

Global Physiographic and Climatic Maps to Support Revision of Environmental Testing Guidelines

Eric V. McDonald
Steven N. Bacon
Scott D. Bassett
Sara E. Jenkins

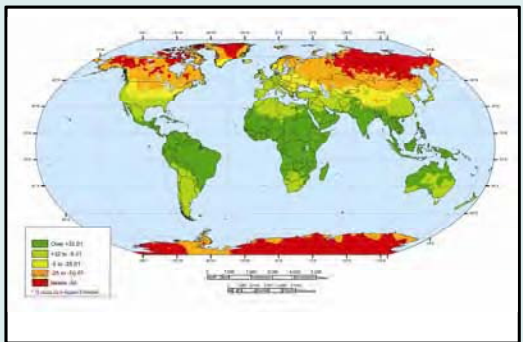
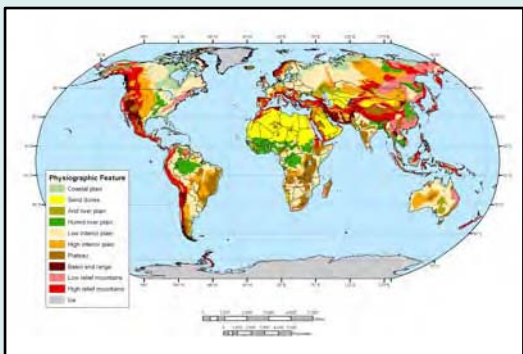
FINAL REPORT

DRI/DEES/TAP--2009-R43-FINAL
July 6, 2009

Prepared by
Desert Research Institute,
Division of Earth & Ecosystem Sciences

Prepared for
U.S. Army Yuma Proving Ground, Natural Environments Test Office
301 C Street, Bldg 2024, Yuma, AZ 85365-9498

Under contract
W9124R-07-C-0028/CLIN 0001-ACRN-AA



DISTRIBUTION STATEMENT A:

Distribution is unlimited, Approved for public release; July 2009. Other requests for this document shall be referred to Natural Environments Test Office, U.S. Army Yuma Proving Ground, Arizona.

Destroy by any method that will prevent disclosure of contents or reconstruction of the document. Do not return to originator.

REPORT DOCUMENTATION PAGE*Form Approved*
OMB No. 0704-0188

The public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY)

06 JUL 2009

2. REPORT TYPE

Final Report

3. DATES COVERED (From - To)

1 Dec 2005 - 31 Jul 2009

4. TITLE AND SUBTITLE

Global Physiographic and Climatic Maps to Support Revision of Environmental Testing Guidelines

5a. CONTRACT NUMBER

W9124R-07-C-0028/CLIN 0001-ACRN-AA

5b. GRANT NUMBER**5c. PROGRAM ELEMENT NUMBER****5d. PROJECT NUMBER****5e. TASK NUMBER****5f. WORK UNIT NUMBER****6. AUTHOR(S)**Eric V. McDonald
Steven N. Bacon
Scott D. Bassett
Sara E. Jenkins**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**Desert Research Institute, Div. Earth & Ecosystem
Sciences
2215 Raggio Pkwy
Reno, NV
89512Eric McDonald
Eric.McDonald@dri.edu
775-673-7302**8. PERFORMING ORGANIZATION REPORT NUMBER**

DRI/DEES/TAP--2009-R43-FINAL

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)U.S. Army Yuma Proving Ground, Natural Env. Test Office
301 C St.
Yuma, AZ 85365**10. SPONSOR/MONITOR'S ACRONYM(S)****11. SPONSOR/MONITOR'S REPORT NUMBER(S)****12. DISTRIBUTION / AVAILABILITY STATEMENT**

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

This report contains color.

14. ABSTRACT

This report is part of an overarching tier of studies mapping the physiographic and climatic characteristics of the globe that are significant to military operations, including the methodology used to derive the maps. The report is intended as a base for more detailed analyses such as terrain analog studies and for military environmental testing policy and guidelines. The second tier of studies will compare specific global military operating environments (GMOEs) (such as a desert region) to similar (analogous) environments within U.S. controlled properties. The third tier of studies will be detailed efforts such as characterization of vehicle test courses, dust studies, and descriptions of specific sites within an installation or area. This report features 15 maps of the world describing the imagery base map, physiography, dust potential, permafrost and ice extent, elevation, and land cover as relevant to military operations. The series of climate maps depicts the distribution of source weather stations, temperature extremes, maximum winds, average precipitation and relative humidity. The methodology to derive the maps is fully documented.

15. SUBJECT TERMS

landform analysis, geomorphology, soils, topography, MODIS, ecoregions, surface properties, terrain analysis

16. SECURITY CLASSIFICATION OF:**a. REPORT**
Unclassified**b. ABSTRACT**
Unclassified**c. THIS PAGE**
Unclassified**17. LIMITATION OF ABSTRACT**
UU**18. NUMBER OF PAGES**
53**19a. NAME OF RESPONSIBLE PERSON**
Natural Env. Test Office**19b. TELEPHONE NUMBER (include area code)**
928-328-3904

Global Physiographic and Climatic Maps to Support Revision of Environmental Testing Guidelines

Eric V. McDonald
Steven N. Bacon
Scott D. Bassett
Sara E. Jenkins

FINAL REPORT
DRI/DEES/TAP--2009-R43-FINAL
July 6, 2009

Prepared by
Division of Earth & Ecosystem Sciences
Desert Research Institute, Nevada System of Higher Education

Prepared for
U.S. Army Yuma Proving Ground, Natural Environments Test
Office

Under contract
W9124R-07-C-0028/CLIN 0001-ACRN-AA

EXECUTIVE SUMMARY

Introduction

The Army must provide equipment to the Warfighter that will ensure mission success under any conditions, wherever U.S. forces may be deployed worldwide. This requires that the materiel RDTE (Research, Development, Test and Evaluation) community has an in-depth understanding of potential Global Military Operational Environments (GMOE) including climate and terrain, plus the potential effects of these environmental factors on equipment performance.

Current applicable DOD guidelines for consideration of environmental effects on equipment performance do not provide adequate descriptive information. The primary focus in the post-WWII decades has been on the humid-temperate regions of Europe. Non-temperate regions were considered extreme and were described primarily by simplified climatic factors such as max/min temperatures and daily temperature or temperature-humidity cycles. This approach discounts the effects of seasonality, precipitation patterns, vegetation, and possibly most importantly for ground operations, the terrain.

This study was sponsored by the Natural Environments Test Office (NETO) of the U.S. Army Yuma Proving Ground (YPG), Arizona. YPG is a subordinate activity of the U.S. Army Developmental Test Command (DTC), a major component of the U.S. Army Test and Evaluation Command (ATEC).

The effort was conducted by the Desert Research Institute as part of the overall initiative of updating applicable Department of Army guidelines for consideration of environmental effects during RDTE of materiel. The primary application is the revision of Army Regulation (AR) 70-38 Research, Development, Test, and Evaluation of Materiel for Extreme Climatic Conditions. The proposed revision of AR 70-38 describes and defines strategic level Global Military Operational Environments (GMOE), incorporating the concept of Bailey's (1998) "ecoregions" classification scheme as an organizing principle.

Data sources for these maps include various remote sensing datasets, readily available online terrain and surface characteristic databases, previously published map products, as well as original map data products generated by the Desert Research Institute. The map series includes the following products, with brief explanations of methodology and terminology incorporated into the production of each:

1. Global Physiographic Map
2. Global Dust Potential Map
3. Global Permafrost and Ground Ice Extent Map
4. Global Elevation Map
5. Global Land Cover Map
6. Global Climatic Maps (set of 8)

It should be noted that the suite of maps was produced at global, strategic scales for the purpose of a general overview of the types and spatial distribution of potential environmental and climatic factors likely to be encountered during military operations. As a result the maps are not intended for use in detailed or site-specific hazards analyses. Future work can expand the current methodologies to characterize specific areas or hazards of military interest at more detailed and tactical scales (e.g., McDonald et al., 2009).

Acknowledgements

The authors greatly acknowledge the helpful comments, suggestions, and contributions by Graham Stullenbarger, Linda Spears, Wayne Lucas, John Hawk, and Valerie Morrill of YPG-NETO. We also appreciate the comments and suggestions made during a peer-review meeting of the map products by Russell Harmon of ARO, Charles Ryerson of ERDC-CRREL-NH, and William Doe III of the Institute for Environmental Studies, Western Illinois University. This work was funded through the U.S. Army Yuma Proving Ground, Natural Environments Test Office under Contract W9124R-07-C-0028/CLIN 0001-ACRN-AA.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	A
LIST OF TABLES.....	E
LIST OF FIGURES.....	F
1.0 INTRODUCTION	1
2.0 GLOBAL PHYSIOGRAPHIC MAP.....	3
2.1 PHYSIOGRAPHIC MAPPING	3
2.2 PHYSIOGRAPHIC CLASSES	3
2.2.1 Coastal Plain	3
2.2.2 Sand Sea / Dune	4
2.2.3 Arid River Plain	4
2.2.4 Humid River Plain	5
2.2.5 Low Interior Plain.....	5
2.2.6 High Interior Plain	6
2.2.7 Plateau	6
2.2.8 Basin and Range	7
2.2.9 Low Relief Mountains	7
2.2.10 High Relief Mountains	8
2.2.11 Continental Ice.....	8
3.0 GLOBAL DUST POTENTIAL MAP.....	12
3.1 DUST POTENTIAL MAP.....	12
3.2 DUST POTENTIAL HAZARDS BASED ON GLOBAL SOILS MAP	12
3.2.1 Non or weakly developed soils.....	13
3.2.2 Moderately developed soils	14
3.2.3 Strongly developed soils	15
3.3 DUST POTENTIAL HAZARDS OF LOESS DEPOSITS.....	16
3.3.1 Loess distribution map.....	17
3.4 DUST POTENTIAL HAZARDS BASED ON PERMAFROST EXTENT	17
3.4.1 Permafrost distribution map	17
3.5 DUST POTENTIAL HAZARDS BASED ON GLOBAL PHYSIOGRAPHIC MAP	17
4.0 GLOBAL PERMAFROST AND GROUND ICE EXTENT MAP.....	20
4.1 PERMAFROST AND GROUND ICE EXTENT MAP.....	20
4.2 PERMAFROST AND GROUND ICE EXTENT CLASSES	20
4.2.1 None (0%).....	21
4.2.2 Isolated Patches (0 – 10%).....	21
4.2.3 Sporadic (10 – 50%)	21
4.2.4 Discontinuous (50 – 90%).....	21
4.2.5 Continuous (90 – 100%).....	21
4.2.6 Continental Ice.....	22
5.0 GLOBAL ELEVATION MAP.....	24
5.1 ELEVATION MAP.....	24
6.0 GLOBAL LAND COVER MAP	26
6.1 LAND COVER MAP.....	26
6.2 TROPICAL FOREST MAP.....	27

7.0 GLOBAL CLIMATIC MAPS.....	30
7.1 CLIMATE SOURCE DATA.....	30
7.1.1 Climate station interpolation procedures	30
7.2 CLIMATIC MAPS	31
7.2.1 Maximum temperature map	31
7.2.2 Minimum temperature map.....	32
7.2.3 Relative humidity map.....	32
7.2.4 Average annual precipitation map.....	33
7.2.5 Average wind speed map.....	33
7.2.6 Wind gust map.....	34
7.2.7 Maximum sustained winds map	35
8.0 REFERENCES	44

LIST OF TABLES

Table 2-1.	Physiographic features used to characterized the world at continental scales	9
Table 3-1.	List of 65 soil suborders of the world according to USDA-NRCS soil taxonomy	18
Table 5-1.	Area distribution of elevation breaks	24
Table 6-1.	Global land cover categories	26
Table 6-2.	Area distribution of global land cover	27
Table 6-3.	Global ecosystem classes	27
Table 7-1.	Areal distribution of global maximum temperature	31
Table 7-2.	Areal distribution of global minimum temperature	32
Table 7-3.	Areal distribution of global maximum percent relative humidity	33
Table 7-4.	Areal distribution of global average annual precipitation	33
Table 7-5.	Areal distribution of global average wind speed	34
Table 7-6.	Generalized wind speed description for five selected categories	34
Table 7-7.	Areal distribution of global maximum wind gusts	35
Table 7-8.	Areal distribution of global maximum sustained winds	35

LIST OF FIGURES

Figure 2-1.	MODIS digital imagery for physiographic terrain identification	10
Figure 2-2.	Global physiographic map	11
Figure 3-1.	Global dust potential map	19
Figure 4-1.	Global permafrost extent map.....	23
Figure 5-1.	Global elevation map	25
Figure 6-1.	Global land cover map	28
Figure 6-2.	Global tropical forest map	29
Figure 7-1.	Global distribution of weather stations	36
Figure 7-2.	Global maximum temperature map	37
Figure 7-3.	Global minimum temperature map	38
Figure 7-4.	Global relative humidity map	39
Figure 7-5.	Global average annual precipitation map	40
Figure 7-6.	Global average wind speed map	41
Figure 7-7.	Global maximum wind gusts map	42
Figure 7-8.	Global maximum sustained wind speed map	43

1.0 INTRODUCTION

The military operating environments and hazardous factors facing the United States Department of Defense personnel and materiel are varied, and can include what are generally considered climatic extremes. As such, it is essential to identify the potential natural factors inherent in these extreme environments that may directly impact military operations. To develop equipment that ensures mission success under any environmental conditions, extreme or not, the Army's Research Development, Test and Evaluation (RDTE) community must apply this understanding of these environmental hazards and where they are located globally throughout the acquisition process.

The maps presented in this report provide a global overview of the worldwide military operating environments which reveal areas of the world that have analogous environmental features of terrain, climate, and vegetation. This is the first level of effort to understand and compare areas of interest to sites that are within the U.S. or are otherwise accessible to the RDTE community. Continuing studies will address more detailed levels that bring this understanding to an in depth characterization of specific areas and their analog test sites.

This report provides documentation of methods, statistical approaches, and sources of information used to generate 15 global maps depicting environmental conditions with the potential to influence military activities and equipment operation. The mapping was performed under Contract W9124R-07-C-0028/CLIN 0001-ACRN-AA to support the efforts of U.S. Army Yuma Proving Ground Natural Environments Test Office (TEDT-YP-NE) and to update current environmental guidelines such as Army Regulation (AR) 70-38: Research, Development, Test, and Evaluation of Materiel for Extreme Climatic Conditions.

The proposed revision of environmental guidelines describes and defines Global Military Operational Environments (GMOE) at a strategic level, incorporating Bailey's (1998) "ecoregions" classification scheme as an organizing principle. The additional

global maps presented in this report will be used to both directly supplement the Bailey's ecoregions maps and will be used to instruct and guide revision efforts of other documents through presentation and summary of a wide range of global environmental conditions. In other words, the attached maps provide multiple views of key global environmental conditions that will enhance identification of the type and the global distribution of environmental conditions most likely to impact military operations.

Use of these preliminary, small-scale maps should be restricted to situations where a generalized understanding of physiographic features and surface characteristics is useful. This suite of maps is not recommended as a data source for situations in which a highly detailed, large-scale interpretation of surface characteristics is necessary, or for the establishment of maximum or minimum values of factors such as temperature. Future work, if requested, can expand the current methodologies employed in this report to devise products suitable for larger, tactical scale mission planning (e.g., McDonald et al., 2009).

2.0 GLOBAL PHYSIOGRAPHIC MAP

2.1 Physiographic Mapping

The definition of a physiographic feature, as used to develop the global physiographic map is defined by any region where all terrain elements are similar in geologic structure and climate, which has consequently had a unified geomorphic history and whose pattern of regional relief differs significantly from that of adjacent regions (modified from Bates and Jackson, 1987). Mapping of physiographic features was interpretive in nature and performed within a geographic information system (GIS) platform. This goal was accomplished by identifying terrain elements at a map scale of 1:5,000,000 using MODerate-resolution Imaging Spectroradiometer (MODIS) satellite imagery with surface reflectance products computed from 1-7 wavelength bands from Hearn et al. (2003) (Figure 2-1).

2.2 Physiographic Classes

Eleven major physiographic features were delineated for the global physiographic map to best represent terrain attributes with respect to global military operating environments (Table 2-1). Many of the features and definitions used in this mapping exercise are modified from other global physiographic characterization studies (e.g., Hammond, 1954; Bostock, 1967; FAO, 1999; Barton et al., 2003; Pidwirny, 2006). The assignment of dust potential rating classes to physiographic features is based on the typical surface characteristics and soil properties found associated with these types of features from geologic and geomorphic maps from southwest U.S.

2.2.1 Coastal Plain

Coastal Plain is a physiographic feature that has a global area of ~6,300,000 mi² (~16,300,000 km²) composed of mostly level terrain having relatively low relief and flat slopes of variable width typically situated between Low Interior Plains and the shoreline of an ocean or sea. This feature is characterized by open areas having surface materials consisting of variable mixtures of sediment that range from silt and clay to sand and gravel often associated with complex meandering stream networks, bays, and other coastal features. The dust potential of this feature where surfaces are disturbed in arid

environments is generally Low. The elevation of this feature typically ranges from 0 to 500 ft (0 to 150 m). The most common elevation within the feature is sea level extending up to 3 ft (up to 1 m) (Figure 2-2).

2.2.2 Sand Sea / Dune

Sand Sea / Dune is a physiographic feature with a global area of ~4,600,000 mi² (~12,000,000 km²), consisting mostly of level and hilly terrain in the form of mounds, ridges, or hills of wind-blown sediment, either bare or covered with vegetation. Surface materials are composed mostly of loose and well-sorted sand and minor silt. Sand Sea / Dune fields, also known as ergs, are vast regions where sand accumulates into systems of hills or mega-dunes that exceed 300 ft (100 m) in height or as relatively flat sandy plains, which are both found in the Sahara Deserts of North Africa and the Arabian Peninsula. In areas where the source of sandy sediment is relatively low, linear and relatively narrow (barchan) shaped dunes are often underlain by hard and competent bedrock, gravelly desert pavement (regs), or silty playa/sabkha surfaces, which are exposed between the ridges of linear dunes. The dust potential of this feature in semi-arid to arid environments can be Very High. The elevation of this feature ranges from 0 to 3200 ft (0 to 1000 m), but mostly from 0 to 1600 ft (0 to 600 m). The most common elevation within the feature is 1000 ft (300 m) (Figure 2-2).

2.2.3 Arid River Plain

Arid River Plain is a physiographic feature that has a total area of ~1,000,000 mi² (~2,600,000 km²) composed of flat to hilly terrain. The area of an Arid River Plain is drained by a network of poorly to moderately developed anastomosing and braided rivers and associated tributaries across mostly low to moderate slopes. Surface materials consist of variable mixtures of sediment that range from silt and clay to sand and gravel. Arid River Plains often occur within continental settings and are internally drained such as the Caspian Sea region of southwest Asia or drain to the ocean, such as the Nile River in Egypt and the Tigris and Euphrates Rivers in Iraq. Regions characterized as Arid River Plain are typically located within semi-arid to arid environments and receive relatively less precipitation than Humid River Plains. The dust potential of disturbed surfaces in

arid environments is typically High. The elevation of this feature ranges from 0 to 1000 ft (0 to 300 m), but mostly from 300 to 650 ft (100 to 200 m). The most common elevation within the feature is ~500 ft (~150 m) (Figure 2-2).

2.2.4 Humid River Plain

Humid River Plain is a physiographic feature that has a global area of ~3,400,000 mi² (~8,900,000 km²) that commonly includes the area drained by numerous well-developed river systems and associated dense network of tributaries. Slopes within the feature range from low near Coastal Plains to moderate associated with dissected rolling hills adjacent to Low Interior Plains and Plateaus. Surface materials consist of variable mixtures of sediment that range from silt and clay to sand and gravel that is often mantled by a thick organic silty and clayey soil. Regions characterized as Humid River Plain typically occur within temperate to tropical environments having high precipitation and bordered by High and Low Relief Mountains or Interior Plains and Plateaus, such as the Amazon River Basin in South America and the Congo River Basin in Africa. The dust potential of disturbed surfaces under dry conditions within this physiographic feature is generally Low. The elevation of this feature ranges from 0 to 1500 ft (0 to 450 m), but mostly from 300 to 1000 ft (100 to 300 m). The most common elevation within the feature is ~300 ft (~100 m) (Figure 2-2).

2.2.5 Low Interior Plain

Low Interior Plain is a broad upland physiographic feature that has a total area of ~12,300,000 mi² (~31,800,000 km²) consisting mostly of level terrain. Low Interior Plains are often bounded by Coastal Plains, High Interior Plains or Low and High Relief Mountains. This feature has relatively low relief and mostly flat to gentle slopes that are often associated with meandering and straight stream networks, as well as steeper slopes that are commonly associated with major stream valleys. Surface materials consist of variable mixtures of sediment that range from clay and silt to sand and gravel. A relatively thick silt cap (loess sheet) often covers Low Interior Plain surfaces within semi-arid to arid environments, such as the central interior of Australia; therefore the dust potential of disturbed surfaces is typically Moderate. The elevation of low interior plains

typically ranges from 500 to 2000 ft (150 to 600 m). The most common elevation within the feature is ~1000 ft (~300 m) (Figure 2-2).

2.2.6 High Interior Plain

High Interior Plain is a broad upland physiographic feature that has a total area of ~6,500,000 mi² (~16,700,000 km²) consisting mostly of level and rolling terrain. This feature exhibits low to moderate slopes that often have straight stream networks having drainage divides with steep slopes which are commonly associated with major stream valleys. Surface materials consist of variable mixtures of sediment that range from clay and silt to sand and gravel. A relatively thick silt cap (loess sheet) is often present within temperate to arid environments, such as the central interior of North America and Eurasia, therefore the dust potential of disturbed surfaces is mostly High. The elevation of High Interior Plains typically ranges from 1000 to 5000 ft (300 to 1500 m). The most common elevation within the feature is ~1600 ft (~500 m) (Figure 2-2).

2.2.7 Plateau

Plateau is a physiographic feature that has a total area of ~4,500,000 mi² (~11,500,000 km²) consisting of broad and rugged mountainous terrain. A plateau is an extensive region of land considerably elevated more than 500 to 1000 ft (150 to 300 m) above adjacent regions or above sea level and is commonly limited on at least one side by an abrupt descent. It also has a nearly flat or smooth surface, but is often dissected by deep valleys and surmounted by Low or High Relief Mountains, as well as has a large part of its total surface at or near the summit level. A Plateau is usually higher in elevation and exhibits more noticeable relief than a High Interior Plain. Surface materials consist mostly of loose sandy, gravelly, and cobbly sediment underlain by competent and resistant bedrock. A network of deeply incised drainages or valleys are often present having slopes that range from steep to precipitous, such as the Colorado Plateau in the southwest United States. A relatively thick silt cap (loess sheet) is often present within semi-arid to arid environments, such as the central interior of North America, Africa, and Eurasia, therefore the dust potential of disturbed surfaces typically is High. The elevation of Plateau features typically range from 1000 to 7200 ft (300 to 2200 m). The most

common elevation within the feature is ~3600 ft (~1100 m), but can reach elevations as high as ~16,400 ft (~5000 m) adjacent to the Himalayan Mountains of central Asia (Figure 2-2).

2.2.8 Basin and Range

Basin and Range is a physiographic feature that has a total area of ~1,100,000 mi² (~3,000,000 km²) consisting of broken, flat and rugged mountainous terrain. The Basin and Range is characterized as a region that exhibits a series of relatively parallel and longitudinal, asymmetric Low and High Relief Mountains separated by broad and linear intervening basins or Low Interior Plains. Surface materials of the Low and High Relief Mountains consist mostly of loose sandy, gravelly, and cobbly sediment underlain by competent and resistant bedrock, whereas the intervening basins materials range from clay and silt to sand and gravel. Many basins contain lakes, playas, and alluvial plains providing a source of primary silt, as well as secondary silt that influences the development of a regional silt cap (loess sheet) of variable thickness. As result, the dust potential of disturbed surfaces is generally Very High within semi-arid to arid environments, such as the Basin and Range Province in the western United States. The elevation of the Basin and Range is between 1000 to 16,400 ft (300 to 5000 m). The most common elevation of both the basins and ranges within the feature is between ~3600 and 7200 ft (~1100 and 2200 m), but the elevation of the mountainous ranges commonly occur between ~9,800 and 13,100 ft (~3000 and 4000 m) (Figure 2-2).

2.2.9 Low Relief Mountains

Low Relief Mountains is a physiographic feature that has a total area of ~4,000,000 mi² (~10,400,000 km²) consisting of hilly to rugged mountainous terrain that often is traversed by well-developed river valleys. Low Relief Mountains are characterized as a region of relatively low to moderate relief that has slopes that range from moderate to very steep, such as the Appalachian Mountains in eastern United States. Surface materials consist mostly of loose sandy, gravelly, and cobbly sediment underlain by competent and resistant bedrock, whereas within narrow river valleys, surface materials range from clay and silt to sand and gravel. The dust potential of disturbed

surfaces in temperate to arid environments is Moderate. The elevation of Low Relief Mountains typically ranges from 0 at the base to 4000 ft (0 to 1200 m). The most common elevation within the feature occurs between ~650 and 1600 ft (~200 and 500 m) (Figure 2-2).

2.2.10 High Relief Mountains

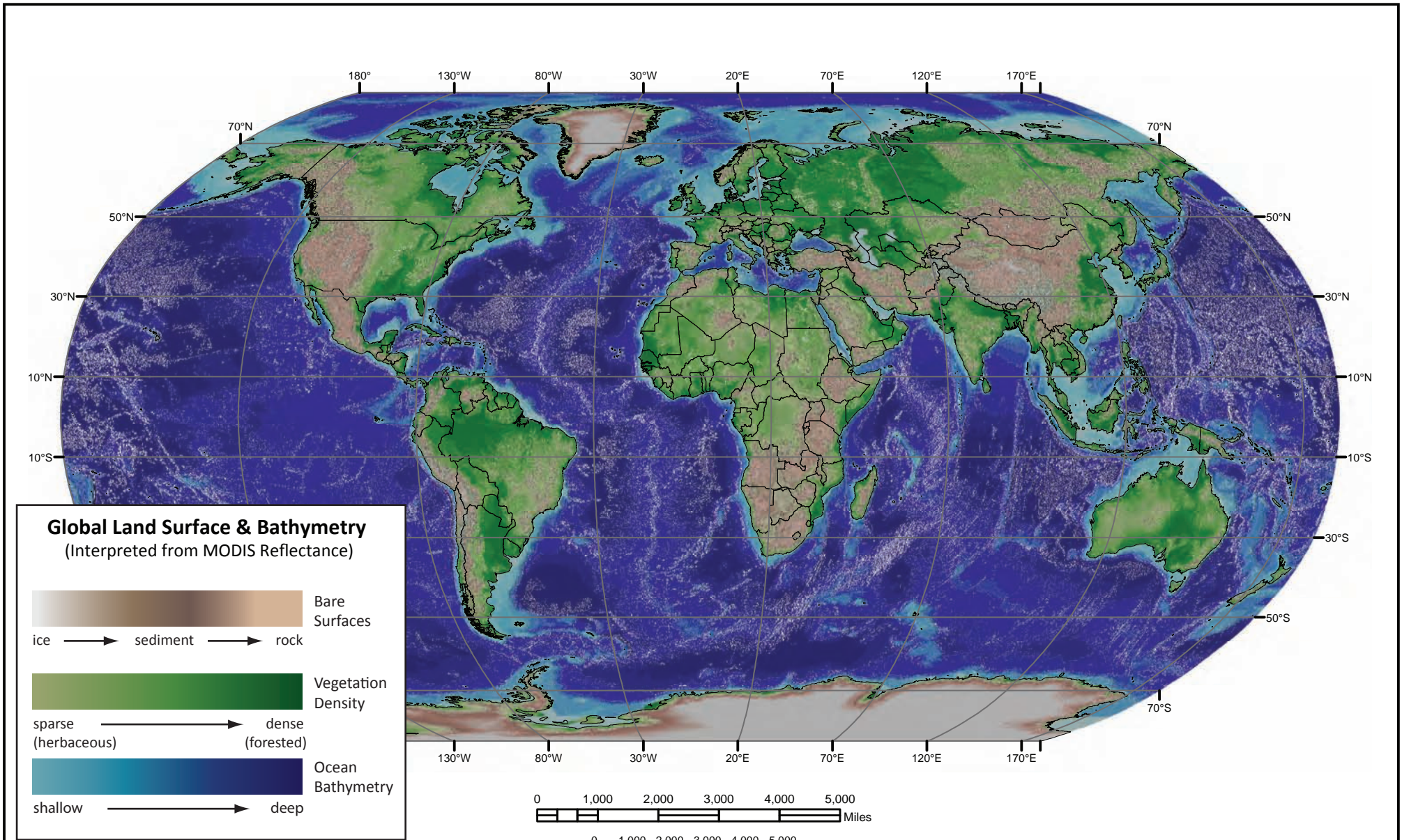
High Relief Mountains is a physiographic feature that has a total area of ~6,100,000 mi² (~15,800,000 km²) consisting of steep and rugged mountainous terrain that is crossed by well-developed river valleys. High Relief Mountains are characterized as a region of relatively high relief that has slopes that range from low to precipitous, but mostly are high to precipitous, such as the Sierra Nevada Range and Rocky Mountains in the western United States and the Himalayan Mountains in central Asia. Surface materials consist mostly of a thin veneer of loose sandy, gravelly, and cobbly sediment underlain by competent and resistant bedrock, whereas within narrow river valleys, surface materials range from silt to sand and gravel. The dust potential of disturbed surfaces typically is Very Low in mountain settings. The elevation of High Relief Mountains can occur adjacent to sea level at their base (e.g. the Andes) to the highest point on Earth (Mount Everest in the Himalayas), ranging from 0 to 29,035 ft (0 to 8850 m). The most common elevation within the feature is between ~1000 and 16,400 ft (~300 and 5000 m), centered near ~3300 ft (~1000 m) (Figure 2-2).

2.2.11 Continental Ice

Continental Ice is a physiographic feature that has a total area of ~6,000,000 mi² (~15,500,000 km²) consisting of broad expansive glaciers and steep and rugged mountainous terrain that covers nearly entire continental regions, such as in Antarctica and Greenland. Surface materials are predominantly composed of snow and ice, and where bare bedrock is exposed within mountainous or coastal regions, consists of loose sandy, gravelly, and cobbly sediment, therefore the dust potential is None. The elevation of continental ice ranges from 0 to 13,100 ft (0 to 4000 m). The most common elevation within the feature is between ~6600 and 12,100 ft (~2000 and 3700 m), centered near ~10,200 ft (~3100 m) (Figure 2-2).

TABLE 2-1. PHYSIOGRAPHIC FEATURES USED TO CHARACTERIZE THE WORLD AT CONTINENTAL SCALES

This Study		Hammond (1954)		Bostock (1967)		FAO (1999)		Barton et al. (2003)		Pidwrny (2006)	
No.	Physiographic Feature (dust potential rating class)	No.	Physiographic Feature	No.	Physiographic Feature	No.	Physiographic Feature	No.	Physiographic Feature	No.	Physiographic Feature
1	Coastal Plain (Low)	1	Nearly Flat Plains	1	Coastal Plain	1	Valley Floor	1	Coastal Plain	1	Low Plains
2	Sand Sea / Dunes (Very High)	2	Rolling and Irregular Plains	2	Plains	2	Depression	2	Interior Plain	2	High Plains
3	Arid River Plain (High)	3	Plains with Hills	3	Lowlands	3	Low Gradient Foothlope	3	Valley	3	Plateaus
4	Humid River Plain (Low)	4	Dissected Tablelands	4	Basin	4	Plain	4	Lowland	4	Low Mountains
5	Low Interior Plain (Moderate)	5	Hills	5	Uplands	5	Plateau	5	Upland	5	Middle Mountains
6	High Interior Plain (High)	6	Low Mountains	6	Plateau	6	Escarpment Zone	6	Plateau	6	High Mountains
7	Plateau (High)	7	High Mountains	7	Hills	7	Uniform Mountains Slope	7	Basin and Range		
8	Basin and Range (Very High)	8	Ice Caps	8	Highlands	8	Hills	8	Mountains		
9	Low Relief Mountains (Moderate)			9	Mountains	9	Mountainous Highland				
10	High Relief Mountains (Very Low)					10	Ridges				
11	Continental Ice (None)					11	Isolated Mountain				
						12	Mountains				



Map developed using Modis satellite imagery by:
Steven N. Bacon, Eric V. McDonald, Scott D. Bassett, and Jermey D. Burke,
Terrain Analysis Program, Desert Research Institute.

Modis imagery from:
Hearn, P. Jr., Hare, T., Schruben, P., Sherrill, D., LaMar, C., Tsushima, P., 2003,
Global GIS: Global Coverage, Developed by USGS, American Geological
Institute, DVD-ROM.

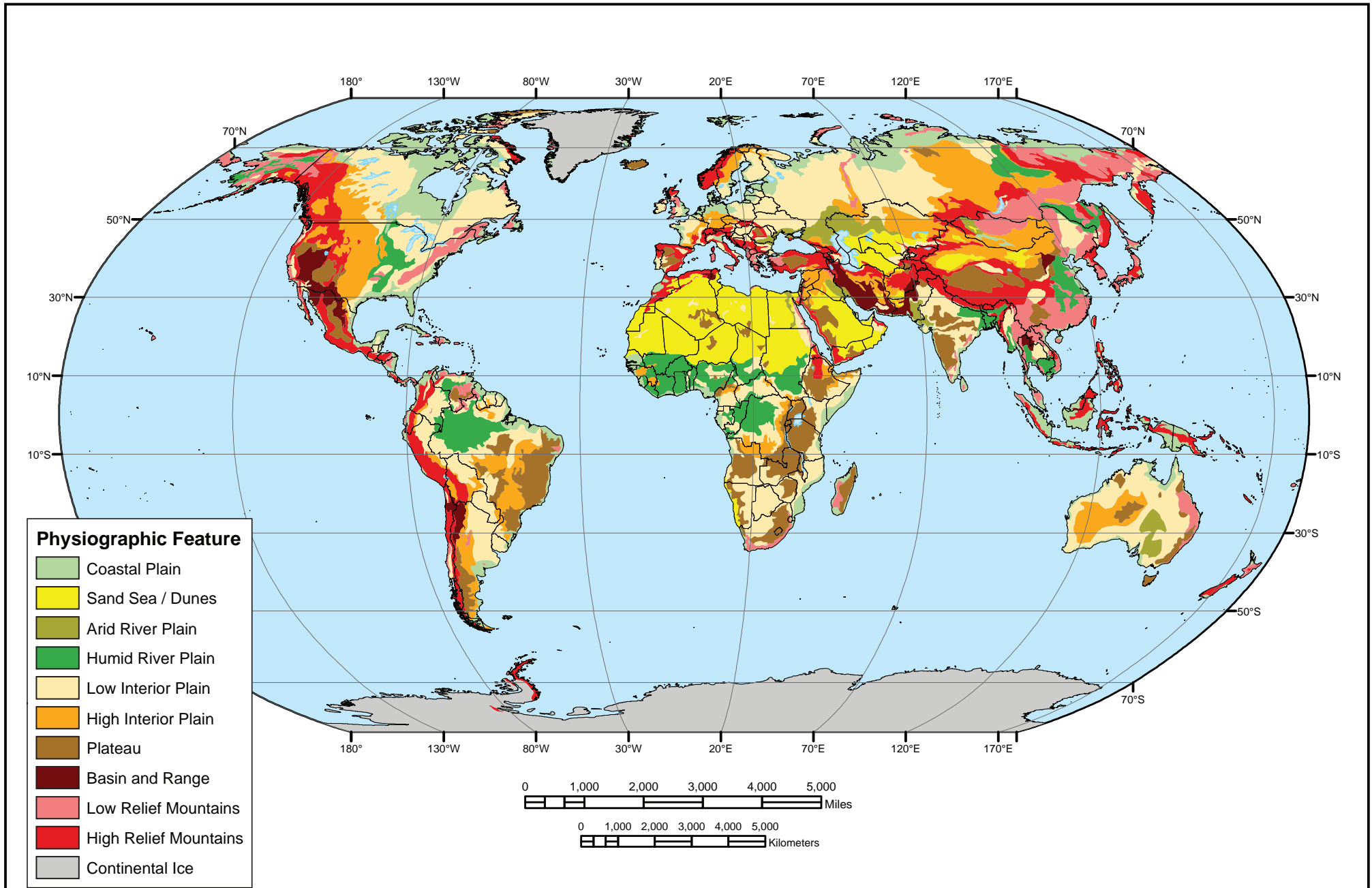
Projection:
World Robinson, WGS 1984.



GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
REVISION OF ENVIRONMENTAL TESTING GUIDELINES
MODIS Digital Imagery for Physiographic Terrain Identification

DATE: 6-02-09

FIGURE 2-1



Map developed using Modis satellite imagery at a fixed scale of 1:5,000,000 by:
 Steven N. Bacon, Eric V. McDonald, Scott D. Bassett, and Jerney D. Burke,
 Terrain Analysis Program, Desert Research Institute.

Projection:
 World Robinson, WGS 1984.



GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
 REVISION OF ENVIRONMENTAL TESTING GUIDELINES
Global Physiographic Map

DATE: 6-02-09

FIGURE 2-2

3.0 GLOBAL DUST POTENTIAL MAP

3.1 Dust Potential Map

The global dust potential map is based on the integration of (1) the global soil map of the United State Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS) at the suborder level according to the soil taxonomic system (Soil Survey Staff, 1999); (2) the global distribution of mapped loess deposits; (3) the Circum-Arctic permafrost and ground ice map of Brown et al. (1998); and (4) the global physiographic map and associated dust potential hazard classes presented in this report (see Section 2.0; Table 2-1). A six-fold hazard class system (None, Very Low, Low, Moderate, High, and Very High) was developed to categorize the disturbed (anthropogenic) dust potential for significant amounts of dust emission on a global scale during dry environmental conditions. The dust potential was quantified by assigning a numerical value to each hazard class, and normalizing the summed hazard ratings for each of the aforementioned four dust potential map products to match the original six-fold rating class scheme (Figure 3-1).

3.2 Dust Potential Hazards based on Global Soils Map

The USDA-NRCS global soils map used for dust potential hazards is a derivative product that represents a translation from FAO to USDA soil taxonomy (Soil Survey Staff, 1999). It is generated from the overlay of the NRCS soil climate map on FAO soil classification maps (e.g. FAO-UNESCO-ICRIS 1988; 1990; 1998), which at present, are the only global soils maps available. For background, soil is considered to be a 3-dimensional body with properties that reflect the impact of (1) climate, (2) vegetation and fauna, (3) topography, (4) parent material, and (5) length of time (e.g., Nachtergaele et al., 2000). The FAO soil classification system is defined in terms of measurable and observable properties of the soil itself having diagnostic horizons (FAO-UNESCO-ICRIS, 1988). The USDA Soil Taxonomy (Soil Survey Staff, 1999) also classifies soil orders according to the presence or absence of diagnostic soil horizons, as a reflection of the degree of soil development. Therefore, each of the 106 individual global FAO soil units can be correlated by soil development, material, and major geographical zone to 65 soil suborders (e.g. order Aridisol “arid soil”, suborder Argid “arid clay-rich soil” within the USDA soil taxonomy system). Each USDA suborder was then assigned a specific dust hazard class based on typical

attributes that cause dust emission when the upper 1.0 foot (0.3 meter) of the soil profile is disturbed under dry environmental conditions (Table 3-1; Figure 3-1).

The criteria used to assign specific hazard classes to soil units include the following: (1) geographical zone; (2) silt, clay, and sand particle-size fraction; (3) salt content; and (4) approximate depth to groundwater. The following sub-sections provide a brief description of each major soil order. Individual soil orders and suborders are described in more detail in the USDA publication *Soil Taxonomy* (Soil Survey Staff, 1999).

3.2.1 Non or weakly developed soils

Rock: outcrops of bare rock with no soil development were designated to have a dust potential hazard of None (Table 3-1).

Entisols: are mineral soils formed in recent deposits with minimal to no genetic horizon development. The unifying feature of this diverse and widely distributed soil order is their lack of soil formation beyond the earliest stages of development; they are either very young deposits, or have not responded to soil-forming influences. Dust potential varies within this order as a function of typical soil water content and its seasonal distribution (Table 3-1).

Andisols: are young, poorly weathered soils that are commonly formed on volcanic ash and cinders located proximal to – and downwind of – volcanic centers. They are defined by a set of andic properties that include a high percentage of volcanic glass and/or poorly crystallized or amorphous iron and aluminum minerals, often with thick organic horizons, and a high water holding capacity. Except for Aquands (defined by near-surface water), this order exhibits Moderate to Very High variable dust potential hazards depending on amount and seasonality of the soil moisture regime (Table 3-1).

Inceptisols: are soils in which incipient profile development is evident, though ‘mature’ soil properties are not yet distinguishable. Generally formed in young deposits, they are most common to mountainous areas, particularly in the tropics. Similar to Entisols, this soil order

is widely distributed and diverse, but displays somewhat greater profile development. Potential dust hazards vary with regional climate, and are generally Low. Ustepts and Xerepts exhibit a High dust potential due to limited soil moisture content (Table 3-1), particularly during the dry season.

Gelisols: are young soils that form slowly under cold and/or frozen conditions for much of the year. Permafrost beneath the soil surface is a defining characteristic of this soil suborder, and many show evidence of cryoturbation as water expands and contracts during freeze/thaw cycles. Because these soils are typically frozen or saturated by water for the majority of the year, dust potential hazard is None or Very Low (Table 3-1).

Histosols: are the soils of bogs and wetlands, most common in cold climates. They exhibit little profile development due to the anaerobic (oxygen-poor) bog or wetland condition, which hinders decomposition of organic materials. Horizon characteristics in Histosols vary with the type of organic material input, rather than mineral accumulation and translocation. High water content produces a Very Low dust potential hazard for all Histosols (Table 3-1).

3.2.2 Moderately developed soils

Aridisols: constitute the most widely distributed global soil order. These soils are characterized by their relatively low water content; by definition these soils typically cannot exceed 90 consecutive days of soil moisture available to support vegetation growth. Consequently, these soils often exhibit mineral accumulations at depth – that under higher moisture regimes would be flushed from the profile – including calcium carbonate, gypsum, soluble salts, or sodium. Some Aridisols have clay-rich subsurface horizons that may represent a previous period of soil formation under wetter climatic conditions. These soils are often capped with desert pavement, a one clast-thick layer of pebbles supported on an accretionary layer of windblown silt. When pavements are removed, this fine silt is subject to rapid wind erosion. This soil order tends to have a High to Very High dust potential hazard (Table 3-1), a result of the brief moisture availability and/or accretionary silt cap.

Vertisols: have a relatively high clay content (>30%). They are identified by the swelling and shrinking of clays within the soil profile, which occurs through consecutive wetting and drying of calcium and magnesium-rich clays. They are characteristic of subhumid to semiarid environments with bimodal moisture availability, but can be found in a few cold environments as well. During dry periods, large cracks develop in the soil profile, which are subsequently healed during wet times. Progressive cracking and swelling causes large soil blocks to shift slightly and rub against each other, producing slick-sided, tilted surfaces (slickensides). Dust potential hazards are highly variable for the Vertisol order. In humid or cold climates, dust hazard potential is None to Moderate; under regimes with hot and dry summers (e.g. Torrerts, Xererts), dust potential hazards are High to Very High (Table 3-1).

Mollisols: are organic-rich, highly fertile soils, typically with clay-rich subsurface horizons. Most develop under grass vegetation, but Mollisols may also occur in forested regions. Dust potential hazards are highly variable for the Mollisol order and are dependent on moisture availability within the soils. In humid or cold climates, dust hazard potential is Very Low to Moderate; under regimes with hot or dry summers (e.g. Xerolls, Rendolls) dust potential hazards are High to Very High when soils are disturbed (Table 3-1).

Alfisols: form in forested environments and are more highly weathered than other moderately developed soil orders. In the subsurface, moderate cation leaching and strong silicate clay accumulation are diagnostic features. Dust potential hazards are extremely variable for Alfisols and are dependent on moisture availability within the soils. In humid or cold climates, dust hazard potential is Very Low to Moderate; under regimes with dry summers (e.g. Xeralfs) dust potential hazards are High when soils are disturbed (Table 3-1).

3.2.3 Strongly developed soils

Ultisols: develop as a result of strong clay weathering and accumulation in the subsurface, accompanied by available cation deficiency. These factors are typically associated with moist, warm climates; soils form beneath a broad variety of ecosystems, from forests to savannas to swamps. These soils, like other clay-rich soils, tend to have a Very Low to

Moderate dust potential when disturbed, except where associated with seasonally dry summer moisture regimes (e.g. Xerults) (Table 3-1).

Spodosols: are acidic, sandy forest soils with low base saturation. They form under moist to wet conditions with a broad range of temperature regimes, and are typically associated with forest vegetation, particularly coniferous forests whose decaying needles supply necessary acidity for soil formation. Acid leaching produces a diagnostic, white, leached horizon in the subsurface that has been stripped of available minerals. High water content and a thick organic cap yield a Very Low dust potential when disturbed (Table 3-1).

Oxisols: are the most highly weathered soils in the USDA-NRCS soil taxonomy system. These form in hot climates with continual moisture availability, typically thought to occur only beneath tropical rainforests, though some Oxisols (e.g. Torrox) occur in hot and dry environments, likely remnants from a previously warm and wet climate. They are identified by their relatively high, non-swelling, low-acidity clay content which lends stability and resistance to compaction to these soils. Dust potential hazards are highly variable for Oxisols and are dependent on moisture availability within the soils. In humid to wet environments, dust hazard potential is Very Low to Moderate; under hot and dry regimes (e.g. Torrox) dust potential is Very High when soils are disturbed (Table 3-1).

3.3 Dust Potential Hazards of Loess Deposits

Loess is a terrestrial deposit of eolian (wind-blown) dust composed predominately of silt-sized particles. Most loess deposits have been altered to some degree by soil-forming processes as deposits have accumulated through time, and their unique properties create highly fertile agricultural soils that are some of the most productive in the world. Loess deposits cover approximately 10% of the Earth's land surface and are generally associated with semi-arid to semi-humid regions, as well as downwind of desert areas. Loess deposits are found on all continents, except for Antarctica (Busacca and Sweeney, 2005).

3.3.1 Loess distribution map

The world distribution map of major loess deposits of Busacca and Sweeney (2005) was also incorporated into global dust potential map. Based on a high silt content and occurrence within relatively arid regions, these deposits are classified as having a High dust potential when disturbed during the dry season (Figure 3-1), regardless of soil taxonomy.

3.4 Dust Potential Hazards based on Permafrost Extent

The Circum-Arctic permafrost and ground ice map of Brown et al. (1998) was integrated with the USDA-NRCS soil and loess deposit maps to better define the spatial distribution of areas that exhibit no dust potential. The subsequent Section 4.0 discusses the permafrost extent mapping of Brown et al. (1998) in more detail.

3.4.1 Permafrost distribution map

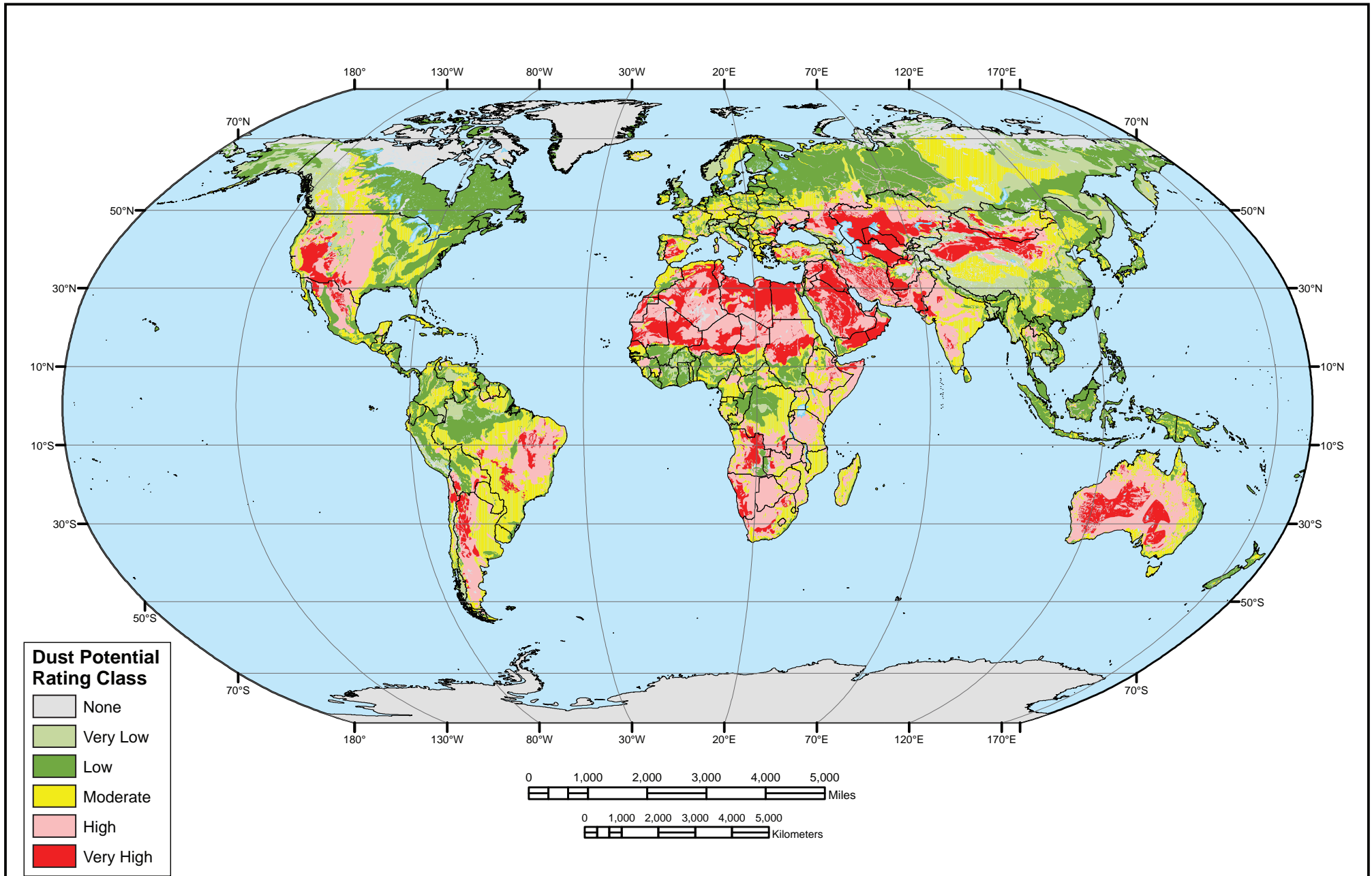
The global distribution of continuous (90-100%) and discontinuous (50-90%) extent of permafrost and ground ice was considered to have no dust potential (None), based on the presence of continental ice or glaciers (surface ice) and permafrost (ground ice) throughout the year (see Section 4.0; Figure 4-1). In areas where permafrost soils were mapped by the USDA-NRCS (e.g. Gelisols), permafrost/ground ice coverage from the Brown et al. (1998) map was given preference in determining dust potential.

3.5 Dust Potential Hazards based on Global Physiographic Map

The assignment of dust potential rating classes to physiographic features is based on the general surface characteristics (smooth or rough) and soil properties (particle size distribution) of each of the eleven physiographic map features, independent of environmental conditions. Section 2.0 discusses the global physiographic mapping and associated dust potential rating classes in more detail.

TABLE 3-1. LIST OF 65 SOIL SUBORDERS OF THE WORLD ACCORDING TO USDA-NRCS SOIL TAXONOMY (1999) CLASSIFICATION SYSTEM, WITH ASSIGNED DUST POTENTIAL RATING HAZARD CLASSES

NON OR WEAKLY DEVELOPED SOILS							
Entisols	Dust Potential	Inceptisols	Dust Potential	Andisols	Dust Potential	Gelisols	Dust Potential
Aquepts	Very Low	Aquepts	Very Low	Aquands	Very Low	Turbels	None
Orthents	Moderate	Cryepts	Very Low	Ustands	Moderate	Histels	Very Low
Fluvents	High	Gelepts	Very Low	Vitrands	Moderate	Orthels	Very Low
Psamments	Very High	Anthrepts	Low	Cryands	High		
		Udepts	Low	Xerands	High	Histosols	Dust Potential
		Ustepts	High	Torrands	Very High	Fibrists	Very Low
		Xerepts	High			Hemists	Very Low
						Saprists	Very Low
MODERATELY DEVELOPED SOILS							
Aridisols	Dust Potential	Vertisols	Dust Potential	Mollisols	Dust Potential	Alfisols	Dust Potential
Argids	High	Cryerts	None	Aquolls	Very Low	Aqualfs	Very Low
Cryids	High	Aquerts	Very Low	Cryolls	Very Low	Cryalfs	Very Low
Calcids	Very High	Uderts	Low	Gelolls	Very Low	Udalfs	Low
Cambids	Very High	Usterts	Moderate	Udolls	Low	Ustalfs	Moderate
Durids	Very High	Xererts	High	Albolls	Moderate	Xeralfs	High
Gypsids	Very High	Torrerts	Very High	Ustolls	Moderate		
Salids	Very High			Rendolls	High		
				Xerolls	High		
STRONGLY DEVELOPED SOILS						MISCELLANEOUS	
Ultisols	Dust Potential	Spodosols	Dust Potential	Oxisols	Dust Potential	Type	Dust Potential
Aquults	Very Low	Aquods	Very Low	Aquox	Very Low	Ice	None
Humults	Low	Cryods	Very Low	Perox	Very Low	Rock	None
Udults	Low	Gelods	Very Low	Udox	Low	Shifting Sand	Very High
Ustults	Moderate	Humods	Very Low	Ustox	Moderate		
Xerults	High	Orthods	Very Low	Torrox	Very High		



Map developed from the integration of dust potential rating classes assigned to physiographic feature and NRCS Global Soil Map units by: Steven N. Bacon, Eric V. McDonald, Scott D. Bassett, and Jermy D. Burke, Terrain Analysis Program, Desert Research Institute.

Projection: World Robinson, WGS 1984.

GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
 REVISION OF ENVIRONMENTAL TESTING GUIDELINES
Global Dust Potential Map

DATE: 6-02-09

FIGURE 3-1



4.0 GLOBAL PERMAFROST AND GROUND ICE EXTENT MAP

4.1 Permafrost and Ground Ice Extent Map

Permafrost is a layer of soil, sediment or rock at varying depths below the surface in which the temperature has remained at or below freezing continuously for at least two years. It occurs both on land and beneath offshore arctic continental shelves, and underlies about 22% of the Earth's surface (Permafrost subcommittee, 1998). Ground ice is mostly frozen water which has remained well below freezing for more than two years, which also includes alpine glaciers in mountainous regions and thick continental ice caps. The thickness of permafrost and related features is variable at many scales and typically is governed by overburden cover. Lowlands, highlands, and intra- and intermontane depressions are typically characterized by thick overburden cover of greater than 15-30 ft (5-10 m), whereas mountains and plateaus exhibit thin overburden cover less than 15-30 ft (5-10 m) and exposed bedrock (Brown et al., 1998). The circum-arctic map of permafrost and ground ice conditions in the northern hemisphere of Brown et al. (1998) was modified to better show the distribution of these features at a global scale. The original mapping of Brown et al. (1998) was developed in collaboration with the Cold Regions Research and Engineering Laboratory (CRREL) and U.S. Geological Survey (USGS).

4.2 Permafrost and Ground Ice Extent Classes

The six permafrost and ground ice classes of Brown et al. (1998) were used to best approximate conditions of concern for military operating environments in arctic terrain (Figure 4-1). The six classes of permafrost extent are estimated in percent area (None; 0-10%; 10-50%; 50-90%; 90-100%; and Continental Ice). The global physiographic mapping of high relief mountains of Section 2.0 of this report was used for regions in the southern hemisphere that were not included on the map of Brown et al. (1998). The high relief mountains in the southern hemisphere were assigned permafrost and ground ice content classes based on correlation with the mapping of Brown et al. (1998), derived from the combination of elevation and presence of alpine glaciers.

4.2.1 None (0%)

Regions of the Earth centered near the equator between the latitudes of 25°N and 25°S typically do not have any form of permafrost or ground ice. These regions are classified as having no permafrost (0%) (Figure 4-1).

4.2.2 Isolated Patches (0 – 10%)

High relief mountains or high and low interior plains between the latitudes of 60°N and 40°N in the northern hemisphere and near the latitude of 50°S in the southern hemisphere that are neither covered by alpine glaciers, nor persist higher than ~15,000 ft (4600 m), typically exhibit small pockets of permafrost. These regions are classified as having isolated permafrost (0 – 10%) (Figure 4-1).

4.2.3 Sporadic (10 – 50%)

High relief mountains at elevations above ~15,000 ft (4600 m) near the latitude of 30°N in the Himalayan Mountains that are not covered by alpine glaciers or high and low interior plains at much lower elevations near the latitude of 60°N, typically exhibit variable permafrost extent. These regions are classified as having sporadic permafrost (10 – 50%) (Figure 4-1).

4.2.4 Discontinuous (50 – 90%)

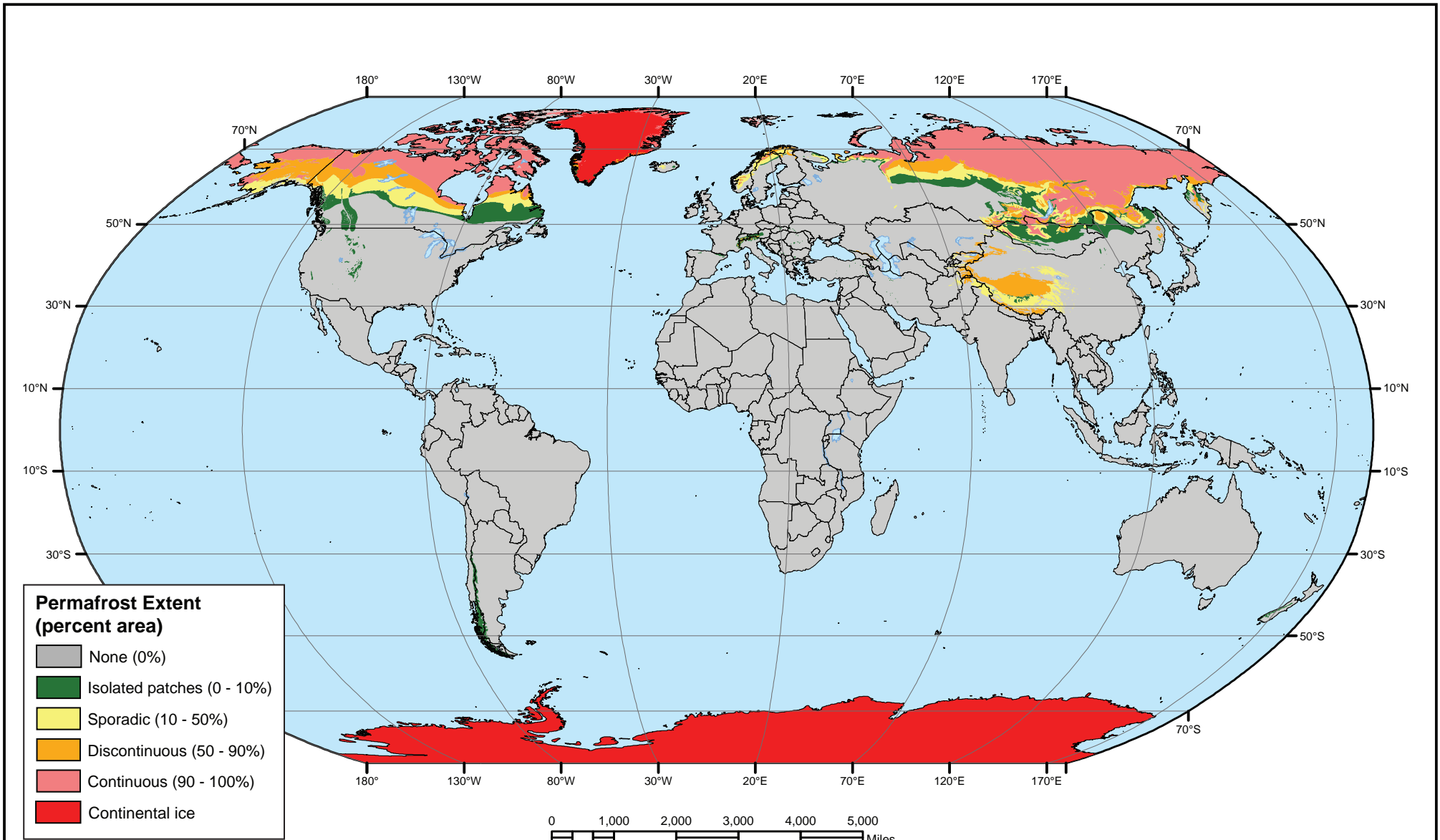
High relief mountains and plateaus at high elevations above ~15,000 ft (4600 m) between the latitudes of 30°N and 40°N in the Himalayan Mountains and near 50°N in Mongolia and Siberia that are not covered by alpine glaciers or high and low interior plains at much lower elevations between the latitudes of 60°N and 70°N exhibit an irregular mosaic of permafrost. These regions are classified as having discontinuous permafrost (50 – 90%) (Figure 4-1).

4.2.5 Continuous (90 – 100%)

High and low interior plains at low elevations of the latitudes of 50°N in Siberia and 50°N and 60°N in North America typically exhibit permanent permafrost. These regions are classified as having continuous permafrost (90 – 100%) (Figure 4-1).

4.2.6 Continental Ice

Regions covered by extensive alpine glaciers and ice caps in Greenland and Antarctica are classified as continental ice (Figure 4-1).



Map by:
 Steven N. Bacon, Eric V. McDonald, and Scott D. Bassett,
 Terrain Analysis Program, Desert Research Institute

Modified from:
 Brown, J., Ferrin, Jr. O.J., Heginbottom, J.A., and Melnikov, E.S., 1998,
 revised 2001, Circum-arctic map of permafrost and ground ice conditions.
 Boulder, CO: National Snow and Ice Data Center/World Data Center for
 Glaciology. Digital media.

Projection:
 World Robinson, WGS 1984.



GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
 REVISION OF ENVIRONMENTAL TESTING GUIDELINES
Global Permafrost Extent Map

DATE: 6-02-09

FIGURE 4-1

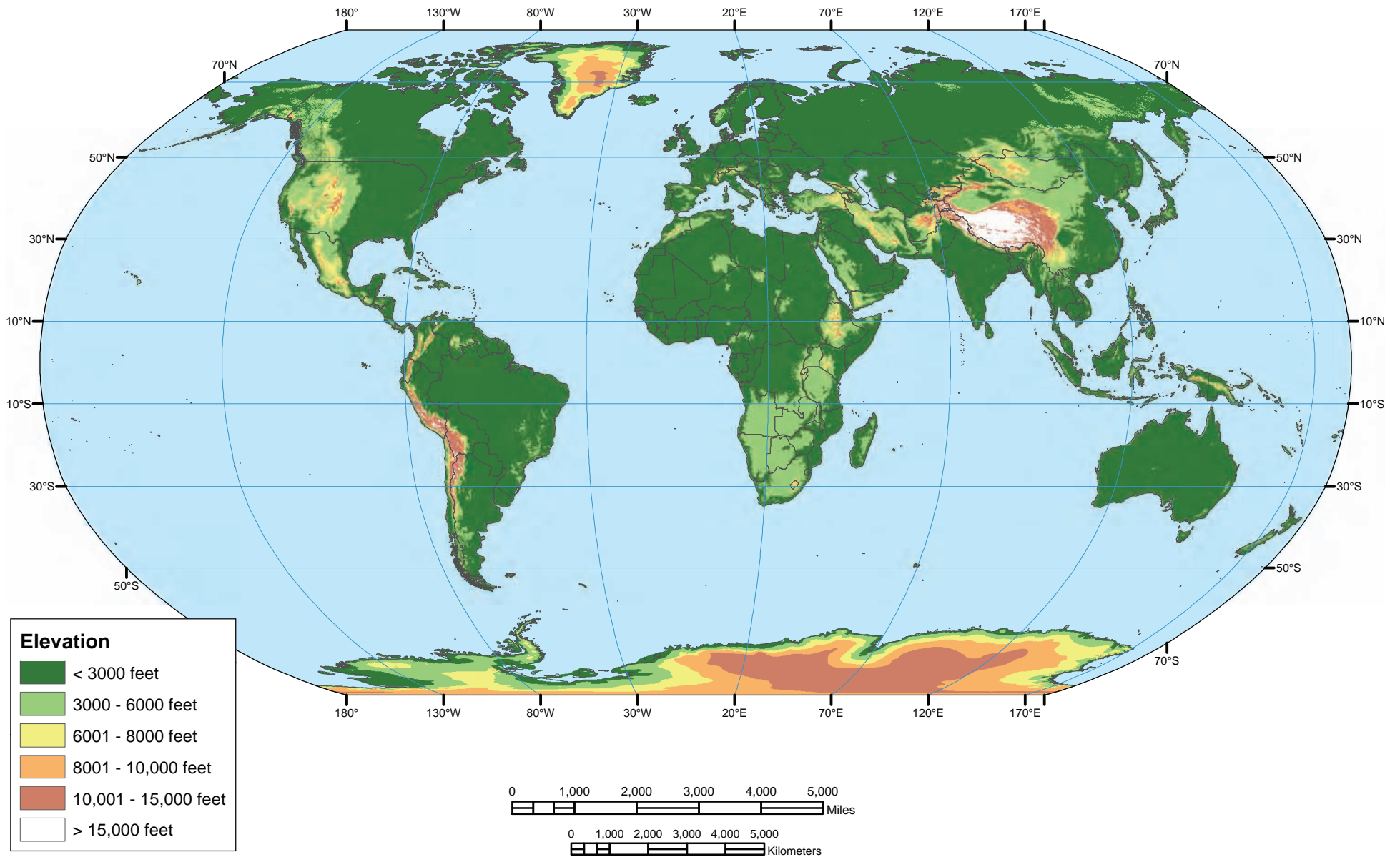
5.0 GLOBAL ELEVATION MAP

5.1 Elevation Map

GTOPO30, a digital elevation model (DEM) obtained from the U.S. Geological Survey (Hearn et al., 2003), served as the base for topographic classification of terrestrial surfaces. The DEM horizontal grid spacing is 30 arc seconds resulting in a pixel resolution of 2,751 feet (839 meters). The total range of elevation values extends from some 1,312 feet (400 meters) below sea level at the Dead Sea to over 28,000 feet (8,540 meters) above sea level in the Himalayas. A total of six global elevation classes were selected to depict areas from slightly below sea level to over 15,000 feet (4,573 meters) (Figure 5-1). The percent global distribution by elevation class ranged from just over 1% at the highest elevations to 71% at the lower elevations (Table 5-1).

Table 5-1. Area distribution of global elevation breaks.

Elevation		Area		Percentage of total area
feet	meters	mi ²	km ²	
Below 3,000	Below 915	39,581,380	102,515,774	72%
3,000 to 6,000	915 to 1,829	8,951,478	23,184,329	16%
6,000 to 8,000	1,829 to 2,439	2,369,440	6,136,849	4%
8,000 to 10,000	2,439 to 3,049	1,805,319	4,675,776	3%
10,000 to 15,000	3,049 to 3,573	2,083,557	5,396,411	4%
Over 15,000	Over 3,573	611,939	1,584,924	1%



Map compiled and modified by Scott D. Bassett, Steven N. Bacon, Julie a. Koruna, Eric V. McDonald and Sara E. Jenkins, Terrain Analysis Program, Desert Research Institute.

Data Source: U.S. Geological Survey GTOPO30 digital elevation model (DEM), available online at: <http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html>

Projection: World Robinson, WGS 1984.



GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
 REVISION OF ENVIRONMENTAL TESTING GUIDELINES
Global Elevation Map

DATE: 6-02-09

FIGURE 5-1

6.0 GLOBAL LAND COVER MAP

6.1 Land Cover Map

GIS layers and the associated metadata obtained from the U.S. Geological Survey’s Global Land Cover Characteristics Database (GLCC) served as the base for all land cover information. Two maps, global land cover and global tropical forest, were generated using GLCC data (Figures 6-1 and 6-2). The eight global land cover categories – plus water – represent a lumping of the USGS land use/land cover modified level 2 legend (see Table 6-1). A detailed description of the USGS land use/land cover system may be found in Anderson et al. (1976). The relative proportion each land cover category comprises for the globe varies from less than 1% to over 23% (Table 6-2). The forest land cover comprises the greatest percentage of area, with urban representing the lowest.

Table 6-1. Global land cover categories cross-walked into the USGS land use/land cover modified level 2 system.

Global Land Cover	USGS Land Use/Land Cover
Urban	Urban and Built-Up Land
Cropland/Pasture	Dryland Cropland and Pasture
	Irrigated Cropland and Pasture
	Mixed Dryland/Irrigated Cropland and Pasture
	Cropland/Grassland Mosaic
Grassland	Cropland/Woodland Mosaic
	Grassland
	Savanna
Shrubland	Herbaceous Wetland
	Shrubland
	Mixed Shrubland/Grassland
Forest	Deciduous Broadleaf Forest
	Deciduous Needleleaf Forest
	Evergreen Broadleaf Forest
	Evergreen Needleleaf Forest
	Mixed Forest
	Wooded Wetland
Water	Water Bodies
Barren	Barren or Sparsely Vegetated
Tundra	Herbaceous Tundra
	Wooded Tundra
	Mixed Tundra
	Bare Ground Tundra
Snow/Ice	Snow or Ice

Table 6-2. Area distribution of global land cover.

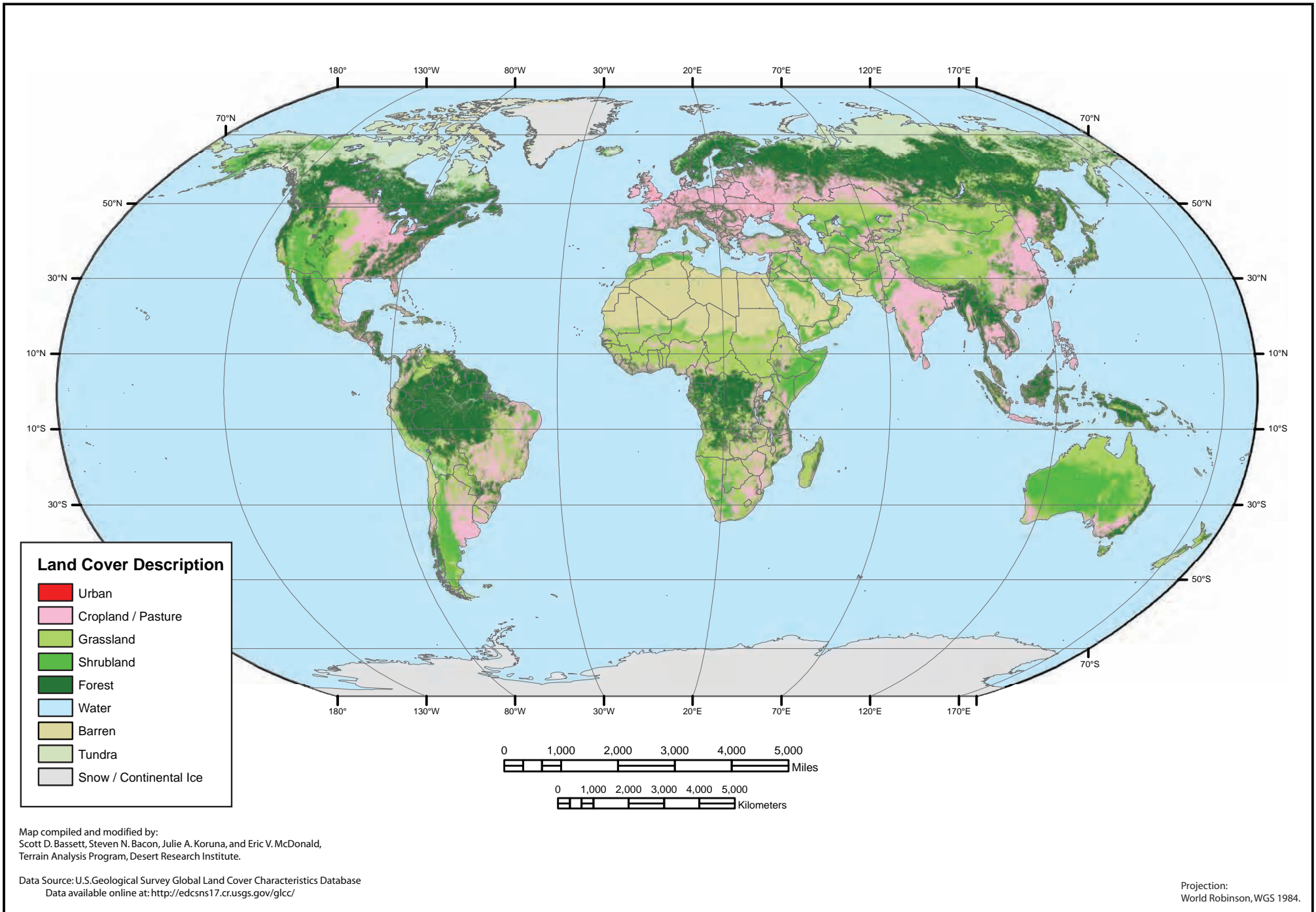
Land Cover	Area		Percentage of total area
	mi ²	km ²	
Urban	109,559	283,760	<1%
Cropland/Pasture	11,162,401	28,910,619	19%
Grassland	10,747,560	27,836,180	18%
Shrubland	7,430,293	19,244,458	12%
Forest	13,917,235	36,045,639	23%
Barren	6,775,914	17,549,618	11%
Tundra	3,551,948	9,199,546	6%
Snow/Ice	6,252,369	16,193,636	10%

6.2 Tropical Forest Map

The tropical forest locations represent classes identified by the GLCC global ecosystems GIS layer and associated legend (Olson, 1994). The global ecosystem classes combined to represent tropical forest locations may be seen in Table 6-3. The total tropical forest area for the globe is 5,049,307 mi² (13,077,704 km²) comprising roughly 9% of the total land area.

Table 6-3. Global ecosystem classes combined to represent tropical forest locations

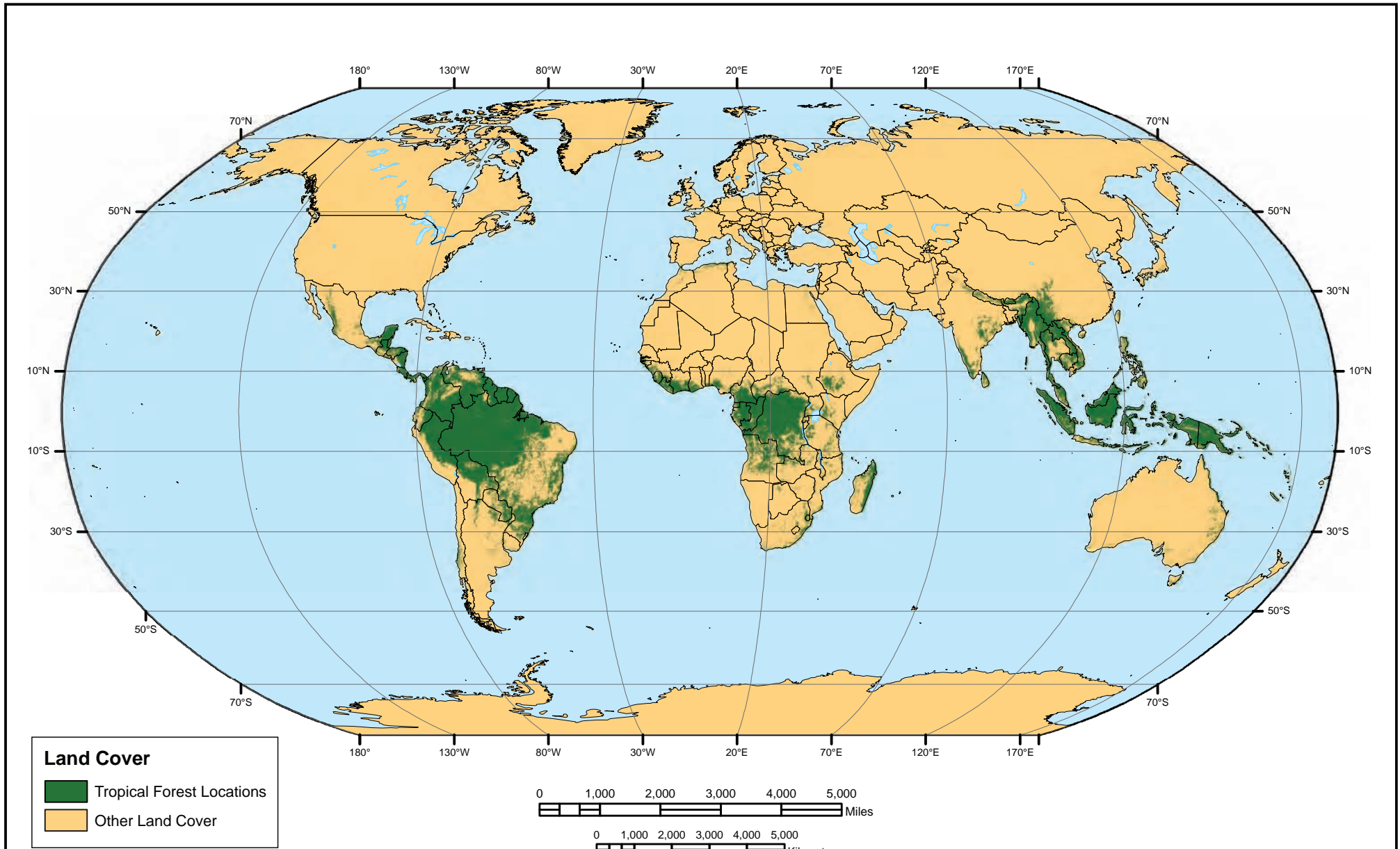
Global Ecosystem Class	
Montane Tropical Forest	Tropical Degraded Forest
Seasonal Tropical Forest	Rain Green Tropical Forest
Tropical Rainforest	



GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
 REVISION OF ENVIRONMENTAL TESTING GUIDELINES
Global Land Cover Map

DATE: 6-02-09

FIGURE 6-1



Map compiled and modified by:
 Scott D. Bassett, Steven N. Bacon, Julie A. Koruna, and Eric V. McDonald,
 Terrain Analysis Program, Desert Research Institute.

Data Source: U.S. Geological Survey Global Land Cover Characteristics Database
 Data available online at: <http://edcns17.cr.usgs.gov/glcc/>

Projection:
 World Robinson, WGS 1984.



GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
 REVISION OF ENVIRONMENTAL TESTING GUIDELINES
Global Tropical Forest Map

DATE: 6-02-09

FIGURE 6-2

7.0 GLOBAL CLIMATIC MAPS

7.1 Climate Source Data

The climatic information for this suite of maps was derived using the National Climatic Data Center's (NCDC) global surface summary of daily climatic data. These maps depict maximum and minimum temperature, relative humidity, annual precipitation, wind speed, maximum wind gusts and maximum sustained winds. The data collected for this exercise represent daily weather station measurements taken from January 1994 through March 2006. Although the metadata for the NCDC daily climatic dataset makes reference to 8000 stations being included in any single data file, a total of 22,549 possible stations are contained within the January 1994 through March 2006 data files (Figure 7-1). Some of the stations do not record year-round measurements. Stations which do not record information for at least half a year were not considered for any map analyses. Furthermore, some of the stations are located over open water, and as such, played an insignificant role where interpolation among points was required.

7.1.1 Climate station interpolation procedures

The NCDC weather station measurements represented a spatial depiction of climatic variables as points and had to be spatially interpolated to create a continuous global climate surface. An inverse distance weighted (IDW) function was applied to create the continuous global surface (Watson and Philip, 1985). Although other spatial interpolation techniques (e.g. two-dimensional minimum curvature spline interpolation or kriging) may be more complex mathematically, the amount of point data and scale of use dictated the use of the IDW technique. Furthermore, the more advanced techniques for extrapolating climatic information across unsampled regions use advanced modeling techniques which incorporate topography and latitude gradients (Daly et al., 2002). These techniques require a great deal of time, financial resources, and field verification to create on a subcontinental scale and are intended to be used at a much finer resolution than the climatic maps created here. As with any spatial interpolation technique, IDW interpolated values are less accurate where the density of points decreases. In general, the climatic variables estimated using IDW are better in highly populated areas where weather station

densities are greater. In low population density areas such as the large deserts, tropical forest and arctic region climatic condition estimates are likely to contain the greatest error.

7.2 Climatic Maps

The climatic information, consisting of maximum and minimum temperature, relative humidity, annual precipitation, wind speed, maximum wind gusts and maximum sustained winds, are presented below.

7.2.1 Maximum temperature map

A maximum temperature GIS layer was created by determining the maximum temperature for each weather station during the 1994-2006 data collection time. All temperature measurements are in degrees Fahrenheit. The relative distribution of maximum temperatures accurately reflects hot desert regions with the maximum temperature values being higher in those regions (Figure 7-2). Global temperature maximums for most locations fall within the 85 to 105 degrees Fahrenheit range (29.44 to 40.56 degrees Celsius), with slightly less than 2% of the globe experiencing maximum temperatures exceeding 120 degrees Fahrenheit (48.89 degrees Celsius) (Table 7-1).

Table 7-1. Areal distribution of global maximum temperature.

Temperature		Area		Percentage of total area
degree Fahrenheit	degree Celsius	mi ²	km ²	
Below 85	Below 29.44	10,762,762	27,863,500	19%
85.01 to 105	29.45 to 40.56	30,004,046	77,676,875	53%
105.01 to 110	40.57 to 43.33	5,438,182	14,078,800	10%
110.01 to 120	43.34 to 48.89	9,221,285	23,872,800	16%
Over 120	Over 48.89	1,029,731	2,665,850	2%

7.2.2 Minimum temperature map

A minimum temperature GIS layer was created by determining the minimum temperature for each weather station during the 1994-2006 data collection time. All temperature measurements are in degrees Fahrenheit. The relative distribution of minimum temperatures depicts colder temperatures near the poles and areas that experience continental temperature modulation, such as the Eurasia land mass (Figure 7-3). Temperature minimums for over half the globe are greater than -5 degrees Fahrenheit (-20.56 degrees Celsius) with over 25% of the global landmass exhibiting minimum temperatures below -25 degrees Fahrenheit (-31.67 degrees Celsius) (Table 7-2).

Table 7-2. Areal distribution of global minimum temperature.

Temperature		Area		Percentage of total area
(degrees Fahrenheit)	(degrees Celsius)	mi ²	km ²	
Over 32	Over 0	20,939,460	54,209,750	37%
32 to -5	0 to -20.56	12,396,007	32,091,775	22%
-5.01 to -25	-20.57 to -31.67	4,732,935	12,253,000	8%
-25.01 to -50	-31.68 to -45.56	9,860,326	25,527,200	18%
Below -50	Below -45.56	8,527,278	22,076,100	15%

7.2.3 Relative humidity map

Relative humidity measurements were not available within the NCDC database and had to be computed using dew point and temperature measurements. The relative humidity in percent (RH) was calculated using the following equation:

$$RH = (E/E_s) * 100$$

where E is the actual vapor pressure computed using the equation:

$$E = 6.11 * 10.0^{(7.5 * T_{dc} / (237.7 + T_{dc}))}$$

where T_{dc} is the dew point temperature in degrees Celsius

and E_s is the saturation vapor pressure computed using the equation:

$$E_s = 6.11 * 10.0^{(7.5 * T_c / (237.7 + T_c))}$$

where T_c is the air temperature in degrees Celsius

The global daily average maximum percent relative humidity is lowest in desert regions and highest in tropical zones (Figure 7-4). Daily average maximum relative

humidity for over 80% of the global landmass lies between 40% and 80% (Table 7-3). Very few locations have average daily maximum values below 20%.

Table 7-3. Areal distribution of global maximum percent relative humidity.

Maximum Relative Humidity	Area		Percentage of total area
	mi ²	km ²	
0 to 20%	46,815	121,200	<1%
20.01 to 40%	6,074,886	15,727,150	11%
40.01 to 60%	13,566,697	35,122,550	24%
60.01 to 80%	33,002,399	85,439,250	58%
80.01 to 100%	3,765,209	9,747,675	7%

7.2.4 Average annual precipitation map

Global average annual precipitation was created using daily precipitation amounts for every station. Daily amounts were summed for every year from 1994 through 2006. Annual average was then computed, and classified into five categories (Table 7-4). Average annual precipitation amounts are in inches. Desert regions have the least amount of precipitation, with the tropical areas containing the largest amounts of precipitation (Figure 7-5). Approximately 42% of the world has less than 20 inches (508 millimeters) of rainfall annually.

Table 7-4. Areal distribution of global average annual precipitation.

Average annual precipitation		Area		Percentage of total area
inches	millimeters	mi ²	km ²	
Less than 4	Less than 101.6	2,245,952	5,814,500	4%
4.01 to 10	101.61 to 254	6,997,611	18,115,975	12%
10.01 to 20	254.01 to 508	15,065,608	39,003,050	27%
20.01 to 80	508.01 to 2,032	29,689,644	76,862,925	53%
Greater than 80	Greater than 2,032	2,457,192	6,361,375	4%

7.2.5 Average wind speed map

Global average wind speed was calculated from daily mean wind speed measurements taken from 1994 through 2006. Wind speed measurements reflect speed in knots and are accurate to 0.1 knots (0.19 km/h). The lowest average wind speeds occur in heavily forested areas with the highest values occurring in Antarctica (Figure 7-6). Just

under 90% of the globe has average wind speeds below 10 knots (18.52 km/h) (Table 7-5).

Table 7-5. Areal distribution of global average wind speed.

Average wind speed		Area		Percentage of total area
knots	km/h	mi ²	km ²	
Less than 3	Less than 5.56	5,481,820	14,191,775	10%
3.01 to 10	5.57 to 18.52	44,254,697	114,570,100	78%
10.01 to 20	18.53 to 37.04	6,339,044	16,411,025	11%
20.01 to 40	37.05 to 74.08	349,389	904,525	1%
Greater than 40	Greater than 74.08	31,056	80,400	<1%

7.2.6 Wind gust map

Global wind gusts were taken from daily wind gust measurements contained within the 1994 through 2006 NCDC dataset described above. Wind gusts are defined as “the maximum 3-second wind speed forecast to occur within a 2-minute interval at a height of 10 meters”. Most of the globe experiences wind gusts above 34 knots (62.97 km/h) (Figure 7-7). The categories selected to represent wind gust breaks approximate wind speeds under which specific kinds of damage to structures or vegetation are probable. For instance, wind gusts that exceed 63 knots (116.67 km/h) are indicative of hurricane devastation (see Table 7-6). The relative contribution of the gust speed classes by global area ranges from less than 1% to 69% (Table 7-7).

Table 7-6. Generalized wind speed description for five selected categories.

Wind speed		Description
knots	km/h	
Less than 6	Less than 11.11	Light breeze, wind felt
6.01 to 19	11.12 to 35.19	Light breeze, leaves begin to sway
19.01 to 34	35.20 to 62.97	Moderate gale, inconvenience in walking
34.01 to 63	62.98 to 116.67	Strong gale, trees losing limbs or uprooting
Greater than 63	Greater than 116.67	Hurricane force winds

Table 7-7. Areal distribution of global maximum wind gusts.

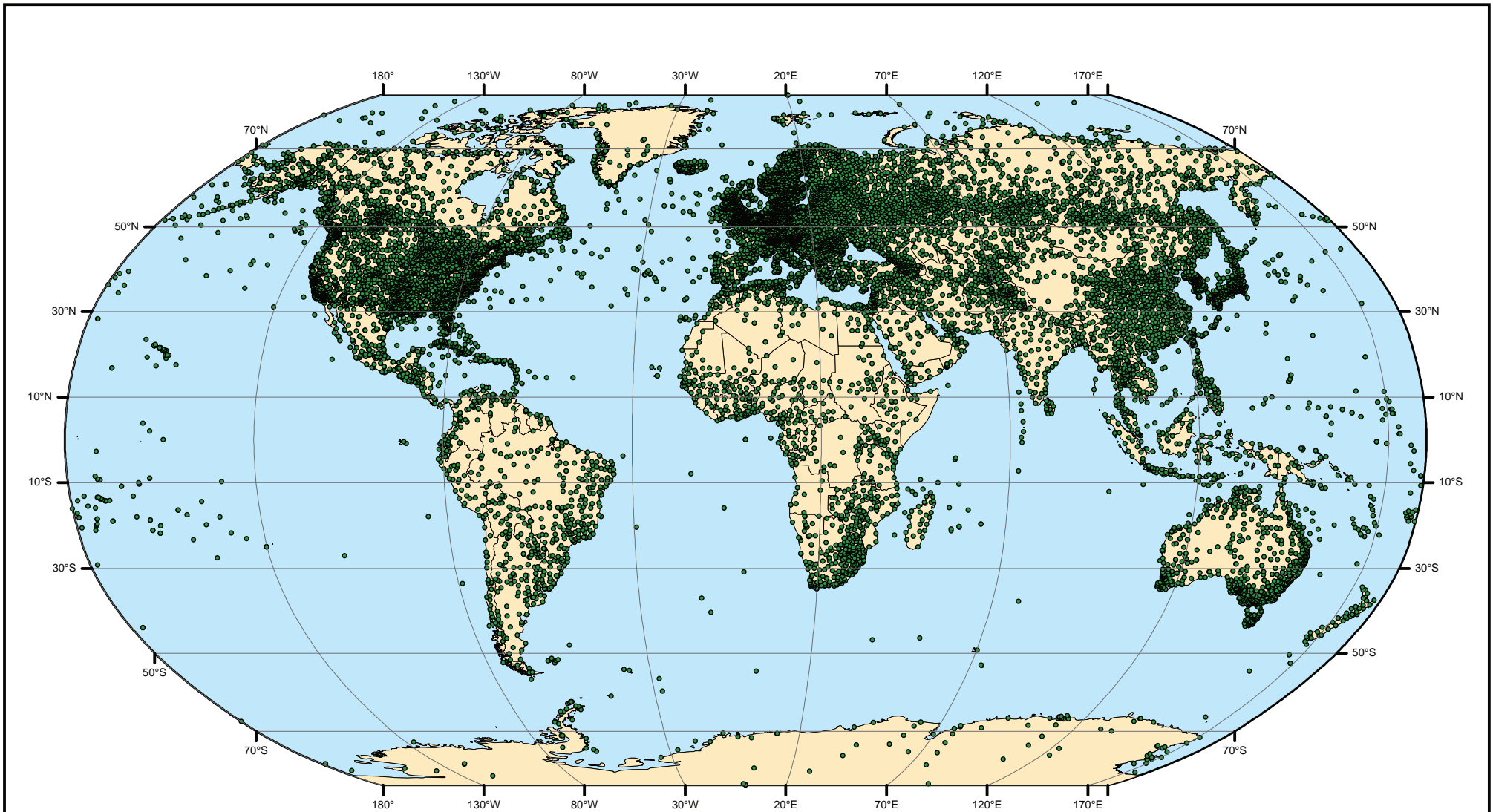
Wind speed		Area		Percentage of total area
knots	km/h	mi ²	km ²	
Less than 6	Less than 11.11	12,505	32,375	<1%
6.01 to 19	11.12 to 35.19	1,118,824	2,896,500	2%
19.01 to 34	35.20 to 62.97	9,172,219	23,745,775	16%
34.01 to 63	62.98 to 116.67	38,739,098	100,290,875	69%
Greater than 63	Greater than 116.67	7,284,810	18,859,500	13%

7.2.7 Maximum sustained winds map

Global maximum sustained wind speeds were taken from daily sustained wind speed measurements contained within the 1994 through 2006 NCDC dataset described above. Sustained wind speeds are calculated by the National Hurricane Center using a one minute moving average, thus reflecting the maximum average wind speed which occurs for any single minute during a single day. Most of the global landmass experiences maximum sustained wind speeds above 34 knots (62.97 km/h) (Figure 7-8). The wind gust table description for wind speeds has the same categorization and descriptions for maximum sustained wind speed classes (Table 7-8). The relative contribution of the wind speed classes by global area ranges from less than 1% to 74% (Table 7-8).

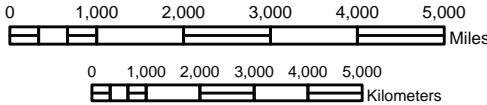
Table 7-8. Area distribution of global maximum sustained winds.

Wind speed		Area		Percentage of total area
knots	km/h	mi ²	km ²	
Less than 6	Less than 11.11	27,202	70,425	<1%
6.01 to 19	11.12 to 35.19	2,004,149	5,188,500	4%
19.01 to 34	35.20 to 62.97	8,887,279	23,008,100	16%
34.01 to 63	62.98 to 116.67	42,049,100	108,860,075	74%
Greater than 63	Greater than 116.67	3,488,275	9,030,725	6%



Legend

- Weather Station



Map compiled and modified by Scott D. Bassett, Steven N. Bacon, Julie A. Koruna, and Eric V. McDonald, Terrain Analysis Program, Desert Research Institute.

Data Source: 1994-2006 NCDC/NOAA Global Surface Summary Worldwide
 Stations available online at: <ftp.ncdc.noaa.gov/pub/data/globalsod>

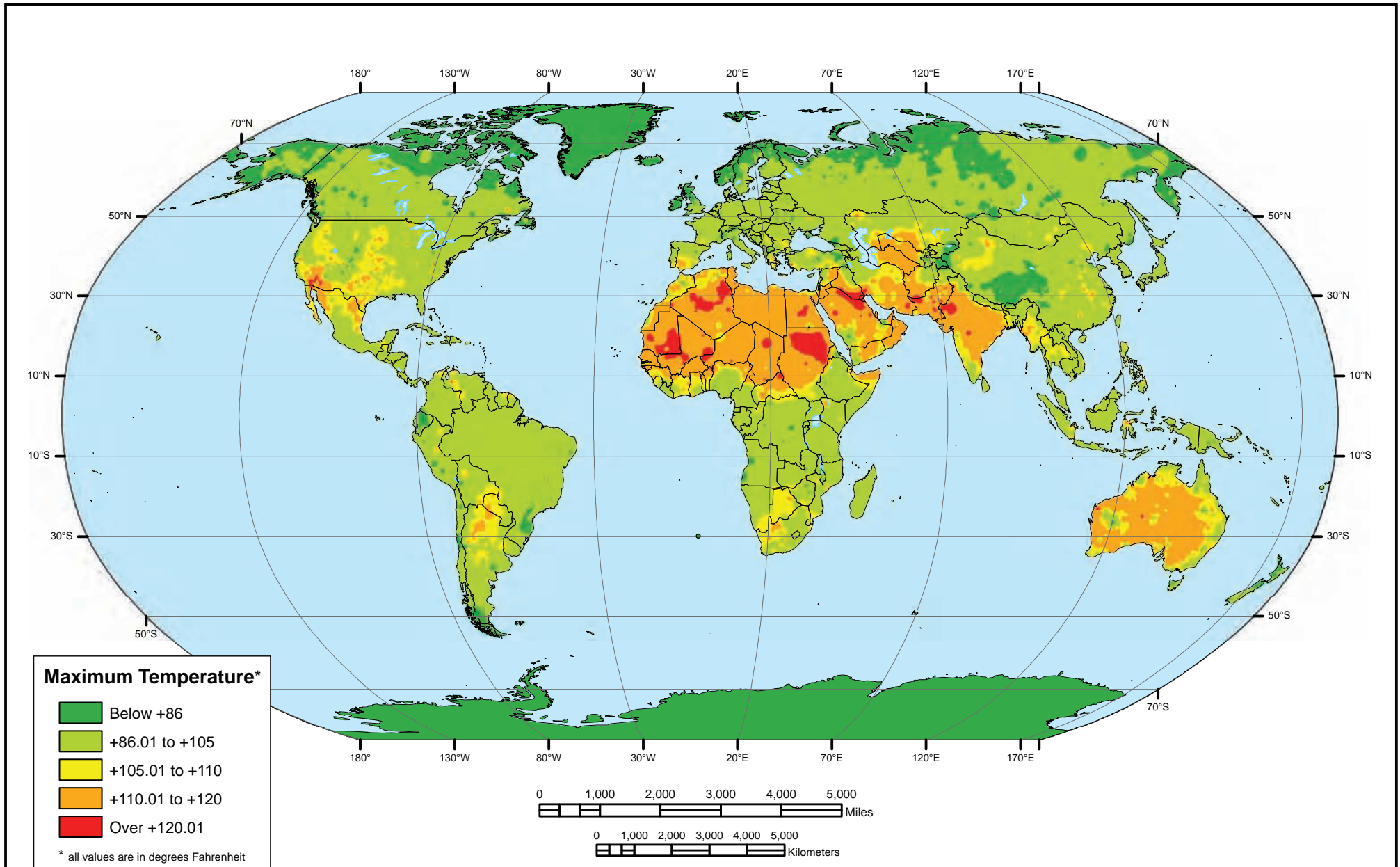
Projection:
 World Robinson, WGS 1984.



**GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
 REVISION OF ENVIRONMENTAL TESTING GUIDELINES
 Global Distribution of Weather Stations**

DATE: 6-02-09

FIGURE 7-1



Map compiled and modified by Scott D. Bassett, Steven N. Bacon, Julie A. Koruna, and Eric V. McDonald, Terrain Analysis Program, Desert Research Institute.

Data Source: 1994-2006 NCDC/NOAA Global Surface Summary Worldwide
 Stations available online at: <ftp.ncdc.noaa.gov/pub/data/globalsod>

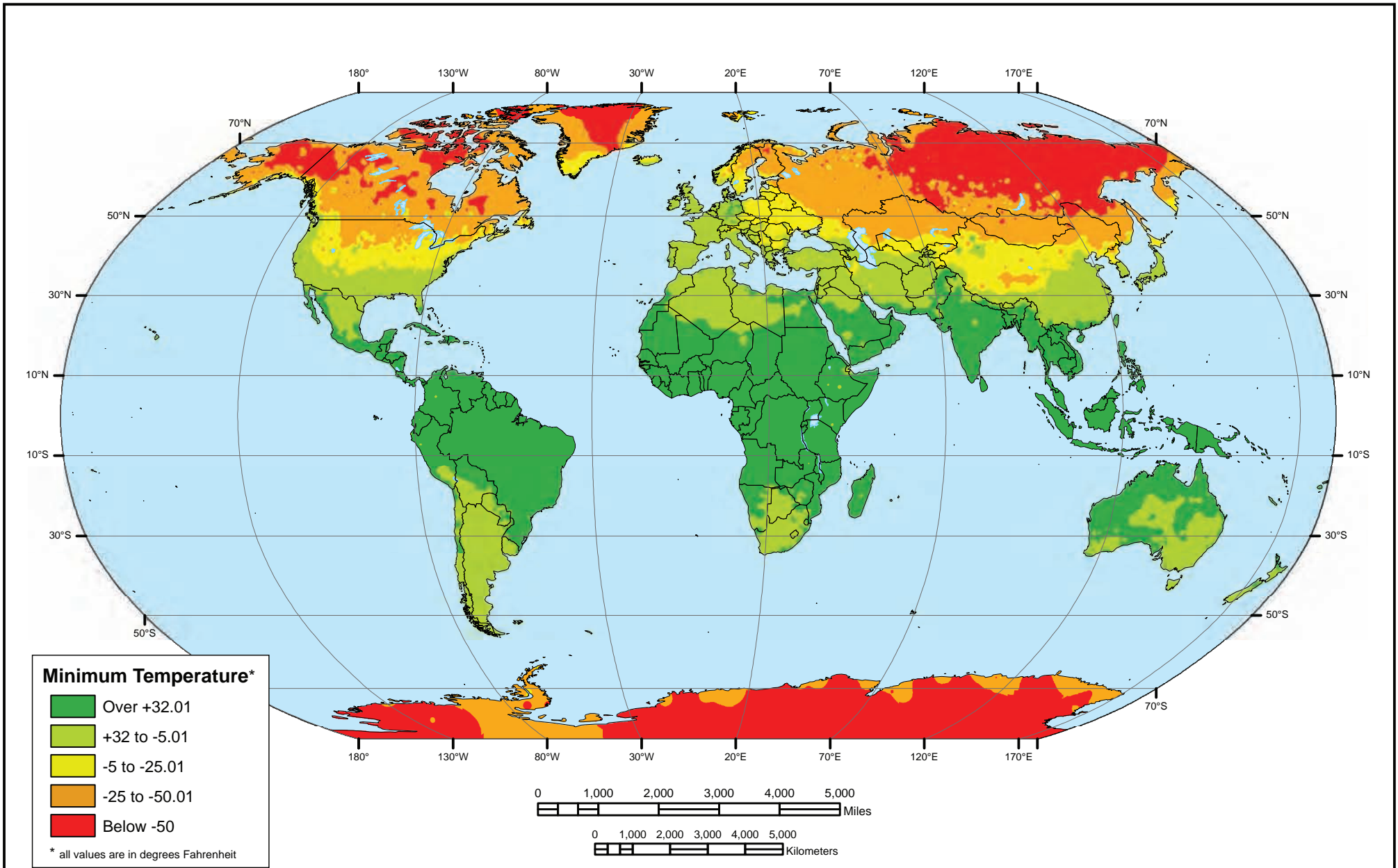
Projection:
 World Robinson, WGS 1984.



GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
 REVISION OF ENVIRONMENTAL TESTING GUIDELINES
Global Maximum Temperature Map

DATE: 6-02-09

FIGURE 7-2



Map compiled and modified by Scott D. Bassett, Steven N. Bacon, Julie A. Koruna, and Eric V. McDonald, Terrain Analysis Program, Desert Research Institute.

Data Source: 1994-2006 NCDC/NOAA Global Surface Summary Worldwide
 Stations available online at: <ftp.ncdc.noaa.gov/pub/data/globalssod>

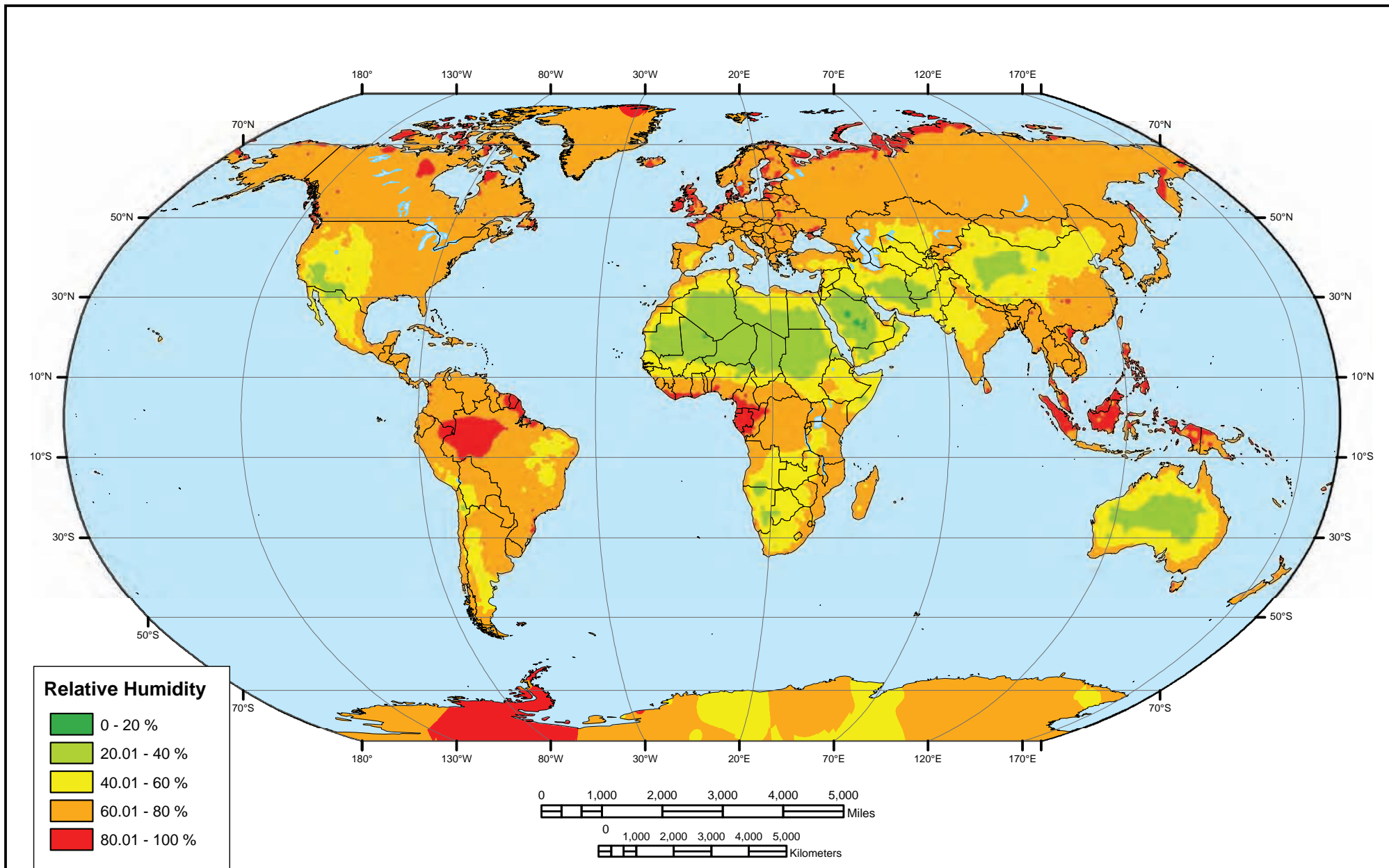
Projection:
 World Robinson, WGS 1984.



GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
 REVISION OF ENVIRONMENTAL TESTING GUIDELINES
Global Minimum Temperature Map

DATE: 6-02-09

FIGURE 7-3



Map compiled and modified by Scott D. Bassett, Steven N. Bacon, Julie A. Koruna, and Eric V. McDonald, Terrain Analysis Program, Desert Research Institute.

Data Source: 1994-2006 NCDC/NOAA Global Surface Summary Worldwide
Stations available online at: <ftp.ncdc.noaa.gov/pub/data/globalssod>

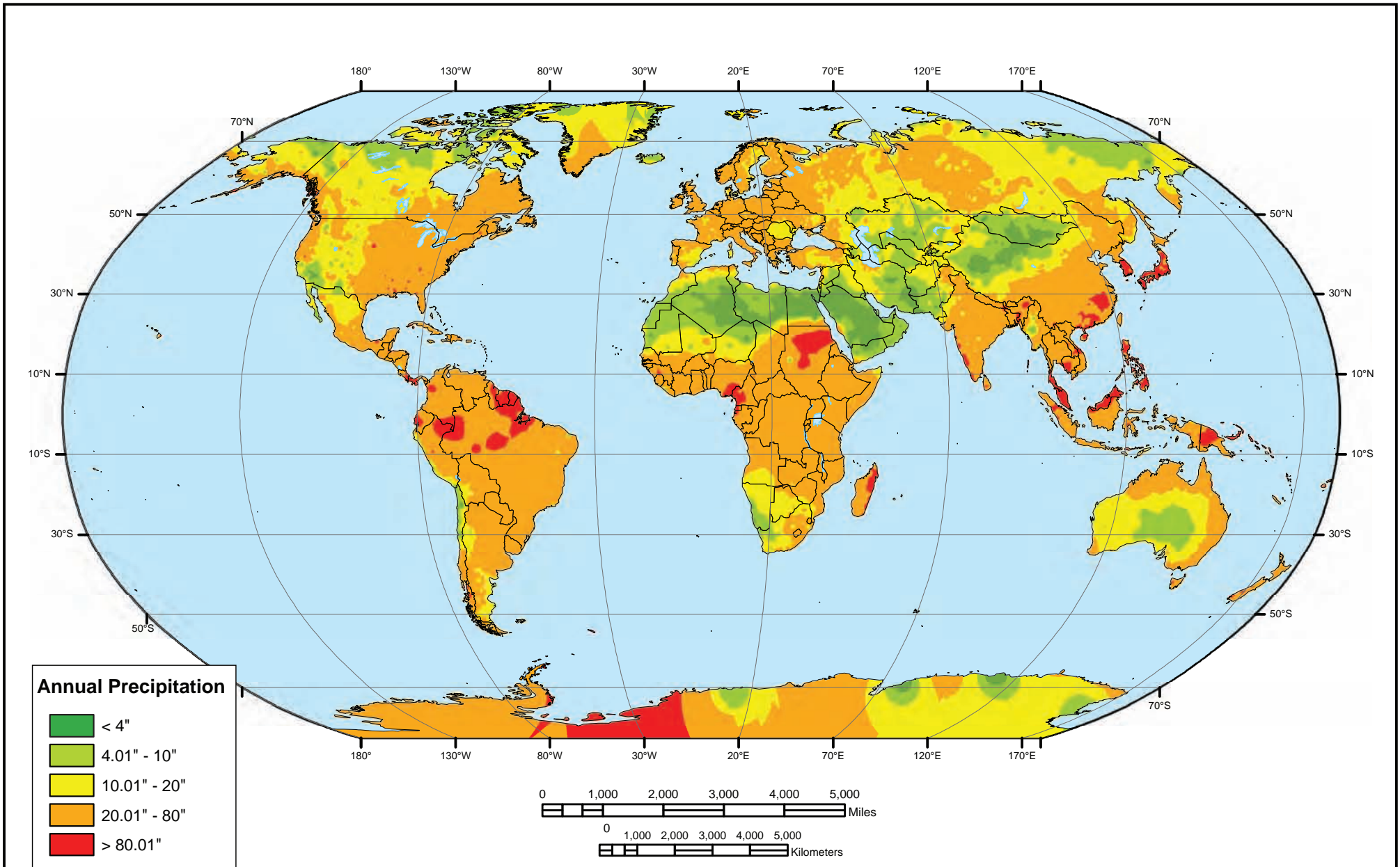
Projection:
World Robinson, WGS 1984.



GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
REVISION OF ENVIRONMENTAL TESTING GUIDELINES
Global Relative Humidity Map

DATE: 6-02-09

FIGURE 7-4



Map compiled and modified by Scott D. Bassett, Steven N. Bacon, Julie A. Koruna, and Eric V. McDonald, Terrain Analysis Program, Desert Research Institute.

Data Source: 1994-2006 NCDC/NOAA Global Surface Summary Worldwide
Stations available online at: <ftp.ncdc.noaa.gov/pub/data/globalsod>

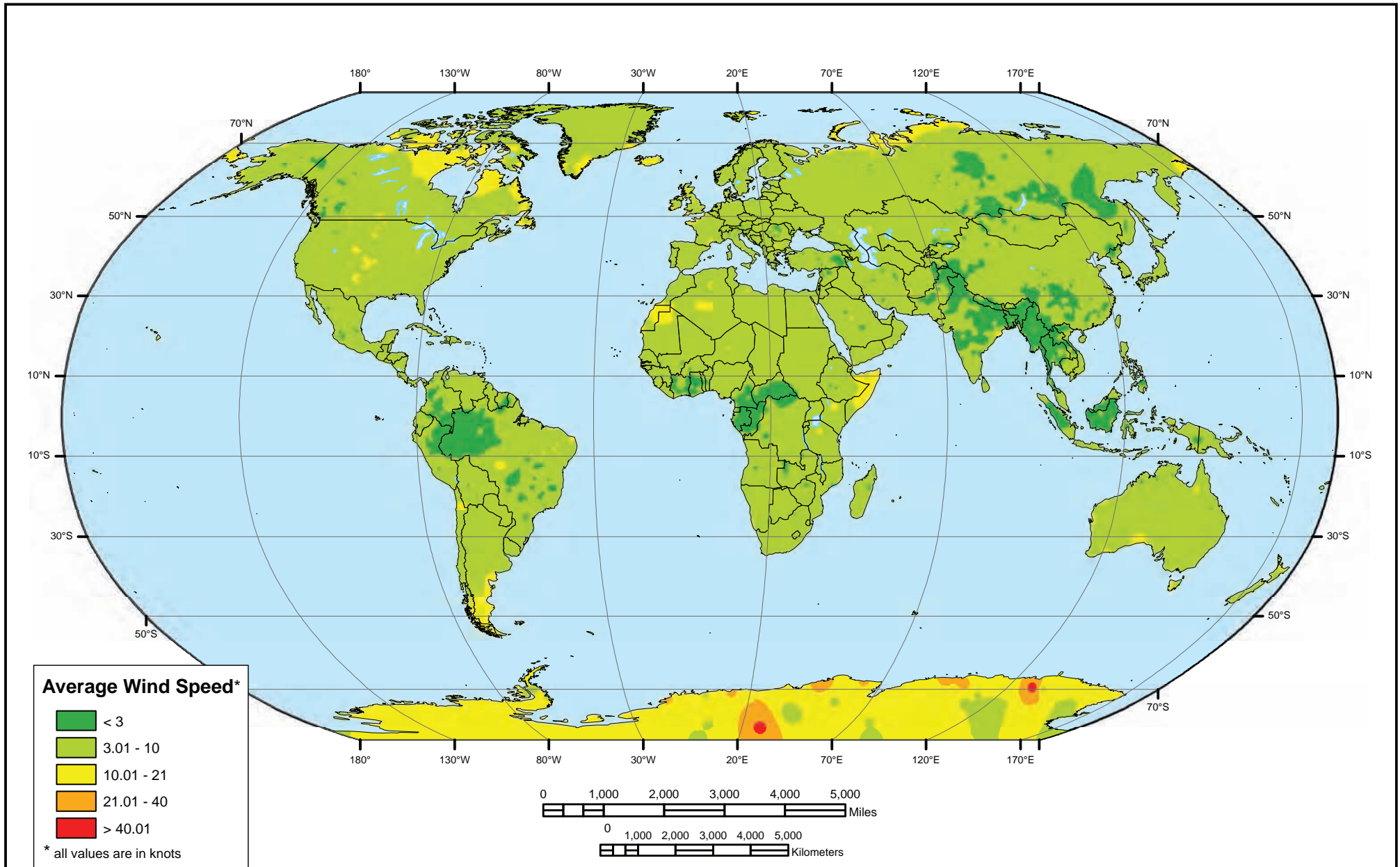
Projection:
World Robinson, WGS 1984.



GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
REVISION OF ENVIRONMENTAL TESTING GUIDELINES
Global Average Annual Precipitation Map

DATE: 6-02-09

FIGURE 7-5



Map compiled and modified by Scott D. Bassett, Steven N. Bacon, Julie A. Koruna, and Eric V. McDonald, Terrain Analysis Program, Desert Research Institute.

Data Source: 1994-2006 NCDC/NOAA Global Surface Summary Worldwide
 Stations available online at: <ftp.ncdc.noaa.gov/pub/data/globalsod>

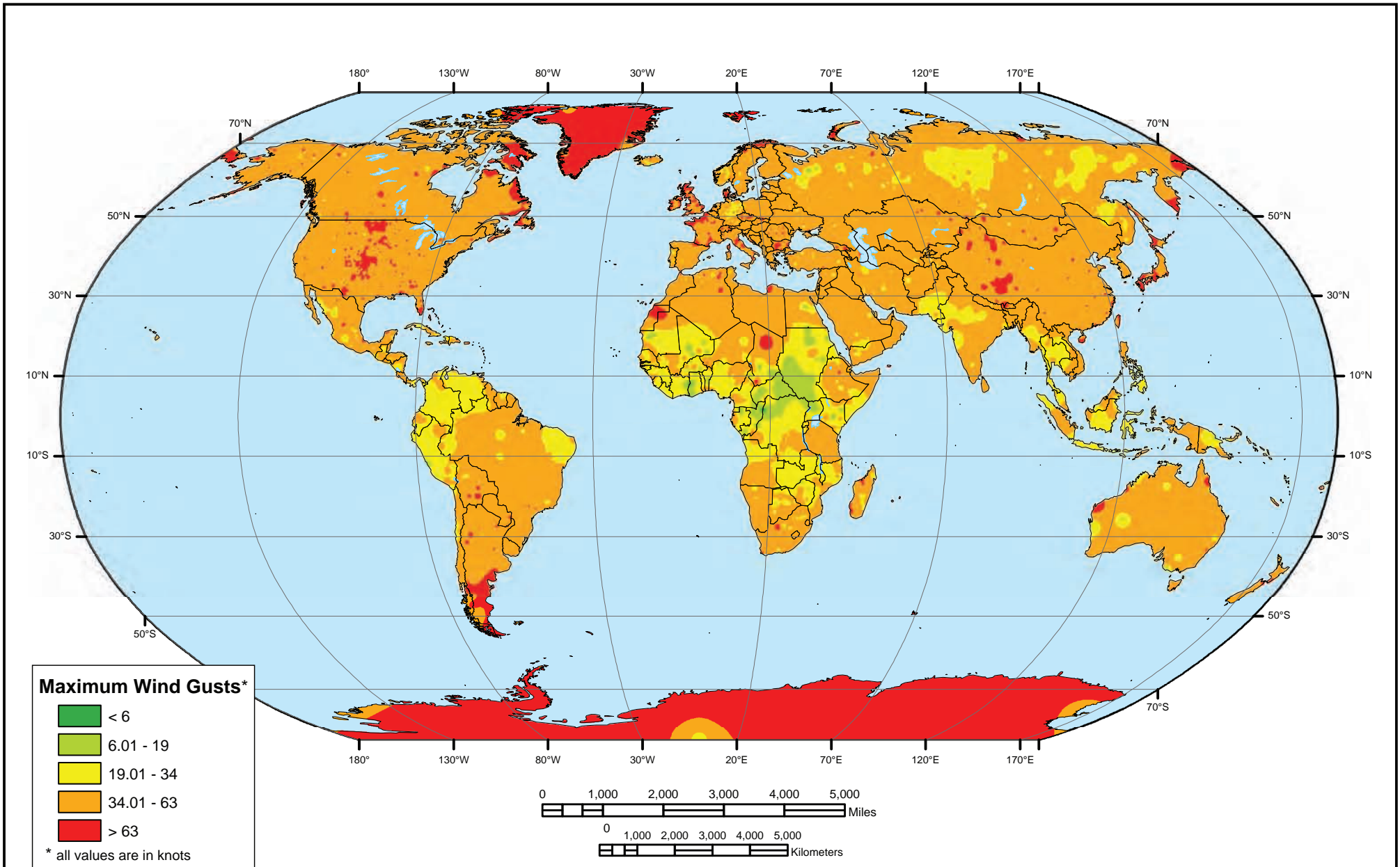
Projection:
 World Robinson, WGS 1984.



GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
 REVISION OF ENVIRONMENTAL TESTING GUIDELINES
Global Average Wind Speed Map

DATE: 6-02-09

FIGURE 7-6



Map compiled and modified by Scott D. Bassett, Steven N. Bacon, Julie A. Koruna, and Eric V. McDonald, Terrain Analysis Program, Desert Research Institute.

Data Source: 1994-2006 NCDC/NOAA Global Surface Summary Worldwide
 Stations available online at: <ftp.ncdc.noaa.gov/pub/data/globalsod>

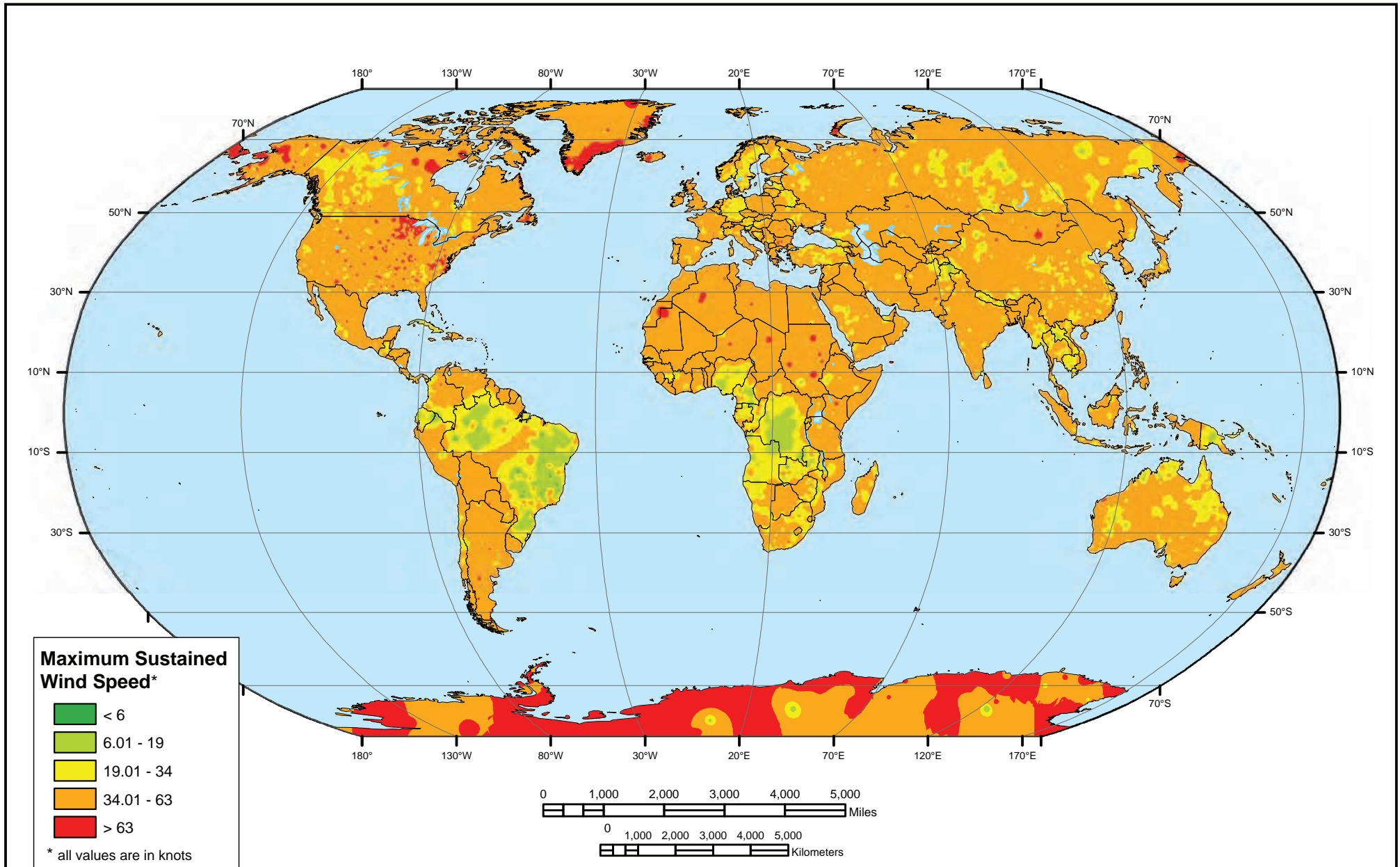
Projection:
 World Robinson, WGS 1984.



GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
 REVISION OF ENVIRONMENTAL TESTING GUIDELINES
Global Maximum Wind Gusts Map

DATE: 6-02-09

FIGURE 7-7



Map compiled and modified by Scott D. Bassett, Steven N. Bacon, Julie A. Koruna, and Eric V. McDonald, Terrain Analysis Program, Desert Research Institute.

Data Source: 1994-2006 NCDC/NOAA Global Surface Summary Worldwide
 Stations available online at: <ftp.ncdc.noaa.gov/pub/data/globalsod>

Projection:
 World Robinson, WGS 1984.



GLOBAL PHYSIOGRAPHIC AND CLIMATIC MAPS TO SUPPORT
 REVISION OF ENVIRONMENTAL TESTING GUIDELINES
Global Maximum Sustained Wind Speed Map

DATE: 6-02-09

FIGURE 7-8

8.0 REFERENCES

- Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E., 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geological Survey Professional Paper 964, 28 pp.
- Bailey, R.G., 1998. Ecoregions: The Ecosystem Geography of the Oceans and Continents. Springer-Verlag, Inc., New York: 176 pp.
- Barton, K.E., Howell, D.G., and Vigil, J.F., 2003. The North American tapestry of time and terrain. U.S. Geological Survey, Geologic Investigation Series I-2781. (map scale: 1:8,000,000).
- Bates, R.L., and Jackson, J.A., (eds.), 1987. Glossary of Geology: American Geological Institute, Alexandria, VA, 3rd edition, 788 pp. © 2003 American Geological Institute.
- Bostock, H.S., 1967. Physiographic regions. The national atlas of Canada. (map scale: 1:15,000,000).
- Brown, J., Ferrians, O.J., Jr., Heginbottom, J.A., and Melnikov, E.S., 1998 (revised 2001). Circum-arctic map of permafrost and ground ice conditions. Boulder, CO: National Snow and Ice Data Center for Glaciology. Digital media.
- Busacca, A.J., and Sweeney, M.R., 2005. Loess. In: Hill, D., (ed.), Encyclopedia of soils in the environment. Academic Press, p. 364-373.
- Daly, C., Gibson, W.P., Taylor, G.H., Johnson, G.L., Pasteris, P., 2002. A knowledge-based approach to the statistical mapping of climate. *Climate Research*, v. 22, p. 99-113.
- FAO [Food and Agriculture Organization], 1999. Soil and physiographic database for north and central Eurasia 1:5,000,000. [CD-ROM]. FAO land and water digital media series #07. Version 1.0 for Windows. UNESCO, Paris.
- FAO-UNESCO-ISRIC, 1988. Revised legend of the soil map of the World. World Soil Resources Report n0 06. FAO, Rome Italy.
- FAO-UNESCO-ISRIC, 1990. Revised legend of the soil map of the World. World Soil Resources Report n0 06. FAO, Rome Italy.
- FAO-UNESCO-ISRIC, 1998. World reference base for soil resources. World Resources Report, #84. FAO, Rome, 88 pp.

- Hammond, E.H., 1954. Small-Scale Continental Landform Maps. *Annals of the Association of American Geographers*, v. 44, p. 33-42.
- Hearn, P., Hare, T., Schruben, P., Sherrill, D., LaMar, C., and Tsushima, P., 2003. *Global GIS, A Digital Atlas of Planet Earth, Digital Data Series DDS-62 A-H*, U.S. Geological Survey.
- McDonald, E.V., Bacon, S.N., Bassett, S.D., and Jenkins, S.E., 2009. *Catalog of Analogs: Terrain Similarities between the U.S. Army Yuma Proving Ground and central southwest Asia – Final Report*, Prepared for U.S. Army Yuma Proving Ground, Natural Environments Test Office by Desert Research Institute. May 21, 2009, 95 pp.
- Nachtergaele, F.O., Spaargaren, O., Deckers, J.A., Ahrens, B., 2000. New developments in soil classification World Reference Base for Soil Resources. *Geoderma*, v. 96, p. 345-357.
- Olson, J.S., 1994. *Global ecosystem framework-definitions*. USGS EROS Data Center Internal Report, Sioux Falls, SD., 38 pp.
- Permafrost subcommittee, 1998, *Glossary of permafrost and related ground ice terms*. National Research Council of Canada. Technical memorandum, No. 142, 156 pp.
- Pidwirny, M., 2006. *Fundamentals of Physical Geography*, 2nd Edition. November, 16. <http://www.physicalgeography.net/fundamentals/contents.htm>.
- Soil Survey Staff, 1999. *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys*, Second Edition. USDA Handbook Number 436.
- Wilson, D.F. Philip, G.M., 1985. A refinement of inverse distance weighted interpolation. *Geo-Processing*, v. 2, p. 315-327.