Adaptation Framework for Large Infrastructures

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Infrastructure and Climate Change Adaptation

- Infrastructure development is big game for business and policy
- Construction based on past weather data, while climate change is a future phenomenon. The underlying assumptions may drastically change.
- Type 1 and 2 errors
  - Type 1 (alpha error): *false positive* – taking preventive measures but the event does not occur. Sunk cost of insurance, excessive prevention, Over-adaptation??
  - Type 2 (beta error): *false negative* – not taking any preventive measures and the event occurs. Massive destruction, excessive palliative costs??
- Insurance markets could facilitate climate change adaptation
  - Risk management for exposed infrastructure assets
  - Facilitate better adaptation practices for exposed assets
  - Managing extreme weather events (e.g. heating, cooling, rainfall) through insurance products
  - Managing catastrophic events (hurricanes, cyclones etc) through financial instruments

What is at Stake?

Investment in Infrastructure as a percentage of GDP in billion USD at 2004-05 prices

	2006-07		**2011-12**	
	Investment*	% of GDP	Investment*	% of GDP
Public Sector (Centre + State)	36.17	4.23	80.56	6.45
Private Sector	10.26	1.20	36.10	2.89
Total	46.43	5.43	116.66	9.34

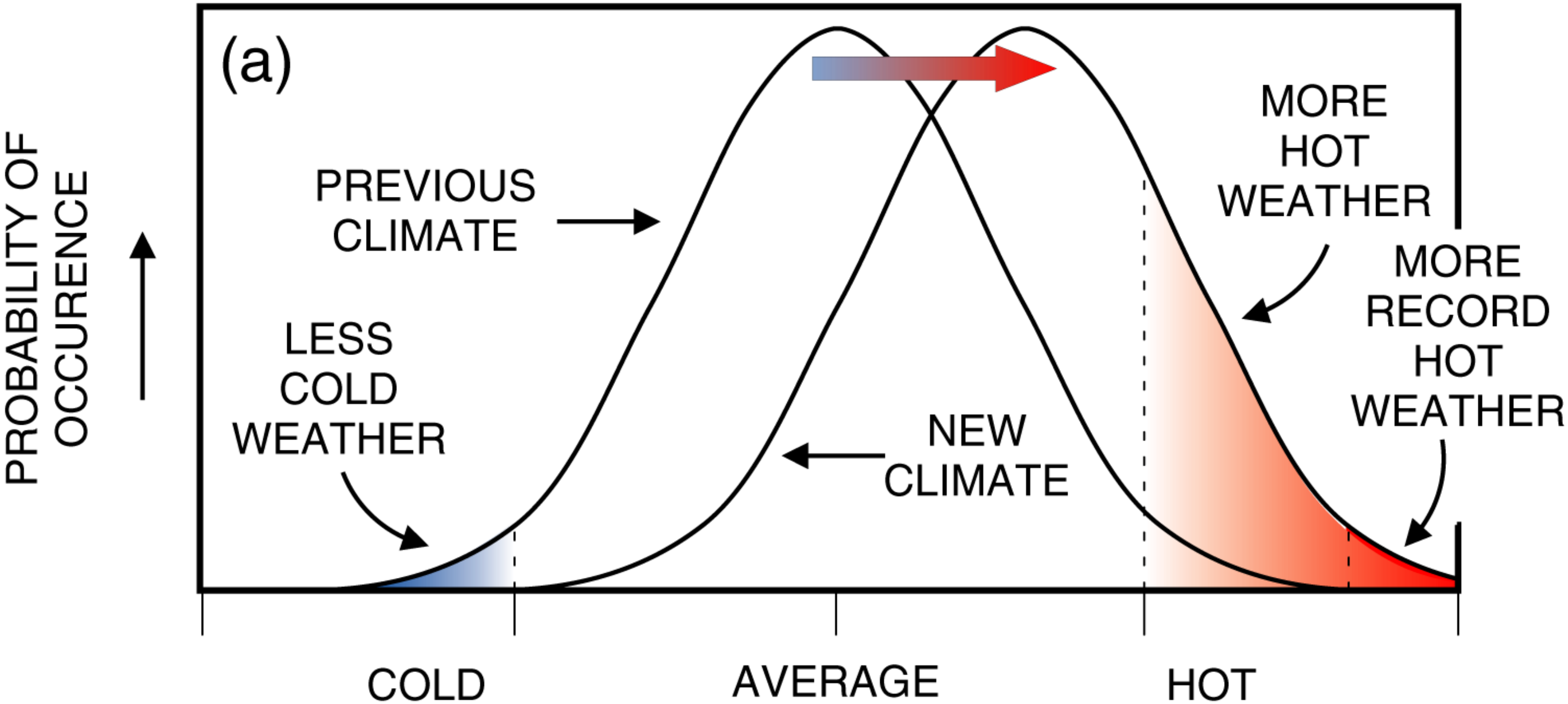
- Growth Targets: 9% GDP growth rate (EFYP)
- Decadal population growth: 1.5 – 2%
- Total EYFP infrastructure investments: $456 billion
  - 12 FYP Target: ***$1.025 trillion*** infrastructure investments
  - Requirements much higher
- Private investments will be attracted only when risk management done

Source: Central Statistical Organization for 2006–07, RBI Statistics for Exchange Rate and GDP at constant prices, and computations by the Planning Commission for 2011–12

Why is CC adaptation a challenge?

- System thresholds
  - Planning for future: Historical weather Vs future CC projections
  - Climate system can react abruptly with limited warning signs before planned system thresholds are crossed (Stocker, 1999)
  - More than the averages, extremes events are a cause of concern
    - Extreme Weather Event: An event that is rare at a particular place and time of year
    - "Rare" is defined as the highest or lowest 10% (IPCC, 2007)
- Unaccounted risks can wash away developmental benefits
  - Limited resources; Every resource unit has opportunity costs
  - Socio-economic already stressed with stressors like population growth, increased urbanization, resource use, and economic growth (MoEF, 2010; Sahoo & Dash, 2009; Straub, 2008; Garg, et al., 2007; Sathaye, et al., 2006)
- 'Climate' and 'weather' are related terms
  - While climate is what one expects or '30-year average weather' and weather is what one gets (WMO, 2011; Allen, 2003)

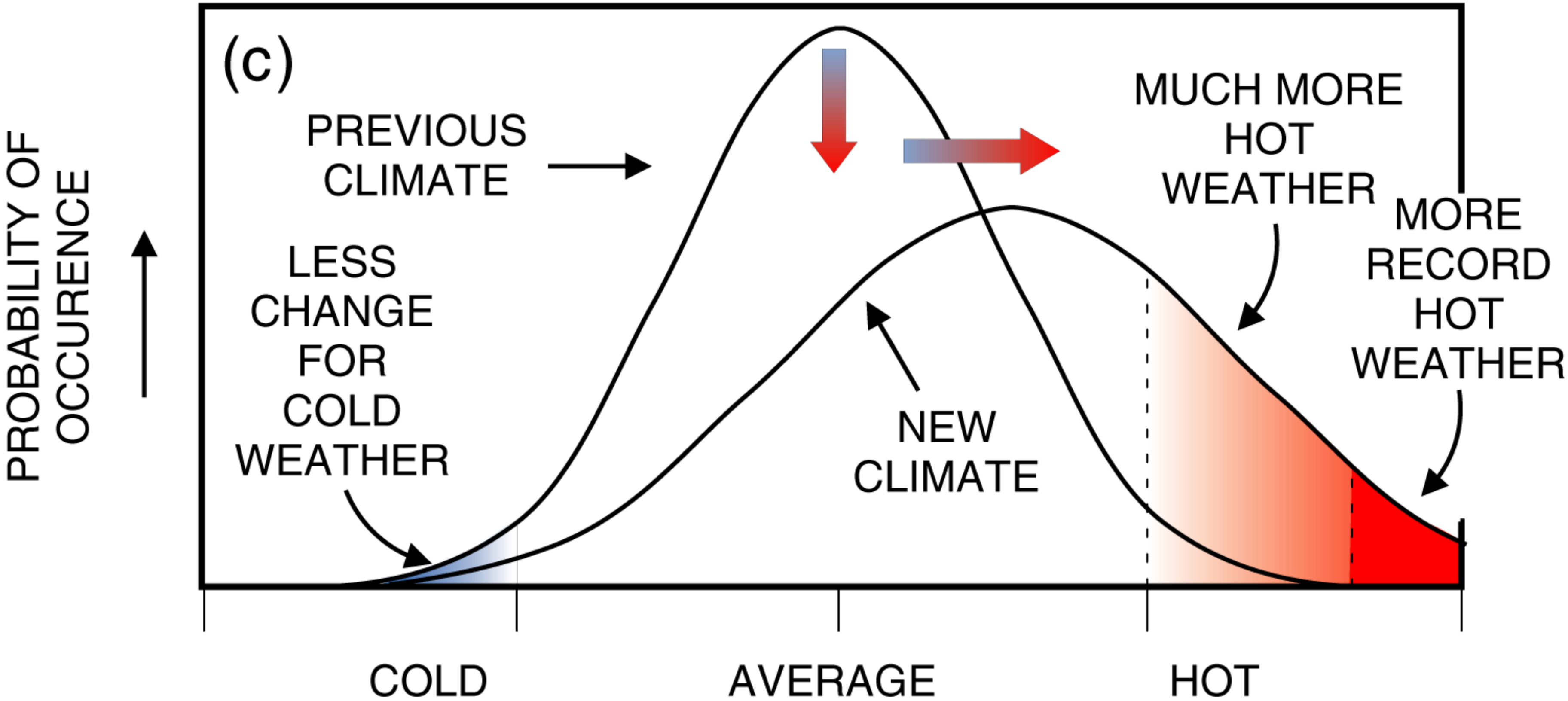
Increase in Mean



Large percentage change in extremes

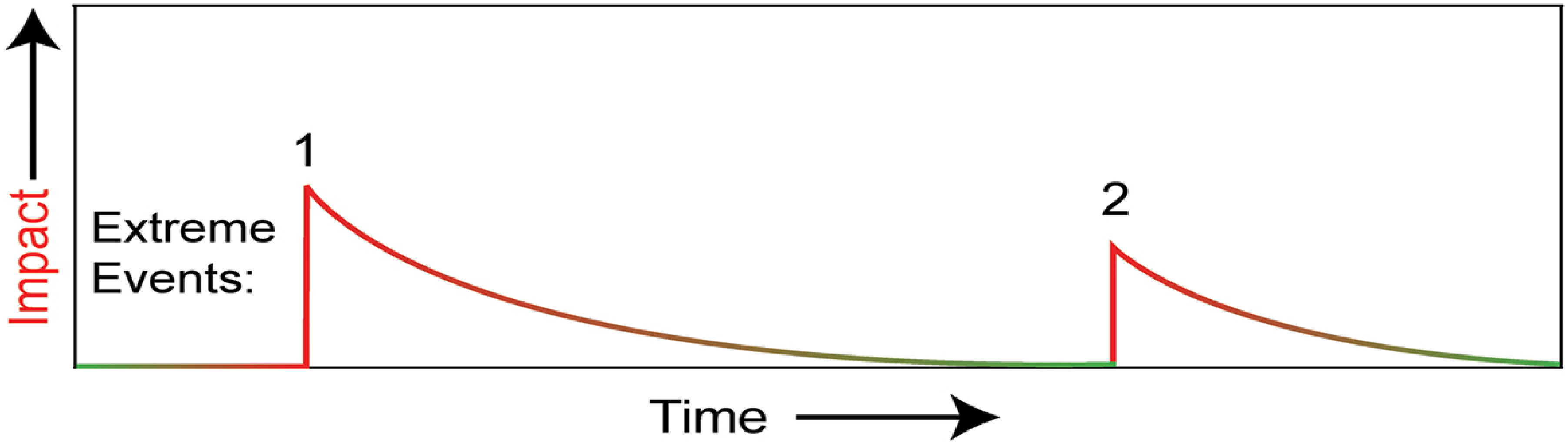
- India <u>temperature</u> rise 0.51°C (1901–2007) (Kothawale et al., 2010)
- <u>Precipitation</u>: Annual Average 848 mm with SD of 83 mm (1871-2009) (INCCA, 2010)
  - 3 Decade average -0.4mm/year (Variable with no trends)

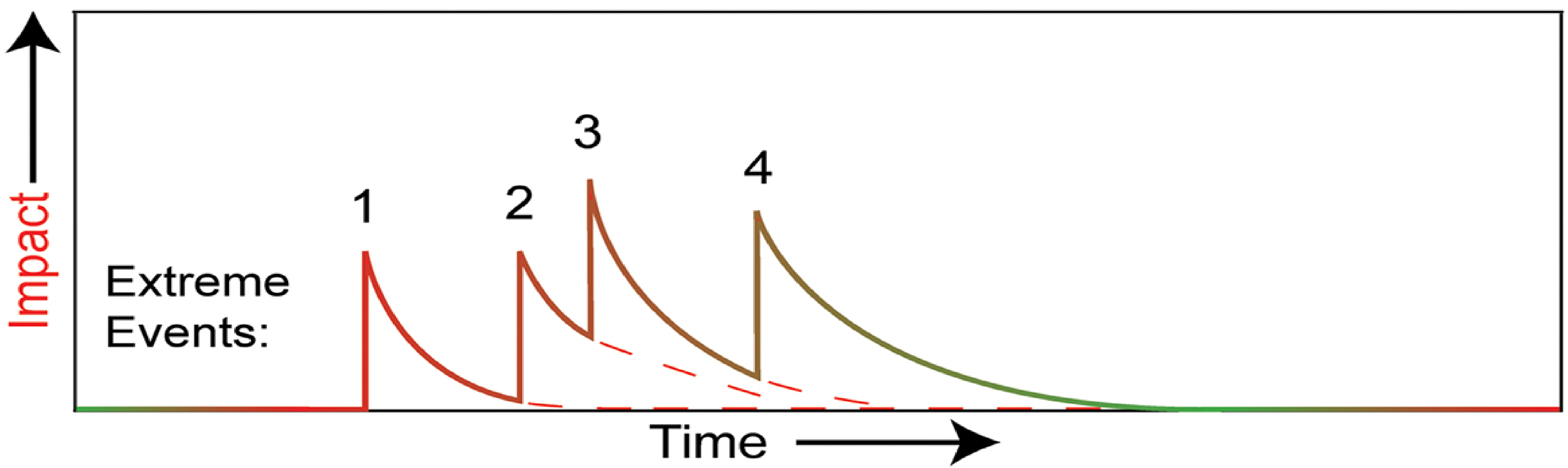
Increase in Mean & Variance



Much bigger percentage changes in extremes

Extreme Events & System Recovery





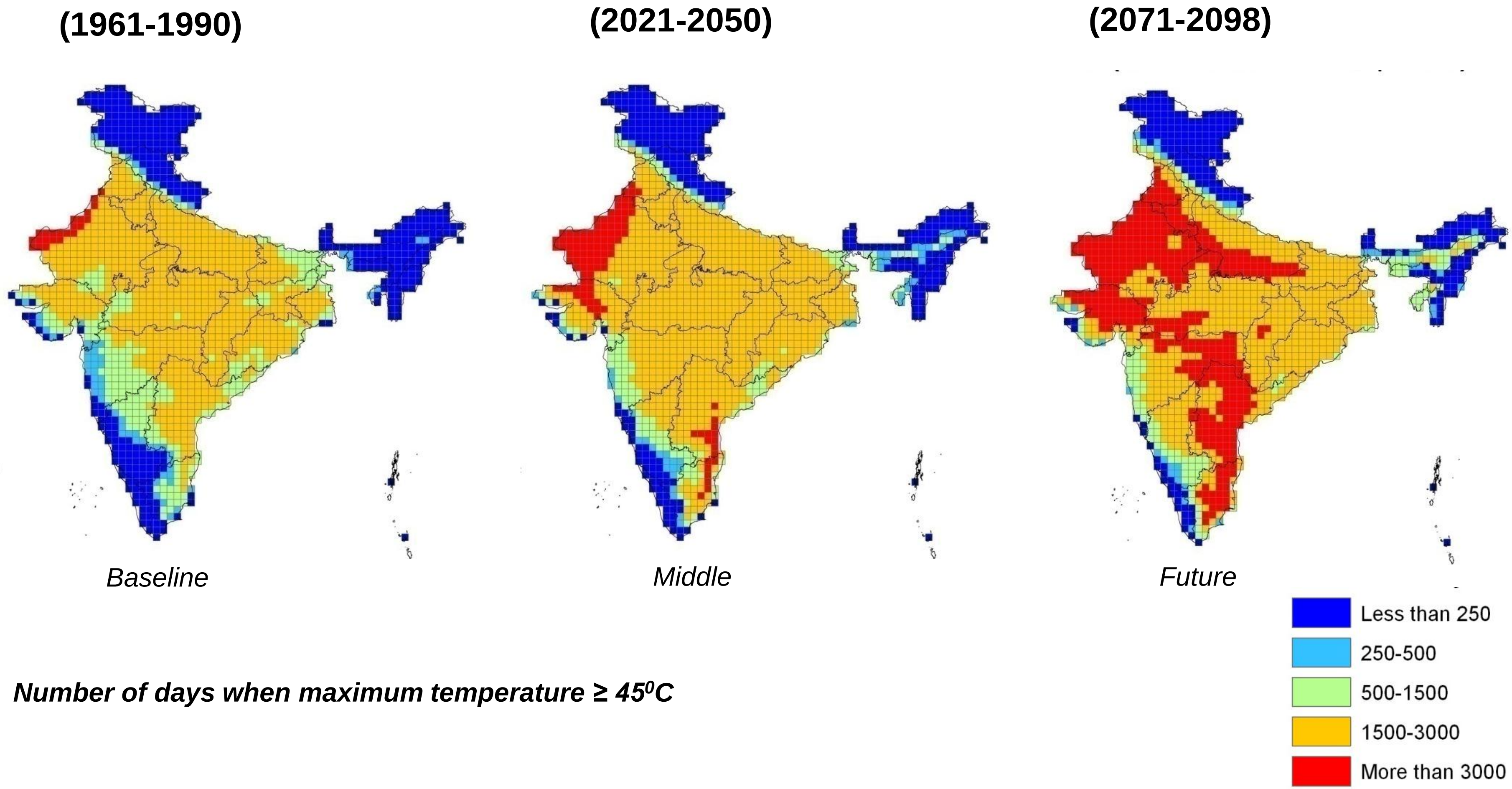
Projections for India

- India Projections:
  - Mean min & max temperatures may increase by 2–4° C as a result of climate change (Kumar, et al., 2006; INCCA, 2010)
  - Annual mean surface air temperature rise by 2030's ranges from 1.7°C to 2°C
  - Mean sea-level rise along Indian coasts estimated to be about 1.3mm/year
  - Cyclonic disturbances: Frequency is declining marginally but the intensity is increasing
  - 3% to 7% increase in all-India summer monsoon rainfall in the 2030's (w.r.t. 1970) (INCCA, 2010)
- Future CC projection models also have uncertainty and range
  - 1961-1990 – modelled baseline
  - 2021-2050 – medium term
  - 2071-2098 – long term

Regional Temperature & Rainfall Projections: Snapshot

- Regional Projections: Annual Rainfall Increase in 2030s w.r.t 1970
  - Himalayan region: 5 to 13%
  - West coast: 6 to 8 %; winter rainfall to decrease
  - East coast: 0.2% to 4.4 %; Winter rainfall to decrease
  - North- Eastern Region 0.3% to 3%.; Substantial winter rainfall decrease

	1970- 2030			
	Mean Annual Rainfall	SD	Mean Annual Temperature	SD
Himalayan	↑↑↑	↑↓↔	↑↑↑	↑↑↑
West Coast	↑↑↑	↑↓↑	↑↑↑	↑↔↔
East Coast	↑↓↑	↓↓↓	↑↑↑	↑↑↑
North East	↑↑↑	↑↑↑	↑↑↑	↑↑↑

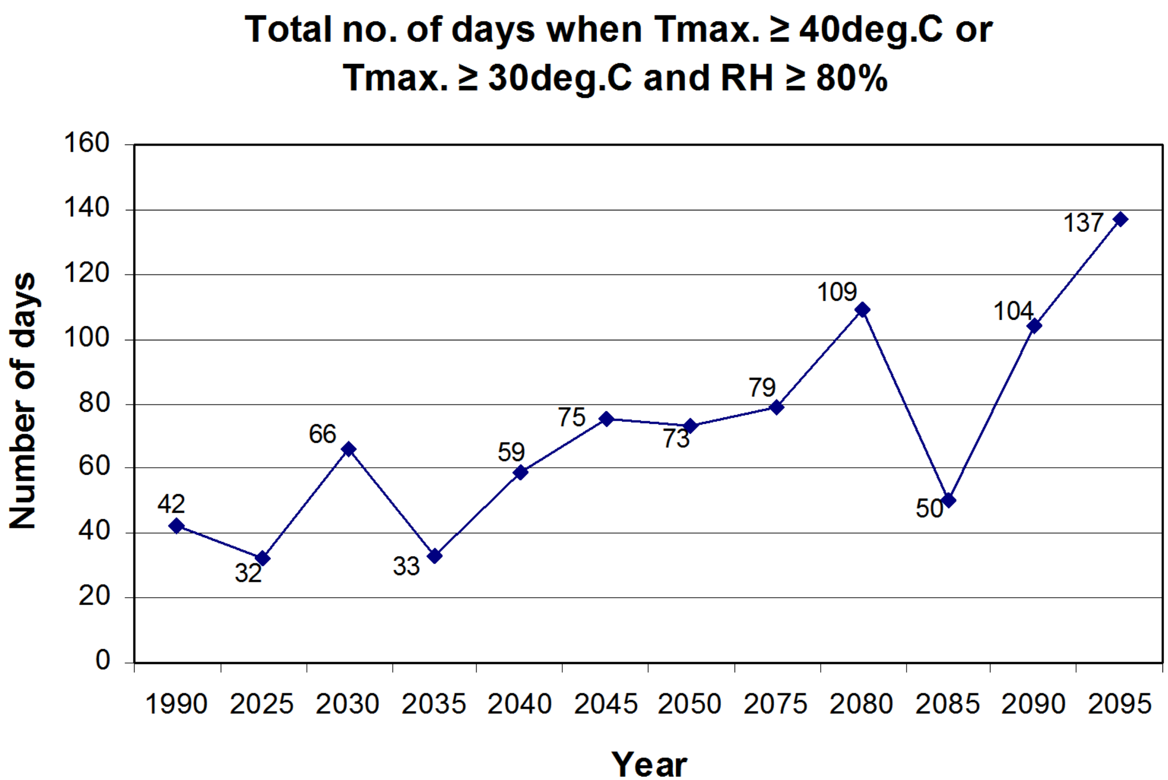


Number of days when maximum temperature ≥ 45⁰C

Example: Future climate of Paris in 2080 under the SRES A2 scenario could become the current climate of Cordoba (South of Spain)

•*Infrastructure designed to last 100 yrs must face current climate of Paris and be adapted to Cordoba's climate* *(Hallegatte et al., 2007)*

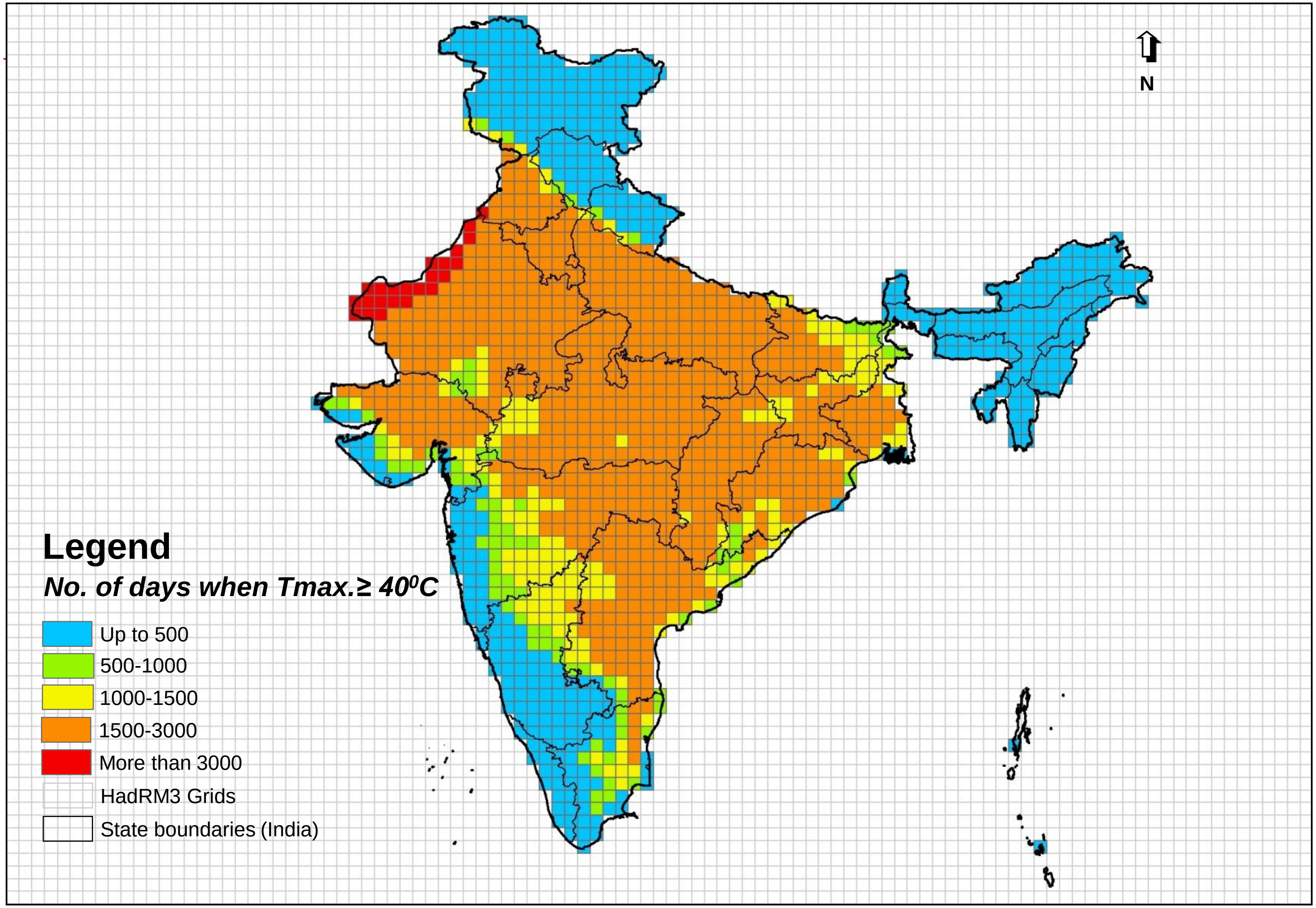
Need for Air-conditioning: Analysis for Goa, India



- Number of days needing air-conditioning is on a rise in future
- Weather projection more than a week in advance is hazardous (mainly due to cloud modeling uncertainties and boundary condition matching), but climatic trends over a longer period could be projected more robustly
- We are not sure whether we live the next second, but we are sure to be dead after 100 years!

Data set	Number of days when Tmax. ≥ 40^0C (A)	Exclusive number of days when Tmax. ≥ 30^0C and RH ≥ 80% (B)	A + B	Total days in the period
A1B-Baseline (1961-1990)	4	943	**947**	10957
A1B-Middle (2021-2050)	20	1654	**1674**	10957
A1B-Future (2071-2098)	216	2661	**2877**	10227

CDD Example for India: Above 40 deg C (1.1.1961 – 31.12.1990)

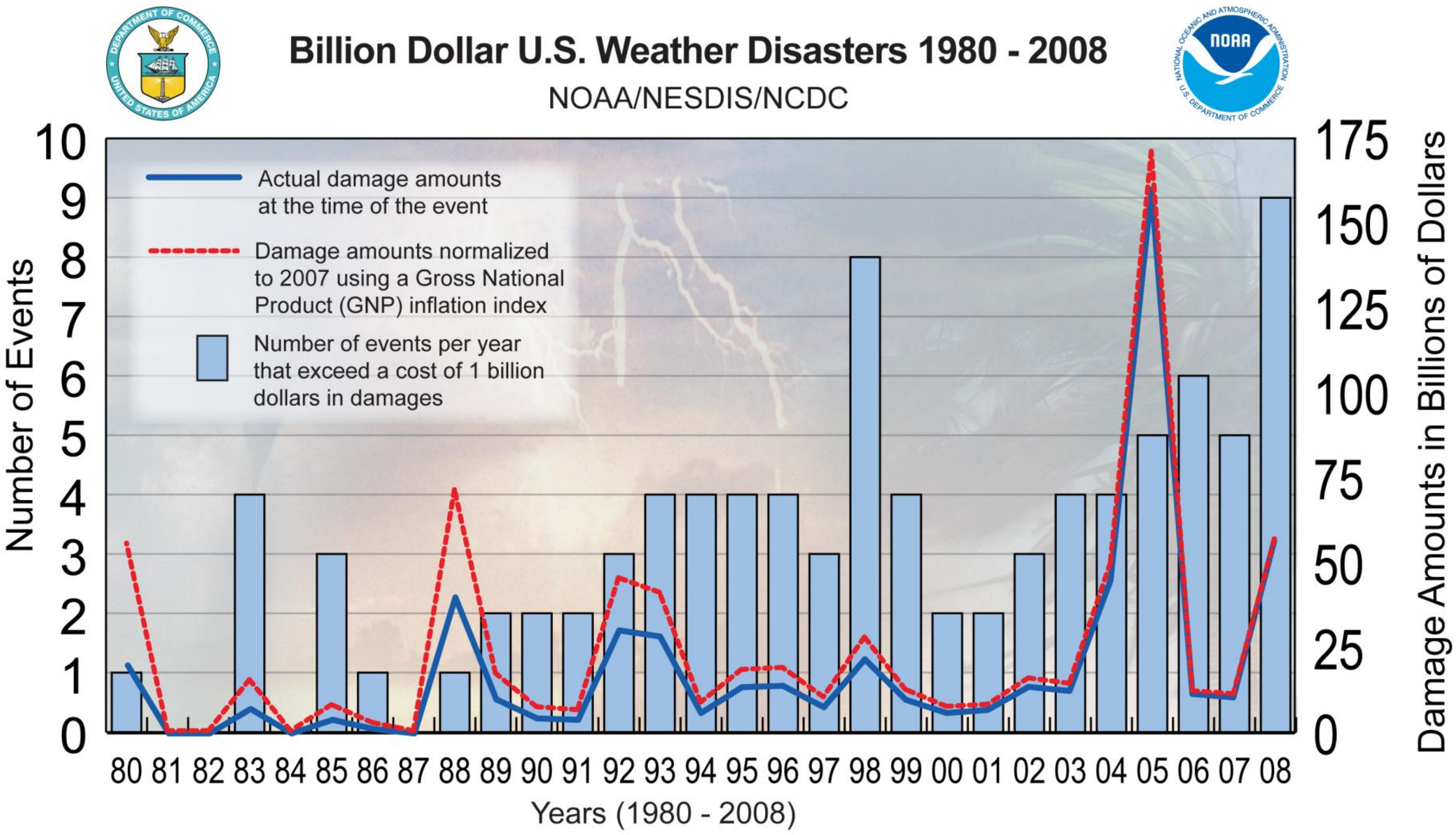


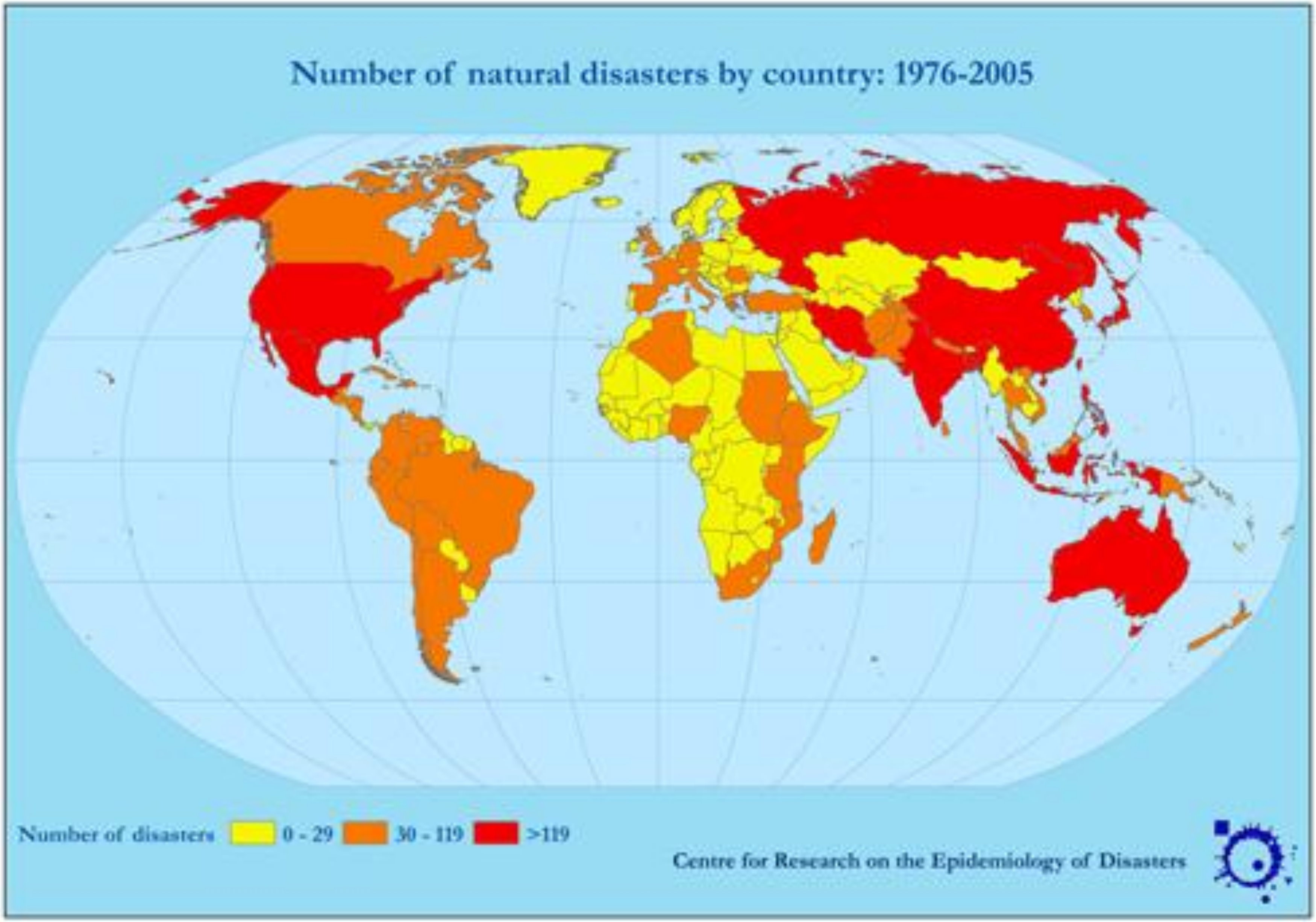
Temperature on each day is known, CDD could easily be worked out

External boundaries not authenticated

Weather related damages

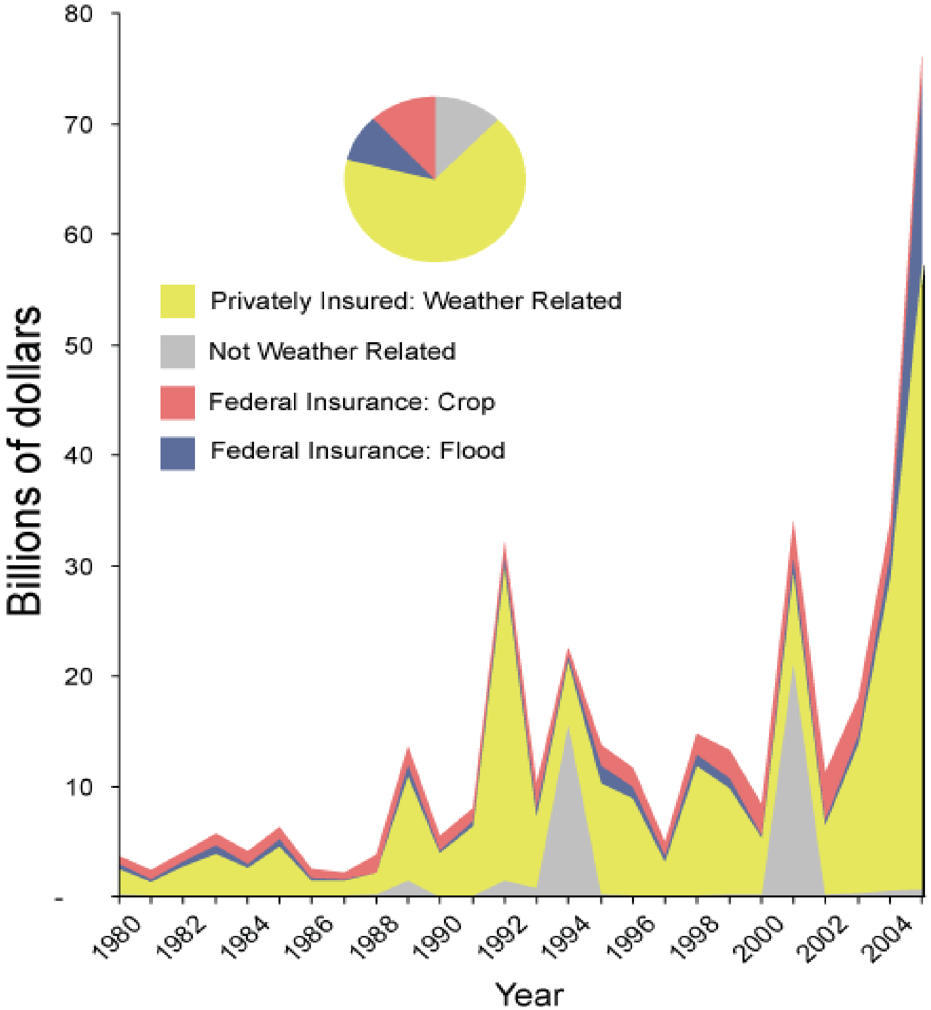
Weather and climate extremes are among the most serious challenges to society in coping with global warming





Source: EM-DAT - The International Disaster Database; Centre for Research on the Epidemiology of Disasters – CRED

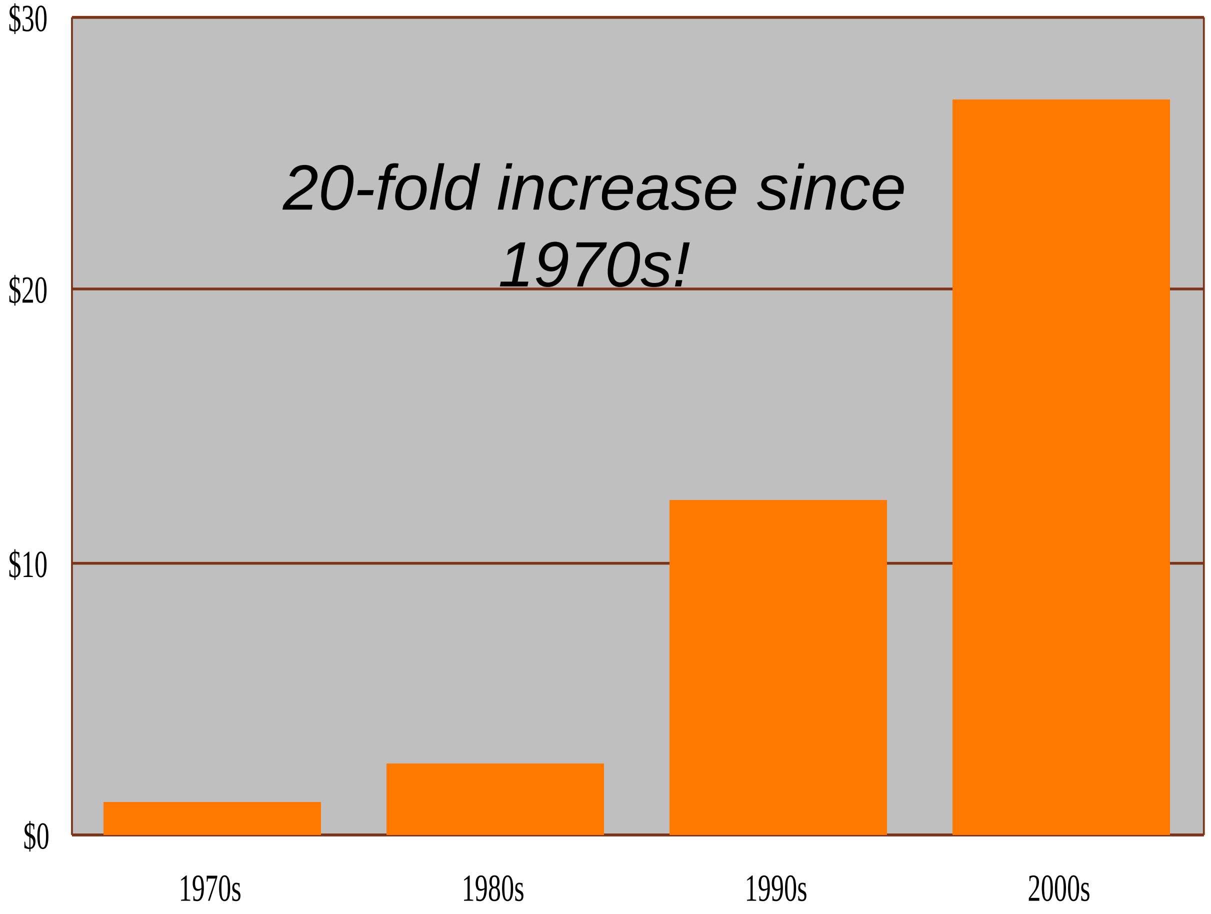
Insured Losses from Catastrophes



- Weather-related insurance losses in the U.S. are increasing.
- Typical weather-related losses today are similar to those that resulted from the 9/11 attack (shown in gray at 2001 in the graph).
- About half of all economic losses are insured, so actual losses are roughly twice those shown on the graph

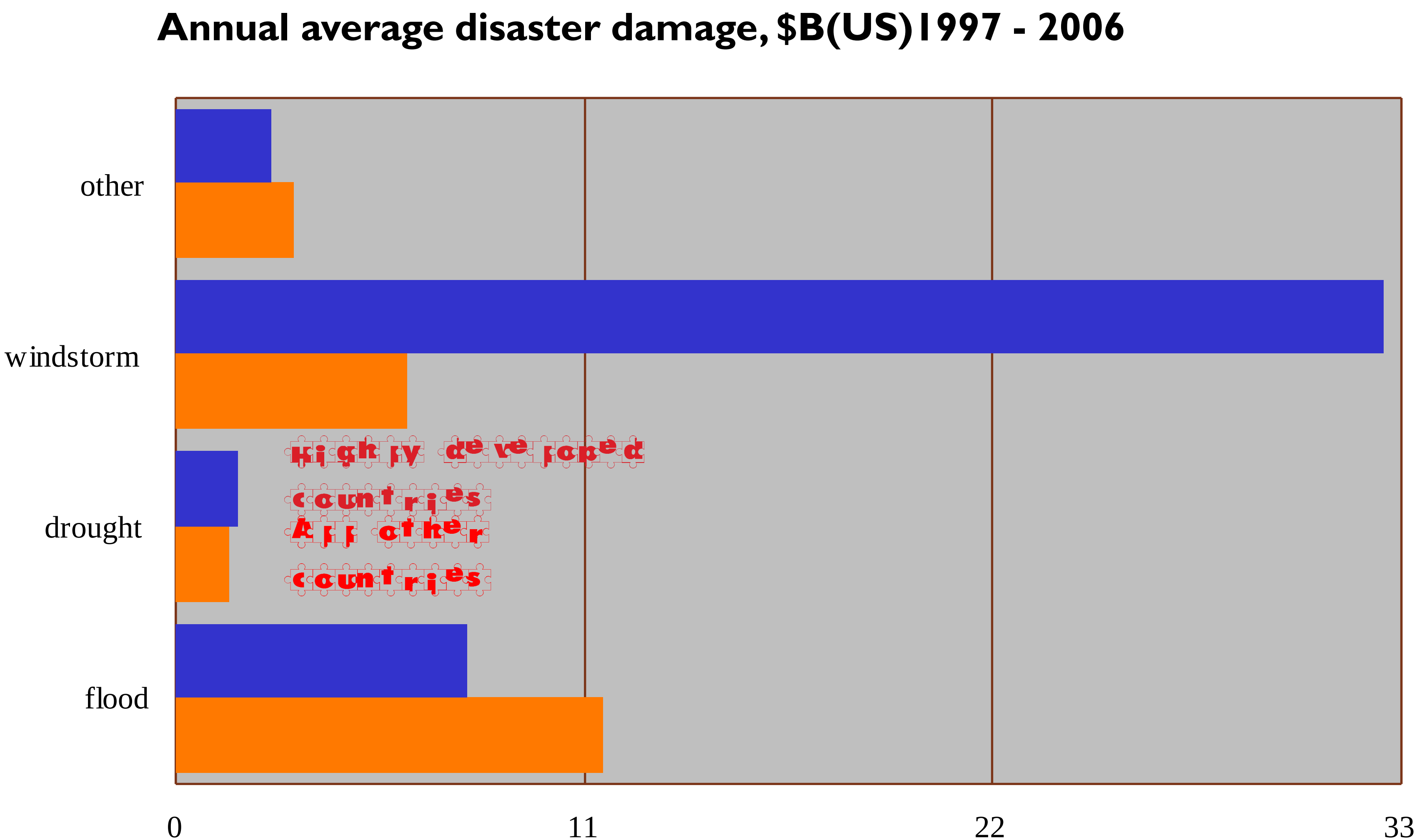
Severe weather claims paid

Annual global insurance disaster claims, US$B



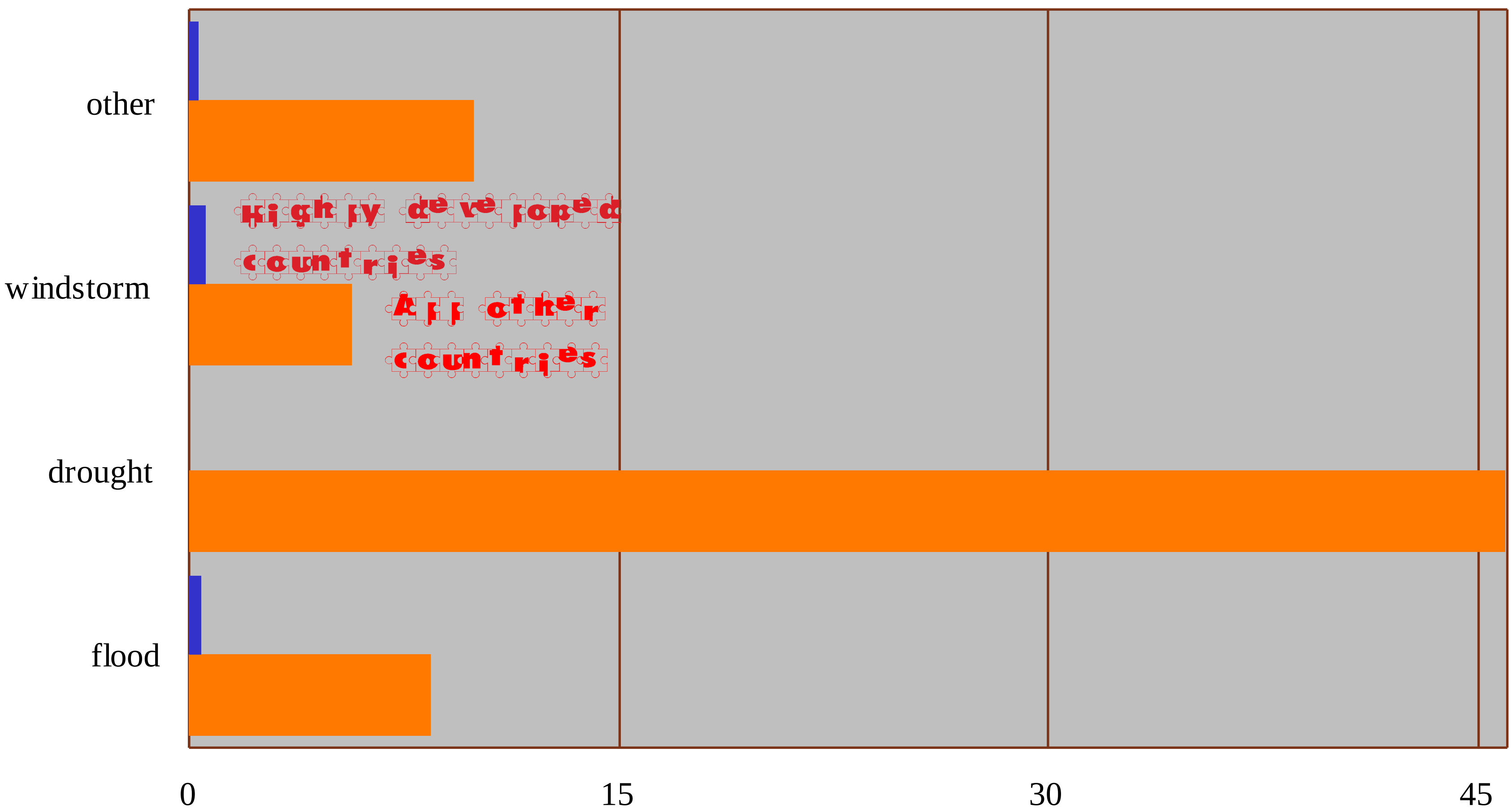
- More people and infrastructure at risk
- Aging infrastructure
- Changing climate

Global weather damage



Global weather fatalities

Annual average number of people killed, thousands, 1997 - 2006



Some possible impacts on various infrastructures

Types of Risks (Rail-road infrastructure)

Group	Risk Category		Example
Primary Risk	Physical	Exposure risks due to increase frequency and variability of climate variables.	Damage to tracks, railway infrastructure
Allied Risk	Regulatory	Binding agreements; Influence of international policies	Change in fuel mix; Additional taxes
Allied Risk	Supply Chain	Effect on essential supplies of petroleum, fertilizer, food grains	Annual Freight traffic to the tune of Rs. 297crore (2010-11)
Allied Risk	Product & Technology	Improvement in technologies to meet regulations	Existing assets may become redundant

Source: Carmianti (2010); Vespermann & Wittmer (2010); Lash & Wellington (2007); IRM, (2002)

Some Impacts (Railways and Roads)

CCC Parameter	Temperature, Precipitation, Extreme Events

Direct Impacts	- Physical Damage
	  - E.g. , Joint Expansions, Rail cracks
	  - Traffic disruptions due to various reasons
	- Supply Chain Impacts

Indirect Impacts	- I/S choices influenced by Carbon constraints (when?) - Enhanced cooling / Heating requirements - Modal shifts - Mitigation Pressures on existing I/S
Risk Management	- Securing rail-road's safety through interventions, e.g. technology up-gradation, better communication to reduce damages etc - Insurance driven Vs in-house

Some Impacts (Energy Infrastructure)

CCC Parameter	Temperature, Precipitation, Extreme Events
Direct Impacts	• Change in demand pattern: heating & cooling requirements • Supply of conventional fuel • Hydro-power dependent on water supply • Strict emission reduction norms • Redundant assets due technological change • Physical damage due to extreme events • Excessive siltation in dams
Indirect Impacts	• Supply chain disruptions • Efficiency Norms • Carbon constraints
Risk Management	Forward Contracts; PPA; Technology Up-gradation; Energy efficiency; Switch to renewable sources of supply; Insurance; Catastrophe Bonds; Emissions Trading

Some Impacts (Water Supply & Irrigation)

CCC Parameter	Precipitation, Temperature, Extreme events
Direct Impacts	Variability in water supply
	Enhanced evapo-transpiration
	Depleting ground water table, water supply Demand changes

Some Impacts (Health & Housing)

CCC Parameter	Temperature, Precipitation, Extreme Events
Direct Impacts	Increased number of diseases - Malaria/Breathing disorders Sea level rise to affect houses on the coast
	Migrations Space cooling/ heating
Risk Management	Better housing infrastructure and building standards Insurance More health services Dykes on the coast Better communication Official Development Assistance

Transport Indicators (2008)

Indicator	Measurement	Estimates
Network Speed	Average Journey speed	23 kmph
Public Transport Mode Share	PT Trips/Total Motored Trips	10%
Walkability	Footpath Length /Road Length	23%
Fatality Index	No. of Fatalities/Lakh Popn	18
IPT Index	Registered IPT Vehicles / Lakh Popn	450
Non-Moto[illegible]l T[illegible] I[illegible]	% of NMT Trips in Total Trips	33%
F[illegible]n[illegible]	[illegible]R[illegible] [illegible]h	18%





Source: Department of Town & Country Planning, Govt. of Haryana (2010).

Transport Indicators (2031)

Indicator	Do Nothing	Benchmark
Average Journey Speed	11 kmph	30 kmph
Public Transport Mode Share	4%	70%
Walkability	5-10%	100%
Cyclability	0%	30-50%
Fatality Index	20+	Reduce by 50%
On Street Parking Index	30-50%	0-5%
[illegible]	[illegible]	30-50%
[illegible] sq. km.)	5 kg	Reduce by 50%

If nothing is done, these figures may be worse

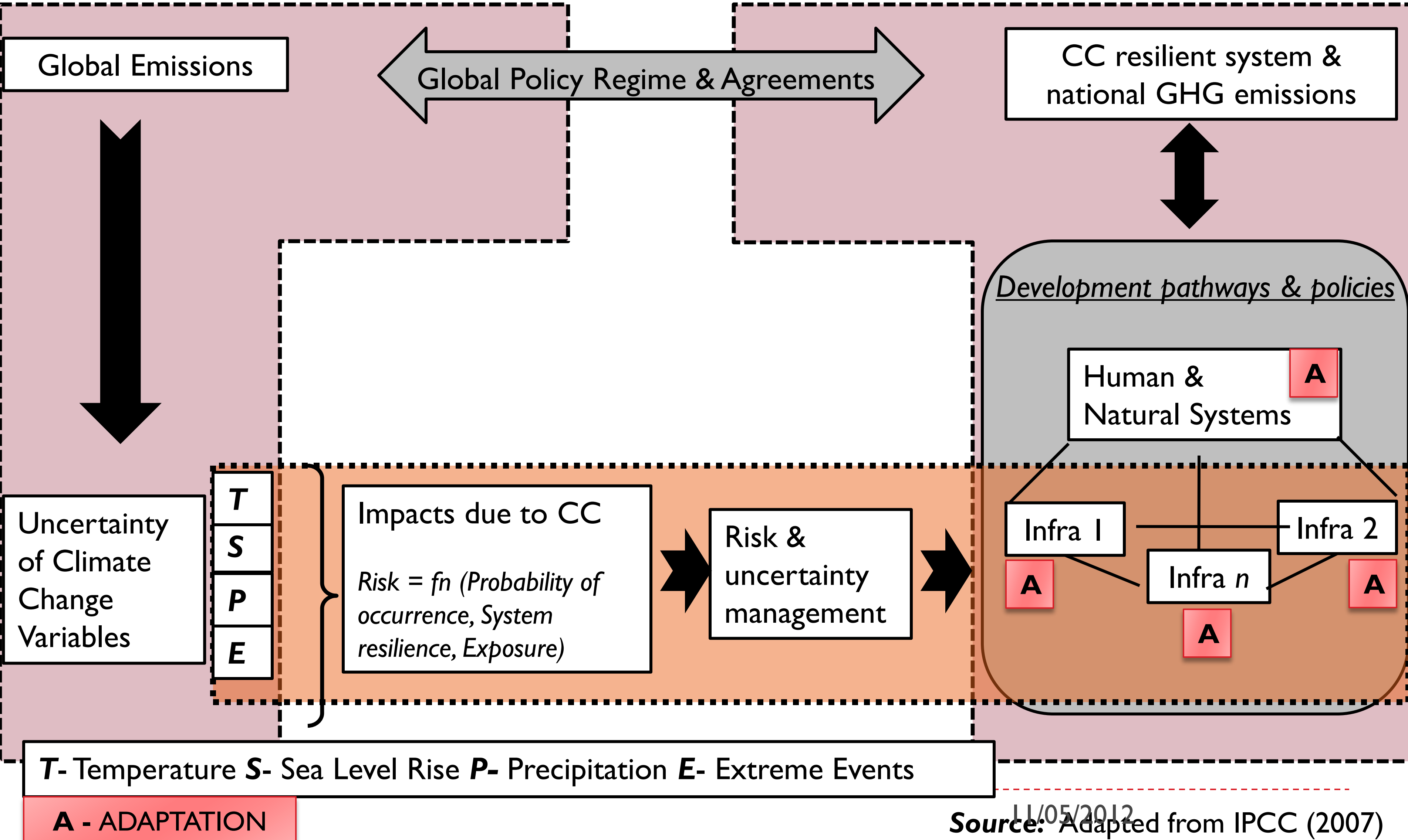
Background assumptions may have to be revisited to incorporate CC impacts

City flooding may change population distributions

Source: Department of Town & Country Planning, Govt. of Haryana (2010).

Possible adaptation framework and Konkan Railway example

Integrated CC Assessment for Infrastructure



Source: Adapted from IPCC (2007)

Risk Valuation

Economic Loss (EL) = Infrastructure loss (Stock) + Operating Loss (Flow)

EL = f (SDV i, SCV j, CCV k) + f (OV l)

SDV: Sustainable Development Variables

SCV: System Condition Variables

CCV: Climate Change Variables

i = Insurance, Building Standards etc.

j = Warehousing, technology (cyclone warnings) etc.

k = Extreme Events, Sea level rise, Rainfall etc.

l = Cargo handled, cargo growth rate, Type of cargo etc.

Adaptation will be captured in SDV i, SCV j

Vulnerability will be captured in SDV i, SCV j, CCV k

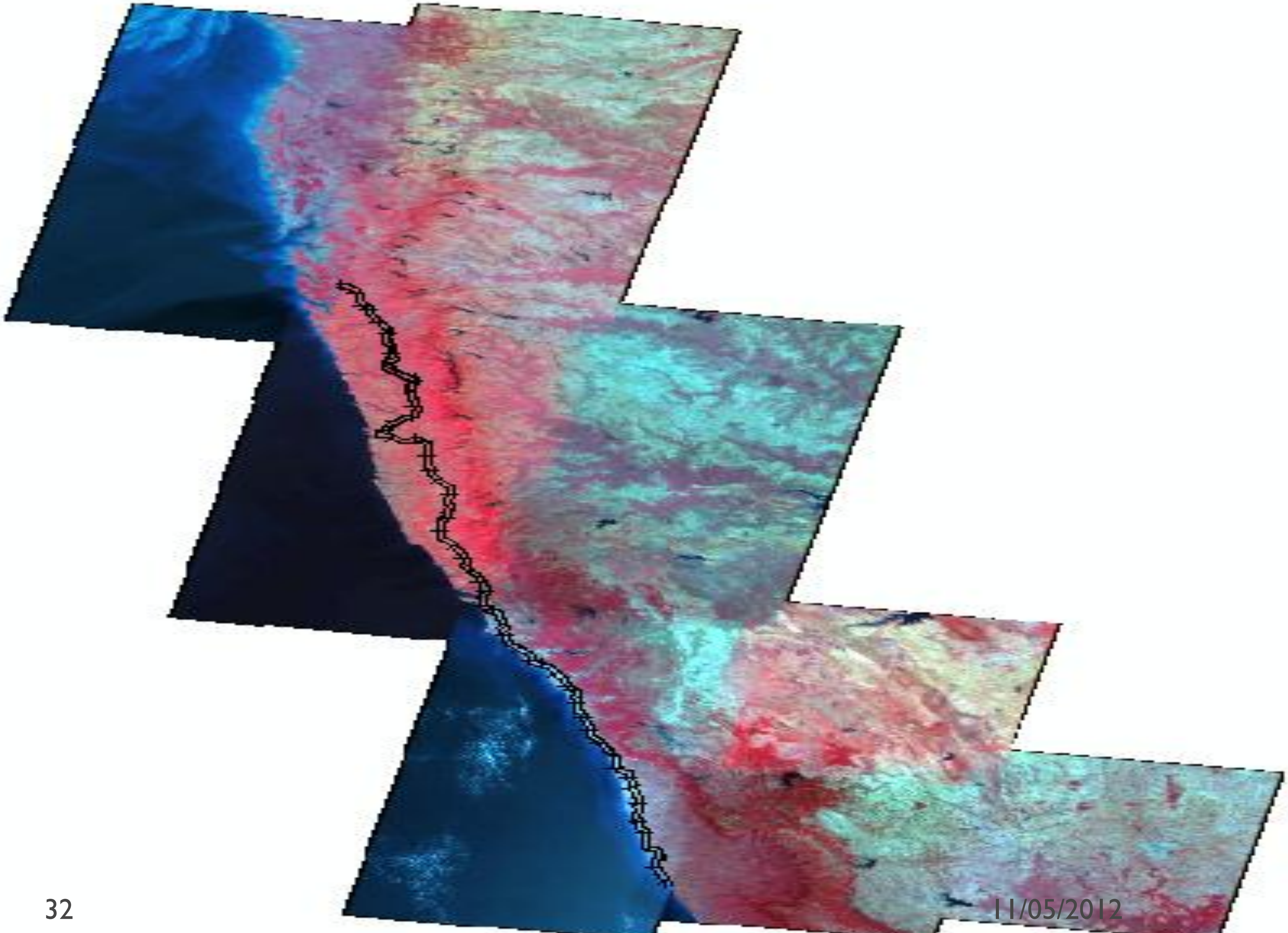
Where incidence of loss will happen when, CCV k $\geq$ T k (Critical threshold for variable k)

Konkan Railway

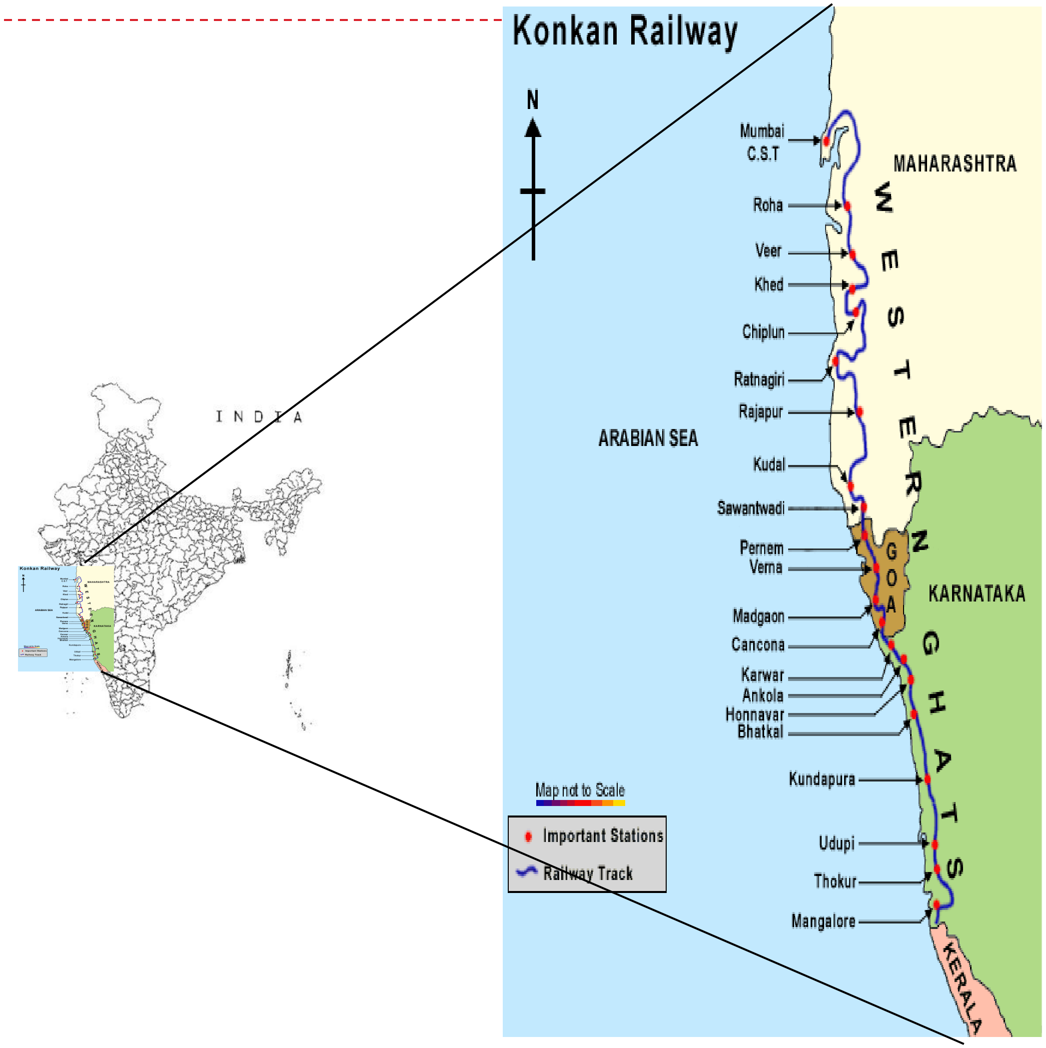
- Connects two important ports of Mangalore and Mumbai
- First major infrastructure project to be taken on BOT basis
- Built on an extremely rugged terrain
  - 1998 Bridges (179-Major; 1819-minor) and 92 tunnels
  - Mountainous terrain with many rivers
  - Landslides a common problem due to excessive rainfall
  - First time IR built tunnels longer than 2.2 kms
  - More than 1000 cuttings in the track
- Exposed to excessive precipitation resulting in land slides - hampering train operations and safety

Source: KRCL; Kapshe, et al. (2003)

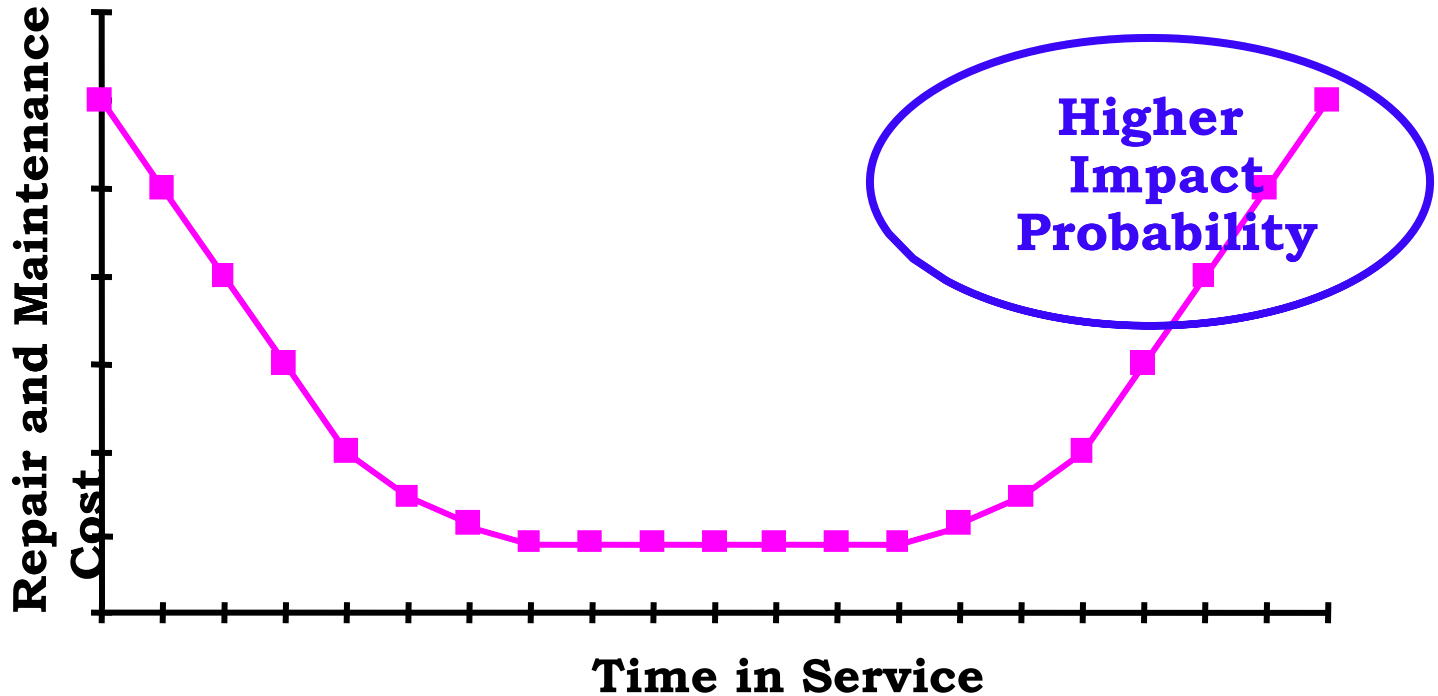
Konkan Rail Route overlaid False Color Composite (LANDSAT TM- Mosaic Images (1999-2000 & 2001)




मानचित्र
LWAY
N
TO SURAT
पश्चिम रेलवे
Western Railway
वसई रोड
VASAI ROAD
मनमाड
MANMAD
TO JALGAON
कल्याण
KALYAN
ठाणे
THANE
मध्य रेलवे
Central Railway
मुंबई छ. शि. ट.
MUMBAI C. S. T.
दिवा
DIVA
चर्चगेट
CHURCHGATE
कर्जत
KARJAT
महाराष्ट्र
MAHARASHTR
पनवेल
PANVEL
रोहा / ROHA
पुणे
PUNE
दौंड
DAUND
चिपलूण / CHIPLUN
सातारा
SATARA
कराड
KARAD
रत्नागिरी / RATNAGIRI
सांगली
SANGLI
कोल्हापुर
KOLHAPUR
मिरज
MIRAJ
बेलगाम
BELGAUM
गोवा
GOA
लोंडा
LONDA
हुबली
HUBLI
दक्षिण पश्चिम रेलवे
South Western Railway
कैसल रॉक
CASTLE ROCK
मडगांव / MADGAON
कर्नाटक
KARNATAKA
कारवार / KARWAR
तालगुप्पा
TALGUPPA
उडुपि / UDUPI
Change Point
ठोकूर / THOKUR
पाडिल
PADIL
मंगलूर / MANGALORE
ARABIAN SEA
LEGEND

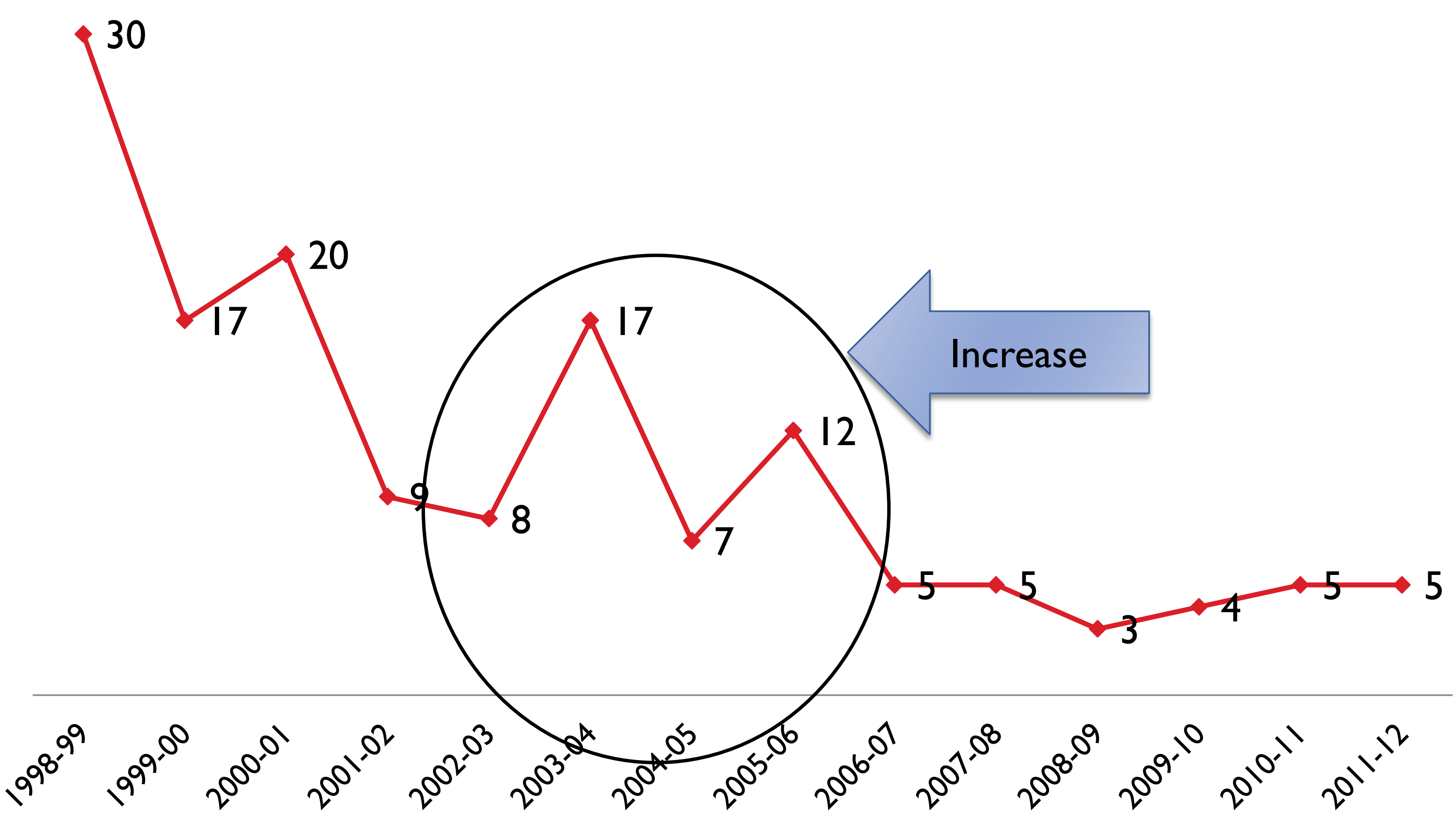

INDIA
Konkan Railway
N
Mumbai C.S.T
MAHARASHTRA
Roha
Veer
Khed
Chiplun
Ratnagiri
Rajapur
ARABIAN SEA
Kudal
Sawantwadi
Pernem
Verna
GOA
KARNATAKA
Madgaon
Cancona
Karwar
Ankola
Honnavar
Bhatkal
Kundapura
Udupi
Thokur
Mangalore
KERALA
WESTERN GHATS
Map not to Scale
Important Stations
Railway Track

Infrastructure Maintenance Costs

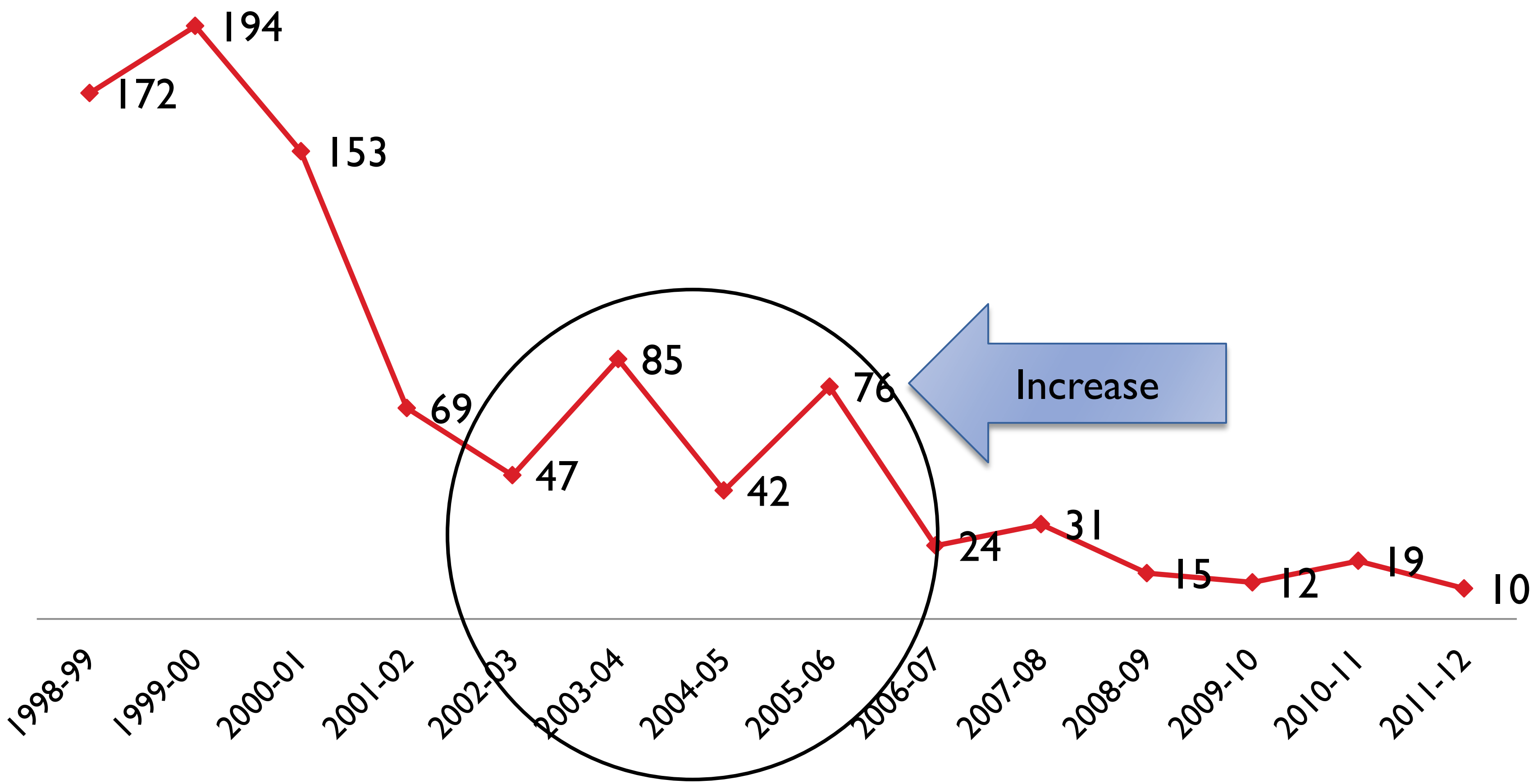


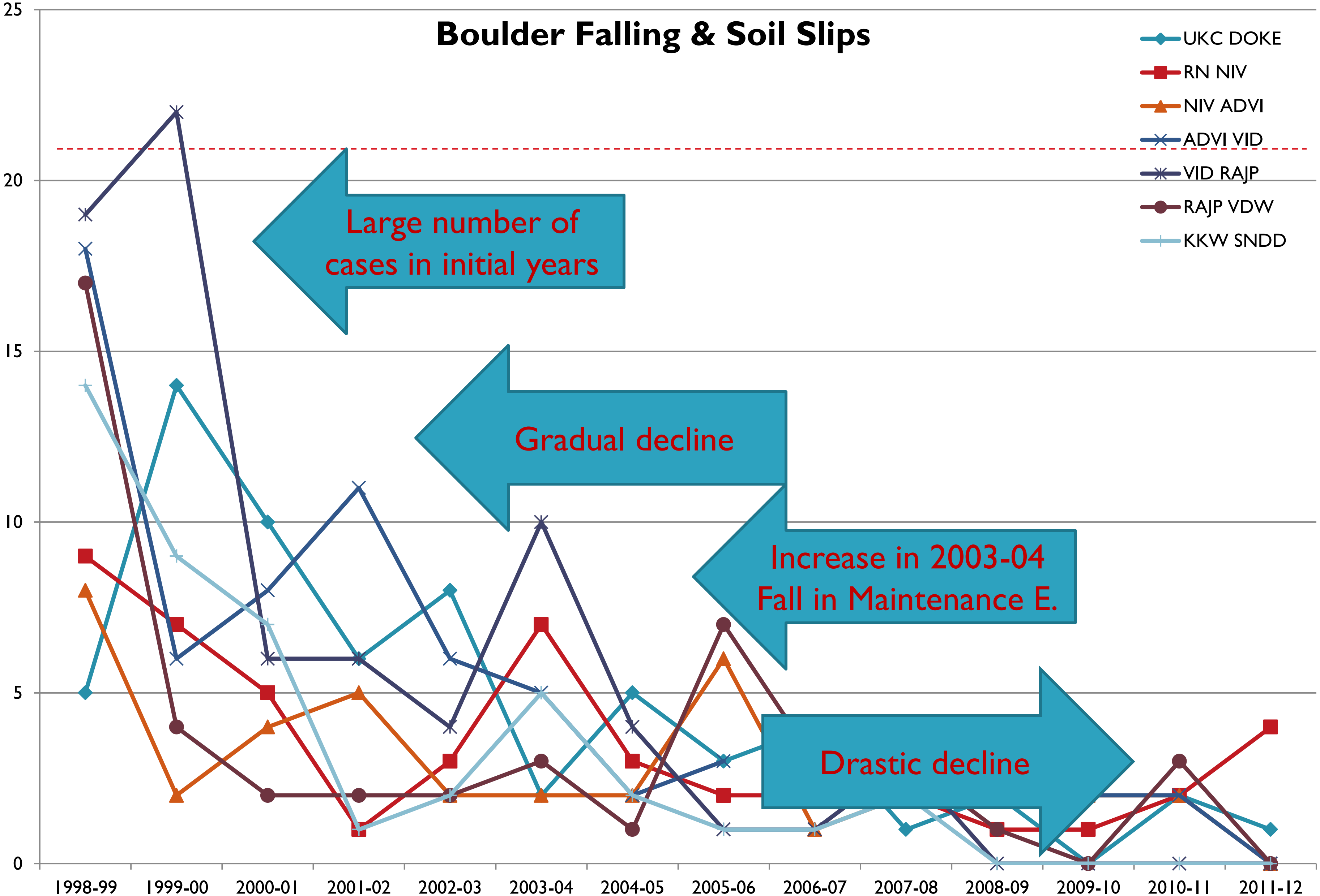
- Classical Bath Tub Curve:
  - An initial period during which time the system is 'running-in'.
  - A period during which there is a constant, stable and low failure rate.
  - A wear-out period during which the failure rates increase dramatically.

Boulder falling & Landslides with Traffic Interruptions



Total cases of Boulder falling & Landslides




Boulder Falling & Soil Slips
UKC DOKE
RN NIV
NIV ADVI
ADVI VID
VID RAJP
RAJP VDW
KKW SNDD
Large number of cases in initial years
Gradual decline
Increase in 2003-04 Fall in Maintenance E.
Drastic decline
25
20
15
10
5
0
1998-99
1999-00
2000-01
2001-02
2002-03
2003-04
2004-05
2005-06
2006-07
2007-08
2008-09
2009-10
2010-11
2011-12

Reverse Impact Matrix

Forcing Variables \ Dependent Variables	***Environmental Variables***	***Project Components***
Environmental Variables	Quadrant 2: Environmental impact inter-linkages	Quadrant 3: Reverse Impact (impacts of environment on project)
Project Components	Quadrant 1: Forward Impact (impacts of project on environment)	Quadrant 4: Project's impact on other projects

Source: Kapshe, et al. (2003)

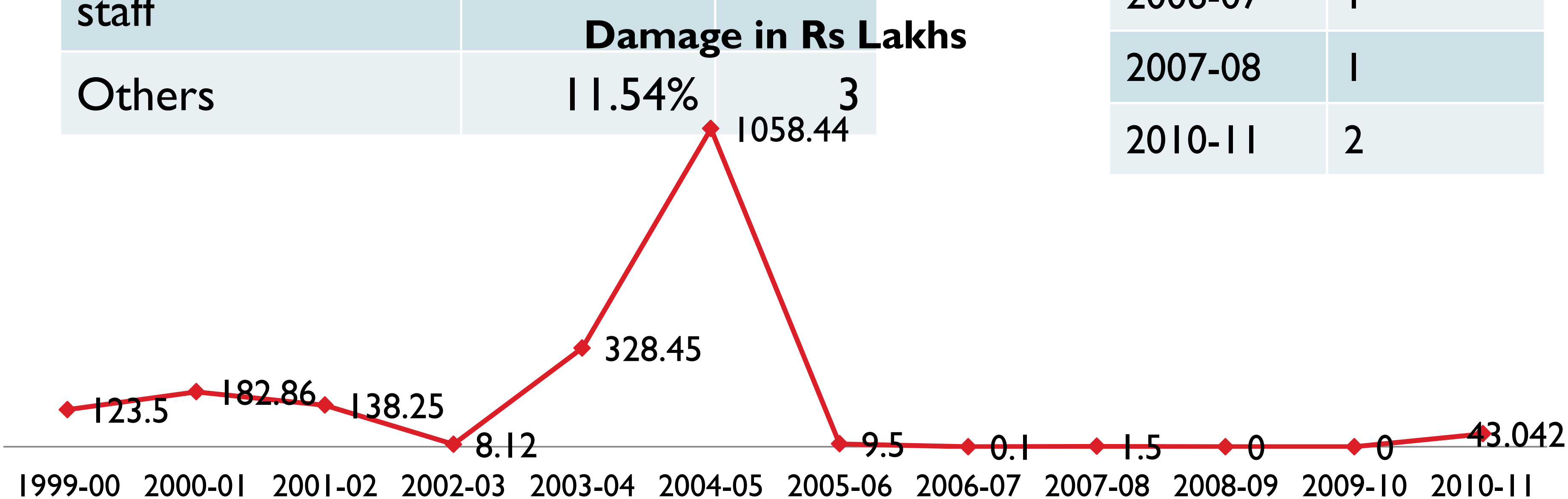
Climate Impact Matrix

Forcing Variables \ Dependent variables		Temperature	Rainfall	Sea level rise	Extreme events	Water logging	Vegetation growth	Land slide	Safety/Efficiency	Maintenance	Traffic volume
		Environmental Variables							Project Components		
Environmental Variables	Temperature		L	M	L	--	L	--	--	--	L
	Rainfall	L		--	M	M	M	H	L	L	M
	Sea level rise	--	--		--	M	L	M	L	--	L
	Extreme events	--	L	--		M	--	M	L	--	M
	Water logging	--	--	--	--		--	L	L	--	M
	Vegetation growth	L	L	--	--	--		L	--	L	--
	Land slide	--	--	--	--	M	L		M	L	H
Project Components	Safety/Efficiency	--	--	--	--	L	--	L		M	M
	Maintenance	--	--	--	--	M	L	H	H		M
	Traffic volume	--	--	--	--	--	--	--	L	M	

Accident Statistics

Cause	Proportion	#
Natural	61.54%	16
Material Failure	11.54%	3
Failure of Railway staff	15.38%	4
Others	11.54%	3

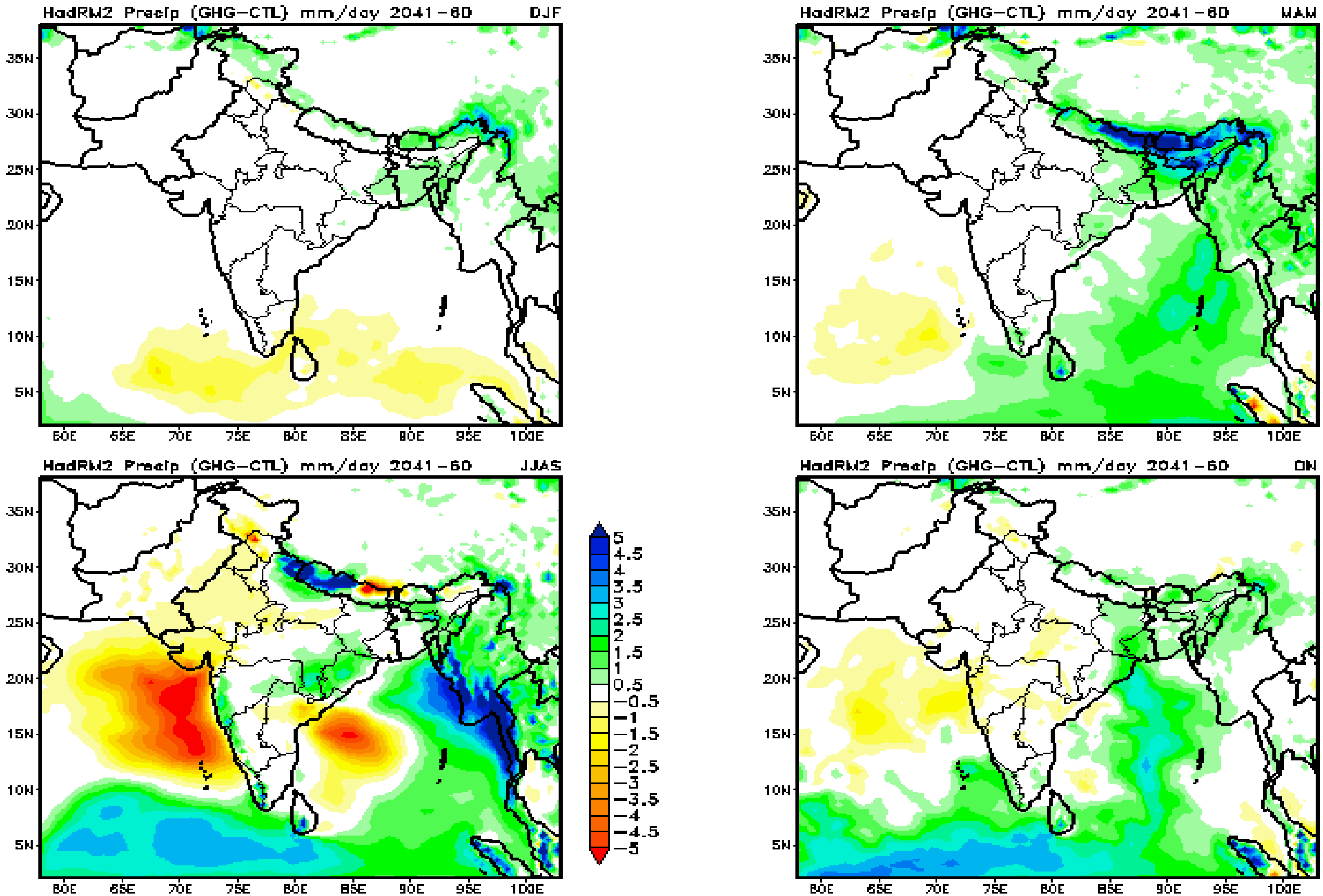
Year	#
1999-00	4
2000-01	9
2001-02	1
2002-03	2
2003-04	5
2004-05	2
2005-06	1
2006-07	1
2007-08	1
2010-11	2



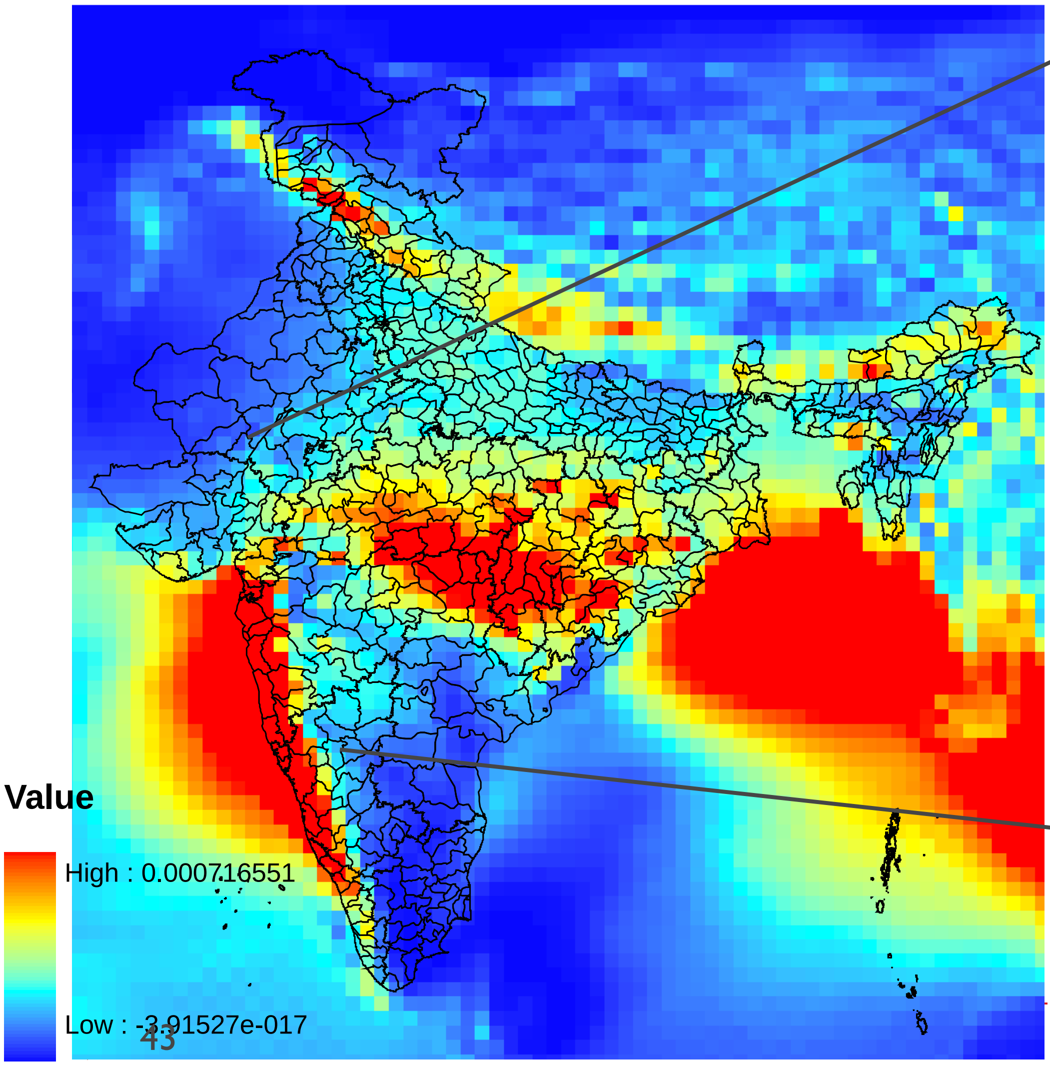
Framework for adaptation for CC Impacts

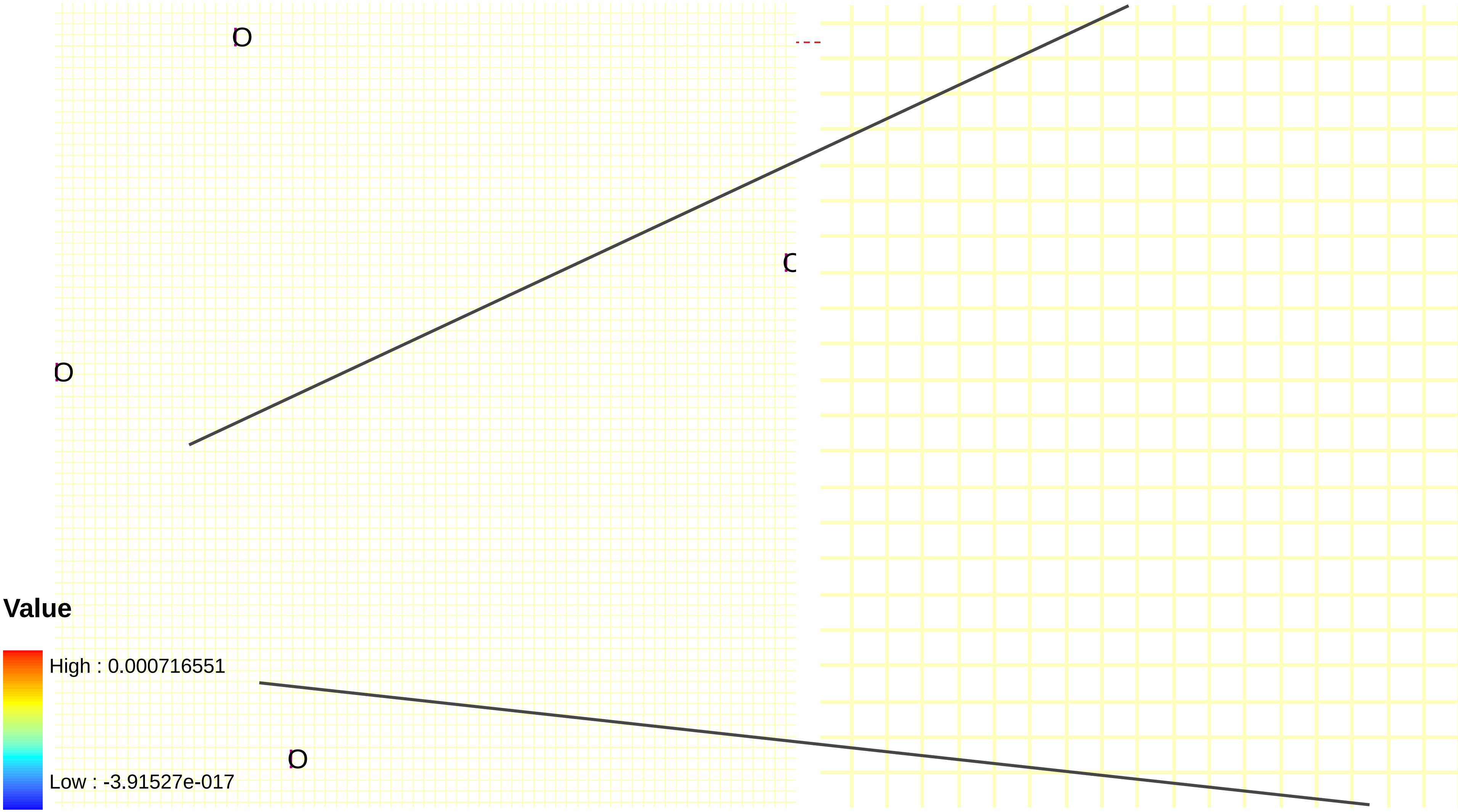
- Impact matrix creation and analysis
- Identify critical climate change (CC) parameters
- Estimate damage function
  - Historical relationship between economic damages and CC impacts
  - Adjust for intensity and frequency of climatic impacts
- Get future projections for CC parameters
- Estimate economic losses in future and their probability distribution
- Adjust for discontinuities, if likely to be considerable
- Analyze alternatives to manage these losses and associated risks, and likely cost of these alternative options
  - Annualized highest loss scenario (from Insurance company's perspective)
  - Annualized lowest damage scenario (asset owner's perspective)
  - Risk weighted average

Rainfall Pattern

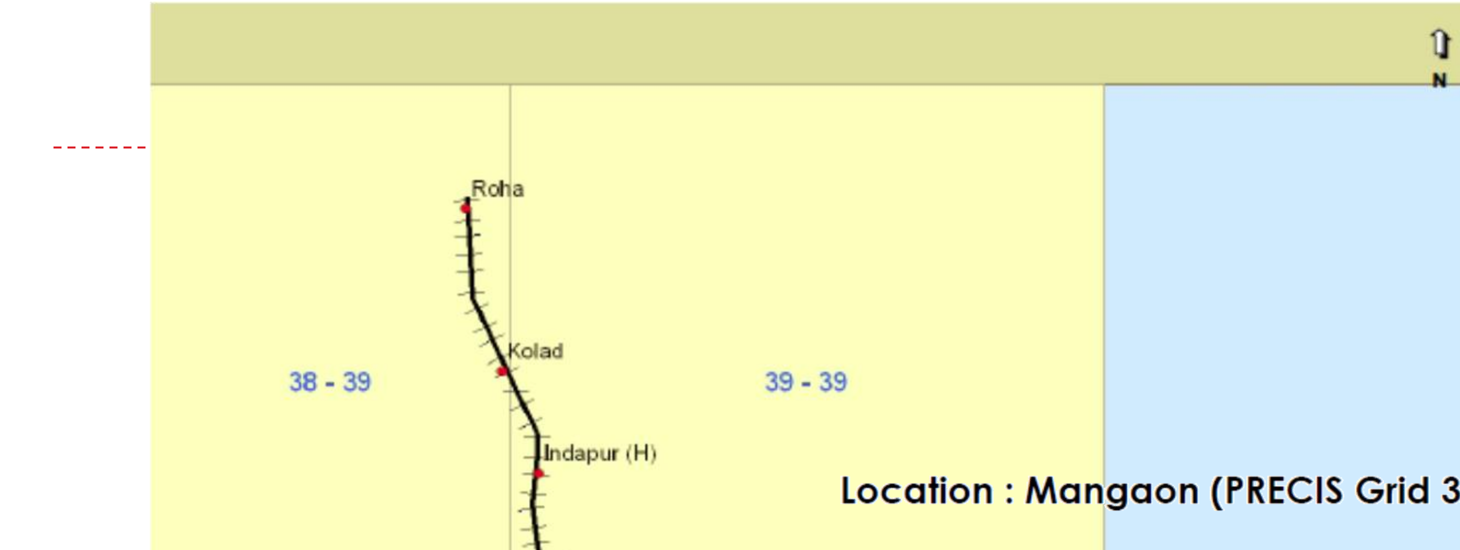


Spatial pattern of projected seasonal precipitation change (mm) for 2050 relative to 1990s

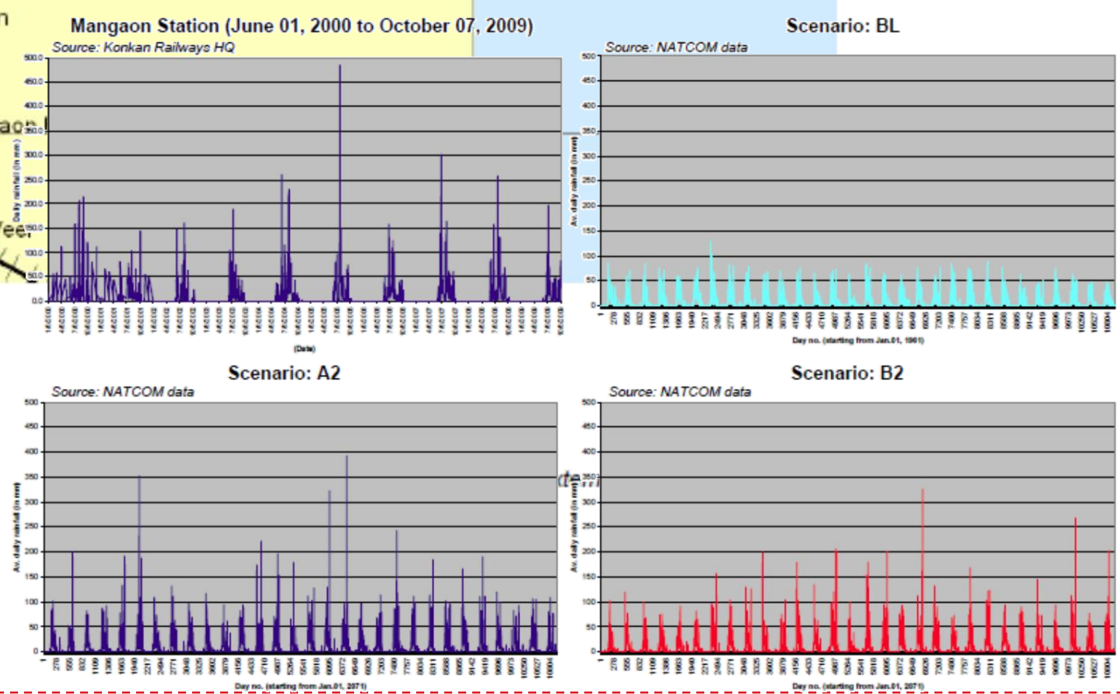

Value
High : 0.000716551
Low : -3.91527e-017


Value
High : 0.000716551
Low : -3.91527e-017

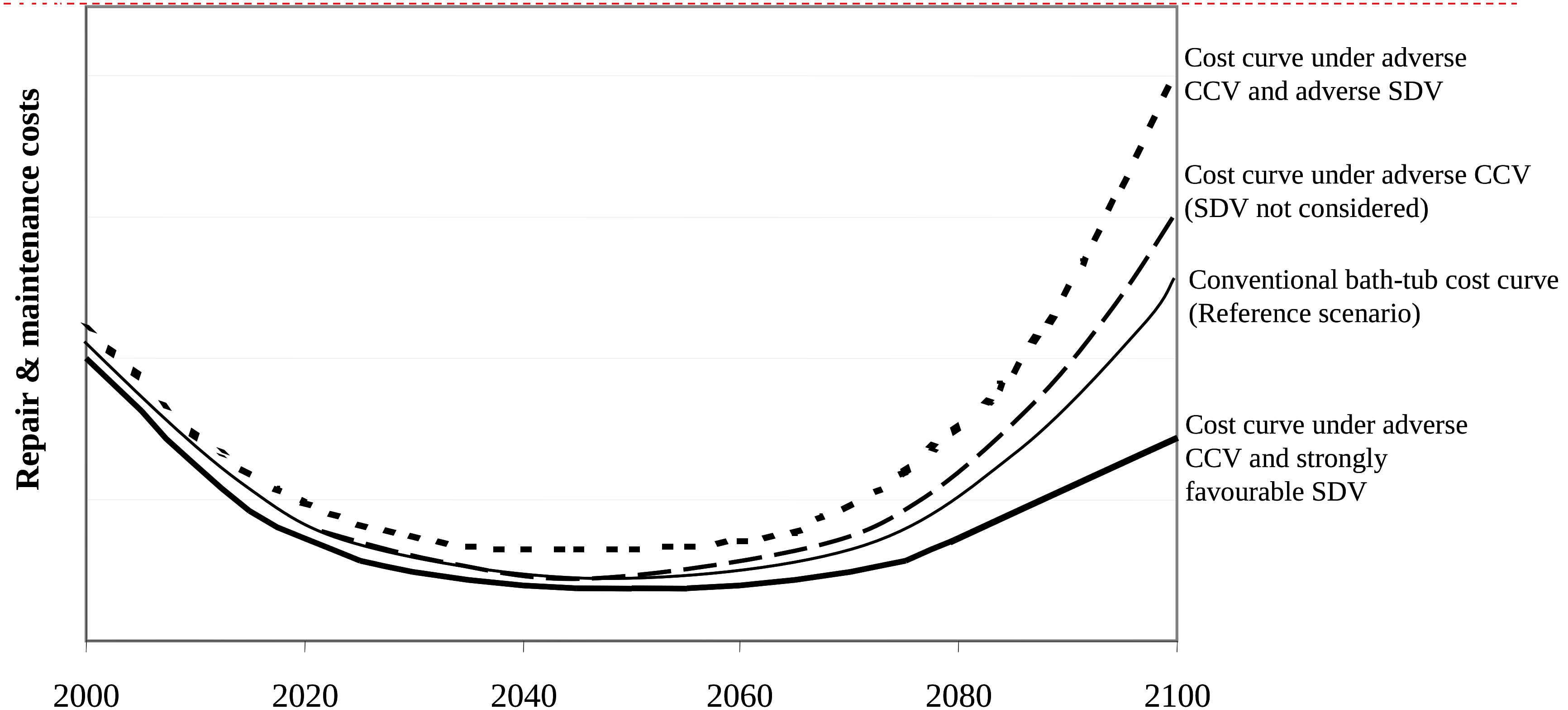
Mangaon and PRECIS Grid



Location : Mangaon (PRECIS Grid 39-39)

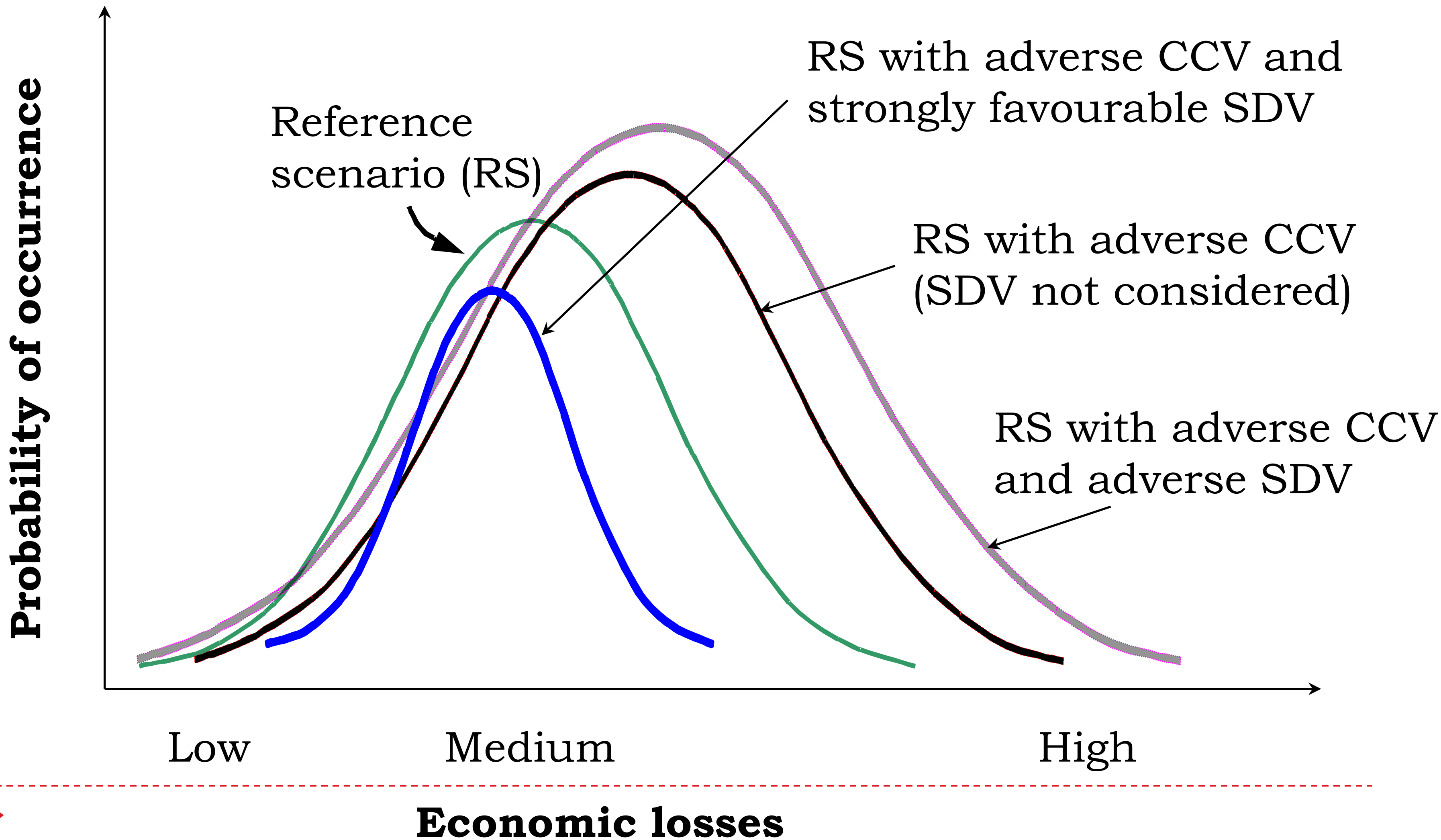


Maintenance Cost: Compound Impacts SC, CCV & SDV



- Long-life assets commissioned now will have higher failure rates after a century when they become old.
- Climate change shall also exacerbate in later part of the 21st century. Therefore, impact probability and costs on the infrastructure would increase significantly in later years.

Economic Loss & Probability of Occurrence



WB Kolkata study

Source: WB report No, 53282-IN (through INRM)

Damage Assessment (Floods)- Residential

Stock Damage: Building & Property | Flow Damage: Loss of Income

Proportion of damaged buildings requiring repairs (R_f)

$$R_f = M_t + \text{Max}\,(D3*1, D2*0.75, D1*0.5) * \{(1-M_t)/10\}$$

M_t= Minimum Threshold per building type

D1= No. of days of inundation depths of 0.25m-0.75m

D2 = No. of days of inundation depths of 0.75m-1.5m

D3= = No. of days of inundation depths of >1.5m

Damage to residential building (D_{RB}) in each category

$$D_{RB} = HH * I * P * S * [(Cb * R_f * Dh) + (1-R_f) * Cc]$$

HH = Total no. of household in affected area

C_b = Building construction costs

I= percentage of area inundated in the affected area

C_c= Cleanup cost

P= Percentage of composition of different categories

S= Proportion of damaged buildings requiring repair costs

D_h= Damage factor of a building needed repairs (assume to be 0.06)

Source: World Bank (2011).

Damage Assessment (Floods)- Residential … (2)

Damage to Residential Property (D_{RP}) in each income category

D_{RP}= **HH * Y * C * S * D_P * I**

HH= Total number of household in each income category in the affected area

Y= Average income in a household income category in 2050

C= Savings rate in an income category for 5 yrs

S= Proportion of total households in first floor

D_p= Property damage facto

I- percentage of area inundated in the affected area

Property damage factor(D_P)

D_P= **Max (D3 *.33, D2* 0.025, D1*0.02)**

D1= No. of days of inundation depths of 0.25m-0.75m

D2 = No. of days of inundation depths of 0.75m-1.5m

D3= = No. of days of inundation depths of >1.5m

Source: World Bank (2011).

Damage Assessment (Floods)- Residential … (3)

Residential Income Loss: Affects both residents and migrants

- Income Loss for residents in organized sector not computed
- Income loss for residents in unorganized sector:
  - 90% of HH in the lowest annual HH income bracked (<75,000) are employed in the unorganized sector
  - 50% of HH in the medium annual HH income bracked (75,000 – 150,000) are employed in the unorganized sector
  - 50% of HH in the higher annual HH income bracked (150,000 – 300,000) are employed in the unorganized sector
  - 50% of HH in the income bracket >300,000 are considered in the organized sector

25% of migrant workers coming daily to KMC are in unorganized sector

Migrant workers earn 33% less on average than for an average urban resident worker

Income loss D_t in each income group is give by

$$\mathbf{D_t = I * D_t}$$

I = income per day in each income category

D_t = No. of lost work days due to flooding in each for ward for KMC residents & average for whole ward of KMC area fro migrant workers