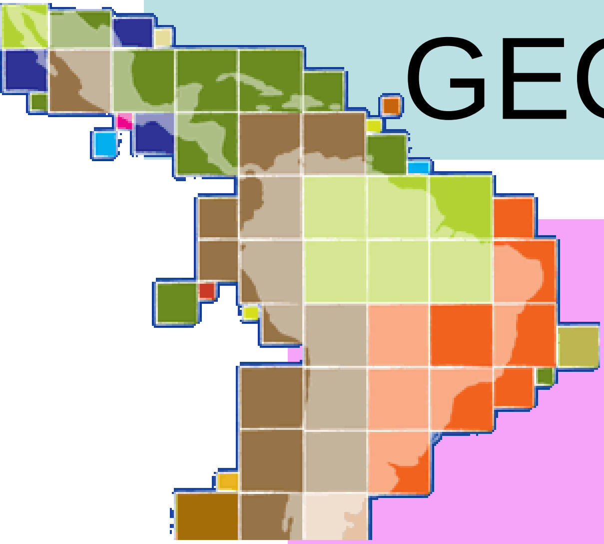


ENVIRONMENTAL GEOMORPHOLOGY



Andrew Goudie
St Cross College
Oxford

GEOMORPHOLOGY 2009
Melbourne, Australia, 7-12 July 2009

St Cross College

QUESTIONS

- Is geomorphology useful?

- Are geomorphologists useful?

BRAZIL - SINAGEO

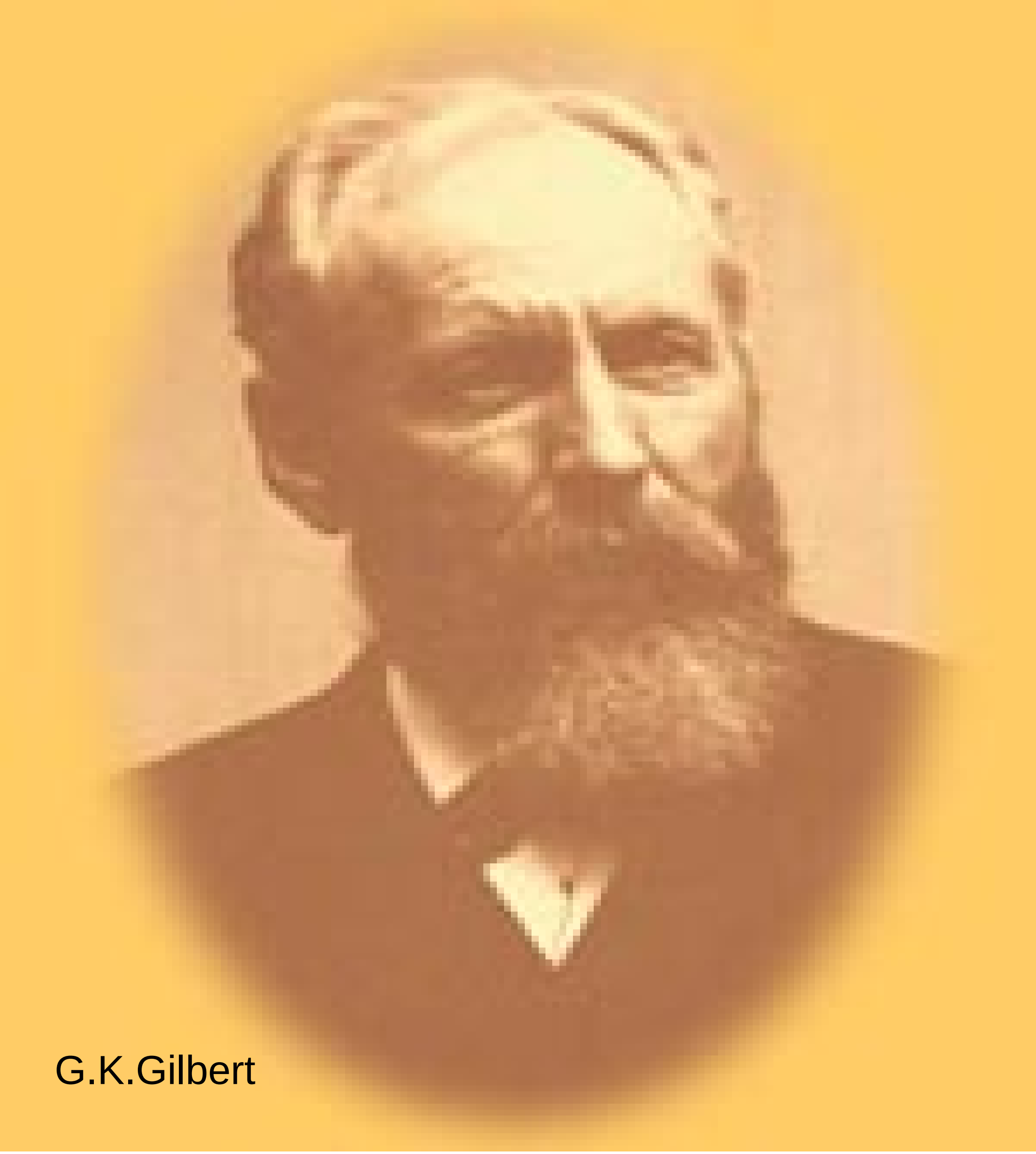
- Desertification & Arenisation
- Eucalyptus plantations and water flow
- Cow erosion
- Flood zoning in Manaus
- Urban effects on landslides and river networks
- Salt weathering of buildings in Rio
- Avulsion of rivers in the Pantanal

SKILLS OF THE PHYSICAL GEOGRAPHER

- Concern with systems & inter-relationships
- Ability to recognize forms & read landscape: ‘an eye for country’
- Distributions & their correlations
- Technical ability – maps, RS, GIS, monitoring
- Knowledge of process
- Recognition of timescales of change
- Areas are different

HISTORY

- 1870s The American West (Powell, Gilbert)
- 1930s The Dust Bowl & TVA (Horton)
- 1950s Resource Development (e.g. CSIRO in Australia)
- 1970s Construction boom in the Middle East, & Environmental Impact Statements
- 1990s Impact of global change
- Current boom in minerals offshore & onshore



G.K.Gilbert

Big Hugh
Bennett

W.S.Chepil

ROLES

1) Mapping of landforms to find hazardous sites, mineral resources, and to describe physical habitat
2) Mapping of other phenomena (e.g. soils) through their association with landform elements

ROLES

3) Identifying rates of change of hazardous phenomena

4) Identifying causes of changes & hazards

5) Predicting and modelling future hazards

6) Post event surveys of hazardous events

ROLES

- 7)Pre construction EIA and post construction surveys and assessments
- 8)Devising management solutions to geomorphological problems and involvement with policy. Hard versus soft solutions. Zoning
- 9)Role in public education and in Geoconservation

MAPPING

- Mapping of resources, hazards, slope angles, trafficability, etc. using base maps, airphotos, walking the ground, etc. to produce a geomorphological map.
- Using landforms to map phenomena related to them (e.g.soils) through catenas and toposequences.


VOLVO
HM

Indonesian tsunami 2004.

October 9, 2005

Debris cones

Pakistan Earthquake

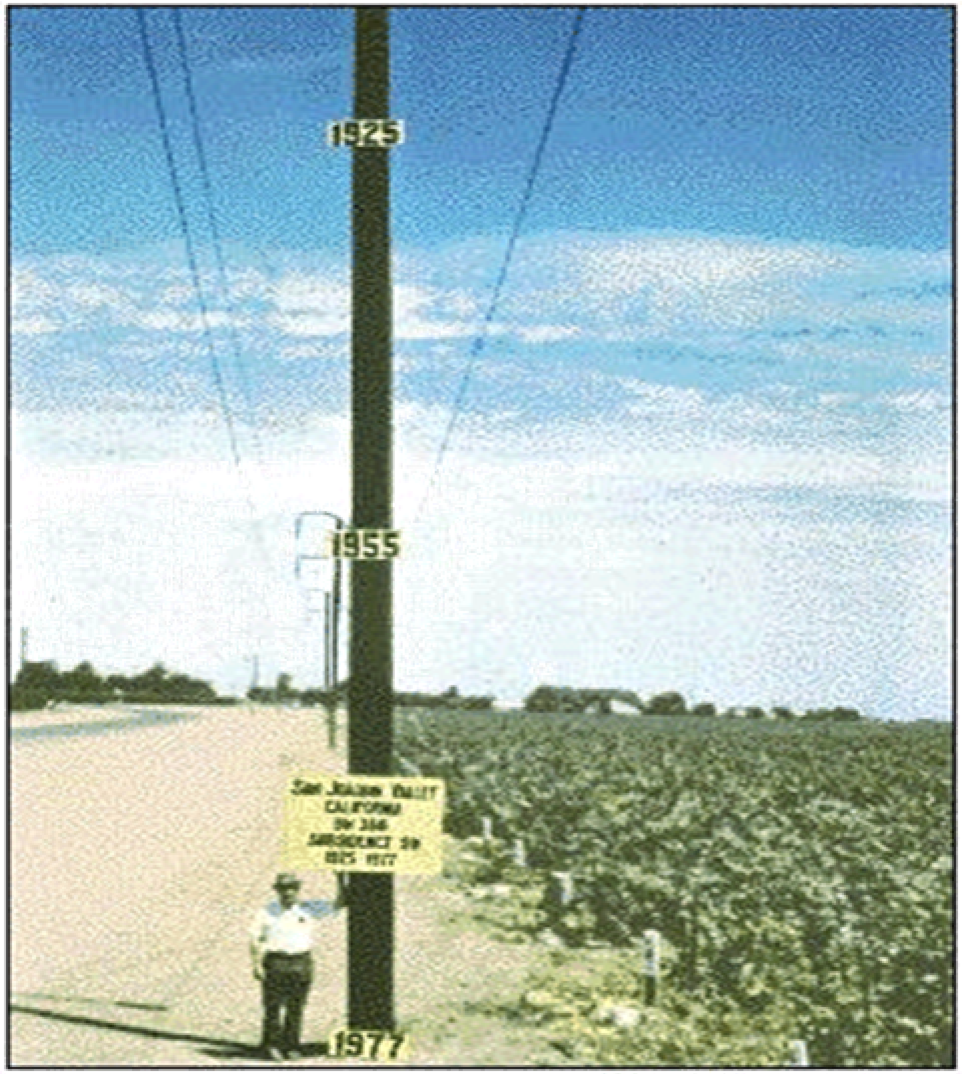
September 15, 2002

GEOMORPHOLOGICAL HAZARDS: deserts

- Dune encroachment
- Soil deflation
- Gully development
- Fan entrenchment
- Flash floods
- Salt weathering
- Dust storms
- Subsidence
- Hydrocompaction

DUST STORM - OUTBACK AUSTRALIA

Figure 94. Some of the most severe recorded land subsidence in history occurred in the western San Joaquin Valley near Mendota, where the land surface has subsided nearly 30 feet.



R. Ireland, U.S. Geological Survey

PERIGLACIAL HAZARDS

- Permafrost decay (thermokarst)
- Pingo/Palsa/Frost heave growth
- Thaw floods
- Glacier surges
- Ice Jams
- Debris flows
- Coast and river bank erosion
- Avalanches

The typical deformed moraine of a surging glacier

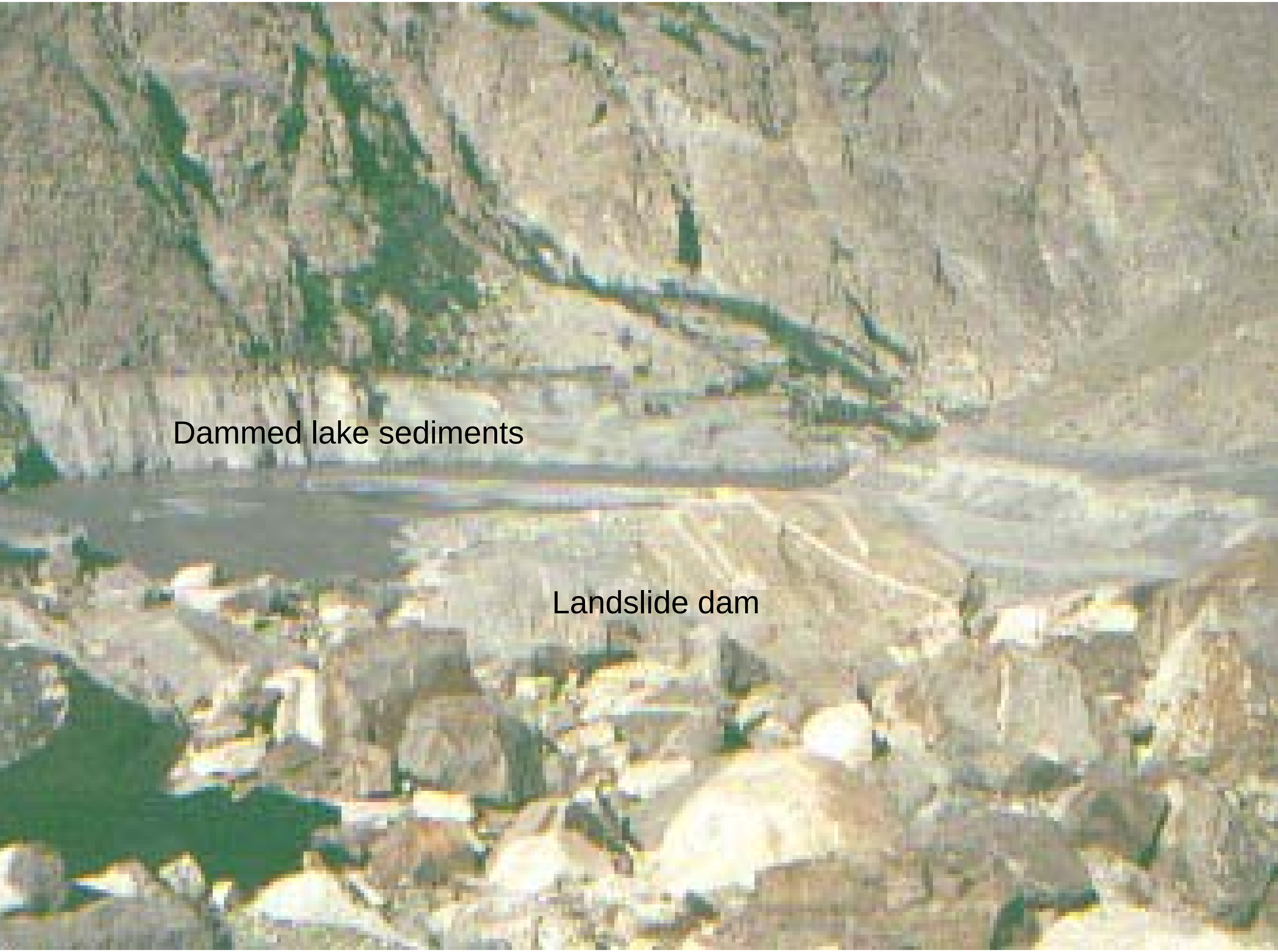
COASTAL HAZARDS

- Sea level change
- Dune decay and encroachment
- Bar formation
- Coast retreat
- Hurricane attack
- Salt marsh invasion
- Tsunami

15 6 2002

HAZARDOUS HUNZA

- Glacier surges
- Enormous denudation
- Enormous siltation
- Glacier dams
- Mudflow dams
- Meltwater channel shifts
- Salt weathering
- Mudflow damage
- Rock falls
- Landslides
- Dust storms

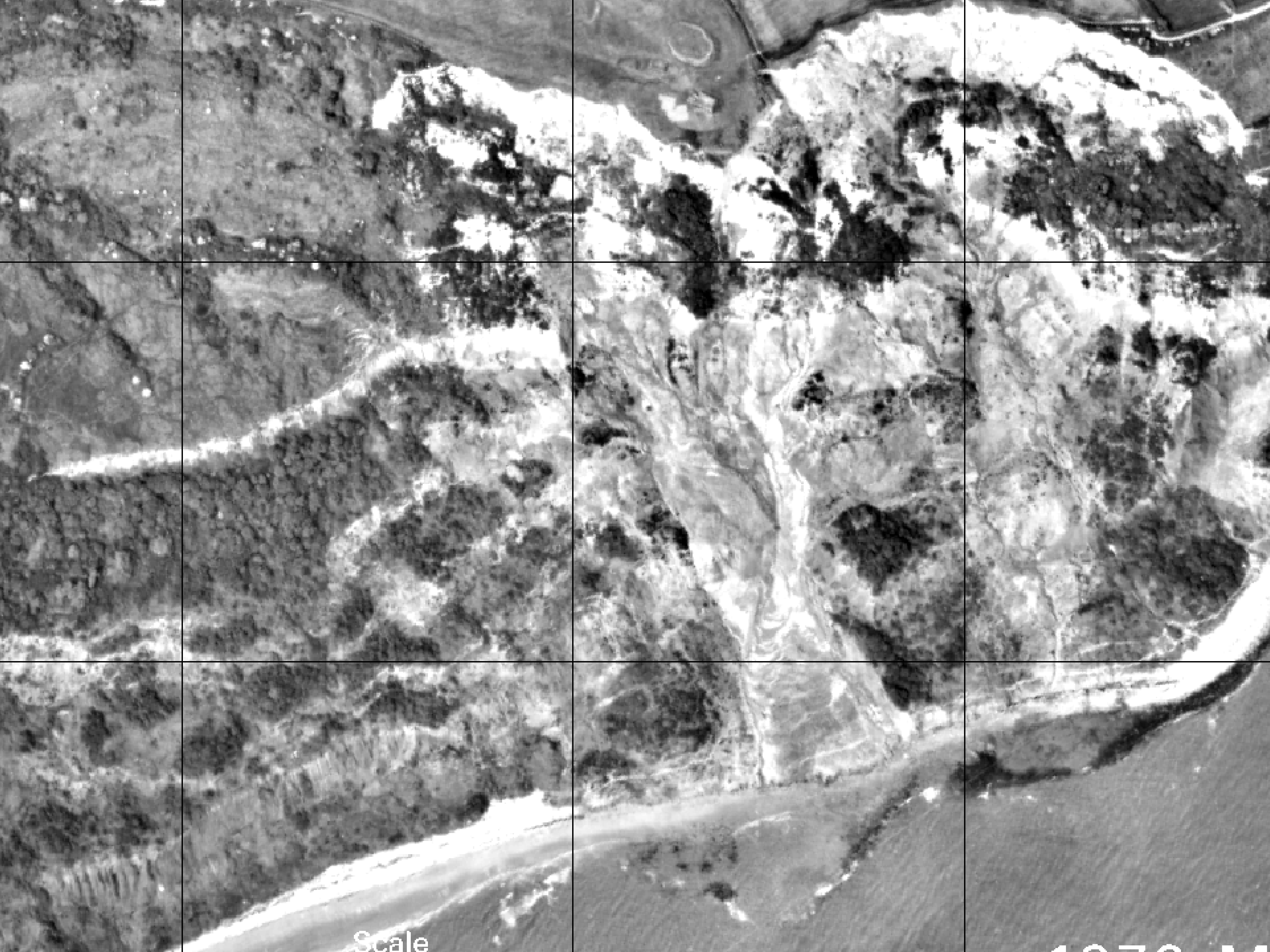

Dammed lake sediments
Landslide dam


Culvert
Mudflow not water flow!

Culvert and boulder

DETERMINING RATES OF CHANGE

- Air photographs
- Remote sensing images
- Sequential maps
- Ground photographs
- Archival descriptions
- GPS and re-survey
- Hardware monitoring
- Sedimentation in swamps, lakes, bogs,etc.
- Archaeological sites


Scale

POST-EVENT ASSESSMENT

- Record nature of an event
- What damage was done to structures?
- What geomorphological change was achieved?
- What were the discharges involved (use of slackwater deposits)?
- Which areas were sensitive and which were not?
- Were there special processes operating?

POST-CONSTRUCTION ASSESSMENT

- Record nature and location of damage
- Record the situations where engineering solutions have proved to be right
- Record those situations where engineering solutions have proved to be wrong


Narrow beach
Landslides
The Cobb
Monmouth Beach
LYME REGIS,
DORSET, UK


LYME REGIS

LYME REGIS

- Built on old landslide complex on Lias Clays
- Beach sediment not being replenished because of Holocene depletion and role of updrift landslide complexes
- Construction of harbour stops longshore drift and disrupts equilibrium shape
- Mining of beach materials
- Advice on solutions

EARTHQUAKE ZONING

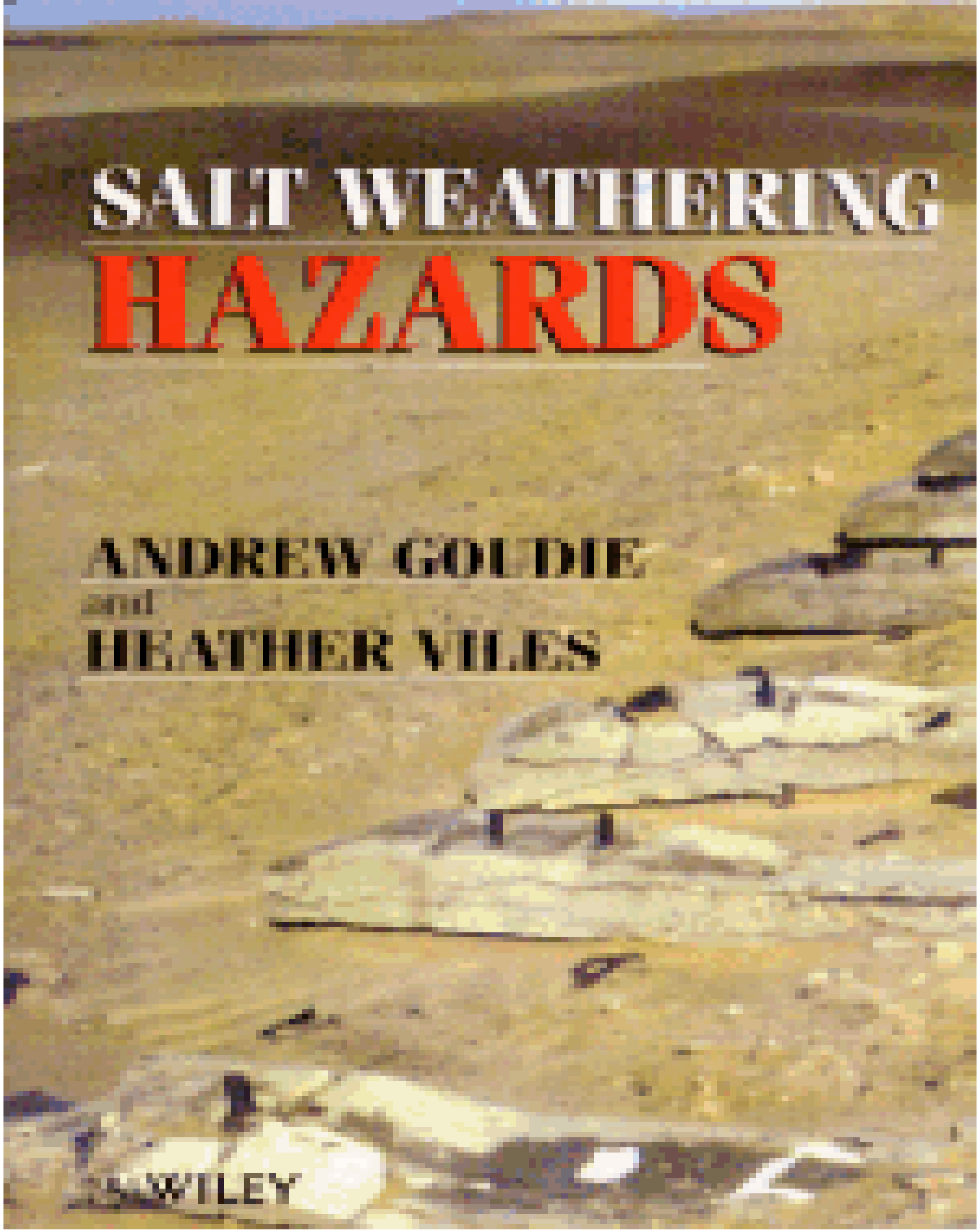
- Artificial fills, unconsolidated materials, wet areas
- Karst
- Liquefaction prone areas
- Faults and Rock contrasts
- Mass movement zones
- Tsunami zones

NEOTECTONICS

- Deformation of river terraces & shorelines
- River course offsets
- Changes in river channel form
- Elevated coral reefs
- Displacement of man-made structures
- Dated sag ponds
- Changes recorded by GPS, tide gauges, repeat levelling, etc.

FLOOD PLAIN ZONING

- Geomorphological features: active channels, point bars, oxbows, levees, backswamps, splays
- Topographical surveys
- Old high flood levels: damage, historical records, lichens, cracked boulders, broken trees, trash, air photos
- Soil development
- Vegetation assemblages



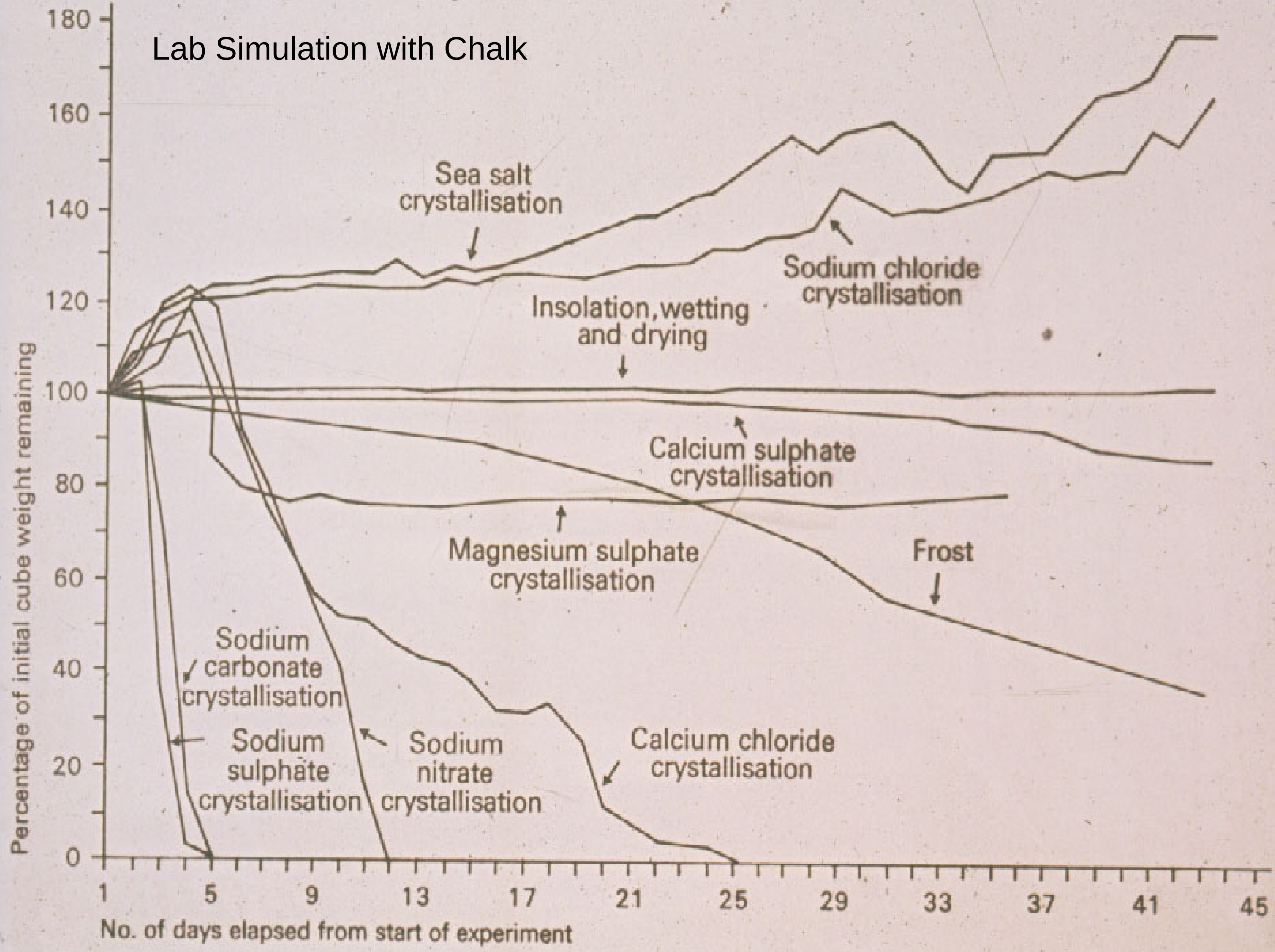
SALT WEATHERING
HAZARDS

ANDREW GOUDIE
and
HEATHER VILES

WILEY

EQUIPMENT WORKING OVERNIGHT

Lab Simulation with Chalk



SALT HAZARD ASSESSMENT

- Where is the damage?
- What are the controls? Salinity, nature of salts, groundwater depth, nature of ground materials
- Lab. assessment of resistant materials
- Finding of resistant materials
- Sensitive areas – zoning maps
- Other solutions

AGGRESSION

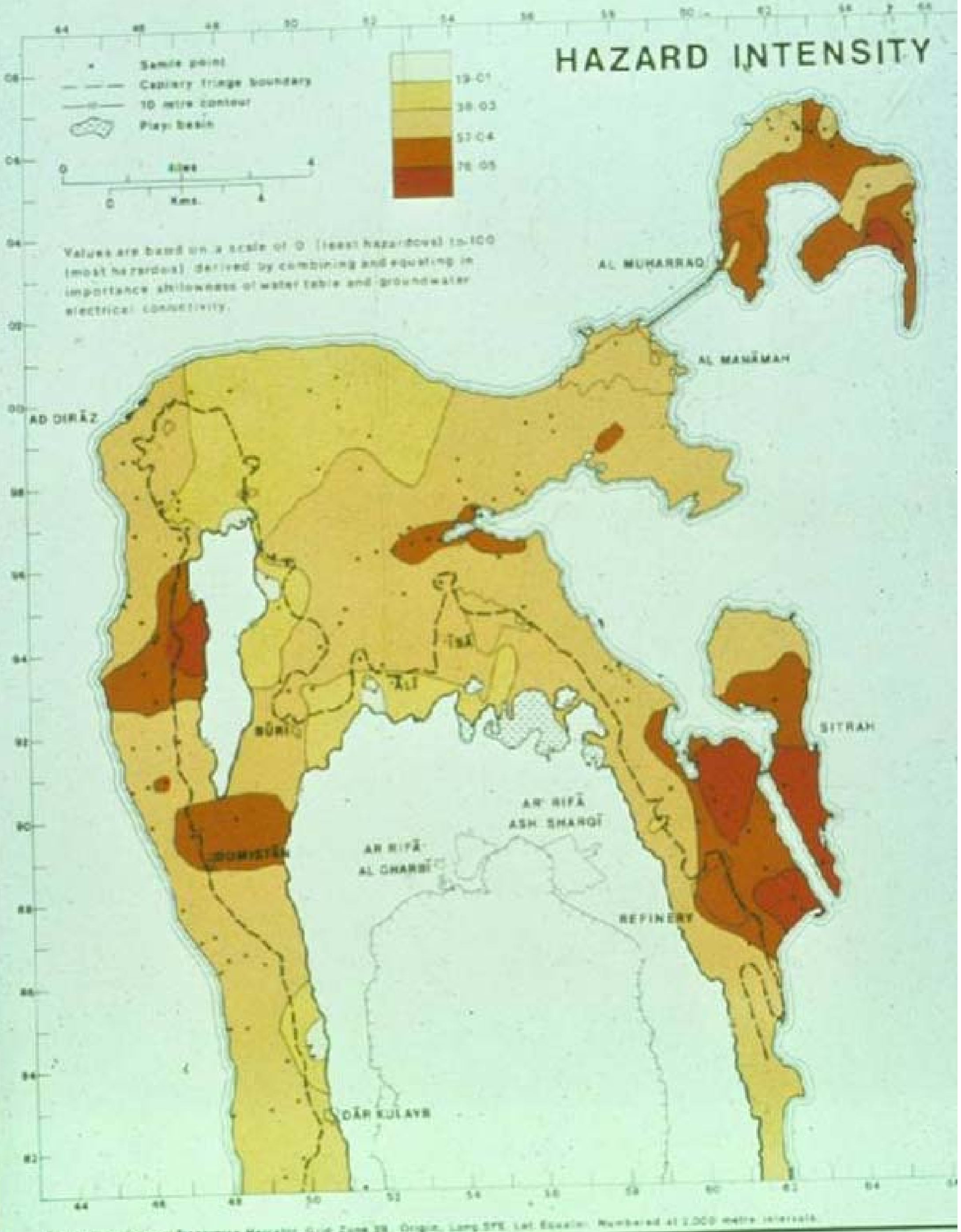
- Some salts are highly aggressive, especially salts that hydrate such as sodium sulphate, magnesium sulphate and sodium carbonate.
- These expand some 300% on hydration

Namibia pipeline

Bahrain nurses home

Sir Ronald Cooke

HAZARD INTENSITY



Values are based on a scale of 0 (least hazardous) to 100 (most hazardous) derived by combining and equating in importance shallowness of water table and groundwater electrical conductivity.

GRID DATA – Universal Transverse Mercator. Grid Zone 39. Origin, Long 51°E. Lat Equator. Numbered at 2,000 metre intervals.

MASS MOVEMENT PREDICTION

- Maps of previous landslide occurrence
- Maps of risk based on GIS and incorporating geology, relief, groundwater, vegetation, etc.
- Dating of past events (e.g. using dendro)
- Measurement of shear strength of materials to establish factor of safety etc.

LANDSCAPE INTERPRETATION

- The explanation of diverse and beautiful landscapes to the general public
- Nature trails
- Boards
- Interpretation centres
- Websites

WESTERN USA ANNUAL VISITORS (millions)

Badlands	1.02
Bryce Canyon	1.75
Canyonlands	0.44
Capitol reef	0.65
Death valley	1.2
Grand Canyon	4.6
Yosemite	3.8
Arches	0.84
Zion	2.4

GRAY on VALUING GEODIVERSITY

- Intrinsic or Existence value
- Cultural value to society (including spiritual value)
- Aesthetic value – visual appeal
- Economic value (e.g. tourism, resources)
- Functional value in Earth Systems
- Educational and research value

GRAY (2004, p. 348)

‘Geodiversity underpins biodiversity and its life-support system, therefore creating an inextricable link between the two’.

LANDFORMS AS HABITAT

- Particular landforms are habitats, so that the protection of existing landforms or the reconstruction/reclamation of damaged landforms can be an important contribution to maintaining biodiversity
- Creation of new landscapes (e.g. quarries) that are in harmony with the geomorphological environment.

THREATS TO GEODIVERSITY

- Mineral extraction
- Landfill and quarry reclamation
- Land development and urban expansion
- Coastal erosion & protection
- River management (e.g. channelisation)
- Vegetation removal or afforestation
- Agriculture
- Recreation and tourism
- Military activity
- Future Climate change

GEOCONSERVATION

- UNESCO World Heritage Sites
- IUGS/UNESCO Global Geosites
- Geoparks
- US National Parks, National Natural Landmarks, National Wild & Scenic Rivers, State Parks, etc.

Current international initiatives to promote, protect and conserve geoheritage

World Heritage of UNESCO

PATRIMONIO MUNDIAL • WORLD HERITAGE • PATRIMOINE MONDIAL

UNESCO Geoparks

UNESCO
GLOBAL
GEOPARKS
NETWORK

ProGeo activity

ProGEO
The European Association for the
Conservation of the
Geological Heritage

IAG Geomorphosites Working Group

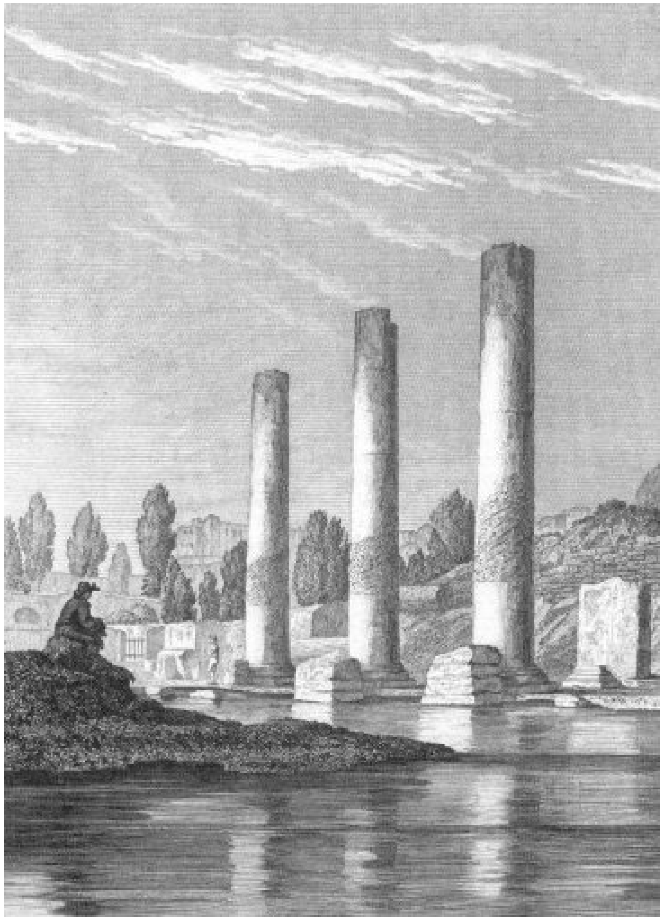
GEOMORPHOLOGY
GEOMORPHOLOGIE

Special events, e.g. International Year of the Planet Earth

planetearth®
Earth Sciences for Society

Sites under review 2007/8 with a geomorphological component for which IAG reviewers have been suggested

- Pirin, Bulgaria (Glacial lakes, etc.)
- Mount Sanqingshan, China (Granite landforms)
- New Caledonia (Reefs and lagoons)
- Surtsey, Iceland (Volcanic and coastal evolution)
- Phlegraean area, Italy (Sea-levels)
- Hovsgol Lake, Mongolia (Permafrost and lakes)
- Putorana Plateau, Russia (Basalt terrain)
- Glarus, Switzerland (Overthrust tectonics)



Should geomorphologists take a lead?

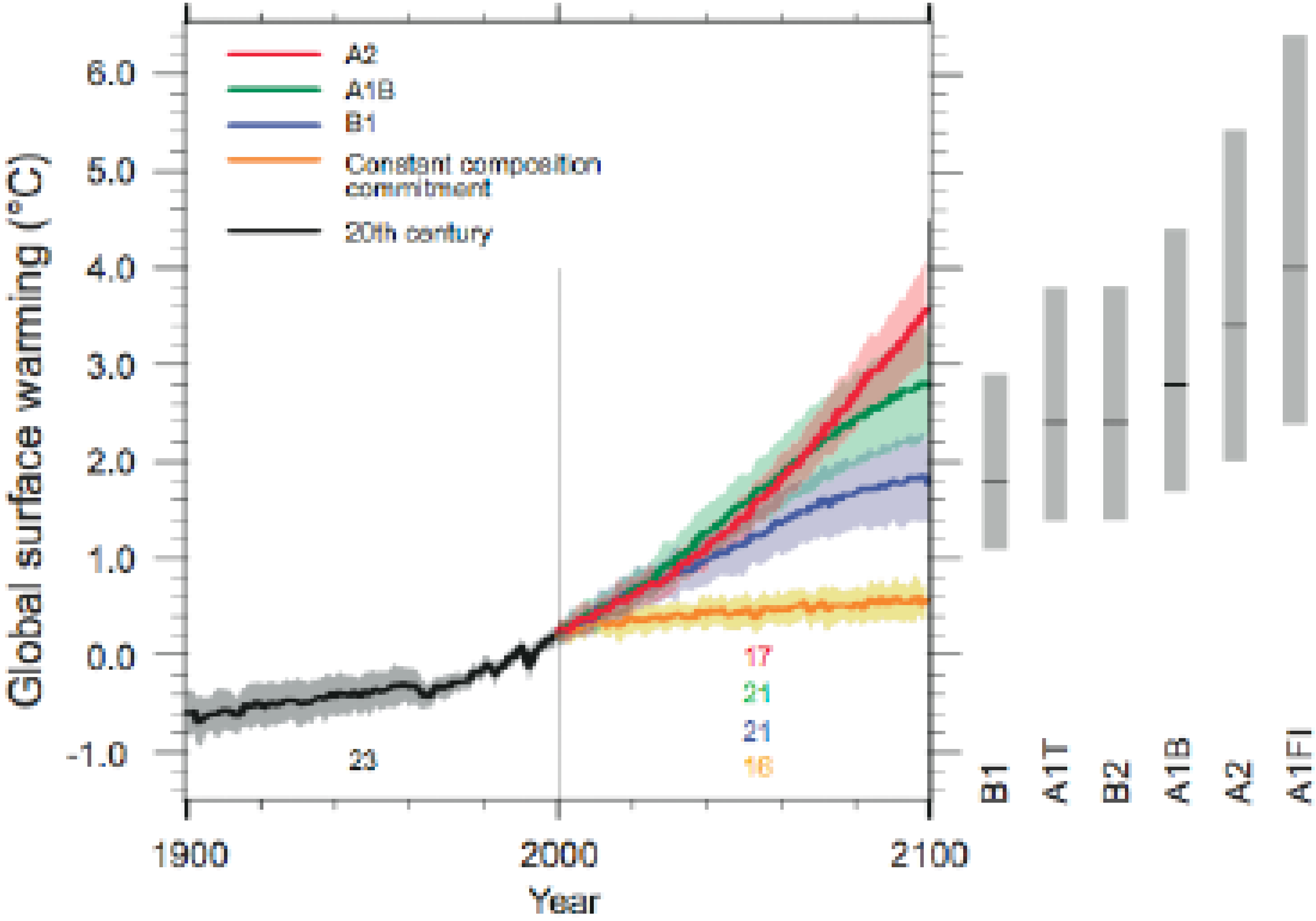
What is missing on the World Heritage List (examples) ?

1. Inselbergs and granite weathering features of Central Namibia
2. Paricutin volcano, Mexico
3. Wadi Rum sandstone terrain, Jordan
4. Gypsum karst, Ukraine
5. Limestone pavements, Burren, Ireland
6. Cockpit karst, Jamaica
7. Badlands, South Dakota, USA
8. Okavango inland delta, Botswana

GLOBAL CHANGE HOTSPOTS

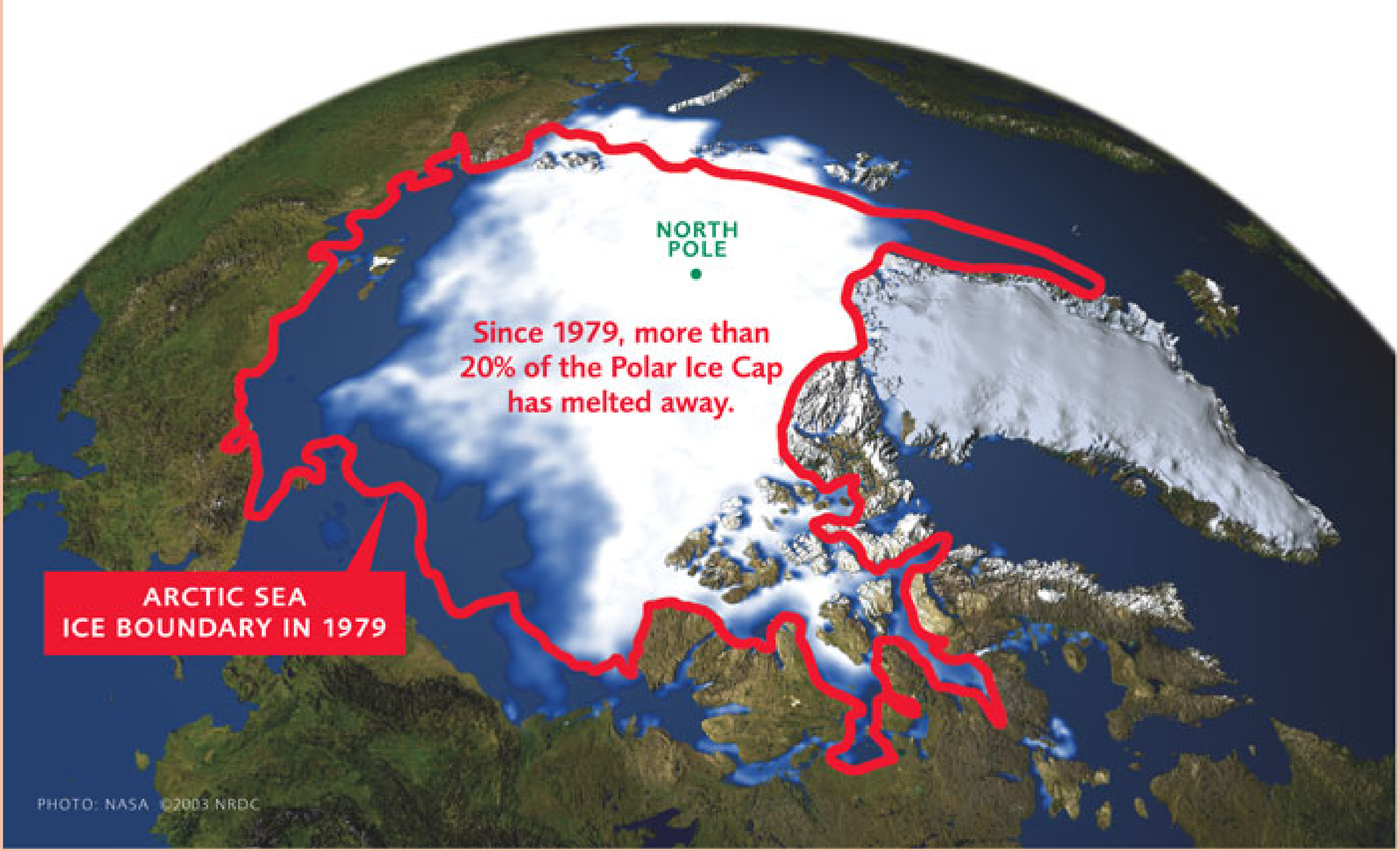
- Severe changes predicted (e.g. High latitudes, High Plains of USA)
- Sensitivity because of fragility
- Sensitivity because of position (e.g. Bangladesh)
- Sensitivity because of thresholds (e.g. dune movement in High Plains of USA, coral bleaching, melting of permafrost)

IPCC 2007

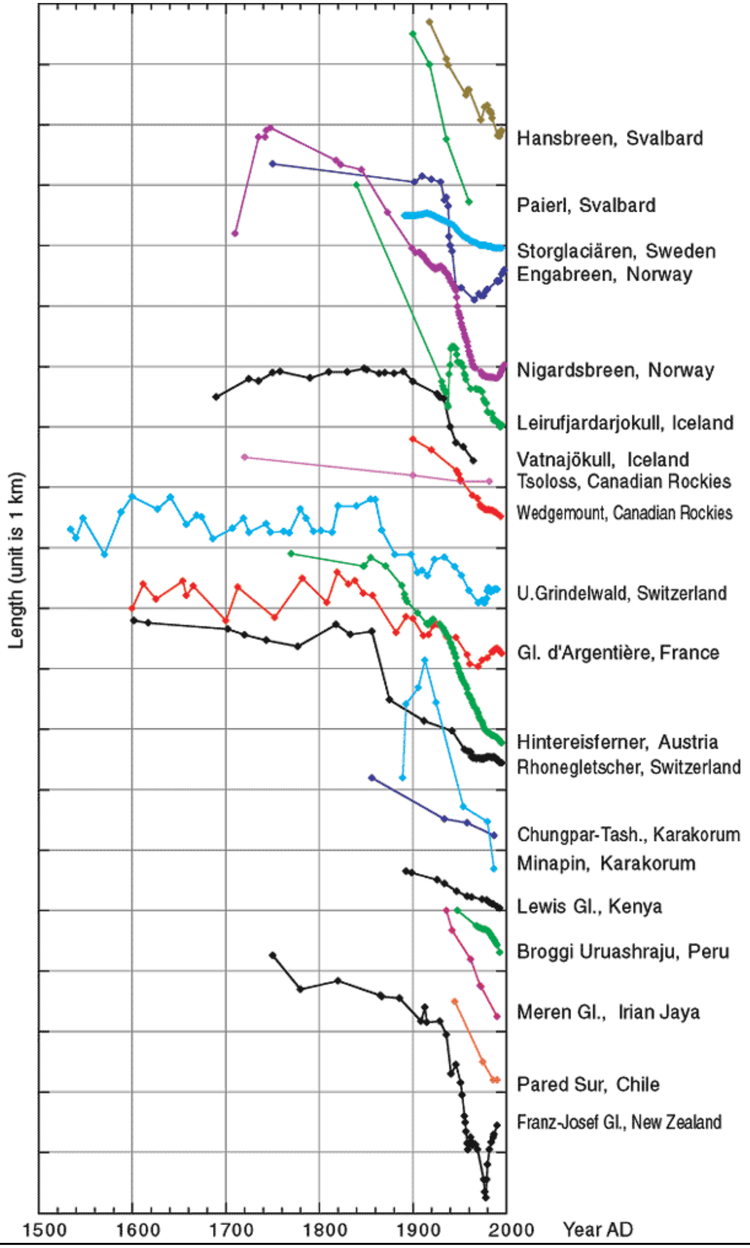


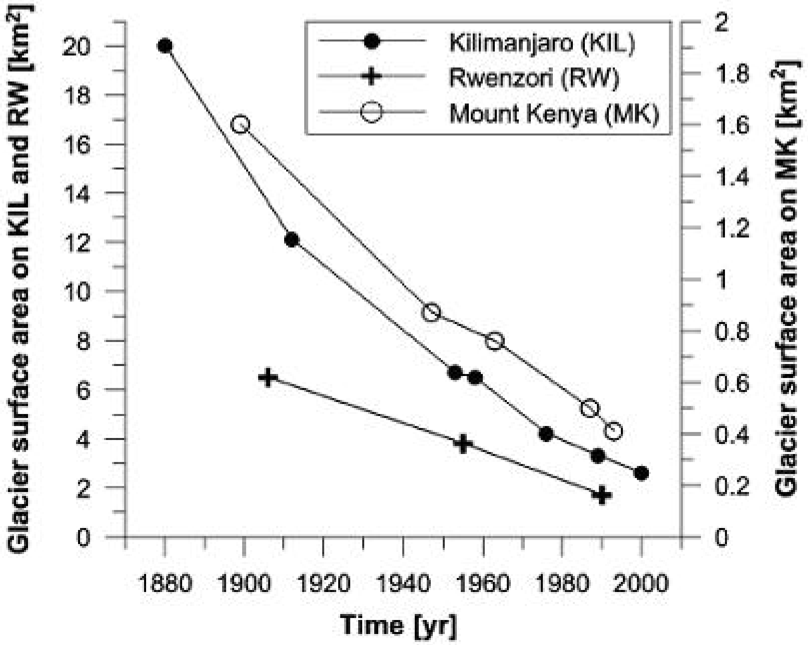
Warming scenarios

IT HAS ALL STARTED TO HAPPEN

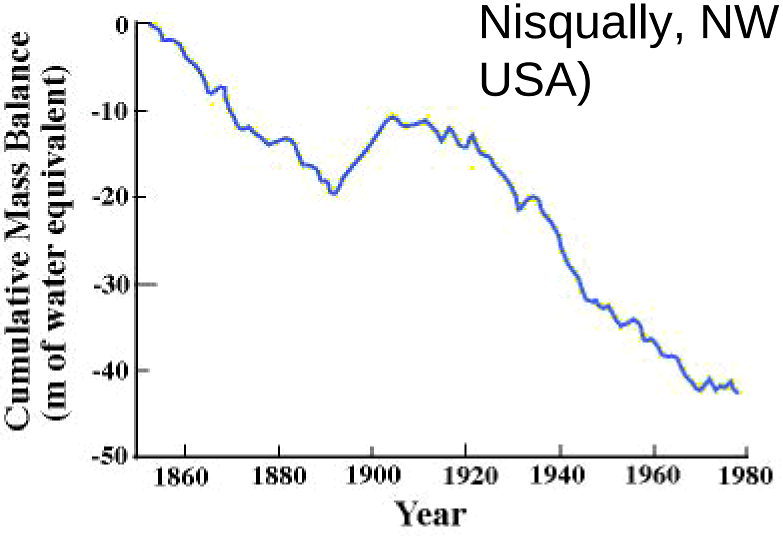


GLACIER RETREAT

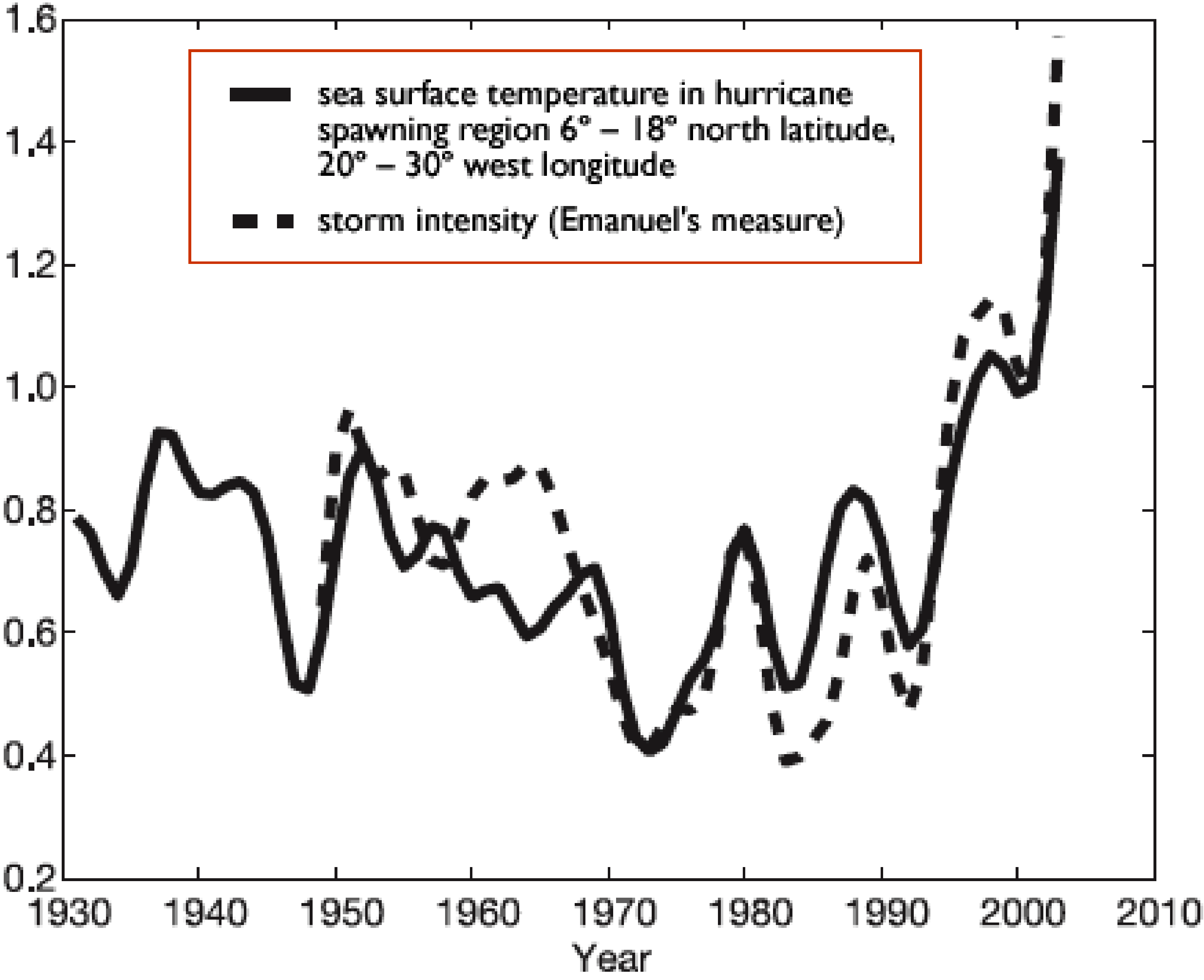




Nisqually, NW USA)



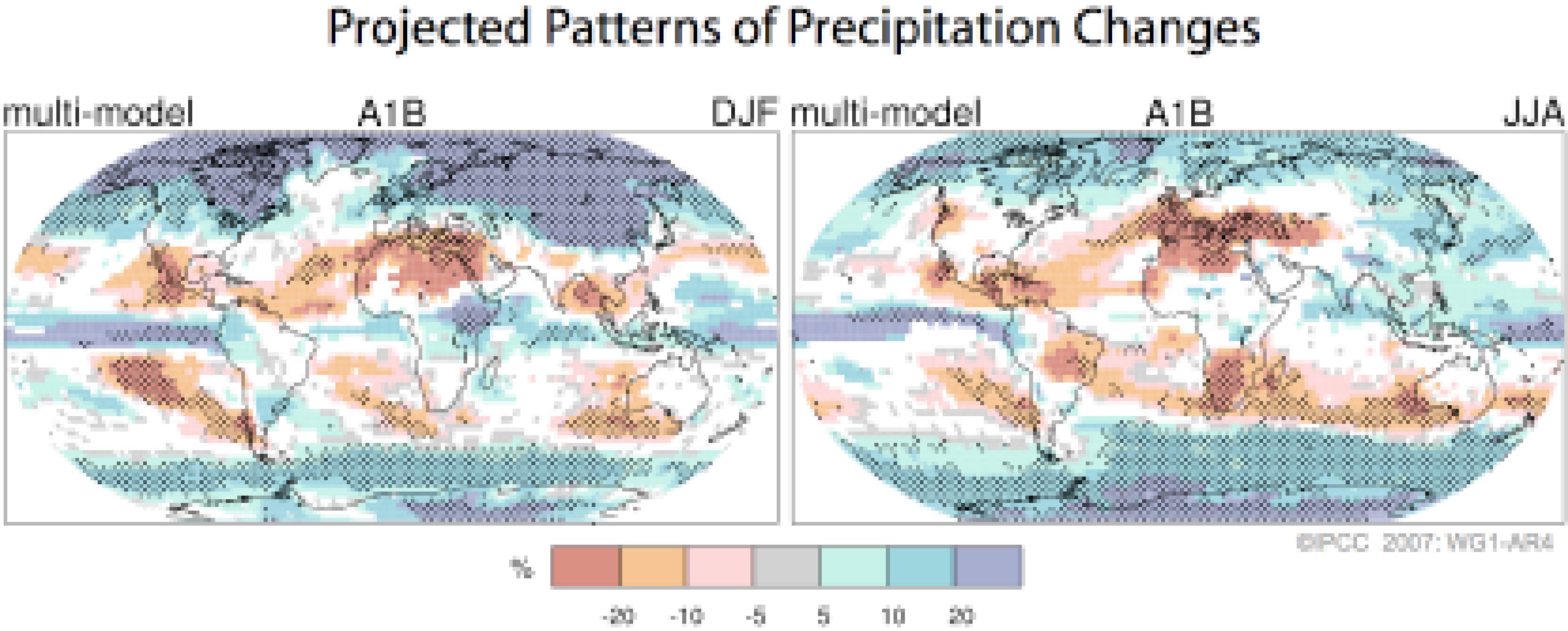
Hurricane intensity vs. ocean temperature



HOT SPOTS

- Ice bodies sensitive to wave attack as ice shelves retreat
- Valley glaciers
- Permafrost – negative mean annual temperatures
- Dunes at vegetation threshold
- Coral reefs in hot water – 30^{o}C threshold
- Hurricane prone coasts – 27^{o}C threshold

IPCC 2007



Projected Patterns of Precipitation Changes

FIGURE SPM-6. Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {Figure 10.9}

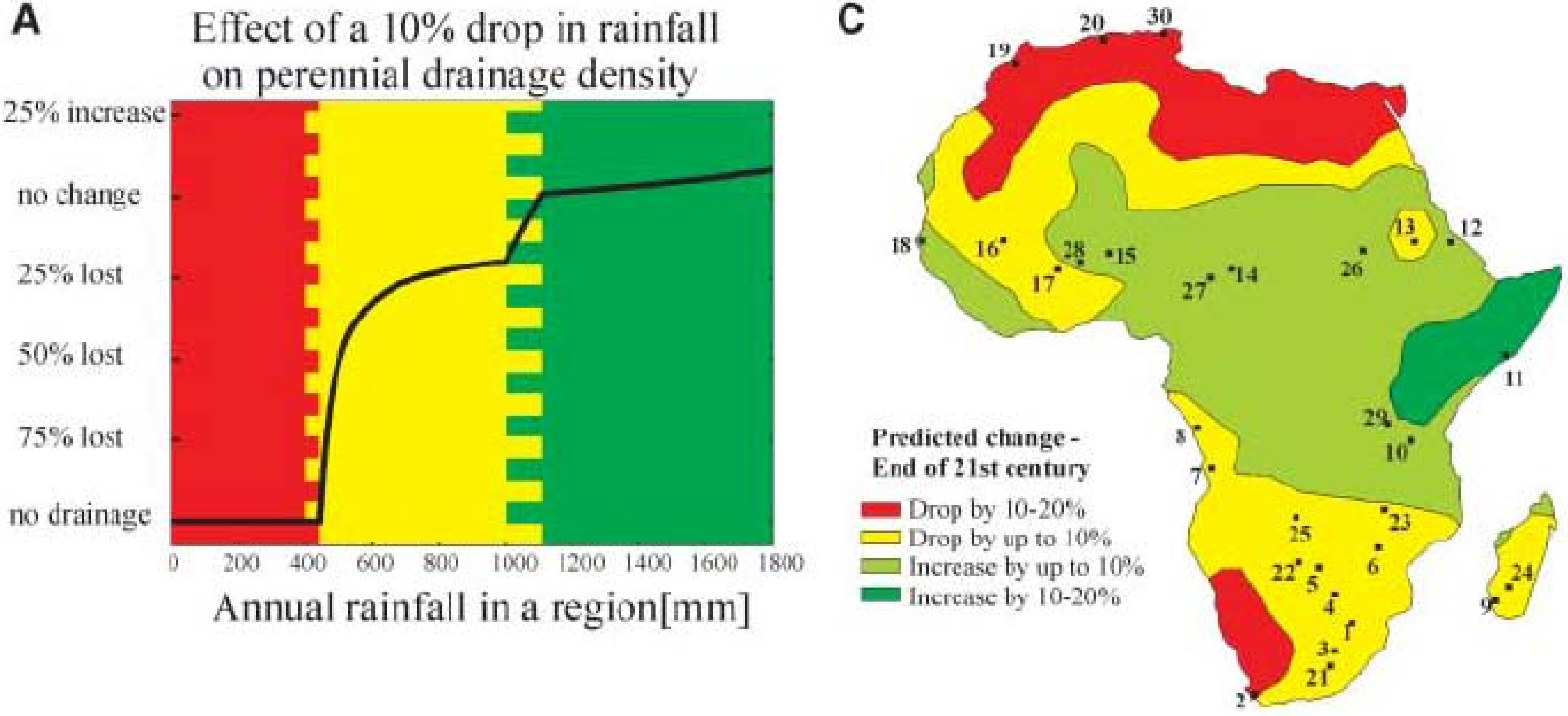
Amazonia Drought (2005) and potential forest die-back

AMAZONIA

- Of the 23 global climate models employed by the IPCC 2007, 50-70% predict a >20% reduction of dry-season rainfall in E. Amazonia, 40% in central Amazonia and 20% in the west (Malhi).
- The Hadley Centre model suggests that precipitation averaged across Amazonia *could* be reduced from c 1800 mm to 1100 mm by the 2040s.

AMAZONIA CONTINUED

- Soil moisture could re reduced by a temperature rise of c 3.3 degrees this century
- Forest removal by deforestation and increasing fires could lead to local climate effects due to changes in albedo, roughness of canopy surface, reduced moisture inputs to air from evapotranspiration, etc.



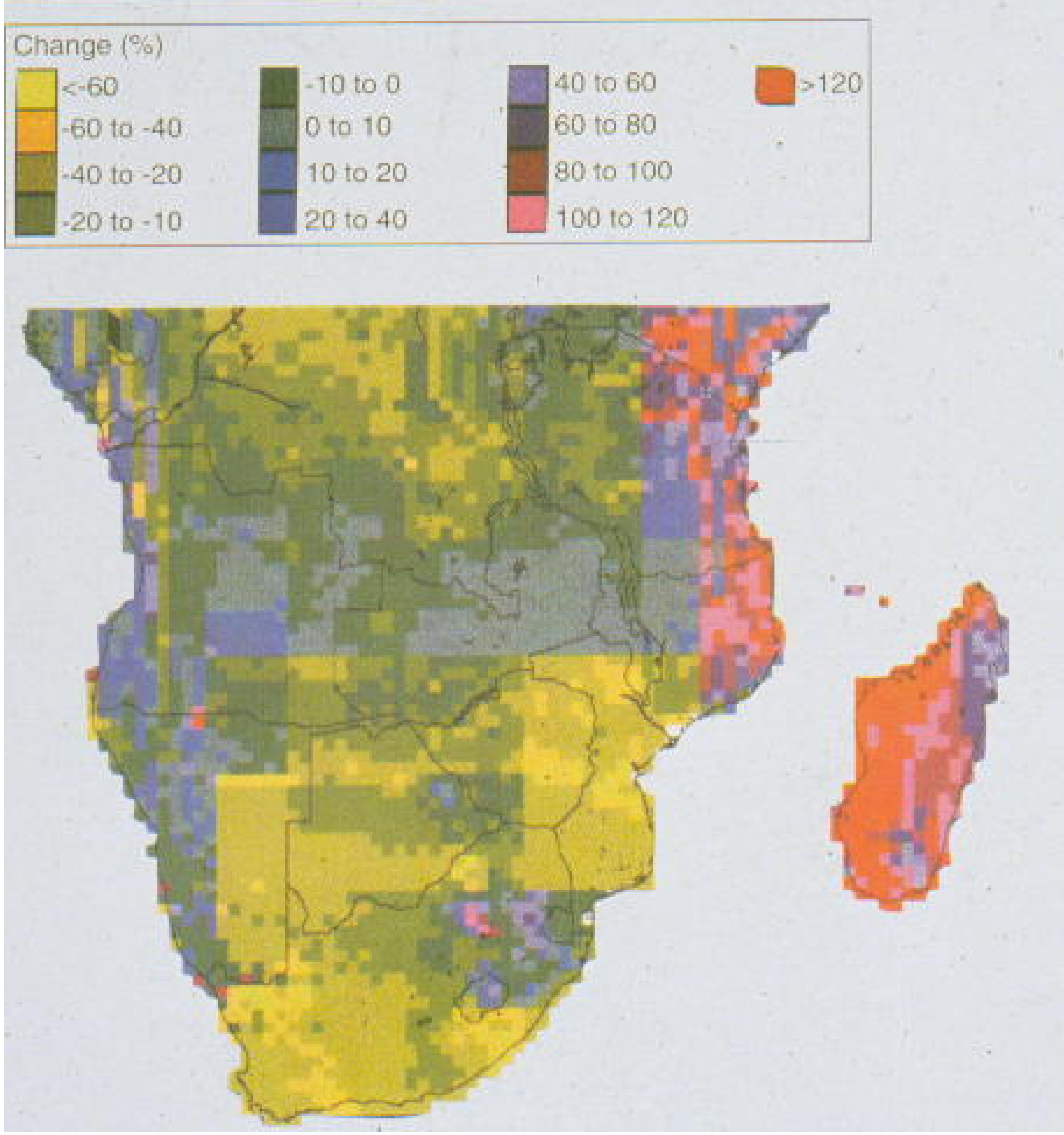
De Wit and Stankiewicz, *Science*, 2006.

PRECIPITATION CHANGE

- Overall global increase
- Some intensification of tropical circulation
- Northward displacement of sinking Hadley cell air
- Increase in UK winter rainfall and decrease in summer rainfall
- More moisture availability in cold regions
- Changes in rainfall intensity

STREAM RUNOFF

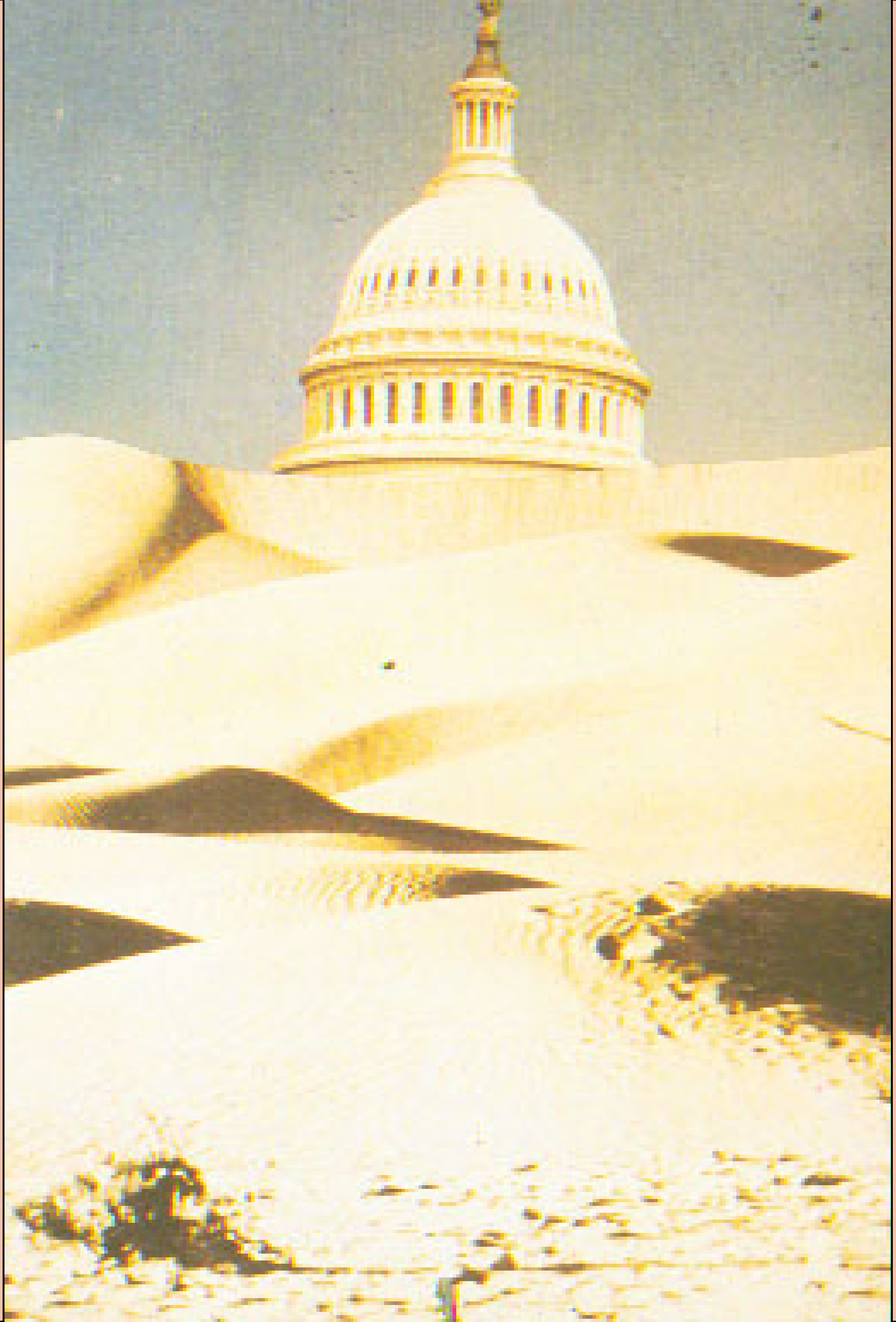
- In arid regions, an increase of temperature by c 2 degrees, and a reduction in precipitation of c 10% can lead to a discharge reduction of c 60 or more %.



Hadley Centre predictions of change in runoff by 2050

Sheffield and Wood, *Climate Dynamics*, 2008

‘Under the future projections, the models show decreases in soil moisture globally for all scenarios with a corresponding doubling of the spatial extent of severe soil moisture deficits and frequency of short-term (4-6-month duration) droughts from the mid-twentieth century to the end of the twenty-first. Long-term droughts become three times more common. Regionally, the Mediterranean, west African, central Asian and central American regions show large increases notably for long-term frequencies as do mid-latitude North American regions.’



A new Dust Bowl?

A black blizzard in the dirty thirties

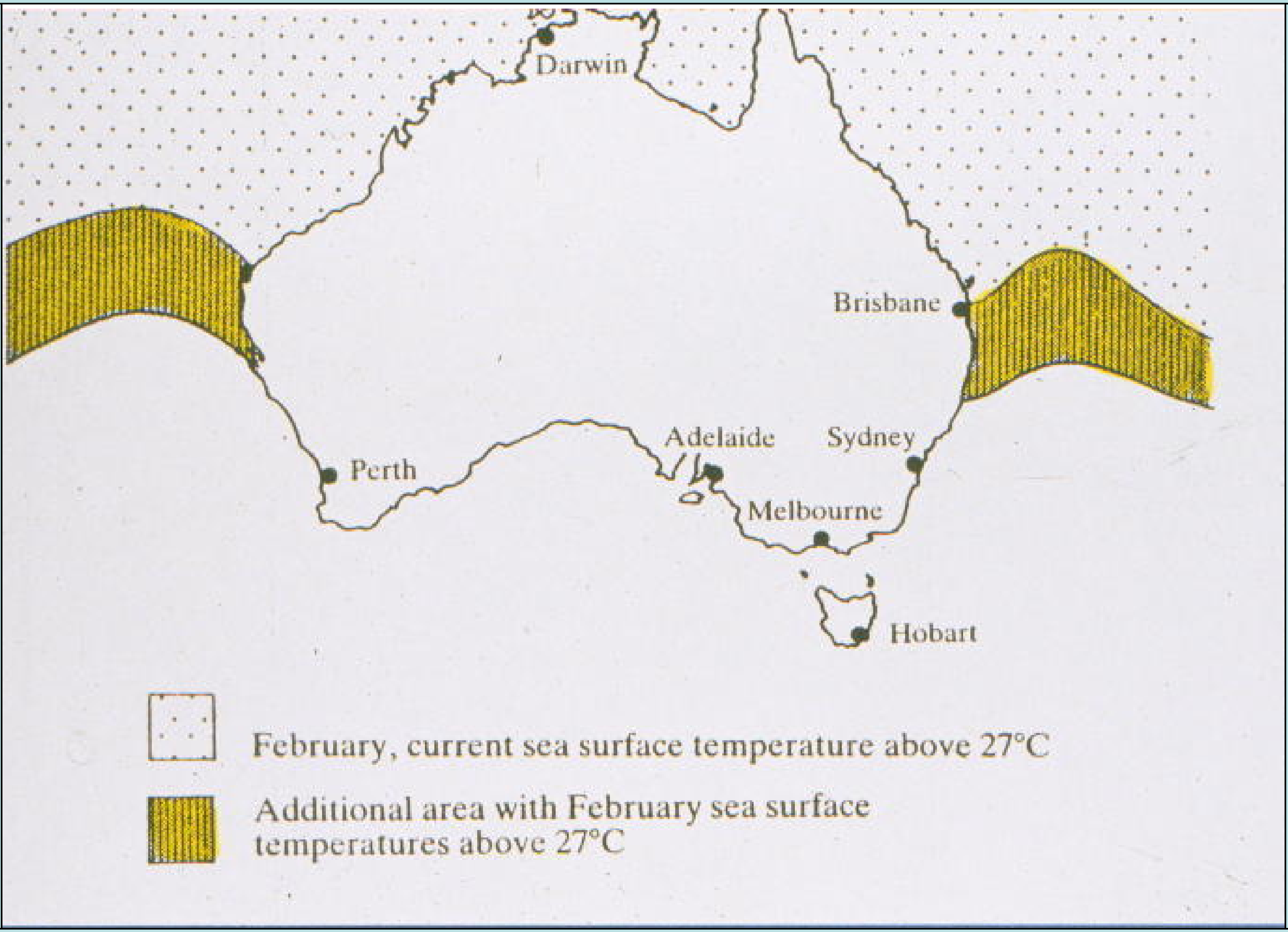
DUNE REACTIVATION

- Holocene history of instability
- The lesson of the Dust Bowl
- Stores of available surfaces as result of past climates
- Critical nature of rainfall/vegetation threshold for wind action

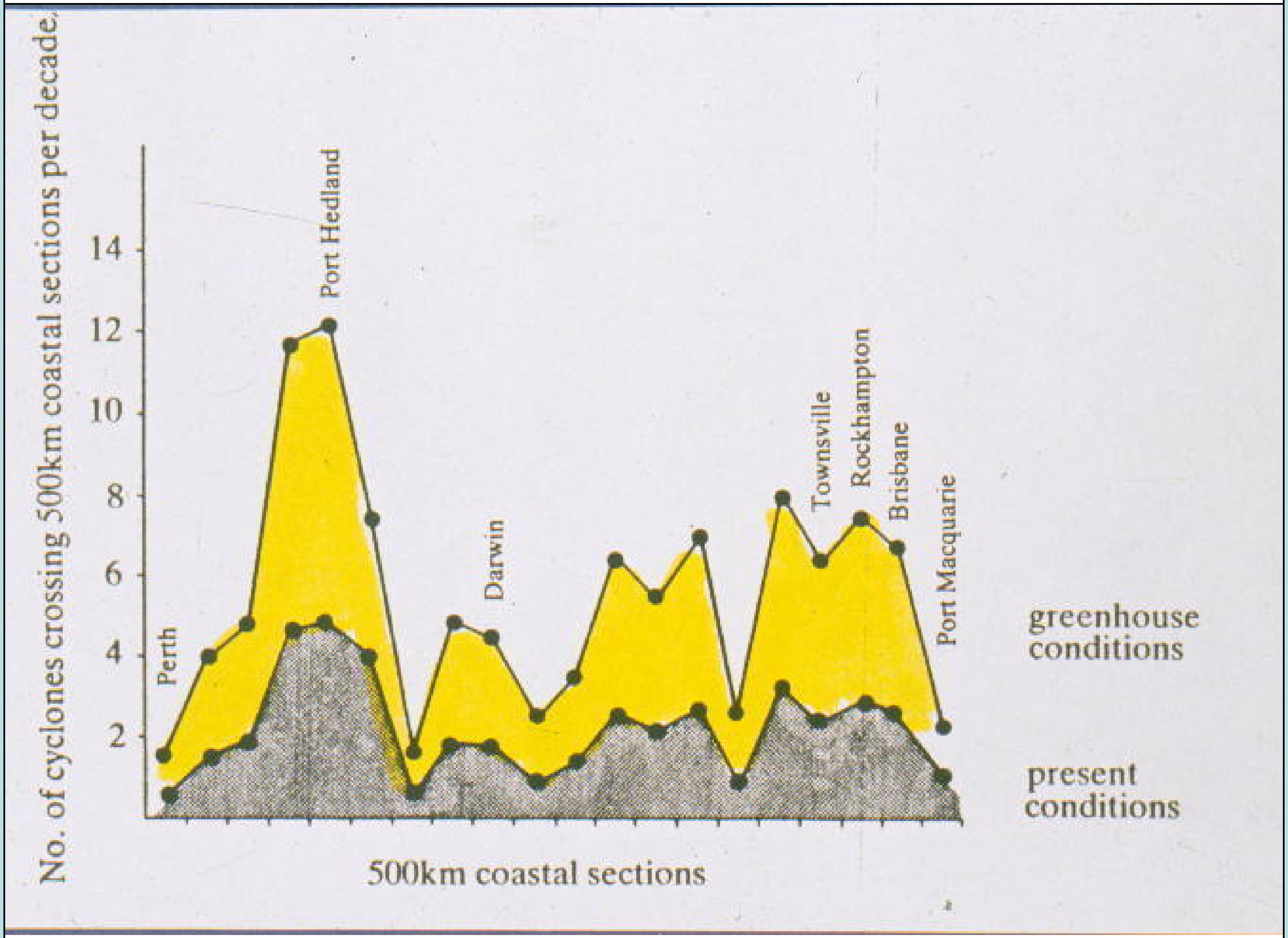
The Mega-Kalahari

- Modelling by David Thomas suggests that from South Africa to Angola the whole Kalahari sandveld could be re-activated


Los Mochis
La Paz
zatlan


Darwin
Brisbane
Perth
Adelaide
Sydney
Melbourne
Hobart
February, current sea surface temperature above 27°C
Additional area with February sea surface temperatures above 27°C

AUSTRALIAN CYCLONES UNDER GREENHOUSE CONDITIONS



HURRICANES

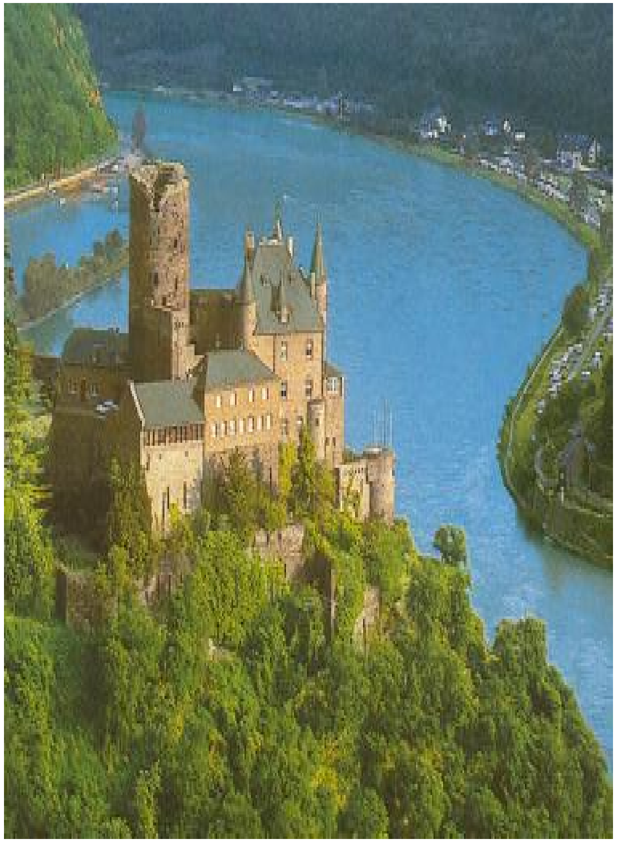
- Sea water temperature threshold of 27^oC
- Increase in geographical spread?
- Increase in intensity?
- Increase in frequency?
- Warm water is not the only control of hurricane formation

HURRICANE EFFECTS

- Slope destabilisation
- Scouring of river channels
- Inputs of sediment into reefs and lagoons
- Raised sea level – storm surges
- Increased wave attack on atolls, etc.

THE RHINE – SHABALOVA ET AL

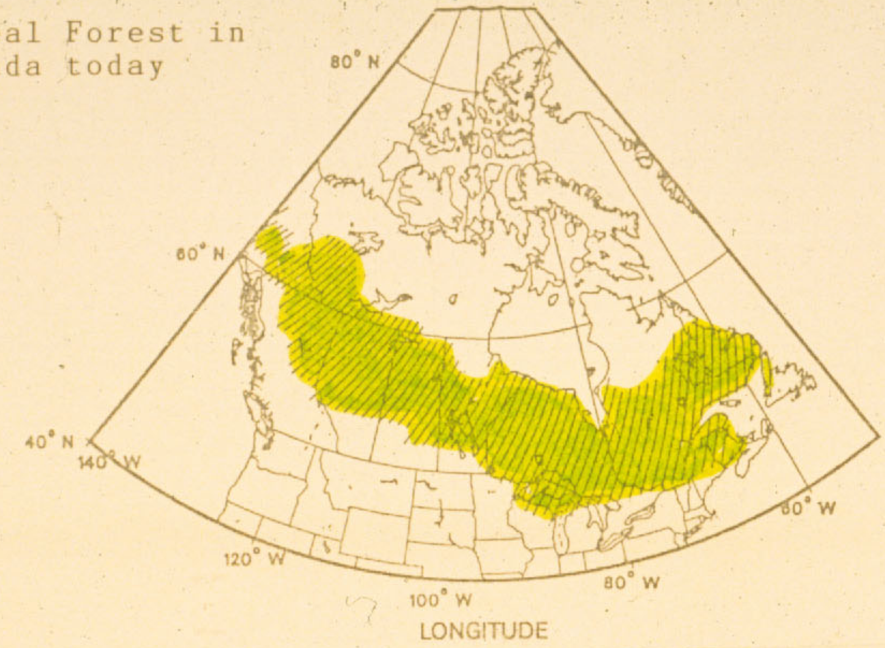
- The Rhine’s discharge will become markedly more seasonal with mean discharge decreases of about 30% in summer, and increases by about 30 percent in winter by the end of the century
- The summer decrease is due to decrease in precipitation + increase in evapotranspiration
- The winter increase is caused by increased precipitation, reduced snow storage and increased early melt



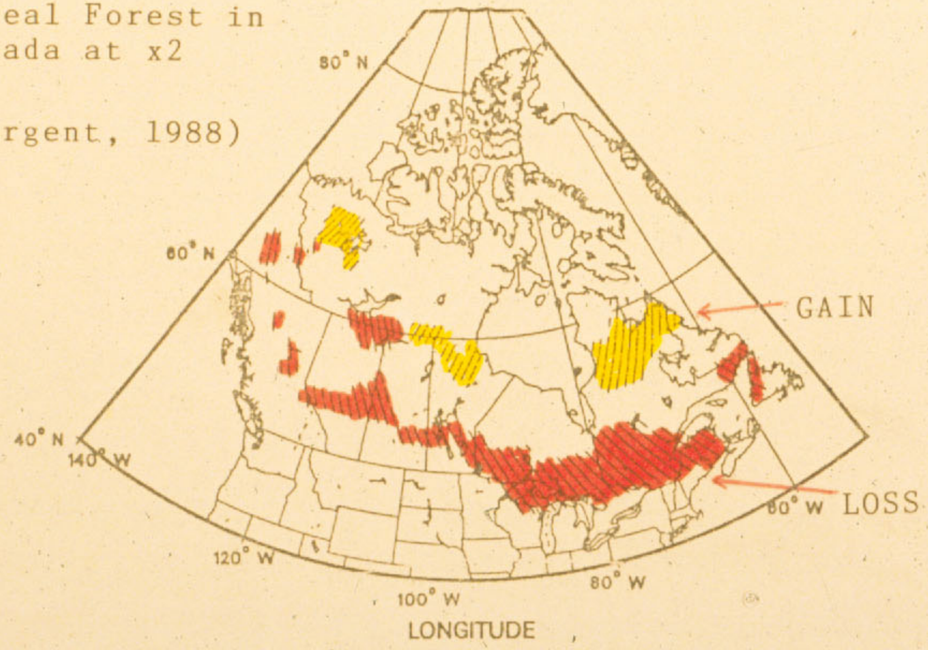
ALTITUDINAL SHIFT IN VEGETATION

- Lapse rates suggest that vegetation will shift c 180 m for every degree rise in temperature
- This implies that vegetation belts (and snowlines, etc.) will migrate by some hundreds of metres.

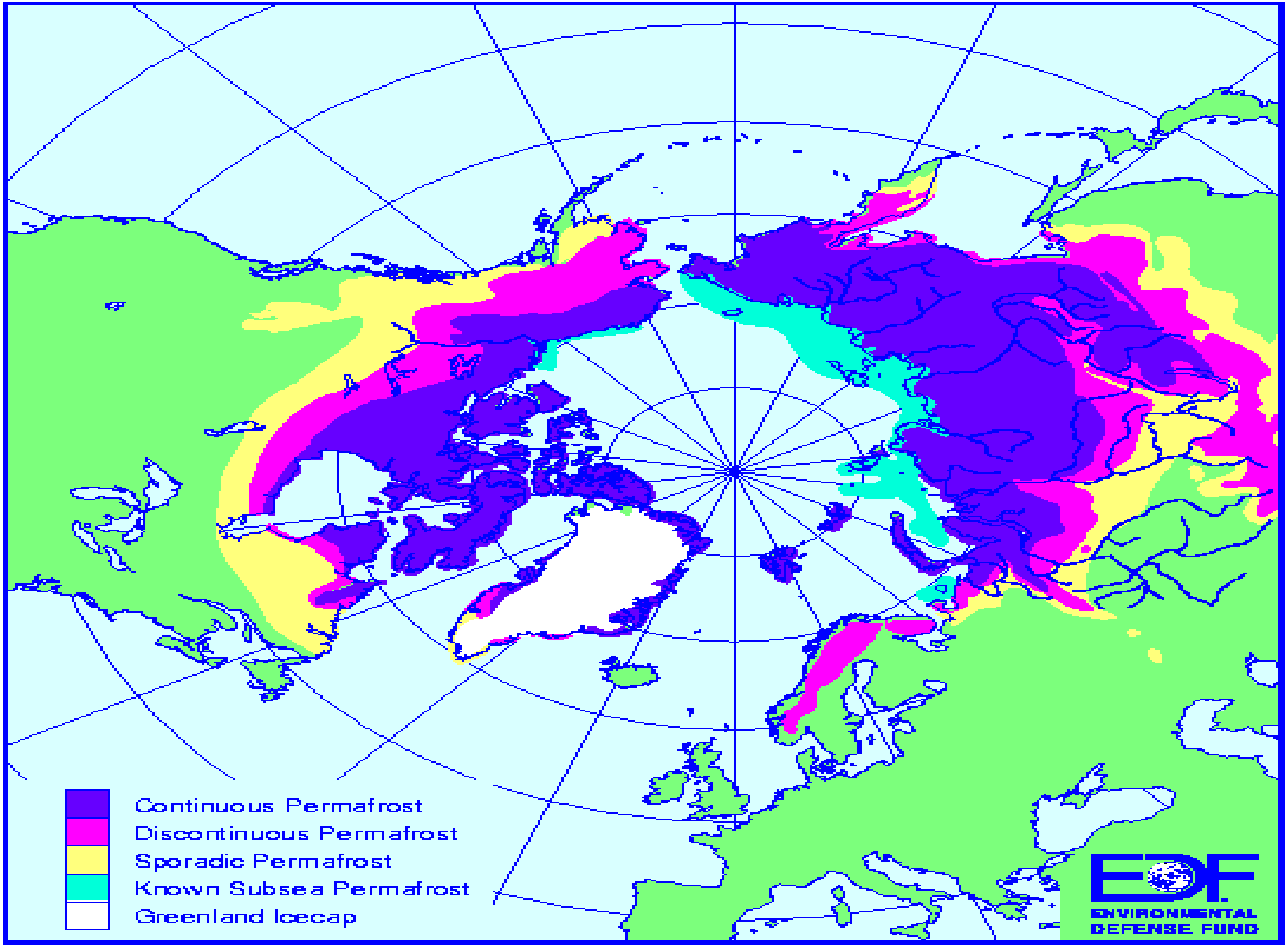
Boreal Forest in
Canada today



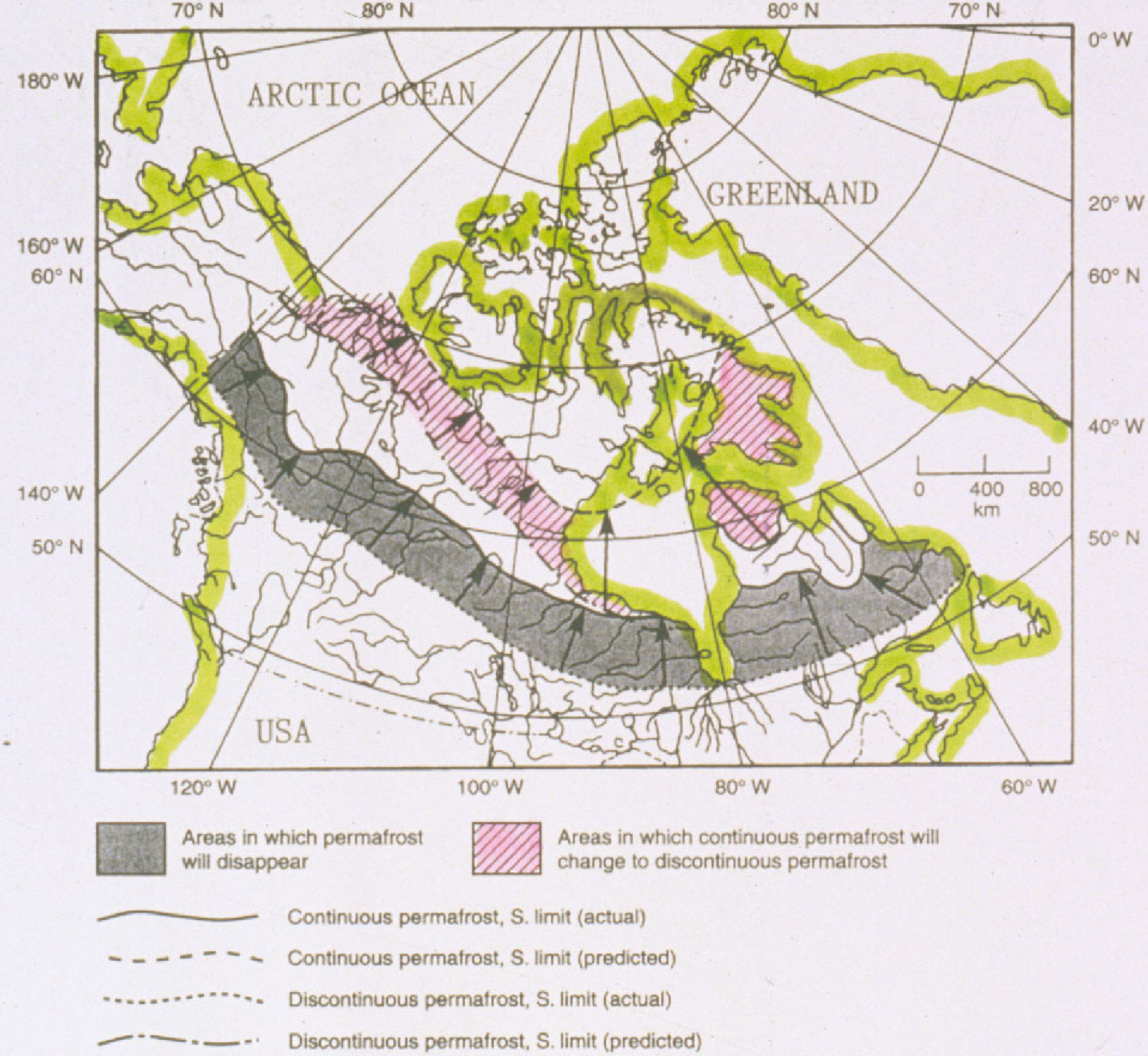
Boreal Forest in
Canada at x2
CO_2
(Sargent, 1988)



Distribution of Permafrost



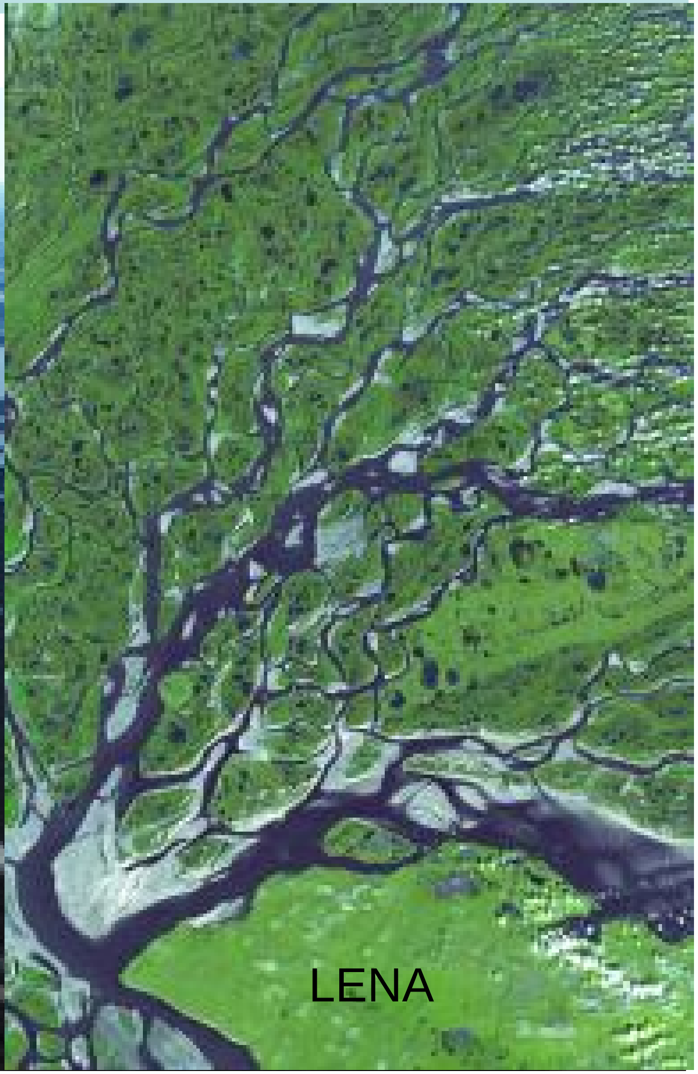
Maps compiled from various sources;
see tables for citations.


70° N
80° N
80° N
70° N
0° W
180° W
ARCTIC OCEAN
GREENLAND
20° W
160° W
60° N
60° N
40° W
0
400
800
km
140° W
50° N
50° N
USA
120° W
100° W
80° W
60° W
▩ Areas in which permafrost will disappear
▨ Areas in which continuous permafrost will change to discontinuous permafrost
Continuous permafrost, S. limit (actual)
Continuous permafrost, S. limit (predicted)
Discontinuous permafrost, S. limit (actual)
Discontinuous permafrost, S. limit (predicted)

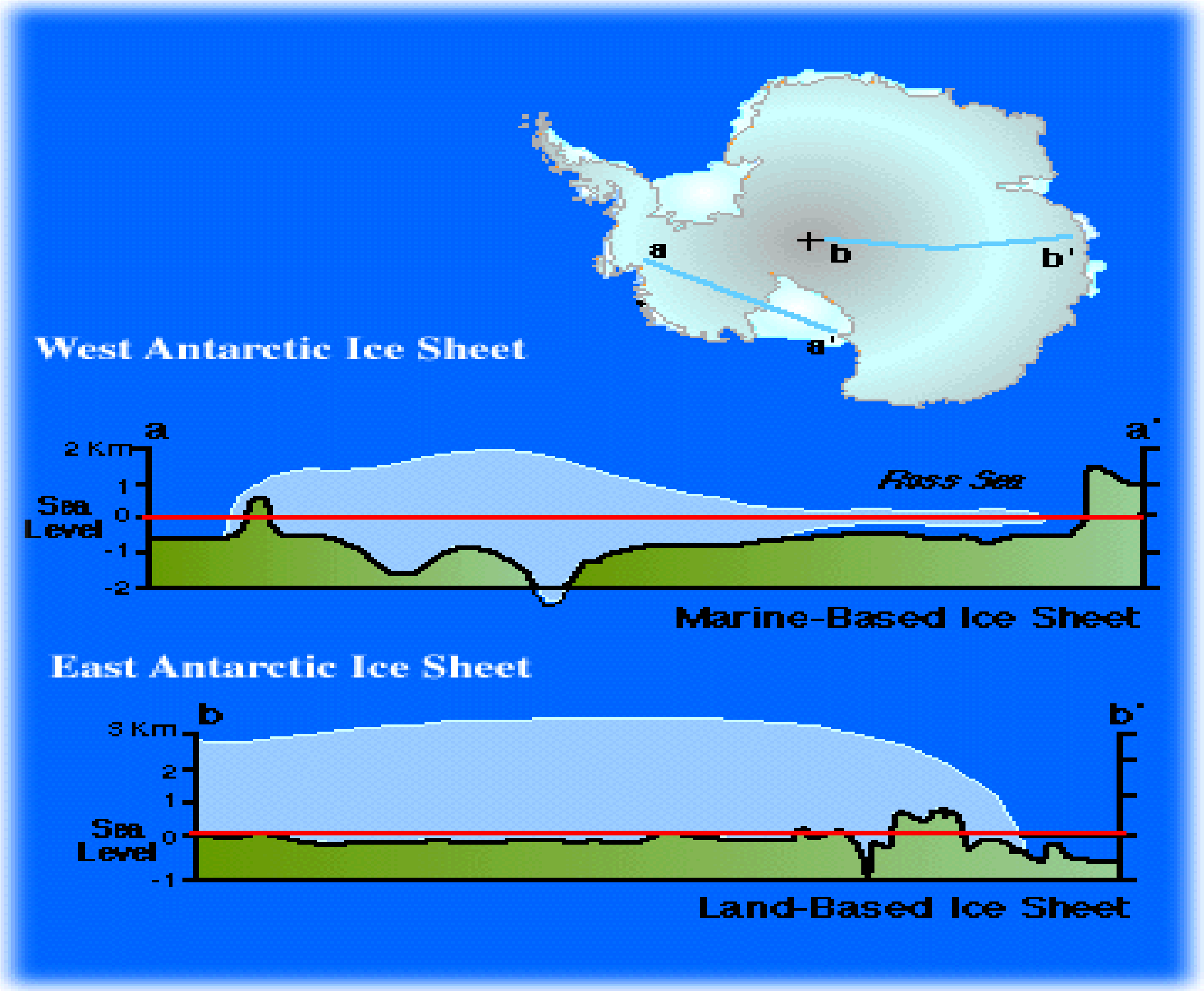
PERIGLACIAL AREAS

- Retreat of permafrost
- Thermokarst
- Removal of glue from slopes
- Erosion of shores and banks
- Deeper active layer – debris flows, etc.
- Change in runoff seasonality
- Changes in groundwater recharge

THERMOKARST



Shishmaref, Alaska


a
b
b'
a'
West Antarctic Ice Sheet
a
a'
2 Km
1
Sea Level
0
-1
-2
Ross Sea
Marine-Based Ice Sheet
East Antarctic Ice Sheet
b
b'
3 Km
2
1
Sea Level
0
-1
Land-Based Ice Sheet

THE BIG ISSUE

- Ice sheets will be subjected to increased ablation (melting), the buoyancy effects of rising sea levels, the effects of ice shelf disappearance on wave attack, and the wasting effects of warmer oceans
- On the other hand, higher temperatures will lead to more snowfall and thus to higher rates of accumulation

GLACIERS

- Since Little Ice Age general retreat of c 20-70m per year
- Glaciers of European Alps have lost c 50% of their volume since the LIA
- Tidewater glaciers retreat especially quickly – The Columbia glacier in Alaska retreated 13km between 1982 and 2000
- East African glaciers occupy one third to one sixth of former area

Columbia Glacier c. 1980

Columbia Glacier 2005

Arapaho Glacier 1898

Arapaho Glacier 2003

Mt. Kilimanjaro-- February 17, 1993

Mt. Kilimanjaro-- February 21, 2000

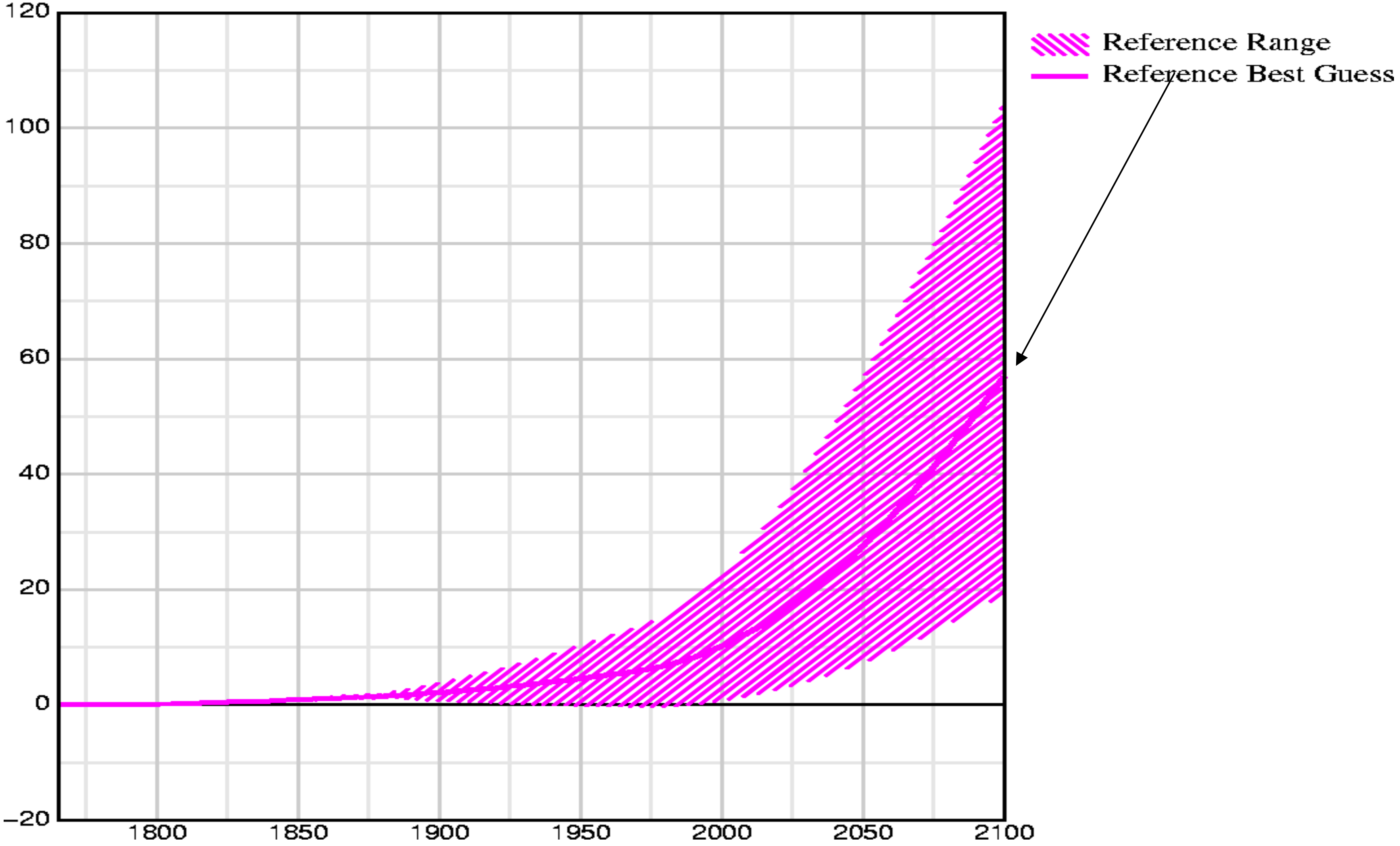
SEA LEVEL RISE

- During the 20th century the rate of rise averaged c 1.5-2.0 mm per year
- During the 21st century the rate of rise is likely to be c 5 mm per year

Sea Level Change (cm) w.r.t. 1765

Reference: IPCC emissions scenario 92a

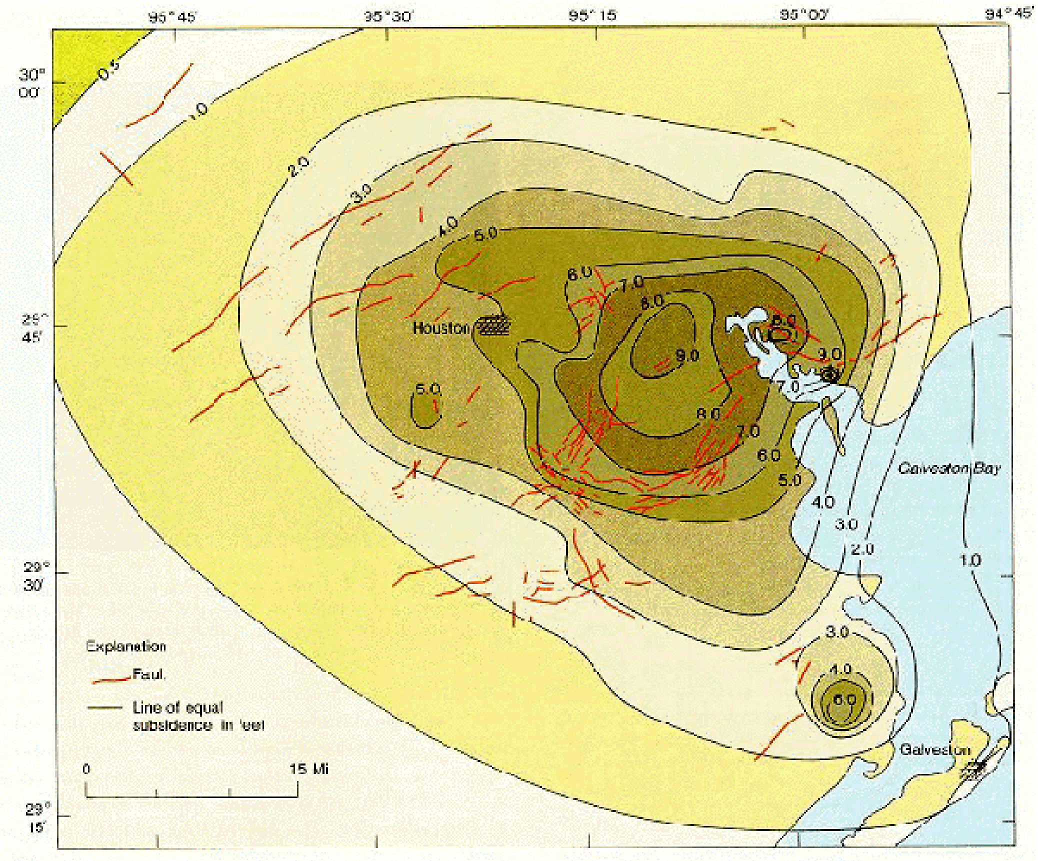
Policy: IPCC emissions scenario 92a



SUBSIDING AREAS

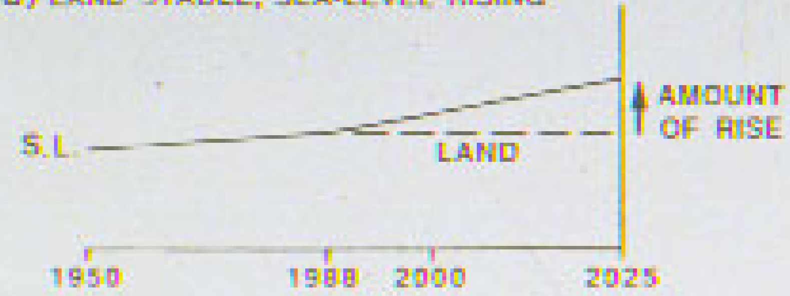
- Deltas, atolls
- Tectonic sinking
- Isostatic compensation
- Groundwater and hydrocarbon removal
- Compaction of organic sediments

Houston/Galveston

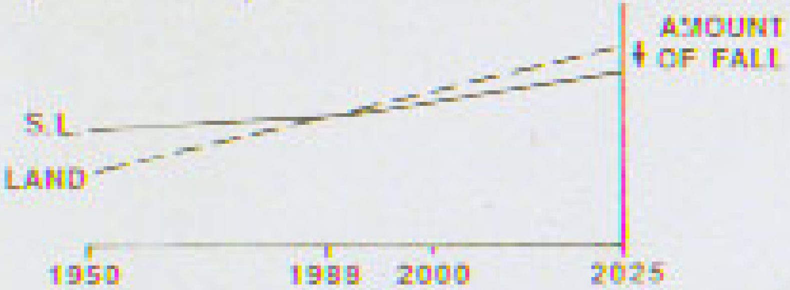


Central valley, California

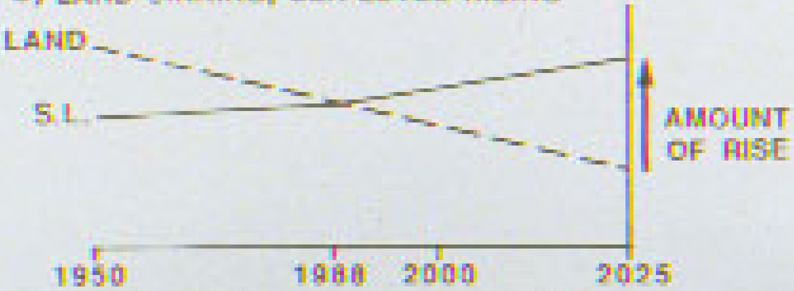
a) LAND STABLE, SEA-LEVEL RISING



b) LAND RISING, SEA-LEVEL RISING



c) LAND SINKING, SEA-LEVEL RISING



SENSITIVE COASTS

- Beaches
- Salt marshes
- Mangrove swamps
- Deltas
- Coral reefs
- Lagoons

MISSISSIPPI BIRDSFOOT

MISSISSIPPI BIRDSFOOT

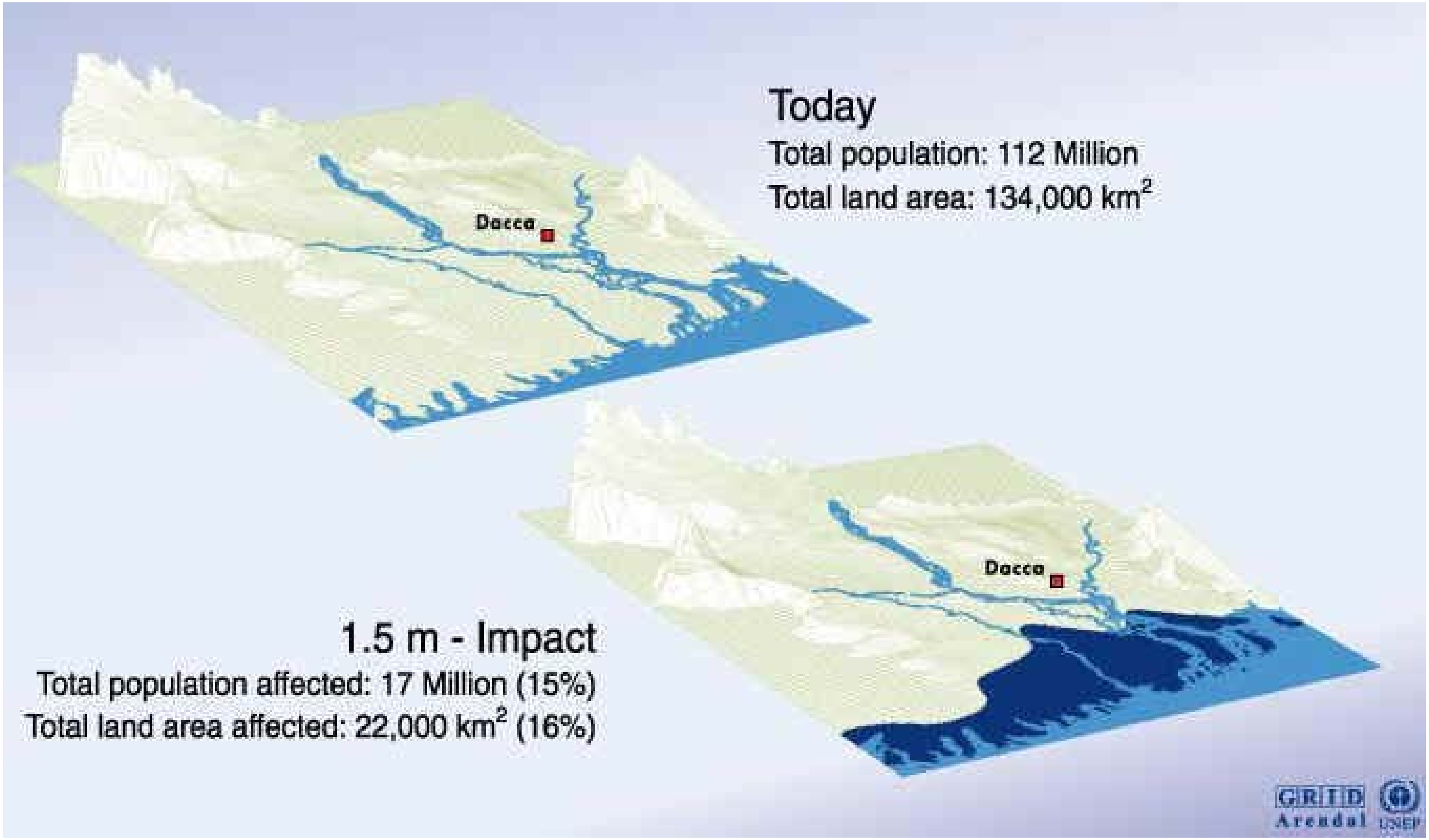
- Subsidence
- Accelerating sea level rise
- Diversion of flow to other mouths
- Reduction in nourishment due to embankments
- Reduction of silt loads by cascades of dams

NILE DELTA

- An area of ongoing subsidence
- Sea-level rise
- Sediment starvation by Aswan and other dams
- Sensitivity of salt/fresh water interface


26°N
INDIA
BANGLADESH
DHAKA
24°N
5m
5m
3m
3m
CALCUTTA
2m
1m
22°N

BANGLADESH AND THE GANGES/BRAMAPUTRA DELTA



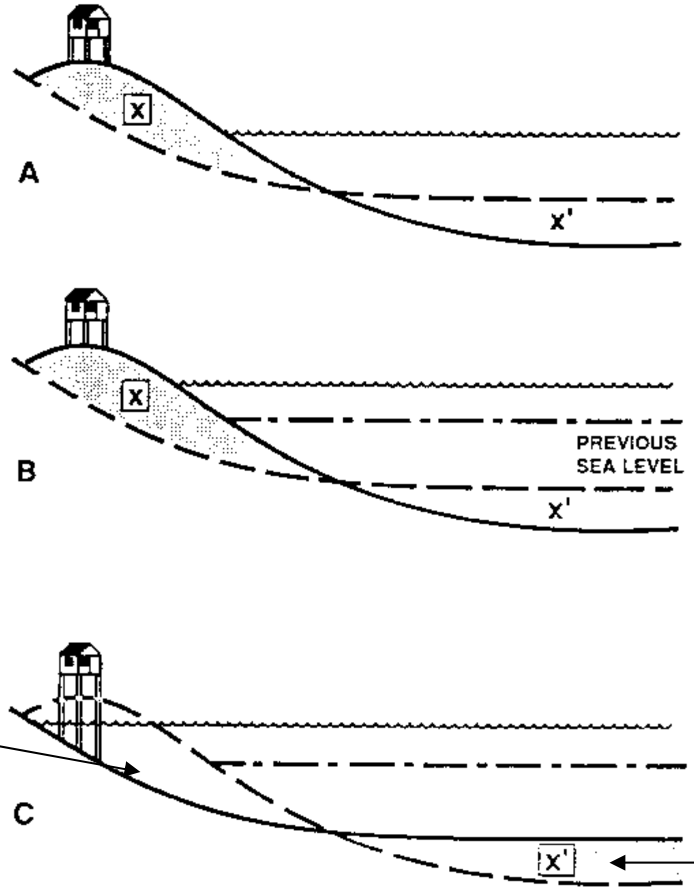
CORAL REEFS

- Increase in sea surface temperatures will cause stress (bleaching) or stimulus
- Increase in storm frequency and intensity will build up islands, erode reefs, change species composition
- Increase in sea levels will stimulate reef growth (if slow), but will cause inundation (if fast) or if corals are stressed by siltation

SALT MARSH VULNERABILITY

- Less sensitive – areas of high sediment input, areas of high tidal range (with high sediment transport potential), areas with effective organic accumulation
- More sensitive – areas of subsidence, areas of low sediment input, slow growing mangroves, micro-tidal areas, reef settings (lack of allogenic sediment), constrained by sea walls

BRUUN RULE



EROSION

DEPOSITION

About 100 m of erosion for 1 m rise in sea level on sandy beach

ACCELERATING COASTAL EROSION

- Sea level rise and the Bruun Rule
- Reduced beach nourishment because of dams
- Reduced beach nourishment because of ‘defence’ structures
- Increasing storm activity?

SYNERGIES

- Permafrost degradation
- Coastal flooding
- Coastal erosion
- Coral reefs
- Moisture deficits and drying of lakes

GLOBAL WARMING AND HAZARDS

- Droughts and dunes and dust
- Hurricanes
- Permafrost degradation
- Ground subsidence
- Glacier retreat
- Sea-level rise
- Coast erosion

GEOMORPHOLOGICAL RESEARCH

- Monitor change
- Model future changes
- Identify vulnerable ‘hot spots’
- Consider mitigation strategies
- Consider feedbacks of geomorpholgical change

GEOMORPHOLOGY 2009

Melbourne, Australia, 7-12 July 2009