World City Risk 2025

August 2014

Cambridge World City Risk Atlas

Threat Hazard Maps of the World

Centre for
Risk Studies

UNIVERSITY OF CAMBRIDGE
Judge Business School

World City Risk 2025

The Cambridge World City Risk Atlas is a compilation of threat hazard maps produced for the World City Risk 2025 project

This Atlas is a companion volume to the reports and presentations on the World City Risk 2025 project, available at
http://cambridgeriskframework.com/wcr

The Cambridge Centre for Risk Studies acknowledges the generous support provided for this research by Lloyd's

LLOYD'S

Results and outputs of this research do not imply any endorsement by Lloyd's

Any errors and omissions are entirely those of the research team of the Cambridge Centre for Risk Studies

We acknowledge the generous support from all of the supporters of the Centre for Risk Studies for the development of the Cambridge Risk Framework, Catastronomics methodologies, and underlying datasets used in this analysis

Overview of Threat Models

	ID	Threat	Phase	Hazard Map	Severity Scale	Cause	Projection	Uncertainty
Natural Catastrophe & Climate								
1.1	EQ	**Earthquake**	1	United States Geological Survey; GSHAP	Ms (Surface-wave Magnitude)	Natural	Constant	Low
1.2	VE	**Volcanic Eruption**	1	Smithsonian Institute of Volcanology	VEI (Volcanic Explosiivity Index)	Natural	Constant	Medium
1.3	HU	**Tropical Windstorm**	2	EM-DAT; Pacific Research Center; Munich Re	Saffir-Simpson CAT Hurricane Scale	Natural	CC Trend	Low
1.4	WS	**Temperate Windstorm**	2	EM-DAT Windstorm Database	Beaufort Wind Scale	Natural	CC Trend	Low
1.5	FL	**Flood**	1&2	UNEP/DEWA/GRID-Europe Flood Risk Rating	Depth and velocity of flood water	Natural	CC Trend	Low
1.7	TS	**Tsunami**	2	NOAA NCDC Historical Tsunami Database	Run-up height	Natural	CC Trend	Medium
1.8	DR	**Drought**	2	US National Center for Atmospheric Research	Palmer Drought Severity Scale	Natural	CC Trend	Medium
1.10	FR	**Freeze**	2	Global Climate Zoning Map	Degree-Days below 0C	Natural	CC Trend	Medium
1.11	HW	**Heatwave**	2	Global Climate Zoning Map	Degree-Days Above 32C	Natural	CC Trend	Medium
Financial, Trade & Business								
2.1	MC	**Market Crash**	1	IMF Banking Network Core-Periphery Designation	S&P500 Index reduction	Man-Made	Dynamic	High
2.2	SD	**Sovereign Default**	1	S&P National Credit Ratings	% Devaluation of national currency	Man-Made	Dynamic	Medium
2.3	OP	**Oil Price Shock**	2	UN imported oil intensity of GDP output	% increase in oil price (Brent Crude)	Man-Made	Dynamic	Medium
Political, Crime & Security								
3.1	IW	**Interstate War**	1	Cytora Interstate Conflict Scenario Set	War Magnitude Scale	Man-Made	Dynamic	High
3.2	SP	**Separatism**	1	Encyclopedia of Modern Separatist Movements	Civil War Intensity (deaths)	Man-Made	Dynamic	Medium
3.3	TR	**Terrorism**	1	IEP START Global Terrorism Index	Terrorism Severity Scale	Man-Made	Dynamic	Medium
3.4	SU	**Social Unrest**	2	Cytora Social Unrest Event Index	Social Unrest Severity Scale		Dynamic	Medium
Technology & Space								
4.1	PO	**Power Outage**	2	Nation Master Electrical Outage Report	City-Days of Outage	Man-Made	Constant	Medium
4.2	CY	**Cyber Catastrophe**	1	McAfee International Cyber Risk Report	Cyber Magnitude & Revenue@Risk	Man-Made	Dynamic	High
4.3	SS	**Solar Storm**	2	US National Oceanic and Atmospheric Administration	US NOAA Space Weather Scale	Natural	Constant	High
4.4	NP	**Nuclear Meltdown**	2	World Nuclear Association Information Library	Intntl Nuclear Events Scale (INES)	Man-Made	Constant	Low
Health & Environmental								
5.1	HE	**Human Epidemic**	1	Emerging Infectious Diseases, Institute of Zoology	US CDC Pandemic Severity Index	Natural	Dynamic	Medium
5.2	PE	**Plant Epidemic**	2	Wallingford Distribution Maps of Plant Diseases	Staple Crop (Wheat) Price Index	Natural	Dynamic	Medium

World Cities Location Map

This study reviews the risk of economic output loss from catastrophes affecting 300 of the world's leading cities, shown here.

These include the largest cities of the major national economies of the world, with the strongest economies accounting for a greater number of cities featured in the selection.

It also includes cities in emerging nations and cities representative of less developed regions.

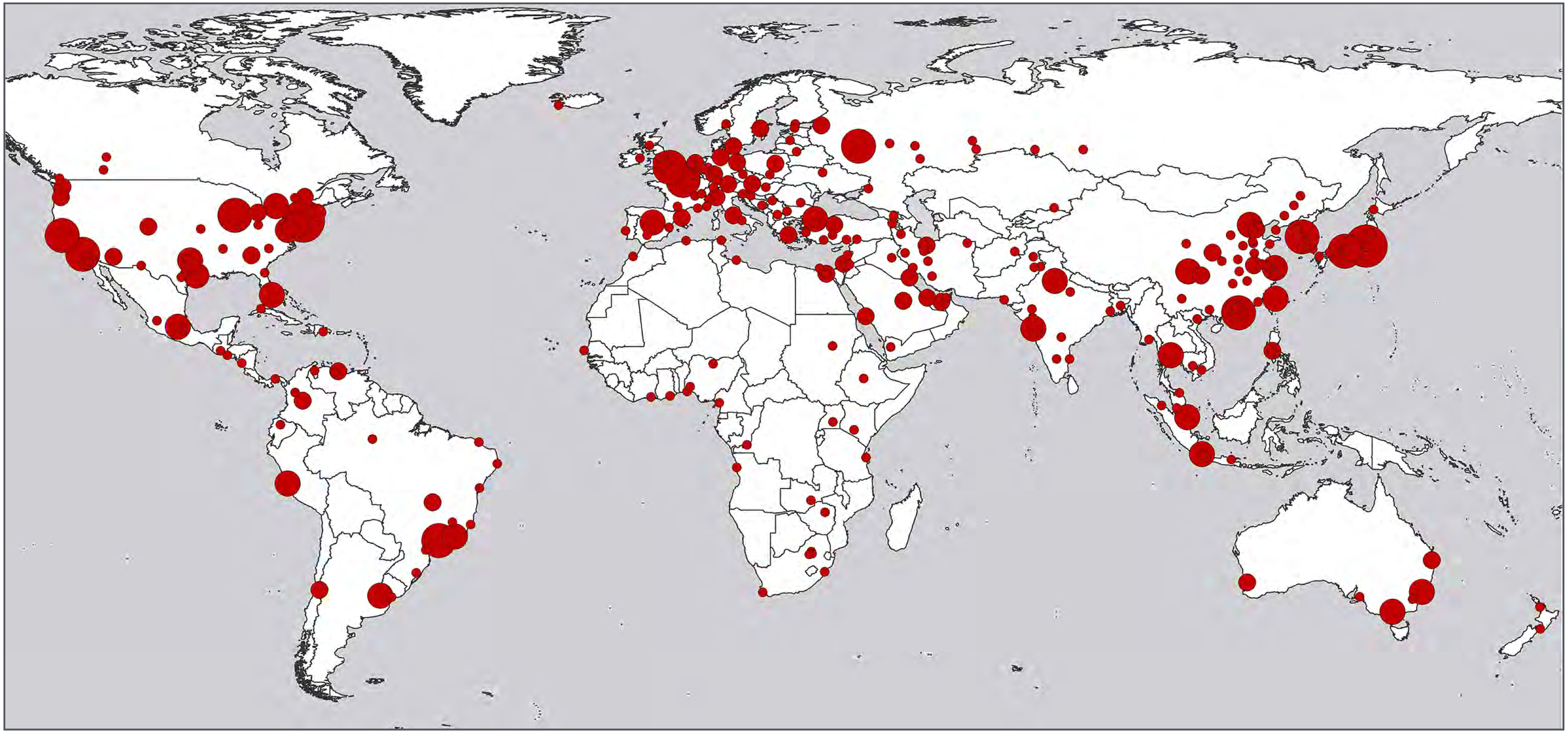
The selection includes all the world's cities with population of over 3 million and includes half of all of the capital cities in the world.

Collectively, this group of cities generates around half of the world's GDP today.

Trends suggest that these 300 cities will be responsible for two-thirds of the world's GDP in 2025.

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies

World Cities by Current GDP



City GDP ($US Bn)

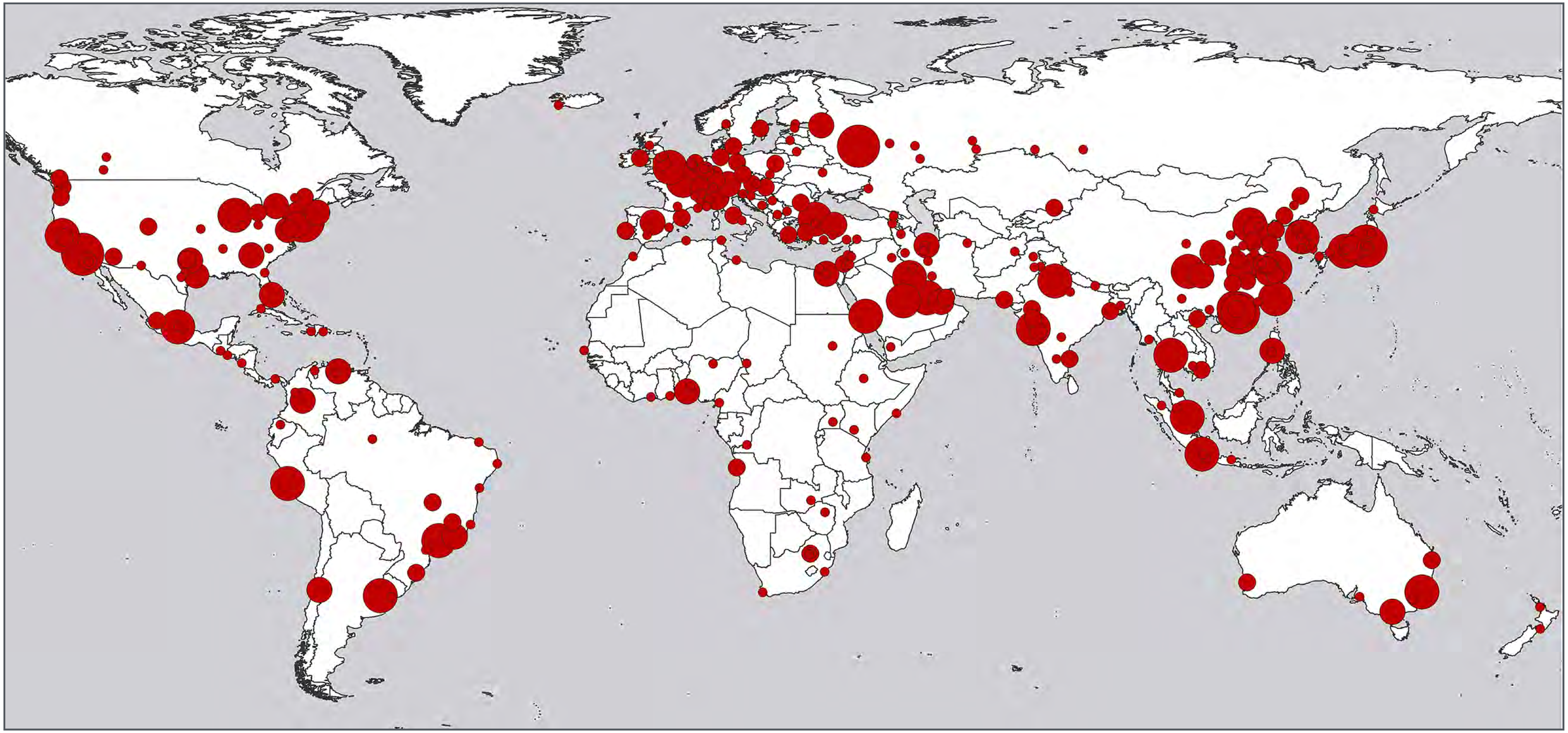
- 2 - 100
- 101 - 200
- 201 - 400
- 401 - 800
- 800 - 1635

Top 10 Cities by GDP ($US Bn)

1	JPN	**Tokyo**	1313
2	USA	**New York**	1013
3	USA	**Los Angeles**	774
4	FRA	**Paris**	619
5	GBR	**London**	580
6	KOR	**Seoul**	562
7	RUS	**Moscow**	525
8	JPN	**Osaka**	523
9	BRA	**São Paulo**	516
10	USA	**Chicago**	480

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies

Estimated World Cities GDP - 2025



City GDP ($US Bn)

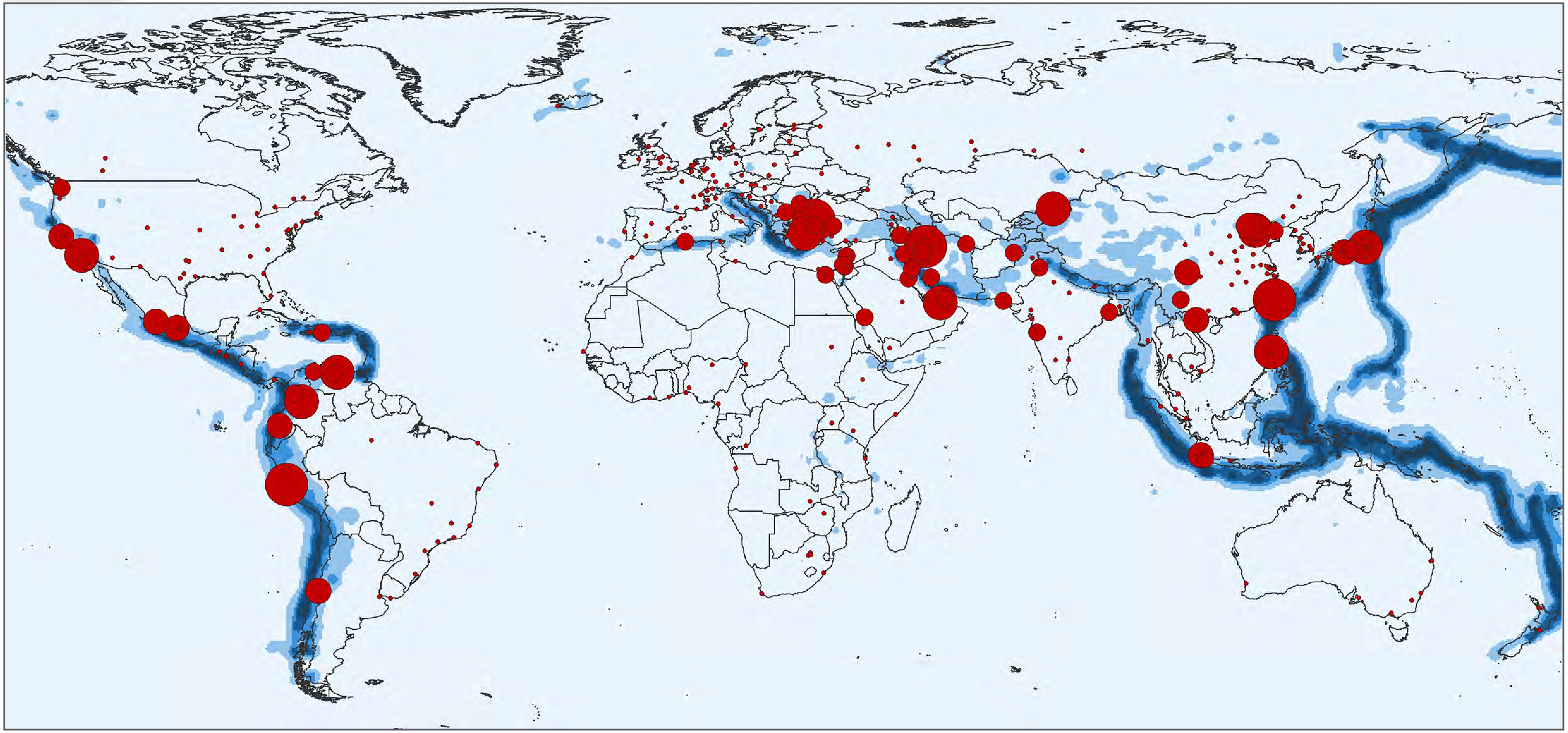
- 2 - 100
- 101 - 200
- 201 - 400
- 401 - 800
- 800 - 1635

Top 10 Cities by GDP ($US Bn)

1	JPN	**Tokyo**	1634
2	USA	**New York City**	1144
3	RUS	**Moscow**	1100
4	CHN	**Hong Kong**	920
5	USA	**Los Angeles**	880
6	BRA	**São Paulo**	778
7	FRA	**Paris**	764
8	KOR	**Seoul**	761
9	CHN	**Shanghai**	706
10	ARG	**Buenos Aires**	706

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies

Earthquake



City GDP@Risk (US$ Bn)

- 0 - 1.5
- 1.5 - 5
- 5 - 10
- 10 - 20
- 20 - 36

Earthquake Hazard

Peak Ground Acceleration (cm/s2) at 475 year return period

- 0- 100
- 101 - 250
- 251 - 400
- 401 - 600
- 601 - 1,050

Earthquake risk is highly localized and depends on the seismic fault structures in and around the city. This study does not attempt a detailed seismic source analysis but uses United States Geological Survey assessments of the design load spectral response acceleration at the centroid of each city, together with peak ground acceleration mappings from United Nations Environmental Program (shown here at 475 year return period), and a historical catalogue of earthquake events from the Significant Earthquake Database of US National Geophysical Data Center, to categorize cities by seismic hazard.
These are used to assess the likelihood and consequences of each city experiencing characteristic scenarios:

EQ1 A 'Large Magnitude Earthquake' (Ms6.5) within the city boundaries. Centroid of city experiences VII (PGA 250-400)

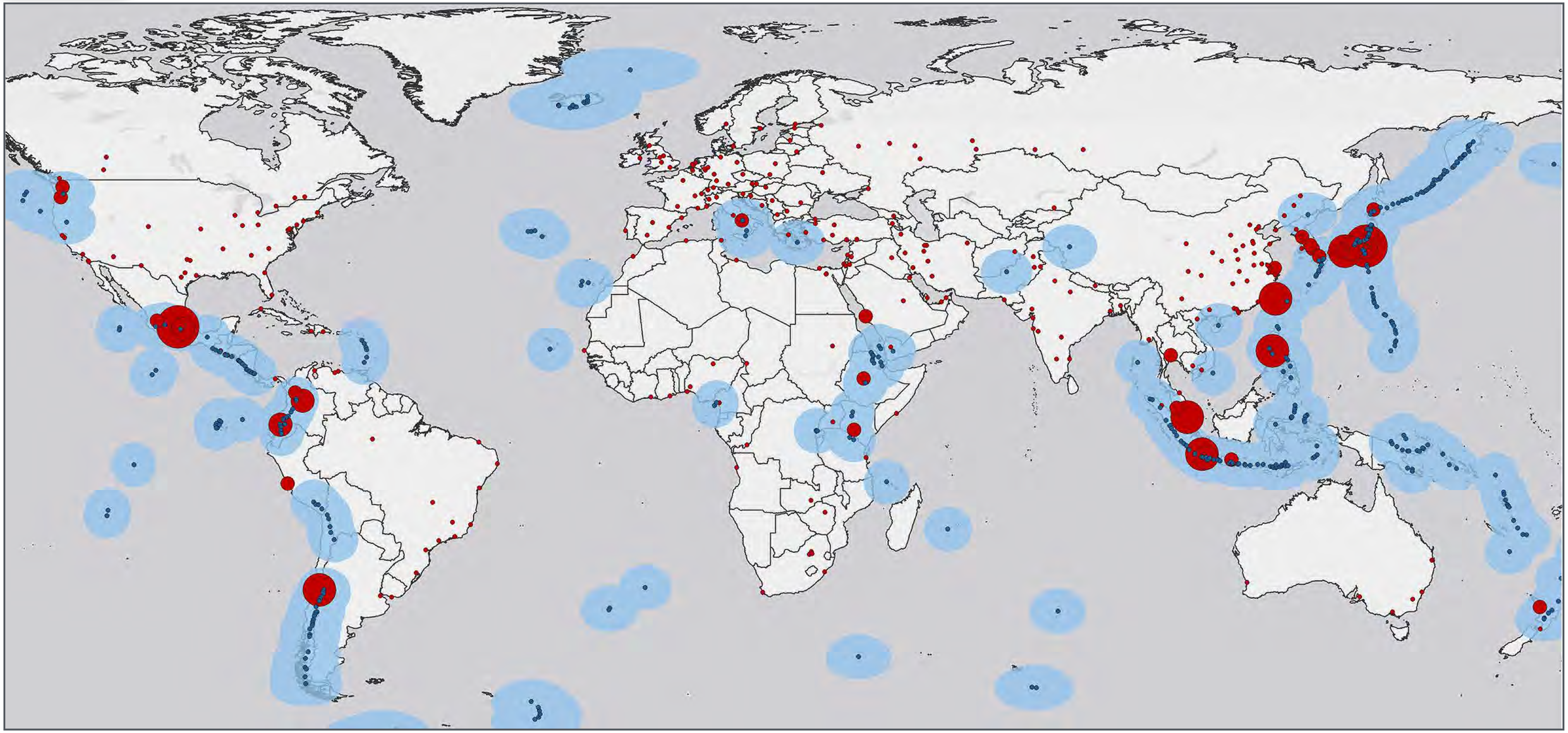
EQ2 A 'Great Earthquake' (Ms7.0) with its epicentre close to the edge of the city, just outside its boundaries. Centroid of city experiences VIII (PGA 400-600)

EQ3 A 'Great Earthquake'' (Ms7.5) occurring at shallow depth with its epicentre close to the centre of the city. Centroid of city experiences IX (PGA 600-1000)

Top 10 Cities by GDP@Risk ($US Bn)

1	PER	**Lima**	36
2	IRN	**Tehran**	35
3	TUR	**Istanbul**	30
4	TWN	**Taipei**	30
5	CHN	**Tianjin**	21
6	JPN	**Tokyo**	19
7	USA	**Los Angeles**	18
8	TUR	**Izmir**	14
9	PHL	**Manila**	13
10	KAZ	**Almaty**	13

Volcanic Eruption



City GDP@Risk (US$ Bn)

- 0.00 - 0.50
- 3.51 - 1.00
- 1.01 - 2.00
- 2.01 - 7.00
- 7.00 - 11,65

Volcanic Eruption Threat

- Volcano - Last eruption since 1900
- Area within 500km of a volcano

Volcanic eruption threatens the economic activity of cities mainly through ash clouds, which can cause disruption a long way from the volcano itself. The database of the Global Volcanism Program of the Smithsonian Institution provides the location and eruption history of the volcanoes of the world. This analysis does not assess the volcanic hazard of individual volcanoes but categorizes them by eruption history and potential for large future eruptions of Volcanic Explosivity Index of 4 to 7. Volcanoes within 1000 km of each city are considered, and their historical rates of eruption are analyzed to estimate average eruption rates. This mapping shows a 500km radius around each active volcano, a typical extent of a significant ash fallout from a VEI 5 eruption. Each city is analyzed for the GDP impact and likelihood of experiencing characteristic scenarios:

VE1 Ashcloud shuts city for extended period, and covers it with several centimeters of ash, preventing air travel, road traffic, port functions, and normal business activity.

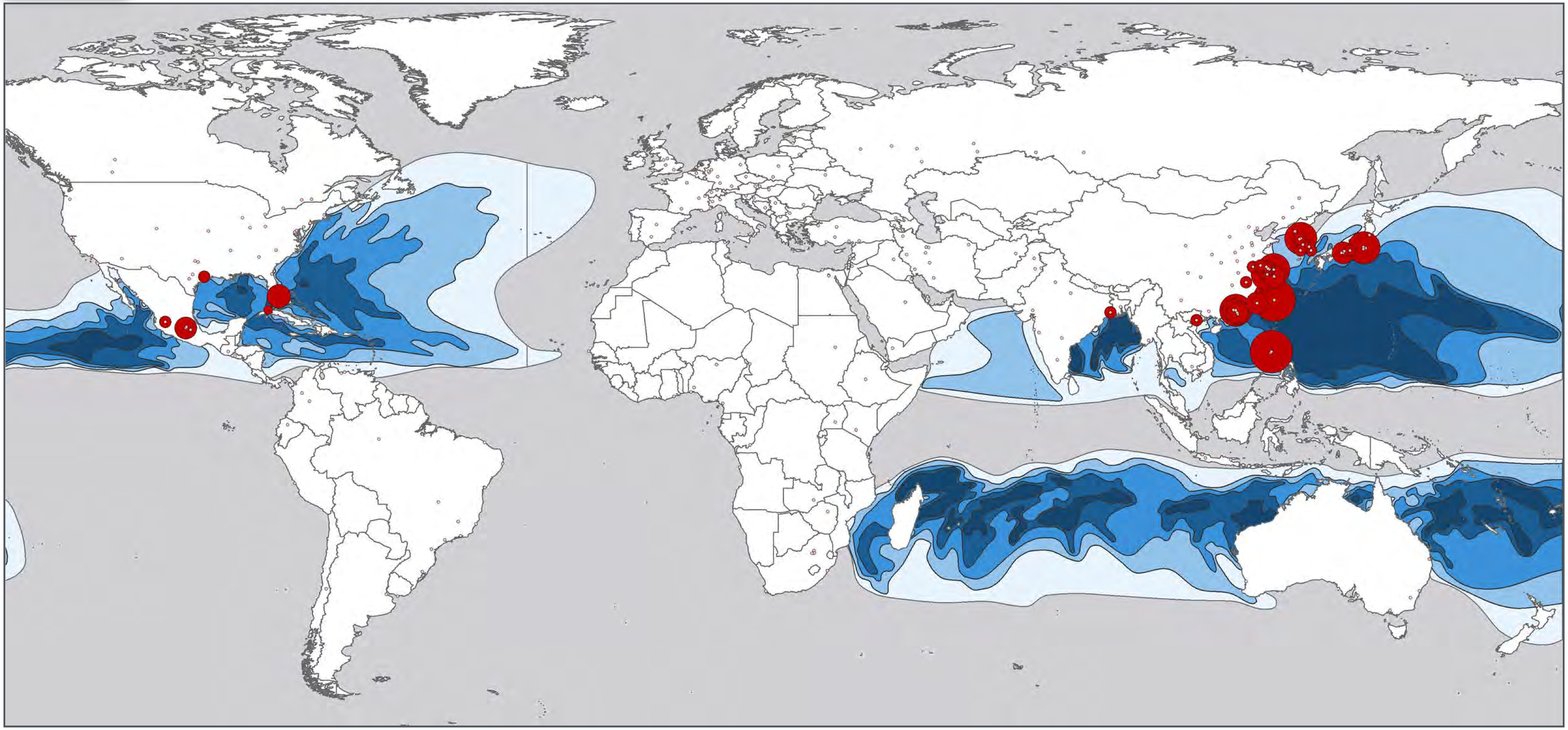
VE2 Ashcloud covers city to 1m depth, entailing lengthy recovery process

VE3 Parts of city impacted by direct effects of volcanic eruption (pyroclastic gases, lahar flows etc.). City evacuated and population not allowed to return for some time.

Top 10 Cities by GDP@Risk ($US Bn)

1	MEX	**Mexico City**	12
2	JPN	**Tokyo**	9
3	TWN	**Taipei**	7
4	PHL	**Manila**	6
5	IDN	**Jakarta**	4
6	SGP	**Singapore**	4
7	JPN	**Osaka**	4
8	CHL	**Santiago**	4
9	ECU	**Quito**	2
10	COL	**Bogotá**	2

Windstorm



City GDP@Risk (US$ Bn)

- 0.00 - 3.50
- 3.51 - 10.00
- 10.01 - 20.00
- 20.01 - 45.00
- 45.01 - 81.14

Windstorm Threat Zones

Wind speed with 10% probability of exceedance in 10 years

- 1) 118-153 km/hr
- 2) 154-177 km/hr
- 3) 178-209 km/hr
- 4) 210-249km/hr
- 5) 250+ km/hr

Windstorm threats consist of tropical storms and temperate windstorms. By far the most destructive storms are tropical storms, known as *hurricanes*, *cyclones*, and *typhoons* in different parts of the world. The mapping here shows the Pacific Research Center zoning for the likelihood of hurricane force wind speeds from tropical storms, Wind speed assessments for both tropical and temperate wind storms are derived from United Nations Environmental Program and EM-DAT International Disaster Database of the Centre for Research on the Epidemiology of Disasters. Each city is analyzed for the GDP impact and likelihood of experiencing characteristic windstorm scenarios:

HU1 Category 1 Hurricane, windspeed 118-153 km/hr
HU2 Category 3 Hurricane, windspeed 178-209 km/hr
HU3 Category 5 Hurricane, windspeed >250 km/hr

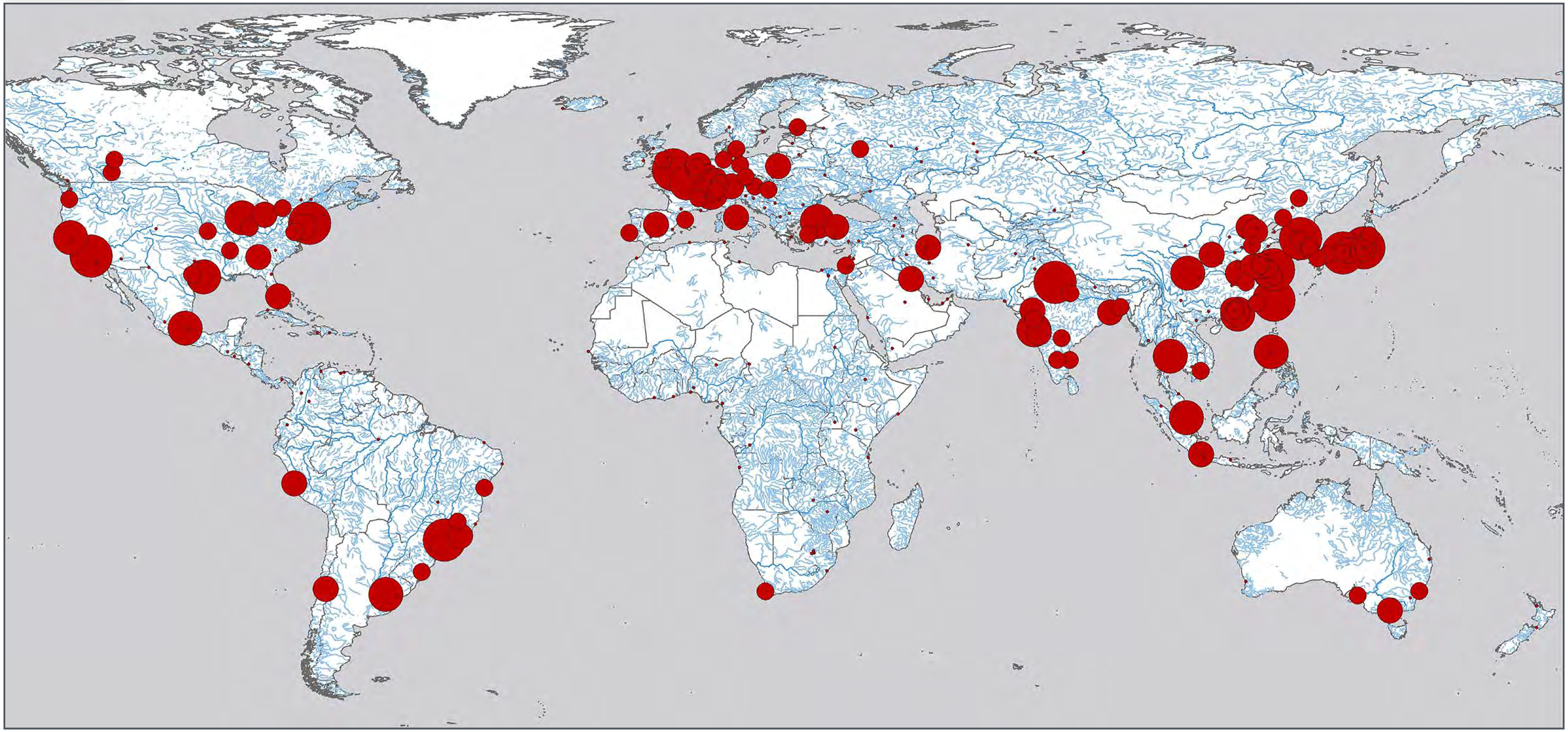
WS1 Wind Storm of Beaufort Scale 10: Storm (wind speeds >89 km/hr)
WS2 Wind Storm of Beaufort Scale 11: Violent Storm (wind speeds >103 km/hr)
WS3 Wind Storm of Beaufort Scale 12: Hurricane (wind speeds >118 km/hr)

Top 10 Cities by GDP@Risk ($US Bn)

1	TWN	**Taipei**	81
2	PHL	**Manila**	60
3	KOR	**Seoul**	44
4	JPN	**Tokyo**	29
5	CHN	**Hangzhou**	28
6	CHN	**Shanghai**	26
7	CHN	**Dongguan**	26
8	CHN	**Xiamen**	.18
9	CHN	**Ningbo**	18
10	JPN	**Osaka**	19

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies

Flood



City GDP@Risk (US$ Bn)

- 0.00 - 1.00
- 1.00 - 2.50
- 2.50 - 4.00
- 4.00 - 8.50
- 8.50 - 17.65

Flood risk for a city arises from three main causes:
Coastal storm surge: where ocean water overtops coastal flood defences
Riverine flood: where a river bursts its banks
Flash flood: where the urban drainage system is overwhelmed by rainfall
Some cities experience several of these flood types. Detailed flood risk assessment has not been carried out for each city, but each city is categorized using flood hazard analysis by United Nations Environmental Program and the Global Archive Map of Extreme Flood Events of Dartmouth Flood Observatory. Cities are categorized by their locations on storm surge-prone coastlines, historical riverine flood events, and past incidences of extensive flash floods. This map shows cities on a hydrology mapping of major river systems. Cities are assigned the likelihood of experiencing characteristic flood scenarios and the GDP losses that would result.

FL1 10% of city affected by flooding, reaching 1m depth in parts, low velocity water, months recovery period

FL2 25% of city area affected by flood waters that reach over 3m depth (more than one storey) in parts; Moderate velocity flowing water moderately contaminated.

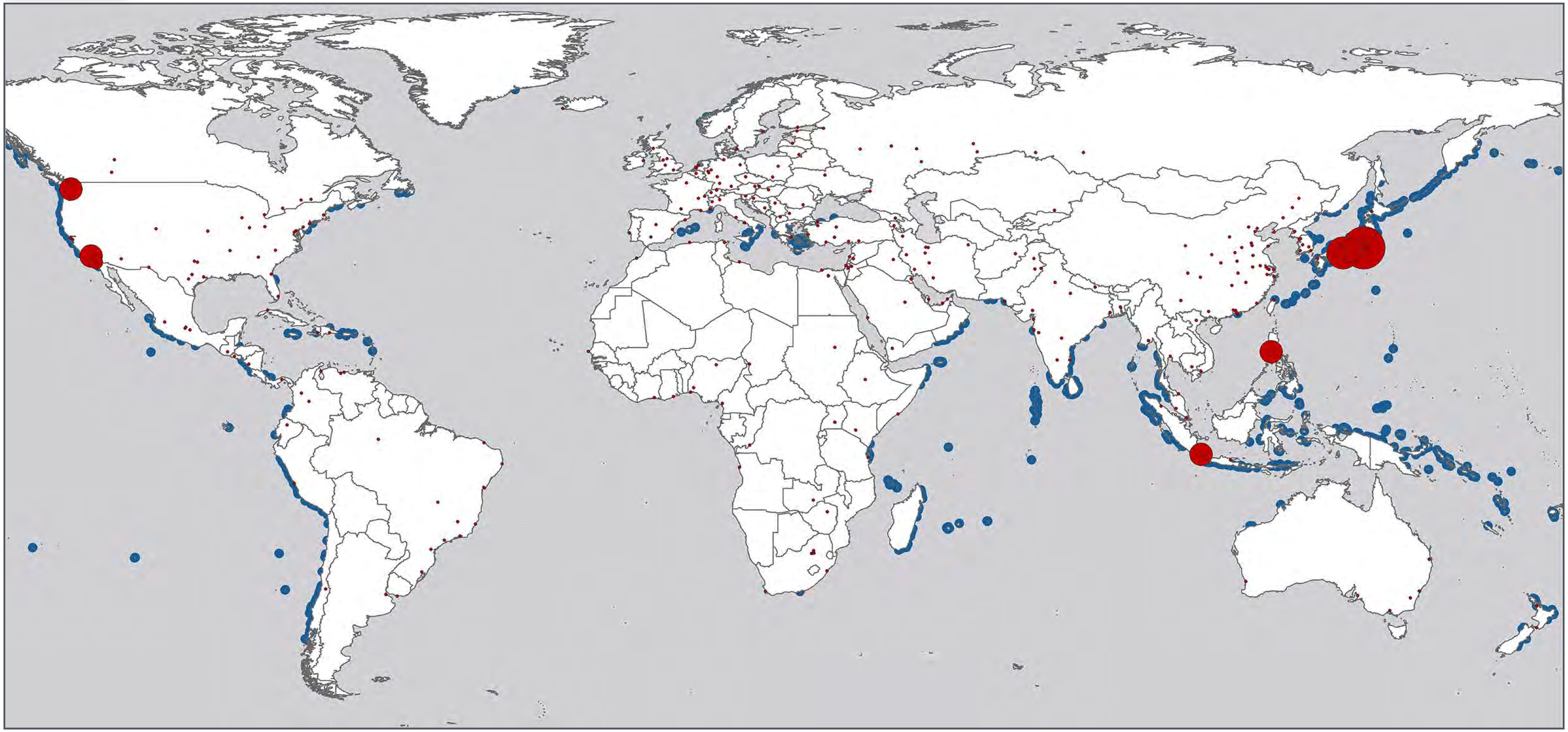
FL3 Over 50% of city land area affected by flooding, reaching more than two storeys in parts, high velocity destructive water flows and highly polluted waters

Top 10 Cities by GDP@Risk ($US Bn)

1	JPN	**Tokyo**	17
2	JPN	**Osaka**	13
3	USA	**Los Angeles**	13
4	USA	**New York**	13
5	BRA	**São Paulo**	11
6	IND	**Delhi**	11
7	TWN	**Taipei**	10
8	CHN	**Shanghai**	9
9	KOR	**Seoul**	9
10	GBR	**London**	9

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies

Tsunami



City GDP@Risk (US$ Bn)

- 0.00 - 0.10
- 0.11 - .25
- 0.25 - 0.90
- 0.90 - 1.50
- 1.50 - 3.75

Tsunami Threat

Tsunami events - Since 1900 over 1m height

Coastal cities have a threat of tsunami risk when a major earthquake, submarine landslide, or oceanic meteorite triggers sea waves that wash ashore. The most severe tsunami threat comes from large magnitude earthquakes that occur a short distance off-shore and that trigger large run-up waves that may over-top city flood defenses. Historical records and tsunami hazard assessments such as those from the US National Oceanic and Atmospheric Administration indicate the most tsunami-prone coastlines, such as those mapped here. Tsunami threat for each city is analyzed by GDP impact and likelihood of experiencing characteristic scenarios

TS1 Tsunami with 3m run-up

TS2 Tsunami with 6 m run-up

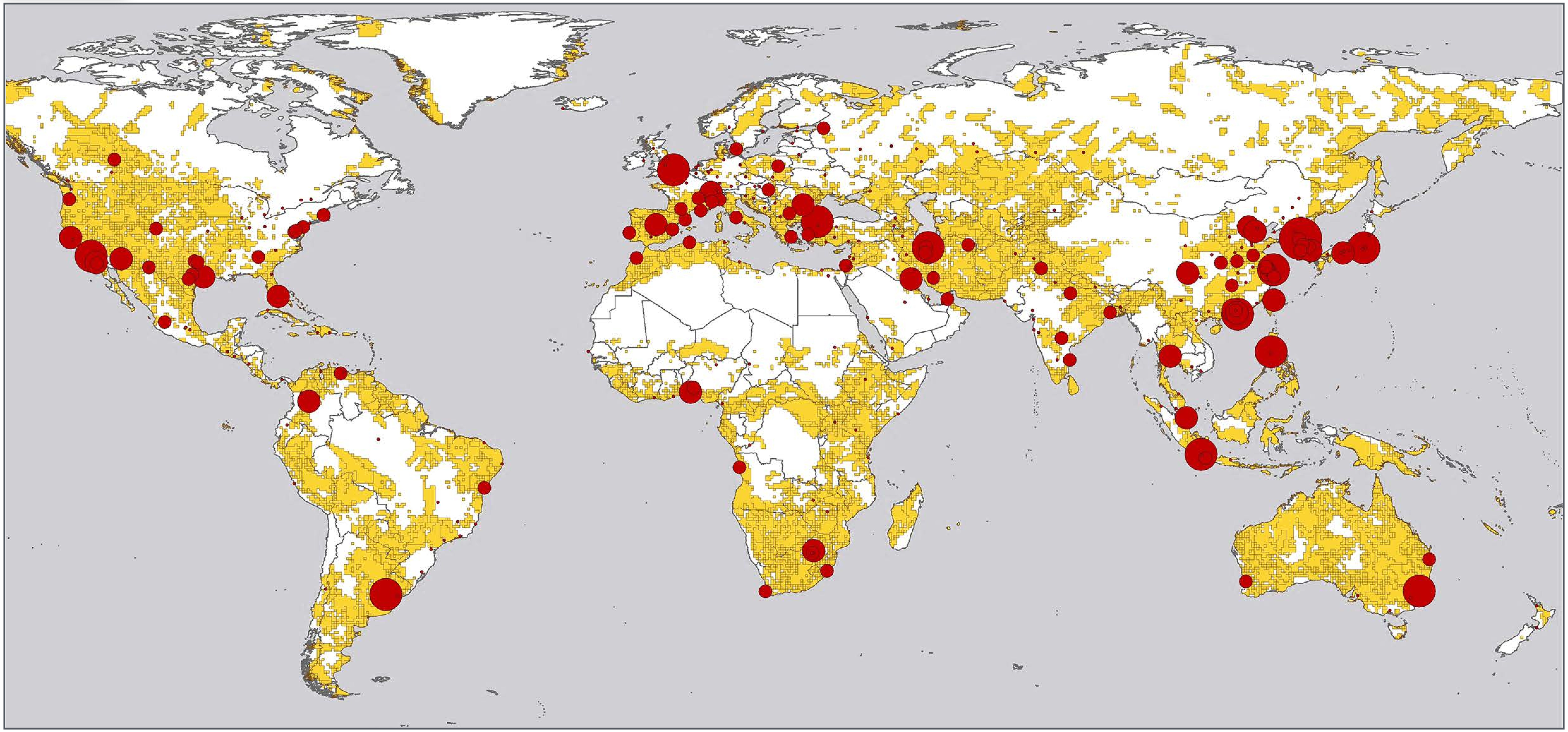
TS3 Tsunami with 12 m run-up

Top 10 Cities by GDP@Risk ($US Bn)

1	JPN	**Tokyo**	3
2	JPN	**Osaka**	1
3	IDN	**Jakarta**	.8
4	JPN	**Nagoya**	.6
5	USA	**Los Angeles**	.5
6	PHL	**Manila**	.5
7	USA	**Seattle**	.4
8	JPN	**Yokohama-shi**	.2
9	JPN	**Kobe-shi**	.1
10	JPN	**Sendai**	.1

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies

Drought



City GDP@Risk (US$ Bn)

- 0.00 - 0.20
- 0.21 - 0.50
- 0.51 - 1.50
- 1.51 - 4.00
- 4.00 - 6.00

Drought Threat

Drought Events from 1980 - 2001

Drought can pose a serious threat in many economic sectors, and extended droughts cause significant social disruption. Droughts occur from rainfall deficits. Worldwide studies of drought risk by World Bank and historical drought events catalogued by United Nations Environmental Program, as depicted here, provide analysis of the frequency and severity of droughts. Characteristic scenarios use the Palmer Drought Index, as interpreted by US National Integrated Drought Information System, to assess the potential impact on each city's GDP, and probability of occurrence:

DR1 D2 'Severe Drought': Localized drought causes water consumption restrictions for that city for 6 months, resulting in water rationing for businesses and residential. Water prioritized for industry, agriculture and emergency provision

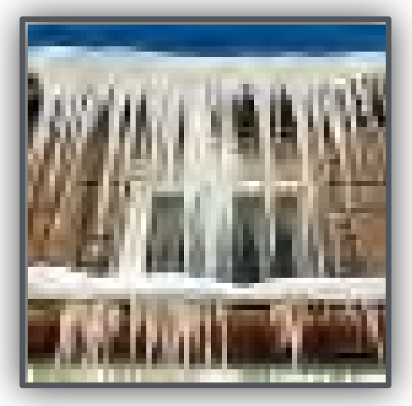
DR2 D3 'Extreme Drought' Three successive seasons of record levels of below average rainfall results in major water shortages for several years

DR3 D4 'Exceptional Drought', sustained for multiple years. Major change in precipitation patterns causes extended drought, which results in severe water consumption restrictions for several years

Top 10 Cities by GDP@Risk ($US Bn)

1	KOR	**Seoul**	6
2	USA	**Los Angeles**	3
3	IDN	**Jakarta**	3
4	JPN	**Tokyo**	2
5	GBR	**London**	2
6	CHN	**Hong Kong**	2
7	ARG	**Buenos Aires**	2
8	TUR	**Istanbul**	1
9	IRN	**Tehran**	1
10	PHL	**Manila**	1

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies



Freeze

City GDP@Risk (US$ Bn)

- 0.00 - 0.46
- 0.46 - 0.93
- 0.93 - 1.40
- 1.40 - 1.87
- 1.87 - 2.34

Extreme temperature events are most disruptive in climatic regions where they occur only rarely and cities are not well prepared, Extreme freeze events in temperate climatic regions disrupt transport, close airports and ports, and damage infrastructure. Temperature records and historical weather accounts, including those compiled by World Health Organization, EM-DAT, and US Centres for Disease Control, provide analysis of freeze threat. Cities are shown here on Köppen–Geiger climate zones. Duration and severity provide degree-day severity metrics for freeze events. Cities are analyzed by the likelihood of experiencing characteristic scenarios and their vulnerability to them:

FR1 Freeze of up to 5 deg below 0 deg Celcius for 3 weeks (-20-100 Degree-days) with some snow and ice, moderate winds

FR2 Freeze of up to 10 deg below 0 deg Celcius for 8 weeks, combined with deep snow and high winds

FR3 Freeze of up to 20 degrees below 0 deg Celcius for 12 weeks, combined with heavy snow and severe ice loads periodically

Top 10 Cities by GDP@Risk ($US Bn)

1	USA	**New York**	2
2	RUS	**Moscow**	1
3	KOR	**Seoul**	1
4	JPN	**Tokyo**	1
5	USA	**Chicago**	1
6	CHN	**Beijing**	.8
7	USA	**Washington DC**	.7
8	FRA	**Paris**	.6
9	CAN	**Toronto**	.5
10	GBR	**London**	.5

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies

Heat Wave

City GDP@Risk (US$ Bn)

- 0.00 - 0.23
- 0.23 - 0.47
- 0.47 - 0.71
- 0.71 - 0.95
- 0.95 - 1.19

Extreme temperature events are most disruptive in climatic regions where they occur only rarely and cities are not well prepared. Heat waves are less destructive than freeze events but cause social harm, public health issues for the older population and those with health problems, and disruption to many economic processes and activities. Energy demand for air conditioning can outstrip supply and cause systemic failure. Temperature records and historical weather accounts, including those compiled by World Health Organization, EM-DAT, and US Centres for Disease Control, provide analysis of heat wave threat. Cities are shown here on Köppen–Geiger climate zones. Duration and temperature above 32° C provide degree-day severity metrics for heat waves. Cities are analyzed by the likelihood of experiencing characteristic scenarios and their vulnerability to them:

HW1 Heatwave of 1-5° above 32° C for 4 weeks (20-100 Degree-days)

HW2 Heatwave of 1-8° above 32° C for 8 weeks (50-500 Degree-days)

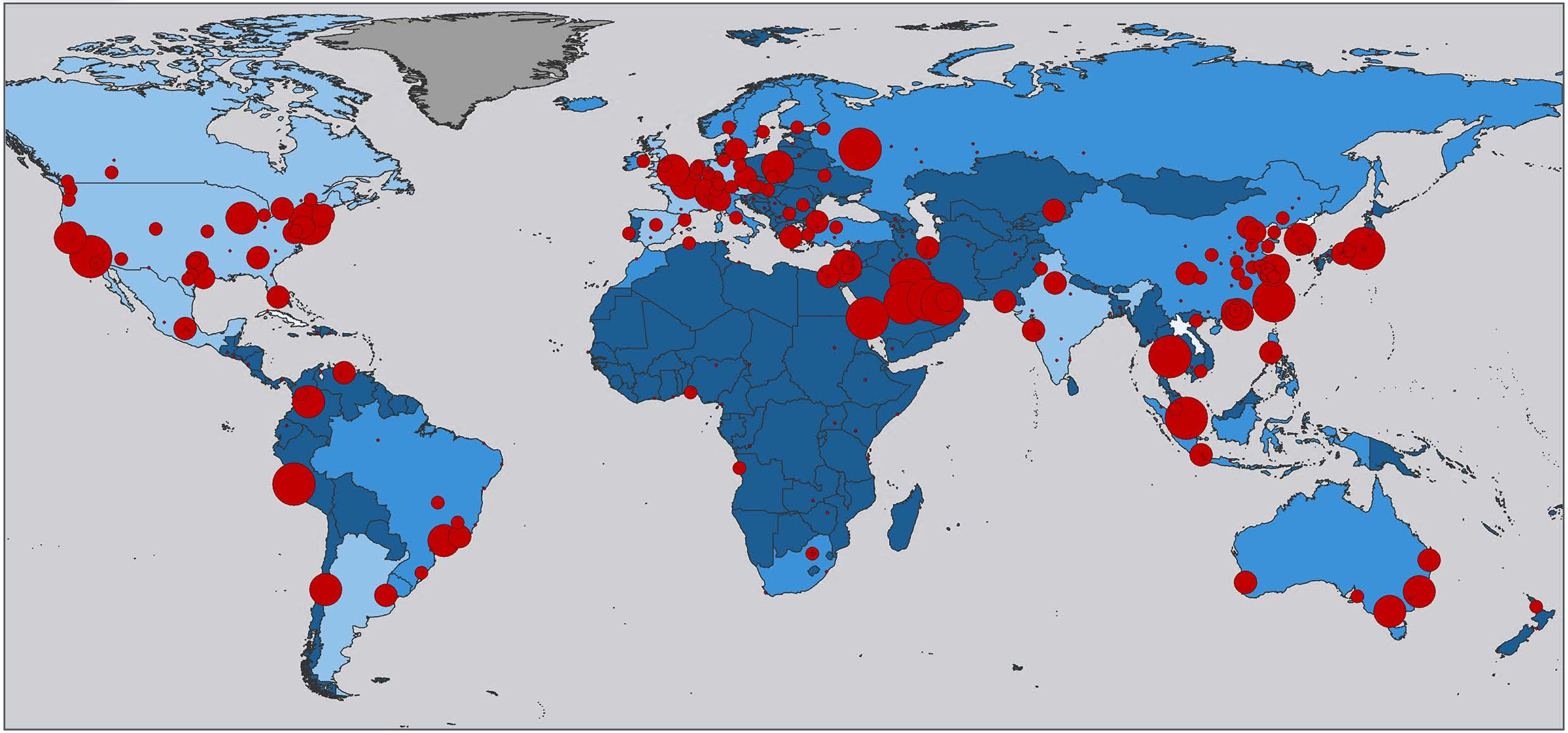
HW3 Heatwave of 1-12° above 32° C for 16 weeks (112-1300 degree-days)

Top 10 Cities by GDP@Risk ($US Bn)

1	USA	**New York**	1
2	FRA	**Paris**	.7
3	JPN	**Tokyo**	.6
4	USA	**Chicago**	.5
5	CHN	**Shanghai**	.5
6	AUS	**Sydney**	.4
7	USA	**Washington DC**	.3
8	USA	**Los Angeles**	.3
9	RUS	**Moscow**	.3
10	GBR	**London**	.2

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for **Risk Studies**

Financial Crisis - Market Crash



City GDP@Risk (US$ Bn)

- 0.00 - 2.00
- 2.01 - 5.00
- 5.01 - 9.00
- 9.01 - 16.00
- 16.00 - 28.58

Financial Crisis Threat

- A: Peripheral to International Financial System but Highly Affected
- B: Local Markets Volatile - Influenced by International Financial System
- C: Integral part of International Financial System - Stable, interlinked markets
- D: Isolated from International Financial System
- No Data

Disruption to the stock markets reduces capital available for commercial activity and erodes investment returns. The threat of a financial crisis as a result of a shock from the endemic internal mechanisms of the market are considered here, such as an asset bubble, banking crisis, and credit crunch. Analysis of the stock market volatility of daily indexed returns for major markets since 1970, and historical financial crises since 1800s, provides metrics for the frequency and severity of market crashes that might be expected in each of the national markets around the globe. Markets are closely interconnected in the global financial system, and the importance of each national market is derived from International Monetary Fund identification of core and peripheral markets. This affects the likelihood of market crashes resulting from contagion effects from other, closely linked markets. The analysis considers the city consequences and likelihoods of characteristic scenarios of financial crises:

MC1 Stockmarket Index drops 10% peak to trough in single year (e.g. Asian Crisis 1997)

MC2 Stockmarket Index drops 50% peak to trough in single year (e.g. SubPrime 2008)

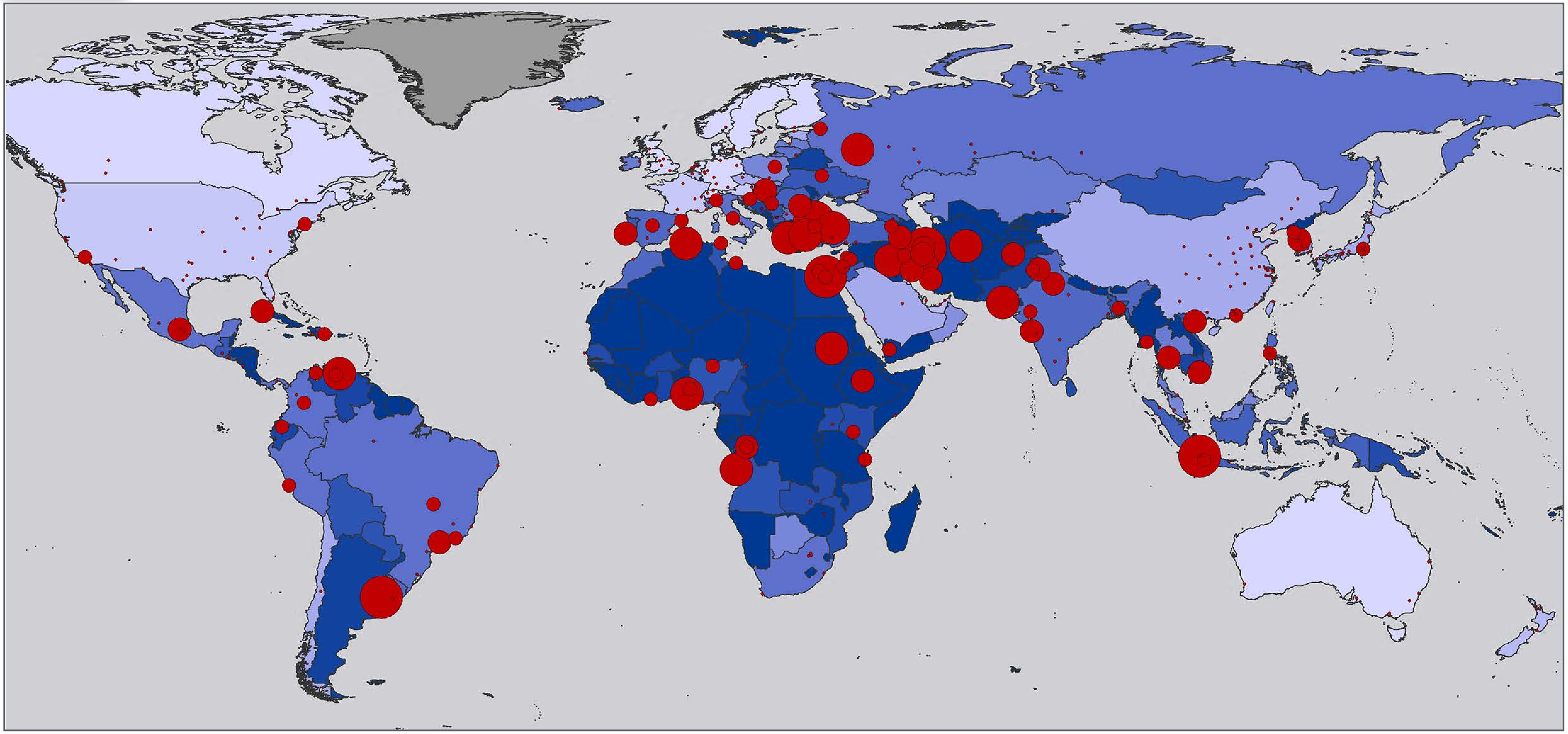
MC3 Stockmarket Index drops 85% in a single quarter (e.g. Wall Street Crash 1929)

Top 10 Cities by GDP@Risk ($US Bn)

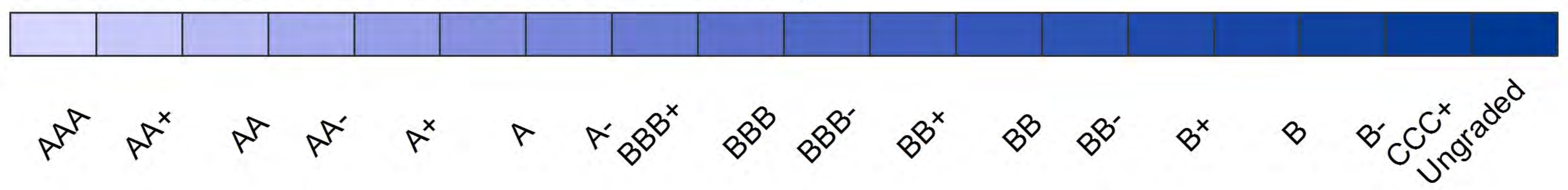
1	TWN	**Taipei**	28
2	USA	**New York**	25
3	JPN	**Tokyo**	22
4	KWT	**Kuwait City**	22
5	SAU	**Riyadh**	21
6	THA	**Bangkok**	20
7	SAU	**Jeddah**	20
8	QAT	**Doha**	19
9	USA	**Los Angeles**	19
10	ARE	**Abu Dhabi**	18

UNIVERSITY OF CAMBRIDGE Judge Business School
Centre for Risk Studies

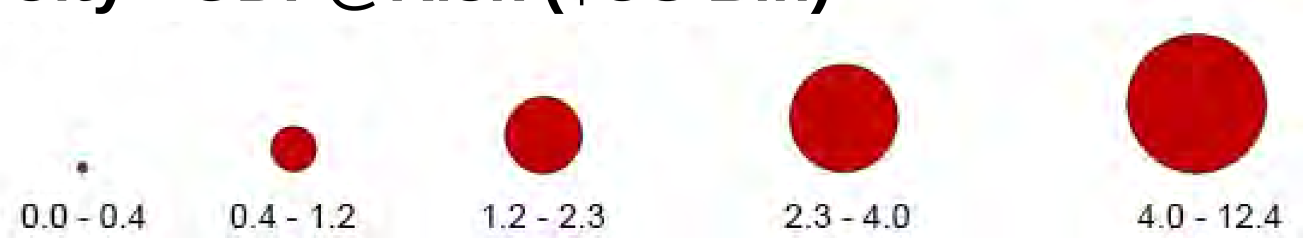
Sovereign Default



Credit Rating: Threat Assessment Grading



City - GDP@Risk ($US Bin)



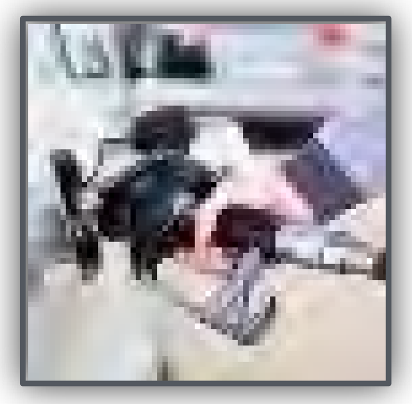
Sovereign default, where a national government is unable to meet its financial obligations or honour its treasury bonds, results in devaluation of the national currency and the loss of foreign direct investment, which can have significant impact on the economic outputs of cities in that country. The published national credit rating of Standard and Poor's for June 2014 (pre-dating the Argentina default of July 2014) is used to assess the probability of national default, combined with an historical perspective of past defaults by countries from the post-1810 catalogue of Reinhart & Rogoff. The national assessment is applied to all cities in that country, to assess GDP loss and probability of the characteristic scenario of default:

SD1 Country defaults and reschedules its debt, devalues its currency substantially; Investors flee. National economy loses substantial foreign direct investment

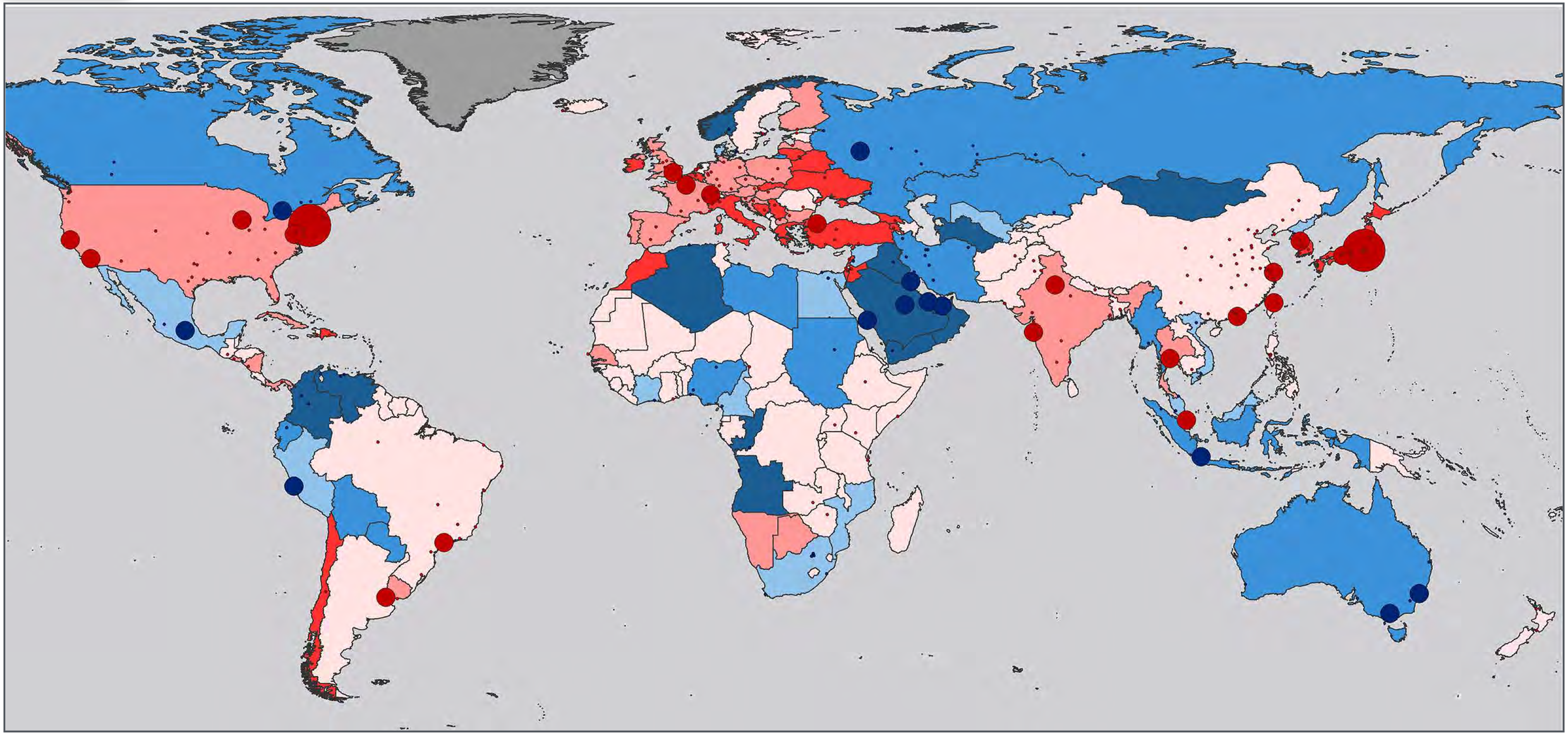
Top 10 Cities by GDP@Risk ($US Bn)

1	ARG	**Buenos Aires**	12
2	TUR	**Istanbul**	10
3	IRN	**Tehran**	9
4	EGY	**Cairo**	8
5	IDN	**Jakarta**	7
6	VEN	**Caracas**	4
7	TUR	**Ankara**	3
8	ALG	**Algiers**	3
9	SDN	**Khartoum**	3
10	IRN	**Meshed**	3

UNIVERSITY OF CAMBRIDGE
Judge Business School
Centre for Risk Studies



Oil Shock



City GDP@Risk (US$ Bn)

- 15.00 - 23
- 5 - 15
- 0.01 - 5
- - 0.01 - -5
- -15 - -5

Financial Crisis Threat

- A - High Vulnerability
- B - Moderate Vulnerability
- C - Some Vulnerability
- X - Exports marginally more oil than it consumes - economy would marginally
- Y - Exports significantly more oil than it consumes - economy would benefit
- Z - Exports a lot more oil than it consumes - Economy would see significant benefit
- No Data

Sudden increases in the price of key commodities are disruptive to economic prosperity, most critically the cost of energy, as represented by oil price. World Bank data on the energy intensity of each country, (i.e. the consumption of fossil fuels to produce a unit of GDP), provides insights into the sensitivity of that country's economy to an oil price shock. This is complicated by the fact that some countries are net exporters of oil, and a price increase would be beneficial to the country's balance of trade. The historical volatility of oil prices and how often past price shocks have occurred is taken as a benchmark for future likelihoods. The characteristic scenarios for oil price shocks gives impacts on the GDP of each city:

OP1 Sudden increase in oil price by 10%

OP2 Sudden increase in oil price by 25% (similar to Oil Price crisis of 1974)

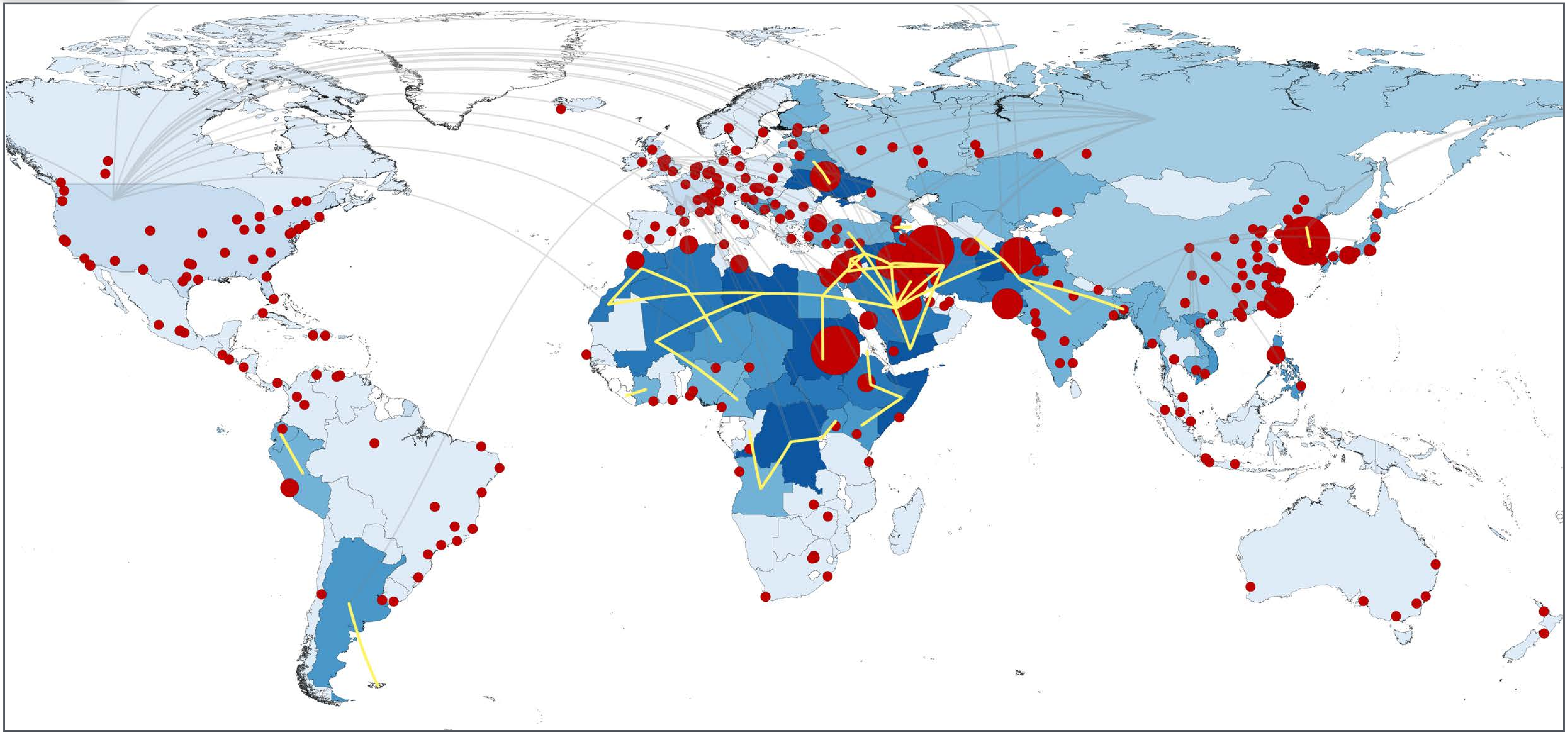
OP3 Sudden increase in oil price by 50%

Top 10 Cities by GDP@Risk ($US Bn)

1	JPN	**Tokyo**	21
2	USA	**New York**	15
3	KOR	**Seoul**	12
4	USA	**Los Angeles**	12
5	FRA	**Paris**	10
6	SGP	**Singapore**	9
7	TUR	**Istanbul**	9
8	GBR	**London**	8
9	JPN	**Osaka**	8
10	TWN	**Taipei**	7

University of Cambridge Judge Business School | Centre for Risk Studies

Interstate War



City GDP@Risk (US$ Bn)

- 0.00 - 8.23
- 8.23 - 16.4
- 16.4 - 24.6
- 24.6 - 32.9
- 32.9 - 41.1

Interstate War Threat

- A Very High Threat of Interstate Conflict
- B High Threat of Interstate Conflict
- C Moderate Threat of Interstate Conflict
- D Low Threat of Interstate Conflict
- E Major Power with Some Threat of Conflict
- F Major Power with Very Low Threat of Conflict
- G Conflict is Possible but No Scenarios Identified

Lines of Conflict

- Conflict with world superpower state
- Conflict among other states

Wars have had major impacts on economic growth throughout history. Wars are less common since 1945 – 'the Long Peace' – than in previous eras, but still pose major threats. Using analysis from Cytora Ltd. countries are graded by military power and over 100 candidate scenarios for future interstate wars are shown using an index of hostility between nations, counting acts of enmity, political friction, and history of their belligerence. Wars are likely to occur between minor military powers, major to minor, and between major powers (yellow lines). Superpowers may conduct military operations against other nations (grey lines). No conflicts occur between superpowers. Characteristic scenarios are assessed for protagonist cities:

IW1 City mobilized for war, but not attacked; mobilization switches civilian commerce to military production; population gripped by fear, consumer demand drops, parts of population flees. Investor confidence is affected; Conflict lasts a year.

IW2 City suffers sporadic attack from occasional missiles or aerial bombardment, possible damage to city infrastructure from military cyber attack; City is mobilized for war; significant emigration of population from city. Investors withdraw.

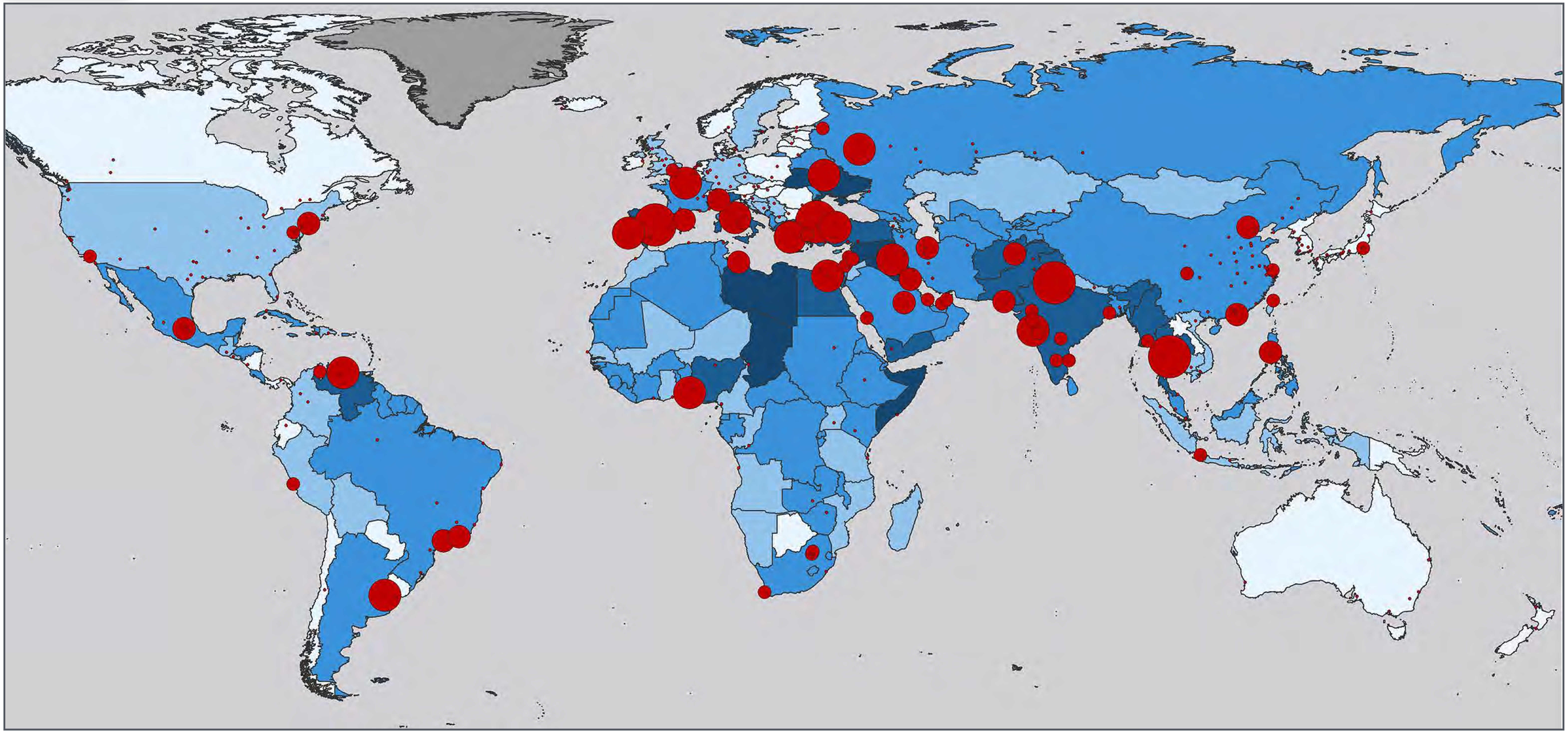
IW3 City is the target of strategic bombing by enemy forces, destroying industrial and commercial output and military facilities in the city; Major emigration by population. Possible rebuilding afterwards by major injection of capital. Conflict lasts 3 years.

Top 10 Cities by GDP@Risk ($US Bn)

1	IRN	**Tehran**	41
2	SDN	**Khartoum**	35
3	KOR	**Seoul**	32
4	IRQ	**Baghdad**	29
5	ISR	**Tel Aviv**	22
6	UKR	**Kiev**	21
7	TWN	**Taipei**	20
8	SAU	**Riyadh**	18
9	PAK	**Karachi**	18
10	KWT	**Kuwait City**	17

UNIVERSITY OF CAMBRIDGE Judge Business School
Centre for Risk Studies

Social Unrest



City GDP@Risk (US$ Bn)

- 0.00 - 0.10
- 0.11 - 0.20
- 0.21 - 0.60
- 0.61 - 1.40
- 1.40 - 3.55

Social Unrest Threat

- A - Very High Threat of Social Unrest
- B - High Threat of Social Unrest
- C - Moderate Threat of Social Unrest
- D - Moderately Low Threat of Social Unrest
- E - Low Threat of Social Unrest
- No Data

Political protests, civil disorder, riots, and sectarianism are all forms of social unrest that can disrupt the economy. At its most extreme, social unrest becomes violent, and if organized and armed can turn into separatist violence and civil war. Incidents of political protest over the past five years in major cities of the world have been tracked by Cytora Ltd., and combined with indices of social unrest, including socioeconomic factors, demographic pressures, government stability, and social violence. Potential for social unrest to escalate into separatism disputes are catalogued from the Encyclopedia of Modern Separatist Movements. Characteristic scenarios are considered separately for social unrest, shown here, and the more violent forms of separatist instability:

SU1 Social Unrest causes riots and protests in the streets for months; violent confrontations with police;

SP1 Incidents of sectarian fighting between armed gangs and private militias in the streets of the city for multiple years

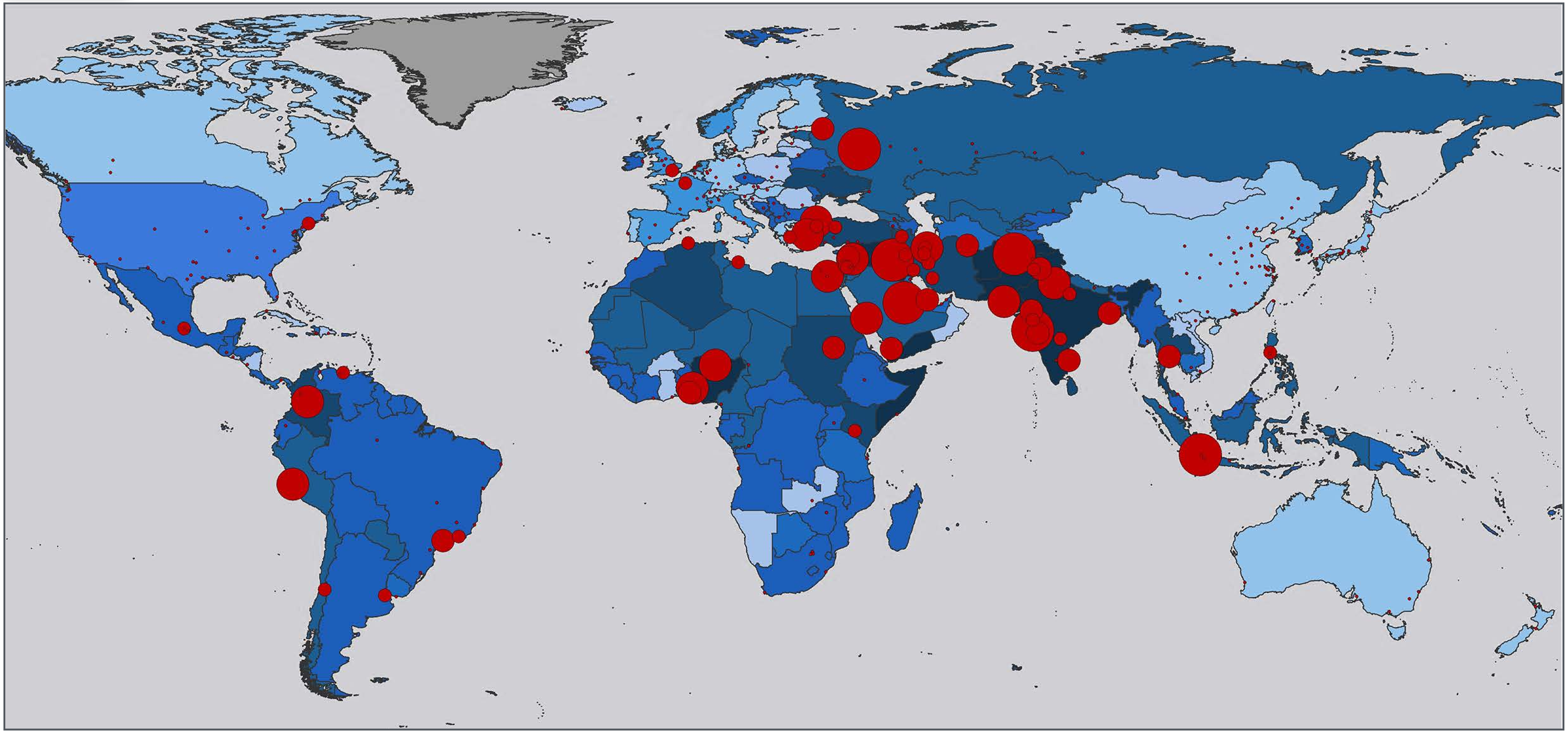
SP2 Civil war involves months of street fighting between well-organized and well-equipped armies, using heavy weaponry in sectarian divide in country.

Top 10 Cities by GDP@Risk ($US Bn)

1	TUR	**Istanbul**	3
2	IND	**Delhi**	2
3	THA	**Bangkok**	2
4	ESP	**Madrid**	1
5	VEN	**Caracas**	1
6	IND	**Mumbai (Bombay)**	1
7	EGY	**Cairo**	1
8	TUR	**Ankara**	1
9	ITA	**Rome**	1
10	RUS	**Moscow**	1

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies

Terrorism



City GDP@Risk (US$ Bn)

- 0.00 - 0.25
- 0.26 - 0.80
- 0.81 - 1.50
- 1.51 - 2.60
- 2.61 - 7.94

Terrorism Threat

- A: Very High Terrorism Activity
- B: High Terrorism Activity
- C: Campaigns of Large Scale Terrorist Attacks Possible
- D: Potential Campaigns of Small Scale Terrorist Attacks
- E: Some Possibility of Sustained Campaigns of Small Scale Terrorist Attacks
- F: Highest Value Target for Terrorists, Very Highly Defended Security
- G: High Value Target for Terrorists, Highly Defended by Security
- H: Strong Counter-Terrorism Interdicts Most Terrorist Plots
- I: Low Terrorism Activity

Terrorist attacks have a long history of targeting cities and economies. However, counter-terrorism actions by security services limit the risk by interdicting attempted attacks. The threat from terrorism is the likelihood of terrorists evading security interdiction. Terrorism activity is tracked by the Global Terrorism Index of US Institute for Economics and Peace, supplemented by a specific analysis of city terrorism risk for this study by Dr. Gordon Woo, architect of the RMS Terrorism Risk Model, and an analysis of recent patterns of terrorism activity in the Maghreb and sub-Saharan Africa by Cytora Ltd. Characteristic scenarios of terrorism on cities were analyzed:

TR1 Terror campaign with small arms and limited resources e.g. shootings, poisonings, food chain sabotage etc., with repeated attacks over a period of many months that causes fear and distrust in urban population.

TR2 Well resourced and organized terrorist attacks on high profile targets e.g. major truck bombings, airplanes into buildings or other surprise destructive events, causes horrific loss of life and major destruction to property in and around city centre

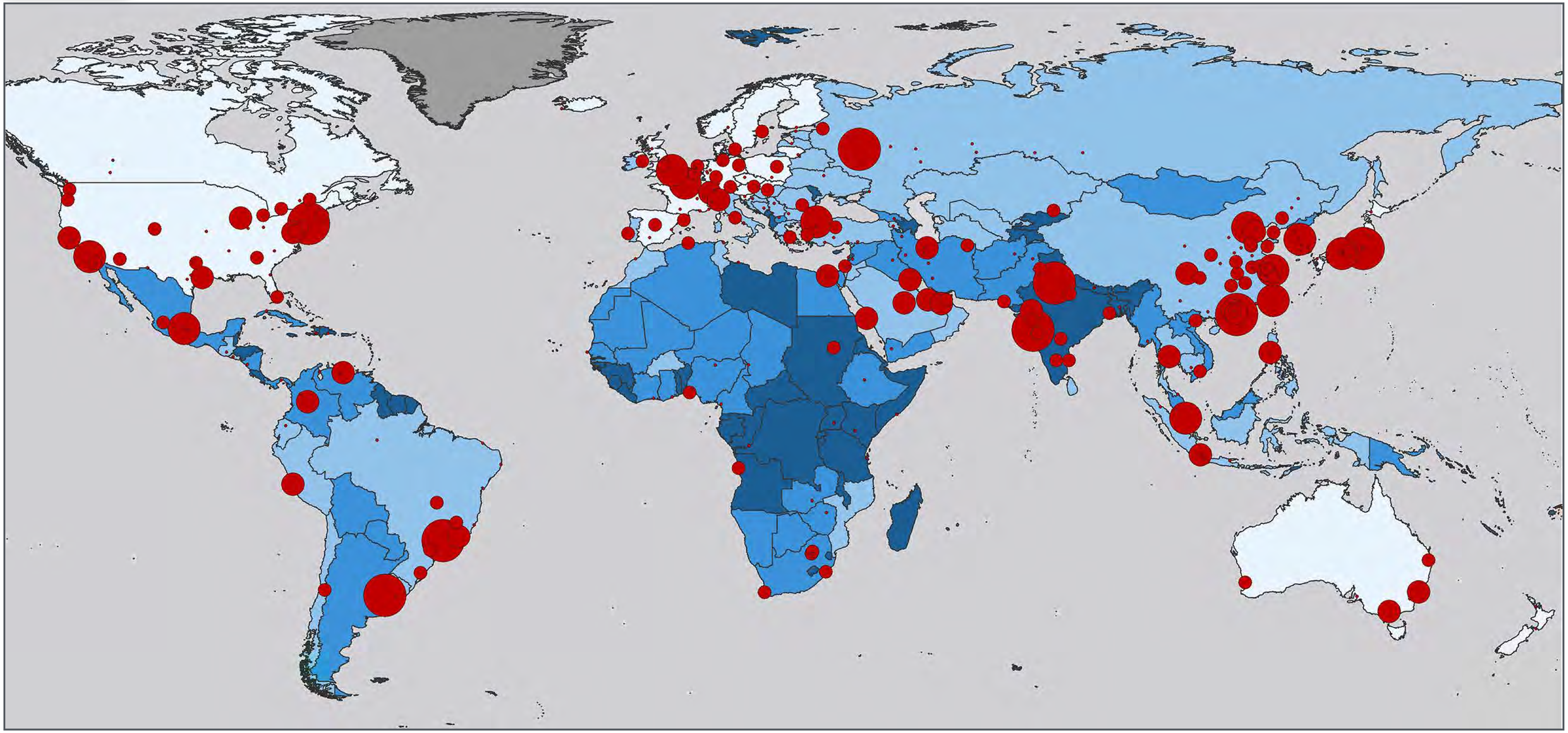
TR3 WMD Terrorist Attack - City is attacked by sophisticated terrorist operation using weapons of mass destruction; (e.g. anthrax, air-dispersed bio-weapons, chemical or radioactive contaminant, or small yield nuclear detonation) kills large numbers of people and contaminates many buildings in Central Business District

Top 10 Cities by GDP@Risk ($US Bn)

1	IND	**Mumbai (Bombay)**	7
2	AFG	**Kabul**	6
3	RUS	**Moscow**	6
4	IRQ	**Baghdad**	5
5	IDN	**Jakarta**	4
6	SAU	**Riyadh**	4
7	IRN	**Tehran**	2
8	PER	**Lima**	2
9	COL	**Bogota**	2
10	SAU	**Jeddah**	2

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies

Electrical Power Outage



City GDP@Risk (US$ Bn)

- 0.00 - 0.20
- 0.21 - 0.50
- 0.51 - 0.85
- 0.86 - 1.30
- 1.30 - 2.27

Electrical Power Outage Threat

- A - Very High Threat of Outages (>50 a year)
- B - High Threat of Outages (10-50 a year)
- C - Moderate Threat of Outages (1-10 a year)
- D - Low Threat of Outages (<1 a year)

An extended electrical power outage can cripple economic activity. Power outages result from a wide variety of causes, including other types of threats in this analysis, but the main causes are non-external: accidental damage, power generation shortfalls, operator errors, and component failures. Power disruption statistics for countries from Nation Master Electrical Outage Reports show the fragility of the power grid to shocks and the potential for lengthy and sustained power cuts. Analysis of past power outages in cities indicates the impact of the duration of power loss for the city's population and economic output. The characteristic scenarios are expressed as numbers of 'City-Days' of power loss:

PO1 One City-Day of Power Loss (100% of city loses power for 1 day or 50% of city loses power for 2 days, etc.)

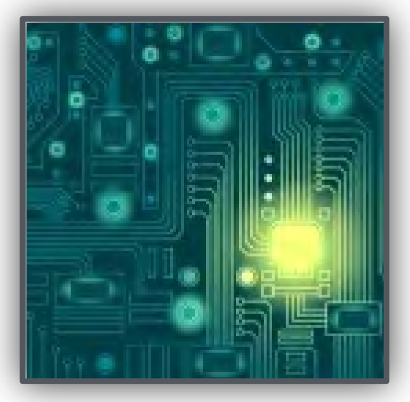
PO2 A 5-City-Day event (100% of city loses power for 5 days, 50% of city loses power for 10 days, etc.)

PO3 A 10 City-Day event (100% of city loses power for 10 days)

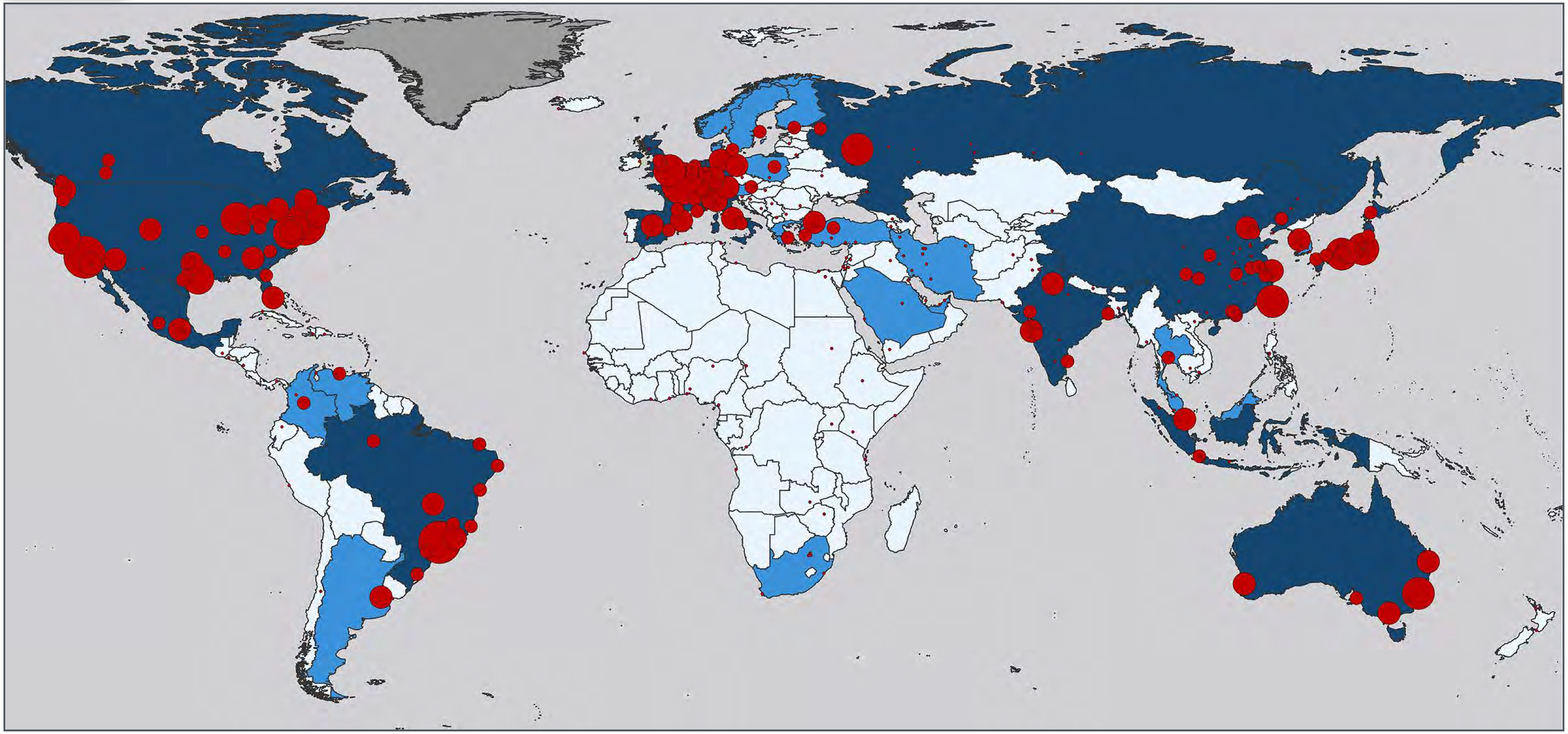
Top 10 Cities by GDP@Risk ($US Bn)

1	JPN	**Tokyo**	2
2	IND	**Mumbai (Bombay)**	1
3	RUS	**Moscow**	1
4	IND	**Delhi**	1
5	USA	**New York**	1
6	ARG	**Buenos Aires**	1
7	BRA	**São Paulo**	1
8	CHN	**Hong Kong**	1
9	USA	**Los Angeles**	1
10	MEX	**Mexico City**	1

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies



Cyber Catastrophe



City GDP@Risk (US$ Bn)

- 0.00 - 0.50
- 0.51 - 1.50
- 1.51 - 4.00
- 4.01 - 8.00
- 8.01 - 14.08

Cyber Catastrophe Threat

- A: High Cyber Threat (High Priority Target for Cyber Attackers)
- B: Moderate Cyber Threat (Medium Priority Target for Cyber Attackers)
- C: Low Cyber Threat (Low Priority Target for Cyber Attackers)

Economic output from modern service sector economies is heavily reliant on information technology, so cyber attacks, major failures of software, IT, and business applications have increasing potential to significantly impact city GDP. Targeting of different countries by cyber hackers is taken from statistics in McAfee International Cyber Risk Report. The vulnerability of each city's economy to failures of information technology is derived from service sector reliance on IT from OECD national economic data. Characteristic scenarios of cyber attacks are assessed by likelihood and potential impact:

CY1 A sporadic set of technology failures, e.g. GPS outages, accidental technical faults, cyber attacks on individual organizations, reduces outputs of companies with high dependence on technology, and consumer confidence is affected.

CY2 Systemic cyber attack, e.g. Sybil logic bomb, causes heavy losses to many commercial companies operating in that city and undermines confidence of general public in IT systems in general.

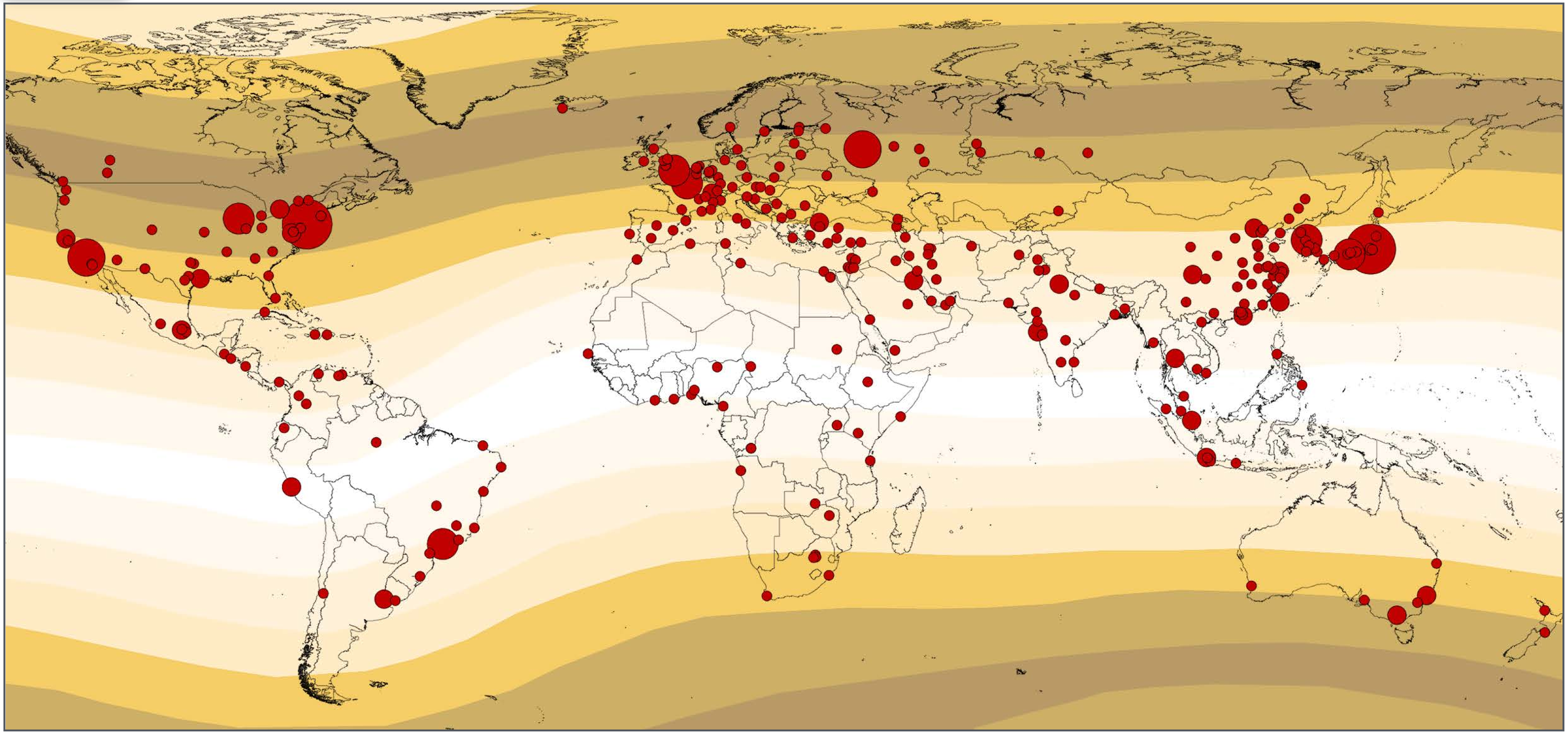
CY3 Cyber attacks on critical infrastructure destroys the power distribution grid and causes power loss in the city for many months

Top 10 Cities by GDP@Risk ($US Bn)

1	USA	**New York**	14
2	USA	**Los Angeles**	10
3	BRA	**São Paulo**	9
4	FRA	**Paris**	8
5	GBR	**London**	7
6	JPN	**Osaka**	7
7	RUS	**Moscow**	6
8	USA	**Chicago**	6
9	JPN	**Tokyo**	6
10	USA	**San Francisco**	5

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies

Solar Storm



City GDP@Risk (US$ Bn)

- 0.00 - 0.48
- 0.48 - 0.96
- 0.96 - 1.45
- 1.45 - 1.93
- 1.93 - 2.42

Solar Storm Threat

- A Very High Threat from Solar Storm Events
- B High Threat from Solar Storm Events
- C Moderate Threat from Solar Storm Events
- D Moderately Low Threat from Solar Storm Events
- E Low Threat from Solar Storm Events
- F Very Low Threat from Solar Storm Events

Solar activity can create geomagnetic and solar radiation storms on earth which can damage electrical circuitry and power transmission systems. These are generated by X-class solar flares, of magnitudes 20 and above, as highlighted in Lloyd's emerging risk report. The observed frequency of solar flares of different magnitudes since 1976 provides extreme value likelihoods for very large solar flares. Their effects on the earth are amplified by the geomagnetic field, as mapped above. Cities located in the strongest geomagnetic latitudes will be worse affected. The study uses the Space Weather Scale for Solar Radiation Storms defined by the US National Oceanic and Atmospheric Administration, to define characteristic scenarios for evaluation of effects on individual cities:

SS1 Radiation storm level S4, equivalent to solar flare of X20.

SS2 Radiation storm level S5 equivalent to solar flare of X40 (Similar to 'Carrington Event')

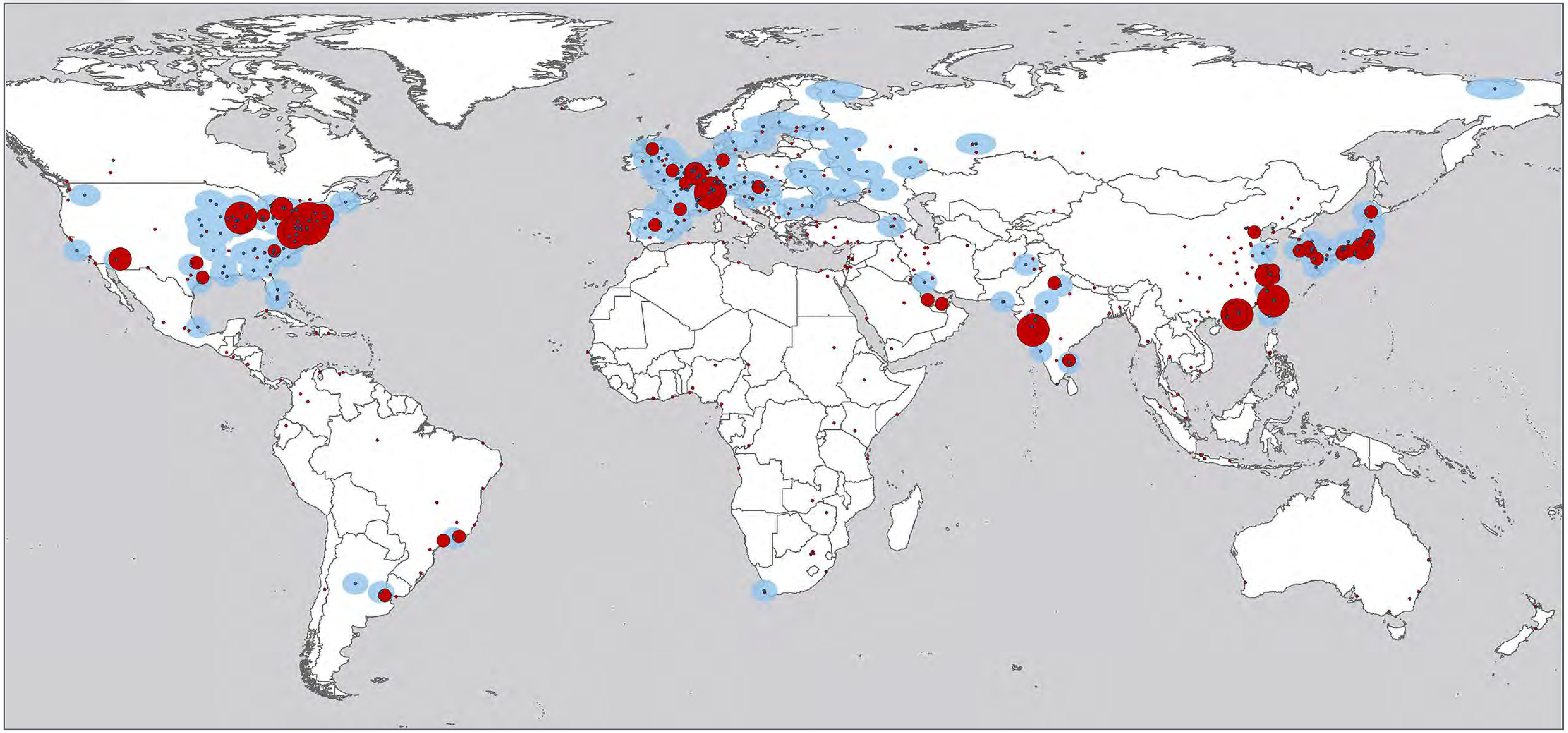
SS3 Radiation storm level S6+ (Beyond 5-point NOAA Scale). Estimated effects of solar flare of X60 - also known as a class Z event.

Top 10 Cities by GDP@Risk ($US Bn)

1	JPN	**Tokyo**	2
2	USA	**New York**	2
3	RUS	**Moscow**	1
4	USA	**Los Angeles**	1
5	FRA	**Paris**	1
6	GBR	**London**	1
7	KOR	**Seoul**	1
8	USA	**Chicago**	1
9	BRA	**São Paulo**	.9
10	JPN	**Osaka**	.9

UNIVERSITY OF CAMBRIDGE
Judge Business School
Centre for Risk Studies

Nuclear Power Accident



City GDP@Risk (US$ Bn)

- 0.00 - 0.04
- 0.05 - 0.14
- 0.14 - 0.40
- 0.40 - 0.80
- 0.80 - 1.42

Nuclear Accident Threat

- Area within 250km of a Nuclear Power Plant
- Nuclear Power Plant Operational (2014 - 2025)

Nuclear power plants are built as close as possible to the locations of greatest demand, balancing safety with economics. The World Nuclear Association Information Library provides locations of operational reactors and those that are scheduled to come online within the next decade. The mapping above shows cities within 250km of operational reactors – the extent of significant fallout from a major core meltdown of grade 7 on the International Nuclear Events Scale. Recorded catalogues of nuclear incidents provides average accidents per year of operation of a reactor, applied to all reactors. Fallout from a major core meltdown provides the characteristic scenarios, assessed in terms of radioactive deposit densities, illustrated by distance away from a historical INES 7 event:

NP1 City receives radioactive fallout of >0.01Bq/km3 (0.3 Curies of C137), similar to within 200km of Chernobyl 1986 or 120km of Fukushima 2011

NP2 City receives radioactive fallout of >0.1Bq/km2 (3 Curies of C137) similar to within 70 km of Chernobyl 1986 or 50km of Fukushima 2011

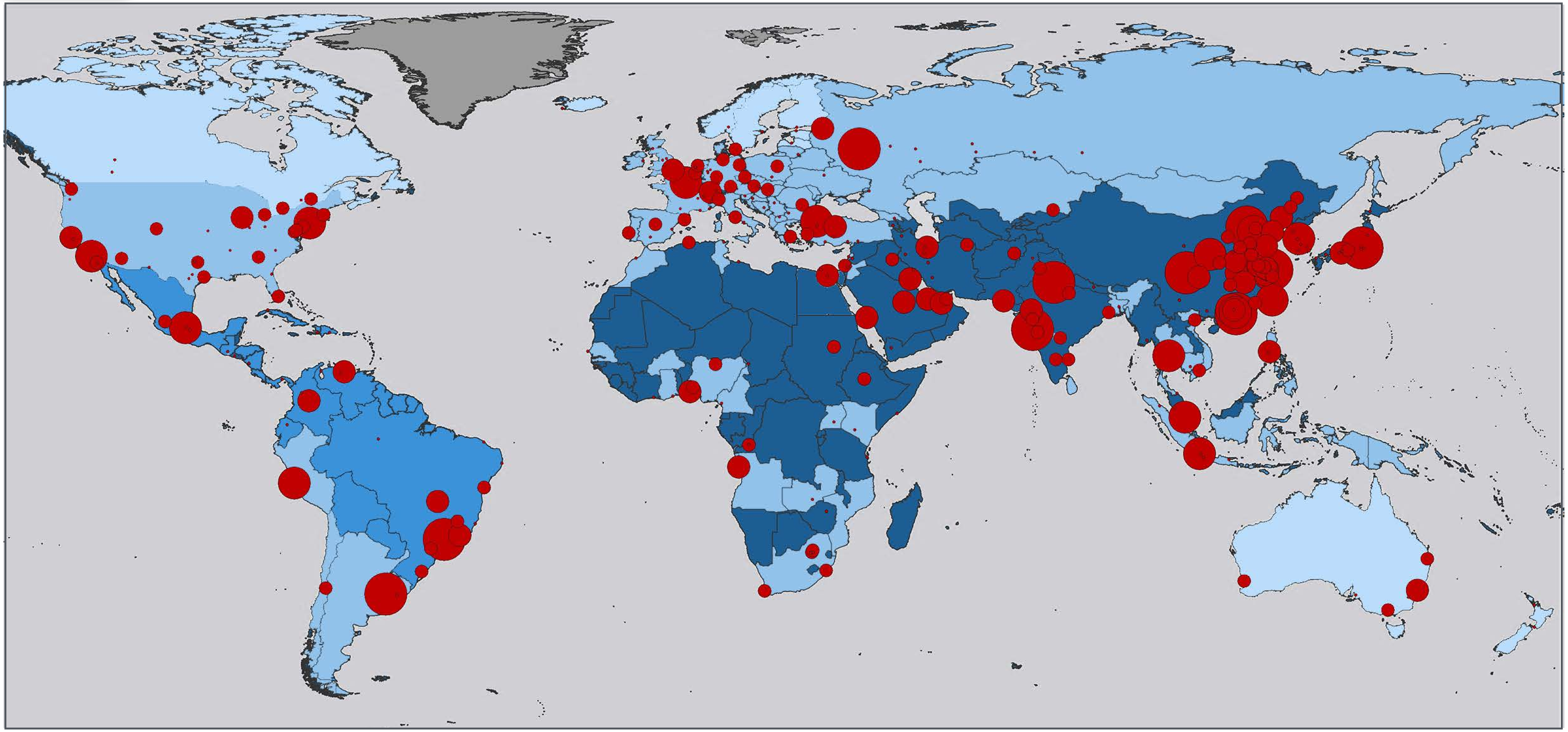
NP3 City receives radioactive fallout of >1Bq/km2 (30 Curies of C137) similar to within 30km of Chernobyl INES 7 event in 1986

Top 10 Cities by GDP@Risk ($US Bn)

1	USA	**New York**	1
2	CHN	**Hong Kong**	.8
3	USA	**Chicago**	.6
4	CHE	**Berne**	.6
5	TWI	**Taipei**	.5
6	IND	**Mumbai (Bombay)**	.5
7	USA	**Washington DC**	.4
8	CAN	**Toronto**	.3
9	CHN	**Shenzhen**	.3
10	USA	**Philadelphia**	.3

University of Cambridge Judge Business School | Centre for Risk Studies

Human Epidemic



City GDP@Risk (US$ Bn)

- 0.00 - 1.00
- 1.01 - 3.00
- 3.01 - 5.00
- 5.01 - 9.00
- 9.01 - 18.96

Human Epidemic Threat

- A: High Threat of Emerging Infectious Diseases
- B: Moderately High Threat of Emerging Infectious Diseases
- C: Possible Threat of Emerging Infectious Diseases
- D: Low Threat of Emerging Infectious Disease

Human epidemics can cause widespread death and illness and result in extensive major disruptions to the economy of cities. Nature continues to evolve new emerging infectious diseases for which medical science has no treatment. A 2007 study on global trends in emerging infectious diseases by UK Institute of Zoology provides the threat grading for different countries shown above. Once an infectious disease is in circulation in the human population, modern air travel ensures that it is rapidly spread around the world and can be expected in all major cities, as a pandemic. Cities vary considerably in their ability to deal with a public health crisis. World Health Organization ranking of each country's healthcare system is used to assess the overall impact of pandemics on cities in each country. Characteristic scenarios range from localized epidemics to global pandemics:

HE1 Localized epidemic of new emergent disease with case fatality rate (CFR) of 10% causes public health emergency and fear in population, leads to loss of tourism trade

HE2 Pandemic influenza virus infects 43% of the population, with CFR of 0.3%

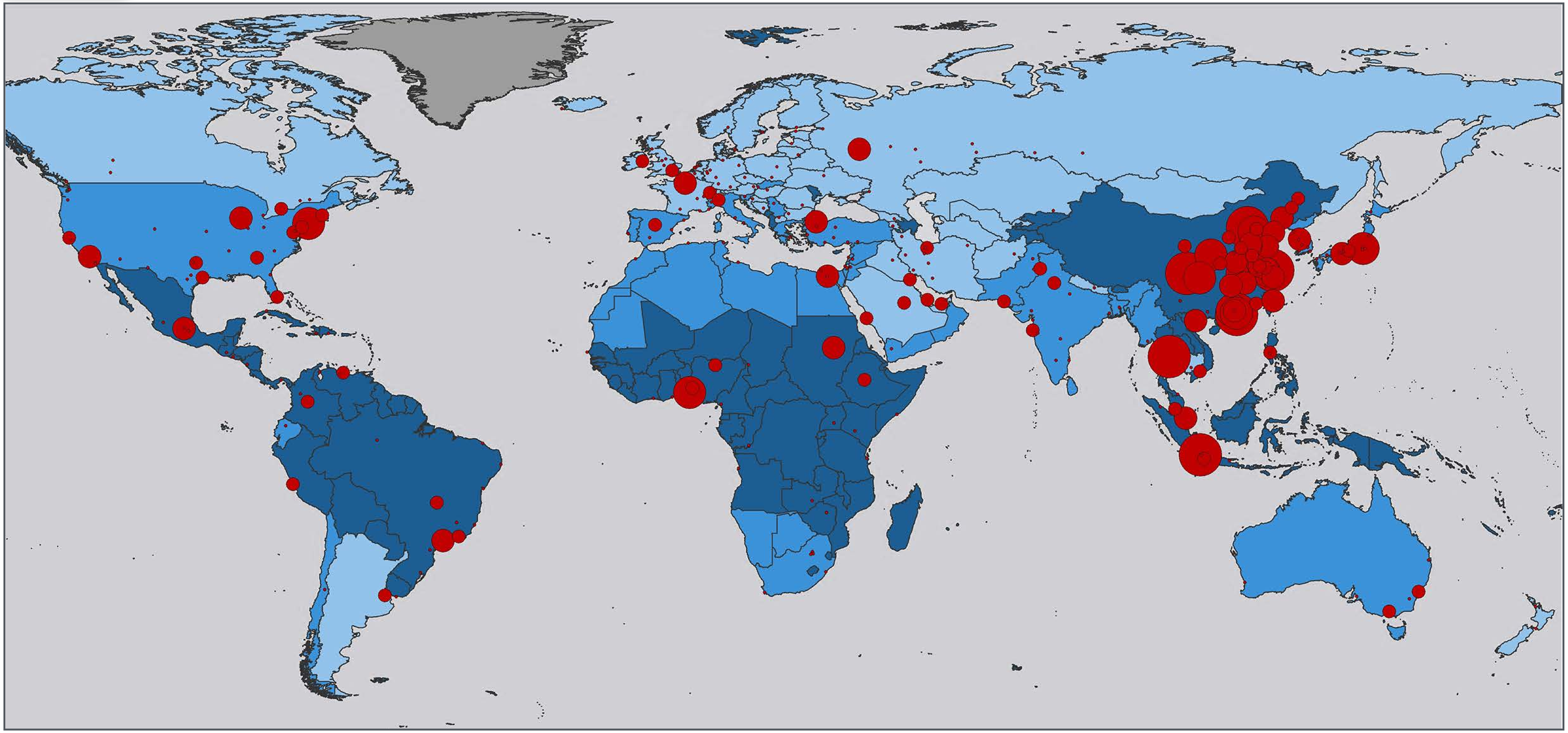
HE3 Pandemic of high fatality disease (3% case fatality rate)

Top 10 Cities by GDP@Risk ($US Bn)

1	CHN	**Hong Kong**	18
2	RUS	**Moscow**	14
3	CHN	**Shanghai**	14
4	BRA	**São Paulo**	12
5	JPN	**Tokyo**	12
6	CHN	**Beijing**	11
7	IND	**Mumbai (Bombay)**	11
8	IND	**Delhi**	10
9	CHN	**Chengtu**	10
10	ARG	**Buenos Aires**	10

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies

Plant Epidemic



City GDP@Risk (US$ Bn)

- 0.00 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 1.70
- 1.71 - 3.83

Human Epidemic Threat

- A - High Threat of Plant Epidemic in Local Crops
- B - Moderate Risk of Plant Epidemic in Local Crops
- C - Low Risk of Plant Epidemic in Local Crops

One of the major causes of food shortages and price increases is crop disease and harvest failures. Distribution Maps of Plant Diseases from Plantwise CAB International show the likelihood of plant diseases occurring in major staple crops, like wheat and rice, summarized in this mapping of the threat of plant epidemics. The impact of staple crop failures is greatest in those cities where agriculture makes up a high proportion of the economy, from OECD national economic data. Widespread epidemics and harvest failures cause hikes in global food prices that affect all cities. Characteristic scenarios of plant epidemics have different likelihoods and effects on each city and are used to assess the GDP@Risk:

PE1 Localized plant epidemic affects prices of staple foods in city markets

PE2 National plant epidemic affects price of staple foods in city markets

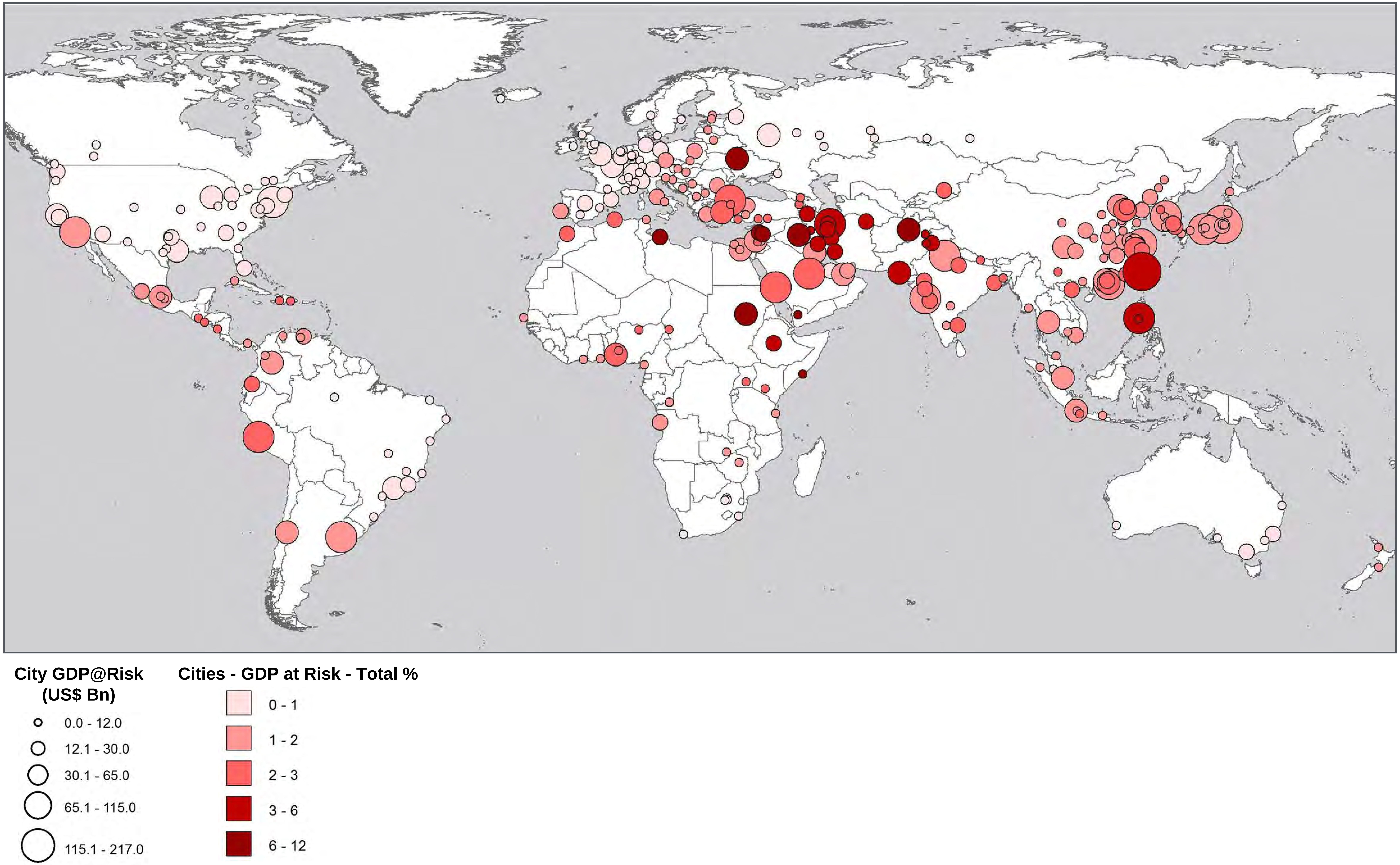
PE3 International Plant Epidemic affects price of stable foods in city markets

Top 10 Cities by GDP@Risk ($US Bn)

1	CHN	**Hong Kong**	3
2	CHN	**Shanghai**	2
3	CHN	**Beijing**	2
4	THA	**Bangkok**	2
5	IDN	**Jakarta**	2
6	CHN	**Chengtu**	2
7	CHN	**Guangzhou**	1
8	CHN	**Shenzhen**	1
9	CHN	**Tianjin**	1
10	JPN	**Tokyo**	1

UNIVERSITY OF CAMBRIDGE Judge Business School | Centre for Risk Studies

Total GDP@Risk from All Threats Combined



UNIVERSITY OF CAMBRIDGE
Judge Business School
Centre for
Risk Studies