Intercomparison of meteorological analyses and trajectories in the Antarctic lower stratosphere with Concordiasi superpressure balloon observations

Lars Hoffmann[1], Albert Hertzog[2], Thomas Rößler[1], Olaf Stein[1], and Xue Wu[1,3]

[1]Jülich Supercomputing Centre, Forschungszentrum Jülich, Jülich, Germany; [2]Laboratoire de Meteorologie Dynamique, Ecole Polytechnique, IPSL, Palaiseau, France; [3]Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

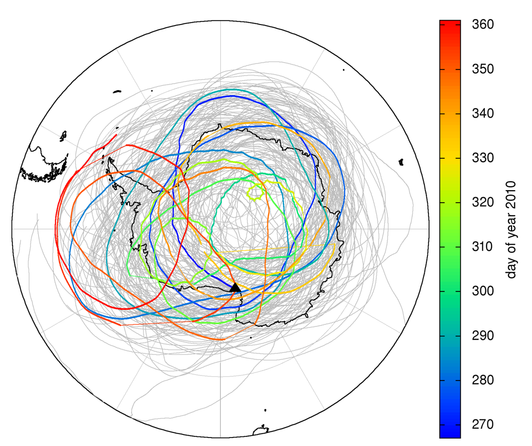
l.hoffmann@fz-juelich.de

Key points

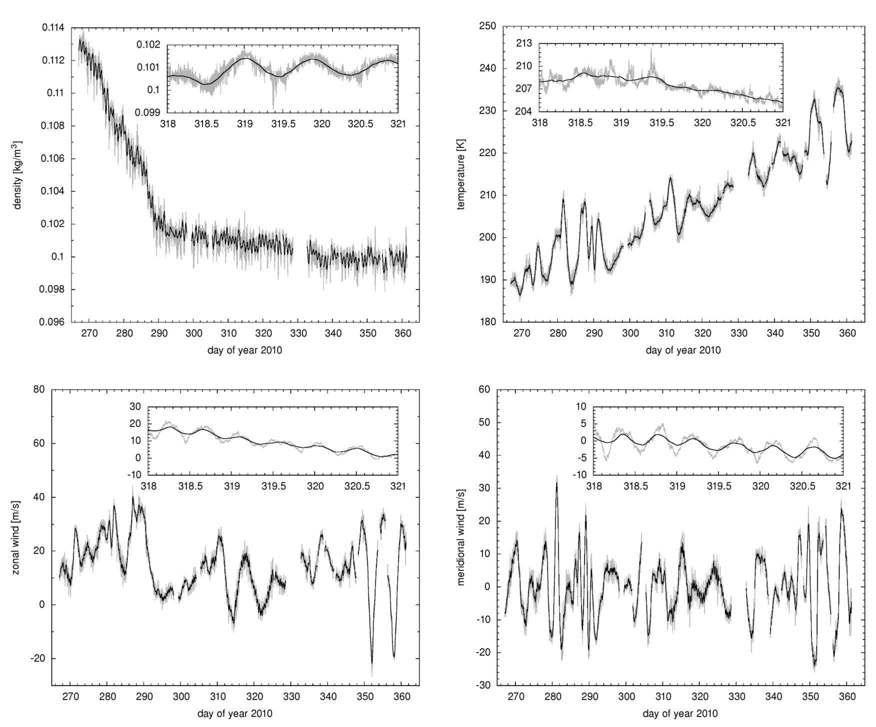
- Using superpressure balloon (SPB) observations during the Concordiasi field campaign in Antarctica in September 2010 to January 2011, we evaluated trajectory calculations of our new Lagrangian particle dispersion model MPTRAC.
- In addition, we directly compared temperatures and winds of five meteorological analyses in the Antarctic lower stratosphere, a region of the atmosphere that is of major interest regarding chemistry and dynamics of the polar vortex.
- Although case studies suggest that the accuracy of trajectory calculations is sometimes influenced by meteorological complexity, evaluation results are satisfactory and compare well to earlier studies using SPB observations.

Superpressure balloon observations

- The Concordiasi field campaign covered 19 SPB flights (colored curve highlights flight #4). The balloons drifted over Antarctica at altitudes of 17 – 18.5 km for up to three months:



- Time series of balloon measurements during Concordiasi flight #4 (gray: 60-s raw data; black: 15-h low-pass filtered data):

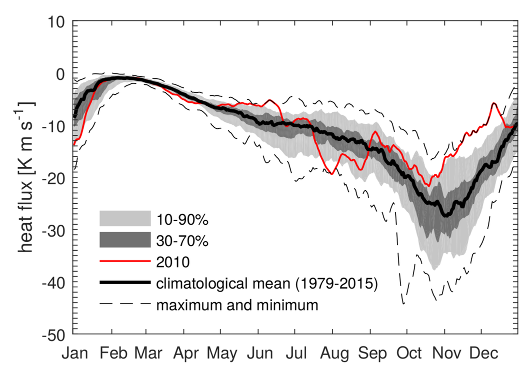


Meteorological data and conditions

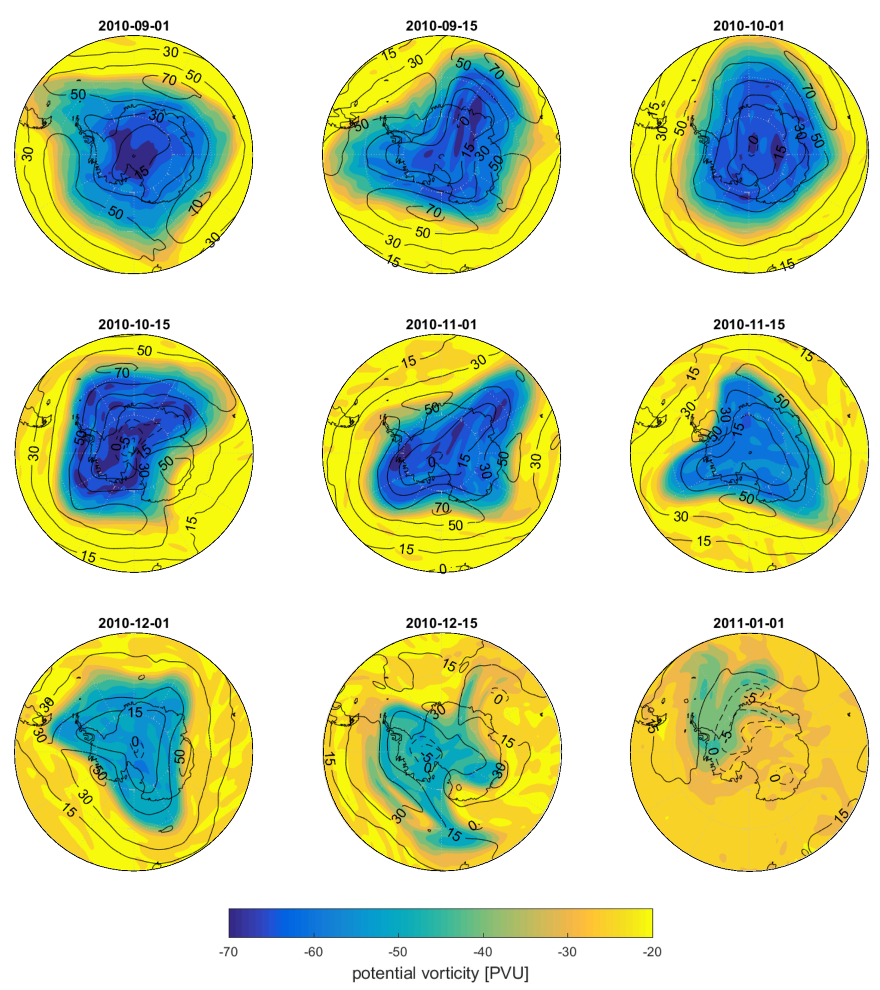
- Our comparison covers ECMWF operational analysis, ERA-Interim, MERRA, MERRA-2, and NCEP/NCAR reanalysis data:

Data Product	Temporal Resolution	Top Level	Vertical Levels	Horizontal Resolution
ECMWF OA	3 h	0.01 hPa	91	0.125° × 0.125°
ERA-Interim	6 h	0.1 hPa	60	1.000° × 1.000°
MERRA-2	3 h	0.01 hPa	72	0.500° × 0.667°
MERRA	3 h	0.1 hPa	42	1.250° × 1.250°
NCEP/NCAR	6 h	10 hPa	17	2.500° × 2.500°

- The Concordiasi measurements cover the final stratospheric warming and decay of the Southern Hemisphere polar vortex during 2010/2011 austral spring to summer.
- Activity of the polar vortex at 50 hPa as represented by the 45-day running mean of the eddy heat flux between 45 and 75°S (obtained from NASA Ozone Watch, based on MERRA-2):

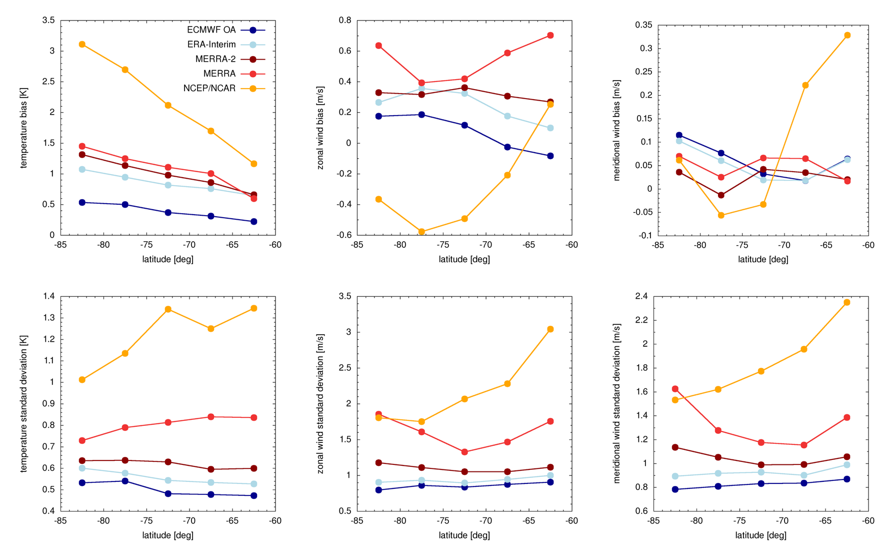


- ERA-Interim potential vorticity (PVU; shaded surface) and zonal wind (m/s; black contours) on the 475 K isentropic surface:



Direct comparison of meteorological data

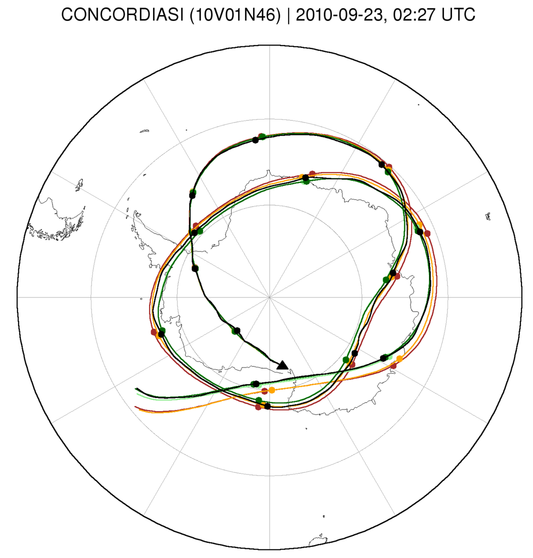
- Background temperatures of the analyses have a mean precision of 0.5 – 1.4 K and a warm bias of 0.4 – 2.1 K wrt the balloon data. Zonal and meridional winds have a mean precision of 0.9 – 2.3 m/s and a bias below ±0.5 m/s.
- Standard deviations related to small-scale fluctuations (due to gravity waves) are reproduced at levels of 15 – 60% for temperature and 30 – 60% for the horizontal winds.



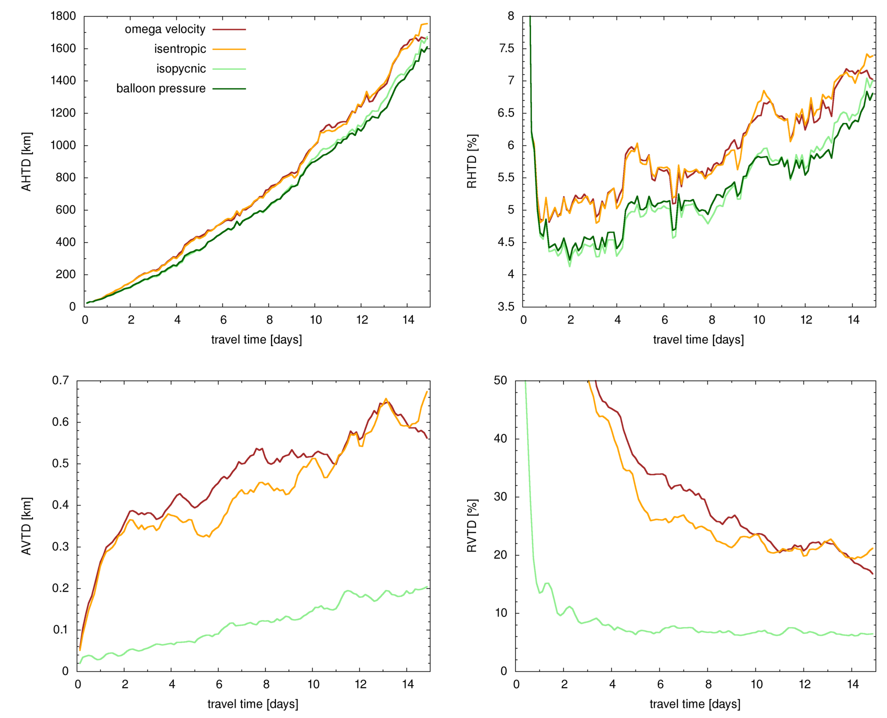
- Considering that a reduced subset of balloon observations has been assimilated into most analyses (except for NCEP/NCAR), differences found here indicate that other observations, the forecast models, and the data assimilation procedures still have significant impact.

Analysis of vertical motions

- After launch, SPBs ascend and expand until they reach a float level where the atmospheric density matches the balloon density. On this isopycnic surface a balloon is free to float horizontally with the motion of the wind, behaving like a quasi-Lagrangian tracer in the atmosphere.
- Example of a 15-day segment of a balloon trajectory (black) and trajectory calculations using different vertical motions (other colors):

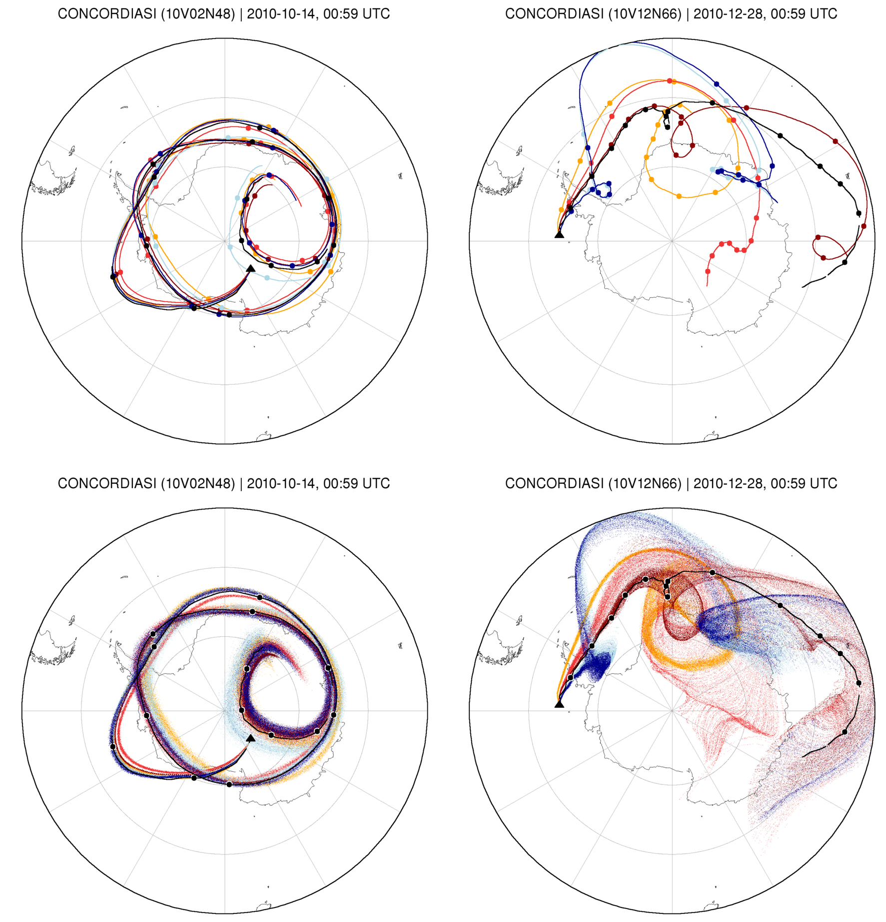


- Isopycnic trajectories (ρ = const) or nudging to balloon pressure measurements provides better results than isentropic trajectories (θ = const) or using vertical velocities from the analyses:



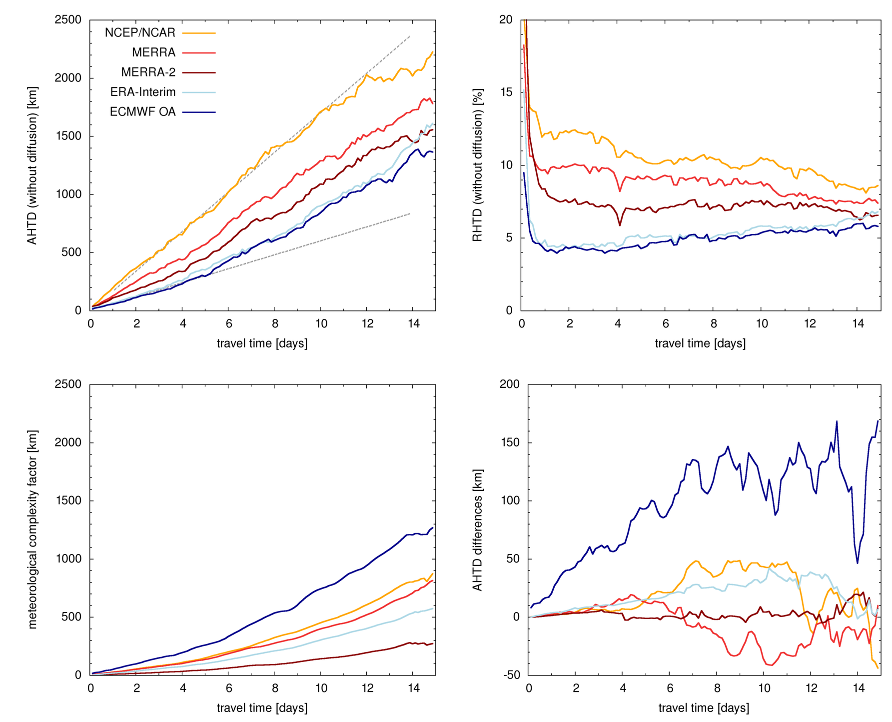
Evaluation of trajectory calculations

- Examples of 15-day trajectory calculations for different analyses for a case of low (left) and high (right) meteorological complexity. Upper panels show simulations without diffusion and lower panels show dispersion simulations using ensembles of 1000 trajectories:



- Dispersion simulations reveal difficulties with the representation of subgrid-scale wind fluctuations, as the spread of air parcels simulated with different analyses was not consistent.

- To quantify the differences between the trajectory calculations, we compared absolute and relative horizontal transport deviations (AHTDs and RHTDs) for a set of 104 samples of 15-day trajectories. The meteorological complexity factor was estimated by calculating AHTDs wrt to the ensemble mean:



- Relative horizontal transport deviations are in the range of 4 – 5% (ECMWF OA) to 9 – 12% (NCEP/NCAR). Error growth rates (gray lines) are in the range of 60 – 170 km/day. Meteorological complexity factors vary between the analyses, but they are generally smaller than the AHTDs in this statistical evaluation.

Code availability

- The code of the MPTRAC model is available under the terms and conditions of the GNU General Public License, Version 3, from the repository at `https://github.com/slcs-jsc/mptrac`.

References

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