Innovations in Hot Water Drilling at the South Pole

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Two South Pole Neutrino Detectors

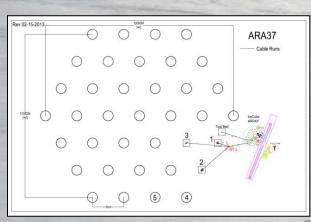


IceCube Detector In Operation Construction 2004-2011

Enhanced Hot Water Drill 5 MW φ60cm x 2500m in 48hr

Two Hot Water Drilling Systems



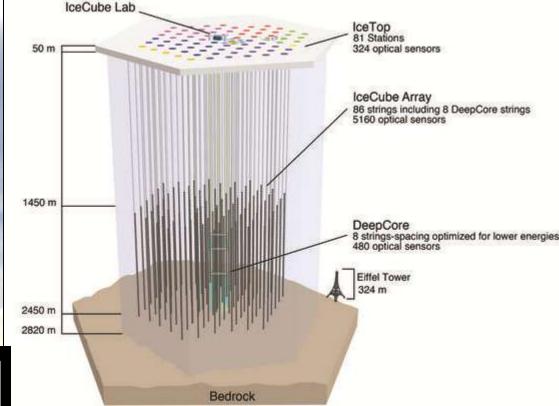


Askaryan Radio Array (ARA) Under Construction

ARA Hot Water Drill 300 kW, mobile φ16cm x 200m in 10hr

IceCube Overview

- 1 km³ neutrino telescope
- Transforms 1 billion tons of ice into a particle physics detector



Ice converts neutrino to blue light

WHY?

- New window into the cosmos
- Discovery machine

WHY THE SOUTH POLE?

- Lots of ICE
 - Transparent and clear
 - Large volume
- Sufficient infrastructure

More Info:

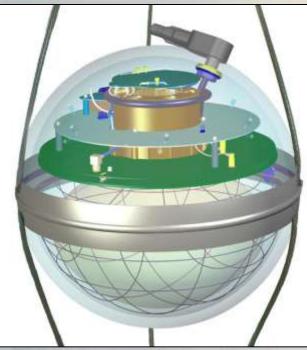
PTC 2009 (Madison) – Francis Halzen Overview of the IceCube Project

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IceCube Overview – INSTRUMENTATION

- Digital Optical Module
 - Down-facing Photomultiplier Tube (PMT)
 - On-board computer
 - Glass sphere (φ14", 10000psi+)
- Cables (downhole and surface)
- IceCube Lab
 - Data collection, processing, storage, data link to North

Digital Optical Module (DOM)





DOM being deployed into hole

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60 DOMs per String



Enhanced Hot Water Drill (EHWD) Requirements

Why Hot Water?

- Hot Water + Ice = Hole

- Fast
- Need a water-filled hole
 - DOMs freeze in and become optically coupled with ice sheet
 - Fluid supports hole so it doesn't collapse in on itself
 - Allows us to circulate water

WATER PUMP HEAT SHOOT OUT NOZZLE RECIRCULATE

System Requirements

- 86 holes, each 60 cm (24 in) in diameter and 2.5 km (1.6 miles) deep
- 17.2 million gallons of ice to melt!
- 7 field seasons (2004-2011)
- Compatible with South Pole environment and logistics
- Co-support deployment of in-ice instrumentation

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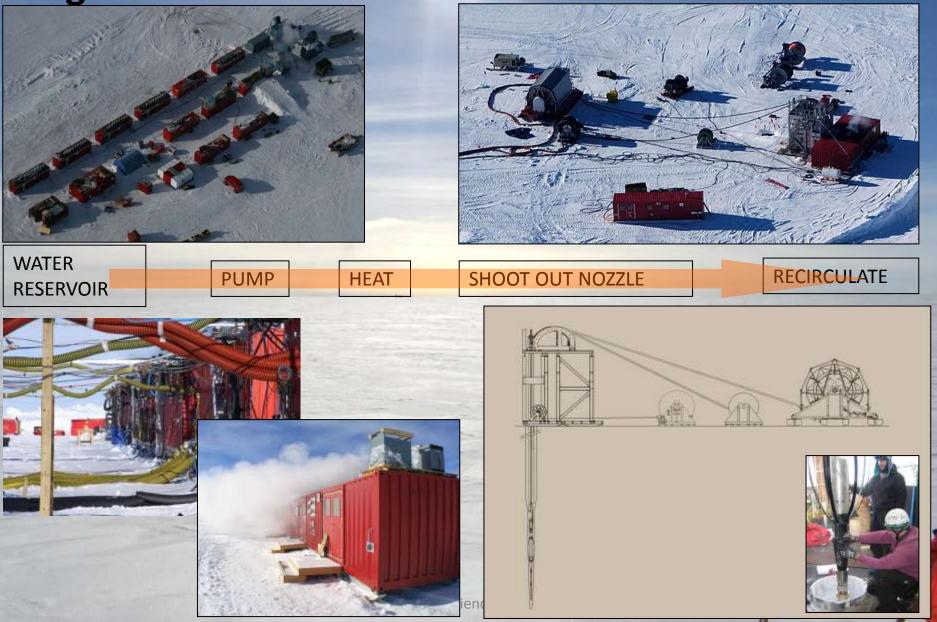
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FUEL EFFICIENCY IS A DESIGN DRIVER!

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- Co-support deployment of in-ice instrumentation

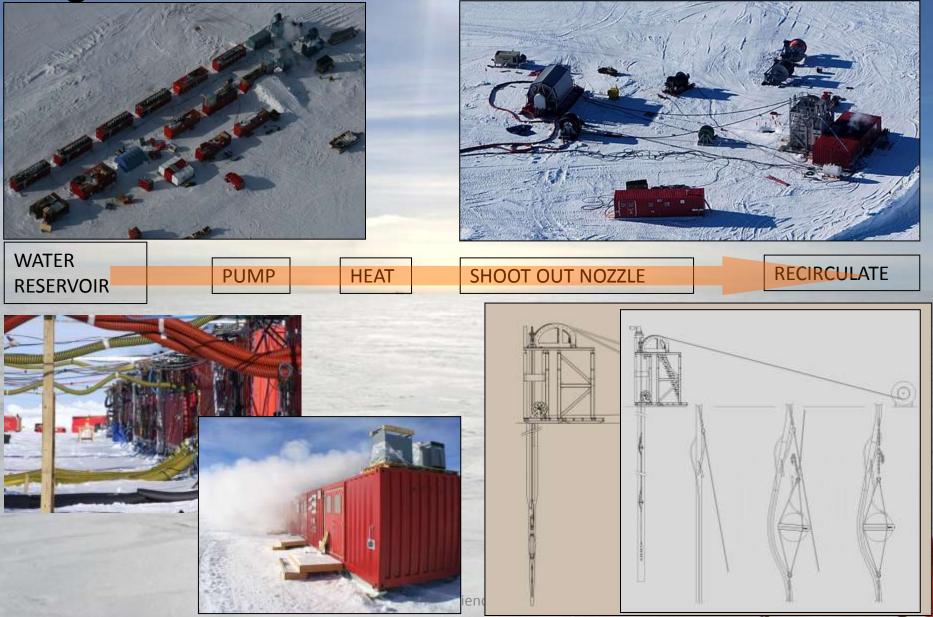
Enhanced Hot Water Drill (EHWD)

Design

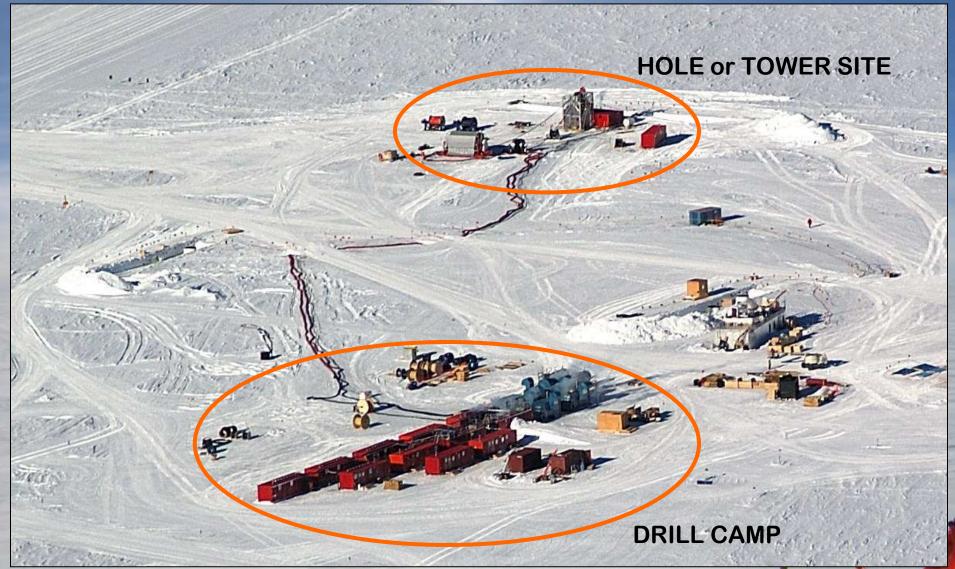


Enhanced Hot Water Drill (EHWD)

Design



Enhanced Hot Water Drill (EHWD) Design



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EHWD Stats and Specs

2005

- IceCube has delivered ~9.5 million lbs to SPole, half of which is fuel
- 4.7 MW of thermal power output
 - That's 6300 horsepower
 - Equivalent to a locomotive at full power, or...
 - 8 Nascars racing at full speed
 - All this shot out of a ¾" nozzle!
- Mileage = 1400 gallons of fuel per mile
- Each hole requires 3 Herc flights
- We have drilled 86 holes, and have melted enough ice for 794 million cocktails!

<u>SPECS</u>

- 5 MW (4.7 MW thermal, 300 kW elec)
- 200 GPM, 88°C, 1000 psi
- 1.4 million lb
- 2.1 m/min max drill speed
- φ60cm x 2500m hole
 - 31 hr drill
 - 48 hr turnover
 - 4500 gal fuel
- 24/7 operation, total crew of 30

Enhanced Hot Water Drill (EHWD) Notables and Takeaways

Notables

- Advanced computer control system
- High-efficiency water heaters, 92% HHV
- Instrumented drillhead
- Thermal modeling and drill strategy
- Giant hose reel with continuous custom hose
- Independent firn drill

<u>Takeaways</u>

- Wide range of electric and mechanical systems implemented at South Pole
- Hole modeling and freeze back tools
- Hose and its challenges
- Nozzle velocity very important
- Independent firn drill incredibly valuable
- Generator heat recovery
- Rodwell strategies
- Strong safety and fuel-conservation cultures make a difference
- Staffing RETAIN EXPERIENCE



Enhanced Hot Water Drill (EHWD) Performance

Hole Profiles (depth vs time)

Good indication of performance •

How Did It Do?

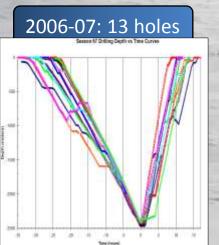


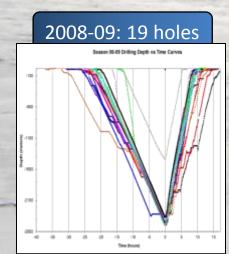
Enhanced Hot Water Drill (EHWD) Performance

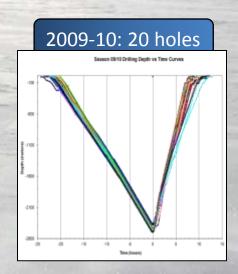
Hole Profiles (depth vs time)

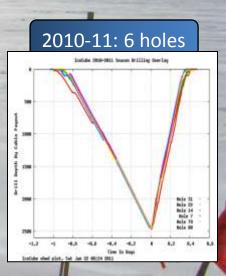
- Good indication of performance
- Trend highlights reliability and experience











IceCube Detector

Construction completed Dec 2010

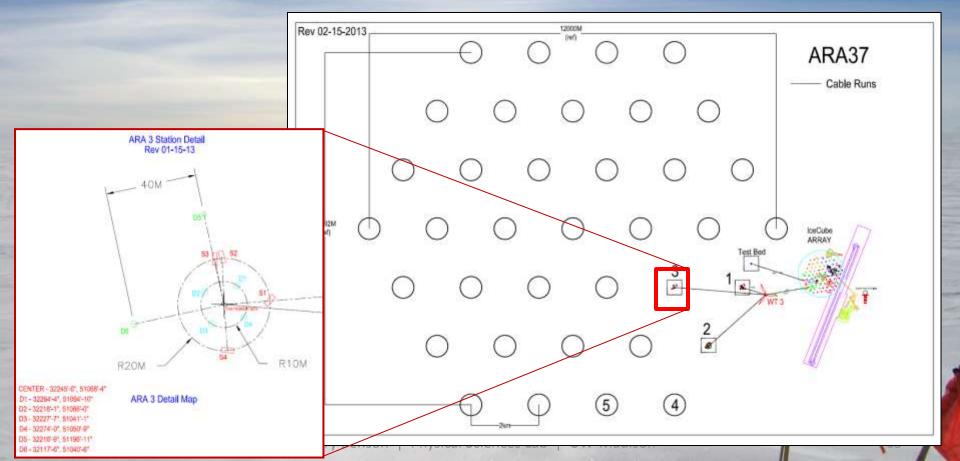
EHWD parted out, but most equipment still @ South Pole (under NSF custodianship)

<u>ARA</u>

Proof of concept stage began Jan 2011 New drill

ARA Overview

- ARA = Askaryan Radio Array = Neutrino Telescope
- Detects RADIO signature from neutrino interaction with ice
- Very large area (100 km²)
 - ARA37 = 37 "Stations"
 - 6 holes/station
 - 222 holes
- Closely coupled with IceCube



ARA Overview - INSTRUMENTATION

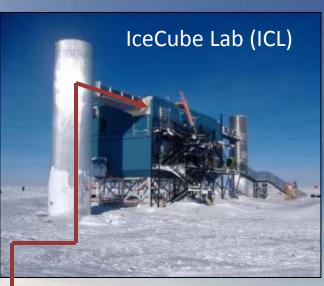
- Antennas
 - Vertically polarized (2 per hole)
 - Horizontally polarized (2 per hole)
- Electronics
 - Downhole
 - Surface
- Deployment kit and cables
- IceCube Lab
 - Data collection, processing, storage, data link to North



Antennas 2 pairs/hole



Antenna being deployed into hole





Down-hole and surface electronics

ARA Hot Water Drill (ARAHWD) Requirements

Hole Requirements

- DRY hole
- φ6", minimum
- 200m usable depth
- 2 holes/day (achievable with 2 shifts/day)
- Spread over large area and away from South Pole Station

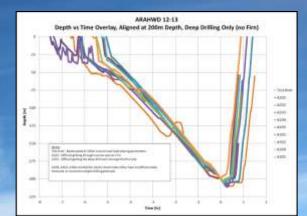
Hot Water Chosen

- Experience
- Equipment
- Proven technique, lowest risk option

ARA HOT WATER DRILL

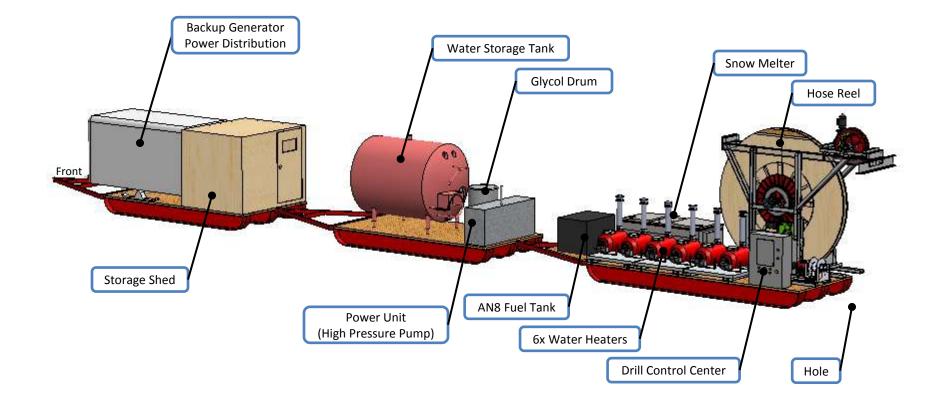
T. Benson, PSL

3 sled train configuration, 34k lb dry weight 300 kW thermal power 12 gpm, 85°C, 1000 psi φ16cm x 200m DRY hole in 7hr crew of 5/shift

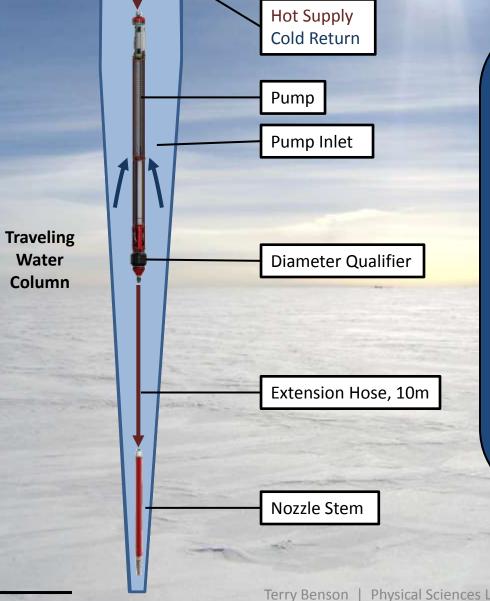


Overlay of 2012-13 hole profiles

- Askaryan Radio Array (ARA): Neutrino detector under construction at the South Pole
- Hole Requirements: φ16cm x 200m depth, DRY, 2 holes/day (with 2 shifts)
- New Technique: Pump hole dry during drilling process, pump travels with drillhead
- Successful 2012-13 field season
 - Inaugural season for updated system and new drill method
 - 12x production holes (12 planned)
 - All ARA detector instrumentation successfully deployed
 - 1 hole per day with 1 shift (12 hour shifts last season, 10 hour shifts within reach)



Innovation in Technique



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Dry Hole

New Drilling Method: PUMP/DRILL AT SAME TIME

Recirculated water column travels down with drillhead. Hot water sprays out nozzle and travels some distance back up the hole to the pump, where the water is pumped back to the surface. Hole diameter is developed between nozzle and pump.

- Closes loop and returns water during • drilling
 - No snow melting, net water production
 - System capacity effectively doubled from lost water / snow melting method
- Leaves dry hole above ٠
 - No freezeback!
 - 1 step = faster production rate

ARA Hot Water Drill (ARAHWD) Challenges and Takeaways

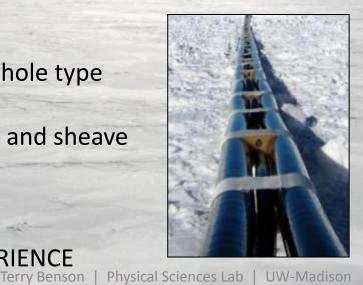
Challenges

- Freezeback 4x faster than IceCube
- Dry hole
- Reliability
- Portability

<u>Takeaways</u>

- New drilling technique
- Performance models and more hole modeling
- Video logging hole
- New discoveries about hole type
- Hose and cable bundle
- Load splitting hose reel and sheave without level winding
- Instrumentation
- Operations and Tools
- Staffing RETAIN EXPERIENCE

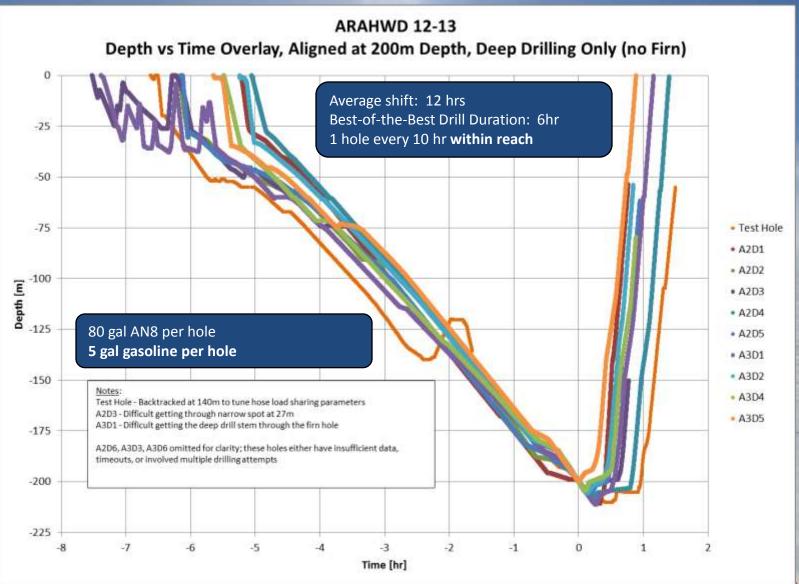




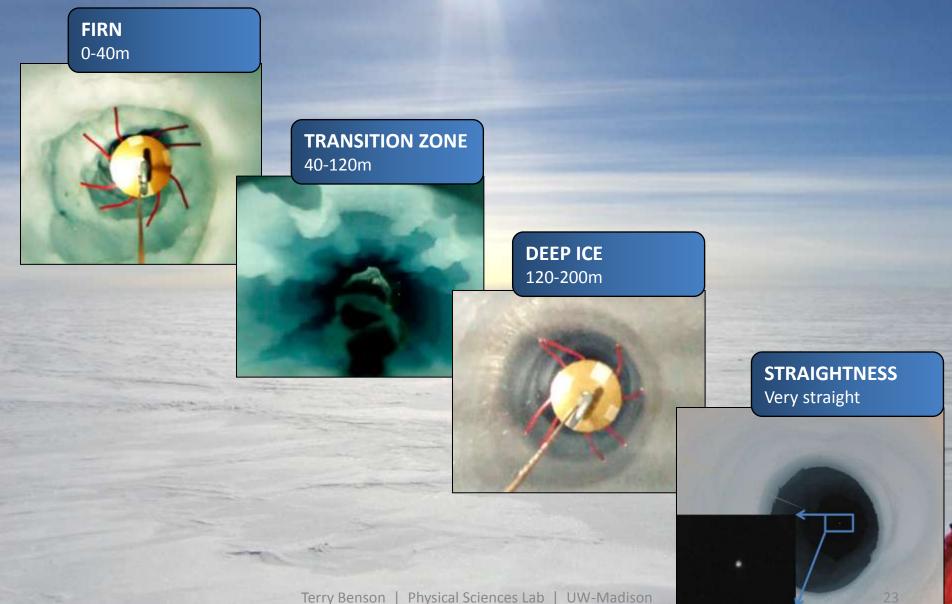




ARA Hot Water Drill (ARAHWD) Performance



ARA Hot Water Drill (ARAHWD) Performance – Hole Quality



Conclusion

Last 10 years of hot water drilling at South Pole

- EHWD: Most massive system of its kind, LOTS of lessons learned and innovations along the way
- **ARAHWD**: New portable drilling technique that works great (drill/pump, using water to make dry holes)

New tools for the future

- Thermal hole modeling and HWD system performance modeling
- Independent Firn Drill
- ARAHWD (and further development)
- Fuel-saving measures
- Skillsets

Questions

CONTACT

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WEBSITES

- psl.wisc.edu
- wipac.wisc.edu
- icecube.wisc.edu
- ara.physics.wisc.edu

EHWD Seasonal Equipment Site (SES, Drill Camp)

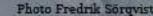
olarhaven

SHOP

MHP:

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MHP4



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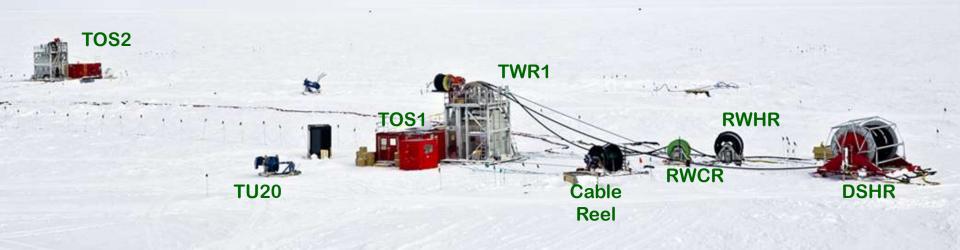
DCC

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SEW

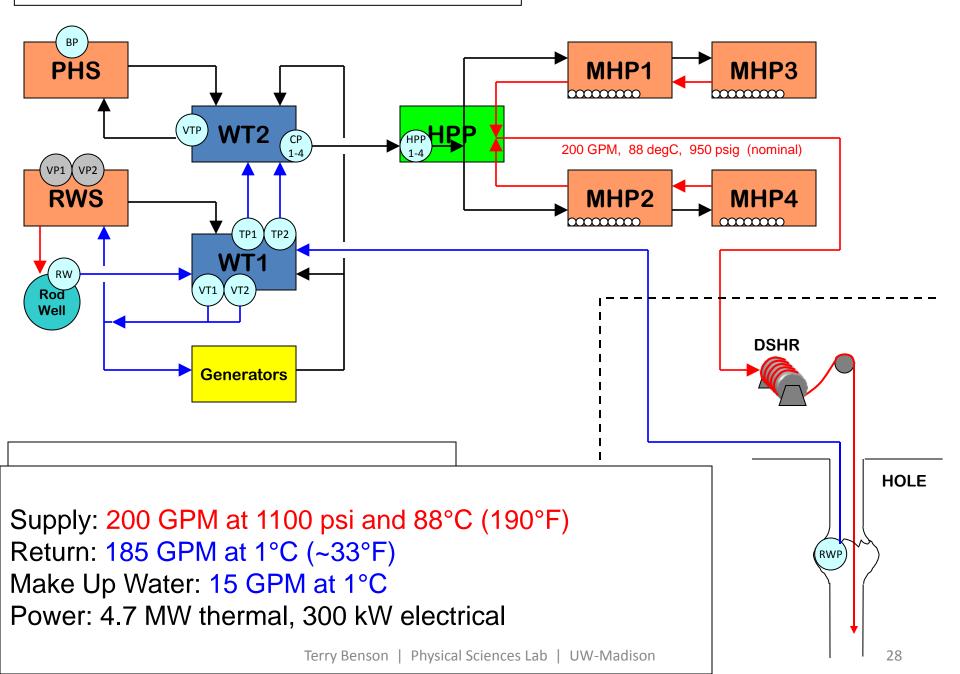
MECC

EHWD Tower Operations Site (TOS)





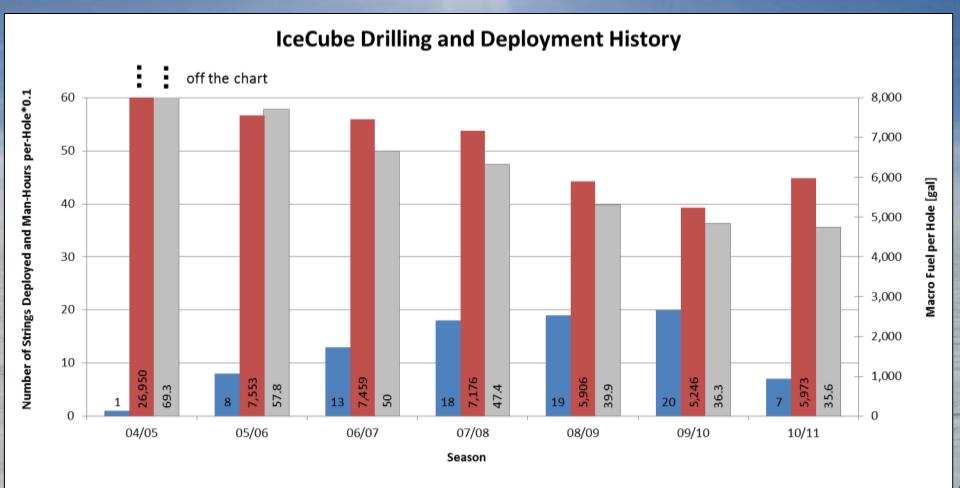
Enhanced Hot Water Drill Hydraulic Summary



EHWD System Specs

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Enhanced Hot Water Drill (EHWD) Performance

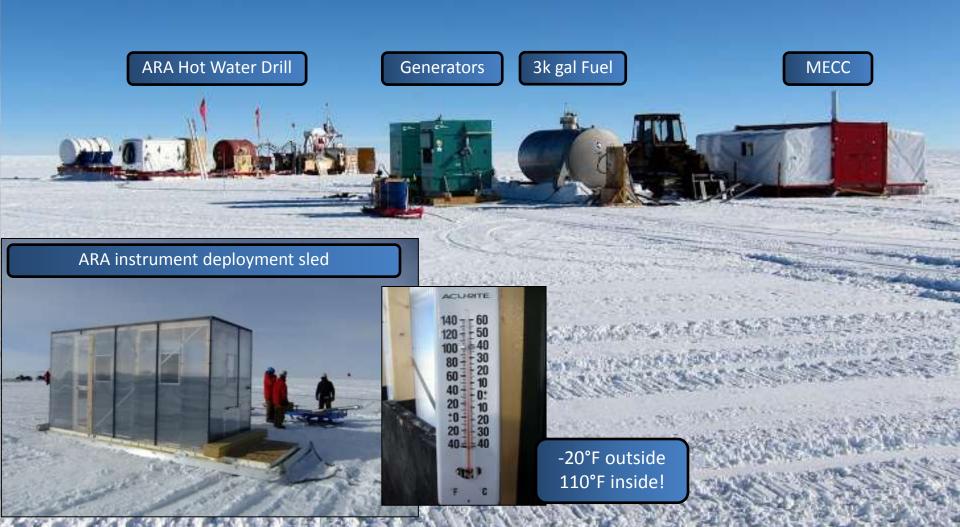


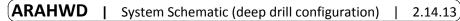
Number of Strings Deployed

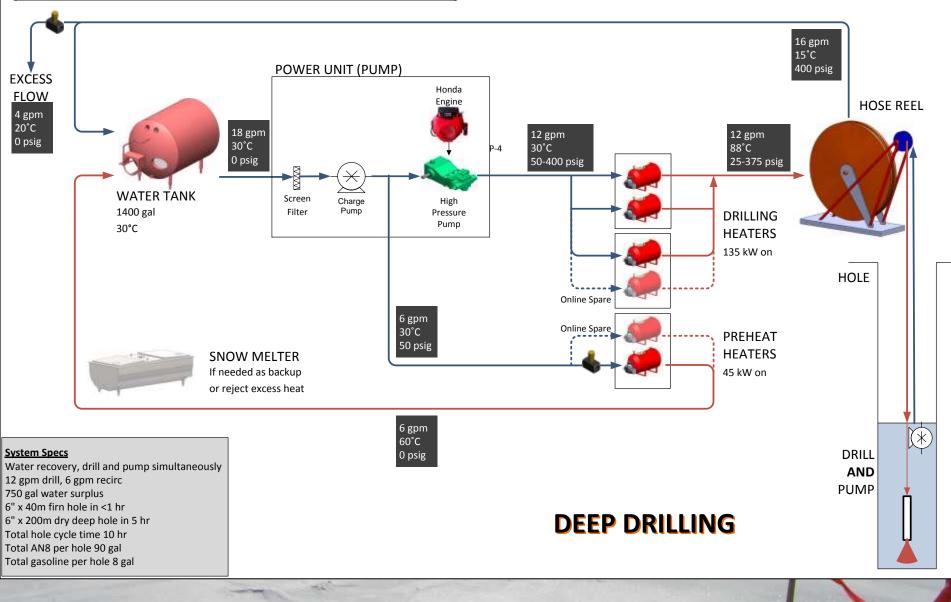
Average Man-Hours per Hole Drilled and Deployed * 0.1

Macro Fuel per Hole

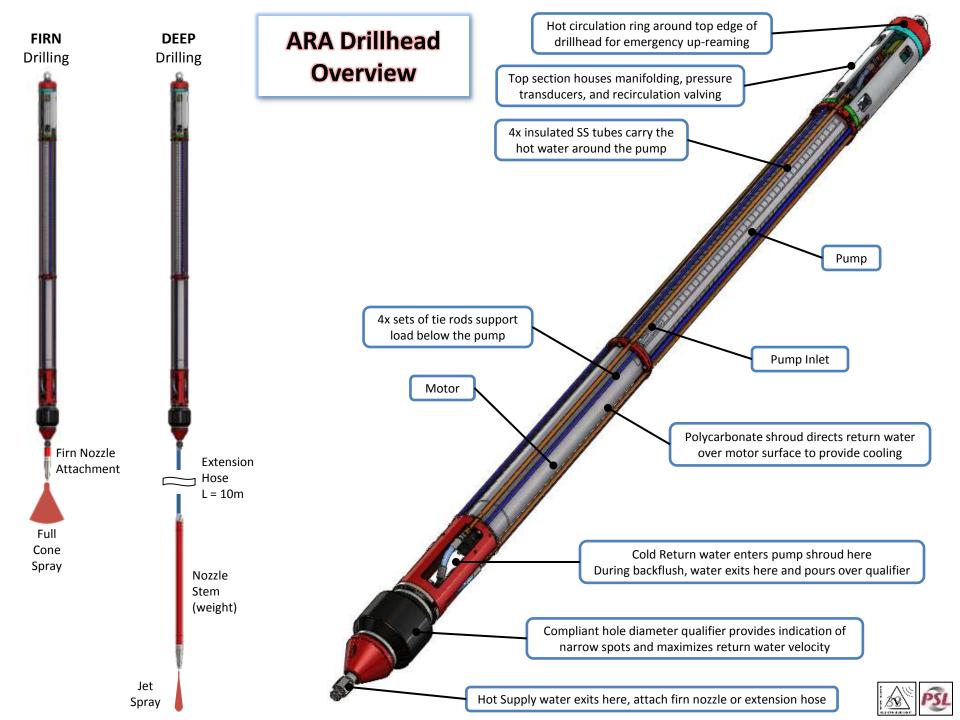
ARA Station







Terry Benson | Physical Sciences Lab | UW-Madison



ARA Hose Reel Overview

Hose and cable bundle

- 2x hoses and 1x combo cable
- Multi-reel joined at hole not a solution
 - Load to be shared amongst all 3 members, intricate syncing control would be _ required
 - Extra task at hole of joining/separating members
- Manufactured umbilical with round cross-section too expensive, too big
- Decided to build custom from separate pieces, resulting in a ribbon profile

Single width spiral configuration

- Accommodates hose bundle design with ribbon cross-section
- Improves safety and reduces complexity by eliminating level wind and associated fleet distance
- 2x familiar applications that have succusfully utilized this design
 - Rapid Air Movement (RAM) Drill
 - Independent Firn Drill
- Large diameter required to accommodate full length of hose, so design incorporates a 45° pivot to allow the reel to fit on an LC-130 aircraft

Dual-drive, load sharing system

- A dry hole results in high down-hole loads (no bouyancy)
- High loads + many layers would collapse the lower layers of hose if using only the drum to react the load
- Motorized sheave utilizes friction with the bundle to react a majority (~80%) of the down-hole load, like a capstan winch
- In this mode, the sheave operates in velocity mode and is master to the drum, therefore payout and speed is directly controlled without effects of changing diameter
- The drum operates in torgue mode and is slave to the sheave, and the hose is wrapped onto the drum at only 20% down-hole load

Motorized sheave operates in speed mode during deep drilling, is master to drum

Structural Insulated Panels

(SIPs) used for flanges

Mounting face for beam and trolley hoist

> Redundant load cells

Other Side: 2-port rotary hydraulic union Failsafe disc brack Heated valving box

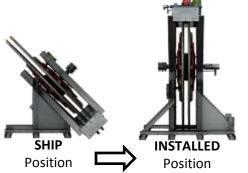
Payout/speed

encoder

Electrical slip ring (480v 3ph, comms)

Drum operates in *torque* mode during deep drilling, is slave to sheave





Bundle X-section

Skis allow for light towing on snow



Туре	Hot water drill						
Configuration	Towable 3-sled train						
	CAT 953 or equivalent for short moves						
Tow Vehicle	D6 or equivalent for long moves						
	Packed roads and pads required						
Nominal Hole Dia	16-20 cm (6-8 in)						
Max Hole Depth	210 m						
	Water-filled (traditional) hole						
	Dry hole (drill/pump simultaneous)						
Capabilities	Closed-circuit firn drilling (requires upgrade)						
	Off-site drilling with backup generator						
	Snow melting, if required						
	300 kW thermal						
	22 gpm total flow						
	12 gpm nominal drill flow						
		drill/pump simultaneous metho	d)				
	1000 psi max system pressure						
Capacities	1700 lb max total down-hole load						
	1400 gal insulated water storage						
	240 gal online AN8 fuel tank						
	120 gal online glycol tank						
	30 kW (sea level) backup generator, 480VAC 3-phase						
	24 kW steady state						
Elec Power Consumption 33 kW peak (est.)							
	480VAC 3-phase 60-amp connection in						
Crew Size	5						
	Generators						
	Reserve online water tank						
Auxiliary Equipment	Reserve glycol and gasoline barrels						
	NHG heater and wind breaks						
	MECC (warm space for breaks, meals, and meetings)						
Target Hole Peformance							
Hole Specs	16 cm (6 in) diameter x 200 m	n DRY, @ South Pole					
Drill Time	7 hours						
Cycle Time	10 hours						
AN8 Fuel	78 gal						
Gasoline	5 gal						
Sled-by-Sled	Sled 1	Sled 2	Sled 3				
	Power distribution, backup		Water heating, snow melting				
Function		Water storage and pumping					
	gen, storage	The second second	control, and hole ops				
	11,000 lb	8,000 lb	15,000 lb				
Weight EST., dry (wet)	(11,000 lb)	(20,000 lb)	(18,000 lb)				
	16 ft x 8.5 ft w/o tongue	16 ft x 8.5 ft w/o tongue	20 ft x 7.75 ft w/o tongue				
Footprint, L x W	Tongue adds approx 10 ft to	Tongue adds approx 10 ft to	Tongue adds approx 10 ft to				
	length	length	length				
		hipping position to allow trans					

Challenges at South Pole

- Antarctica: The coldest, windiest, and driest place on earth
- Station "open" during short austral summer, Oct-Feb
- Average Annual Temp is -49°C
- Average Summer Temp is -33°C
- Winter Temps to -80°C
- World's largest desert, DRY
- Altitude is ~10,000 ft
- Isolated

Hot Water Drill Design Template

- Define hole size and quantity
- How fast do they need to be drilled?
- ✓ Required thermal power
- Upper water temperature limit is boiling (South Pole: 88°C)
- ✓ Required flow

 \checkmark

- Find the right hose
- Maximize pressure -> Maximize nozzle velocity -> Maximize drill speed
- Pump, heater, tank sizing, etc.
 - Requirements + Budget + Time = Component Selection