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Methods for Comparing Global Vegetation Maps

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Foreword

IIASA's projects within the Environment Program are devoted to investigating the interaction of human development activities and the environment, particularly in terms of the sustainable development of the biosphere. The research is policy-oriented, interdisciplinary, international in scope and heavily dependent on collaboration with a network of research scientists and institutes in many countries. The importance of IIASA's Environment Program stems from the fact that the many components of the planetary life-support systems are being threatened by increasing human activity, and that these problems are not susceptible to solution by singular governments or even, international agencies. Instead, resolution of the difficulties will demand concerted and cooperative actions by many governments and agencies, based on valid understanding of the earth's environmental systems. Establishment of a basis for international cooperation, and production of accurate global environmental perceptions are both hallmarks of IIASA's Environment Program.

Foremost among the global environmental issues of concern are those involving increasing concentrations of greenhouse gases and changing climate. Problem solutions will only become apparent after collection and analysis of pertinent data, testing of relevant hypotheses, genesis of mitigation strategies and investigation of the efficacy of the strategies that are developed. All of these activities can support development of, or be supported by, the appropriate mathematical models of the biosphere. Therefore, the Biosphere Dynamics Project has been focused on the creation of models that can describe the processes in the biosphere that result in vegetation dynamics. The models are being designed to define the biotic and ecological results of measures suggested to slow or stop increases in greenhouse gases. The models must be capable of documenting whether, and if so by how much, vegetational communities would benefit from mitigation actions, as well as describing how the terrestrial biosphere will respond in its role as carbon source and sink.

A major study is aimed at examining the potential future geographic configurations of the world's vegetation biomes under specified, steady-state distributions of global climate variables. Much progress has been made since work first began in Spring, 1988. Global climate databases have been developed for both current conditions and projected climate change. A geographic information system has been built for efficiently producing color maps of the various scenarios. The complexity of the resulting maps focused attention on the need for statistics and procedures for objectively comparing global vegetation maps. The study summarized in this report makes such methods available.

Prof. Bo R. Döös
Leader
Environment Program

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About the Author

Robert A. Monserud is Principal Mensurationist for the Intermountain Research Station (U.S.D.A. Forest Service) in Moscow, Idaho, USA. He earned a B.A. degree in Mathematics at the University of Iowa in 1968, a M.S. degree in Forest Management in 1973 and a Ph.D. degree in Forest Biometrics and Mensuration in 1975, both at the University of Wisconsin in Madison. Since joining the Intermountain Research Station in 1975, Monserud has worked on various problems centered on modeling stand dynamics and site productivity for uneven-aged mixed-species forests. For the past six years, Monserud has served as associate editor of *Forest Science.* He has also served as invited Visiting Professor at the University of California, Berkeley and as Research Scholar at IIASA (Summer, 1990). His four dozen publications address a diverse mix of forest modeling problems, including height and diameter growth, regeneration, mortality, mixed-species simulation, plot edge bias, insect damage, site productivity, soils, genetics, dendrochronology and time series analysis, optimal stand management, expert systems, and global vegetation modeling.

Contents

Methods for Comparing Global Vegetation Maps

*Robert A. Monserud**

1 ABSTRACT

Objective statistical methods are presented for comparing global vegetation maps. The methods are illustrated by comparing maps resulting from applying a modified Holdridge plant/climate hypothesis to various global climate projections and to current vegetation (the baseline). Five general circulation model projections (GFDL, GFDL-Qflux, GISS, OSU, UKMO) of expected climate resulting from doubling current CO_2 levels were used as input to the modified Holdridge model. The Kappa statistic proved to be a useful and straightforward measure of agreement between maps. Furthermore, individual kappa statistics for comparing a given vegetation zone between two maps clearly indicated differences and similarities between maps. Additional summary statistics compare the change in area, latitude, and longitude between maps for each vegetation zone, as well as the distance and direction that each vegetation zone has shifted.

2 INTRODUCTION

Recent research by the Biosphere Dynamics Project at the International Institute for Applied Systems Analysis (IIASA) has produced global vegetation maps corresponding to various hypotheses of climate change (Leemans 1989, Prentice et al. 1989). The maps are produced by a geographic information system developed by Leemans that contains relevant climatic and physical data for the land surface of the earth. Because of the complexity of the resulting vegetation patterns, it is difficult to objectively compare any two such maps. The focus of this paper is on the development of objective statistics for summarizing differences and similarities between global vegetation maps.

3 GLOBAL VEGETATION MAPS

Expected global vegetation maps are obtained by first stating a hypothesis regarding the factors affecting vegetation and then solving and plotting the outcome of that hypothesis for a network of points that represent the earth's land surface. Absolutely necessary is a series of databases that associate the relevant factors with all locations in the network of points or cells. The procedures and series of computer programs that produce the maps and provide the structure and organization for an otherwise overwhelming mass of data is called a Geographic Information System (GIS). Relying heavily on Fortran

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and the UNIRAS graphical library (version 6.1), Leemans developed a global geographic information system called BIOGIS for map construction and plotting as well as database development.

3.1 Geographic database

Leemans (1989) and Leemans and Cramer (1990) describe the development of a series of global geographic databases containing various climatic and physical information for the entire land surface of the earth (see also Options 1990). Grid size is 0.5° latitude by 0.5° longitude, which covers approximately 55 km^2 at the equator. This network contains approximately 63,000 pixels and was obtained by interpolating and smoothing a database representing over 5,500 weather stations worldwide. The resulting database contains mean monthly temperature, precipitation, and percent cloudiness for all cells, which can be indexed by latitude, longitude, and elevation. The monthly means were obtained by averaging between 10 and 40 years of weather records, mostly between the years 1931–60. Note that the additional cells that represent oceans, large bodies of water, and Antarctica are ignored because they are "structural zeros" (Bishop et al. 1975) in any analysis comparing changes in terrestrial vegetation.

3.2 Holdridge Life Zone Classification

The maps that will be used to illustrate the procedures developed in this paper will all be generated from a refinement of a vegetation hypothesis stated by Holdridge (1947, 1967). Holdridge held that the natural vegetation in an area could be determined objectively by the climate. Holdridge defined life zones that were based on three climatic parameters: biotemperature, mean annual precipitation, and a simple estimate of the potential evapotranspiration (PET) ratio (namely, the ratio of annual PET to annual precipitation). Holdridge then used biotemperature to delineate latitudinal and elevational life zones and the PET ratio to differentiate humidity provinces. Finally, a strong geometric structure was imposed on the life zones, which could then be displayed as hexagons of constant size in a two–dimensional space (Fig. 1).

Even though Holdridge's hypothesis is simplistic, it has nevertheless proven useful in elucidating both the importance and limitations of climate as a determinant of vegetation. This simplicity is probably the main attraction of the hypothesis, for it requires only climatic data that is generally available. Emanuel et al. (1985a, 1985b) were first to apply Holdridge's system to the entire globe. By working with a more complete and sophisticated climate database (e.g., a lapse rate was used to adjust temperature for elevation), Leemans (1989) improved upon their efforts, especially inmountainous areas.

3.3 Climate Change

Holdridge's hypothesis is intrinsically static. Vegetation is viewed as responding immediately to a change in climate. With such a naive viewpoint, vegetation is not seen to have any transient response, any feedback or delay, any dynamics. In spite of these limitations, the approach nevertheless has some utility in the absence of a workable dynamic alternative for the global scale. Because the Holdridge system uses only basic climatic variables (temperature, precipitation) that are generally available, it is straightforward to predict a vegetation response to any climate scenario that can be expressed with those variables.

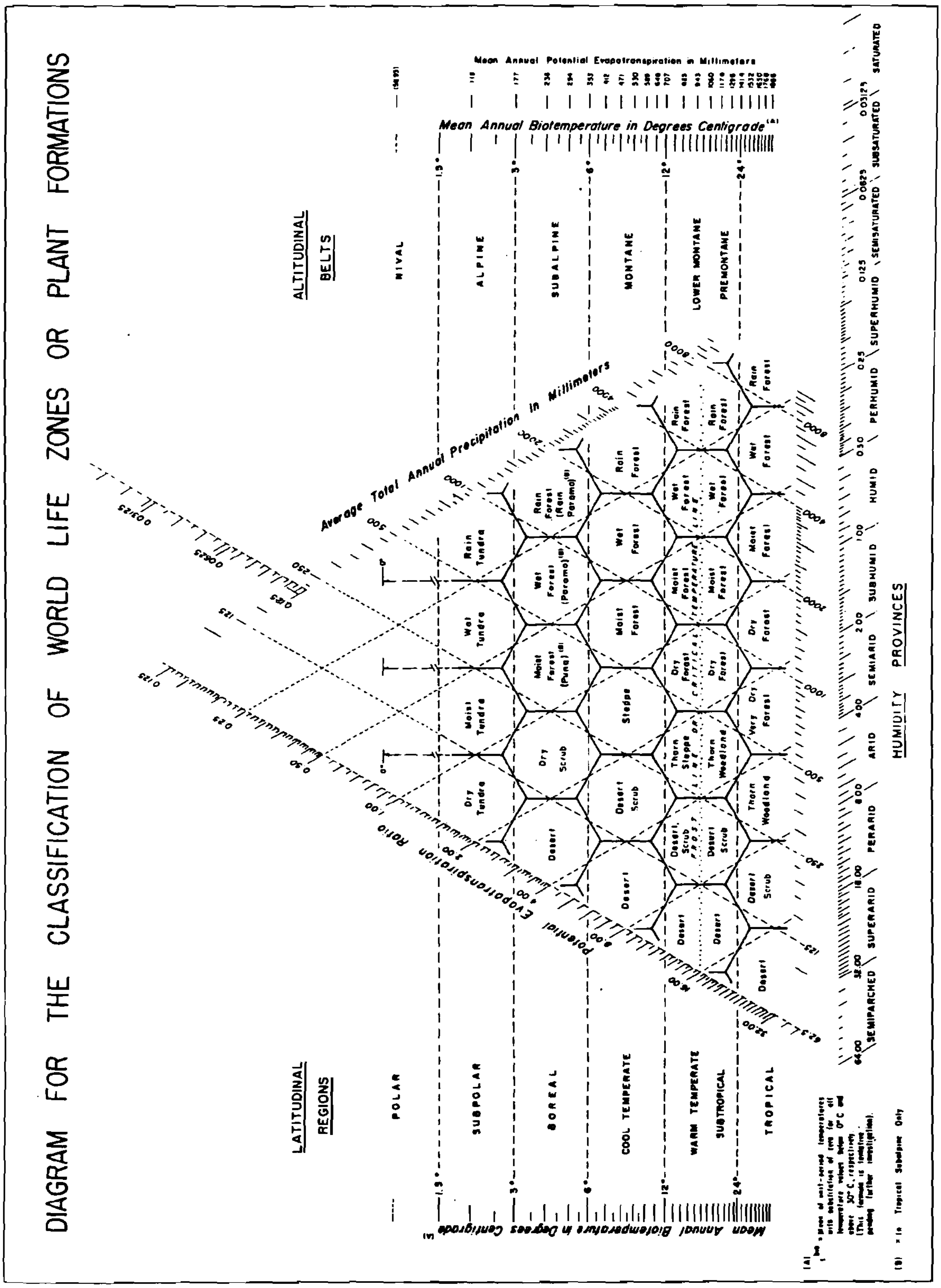

Figure 1: The Holdridge classification of world life zones (Holdridge 1967).

General circulation models (GCM's) of the atmosphere have become increasingly popular tools for predicting the climatic response to a variety of global atmospheric disturbances. GCM's attempt to numerically simulate the dynamics of the atmosphere, coupled with the surface water and energy balances (Harrison 1990). After dividing the earth's surface and atmosphere vertically into strata and horizontally into grid cells and then specifying initial conditions, the equations of state are simultaneously solved for all cells in all strata, while constraining for conservation of energy and momentum (Hansen et al. 1983). Basically this amounts to solving the Navier–Stokes equations for the movement of a fluid around a sphere. In this study, five different GCM predictions were used to estimate the global climatic response to a doubling of CO_2:

GFDL Geophysical Fluid Dynamics Laboratory of NOAA, Princeton (Wetherald and Manabe 1986, Manabe and Wetherald 1987).

GFDL-Qflux Geophysical Fluid Dynamics Laboratory–Ocean heat flux version (Manabe and Wetherald 1987, Jenne 1989).

GISS Goddard Institute for Space Studies, NASA, Columbia U. (Hansen et al. 1983).

OSU Oregon State University, Corvallis (Schlesinger and Zhao 1989).

UKMO United Kingdom Meterological Office (Mitchell 1983, Wilson and Mitchell 1987).

In addition to the main citations listed above, detailed descriptions and comparisons of these models can be found in Harrison (1990), Jenne (1989), and Schleshinger and Mitchell (1987).

3.4 Holdridge Map Construction

Climatic output from these GCM projections was used as input to Leemans' (1989) modified Holdridge life zone model. Several steps are needed to create the global vegetation scenarios.

1. Using the current climate database as input (Leemans and Cramer 1990), a base map is constructed by combining Holdridge's 39 vegetation classes until the resulting map most closely resembles the current vegetation map of Olson et al. (1982). The resulting Holdridge base map has 14 vegetation zones (Options 1990). This exercise is far from straightforward because Olson et al. used definitions of vegetation classes (a total of 57) that do not correspond to Holdridge's definitions of vegetation classes.

2. For each GCM, the differences between the control run and the doubled CO_2 run are determined. The absolute value of the temperature differences and the ratio of the precipitation estimates are calculated for each pixel.

3. A climate change database is created by adding these temperature differences to temperature in the current climate database and by multiplying precipitation by the ratio of precipitation predicted by the two GCM runs.

4. The modified Holdridge classification (14 vegetation zones) is again run using the respective climate change database for each GCM.

Global vegetation maps were then produced by using the resulting files with BIOGIS. The baseline Holdridge map thus displays a current vegetation scenario (climate of $1\times CO_2$) while the respective GCM comparisons desplay $2\times CO_2$ scenarios.

4 COMPARING GLOBAL VEGETATION MAPS

When the resulting maps are plotted in color, it is possible to visually examine and compare the maps for differences (e.g., see Options 1990). This is nearly impossible in black and white (cf. Leemans 1989). Comparison in color is nevertheless difficult and tedious, for the maps are quite complex, even when the number of vegetation zones is as few as fourteen. An additional problem becomes apparent: because there are so many pixels (62,483), the map examiner usually compares only small subsets of points, points subjectively chosen because they represent regions that the examiner is familiar with. The result of the comparison is often a subjective judgement based on incomplete information. The need for an objective measure of agreement between two given maps is obviously great.

4.1 Statistical Considerations

There is a large and growing literature for analyzing spatial patterns and spatial processes (e.g., Pielou 1977, Ripley 1981, Cliff and Ord 1981, Gaile and Willmott 1984). This literature is devoted almost exclusively to answering the following question: "What underlying process could have produced this map or spatial pattern?" Surprisingly, the answer is trivial when working within the framework of a GIS: the underlying process is known exactly. It is the interaction of the hypothesis and the relevant features of the terrain programmed into the GIS. The map is a picture of this interaction.

Thus the real question of interest involves the comparison of two maps generated by known processes. This is properly a question of agreement—pixel by pixel agreement. Bishop et al. (1975, p. 394) explain that the distinction between agreement and association for nominal data is that for two responses to agree they must fall into the identical category, while for two responses to be perfectly associated it is only necessary to be able to predict the category of one response from the category of the other. A table displaying paired responses may exhibit high association along with either high or low agreement.

Although much work has been done on various measures of association, the literature on judging agreement is quite small. In their seminal work on measures of association, Goodman and Kruskal (1954) considered agreement to be a special case. Given a table displaying the results of two observers assigning each of N items into one of c categories, the categories for rows in a table of agreement must appear in exactly the same order as the categories for columns. This simple restriction gives meaning to the main diagonal of any agreement table (Bishop et al. 1975).

4.2 The Kappa Statistic

The contributions of Goodman and Kruskal (1954) notwithstanding, the seminal work on agreement is Cohen (1960). Consider the following table of agreement displaying the resulting joint proportions after two observers (or maps) assigned each of N items into one of c categories:

Map A Categories	Map B Categories 1	2	...	c	Total
1	p_{11}	p_{12}	...	p_{1c}	$p_{1.}$
2	p_{21}	p_{22}	...	p_{2c}	$p_{2.}$
⋮	⋮	⋮	⋱	⋮	⋮
c	p_{c1}	p_{c2}	...	p_{cc}	$p_{c.}$
Total	$p_{.1}$	$p_{.2}$	...	$p_{.c}$	1

The main diagonal contains the proportions of observed agreement between the two maps for each category. Their sum is the overall proportion of observed agreement:

$$p_o = \sum_{i=1}^{c} p_{ii}$$

Although p_o is the simplist and most frequently used index of agreement (it is often called an *intraclass correlation coefficient*), it is not without problems (Fleiss 1981). It is reasonable to expect that some degree of agreement will occur by change alone. Cohen (1960) discovered a natural means for correcting for chance. Observing that the marginal totals contain information about the magnitude of chance agreement, Cohen calculated the overall proportion of chance–expected agreement

$$p_e = \sum_{i=1}^{c} p_{i.}p_{.i}$$

that occurs if the rows are independent of the columns. (Note that Scheffe's dot notation is used to indicate marginal totals.) Although the difference $p_o - p_e$ is a useful measure of agreement, Cohen improved it by normalizing by the largest possible value for the given marginal totals (namely, $1 - p_e$). The resulting statistic is called *kappa*:

$$\hat{\kappa} = \frac{p_o - p_e}{1 - p_e}$$

Kappa has desireable properties. It takes on a value of 1 with perfect agreement ($p_o = 1$). It has a value close to zero when the observed agreement is approximately the same as would be expected by chance ($p_o \approx p_e$). Furthermore, an individual $\hat{\kappa}_i$ can be calculated for each category. In that case, the overall value of $\hat{\kappa}$ is also equal to a weighted average of the individual $\hat{\kappa}_i$'s. In addition, the kappa statistic does not assume that the marginal probabilities are equal for the two observers or maps.

Because the asymptotic sample variance of $\hat{\kappa}$ has been derived, it is straightforward to do hypothesis testing with kappa (see excellent summary by Fleiss 1981, Chapter 13). This is rarely an interesting way to compare two maps, however, because of the rather large sample sizes involved. (With $N = 62,483$, almost *any* two global maps will be significantly different.)

A much more useful way to use kappa for map comparison is provided by Landis and Koch (1977). They have characterized different ranges of $\hat{\kappa}$ based on the degree of agreement that they suggest. Values greater than approximately 0.75 indicate very good to excellent agreement (1.0 is perfect agreement), values between 0.4 and 0.75 indicate fair to good agreement, and values of 0.4 or less indicate poor agreement. Values close to 0.0 mean that the agreement is no better than would be expected by chance. Although it is possible to have a minimum value that is negative, a negative $\hat{\kappa}$ indicates exceedingly poor agreement. Threshold values used in the current paper for separating the different degrees of agreement for the kappa statistic are listed in the following table:

of agreement for the

Lower bound	Degree of Agreement	Upper bound
<0.05	no	0.05
0.05	very poor	0.20
0.20	poor	0.40
0.40	fair	0.55
0.55	good	0.70
0.70	very good	0.85
0.85	excellent	0.99
0.99	perfect	1.00

Although the kappa statistic appears well suited to judging agreement between maps, very few applications could be found in the literature. Congalton et al. (1983) is a notable exception (note that they term the statistic "KHAT").

5 HOLDRIDGE MAP COMPARISONS

A convenient way to describe important features of a map is in terms of latitude and longitude. Table 1 lists the following statistics describing the distribution of vegetation zones in the modified Holdridge baseline map with respect to latitude and longitude:

1. the minimum,
2. the 20th percentile,
3. the median (50th percentile),
4. the 80th percentile,
5. the maximum,
6. the mean,
7. the standard deviation.

The point of these statistics is to allow the examiner to picture the distribution of vegetation in an objective manner. Of course, the map itself is available for seeing the distribution of vegetation. The arbitrary minimum for longitude (a circular function) is -168.5°, which is the western border of Alaska, and the maximum is +189.5°, which is the eastern border of Siberia (Greenwich is zero). With apologies to colleagues from the southern hemisphere, the south pole is –90° latitude and the north pole is +90° latitude (the equator is zero). Note that the mean is probably not as good a measure of central tendency as is the median, for the mean can be influenced greatly by values in the tails of the distribution (e.g., the latitude of a relatively small amount of tundra in the mountains of South America is averaged with a large expanse of tundra in the northern hemisphere).

A natural way to compare different vegetation maps is in terms of a change in area, as well as the distance and direction that the vegetation classes have moved. For each comparison map, a table is provided that lists the change in area and the kappa statistic for judging agreement with the baseline map. Tables are then provided that list both the distance and direction that each vegetation zone has moved (shifted) between the baseline map and the comparison map. Additional tables list changes in both latitude and longitude from the baseline map, for each vegetation class. The same descriptive statistics that are tabulated for the baseline map are calculated for the comparison maps; differences in these statistics are then tabulated.

Table 1: The distribution of vegetation zones with respect to latitude and longitude for the modified Holdridge baseline map.

	Latitude (units = degrees) Descriptive statistics for Baseline Map						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	-55.0	63.5	70.5	77.0	83.0	66.1	18.4
Cold Parklands	-52.0	43.5	60.0	65.5	74.5	51.2	22.8
Forest Tundra	-55.5	56.5	64.0	68.0	74.0	60.2	14.8
Boreal Forest	-56.0	50.0	56.5	62.0	70.5	53.7	16.6
Cool Desert	-52.5	33.0	42.0	46.5	53.5	30.8	28.8
Steppe	-53.5	39.5	45.5	50.0	58.5	43.1	13.9
Temperate Forest	-52.5	39.0	45.5	52.5	62.0	40.0	22.8
Hot Desert	-45.0	4.0	23.0	30.0	46.5	14.9	22.0
Chapparal	-43.0	-34.0	31.5	37.5	52.5	7.7	33.7
Warm Temperate Forest	-40.5	-2.5	28.0	36.0	45.5	18.4	24.0
Tropical Semi-Arid	-35.0	-22.0	4.5	16.5	39.5	-0.3	20.7
Tropical Dry Forest	-34.5	-17.0	-1.5	14.0	41.0	-0.7	17.2
Tropical Seasonal Forest	-34.0	-15.0	-3.0	17.5	41.0	-0.4	16.7
Tropical Rain Forest	-24.5	-6.5	-1.0	6.5	28.0	0.7	8.7

	Longitude (units = degrees) Descriptive statistics for Baseline Map						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	-167.0	-86.0	-41.5	96.0	189.5	-8.4	93.8
Cold Parklands	-165.0	-71.0	104.0	132.0	159.0	60.4	101.1
Forest Tundra	-168.0	-105.0	83.5	126.0	190.0	33.3	108.0
Boreal Forest	-168.5	-100.0	47.0	104.0	173.0	15.5	93.6
Cool Desert	-123.0	-68.5	59.5	88.5	117.5	29.9	73.4
Steppe	-123.0	-103.5	45.5	82.5	143.5	17.6	84.0
Temperate Forest	-156.0	-79.0	17.0	56.5	177.5	9.3	77.1
Hot Desert	-117.5	3.5	31.5	65.0	149.5	36.9	51.7
Chapparal	-123.0	-67.0	23.8	116.0	152.0	18.0	85.8
Warm Temperate Forest	-156.0	-84.0	36.0	115.0	178.0	21.9	94.4
Tropical Semi-Arid	-120.0	3.5	36.0	126.0	150.5	45.6	67.3
Tropical Dry Forest	-119.5	-60.0	22.0	76.0	166.5	13.0	65.9
Tropical Seasonal Forest	-156.5	-59.5	0.3	45.5	178.0	-3.0	64.5
Tropical Rain Forest	-94.5	-69.5	-14.5	113.5	179.0	14.5	86.6

Table 2: Change in area between the GFDL map and the baseline map. The kappa statistic for assessing agreement between maps is 0.43. This indicates only *fair agreement* with the baseline map.

	Area Comparison (units = 1000 km^2)				
Vegetation Zone	Baseline Map	Comparison Map	Stable Area	% Stable Area	Kappa statistic
Tundra	1036.89	429.29	429.29	41.4%	0.62
Cold Parklands	280.99	284.47	89.04	31.7%	0.32
Forest Tundra	885.71	394.17	15.94	1.8%	-0.04
Boreal Forest	1512.04	961.49	144.23	9.5%	-0.00
Cool Desert	401.76	304.43	138.91	34.6%	0.37
Steppe	741.13	1158.90	400.81	54.1%	0.35
Temperate Forest	997.77	1185.85	407.69	40.9%	0.30
Hot Desert	2085.22	2065.00	1830.82	87.8%	0.86
Chapparal	562.86	740.61	40.50	7.2%	0.02
Warm Temperate Forest	321.67	195.58	34.75	10.8%	0.11
Tropical Semi-Arid	953.36	1398.89	814.77	85.5%	0.66
Tropical Dry Forest	1485.48	1956.96	1216.70	81.9%	0.66
Tropical Seasonal Forest	1507.83	1002.29	689.08	45.7%	0.52
Tropical Rain Forest	845.77	1540.65	843.04	99.7%	0.68
Totals:	13618.49	13618.58	7095.57	52.1%	0.43

5.1 GFDL Comparisons

Table 2 compares the change in area between the GFDL projection (Manabe and Wetherald 1987, Wetherald and Manabe 1986) and the Holdridge baseline map. The total area of each vegetation zone is displayed for the baseline map and the comparison map. The size of the stable area is presented (i.e., the area catagorized identically in both maps), along with the percentage of the baseline map that remained stable. These area statistics allow one to determine how much a vegetation zone is shrinking, expanding, stable, or shifting. The kappa statistic is also calculated for each vegetation zone and for the entire map. Note that the kappa statistic is often close to the proportion of stable area but only when a given zone has approximately the same area in both maps. This similarity breaks down if a zone is expanding or shrinking from one map to another. For example, over 99% of the original area in Tropical Rain Forest is stable in the GFDL projection. However, the amount of Tropical Rain Forest predicted by GFDL has doubled. Thus the kappa statistic for Tropical Rain Forest is 0.68 instead of being near 0.99.

The overall value of kappa for the GFDL comparison is 0.43. This indicates *fair agreement* with the baseline map. Furthermore, only 52% of the area has remained stable. Zones that expanded greatly are Steppe, Tropical Semi-Arid, Tropical Dry Forest, and Tropical Rain Forest. Zones undergoing considerable shrinkage are Tundra, Cold Parklands, Boreal Forest, and Tropical Seasonal Forest. Judging by the kappa statistic, the only zones that show at least good agreement with the baseline map are Tundra, Hot Desert, Tropical Semi-Arid, Tropical Dry Forest, and Tropical Rain Forest. Hot Desert, of course, is the most stable zone. The locations of the Forest Tundra, Boreal Forest, and Chapparal zones have almost completely changed.

Table 3 lists both the distance and direction that vegetation zones have shifted between the GFDL projection and the baseline map. The median of eight vegetation zones shifted more than 1000 km, and the median of four zones shifted more than 2000 km (Boreal Forest, Cool Desert, Tropical Rain Forest, and Warm Temperate Forest). The first three of these large shifts were to the east, while the center of the Warm Temperate Forest shifted west. Generally, most of the shifts listed in the bottom half of Table 3 are northerly.

Table 4 lists changes in latitude between the GFDL projection and the baseline map. The upper portion of the table lists any north/south shift in a vegetation zone. A positive value in the upper portion of the table indicates a shift to the north; a negative value indicates a southerly shift. The lower half of Table 4 lists the polar change in latitude. A positive value indicates a shift toward either pole and a negative value indicates a shift towards the equator. Except for minor shifts towards the equator in the median of the tropical zones, all other shifts are toward the poles, the north pole in particular. The largest shifts (using the median) are 12° for Chapparal, 9° for Warm Temperate Forest, and 8° for Steppe and Temperate Forest.

Table 5 lists the East/West shift in longitude between the GFDL projection and the baseline map. A shift to the east is positive and a shift to the west is negative. Changes in longitude are far more variable than changes in latitude and thus are more difficult to interpret without looking at the maps. The largest shifts (using the median) are 35° east for Boreal Forest, 30° east for Tropical Rain Forest, 29° east for Cool Desert, and 24° west for Warm Temperate Forest.

Table 3: The distance (upper half of the table) and direction (lower half) that vegetation zones have shifted from the baseline map to the GFDL map.

	Distance Shifted from base map (units = 100 km)					
Vegetation Zone	Min	20%	Median	80%	Max	Mean
Tundra	24.0	7.3	5.7	22.3	1.2	11.1
Cold Parklands	4.0	88.1	7.5	6.8	9.5	15.7
Forest Tundra	3.7	7.5	5.9	6.2	6.7	7.5
Boreal Forest	1.3	7.5	20.9	9.2	11.5	9.1
Cool Desert	19.5	6.8	23.5	13.7	20.3	16.2
Steppe	19.5	8.7	16.3	19.0	22.5	11.1
Temperate Forest	9.0	7.9	11.0	14.9	16.7	10.3
Hot Desert	6.2	13.5	2.7	5.1	2.8	8.2
Chapparal	7.8	85.2	15.9	51.6	14.5	41.5
Warm Temperate Forest	8.3	11.6	24.6	17.2	27.3	10.3
Tropical Semi-Arid	9.2	9.0	1.2	11.7	7.8	3.6
Tropical Dry Forest	7.7	3.8	9.5	26.6	12.9	7.8
Tropical Seasonal Forest	7.2	6.1	12.6	57.7	5.3	8.3
Tropical Rain Forest	58.9	5.0	33.4	15.0	10.0	3.0

	Direction of Shift from base map					
Vegetation Zone	Min	20%	Median	80%	Max	Mean
Tundra	NE	NE	NW	W	W	W
Cold Parklands	NW	E	NE	E	E	NE
Forest Tundra	E	NE	NW	E	N	W
Boreal Forest	NE	NW	E	E	NE	NE
Cool Desert	W	N	E	E	NE	NE
Steppe	W	N	NE	NE	NE	NE
Temperate Forest	W	N	NE	NE	N	N
Hot Desert	SW	N	NW	NW	N	NW
Chapparal	S	N	NW	W	N	NW
Warm Temperate Forest	S	E	W	NE	N	NE
Tropical Semi-Arid	S	W	SE	N	N	W
Tropical Dry Forest	SW	W	NW	NW	N	NW
Tropical Seasonal Forest	S	S	E	E	NW	E
Tropical Rain Forest	W	E	E	NW	N	NE

Table 4: Change in latitude between the GFDL map and the baseline map. The upper half of the table lists the North/South change in latitude and the lower half lists the polar change in latitude. Table entries are differences in descriptive statistics between the two maps.

	North/South Change in Latitude (units = degrees) Shift north: positive; shift south: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	20.0	5.0	5.0	3.0	0.0	3.2	1.7
Cold Parklands	3.0	7.0	6.0	3.5	5.5	9.6	-7.2
Forest Tundra	1.0	5.5	4.5	4.0	6.0	4.0	-0.4
Boreal Forest	1.0	6.0	6.5	5.5	9.5	6.3	-2.6
Cool Desert	0.0	6.0	3.0	4.5	13.5	7.8	-1.3
Steppe	-1.0	7.5	8.0	10.0	19.5	9.1	-0.6
Temperate Forest	-3.5	7.0	8.0	8.5	15.0	9.2	-1.1
Hot Desert	-5.0	12.0	2.0	2.5	2.5	3.8	0.1
Chapparal	-7.0	72.0	12.0	11.0	13.0	31.6	-14.8
Warm Temperate Forest	-7.5	-3.0	9.0	11.5	24.5	6.3	8.5
Tropical Semi-Arid	-8.0	-2.0	-1.0	10.5	7.0	0.5	3.7
Tropical Dry Forest	-6.5	-0.5	5.5	10.0	11.5	2.8	4.6
Tropical Seasonal Forest	-6.5	-5.5	3.5	9.5	4.5	2.3	6.3
Tropical Rain Forest	-14.0	0.0	1.0	8.0	9.0	1.9	3.2

	Polar Change in Latitude (units = degrees) Shift to Poles: positive; Shift to Equator: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	-20.0	5.0	5.0	3.0	0.0	3.2	1.7
Cold Parklands	-3.0	7.0	6.0	3.5	5.5	9.6	-7.2
Forest Tundra	-1.0	5.5	4.5	4.0	6.0	4.0	-0.4
Boreal Forest	-1.0	6.0	6.5	5.5	9.5	6.3	-2.6
Cool Desert	0.0	6.0	3.0	4.5	13.5	7.8	-1.3
Steppe	1.0	7.5	8.0	10.0	19.5	9.1	-0.6
Temperate Forest	3.5	7.0	8.0	8.5	15.0	9.2	-1.1
Hot Desert	5.0	12.0	2.0	2.5	2.5	3.8	0.1
Chapparal	7.0	4.0	12.0	11.0	13.0	31.6	-14.8
Warm Temperate Forest	7.5	3.0	9.0	11.5	24.5	6.3	8.5
Tropical Semi-Arid	8.0	2.0	-1.0	10.5	7.0	-0.0	3.7
Tropical Dry Forest	6.5	0.5	2.5	10.0	11.5	1.3	4.6
Tropical Seasonal Forest	6.5	5.5	-2.5	9.5	4.5	1.5	6.3
Tropical Rain Forest	14.0	0.0	-1.0	8.0	9.0	1.9	3.2

5.2 GFDL-Qflux Comparisons

The GFDL-Qflux projections differ from the regular GFDL projections in that ocean heat flux is statically incorporated into the model (Jenne 1989). This allows for somewhat more realistic heat transfer by the oceans. The kappa statistic and changes in area between the GFDL-Qflux projection (Manabe and Wetherald 1987) and the Holdridge baseline map are listed in Table 6. Table 7 lists the distance and direction that the vegetation zones have shifted from the modified Holdridge map to the GFDL-Qflux map. Table 8 lists changes in latitude and Table 9 lists the East/West shift in longitude between the GFDL-Qflux projection and the baseline map.

The map produced by the GFDL-Qflux projection is remarkably similar to the Holdridge baseline map, judging from the myriad of statistics assembled in tables 6–9. The overall kappa statistic is 0.84, indicating *very good agreement* with the baseline map. Furthermore, the kappa statistics for every one of the individual vegetation zones all are greater than 0.70, indicating at least very good agreement with the baseline map. The area of almost all vegetation zones is quite stable (84%), with the only large change being an expansion of the Tropical Rain Forest. There are no shifts in latitude (of the median) of more than 5.5°, and the only large shift in longitude is 34° east for the center of the Tropical Rain Forest — a shift of 3800 km.

5.3 GISS Comparisons

The kappa statistic and changes in area between the GISS Model 2 projection (Hansen et al. 1983) and the Holdridge base map are listed in Table 10. Table 11 lists the distance and direction that the vegetation zones have shifted from the modified Holdridge map to the GISS map. Table 12 lists changes in latitude and Table 13 lists the East/West shift in longitude between the GISS projection and the baseline map.

The overall value of kappa for the GISS comparison is 0.51. This indicates *fair agreement* with the baseline map. Furthermore, only 56% of the area has remained stable. Zones that expanded greatly are Temperate Forest, Tropical Semi-Arid, Tropical Dry Forest, and Tropical Rain Forest. Zones undergoing noticeable shrinkage are Tundra, Forest Tundra, Hot Desert, and Tropical Seasonal Forest. Judging by the kappa statistic, the only zones that show good agreement with the baseline map are Tundra, Steppe, Hot Desert, Tropical Semi-Arid, Tropical Dry Forest, and Tropical Rain Forest. Hot Desert, of course, is the most stable zone judging from kappa. The locations of the Warm Temperate Forest and Chapparal zones have almost completely changed.

All shifts in latitude are toward the north pole (Table 12). The largest shifts (using the median) are 10° for Chapparal, 8° for Warm Temperate Forest, and 9° for Tropical Seasonal Forest. The largest shifts in longitude (using the median) are 45° west for Tropical Seasonal Forest, 27° east for Boreal Forest, 22° east for Cool Parklands, 29° east for Cool Desert, 24° west for Warm Temperate Forest, and 45° west for Tropical Seasonal Forest (Table 13).

Table 11 integrates the separate latitude and longitude data into a distance and direction that each vegetation zone has shifted. The center (median) of 9 of the 14 vegetation zones have shifted over 1000 km, mostly in an easterly or northerly direction. The center of the Tropical Seasonal Forest has shifted the most, over 5000 km west.

5.4 OSU Comparisons

The kappa statistic and changes in area between the OSU projection (Schlesinger and Zhao 1989) and the Holdridge base map are listed in Table 14. Table 15 lists the distance and direction that the vegetation zones have shifted from the modified Holdridge map to the OSU map. Table 16 lists changes in latitude and Table 17 lists the East/West shift in longitude between the OSU projection and the baseline map.

The overall value of kappa for the OSU comparison is 0.57. This indicates *good agreement* with the baseline map. Furthermore, 61% of the area has remained stable. Only two zones expanded greatly: Tropical Semi-Arid and Tropical Rain Forest (which doubled in size). Only the Tundra and Tropical Seasonal Forest Zones have noticeable shrinkage. Judging by the kappa statistic, all but 5 zones show good agreement with the baseline map.

The only large shift in latitude (using the median) is 9° for Chapparal (Table 16). The largest shifts in longitude (using the median) are 23° east for Boreal Forest, 15° east for Cool Parklands, 13° east for Warm Temperate Forest, and 20° east for Tropical Seasonal Forest (Table 17). The centers of only the Boreal Forest, Warm Temperate Forest, and Tropical Seasonal Forest have shifted more than 1000 km, all to the east.

5.5 UKMO Comparisons

The kappa statistic and changes in area between the UKMO projection (Mitchell 1983, Wilson and Mitchell 1987) and the Holdridge base map are listed in Table 18 (note that this version of the UKMO model did not include the revised cloud water model recently reported by Mitchell et al. 1989). Table 19 lists the distance and direction that the vegetation zones have shifted from the modified Holdridge map to the UKMO map. Table 20 lists changes in latitude and Table 21 lists the East/West shift in longitude between the UKMO projection and the baseline map.

The overall value of kappa for the UKMO comparison is 0.35. This indicates *poor agreement* with the baseline map. Furthermore, only 44% of the area has remained stable. Zones that expanded greatly are Temperate Forest, Chapparal, Tropical Semi-Arid, Tropical Dry Forest, and Tropical Rain Forest. Zones undergoing considerable shrinkage are Tundra, Forest Tundra, Boreal Forest, Cool Desert, and Tropical Seasonal Forest. Judging by the kappa statistic, the only zones that show good agreement with the baseline map are Tundra, Hot Desert, Tropical Semi-Arid, Tropical Dry Forest, and Tropical Rain Forest. This is reinforced by Table 19, which indicates that the centers of only these 4 vegetation zones have shifted less than 1000 km. Hot Desert, as always, is the most stable zone. The locations of the Forest Tundra, Boreal Forest, Chapparal, and Warm Temperate Forest zones have changed almost completely.

Almost all latitudinal statistics indicate shifts towards the north pole. The largest shifts (using the median) are 11° for Temperate Forest, 15° for Chapparal, 16° for Warm Temperate Forest, and 16° for Tropical Seasonal Forest (Table 20).

Changes in longitude are much larger and more variable than changes in latitude (Table 21). The largest shifts (using the median) are 21° east for Cold Parklands, 44° west for Forest Tundra, 38° east for Boreal Forest, 34° east for Cool Desert, 32° east for Steppe, 40° west for Warm Temperate Forest, 42° west for Tropical Seasonal Forest, and 23° east for Tropical Rain Forest.

5.6 Between–GCM Comparisons

It is also interesting to compare the maps produced by the 5 GCM projections with each other. Table 22 summarizes the overall kappa statistic for agreement between any two pair of maps discussed in this paper. The greatest similarities are between the GISS and OSU maps and between the GFDL and UKMO maps; the kappa statistics for both comparisons indicate *very good agreement.* The only pair indicating *poor agreement* is between GFDL-Qflux and UKMO, although the agreement between the two different GFDL projections is only *fair.* All other comparisons indicate *good* agreement. Clearly, the incorporation of ocean heat flux into the GFDL model has resulted in predictions that are much closer to the baseline map.

5.7 Olson Comparisons

The final comparison is between the current vegetation map of Olson et al. (1982) and the map of Holdridge (1947, 1967). Recall from the first step in Section 3.4 that Holdridge and Olson used different definitions for their vegetation zones. This makes an exact comparison of the two maps impossible. By combining Olson's zones using the same 14 vegetation zones as used to build the modified Holdridge base map, an approximate comparison is nevertheless possible.

The kappa statistic and changes in area between the modified maps of Olson and Holdridge are listed in Table 23. The overall kappa statistic is 0.40, which is the threshold value of Landis and Koch (1977) separating *poor agreement* from *fair agreement.* Only 35% of the area overlaps in the same vegetation zones. Only four of the vegetation zones had a kappa statistic that indicated *good agreement*: Tundra, Boreal Forest, Hot Desert, and Tropical Rain Forest. Clearly, these two maps illustrate a decidedly different view of the world.

Table 5: Change in longitude between the GFDL map and the baseline map. Table entries are differences in descriptive statistics between the two maps.

	East/West Change in Longitude (units = degrees) Shift East: positive; shift West: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	11.5	10.5	-3.5	-121.0	-8.5	-25.2	-31.5
Cold Parklands	-3.0	138.0	7.0	13.0	30.5	18.7	-4.7
Forest Tundra	5.5	7.5	-7.0	11.5	-1.0	-11.7	5.5
Boreal Forest	1.0	-5.0	35.5	14.5	17.0	9.5	14.7
Cool Desert	-29.0	-1.5	29.0	17.5	25.5	15.1	14.6
Steppe	-30.0	-3.0	19.0	24.5	16.0	6.0	8.1
Temperate Forest	-12.5	1.5	9.0	19.0	-1.5	-1.3	7.1
Hot Desert	-3.5	-1.5	-1.5	-4.5	0.0	-6.6	-0.8
Chapparal	-1.0	-28.0	-9.8	-63.5	-2.0	-22.0	-11.4
Warm Temperate Forest	0.0	10.0	-24.0	14.0	0.0	7.3	0.2
Tropical Semi-Arid	-2.5	-8.5	0.5	0.5	0.5	-3.2	7.9
Tropical Dry Forest	-3.0	-3.5	-6.5	-23.0	-2.5	-6.4	4.2
Tropical Seasonal Forest	0.0	-0.5	10.8	55.5	-2.0	7.1	10.0
Tropical Rain Forest	-61.0	4.5	30.0	-11.0	0.0	1.9	-8.1

Table 6: Change in area between the GFDL-Qflux map and the baseline map. The kappa statistic for assessing agreement between maps is 0.84. This indicates *very good agreement* with the baseline map.

	Area Comparison (units = 1000 km^2)				
Vegetation Zone	Baseline Map	Comparison Map	Stable Area	% Stable Area	Kappa statistic
Tundra	1036.89	969.27	958.90	92.5%	0.96
Cold Parklands	280.99	202.20	188.80	67.2%	0.77
Forest Tundra	885.71	882.56	765.26	86.4%	0.85
Boreal Forest	1512.04	1542.45	1340.41	88.6%	0.86
Cool Desert	401.76	351.53	306.02	76.2%	0.81
Steppe	741.13	666.44	564.13	76.1%	0.79
Temperate Forest	997.77	1158.68	902.82	90.5%	0.82
Hot Desert	2085.22	2002.17	1933.61	92.7%	0.94
Chapparal	562.86	541.69	456.11	81.0%	0.82
Warm Temperate Forest	321.67	339.36	260.51	81.0%	0.78
Tropical Semi-Arid	953.36	862.52	700.56	73.5%	0.76
Tropical Dry Forest	1485.48	1410.11	1111.98	74.9%	0.74
Tropical Seasonal Forest	1507.83	1442.78	1157.06	76.7%	0.77
Tropical Rain Forest	845.77	1246.79	830.77	98.2%	0.78
Totals:	13618.49	13618.53	11476.94	84.3%	0.84

Table 7: The distance (upper half of the table) and direction (lower half) that vegetation zones have shifted from the baseline map to the GFDL-Qflux map.

	Distance Shifted from base map (units = 100 km)					
Vegetation Zone	Min	20%	Median	80%	Max	Mean
Tundra	0.6	0.6	0.6	0.7	0.	1.0
Cold Parklands	0.	29.2	6.2	1.9	2.8	7.5
Forest Tundra	0.	2.5	2.2	2.3	0.	1.9
Boreal Forest	0.	1.2	2.2	1.4	4.0	1.2
Cool Desert	0.6	0.9	1.0	4.7	0.3	3.3
Steppe	0.3	0.	2.8	3.6	4.3	3.8
Temperate Forest	14.8	1.4	4.2	8.5	2.2	2.8
Hot Desert	0.	24.0	2.1	2.4	0.6	2.4
Chapparal	0.	0.9	2.7	0.7	4.5	2.6
Warm Temperate Forest	3.9	9.7	6.5	1.1	1.7	3.7
Tropical Semi-Arid	0.	5.7	6.3	2.7	0.6	7.8
Tropical Dry Forest	0.6	2.7	4.6	33.2	11.7	3.7
Tropical Seasonal Forest	0.6	1.7	10.8	1.2	9.6	1.3
Tropical Rain Forest	60.1	2.8	38.4	14.1	6.1	6.6

	Direction of Shift from base map					
Vegetation Zone	Min	20%	Median	80%	Max	Mean
Tundra	E	NE	NW	W	E	W
Cold Parklands	E	W	S	W	W	W
Forest Tundra	E	E	E	E	E	E
Boreal Forest	E	W	E	E	NE	E
Cool Desert	N	W	SE	E	E	SW
Steppe	E	E	E	E	SE	E
Temperate Forest	E	NE	E	E	N	NE
Hot Desert	E	S	W	W	S	W
Chapparal	E	E	NE	NW	S	NE
Warm Temperate Forest	S	N	NW	N	N	NW
Tropical Semi-Arid	E	W	NW	W	N	W
Tropical Dry Forest	S	SE	S	W	W	SE
Tropical Seasonal Forest	S	S	E	NE	W	E
Tropical Rain Forest	W	E	E	NW	N	NE

Table 8: Change in latitude between the GFDL-Qflux map and the baseline map. The upper half of the table lists the North/South change in latitude and the lower half lists the polar change in latitude. Table entries are differences in descriptive statistics between the two maps.

	North/South Change in Latitude (units = degrees) Shift north: positive; shift south: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	0.0	0.5	0.5	0.5	0.0	0.3	0.0
Cold Parklands	0.0	-0.5	-5.5	-0.5	0.0	-1.9	2.2
Forest Tundra	0.0	0.5	0.5	0.0	0.0	0.9	-1.7
Boreal Forest	0.0	0.5	0.5	0.5	3.5	0.3	0.1
Cool Desert	0.5	0.0	-0.5	-0.5	0.0	-1.8	1.4
Steppe	0.0	0.0	-0.5	-0.5	-3.5	-0.5	0.3
Temperate Forest	-0.5	1.0	1.5	1.5	2.0	2.1	-1.5
Hot Desert	0.0	-21.5	-0.5	0.0	-0.5	-0.5	0.5
Chapparal	0.0	0.0	1.5	0.5	-4.0	2.0	0.1
Warm Temperate Forest	-3.5	8.5	2.5	1.0	1.5	3.0	-1.2
Tropical Semi-Arid	0.0	-0.5	4.0	0.5	0.5	0.8	0.7
Tropical Dry Forest	-0.5	-1.5	-4.0	-2.5	0.0	-1.6	-0.1
Tropical Seasonal Forest	-0.5	-1.5	0.0	1.0	0.5	0.1	1.0
Tropical Rain Forest	-5.0	-0.5	1.0	10.0	5.5	2.7	3.6

	Polar Change in Latitude (units = degrees) Shift to Poles: positive; Shift to Equator: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	0.0	0.5	0.5	0.5	0.0	0.3	0.0
Cold Parklands	0.0	-0.5	-5.5	-0.5	0.0	-1.9	2.2
Forest Tundra	0.0	0.5	0.5	0.0	0.0	0.9	-1.7
Boreal Forest	0.0	0.5	0.5	0.5	3.5	0.3	0.1
Cool Desert	-0.5	0.0	-0.5	-0.5	0.0	-1.8	1.4
Steppe	0.0	0.0	-0.5	-0.5	-3.5	-0.5	0.3
Temperate Forest	0.5	1.0	1.5	1.5	2.0	2.1	-1.5
Hot Desert	0.0	13.5	-0.5	0.0	-0.5	-0.5	0.5
Chapparal	0.0	0.0	1.5	0.5	-4.0	2.0	0.1
Warm Temperate Forest	3.5	3.5	2.5	1.0	1.5	3.0	-1.2
Tropical Semi-Arid	0.0	0.5	4.0	0.5	0.5	0.2	0.7
Tropical Dry Forest	0.5	1.5	4.0	-2.5	0.0	1.6	-0.1
Tropical Seasonal Forest	0.5	1.5	0.0	1.0	0.5	-0.1	1.0
Tropical Rain Forest	5.0	0.5	-1.0	10.0	5.5	2.7	3.6

Table 9: Change in longitude between the GFDL-Qflux map and the baseline map. Table entries are differences in descriptive statistics between the two maps.

	East/West Change in Longitude (units = degrees) Shift East: positive; shift West: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	1.0	0.5	-0.5	-1.5	0.0	-2.0	-1.3
Cold Parklands	0.0	-36.3	-2.0	-4.0	-9.5	-10.1	5.4
Forest Tundra	0.0	4.0	4.5	5.5	0.0	2.9	-0.0
Boreal Forest	0.0	-1.5	3.5	2.5	2.5	1.7	2.0
Cool Desert	0.0	-1.0	1.0	6.0	0.5	-2.7	5.1
Steppe	0.5	0.0	3.5	5.0	3.0	4.6	-0.9
Temperate Forest	22.0	1.0	5.0	12.5	0.0	1.9	-1.0
Hot Desert	0.0	-1.5	-2.0	-2.5	0.0	-2.2	2.0
Chapparal	0.0	1.0	2.3	-0.5	0.0	1.3	-2.0
Warm Temperate Forest	0.0	-2.0	-6.0	-0.3	0.0	-1.5	0.4
Tropical Semi-Arid	0.0	-5.5	-4.0	-2.5	0.0	-6.9	0.0
Tropical Dry Forest	0.0	2.0	1.0	-30.5	-14.0	2.9	-1.1
Tropical Seasonal Forest	0.0	0.0	9.8	0.5	-11.5	1.1	1.9
Tropical Rain Forest	-61.0	2.5	34.5	-8.0	0.0	5.3	-4.1

Table 10: Change in area between the GISS map and the baseline map. The kappa statistic for assessing agreement between maps is 0.51. This indicates *fair agreement* with the baseline map.

	Area Comparison (units = 1000 km^2)				
Vegetation Zone	Baseline Map	Comparison Map	Stable Area	% Stable Area	Kappa statistic
Tundra	1036.89	543.24	543.24	52.4%	0.72
Cold Parklands	280.99	238.52	126.58	45.0%	0.53
Forest Tundra	885.71	589.30	170.28	19.2%	0.18
Boreal Forest	1512.04	1348.85	661.41	43.7%	0.39
Cool Desert	401.76	234.82	138.24	34.4%	0.43
Steppe	741.13	693.53	441.27	59.5%	0.60
Temperate Forest	997.77	1343.04	588.64	59.0%	0.45
Hot Desert	2085.22	1763.12	1597.18	76.6%	0.80
Chapparal	562.86	544.36	52.64	9.4%	0.06
Warm Temperate Forest	321.67	190.84	29.92	9.3%	0.10
Tropical Semi-Arid	953.36	1673.80	844.92	88.6%	0.61
Tropical Dry Forest	1485.48	1935.17	1140.01	76.7%	0.62
Tropical Seasonal Forest	1507.83	788.75	441.42	29.3%	0.35
Tropical Rain Forest	845.77	1731.22	831.83	98.4%	0.62
Totals:	13618.49	13618.58	7607.58	55.9%	0.51

Table 11: The distance (upper half of the table) and direction (lower half) that vegetation zones have shifted from the baseline map to the GISS map.

	Distance Shifted from base map (units = 100 km)					
Vegetation Zone	Min	20%	Median	80%	Max	Mean
Tundra	23.1	4.5	4.3	23.1	1.2	12.3
Cold Parklands	3.4	92.5	12.4	6.3	7.9	18.7
Forest Tundra	6.8	5.2	3.3	3.0	6.7	4.5
Boreal Forest	1.2	5.5	16.0	7.5	6.4	9.3
Cool Desert	19.0	5.1	25.0	12.2	20.0	17.5
Steppe	18.9	3.1	11.8	17.9	8.4	3.1
Temperate Forest	9.0	6.2	10.0	12.6	9.5	8.8
Hot Desert	6.7	16.2	8.4	7.9	1.1	15.3
Chapparal	10.6	81.3	11.2	38.4	16.9	33.9
Warm Temperate Forest	8.3	7.8	23.8	14.2	11.1	6.7
Tropical Semi-Arid	9.2	3.5	9.1	11.1	7.2	3.2
Tropical Dry Forest	9.9	1.7	7.8	9.2	8.9	3.6
Tropical Seasonal Forest	6.1	18.4	50.8	60.1	5.4	7.7
Tropical Rain Forest	15.6	5.5	17.3	12.2	13.9	7.4

	Direction of Shift from base map					
Vegetation Zone	Min	20%	Median	80%	Max	Mean
Tundra	N	NE	NW	W	W	W
Cold Parklands	N	E	E	E	E	E
Forest Tundra	NE	NE	NE	NE	N	NW
Boreal Forest	NE	NW	E	E	E	NE
Cool Desert	W	N	E	E	NE	E
Steppe	W	NW	E	E	N	NE
Temperate Forest	W	N	NE	E	N	N
Hot Desert	SW	N	W	W	N	W
Chapparal	S	N	N	W	E	N
Warm Temperate Forest	S	E	W	NE	N	N
Tropical Semi-Arid	S	SW	NE	N	N	NE
Tropical Dry Forest	S	W	N	N	NE	NW
Tropical Seasonal Forest	S	SW	W	E	NW	NE
Tropical Rain Forest	S	SE	E	W	N	W

Table 12: Change in latitude between the GISS map and the baseline map. The upper half of the table lists the North/South change in latitude and the lower half lists the polar change in latitude. Table entries are differences in descriptive statistics between the two maps.

	North/South Change in Latitude (units = degrees) Shift north: positive; shift south: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	20.5	4.0	3.5	2.0	0.0	3.2	-0.5
Cold Parklands	3.0	5.5	4.5	2.5	4.0	8.2	-8.0
Forest Tundra	5.5	4.5	2.5	2.5	6.0	3.3	-2.7
Boreal Forest	1.0	4.5	4.5	3.5	2.0	5.2	-4.5
Cool Desert	0.5	4.5	0.5	0.5	13.0	1.7	0.2
Steppe	-1.0	2.5	2.5	2.5	7.5	2.3	1.5
Temperate Forest	-3.5	5.5	6.5	5.5	8.5	7.8	-2.3
Hot Desert	-5.5	13.5	2.0	2.0	1.0	5.1	-1.5
Chapparal	-9.5	69.5	10.0	9.0	2.5	28.7	-13.4
Warm Temperate Forest	-7.5	0.0	8.0	8.5	10.0	5.7	4.8
Tropical Semi-Arid	-8.0	-2.5	3.3	10.0	6.5	1.4	3.8
Tropical Dry Forest	-8.5	-0.5	7.0	8.0	4.0	3.0	4.0
Tropical Seasonal Forest	-5.5	-7.8	9.5	13.0	4.5	4.7	8.3
Tropical Rain Forest	-14.0	-3.0	-1.0	0.0	12.5	-1.7	2.8

	Polar Change in Latitude (units = degrees) Shift to Poles: positive; Shift to Equator: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	-20.5	4.0	3.5	2.0	0.0	3.2	-0.5
Cold Parklands	-3.0	5.5	4.5	2.5	4.0	8.2	-8.0
Forest Tundra	-5.5	4.5	2.5	2.5	6.0	3.3	-2.7
Boreal Forest	-1.0	4.5	4.5	3.5	2.0	5.2	-4.5
Cool Desert	-0.5	4.5	0.5	0.5	13.0	1.7	0.2
Steppe	1.0	2.5	2.5	2.5	7.5	2.3	1.5
Temperate Forest	3.5	5.5	6.5	5.5	8.5	7.8	-2.3
Hot Desert	5.5	13.5	2.0	2.0	1.0	5.1	-1.5
Chapparal	9.5	1.5	10.0	9.0	2.5	28.7	-13.4
Warm Temperate Forest	7.5	0.0	8.0	8.5	10.0	5.7	4.8
Tropical Semi-Arid	8.0	2.5	3.3	10.0	6.5	0.8	3.8
Tropical Dry Forest	8.5	0.5	4.0	8.0	4.0	1.5	4.0
Tropical Seasonal Forest	5.5	7.8	3.5	13.0	4.5	3.9	8.3
Tropical Rain Forest	14.0	3.0	1.0	0.0	12.5	0.4	2.8

Table 13: Change in longitude between the GISS map and the baseline map. Table entries are differences in descriptive statistics between the two maps.

	East/West Change in Longitude (units = degrees) Shift East: positive; shift West: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	5.0	2.0	-5.5	-119.5	-8.5	-28.3	-26.5
Cold Parklands	-1.0	147.0	22.0	13.0	25.5	26.1	-1.7
Forest Tundra	4.5	2.3	4.0	2.5	-0.5	-4.9	2.8
Boreal Forest	0.5	-3.5	26.5	13.0	17.0	12.0	9.6
Cool Desert	-28.0	-1.0	30.5	16.0	25.5	18.4	5.8
Steppe	-29.0	-1.5	15.0	25.5	-0.5	2.3	7.2
Temperate Forest	-12.5	1.0	9.5	17.5	-1.0	1.8	1.9
Hot Desert	-3.5	-5.5	-8.0	-8.0	0.0	-13.4	-3.5
Chapparal	-1.0	-24.0	0.8	-45.5	25.5	-11.2	-11.0
Warm Temperate Forest	0.0	7.0	-23.5	12.5	0.0	2.0	0.1
Tropical Semi-Arid	-2.5	-2.0	7.5	0.0	0.5	2.5	3.9
Tropical Dry Forest	-3.5	-1.5	0.0	2.0	9.5	-1.4	4.3
Tropical Seasonal Forest	0.0	-15.5	-44.8	58.0	-2.5	5.1	14.6
Tropical Rain Forest	-1.5	4.0	15.5	-11.0	0.0	-6.5	-9.5

Table 14: Change in area between the OSU map and the baseline map. The kappa statistic for assessing agreement between maps is 0.57. This indicates *good agreement* with the baseline map.

	Area Comparison (units = 1000 km^2)				
Vegetation Zone	Baseline Map	Comparison Map	Stable Area	% Stable Area	Kappa statistic
Tundra	1036.89	595.58	595.58	57.4%	0.77
Cold Parklands	280.99	269.45	163.28	58.1%	0.61
Forest Tundra	885.71	599.74	193.68	21.9%	0.22
Boreal Forest	1512.04	1413.87	780.57	51.6%	0.46
Cool Desert	401.76	319.00	224.52	55.9%	0.61
Steppe	741.13	868.87	551.78	74.5%	0.66
Temperate Forest	997.77	1156.53	665.26	66.7%	0.58
Hot Desert	2085.22	1943.39	1776.40	85.2%	0.86
Chapparal	562.86	489.21	142.46	25.3%	0.24
Warm Temperate Forest	321.67	245.35	90.74	28.2%	0.30
Tropical Semi-Arid	953.36	1214.00	702.05	73.6%	0.62
Tropical Dry Forest	1485.48	1485.83	976.84	65.8%	0.62
Tropical Seasonal Forest	1507.83	1014.76	570.13	37.8%	0.42
Tropical Rain Forest	845.77	2003.05	845.77	100.0%	0.56
Totals:	13618.49	13618.61	8279.06	60.8%	0.57

Table 15: The distance (upper half of the table) and direction (lower half) that vegetation zones have shifted from the baseline map to the OSU map.

	Distance Shifted from base map (units = 100 km)					
Vegetation Zone	Min	20%	Median	80%	Max	Mean
Tundra	2.6	4.7	4.1	9.3	0.1	8.1
Cold Parklands	3.4	5.1	8.9	5.0	6.6	9.0
Forest Tundra	0.6	4.8	2.5	5.1	2.8	2.5
Boreal Forest	1.1	5.8	13.7	5.7	2.0	6.8
Cool Desert	18.9	4.7	4.3	9.3	13.7	5.0
Steppe	17.9	3.7	6.9	10.9	8.5	4.2
Temperate Forest	9.0	4.6	5.2	5.9	9.5	7.3
Hot Desert	4.3	14.8	4.2	7.4	5.4	12.7
Chapparal	6.7	76.0	9.8	31.0	16.4	27.5
Warm Temperate Forest	7.8	8.0	12.7	11.0	11.1	14.5
Tropical Semi-Arid	7.0	6.4	7.0	8.7	3.3	4.8
Tropical Dry Forest	7.7	4.7	5.0	9.0	2.9	9.8
Tropical Seasonal Forest	5.6	9.8	22.8	38.6	1.7	11.7
Tropical Rain Forest	8.7	8.4	1.2	16.3	13.9	12.7

	Direction of Shift from base map					
Vegetation Zone	Min	20%	Median	80%	Max	Mean
Tundra	E	NE	NW	W	W	W
Cold Parklands	N	N	E	E	E	NE
Forest Tundra	N	NE	NE	E	N	N
Boreal Forest	E	NW	E	E	NE	NE
Cool Desert	W	N	E	E	NE	NE
Steppe	W	NW	NE	E	N	N
Temperate Forest	W	N	NE	NE	N	NW
Hot Desert	SW	N	NW	W	W	NW
Chapparal	S	N	N	W	E	N
Warm Temperate Forest	S	NE	E	E	N	E
Tropical Semi-Arid	SW	SW	E	N	N	E
Tropical Dry Forest	SW	S	E	NE	N	E
Tropical Seasonal Forest	S	W	E	E	N	E
Tropical Rain Forest	S	SE	SE	W	N	W

Table 16: Change in latitude between the OSU map and the baseline map. The upper half of the table lists the North/South change in latitude and the lower half lists the polar change in latitude. Table entries are differences in descriptive statistics between the two maps.

	North/South Change in Latitude (units = degrees) Shift north: positive; shift south: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	0.5	4.0	3.5	2.0	0.0	2.9	-0.1
Cold Parklands	3.0	4.5	4.0	2.0	4.0	6.5	-6.4
Forest Tundra	0.5	4.0	2.0	2.0	2.5	2.3	-1.5
Boreal Forest	0.5	4.0	4.0	3.5	1.5	4.4	-3.6
Cool Desert	0.0	4.0	1.0	2.0	11.0	3.4	-0.1
Steppe	-1.0	3.0	3.5	4.0	7.5	3.7	0.2
Temperate Forest	-3.5	4.0	4.5	5.0	8.5	5.9	-1.5
Hot Desert	-3.0	13.0	2.0	1.5	2.0	4.9	-2.0
Chapparal	-6.0	68.0	8.5	7.5	1.0	24.5	-9.6
Warm Temperate Forest	-7.0	4.0	3.5	4.0	10.0	2.9	3.5
Tropical Semi-Arid	-6.0	-4.0	-2.0	7.5	3.0	-1.5	3.8
Tropical Dry Forest	-6.5	-4.0	0.0	6.5	2.5	0.1	4.4
Tropical Seasonal Forest	-5.0	-1.5	3.0	10.5	1.5	3.3	5.0
Tropical Rain Forest	-7.5	-3.0	-0.5	3.0	12.5	-1.0	3.6

	Polar Change in Latitude (units = degrees) Shift to Poles: positive; Shift to Equator: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	-0.5	4.0	3.5	2.0	0.0	2.9	-0.1
Cold Parklands	-3.0	4.5	4.0	2.0	4.0	6.5	-6.4
Forest Tundra	-0.5	4.0	2.0	2.0	2.5	2.3	-1.5
Boreal Forest	-0.5	4.0	4.0	3.5	1.5	4.4	-3.6
Cool Desert	0.0	4.0	1.0	2.0	11.0	3.4	-0.1
Steppe	1.0	3.0	3.5	4.0	7.5	3.7	0.2
Temperate Forest	3.5	4.0	4.5	5.0	8.5	5.9	-1.5
Hot Desert	3.0	13.0	2.0	1.5	2.0	4.9	-2.0
Chapparal	6.0	0.0	8.5	7.5	1.0	24.5	-9.6
Warm Temperate Forest	7.0	-1.0	3.5	4.0	10.0	2.9	3.5
Tropical Semi-Arid	6.0	4.0	-2.0	7.5	3.0	1.5	3.8
Tropical Dry Forest	6.5	4.0	0.0	6.5	2.5	-0.1	4.4
Tropical Seasonal Forest	5.0	1.5	-3.0	10.5	1.5	2.5	5.0
Tropical Rain Forest	7.5	3.0	0.5	3.0	12.5	-0.4	3.6

Table 17: Change in longitude between the OSU map and the baseline map. Table entries are differences in descriptive statistics between the two maps.

	East/West Change in Longitude (units = degrees) Shift East: positive; shift West: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	4.0	3.5	-3.5	-40.0	-0.5	-17.4	-17.5
Cold Parklands	-1.0	1.5	14.8	10.0	19.0	8.4	4.9
Forest Tundra	0.0	3.0	2.5	11.5	0.0	-0.4	3.6
Boreal Forest	1.5	-5.5	22.5	8.5	3.0	7.6	8.8
Cool Desert	-28.0	-1.5	5.0	12.0	11.0	3.4	9.2
Steppe	-27.5	-2.0	7.5	14.5	-3.0	1.0	4.2
Temperate Forest	-12.5	-1.5	2.0	3.0	-1.0	-3.8	1.3
Hot Desert	-3.5	-3.0	-3.5	-7.5	-6.5	-10.8	-2.8
Chapparal	-1.0	-6.0	2.8	-36.0	24.5	-3.4	-11.3
Warm Temperate Forest	0.0	6.0	12.5	11.5	0.0	13.5	0.7
Tropical Semi-Arid	-2.5	-4.5	6.0	2.5	0.0	4.1	6.8
Tropical Dry Forest	-3.0	-1.5	4.5	5.0	-1.0	8.8	6.9
Tropical Seasonal Forest	0.0	-9.0	20.3	36.0	0.0	10.0	6.8
Tropical Rain Forest	-2.5	7.0	1.0	-14.5	0.0	-11.3	-12.9

Table 18: Change in area between the UKMO map and the baseline map. The kappa statistic for assessing agreement between maps is 0.35. This indicates *poor agreement* with the baseline map.

		Area Comparison (units = 1000 km^2)			
Vegetation Zone	Baseline Map	Comparison Map	Stable Area	% Stable Area	Kappa statistic
Tundra	1036.89	401.65	401.65	38.7%	0.63
Cold Parklands	280.99	171.03	55.58	19.8%	0.30
Forest Tundra	885.71	344.51	15.90	1.8%	-0.03
Boreal Forest	1512.04	1019.82	138.45	9.2%	-0.00
Cool Desert	401.76	208.69	49.93	12.4%	0.14
Steppe	741.13	717.81	239.33	32.3%	0.28
Temperate Forest	997.77	1297.57	197.46	19.8%	0.08
Hot Desert	2085.22	1993.54	1720.21	82.5%	0.81
Chapparal	562.86	856.76	2.47	0.4%	-0.04
Warm Temperate Forest	321.67	287.85	9.57	3.0%	0.01
Tropical Semi-Arid	953.36	1663.04	801.76	84.1%	0.57
Tropical Dry Forest	1485.48	2605.21	1174.08	79.0%	0.51
Tropical Seasonal Forest	1507.83	765.23	382.36	25.4%	0.30
Tropical Rain Forest	845.77	1285.85	813.45	96.2%	0.74
Totals:	13618.49	13618.55	6002.21	44.1%	0.35

Table 19: The distance (upper half of the table) and direction (lower half) that vegetation zones have shifted from the baseline map to the UKMO map.

	Distance Shifted from base map (units = 100 km)					
Vegetation Zone	Min	20%	Median	80%	Max	Mean
Tundra	24.6	7.6	5.7	22.8	0.3	12.5
Cold Parklands	21.2	93.8	12.0	5.9	8.0	15.2
Forest Tundra	23.2	9.6	19.6	4.3	6.7	11.6
Boreal Forest	1.2	9.5	21.9	10.3	11.5	14.3
Cool Desert	19.6	6.7	27.0	14.2	21.7	22.8
Steppe	25.8	7.6	24.1	20.7	19.5	13.3
Temperate Forest	9.0	15.5	14.8	22.3	9.5	13.2
Hot Desert	8.6	14.2	3.4	5.1	7.7	8.7
Chapparal	12.3	85.8	18.1	36.4	10.1	39.5
Warm Temperate Forest	13.9	31.3	39.3	15.4	20.0	24.6
Tropical Semi-Arid	9.2	10.5	8.5	16.8	10.0	5.7
Tropical Dry Forest	8.9	2.4	7.6	39.3	14.7	10.5
Tropical Seasonal Forest	10.0	20.1	50.0	63.4	10.0	12.1
Tropical Rain Forest	58.8	1.8	25.6	10.2	21.2	2.1

	Direction of Shift from base map					
Vegetation Zone	Min	20%	Median	80%	Max	Mean
Tundra	NE	NE	NW	W	W	W
Cold Parklands	N	E	E	E	E	E
Forest Tundra	N	N	W	NE	N	W
Boreal Forest	NE	N	E	E	NE	NE
Cool Desert	W	N	E	E	NE	NE
Steppe	W	NW	E	E	E	NE
Temperate Forest	W	NW	NE	E	N	N
Hot Desert	SW	N	NW	NW	NW	NW
Chapparal	S	N	NE	W	N	N
Warm Temperate Forest	S	N	NW	NE	N	NW
Tropical Semi-Arid	S	W	NE	N	N	NW
Tropical Dry Forest	SW	NW	NW	W	NE	NW
Tropical Seasonal Forest	S	SW	NW	E	N	NE
Tropical Rain Forest	W	S	E	NW	N	NE

Table 20: Change in latitude between the UKMO map and the baseline map. The upper half of the table lists the North/South change in latitude and the lower half lists the polar change in latitude. Table entries are differences in descriptive statistics between the two maps.

	North/South Change in Latitude (units = degrees) Shift north: positive; shift south: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	20.5	6.0	5.0	2.5	0.0	5.3	-1.1
Cold Parklands	19.0	3.5	5.5	2.5	4.5	6.9	-5.4
Forest Tundra	20.5	8.5	5.0	3.5	6.0	5.0	-1.0
Boreal Forest	1.0	8.5	7.5	5.5	9.5	7.9	-5.2
Cool Desert	0.5	6.0	3.5	6.5	14.0	10.6	-4.9
Steppe	-1.0	6.5	7.0	6.5	8.0	7.0	-0.1
Temperate Forest	-3.5	10.0	11.0	9.0	8.5	11.7	-2.9
Hot Desert	-7.0	12.5	2.5	3.0	5.5	4.5	0.2
Chapparal	-11.0	74.5	15.0	13.5	9.0	35.4	-17.2
Warm Temperate Forest	-12.5	27.0	16.0	12.5	18.0	12.5	6.1
Tropical Semi-Arid	-8.0	-2.0	6.5	15.0	9.0	3.9	5.1
Tropical Dry Forest	-7.5	1.0	4.0	12.0	11.5	4.3	4.5
Tropical Seasonal Forest	-9.0	-10.0	16.0	14.0	9.0	6.1	9.9
Tropical Rain Forest	-16.0	-1.5	0.5	6.5	19.0	0.9	3.3

	Polar Change in Latitude (units = degrees) Shift to Poles: positive; Shift to Equator: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	-20.5	6.0	5.0	2.5	0.0	5.3	-1.1
Cold Parklands	-19.0	3.5	5.5	2.5	4.5	6.9	-5.4
Forest Tundra	-20.5	8.5	5.0	3.5	6.0	5.0	-1.0
Boreal Forest	-1.0	8.5	7.5	5.5	9.5	7.9	-5.2
Cool Desert	-0.5	6.0	3.5	6.5	14.0	10.6	-4.9
Steppe	1.0	6.5	7.0	6.5	8.0	7.0	-0.1
Temperate Forest	3.5	10.0	11.0	9.0	8.5	11.7	-2.9
Hot Desert	7.0	12.5	2.5	3.0	5.5	4.5	0.2
Chapparal	11.0	6.5	15.0	13.5	9.0	35.4	-17.2
Warm Temperate Forest	12.5	22.0	16.0	12.5	18.0	12.5	6.1
Tropical Semi-Arid	8.0	2.0	6.5	15.0	9.0	3.3	5.1
Tropical Dry Forest	7.5	-1.0	1.0	12.0	11.5	2.9	4.5
Tropical Seasonal Forest	9.0	10.0	10.0	14.0	9.0	5.3	9.9
Tropical Rain Forest	16.0	1.5	-0.5	6.5	19.0	0.9	3.3

Table 21: Change in longitude between the UKMO map and the baseline map. Table entries are differences in descriptive statistics between the two maps.

	East/West Change in Longitude (units = degrees) Shift East: positive; shift West: negative						
Vegetation Zone	Min	20%	Median	80%	Max	Mean	SDev
Tundra	12.0	8.0	-4.0	-121.5	-2.0	-27.7	-32.5
Cold Parklands	-1.0	144.5	20.5	12.0	25.0	20.5	-2.0
Forest Tundra	5.5	2.5	-43.5	5.0	-0.5	-20.1	4.8
Boreal Forest	0.5	-1.5	37.5	17.5	17.0	19.1	13.1
Cool Desert	-29.0	-1.0	33.5	17.0	28.5	21.8	13.3
Steppe	-40.0	-3.0	31.5	29.5	34.5	14.2	11.7
Temperate Forest	-12.5	-13.5	12.0	33.5	-2.0	-2.7	14.3
Hot Desert	-5.0	-2.5	-2.0	-4.0	-6.5	-6.7	-2.4
Chapparal	-0.5	-21.5	8.3	-42.5	-2.5	-2.2	-12.9
Warm Temperate Forest	0.0	8.0	-39.5	8.0	0.0	-20.1	-3.9
Tropical Semi-Arid	-2.5	-10.0	4.0	-2.0	0.0	-3.4	8.0
Tropical Dry Forest	-3.5	-2.0	-5.5	-35.5	9.5	-8.4	0.3
Tropical Seasonal Forest	0.0	-16.0	-42.3	61.5	0.0	9.0	18.6
Tropical Rain Forest	-61.0	0.5	23.0	-6.5	0.0	1.6	-3.2

Table 22: Kappa statistic and the corresponding qualitative degree of agreement between all possible pairs of Holdridge maps examined.

	Kappa Statistic and Degree of Agreement between maps					
	Holdridge	GFDL	GFDL-Qflux	GISS	OSU	UKMO
Holdridge	1.00	0.43	0.84	0.51	0.57	0.35
GFDL	Fair	1.00	0.43	0.67	0.65	0.71
GFDL-Qflux	V. Good	Fair	1.00	0.53	0.58	0.35
GISS	Fair	Good	Fair	1.00	0.75	0.62
OSU	Good	Good	Good	V. Good	1.00	0.56
UKMO	Poor	V. Good	Poor	Good	Good	1.00

Table 23: Change in area between the modified Olson map and the modified Holdridge baseline map. The kappa statistic for assessing agreement between maps is 0.40, which is on the borderline between *poor* and *fair* agreement with the baseline map.

	Area Comparison (units = 1000 km^2)				
Vegetation Zone	Baseline Map	Comparison Map	Stable Area	% Stable Area	Kappa statistic
Tundra	1036.89	938.52	521.81	50.3%	0.62
Cold Parklands	280.99	206.94	20.16	7.2%	0.08
Forest Tundra	885.71	173.61	107.64	12.2%	0.19
Boreal Forest	1512.04	1612.26	915.84	60.6%	0.55
Cool Desert	401.76	199.93	79.06	19.7%	0.26
Steppe	741.13	394.01	201.42	27.2%	0.43
Temperate Forest	997.77	318.60	88.01	8.8%	0.19
Hot Desert	2085.22	1615.64	1248.15	59.9%	0.64
Chapparal	562.86	2083.10	194.41	34.5%	0.13
Warm Temperate Forest	321.67	575.71	71.56	22.2%	0.16
Tropical Semi-Arid	953.36	1071.76	274.47	28.8%	0.24
Tropical Dry Forest	1485.48	562.01	289.86	19.5%	0.30
Tropical Seasonal Forest	1507.83	802.13	410.94	27.3%	0.35
Tropical Rain Forest	845.77	423.58	315.21	37.3%	0.55
Totals:	13618.49	10977.80	4738.54	34.8%	0.40

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