REPORT ON A SPECIAL MEETING ON AVHRR DATA PREPROCESSING AND COMPOSITING METHODS

Initiated by the IGBP Land Cover Change Steering Group

Hosted by the Canada Centre for Remote Sensing
12-14 March 1990
Ottawa, Ontario, Canada

Prepared on behalf of the attendees by

Philippe M. Teillet
Senior Research Scientist
Canada Centre for Remote Sensing
1547 Merivale Road
Nepean, Ontario K2G 4V3
Canada

REPORT ON
A SPECIAL MEETING ON AVHRR DATA PREPROCESSING AND COMPOSITING METHODS

Initiated by the IGBP Land Cover Change Steering Group

Hosted by the Canada Centre for Remote Sensing
12-14 March 1990
Ottawa, Ontario, Canada

Prepared on behalf of the attendees by

Philippe M. Teillet
Senior Research Scientist
Canada Centre for Remote Sensing
1547 Merivale Road
Nepean, Ontario K2G 4V3
Canada

REPORT ON
A SPECIAL MEETING ON AVHRR DATA
PREPROCESSING AND COMPOSITING METHODS

P.M. Teillet
Canada Centre for Remote Sensing
April 1990

I. INTRODUCTION

A "Special Meeting on AVHRR Data Processing and Compositing Methods" took place in Ottawa, Canada, March 12-14, 1990, hosted by the Canada Centre for Remote Sensing (CCRS). The meeting was initiated by the International Geosphere-Biosphere Program (IGBP) Land Cover Change Steering Group and eighteen people attended (list attached). The impetus for this gathering was an urgent requirement to address issues regarding the standardization of AVHRR data processing and compositing methods. Numerous agencies in various countries are embarking on large-scale land cover change investigations based on AVHRR data and it is important to standardize the methodologies involved as much as possible as we work toward continental and global products. The preprocessing methods are critical because they provide the quantitative underpinnings that are necessary for remote sensing to play a strong role in long-term, interdisciplinary studies on regional and global scales.

Part of the first day was taken up by status reports from some of the participants.

- J. Cihlar, CCRS, Ottawa, outlined the context of the meeting with respect to the IGBP Land Cover Change Steering Group.
- F. Sadowski, USGS/EROS Data Center (EDC), Sioux Falls, South Dakota, spoke on "Activities for Developing Periodic AVHRR 1km Data Sets" for the United States.
- S.M. Singh, University of Reading, could not attend at the last minute, but sent along some material, which was tabled, on "Near Real-Time Atmospheric Correction to AVHRR Data".
- O. Arino, LERTS, Toulouse, France, addressed AVHRR preprocessing issues, with emphasis on "Simulation for Atmospheric Corrections" and on the pilot studies in Africa.
- A. Condal, Université Laval, Sainte-Foy, Québec, outlined "Activities at Laval University in Support of AVHRR Image Analysis" and his particular interests in thermal channel analyses.
- G. Gutman, NOAA/NESDIS, Washington, D.C., gave a presentation on "Viewing Geometry Aspects of Maximum-Value Compositing of Vegetation Indices". He also briefly outlined a vegetation index workshop held on 26-27 February 1990 at NOAA.
- J. Hervas, JRC, Ispra, Italy, spoke on "The AVHRR Data Processing Approach at the JRC-Ispra's Vegetation Monitoring in Tropical Areas Project".

- G. Pittella, ESA/EPO, Frascati, Italy, provided information on the "ESA-Earthnet TIROS Coordinated Network HRPT Data Processing and Standard Product Distribution".
- P.M. Teillet, CCRS, Ottawa, summarized some research results on "Radiometric Calibration and Correction Procedures for AVHRR Data Channels 1 and 2".
- C. Brest, NASA/GISS, New York, New York, gave a presentation on "Radiometric Calibration and Monitoring of NOAA AVHRR Channel 1 for ISCCP".
- M. D'Iorio, CCRS, presented recent research results on NDVI compositing with and without radiometric calibration, and chaired the technical interchange on compositing approaches.
- J. Eidenshink, EDC, showed a video featuring 31 weekly composites of the Northern Great Plains of the United States from April to October in 1988. The data set is available on a CD-ROM. IMDISP software can be used to read it. Both the CD-ROM and the software can be made available.

The following sections summarize the recommendations that came out of the discussions at the 2½ day meeting.

II. RADIOMETRIC CALIBRATION

1. It was agreed that AVHRR preprocessing should include calibration of all five channels. A major issue here is the uncertainty associated with proper calibration of channels 1 and 2 due to lack of on-board calibration capability and the observed degradation in sensor performance. A variety of approaches are being used to monitor the observed degradation in sensor performances and, although they show comparable trends, the results from the different approaches are not often in close agreement. Therefore, the group discussed the need for guidance from NOAA in recommending appropriate calibration coefficients for operational use. It was decided that a letter should be sent to Peter Abel of NOAA/NESDIS, host of an upcoming calibration meeting (27-28 March 1990) in Washington, D.C., to convey the group's concerns about the utilization of operational calibration coefficients. (The letter was prepared by Phil Teillet, CCRS, with inputs from Frank Sadowski, EROS Data Center, and sent on 20 March 1990. A copy is included at the end of this report.) The studies of NOAA-7 and NOAA-9 AVHRRs must be coalesced as soon as possible into a final recommendation for calibration coefficients to enable the development of a historic archive.

2. Landsat TM and SPOT HRV imagery of White Sands should be collected routinely in order to facilitate AVHRR calibration by transfer and by other methods involving White Sands. IGBP support for the purchase of the image CCTs could be considered.

3. Wherever and whenever possible and appropriate, different post-launch calibration methods should be tried at a common site and/or on a common data set.

4. In each of channels 1 and 2, the apparent reflectance at the sensor should be computed using:

$$\rho^* = \frac{D - D_o}{G} \; \frac{\pi d_s^2}{E_o \cos \theta_s} ,$$

where

ρ^* = apparent reflectance,
D = digital signal level (counts),
D_o = zero-radiance digital signal level (counts),
G = gain coefficient (counts/W/m^2 sr μm),
d_s = solar distance (A.U.),
E_o = exoatmospheric solar irradiance for the channel (W/m^2 μm),
θ_s = solar zenith angle (degrees).

Note that prelaunch calibration coefficients given by NOAA are expressed in terms of effective normalized albedo (in percent) such that albedo $A = \gamma D + \delta = 100 \, \rho^* \cos \theta_s \, d_s^{-2}$. Therefore, the correspondence between coefficients is given by

$$G = \frac{100 \, \pi}{\gamma \, E_o} \quad \text{and} \quad D_o = \frac{-\delta}{\gamma} .$$

5. Scene or pass averages of space-view data should be used for the zero-radiance offset values. Given the relatively stable behaviour of these offsets for AVHRR, values obtained from a scene or pass within a few hours or days of the scene being processed will be adequate. Nevertheless, data processing software should be able to read and assess the space-view data.

6. Neckel and Labs or Iqbal values should be used for the exoatmospheric solar irradiances, not Thekakera values.

7. Calibration investigations should bear in mind that there are two aspects to the operational use of calibration coefficients. One is the calibration of retrospective AVHRR data based on the best available results over time for each instrument. The other is the need to extrapolate recent calibration results when processing current data on a near-real-time basis. Hence, there is an interest in clear historical trends and a concern about the frequency of calibration updates. With regard to extrapolating calibration results, preliminary reports on the problems with the NOAA-11 AVHRR calibration are particularly worrisome for on-going data processing.

8. If clear trends can be established in the AVHRR gain changes, time interpolation should be used to obtain calibration coefficients between updates.

9. It would be of considerable interest and use to have a periodic calibration coefficient update bulletin of some kind for the key remote sensing systems, including AVHRR. The bulletin should be relatively brief, very widely disseminated, and issued once or twice a year.

10. Phil Teillet, CCRS, is to act as the point-of-contact on calibration issues for interested AVHRR investigators involved in IGBP-related activities.

III. ATMOSPHERIC CORRECTION

1. The impact of atmospheric effects on NDVI is on the order of 0.02-0.04 for Rayleigh scattering, 0.04-0.08 for water vapour absorption, and 0.04-0.2 for aerosol scattering.

2. It was agreed that a Rayleigh scattering correction, including adjustment for base topography, should be part of the AVHRR preprocessing in channels 1 and 2. Phil Teillet, CCRS, is to provide the recommended Rayleigh optical depths for standard pressure and temperature conditions for standard atmospheric models (cf. table at the end of this report). Until a better global digital terrain model is identified, ETOPO5 (2160 lines by 4320 pixels) is to be used for the base topography. A copy of ETOPO5 may be obtained from Frank Sadowski at EROS Data Center, or Alan Cross at UNEP/GRID.

3. It was agreed that a correction for ozone in channel 1 should be based on concentration values from standard climatic tables with latitudinal and seasonal dependence. Chris Brest, NASA/GISS, is to provide the recommended values (cf. table at the end of this report).

4. Several possible approaches to a water vapour absorption correction were discussed, but no agreement was reached on a common method. Further investigation is recommended.
   (a) A standard climatology with lat/long and seasonal dependence would allow a rough correction to be implemented easily, although it would clearly not capture day-to-day and spatially localized variations. The McClatchey atmospheres would be the standard data sets in this context.
   (b) Water vapour concentration from a world-wide grid of radiosondes or from meteorological satellites should now be available. However, the acquisition and use of such data may not be straightforward, and there are likely to be non-uniformities in coverage.

(c) Channel 4 minus channel 5 temperature values tend to be correlated to water vapour and may provide a reasonable method if it can be validated.
(d) AMSU (Advanced Microwave Sounding Unit) data (starting 1993) may provide the necessary water vapour information.

5. Several possible approaches to aerosol scattering corrections were discussed.
   (a) Based on an extensive observational data set, CCRS has identified a commonly occurring aerosol condition for very clear atmospheres near Ottawa: aerosol optical depth of 0.05 at 550 nm, and a Junge exponent of 3.5. Because the NDVI compositing process tends to select clearer atmospheric conditions, CCRS plans to use this aerosol optical depth as a minimum correction. The EROS Data Center may adopt the same values, thus providing uniformity over most of North America. Because aerosols in the rest of the world do not necessarily have the same character, the other agencies at the meeting indicated that they prefer to have no aerosol correction until a better approach is developed.
   (b) If a standard climatology with lat/long and seasonal dependence can be identified, it would allow a rough correction, although it would clearly not capture day-to-day and spatially localized variations and might not lead to any improvement.
   (c) Sun-photometer grids have been proposed for some parts of the world, such as parts of Africa, where the aerosols vary considerably.
   (d) There are satellite sensors (such as SAM-II) that measure aerosols, but the use of such data in operational processing is far from straightforward.
   (e) There is a NOAA product that provides aerosol optical depths over the oceans and other large bodies of water. It is not obvious how to achieve the same thing over land. AVHRR pixels are large and generally preclude the use of dark targets or targets of known reflectance to estimate path radiance and hence aerosol optical depth.

6. Approaches to aerosol corrections require investigation. The spatial and temporal variability of these atmospheric constituents makes correction difficult on a global basis. Common correction approaches may only be possible on a continent by continent basis.

7. Not surprisingly, there was no agreement as to what atmospheric radiative transfer code to use. Nevertheless, code intercomparisons were deemed to be unnecessary because the better codes tend to disagree only for large aerosol optical depths and large off-nadir angles. The proper use of a given atmospheric code is a greater concern than which code to use. For example, monochromatic radiative transfer computations should not be used to represent AVHRR channels 1 and 2. Bandpass calculations based on 0.005-micrometer spacing or better are recommended.

IV. GEOMETRIC CORRECTION

1. Frank Sadowski, EDC, provided a table summarizing AVHRR geometric rectification procedures at EDC, CCRS, JRC, and UNEP/GRID (a copy of the table is included at the end of this report). Of particular note is EDC's use of image-to-image registration procedures, with control provided by AVHRR reference images, for improving the spatial precision (0.5 pixel rms) of its composited data sets. Also of interest is the plan of CCRS to use degraded Landsat MSS image chips for control in image-to-map registration procedures.

2. Map projections for AVHRR:
   (a) EDC: using Lambert Azimuthal Equal Area for the North American Continent, based on the recommendation of USGS cartographic expert John Snyder. EDC considers the equal area projection most appropriate for subsequent use in a geographic information system (GIS).
   (b) ESA: not geocoding AVHRR imagery.
   (c) JRC: Universal Transverse Mercator, plus lat/long Earth Location Points.
   (d) CCRS: Lambert Conformal Conic, but also considering a lat/long tessellation.

   Jenny Murphy, CCRS, reported that other countries may choose equal area projections (not necessarily Lambert). She noted that the Landsat Technical Working Group (LTWG) has come to the conclusion that map projections cannot be standardized. In the context of global investigations and the production of AVHRR data sets, however, efforts to standardize map projections should continue, at least on a continent-by-continent basis. CEOS (Committee on Earth Observation Systems) recommends that map projection information be provided on all image CCTs and that there be an exchange of various transformations in use. There are packages available now (from MDA for example) for converting various projections to lat/long.

3. Operational issues pertinent to individual organizations may eventually dictate map projections. However, efforts must continue to identify the effects of resampling data from projection to projection or lat/long to projection have on the utility of the data.

V. DATA PROCESSING FLOW CONSIDERATIONS

1. Raw data are considered to be AVHRR channels 1 to 5 at 10 bits.

2. It was agreed that the proper processing sequence for each image used in the compositing is as follows.
   (a) orbit modeling;
   (b) ground control;

(c) establish transformation to map projection;
(d) radiometric calibration;
(e) atmospheric correction;
(f) computation of NDVI and geophysical parameters;
(g) resampling.

The last two steps can be interchanged if the resampling is nearest-neighbour, although the ramifications of this need to be investigated.

3. The use of block-based processing and radiometric look-up tables is recommended, although the details may differ from system to system.

4. Explicit cloud screening is not considered to be robust enough yet for operational use.

5. It was recommended that a common data distribution format be adopted. This group looks to the CEOS for guidance and will try to conform to the proposed format.

6. During the processing flow, EROS Data Center takes AVHRR data through radiometric calibration and atmospheric correction at 10 bits. The resulting surface reflectances are scaled from 0 to 1000. To scale to byte data, this range of values is compressed to 0 to 400 (maintaining a precision of 0.0025 in reflectance per count), and then truncated at 8 bits such that values from 255 to 400 (63% reflectance and greater) are set to 255. The data compression is applied prior to resampling.

7. Processing outputs:
   (a) EDC: - Raw HRPT (frame or pass), all archived;
   - Level 2 (calibrated, corrected, geocoded) all processed data archived;
   - Composite (selectable areas), all processed data archived;
   (b) ESA/EPO: - Raw HRPT (1440 lines x 2048 pixels), with appended gridded information, all archived;
   - Geophysical products archived;
   - Higher-level products planned for future;
   (c) JRC: - Internal format (ERDAS);
   - Raw data plus appended gridded information;
   - Geophysical products;
   - Composites (selected), whole orbits;
   (d) NOAA/NESDIS: - GVI composite (daily, 7-day max DVI), selected areas or global;
   - High-resolution data by special order;
   (e) CCRS: - Raw HRPT (frame or pass), almost all archived;
   - Level 2 (calibrated, corrected, geocoded), all processed data archived;
   - Composite (selectable areas), all processed data archived.

8. NDVI scaling approaches for 8-bit representation (N.B., these equations were developed for digital signal levels; they will need to be changed for NDVI based on reflectance ρ):

   (a) $[200\,(\frac{\rho_2 - \rho_1}{\rho_2 + \rho_2}) + 50]$ (negative values set to zero);

   (b) EDC: $100[(\frac{\rho_2 - \rho_1}{\rho_2 + \rho_1}) + 1.005]$;

   (c) CCRS, LERTS, and others: $350[(\frac{\rho_2 - \rho_1}{\rho_2 + \rho_1}) + 0.05]$

   (negative values set to zero; values greater than 255 set to 255).

VI. COMPOSITING

1. It was recommended that the output data set from the compositing process contain 10 bands:
   (a) maximum NDVI;
   (b) channel 1, calibrated and corrected for radiometric and atmospheric effects;
   (c) channel 2, calibrated and corrected for radiometric and atmospheric effects;
   (d) channel 3, calibrated;
   (e) channel 4, calibrated;
   (f) channel 5, calibrated;
   (g) solar zenith angle;
   (h) satellite zenith angle (no limits for now);
   (i) relative azimuth between sun and satellite;
   (j) reference to date and source image for the selected NDVI.

2. The compositing time period is likely to depend on application and location, among many other factors. The growing season is very short in some regions of Africa, for example. CCRS and JRC use a 10-day period tied to days of the month (1-10, 11-20, 21-end of month). EROS Data Center uses a 14-day period, beginning on a Friday and ending on a Thursday, with 7-day outputs also available. However, all processed data are archived daily and so it is possible to recreate composites on any interval. NOAA provides a 7-day GVI product. The IGBP is requested to provide advice on the compositing period.

3. System limitations currently impose a single criterion for selection of the best NDVI. Other selection models (alternative to maximum NDVI) should also be investigated.

Possibilities include: average of highest NDVI values; use of thermal channels; near to maximum NDVI values on same day as selected adjacent pixels; day of observation; etc.

4. A better understanding as to why, in some studies, maximum NDVI has been found to favour the forward scattering direction at off-nadir pixels is needed. In this respect, care must be taken to allow for biases as a result of the location of receiving stations (for example, the central location of the EDC reception station means Western U.S. observations received at EDC are usually in the forward scattering direction).

5. Cloud screening should be investigated, including when it should be done in the data flow. Presently, no cloud screening is being done operationally (other than through the maximum NDVI selection process itself). NOAA/NESDIS is developing a cloud screening algorithm directed at the operational distinction between cloudy and clear pixels of each orbit, which will then be appended as one byte of information to level 1-B data.

6. It was noted that prelaunch calibration is a strict minimum requirement. The use of prelaunch calibration makes a big difference in maximum NDVI compositing, whereas the incremental improvement from an updated calibration appears to be small (for the NOAA-9 AVHRR tests carried out to date).

7. There should be a study on whether atmospheric correction of selected maximum NDVI is better than selecting the maximum of the atmospherically corrected NDVI.

VII. OTHER ISSUES

1. Calibrated and atmospherically corrected AVHRR data will provide NDVI values that are still subject to variations due to surface reflectance characteristics. BRDF (bidirectional reflectance distribution function) research is a high-priority area.

2. There is a future requirement for broadband albedo estimated from AVHRR channels 1 and 2. BRDF effects will be involved. The albedo should probably be computed prior to atmospheric correction rather than after.

3. Although not studied in the AVHRR context, there have been investigations of soil-adjusted vegetation indices (by Guyot and by Huete, to give two examples). Soil differences can influence NDVI through AVHRR channel 1, with the problem worse near nadir, and so some work should be pursued in this area in the future.

4. There was general agreement that a standard data set would allow evaluation of

consistency for implementing processing procedures with the different models, software, and hardware being used by various groups. There was no time to go into details. Frank Sadowski, EDC, volunteered to give the matter some thought and report at the next meeting of the IGBP Land Cover Change Steering Group. Several groups said they would be prepared to provide a data set.

VIII. CONCLUDING REMARKS

This report outlines recommendations made at a "Special Meeting on AVHRR Data Processing and Compositing Methods", held in Ottawa, Canada, March 12-14, 1990. In some instances, common approaches were agreed upon whereas, in other cases, it was recommended that further investigation is needed or it was recognized that agreement was not possible. The general consensus was that the meeting was very worthwhile and that another similar meeting should take place in the United states or Europe a year or two from now.

In summary, agreement was reached on the following points.

1. Radiometric Calibration:
   - radiometric calibration of all five channels;
   - routine collection of White Sands imagery by other, calibrated sensors;
   - application of different calibration methods on common sites/datasets as appropriate;
   - zero-radiance offset values based on space-view data;
   - exoatmospheric solar irradiances based on Neckel and Labs or Iqbal (both are very similar);
   - interest in clear historical trends as well as concern about the frequency of calibration updates;
   - time interpolation of calibration coefficients between updates if clear trends established.

2. Atmospheric Correction:
   - Rayleigh scattering correction, including topography;
   - ozone correction in channel 1 based on standard climatic tables;
   - approaches to water vapour and aerosol corrections require investigation;
   - bandpass (as opposed to monochromatic) atmosphere computations.

3. Geometric Correction:
   - efforts to standardize map projections, at least on a continent-by-continent basis, should continue;
   - effects of resampling on data require study.

4. Data Flow Considerations:
    - the proper processing sequence for each image used in the compositing;
    - block-based processing and radiometric look-up tables;
    - no explicit cloud screening;
    - common data distribution format based on CEOS recommendation.

5. Compositing:
    - specifics of the 10-band compositing output;
    - advice is needed from IGBP on the compositing period;
    - single criterion for selection of best NDVI;
    - other selection models require investigation;
    - the relationship between maximum NDVI and the forward scattering direction needs study;
    - cloud screening requires investigation;
    - prelaunch calibration is a strict minimum requirement with regard to compositing;
    - the order of atmospheric correction in the selection procedure for best NDVI needs study.

6. Other Issues:
    - BRDF research is a high-priority area;
    - estimate of broadband albedo from AVHRR data is a future requirement;
    - soil-adjusted vegetation indices should be investigated in the AVHRR context;
    - intercomparisons of procedures based on standard data sets.

In summary, common agreement has yet to be achieved on the following points.

1. Atmospheric Correction:
    - approach to water vapour correction;
    - approach to aerosol scattering correction;
    - choice of radiative transfer code.

2. Geometric Correction:
    - geometric rectification procedure;
    - map projection.

3. Data Flow Considerations:
    - processing output products;
    - approaches for 8-bit scaling of NDVI.

4. Compositing:
   - compositing time period.

Clearly, not all issues were resolved, but important lines of communication have been opened up. Hopefully, the IGBP Land Cover Change Steering Group will consider this to be a step in the right direction. Finally, it was agreed that this report should receive wide circulation and any further information or guidance on the part of any reader will be appreciated.

AVHRR GEOMETRIC RECTIFICATION PROCEDURES

ATTRIBUTE	EDC	CCRS	JRC	GRID-GENEVA
Image-to-Map Procedures				
Systematic Rectification	Geometric transformations based on sensor and orbital models updated with daily ephemeris data	Correction for earth curvature	Geometric transformations based on sensor and orbital models	ICARUS function (ELAS software) uses a selected "tie point" to systematically rotate and resample each scene to a specified map projection
Precision Adjustments	Update platform model based on World Data Bank II linework	Polynomial transformation using ~25 GCPs per scene	Orbital model refined with user selected GCPs Also use polynominal transformation with GCPs	Polynomial transformation using 50-60 GCPs per scene
Image-to-Image Procedures	Update sensor and platform model with control from auto-correlation using AVHRR reference images	Image shift to match with World Data Bank II linework Plans call for auto-correlation using degraded Landsat MSS chips		
Capabilities for Map Projections	USGS General Cartographic Transformation Package (GCTP)	Several options typically Lambert Conformal Conic	Mercator, Lambert Conformal Conic	
Options for Resampling	NN=Nearest Neighbor, BI=Bilinear Interpolation, CC=Cubic Convolution, PSF=Point Spread Function Deconvolution, UST=User Specified Table of Resampling Weights	NN, BI, CC	NN, CC	
Software System	AVHRR Data Acquisition and Processing System (ADAPS) System rectification is accomplished with a licensed Geometric Correction Model	ARIES, Version 3 (DIPIX)	Custom-developed procedures within ERDAS environment	ELAS
Hardware System	VAX 3900	MicroVAX	VAX, IBM-AT PC	VAX 3600

WAVELENGTH (MICROMETERS)	RAYLEIGH OPTICAL DEPTH	WAVELENGTH (MICROMETERS)	RAYLEIGH OPTICAL DEPTH	WAVELENGTH (MICROMETERS)	RAYLEIGH OPTICAL DEPTH	WAVELENGTH (MICROMETERS)	RAYLEIGH OPTICAL DEPTH
0.300	0.1208E+01	0.600	0.6815E-01	0.900	0.1322E-01	1.200	0.4159E-02
0.305	0.1126E+01	0.605	0.6589E-01	0.905	0.1293E-01	1.205	0.4090E-02
0.310	0.1050E+01	0.610	0.6372E-01	0.910	0.1265E-01	1.210	0.4022E-02
0.315	0.9808E+00	0.615	0.6164E-01	0.915	0.1237E-01	1.215	0.3956E-02
0.320	0.9172E+00	0.620	0.5965E-01	0.920	0.1210E-01	1.220	0.3891E-02
0.325	0.8587E+00	0.625	0.5773E-01	0.925	0.1184E-01	1.225	0.3828E-02
0.330	0.8049E+00	0.630	0.5590E-01	0.930	0.1159E-01	1.230	0.3766E-02
0.335	0.7553E+00	0.635	0.5413E-01	0.935	0.1134E-01	1.235	0.3705E-02
0.340	0.7095E+00	0.640	0.5244E-01	0.940	0.1110E-01	1.240	0.3646E-02
0.345	0.6672E+00	0.645	0.5081E-01	0.945	0.1087E-01	1.245	0.3587E-02
0.350	0.6280E+00	0.650	0.4924E-01	0.950	0.1064E-01	1.250	0.3530E-02
0.355	0.5917E+00	0.655	0.4773E-01	0.955	0.1041E-01	1.255	0.3474E-02
0.360	0.5580E+00	0.660	0.4629E-01	0.960	0.1020E-01	1.260	0.3419E-02
0.365	0.5266E+00	0.665	0.4489E-01	0.965	0.9987E-02	1.265	0.3365E-02
0.370	0.4975E+00	0.670	0.4355E-01	0.970	0.9781E-02	1.270	0.3312E-02
0.375	0.4704E+00	0.675	0.4226E-01	0.975	0.9581E-02	1.275	0.3260E-02
0.380	0.4451E+00	0.680	0.4101E-01	0.980	0.9386E-02	1.280	0.3209E-02
0.385	0.4215E+00	0.685	0.3981E-01	0.985	0.9196E-02	1.285	0.3159E-02
0.390	0.3994E+00	0.690	0.3866E-01	0.990	0.9010E-02	1.290	0.3111E-02
0.395	0.3788E+00	0.695	0.3754E-01	0.995	0.8829E-02	1.295	0.3063E-02
0.400	0.3595E+00	0.700	0.3647E-01	1.000	0.8653E-02	1.300	0.3016E-02
0.405	0.3415E+00	0.705	0.3544E-01	1.005	0.8481E-02	1.305	0.2970E-02
0.410	0.3245E+00	0.710	0.3444E-01	1.010	0.8314E-02	1.310	0.2924E-02
0.415	0.3086E+00	0.715	0.3347E-01	1.015	0.8150E-02	1.315	0.2880E-02
0.420	0.2937E+00	0.720	0.3254E-01	1.020	0.7991E-02	1.320	0.2836E-02
0.425	0.2797E+00	0.725	0.3164E-01	1.025	0.7835E-02	1.325	0.2794E-02
0.430	0.2665E+00	0.730	0.3078E-01	1.030	0.7683E-02	1.330	0.2752E-02
0.435	0.2541E+00	0.735	0.2994E-01	1.035	0.7535E-02	1.335	0.2711E-02
0.440	0.2424E+00	0.740	0.2913E-01	1.040	0.7390E-02	1.340	0.2670E-02
0.445	0.2313E+00	0.745	0.2835E-01	1.045	0.7249E-02	1.345	0.2631E-02
0.450	0.2209E+00	0.750	0.2759E-01	1.050	0.7111E-02	1.350	0.2592E-02
0.455	0.2111E+00	0.755	0.2686E-01	1.055	0.6977E-02	1.355	0.2554E-02
0.460	0.2018E+00	0.760	0.2615E-01	1.060	0.6845E-02	1.360	0.2516E-02
0.465	0.1930E+00	0.765	0.2547E-01	1.065	0.6717E-02	1.365	0.2479E-02
0.470	0.1847E+00	0.770	0.2481E-01	1.070	0.6592E-02	1.370	0.2443E-02
0.475	0.1769E+00	0.775	0.2417E-01	1.075	0.6470E-02	1.375	0.2408E-02
0.480	0.1695E+00	0.780	0.2355E-01	1.080	0.6350E-02	1.380	0.2373E-02
0.485	0.1624E+00	0.785	0.2295E-01	1.085	0.6233E-02	1.385	0.2339E-02
0.490	0.1557E+00	0.790	0.2237E-01	1.090	0.6119E-02	1.390	0.2305E-02
0.495	0.1494E+00	0.795	0.2181E-01	1.095	0.6008E-02	1.395	0.2272E-02
0.500	0.1433E+00	0.800	0.2126E-01	1.100	0.5899E-02	1.400	0.2240E-02
0.505	0.1376E+00	0.805	0.2073E-01	1.105	0.5792E-02	1.405	0.2208E-02
0.510	0.1322E+00	0.810	0.2022E-01	1.110	0.5688E-02	1.410	0.2177E-02
0.515	0.1270E+00	0.815	0.1973E-01	1.115	0.5586E-02	1.415	0.2146E-02
0.520	0.1221E+00	0.820	0.1925E-01	1.120	0.5487E-02	1.420	0.2116E-02
0.525	0.1174E+00	0.825	0.1878E-01	1.125	0.5389E-02	1.425	0.2086E-02
0.530	0.1130E+00	0.830	0.1833E-01	1.130	0.5294E-02	1.430	0.2057E-02
0.535	0.1087E+00	0.835	0.1789E-01	1.135	0.5201E-02	1.435	0.2029E-02
0.540	0.1047E+00	0.840	0.1746E-01	1.140	0.5110E-02	1.440	0.2001E-02
0.545	0.1008E+00	0.845	0.1705E-01	1.145	0.5021E-02	1.445	0.1973E-02
0.550	0.9711E-01	0.850	0.1665E-01	1.150	0.4934E-02	1.450	0.1946E-02
0.555	0.9359E-01	0.855	0.1626E-01	1.155	0.4849E-02	1.455	0.1919E-02
0.560	0.9023E-01	0.860	0.1588E-01	1.160	0.4765E-02	1.460	0.1893E-02
0.565	0.8703E-01	0.865	0.1552E-01	1.165	0.4683E-02	1.465	0.1867E-02
0.570	0.8396E-01	0.870	0.1516E-01	1.170	0.4604E-02	1.470	0.1842E-02
0.575	0.8103E-01	0.875	0.1481E-01	1.175	0.4525E-02	1.475	0.1817E-02
0.580	0.7822E-01	0.880	0.1448E-01	1.180	0.4449E-02	1.480	0.1792E-02
0.585	0.7554E-01	0.885	0.1415E-01	1.185	0.4374E-02	1.485	0.1768E-02
0.590	0.7297E-01	0.890	0.1383E-01	1.190	0.4301E-02	1.490	0.1745E-02
0.595	0.7050E-01	0.895	0.1352E-01	1.195	0.4229E-02	1.495	0.1721E-02

WAVELENGTH (MICROMETERS)	RAYLEIGH OPTICAL DEPTH	WAVELENGTH (MICROMETERS)	RAYLEIGH OPTICAL DEPTH	WAVELENGTH (MICROMETERS)	RAYLEIGH OPTICAL DEPTH	WAVELENGTH (MICROMETERS)	RAYLEIGH OPTICAL DEPTH
1.500	0.1699E-02	1.800	0.8179E-03	2.100	0.4411E-03	2.400	0.2584E-03
1.505	0.1676E-02	1.805	0.8088E-03	2.105	0.4369E-03	2.405	0.2562E-03
1.510	0.1654E-02	1.810	0.7999E-03	2.110	0.4327E-03	2.410	0.2541E-03
1.515	0.1632E-02	1.815	0.7911E-03	2.115	0.4287E-03	2.415	0.2520E-03
1.520	0.1611E-02	1.820	0.7824E-03	2.120	0.4246E-03	2.420	0.2499E-03
1.525	0.1590E-02	1.825	0.7739E-03	2.125	0.4206E-03	2.425	0.2479E-03
1.530	0.1569E-02	1.830	0.7655E-03	2.130	0.4167E-03	2.430	0.2458E-03
1.535	0.1548E-02	1.835	0.7571E-03	2.135	0.4128E-03	2.435	0.2438E-03
1.540	0.1528E-02	1.840	0.7489E-03	2.140	0.4090E-03	2.440	0.2418E-03
1.545	0.1509E-02	1.845	0.7408E-03	2.145	0.4052E-03	2.445	0.2399E-03
1.550	0.1489E-02	1.850	0.7328E-03	2.150	0.4014E-03	2.450	0.2379E-03
1.555	0.1470E-02	1.855	0.7250E-03	2.155	0.3977E-03	2.455	0.2360E-03
1.560	0.1451E-02	1.860	0.7172E-03	2.160	0.3940E-03	2.460	0.2341E-03
1.565	0.1433E-02	1.865	0.7095E-03	2.165	0.3904E-03	2.465	0.2322E-03
1.570	0.1415E-02	1.870	0.7019E-03	2.170	0.3868E-03	2.470	0.2303E-03
1.575	0.1397E-02	1.875	0.6945E-03	2.175	0.3832E-03	2.475	0.2284E-03
1.580	0.1379E-02	1.880	0.6871E-03	2.180	0.3797E-03	2.480	0.2266E-03
1.585	0.1362E-02	1.885	0.6798E-03	2.185	0.3763E-03	2.485	0.2248E-03
1.590	0.1345E-02	1.890	0.6726E-03	2.190	0.3728E-03	2.490	0.2230E-03
1.595	0.1328E-02	1.895	0.6656E-03	2.195	0.3694E-03	2.495	0.2212E-03
1.600	0.1311E-02	1.900	0.6586E-03	2.200	0.3661E-03	2.500	0.2194E-03
1.605	0.1295E-02	1.905	0.6517E-03	2.205	0.3628E-03		
1.610	0.1279E-02	1.910	0.6449E-03	2.210	0.3595E-03		
1.615	0.1263E-02	1.915	0.6381E-03	2.215	0.3563E-03		
1.620	0.1248E-02	1.920	0.6315E-03	2.220	0.3531E-03		
1.625	0.1232E-02	1.925	0.6250E-03	2.225	0.3499E-03		
1.630	0.1217E-02	1.930	0.6185E-03	2.230	0.3468E-03		
1.635	0.1202E-02	1.935	0.6121E-03	2.235	0.3437E-03		
1.640	0.1188E-02	1.940	0.6058E-03	2.240	0.3406E-03		
1.645	0.1173E-02	1.945	0.5996E-03	2.245	0.3376E-03		
1.650	0.1159E-02	1.950	0.5935E-03	2.250	0.3346E-03		
1.655	0.1145E-02	1.955	0.5874E-03	2.255	0.3316E-03		
1.660	0.1131E-02	1.960	0.5814E-03	2.260	0.3287E-03		
1.665	0.1118E-02	1.965	0.5755E-03	2.265	0.3258E-03		
1.670	0.1104E-02	1.970	0.5697E-03	2.270	0.3229E-03		
1.675	0.1091E-02	1.975	0.5640E-03	2.275	0.3201E-03		
1.680	0.1078E-02	1.980	0.5583E-03	2.280	0.3173E-03		
1.685	0.1066E-02	1.985	0.5527E-03	2.285	0.3145E-03		
1.690	0.1053E-02	1.990	0.5471E-03	2.290	0.3118E-03		
1.695	0.1041E-02	1.995	0.5417E-03	2.295	0.3091E-03		
1.700	0.1028E-02	2.000	0.5362E-03	2.300	0.3064E-03		
1.705	0.1016E-02	2.005	0.5309E-03	2.305	0.3037E-03		
1.710	0.1005E-02	2.010	0.5256E-03	2.310	0.3011E-03		
1.715	0.9928E-03	2.015	0.5204E-03	2.315	0.2985E-03		
1.720	0.9813E-03	2.020	0.5153E-03	2.320	0.2960E-03		
1.725	0.9700E-03	2.025	0.5102E-03	2.325	0.2934E-03		
1.730	0.9588E-03	2.030	0.5052E-03	2.330	0.2909E-03		
1.735	0.9477E-03	2.035	0.5002E-03	2.335	0.2884E-03		
1.740	0.9369E-03	2.040	0.4954E-03	2.340	0.2860E-03		
1.745	0.9262E-03	2.045	0.4905E-03	2.345	0.2835E-03		
1.750	0.9156E-03	2.050	0.4857E-03	2.350	0.2811E-03		
1.755	0.9052E-03	2.055	0.4810E-03	2.355	0.2787E-03		
1.760	0.8949E-03	2.060	0.4764E-03	2.360	0.2764E-03		
1.765	0.8848E-03	2.065	0.4718E-03	2.365	0.2740E-03		
1.770	0.8748E-03	2.070	0.4672E-03	2.370	0.2717E-03		
1.775	0.8650E-03	2.075	0.4627E-03	2.375	0.2694E-03		
1.780	0.8553E-03	2.080	0.4583E-03	2.380	0.2672E-03		
1.785	0.8458E-03	2.085	0.4539E-03	2.385	0.2650E-03		
1.790	0.8363E-03	2.090	0.4496E-03	2.390	0.2627E-03		
1.795	0.8270E-03	2.095	0.4453E-03	2.395	0.2606E-03		

Based on equation (1) in "Rayleigh Optical Depth Comparisons From Various Sources", P.M. Teillet, Applied Optics, Vol.29, No.13, 1 May 1990, pp. 1897-1900.

OZONE CONCENTRATIONS:

Average column amount (cm-atm STP) in 10-degree latitude zones and by month.

	SOUTH																	NORTH
J	.304	.308	.316	.317	.296	.270	.252	.245	.241	.236	.240	.262	.311	.354	.371	.381	.382	.378
F	.285	.295	.304	.303	.286	.266	.252	.245	.241	.236	.240	.262	.311	.365	.397	.404	.400	.431
M	.290	.296	.300	.291	.275	.263	.251	.245	.243	.242	.249	.273	.318	.370	.411	.435	.441	.436
A	.266	.291	.305	.299	.282	.265	.251	.243	.243	.247	.258	.284	.324	.368	.405	.431	.443	.445
M	.295	.313	.316	.312	.296	.275	.255	.243	.244	.250	.263	.288	.321	.356	.385	.399	.401	.398
J	.296	.301	.336	.328	.314	.287	.259	.246	.245	.252	.264	.282	.307	.334	.351	.360	.363	.361
J	.301	.336	.343	.342	.330	.305	.271	.250	.248	.255	.265	.278	.294	.318	.335	.331	.321	.314
A	.307	.322	.342	.353	.346	.296	.256	.252	.249	.255	.262	.271	.284	.299	.311	.309	.297	.285
S	.263	.316	.358	.372	.353	.316	.281	.258	.251	.253	.257	.264	.275	.290	.300	.301	.285	.254
O	.282	.322	.360	.372	.349	.315	.282	.258	.249	.247	.249	.257	.270	.286	.303	.305	.298	.291
N	.346	.355	.364	.355	.325	.296	.272	.254	.244	.240	.242	.251	.272	.296	.312	.321	.329	.313
D	.344	.346	.346	.336	.310	.281	.261	.249	.241	.236	.237	.254	.285	.315	.328	.328	.341	.336

Provided by NASA/GISS; based on E. Hilsenrath and B.M. Schlesinger, 1981, "Total Ozone Seasonal and Interannual Variations Derived From the 7 Year Nimbus-4 BUV Data Set", J. of Geophysical Research, Vol.86, No.C12, pp.12087-12096, and on J.R. London, B.D. Bojkov, S. Ottmans, and J.F. Kelly, 1976, "Atlas of the Global Distribution of Total Ozone, July 1957 - July 1967", Tech. Note NCAR/TN/113+STR, Nat. Center for Atmos. Res., Boulder, Colorado.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Surveys, Mapping and Remote Sensing Sector
Secteur des levés, de la cartographie et de la télédétection

Canada Centre for Remote Sensing
2464 Sheffield Road
Ottawa, Ontario
K1A 0Y7

Centre canadien de Télédétection
2464, chemin Sheffield
Ottawa (Ontario)
K1A 0Y7

Your file Votre référence

Our file Notre référence

20 March 1990

IGBP

Dr. Peter Abel
Physics Branch
NOAA/NESDIS (E/RA14)
WWB, Room 711
Washington, D.C. 20233

Dear Dr. Abel:

A special meeting on "AVHRR Data Processing and Compositing Methods" took place in Ottawa, Canada, March 12-14, 1990. The meeting was initiated by the International Geosphere-Biosphere Program (IGBP) Land Cover Change Steering Group and eighteen people attended (list attached). The impetus for this gathering was an urgent requirement to address issues regarding the standardization of AVHRR data processing and compositing methods. Numerous agencies in various countries are embarking on large-scale land cover change investigations based on AVHRR data and it is important to standardize the methodologies involved as much as possible as we work toward continental and global products. The preprocessing methods are critical because they provide the quantitative underpinnings that are necessary for remote sensing to play a strong role in long-term, interdisciplinary studies on regional and global scales.

A key aspect of AVHRR preprocessing is radiometric calibration of the individual channels and a particular problem is the post-launch calibration of channels 1 and 2. A variety of approaches are being used to monitor the observed degradation in sensor performance and several of these were outlined at the meeting by Christopher Brest (GISS) and myself. These methods take a lot of effort and, in most cases, have provided few updates for any given AVHRR sensor. Although they show comparable trends, the results from the different approaches are not often in close agreement. The IGBP and related investigators are looking for clear trends, either from one reliable approach or from a middle-of-the-road solution such as the one Brian Markham has proposed for the NOAA-9 AVHRR. Therefore, we are essentially looking for guidance from your forthcoming calibration meeting in Washington, D.C. on the selection of appropriate calibration coefficients for operational use.

16 March 1990

There are two aspects to the operational use of calibration coefficients that should be noted. One is the calibration of retrospective AVHRR data based on the best available results over time for each instrument. The other is the need to extrapolate recent calibration results when processing current data on a near real-time basis. Hence, there is an interest in clear historical trends and a concern about the frequency of calibration updates. With regard to extrapolating calibration results, preliminary reports on the problems with the NOAA-11 AVHRR calibration are particularly worrisome for on-going processing of NOAA-11 data.

Your meeting at the end of the month will undoubtedly come up with many suggestions for courses of action. Nevertheless, a few of the ideas that were mentioned in our meeting are worth passing on to you. Wherever and whenever possible and appropriate, different post-launch calibration methods should be tried at a common site and/or on a common data set. Also, it would be of considerable interest and use to have a periodic calibration update bulletin of some kind for the key remote sensing systems of interest, including AVHRR. The bulletin should be relatively brief, very widely disseminated, and issued once or twice a year.

I have agreed to act as the point-of-contact for the IGBP Land Cover Change Steering Group regarding calibration issues. It is very frustrating that I cannot attend your meeting because of bureaucratic constraints newly imposed here. On behalf of all of the attendees at our AVHRR preprocessing and compositing meeting, I wish you all the best for a successful calibration meeting.

Sincerely,

Phil Teillet

Dr. Philippe M. Teillet
Senior Research Scientist
(613)952-2756 (Phone)
(613)952-9783 (FAX)

PMT/ak

Attendees

Special Meeting on AVHRR Data Preprocessing and Compositing Methods

12-14 March 1990
Ottawa, Ontario, Canada

ARINO, O., CNES/LERTS, Toulouse, France.

BREST, C., GISS, New York, N.Y., U.S.A.

CIHLAR, J., CCRS, Ottawa, Ontario, Canada.

CONDAL, A., Université Laval, Sainte-Foy, Québec, Canada.

CROSS, A., UNEP GRID, Geneva, Switzerland.

D'IORIO, M., CCRS, Ottawa, Ontario, Canada.

EIDENSHINK, J., EROS Data Center, Sioux Falls, S.D., U.S.A.

FEDOSEJEVS, G., Intera Technologies Ltd., Ottawa, Ontario, Canada.

FISHER, T., CCRS, Ottawa, Ontario, Canada.

GUTMAN, G., NOAA/NESDIS, Washington, D.C., U.S.A.

HERVAS, J., JRC, Ispra, Italy.

MANORE, M., CCRS, Ottawa, Ontario, Canada.

MURPHY, J., CCRS, Ottawa, Ontario, Canada

PITTELLA, G., ESA/EPO, Frascati, Italy.

ROYER, A., Université de Sherbrooke, Sherbrooke, Québec, Canada.

SADOWSKI, F., EROS Data Center, Sioux Falls, S.D., U.S.A.

SCHANZER, D., Intera Technologies Ltd., Ottawa, Ontario, Canada.

TEILLET, P., CCRS, Ottawa, Ontario, Canada