Analysis of the U.S. Air Force Defense Meteorological Satellite Program Imagery

for Global Lightning

for

NASA Marshall Space Flight Center

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1. Introduction

The U. S. Air Force operates the Defense Meteorological Satellite Program (DMSP), a system of near-polar orbiting satellites designed for use in operational weather forecasting and other applications. DMSP satellites carry a suite of sensors that provide images of the earth and profiles of the atmosphere. The National Snow and Ice Data Center (NSIDC) at the University of Colorado has been involved with the archival of DMSP data and its use for several research projects since 1979. This report summarizes the portion of this involvement funded by NASA under Research Grant NAG8-1093.

2. Background and Previous Work

NSIDC provided archival and distribution services for hard-copy images from the DMSP with NOAA/NESDIS support from 1979 until 1995. The DMSP/Operational Linescan System (OLS) visible and thermal infrared collection consisted of more than 1 million hard copy images covering the period 1973 to 1991. The production of these images ended in 1991 when the Air Force began to generate digital data for its internal Department of Defense (DOD) users.

NASA's active interest in the DMSP data at NSIDC began about 1990 when a pilot project to extract information about the occurrence of lightning from OLS images was undertaken, with NASA support, at NSIDC. In addition, NASA identified several other research needs for data from the DMSP sensors. Beginning in 1991, NASA, the DOD and NOAA began a multi-agency effort to ensure that the digital data from the DMSP system would be made available to the general research community. With NAG8-882 (15 May 1991 – 14 May 1995), NASA provided funds for equipment purchases that supported the processing and recording of the digital DMSP data for archival by NOAA. Eventually a digital data archive for all of the DMSP multi-sensor data was established at NOAA's National Geophysical Data Center (NGDC). With NASA's support, NSIDC played an important role in establishing the Digital DMSP Archive at NGDC. This archive

continues to support research activities in many disciplines, including projects undertaken by NASA.

NAG8-882 also supported the manual detection of lightning information from both the hard-copy OLS images and the newly available digital data. NASA's Marshall Space Flight Center (MSFC) Dr. Steven Goodman and NSIDC collaborated on the regular analysis of OLS data aimed at the creation of a nighttime lightning climatology. A global database of nighttime thunderstorm occurrence during the 1984-87 time period was created (Goodman and Christian, 1993) and then extended into the early 1990s with the digital data.

3. The DMSP System as a Source of Lightning Information

The DMSP system consists of a minimum of two satellites in near-polar (inclination of 98.7 degrees) sun synchronous orbits at 825-km altitude. Orbital period is 102 minutes, and the equatorial node steps around the equator at 25-degree longitude increments on each successive orbit. A suite of sensors designed to scan the earth's surface and atmosphere and near-earth space environment are mounted on each DMSP satellite. The Operational Linescan System (OLS) sensor collects visible and thermal infrared data across a swath that is 3000 km across.

Lightning (in-cloud and cloud-ground) signatures on DMSP/OLS images appear as short horizontal streaks due to the on-board data processing. The lightning signatures result from the OLS scanning across the cloud top. The lightning signatures are only a fraction of the total lightning occurrence in the storm. The time between scan lines (i.e. the approximate time between adjacent scan line samples of the same thunder cloud) is only a few milliseconds, so depending on the actual frequency of lightning discharges in the cloud, the recorded signature could be one or more than one discharge.

4. Software Development

Prior to NAG8-1093, DMSP OLS analog film data, archived at the NSIDC, were examined for evidence of lightning signatures. Lightning signatures appear on the film data as horizontal lines in the 2.7-km resolution nighttime visible band imagery. An analyst would manually digitize the signatures and record the latitude and longitude coordinates, along with the associated time of the lightning event. For example, the 1986 annual lightning distribution is derived from more than 40,000 filmstrips (Reference: Goodman, S. J. and H. J. Christian, 1993: Global Observations of Lightning, in "Atlas of Satellite Observations related to Global Change," Gurney, Foster, and Parkinson, ed., Cambridge University Press, 191-219).

Transitioning the lightning study from analog imagery to digital data, a task undertaken with NAG8-1093 proved a rather complex task and an opportunity to greatly enhance the accessibility of this valuable data set. Previously access to, and analysis of, the analog data required a great deal of manual labor and human expertise for everything from filing the images to geolocating the data. The transition to a digital format allowed many of these labor-intensive tasks to be automated.

To lay the groundwork for lightning detection from DMSP digital data NSIDC developed a suite of tools and utilities for general use with the DMSP Digital Archive which includes the following applications and toolkits:

Applications:

Popview - Polar Orbiter Perspective Viewer: X based image display for OLS native format files including both full-resolution and interim sample browse data. NSIDC provided support for all standard X features such as user definable application defaults and full window manager support, as well as:

- brightness and contrast controls
- color and tint controls

- smooth scrolling and immediate screen refresh (backing store)
- toggle-able overlays of coastlines, rivers, political boundaries, and graticule
- interactive reading of latitude, longitude, calibrated data value, and time of data acquisition
- linked display of meta-data
- point-and-click file browsing,
- capability to open just part of a file on workstations with limited memory
- image zoom, flip, and crop (any size),
- print image to PostScript printer or file and live link to graphical orbit mapper.

Gomap - Graphical Orbit Mapper: X based graphical orbit finder, displays orbit and currently viewed scene on global map. Includes user definable application defaults and full window manager support, 4 different global views, orthographic, equatorial, north and south polar, user selectable maps provide choice of coastlines, islands, and lakes, rivers, political boundaries and a graticule.

IMDB - Image Database: An Empress RDBS database of DMSP digital data that includes satellite, sensor, and granule information such as sensor information, orbit parameters, orbit start and end times, and orbit start and end locations.

IMSystem - Inventory Management System: X based interface to allow ingest of DMSP digital data into the image database from a variety of media. IMSystem is also able to run reports on the database to weed out duplicate or inaccurate information.

IMSearch - Image Search: X based interface to the image database that allows searching of the database by satellite, sensor, date range, and pass direction. IMSearch interfaces with gomap to allow searching on geographic areas and to display the orbital coverage of search results. IMSearch also interfaces with popview to display online or near-line imagery. For offline data IMSearch prompts the user for the appropriate media and extracts the requested granules to disk.

Toolkits:

pop_data - image data structures and methods for polar orbiters

ols_work - interface to OLS native file formats

pop_util - useful utilities for pop image data structures

ols_geom - sensor geometry and geolocation functions for OLS including Earth Curvature Correction on a spherical model (quick) and systematic navigation using an ellipsoidal model (more accurate)

oce - crude inverse navigation model for full orbit strips (provides a first guess to the more accurate inverse function)

mkecc - generate Earth Curvature Correction tables

models - object-oriented modeling package including 1 and 2-d arbitrary order polynomials, cubic splines, matrix memory management, matrix factorization, and singular value decomposition

cdb - coastlines database generation, maintenance, and object-oriented applications interface

maps - generalized map transformations and object-oriented applications interface including navigational computations and generic gridding schema.

xgrabsc+ - modified version of public-domain screen dump tool (provides print capabilities for popview and gomap)

xmag+ - modified version of public-domain screen magnifier tool (provides zoom function in popview)

5. Lightning Detection

While lightning has a distinctive signature in the OLS visible band that humans recognize rather easily, its actual appearance on the imagery varies a great deal. Lightning signatures in the OLS visible band vary in height, width, brightness, proximity to clouds, proximity to cities, etc. Once we started building the algorithm we realized that the classification of a feature as lightning by a human depends on a great deal of contextual information. When we started listing all of the contextual information and how much it might influence the classification we realized we would have to test an enormous amount of data to come up with a reasonable set of weights. And once we started considering weights we naturally turned our attention to neural networks.

The automated lightning detection system developed at NSIDC uses a number of coarse and fine-grained filters to eliminate the majority of the data, which clearly does not contain a lightning signature. Suspected lightning signatures are then passed to a neural network, which has been trained to differentiate between lightning signatures, and other similar looking features (moonlit clouds, cities, fires, scanline noise and dropout, etc.). The networks used in the lightning detection software were constructed and trained using NASA's NETS software package. To partially compensate for the effects of lunar illumination a set of four networks, indexed to the phase of the moon, were trained simultaneously.

The automated algorithm was completed and tested against manual analyses of approximately 40 orbits. The results, with a complete error analysis, were presented to Dr. Goodman.

6. Data Production

The automated lightning detection system has processed 16470 DMSP Operational Linescan System (OLS) orbits from DMSP Satellites F-10, F-12, and F-14. The study period begins in February 1994 and extends to March 1998. Data gaps are present from July 1994 through April 1995, and the month of November 1997.

Month	Satellite	# of Orbits	# of signatures
FEB94	F10	374	7206
MAR94	F10	420	7880
APR94	F10	399	7042
MAY94	F10	377	7029
JUN94	F10	417	6828
JUL94	none		
AUG94	none		
SEP94	none		
OCT94	none		
NOV94	none		
DEC94	none		
JAN95	none		
FEB95	none		
MAR95	none		
APR95	none		

MAY95	F12	420	8440
JUN95	F12	418	7855
JUL95	F12	437	8405
AUG95	F12	415	7654
SEP95	F12	408	7747
OCT95	F12	407	6991
NOV95	F12	404	5699
DEC95	F12	344	4285
JAN96	F12	378	5171
FEB96	F12	280	4297
MAR96	F12	315	4160
APR96	F12	384	7127
MAY96	F12	339	6401
JUN96	F12	351	6627
JUL96	F12	377	6592
AUG96	F12	392	8697
SEP96	F12	361	8218
OCT96	F12	368	6211
NOV96	F12	341	4723
DEC96	F12	417	7860
JAN97	F12	409	4550
FEB97	F12	182	2244
MAR97	F12	374	6624
APR97	F12	380	8178
MAY97	F12	146	2681
MAY97	F14	342	6664
JUN97	F12	336	6726
JUN97	F14	342	7101
JUL97	F12	387	6329
JUL97	F14	393	6072
AUG97	F12	356	7052
AUG97	F14	438	9858
SEP97	F12	319	7288
SEP97	F14	198	4999
OCT97	F12	222	4382
OCT97	F14	381	9431
NOV97	none		

DEC97	F12	363	5507
DEC97	F14	411	5572
JAN98	F12	218	3032
JAN98	F14	241	5394
FEB98	F12	72	1092
FEB98	F14	184	2546
MAR98	F12	32	629
MAR98	F14	198	3745
TOTAL:	F10/F12/F14	16467	296841

These data have been transferred to NASA MSFC via ftp.

Northeast Peripherals external 8mm tape drive (NASA serial number 1222294) was loaned by NASA MSFC to NSIDC in order to assist with ingest of DMSP Digital Archive tapes for lightning signature detection. This external tape drive was connected to the processing workstation (SGI Indigo) and effectively doubled the tape ingest rate. With the conclusion of this project, the tape drive will be packaged for shipping and returned to NASA MSFC.

7. Summary

This grant resulted in the development of an important database of lightning information, providing a unique source of information concerning the spatial and temporal distribution of global lightning. This information is being applied to studies of climate, hydrological cycles and the global electric circuit, and has been used in conjunction with the analysis of data from NASA's Lightning Imaging Sensor.

This grant also represented a significant portion of NASA's contribution to the development of the Digital DMSP Archive at NGDC. This activity currently supports broad access to the DMSP data stream by a diverse user community. Some examples of research using the DMSP data stream include:

- Biomass fire detection
- Snow cover and sea ice extent
- Synoptic cloud climatologies
- Internal gravity wave detection
- Vapor trail climatologies
- Light pollution studies
- Tabular ice berg monitoring
- Polynya monitoring
- Meteorological case studies
- Environmental disaster case studies
- Aurora monitoring
- Volcano monitoring

8. Publications

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10. Acronym List

DMSP	Defense Meteorological Satellite Program
OLS	Operational Linescan System
NGDC	National Geophysical Data Center
AFGWC	Air Force Global Weather Central
NSIDC	National Snow and Ice Data Center
DOD	Department of Defense
NASA MSFC	NASA Marshall Space Flight Center
NASA LARC	NASA Langley Research Center