A Proposed Analysis of the Time-Dependent Changes in the Radiometric Sensitivities of SeaWiFS Bands 1 through 6

(Any application of time-dependent corrections to these bands in the operational products will not occur until the next reprocessing.)

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1. Background

This analysis is a continuation of work presented in two previous manuscripts

Barnes, R. A., R. E. Eplee, Jr., and F. S. Patt, 1998: SeaWiFS measurements of the moon, Proc. SPIE, 3498, 311-324, and

Barnes, R. A., R. E. Eplee, Jr., F. S. Patt, and C. R. McClain, 1999: Changes in the radiometric sensitivity of SeaWiFS determined using lunar and solar-based measurements, App. Opt., in press.

Both manuscripts can be found on the SIMBIOS homepage (http://simbios.gsfc.nasa.gov), under News and Information and then under Publications and Presentations. If you cannot download these manuscripts, please let me know. I can send you a hardcopy of each of them.

2. Introduction

The SPIE paper looked at SeaWiFS lunar measurements taken from November 1997 to July 1998. The Applied Optics paper looked at measurements over a longer time interval, from November 1997 to November 1998. In both manuscripts (SPIE, Figure 4; Applied Optics, Figure 5), there was a scatter of about one half to one percent about the trend lines for the measurements. The pattern in this scatter was similar for all of the SeaWiFS bands. This was an indication that much of the scatter was not instrument based but an artifact of the normalizing factors in the analysis (moon-sun distance, lunar phase angle, and so forth).

For the SPIE paper, the scatter in the trends was reduced by about a factor of two using a normalization to the values from band 5 (555 nm). Such a normalization paralleled the use of the band2/band5 and band3/band5 ratios used in some ocean color algorithms. The trends from the “band 5 normalized” results (SPIE, Figure 5) were close to zero except for the atmospheric correction bands (bands 6, 7 and 8). The assumption behind the “band 5 normalization” was that band 5 was not changing over time.

For the Applied Optics paper, the scatter in the trends was reduced using a normalization to the average for bands 1 through 6. The assumption behind this normalization was that, on the average, these bands - as a set - were not changing. The plot for band 6 (Applied Optics, Figure 6), showed the trend to be largely removed. The values for the final three months in the band 6 panel were close to unity. In the Concluding Remarks section of the Applied Optics paper, there was a short discussion of the factors that led us to believe that there was no instrument degradation for these bands.

For each manuscript, an assumption was made as to which band (or bands) had no time dependent trend. For each manuscript, bands 7 and 8 had definite trends with time.

3. Trends in the Data Set (through May 1999)

We now have lunar measurements over a period of 19 months. Only 15 measurements are used here. For one month (August 1997) there was no lunar measurement, due to problems with the spacecraft. For three months (January 1998, June 1998, and February 1999), the measurements were made at lunar phase angles less that 6°. For these angles there is a problem with the correction for the reflectance of the moon (Applied Optics, k_4). Now that this problem is known, each lunar measurement is made as close to 7° as possible.

The data used here, for bands 1 through 6, are listed in Table 1. They are the summed radiances (S) described in the SPIE paper (with the geometric corrections applied). The dates for the measurements are given as the number of days after the first SeaWiFS image of the Earth on September 4, 1997. This table, and the ones that follow, are included to give the complete data set used in this analysis. The tables allow the reader to make independent calculations.

Table 1. Summed Spectral Radiances for the SeaWiFS Lunar Measurements. The units for the summed radiances (S) are mW cm^{-2} sr^{-1} μm^{-1}.

Date	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
71.266	361.400	436.899	505.525	503.294	534.833	514.183
100.828	360.448	435.829	504.828	502.434	534.658	514.436
159.192	360.991	436.972	505.942	503.987	535.310	513.848
188.889	363.838	440.433	510.146	507.447	538.794	517.690
219.752	358.095	433.813	502.371	500.617	531.340	509.327
249.380	357.125	432.099	500.830	499.453	529.850	508.498
278.870	361.212	437.112	506.623	504.410	535.031	512.414
366.311	361.596	438.244	508.464	505.616	536.721	514.404
395.733	362.012	438.311	508.548	506.357	537.662	515.550
425.843	361.635	438.507	508.418	506.291	537.518	515.171
455.332	363.922	441.132	511.944	510.170	540.961	518.909
484.889	359.042	434.454	504.448	502.360	533.461	511.137
544.204	356.848	432.205	502.651	500.553	531.465	509.631
572.727	367.225	445.032	516.799	514.754	546.245	523.298
603.378	357.164	433.152	502.867	501.037	530.680	508.466

To get the data in Table 1 onto a uniform scale, the values are set to unity for the date of the first lunar measurement. These values are listed in Table 2

Table 2. Spectral Radiances from Table 1 Set to Values of Unity on the Day of the First Lunar Measurement.

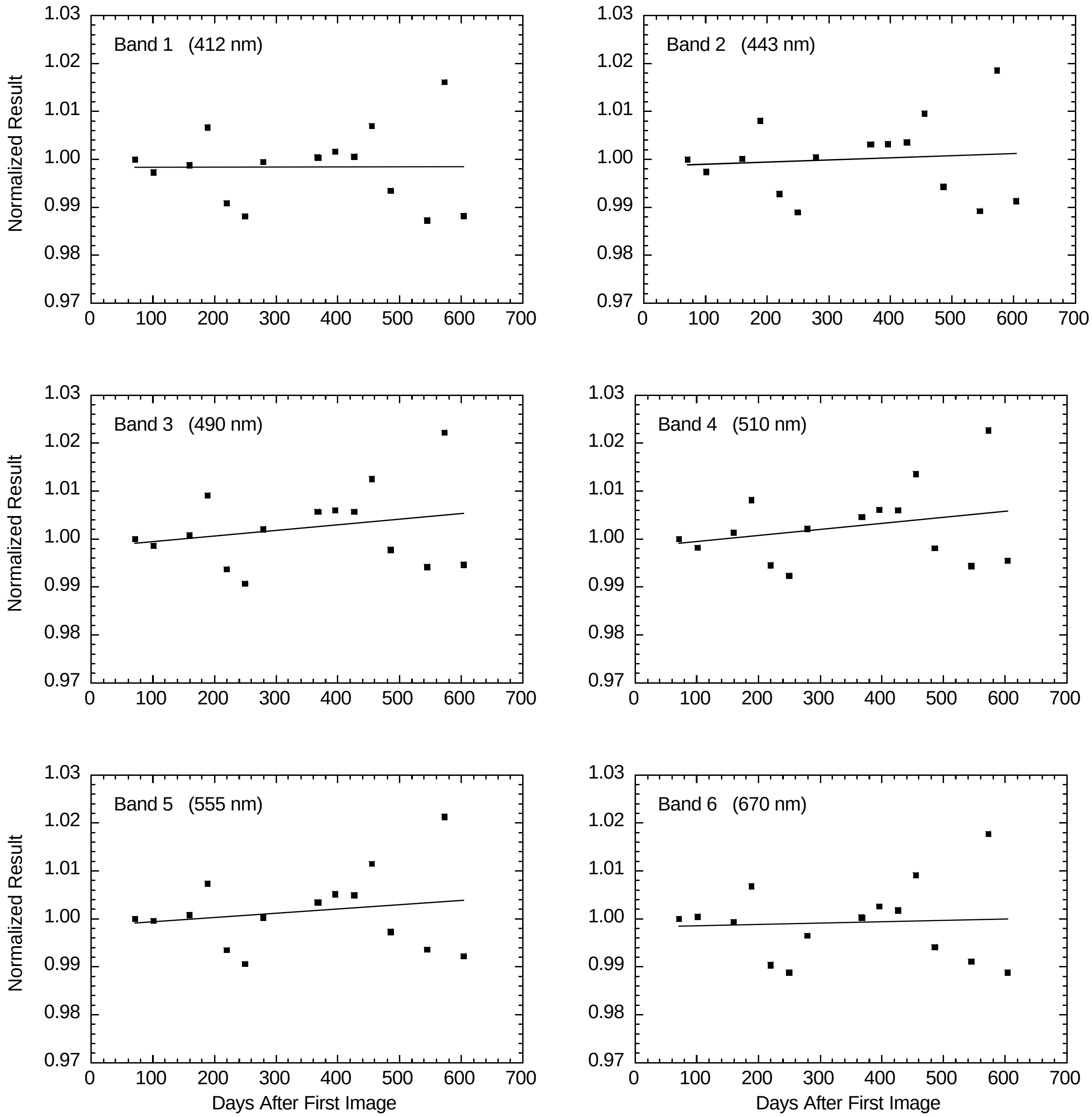
Date	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
71.266	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
100.828	0.99737	0.99755	0.99862	0.99829	0.99967	1.00049
159.192	0.99887	1.00017	1.00082	1.00138	1.00089	0.99935
188.889	1.00675	1.00809	1.00914	1.00825	1.00741	1.00682
219.752	0.99085	0.99294	0.99376	0.99468	0.99347	0.99056
249.380	0.98817	0.98901	0.99071	0.99237	0.99068	0.98894
278.870	0.99948	1.00049	1.00217	1.00222	1.00037	0.99656
366.311	1.00054	1.00308	1.00581	1.00461	1.00353	1.00043
395.733	1.00169	1.00323	1.00598	1.00609	1.00529	1.00266
425.843	1.00065	1.00368	1.00572	1.00595	1.00502	1.00192
455.332	1.00698	1.00969	1.01270	1.01366	1.01146	1.00919
484.889	0.99347	0.99440	0.99787	0.99815	0.99743	0.99408
544.204	0.98741	0.98926	0.99431	0.99455	0.99370	0.99115
572.727	1.01612	1.01862	1.02230	1.02277	1.02134	1.01773
603.378	0.98828	0.99142	0.99474	0.99552	0.99224	0.98888

The data in Table 2 can be used to create a figure that is similar to (SPIE, Figure 4) and (Applied Optics, Figure 5). This figure (Figure 1 below) shows the same, relatively large scatter about the trend lines that was found in the two previous manuscripts. For each band, the measurement on day 573 has a difference from the trend line of about 2%.

In Figure 1, the trend lines for bands 1 and 6 are very close to flat. For the other bands, the trends are upward with time. Of course, the measurement on day 573 may have a significant effect on the trends.

For the first day of the lunar measurements, the value of each trend line is very close to unity. To me, this indicates that there is no significant non-linearity in the trends. Also, as shown in the SPIE and Applied Optics papers, the pattern of the scatter about the trend lines is nearly identical from band to band. To me, this is an indication that the source of the scatter is outside of the instrument.

Figure 1. Trends in the SeaWiFS Lunar Measurements. The data for this figure comes from Table 2.



Linear Regression Coefficients for the Panels in Figure 1 ($y=a_0+a_1*x$)

Band	a_0 (dimensionless)	a_1 (day^{-1})
1	0.998313	$3.79595x10^{-7}$
2	0.998565	$4.52446x10^{-6}$
3	0.998271	$1.1842x10^{-5}$
4	0.998241	$1.2679x10^{-5}$
5	0.998441	$8.96772x10^{-6}$
6	0.998243	$2.95409x10^{-6}$

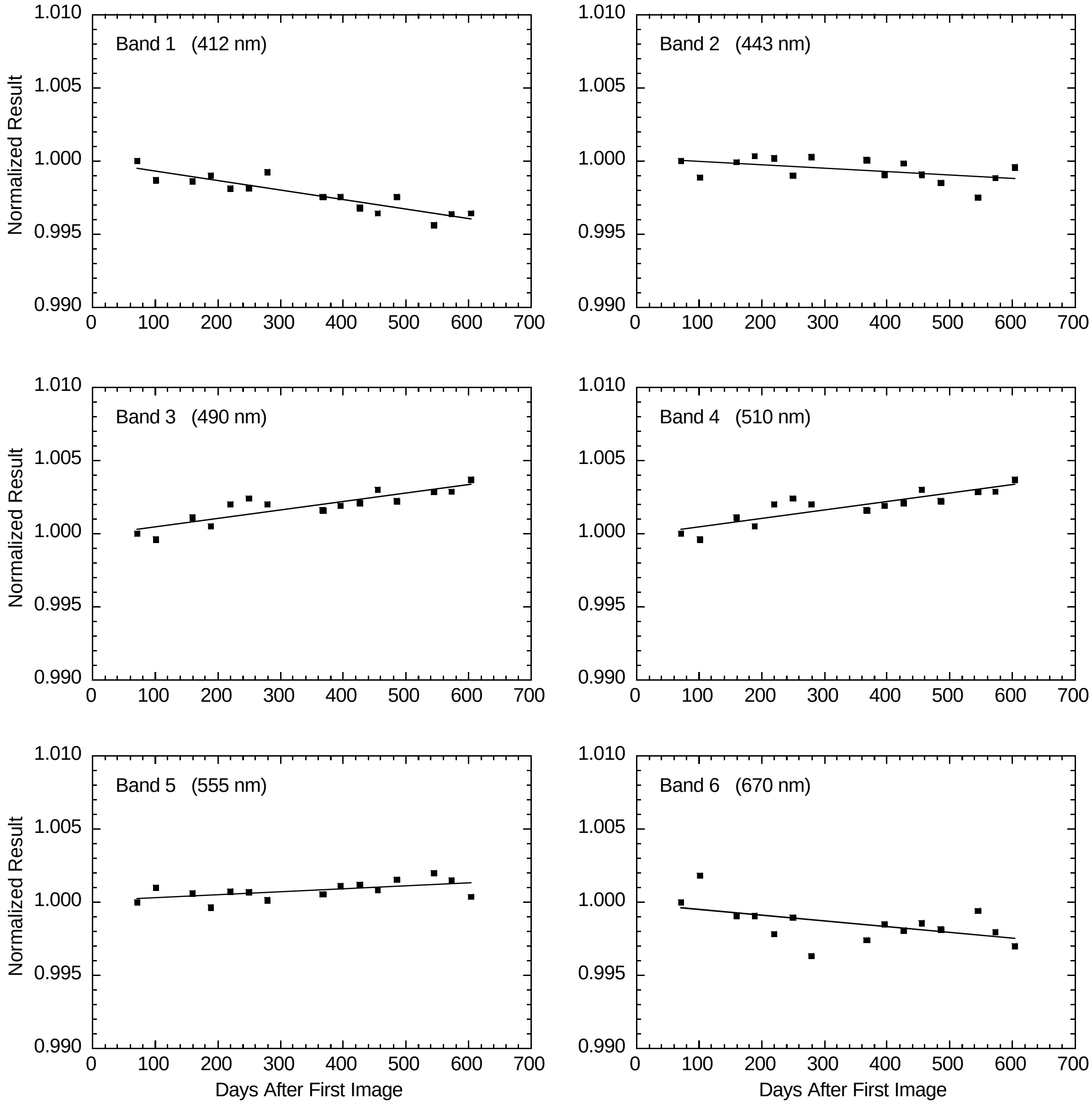
As was done for the Applied Optics paper, it is possible to normalize the values in Table 2 to the average value for the six bands. This renormalization removes much of the scatter in the trend lines. For example, the normalizing factor on day 573 is 1.01981; on day 603, it is 0.99185.

Table 3. Values from Table 2 Renormalized to the Average for the Six Bands.

Date	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
71.266	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
100.828	0.99870	0.99888	0.99996	0.99963	1.00101	1.00183
159.192	0.99862	0.99992	1.00058	1.00113	1.00065	0.99910
188.889	0.99901	1.00034	1.00139	1.00051	0.99967	0.99909
219.752	0.99813	1.00023	1.00106	1.00199	1.00076	0.99783
249.380	0.99817	0.99902	1.00074	1.00241	1.00071	0.99895
278.870	0.99927	1.00027	1.00196	1.00200	1.00016	0.99635
366.311	0.99755	1.00008	1.00280	1.00161	1.00053	0.99744
395.733	0.99755	0.99908	1.00182	1.00192	1.00113	0.99851
425.843	0.99684	0.99986	1.00189	1.00212	1.00119	0.99810
455.332	0.99640	0.99909	1.00206	1.00302	1.00084	0.99859
484.889	0.99756	0.99850	1.00198	1.00225	1.00154	0.99817
544.204	0.99564	0.99750	1.00261	1.00285	1.00199	0.99941
572.727	0.99638	0.99883	1.00244	1.00290	1.00150	0.99796
603.378	0.99640	0.99957	1.00292	1.00370	1.00039	0.99701

The data in Table 3 can be used to create a figure that is similar to (Applied Optics, Figure 6). This is done in Figure 2. With the reduction in scatter in Table 3, it is possible to adjust the ordinates in the panels for Figure 2 to ±1% about unity (0.99 to 1.01). Using this vertical scale, the slopes in the trend lines look significant. [In the Applied Optics paper, the ordinates for the figures has limits of 0.92 and 1.02. This was done to keep the x and y axes of the panels consistent – allowing easier visual comparisons of the data. The y axis limits in Figure 2 cover the same interval as the three parallel lines in the Applied Optics figures.]

Figure 2. Trends in the SeaWiFS Lunar Measurements. Here, the values in Figure 1 have been normalized to the average for the six bands. This reduces the scatter about the trend lines. It is assumed that most of the scatter in Figure 1 comes from effects that are external to the instrument.



Linear Regression Coefficients for the Panels in Figure 2 ($y=a_0+a_1*x$)

Band	a_0 (dimensionless)	a_1 (day^{-1})
1	0.999962	-6.49067×10^{-6}
2	1.00021	-2.35564×10^{-6}
3	0.999929	4.94097×10^{-6}
4	0.999903	5.76555×10^{-6}
5	1.0001	2.05951×10^{-6}
6	0.999896	-3.92934×10^{-6}

In Figure 2, there is a wavelength dependence to the slopes of the trend lines. For bands 1 and 6, the trend lines slope downward. For bands 3 and 4, the trend lines slope up. For bands 2 and 5, the slopes of the trend lines are intermediate between the extremes. With respect to the trends at 490 nm and 510 nm, there is a "falling off" in the slopes with decreasing wavelength (into the blue) and with increasing wavelength (into the red).

4. Current Analysis

In the Applied Optics paper, it was assumed that bands 1 through 6 were not changing, that is, that the slopes in their trend lines were zero. [However, a close look at Figure 6 of the Applied Optics paper shows the same pattern in trends among the bands that is found in Figure 2, above. It is just not as obvious.] The data in the panels of Figure 2 indicate that the slopes of the trend lines are not the same.

It is possible to continue with the assumption in the Applied Optics paper – that, <u>on the average</u>, bands 1 through 6 are not changing. This requires an explanation of why some bands are going up (becoming more sensitive radiometrically) and some are going down. It also requires an explanation of the wavelength dependence to these changes.

Here is an alternate assumption. We know of no mechanism that will cause bands 3 and 4 to become more sensitive radiometrically, while causing different changes in the other bands. Therefore, let us assume that bands 3 and 4 are not changing – or changing the least in the set of 6 bands. This assumption leads to a normalization of the values in Table 2 by the average of bands 3 and 4, rather than the average of bands 1 through 6. When this is done, the results in Table 4 are obtained.

Table 4. Values from Table 2 Renormalized to the Average of Bands 3 and 4.

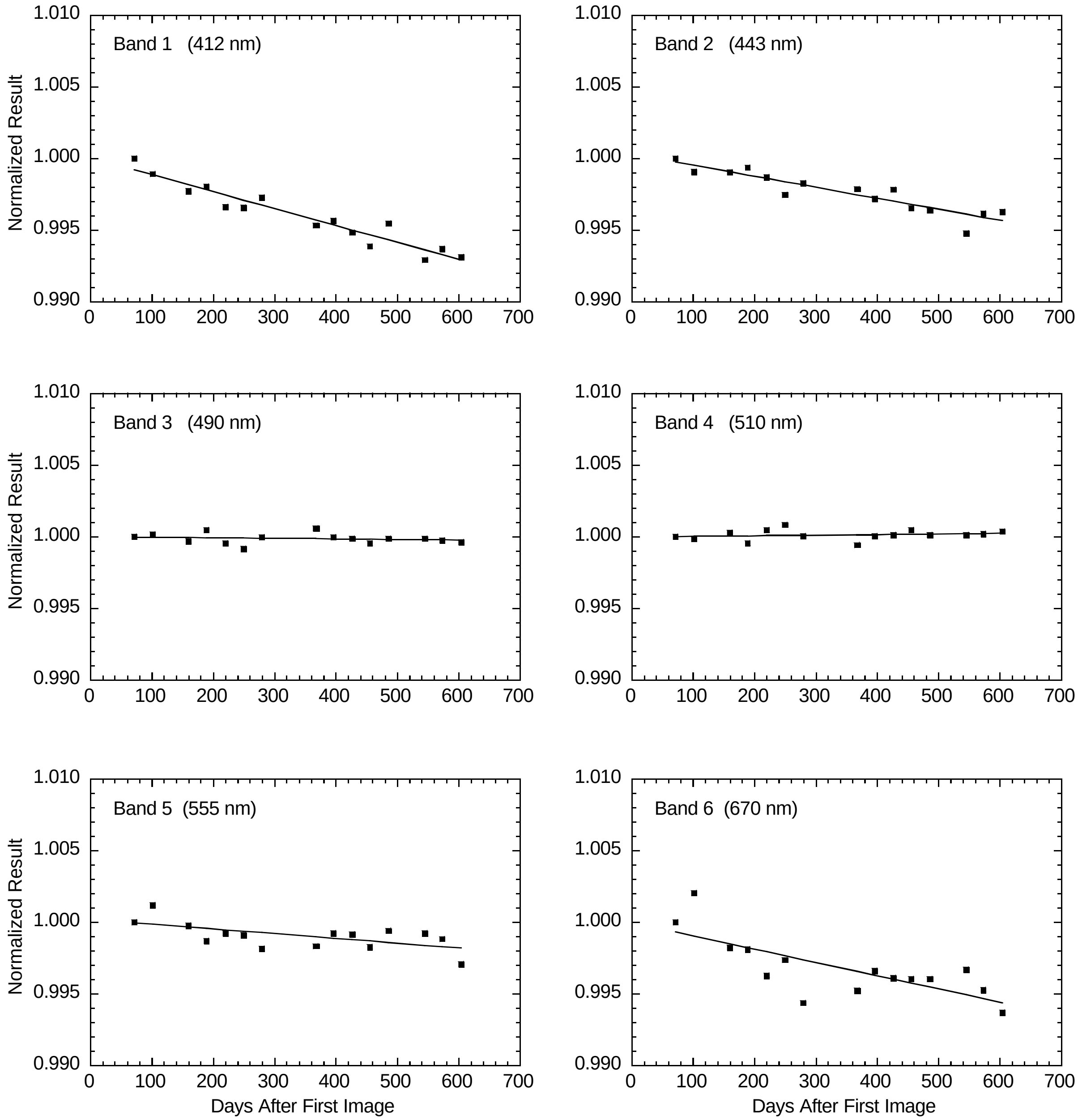
Date	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
71.266	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
100.828	0.998907	0.999094	1.000165	0.999835	1.001219	1.002039
159.192	0.997770	0.999068	0.999723	1.000277	0.999792	0.998250
188.889	0.998066	0.999397	1.000441	0.999559	0.998721	0.998141
219.752	0.996614	0.998709	0.999537	1.000463	0.999244	0.996315
249.380	0.996603	0.997451	0.999165	1.000835	0.999137	0.997382
278.870	0.997293	0.998297	0.999977	1.000023	0.998180	0.994379
366.311	0.995352	0.997876	1.000596	0.999404	0.998325	0.995242
395.733	0.995686	0.997217	0.999947	1.000053	0.999260	0.996647
425.843	0.994843	0.997855	0.999884	1.000116	0.999187	0.996106
455.332	0.993881	0.996554	0.999524	1.000476	0.998301	0.996063
484.889	0.995458	0.996389	0.999861	1.000139	0.999426	0.996061
544.204	0.992932	0.994793	0.999879	1.000121	0.999265	0.996695
572.727	0.993725	0.996166	0.999771	1.000229	0.998828	0.995297
603.378	0.993115	0.996275	0.999611	1.000389	0.997091	0.993723

Figure 3 gives plots of the data in Table 4. In Figure 3, the slopes of the trends for bands 3 and 4 are zero. For the other bands, the trend lines slope down.

Linear Regression Coefficients for the Panels in Figure 3 ($y=a_0+a_1*x$)

Band	a_0 (dimensionless)	a_1 (day^{-1})
1	1.00005	-1.18143×10^{-5}
2	1.0003	-7.69166×10^{-6}
3	1.00001	-4.12139×10^{-7}
4	0.999987	4.12159×10^{-7}
5	1.00019	-3.2883×10^{-6}
6	0.99998	-9.255×10^{-6}

Figure 3. Trends in the SeaWiFS Lunar Measurements. Here, the values in Figure 1 have been normalized to the average of bands 3 and 4.



For the Coastal Zone Color Scanner (Hovis, W. A., J. S. Knoll, and G. R. Smith, 1985: Aircraft measurements for calibration of an orbiting spacecraft sensor, Appl. Opt., 24, 407-410) there was a 25% degradation in the 443 nm band over the course of 7 years. The change was significantly less for the green band. For the SeaWiFS diffuser, there has been a "yellowing" that has caused about a 5% degradation in band 1 and a 4% degradation in band 2 over the course of a year (Applied Optics, Figure 10). We had expected to see a similar pattern of changes in the blue bands in SeaWiFS. From Figure 3, it appears that there was about a 0.7% decrease in band 1 and about a 0.4% decrease in band 2 over the interval from day 71 after launch to day 603. A plausible mechanism for this change is the yellowing of the telescope mirror. For SeaWiFS, the primary mirror is "hidden" inside a rotating cylinder. The aperture in the cylinder allows in light, but limits exposure to the outside environment.

In the Applied Optics paper, it was assumed that the changes in SeaWiFS bands 7 and 8 were due to the deterioration of the photodiodes from exposure to near-infrared radiation. It may be possible that we are now seeing this effect in band 6.

At its core, this analysis is an examination of a set of assumptions concerning which bands in SeaWiFS are changing and which are not.

- In the SPIE paper, the assumption was that band 5 did not change.
- In the Applied Optics paper, the assumption was made that, on the average, bands 1 through 6 did not change
- Here, the assumption is made that, on the average, bands 3 and 4 do not change.

For the assumption here, there is speculation about 2 mechanisms for change in the radiometric sensitivity. In the blue, the changes are due to the yellowing of the telescope mirror presumably from contamination from solarized organics). In the red and near infrared, the change is due to the deterioration of the photodiodes from near infrared radiation.

What are your comments?