Ice Drilling Design and Operations (IDDO)
Technical Advisory Board
April 20 & 21, 2010
University of Wisconsin – Madison
Room 351, Space Science and Engineering Building
1225 W. Dayton Street
Madison, WI USA

On April 20 and 21, 2010, the Ice Drilling Design and Operations (IDDO) group's Technical Advisory Board (TAB) met to discuss technical issues presented in drilling rock and ice. The intent of the meeting was to obtain feedback from industry experts and incorporate this feedback into drill planning, design and operations. Nearly half of the Technical Advisory Board members were present as well as personnel from IDDO, the Ice Drilling Program Office (IDPO) and a representative from the IDPO Science Advisory Board (SAB).

Attendees

Name	Group	Organization Affiliation
Mary Albert	IDPO	Dartmouth College
Charlie Bentley	IDDO/IDPO	University of Wisconsin-Madison
George Cooper	TAB Substitute	University of California-Berkeley
Kristina Dahnert	SSEC/IDDO	University of Wisconsin-Madison
William Eustes	TAB	Colorado School of Mines
Mike Gerasimoff	IDDO	University of Wisconsin-Madison
Chris Gibson	IDDO	University of Wisconsin-Madison
William Harrison	TAB	University of Alaska-Fairbanks
Mark Hobson	SSEC	University of Wisconsin-Madison
Jay Johnson	IDDO	University of Wisconsin-Madison
Tanner Kuhl	IDDO	University of Wisconsin-Madison
Bill Landucci	IDDO	University of Wisconsin-Madison
Don Lebar	IDDO	University of Wisconsin-Madison
Nicolai Mortensen	IDDO	University of Wisconsin-Madison
Steve Polishinski	IDDO	University of Wisconsin-Madison - Contract
Ross Powell	SAB	Northern Illinois University
Alex Pyne	TAB	Victoria University of Wellington
Alex Shturmakov	IDDO	University of Wisconsin-Madison
Joe Souney	IDPO/SCO	University of New Hampshire
Tony Wendricks	IDDO	University of Wisconsin-Madison - Contract

TABLE OF CONTENTS

(Day 1 – 4/20/10)

Welcome

Charlie Bentley initiated the meeting by welcoming all in attendance and providing an updated agenda for the meeting. As volcanic ash over Europe prevented the flights and attendance of Laurent Augustin and Steffen Bo Hansen, the original agenda was revised to allow phone conferences with those in Europe during certain topics of discussion.

Introductions/Logistics (Wendricks)

Summary of IDPO/IDDO Structure (Albert)

- 2008 – NSF wanted a new paradigm, a cooperative agreement rather than a contract.
  - Separate science office and drilling technology group
  - Previously drills were developed quickly and under the gun; things can now be planned 5-10 years in advance
- Vision – To enable discoveries about changes in climate and the environment, using evidence from glaciers and ice sheets, to inform environmental policy.
- Mission – To conduct integrated planning for the ice drilling and technology communities and to provide drilling technology and operations support that will enable the community to advance the frontiers of climate and environmental science.
- Goals
  - Long/short term integrated science and drilling technology plans in collaboration with the science communities
  - Identify new technology, seek funding, acquire new technology
  - Provide needed equipment – drills, equipment, expertise
  - Enhance community communication and information exchange
- Collaboration – Three organizations involved (Dartmouth College, University of New Hampshire, University of Wisconsin-Madison); The IDPO and IDDO have advisory boards that work to formulate Long Range plans for each organization:
  - IDPO - SAB (Science Advisory Board) members represent all aspects of the ice drilling/science/logging community and develop and annually review the Long Range Science Plan (formerly the 5-Year Science Plan).
  - IDDO - TAB (Technical Advisory Board) members represent a host of drilling technologies and develop and annually review the Long Range Drilling Technology Plan (formerly the 5-year Drilling Technology Plan).
  - Updated plans will be available on the web in June 2010.
- Additional information available at www.icedrill.org

Summary of IDPO-SAB Meeting (Albert)

- SAB Organizational Chart – a broad spread of scientific interests
- TAB Organizational Chart – a broad spread of drilling experience and expertise
- Charge to the SAB
  - Science drives the drilling: A draft of the Long Range Science Plan will be on the web for community review by June 2010. This is a living document and will be updated annually.
- SAB Recommendations
  - Planning for drilling technology needs to include consideration of the cost and availability of logistics from earliest planning stages through project fulfillment.
  - Drills and technology should be developed with an eye for variety
  - Designs should be such that necessary support logistics do not impede execution of the science.
- SAB Priority Investments
  - Maintain agile coring/drilling capability (Badger Eclipse, hand augers)
  - Two logging winches 1km, 4km
  - Replicate coring capability (DISC drill)
  - Purchase/design intermediate coring drill utilizing NZ or Danish Hans Tausen design

    - Conceptual design for fast, narrow hole access to ice sheet bed
    - Conceptual design for DISC drill upgrades to enable use in East Antarctica/other colder regions
    - Conceptual design for large hole access through ice sheet for deployment of subglacial rovers
- Collaboration funded for 5 years. The Cooperative Agreement (CA) gives NSF more flexibility with funding as opposed to a contract. The CA term can be extended after 5 years.

SAB Meeting Results

- NSF vision for research community organization
    - Fruit basket analogy to have cryospheric science community under one organizational umbrella. Different disciplines but let the cryosphere community decide how they will organize.
        - Possible combination of all polar, sea ice, and NICL archive science
- Relationship of IDPO to other groups, i.e. Ice Core Working Group (ICWG), etc.
    - SAB members represent their sub-community in two-way communication, bring working group white papers to Long Range Science Plan
    - IDPO encourages the ICWG to choose additional members, decide on the next deep drilling site, etc.
- Intermediate drill for ice coring (~400-1500m depths)
    - ICWG white paper stating science drivers
    - U.S. only or U.S.-led efforts
    - South Pole or Hercules Dome both near-term priorities for questions of WAIS history
    - Currently under discussions led by Eric Saltzman and Eric Steig
    - NSF sympathetic to quick response on funding and development
- Nomination of additional SAB members to broaden reach to community
    - Gary Clow, appointed chief scientist for WAIS logging, replaces Kurt Cuffey on SAB
    - Ryan Bay (physics)
    - Jill Mikucki (clean subglacial)
    - Not yet confirmed: Nancy Bertler (int'l), Sam Mukasa (basal rock drilling)
- Long Range Science Plan, 2010-2020 currently under development
    - Science Areas – climate, ice flow history and response, sub-ice environment and habitat
    - Communities – ice cores, borehole logging, subglacial, other (physics)
    - Overviews of science with schedule plan for field seasons and development projects
    - Draft plan by IDPO and SAB to be put on web for community input in May, finalized for year in June. Updated annually.
- Development Projects
    - Logging winches – logging community discussing needs given that IceCube winch will be available after next season.
        - Logging community has a fast access drill on their wish list
        - (Gerasimoff) WISSARD capacity can be dialed down for small holes, but a mechanical hole is preferable to a hot water hole for logging purposes.
    - Replicate coring – conceptual design complete, design and prototype underway. Ready for use during 2011-12 season.
    - Agile intermediate drill – Strong community push to NSF on accelerated acquisition for South Pole or Hercules Dome.
        - Tanner Kuhl (IDDO) to visit NEEM to view drill designs this July.
        - Intermediate, fast access does not necessarily mean Twin Otter or Helo-transportable
    - Access through ice shelf – design and construction via WISSARD stimulus funding through universities to Ice Coring & Drilling Services (ICDS)
    - Identification of new drilling fluid to be identified by IDDO by 2011
    - Agile drills need attention
- (Albert) Raytheon Polar Services (RPSC) is planning for two years of site rework at WAIS Divide following the 2010-11 season
    - IDPO working with RPSC and the community to find other options.
    - Rework costs estimated at $8 million and was not budgeted in the original plan

Intermediate-Depth Drill

Discussion of Intermediate-Depth Drills was joined via phone by Laurent Augustin (France) and Steffen Bo Hansen, Sigfus Johnsen and Trevor Popp (Denmark).

- Steffen described the Danes' overall good experience with the Hans Tausen Drill
    - Unit is flexible, lightweight and designed to be twin otter-transportable.
    - Can be used for both dry and wet drilling
    - Drill can utilize two chip transfer methods using a pump or a series of boosters
    - Used down to 400m at Flade Isblink, Greenland
        - Small 10m liquid column adequate at bottom of hole
        - Could likely have gone deeper
    - NEEM drill is very similar in design, just longer – similar head to Hans Tausen
    - (In response to Pyne question) Steffen stated that if the HT drill were to be redesigned they would definitely incorporate a perforated outer chips barrel as in the NEEM drill. Better pressure/fluid flow.
- Alex Pyne then presented the Victoria University of Wellington's (VUW) drill design
    - VUW Ice Core Drill Design Specifications
        - Based on Danish Hans Tausen design and modified with JARE-NEEM externally perforated chips chamber. Danish pump design and booster options for dry and wet drilling.
        - Cutting heads and core tubes for both dry and wet drilling
            - Dry Cutting: 126mm, thick head flights, poly barrel flights
                - Little room between flights and outer barrel to keep chips moving upward.
            - Wet Cutting: 130-132mm, thinned head flight, aluminum barrel flights
                - Fluid flow and pumping, so larger gap necessary and beneficial between inner and outer barrel.
        - (Hansen) One test at NEEM last year with smooth bore outer barrel. No change seen over ribbed outer barrel, but the pump is then relied upon with a smooth bore. Likely need grooves in outer tube when using only a booster. With grooves, the same tube can be used for dry/wet drilling. The cutting head is the same at that used with the EPICA configuration (in response to a question from Bentley).
        - (Pyne) NEEM hole is 132mm due to viscosity of fluid used (Coasol, Estisol mixture). Wet EPICA hole was 129.6mm.
            - Estisol with no densifier will be used for VUW drilling at Roosevelt Island. The testing at NEEM may only be for dry drilling.
        - (Johnsen) HT pump is not very strong, but it pumps enough
            - Two pistons in anti-phase; valves open when piston goes down and close when piston goes up; fluid is sucked in between the pistons.
        - (Pyne) Modification suggested is adding a booster without putting holes in the inner shaft.
            - Johnsen and Hansen suggest keeping the holes in the inner shaft. Shaft has natural self-cleaning feature because of rotation.
    - Anti-torque section
        - (Hansen) Outside springs are very efficient compared to length of unit. Springs are pre-bent, so equal force is distributed through the length of the spring. Design used for many years. Successful and simple implementation of hammer. Prevents stick situations when using intermediate winch (not very strong). WOB previously determined by transducer, but now use strain gauge built into top wheel of tower (sheave).
        - (Pyne) VUW hammer modification to clamp logging cable head. No electronics in pressure chamber, only the motor.
    - Pressure Tube, Motor Drive Coupling & Perforated Chips Chamber
        - 160VDC, 300W nom. Motor
        - 80:1 gearbox, 40Nm, 60rpm
        - (Hansen) Top of hollow shaft has bearing section that takes the load when breaking core. Three spring-loaded release pins for separation in ~10 seconds. Easier pullout of inner barrel due to holes in outer barrel (pressure differential).
        - (Hansen) Bayonet fitting – if hammer cannot break the core, drill is run in reverse and the pin will slide and pull up adding an extra jolt from the super banger.

    - Can re-engage the core barrel if it is left down hole. In stuck situation, can leave barrel down hole, bring everything else out and give the glycol more exposure to melt out the barrel.
- Hans-Tausen Pump and Booster combination of non-perforated hollow shaft
  - (Sigfus) Very lubricating effect of new fluid used at NEEM made barrel separation easy.
  - (Sigfus) Three fingers on pump assembly to make sure pump doesn't turn at bottom of chips chamber. Fingers are easier to fix than the former sleeve design. Can now inspect the pump, as it is no longer hard mounted in the chips chamber.
  - Valves - (Hansen) Very important in deep drilling, as they allow liquid to flow through inside of drill resulting in higher tripping speeds. Must ensure valves are open for descent. Valves close when drill motor begins rotating.
- Mast design - (Hansen) Hans-Tausen design uses old lightweight design. VUW mast design looks good, particularly for deep drilling (rugged for 1000m capability). Would suggest a second lighter option for twin otter transport.
  - (Pyne) VUW has four section box-style mast, mechanically assembled from folded aluminum sections. Electric-hydraulic mast tilt and traverse.
  - (Pyne) Mast not over-designed for loads anticipated. Lighter design would mean carbon fiber and additional expense.
- Winch - (Pyne) Wire-line logging winch, with fine control as well as enough strength to break core (12000N). Load pin on top sheave, 4-section mast, internal tie rods, hydraulic mast traverse cylinder, internal core break and drill control.
  - Winch drive motor is electric DC motor going through a gear box. Standard DC controller to power motor. Erred toward having more system power and breaking power rather than speed.
- (Cooper) Fluid flow ok on ascent?
  - Pyne – Drill is full of chips and core, so only place for fluid to flow is on outside of drill. NEEM has made the borehole larger for this reason. NEEM borehole is 132mm with 98mm core.
- Dataline Drill Logging winch – ¼" diameter cable (NEEM is 3/16"). This gives more breaking strength. Implementing cable connection in Anti-torque section to easily add logging tool without re-terminating cable.
- Using 1 of 4 conductors to sense when anti-torque blades are rotating. Common to HT drill.
- Drill Trench & Tent
  - VUW has to design both the drill and camp infrastructure
  - All can be transported by twin otter
  - Drill trench (2.5m deep, 4m wide) covered with a tent (21-22m long) that can be separated in the middle in order to remove snow (Similar to British setup on Berkner Island, which used Weatherhaven tents, but smaller)
    - (Albert) Some in U.S. would like IDPO/IDDO to design something similar and not have to rely so much on logistics provider
  - Fiberglass casing in smaller diameter (150 mm nom borehole) to NEEM (200 mm nom borehole)
  - Drill will also perform all reaming for casing installation
  - Services tent: 9kW generators (2), 4kW air compressor, garage
- Proposed dirty ice cutter head with TSP diamond – similar to standard head, but a ring of diamond instead of individual cutters, similar to a wood rasp. Core capture can be used as a basket mechanism in soft sediment. Impregnated diamond cutters do not give a sharp enough edge to cut ice. TSP is better.
- (Shturmakov) How much would it cost to replicate this drill system?
  - (Pyne) Current budget of $850,000NZ. U.S. may have cheaper access to materials (barrels, etc.) Hope to give IDDO a better estimate in a few months.
  - (Cooper) What does that number include? (Pyne) Everything, including the mast, generators, etc.
- (Bentley) How do we define the term Intermediate depth drill? Does twin otter limit depth?
  - (Pyne) Limit at the moment is 1000m (limited by winch weight of 330kg). Could go deeper, but seals and pressure concerns would come into play. Current science interest doesn't seem over 1000m.
  - (Gerasimoff) Over 300-350m, you're no longer talking about a dry drill. Next question is how much cable and how many bells and whistles.
  - (Albert) U.S. community wants something smaller, but adaptability in case you have a Herc available. Possibly different winch options, but same sonde.

        - (Hansen) Have used HT drill to 3000m, but 1000m seems a reasonable estimation for the new VUW design. A matter of what type of winch you can deploy. You can go deeper, but would need a longer drill (core/drill tubes). Higher liquid column would be needed. Haven't found the depth border where fluid becomes essential.
            - (Cooper) Depends on temperature of ice and hole creep.
            - (Hansen) Pressure of the ice where it is cut also plays a role.

International Partnerships in Ice Core Sciences (IPICS) – Problems and solutions related to drilling warm ice

- Review - (Augustin) Melting and refreezing on shoes prevents penetration. Have to bring drill all the way back out, clean everything and go back down. This is very time-consuming.
- 'Cognac bomb' utilized - plastic bag of ethanol water solution attached along hollow rotating shaft. Bag punctured by sharp screw. Prevents immediate refreezing of ice. Allows for several more centimeters of penetration.
- Problem began around 3200m depth at Dome C around -5C. 1.4L of 50% ethanol, 50% water solution. 8m/day in 8 runs while working 17 hours/day. Worked well for next 50m down to 3250m. Subsequently only 4m/8 runs. Very difficult after this.
    - Frank had good results at DML with less ethanol in the solution.
    - (Cooper) Could methanol be used? Lower melting point than ethanol and very miscible with water.
    - Penetration rates drop between -4°C and -6°C.
- (Hansen) Ethanol gets to depth but makes for difficult drilling. Trick is to not use too much and therefore create slush and extra ice chips by eating the hole wall. NGRIP is very different from the DISC Drill, so experiences might be different. Optimistic that new greasy liquid used at NEEM will prevent refreezing of water onto metal. New NEEM cutters also have special coating.
    - (Hansen to Shturmakov) Will have to ask Jakob Schwander for name of nano-coating material used in Switzerland.
    - (Hansen) 0°C to -5°C estimated at NEEM.
    - (Cooper) Equivalent coating problems in oil drilling industry with clay sticking. Very high polish on cutter edge can help cuttings slide over. Teflon would wear off quickly. Polish sliding surface as much as you can.
        - (Hansen) Teflon coating has been unsuccessful with barrels, etc.
    - (Johnsen) – Key is to not use too much ethanol. If you have a failed run (no core) you leave ethanol, chips and slush in the hole. Japanese use Teflon on drill head. Very successful in second to last season, but not in last season. Originally wanted to use glycol, but this produced more chips and plugged the hole. Should bring all of the ethanol back to the surface after each run (consumable). Also planning for cutters with smaller diameter hole this summer at NEEM.
    - (Johnson) How do you determine you've recovered all of the ethanol at the end of each run?
        - (Johnsen) Not measured, you see this by the amount of chips you bring back.
    - (Johnson) Do you remove the ethanol before sending the fluid back down hole?
- (Augustin) – Near the end of the EPICA project, the short version of the EPICA drill (the HT drill) was being used. Components below the motor section, including the chips chamber and the core barrel with core were put in a warm bath of pure D30 at -3°C.

Warm Ice and the DISC Drill (Johnson)

- (Augustin) May be able to play with the two separate motors to increase pump flow and reduce refreezing on cutters.
- Target depth is 3350m (~70m from bed)
- No temperature logging history for current borehole
    - Current temperature sensors in drill have data lag
- Preparing drill for use of ethanol water solution (EWS)
    - Need method to deploy EWS to bottom of hole
        - Propose canister that would open when touching bottom. Do not have independently rotating barrels to implement and break an EWS bag.
            - (Pyne) Could connect canister to the pump and control how much ethanol you deploy and tune the system. A better control/metering system could determine the amount of ethanol needed.

  - What concentration and how much to use?
    - Estimate 0.5-1.5L/run
- High flow pump
  - Chips transported with the fluid rather than mechanically
  - Improved flushing/cooling at the cutter head
- Different cutter geometries?
- Surface coatings for cutters/head?
  - (Cooper) Important to keep good flow path behind cutter.
- How to remove ethanol from the drilling fluid? How do we tell how much is in the drilling fluid?
- (Souney) Have you heard from RPSC on permits?
  - (Johnson) Sent rough numbers to Matthew on usage rates.
- (Pyne) Where is the water coming from, the cutting process or water crystals between the ice?
  - (Johnson) Likely from the cutting process itself.
  - (Johnsen) Melting came at -10°C at GRIP (must be the cutting process).
- (Mortensen) Original temp sensor was for fluid temp, but is coupled so closely to the drill tube that it actually senses drill temperature.
  - (Pyne) Do you need to let drill warm up at bottom first (experienced at Domes C, F)?
    - (Augustin) Sometimes waited 1-2 hours at bottom for drill to warm up, but travel time is so long that drill should have acclimated.
    - (Mortensen) Temperature of cutters is really the important part.
  - (Cooper) Can you slow everything down (rpm) to reduce heat over time?
    - (Kuhl) Japanese noticed no difference in cutting speed and melting. Cutter rake angle is the important part.
    - Icing on shoes is critical; suggest to use rear shoes
  - (Cooper) 70-80% of heat in rock cutting goes into the chips.
    - (Kuhl) This could be the saving grace of the DISC drill as it transports chips away from the head.
- (Kuhl) What is benefit of EWS solution versus just a smaller amount of straight ethanol?
  - (Hansen) Pure ethanol did not seem to work well in tests.
- (Cooper) When using ethanol, Augustin said the core becomes stuck in barrel. Why is this? Can methanol be used instead?
  - (Pyne/Hansen) Water mixes with your EWS and starts to refreeze on ascent trip.
  - Need method for removing cores that refreeze in the barrel.
    - Can you insert a slippery, polymeric liner?
      - DISC fiberglass tubes aren't slick enough.
      - (Cooper) This liner might not help, as you get a compressive effect when the ice crystals freeze between the core and the barrel wall.
    - (Hansen) Can the DISC Drill run without the fiberglass core barrel sleeve? Issues supporting core further up, but clearance should prevent sticking core in barrel. Russians had success with this. Danes had to use low pitch in warm ice. Low clearance between cutting edge and shoes. Doesn't take long for 1-2mm of ice to buildup. New step cutters made for NEEM (Victor Zagorodnov design) to try in warm ice.
    - Could run pump after core break to remove extra chips.

Drilling Fluids for the Future (Gerasimoff)

- Background
  - Half century of history
  - Provides hydrostatic compensation in borehole; no casing needed; provides lubrication
  - Hydrophilic/hydrophobic fluids
  - Japan continues to use n-butyl acetate, but U.S. has banned it and currently uses 141b, though 141b is no longer available due to the Montreal Protocol
- Need replacement for 141b
- Short-term research goals
- Antarctic treaty requirements
- Other fluids – silicone oils
- Caution so we don't create new problems as we solve old ones ("Cane Toads")

- (Hansen) NEEM fluid not suited to many places in Antarctica due to viscosity
    - Planned to drill 134mm hole but could decrease diameter to 132mm with 1m/s travel speed
    - Perfect for Greenland
    - Nice for mechanical reasons (lubrication)
    - Transports chips well
    - Dissolves some rubbers (gloves, boots)
    - Estisol derived from coconut oil
    - No explosive risk and extremely low vapor pressure and evaporation, so no need for intense ventilation
    - Fatty ester
    - Density mixed to 9.2/9.3, or 2:1 Estisol to Coasol
- (Pyne) Does a film remain on the core after transport back to Europe?
    - (Hansen) This fluid does take very long to evaporate.
    - (Gerasimoff) Considered a dry cleaning operation?
        - (Hansen) Have considered this, but have not implemented.
    - (Bentley) Does remaining fluid on core bother scientists?
        - (Hansen) Mechanical cleaning is sufficient and surface is cut away.
        - (Powell) Little diffusion into the ice?
            - (Hansen) Unsure, as cores are still in storage at NEEM.
- (Augustin) Those in Grenoble, France are working on a new, non-toxic, non-flammable fluid good at low temperatures. Looking into silicone oils. Difficult to find something new. Russians do not have any leads. Japan is happy with n-butyl for now, but may look in a few years for a new fluid for coastal drilling.

RAM Drill

- System Overview
    - Two sled-mounted diesel engine driven air compressors
        - 400cfm each at 200 psi rated
    - Hose Reel sled
        - Integrated drilling platform
        - 100m of 1.5" air hose
        - 6.5kW generator
        - Spares and tool storage
    - Drill
        - Drills a 4" hole
        - Powered by compressed air
        - Purely rotary, not hammer
- Deployment and setup
    - Requires 2+ LC-130 flights, not including tow vehicle
    - Total shipping weight ~19,500 lbs.
    - Requires heavy equipment support to assemble reel on sled
    - 1.5 days to set up with two people
- Drill
    - Two 1hp air motors coupled with planetary gear reducer
    - Head spins at 2500rpm
    - Four tool steel cutters
    - Two sets of centering blades
    - Adjustable booster nozzle at top of drill
    - Exhaust air ejects the cuttings from hole
    - Drill motor section and head weigh 200 lbs (tungsten bar stock material to add weight).
    - Works well if you can reduce porosity in the firn layer (by packing it with chips). Liner casings get blown out by the drill. Nylon parachute material did not work either.
        - (Pyne) Problems throughout firn or just at certain depths?
            - (Johnson) All throughout firn and plume regenerates when you reach firn-ice transition.
        - (Johnson) Cannot reenter hole, as 'chips casing' is blown out when you come out of the hole.
- Operation

  - Rig is rough positioned by tow vehicle and drill is fine positioned via an adjustable carriage (struts) on the sled.
  - Speed and direction of hose payout is controlled via pendant
  - Ethanol is injected into the air stream to prevent icing in the hose
    - 0.7 L consumed per 90m hole
  - (Pyne) Is the hole plumb?
    - (Johnson) Can usually see bottom at 60m with light tests. Depends how hard you push the drill. Can drill up to 6m/minute.
  - (Johnson) Temp of air is measured at aftercoolers when exiting compressors.
- Past Deployment
  - 02-03 Onset-D
    - 226 holes
    - Target depth 60m
    - Avg. depth 56m
    - 12,686m total
  - 08-09 Upper Thwaites
    - 176 holes
    - Target depth 60m
    - Avg. depth 46m
    - 8,109m total
  - 09-10 Lower Thwaites
    - 132 holes
    - Target depth 90m
    - Avg. depth 74m
    - 9,782m total
- Performance
  - Capable of drilling to 95m
    - Firn permeability and conditions greatly affect the actual depth possible.
  - 6m/minute max drill rate
  - 25 minute cycle time for 90m hole
  - ~5 gallons of fuel consumed per hole
  - (Pyne) Casing upper part could lead to much greater depths.
  - (Johnson) After first 5-6m of firn, hole is very clean and good for logging
- Conclusion
  - Cons
    - Hose reel has to be removed from sled for aircraft transport
    - Big, heavy system
    - 2+ LC-130 flights
    - Inconsistent ultimate hole depth
  - Pros
    - Fast cycle times
    - Finished hole is clean, dry
    - Operated by 1-2 people
    - Traversable
    - Proven robust, reliable
  - Future recommendations
    - Multi-wrap hose reel
      - Incorporate design that would not require removal of reel from sled for shipping, as this would greatly reduce setup time
    - Locate ethanol injector upstream of aftercoolers
    - Add power generation capabilities to compressors
      - Would eliminate need to run a separate generator
    - Further investigate ways to reduce air loss to the firn
  - ~200lbs. WOB when drilling

- (Bentley) Mention of UW Astrophysicists interested in many 200m holes at South Pole. RAM Drill will be tested at Pole this upcoming season. Firn is porous and altitude is high, so not optimistic. They would then make modifications if the concept was promising. Maybe only partial casing needed.

DISC Drill

- 2009-10 season had beautiful weather and skies
- Arch
    - Floor buckled another 2” since last season
    - Drill side is 2” narrower at the mid point than at the end of the previous season
    - Overall, midpoint of arch is ~5” narrower than when built
    - Slot walls only required minor recutting
- Schedule
    - Camp opening delayed by 2-3 weeks
    - Drilling initially scheduled to start December 10th, but started on December 14th
    - Two extra days of drilling at end of season, finishing on January 25th
- Season Start-up & Drilling
    - Goals
        - Spool the 3800m cable onto the winch and terminate the ends
        - Drill to 2600m
        - Produce high quality ice core
        - Test thin kerf core barrel and cutter head
        - Test two-stage pump
        - Test screen fill tubes
        - Test stabilizers at top of core barrel
    - Spooling New Drill Cable
        - 3800m cable replaced 2800m cable
        - Tension lost on a few wraps during spooling
        - Tripping speeds adjusted at drum ends to account for cable slack; issue corrected mid-season
    - Cable Termination
        - Termination took 2.5 days
        - Very successful, with little loss over all optical fibers
    - Level wind Controller
        - Tracking system monitors angle of the cable and keeps it within a predetermined range
        - Level wind runs independent of the winch
        - Solved the tracking problems experienced with older system
    - Drilling Info
        - Starting depth: 1514.200m
        - Ending depth: 2564.370m
        - Total meters drilled: 1050.17
        - Total days at WAIS: 65
            - 15 days for Arch opening, slot work, set up, crew arrival
            - 3 days for NICL/ICDS shakedown
            - 2 days of 2 shift operation
            - 34 days of 3 shift operation
            - 1 day of 1 shift operation (last day)
            - 5 days off
            - 1.5 days lost due to mechanical problems
            - 3 days for packing
        - Average production rate during three-shift operation was 25.8m per day
        - Tripping Speeds
            - Descended at up to 1.2m/s with the pump running
            - Ascended at 1.6m/s
        - Cutter Speed
            - 80rpm continues to be the sweet spot
        - Penetration rates

      - Varied with ice conditions
      - Generally 3.0-4.0mm/s
      - A pitch of ~4mm produced the best quality cores
    - Bore hole fluid density
      - Density was maintained at .920 @ -31°C throughout the season
      - Fluid was mixed to .935 @ -31°C to compensate for 141B loss
    - Total fluid loss for the season was 25%.
      - Loss for 2008-09 was 37%.
      - Loss for 2007-08 was 35%.
      - 27,380L (7,233 gal) of drilling were used.
        - 19,667L (5,195 gal) of Isopar K
        - 7,714L (2,038 gal) of 141b
- Testing
  - Two-stage Pump
    - Tested over the course of three shifts
    - Pump motor ran about 10°C hotter than with the single-stage pump
    - Pump torque also ran higher than original pump
    - Core lengths of 3.3m-3.4m achieved, but no obvious indication that this pump increased length
  - Screen Fill Tubes
    - Tested for two drill runs
    - Did not improve the chip packing.
    - Troublesome and time-consuming to clean
    - Did not increase core lengths
  - Thin Kerf Core Barrel
    - Thin kerf barrel and new cutter head create a borehole diameter of 163mm
    - Older core barrel creates a borehole diameter of 170mm
    - Fewer chips created during drilling with thin kerf design
    - Increase in core lengths by 0.5-0.6m
    - Shorter anti-torque blades installed to access thin kerf hole
    - Issue with set screws becoming lose and fiberglass shifting at one junction
- Challenges
  - Screen Cleaning System
    - Screen cleaning heat tube heater failed during 2008-09 season
    - Spare circuit board brought for heater unit this season
    - Heater failed to work once again
    - RPSC carpenters attempted to build an auxiliary box/fan setup, but flow was not adequate
    - Returned to use of the tiered drying box built in 08-09.
  - Azimuth
    - The drill does not provide a consistent azimuth reading
    - Question as to its validity in previous seasons, particularly when drill sections were changed out
    - Confidence in azimuth is absolutely necessary for the 2010-11 drill season, per the Chief Scientist
  - Cable Void Filler
    - New cable was not properly cleaned by manufacturer
    - Negatively impacted penetration at startup
    - Scotch-Brite pads used during tripping for cleaning
  - Borehole Inclination
    - Borehole inclination rapidly increased from 3.5° (from previous season) to just over 5°
    - Stabilizers removed from the top of the core barrel
    - Cutters machined for side-cutting ability (4/10mm wide x 3mm long lip on outer edge of cutter)
    - Core dog cages machined down to allow drill to hang more freely and allow side cutter to direct drill
    - Collars (used during screen fill tube testing) machined to hold stabilizers and re-inserted on upper end of screen barrels (between sections four and five)
    - Reaming performed between 6m-15m from the bottom of the hole each run for a portion of the season
    - All efforts stabilized and decreased inclination down to ~4° (graph)

  - Crown Sheave Repair
    - Bolts attaching the bearing hub to sheave failed
    - Failure likely caused by to much compliance in the assembly
    - Bearings likely not the issue
  - Level Wind Sheave Repair
    - One of two bearings failed at 1710m depth on ascent
    - Remaining bearing greased and monitored
    - Drill slowly brought to surface at 0.1m/s
    - Drill retrieval took 6 hours
  - Thin Kerf Cutter Head
    - Core dog cages machined down in an effort to correct increasing borehole inclination
    - The added clearance permitted excessive flexing of the cutter head during core breaks which resulted in fatigue failure
    - Spare cutter head then used with shimmed core dog cages
    - Cutter head caliper measurements taken on spare head between each run to inspect for degradation
  - Additional Challenges
    - Inclinometer failure on Instrument section 'K'
    - WOB sensor failure in Anti-torque section 'B'
    - Instrument sections 'J' and 'L' have pressure leaks
    - 'Z' pump failed late in the season while being used on Motor section 'Y'
    - Small leak in centrifuge nitrogen system
      - Attempts to locate/repair the leak have been unsuccessful
- Charlie Bentley – Seven Decades on the Ice
  - Charlie started going to Antarctica in the 1950's and has been there EVERY DECADE since!
  - Charlie gave a nice presentation entitled "IGY: 1956-1959" and cake was enjoyed by all
- Work Items for Next Season
  - Winch
    - Rework level wind sheave
    - Upgrade tracking arm to permanent, sealed fixture; extend prongs on fork
  - Sonde
    - Understand, implement and test azimuth function
    - General cutter/core dog maintenance
    - cutter heads
  - Tower
    - Rework crown and reaction sheave assemblies
  - Control system
    - Minor software work
  - Misc.
    - Rebuild hot air blower
    - Ready drill for warm ice
  - Bore hole inclination
    - Design and procure modified cutters for side-cutting
- Next Season
  - Re-install crown, reaction and level wind sheaves
  - Current SCO goal is to drill as close to the bedrock as possible, without risking bedrock or water contamination under the ice sheet.
    - 3350m is the tentative goal
  - To achieve this goal:
    - Continue use of thin kerf core barrel (3.2-3.4m cores)
    - 23 drilling days
    - Unsure how warm ice will impact current drilling rates

- (Eustes) Is replicate drilling being tried anywhere else first? This is an expensive borehole.
  - No, as the DISC Drill is very expensive to transport and no other test holes are big enough.
  - Logging will be done before replicate, just in case damage is done to the hole during replicate.

Controlling Inclination (Mortensen)

- DISC Drill borehole inclination graph
  - Inclination climbed from 3.5° to over 5° during 2009-10
- Causes of Inclination
  - Any amount of inclination results in bending of the drill pointing the cutter head 'outwards' thus increasing the inclination. The increased inclination results in increased gravitational load leading to increased bending and increased misalignment of the cutter head – runaway!
  - Heavy weight-on-bit will tend to amplify this effect
  - Note: Since inclination breeds more inclination, you'd expect inclination to build exponentially
  - (Cooper) If mid stabilizer is easily moved, try moving it down a few sections. The bend can be a critical point.
  - (Eustes) How straight does it need to be?
    - NBM – Science wants straight layers; science requirements requires <5°
  - (Eustes) Error in instrumentation reading can be as much as 1°?
    - Tilt mounted sensor; angle changes as drill rotates going down hole in anti-torque 'roadways'
    - Sampling rate is 1/sec so every about every 1.2m
    - (Pyne) Desire to mount sensor vertical?
      - Yes, as this sensor does other things as well (accelerometer). We're augmenting this sensor with a designated and accurate inclinometer.
- Remedies
  - Determine accurately where the drill's center of mass is.
  - Model how the drill bends in a static situation with uniform load and determine optimum location of stabilizers
  - Develop specialty cutters
    - Cutters with a narrow ridge standing out towards borehole wall. The narrower the ridge, the more aggressively the cutters side cut. This was the style of cutter improvised at WAIS.
    - Flared cutters, i.e. cutters with cutting edges that are intentionally pointed slightly outwards.
  - Design, fabricate and install stabilizers onto DISC Drill.
  - (Pyne) Does rotation speed affect directional properties?
    - (Cooper) Unlikely.
  - (Mortensen) If flared cutters are made, intend to flare outer edge only 1 degree or so.
  - (Cooper/Pyne) Tapered diamond bits have diamonds running up along the side. Better at reaming than the DISC design.

Replicate Ice Coring System

- Introduction (Shturmakov)
  - Science drive for replicate coring – entire new holes are expensive; replicate coring at interesting depths is quicker
  - Project history –Will need new core and screen barrels, new cutter head, new replicate/actuator mechanism and modified instrument section.
  - Major science requirements
    - Core characteristics
      - 1-2m cores
      - 100mm core diameter target
      - Up to 400m of replicate core
      - Ice pieces fit snugly without gaps
    - Hole characteristics
      - Parent hole must remain open and useable after replicate
      - Should be possible at any location of the hole starting 100m below casing
      - Required that deviation be performed on up hill side of hole to ease logging
      - Any permanent equipment left in the borehole must match or be greater than borehole diameter to not impede logging
      - Up to four deviations to a depth of particular interest is desired
- System Overview (Mortensen)

- DISC Drill with Actuators
    - Actuatable Drill
    - Two actuator sections
    - Each deviation requires ~30m to deviate one borehole diameter
- Main System Components
    - Actuators - Convert the electrical current and voltage from the motor controllers into force and horizontal travel.
    - GUI – Driller inputs direction of deviation along with an ‘effort’ parameter.
    - Control Module – Six motor controllers with closed loop torque and speed control. Digital Controller with array of sensors. Computes actuator forces ‘on the fly’. Control module gets info from orientation sensor
    - Orientation Sensor – Permits the system to ‘know’ the orientation of the drill in 3D space, real-time.
- Deviation
    - Possible methods
        - Side push – pushing drill uniformly toward borehole wall
        - Initial angle – run two actuator sections in the inverse from one another
- Anti-torque influence is under question; difficult to achieve with this actuator setup
    - May be able to use current spring leaf anti-torques
- Operator’s perspective image
- Navigation
    - The science requirements specify up to four deviations within the same volume of ice.
    - For this reason, it is necessary to consider unintentional intersect.
    - Use of 3D navigation together with actuators allow trajectories of deviation boreholes to be controlled
- (Pyne) Can you process data on a daily basis?
    - (Mortensen) Data processing is not that difficult, but presenting it in a meaningful way (3D plot) is more difficult.
    - (Eustes) Commercial anti-collision software available

- Mechanical Development (Gibson)
    - Upper sonde diagram shown
        - Motor section oil-filled and sealed from chips
        - Safety factor of 1.5 on cable connection to sonde
    - Design analysis plans for a safety factor of 2
    - 500N of force at cutter head and 1000N at actuators for minimum length 1m core
    - Actuator Assembly diagram shown
        - Fail safe joint will retract actuators when enough force is pulled on the cable
    - Component Strength/Materials chart shown
    - Sonde component revisions
        - Update core/chip barrels to reduce diameter
        - Optimize sonde length
            - Decreases radial force at cutter
            - Decreases number of trips
            - Decreases total time to core
        - Milling cutter will be used to side cut original deviation
    - Replicate development schedule
        - Detailed actuator design and analysis
        - Prototype actuator assembled and shown
        - Initial failsafe testing complete
        - Additional in-house prototype testing planned for April-August
            - Continue development testing failsafe
            - Characterize actuation force profiles
            - Ice testing: anti-torque/stick-slip
                - Can oscillate actuator arms to allow downward travel in stick slip situations
        - Order production components for three sondes

        - Production assembly/validation tests
        - Anticipate deployment to WAIS Divide in January 2012
    - Anti-torque
        - Testing to define anti-torque geometry
            - Anti-torque of current DISC Drill ~120Nm
            - Ice compressive strength 10 to 60MPa
                - Contact area >150mm^2
    - (Pyne) If 4 holes of core are needed from the same depth, is this a problem?
        - (Cooper) Kick off points can be different. Will end up with longer and shorter holes.
        - (Mortensen) New concept of steering the drill to avoid intersect as we know where the drill is with our orientation sensor.
            - Primarily rely on magnetic sensor when drill is stationary or drilling slowly. Also rely on gyro-stabilization.
- Onboard Control System
    - Features of Motor Controller
        - Six channels
            - One brush DC motor per lever
            - Six motors need to be controlled
        - Each channel includes closed loop torque and speed control
        - The motor controller channels reside on one printed circuit board, which interfaces mechanically and electrically to the digital board
        - To ensure good noise performance, the power board is electrically isolated from the digital board
            - Power board is part of the drill's power system, while the digital board is part of the signal system
    - Channel design diagram shown
    - Installation into Instrument Section
        - Control module takes the place of former sensor board
        - Functionality previously held by the sensor board is now incorporated into digital board
        - Connections to the actuator sections and external sensors are made through the instrument section's end caps using pressure-rated sealed connectors
    - Performance
        - Motor driver's current loop can reverse current from 'full on forward' to 'full on reverse' in ~10ms
            - Can assist with stick-slip
        - The mechanical time constant of the DC Servo motors is ~5ms (in reality this will be slower due to inertia of reducer and linkage
- Features of Sensor/Digital Board (Landucci)
    - Six strain gauge circuits to support upper and lower replicate actuators
    - On-board 3-axis accelerometer
    - 2-axis inclinometer
    - On-board pressure and temp sensors
    - Hall sensor inputs for actuator position feedback (6 total, one per actuator)
    - On-board freescale digital signal controller with integrated 12-bit analog digitizers
    - Sensor/Digital Board Block Diagram
        - Taking out the cabling error by digitizing info on the board
    - Accelerometer
        - 3-axis inertial sensor with digital interface
        - Old board/cabling layout vs. new board layout shown
    - Inclinometer
        - Dual-axis inclination with digital interface
        - +/- 30° measurement range
        - 0.0025° resolution
        - Mounted in machined end-cap recess for alignment
    - Future developments
        - Eliminate one of the two Tern processor boards
        - Add energy storage device and support circuitry to facilitate emergency retraction of actuators

            - Can add battery or capacitor array
        - Eliminate second Tern and replace with microcontroller-based surface communication board
    - Discussion
        - (Kuhl) We can depress the levers manually by pulling up in the event of a power failure. Is battery backup necessary?
            - (Mortensen) This is an expensive borehole and our first attempt at replicate so a backup method is necessary.
        - (Cooper) Schlumberger had bad experience with batteries downhole due to power cycling.
            - (Mortensen) DISC Drill's sealed chamber should prevent this problem.
        - (Pyne) In the new smaller hole, is your clearance adequate if you're using the same-sized upper sonde sections? How tight can you bend in the new replicate hole?

<u>Blue Ice Drill</u>

- Engineering Requirements
    - Cores
        - 9.5-inch diameter
        - 1.2m max length
        - 15m max depth
    - Production
        - 42m/day
        - Up to 7 sites per day
        - 0.5m/minute drilling rate
    - Physical Limitations
        - 1100 lbs. max weight
        - 2.2m max component length for helo transport
- Drill Design
    - Double-barrel, electro-mechanical
    - Down-hole motor/reducer
    - Anti-torque from surface
    - Surface tri-pod structure
    - Electric capstan winch
    - Core Recovery Tool (CRT)
    - Drill diagram shown
        - Downhole assembly diagram shown
            - Motor section
            - Core barrel connect pins (x3)
            - Outer barrel (11.21" OD)
            - Barrel clamp handle
            - Core barrel with flights
            - Coring head
        - Core barrel diagram shown
            - SS ring with quick-pin connecting holes
            - Chip windows (x3)
            - Barrel strips (x5, bonded to outer barrel)
            - Helical flight (x3, 35° angle)
            - Fiberglass barrel (9.63" ID)
        - Motor section diagram shown
            - Winch line swivel
            - Anti-torque stem mount
            - Electrical connection
            - Motor can
            - Slide hammer
            - Barrel stabilizers (x3)
            - Outer barrel drive plate
            - Core barrel quick-pin

  - Core barrel drive plate
  - Spline shaft cover
  - Wiper seal
  - 28:1 2-stage planetary gear reducer
  - 6hp 3-phase induction motor
    - Controlled with VFD (1-phase input)
- Cutter head
  - Coring head
    - 416 SS
    - 9.63” ID, 11.21” OD
  - Cutters (x3)
    - 30° rake angle
    - 5° clearance angle
    - Thin kerf=0.918”, wide kerf=1.015”
  - Penetration shoes (x3)
    - Shims for 0.5-15mm pitch
  - Core dogs
    - Angled, off-centerline for scoring
    - Penetration depths=0.7” 0.5”
  - Head cover (delrin)
- Core Recovery Tool diagrams shown
- Power and Control
  - Generator: 6.5kW, 240V, 1-phase
    - 5kW will be tested
  - Variable frequency drive
    - Speed/torque control, limits
    - Ramp up/down parameters
  - Custom control box
  - Interlocks on anti-torque handlers
    - Drill motor on/off
    - Operator safety
  - Winch motor (Milwaukee drill)
  - Power diagram shown
- Testing
  - Core dog geometry tested at ICDS warehouse
    - 5-6 dog geometries tested with short side of core dog mounted on center line
  - CRREL testing scheduled for May 2010
    - Full drill system test at -50°C

- Discussion
  - Weight of system will determine its depth range
  - Novel feature of downhole motor and reducer
  - Tall tower allows for vertical delivery of core, due to its weight and size
  - System is too heavy to be dealt with via surface motor and torsion stems; tower eliminates operator lifting
  - Technology follows from Eclipse, 4-Inch and Prairie Dog
  - 3.2” of travel in slide hammer to assist with core break
  - 6hp motor packed into small (2hp) case
    - Can only run for ~15min. without overheating
  - Science of this core measures carbon, so drill can have no sources of contamination (lubricants, etc.). Sealed bearing, wiper and spline shaft covering also prevent contamination.
  - Cutter head
    - Aggressive rake angle, but standard head
    - Unique core dogs with angled cutting face and off-centering allow for core scoring
  - Core recovery – two thoughts
    - Use the drill and its 6 core dogs spaced 60 degrees apart
      - Longer than traditional dogs

        - Good score line to help dogs fully engage and hopefully all six engage on the same linear plane
      - CRREL developed tilt mechanism in the 1980’s for a 12” core drill
        - Current CRT setup uses tilt mechanism and three dog mounts at bottom of core barrel. If drill can’t break core, it can be rotated in reverse. The dogs will retract and the drill can be brought up over the core.
    - Barrel weight with chips and core is about 200 lbs. Science side has worked to incorporate the tilting and delivering of the core.
    - VFD could see ambient temps down to -30C.
      - Designing system for down to -40C.
        - Resistive heating assistance.
    - Unique project – one year to design test and deploy system
    - Very old ice
      - Scientists want massive quantities of ice to detect very old trace gases
    - 7 cores (1 ton of ice) per melter run
    - Idea of large core is to minimize surface area

WISSARD Hot Water Drilling System

- System Overview
  - WISSARD – Whillans Ice Stream Subglacial Access Research Drilling
  - Program with a glacial lake aspect (LISSARD) and a submarine aspect (RAGES) – disparate requirements for bore size (=heat flux)
  - Geomicrobiology aspect (GBASE) requires clean access for sample integrity
  - Environmental stewardship requires ‘clean access’ to prevent disruption of sub-glacial ecology
- Design Requirements
  - 10 million Btu/hr heat flux to water (~3 Megawatt; ~4000 HP; 0.85 of IceCube project)
  - High energy conversion efficiency (>85% LHV basis)
  - Controllable heat flux
  - Commercially available
  - Adaptable to:
    - Environmental requirements
    - Transport and traverse requirements (to fit ISO inter-modal “envelope” & C-17)
    - Process variability (water flow rate & temperature)
    - Saltwater exposure
- Prior Art
  - Previous designs use multiple commercial pressure-washer heaters (PWH)
  - We would need ~14 of largest PWH's
  - PWH proven to be difficult to control:
    - no true thermostat (high-limit safety, only)
    - fixed firing rate x integral number of units
    - large number of units = synchronizing + sequencing issues
  - Strictly speaking, PWH systems are not self-correcting– they’re metastable; system-specific experience and operator intervention is required to maintain reasonable control of a PWH system
- New Direction
  - Due to drawbacks of PWH, we consider a new system based on a commercial *thermal fluid heater* to be desirable. It will :
    - Feature COTS heater-control systems
    - Be configurable to tolerate saltwater
    - Minimize the operators’ learning curve
    - Maximize the potential for scientific program success
- Basis of System
  - Modulating burner firing 1 through 10 MM Btu/hr
  - Thermal fluid (“oil”) heated in closed loop
  - US Coast Guard (environmental and safety) and ASME (construction, individual inspection and testing) approved systems

  - Thermal Fluid (‘Oil’) of low toxicity
  - Heat from closed-loop oil transferred to drilling water *via* heat exchangers (ASME certified devices)
- Advantages
  - *One* system, *one* learning curve
  - Highest power rating available throughout program—flexibility that can maximize speed
  - Adaptable: stable but operator-variable water temperature and flow rate
  - Autonomous, feedback-control loops add safety, reliability
  - Can over-winter in field (oil doesn’t expand on freezing)
  - Faster start-up: less seed water required
- Additional Facts
  - 75-380 l/m (20-100 USGPM) water flow
  - Options for secondary heat recovery including a finned secondary flue-gas-to-thermal-fluid heat exchanger, and a combustion-air pre-heater
  - Secondary heat recovery raises fuel efficiency into 88-94% LHV range; saves >10 tons of fuel over life of project
- Heat Exchangers & Saltwater Handling
  - Two heat exchangers: one large (main drilling hot water) and one for Rodriguez well (make-up and ‘domestic’ water requirements)
  - Heat exchangers to withstand saltwater with tubes and tube-sheets of well-known copper-nickel alloy UNS C71500 (CuNi30
  - a thermal-fluids heater makes other salt-water handling ‘work-around’ possible
- New Hose
  - ICDS has recently finalized Kutting® UK as the vendor for the WISSARD system’s hose
  - Design is similar to ones used by BAS: braided Kevlar® burst- and tensile-strength braiding; extruded thermoplastic liner
  - Open-weave, outer tensile-strength braiding is sandwiched between two layers of extruded thermoplastic sheathing, making it highly resistant to ‘milking’
    - 1000 meters without couplings
    - Larger inner diameter (1.5”) means lower operating pressure for the same flow rate
    - Savings in pumping power
    - Savings in equipment design (lower pressure ratings)
- Hose Reel
  - Hose reel itself *shuttles*; this minimizes bending-induced wear and tear
  - Simple mechanism with feedback control
  - Direct hauling of hose (no capstan; no ‘milking’ of the sheath; longer hose life)
  - Enclosed in special 20’ ISO container
  - Sheaves, HIAB® crane to be mounted to top of ISO
- Water Filtration & Clean Access Equipment
  - Necessary for environmental stewardship and for scientific integrity
  - System should be able to address:
    - Removal of particulates
    - Removal of living and dead organisms
    - Rendering of any organisms remaining in bore water non-viable
    - Sequestering of organic compounds (in discussion)
- Filtration Components
  - Primary Filtration: very high flow- and particulate-capacity pleated fiber cartridge filter; ~0.5 micron nominal target-particle size
  - Ultraviolet light irradiation at λ=185 nm to break-down organic compounds
  - 1000 lbs. acid-washed, granulated activated carbon, with contact time approaching a dialysis-water standard (in discussion)
  - Ultra-filtration at 0.22 micron (99.98% eff.)
  - Final λ= 240 nm UV bombardment, to kill organisms escaping ultra-filtration & disrupt DNA
  - Pasteurization, by rapid rise in temperature to circa 95°C (a further check on organisms and DNA)
- Capture of Basal Particulates
  - Sand and larger particles cannot reach the surface because their settling velocity exceeds the upward velocity of the drilling water return flow

    - Most of these would be generated during drilling of basal ice, and are of scientific interest
    - Desired to not let these particles drop into the sub-glacial environment where they would affect subsequent sampling work
    - We propose developing a Coanda-effect pump, wherein part of the pressurized water entrains bore water and filters large particles through a fine-mesh screen; these are collected in a cylindrical bowl for later retrieval
- Clean Access
    - Bore Access Environment to be controlled via the "Moon Unit (MU)" , modeled after an oceanographic 'moon pool'
    - MU Controls air movement across bore opening; air can be filtered, positive pressurized
    - Penetration points into the covered module can be opened and closed according to need
    - To be fitted, where required, with access ways to laboratory modules (configuration TBD)
    - UV bombardment modules to sanitize hoses and other equipment, dust, lint, etc. falling through bore opening
- Sledge Layout
    - Layout capitalizes on a flexible "over-the-side" launch of drilling equipment rather than "over-the-transom"
    - HIAB® - type crane to manipulate hose means increased flexibility to layout: all service bores (Rodriguez, recovery, recirculation) and main bore developed from one setup; well pumps and other heavy components handled with ease
    - Heavier HIAB® - type crane on 40' ISO mounting, to manipulate scientific apparatus (including SIR)
    - More flexibility to accommodate scientific equipment sledges alongside the Moon Unit
- Conclusion
    - WISSARD Hot-water drill system <u>conceptual design</u> is essentially complete
    - <u>Design embodiment</u> to proceed hand-in-hand with procurement:
        - Hose
        - Filtration
        - Heater (c / w heater controls, fluid pumping, scavenger)
        - Main Hose Reel and Sheave
        - Shell-and-tube Heat exchanger
        - Process-control system design
        - Rodriguez and Recovery Well Systems
        - Electrical Systems: final power requirement assessment, layout, procurement, & build
- Discussion
    - 5-10 bores per year for the two years of the project
    - New fluid is FDA approved for incidental contact with potable camp water
    - Heater loop is autonomous and controlled by its own PLC
        - If flame goes out for even half a second, the system will shut down and requires operator attention to restart
    - Different loops to separate salt and clean water when necessary
        - Third loop will drill firn holes quickly (3mW)
    - Maximum temp of thermal fluid is 450°F
        - No steam hazard, as system would shut down and dump water before it could turn to steam
    - 'Cold pot' fluid expansion tank
        - At room temp, tank will only be 1/3 full, at full temp tank will be 2/3 full
    - Thermal Fluid Heater is 8' in diameter and 25' long
    - Booster pump chosen over triplex pump; centrifugal
        - Brings water in at 40-60psi and ejects it at 1200psi
    - U-tube heater diagram with thermal fluid loop
        - To increase heat output, increase amount of thermal fluid entering heater
    - Hose reel ISO container will be closed during operation with UV lights for additional sterilization
    - Activated carbon will likely be consumable each year
    - Distance between rod well and borehole?
        - (Gerasimoff) Likely not far enough at 40ft. currently; will try to keep rod well deep, well below firn ice transition
    - How flammable is the fluid?

        - (Gerasimoff) Flash point is 700F
        - Flanges are standard ASTM rated to 300 lbs., well over what is required.
        - All welds (100%) in thermal fluid loop are TIG welded and will be x-rayed after bending.
    - Coast Guard approval addresses safety and environmental protection (i.e. bouncing during transport, as these units are usually rigid mounted)
    - Stack will only be 6-12 ft. long
        - Flue gas will not be below 300 degrees when leaving the stack (no condensing concerns)
    - (3) CAT Challengers and Quad Track for pulling

(Day – 4/21/10)

Hole Logging and Instrumenting

- Temperature logging is very important for isotope studies
- Any problem with logging after replicate coring is complete?
    - (Cooper) Talk to oil field loggers regarding logging in multi-lateral holes (i.e. Schlumberger)
- Types
    - Temperatures
    - Inclinometer
    - Optical
    - Caliper could be used for vertical strain
- Will hole logging damage the borehole prior to replicate coring?
- (Souney) Only two proposals expected at this point:
    - Gary Clow's temperature logging (already built)
    - Ryan Bay's optical logging
    - Pending sonic logging (Anandakrishnan, Waddington)
- (Pyne) Ensure with logging community that their logging equipment has a weak link to the cable, so you wouldn't loose the cable in the hole and prevent replicate.

IDDO Equipment Inventory (Lebar)

- Hand Augers
    - SIPRE, PICO and Kovacs designs
    - Core diameters 79-140mm
    - Depths 5-21m
- Shallow Depth Tethered Systems
    - 2-Inch
        - 51mm core
        - 42m depth
    - Badger Eclipse
        - Currently have two different designs
        - Will have a third design when UNH system is given to ICDS
        - 81mm core
        - 300+m depth
    - 4-Inch (3 winches; 100, 200, 400m)
        - 104mm core
        - 350m depth
- Deep Tethered Systems
    - DISC
        - 122mm core
        - 4000m depth
    - Replicate
        - 100mm core
        - Up to 400m of total replicate core
- Specialty Drills
    - Prairie Dog

    - 102mm core
    - 40m depth
  - Koci Drill
    - 80mm core
    - 40m depth
  - Chipmunk
    - 51mm core
    - 0.5m depth
- Non-coring Drills
  - Rapid Air Movement (RAM) Drill
    - Used for drilling shot holes for seismic work
    - 102mm hole diameter
    - Up to 90m hole depth depending on firn
  - “Portable” Hot Water Drills
    - Used primarily for shot holes
    - Transportable by Twin Otter

<u>Ice Driller’s Workshop</u>

- Questions raised by some members of the Ice Core Working Group regarding characterizations of the small coring drills, i.e. their performance
- Emphasis in Long-Range Science Plan and Long-Range Technology Plan on need for good small or “agile” drills
- Objectives of Workshop
  - Fundamental Questions:
    - What factors determine the quality of an ice drill and the quality of a drilling operation?
    - What drill parameters affect the qualities of a drill and drilling operation?
    - What is the relationship between the drill parameters and the quality of the drill and it’s operation?
  - Look at the agile drills
    - 4-Inch
    - Eclipse
    - Hand Augers
    - RAM
  - Determine course of action for further development
  - Review and evaluate IDDO field procedures (if time)
- Workshop Outcomes
  - Need for focus on maintenance of both:
    - Equipment
    - Human infrastructure
      - Contract drillers are aging and need to convey knowledge to younger upcoming drillers
      - Need ongoing training
      - Do not have work/projects for all drillers every year
  - Hand augers
    - New hand auger should be designed to replace the SIPRE, PICO and Kovacs hand augers
    - Need good instructions including video for users
      - Make video available on web as well as send a DVD out with each drill system
  - Eclipse Drill
    - Control boxes not reliable or ergonomic and are big and heavy
    - Barrels not interchangeable and should be
    - Should be traversing and ‘regular’ model, instead of standardizing
  - 4-Inch
    - Control boxes not reliable or ergonomic and are big and heavy
    - New barrels needed
    - Drill is heavy but has advantages
  - RAM Drill
    - Need to understand factors of performance
    - New multi-wrap hole reel

        - Extremely fast
- Discussion
    - Hi-tech control boxes cannot be fixed in the field if failure occurs.
        - (Gerasimoff) Need to consider redesign. Duality has been stripped out of the Eclipse control boxes. Both the drill and winch motors are run off of one Variac and cannot be run at the same time. A second box is shipped for redundancy.
        - (Mortensen) Large boxes could be replaced with small solid state controllers, but people have been looking for off-the-shelf items and these are not usually rated for cold. Drillers have a love-hate relationship with Variacs.
            - (Gerasimoff) – Geological Survey of Canada tried an off-the-shelf Boston Gear controller, but would not run with Honda generator. Need to understand the history before redesign.

<u>Koci Drill System</u>

- System Specifications
    - Shipping Weight=2040 lbs.
    - Field Deployment
        - Deployed weight=1780 lbs (1750 lbs. in 2008)
        - Entire drill system can be slung from Bell 212 (1 load)
    - In-Field Transport
        - All cases <200 lbs.
        - Man-portable ~0.5km in rough terrain
    - Assembly /Disassembly
        - Set-up ~3 hours (not including site preparation)
        - Take-down ~2 hours
    - Operators
        - 3 minimum
        - 5-6 optimum (including core handlers)
    - IDDO's first attempt to drill ice with rock debris
        - First seen as modified hand auger, but need ability to change pitch quickly when drilling rock; went to drill tower/drill press setup
    - Two Honda 2k generators in parallel
    - Fiberglass drill rods
    - Chain come alongs for stabilizing lines
    - Driller actually feels WOB, you don't impose a steady feed rate
    - Standard concrete drill motor
    - Rack is used for core break, but faster to lower and recover drill string with capstan winch and rope
    - Issue finding places to keep the cores cold; little surface snow in valley
- Performance History
    - Beacon and Mullins Valleys, Antarctica
        - Original system
            - 2006: multiple holes 1-5m, deepest=10m
        - 2nd Generation
            - 2008: 5 holes of 1, 4, 16, 23, 28m
        - Improved 2nd Generation
            - 2009: 6 holes of 2, 6, 7, 14, 18, 34m
    - Scientists originally said clean ice would appear after 5m, but dirty (debris) ice found even at 34m depth
    - Rock to ice ratio very variable, 10-90% ice
    - Substantial sand layers encountered; heat is big problem with mixed media drills as this creates sludge
    - If we could get the material to stand still, we could drill it, but it often rattles in the hole bottom
    - About 160 degree kerf limit with carbide inserts on coring head
- Core Head
    - Hardened S7 tool steel – impact strength suffered; possibly hardened too much or cold damage issues
        - Unhardened S7 tool steel actually worked well
    - (Pyne) Could weld or layer tungsten carbide pads as opposed to hardening head.
    - (Cooper) Could use high strength, high ductility martensitic aging steel.

  - Would like to have braised insert instead of bolt on
    - Cutter has a tendency to break across weak point at screw
  - Idea of load needed with split-ring collet?
    - Breaks were easy
  - Inserts developed by Kennaemetal, likely for making interrupted cuts in metal
    - Cut ice very well, not quite tough enough for rock
    - 30° positive rake angle, not a drag cutter
  - 100% core recovery. Big improvement over previous years and over drills with dogs.
  - 3" core (76mm)
- Core Recovery
  - 2009 Modifications
    - Tapered ID Core Head
      - Minimal clearance at opening to catch chips surrounding core
      - Geometry based on prior, successful designs
    - Split–Ring Collet
      - Based on designs used in rock coring drills
      - Actuated by tapered core head
- Core Barrels
  - 2009 Modifications
    - SS core barrel with welded SS flights
    - Optimized pitch angle and height
    - Attachment ring for bolt-on heads
    - Reinforced upper barrel
    - Centering pads at top of barrel
    - Collet stop screws
  - Previously used SS barrels with poly flights attached; now have SS barrels with welded SS flights
- Ice Cement and Rock
  - 2009 Modifications
    - Strengthened coring drill
    - Rock auger
    - Rock bit (non-coring)
  - Auger implemented on drill string for first few meters of rock with very little ice; flights often come up empty
    - Downhole vacuum not very successful and does not pick up sludge
  - Can reduce rotary speed, but not enough to reduce heat
    - Runs best at about 100 rpm
- Drill Motor
  - 2009 Modifications
    - New 4-speed gear reducer
      - 2.8kW
      - 150Nm max torque
    - Increased torque at low rpm
    - Removed soft-start circuitry
    - New adaptor to drill string
- Winch
  - 2009 Modifications
    - Self-tailing capstan winch with motor
      - 2000 lbs. max pulling force
      - 2-speed gear box
      - This yachting-style winch works well, but is undersized for anything over 40m
    - 0.5hp brushed DC motor
    - Base-mounted
    - Hand-crank option
    - Used as belay point for lowering drill string
- Current Capabilities
  - Consistently drill and recover 45cm long cores in:

    - Clean ice
    - Ice containing rocks <160° of kerf due to heat and strength of carbide cutters
    - Sand frozen in ice
    - Shallow consolidated sand deposits with trace ice
  - Good core quality
  - Depth capacity
    - ~50 m in clean or slightly rocky ice (sand, rocks <3cm)
    - ~35 m in moderately rocky ice
    - <10 m in ice containing substantial debris
      - Thick sand deposits (>0.5m) with trace ice
        - Large and or frequent rocks (>10 cm, >2 large rocks per meter)
    - Large rocks (up to 100% hole area) and shallow gravel deposits can be drilled with non-coring rock auger and bit
      - Depth limited to <35m
      - Thickness limited by heat generation
    - Depth in rock limited by torsional and flexural rigidity in the drill string
      - Fiberglass tubes get wound up
  - Downhole cam used, but cuttings block clear view of hole bottom
  - (Pyne) Could change design of head to include a ‘junk basket’
    - (Eustes) Need fluid for this
  - Good transportability, but likely a dead end for drilling in more difficult valley areas
    - (Gerasimoff) Likely need an air drill
  - No clearance for fluid use in the valleys at this point
- Main Limitations
  - Cutter breakage
  - Core head damage
  - Drill string torsional and flexural rigidity
  - Heat generation from drilling rock
  - Mobile rock (gravel)
  - Collection of rock cuttings and/or sludge
- Future Drill Development
  - Enhanced rock drilling capacity
    - Air flush/cooling
      - Must have approximately -10C ambient temperature or below for the compressed air (Webster experience)
    - Cutter material and geometry
      - Coating or wear pads on critical areas of heads
    - Percussion with down-hole hammer
  - Continuous-flight rock auger
  - Access to depth, then coring
- Discussion
  - Ambient air temp -30°C to -20°C at season start, but up over freezing by end of season
    - Difficult to keep cores frozen
    - Similar experience with Webster drill in both Arctic and Antarctic
  - Need good science requirements – if only need a small sample from certain depth, augering the top meters should be focused on
  - (Pyne/Cooper) Downhole hammer is difficult in ice
    - Drag cutting is better solution
    - Lose percussion if you can’t get WOB
  - Continuous flight auger
    - Likely not transportable to remote locations
  - Very little success with Russian permafrost drill farther up in Beacon Valley
  - Webster Drill blows cuttings from hole
    - Impregnated diamond bits
    - Tubing designed for water (not optimal for air)
    - Have used drill fluid in the Dry Valleys in the past

    - (Pyne) 100cfm, 150psi was undersized compressor and was a sling load
  - Trade off – Webster drill needs 4-5 helo loads while Koci Drill currently only needs one flight
  - (Pyne) IDDO has ability to do innovation that companies like Webster can't do because they need to also focus on commercial return;
    - This limits innovation money

Long Range Drilling Technology Plan

- SAB recommended 'other challenges'
  - Explore new drilling fluids
  - Maintain agile drill systems
  - Develop intermediate drill system
- Logging Winch
  - Potential use of IceCube equipment
  - Logging community determining what they want
- Make note that SAB requests are not prioritized
  - (Powell) Suggest bullet points
- Chipmunk Drill
  - Documentation will be updated when needed
  - List improvements needed
- Hand Augers
  - New design; phase out IDDO responsibility for other models
    - Kovacs models are owned and should be maintained by RPSC
  - Develop good instructions/video for operators
  - Implement equipment tracking system
  - Issue new design from Madison and not through Berg Field Center (BFC)
  - Possibly implement split ring collet on hand augers for more consistent, reliable performance
  - Inventory
    - 6-7 PICO augers
    - 6-7 Kovacs augers
    - 2-3 SIPRE augers
- Prairie Dog
  - Has only been used by Jay Kyne, but is requested more frequently now
  - Have draft of Operator's Manual
  - Community needs more awareness of this and other systems available
    - (Kuhl) Do we need to send a driller with this system?
      - (Gerasimoff) A few changes could make this suitable for scientist to operate.
  - (Souney) Suggest creating a matrix of equipment available
    - Depth vs. drill type
    - Number of drillers needed
    - Transportation requirements
- Sidewinder
  - Have built more as demand has increased
  - Josh to review design for safety modifications
  - Very useful system
- Blue Ice Drill
  - Mary will get clarification from NSF as to who retains the equipment when the project is complete
  - Helo-transportable
  - Two drillers for deployment
- 2-Inch Drill
  - Requires technical attention before becoming an issuable item
  - Originally intended for high altitude

- Badger-Eclipse
  - Need different names for each of the three different designs
  - Downhole and surface parts are not interchangeable between systems

- 4-Inch Drill
    - New transport boxes
    - Determine how many winches to maintain (100m, 200m, 400m)
    - Explore new cable connections/sealed motor so system can be used in water
- Electrothermal Drill
    - Western Washington is designing smaller model for Mt. Waddington
    - Cannot be used in cold ice
    - 6” system available at University of Washington
- Koci Drill
    - No current plans to repair/upgrade/deploy system
- Portable Hot Water Drill
    - One currently ready for deployment; additional one could be ready with minimal work
- RAM Drill
    - Askaryan Radio Array (ARA) will use drill for up to next 3 years at South Pole

TAB Meeting – 2011

- SAB meets in mid-March 2011 in conjunction with NSF site visit at IDDO.
- Suggest for TAB to meet early to mid-April to work around NEEM deployment of some members.