Give Me a Few Hours: Missing Timescales in Rubin Cadence Simulations

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with support of the LSST Transient and Variable Stars Collaboration

Abstract

In this Cadence Note, we analyze the distribution of visit separations for a range of Rubin Observatory cadence simulations. The limiting temporal resolution of a time-domain survey in detecting transient behavior is set by the time between observations of the same sky area. **Current simulations are strongly peaked at the 22 minute visit pair separation and provide effectively no constraint on temporal evolution within the night.** This choice will necessarily prevent Rubin from discovering a wide range of astrophysical phenomena in time to trigger rapid followup. We present a science-agnostic metric to supplement detailed simulations of fast-evolving transients and variables.

1 Science Case

As a supplement to other Cadence Notes which treat specific classes of fast transients (e.g., Andreoni et al.) and accreting sources (e.g., Raiteri et al., Bonito & Venuti et al.), we present a source-agnostic analysis of the time gaps present in current cadence simulations. While detailed metrics simulating specific object classes are important in determining the science impacts of specific cadence choices, they require extensive development by domain experts and may not span the discovery space. Additionally it is challenging to weight specific object classes against one another. We suggest here the utility of higher-level metrics in conjunction with domain knowledge.

The (logarithmic) time separation of visits to a given sky area encapsulates the most basic information content of a time-domain survey. Our goal is to maximize the information we gain from these visits about time-varying objects. As discussed by Richards et al. (2018), an ideal survey for source class-agnostic discovery and variability characterization would be uniform in $\log \Delta t$–it would be sensitive to variations on all timescales, from the length of a single exposure up to ten years.

In practice, of course, a ground-based survey cannot achieve this uniformity due to diurnal and seasonal cycles. However, the current cadence families explored are still far from effective at probing the full range of accessible timescales. In particular, the use of closely-spaced observation pairs leaves an "intra-night desert" preventing real-time discovery and timely followup of any phenomena varying on timescales of a few hours to a day. This includes stellar flares; young supernovae; gamma-ray bursts, orphan afterglows, and other relativistic transients; kilonovae; and rare new kinds of fast extragalactic transients (e.g., FBOTs). This

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also includes short-timescale variability of AGN, particularly with low-mass supermassive black holes and accreting intermediate mass black holes, which are expect to be most variable on hours to days timescales (Burke et al., 2020). Unfortunately there are no objects varying on these timescales represented on the current radar plots in PSTN-051.

Because the current Deep Drilling Fields are scheduled as single blocks of observations, they also do not provide leverage for intra-night variability. Cadences that provide revisits on 1-day timescales are still useful for discovery of fast transients, although the opportunity for very timely early followup is lost.

To analyze the current simulations, we used the built-in `lsst.sims.maf.metrics.TgapsMetric` with logarithmic bins from 30 seconds to 10 years. We only computed pairwise separations (`allGaps=False`) and summed the resulting histograms for an NSIDE=64 healpix grid, so our histograms provide a comprehensive view of all time gaps. Figure 1 presents these time gap histograms for several illustrative example runs. We also computed a normalized cumulative distribution function (CDF) of the resulting histogram, and defined a new metric (`TgapsPercentMetric`) which represent the percentage of observation pairs with timescales between 2 hours and 14 hours (same night revisits) and between 14 and 38 hours (next-night revisits). Table 1 summarizes these metrics.

Despite the possibility of observing fields with time gaps longer than two hours but before the end of the current night, we find that less than 1% of visits are spaced in this critical timescale across all survey families. We stress that there is no inherent limitation preventing observations in this time range. One-night cadence timescales are somewhat better covered, with 7–12% of visit gaps in this timescale–but a subset of simulations have sub-percent fractions at 1-day timescales as well. These observing strategies would be catastrophic for discovery of fast-evolving transients.

2 Cadence comparisons and recommendations

[Q1] *Are there any science drivers that would strongly argue for, or against, increasing the WFD footprint from 18,000 sq. deg. to 20,000 sq.deg.? Note that the resulting number of visits per pointing would drop by about 10%. If available, please mention specific simulated cadences, and specific metrics, that support your answer.*

Generally, we expect the increased number of visits in the smaller WFD footprint would provide more effective time sampling. However, current simulation families do not distribute the additional visits at the relevant timescales and so do not provide a major improvement in the relevant metrics. The `wfd_depth`, `filt_dist`, and `footprint` simulations are comparable to or slightly worse than the current `baseline` simulations, with the exception of the `fbs_1.7footprint_tunefootprint_#` simulations, which have catastrophically low (sub-percent) coverage at 1-day timescales.

[Q2] *Assuming that current system performance estimates will hold up, we plan to utilize the additional observing time (which may be as much as 10% of the survey observing time) for visits for the mini-surveys and the DDFs (with an implicit assumption that the main WFD survey meeting SRD requirements will always be the first priority). What is the best scientific use of this time? If available, please mention specific simulated cadences, and specific metrics, that support your answer.*

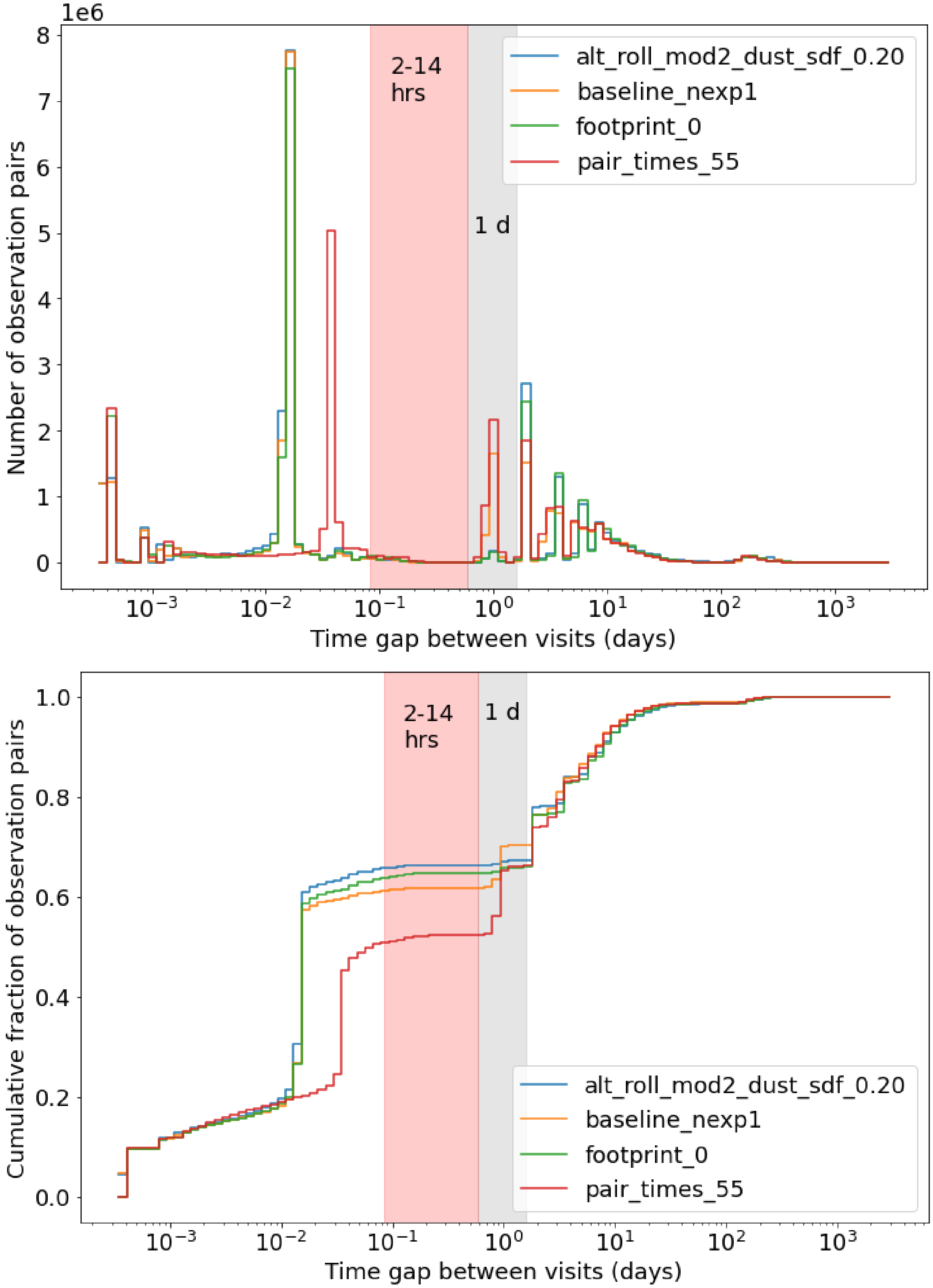

Figure 1: Histogram (top) and normalized cumulative histogram (bottom) of the time gaps between visits to the same sky position, for several representative simulations. Shaded regions highlight the 2–14 hour and 14–38 hour ranges for which we compute metrics (Table 1).

OpSim run	`TgapsPercentMetric` 2–14 hours	`TgapsPercentMetric` 14–38 hours
baseline_nexp1	0.5%	8.6%
baseline_nexp2	0.5%	8.2%
third_obs_pt15	0.3%	8.5%
third_obs_pt30	0.4%	8.2%
third_obs_pt45	0.4%	8.1%
third_obs_pt60	0.5%	8.0%
third_obs_pt90	0.7%	7.6%
third_obs_pt120	0.8%	7.3%
pair_times_11	0.4%	7.5%
pair_times_55	1.3%	**13.9%**
wfd_depth_scale0.65	0.3%	7.9%
wfd_depth_scale0.99	0.2%	8.6%
footprint_0	0.6%	0.2%
footprint_stuck_rolling	0.4%	7.1%
footprint_big_sky	0.2%	8.8%
filterdist_indx1	0.3%	9.2%
rolling_scale0.2_nslice2	0.8%	0.1%
rolling_scale1.0_nslice3	0.8%	0.1%
alt_roll_mod2_dust_sdf_0.2	0.5%	0.6%
roll_mod2_dust_sdf_0.20	0.3%	8.4%
rolling_nm_scale1.0_nslice2	0.6%	8.9%
rolling_nm_scale0.90_nslice3_fpw0.9_nrw1.0	0.8%	**12.6%**

Table 1: Median percent of observations probing intra-night and 1-day timescales. We selected representative examples from within the filter families for brevity. The best-scoring metrics are bolded, while extremely low values are marked in red.

We would suggest the increased visits be used to provide a "variability wedding cake" survey approach that would more broadly explore the discovery space in $\log \Delta t$. This might include point-and-stare "movie-mode" observations of a small subset of fields to provide sensitivity to very short timescale variability; adding third observations within the night (triplets) to WFD fields; and maximizing the season length to provide sampling on many month timescales. For efficiency these additional observations might only use a subset of the available filters. No current simulation families capture these ideas.

[Q3–4] *No response.*

[Q5] *Are there any science drivers that would strongly argue for, or against, obtained two visits in a pair in the same (or different) filter? Or the benefits or drawbacks of dedicating a portion of each night to obtaining a third (triplet) visit? If available, please mention specific simulated cadences, and specific metrics, that support your answer.*

Paired observations need to be closely spaced for linking of main-belt asteroids to succeed (Jones et al., 2018). However, even the fast transients discussed above will not vary detectably on a twenty minute baseline. **Only by switching filters between observations in a pair (as in the current baseline) does the second observation provide non-redundant information about even fast-evolving transients.**

Could the visit pairs be more widely spaced? The `pair_times` family considered spaces as large as 55 minutes. A longer interval would improve detectability of short-timescale variations if the visit pairs are in the same filter, but the larger spacing is of less advantage in the generally more informative mixed-filter pairs. Accordingly, we suggest that mixed filter pairs be retained as the baseline. We do note that the largest pair-spacing simulation, `pair_times_55`, provides the best metric values for both the 2–14 and 14–38 hour timescales of all the simulations to date.

Most Main Belt Asteroids ($\sim 80\%$; M. Juric, priv. comm) are discovered in the first three years of the survey. Accordingly a move to much wider visit pairs ($>$ 2 hours) later in the survey might enhance fast transient discovery without compromising solar system science.

"Triplet" observations (the "Presto-Color" strategy, Bianco et al.) add a third nightly observation in one of the two filters of the visit pair, and so present the best means of capturing the intranight variability of fast transients. Suprisingly, the current `third_obs_pt#` simulations show almost *no* improvement in 2–14 hour timescale coverage. **The current triplet implementation thus provides little improvement over the baseline strategy, as it does not provide sufficiently wide time sampling nor enough additional visits to substantially change the fraction of observations in the intra-night desert.** Further improvements to the scheduler implementation of this strategy are necessary for triplet observations to reach their potential.

[Q6] *Are there any science drivers that would strongly argue for, or against, the rolling cadence scenario? Or for or against varying the season length? Or for or against the AltSched N/S nightly pattern of visits? If available, please mention specific simulated cadences, and specific metrics, that support your answer.*

Rolling cadences provide the best means of allocating additional observations into the 2 hours–1 night window critical for rapid discovery of fast-evolving transients. Current simulations show a wide range of performance; the `rolling_scale` and `alt_roll` simulations have very poor (sub-percent) coverage of one-day timescales. `rolling_nm_scale1.0_nslice2` is close to the `baseline`, and `rolling_nm_scale0.90_nslice3_fpw0.9_nrw1.0` approaches the `pair_times_55` simulation in its effective timescale coverage. We suggest continued investigation into how best to distribute the rolling visits in time.

[Q7] *No response.*

References

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