SAA and Moon Proximity Effects on NEOWISE Single-exposure Source Detection Reliability

WSDC D-T046

I. Introduction

The fractional reliability of NEOWISE Single-exposure source detections as a function of proximity to the boundary of the South Atlantic Anomaly (SAA) and to the Moon is examined in this memo. Reliability in this context refers to the probability that a given NEOWISE source detection corresponds to an actual astronomical source of infrared radiation on the sky, at the position and time of the detection.

For the purpose of this study, we use positional association with a source in the AllWISE Source Catalog as a proxy for reliability of a NEOWISE detection. The AllWISE Catalog is both deeper and better vetted for unreliable detections than the NEOWISE single exposures. Nonetheless, AllWISE Catalog association is not a perfect indicator of reliability. Real sources that have moved significantly since the time of the primary WISE mission, or that have brightened above the AllWISE detection limit may not have AllWISE associations. Low SNR NEOWISE noise detections can align by chance with a faint, real AllWISE Catalog source. The AllWISE Catalog is not perfectly reliable at all flux levels, so there is a non-zero chance that a spurious NEOWISE detection can associate with a spurious AllWISE Catalog entry. However, the degree of contamination from these exceptions is expected to be very small, and should not significantly influence the findings of this study.

The general approach for investigating the effects of SAA and Moon proximity are the same. We select a large sample of NEOWISE detections that span a specified range of distances from the SAA boundary or the Moon. The fractional distribution of NEOWISE detections with and without AllWISE Catalog associations are then computed. A comparison of the two distributions provides a measure of the contamination by unreliable detections as a function of SAA boundary or Moon distance.

II. Reliability as a Function of SAA Separation

When the WISE/NEOWISE spacecraft is near or within the boundaries of the SAA, the number of charged particles that strike the detectors increases greatly relative to the ambient strike rate away from the SAA. These charged particle strikes trigger spurious source detections that are present in the NEOWISE Single-exposure source database.

Each Single-exposure source database entry contains a *saa_sep* value that indicates the distance of the spacecraft from the nominal SAA boundary at the time the detection was made. We investigate how the average reliability of NEOWISE source detections varies with the value of *saa_sep* to provide guidance for interpreting NEOWISE detections.

1. Sample Selection

Candidate detections from the first two days of the NEOWISE Reactivation survey are selected from the Single-exposure Source DB using the following criteria:

- *cntr < 4427301010010000001* (first two days of the survey)
- *saa_sep < 20* (within 20° of the SAA boundary or within the SAA)
- *cc_flags like '0000'* (not flagged as a spurious detection of or contaminated by a known image artifact)
- *moon_masked = 0* (not in region that may be contamined by scattered moonlight

These criteria return 7,524,073 DB entries. We subdivide the detections by whether or not they have W1 or W2 detections, and whether or not they have AllWISE Catalog associations within 3 arcsec. To minimize chance associations between spurious NEOWISE detections and faint AllWISE Catalog sources, we also require that the NEOWISE and AllWISE magnitudes must agree to within 0.5 mag in the specific band to be considered a "reliable" detection. NEOWISE detections that do not have AllWISE Catalog associations, or for which the brightness differs from an associated AllWISE source by

more than 0.5 mag are considered "unreliable." The breakdown of the NEOWISE source detections by band and "reliability" is given in Table 1.

Table 1 - Breakdown of Sample NEOWISE Detections by Band and Reliability

Band	Total	Reliable	Unreliable
W1	6,253,745	3,394,753	2,858,992
W2	3,679,828	1,685,868	1,993,960

The NEOWISE sample W1 and W2 source count curves are shown in Figures 1 and 2, respectively. In each, the total source counts are given by the black curves. The source counts of "reliable" detections (those with AllWISE associates where the W1 mags agree to within 0.5 mags) are given by the blue curves. The red curves display the source counts of "unreliable" detections (those without AllWISE associations or for which the NEOWISE and AllWISE brightnesses differ by more than 0.5 mags).

The soure count curves of the "reliable" detections with AllWISE associations are well behaved, following power law distributions between the saturation levels and the point where detection completeness begins to drop off due to the Single-exposure sensitivity. In contrast to the "reliable" source counts, the distribution of the "unreliable" detections is much more erratic, exhibiting unexpected variations with brightness.

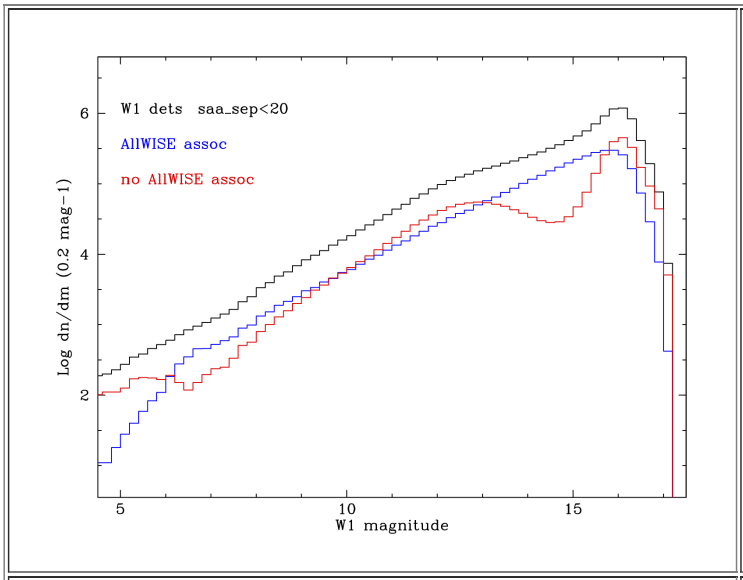

Figure 1 - W1

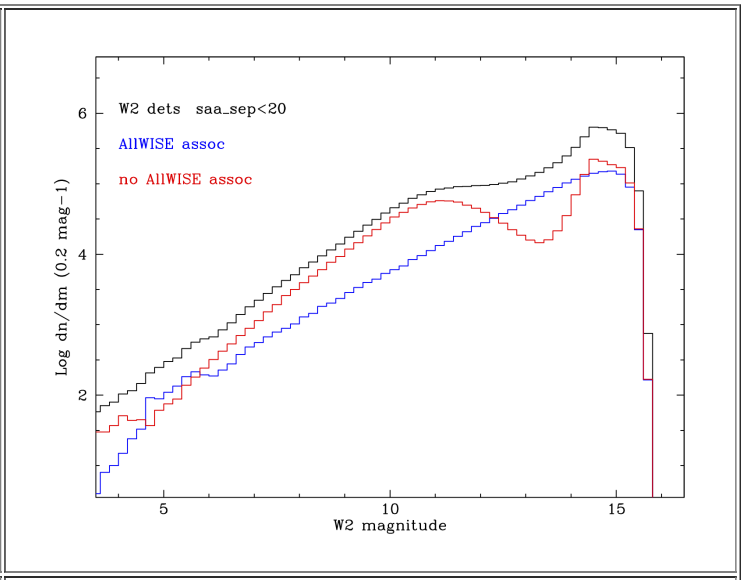

Figure 2 - W2

W1 (left) and W2 (right) NEOWISE Single-exposure source count curves. Total counts in the study sample are shown by the black curves. Blue curves show the counts for "reliable" detections (those with AllWISE associates where the W1 mags agree to within 0.5 mags). Red curves show the counts for "unreliable" detections (those without AllWISE associations or for which the NEOWISE and AllWISE brightnesses differ by more than 0.5 mags).

2. Reliability as a Function of SAA Boundary Separation

Figures 3 and 4 illustrate how the fraction of all "reliable" and "unreliable" NEOWISE source detections in the sample vary as a function of the distance to the SAA boundary as indicated by the *saa_sep* column in the source DB records. The fractional values are computed as the ratio of the number of reliable and unreliable detections to the total number of detections in 1.0 deg wide bins in *saa_sep*.

The fractional reliability of W1 and W2 detections remains relatively constant down to within **~4 deg of the SAA boundary**. The fraction of unreliable detections rises quickly with decreasing *saa_sep*, presumably caused by the increasing flux of charged particles striking the detectors.

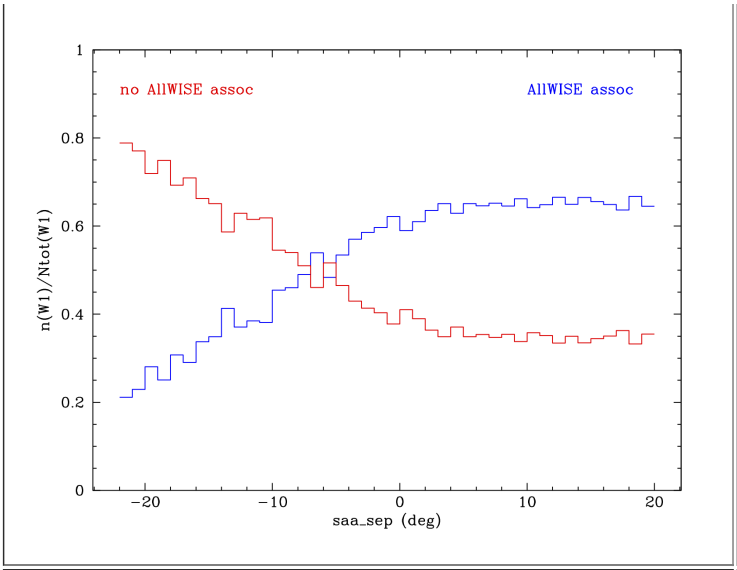

Figure 3 - W1

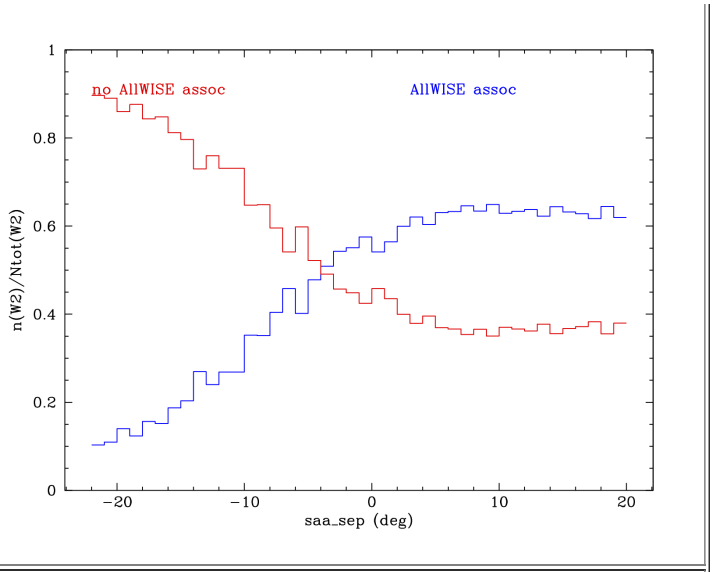

Figure 4 - W2

W1 (left) and W2 (right) NEOWISE Single-exposure source detection fractional reliability as a function of SAA boundary distance (*saa_sep*). Negative values of *saa_sep* indicate that NEOWISE is within the SAA boundary. Blue curves show the distributions for "reliable" detections (those with AllWISE associates where the W1 mags agree to within 0.5 mags). Red curves show the distributions for "unreliable" detections (those without AllWISE associations or for which the NEOWISE and AllWISE brightnesses differ by more than 0.5 mags).

III. Reliability as a Function of Moon Distance

When WISE/NEOWISE observes close to the Moon scattered light can produce raised background levels as well as distinct features such as ghosts and diffractions. These features can trigger spurious detections and thus a decrease in the net detection reliability in images taken close to the Moon. In this section, we investigate how the average reliability of NEOWISE source detections varies with Moon separation distance.

Unlike the SAA distance described above, the Single-exposure source database entries do not contains the *moon_sep* value that indicates the distance of the telescope boresight to the Moon. However, this parameter is contained in the NEOWISE image metadata table, so the individual source detections can be tagged with the approximate Moon distance taken from the image metadata table. The frame metadata tables do not contain the position angle of the vector between the NEOWISE observation and the Moon, so this analysis is limited to the azimuthally-averaged effects.

1. Sample Selection

The first step in selecting a test sample identified NEOWISE exposures that satisfy the following critieria in a query on the Single-exposure Image Metadata table:

- *moon_sep* < 50 (within 50 deg of the Moon)
- *qual_frame = 10* (Good image quality and no other quality issues)
- *saa_sep* > 0 (Beyond the worst SAA contamination)
- *ra between 50 and 100* (to limit size of data set and avoid densest parts of the galactic plane

This query produced a list of 93,582 NEOWISE Single-exposures taken during the first three years of the Reactivation survey. The *moon_sep* values from the image metadata records for these exposures were then appended to the Single-exposure source detections from the corresponding images. We further required each Single-exposure detection to satisfay these requirements:

- *saa_sep > 0* (per above)
- *cc_flags like '0000'* (not flagged as a spurious detection of or contaminated by a known image artifact)

This query returns a list of 640,792,088 detections in the selected exposures. To generate a more manageable sample, we further limited the detections to have *68<ra<73*. This yielded a list of 92,013,286 detections that still provide very good

sampling of *moon_sep* values in range <20 deg.

As above, we subdivide the detections by whether or not they have W1 or W2 detections, and whether or not they have AllWISE Catalog associations within 3 arcsec. To minimize chance associations between spurious NEOWISE detections and faint AllWISE Catalog sources, we also require that the NEOWISE and AllWISE magnitudes must agree to within 0.5 mag in the specific band to be considered a "reliable" detection. NEOWISE detections that do not have AllWISE Catalog associations, or for which the brightness differs from an associated AllWISE source by more than 0.5 mag are considered "unreliable." The breakdown of the NEOWISE source detections by band and "reliability" is given in Table 2.

Table 2 - Breakdown of Sample NEOWISE Detections by Band and Reliability

Band	Total	Reliable	Unreliable
W1	83,312,839	60,029,592	23,283,247
W2	49,345,718	31,199,339	18,146,359

The NEOWISE sample W1 and W2 source count curves are shown in Figures 5 and 6, respectively. In each, the total source counts are given by the black curves. The source counts of "reliable" detections (those with AllWISE associates where the W1 mags agree to within 0.5 mags) are given by the blue curves. The red curves display the source counts of "unreliable" detections (those without AllWISE associations or for which the NEOWISE and AllWISE brightnesses differ by more than 0.5 mags).

In contrast to the near-SAA sample above, the NEOWISE detections within 20 deg of the Moon are highly reliable over most of the brightness range. The fractional reliability drops significantly only for detections of saturated sources, and within a magnitude or so of the faint detection limit where completeness begins to drop off.

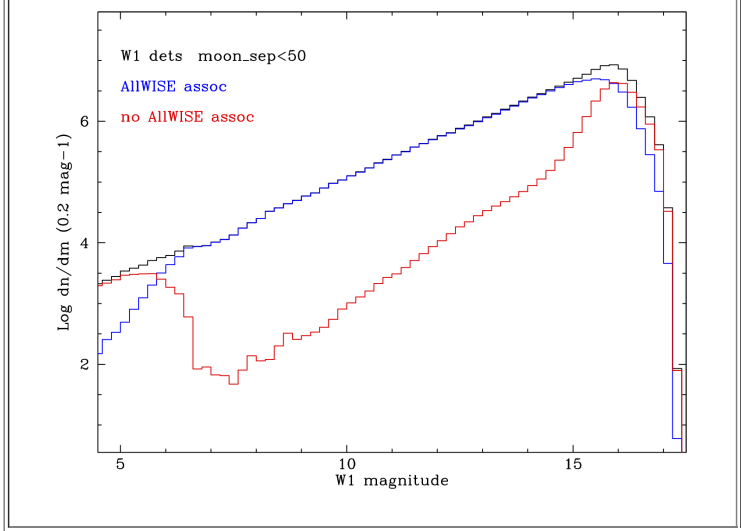

Figure 5 - W1

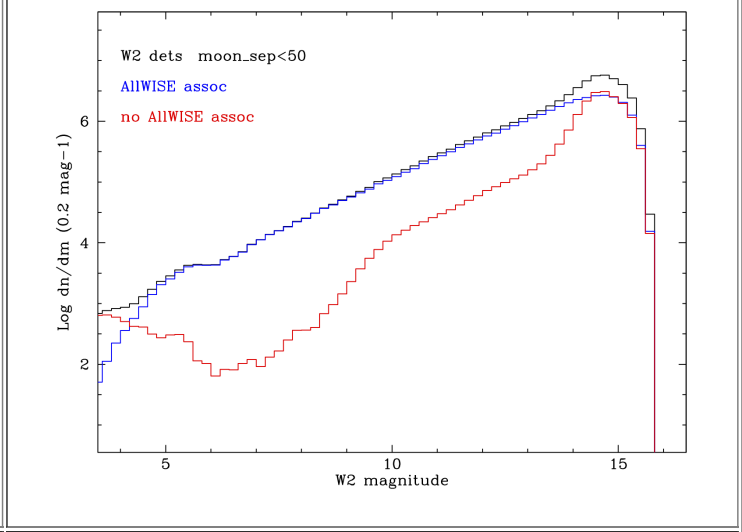

Figure 6 - W2

W1 (left) and W2 (right) NEOWISE Single-exposure source count curves. Total counts in the study sample are shown by the black curves. Blue curves show the counts for "reliable" detections (those with AllWISE associates where the W1 mags agree to within 0.5 mags). Red curves show the counts for "unreliable" detections (those without AllWISE associations or for which the NEOWISE and AllWISE brightnesses differ by more than 0.5 mags).

2. Reliability as a Function of Moon Separation

Figures 7 and 8 illustrate how the fraction of all "reliable" and "unreliable" NEOWISE source detections in the sample vary as a function of the angular distance to the Moon as indicated by the *moon_sep* value. The fractional values are computed as the ratio of the number of reliable and unreliable detections to the total number of detections in 1.0 deg wide bins in *moon_sep*.

The fractional reliability of W1 and W2 detections remains relatively constant down to within **~25 deg of the Moon**. In W1, the fractional reliability diminishes only slight until a Moon separation value of ~14 deg where the it drops

dramatically. In W2, the reliability drops more steadily than in W1. There is also an abrupt drop in reliability near a Moon separation of ~14 deg in W2.

As already mentioned, the NEOWISE Single-exposure source detection records do not carry the *moon_sep* values, so it is difficult to make precise selections based on it. However, the source DB records do contain the *moon_masked* flag that indicates whether or not the detection falls within a circular "mask" region centered on the Moon. The diamters of the circular masks are 39 deg in W1 and 47.4 deg in W2. Therefore, use of the *moon_masked* flag can be used to restrict selections to regions where the fractional reliability is only very slightly below the values at large distances from the Moon.

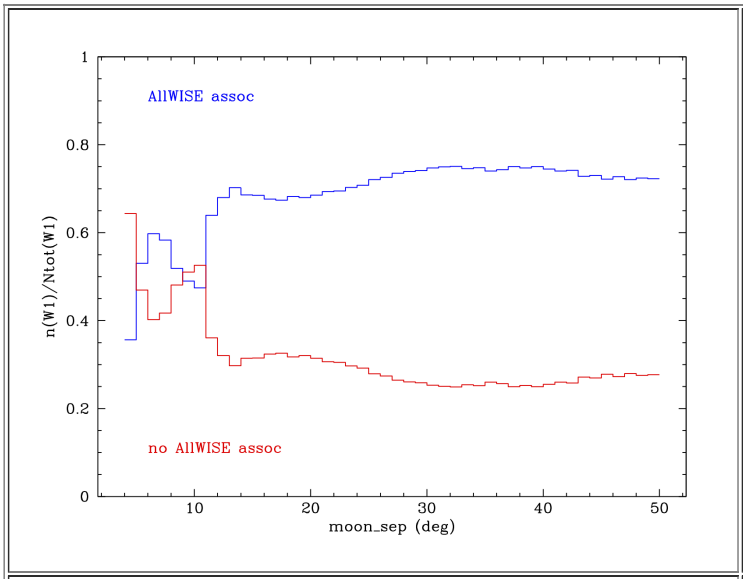

Figure 3 - W1

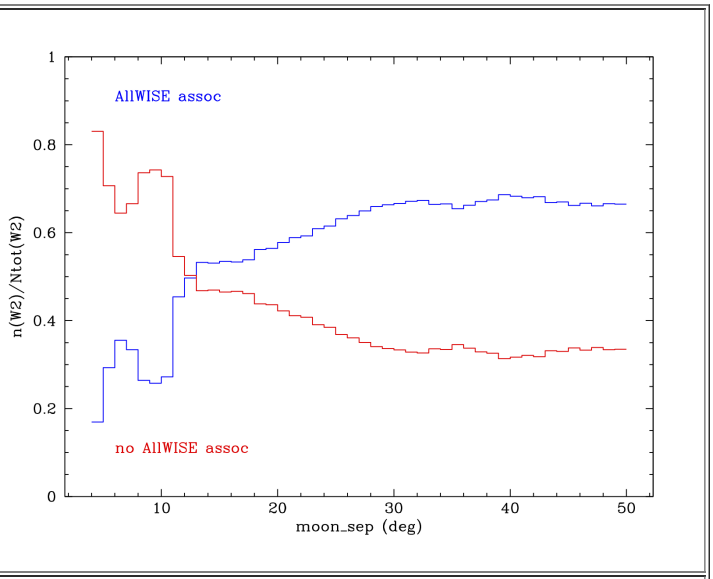

Figure 4 - W2

W1 (left) and W2 (right) NEOWISE Single-exposure source detection fractional reliability as a function of Moon distance (*moon_sep*). Blue curves show the distributions for "reliable" detections (those with AllWISE associates where the W1 mags agree to within 0.5 mags). Red curves show the distributions for "unreliable" detections (those without AllWISE associations or for which the NEOWISE and AllWISE brightnesses differ by more than 0.5 mags).

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R. Cutri - IPAC