Vertical cloud structure of warm conveyor belts – a comparison and evaluation of ECMWF (re-)analyses, CloudSat and CALIPSO data

Hanin Binder, Maxi Boettcher, Hanna Joos, Michael Sprenger and Heini Wernli

**Motivation and goal of the study**
- Only a few observational studies exist on warm conveyor belts (WCBs), most knowledge about these dynamically and physically important airstreams is based on (re-)analysis and forecast data.
- **Goals** of this study:
  - Gain an observational perspective on WCBs by combining for 11 Northern Hemisphere winters satellite observations with ECMWF analyses and reanalyses.
  - Characterize the vertical cloud and precipitation structure of WCBs in terms of vertical extent, radar reflectivity and ice water content.
  - Evaluate the representation of ice and snow in WCB clouds in the ECMWF (re-)analysis data.

**Case study**
Overpass of an explosive cyclone at the time of strongest intensity at 00 UTC 14 Jan 2014

**Spatial distribution of the matches**
- Spatial distribution of the matches consistent with the WCB climatology.
- Most matches occur in the outflow at 7-9km height.
- All WCBs increase in lat. with WCB height up to 8km, decrease above.
- Strong WCBs: Lat. ~constant with increasing WCB height (mean at ~35°N), and, apart from inflow, lower than for all WCBs.

**ER5-based hourly accumulated surface precipitation for all and strong WCBs as a function of WCB height**
- Maximum sfc precipitation during WCB ascent, peak at 
  - All WCBs
  - Strong WCBs
- Almost twice as much sfc precipitation associated with strong compared to all WCBs.
- Most of the precipitation is associated with the large-scale scheme.

**Case study**
Overpass of an explosive cyclone at the time of strongest intensity at 00 UTC 14 Jan 2014

**ER5-based hourly accumulated surface precipitation for all and strong WCBs as a function of WCB height**
- Maximum sfc precipitation during WCB ascent, peak at 
  - All WCBs
  - Strong WCBs
- Almost twice as much sfc precipitation associated with strong compared to all WCBs.
- Most of the precipitation is associated with the large-scale scheme.

**Composites of all WCBs**
- Vertical profiles of measured or modeled variables as a function of WCB height
- **Climatology**
  - Low-level clouds above WCB inflow (\(z_{WCB} \leq 2\)km), with cloud-top heights at 4-6km.
  - During the ascent (\(z_{WCB} \geq 2\)km), WCBs form part of deep, strongly precipitating clouds.
  - The outflow (\(z_{WCB} \geq 7\)km) is located near the top of thin ice clouds.
  - High-low-level PV below ascending WCBs, intense in the outflow.

- **Composites of strong WCBs**
  - **Climatology**
    - CF. red line in latitude-height plot: inflow, ascent and outflow in composites occurs at approximately the same latitude.

Summary and conclusions
- **WCB air masses form part of vertically extended, strongly precipitating clouds**, in particular during their ascent. The cloud parts below and above the WCB air parcels often form in air masses with comparatively weak ascent.
- **Convection** can occur above the WCB inflow (consistent with Oertel et al. 2019, QRMS).
- In the upper troposphere, after the main ascent phase, the WCB air parcels form part of thin ice clouds or they are cloud-free.
- The **ERA5 reanalyses and IFS operational analyses** are able to capture the broad structure of snow and ice water contents remarkably well, but the peak values are underestimated and the transition between cloudy and cloud-free regions is smoother.

**Motivation and goal of the study**
- Only a few observational studies exist on warm conveyor belts (WCBs), most knowledge about these dynamically and physically important airstreams is based on (re-)analysis and forecast data.
- **Goals** of this study:
  - Gain an observational perspective on WCBs by combining for 11 Northern Hemisphere winters satellite observations with ECMWF analyses and reanalyses.
  - Characterize the vertical cloud and precipitation structure of WCBs in terms of vertical extent, radar reflectivity and ice water content.
  - Evaluate the representation of ice and snow in WCB clouds in the ECMWF (re-)analysis data.

**Case study**
Overpass of an explosive cyclone at the time of strongest intensity at 00 UTC 14 Jan 2014

**Spatial distribution of the matches**
- Spatial distribution of the matches consistent with the WCB climatology.
- Most matches occur in the outflow at 7-9km height.
- All WCBs increase in lat. with WCB height up to 8km, decrease above.
- Strong WCBs: Lat. ~constant with increasing WCB height (mean at ~35°N), and, apart from inflow, lower than for all WCBs.

**ER5-based hourly accumulated surface precipitation for all and strong WCBs as a function of WCB height**
- Maximum sfc precipitation during WCB ascent, peak at 
  - All WCBs
  - Strong WCBs
- Almost twice as much sfc precipitation associated with strong compared to all WCBs.
- Most of the precipitation is associated with the large-scale scheme.

**Composites of all WCBs**
- Vertical profiles of measured or modeled variables as a function of WCB height
- **Climatology**
  - Low-level clouds above WCB inflow (\(z_{WCB} \leq 2\)km), with cloud-top heights at 4-6km.
  - During the ascent (\(z_{WCB} \geq 2\)km), WCBs form part of deep, strongly precipitating clouds.
  - The outflow (\(z_{WCB} \geq 7\)km) is located near the top of thin ice clouds.
  - High-low-level PV below ascending WCBs, intense in the outflow.

- **Composites of strong WCBs**
  - **Climatology**
    - CF. red line in latitude-height plot: inflow, ascent and outflow in composites occurs at approximately the same latitude.

Summary and conclusions
- **WCB air masses form part of vertically extended, strongly precipitating clouds**, in particular during their ascent. The cloud parts below and above the WCB air parcels often form in air masses with comparatively weak ascent.
- **Convection** can occur above the WCB inflow (consistent with Oertel et al. 2019, QRMS).
- In the upper troposphere, after the main ascent phase, the WCB air parcels form part of thin ice clouds or they are cloud-free.
- The **ERA5 reanalyses and IFS operational analyses** are able to capture the broad structure of snow and ice water contents remarkably well, but the peak values are underestimated and the transition between cloudy and cloud-free regions is smoother.