THE POTENTIAL FOR DETERMINING HISTORIC SEA-ICE EXTENT FROM 1960'S NIMBUS HRIR SATELLITE DATA

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1. INTRODUCTION

It is of critical importance in the study of Earth Sciences and climate to reliably extend our data sets farther back in time to incorporate early space missions. This presents difficulties, as most original data sets have been lost. The time to recover this information is running out as the data, hardware and expertise are rapidly dying out. If secondary sources can be reconstructed from data processed in that era and reprocessed using modern methods, they can be valuable additions to the research community.

2. BACKGROUND

A critical need in climate research is to obtain continuous high quality data records and images as far back in time as is practical. The existing climate satellite base line data runs from 1978 to the present. While earlier records are known, most researchers ignore them as they were considered low quality. The problem was not with the quality of the data; rather it was the computational horsepower and processing that were low quality relative to the more modern records. While the space age began in 1957, satellites dedicated to visible or near infrared imaging for weather or climate purposes did not practically begin until the mid 1960's. The early NASA Nimbus Series (Nimbus I, II, and III) are excellent examples [1]. The Nimbus HRIR (High Resolution Infrared Radiometer) Instrument (Nimbus I, II, and II), used a lead Selenide (PbSe) detector to detect +/- 1 degree K IR Radiation in the 3.4 and 4.2 micron bands.

The images from early exploration missions of the Argon, Corona, Lunar Orbiter and Apollo programs are additional resources, largely untapped by the community that can be integrated as a resource for data continuity and as an independent source of Earth imagery. The 2007 paper on the orthorectified image mosaic of Antarctica from the 1963 Argon satellite establishes that historic data can be recovered and is still significant [2]. The Nimbus global data coverage, time-series data, covers the period from 1964-1978 and could potentially extend the climate record at the poles by 50% from the base 1979-2009 period.

Nimbus I collected data from August 28th-September 22nd 1964. Nimbus II collected data from May 15th 1966-January 18th 1969. Nimbus III collected data from April 14th 1969-January 22nd 1972 [3]. These time widows nicely coincide with the Arctic sea ice minimums. Data coverage was global with twice daily acquisitions (day & night). In further research into the era of Nimbus data the co-authors have found other Nimbus II and III era images from the time of the Apollo lunar program. Apollo earth orbiting (Apollo 7 and 9, October 19, 1968 and March 3-13 1969) as well as the lunar missions (Apollo 8, 10-12, 14-17) obtained high resolution, high quality Hasselblad and Apollo SIM Bay visible light color and black and white images of the Earth. The co-authors are in the process of matching the timing between the Apollo images and Nimbus images to provide the climate change research community quality data regarding the state of the Arctic and Antarctic ice pack during this era.

The value of obtaining the original Nimbus images as well as the mixed Nimbus/Apollo imagery is to provide to the climate change community a precisely timed set of images and mid IR data that can help researchers to reconstruct from the early 1960’s space missions, images and data to help move back in time the state of the Arctic and Antarctic ice pack to provide a longer term record of space based images of these regions of the Earth.

Unfortunately it appears the original tapes were erased along with 200,000 other tapes due to media quality issues in the 1970's. This original data contained all the timing and calibration data needed to fully geo-rectify the data. Fortunately, Goddard Space Flight Center (GSFC) rescued a version of the data and 2007 they began a process to recover 1703 of these post-processed NIMBUS II HRIR tapes. The recovery process involved using specially developed tape drives and processing techniques to read the 800 bpi, 7-track tapes [4].

3. IMAGE CORRECTION

The recovered Nimbus HRIR files have a systemic error that reduces their utility for ice studies. If an algorithm could be found to correct this, it would greatly increase the value of the HRIR data. The original Nimbus data was recorded as analog waveforms, which were received and displayed in analog form and stored for later processing. Only the later GSFC post-processed tapes still survive.

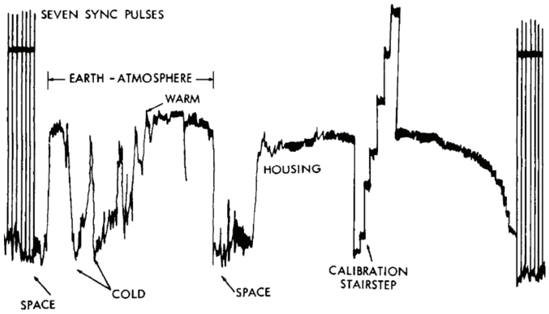

Figure 1. Structure of a raw Nimbus Image Row showing synchronization pulses and calibration steps

These tapes had been geometrically and radiometrically corrected and rectified with the surviving data truncated by removing all calibration and synchronization pulses before it was written to tape (figure 1.). These data records are the grid point maps with special analysis. This data is stored in TAP (tape emulation format).

In 2009 the Lunar Orbiter Image Recovery Project (LOIRP) team researched artifact correction algorithms, based upon our reprocessing of Lunar Orbiter images. A study of the data by NSIDC and the LORIP team revealed that jitter in the digitization process of the original Nimbus recording is the cause of a repeating, semi-random horizontal shift in each swath. Additional analysis further revealed out of range samples at the left of many swaths whose pattern was so tightly correlated with the artifact as to suggest a means for error correction.

Further analysis of the image reveals that jitter caused a repeatable shift in the data (Figure 2. left image). Our analysis indicates (right hand image) a means to correct the errors that may be generally applicable. This method was tested by manually shifting ~60 swaths overlapping with lake Michigan. Each swath was shifted left until any out of range temperature samples at the left were no longer visible. The magnitude of shift, denoted as the swath's s-Value, ranged between 0.0 and 3.5 pixels (w/1 HRIR sample exactly equal to 1 pixel). However, with 2470 files to process, and approximately 1100 swaths per file, there are over 2.7 million swaths to correct, rendering a manual solution impractical.

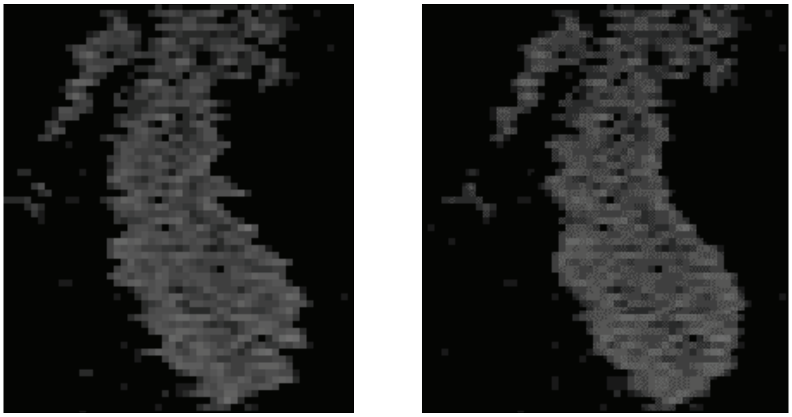

Figure 2. Preprocessed and post processed HRIR images of Lake Michigan from 1966. One the left image, note the "tearing" of Lake Michigan at the pixel (swath) level. The quality of the result on the right image reveals that the correction solution found is highly viable.

4. AUTOMATING THE CORRECTION PROCEDURE

A potential technique for automating the image correction is information cue exploitation is facilitated by identification of a method for determining sufficient ground truth data to train a probability density estimator. Leveraging a small collection of analog photo facsimile images in the Nimbus II User's Guide, and matching each with its equivalent associated TAP file enables recovering a set of truthed s-Values for each matched pair.

Each recovered truthed s-Value provides a data point consisting of four elements, denoting *e1, e2, e3, e4*:

- *e1*: s-Value
- *e2*: estimated localization of any temperature gradient change observed

- *e3*: estimate(s) of the coherency of any vertical contours of features passing through the swath, for before and after correction
- *e4*: the difference between the recovered s-Value for this swath and the swath directly above

A joint distribution, denoting as P_1, is fitted over all truthed data points recovered. The chain rule is applied to get P_3, via: $P_1(e1, e2, e3, e4) = P_2(e2, e3)\ \ P_3(e1, e4 \mid e2, e3)$. Denotation is further introduced with: s^i - a swath of interest with an unknown s-Value, and with: s^{i-1} - the swath directly above s^i , also with an unknown s-Value. Then, for each s^i, values for *e2* and *e3* are directly calculated for s^i, and put into P_3 yielding a probability density estimator for s^i , denoting as $P_{4i.}$. P_{4i} is a function of *e1* and *e4* for s^i, however as a value for *e4* requires s-Values for s^i and s^{i-1}, evaluating P_{4i} is then in turn a function of s-Values for s^i and s^{i-1}. The resulting coupling usefully captures the dependencies present in the data, and is solved as an inference problem on a cluster graph to provide a single MAP (maximum a posterior) assignment over the set of all s-Values in each TAP file.

Additional details, omitted for brevity, are available on topics including:

- How aspects of the processing described above are wrapped within outer loops to:
- Perform cross validation (minimizing overfitting risk by providing generalization estimates)
- Optimize how the calculations are implemented for both *e2* and *e3* (by maximizing a utility function sensitive to both accuracy and computational burden)
- Additional reporting provided regarding the detection of any ill-conditioned s-Value estimates
- Other training data sources (geo-referenced) should be considered.

4. CONCLUSION

Based on the work conducted to this point, the authors feel that is possible to reconstruct the sea-ice extent as a time series covering the 1960s and 1970s at a monthly resolution. This will require a significant effort to finish the s-Value algorithms to remove the “jitter”. Only then can we begin the process of determining the sea-ice edge. The process will require multiple images at the same location through time and the use of complimentary data to distinguish clouds from ice.

5. REFERENCES

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