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

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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.

Data and Method

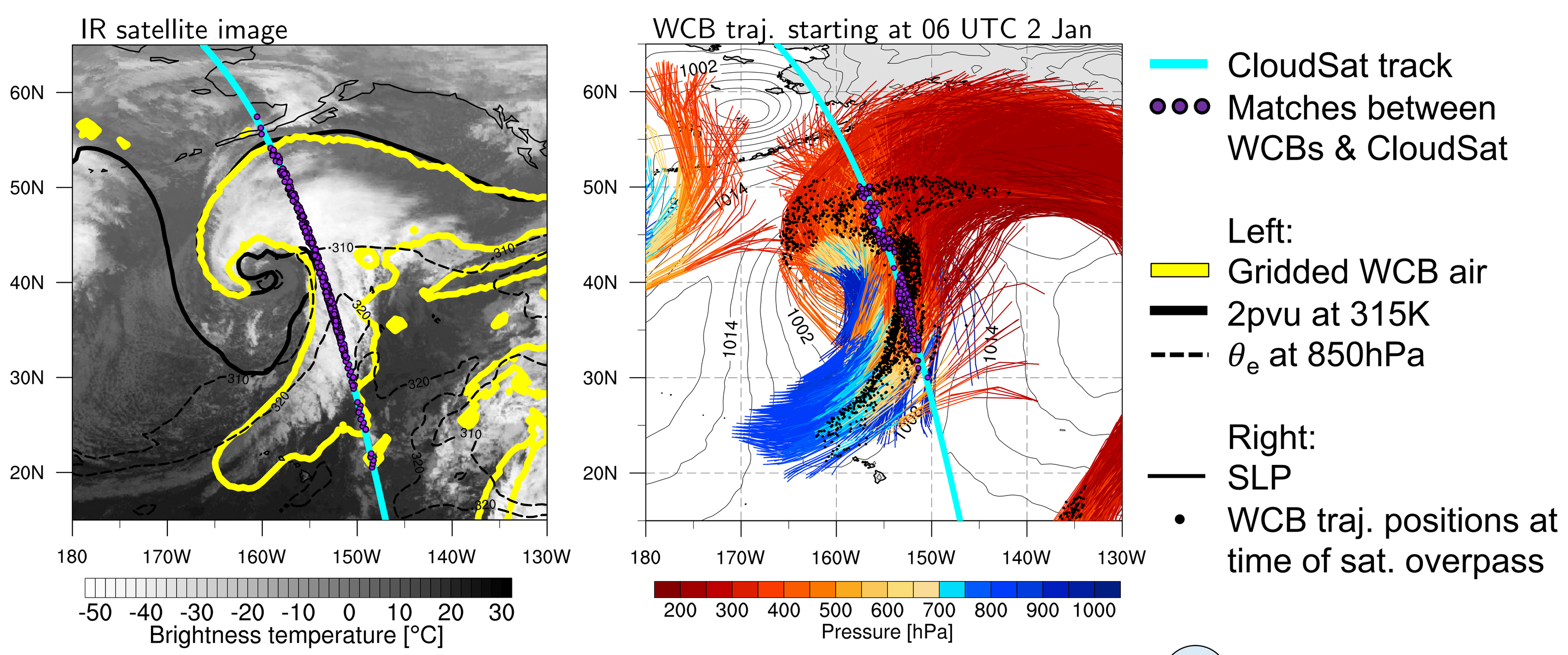
- WCB trajectories based on ERA5 reanalyses for climatological analyses and on IFS operational analyses (cycle 40r1) for a case study
  - WCB selection criterion: Ascent > 600 hPa in 2 days in the vicinity of an extratropical cyclone (Madonna et al. 2014, *J. Clim.*)
- Observations from polar-orbiting satellites:
  - Reflectivity profiles from the CloudSat radar (Stephens et al. 2002, *BAMS*)
  - Ice water content (IWC) profiles from DARDAR (Delanoë and Hogan 2010, *JGR*), a combination of CloudSat radar and CALIPSO lidar data
  - 1.1 km horizontal and 60 m vertical resolution
- Identification of matches between WCB air parcels and satellite overpasses for 11 NH winters (Dec 2006 to Jan 2016)
  → 236'385 matches ("match": WCB air parcel is within 50 km of satellite)
- Selection of "strong WCBs": 5% of matching WCB air parcels with highest reflectivities in each 0.5 km height bin

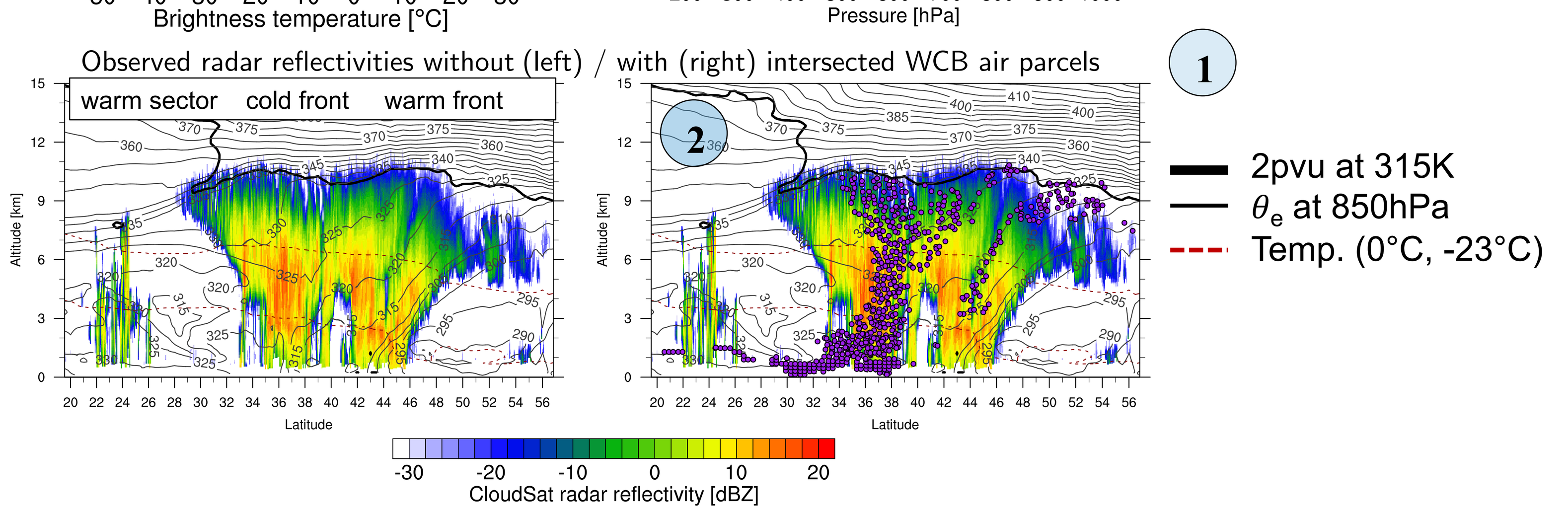
Summary and conclusions

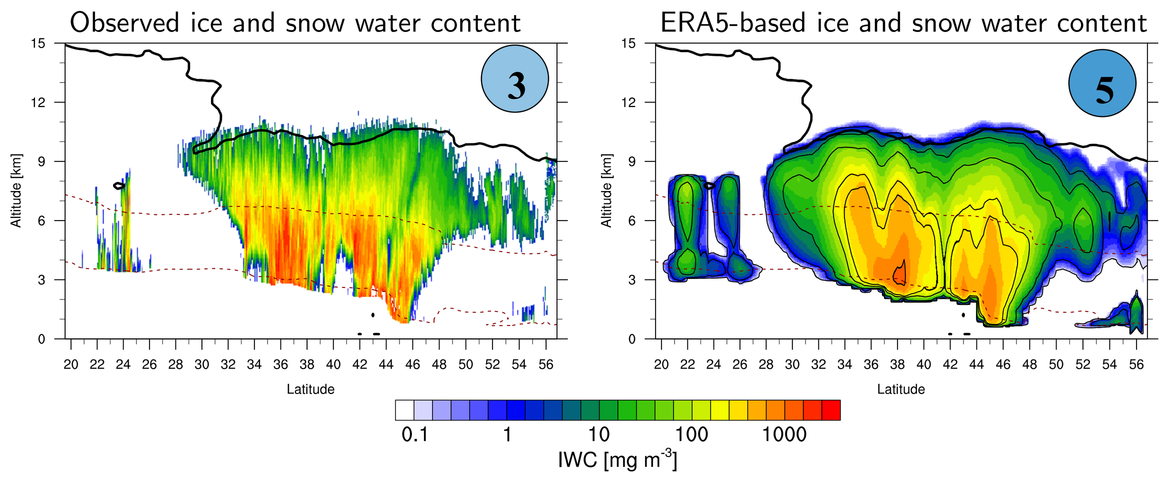
1. WCB air masses form part of vertically extended, strongly precipitating clouds, in particular during their ascent. The cloud parts below and above the WCB air parcels often form in air masses with comparatively weak ascent.
2. Convection can occur above the WCB inflow (consistent with Oertel et al. 2019, *QJRMS*).
3. In the upper troposphere, after the main ascent phase, the WCB air parcels form part of thin ice clouds or they are cloud-free.
4. The highest radar reflectivities along WCBs typically occur at relatively low latitudes (mean ~35°N). They are associated with particularly deep and strongly precipitating clouds that occur not only during the ascent, but also in the inflow and outflow region.
5. 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.

Case study

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



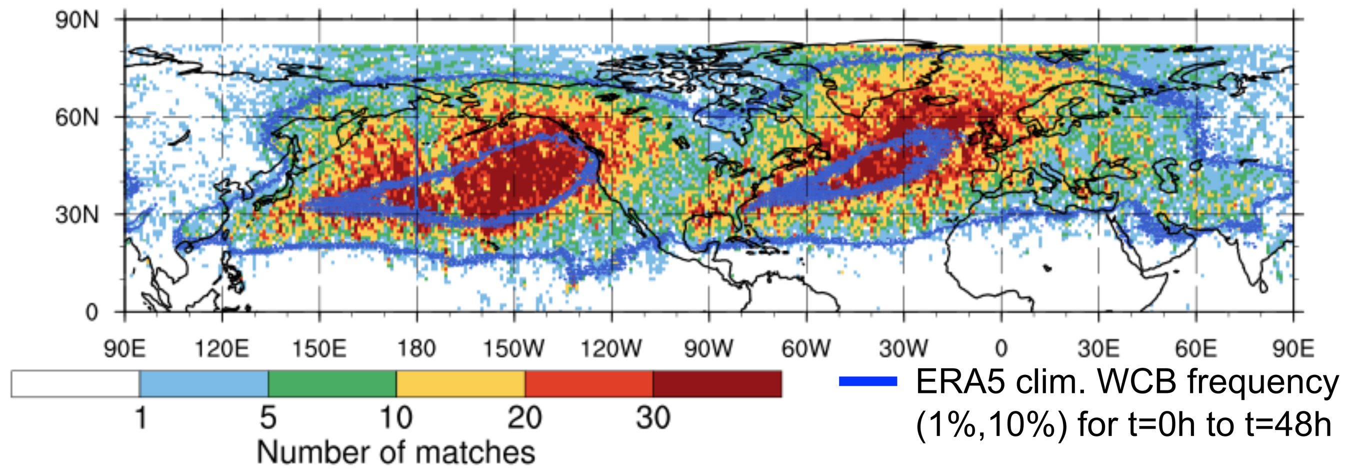


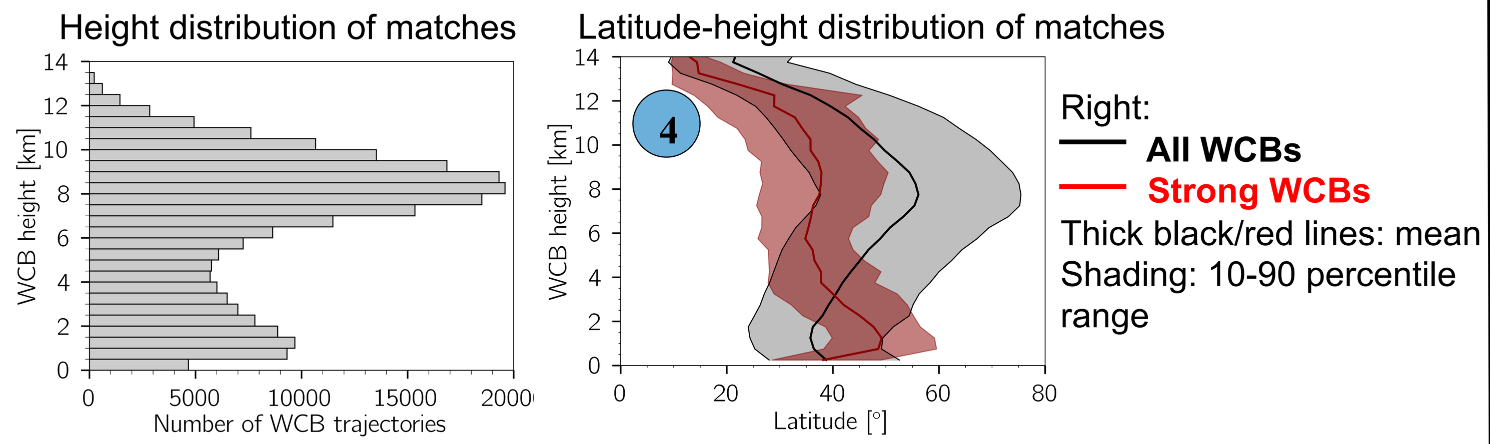


- Warm sector: Shallow-to-midlevel convection above the WCB inflow.
- Cold and warm front: Strongly ascending WCB air masses form part of deep clouds, but not the entire cloud system is WCB air.
- Below 6-8km: high reflectivities and IWC values indicate heavy precipitation in the form of snow (rain) above (below) the 0°C isotherm. Above 6-8 km: ice clouds in the WCB outflow.
- The IFS operational analyses capture the broad structure and distribution of snow and ice associated with the WCB clouds.

Climatology

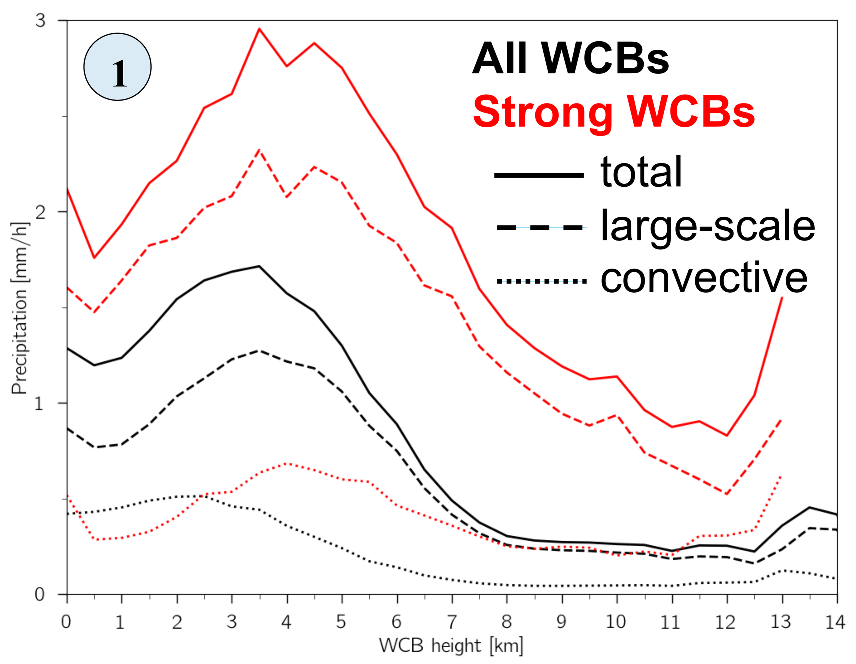
Spatial distribution of the matches





- 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.

ERA5-based hourly accumulated surface precipitation for all and strong WCBs as a function of WCB height



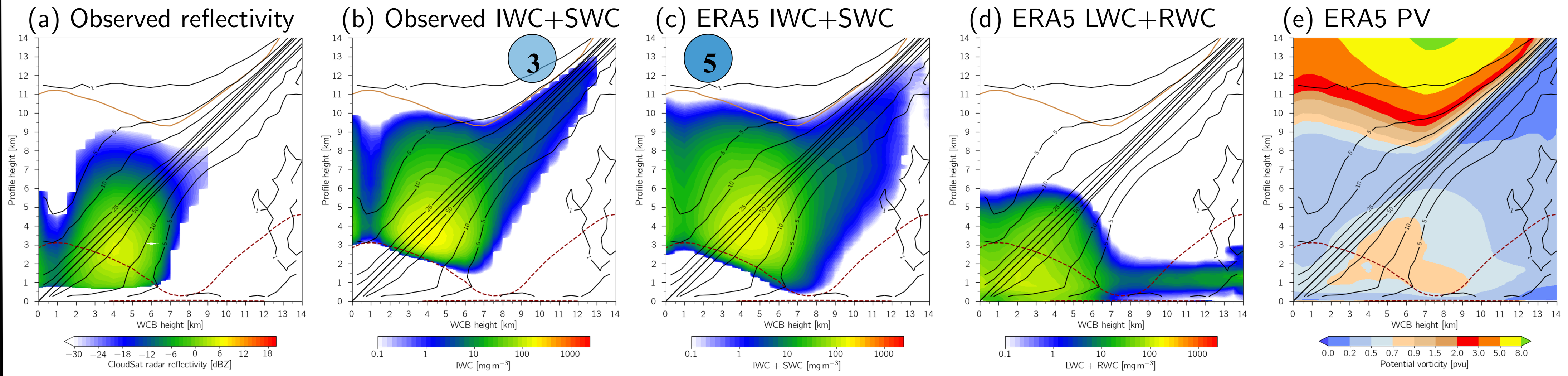
- Maximum sfc precipitation during WCB ascent, peak at z_{WCB}~3-4km (4-5km) for all (strong) WCBs.
- Almost twice as much sfc precipitation associated with strong compared to all WCBs.
- Most of the precipitation is associated with the large-scale scheme.

x-axis: height of the matching WCB air parcels (z_{WCB})
y-axis: mean precipitation over all WCB air parcels at specific height

Composites of all WCBs (1)

Vertical profiles of measured or modeled variables as a function of WCB height

x-axis: height of the matching WCB air parcels (z_{WCB})
y-axis: mean profiles of measured or modeled variables over all WCB air parcels at specific height
→ Cf. black line in latitude-height plot: up to z_{WCB}~8km composites can be regarded as a cross section from south to north through poleward ascending WCB air, for z_{WCB}>8km cross section from north to south

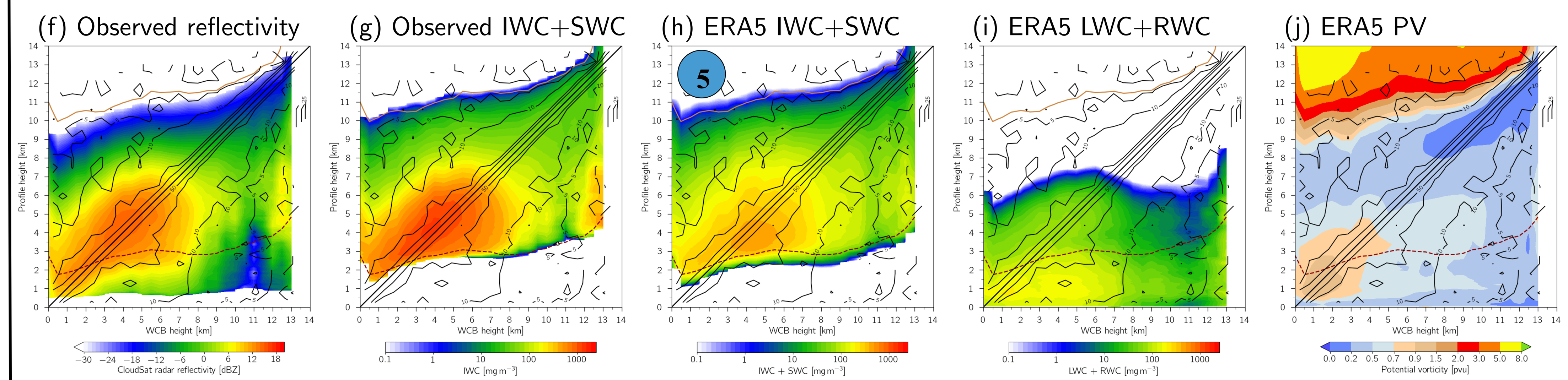


2pvu – – 0°C isoline —— WCB trajectory frequency (contours at 1, 5, 10, 25, 50 and 100%), with 100% occurring on diagonal

- Low-level clouds above WCB inflow (z_{WCB}~0-2km), with cloud-top heights at 4-6km.
- During the ascent (z_{WCB}~2-7km), WCBs form part of deep, strongly precipitating clouds.
- The outflow (z_{WCB}>7km) is located near the top of thin ice clouds.
- High low-level PV below ascending WCBs, low PV in the outflow.
- Observed (b) and modeled (c) ice and snow are remarkably similar.

Composites of strong WCBs (4)

→ Cf. red line in latitude-height plot: Inflow, ascent and outflow in composites occurs at approximately the same latitude.



Compared to all WCBs:

- Higher reflectivities, snow, ice, rain and liquid water contents at WCB height (diagonal) and everywhere else in the troposphere. Deep clouds also above the inflow and in the outflow.
- High low-level PV at lower WCB heights.