ANALYSIS OF AIRBORNE SNOW SURVEY SAMPLE SIZE

An investigation of sampling efficiency using historical data

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Overview

- Introduction to Airborne Snow Survey program
- Goals of the Capstone Project

- Methods and Expected Outcomes
- Timeline for Project

Why Snow Matters

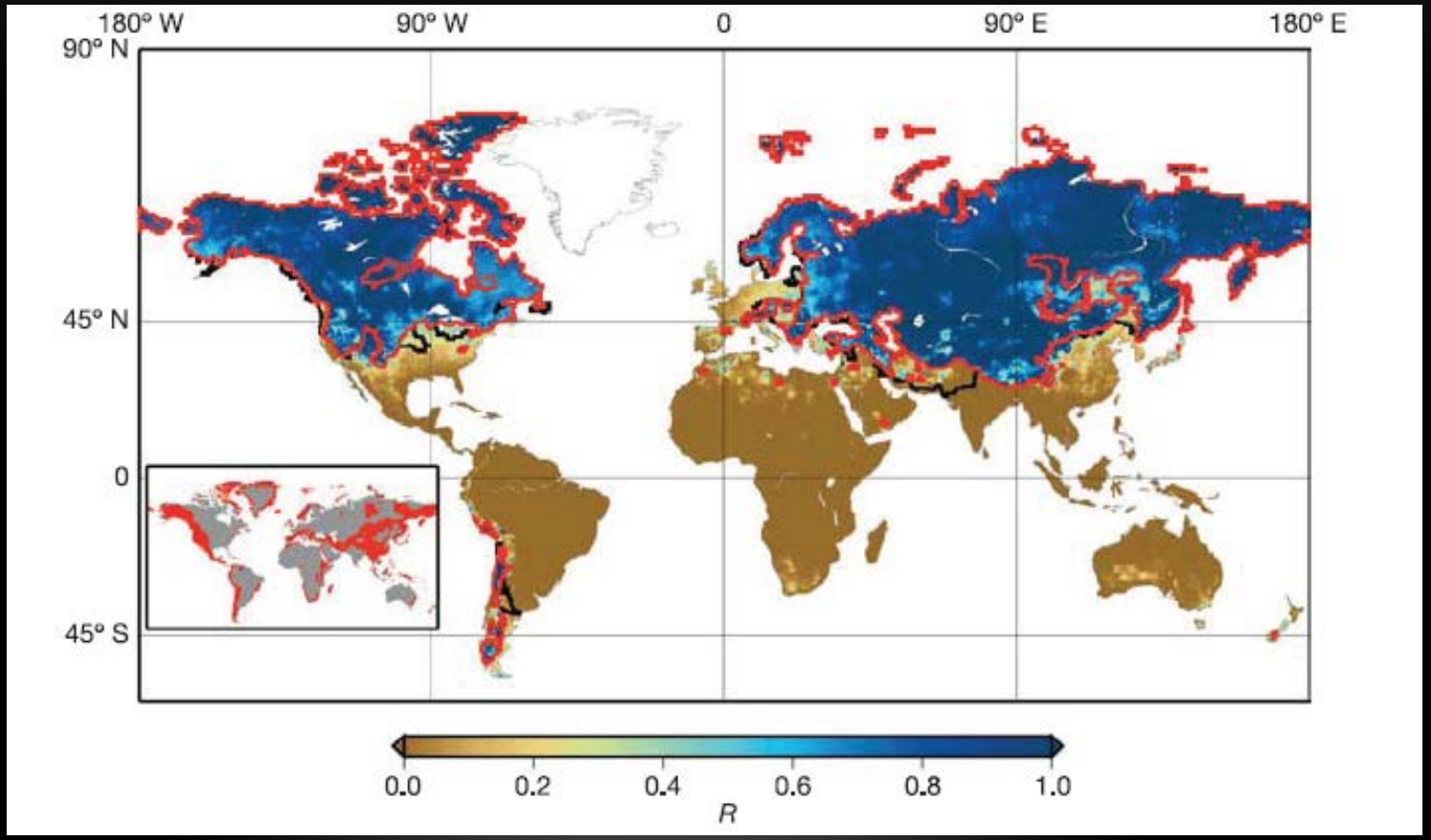
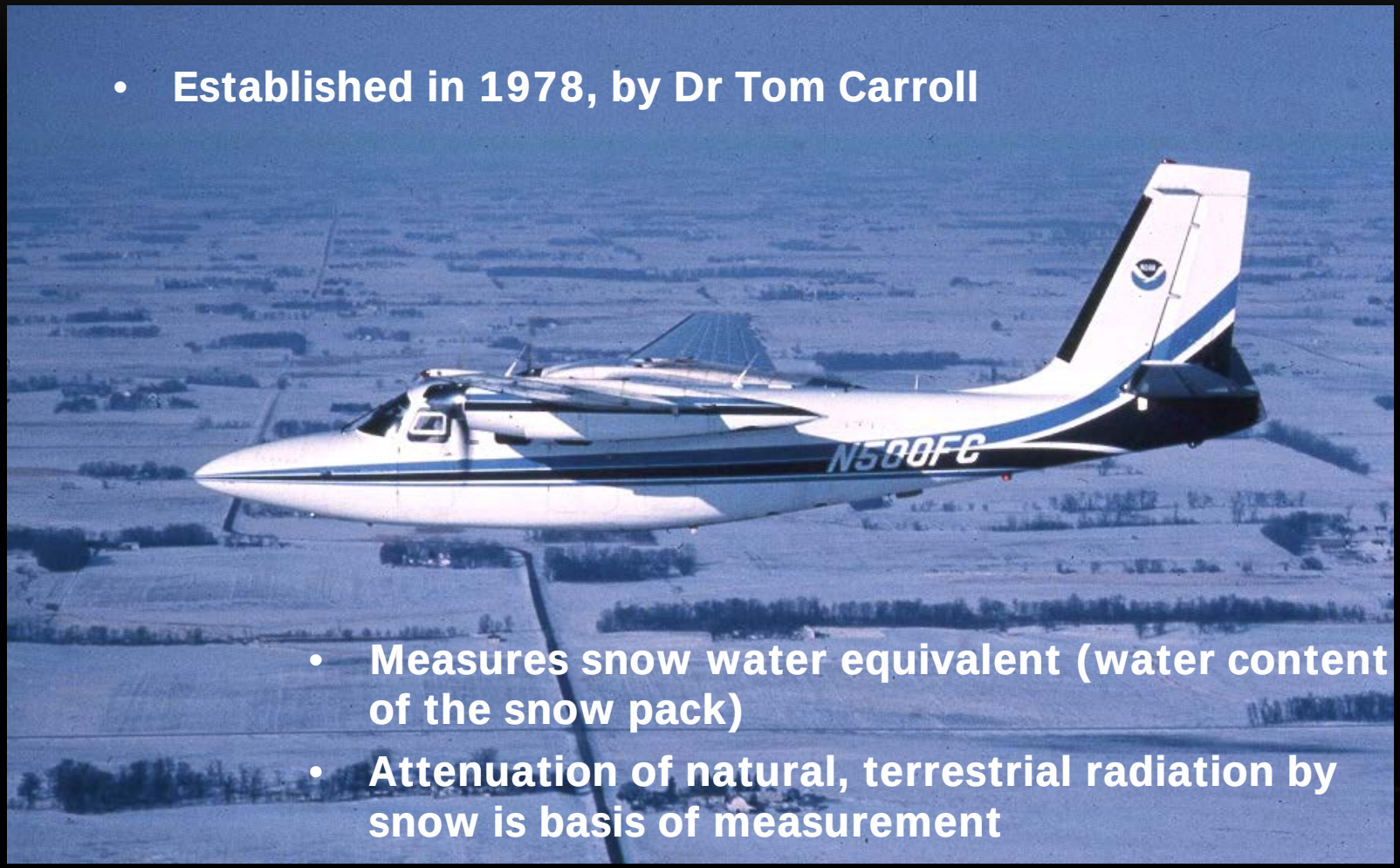


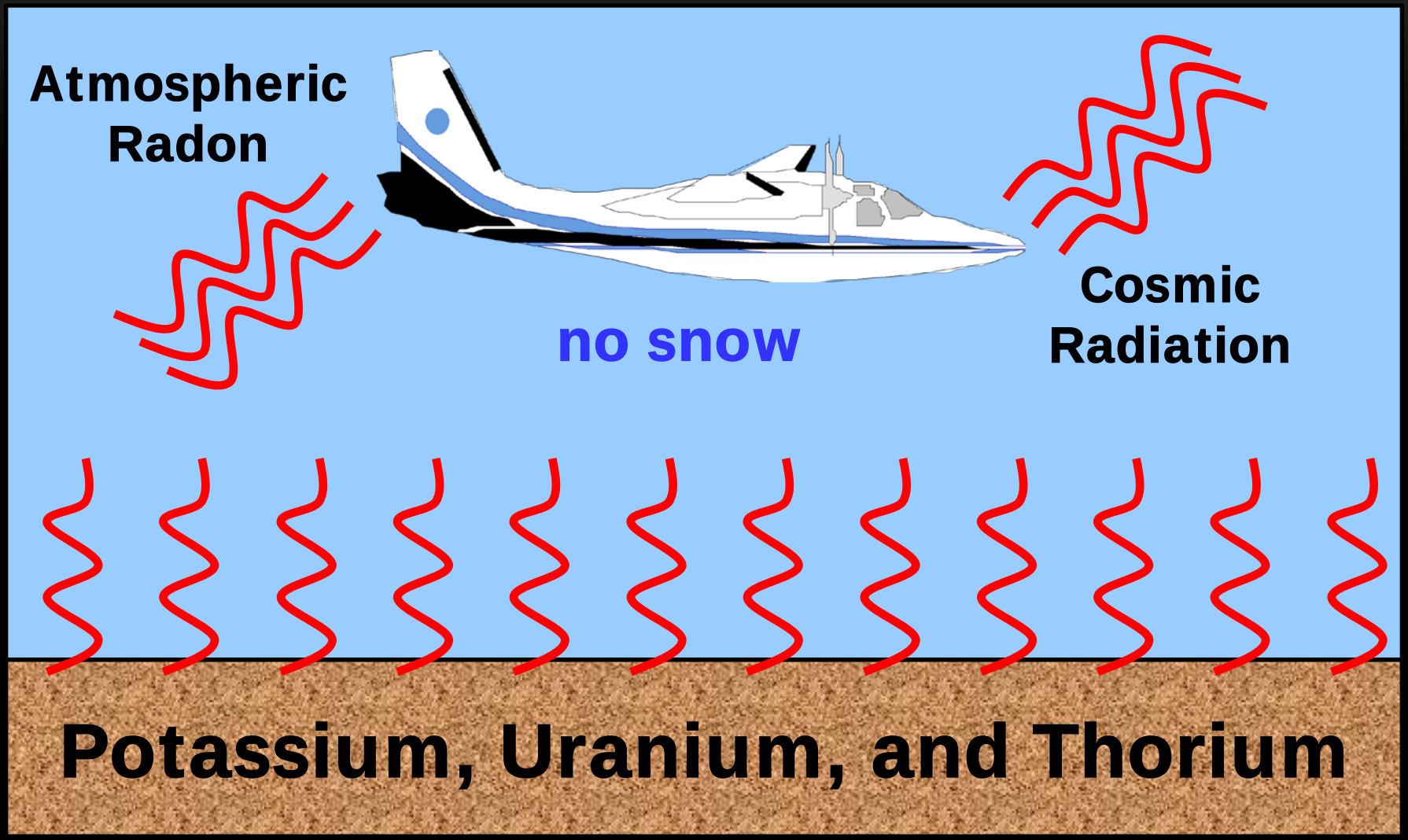
Figure 1 – Percentage of average annual snowfall divided by annual runoff. (**Barnett 2005)**

History of NOAA's Airborne Snow Survey Program

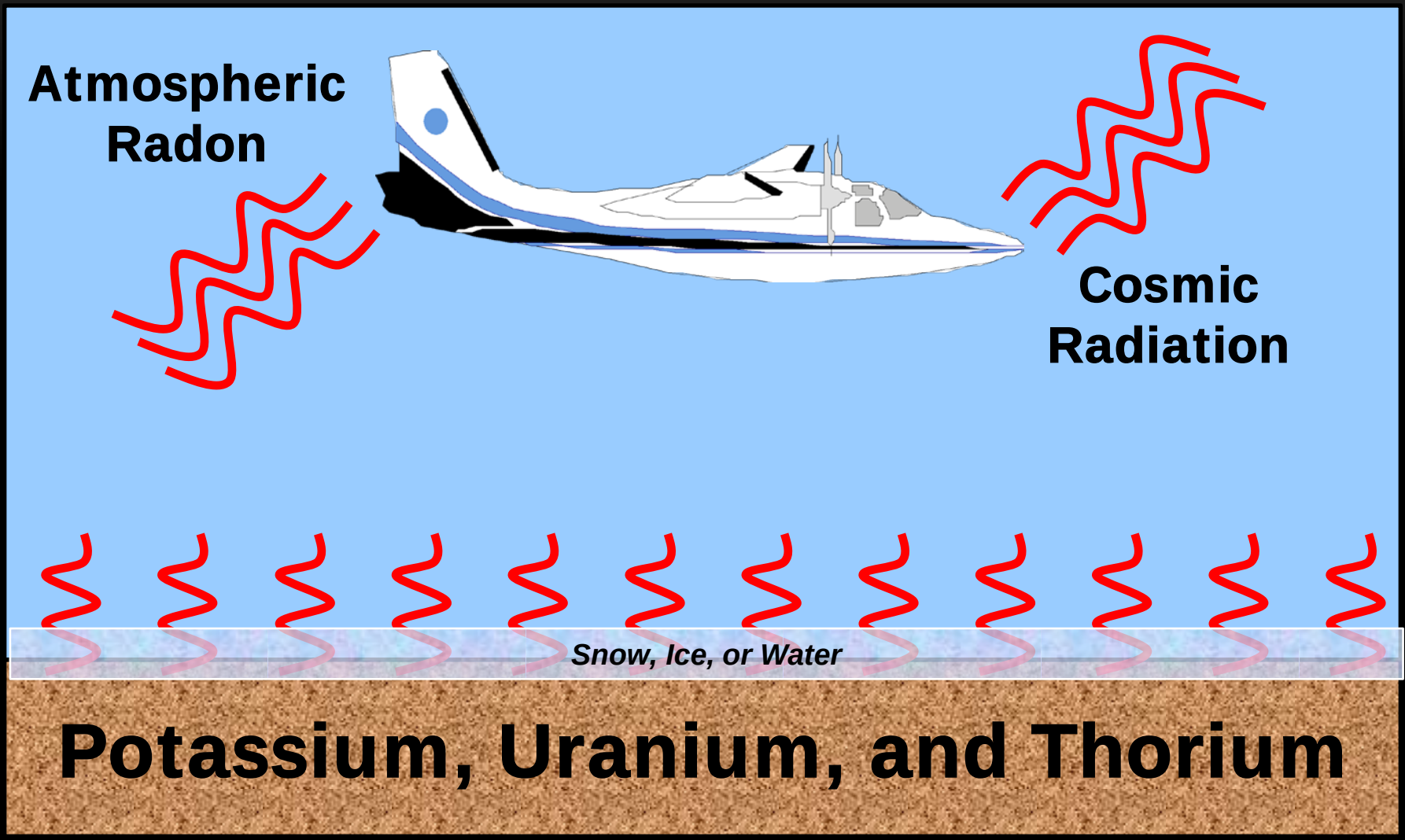


- Established in 1978, by Dr Tom Carroll
- Measures snow water equivalent (water content of the snow pack)
- Attenuation of natural, terrestrial radiation by snow is basis of measurement

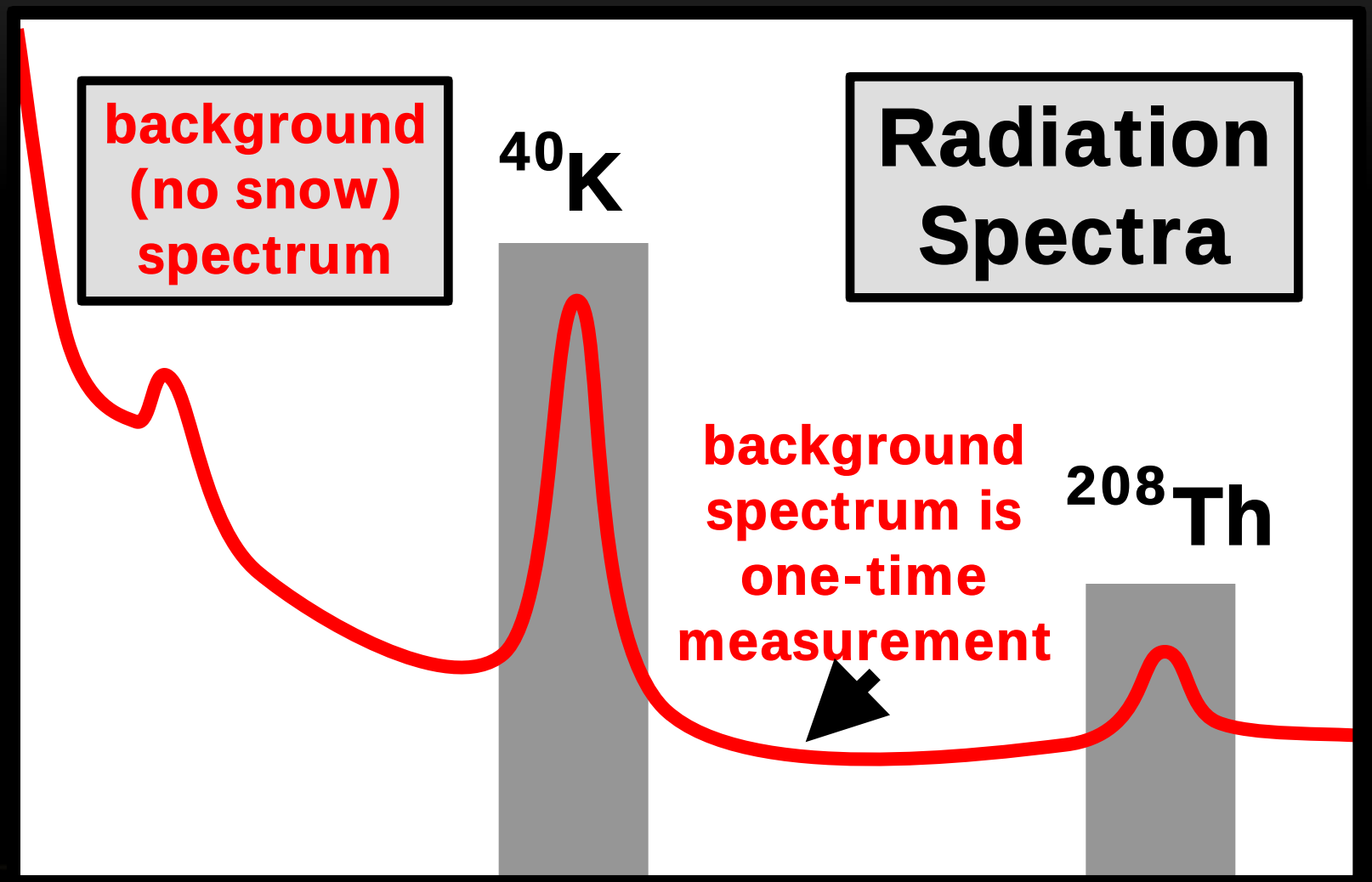
Natural Terrestrial Gamma Radiation



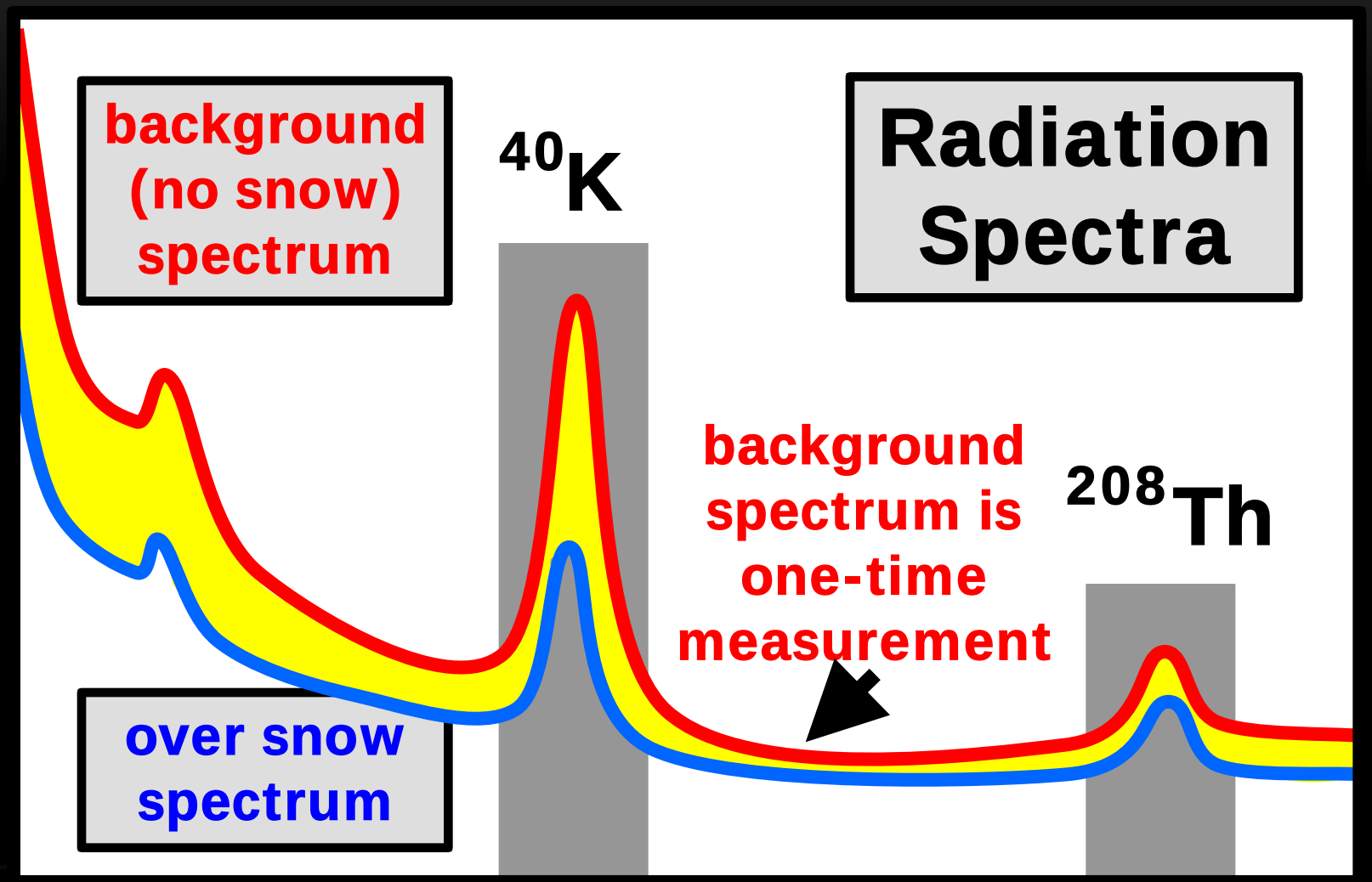
Natural Terrestrial Gamma Radiation



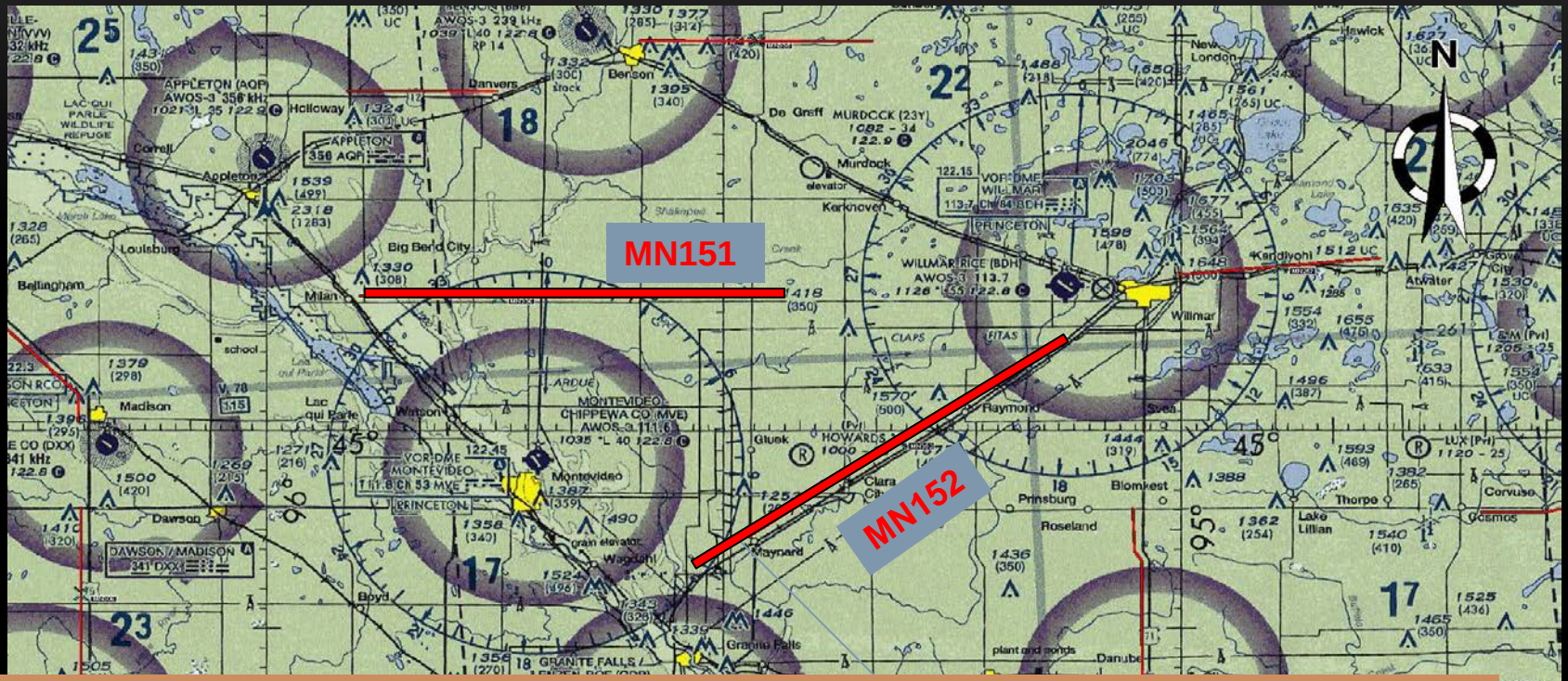
Natural Terrestrial Gamma Radiation



Natural Terrestrial Gamma Radiation

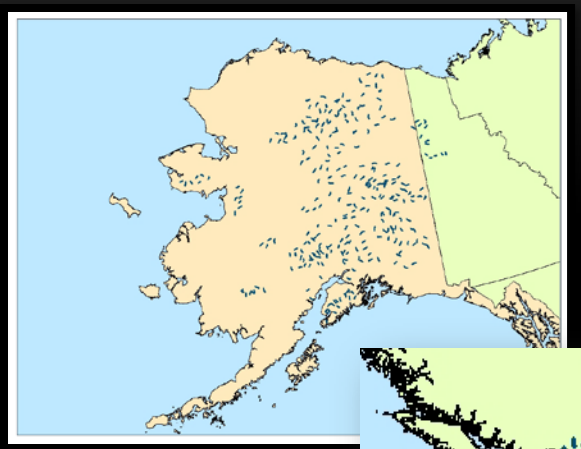


Flight Lines

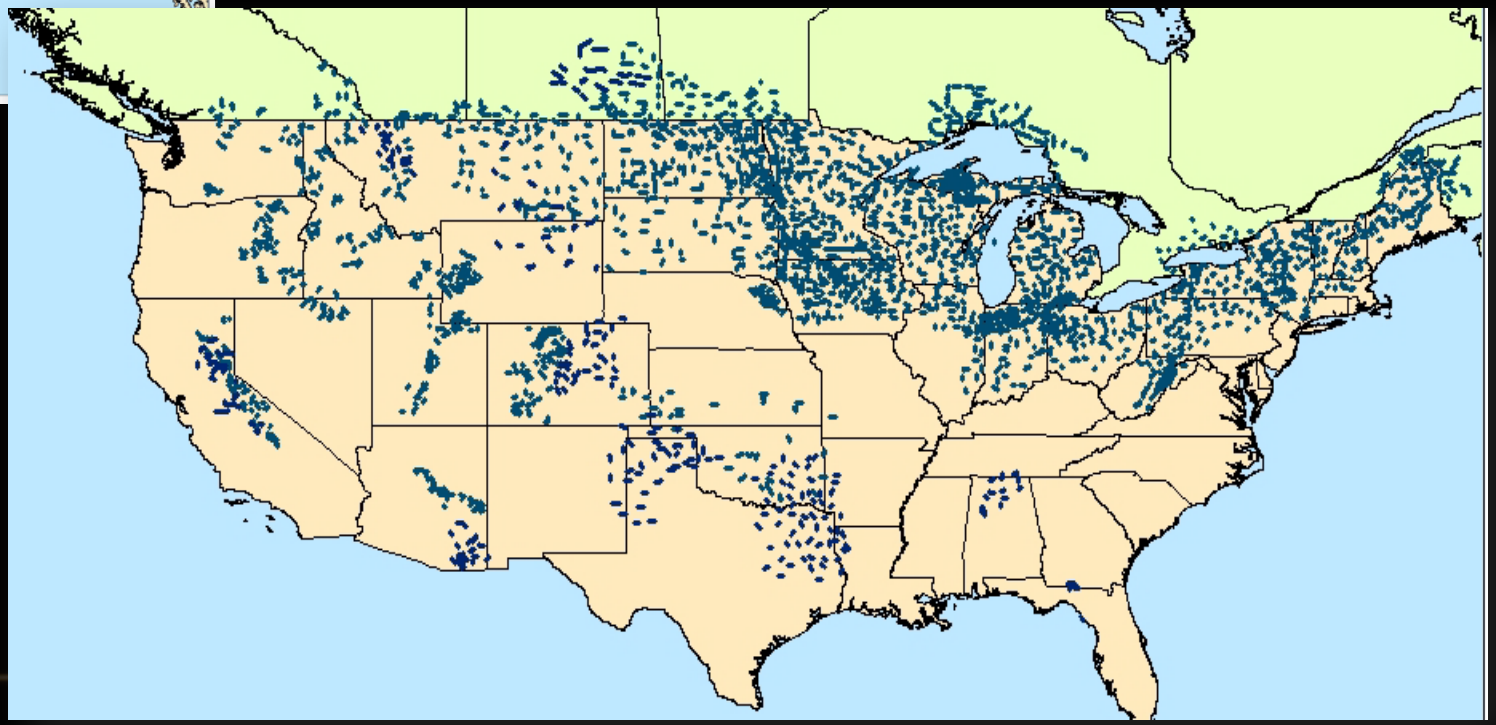


- ~12 mi long by 1,000 ft wide (2 mi² area)
- Each line has a unique background radiation signature (potassium, thorium, total gamma)

NOAA's Airborne Flight Line Gamma Database: 2016



Over 2600 individual flight lines throughout United States and portions of Canada



Flight Line Output

- Processing occurs in 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.

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SRUS43 KMSR 201859
RRMASP

.BR GAMMA 110220 /SAIRF/SWIRF
:TO ------ Service Hydrologist (Please give HARDCOPY to SH)
:FROM ---- Andy Rost, (952) 361-6610, Minneapolis, Minnesota
:Visit our web page at http://www.nohrsc.noaa.gov
:SUBJECT - AIRBORNE SNOW WATER EQUIVALENT DATA                        110220185906
:-------------------------------------------------------------------------------
: Total No. of flight lines sent = 15
:-------------------------------------------------------------------------------
:Line   Survey    %SC   SWE   SWE %SM Est Fall  %SM  Pilot
:No.    Date          (in) (35%) (M) Typ Date  (F)  Remarks
:===============================================================================
MB101  DY110220 / 100 / 3.3 : 3.4, 37 101102     36 ,  0
MB102  DY110220 / 100 / 3.8 : 2.5, 14 101102     14 ,  0 Thick Snow
MB103  DY110220 / 100 / 4.1 : 3.5, 24 101102     23 ,  0
MB104  DY110220 / 100 / 3.8 : 4.0, 38 101102     38 ,  0 Large Drifts
MB108  DY110220 / 100 / 2.4 : 2.2, 30 101102     30 ,  0 bln sn, some fields sc95%
MB109  DY110220 / 100 / 2.4 : 2.5, 36 101102     35 ,  0 Flew 0.5nm south of line
MB110  DY110220 / 100 / 2.9 : 2.7, 31 101102     31 ,  0 Red R heavily snow covered
MB112  DY110220 / 100 / 3.0 : 3.1, 38 101102     37 ,  0 drifted sn, chnls sn-cvrd
MB117  DY110220 / 100 / 3.1 : 2.5, 23 101102     23 ,  0 lg drifts
MB118  DY110220 / 100 / 4.6 : 4.1, 25 101102     24 ,  0 Lg Drifts and slushy creek
MB122  DY110220 / 100 / 3.6 : 3.3, 28 101104     28 ,  0
MB123  DY110220 / 100 / 4.4 : 3.5, 20 101104     19 ,  0
MB124  DY110220 / 100 / 3.9 : 3.0, 18 101104     18 ,  0
MB125  DY110220 / 100 / 4.2 : 3.9, 29 101104     29 ,  0 Whitewater Lake Frozen
MB133  DY110220 / 100 / 3.0 : 2.5, 25 101102     25 ,  0 lg drifts
.END
All lines in the vicinity of Brandon, Manitoba and southwest of
Winnipeg completed. Large drifts and blowing snow encountered along the
flight lines. Snow cover southwest of Winnipeg was still 100 percent
but looked to be less deep than in Saskatchewan and western Manitoba.
Everything is fzn. Tomorrow, Monday, our intention is to complete what
remains of the survey around the greater Winnipeg region.
NNNN
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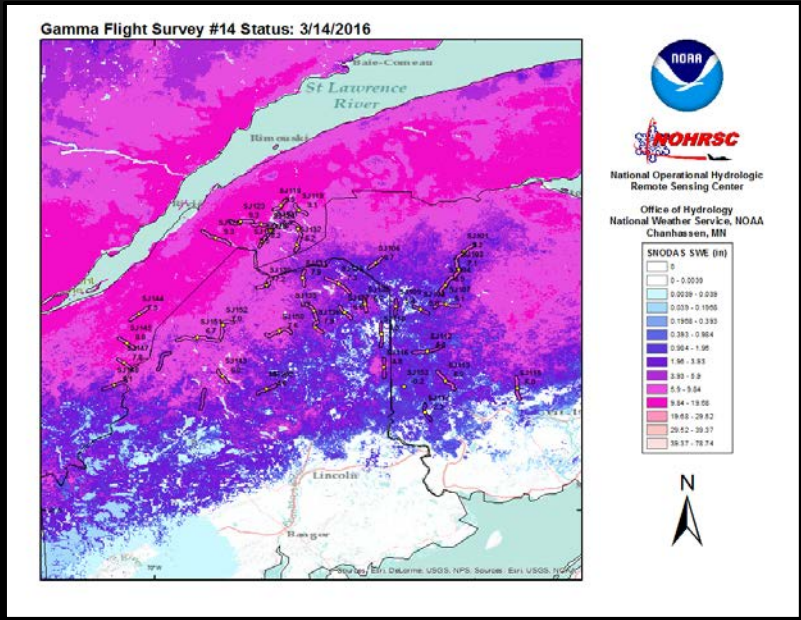
Accuracy of data

- Airborne measurements typically accurate to within 1 cm or 5% soil moisture
- Accuracy varies based on overall background and environmental factors during measurement
- Can measure up to 100 cm of SWE, dependent on total amount of background radiation

Flight Line Data

Used to determine
mean areal snow-water
equivalent (in cm)

- Each flight line results in a single SWE measurement.
- Midpoint of flight line is used for spatial analysis and creation of snow-water equivalent rasters.



Flight Line Output

How is this data used?

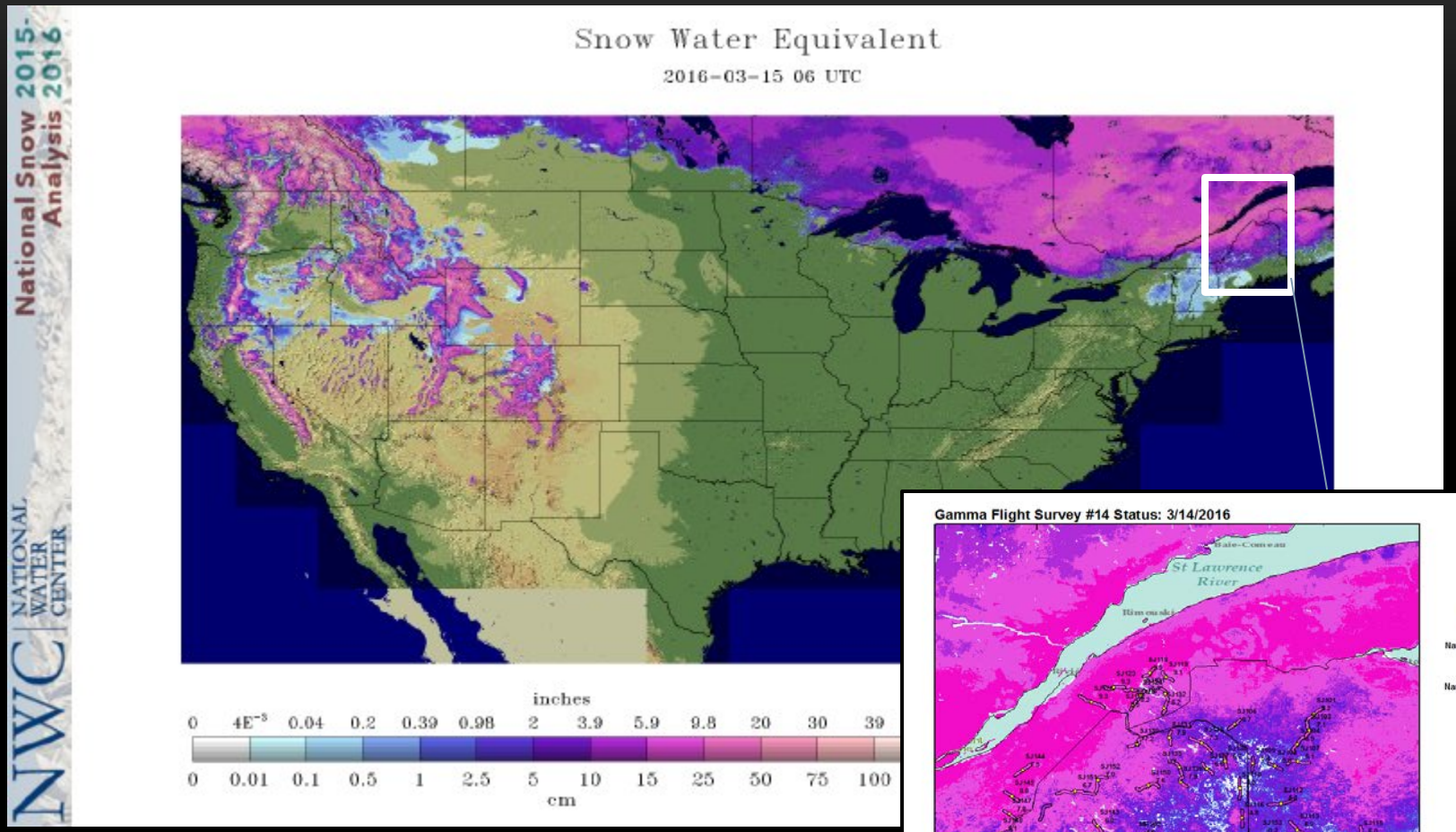
Measurements used to

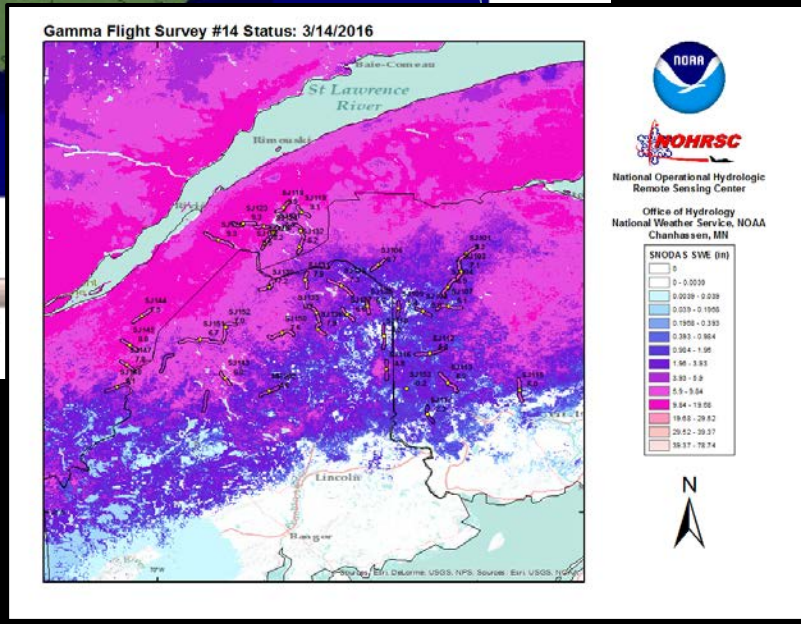
- Predict snowmelt runoff by:

  River Forecasters
  Weather Forecasters

- Validate observations and models

  Snow models, Ground and Satellite Obs





Airborne Data is used to create Gamma SWE Image, which is then incorporated into National Snow Analysis. (http://www.nohrsc.noaa.gov)

Survey Creation

- Surveys requested by a River Forecast Center.
- Some forecasters ask for specific lines, basins, or general areas.

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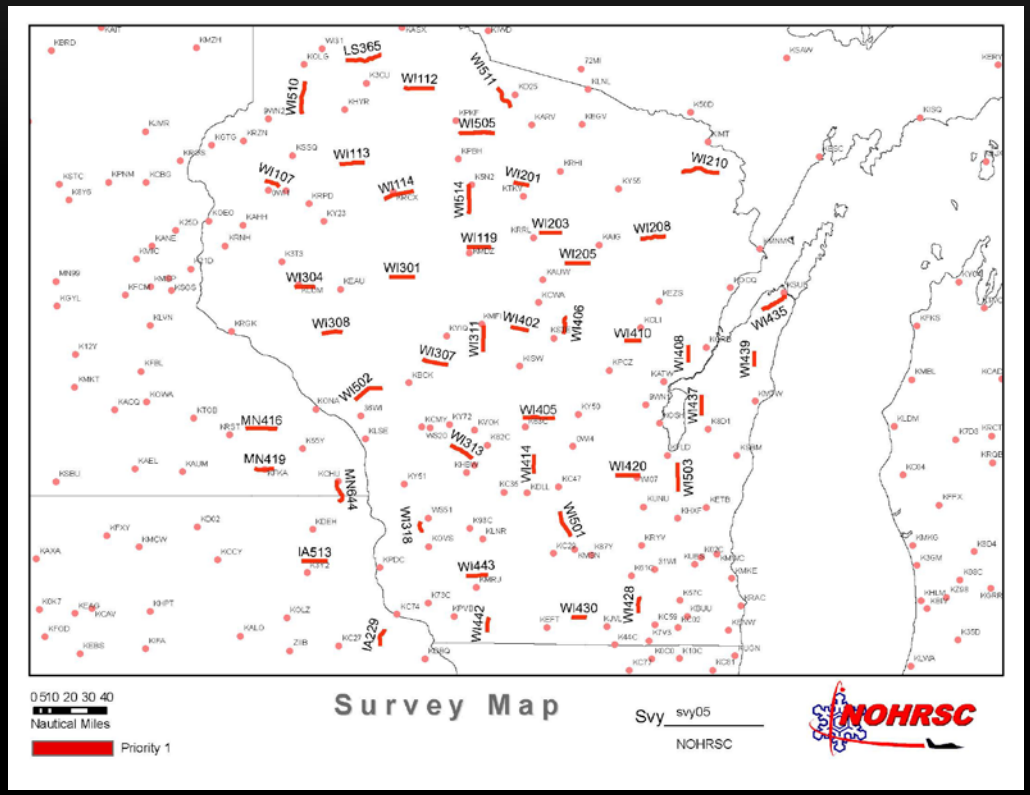
- There are also “canned” surveys that are flown every year as part of the National Snow Analysis
- Lines are compiled into a single text document and sent to the mission crews (pilots)

Survey Execution

- Pilots create maps
- Stage the aircraft
- Fly as many lines as possible based on weather, maintenance and future tasking
- 100 percent execution is rare.



Capstone Objectives

- Increase the efficiency at which airborne surveys are conducted by removing samples in areas with high amounts of spatial autocorrelation

- Each sample represents approximately 5 minutes of effort, representing approximately 8 gallons of fuel, as well as additional time spent at 500 feet instead of at a safer altitude.

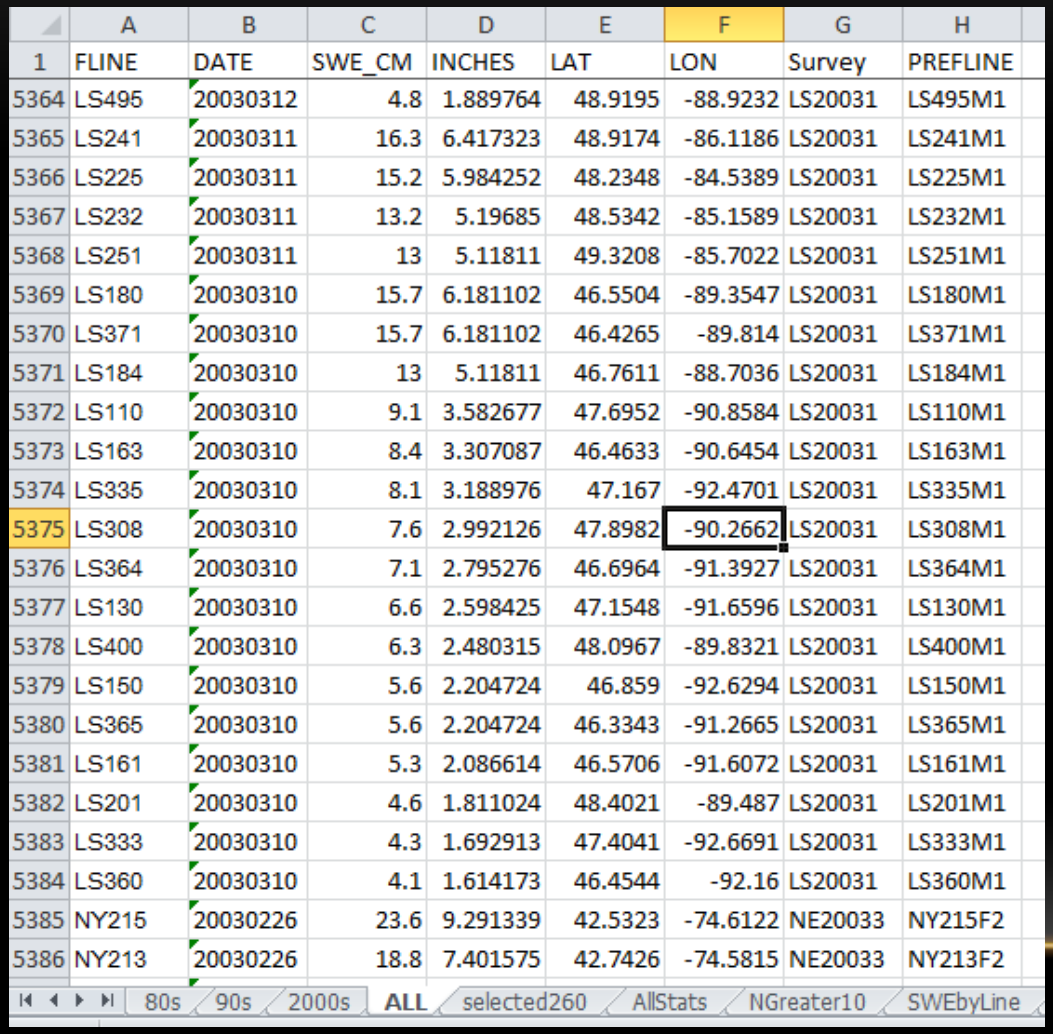
SPATIAL VARIATION OF SNOW-WATER EQUIVALENT

- In general, variability is higher at smaller scales due to drifting and vegetation effects
- At the watershed and regional scale, variability decreases, with large scale weather and temperature patters representing the dominant factors
- A single flight line is representative of the average SWE at the watershed scale, while airborne surveys are conducted at the regional level.

Survey Data

- Roughly 10-15 surveys flown every snow season.
- Each survey has anywhere from 50 to 300 lines.
- Surveys can take anywhere from 1 day to 1 month, depending on number of lines, weather, and aircraft availability

Flight Line Data



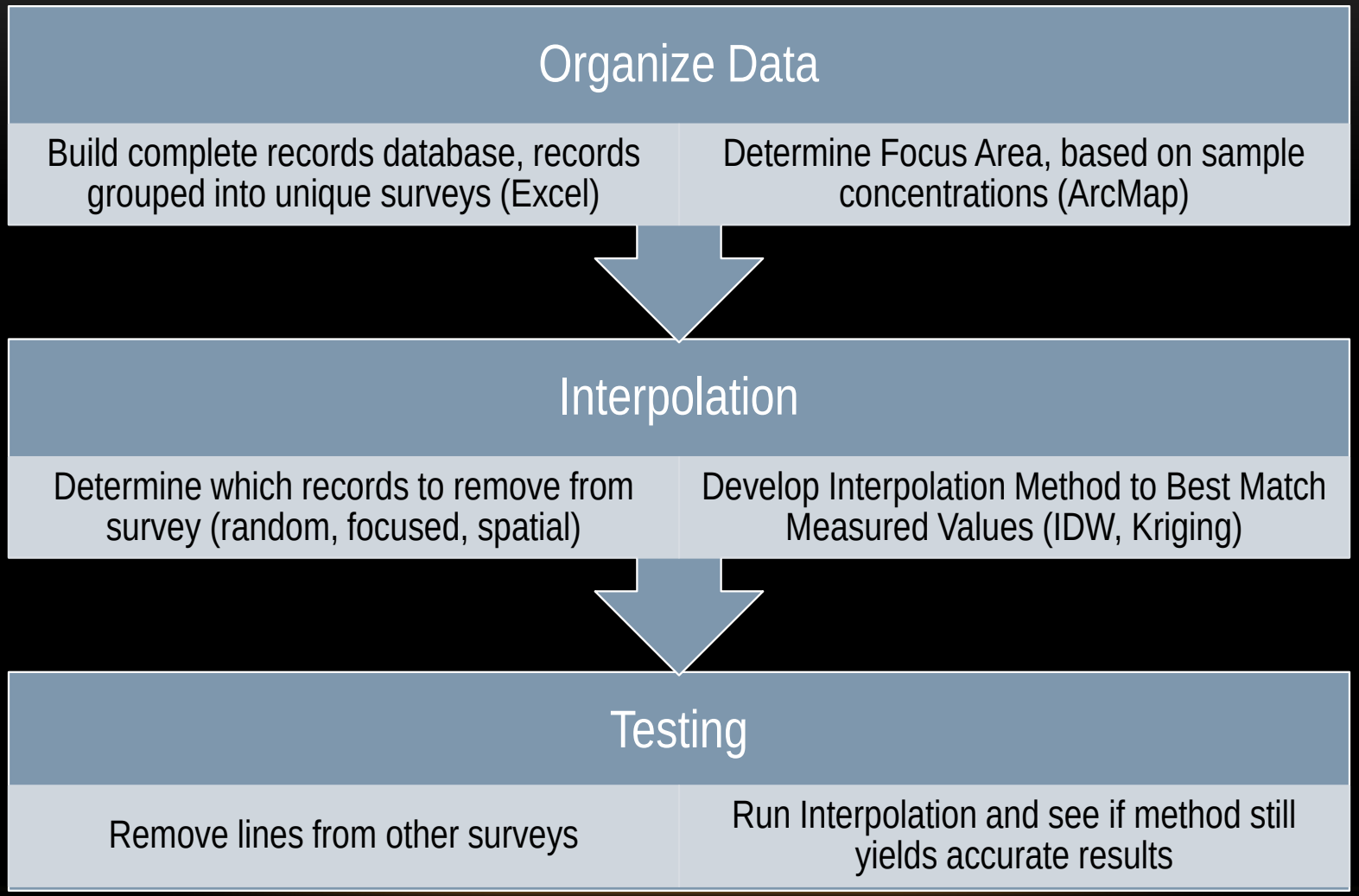
	A	B	C	D	E	F	G	H
1	FLINE	DATE	SWE_CM	INCHES	LAT	LON	Survey	PREFLINE
5364	LS495	20030312	4.8	1.889764	48.9195	-88.9232	LS20031	LS495M1
5365	LS241	20030311	16.3	6.417323	48.9174	-86.1186	LS20031	LS241M1
5366	LS225	20030311	15.2	5.984252	48.2348	-84.5389	LS20031	LS225M1
5367	LS232	20030311	13.2	5.19685	48.5342	-85.1589	LS20031	LS232M1
5368	LS251	20030311	13	5.11811	49.3208	-85.7022	LS20031	LS251M1
5369	LS180	20030310	15.7	6.181102	46.5504	-89.3547	LS20031	LS180M1
5370	LS371	20030310	15.7	6.181102	46.4265	-89.814	LS20031	LS371M1
5371	LS184	20030310	13	5.11811	46.7611	-88.7036	LS20031	LS184M1
5372	LS110	20030310	9.1	3.582677	47.6952	-90.8584	LS20031	LS110M1
5373	LS163	20030310	8.4	3.307087	46.4633	-90.6454	LS20031	LS163M1
5374	LS335	20030310	8.1	3.188976	47.167	-92.4701	LS20031	LS335M1
5375	LS308	20030310	7.6	2.992126	47.8982	-90.2662	LS20031	LS308M1
5376	LS364	20030310	7.1	2.795276	46.6964	-91.3927	LS20031	LS364M1
5377	LS130	20030310	6.6	2.598425	47.1548	-91.6596	LS20031	LS130M1
5378	LS400	20030310	6.3	2.480315	48.0967	-89.8321	LS20031	LS400M1
5379	LS150	20030310	5.6	2.204724	46.859	-92.6294	LS20031	LS150M1
5380	LS365	20030310	5.6	2.204724	46.3343	-91.2665	LS20031	LS365M1
5381	LS161	20030310	5.3	2.086614	46.5706	-91.6072	LS20031	LS161M1
5382	LS201	20030310	4.6	1.811024	48.4021	-89.487	LS20031	LS201M1
5383	LS333	20030310	4.3	1.692913	47.4041	-92.6691	LS20031	LS333M1
5384	LS360	20030310	4.1	1.614173	46.4544	-92.16	LS20031	LS360M1
5385	NY215	20030226	23.6	9.291339	42.5323	-74.6122	NE20033	NY215F2
5386	NY213	20030226	18.8	7.401575	42.7426	-74.5815	NE20033	NY213F2

80s | 90s | 2000s | ALL | selected260 | AllStats | NGreater10 | SWEbyLine

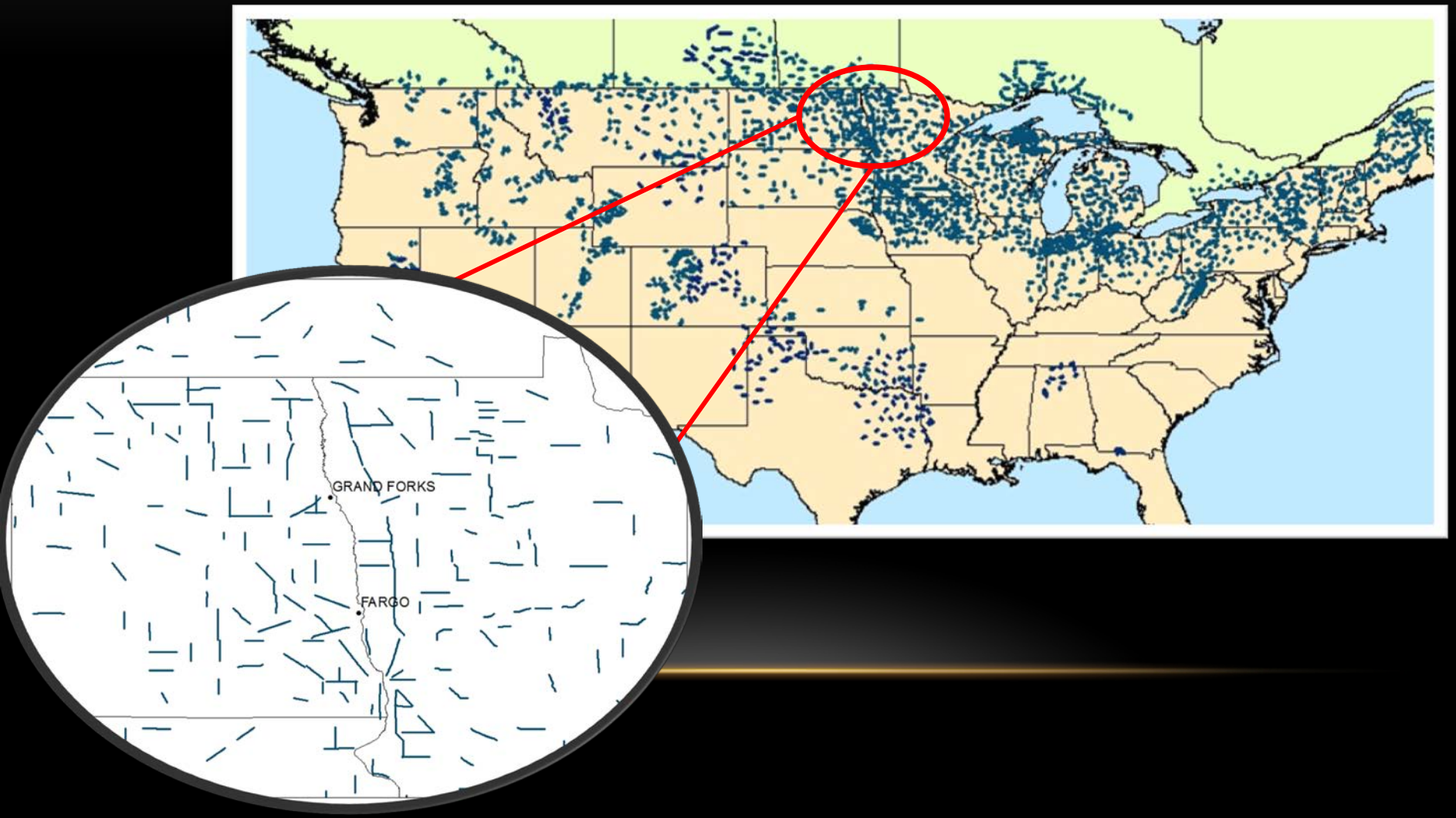
Each flight line is represented by a single record

- SWE in both inches and cm
- Midpoint in lat/lon
- Date of flight
- Grouped by survey

METHODS/PROCESS



Focus Area – Red River of the North



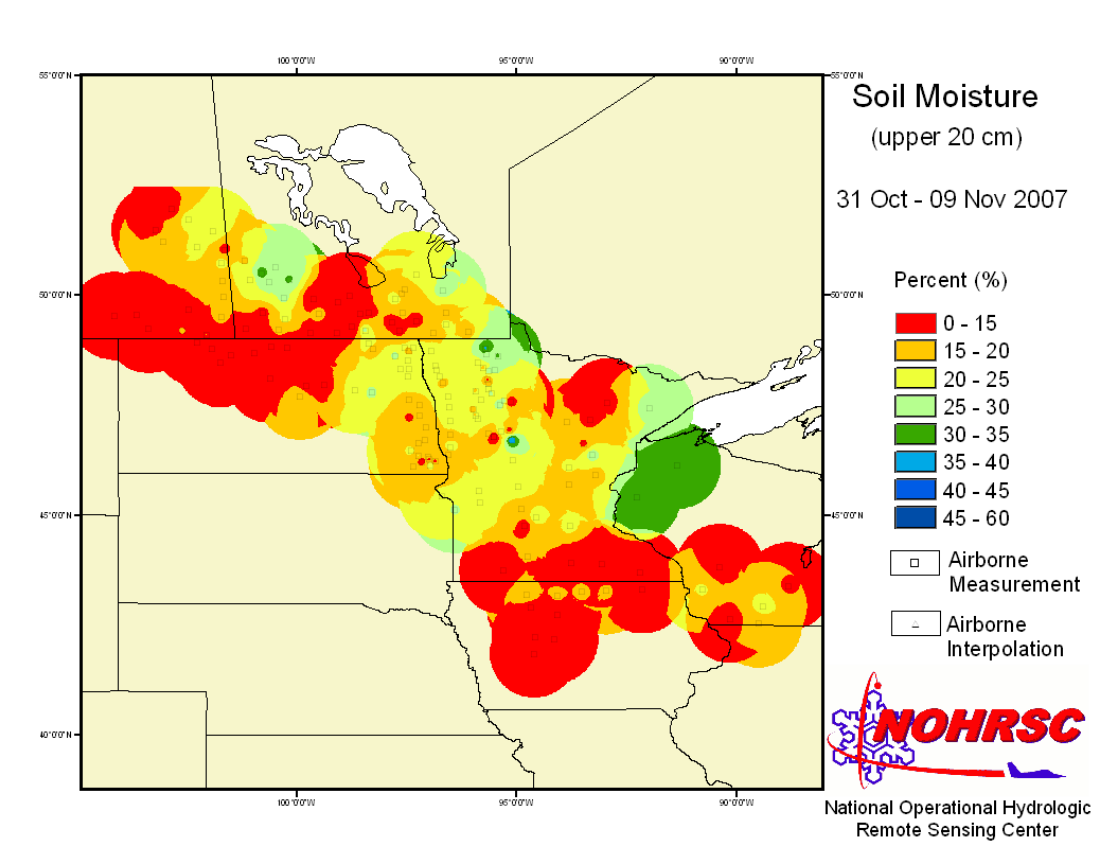
SURVEY DATA TO BE USED IN THIS STUDY

- Study area: North Dakota / W MN
- First flown in 1980
- Over 200 individual flight lines
- Survey conducted multiple times each season
- Relatively flat

Soil Moisture Surfaces

Mid-points of survey lines used to create soil moisture and SWE surface

IDW (Inverse Distance Weighting) interpolation method used to create surface



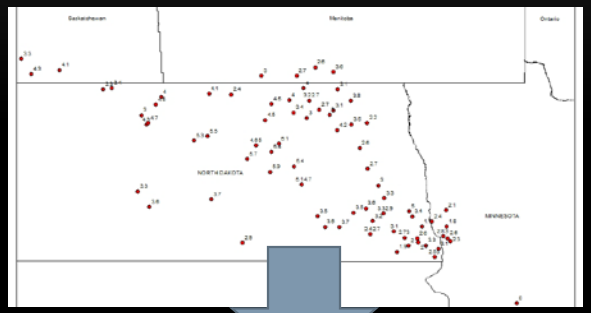
Outputs used for planning surveys and as inputs for different models

Optimized sampling and error assessment

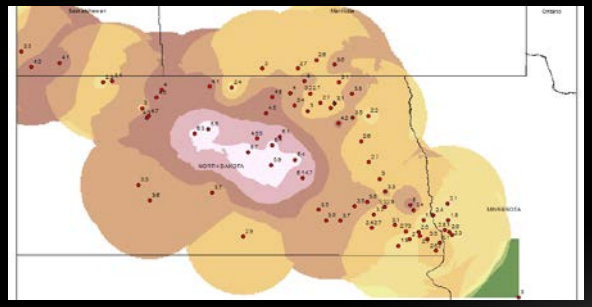
- Use all points to create a surface
- Decrease sample number using one of following methods:
  - Random; Stratified (select random points within a watershed basin); Focused (remove lines that exhibit high SWE autocorrelation)
- Create new interpolated surface using sample points
- Compare to original surface using all points and calculate error

ACCURACY ASSESSMENT

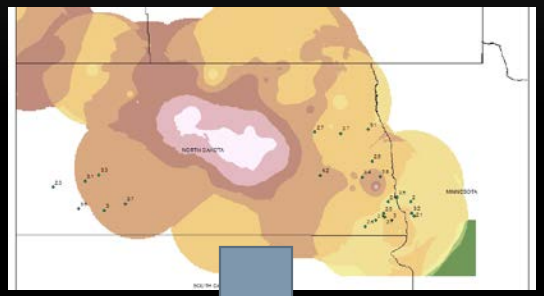
1 Optimized Sample



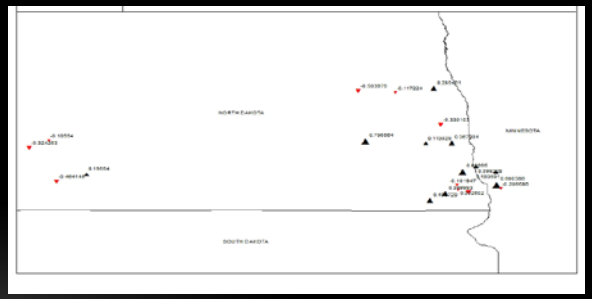
2 SWE Surface using interpolation method



3 Assign interpolated values to flight lines removed from optimized sample



4 Calculate differences between interpolated values and measured values to determine errors



ASSESSMENT

Survey	N	Sampling	Interpolation	Error (RMSE)
Survey 1 Survey 2 Survey 3 Survey 4 Survey 5	All points	All	IDW	n/a
Survey 1,2,3,4,5	Reduction by 5% (N=)	Random Stratified	IDW, Kriging IDW, Kriging	
Survey 1,2,3,4,5	Reduction by 10% (N=)	Random Stratified	IDW, Kriging IDW, Kriging	

Timeline

- February - combine all survey data into one master file
- March - identify surveys to be used for testing
- April - determine accuracy requirements for different surveys
- May - investigate factors that will most greatly affect variability (SWE, elevation, time of year, ?)
- June/July determine best interpolation method to delivery accuracy requirement based on variability factors
- August - Test methods on remaining surveys to see if accuracy requirements are met
- September - summarize findings and organize presentation
- October - deliver results to National Water Center as part of a seminar

Key Literature/Resources

- **Adam, J.C., Hamlet, A.F., Lettenmaier, D.P.** 2009. Implications of global climate change for snowmelt hydrology in the twenty-first century. *Hydrological Processes* 23, 962-972.
- **Barnett ,T.P., Adam J.C., Lettenmaier, D.P.** 2005. Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature* 438, 303-309.
- **Chang H., Il-Won, J.** 2010. Spatial and temporal variation changes in runoff caused by climate change in a complex and large river basin in Oregon. *Journal of Hydrology* 388, 106-207.
- **Fortin, R., Sander, L., Nadeau, M., Grasty R.L.** 2008. An airborne gamma-ray snow survey in the James Bay Region. *Proceedings of the 65th Eastern Snow Conference, Fairlee, Vermont USA 2008.* http://www.easternsnow.org/proceedings/2009/fortin_et_al.pdf . Accessed 20 June 2011.
- **Mote P., Hamlet, A., Salathe, E.** 2008. Has Spring snowpack declined in the Washington Cascades? *Hydrol. Earth Syst. Sci.* 12, 193-206.
- **Stewart, I.T., Cayan, R.D., Dettinger, M.D.** 2005. Changes toward earlier streamflow timing across western North America. *Journal of Climate* 18, 1136-1155.
- Eastern/Western Snow Conference Proceedings
- **Clark et al –** 2011. Representing spatial variablility of snow-water equivalent in hydrologic and land –surface models: a review.