IceCube

Neutrino Observatory

Management & Operations Plan
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Revision 1.0

IceCube

MANAGEMENT & OPERATIONS PLAN

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Revision History

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List of Acronyms and Terms

AAGS	NSF Antarctic Astrophysics and Geospace Sciences program
ADC	Analog-to-digital converter chip
AMANDA	Antarctic Muon and Neutrino Detection Array
ATWD	Analog transient wave digitizer
Condor	UW–Madison workload management system for compute-intensive jobs
CF	Common Fund
Channel working group	The refined data streams are first sent to channel working groups for initial analysis
CTSC	Center for Trustworthy Scientific Cyberinfrastructure
DACS	NSF Division of Acquisition and Cooperative Support
DAQ	Data acquisition system
DOM	Digital optical module
DOMCal	DOM in situ self-calibration system
DOMHub	Surface cable terminus with readout electronics and low-level data acquisition function
DOR	DOM readout electronics PCI card
DSI	Data Systems International
E&O	Education and outreach
EMI	Electromagnetic interference
GPU	Graphical processing units
GridFTP	An extension of the standard file transfer protocol (FTP) for use with Grid computing
HPC	High-performance computing
HPSS	High performance storage system
HSM	Hierarchical storage management
HTC	High-throughput computing
I3MS	IceCube messaging system
ICB	IceCube Collaboration Board, the entity that guides and governs the scientific activities
IceCube Live	The system that integrates control of all of the detector's critical subsystems
IceProd	IceCube simulation production custom-made software
IceSim	IceCube simulation software package tools
IceTray	IceCube core analysis software framework is part of the IceCube core software library
ICL	IceCube Laboratory (South Pole)
IOFG	International Oversight and Finance Group

ITS	IceCube transport system
JADE	Java archival and data exchange
LED	Light emitting diode
M&O	Management and operations
M&OP	Management & Operations Plan
MoU	Memorandum of Understanding, between UW–Madison and all collaborating institutions
MPS	NSF Directorate for Mathematical & Physical Sciences
MREFC	Major Research Equipment & Facilities Construction
MSPS	Megasamples per second
OPP	NSF Office of Polar Programs
OSG	Open Science Grid
PA	NSF Particle Astrophysics Program
PCTS	Physical Sciences Laboratory cable test system
PHY	NSF Division of Physics
Physics working group	Physics working groups perform high-level analysis and develop specific analysis tools
PLR	NSF Division of Polar Programs
PMT	Photomultiplier tube
PnF	Processing and filtering
SAC	Science Advisory Committee
SCAP	IceCube Software & Computing Advisory Panel
Science DMZ	A secure computer subnetwork designed for high-volume data transfers
SIP	Support Information Package
SNEWS	Supernova Early Warning System network
SNDAQ	Supernova data acquisition
SPS	South Pole System (at the South Pole)
SPTR	IceCube dedicated high-capacity South Pole TDRS relay system.
SPTS	South Pole Test System (at UW Madison)
TDRS	A Tracking and Data Relay Satellite is type of a satellite that forms part of the TDRSS
TDRSS	The Tracking and Data Relay Satellite System is a network of communications satellites
TFT Board	Trigger Filter and Transmission Board
TS	Test statistic
UPS	Uninterruptible power supply
USAP	United States Antarctic Program
UW	University of Wisconsin–Madison, host institution of the IceCube

	Collaboration
VCRGE	Office of the Vice Chancellor for Research and Graduate Education, at UW–Madison
WBS	Work breakdown structure
WIMPs	Weakly interacting massive dark matter particles
WIPAC	Wisconsin IceCube Particle Astrophysics Center (former IRC)
XSEDE	Extreme Science and Engineering Discovery Environment

1 Preface

In the first five years of full operation (May 2011 to present), the IceCube Neutrino Observatory has demonstrated its enormous science potential. In 2013, the groundbreaking discovery of an astrophysical neutrino flux was announced, which fundamentally changed the way the observatory was viewed both externally and internally. IceCube has advanced beyond discovery, and expectations have risen: interest in the observatory's data products is rapidly expanding in this new era of multimessenger astronomy. IceCube is responding to these new demands on both technical and social fronts. New institutions are joining the IceCube Collaboration, either in the capacity of associate members to work on specific analysis topics or as full members interested in contributing resources to the facility to exploit a broader range of science. New MoUs are being produced between IceCube and other astrophysical observatories to exchange archival and real-time data. The M&O organization and the Collaboration together have made enormous advances in better understanding how the detector responds and how to better use the detector for both existing and novel scientific aims.

Realization of our scientific vision now more than ever requires the attention of a highly technically competent and dedicated team to oversee the reliable operation of the IceCube Neutrino Observatory facility. Our approach to the planning and execution of IceCube management and operations is based on nearly a decade of experience, over which time the combined teamwork of the centralized M&O organization WIPAC and the IceCube Collaboration has streamlined the process. Tasks range from detector hardware and firmware maintenance to characterization of the ice optics, from production of massive simulated data sets to organizing outreach activities and communicating scientific results to the press. Each aspect of the M&O is proven through extensive use to maximize the facility's scientific and educational potential.

This Management & Operations Plan (M&OP) describes management, roles and responsibilities, lines of authority and communications, critical or significant project activities, and performance objectives and milestones. The M&OP identifies the budget allocation of the various funding sources, including the direct NSF funding provided through this award and the Common Fund.

Section 2 reviews the scientific vision and objectives that IceCube is designed to achieve and provides a timeline of key milestones. Section 3, Technical Approach, specifies the M&O requirements necessary for IceCube to achieve its design objectives. Section 4, Management Approach, identifies the tasks required to meet the technical requirements and explains how we will perform them. Section 5, Cost Overview, provides a breakdown of costs by funding source.

2 Achievement of Scientific Vision

Although IceCube was conceptually designed as a discovery instrument, with time, its main scientific goals have attained a sharper focus and the IceCube project is as relevant as ever. At the same time, the detector has already achieved a performance that is significantly superior to what had been anticipated, with a neutrino collection area that is larger by a factor of 2 to 3, depending on the energy, and an angular resolution of muon tracks that is less than 0.5 degrees. We have implemented new methods for energy measurement that is on the order of 10% for particle showers.

2.1 Cosmic Neutrinos and the Impact of IceCube Results

IceCube is sensitive to neutrinos with energies above a threshold of approximately 0.1 TeV. Using the Earth as a filter, a flux of neutrinos has been identified that is consistent with atmospheric origin; see Figure 2.1-1. However, in seven years of data, a clear excess of events is observed at energies beyond 100 TeV[1], which cannot be accommodated by the atmospheric flux. Its statistical significance is 6 sigma.

[1] M. G. Aartsen et al. (IceCube) 2015 Phys. Rev. Lett. 115 081102 [1507.04005]; C. Weaver 2014 Spring APS Meeting, Savannah, Georgia, USA; S. Schoenen and L. Rädel 2015 Proceedings of ICRC2015 1079 642.

While IceCube only measures the energy deposited by the secondary muon inside the detector, Standard Model physics allows one to infer the energy spectrum of the parent neutrinos. For the highest energy event shown in Figure 2.1-1, the most likely energy of the parent neutrino is almost 10 PeV. The muon energy loss measured in the detector is 2.6±0.3 PeV. The cosmic flux is well described by a power law with a spectral index of 2.13±0.13 and a normalization at 100 TeV neutrino energy of $(0.90^{+0.30}_{-0.26}) \times 10^{-18}$ $GeV^{-1}cm^{-2}sr^{-1}s^{-1}$. The neutrinos contributing to this fit cover the energy range of 191 TeV to 8.3 PeV. However, we have also identified, in analyses that extend to lower energies, an excess of neutrino events from sources in the 30-100 TeV energy range—a neutrino flux well above the extrapolation to lower energies of the throughgoing cosmic muon neutrino flux measurement[2]. The conclusion to be drawn is that the astrophysical flux measured by IceCube is not featureless and cannot be described by a single spectral index.

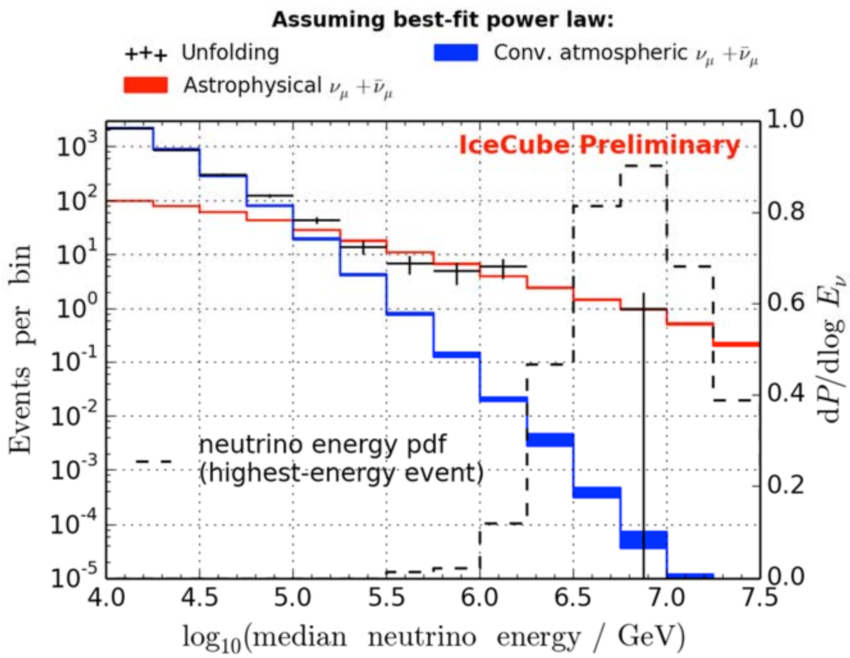


Figure 2.1-1: *Spectrum of secondary muons initiated by muon neutrinos that have traversed the Earth, i.e., with zenith angle less than 5 degrees above the horizon, as a function of the energy they deposit inside the detector. For each reconstructed muon energy, the median neutrino energy is calculated assuming the best-fit spectrum. The colored bands (blue/red) show the expectation for the conventional and astrophysical contributions. The black crosses show the data. Additionally, the neutrino energy probability density function for the highest energy event assuming the best-fit spectrum is shown (dashed line).*

The alternative method to isolate cosmic neutrinos from background is to select neutrinos originating inside the detector, their well-measured energy allowing a clear separation between neutrinos of atmospheric origin and those of cosmic origin. The geometry of the veto and active signal regions was optimized to reduce the background of atmospheric muons and neutrinos to a handful of events per year while keeping 98% of the cosmic signal. The four-year data set presently analyzed contains a total of 54 neutrino events with deposited energies ranging from 30 to 2000 TeV; see Figure 2.1-2[3]. A purely atmospheric explanation can be excluded at 7 sigma. In the fourth year, muon tracks were found that

[2] M. Aartsen et al. (IceCube Collaboration) 2015 [1502.03376]; M. Aartsen et al. (IceCube Collaboration) 2014 [1410.1749]

[3] M. Aartsen et al. (IceCube Collaboration) 2014 Phys.Rev.Lett. 113 101101 [1405.5303]

deposited ~500 TeV energy inside the detector, produced by PeV-energy parent neutrinos. One of them reconstructs through IceTop, IceCube's surface array, with no evidence for an air shower.

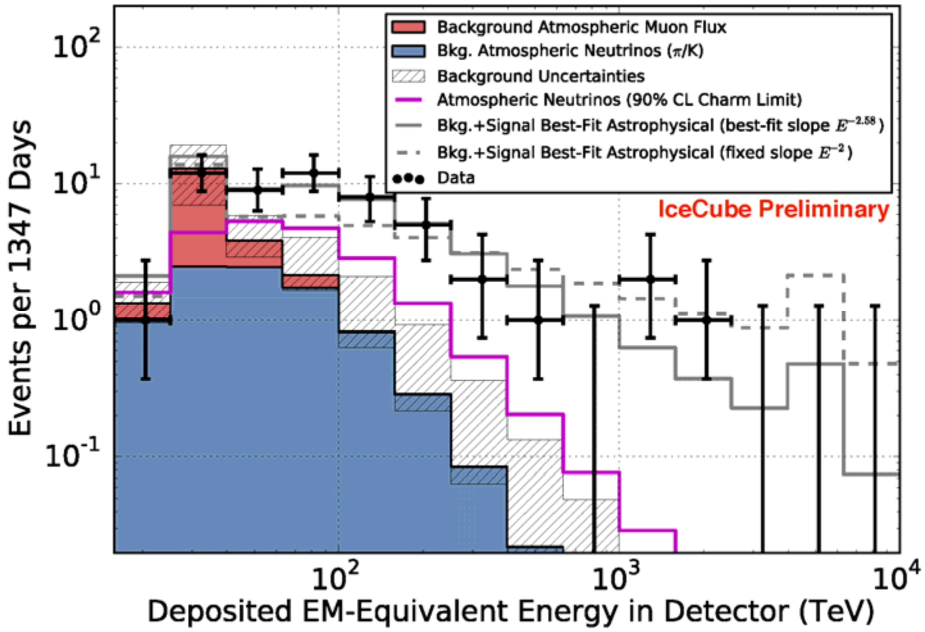


Figure 2.1-2: *Deposited energies of muons observed in four years of data. The hashed region shows uncertainties on the sum of all backgrounds. The atmospheric muon flux (red) and its uncertainty is computed from simulation to overcome statistical limitations in our background measurement and scaled to match the total measured background rate. The atmospheric neutrino flux is derived from previous measurements of both the pi, K and charm components of the atmospheric spectrum. Also shown are two power-law fits to the spectrum.*

The flavor composition of the flux, after corrections for the acceptances of the detector to the different flavors, is consistent with a flux equally shared between the different flavors as anticipated for a flux originating in cosmic sources. It is also consistent with the flux of muon neutrinos penetrating the Earth shown in Figure 2.1-1 at energies above 100 TeV.

Interestingly, a variety of analyses that have pushed the threshold to lower energies suggest that the cosmic neutrino flux dominates the atmospheric background above an energy that may be as low as 30 TeV, with an energy spectrum that cannot described as a single power, as was the case for the muon neutrino flux through the Earth for energies exceeding 100 TeV.

A study of the neutrino arrival directions reveals that the observed neutrino flux is consistent with an isotropic distribution indicating an extragalactic origin. The production of PeV neutrinos is inevitably associated with the production of PeV gamma rays: hadronic accelerators produce fluxes of both neutral and charged pions that are the parents of gamma rays and neutrinos, respectively. For cosmic sources, the gamma rays cascade in the microwave and infrared background and reach Earth with reduced energies that are conveniently within the sensitivity range of the Fermi satellite. Figure 2.1-3 shows the gamma-ray flux accompanying an $E^{-2.15}$ neutrino spectrum with an exponential cutoff around a PeV. While it describes the IceCube data only on average, the gamma-ray spectrum, after propagation, matches the extragalactic isotropic diffuse gamma-ray background measured by Fermi. We here assumed equal production of pions of all three charges in the cosmic beam dump. This exercise indicates that the contribution of gamma rays accompanying IceCube neutrinos to Fermi's extragalactic flux is significant, suggesting a common origin of some of the sources at some level. More importantly, the roughly equal energy densities of neutrinos and gamma rays imply that the nonthermal universe is unlikely to be understood on the basis of electromagnetic processes, which has been the routine approach until now.

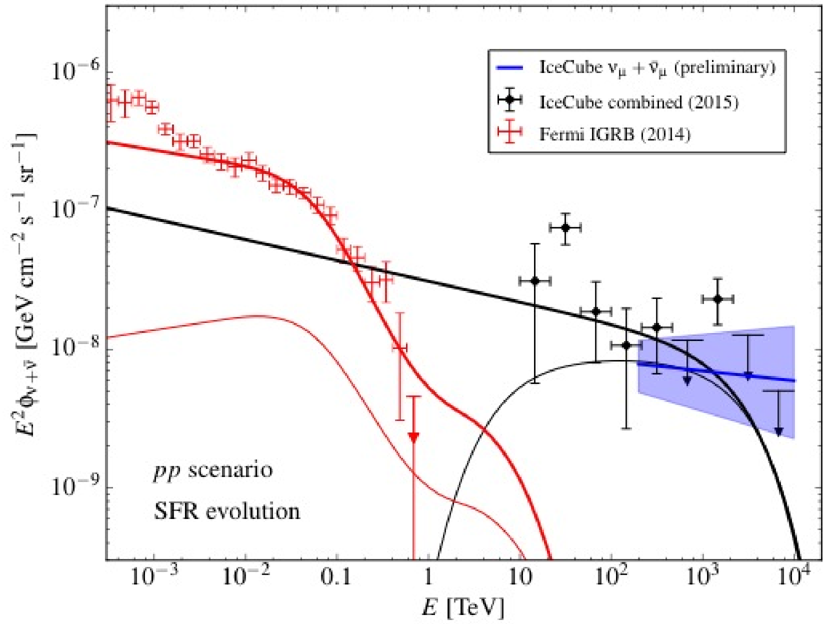


Figure 2.1-3: *The astrophysical neutrino flux (black line) observed by IceCube and the corresponding gamma-ray flux (red line) observed by Fermi after cascading through the extragalactic background light. The calculation assumes that the decay products of neutral and charged pions from hadronic interactions are responsible for the nonthermal emission in the Universe. The black data points are obtained from neutrino events starting inside the detector. Also shown is the best fit to the flux above 220 TeV of high-energy muon neutrinos penetrating the Earth.*

2.2 IceCube Science Beyond Cosmic Neutrinos

When considering the goals of detector operations, it is important to recognize that IceCube data impact science beyond neutrino astronomy. An incomplete list of analyses performed by IceCube working groups includes:

- We have measured the atmospheric neutrino spectrum for both electron and muon neutrinos to about 30 TeV, an energy above which cosmic neutrinos dominate. The highest energy neutrinos observed at accelerator laboratories have energies of less than 1 TeV. IceCube measurements result in new best limits on violations of Lorenz invariance and Einstein’s equivalence principal.
- This data also allow us to revisit the study of neutrino mass in a new energy regime. We have performed competitive measurements of the atmospheric oscillation parameters confirming the validity of the three-flavor framework in a previously unexplored energy range.
- We have obtained an exclusion limit on the existence of an eV-mass sterile neutrino, possibly accommodating the LSND “anomaly” that improves by an order of magnitude the sensitivity of current accelerator experiments.
- We have established that the arrival directions of the highest energy Galactic cosmic rays are not uniformly distributed in the sky. We have discovered that, unlike what has been previously claimed, the anisotropies survive to PeV energies.
- At the highest neutrino energies, we have extended the neutrino sensitivity of IceCube to the southern sky.
- We have established the best sensitivity to neutrinos produced by extragalactic cosmic rays interacting with microwave photons, the so-called cosmogenic or GZK neutrinos.

- We have ruled out gamma-ray bursts as the sources of extragalactic cosmic rays, establishing a flux limit at the level of less than 1% of the cosmic neutrino flux observed.
- We have established world-best limits on the existence of particle dark matter with spin-dependent interactions with ordinary matter. In the alternative case of dominant spin-independent interactions, direct searches obtain the best limits.
- A measurement of the cosmic-ray flux in the PeV to EeV energy range with an unprecedented precision has revealed new structures in the cosmic-ray spectrum around 10^{17} eV.
- We are ready to observe the next Galactic supernova explosion with unmatched sensitivity.

In the next section, we describe the discovery of cosmic neutrinos and confirmation of this discovery through independent analyses of IceCube data[4].

2.3 Five-Year Roadmap

The previous five-year roadmap focused on the transition of the ICNO facility from a construction phase to one of stable operations. During this successful transition, IceCube discovered a signal of high-energy neutrinos clearly standing out from the spectrum of atmospherics. This enormously successful result nevertheless places new exigencies on the facility operations. While the operations team fully intends to continue to improve on the methodology which helped bring about this success, the next five years will be much more than a mere continuation of the previous five. The sharing of data products with the community in the form of bidirectional real-time alerts and access to archived data has expanded and will continue to expand as new MoUs are signed with other astrophysical observatories. New algorithms for identification and reconstruction of the high-energy neutrinos are being developed to improve the number and quality (e.g., angular position, energy, and lepton flavor) of the samples. And then of course there is the multitude of ideas that may be forming in the minds of Collaboration members at this very moment, or have not yet formed. Fully exploiting the observatory's science potential means that the facility operations team must be prepared to respond to as-yet-unknown requests for new detector configurations, ice measurements, upgrades, and data products.

The ICL-based farm of processing servers and data acquisition compute hosts no longer present bottlenecks and are not foreseen to in the near future. As a result, the cycle of ICL computing upgrades has been relaxed, and a single 100% upgrade of the commodity compute elements in ICL will performed in the next five years, split across two polar seasons. On the contrary, access to sufficient computing resources in the north remains a challenge for IceCube. The complicated optics of the ice demands large numbers of graphics processing cores to track photons in the ice for the purposes of event reconstruction and simulation of detector response. Generation of hadronic interactions in the cores of extensive air showers high above the polar plateau needs large farms of CPUs. IceCube M&O in the next five years will extend access by the Collaboration to computing resources within the central cluster at Madison, will provide better frameworks to access dedicated and opportunistic distributed resources, and will propose access to supercomputing resources.

The discovery of high-energy astrophysical neutrinos is a clear demonstration of the validity and success of the NSF large facilities program and the ongoing investments in facility operations. New outreach methods that leverage mass media channels will build upon the existing successful E&O and communications program supported by M&O.

The next five years features two external reviews as opposed to a single midterm review in the previous five-year cycle. The PY2 review will critically assess the performance of the IceCube M&O and provide feedback to the NSF and to the M&O leadership with sufficient time to implement changes. The PY4

[4] For a detailed discussion and further references to the original publications, see T.K. Gaisser and F. Halzen, Ann. Rev. Nucl. Part. Sci. **64**, 101 (2014).

review will re-evaluate the M&O and in particular examine the quality of response to requests given in the previous review. The outcome of this second review will inform NSF's decision to rebid the M&O at the conclusion of this five-year cycle.

3 Technical Approach

As a discovery instrument with multiple scientific objectives, IceCube requires many varied search strategies. It looks for steady point sources of muon neutrinos in the northern sky—for example, active galactic nuclei or supernova remnants. Other searches target transient point sources such as gamma-ray bursts or supernovae in progress. Yet another objective is to characterize the recently discovered extraterrestrial neutrino flux coming from the entire sky and to follow up detections of high-energy astrophysical neutrinos with multimessenger observations by promptly alerting other telescopes. To achieve these multiple objectives, IceCube must be properly calibrated and continuously monitored to ensure high quality data. It also requires computing and facilities infrastructure, and the corresponding maintenance and updates necessary to achieve high standards of reliability and quality.

This section sets the technical M&O requirements and specifications ensuring IceCube reliably and continuously provides the capability to achieve its scientific objectives.

3.1 Detector Description and Performance

Required Capabilities. IceCube is designed to detect muons and cascades over a wide energy range. The string spacing was chosen in order to reliably detect and reconstruct muons with energies over 1 TeV and to precisely calibrate the detector using flashing LEDs and atmospheric muons. Because of the attenuation and scattering of light, a certain density of sensors is required to obtain many measurements along each track, which is important for pointing accuracy, background rejection, and energy measurement. The optical properties of the South Pole ice have been measured with various calibration devices and are used for modeling the detector response to charged particles. Muon reconstruction algorithms allow measurement of the direction and energy of tracks that come from all directions.

The depth requirement was driven by two constraints: a) to deploy below the region where air bubbles contribute to light scattering (1400 m), and b) to maximize the use of the remaining depth without risking too close an approach to bedrock (2800 m). Exploratory measurements with the Antarctic Muon And Neutrino Detector Array II (AMANDA-II) verified that the ice is clearer in the region below 2100 m. The greater clarity helps with reconstruction, and the greater depth minimizes background effects.

Some of the high-level design goals include:

- Angular resolution for muons (E^{-2} spectrum): <1° (Actual: 0.5°)
- Angular resolution for muons at 1000 TeV: <0.7° (Actual: 0.4°)
- Muon Effective area at 10 TeV: 0.9km^2 (Actual: 0.9 – 1 km^2)
- Livetime: >95% (Actual 2015/16 run: 99.8%)

Infrastructure. The final configuration of the detector, (Figure 3.1-1), consists of 86 strings with an instrumented depth range from 1450 m to 2450 m below the surface. There are 60 optical sensors mounted on each string, with equal spacing for standard strings. On the eight strings of the DeepCore subarray, 50 sensors are deployed at a smaller spacing of 7 m between 2100 m and 2450 m, with 10 sensors above 1950 m for additional veto functions. In addition, there are 324 sensors deployed in 162 IceTop detector tanks on the surface of the ice directly above the strings. The sensors are connected to the IceCube Lab (ICL) with a cable containing copper wires, one twisted pair for each pair of sensors. The ICL supports all data processing infrastructure to trigger, build events, and process the data.

M&O Requirements. All subsystems in the IceCube infrastructure require effort to maintain and operate. Even though some hardware systems are frozen into the ice, the overall system will undergo changes in time. Calibration constants change over time, data rates change due to the seasonal fluctuations of the atmosphere, and sensors may develop defects and need quick attention to avoid serious system-wide problems. The major effort is required for maintenance and operation of the complex computer systems in the ICL and for data management.

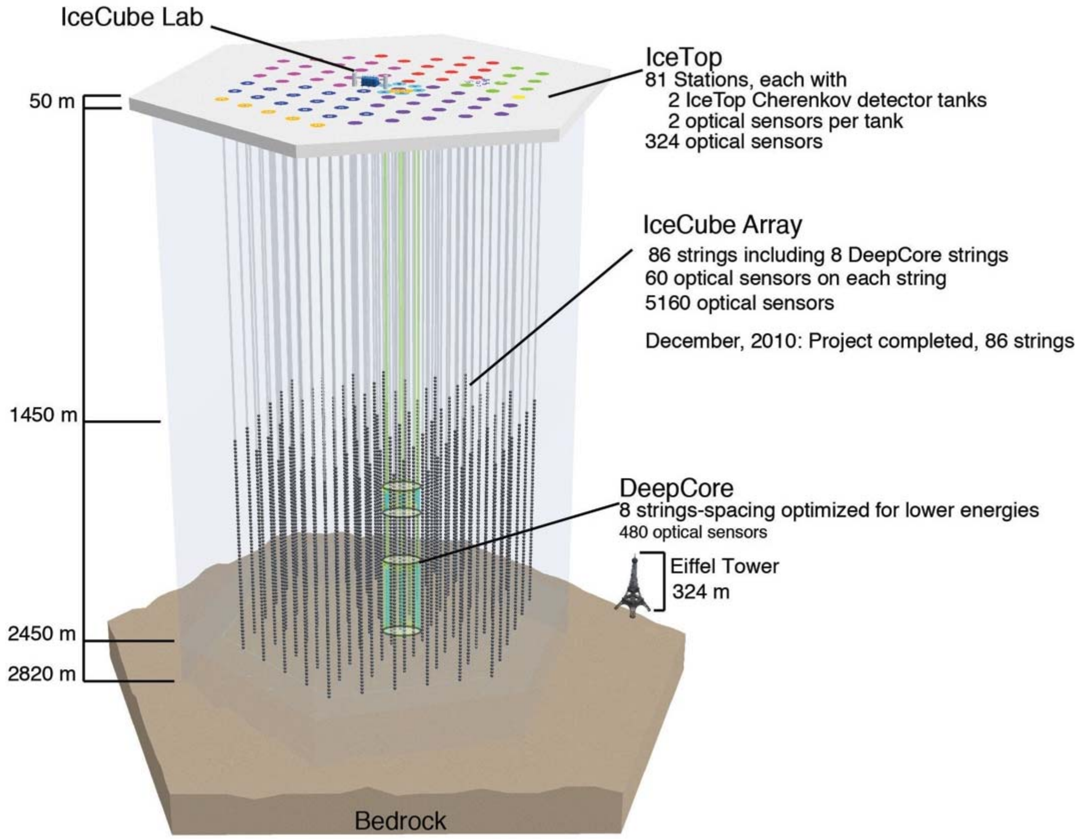


Figure 3.1-1. Schematic View of IceCube Detector. *The detector must be calibrated and continuously monitored to ensure collection of high-quality scientific data.*

3.1.1 Digital Optical Modules (DOMs)

Required Capabilities. Each sensor is required to detect the Cherenkov light emitted by charged particles with high sensitivity and a time resolution of a few nanoseconds and high dynamic range. Requirements include:

- Time resolution: 5 nsec (Actual: ~3 nsec)
- Time synchronization to master clock: <3 nsec (Actual: 1.5 nsec)
- Noise rate (with deadtime): 500 Hz (Actual: ~350 Hz)
- Linear dynamic range: 200PE/15 nsec (Actual: ~500 PE/15 ns)
- Failure rate (permanent failures): <5%/15yr (Forecast: <2.5%/15yr)
- Deadtime within run: <1% (Actual: < 0.01%)

For IceCube, timing precision at the level of a few nsec is necessary to maximize the accuracy of angular reconstruction; when looking for point sources of neutrinos in the sky, having two tracks pointing to the same spot within 0.5 degrees is more significant than having them point to the same spot within 1 degree, because random background tracks are four times more likely to occur within 1 degree.

The dynamic range of 200 photoelectrons per 15 nsec is relevant in IceCube DOMs in order to measure light near high-energy tracks, which is directly proportional to their energy (loss). For extremely high energies, the light will saturate nearby DOMs, and the energy must be determined with more distant DOMs, requiring a precise simulation of the photon propagation over large distances.

For IceTop DOMs, the dynamic range is important because cosmic ray air showers are studied across a wide energy spectrum (about four orders of magnitude), and the signals grow with shower energy.

The noise rate affects the trigger rate, the bandwidth, and most importantly the reconstruction quality and the sensitivity to neutrino bursts from the core collapse of supernovae. Aside from the goal of a low noise rate, it is equally important that the noise is predictable, stable and free of spikes.

Infrastructure—the As-Built DOM. Each sensor consists of a 25 cm photomultiplier tube (PMT), connected to a waveform recording data acquisition circuit capable of resolving pulses with nanosecond precision and performing within the requirements as listed above.

Each DOM (Figure 3.1-2) triggers autonomously on single photons and sends time-stamped, packetized hit data to the surface. A 33 cm diameter pressurized glass sphere holds the Hamamatsu R7081-02 photomultiplier tube plus associated electronics. These electronics include a high voltage generator, a resistive divider PMT base, a flasher board (containing 12 light emitting diodes, with programmable drivers), and a main board containing a complete data acquisition (DAQ) system. The DAQ includes two separate waveform digitizer systems. The first is the analog transient waveform digitizer (ATWD), which uses a custom switched-capacitor array chip to collect 128 samples of the PMT output at 300 megasamples per second (MSPS). The ATWD has three independent channels for each PMT providing 16 bits of dynamic range. The second digitizer system uses a commercial 40 MSPS 10-bit ADC chip to record 6.4 μsec of data after each trigger.

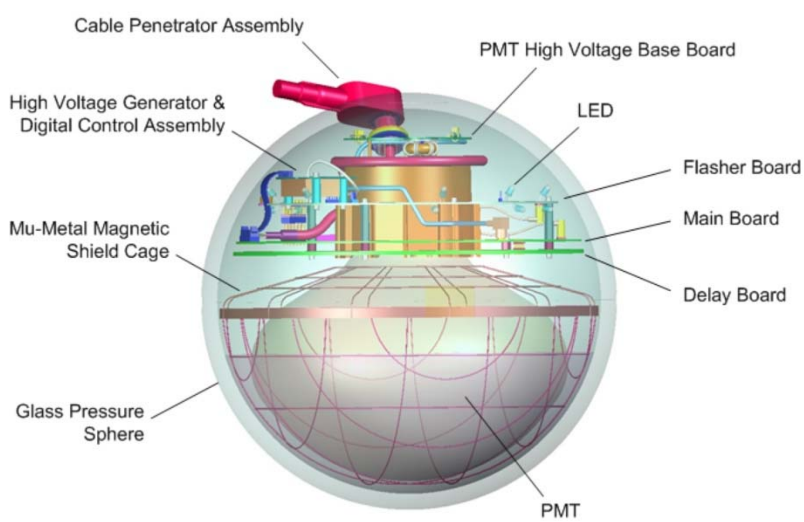


Figure 3.1-2. Digital Optical Module. *As the heart of the detector, DOMs require regular monitoring to detect performance issues that affect the quality of physics data.*

M&O Requirements. The system parameters, such as gains of all amplifiers, noise rates, time resolution, master clock synchronization, photodetection efficiency, and trigger thresholds need to be monitored from run to run, and even in shorter time intervals. Due to the large number of sensors, even occasional perturbations of individual sensors can have detrimental effects on the data quality. While overall a high reliability and stability has been achieved, experience shows that regular monitoring and a rigorous assessment of the observed and often complex issues is required to ensure high data quality. Detailed calibration programs need to be performed on all sensors at regular time intervals. Higher-level tests with LED flashers and downward-going cosmic ray muons are used to verify the system time stability between neighboring DOMs and monitor the DOM charge response.

3.1.2 IceTop

Required Capabilities. The IceTop surface detector array is designed to detect cosmic ray air showers in the energy range from 500 TeV to energies well beyond 1 EeV. Full trigger efficiency is required above 1 PeV for events with the core in the array. Coincidences with the In-Ice detector string array, the main detector of IceCube, allow performance of 3 tasks: a) cosmic ray physics over a wide energy range, b) special cross-calibrations, and c) certain veto functions. The ice in the tanks must be clear and remain clear without cracks over many years. The stations are exposed to and must survive annual temperature cycles down to below -50°C.

Infrastructure—the As-built IceTop Detector. The surface air shower array, IceTop, consists of ice Cherenkov detector tanks each containing two DOMs, which are operated at different gains for increased dynamic range. Two such tanks are associated with each string. The tanks are embedded in the snow just below the surface to minimize drifting of snow. IceTop detects and measures the position and direction of cosmic ray air showers, which also contain muons that penetrate to IceCube depth.

M&O Requirements. The DOMs used in the IceTop tanks must be serviced like all other DOMs. However, the lower gain of every other sensor and the different noise condition from cosmic rays result in different observables and make the IceTop array a complete detector system on its own. Special expertise is needed to service the IceTop array, both at the DOM level as well as at the DAQ level.

The increase of the snow layer on top of the tanks negatively affects the detector efficiency and energy threshold. Annual measurements of the depth of snow on all tanks must be performed, and this information is updated in a database used for reconstruction and simulation. Furthermore, the decision that snow maintenance will be minimized has necessitated augmentation of the IceTop stations with additional detector elements to mitigate this issue and restore IceTop efficiency to prior levels.

Comparing the IceCube (In-Ice) measurement of muons with the IceTop system is one important test of proper calibration and of the reconstruction software. This is an ongoing comparison through the life of IceCube to make sure that everything continues to function as designed, i.e., calibrations or reconstructions or their interfaces have not become corrupted.

3.1.3 Central Electronics and Data Processing System (Counting House)

Required Capabilities. The array of DOMs in the deep ice and in IceTop needs to be supplied with power, communication and control functions. All sensors are connected to the central data acquisition electronics by cables. A pair of DOMs shares one twisted pair of copper wires. The data are collected in the ICL, located at the geometric center of the IceTop array. Data include full waveforms for all hits in time coincidence between two neighboring DOMs, plus summaries of isolated hits. The data streams from the sensors arrive asynchronously via a digital communications protocol. In the ICL, higher multiplicity coincidences are formed to trigger on muons or cascades in the deep ice, or air showers observed in IceTop. The bandwidth allocation depends on the satellite bandwidth availability at the South Pole. It is a system requirement to store data locally in case of an extended failure of the satellite transmission system.

Infrastructure—Data Acquisition and Data Processing System. An overview of the system architecture is given in Figure 3.1-3. Each string (5 cm diameter and typically 3 km long cable) is connected to one DOMHub, a computer with custom PCI cards that perform the three low-level functions listed below. The central data acquisition performs three functions:

- receive data streams from DOMs, perform format changes, form event triggers and build events;
- provide power and slow control functions to DOMs; and
- perform synchronization of all DOM clocks with the system master clock.

M&O Requirements. While the system is designed to perform most functions automatically, the maintenance and operation require professional staff to ensure long-term reliability and stable operation of the experiment.

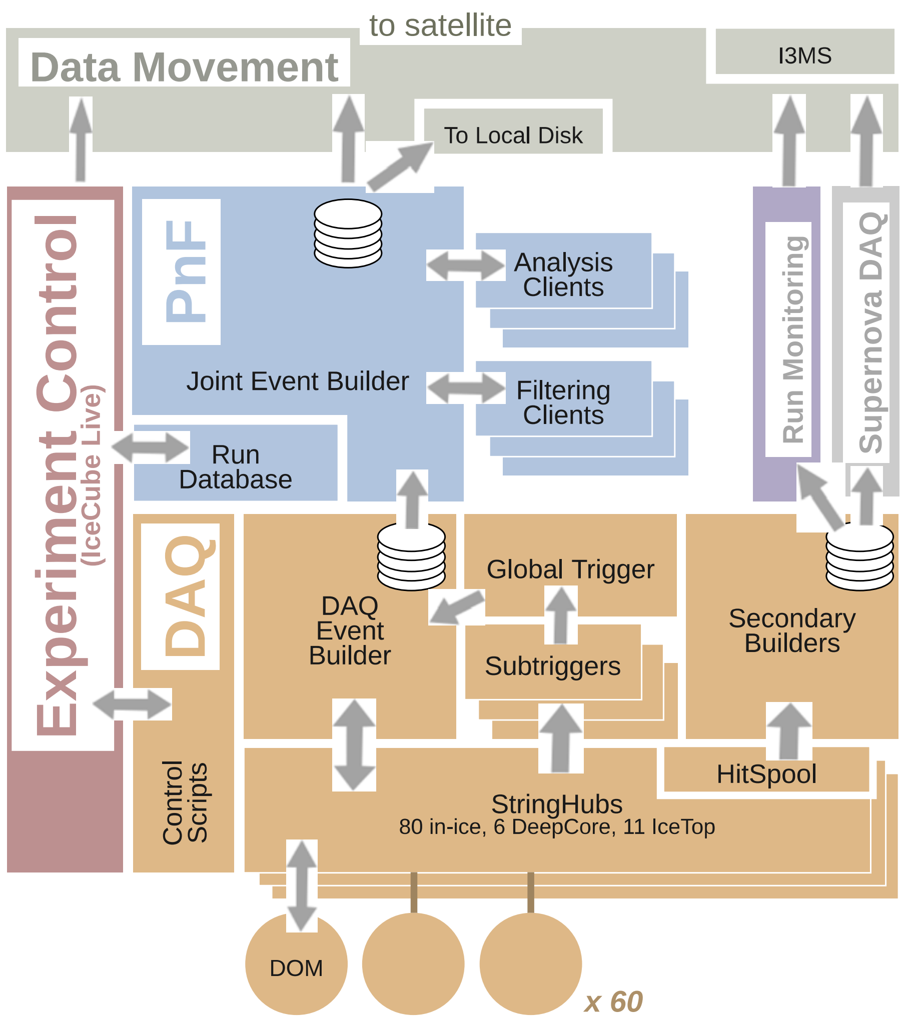


Figure 3.1-3. Detector Data System Architecture. *The data system controls the detector and collects, processes, transmits and stores IceCube and IceTop scientific data.*

3.2 IceCube Infrastructure

3.2.1 United States Antarctic Program (USAP) Infrastructure

Required Capabilities. The IceCube Laboratory (ICL) is one of the core facilities that make up the IceCube Observatory at the South Pole. It fulfills the requirement for a centralized computing facility and physical interface between the IceCube cables and the DOMHubs and associated data processing equipment. Stable electrical power to the IceCube detector is required as a sustained power outage could lead to damage of both surface electronics and in-ice electronics. Additional infrastructure that is required for IceCube management and operations functions are the South Pole Station and the cargo and logistics capability provided by the NSF Antarctic support contractor. IceCube also requires network access to the South Pole, and within the South Pole Station network, for data transfer and communications for network remote access, email, and other basic services. In addition, IceCube needs the capability of transferring data from the South Pole to the IceCube data warehouse in Wisconsin through a number of different pathways depending on the priority of the data.

Infrastructure. The IceCube computing systems located in the ICL (Figure 3.2-1) produce in excess of 30 kW of waste heat which must be removed from the data center. To reduce energy consumption of the data center the cold external air is used for cooling through an air mixing and handling system. Due to the very high density of equipment in the ICL, a failure of the cooling system can result in critical damaging temperatures within 30 minutes. A high level of reliability and monitoring of the cooling system is therefore required. The NSF support contractor is responsible for the operations, maintenance, monitoring, and response to incidents involving the cooling system. The communications infrastructure, in the form of high-speed satellite data connections and the physical backbone at the South Pole, is also maintained by the NSF Antarctic support contractor.

M&O Requirements. The basic framework of frequent communications (regular conference calls during season planning), one-on-one contacts (NSF support contractor program manager, NSF program officer), Support Information Package (SIP) development, and ad hoc meetings ensure that the USAP program will continue to provide IceCube with needed USAP infrastructure.

Figure 3.2-1. IceCube Laboratory (ICL). *The ICL at the South Pole houses the online computing system which is critical to mining data from IceCube.*

3.2.2 IceCube South Pole System (SPS)

Required Capabilities. IceCube requires a surface computing system that supports the data acquisition and filtering tasks carried out by the real-time systems. Data archive systems must be able to handle the Level 0 data volume generated from the IceCube detector – O(300 TB) per year.

Infrastructure. The SPS hardware includes DOMHub computers, commodity server class computers, remote console equipment, and network hardware. Two Iridium RUDICS modems provide low-bandwidth connectivity 24/7 for detector control and monitoring.

M&O Requirements. The SPS must maintain very high reliability to support IceCube data taking in a robust manner with minimal intervention. Also, the system must be manageable for the winterover operators, who are different and are re-trained every year.

System administrators, in conjunction with on-site winterovers, are responsible for the maintenance and operations of the South Pole computing system. This includes preventive maintenance, troubleshooting, and upgrades.

3.2.3 IceCube UW Infrastructure

3.2.3.1 South Pole Test System (SPTS)

Required Capabilities. IceCube requires a test system that replicates the basic functionality and performance characteristics of the production SPS computing system and includes a reasonable proxy representation of the detector and DAQ systems.

The SPTS provides an environment to build and verify software subsystems and perform hardware and software evaluations prior to deployment on the production system at the South Pole. The system must adequately represent the live detector systems at a small fraction of the cost in hardware and maintenance resources.

Infrastructure. The SPTS is a scaled-down version of the operational SPS located on the UW–Madison campus. System infrastructure is similar to that deployed on the production system including matching power and network devices. All major subsystems are represented, some of them with a reduced number of nodes. Nonetheless, infrastructure is in place to expand the number of available nodes for specific high-scale tests by temporarily integrating nodes from the offline cluster.

Evaluation of software and firmware DAQ updates is accomplished on the SPTS via one or more of the following means:

- 8 real DOMs kept at subfreezing temperatures for evaluation of firmware and software updates,
- a full string of DOM main boards connected to a DOMHub for string-level tests, and
- a special playback mode of real untriggered data streams coming directly from the deployed DOMs that have been captured at the SPS for use in the SPTS to generate realistic load conditions.

M&O Requirements. System administrators manage the test system responding to software developers and other engineers' requirements. They are responsible for hardware and software maintenance and operations on the SPTS.

3.2.3.2 Data Warehouse and Storage Infrastructure

Required Capabilities. IceCube generates about 1 TB of raw data every day. Only about 10% of that can be transferred out via satellite due to limited bandwidth. A reliable system is needed to store all the generated data to enable long-term archiving and to manage transfers. The data generated by the detector is its most precious output, so the archiving systems have to ensure its integrity.

IceCube requires a data warehouse at UW–Madison consisting of software to facilitate receiving and archiving of data from the South Pole, standards for organizing the data, such as directory structure and metadata, and a high-performance storage system that enables efficient offline data processing and analysis.

Including simulation, IceCube generates close to 1 PB of data every year. Out of that, about 700 TB need to be archived and preserved for the long term due to their uniqueness or their relevance to reproducing published scientific results.

Infrastructure. The storage infrastructure at UW–Madison's data center consists of disk storage servers organized in a cluster file system architecture. This provides the required performance and scalability for handling expansions and turnover efficiently and securely.

IceCube software engineers have developed a software application named JADE to handle the IceCube data end-to-end. JADE manages the data collection and storage at the South Pole, the satellite data transfers, the data ingest at the UW–Madison data warehouse, and the replication to external archive sites for long-term preservation.

In order to provide cost-effective long-term data preservation services, we leverage large data centers at collaborating institutions NERSC and DESY-Zeuthen that already operate large automated tape libraries as part of their services to other experiments.

The NERSC archive is a hierarchical storage management system (HSM) that has been running since 1998. It currently holds 100 PB of data and handles about 100 TB of input/output every day. The HPSS software is used to manage the tape backend. NERSC actively partners with Globus, DSI, and HPSS developers to improve HPSS functionality.

DESY has been providing automated tape archive services for particle physics experiments for more than 20 years. The tape archive system at the DESY-Zeuthen site, where part of the IceCube data is replicated, stores a total of about 15 million files and 2.5 PB of data for several experiments. The OSM software is used to manage the tape backend.

M&O Requirements. System administrators experienced in managing disk enclosures, storage networks, servers, and cluster file system software maintain and operate the storage infrastructure. They ensure that data is available for data processing and analysis tasks and that it is delivered with maximum performance.

As the collected data set grows and new analyses are developed, the load on data access services increases as well. Part of this data processing and analysis demand comes from a more intense usage of distributed computing (Grid) resources. The IceCube data warehouse and storage infrastructure, and in particular the data export services responsible for providing remote access to the data, will need to evolve to cope with the extra load and maintain high performance and reliability.

The JADE data handling software and services will require maintenance and support, to tailor them to the evolving needs of the scientific community. Metadata and cataloging needs will also evolve as the data set grows and new analyses appear.

3.2.3.3 Central Computing Resources

Required Capabilities. IceCube requires a core high-throughput computing (HTC) cluster to perform offline processing and analysis of real data and for the production of simulation data sets. The system must be closely coupled to the storage infrastructure for efficient data processing.

Infrastructure. The current IceCube HTC cluster at UW–Madison consists of nearly 200 servers providing a total of around 7000 CPU job slots and 350 GPU job slots. The HTCondor software, a state-of-the-art workload management system developed at the computer sciences department of UW–Madison, handles job scheduling at the HTC cluster.

M&O Requirements. The IceCube system administrators support users by providing guidance on HTC best practices. They also support the delivery of science-ready data by ensuring that offline processing tasks run with appropriate priority and that the end-to-end infrastructure stack (computing, network, and storage) is available and delivers optimum performance.

3.2.3.4 Core Data Center Infrastructure

Required Capabilities. The data center infrastructure is the glue that connects the major computing resources of IceCube. Required core infrastructure systems include distributed authentication, DNS, and e-mail. Also, a large number of servers and services need to be deployed and maintained, such as database services, web services or tailored application servers, to fulfill science needs.

The IceCube Collaboration is distributed throughout 12 countries. Many of the data products and services are hosted at the UW–Madison data center, therefore excellent network connectivity is essential. Also, a large part of the IceCube computing requirements will be met using distributed resources, so reliable, high-speed access to the UW–Madison data center storage infrastructure is required to use these resources efficiently.

Infrastructure. IceCube computing facilities are currently hosted in two UW–Madison locations, one off campus at the WIPAC offices and the other on campus at the Physics Department. Together they provide the total capacity to power and cool about 170 kW of IT equipment. This is expected to be sufficient for IceCube's needs in the next five years, as improvements in energy efficiency in new generations of hardware will enable a net capacity growth within a constant power envelope.

M&O Requirements. Several systems administrators share duties to maintain the UW–Madison data center infrastructure services. This includes patching, monitoring, troubleshooting core services, and responding to user needs among other tasks.

3.2.4 Distributed Computing Infrastructure

Required Capabilities. The analysis of experimental data requires a suitable amount of simulated data that reproduces the detector response to a well-defined set of physics events. The IceCube observatory's event rate is overwhelmingly dominated by cosmic-ray-induced background events, which must be eliminated through a complex event selection process. A large amount of simulated data needs to be generated in order to perform high-quality physics analyses. Dedicated computing resources at the level of several thousand CPU cores are needed to perform the required simulation and analysis tasks. The available capacity will increase with time along with rising needs.

Infrastructure. In order to reach this capacity, IceCube relies on distributed resources available from collaborating institutions. The current capacity plan foresees providing 10% of the CPUs needed for simulation at the UW–Madison data center, 25% at DESY-Zeuthen, and 65% at other collaboration sites. For GPUs, the plan is to provide 50% of the needs at UW–Madison and 50% at other collaboration sites.

The collaborating institution DESY-Zeuthen provides a Tier-1 data center, which assumes a number of core computing activities to complement UW's. The goal is to leverage additional locations to ensure that core data processing and analysis services are highly resilient. The DESY-Zeuthen data center supplies significant computing and storage infrastructure for simulation and analysis and also acts as a replication site for the long-term archiving of IceCube data sets.

M&O Requirements. Support personnel at all sites coordinate and manage the distributed computing effort to produce the needed simulation. In addition, IT professionals at the UW–Madison data center manage the IceCube Grid infrastructure and tools needed to exploit distributed resources and to provide efficient remote access to the data.

3.3 Overview of Events to Publications

Reconstructing neutrino events with energies from 10 GeV to 1000 PeV, the energy range in which IceCube's science portfolio includes neutrino physics, dark matter searches, and the observation of cosmic neutrinos, requires precise recording of everything from single photons up to large pulses lasting several microseconds. Proper maintenance and operation of the detector and its supporting infrastructure (Sections 3.1 and 3.2) allow for capture of the targeted events, analysis of the data, and publication of results that contribute to science and education (Figure 3.3-1).

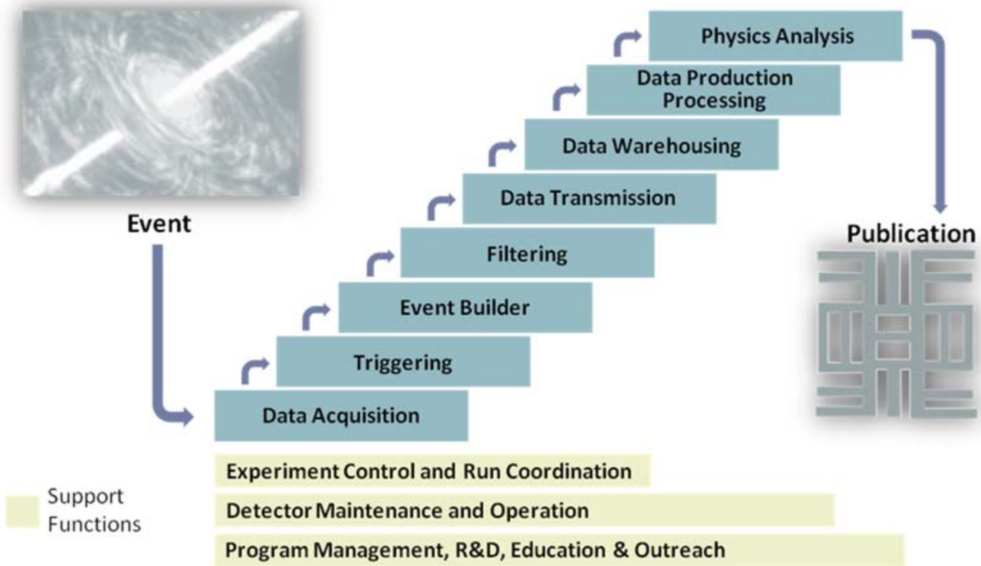


Figure 3.3-1. IceCube Path to Science. *Our approach to IceCube M&O is structured to support all tasks required to produce science—from event to publication.*

Detector maintenance and operations provides the online framework for the capture of astrophysical events of interest. This process begins at the DOMs in the ice, which continuously time-stamp and digitize photomultiplier tube pulses originating either from passage of charged particles or from intrinsic light background in the DOMs themselves. Data is digitally transferred to the surface where computers order the hits in time and trigger on resulting patterns of scientific interest to separate them from the intrinsic noise. Once a trigger is issued, hits close to the trigger times are assembled into file-based event data structures by event builder processes and sent to the PnF filtering system, which may be regarded as a second level trigger. Filtering further selects out potentially interesting events such as upgoing muons, high-energy neutrino candidates, and several others from triggered events for daily transmission via satellite. All triggered events are recorded to disk storage, however, which are physically shipped north at the end of the austral summer season. A separate process (JADE) takes care of managing the data streams, buffering data, sending the PnF stream to the satellite and writing the bulk of the data locally on disk.

Recently, PnF has been equipped with the ability to generate real-time alerts to be sent to external observatories when extremely interesting events are found in the data stream. Optical observatories, for example, may elect to examine the area of sky where these targets of opportunity occur and make follow-up searches for associated optical signals. These multimessenger collaborations hold high promise to aid in the eventual identification of objects that produce high-energy neutrinos.

A run coordinator oversees and configures the online systems through a global experiment control system called *IceCube Live* to focus data collection on areas of scientific interest prioritized by the IceCube Collaboration. Data filters are annually proposed by working groups in the Collaboration and are reviewed by the Trigger Filter and Transmission (TFT) Board that allocates resources such as computing and data transfer bandwidth.

Each data stream is reprocessed after transmission to the Northern Hemisphere data center, where more computing power is available and more sophisticated reconstruction algorithms can be applied. The reprocessing takes place within only a few weeks after the data are taken at the South Pole. At this point, the science-ready data are available to the IceCube scientific collaboration. The refined data streams are first evaluated by the channel working groups for initial analysis and for possible recommendation for further filtering. The physics working groups typically only access the processed data for high-level analysis and development of specific tools needed to execute the analyses. The analysis coordinator manages the analysis process, which typically includes formal analysis and unblinding proposals and an approval process. The Publication Committee manages the publication review processes.

4 Management Approach

Our approach to IceCube M&O—from science event to publication—is to maximize the scientific discovery potential by drawing on talent and resources from Collaboration institutions to support both M&O and science tasks. The first part of this section (Section 4.1) describes how we are organized to perform the M&O functions for IceCube in this distributed model and how we provide accountability for task execution. The second part (Section 4.2) identifies the tasks required to meet the technical requirements and specifications discussed in Section 3, and explains how we perform each task.

4.1 Organization

The IceCube M&O management organization integrates the IceCube Collaboration and the host institution, the University of Wisconsin–Madison (Figure 4.1-1). The principal investigator is responsible to the UW vice chancellor for research and the National Science Foundation for the overall scientific direction of the IceCube Neutrino Observatory. The Collaboration spokesperson appoints collaborating scientists to serve as the coordinators in each of the major M&O functions: physics analysis, and research and development. These appointments are subject to the concurrence of the Collaboration. The director of operations appoints technical professionals to serve as managers of the two M&O functions that are predominantly centered at UW–Madison: detector maintenance and operations and computing and data management. The managers in these areas work with their scientific counterparts to ensure the detector operates reliably and the data taken by the detector can be analyzed in a timely way.

The IceCube spokesperson and the director of operations are jointly responsible for the success of the IceCube M&O program, with the spokesperson directly accountable to the Collaboration and the director of operations accountable to the National Science Foundation through the University of Wisconsin–Madison as the host institution for the M&O program.

The spokesperson-appointed coordinators and the director of operations-appointed managers are successful through the efforts of collaborating scientists, technical professionals, and managerial and administrative support staff. The entire M&O scope of work is sorted in a Work Breakdown Structure - WBS (included as Appendix 1 of this plan), and the WBS tasks are defined in a detailed Memorandum of Understanding (MoU) approved by the IceCube collaborating institutions.

Every task in the MoU is assigned to an institution. The principal investigators (PIs) at the institutions are responsible for ensuring that the work is completed on schedule. If an institution is not able to fulfill an agreed upon commitment, the institutional PI is responsible for ensuring that the work is assigned to another institution before there are adverse impacts to the M&O program. The institutional MoUs also include a list of the physics group members and a head count of faculty, scientists, postdocs, and graduate students. The institutional MoUs are revised twice a year at the IceCube Collaboration meetings. (A summary of the most current MoU head count, level of committed contribution, and a summary of the collaborating institutions evolvement over time are included as Appendix 2 of this plan).

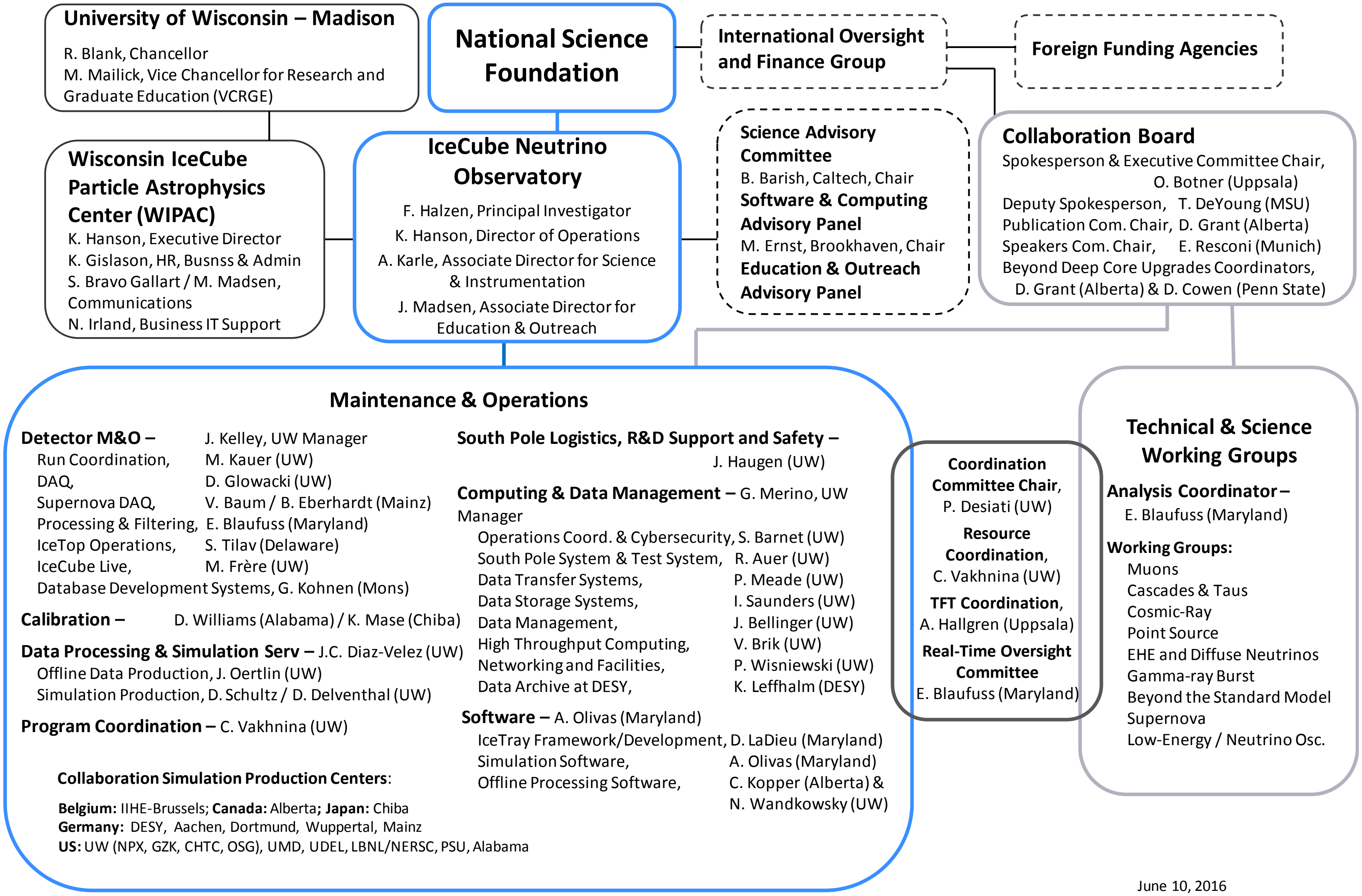


Figure 4.1-1. IceCube Organization. *Our organization maximizes the use of both Collaboration resources and core resources managed by UW while maintaining clear lines of accountability to the NSF.*

4.1.1 The U.S. National Science Foundation (NSF)

The NSF is the executive agent with responsibility for seeing that the IceCube detector meets its objectives, requirements and technical performance. The NSF has a special role in IceCube because of its Host Laboratory responsibilities in managing operation of the Amundson-Scott South Pole Station. These responsibilities include safety; physical qualification; transport of personnel, fuel and equipment; and the provision of housing, food service, support personnel, logistical support, IT support, and general infrastructure support. The IceCube M&O award is co-funded by the Division of Polar Programs and the Particle Astrophysics Program within the Division of Physics. The respective program directors provide continuous oversight and guidance through direct communication with the IceCube PI and director of operations.

4.1.2 International Oversight and Finance Group (IOFG)

The International Oversight and Finance Group (IOFG) was created in 2004 to provide oversight and financial support for the IceCube Neutrino Observatory (including construction phase, management & operations and research phases). The group organizes annual oversight reviews of the operations and meets annually to discuss detector performance and physics. The group also sets policies for receiving periodic progress reports on all aspects of the detector operation and by all the performers in the collaboration, and for conducting external reviews when appropriate.

Membership. A representative of the National Science Foundation chairs the IOFG. Membership is comprised of representatives of the funding agencies in the partner countries supporting the construction and operation of IceCube Neutrino Observatory, currently the funding agencies from Belgium, Germany, Sweden, and the United States. The IOFG is informed by the spokesperson of the Collaboration, the director of operations, the principal investigator and others as appropriate.

Decisions. The IOFG is committed to operate through discussion and consensus. The executive agent (the NSF) will make final decisions on matters before the group related to the operation of IceCube.

Issues that may come before the group include:

- Approval of a formal charter for the group.
- Review of Memoranda of Understanding (MoU) between the various institutions.
- Concurrence on the Management & Operations Plan.
- Funding issues.
- Concurrence on the Collaboration’s plans for new membership in the collaboration.
- Data sharing and data management policies.
- Coordination regarding press releases and education and outreach activities.
- Input on seasonal flight and personnel logistics planning.
- Other matters related to successful operation of the IceCube Neutrino Observatory for science.

4.1.3 University of Wisconsin–Madison

IceCube Oversight. The lead executive officer of the University of Wisconsin–Madison is the Chancellor. The Chancellor delegates responsibility for research activities to the vice chancellor for research and graduate education (VCRGE). The VCRGE maintains oversight of the IceCube Neutrino Observatory and appoints the IceCube director of operations. The IceCube principal investigator and the director of operations report directly to VCRGE. The director of operations contacts the vice chancellor for research when significant developments occur or important issues arise.

The IceCube associate director for science and instrumentation reports to the director of operations and advises primarily on matters related to science, coordination committee and instrumentation.

The IceCube associate director for education and outreach (E&O) reports to the director of operations and leads the IceCube E&O program. The associate director for E&O works with the NSF and the IceCube Collaboration to establish E&O priorities and strategies and to provide support for ongoing activities and to respond to outside requests.

Wisconsin IceCube Particle Astrophysics Center. The IceCube operations organization is located within the Wisconsin IceCube Particle Astrophysics Center (WIPAC). WIPAC is IceCube's primary interface to the UW administrative and support systems, established within the Office of the VCRGE to coordinate the multiple roles of the university:

- Lead institution for the IceCube construction project;
- Host institution for initiating and continuing IceCube management and operations;
- Administrator of services such as accounting, purchasing and human resources;
- Coordinating institution for IceCube education and outreach activities; and
- Collaborating institution with the largest participating research group.

The IceCube M&O management organization is a beneficiary of the robust UW–Madison human resource system, which includes strategies to recruit, develop, and retain a diverse workforce. UW–Madison is committed to hiring the right talent to ensure that the university continues to be a world-class institution of higher education. The university's goal is to provide opportunities for talented people from all backgrounds to help us maintain a highly productive, welcoming, empowering, and inclusive community. UW–Madison encourages women, minorities, veterans, and people with disabilities to apply for our vacancies. IceCube M&O will continue to strive to attract outstanding candidates from underrepresented groups.

4.1.4 IceCube Collaboration

The Collaboration plays a leading role in IceCube, guiding both science and M&O. The benefits of this distributed organizational model are 1) the ability to draw highly qualified and specialized personnel from Collaboration institutions to perform specific tasks in support of science or M&O, and 2) the education and training opportunities through hands-on IceCube participation for faculty, postdocs and students from multiple Collaboration institutions. The institutions collaborating in the IceCube Neutrino Observatory are listed in the IceCube Governance Document (included as Appendix 4 of this plan).

IceCube Collaboration Board. The IceCube Collaboration Board (ICB) is the policy-making entity that guides and governs the scientific activities of the Collaboration. It consists of a representative from each collaborating institution as described in detail at the IceCube Governance Document (included as Appendix 4 of this plan). It establishes, and as necessary, amends governance procedures and has oversight and authority over science policy and goals, membership, data access, publications, representation of IceCube at topical and general conferences, analysis teams, and education and outreach. The principal investigator is an ex-officio member of the ICB.

Executive Committee. The spokesperson, in consultation with the ICB, the PI and the director of operations, appoints and chairs the Executive Committee of the ICB (Figure 4.1-2). The term of the members is two years. The job of this committee is to advise the spokesperson in proposing actions to the ICB and in making interim decisions. The members of the Executive Committee represent major groups, functions and competencies within the Collaboration.

	Name and Institution	Area of Expertise/Responsibility
Spokesperson	Olga Botner, Uppsala University	Overall direction of IceCube Collaboration
Member	Tom Gaisser, former Spokesperson, University of Delaware	Cosmic-ray physics, IceTop aspects
	Greg Sullivan, former Spokesperson, University of Maryland	Neutrino and gamma-ray astronomy
	Albrecht Karle, University of Wisconsin–Madison	All aspects of detector operation, Associate Director for Science & Instrumentation, liaison with R&D
	Christopher Wiebusch, RWTH Aachen	Neutrino physics, operations
	Marek Kowalski, Humboldt-Universität zu Berlin	High-energy cross-section
	Darren Grant, University of Alberta	Chair of the publications committee, PINGU Co-Lead
	Tyce DeYoung, Michigan State University	Deputy spokesperson, neutrino oscillations, PINGU
	Erik Blaufuss, University of Maryland	Analysis Coordinator
Ex-Officio Member	Francis Halzen, Principal Investigator, University of Wisconsin	Neutrino astronomy & high-energy physics, overall scientific direction
	Kael Hanson, Director of Operations University of Wisconsin–Madison	Project and Operations Management, NSF Primary Contact for IceCube Operations

Figure 4.1-2. Executive Committee of Collaboration Board

IceCube Collaboration Meetings. IceCube Collaboration meetings are held at least twice a year with one meeting in Europe and one in the United States. These meetings serve as a forum for the presentation of scientific results, and for communicating project progress and status to the entire collaboration. Official Collaboration Board meetings are conducted during these meetings.

Collaboration Institution Tasks. Tasks are rotated in a fair and equitable manner, taking account of the special interests and capabilities of each institution. Tracking and transparency is provided as part of the MoU Scope of Work Summary (included as Appendix 2 of this plan). This summary matrix provides a breakdown of tasks by WBS Level 2 and by collaborating institution that provides the foundations of the MoU with each institution.

4.1.5 Key Personnel

Our key personnel form the leadership team that ensures the success of the IceCube M&O and the timely exploitation of its scientific discovery and education and outreach potential. This section discusses the roles and responsibilities of these personnel. Key personnel (Figure 4.1-3) are employees of the Host Institution, University of Wisconsin–Madison. UW–Madison will seek concurrence from the NSF prior to any changes in the appointments.

Name	Position	Responsibilities
Francis Halzen	Principal Investigator	Responsible for the overall success of the IceCube Neutrino Observatory
Kael Hanson	Director of Operations, Co-Principal Investigator	Ensures operations meet established performance goals and the needs of NSF and the IceCube Collaboration.
Albrecht Karle	Co-Principal Investigator, Associate Director for Science and Instrumentation	Supervises technical performance of the IceCube detector infrastructure, ensuring that it meets IceCube science objectives
James Madsen	Associate Director for Education and Outreach	Responsible for planning and executing of education and outreach activities

Figure 4.1-3. IceCube Key Personnel

4.1.6 Advisory Committees

4.1.6.1 Science Advisory Committee

In consultation with the collaboration, the principal investigator and the spokesperson appoint a Scientific Advisory Committee (SAC) of external experts. The role of the SAC is to make recommendations on the IceCube scientific goals and on any other matters that may affect the scientific activities of the IceCube Neutrino Observatory. The SAC typically meets annually. The current chairperson is Barry Barish from Caltech.

4.1.6.2 Software & Computing Advisory Panel

The IceCube Software & Computing Advisory Panel (SCAP) is composed of experts in the fields of software development and scientific computing. The SCAP advises the IceCube spokesperson and director of operations on the most efficient and effective computing resources for IceCube, including on-line computing; on-line and off-line data processing and filtering; off-line computing facilities; and simulations and analysis tools support. The spokesperson and the director of operations appoint the SCAP members and the chairperson. Meetings are held once each year. The current chairperson is Michael Ernst from Brookhaven National Laboratory.

4.1.7 M&O Coordination Boards and Organizations

The purpose of coordination organizations is to ensure that M&O tasks from raw data to publications are properly planned and executed. These organizations make certain that the resources committed in their areas of activity are realized and used efficiently and effectively. Examples include the following.

4.1.7.1 Coordination Committee

A close relationship between the operational activities and the scientific investigations is a prerequisite for achieving the science goals of the IceCube Collaboration and the proper operation of the observatory. Establishing appropriate science requirements and in-kind manpower to operate the experiment's infrastructure is the main task of the IceCube Coordination Committee.

The charge of the Coordination Committee is to provide high-level coordination of tasks related to M&O activities and to technical support for the IceCube physics data analyses. To achieve this, the committee manages the dependencies between operational areas and physics working groups, in order to keep track of the essential in-kind contribution service tasks. Coordination between working groups and the coordinators of the operational areas is the principal means for optimizing the use of the experiment infrastructure in achieving science goals.

The committee is comprised of the spokesperson-appointed M&O coordinators and channel working group leaders (shown in Figure 4.1-4), key personnel, and others as needed. The chair of the Coordination Committee works with the M&O coordinators to provide a list of service tasks needed in the specific operational areas, with priority level and estimated labor contribution (FTE); with the leaders of the channel working groups to establish the science requirements and a list of service tasks needed to accomplish the requirements (see organizational chart in Figure 4.1-1); and with the members of the committee to establish specific communication channels with institutional leaders to advertise the list of needed service tasks and negotiate involvement through specific MoUs. The MoUs are typically updated and renewed twice a year, at each collaboration meeting.

The Coordination Committee makes sure that the “negotiated” deliverables and the pledges by the institutional leaders match and that service tasks are executed. The chair of the Coordination Committee sets up milestones for each of the assigned tasks to benchmark the status of service tasks. Students and postdocs working on those tasks get visibility and credit by providing reports at the IceCube weekly phone calls.

The committee typically meets on a monthly basis to address technical and resource issues, and to advance strategic goals. The committee is the primary point for determining priorities and resolving resource conflicts that arise at lower levels in the organization but also for making sure that operational activities are in correct synchronization with the changing science goals. Issues that cannot be resolved by the Coordination Committee are resolved by the spokesperson and director of operations.

Position	**Name**	**Institution**
ICC Chair	Paolo Desiati	UW–Madison
Resource Coordinator	Catherine Vakhnina	UW–Madison
M&O Coordinators:		
Detector Operations	John Kelley	UW–Madison
Computing	Gonzalo Merino	UW–Madison
Simulation Production	Juan Carlos Díaz Vélez	UW–Madison
Software	Alex Olivas	UMD
Calibration	Dawn Williams	U of Alabama
Analysis Coordinator	Erik Blaufuss	UMD
Channel Working Group Leaders:		
Muon Channel	Juan Antonio Aguilar Sanchez	ULB
	Jonathan Dumm	Stockholm
Cascade Channel	Joanna Kiryluk	Stony Brook
	Dawn Williams	U of Alabama
Low Energy	Jason Koskinen	NBI
	Sebastian Böser	U of Mainz
	Ken Clark	U of Toronto
Cosmic Ray	Timo Karg	DESY
	Katherine Rawlins	U of Alaska - Anchorage

Figure 4.1-4. Coordination Committee

4.1.7.2 Trigger Filter and Transmission (TFT) Board

The role of the TFT Board is to maximize transmission of scientifically valuable data within the constrained resources of the South Pole system in support of IceCube’s scientific objectives. It coordinates proposals for revisions or introduction of new DAQ trigger and software settings and online filter streams. It acts as an interface between the IceCube collaboration, specifically the analysis groups and the core operations groups of IceCube. The TFT will also recommend settings for initial offline data processing in the north. The annual review cycle continuously enhances the science output of the detector.

The TFT Board works with the Coordination Committee for identifying service tasks needed to accomplish its goals.

4.1.7.3 Detector Operations Working Group

The detector operations working group is responsible for day-to-day operation of the detector, including data acquisition, filtering, transmission, offline processing, calibration, and maintenance. The working group is responsible for maintaining a high detector uptime and ensuring high-quality data are delivered to the Collaboration. The detector operations manager is responsible for coordinating group activities via a weekly teleconference. The run coordinator reviews proposals for nonstandard operations on the detector, including commissioning and calibration runs, and tracks detector uptime. Subsystem experts are also involved, including online systems software engineers, calibration group members, IT experts, and other physicists.

4.1.7.4 Analysis Coordination Working Groups

The responsibility of the working groups is twofold: a) coordinate analysis activities amongst nearly 50 institutions in the collaboration and b) provide a framework for coordinating analysis with operations and technology development for an integrated focus on IceCube science and technology issues and needs. The working groups provide specialized expertise and general support to M&O tasks that include maintaining the data warehouse; developing data preparation scripts; and supporting detector calibration and verification of its performance. Tasks for each collaboration member are described in general in their MoUs. The Collaboration assigns a leader responsible for each functional area to coordinate Collaboration institution resources in that area.

4.1.7.5 Real-Time Oversight Committee

Real-time coordination of alerts to and from IceCube provides one of the best opportunities to identify potential sources of our astrophysical neutrino sample by identification of transient phenomena in electromagnetic signals or gravitational waves. These alerts take two forms: alerts generated by IceCube and those generated by other observatories. In both cases, careful oversight is required to ensure that IceCube's public or private response under MOUs is both prompt and scientifically correct. In order to address this need for oversight, the Real-Time Oversight Committee (ROC) has been formed. This group is charged with:

- Overview of our real-time programs to ensure they are complete, correct, prompt, and well integrated with each other;
- Rapid decision on significant real-time alerts and responses within IceCube.

These actions are to be handled as quickly as possible by the available members of the ROC (not requiring all be present for a quick response) and without outside approval from working groups or the ICB. Reporting on activities to the physics working groups, analysis call, collaboration email, and/or ICB should happen as quickly as possible following significant actions.

4.1.8 Physics Analysis Coordination

Physics analysis includes tasks that are not included in the M&O core and in-kind budgets but are essential to complete the process from science event to publication. These tasks are supported through research grants to the collaborating groups.

4.1.8.1 Analysis Coordinator

IceCube reaches its greatest potential both in achieving its scientific objectives and in education and outreach by balancing centralized M&O resources with resources distributed among Collaboration members and maximizing the benefits of the specialized expertise of each collaborating institution, both in M&O and in analysis.

The distributed model is illustrated in Figure 4.1-5. Analysis tasks are divided among channel working groups and physics working groups. The channel working groups perform initial analysis at the level of the topology of the IceCube events. They also develop and benchmark new reconstruction algorithms, energy estimates, and filtering scripts. The physics working groups develop the high-level analysis strategies as well as the specific tools needed to execute the analyses. The physics working groups also debate the statistical interpretation of results and updates on physics scenarios. IceCube data analysis is coordinated by the IceCube Collaboration under the leadership of the analysis coordinator, a position appointed by the spokesperson with concurrence of the ICB. Analysis funding is provided directly to the IceCube collaborating groups by their respective funding agencies.

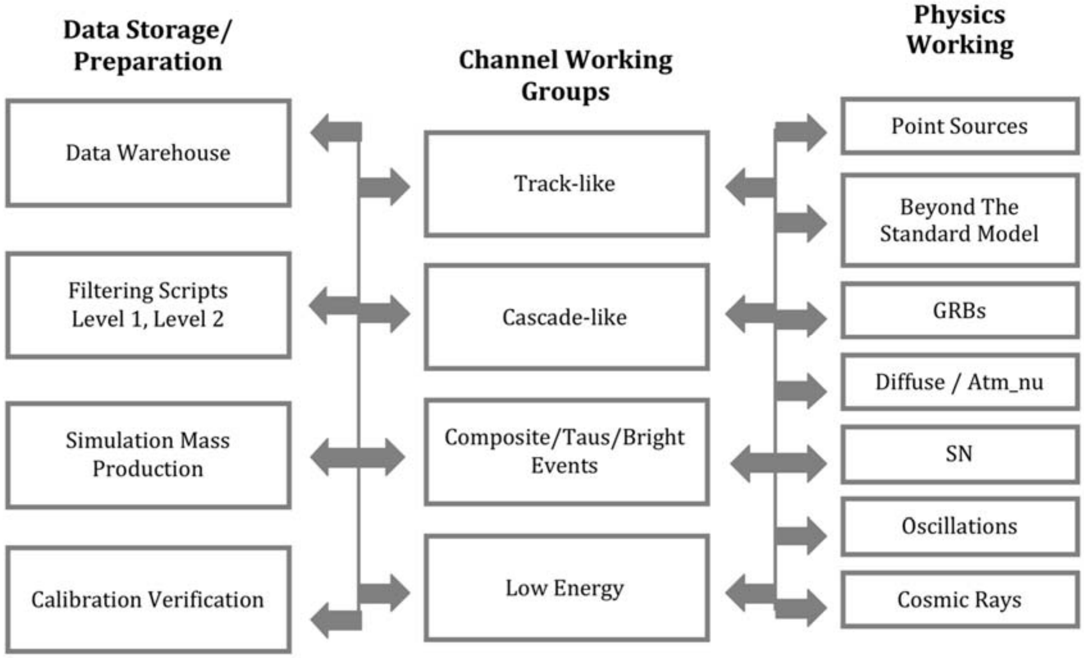


Figure 4.1-5. Data Analysis. *Shown is a schematic view of the distributed data analysis organization and its connection with M&O data storage and preparation functions.*

The analysis coordinator uses several communication mechanisms to coordinate analysis activities and ensure high-quality data analysis using the best resources available to the Collaboration. The weekly data analysis teleconference discusses activities of the physics working groups and their connection with the channel working groups. The physics working groups hold biweekly teleconferences, supplemented by two weekly plenary teleconferences on topics of more general interest.

Conscious and unconscious biases can impact the robustness of physics analyses and results. IceCube has adopted the Collaboration policy to perform analyses in a “blind” manner to prevent the analyzer from biasing the result toward their own preconceptions while their analysis is under development. Application of blindness can be performed in different ways, including time and direction scrambling, and restricting analysis development to smaller subsets of the data sample. The blinding policy for IceCube does not prevent full exploration of the data, especially for calibration, verification, and reconstruction. Moreover, in the event of multiple analyses of the same data sample, the unblinding of one analysis does not bias the status of any other analysis. Application of this policy is neither centralized nor controlled by a specific authority; rather, the physics working group assigned to perform the analysis is responsible for blinding the final answer while analysis procedures are being set. Once the analysis is approved by the Collaboration, the permission to unblind is granted, and the final results are produced.

4.1.8.2 Publication Committee

After discussion and positive reception by the Collaboration of the results of an analysis, a working group produces a draft paper with supporting web pages. To be acceptable for publication, physics papers must have significantly better sensitivity than previous IceCube published results and/or demonstrate a substantially improved method. The Publication Committee regulates and manages the review process for IceCube papers. It consists of senior physicists, the analysis coordinator, and the Collaboration spokesperson. The Publication Committee sets standards and procedures for publication of papers and conference proceedings to ensure a high standard of quality and integrity for IceCube scientific papers. Moreover, through organized review panels, the Committee participates actively in the refereeing process of each paper and contribution to conference proceedings.

4.1.9 Milestones

On an annual basis, the management and operation of the ICNO involves the following periodic activities (Figure 4.1-6):

Month	Activity
January – December	Assess annual computing needs, augment central cluster as required
March	Submission of Support Information Package (SIP) for following polar season
April	Submission of interim 6-month project report to NSF program officers
April – May	Spring meeting of the IceCube Collaboration
May	Start of IceCube annual run
May	Recruitment of winterover experiment operators for following polar season
June	Annual submission of M&O Plan
June – September	Purchase and testing of equipment for following polar season
August – September	Winterover training
Early September	Season safety and readiness review
Late September	Shipment of equipment to Pole
September – October	Fall meeting of the IceCube Collaboration
October	Submission of annual project report to NSF program officers
November – February	Polar season – maintenance/upgrades

Figure 4.1-6. Management & Operations Periodic Milestones

In addition, several high-level project milestones have been identified (Figure 4.1-7). Detail on longer-term project technical goals will be further developed in subsequent M&O Plan documents.

Date	Milestone
Nov 2016	Completion of XSEDE computing allocation
Sept 2017	Completion of long-term archive baseline data import to NERSC
Oct 2017	PY2 M&O review
Jan 2018	Deployment of scintillator panels based on SiPM photodetectors
Jan 2018	SPS computing upgrade phase I complete
TBD	Integration of IceCube HTC into OSG
Jan 2019	SPS computing upgrade phase II complete
Jan 2019	Deployment of scintillator panels with new data acquisition system
Mar 2020	PY4 M&O review
May 2021	Final project report M&O 2016-2021

Figure 4.1-7. Management & Operations High-Level Milestones

4.1.10 Reports and Reviews

The IceCube Neutrino Observatory reports are distributed within the IceCube organization, including the Collaboration, host institution, and various advisory and oversight committees, and are submitted to the National Science Foundation.

Annual Report. The annual report will describe progress made based on objectives in the annual M&O Plan. Significant differences between planned and actual accomplishments will be discussed. The report will consist of a summary of work accomplished during the reporting period, including major technical accomplishments, an assessment of current or anticipated problem areas and corrective actions, and progress in the area of project governance.

Interim Report. The midyear interim report will include a brief summary of the status of all M&O activities, including a section on the overall status and performance of the data handling and detector systems. It will also include highlights and accomplishments, specific comments on detector performance such as uptime and scheduled maintenance, failures, software releases and test results, major procurements planned or placed, an assessment of the overall labor effort, and any other performance data that is needed to characterize the overall data system performance.

Final Report. The final report will include a summary of all 60 months of the IceCube M&O award.

Common Fund Annual Report. The Common Fund (CF) report is prepared by the IceCube resource coordinator on an annual basis. The IceCube M&O Common Fund was created 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. The Common Fund report summarizes the status of past CF contributions and expenditures. In addition, the report includes a list of the major annual upgrades to the South Pole System (SPS), South Pole Test System (SPTS), UW data warehouse and UW data center.

Annual Reviews. NSF will conduct reviews of the IceCube Management & Operations activities through annual site visits of cognizant program officers that will address management issues, cost and performance objectives, and scientific and technical performance. The NSF may also conduct site visits and reviews on special topics. An external panel review covering, at a minimum, project management, cost and performance objectives, and scientific and technical performance will be organized after the second and fourth project years to inform NSF's decision on potential pathways for the support of IceCube M&O activities beyond 2021. NSF will invite IOFG members to participate in this review.

4.2 Management & Operations Plan

Building on our past experience, we have developed a plan to maintain and operate the detector and manage our collaboration resources to go from raw data to physics publications in a timely and efficient manner. Our plan maximizes IceCube's scientific potential and educational value by distributing both analysis and M&O tasks among collaborators. This structure draws the best expertise from collaborating institutions while also offering opportunities to educate scientists and engineers through hands-on experience with IceCube.

We provide accountability mechanisms in MoUs and strong leadership to coordinate distributed resources. In this section we present our plan by explaining how we will perform each task required to meet the technical requirements and specifications described at a top level in Section 3 and listed in detail in this section.

The operations organization has six primary elements: program coordination, detector maintenance and operations, computing and data management services, data processing and simulation services, software, and calibration:

1) Program Coordination: management and administration, engineering and R&D support, USAP support and safety, coordination of education and outreach, communications and other services typically provided by a scientific host laboratory.

2) Detector Maintenance and Operations: run coordination and winterover personnel, data acquisition (DAQ), online filters (PnF), detector monitoring, experiment control, surface detector operations, and supernova system.

3) Computing and Data Management: filtering data at South Pole for satellite transmission, incorporating data into the data warehouse; maintenance of data warehouse and UW data center and support the distributed computing infrastructure. Maintenance of data archiving system, networking and security infrastructure, core online/offline software code repository and build system.

4) Data Processing and Simulation Services: manage and execute production of offline data processing to generate general-purpose Level 2 data (with refined event reconstruction) and science working group specific Level 3 data (with event reduction defined by channel working groups). Manage and execute production of simulation data to provide sufficient cosmic-ray-induced and neutrino-induced events in the IceCube observatory for all physics working groups. Produce simulation data at the general-purpose Level 2 and provide the tools for working groups to produce Level 3 data. Coordination of the regular release of science-level experimental data from refereed-journal published results and the release of real-time alerts authorized by the Real-Time Oversight Committee.

5) Software: managing simulation software tools and maintain detector simulation software (IceSim), maintain and verify simulation of event generation, photon propagation and geometry calibration. Develop core common reconstruction tools in order to process raw waveform data to ultimately reconstruct muon tracks, shower events, direction, energy, and background probability of in-ice events, as well as to reconstruct cosmic-ray air showers. Develop and maintain high-level analysis tools to maximize the efficiency of turning reconstructed data into physics results. Perform data quality checks to support final selection of science-ready data and coordinate, develop and monitor common reconstruction for offline data processing.

6) Calibration: translation of detected quantities such as time and charge into physical quantities such as particle type, energy, and direction requires an understanding of the detector response to photons travelling through the glacial ice medium. Moreover, it demands an understanding of the ice itself. This area manages the activities and data needed to achieve both of these goals.

4.2.1 Program Management

4.2.1.1 Program Administration

The primary program administration task is to ensure that the resources needed to perform each task, regardless of source, are available when needed and used efficiently to accomplish the task requirements and achieve IceCube's scientific objectives.

Operations Management and Science Support. We provide leadership to manage the effectiveness and efficiency of all services and ensure communication among the Collaboration, NSF, partner funding agencies, and the M&O functions. We prepare strategic plans and conduct formal risk management to achieve objectives.

Computing Infrastructure Management. We manage computing resources to maximize uptime of all computing services and availability of required distributed services, including storage, processing, database, grid, networking, interactive user access, user support, and quota management.

Financial Management. We manage IceCube finances, including NSF funding, a Common Fund supported by cash from the European and Asian Pacific collaborating institutions, and in-kind contributions from collaborating institutions, providing accountability through an audit trail for all funds regardless of source. The complete description of the funding sources can be found in section 5.1 "Funding Sources."

Performance Management and Reporting. In cooperation with NSF, we establish performance measures that are meaningful to evaluating our performance against M&O objectives. Performance measures are shown in Figure 4.2-1. We also establish with NSF a set of reporting deliverables that fulfill NSF internal and external requirements for oversight.

Key Performance Indicator	Annual Objective	Rationale
Detector Uptime	99%	Key performance measure of time that the detector was sensitive to transient astrophysical events or signals
Detector Clean Uptime	95%	Key indicator of production of pristine data for physics analysis with no contamination and no serious alerts
Supernova System Uptime	95%	Performance measure of time that the detector was sensitive to Galactic core-collapse supernova events
IceCube Live Uptime	99.9%	Critical to ability to resolve detector performance issues
South Pole System Uptime	99%	Critical to collection and storage of data
Latency Raw to L2 Processed Data	2 weeks	Demonstrates maturity in the processing pipeline, reduces time to release of highly significant astrophysical phenomena to the community

Figure 4.2-1. Proposed Performance Measures

4.2.1.2 Engineering and R&D Support

The engineering and R&D tasks are limited to the minimum tasks required to support day-to-day operations of the detector. R&D supports efforts to address electromagnetic interference (EMI) in the Dark Sector, snow depth mitigation for the IceTop array, enhancements to the performance of the IceCube Laboratory electronics and computing, and the ability to interface with externally funded R&D activities, especially those that intend to use the IceCube facilities, infrastructure, or data flow.

4.2.1.3 USAP Support and Safety

IceCube personnel prepare detailed support requirements and identify the most cost effective approach to meeting the requirements, through the annual planning cycle, direct communication with the NSF Antarctic Support Contractor, and the submission of the Support Information Package (SIP). Safety of personnel and equipment is vital to the smooth operation of a facility. This area is also responsible for ensuring that IceCube M&O personnel and collaborators participating in the USAP comply with USAP and follow good practice when deploying to the South Pole or otherwise working in the context of the program. Pre-season planning reviews will streamline logistics and address safety concerns.

4.2.1.4 Education and Outreach (E&O) Coordination

As a part of the IceCube Collaboration MoUs, each member contributes support to E&O. The associate director for education and outreach, working with NSF and IceCube leadership, establishes E&O priorities, provides support to ongoing activities, and responds to outside requests that support priorities by identifying appropriate resources within the Collaboration, assigning tasks, and providing oversight. Figure 4.2-2 describes examples of ongoing and high-impact IceCube E&O activities.

E&O Activity Title	Description	Benefit
Enhance STEM interest and understanding of K-12 students	Reach high school students and teachers through IceCube Masterclasses, internships, and the Upward Bound program, and K-12 classrooms through webcasts from the South Pole.	Provide connections to ongoing science and to working scientists and staff, including targeted programs for underrepresented groups.
Undergraduate research experiences and high school teacher South Pole deployments	Increase STEM awareness through undergraduate research experiences and South Pole deployments for high school teachers who are integrated into the UWRF Upward Bound (UB) program.	Provide firsthand science experiences for undergraduates and high school teachers, provide role models to inspire next generation STEM professionals.
Developing captivating media to communicate science	Craft accessible multimedia resources that describe IceCube science and technology. Ongoing efforts include creating inviting web content, designing and producing graphics for E&O programs and events, and developing portable scale models of the detector, with LEDs to display data.	Contribute to the NSF Broader Impact goal to "build the capacity of the Nation to address societal challenges using a suite of formal, informal, and broadly available STEM educational mechanisms."
Communication workshops	Build internal E&O capacity by developing and implementing semiannual communication skills workshops in conjunction with IceCube Collaboration meetings.	Strengthen ability of STEM practitioners to communicate science and technology in accessible language appropriate for an intended audience of STEM professionals.

Figure 4.2-2. Examples of E&O Activities

4.2.1.5 Communications

IceCube communication efforts, in support of the collaboration, include disseminating information about IceCube and our activities through press releases, news articles, and other means to reach audiences that are growing both in number and in diversity. We will also increase audience reach through our digital channels (website and social networks), produce more multimedia content, and develop additional multilingual materials, especially in Spanish. Finally, we will continue working with organizations representing underrepresented communities to increase the visibility of IceCube in their communities through articles in their media and participation in their training and outreach programs.

During the first year of this grant, we expect to produce 2-3 press releases and several dozen news articles for our website. In addition, we will start regular production of videos to explain the IceCube detector and its science, from neutrino astronomy to neutrino oscillations and other topics, to lay audiences. One goal of these videos is also to show the diversity of the IceCube team, especially highlighting the contribution of young researchers. The videos will be shot in English and later subtitled, first in Spanish and likely a few other languages.

In conjunction with newly produced audiovisual resources, we will relaunch our YouTube channel to achieve the full potential of audiovisual communication. Videos will boost views to our website and create synergies with users from other social networks.

4.2.2 Detector Maintenance and Operations

The IceCube detector maintenance and operations manager is accountable for the overall performance of the people, hardware and processes required to execute the operational plan of the detector at the South Pole in order to acquire high-data quality, meet necessary data throughput rates, provide appropriate technical documentation, maintain a problem reporting system, maintain a software library and revision history, and demonstrate overall system sustainability.

The detector M&O manager holds weekly phone calls with the detector operations group on run coordination and detector operations matters, prepares periodic reports to NSF, prepares budgets, manages expenses, serves as a member of the Coordination Committee, resolves personnel matters, organizes planning for the austral summer, supports the SPTS, and is generally responsible for the overall coordination and performance of the detector through management of subsystem leads.

4.2.2.1 Run Coordination

During normal operations, the run coordinator ensures that data is being taken with high uptime and that the data is of the highest quality, with emphasis on data stability. The austral summer brings increased activity to the detector through planned maintenance of the computing networking and detector subsystems.

The run coordinator oversees the detector-related activities of subsystem experts and operators both at the South Pole and in the Northern Hemisphere, carefully documenting the run operation and auditing its effects on the data. All special operations requests are reviewed by the run coordinator to ensure the stability of the detector. Documentation and communication include weekly monitoring reports, daily reports of data transfers from the South Pole, e-mail alerts on error conditions, regular data verification reports, weekly winterover reports, and other communications with stakeholders using a variety of media.

4.2.2.2 Data Acquisition (DAQ)

The basic DAQ hardware surface component is the DOMHub, a rack-mounted computer that houses both commercial and customized hardware and is connected to up to 64 DOMs. A GPS master clock system provides accurate timing to the DOMHubs. The DOMHubs and their internal components, as well as associated cabling, must be maintained to prevent malfunctions and repaired quickly as necessary to minimize detector downtime and maintain a high quality of data.

The winterovers maintain and repair the DAQ hardware at the South Pole; the monitoring and paging system alerts them to failures of any DOMHub components, at which point they can exclude the faulty hardware from the detector while it is repaired. Upgrades to the hardware are tested at the SPTS and/or PCTS prior to deployment at the SPS.

A number of custom surface hardware components contain obsolete parts and cannot easily be remanufactured. While the failure rate of these components is currently low relative to the inventory of spares, support engineers investigate alternative solutions using modern electronics as a contingency plan in case an upgrade is necessary to maintain the operation of the detector.

DAQ software collects raw hits from the individual DOMs, rejecting noise hits and forming triggers with all the relevant data for physics events in the detector. Additionally, all raw hits from the detector are buffered for a limited time and can be saved for analysis in special cases (HitSpooling). Diagnostic and calibration data are also collected, as are raw counting rates for all DOMs, used for the supernova triggers. Performance of the DAQ software is a major driver of the quality of data for physics analysis.

DAQ software engineers are accountable for the uptime of the DAQ and the integrity, correctness, and completeness of the data it produces. They also provide appropriate documentation for the operators.

They regularly test and upgrade DAQ software systems—including DOM software, DOM readout card device drivers, DOMHub software, triggers, event builder, secondary builders, and control scripts—while responding to evolving science needs. The software engineers also maintain interfaces to other online systems, including the supernova DAQ and detector monitoring.

Collaboration physicists from physics working groups, using Monte Carlo simulation of signals, develop new triggering algorithms for use in the DAQ. Physics working groups propose new trigger algorithms to the Trigger Filter and Transmission (TFT) Board. Once approved by the board, the triggers are adapted, tested and deployed within the DAQ triggering system.

The DOM firmware consists of a low-level FPGA design that controls the DOM hardware. A DOM firmware engineer supplies required FPGA modifications, maintains the code base, and updates documentation as needed. New physics requirements and hardware/software upgrades during the experimental program may require additional features in either the DOM or DOR FPGA designs.

A small fraction of DOMs (0.4%) have malfunctioned and must be operated as part of normal data taking in a nonstandard configuration. A typical solution is to bypass the failed or malfunctioning component within the DOM or to bypass the DOM completely. The detector operations group, working with the winterovers, excludes problem DOMs from the array and creates new standard run configurations as needed, tracking problem DOMs and performing studies on problem DOMs to develop solutions or workarounds that minimize impact of malfunctions on data quality.

4.2.2.3 Online Filters (Processing and Filtering—PnF)

The volume of data produced by the data acquisition system exceeds the limited bandwidth available in IceCube's TDRSS satellite allowance. An online processing and filtering (PnF) system is used to apply a set of first-level event selections to the collected data, transmitting only those selected events. PnF system expertise is required to maintain the online system, ensure filters are being properly applied, and respond to and debug unexpected errors.

PnF system experts maintain the online system, ensure filters are being properly applied, and respond to and debug unexpected errors. This effort ensures that the online filtering system produces the highest quality data. Maintenance is performed at the start of each new physics run and on an as-needed basis at other times. This will include requests from the TFT Board to support new analysis priorities and alert categories.

The online PnF system supports several event formats, including highly compressed formats that allow for more efficient use of IceCube's satellite bandwidth and have enabled a new set of filters to be added. Additionally, all events are saved using this compressed format at the South Pole, allowing for reduced archival data sample sizes.

Collaboration physicists and software engineers work together to define fast, robust analysis schemes that can alert other telescopes for follow-up observation of interesting events, localized in time and/or direction. The online follow-up system sends a continuous stream of neutrino events to servers in the Northern Hemisphere, using the I3MS Iridium system, and a real-time alert system is in place for high-energy starting events (HESE), IceCube's most signal-rich sample of astrophysical neutrinos.

4.2.2.4 Detector Monitoring

The IceCube Live detector monitoring system provides a comprehensive set of tools for assessing and reporting of data quality. It collects raw subsystem data on the SPS during and on completion of a run. It then sends these data to the Northern Hemisphere via satellite where they are processed and presented through a web-based user interface. The system is critical to the ability to perform short-term and long-term analyses of detector performance.

The monitoring coordinator oversees development and testing of the monitoring system, which is implemented by IceCube Live software engineers and other operations subsystem experts. IceCube collaborators participate in daily monitoring shift duties by reviewing information presented on the web pages and evaluating and reporting the data quality for each run. The shift takers, frequently graduate students, compile reports on detector performance during their shift. A summary of the monitoring shift is given at weekly teleconferences, where experts determine if the detector is operating as expected or take action to correct malfunctions.

Problems can occur with individual DOMs, groups of DOMs, DOMHubs (entire strings), or racks of DOMHubs (groups of strings). Detector operators and winterovers must be alerted immediately when a problem occurs since the loss of a single DOM affects the overall quality of the data. Automatic alerting and automatic diagnosis of the problem help to limit the amount of time of a detector outage or degradation in data quality. The detector operations group and IceCube Live software engineers work with SPS system administrators to maintain and develop the automatic alert paging and e-mail system.

4.2.2.5 Experiment Control

The IceCube Live experiment control system integrates control of all of the detector's critical subsystems into a single, virtual command center. It provides an interface for monitoring the detector both via automated alerts and with interactive screens for displaying the current and historical state of the detector and associated subsystems. Web-based and command-line user interfaces provide maximum accessibility and flexibility to the operators located both locally at the South Pole and remotely in the Northern Hemisphere. IceCube Live is mirrored on SPTS to test upgrades and changes before deployment. Data quality designations for each run period are collected and indicate to the collaboration which data can be included for further processing and analysis.

The IceCube Live software engineers are accountable for uptime of IceCube Live and for maintaining, troubleshooting, supporting and evolving the interface to subsystems that control and monitor the detector. The software engineers continue to develop IceCube Live to integrate all subsystems, and add features as the behavior of the detector changes. During stable operations, the software engineers support physics working groups and operators to add needed functionality and respond to evolving science needs.

4.2.2.6 Surface Detector Operations

IceTop by itself includes all aspects of a major experiment, requiring its own tools for calibration, monitoring, reconstruction, and simulation. The IceTop DOMs are embedded in ice contained in tanks on the surface, which are subject to environmental changes that must be monitored. Data rates in individual DOMs are significantly higher, and typical signals are much larger than in the deep detector. In addition, specialized modes of operation are required to maximize IceTop's science potential, which includes the study of solar particle activity and high-altitude weather in addition to cosmic-ray science.

An IceTop data specialist coordinates monitoring of the physical condition of the IceTop detectors, including annual surveys of snow accumulation above the tanks and surrounding environmental conditions at the South Pole. The data specialist also coordinates monitoring the quality of IceTop data and any corrective actions required to address malfunctions or other conditions that degrade IceTop data.

Snow accumulation above the IceTop tanks increases the energy threshold of the detector for cosmic-ray air showers and decreases the trigger rate by approximately 15% per year, negatively impacting the science capabilities of the array. Initial maintenance and operations included snow management plans that involved removal of the snow from the tanks; however, the support cost of this approach has proven burdensome, and it has been discontinued.

The efficiency of the array is being restored by installing low-cost scintillator modules above the IceTop stations. Four prototype modules have been installed in the 2015–16 austral summer season and use existing IceCube cabling to connect back to the ICL. A support engineer is responsible for refining the design of the modules for deployment over the full IceTop array over the next five years, including a new cabling system to connect to the ICL.

IceACT is a prototype air Cherenkov telescope (ACT) deployed at the ICL in the 2015--16 austral summer season. The instrument uses a 50.7 cm Fresnel lens with a 12º field of view and a 7-pixel SiPM camera to detect the atmospheric Cherenkov light from cosmic ray air showers during dark, cloud-free periods of the polar night. Air showers are measured in coincidence with IceTop, using a DOM mainboard to timestamp trigger signals and record them in the IceCube data stream. Coincident air shower events will be used to extend IceTop's energy reach to below 1 PeV, to validate IceCube's absolute pointing, and to calibrate the veto efficiency of IceTop for atmospheric muons and neutrinos.

4.2.2.7 Supernova Operations

Supernova data acquisition (SNDAQ) receives the single photoelectron trigger scalar data produced by IceCube DAQ software and looks for a rate excess over the entire detector. For runs with no rate excess, the data are compressed to monitor the entire detector. In the event that an excess is found, an alarm is issued and sent via the IceCube Transport System (ITS), and more detailed data are saved, including all untriggered DOM readouts (HitSpooling). If monitors conclude that the alarm is significant, an additional alarm is sent to the Supernova Early Warning System (SNEWS).

Collaboration scientists are responsible for SNDAQ development. Core software engineers are responsible for integrating SNDAQ into the experiment control, monitoring, and DAQ systems. The supernova working group maintains a shift system to ensure that at least one monitor is checking alerts at all times.

4.2.3 Computing and Data Management

The computing and data manager is accountable for the overall performance of the personnel, hardware, software, and processes required to support IceCube computing and data management from detector event to publication. The manager holds weekly teleconferences on operations issues, provides input to status reports to NSF, prepares and manages budgets, serves as a member of the Coordination Committee, and develops long-term strategies to maximize the benefit to IceCube science from evolving computing and data management technologies.

4.2.3.1 Data Storage and Transfer

Data is transferred from the South Pole using two mechanisms: 1) short messages and monitoring information over a system using Iridium satellites and 2) over the dedicated high-capacity SPTR (South Pole TDRS Relay) system for the bulk of IceCube data. About 100 GB of filtered data is transferred daily via satellite. The total amount of data generated by IceCube in one day is about ten times larger, at 1TB. Two copies of this data are archived on disk at the South Pole and are shipped to UW–Madison once a year, during the austral summer, for long-term archive.

IT specialists monitor and archive the data transfer from the South Pole. They address specific high-priority transfer needs that are requested by the Detector Operations team during data taking or any data related issues that might arise for the near real-time data processing.

A software engineer maintains the data handling software JADE. JADE manages the data collection and storage at the South Pole, the satellite data transfers, the data ingest at the UW–Madison data warehouse and the replication to external archive sites for long-term preservation. One of the goals of this project is to improve the functionality of the data handling software by adding missing key features such as the capability to efficiently index the metadata. A new catalog service will be developed that will provide users access to the file metadata database and will enable efficient searching of any file produced by IceCube. This tool will also allow managing storage allocations or data retention policies in a more efficient way.

Data from the detector is processed, analyzed, and stored in intermediate and final stages at the UW–Madison disk storage infrastructure. System administrators operate the data storage infrastructure and ensure that active data is available and that the system provides the required performance and capacity.

The storage system administrators also handle periodic hardware and software upgrades to the storage infrastructure and take care of cluster file system operations such as accounting, quota management, disk server load balance, etc. In order to benefit from technological improvements in storage density and energy efficiency, the baseline plan is to replace the disk systems every five years.

Of the 1 PB of data generated every year, about 700 TB will need to be archived and preserved in the long term due to their uniqueness or their relevance to reproducing published scientific results. The most cost-effective technology for archiving this data is magnetic tape. Automated tape libraries at the PB scale are not commodity infrastructure in terms of hardware or software. There are very high maintenance and fixed costs associated with operating them. In order to provide cost-effective long-term data preservation services, we leverage large data centers at collaborating institutions NERSC and DESY-Zeuthen that already operate on a large scale and can provide long-term data archiving and curation as a service.

A software engineer is developing a software layer to interface the IceCube data warehouse and the remote long-term archive systems. This service will manage data transfers and will ensure that data products stored in the long-term archive are registered in the data catalog so that they can be found and accessed transparently by IceCube applications.

4.2.3.2 Core Data Center Infrastructure

IceCube requires a flexible and highly available set of computer systems to support operations. Some are highly visible and transversal, such as e-mail or authentication services. Others are more focused and less visible but play equally vital roles in science outcomes. Examples of these are application servers to host real-time alert services or experiment monitoring services for remote shifters.

Given the size and distributed nature of the IceCube computing infrastructure, the network is a core component. One of the key issues in designing and operating the IceCube data center network is to ensure that it is optimized for high-volume bulk data transfers while keeping critical infrastructure secure. For bulk data movement, a Science DMZ has been implemented to provide adequate performance and appropriate compensating controls to ensure the security of those services.

IceCube network administrators are responsible for uptime and performance optimization of the IceCube network, which includes maintenance, support, configuration, and customization of the system when necessary. They also monitor the health of the devices and configurations to identify system bottlenecks and potential hardware problems and analyze security logs for suspicious behavior and traffic signatures. During operations, network administrators respond to the needs of scientists, software developers, project engineers, and detector operators to maximize network reliability and provide customized solutions to optimize performance.

IT specialists maintain a cybersecurity program at the UW–Madison data center. These activities ensure that the policies and security controls continue to provide access for legitimate users within the IceCube Collaboration but maintain a highly secure network environment that is robust against hostile attacks. In particular, ensuring secure and stable operation of the detector computing systems at the South Pole and the data handling facilities at UW–Madison remain a priority. In addition, we maintain contact with other NSF large facilities and cybersecurity programs such as the Center for Trustworthy Scientific Cyberinfrastructure (CTSC) to share knowledge and ensure that WIPAC’s practices are consistent with those accepted in the larger community.

4.2.3.3 Central Computing Resources

In order to efficiently process and analyze the large amounts of real and simulated data involved in the IceCube analysis process, a large HTC cluster is available for the Collaboration at the UW–Madison data center. The system is closely coupled to the storage infrastructure for efficient data processing.

Graphics processing units (GPUs) have been found to be a very effective resource for simulating photon propagation in the ice. A GPU-based cluster is available at the UW–Madison data center as part of the

HTC cluster infrastructure. The current IceCube HTC cluster at UW–Madison consists of nearly 200 servers providing a total of about 7000 CPU and 350 GPU job slots. The cluster uses the HTCondor software for job scheduling and management.

IceCube system administrators maintain and operate the cluster. They collaborate closely with the HTCondor development team at the computer sciences department of UW–Madison, providing feedback on specific use cases and ensuring the system fulfills IceCube's evolving needs.

In order to benefit from technological advances and improvements in energy efficiency, the baseline plan is to replace the servers in the HTC cluster every five years.

4.2.3.4 Distributed Computing Resources

To obtain the computing resources required to process vast amounts of data, IceCube relies on distributed resources available from Collaboration institutions.

In addition to the collaboration resources, IceCube will continue to tap into opportunistic resources (mostly from Grid projects in the US and Europe) as much as possible. This is an effective and efficient way to produce larger statistics of simulated data, enabling the higher precision required for some analyses.

Several of the nation's most advanced computing systems that are part of the Extreme Science and Engineering Discovery Environment (XSEDE) have GPU nodes. This makes them especially attractive for their potential in increasing IceCube simulation capabilities. Our goal is to actively explore the possibility of using these resources for generating IceCube simulation. We will regularly request compute time allocations and work together with XSEDE expert personnel to develop interfaces for integrating these resources into the IceCube distributed workload management system.

The efficient use of distributed resources requires coordination among the different sites as well as the use of Grid software such as job meta-scheduling and data access tools. IceCube system administrators maintain and operate the core services of this IceCube Grid infrastructure. Wherever possible, standard tools are used to manage the Grid resources, which engineers then interface with IceCube specific software. In order to manage this process efficiently, it is essential to maintain close contact with the distributed scientific computing community. We ensure this by participating in the Open Science Grid (OSG) project and the National Data Service initiative. One of the goals of this project is to integrate the IceCube HTC cluster into OSG, contributing back to this large research infrastructure that is so important for our mission.

The data generated in this large distributed infrastructure is transferred back to the central data warehouse at UW–Madison using high-throughput links and the GridFTP protocol. IceCube system administrators manage the middleware services needed for providing high-performance remote access to the data.

4.2.3.5 South Pole System (SPS)

The SPS is a computing system developed and maintained by IceCube system administrators that supports the data acquisition and filtering tasks carried out by the detector real-time systems. The SPS hardware includes DOMHub computers, commodity server class computers, and network hardware. It also contains infrastructure services such as DNS, mail, monitoring, and databases.

The operating system and configuration management tools used on the SPS are the same as the ones used for all services in the UW–Madison data center. This allows system administrators to apply consistent procedures across systems and efficiently manage version control, patching, software updates, monitoring, and maintenance.

The computer servers in the SPS will be replaced on average every four years in order to profit from technological advances that maximize computing power per kilowatt and minimize the risk of component failures.

The IceCube network connects the detector systems in the ICL and the South Pole station with the USAP network and, through that, with the data center at UW–Madison. It must comply with policies and regulations of NSF and the University of Wisconsin. The SPS system administrators are responsible for uptime and performance optimization of the IceCube network, including maintenance, support, configuration, and customization of the system when necessary. Network support tasks also include monitoring the health of the devices and configurations to identify system bottlenecks and potential hardware problems. The SPS systems are isolated from the USAP and other external networks by means of a firewall. Security logs are monitored for suspicious behavior and traffic signatures.

4.2.3.6 South Pole Test System (SPTS)

The primary purpose of the SPTS is to build and test software in advance of operational deployment in the South Pole System (SPS). Software developers use the SPTS to debug system changes safely in a non-production environment. The close physical and logical match to the SPS allows system maintainers to verify hardware and identify potential system side effects introduced by software upgrades or configuration changes.

IceCube system administrators are responsible for hardware maintenance and operations of the SPTS. During testing, system administrators support software developers and engineers to maximize hardware reliability and provide customized solutions to increase testing time.

Prior to any hardware upgrade in the SPS, thorough evaluation takes place in the SPTS in order to validate and select the best platform to be deployed in production.

DOM hardware engineers maintain and upgrade the system to ensure maximum uptime when the system is required for testing. They provide support to those wishing to add features as required in response to new science needs and to evolve the functionality of the SPTS as appropriate.

The SPTS operating systems software is based on the Scientific Linux distribution and it is kept in synchronization with the SPS system. System administrators are responsible for system maintenance, troubleshooting, and upgrades for the SPTS operating systems. The same mechanisms as in SPS are used for system configuration control, monitoring, and patch management.

4.2.4 Data Processing and Simulation Services

The data processing and simulations services manager is accountable for the overall processing of calibrated data products, including generation of Monte Carlo simulations and offline filtering of data collected by the IceCube detector to support physics analyses by the IceCube Collaboration and final data products to be made publicly available to the scientific community. The manager holds regular teleconferences on production issues and serves as a member of the Coordination Committee in order to work with managers responsible for computing and data management, calibration, and detector operations to address critical issues related to production and to develop long-term strategies to maximize the benefit to IceCube science.

4.2.4.1 Offline Data Production

Data arriving in the north are compressed and stripped of all unnecessary information to conserve transfer bandwidth. In a first processing step, the data must be unpacked and uncompressed, and calibrations must be applied to these data to convert raw DAQ measurements into physical quantities. The reconstructions used at the South Pole to form the filter decisions must then be reapplied to the calibrated data and all intermediate results stored together with the data to allow studies of the filter performance. A software engineer monitors the execution of the processing scripts and verifies regularly the quality of the data.

The complex reconstructions required allowing the suppression of the high muon background from cosmic ray initiated air showers from the neutrino signal are computationally intensive. To make the best use of the computing resources in the IceCube Collaboration, these reconstructions must be run centrally and results made available in the data warehouse for consumption by the different physics analysis working groups. Execution of the processing scripts is actively monitored and the quality of data is regularly verified by members of the production team. Plots of various reconstruction parameters are provided to the Collaboration through a web interface for quality assurance.

4.2.4.2 Simulation Production

Coordination of simulation production and resources involves management of multiple dependencies across M&O and the Collaboration. These include, for example, detector geometry calibration, charge and time calibration, and detector configuration uploaded into the database; maintenance of simulation software; and physics demand and dataset priority agreed with the Collaboration and matched with current computing infrastructure capacity. The simulation production coordinator is responsible for coordinating with other groups in the Collaboration to assess the impact of these tasks on physics analyses and understand issues involving computing infrastructure. The coordinator ensures proper production of data to verify simulation releases before full production is enacted.

In order to detect physics events caused by high-energy neutrinos, the large background of cosmic muons events must be rejected while retaining the highest signal efficiency. Simulation data are essential in this analysis procedure and a large number of cosmic muon events must be produced. The coordinator determines the computing and storage requirements for generation of Monte Carlo simulations and communicates with the data management manager to insure that these needs are met.

Simulation of Cherenkov light in the ice is done by directly propagating individual photons accounting for the state of the art properties of glacial ice. Such component of simulation needs graphics processing units (GPU). GPUs are an essential component of the distributed computing infrastructure. The addition of data filtering and processing adds further complexity. A physicist supports this task by performing runtime basic data checks to verify evident configuration errors; low and high level data verification by comparing simulation data from different production sites and different historical simulation releases to experimental data; and analysis-level data checks expected by working groups for the very early stages of physics analyses. The physicist maintains the simulation production web portal to keep all stakeholders informed of simulation production status and issues.

4.2.4.3 Public Data Products

The IceCube Collaboration already provides public access to event reconstruction information for events selected as neutrinos for specific published results as well as real-time alerts to other observatories around the world in order to provide early warning of interesting cosmic events, share data, and combine observations through collaborations defined through Memoranda of Understanding (MoUs). The plan, as described in the IceCube Collaboration data sharing policy, is to also release primary event data on all events transferred from the detector over the satellite. The data sets will be provided in an open format to be usable by researchers outside of the collaboration. Documentation and tools will be maintained as well.

As usage increases, the public data sets themselves will need to be maintained so that improvements are implemented and issues corrected. Also, user support will be needed so that queries from external users are addressed. A team of two IT specialists will initially take care of developing and rolling out the IceCube open data service. One of them will have a physics-oriented focus, working on the formats and tool specification as well as providing user support. The other will have a technical focus, working on the implementation of web services and other tools needed to make the data accessible to other communities.

4.2.5 Software

The management of the software effort is divided into five groups, each with an individual manager overseeing the effort. The five groups are: core, simulation, reconstruction, science support tools, and infrastructure. The IceCube software coordinator is responsible for coordinating maintenance of all five software groups. The software coordinator also conducts regular software training sessions for IceCube collaborators.

Future efforts will focus on improving the speed, efficiency, and robustness of production software through training, workshops, and the integration of modern tools, such as Clang's Static Analysis, a bug finding tool, into IceCube's development workflow. The goal is to maximize efficient use of all of IceCube's computing resources, such as disk space, CPU, and GPU power while increasing background simulation samples, which is critical for several analyses.

4.2.5.1 Core Software

IceCube's core software library consists of the IceTray framework, a set of basic modules and data containers, and a wide range of open source tools that are used in the development of calibration, simulation, reconstruction, and analysis modules. A robust set of Python bindings is also included, which facilitates the use of advanced analysis environments and 3-D graphical event displays. This group is currently managed by the software coordinator.

Central databases, with mirrors in key locations to enhance efficiency of data access, store key IceCube information such as detector geometry and calibration, configuration, and run summaries. Database locations include the South Pole, Belgium, and Madison. Keeping the contents of these databases well organized, synchronized, operating, and available is key to ensuring that all parts of IceCube data analysis are well understood and repeatable. A software engineer will maintain and extend the database tables and will maintain all code to update and query the database. Continuous support for data insertion at the South Pole and in the Northern Hemisphere provides all necessary information for data processing. In order to simplify long-term maintenance and reduce redundant information, we will develop a new database system that will leverage detector status information already in the IceCube Live monitoring system.

4.2.5.2 Simulation Software

IceCube's simulation software has to cover a wide dynamic range, supporting low energy at the GeV scale as well as ultra-high-energy at the EeV scale, while running on large-scale, heterogeneous computing systems that include batch processing clusters and grids. This requires a dedicated framework (IceProd) to coordinate data set management and result tracking. IceProd is a database-driven scheduling and management software package that catalogs simulation data sets and optimizes the usage of computing resources. Local support by the simulation production coordinators to resolve problems and incompatibilities of different systems is a critical task to maximize resource usage. Computer scientists will maintain configurations of the available resources and adapt to individual policies and restrictions of distributed production sites. As recommended by the SCAP, the system will incorporate third-party Grid middleware products to reduce long-term maintenance associated with an entirely in-house framework. This group is currently managed by a professor from Alberta University.

4.2.5.3 Reconstruction Software

IceCube's reconstruction software runs online for filtering at the Pole and offline in the north, for higher filter levels and as a starting point for analysis. The reconstruction software is managed by a postdoc from Brussels ULB. The reconstruction software historically consisted of 60 extra projects on top of core software. This effort has recently been refactored and shared with a postdoc from Drexel University managing science support tools.

4.2.5.4 Science Support Tools

This new group is a spin-off from the reconstruction group, but is still tightly coupled with the reconstruction effort, since the software will still be bundled together in releases. The purpose of this group is to manage common software tools used at filter and analysis levels beyond L2, including IceCube's open source effort. This group is managed by a postdoc at Drexel University.

4.2.5.5 Software Development Infrastructure

Software development in IceCube is a worldwide, distributed effort with more than 100 contributors and running on several different platforms to maximize grid resources. Critical software development tools, such as a central repository, ticketing system, and continuous build test system, will be maintained by a computer scientist, using industry standards such as Subversion, Trac, and Buildbot.

4.2.6 Calibration

IceCube calibration provides a common set of detector calibration constants that translate IceCube DOM signals into recorded charge and time, which are then used to reconstruct neutrino energy, position, time and direction. As photons typically propagate tens to hundreds of meters in ice before being recorded by a DOM, the measurement of the optical properties of the ice is a critical part of the calibration process. Calibration methods and devices include the onboard calibration electronics, LED flashers, which are co-located on each DOM, cosmic ray muons, a camera, and calibration lasers. Calibration constants are stored in the IceCube database or in the software repository and documented on the internal wiki and Docushare systems.

4.2.6.1 Detector Calibration

The time synchronization of the DOM internal clocks with the master clock on the surface is continuously monitored with the Reciprocal Active Pulsing procedure, the results of which are available in the IceCube monitoring system. Every year, the in-ice DOM discriminator thresholds, high-voltage settings, and other DOM constants are calibrated using the onboard electronics system (DOMcal) and adjusted using data from cosmic ray muons in the ice. IceTop DOMs are calibrated once per month. The run coordinator organizes the calibration runs, which are performed by the winterover personnel, in order to minimize detector down time. IceCube postdocs and students vet this data under the supervision of the calibration coordinator, report the data at weekly teleconferences, and archive the results on the wiki. The calibration constants are stored in the database. The DOM digitizer baseline and PMT and electronics gain are the most important calibration constants for converting raw DOM waveforms to measured voltage and are set to their final values using data from physics runs. The digitizer baselines are monitored continuously with forced-trigger “beacon” launches. The beacon waveforms are collected in the IceCube Live monitoring system and are stored in the IceCube Live database. The PMT gains are continuously monitored with collected charge from cosmic ray muons interacting in the ice, also collected in IceCube Live. Baselines are stable to within 4 microvolts and the gains for most DOMs are stable to within 1%. Monitoring shifts taken in turn by all collaboration members report any deviations, which are then followed up by the calibration coordinator and the operations coordinator as needed.

The DOM effective optical sensitivity in ice is an active area of study, with the aim of reducing our current uncertainty of 10%. PMT quantum efficiency was measured in the lab during the DOM design phase, but local effects of the ice alter the *in situ* efficiency of the DOMs. Cosmic ray muons are used to measure the mean DOM efficiency and will be used to measure the individual variation in DOM efficiency, which is also being studied with LED flashers. Both muon and flasher data are being used to refine the model of the angular variation in the DOM sensitivity. Further precision measurements of the DOM sensitivity are also being carried out in the lab using a DOM in water (previous measurements were in air). Progress of these analyses is reported on in weekly teleconferences, with the results archived on Docushare.

4.2.6.2 Ice Properties

The ice consists of two components: the untouched “bulk ice” between strings and the refrozen “hole ice,” which was melted during IceCube construction and drilling. The optical absorption and scattering lengths of the bulk ice are measured using the LED flashers, which are located on each DOM. Flasher data is collected in dedicated calibration runs during the Antarctic summer, organized by the calibration coordinator, with the data stored in the IceCube data warehouse and documented on the wiki. The hole ice is a current area of study by IceCube students and postdocs, as it modifies the angular acceptance of the DOM due to bubbles trapped in the refrozen column. A camera at the center of the detector has shown that at least in one location, the bubbles were trapped in a dense central column in an otherwise clear refrozen hole. Current modeling efforts are underway using LED flasher data to determine the size, scattering length, and location of this column. Progress of these analyses is reported on in weekly teleconferences, with the results archived on Docushare.

5 Cost Overview

IceCube M&O finance management includes NSF funding, a Common Fund supported by cash payments by European, Canadian and Asian Pacific collaborating institutions, and in-kind contributions from collaborating institutions, providing accountability through an audit trail for all funds regardless of source.

The M&O budgets are based on a detailed, bottom-up analysis of the costs required to complete each task in the M&O Work Breakdown Structure (WBS) (included as Appendix 1 of this plan). These costs are very well understood and are based on actual experience during past years of M&O. There is no explicit budgeting for contingency as was done for the IceCube MREFC project.

5.1 Funding Sources

The NSF IceCube five-year M&O award covers federal fiscal years 2016–2021 (April 1, 2016–March 31, 2021). NSF intends to provide a total of $35,000,000 over the term of five years ($7,000,000 per year), with the support split equally between the Polar programs and physics divisions. The expectation is that annual increases typically expected due to escalation will be offset by efficiencies in the program.

In addition to the NSF M&O award, which also covers the U.S. annual contributions to the Common Fund (CF), other sources of funds for the M&O core activities are the European, Canadian, and Asia/Pacific annual contributions to the CF, NSF analysis base grants and institutional in-kind contributions.

Sources of Funds: there are four different sources of funds for the IceCube M&O program:

NSF M&O Core	This NSF award mostly covers labor, travel and partially capital, M&S & services for: • UW–Madison, six U.S. subawardees, and one UW shared grant • Core activities mostly under detector ops. & maint., computing & data mgmt., program mgmt. • U.S. cash contribution to the M&O Common Fund
NSF Base Grants	The NSF IceCube analysis base grants support labor and travel for: • M&O activities mostly done by graduate students and postdoctoral researchers • Data quality, reconstruction & simulations, calibration, monitoring, filtering & triggering
U.S. Institutional In-Kind	U.S. institutional in-kind contributions mostly cover labor, travel and M&S for: • M&O activities mostly done by faculty and administration members • Fellowships and university funded activities, computing power & cooling
Europe & Asia Pacific In-Kind	Europe, Canada & Asia Pacific in-kind contributions cover labor, travel and HW/SW for: • M&O activities done by non-U.S. scientists, engineers and other team members • Data quality, reconstruction & simulations, calibration, monitoring, filtering & triggering • Non-U.S. cash contribution to the M&O Common Fund that covers most of the capital equipment and service agreements for the computing upgrades

5.1.1 NSF IceCube M&O Award

The following figure describes the NSF M&O award budget by cost categories (Figure 5.1-1) for UW and all US subaward institutions.

Cost Category (including indirect)	FY2016-FY2021
Labor	$26,276
Materials & Supplies	$603
Travel	$1,464
Services and Service Agreements	$1,184
Subawards with U.S. collaborating institutions	$4,936
Capital Equipment	$538

Figure 5.1-1. NSF IceCube M&O Award – *Cost by Category (in $k)*

Labor: The primary basis of estimate for effort level is experience from executing identical or similar tasks in past years. Management judgments applied to estimates include whether past allocations were correct and the extent to which task over time will require the same, more, or fewer resources.

Materials and Supplies (M&S): Expenses related to computing infrastructure are the major cost driver in this category. Cost estimates support several different operational tasks. For example, planned operations require sufficient disk media at the South Pole to store two copies of the raw data, and sufficient resources for the northern data center to perform backups of various storage systems. The plan also includes personal computers, UPS batteries for the South Pole System, physical qualification examinations, calibration and engineering supplies, and spare items such as memory, disk or network expansions. Other M&S expenses include shipping and packing.

Travel: The budget is based on an estimated number of domestic and foreign trips, multiplied by total FTE for each labor category. The travel direct rates take into consideration airfare and transportation, lodging and per diem expenses. Travel expenditures include travel to domestic and foreign IceCube collaboration meetings, training, reviews, IceCube meetings, and travel expenses in Christchurch on the way to/from Antarctica.

Capital Equipment: These include expenditures for computing infrastructure upgrades.

Services and Service Agreements: Computing infrastructure and software maintenance services for the South Pole System, UW data center, data warehouse and networking are the major cost drivers for services and service agreements. This category includes maintenance contracts, licenses, operating systems, warranties, and technical support. Because of the need for high availability and reliability of computing infrastructure, we reduce risk through having service agreements with vendors of major commercial off-the-shelf equipment.

Subawards with U.S. collaborating institutions: The IceCube M&O roles and responsibilities of six U.S. institutional subawards and one UW shared grant are described in Figure 5.1-2.

Institution	Major Responsibilities
Lawrence Berkeley National Lab.	Data acquisition maintenance, computing infrastructure, long-term data archive
Pennsylvania State Univ.	Simulation production, DAQ firmware support
Univ. of Delaware, Bartol Institute	IceTop calibration, monitoring and maintenance
Univ. of Maryland at College Park	Overall software coordination, IceTray software framework, online filter, simulation software
Univ. of Alabama at Tuscaloosa	Detector calibration, reconstruction and analysis tools
Michigan State University	Simulation software, simulation production
Univ. of Wisconsin–River Falls	Education and outreach coordination

Figure 5.1-2: IceCube M&O U.S. Subawards and Shared Grant – *FY2016 Major Responsibilities*

5.1.2 IceCube M&O Common Fund

The IceCube M&O Common Fund (CF) was created in April 2007, the start of formal operations, 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 CF based on the total number of the institution's Ph.D. authors.

The Collaboration updates the Ph.D. author count twice a year at the collaboration meetings in conjunction with the update to the IceCube M&O responsibilities in the institutional Memorandum of Understanding. Effective April 1, 2010, the annual established rate per Ph.D. author is $13,650.

Common Fund Expenditures. 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. The 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 disks 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 Cooperative Agreement with NSF.

The Common Fund expenditures are divided into two categories: U.S. Common Fund and non-U.S. Common Fund.

Common Fund Contributions. The planned contributions to the IceCube M&O Common Fund during the 9th year of IceCube operations (April 2015 – March 2016), is based on the Ph.D. authors head count in the institutional MoUs v18 from April 2015. The actual contributions were about $62k less than planned (Figure 5.1-3).

IceCube M&O	Ph.D. Authors, April 2015	Planned ($k)	Actual ($k)
Total CF Planned	**137**	**$1,870**	**$1,807**
U.S. Contribution	73	$996	$996
Non-U.S. Contribution	64	$874	$811

Figure 5.1-3. Planned vs. Actual CF Contributions – *Year 9 of M&O, April 1st, 2015 – March 31st, 2016*

The following table provides the most recent detailed breakdown of the Ph.D. authors headcount based on MoUs v.20.0, April 2016 (Figure 5.1.-4).

	Total Ph.D. Authors	Faculty	Scientists / Post Docs	Ph.D. Students
U.S. Institutions Subtotal	**78**	40	38	38
Non-U.S. Institutions Subtotal	**61**	38	23	85
Total U.S. & Non-U.S.	**139**	**78**	**61**	**123**

Figure 5.1-4. IceCube Collaboration – *Authors head count based on the institutional Memorandum of Understanding v20.0 (April 2016)*

5.1.3 Institutional In-Kind Contribution

In addition to the U.S. M&O core funds and U.S. base grants support, IceCube MoUs define in-kind contributions of distributed M&O labor and computing resources from collaborating institutions.

This represents a transition from a centralized management and funding approach during IceCube's construction phase to a more distributed model of management and funding for M&O. (Figure 5.1-5).

The distributed model results in increased financial contributions to the Common Fund and in-kind labor contributions to M&O tasks from European, Canadian, and Asia Pacific collaborators. It also results in a greater emphasis on direct NSF funding to U.S. collaborating institutions. In-kind contributions by each collaborating institution are included in the Memorandum of Understanding (MoU). (Summary of the MoU Scope of Work is included as Appendix 2 of this plan).

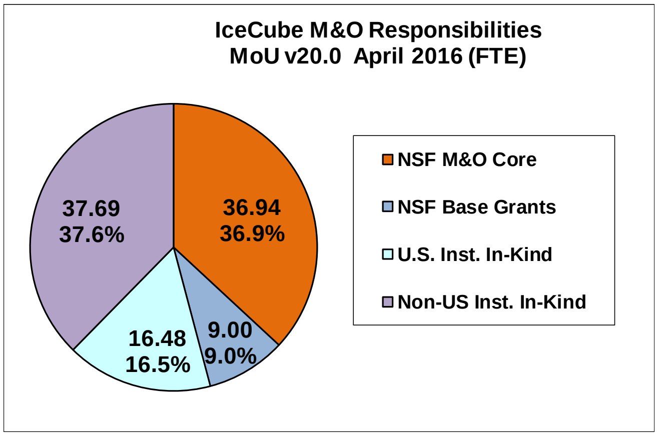


Figure 5.1-5. IceCube M&O Distributed Management and Funding Model (FY2016). *Based on the institutional Memorandum of Understanding v20.0 (April 2016)*

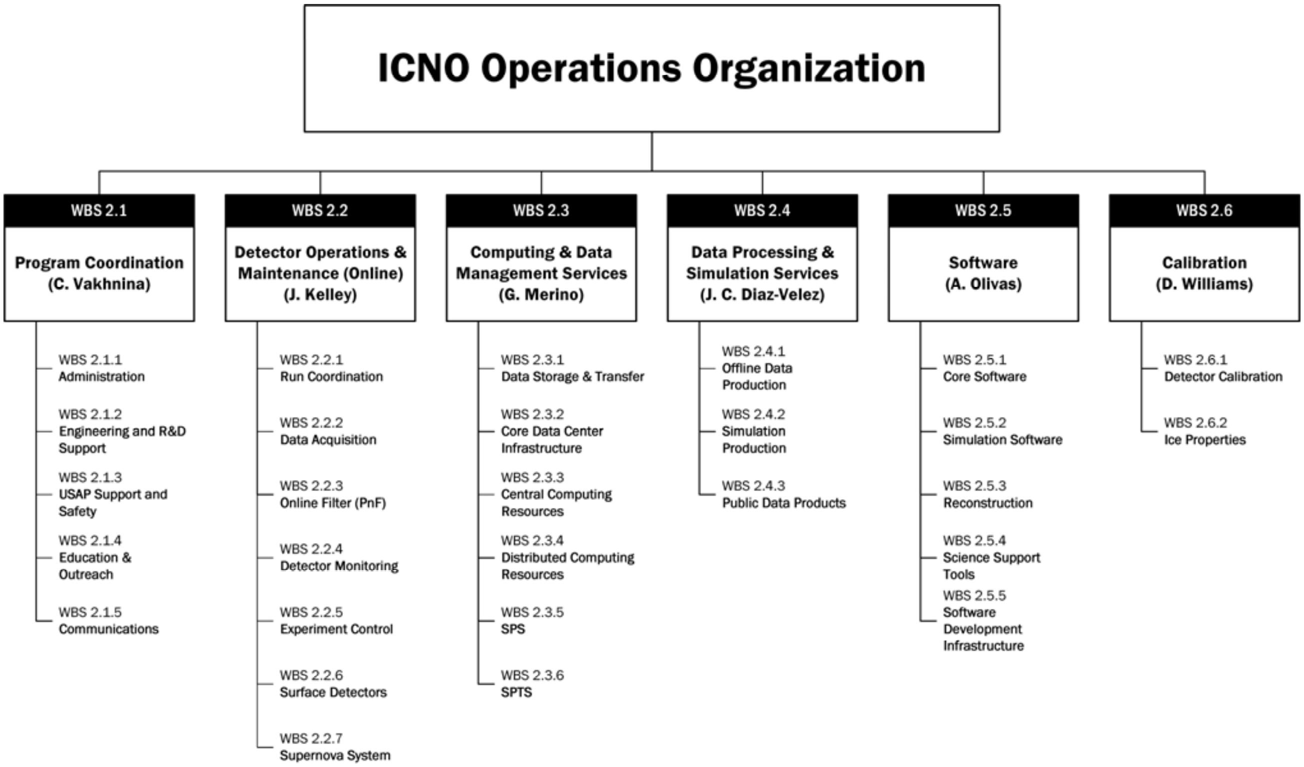
5.2 Computing Infrastructure Upgrade Plan

Computing infrastructure is the major cost driver in IceCube M&O expenses for capital equipment, computing services, and materials and supplies. The annual upgrade plan assumes consolidation of computing and storage infrastructure, with an expectation to upgrade the existing systems both at the South Pole and in the north every 4 years on average. The multiyear computing capacity planning is presented and reviewed periodically at the Software and Computing Advisory Panel (SCAP) meeting. The materials and supplies upgrade plan supports several different operational items, such as disk media at the South Pole to store raw and filtered data and sufficient spare parts for addressing operational issues in the South Pole System during the winter months. Other expenses include software purchases. Computing infrastructure and software both at the South Pole and at UW are also the major cost drivers for service agreements, which include warranties, technical support, licenses, and work by software programming consultants.

Appendix 3 includes a list of FY2016/2021 major IceCube purchases for the South Pole System (SPS) upgrade, for the South Pole Test System (SPTS) upgrade, and for the UW data warehouse and UW data center upgrades.

Appendix 1: IceCube M&O Work Breakdown Structure

May 2016



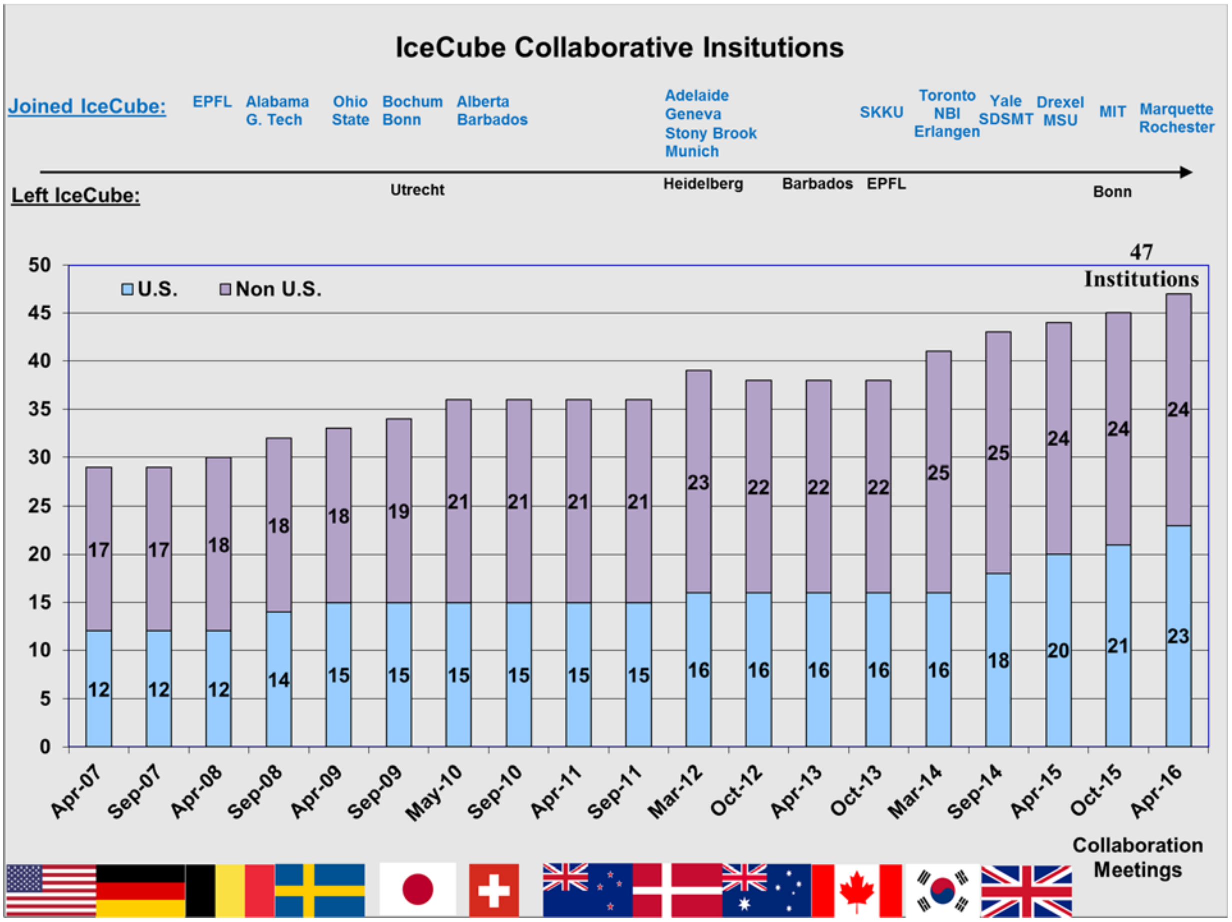
Appendix 2: IceCube M&O Memorandum of Understanding

Effort and Authors Head Count Summary

v 20.0, April 15, 2016	Authors Head Count				IceCube Authors: M&O Responsibilities (FTE)					
Institution (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 Triggering & Filtering	WBS 2.5 Data Quality, Reconstruction & Simulation Tools	**Total**
University of Alabama (Dawn Williams)	2	(2	0	1)		0.20	0.00	0.35	0.20	0.75
University of Alaska (Katherine Rawlins)	1	(1	0	0)				0.20	0.20	0.40
Clark Atlanta (George Japaridze)	1	(1	0	0)		0.02				0.02
Drexel University (Naoko Kurahashi Neilson)	2	(1	1	2)	0.05	0.06	0.55	0.50	0.30	1.46
Georgia Tech (Ignacio Taboada)	1	(1	0	1)		0.23		0.25		0.48
LBNL (Spencer Klein)	5	(3	2	3)	0.13	0.24	0.53		0.15	1.05
Marquette University (Karen Andeen)	2	(1	1	0)	0.30	0.30	0.30		0.10	1.00
Massachusetts Institute of Technology (Janet Conrad)	3	(1	2	2)	0.10	0.10			1.45	1.65
Michigan State University (Tyce DeYoung)	5	(2	3	2)	0.35	0.48	0.41		1.16	2.40
Ohio State University (James Beatty)	4	(1	3	0)		0.35	0.10		0.05	0.50
Pennsylvania State University (Doug Cowen)	4	(1	3	3)	0.40	0.82	0.33	0.00	1.12	2.67
South Dakota School (Xinhua Bai)	1	(1	0	1)	0.05	0.05			1.10	1.20
Southern University (Ali Fazely)	3	(2	1	0)		0.02	0.30		0.60	0.92
Stony Brook University (Joanna Kiryluk)	1	(1	0	2)	0.05	0.05		0.50	0.30	0.90
University of California, Berkeley (Buford Price)	3	(1	2	0)	0.40	0.27		0.25	0.38	1.30
University of California, Irvine (Steve Barwick)	1	(1	0	1)		0.02				0.02
University of Delaware (Tom Gaisser)	7	(4	3	2)	0.50	0.80		0.20	0.95	2.45
University of Kansas (Dave Besson)	1	(1	0	0)	0.10	0.02				0.12
University of Maryland (Greg Sullivan)	6	(3	3	4)	1.20	0.96	1.63	0.40	0.73	4.91
University of Rochester (Segev BenZvi)	1	(1	0	1)		0.35			0.50	0.85
University of Wisconsin, River Falls (Jim Madsen)	3	(3	0	0)	0.60	0.20			0.10	0.90
University of Wisconsin, Madison (Albrecht Karle)	20	(6	14	12)	2.23	4.70	1.40	0.30	1.80	10.43
Yale University (Reina Maruyama)	1	(1	0	1)	0.05	0.05			0.10	0.20
U.S. Institutions Subtotal	78	(40	38	38)	6.51	10.28	5.55	2.95	11.29	36.57
DESY-Zeuthen (Marek Kowalski)	8	(6	2	10)	0.60	0.17	1.65	0.35	1.25	4.02
RWTH Aachen (Christopher Wiebusch)	2	(1	1	9)	0.30	1.07	0.70	0.20	1.05	3.32
Universität Dortmund (Wolfgang Rhode)	2	(1	1	6)		0.03	0.55	0.80	1.00	2.38
Universität Mainz (Lutz Köpke)	3	(2	1	8)	0.50	0.75	0.30	0.50	0.20	2.25
Universität Wuppertal (Klaus Helbing)	2	(1	1	7)	0.10	0.50	0.20	0.45	0.60	1.85
Humboldt Universität Berlin (Marek Kowalski)	1	(1	0	5)	0.10			0.20	0.05	0.35
Universität Bochum (Julia Tjus)	2	(1	1	3)		0.03		0.10	0.20	0.33
Technische Universität München (Elisa Resconi)	2	(1	1	3)		0.05			0.60	0.65
Universite Libre de Bruxelles (Juan Antonio Aguilar Sanchez)	3	(1	2	3)	0.10	0.62	0.45	0.45	0.50	2.12
Universite de Mons (Evelyne Daubie)	1	(0	1	0)		0.10	0.55			0.65
University of Gent (Dirk Ryckbosch)	2	(1	1	4)	0.10	0.03			0.40	0.53
Vrije Universiteit Brussel (Catherine de Clercq)	5	(2	3	2)	0.20	0.12	0.25	0.50	2.25	3.32
Stockholm University (Klas Hultqvist)	5	(4	1	2)	0.30	0.06		1.00	0.15	1.51
Uppsala University (Olga Botner)	3	(3	0	2)	1.00	0.13		0.35		1.48
University of Alberta (Darren, Grant)	3	(2	1	2)	0.85		1.25	0.35	0.50	2.95
University of Oxford (Subir Sarkar)	1	(1	0	0)	0.10	0.02				0.12
University of Canterbury (Jenni Adams)	1	(1	0	2)	0.05	0.05		0.40	0.10	0.60
University of Adelaide (Gary Hill)	2	(1	1	1)					1.90	1.90
Chiba University (Shigeru Yoshida)	6	(3	3	2)		0.28		0.15	1.05	1.48
Université de Genève (Teresa Montaruli)	2	(1	1	3)	0.20	0.20		0.40	1.25	2.05
Universität Erlangen-Nürnberg (Gisela Anton)	1	(1	0	4)	0.10				0.75	0.85
Niels Bohr Institute (Jason Koskinen)	1	(1	0	2)	0.15	0.06	0.20	0.25	0.30	0.96
University of Toronto (Kenneth Clark)	1	(1	0	0)			0.35		0.10	0.45
Sungkyunkwan University (Carsten Rott)	2	(1	1	5)	0.30	0.12		0.85	0.55	1.82
Non-U.S. Institutions Subtotal	61	(38	23	85)	5.05	4.39	6.45	7.30	14.75	37.94
Total U.S. & Non-U.S.	139	(78	61	123)	11.56	14.67	12.00	10.25	26.04	74.51
Changes since last official version are colored red										

IceCube Collaborating Institutions

The following chart summarizes evolvement of the U.S. and non-U.S collaborating institutions over time.



Changes to the IceCube Collaborating institutions in FY2016:

Following the October 2015 fall collaboration meeting, the University of Rochester, with Segev BenZvi as the institutional lead, and Marquette University, with Karen Andeen as the institutional lead, were approved as full members of the IceCube Collaboration.

As of April 2016, the IceCube Collaboration consists of 47 institutions in 12 countries (25 U.S. and Canada, 18 Europe, and 4 Asia Pacific). The IceCube collaborating institutions are listed in the IceCube Governance Document (included as Appendix 4 of this plan).

Appendix 3: IceCube Computing Infrastructure FY2016/2021 Upgrade Plan

The computing infrastructure systems include the South Pole System (SPS), the South Pole Test System (SPTS), the data warehouse, the UW data center, and networking. The following table summarizes the M&O computing infrastructure upgrade budget by subsystem.

Type of Funds	Sub System	YEAR1 (Direct $k)	YEAR2 (Direct $k)	YEAR3 (Direct $k)	YEAR4 (Direct $k)	YEAR5 (Direct $k)	YEARS 1-5 (Direct $k)
US CF	UW Data Center	$78k	$37k	$83k	$99k	$93k	**$390k**
	South Pole System	$8k	$14k	$21k	$43k	$38k	**$123k**
	South Pole Test System	$5k	$5k	$35k	$32k	$21k	**$98k**
	Data Warehouse	$16k	$64k	$0k	$0k	$80k	**$160k**
	DOMHubs	$5k	$25k	$65k	$36k	$35k	**$166k**
	Networking	$11k	$25k	$9k	$22k	$0k	**$67k**
US CF Total		**$123k**	**$170k**	**$213k**	**$232k**	**$266k**	**$1,004k**
Non US CF	UW Data Center	$457k	$390k	$218k	$282k	$275k	**$1,624k**
	South Pole System	$28k	$187k	$338k	$173k	$15k	**$742k**
	South Pole Test System	$162k	$0k	$0k	$149k	$0k	**$311k**
	Data Warehouse	$37k	$224k	$195k	$87k	$94k	**$638k**
	Networking	$109k	$0k	$0k	$0k	$0k	**$109k**
Non US CF Total		**$794k**	**$801k**	**$751k**	**$692k**	**$385k**	**$3,423k**
Grand Total		**$917k**	**$971k**	**$964k**	**$924k**	**$651k**	**$4,426k**

IceCube M&O Computing Infrastructure Upgrades Budget by Subsystem ($k)

The non-U.S. contribution to the Common Fund covers most of the capital equipment expenditures and their associated service agreements fees. The following table summarizes the M&O computing infrastructure upgrades budget by subsystem and cost category.

Type of Funds	Sub System	Capital Equipment	Materials & Supplies	Services	YEARS 1-5 (Direct$)
US CF	UW Data Center	$175k	$0k	$215k	**$390k**
	South Pole System	$25k	$98k	$0k	**$123k**
	South Pole Test System	$53k	$9k	$36k	**$98k**
	Data Warehouse	$160k	$0k	$0k	**$160k**
	DOMHubs	$125k	$25k	$16k	**$166k**
	Networking	$0k	$0k	$67k	**$67k**
US CF Total		**$538k**	**$132k**	**$334k**	**$1,004k**
Non US CF	UW Data Center	$1,454k	$0k	$170k	**$1,624k**
	South Pole System	$742k	$0k	$0k	**$742k**
	South Pole Test System	$311k	$0k	$0k	**$311k**
	Data Warehouse	$519k	$0k	$119k	**$638k**
	Networking	$109k	$0k	$0k	**$109k**
Non US CF Total		**$3,134k**	**$0k**	**$288k**	**$3,423k**
Grand Total		**$3,672k**	**$132k**	**$623k**	**$4,426k**

IceCube M&O Computing Infrastructure Upgrades Budget by Subsystem and Cost Category ($k)

Following is a summary of the proposed computing infrastructure upgrades per each major subsystem, including annual planned quantities and total U.S. and non-U.S. direct cost.

Unit definition:

- **CPU:** HEP-SPEC06, a CPU benchmark used extensively in other high-energy physics experiments
- **GPU:** "normalized gpu units" which is the computing power of an Nvidia GeForce GTX680 GPU
- **Disk/Tape:** Terabytes, defined as 10^{12} bytes

Appendix 4: IceCube Collaboration Governance Document

Revision 8.5, April 2016

IceCube Collaboration Governance Document

Revision 8.5, April 2016

Collaboration Objectives

The IceCube Collaboration (the Collaboration) is an organization of scientists who collectively participate in a research program with the IceCube Observatory at the NSF South Pole Amundsen-Scott station. IceCube consists of a surface array, IceTop, and a deep ice array IceCube. Henceforth, IceCube stands for the IceCube Observatory. The primary goal is the study of high-energy neutrinos from cosmic sources, but the program also encompasses a broader array of topics made possible by the IceCube observatory.

Definitions

The Host Institution for the IceCube project is the University of Wisconsin-Madison (UW) with the P.I. defined by the M&O grant to the Host Institution. Responsibilities are defined in the Cooperative Agreement with NSF. The Operations Phase of IceCube is specified as the period when activities are governed by the M&O Cooperative Agreement between UW and the NSF. The Memorandum of Understanding (MoU) governing institutional responsibilities for M&O consists of a single MoU between the host institution and each constituent institution. The International Oversight and Finance Group functions are defined in the Maintenance and Operations Plan (excerpt attached in Appendix D). The organization for the operation of IceCube is shown in the organization chart of Appendix C.

Operation of the IceCube detector is organized within the IceCube Coordination Committee (ICC) chaired by the Associate Director for Science and Instrumentation. The main functions are Detector Maintenance & Operations; Computing and Data Management; Triggering & Filtering; and Data Quality, Simulation & Reconstruction Tools, as shown in the Organization chart. Some key positions in the ICC are appointments of the host institution; most positions are filled by collaboration scientists chosen for their expertise by the Chair of the ICC in consultation with the Spokesperson.

Collaboration Membership

The IceCube Collaboration consists of scientists at Collaboration Constituent Institutions. The condition for membership and for institutional recognition is that the group makes a significant contribution to IceCube. Significant contributions will include a contribution to the common fund proportional to the number of Ph.D. scientists in the group as well as contributions to detector operations and data analysis. The proposed contributions, role in the scientific program, and personnel are to be detailed in the MoU that is updated annually.

Current members of the Collaboration as of the date of revision of this document come from the institutions listed in Appendix A. (This Appendix also lists the initial institutions of IceCube.) Any scientist or group of scientists may apply to the Spokesperson of the Collaboration for membership of their institution in IceCube. Admission of new institutions requires approval by a two-thirds majority of the IceCube Constituent Institutions, under consideration of the proposed contributions and role in the research program. Scientists who join member groups at Institutions that were members of the Collaboration prior to IceCube completion will automatically be accepted as members of the Collaboration. At all other institutions the addition of new senior personnel will require approval by the IceCube Collaboration Board.

An individual scientist or a group of scientists may be accepted as associate members of IceCube if they are sponsored by an IceCube collaborating institution to work on a specific aspect of analysis and/or service. The arrangement should be clarified in an MoU that describes the subject in which the associate will participate, the term of association and any other details.

Membership of an individual or Institution may be revoked by the Spokesperson for just cause, e.g. actions detrimental to IceCube. A concurring vote by two-thirds of all Constituent Institutions is required. Only active votes will be counted.

Collaboration Board

1. Functions and Responsibilities

The Collaboration Board is the policy-making entity that guides and governs the scientific activities of the Collaboration. It establishes, and as necessary amends, governance procedures and has oversight and authority over:

- science policy and goals
- membership
- data access
- publication
- representation of IceCube at topical and general conferences
- analysis teams
- education and outreach

The Collaboration Board, through the Collaboration Spokesperson, maintains contact and communication with the Director of Operations at the host institution.

It advises the Director on the detector operation for scientific investigations and maintenance, and participates in the discussion, as articulated by the Director of Operations, of the potential or possible use of the IceCube facility as a resource for new initiatives.

The Collaboration Board ratifies the Collaboration Governance document and may introduce amendments to it.

The Collaboration Board ratifies the Cooperative Agreement between the NSF and Host Institution, and may suggest amendments to it.

The Collaboration Board, during the operation phase of IceCube, advises the Director of Operations on selection of personnel that hold key responsibilities for the Maintenance and Operation of the detector.

Concerns of the Collaboration members are addressed to Collaboration Board members who, when appropriate, bring those before the Collaboration Board for its consideration.

At the request of a Board member the Board may require a detailed verbal, or written, report from the Spokesperson on any action.

2. Membership

Each Collaboration Constituent Institution is represented on the Collaboration Board by at most two members of whom one is voting whereas the other is a non-voting adjunct member. The number of votes per institution depends on number of Ph.D. physicists (see for the key section 6 below).

Early Career scientists in the Collaboration are represented by two additional, at-large, members chosen collectively by Early-Career Collaboration participants. The term of service is two years, not renewable, and the terms overlap - i.e. one new representative is elected every year. Election rules for Early Career scientists are given in Appendix B. Of the two members, one is voting whereas the other is a non-voting adjunct member. Information of who is voting should be given to the Spokesperson before each meeting of the Collaboration Board.

During the IceCube operation phase, the P.I. of the M&O grant from NSF (the IceCube P.I.) and the Associate Director for Science are ex-officio members of the Collaboration Board.

3. Officers

The Collaboration Board is chaired by the Collaboration Spokesperson. The Spokesperson is an ex-officio, non-voting member of the Collaboration Board. The Spokesperson is elected by the Ph.D. members of the collaboration. The election procedure is as follows:

- The Spokesperson appoints two Collaboration members who serve as a nomination commission.
- Nominations are sought from the Collaboration at large. Each constituent Institution may offer any number of candidate nominees.
- The nomination commission notifies each nominee that she/he has been proposed. Within two weeks each nominee shall inform the nomination commission if he/she is willing to be listed as a nominee. All who do so, compose the final slate of viable nominees.
- The Spokesperson is chosen by majority vote of all Ph.D. physicists in the Collaboration.
- If none of the candidates gets more than 50% of the votes in the first round the choice between the two names with the most votes is decided in a second round.

Each nominee is urged to prepare a statement that contains her/his assessment of the state of IceCube, goals and plans for action to be taken during his/her tenure as Spokesperson. The text of the statement should accompany the nominee's acceptance notice to the nomination commission who will distribute it with the ballot to the Collaboration membership.

The Spokesperson may select a Deputy Spokesperson. The Board ratifies the choice. The Deputy performs the duties of the Spokesperson when necessary if the Spokesperson is unable to do so. The Deputy is an ex-officio, non-voting member of the Collaboration Board. If the Spokesperson or Deputy is a regular Collaboration Board member, a replacement is chosen by the affected Institution. The period of office of the Spokesperson and the Deputy Spokesperson is two years, renewable - but at most four consecutive years.

The Spokesperson, as Collaboration Executive

- organizes and chairs Collaboration Board meetings
- during the IceCube operations phase is the interface between the collaboration Board and the Director of Operations at the Host Institution, communicating with the Director on behalf of the Collaboration Board.
- arranges general Collaboration meetings
- speaks for the Collaboration in interaction with the scientific community
- speaks for the Collaboration in interaction with the general public
- selects members of Collaboration advisory committees subject to concurrence by Collaboration Board majority vote
- communicates with the International Oversight and Finance Group (see Appendix D) on behalf of the Collaboration Board.
- calls for and oversees formal votes on particular issues

4. Executive Committee

The Spokesperson, in consultation with the Collaboration Board and, with the P.I. and the Director of Operations, appoints and chairs an Executive Committee of the Collaboration Board. The term of the Executive members is two years. The job of the Executive Committee is to advise the Spokesperson in proposing actions to the Collaboration Board and in making interim decisions. The members of the Executive Committee should represent major groups, functions and competences within the Collaboration.

5. Meetings

As a rule, the Collaboration Board meets during general Collaboration meetings. More frequent telephone or video conferences may be called by the Spokesperson, with normally two weeks prior notice having been given Board members. At a minimum, representation of two-thirds of all Constituent Institutions is required to constitute a quorum. The Spokesperson will appoint a secretary to each Collaboration Meeting for writing the minutes. The minutes will include all decisions that were taken. Minutes will be posted on the IceCube private www site within one week following the meeting, following approval by the Collaboration Board members.

6. Voting procedure

In general, matters before the Collaboration Board are settled by consensus of its members. At a meeting of the Collaboration Board, a show of hands will be called for to determine if there is consensus. If there is no consensus, a formal vote will be ordered by the Spokesperson. A formal poll can also be requested by a Collaboration Board member. In both cases, the polling will be done by Email within one week of the meeting. Each institution has one vote weighted by a factor depending on the number of affiliated PhD physicists. The weight is equal to the square root of the number of PhD physicists, rounded to the nearest integer. The weights are fixed once per year. In case of a tie vote, the Spokesperson casts a vote. Only active votes will be counted. Abstentions or absences do not count. Results will be announced to the Collaboration Board by the Spokesperson. All votes will be open, except where persons are concerned. The voting procedure for the Spokesperson is described in section 3.

7. Education and Outreach

The IceCube collaboration collectively and individually participates in and provides support for efforts in public outreach and education on subjects related to its science. The Spokesperson, with Collaboration Board concurrence, responds to requests for information from the media or may take the initiative providing material. The Director of Operations, with Collaboration Board concurrence, appoints a Collaboration member to lead an education program for students and teachers at all levels. The Collaboration maintains coordination and cooperation with other ongoing education initiatives. All new scientific material to be released for purposes of public outreach or education containing other than previously published data or results must have been agreed upon by the Collaboration Board.

8. Collaboration Policies and Procedures

Meetings

Collaboration meetings are held at least two times in a year. Locations are distributed among Collaboration Constituent institutions, chosen by the Spokesperson, and ratified by Board concurrence. The hosting institution is responsible for physical meeting arrangements. Agendas are set by the Spokesperson together with the hosting institution, the Analysis Coordinator, the working group leads and the operations managers (i.e. members of the ICC), with concurrence of the Collaboration Board.

Data Reduction and Analysis

Raw, unfiltered data written to tape at Pole are transported to the UW data center for archival storage unless directed otherwise by the Collaboration Board. Filtered data are transmitted daily via satellite link to the UW data center and stored on disk. Additionally, the filtered data will be copied via internet to DESY and stored on disk as a second official copy.

All current IceCube members have access to archived data. Associate membership in IceCube gives the Associate access to IceCube data and software for the sole purpose of pursuing a particular analysis. The analysis should augment the science that can be done with IceCube alone.

The Collaboration Board consents to the appointment of Collaboration members who have been chosen jointly by the Spokesperson and Director of Operations. These include the Analysis Coordinator and Working Group conveners. The term of service for the Analysis Coordinator and Working Group conveners is two years, renewable. The Analysis Coordinator assumes responsibility for organization and management of data analysis efforts.

It is the intention of the Collaboration to place the data in the public domain as soon as it is reasonable to do so from a scientific point of view (see appendix E). The Collaboration Board shall determine rules for access to the data.

Detector operations and monitoring

The Spokesperson with Collaboration Board concurrence appoints a Collaboration member to organize and lead a group responsible for detector Monitoring, Maintenance and

Calibration. The term of service is one year, renewable. Detector monitoring is a collaboration-wide shared responsibility.

9. Topical and General Conference Presentations

The Spokesperson, with concurrence of the Collaboration Board, appoints a Collaboration member to chair a Speakers Committee. The period of office of the chair is 2 years, renewable – but at most 4 consecutive years. The duration is counted from the day the chair assumes office, independent of possible prior Speakers Committee membership. The designated chairperson chooses three other members of this Speakers Committee. The term of the members of the Speakers Committee is 2 years, renewable – but at most 4 consecutive years. A later re-accession, with the consensus of the chair, is possible after a break of at least 2 years. A rapid decision channel (chair + Spokesperson) can be enabled if there is insufficient time to involve the whole committee. Invitations to present Collaboration results, or performance reviews, are submitted to the Speakers Committee. The Speakers Committee chooses the speaker.

The Speakers Committee maintains records of conference presentations. The conference organization is notified by the Spokesperson of the identity of the nominated speaker and the subject of the talk and its approval is sought.

In order to present previously unreported data and/or results approval must be obtained from the Spokesperson, with Collaboration Board concurrence. The Spokesperson has the right to hold new results in order to approve final text, figures, and tables.

Transcriptions of verbatim reports of approved presentations to be included in conference proceedings are posted on the IceCube www site not later than two weeks before the editorial deadline to allow review, comments and suggestions for revisions by the Collaboration. Such controls do not normally apply to colloquium or seminar talks at members' home or other institutions on personal invitation but the Analysis Coordinator must be made aware of any new results which differ from results already public or might be controversial. For presenting such results Analysis Coordinator approval must be obtained.

Reports in proceedings are normally bylined by a single name (the presenter's) followed by "for the IceCube Collaboration". The complete author list in alphabetic order should if possible be included. Otherwise a reference is made to the complete author list elsewhere. Deviations from this rule are possible on a case by case basis but require justification. Requests are handled by the Publication Committee. The Collaboration Board constructs the author list from compilations provided it by Constituent Institution representatives. Others who have contributed to a particular effort may be included as authors. Individual requests not to be included as authors are acceded to without prejudice. Any Constituent Institution representative may request a variance from the default listing to allow a conference presentation authored by a subset of members and others who have contributed to a particular special (usually technical) subject. A concurring vote by two-thirds of all Constituent Institutions is required for approval. Only active votes will be counted.

10. Publications

The Spokesperson, with concurrence of the Collaboration Board, appoints a Collaboration member to chair a Publications Committee. The period of office of the chair is 2 years, renewable – but at most 4 consecutive years. The duration is counted from the day the chair assumes office, independent of possible prior Publication Committee membership. The designated chairperson chooses nine other members of this Publications Committee. The term of the members of the Publication Committee is 2 years, renewable – but at most 4 consecutive years. A later re-accession with the consensus of the chair is possible after a break of at least 2 years.

The Publication Committee oversees and coordinates submission of papers and proceedings reports in coordination with the analysis coordinator and the working group leaders as described in Appendix C.

Results are to be submitted for publication in refereed journals. Drafts of research results are prepared by the analysis teams; drafts of papers on technical matters are prepared by the cognizant individuals. The internal review procedure is described in Appendix C. Journal articles are bylined by the full author list in alphabetical order. The Collaboration Board constructs the author list from compilations provided it by Constituent Institution representatives. As a rule collaborators may become authors six months after joining the collaboration. They are normally removed from the list one year after leaving. This period may be extended in special cases of former collaborators who contributed essential effort to the construction of IceCube. Others who have contributed to a particular effort may be included as authors. Individual requests not to be included as authors are acceded to without prejudice. Any Constituent Institution representative may request a variance from the default listing to allow submission of a paper for publication authored by a subset of members and others who have contributed to a particular special (usually technical) subject. A concurring vote by two-thirds of all Constituent Institutions is required for approval. Only active votes will be counted.

Associate members only appear on the author list for the publication(s) directly related to their analysis and agree not to publish independently results based on private IceCube software or data.

11. Ph.D. Research

Research topic assignments are the responsibility of the students and faculty supervisors. Discussions among faculty supervisors and Collaboration Board members are encouraged to avoid serious overlaps in subject matter and/or analysis methodology. The Spokesperson maintains a list of completed and current theses. Texts of theses are posted to the IceCube private www site and may be posted at the institution www site. Titles and author names are posted on the official IceCube www site.

12. Amendments

This document will be reviewed for proposed amendments as necessary. Any member of the collaboration may bring such proposals to the Collaboration Board's attention. Proposed amendments to this charter will be considered during regular meetings of the Collaboration Board. A concurring vote by two-thirds of all Constituent Institutions is necessary to pass an amendment. Only active votes will be counted.

Appendix A: IceCube Institutions

(ordered alphabetically according to location)

a. Initial IceCube Institutions (application 1999 to NSF):

i. CTSPS, Clark-Atlanta University, Atlanta, USA
ii. Southern University and A&M College, Baton Rouge, USA
iii. Lawrence Berkeley National Laboratory, Berkeley, USA
iv. University of California-Berkeley, Berkeley, USA
v. Université Libre de Bruxelles, Brussels, Belgium
vi. University of California-Irvine, Irvine, USA
vii. University of Kansas, Lawrence, USA
viii. University of Wisconsin, Madison, USA
ix. Universität Mainz, Mainz, Germany
x. Bartol Research Institute, University of Delaware, Newark, USA
xi. University of Pennsylvania, Philadelphia, USA
xii. Institute for Advanced Studies, Princeton, USA
xiii. Stockholm Universitet, Stockholm, Sweden
xiv. Uppsala Universitet, Uppsala, Sweden
xv. BUGH Wuppertal, Wuppertal, Germany
xvi. DESY-Zeuthen, Zeuthen, Germany

b. IceCube Institutions as of April 2016:

i. III Physikalisches Institut, RWTH Aachen University, Aachen, Germany
ii. Adelaide School of Chemistry and Physics, University of Adelaide, Adelaide, Australia
iii. Dept. of Physics and Astronomy, University of Alabama, Tuscaloosa, USA
iv. Dept. of Physics and Astronomy, University of Alaska Anchorage, Anchorage, USA
v. CTSPS, Clark-Atlanta University, Atlanta, USA
vi. School of Physics and Center for Relativistic Astrophysics, Georgia Institute of Technology, Atlanta, USA
vii. Dept. of Physics, Southern University, Baton Rouge, USA
viii. Dept. of Physics, University of California, Berkeley, USA
ix. Lawrence Berkeley National Laboratory, Berkeley, USA
x. Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Germany
xi. Fakultät für Physik & Astronomie, Ruhr-Universität Bochum, Bochum, Germany
xii. Université Libre de Bruxelles, Brussels, Belgium
xiii. Vrije Universiteit Brussel, Brussels, Belgium
xiv. Dept. of Physics, Chiba University, Chiba, Japan
xv. Dept. of Physics and Astronomy, University of Canterbury, Christchurch, New Zealand
xvi. Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
xvii. Dept. of Physics, University of Maryland, USA
xviii. Dept. of Physics and Center for Cosmology and Astro-Particle Physics, Ohio State University, Columbus, USA
xix. Dept. of Physics, TU Dortmund University, Dortmund, Germany
xx. Particle Physics at Drexel, Drexel University, Philadelphia, PA, USA
xxi. Dept. of Physics, University of Alberta, Edmonton, Alberta, Canada
xxii. Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

xxiii. Dépt. physique nucléaire et corpusculaire, Université de Genève, Geneva, Switzerland
xxiv. Dept. of Subatomic and Radiation Physics, University of Gent, Gent, Belgium
xxv. Dept. of Physics and Astronomy, University of California, Irvine, USA
xxvi. Dept. of Physics and Astronomy, University of Kansas, Lawrence, USA
xxvii. Dept. of Physics, University of Wisconsin, Madison, USA
xxviii. Institute of Physics, University of Mainz, Mainz, Germany
xxix. Department of Physics, Marquette University, Milwaukee, WI, USA
xxx. Massachusetts Institute of Technology, Cambridge, MA, USA
xxxi. Université de Mons, Mons, Belgium
xxxii. Exzellenzcluster Universe, Technische Universität München, Munich, Germany
xxxiii. Bartol Research Institute and Department of Physics and Astronomy, University of Delaware, Newark, USA
xxxiv. Department of Physics and Astronomy, Michigan State University, East Lansing, MI, USA
xxxv. Dept. of Physics, University of Oxford, Oxford, UK
xxxvi. Dept. of Physics, University of Wisconsin, River Falls, USA
xxxvii. Dept. of Physics, South Dakota School of Mines and Technology, Rapid City, SD, USA
xxxviii. Department Of Physics and Astronomy, University of Rochester, Rochester, NY, USA
xxxix. Dept. of Physics, Sungkyunkwan University (SKKU), Seoul, South Korea
xl. Oskar Klein Centre and Dept. of Physics, Stockholm University, Stockholm, Sweden
xli. Dept. of Physics and Astronomy, Stony Brook University, Stony Brook, NY, USA
xlii. Dept. of Physics, University of Toronto, Toronto, Canada
xliii. Dept. of Physics, Pennsylvania State University, University Park, USA
xliv. Dept. of Physics and Astronomy, Uppsala University, Uppsala, Sweden
xlv. Dept. of Physics, University of Wuppertal, Wuppertal, Germany
xlvi. Dept. of Physics, Yale University, New Haven, CT, USA
xlvii. DESY, Zeuthen, Germany

Appendix B: IceCube Early Career Scientist Elections

a. **Definition of IceCube EC Scientist**: An Early Career scientist is a member of the IceCube collaboration who has received their Ph. D. within 7 years of the most recent past January 1st, but who has not received an assistant professor or tenured position; or who is a graduate student who has been on the author list for two years.
b. **Election Oversight Committee**: The EC representatives will annually and prior to the elections appoint a committee of two members taken from the entire collaboration, excluding persons eligible, to oversee the election.
c. **Nominations for EC Representative**: The current year's representatives will solicit nominations collaboration-wide for EC representatives. These nominations will be collected by the members of the oversight committee and posted. Self-nomination is permitted. Only Early Career scientists who have received their Ph. D. can be nominated.
d. **Voting**: Each EC scientist possesses one vote. The vote is sent to the oversight committee. One is allowed to vote for one's self. Votes are counted privately by the

oversight committee. The person receiving the top vote count will be announced by this committee as the new EC scientist representative. In the event of a tie, a tie-breaking round of voting with the ballot containing just the tie-holders will be held.

Appendix C: IceCube Maintenance, Operations and Data Analysis Plan

This document sets forth the plan for the organization and implementation for M&O and Data Analysis during the operations phase of IceCube.

M&O and Physics Analysis

- Planning Documentation
- Analysis Coordination
- Internal review Process
- Talks

Planning Documentation

Planning documentation is composed of this document in its entirety, which lays out the plan for M&O and data analysis of IceCube data. This plan will be reviewed by the IceCube Director of Operations and the IceCube collaboration and once approved will be implemented. Approval and/or modification requires the data analysis plan to be accepted by:

1. IceCube PI
2. IceCube Collaboration Spokesperson
3. IceCube Director of Operations
4. IceCube Collaboration Board

This document should not conflict with the IceCube collaboration governance document. If there are any conflicts the collaboration governance document takes precedent.

Analysis Coordination

Analysis coordination has two tasks that are:

- Analysis Coordinator
- Working Groups

The analysis coordinator has authority over the working groups as laid out in this document.

Analysis Coordinator

a) Selection of Analysis Coordinator

The procedure for selecting the Analysis Coordinator is by appointment from the Spokesperson with concurrence of the Collaboration Board.

b) Term of Analysis Coordinator

The term of the Analysis coordinator will be two years. The current Analysis Coordinator may be nominated to remain as Analysis Coordinator.

c) Responsibilities of Analysis Coordinator

The responsibilities of the analysis coordinator are the overall organization and oversight of the working groups and physics analysis of the IceCube data. Specifically the Analysis Coordinator will:

1. Have oversight of the physics analysis
2. Aid in defining the physics working groups
3. Aid in selection of working group leaders
4. Have input on internal review processes for publications and talks
5. Have input on the distribution of talks
6. Have oversight of analysis documentation

Working Groups

a) Preliminary list of working groups

Working groups are organized a) according to event topologies and the related filter and reconstruction methods and b) according to physics topics. Topology-driven groups can be, for instance:

1. Muons
2. Cascades
3. Hybrid events
4. ...

with the physics topics such as AGN, GRB, WIMPs etc... as subcategories in each working group with the same physics topic across groups. A possible grouping according to physics topics would be:

1. Diffuse cosmic and atmospheric neutrinos
2. Point Source Searches
3. GRB neutrinos
4. neutrinos from WIMP annihilation
5. Cosmic ray studies
6. Exotic particles like magnetic monopoles or Q-balls
7. MeV neutrinos from Supernova bursts
8. Extremely High Energy Phenomena (EHE)

with detector and reconstruction methods as tools to be developed across different working groups. Definition of groups will be kept dynamically, with the list above representing the 2010 status.

b) Selection of Working Groups & Group Leaders

The Analysis Coordinator will coordinate and implement the analysis effort for the IceCube detector in order for it to accomplish its scientific mission. The analysis coordinator, with input from the entire collaboration, will determine the physics benchmarks and processes and organize physics working groups to ensure that these processes are measured. The Analysis Coordinator together with the Spokesperson will select the working group leaders with input from the IceCube collaboration and IceCube Director of Operations. The term of office of a working group leader is 2 years, renewable.

c) Responsibilities at Working Group Level

The physics working group leaders have direct responsibility for organizing the individual data analyses of the IceCube detector. They will:

1. Organize their physics working group
2. Define & verify standard datasets for their particular physics processes
3. Verify the operation and performance of the IceCube detector, primarily as it pertains to their physics processes of interest
4. Document the physics analysis and approved results with memos
5. Document analysis tools with memos
6. Place memos on Docushare for collaboration access and maintain the Docushare areas related to their working group
7. In addition to memos on Docushare, maintain a (possibly separate) web page that describes the status of the WGs activities
8. Approve standard results from their group to be submitted to the collaboration board for publication and presentation.
9. Request a paper committee for journal publication of approved results

The people within a physics working group should generally be organized by the working group leader, with a mailing list established. However, all physics working group activity is open to the entire collaboration at any time. Regular meeting times and activities should be established whenever possible to encourage all who are interested to be able to plan on participation. The working groups are encouraged to schedule regular biweekly teleconferences and/or videoconferences.

Internal Review Process

Internal review is the process by which the IceCube collaboration will assure uniform and high standards for the publication and communication of physics results to the community. Analyses of IceCube data and preparation of physics results require three levels of approval:

1. Approval of analysis before application to data samples
2. Approval as preliminary result for communication at conferences and talks
3. Approval of final results for publication in refereed journals

a) Approval of analysis

The IceCube collaboration requires that precautions are taken that prevent the analyzer from biasing the analysis results toward their own preconceptions while their analysis is under development. Physics working groups are charged with ensuring that analyses are developed in an unbiased manner through the application of the appropriate techniques (e.g. blindness).

Analyses undergo review by at least two dedicated reviewers, one working group appointed, and one analysis coordinator appointed. While all collaboration members are encouraged to review and comment on analyses, the reviewers are charged to follow the analysis through the:

1. Review and approval in the working group.
2. Presentation, review and approval at the weekly analysis call.
3. Initial presentation of results at the weekly analysis call.

A period of at least two weeks is required between the first presentation of an analysis for review at the weekly analysis call before analysis approval can be granted to allow sufficient time for collaboration review. Review and approval of the working group is granted by the working group convener(s) and final analysis approval is granted by the analysis coordinator.

b) Approval of preliminary results for talks

For approval of preliminary results to be disseminated to the community at scientific talks and conferences the following must happen:

1. Approval by physics working group.
2. Presentation at two consecutive weekly analysis calls where approval is sought from the collaboration.
3. Approval by the Analysis Coordinator.

Normally, a memo or wiki page with supporting information should be disseminated to the collaboration no less than two weeks before the decision on the analysis call.

Upon approval, the result becomes an official preliminary result that is available for use in talks and conferences by any collaboration member. The result will be placed in a common collaboration area on the IceCube web pages by the physics working group.

c) Publication of papers

The publication of a result in a paper is initiated within a physics working group. The results to be published must be approved by the collaboration as described above. An outline for the paper will have been presented and discussed on the weekly analysis call for approval by the collaboration. Once a draft of the paper exists, the working group leader(s) will contact the chair of the publication committee to jointly appoint a referee panel consisting of one working group internal expert and one collaboration member from outside the working group. The panel will be led by a publication committee member. The task of the referee panel will be to review the draft and see to it that any remaining physics issues are resolved. Once the draft is deemed mature, the referee panel (extended at this stage to include an additional collaboration member) then oversees and approves the steps 3-6 listed below, leading to journal submission.

1. A paper outline is created and approved within the physics working group, outlining the paper contents, key figures and conclusions being drawn.

2. The paper outline is presented at the weekly analysis call, and 1 week is permitted for comments and discussion before the paper outline is approved.
3. The mature draft of the paper is sent to the collaboration. Two weeks are allowed for all comments on the paper. The paper, the comments, and answers to the comments are all to be posted on the paper's webpage.
4. When the collaboration review results in substantial requested changes to the paper, a new version of the paper that addresses these changes will be posted to the paper's webpage and circulated to the collaboration. This may result in an extension to the original two week review period.
5. When the referee panel is satisfied that questions and comments have been satisfactorily addressed, the final draft of the paper is presented to the collaboration for approval.
6. The publication committee considers the paper for submission. The decision to submit is made by the Spokesperson and the chair of the publication committee.

The publication of technical results in a paper, not originating from a physics working group, is initiated by the primary authors via an outline for the paper presented and discussed on the weekly analysis call for approval by the collaboration. Once a draft of the paper exists, the authors will contact the chair of the publication committee who will appoint a referee panel composed of two collaboration experts on the technical topic and one additional collaboration member. The panel will be led by a publication committee member. Where appropriate, the paper may be first reviewed within a channel working group and then follow the steps 3-6 listed above. In the case where a channel working group is not available to review the paper draft to approve its mature state, the paper will follow the six step procedure outlined above with the following substitutions for steps 3 and 4:

3. A first draft of the paper is sent to the collaboration. Two weeks are allowed for comments which should be mainly of a substantive nature, but can also be editorial. The paper, comments, and answers to comments should all be posted on the web.
4. When the referee panel is satisfied that questions and comments have been satisfactorily addressed, a second draft will be presented to the collaboration. These comments should be editorial in nature. The paper, comments, and answers to comments should all be posted on the web.

d) Unusual physics topics or topics of a general nature

In the event of an analysis that does not fall within a physics working group, the analysis coordinator will contact the chair of the publication committee to jointly appoint a referee panel.

A topic of a general nature or a physics topic which should be dealt with in publication but is not being addressed can be brought before the Collaboration Board by the Spokesperson, the chair of the publication committee and/or the analysis coordinator. The Collaboration Board appoints an individual (or individuals) responsible for producing a paper outline followed by a draft paper and if necessary for performing the analysis.

e) Circumstances requiring express analysis

If a case arises that would require an express analysis of IceCube data in order to increase the impact in a timely way (e.g. A strong flaring object such as occurred for the "naked-eye" GRB) the Analysis Coordinator and/or Spokesperson have the authority to circumvent the normal time periods for review. The Analysis coordinator and Spokesperson can at their discretion ask for concurrence from the executive committee and/or ICB.

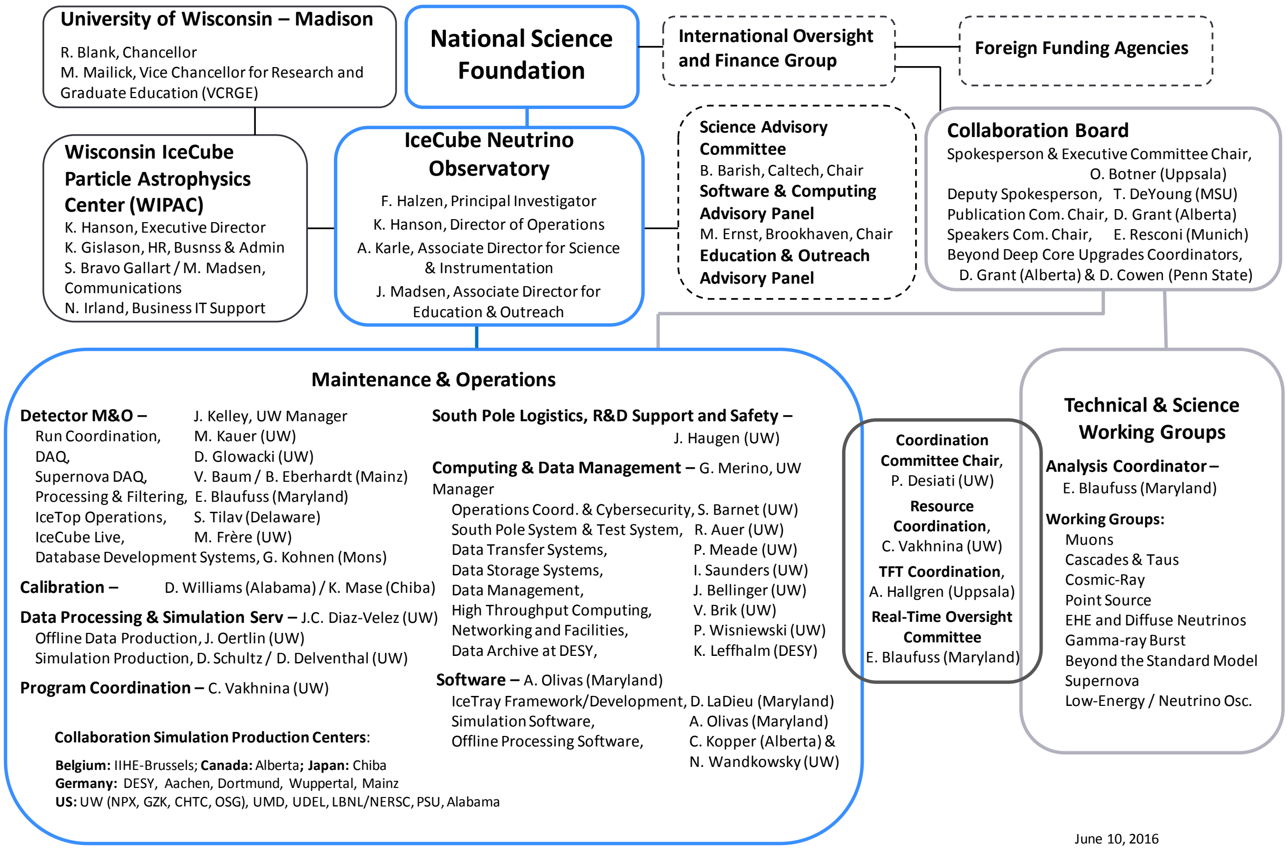
Non-IceCube publications by IceCube members

Collaboration members co-authoring non-IceCube publications which at any level relate to IceCube (for instance relying on internal discussions within IceCube, using IceCube infrastructure (hardware or software), or relying heavily on published IceCube results) should notify the IceCube Publication Committee prior to the submission of any manuscript to archive or journal. The Publication Committee may decide to forward such information to the full collaboration.

Talks

The policy on talks and presentations and on the speakers committee is set forth in section 9.

IceCube M&O Organization



Appendix D: International Oversight and Finance Group - IOFG

The International Oversight and Finance Group (IOFG) is a committee created in 2004 to provide oversight and financial support for the IceCube Neutrino Observatory (including Construction phase, Maintenance & Operations and Research phases). The Group organizes annual oversight reviews of the operations and meets annually to discuss detector performance and physics. The Group also sets policies for receiving periodic progress reports on all aspects of the detector operation and by all the performers in the collaboration, and for conducting external reviews when appropriate.

Membership

A representative of the National Science Foundation chairs the IOFG. Membership is comprised of representatives of the funding agencies in the partner countries supporting the construction and operation of IceCube Neutrino Observatory, currently comprised of funding agencies from Belgium, Germany, Sweden, and the United States. The Group is informed by the Spokesperson of the Collaboration, the Director of Operations, the Principal Investigator and others as appropriate.

Decisions

The Group is committed to operate through discussion and consensus. The Executive Agent (the NSF) will make final decisions on matters before the group related to the operation of IceCube.

Issues that may come before the Group include:

- Approval of a formal charter for the Group.
- Review of Memoranda of Understanding (MOU) between the various institutions.
- Concurrence on the Maintenance and Operations Plan.
- Funding issues.
- Concurrence on the Collaboration's plans for new membership in the collaboration.
- Data sharing and data management policies.
- Coordination regarding press releases and education and outreach activities.
- Input on seasonal flight and personnel logistics planning.
- Other matters related to successful operation of the IceCube Neutrino Observatory for science.

Appendix E: Dissemination and Sharing of IceCube Research Results and Data

This defines the IceCube strategy for providing access to research results and data by the broader research community. NSF policies and guidance promote efforts by grantees to produce the timely publication of results and to make data and software available to other researchers. In addition, the Parties to the Antarctic Treaty agree that, to the greatest extent feasible and practicable, scientific observations and results from Antarctica shall be exchanged and made freely available.

IceCube is a facility-class experiment with the primary goal to identify sources of astrophysical neutrinos. NSF supports a wide range of approaches to the release of facility data, e.g., the particle physics model where data is exclusively available to members of the collaboration and the astronomy model where data are readily made public.
The Large Hadron Collider experiments follow the particle physics model; the Atacama Large Millimeter/submillimeter Array (ALMA) – the astronomy model; and, the Wilkinson Microwave Anisotropy Probe (WMAP) – an intermediate model. IceCube is similar to WMAP and large air shower experiments where data is collected, analyzed, published and released.

The public release of data in a scientifically meaningful way is not a trivial undertaking. Currently there are three ways to access IceCube data:

1. IceCube Collaboration Membership
2. Associate Membership
3. Direct Access to IceCube Public Data Pages

IceCube Collaboration Membership – The IceCube Collaboration consists of scientists at Collaboration Constituent Institutions. The condition for membership and for institutional recognition is that the group makes a significant contribution to IceCube.
Any scientist or group of scientists may apply to the Spokesperson of the Collaboration for membership of their institution in IceCube. Details on these arrangements can be found elsewhere in this IceCube Collaboration Governance Document. New groups join the IceCube Collaboration every year providing evidence that membership is a proven way to access IceCube data.

Associate Membership – Scientists outside the IceCube Collaboration who have a concept for a particular analysis can apply to the Collaboration for Associate Membership for the purpose of performing a particular analysis or class of analyses within the Collaboration. Papers that cover the research in question are co-signed by the associate and the collaboration. The Associate Member has no other rights or responsibilities within IceCube. Associate Membership may be preferred over joining the Collaboration, a rather lengthy process that requires financial and service contributions operations.
There are a number of active Associate Members including the University of Tokyo and the South Dakota School of Mines and Technology.

Direct Access to IceCube Public Data Pages – Raw data is securely stored and backed up, consistent with NSF policy. Extracting science from the data requires the use of elaborate hardware and software tools developed by the Collaboration. Like any other particle physics detector, data directly relevant to a scientific issue are obtained after analysis chains that typically require the coordinated efforts of several members of the Collaboration.

In order to be responsive to both the scientific communities' need for usable scientific data and to the NSF requirement for public access to unselected data, IceCube plans to release data in two ways.

1. Release of event reconstruction information for events selected as neutrinos from the overwhelming background of cosmic ray muons.
2. Release of primary event data on all events transferred north over the satellite and used as the basis for analyses.

Data will be made available upon publication of results. For example, when the initial searches for point sources, neutrinos from transient sources, and diffuse astrophysical neutrinos are published the relevant event information associated with this analysis will be made available in an easy to read format. The event information will include reconstructed direction (right ascension, declination), time, reconstructed energy, and quality information of these events. Partial information may be made available earlier.

The IceCube Collaboration has created a data release webpage that serves as the entry point for future data releases to the scientific community, http://www.icecube.wisc.edu/science/data. Initially, this webpage contains release of the 2000-2006 AMANDA data. The URL to IceCube data release webpage is an explicit reference in the corresponding journal publication and will remain the same during IceCube operations (Abbasi *et al* (IceCube Collaboration) Phys.Rev.D79:062001, 2009. e-Print: arXiv:0809.1646). A second, similar, entry point will be developed and made available to the public for the release of "primary" data.

IceCube data releases will follow a similar procedure as the process used to release the AMANDA data. The first paper completed on the combined seven-year data set was the point source analysis. The initial release included right ascension and declination. A second update included identifiers for events included in a publication on atmospheric neutrinos and the Lorentz invariance. This sample is a subset of the full point source data set and meets the highest purity requirements. The final update to the data release page for AMANDA included the event times at full precision after a time dependent analysis on this event sample was completed.

During the operations phase of IceCube it is anticipated that IceCube neutrino data will be released within two to three years after the completed run in which the data are acquired. It is anticipated that the event information will consist of the reconstructed event information and quality information, including the likelihood that an event is caused by a neutrino. The event information might also include a measurement on the probability of the event being a muon or a cascade.

Important requirements for data release are: 1) the IceCube Collaboration's analyses are completed in accordance with the Collaboration's internal approval processes, which include adhering to the principles of blind analyses where practical, and, 2) the calibrations and reconstructed event information is high quality and it is unlikely the information will need to be changed or corrected.

Once IceCube is in steady state operation we continue to plan on annual cycles of data runs beginning in April. Data runs will consist of defined conditions of triggers, thresholds and operational conditions of the detector. The working groups analyze these data sets for the various physics analyses. A reasonable assumption is that ten to fifteen publications will be made using the annual data set and completed on a time scale of two years. Approximately two years after the annual data run is complete it is reasonable to expect that event information can be released. The data release cycle will follow the run completion cycle with a fixed time delay.

The sequence from data taking to publication can be summarized as follows:

1. Data Taking Run (~12 months)
2. Data Processing by Adding IceCube Event Reconstructions
3. Data Analyses for Specific Science Goals
4. Preparation of the Final Data Set
5. Perform Final Physics Analyses and Un-Blind Results
6. Publish Results
7. Release Data Set 1
8. Release Data Set 2

Data Release Set 1 – reconstructed events for the scientific community

The released data that is already reconstructed and most background events will have been removed from the final dataset published, will consist of the following quantities:

Event Time (MJD)
Direction (RA, Dec)
Directional Error
Degrees of Freedom in Fit
Energy Estimator
Flags to Indicate Event Type (e.g., track like, cascade like, etc.)

We plan to release these data in versions of event catalogs. We may revise a catalog of an earlier year to update information to include better reconstruction algorithms and filtering processes to offer a combinable set of data to the scientific community. Based on feedback from this community we may add more information in later releases to accommodate all types of community requests.

Data Release Set 2 – Public access of primary data

The release that contains all the primary detector data, which is calibrated, but not reconstructed, will consist of the following quantities:

Run/Event header with trigger information, event data and time, etc…
Array of all DOM signals with calibrated position, time, and charge (x,y,z,t,q)

We plan to release these events as yearly sets with the entire primary data in binary files on a time scale consistent with the release of data set 1. We will also supply on the website additional documentation to the public including a description of the binary data format, a general description of the detector quantities and what they represent, some illustrative event display pictures, links to relevant publications documenting the detector, and may possibly supply an event reader for a single platform and language. The anticipated size of one full year primary data is several to ten Terabytes, and may optionally require a small charge to cover the cost of physical media or internet server usage.