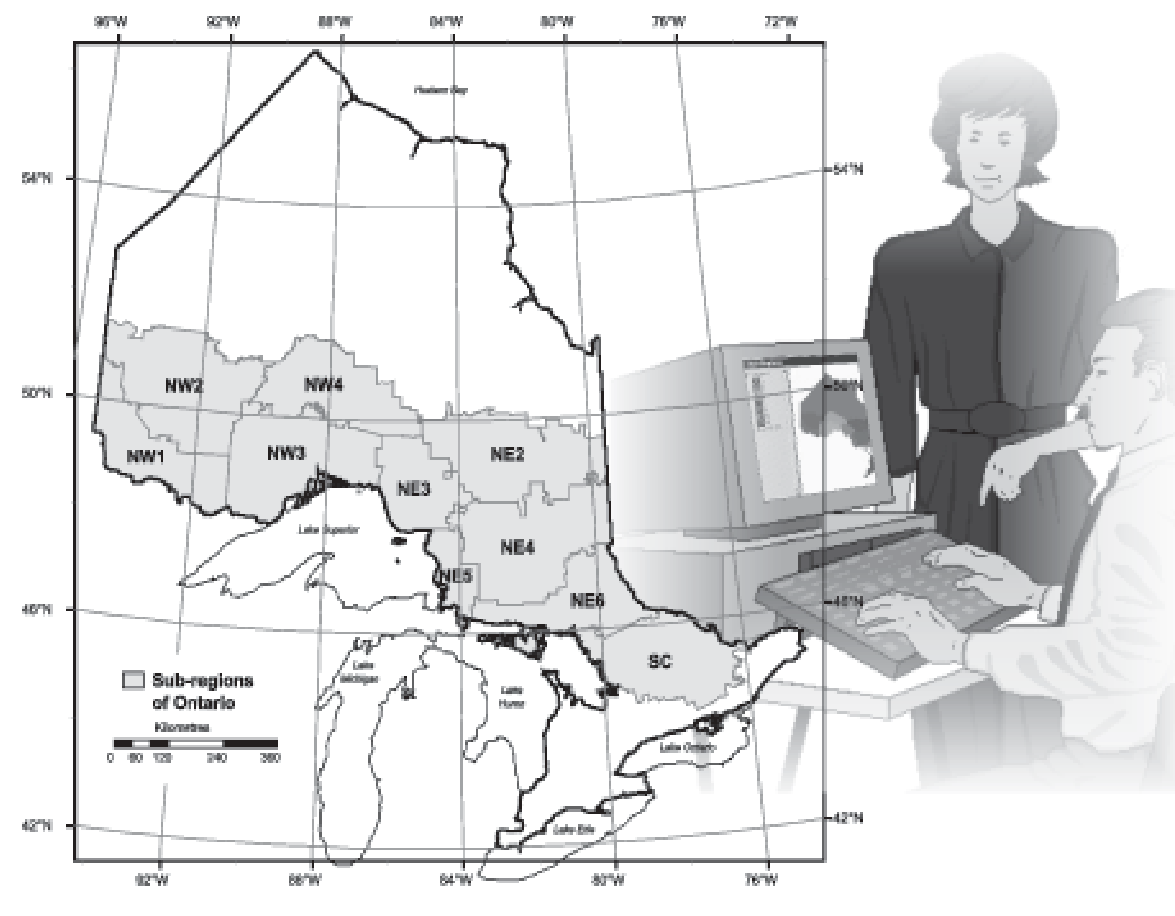
Forest Research Information Paper No. 156

Regional-Scale Forest Net Primary Productivity Assessment Software (NPPAS):

A User's Guide



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Regional-Scale Forest Net Primary Productivity Assessment Software (NPPAS):

A User's Guide

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2003

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Canadian Cataloguing in Publication Data

Schnekenburger, Frank, 1960-
Regional-scale forest net primary productivity assessment software (NPPAS): a user's guide

(Forest research information paper, ISSN 0319-9118; no. 156)
Includes bibliographical references.
ISBN 0-7794-4979-7

1. NPPAS (Computer file).
2. Forest mapping—Ontario—Computer programs.
3. Forests and forestry—Ontario—Computer programs.
4. Forests and forestry—Mensuration—Computer programs.
5. Medical climatology—Ontario.
I. Perera, A. (Ajith).
II. Ontario Forest Research Institute.
III. Title.
IV. Series.

SD387.M3 S33 2003 634.9'285'09713 C2003-964012-4

This paper contains recycled materials.

Abstract

Monitoring and assessing net primary productivity (NPP) has become an important aspect of forest landscape management. In Ontario, the formal forest management planning process requires reporting on regional-scale NPP. We developed a software package known as *Net Primary Productivity Assessment Software* or *NPPAS* to enable inexpensive and rapid assessment of NPP at 1 m spatial resolution and at 1-year intervals, using AVHRR-NDVI imagery (AVHRR stands for *advanced very high resolution radiometer;* NDVI is *normalized difference vegetation index*). While this software is customized for use in Ontario, its principles are applicable to other northern forest landscapes. This report provides an overview of NPPAS and directions for the first-time user.

Acknowledgements

This study was funded by the Ontario Ministry of Natural Resources. We thank Larry Band and Ferko Csillag, whose previous studies in Ontario provided the baseline data and methods for developing NPPAS. Tarmo Remmel and Kevin Weaver assisted in obtaining and rectifying AVHRR imagery. Abby Obenchain edited and proofed the manuscript.

Table of Contents

Introduction

This guide is designed to help users understand the principles, structure, and properties of *Net Primary Productivity Assessment Software (NPPAS)* and to provide a guide to installing and operating the software. We developed NPPAS to assist forest management planners and other resource professionals in assessing Ontario's forest *net primary productivity* (NPP) at a regional scale, as required by the *Forest Management Planning Manual for Ontario's Crown Forests* (OMNR 1996).

In the simplest sense, NPP in an ecosystem is the difference between its ability to fix atmospheric carbon through photosynthesis (*gross primary productivity*) and its release of carbon during respiration. Because it is the most fundamental ecosystem process that energizes all other ecosystem functions, NPP has received global scientific attention for decades. More recently, scientific interest in NPP has escalated due to its role in the global carbon cycle.

NPP measures the ability of ecosystems to sequester carbon, expressed as the rate of carbon accumulation in an ecosystem, per unit time and area (Chen et al. 1999). It is therefore useful in monitoring changes in carbon cycling due to human activity, global climate change, and elevated carbon dioxide (CO_2) levels (e.g., Jiang et al. 1999, Peng and Apps 1999). In addition, forest disturbances such as harvesting, fire, and insect attacks can cause an immediate, negative impact on NPP (Chen et al. 2000), and these effects may vary with the severity of the disturbance and forest type (Wang et al. 2001). Due to these reasons, NPP is generally considered a versatile indicator of the functioning of forest landscapes subject to natural and anthropogenic disturbances. In Ontario, the forest management planning process stipulates the assessment of NPP across management units and planning regions (OMNR 1996) as an indicator of forest sustainability.

Many methods for estimating forest productivity have been developed, and they vary in scientific approach, spatial and temporal scale, and data requirements (Peng and Apps 1999, Band 2000). NPP estimates may be derived in 2 ways: empirical predictions or mechanistic simulations. With the first and more traditional approach, NPP is estimated by statistical extrapolations of direct measurements using allometric equations. With the second, more recent approach, NPP is predicted by simulating ecophysiological processes mechanistically. NPP can also be estimated based on the ecological system in question, for example, a tree, a stand of trees, a forest landscape, or a forested region. The spatial resolution/extent and temporal interval/period of NPP estimates will also change depending on the ecological scale.

Given the broad spatial scale of Ontario's forest management planning regions (agglomerations of forested landscapes), the options for estimating NPP are (a) bottom-up agglomeration of stand-level estimates via empirical models; (b) mechanistic prediction of tree-, stand-, or landscape-level ecological processes, with bottom-up agglomeration; and (c) mechanistic prediction directly at the regional scale. The first 2 options may be impractical because extrapolating fine-scale models to very large spatio-temporal scales is time consuming and expensive. For example, the stand-level model FOREST-BGC (Running and Coughlan 1988) uses many input variables, such as daily total short-wave radiation, air temperature, dew point, and precipitation, to predict carbon, water, and nitrogen cycles. At the landscape level, process models such as the Regional Hydro-Ecological Simulation System (RHESSys) provide daily estimates of net photosynthesis and watershed yield through integrating spatially explicit physical and biological data, such as climate, topography, landcover type, and leaf area index (Band et al. 1993).

At the regional scale, estimating NPP mechanistically and directly is more practical and cost effective. For example, Waring and Running (1998) demonstrated how to predict NPP as a function of vegetative greenness (as assessed using remotely sensed data), total incoming solar radiation, and some measure of light use efficiency. This method has been successfully used as a prototype in Ontario (Band et al. 1999; Band 2000). NPPAS follows this approach and provides rapid and low-cost estimates of NPP for Ontario's forest management planning process.

Figure 1. *A map of Ontario showing the regions used in the analysis: NW=northwest, NE=northeast, SC=southcentral.*

Spatial and Temporal Extent of NPPAS

Figure 1 shows the area applicable to NPPAS in the boreal and Great Lakes-St. Lawrence forest regions of Ontario. NPP surfaces for the sub-regions (those used in forest management planning range from 1.4 to 6.3 M ha) are generated at 1 km resolution at monthly intervals for the growing season (April-October). Monthly mean NPP values and their standard errors also are generated for each region.

An overview of NPPAS structure

As illustrated in Figure 1, NPPAS contains several steps of data analyses and modelling. NPP is estimated by 2 component processes, *absorbed photosynthetically active radiation (APAR)* and *light use efficiency (LUE)*, which are assessed separately as follows.

Estimating APAR

APAR is the product of *photosynthetically active radiation (PAR)* and *fraction of absorbed PAR (FPAR).* In NPPAS, PAR is calculated as follows: The mountain microclimate simulator model MT-CLIM (Running et al. 1987) is used to estimate total short-wave radiation at each weather station. MT-CLIM extrapolates meteorological data from base stations to adjacent mountainous terrain, accounting for differences in elevation, slope, aspect, and latitude (Running et al. 1987, Glassy and Running 1994). The model generates estimates of site air temperature, humidity, precipitation, and incoming *total shortwave radiation (TSWR).* Data inputs of the model include station latitude, elevation, and daily minimum and maximum temperature and precipitation. The model is run for each station and year of data, in non-spatial mode at a daily time step, to produce daily estimates of

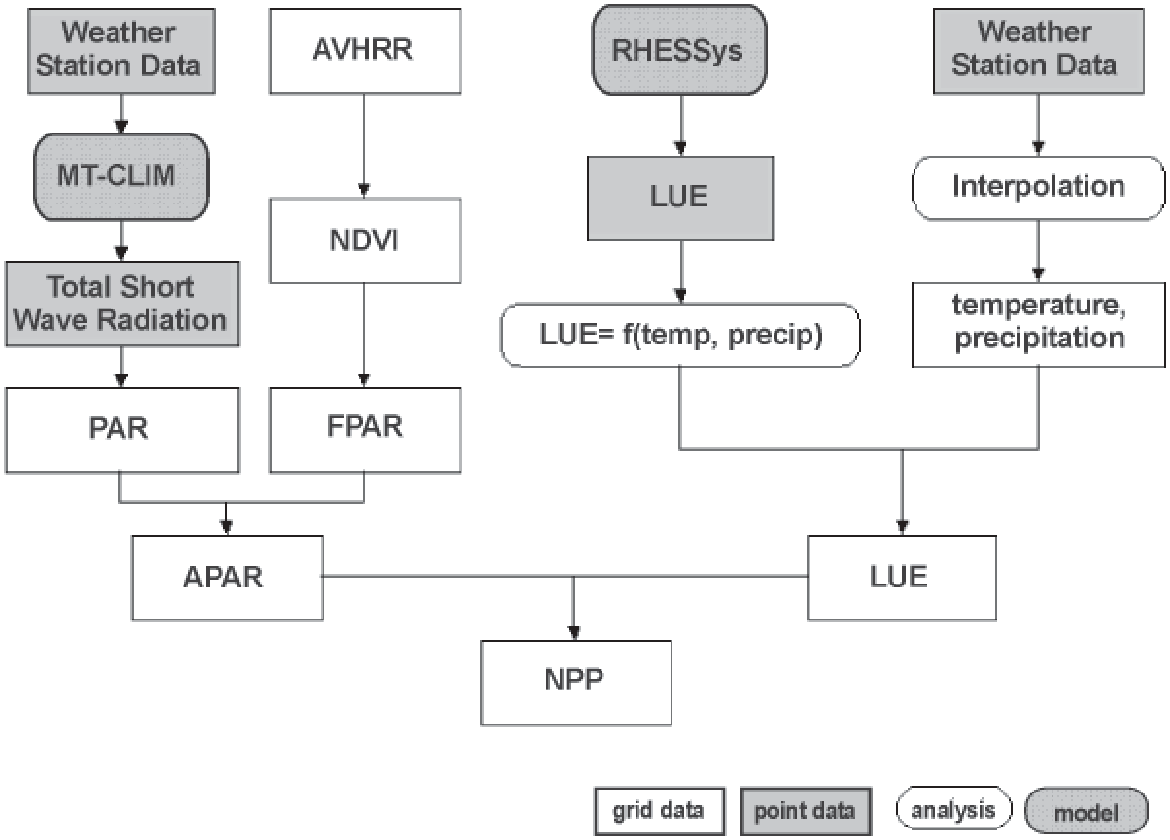

Figure 2. *A schematic overview of the Net Primary Productivity Assessment Software (NPPAS): data input, flow, analyses, and models used in generating net primary productivity (NPP) surfaces. MT-CLIM = Mountain Climate Simulator, PAR = photosynthetically active radiation, AVHRR = advanced very high resolution radiometer, NDVI = normalized difference vegetation index, FPAR = fraction of absorbed PAR, APAR = absorbed photosynthetically active radiation, RHESSys = Regional Hydro-Ecological Simulation System, LUE = light use efficiency.*

TSWR. These results are aggregated to yield monthly estimates of TSWR at each station. PAR is estimated to be 50% of total short-wave radiation (Waring and Running 1998). These point estimates are interpolated to a 1 km grid for Ontario using thin-plate splines, producing a monthly PAR surface for the growing season.

A monthly NDVI composite image is generated from 10-day composite NDVI images. The NDVI values are rescaled to range from -1.0 to 1.0. NDVI has been shown to correlate well with measures of canopy structure and function, such as leaf area index, FPAR, and productivity (Goward et al. 1985, Nemani and Running 1989, Goward et al. 1994). FPAR is derived from NDVI based on the following equation (Goward et al. 1994):

$$FPAR = NDVI * 1.21 – 0.04$$

Given PAR and FPAR surfaces for each month, APAR is derived as follows:

$$APAR = PAR * FPAR$$

Estimating LUE

LUE is a measure of the amount of carbon yield per unit energy or energy-conversion efficiency (Running 1990). It is estimated as a function of *net photosynthesis (PSN)* and APAR. PSN for Ontario's forest landscape has been estimated by Band (1993a, b) using RHESSys, based on 4 study sites: the Petawawa National Forest Institute near Pembroke, the Turkey Lakes Experimental Watershed north of Sault Ste. Marie, Rinker Lake north of Thunder Bay, and the Temagami District in central

Ontario. These sites spanned a broad gradient, from the southeast to the northwest. For the same sites and periods, PAR was estimated using MT-CLIM, as described previously. Monthly estimates of LUE were calculated at each site as follows:

LUE = PSN / APAR

Using linear regression, an equation was developed relating LUE (the dependent variable) to the following weather station data (the independent variables)—mean monthly temperature, mean monthly precipitation, and annual growing degree days above 5°C—at each of the 4 RHESSys study sites. In NPPAS, mean monthly temperature and precipitation point estimates from the weather stations are interpolated to a regular 1 km grid for the province. At each grid point, LUE is estimated by applying the equation and the interpolated weather data for that point, and a monthly LUE surface is derived.

NPPAS estimates monthly NPP surfaces, derived as the product of the APAR and LUE surfaces. The mean NPP and standard error of the 1 km grid estimates are also calculated for each region of Ontario.

Input Data Requirements for NPPAS

In the following description of data requirements, we refer to appendices 1-7 using the examples from a beta test that estimated NPP surfaces for 7 years (1993-2000).

NDVI Data

NDVI surface images for Ontario can be acquired from the Manitoba Remote Sensing Centre, Manitoba Conservation (see Appendix 1 for contact information). The NDVI images have the following characteristics (Appendix 2):

Sensor:	AVHRR
Spatial extent:	province of Ontario
Spatial resolution:	nominal 1 km^2
Composite period:	10 day
Value range:	0 to 20000

NDVI images are received in Arc/Info format (**.bil** and ***.hdr** files). Appendices 2 and 3 list the geo-spatial and spectral parameters for these images, respectively. They need to be converted to Arc/Info grids for subsequent processing.

Three NDVI images are provided for each month of the growing season. The 3 periods span days 1-10, 11-20, and 21-month's end. Each composite image is a 10-day maximal pixel value combination of all NDVI images taken during the 10-day period. The purpose of the composite is to compensate for periods and areas of cloud cover and to provide a relatively complete, cloud-free image of NDVI.

In spite 10-day composite processing, the presence of cloud cover can be a problem in some NDVI images. Hence, monthly composite images are developed from the 10-day composites, yielding 1 image for each month (April-October) of each year to provide cloud-free coverage. In the original NDVI images sent from Manitoba, values range from 1 to 20,000. These values need to be rescaled to range from -1 to 1 for use in NPPAS.

Climate Data

Environment Canada's Atmospheric Environment Services (see Appendix 1 for contact information) provides weather data for 290 weather stations across Ontario, as well as stations in Manitoba and Quebec that border Ontario. This data consists of daily minimum and maximum temperatures and total precipitation at each station, annually.

Station Data Files

Data on each climate station (e.g., station latitude, longitude, and elevation) is stored in the files **OntarioStations.txt**, **ManitobaStations.txt**, and **QuebecStations.txt**. The key attributes for each station that need to be extracted from these files are station ID number, latitude, longitude, and elevation; these attributes are used as parameters in the MT-CLIM model. Appendix 4 provides details of these files.

Climate Data Files

There is a climate data file for each climate district in Ontario (601 to 616), as well for 2 districts in Manitoba (503, 506) and 2 in Quebec (708, 709) that border Ontario. Files are named by province and district number, e.g., **Ontario601.txt** (see Appendix 5 for the complete list of input data files). Data in these files are stored as ASCII text in a format defined by Environment Canada for climate data and are described in the file

Table 1. *Units of measure for variables used in the Net Primary Productivity Assessment Software (NPPAS).*

Variable	Units of Measure
Minimum daily temperature	°C
Maximum daily temperature	°C
Monthly mean temperature	°C
Daily total precipitation	mm
Monthly total precipitation	mm
NDVI[1]	
source data	unitless, ranging from 0 to 20,000
Arc/Info grids	unitless, ranging from -1 to 1
Daily total shortwave radiation	KJ/m^2
Monthly total shortwave radiation	KJ/m^2
Arc/Info point coverages	MJ/m^2/month
FPAR[2]	unitless, ranging from 0 to 1
PAR[3]	MJ/m^2/month
APAR[4]	MJ/m^2/month
LUE[5]	gC/MJ APAR
NPP[6]	gC/m^2/month

[1] *NDVI = normalized difference vegetation index*
[2] *FPAR = fraction of absorbed PAR*
[3] *PAR = photosynthetically active radiation*
[4] *APAR = absorbed photosynthetically active radiation*
[5] *LUE = light use efficiency*
[6] *NPP = net primary productivity*

EnvCanClimateStandard.txt (included in the distribution in the sub-folder **\ClimateData\AESDocuments**). NPPAS reads these files based on this format. Table 1 provides the units of measure for climate and other variables used in NPPAS.

Using the Software

NPPAS contains a SAS module and an Arc module. The SAS module processes AES climate station data and generates files of point estimates of mean monthly temperature, total monthly precipitation, and total monthly shortwave radiation. The Arc module manages the spatial data, carries out spatial interpolation, and generates NPP surfaces. These 2 modules and all supporting data are part of the software distribution, described in Appendices 6 and 7.

SAS Module

This module analyzes the climate data using the SAS data management software system, one of the standard analysis software packages used by the Ontario Ministry of Natural Resources (OMNR).

This module can be used to:

- Read, format, and clean the AES climate station data
- Predict total daily solar radiation at each climate station for each year of data, using the climate simulator MT-CLIM
- Generate data files that contain daily point estimates of solar radiation, mean daily temperature, and total precipitation for each climate station and for each year of data

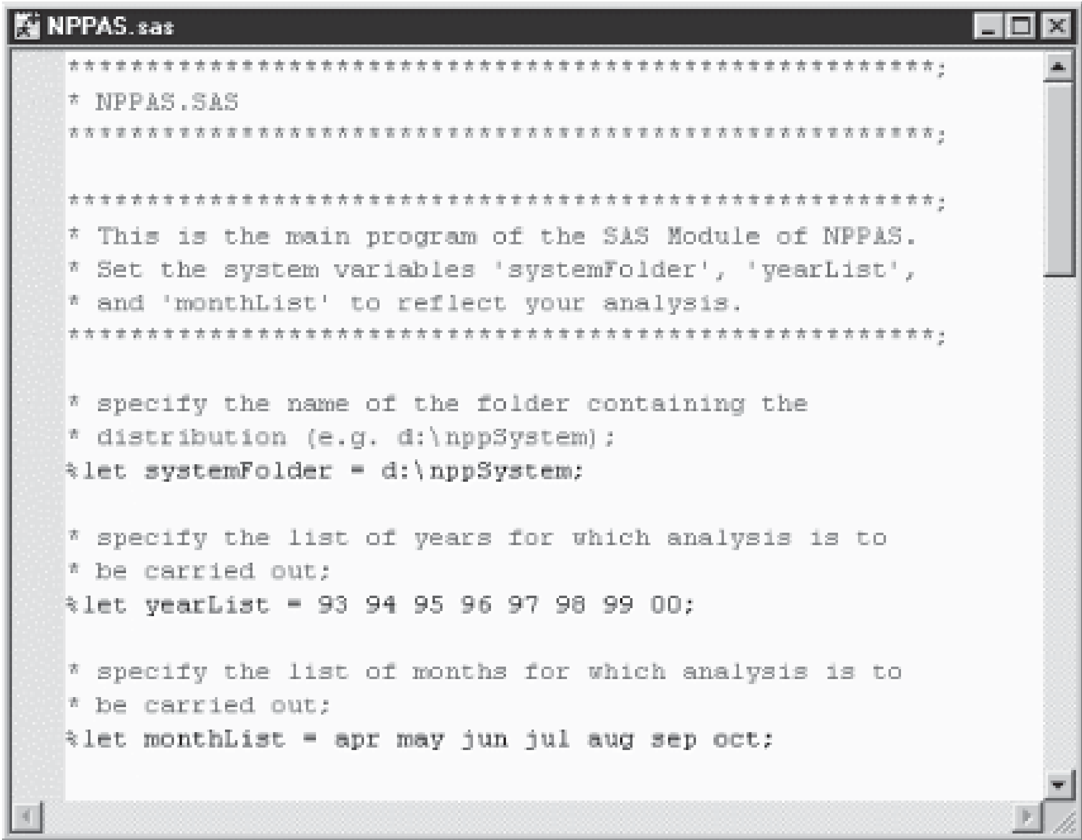

Figure 3. *Example of the configuration file for the Net Primary Productivity Assessment Software (NPPAS) SAS module.*

This module includes a library of SAS programs (for a complete description, see Appendix 8). The user will have to load and execute only **NPPAS.sas,** which coordinates the execution of all other SAS programs in the module.

To run the SAS module:

1. Start a SAS session on your computer (go to **Start - Programs - The SAS System**).
2. In the editor that SAS provides at startup, open the main NPP system file, **NPPAS.sas**, which is located in the **\SASPrograms** folder of the distribution (Figure 3).
3. Edit this file to specify:
   a. The folder containing the NPP system distribution (e.g, **d:\nppSystem**)
   b. The list of years for which the analysis is being conducted (e.g., **93 94 95 96 97 98 99 00**)
   c. The list of months for each year of analysis (e.g., **apr may jun jul aug sep oct**)
4. Modify the 3 lines in the header file (Figure 3) to specify the attributes:
   - %let **systemFolder** = **d:\nppSystem**
   - %let **yearList** = **93 94 95 96 97 98 99 00**
   - %let **monthList =apr may jun jul aug sep oct**

   Caution: Do not change the names of the variables themselves (i.e., systemFolder, yearList, monthList).
5. Save the file.
6. Execute (run) the file by selecting the **Run menu** and the **Submit** item.

NPPAS.sas will execute all other programs of the module; progress of the analysis can be monitored in the **Log** window of the SAS viewer. The results of the analysis will be stored in the **\PointData** folder of the distribution, ready for use in the Arc module.

Arc Module

The NPPAS Arc module generates the NPP surfaces, as well as surfaces (at 1 km resolution) of several

```
/**********************************************************************
/*
/* File:    nppas.aml
/* Purpose: Main batch program that runs all other programs.
/* Usage:   &r nppas
/*          Run from within the %NPPAS%\arcdata\ workspace
/* Notes:   Edit the year list before running.
/*
/**********************************************************************

/* specify the list of years for analysis; use the last two digits of
/* each year (do not modify the variable name, .yearList):
&s .yearList = 93 94 95 96 97 98 99 00

/* specify the months of each year for analysis; use the three character
/* abbreviation as indicated here:
&s .monthList = apr may jun jul aug sep oct
```

Figure 4. *Example of a configuration file for the Net Primary Productivity Assessment Software (NPPAS) Arc module.*

intermediate data layers, such as APAR, FPAR, PAR, and LUE. This module is implemented in Arc/Info using AML scripts (Appendix 9).

Inputs for this module are:

- Monthly composite NDVI surfaces for the months April to October inclusive, for each year of analysis (provided for 1993-2000 in the current distribution)
- A surface of the provincial extent at 1 km resolution, provided as a grid named **prov1km**
- A surface of long-term annual growing degree days above 5°C, provided as a grid named **growdd**
- A surface of water bodies, provided as a grid named **watermask4**
- A surface containing sub-regional boundaries, provided as a grid named **subreggrid**
- The text files generated by the SAS module, containing the point estimates of temperature precipitation and TSWR

The grids **prov1km, growdd, watermask4**, and **subreggrid** are part of the distribution and are located in the **%NPPAS%\ArcModule** workspace.

The point estimates of climate data are generated by the SAS module and are stored in the **%NPPAS%\PointData** folder.

This module is used to:

- Read point estimates of climate data generated by the SAS module (monthly temperature, precipitation, and TSWR) and interpolate these values to a 1 km grid of provincial extent
- Store and process NDVI surfaces
- Generate surfaces of FPAR, PAR, APAR, LUE, and NPP, for each month of each study year, as 1 km grids of provincial extent
- Generate tables of NPP values for each sub-region of the analysis

To run the Arc module:

1. In a text editor, open the system configuration file **NPPAS.aml**. This file is located in the **%NPPAS%\ArcModule** folder of the distribution. Edit the line that specifies the years of the analysis: **&s .yearlist = 93 94 95 96 97 98 99 00**.
2. Modify this list to reflect the years you wish to analyze (Figure 4) using only the last 2 digits of each year.
3. Save the file.
4. Edit the line that specifies the months of year of the analysis: **&s .monthList = apr may jun jul aug sep oct**.
5. Start Arc/Info. At the console prompt, set the workspace to that of the **%NPPAS%\ArcModule**, e.g., **w d:\NPPAS\ArcModule**.

*Caution: You must be in the **ArcModule** workspace of the distribution before running the module.*

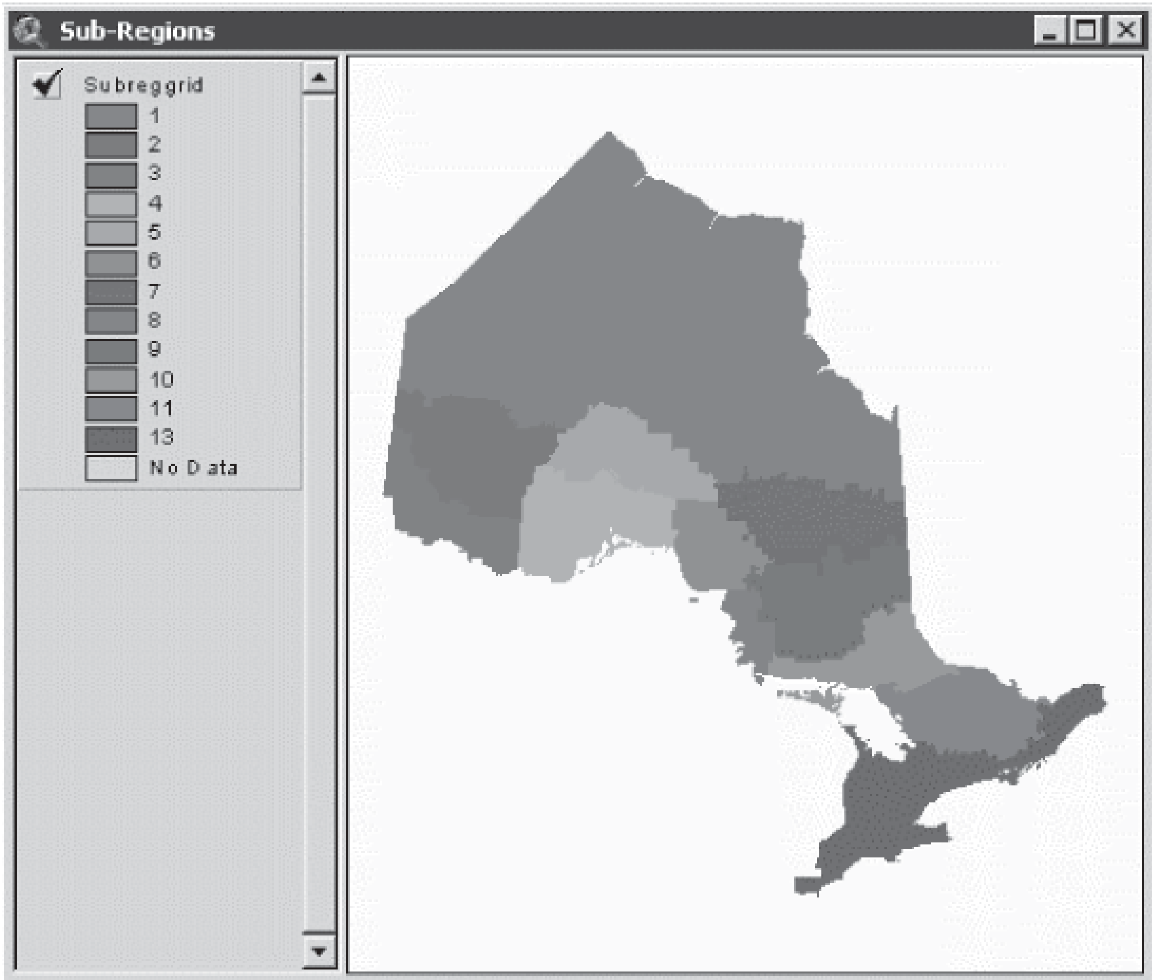

Figure 5. *Default sub-region grid* ***subreggrid****, as used in the net primary productivity analysis.*

6. Execute the module by submitting the following command: **&r NPPAS.aml**.

NPPAS will conduct the entire analysis, displaying progress messages during processing.

Changing Regions of Analysis

NPPAS generates NPP estimates for each region defined in the grid **subreggrid.** These are point estimates, with 1 NPP value generated for each cell of each region.

Figure 5 shows the default regions used in NPPAS. To conduct an analysis using a different set of regional boundaries, replace the **subreggrid** with a grid of the same name that contains those boundaries, and then re-run the analysis. Each region should be uniquely numbered, from **1** to **n**, where **n** is the number of regions.

Output Results

NPPAS generates a range of spatial and non-spatial output data as part of each analysis.

Spatial Output: Monthly

For each month of each year of the analysis, NPPAS creates grids of the following surfaces: NDVI, FPAR, TSWR (MJ/m^2/month), PAR (MJ/m^2/month), APAR (MJ/m^2/month), LUE (gC/MJ APAR), NPP (gC/m^2/month), total monthly precipitation (mm), and mean monthly temperature (°C).

These are continuous surfaces of provincial extent and 1 km spatial resolution.

NPPAS also creates point coverages, based on the climate data generated by the SAS module, for the following variables:

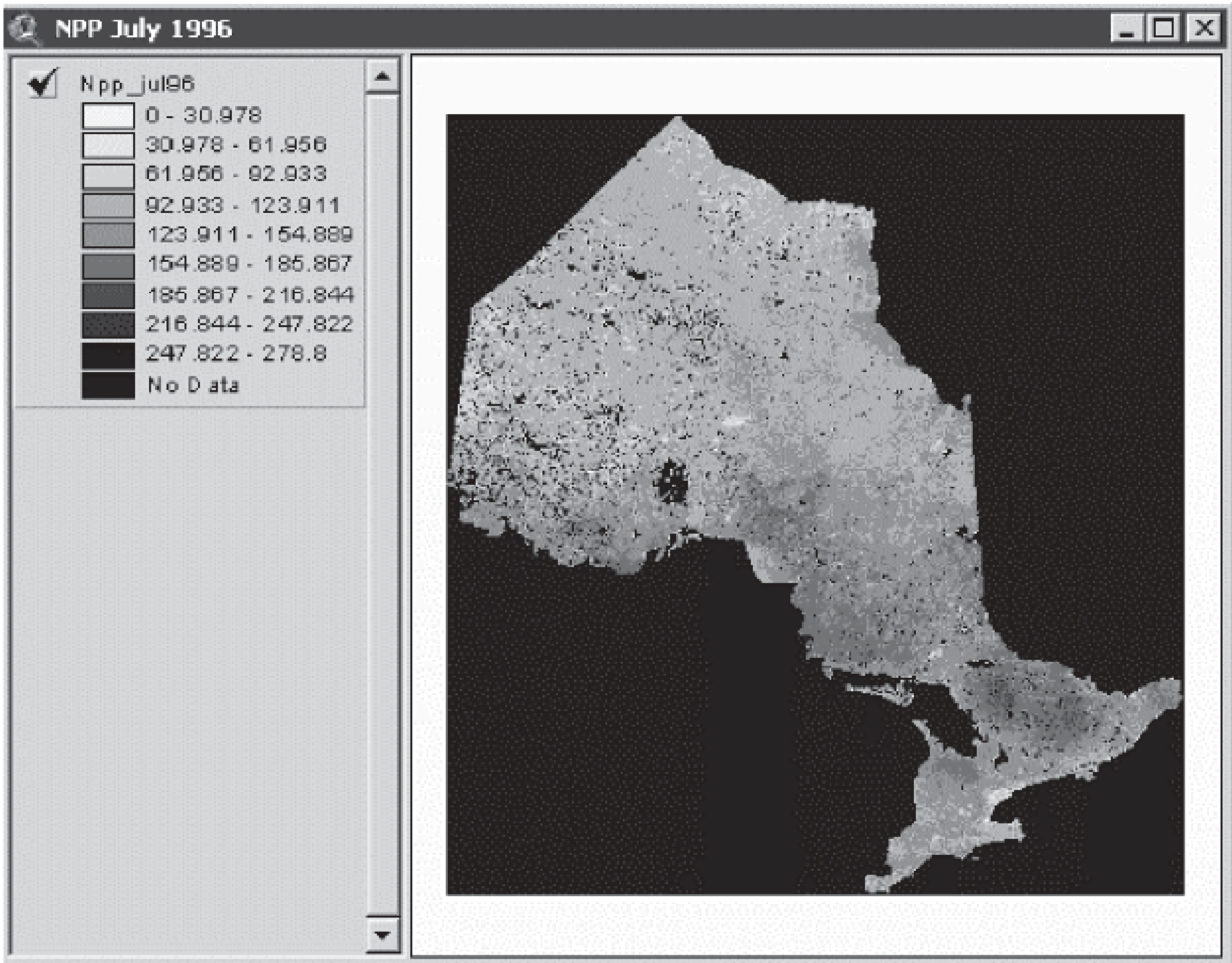

Figure 6. *Sample output of Net Primary Productivity Assessment Software (NPPAS): net primary productivity (NPP) surface for July 1996.*

- total monthly precipitation (mm)
- mean monthly temperature (°C)
- total monthly shortwave radiation (MJ/m^2/month)

These surfaces contain point estimates of these variables at the location of each weather station that provided data.

These grids and point coverages are stored in the **%NPPSystem%\ArcModule** workspace, with a separate folder for each year (e.g., **%NPPAS%\ArcModule\1995**). These grids can be viewed using ArcView or Arc/Info (e.g., Figure 6).

Grids are named with a prefix that identifies the variable (e.g., **ndvi**), followed by a month-year suffix (e.g., **_aug95**), to yield grid names such as **ndvi_aug95**. Appendix 7 describes the grid and point coverage naming convention in detail.

Spatial Output: Annually

NPPAS generates a grid surface of total annual NPP for each year. These grids are named using the following format: **nppannual_*yy***, where ***yy*** is the year, e.g., **nppannual_96**. These grids are stored in the workspace corresponding to the year (e.g., **%NPPAS%\ArcModule\1996\nppannual_96,** illustrated in Figure 7).

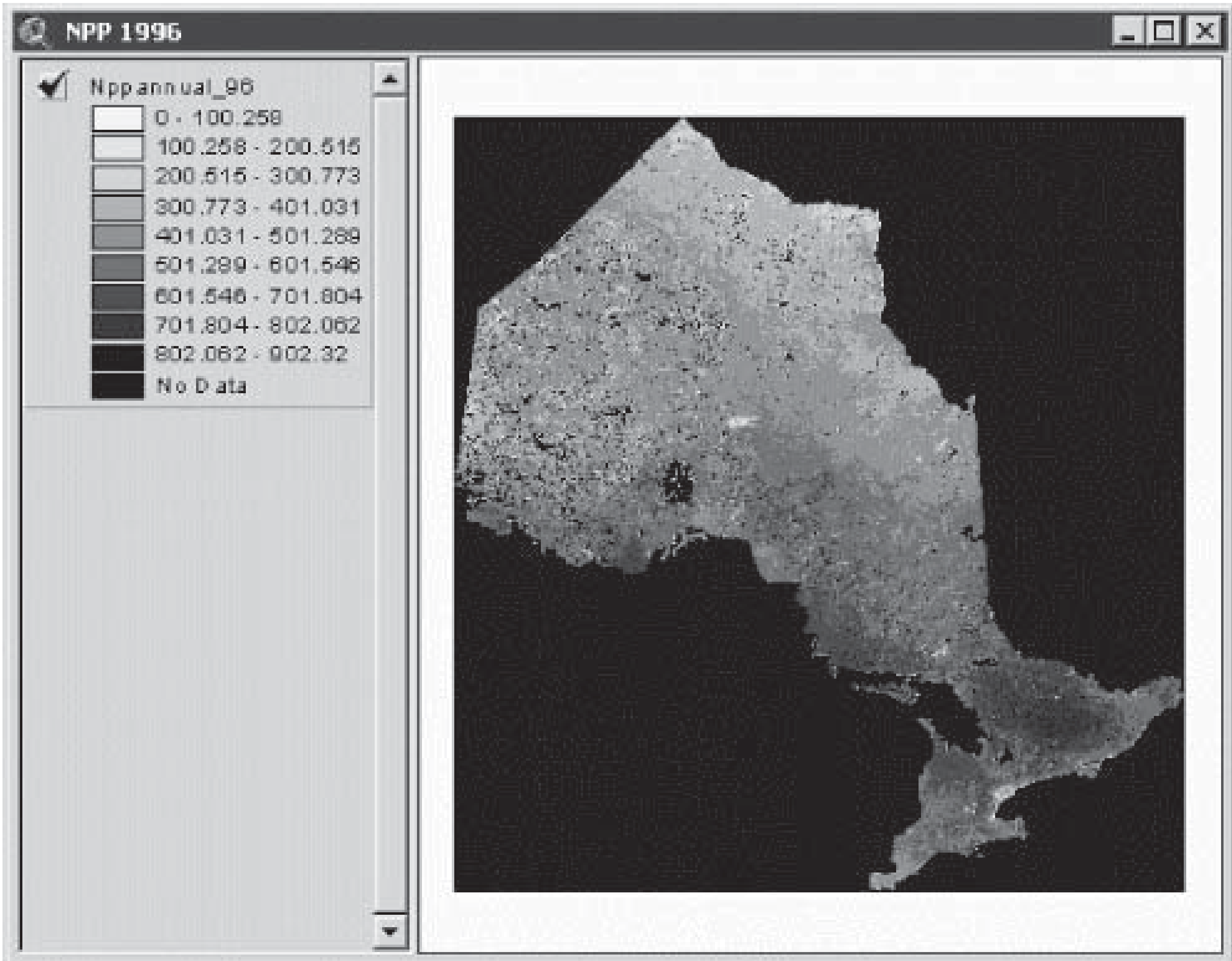

Figure 7. *Sample output of Net Primary Productivity Assessment Software (NPPAS): annual net primary productivity (NPP) surface for 1996.*

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Appendices

Appendix 1 - NDVI and Climate Data Source Contacts

1) NDVI Data

Data Manager
Manitoba Remote Sensing Centre
Geomatics Branch
Manitoba Conservation
1007 Century Street
Winnipeg, MB R3H 0W4
(204)945-6595

In the following correspondence from Roy Dixon to Frank Schnekenburger on February 12, 2002, OMNR is granted the right to distribute the NDVI data to OMNR agencies and staff:

> Hello Frank,
>
> Please accept this e-mail as permission to share NOAA/AVHRR digital data supplied to you by the Manitoba Remote Sensing Centre with other agencies within the Ontario Ministry of Natural Resources.
>
> Roy Dixon, A/Manager
> Geomatics
> Manitoba Conservation
> 1007 Century Street
> Winnipeg, MB R3H 0W4
> rdixon@gov.mb.ca
> Telephone (204)945-6594

2) Climate Data

Climate data was provided by Bryan Smith at Atmospheric Environment Services, Environment Canada:

Environment Canada
Ontario Region
4905 Dufferin Street
Downsview ON M3H 5T4
(416)739-4757
Fax: (416)739-4603

Appendix 2 - NDVI Image Parameters

Contents:	Master Georeferencing Segment for File
Georeference units :	LCC E008
Projection:	Lambert Conformal Conic
Datum - ellipsoid :	NAD 83 - GRS 1980
Upper-left corner:	-149000.000 E 7568000.000 N
Upper-right corner:	2148000.000 E 7568000.000 N
Image centre:	999500.000 E 6659500.000 N
Lower-left corner:	-149000.000 E 5751000.000 N
Lower-right corner:	2148000.000 E 5751000.000 N
Pixel size:	1000.000 E 1000.000 N
Upper-left corner:	97d34’48.28" W Long 57d55’50.22" N Lat
Upper-right corner:	61d19’41.09" W Long 52d37’32.17" N Lat
Image centre:	81d19’57.68" W Long 48d42’00.23" N Lat
Lower-left corner:	96d43’35.09" W Long 41d35’57.90" N Lat
Lower-right corner:	71d16’17.17" W Long 38d07’32.66" N Lat
True origin:	95d00’00.0000"W 0d00’00.0000"N
1st std parallel:	49d00’00.0000"N
2nd std parallel:	77d00’00.0000"N

Appendix 3 - NDVI File Parameters

Following are descriptions of the spectral bands contained in each original source file from the Manitoba Remote Sensing Centre.

1996, 1997, 1998, and 2000 data sets

1 - AVHRR band 1
2 - AVHRR band 2
3 - AVHRR band 3
4 - AVHRR band 4
5 - AVHRR band 5
6 - NDVI
7 - Satellite zenith
8 - Sun zenith
9 - Relative azimuth
10 - Relative date

1999 data set

1 - AVHRR band 1
2 - AVHRR band 2
3 - AVHRR band 3
4 - AVHRR band 4
5 - AVHRR band 5
6 - Satellite zenith
7 - Sun zenith
8 - Relative azimuth
9 - NDVI
10 - Relative date

Appendix 4 - Climate Station Attribute Information

Climate station attribute data is stored in ASCII text data files. Key attributes are station ID, latitude (degrees, minutes), longitude (degrees, minutes), and elevation. There is 1 data file for each province, named as follows: **OntarioStations.txt**, **ManitobaStations.txt**, **QuebecStations.txt**. These files are stored in the sub-folder **\ClimateData\StationMetaData\.**

The field structure for each file is defined below. NPPAS expects these files to have this field structure. Note that the Ontario file structure differs from that of Manitoba and Quebec.

Province	**Field positions** *(value ranges represent the character positions of the fields):*	
Ontario *file name:* **OntarioStations.txt**	stationID	**9-38**
	latitude degrees	**47-48**
	latitude minutes	**50-51**
	longitude degrees	**54-55**
	longitude minutes	**57-58**
	elevation	**62-65**
Manitoba *file name:* **ManitobaStations.txt**	stationID	**9-32**
	latitude degrees	**40-41**
	latitude minutes	**43-44**
	longitude degrees	**47-49**
	longitude minutes	**51-52**
	elevation	**55-58**
Quebec *file name:* **QuebecStations.txt**	*Same as Manitoba.*	

Appendix 5 - List of Climate Data Input Text Files

There is 1 file for each climate district in Ontario and 2 each for Manitoba and Quebec. The file names are a combination of the province name and climate district number. These files are stored in the sub-folder **\ClimateData\AESData**.

Ontario	Manitoba	Quebec
Ontario601.txt	Manitoba503.txt	Quebec708.txt
Ontario602.txt	Manitoba506.txt	Quebec709.txt
Ontario603.txt		
Ontario604.txt		
Ontario605.txt		
Ontario606.txt		
Ontario607.txt		
Ontario608.txt		
Ontario609.txt		
Ontario610.txt		
Ontario611.txt		
Ontario612.txt		
Ontario613.txt		
Ontario614.txt		
Ontario615.txt		
Ontario616.txt		

Appendix 6 - Description of the Directory Structure of the Distributed Version of NPPAS

Following is a description of the directory structure of the distributed version of Net Primary Productivity Assessment Software (NPPAS). The contents of each folder of the system are identified. To work properly, the software requires this directory structure and the specified file names. The folders must be read-writeable by the system; for example, you cannot run the system with these folders on CD.

In the following path names, **%NPPAS%** represents the path to the folder in which the software is installed. For example, if the software is installed in **D:\2003_WORK\NPPAS**, then **%NPPAS%** represents the path **D:\2003_WORK\NPPAS**.

%NPPAS%\SASModule\: **This folder contains the library of programs of the SAS module.**

%NPPAS%\ClimateData\: **Contains folders and files required to store, manage, and analyze the climate data. It is used chiefly by the SAS module.**

%NPPAS%\ClimateData\AESData\: Contains the climate data provided by Environment Canada. There is 1 file for each AES weather region. The format of the contents of these files is described in Appendix 8; documentation for the data is provided in the %NPPAS%\ClimateData\AES Documentation folder.

%NPPAS%\ClimateData\AESDocumentation\: Contains the documentation for the climate data provided by Environment Canada. It includes a description of the data and record structure of the files: envCanClimateStandard.txt, guide.txt, MANCAT.WP.doc, OntCat.txt, and QUECAT.doc.

%NPPAS%\ClimateData\StationMetaData\: Contains information about the weather stations, including station number, name, province, latitude, longitude, elevation, and the begin and end dates of weather records. There is a file for each province used in the study: ManitobaStations.txt, OntarioStations.txt, and QuebecStations.txt. The files contain field descriptors and are in plain ASCII text.

%NPPAS%\ClimateData\MtClim31\: Contains Version 3.1 of the MT-CLIM climate simulator model, in an executable file (mtclim31NT.exe). It also contains supporting documentation and sample input-output files provided with the MT-CLIM distribution. The documentation describes the input and output file formats for the model. NPPAS is designed to work within these specifications.

%NPPAS%\ClimateData\MtClimData\: Contains the files input and output text files of the MT-CLIM model. There are 3 files for each combination of climate station and year: 2 input files for the MT-CLIM model and 1 output file. All are in ASCII-text format. The files can be distinguished by their extension:

1) ***.txt files** are the input climate data files (which are used as input into the **MT-CLIM** model); each contains a record for each day of the year. Each record contains 4 columns:

julian day (of the year)
daily maximum temperature
daily minimum temperature
total precipitation

For the sample analysis, 2,041 such text files were created.

2) ***.ini files** are the input parameter files; they contain information about the climate station itself, required by the **MT-CLIM** model.

3) ***.mtcout files** are the output climate data files; the original climate variables of the input climate data files, plus dew point and total solar radiation, and the variables being predicted by the model:

julian day (of the year)
daily maximum temperature
daily minimum temperature
dew point
total solar radiation
total precipitation

%NPPAS%\ClimateData\SASDataSets\: Contains SAS datasets generated by NPPAS during an analysis; it is managed by NPPAS.

Appendix 7 - Arc/Info Grid and Point Coverage File Naming Conventions

Following are the names of grids used for the various types of data. Example provided is for August 1999 grids.

Data	Grid Name	Example
Ndvi	ndvi_*mmmyy*	ndvi_aug99
tswr	tswr_*mmmyy*	tswr_aug99
fpar	fpar_*mmmyy*	fpar_aug99
par	par_*mmmyy*	par_aug99
apar	apar_*mmmyy*	apar_aug99
lue	lue_*mmmyy*	lue_aug99
npp	npp_*mmmyy*	npp_aug99
temperature	mtem_*mmmyy*	mtem_aug99
precipitation	mpre_*mmmyy*	mpre_aug99

Data	Grid Name	Example
tswr	tswrp_*mmmyy*	tswrp_aug99
temperature	mtemp_*mmmyy*	mtemp_aug99
precipitation	mprep_*mmmyy*	mprep_aug99

Appendix 8 - Library of SAS Programs

1. NPPAS.sas: The main controlling program. Executes all other programs of the module and allows user to specify analysis parameters.

2. ReadStationDataOntario.sas: For Ontario, reads the raw AES climate station data (latitude, longitude, elevation) from the ASCII text file provided by AES.

Input: **Ontario.txt,** the raw ASCII text station data files from AES (latitude, longitude, elevation)

Output: **sas.stationsOntario**

- 1 observation for each station
- Fields: station, elevation (m), latitude (decimal degrees), longitude (decimal degrees), (plus supporting fields) / / for stations with non-missing elev, lat, long only

3. ReadStationDataQuebec: Same as **ReadStationDataOntario.sas** but reads data for Quebec and selects a subset of stations from along the border.

Input: **Quebec.txt**, the raw ASCII text station data files from AES (latitude, longitude, elevation)

Output: **sas.stationsQuebec**

- 1 observation for each station
- Fields: station, elevation (m), latitude (decimal degrees), longitude (decimal degrees), (plus supporting fields) / / for stations with non-missing elev, lat, long only

4. ReadStationDataManitoba: Same as **ReadStationDataOntario.sas** but reads data for Manitoba and selects a subset of stations from along the border.

Input: **Manitoba.txt**, the raw ASCII text station data files from AES (latitude, longitude, elevation)

Output: **sas.stationsQuebec**

- 1 observation for each station
- Fields: station, elevation (m), latitude (decimal degrees), longitude (decimal degrees), (plus supporting fields) / / for stations with non-missing elev, lat, long only

5. MergeStationData.sas: Merges the station data of Ontario, Quebec, and Manitoba.

Input: **sas.stationsOntario**, **sas.stationsManitoba**, **sas.stationsQuebec**

Output: **sas.stations**

- 1 observation per station
- Fields: station, elevation (m), latitude (decimal degress), longitude (decimal degrees), (plus supporting fields) / / for stations with non-missing elev, lat, long only

6. ReadClimateData.sas: Reads the climate data as provided by Environment Canada (ASCII text files with a fixed format described in the file **guide.txt**), for Ontario, Quebec, and Manitoba stations.

Input: the raw ASCII text climate data files from AES

Output: **sas.climate**

- The raw data for temperature and precipitation (without change of units) and including flag variables
- Variables: maxTemp minTemp meanTemp totRain totSnow totPrecip (plus a flag variable for each)
- One observation per region, station, year, month, day

Output: **sas.climate2**

- Same format as **sas.Climate** but units of measure converted to those used in **MT-CLIM** (no flag fields)
- Fields: region, station, year, month, day, maxTemp, minTemp, totPrecip
- maxTemp and minTemp are in degrees C; totPrecip is in mm (as required for **MT-CLIM Version 3.1**)

7. JulianDay.sas: Generates julian days from the month and day fields.

Input: **sas.climate2**

Output: **sas.climate3**

- Fields: region, station, year, month, day, julianDay, maxTemp, minTemp, totPrecip

8. CheckStationData.sas: Checks that there is a record in **sas.stations** for each station for which there is data in **sas.climate3 (**note: because only border stations of Manitoba and Quebec are in **sas.stations**, many Manitoba and Quebec climate records show up as problems).

Input: **sas.stations**, **sas.climate3**

Output: none (just 2 temporary SAS datasets that serve as a check for number of observations)

9. DropMissingStations.sas: Drops from the climate3 data set data for which the station does not occur in the Ontario.txt file, as well as Manitoba and Quebec stations deemed not close enough to the border.

Input: **sas.climate3**

Output: **sas.climate3**

10. StatsRegionYearDay.sas: Calculates mean values for maxTemp, minTemp, and totPrecip for each region, year and day, averaging over all available stations. Results may be used to fill missing values for a station based on its region.

Input: **sas.climate3**

Output: **sas.statsRegionYearDay**

- Records: 1 per region, year, and day
- Fields: region, year, month, day, julianDay, meanMaxTemp, meanMinTemp, meanTotPrecip, nMaxTemp, nMinTemp, nTotPrecip

11. StatsStationMonth.sas: Calculates the mean of maxTemp and minTemp and the sum of totPrecip for each region, station, year, and month.

Input: **sas.climate3**

Output: **sas.statsStationMonth**

- Records: 1 per region, station, year, and month
- Fields: region, station, year, month, meanMaxTemp, meanMinTemp, sumTotPrecip

12. CountDataDays: Counts the number of days of data available for each station and year. Complete station-years should have 365 or 366 days of data.

Input: **sas.climate3**

Output: **sas.numDataDays**

- Records: 1 per station and year
- Fields: region, station, year, numDays

13. DropSparseStationYears.sas: Removes from the climate data set station-years that have fewer than a specific number of days of data.

Input: **sas.climate3, sas.numDataDays**

Output: **sas.climate3b**

- Fields: region, station, year, month, day, julianDay, maxTemp, minTemp, totPrecip

14. FillMissingValues.sas: For missing values in the climate data set, fills with mean values from the corresponding region, year, and day. Handles each variable separately (maxTemp, minTemp, totPrecip).

Input: **sas.climate3b, sas.statsRegionYearDay**

Output: **sas.climate4**

- Records: 1 per region, station, year, and day
- Fields: region, station, year, month, day, julianDay, maxTemp, minTemp, totPrecip

15. CheckWeatherData.sas: Checks that the weather data is consistent following the fill. Outputs problem records into a temporary file called **problems**. If there are no problems, the file will be empty.

Input: **sas.climate3, sas.numDataDays**
Output: **sas.climate3b**
- Fields: region, station, year, month, day, julianDay, maxTemp, minTemp, totPrecip

14. FillMissingValues.sas: For missing values in the climate data set, fills with mean values from the corresponding region, year, and day. Handles each variable separately (maxTemp, minTemp, totPrecip).
Input: **sas.climate3b, sas.statsRegionYearDay**
Output: **sas.climate4**
- Records: 1 per region, station, year, and day
- Fields: region, station, year, month, day, julianDay, maxTemp, minTemp, totPrecip

15. CheckWeatherData.sas: Checks that the weather data is consistent following the fill. Outputs problem records into a temporary file called **problems**. If there are no problems, the file will be empty.
Input: **sas.climate4**
Output: **work.problems** (temporary file)

16. MakeMTCLIMDataFiles.sas: Generates 1 text file of ASCII climate data for each station-year in **sas.climate4**. The files are in the format required for **MT-CLIM**. Creates the file **sas.numObsStationYear**, which contains the number of observations per station-year (i.e., number of observations in each output text file).
Input: **sas.climate4**
Output:
- 1 text file for each station-year in **sas.climate4**. Filename format: **mt_*station_year*.txt**, where station and year are substituted with values (each file has 3 lines of header text)
- The number of lines of data in each file will be 365 (non-leap year) or 366 (leap year)

- sas.numObsStationYear:
- Nobs: 1 per station, year
- Fields: region, station, year, numObs

17. MakeMTCLIMIniFiles.sas: For every station-year in **sas.numObsStationYear**, creates the **ini** files required to run **MT-CLIM**. The station-years for which ini files are generated are those that were processed in **MakeMTCLIMData.sas**, as indicated in **sas.numObsStationYear.**
Input: **sas.stations** (for station elevation and latitude)
sas.numObsStationYear (for number of observations per station-year and list of station-years generated by **MakeMTCLIMData.sas**)
Output:
- 1 text file for each station year in **sas.numObsStationYear**. Filename format: **mt_*station_year*.ini**, where station and year are substituted with values **sas.stationYear**
- Records: 1 per station, year
- Fields: region, station, year, number of observations, latitude and elevation for each station-year

18. RunMTCLIM.sas: For each station-year in the file **sas.numObsStationYear**, runs **MT-CLIM,** generating an **MT-CLIM** output file for each station-year. This presumes that the corresponding input climate data file and **ini** file have been created for each station-year.
Input: **sas.numObsStationYear**
Output:
- Generates **MT-CLIM** output file for each station-year in **sas.numObsStationYear**, by calling **MT-CLIM**
- Filename format: **mt_*station_year*.mtc43**

19. ReadMtclimResults.sas: Reads the **MT-CLIM** output file for each station-year in the **sas.numObsStationYear** file and combines all the data into 1 SAS dataset, **sas.mtclimResults.**

Output: **sas.mtclimResults**

- Records: 1 per station, year, month, day
- Fields: region, station, year, month, day, julianDay, maxTemp, minTemp, totPrecip, solarRad
- Units: temp = degrees C, totPrecip = mm, solarRad = kJ/m^2/day

20. MergeMtclimResults.sas: Merges the solar radiation results from **MT-CLIM** (**sas.mtclimResults**) with the original temp and precip data (**sas.climate4**) to create a single climate data file (**sas.climate5**).

***Input*:** **sas.climate4**
sas.mtclimResults

Output: **sas.climate5**

- Records: 1 per station, year, month, day
- Fields: region, station, year, month, day, julianDay, maxTemp, minTemp, totPrecip, solarRad
- Units: temp = degrees C, totPrecip = mm/day, solarRad = kJ/m^2/day

21. StatsStationMonth2.sas: Calculates the mean temperature, total precipitation, and total solar radiation per month for each station and month of available data in **sas.climate5**.

Input: **sas.climate5**

Output: **sas.statsStationMonth2**

- Records: 1 per station, year, month
- Fields: region, station, year, month, meanMaxTemp, meanMinTemp, sumTotPrecip, sumSolarRad
- Units: temp = degrees C, sumTotPrecip = mm/month, sumSolarRad = kJ/m^2/month

22. SolarRadStats.sas: Generates and prints means of unadjusted solar radiation by region and month (i.e., estimates of solar radiation generated by **MT-CLIM**).

***Input*:** **sas.statsStationMonth2**

Output: none - printed output only

23. StatsStationMonth3.sas: Merges the station monthly stats with the lat/long of each station to produce a file containing location and monthly climate for each station. Use to generate text files of point data for solar radiation.

Input: **sas.statsStationMonth2**

Output: **sas.statsStationMonth3**

- Records: 1 per station, year, month
- Fields: region, station, year, month, meanMaxTemp, meanMinTemp, sumTotPrecip, sumSolarRad, latitude, longitude
- Units: temp = degrees C, sumTotPrecip = mm/month, sumSolarRad = kJ/m^2/month

24. AdjustSolarRad.sas: Adjusts the solar radiation estimates produced from **MT-CLIM** for station latitude. Drops jan, feb, mar, nov, dec from the file.

Input: **sas.statsStationMonth3**

Output: **sas.statsStationMonth4**

- Records: 1 per station, year, month
- Fields: region, station, year, month, meanMaxTemp, meanMinTemp, sumTotPrecip, sumSolarRad, latitude, longitude
- Units: temp = degrees C, sumTotPrecip = mm/month, sumSolarRad = kJ/m^2/month

25. CreateSolarRadPointFiles.sas: Creates text point files of solar radiation estimates for import into Arc/Info as point coverages. In this process, solar radiation is converted to units of MJ/m^2/month.

Input: **sas.statsStationMonth4**

Output: **no SAS data files created**

Notes:

- Generates 2 sets of text files for each year and month (***.txt** and ***.aml**). Each contains 1 record for each station and the following fields: unique_id, longitude, latitude, solarRadiation, station_id.
- Each pair of files is identical, but file names end in **.aml** and **.txt**. The **.aml** files have **END** on the last line.
- The files are written to the **%NPPSytem%\pointData\tswrPointData** directory.
- Also creates the file **%NPPSytem%\pointData\tswrpFileList.txt**, which is a list of the base names of all files (***.aml** and ***.txt**) produced.

26. StatsStationClimate.sas: Generates point files of monthly mean of daily temp (maxTemp - minTemp) and the monthly sum of totPrecip for each station and month for use in generating climate surfaces. Creates text files of the data, 1 file for each year and month, which will serve as input into point coverages. Each file contains 1 observation for each station. There are 2 versions of the file: 1 for mean temperature and 1 for total precipitation.

Input: **sas.climate3** (these data are used because missing data have not been filled)

Output: **sas.statsStationClimate**

Notes:

- Generates 2 sets of text files for each year and month (***.txt** and ***.aml**). Each contains 1 record for each station and the following fields: unique_id, longitude, latitude, meanMonthlyTemp, station_id.
- Each pair of files is identical, but file names end in **.aml** and **.txt**. The **.aml** files have **END** on the last line.
- Monthly mean temperature files are written to **NPPSytem%\pointData\mtempPointData**.
- Total monthly precipitation files are written to **%NPPSytem%\pointData\mprepPointData**.
- Creates the files **%NPPSytem%\pointData\mtemFileList.txt** and **%NPPSytem%\pointData\mtempFileList.txt**, which contain a list of the base names of all files (e.g., **mprep_jun99.aml**).

Appendix 9 - The Arc/Info Module

Library of AML Programs

This appendix describes the programs that make up the Arc/Info module of the Net Primary Productivity Assessment Software (NPPAS). The programs are implemented as AML scripts.

1. nppSystem.aml: The main batch program that runs all other AML programs of the NPPAS system. Provides configuration information for the system.

Input: as defined for the programs below

Output: as defined for the AML programs below

Usage: **&r nppSystem.aml** run from within the **Arcmodule**\ workspace

2. pointCovBatch.aml: Generates point coverages from temperature, precipitation, and tswr data files generated from SAS.

Input: SAS-generated text files of point data for monthly mean temperature, monthly total precip, and monthly tswr

Output: point coverages of monthly mean temperature, monthly total precip, and monthly tswr

Usage: **&r pointcovBatch** run from within the **Arcmodule**\ workspace (descends year workspaces as required)

Notes: uses the **pointcov.aml** file and creates coverages in each year's workspaces

3. pointCov.aml: Creates a point coverage with x,y,z from a text file.

***Input*:** SAS-generated text files of point data for monthly mean temperature, monthly total precip, and monthly tswr

Output: point coverages of monthly mean temperature, monthly total precip, and monthly tswr

Usage: **&r pointcov** <text file directory> <text file of file names>

4. splineBatch.aml: Carries out spline interpolation from temperature, precipitation, and tswr point coverages.

Input: point coverages of monthly mean temperature, monthly total precip, and monthly tswr

Output: grids of monthly mean temperature, monthly total precip, and monthly tswr, placed in each year's workspace

Usage: **&r splineBatch** run from within **Arcmodule**\ (it descends year workspaces as required)

Notes: uses the **spline.aml** file for the processing work; creates grids in each year's workspaces

5. spline.aml: Carries out spline interpolation of the specified point coverage for each month.

Input: point coverages of monthly mean temperature, monthly total precip, and monthly tswr

Output: grids of monthly mean temperature, monthly total precip, and monthly tswr, placed in each year's workspace

Usage: **&r spline in_point_cover out_grid** year tension

Notes: run from within a year's workspace (it expects the prov1km and interp grids to be in the parent folder)

6. lueBatch.aml: Generates an lue grid as a function of monthly mean temperature, total monthly precipitation, and annual growing degree days above 5^{o} C. Processes each month of each year. This version is based on the monthly mean climate surfaces derived through interpolating AES data.

Input: grids of monthly mean temperature and total precipitation (**mtem_%month%%year%** and **mpre_%month%%year%**); grid of growing degree days (**Arcmodule**\growdd)

Output: grids of lue for each month and year, in each year's workspace

Usage: **&r lueBatch** run from within the **Arcmodule**\ workspace; descends each year's workspace as required

Notes: requires the growdd and prov1km grids in the **Arcmodule**\ workspace

7. nppBatch.aml: Generates grids of npp surfaces and processes each month of each year.

Input: grids of lue, ndvi and tswr
Output: grids of par, fpar, apar, npp
Usage: **&r nppBatch** run from within the **Arcmodule**\ workspace; descends each year's workspace as required.

8. nppAnnualBatch.aml: Generates grids of total annual npp surfaces and processes each year.
Input: grids of npp for each month of each year
Output: grids of total annual npp for each year
Usage: **&r nppAnnualBatch** run from within the **Arcmodule**\ workspace; descends each year's workspace as required

9. nppValues: Extracts npp values from the npp grids, and writes them to a text file for further processing in SAS or other package.
Input: grids of npp surfaces; grid of sub-regions (i.e., subreggrid)
Output: text file of npp values, 1 file for each year (e.g., **npp93.txt**); output files are written into the **Arcmodule**\ folder
Usage: **&r nppValues** run from within **Arcmodule**\ workspace; descends year workspaces as required
Notes: in the output file, sub-regions are numbered as per the numbering convention used in the subreggrid grid; to simplify processing of the resulting text files, manually replace **MISSING** with –9999; the output files cannot exist before the aml is run

51790
(0.3k P.R. 03 07 31)
ISBN 0-7794-4979-7
ISSN 0319-9118