DFID FRP Project ZF0216 - Global cloud forest hydrology context.
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Executive Summary

The purpose of ZF0216 is to create an online map-centred database (with a 1km grain) of: the tropics-wide extent of cloud forests; the water production of tropical mountain regions; the dependence of downstream populations on this water production; and the likely impacts of current and future land use and climate change in these areas. The purpose is to indicate the hotspots of dependence on mountain (and particularly cloud forest) water as well as the hotspots of land use and climate change threat to this dependence.

The research activities involve the collation, harmonisation, quality control and integration of existing global datasets and satellite remote sensing data and the GIS (Geographical Information Systems) and computer modelling -based analysis of these datasets. We aim to produce the best possible spatial assessment of the tropics-wide distribution of cloud forest, to characterise these cloud forests in terms of actual threat from land use change (using available remote sensing data), to characterise the past and future climate change around these forests using available satellite and ground based climatologies for the last 50 years and 50-yr climate change scenarios of at least two GCMs (General Circulation Models of the atmosphere). Finally to produce maps of the cloud forest remaining (resources), cloud forest loss through land use change (last 10 years), and cloud forest threat (next 50 years) scaled by nation and by administrative region to serve as a basis for the prioritisation of management and conservation efforts.

Any international development initiative must take into account the availability of sufficient volumes of clean, temporally reliable water resources since these are fundamental to maintaining human health, agriculture and transport. Though tropical mountains occupy a relatively small proportion of the tropical land mass (and its water), they are areas of very high rainfall and low evaporation which are thus extremely wet. They are, moreover, dominated by lateral fluxes of water which drain to the (drier) lowlands making tropical mountains net suppliers of water to tropical lowlands. Even where those lowlands are themselves wet, such as is the case for much of lowland South America, the effects of the seasonality of lowland rainfall is often offset by the constancy of montane water inputs. The montane areas may thus be seasonally important in the maintenance of lowland flows even if they are not annually important sources of water in volumetric terms. This research provides an overview of the water resources of the montane tropics and of the potential impact of land use and climate change upon those resources and thus on the populations that currently receive them. Thus, the project sets the context for other intensive hydrological monitoring and modelling studies, within the FLOWS cluster for example, by providing a broad overview of water-important tropical mountains and those which are or which will be threatened by human activity, in terms of their ability to maintain the necessary flows to populations downstream. Providing such a

tropics-wide assessment allows single country or site studies to be seen within the broader context of tropical montane and TMCF hydrology across a range of environments and human population pressures.

Background

Water can be a constraint to development even in very hydrologically wet environments such as the Latin American Lowlands that receive high inputs of rainfall. The constraint is imposed either by an inconstancy of supply (seasonally, inter-annually or cyclically) since the tropical lowlands are subject to high rainfall variability over all of these periods. The constraint could also be through the availability of sufficient water but which is provided too rapid for capture or use (*e.g.* high stormflow volumes and low or declining baseflows). Finally the constraint can be imposed by the availability of sufficient quantity of water but not sufficient quality *i.e.* with a high sediment load making it unsuitable for certain activities (*eg.* hydropower generation) or more prone to harbouring disease vectors.

Previous global-scale analyses of water resources are rare and no studies known to the authors have looked at the hydrological contribution of tropical mountains in general and tropical montane cloud forests in particular at a tropics-wide scale and with reference to impacts of climate change and land use/cover change (LUCC). The only really global scale analysis which has a focus on water resources and their use is that of SHI/UNESCO (1998) and is compiled at the national grain with a global extent, based on country-level records. However, A wide variety of studies have looked at the issue of climate (Bonell, 1998) and land use change (Bruijnzeel, 1990; 2000) in tropical montane cloud forests but these have been overwhelmingly single-site studies or reviews of multiple single-site studies to generate a tropics-wide overview. Whilst being of great use in better understanding the range and extent of potential impacts, such site-based studies do not provide an overview of the water productive capacity of cloud forests spatially nor a spatial integration of the potential impact of climate and land use change. The present study, having a grain of 1km and a tropics-wide extent as well as being data-based and analytical, rather than review based, will provide much more spatial detail on the hydrological regimes of tropical mountains and tropical montane forests and potential human impacts and will allow (a) better extrapolation across the tropics from the more sophisticated and detailed site scale studies and (b) better identification of productive areas and spatial prioritisation of water productivity protection at national and regional scales across the tropics.

The demand for this project was identified in discussion with FRP alongside their detailed site scale studies in cloud forests Costa Rica (R771). This research aims to place those studies within the wider context of hydro-meteorological and landscape variability across the tropics.

Project Purpose

The purpose of the project is to create an online map-centred database (with a 1km grain) of: the tropics-wide extent of cloud forests; of the water production of tropical mountain regions; of the dependence of downstream populations on this water production; and of the likely impacts of current and future land use and climate change in these areas. We will in the end indicate the hotspots of dependence on mountain (and particularly cloud forest) water and of the land use and climate change threat to this dependence.

This work addresses the identified constraint to development which is provided by deleterious human impacts on high quality water resource production in the tropics by providing the context for previous and ongoing detailed site-scale studies and by providing a freely accessible data-bank of areas prioritised by their water production and the threat to populations of changes to this water production by anthropic land use and climate change, across the tropics. The results will contribute towards a policy-brief and the ongoing Tropical Montane Cloud Forest Initiative led by UNEP-WCMC.

Research Activities

The research activities are listed below. The project is ongoing so further detail is provided only for those components that are complete or near completion. In all cases results are preliminary and subject to confirm by the time of the republication of this document in final form as the final technical report (FTR).

1. Collect the data and do the analysis to produce a 1km resolution global map of the distribution of cloud forests according to satellite-derived forest and ground level cloud presence and make these available to decision makers via a website.

There are no good assessments of the global distribution of cloud forests. The best available dataset is a file of 567 points that have been called cloud forests in the literature and by scientists in the field compiled by UNEP-WCMC (Aldrich et al. (1997). Though this database provides a useful overview of the distribution of cloud forests it tells us very little about their coverage and extent since each site is represented by a single point which may represent a small forest of a few hundred hectares or a large expanse of forest. Cloud forests are also, of course, a continuum of forest types dependent upon the intensity of the climate in which they are found and no data on forest environment is available in this database.

The UNEP-WCMC database contains no information on the severity of the cloud forest condition found at each of these sites, thereby assuming they are –effectively – homogeneous. Cloud forests have traditionally been mapped on the basis of altitudinal limits and forest cover. Whilst cloud forests do not usually occur in lowland areas, they do occupy a rather broad distribution of altitudes depending on other factors than altitude. Thus, altitudinal limits may not be the best approach to mapping their extent accurately. Most maps for the distribution of cloud forest are generated by imposing altitudinal limits for example all forest above 1400m in Costa Rica, Julio Calvo pers. comm. and including the cloud forest assessments of Bubb et al. (2004) and Bubb and Das (in press) in which national and regional altitudinal limits are specified and all forest within those limits is classed as cloud forest. Such assessments estimate the total cover of cloud forest to be of the order of 215 000 km^2 (0.26% of the earths land surface, 0.5% of the tropics and only 1.4 % of the total areas of the world's tropical forests). 43% of these cloud forests can be found in Asia, 41 % in the Americas and 16% in Africa. Though the UNEP-WCMC point dataset can be used to test that cloud forests occur in roughly the same areas, there is no observed dataset available upon which to test the modelled assessment of cloud forest extent.

Cloud forests are defined not according to altitude but as forests affected by frequent and/or persistent ground level cloud (Grubb, 1977). The cloud significantly affects the energy, light and temperature regimes and imports potentially large amounts of water as rainfall and horizontal precipitation. Thus the presence of ground-level cloud produces a very different environment to that in which we find other types of montane (and lowland) rainforest. Since there is a positive relationship between the presence of ground level cloud (fog) and altitude, then cloud forests tend to occur within the range of altitudes between the lifting condensation level for upwelling air and the high altitude temperature minima at which tree-like vegetation is replaced by grassland and paramo. Unfortunately, because sea level temperature and saturated adiabatic lapse rates are highly spatially variable at the continental scale across the tropics, the altitudinal bands at which ground level cloud occurs are also likely to be highly variable. Mesoscale climate dynamics will also ensure that there is not a simple relationship between altitude and cloud frequency. A simple example is shown in Figure 1, which represents an assessment of cloud frequency based on four years (400 images) of MODIS cloud mask data for Costa Rica.

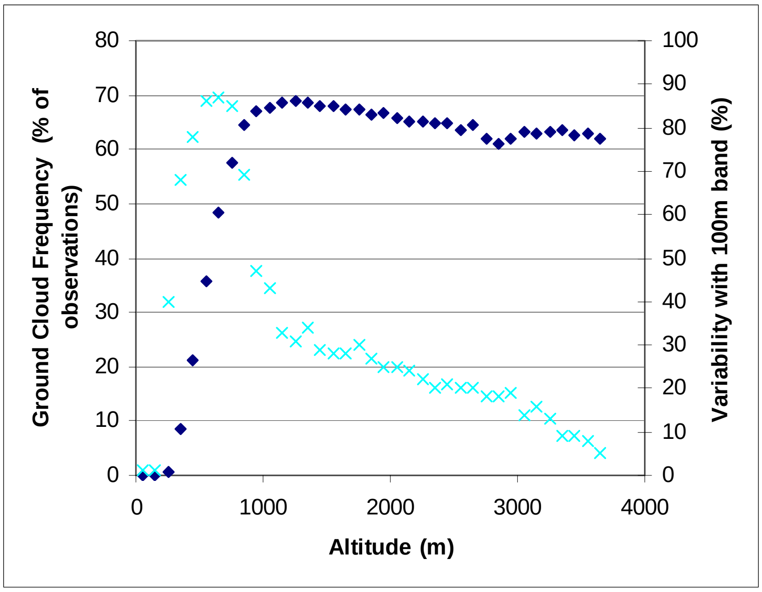

Figure 1. Cloud frequency versus altitude for Costa Rica. Means for 100m altitudinal bands for the whole country.

Clearly there are areas of the country that receive ground level cloud (fog) from 300masl upwards but there is a clear peak of 68.6% between 1250m to 1350m from which point ground level cloud cover is consistently high (>60%). The relationship of frequency to altitude is linear from the lowlands through to 1000m, beyond which there is a fairly persistent ground level cloud bank. This supports the notion that cloud forest should occur in Costa Rica at altitudes above approx. 1400 masl. There is, however, a great deal of spatial variation within these altitudinal bands. The spatial variability is greatest between 500 and 1000 metres (associated with diurnal variation in the lifting condensation level and spatial variation in sea level temperature, humidity and pressure) altitude and decreases with altitude thereafter. 1400 masl is the lowest altitude at which cloud cover is both high on average and with low spatial variation. Costa Rica is likely to be a case in which altitude and cloud forest are more strongly related than for most countries since it occupies a very narrow isthmus, is dominated by the NW trades which bring high humidity air which rises orographically up the Atlantic slopes. Mountains in continental settings with more complex climate dynamics may not be so well behaved!

Recognising the importance of ground level cloud cover to montane environments and thus to cloud forests means that we must move away from the traditional altitudinal definitions to ones based on the frequency and persistence of the controlling factor : ground level cloud cover (which just happens to correlate with altitude because of the effect of adiabatic lapse rates on moisture condensation).

Thus for this project we map cloud forests on the basis of :

(a) the frequency of cloud (later ground-level cloud too) as determined from the HIRS (Jin et al., 1996; Wylie et al., 2004) satellite cloud climatology,
(b) the presence of a forest vegetation cover as assessed from GLC_2K[1] land cover data (later MODIS VCF data too),
(c) by exposure to prevailing winds since exposed areas are much more likely to receive substantial inputs of ground level cloud than leeward, sheltered sites, particularly under maritime geographic conditions.

The frequency of ground level cloud

The HIRS dataset (Jin et al., 1996; Wylie et al., 2004), a 22 year (1979-2001) satellite cloud climatology from the NOAA, has been analysed here to define long term mean cloud frequency and persistence (coefficient of variation of monthly frequency) across the tropics on an interpolated 1km grid. This will, at a later stage, be coupled with tropics-wide assessment of the average climatic lifting condensation level for each altitude, again on a 1km basis to produce a 1km assessment of ground level cloud frequency. Figure 2 shows the global distribution of cloud frequencies (%) in comparison with the distribution of UNEP-WCMC cloud forest sites (black dots). Clearly the cloud forests cluster in the highest cloud frequency (whitest) areas (>70,80,90% frequency). The results indicate that all UNEP-WCMC cloud forest sites occur in areas of cloud

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[1] Global Land Cover 2000 database. European Commission, Joint Research Centre, 2003, http://www.gvm.jrc.it/glc2000

freq >50% but not all areas with cloud frequencies >50% are occupied by cloud forests. 100% of the UNEP-WCMC sites occur at cloud frequencies >50%, 78% at cloud frequencies>80% and 32% at cloud frequencies >95%.

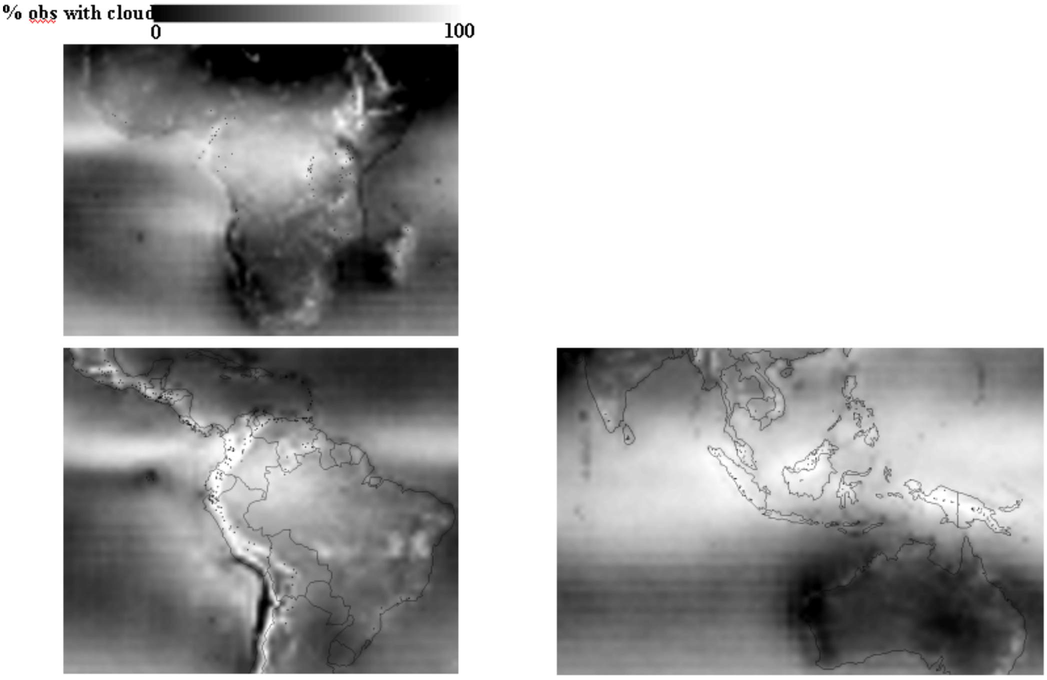

Figure 2 Cloud frequencies and cloud forest presence.

The presence of forest vegetation cover

This is assessed from GLC_2K data by reclassifying the data taking all forest classes (1-12, 17 and 18). This includes the main forest classes but also forest-tree and forest-shrub mosaics. Since we are working with low, stunted, montane forests in highly fragmented and heterogeneous environments, it is important to include these classes in order to have the most accurate assessment of forest cover. Also since we are concerned with forest fragmentation as well as full-scale deforestation, these mosaics must be taken into account.

Exposure to prevailing winds

Cloud frequency and persistence is only a partial measure of the exposure of an ecosystem to cloud. There are essentially a continuum of cloud forest exposures to cloud which range from the highly exposed windward forests to rather calm, sheltered leeward forests. The windward forests are subject to high frequencies and magnitudes of impacting cloud droplets and wind driven rain (e.g. the Atlantic slopes of Costa Rica and many island and maritime cloud forests). Leeward forests e.g. those in the interandean valleys are much more subject to cloud droplet sedimentation from passing cloud and to much less wind driven rain. At a given cloud frequency the exposure of a forest to cloud will depend upon the topographic exposure to the dominant cloud bearing winds. Thus cloud forests may be present in areas of relatively low cloud frequency if those areas are subject to high lateral fluxes of cloud. Thus for each cell the azimuth of the slope was calculated and used alongside global 1km windfields which we generated generated from long term mean sea level pressure fields[2] supplied by the British Atmospheric Data Centre (BADC). Wind exposed areas were calculated as those areas facing the same hemisphere as the incoming winds. More sophisticated measures of exposure (e.g. Ruel, 2002) could have been used but are computationally very difficult at the global scale.

Cloud forest were characterised as those with high cloud frequency (>70%), forest cover, exposed to the dominant wind bearing winds and also greater than 500 masl so as to rule out lowland areas. The resulting maps are very much a first draft which require further work. Comparing with the distributions produced by Bubb et al. (2005) these are probably an overestimate, especially in central Africa where we have some of the least well-known forests globally. Overall these distributions are similar to those of Bubb et al., though more extensive, for Latin America, most similar for South East Asia but very different for Africa. According to Bubb et al. the distribution of cloud forest in Africa is relatively minor. This means that the cloud forest coverage estimate of 0.5% of the tropics in Bubb et al. (2004) rises to 5.6% in the current estimation. This compares with the 51% of land covered by all forests in the tropics, meaning that using the current analysis cloud forests represent around 10% of all tropical forests compared with 2.5% offered by Bubb et al. (2004). A more recent estimate of Bubb and Das (in press) reduces the area of cloud forest to 215000 km' 1.4% of tropical forests. The only other estimate in the literature is that of Bockor (1979) of 500 000 km^2, 3.2% of tropical forests. However, no previous analysis has not been statistically validated against the known cloud forest data points, nor any other source, and in many areas known cloud forests occur outside of the mapped distributions. This analysis shows that there is still a great deal of uncertainty over the extent and distribution of cloud forests. The next iteration of this work will combine the atmospheric cloud cover with climate datasets to determine the frequency of ground level cloud. This may reduce the extent of cloud forest globally and particularly in very continental settings such as central Africa, hence the results presented here are preliminary. Both results will be statistically validated against the cloud forest points dataset. The estimation of the areal coverage of cloud forest is likely to fall sharply.

The resulting maps have been made available at www.ambiotek.com/cloudforests in draft form as a PDF file. An agreement with UNEP-WCMC is underway in order that WCMC assist in the integrate of these new data with existing databases and their interface with end users. An example map is given in Figure 3.

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[2] `http://www.badc.rl.ac.uk/data/gmslp/`

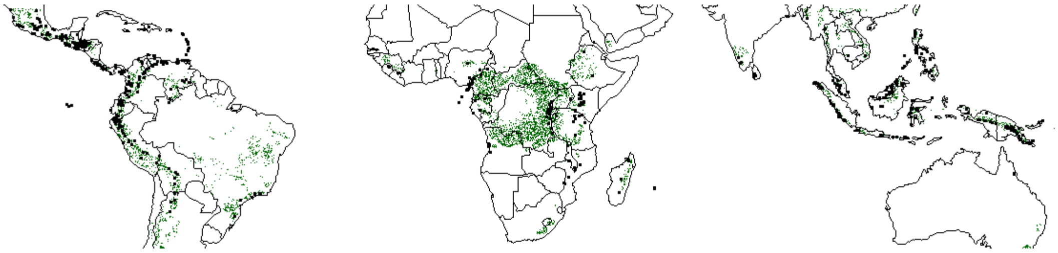

Figure 3 Modelled distribution of cloud forest according to cloud frequency (>=70%) and forest cover. UNEP-WCMC cloud forest points are superimposed.

These results are summarised by country in Table 1. It is clear that with these data a number of African countries have the greatest area of cloud forest and the greatest percentage of national territory under cloud forest.

Name	Cloud forests as a % of national territory	Name	Area of cloud forest (km^2)
Equatorial Guinea	35.9	Zaire	766823
Cameroon	34.3	Brazil	333185
Central African Republic	34.2	Central African Republic	253382
Burundi	32.5	Indonesia	211880
Uganda	28.6	Peru	204517
Zaire	27.9	Angola	191062
Taiwan	22.1	Cameroon	186071
Gabon	19.9	Sudan	155843
Rwanda	19.1	Mexico	128606
Costa Rica	19.0	Colombia	115554
Papua New Guinea	18.8	Argentina	109724
Lesotho	18.7	Ethiopia	107310
Ecuador	18.6	Bolivia	92030
Guinea	15.4	Papua New Guinea	89422
Honduras	14.6	Venezuela	80109
Philippines	13.4	Uganda	80070
Peru	13.3	Gabon	59438
Angola	13.0	Ecuador	53762
Malaysia	11.7	Burma	51881
Mexico	11.5	Madagascar	49020
Indonesia	11.2	Nigeria	49009

Table 1 Countries with greater than 10% cloud forest cover in rank order of percentage cover and countries with highest cloud coverage in range order of cloud forest extent (km^2)

In a preliminary validation of the model against the UNEP-WCMC cloud forest database it is clear that only 31% of the UNEP-WCMC cloud forests occur in areas defined as cloud forest in this analysis. At the 1km scale there is clearly error in both databases and a sensitivity analysis to cloud cover is underway as is an analysis of the distribution of the UNEP-WCMC forests on windward/leeward slopes. Moreover, the largest source of error (overestimation) may be that satellite observed cloud is not very representative of the impaction of that cloud with the ground in some areas (especially central Africa). Thus the analysis carried out to produce Figure 2 is being extended to the tropical scale in order that an improved estimate of ground level cloud can be produced and tested. This awaits the finalisation of code improvements to the PCRASTER GIS to facilitate working with larger datasets. This would should be complete by the end of the first week of August and will allow much more rapid progress in this area. The next iteration of this analysis will thus (a) combine cloud frequency with ground level atmospheric condensation frequency to give ground level cloud, (b) compare GLC_2K and MODIS VCF measures of land cover, potentially remove the requirement for forests to be windward and potentially remove the altitude minima at 500m since this will be accounted for by the adiabatic lapse rate calculations under (a).

2. Characterise the cloud forests in terms of actual threat from land use change based on spatially varying rates over the last 10 years and future threat as defined by current accessibility (roads) and population trends

This work was intended to a comparison of two global datasets for land use : the 1991/92 USGS 1km (GLCC) land cover classification and the 1km year 2000 GLC_2K (global land cover database) in order to characterise land use change. Though neither are perfect datasets, they are the best available for global analysis of land cover trends in spatial detail. Since they are based on satellite data, particular difficulties are experienced in tropical montane environments because of the persistence of cloud cover (which renders the forest invisible to the visible and near infra red wavelengths used by the AVHRR, SPOT VGT and DMSP satellites). There were considerable difficulties in the comparison of the datasets arising from (a) different methodologies and satellites used in the assessments, (b) different classifications used and (c) different continental basemaps meaning that the two assessments do not overlay perfectly. Attempts at improving these data are ongoing but meanwhile an alternative strategy was developed. Rather than compare two very different assessments, we used the best of those assessments, the GLC_2K, to compare with a global assessment of potential (original) forest cover generated by modelling the climatic limits of forest from high resolution climate grids (the GFW[3] dataset). First we quality controlled both datasets for accurate georeferencing etc. Then by reclassifying the GLC_2K data into forest cover (classes 1 to 12,17 and 18) and identifying the areas that have the climatic potential to be forest in GFW but that are no longer forest in GLC_2K, we obtain a global assessment of forest loss with a 1km resolution including areas of forest fragmentation (in which a forest-agriculture mosaic remains).

The resulting map is shown in Figure 4 with yellow areas representing areas that have undergone deforestation and forest fragmentation:

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[3] World Resources Institute, in collaboration with the World Conservation Monitoring Centre and the World Wildlife Fund. In: D. Bryant, et al., The Last Frontier Forests: Ecosystems and Economies on the Edge. (World Resources Institute: Washington, DC, 1997).

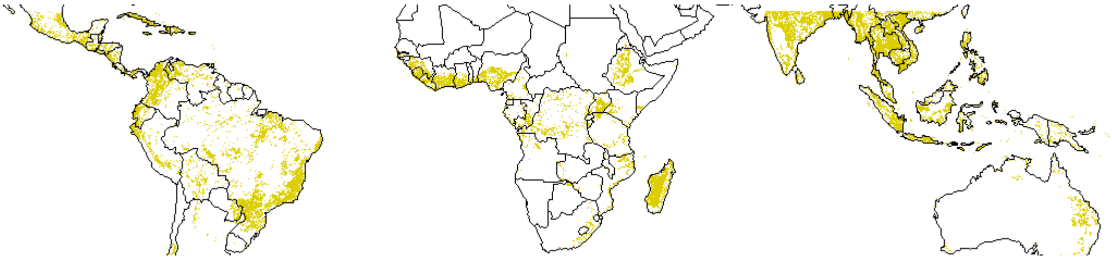

Figure 4 The global extent of deforested and forest-fragmented areas.

These results are summarised, by country, in table 2 in which it is clear that the countries with greatest deforestation by area and by percent of national territory are usually large and lowland-dominated countries as well as heavily populated small islands.

Name	Deforested area (km^2)	% of national territory deforested	Name	Deforested area (km^2)	% of national territory deforested
Brazil	1754258	32.0	Eritrea	8160	100.0
India	880968	67.1	Djibouti	508	100.0
Indonesia	665840	40.8	Bangladesh	56715	92.1
Tanzania	582767	53.4	Haiti	21091	89.1
Madagascar	420903	77.9	Ethiopia	238174	88.6
Thailand	417430	80.6	Uruguay	3274	86.0
Colombia	409670	41.6	Cuba	79840	84.1
Burma	354356	66.3	Chile	25683	83.1
Mexico	329847	41.7	Puerto Rico	5530	80.8
Zaire	307556	16.3	Thailand	417430	80.6
Australia	292008	47.6	New Zealand	8488	80.0
Vietnam	253504	77.1	Sierra Leone	55837	78.8
Nigeria	243817	57.9	Madagascar	420903	77.9
Ethiopia	238174	88.6	Vietnam	253504	77.1
Venezuela	204025	30.2	Gambia	8895	76.5
Peru	194980	19.4	Botswana	11298	76.0
China	174696	51.8	Dominican Republic	31138	73.6
Ivory Coast	164006	69.3	Uganda	103212	71.6
Laos	160605	64.9	Burundi	7857	71.0
Philippines	155707	70.0	Rwanda	5133	70.7
Bolivia	139777	22.7	Philippines	155707	70.0

Table 2 Countries with greater than 70% of their territorial area deforested in rank order of percentage deforested and countries with highest areas deforested in rank order of area deforested (km^2).

Repeating the analysis but excluding classes 11,12,17 and 18 of the GLC_2K produced a map of areas of complete forest-agriculture conversion, which is a hydrologically significantly different situation to forest loss in areas in which a significant forest cover remains in the agricultural landscape.

Figure 5 The global extent of completely deforested areas.

In order to look at cloud forest loss, we must first recalculate the cloud forest distribution to be representative of the distribution of potential (or original) cloud forest, rather than the cloud forest obtained from the GLC_2K assessment. This produces the distribution shown in Figure 6 (which is not very different from the current distribution of cloud forests):

Figure 6 The climatically potential (original) distribution of cloud forests before large scale human land use change

The distribution is still very restricted because the cloud conditions which produce cloud forest are highly restricted. Checking data quality indicates that there are no false positive (i.e. areas that are currently cloud forest but are outside of the areas in which forest is possible from the independent GFW dataset).

By combining the cloud forest distribution assessment with the deforestation assessment (for fragmentation and complete forest loss), we obtain an assessment of the extent of deforestation of cloud forest areas. The distribution of deforested and fragmented cloud forests is shown in Figure 7, with green areas representing areas of potential cloud forest (as Figure 6) and red areas representing those potentially cloud forest areas in which forest is no longer present or is fragmented according to the GLC_2K dataset.

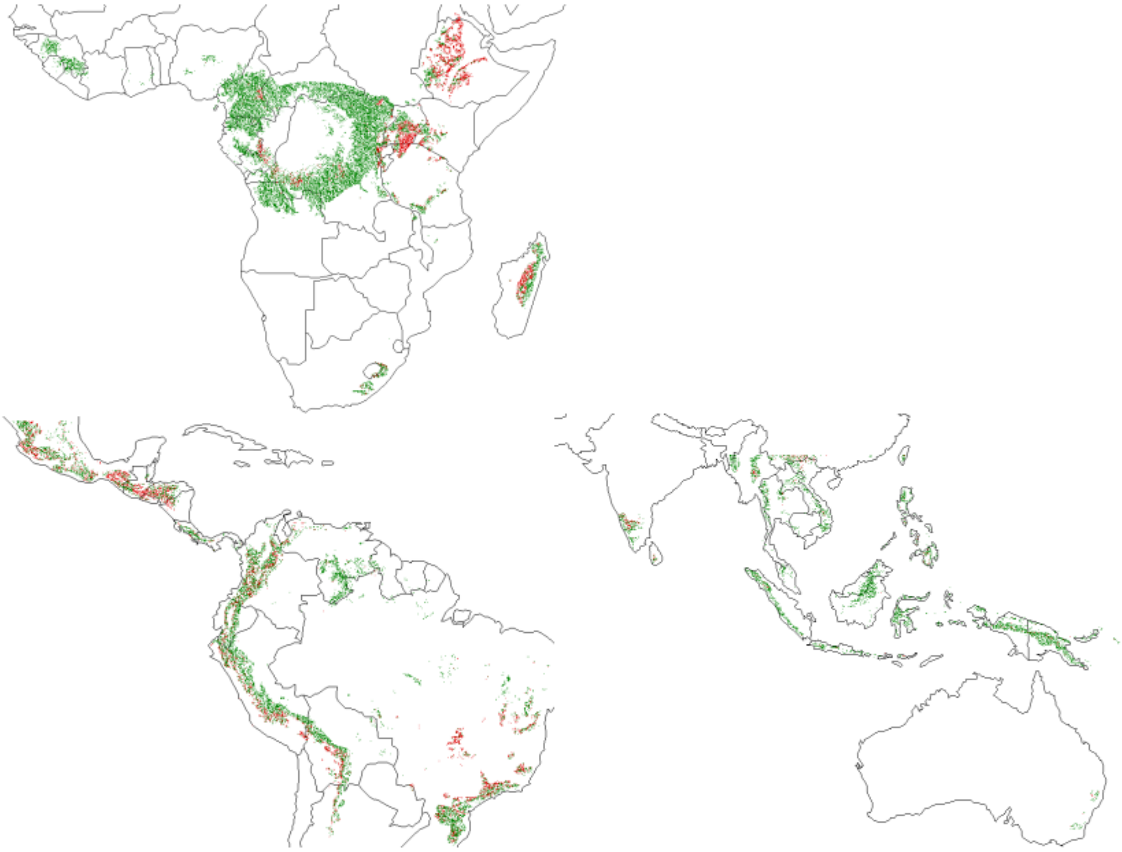

Figure 7 Land use change in the cloud forests. Green = potential (original) cloud forest, red= deforested potential (original) cloud forest.

A summary by country (Table 3) indicates that Ethiopia has lost the most cloud forest by area (72% of its original cover), Eritrea has lost all of its cloud forests (100%). Other countries with significant losses have included Rwanda, Guatemala and many of the other countries of central America (except Costa Rica). These results are a first step towards the prioritisation of cloud forest research and management actions in environments where there is (a) considerable change (such as these environments) and (b) significant potential hydrological and water resource impact (as we will see from later analyses towards the completion of this project). The results are likely to change with the next iteration of the cloud forest assessment.

Name	**Deforested and fragmented cloud forest km^2**	**Name**	**% of original national cloud forest deforested**
Ethiopia	5435	Eritrea	100.0
Brazil	4979	Ethiopia	72.2
Mexico	4625	Rwanda	68.6
Peru	4248	Guatemala	59.3
Uganda	3968	Paraguay	58.8
Colombia	3245	El Salvador	58.2
Madagascar	3226	Chile	52.1
Zaire	2970	Nicaragua	51.8
Bolivia	2944	Uganda	50.9
Tanzania	2793	Honduras	50.1

Honduras	2717	Tanzania	42.7
Guatemala	2534	Mexico	41.6
India	2282	Madagascar	39.7
Ecuador	1952	Sri Lanka	38.8
Kenya	1821	Burundi	36.6
Congo	1581	Brazil	36.6
Venezuela	1465	Kenya	36.3
Indonesia	1321	Mozambique	28.7
Argentina	1054	Belize	28.0
Cameroon	995	India	26.9
China	924	Bolivia	26.6
Nicaragua	639	Argentina	26.2
South Africa	543	Colombia	25.3
Gabon	434	Panama	25.2
Philippines	355	Peru	25.1
Burma	285	China	24.7
Vietnam	255	Lesotho	22.5
Papua New Guinea	217	Ecuador	21.0

Table 3 Deforested and fragmented cloud forest by country ranked by forest area lost and by percentage of national original cloud forest lost.

Clearly deforestation of cloud forests is much more fragmented and less intense compared with the lowland forests, largely because of the difficult environmental conditions in which we find cloud forests (steep slopes, very wet, low sunlight), which makes them unsuitable for many agricultural activities and logistically difficult in terms of access and resource removal. Also contrary to the situation in the lowlands, the cloud forests of Latin America and the Caribbean have seen significantly greater forest loss than those in Africa and south east Asia. The notable exception to this pattern are the countries of Rwanda, Tanzania, Burundi, Uganda, Kenya and Ethiopia, all of which have recorded cloud forests according to UNEP-WCMC and all of which have significant loss of forest in the environments in which cloud forests are found, according to this analysis.

This work is, again, preliminary and is highly dependent on the quality of the GLC_2K land cover database. Though this is the best available land cover classification we will test the outcomes of this analysis against MODIS vegetation continuous fields (VCF) data in order to be sure that the outcomes are as stated.

3. Characterise climate change around cloud forests based on historic datasets covering the last 50 years

This work is planned to start in earnest in August though some initial work has already been completed. The final analysis will characterise climate change around cloud forests in terms of temperature and precipitation. Here we present the results of work to characterise climate change in cloud forest areas in terms of cloud cover. Since cloud forests (and their hydrology) are defined by cloud cover, a change in cloud cover will have major impact for the ecosystem and its functioning. To assess changes in cloud cover in cloud forest areas we used an observed satellite cloud climatology from the HIRS sensor

The method used was to extract cloud frequency data for all grid squares with a UNEP-WCMC cloud forest in for each month from 1979-2001. We then calculate the change in frequency of clear (no cloud) observations for each cloud forest cell between the periods (1979-1990) and (1991-2001).

The results (Figure 8) indicate a decrease in clear days (increase in cloudiness) for TMCFs near the equator and an increase in clear days (decrease in cloudiness) at latitudes of 10-20º N and S. In terms of distribution there seems to be much more significant cloud loss over cloud forests in South East Asia, South America shows an increase in cloud, central America is mixed and Mexico shows overall cloud-decrease as do some of the heavily deforested countries of Africa. Work is in progress to test for potential instrumental drift over the same period and to compare these results with ground based observations over a longer period in order to confirm the outcomes stated (at this stage the patterns in the ground based data appear to be similar to those from the satellite instrument).

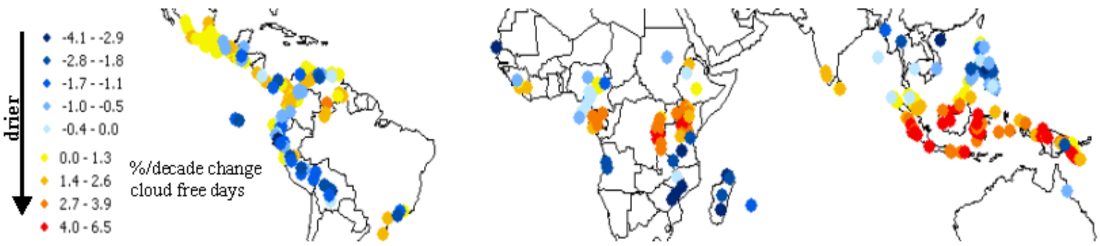

Figure 8 Cloud cover change in the world's cloud forests : an early indicator of climate change?

4. Characterise climate change based on the climate scenaria of at least two GCM (general circulation models)

This work is planned to start in August.

5. Apply simple water balance models to the datasets in order to characterise the magnitude and direction of water resource change resulting *from the land use change and the climate change historically and over the next 50 years*

This work is planned to start in September.

6. Produce a final map of cloud forest remaining (resources), cloud forest loss (last 10 years) and cloud forest threat (next 50 years) scaled by nation and by administrative region in order that the remaining cloud forest resources can be clearly seen and that the nations/regions in which cloud forest management/conservation efforts should be prioritised are also clear to decision makers at the global, national and regional scales. Water resource changes will be analysed with reference to the size of downstream populations affected in each region

This work is planned to start in September.

Special resources employed

Modelling at the tropics wide scale using 90m and 1km resolution data produces some significant technical challenges in terms of processing power required, volumes of data generated and software limitations. In order to solve these the following was necessary:

(a) construction of a high performance computing cluster from 6 existing computers.

(b) rewriting of aspects of the PCRASTER GIS to handle 64 bit processing and thus be capable of accessing more computer memory and larger files.

(c) deployment of 1 terabyte NAS (network accessed storage).for data storage and as an ftp server

Outputs

The outputs of the project are described below. Dissemination will begin once the final results of the project are available by mid September. An Agreement with UNEP-WCMC will see this work link with their cloud forest agenda.

Open web-access to this knowledge in map form (at www.ambiotek.com/cloudforests for development and conservation agencies at three scales:

(a) tropics-wide knowledge to assist prioritisation by international development and conservation agencies

(b) national scale knowledge for national development and conservation organisations

(c) regional scale knowledge for regional development and conservation organisations

Supported with separate policy briefs aimed at each of those communities.

All anticipated outputs have been produced so far though there have been various adaptations of methodology to cope with data quality/uncertainty issues (as discussed in the text).

Contribution of Outputs

Much of the work shown is suitable for publication, some of which (the cloud cover change work) in top quality journals such as Science/Nature. Initially data will be made available at www.ambiotek.com/cloudforests and an email sent to organisations working in cloudforests (as listed in the UNEP-WCMC database) in order to make them aware of the work. The data will also be made available, with the FTR to UNEP-WCMC TMCF Initiative who will integrate it with their Cloud Forest Agenda activities.

Needs for further work is as yet unclear but will become clearer by the time the FTR is due.

References

Balek, J. (1983). "Developments in water science. hydrology and water resources in tropical regions." Elsevier. *

Bonell, M. (1998) Possible impacts of climate variability and change on tropical forest hydrology. Climatic Change, 39: 215-272.

Bruijnzeel, L. A. (1990). "Hydrology of moist tropical forests and effects of conversion: a state of knowledge review", Humid Tropics Programme'. UNESCO, Paris.

Bruijnzeel, L.A. (2000). "Tropical forests and water yield" Paper prepared for the IUFRC Task Force on Forests and Water. IUFRC, Laxenburg, Austria.

SHI/UNESCO (1998) "World water resources at the beginning of the 21st century". UNESCO Division of Water Sciences research monograph by State Hydrological Institute, St. Petersburg.

Grubb, P J (1977) Control of Forest Growth and Distribution on Wet Tropical Mountains: with Special Reference to Mineral Nutrition. *Annual Review of Ecology and Systematics*, Vol. 8, Pages 83-107

Aldrich, M. Billington, C., Edwards, M. amd Laidlaw, R. (1997) A Global directory of tropical montane cloud forests. UNEP World Conservation Monitoring Centre, Cambridge, UK.

Bubb, P., May, I., Miles, L. and Sayer, J. (2004) Cloud forest Agenda.UNEP-WCMC, Cambridge, UK.

Bubb, P. and Das, S. (in press.) Mapping Tropical Montane Cloud Forest. Bruijnzeel, L.A., Juvik, J., Scatena, F.N., Hamilton, L.S. & Bubb, P. (editors), Forests in the mist: Science for Conserving and Managing Tropical Montane Cloud Forests. University of Hawaii Press, Honolulu (in press).

Jin, Y., W.B. Rossow, and D.P. Wylie, 1996: Comparison of the climatologies of high-level clouds from HIRS and ISCCP. J. Climate., 9, 2850-2879.

Ruel J-C., Mitchell S.J., Dornier M. (2002) A GIS Based Approach to Map Wind Exposure for Windthrow Hazard Rating. Northern Journal of Applied Forestry, Volume 19, Number 4 pp. 183-187

Wylie, D.P., W. P. Menzel, H. M. Woolf, K. I. Strabala, 1994: Four Years of Global Cirrus Cloud Statistics Using HIRS., J. of Climate, 7, 1972-1986