Practical navigation for mountain travelers using map, compass and altimeter

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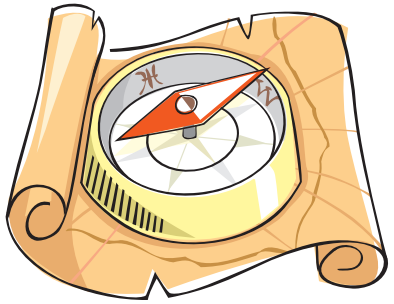
Version 1.0

Intent of this document

Outline

- This guide is intended to give the reader a practical understanding of navigation using compass, map, altimeter and GPS device (Global Positioning System) in the mountains of the United States and other parts of the world.
  - The content is based on my own experience as a mountaineer, alpinist, hiker and skier. This is just my own opinion and it may be right or wrong. Use your own judgement in all circumstances.



Outline

Equipment

Outline

- The map
  - This is the single most important piece of equipment you need to navigate in the mountains.
- The compass
  - The compass will help orient the map and its needle will always point to the Magnetic North (MN). A compass with a mirror is preferred for accuracy of bearing and it can also be used as a signaling device in case you are searched.
- The altimeter
  - When calibrated regularly, the altimeter will significantly help the mountain traveler reach his/her goal and find his/her location on the map. Altimeters can be mechanical or electronic.

Equipment (cont)

Outline

The GPS device

- GPS devices available today are small and portable enough for practical use in the back country for navigation. They are extremely valuable and very accurate (3m or 10ft) when you have a full view of the sky.
- However, they run on batteries and are made of sensitive electronics. The Department of Defence can change the accuracy of the GPS system any day. Hence the GPS must be used in addition to the map and compass, not instead of the map and compass.
- GPS devices can give you your ABSOLUTE locations in a few minutes anywhere on earth, while compass, map and altimeters can only give you your location RELATIVE to your starting point.
- For all electronic equipment, make sure that you have extra batteries and you know how to change them.

Basic steps in navigation

Outline

- Preparation: either at home or in your tent or hut. This is a very important step in which the route will be established and the navigation plan will be written down.
- Calibration at the starting point: starting from a known point is critical to the final accuracy of the navigation.
- Execution: actual navigation using map, compass, altimeters and GPS following the established navigation plan.
- Feedback for next time: What worked? What did not work? Was the route safe and easy to navigate? Learn from your experiences, write it down.

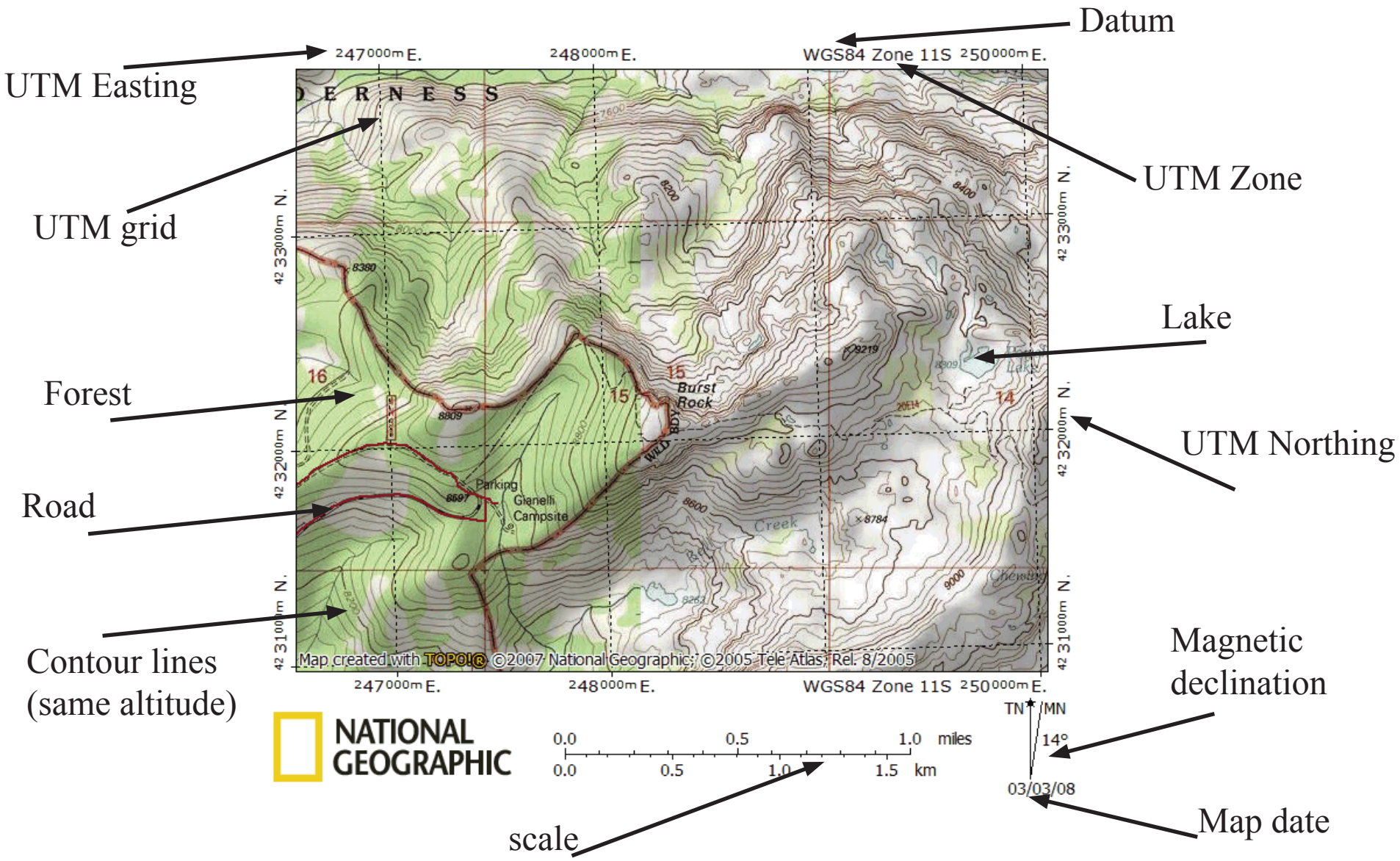
The map

Outline

- Maps are a 2D flat projection of earth, or a portion of it.
  - Symbols (http://erg.usgs.gov/isb/pubs/booklets/symbols/) are used to identify important features, like house, forest, rocks, glaciers, summits, passes etc. Familiarize yourself with the legend of the map to be able to recognize those elements on the map before your trip.
  - Map are made using a specific projection (Universal Transverse Mercator, UTM, etc) which is a way of projecting a sphere onto a flat piece of paper.
  - Map are made using a specific datum (reference point for the grid)
  - Map are made with a specific scale from earth, 1:24000 means that distance on the map are 24'000 times smaller than in reality.

The map (cont)

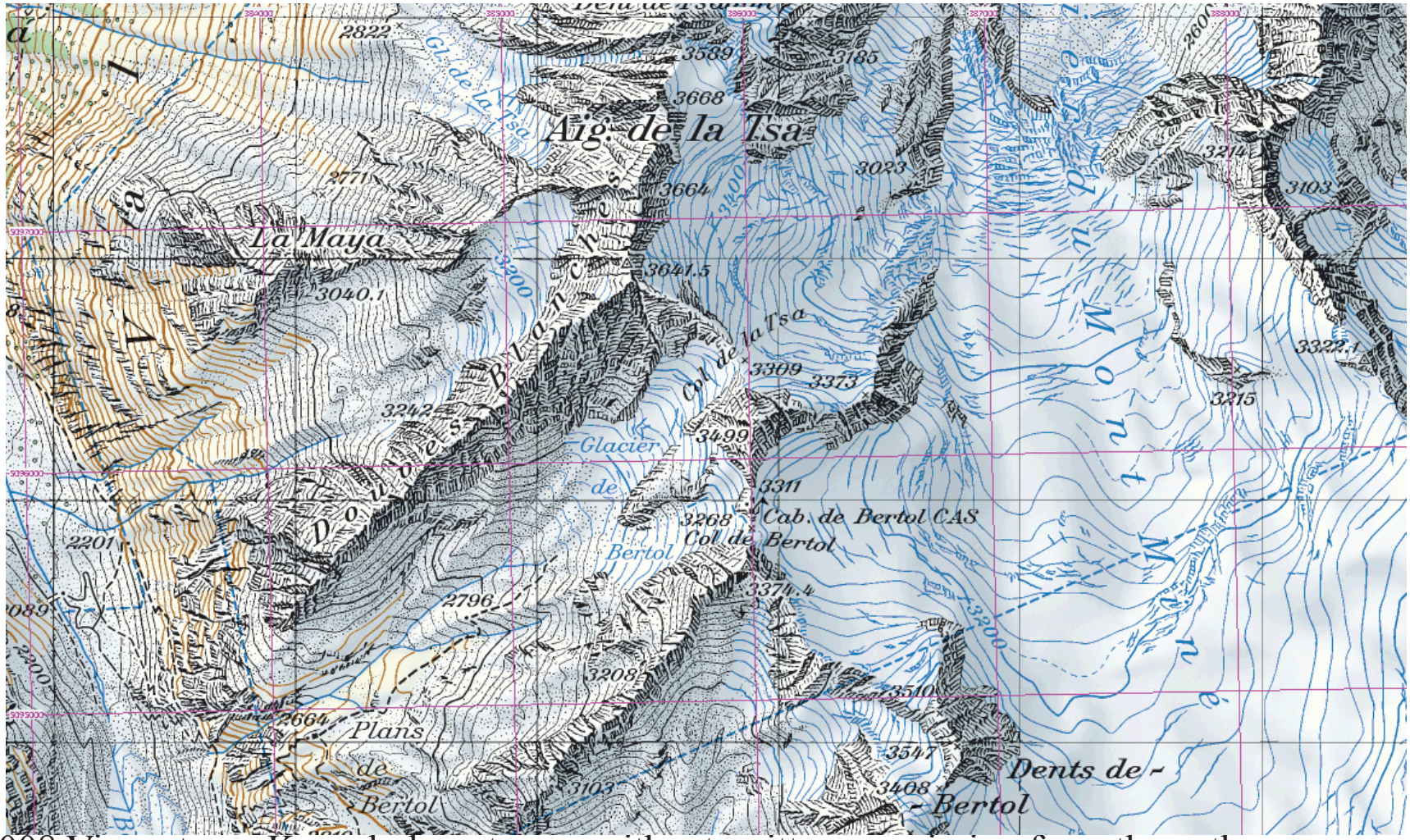
Outline



Other types of maps

Outline

- Some maps have more or less details, below is an example of a detailed Swiss map at the 1:50’000 scale.



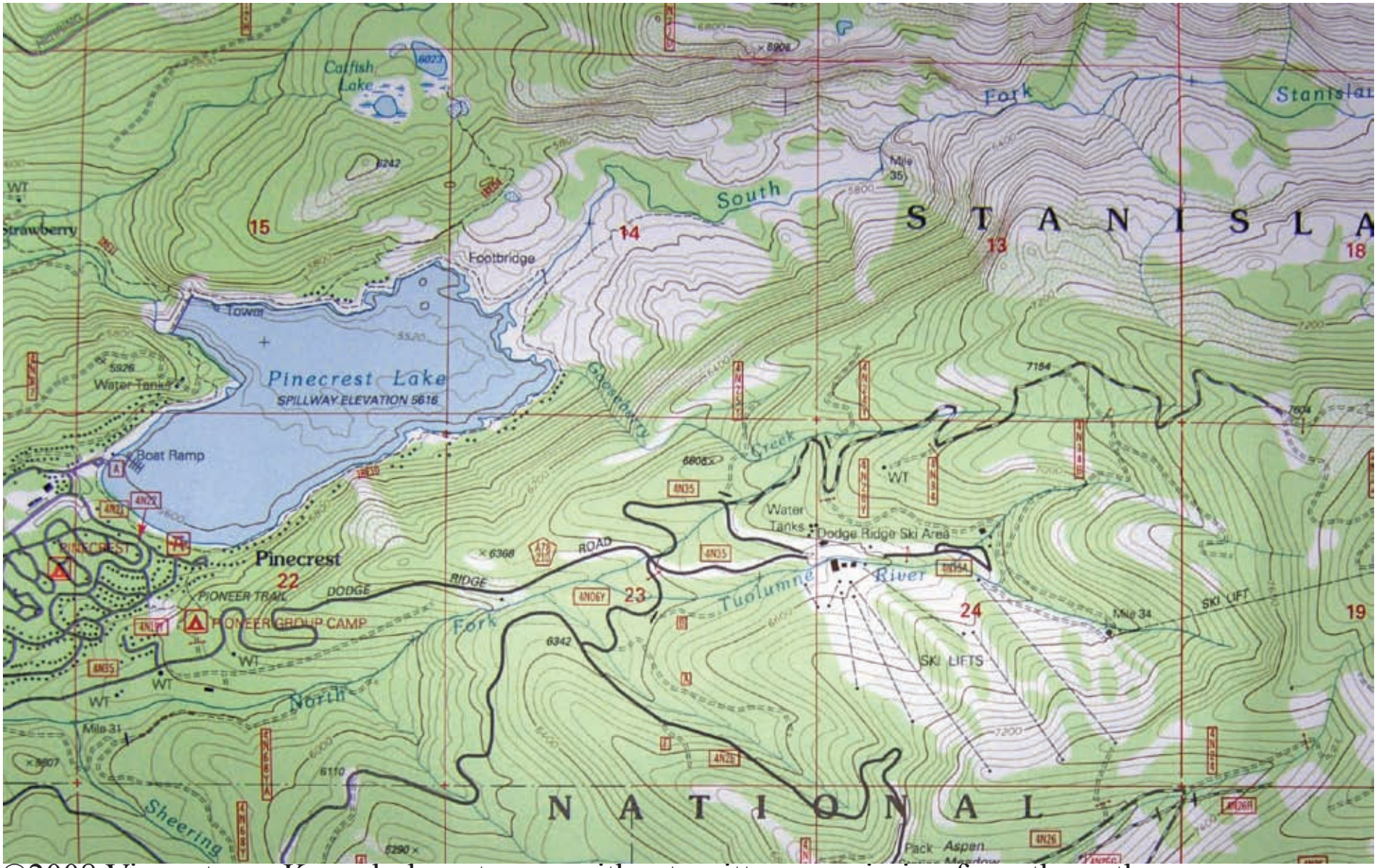
Software maps

Outline

- Software maps are available from a few vendors (like TOPO!Map from National Geographic)
  - They have the same details as the USGS 7.5' Quadrangle maps in the USA and can be printed for any area of interest on waterproof paper
  - They often include some basic route tracing tools, to help with route planning and compass/altimeter direction and altitudes (way-points)
  - A GPS unit can be connected to the software and transfer routes or tracks from and to the GPS unit.
  - Some GPS units have software maps included, but those are not generally high quality navigation maps (except for National Parks)

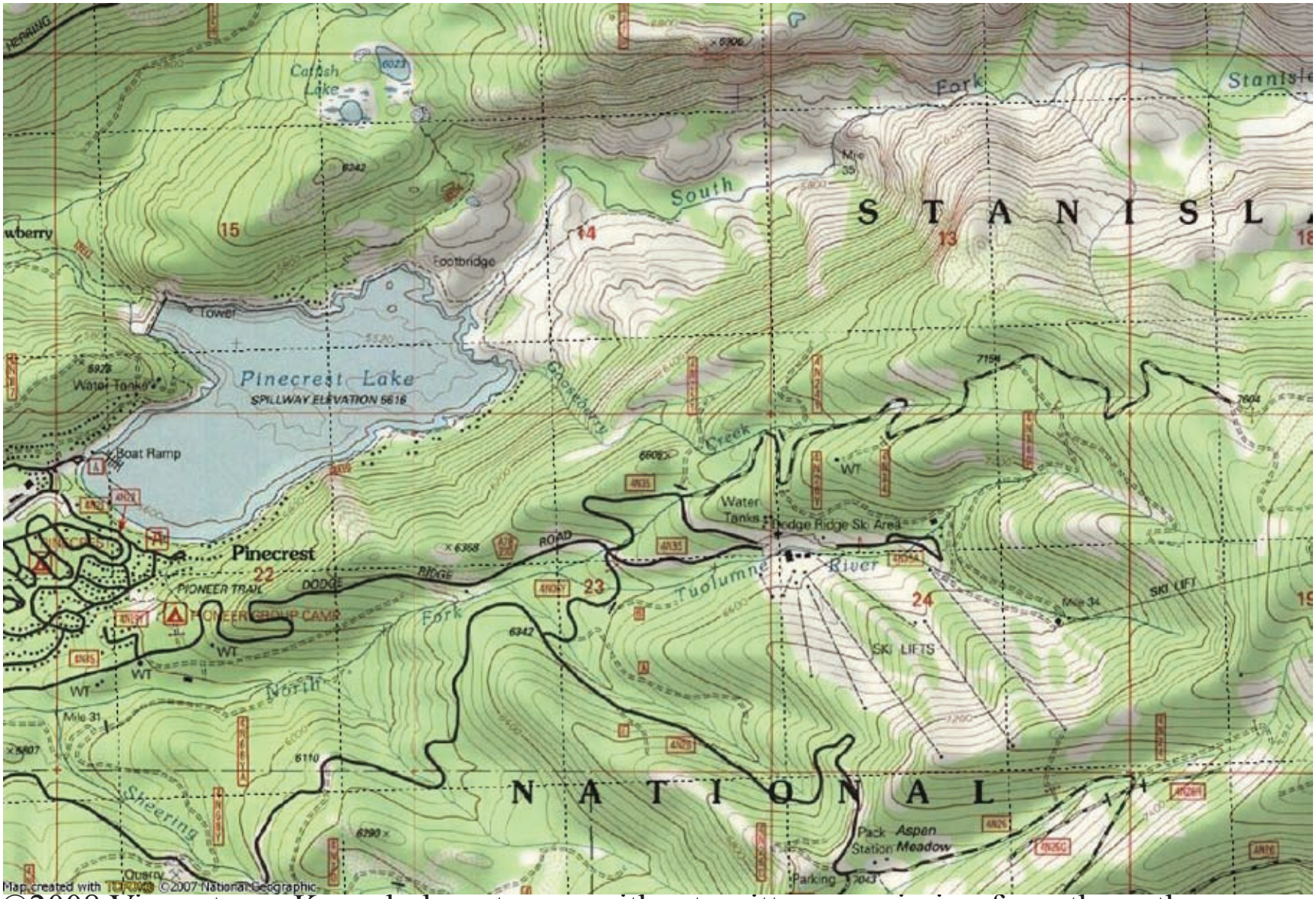
Comparison of maps: USGS 1:24K 7.5’

Outline



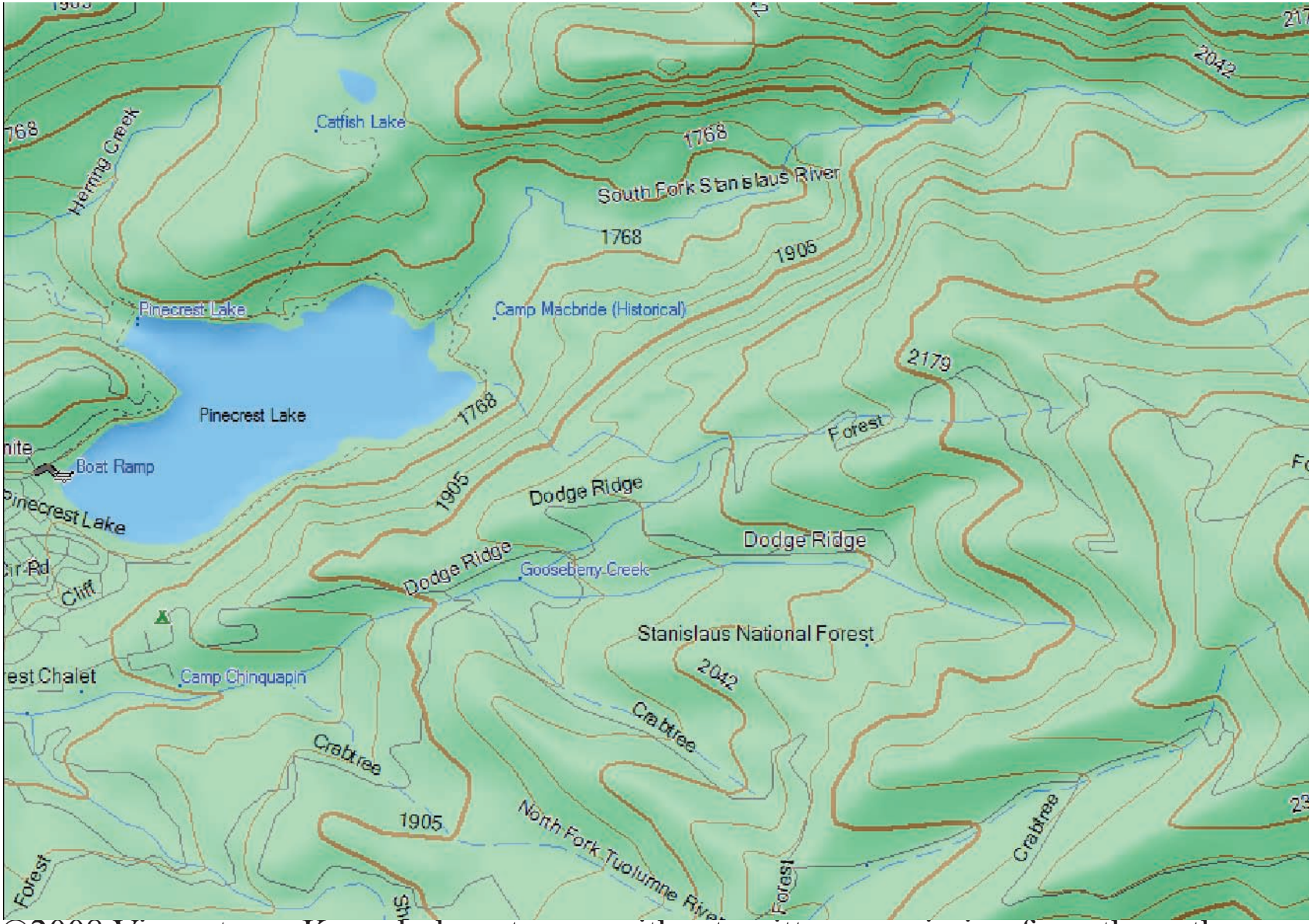
Comparison of maps: TOPO!Map National Geographic

Outline



Comparison of maps (GPS Garmin US Topo 2008)

Outline



Google Earth

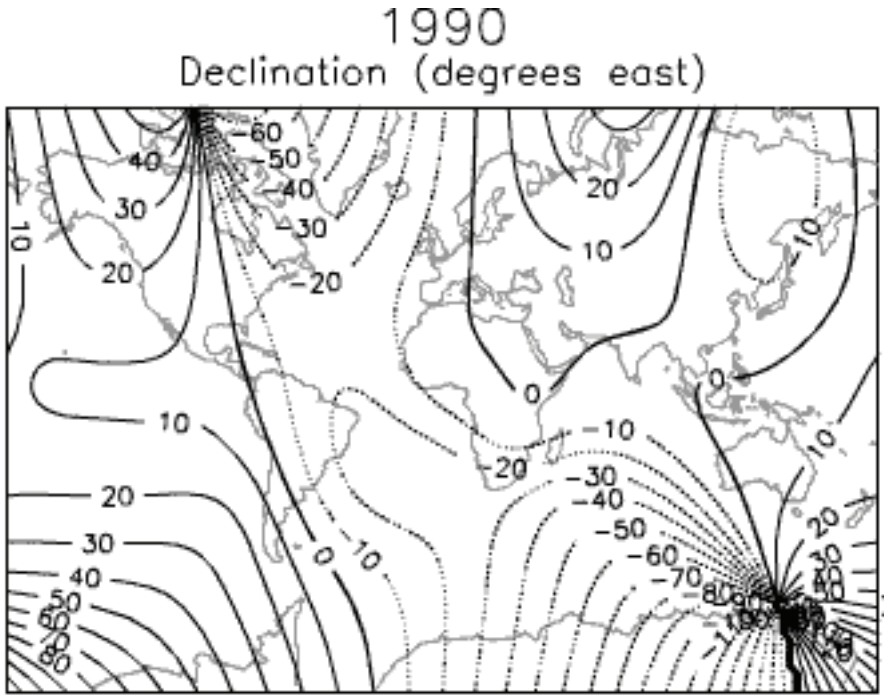
Outline

- Google Earth is not a map but can be used to help familiarize with the type of terrain you may encounter during your mountain travel (free software available on (http://earth.google.com/)

Magnetic declination

Outline

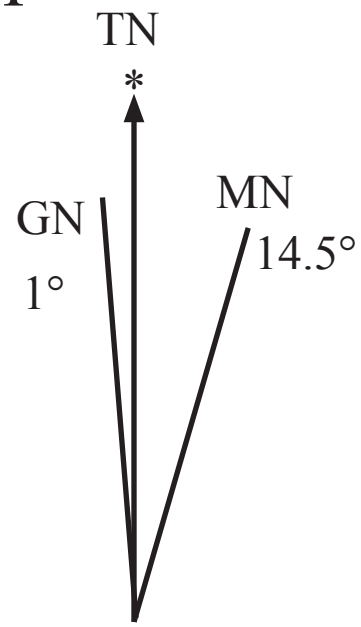
- The magnetic declination is the angle difference between the true north pole and the source of the magnetic field pointed at by the compass needle
  - It varies with time, so make sure that your map date is recent (<5 years)



Magnetic declination (cont)

Outline

- Each map should have a symbol or the magnetic declination mentioned for the center of the map.
  - The usual symbol for this is on the right:
    - TN stands for True North (north pole)
    - MN stands for Magnetic North (needle)
    - GN stands for Grid North (map grid)



- The compass needs to be adjusted to account for the magnetic declination (more in the compass section)

Map datum

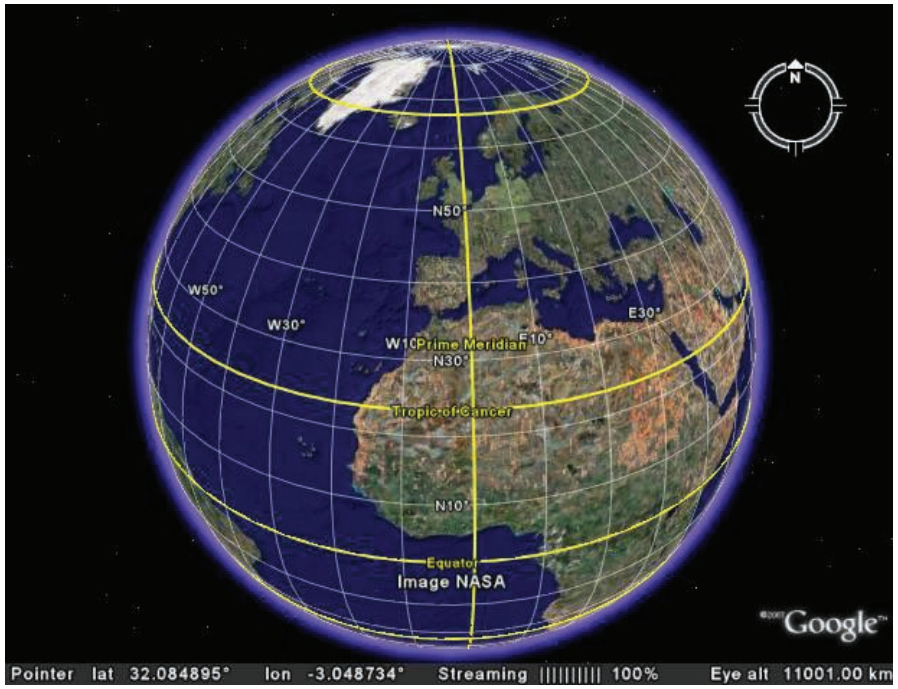
Outline

- The map datum is a reference point used to lay the grid on top of the map.
  - For USGS 7.5' maps it is NAD27 CONUS (1927 continental US)
  - If you use software maps (i.e. TOPO! Maps) and a GPS set it to WGS84 (more recent, more accurate reference)
- When given a coordinate (i.e. UTM) make sure that you use the same datum.
  - Using a different datum may results in large (up to 200m in the Continental US) discrepancies in the real location!

Map grids/coordinate

Outline

- The most well known coordinate system is latitude and longitude
  - Earth is divided in 360°, starting on Greenwich, UK for longitude (joining at the poles)
  - Earth is also divided in 360° starting at the equator, for latitude.



Latitude and Longitude

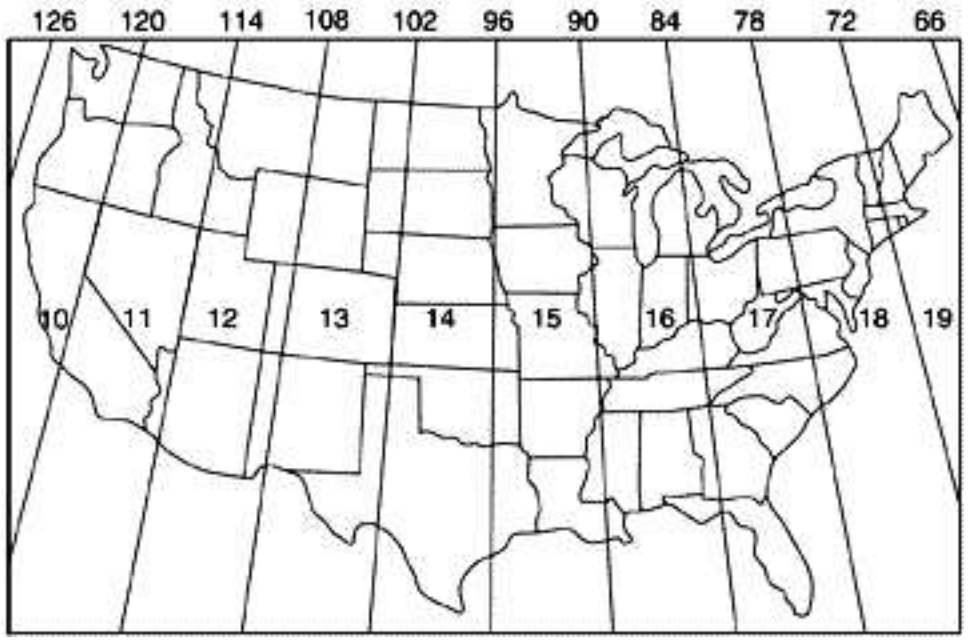
Outline

- Latitude and longitude coordinate are given in degree.
  - The simplest way to give a lat/lon is to used decimal degree: N38.2346 W120.2398.
  - Some maps have degrees, minutes and seconds for lat/lon: N38° 45’ 76” W 120° 34’ 65”
  - Some conversion between those format may be required:
    - 38.5° is 38° 30’ 0” (similar to Hour Minute Second HMS system)
- Lat/Lon coordinate are not easy to map back on a paper map, hence UTM grid is preferred.

Map grids/coordinate

Outline

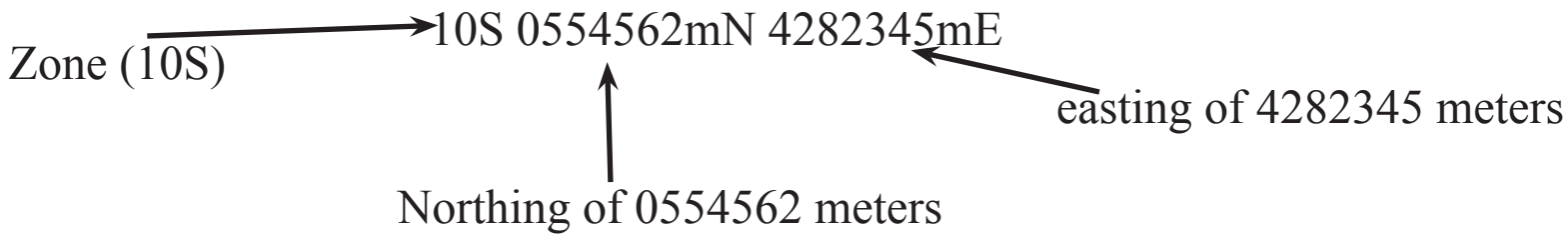
- The most used grid system is the Universal Transverse Mercator (UTM). Earth is divided in Zones.
  - The UTM grid preserves the straight directions on the map and limits the distortion to a minimum for latitude below 84°



UTM Gird

Outline

- Earth is divided into 60 N-S zones, 6° each in longitude
  - In each zone the coordinates are measured North and East in meter (39.37inches or approximately 1 yard)
  - UTM grid are printed on the USGS 7.5' maps (scale 1:24'000) allowing simple determination of the coordinate on a map.
  - GPS device can be set to various grid system, including UTM
  - Make sure you use a coherent datum between your map and GPS (NAV27 for USGS 7.5' maps or WAS84 for software maps)
    - UTM coordinate format is the following:



UTM grid (cont)

Outline

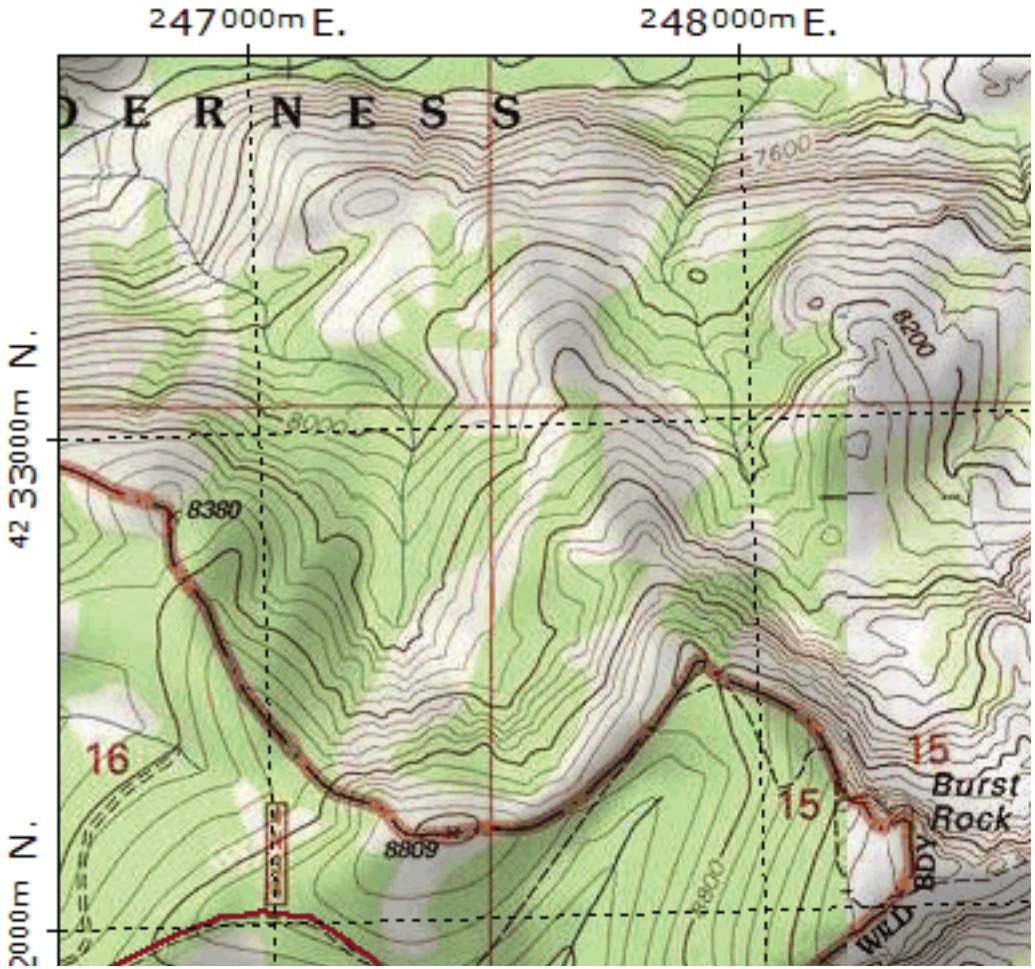
- To simplify exchange of coordinate when the area is small, it is possible to use only 6 numbers to give approximate coordinates
  - Since the Zone (10S) is usually common for a small area, there is no need to specify it every time if the travelers are navigating in the same small area.
  - Also the first 2 digits of the Northing and Easting is usually common (unless the area is just over the boundary of a digit change)
  - The last 2 digits of the easting and northing can also be ignored if the accuracy can be limited to an area of 100m by 100m.
    - Hence only the 6 red digits (545/823) in the coordinate below could be used (known as UTM triplets)

10S 0554562mN 4282345mE

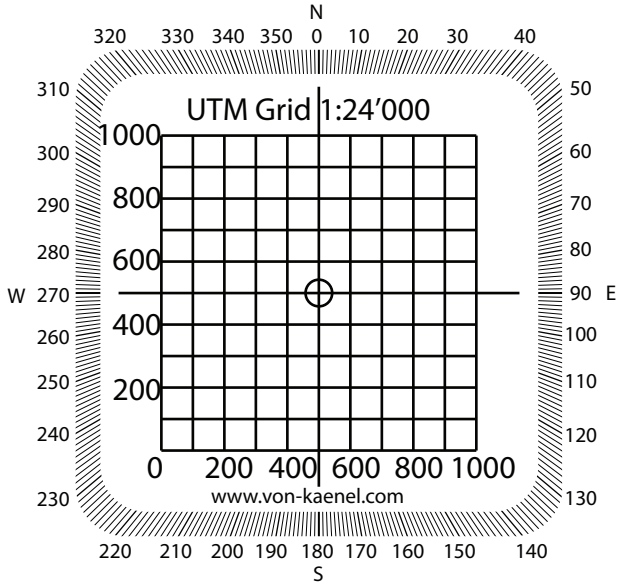
UTM grid and Map location

Outline

- To locate a UTM coordinate on the map, your map needs to have the grid overlaid (dashed line below)



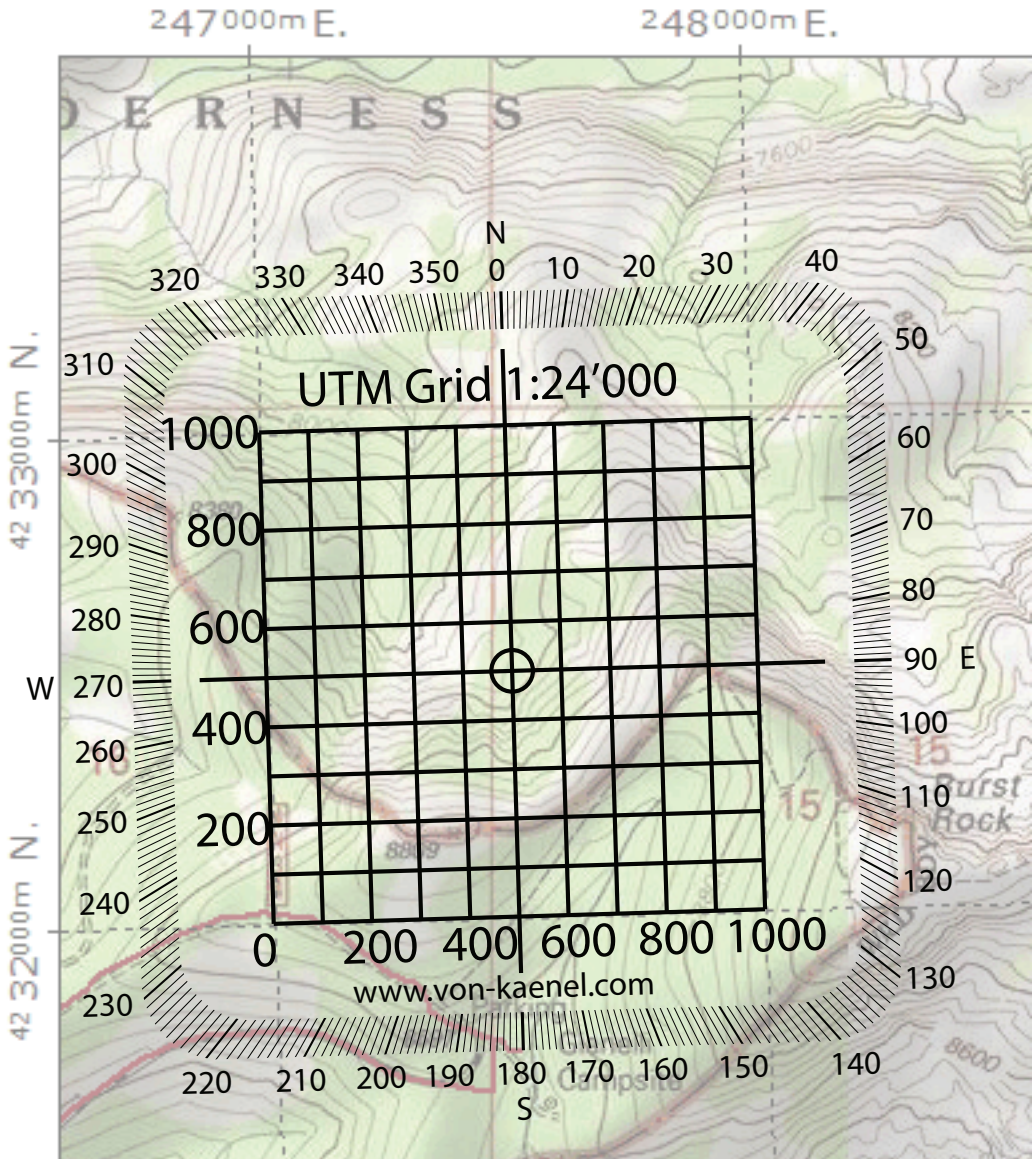
- You also need a UTM grid overlay (print the one below if you do not have one)



UTM grid and Map location (cont)

Outline

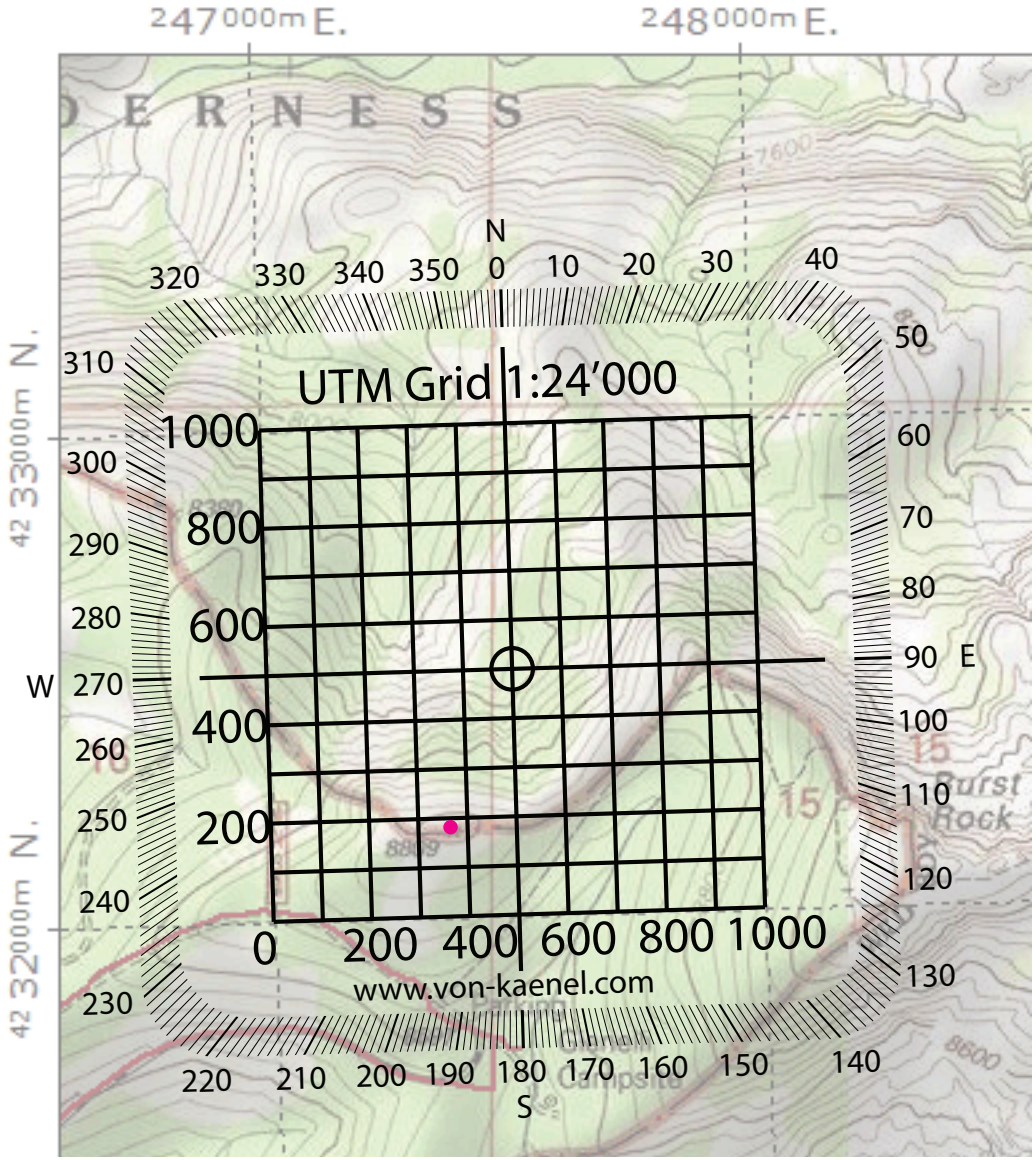
- Place the grid on top of the map and align it to the UTM square corresponding to your coordinate
- On the right for example: 4232000mN 247000mE, to lower left corner of grid, growing number going up (N) and right (E)



UTM grid and Map location (cont)

Outline

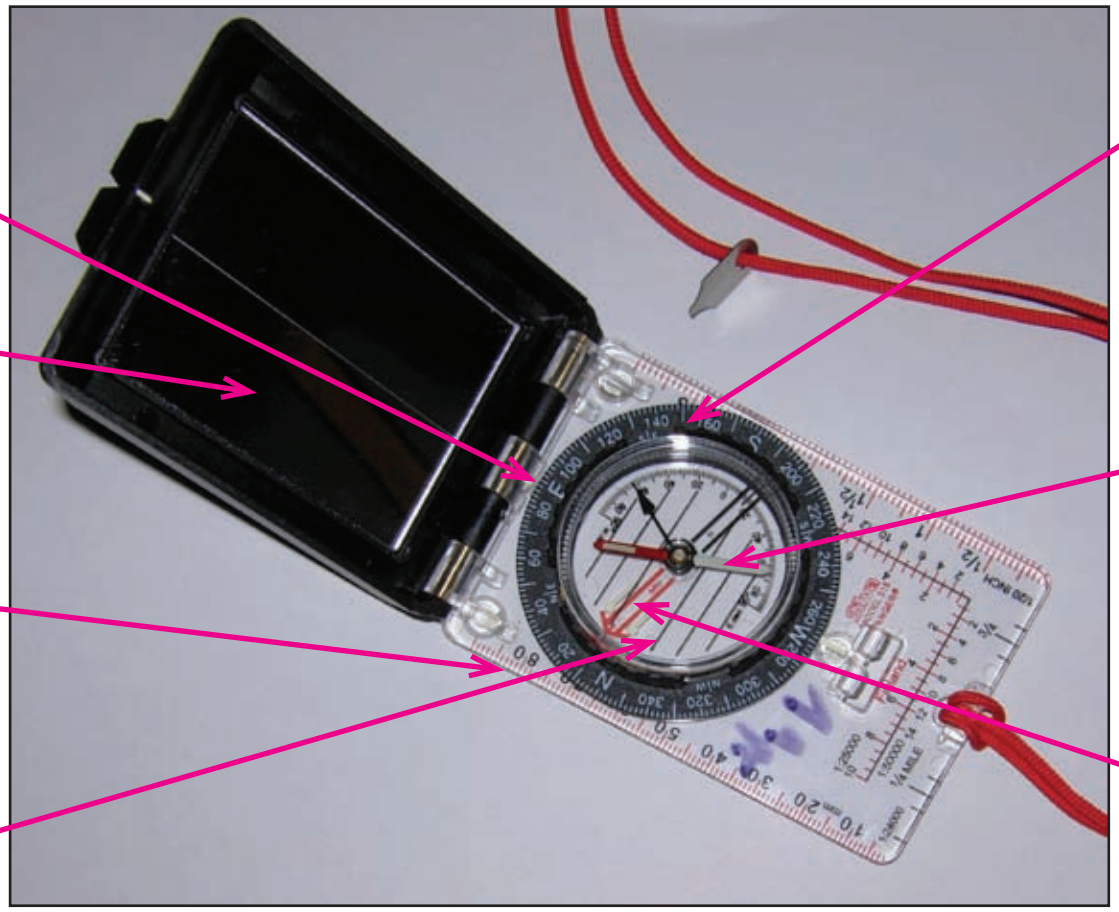
- Assuming your UTM coordinates are 11S 4232190mN 247360mE, you can use the grid to point at the location on the map (red dot)
  - Each square on the grid is 100m by 100m (~330ft x 330ft), allowing you to have an accuracy of ~20m/60ft on the map.



Compass

Outline

- Many different type of compass exist, a mirror is highly recommended for accurate bearing in the field.

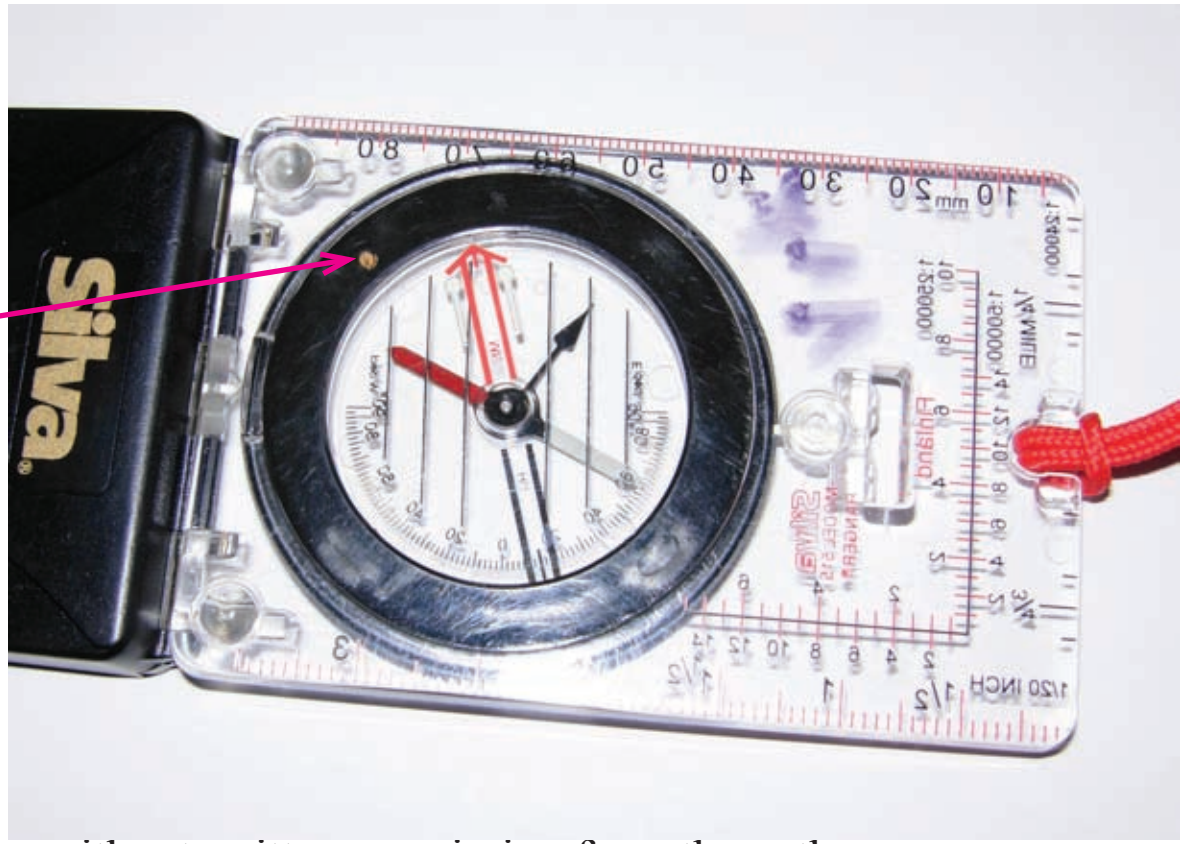


Compass (cont)

Outline

- Compass that can have a magnetic declination adjustment are best
  - A small screw is usually visible form the back of the compass and allow you to adjust the declination

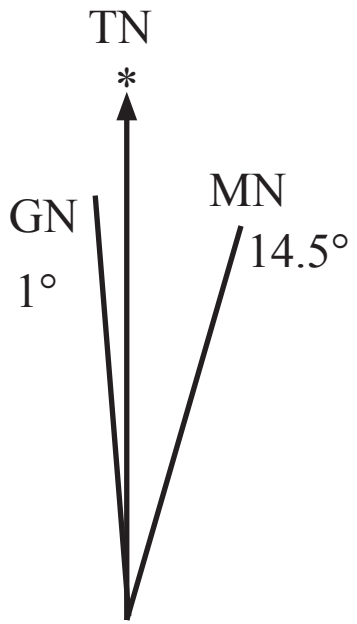
Magnetic declination adjustment screw



Compass, magnetic declination adjustment

Outline

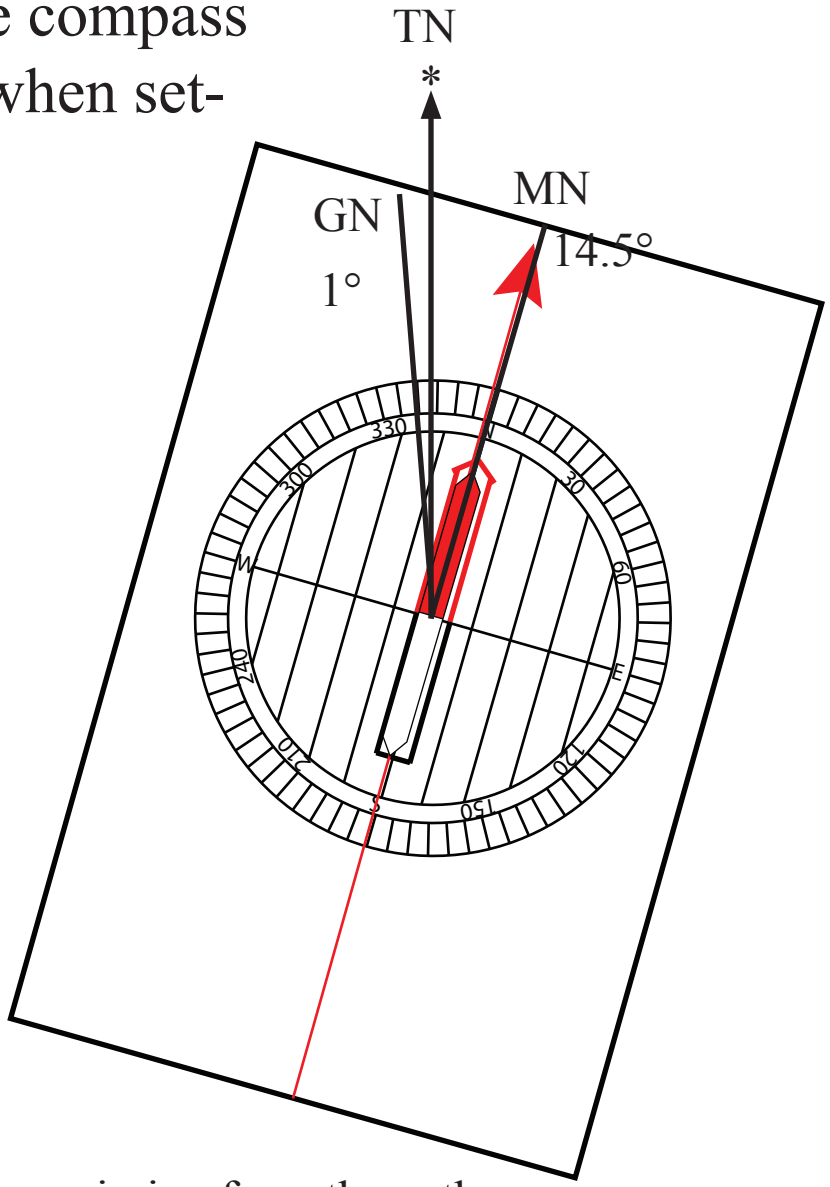
- Your compass needs to be adjusted for the magnetic declination (difference between the true North (pole) and the direction the magnetic needle is pointing at)
- There are 2 possibilities, either adjusting for true North or for the Grid North (grid direction on the map)
  - Adjusting to True North require to align the compass Orienting lines to the edge of the map to get an accurate reading
  - Adjusting to Grid North require to align the compass Orienting lines to any of the vertical grid lines to get accurate reading (recommended but needs to be consistent with GPS and other in your party)



Adjustment of declination on compass: Magnetic North

Outline

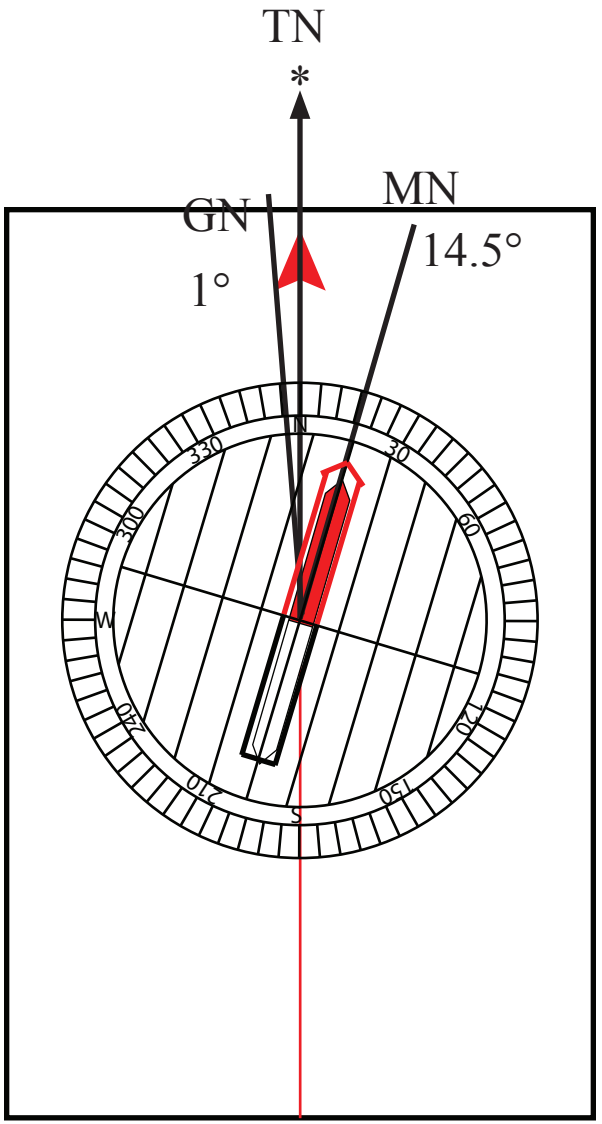
- Without declination adjustment, the compass would point at the magnetic north when setting it on 0º



Adjustment of declination on compass: True North

Outline

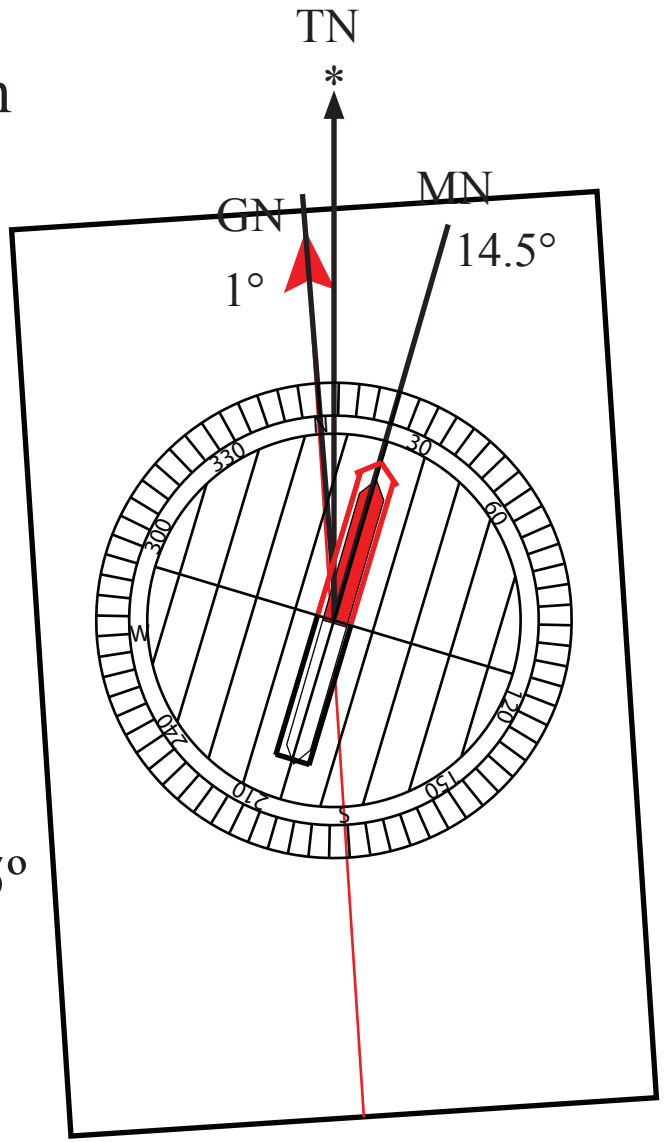
- With declination adjustment, the compass would point at the true north when setting it on 0º
- The 0º/N on the dial does not match anymore with the orienting arrow. The difference in degree is the magnetic declination
- The compass is adjusted to point to the true North
  - The declination adjustment was 14.5º in this example (not to scale on the dial).



Adjustment of declination on compass: Grid North

Outline

- With declination adjustment, the compass would point at the true north when setting it on 0º
- The 0º/N on the dial does not match anymore with the orienting arrow. The difference in degree is the difference between the magnetic declination and the grid declination.
- The compass is adjusted to point to the grid North.
  - The declination adjustment was 15.5º in this example (not to scale on the dial).



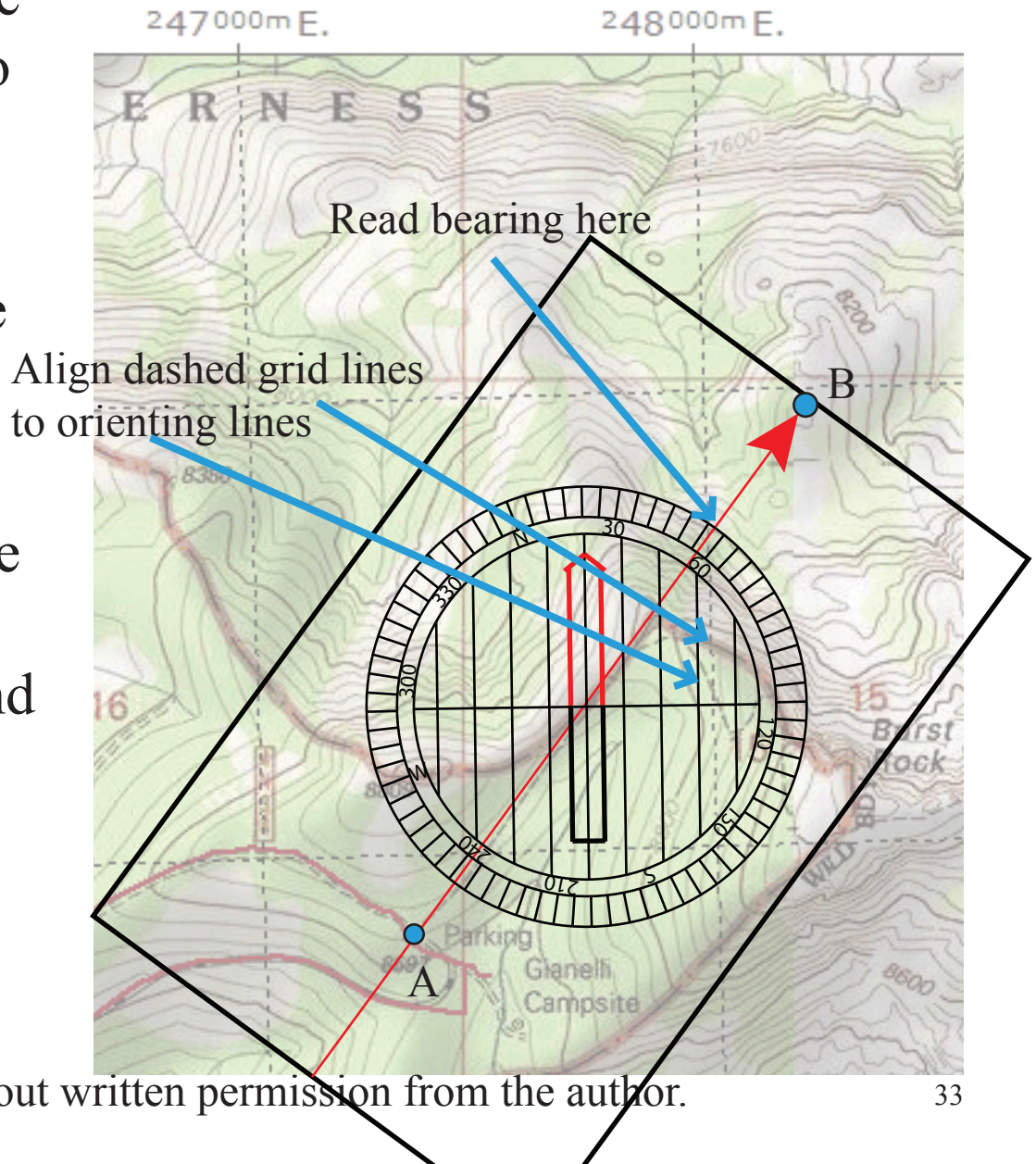
Bearing converter

Outline

Bearing with compass and map

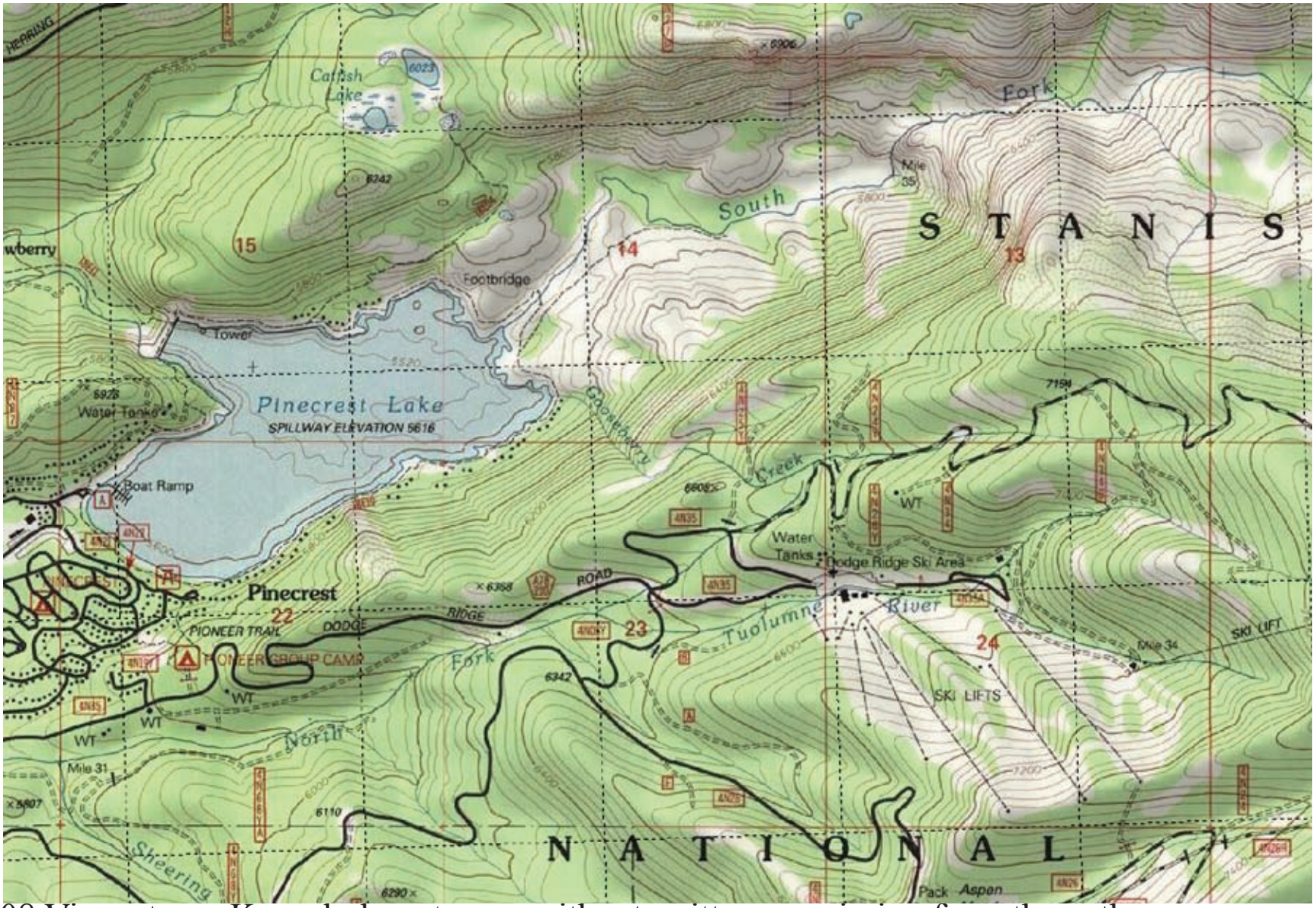
Outline

- The bearing is the angle the compass should be set at to take a specific direction to reach your goal.
- Ignore the magnetic needle during this process
- If you are at point A and want to go to point B, place the edge or center line of the compass on A and B and align the orienting lines to the grid (Grid N) or map edge (true North) with the red side pointing up to the map north



Bearing with map and compass animated

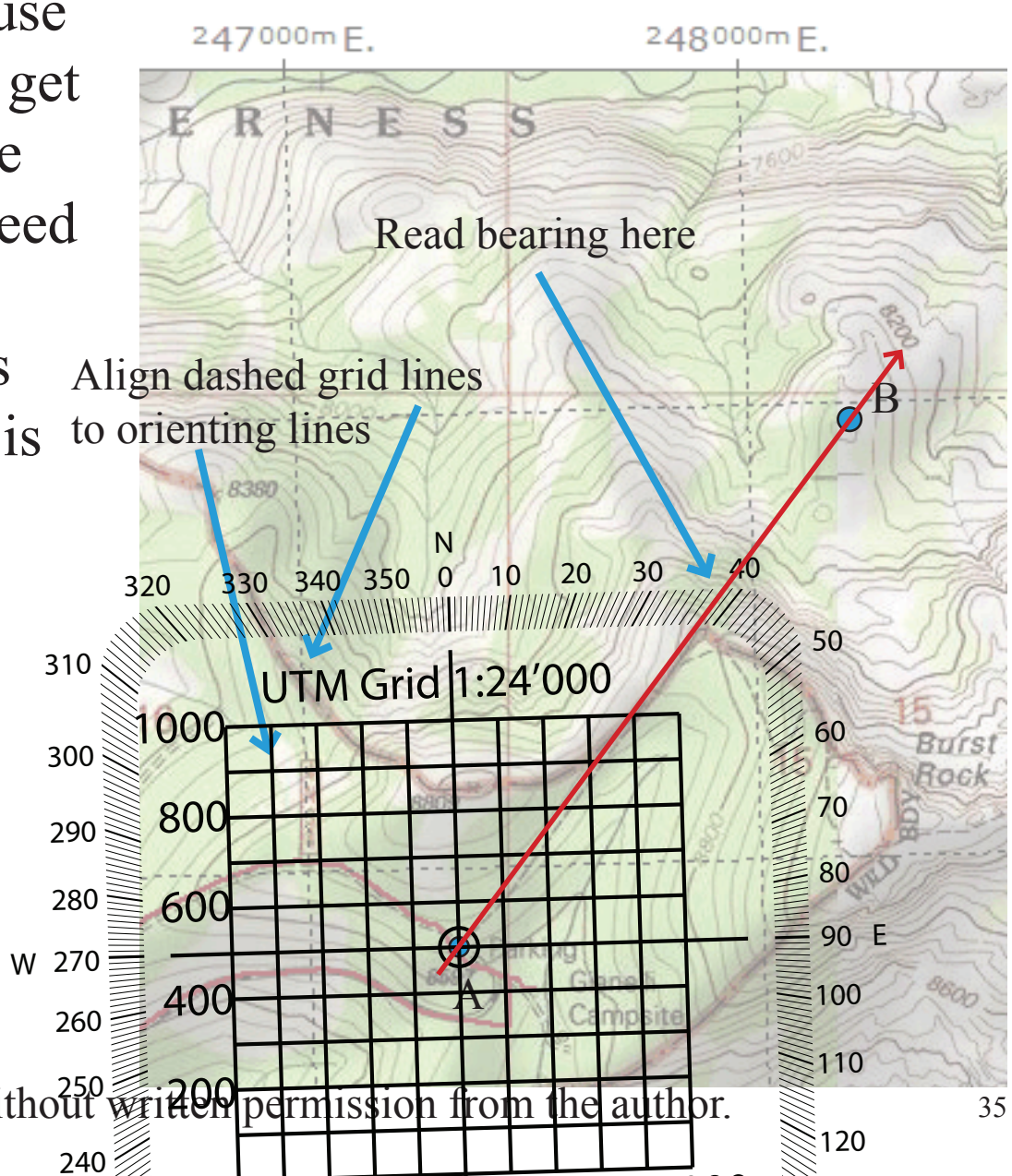
Outline



Bearing with compass and map

Outline

- Alternatively you could use the UTM grid overlay to get an accurate reading of the bearing. However, you need to set your compass (and GPS) to grid north in this case since the alignment is done on the grid
- Place the center of the UTM grid on point A and trace a line (in red on the figure) to point B and read the bearing on the scale in degree (grid north)



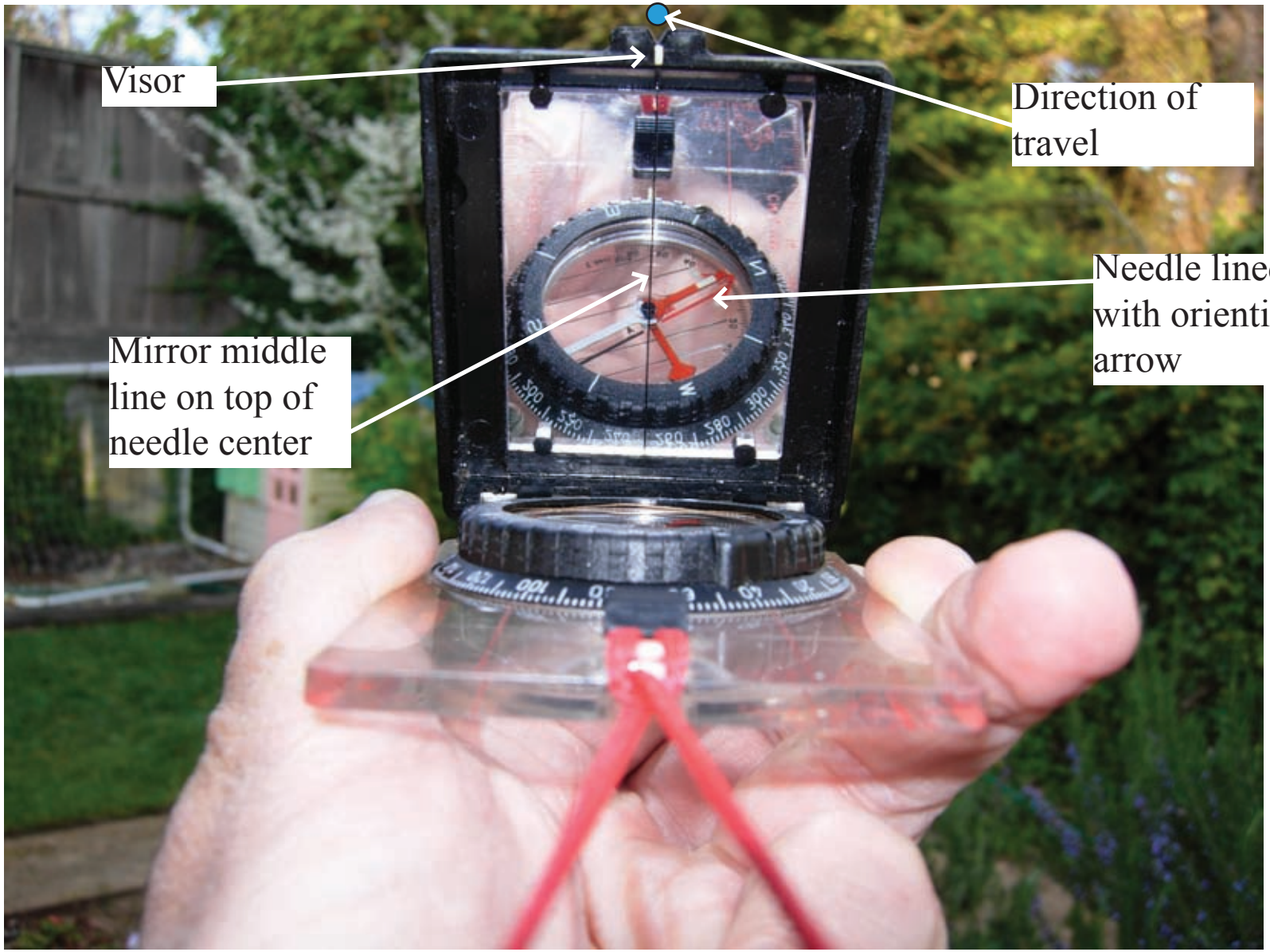
Bearing in the field

Outline

- To use the bearing as a direction of travel in the filed you have to:
  - Set the correct declination on the compass (either grid or true North)
  - Set the bearing on the dial of the compass, place compass in front of you horizontally and away from any metallic object.
  - Point the compass so that the magnetic needle is exactly in the box defined by the orienting arrow (be careful of the color matching too, ignore the clinometer if there is one)
  - Use the mirror of the compass to verify the correct alignment of the needle and the orienting arrow
  - Use the visor to see what is the direction in the field

Bearing with a mirror compass

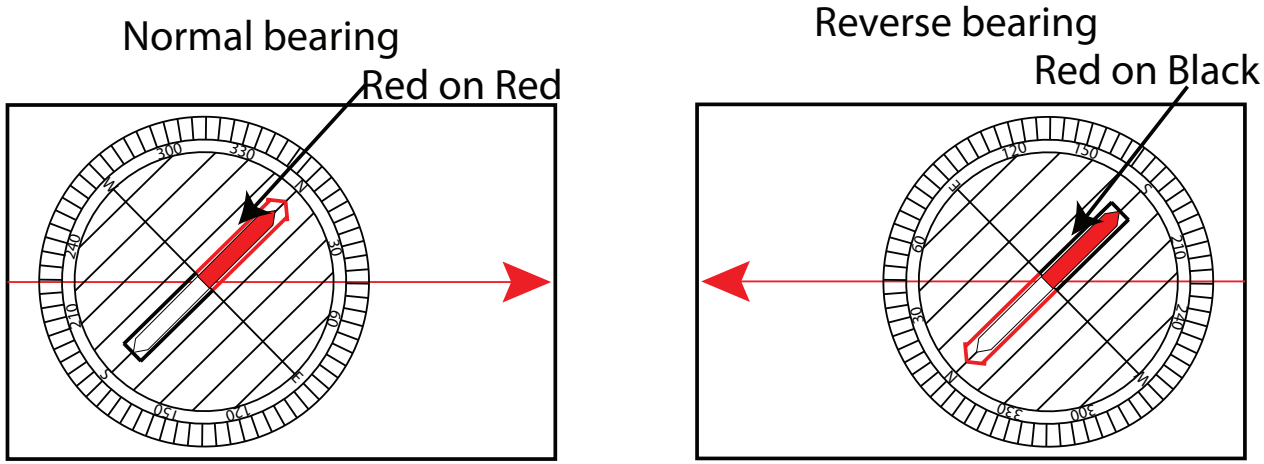
Outline



Reverse bearing

Outline

- It is useful to know how to take the reverse bearing for the way back to the starting point of your walk.
  - Either calculate a new bearing by adding or subtracting 180° to your original bearing, i.e. if your bearing was 23°, the reverse bearing will be 23+180=203°, or if it was 270°, the reverse bearing will be 270-180=90°
  - Alternatively, you could use the same bearing on the compass and align the red portion of the magnetic needle to the black section of the orienting arrow on the compass



The altimeter is measuring atmospheric pressure

Outline

- Altimeters are devices that measure the air pressure and calculate indirectly the altitude
  - The air pressure decreases with altitude following the equation:

$$P = P_0 \bullet e^{\frac{-M \cdot g \cdot altitude}{R \cdot T_{sealevel}}}$$

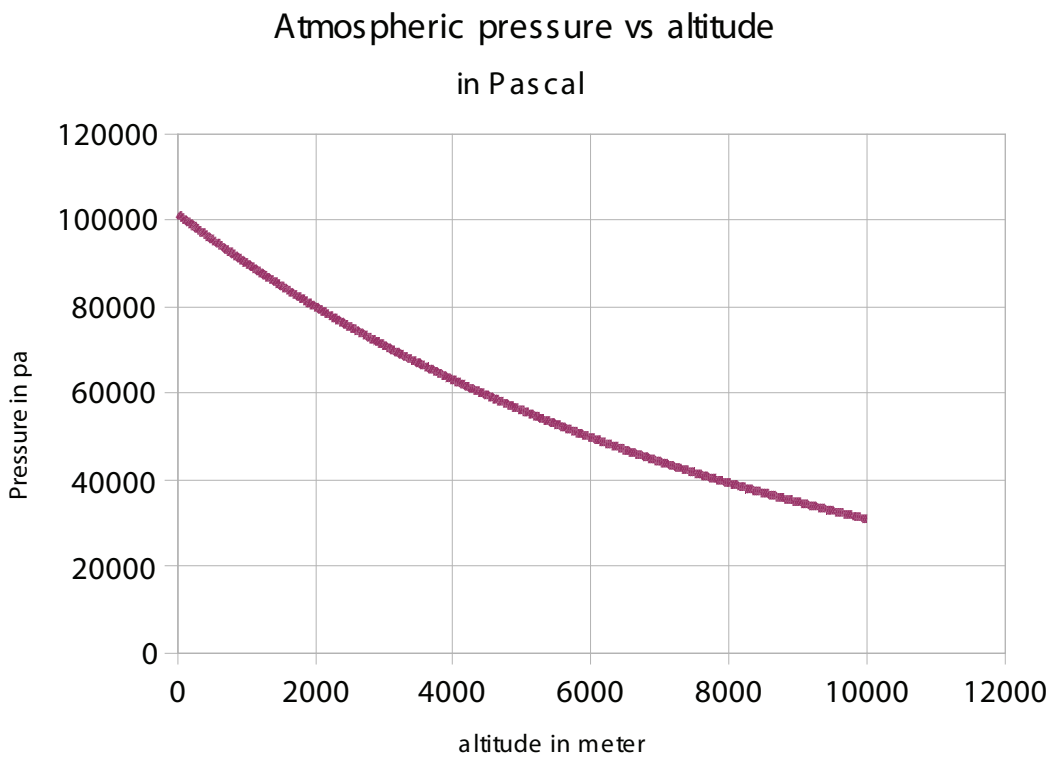
$$P_0 = 101325 Pa$$

$$m = 0.02897 kg / mole$$

$$T_{sea} = 288 K$$

$$R = 8.31451 J / K / mole$$

$$g = 9.80665 m / s^2$$



Altimeters need calibration

Outline

- The altimeter measure the atmospheric pressure which is not constant over time, temperature for the same altitude
  - The formula on the previous page shows that the Temperature has an influence on atmospheric pressure, hence the altimeter will not be accurate if the temperature changes.
  - Also, depending on the meteorologic conditions, the atmospheric pressure will change (high pressure system)
- For those reasons, the altimeter needs to be calibrated regularly to be usable for navigation
  - Calibrate the altimeter at the starting point of your travel and then each time you are certain of the altitude (summit, pass, marked point on the map, etc) or every 3h or ~8km/5miles travel.

Altimeter, mechanical or electronic

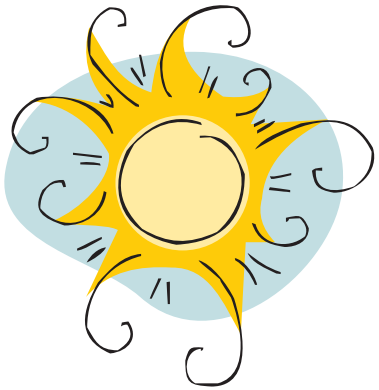
Outline

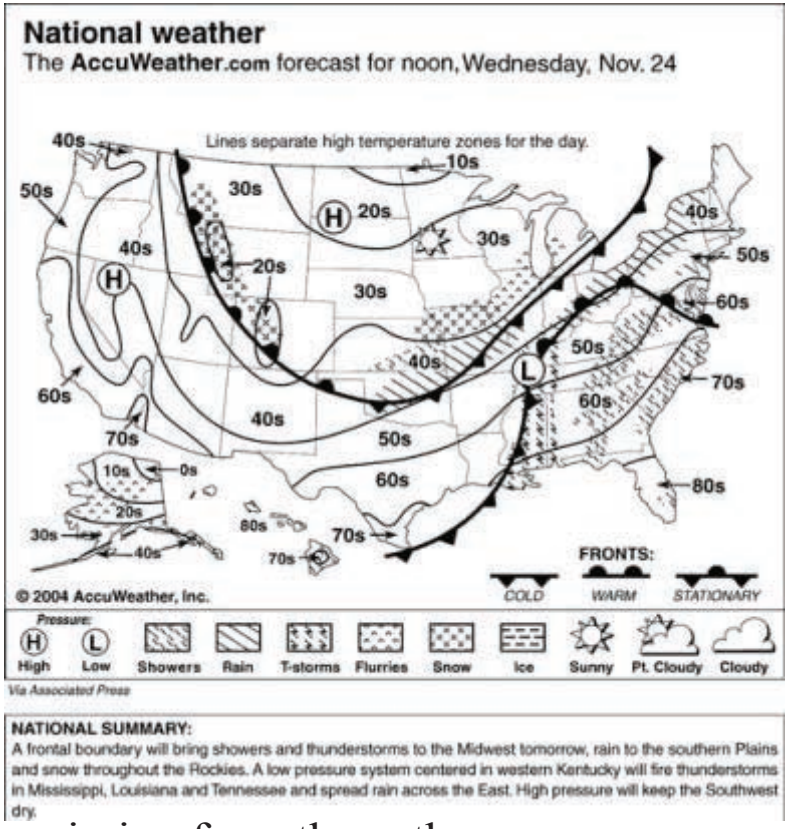
- Altimeters are either mechanical or electronic. In both cases they need calibration regularly to perform as a navigation instrument.
  - The accuracy is usually in the order of 10m/30ft in typical conditions (some watch/altimeter may not meet this level of accuracy)
  - For the electronic version, make sure that you have replacement batteries.

Altimeter as weather trend prediction

Outline

- When the altimeter is stationary (camp, overnight, etc) it can be used to follow the atmospheric pressure trend
  - If the pressure decreases (meaning the altitude on the altimeter will increases over time), the weather may deteriorate.
  - If the pressure increases (meaning the altitude on the altimeter will decreases over time), the weather may stay the same or improve.





GPS devices

Outline

- GPS devices receive signal from multiple satellites and are able to determine their position on earth (latitude/ longitude and altitude)
  - GPS devices are electronic, hence needs batteries to operate, make sure you have spare batteries for your navigation needs.
  - GPS devices can include many features but the main one that is available on all units is the fact that you can get your exact location (lon/lat or UTM for example) in a few minutes.
  - In some cases, the GPS will not be able to “see” enough satellites to determine the locations (dense forest, when view of sky is blocked by mountains sides, in a canyon, etc) hence GPS must be always complemented by map, compass and altimeter for safe travel in mountains.

GPS references

Outline

- A detailed white paper on how to use a GPS with map and compass can be found on the Garmin web site: "How to use a GPS with map and compass" (http://www8.garmin.com/manuals/UsingaGarminGPSwithPaperLandMaps_Manual.pdf)
- A good guide for the beginner can be found on this link: "GPS for beginners" (http://www8.garmin.com/manuals/GPSGuideforBeginners_Manual.pdf)

GPS features

Outline

- The main feature is that you can get the position of the GPS in a few minutes or less in many format/grid systems (i.e. UTM, Longitude/latitude and even altitude)
- Some GPS have build in pressure sensing altimeters that can be calibrated automatically with the GPS positioning system. This is very nice and could be used as altimeter for navigation.
- Mapping GPS have a memory that can contain basic maps (depending on the area 1:100k usually down to 1:24k in National parks). This is useful when the map is 1:24k. The 1:100k ones are not good enough for serious navigation.
- Some GPS have a build in magnetic detector that can be used as a compass (stationary compass, no need to move to detect direction). As of today (2008) the GPS with compass are not accurate enough or do not allow clear pointing (like the mirror compass).

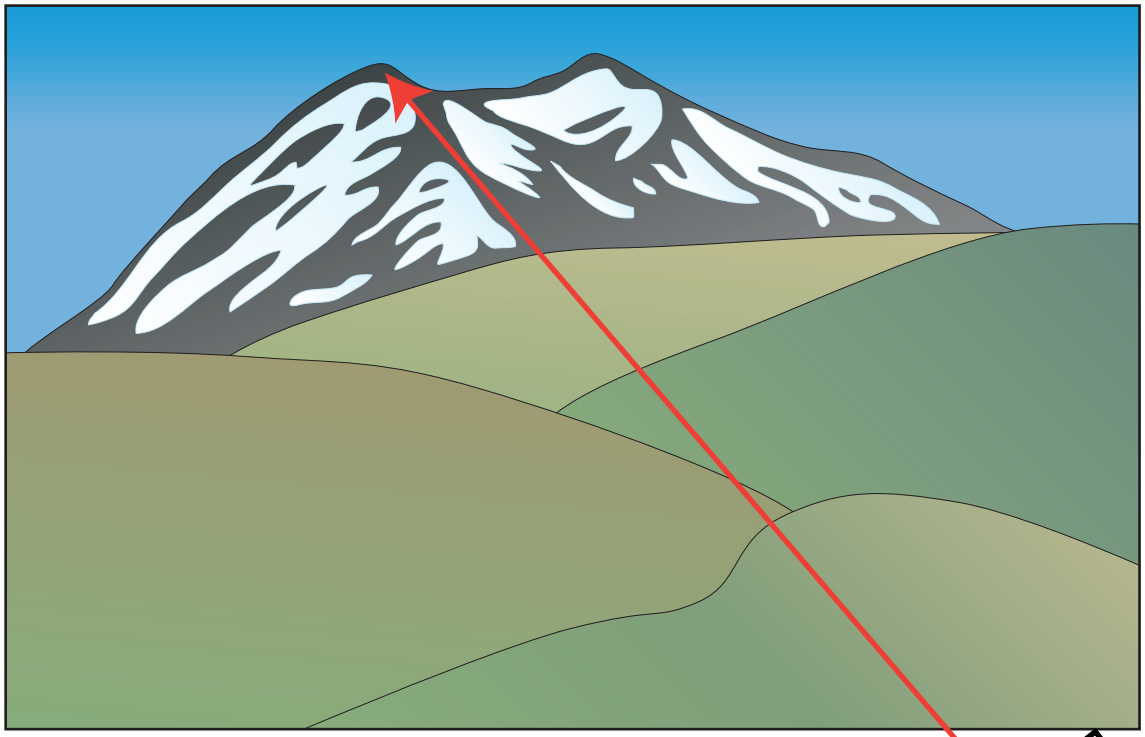
Taking a bearing in the field

Outline

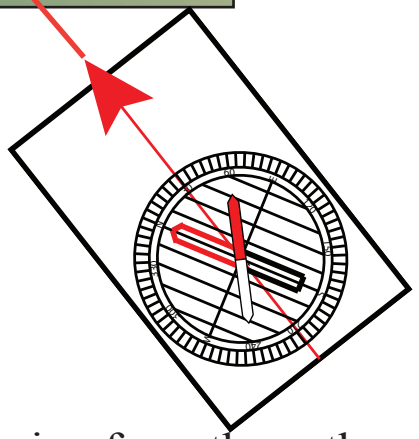
- To take a bearing in the field, make sure that you do not have any metallic item close to the compass and follow the steps:

Taking a bearing step 1

Outline

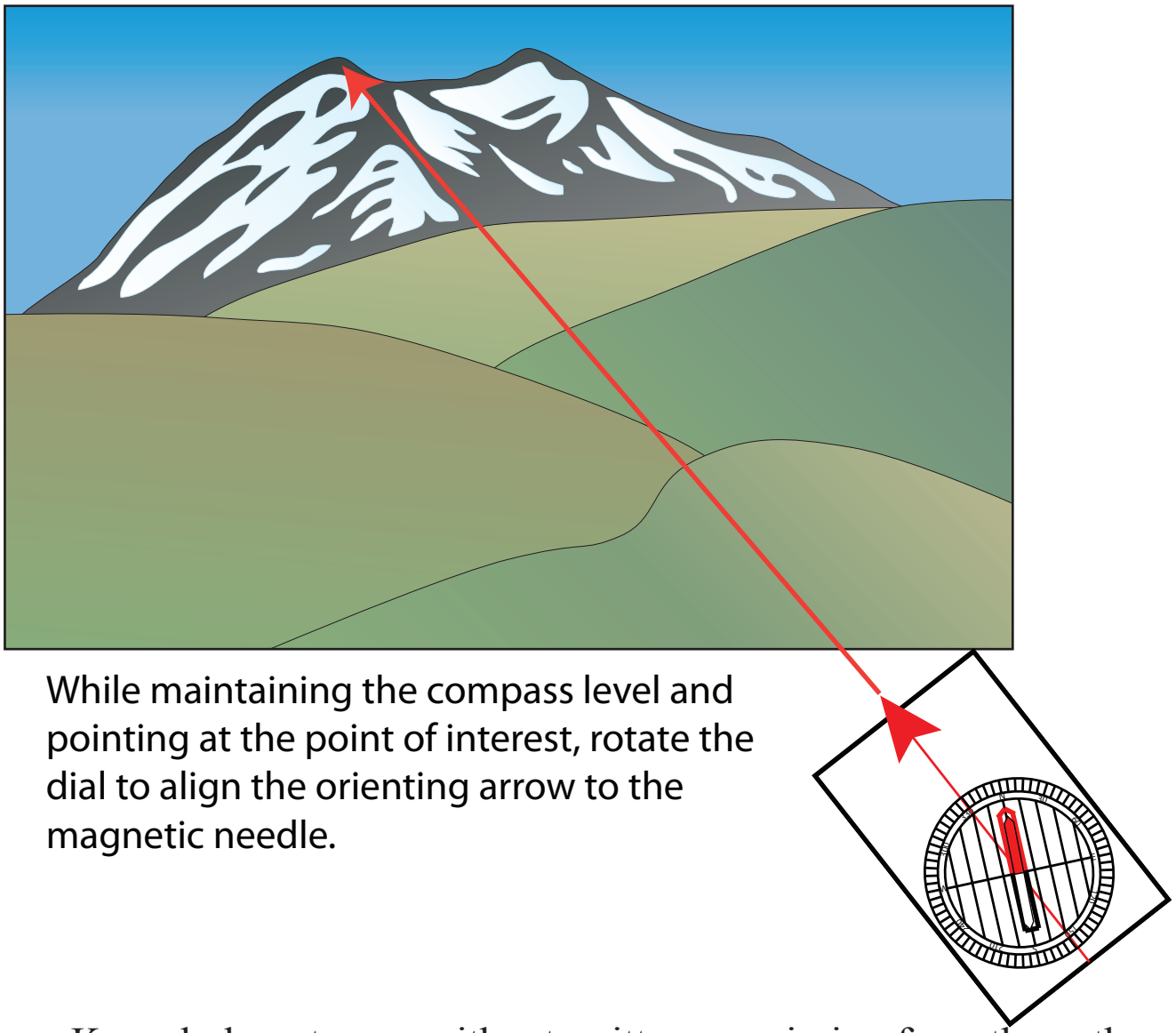


Aim the compass to the point you want the bearing, maintain it level so that the needle is free of movement, do not have any other metalic item close (car, pocket knife, other compass, watch, ski pole, etc)



Taking a bearing step 2

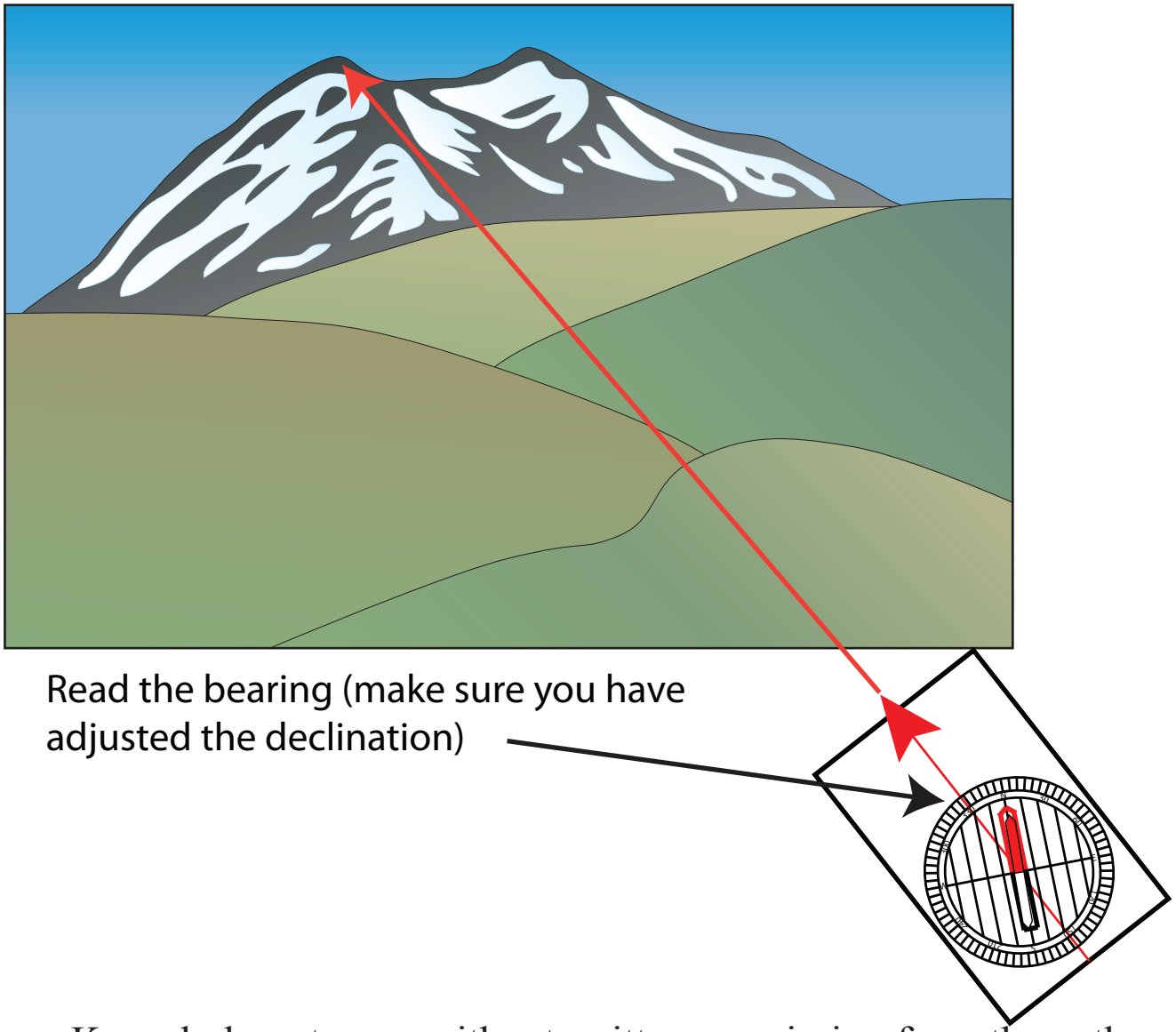
Outline



While maintaining the compass level and pointing at the point of interest, rotate the dial to align the orienting arrow to the magnetic needle.

Taking a bearing step 3

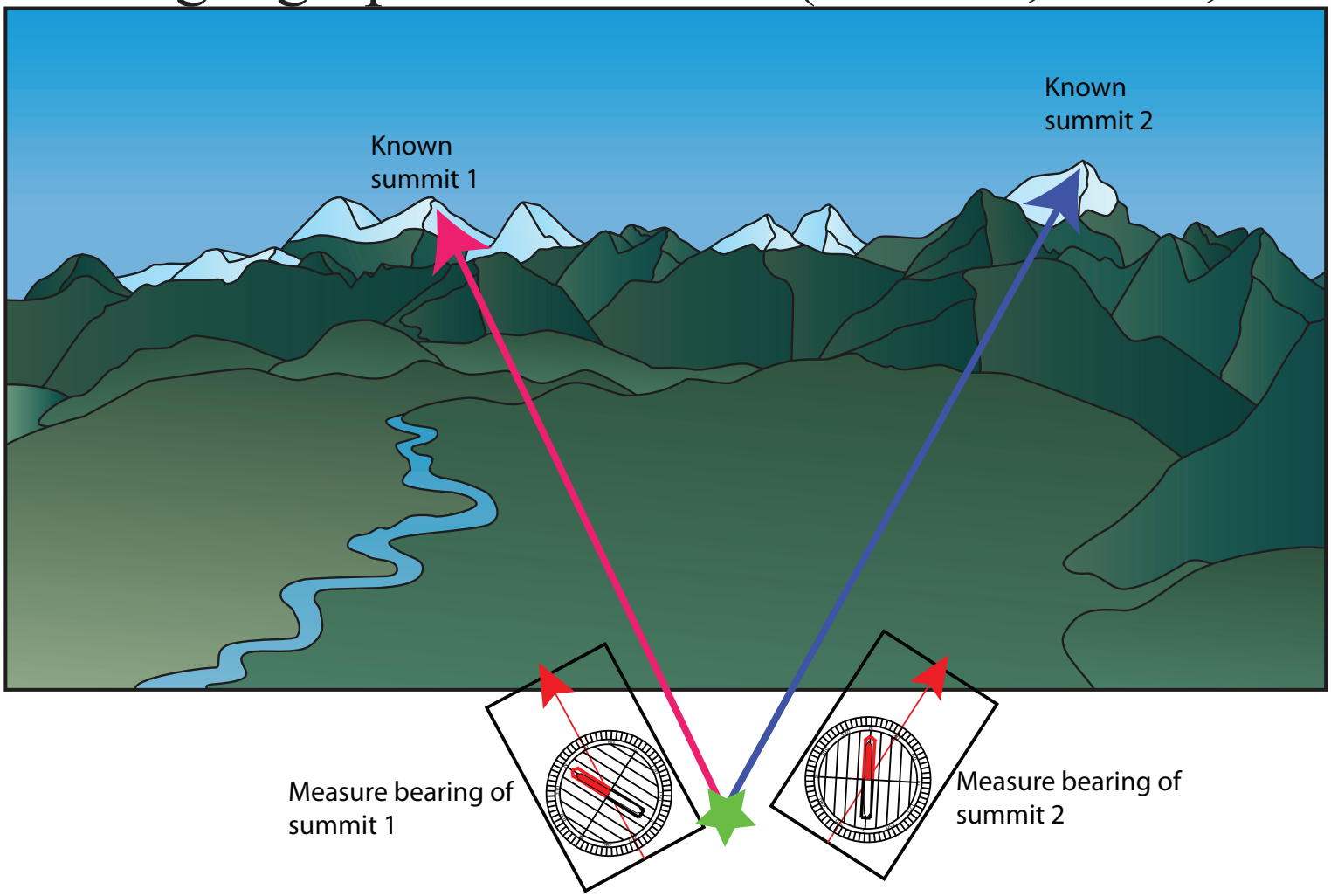
Outline



Determining your location with compass, map and altimeter (step 1)

Outline

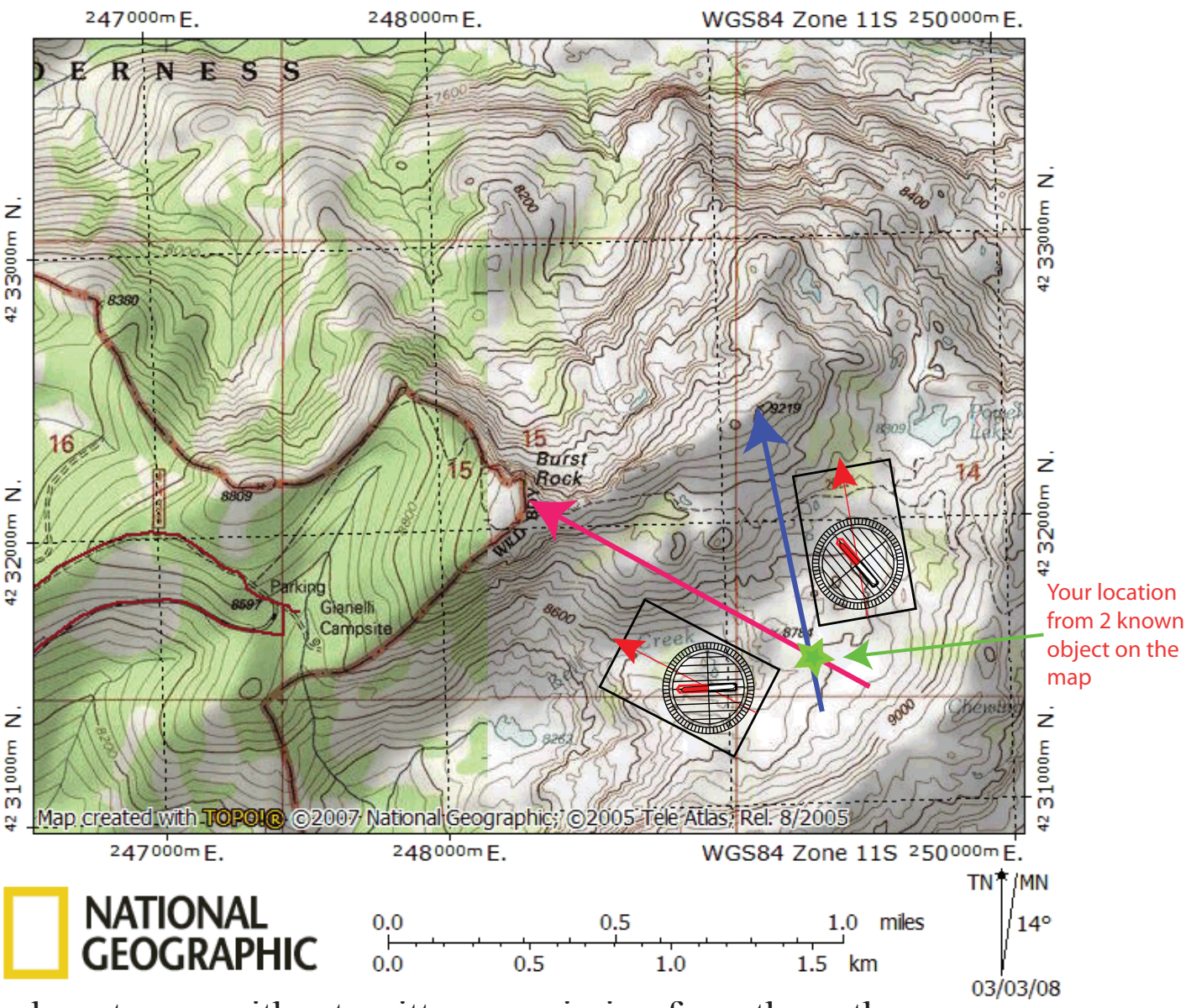
- You can determine your location by taking 2 bearings at 2 known geographical features (summit, lakes, road, etc)



Determining your location with compass, map and altimeter step 2

Outline

- Then report the 2 bearing on the map, the intersection is close to your location
- The angle between the 2 bearing should be ~90° for accuracy



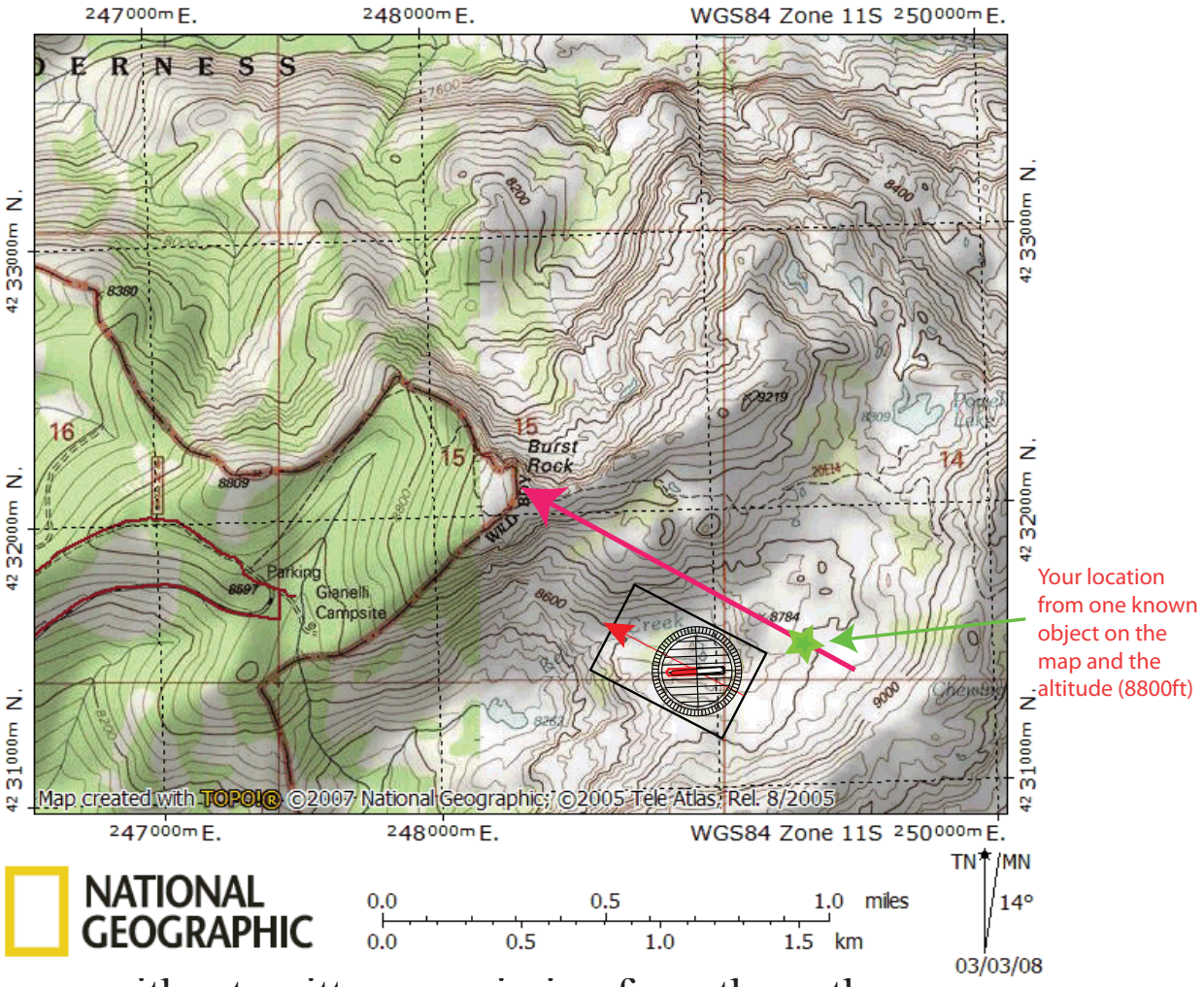
Determining your location with compass, map: Animation

Outline

Determining your location with map, compass and altimeter (alternative 1)

Outline

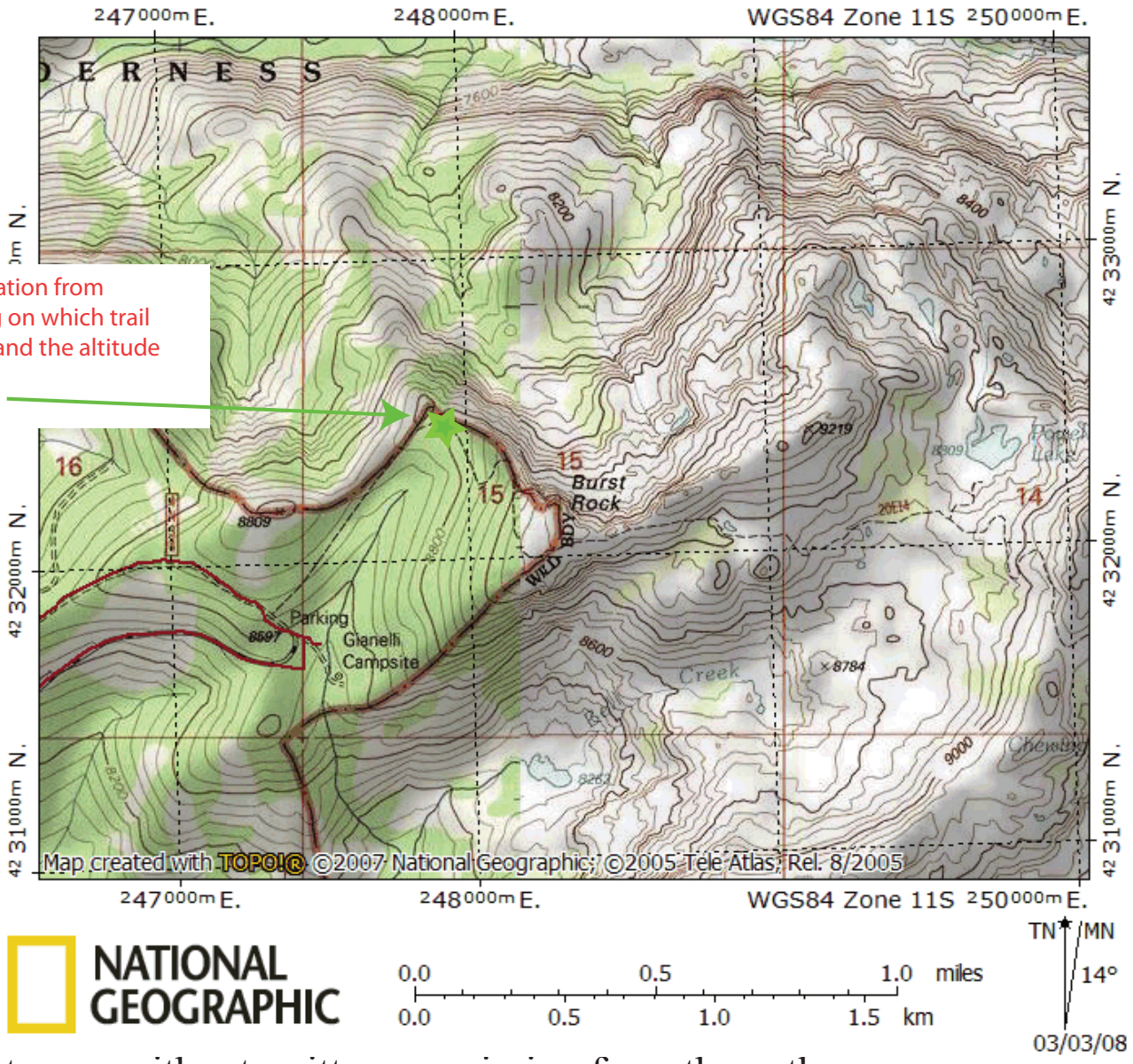
- If you only have one know geographical feature in sight and the altitude, you can determine your location also.
  - Report the bearing on the map and the crossing between the bearing and the contour line with your altitude is close to your location



Determining your location with map, compass and altimeter (alternative 2)

Outline

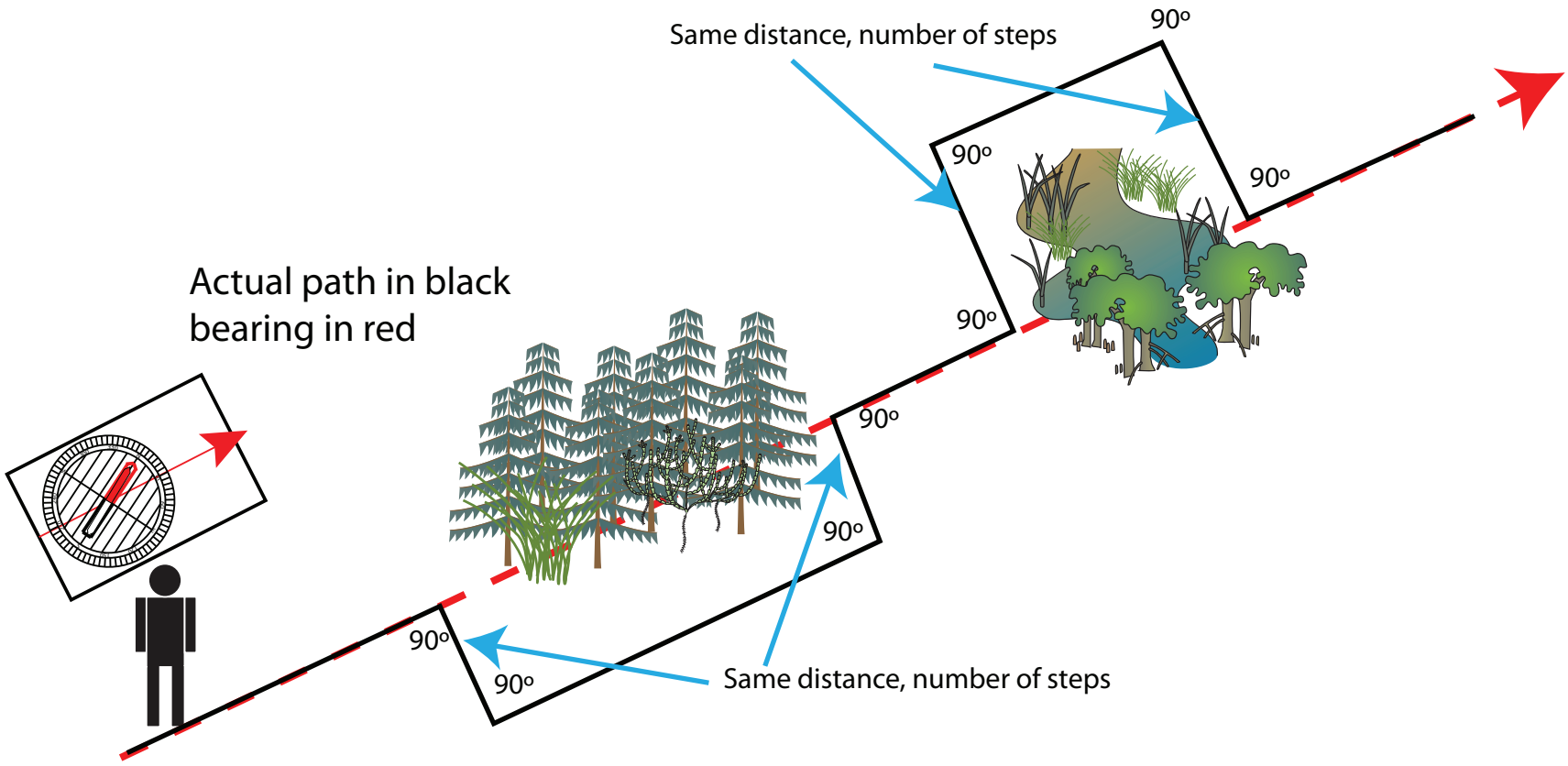
- If you know that you are on a specific trail/road and have an altitude you can deter-mine your location.



Avoiding obstacle when following a bearing

Outline

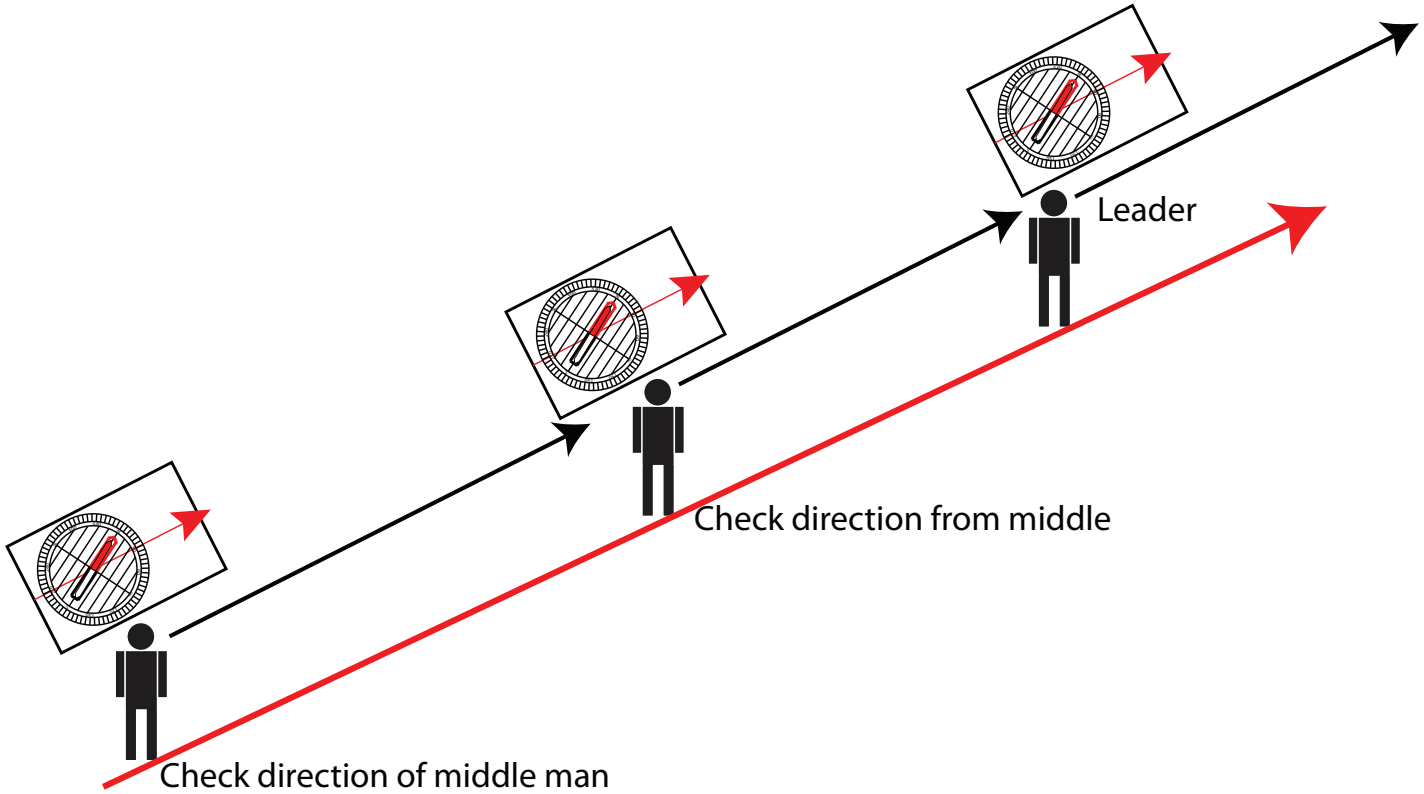
- To avoid obstacles on the path you may need to make 90° angle off the path, count your steps, then go back on the bearing and finally do a 90° towards the path using the same number of step to get back on track.



Following a bearing with limited visibility

Outline

- When you have to follow a bearing with limited visibility, you can improve the accuracy of the direction by spacing out 2 or 3 people with compass (all same bearing) and the leader is checked by the middle man and the middle man is checked by the last person
- Radios may be necessary if the wind is blowing to correct the direc-tion of the leader.



Timing your walk, pacing

Outline

- You can estimate how long it is going to take to walk between 2 points in the mountains if you know the distance and elevation (gain or loss) between the 2 points.
  - As a rule of thumb I have used 5km/h (3miles/h) for horizontal distance
  - For elevation gain, I have used 300m/h (1000ft/h)
  - For elevation loss, I have used 600m/h (2000ft/h)
- Adding the above contributions will give you an approximate timing of your walk.
  - For skiing, these values will be different, especially the elevation loss one, since it may be much faster.

Timing your walk, pacing, example

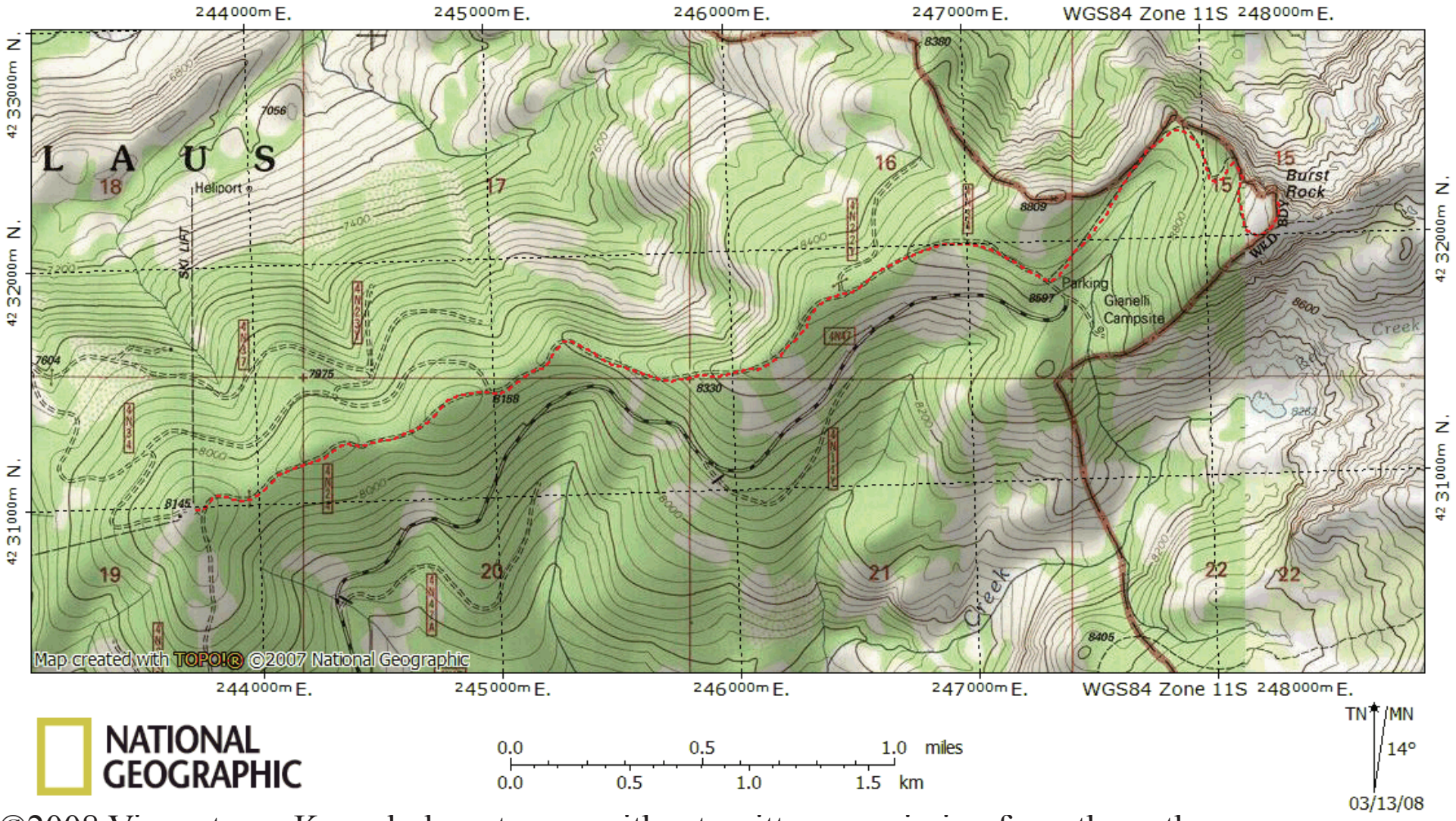
Outline

- For example if you have to travel 10km with 600m of elevation gain but 200m of elevation loss the approximate time for the walk will be:
  - 10km at 5km/h => 2 hours
  - 600m of elevation gain at 300m/h => 2 hours
  - 200m of elevation loss at 600m/h => 20 minutes (1/3 of an hour)
  - The total would be 4 hours and 20 minutes.
- You need to adjust those values (5km/h, 300m/h and 600m/h) according to your own pace.
  - Once this is done, this technique can be used to approximate location on a trail and help you in you navigation

How to prepare for mountain travel with map, compass, altimeter (1)

Outline

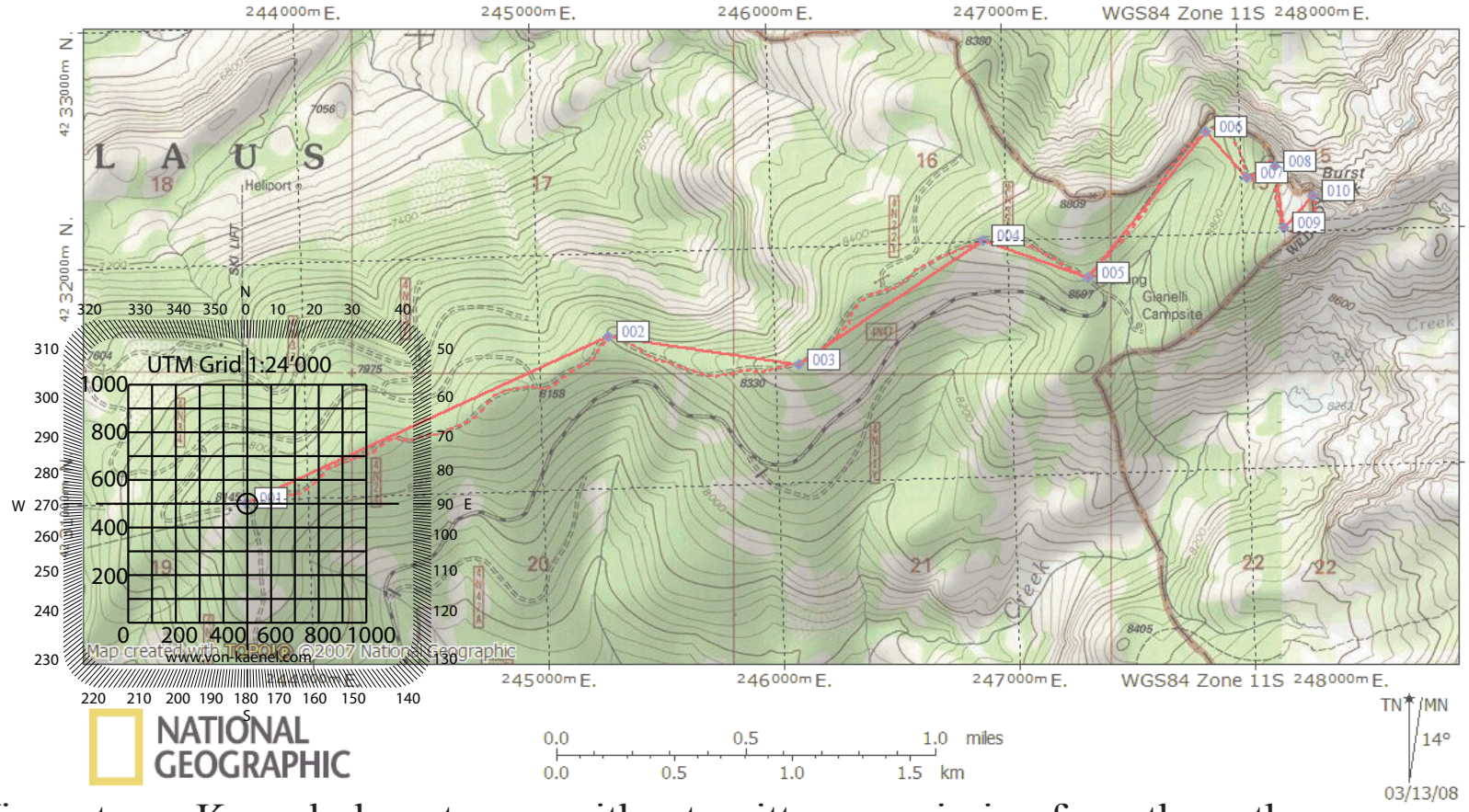
- Trace your intended route on the map:



How to prepare for mountain travel with map, compass, altimeter (2)

Outline

- Place way points to approximate your route at location that are easily identifiable like summit, ridge, road, trail crossing, lake, river crossings, pass, etc) so that you can be certain to have reached the way point in the field.



How to prepare for mountain travel with map, compass, altimeter (3)

Outline

- Then measure the bearing, distance and altitude for each way point (true North recommended, grid North also convenient)
  - If you have a software map, this can be done automatically (i.e. TOPO Map form NG)

Way point	Altitude in m	bearing to next (ºTN)	distance in km
001	2484	65.34	1.69
002	2501	98.39	0.82
003	2582	56.06	0.94
...			

How to prepare for mountain travel with map, compass, altimeter (4)

Outline

- Finally create a table (or spreadsheet) with all the way points, altitude, bearing, UTM coordinate, timing information (from pacing) and characteristic of the way point (summit, pass, lake, etc) (see next page)
  - For the return travel, you can calculate the reverse bearing (bearing ±180°) or use the same bearing but align the red magnetic needle to the black orienting arrow.
  - If you have a GPS, transfer all way points into your unit and make a route of them. Also enable the "tracking" function on the GPS to log all your travel inside the GPS, if you have enough batteries, maintain your GPS on all the time of travel.

How to prepare for mountain travel with map, compass, altimeter (5)

Outline

- Spreadsheet/Table example: (can be found on this link)

Example of spreadsheet for mountain navigation with Map, compass, altimeter and GPS

Vincent von Kaenel

UTM grid, datum NAD83

Pacing information

horizontal distance	5	km/h
Vertical ascent	300	m/h
vertical descent	600	m/h

Way point	UTM Zone	Easting mE	Northing mN	Altitude m	Bearing TN degree	Distance km	approx time (minutes)	Cumulative time (minutes)	Note
1	11S	243733	4230992	2484	65	1.69	24	0	Calibrate altimeter
2	11S	245291	4231649	2501	98	0.82	26	24	follow ridge top
3	11S	246097	4231504	2582	56	0.94	23	50	follow ridge top
4	11S	246895	4232006	2639	109	0.47	6	72	follow ridge top
5	11S	247335	4231835	2633	39	0.79	19	79	Calibrate altimeter, crossing Trails
6	11S	247854	4232438	2683	138	0.26	9	98	
7	11S	248022	4232237	2712	68	0.13	3	107	
8	11S	248143	4232282	2701	172	0.26	17	110	
9	11S	248173	4232020	2770	43	0.18	4	127	
10	11S	248302	4232152	2754				130	Calibrate altimeter

How to prepare for mountain travel with map, compass, altimeter (6)

Outline

- Print the spreadsheet and take it with you. Make sure that someone know where you are going and when to expect you back.
- You could also leave a copy of the spreadsheet in your car at the trail head.
- Adjust your compass for the declination of the area you will be travelling in. Make sure the map datum is coherent with the GPS and map (USGS 7.5' use NAD27).
- Load the way points and routes into your GPS if you have one. Make sure you know how to use it
- Get extra batteries for the electronic equipment
- Make sure that at least 2 people in your group know about navigations techniques. Try them in a known area.
- Check weather forecast, check your itinerary in Google Earth.

Execution of the plan in the field

Outline

- Follow your plan! Calibrate the altimeter at the start. Take additional notes (need a pencil) on the way in like special features that will help on the way back (rock formation, cornices in the winter, dangerous slopes.
- Follow your progress on the map. Calibrate your altimeter when you know for sure the altitude (summit, pass, trail crossing, etc)
- Turn on your GPS from the start if you have enough batteries, enable tracking function.
- Synchronize your digital camera time with your GPS so that you can determine exactly where your picture were taken with the track log or using a software (RoboGeo http://www.robogeo.com/home/)
- If you plan is going into a dangerous area (rocks, avalanche) change the plan, do not take any additional risks.

After the travel

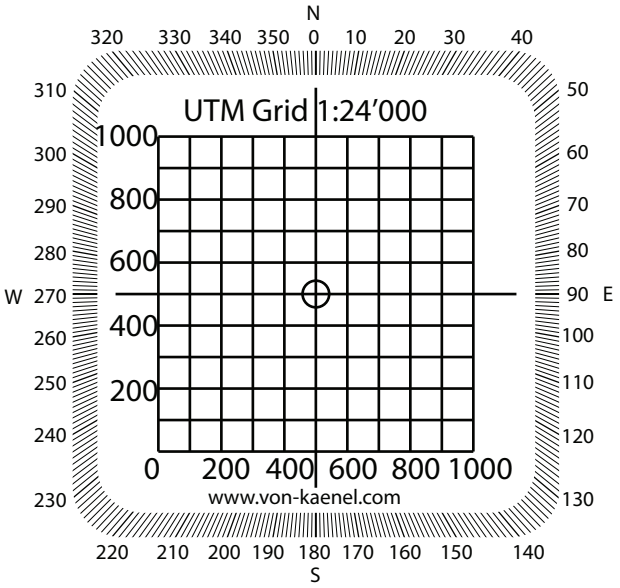
Outline

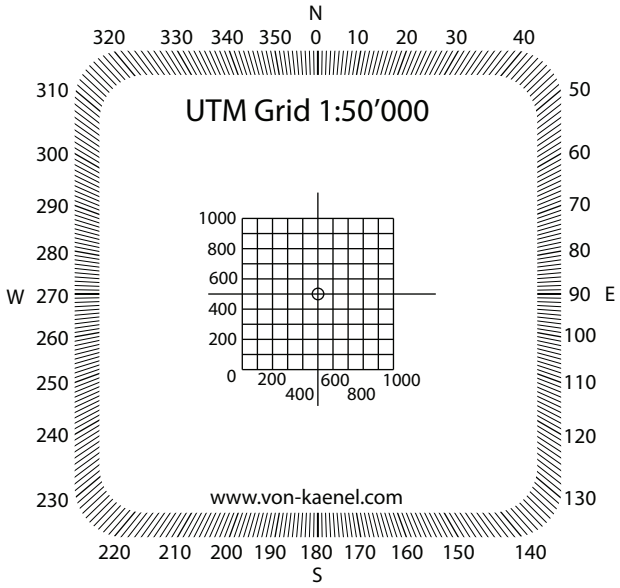
- After the trip, save your spreadsheets, map, additional notes and all documents for next time!
  - Add comments on what was good and what was not that good.
    - Save your GPS track log for future reference
    - Improve your organization for your next trip if possible.
    - You could publish on the web all this information, including pictures, someone may find it useful and will not get lost!

Annex

Outline

- UTM grid overlays for 1:24’000 and 1:50’000 maps





References

Outline

- USGS: http://www.usgs.gov/
- Garmin GPS: http://www.garmin.com/
- Topo!Maps : http://www.natgeomaps.com/
- RoboGeo: http://www.robogeo.com/home/
- Google Earth: http://earth.google.com/
- The site where you found this document: http://www.von-kaenel.com/
- Symbols for diagrams courtesy of the Integration and Application Network (ian.umces.edu/symbols), University of Maryland Center for Environmental Science.

Notes

Outline