Sample Density Analysis and Optimization Strategies for NOAA's Airborne Snow Water Equivalent Surveys

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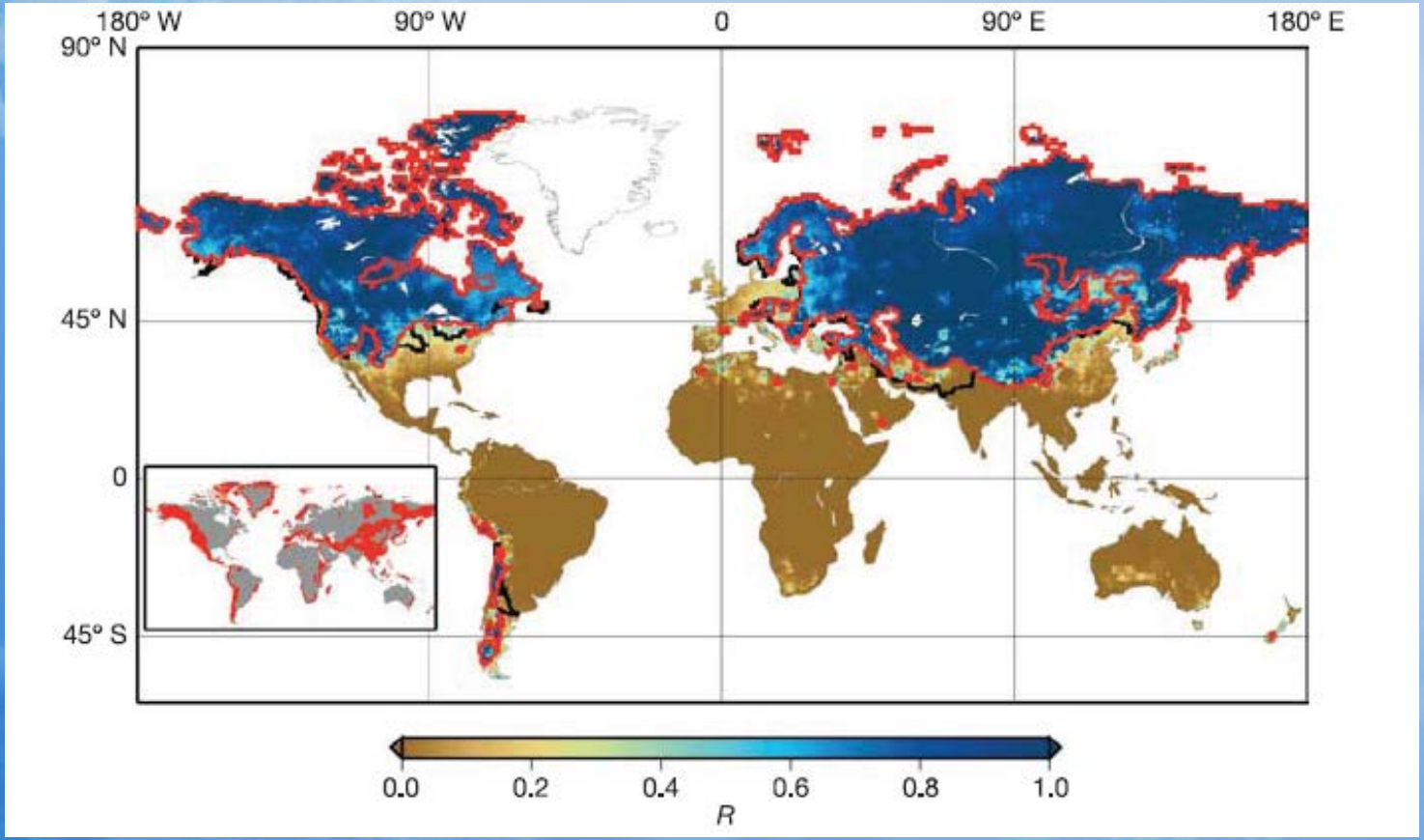
Overview

- Introduction to the Snow Survey Program
- Goals of Capstone Project
- Data and Methods
- Results
- Recommendations

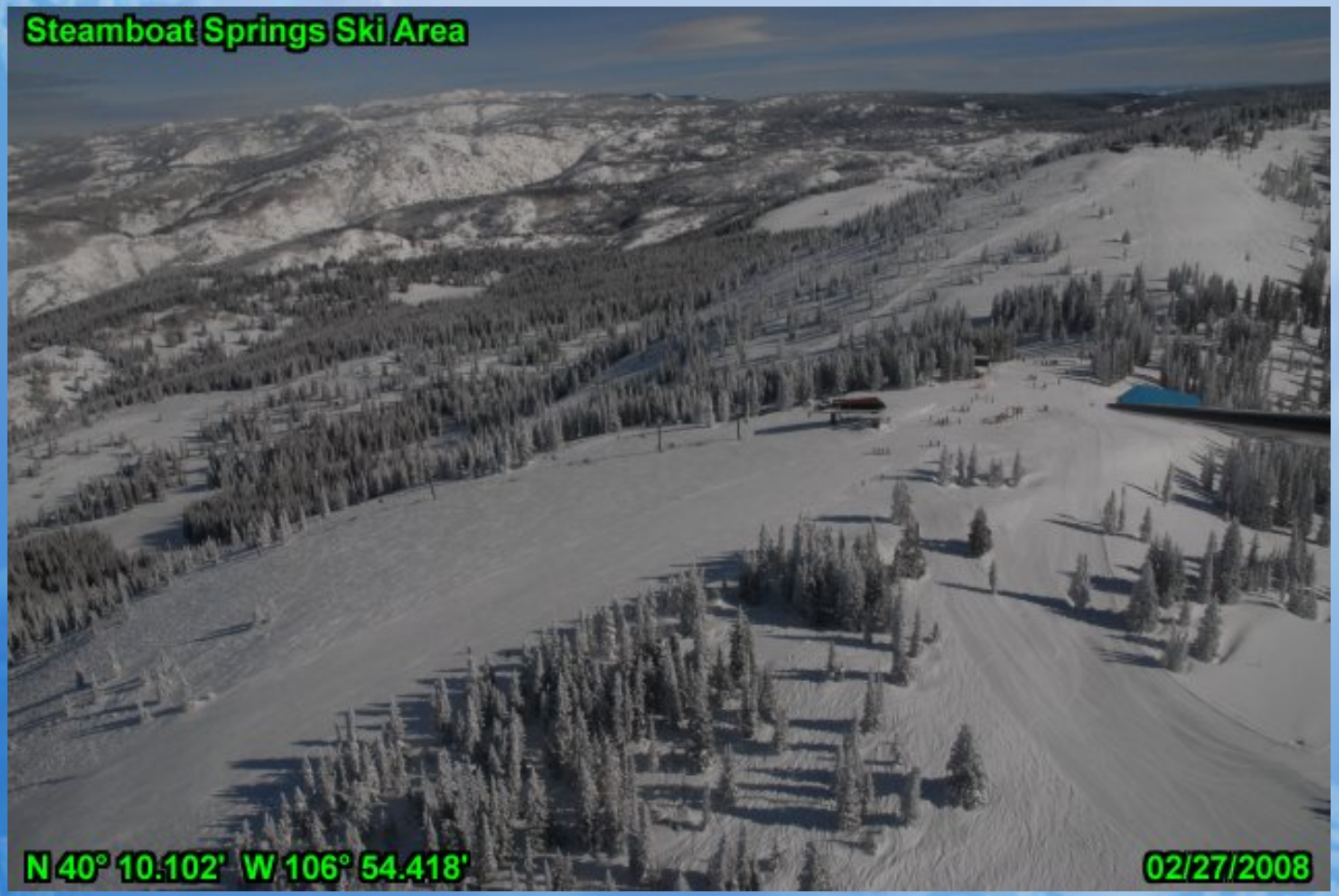
Why Snow Matters



Percentage of average annual snowfall divided by annual runoff.
(Barnett 2005)

Water Supply

Winter Tourism



Flooding

NOAA's Airborne Snow Survey

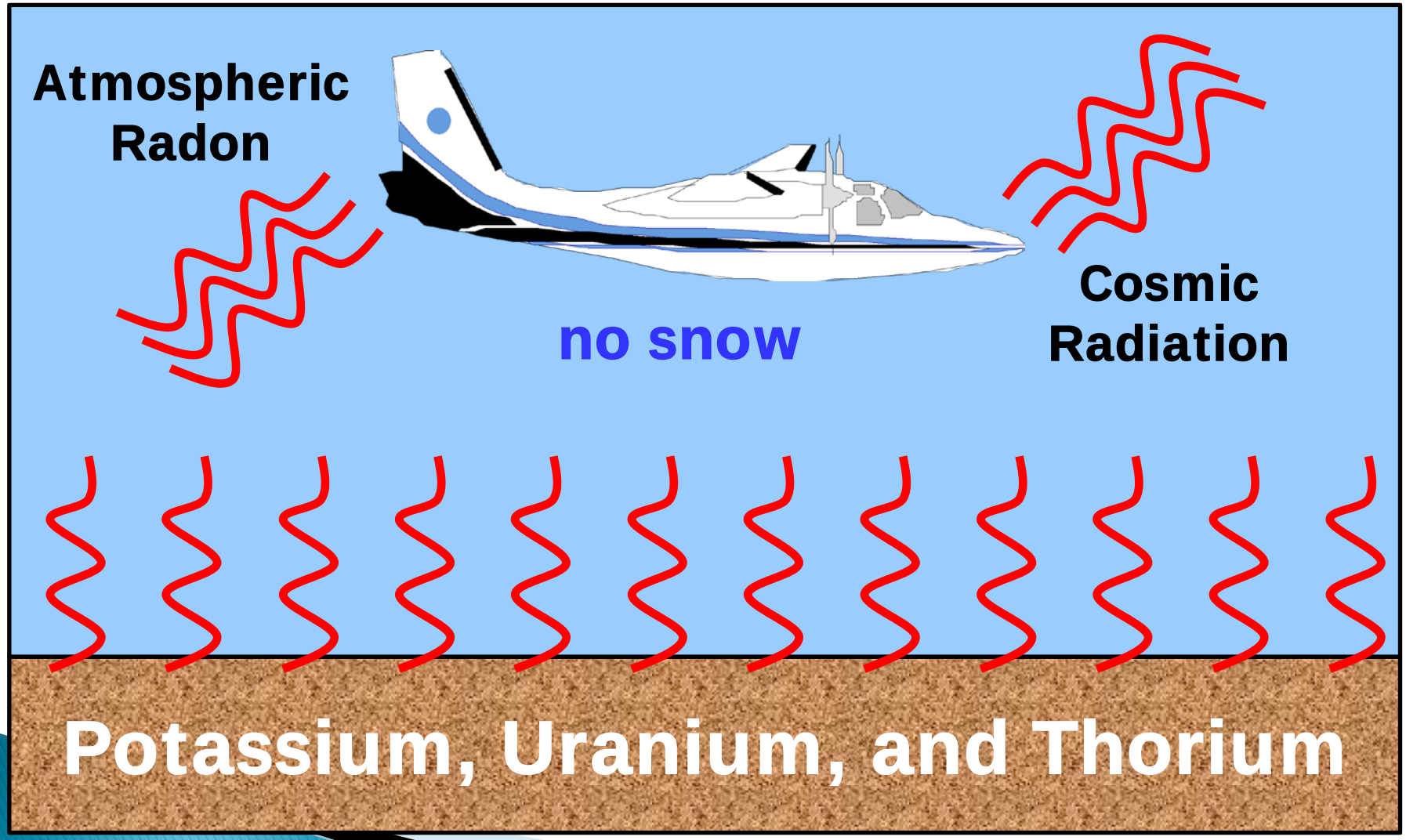
History

- Started in late 1970s by Dr Tom Carroll
- Originally limited to Upper Midwest
- Expanded in 1980s to mountainous areas
- Now includes over 2600 flight lines in over 35 states and Canadian provinces
- Supports NOAA offices, as well as collaboration with NASA, USACE, and regional water managers.

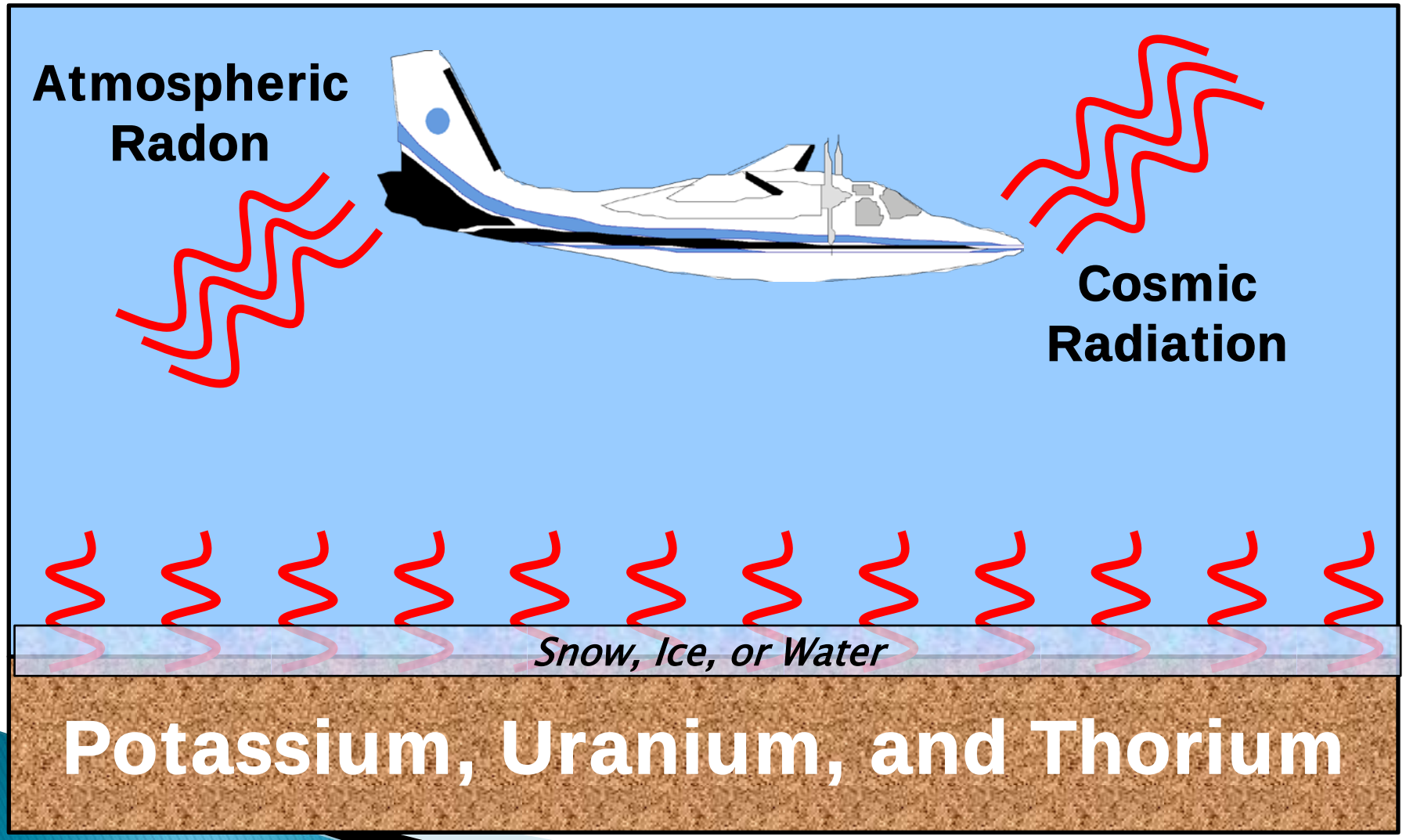
Gamma Detection Theory

- Natural Background Radiation signal present in soil is attenuated by water
- Using an aircraft-mounted gamma radiation spectrometer can measure this radiation signal
- Software in the aircraft compares snow-covered radiation signal against bare ground signal in order to compute snow-water equivalent
- Values represent mean areal snow-water equivalent for a given flightline

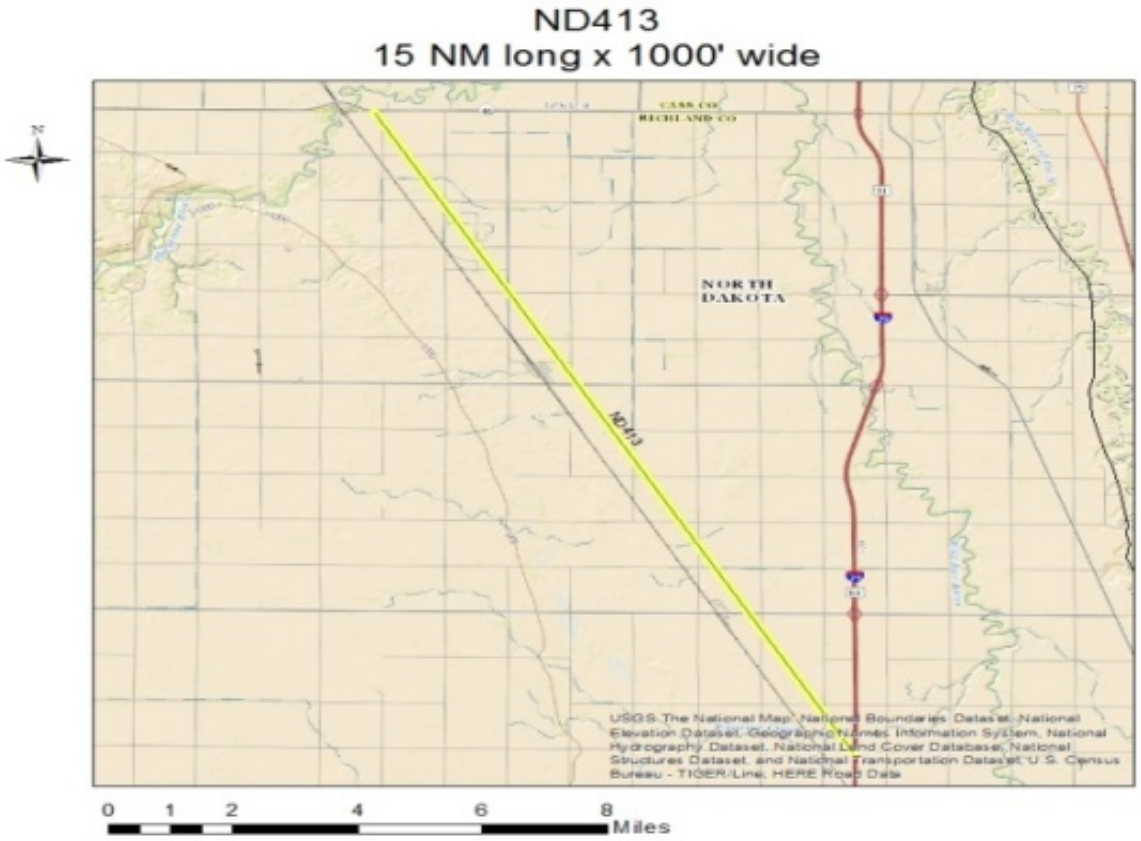
Natural Terrestrial Radiation



Radiation Attenuated by Water



The Flight Line Spatial Data



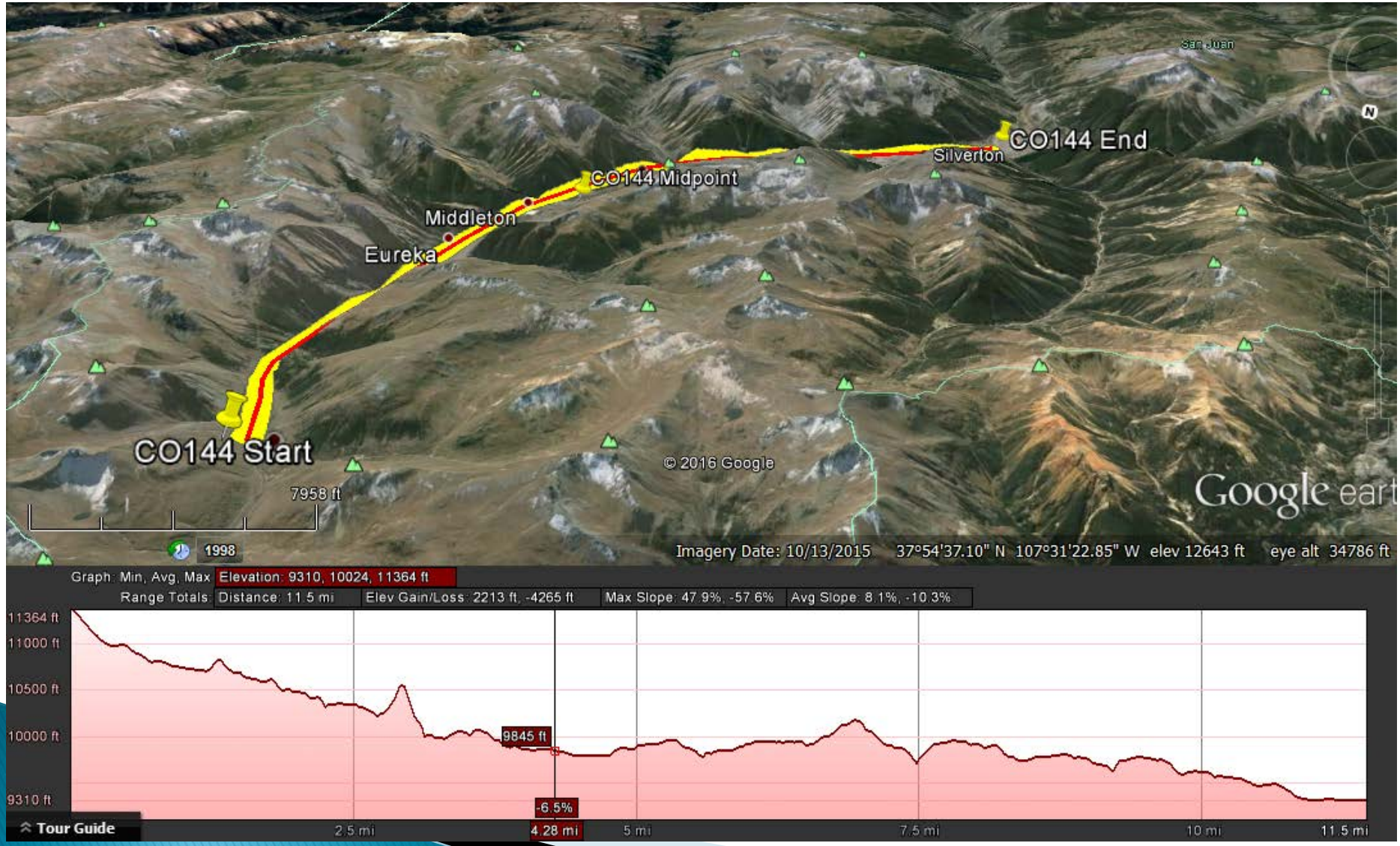
- Designed to allow for continuous data for approximately 5 minutes to account for spatial variability of snow-water equivalent
- Swath of sensor at 500’ above ground is ~1000’
- Line represents surface area of roughly 2.5 square miles.

The Flight Line Background Data

ND408	3017	859	29540	23.2AI	151101	23.2
ND409	2849	865	29780	21.3AI	151101	21.3
ND410	3107	953	31120	19.3AM	151009	19.3
ND411	3105	1154	36780	16.5AM	151007	16.5
ND412	3064	1089	34800	17.6AM	151006	17.6
ND413	2453	757	27180	21.0AI	151101	21.0
ND414	2500	666	25670	21.5AM	151006	21.5
ND415	2999	961	32250	17.4AM	151006	17.4
ND416	2673	828	28620	21.7AM	151009	21.7
ND417	2289	520	22420	20.3AM	151006	20.3
ND418	3222	1054	33120	22.5AI	151101	22.5
ND419	2848	1015	34680	27.0AM	151009	27.0
ND420	2532	747	28150	20.5AM	151009	20.5
ND421	3012	887	31740	22.6AI	151101	22.6
ND422	3143	988	32790	23.5AM	151010	23.5
ND423	2894	871	30040	24.2AM	151010	24.2
ND424	2969	901	30280	22.1AI	151101	22.1

- Background data for line includes normalized “count rates” for potassium, thorium, and total counts
- Also includes background soil moisture information used for snow-water equivalent calculation

The Flight Line Mountain Lines



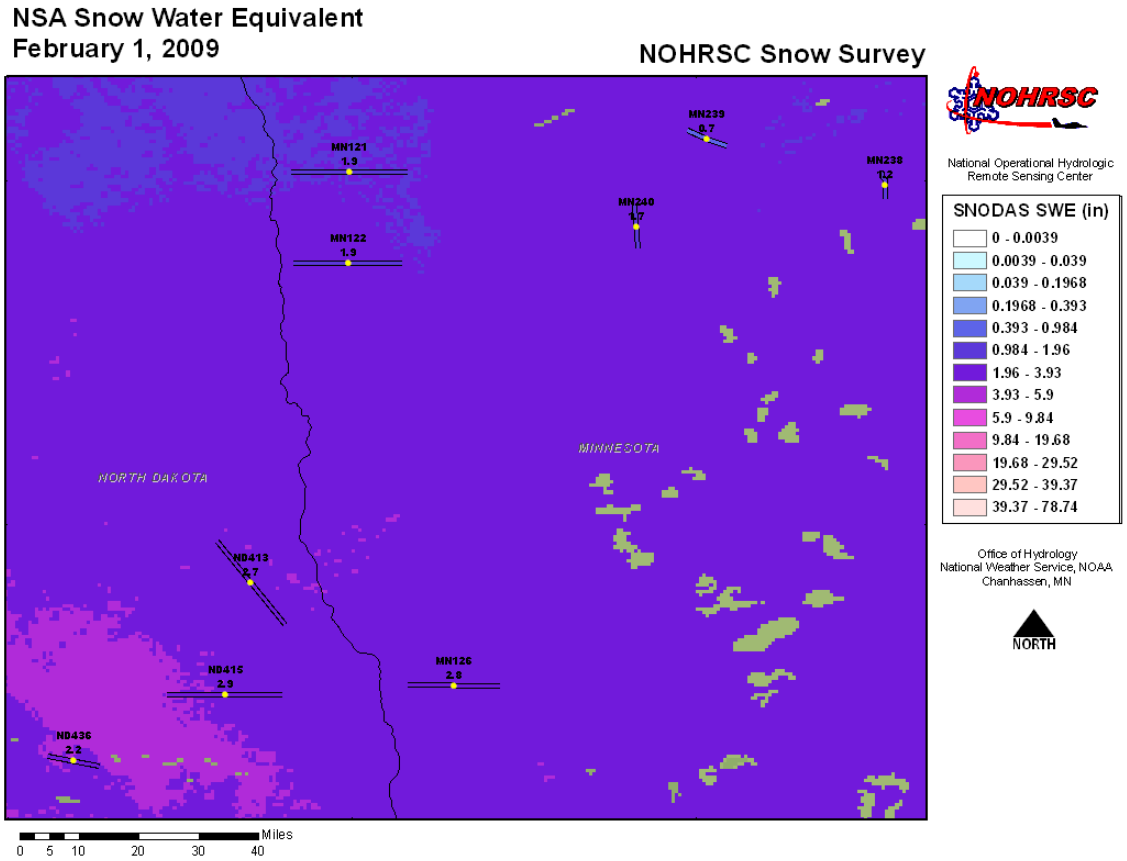
The Flight Line Output

- Processing occurs real-time in the aircraft.
- Data are sent to NWC on a daily basis for quality control
- Published to the web in a SHEF format.

```
SRUS43 KMSR 041334
RRMASP

.BR GAMMA 090204 /SAIRF/SWIRF
:TO ------ Service Hydrologist (Please give HARDCOPY to SH)
:FROM ---- Don Cline, (952) 361-6610, Minneapolis, Minnesota
:Visit our web page at http://www.nohrsc.noaa.gov
:SUBJECT - AIRBORNE SNOW WATER EQUIVALENT DATA                    090204133417
:-------------------------------------------------------------------------------
: Total No. of flight lines sent = 4
:-------------------------------------------------------------------------------
:Line   Survey    %SC   SWE   SWE %SM Est Fall  %SM  Pilot
:No.    Date          (in) (35%) (M) Typ Date  (F)  Remarks
:===============================================================================
MN126  DY090201 / 100 / 2.8 : 2.6, 32 AM  81102 , 32 drftg sno
ND413  DY090201 / 100 / 2.7 : 2.1, 23 AM  81103 , 23 fld stbl
ND415  DY090201 / 100 / 2.9 : 2.6, 29 AM  81103 , 29 drftg sno
ND436  DY090201 / 100 / 2.2 : 2.1, 33 AM  81102 , 33 fld stbl
.END
100 percent snow cover throughout area.  All water bodies frozen. No
signs of new snow.  Windswept snow throughout area.
NNNN
```

The Flight Line Output

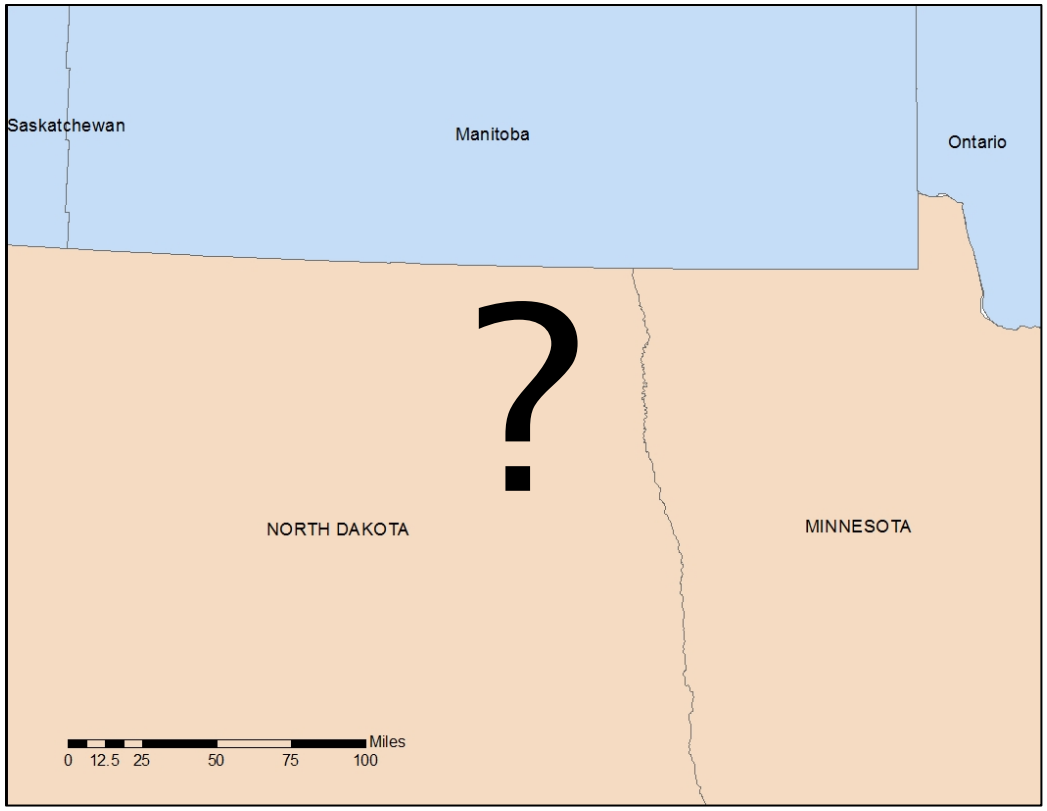


- Each line represents mean areal snow-water equivalent
- Midpoint of line used for spatial analysis
- Values used to create SWE surface grids

The Flight Line Accuracy

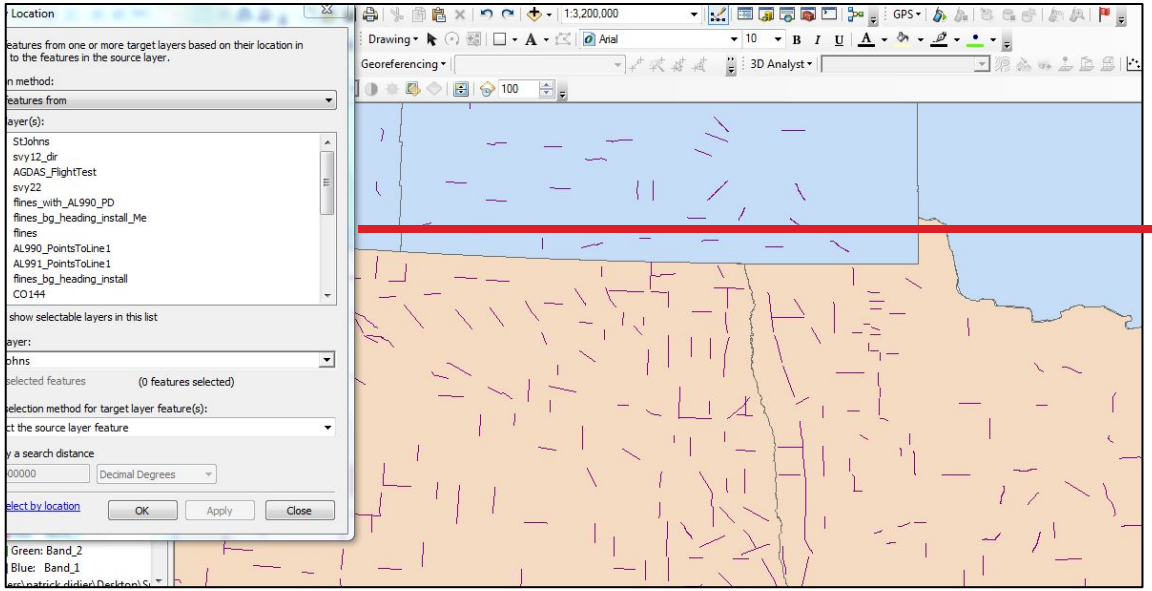
- Measurements accurate to within 1 cm of SWE or 5% soil moisture
- Accuracy varies based on overall background and environment
- Can measure up to 39 inches of SWE, depending on total amount of background radiation

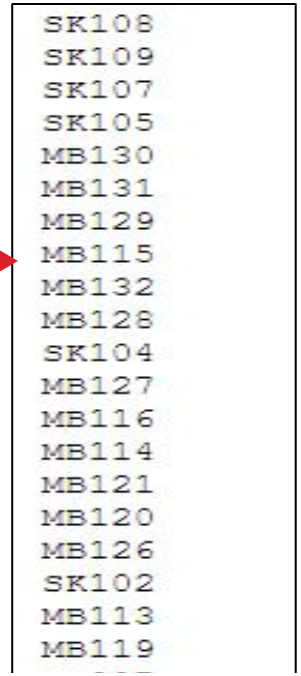
Survey Creation: RFC



- River Forecast Center (RFC) will make request for an airborne survey
- Some forecasters will make requests for specific flight lines, basins, or general areas
- Some surveys are “canned” surveys that are flown every year

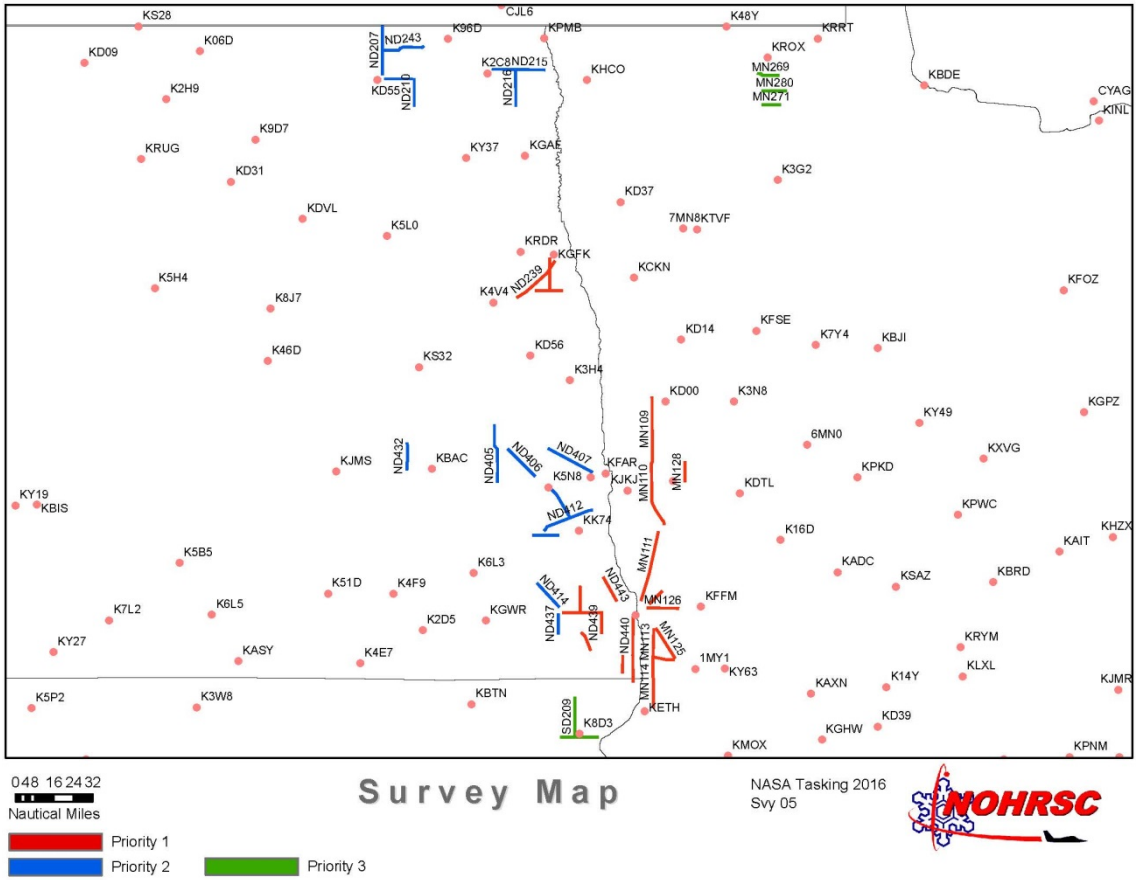
Survey Creation: OWP





- Using Arc Tools, the Principal Investigator at the Office of Water Prediction (Chanhassen) will create a text file of the lines to be flown based on the RFC request and the available lines in the area
- This text file is then sent to the pilots

Survey Creation: AOC



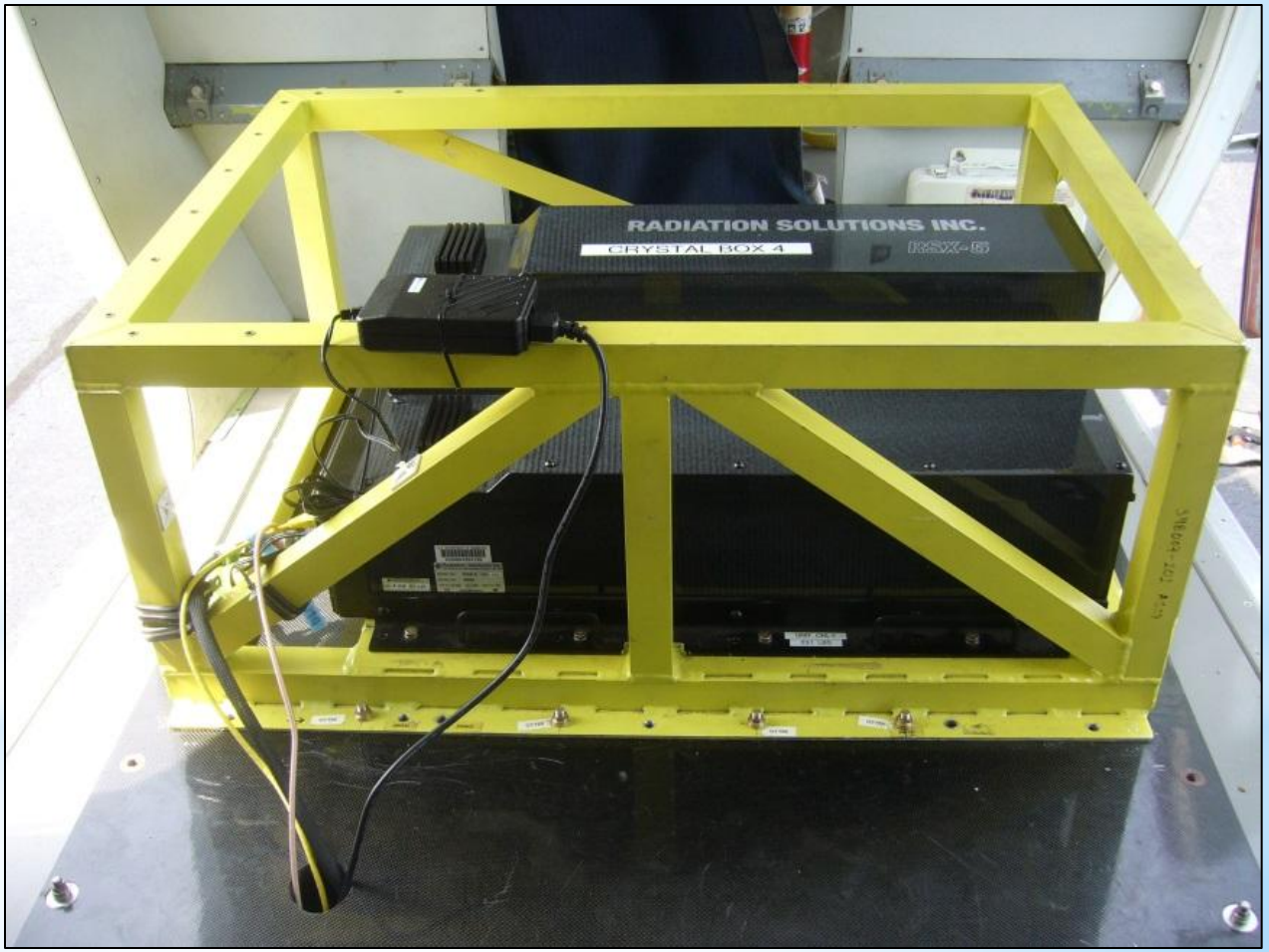
- Pilots at NOAA's Aircraft Operations Center create survey files from text file
- Survey files include maps, survey shapefiles and pointfiles to be used for navigation

Survey Execution: AOC

- Limitations
  - Daylight
  - Weather
  - Maintenance
  - Crew Duty
  - Logistics

*Limitations

Total Sensor Packages: 3



*Limitations

Calibrated Aircraft: 3

1 AC-695 JetProp Commander

2 DHC-6 Twin Otters

*Limitations

Trained
Mission
Commanders:8

Capstone Objectives

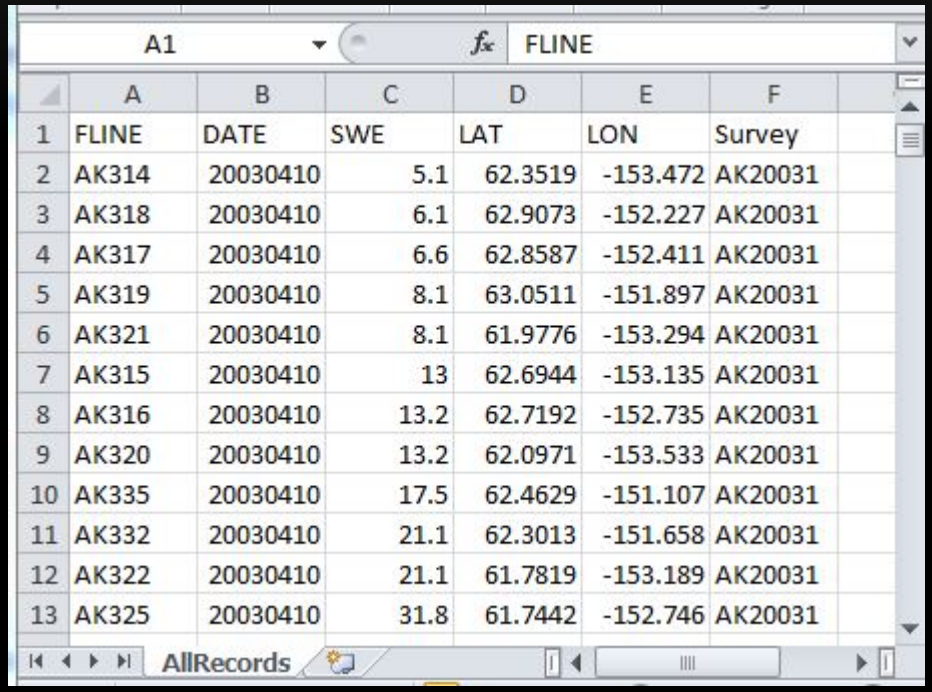
- Rigorous Analysis of Survey Efficiency
  - Investigate whether some lines can be skipped due to high degree of spatial autocorrelation
  - Determine whether interpolation methods can yield satisfactorily low sample errors in interpolated values
- Reduce Overall Survey Effort
  - Fuel savings
  - Increased safety due to less time an low altitude
- Increase Overall Survey Value
  - Increase areal survey footprint without a corresponding decrease in accuracy
  - Reduce extraneous effort in areas where it is unneccesary

DATA AND METHODS

- Available Data
- Suitability Analysis
- Sample Optimization
- Data Interpolation
- Application

AVAILABLE DATA

- http://www.nohrsc.noaa.gov/snowsurvey/historical.html
- Contains 36 years of snow and soil moisture data
- Data compiled into one spreadsheet containing records for every flight line flown (over 25,000 records)

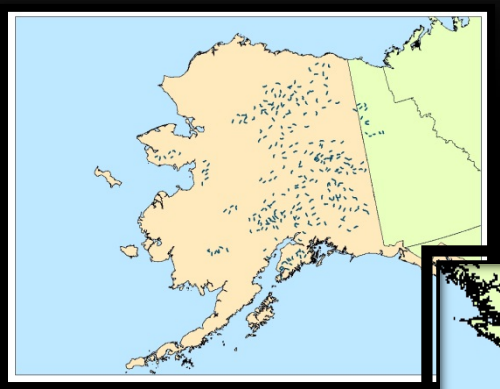


A1 | FLINE

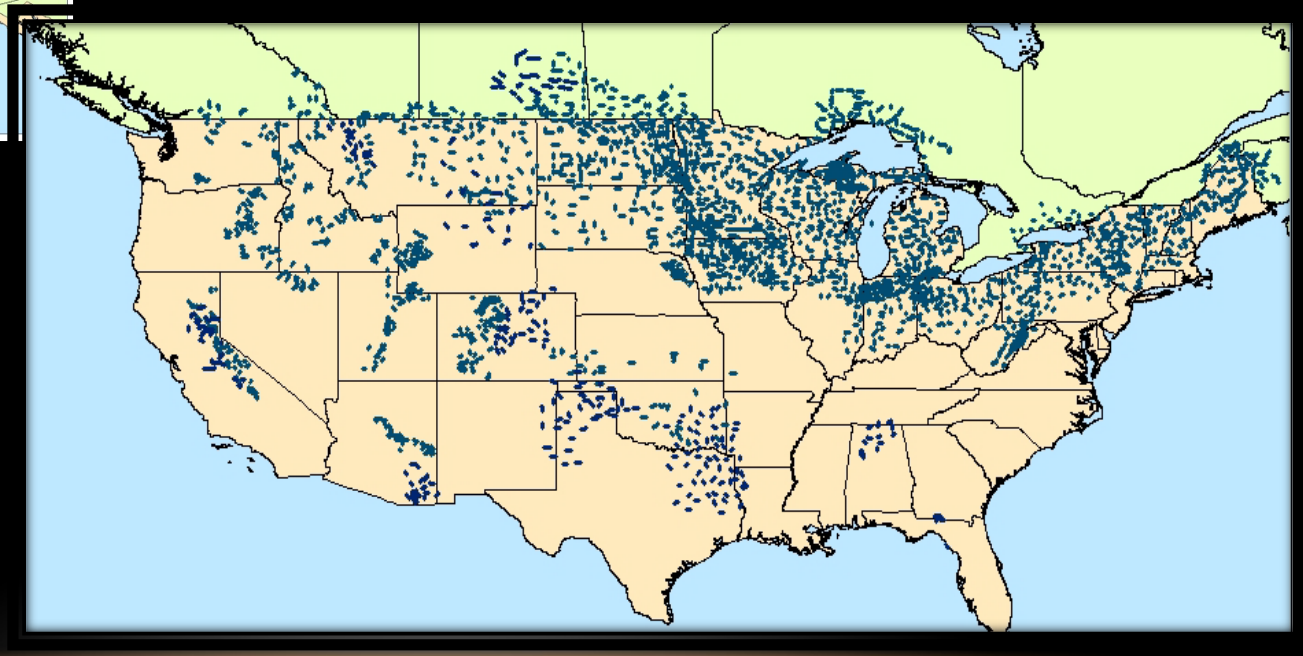
	A	B	C	D	E	F
1	FLINE	DATE	SWE	LAT	LON	Survey
2	AK314	20030410	5.1	62.3519	-153.472	AK20031
3	AK318	20030410	6.1	62.9073	-152.227	AK20031
4	AK317	20030410	6.6	62.8587	-152.411	AK20031
5	AK319	20030410	8.1	63.0511	-151.897	AK20031
6	AK321	20030410	8.1	61.9776	-153.294	AK20031
7	AK315	20030410	13	62.6944	-153.135	AK20031
8	AK316	20030410	13.2	62.7192	-152.735	AK20031
9	AK320	20030410	13.2	62.0971	-153.533	AK20031
10	AK335	20030410	17.5	62.4629	-151.107	AK20031
11	AK332	20030410	21.1	62.3013	-151.658	AK20031
12	AK322	20030410	21.1	61.7819	-153.189	AK20031
13	AK325	20030410	31.8	61.7442	-152.746	AK20031

AllRecords

THE FLIGHT LINE DATABASE: 2016

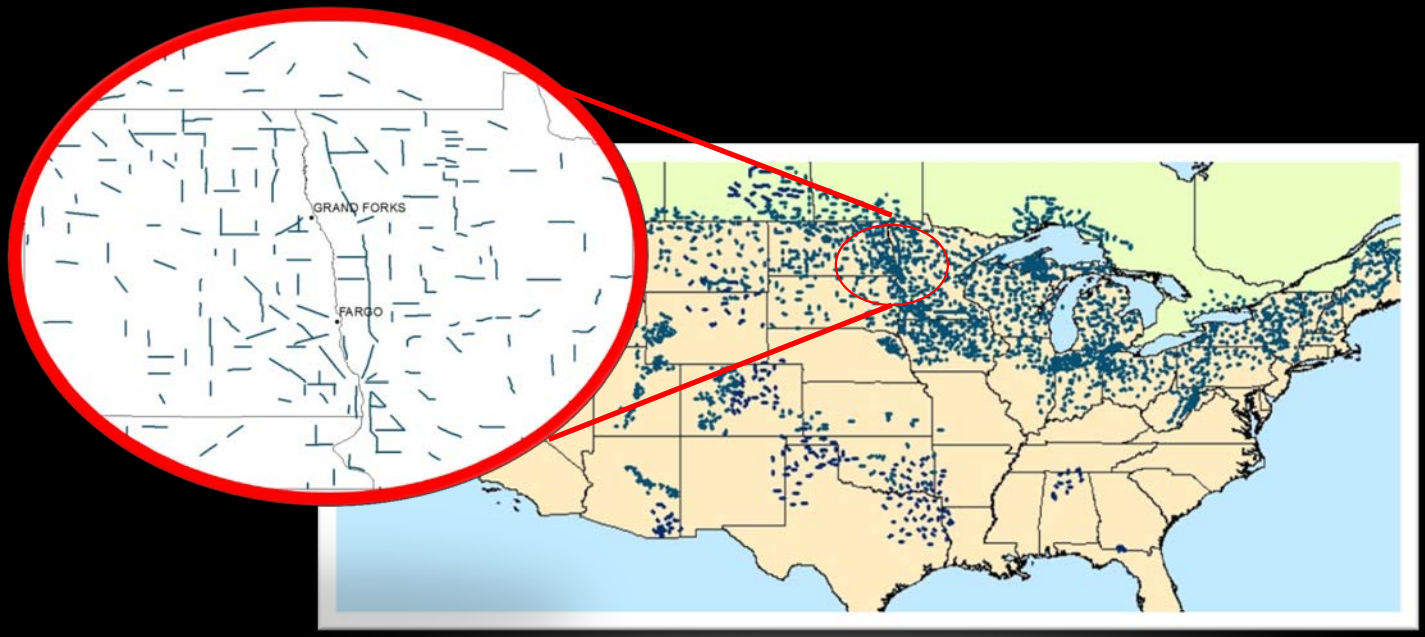


Over 2600 Flight Lines in more than 40 states and provinces



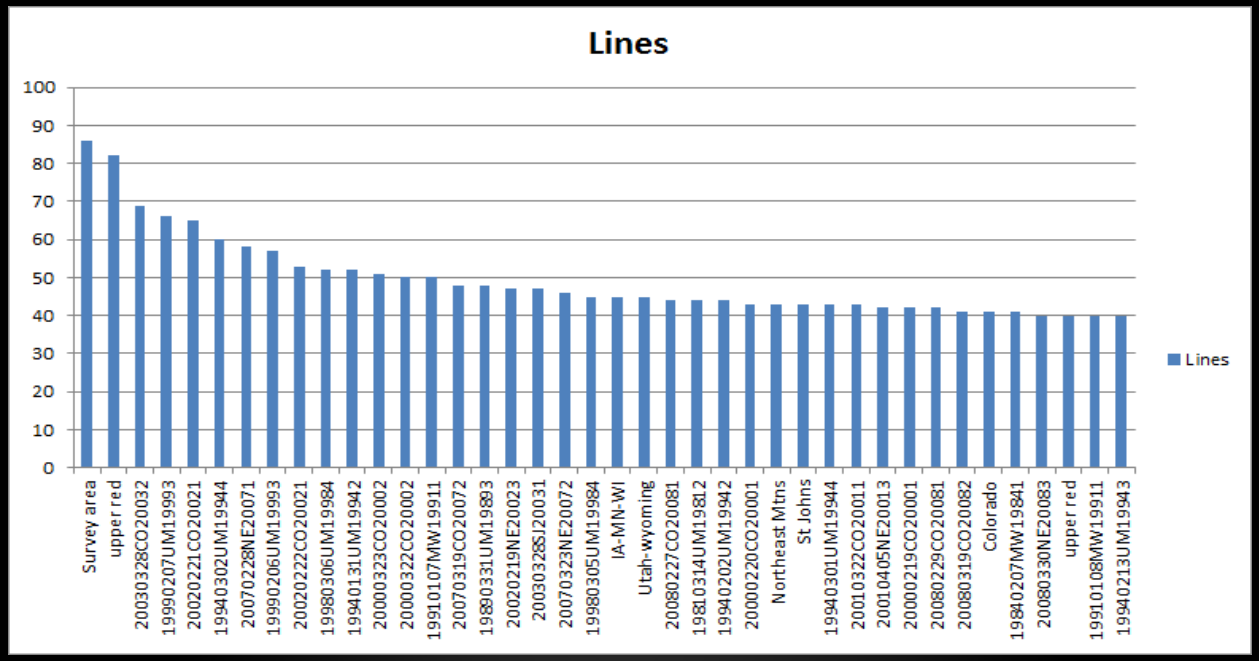
SUITABILITY ANALYSIS

- Looking for surveys with potential for over-sampling (lots of lines)
- Limited temporal variation (flown in a single day)
- Limited geographic extent (lines clustered)
- Low variability of terrain (flat)

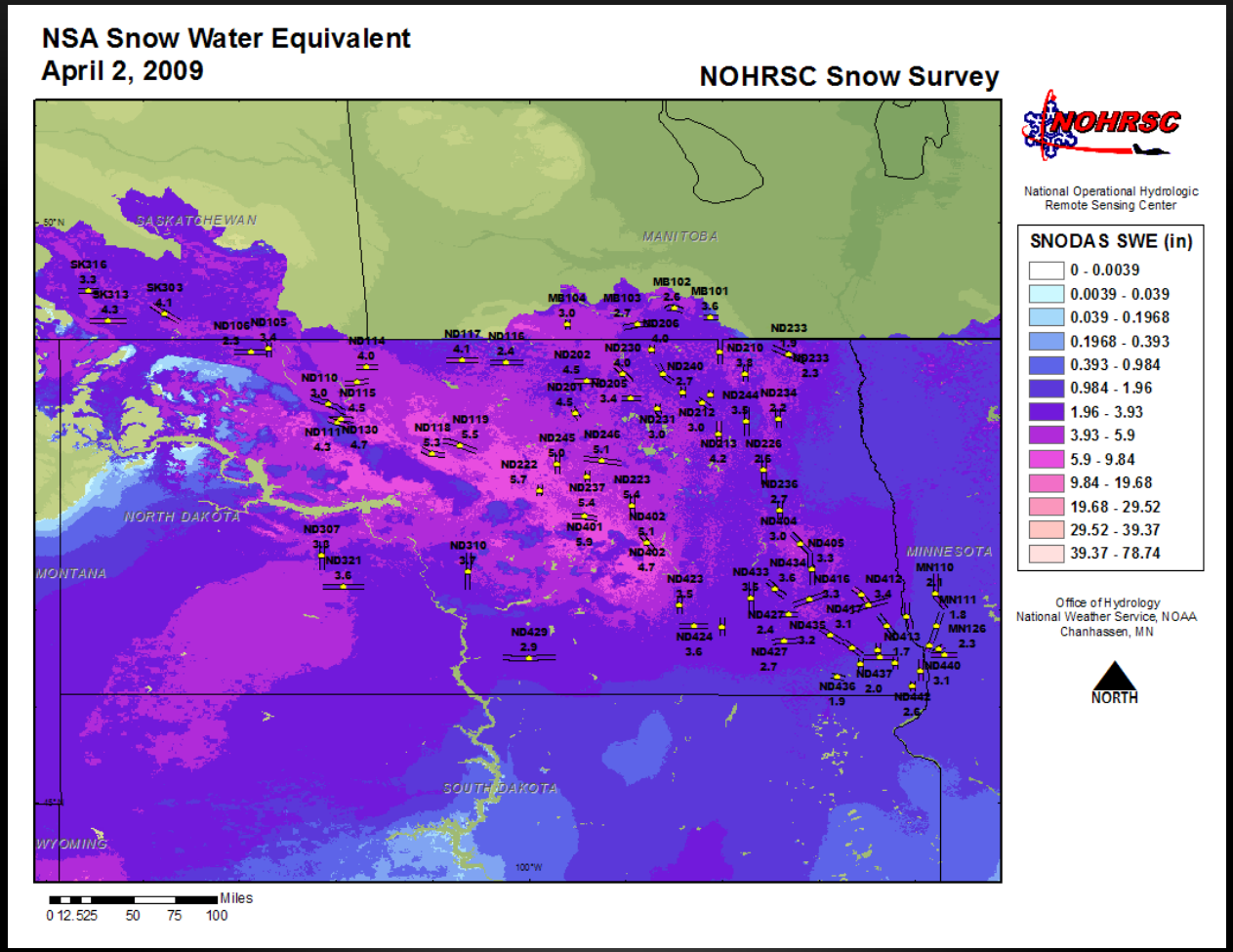


SUITABILITY ANALYSIS

- Surveys grouped into single days
- Total line counts for days charted.
- Found instance of a single day in Upper Red River with 84 lines



NATIONAL SNOW ANALYSIS: GAMMA SWE IMAGE – APRIL 2, 2009



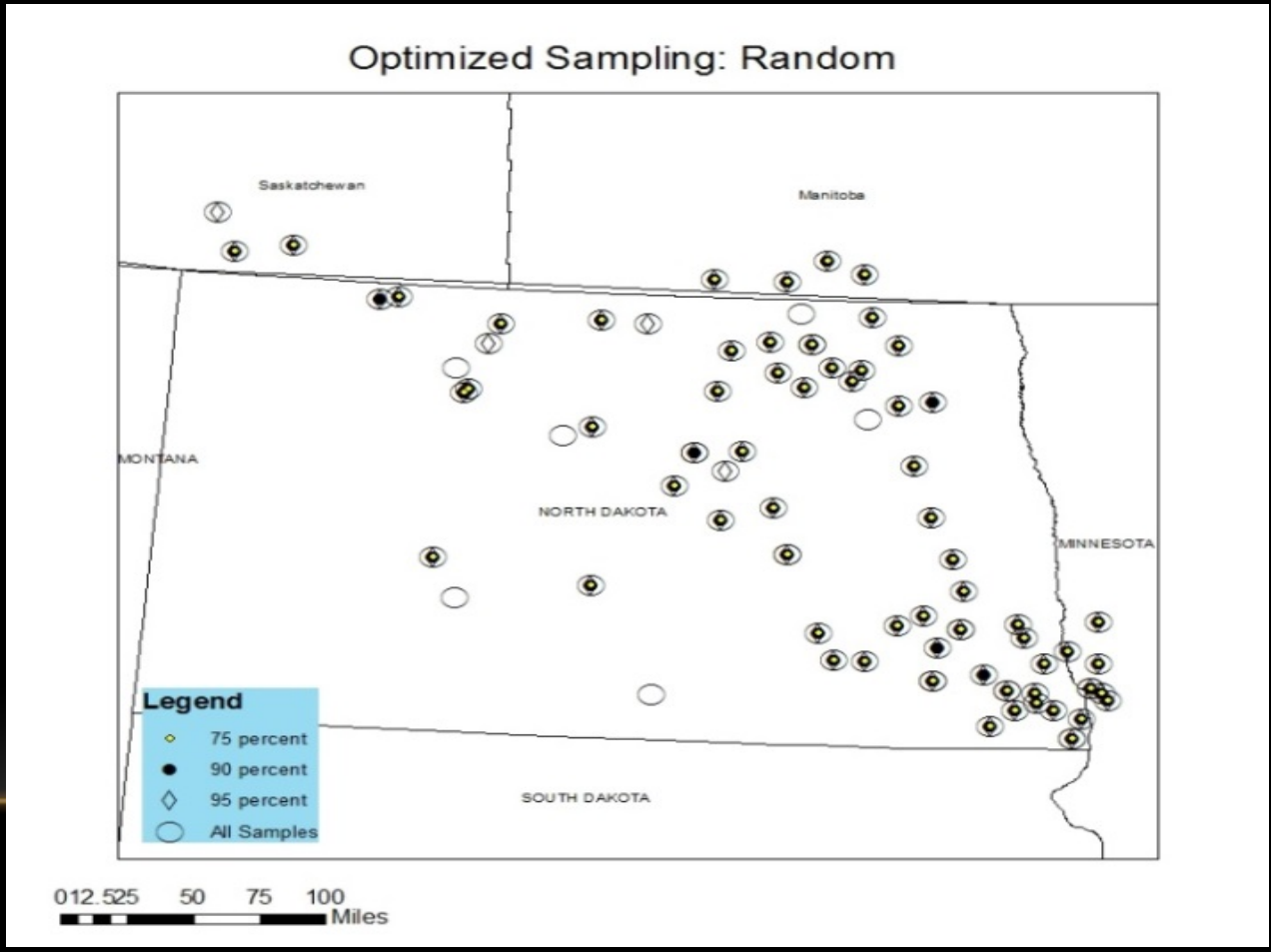
Optimized Sampling and Error Assessment

- Decrease sample number using one of following methods:
  - Random and Density-Dependent
  - Focused and Subjective
  - Reduce samples by 5, 10, and 25 percent for each method

- Create new interpolated surface using remaining sample points
- Extract values from new surfaces and apply them to “removed” samples
- Calculate sample error for interpolated points

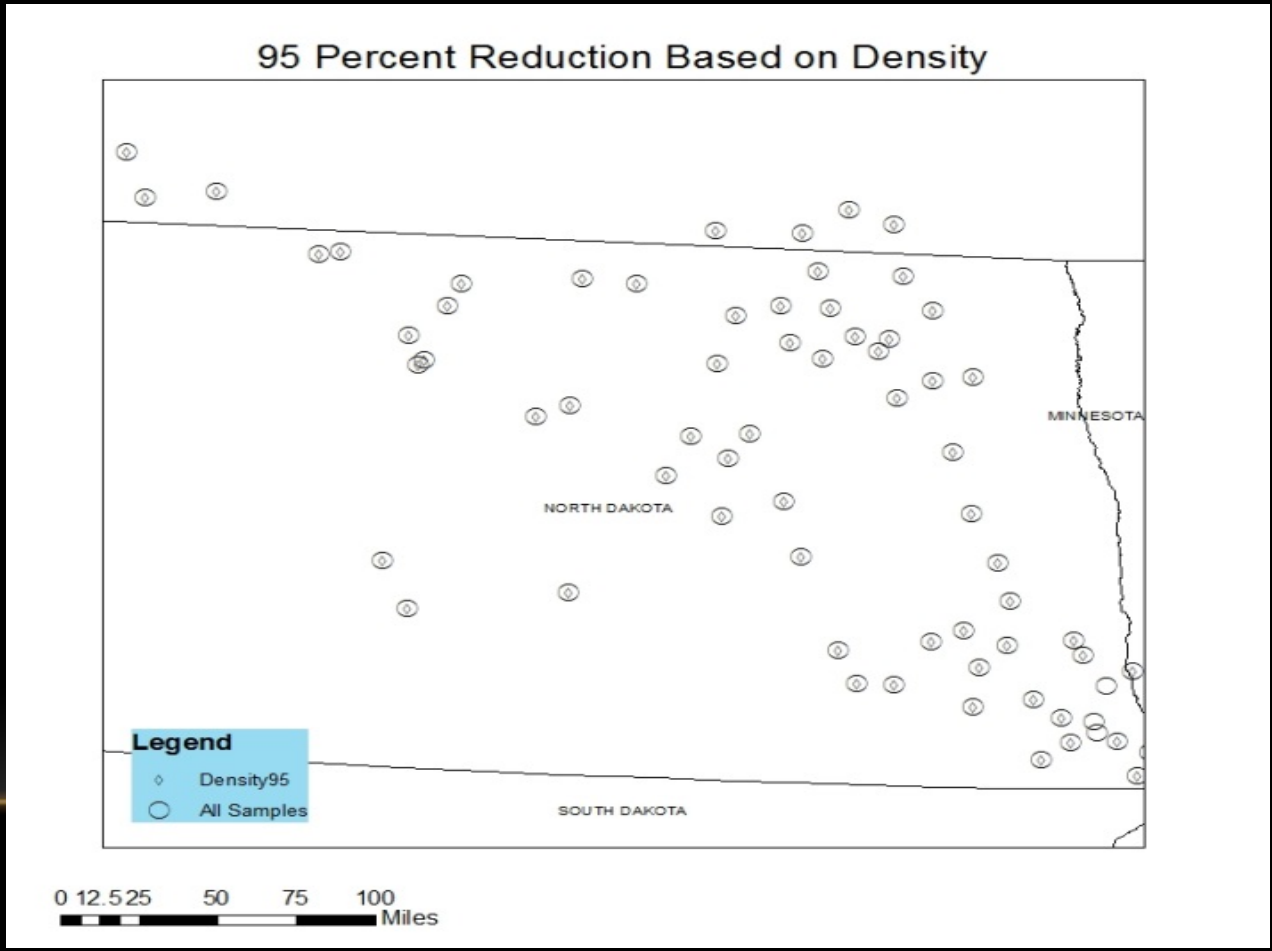
SAMPLE OPTIMIZATION METHODS: RANDOM

- Used random fucntion in excel
- Sorted by random score and eliminated based on random number field
- Reduced to 95, 90, and 75 percent levels



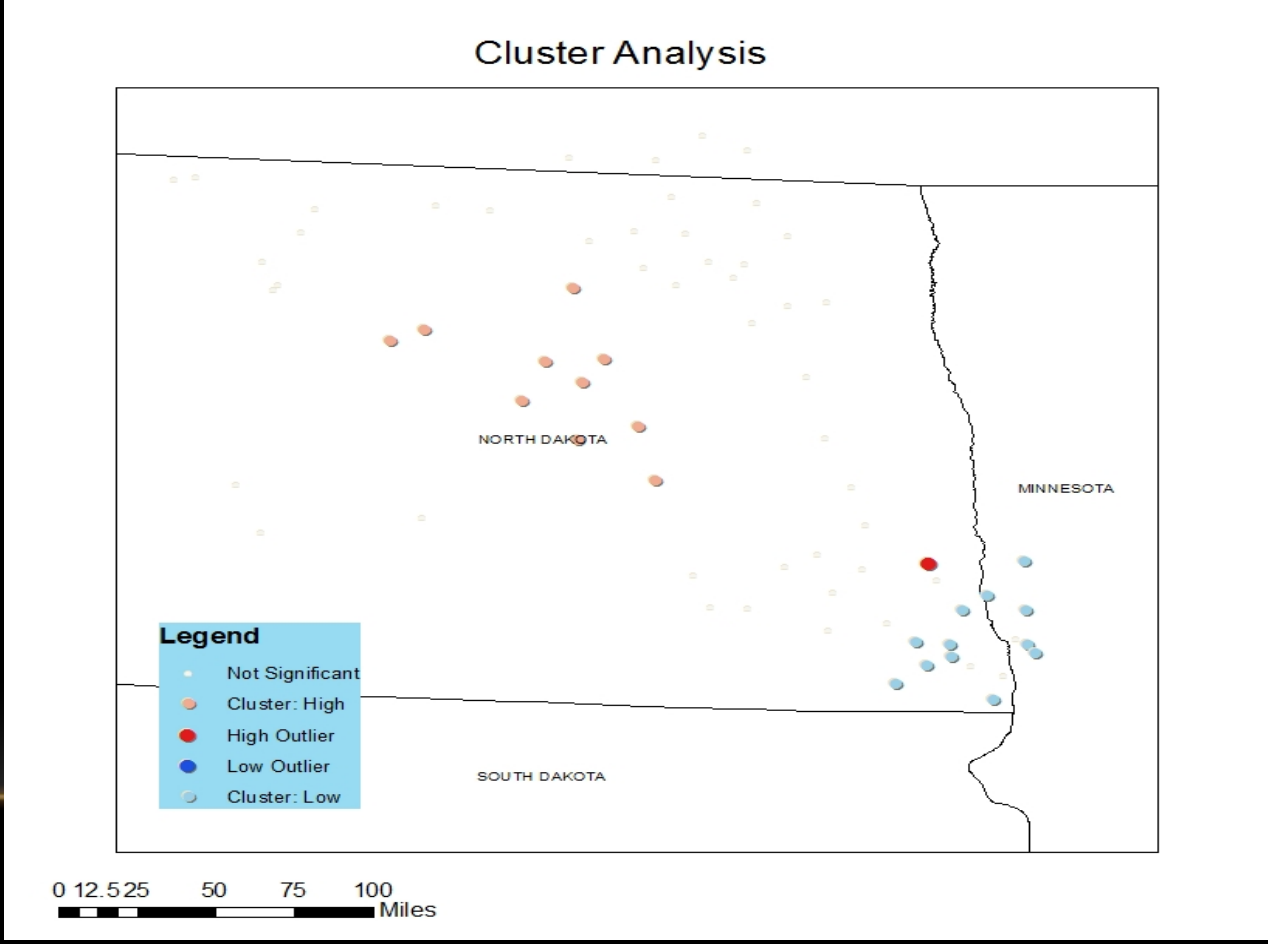
SAMPLE OPTIMIZATION METHODS: DENSITY DEPENDENT

- Used Kernel Density Tool in ArcMap
- Eliminated lines with highest density values
- Same total samples as done on random optimization method



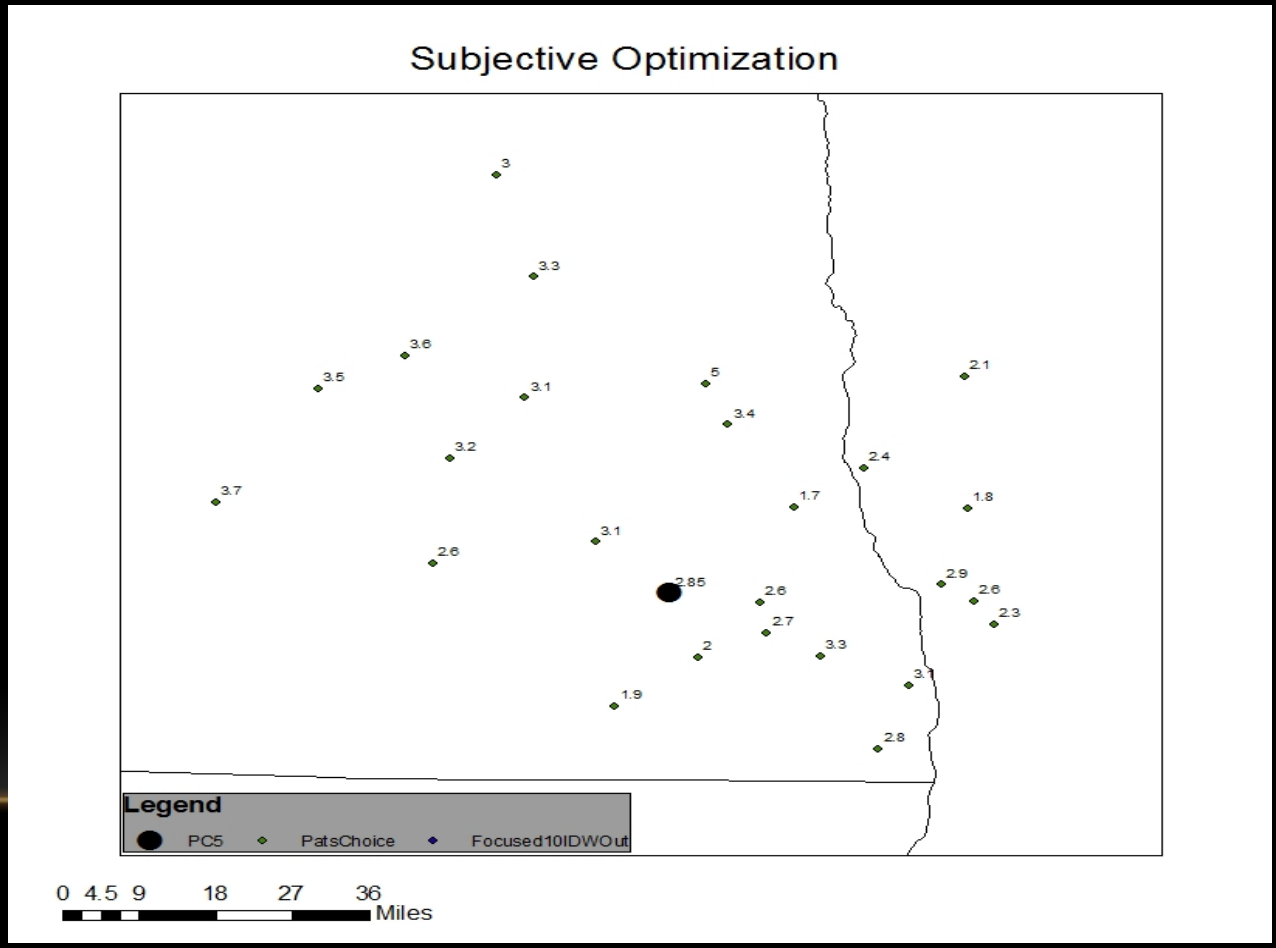
SAMPLE OPTIMIZATION METHODS: FOCUSED

- Used Anselin Cluster Analyis Tool in ArcMap
- Eliminated lines with highest cluster scores (Moran's I and significant p-value)
- Like density optimization, process had to be iterative

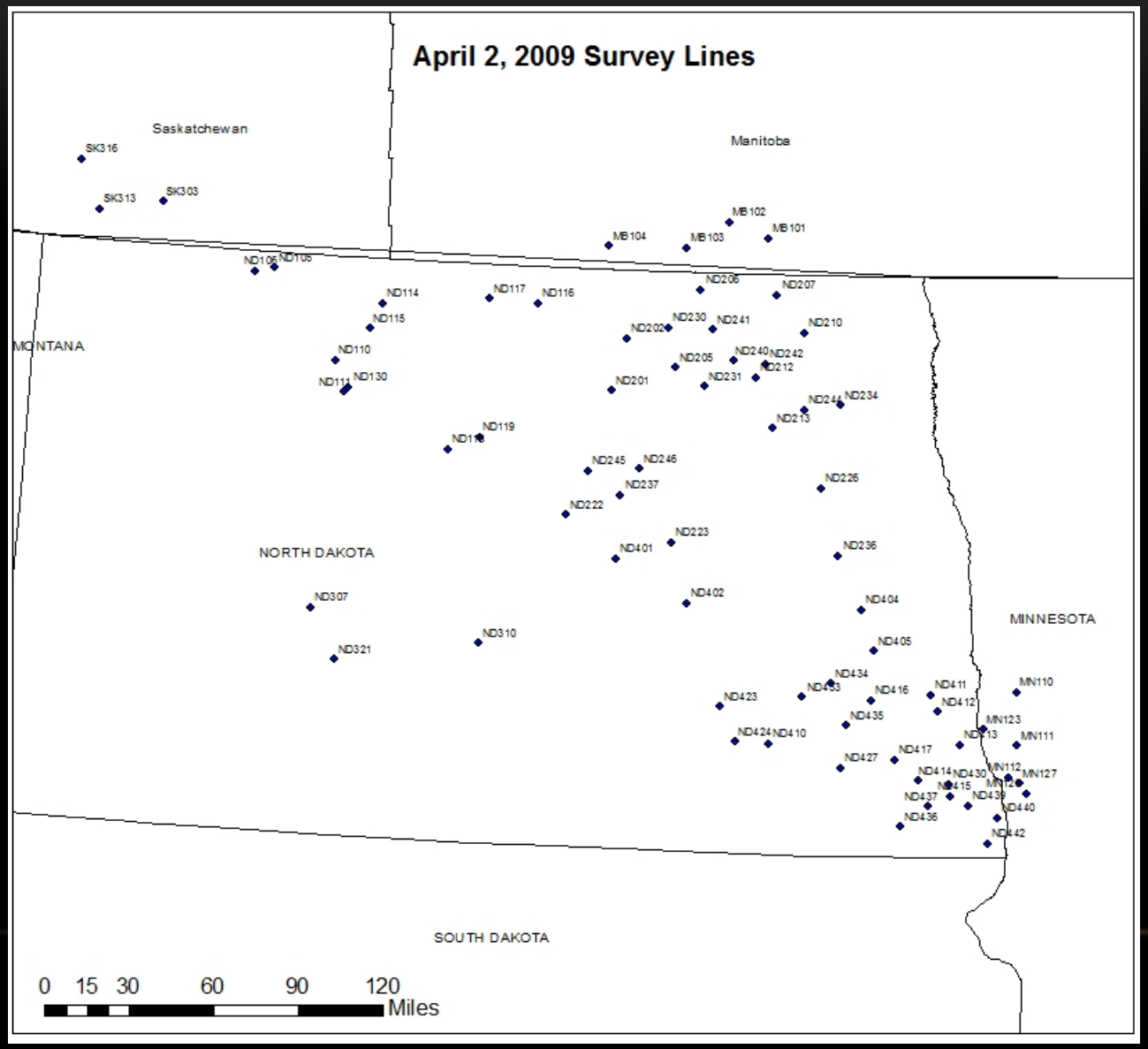


SAMPLE OPTIMIZATION METHODS: SUBJECTIVE

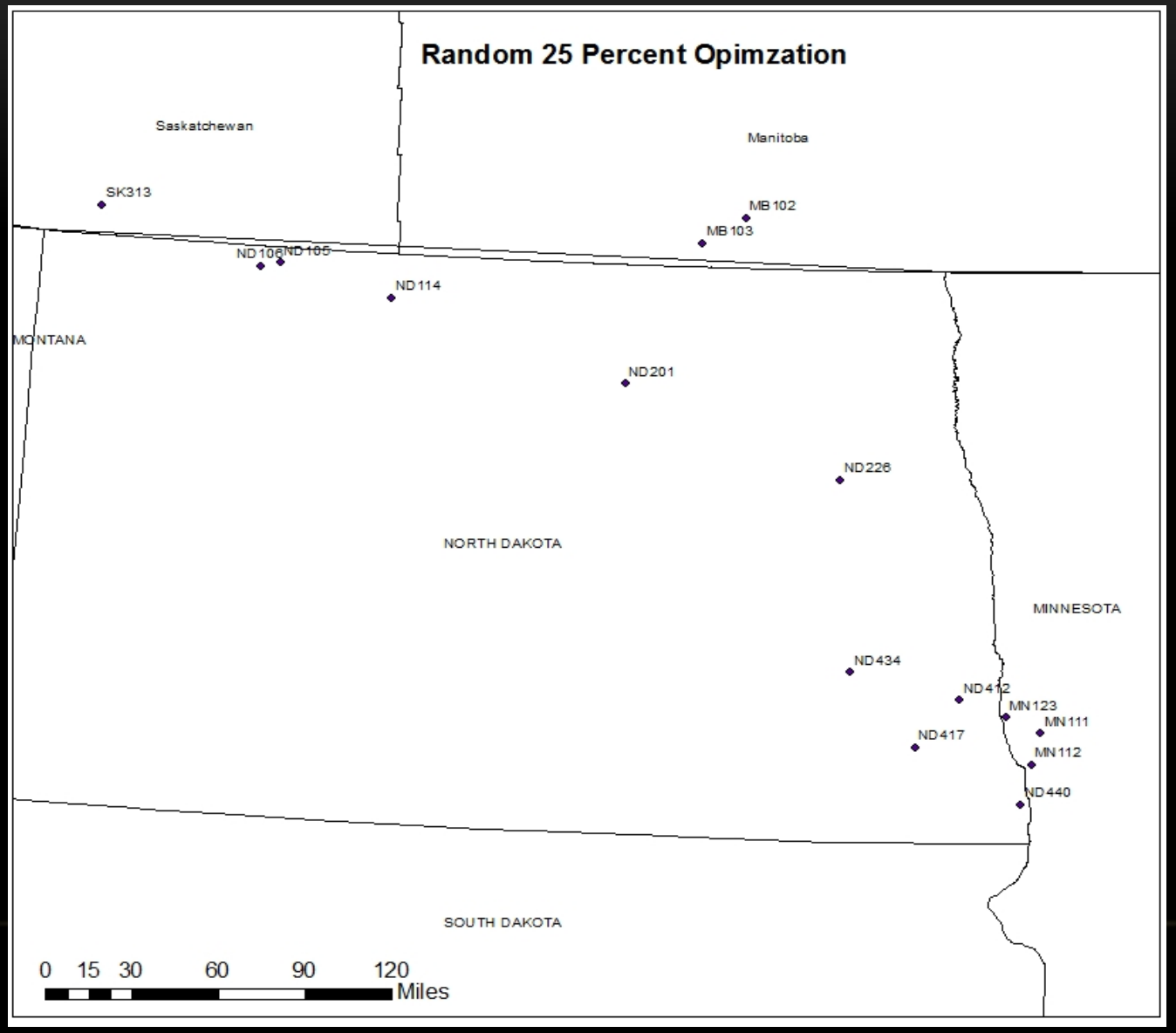
- Similar in theory to the focused optimization
- Basically removed values that “felt” the most similar



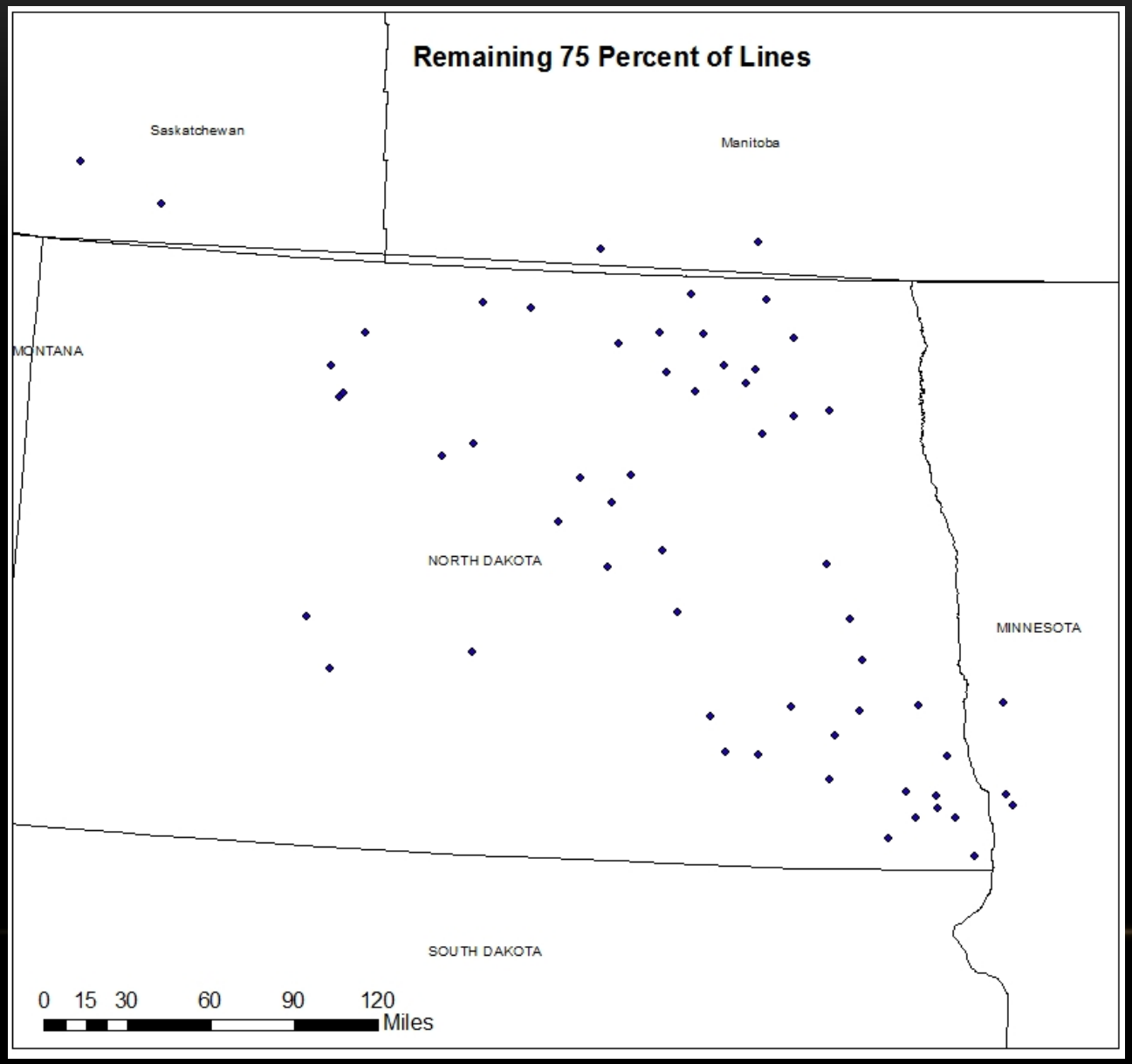
Optimization/Interpolation/Error Analysis: Step 1: Add Survey Data to ArcMap



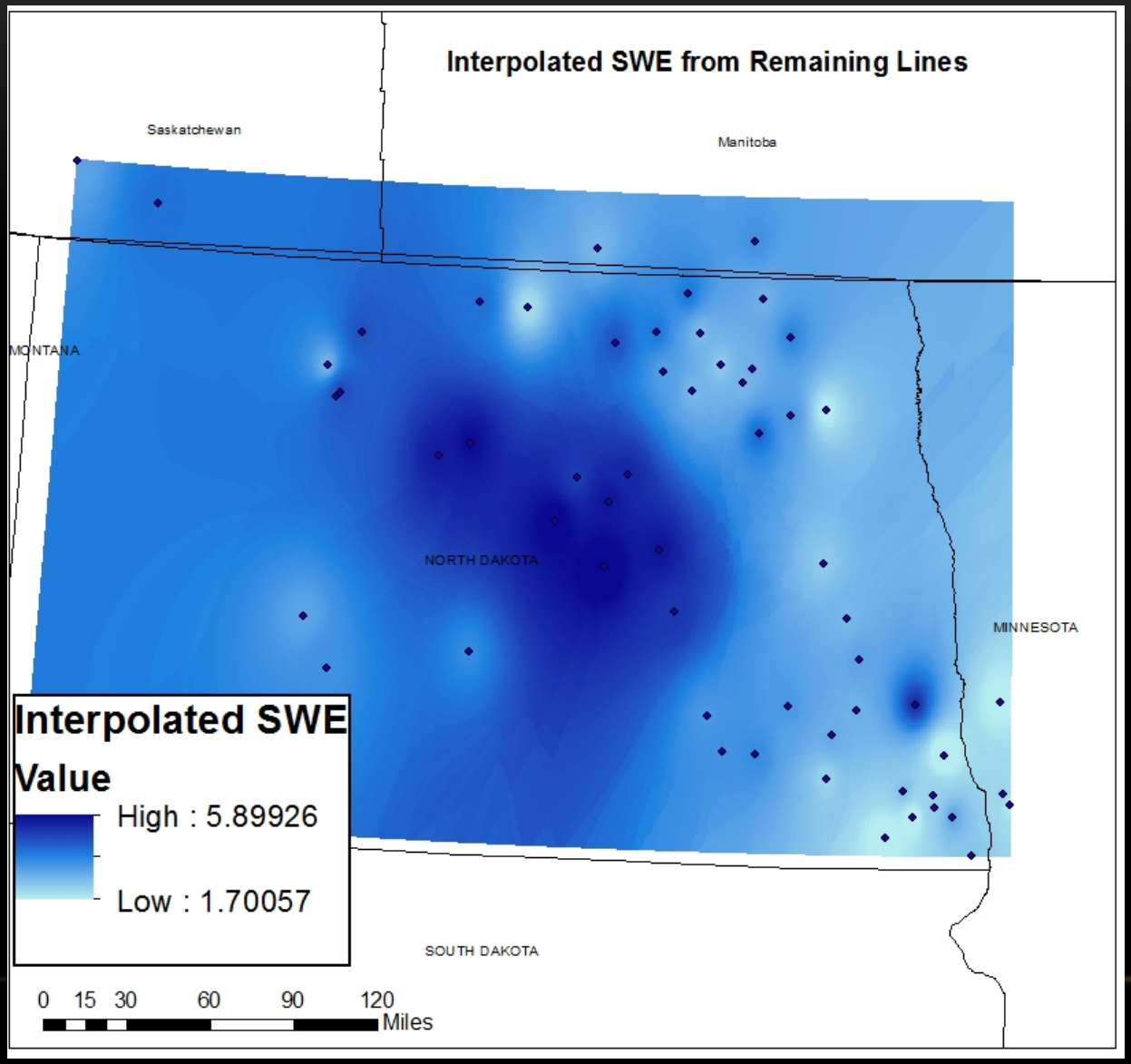
Optimization/Interpolation/Error Analysis: Step 2: Export Lines to be Removed as a Separate Shapefile



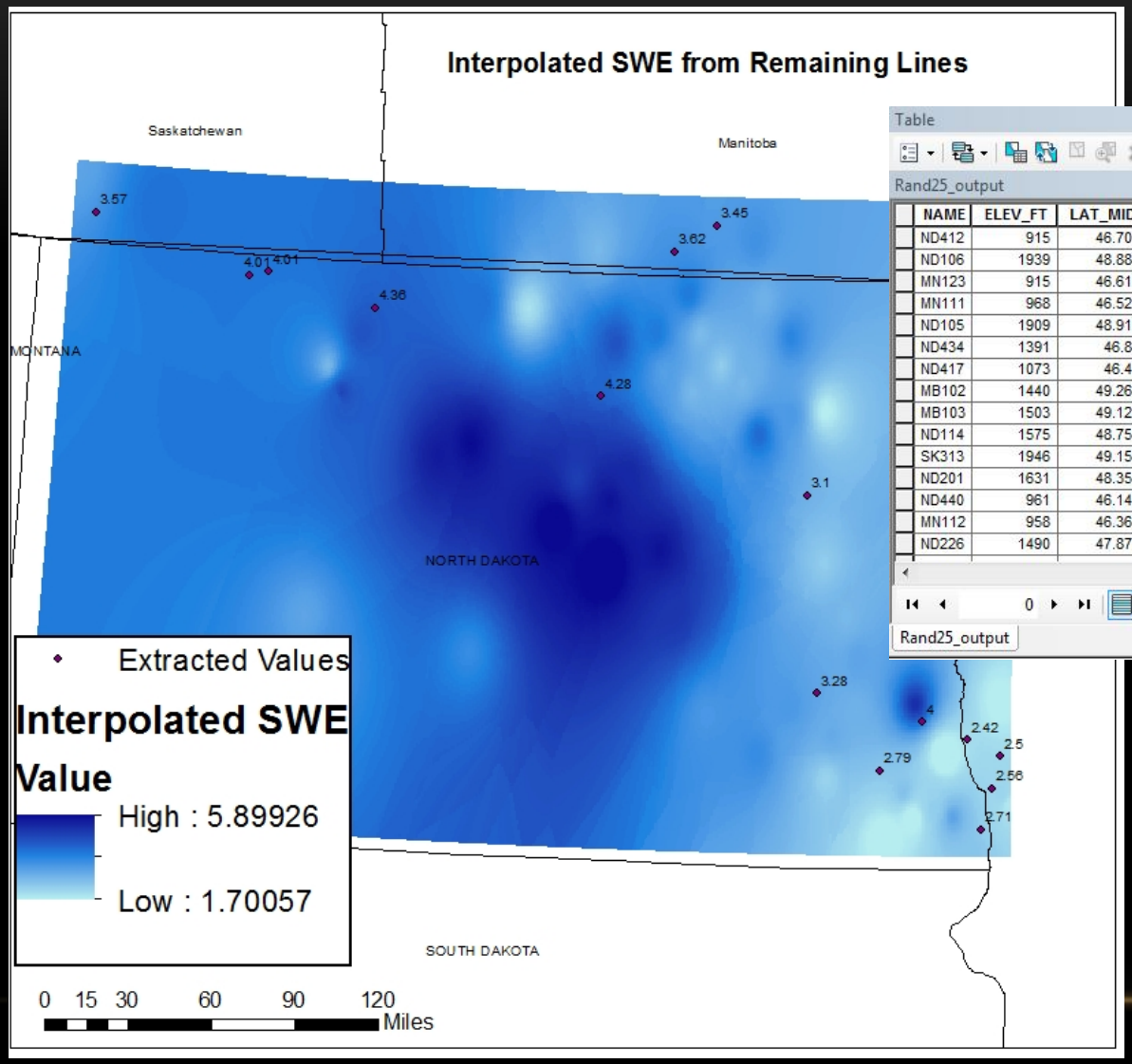
Optimization/Interpolation/Error Analysis: Step 3: Switch Selection and Export Remaing Lines as Separate Shapefile



Optimization/Interpolation/Error Analysis: Step 4: Create Interpolated Surface Using Remaining Lines



Optimization/Interpolation/Error Analysis: Step 5: Extract Values from Interpolation Surface to Removed Lines



Table

Rand25_output

NAME	ELEV_FT	LAT_MIDPNT	LON_MIDPNT	SWE	rando	IDW_SWE
ND412	915	46.704421	-97.076658	3.4	100	4
ND106	1939	48.889153	-102.392587	2.3	99	4.01
MN123	915	46.613626	-96.74112	2.4	99	2.42
MN111	968	46.528187	-96.48617	1.8	99	2.5
ND105	1909	48.913817	-102.246082	3.4	98	4.01
ND434	1391	46.84434	-97.877026	3.6	97	3.28
ND417	1073	46.44879	-97.397074	3.1	95	2.79
MB102	1440	49.267321	-98.747507	2.6	91	3.45
MB103	1503	49.123978	-99.067169	2.7	91	3.62
ND114	1575	48.759696	-101.396769	4	91	4.36
SK313	1946	49.153663	-103.629961	4.3	91	3.57
ND201	1631	48.359093	-99.603912	4.5	91	4.28
ND440	961	46.144936	-96.626121	3.1	89	2.71
MN112	958	46.362269	-96.549065	2.9	86	2.56
ND226	1490	47.875328	-97.981234	2.6	86	3.1

0 (0 out of 15 Selected)

Rand25_output

Optimization/Interpolation/Error Analysis: Step 6: Calculate Sample Error By Comparing Measured Values Against Interpolated Values (Excel)

F	G	H	I	J	K	L	M	N
NAME	ELEV_FT	LAT_MIDPNT	LON_MIDPNT	SWE	random	Inter_SWE	Error (InterSWE-SWE)	
ND412	915	46.70442093640	-97.07665774310	3.40000000000	100	3.99965858459	0.59965858459	
ND106	1939	48.88915309480	-102.39258744100	2.30000000000	99	4.01117229462	1.71117229462	
MN123	915	46.61362623300	-96.74111976550	2.40000000000	99	2.41969919205	0.01969919205	
MN111	968	46.52818712010	-96.48616951920	1.80000000000	99	2.49825453758	0.69825453758	
ND105	1909	48.91381716580	-102.24608241400	3.40000000000	98	4.01129531860	0.61129531860	
ND434	1391	46.84433968290	-97.87702622620	3.60000000000	97	3.27522349358	-0.32477650642	
ND417	1073	46.44878980670	-97.39707365980	3.10000000000	95	2.79006004333	-0.30993995667	
MB102	1440	49.26732064630	-98.74750682560	2.60000000000	91	3.44538807869	0.84538807869	
MB103	1503	49.12397831870	-99.06716857080	2.70000000000	91	3.61531877518	0.91531877518	
ND114	1575	48.75969635550	-101.39676937600	4.00000000000	91	4.36221122742	0.36221122742	
SK313	1946	49.15366330900	-103.62996072100	4.30000000000	91	3.57177877426	-0.72822122574	
ND201	1631	48.35909298450	-99.60391153770	4.50000000000	91	4.28274822235	-0.21725177765	
ND440	961	46.14493622190	-96.62612148720	3.10000000000	89	2.70775723457	-0.39224276543	
MN112	958	46.36226871410	-96.54906475140	2.90000000000	86	2.55510091782	-0.34489908218	
ND226	1490	47.87532755440	-97.98123369590	2.60000000000	86	3.09501314163	0.49501314163	
							0.63742439455	Sample Error in Inches

ACCEPTABLE ERROR

- Error for interpolation will depend on spatial variability of the snowpack
- Instrument error: ~1 cm
- Interpolation error should be no more than instrument error

RESULTS

SURVEY Date	OPTIMIZATION	PERCENTAGE	SAMPLES	INTERPOLATION	SAMPLE ERROR (cm)
4/2/2009	N/A	100	73	n/a	n/a
4/2/2009	RANDOM	95	69	IDW	0.99
4/2/2009	RANDOM	95	69	Krig	1.85
4/2/2009	RANDOM	90	66	IDW	1.70
4/2/2009	RANDOM	90	66	Krig	1.45
4/2/2009	RANDOM	75	58	IDW	1.63
4/2/2009	RANDOM	75	58	Krig	1.73
4/2/2009	Density	95	69	IDW	1.70
4/2/2009	Density	95	69	Krig	1.08
4/2/2009	Density	90	66	IDW	1.40
4/2/2009	Density	90	66	Krig	1.50
4/2/2009	Density	75	58	IDW	1.24
4/2/2009	DENSITY	75	58	Krig	1.23

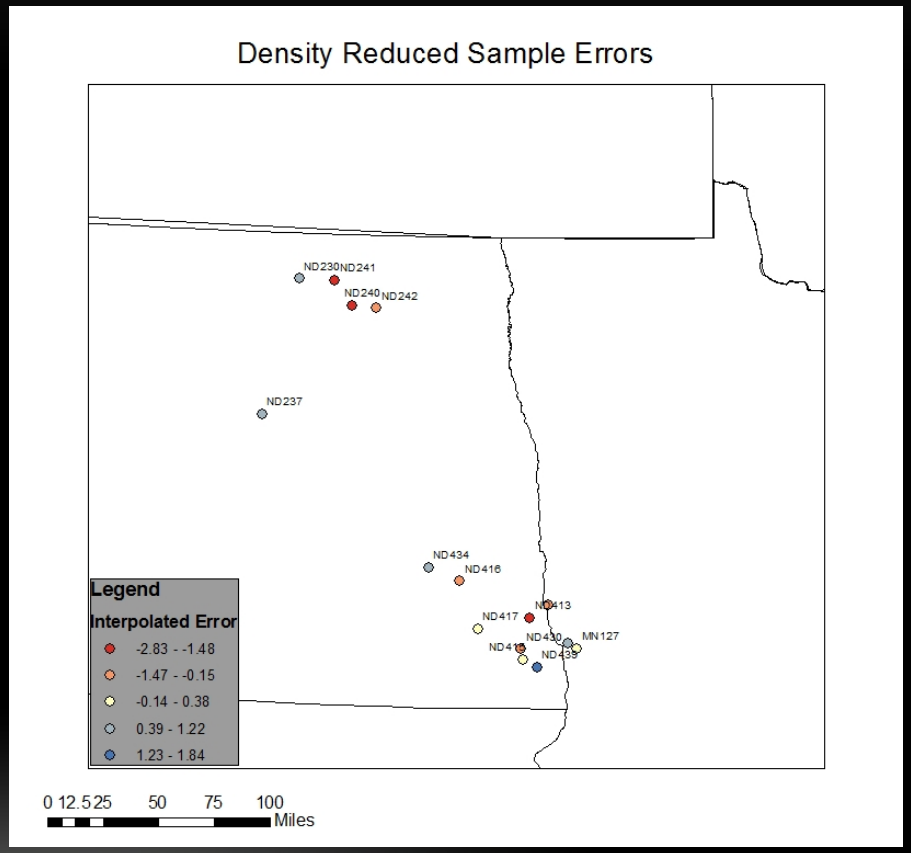
RESULTS

SURVEY Date	OPTIMIZATION	PERCENTAGE	SAMPLES	INTERPOLATION	SAMPLE ERROR (cm)
4/2/2009	Focused	95	69	IDW	1.93
4/2/2009	Focused	95	69	Krig	1.73
4/2/2009	Focused	90	66	IDW	2.06
4/2/2009	Focused	90	66	Krig	2.16
4/2/2009	Focused	75	58	IDW	2.44
4/2/2009	Focused	75	58	Krig	2.44
4/2/2009	Visual	95	69	IDW	0.51
4/2/2009	Visual	95	69	Krig	0.69
4/2/2009	Visual	90	66	IDW	0.58
4/2/2009	Visual	90	66	Krig	0.76
4/2/2009	Visual	75	58	IDW	0.51
4/2/2009	Visual	75	58	Krig	0.86

ERRORS

- Overall sample error impacted by handful of outliers that were well outside of 1 cm tolerance

Line	deltaCM
MN123	-1.01
ND434	0.86
ND417	0.38
MN112	0.88
ND415	0.12
ND237	0.99
ND416	-0.15
ND230	0.86
ND241	-1.48
ND240	-2.02
ND430	-0.26
ND242	-0.36
ND413	-2.83
MN127	0.25
ND439	1.84



TESTING METHOD FOR ANOTHER DATE

Using a density-dependent reduction on a similar survey from 1994 yielded sample errors in excess of 4 cm SWE, which would be well outside of acceptable tolderance

SURVEY Date	OPTIMIZATION	PERCENTAGE	SAMPLES	INTERPOLATION	SAMPLE ERROR (cm)
3/2/1994	Density	89	58	IDW	4.14
3/2/1994	Density	89	58	Krig	4.34

CONCLUSIONS

- Random reduction method came closest to acceptable results
- Density-dependent method came close, but even the marginal results that were achieved in the study area could not be duplicated in another similar sample survey.
- Focused reduction method results were well outside of tolerance for acceptable sample error
- Subjective method proved indeed that some nearby lines could be interpolated after the fact, but that its impossible to derive which ones without actually conducting the survey.

RECOMMENDATIONS

- Continue to create surveys based on current methodology
- Conduct further review of other surveys to determine if there are certain flight line areas that are more prone to spatial autocorrelation than suggested within this project.
- Look at specific lines to create an index for how much each line contributes to the overall snow-water equivalent analysis.

QUESTIONS?

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