cold front typically propagating poleward and eastward

Structure of an extratropical (Browning 1999).
Warm conveyor belts (WCBs)

- Strongly ascending airstreams along the cold front typically propagating poleward and eastward
Warm conveyor belts (WCBs)

- Strongly ascending airstreams along the cold front typically propagating poleward and eastward
- Potential vorticity (PV) modification through cloud diabatic processes

**Slantwise ascending WCB**
**Background and Motivation**

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- Strongly ascending airstreams along the cold front typically propagating poleward and eastward
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*Slantwise ascending WCB*

Intensification of cyclones
Warm conveyor belts (WCBs)

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Background and Motivation

Intensification of cyclones

Modification of large-scale flow
Wernli and Davies 1997, QJR; Joos and Wernli 2012, QJR; Madonna et al. 2014, CLI; Joos and Forbes 2016, QJR
Background and Motivation

Embedded convection
‘Escalator-elevator’ concept
Neiman et al. 1993, MWR

Embedded convection
‘elevator’

Slantwise ascending WCB
‘escalator’
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PV -
PV +
PV -
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**Background and Motivation**

High-resolution convection-resolving simulations of convective ascent

- Separation between slantwise and convective ascent (Rasp et al. 2016, MWR)

![ConvectiveTrajectories](image1.png) ![SlantwiseTrajectories](image2.png)

**Evolution of pressure with time for 10 randomly selected ascending trajectories:**

- a) Convective trajectories and b) non-convective trajectories (Rasp et al. 2016).
Research questions

I. How frequent is embedded convection in WCBs?

Case studies and climatology of embedded convection in WCBs based on geostationary satellite data in the N-Atlantic region and Europe.
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I. How frequent is embedded convection in WCBs?
Case studies and climatology of embedded convection in WCBs based on geostationary satellite data in the N-Atlantic region and Europe

II. How well is embedded convection represented in high-resolution convection-resolving simulations?
• What is the effect of embedded convection on diabatically induced PV anomalies and on surface precipitation?

Online trajectories in convection-resolving simulations at 2 km resolution
I: Where does convection occur?
I: Where does convection occur?
II: COSMO setup

- $\Delta \text{lon}/\Delta \text{lat} = 0.02^\circ$ -> convection-permitting
- 1500 x 1500 grid points
- 21 Sep 2016 – 25 Sep 2016
- Initial and boundary conditions: ECMWF analyses

WCB trajectories from ECMWF
II: COSMO setup

- $\Delta$lon/$\Delta$lat = 0.02° -> convection-permitting
- 1500 x 1500 grid points
- 21 Sep 2016 – 25 Sep 2016
- Initial and boundary conditions: ECMWF analyses
- ~ 4 000 online trajectories$^{1,2}$
  $\Delta t = 20$ s

starting positions:
$\Delta$lon/$\Delta$lat = 1°
$\Delta h = 250 \text{ m} – 2500 \text{ m}$

starting time:
every 3 hours

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$^1$ Miltenberger et al. 2013, Geosci. Model Dev.
$^2$ Miltenberger et al. 2014, COSMO Technical Report
II: Preliminary results

WCB online trajectories at 16 UTC 22 September 2016

**WCBs:**
600 hPa ascent in 48 h
II: Preliminary results

WCB online trajectories at 16 UTC 22 September 2016

**WCBs:**
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**Convective WCB trajectories:**
400 hPa ascent time < 150 min
II: Preliminary results

WCB online trajectories at 16 UTC 22 September 2016

**WCBs:**
600 hPa ascent in 48 h

**Convective WCB trajectories:**
400 hPa ascent time < 150 min

- **Convective trajectories**
- **Slantwise trajectories**
- **Convective ascent**
II: Preliminary results

WCB online trajectories at 16 UTC 22 September 2016

- Convective trajectories
- Slantwise trajectories
- Convective ascent
Embedded convection is particularly frequent in, but not limited to the WCB inflow region ahead of cold front.

Online trajectories qualitatively represent the WCB ascent.

Online trajectories can distinguish between convective ‘elevator’-like and slantwise ‘escalator’-like WCB ascent.
Current problems

- Domain size

  1800 x 1800 grid points (WCB size, movement across N-Atlantic, 2 km resolution)

- Online trajectories

  Pre-defined starting locations (10 000 trajectories)

  Calculation from start time until end of simulation (massive output)

- ETH cluster, Piz Daint?
Thank you
References

Binder, H., Boettcher, M., Joos, H. and Wernli, H. (2016). The role of warm conveyor belts for the intensification of extratropical cyclones in northern hemisphere winter. JAS.


Joos, H. and Forbes, R.M. (2016). Impact of different IFS microphysics on a warm conveyor belt and the downstream flow evolution. QJR.

Joos, H. and Wernli, H. (2012). Influence of microphysical processes on the potential vorticity development in a warm conveyor belt: a case-study with the limited-area model COSMO. QJR.


Miltenberger, A.K., Pfahl, S. and Wernli, H. (2013). An online trajectory module (version 1.0) for the nonhydrostatic numerical weather prediction model COSMO. Geosci. Model Dev.


Data

- Meteosat Second Generation Satellites Schmetz et al. 2002, BAMS
  12 SEVIRI channels (± -67.5°N, -67.5°E)

  - Cloud top pressure $c_{topp}$
    9 km resolution Saunders 2002, EUMETSAT

  - Cloud type classification $CAI – Cn & Ci$
    9 km resolution Lutz 1999, EUMETSAT

Geographical bounds of MSG – 0 degree satellites.

more information about available EUMETSAT products at http://navigator.eumetsat.int/
Eulerian perspective

Meteosat Second Generation retrievals for cyclone ‘Vladiana’ on 23 September 2016

WCB air mass position

cloud top pressure

cloud type classification
How often is convection embedded in WCBs?

Cloud type frequency for *Vladiana* WCBs averaged over 20 Sep 2016 – 24 Sep 2016

- **WCBs dominated by ice clouds**
- **Deep convection in WCB inflow, ascent and outflow**

#WCB air parcels $\sim 10^6$
Selection criteria for convectively-influenced cirrus clouds:

- Ci-dominant grid points: gridded Ci fraction > 50%
- Start 3-day backwards trajectories from Ci-dominant grid points (50 hPa – 50 hPa, Δp = 50 hPa)
- T < -30 °C (ice cloud regime)
- p(traj) < ctopp + Δp (trajectories are not located above clouds)
- Trajectories must be inside high cloud all the time (high-cloud fraction > 10%)
- Fraction of Cn clouds > 50% for at least 1 time step
How often is convection embedded in WCBs?

Cloud type frequency for *Vladiana* WCBs averaged over 20 Sep 2016 – 24 Sep 2016

Cloud type frequency for all WCBs averaged over 15 Sep 2016 – 19 Oct 2016

#WCB air parcels ~ $10^6$

#WCB air parcels ~ $160 \times 10^6$

- WCBs dominated by ice clouds
- Deep convection in WCB inflow, ascent and outflow
CloudSat - DARDAR

Additional Material
Cloud radar
How often is convection embedded in WCBs?
Cloud type frequency for *Vladiana* WCBs
averaged over 20160920_12 – 20160924_23

Cloud type frequency for all WCBs
averaged over 20160915_00 – 20161019_00
Observations of embedded convection in WCBs

- Occurrence of convective activity embedded within slantwise WCB ascent
  e.g. Binder 2016, PhD thesis, Flaounas et al. 2016, QJR
- 30% of ‘convective precipitation’ overlap with ‘WCB diagnosed precipitation’ in Mediterranean cyclones (Flaounas et al. 2017, ClimDyn)

Composite time series of intense cyclone precipitation related to WCBs and deep convection centered at maximum relative vorticity (Flaounas et al. 2017).