Drilling from IceCube to Upgrade

IceCube Upgrade
NSF Re-baseline Review
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Jeff Cherwinka – UW Physical Sciences Lab

- IceCube EHWD System Engineer
  - Joined IceCube 2002
  - 6 trips to South Pole ~9+ months on ice
  - Lead Integration, Verification & Test for EHWD
  - Involved in shipment of EHWD to Pole and initial operation
- LZ Dark Matter Experiment Chief Engineer 2012 – Present
- IceCube GEN2 Project Engineer
- 36 years leading projects to design, engineer, fabricate and install physics research equipment around the world.

Drilling for the Upgrade Builds on IceCube Experience

- The Upgrade Drill will be a refurbished version of the Enhanced Hot Water Drill (EHWD) used to drill the 86 existing IceCube holes.
  - 760 lpm (200 gpm) of 88 C (190 F) water -> 4.7 MW thermal, 0.3 MW electric
  - 2.2 m/min maximum drill speed
  - Continuous operation with 30 people (3 shifts of 10)
- Much of the EHWD was left at the South Pole at end of drilling in 2011 and needed evaluation and refurbishment
- Some of the equipment went to other projects such as WISSARD and needed more substantial rework or complete replacement
- Many people that worked on EHWD design fabrication and operation are now on the ICU drill team

EHWD -> ICU Drill

Level of Rework

- Minor
- Moderate
- Major
- **NEW**

Other Buildings:

- Drill Control Center
- Electrical Shop
- Mechanical Shop
- MECC

192 GPM, 2°C, 10 psig

Preheat System
+375 kW (3 of 4 htrs)

Water Tank 2
18°C

Water Tank 1
10°C

High Pressure Pumps
40 psig → 1100 psig

200 GPM, 88°C, 1100 psig

Main Heating Plant 1
+1000 kW (8 of 9 htrs)

Main Heating Plant 3
+875 kW (7 of 9 htrs)

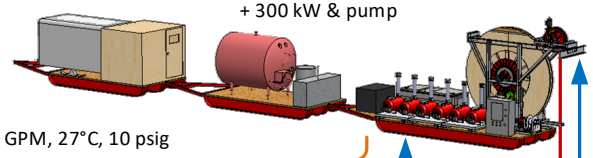
Main Heating Plant 2
+1000 kW (8 of 9 htrs)

Main Heating Plant 4
+750 kW (6 of 8 htrs)

40 GPM
10°C
80 psig

30 GPM
50°C
10 psig

ARA Hot Water Drill
Used for Rodwell Maintenance
+ 300 kW & pump



18 GPM, 27°C, 10 psig

10 GPM, 10°C, 80 psig

GEN 1
GEN 2
GEN 3
PDM

Generators
+ 318 kW heat recovery
(while consuming 250 kW electrical)

Drill Control System

10 GPM
78°C
400 psig

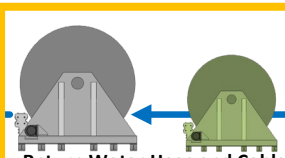
18 GPM
2°C
10 psig

Rodwell

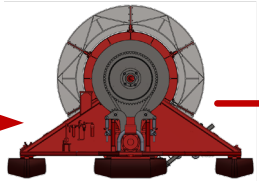
SES
Stationary
all season

TOS
Moves
every
hole

Up to
360m
separation

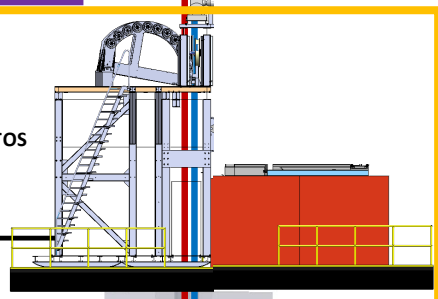


Return Water Hose and Cable Reels



Drill Supply Hose Reel

Cable Reel, Tower, and TOS



Return Water Pump

Drillhead

IceCube Can Drill & Install every 48 hours

Demonstrated repeatable drilling & installation with repair and maintenance for 20 holes in a season. Achieving this rate required learning and we still remember

2003-4 Hose reel shipped to Pole and assembled

2004-5 **1**x Hole, Most of season spent assembling drill, then Drill & Install
- Heat Transfer limit -> higher nozzle velocity
- High Pressure pump motors overheating -> new motors
- 2x 12+ hour shifts, 18 drillers -> 3x 9 hour shifts 30 drillers + manager

2005-6 **8**x Holes - Major revisions to drill (Hose, Tower), Start of first hole Dec 19
- Air in fuel -> pressurized fuel system

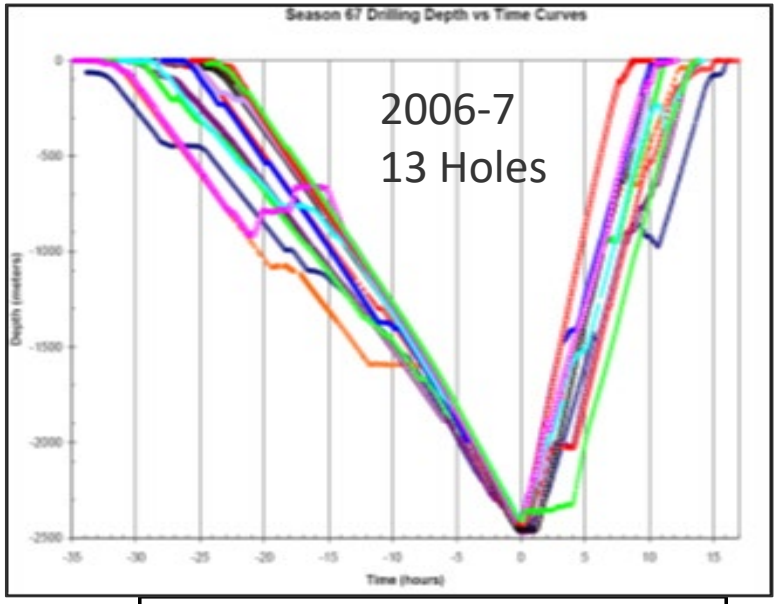
2006-7 **13**x Holes – Start of first hole Dec 11, 8 hose sections replaced, Firn in series
- Hose failures -> Heat hose to -50 C or above during night
- Firn drilling takes a lot of time -> Independent Firn Drill (IFD)

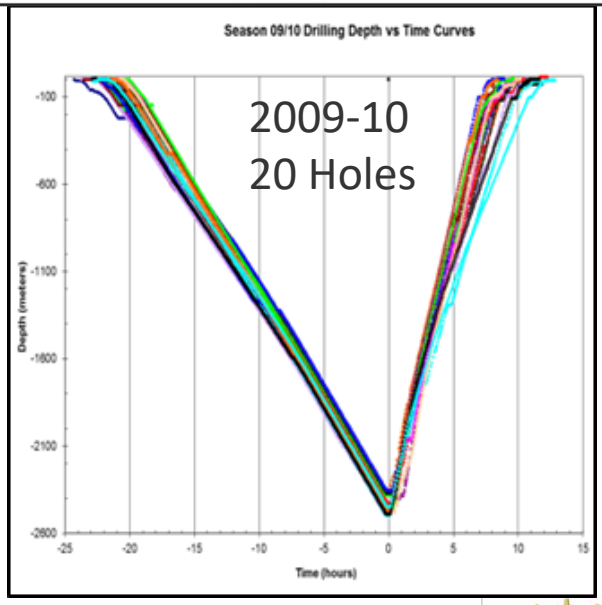
2007-8 **18**x Holes - Drilling limited by fuel availability, Start first hole Dec 5
- Hole modeling & logging allows reduced lifetime and fuel savings
- Better management of rod well and idle heat usage for fuel savings

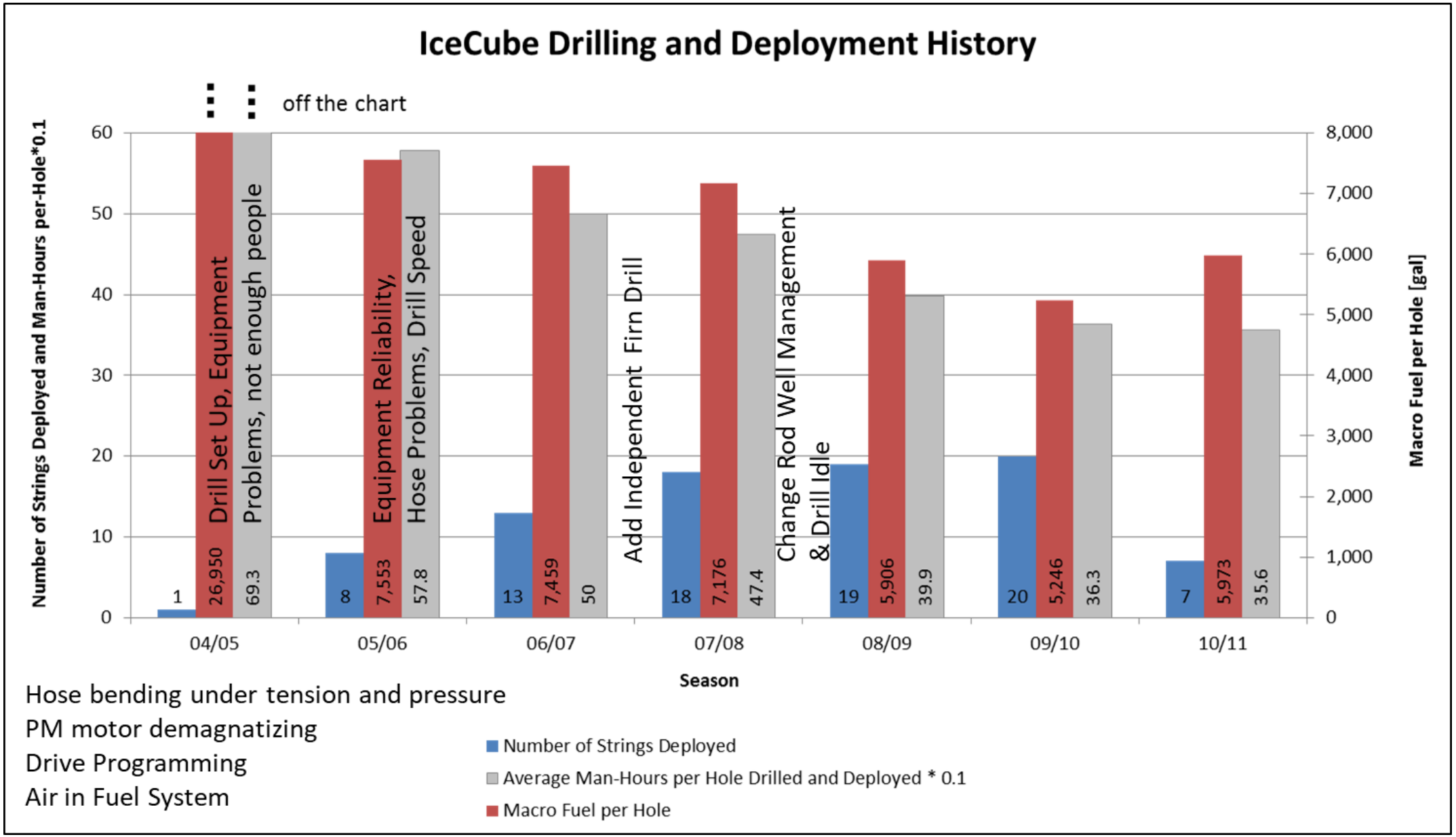
2008-9 **19**x Holes - Experienced crew & optimized equipment yield consistent holes

2009-10 **20**x Holes - And it's repeatable

2010-11 **7**x Holes Pack drill for storage and disposition to WISSARD






IceCube Drilling and Deployment History
off the chart
Number of Strings Deployed and Man-Hours per-Hole*0.1
Macro Fuel per Hole [gal]
Season
04/05
05/06
06/07
07/08
08/09
09/10
10/11
1
26,950
69.3
Drill Set Up, Equipment Problems, not enough people
8
7,553
57.8
Equipment Reliability, Hose Problems, Drill Speed
13
7,459
50
Add Independent Firn Drill
18
7,176
47.4
Change Rod Well Management & Drill Idle
19
5,906
39.9
20
5,246
36.3
7
5,973
35.6
Hose bending under tension and pressure
PM motor demagnatizing
Drive Programming
Air in Fuel System
Number of Strings Deployed
Average Man-Hours per Hole Drilled and Deployed * 0.1
Macro Fuel per Hole

Lessons Learned & Implemented

- Water quality was not a criteria for EHWD. Water contamination from particulates, and bubbles from entrained air have proven to be issues and will be improved
- The northern hemisphere support group did help solve problems and improve solution implementation time. This was a dedicated person on shift in the north with a phone.
- Testing and training in the drill test bed at PSL helped avoid problems in the field and helped resolve them when they occurred. This facility has been retained and will continue to be used. All drillers and most installers get some training before heading to the ice.
- A meeting of all drillers before start of drilling to insure the equipment and people are ready proved to be helpful.
- Shift Lead with Deputy Lead as safety officer worked well. Drill Manager separate.
- Restarting the EHWD has shown we could have done better at documentation and archiving. The upgrade is working to improve this.
- Reliable snow machines are important for efficiency and safety.
- DOMs proved to be extremely reliable.

People are Key

- ❖Getting good people is important
- ❖Keeping Experienced people is even more important
- ❖ICU is fortunate to have many experienced people still available

- ○ Good Pay
- ○ Year Round Insurance
- ○ Summer Training
- ○ Treating people well

Logistics Experience

- The Logistic path to the South Pole is long and there are many serial steps. Every step had an issue at some point in the project. These are often out of the projects control
- Starting things into the Logistic path as early as possible yielded the best results
- Communicating with people as directly as possible helped eliminate and resolve problems
  - Air National Guard officers visited UW-PSL to look at cargo and talk about issues
  - RPSC also visited PSL and invited IceCube planners to their offices in Denver to work out details
  - IceCube had direct contacts at Port Hueneme to talk about arrival and shipment details
  - IceCube had direct contacts in Christchurch to talk about arrival and shipment details
- There were delays getting people to the South Pole… plan some float
- There were delays getting cargo to the South Pole… plan some float
- The project was completed successfully!

Drilling Requirements Comparison

	EHWD (Gen1)	ICU	Ratio (ICU/Gen1)
HOLE DEPTH	2450 m	2600 m	1.06
HOLE SIZE	45 cm dia for 37 hr lifetime	52 cm dia for 45-55 hr lifetime	1.38 (volume)
TIME TO DRILL HOLE	34 hr (typical)	53 hr (average)	1.57
ARRAY	125 m hole spacing	22 m hole spacing, center of IceCube	
ICE QUALITY	NA	Better and less bubbles	
HOLES	86 holes in 7 seasons	7 holes in 1 season	
DRILL TEAM	30	28	
LOGISTICS	LC130, primarily	Vessel and Traverse, primarily	
INSTRUMENTS	60 per string	115 per string	1.92

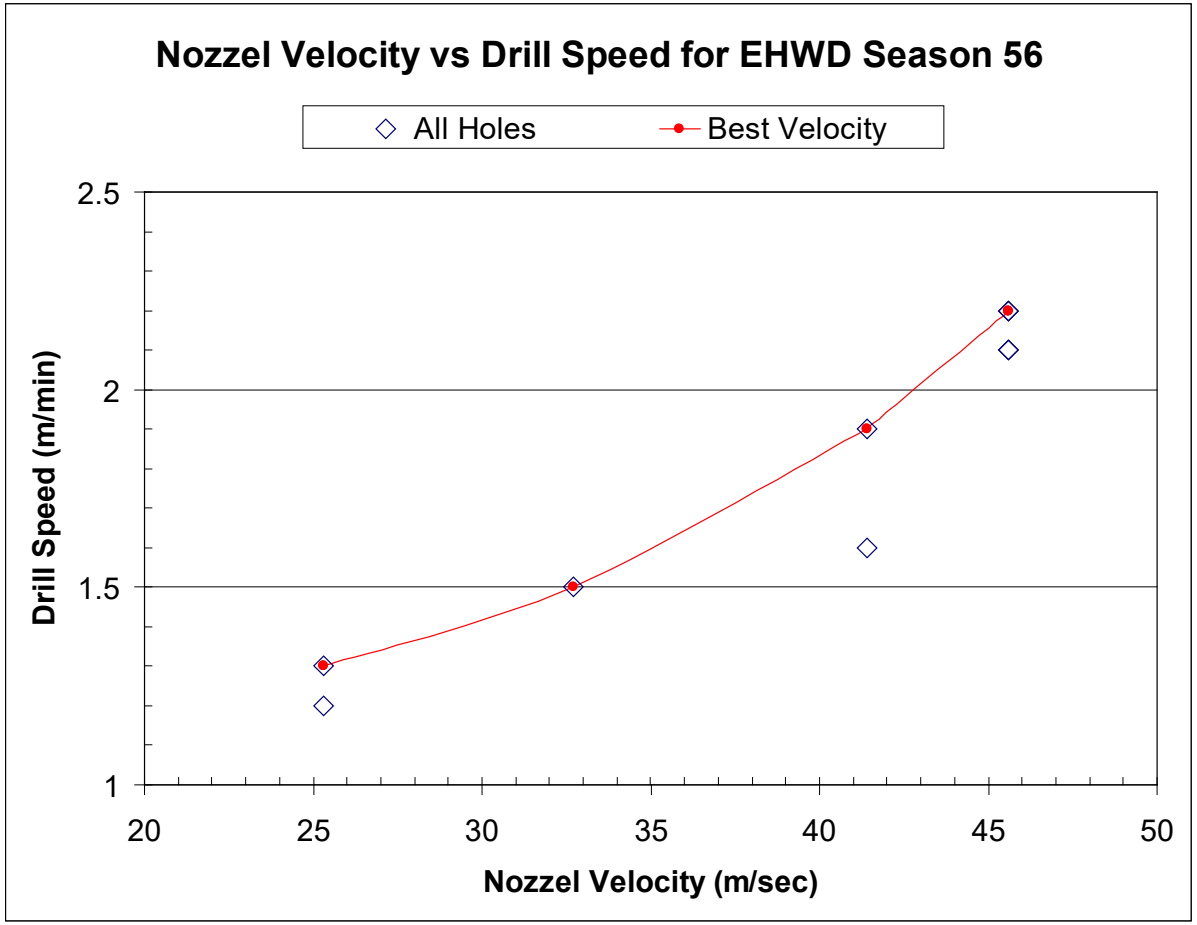
SUMMARY

- IceCube GEN1 drilling and deployment was not easy and it had a very difficult first year, but then continuous improvement led to consistent performance above expected installation rates.
- The lessons learned have already been incorporated into improvements in the EHWD equipment and should benefit the ICU.
- The rest of the knowledge from those hard learned lessons is still in the hearts and minds of the many member of the ICU team that were involved in the original IceCube construction.
- Upgrade drilling, using a refurbished EHWD, requires holes that are a little deeper and larger, but is a straight forward extension of proven drilling methods.

Backup Slides

Making measurements allowed improvements

- While we attempted to model hole drilling with CFD we learned the most with experiments during drilling. Nozzle Velocity is key to maximum drill speed
- We also logged holes to verify and improve hole drilling and freeze back model
- ICU will study different reaming strategies and water quality impact on the hole ice
- We are thinking about other things that might be useful for GEN2 like freezeback pressure and it's mitigation



Enhanced Hot Water Drill (EHWD)

IceCube, South Pole 2004-2011

Seasonal Equipment Site (SES), aka Drill Camp

Enhanced Hot Water Drill (EHWD)

IceCube, South Pole 2004-2011

Tower Operations Site (TOS)

Drill season: IceCube and IceCube Upgrade

	Upgrade	IceCube	ratio
Drill volume/m^3 (measure of drill time)	2150	1560	**1.34**
Equivalent number of strings	7	9.7	
Drill population	28	30	1.07
Scale factor of duration/hole			**1.43**
Modules per string (measure of deployment effort)	115	60	1.91
Complexity of modules	1.2	1.0	1.3
Equivalent number of modules deployment effort	150	60	**2.4**
Deployment population	10	10	1.0

Scale factor time required for 7 strings:
Drilling:

- based on pure drill time and population: 1.43
- Installation: 2.4

Effort scale factor weighted by relative effort of drilling and installation: 1.71

Note: non-drilling time between holes is here scaled the same way (1.4) as the actual drill time.
This is a realistic, probably conservative assumption,
When comparing to IC full production drilling.
Eg, shorter moves make things easier for Upgrade.

Drill season: IceCube and IceCube Upgrade

Scale factor for time required per string deployed:

Drilling:

- based on pure drill time and population: 1.43

Installation:

- Based on # of modules per string and complexity: 2.4

Overall scale factor for effort weighted by relative population of drilling and installation: 1.69

Time required for drilling and installation based on scaling model:

7 Upgrade strings = 11.8 IceCube strings

IceCube would drill 20 holes from start of December to about January 28.
Upgrade has schedule to drill 7 holes from 12/14 to 1/21. Scales well with may be a week to spare in Upgrade.

Operations

- Drill season operations
  - See Dar's talk
- Hole life cycle
  - Firn Drill
  - Deep Drill + Ream
  - Turn over to Deployment Team
  - Move reels to other TOS
  - Repeat
- Deep Drill and Ream
  - SES team ensures a reliable and steady flow of hot water is supplied to TOS
  - TOS team drives drill and maintains safe/smooth operation of reels
  - Driving drill involves constant monitoring of system parameters and referencing drilling strategy speed charts
- Other Operations
  - Instrument installation
  - Hole moves
  - Maintenance and repair