Contrails Functional Requirements

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Gerd Wendler
Martin Stuefer
Linda M. Burke
Bruce A. Toth

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Overview

1.1 *Statement of purpose*

Aircraft exhaust condensation trail (contrail) formation is a frequently occurring phenomenon. It is of practical importance for the military due to the adverse effect on aircraft camouflage. A locally strong increasing contrail formation due to the increasing aircraft traffic is also of high interest for scientists. Atmospheric radiation transfer processes are affected and the chemical state of the atmosphere is being modified; both processes potentially causing climatic change. For the subarctic setting of Fairbanks, Alaska in March 2000 we initiated an observational program to establish a contrail database, which includes contrail characteristics, FAA flight data, and atmospheric measurements derived from radiosonde ascents at Fairbanks International Airport. The analysis of contrail characteristics is based on all-sky digital camera imagery and direct observations of aircraft.

Using our substantial database and a conventional theory of mixing clouds, a combined hit rate for correctly forecasting the occurrence and non-occurrence of contrails of 91 percent was obtained. Mean contrail factors of 0.0365 g $(kg\ K)^{-1}$ were used to parameterize the mixing of water vapor included in aircraft exhaust gases with the ambient air. The layers in the subarctic atmosphere above Fairbanks, where contrails are likely to form, have been calculated for different years and seasons. During the winter months the contrail layers are about 3310 m thick, which is almost twice the thickness than during the summer months (1867 m). In general, cold temperatures and high relative humidity at flight level favor the formation of contrails. These conditions are frequently found close to the tropopause with more being observed in the upper troposphere than in the lower, but dryer, stratosphere.

Using the Air force Weather Agency's (AFWA) 5th generation Mesoscale Modeling System (MM5) regional forecast output, we are able to predict the layers of the atmosphere, in which contrails are expected to form.

1.2 *Summary of architecture*

The contrail layer output files and charts are generated using the wgrib-afwa data extraction routine and perl scripts. Figure 1 illustrates the data flow and processing order.

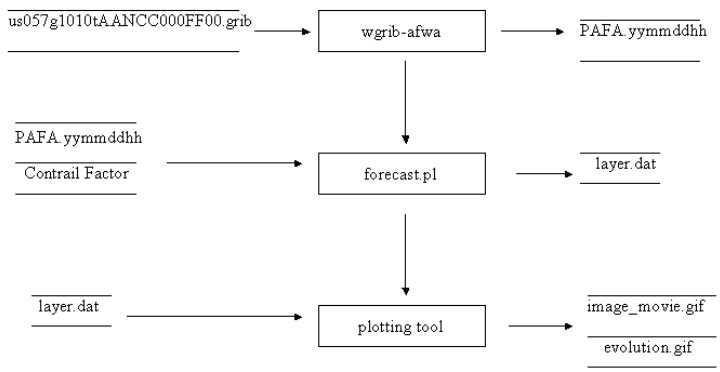

Figure 1: Architecture Flowchart

2 Contrails Forecast Process

2.1 Functional Requirements

2.1.1 The Contrail Forecast Technique (CFT) process shall be applicable for pre-defined model grid- points of different MM5 theater areas (geographic latitude and longitude).

2.1.2 The CFT process shall use contrail factors as parameterization for the aircraft specific combustion and the state of the aircraft performance. An adiabatic mixing of the aircraft exhaust and the environmental air is assumed.

2.1.3 The CFT process shall incorporate vertical profiles of air-pressure, temperature and humidity at the location (grid- point) of interest.

2.1.4 The CFT Process shall store critical temperatures defining the threshold for saturation (over water) of the aircraft wake, which is responsible for contrail formation.

2.1.5 The CFT Process shall store the lower and upper contrail layer limits in m a.s.l. in ASCII files.

2.1.6 The CFT Process shall use AFWA MM5 gridded binary weather data generated at 3 hour steps for the forecast period.

2.2 Interface Requirements

Input Interfaces

2.2.1 The Contrail Forecast Process shall ingest pressure(Pa), height(m), temperature(K), and vapor mixing ratio(kg/kg) contained in the input file. These data files must be formatted to APL specifications which are listed below:

Record #	# of items	Description of items
1	2	year-mon-mday_hour:min corresponding to date/hour of first forecast; number of hours past initialization
2..n	4	pressure(Pa) height(m) temperature(K) vapor mixing ratio (kg/kg)

The following is a portion of a sample data file:

```
2003-05-09_10:00   4
    7324.17  18207.48  223.95  0.67200E-04
    8865.03  16962.12  222.63  0.49548E-04
   10503.39  15860.38  222.38  0.38694E-04
   12279.57  14843.19  222.95  0.30936E-04
   14170.12  13912.46  222.12  0.23861E-04
   16191.10  13050.40  219.46  0.17395E-04
   18373.36  12244.46  216.88  0.16339E-04
   20714.34  11485.43  215.11  0.24258E-04
   23223.04  10766.35  215.08  0.38446E-04
   25867.68  10081.79  218.47  0.53672E-04
   28622.42   9427.45  223.41  0.87052E-04
   31424.70   8809.78  228.50  0.14473E-03
   34315.93   8214.66  233.52  0.23666E-03
   37248.85   7648.63  238.10  0.36061E-03
   40226.29   7108.31  241.99  0.50471E-03
   43206.38   6598.61  245.25  0.66249E-03
   46193.13   6115.99  248.01  0.83212E-03
   49188.45   5657.47  250.45  0.10118E-02
   52193.25   5220.58  252.80  0.12140E-02
   55205.21   4803.20  255.20  0.14450E-02
   58222.57   4403.53  257.60  0.16917E-02
   61244.02   4020.00  259.88  0.19183E-02
   64268.77   3651.27  262.15  0.21114E-02
   67296.87   3296.13  264.25  0.22892E-02
   70331.40   2953.55  265.87  0.24369E-02
   73279.37   2632.77  267.26  0.25250E-02
   76139.42   2332.03  268.80  0.25346E-02
   78860.47   2054.57  270.43  0.25118E-02
   81440.34   1798.70  272.00  0.25592E-02
   83781.81   1572.08  273.55  0.26311E-02
```

87984.58	1177.55	276.48	0.27707E-02
89845.05	1007.53	277.85	0.28281E-02
85979.37	1363.91	275.04	0.27119E-02
91512.85	857.36	279.12	0.28761E-02
93036.42	721.99	280.20	0.29357E-02
94415.91	600.85	281.22	0.29827E-02
95651.86	493.45	282.09	0.30331E-02
96697.00	403.46	282.75	0.30908E-02
97504.55	334.46	283.15	0.31531E-02
98075.30	286.03	282.95	0.32486E-02
98456.32	253.87	282.41	0.33430E-02

2003-05-09_12:00 6

7300.18	18207.48	224.03	0.68261E-04
8831.46	16962.12	223.06	0.50942E-04
10460.44	15860.38	222.10	0.39372E-04
12229.61	14843.19	222.56	0.32072E-04
14115.01	13912.46	221.49	0.23969E-04
16132.13	13050.40	218.92	0.17550E-04
18311.61	12244.46	216.27	0.17752E-04
20652.45	11485.43	214.28	0.26952E-04
23156.75	10766.35	215.37	0.38920E-04
25791.30	10081.79	218.61	0.56780E-04
28536.64	9427.45	223.49	0.93658E-04
31329.99	8809.78	228.53	0.15472E-03
34214.18	8214.66	233.28	0.24310E-03
37142.66	7648.63	237.70	0.36477E-03
40116.45	7108.31	241.65	0.51771E-03
43092.62	6598.61	244.94	0.67777E-03
46075.36	6115.99	247.74	0.83819E-03
49066.04	5657.47	250.29	0.10066E-02
52065.27	5220.58	252.70	0.11933E-02
55071.11	4803.20	255.16	0.14211E-02
58081.55	4403.53	257.64	0.16883E-02
61095.42	4020.00	259.97	0.19641E-02
64113.67	3651.27	262.06	0.22261E-02
67137.18	3296.13	263.96	0.24627E-02
70168.30	2953.55	265.52	0.26532E-02
73113.71	2632.77	266.84	0.27666E-02
75971.64	2332.03	268.40	0.27449E-02
78691.19	2054.57	269.93	0.27087E-02
81271.16	1798.70	271.32	0.28121E-02
83614.31	1572.08	272.71	0.29955E-02
85814.15	1363.91	274.18	0.31621E-02
87821.77	1177.55	275.57	0.32791E-02
89684.95	1007.53	276.85	0.33539E-02
91356.30	857.36	277.91	0.34115E-02
92884.45	721.99	278.72	0.34363E-02
94270.05	600.85	279.34	0.34594E-02
95512.88	493.45	279.93	0.34524E-02
96565.55	403.46	280.19	0.34434E-02
97380.01	334.46	280.17	0.34255E-02
97956.82	286.03	279.61	0.33974E-02
98342.16	253.87	278.88	0.33797E-02

The aircraft specific contrail factor is defined on the command line after starting the forecast.pl script. The default value represents an average contrail factor of 0.0365 g/kgK .

Output Interfaces

2.2.2 The Contrail Process shall write the Contrail ASCII Output file as described in sections 2.14 and 2.15. The format of the output file is as follows:

Header: Contrail Forecast Fairbanks
Date yyyy-mm-dd_hh:mm tt
hh:mm = Z - hour of forecast
tt = hours after model initialization

Column parameter:
Altitude of forecast level (m a.s.l.)
Pressure (hPa)
Temperature (K)
Dewpoint (K)
Critical Temperature (K)
Relative Humidity (%)
Contrail Formation (blank = no contrail)

Data: comma separated
zzzz.z, pppp.p, TTT.TT, $T_dT_dT_d.T_dT_d$, $T_cT_cT_c.T_cT_c$, ff.f, blank/contrail layer.

```
Contrail Forecast Fairbanks

2003-06-10_10:00   4
height (m), pressure (hPa), temperature (K), dewpoint (K), critical temperature (K), relative humidity (%),
contrail formation
253.9, 983.1, 289.25, 277.98, 236.75, 47.1
286.0, 979.4, 290.81, 278.03, 236.46, 42.8
334.5, 973.9, 292.48, 276.97, 236.01, 35.8
403.5, 966.1, 292.63, 275.97, 235.78, 33.0
493.4, 956.0, 292.13, 275.16, 235.62, 32.2
600.9, 944.1, 291.27, 274.56, 235.50, 32.5
722.0, 930.8, 290.22, 273.99, 235.39, 33.4
857.4, 916.1, 289.02, 273.44, 235.28, 34.6
1007.5, 899.9, 287.65, 272.91, 235.17, 36.4
1177.5, 881.9, 286.08, 272.39, 235.08, 38.8
1363.9, 862.5, 284.34, 271.88, 235.01, 41.9
1572.1, 841.2, 282.36, 271.42, 234.99, 46.2
```

2054.6, 793.2, 277.74, 270.56, 235.22, 59.6
2332.0, 766.5, 275.11, 270.22, 235.68, 70.0
1798.7, 818.4, 280.18, 270.09, 235.04, 51.9
2632.8, 738.3, 272.86, 268.05, 235.27, 69.9
2953.6, 709.2, 271.42, 261.66, 233.21, 47.2
3296.1, 679.2, 269.95, 255.43, 231.92, 31.6
3651.3, 649.3, 268.00, 254.74, 231.59, 34.5
4020.0, 619.4, 265.94, 254.67, 231.39, 40.1
4403.5, 589.5, 263.77, 253.17, 230.96, 41.8
4803.2, 559.6, 261.48, 251.21, 230.44, 42.2
5220.6, 529.8, 258.93, 249.43, 230.00, 44.4
5657.5, 500.0, 256.22, 247.68, 229.57, 47.5
6116.0, 470.2, 253.33, 245.47, 229.06, 49.6
6598.6, 440.4, 250.17, 242.31, 228.34, 48.6
7108.3, 410.6, 246.59, 238.55, 227.52, 46.6
7648.6, 380.7, 242.61, 234.71, 226.73, 45.9
8214.7, 351.3, 238.01, 231.18, 226.14, 49.7
8809.8, 322.2, 232.94, 227.98, 225.84, 58.9
9427.5, 294.0, 227.81, 222.22, 224.60, 53.3
10081.8, 266.2, 223.08, 216.01, 223.08, 43.1, contrail formation expected
10766.4, 239.5, 218.06, 211.87, 222.22, 46.1, contrail formation expected
11485.4, 213.8, 216.29, 208.65, 220.73, 37.4, contrail formation expected
12244.5, 189.8, 218.64, 205.04, 218.80, 17.2, contrail formation expected
13050.4, 167.4, 221.31, 202.81, 217.38, 9.1
13912.5, 146.6, 222.76, 203.72, 216.18, 8.8
14843.2, 127.1, 223.59, 204.97, 214.94, 9.5
15860.4, 108.8, 224.08, 206.03, 213.62, 10.4
16962.1, 92.0, 225.22, 207.09, 212.18, 10.6
18207.5, 76.2, 226.78, 208.24, 210.59, 10.4

2003-06-10_12:00 6
height (m), pressure (hPa), temperature (K), dewpoint (K), critical temperature (K), relative humidity (%), contrail formation
253.9, 982.6, 286.21, 277.45, 237.27, 55.2
286.0, 978.9, 287.48, 277.68, 236.99, 51.7
334.5, 973.3, 289.11, 277.77, 236.62, 46.8
403.5, 965.4, 290.01, 277.39, 236.31, 43.0
493.4, 955.3, 290.36, 276.58, 236.01, 39.8
600.9, 943.3, 289.99, 275.75, 235.80, 38.4
722.0, 930.0, 289.22, 274.95, 235.62, 38.1
857.4, 915.2, 288.20, 274.17, 235.47, 38.4
1007.5, 899.1, 286.99, 273.39, 235.32, 39.3
1177.5, 881.0, 285.52, 272.65, 235.19, 41.0
1363.9, 861.6, 283.84, 272.01, 235.11, 43.7
1572.1, 840.3, 281.89, 271.50, 235.08, 48.0
1798.7, 817.5, 279.79, 271.02, 235.13, 53.5
2054.6, 792.3, 277.52, 270.55, 235.28, 60.5
2332.0, 765.6, 275.31, 269.89, 235.44, 67.3
2632.8, 737.5, 273.48, 267.45, 234.75, 63.9
2953.6, 708.5, 272.03, 261.68, 233.09, 45.2
3296.1, 678.6, 270.32, 258.70, 232.36, 40.3
3651.3, 648.7, 268.20, 259.73, 232.52, 51.4
4020.0, 618.9, 266.01, 259.36, 232.52, 59.0
4403.5, 589.0, 263.74, 257.35, 232.04, 59.6
4803.2, 559.2, 261.39, 254.83, 231.40, 58.2
5220.6, 529.4, 258.82, 252.33, 230.80, 57.8

```
6116.0, 469.8, 253.19, 246.87, 229.52, 57.1
6598.6, 440.0, 250.05, 243.23, 228.63, 53.6
5657.5, 499.6, 256.11, 249.74, 230.19, 57.7
7108.3, 410.2, 246.52, 238.94, 227.63, 48.7
7648.6, 380.4, 242.53, 234.81, 226.76, 46.7
8214.7, 350.9, 237.81, 231.94, 226.43, 54.9
8809.8, 321.9, 232.78, 228.75, 226.26, 65.2
9427.5, 293.7, 227.62, 223.41, 225.16, 62.4
10081.8, 265.9, 222.85, 217.36, 223.56, 52.2, contrail formation expected
10766.4, 239.1, 217.73, 212.52, 222.54, 52.1, contrail formation expected
11485.4, 213.5, 215.38, 209.02, 221.04, 44.0, contrail formation expected
12244.5, 189.4, 217.30, 205.28, 218.92, 20.9, contrail formation expected
13050.4, 166.9, 219.82, 202.85, 217.41, 10.9
13912.5, 146.1, 221.47, 203.51, 216.18, 9.9
14843.2, 126.6, 222.68, 204.83, 214.93, 10.4
15860.4, 108.3, 223.37, 205.94, 213.60, 11.2
16962.1, 91.5, 224.47, 207.03, 212.17, 11.4
18207.5, 75.8, 226.02, 208.18, 210.57, 11.3

…..

70261 PAFA Fairbanks Sounding - Contrail Layer Altitudes

 4 hours forecast, 10081.8, 12275.5,
 6 hours forecast, 9935.5, 12567.5,
 9 hours forecast, 9869.5, 12737.5,
 12 hours forecast, 9882.5, 12636.5,
 15 hours forecast, 9885.5, 12485.5,
 18 hours forecast, 9903.5, 12694.5,
 21 hours forecast, 9998.5, 12734.5,
 24 hours forecast, 9980.5, 12531.5,
 27 hours forecast, 10012.5, 12473.5,
 30 hours forecast, 9839.5, 12463.5,
```

2.2.3 The Contrail Process shall log status and error messages to the screen.

User Interfaces

None.

2.3 Operational Requirement

2.3.1 The Contrail Process shall run under MAC OS10.2 or any other UNIX based operating system.

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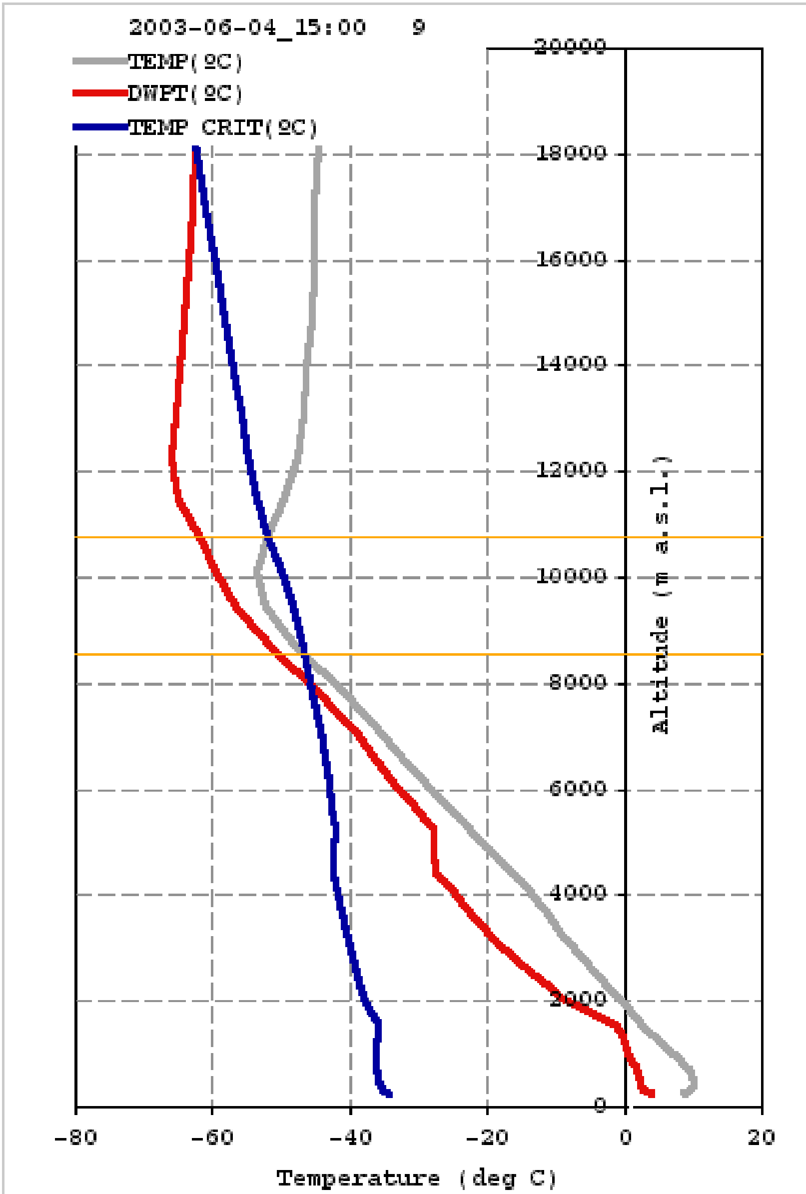
Appendix A Acronyms and Abbreviations

Acronym	Definition
AACGM	Attitude Adjusted Corrected Geomagnetic
ACE	Advanced Composition Explorer
AFCCC	Air Force Combat Climatology Center
AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Laboratory
AFSCN	Air Force Satellite Control Network
AFSPACECOM	Air Force Space Command
AFSWC	Air Force Space Weather Center
AFWA	Air Force Weather Agency
AFWIN	Air Force Weather Information Network
AF/XOW	Air Force Director of Weather
APL	Applied Physics Laboratory of Johns Hopkins University
ASCII	American Standard Code for Information Interchange
a.s.l.	above sea level
ASPAM	Atmospheric Slant Path Analysis Model
AVHRR	Advanced Very High Resolution Radiometer
AVN	Aviation Model
AVO	Alaska Volcano Observatory
BATS	Biosphere-Atmosphere Transfer Scheme
CARMA	Community Aerosol Research Model from Ames/NASA
CF	Contrail Factor
CLASS	Canadian Land Surface Scheme
CME	Coronal Mass Ejections
COE	Common Operating Environment
DII	Defense Information Infrastructure
DMSP	Defense Meteorological Satellite Program
Dst	Disturbance, storm
ECMWF	European Center for Medium-Range Weather Forecasts
EIT	Extreme Ultraviolet Imaging Telescope
EVA	Extravehicular Activities
FAC	Field Aligned Currents
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FSL	Forecast Systems Laboratory
FTP	File Transfer Protocol
GI	Geophysical Institute
GIC	Ground Induced Currents
GIF	Graphic Interchange Format
GIT	Georgia Institute of Technology
GMT	Generic Mapping Tools
GOLD	Geophysical On-Line Data
GOES	Geostationary Operational Environment Satellite
GRIB	Gridded Binary
GSE	Geocentric Solar-Ecliptic

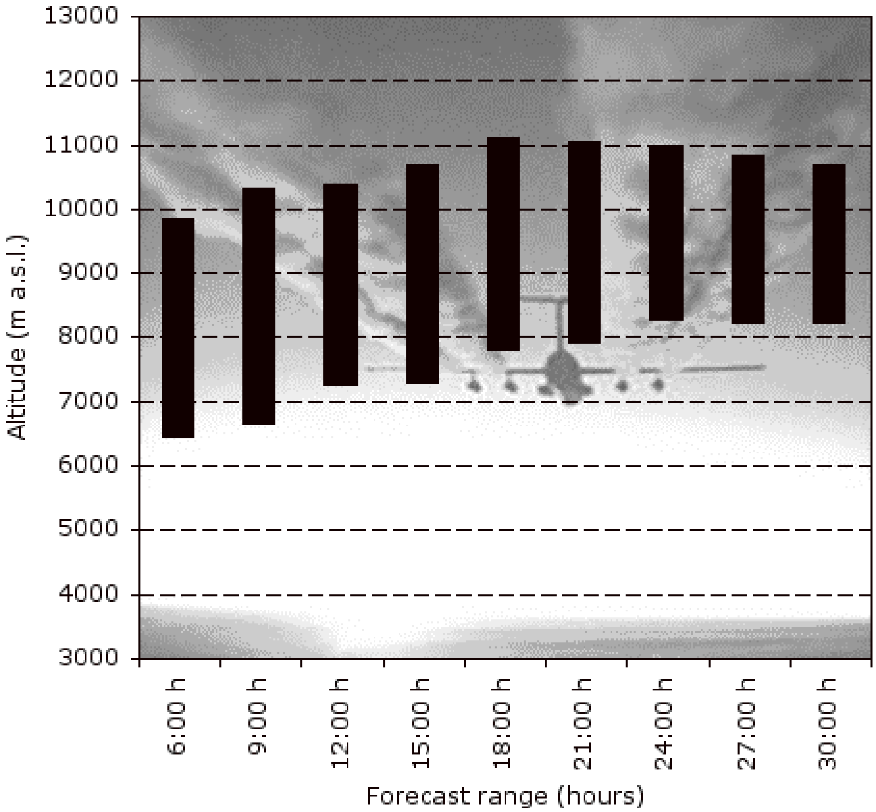
GSFC	Goddard Space Flight Center
HLBL	High Latitude Boundary Layer
IDL	Interactive Data Language
IMF	Interplanetary Magnetic Field
ISS	International Space Station
JHU	Johns Hopkins University
Kp	Planetary Index of Geomagnetic Activity
LAN	Local Area Network
LAPS	Local Analysis and Prediction System
LASCO	Large Angle Spectroscope Coronagraph
LEO	Low-attitude Earth Orbit
LSM	Land Surface Model
MATCH	Model of Atmospheric Transport and Chemistry
MeV	Million Electron Volts
MM5	Fifth Generation Mesoscale Model
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
netCDF	Network Common Data Form
NGDC	National Geophysical Data Center
NGM	Nested Grid Forecast Model
NOAA	National Oceanic and Atmospheric Administration
NOGAPS	Navy Operational Global Atmospheric Prediction System
NRL	Naval Research Laboratory
NWP	Numerical Weather Prediction
OWS	Operational Weather Squadron
PACE	Polar Anglo-American Conjugate Experiment
PBL	Planetary Boundary Layer
PCA	Polar Cap Absorption
PFRR	Poker Flat Research Range
PNG	Portable Network Graphics
RBE	Radiation Belt Environment
SAA	South Atlantic Anomaly
SABER	Sounding of the Atmosphere using Broadband Emission Radiometry
SD	Space Department of the Applied Physics Laboratory
SDFM	Surface Dust Flux Model
SDP	Software Development Plan
SEC	Space Environment Center
SEE	Solar EUV Experiment
SEON	Solar Electro-optical Observing Network
SEP	Solar Energetic Particles
SFOC	Space flight Operations Center
SOHO	Solar and Heliospheric Observatory
SPE	Solar Particle Event
STP	Solar Terrestrial Physics

SWOC	Space Weather Operations Center (Offutt)
SWXS	Space Weather Squadron
SXI	Soft X-ray Imager
Tcl	Tool Command Language
Tk	Toolkit
Tix	Tk Interface Extension
UAF	University of Alaska, Fairbanks
UCAR	University Corporation for Atmospheric Research
UCB	University of Colorado, Boulder
UPOS	University Partnering for Operational Support
UTC	Coordinated Universal Time
WDC	World Data Center
WF	Weather Flight
WMO	World Meteorological Organization
XDR	External Data Representation

Appendix B Sample Output



Forecast profile of temperature, dew-point and the critical temperature for contrail formation. Contrails are likely to be formed at levels, where Tcrit > T (layer limits are marked by the horizontal yellow lines.



Six to 30 hour forecasts of contrail layer altitudes in increments of 3 hours.