IceCube Neutrino Observatory

Management & Operations Interim Report

PY1H1 (April 1, 2021 - September 30, 2021)

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Foreword

This FY2021 (PY1) Interim Report is submitted as required by the NSF Cooperative Agreement OPP-2042807. This report covers the 5-month period beginning April 1, 2021 and ending August 31, 2021. The status information provided in the report covers actual common fund contributions received through September 30, 2021 and the full 86-string IceCube detector (IC86) performance through August 31, 2021.

1 Financial/Administrative Performance

The University of Wisconsin–Madison has established two separate accounts with supporting charge numbers for collecting IceCube M&O funding and reporting related costs: 1) NSF M&O Core account, 2) U.S. Common Fund account.

The first PY1 installment of $5,332,687 was released to UW–Madison to cover the costs of management and operations during the first nine months of PY1: $900,900 was directed to the U.S. Common Fund account based on the number of U.S. Ph.D authors in the last version of the institutional MoUs, and the remaining $4,431,787 was directed to the IceCube M&O Core account. The second PY1 installment of $1,777,562 is expected to be released to UW–Madison to cover the costs of management and operations during the last quarter of PY1: $300,300 will be directed to the U.S. Common Fund account, and the remaining $1,477,262 will be directed to the IceCube M&O Core account (Table 1).

PY5: FY2021/FY2022	**Funds Awarded to UW (Apr 1, 2021–Dec 31, 2021)**	**Funds To Be Awarded to UW (Jan 1, 2022 – March 31, 2022)**
IceCube M&O Core account	$4,431,787	$1,477,262
U.S. Common Fund account	$900,900	$300,300
TOTAL NSF Funds	**$5,332,687**	**$1,777,562**

Table 1: NSF IceCube M&O funds – PY1 (FY2021/FY2022).

Of the IceCube M&O PY1 Core funds, $1,029,889 were committed to the U.S. subawardee institutions based on their statement of work and budget plan. The institutions submit invoices to receive reimbursement against their actual IceCube M&O costs. Table 2 summarizes M&O responsibilities and total PY1 funds for the subawardee institutions.

Institution	**Major Responsibilities**	**Funds**
Lawrence Berkeley National Laboratory	DAQ maintenance, computing infrastructure	$82,689
Pennsylvania State University	Computing and data management, simulation production, DAQ maintenance	$23,098
University of Delaware, Bartol Institute	IceTop calibration, monitoring and maintenance	$174,104
University of Maryland at College Park	IceTray software framework, online filter, simulation software	$635,360
University of Alabama at Tuscaloosa	Detector calibration, reconstruction and analysis tools	$30,101
Michigan State University	Simulation software, simulation production	$84,537
Total		**$1,029,889**

Table 2: IceCube M&O subawardee institutions, major responsibilities and funding – PY1 (FY2021/FY2022).

IceCube NSF M&O Award Budget, Actual Cost, and Forecast

The current IceCube NSF M&O 5-year award was established in the middle of Federal Fiscal Year 2021, on April 1, 2021. The following table presents the financial status and estimated balance at the end of PY1 of the 5-year award.

Total awarded funds to UW–Madison (UW) for supporting IceCube M&O from the beginning of PY1 through December 2021 are $5,332,687. With the second PY1 planned installment of $1,777,562, the total PY1 budget is $7,110,249. Total actual cost as of September 30, 2021 is $2,819,291 and open commitments against purchase orders and subaward agreements are $795,691. The current balance as of September 30, 2021 is $3,495,267. With a projection of $3,422K for the remaining expenses during the final six months of PY1, the estimated balance at the end of PY1 is $73K, which is 1.0% of the PY1 budget (Table 3).

(a)	(b)	(c)	(d)= a-b-c	(e)	(f=d-e)
Year 1 Budget Apr 2021-Mar 2022	**Actual Cost to Date** through Sept 30, 2021	**Open Commitments** on Sept 30, 2021	**Current Balance** on Sept 30, 2021	**Remaining Projected Expenses** through Mar 31, 2022	**End of PY1 Forecast Balance** on Mar 31, 2022
$7,110K	**$2,819K**	**$796K**	**$3,495K**	**$3,422K**	**$73K**

Table 3: IceCube NSF M&O award budget, actual cost, and forecast.

IceCube M&O Common Fund Contributions

The IceCube M&O Common Fund was established to enable collaborating institutions to contribute to the costs of maintaining the computing hardware and software required to manage experimental data prior to processing for analysis.

Each institution contributes to the Common Fund, based on the total number of the institution's Ph.D. authors, at the established rate of $13,650 per Ph.D. author. The Collaboration updates the Ph.D. author count twice a year before each collaboration meeting in conjunction with the update to the IceCube Memorandum of Understanding for M&O.

The M&O activities identified as appropriate for support from the Common Fund are those core activities that are agreed to be of common necessity for reliable operation of the IceCube detector and computing infrastructure and are listed in the Management & Operations Plan. These activities directly support the functions of winterover technical support at the South Pole, hardware and software systems for acquiring and filtering data at the South Pole, hardware and software systems for transmitting data via satellite and disk to the UW data center, systems for archiving the data in the central data warehouse at UW and UW data center operations as listed in the IceCube M&O Cooperative Agreement.

Table 4 summarizes the planned and actual Common Fund contributions for the period of April 1, 2021–March 31, 2022, based on v29.0 of the IceCube Institutional Memorandum of Understanding, from March 2021. The remaining contributions from non-U.S. collaborators are still underway, and it is anticipated that the planned contributions will be fulfilled.

	Ph.D. Authors	Planned Contribution	Actual Received
U.S.	88	$1,201,200	$900,900
Non-U.S.	73	$1,010,100	$360,846
Totals	**161**	**$2,211,300**	**$1,261,746**

Table 4: Planned and actual Common Fund contributions for the period of April 1, 2021–March 31, 2022.

2 Management and Operations Status and Performance

WBS 2.1: Program Coordination

Education and Outreach

The E&O team has continued to seek new opportunities and develop new partnerships to best use available resources and personnel.

Our PY1 focus areas are:

1. *Reaching high school students and teachers* through IceCube Masterclasses and South Pole webcasts targeting K-12 classrooms and the public. Masterclasses are one-day events held at IceCube Collaboration campuses that give high school students and accompanying teachers a chance to experience real research using IceCube data.

2. *Increasing STEM awareness* through undergraduate research experiences and South Pole deployments for educators who are integrated into the UWRF Upward Bound (UB) program.

Most IceCube institutions hold their masterclasses in the first few months of the year. Internal encouragement and recruiting of IceCube institutions for masterclasses in 2022 has begun. Web materials have been updated with a significant effort to produce content in Japanese. We are hoping that masterclasses can be in person but if not will offer them virtually.

In the reporting period, we held three South Pole webcasts. The first was in April, in conjunction with IceCube masterclasses. The second and third were both in June, one for a joint meeting of the Castro Valley Science and Rotary clubs, the other for a public lecture series hosted by Oxford University. All three had strong attendance.

Deployments to the South Pole continue to be constrained by the COVID pandemic. We remain in contact with the educator we had selected in conjunction with the PolarTREC program to deploy to the South Pole, and look forward to having her on the team in a future season when that is possible.

High school students in the 2021 summer UWRF Upward Bound program, led by longtime IceCube educators Eric Muhs and Steve Stevenoski, learned about communicating science using stop action videos. WIPAC hosted a summer virtual research program for five high school students. The UWRF summer REU program was held virtually with a diverse group of eight students from across the country, exceeding the goal to have at least 50% of students from groups underrepresented in physics. They participated in the virtual IceCube boot camp and worked on neutrinos oscillations, data analysis and simulations, and sensor fabrication troubleshooting.

As part of IceCube's 10th anniversary celebrations this year, IceCube E&O helped host two public events. In a virtual event hosted by the University of Oxford Department of Physics, IceCube collaborators spoke about IceCube and its achievements, and IceCube winterovers called in from the South Pole to talk about life at the bottom of the world. The other event, hosted by UW–Madison, was held in person and presented online; three UW–Madison IceCube collaborators talked about IceCube's past, present, and future in front of an audience of over 50 live attendees and over 100 virtual connections.

The UW team (WIPAC, Field Day, and the Wisconsin Institutes of Discovery) that developed the IceCube virtual reality experience (VRE) has received funding for a five-year polar education project. *EHR-Polar DCL: Expedition VRctica: Utilizing Public Library Systems To Engage Rural and Latinx Communities in Polar Research* will redo the IceCube VRE and produce four new Polar VREs.

Communications

Producing captivating web and print resources, graphic designs, and displays is a core mission for IceCube Communications. With 2021 marking the 10th year of IceCube operation as a fully instrumented detector, IceCube Communications produced a campaign to celebrate the first decade. The products from the celebration, available on the IceCube turns ten web page, include:

1. *IceCube 10-year logos and graphics* for our social media profiles.
2. *IceCards*, an album of real postcards mailed by collaborators around the globe containing favorite memories and lessons from their time in IceCube.
3. *A timeline of IceCube's history*, including the events in neutrino physics that made our experiment possible.
4. *IceCube: 10 Years of Neutrino Research from the South Pole*, a five-minute video reviewing IceCube's first decade of discovery featuring IceCube collaborators from around the world, ranging from graduate students to full professors.
5. *The IceCube Mosaic*, a composite picture celebrating 10 years, composed of photos of collaboration members and other memorable images.
6. *The IceCube Cake*, an elaborate two-tier IceCube-themed "birthday" cake made by a UW–Madison graduate student. A gallery of photos and videos about the cake can be found on the IceCube turns ten web page.

Figure 1: The IceCube 10-year logo, mosaic, and cake.

WBS 2.2: Detector Operations and Maintenance

During the period from April 1 to September 30, 2021, the detector uptime, defined as the fraction of the total time that some portion of IceCube was taking data, was 99.9%, exceeding our target of 99% and close to the maximum possible, given our current data acquisition system. The clean uptime for this period, indicating full-detector analysis-ready data, was 99.5%, greatly exceeding our target of 95%. This high clean uptime is in part due to the successful power supply maintenance concluded during the 2019–20 pole season. Other key performance metrics are listed in Table 5; in all cases performance metrics were met.

Figure 2 shows a breakdown of the detector time usage over the reporting period. The partial-detector good uptime was 0.55% of the total and includes analysis-ready data with fewer than all 86 strings. The excluded uptime of 0.8% includes maintenance, commissioning, and verification data. The unexpected detector downtime was limited to 0.1%.

Performance Metric	**Objective**	**Achieved**	**Description**
Total Detector Uptime	>99%	99.9%	Detector taking data in some configuration
Clean Detector Uptime	>95%	99.5%	Full-detector data usable by all analyses
IceCube Live Uptime	>99.9%	99.92%	Control/monitoring functioning
Supernova System Uptime	>99%	99.8%	Supernova DAQ online taking data
L1 Processing Latency	<60 s	27 s	90% quantile of time from event in ice to processed event on disk

Table 5: Detector operations and maintenance key performance parameters.

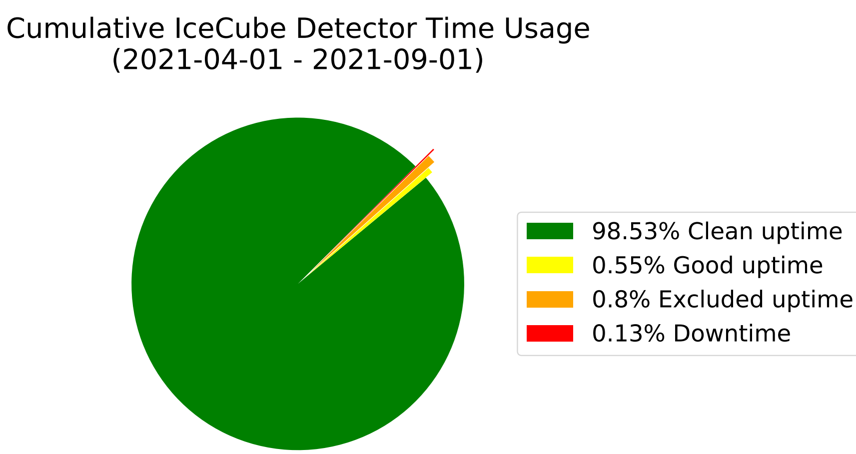

Figure 2: Detector uptime for the current reporting period.

The total number of active DOMs in the data stream is currently 5405 (98.5% of deployed DOMs), plus three DOM-mainboard-based scintillator panels. No DOMs failed during this reporting period; the previous DOM failures were in December 2018.

Detector operations milestones for PY1 are shown in Table 6. The primary milestone in this reporting period is the IC86-2021 physics run start (**WBS 2.2.1 Run Coordination**), which started

WBS L3	Planned	Actual	Milestone
2.2.1	05/31/21	05/27/21	IC86-2021 run start
2.2.1	08/02/21	07/01/21	21/22 WinterOvers begin training
2.2.1	11/15/21	TBD	21/22 WinterOvers deploy, replace outgoing WO crew
2.2.3	10/15/21	n/a	Field season readiness review completed
2.2.9	01/28/22	TBD	Operating system upgrade of SPS servers completed

Table 6: WBS 2.2 Detector operations and maintenance PY1 milestones.

on schedule on May 27, 2021. The physics run start included the standard detector recalibration and tuning but no major trigger or filter changes.

Because of the ongoing impact of COVID-19, the 2021–22 South Pole season has been scaled back, impacting several upcoming milestones. Operationally critical cargo (e.g. storage disks and UPS batteries) will be delivered, and important maintenance will still be carried out by the winterovers and one additional summer deployer (winterover manager R. Auer). The usual planned field season readiness review, however, has been cancelled since all non-critical activities have been delayed, such as surface array deployments.

The **South Pole System (SPS; WBS 2.2.9)** computer operating system upgrade, delayed from 2019—20 due to COVID-19, will proceed this summer season, with the exception of a few core infrastructure servers. This operating system upgrade ensures compatibility with current and future IceCube data processing software and enables long-term security support. The SPS configuration management system, Puppet, will be upgraded at the same time.

Two new winterovers, Moreno Baricevic and Wenceslas Marie-Sainte, were hired and started in-person training at the UW Physical Sciences Laboratory (PSL) in July 2021 and at WIPAC in August 2021. Winterover training involves in-depth, hands-on exercises on all online computing and detector subsystems using the IceCube South Pole Test System (SPTS). Training began one month early this year at PSL with the IceCube Upgrade drill team so that the winterovers could support a few on-site investigative activities, given that all Upgrade summer deployment have been canceled for 2021–22.

Planning and definition of interfaces to integrate the IceCube Upgrade into the existing **data acquisition software (DAQ, WBS 2.2.2)** have begun. Minor release ”Akupara2” was installed on July 12, 2021 and fixes some minor bugs associated with the Python3 upgrade. Current work is focused on preparations for the OS upgrade and involves extensive testing on SPTS and node-by-node procedure documentation.

The online data **processing and filtering system (PnF, WBS 2.2.3)** was updated for the IC86-2021 run start. While most event filtering was unchanged, new IceTop hit information was added to the **realtime event stream (WBS 2.2.8)** in order to facilitate faster veto detection. Figure 3 shows the event processing latency; for 90% of the events, this was under 30 s. PnF outages do not impact data-taking uptime, but low latency is important for real-time followup alerts to the wider community.

A new major release of the IceCube Live **experiment control and monitoring software (WBS 2.2.4 & 2.2.5)** was installed on June 29, 2021, I3Live v4.4.0 ”Enterprise”. This version, in addition to bug fixes, this release supported the upgrade of SPS to Python3. Support ended for the previous version of Python on January 1, 2020. The ”Enterprise2” minor release was installed on September 21, 2021 with changes to support the upcoming operating system upgrade.

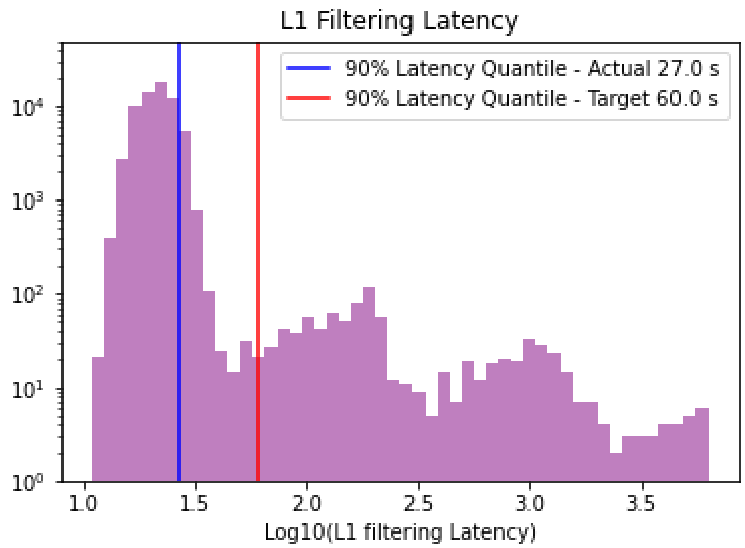

Figure 3: Event processing latency for the reporting period ($\log_{10}$(seconds); lower is better).

IceTop and the surface array (WBS 2.2.6) have been functioning smoothly. The elevated scintillator panels, antennas, and FieldHub of the prototype surface station took data through another winter with minimal apparent drifting (Fig. 4). While new planned station deployments for 2019–20 and 2020–21 have been postponed due to logistics constraints, a DAQ electronics swap is planned for this December/January that fixes some issues with radio signal acquisition. The electronics are interface-compatible and can be swapped in by the winterovers.

Figure 4: Elevated scintillator panel at the end of the winter (Sept. 27, 2021).

The **supernova data acquisition system (SNDAQ, WBS 2.2.7)** is running stably, and preparations for the OS upgrade are in progress. Maintenance of the software, however, is complicated by a legacy C++ codebase and reliance on the ROOT data analysis framework. Development of a new version of SNDAQ based on Python (PySNDAQ) is in progress; basic data ingest and significance calculation on a test system has been demonstrated.

Detector Operations Labor Assessment

A detailed list of M&O supported labor is included in the Appendix *Staffing Matrix by WBS L3*. Planned and actual labor are very close with the exception of two personnel departures during this reporting period. Senior DAQ software developer Dave Glowacki retired in July, and IceCube Live developer Colin Burreson left for industry in late September. Developer Tim Bendfelt has taken over as lead DAQ developer.

Detector operations (WBS 2.2) has historically been adequately staffed for IceCube M&O, reflected in high detector uptime and hardware/software stability. The departures of two long-time developers as well as the additional resources needs of the integrating the new systems for the IceCube Upgrade (see next paragraph) present a risk: the 2021-2026 M&O budget did not allow replacement of Glowacki. However, a new search for a DAQ developer to replace Burreson will be launched in the 2nd half of PY1.

The online software plan for expansions like the Upgrade relies on tight integration into the current IceCube DAQ and filtering systems rather than a new design, saving significant time and labor. This is possible because the IceCube operations software has been well-maintained and modernized over the course of previous MO periods. However, significant effort is still needed across all L3 areas in order to expand the system to incorporate new sensors, calibration instruments, and their data products. Specifically, one additional FTE for 2.2.2 Data Acquisition (as originally requested in the proposal) will ensure that data acquisition systems are ready at the time of IceCube Upgrade deployment. An additional 0.5–1.0 FTE DevOps engineer in 2.2.9 South Pole Systems would also allow modernization of the configuration management and monitoring systems of the computing cluster at South Pole.

WBS 2.3: Computing and Data Management Services

During the period from April 1 to September 30, 2021, the core infrastructure Uptime, defined as the fraction of the total time that the core infrastructure located at UW-Madison was accessible to the collaboration, was 97-99% depending on the service. This exceeds our target of an average uptime of 95%.

Similarly, the non-core infrastructure, was also working at 95-99%. Major outages of non core infrastructure were caused by interruptions in the UW-Madison campus chilled water (used for cooling the equipment), which are out of our control. The workflow management software (IceProd) has been up 97% of the time. Filtered data from the South Pole is currently transferred to Madison on average within less than 24 hours. The replication of our processed data is currently a number of weeks behind the current data. We are currently catching up and will be up-to-date within a week or two.

We grew from 7 users reported earlier in the year to 13. We continue to recruit new users and improve the system user-friendliness to recruit new users.

Computing and Data Management milestones for PY1 are shown in Table 8. We have completed the experimental data ingest to NERSC ahead of schedule. It took us less than 90 days from data arrival from the South Pole via retro-cargo in Madison until the data was archived at NERSC. The archive at NERSC now includes over 10 years of unfiltered IceCube data.

We continue to work on the Single sign-on implementation and believe we will complete it by the target date or within 60 days of the target date. Unfortunately, supply chain issues, in particular shortages of computing hardware, have caused a delay in acquiring new hardware needed for the

Performance Metric	Objective	Description
Core Infrastructure Uptime	95%	Data warehouse, virtualization infrastructure, data retrieval infrastructure, detector operations infrastructure
Non-core Infrastructure Uptime	90%	Data analysis infrastructure, websites, etc.
Data Transfer Delay	2 days	Time from data taking to arrival in data warehouse, assuming no satellite interruptions
Latency in replication of processed data	7 days	Replication of verified and processed data to archive at DESY
Latency in replication of raw data	90 days	Moving data that arrives via retro-cargo from South Pole to NERSC for archival
IceProd Uptime	90%	Workflow management system
Non-production IceProd users	20	Number of users that use the centralized workflow management system outside of the core simulation production

Table 7: Computing and data management (WBS 2.3) performance parameters.

planned VM infrastructure upgrade. Our preferred vendor cannot give us an estimate when the hardware may be available. Other computing acquisition projects have seen lead times of up to 300 days for certain components. We are exploring alternatives, including different vendors and combining our VM infrastructure with that hosted by central campus IT. We are still waiting for a cost model from central campus IT to see whether moving our VM infrastructure is feasible.

WBS L3	Planned	Actual	Milestone
2.3.1	12/31/21	06/30/21	CY 2020 experimental data ingested into NERSC LTA
2.3.2	09/15/2021	TBD	Single sign-on (Keycloak) implemented
2.3.3	10/08/2021	TBD	VM infrastructure upgrade complete

Table 8: WBS 2.3 Computing and data management PY1 milestones.

Computing and Data Management Labor Assessment

The computing group has witnessed a decline in staffing with an increase of responsibilities. The computing operations team (WBS 2.3.1-3) has shrunk by 30% over the course of the last decade: 1 storage engineer, 1 help desk person, 1 sysadmin, and 1 network engineer. WIPAC mitigated the loss of the network engineer by transitioning to a model where UW-Madison campus IT manages the IceCube networks. At the same time, the overall responsibilities for the operations have increased, e.g. size of filesystems, number of users, and notably an increasing reliance on heterogeneous hardware systems. While operations continues to meet the key performance metrics, infrastructure improvement has slowed significantly and the risk of losing critical institutional knowledge has increased dramatically. Ultimately, modernizing systems to make use of contemporary computing technology (cloud, containers) is very slow given the competing demands on a shrinking team. Adding back support personnel, even of order 1 FTE, could result in a dramatic improvement in the ability of the M&O program to respond to the changing technology landscape.

There are currently no human effort and physical resources allocated within WBS 2.3 for the

Upgrade. At the current estimate of a 10% data rate increase, we expect that data transfer software will have no issue handling the increased load. Yet, the data warehouse, data processing resources, and simulation workflow will be impacted. We expect that there will also be an increase in the resource requirements for simulation and data processing.

An expected change within IceCube and the Upgrade is the transition to more machine learning based data analysis. This will require rethinking the data analysis CI currently deployed. The current dedicated CI is at least 5 years old and was purchased with a focus on mass data processing and simulation production. We are expecting (and already experiencing in some cases) an increasing demand for accelerated hardware (GPU and FPGAs) to accommodate ML model training and inference. The M&O 5 plan includes a dedicated hire in PY2 to support these needs. We are accelerating the schedule for hiring and will have begun this search in the early parts of the 2nd half of PY1.

WBS 2.4: Data Processing and Simulation Services

WBS L3	Date	Milestone
2.4.1	01/14/22	Offline filter requirements captured - IC86-2022 run
2.4.2	11/01/21	Datasets SnowStorm / ESTES completed

Table 9: WBS 2.4 Data processing and simulation PY1 milestones.

Key performance parameters for Computing and Data Management are tabulated in Table 10.

Performance Metric	Objective	Achieved	Description
L2 processing latency	2 weeks	8.5 days	80% quantile time from event in ice to L2 processed file in the data warehouse
Simulation Production Efficiency	90%	86%	Total useful time (completed jobs) divided by total computing time
Simulation Requests	60 days	110 days	90% quantile request to production

Table 10: Data processing and simulation (WBS 2.4) performance parameters.

Data Processing

Current offline data processing is running on the IceProd2 framework on opportunistic grid computing resources, distributed across the globe. The move required some coordination with the distributed infrastructure team to implement additional features needed to support this task.

The detector run for the IC86-2021 season began on May 27, 2021. Filtering and processing scripts where validated by technical leads from each physics working group with data recorded during the 24-hour test run using the new DAQ configuration and updated software stack. Observed differences with respect to the previous season are consistent with statistic fluctuations.

During previous years, an effort was done to clean up filters reconstructions and libraries no longer needed in offline reconstruction resulting in a 36% reduction of CPU utilization and a comparable reduction in memory requirements. Resources consumed for the offline production resulted in

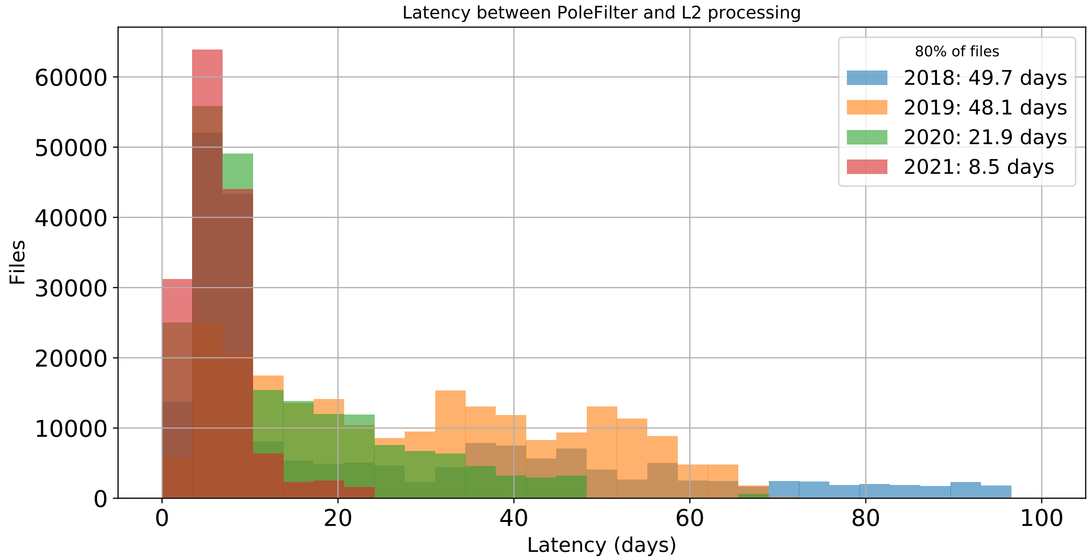

Figure 5: L2-processing latency distribution for the last four years. Minimum latency is determined by the weekly data validation process in the North.

approximate 480,000 CPU hours of processing time and consistent with prior estimates. We are currently reviewing existing filters and reconstructions with the aim of streamlining offline processing at Level 2 and Level 3.

Additional data reprocessing campaigns will be needed as further improvements in calibration and feature extraction are developed. The current refinements do not yield sufficient improvements to warrant the expense of roughly $1,000,000 in compute time and person-hours. We anticipate that future improvements in calibration resulting from the IceCube Upgrade will require additional reprocessing campaigns.

We recently established a new performance metric for Level-2 processing. We set an an objective to reduced the time from triggered events in ice to processed L2 file in the data warehouse for 80% of the files. A result of our new focus on this metric was that the latency of data at L2 was reduced from almost 50 days in 2018 to only 8.5 days in 2021 (see Figure 5).

Monte Carlo Simulation Production

The production of Monte Carlo simulations is based on the IC86-2020 detector configuration. This configuration is representative of pass previous trigger and filter configurations included in pass2. As with previous productions, direct generation of Level 2 background simulation data is used to reduce storage space requirements. The transition to the 2020 configuration was done in conjunction with a switch to a new combined simulation-reconstruction combined software suite.

New features in the simulation software include individually calibrated PMT waveforms, optimized event re-sampling for low-energy background simulation, and improved models of the optical properties of the ice. Direct photon propagation is currently done on dedicated GPU hardware at several IceCube Collaboration sites and through opportunistic grid computing. The number of such resources continues to grow along with further software optimizations for GPU utilization.

The simulation production team organizes periodic workshops to explore better and more efficient ways of meeting the simulation needs of the analyzers. This includes both software improvements as well as new strategies and providing the tools to generate targeted simulations optimized for individual analyses instead of a one-size-fits-all approach. New strategies have been developed for dynamically simulating of systematic uncertainties in our understanding of ice properties, hole-ice and DOM sensitivity and determining their impact on physics analyses.

Throughput has continually increased due to incorporation of an increasing number of dedicated and opportunistic resources and a number of code optimizations. New monitoring tools are currently being developed in order to keep track of efficiency and further optimizations. New procedures have been implemented for coordinating allocating resources and priorities for simulations produced by working groups as well as individuals. These efforts include performance metrics to reduce the time between a request by a group or individual and the completion of such request. We are currently far from reaching our objectives but are making progress in this regard.

Computing Resource Needs

light-gray	**CORSIKA**	**MuonGun**	**Diffuse**	**OscNext**	**IceTop**	**Total**
CPU (years)	30000	23	58	2112	1157	33350
GPU (years)	2400	95	680	184	0	3359
Storage (TB)	3330	10	10	60	200	3610

Table 11: Estimated resource requirements for the main Monte Carlo data sets needed for physics analyses. `CORSIKA` simulation assumes DOM-oversizing factor of 5.

Simulation production requirements are primarily dominated by background simulations with `CORSIKA` given that there is roughly a factor of 10^6 cosmic-ray induced muons triggering the detector for each neutrino event. Background simulations for the in-ice array require roughly 30k years of CPU time and about 2.4k years of GPU time to produce and filter. This is in addition to IceTop surface array simulations and signal simulation (including systematics). As an alternative to this amount of background simulation, we can also simulate final-state muons that can be weighted according to a parametrized flux calculated from `CORSIKA` simulations using the same approach of MUPAGE which was developed by the ANTARES Collaboration . These `MuonGun` simulations are significantly more efficient to produce, requiring about 6M CPU-hours and comparable GPU time to simulate in order to meet our goals. These simulations have to be validated against `CORSIKA`, but this requires a significantly smaller data set.

Key achievements include:

- improvements in hardware simulation including individually calibrated PMT waveforms, and improved models of the optical properties of the ice;
- addition of support for future detector hardware;
- optimization to improve efficiency and utilization of resources;
- new catalog of Monte Carlo datasets and simulation requests;
- improved monitoring of data processing and simulation production;

Data Processing and Simulation Services Labor Assessment

There are currently 2.4 FTEs assigned to WBS 2.4. There are no current plans to increase the number of FTEs working on Data Processing and Simulation Service though we anticipate an increase demand of labor from the extensions to the IceCube detector. Mitigation of risk of labor shortages due to this additional scope is being handled through promulgation of the simulation mass production middleware (IceProd) to permit individual users to profit from the scheduling and data provenance services provided by this software.

WBS 2.4.0 and 2.4.2 DIAZ-VELEZ, JUAN CARLOS (Lead) : Coordination of Offline Processing and Simulation Production efforts with analysis working groups. Oversees Offline Data Production. Evaluates shared resource needs for large-scale simulations and data processing for IceCube collaboration and coordinates with Physics Working Group Technical Leads and Computing and Data Management tea to evaluate computing needs and priorities for Monte Carlo production datasets. Maintains and optimizes workflow scripts, and provides support for Physics Working Groups to manage production datasets.

WBS 2.4.1 SNIHUR, ROBERT : Experimental data processing and reduction. Interface with collaboration working groups to deliver analysis-ready data. Manages day to day operations for data processing at North and coordinates with Working Group Technical Leads to validate data and processing scripts. Coordinates with Detector Operations team to validate detector runs.

WBS 2.4.1 and 2.4.2 EVANS, ERIC : Software development of automated data validation tools to detect potential problems involving software and/or human errors in data processing and simulations.

WBS 2.4.2 SOLDIN, DENNIS : Maintains and optimizes workflow scripts for simulations of the IceTop surface array and manages dataset submission and monitoring.

WBS 2.5: Software

WBS L3	Date	Milestone
2.5.1	06/30/2021	Summer 2021 software release
2.5.1	09/30/2021	Fall 2021 software release
2.5.1	12/17/2021	Winter 2021 software release
2.5.1	03/11/2022	Spring 2022 software release

Table 12: WBS 2.5 Software PY1 milestones.

Key performance parameters for Software are tabulated in Table 13.

The plan for this period was to generate two releases, however no releases were generated. In November 2020 the CD system was offline due to third-party feature deprecations, which broke the reporting system. Shortly after this, the software group initiated the transition, in planning for several years and a significant undertaking, from the subversion repository to GitHub, which further delayed the reactivation of the CD system. The repository transition, which took longer than anticipated, delayed the transition of subversion-based CI system as well.

Performance Metric	Objective	Description
Releases per year	4	Quarterly releases meeting minimal quality standards
Test coverage, minimum	66%	Fraction of lines of code executed in the test suite
CI min uptime	90%	Fraction of days all tests pass on all supported platforms
CD min uptime	50%	Fraction of days full-chain tests pass on single platform
Critical ticket max lifetime	1 month	At least 90% of critical tickets resolved within this timescale

Table 13: Physics software (WBS 2.5) performance metrics.

Both the CI and CD systems were brought online after the successful transition to GitHub, however the CD system reported consistent failures, indicating at least one commit over the nearly four month period of downtime, from late November 2020 through early March 2021, that affected physics distributions in an unknown way. This is what the CD system was designed to detect, however it was designed to be able to issue alerts over short timescales as opposed to narrowing in on an offending commit buried in several hundred commits over several months.This is still an on-going investigation where releases are suspended until the commit is identified. In order to aid in the investigation, the CD system needed to be refactored to run in a distributed environment without access to a database.

The refactor was completed in September 2021 where a winter release in December is highly anticipated. There were no critical tickets whose lifetime extended beyond one month. The test coverage remains at 50%, below our stated goal of 66%. The CD system is offline pending the investigation. The CI uptime for this time period is estimated to be around 33%, well below the goal of 90%.

Software Labor Assessment

M&O harvests a significant amount of labor under 2.5 from resources, mostly graduate students and postdocs, contributed in-kind by IceCube collaborating institutions. These are coordinated through the semi-annual statements of work collected as part of the IceCube resource coordination process. This includes work to maintain core software infrastructure, development of new reconstruction and analysis software frameworks, and support for simulation and analysis of the upcoming Upgrade extension.

Despite the large pool of contributed effort, maintenance of the IceCube software systems does require the daily attention of a dedicated, professional team of software engineers to handle the manifold aspects of rigorous software maintenance and maintenance of the development and build environments. The M&O revised budget and current 5-year plan includes support for an additional simulation programmer in the 3rd year of the program. Plans for this hire have been accelerated. A search is expected to begin before the end of PY1.

WBS 2.6: Calibration

We continue to refine measurements of the optical properties of the South Pole ice that comprises the majority of our detector, as well as the IceCube DOM response to photons. Precise modelling of both is fundamental to converting detector observables into physical measurements such as neutrino direction, energy, and absolute flux.

Ice characterization

After the release of a new bulk ice model, called SpiceBFRv2[1], in March 2021 the focus has shifted towards improving tilt modeling. Tilt describes the undulation of layers of constant optical properties over the face of the detector and is e.g. required for precise cascade energy reconstruction. To-date tilt modeling has been based solely on stratigraphy measurements performed by the dust logger during the deployment of the array. We have now been able to show that it can independently be deduced from LED calibration data. In addition to confirming the magnitude of tilt along its primary direction orthogonal to the flow, we were able to discover a tilt component along the flow. This result was cross-checked with data from ground penetrating radar in particular from the PolarGap campaign.

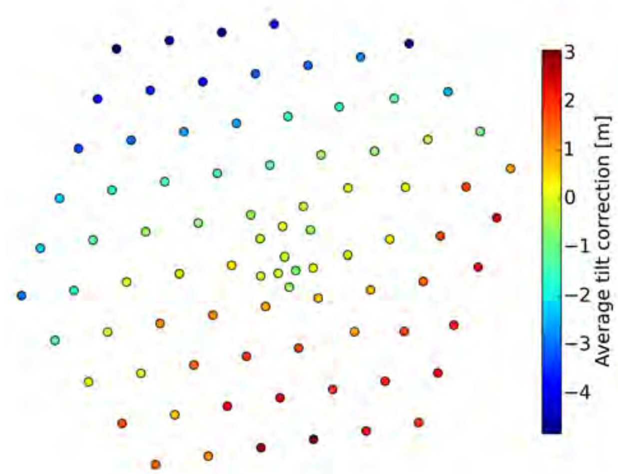

Figure 6: Per-string average corrections to the default tilt model as fitted to flasher data. A near constant slope in the direction of flow is observed.

Traditionally ice fits requiring computationally intensive simulations for each tested parameter combination. A recently concluded study explored the possibility to use machine learning techniques to train a neural network to predict the outcome of arbitrary parameter combinations based on a sparse set of input simulations. This technique may in the future result in significant speed-ups in determining ice properties.

DOM characterization

The uncertainty on the absolute detection efficiency of our DOMs is a systematic considered in most analyses. A new iteration of an established study employing minimum ionizing muons as standard sources of known light emission is currently being finalized. It will update the recommendation to a new ice model and reduce the uncertainty range that has to be considered.

Knowledge of the DOM positions in the ice is important for the event reconstruction. The baseline assumption is that their horizontal coordinates are the same as those of the drilled hole at the surface. It is though known that the hole deviates from the straight vertical line by up to a few m laterally. A new attempt to determine individual DOM positions using a large sample of muon

[1] describing the ice anisotropy effect through the cumulative light deflection caused by the birefringent microstructure of the glacial ice and yielding near perfect data-MC agreement for previously hard to match variables

tracks is being made and is showing promising first results. A continued effort is needed to include a larger number of DOMs and to validate the results.

Upgrade related activities

The IceCube Upgrade will further boost our ice understanding and also pose unique challenges as currently subdominant effects, such as the precise shape of the scattering function, become relevant. In preparation for the IceCube Upgrade we are facilitating discussion of and simulation for the calibration devices (i.e. Pencil Beam, POCAM, camera systems, LED flashers, dust-logger). The past months saw a number of discussions on photomultiplier properties as well as a simulation study identifying observables to distinguish different ice anisotropy scenarios based on Pencil Beam data.

Staffing Matrix by WBS L3
Management and Operations of the IceCube Neutrino Observatory 2021-2026
University of Wisconsin - Madison

WBS Level 3	Institution	Labor Category	Names	PY1-PY5 Planned Tasks	PY1 Q1-Q2 Actual Tasks	YEAR1 FTE PLANNED	YEAR1 FTE Q1-Q2 ACTUAL	Notes
2.2.0 Detector Operations & Maintenance	**UW**	Scientist	**KELLEY, JOHN**	Detector Maintenance and Operations Manager	Same as planned	0.50	0.50	
2.2.0 Detector Operations & Maintenance Total						**0.50**	**0.50**	
2.2.1 Run Coordination	**UW**	System Administrator	**AUER, RALF**	Winterover coordinator, hiring and training of winterovers	Same as planned	0.20	0.20	
		Winter Over	**UW Winter Overs**	Operate Detector (Winterovers)	Same as planned	1.50	1.50	
2.2.1 Run Coordination Total						**1.70**	**1.70**	
2.2.2 Data Acquisition	**UW**	Scientist	**KELLEY, JOHN**	DOM software: DOR device driver, DOMHub scripts, DOMCal	Same as planned	0.25	0.25	
		Software Engineer	**BENDFELT, TIMOTHY**	IceCube DAQ: StringHub and domapp; Upgrade integration	Same as planned	0.75	0.75	
			GLOWACKI, DAVID	IceCube DAQ: command-and-control server, testing infrastructure	Same as planned	0.50	0.35	Retired at the end of July 2021
				IceCube DAQ: trigger and event builder	Same as planned	0.50	0.35	
	PSU	Scientist	**ANDERSON, TYLER**	Firmware development and support for DOMHub upgrade	-	0.00	0.00	Scheduled for PY3
		Postdoctoral Scientist	**FIENBERG, AARON**	DOM firmware development and support	Same as planned	0.10	0.00	
	LBNL	Engineer	**STEZELBERGER, THORSTEN**	Maintain DAQ Hardware (Hubs, DOR, Clocks, GPS)	Same as planned	0.13	0.13	
2.2.2 Data Acquisition Total						**2.23**	**1.83**	
2.2.3 Online Filter (Pnf)	**UMD**	Scientist	**BLAUFUSS, ERIK**	Maintain online filters	Same as planned	0.20	0.20	
		Software Engineer	**SCHMIDT, TORSTEN**	Maintain and develop PnF software, support operations to respond to and debug unexpected errors	Same as planned	0.25	0.25	
2.2.3 Online Filter (Pnf) Total						**0.45**	**0.45**	
2.2.4 Detector Monitoring	**UW**	Scientist	**KAUER, MATTHEW**	Training and coordinating monitoring shifters	Same as planned	0.30	0.30	
		Software Engineer	**BRAUN, JAMES**	I3MS Iridium messaging system software	Same as planned	0.43	0.43	
			BURRESON, COLIN	IceCube Live monitoring system: web interface, databases	Same as planned	0.90	0.90	
				Supernova alert interface, DAQ monitoring, and visualization in IceCube Live	Same as planned	0.10	0.10	
			FRERE, MICHAEL	IceCube Live lead developer	Same as planned	0.75	0.75	
	UD	Scientist	**TILAV, SERAP**	IceTop data monitoring	Same as planned	0.30	0.30	
2.2.4 Detector Monitoring Total						**2.78**	**2.78**	
2.2.5 Experiment Control	**UW**	Software Engineer	**BRAUN, JAMES**	IceCube LiveControl experiment control software: alerts and component communication	Same as planned	0.50	0.50	
			FRERE, MICHAEL	IceCube LiveControl experiment control software: operator interface	Same as planned	0.25	0.25	
2.2.5 Experiment Control Total						**0.75**	**0.75**	
2.2.6 Surface Detector Operations	**UW**	Scientist	**KAUER, MATTHEW**	Test and commission experimental apparatus for restoring IceTop detector efficiency	Same as planned	0.20	0.20	
	UD	Scientist	**TILAV, SERAP**	Coordinate IceTop Operations	Same as planned	0.25	0.25	
2.2.6 Surface Detector Operations Total						**0.45**	**0.45**	
2.2.7 Supernova System	**UW**	Software Engineer	**BENDFELT, TIMOTHY**	IceCube DAQ: supernova interface, hitspooling	Same as planned	0.25	0.25	
2.2.7 Supernova System Total						**0.25**	**0.25**	
2.2.8 Real-time Alerts	**UMD**	Scientist	**BLAUFUSS, ERIK**	Online realtime alert system implementation, realtime operations lead	Same as planned	0.20	0.20	
2.2.8 Real-time Alerts Total						**0.20**	**0.20**	
2.2.9 SPS/SPTS	**UW**	System Administrator	**AUER, RALF**	Maintain South Pole computing H/W infrastructure and operating systems	Same as planned	0.23	0.23	
				Maintain South Pole Test System computing H/W Infrastructure and operating systems	Same as planned	0.10	0.10	
	MSU	Software Engineer	**NG, CHRISTOPHER**	Northern Test System integration and maintenance		0.50	0.00	NTS operations to date have required less effort than original planned
2.2.9 SPS/SPTS Total						**0.83**	**0.33**	
2.3.0 Computing & Data Management	**UW**	Manager	**RIEDEL, BENEDIKT**	Computing Infrastructure Manager	Same as planned	0.75	0.73	CSSI Elements co-funded
2.3.0 Computing & Data Management Total						**0.75**	**0.73**	
2.3.1 Data Storage & Transfer	**UW**	Software Engineer	**MEADE, PATRICK**	Operate Data transfer from S. Pole to UW Data Warehouse and archive services at S. Pole	Same as planned	0.50	0.50	
		System Administrator	**BARNET, STEVE**	Maintain and Operate Data Storage Infrastructure	Same as planned	0.30	0.30	
			BELLINGER, JAMES	Long term preservation and archive services, data curation	Same as planned	1.00	1.00	
			BRIK, VLADIMIR	Maintain storage system needed for simulation production	Same as planned	0.20	0.20	
2.3.1 Data Storage & Transfer Total						**2.00**	**2.00**	
2.3.2 Core Data Center Infrastructure	**UW**	System Administrator	**BARNET, STEVE**	Operations and cybersecurity manager	Same as planned	0.70	0.70	
			BRIK, VLADIMIR	Maintain Core Data Center Infrastructure Systems	Same as planned	0.10	0.10	
			MAYER, DAVID	IceCube Web Development	Same as planned	0.00	0.00	Was not funded
			SHEPERD, ALEC	Maintain Core Data Center Infrastructure Systems	Same as planned	0.25	0.25	
				Maintain and operate Virtual Machines deployment infrastrucutre	Same as planned	0.50	0.50	
2.3.2 Core Data Center Infrastructure Total						**1.55**	**1.55**	
2.3.3 Central Computing Resources	**UW**	System Administrator	**BRIK, VLADIMIR**	Maintain High Performance Computing services.	Same as planned	0.10	0.10	
			SHEPERD, ALEC	Maintain Central Computing Infrastructure Systems	Same as planned	0.25	0.25	
			COMERFORD D. / NUTTING K.	End-user support for common collaboration services	Same as planned	0.45	0.23	3-month recruitment
2.3.3 Central Computing Resources Total						**0.80**	**0.58**	
2.3.4 Distributed Computing Resources	**UW**	Software Engineer	**WORKFLOW PROGRAMMER**	Expand distributed resource pool and adjust workflow for new resources	-	0.00	0.00	Was not funded
		System Administrator	**BRIK, VLADIMIR**	Maintain distributed high-throughput cluster	Same as planned	0.60	0.60	
			SCHULTZ, DAVID	Core distributed software maintenance	Same as planned	0.50	0.50	
				Maintain workflow management system	Same as planned	0.40	0.40	
				Manage Production Software Team	Same as planned	0.10	0.07	CSSI Elements co-funded
			EVANS, ERIC	Core software maintenance	Same as planned	0.50	0.37	CSSI Elements co-funded
	MSU	Postdoctoral Scientist	**MSU PO**	Simulation production site manager at MSU	-	0.00	0.00	Starts in PY3
			HALLIDAY, ROBERT	Simulation production site manager at MSU	-	0.00	0.25	Tasks taken over from C. Ng during this period
2.3.4 Distributed Computing Resources Total						**2.10**	**2.19**	

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2.4.0 Data Processing and Simulation Services	**UW**	Data Scientist	**DIAZ-VELEZ, JUAN CARLOS**	Coordination of Offline Processing and Simulation Production efforts with analysis working groups	Same as planned	0.25	0.25	
2.4.0 Data Processing and Simulation Services Total						**0.25**	**0.25**	
2.4.1 Offline Data Production	**UW**	System Administrator	**EVANS, ERIC**	Data validation tool development	Same as planned	0.10	0.10	
		Data Scientist	**SNIHUR, ROBERT**	Experimental data processing and reduction. Interface with collaboration working groups to deliver analysis-ready data	Same as planned	1.00	1.00	
2.4.1 Offline Data Production Total						**1.10**	**1.10**	
2.4.2 Simulation Production	**UW**	System Administrator	**EVANS, ERIC**	Simulation production monitoring and validation	Same as planned	0.40	0.40	
		Data Scientist	**DIAZ-VELEZ, JUAN CARLOS**	Manage Centralized Simulation Production. Maintain, test and update physics aspects of the atmospheric muon and neutrino simulation	Same as planned	0.40	0.40	
	UD	Postdoctoral Scientist	**SOLDIN, DENNIS**	IceCube/IceTop simulation production	Same as planned	0.25	0.25	
2.4.2 Simulation Production Total						**1.05**	**1.05**	
2.5.0 Software	**UMD**	Software Engineer	**OLIVAS, ALEX**	IceCube Software Coordinator	Same as planned	0.75	0.75	
				Core software maintenance, including the framework and i/o project	Same as planned	0.15	0.15	
2.5.0 Software Total						**0.90**	**0.90**	
2.5.1 Core Software	**UW**	Software Engineer	**OFFLINE SUPPORT PROGRAMMER**	Core support including framework, data I/O, waveforms tools	Same as planned	0.00	0.00	Was not funded
	UMD	Scientist	**BLAUFUSS, ERIK**	Filter requests, bandwidth, TFT Board Member	Same as planned	0.35	0.35	
2.5.1 Core Software Total						**0.35**	**0.35**	
2.5.2 Simulation Software	**UW**	Scientist	**CHIRKIN, DMITRY**	Maintain photon propagation project	Same as planned	0.10	0.10	
			HOSHINA, KOTOYO	Support for neutrino simulations and earth model projects	Same as planned	0.33	0.33	
		Software Engineer	**SIMULATION PROGRAMMER (UPGRAD**	PMT, digitization (i.e. DOM MB) simulation, trigger and waveform support	-	0.00	0.00	Was not funded
			GPU PROGRAMMER	GPGPU and concurrency support for all modules that can benefit from concurrent hardware	-	0.00	0.00	Starts in PY2
		Data Scientist	**DIAZ-VELEZ, JUAN CARLOS**	Simulation software programs coordinator	Same as planned	0.25	0.25	
			MEAGHER, KEVIN	Triggered CORSIKA maintenance and development	Same as planned	0.75	0.75	
2.5.2 Simulation Software Total						**1.43**	**1.43**	
2.5.3 Reconstruction	**UW**	Software Engineer	**RECONSTRUCTION SUPPORT PROGRA**	Reconstruction framework support including resource optimizations	-	0.00	0.00	Was not funded
		Data Scientist	**MEAGHER, KEVIN**	Reconstruction software programs coordinator	Same as planned	0.25	0.25	
2.5.3 Reconstruction Total						**0.25**	**0.25**	
2.5.4 Science Support Tools	**UW**	Software Engineer	**VISUALIZATION PROGRAMMER**	Maintenance of IceCube's visualization project	-	0.00	0.00	Was not funded
2.5.4 Science Support Tools Total						**0.00**	**0.00**	
2.5.5 Software Development Infrastructure	**UMD**	Software Engineer	**LADIEU, DON**	Maintenance of DevOps systems, e.g. build, test coverage, CI/CD, VCS, and workflow policy	Same as planned	0.50	0.50	
2.5.5 Software Development Infrastructure Total						**0.50**	**0.50**	
Grand Total						**23.17**	**22.11**	

IceCube M&O MoU SOW Summary v30.0 2021.09
Authors Contribution

v 30.0 September 2021		Authors Head Count				IceCube Authors: M&O Responsibilities (FTE)						
Institution	**Institutional Lead**	**Ph.D. Authors**	Faculty	Scientists / Post Docs	Ph.D. Students	WBS 2.1 Program Management	WBS 2.2 Detector Operations & Maintenance	WBS 2.3 Computing & Data Management	WBS 2.4 Data Processing & Simulation	WBS 2.5 Software	WBS 2.6 Calibration	**Total**
University of Alabama*	**Dawn Williams**	**3**	(2	1	3)	0.50	0.10	0.00	0.00	0.10	0.35	**1.05**
University of Alaska	**Katherine Rawlins**	**1**	(1	0	0)		0.25			0.20		**0.45**
Clark Atlanta	**George Japaridze**	**1**	(1	0	0)	0.00	0.02	0.00	0.00	0.00	0.00	**0.02**
Drexel University	**Naoko Kurahashi Neilson**	**1**	(1	0	4)	0.20	0.35	0.00	0.25	0.00	0.00	**0.80**
Georgia Tech	**Ignacio Taboada**	**1**	(1	0	3)	0.35	0.25	0.00	0.00	0.10	0.00	**0.70**
Harvard University	**Carlos A. Argüelles**	**1**	(1	0	1)	0.25	0.00	0.00	0.00	0.30	0.00	**0.55**
LBNL*	**Spencer Klein**	**2**	(1	1	1)	0.05	0.24	1.08	0.00	0.10	0.00	**1.47**
Loyola University Chicago	**Rasha Abbasi**	**1**	(1	0	0)	0.10	0.05	0.00	0.00	0.00	0.00	**0.15**
Marquette University	**Karen Andeen**	**2**	(1	1	0)	0.20	0.65	0.00	0.00	0.00	0.00	**0.85**
Massachusetts Institute of Technology	**Janet Conrad**	**2**	(1	1	2)	0.10	0.00	0.00	0.20	0.50	0.00	**0.80**
Mercer University	**Frank McNally**	**1**	(1	0	0)	0.15	0.00	0.00	0.00	0.10	0.00	**0.25**
Michigan State University*	**Tyce DeYoung**	**12**	(6	6	12)	0.72	0.37	0.40	0.20	0.85	0.20	**2.74**
Ohio State University	**James Beatty**	**3**	(2	1	1)	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Pennsylvania State University*	**Doug Cowen**	**6**	(2	4	3)	0.30	0.46	0.00	0.00	0.10	0.00	**0.86**
South Dakota School of Mines & Technology	**Xinhua Bai**	**1**	(1	0	1)	0.73	0.07	0.00	0.20	1.00	0.00	**2.00**
Southern University	**Ali Fazely**	**2**	(1	1	0)		0.02	0.30		0.60		**0.92**
Stony Brook University	**Joanna Kiryluk**	**2**	(1	1	2)	0.15	0.10	0.00	0.10	0.45	0.00	**0.80**
University of California, Berkeley	**Buford Price**	**1**	(1	0	0)	0.10						**0.10**
University of California, Irvine	**Steve Barwick**	**1**	(1	0	1)		0.02					**0.02**
University of Delaware*	**David Seckel**	**8**	(5	3	5)	0.45	1.45		0.80	0.40	0.05	**3.15**
University of Kansas	**Dave Besson**	**1**	(1	0	2)						0.60	**0.60**
University of Maryland*	**Greg Sullivan**	**6**	(3	3	3)	1.15	1.76	0.00	0.15	1.55	0.00	**4.61**
University of Rochester	**Segev BenZvi**	**1**	(1	0	1)	0.25	0.30	0.00	0.00	0.10	0.00	**0.65**
University of Texas at Arlington	**Benjamin Jones**	**1**	(1	0	2)	0.20	0.00	0.00	0.00	0.35	0.85	**1.40**
University of Utah	**Carsten Rott**	**1**	(1	0	0)	0.15	0.03	0.00	0.00	0.00	0.00	**0.18**
University of Wisconsin, River Falls	**Suruj Seunarine**	**2**	(2	0	0)	0.00	0.00	0.00	0.00	0.10	0.20	**0.30**
University of Wisconsin, Madison	**Albrecht Karle**	**27**	(5	22	16)	2.23	3.45	0.00	2.10	2.55	1.75	**12.08**
Yale University	**Reina Maruyama**	**1**	(1	0	0)		0.05			0.05		**0.10**
U.S. Institutions Subtotal		**92**	**(47**	**45**	**63)**	**8.33**	**9.98**	**1.78**	**4.00**	**9.50**	**4.00**	**37.59**
DESY-Zeuthen	**Marek Kowalski**	**9**	(6	3	10)	0.95	0.82	1.35	0.00	0.20	0.00	**3.32**
Karlsruhe Institute of Technology	**Andreas Haungs**	**12**	(2	10	6)	0.40	2.10	0.15	0.55	0.45	0.00	**3.65**
RWTH Aachen	**Christopher Wiebusch**	**2**	(1	1	10)	0.62	0.42	0.05	0.50	0.60	0.30	**2.49**
Universität Dortmund	**Wolfgang Rhode**	**2**	(1	1	5)	0.00	1.03	0.00	0.30	0.50	0.00	**1.83**
Universität Mainz	**Lutz Köpke**	**2**	(1	1	7)	0.50	0.65	0.00	0.00	0.20	0.00	**1.35**
University of Münster	**Alexander Kappes**	**2**	(1	1	6)	0.50	0.00	0.00	0.00	0.00	0.00	**0.50**
Universität Wuppertal	**Klaus Helbing**	**2**	(1	1	5)		0.93			0.40	0.20	**1.53**
Humboldt Universität Berlin	**Marek Kowalski**	**1**	(1	0	1)	0.00	0.05	0.00	0.00	0.00	0.00	**0.05**
Universität Bochum	**Julia Tjus**	**3**	(2	1	1)	0.50	0.30	0.00	0.00	0.10	0.00	**0.90**
Technische Universität München	**Elisa Resconi**	**4**	(1	3	8)	0.00	0.05	0.00	0.70	0.40	0.20	**1.35**
Universite Libre de Bruxelles	**J. A. Aguilar Sanchez**	**4**	(3	1	2)	1.15	0.67	0.00	0.00	0.00	0.00	**1.82**
University of Gent	**Dirk Ryckbosch**	**1**	(1	0	2)	0.05	0.03	0.00	0.55	0.05	0.00	**0.68**
Vrije Universiteit Brussel	**Nick van Eijndhoven**	**2**	(2	0	4)	1.00	0.06	0.00	0.10	0.35	0.00	**1.51**
Stockholm University	**Klas Hultqvist**	**3**	(3	0	2)	0.35	0.11	0.00	0.00	0.40	0.80	**1.66**
Uppsala University	**Olga Botner**	**5**	(4	1	1)	0.70	0.58	0.00	0.00	0.00	0.15	**1.43**
University of Alberta	**Juan Pablo Yáñez**	**3**	(2	1	3)	0.00	0.10	0.10	0.45	0.00	0.85	**1.50**
University of Oxford	**Subir Sarkar**	**1**	(1	0	0)	0.10	0.00	0.00	0.00	0.00	0.00	**0.10**
University of Canterbury	**Jenni Adams**	**1**	(1	0	1)	0.05	0.08	0.00	0.00	0.00	0.00	**0.13**
University of Adelaide	**Gary Hill**	**1**	(1	0	1)					0.90		**0.90**
Chiba University	**Shigeru Yoshida**	**6**	(3	3	0)	0.25	0.15	0.00	0.20	0.90	0.00	**1.50**
Université de Genève	**Teresa Montaruli**	**1**	(1	0	1)	0.35	0.05	0.00	0.70	0.00	0.00	**1.10**
Universität Erlangen-Nürnberg	**Uli Katz**	**2**	(1	1	4)	0.20	0.00	0.00	0.00	0.90	0.00	**1.10**
Niels Bohr Institute	**Jason Koskinen**	**4**	(2	2	1)	0.10	0.30	0.00	0.40	0.00	0.10	**0.90**
Sungkyunkwan University	**Carsten Rott**	**3**	(1	2	4)	0.00	0.03	0.00	0.00	0.00	0.80	**0.83**
Queen's University	**Nahee Park**	**1**	(1	0	0)	0.00	0.00	0.00	0.00	0.10	0.00	**0.10**
University of Padova	**Elisa Bernardini**	**1**	(1	0	1)	0.47	0.55	0.00	0.00	0.00	0.00	**1.02**
Non-U.S. Institutions Subtotal		**78**	**(45**	**33**	**86)**	**8.24**	**9.06**	**1.65**	**4.45**	**6.45**	**3.40**	**33.25**
Total U.S. & Non-U.S.		**170**	**(92**	**78**	**149)**	**16.57**	**19.04**	**3.43**	**8.45**	**15.95**	**7.40**	**70.84**

Changes since last official version are colored red

*** IceCube M&O Subawardee Institutions**