Asia Risk Centre
An Affiliate of RMS, Inc.

Centre for Atmospheric Sciences
Indian Institute of Technology Delhi
New Delhi, India

Climate Change and Disease Simulation

Somnath Jha

Presented as Guest Lecture in:

Central Advanced Faculty Training (CAFT) Programme

Indian Council of Agricultural Research (ICAR)

(CAFT programme by Ministry of Agriculture, Govt. of India)

Venue: Division of Plant Pathology, I.A.R.I.

New Delhi 12, India

Dated: October 31st, 2011

Introduction

- *Presently working in Asia Risk Centre, RMS Risk Management Solutions India, Noida, India (period from Aug,2011-present)*
- *RMSI Pvt Ltd., Noida, India (period from Oct, 2010- Jul,2011)*
- *PhD in Atmospheric Sciences, Indian Institute of Technology Delhi , New Delhi (period from 2005-thesis submission process is going on)*
- *Post Graduate in Agricultural Physics in Indian Agricultural Research Institute (I.A.R.I.), New Delhi, India (period from 2003-2005)*
- *Lectures delivered here are the part of the jobs done in various phases of Career in*
    - *Centre for Atmospheric Sciences, Indian Institute of Technology Delhi*
    - *Asia Risk Centre, RMS Risk Management Solutions India*
    - *RMSI Pvt Ltd*

A Short Glimpse of Nature of Works in Asia Risk Centre, My Present Affiliation

Asia Risk Centre - Mission

- Models and schemes for risk catastrophe risk mitigation the Bottom of the Pyramid (BOP)
  - Natural and man-made catastrophe
  - Impact of Climate Changes on their life, health and livelihood.
- Work with all the stake holders in the risk transfer eco space (impacted populations, governments, insurers/reinsurers, brokers and financial markets)
- Catalyst for all the stake holders to develop solutions and help them implement such solutions for the protection of civil societies.
- Solutions based on a solid business proposition and not based on philanthropy or Corporate Social responsibility (CSR) concepts.
- “Solving the problem and challenge at hand” also benefit from implementing the developed solutions.

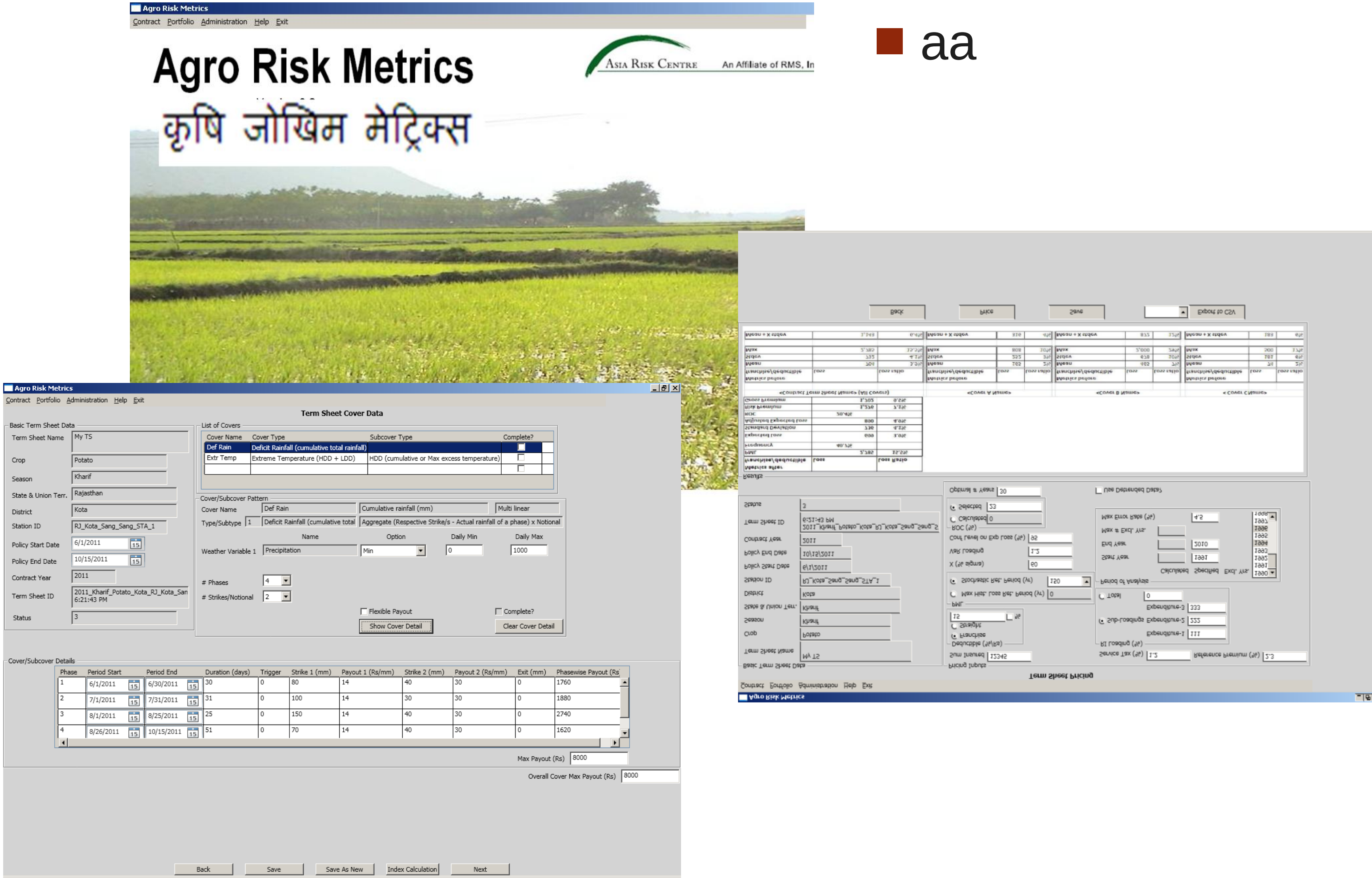
Asia Risk Centre - Vision

- Global leader in helping risk mitigation and management challenges in Asia
  - Agriculture risk,
  - Food safety and micro-insurance domains through global insurance/reinsurance strategies and modern risk management tools
- Risk mitigation strategies that also impact on sovereign risk and global food supply/demand landscape
- Thought leader in these domains to governments, insurers, reinsurers, brokers and those who are at risk
- Initially focus on Asia and also explore African and Latin American environments in future

Asia Risk Centre – Affiliate of RMS

- Capability and capacity for most robust solutions
- ARC operations – three campuses
  - California – solutions architecture
  - Singapore – pan Asian business development
  - India – model and software development

ARC - Crop Insurance Risk, India, China, Mozambique



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LETS START

Contents

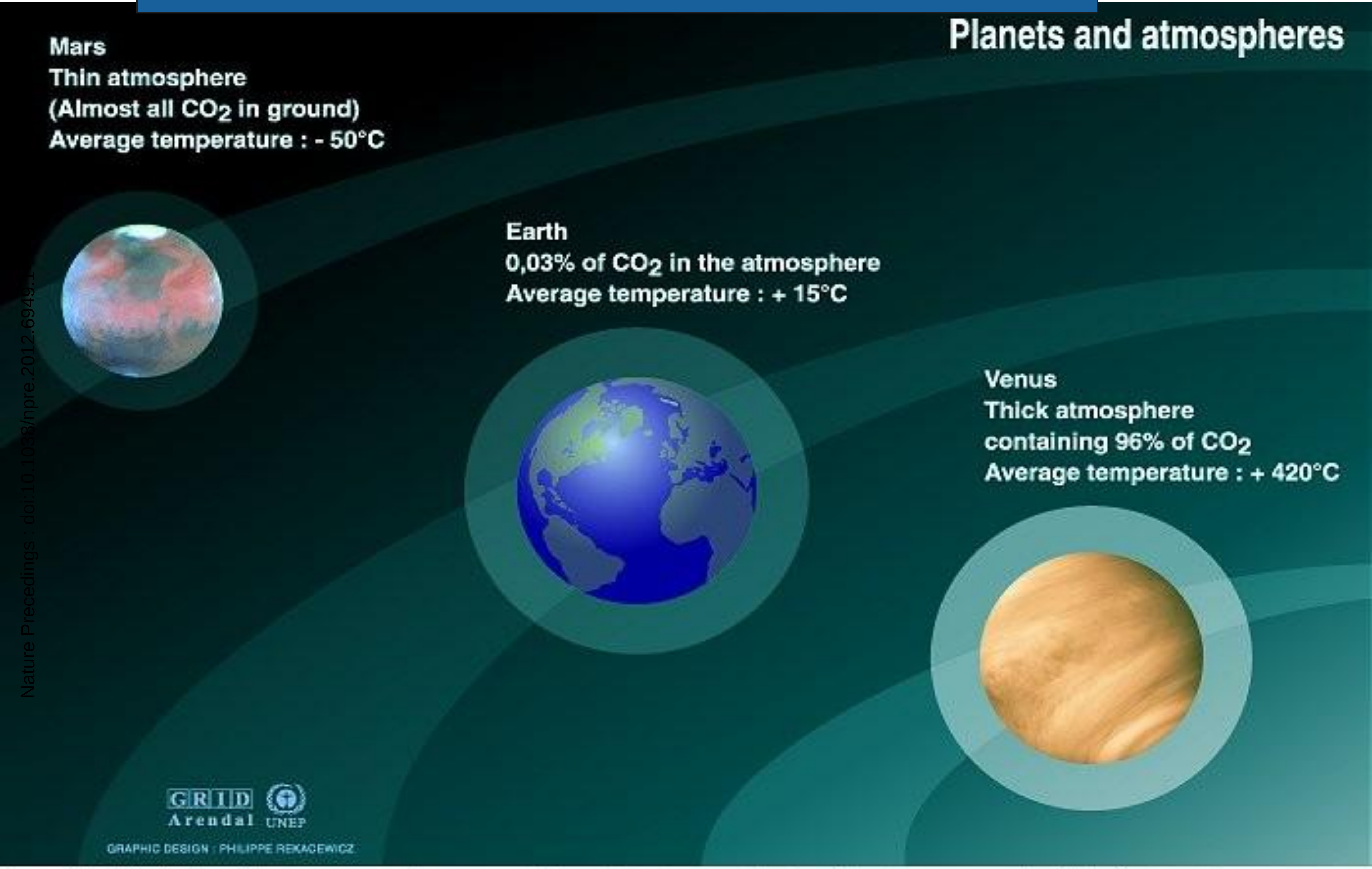
- Part1: Few Climate Change Impacts and Factors
- Part2: Description of State-of-the-science Climate Simulation Tools
- Part3: Introductory description of Regional climate model (i.e. Dynamic Downscaling)
- Part4: Disease Simulation
  - Regional Climate Model Coupled Mango Powdery Mildew Simulation
  - Pandemic Dengue Simulation under future climate scenario

Part One

Few Climate Change Impacts & Factors

Acknowledgement: My works cited in this part have been accomplished during my research in Indian Institute of Technology Delhi in collaboration with Indian Agricultural Research Institute, New Delhi

Earth : The Only Planet with Life



Sources: Calvin J. Hamilton, Views of the solar system, www.planetscapes.com; Bill Arnett , The nine planets, a multimedia tour of the solar system, www.seds.org/billa/tnp/nineplanets.html

Global Climate Change

ΔT over the 20th century…………..
+0.6±0.2°C

Rate of ΔT increase since 1950……
+0.17°C/decade

Sea level rise over 20th century….. +0.1-0.2 m

Change in precipitation………….. +0.5-1%/decade

Extreme events…………………….. +2-4%

………..IPCC (2001)

Climate Change Prediction Uncertainty

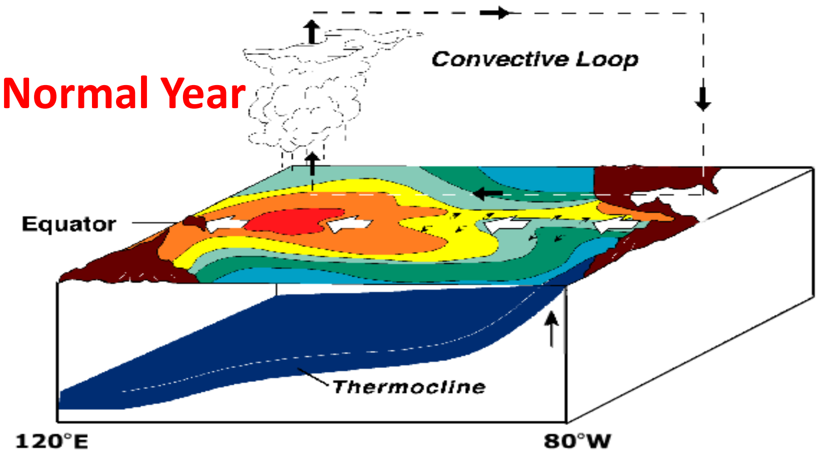
Major Causes are

- **Anthropogenic Activity (Deforestation mainly)**

- **Unpredicting Teleconnection Pattern (El Nino & Southern Oscillation (ENSO) activity, Indian Ocean Dipole etc)**

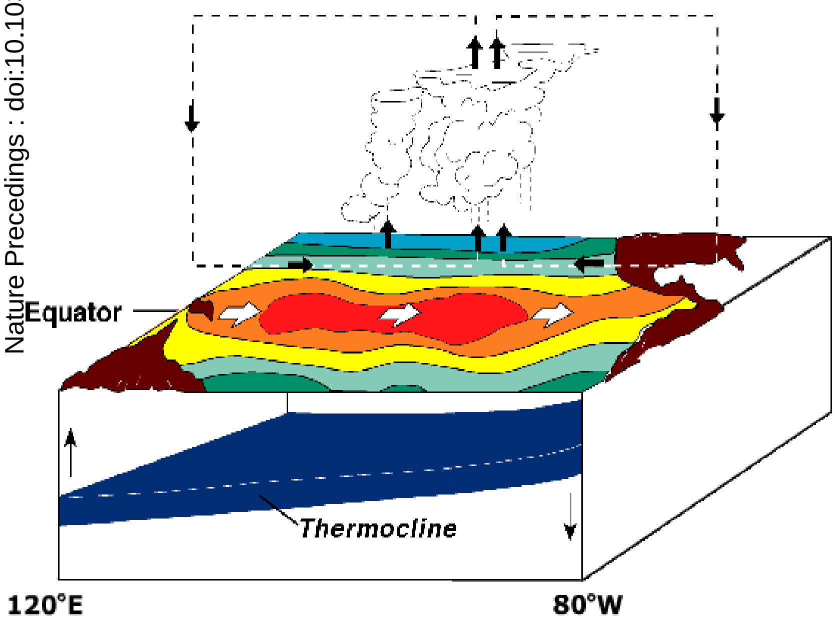
Role of SST: El Nino & Southern Oscillation

Normal Year

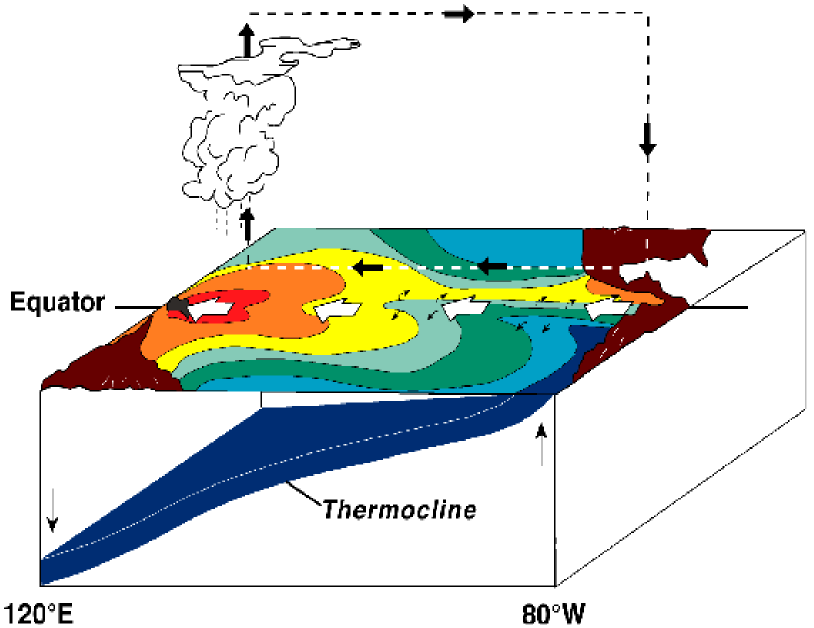


- El Nino & Southern Oscillation (ENSO)
- Various Southern Oscillation Indices; SOI, SOI-EQ, Nino3 etc

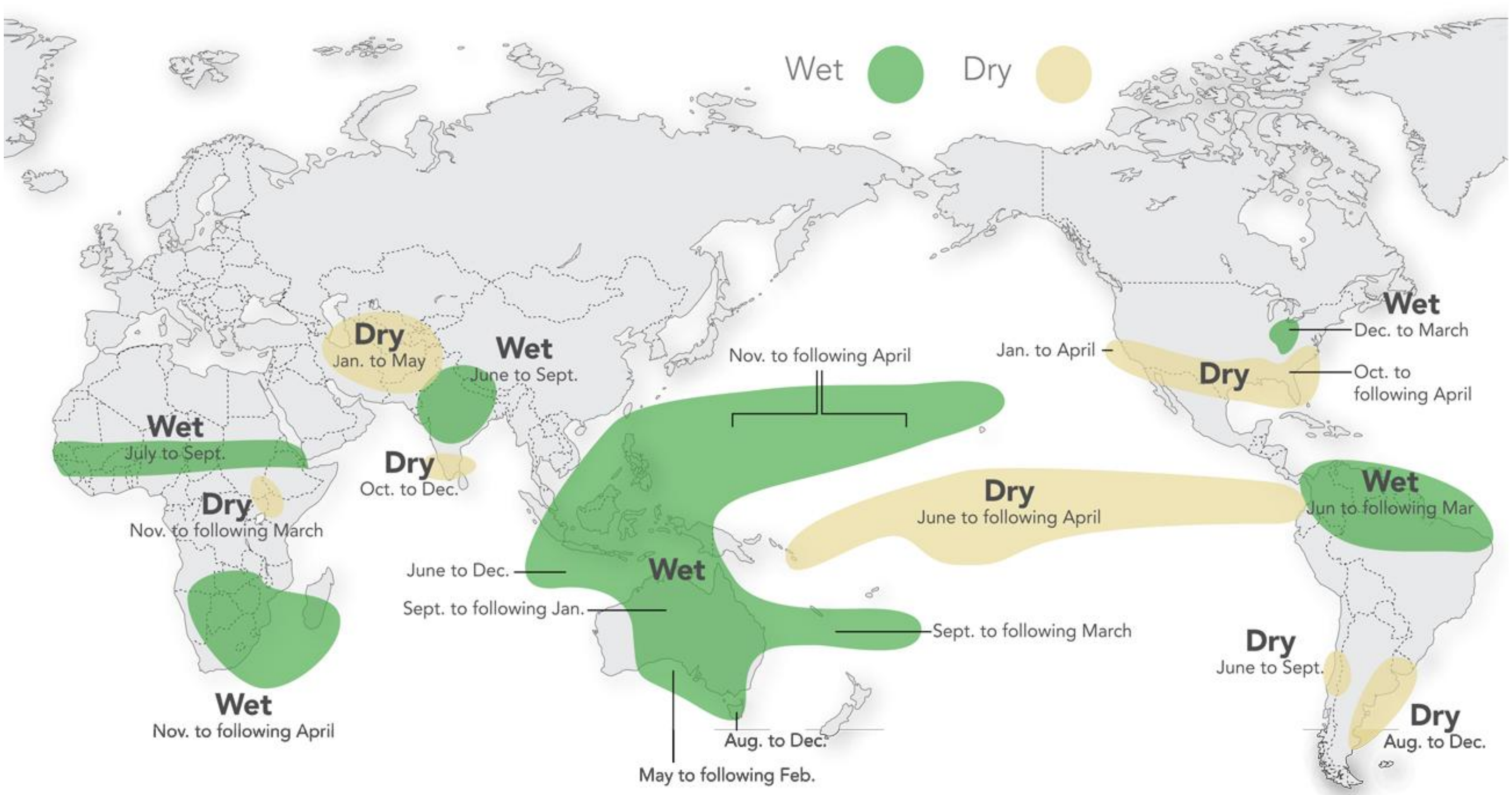
El Nino Year



La Nina



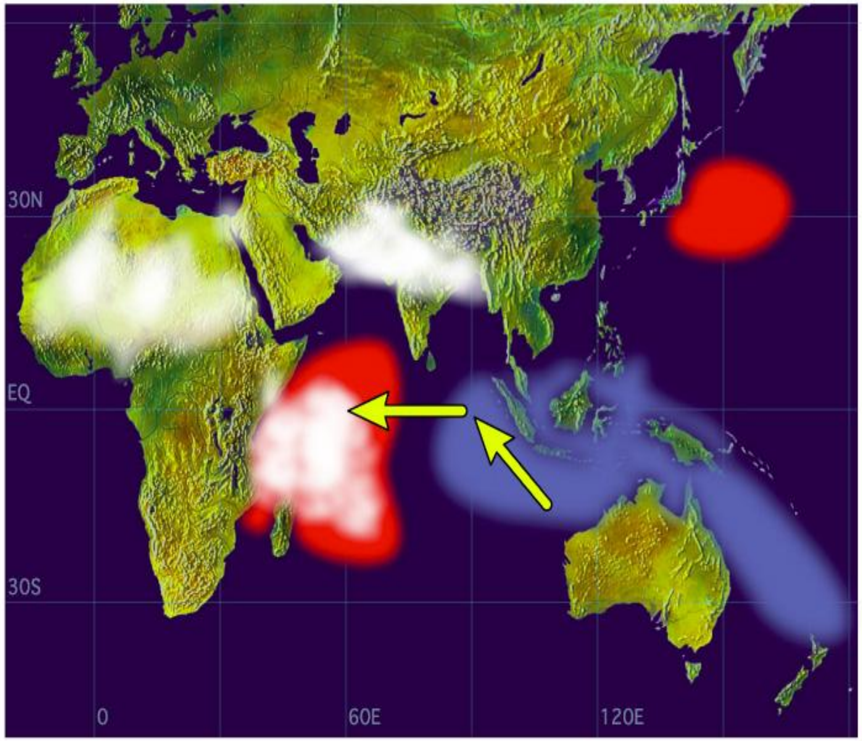
Effect of High ENSO Index on Global Precipitation Pattern



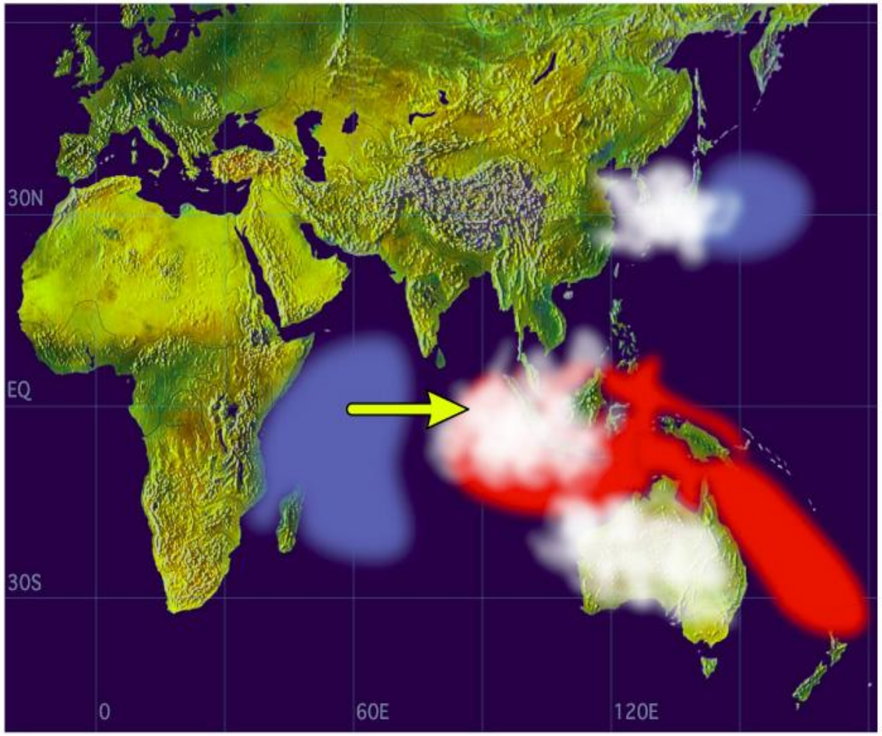
Source:
Ropelewski & Halpert, 1989

Role of SST & Wind: Indian Ocean Dipole

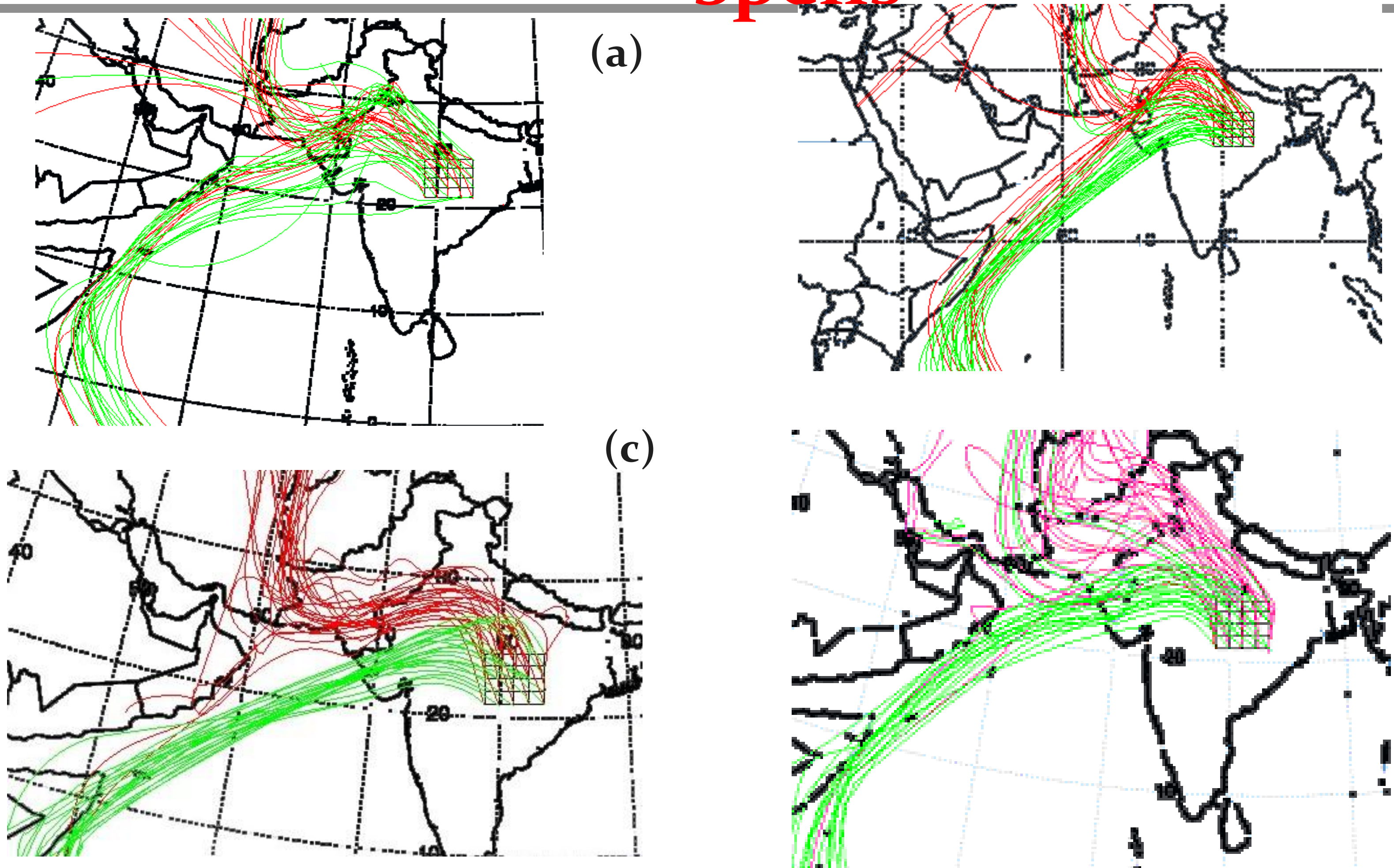
Positive Dipole Mode



Negative Dipole Mode



Role of Wind:Trajectories during the Dry Spells

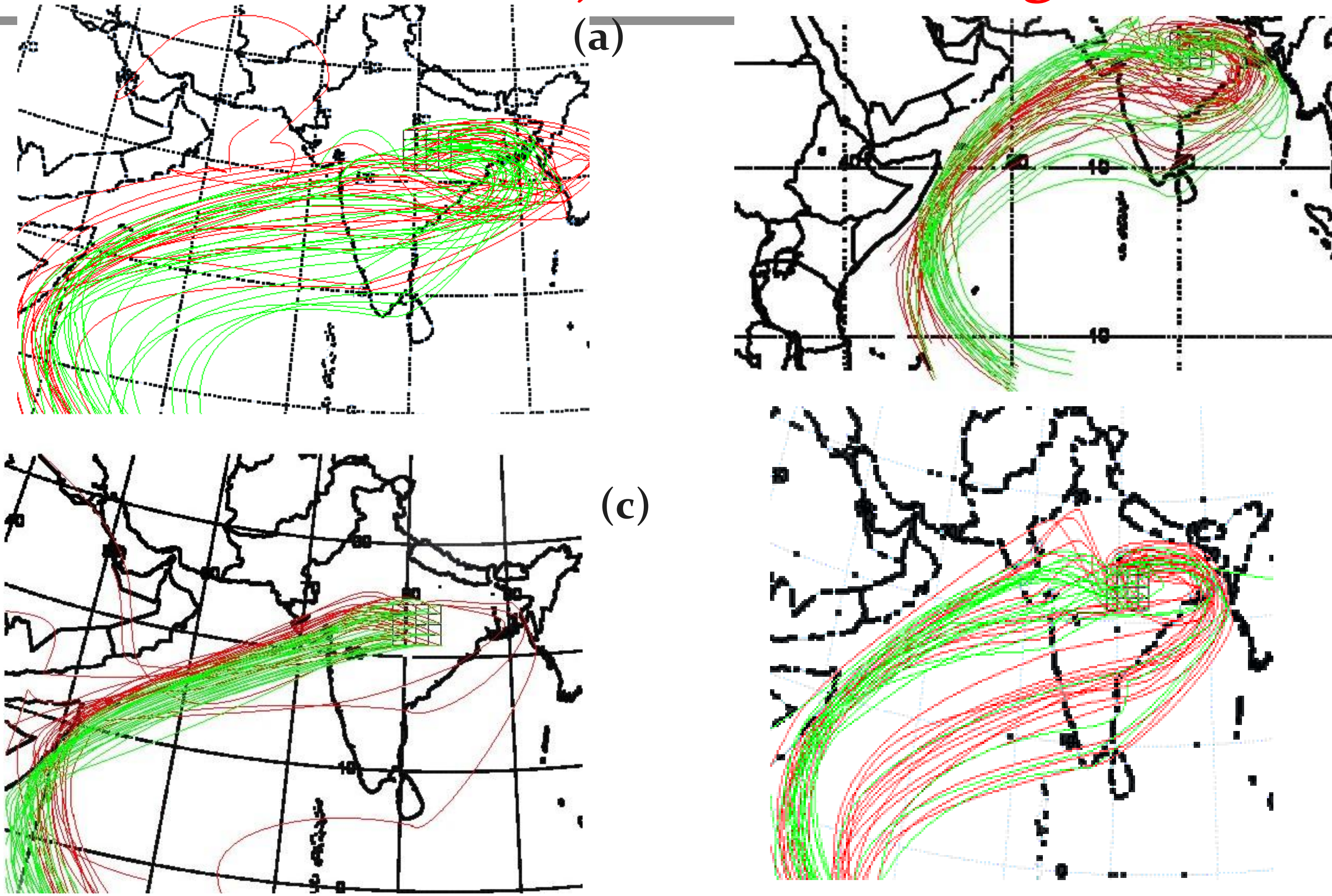


10 day back trajectories from Central India terminating at the 850 (green) and 700 (red), for the dry spells of the Indian summer monsoon. (a) 18 June 2009; (b) 14 August 2005; (c) 16 July 2002; (d) 30 August 2001;

Source: Book "An Introduction to Numerical Weather Prediction Techniques" by T.N. Krishnamurti & L. Bounoua (Chapter 13)

Source: Book "An Introduction to Numerical Weather Prediction Techniques" by T.N. Krishnamurti & L. Bounoua (Chapter 13)

Role of Wind: Trajectories during the Wet Spells



10 day back trajectories from Central India terminating at the 850 (green) and 700 (red), for the wet spells of the Indian summer monsoon. (a) 14 July 2009; (b) 01 August 2005; (c) 31 August 2002; (d) 12 July 2001

Climate Change & Agriculture

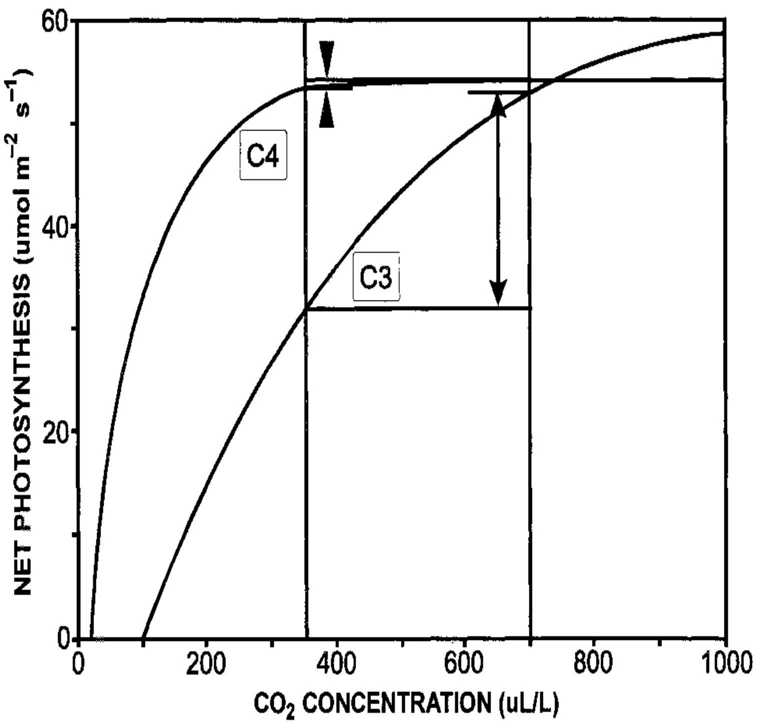


Figure 1: Net photosynthesis of typical C3 and C4 plants versus CO_2 concentration. Arrows show the potential gain at a doubling of CO_2 concentration. (from: Rogers et al., 1994).

(Rotter & Geijn, 1999)

Current growth duration and decrease of post-anthesis (PoA) and total growth duration (Total: emergence to maturity) of widely used cultivars of rice, maize and wheat due to increase in average temperature

Crop, Cultivar	Post-anthesis and total growth duration (days)		Season avg. temp.	Temp. change	Corr. decrease in PoA and Total (%)		Areas representative of temp. range
	PoA	Total	(°C)	(°C)	PoA	Total	
Subtropical (spring) wheat	40	150	10/19	0.0			Syria and Israel
	38	138	11/20	+1.0	-5	-8	
	36	128	12/21	+2.0	-10	-15	
	33	111	14/23	+4.0	-18	-26	
Temperate (spring) wheat	63	273	5/16	0.0			Netherlands, N. Germany
	59	234	6/17	+1.0	-6	-14	
	54	194	7/18	+2.0	-14	-29	
	50	167	9/20	+4.0	-21	-39	
Trop. Maize med.\early;	58	113	23.0	0.0			Subsaharan Africa, (800- 1300 m altitude)
	55	106	24.0	+1.0	-5	-6	
	50	97	25.5	+2.5	-14	-14	
	46	89	27.0	+4.0	-21	-21	
Subtropical rice	59	139	21.0	0.0			Southern France
	52	125	22.0	1.0	-12	-10	
	46	110	23.5	2.5	-22	-21	
	42	100	25.0	4.0	-29	-28	
Tropical rice	42	95	27.0	0.0			Thailand
	39	90	28.0	1.0	-7	-5	
	36	83	29.5	2.5	-14	-13	
	33	77	31.0	4.0	-21	-19	

Calculations based on pre- and post-anthesis temperature requirements from: Van Keulen and Seligman, 1987; Supit et al., 1994; Rötter, 1993; Penning de Vries et al., 1989; Penning de Vries, 1993.

Impact of Climate Change on Northeast Monsoon System of India-Role of Siberian Teleconnection

Somnath Jha[1]

Vinay Kumar Sehgal[2]

Ramesh Raghava[1]

Presented as Lead Talk in INEMREC, 24-25th Feb, 2011, Chennai (http://www.imdchennai.gov.in/lt.pdf)

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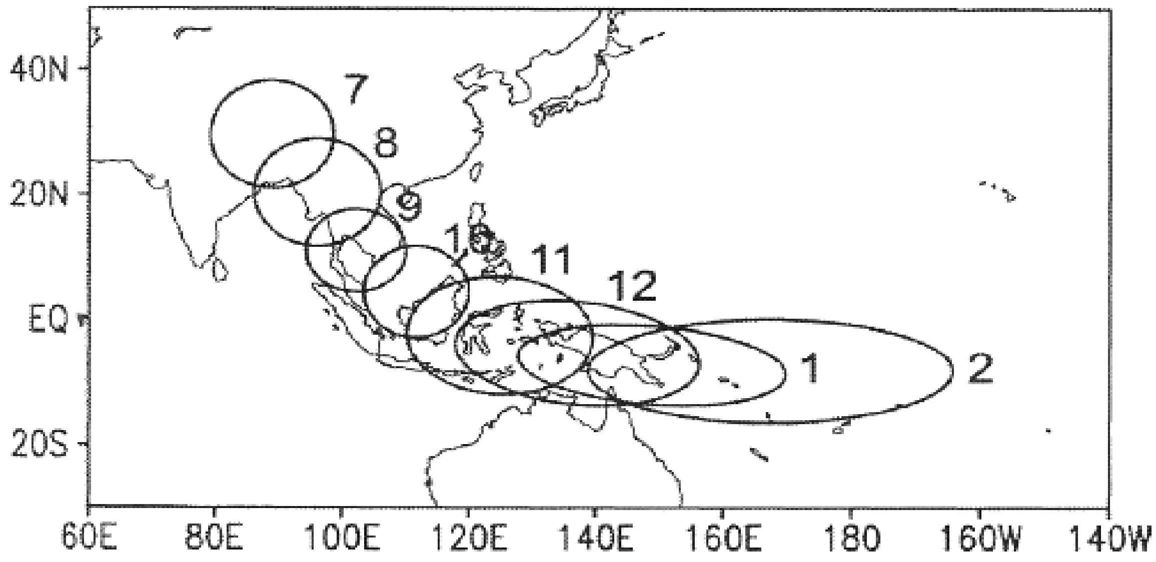
New Delhi

Principal Axis of Monsoon

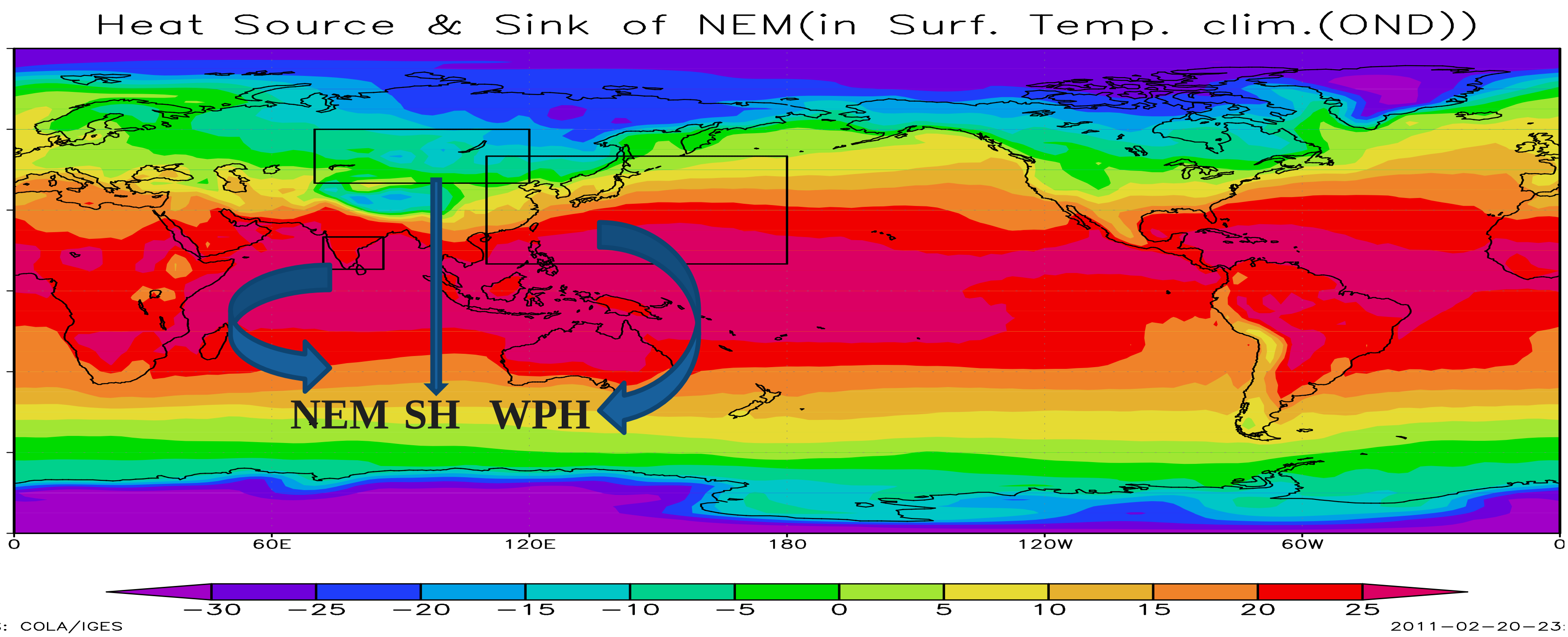


- **Differential Heating is responsible for divergent vertical circulation with ascending lobes at Q1 (heat source) & descending lobes over Q2 (moisture sink)**

- **Seasonal propagation of Heat Source (Q1) associated with heavy Monsoonal precipitation between July & February.** ***The line described by the heat source locations in different months forms the principal axis of the Asian Monsoon***

Courtesy: T.N. Krishnamurthy ('An Introductory Course in Tropical Meteorology')

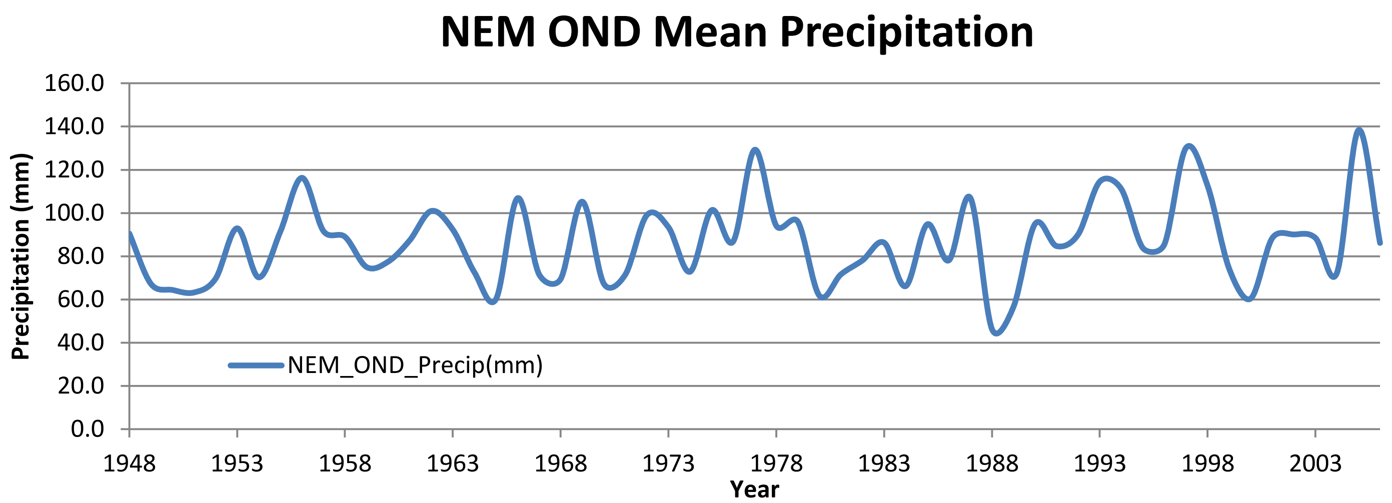
Domain of NEM & Heat Source & Sink



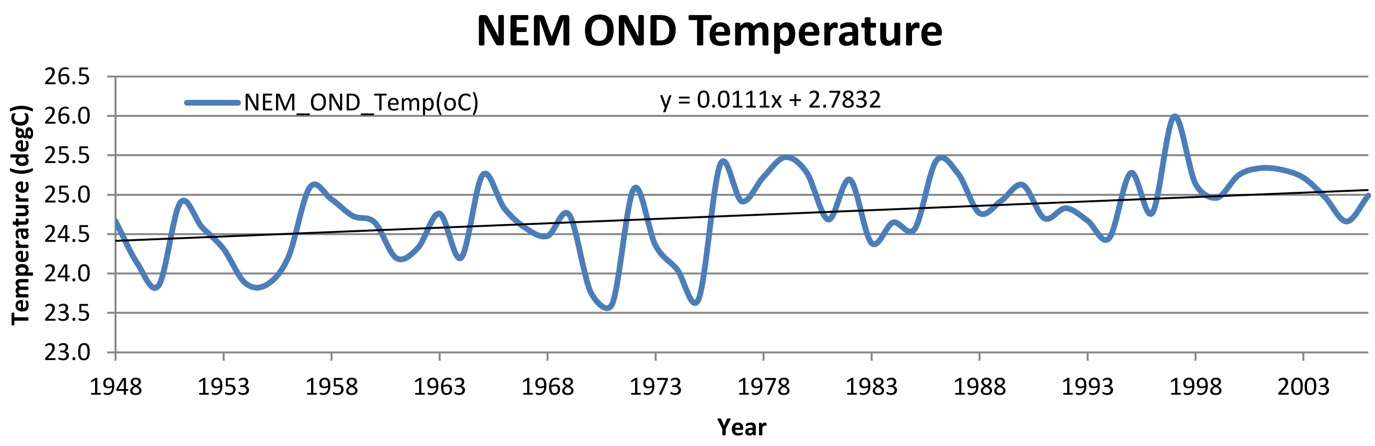
- *NE Monsoon domain in India(NEM): 8^0-20 ^{0}N, 72^0-86^0 E*
- *Siberian High(SH): 40^0-60^0N, 70^0-120^0E*
- *West Pacific High(WPH): 10^0-50^0N, 110^0-180^0E*
- Domain of Region of Interest: *5^0N-80^0N, 60^0N-180^0E*

Nature Precedings : doi:10.1038/npre.2012.6949.1 : Posted 28 Feb 2012

NEM Precipitation &Temperature Trend

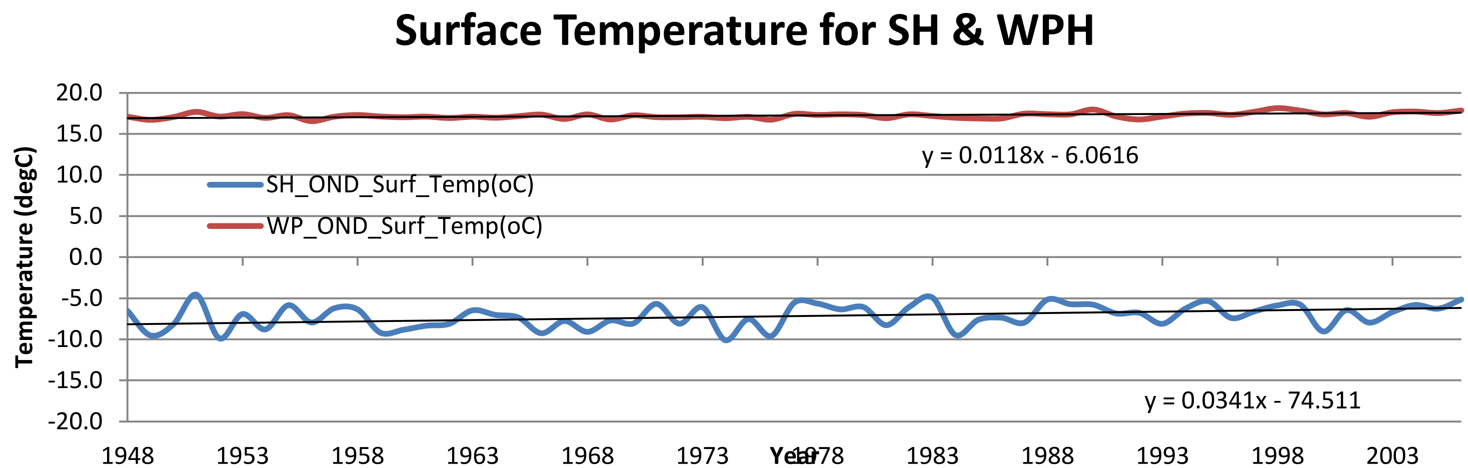


No Significant Trend

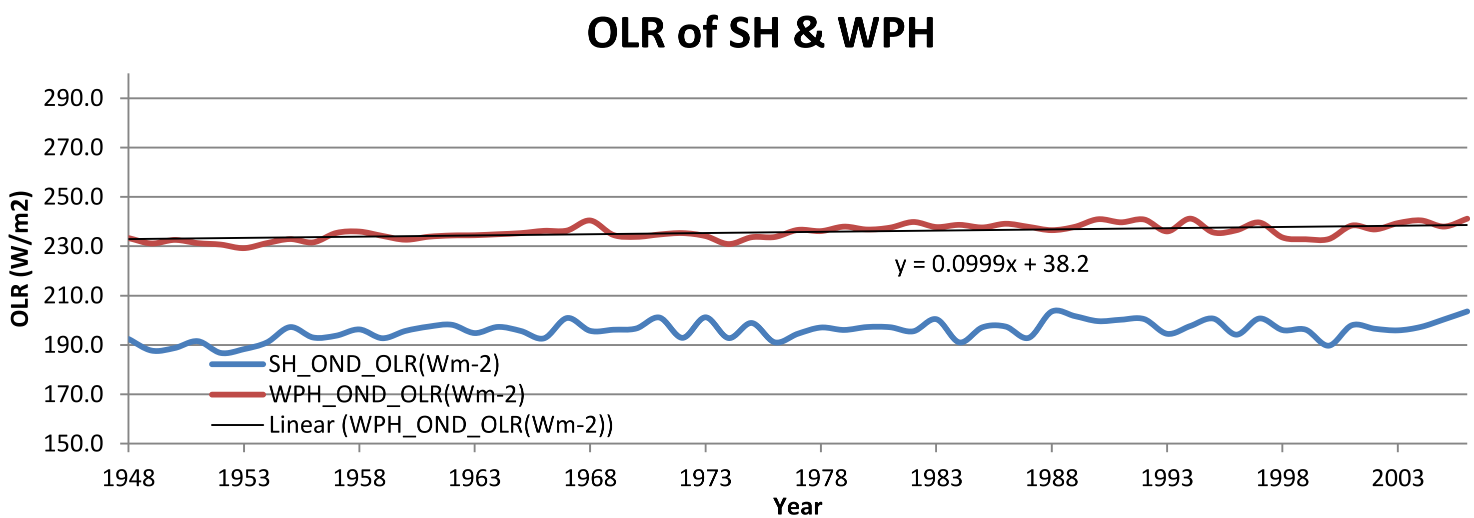


Significant Trend

Surface Temperature & OLR Trend for SH & WPH



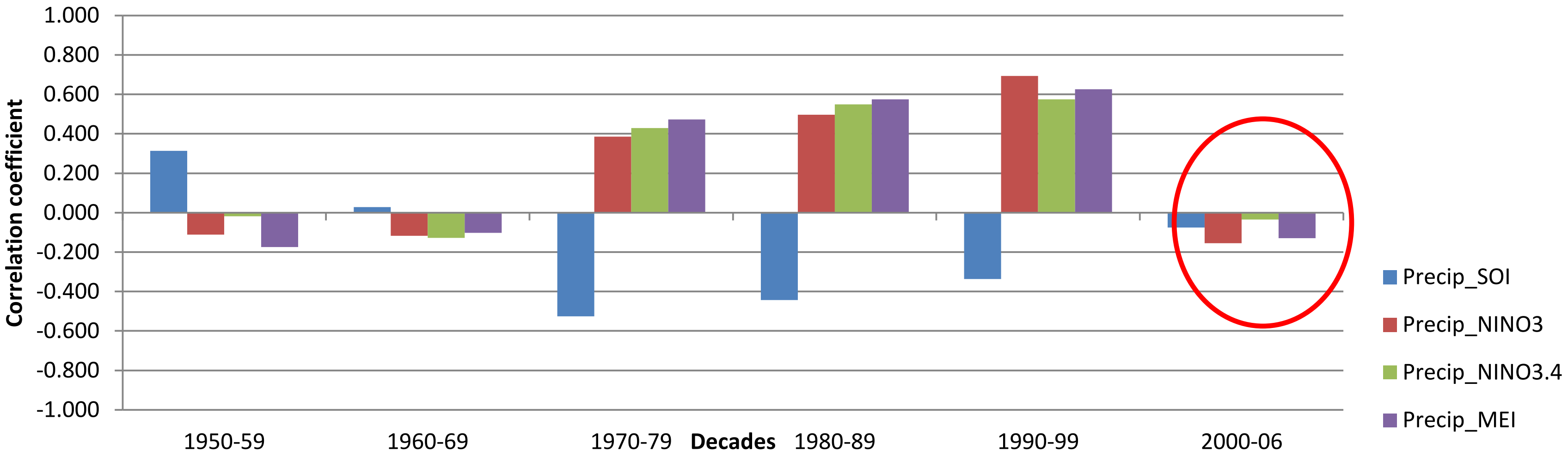
Significant Trend

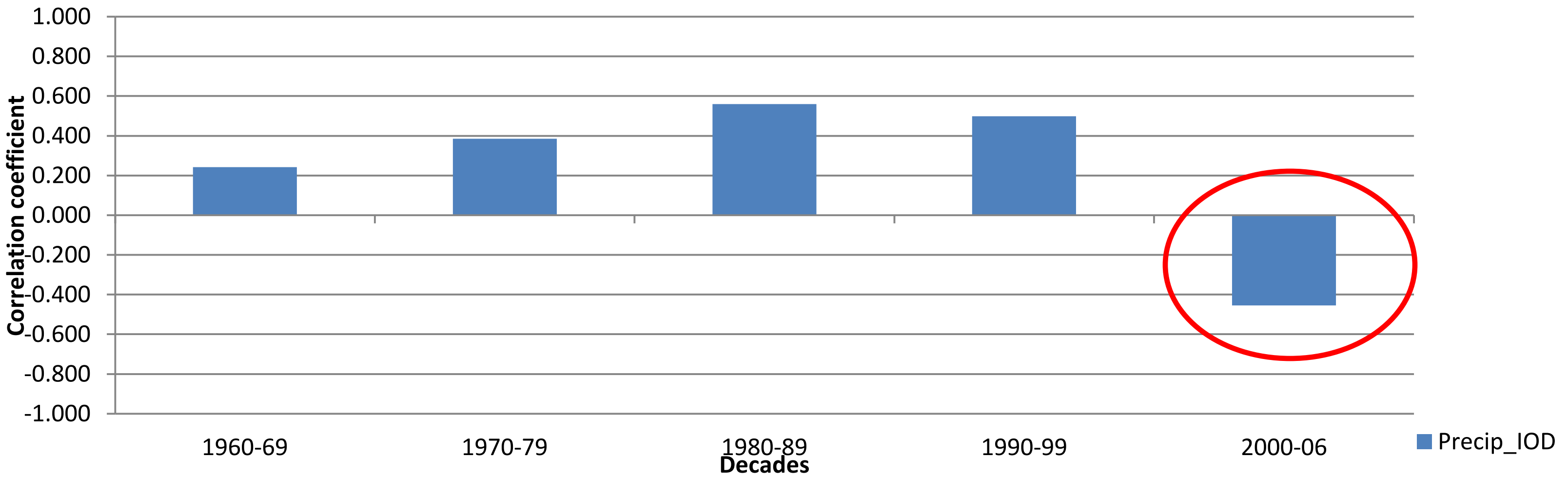


Significan t Trend

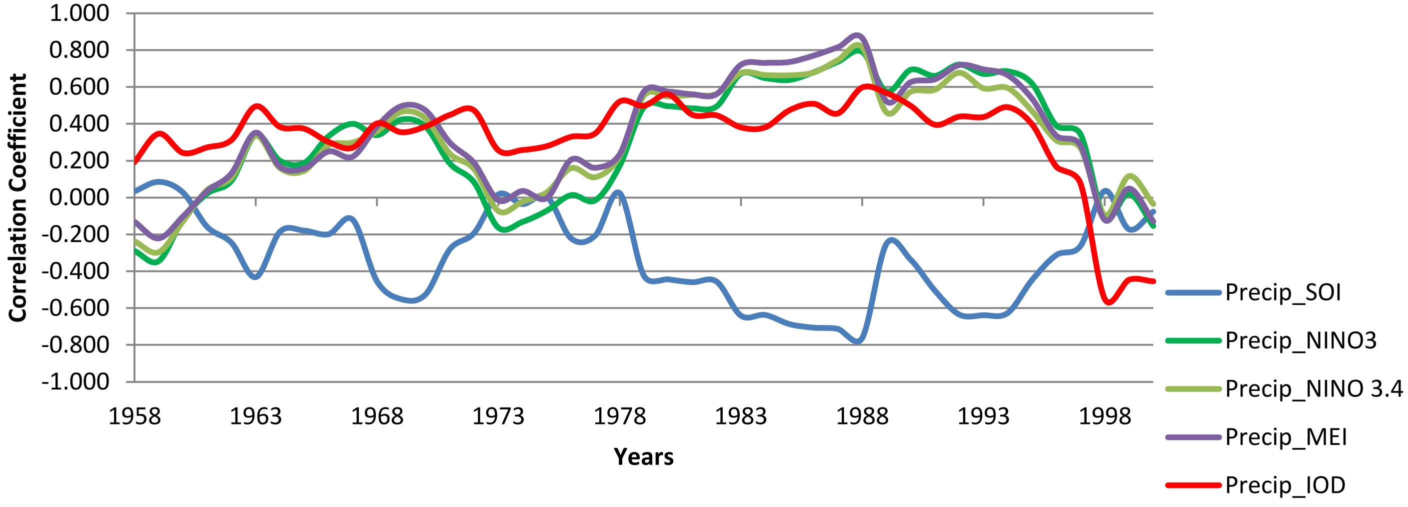
No Significant Trend

Decadal Correlation of NEM Precipitation with ENSO (above) & IOD Indices (below)





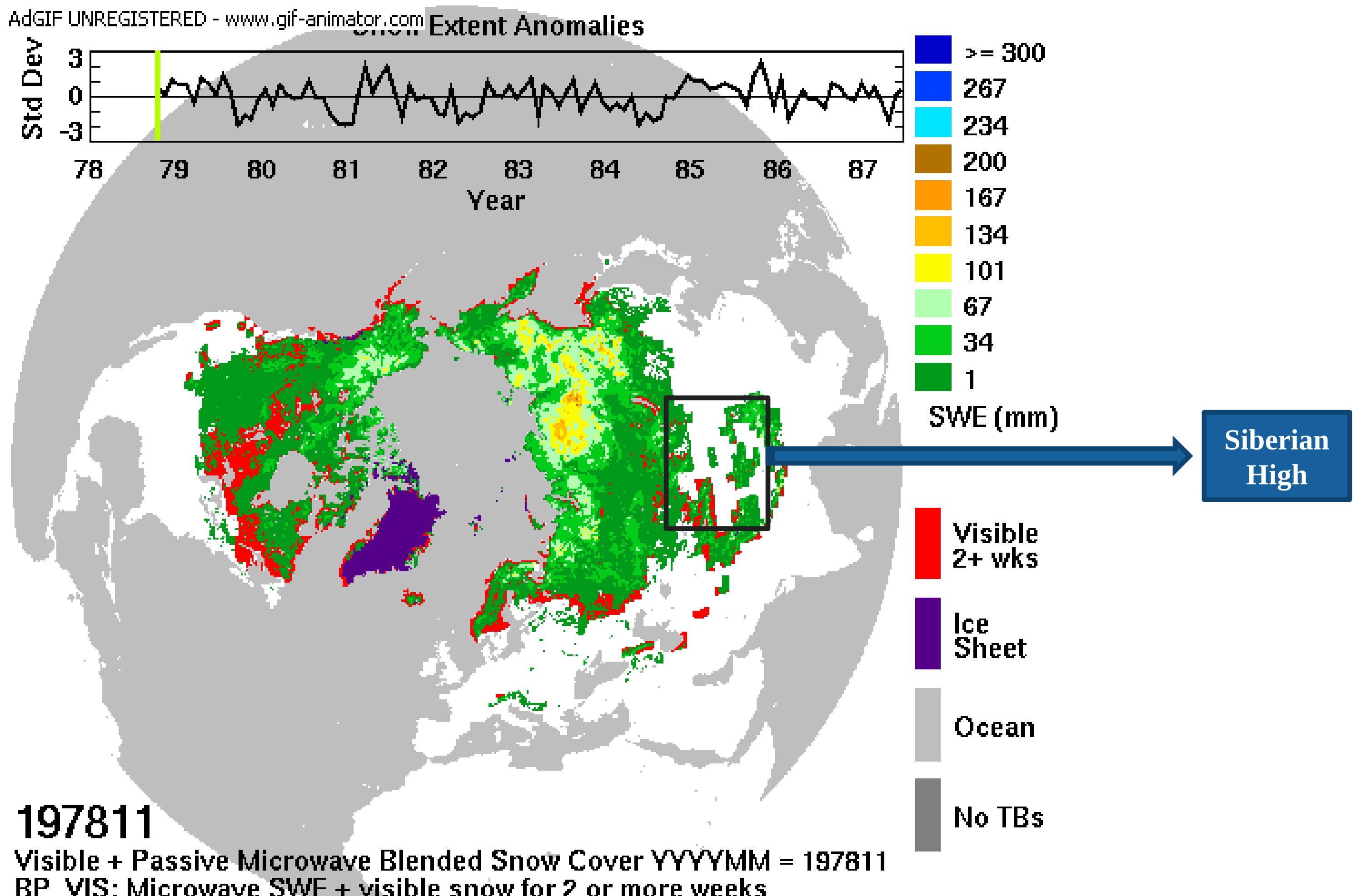
Serial Correlation between NEM Precipitation and ENSO & IOD Indices



•**Serial (10 year running window) correlation reveals that correlation of ENSO indices & DMI with NEM precipitation has increased between the period 1975-1998 and decreased at 1996**

• **Serial correlation of DMI & NEM precipitation remains less than that of ENSO & NEM precipitation during the period 1978-1996 whereas this relation is opposite during the period 1970-1978**

Snow Extent for Oct.,Nov.,& Dec. for 1978-2007



Source:
http://nsidc.org/data/docs/daac/nsidc0271_ease_grid_swe_climatology/browse/viewer.html

(Armstrong, R. L., M. J. Brodzik, K. Knowles, and M. Savoie. 2007. *Global monthly EASE-Grid snow water equivalent climatology*. Boulder, CO: National Snow and Ice Data Center. Digital media.)

TROPMET - 2010

Spatio-temporal Trends of Standardized Precipitation Index for Meteorological Drought Analysis across Agroclimatic Zones of India

Somnath Jha 1 , Vinay K Sehgal 2, R.C. Raghava 1

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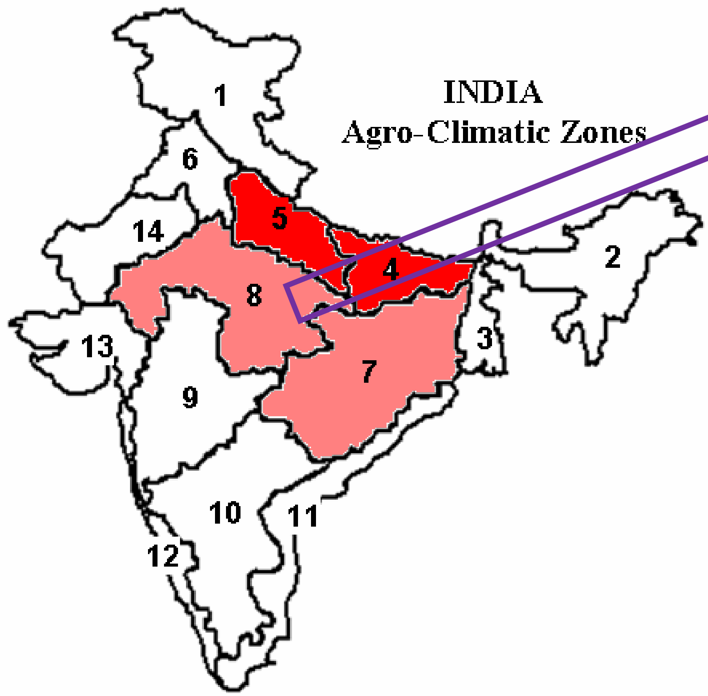
Indian Agricultural Research Institute
New Delhi- 110012 INDIA

20 May, Kolkata

SPI TREND FOR JJAS

ACZ	Tau corr. Coeff.	S value	Z value	P value	Intercept	Slope
ACZ4	-0.367	-565	-3.986	0.000	42.708	-0.0216
ACZ5	-0.264	-406	-2.862	0.004	39.075	-0.0197
ACZ7	-0.188	-290	-2.043	0.041	25.387	-0.0129
ACZ8	-0.226	-348	-2.452	0.014	27.300	-0.0138



Significantly Drying ACZs of India

Climate Change: Crop Duration & Shift in Peak Vegetative Stage

J Indian Soc Remote Sens
DOI 10.1007/s12524-011-0125-z

RESEARCH ARTICLE

Deriving Crop Phenology Metrics and Their Trends Using Times Series NOAA-AVHRR NDVI Data

Vinay Kumar Sehgal · Surabhi Jain · Pramod Kumar Aggarwal · Somnath Jha

Received: 13 December 2010 / Accepted: 23 May 2011

Abstract In this study, an attempt has been made to derive the spatial patterns of temporal trends in phenology metrics and productivity of crops grown, at disaggregated level in Indo-Gangetic Plains of India (IGP), which are helpful in understanding the impact of climatic, ecological and socio-economic drivers. The NOAA-AVHRR NDVI PAL dataset from 1981 to 2001 was stacked as per the crop year and subjected to Savitzky-Golay filtering. For crop pixels, maximum and minimum values of normalized difference vegetation index (NDVI), their time of occurrence and total duration of *kharif* (June–October) and *rabi* (November–April) crop seasons were derived for each crop year and later subjected to pixel-wise regression with time to derive the rate and direction of change. The maximum NDVI value showed increasing trends across IGP during both *kharif* and *rabi* seasons indicating a general increase in productivity of crops. The trends in time of occurrence of peak NDVI during *kharif* dominated with rice showed that the maximum vegetative growth stage was happening early with time during study period across most of Punjab, North Haryana, Parts of Central and East Uttar Pradesh and some parts of Bihar and West Bengal. Only central parts of Haryana showed a delay in occurrence of maximum vegetative stage with time. During *rabi*, no significant trends in occurrence of peak NDVI were observed in most of Punjab and Haryana except in South Punjab and North Haryana where early occurrence of peak NDVI with time was observed. Most parts of Central and Eastern Uttar Pradesh, North Bihar and West Bengal showed a delay in occurrence of peak NDVI with time. In general, the rice dominating system was showing an increase in duration with time in Punjab, Haryana, Western Uttar Pradesh, Central Uttar Pradesh and South Bihar whereas in some parts of North Bihar and West Bengal a decrease in the duration with time was also observed. During *rabi* season, except Punjab, the wheat dominating system was showing a decreasing trend in crop duration with time.

Keywords Phenology · Crop profile · NDVI · Trend · Time series · Indo-gangetic plains

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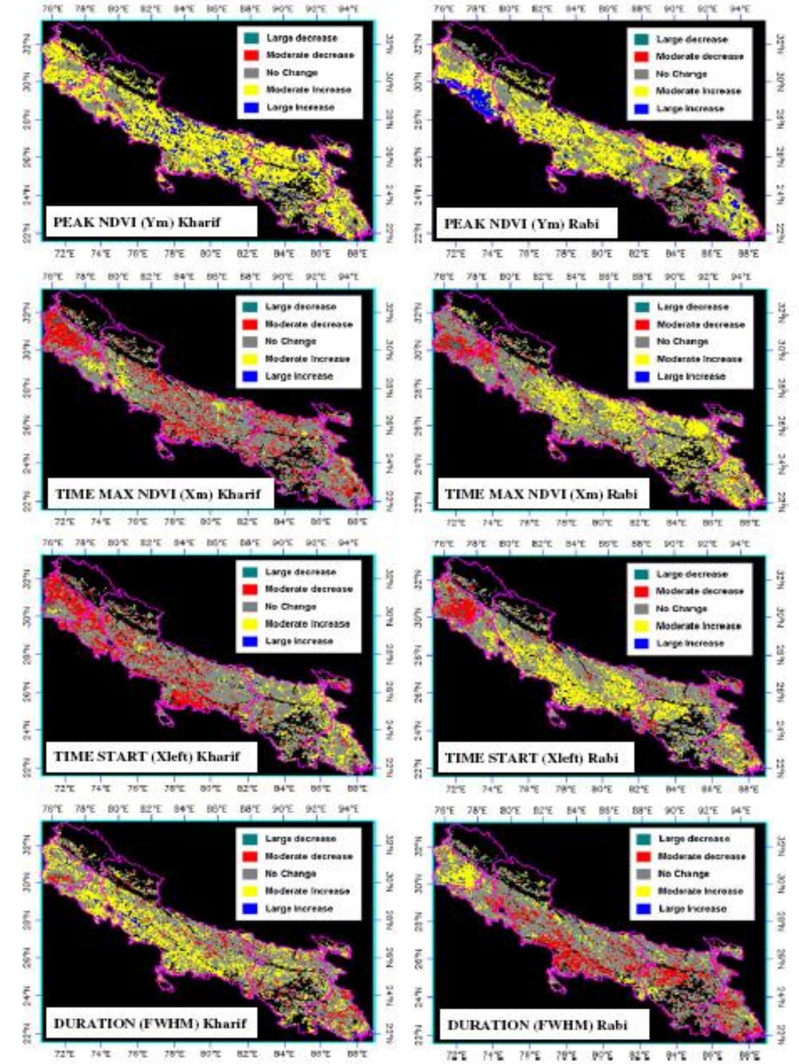
Published online: 15 June 2011



Therefore

- *Local weather variability are not captured due to our inability to comprehend the Global Teleconnection*
- *Uncertainty in weather or climate prediction is our gap to understand this Macro to Micro Integration of Spatio-Temporal climatic Wave*

Therefore Climate Change is ALSO

A slow but gradual change
is going on Silently
in the
biosphere of earth,
NOT merely the change in
Temp., rainfall or crop yield

Part Two

Description of State-of-the-science Climate Simulation Tools

Available State-of-the-science Simulation Tool to Study Climate Variability & Change

- Climate Models
  - General Circulation Models
  - Regional Climate Models
  - Weather Forecast Models
- Climate Diagnostic Study based new code insertion

GCM:A Background

- Earth heat surplus zone : 40º N to 40º S Latitude
- Earth heat deficit zone : 40º to 90º (both hemisphere)
- General Circulation of Fluids over Earth : Equilibrate the temperature inequlibrium by

  (a) Atmospheric Circulation(80%)

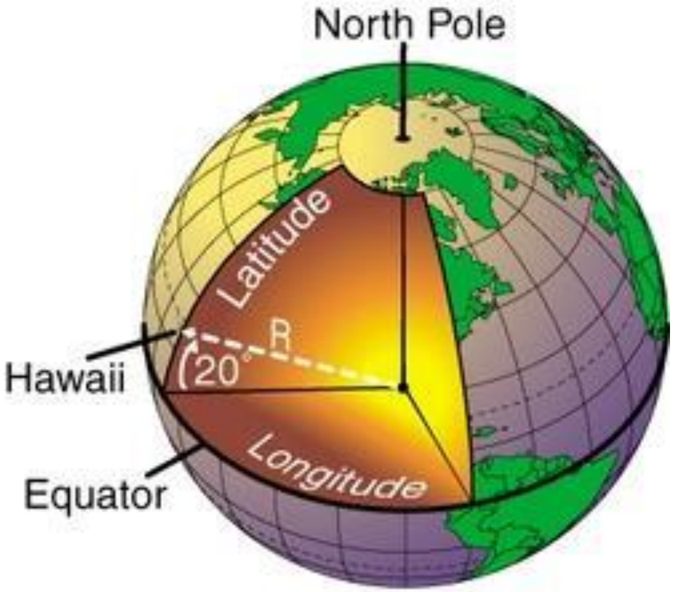
  (b) Oceanic Circulation(20%)

- Numerical prediction Model for paleoclimate prediction or Future climate prediction or Present Realtime high accuracy global prediction SIMULATE THIS GENERAL CIRCULATION OF EARTH as GENERAL CIRCULATION MODEL (4-Dimension),popularly known as GCM
- GCM is of three types:

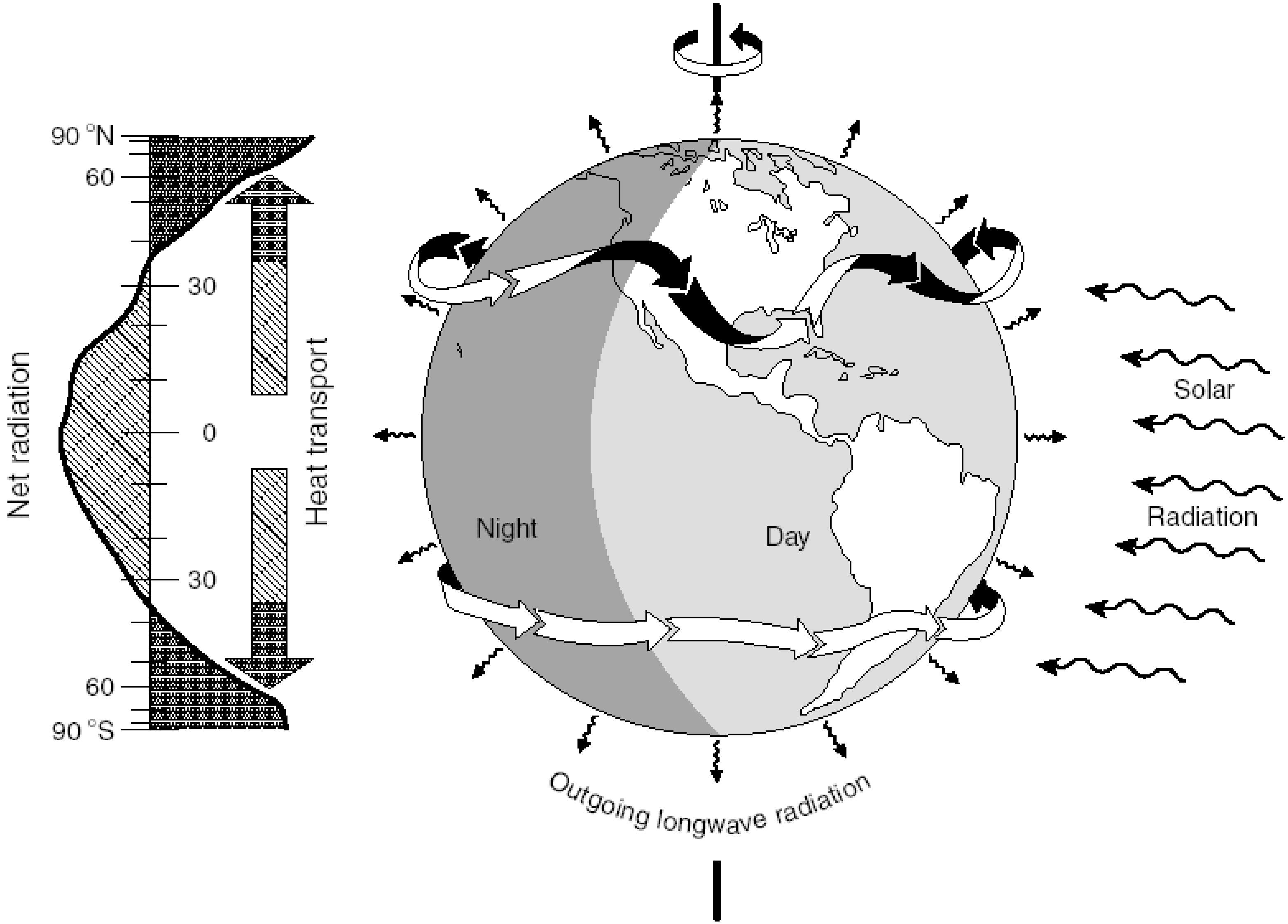
  (a) Atmospheric GCM (AGCM)

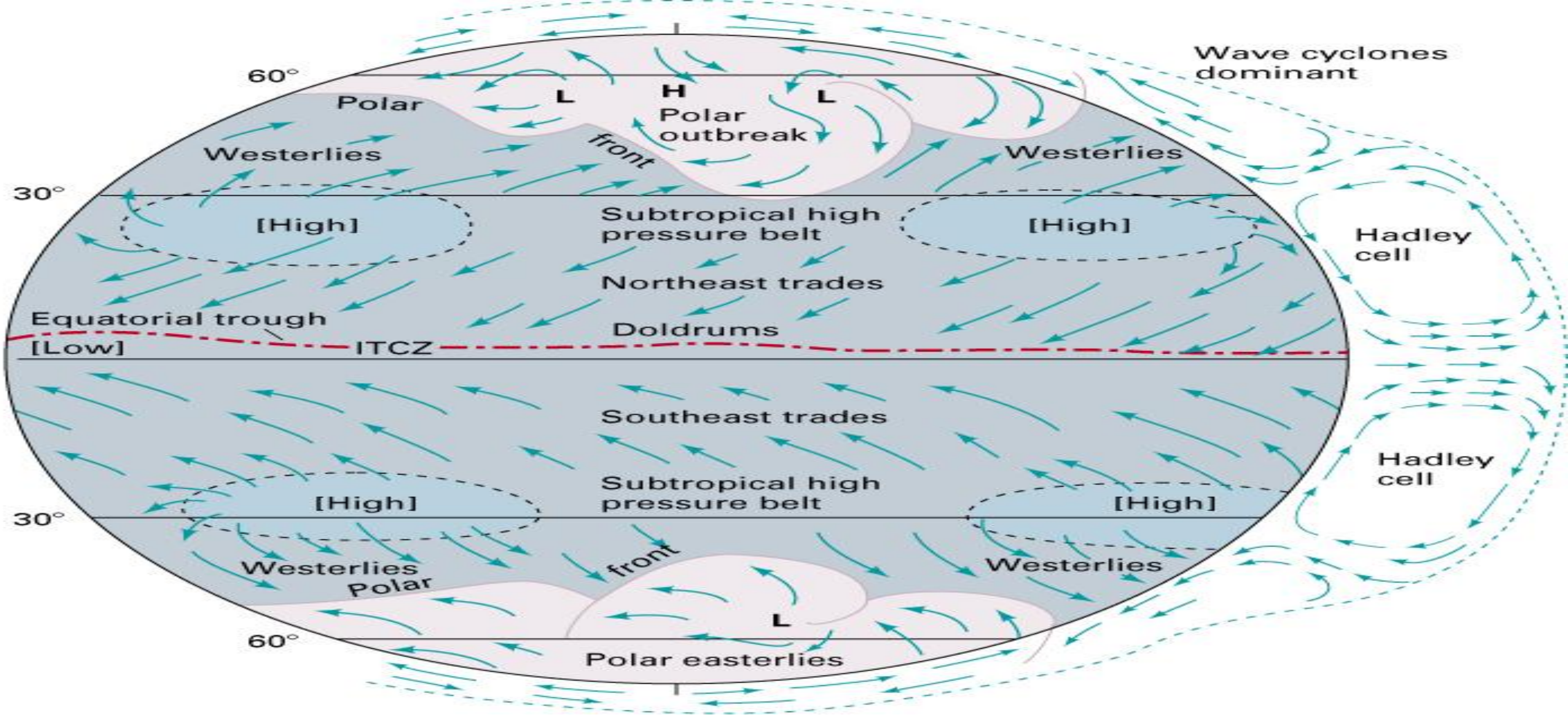
  (b) Oceanic GCM(OGCM)

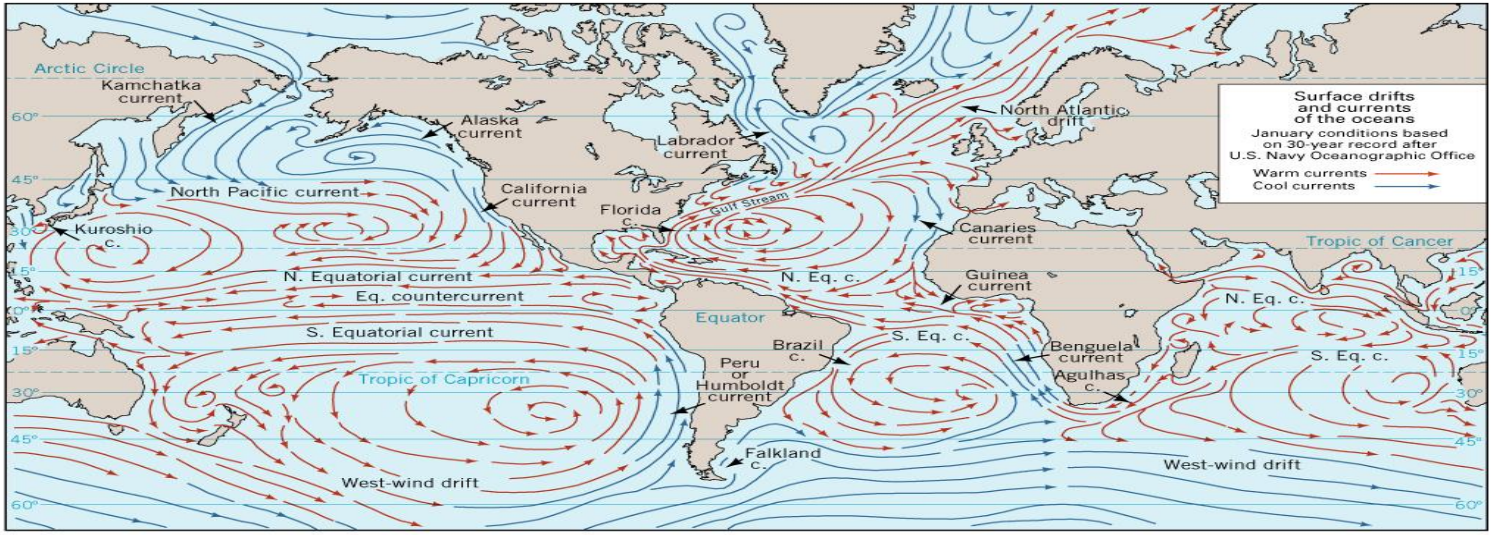
  (c) Coupled A-OGCM

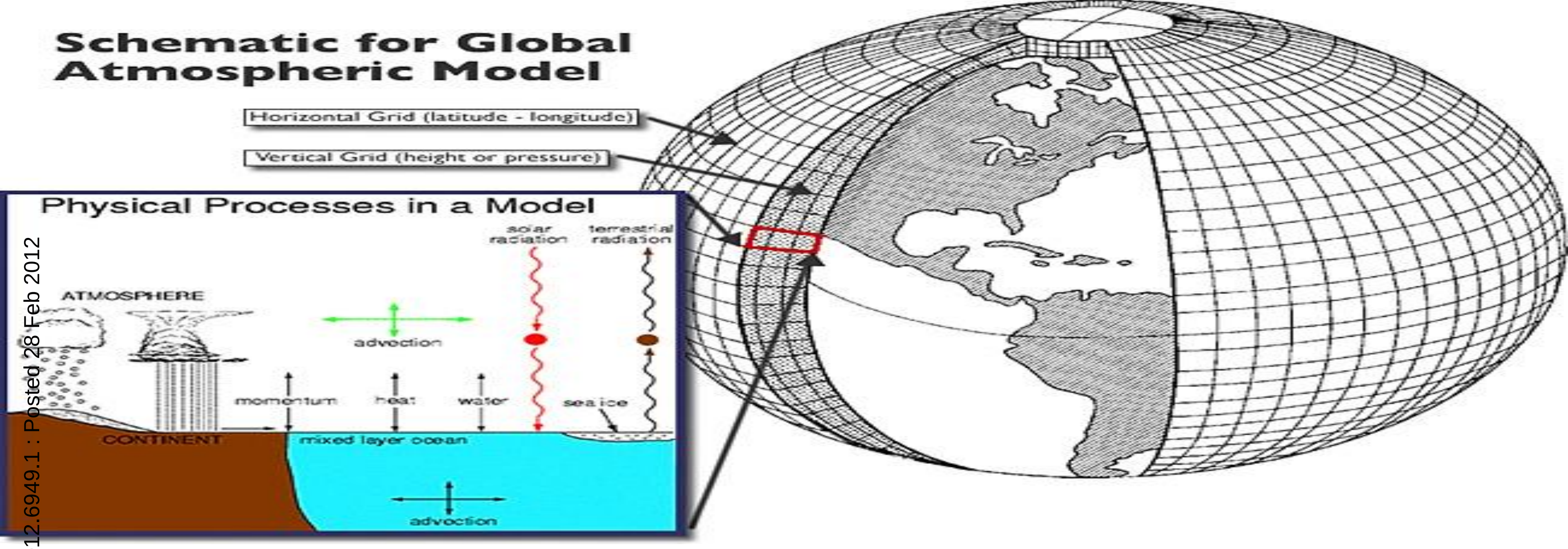


Differential heating of the Earth




Wave cyclones dominant
60°
Polar
L
H
L
Polar outbreak
front
Westerlies
Westerlies
30°
[High]
Subtropical high pressure belt
[High]
Hadley cell
Northeast trades
Equatorial trough
Doldrums
[Low]
ITCZ
0°
Southeast trades
Hadley cell
Subtropical high pressure belt
[High]
[High]
30°
front
Westerlies
Polar
Westerlies
L
60°
Polar easterlies


Arctic Circle
Kamchatka current
60°
Alaska current
Labrador current
North Atlantic drift
Surface drifts and currents of the oceans
January conditions based on 30-year record after U.S. Navy Oceanographic Office
Warm currents
Cool currents
45°
North Pacific current
California current
Gulf Stream
Florida c.
Kuroshio c.
30°
Canaries current
Tropic of Cancer
15°
N. Equatorial current
N. Eq. c.
Guinea current
Eq. countercurrent
N. Eq. c.
0°
Equator
S. Equatorial current
S. Eq. c.
Brazil c.
Benguela current
S. Eq. c.
Peru or Humboldt current
Agulhas c.
Tropic of Capricorn
Falkland c.
West-wind drift
West-wind drift



- Climate models are systems of differential equations based on the basic laws of physics, fluid motion, and chemistry. To "run" a model, scientists divide the planet into a 3-dimensional grid, apply the basic equations, and evaluate the results. Atmospheric models calculate wind, heat transfer, radiation, relative humidity, and surface hydrology within each grid and evaluate interactions with neighboring points.

- General Circulation Models (GCMs) are a class of computer-driven models for weather forecasting, understanding Climate and projecting climate change. These computationally intensive numerical models are based on the integration of a variety of fluid dynamical, chemical, and sometimes biological equations.

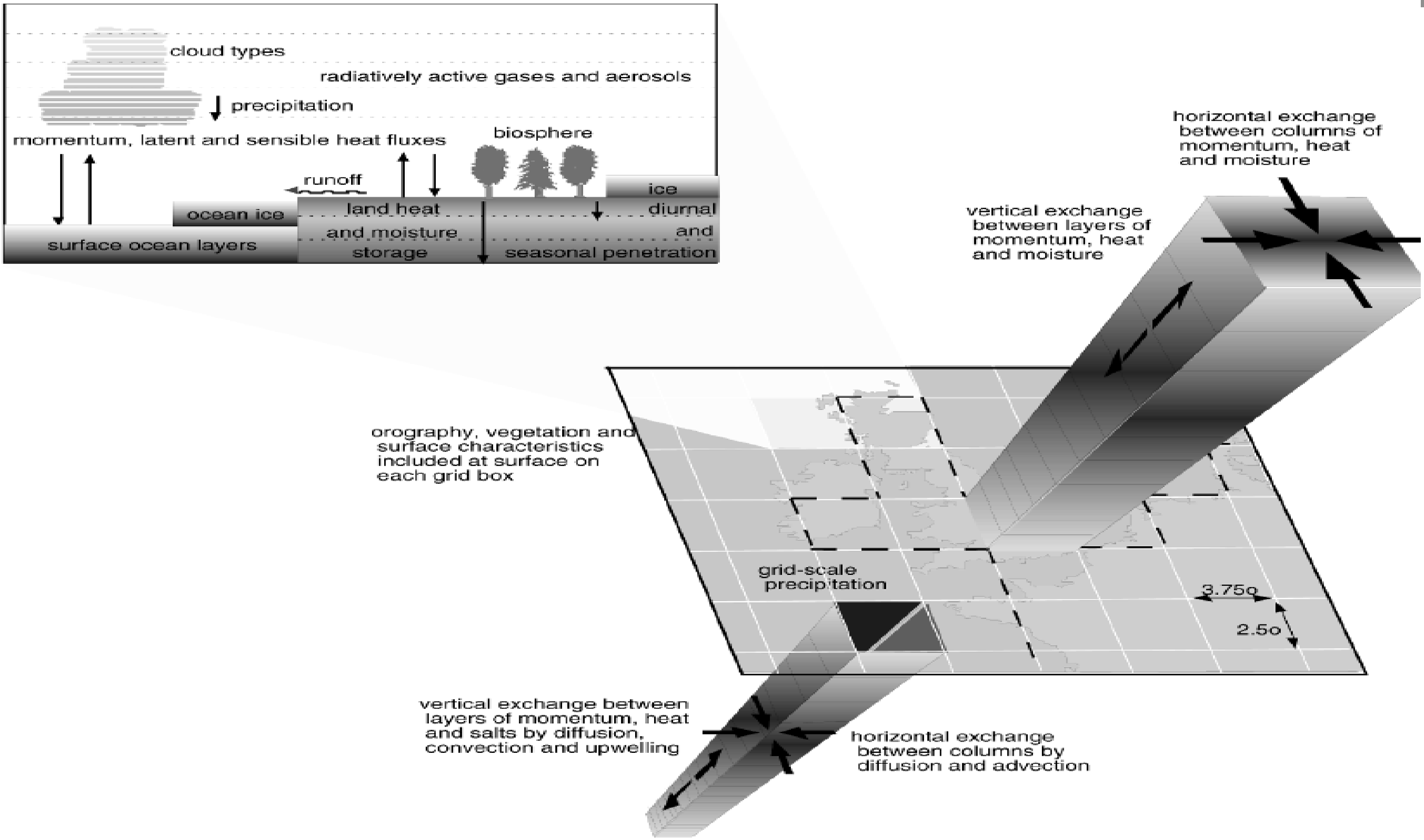
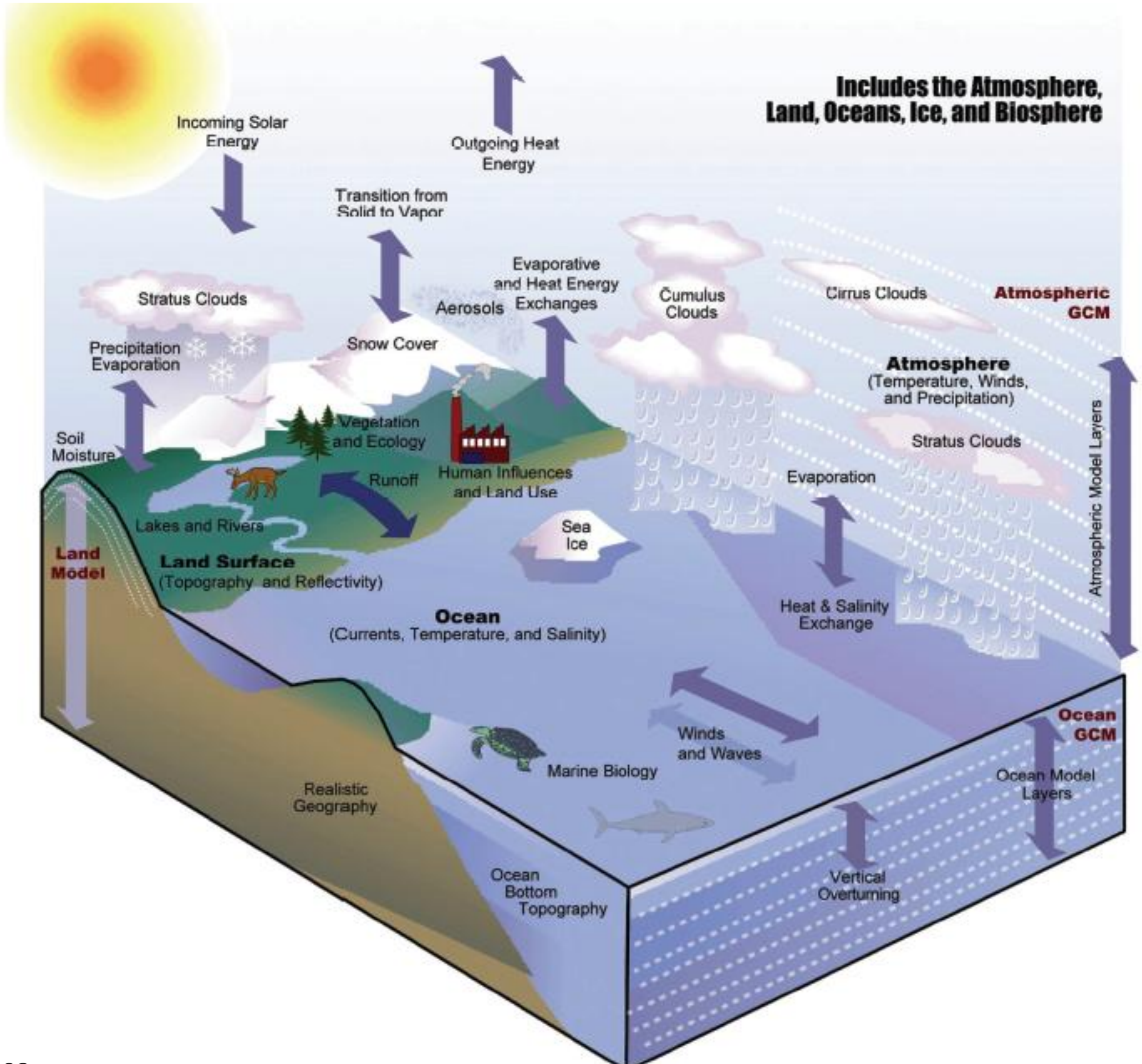


Fig. Conceptual structure of Coupled-Ocean-Atmospheric GCM

The climate system



Karl and Trenberth, 2003

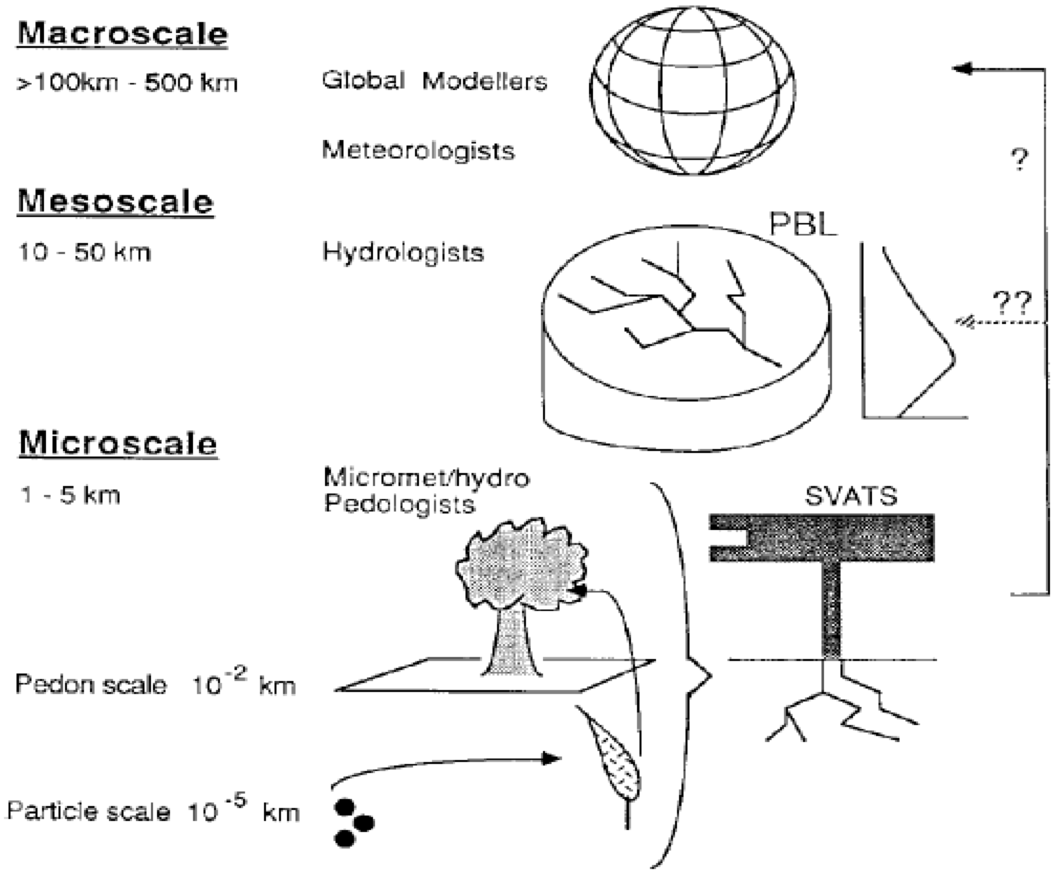
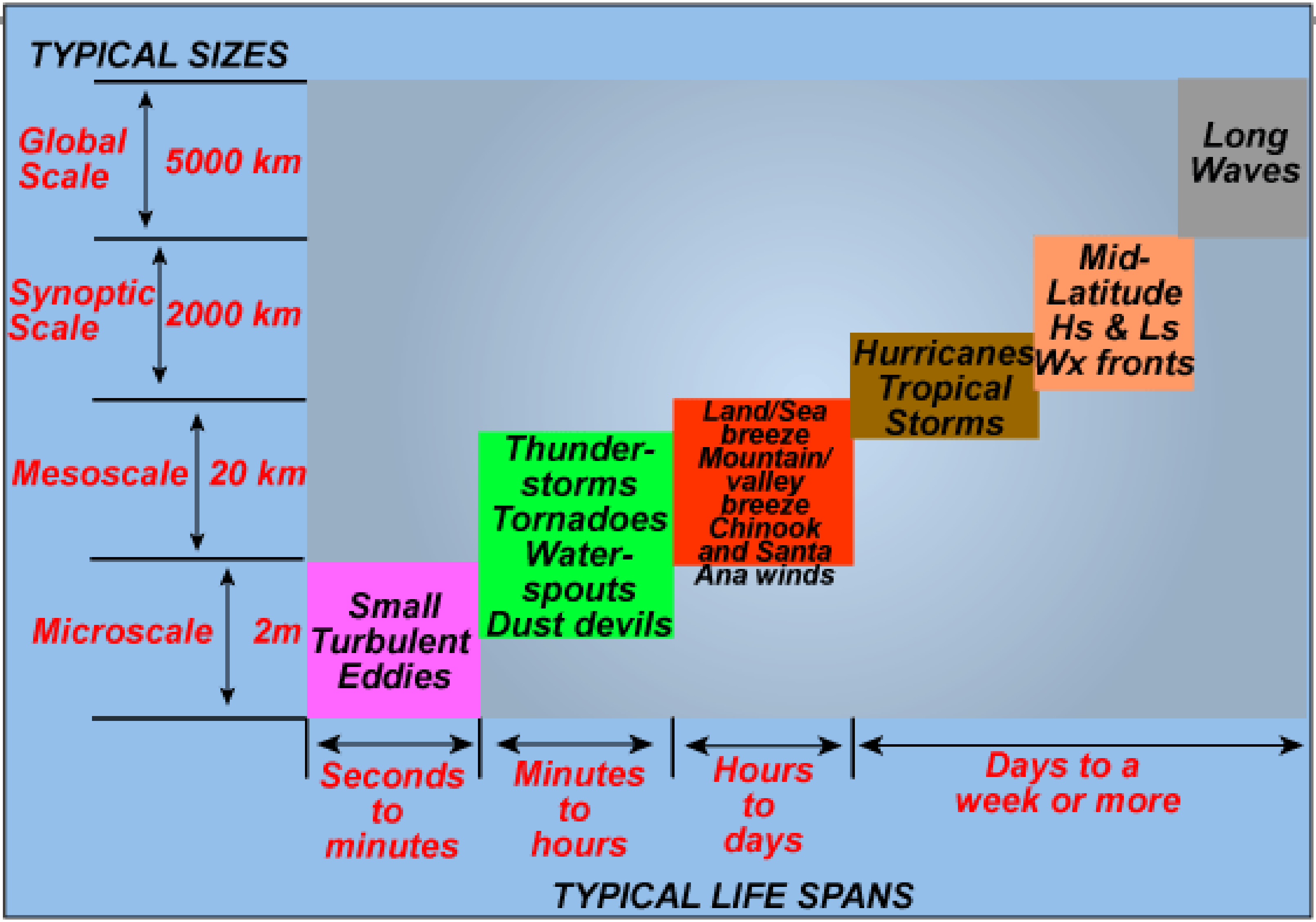


Figure 1. Global climate modellers freely utilise microhydrological and micrometeorological concepts and parameterizations in their coarse resolution models. This exploitation is based on the assumption that scaling of hydrological and other properties is reasonable. Note: SVATS means Soil-Vegetation-Atmosphere-Transfer-Scheme and PBL is the Planetary Boundary Layer (after Henderson-Sellers et al., 1995).

(Bonnel,M.,1998)

TIME AND SPACE SCALE OF ATMOSPHERIC MOTION



The atmosphere in "Primitive Equations"

$$\frac{\partial u}{\partial t} + \vec{V} \cdot \nabla u + \omega \frac{\partial u}{\partial p} - fv + \frac{\partial \phi}{\partial x} = F_X$$

$$\frac{\partial v}{\partial t} + \vec{V} \cdot \nabla v + \omega \frac{\partial v}{\partial p} + fu + \frac{\partial \phi}{\partial y} = F_y$$

$$\frac{\partial \phi}{\partial p} = -\alpha$$

Navier-Stokes equations

$$\frac{\partial T}{\partial t} + \vec{V} \cdot \nabla T + \omega \frac{\partial T}{\partial p} - \alpha\omega / Cp = Q / Cp$$

Thermodynamic Energy Equation

$$\nabla \cdot \vec{V} + \frac{\partial \omega}{\partial p} = 0$$

Continuity Equation

$$p\alpha = RT$$

Ideal Gas Law

$$\frac{\partial q}{\partial t} + \vec{V} \cdot \nabla q \cdot + \omega \frac{\partial q}{\partial p} = S_q$$

Moisture conservation

u, v, ω, T, α, Φ, and q

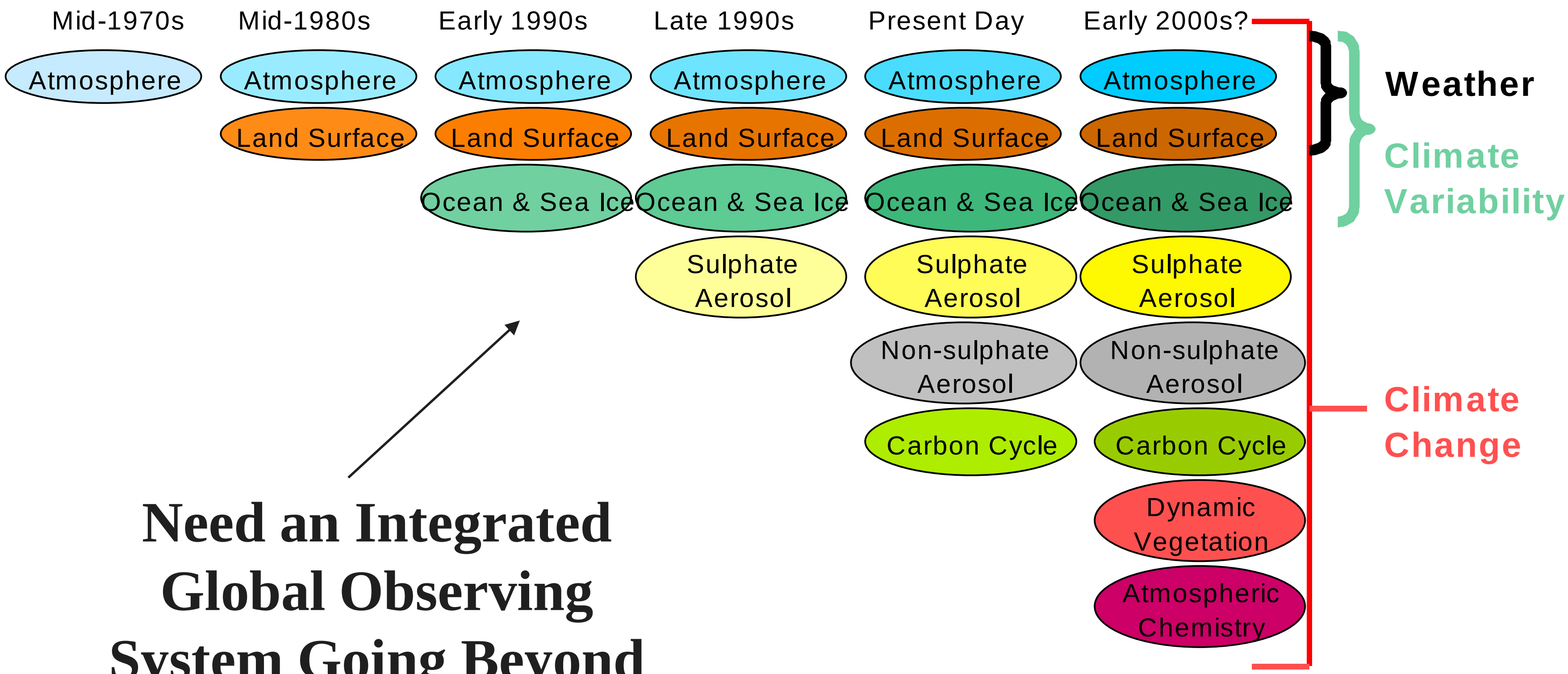
Given
- Three equations of motion (u, v, w)
- Continuity equation (ρ)
- The ideal gas law (p)
- Thermodynamic energy equation (T)
- 6 equations, 6 unknowns u, v, w, p, ρ, T
- (Also: moisture, salinity etc. conservation)

- Too complicated to solve in practice - need to simplify / and turn to <u>computational</u> fluid dynamics!

The Primitive equation
- Explain the basic (large-scale) dynamics of the atmosphere
- In principle: possible to solve (#unknowns = #equations).
- In practice: analytical solutions not possible (e.g. non-linearity)

(Various filtered forms of the equations of motion…)

Overview of Weather and Climate Models and the Required Observations



Need an Integrated Global Observing System Going Beyond the WWW

Ants Leetma, GFDL,NOAA,2007

Part Three

Introductory Description of Regional Climate Models

Model Details

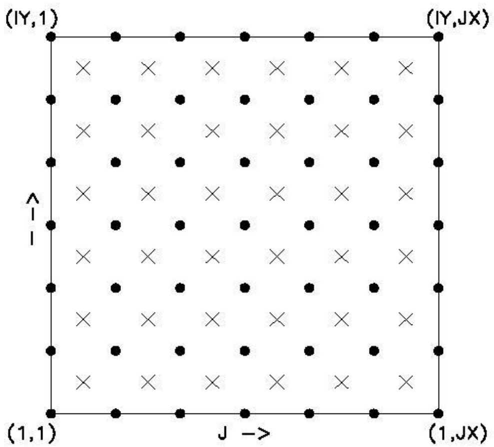
- Model used for study is ICTP Regional Climate Model Version 3 (RegCM3)
- RegCM is a 3-dimensional, sigma-coordinate, primitive equation regional climate model
- RegCM3 is maintained & supported by the Physics of Weather & Climate Group at the Abdus Salam International Centre for Theoretical Physics in Trieste, Italy
- Model developed in Fortran code alongwith Makefile configuration

Computational Requirements

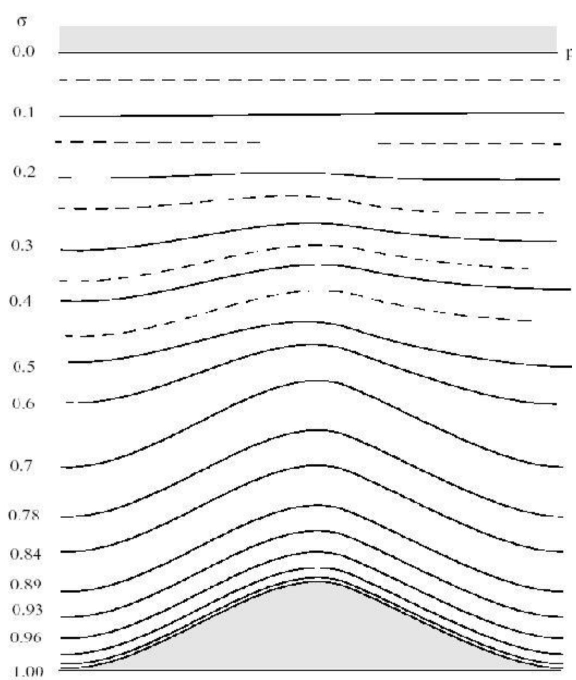
- Successfully run in Parallel processing machines or High performance workstation (Sun, IBM, DEC, SGI etc)
- Portability also proved for PC-Linux, Fedora at PC with limited experimental option and Makefile compatibility
- Makefile compatible for
  - AMD64
  - IBM
  - DEC
  - IFC7
  - IFC8
  - IFC8-64
  - PGI3
  - PGI5
  - SUN
  - SGI
- RAM requirement 2GB (Minimum)
- Harddisk 80 GB (Minimum)
- Operating System required UNIX or Linux
- Knowledge of Fortran and Graphics program (GrADS, Ferret, NCL, Matlab etc)

Model Grid configuration

- Finite differenced model
- Arakawa-b staggered horizontal grid
  - Temperature, moisture and pressure fields are defined on the cross points.
  - The horizontal winds are defined on the dot points.
- Sigma vertical coordinate



$$\sigma = \frac{P - P_t}{P_s - P_t}$$



p = pressure of a layer
p_s = surface pressure
p_t = top level pressure (constant)

The equations of a climate model

Nature Precedings : doi:10.1038/npre.2012.6949.1 : Posted 28 Feb 2012

$$\frac{\partial \overline{V}}{\partial t} + \overline{V} \cdot \nabla \overline{V} = -\frac{\nabla p}{\rho} - 2\overline{\Omega} \times \overline{V} + \overline{g} + \overline{F}_{\overline{V}}$$

Conservation of momentum

$$C_p\left(\frac{\partial T}{\partial t} + \overline{V} \cdot \nabla T\right) = \frac{1}{\rho}\frac{dp}{dt} + Q + F_T$$

Conservation of energy

$$\frac{\partial \rho}{\partial t} + \overline{V} \cdot \nabla \rho = -\rho \nabla \cdot \overline{V}$$

Conservation of mass

$$\frac{\partial q}{\partial t} + \overline{V} \cdot \nabla q = \frac{S_q}{\rho} + F_q$$

Conservation of water

$$p = \rho R T$$

Equation of state

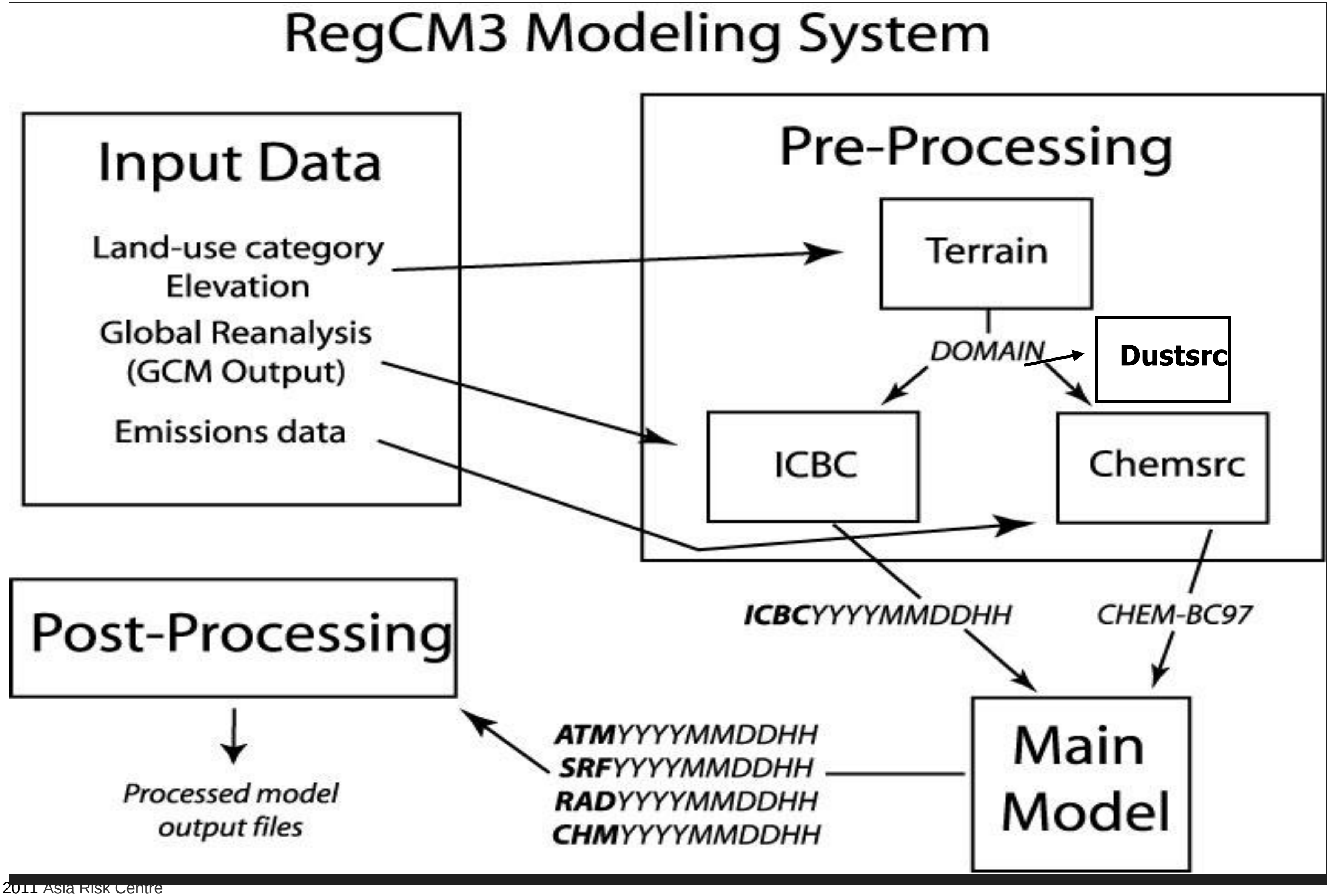
Model physics

- BATS1E Land Surface Model (Dickinson, 1993)
- CCM3 Radiation Scheme
- Planetary Boundary Layer scheme (Holstag,1990)
- SUBEX large-scale precipitation (Pal, 2000)
- Convective precipitation schemes
  - Grell
  - Kuo
  - Betts-Miller
- Ocean flux parameterizations
  - BATS
  - Zeng (1998)

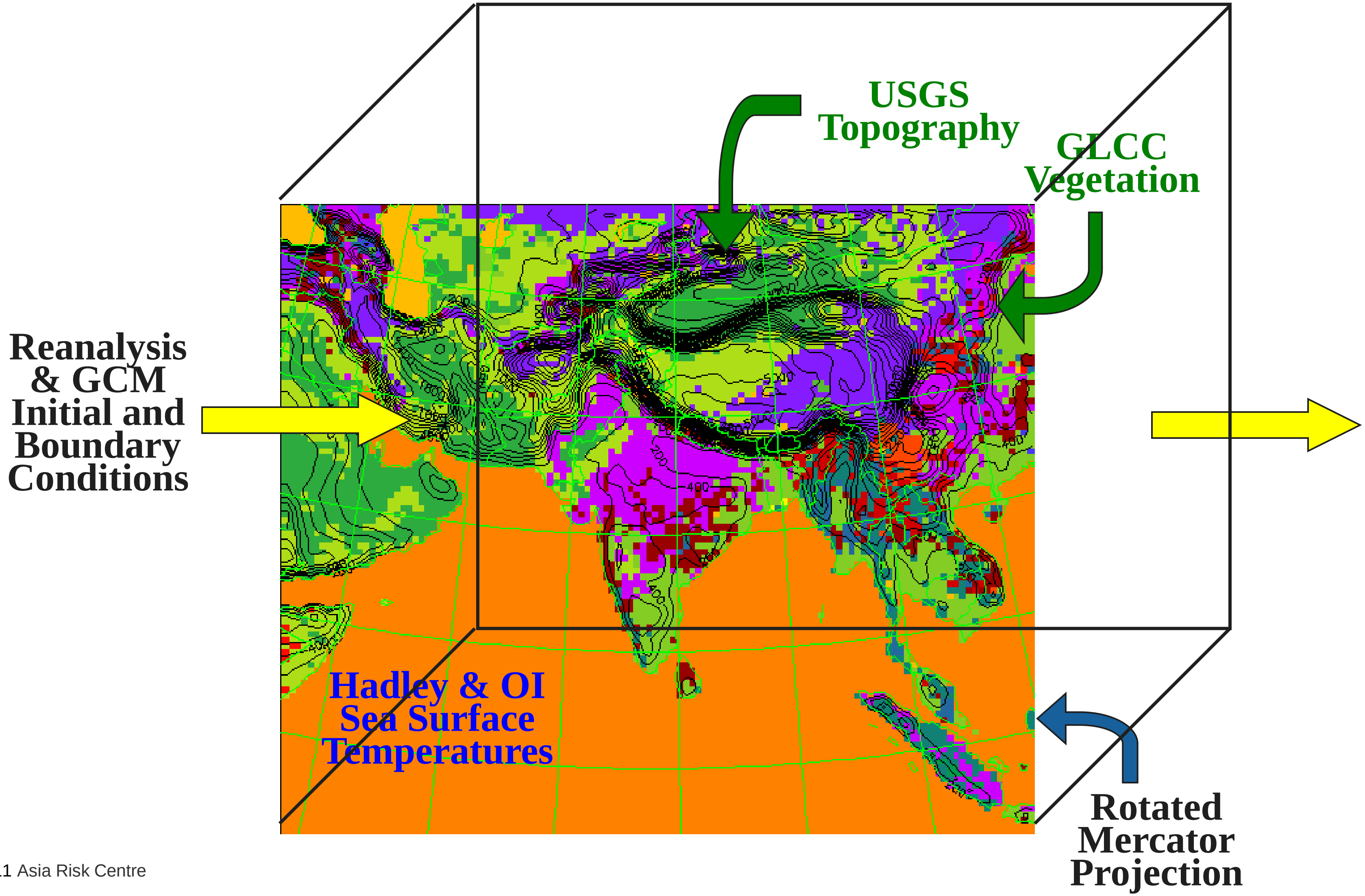
RegCM3 Input Data Requirements

- Surface data (Time-invariant)
  - Topography (GTOPO30 elevation data of USGS)
  - Landuse Landcover data (GLCC landuse datset of USGS)
- Gridded analysis or GCM forcing data
  - 3D field(u,v,w of wind components, RH, Geopotential height, Temperature)
  - 2D field (Surface Pressure & Surface Temperature)
  - GCMs (NNRP1, NNRP2, ERA40, ECWCRP, FVGCM) data resolution is (2.5^0x2.5^0xL17)
- Sea Surface Temperature Data (GISST or OISST)

Overview of Model Structure



Preparing the data & run the model



RegCM3 Output Files

ATMYYYYMMDDHH (Table 8)

Variables	Description
u	Zonal wind (m s^{-1})
v	Meridional wind (m s^{-1})
tk	Temperature (K)
qd	Mixing ratio (g kg^{-1})
qc	Cloud mixing ratio (g kg^{-1})
ps	Surface pressure (Pa)
rt	Total precipitation (mm)
tgrnd	Geopotential height (gpm)
smt	Total soil water (mm)
rb	Base flow (*mm day*−1)

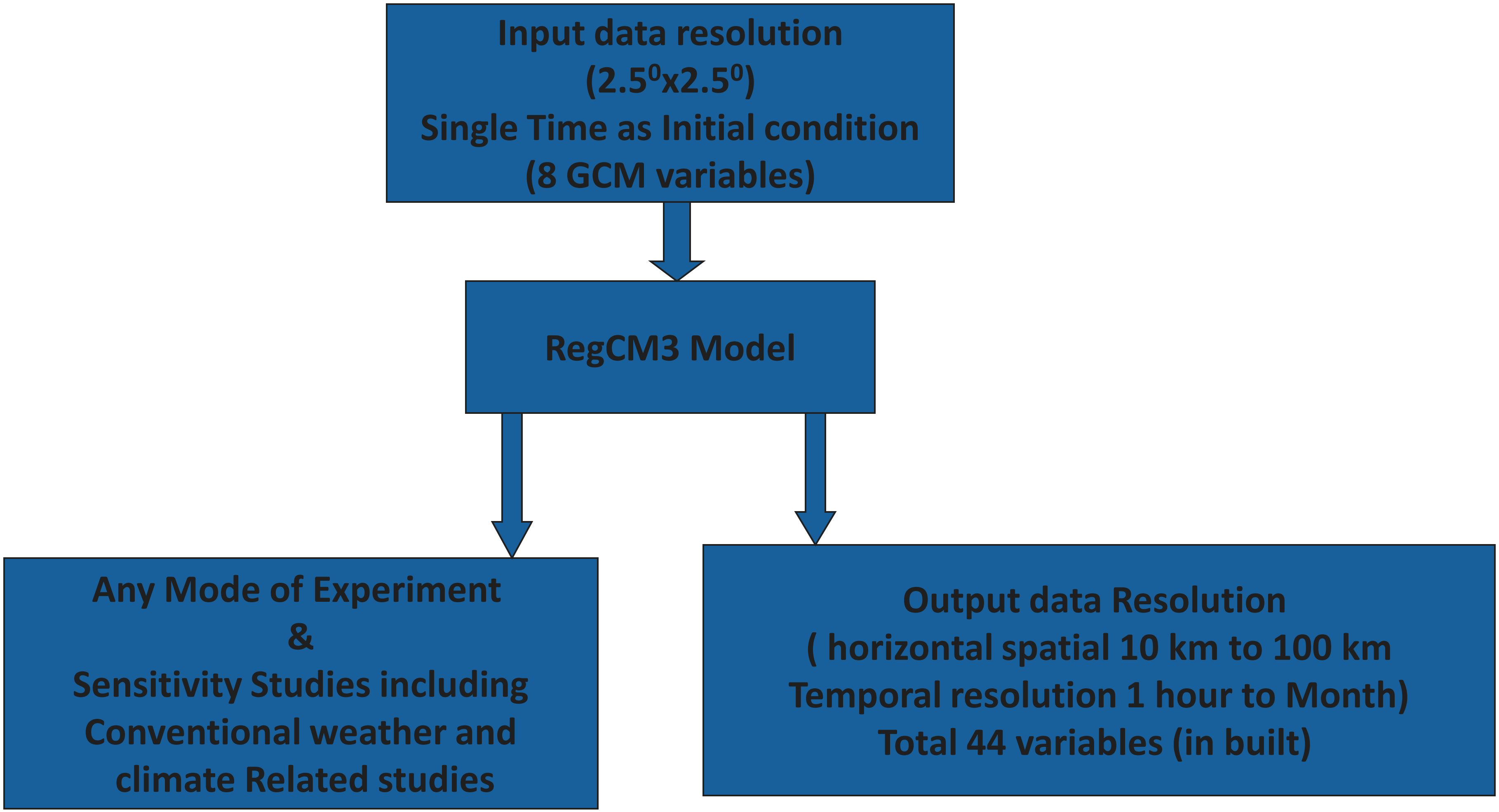
RADYYYYMMDDHH(Table 10)

Variables	Description
fc	Cloud fraction (fraction)
clwp	Cld liquid H_2O path (g m^{-2})
qrs	Solar heating rate (K s^{-1})
qrl	LW cooling rate (K s^{-1})
fsw	Surface abs solar (W m^{-2})
flw	LW cooling of surface (W m^{-2})
clrst	Clear sky col abs sol (W m^{-2})
clrss	Clear sky surf abs sol (W m^{-2})
clrlt	Clear sky net up flux (W m^{-2})
clrls	Clear sky LW surf cool (W m^{-2})
solin	Instant incid solar (W m^{-2})
sabtp	Column abs solar (W m^{-2})
firtp	Net up flux at top (W m^{-2})

SRFYYYYMMDDHH (Table 9)

Variables	Description
ua	Anemometer zonal winds (m s^{-1})
va	Anemometer meridional winds (m s^{-1})
drag	Surface drag stress
tg	Ground temperature (K)
tf	Foliage temperature (K)
ta	Anemometer temperature (K)
qa	Anemometer specific humidity kg kg^{-1}
smu	Top layer soil moisture (mm)
smr	Root layer soil moisture (mm)
rt	Total precipitation (mm day^{-1})
et	Evapotranspiration (mm day^{-1})
rnfs	Surface runoff (mm day^{-1})
snow	Snow water equivalent (mm)
sh	Sensible heat (W m^{-2})
lwn	Net longwave (W m^{-2})
swn	Net solar absorbed (W m^{-2})
lwd	Downward longwave (W m^{-2})
swi	Solar incident (W m^{-2})
rc	Convective precipitation (mm day^{-1})
psrf	Surface pressure (Pa)
zpbl	PBL height (m)

RegCm3 Model Capability



Part Four

Diseases Simulations

1. Mango Powdery Mildew
2. Pandemic Dengue

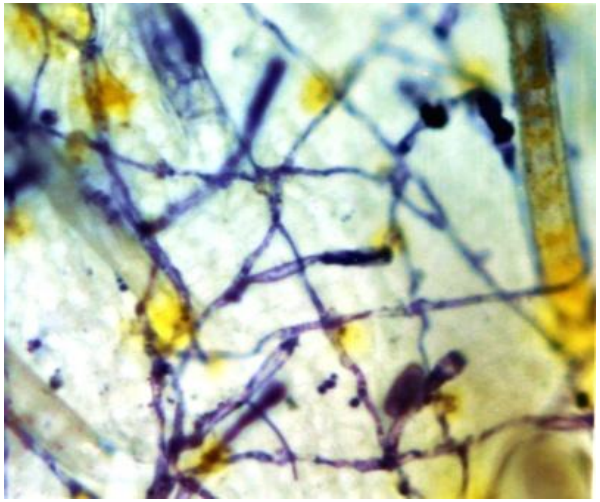
Forecasting Mango Powdery Mildew Disease with High Performance Regional Climate Model

P. Sinha, Division of Plant Pathology, I.A.R.I. New Delhi 12
S. Jha & R. C. Raghava, Centre for Atmospheric Sciences (CAS), I.I.T. Delhi, New Delhi 16

Acknowledgement: *This work has been started and accomplished during my work in* ***Indian Institute of Technology Delhi*** *in collaboration with* ***Indian Agricultural Research Institute, New Delhi****. Few of the left analysis has been completed during my present tenure in* ***Asia Risk Centre, RMS Risk Management Solutions India, Noida, India***

Back Ground: Mango Powdery Mildew Disease

Visible Brown Patch on Panicle



Initial Fungal Development

Kingdom: Fungi Phylum: Ascomycota Class: Leotiomycetes Subclass: Leotiomycetidae Order: Erysiphales Family: Erysiphaceae Genus: *Oidium* Species: *O. mangiferae*

Statistical Disease Model Study done by Dr. P.Sinha

- **Climate Variables →**Hourly Temperature & RH data from December to February for 1994-1995 and 1997 were used by AWS data of I.A.R.I, New Delhi
- **Disease Data→** Observed Mango Powdery Mildew disease infestation (brown patches etc) in Mango orchard, I.A.R.I., New Delhi

Infection Probability based on Temperature (Disease Function)

Infection probability based on temperature index
For predicting the probability of infection based on temperature the following model (Yin *et al*. 1995) has been used,

$$f(T) = \begin{cases} \left(\dfrac{T_{\max} - T}{T_{\max} - T_{opt}}\right)\left(\dfrac{T - T_{\min}}{T_{opt} - T_{\min}}\right)^{(T_{opt} - T_{\min})/(T_{\max} - T_{opt})} & \text{if } T_{\min} \le T \le T_{\max} \\ 0, & \text{otherwise} \end{cases}$$

Parameters in the model are *Tmin*, *Topt* and *Tmax*, which denote the minimum, optimum and maximum temperature (°C) for infection, respectively. The model describes a probability, it has values between 0 and 1. So, *f*(*T*) = 0 at *T* = *Tmin* and *T* = *Tmax* and *f(T)* = 1 at *T* = *Topt*.

In our case for estimate of *ƒ*(T) take the following values Tmin =10°C;Tmax = 36°C; Topt=26°C

Sporulation Rate based on Temperature

Sporulation rate based on temperature

Secondary infection spread of the disease is calculated indirectly based on the effect of temperature on sporulation (Sinha, 2005). The model for sporulation rate (y)

y = (0.002574 T-0.010783){(1-exp[0.22492(T-36)]}.

Daily inoculums potential for spore formation was calculated by hourly accumulating the reciprocal of rate of sporulation

Rate of sporulation (y) = (aT - b){(1 –exp[c (T - 36)])};For hourly data model parameters a=0, b=0.002, c= 0.225 & T = temperature °C

Disease Index: based on Temperature & RH

Disease favourable period
Powdery mildew forecast model simulates primary infection event by the pathogen based on air temperature and high RH hours and estimates hourly risk values on a scale either 0 or 1 basis to correspond unfavouarble or favourable for infection (Sinha, 1999). Consecutive occurrence of favourable values (1) for 3-5 days is considered for infection with assumption that sufficient inoculum is being present in the orchards

To find out Powdery mildew favourable weather period w.r.t. temperature (T) and high RH (≥80%). It is done finding out 0 and 1 with condition T ≥10°C and RH≥ 80%.

Powdery mildew favourable weather period
When T ≥10°C and RH≥ 80%

**New Disease Index: based on Mixing Ratio

Disease favourable period based on water mixing ratio

Powdery mildew favourable weather period
Mixing Ratio ≥ 6.227 (which is equivalent to T ≥10°C and RH≥ 80%)

Mixing Ratio is function of Temperature, RH & Pressure

*** This new approach has been developed by Dr. P. Sinha & Somnath Jha*

Experimental Design

- Model Used : ICTP-RegCM3
- LSP Scheme selected : BATS
- PBL Scheme used : Holstag
- Model domain: 50.5^{0}N to 30.5^{0}S and 10^{0}E to 140^{0}E
- Horizontal resolution: 20 Km Grid spacing
- SST data: Optimum Interpolation of Sea surface data (Reynolds et al., 2002 from NCEP_NCAR dataset)
- GCM data forced : NNRP1 of NCAR centre GCM output for surface fields
- Model Integration : 1st November, 00 hour Preceding Year through 31st March 18 hour for next year with initial condition of 1st November, 00 hour
- High Performance computing interface used : Sun cluster,(28 processor)
- Run node: Parallel Operating Environment (POE)
- Experimentation year selection: 1994, 1995, 1996 & 1997
- New Fortran code coupled into ICTP-RegCM3 model code to derive Disease Index (based on Temperature & RH), Disease sporulation rate, disease function and New Disease Index (based on Mixing Ratio)

Disease Simulation Fortran Code coupled into Model Post-processing Unit


```
      program DiszMain
      implicit none
      integer i,j,dz,ndz,tst
      parameter (tst =739)
      real ps(tst),tk(tst),mr(tst),es(tst),ws(tst)
      real rh(tst),Ft(tst), Tmin,Tmax, Topt,y(tst)
      real a,b,c, pfunc
      parameter (Tmin=283.15, Tmax=309.15, Topt=299.15)
      parameter (a=0.002966313, b=0.024460289, c=0.014204255)
      parameter (dz=1, ndz=0)
      open (23, file='/usr1/jha/Disz_Inp/temp.dat', status='old',
     &                form='unformatted', access='stream')
      open (24, file='/usr1/jha/Disz_Inp/MixR.dat', status='old',
     &                form='unformatted', access='stream')
      open (25, file='/usr1/jha/Disz_Inp/pres.dat', status='old',
     &                form='unformatted', access='stream')
      open (43, file='/usr1/jha/Disz_Ana/RH_form.dat',
     &                status='new', form='formatted')
      open (47, file='/usr1/jha/Disz_Ana/Disease_indx',
     &                status='new', form='formatted')
      open (50, file='/usr1/jha/Disz_Ana/Disease_New_indx',
     &                status='new', form='formatted')
      open (48, file='/usr1/jha/Disz_Ana/Disease_func',
     &                status='new', form='formatted')
      open (49, file='/usr1/jha/Disz_Ana/Disease_sporn',
     &                status='new', form='formatted')
      open (33, file='/usr1/jha/Disz_Ana/temp_form.dat',
     &                status='new', form='formatted')
      open (34, file='/usr1/jha/Disz_Ana/MixR_form.dat',
     &                status='new', form='formatted')
      open (35, file='/usr1/jha/Disz_Ana/pres_form.dat',
     &                status='new', form='formatted')
        pfunc = (Topt-Tmin)/(Tmax-Topt)
       do i = 1, tst
         read(23) tk(i)
         write(33,17) i,tk(i)
c        write(33,*) tk(i),i
         read(24) mr(i)
         mr(i) = mr(i) * 1000
         write(34,18) i,mr(i)
c        write(34,*) i,mr(i)
         if ( mr(i) .ge. 6.227 ) then
           write(50,13) i,dz
         else
           write(50,14) i,ndz
         endif
         read(25) ps(i)
         write(35,19) i,ps(i)
c        write(35,*) i,ps(i)
         es(i) = 6.11*10.0**(7.5*(tk(i)-273.15)/(237.7+(tk(i)-273.15)))
         ws(i) = 621.97*(es(i)/(ps(i)-es(i)))
         rh(i) = (mr(i)/ws(i))*100
         write(43,20) i,rh(i)
c        write(43,*) i,rh(i)
```

Fortran Code contd.


```
        if ( tk(i) .ge. 283.15 .and. rh(i) .ge. 80.0 ) then
          write(47,13) i,dz
        else
          write(47,14) i,ndz
        endif
        if ( tk(i) .ge. Tmin .and. tk(i) .le. Tmax ) then
          Ft(i) = ((Tmax-tk(i))/(Tmax-Topt))*((tk(i)-Tmin)/(Topt-Tmin))
     &            **pfunc
          write(48,15) i,Ft(i)
c         write(48,*) i,Ft(i)
        else
          write(48,14) i,ndz
        endif
        y(i) = (a*tk(i)-b)*(1-exp(c*(tk(i)-Tmax)))
        write(49,16) i,y(i)
c       write(49,*) i,y(i)
      enddo
 13   Format(1x, I3, 1x, I1)
 14   Format(1x, I3, 1x, I1)
 15   Format(1x, I3, 1x, F7.4)
 16   Format(1x, I3, 1x, F7.4)
 17   Format(1x, I3, 1x, F12.8)
 18   Format(1x, I3, 1x, F12.8)
 19   Format(1x, I3, 1x, F12.6)
 20   Format(1x, I3, 1x, F7.3)
      close(23)
      close(24)
      close(25)
      close(43)
      close(47)
      close(48)
      close(49)
      close(50)
      close(33)
      close(34)
      close(35)
      stop
      end
```

Programme to compute Mixing Ratio

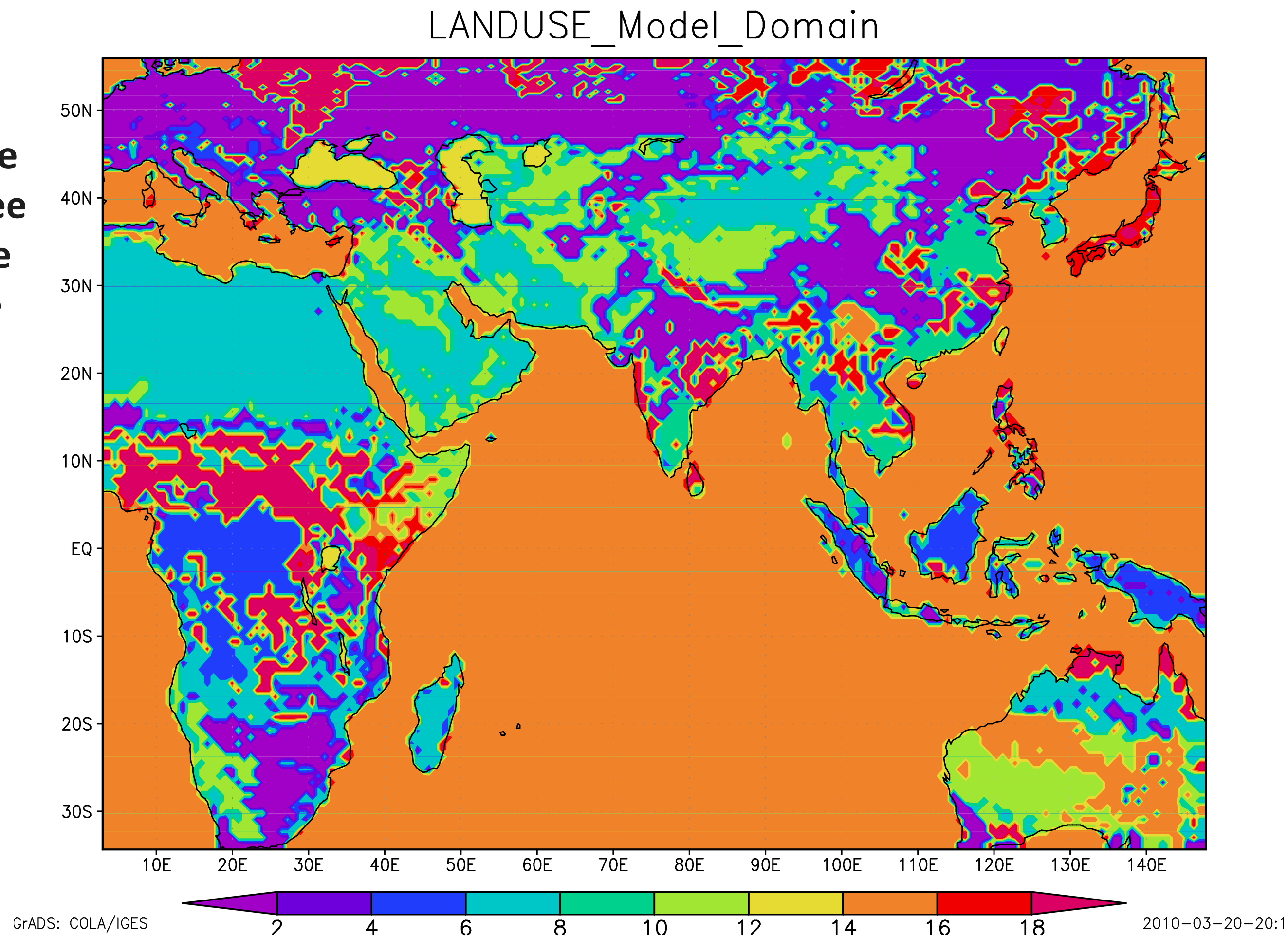
```
      program RHtoMR
      integer i,tst
      real tk,mr,es,ws,rh,mnpres
      parameter (tst=739, tk=283.15, rh=0.8)
      real ps(tst)
      open (25, file='/usr1/jha/Disz_Inp/pres.dat', status='old',
     &               form='unformatted', access='stream')
      sum = 0.0
       do i =1, tst
         read (25) ps(i)
         sum = sum + ps(i)
       enddo
       mnpres = (sum / tst)
       write(*,*) "Mean Pressure is", mnpres
         es = 6.11*10.0**(7.5*(tk-273.15)/(237.7+(tk-273.15)))
c        ws = 621.97*(es/(ps-es))
         ws = 621.97*(es/(mnpres-es))
         mr = (rh*ws)
       write(*,*) "Mixing_Ratio is", mr
      stop
      end
```

Mixing Ration is function of Temperature, Relative Humidity and Mean Pressure of a particular location

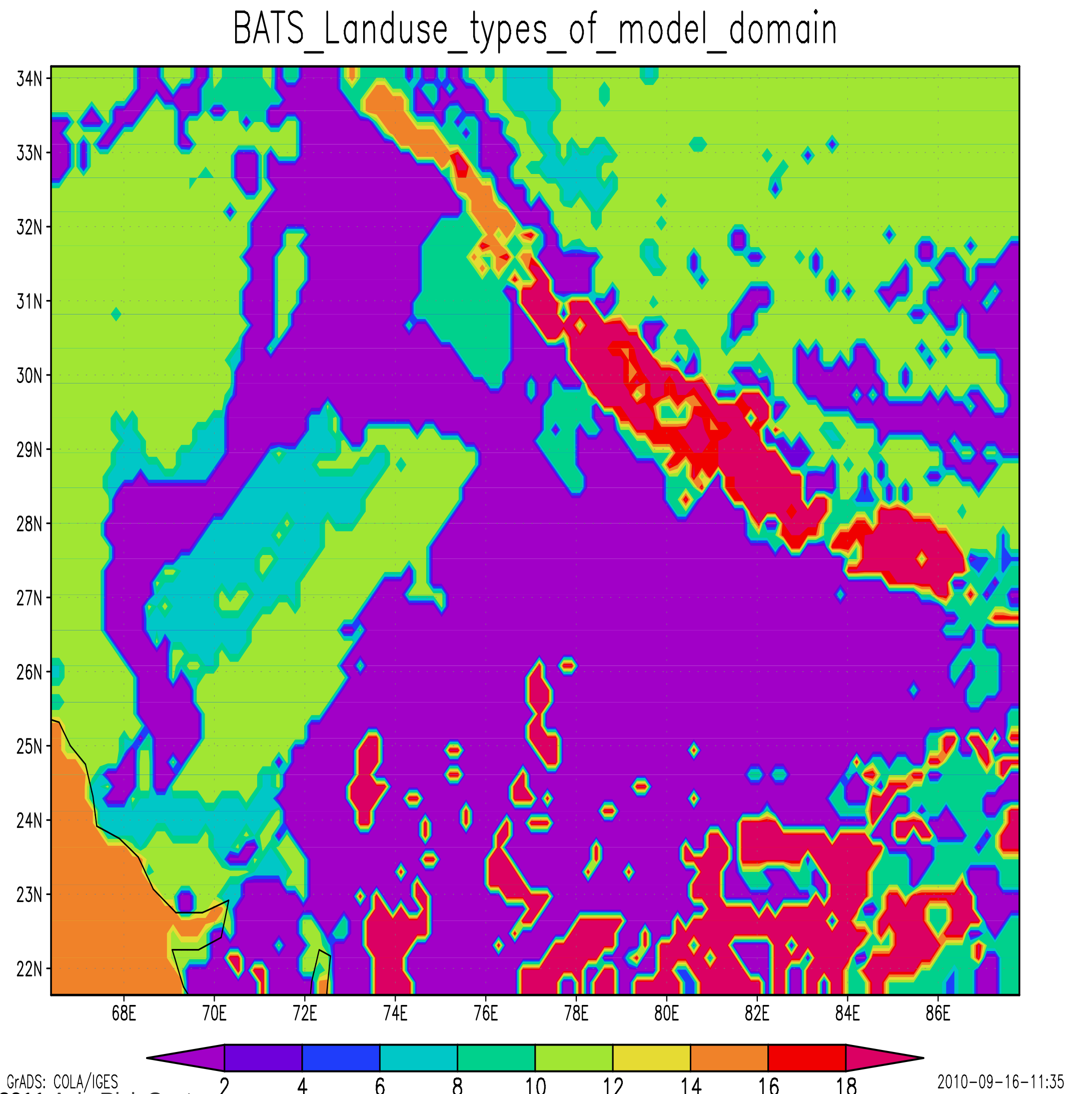
Domain of Experimental Setup

Nature Precedings : doi:10.1038/npre.2012.6949.1 : Posted 28 Feb 2012

BATS vegetation Classes
1. Crop/mixed farming
2. Short grass
3. Evergreen needleleaf tree
4. Deciduous needleleaf tree
5. Deciduous broadleaf tree
6. Evergreen broadleaf tree
7. Tall grass
8. Desert
9. Tundra
10. Irrigated Crop
11. Semi-desert
12. Ice cap/glacier
13. Bog or marsh
14. Inland water
15. Ocean
16. Evergreen shrub
17. Deciduous shrub
18. Mixed Woodland
19. Forest/Field mosaic
20. Water and Land mixture

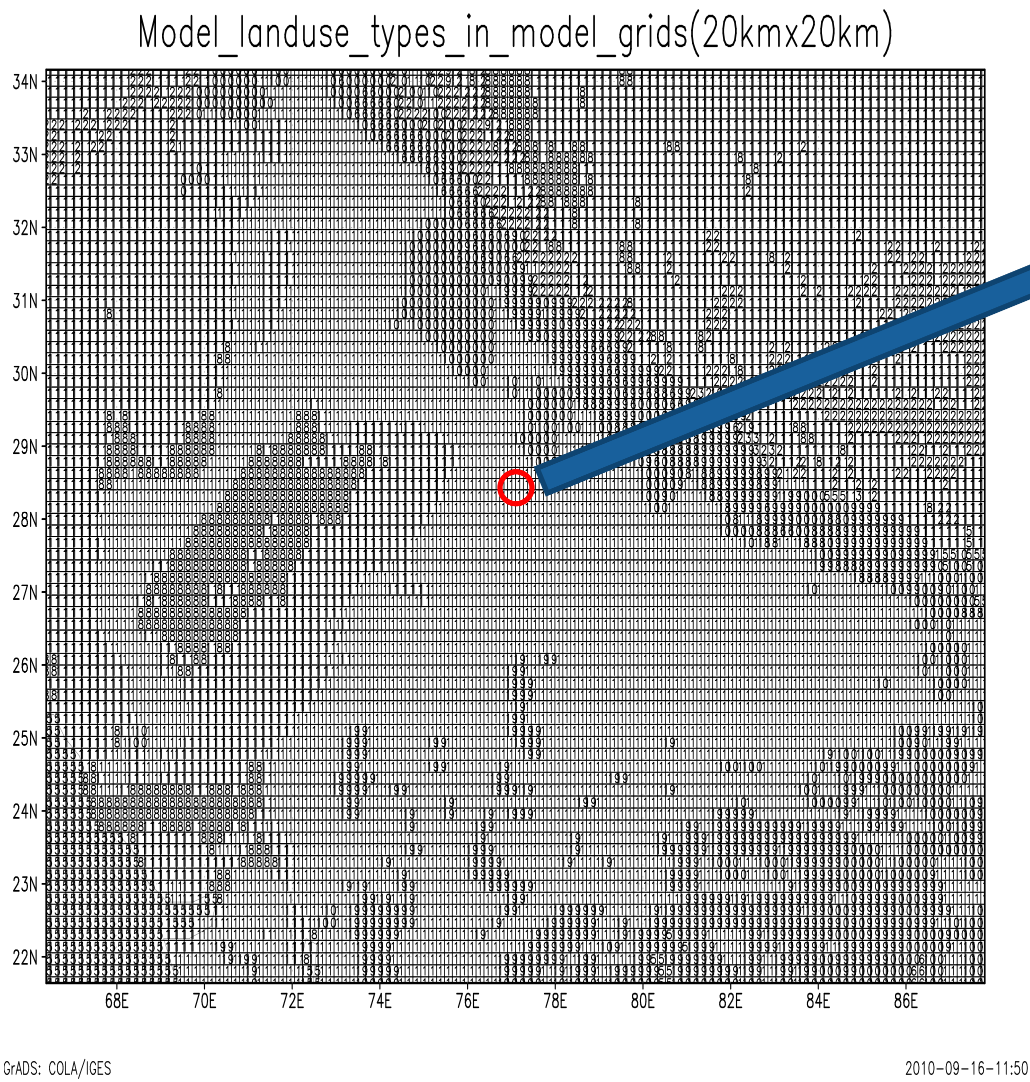


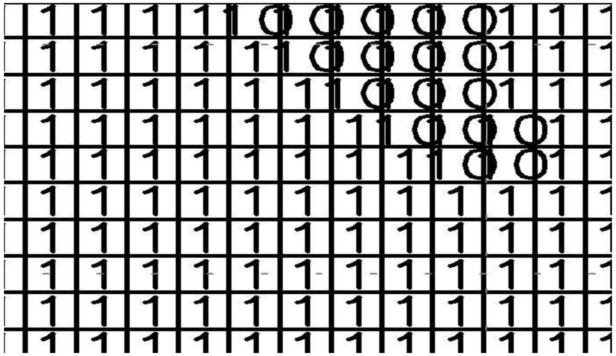
Indian Domain Zoomed In



1: crop/mixed farming [1] 2: short grass [2] 3: Evergreen needleleaf tree [3] 4: Deciduous needleleaf tree [4] 5: Deciduous broadleaf tree [5]
6: Evergreen Broadleaf tree [6] 7:Tall grass [7] 8: Desert [8]
9: Tundra [9] A:Irrigated crop [10] B: Semi-desert [11] C: Ice cap/Glacier [12]
D: Bog/marsh [13] E:Inland water [14] F: Ocean [15] G:Evergreen shrub [16]
H: Deciduous shrub [17] I:Mixed woodland [18] J:Forest or forest mosaic [19]
K: water and land mixture [20]

Fine Model Grids of Indian domain





1: crop/mixed farming [1]
2: short grass [2]
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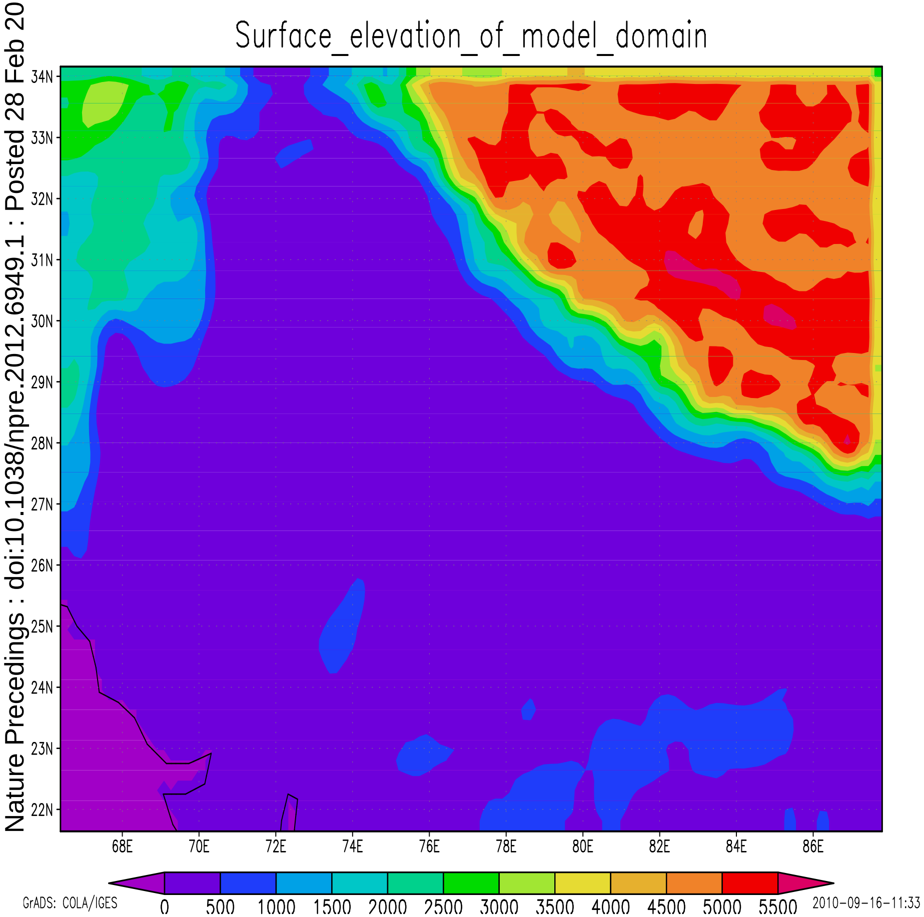
K: water and land mixture [20]

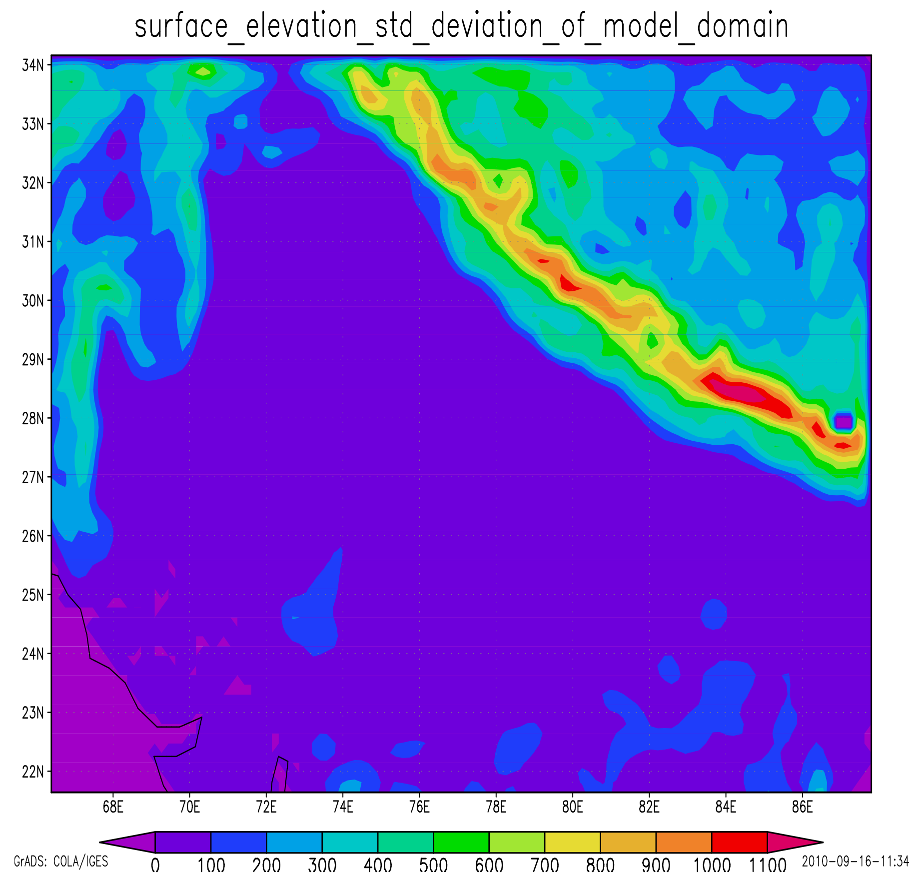
Biophysical Parameters of BATS Vegetation Class

Table 2: BATS vegetation/land-cover

Parameter	Land Cover/Vegetation Type																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Max fractional vegetation cover	0.85	0.80	0.80	0.80	0.80	0.90	0.80	0.00	0.60	0.80	0.35	0.00	0.80	0.00	0.00	0.80	0.80	0.80	0.80
Difference between max fractional vegetation cover and cover at 269 K	0.6	0.1	0.1	0.3	0.5	0.3	0.0	0.2	0.6	0.1	0.0	0.4	0.0	0.0	0.2	0.3	0.2	0.4	0.4
Roughness length (m)	0.08	0.05	1.00	1.00	0.80	2.00	0.10	0.05	0.04	0.06	0.10	0.01	0.03	0.0004	0.0004	0.10	0.10	0.80	0.3
Displacement height (m)	0.0	0.0	9.0	9.0	0.0	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Min stomatal resistence (s/m)	45	60	80	80	120	60	60	200	80	45	150	200	45	200	200	80	120	100	120
Max Leaf Area Index	6	2	6	6	6	6	6	0	6	6	6	0	6	0	0	6	6	6	6
Min Leaf Area Index	0.5	0.5	5	1	1	5	0.5	0	0.5	0.5	0.5	0	0.5	0	0	5	1	3	0.5
Stem (dead matter area index)	0.5	4.0	2.0	2.0	2.0	2.0	2.0	0.5	0.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Inverse square root of leaf dimension ($m^{-1/2}$)	10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Light sensitivity factor ($m^2 W^{-1}$)	0.02	0.02	0.06	0.06	0.06	0.06	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.06	0.02
Upper soil layer depth (mm)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Root zone soil layer depth (mm)	1000	1000	1500	1500	2000	1500	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	2000	2000
Depth of total soil (mm)	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Soil texture type	6	6	6	6	7	8	6	3	6	6	5	12	6	6	6	6	5	6	6
Soil color type	5	3	4	4	4	4	4	1	3	3	2	1	5	5	5	4	3	4	4
Vegetation albedo for wavelengths < 0.7 μm	0.10	0.10	0.05	0.05	0.08	0.04	0.08	0.20	0.10	0.08	0.17	0.80	0.06	0.07	0.07	0.05	0.08	0.06	0.06
Vegetation albedo for wavelengths > 0.7 μm	0.30	0.30	0.23	0.23	0.28	0.20	0.30	0.40	0.30	0.28	0.34	0.60	0.18	0.20	0.20	0.23	0.28	0.24	0.18

Terrain variability of the Domain





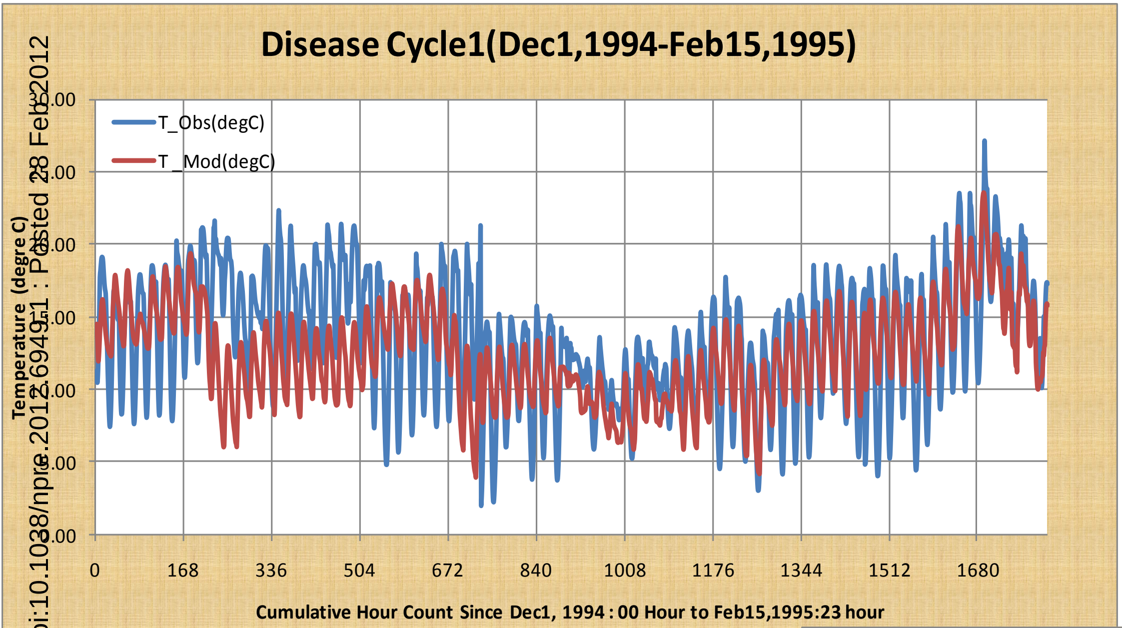
Disease Code Coupled RegCM3 Model Output

- Model output extracted for Delhi regions (grids)
- Model downscaled output climate variables were validated against the I.A.R.I. AWS weather data
- Disease Index (based on Temp. & RH) and New Disease Index (based on Mixing Ratio) are compared and forecast skill of both the approaches has been analysed
- Diseases of the two seasons are described further as

  Disease Cycle 1 (for the Disease of period Dec, 1994 to Feb 1995) &

  Disease Cycle 2 (for the Disease of period Jan., 1997-Feb.1997)

Disease Cycle1

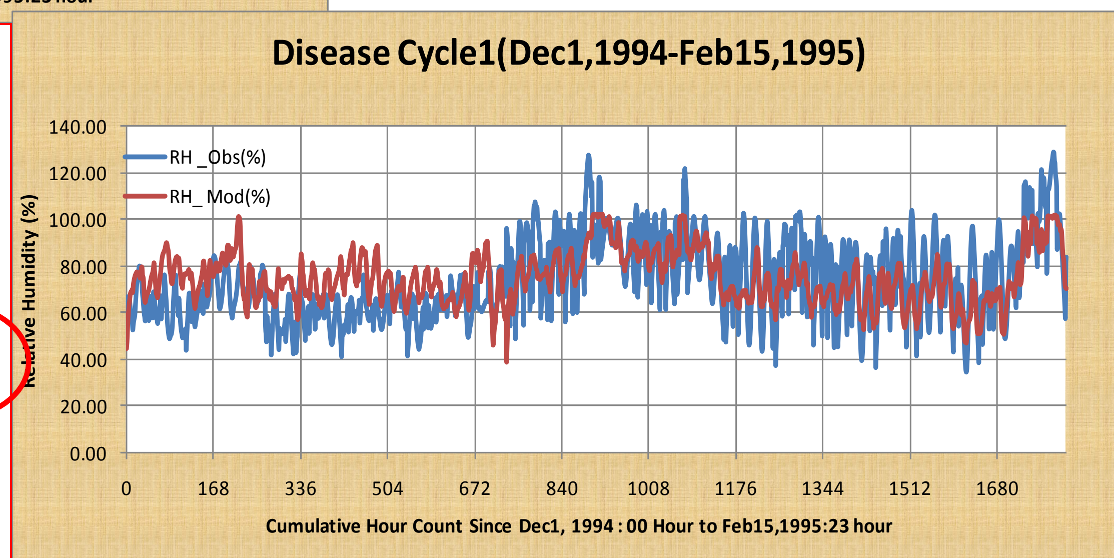


Cumulative Hour Count	Week No.
0	0
168	1
336	2
504	3
672	4
840	5
1008	6
1176	7
1344	8
1512	9
1680	10
1814	11

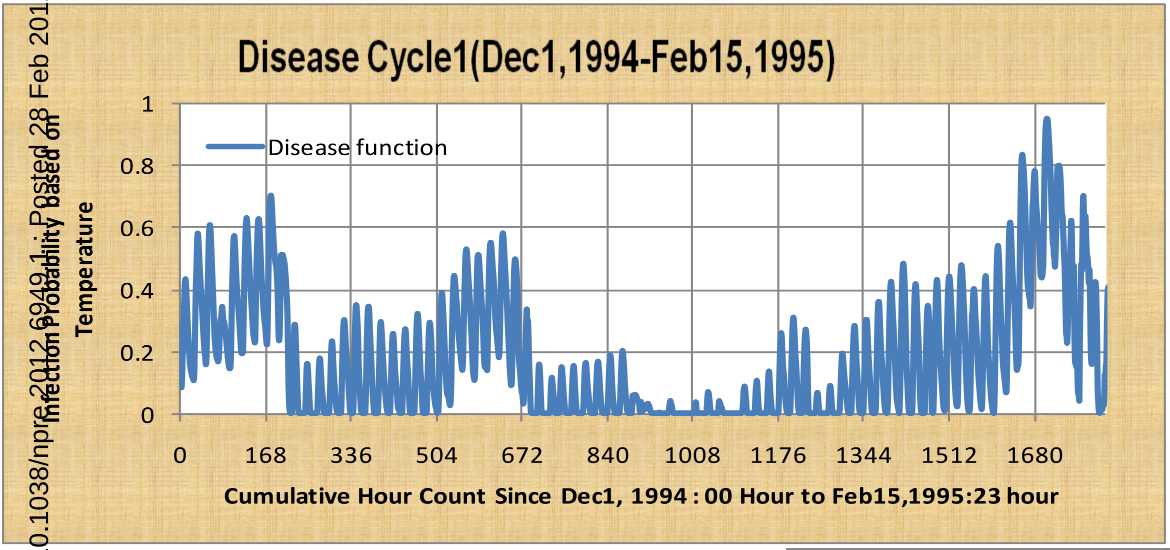
Correlations

		T_Obs(degC)	T Mod	RH _Obs(%)	RH Mod
T_Obs(degC)	Pearson Correlation	1	.707**	-.402**	-.333**
	Sig. (2-tailed)		.000	.000	.000
	N	1814	1814	1814	1814
T Mod	Pearson Correlation	.707**	1	-.326**	-.423**
	Sig. (2-tailed)	.000		.000	.000
	N	1814	1814	1814	1814
RH _Obs(%)	Pearson Correlation	-.402**	-.326**	1	.541**
	Sig. (2-tailed)	.000	.000		.000
	N	1814	1814	1814	1814
RH Mod	Pearson Correlation	-.333**	-.423**	.541**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	1814	1814	1814	1814

**. Correlation is significant at the 0.01 level (2-tailed).



Disease Function and Sporulation Rate



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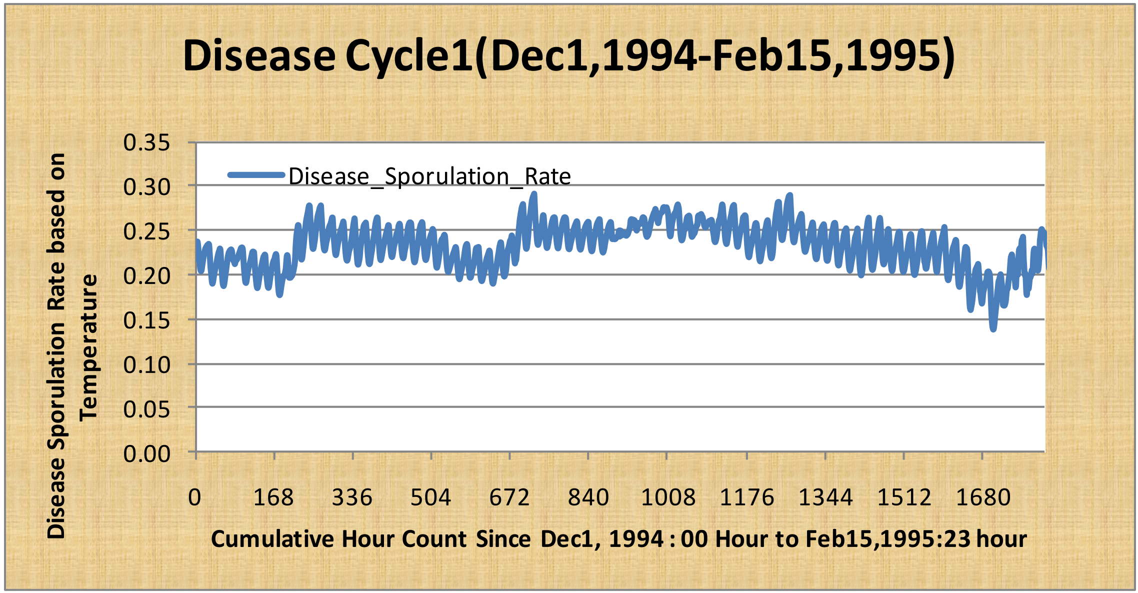
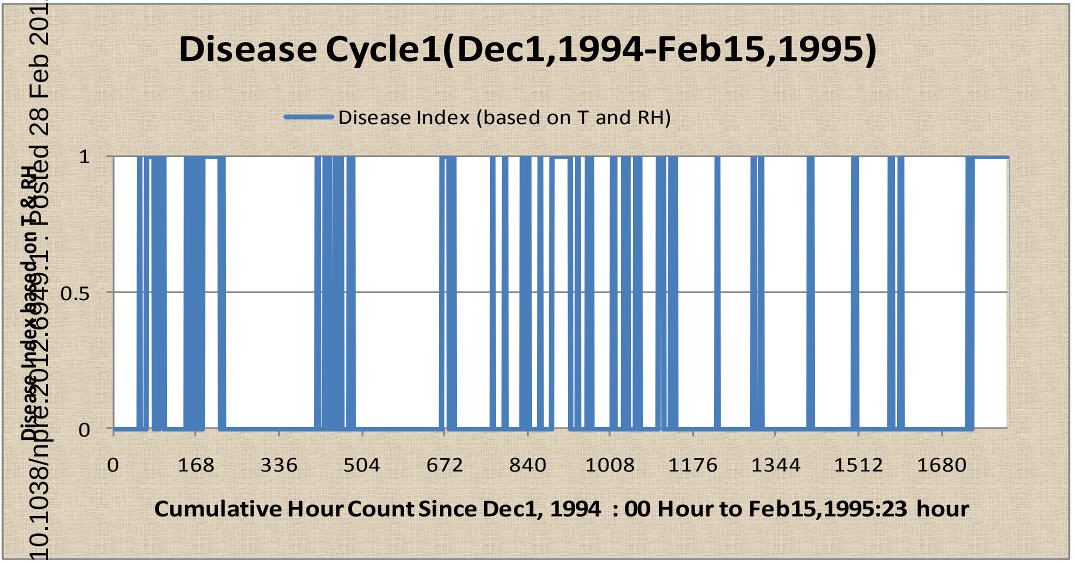


Forecast of Disease Index based on Temp & RH as well as on Mixing Ratio for Disease Cycle 1



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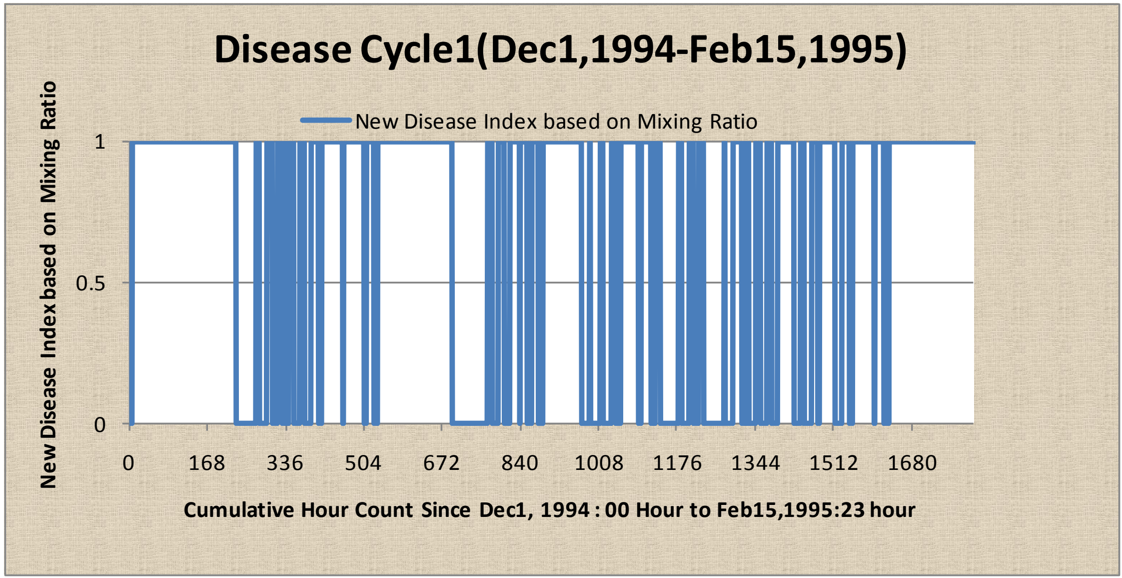
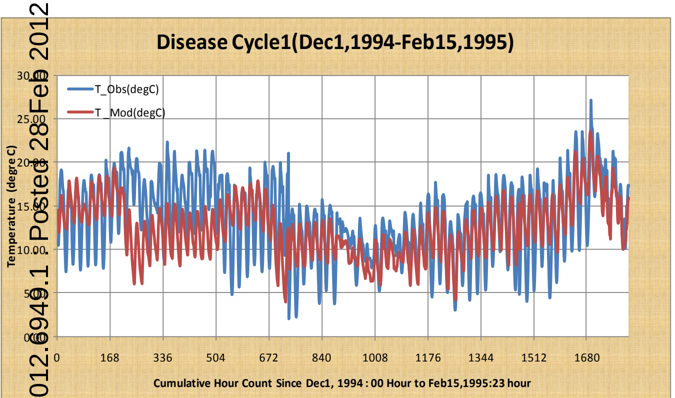
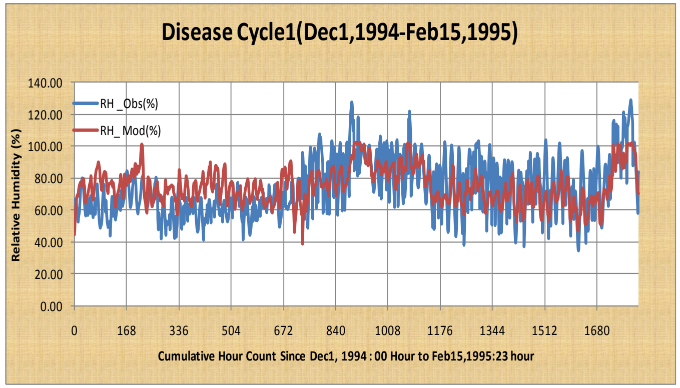
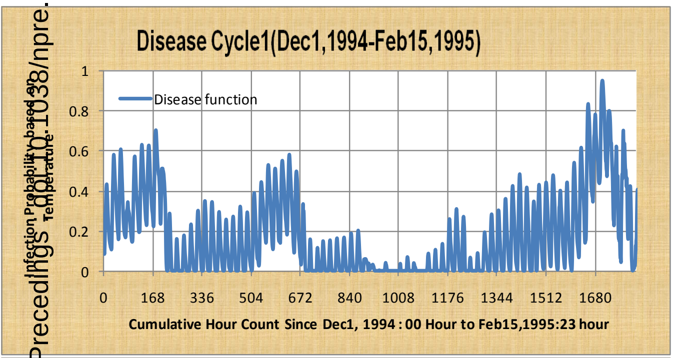
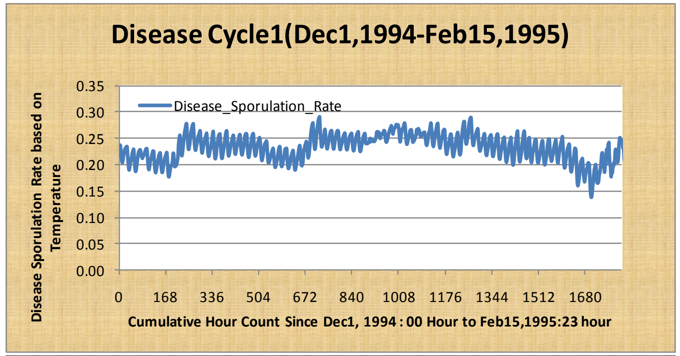


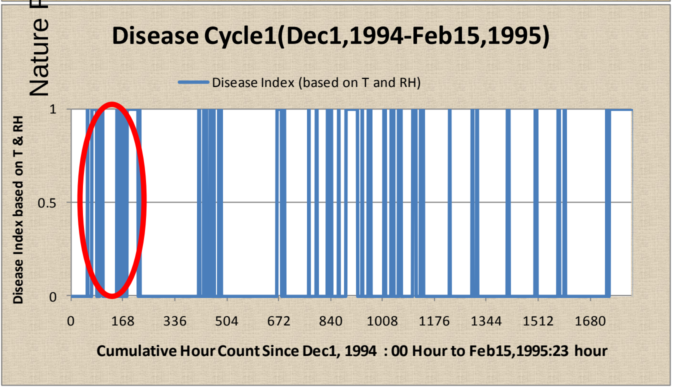
Disease Cycle 1

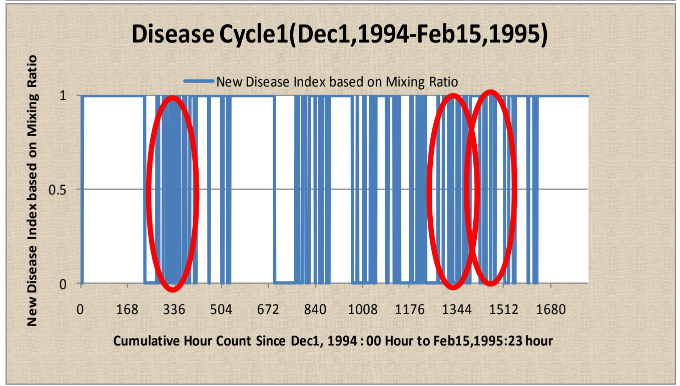






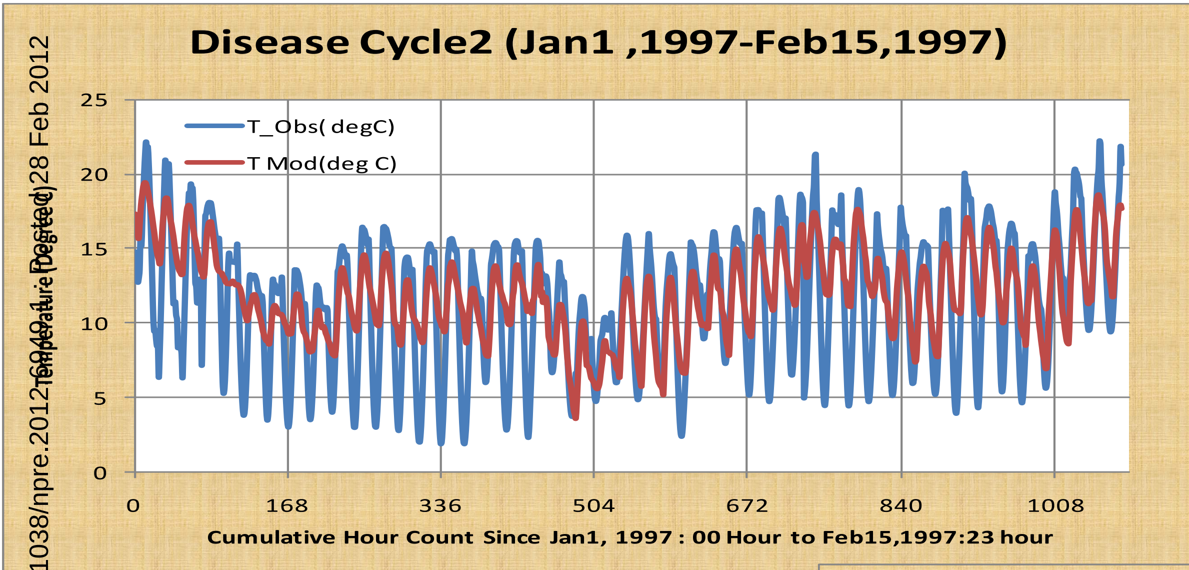






Cumulative Hour Count	Week No.
0	0
168	1
336	2
504	3
672	4
840	5
1008	6
1176	7
1344	8
1512	9
1680	10
1814	11

Disease Cycle 2

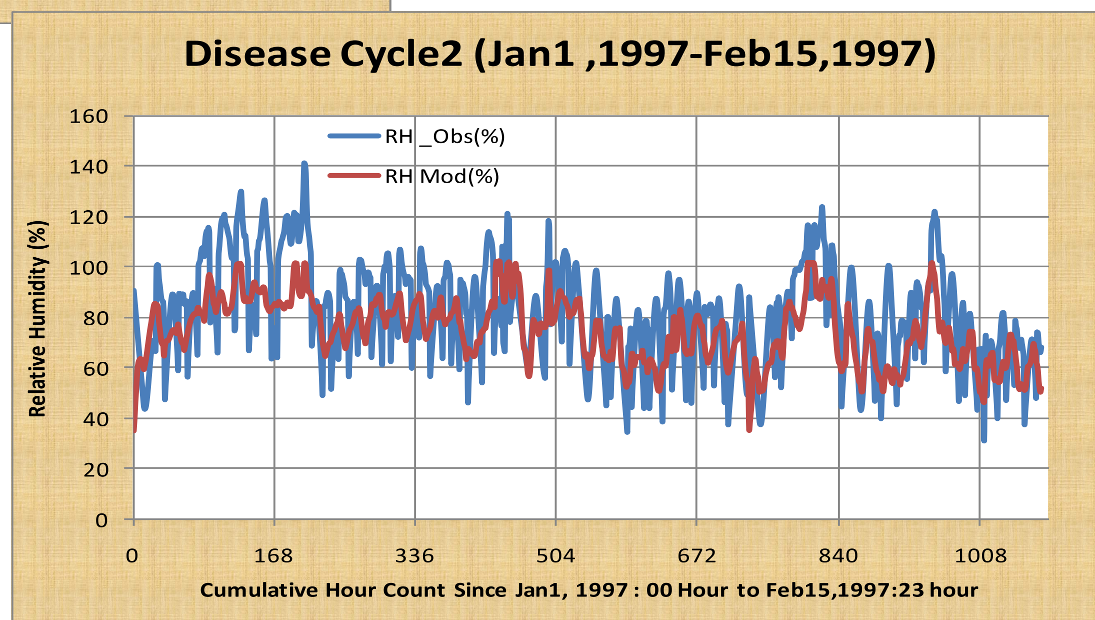


Cumulative Hour Count	Week No.
0	0
168	1
336	2
504	3
672	4
840	5
1008	6

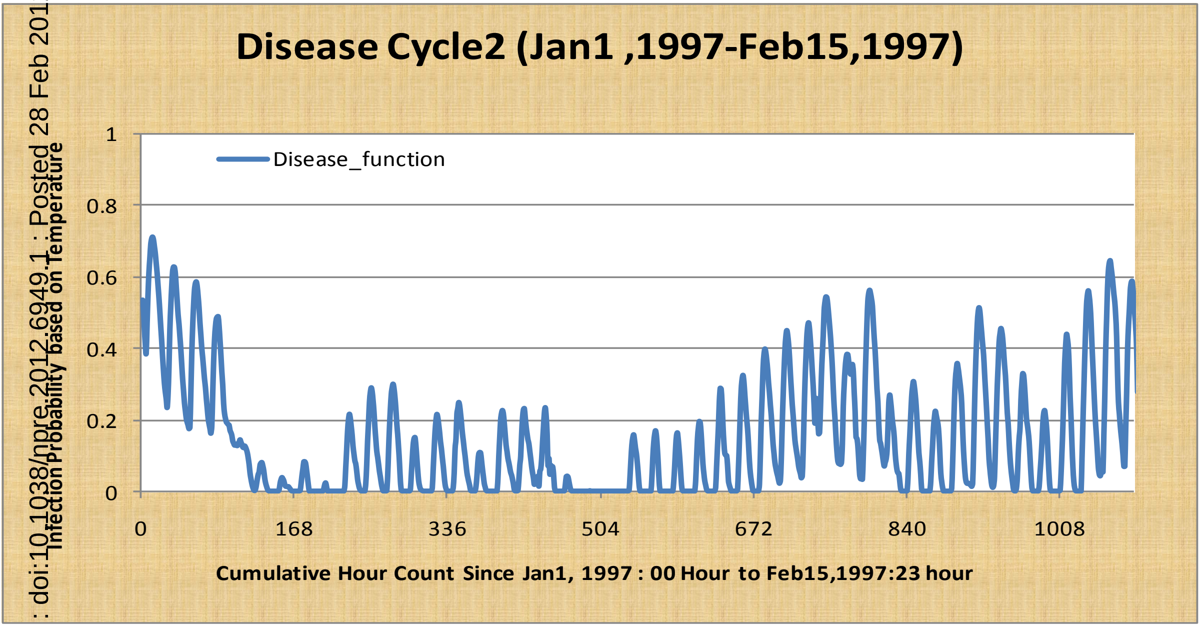
Correlations

		T_Obs(degC)	T Mod	RH _Obs(%)	RH Mod
T_Obs(degC)	Pearson Correlation	1	.768**	-.175**	-.405**
	Sig. (2-tailed)		.000	.000	.000
	N	1082	1082	1082	1082
T Mod	Pearson Correlation	.768**	1	-.212**	-.411**
	Sig. (2-tailed)	.000		.000	.000
	N	1082	1082	1082	1082
RH _Obs(%)	Pearson Correlation	-.175**	-.212**	1	.652**
	Sig. (2-tailed)	.000	.000		.000
	N	1082	1082	1082	1082
RH Mod	Pearson Correlation	-.405**	-.411**	.652**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	1082	1082	1082	1082

**. Correlation is significant at the 0.01 level (2-tailed).



Disease function & Sporulation Rate



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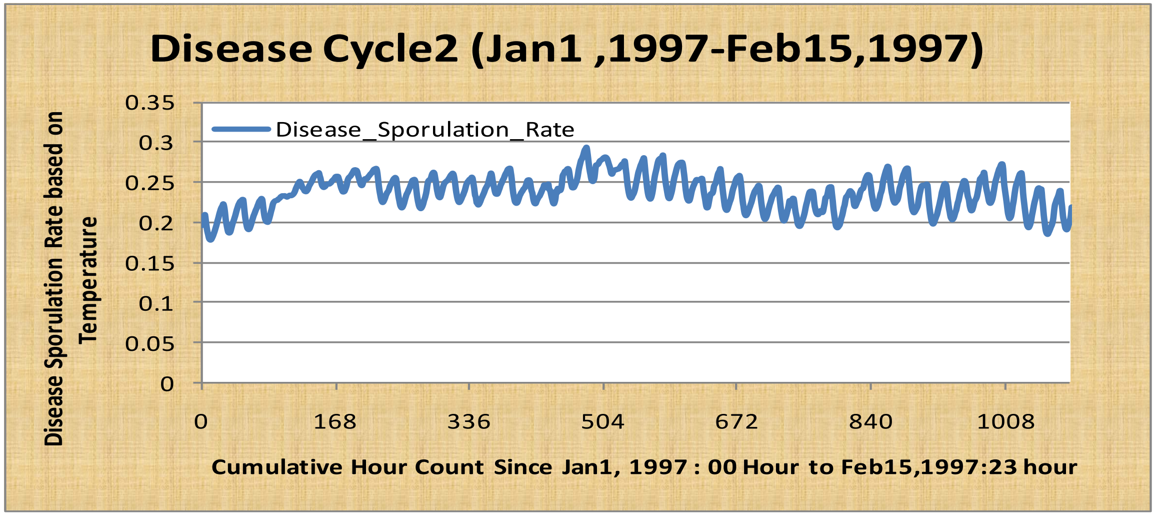
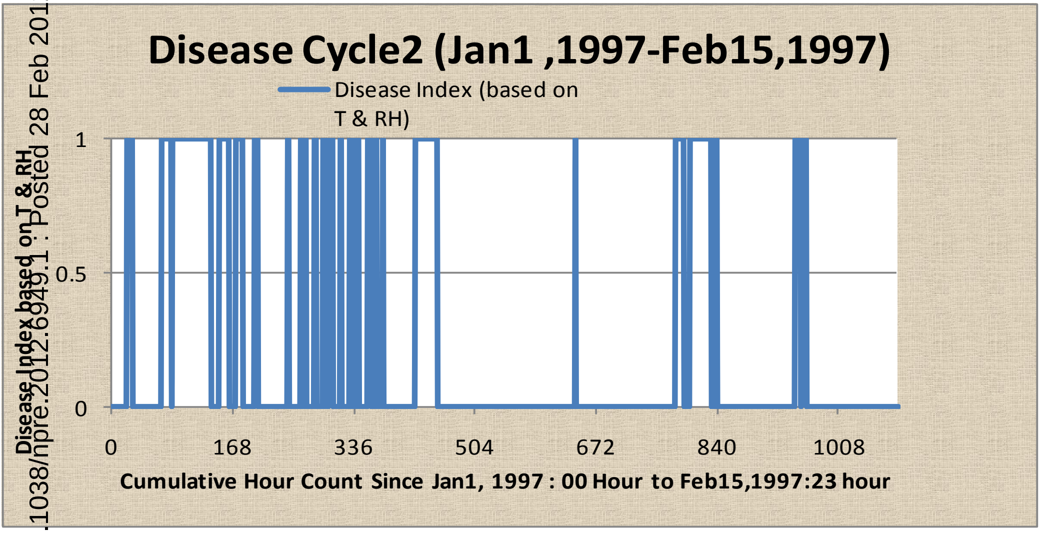
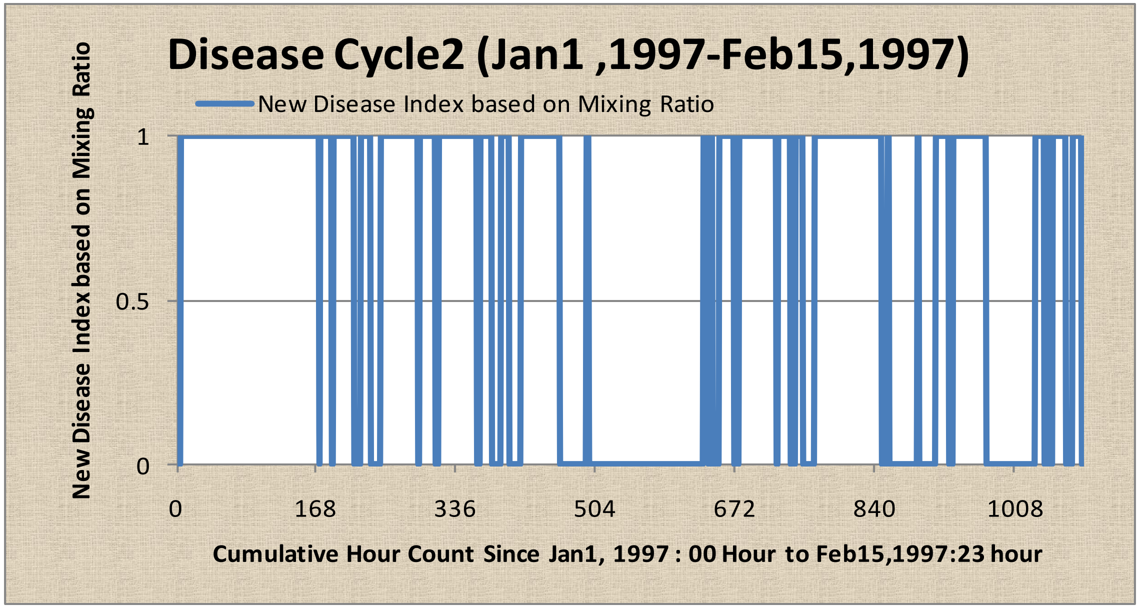


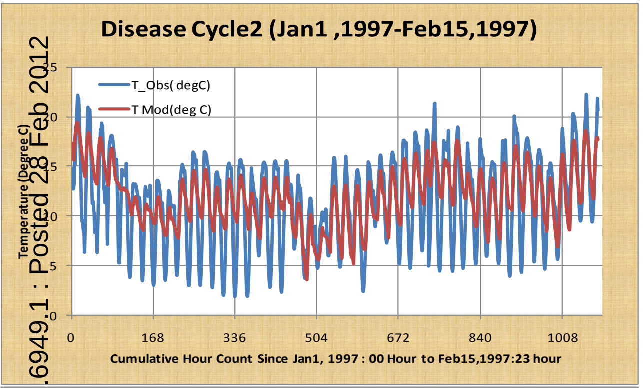
Forecast of Disease Index based on Temp & RH as well as on Mixing Ratio for Disease Cycle 2

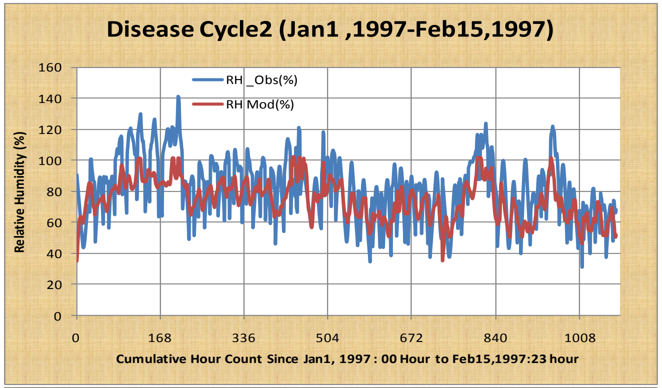


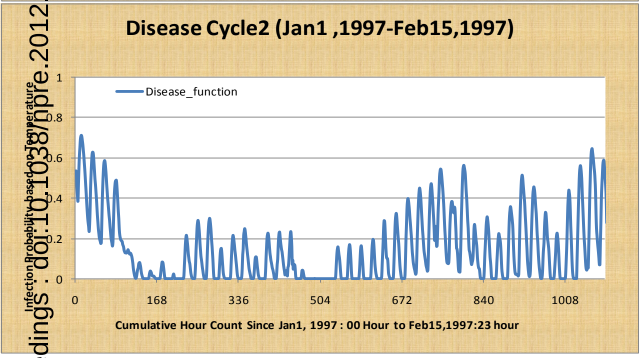
Cumulative Hour Count	Week No.
0	0
168	1
336	2
504	3
672	4
840	5
1008	6

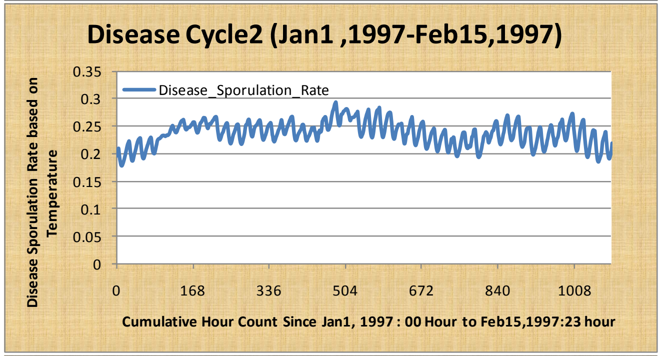


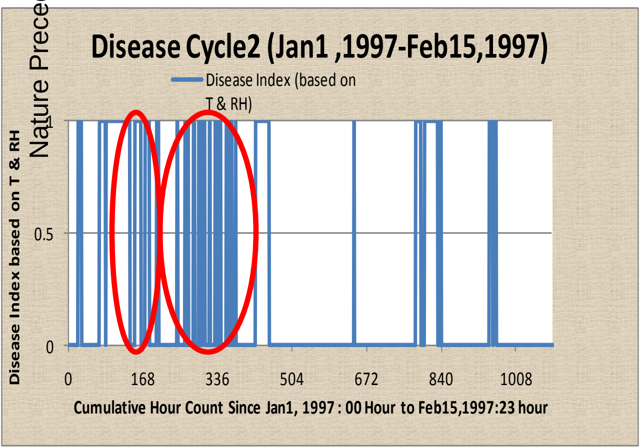
Disease Cycle 2

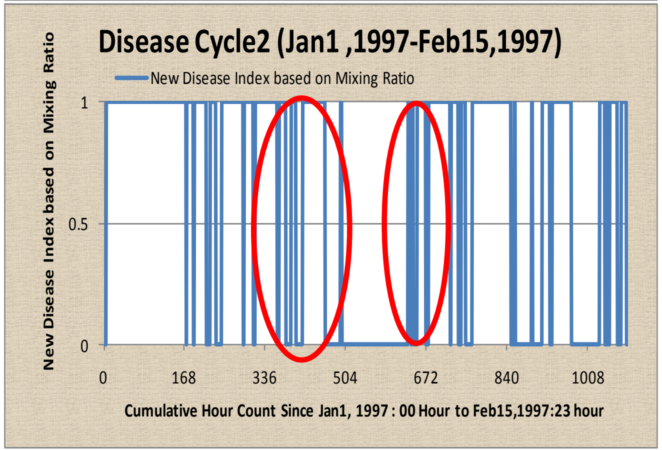












Cumulative Hour Count	Week No.
0	0
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1008	6

Forecast Skill Statistics for Disease Cycle 1

Month	Week No.	Observation	Forecast with Disease Index (T,RH)	Forecast with New Disease Index (Mixing Ration)
December	0	NO	YES	NO
	1	YES	NO	YES
	2	NO	NO	NO
	3	NO	NO	NO
January	4	YES	YES	YES
	5	YES	YES	YES
	6	NO	NO	NO
	7	YES	NO	YES
February	8	NO	NO	NO
	9	NO	NO	YES

Month	Week No.	Observation	Forecast with Disease Index (T,RH)	Forecast with New Disease Index (Mixing Ration)
December	0	NO	False Alarm	Correct Rejection
	1	YES	Miss	Hit
	2	NO	Correct Rejection	Correct Rejection
	3	NO	Correct Rejection	Correct Rejection
January	4	YES	Hit	Hit
	5	YES	Hit	Hit
	6	NO	Correct Rejection	Correct Rejection
	7	YES	Miss	Hit
February	8	NO	Correct Rejection	Correct Rejection
	9	NO	Correct Rejection	False Alarm

Forecast Type	Hit	Miss	False Alarm	Correct Rejection	Corrected Event	Expected Correct Event	Total Event
Forecast with Disease Index (T,RH)	2	2	1	5	7	6	10
Forecast with New Disease Index (Mixing Ration)	4	0	1	5	9	6	10

Forecast Type	Hit (%)	Hit Score (%)	Hit Skill Score (%)
Forecast with Disease Index (T,RH)	20	70	25
Forecast with New Disease Index (Mixing Ration)	40	90	75

Forecast Skill Statistics for Disease Cycle 2

Month	Week No.	Observation	Forecast with Disease Index (T,RH)	Forecast with New Disease Index (Mixing Ration)
January	**1**	NO	YES	NO
	2	YES	YES	NO
	3	YES	NO	YES
	4	YES	NO	YES
February	**5**	YES	YES	YES
	6	NO	YES	YES

Month	Week No.	Observation	Forecast with Disease Index (T,RH)	Forecast with New Disease Index (Mixing Ration)
January	**1**	NO	False Alarm	Correct Rejection
	2	YES	Hit	Miss
	3	YES	Miss	Hit
	4	YES	Miss	Hit
February	**5**	YES	Hit	Hit
	6	NO	False Alarm	False Alarm

Forecast Type	Hit	Miss	False Alarm	Correct Rejection	Corrected Event	Expected Correct Event	Total Event
Forecast with Disease Index (T,RH)	2	2	2	0	2	2	6
Forecast with New Disease Index (Mixing Ration)	3	1	1	1	4	2	6

Forecast Type	Hit (%)	Hit Score (%)	Hit Skill Score (%)
Forecast with Disease Index (T,RH)	33	33	0
Forecast with New Disease Index (Mixing Ration)	50	67	50

Conclusions

- Mango Powdery Mildew coupled RegCM3 output can be used as a satisfactory forecast products
- Numerical models, Regional Climate Model (RCMs) and Weather Forecast Models can be used to study the teleconnecting pattern of crop diseases
- RCMs and Weather forecast models after proper validation can well be used as a good substitute for costly AWS installation
- Mixing Ratio has a better estimation of absolute moisture content and its disease forecasting capability than the combined system of temperature & RH
- Threshold Mixing Ratio of 6.227 is proven to be a good criterion for Mango Powdery Mildew disease triggering

Contd. Conclusions

- New Approach with Mixing Ratio has proven to be a much better and novel approach as developed by US ***(Somnath Jha & P. Sinha, 2011: this work is under review in a peer reviewed international journal with minor revision).***

Climate Model & Pandemic Disease Simulation under Climate Change Scenario (Climate Hazard Sensitivity)

Acknowledgement: *The following work on Pandemic Dengue has been single handedly done as a pilot project during my tenure of employment at RMSI Pvt. Ltd, Noida, India in coordination with Pushpendra Johari, Vice President, Risk & Indurance Unit in RMSI Pvt Ltd, Noida, India. Therefore, this part of the presentation is being done on request of RMSI Pvt Ltd and in presence of Dr. Indu Jain (representative from RMSI Pvt Ltd) for your review with the limitation that the model code will not be displayed or answered*

Pandemic Dengue Disease Simulation for Doubling of Carbon Dioxide IPCC Future Scenario across the Globe

Contents

Introduction: Why to Model Pandemic Dengue?

Nature Precedings : doi:10.1038/npre.2012.6949.1 : Posted 28 Feb 2012

■ *Pandemic Dengue Disease*

- *Dengue (Dengue Fever, Dengue Haemorrhagic Fever, Dengue Shock Syndrome)*
- *Causal Vector Mosquito (Aedes aegypti) which has a survival limit in northern hemisphere till the Jan 10^0 C isotherm & in southern hemisphere till the Jul 10^0 C isotherm*
- *Tropical distribution*
- *No vaccine available*
- *Least explored complex disease dynamics due to tropical distribution*
- *Four closely related DENV virus serotypes available*
- *Special feature of ADE (Antibody-dependent enhancement) due to no cross protection against serotypes*

Review: Linear correlation coefficients between Dengue Larval anomaly to anomalies of various climatic variables

- **Linear correlation coefficient between larval anomaly & temperature anomaly is high & positive for west Africa, Brazil, Argentina, central America, SE Asia, India & East Asia whereas the same is low & negative (value being in the range of -0.3 to -0.1)**

- **Linear correlation coefficient between larval anomaly & precipitation anomaly is high & positive (0.5 to 0.7) for Australia, west & peninsular India, western & southern region of Africa whereas the same for east Asia is negative & low (-0.3 to -0.1)**

- **Linear correlation coefficient between larval anomaly & relative humidity anomaly is positive & low (0.1 to 0.3) for Australia, SE Asia, India & west Africa while the same is the highest value (0.7 to 1) for S. America**

- **Linear correlation coefficient between larval anomaly & cloud cover anomaly is positive & low (0.1 to 0.3) for Australia, India & west & south America**

Source: ***Hopp, M.J. & Foley, J.A. (2003): Worldwide fluctuations in dengue fever cases related to climate variability. Climate Research, 25, 85-94***

- **The mean development period (from egg to adult) is reduced by 2.1 days as the temperature is increased by 5 degree C from 20 to 25 degree C while the same is reduced by 3.7 days as the temperature increased by 5 degree from 25 to 30 degree C for *Aedes aegypti***

Source: ***Surtees, G., Hill, M.N., & Broadfoot, J. (2683c). Survival & development of a tropical mosquito, Aedes aegypti, in Southern England. From Arbovirus Epidemiology Unit, Microbiological Research Establishment, Porton Down, Salisbury, England***

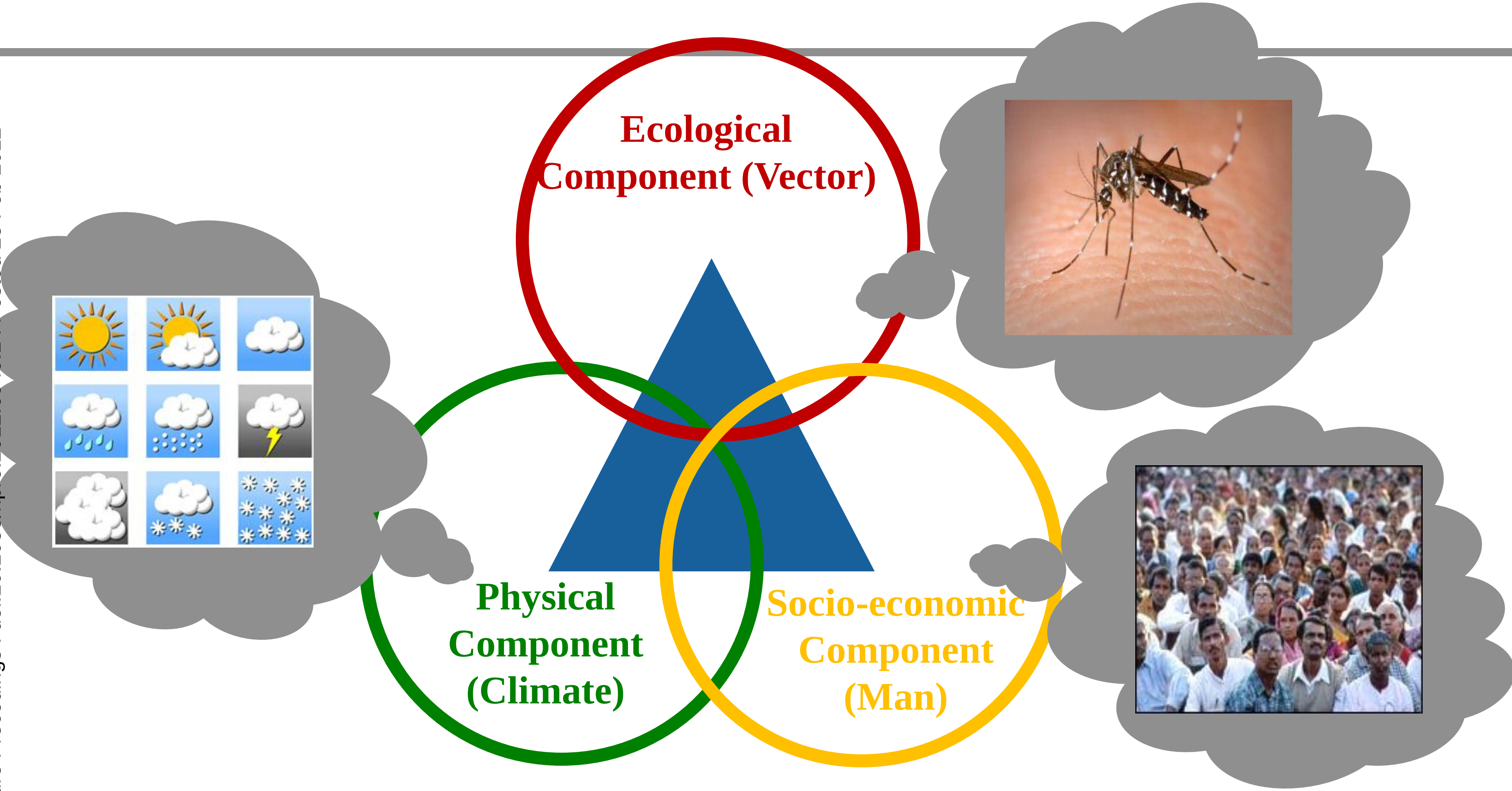
Review: Seasonal variability of Adult female index

- **The Adult Female Index (A.F.I.) is one main driver for Dengue transmission. But the AFI has a typical global pattern of change in various seasons**
- **In January, maximum AFI is found in some portion of Brazil, SE Asia, Northern Australia while the minimum AFI is found in Central African Sahel region, Lower Gangetic plain region of India**
- **In April, the maximum AFI is the same as the trend or pattern during the January**
- **In July, the maximum AFI is found in the whole of central & east India, east Asia, SE Asia, a portion of Brazil whereas the minimum AFI is found in Northern Australia**

Source:* *Hopp, M.J. & Foley, J.A. (2003): Worldwide fluctuations in dengue fever cases related to climate variability. Climate Research, 25, 85-94

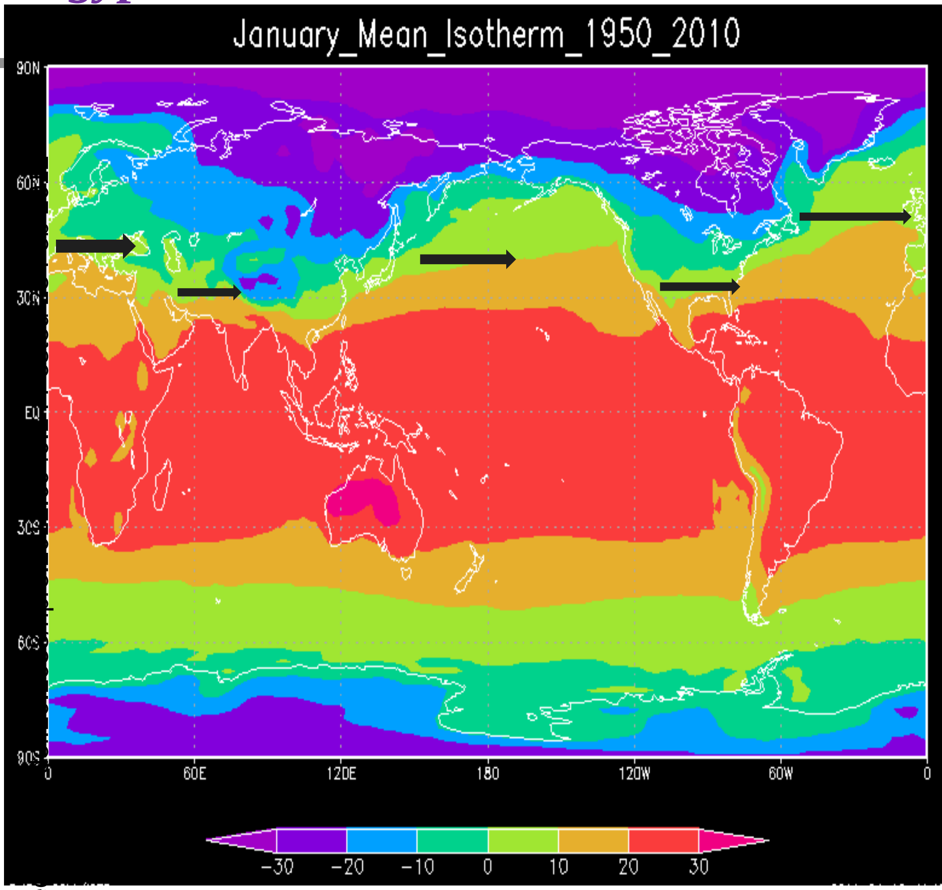
- **In October, the maximum AFI is found in India, especially eastern part of the country India including peninsular portion, SE Asia & portion of Brazil whereas the minimum AFI is found along the Gulf coast of North America & east China coast**

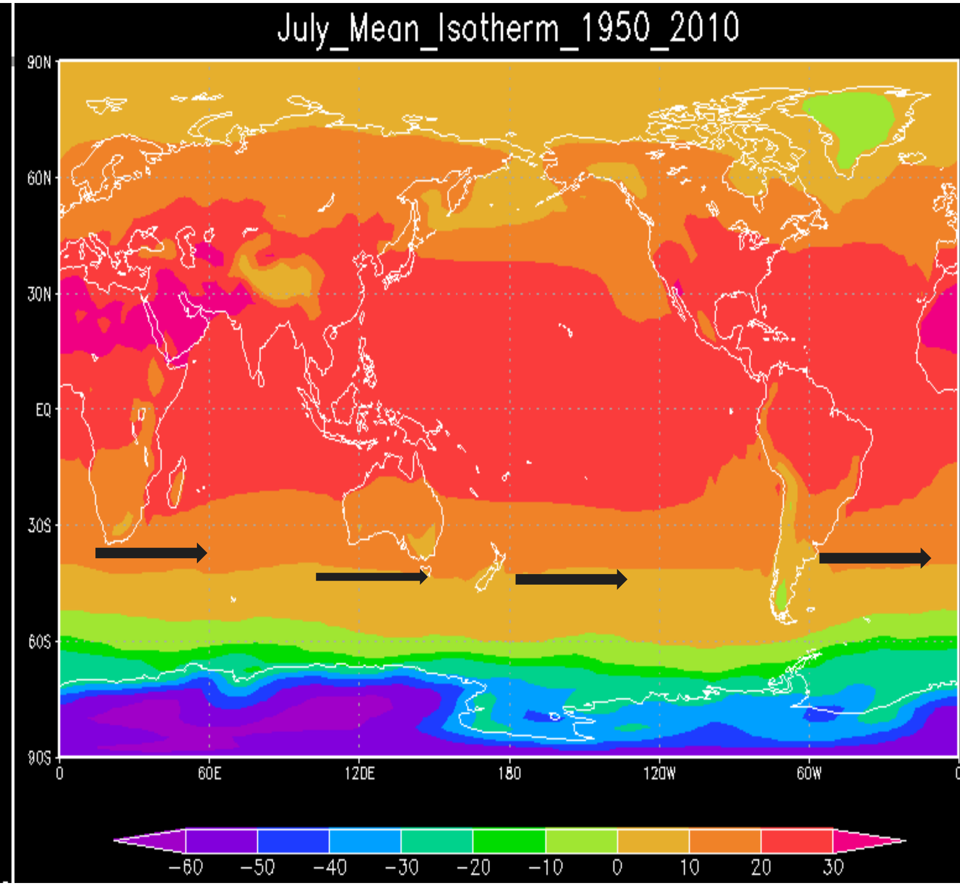
Review: Ideal Pandemic Dengue Model Physics have Three Components



Ideal Pandemic Dengue Model Physics should contain proper representation of three components (viz., Physical, Ecological & Socio-economic component)

Physical component of Dengue Distribution: Geographical Survival Limit of Aedes aegypti





Nature Pre

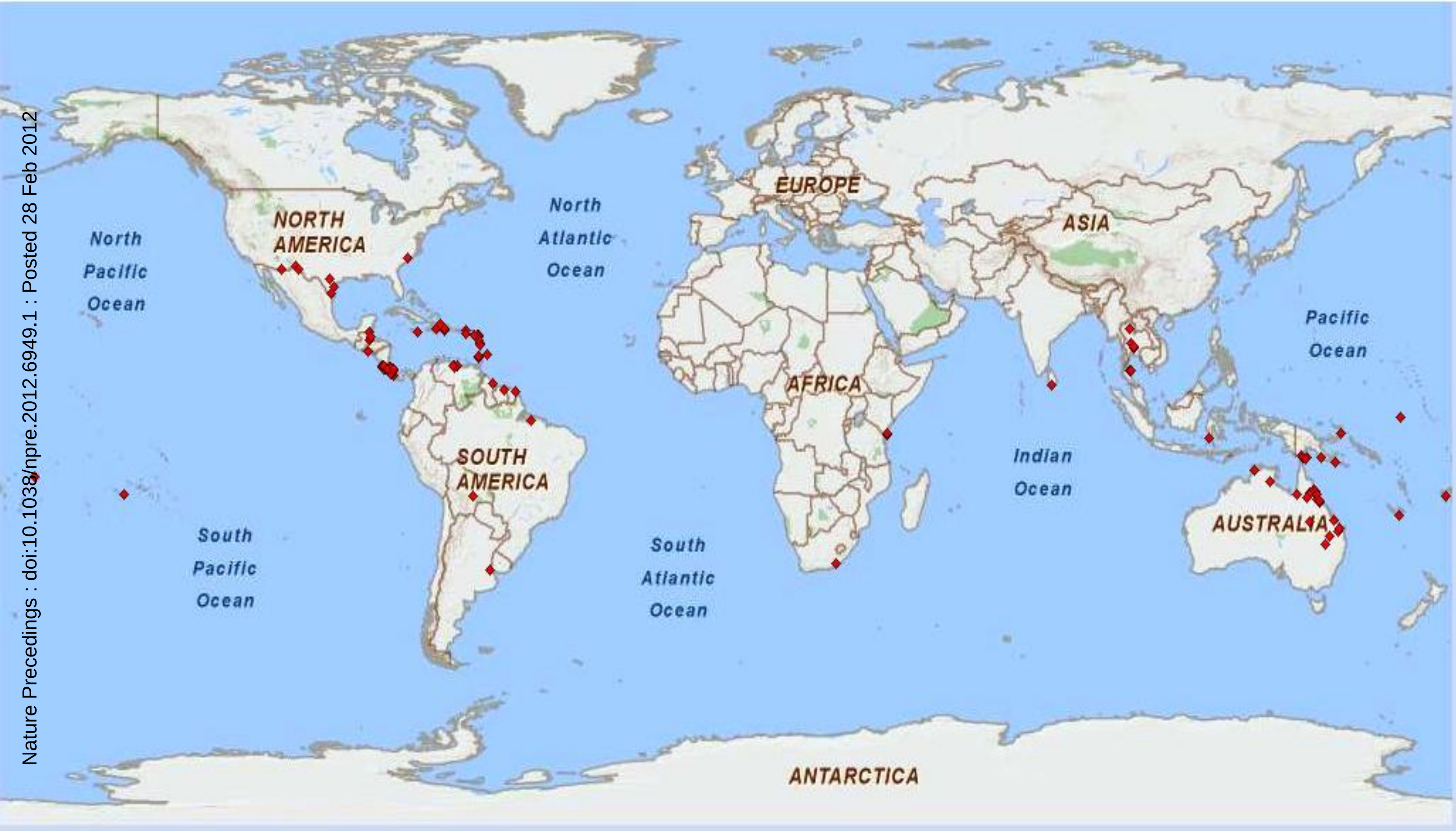
January 10 ^{0} C Isotherm is the northern most limit of survivorship for *Aedes aegypti*

July 10 ^{0} C Isotherm is the southern most limit of survivorship for *Aedes aegypti*

The above temperature maps have been made from ESRL website using surface air temperature data for the month of January and July respectively for a climatic period of 1950-2010 (http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl)

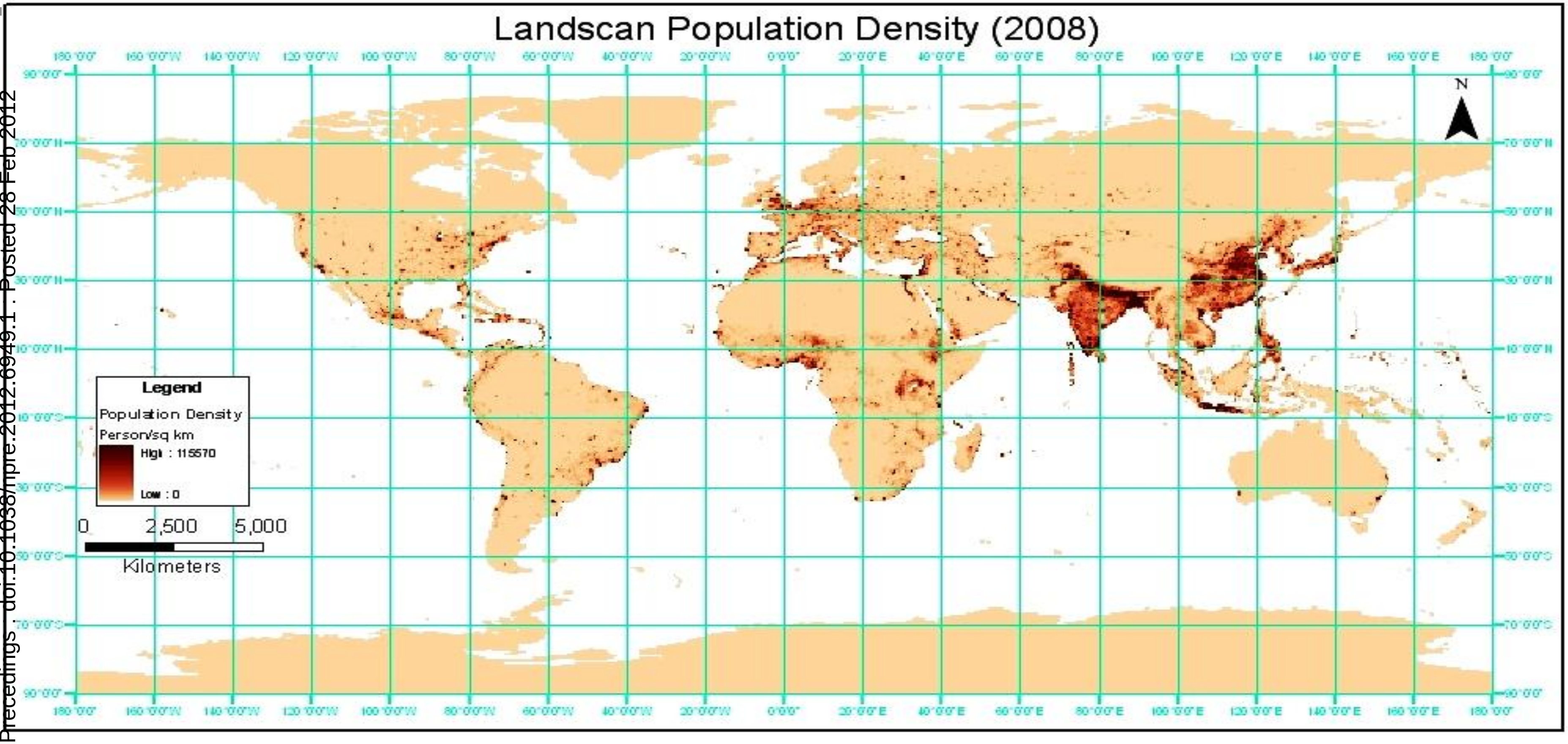
The black arrow s show the 10^{0} C isotherms

Ecological Component of Dengue Distribution: Aedes aegypti Distribution Map (red points on the map) from 1950 to 2010



Source: http://mosquitomap.nhm.ku.edu/mosquitomap/

Socio-economic Component of Dengue Distribution: Population Density & Urban Clusters



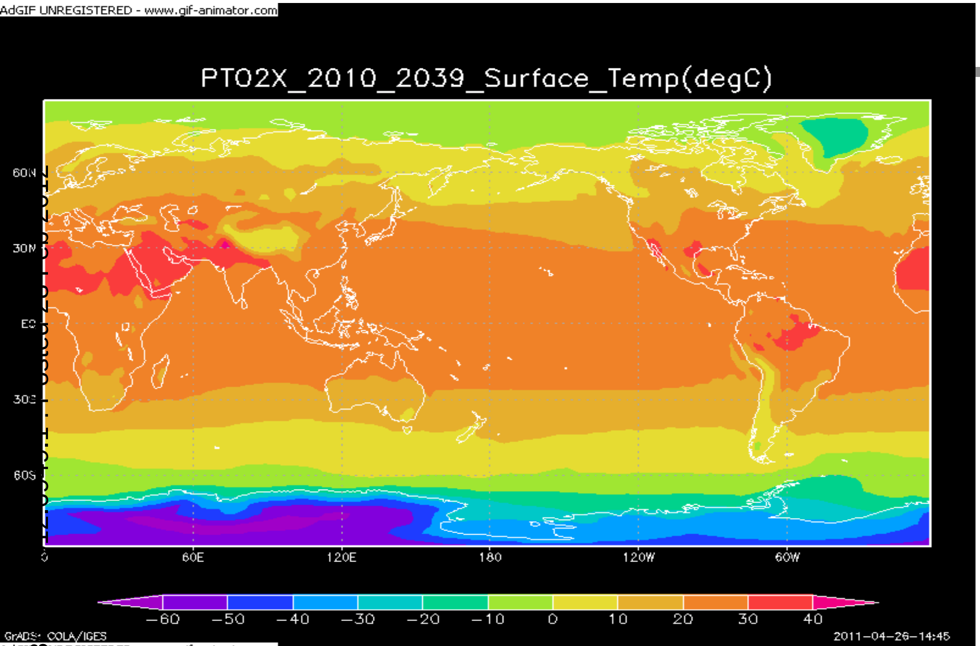
IPCC Fourth Assessment Scenario(2007)

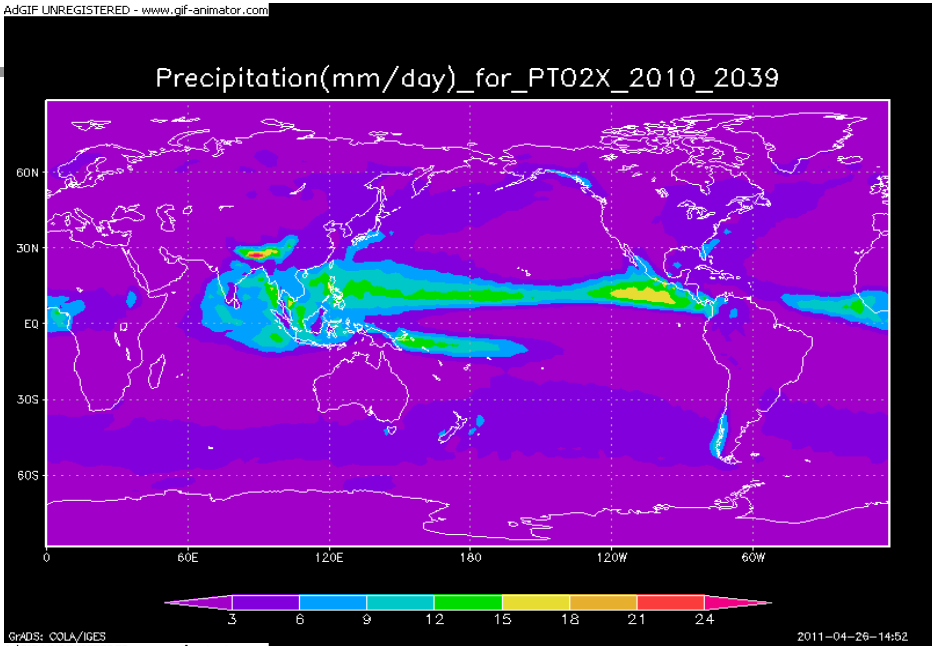
Why to chose the Doubling Of Carbon Dioxide Scenario ?

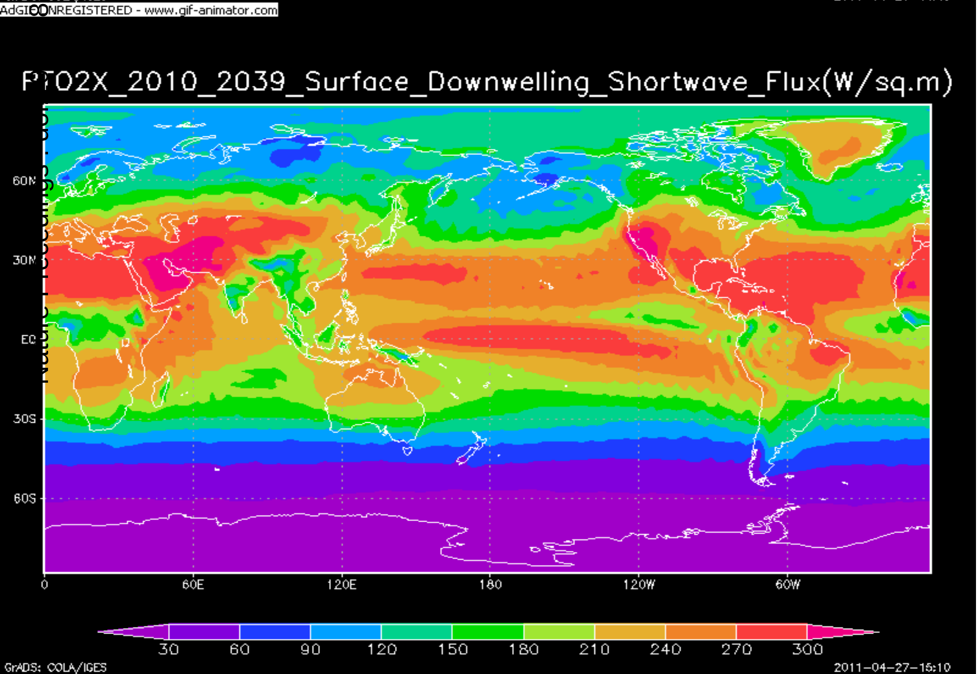
IPCC Scenario Dataset Selection

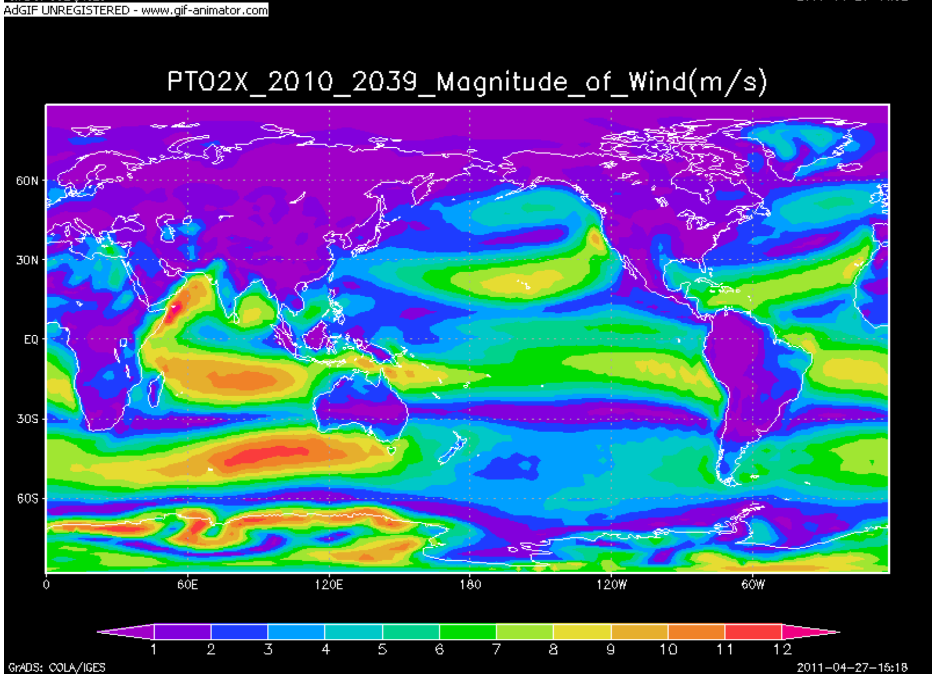
- Scenario Data selected 1PTO2X (30b) for Thirty year averages
    - Short term (2010-2039)
    - Mid term (2040-2069)
    - Long term (2070-2099)
- Non-SRES Scenario: 1PTO2X (1% to double)
    - Experiments run with greenhouse gasses increasing from pre-industrial levels at a rate of 1% per year until the concentration has doubled and held constant thereafter
- Model Name: ECHAM5/MPI-OM (max Plank Institute of Germany)
- Variables taken as input to Pandemic Dengue algorithm
    - Precipitation flux
    - Surface air temperature
    - GDD computed from the air temperature
- Resolution of input data: T63, L31

Future Scenario as par 1PTO2X for Short, Mid & Long term



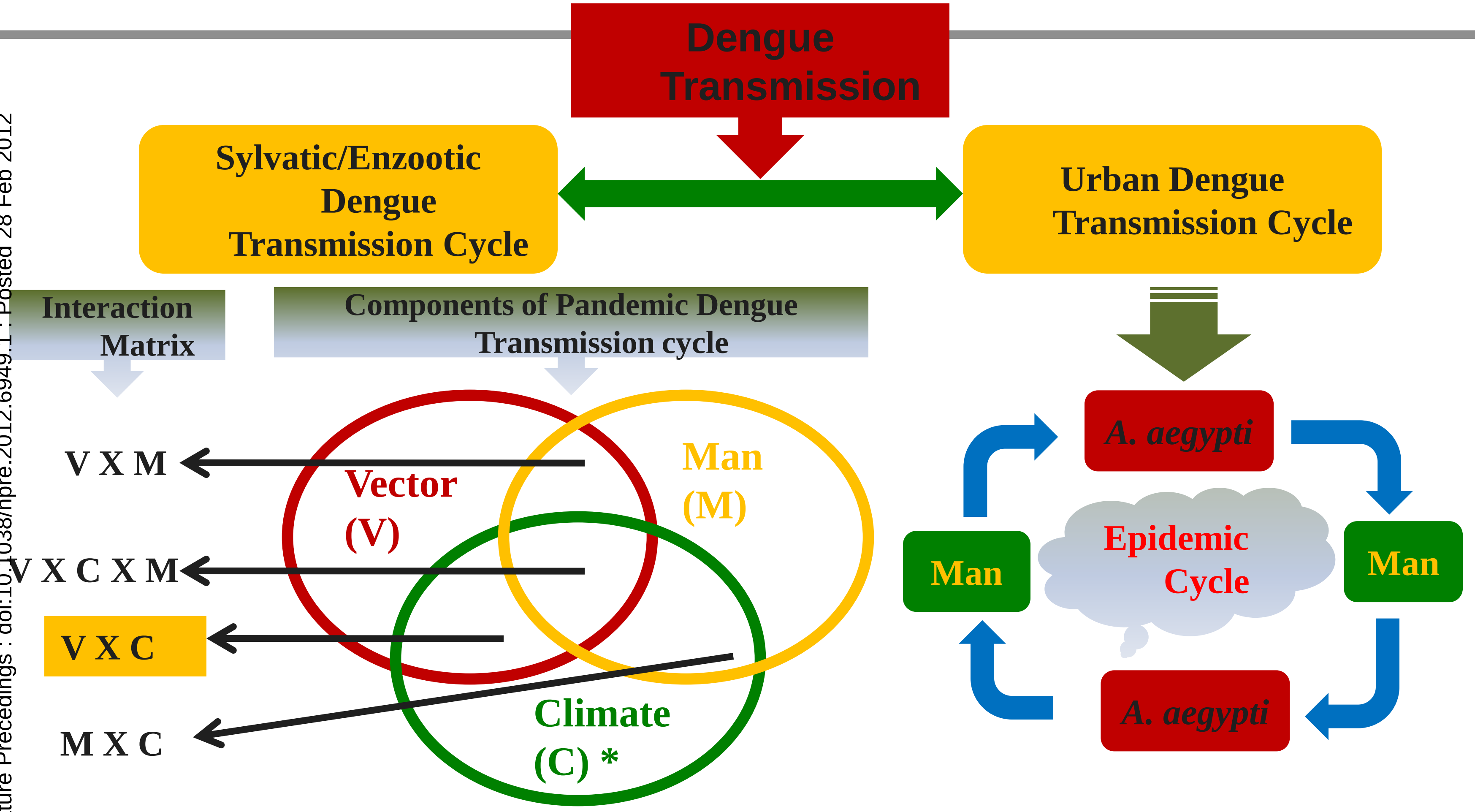






Pandemic Dengue Algorithm (Prototype)

Climate & Vector Interaction: The Most Important Component to Potential Pandemic Dengue Outbreak



***Important:** Climate (C)* controls the natural survivorship & development of life cycle of the Dengue Vector (V), Aedes aegypti. Therefore, Climate & Vector Interaction (V X C) is the most important component of Potential pandemic dengue outbreak. The present algorithm deals with this (V X C) interaction only.*

Pandemic Dengue Algorithm (prototype)

- *The Pandemic dengue algorithm (prototype) is based on the Decision-hierarchy rules*

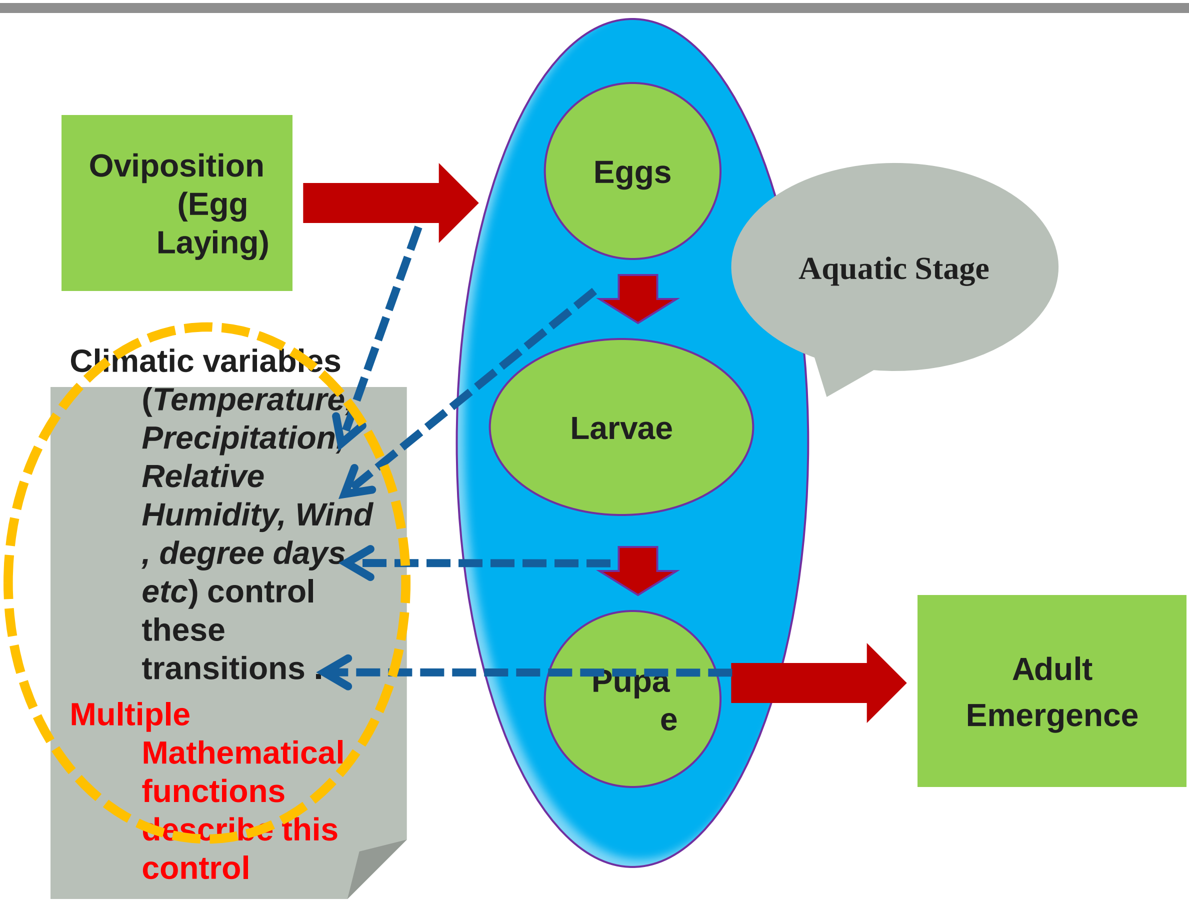
- *It is primarily based on the climatic variables embedded on the decision tree of the pandemic dengue disease causal vector Aedes aegypti*

- *The climate & the vector interaction flow is an important factor for generating favourable disease condition*

- *The favourable climate for the continuation of the life-cycle of dengue causal vector Aedes aegypti has been analyzed through the decision tree*

- *Thus the output of the algorithm depicts the potential dengue favouring climatic condition & the maximum likelihood of the potential disease spread in presence of the vector*

Pandemic Dengue Algorithm (prototype) is based on the interaction of climate-Life cycle of Aedes aegypti



Survivorship & Cumulative Development of Aedes mosquito governed by climatic control:

Hatching requires { Temp > =13 ^{0}C & water > 10mm}

Emergence requires Temperature > 18 ^{0} C

Oviposition requires {Temp > 22^0 C & Water > 10mm}

Source:

Hopp MJ and Foley J. Global-scale Relationships Between Climate and the Dengue Fever Vector Aedes Aegypti. *Climate Change*. 2001; 48: 441-463

Schematic diagram of the decision tree of climate dependent phase transition of the life cycle of dengue vector mosquito *Aedes aegypti*

Pandemic Dengue Algorithm (prototype)

- ***Important Three phases of Dengue Mosquito Lifecycle***
  - *Emergence (Adult or Gonotrophic)*
  - *Oviposition (Egg Laying)*
  - *Hatching (Larva phase)*

- ***Inputs to Pandemic Dengue Algorithm are***
  - *Temperature*
  - *Growing degree day*
  - *Precipitation*

Dataset used in Pandemic Dengue Algorithm:

- ***CRU Ts 3.0 dataset for***
    - ***Daily Mean Temperature***
    - ***Precipitation***

- ***Growing degree day calculated from the daily mean temperature & base temperature of phases of life cycle of Aedes aegypti***

Phases of Lifecycle wise Pandemic Dengue Simulation

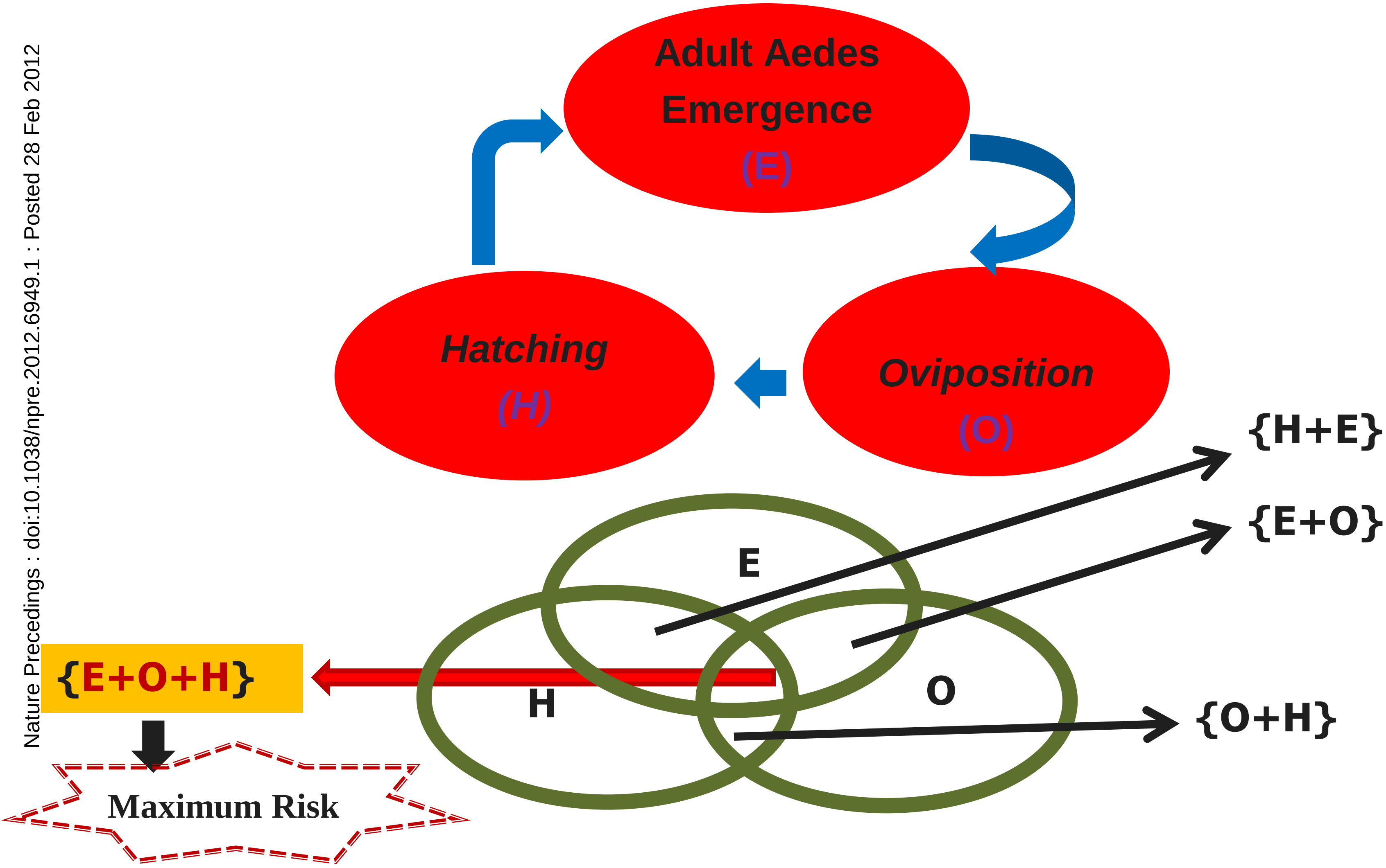
➢ ***Emergence or Adult (E)***

➢ ***Oviposition or Egg Laying (O)***

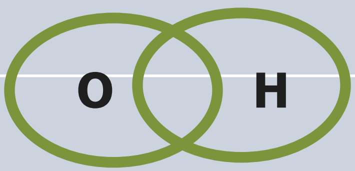
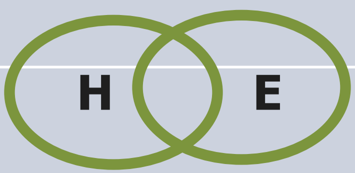
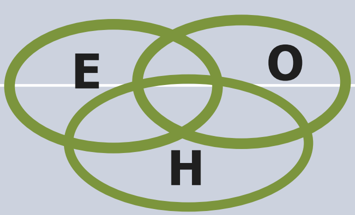
➢ ***Hatching or Larva phase (H)***

Algorithm made in GrADS script programming and run in OpenGrADS

Pandemic Dengue Transmission Phase Cycle as depicted in the algorithm

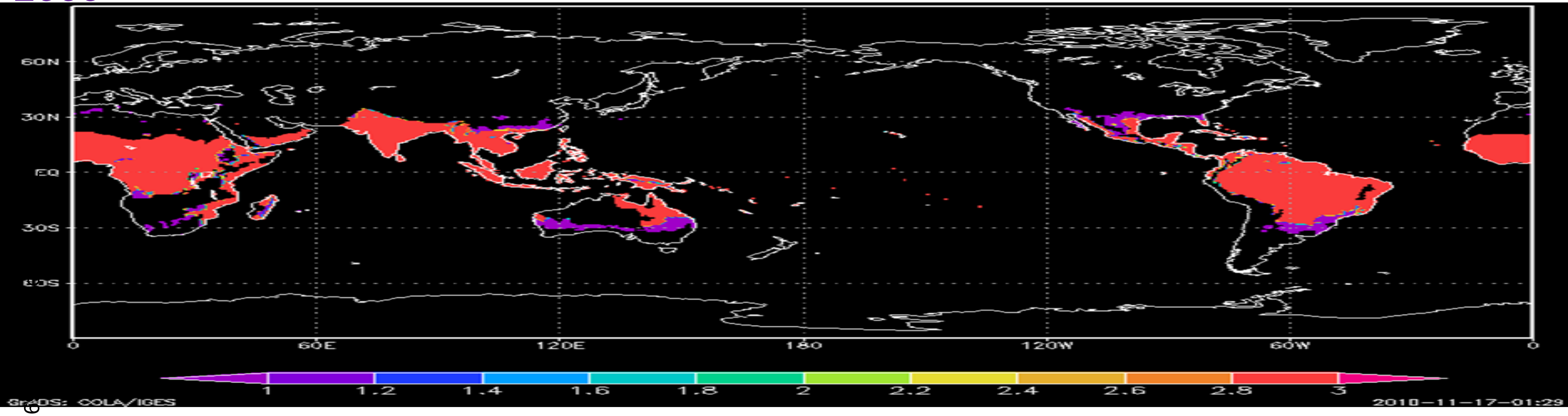


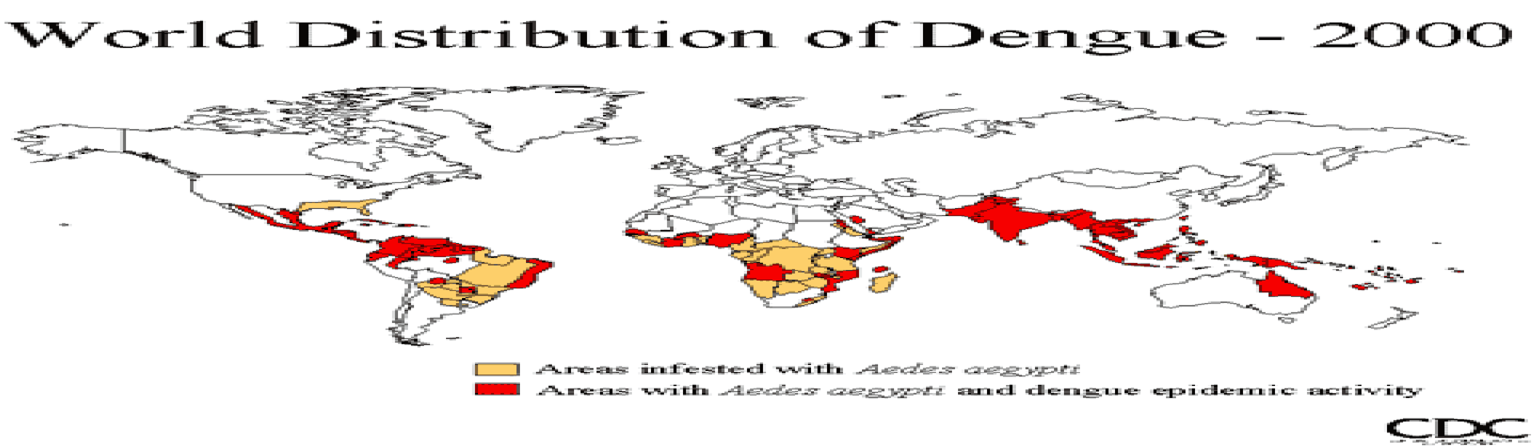
Matrix of Interaction between Climate & Phases of Life-Cycle of Aedes aegypti as depicted in the algorithm

Diagram	Phases of Aedes Life Cycle	Status
	{E+O}= both YES	Favourable for Adult Emergence & Oviposition
	{E=Yes, O=No}	Favourable for Adult Emergence but not congenial for Oviposition
	{O+H}= both YES	Favourable for Oviposition & Hatching
	{O=Yes, H=No}	Favourable for Oviposition but not congenial for Hatching
	{H+E}= both YES	Favourable for Hatching & Adult Emergence
	{H=Yes, E=No}	Favourable for Hatching but not congenial for Emergence
	{E+O+H}=all YES	Favourable for the whole lifecycle of *Aedes* (Emergence, Oviposition & Hatching). These are the regions with maximum risk

Validation

Validation: Pandemic Dengue Algorithm output Vs Observed Dengue Incidence for 2000



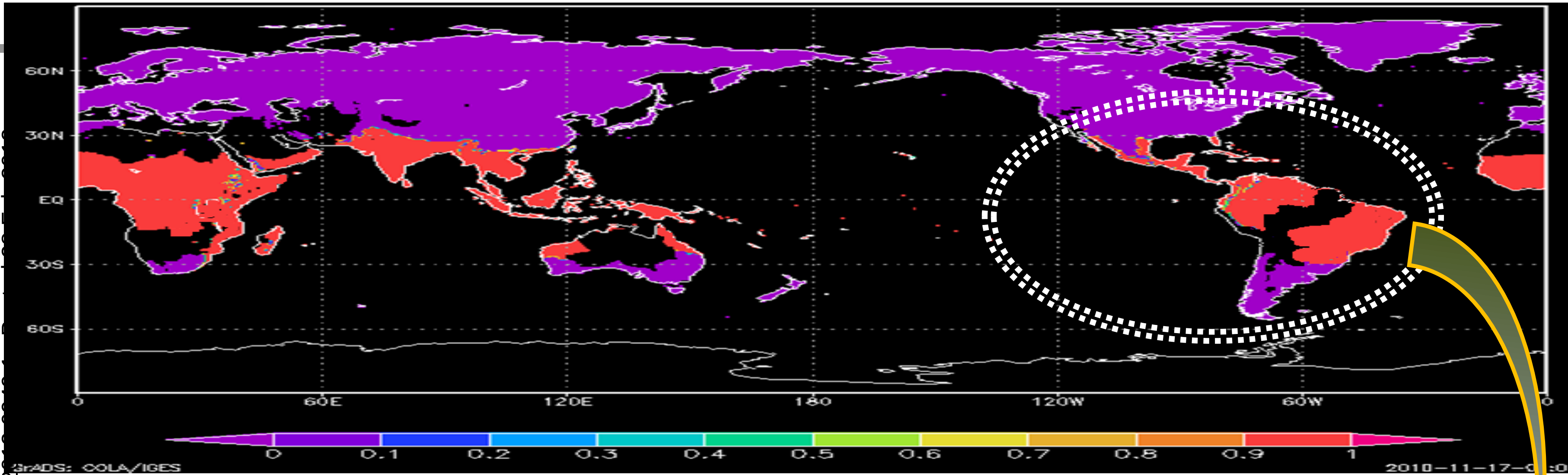


Source: http://www.cdc.gov/ncidod/dvbid/dengmap.htm

The above panel is the Pandemic Dengue Algorithm output for the year 2000 where the red colour distribution (value 3) is the potential dengue prone zone

The bottom panel is the world distribution of dengue 2000 taken from www.cdc.gov website where the zones of yellow & red both colours together show the dengue prone zone in 2000

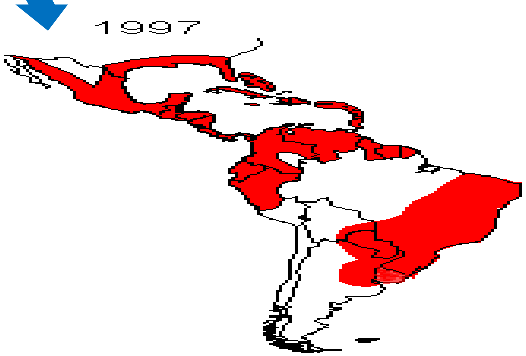
Validation: Pandemic Dengue Algorithm output Vs Observed Dengue Incidence for 1997



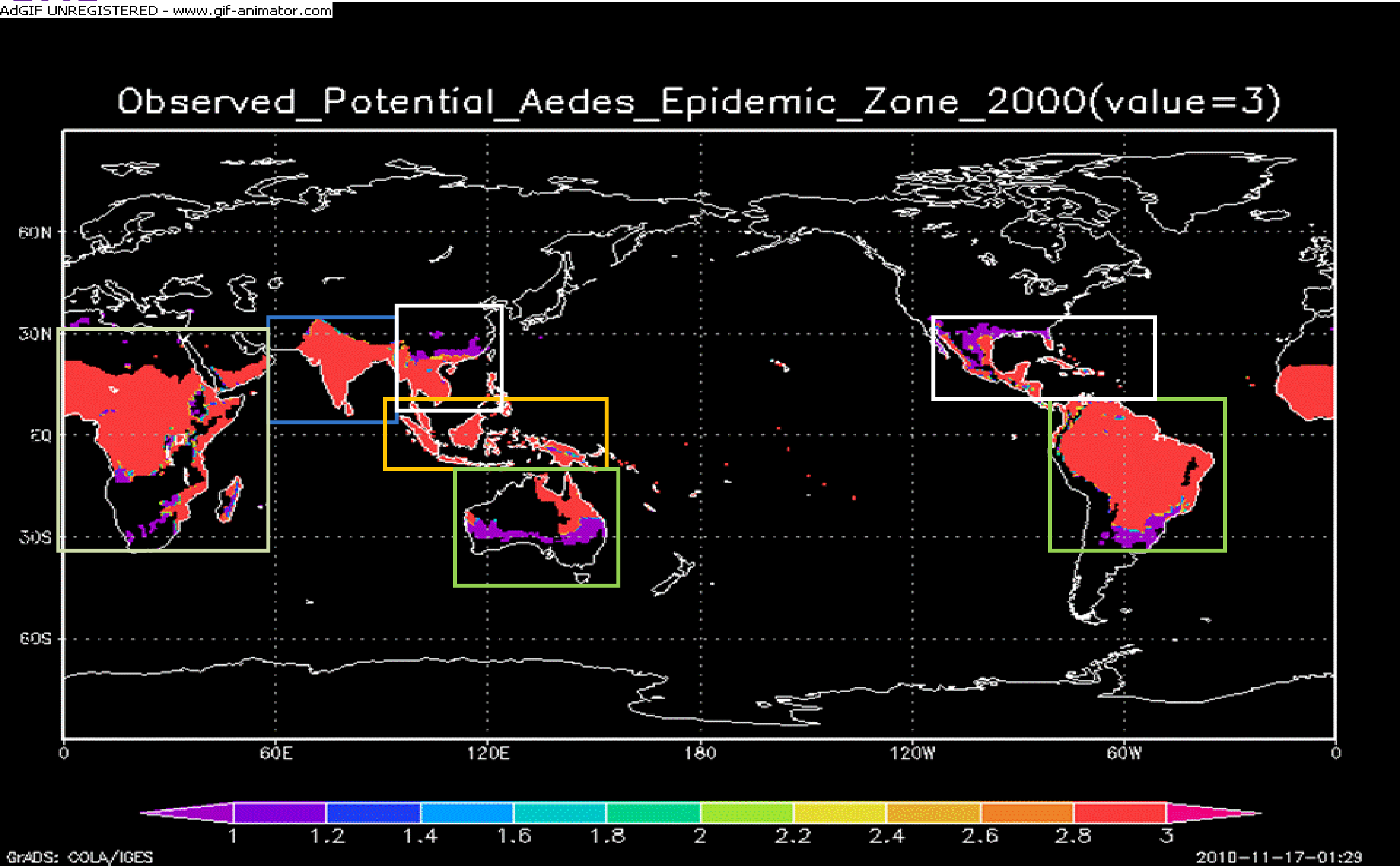
Pandemic dengue prone region with this color (value 1)

The above panel shows Pandemic Dengue Algorithm output for the year 1997 & the bottom panel shows the observed dengue events as occurred in South & Central America in 1997

Source: **Courtesy from: http://sprojects.mmi.mcgill.ca/tropmed/disease/dengue/trends.htm (taken from the Figure 1)**



Validation: Pandemic Dengue Algorithm Output for the year 2000, 2001, 2002

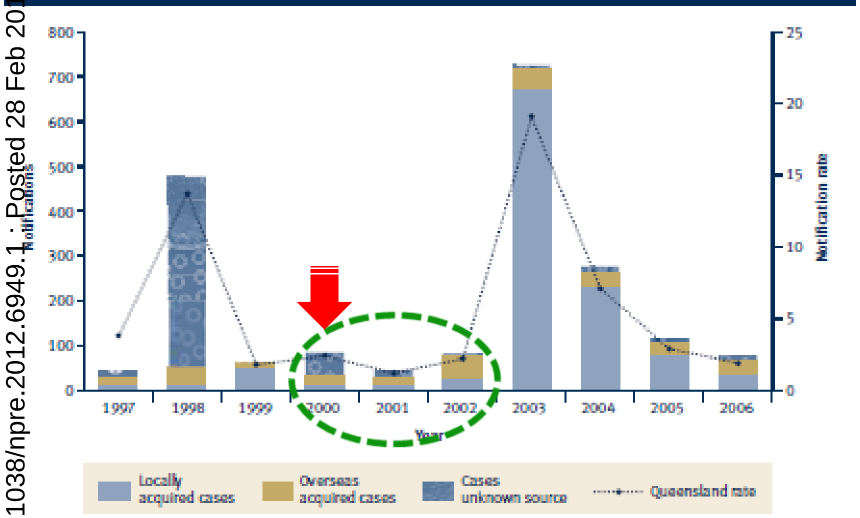


Pandemic dengue prone region with this color (value 3)

Validation: Observed Dengue Epidemics

1. Australia *

Figure 7.2 Dengue notifications by acquisition source, with dengue notification rate per 100,000 population, Queensland, 1997–2006



Source of 1. Australia: Notifiable Disease Report 2002-2006 (*accessed in www.health.qld.gov.au/ph/documents/cdb/notif_dis_reporth.pdf*)

*** Dengue & Mosquito vector are found in Australia only in Queensland (source: Gurugama, P., Garg, P., Perera, J., Wijewickrama, A., & Seneviratne, S. (2010). Dengue Viral Infections. Indian J. Dermatol, Jan-Mar: 55(1): 68-78. doi: [10.4103/0019-5154.60357](10.4103/0019-5154.60357))**

2. Brazil

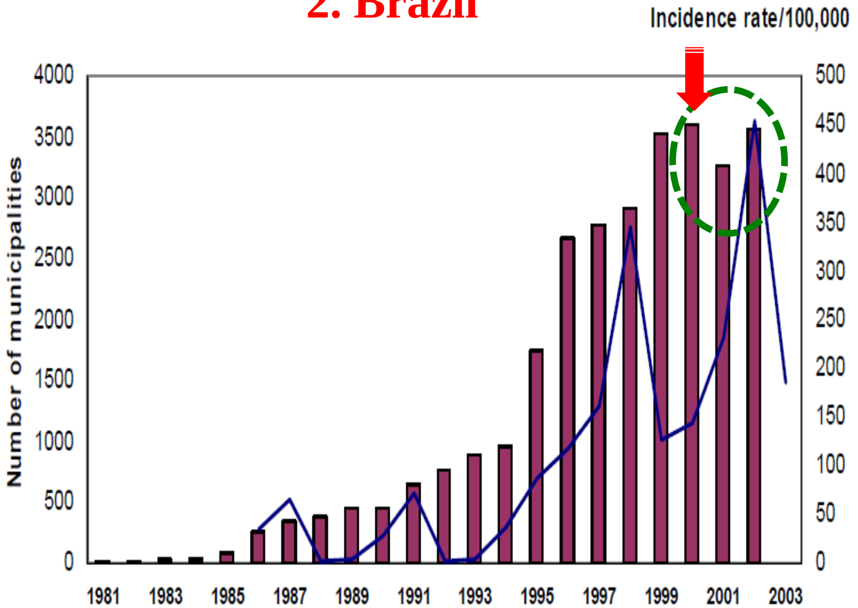
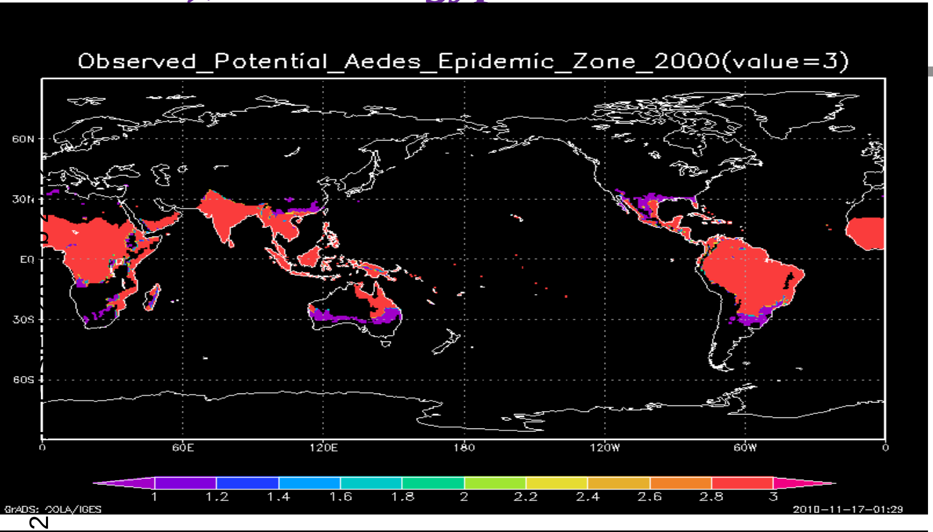
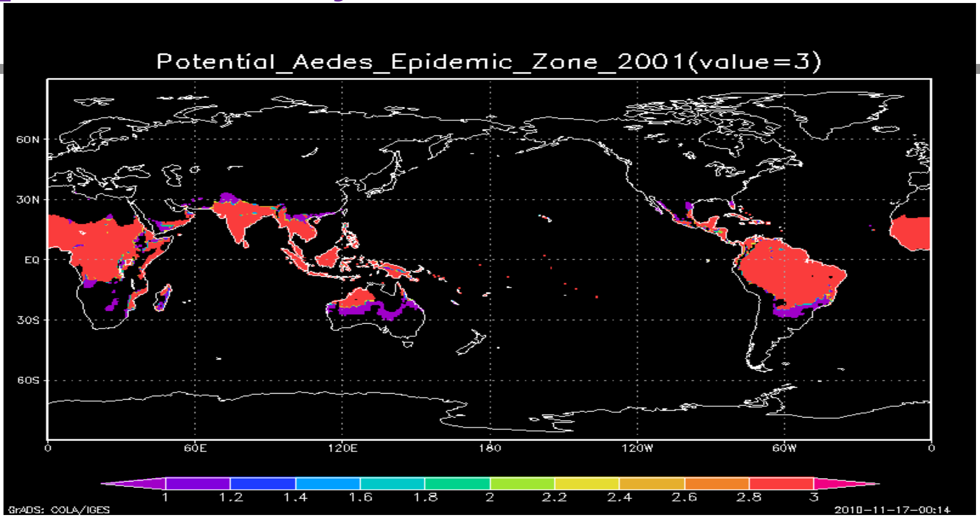


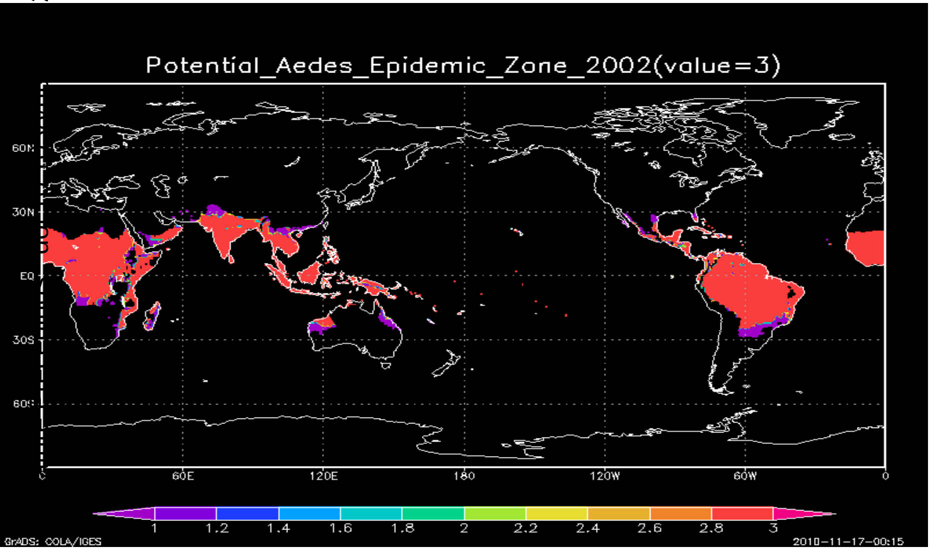
Figure 3. Incidence rate of notified cases of dengue fever and number of municipalities with Aedes aegypti in Brazil, 1986-2003 (Source: SVS)

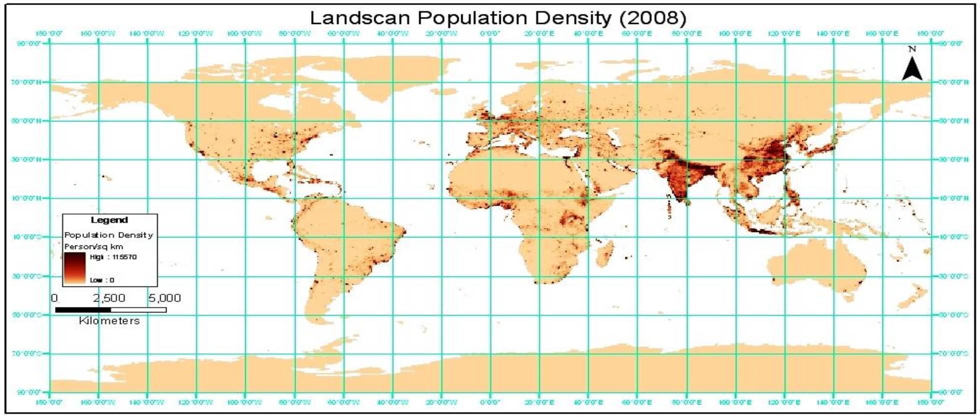
Source of 2. Brazil: Challenges for Dengue Control in Brazil : overview of socioeconomic and environmental factors associated with virus circulation (*accessed in http://library.wur.nl/frontis/environmental_change/10_vilarinhos.pdf)*

Validation: Pandemic dengue algorithm (prototype) Output (Favouring Climate), Aedes aegypti distribution & Population Density





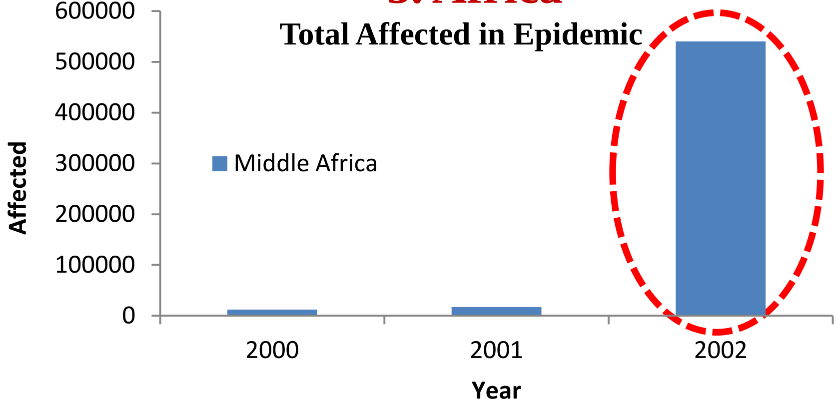




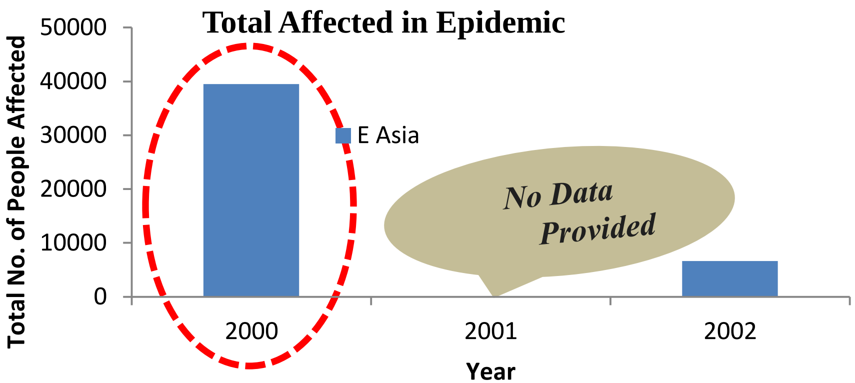
Pandemic dengue prone region with this color (value 3)

Validation: Observed Dengue Epidemics

3. Africa



4. Eastern Asia



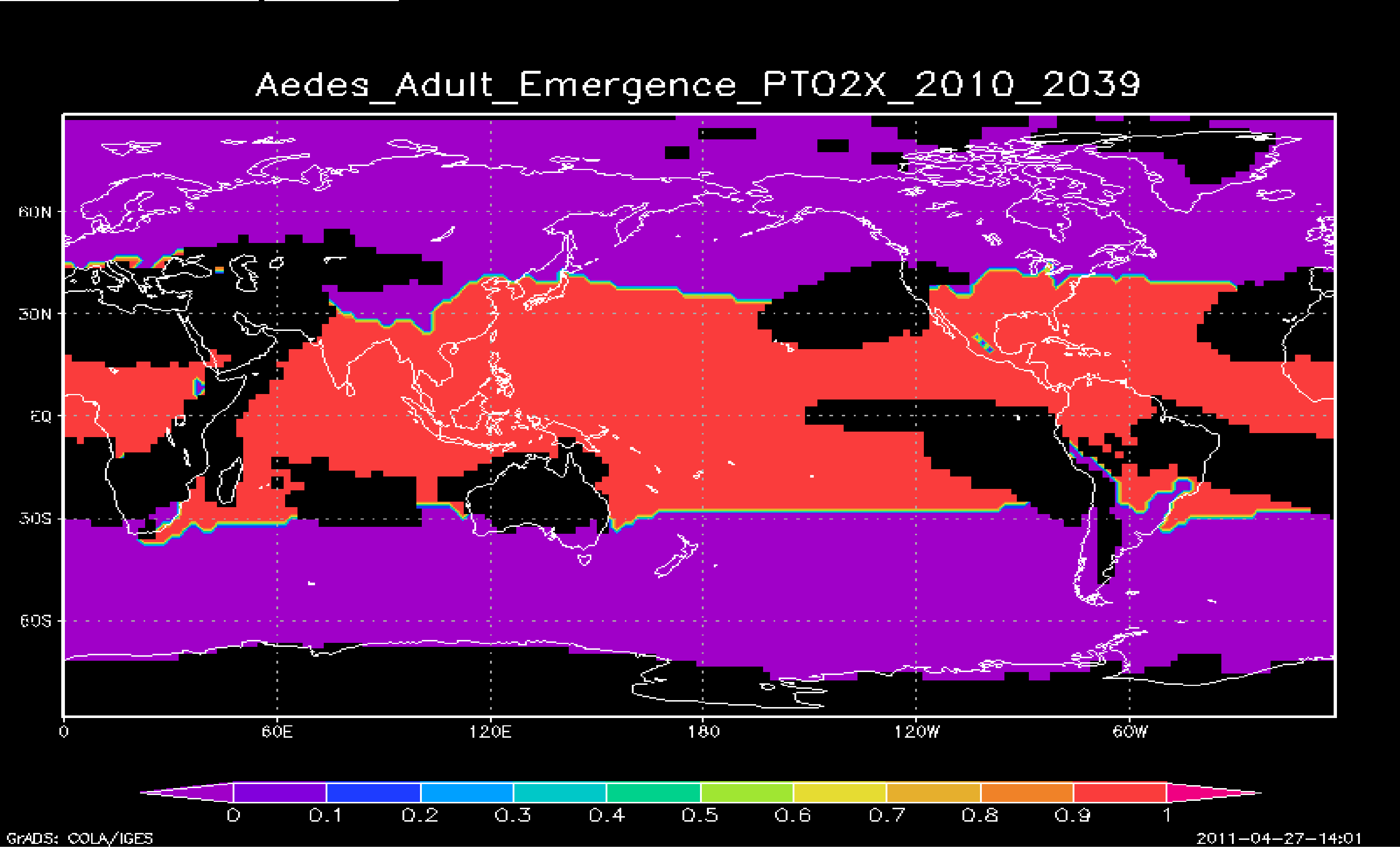
Source for 3. Africa & 4. Eastern Asia: "EM-DAT: The OFDA/CRED International Disaster Database www.emdat.be - Université Catholique de Louvain - Brussels - Belgium"

*** EM-DAT provides the estimate of total affected by Epidemics as a whole, not as a categorical Epidemics**

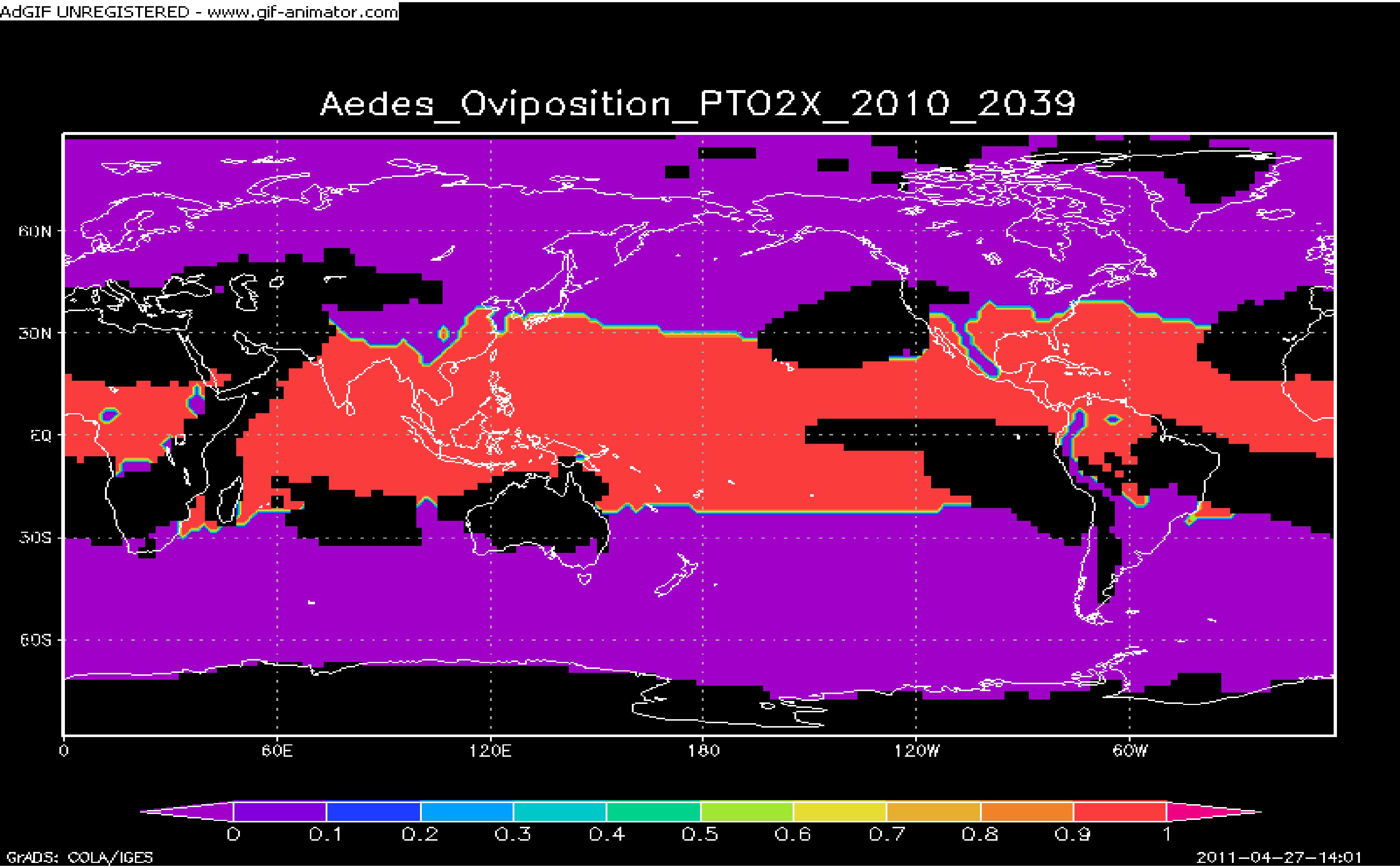
➢ ***Pandemic Dengue Algorithm outputs capture well the global dengue outbreak at macro-scale for the year 1997, 2000, 2001, 2002. The algorithm outputs signify the prevalence of dengue favouring climatic condition whereas the observed dengue data are the result of complex interaction among Climate X Vector X Man. The similar trend of both the results also signify the impact of climate on pandemic dengue outbreak***

Results

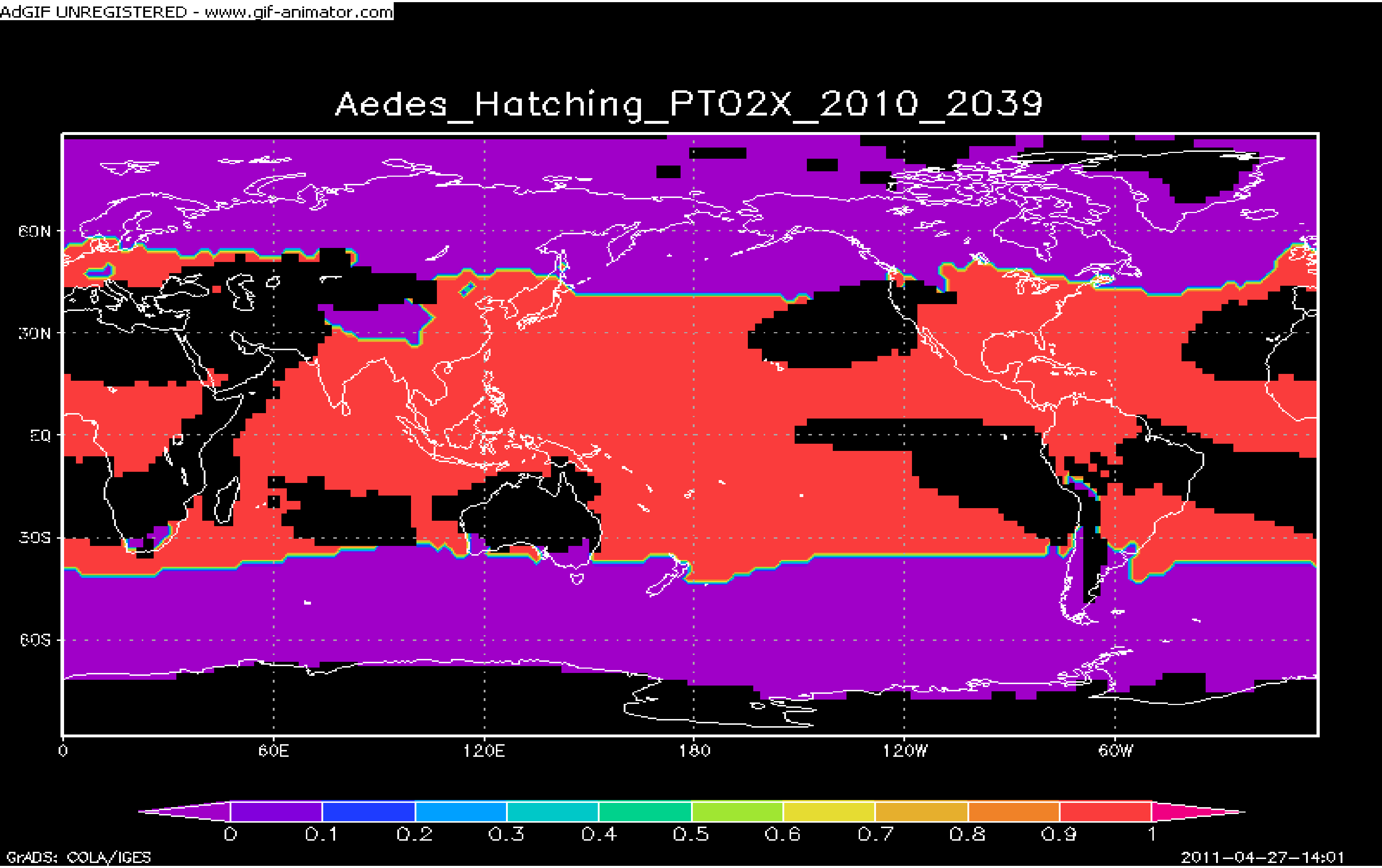
Pandemic Dengue in Future Scenario



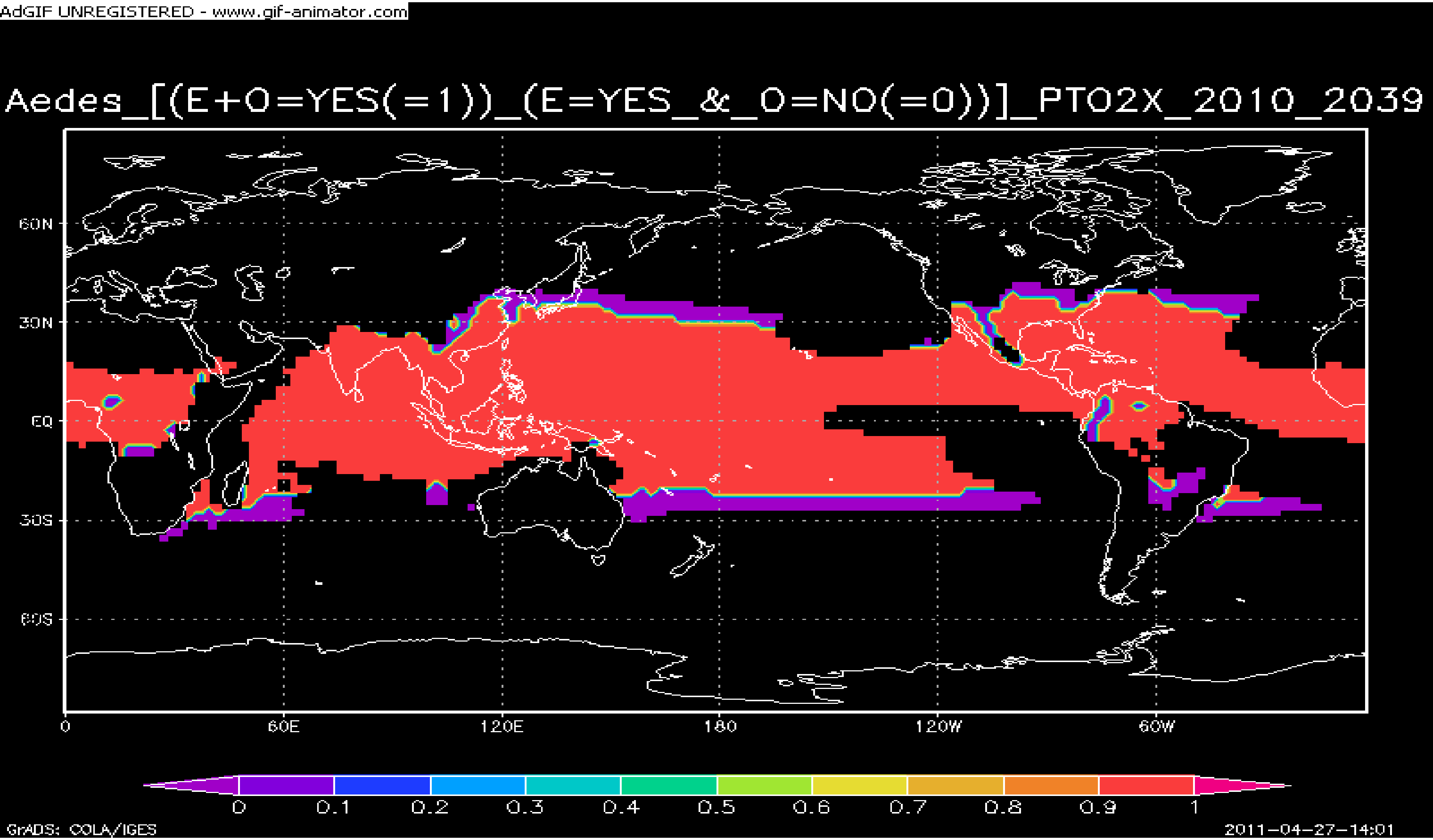
Pandemic dengue emergence prone region with this color (value 1)



Pandemic dengue oviposition prone region with this color (value 1)

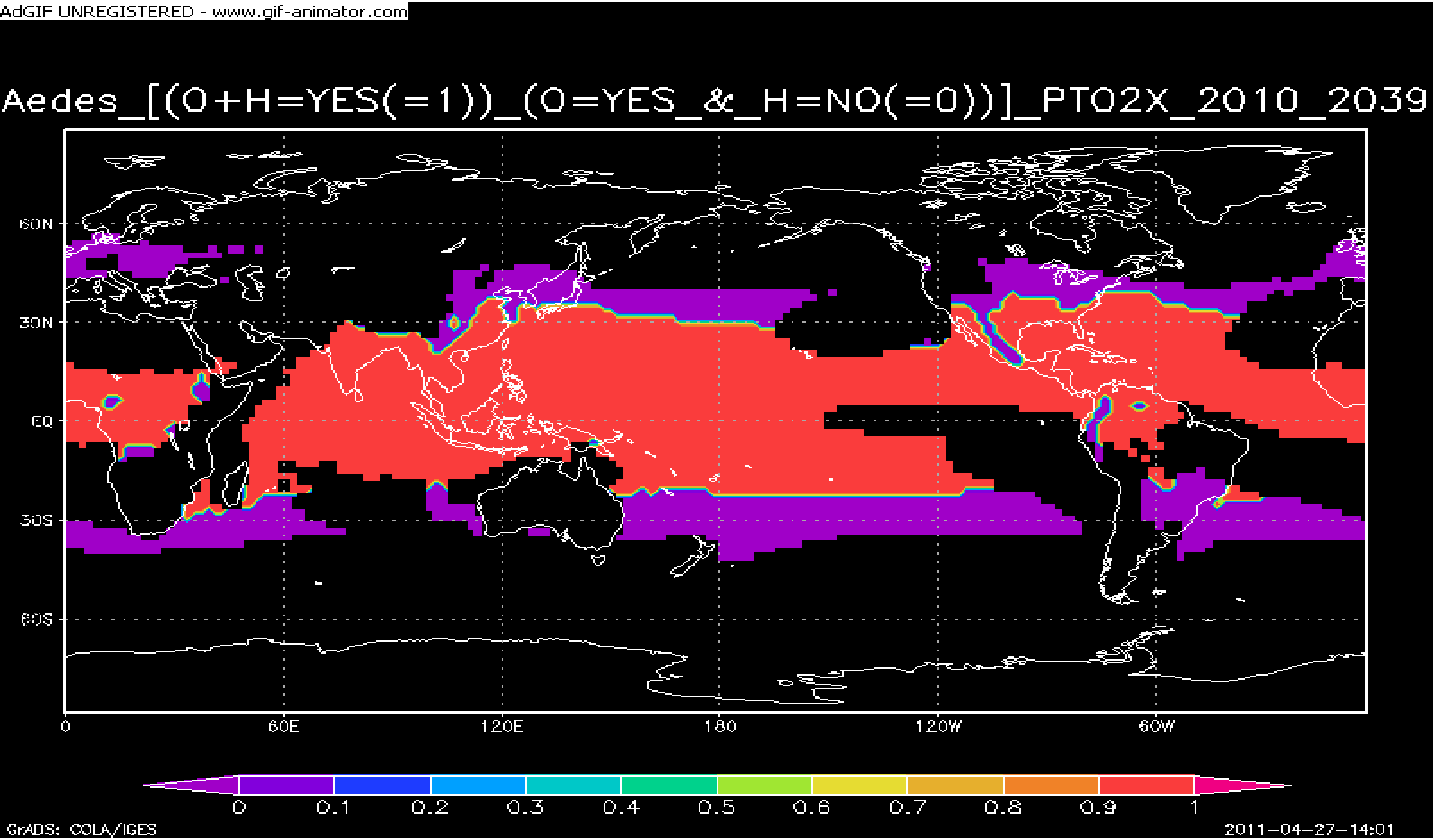


Pandemic dengue hatching prone region with this color (value 1)



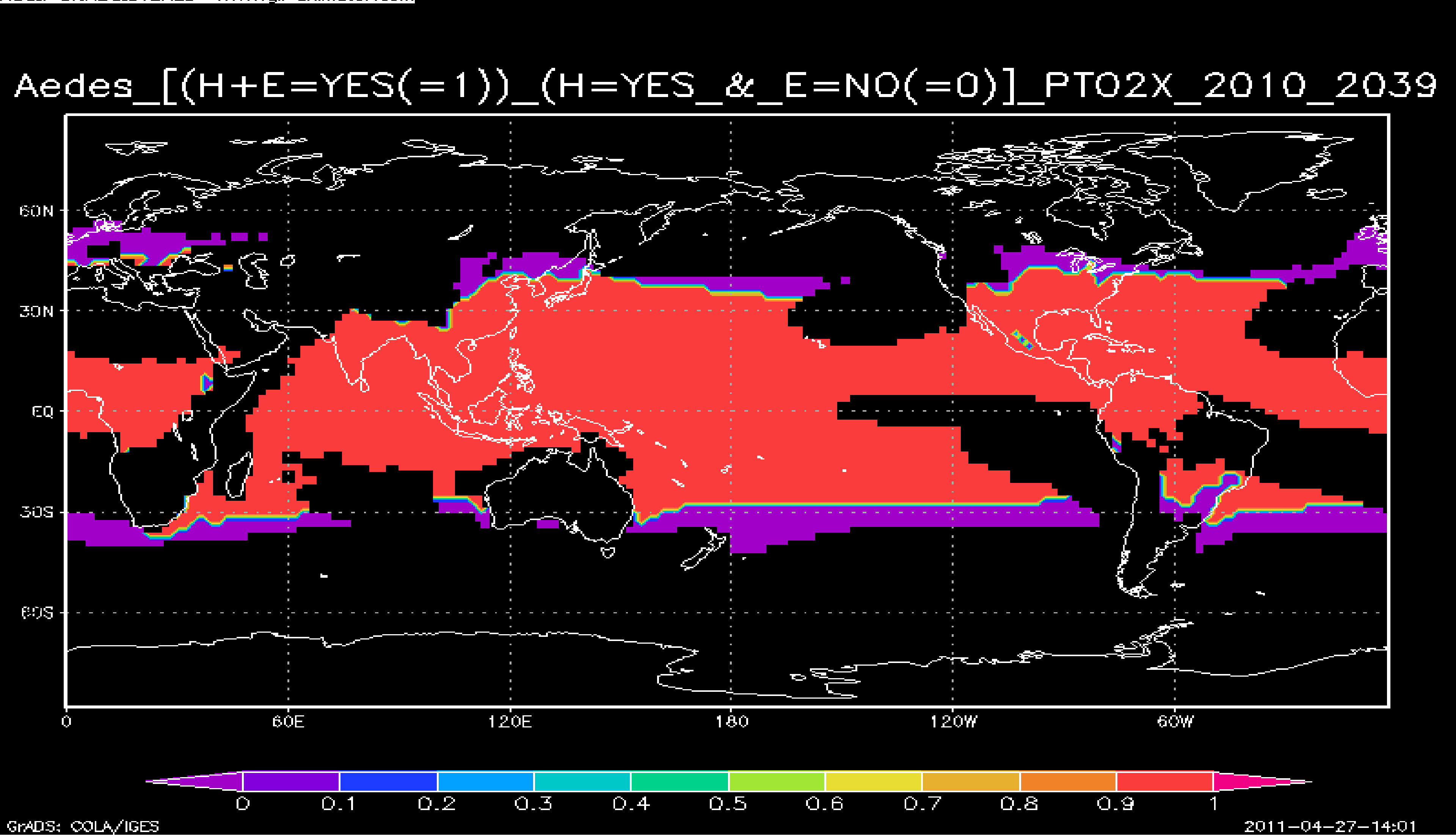
Emergence & Oviposition both are favourable (value 1)

Emergence is favourable but Oviposition is not favourable (value 0)



Oviposition & Hatching both are favourable (value 1)

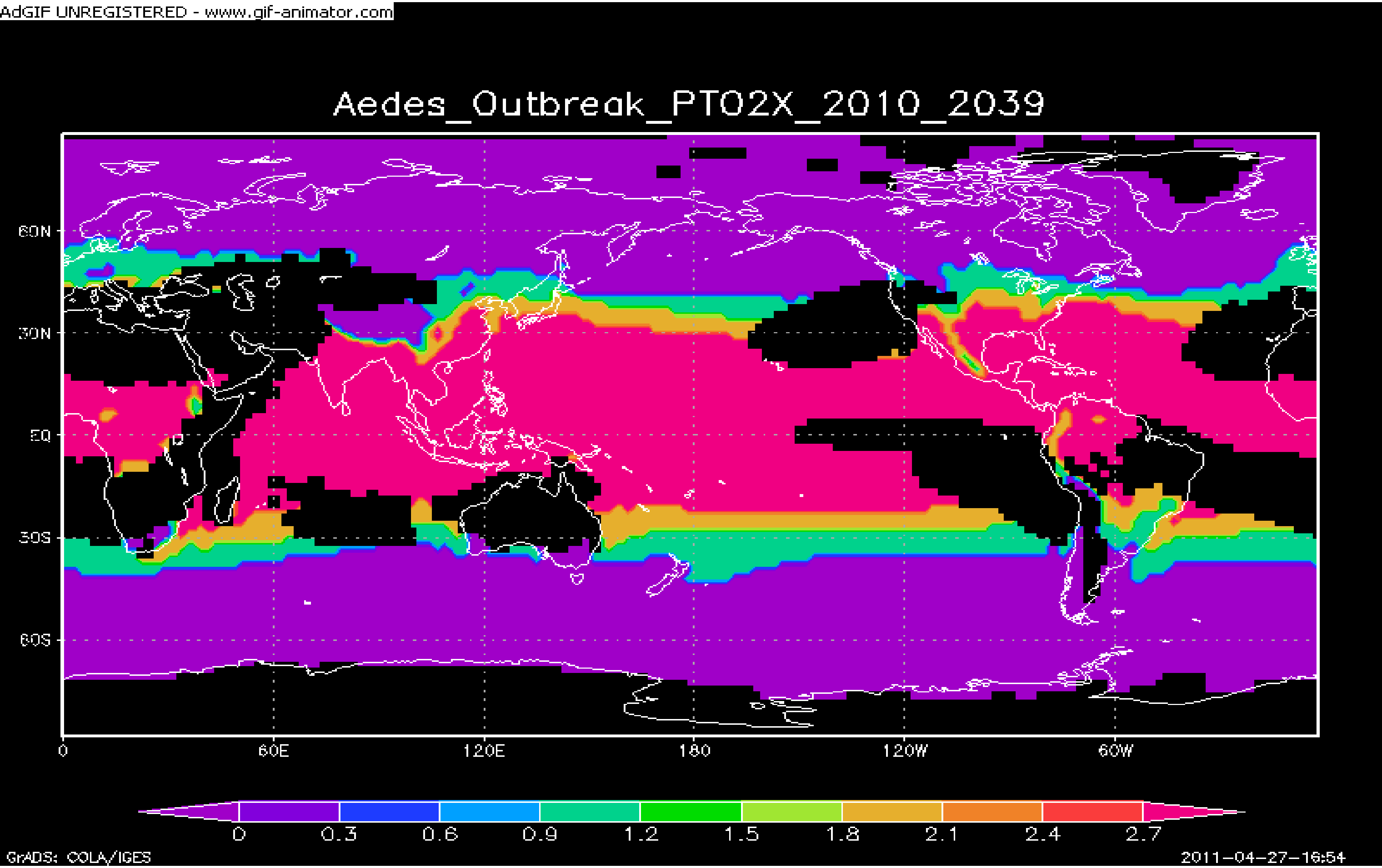
Oviposition is favourable but Hatching is not favourable (value 0)



Hatching & Emergence both are favourable (value 1)

Hatching is favourable but Emergence is not favourable (value 0)

Potential Dengue Outbreak in Future Scenario

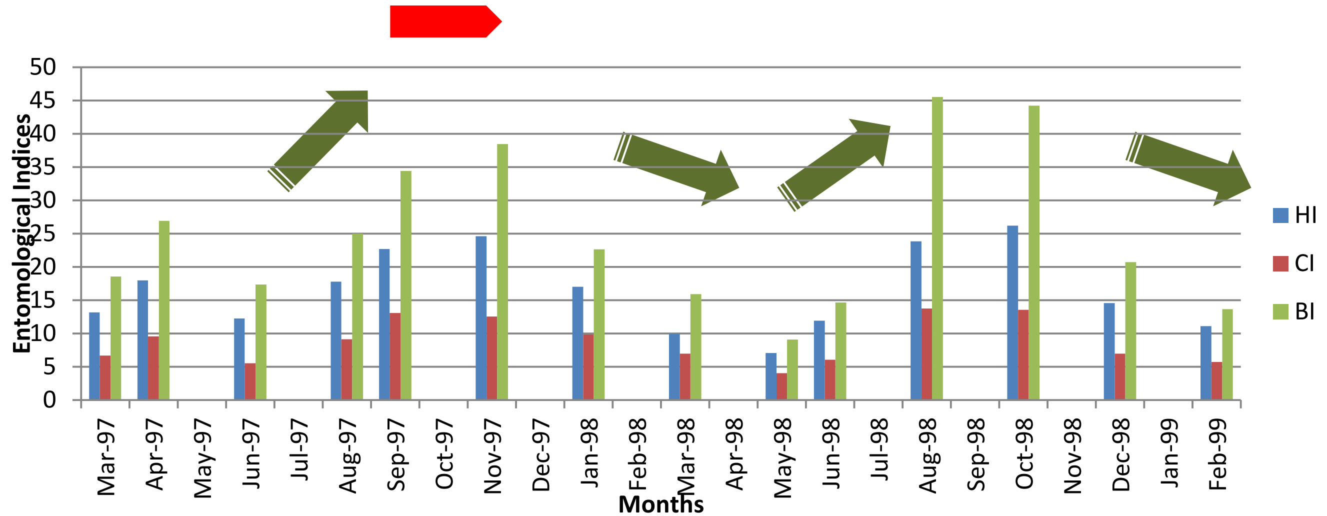


Pandemic dengue prone region with this color (value 3)

Some Challenges Ahead!

Problems: ***Lack of presence of uniform Entomological Indices & its relation with climatic variables***

Seasonal variation of Entomological Indices in Dengue affected villages in Vellore district of Tamil Nadu

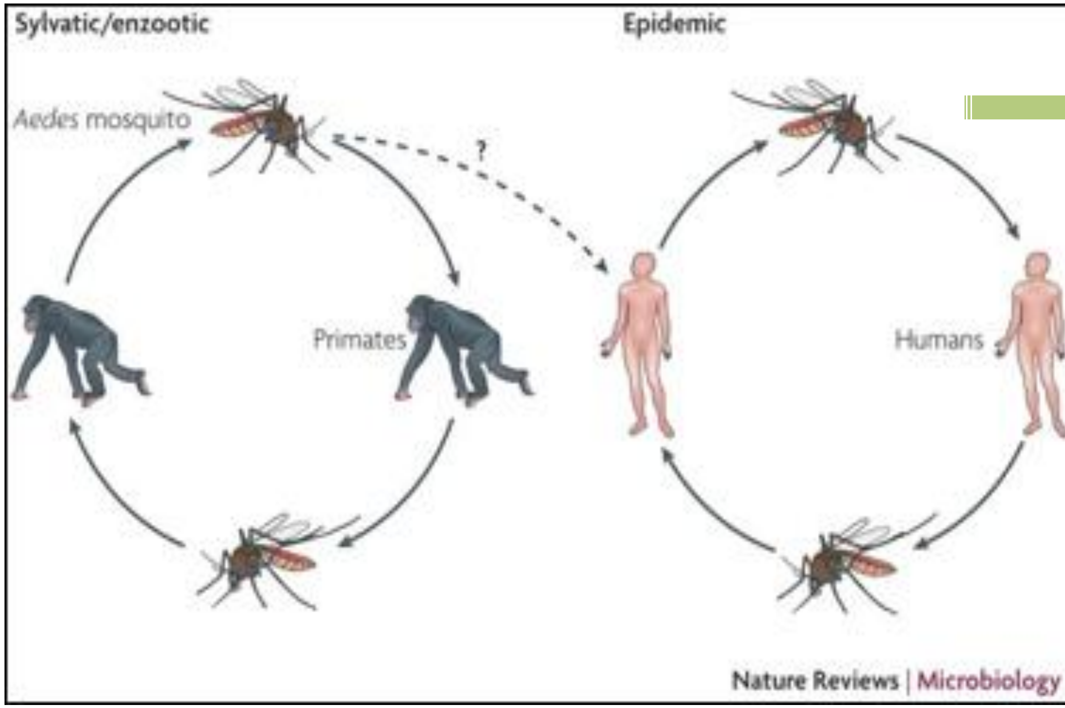


Source: ***Tewari et al., 2004 (http://onlinelibrary.wiley.com/doi/10.1111/j.1365-3156.2004.01103.x/full#t1)***

- **Yotopranoto et al., 2010:** ***HI, CI, BI has a trend for Surabaya city, Indonesia follows January > March > May***

HI: House Index
CI: Container Index
BI: Breteau Index

Problems: *Lack of proper deciphering of the quantifiable complex Man, Vector & Virus Interactions*

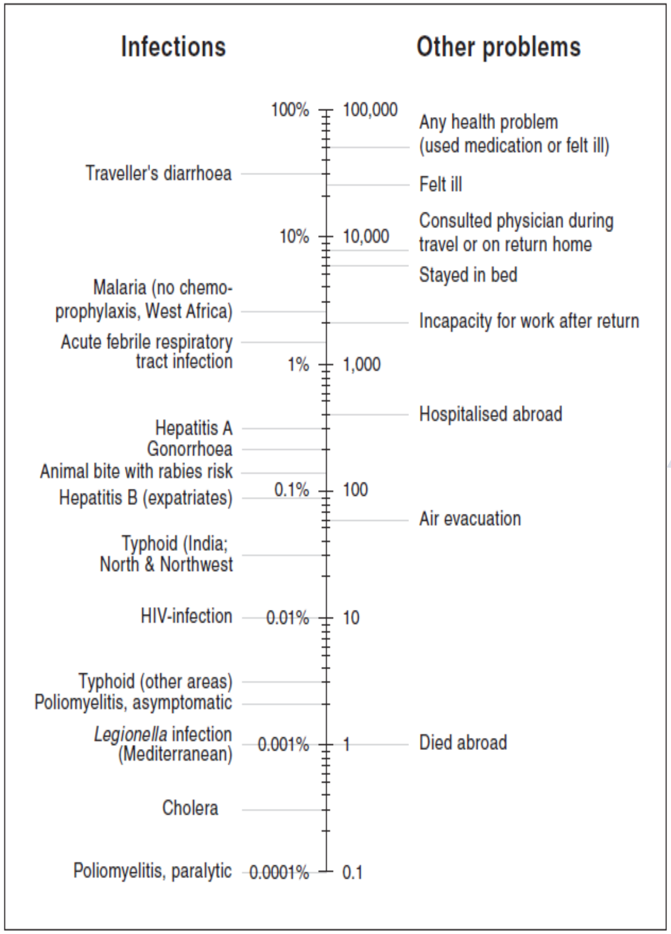


Extrinsic Incubation period

Intrinsic Incubation period

Source:* *http://www.stanford.edu/group/parasites/ParaSites2008/Nkem_Cristina%20Valdoinos/ugonabon_valdovinosc_dengueproposal.htm

Problems: *Lack of proper data for dynamic population flux, an uncertainty factor to the Pandemic Dengue Prediction Models*



No such estimate is available for dengue globally

Population flux across the region & within region via various travelling option adds an uncertainty factor in the Disease prediction modelling

WHO estimate s of relative disease threats to travelers in tropical areas. Note: the scale is logarithmic (Source: Cliff & Hagget, 2004 (http://bmb.oxfordjournals.org/content/69/1/87.full))

Problems: Possibility of development of dynamic disease epidemiology: from Pandemic Dengue to Syndemic Dengue ?

- ***Lack of proper epidemiological dynamics of Dengue***
  - ***Endemic Steady state***

    R0 X S =1 ***(where, R0= basic reproduction number of the infection, S= Susceptible population)***

    If R0 < 1 → disease will die out

    R0 > 1 → disease will spread in population

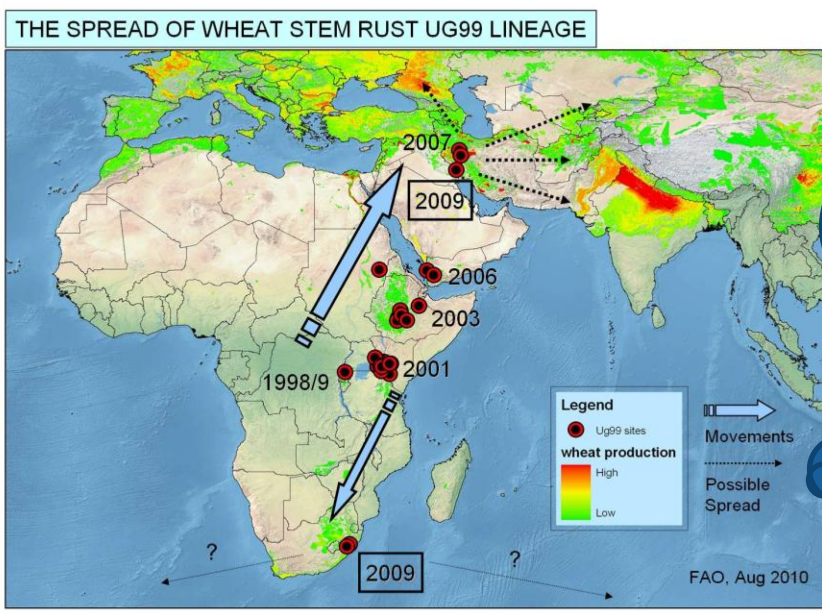
  - ***If R0 value increases much high it becomes Epidemic (local or regional) or Pandemic (global)***

- ***Possibility of development of Syndemic or Comorbid disease due to pandemic dengue & other diseases (Yellow Fever Virus , Japanese Encephalitis) by the same vector in future***

Looking towards Future

- ***Understanding & solving the puzzle of Macro to Micro Spatio-temporal integration of climate signal and its impact on local weather***

- ***Macro to Micro integrated approach: May lead to decrease the uncertainty in climate prediction***



Solving the Problem of Global Food Insecurity, Livelihood Security & Sustainability of Ecosystem

Thank You