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A SYNOPTIC CLIMATOLOGY OF CONTRAIL OUTBREAK EVENTS AND ASSOCIATED SURFACE TEMPERATURE EFFECTS FOR THE SOUTHERN UNITED STATES

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1. INTRODUCTION

The artificial cloudiness, or "contrail cirrus" that results from multiple long-lasting (several hours or more) jet contrails (outbreaks), may alter the surface radiation budget and resultant temperatures, particularly the diurnal temperature range (DTR; Travis et al. 2004). The synoptic conditions associated with these DTR-altering outbreaks, however, are still not fully known. Therefore, the upper atmospheric conditions during such contrail outbreaks were analyzed and composited to reveal the dominant synoptic patterns, as well as each outbreak's impact on the DTR. The analysis was undertaken for the southern United States in two January months (2008, 2009), because of the relatively high incidence of contrail outbreaks in that region during winter.

2. METHODS

We utilize an extensive database of satellite-derived "clear-sky" contrail outbreaks over the southern United States (see Carleton et al. 2008) by extracting those events spanning at least one half of the diurnal cycle of temperature and which cover at least 1,000 km^2. 24 outbreaks met these criteria, and were selected for study. The aggregated impact of outbreaks on maximum and minimum temperatures, and the DTR, was determined by comparing anomalies at stations overlain by outbreaks with those at adjacent stations having similar synoptic atmospheric conditions but not experiencing contrails. Stations possessing similar physical and climatic conditions (e.g. both airports at a comparable elevation, and similar land surface and soil moisture conditions) were chosen for the comparison.

A synoptic climatology (i.e., composite spatio-temporal averages) of atmospheric circulation controls, represented by upper tropospheric (UT) variables accompanying these longer-lasting jet contrail outbreaks, was also developed from North American Regional Reanalysis Data (NARR, Mesinger et al. 2006). Composite average and anomaly patterns of UT temperature, specific humidity, and zonal wind were computed, as well as their horizontal and vertical gradients over the outbreak area. The anomalies were based on the departures from normal over the 32 year period of 1979-2010.

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3. RESULTS AND DISCUSSION

The average DTR for long-lived outbreaks in January 2008 and 2009 was 6.375o ^C smaller than at adjacent non-outbreak stations, a result that is statistically significant at greater than the 95% level. Even when station pairs were normalized to the long-term average DTR for the date, there was still a suppression of 5.5 o^C at the outbreak stations. These results suggest that, at least for this region of the United States for this time of year (January), longer-lived contrail outbreaks occurring in otherwise clear or partly cloudy skies significantly suppress DTR. Moreover, individual stations overlain by outbreaks showed consistency in their vertical atmospheric profiles when compared to normal. A steeper lapse rate in the UT, specifically between 300 mb and 200 mb was noted (Figure 1) as being 16.2 o^C. This lapse rate was 2.5o^C greater than the normal lapse rate between the two levels. This temperature anomaly contrasts with the above-normal temperatures in the lower and middle portions of the atmosphere, but colder than average in the UT layer where most contrails form (around 250 – 200 mb). These below-normal UT temperatures reinforce the hypothesis that jet contrail outbreaks occur more frequently within warm-cored high pressure systems, whereby a colder than normal UT accompanies a higher than normal tropopause, and subsidence warms the middle and lower troposphere. This association is further confirmed by the composite vertical wind profile, which shows below normal zonal winds in the UT (Figure 2).

These long-lived, DTR-suppressing contrail outbreaks also have pattern signatures on synoptic scales. The area covered by each satellite-observed outbreak was defined by two coordinate pairs, creating a gridbox (Figure 3), with an average gridbox size of 3.1x10^5 km ^2 (Table 1). Spatial averages of UT variables were composited across the gridboxes for the 24 outbreaks. Anomalously large horizontal gradients of 300 mb specific humidity, zonal wind, and 200 mb temperature, all of which were several times larger than normal (Table 1), were statistically significant at the 95% level. Moreover, a large vertical gradient in vector winds (wind shear) is also noted over contrail outbreak stations selected for DTR comparisons. The absolute value of the directional shear between 300 mb and 100 mb over these stations was about 7 times greater than normal during outbreaks. 14 of the 24 outbreaks showed warm air advection (i.e., clockwise turning of UT winds) (e.g., DeGrand et al. 2000). Directional wind shear is necessary for the maintenance of contrail outbreaks as it allows contrail clouds to spread horizontally (Jensen et al. 1998).

4. CONCLUDING REMARKS

This study confirms that specific UT conditions accompany long-lived, widespread jet contrail outbreaks in the southern U.S. in January. These include large gradients of temperature, zonal wind, and specific humidity, as well as strong directional shear and lower than normal temperatures at and above the cloud formation level (e.g., Carleton et al. 2008). We intend to apply this approach to other mid-season months and additional U.S. regions having high frequencies of outbreaks (e.g., the Midwest), to further evaluate the synoptic conditions accompanying contrail outbreaks, and their impacts on surface temperatures and DTR. Ultimately, such knowledge could help improve the prediction of contrail outbreaks in near-real time for U.S. regions of high outbreak frequency.

5. ACKNOWLEDGEMENTS

This research was supported by National Science Foundation grants 0819396 and 0819416.

FIGURES

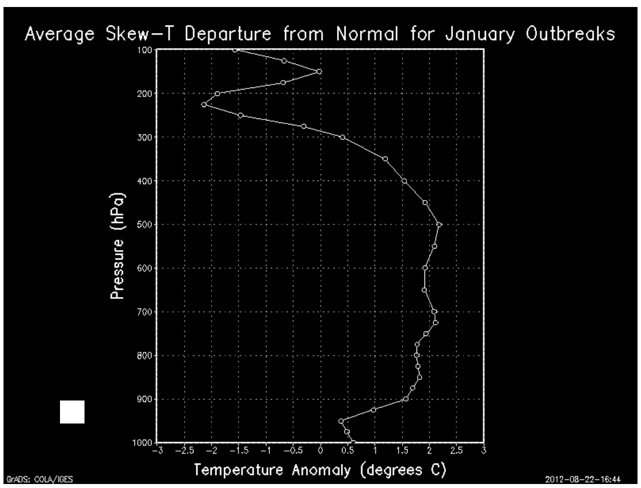

Figure 1. Skew-T of outbreak-averaged temperatures anomaly from normal, for outbreak gridbox stations.

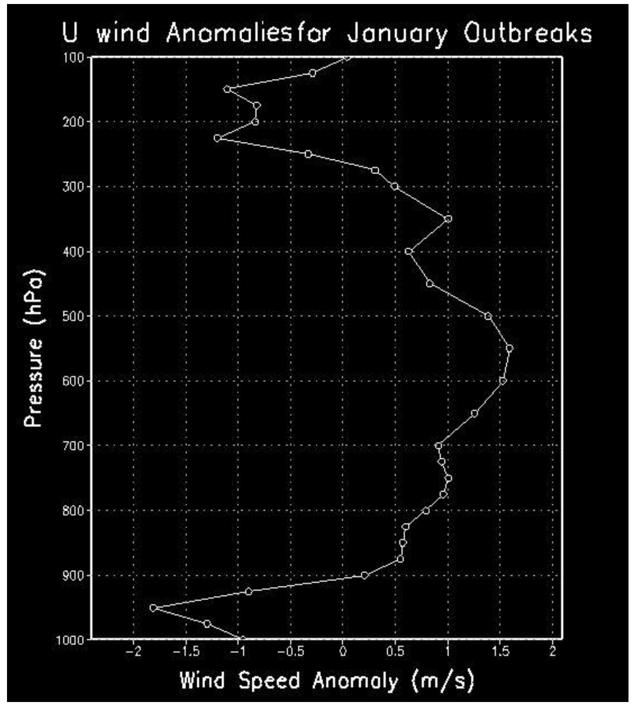

Figure 2. Vertical profiles of outbreak-averaged zonal wind anomalies from normal, for outbreak gridbox stations.

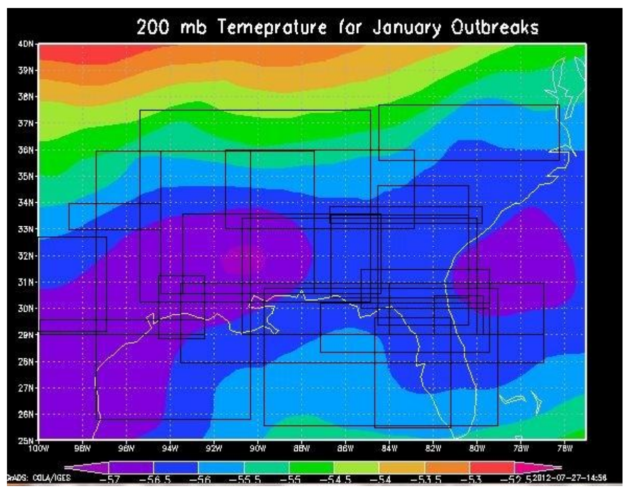

Figure 3. Gridboxes for the 24 jet contrail outbreaks analyzed, with average 200 mb temperature for the 24 outbreaks underlain.

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Table 1- Synoptic Analysis of Jet Contrail Outbreaks in the Southern United States, January 2008 and 2009.

Synoptic analysis of 24 contrail outbreaks analyzed in January 2008 and January 2009. Circulation categories (CIRCUL) at 500 hPa follow DeGrand et al. (2000). Both the departure of the absolute value of vertical shear from the long-term normal (Δ |SHEAR| = S, m/s), and the sign of the temperature advection (S, C = Cold, W= Warm), pertain to the layer 300-100 hPa. Departures of the horizontal gradients of temperature (ΔT-grad, in oC/km) and specific humidity (ΔSH-grad, in g/kg/km) from the long-term normals at 300 hPa, are calculated across the extent of each outbreak. Asterisks (*) indicate statistical significance at $p < 0.05$ level.

Date	CIRCUL	Δ |SHEAR|	S (C, W)	ΔT-grad	ΔSH-grad	Area
1/3/2008	East of Ridge	3.16	W	4.40E-04	4.13E-05	7.58E+05
1/4/2008	East of Trough	-1.74	W	8.03E-04	3.78E-05	2.55E+05
1/7/2008	East of Trough	0.61	C	2.76E-05	1.64E-05	5.18E+04
1/7/2008	East of Trough	3.36	W	1.90E-03	3.22E-05	1.48E+06
1/8/2008	East of Trough	0.38	C	1.95E-03	6.05E-05	2.96E+05
1/8/2008	East of Trough	8.70	W	5.58E-06	3.42E-07	2.58E+05
1/11/2008	Trough Axis	9.44	W	8.82E-04	2.70E-05	7.93E+05
1/14/2008	Trough Axis	3.50	C	2.57E-04	8.65E-05	6.11E+05
1/15/2008	East of Trough	2.95	W	1.20E-03	1.69E-04	2.15E+05
1/18/2008	East of Trough	10.23	W	2.98E-04	1.20E-04	1.59E+05
1/22/2008	East of Trough	-0.81	C	6.97E-04	1.33E-05	5.06E+04
1/23/2008	East of Trough	7.68	C	-8.64E-04	6.83E-05	1.60E+05
1/26/2008	East of Ridge	6.22	W	1.56E-03	1.17E-05	1.77E+04
1/29/2008	East of Ridge	2.82	W	-1.87E-03	5.70E-05	1.82E+05
1/30/2008	Trough Axis	14.58	W	-2.97E-03	1.19E-04	1.52E+05
1/1/2009	East of Ridge	2.78	W	1.31E-03	5.52E-05	5.34E+05
1/1/2009	East of Ridge	-0.74	W	6.31E-04	4.53E-05	5.00E+05
1/5/2009	East of Trough	4.8	C	4.10E-03	2.02E-04	2.60E+05
1/8/2009	Trough Axis	21.43	C	-3.04E-03	9.00E-05	3.99E+05
1/11/2009	East of Trough	0.62	W	-1.00E-03	8.96E-05	6.41E+04
1/11/2009	Trough Axis	1.13	C	6.49E-06	2.51E-04	1.50E+05
1/18/2009	East of Trough	16.84	W	-1.23E-03	1.63E-04	4.03E+04
1/26/2009	East of Ridge	-0.19	C	-1.68E-04	1.16E-04	5.61E+03
1/28/2009	Trough Axis	11.09	C	-5.33E-04	-8.72E-06	4.60E+04
Average:	6 East of Ridge	5.37*	14 W	1.83E-04	8.10E-05*	3.10E+05
	12 East of Trough		10 C			
	6 Trough Axis					

REFERENCES

Carleton, A et al., 2008: Composite Atmospheric Environments of Jet Contrail Outbreaks for the United States. J. Appl. Meteor. Climatol., 47, 641–667

DeGrand, J et al., 2000: A satellite-based climatic description of jet aircraft contrails and associations with atmospheric conditions, 1977–79. J. Appl. Meteor., 39, 1434–1459

Jensen, E et al., 1998: Spreading and growth of contrails in a sheared environment. J. Geophys. Res., 103, 31557–31567

Mesinger, F et al., 2006: North American Regional Reanalysis. Bull. Amer. Meteor. Soc., 87, 343–360

Travis, D et al., 2004: Regional variations in u.s. diurnal temperature range for the 11–14 september 2001 aircraft groundings: evidence of jet contrail influence on climate. J. Climate, 17, 1123–1134