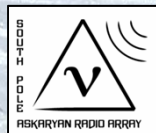


ARA Hot Water Drill Lessons Learned

ARA Review @ NSF
Feb 20-21, 2013

Terry Benson, UW-PSL



ARA Drill Lessons Learned

The drill system worked well from beginning

- No major equipment failures
- No mechanical issues
- No heater issues
- No serious leaks
- No fuel system issues
- Drilled holes that met spec

But there were still many lessons learned!

ARA Drill Lessons Learned

HOSE BUNDLE AND REEL SYSTEM NEEDS SOME WORK

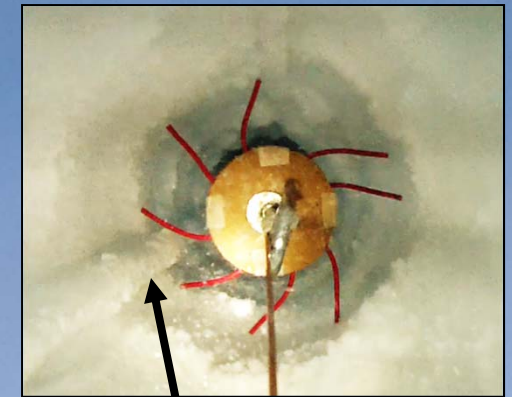
- Hose and bundle damaged at inner layers
- Severe conditions at this location
 - Max tension
 - Highest temperature
 - Minimum pressure
- Drillhead recirculation option
 - Keeps hose pressurized during retract, the hose prefers this
 - Late add-on that did not work this season
- Hose very tough from safety standpoint (no tearing, no leaking), but robustness and reliability must be improved
- Sheave assembly, bundle, and spare hose/cable coming back North. Rework and upgrade plan has been laid out



ARA Drill Lessons Learned

HOLE EVOLVES AFTER DRILLING

- Post-drill video logging revealed unexpected ice features: Vertical ridges of ice and small protrusions formed by water flowing back into the hole from surrounding firn
- 2 sources of water in firn
 - Deposited during lost-water firn drilling
 - Excess water deposited onto ground during drilling
- Solutions
 - Spend less time and water during firn drilling
 - Deposit excess water farther away from hole being drilled
- Delay between firn drilling and deep drilling allows firn hole and surrounding firn to “set” – temporary solution that worked last season, but not one looking to the future
- **Drillhead qualifier does not ultimately qualify the hole for deployment, post-drilling qualification was required**

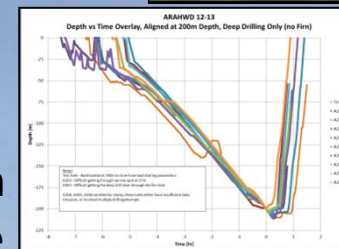
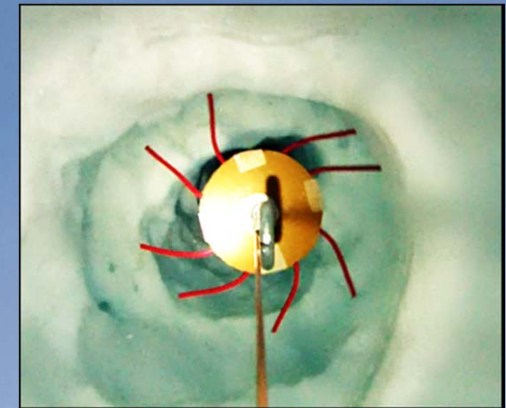


Vertical Ice Ridge

ARA Drill Lessons Learned

FIRN DRILLING METHODS and TIMING

- Aim to minimize water and make more uniform firn hole
- Lost-water firn drilling stores water in firn, drains back into hole during and after drilling
- Lost-water firn drilling creates an oversized, irregular, and slushy hole. Issues threading nozzle stem through firn hole at start of deep drilling = lots of wasted water and time
- Drilling firn at end of day and deep the next morning seemed to help, but not a long-term solution
- Spray pattern and technique can be optimized
- Excess water may be better utilized
- **Valuable upgrade 1:** Centering calipers for nozzle stem
- **Valuable upgrade 2:** Build “closed”-circuit copper tube carrot firn drill head
 - Minimizes/eliminates water lost during firn drilling
 - Water or glycol with current system heating plant, electric also possible
 - Compatible with Independent Firn Drill system
 - Could also be used as post-drill hole reaming tool



ARA Drill Lessons Learned

DATA ACQUISITION, PDAs, and VIDEO LOGGING

- All were extremely valuable
- Wireless PDAs were used constantly to monitor system and make adjustments
 - Streamlined operations
 - Provided history of system variables
- Data logging very valuable to post-analysis
- Video logging provided critical information about hole quality, drill strategy, and deployment readiness.
- That said, there are some bugs and areas to improve
 - Timeouts and resets
 - Wireless performance
 - Add more displayed information, like calculated hole diameter estimate



ARA Drill Lessons Learned

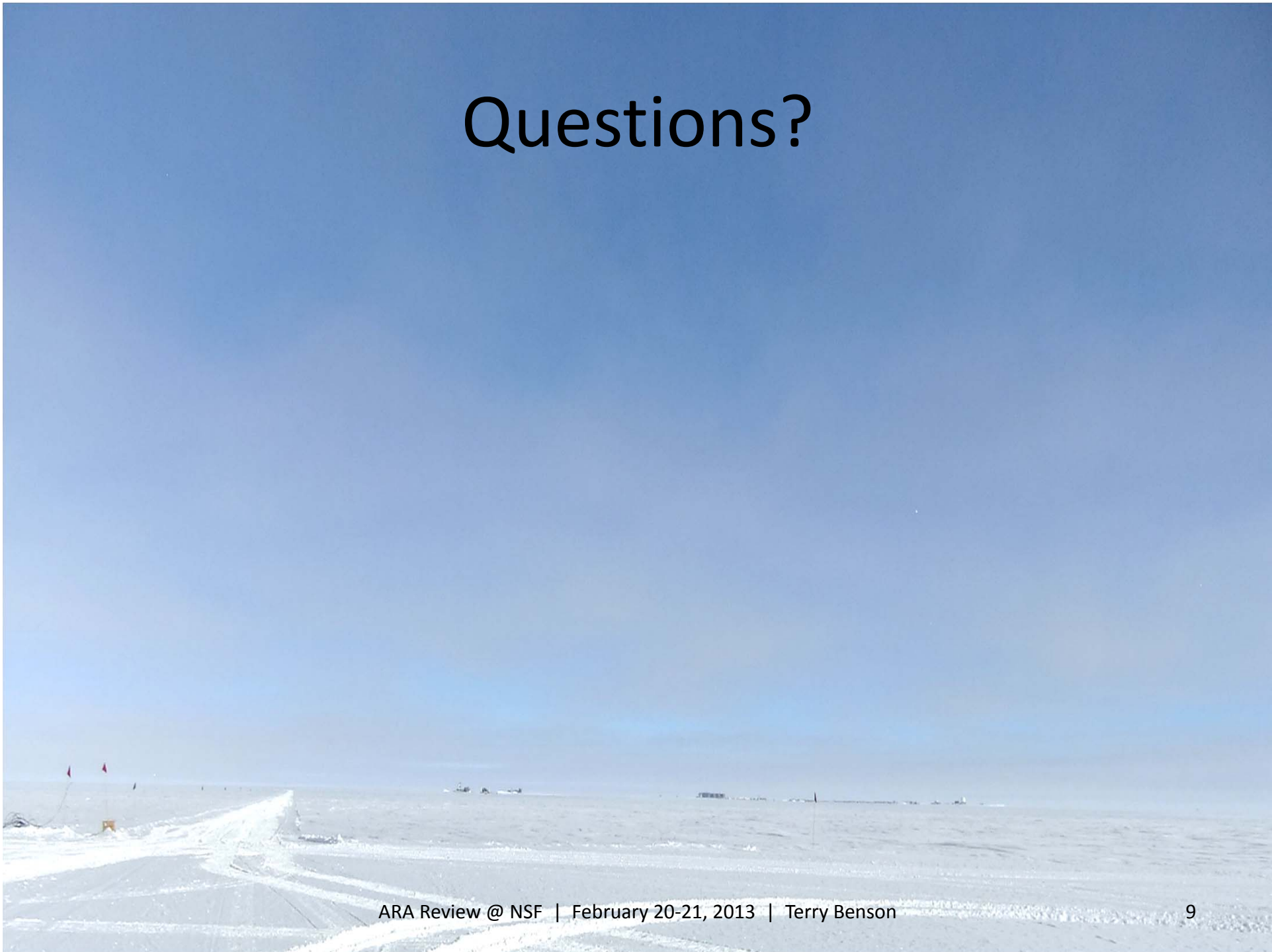
OTHER LESSONS LEARNED

- Online water volume – needed Water Buffalo (2nd reservoir)
- Power Unit – Gas engine a source of anxiety and requires 2nd fuel type, should consider replacing with more reliable electric motor
- Towing and positioning the train – better than anticipated, but need packed surface and “tupperware” under water tank sled (should add to remaining sleds)
- Drillhead and pump performance – great, recirculation needs to be pursued, pressure sensor range, learn true performance limits
- Hose reel and DCC performance – great, laundry list of improvements
- Far-field operations – new territory, but worked well this season
- Team size and expertise – just right this season
- Training and testing in North absolutely necessary
- Although Green Gens very reliable, still need White Gen
- Full confidence established at ICL a very good thing
- Felicia and NGH essential
- Not having cable trenches in place during drilling was very nice

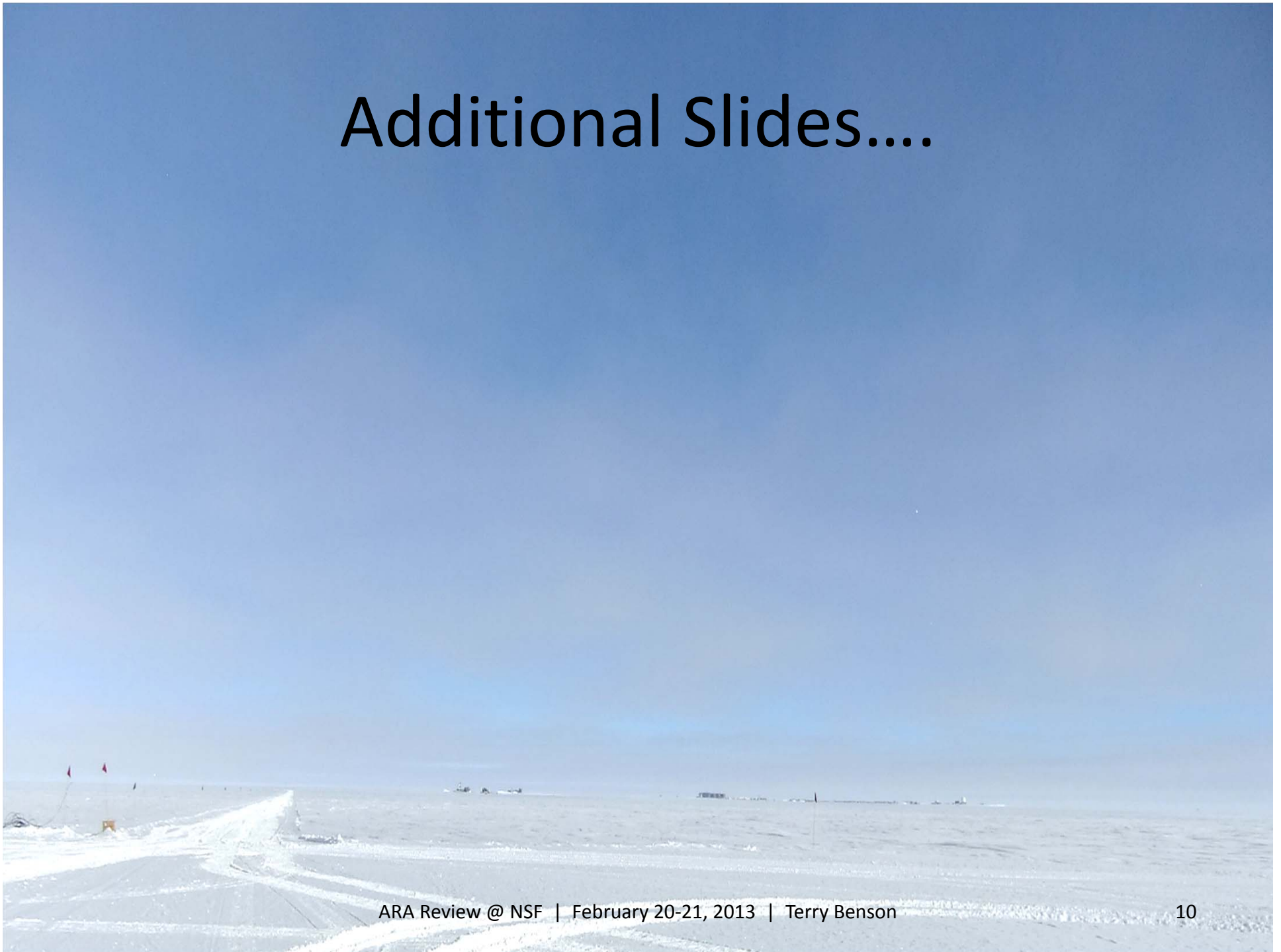
Recommended Activities for 2013

- Address hose reliability, bundle and hose reel issues
- Drillheads: Get recirculation working, centering calipers for nozzle stem, verify higher speed operation, increase pressure sensor range
- Further develop data acquisition
- Explore firm drilling options, build “closed”-circuit drill attachment
- Consider replacing High Pressure Pump gas engine with electric motor
- Assemble documentation and develop User’s Manual

Questions?



Additional Slides....



Addressing Hose Bundle and Hose Reel Issues

- More friction at sheave – add rubber bundle support around sheave, add traction belt
- Better support for inner wraps of bundle – add support strips between inner static layers
- Address vacuum – look for hose that can support full vacuum, rework vacuum breaks
- Maintain pressure in hose and reduce operational risk – get drillhead recirculation working
- Reduce possibility of over temp – safeties and procedures, operating point
- Equalize long-term creep – alternate cold/hot hose functions from hole-to-hole
- Buy replacement hose, re-assess hose selection – further testing in North, discuss with Flex Inc., continue vendor search
- Develop thorough procedure for bundle repair/replace in the field
- Rework sheave assembly mounting and load cell placement

Drillheads

- Non-recirculating (default) versions worked great
- Need to get recirculating working (better for hose, operations, and hole quality)
- New larger-range pressure transducers
- More long-term testing in North to better understand operating limits (over-speed)
- Centering calipers for nozzle stem, and/or stem extensions

Options to improve firn drilling

- Optimize spray pattern and technique
- Excess Water Mini-Rig
 - Utilize excess water, manage and direct it better
 - Parallelizes firn drilling
 - Quality and size may not be sufficient using this method alone, more of a “pilot” hole
- ARAHWD closed-circuit carrot
 - Same principle as IFD, but uses ARAHWD thermal plant
 - New carrot
 - Less/no water deposited into firn
 - Serializes firn drilling
 - Can also be used to post-ream narrow spots in drilled holes
- IFD
 - New carrot
 - Locate/rework/reinstall associated hardware, procure glycol and fill
 - Required power can be supported (along with ARAHWD ops) with current Green Gensets and some minor modifications to IFD
 - Less/no water deposited into firn
 - Parallelizes firn drilling