Expedient Methods in Environmental Indexing

2002 ESI, 2004 UNDP Hotspots Report

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Outline

Outline

The complement of GDP

in the universe of information

We call an Environmental Index: an agglomeration of data, compiled to provide a relative measure of environmental conditions.

- Stocks: Measures of current conditions, pressures on those conditions.
- Capacity: Human impacts, social responses.

Examples

- Stocks
  - SO_x, NO_x, TSP, Radioactive Waste
  - Rate of population increase, Fertilizer use per hectare, Coal consumption.
- Capacity
  - Fertility rate, Under-5 mortality rate.
  - Mean years of education, Energy efficiency, Treaty participation.

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Other work

Environmental Indexing is increasing in Scope and Number.

- UNDP Human Development Index (HDI) - tightly focused: Life Expectancy, Literacy Rate, GDP.
- Prescott-Smith's Wealth of Nations - broadly defined: 36 indicators on Human Wellbeing; 51 indicators on Ecosystem Wellbeing-Stress.
- INNOVEST Eco-Scale - extra-market market information: Analysis and ranking of corporate environmental performance.

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Framework for ESI

"The ESI seeks to make the concept of environmental sustainability more concrete and functional by grounding it in real-world data and analysis."

Environmental Systems (13 variables) Measurements on the state of natural stocks such as air, soil, and water.

Environmental Stresses (15 variables) Measurements on the stress on ecosystems such as pollution and deforestation.

Vulnerability (5 variables) Measurements on basic needs such as health, nutrition, and mortality.

Capacity (18 variables) Measurements of social and economic variables such as corruption and liberty, energy consumption, and schooling rate.

Stewardship (13 variables) Measurements of global cooperation such as treaty participation and compliance.

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Outline

ESI Layout: Variable, Indicator, Component

Variable No.	Variable Code	Variable Name	Indicator
1	SO2	Urban SO_2 concentration	Air Quality
2	NO2	Urban NO_2 concentration	
3	TSP	Urban TSP concentration	
4	WATCAP	Internal renewable water per capita	Water Quantity
5	WATINC	Per capita water inflow from other countries	
6	GMS_DO	Dissolved oxygen concentration	Water Quality
7	GMS_PH	Phosphorus concentration	
8	GMS_SS	Suspended solids	
9	GMS_EC	Electrical conductivity	
10	PRTMAM	Percentage of mammals threatened	Biodiversity
11	PRTBRD	Percentage of breeding birds threatened	
12	ANTH10	Percent of land area having very low anthropogenic impact	Land
13	ANTH40	Percent of land area having high anthropogenic impact	
14	NOXKM	NOx emissions per populated land area	Reducing Air Pollution
15	SO2KM	SO_2 emissions per populated land area	
16	VOCKM	VOCs emissions per populated land area	
17	COALKM	Coal consumption per populated land area	
18	CARSKM	Vehicles per populated land area	
19	FERTHA	Fertilizer consumption per hectare of arable land	Reducing Water Stress
20	PESTHA	Pesticide use per hectare of crop land	
21	BODWAT	Industrial organic pollutants per available fresh water	
22	WATSTR	Percentage of country's territory under severe water stress	
23	FOREST	Percentage change in forest cover 1990-95	Reducing Ecosystem Stress
24	AC_EXC	Percentage of county with acidification exceedence	

Variable No.	Variable Code	Variable Name	Indicator
25	EFPC	Ecological footprint per capita	Reducing Waste and Consumption Pressures
26	NUKE	Radioactive waste	
27	TFR	Total fertility rate	Reducing Popuation Growth
28	GR2050	Percentage change in projected population between 2000 & 2050	
29	UND_NO	Proportion of Undernourished in Total Population	Basic Human Sustenance
30	WATSUP	Percent of population with access to improved drinking water supply	
31	DISRES	Child death rate from respiratory diseases	Environmental Health
32	DISINT	Death rate from intestinal infectious diseases	
33	U5MORT	Under-5 mortality rate	
34	INNOV	Innovation Index	Science/Technology
35	TAI	Technology achievement index	
36	SCHOOL	Mean years of schooling (age 15 and above)	
37	IUCN	IUCN member organizations per million population	Capacity for Debate
38	CIVLIB	Civil & Political liberties	
39	POLITY	Democratic institutions	
40	ESIMIS	Percentage of ESI variables in publicly available data sets	
41	WEFGOV	WEF Survey Questions on Environmental Governance	Environmental Governance
42	PRAREA	Percentage of land area under protected status	
43	EIA	Number of sectoral EIA guidelines	
44	FSC	FSC accredited forest area as a percent of total forest area	
45	GRAFT	Reducing corruption	
46	GASPR	Ratio of gasoline price to international average	
47	WEFSUB	WEF subsidies survey question	
48	SUBFSH	WWF Subsidy measure	
49	ISO14	Number of ISO14001 certified companies per million $ GDP	Private Sector Responsiveness
50	DJSGI	Dow Jones sustainability group index	
51	ECOVAL	Average Innovest EcoValue rating of firms	
52	WBCSD	World Business Council for Sustainable Development members	
53	WEFPRI	WEF Survey Questions on Private Sector Environmental Innovation	
54	ENEFF	Energy efficiency (total energy consumption per unit GDP)	Eco-efficiency
[illegible]	[illegible]	Renewable energy prod. as a percent of total energy consumption	

Computation

$$\text{ESI} = 100 * \Phi\left(\frac{1}{|k|}\sum_{k}\frac{1}{|J_k|}\sum_{j\in J_k}\left(\frac{Y_j - \overline{Y}_j}{\text{var}(y_j)^{1/2}}\right)\right).$$

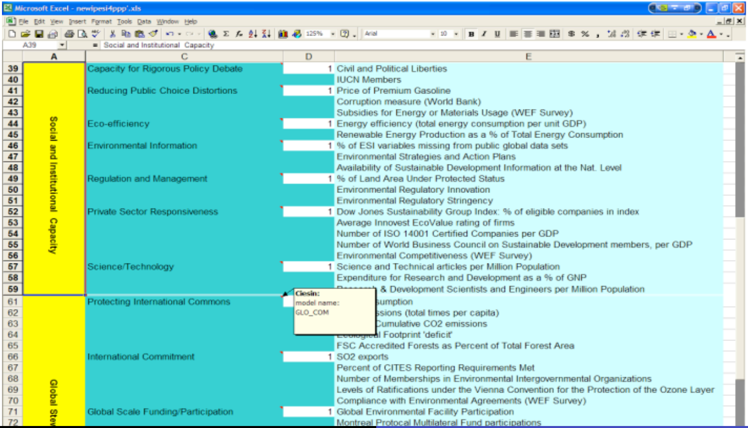
Here

$$\mathbf{Y} = (\mathbf{Y}_{J_1}, \ldots, \mathbf{Y}_{J_k}) = (Y_1, \ldots, Y_{68})$$

where the J's are groups of similar information, and Φ is the inverse standard normal distribution function.

Weighting

Implicitly, the aggregation structure of index belies a weighting or preference for a particular definition of sustainability.

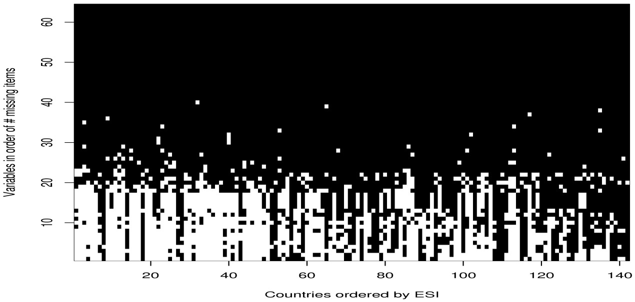


	A	C	D	E
39	Social and Institutional Capacity	Capacity for Rigorous Policy Debate	1	Civil and Political Liberties
40				IUCN Members
41		Reducing Public Choice Distortions	1	Price of Premium Gasoline
42				Corruption measure (World Bank)
43				Subsidies for Energy or Materials Usage (WEF Survey)
44		Eco-efficiency	1	Energy efficiency (total energy consumption per unit GDP)
45				Renewable Energy Production as a % of Total Energy Consumption
46		Environmental Information	1	% of ESI variables missing from public global data sets
47				Environmental Strategies and Action Plans
48				Availability of Sustainable Development Information at the Nat. Level
49		Regulation and Management	1	% of Land Area Under Protected Status
50				Environmental Regulatory Innovation
51				Environmental Regulatory Stringency
52		Private Sector Responsiveness	1	Dow Jones Sustainability Group Index: % of eligible companies in index
53				Average Innovest EcoValue rating of firms
54				Number of ISO 14001 Certified Companies per GDP
55				Number of World Business Council on Sustainable Development members, per GDP
56				Environmental Competitiveness (WEF Survey)
57		Science/Technology	1	Science and Technical articles per Million Population
58				Expenditure for Research and Development as a % of GNP
59				& Development Scientists and Engineers per Million Population
61	Global Stew	Protecting International Commons		sumption
62				ssions (total times per capita)
63				Cumulative CO2 emissions
64				l Footprint 'deficit'
65				FSC Accredited Forests as Percent of Total Forest Area
66		International Commitment	1	SO2 exports
67				Percent of CITES Reporting Requirements Met
68				Number of Memberships in Environmental Intergovernmental Organizations
69				Levels of Ratifications under the Vienna Convention for the Protection of the Ozone Layer
70				Compliance with Environmental Agreements (WEF Survey)
71		Global Scale Funding/Participation	1	Global Environmental Facility Participation
72				Montreal Protocal Multilateral Fund participations

Outline

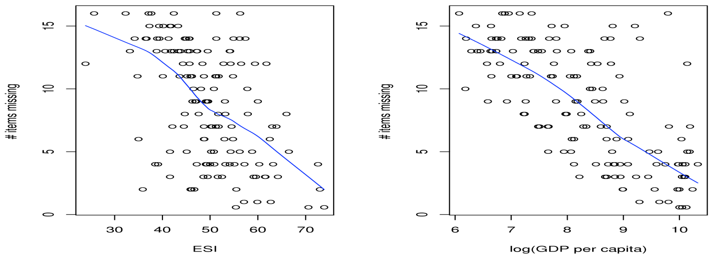
Missingness

Twenty-two percent of final data set missing.



Missingness

Strong possibility of non-random missingness.



Imputation

Van Buuren [2001] and Raghunathan [2001] investigated that a G can be replaced with a set of conditional distributions $G = \prod_{J_k \in K} G_{J_k}$, in many cases. Sequential Regression Multiple Imputation (SRMI) proceeds by partitioning the dataset:

$$\mathbf{Y} = (\mathbf{Y}_{J1}, \ldots, \mathbf{Y}_{Jk}) = (Y_1, \ldots, Y_{68}) = (\mathbf{Y}_m, \mathbf{Y}_o) =$$

$$\mathbf{Y} = (Y_1, \ldots, Y_{|k|-r}, Y_{|k|-r+1}, \ldots, Y_{|k|})$$

$$\mathbf{X} = (Y_1, \ldots, Y_{|k|-r}); \mathbf{Y}^* = (Y_{|k|-r+1}, \ldots, Y_{|k|})$$

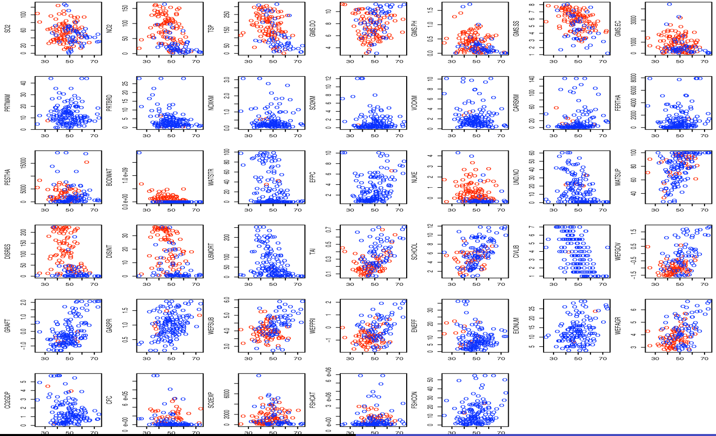
in order of missingness, where r is the number of variables with missing values, and $\mathbf{Y}^*$ is regressed, iteratively, on $\mathbf{X}$.

Imputation

1. The first round of the SRMI algorithm begins by regressing Y_1, the variable with the least missing items, on $\mathbf{X}$.
2. Now Y_1 is entered into $\mathbf{X}$ and the algorithm regresses Y_2 on $(\mathbf{X}, Y_1)$. The algorithm continues until $Y_{|k|}$ is completed by regressing it on $(\mathbf{X}, Y_{|k|-1})$.
3. The next round continues in the same manner, with $(\mathbf{X}, Y_1, \ldots, Y_{|k|})$ the new predictor set.
4. The algorithm cycled through the above steps until the imputed values converged.

We repeated the algorithm $m = 10$ times, averaged the imputed data sets, and calculated the ESI on the final averaged imputed data set.

Imputation


SO2
NO2
TSP
GMS.DO
GMS.PH
GMS.SS
GMS.EC
PRTMAM
PRTBRD
NOXKM
SO2KM
VOCKM
CARSKM
FERTHA
PESTHA
BODWAT
WATSTR
EFPC
NUKE
UNDNO
WATSUP
DISRES
DISINT
U5MORT
TAI
SCHOOL
CIVLIB
WEFGOV
GRAFT
GASPR
WEFSUB
WEFPRI
ENEFF
EIONUM
WEFAGR
CO2GDP
CFC
SO2EXP
FSHCAT
FSHCON

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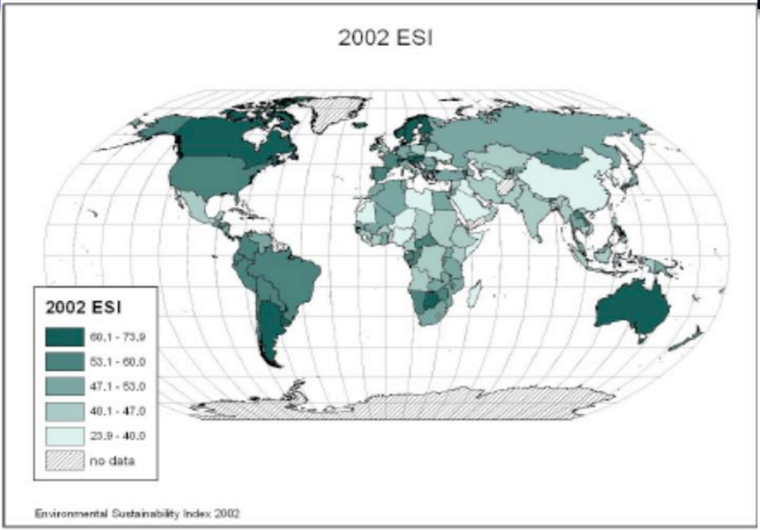
ESI Map


2002 ESI
2002 ESI
60.1 - 73.9
53.1 - 60.0
47.1 - 53.0
40.1 - 47.0
23.9 - 40.0
no data
Environmental Sustainability Index 2002

Outline

Introduction to the Task

Risk, of a disaster, under spatial independence, is as a probabilistic **product** over exposed **elements** and their **vulnerability** to the disaster. A non-trivial **joint** quantification of **Risk**, from multiple disasters, **involves** the determination of **dependencies** between the elements and vulnerabilites. A **Bayesian Network (BN)** - a **Directed Acyclic Graph (DAG)** where the **joint** [probability] **distribution** is the **product** of marginal, **conditionally independent distributions** - can be applied to the problem of divining dependency structure. We investigate BN learning on a composite global disaster dataset of large dimension ($n = 15600, k = 6$) using the **DEAL algorithm** Bottcher and Detlefsen [2002] - which reduces the NP-complete problem by using a **heuristic search** with **random restarts**.

The Bayesian Network

A Bayesian Network $B = (U, D, P)$ is characterized by a **domain**

$$U = (U_1, \ldots, U_{k+m})$$

with $k + m$ elements or **nodes**, a **model**

$$((D))_{i,j} = \chi_{[\{U_i, U_j\}]} \forall 1 < i, j \leq k + m$$

and a joint probability **distribution**

$$p(\overrightarrow{U}) = \prod_{i}^{k+m} p(U_i | pa(U_i))$$

where $U_j \in pa(U_i) \Leftrightarrow D_{i,j} \neq 1$.

The Bayesian Network

B is termed a **Directed Acyclic Graph** or **DAG** with the addition of a final constraint

$$D_{i,j} \rightarrow \neg D_{j,pa(i)}$$

restricting the appearance of cycles (feedback loops).

Risk in a Bayesian Network

Learning a model involves populating the matrix $((D))_{i,j}$, within the acyclic constraint, or analogously adding directed arcs to the graph of nodes $\overrightarrow{U}$. It is important to constrain any learning procedure with a prior or initial model $((D^0))_{i,j}$. Here, recall that $\overrightarrow{U} = \{U_1, \ldots, U_k, U_{m-m+1}, \ldots, U_m\} = \{V_1, \ldots, V_k, H_1, \ldots, H_m\}$ and the initial model is as follows:

$$D^0_{V_i,H_j} \equiv 0$$

Outline

Candidate Data: Peru

The LARED database for Peru [LA RED 2002], indexed by year and location within country. $dim = (19481, 64)$ over $t = 1, \ldots, 30; s = 1, \ldots, 24$.

For each (t, s)

$$H_i = \sum_H \chi_{[H=i]}$$

$$V_i = \sum_{V_i} \chi_{[v_i>0]}$$

Reduced to $dim = (2045, 9)$, $k + m = 9$ nodes.

Peru


Tumbes
Piura
Amazonas
Cajamarca
Lambayeque
Loreto
San Martin
La Libertad
Ancash
Huanuco
Ucayali
Pasco
Junin
Madre de Dios
Huancavelica
Cusco
Ayacucho
Apurimac
Ica
Puno

The Learning Algorithm

The learning algorithm is a random search and restart that returns the existence of arcs in a DAG (some $((D))_{i,j} \forall i, j$) and a network score $S(D)$ on the likelihood of D given the observed data. The algorithm, abbreviated, is as follows:

1. Suggest a local prior probability distribution $p_0(U_i) \forall i$. Set D_0. Set $(iter) = 0$
2. Construct a *joint* prior probability distribution $p_0(\overrightarrow{U})$ - the *master* prior.
3. Let θ_0 be the parameters of p_0. Then $p(\theta_0 | \overrightarrow{U})$ is the initial marginal conditional distribution of parameters.
4. From the data, update θ_0 and thus p_0
5. Score network $S_{(iter)}(D_{(iter)})$; If $S_{(iter-1)} > S_{(iter)}$ end.
6. Perturb the model $D_{(iter)} \rightarrow D_{(iter+1)}$
7. Goto 2

Perturbation

Perturbing $D_{(iter)} \rightarrow D_{(iter+1)}$ by degree d is selecting d nodes at random, (say, $d = 3$ and select o, p, r from $D_{(iter)}$) and exhaustively adding, removing or turning arcs given the initial constraints. For instance, cycle through:

$$d_{o,i} = \begin{cases} 1, & \text{if } d_{o,i} = 0; \\ 0, & \text{if } d_{o,i} = 1; \\ 1, & \text{if } d_{i,o} = 1. \end{cases}$$

Scoring

Scoring the network involves computing the likelihood of the contribution, at each node, of the configuration (i.e. parameterization) of the node given the parents. That is:

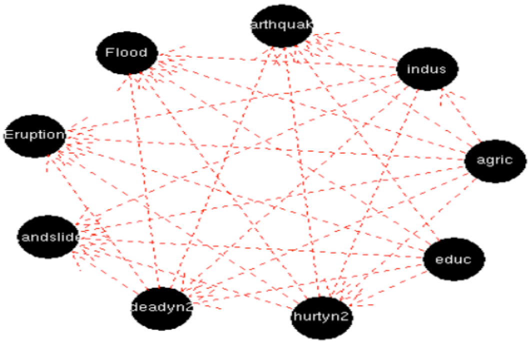
$$S_U = \sum_{u \in \overrightarrow{U}}$$

$$\prod_{u \in pa(u)} \frac{\Gamma(\sum_{u \in pa(u)} \alpha_{u|pa(u)})}{\Gamma(\sum_{u \in pa(u)} \alpha_{u|pa(u)} + \sum_{u \in pa(u)} n_{u|pa(u)})} *$$

$$\prod_{u \notin pa(u)} \frac{\Gamma(\alpha_{u|pa(u)} + \sum_{u \in pa(u)} n_{u|pa(u)})}{\Gamma(\alpha_{u|pa(u)})}$$

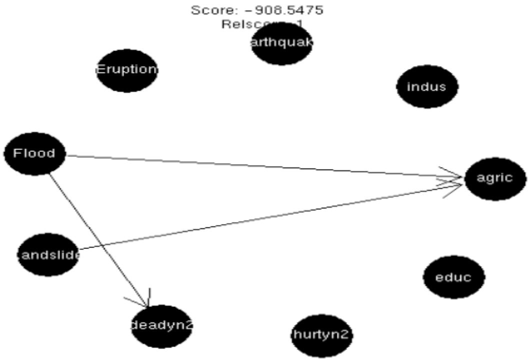
Results

Events classified as strict parents; vulnerabilities as strict children Dead/hurt as intermediate



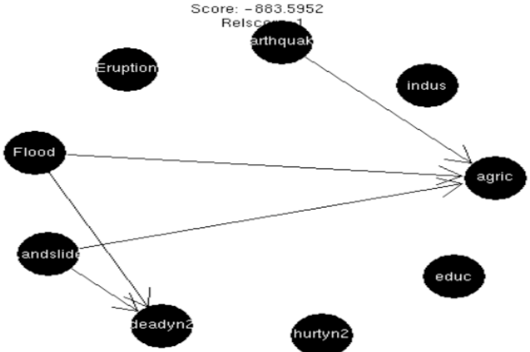
Results

Calculate network score and compare with all possible networks that differ by addition, deletion, or reversal of an arrow



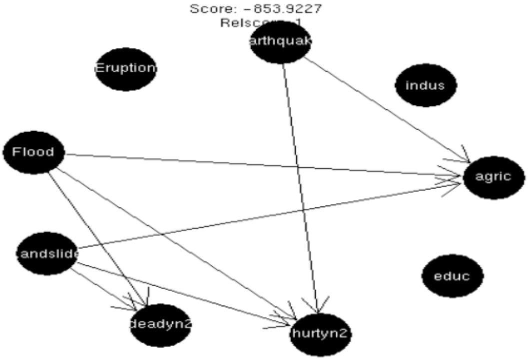
Results

Select network that increases network score the most



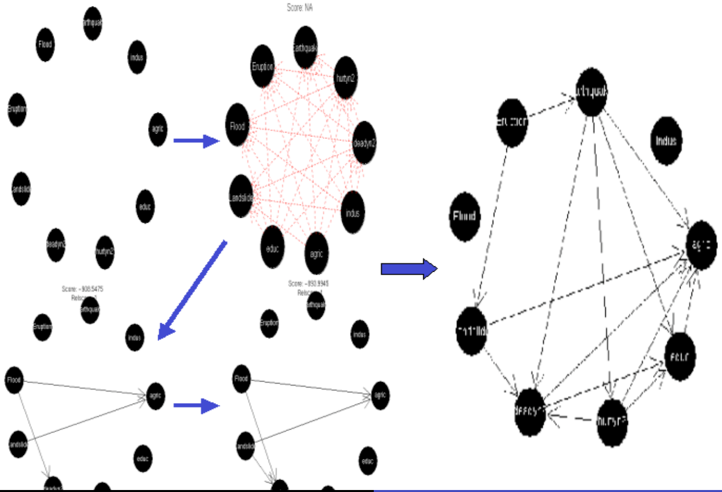
Results

If the network score does not increase, stop. Otherwise repeat.



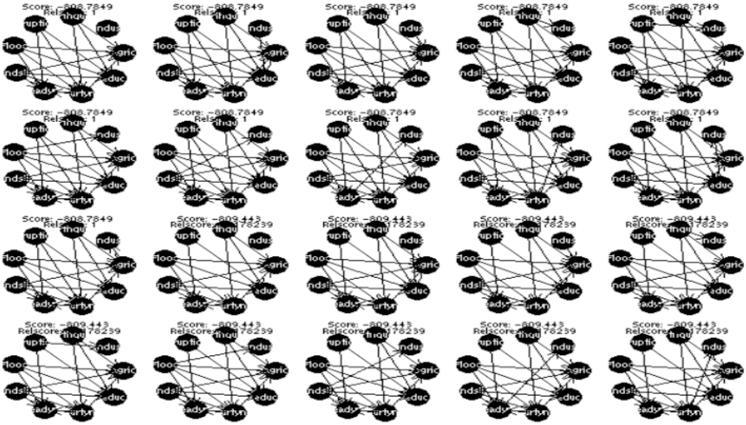
Results

Sample Network



Results

Aggregating, Resampling Networks



Outline

Archetypal High Risk Hotspot

Between 1994-1998: Volcano eruption in Rabaul, Cyclone Justin in the Milne Bay, and the El Nino-induced drought.

The Data

Incidence maps of **flood**, **volcano** and **drought** events; expected peak ground acceleration **(pga)**; and spatially dispersed **population** and **gnp** maps to **one degree lat-long** resolution. This yielded 15600 observations on four dimensions of physical processes, and two dimensions of socio-economic vulnerability. Row-wise deletions of 1407 observations with any missing items yielded a final data matrix of dimension $(14193, 6)$

The Data

x	X-coordinate, decimal degrees of longitude
y	Y-coordinate, decimal degrees of latitude
gnp901d	Gross National Product, 1990 (US)
glp95ag1d	Population count, 1995
floodc	Number of flood events 15 year series
pga1d	Peak ground acceleration, value to be exceeded at the 10 percent probability level, 50 year interval
volcount	Volcanoes – count of the number of volcanoes in the 1-degree grid cell cell
d7531d	Drought – 75 percent below normal precipitation for a 3 month period

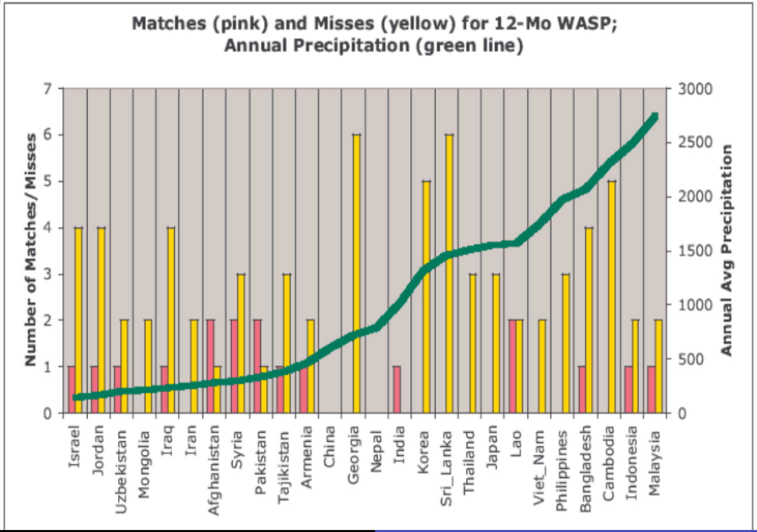
Data Sources - Events

Hazard	Parameter	Period	Resolution	Source(s)
Cyclones	Frequency by wind strength	1980-2000	30"	UNEP/GRID-Geneva PreView
Drought	Weighted Anomaly of Standardized Precipitation (75% below normal precipitation for a 3-month period)	1985-2003	2.5°	IRI Climate Data Library
Floods	Counts of extreme flood events	1985-2003*	1°	Dartmouth Flood Observatory, *World Atlas of Large Flood Events*
Earthquake	Expected peak ground acceleration (10% probability of exceedance in 50 years)	n/a	sampled at 1'	Global Seismic Hazard Program
	Frequency of earthquakes > 4.5 on Richter Scale	1976-2002	sampled at 2.5'	Smithsonian Institution
Volcanoes	Counts of volcanic activity	79-2000	Sampled at 2.5'	UNEP/GRID-Geneva and NGDC
Landslides	Estimated annual probability of landslide or avalanche	n/a	30"	NGI

Data Sources - Exposure

Exposure	Parameter	Period	Resolution	Source(s)
Land	Land area	2000	2.5"	GPW Version 3 (alpha)
Population	Population counts/density	2000	2.5"	GPW Version 3 (alpha)
Economic Activity	National/subnational GDP	2000	2.5"	World Bank DMF
Agricultural Activity	National agricultural GDP allocated to agricultural land area	2000	2.5"	World Bank DMF
Road Density	Length of major roads and railroads	c. 1993	2.5"	VMAP(0)

Drought: It's worth talking about



Extreme Value Fitting

We investigated methods for returning multivariate extremes, starting with bivariate compositions of hazard event and vulnerability.

Taking multivariate **q** we wish to return the set $\mathcal{Q}$ such that.

$$\mathcal{Q} = \{\mathbf{q} || F(\mathbf{Q} \leq \mathbf{q}) - c| < \epsilon\}$$

Restating again, and directly in our context, we want all spatial locations that are extreme in a bivariate sense.

Our *F* is the cumulative distribution function for our multivariate vector **Q**, or, the probability that we observe, for a given observed **q**, a value less extreme. As *F* approaches 1 we are less likely to observe a more extreme value, and thus our observation is quite extreme

Extreme Value Distribution Model

Here, we implemented a symmetric bivariate logistic model [Stephenson 2003]

$$G(z_1, z_2) = exp\{-(y_1{}^{\frac{1}{\alpha}} + y_2{}^{\frac{1}{\alpha}})^{\alpha}\}$$

where $\alpha \in (0, 1]$ is a dependency parameter.

Let $y_i = [1 + \frac{\xi_i(z_i - \mu_i)}{\sigma_i}]^{\frac{-1}{\xi_i}}$ so we don't have to write many things again...

Extreme Value Distribution Model

The bivariate logistic integrates over the margins to a generalized extreme value distribution

$$G(z_i) = exp\{-[1 + \frac{\xi_i(z - \mu_i)}{\sigma_i}]^{\frac{-1}{\xi_i}}\}$$

where (μ_i, σ_i, ξ_i) are the location, scale and shape parameters of the ith univariate distribution.
Uniting the above we can simply let $\mathbf{Q} = (z_1, z_2)$

Extreme Value Distribution Model

We restricted fitting to

$$\mathcal{Q} \supset \mathcal{Q}* = \{\mathbf{q} | q_i > 0, \forall i\}$$

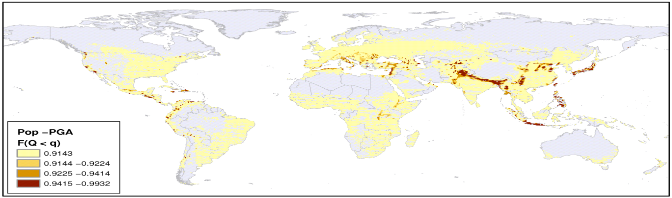
Restated, we censored the fit to all non-zero values. This required a recalculation of F

$$F(\mathbf{Q} \leq \mathbf{q}*) = F_1 + F_2 - F_1 F_2; F_1 = Pr(\mathbf{Q} \leq \mathbf{q}*); F_2 = Pr(\mathbf{Q} \leq \mathbf{q} | \mathbf{Q} > \mathbf{q}*)$$

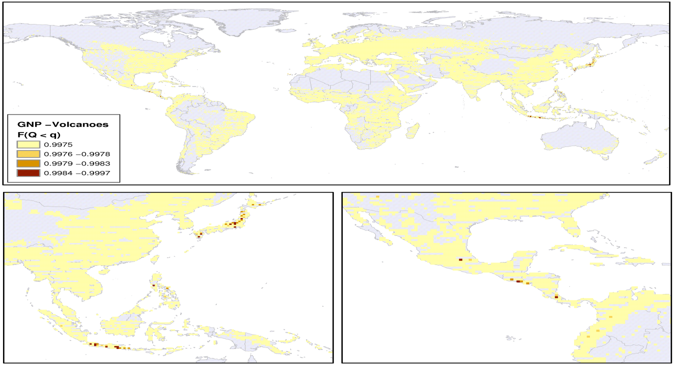
where $\mathbf{q}* \in Q \cap Q*$.

Outline

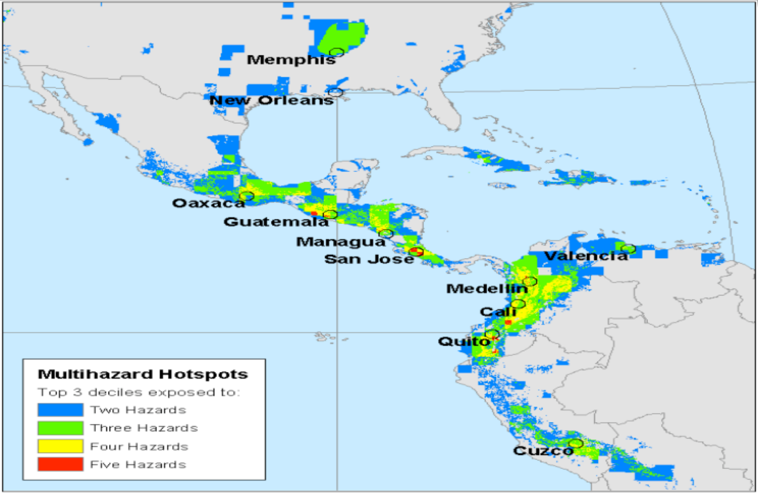
Population vs. Seismicity



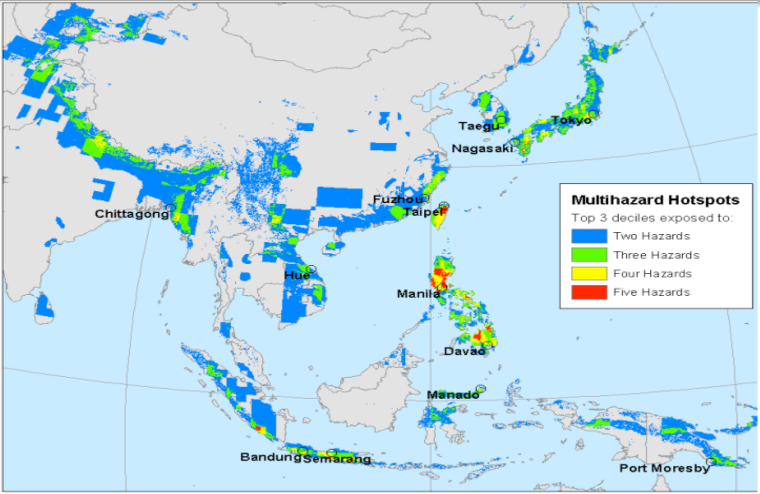
GDP vs. Volcanic Activity



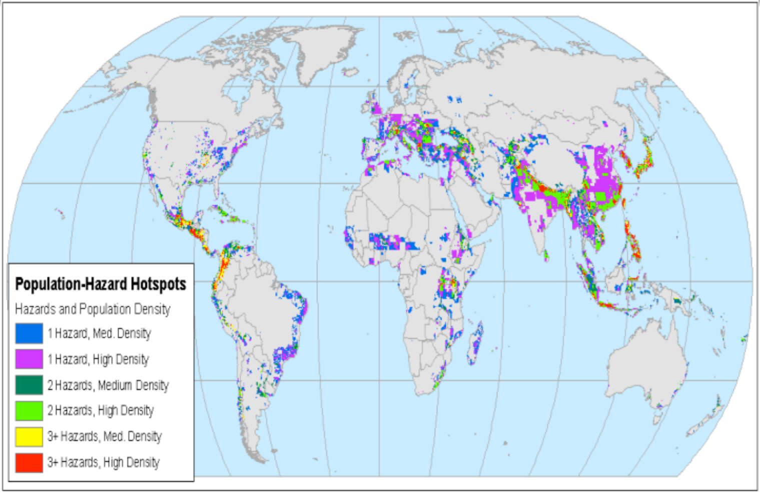
Multiple Hazards



Multiple Hazards



Multiple Hazards



Summary

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- When modeling with environmental data $\grave{o}\ \mu\epsilon\tau\rho o\nu\ \sigma\epsilon\alpha\upsilon\tau o\nu$

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