Proposing An International Collaboration On Lightweight Autonomous Vehicles To Conduct Scientific Traverses And Surveys Over Antarctica And The Surrounding Sea Ice

Frank Carsey and Alberto Behar
Jet Propulsion Laboratory, California Institute of Technology

Abstract

We have continued to develop a concept for use of autonomous rovers, originally developed for use in planetary exploration, in polar science on Earth; the concept was the subject of a workshop, and this report summarizes and extends that workshop. The workshop on Antarctic Autonomous Scientific Vehicles and Traverses met at the National Geographic Society on February 14 and 15, 2001 to discuss scientific objectives and benefits of the use of autonomous rovers. The participants enthusiastically viewed rovers as being uniquely valuable for such tasks as data taking on tedious or repetitive routes, traverses in polar night, difficult or hazardous routes, extremely remote regions, routes requiring only simple instrumentation, traverses that must be conducted at low speed, augments of manned traverses, and scientific procedures not compatible with human presence or combustion engines. The workshop has concluded that instrumented autonomous vehicles, of the type being developed for planetary exploration, have the potential to contribute significantly to the way science in conducted in Antarctica while also aiding planetary technology development, and engaging the public's interest. Specific objectives can be supported in understanding ice sheet mass balance, sea ice heat and momentum exchange, and surface air chemistry processes. In the interval since the workshop, we have concluded that organized program to employ such rovers to perform scientific tasks in the Fourth International Polar Year would serve the objectives of that program well.

1. Introduction

Autonomous surface-roving vehicles are well-established tools for planetary exploration, having been successfully deployed on the Moon and Mars. A close look at the climate of Mars shows that it is remarkably like Antarctica with the notable exceptions of water vapor and atmospheric pressure, both quite small on Mars. This similarity has motivated the use of Earth's polar regions as useful sites for demonstration of capability, and the ever-growing capability of the rover designs has motivated Earth scientists to consider their use for collection of crucial data in these remote sites (Lee et al, 1999). Toward that end a workshop was held in 2001, to be summarized below. In the time since the workshop we have pursued the general issue of application of robotics and automation technology to for science and logistics in the polar regions, and we are convinced that the value of the strategy is significant. In fact, we argue that these technologies can contribute significantly to the Fourth International Polar Year (IPY4) in performing significant science, advancing new technology, training the next generation of scientists, enabling collaborations including both large and small national polar programs, and engaging the public.

2. The Workshop

On February 14 and 15, 2001, a workshop was held at the National Geographic Society in Washington DC to examine the scientific benefits of deploying instrumented autonomous vehicles in Antarctica; conclusions of the workshop were presented and published at the International Symposium on Artificial Intelligence, Robotics and Automation in Space (Carsey et al 2001). Represented at the meeting were US, British, French, and German participants; from the US there were members of the academic and technical communities, NASA centers, and the National Science Foundation. Workshop discussions covered the state of development of autonomous vehicles, the scientific objectives, benefits and limitations of ongoing Antarctic traverse science, the scientific opportunities and requirements for autonomous traverses, the prospective scientific instrumentation for autonomous traverses, the challenges provided to the technical community by both the Antarctic environment and the science objectives, and the tasks to be addressed to develop a scientifically meaningful international multi-agency program in autonomous traverses. It is likely that a follow-up workshop would be beneficial to progress in this area.

3. Traverse Practice Today

Ice sheet traverses were an essential element of early ice sheet exploration and observation in Antarctica and Greenland, and the overland traverse is still today used for science and for camp support by several national Antarctic programs. Long-range scientific traverses have recently resumed in Antarctica, conducted principally as part of the 15 nation International Trans-Antarctic Scientific Expeditions (ITASE; see http://www.antcrc.utas.edu.au/scar/itase/itase.html) program focused on climate-history studies covering the past 200 years. The ITASE program has been strikingly successful through using international teams to address scientific objectives in climatology, geophysics, surface glaciology, remote sensing and meteorology. Short traverses, of scale of 10's of kilometers, are routine tools for surface and firn properties.

4. Autonomous Rover Design Today.

The rovers that have been deployed recently at Mars have performed wonderfully, yet they are clearly not simply transportable to a polar scientific site, and some of the rovers that have worked in polar environments are clearly not designed for long-range autonomous traverses. There are numerous designs at a number of institutions, however, that are appropriate to long-range polar autonomous application; one from JPL is shown in Figure 1. To see some current designs use the web:
http://mars.jpl.nasa.gov/technology/rovers/rovers02.html
http://www.frc.ri.cmu.edu/sunsync/html/Background.htm

5. Science Opportunities Provided By Autonomous Rovers

Here are a the sorts of tasks well suited to autonomous rover implementation:

5.1 Difficult or Hazardous Traverse Routes. Medium and long-range traverses across sea ice or heavily crevassed areas of the ice sheet are challenging yet scientifically interesting.

5.2 Observations in Polar Night. Numerous surface processes are thought to occur during the dark of polar winter, but current sampling is restricted to year-round coastal stations. Winter processes to be studied include, timing, duration and magnitude of snow accumulation and grainsize modification, timing of appearance of chemical species, and the onset of photochemistry in spring.

5.3 Extremely Remote and/or Inhospitable Routes. Some parts of East Antarctica and some mountainous areas of Antarctica are so remote that airborne life-support is logistically difficult.

5.4 Routes Involving Particularly Simple Instrumentation. Acquisition of recent snow accumulation or topography change data for a region may be crucial to comparing data sets or to cal/val for a satellite data set, yet the mission cannot justify a full manned traverse, or the timing of the data requirement may be too urgent to allow planning for a human traverse.

5.5 Augments of Manned Scientific Traverses. Manned traverses are increasingly capable in scientific breadth, but they are inherently one-dimensional; the acquisition of a reduced set of data on tracks orthogonal to the manned traverse can provide 2-D statistics without impacting progress of the main traverse.

5.6 Detailed and Tedious Routes. Mapping routes such as "mowing the lawn" for detailed information in a region are notoriously difficult for operator-controlled systems due to loss of concentration and impatience.

5.7 Instrumentation Requiring Slow Traverse Speed. Certain geophysical observables, e.g. magnetometer and gravimeter data, must be taken at the surface at a speed slower than aircraft speed; for these data sets a rover is ideal.

6. Candidate Science Projects For Autonomous Rovers

A number of scientific programs can be identified for autonomous rovers; we describe three that are characterizable by having instrumentation that is well developed so that these projects can go forward with a minimum of instrument development cost and time.

6.1 Ice Sheet Mass Balance. Autonomous Rovers equipped with sounding radars can map snow accumulation, isochronous layer depths, ice thickness and subglacial topography and condition. A follow-on augmentation with shallow corers in the manner of ITASE would allow determination of snow isotopic and chemical composition. Snow accumulation is required for computation of ice sheet mass balance, either by field measurements or numerical modeling. It is also one of the least explored components of the global hydrological cycle. Tracking of isochronous layers over large distances provides estimates of accumulation rate and deformation and can connect "calendars" at widely separated sites. Ice thickness is also a necessary component for ice sheet models and subglacial topography aids understanding of ice sheet flow. Also possible are evaluation of climate variability in time and space, finely-detailed mapping of basal conditions in regions of transition from frozen to wet, extension of accumulation statistics normal to major traverse lines, mapping of accumulation and isochron depths along ice divides and flow lines, and providing calibration/validation data for satellite data sets (Parkinson et al, 1999).

6.2 Heat and Momentum Exchanges Through Sea Ice. Sea ice regions are characterized by large and variable fluxes of heat and mass between the atmosphere, ice and ocean mixed layer, and the sea ice field is difficult to map with traditional means due to its roughness and the occurrence of open water and thin ice areas. The air-sea-ice system is highly sensitive to climate change (Fetterer and Untersteiner, Polyakov and Johnson, 2000; Rothrock et al, 1999). A light-weight, buoyant rover such as has been described can accommodate this situation by taking Electromagnetic induction or acoustical measurements of sea ice (Perovich et al, 2003) and snowcover thickness as well as surface temperatures, winds, and oceanic salinity over extensive traverses from near shore to the marginal zone through leads and polynyas.

6.3 Snow Surface Chemical Processes. Chemical exchange between the atmosphere and snowpack is complex, and, because of the vast surface area of the polar ice sheets, can have a profound effect on trace components of the polar atmosphere and ice. These processes are particularly dynamic at the end of polar night. While chemical concentrations are miniscule, modern methods offer the prospect of monitoring these processes in situations in which the presence of humans and combustion engines cannot be tolerated, and during periods when field investigation by humans is difficult to support..

7. Robotic Challenges Of Polar Traverses

Robotic capabilities for Antarctic deployment must be addressed considering both science requirements and the environment. A preliminary examination suggests that significant issues will include the capability for traverses of about 100 days, capability to control position at the meter level, crevasse and other hazard detection and avoidance, 24 hour per day operations, collaborating rovers, route selection and decision making, problem self-diagnosis and recovery, power, wind, blowing snow, deep snow, sastrugi, operations with optical systems pointed at the sun, communications, and articulating , self-stowing solar array(s). These issues should be examined for each prospective task for IPY4.

8. Value of Autonomous Rover Strategy In the Context of IPY4

In the context of IPY4, polar rovers can contribute in the areas of:

8.1 Significant Science. We have determined that the autonomous rover (similar to the version being developed for planetary exploration) can enhance current scientific programs and open new windows of study.

8.2 Enabling Polar Scientific Technology. The Antarctic autonomous rover poses a grand challenge to the autonomous vehicle community, and we perceive spin-off value in a number of areas.

8.3 Training a Generation of Scientists. The next generation of scientists will be far more technology-aware than any past generation, and the tools of autonomous robotics will be a basic staple of their methodology.

8.4 Involving a Wide Range of National Programs. Participation in the polar rover fleet can be accomplished at nearly any level. Larger programs can field complete robotic explorers or substantial subsystems, and smaller programs can collaborate with large and small programs to form teams comprised of subsystem providers.

8.5 Engaging Public Interest. There is enormous potential in autonomous vehicles undertaking long and challenging traverses across the ice sheet. Optimizing public interest will of course place requirements on the rover implementation and development program, e.g., it would be desirable to deploy rovers in groups so that each rover can be observed by another. We do not see these requirements as constituting a significant obstacle.

8.6 Improving safety and reducing impact of polar scientific operations. Autonomous rover operations will improve overall safety of human operators by relieving them of some traverse duties; less fuel will be consumed; and impact on the environment will be reduced over traditional fossil-fuel powered traverses.

9. Other Useful Autonomous Vehicles

In addition to autonomous surface vehicles, the robotics world has also generated other systems of established and potential value to the polar science community. In particular, autonomous aircraft have great promise in several areas and have obtained excellent results over the Arctic Ocean (see e.g., http://cires.colorado.edu/~maurerj/class/UAV/aerosonde.htm) and autonomous underwater vehicles (Hayes and Morison, 2002), long of value in the midlatitudes marine environment, are increasingly used in the polar regions. We note that presentations on airborne and underwater autonomous systems will be made during the SCALOP Symposium in which this paper is also intended. These various systems should all be assessed and exploited in the context of advancing polar science.

10. Summary

We conclude that instrumented autonomous vehicles, of the type being developed for planetary exploration, have the potential to contribute significantly to the way science in conducted in Antarctica: improved observations can be made; human safety is enhanced; costs can be reduced; environmental impact will be lessened; and engagement with the public as well as with young scientists will be strengthened. Specific scientific objectives can be supported in understanding ice sheet mass balance, sea ice heat and momentum exchange, surface air chemistry processes, and fine-scale geophysics. There are issues of rover capability and scientific instrumentation that require additional development, but even in the immediate future there are useful implementations to initiate this approach. We recommend that this aspect of the IPY4 opportunity be taken as a core initiative in SCALOP and SCAR and pursued further in the scientific and technology communities so that an international, multi-agency program is generated to address technology development and polar science. We argue that additional focused workshops be considered to develop a specific plan for coordinating relevant aspects of autonomous rover technology and polar science to implement the approach.

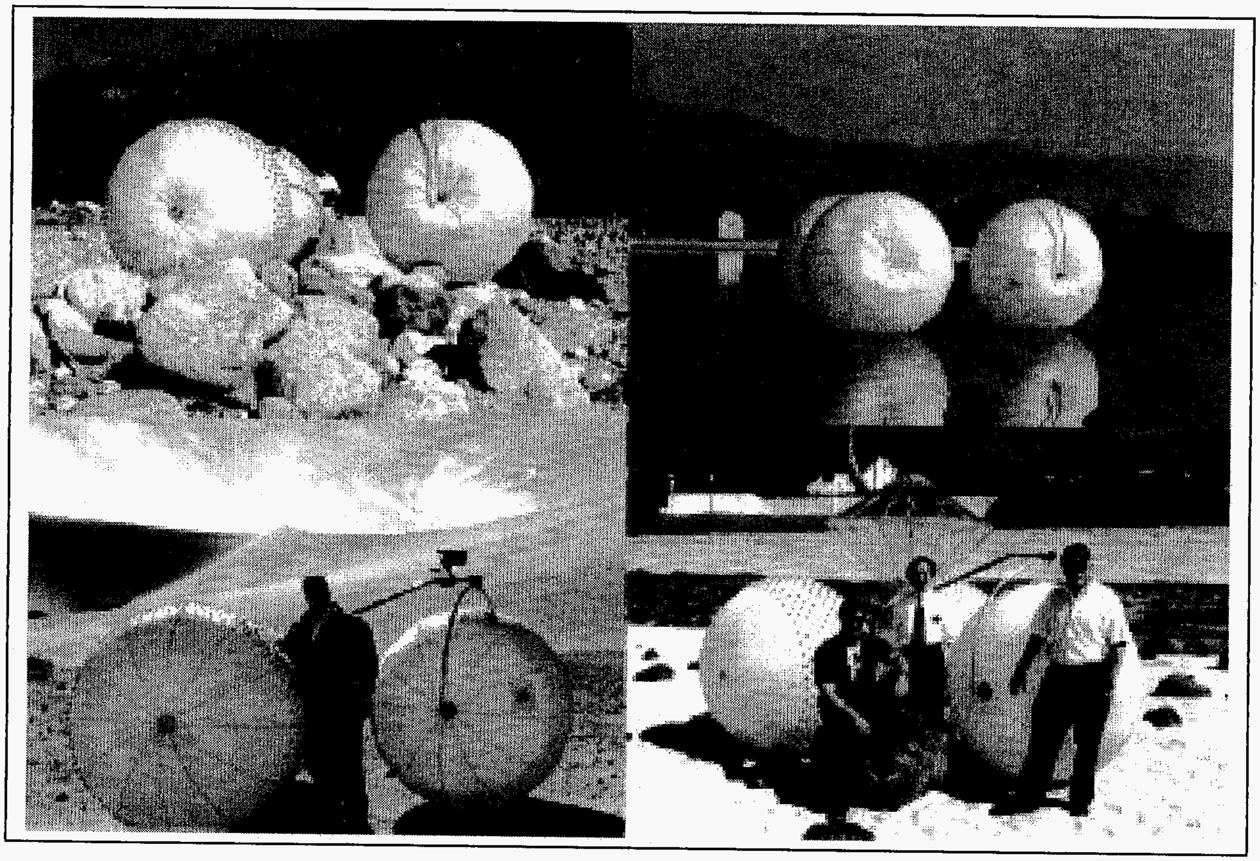

Figure 1 The JPL Inflatable Rover prototype. The prototype has successfully traversed a wide range of surface types. The 1.5 m diameter wheels can roll over 0.5 m obstacles without hesitation; for route management an autonomous vision system will be required.

11. References

Behar, A., F. Carsey and B. Wilcox, Polar traverse rover development for Mars, Europa and Earth, *Aerospace Conference Proc. IEEE, Vol 1*, 389-395

Carsey, F., P. Schenker, J. Blamont, S. Gogineni, K. Jezek, C. Rapley, and W. Whittaker, Autonomous trans-Antarctic expeditions: An initiative for advancing planetary mobility system technology while addressing Earth science objectives in Antarctica, *Proc ISAIRAS* Montreal, 2001.

Fetterer, F., and N. Untersteiner, Observations of melt ponds on Arctic sea ice, *Journal of Geophysical Research, 103* (C11), 24,821-24,835, 1998

Hayes, D. R., and J. H. Morison, 2002, Determining turbulent vertical velocity and fluxes of heat and salt with an autonomous underwater vehicle, in press, *J. Atmos Ocean. Tech., 19* (5), pp. 759–779.

Lee, P., W.A. Cassidy, D. Apostolopoulos, D. Bassi, L. Bravo, H. Cifuentes, M. Deans, A. Foessel, S. Moorehead, M. Parris, C. Puebla, L. Pedersen, M. Sibenac, F. Valdés, N. Vandapel, and W.L. Whittaker, Search for Meteorites at Martin Hills and Pirrit Hills, Antarctica, *Lunar and Planetary Science Conference XXX*, 1999

Parkinson and others. 1999. Arctic sea ice extents, areas, and trends, 1978–1996. *Journ. Geophys. Res.* 104:20837–20856.

Polyakov, I. and M. Johnson. 2000. Arctic decadal and interdecadal variability. *Geophys. Res. Lett.* 27:4097–4100.

Rothrock, D., Y. Yu and G. Maykut. 1999. Thinning of the Arctic sea ice cover. *Geophys. Res. Lett.* 26:3469–3472.

Perovich, D.K., T.C. Grenfell, J.A. Richter-Menge, B. Light, W.B. Tucker III, H. Eicken, Thin and thinner: ice mass balance measurements during SHEBA, Journal of Geophysical Research Oceans, 108, (C3), DOI 10.1029/2001JC001079, 26-1 – 26-21, 2003