Climate Change
Health Consequences & Healthy Solutions

HMS
February 21, 2007

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Co-evolved Systems

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Change

Juveniles

Phase transitions

Punctuated equilibria

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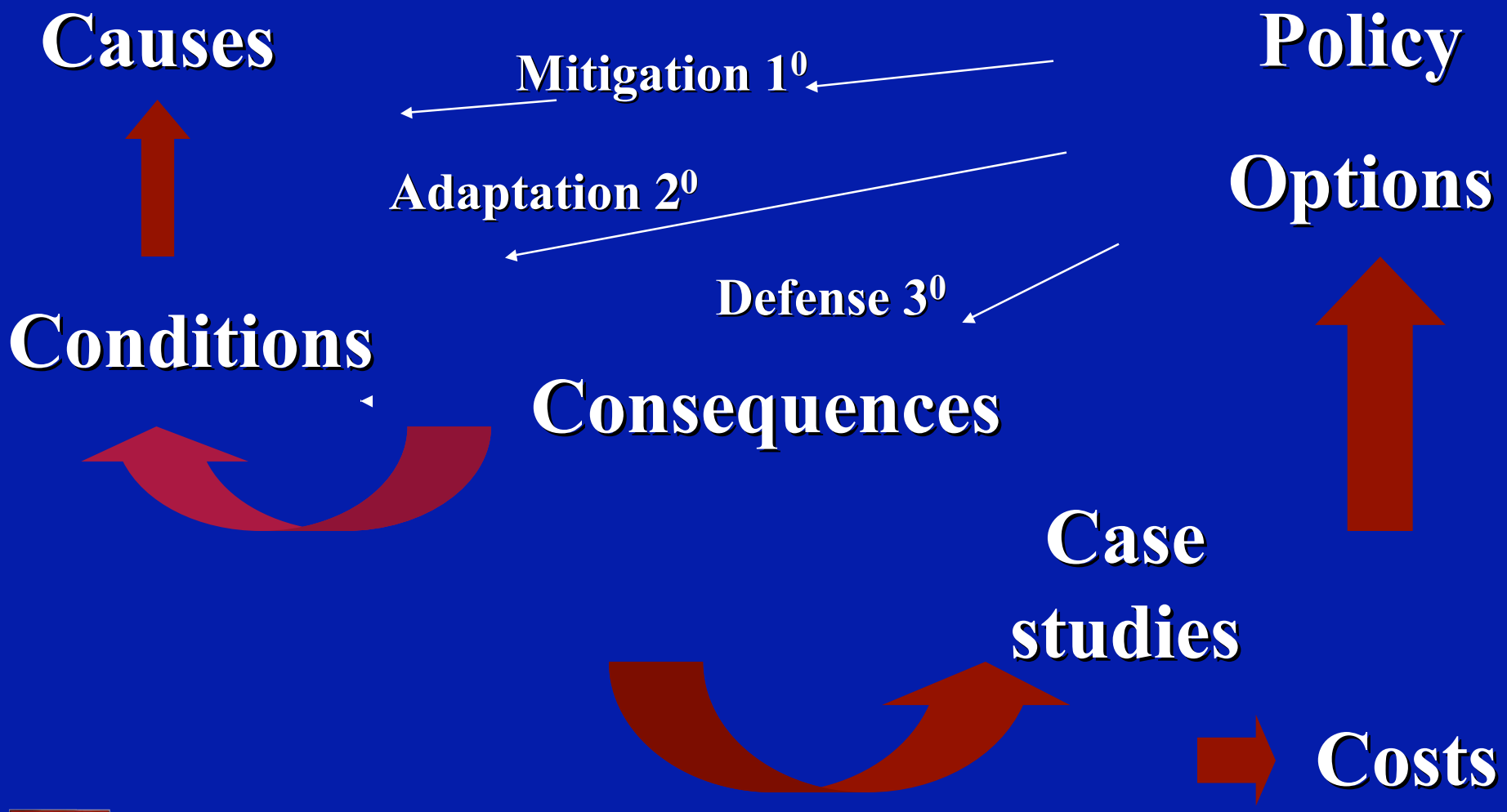
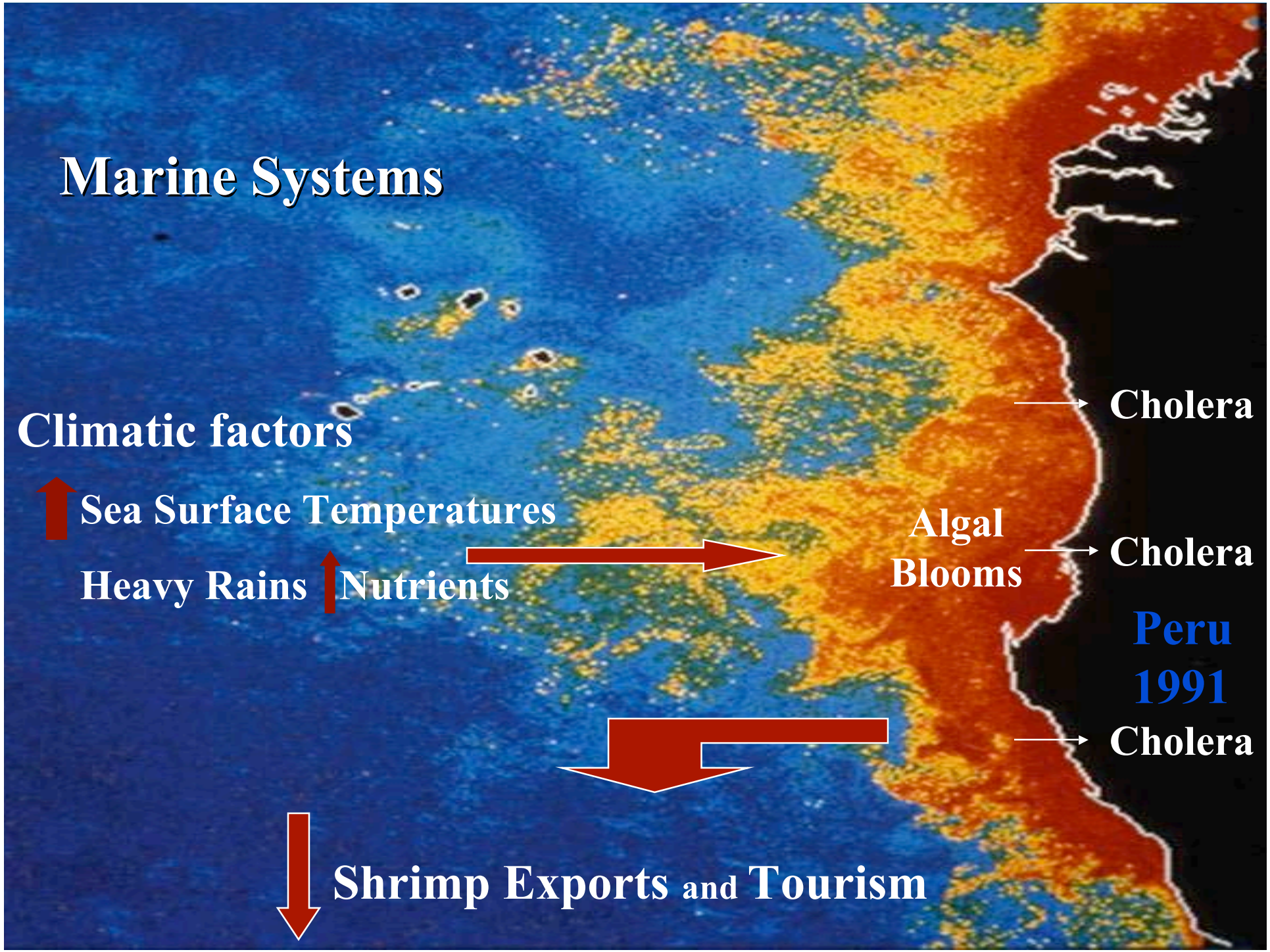
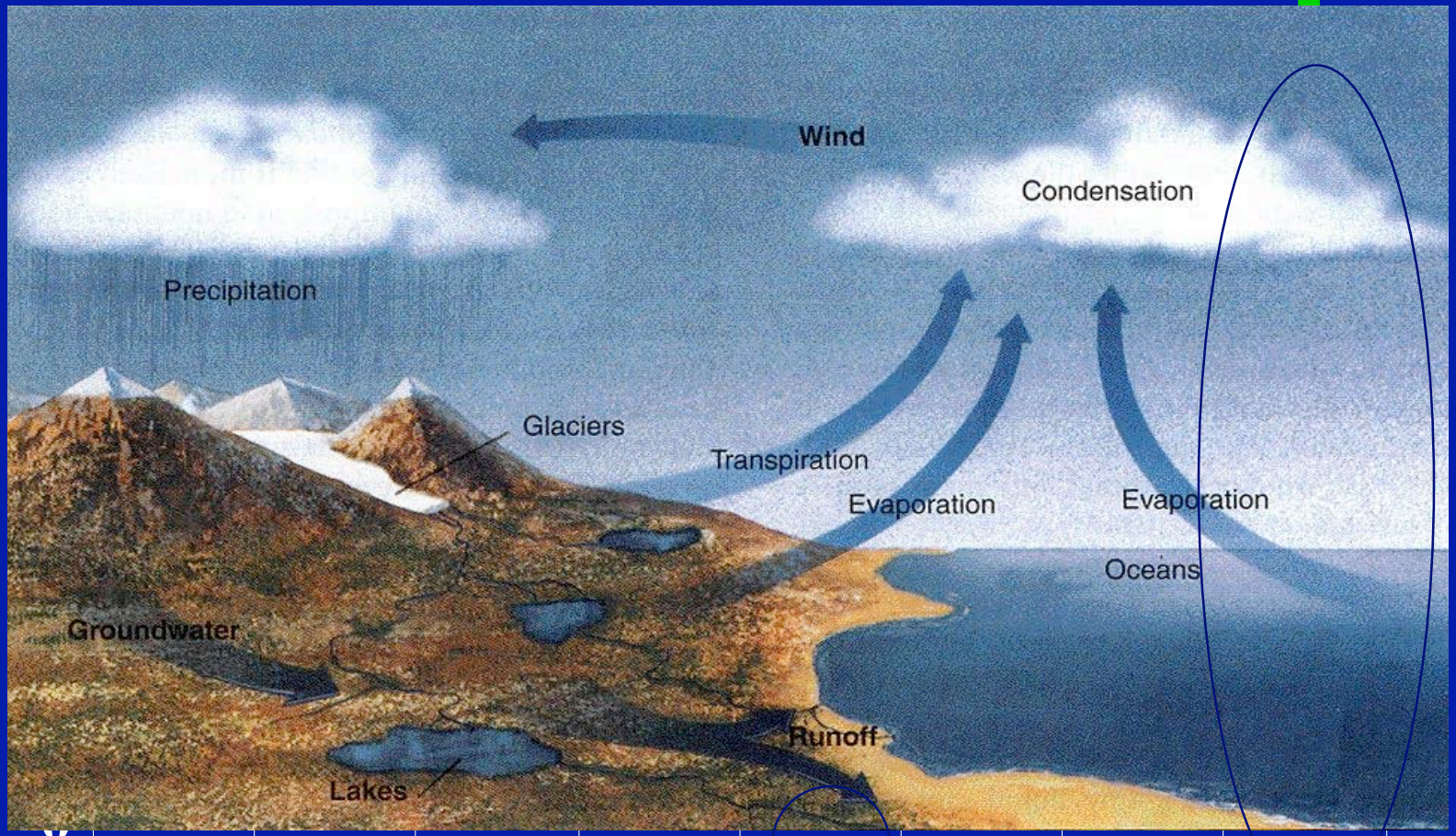
Framework


Causes
Mitigation 1⁰
Policy
Adaptation 2⁰
Options
Defense 3⁰
Conditions
Consequences
Case
studies
Costs


Marine Systems
Climatic factors
Sea Surface Temperatures
Heavy Rains
Nutrients
Algal Blooms
Cholera
Cholera
Peru 1991
Cholera
Shrimp Exports and Tourism

Deep Ocean Warming



A SI MG An Atm CG C WO

Arctic Sea ice Mountain glaciers Antarctic Land ice Greenland ice sheet Cont Ocean

Global Hydrological Cycle

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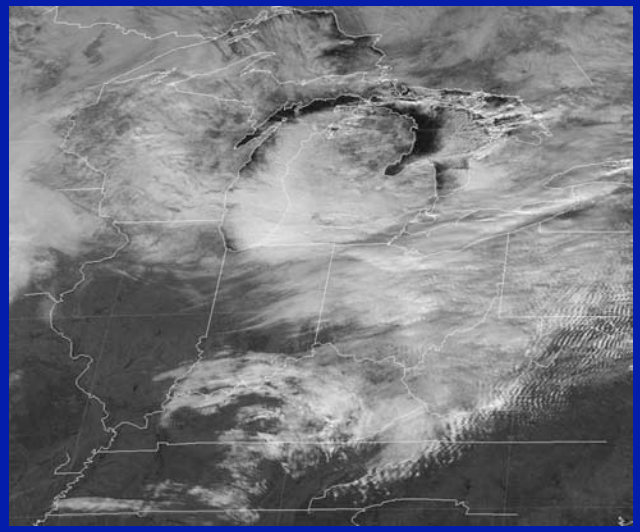
Levitus et al. *Science* 2005

Precipitation over the Continental U.S



Rain ↑ 7%

>2”/d ↑ 14%

>4”/d ↑ 20%

Snow in Buffalo
12-14 feet

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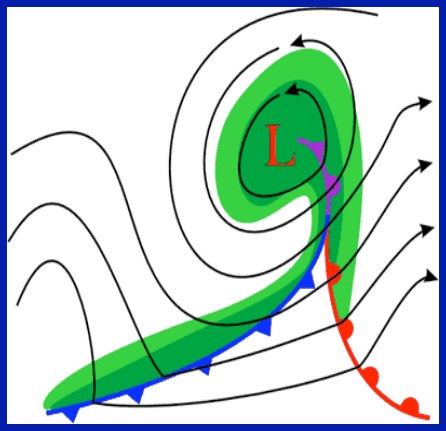
Winter Weather Anomalies

VARIABILTY

- Freeze-thaw cycles
- Ice Storms
- Fog
- Infrastructure
- Municipal expenses

Orthopedics, MVAs, allergies, flowering, pollinators & food security

‘HEAVEN’S BREATH’



Temperature

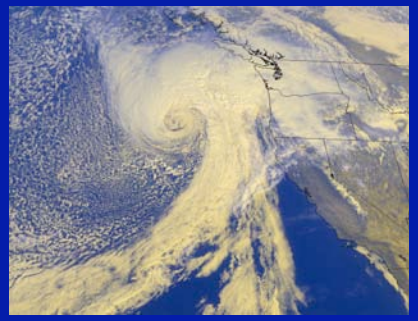
CO_2

Pressure

L

Gradients

Wind



Weather

Fronts

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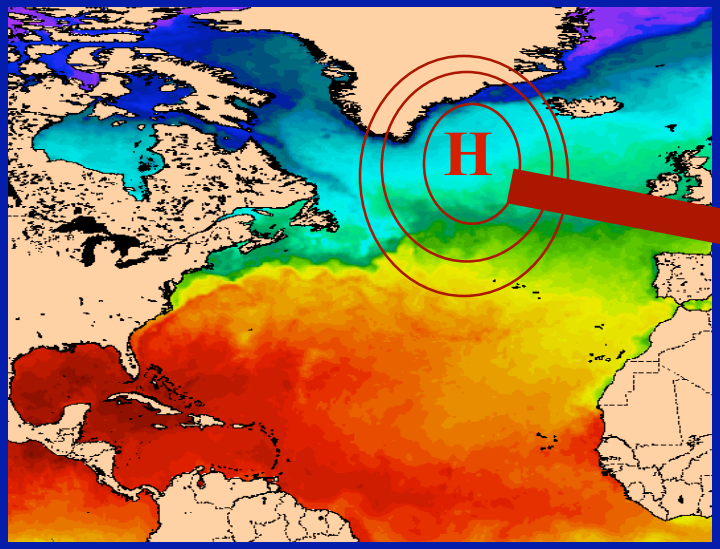
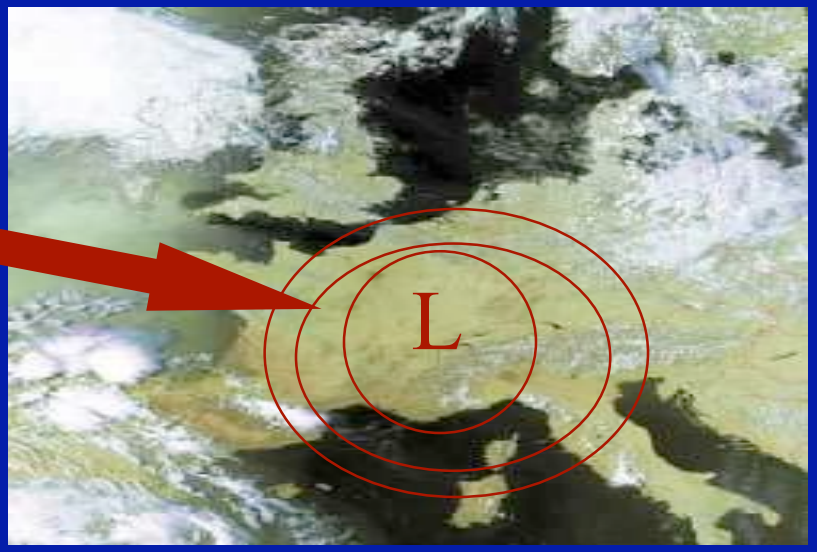
Windstorm Kryill: January 2007

North Atlantic Cold



European Warmth



Wind & Weather

123 mph winds

47 deaths

Power outages: 2m people

P&C damages: € 3.5bn

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O:\NAShutdown.wmv

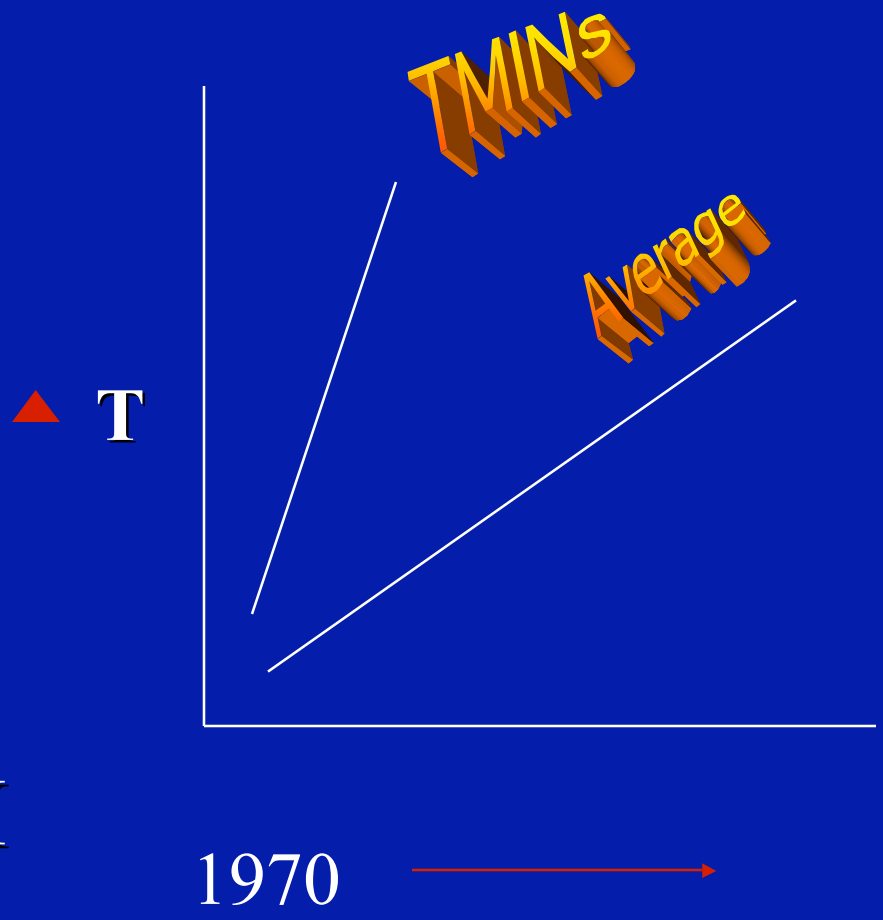
TMINs

Nighttime

&

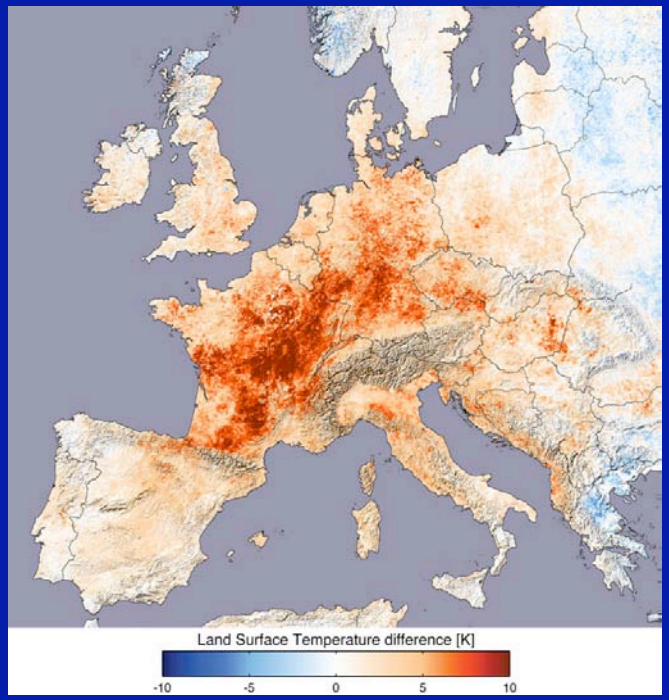
Winter

Temps



Winter and PH

Heatwaves: Europe 2003



Deaths: 21-35,000
- **Crops & livestock: US$12.3 billion**
- **Wildfires: 1.2 million acres**
- **Nuclear plant shutdowns**
- **Hydropower reduced**
- **Alpine glaciers: 10% lost**

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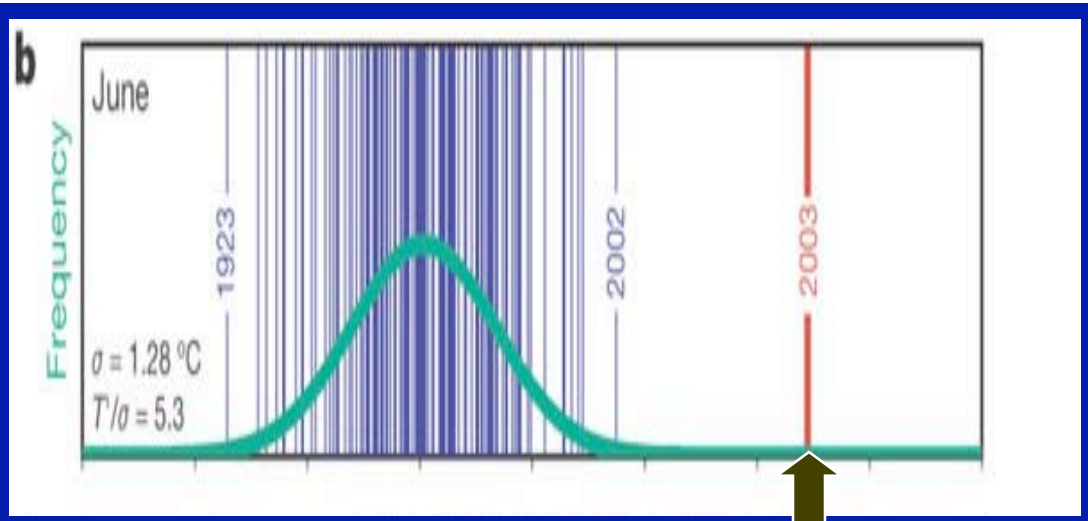
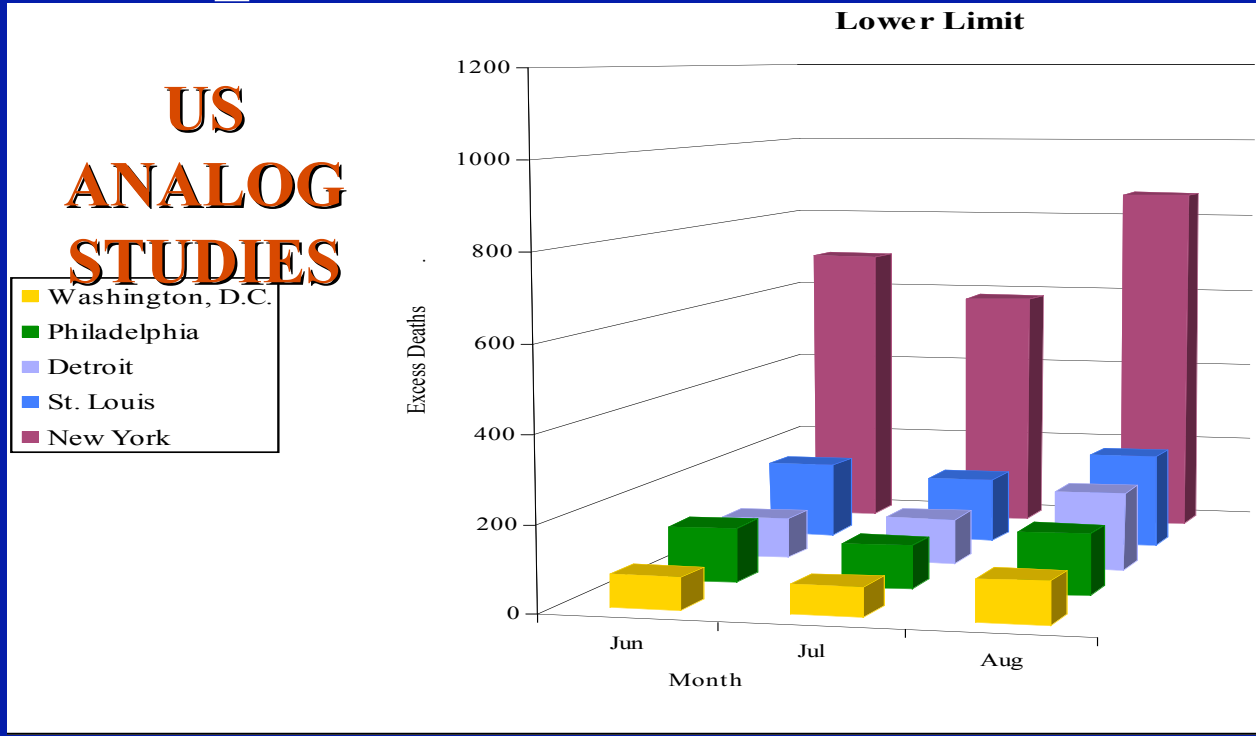


European Summer 2003

Temp 11°F >30yr average
6 std. dev.
from the mean

-Schar *Nature* 2004

US ANALOG STUDIES



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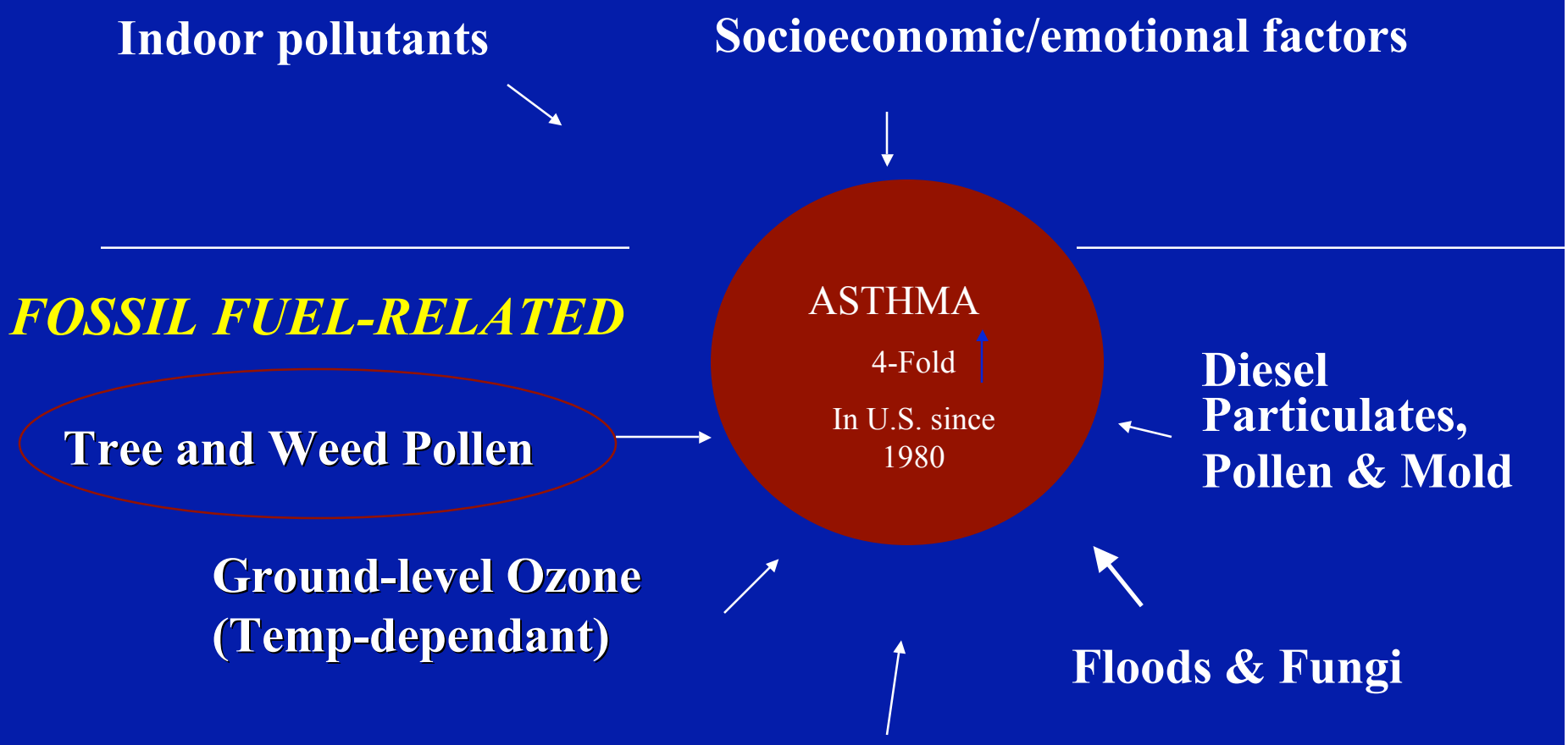
Kalkstein et al. *BAMS* 2007, *in press*

RESPIRATORY & CARDIOVASCULAR DISEASE



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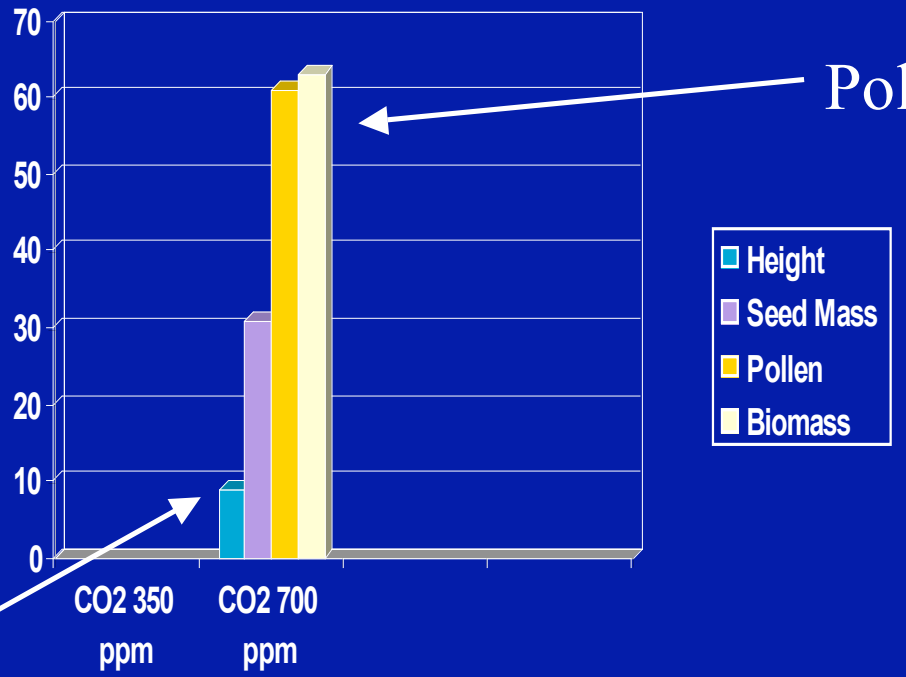
Asthma and CO_2

- Illness
- School absences
- Productivity losses
- Sixth leading cause of chronic disease

Ragweed Growth Under Double CO_2



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Wayne et al., 2002

Loblolly Pines

CO_2 Terrestrial uptake

Poison Ivy

↑ Uruschiol

'FACE'

Soil Fungi

Spores

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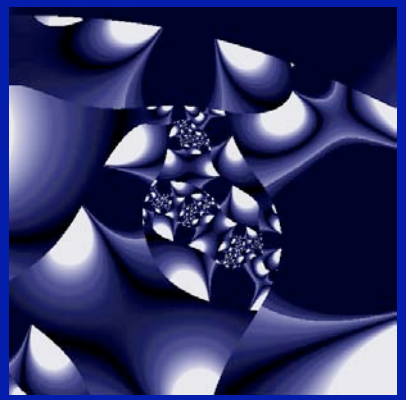
CO_2

Ocean uptake

$$CO_2 + H_2O = HCO_3^- + H^+$$

$$Ca^{++} + HCO_3^- = CaCO_3 + H^+$$



"Osteoporosis"

Shelled marine life

Recovery

p[illegible]$^{++}$]/[H[illegible]

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Climate Change Futures

Infectious and Respiratory Disease

Malaria	3,000 children/day	5-17.4% GDP 1.3 growth rate % pts./yr
West Nile virus	Wildlife	$500 million/yr for S&R
Lyme disease	25,000 cases/yr	$2.5 billion/5 years
Asthma	Fourfold increase in US	$16 billion

Extreme Weather Events

Heat waves 2003 summer	Mortality, crops, forests, Alps	Over $15 billion
Floods 2002 summer	Drownings, WBDOs, VBDs	Over $16 billion

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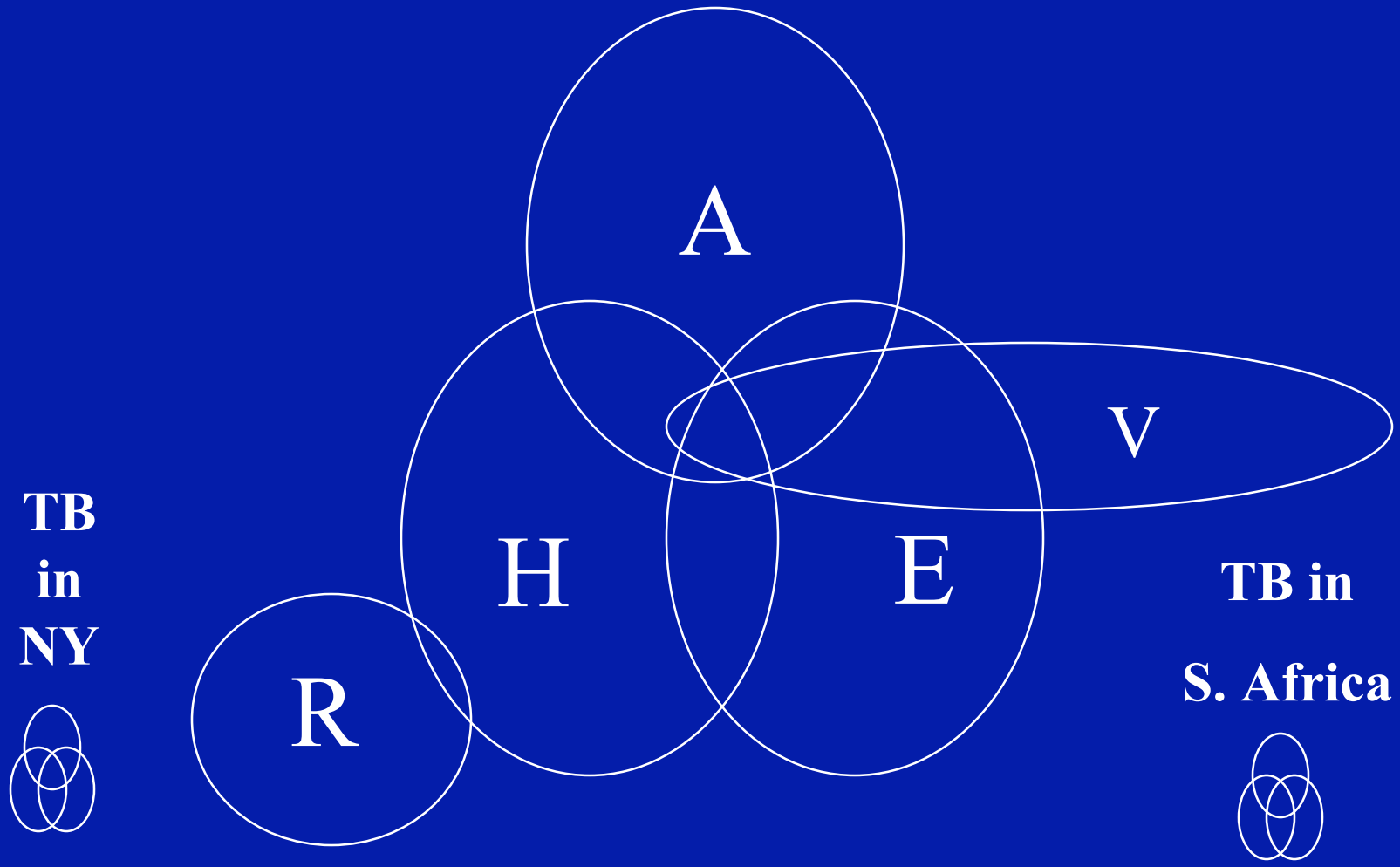
Swiss Re and UNDP

Infectious Disease Transmission



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Vectors

- Mosquitoes
- Bats

- Ticks

- Snails

- Rodents
- Kissing bugs

- Fleas

- Tsetse flies

- Lice
- Plankton

- **Water-borne**
- **Food-borne**
- **Air-borne**
- **Person-to-Person**

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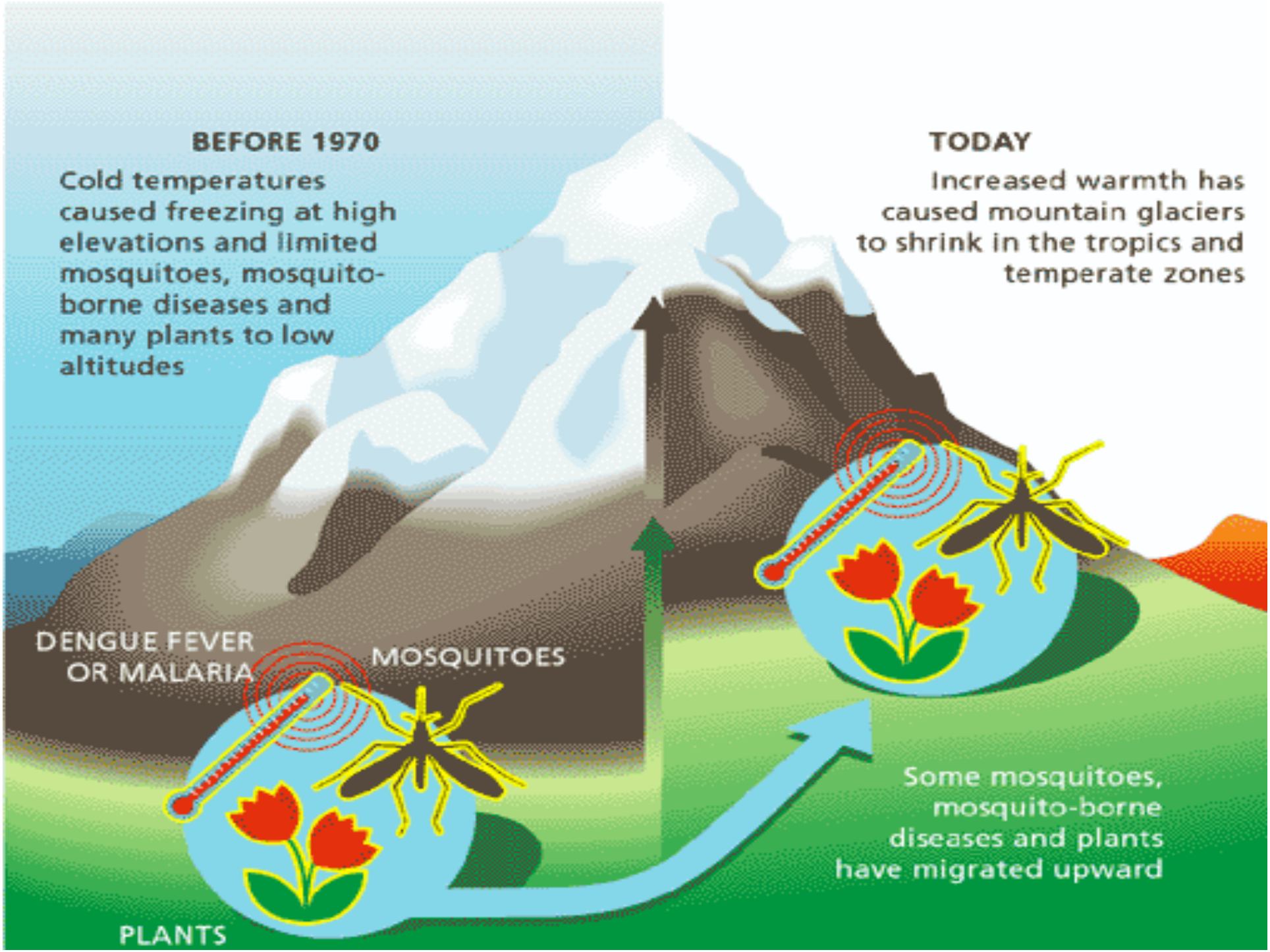
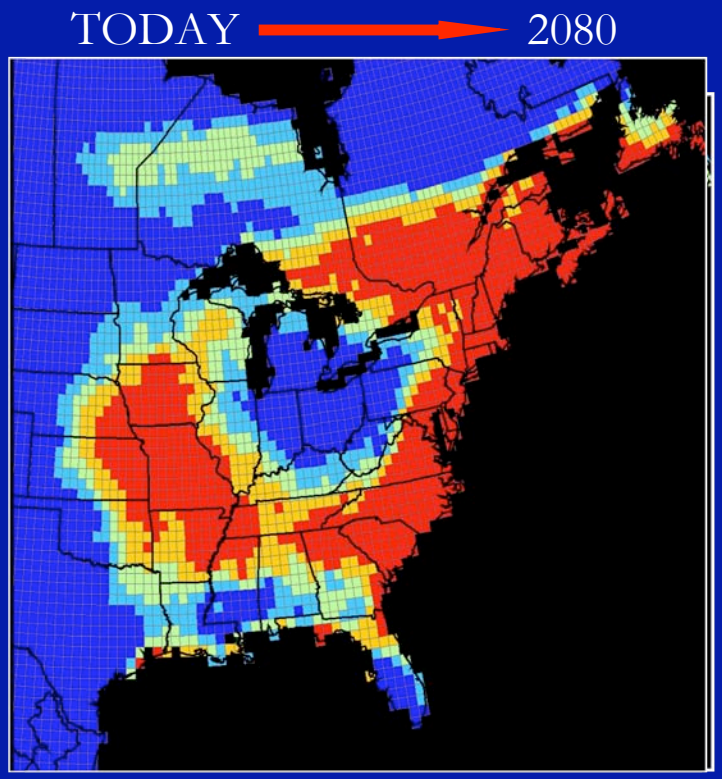

BEFORE 1970
Cold temperatures caused freezing at high elevations and limited mosquitoes, mosquito-borne diseases and many plants to low altitudes
TODAY
Increased warmth has caused mountain glaciers to shrink in the tropics and temperate zones
DENGUE FEVER OR MALARIA
MOSQUITOES
Some mosquitoes, mosquito-borne diseases and plants have migrated upward
PLANTS

Lyme Disease

Suitable range of vector

- **% Change in suitable area by 2080:**
  North America: +69%
  United States: +28%
  Canada: +213%



Brownstein et al., 2005

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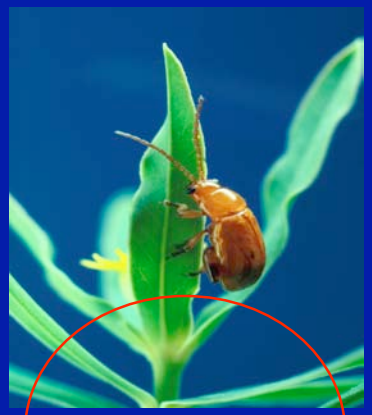
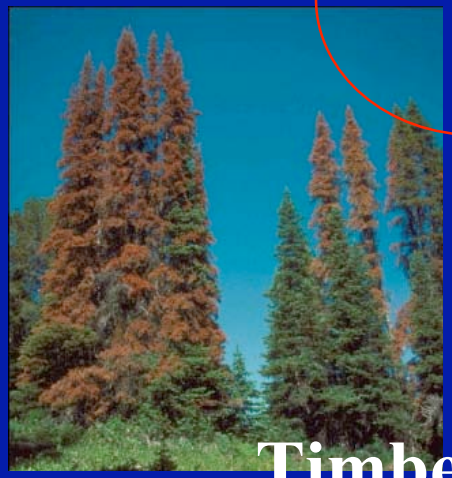
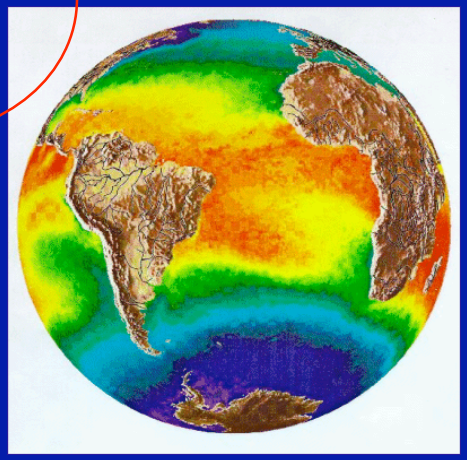
Bark Beetles and Forest Fires

Killing frost

<20^{0}F x 10 days

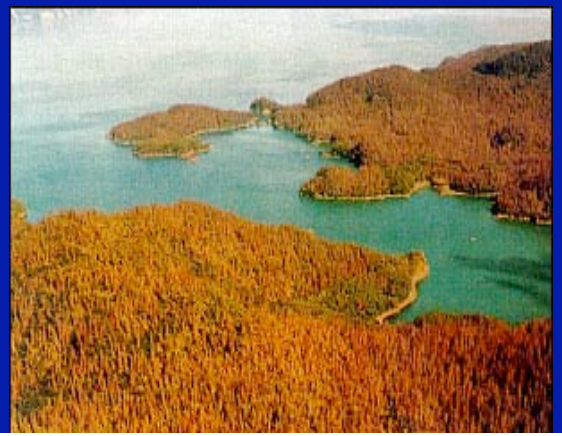






Timber industry

Injury, Respiratory Disease, Water, Wildlife, Property, Carbon Pulse



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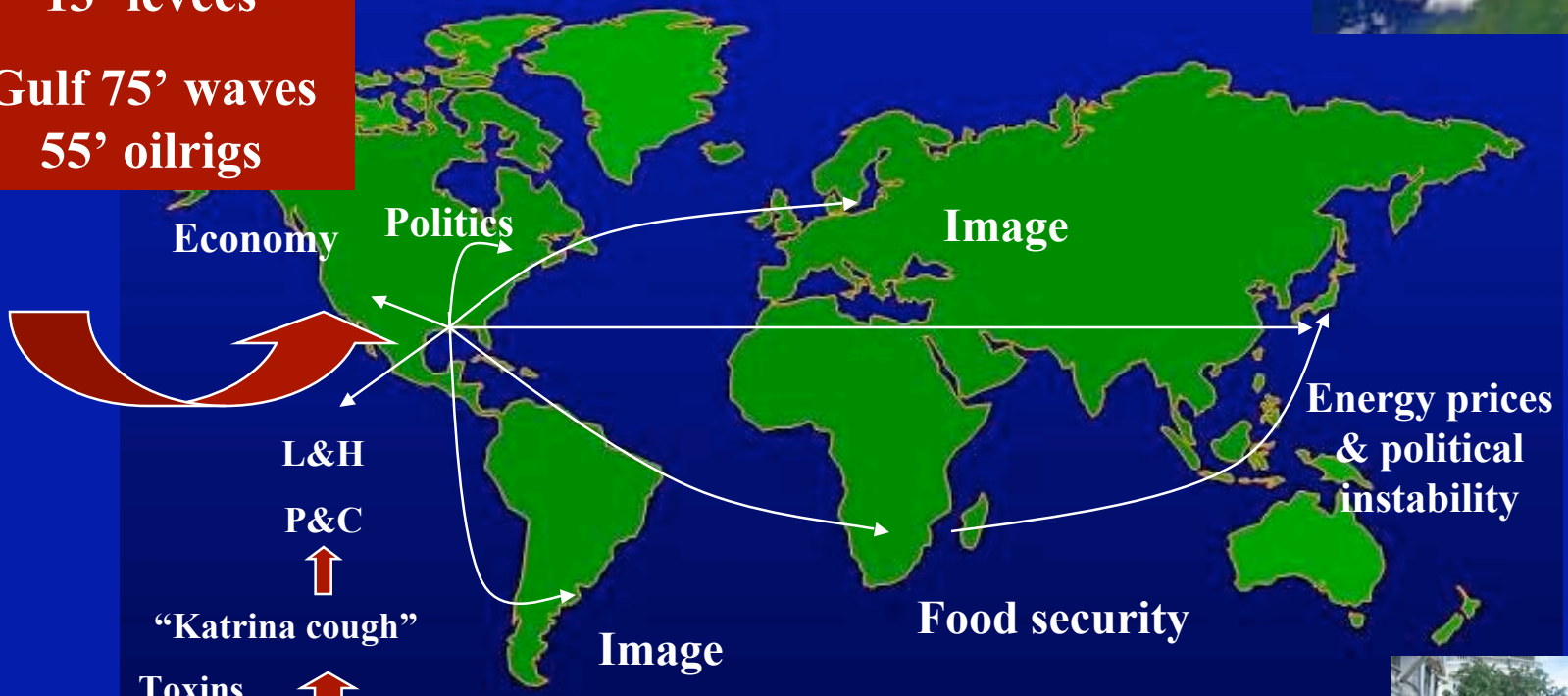
Hurricane Katrina

L. Pontchartrain
28’ high waves
13’ levees

Gulf 75’ waves
55’ oilrigs



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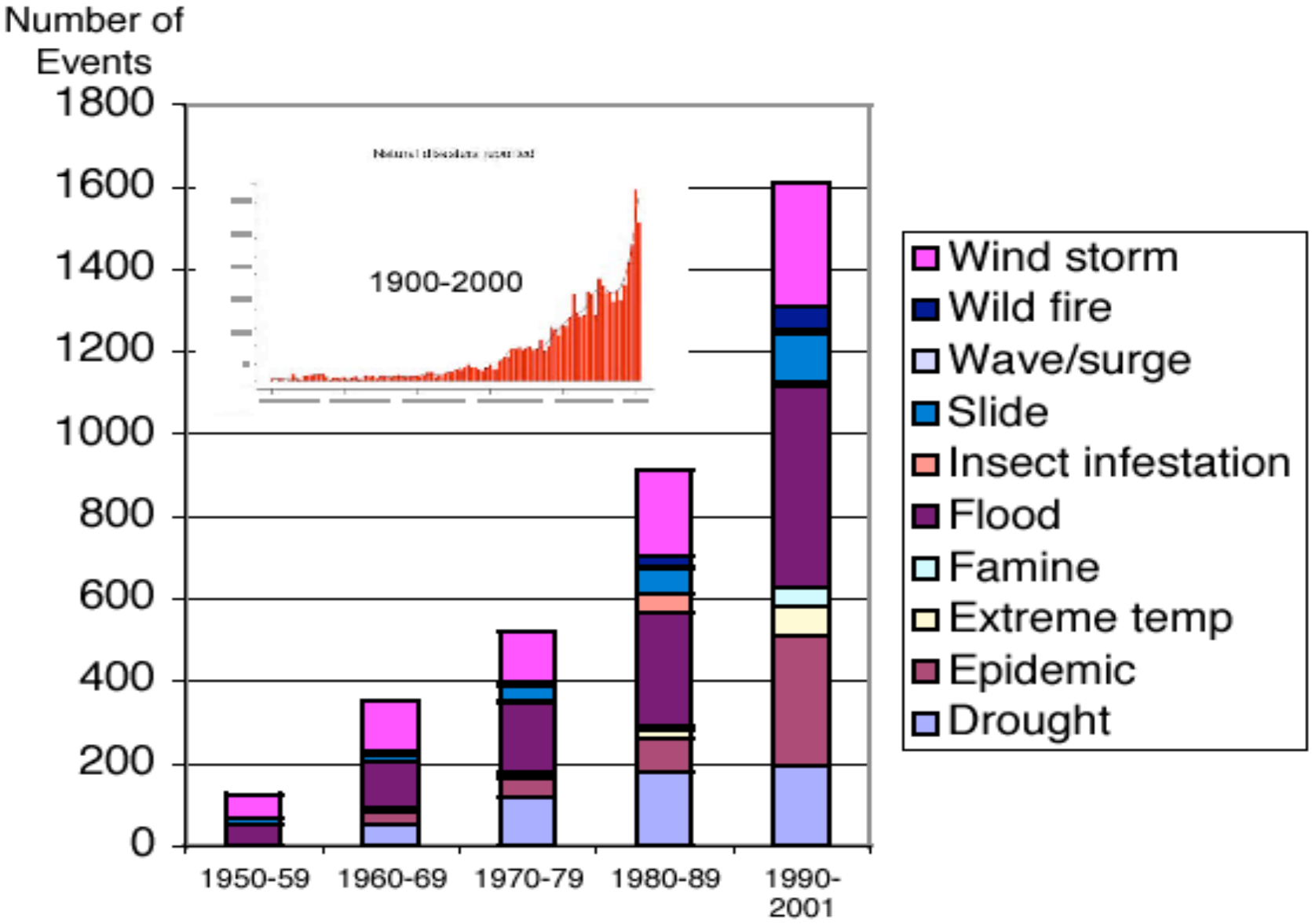
A turning point

Changing Nature and Structure of Events



Sources: OFDA / Center for Research in the Epidemiology of Disasters (CRED) Intl database of Disasters

The Stern Review

The Costs of Climate Change

Damages

5-20% global GDP

Includes non-linear impacts

Adaptation

Hundreds of $billions

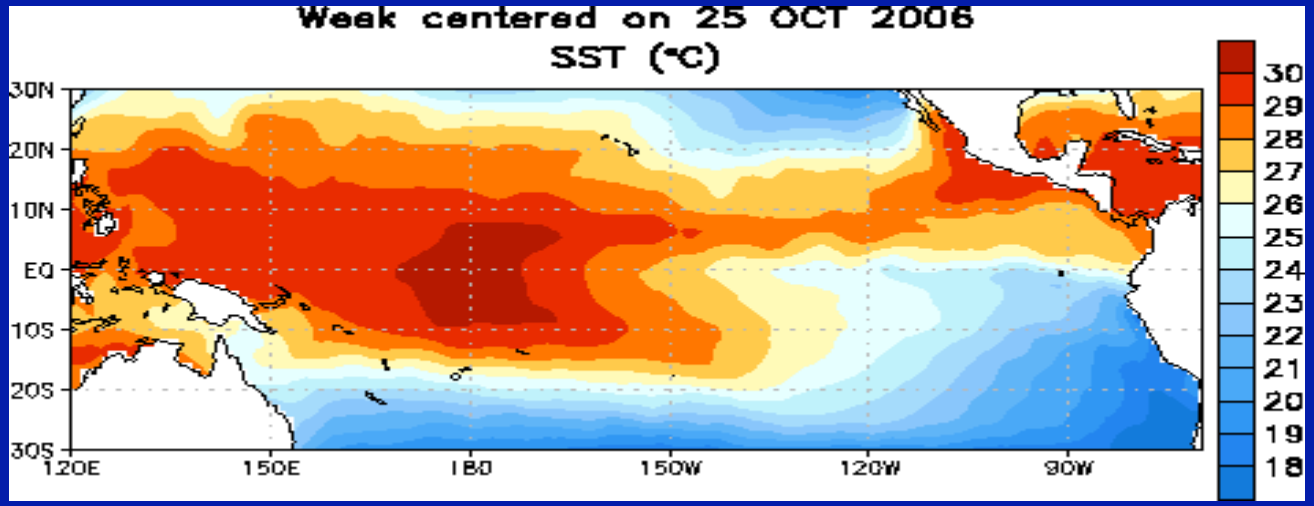
Mitigation

1% of GDP/yr

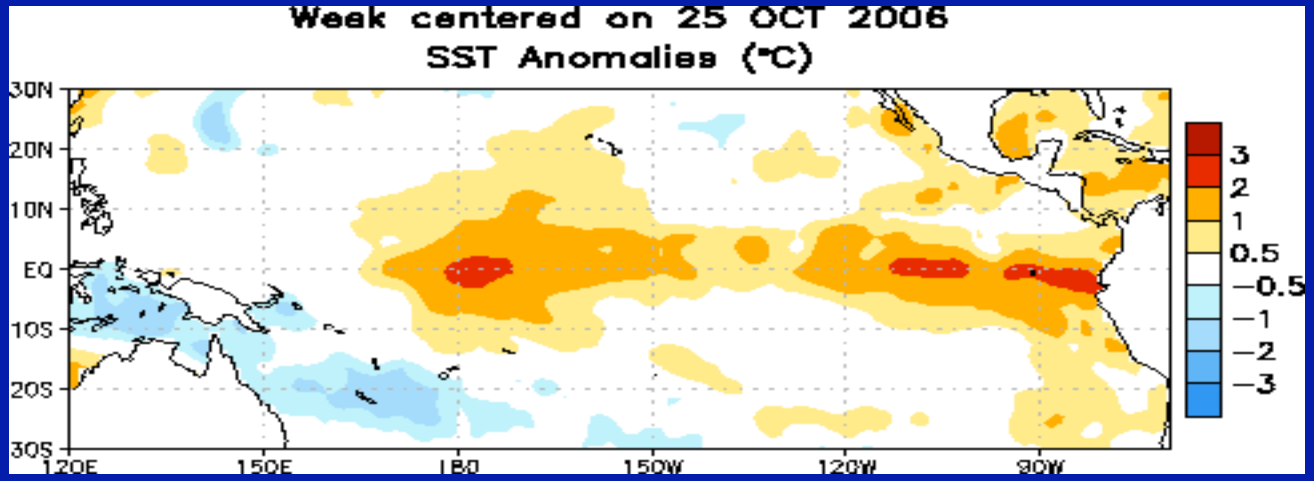
Could be an underestimate

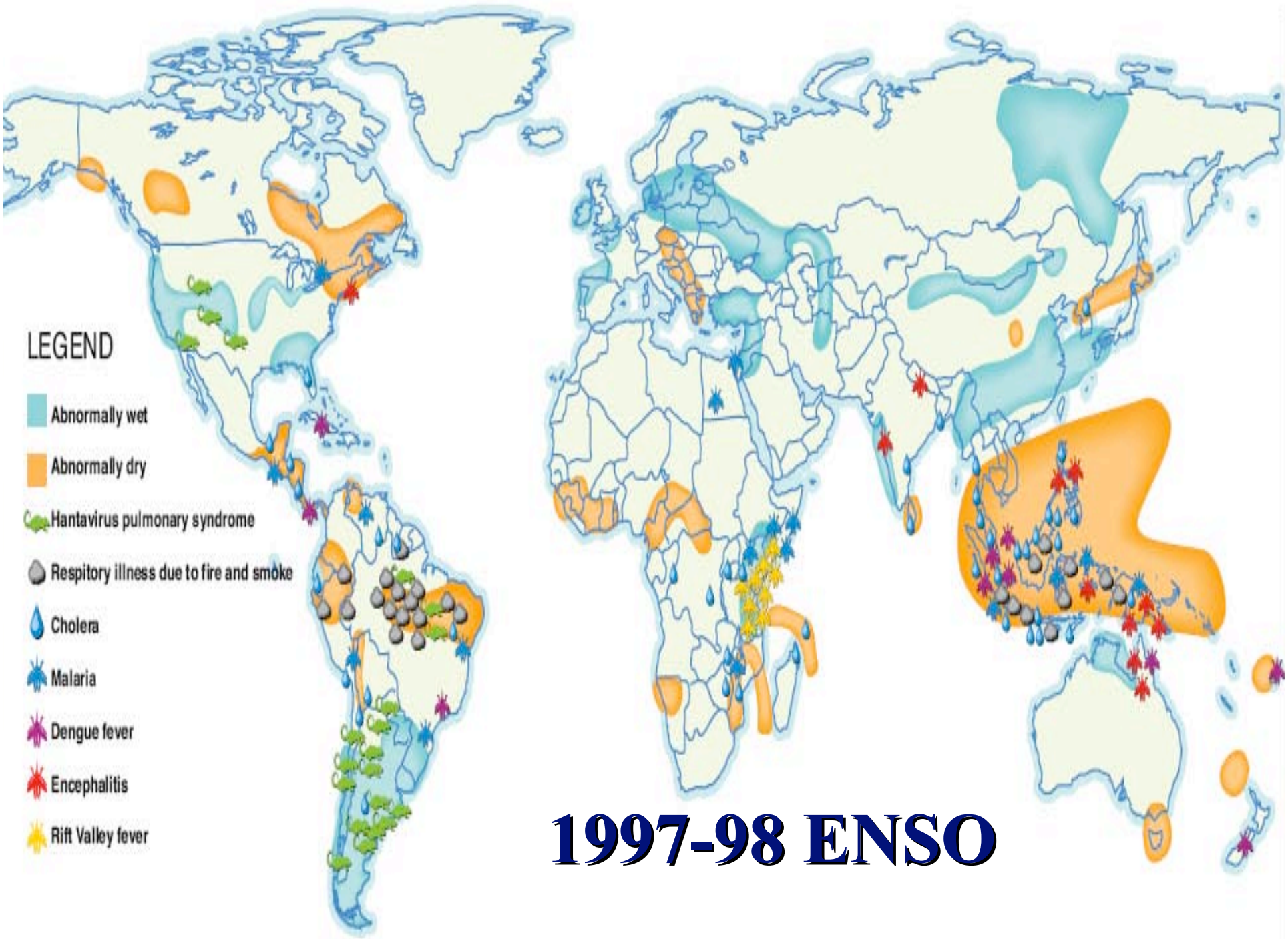
El Niño: 2006-07

Sea Surface Temperatures

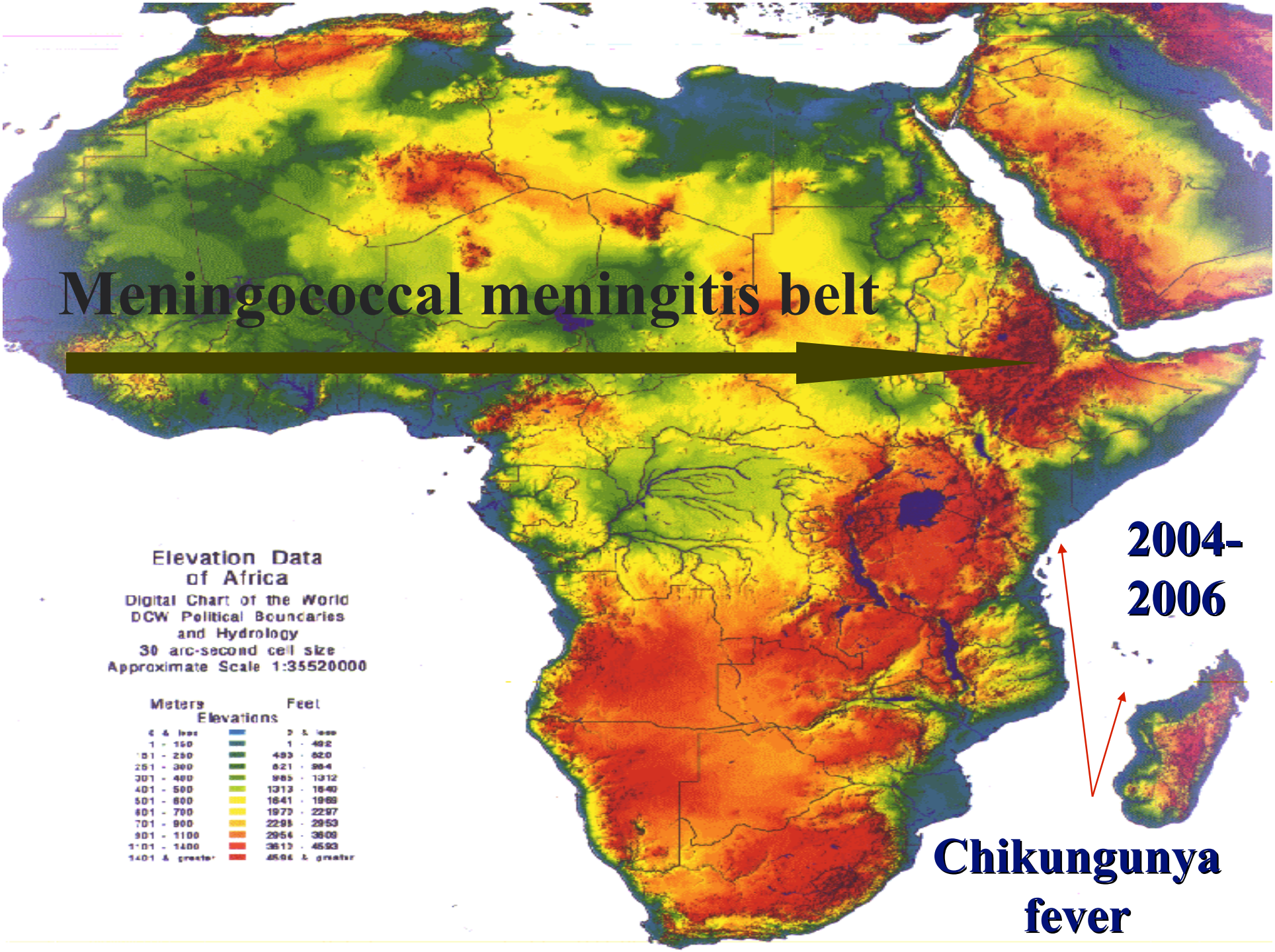


SST Anomalies




LEGEND
Abnormally wet
Abnormally dry
Hantavirus pulmonary syndrome
Respitory illness due to fire and smoke
Cholera
Malaria
Dengue fever
Encephalitis
Rift Valley fever

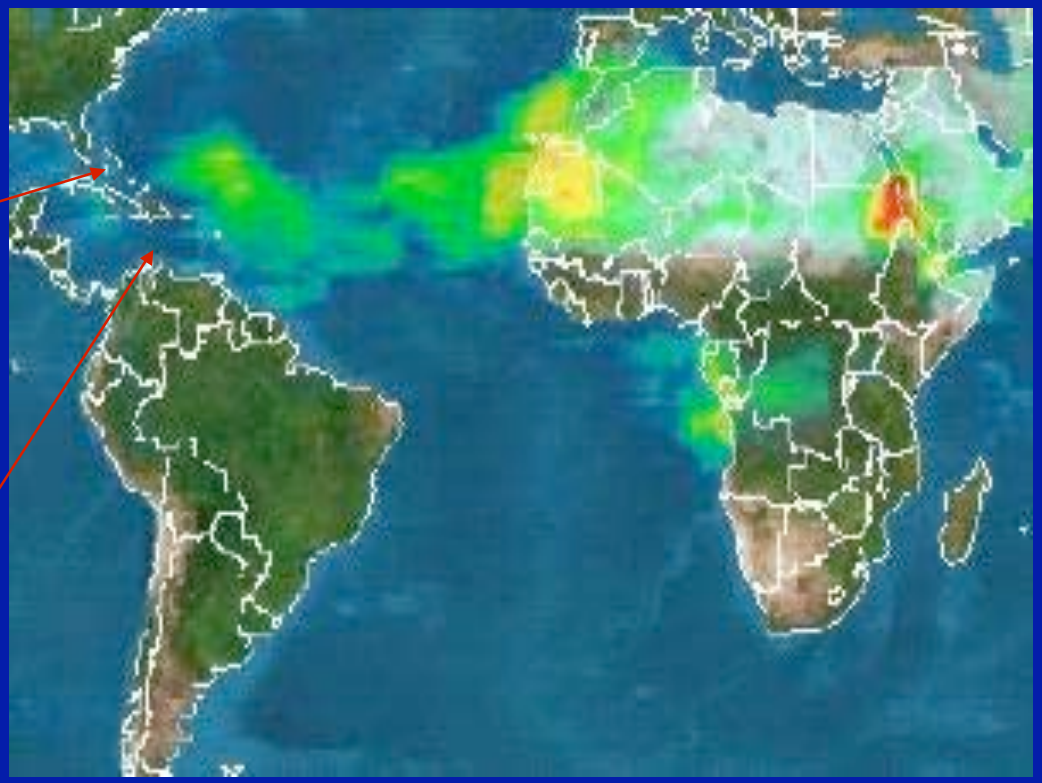
1997-98 ENSO

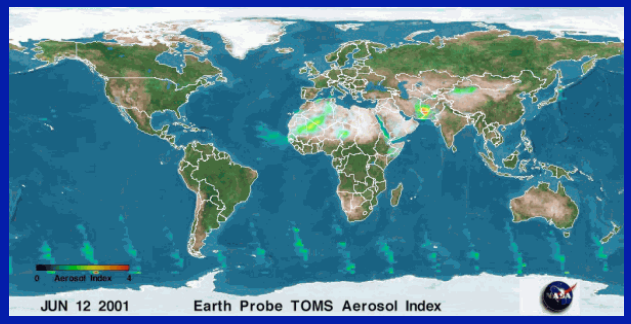

Meningococcal meningitis belt
Elevation Data
of Africa
Digital Chart of the World
DCW Political Boundaries
and Hydrology
30 arc-second cell size
Approximate Scale 1:35520000
Meters
Elevations
Feet
0 & less
1 - 150
151 - 250
251 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 900
901 - 1100
1101 - 1400
1401 & greater
0 & less
1 - 492
493 - 820
821 - 984
985 - 1312
1313 - 1640
1641 - 1969
1970 - 2297
2298 - 2953
2954 - 3609
3610 - 4593
4594 & greater
2004-
2006
Chikungunya
fever

Dust Storms

Aspergillis

Asthma





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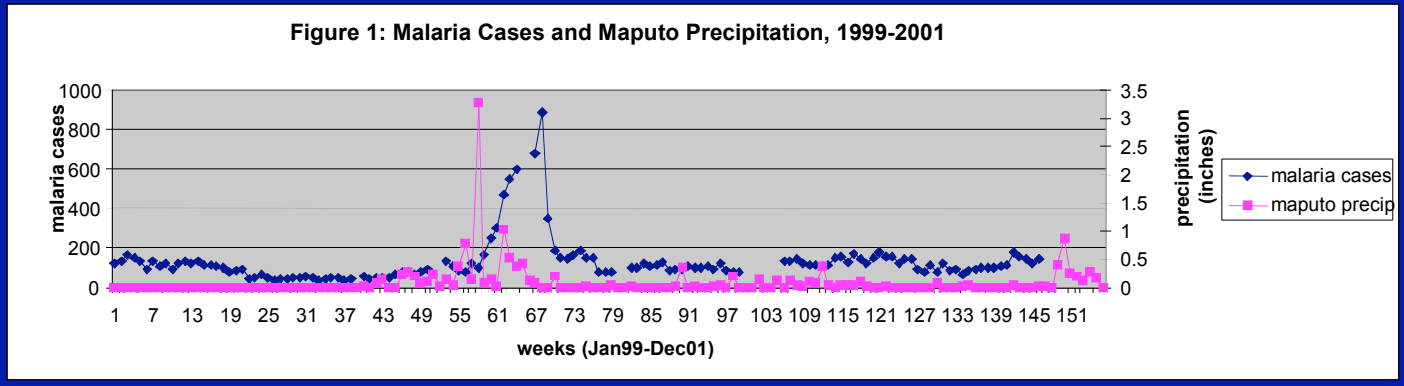
Mozambique Floods 2000

2007



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Fivefold increase in malaria

Cholera
February 2007

Southern Africa
Angola, Namibia, Zambia,
Congo, Mozambique

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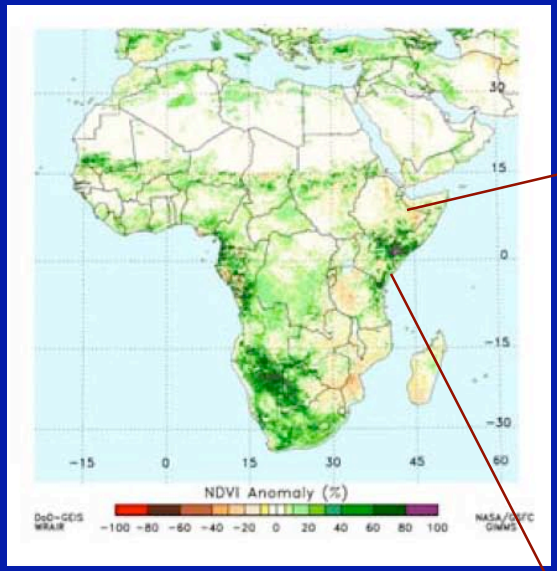
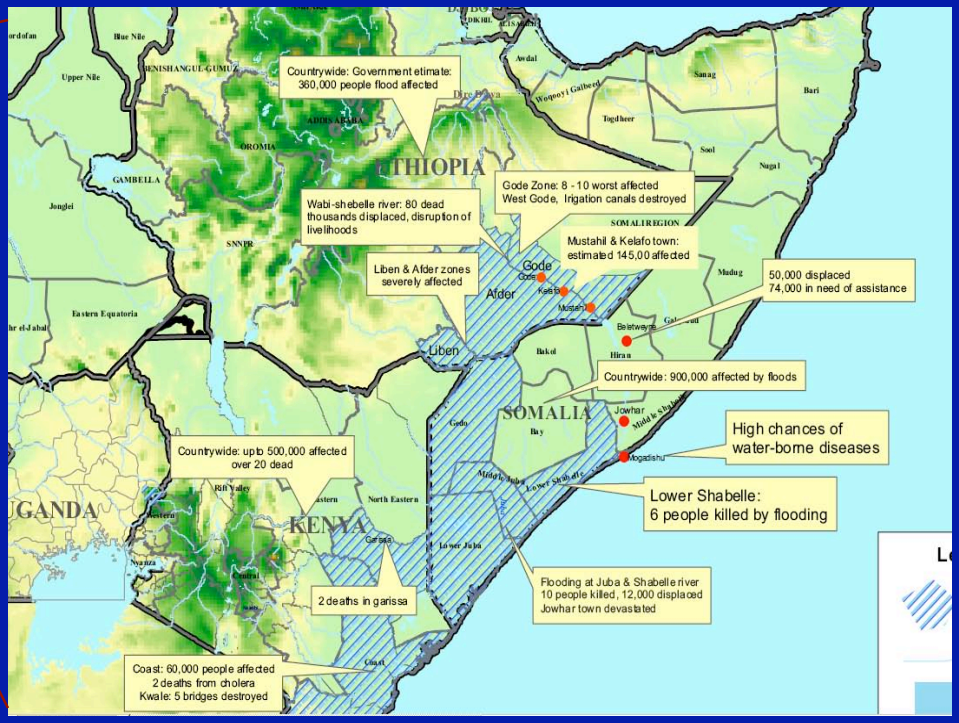
Horn of Africa 2007

Oct/Nov 2006



Malaria



Rift Valley fever

Cholera

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Ag Losses $23 Billion

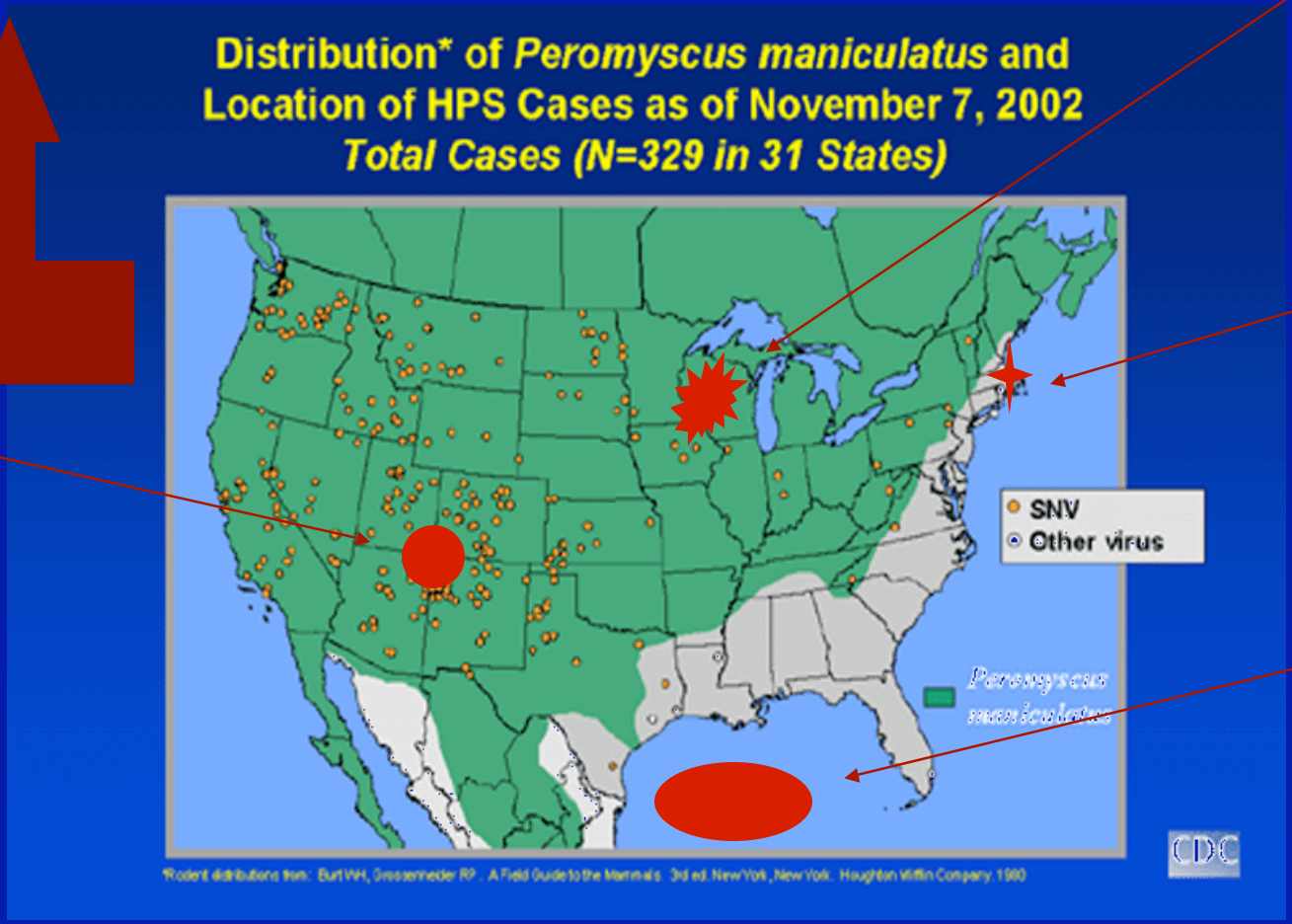
1993 FLOODS

Cryptosporidium

Malaria

HPS

Dead Zone



1993 Drought, Then Early Rains → 10X Explosion of Mice Populations

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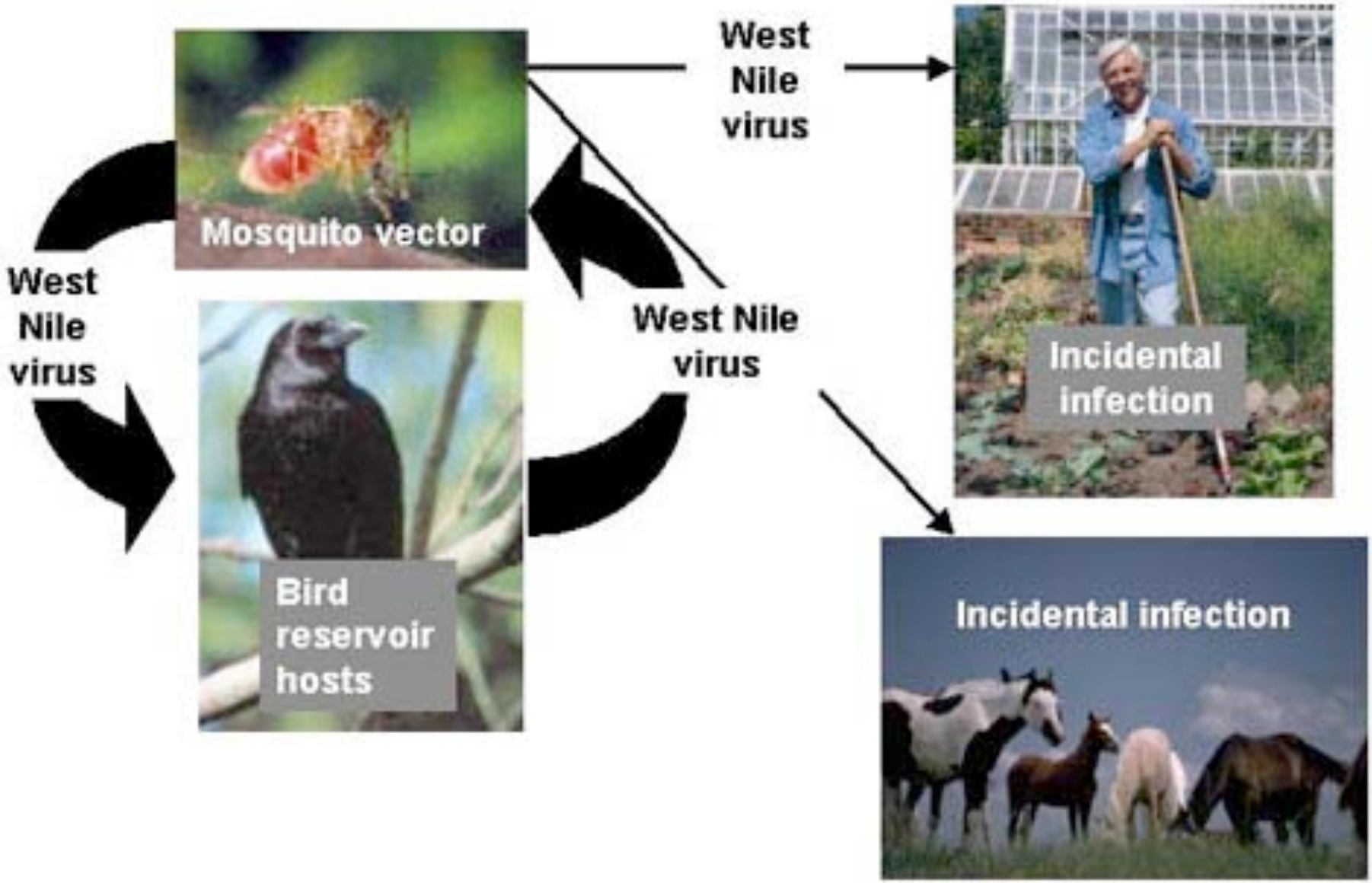
West Nile Virus Transmission Cycle



CDC

Potential Ecological Ripples of West Nile

Raptors

Rodents

Lyme disease
Hantaviruses
Arenaviruses
Leptospirosis
Toxoplasmosis
Plague
Food security

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Freeze-Thaw

Humans

Birds

Forests

Farms

Allergies

Migration

Fruiting trees

Herbivores

Predators

Pests

Parasites

Pollinators

Health

FOOD SECURITY

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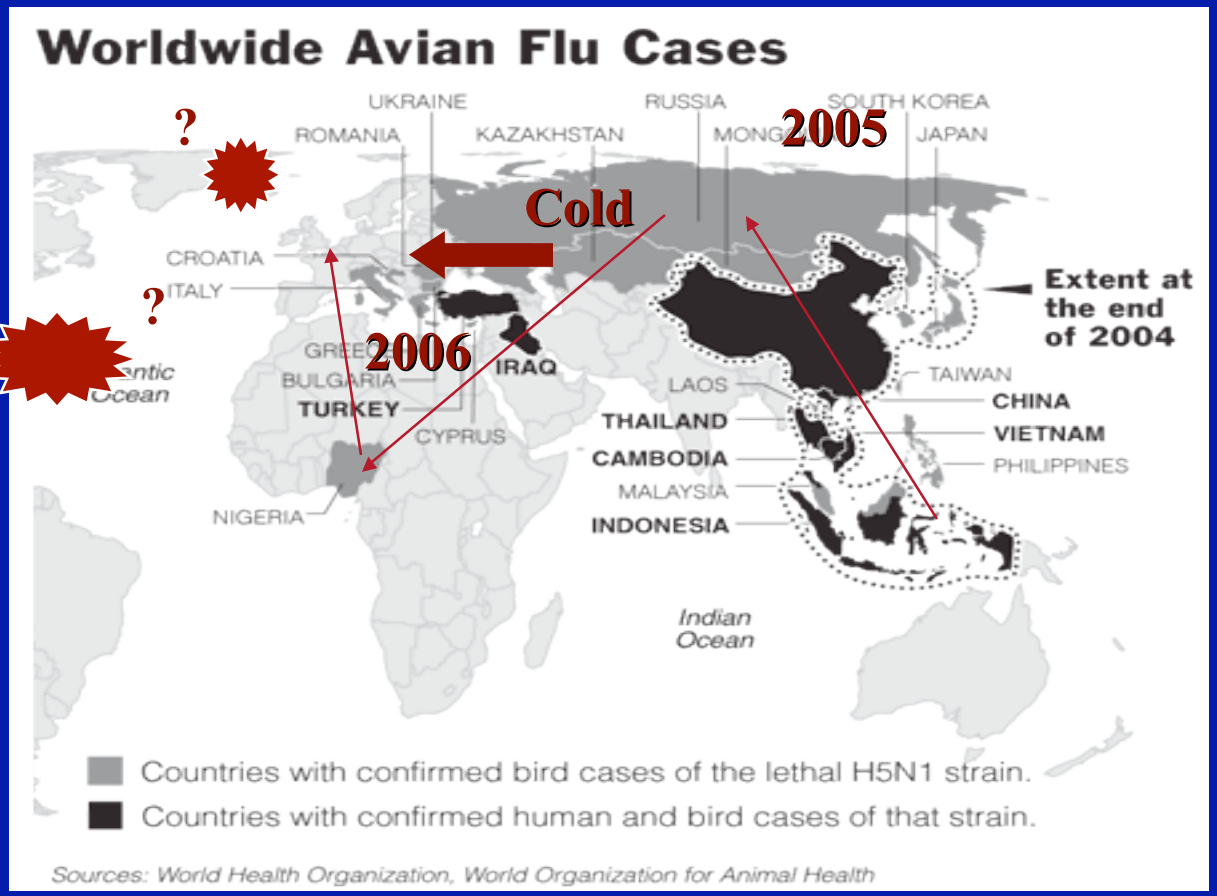
AVIAN FLU and BIRD MIGRATION



Avian Pandemic

- Travel
- Business
- Poultry prices
- Livelihoods
- Food security
- H5N1 in humans

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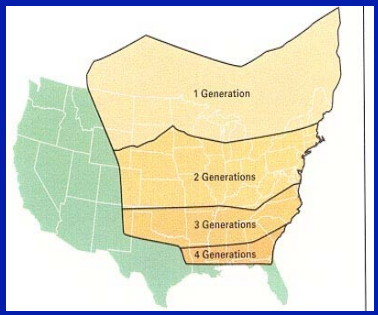
 # Birds killed or culled: 230 million

Climate Change Futures

Natural and Managed Systems



Forests Beetles and wildfires	Millions of acres, timber industry, watersheds, wildlife, carbon pulse	$3 billion in 2003 in US
Agriculture EWEs Pests, pathogens and weeds	Food security	Over $120 billion/yr
Marine systems Coral Bivalves	Food, barriers, salination, livelihoods, insured property Food, filtering	$800 billion $75-150 million
Water Quality and quantity	Agriculture, health, hydropower	$10-40 billion in the US projected

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OIL LIFE CYCLE COSTS

Exploration

Extraction

Transport

Refining

Transport

Petrochemicals

Combustion

Spills
&
Leaks

Benzene

MERCURY

Air Pollution

Acid Rain

Eutrophication
NOxs

Climate Change

Warming Oceans
Coral Reefs
SLR
EWEs
Melting Polar Ice

Harm

Marine

Mammals

Shore birds

Fisheries

Consumers

Livelihoods

Poverty

Conflict

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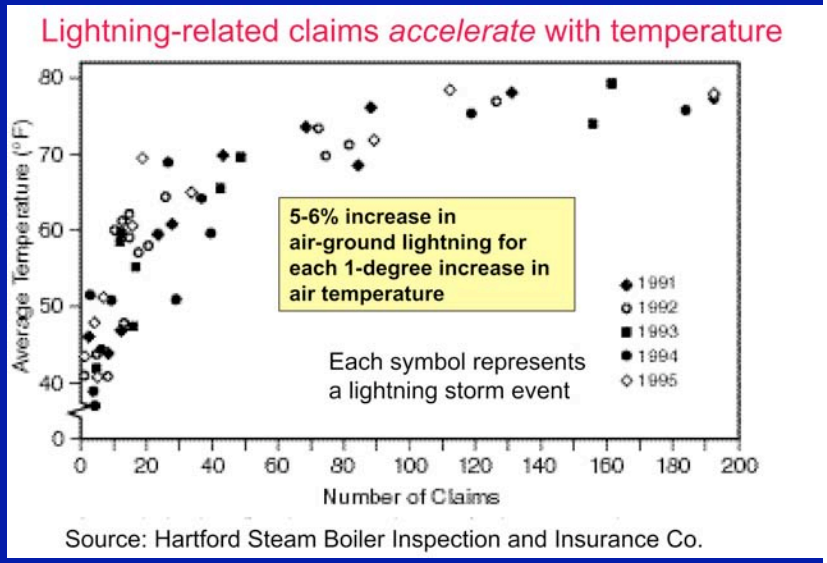
Energy Sector Vulnerabilities

- Storms and interruptions
- Heatwaves and blackouts
- Cooling water and nuclear power plants
- Calving ice shelves/sheets and shipping lanes
- Melting permafrost and pipelines

- Warming → Lightning
- Cooking → Deforestation
- Andean glacier loss → Coal-fired plants



Source: Hartford Steam Boiler Inspection and Insurance Co.

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Confluence of Forces
Convergence of Agendas

- Climate instability
- Availability
- Affordability
- Energy sector vulnerability
- Environmental integrity
- Security and unrest → Venezuela
  → Chad
  → FSU
  → Nigeria
  → Sudan
  → Middle East

Peak oil

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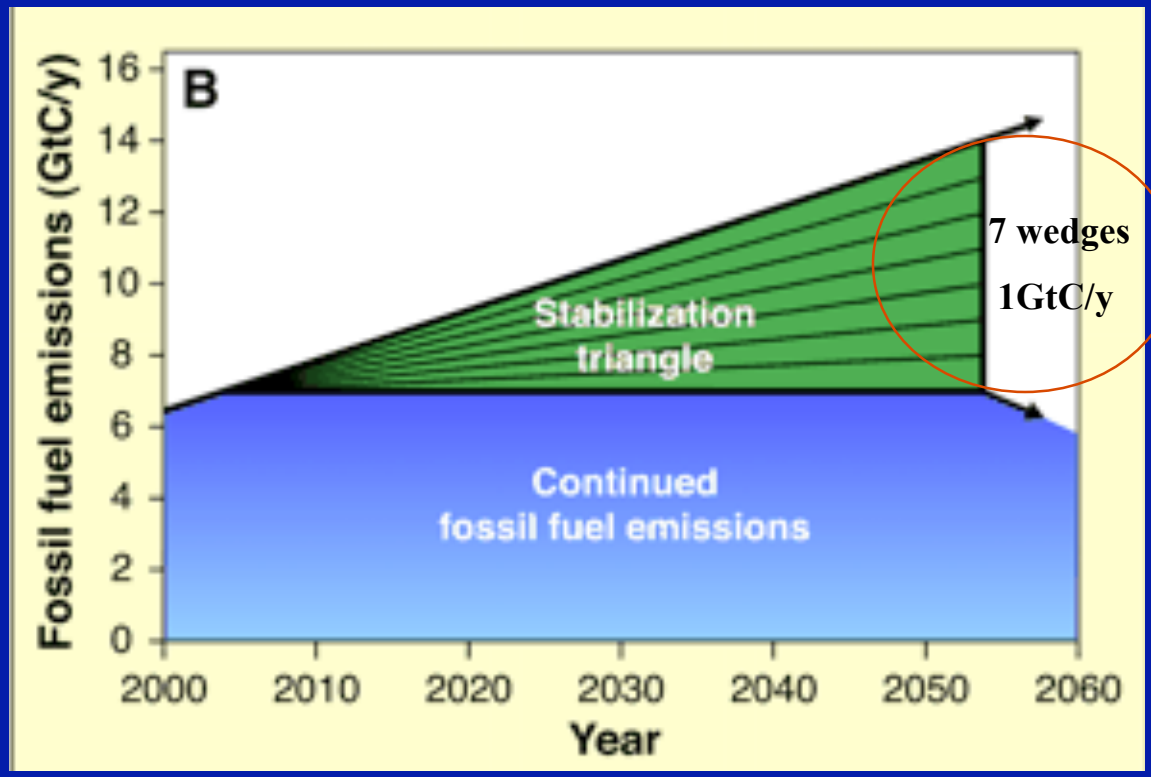
Stabilization Wedges



Bending the Curve

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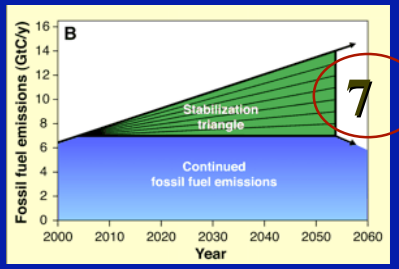
Pacala and Socolow. *Science* 2004

Stabilization Wedges



Energy Efficiency & Conservation

1. CAFÉ Stds., plug-in hybrids, 30-60 mpg
2. Demand Side Mgt. – reduce use
3. Green buildings, heat capture (2/3 lost)
4. Efficient Coal Plants

Renewables

5. Wind
6. PV
7. Renewable H_2, Fuel Cells
8. Biofuels

Natural Sinks

9. Forest nurturing
10. Conservation tillage

Fossil Fuel-based

11. Coal-to-Methane
12. C Capture & Storage (CCS)
13. H_2 Plants w/ CCS
14. Coal-to-Synfuels w/ CCS
15. *Nuclear fission*

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No regrets
LCA needed
Fossil fuel
Nuclear

Green Buildings

Estimated Savings

Respiratory disease: $6 to $14 billion

Allergies and asthma: $1 to $4 billion

Sick building syndrome: $10 to $30 billion

Worker performance: $20 to $160 billion

Lawrence Berkeley National Lab

Studies

Schools with natural light

20% faster on math tests

26% faster on reading tests

Stores with natural light: 40% more sales

Hospitals with better lighting & ventilation: improved patient outcomes

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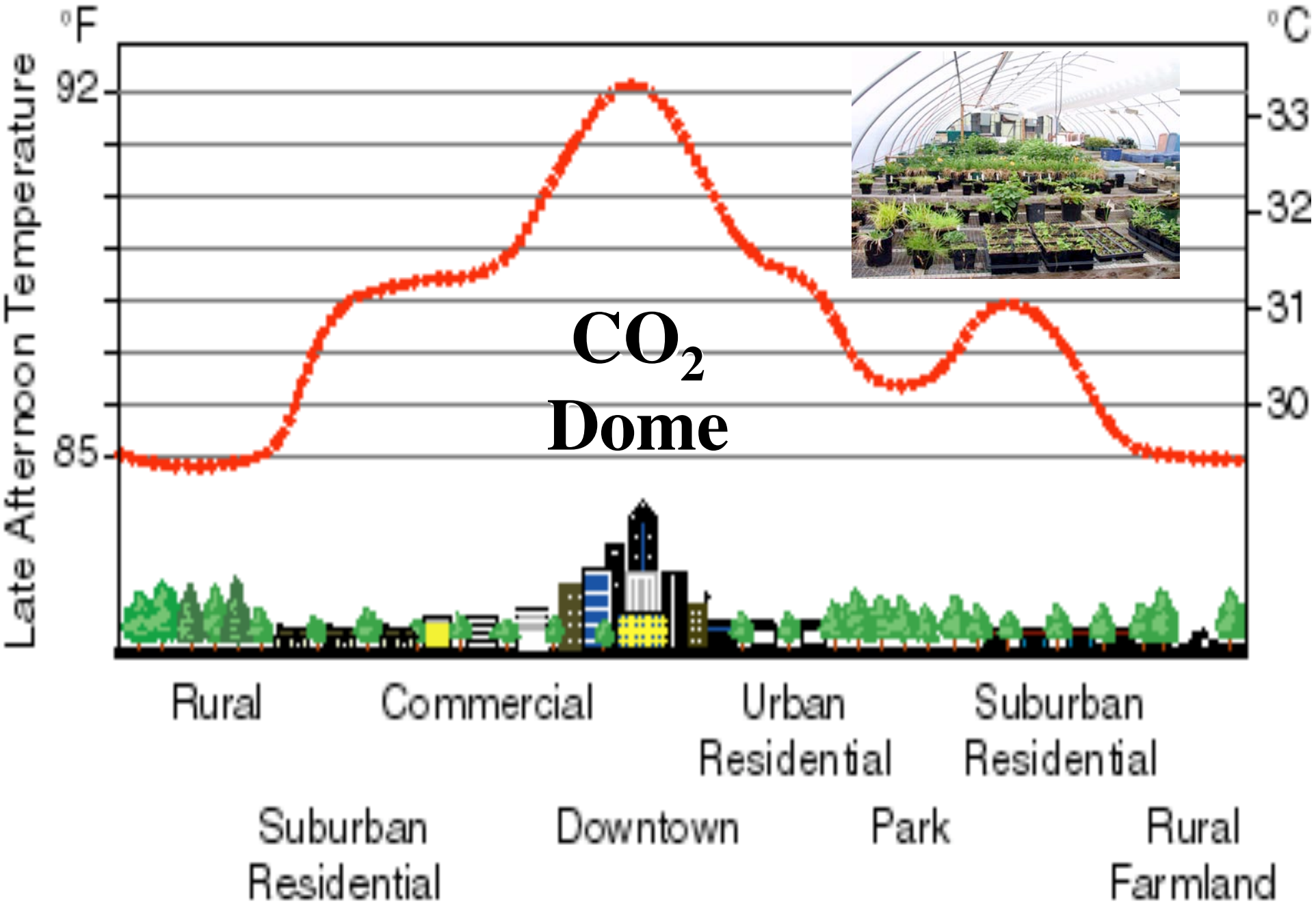
Sketch of an Urban Heat-Island Profile



Harmonizing Adaptation and Mitigation

Distributed Generation

Distributed Development

Water

Purification

Pumping

Irrigation

Desalinization

Schools

Clinics

Homes

Computers

Cooking

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The Stern Review

"Climate change is the greatest market failure the world has ever seen …"

A 60-80% reduction in greenhouse gas emissions is needed to stabilize concentrations.

Policies needed:

1. **A price for carbon through tax, trading or regulation.**
2. **Support innovation and deployment of low-carbon technologies.**
3. **Remove financial and bureaucratic barriers to energy efficiency and renewable energy sources.**
4. **Build the infrastructure for the new, clean energy economy.**

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Financial Instruments for a Clean and Sustainable Energy Transition (FICSET)

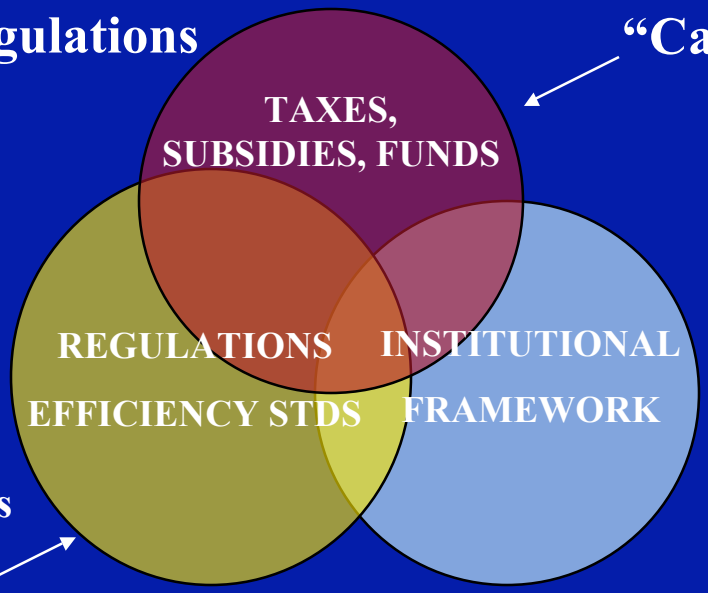
Aligning Rewards and Regulations

Private sector
- Investments
- Insurance
- Ratings

Public sector
- Incentives
- Infrastructure
- R&D
- Procurement practices

"Carrots"

"Sticks"



- Public Health
- Security
- Economy
- Climate Stability

New Energy Plan

- Efficiency, Conservation & Renewables
- Distributed Generation
- Rationalized Transport & Transit
- "Green Buildings" & Smart Growth
- Infrastructure

THE ENGINE OF GROWTH for the 21st CENTURY

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http://chge.med.harvard.edu

http://www.climatechangefutures.org

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For

Q &A

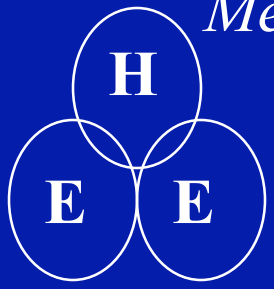
Sustainable Solutions

Goals and criteria

Diversity, Flexibility and Resilience

Multi-purpose for Adaptation and Prevention

Methods



Life Cycle Analysis

SOLAR ENERGY

Energy In

BIOFUELS

Sugar

Corn/stalks

Switch grass

Farm waste

Grease

Fertilizers

E

Recycling

Land/Soils/Food production

Greenhouse gases

NO_xs

CO_2

E **Fermentation**

E **Transport**

Ethanol

E

Combustion

E

Energy Out

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Genetic Shift in Photoperiodic Response Correlated with Global Warming

--Bradshaw & Holzapfel, PNAS 2001

Wyeomyia smithii (pitcher-plant mosquito) –

shift to southern phenotype

shorter daylengths (southern) cue for diapause

fastest response in northern populations

reflecting ↑ TMINs at Boreal latitudes

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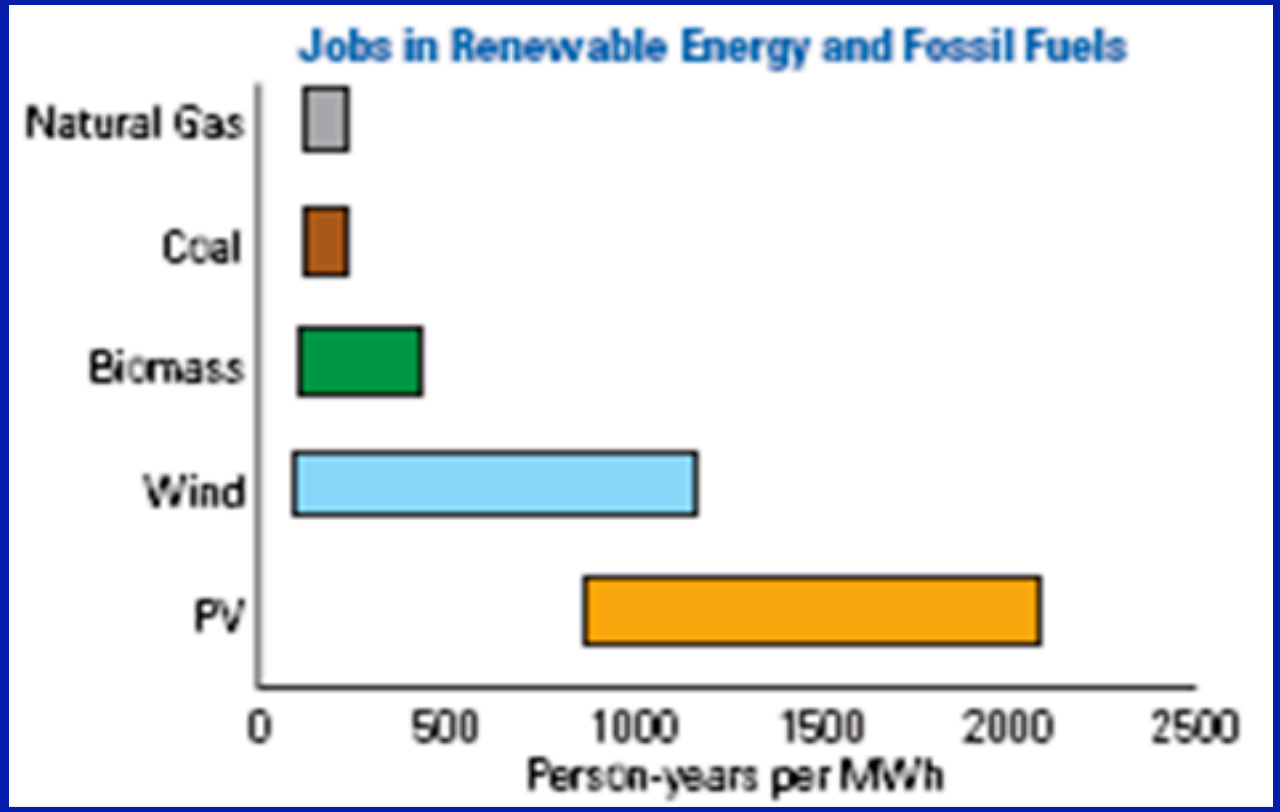
JOBS: FOSSIL FUELS AND RENEWABLE ENERGY



Flavin, C., et al. *American Energy: The Renewable Path to Energy Security.* Worldwatch Institute & Center for American Progress. September, 2006.

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Land to Produce 30% of the Nation's Electricity with Renewables

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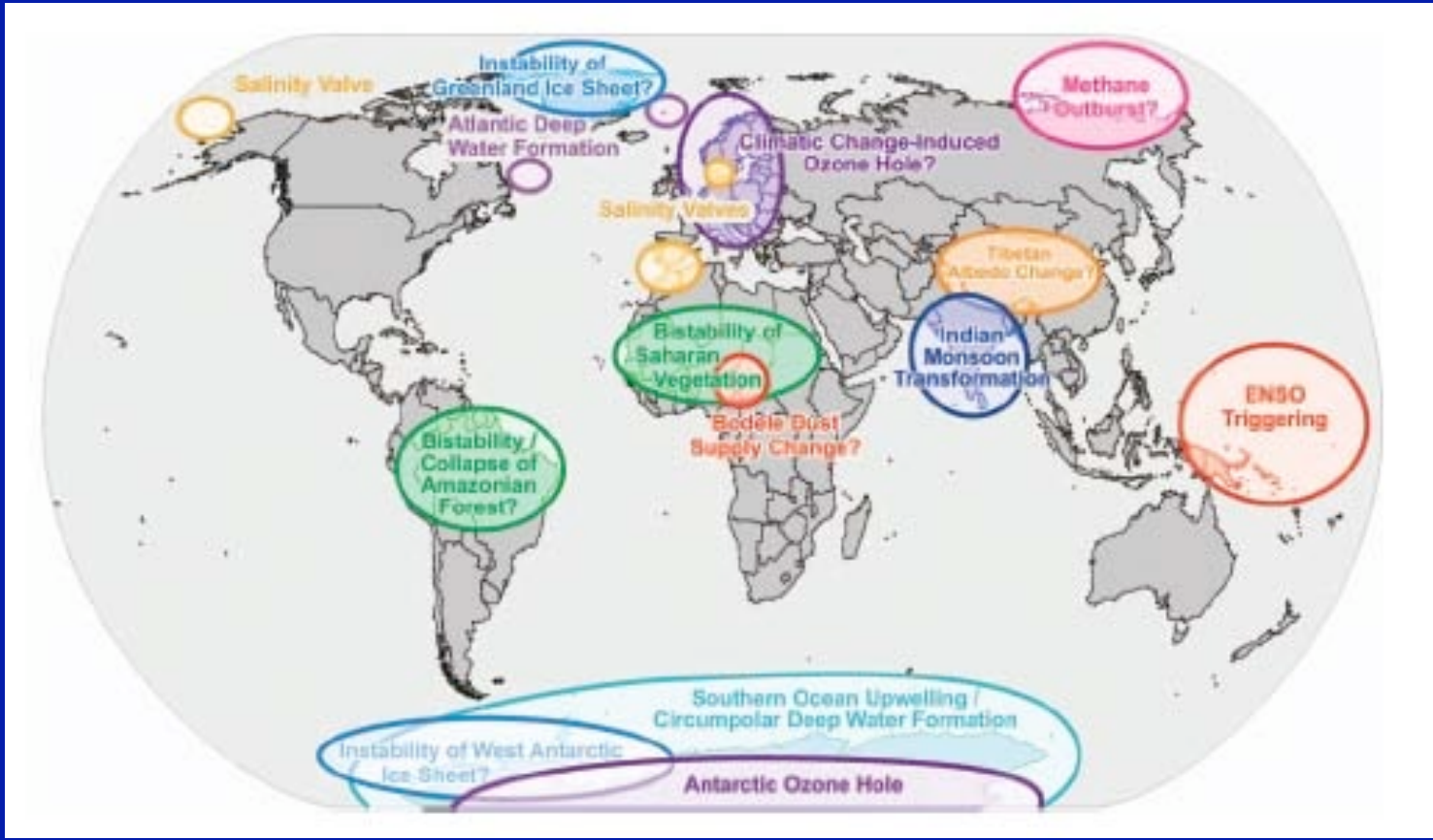
Flavin et al. Worldwatch Institute & Center for American Progress. September, 2006.

Tipping Points



Hans Joachim Schellnhuber
Potsdam and Tyndall Centres
***Nature* 27 Oct 2005**

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CLIMATE CHANGE

- Winter Warming
- Altered Timing of Seasons
- Weather Patterns & Anomalies
- More Winter Precip Falling as Rain
- Freeze/Thaw Cycles
- Wide Swings in Weather & Sequential Extremes

ECOLOGICAL INSTABILITY

RELEASE OF PESTS & PATHOGENS ⇒ EIDs

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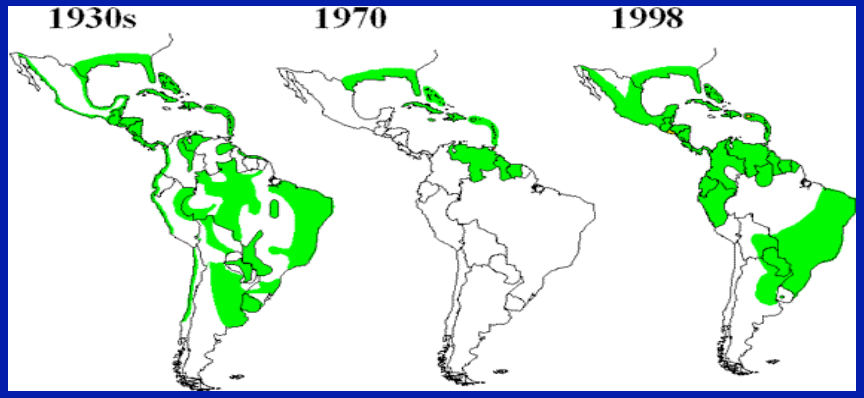
Dengue ("Breakbone") fever/DHF

Jan/Feb 2007

1. Paraguay (Asuncion)
2. Mexico
3. Philippines (Bayugan)
4. Indonesia (Java, Jakarta)
5. Malaysia (Peninsular)



Aedes aegypti

ProMED archives

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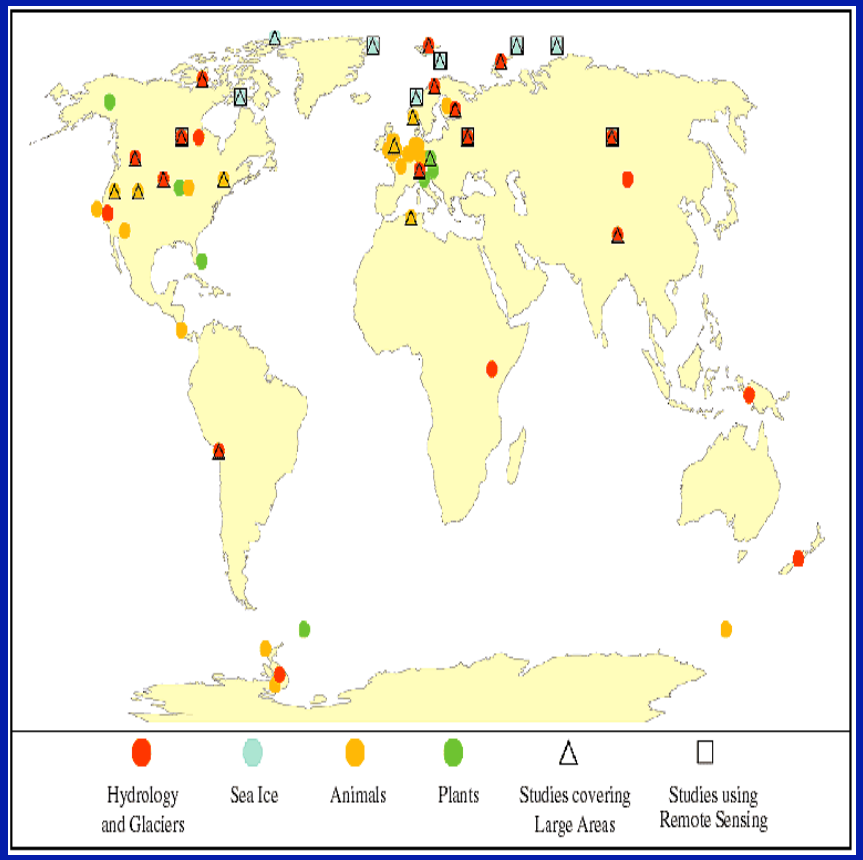
Intergovernmental Panel on Climate Change 2001

Key New Findings

Biological Systems are Reacting

— Latitude and Altitude Shifts

- Plant migrations
- Insects and butterflies
- Timing of bird egglaying
- Marine species distribution



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DISEASES OF TREES

- West Coast US - fungi (*Phytophthora)*
- Alaska -spruce bark beetles now have two generations/year
- East Coast US - hemlock woolly adelgid insects moving north with each warm winter

Diseased and denuded trees become more susceptible to drought and fire.

Conversely, droughts increase vulnerability to pests.

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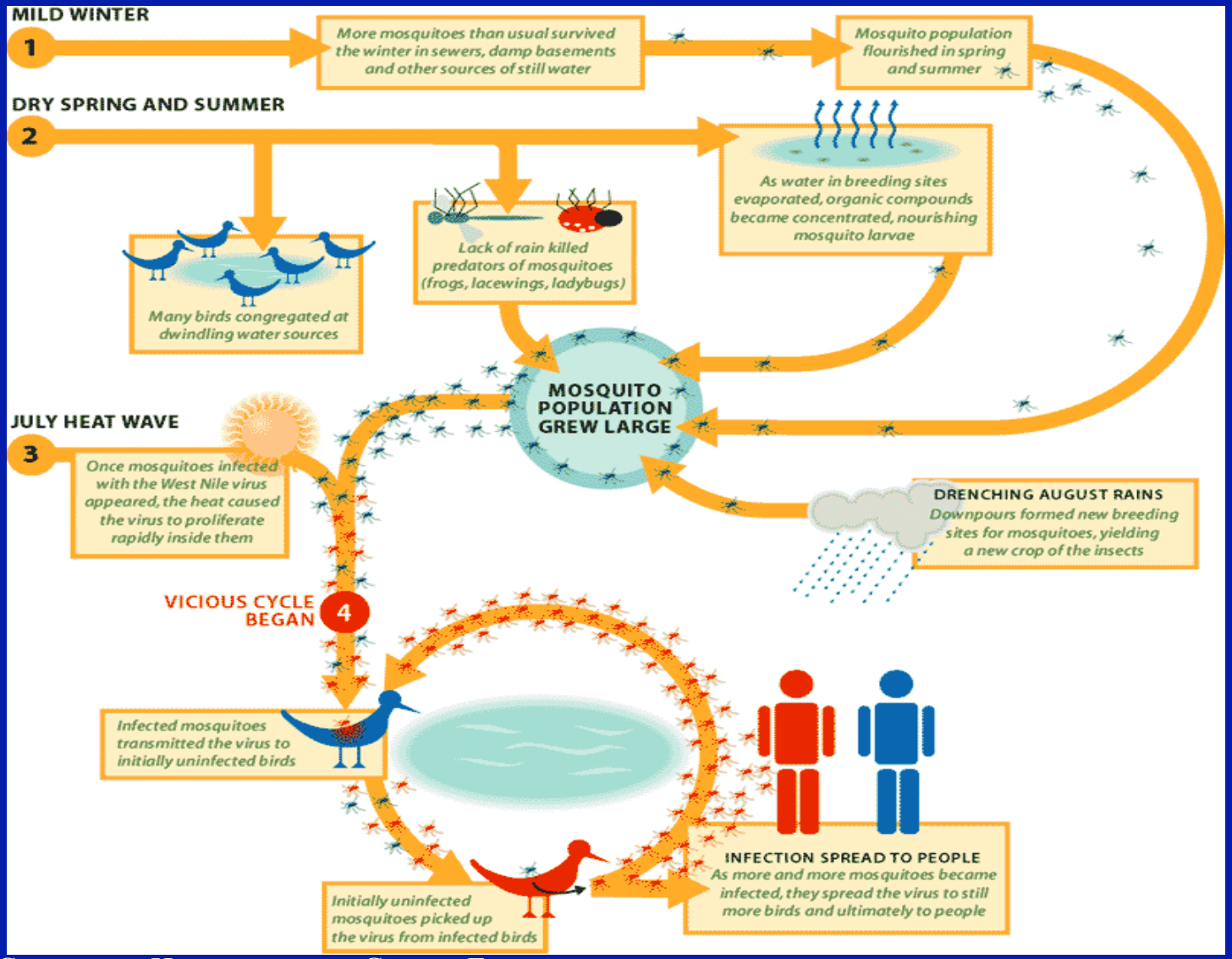
WNV AND DROUGHT



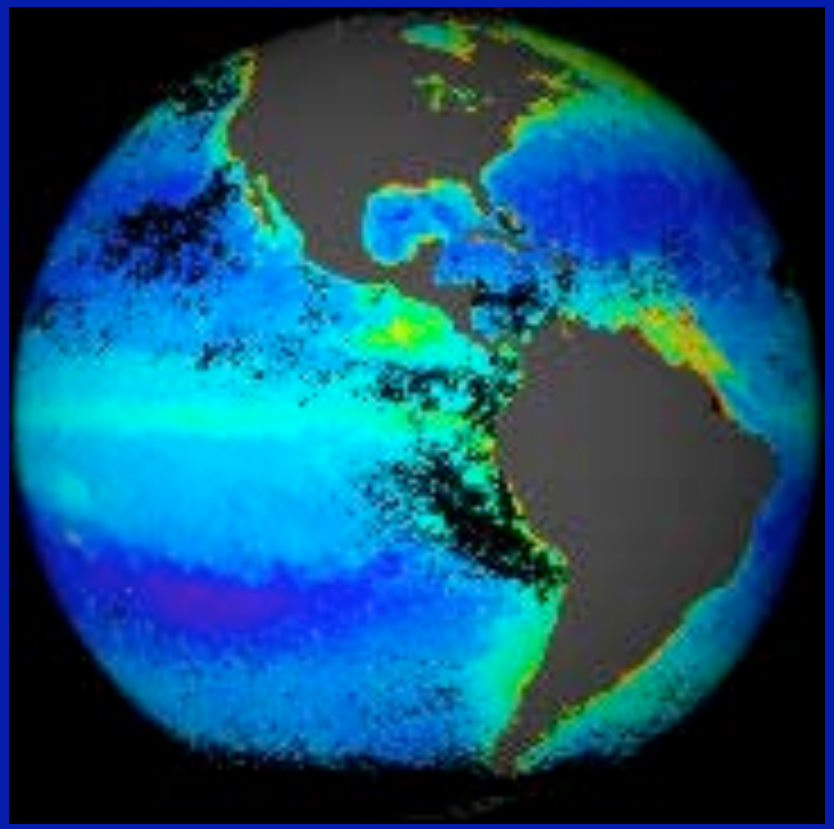
Levels of Solutions

Surveillance & Response

Early Warning Systems

-- Mapping, Monitoring & Modeling

-- Climate forecasting



Environmental, Energy & Economic Policies

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BIODIVERSITY LOSS & EIDS

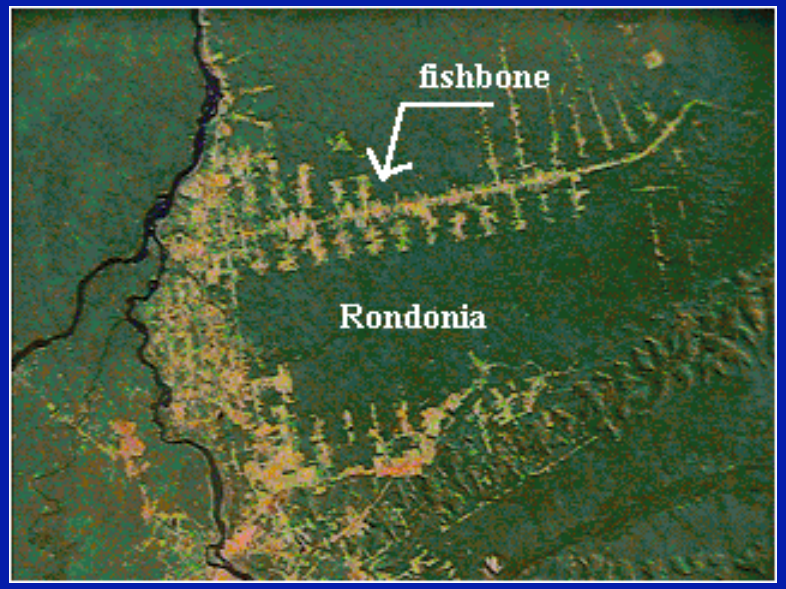
1. **Habitat** loss, fragmentation, simplification & human penetration

2. Declines in **predators**
   - prey, pests & pathogens

3. Loss of **competitors**
   - buffer pathogen abundance

4 Dominance of **generalists** over specialists

5. **Diseases** of wildlife
   - ▲ functional groups (guilds)
   - extinctions



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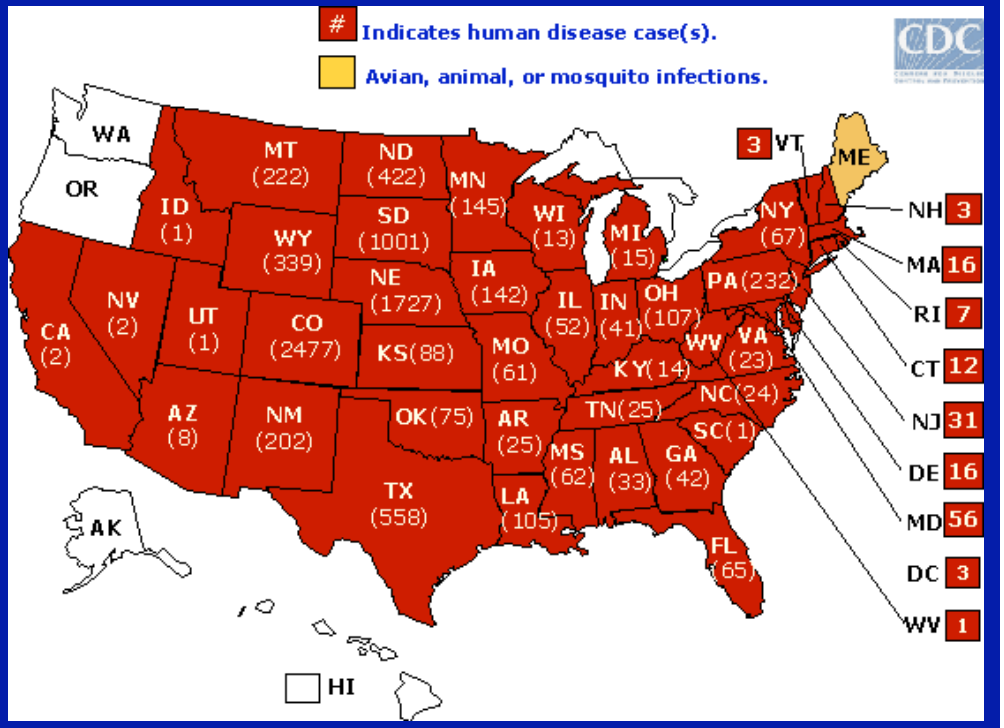
WNV: A DISEASE OF WILDLIFE

2002 - 230 SPECIES, 44 STATES, DC, 5 CANADIAN PROVINCES

- **138 Bird *spp.*, *RAPTORS***
  - ***37 spp. of mosquitoes***
- **HORSES**
- **ZOO animals**
- **REPTILES**



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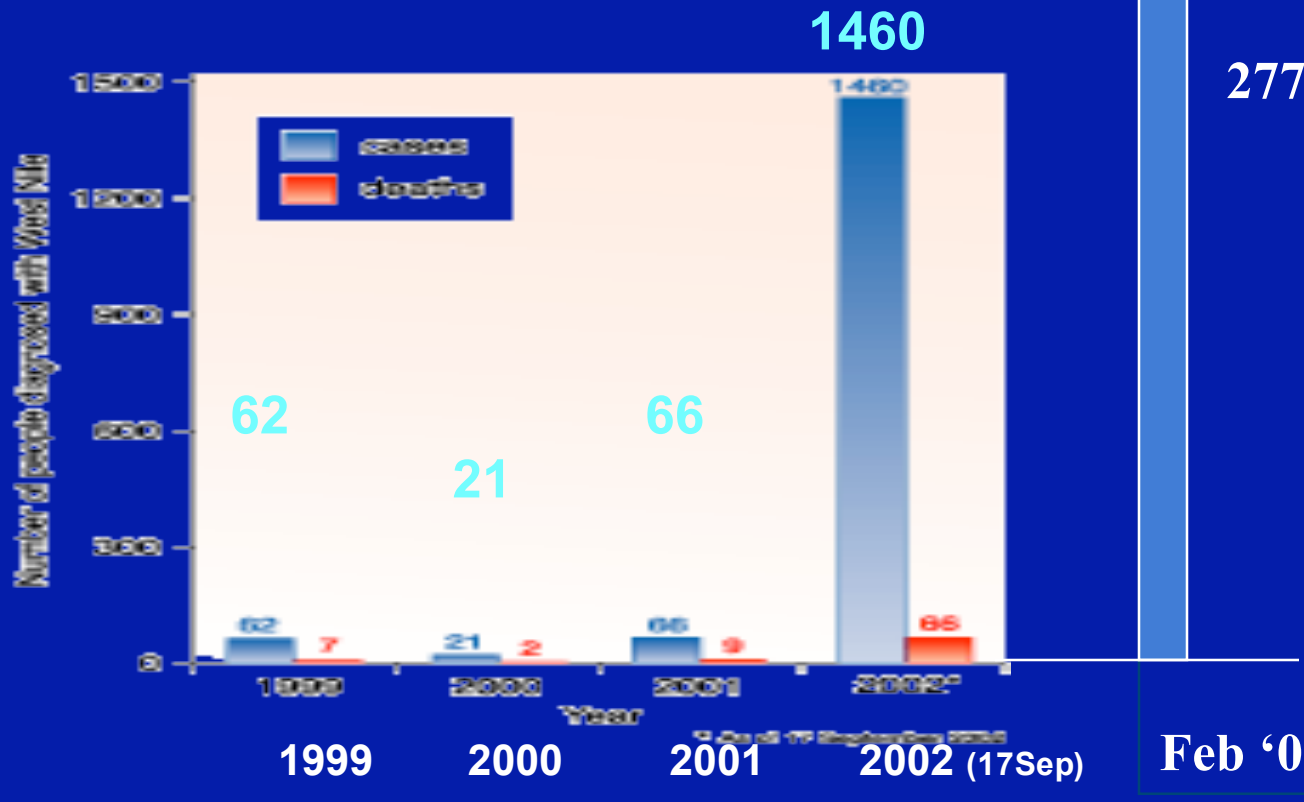
Nov 25, 2003

WEST NILE VIRUS
HUMAN CASES & DEATHS



4161 cases

277 deaths

Feb '03

-*Science* 2002:297:1988

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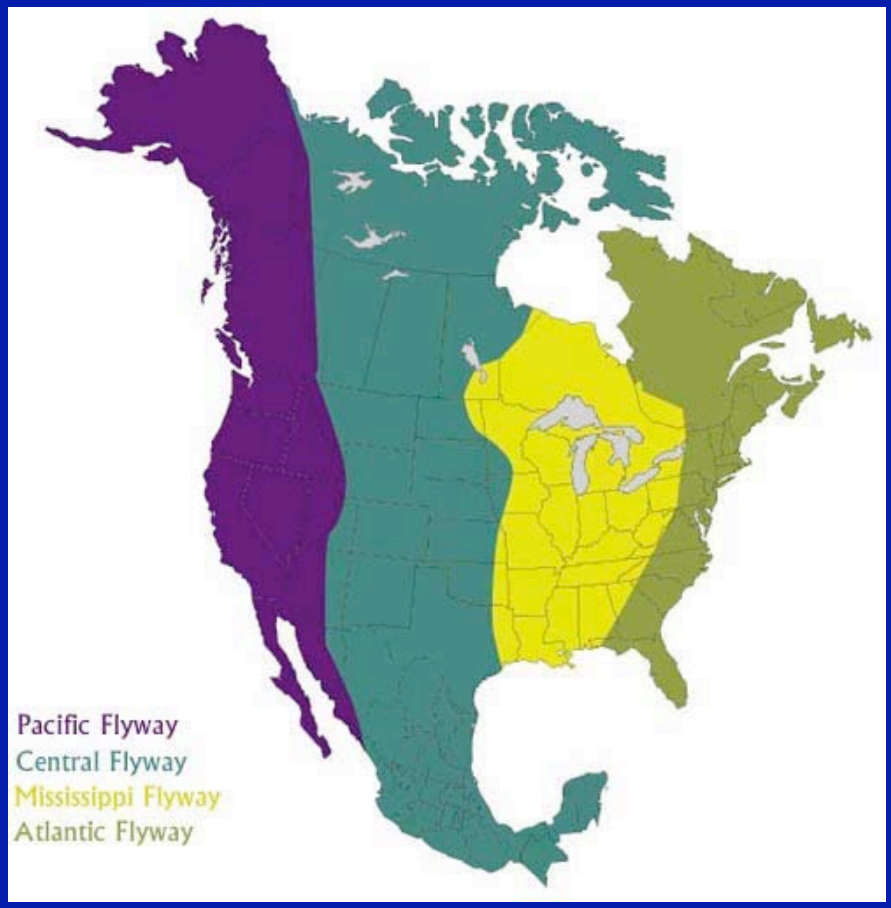
WNV: A DISEASE OF WILDLIFE

230 SPECIES

INFECTED IN 2002

- 134 Bird *spp.*, Raptors
- 14,045 Horses
- Zoo Penguins & Macaques
- Reptiles – Fla. Alligators



AVIAN FLYWAYS

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HURRICANE MITCH

IMPACTS ON HEALTH AND DEVELOPMENT

DISEASE CLUSTER

-- *Malaria* (>30,000 cases)
-- *Dengue fever (>1,000)*
-- *Cholera (>30,000)*
-- *Leptospirosis*

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Climate Change and Environmental Justice

Oil-related health consequences

- **Extraction: Nigeria, Ecuador, Mexico**
- **Refining & benzene**
- **Utility plants & mercury**
- **Air pollution & inner city truck routes**
- **Extreme weather events**
- **Economic inequities**

Vulnerabilities – coping, adaptation, restoration, prevention, public health infrastructure

Mozambique

But no nation is immune

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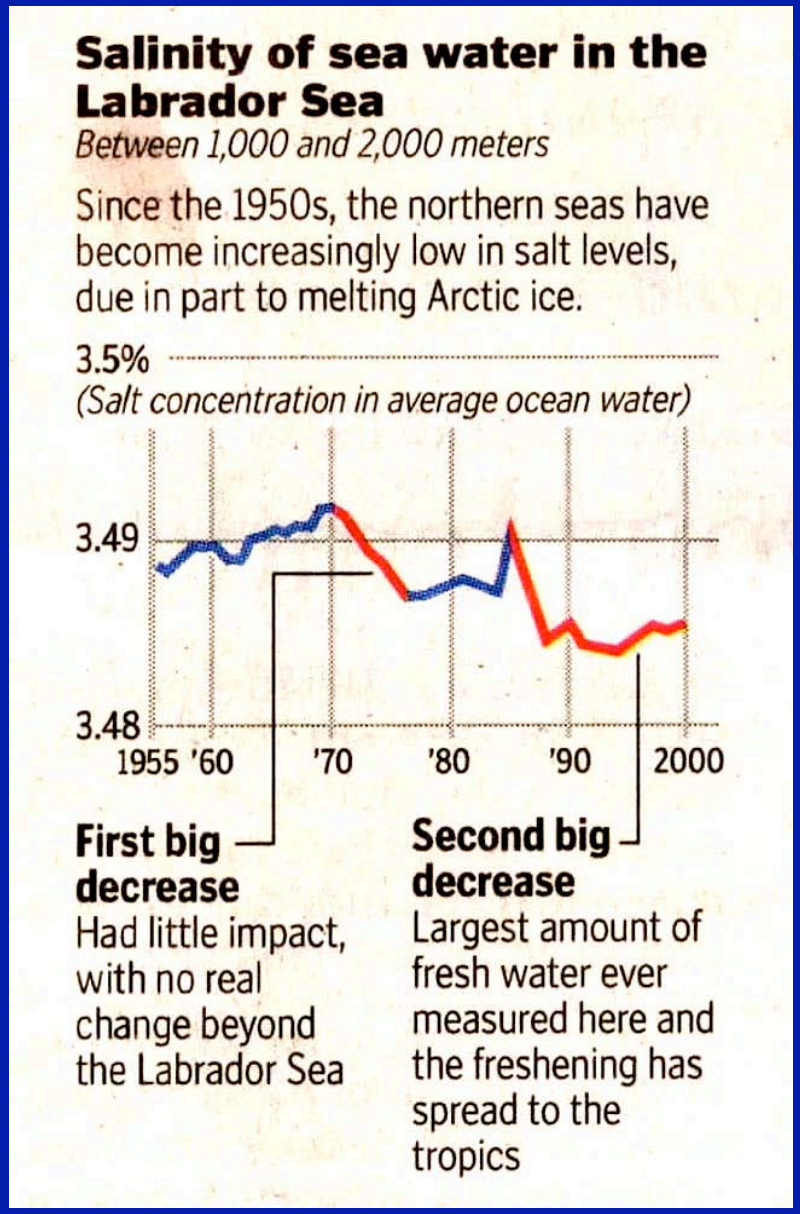
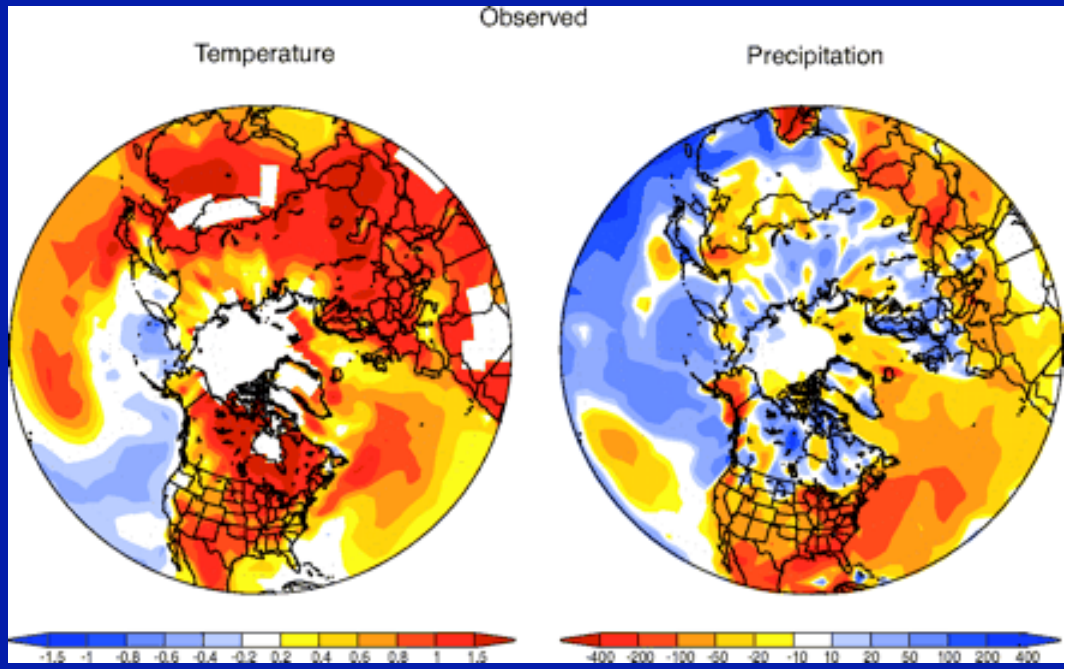
FRESHENING OF THE NORTH ATLANTIC





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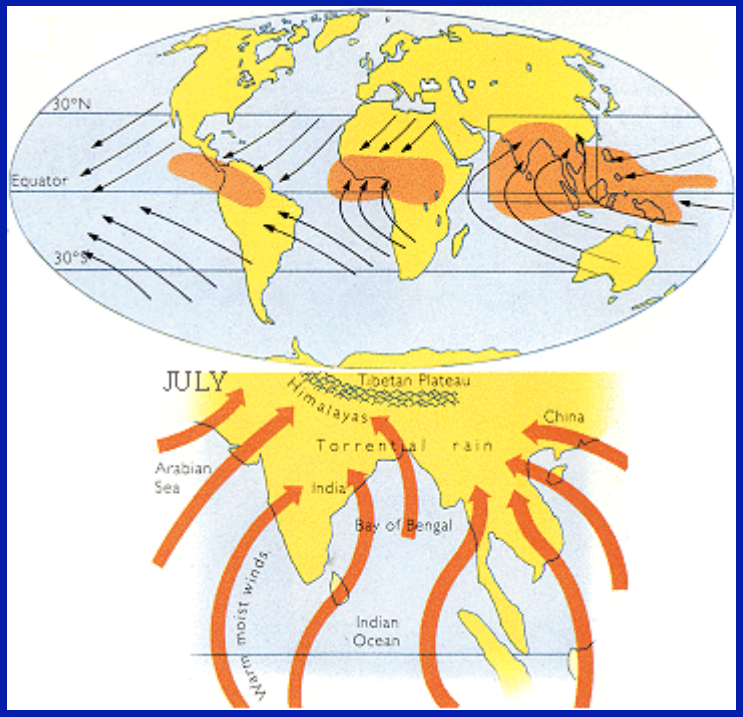
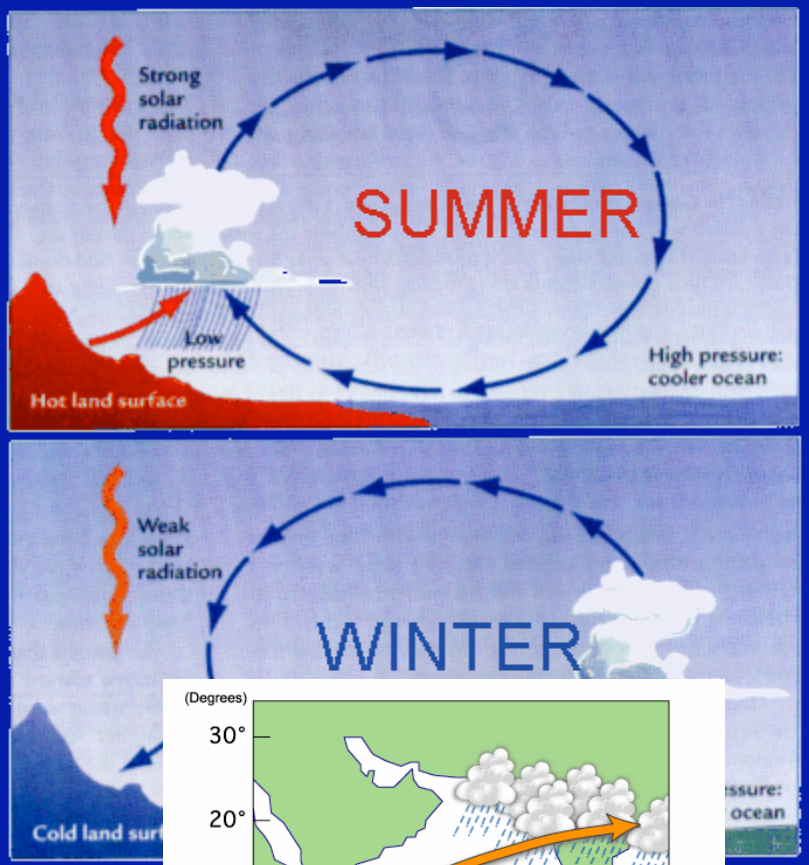
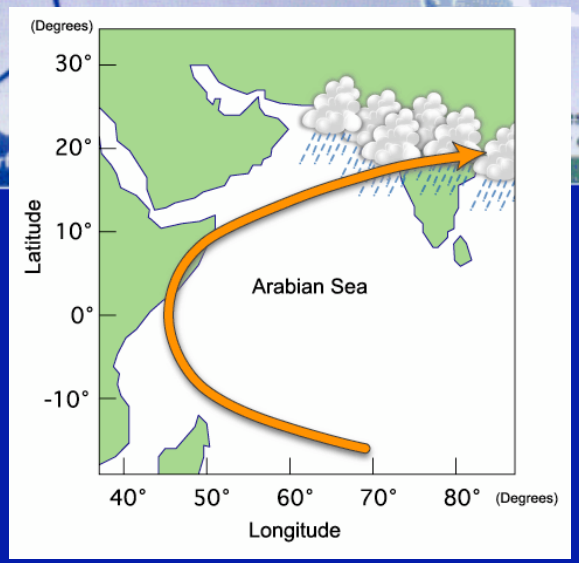
Hoerling and Kumar, Science 2003 ;299: 691

Monsoons







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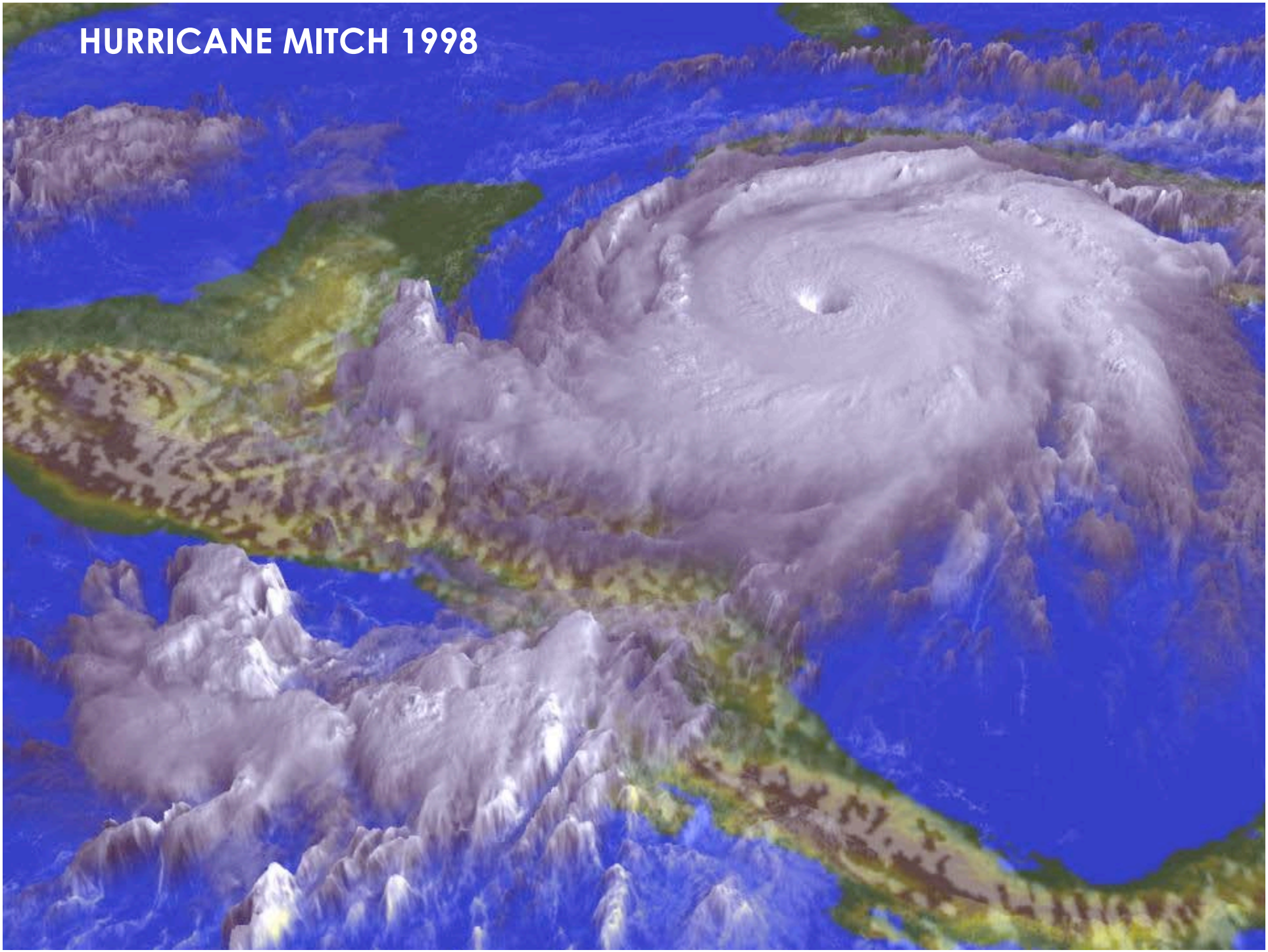
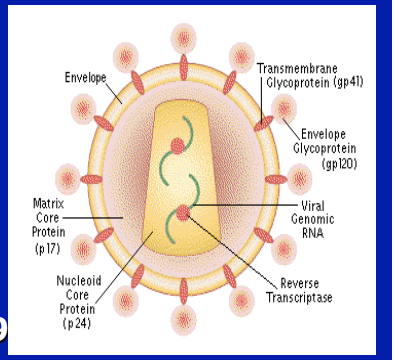

HURRICANE MITCH 1998

HIV AND THE ENVIRONMENT



Viral Evolution

- Coxsackie virus in mice

-Levander & Beck. Selenium and viral virulence. Br Med Bul 19

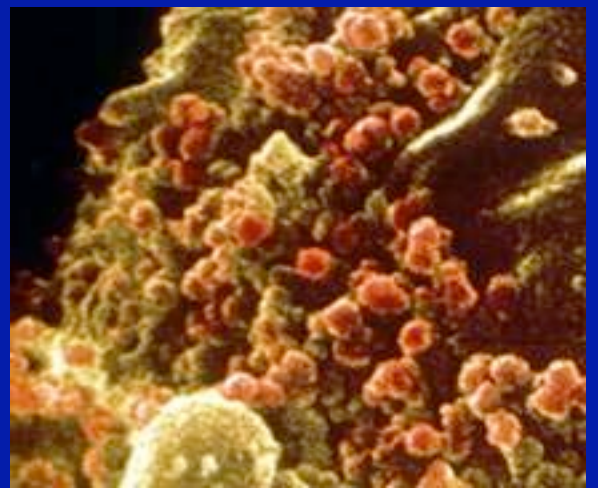
- Malnutrition and burden of disease

-Chndra RK. Nutrition and immunoregulation. J Nutr 1992;122:754

Stress proteins and mutation rates

Immune surveillance system

GEC and Spread



HIV Infected T cell

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US Winter Storms 2007

>65 deaths

in nine states

>6,000 cattle

Power outages

Business interruptions

Buffalo in snow

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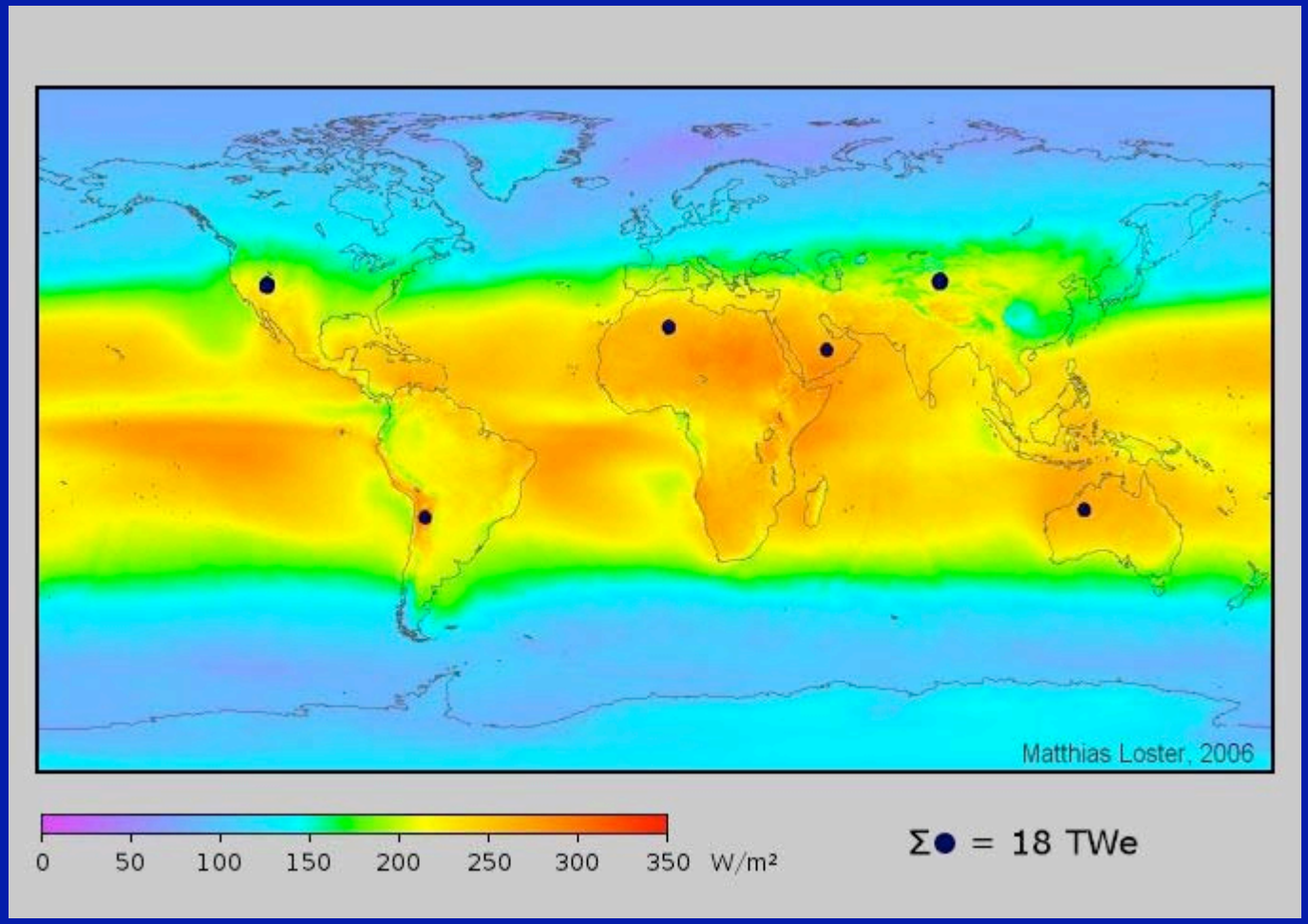
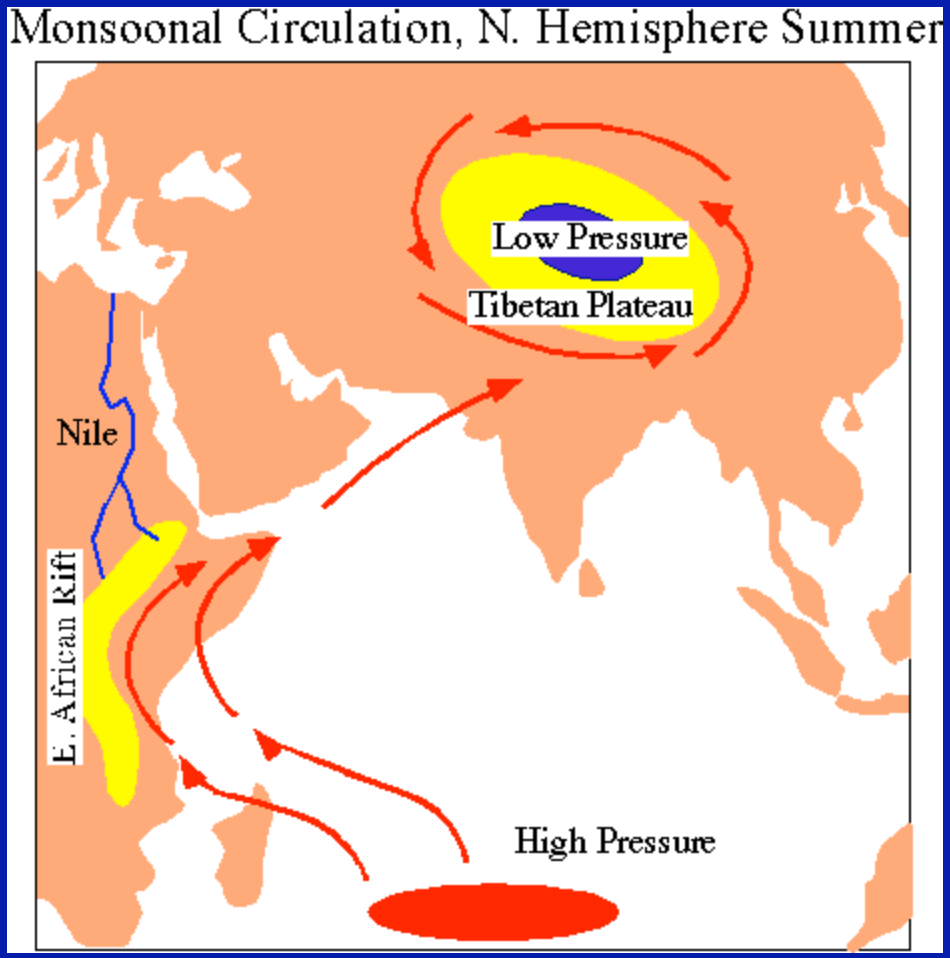
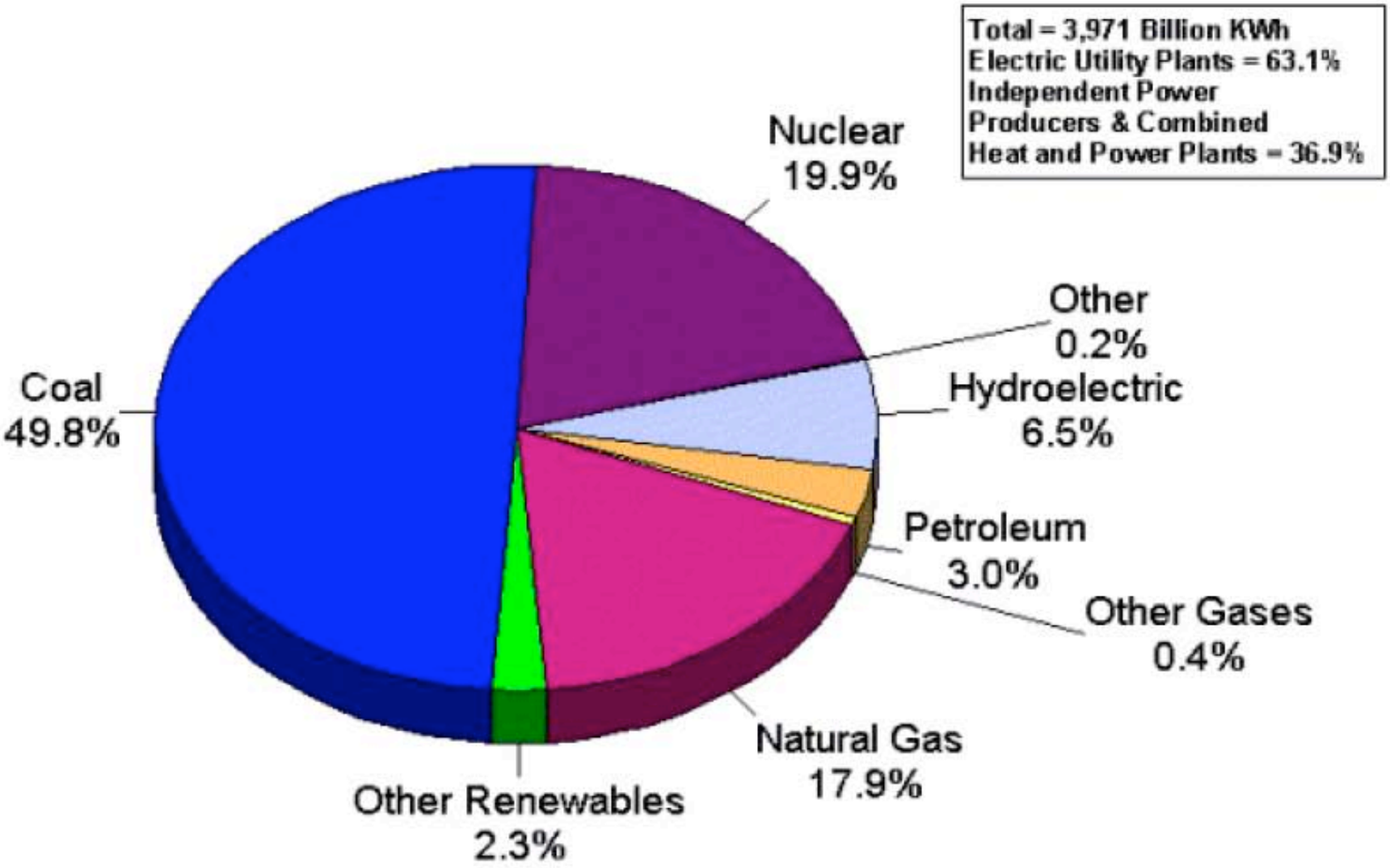

Matthias Loster, 2006
0 50 100 150 200 250 300 350 W/m²
Σ● = 18 TWe


Monsoonal Circulation, N. Hemisphere Summer
Low Pressure
Tibetan Plateau
Nile
E. African Rift
High Pressure

US Electric Power Generation Sources (2004)



Note: Conventional hydroelectric power and hydroelectric pumped storage facility production minus energy used for pumping.

INFECTIOUS DISEASE

A DRIVING FORCE IN HISTORY

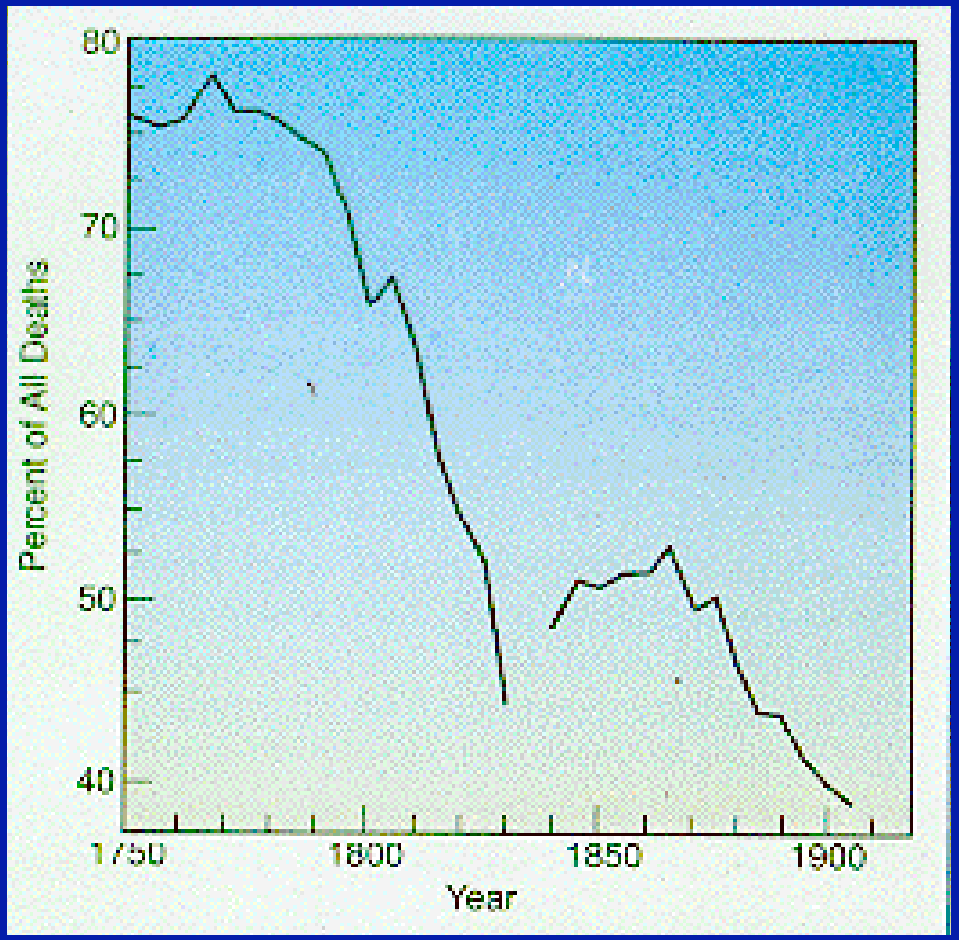
The Bad News

PLAGUE

541 AD

1346 AD

The "Good" News



Cholera, TB, Smallpox

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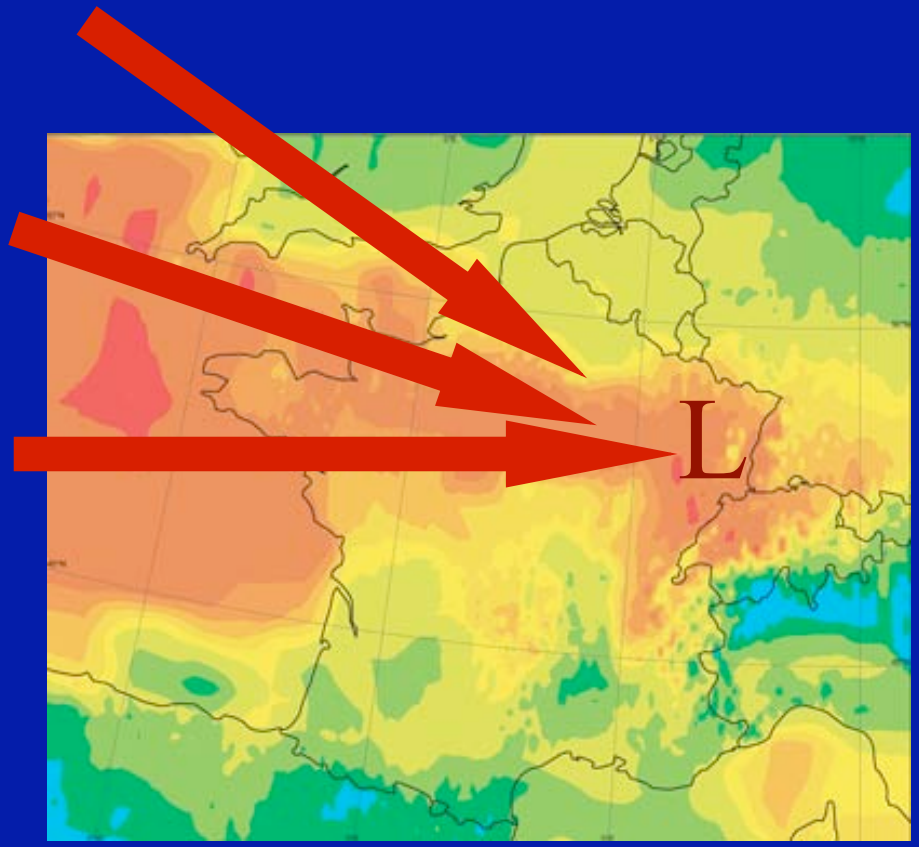
Windstorms Anatol, Lothar and Martin: Dec '99



Sweden, Jan 2005

129 mph winds

120 deaths

300m trees in France

Power outages & business interruptions

€7.2bn insured losses

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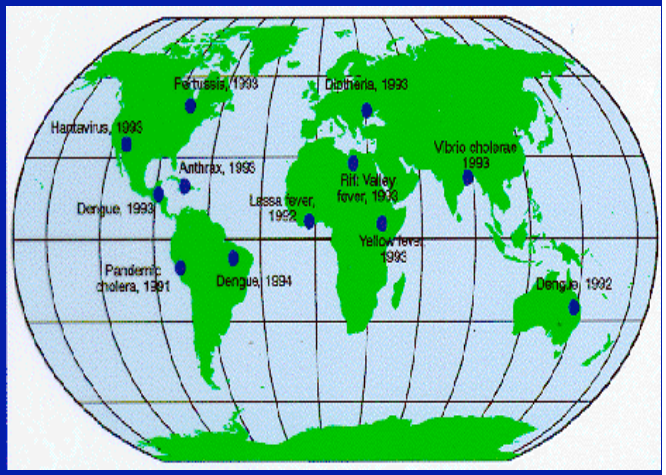
Global Emergence, Resurgence & Redistribution of Infectious Diseases

30 DISEASES "NEW" TO MEDICINE SINCE 1976



HIV/AIDS **Ebola**

Legionnaires' ***E. coli* O157:H7**

Multiple Antibiotic-Resistant Agents

Hantavirus Pulmonary Syndrome

Lyme Disease **Nipah Virus**

Vibrio cholerae* O139** ***Arenaviruses

VECTORS

Mosquitoes
Ticks
Rodents
Bats
Tsetse Flies
Fleas
Lice
Snails
Algae

RESURGENT & REDISTRIBUTING

Malaria, Dengue Fever, West Nile Virus

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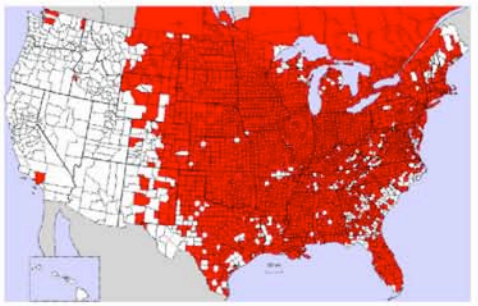
WEST NILE VIRUS IN NORTH AMERICA

[Compiled from CDC, Health Canada, USGS, and ProMED-mail sources as of 14 May 2003]

Joseph P. Dudley

U.S. Army Environmental Programs Directorate

Versar, Inc



U.S.A.

2002

Los Angeles CA

[airport import ?]

1998 [?]

1999

2000

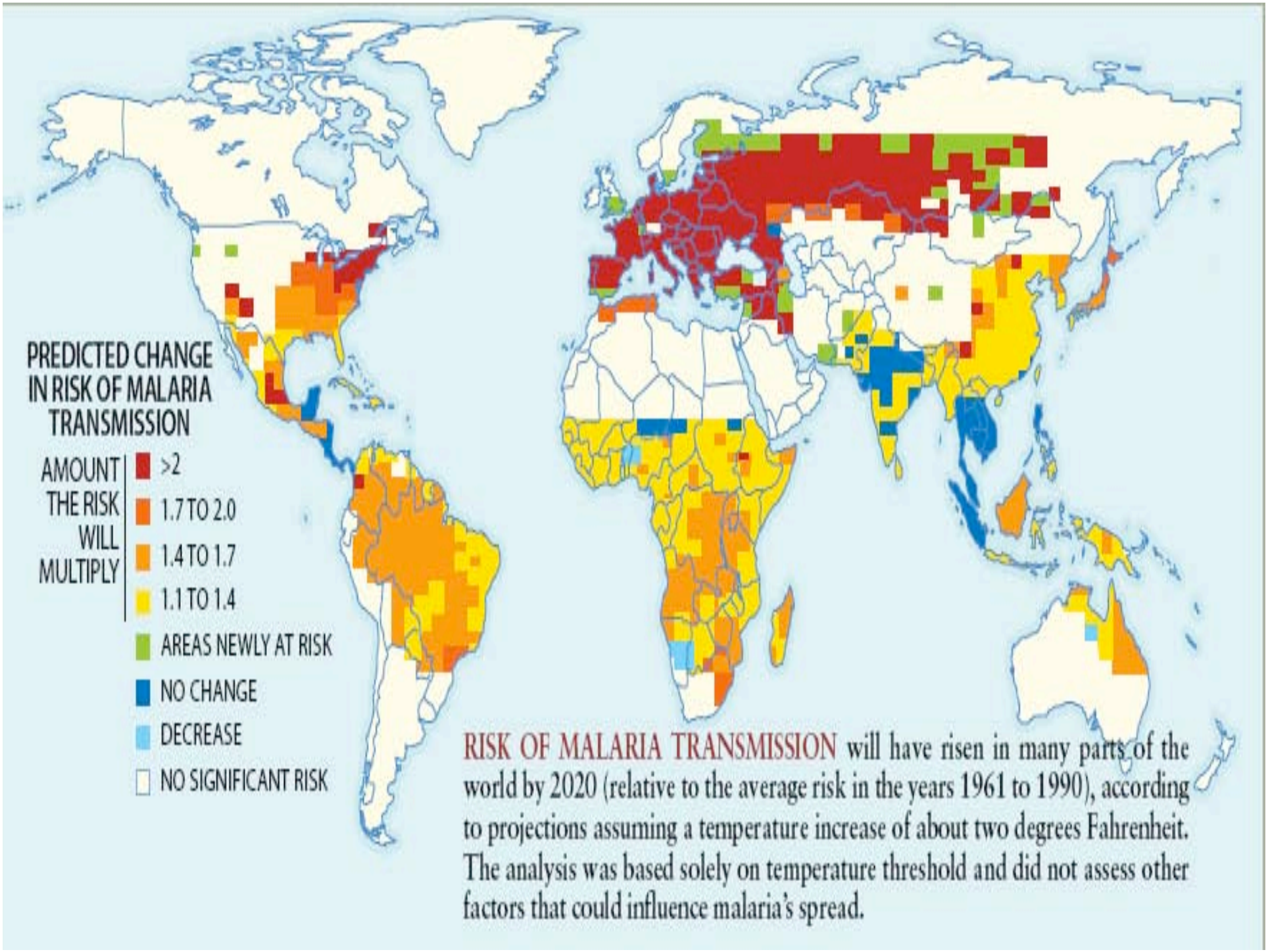
2001

2002

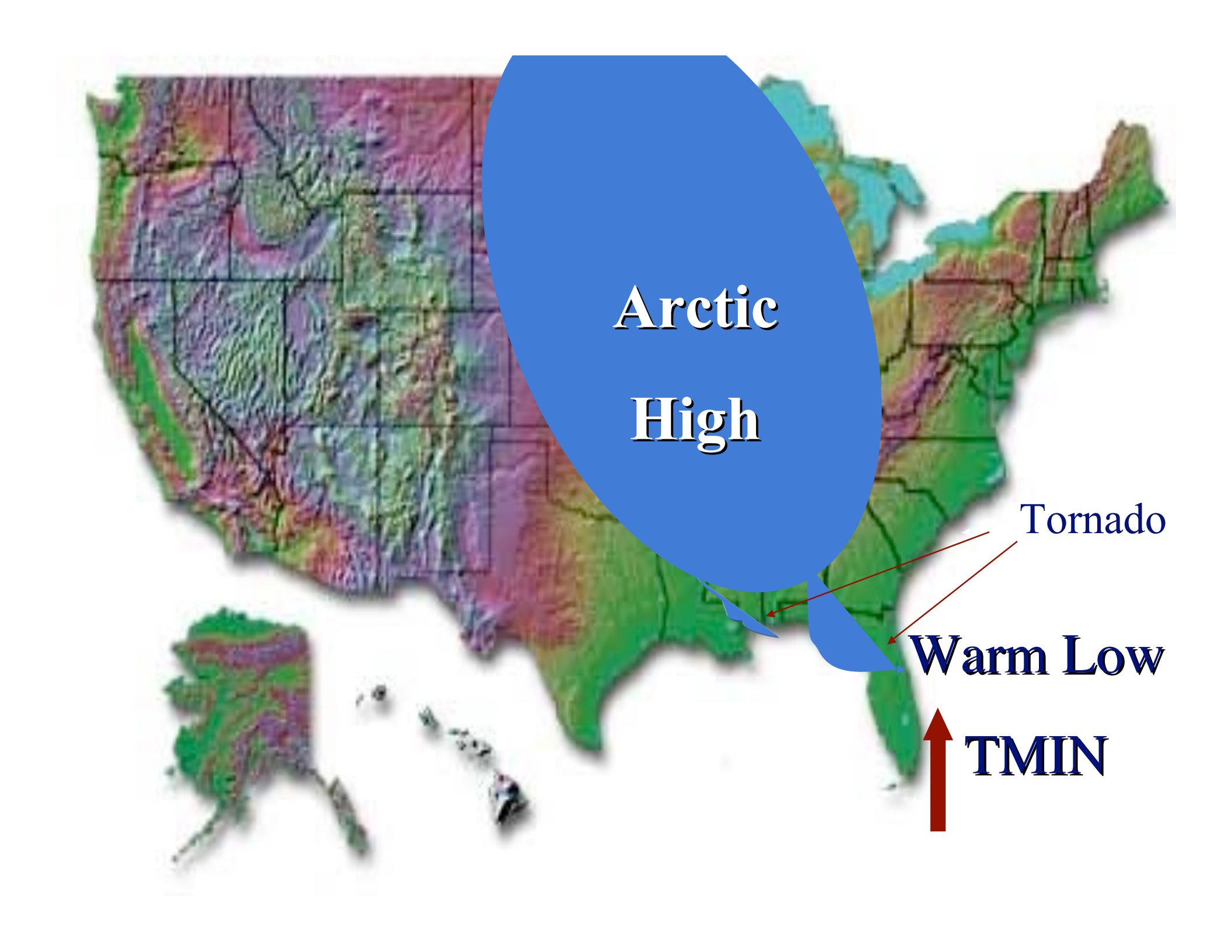
2003

0 300 600

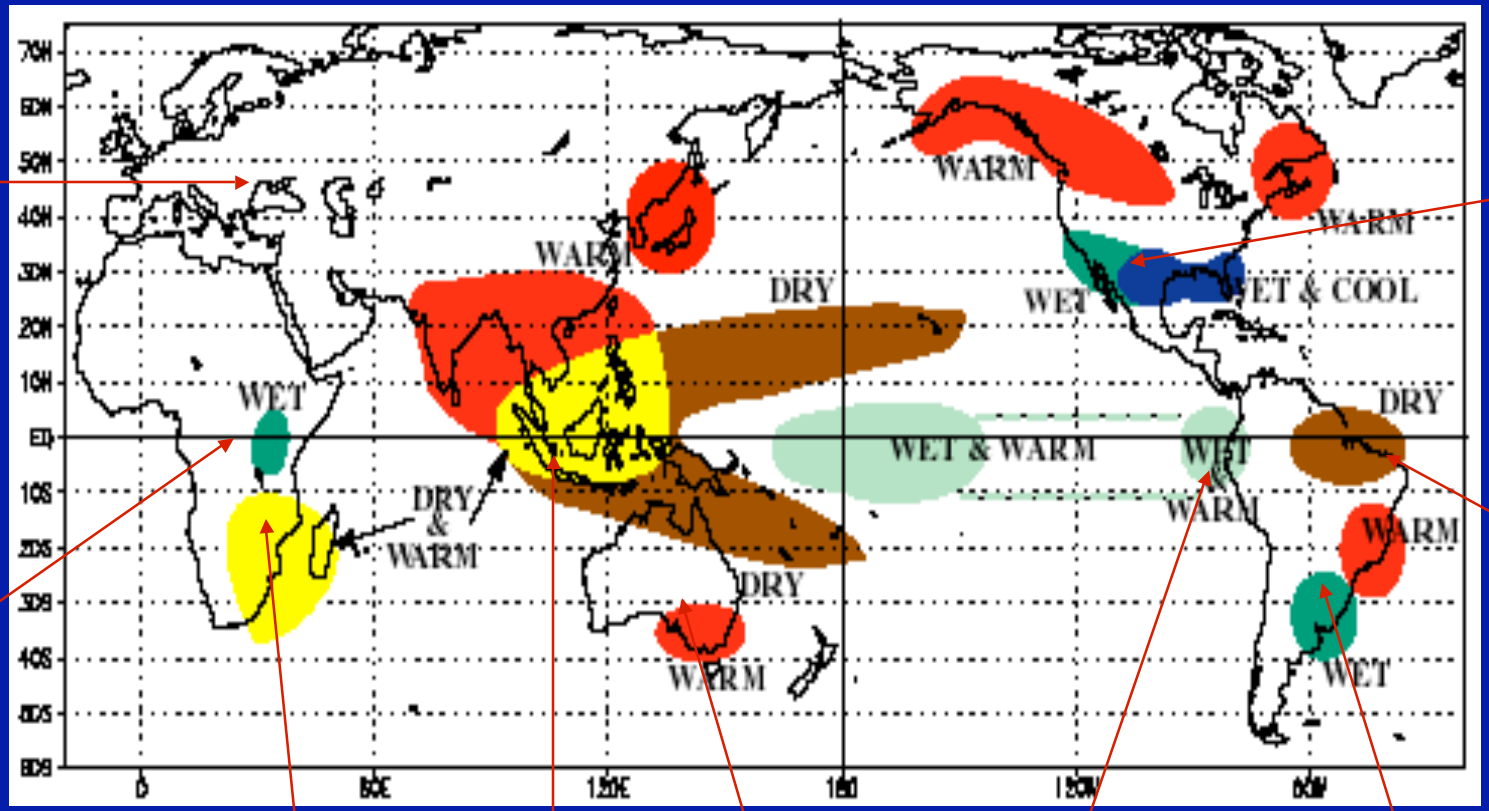
Miles



RISK OF MALARIA TRANSMISSION will have risen in many parts of the world by 2020 (relative to the average risk in the years 1961 to 1990), according to projections assuming a temperature increase of about two degrees Fahrenheit. The analysis was based solely on temperature threshold and did not assess other factors that could influence malaria's spread.


Arctic
High
Tornado
Warm Low
TMIN

ENSO 'Teleconnections'



Heat

Drought

Wind

Winter storms

Drought

Floods

Drought

Floods/Drought

Floods

Drought and wildfires

Floods

Floods

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2006-07

Maps of avian flu animal and human cases -- updated.kmz

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THE CHANGING LANDSCAPE OF RISKS

NUMBER

TYPE

CLUSTERS

SEQUENCES

RATES OF CHANGE

VOLATILITY

NON-LINEARITIES

SURPRISES

CENTER FOR HEALTH AND THE GLOBAL ENVIRONMENT

HARVARD MEDICAL SCHOOL