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A climatology of tropospheric humidity inversions in five reanalyses

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ABSTRACT

Specific humidity is generally thought to decrease with height in the troposphere. However, here we document the existence of specific humidity inversions in five reanalyses: the National Centers for Environmental Prediction (NCEP) second reanalysis (NCEP-2), the European Centre for Medium-Range Forecasts (ECMWF) 40-year reanalysis (ERA-40), the Modern Era Retrospective Analysis for Research Applications (MERRA), NCEP's Climate Forecast System Reanalysis (CFSR), and the ECMWF interim reanalysis (ERA-Interim). These inversions are most frequent in the polar regions. Inversions do occur elsewhere, most notably over the subtropical stratus regions, but are less frequent and likely overproduced depending on the location. Polar inversions are the most persistent in winter and the strongest (as defined by the humidity difference divided by the pressure difference across the inversion) in summer or autumn with low bases (at pressures > 900 hPa). Winter humidity inversions are lower, being near-surface, due to the persistence of low-level temperature inversions associated with these humidity inversions, while summer humidity inversions tend to be located near cloud top providing moisture to prevent the melt season stratus from evaporating. The most important contributions to affect humidity inversions in MERRA are dynamics, turbulence, and moist physics. However, local advection may not play as much of a role as regional humidity convergence. The subtropical stratus inversions are as thick as polar humidity inversions but with higher bases generally at pressures <900 hPa. These inversions are confirmed by rawinsonde data, but there are discrepancies between the observed annual and diurnal cycles in inversion frequency and those portrayed in the reanalyses.

Contents

1. Introduction . . . 166
2. Reanalyses . . . 168
   2.1. NCEP-2 . . . 168
   2.2. ERA-40 . . . 168
   2.3. MERRA . . . 169
   2.4. CFSR . . . 169
   2.5. ERA-Interim . . . 169
3. The specific humidity inversion climatology in the reanalyses . . . 169
4. Comparison to rawinsonde data . . . 175
5. Discussion . . . 180

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6. Conclusions 184
Acknowledgments 186
References 186

1. Introduction

The vertical distribution of water vapor strongly affects radiative transfer as well as cloud and precipitation formation and hence plays a fundamental role in weather forecasting and climate studies. It is generally thought that specific humidity decreases with increasing height in the troposphere (e.g., Fig. 12.4 in Peixoto and Oort, 1992; Wagner et al., 1990; Johnsen and Rockel, 2001). On average, this is indeed the case as can be seen in the profile of the zonal mean of specific humidity from the National Aeronautics and Space Administration (NASA) Goddard Modeling and Assimilation Office (GMAO) Modern Era Retrospective Analysis for Research and Applications (MERRA) in Fig. 1.

However, in certain circumstances there can be specific humidity inversions, or layers in which specific humidity increases with height, in the troposphere. Fig. 2 presents the zonal mean of the vertical profiles of the difference in specific humidity Δq with height in MERRA for each season: (a) December–February or DJF, (b) March–May or MAM, (c) June–August or JJA, and (d) September–November or SON. This Δq is calculated at halfway between each pressure level in MERRA as the simple difference in specific humidity between pressure levels. Now, one can clearly see the areas of positive Δq, i.e. increasing humidity with height, as the blue shading in the polar regions. Over the Antarctic, positive Δq is only over the South Pole from austral autumn (MAM) to spring (SON). Over the Arctic, the largest area of positive Δq occurs in boreal winter (DJF). In boreal spring (MAM) and summer (JJA), there is no mean positive Δq, and the area of mean positive Δq redevelops in boreal autumn (SON). This seems to indicate that humidity inversions would be more numerous in the polar regions during the autumn and winter seasons but does not preclude the existence of humidity inversions in those regions in any other season. Humidity inversions may be less numerous or not strong enough to withstand the averaging.

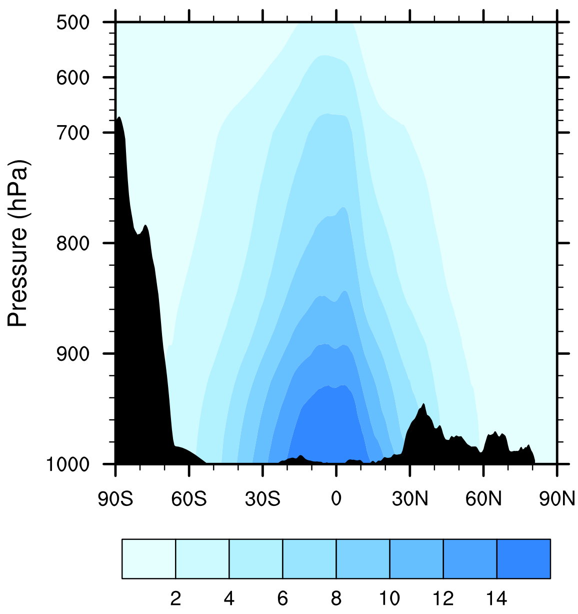

Fig. 1. The zonal mean specific humidity (g kg^{-1}) from MERRA for 1981–2000. The black areas indicate regions that are below ground.

Previously, specific humidity inversions were observed periodically during the Arctic Ocean Experiment 2001 (Tjernström et al., 2004; Tjernström, 2005; Sedlar and Tjernström, 2009), and Gerding et al. (2004) documented the case of a moister layer above a near-surface dry layer observed by lidar on 28 February 2002 on the island of Spitsbergen in the Arctic. More recently, Vihma et al. (2011) investigated humidity inversions over two Svalbard fjords finding that they were connected to temperature inversions occurring simultaneously which was also found by Sedlar et al. (2011) from observations made during two field experiments over the Arctic Ocean. Arctic humidity inversions were also previously documented by Serreze et al. (1995a, 1995b) and modeled by Curry (1983).

These inversions are not limited to the Arctic. Near-surface humidity inversions can be seen from three years of summer and autumn radiosonde profiles over Dome C (Tomasi et al., 2006) and in ten years of radiosonde profiles at 11 coastal sites (Nygård et al., 2013a) in Antarctica. Additionally, Roberts et al. (2010) documented that specific humidity above 900 hPa tends to be higher than surface values over the northeastern Pacific Ocean in MERRA. Humidity inversions have also been observed over the Sichuan Basin (Jiang et al., 2012) and the Tibetan Plateau (Liu et al., 2002), and are associated with a radiative fog event in Nanjing, China (Liu et al., 2010). Humidity inversions outside of the polar regions may go by various other names. For instance, Kloesel and Albrecht (1989) called them "q-reversals." They also may be found when looking at other phenomena, such as stratospheric air intrusions (Di Giralamo et al., 2009).

Such specific humidity inversions might have a radiative impact. Devasthale et al. (2011) implied that humidity inversions in the Arctic would impact longwave radiation especially in winter since the inversion contributes as much as 50% to the total column precipitable water. Other radiative impacts may be associated with their effect on clouds. Sedlar and Tjernström (2009), Solomon et al. (2011), and Sedlar et al. (2011) documented instances of humidity inversions topping Arctic stratus in the summer, and Paluch et al. (1999) gave details of instances of higher free tropospheric specific humidity than in the boundary layer, or in other words, a humidity inversion, over the eastern equatorial Pacific. All of these suggest that these humidity inversions prevent evaporation from cloud-top entrainment (induced by cloud-top radiative cooling), thus promoting continuity of the boundary layer cloud. Furthermore, such inversions would also impact the temperature-lapse rate feedback of the greenhouse effect, particularly at high latitudes where it is more important (Webb et al., 1993; Curry et al., 1995).