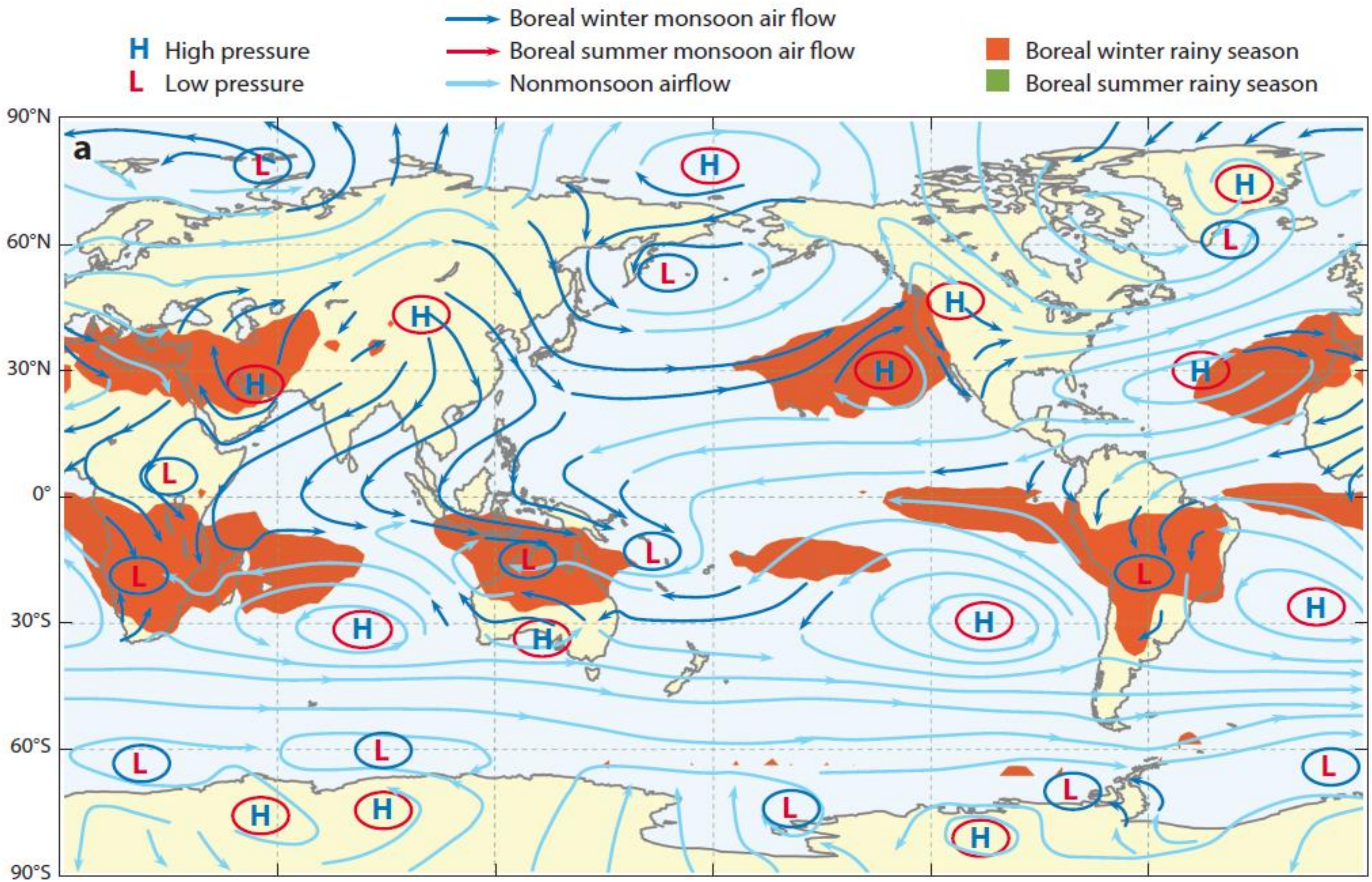
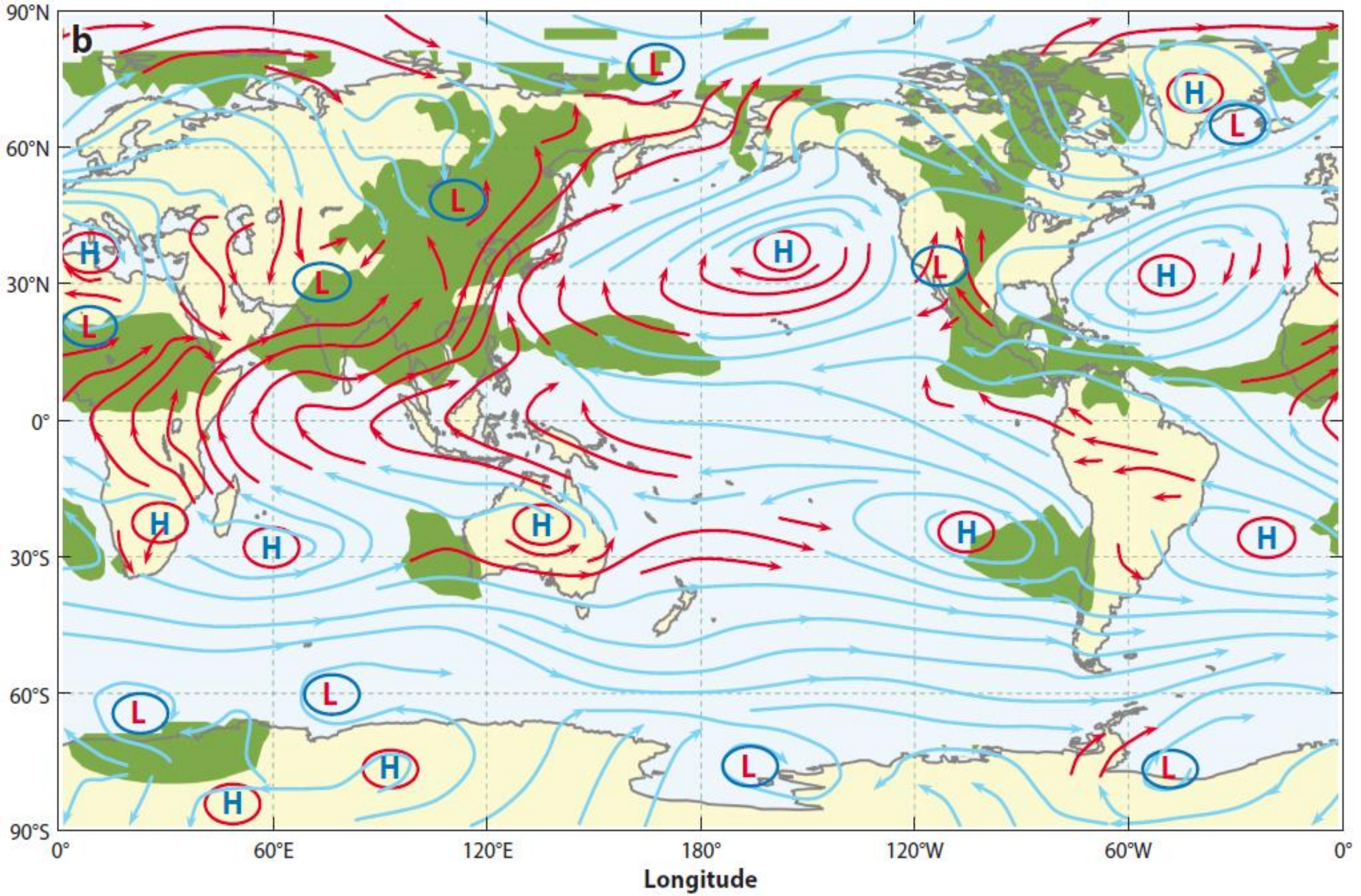
Global Context for Coastal Impacts of Global Monsoon



Seasonality is Important – Vulnerability and Resilience



Impacts

- Physical Impacts – Trends, Extremes, Coastal Population and Infrastructure
- Biogeochemical – Water quality, land-coastal zone interactions, land use land change
- Ecosystem Interactions – Harmful algal blooms, deadzones, habitat loss, etc.
- Data needs are tremendous. Predictions and projections are a great challenge

Vulnerability and Resilience – Data Intensive

Figure 10. Relative vulnerability of coastal deltas as indicated by the indicative population potentially displaced by <u>current</u> sea-level trends to 2050 (Extreme ≥ 1 million; high 1 million to 50,000; medium 50,000 to 5,000; source: IPCC WGII, 2007 - http://www.ipcc.ch/)

Uncertainties are not easily quantified. No-regret decisions needed

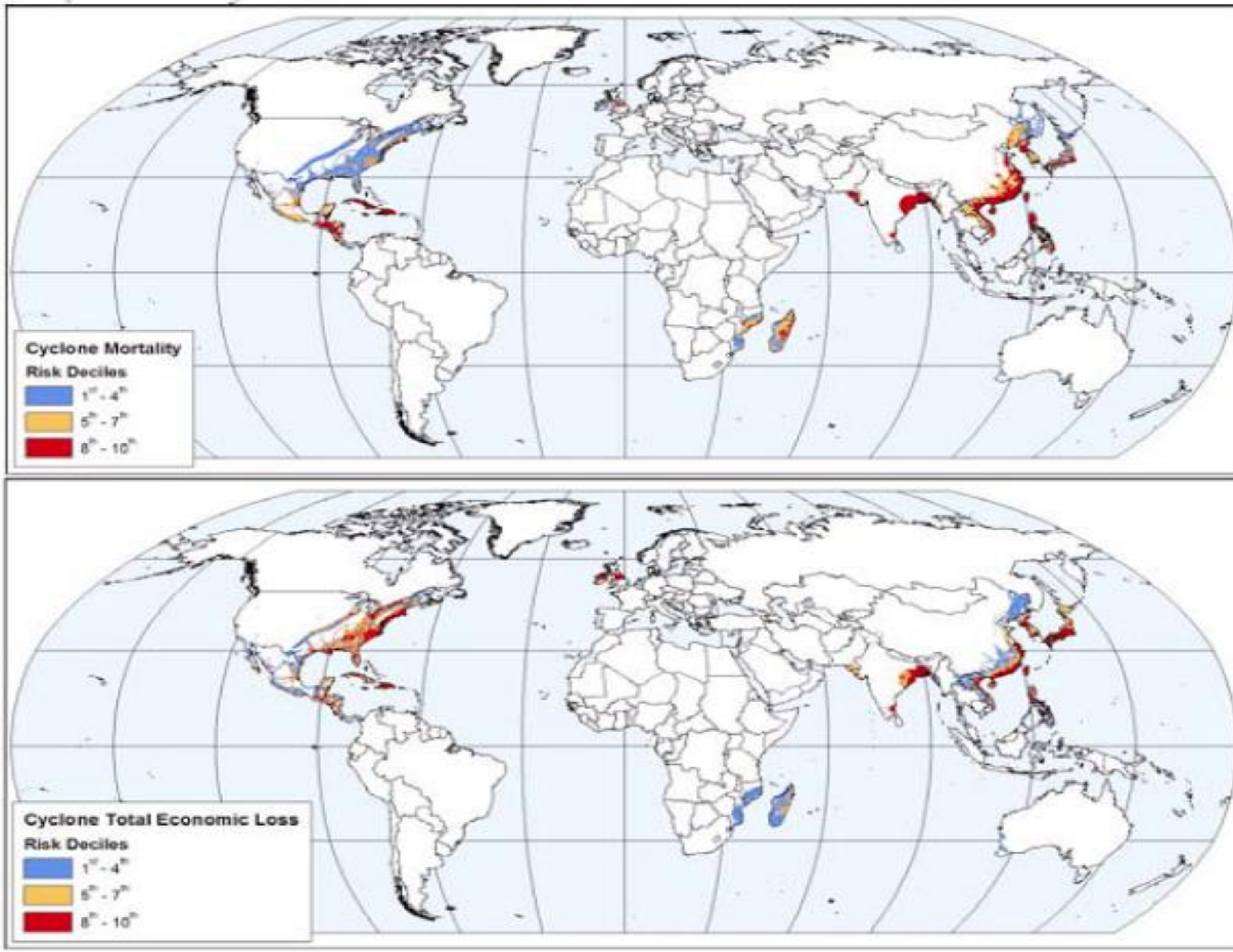


Figure 2. 1: Global distribution of cyclone risk: top: mortality, bottom: economic loss

(Dilley et al., 2005)

Feedbacks to weather and climate remain largely unknown

Figure 2.4: Coastal population and shoreline degradation

(UNEP 2002; data from Burke et al., 2001; Harrison and Pearce 2001)

Solutions may all be about social science and technology: Social Data?

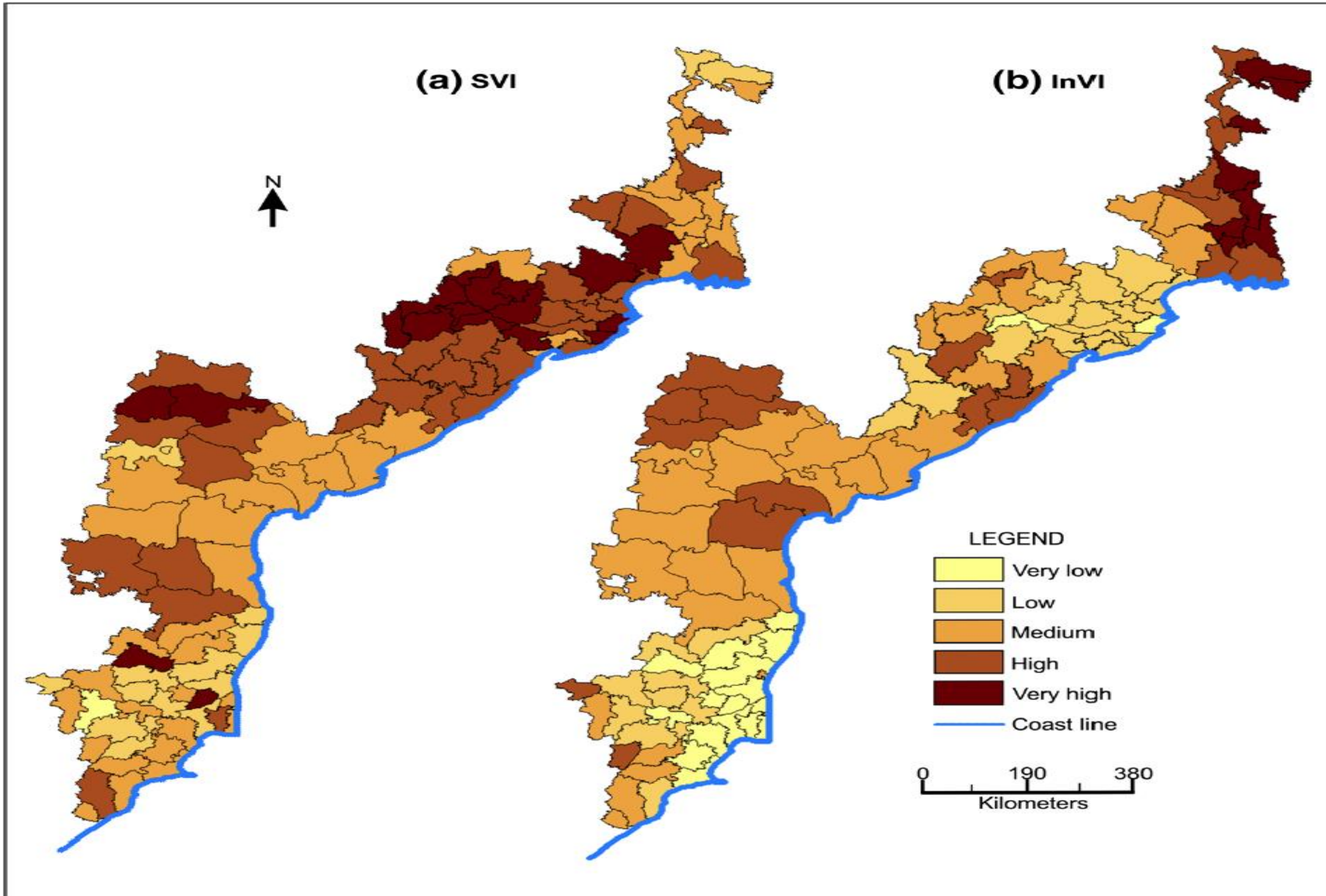


Fig. 5 Socio-economic vulnerability (SVI) and Infrastructure vulnerability (InVI) map of eastern coastal states of India (for location refer Fig. 2)

Keeping in mind again the errors and uncertainties in projections

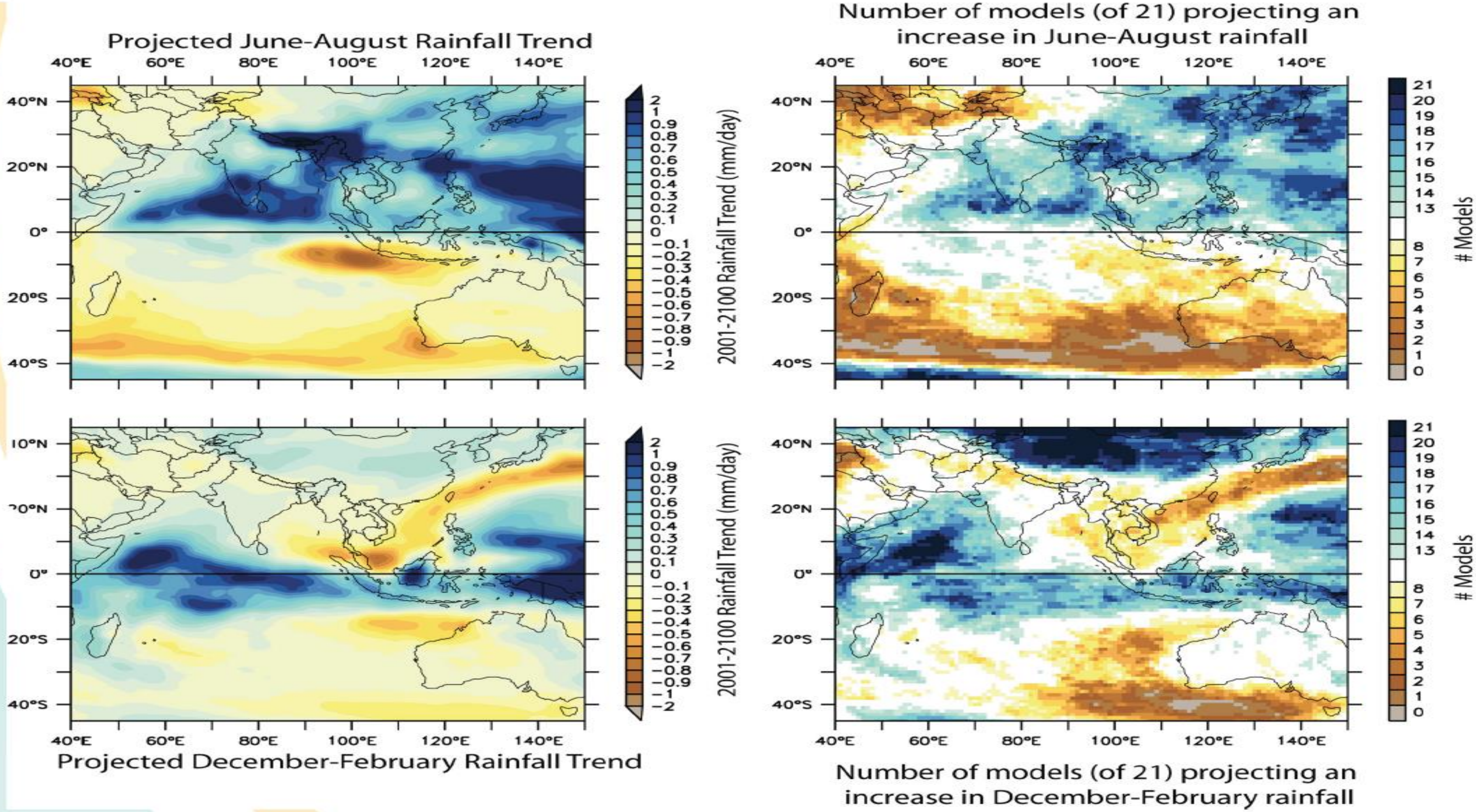
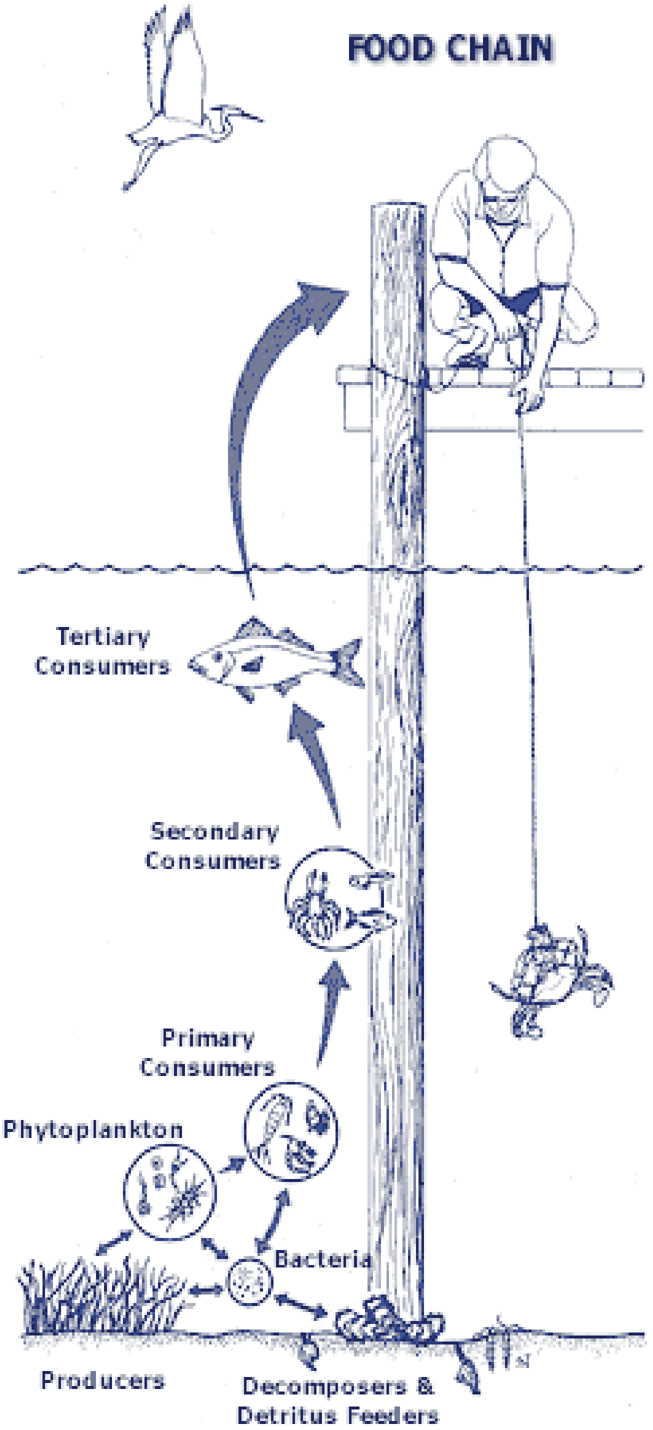


Figure 3: Projected change in precipitation amount over the Asian-Australian monsoon region in June-August (top row) and December-February (bottom row) due to human-induced climate change using the Coupled Model Intercomparison Project-3 models. The left panels show the 2001-2100 trend in mm/day (21-model average), and the right panels show the number of models (of 21) that have an increasing trend. The figure is adapted from Christensen et al. (Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA).

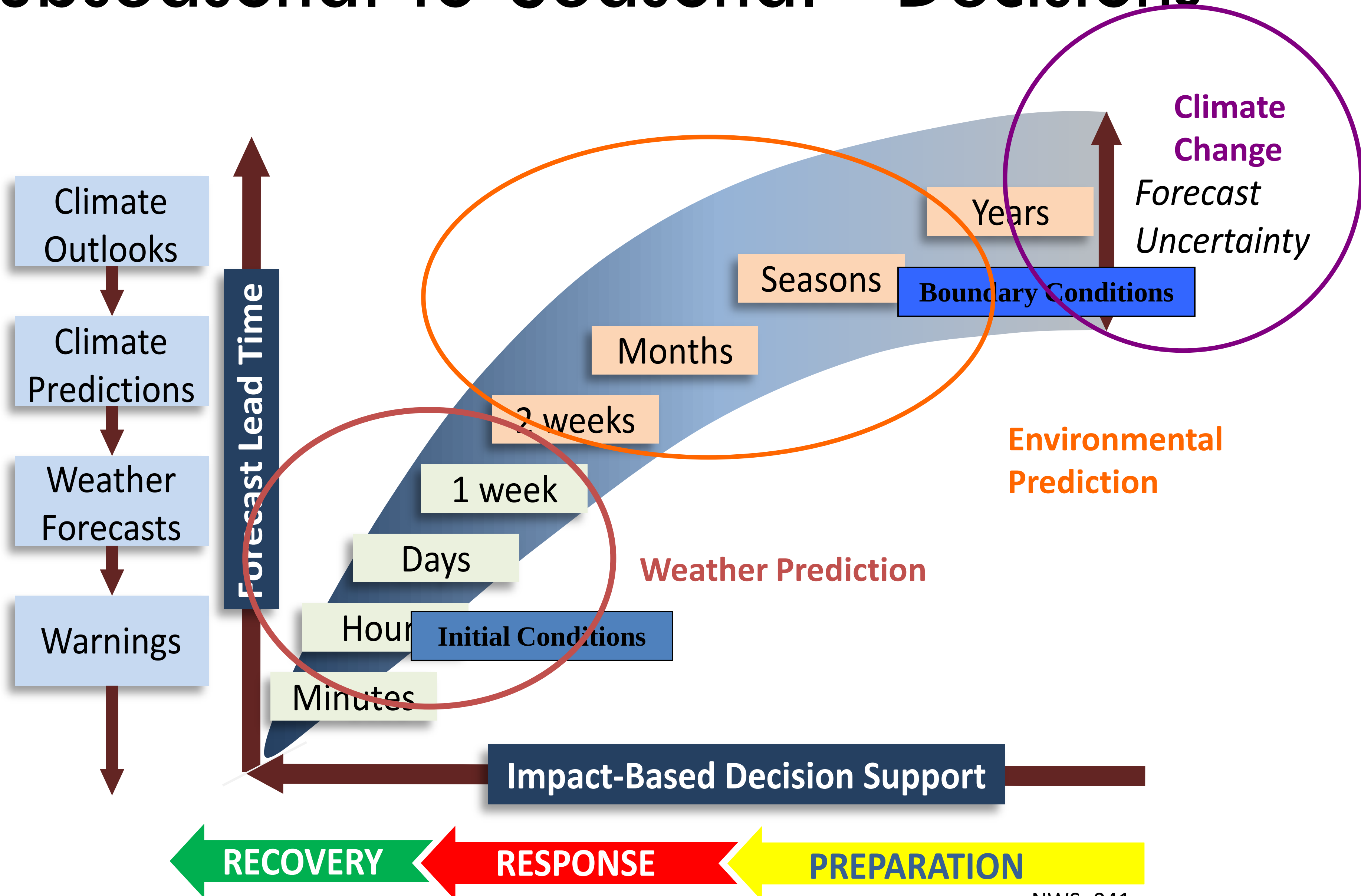
Coastal Impacts: Actionable Information for Decision-Making



What can we learn from Weather Forecasting?

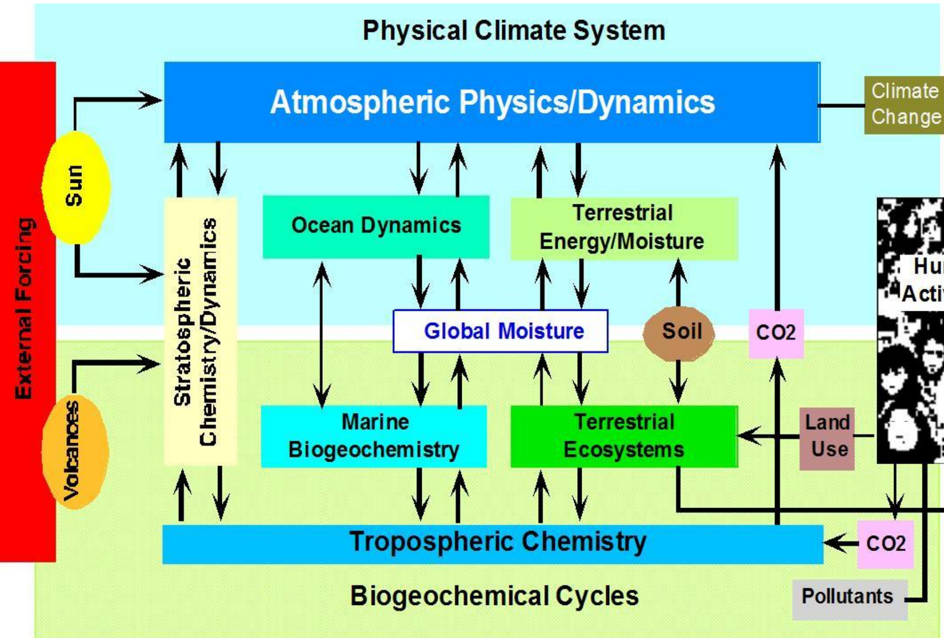
http://www.piqued.us/

Subseasonal-to-Seasonal - Decisions

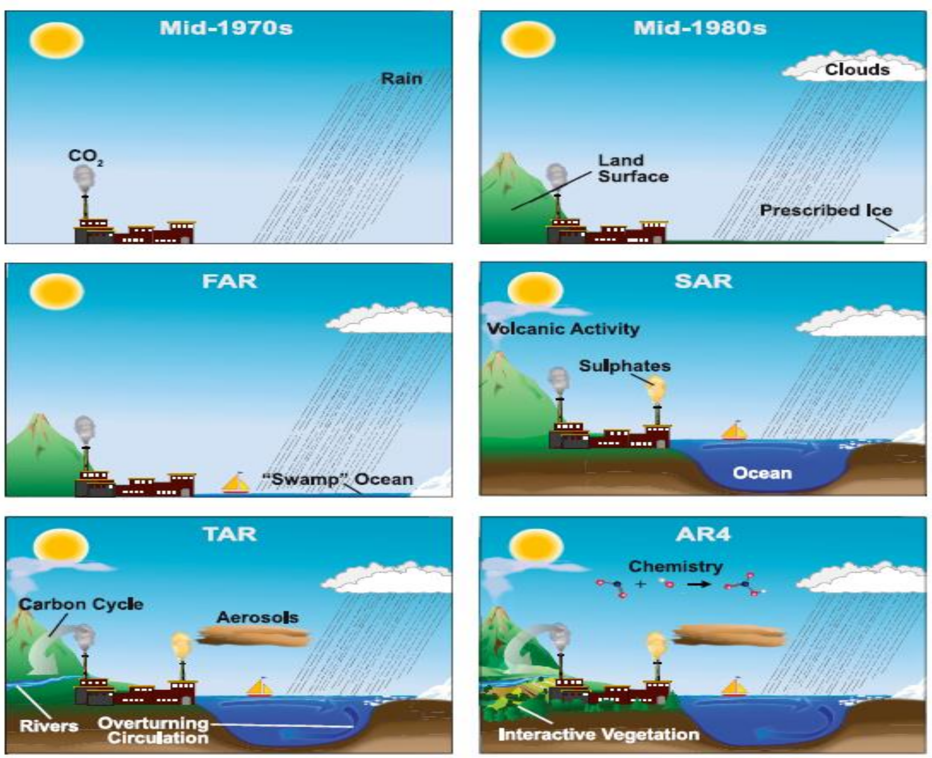


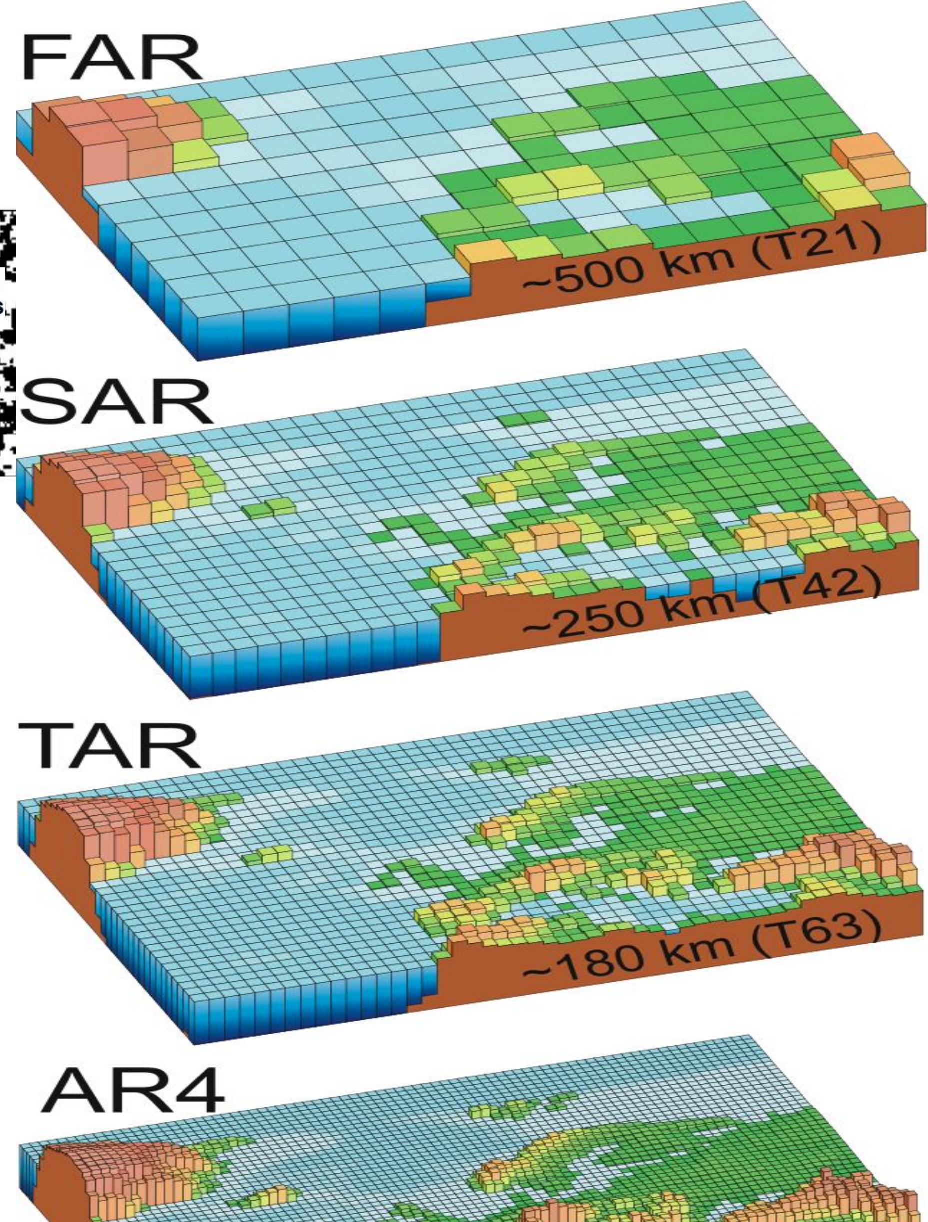
NWS_041

Courtesy: Dr. Wayne Higgins, NOAA

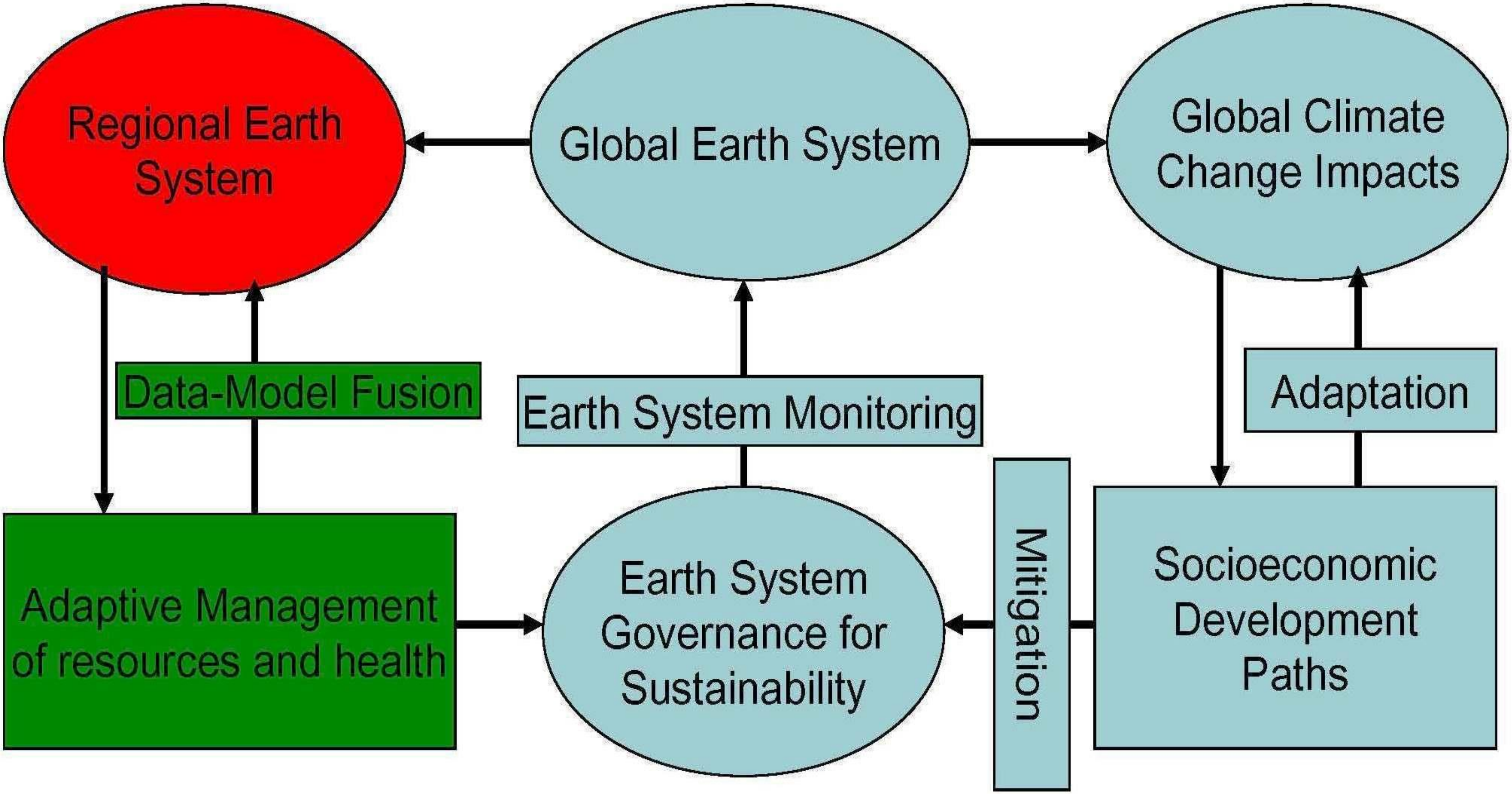


(from Earth System Science: An Overview, NASA, 1988)





Global ESMs for global issues (IPCC negotiations) but regional ESMs for adaptive management, learning-by-doing, and participatory decision-making for sustainability



Murtugudde 2009

Table 1: Effects of weather and climate on infectious diseases in North America and possible impact of climate change on disease incidence and burden

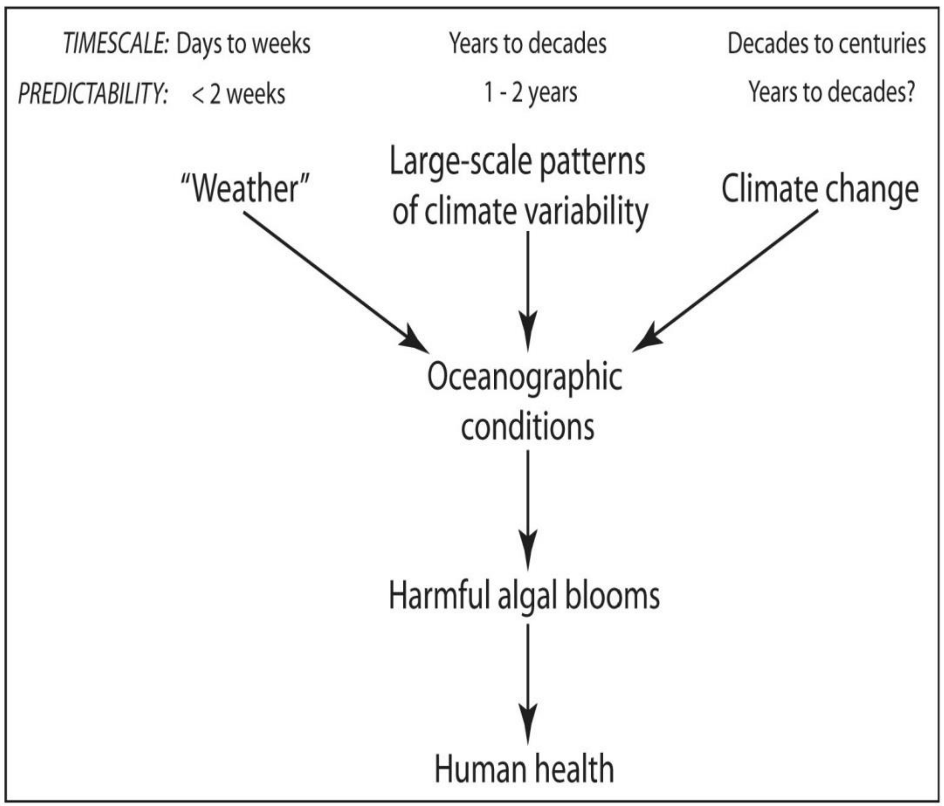
Infectious disease	Known effects of weather and climate	Possible impact of climate change
Zoonotic and vector-borne diseases (e.g., Lyme disease, West Nile virus, dengue, malaria, chikungunya, tularemia, rabies)	• Increased temperature shortens pathogen development time in vectors. This increases the duration of infectiousness, allowing for prolonged periods of transmission to humans. • Changes in climate may expand the geographic range and abundance in both vectors and reservoir hosts. • Warming and altered rainfall patterns may increase populations of reservoir animals and their predators (e.g., rabbits and foxes). • Early onset of favourable transmission conditions may prolong transmission cycles. • Flooding provides breeding habitats for vectors and reservoir hosts, increasing their abundance and geographic range, which may lead to more frequent outbreaks of diseases. • Increased risk of travel-associated illnesses.	• Increased temperature, rainfall variability and altered dynamics of reservoir populations are predicted to increase the transmission of some zoonotic diseases. Changes may permit establishment of novel imported infectious diseases in regions that were previously unable to support endemic transmission. • Changes likely to vary geographically.
Water- and food-borne diseases (e.g., verotoxigenic *Escherichia coli*, *Campylobacter*, *Salmonella*, *Shigella*, *Vibrio*, *Legionella*, *Clostridium botulinum*, *Giardia*, *Cryptosporidium*)	• Survival and persistence of disease-causing organisms directly influenced by temperature. • Increased air and water temperatures improve the survival and proliferation of some pathogens (e.g., *Vibrio*). • Climate conditions affect water availability and quality. • Heavy rainfall and flooding facilitates rapid transportation of disease-causing pathogens into water supplies. • Displacement of environmental refugees because of flooding and extreme weather events are associated with increased risk of water- and food-borne disease transmission.	• Increased temperature and rainfall is predicted to increase the intensity and frequency of water- and food-borne diseases. Risks are particularly elevated in the far North.
Communicable respiratory diseases (e.g., influenza, respiratory syncytial virus, *Streptococcus pneumoniae*)	• Occurrence of respiratory illnesses may decrease as winter temperatures increase. • Changes in climate may increase the concentration of harmful air pollutants, which might enhance invasiveness due to damage of host mucus membranes. • Forced migration of environmental refugees could enhance transmission of disease due to intermingling of populations with introduction of novel diseases into nonimmune populations.	• A shorter, warmer and wetter winter season may reduce the number of respiratory diseases observed. Such effects may be counterbalanced by changes in air quality and mass movements of people.
Invasive fungal diseases (e.g., *Blastomyces dermatitidis*, *Cryptococcus gattii*, *Coccidioides immitis*)	• Ecological and meteorological changes may affect local soil ecology, hydrology and climate, resulting in the persistence of invasive fungal pathogens in the environment and release of infectious spore forms.	• Warm, dry summers in combination with heavy wintertime precipitation provide optimal conditions for infectious fungal spore elaboration and persistence. • Changes likely to vary geographically.

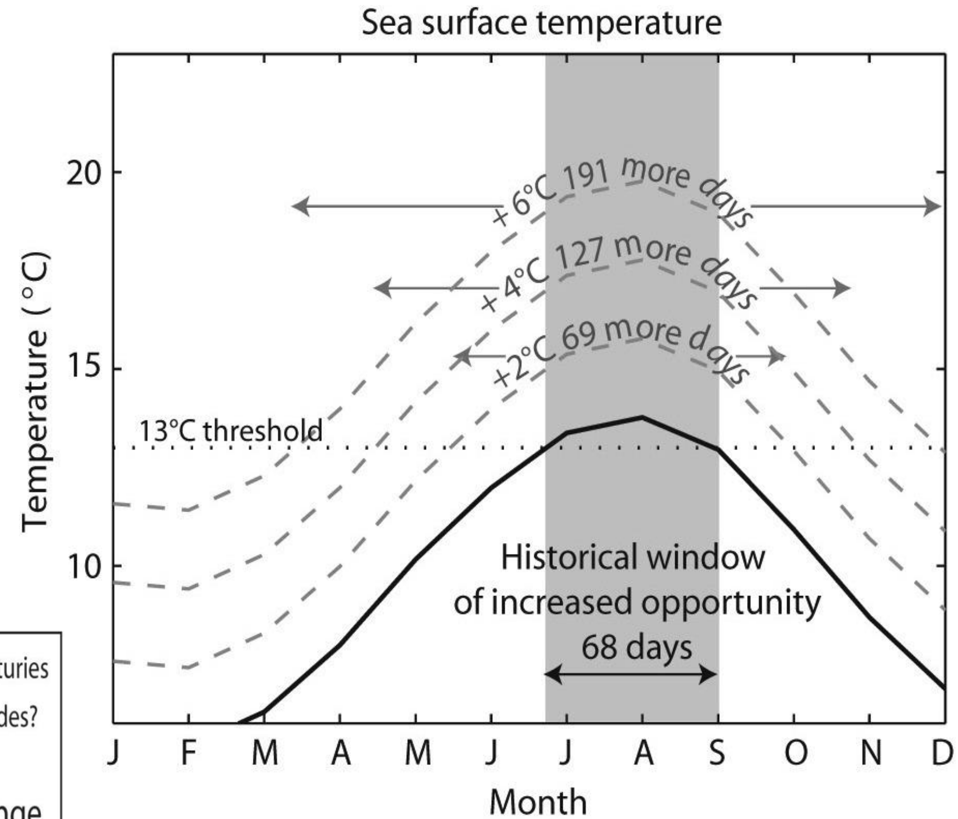
Hippocrates (~400 BC)

Environment and Health

Greer et al. 2008

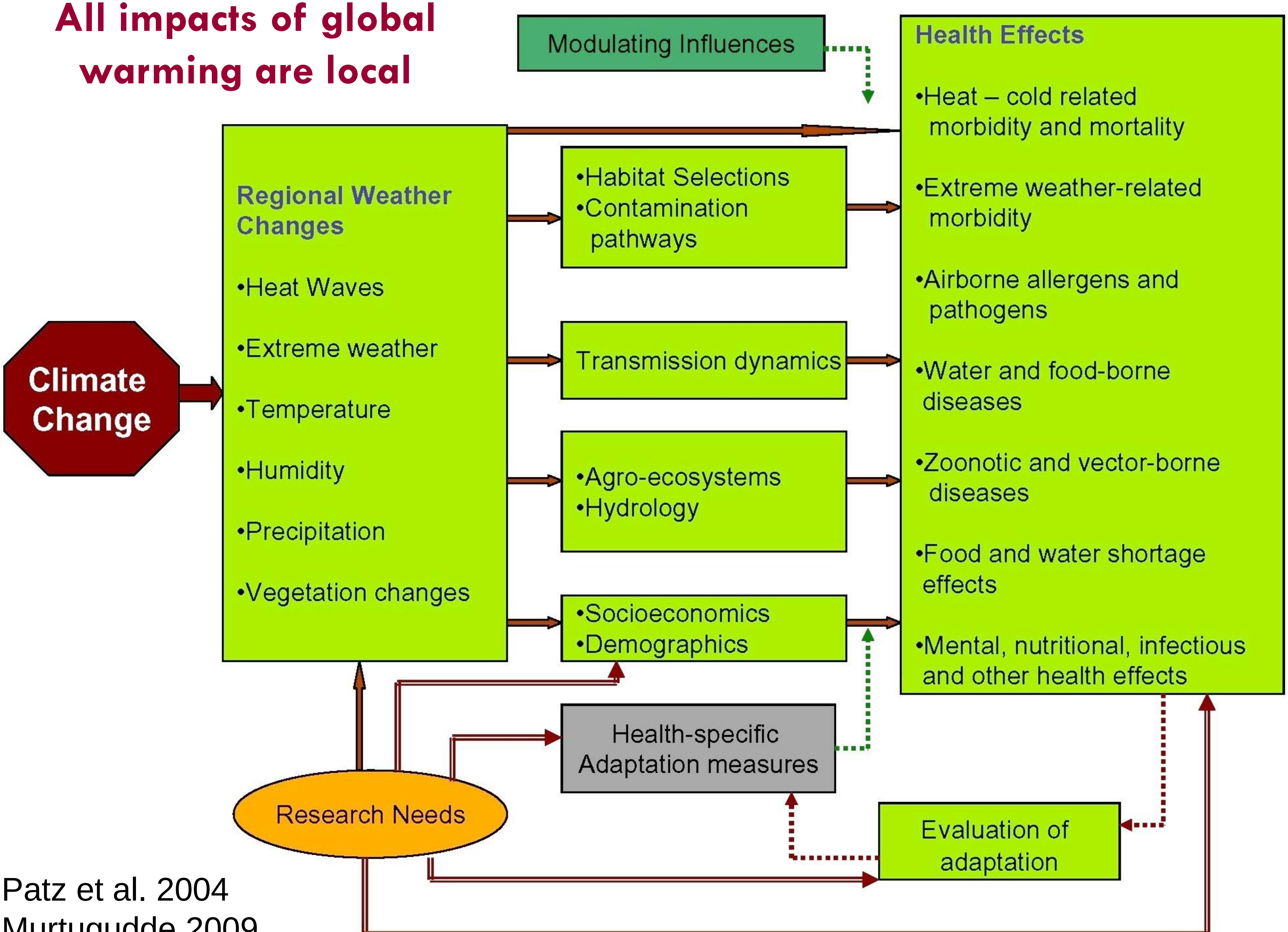
Old Paradigm





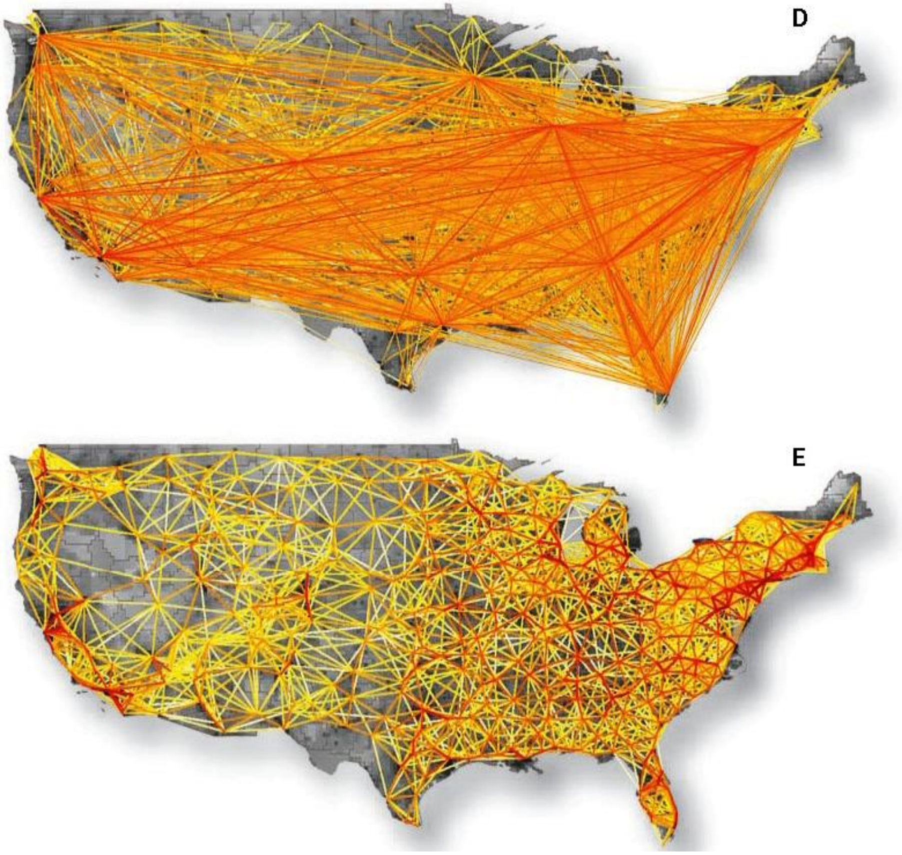
Moore et al. 2008

All impacts of global warming are local

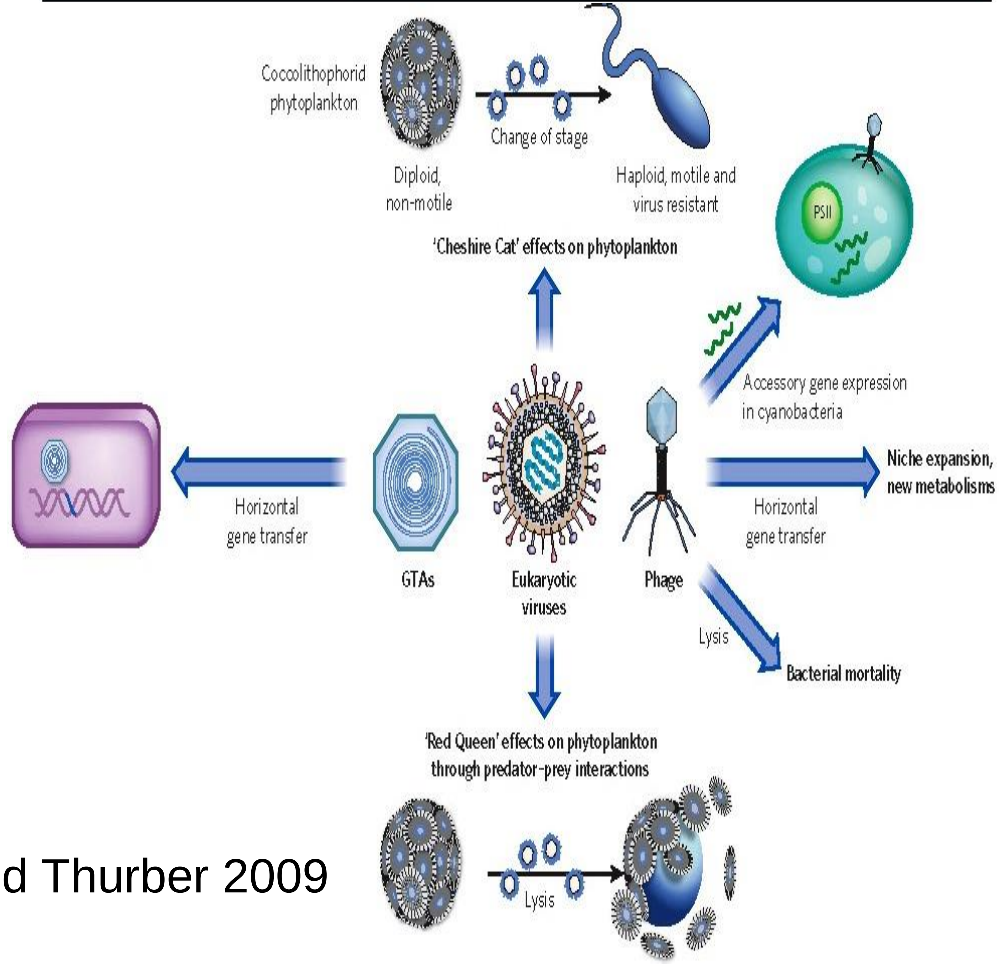


Patz et al. 2004
Murtugudde 2009

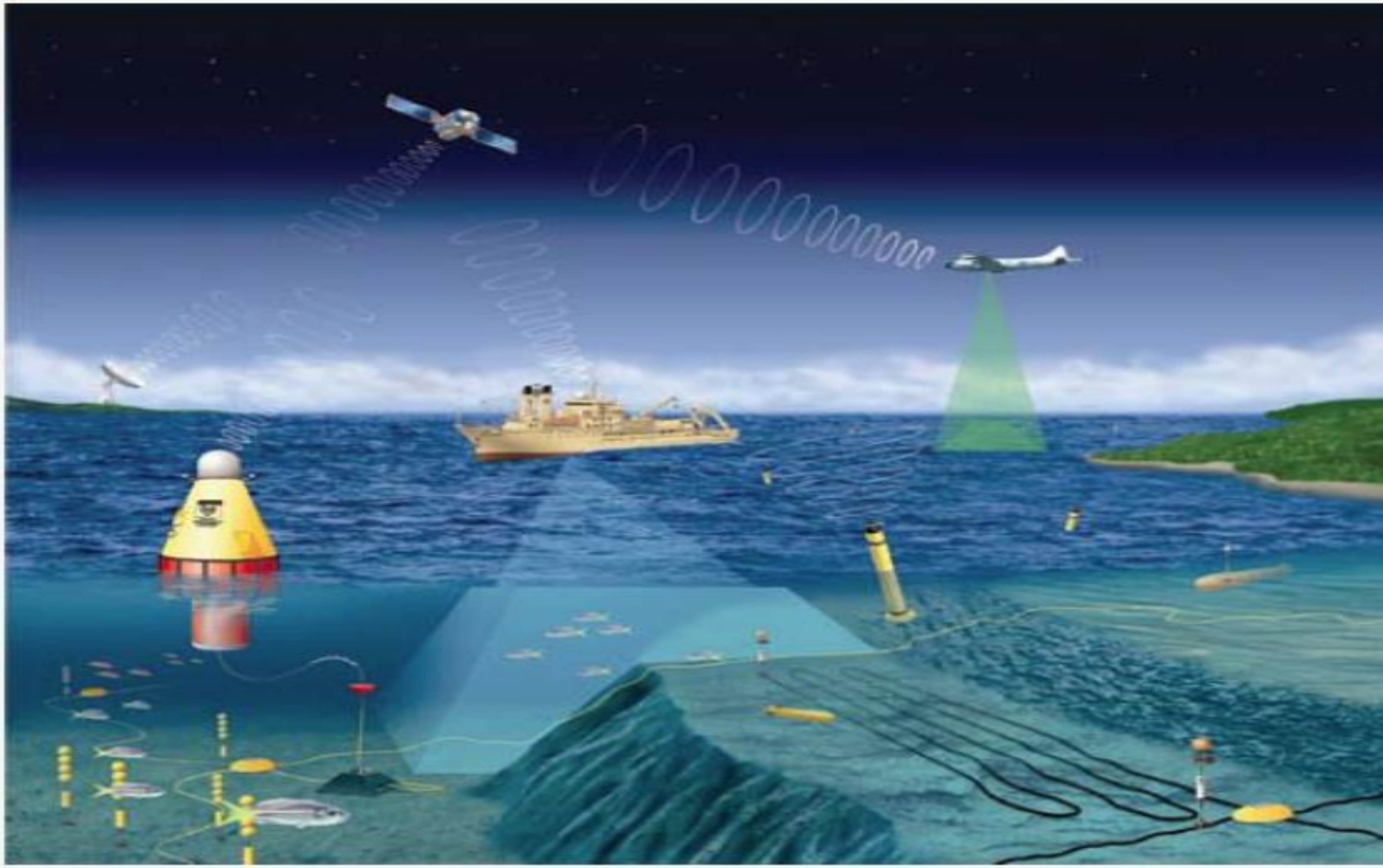
Computational social science: How things spread



Vespignani et al. 2009



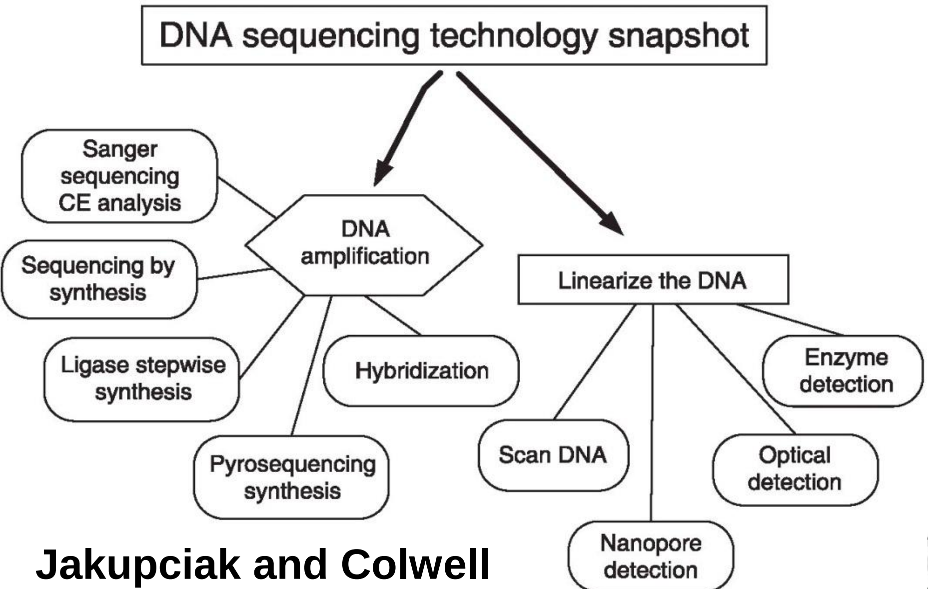
Rohwer and Thurber 2009



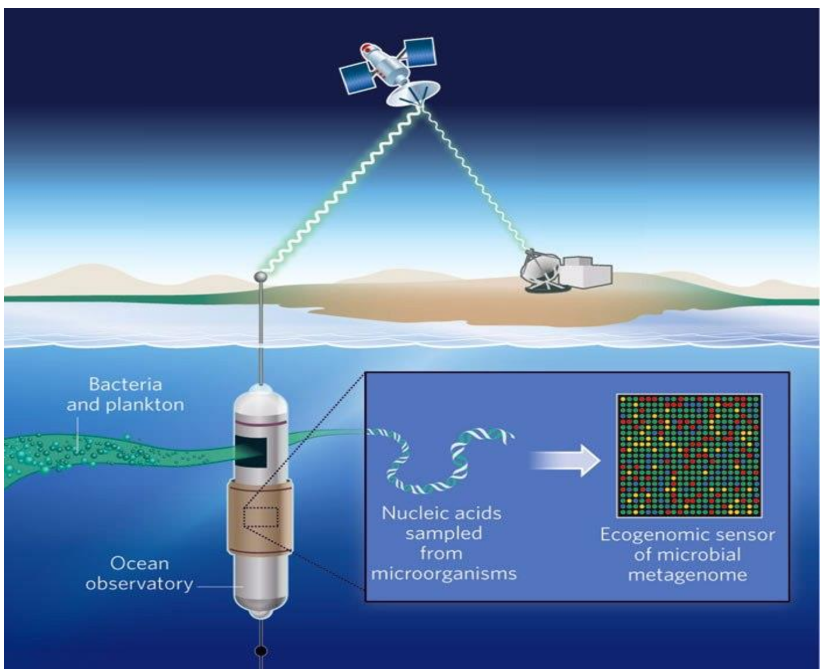
Information on ocean conditions is collected by a diverse network of sources. Observations are then assimilated through weather prediction models to inform forecasts. (Image courtesy of HARRIS Maritime Communications) Sources of weather data include:

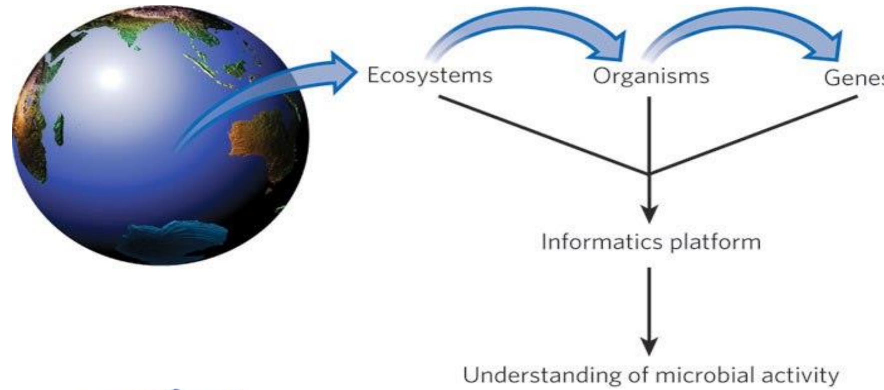
- Automated coastal marine buoys
- Commercial ships and military vessels
- Oil and gas platforms
- Tide and water level installations
- The Doppler radar network
- Automated commercial aircraft
- Reconnaissance aircraft reports
- Satellites

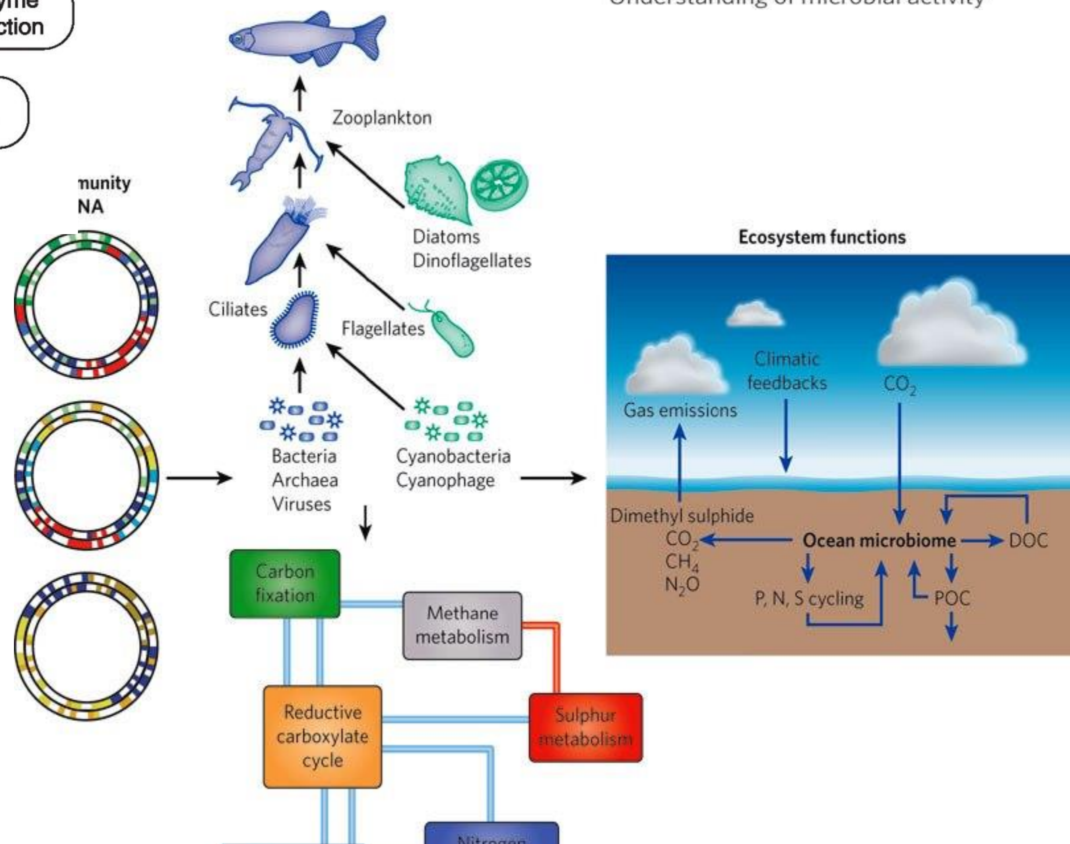
New science and new technologies



Jakupciak and Colwell 2009







Nature 2009

But how much coastal data do we really have? Do countries share coastal data?

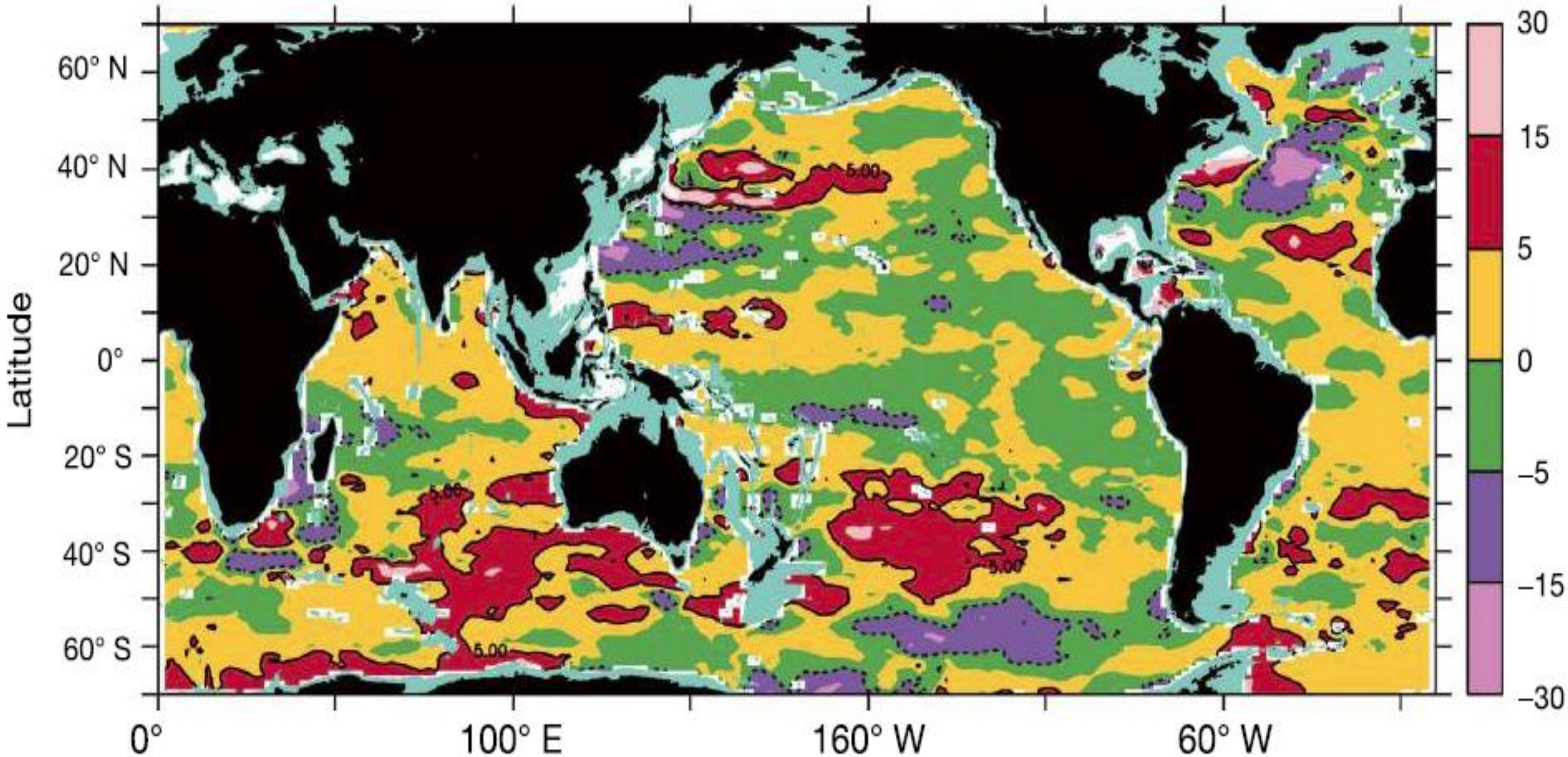
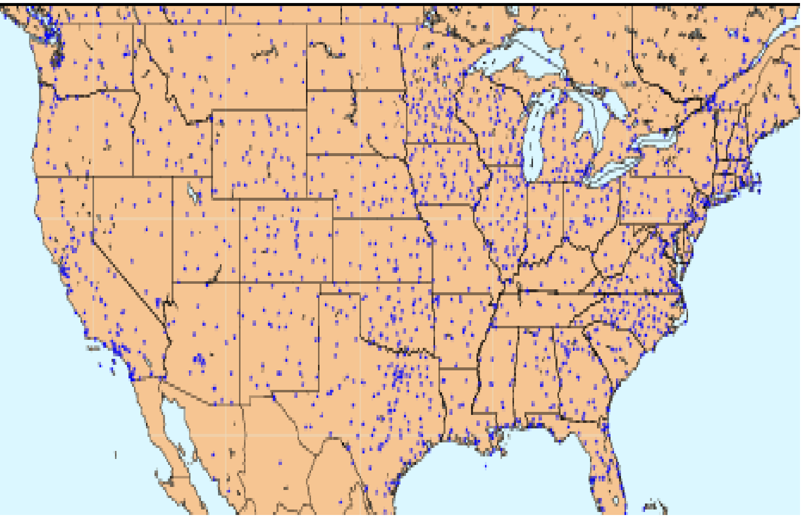
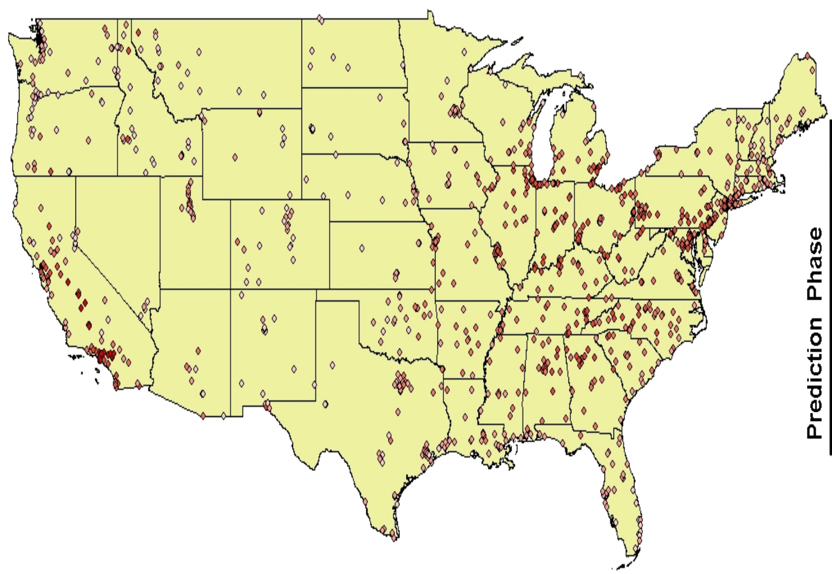
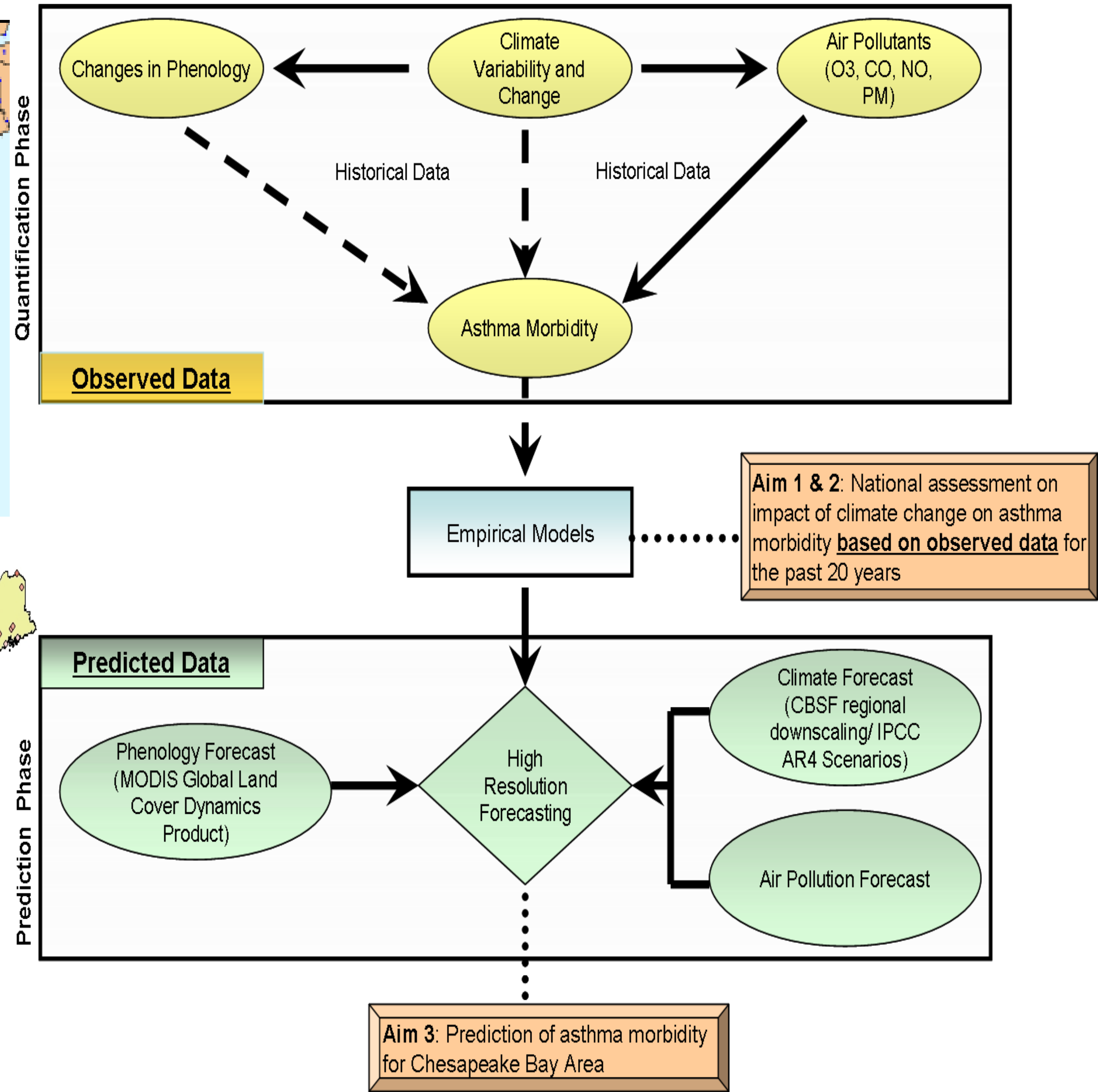


Figure 1.14 The spatial pattern of the trend in Ocean Heat Content (OHC) gain averaged for the depths 0 to 2000m over the years 2004 to 2010. Data as for Figure 13, but using a different interpolation method. A black contour line defines the areas where the heat gain was > than 5W.m^{-2}. A simplified version of Figure 3a in Roemmich *et al.* (2015). Figure courtesy of Dean Roemmich, Scripps Institution of Oceanography, USA.

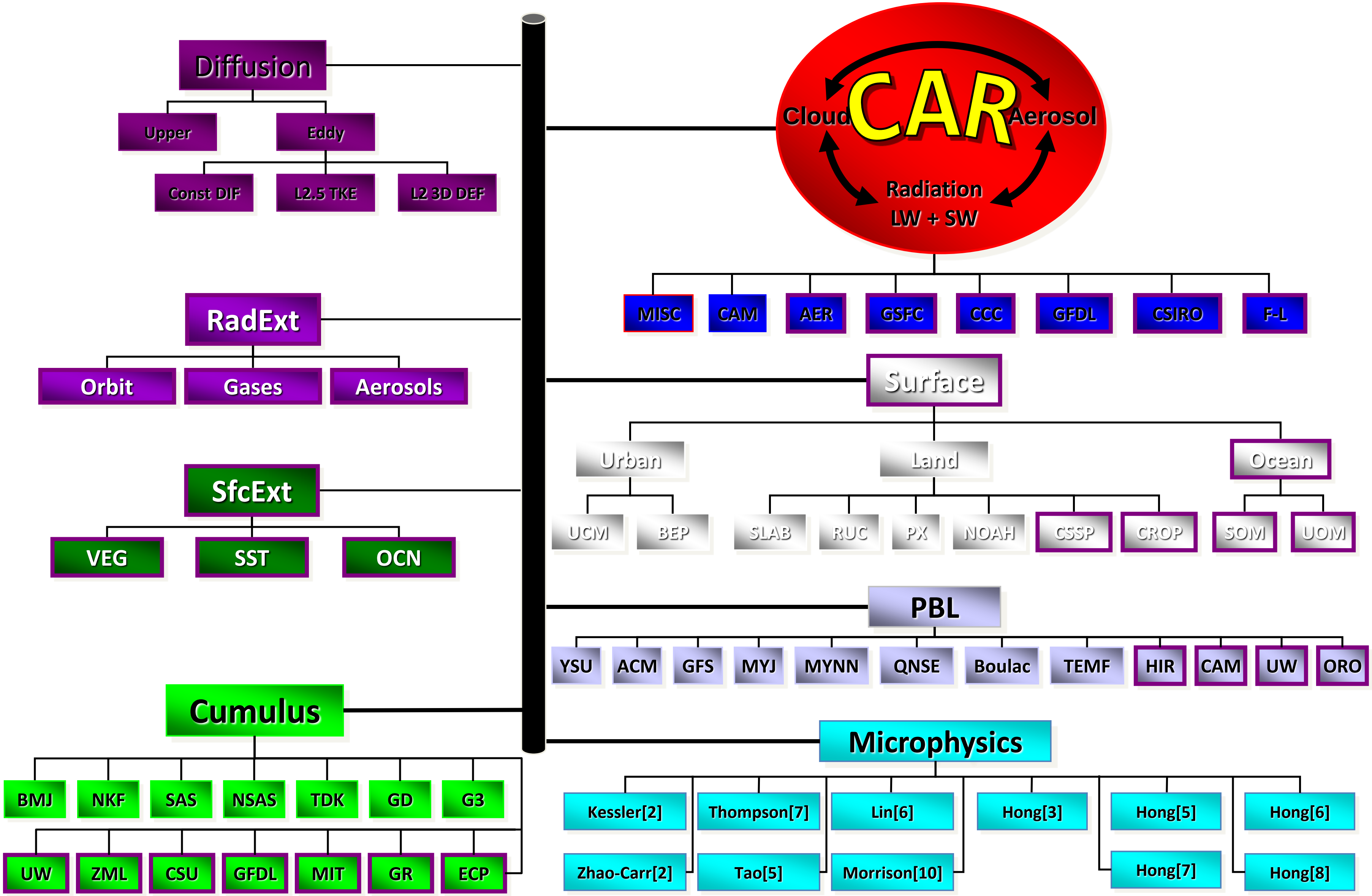
Optimizing the Web of Sensors must combine new platforms to synergize data needs for natural-human system interactions





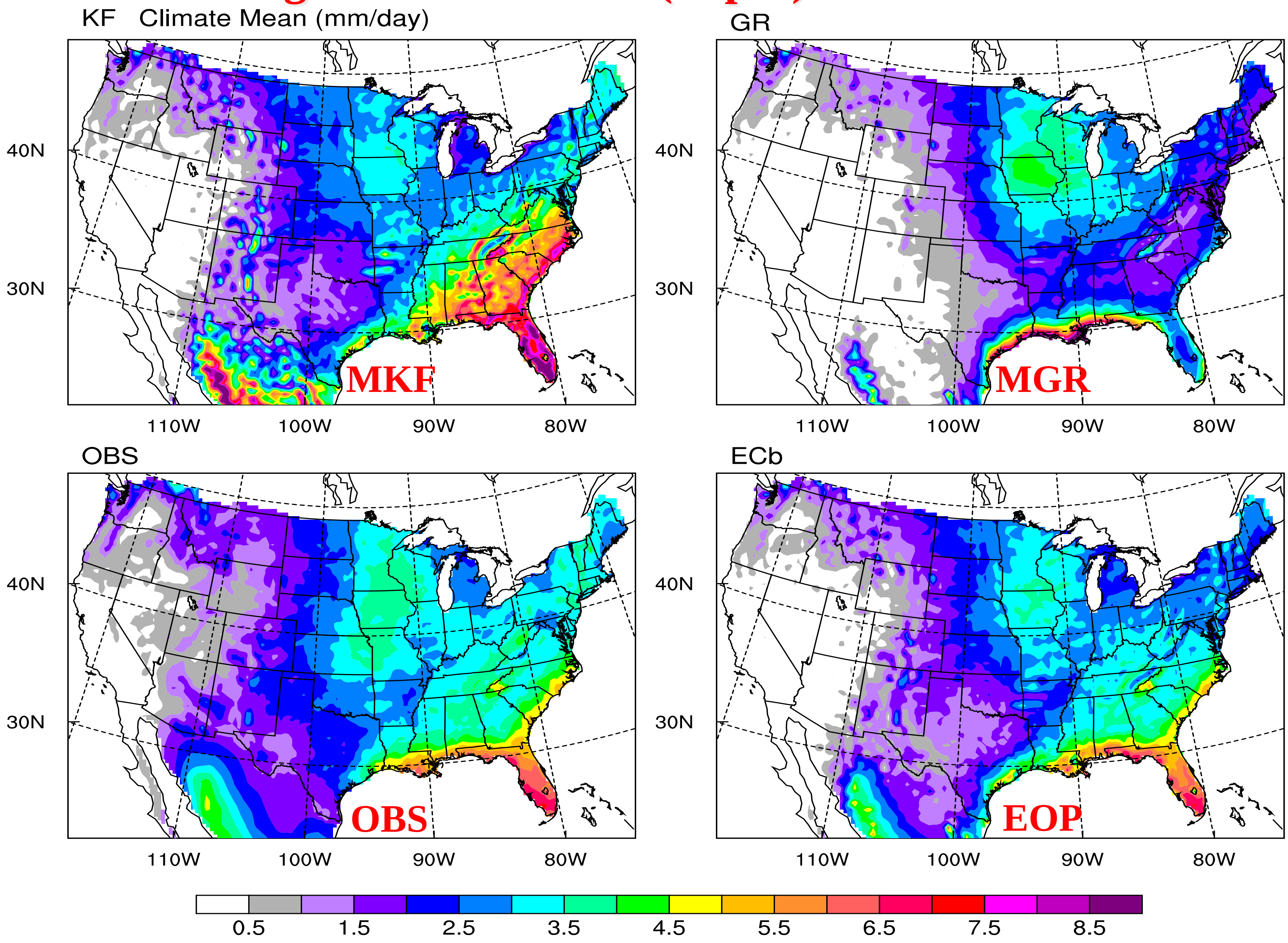


Are the Models Good Enough?

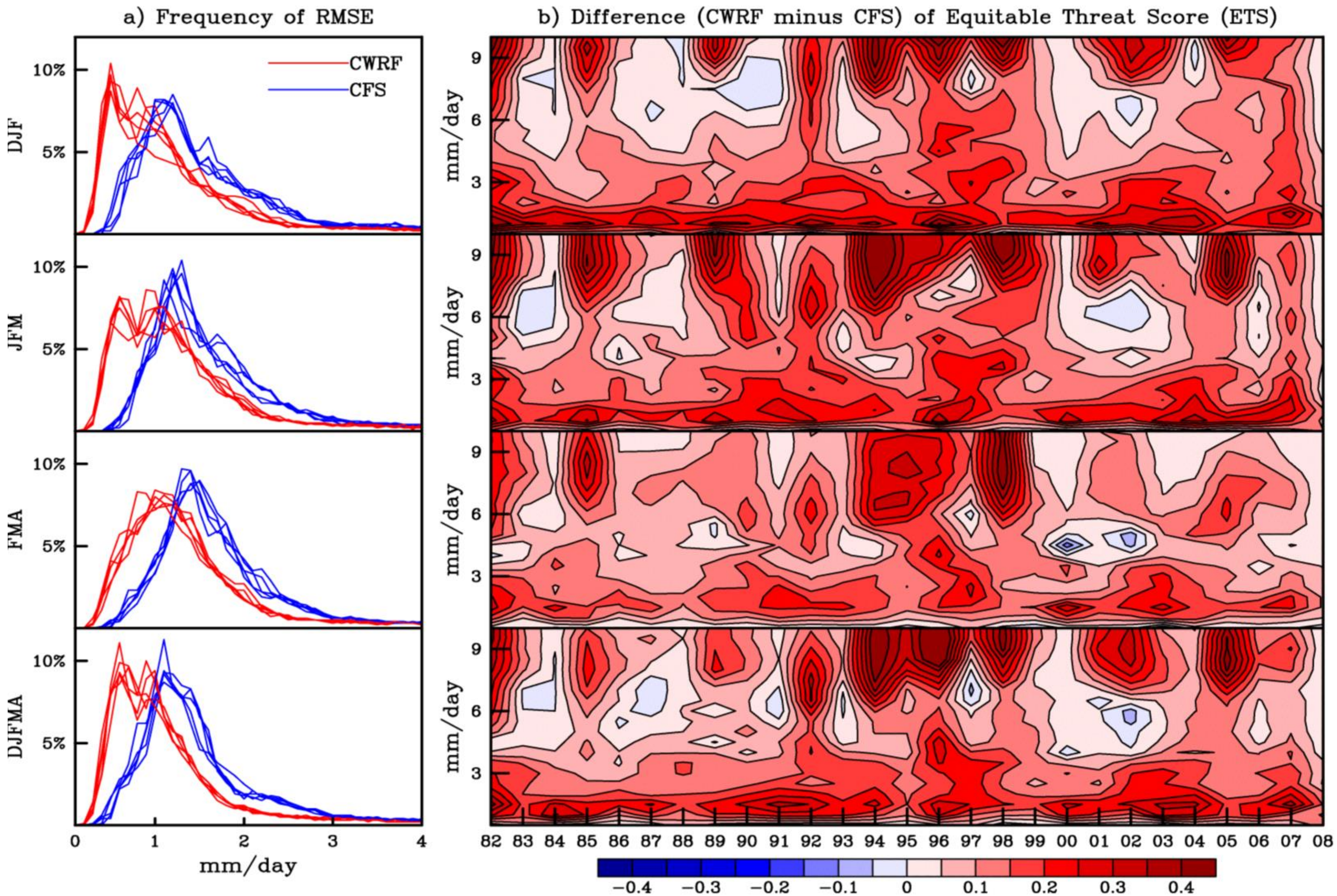


http://cwrf.umd.edu

Paradigms of Convective (Super) Parameterizations -

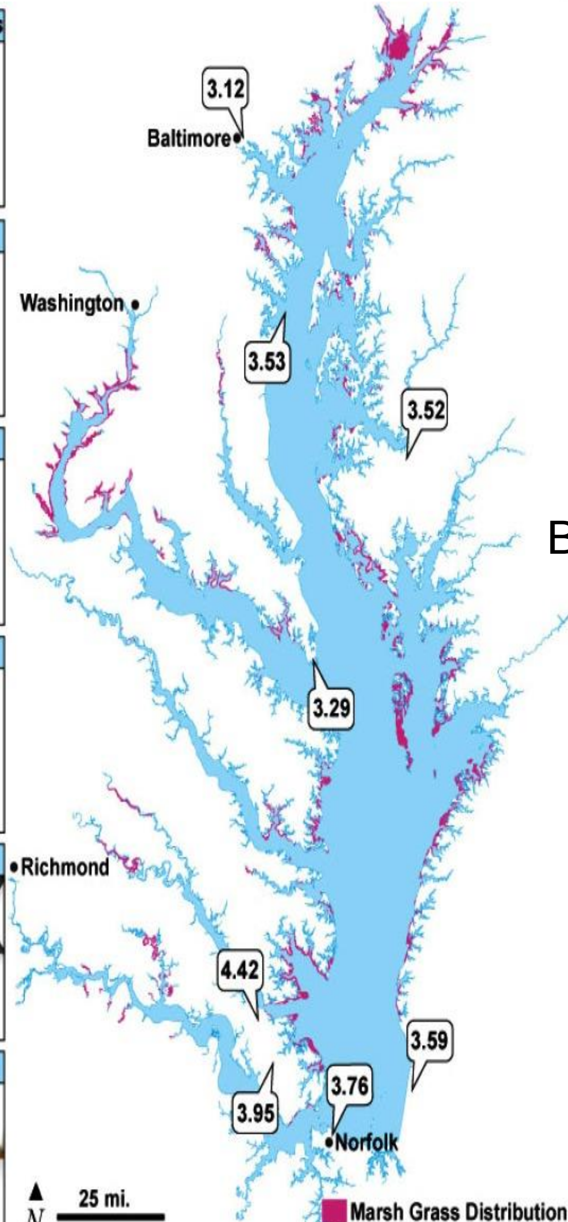


Extreme Events: Locally-forced or Remotely-forced?



a) Spatial frequency distributions of root mean square errors (*RMSE*, mm/day) predicted by the CFS and downscaled by the CWRF and **b)** CWRF minus CFS differences in the equitable threat score (*ETS*) for seasonal mean precipitation interannual variations. The statistics are based on all land grids over the entire inner domain for DJF, JFM, FMA, and DJFMA from the 5 realizations during 1982-2008. *From* Yuan and Liang 2011 (GRL).

An Example



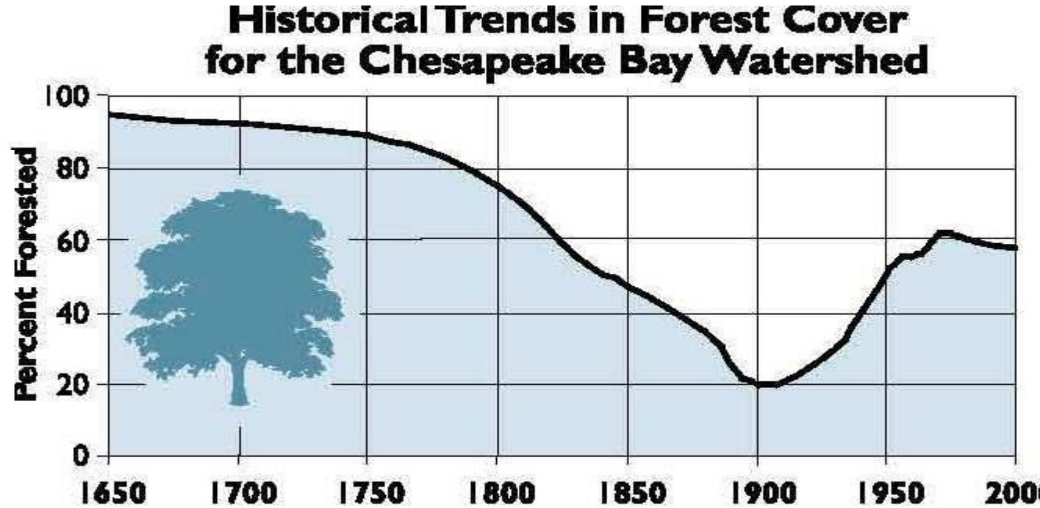


Figure 6-1. After bottoming out in the early 1900s, forest cover regained acreage throughout much of the last century. Recent decades show a slight decline.

Boesch and Greer 2003

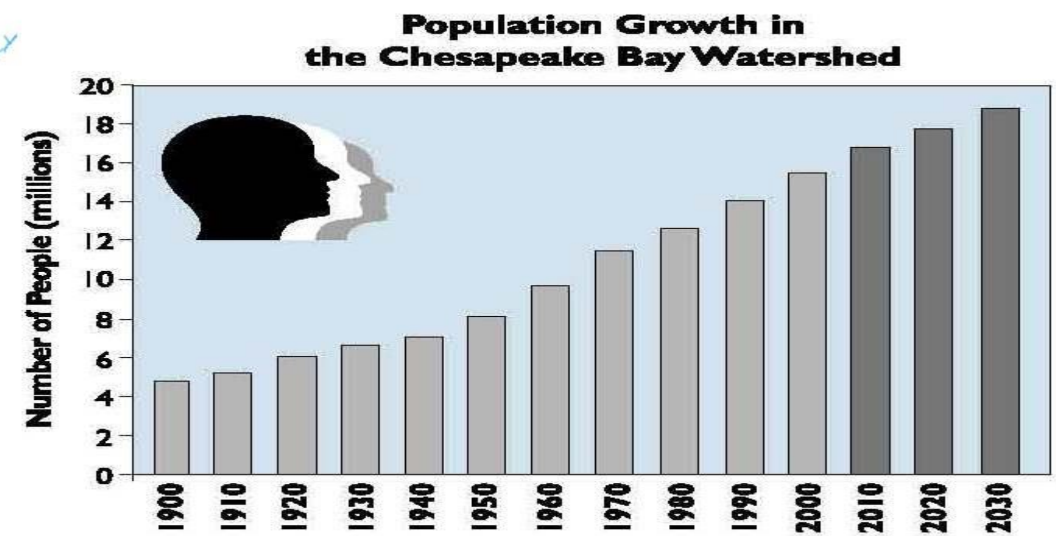
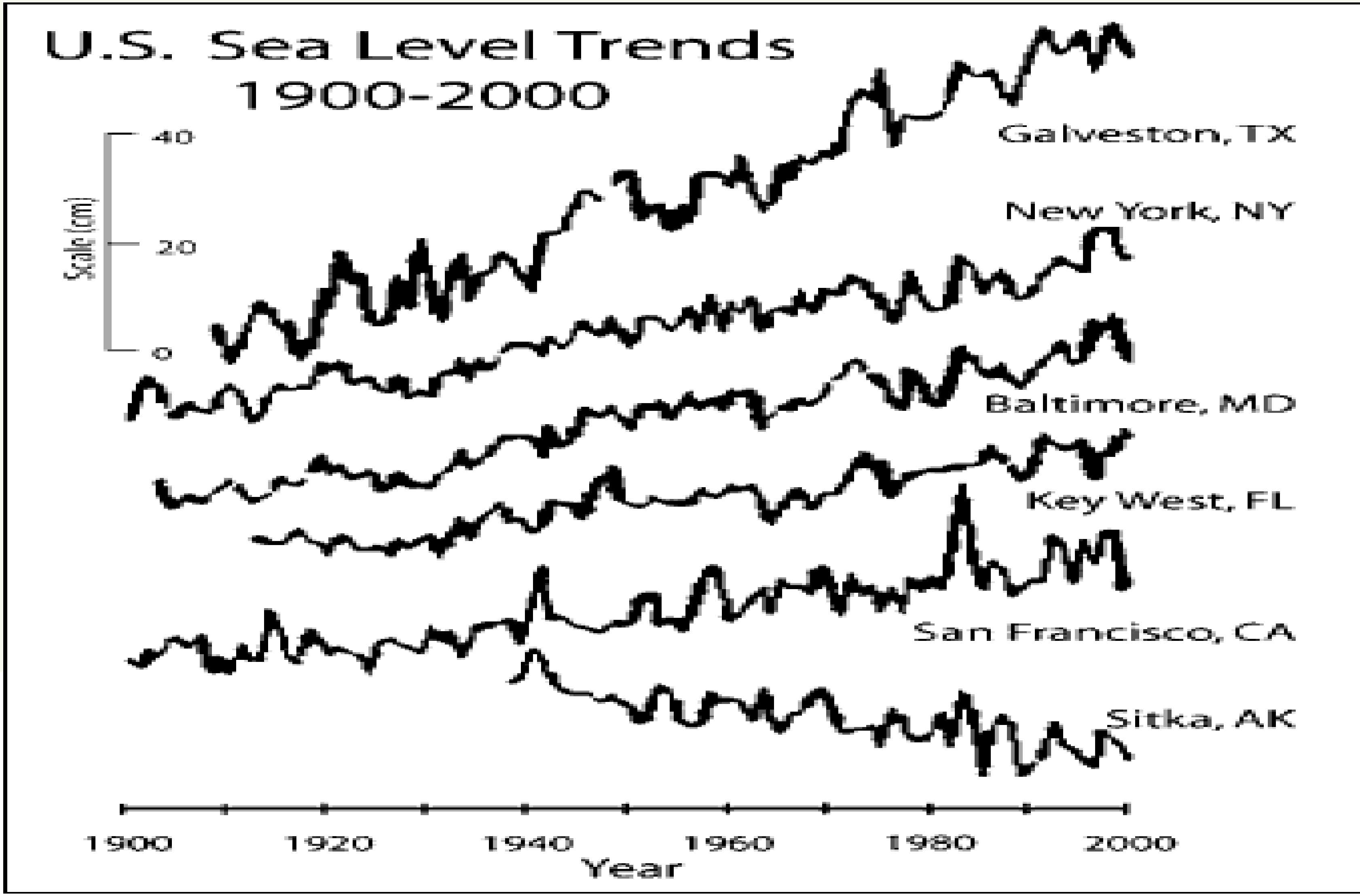


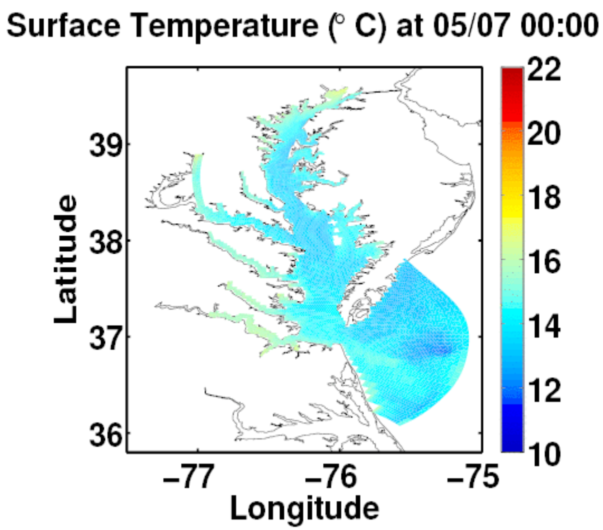
Figure 2-1. Since the beginning of the last century, population levels have shown a steady increase in the Bay watershed. Experts predict that numbers will continue to rise through the next three decades.

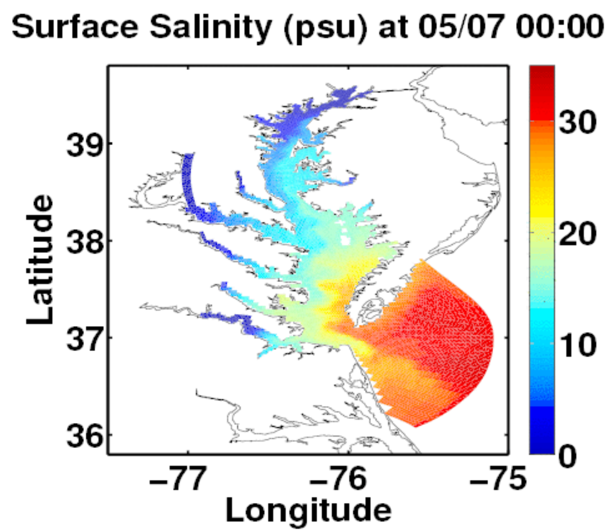
Regional Specificity is critical for usability and use

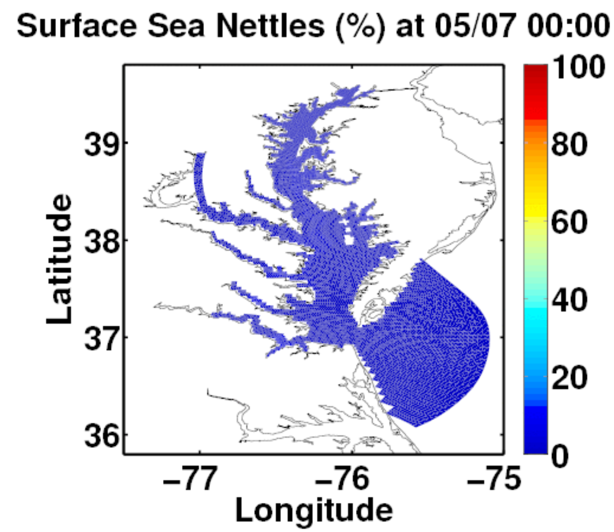


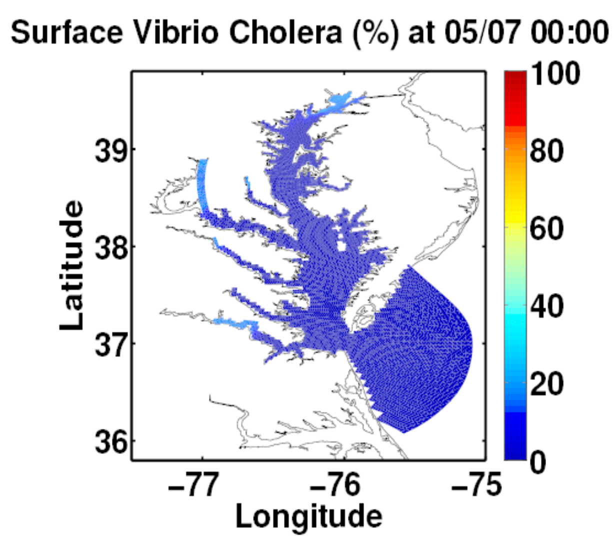
Measured sea level rise, in centimeters, for selected U.S. cities from 1900 to 2000. Rises in sea levels can exacerbate erosion and leave low-lying areas more vulnerable to severe weather. (Data from NOAA, Graph available from the US EPA)

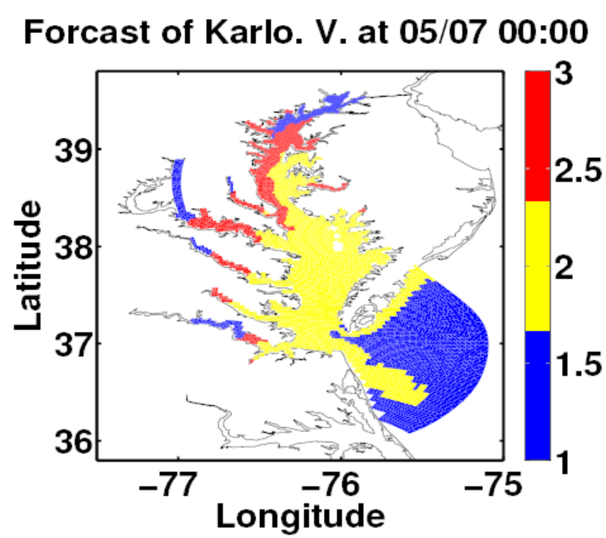
14 Days Ocean Forecasts (2013/05/07-2013/05/21)



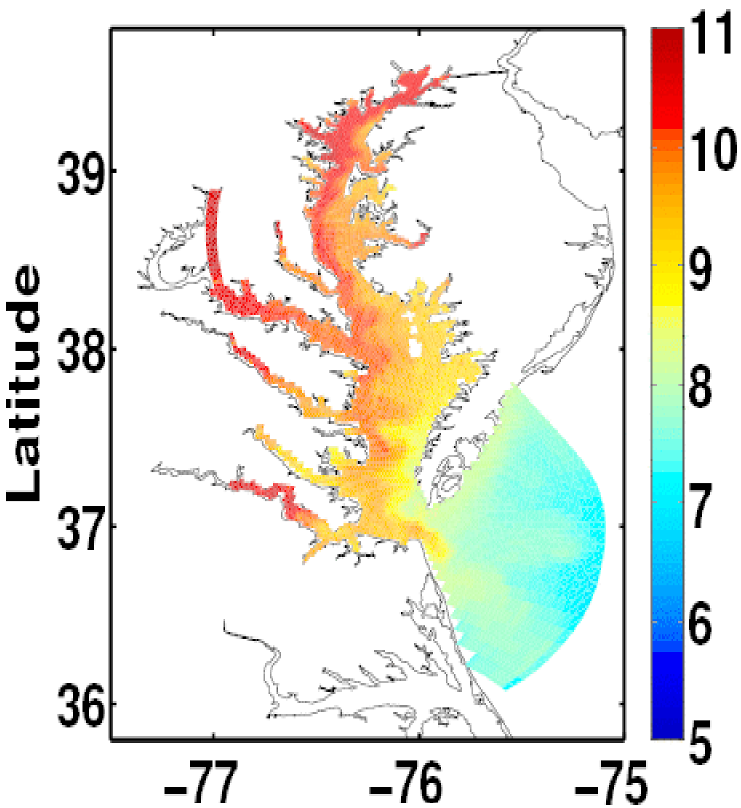






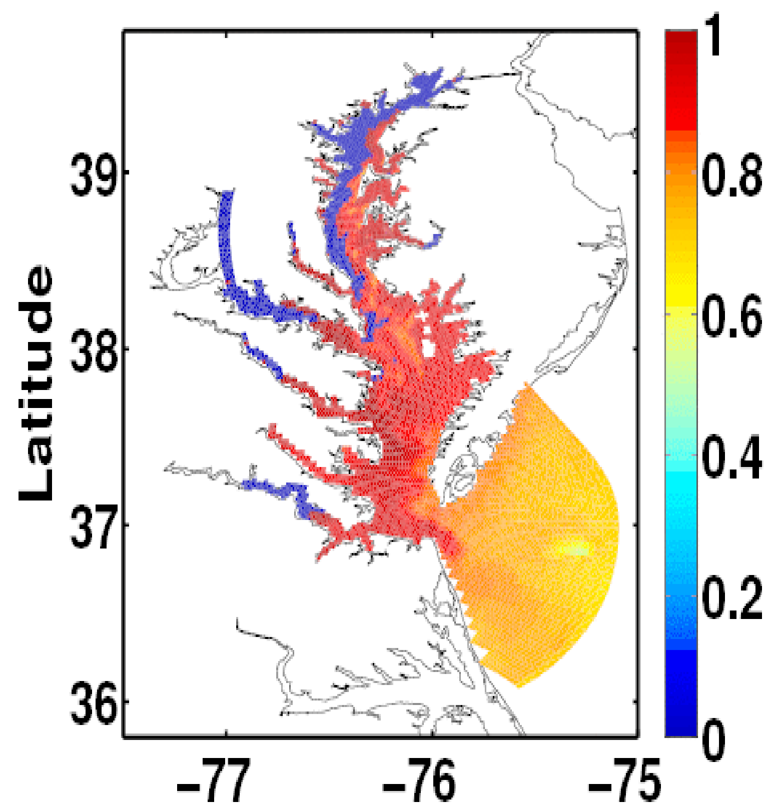


Forcast of DO at 05/07 00:00

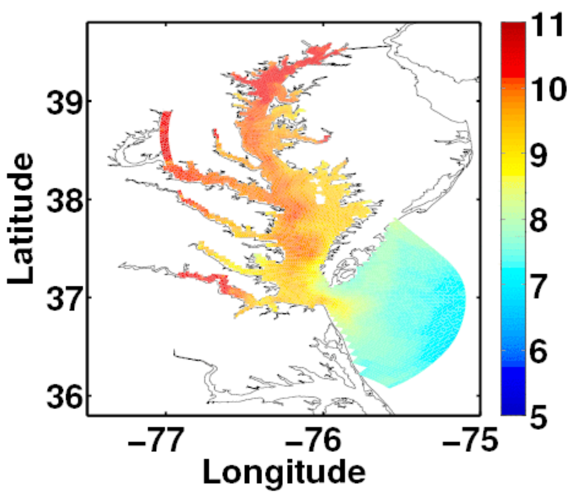


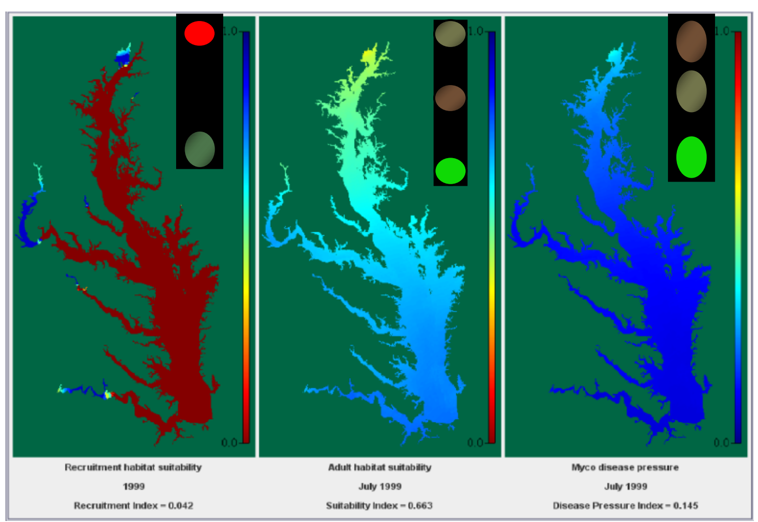
What do the users really want?

Forcast of SBI at 05/07 00:00

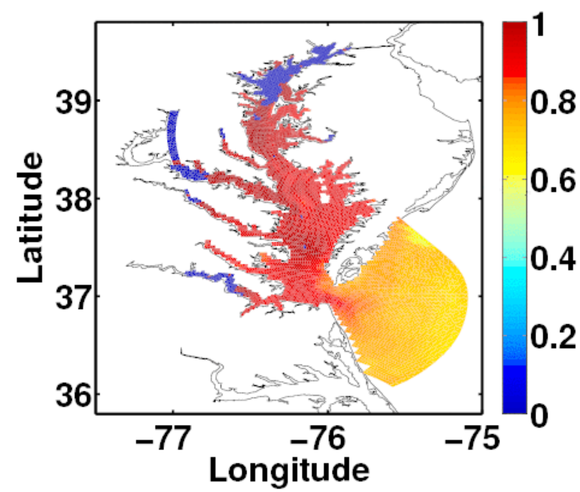


Forcast of DO at 05/01

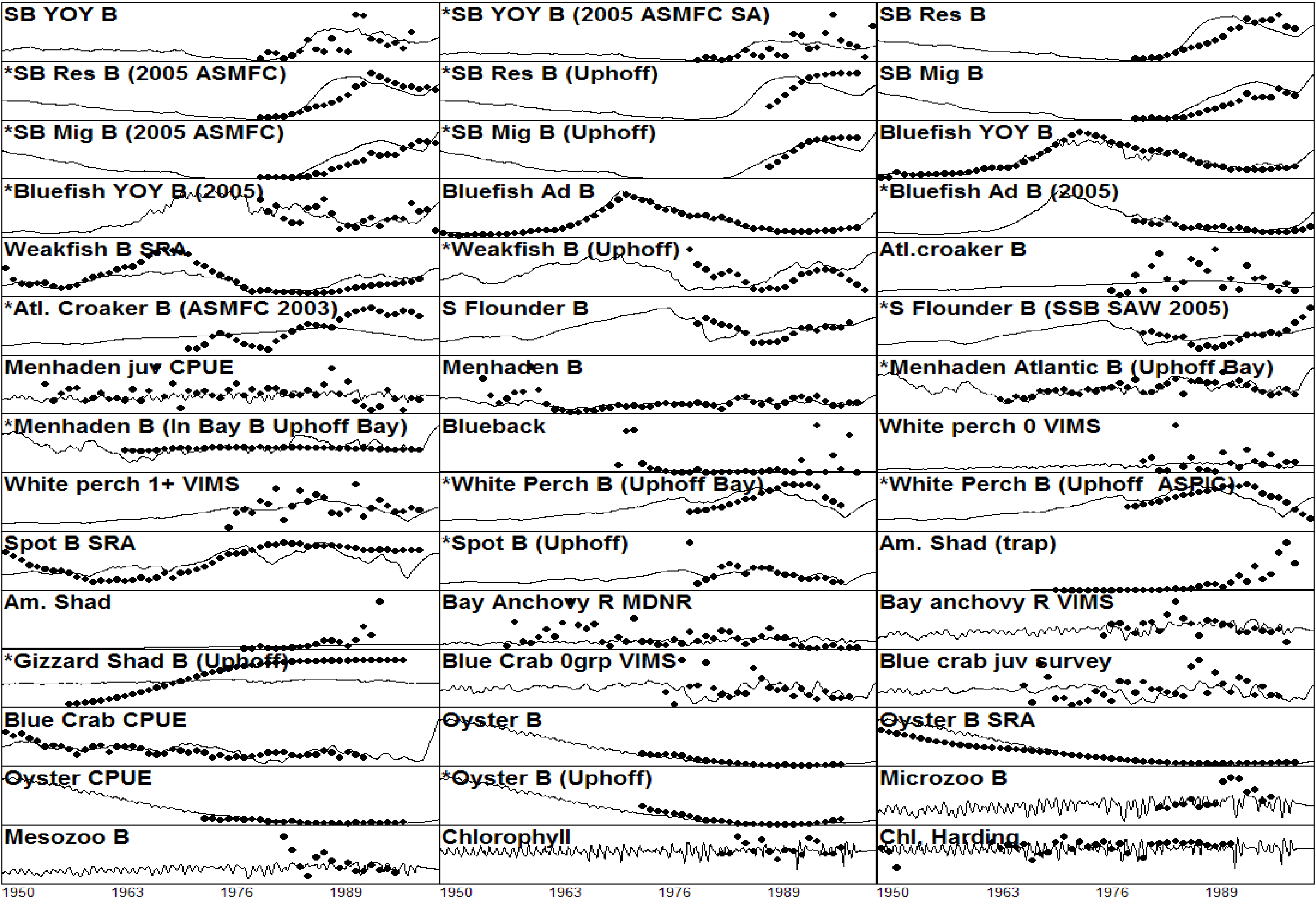




Forcast of SBI at 05/01

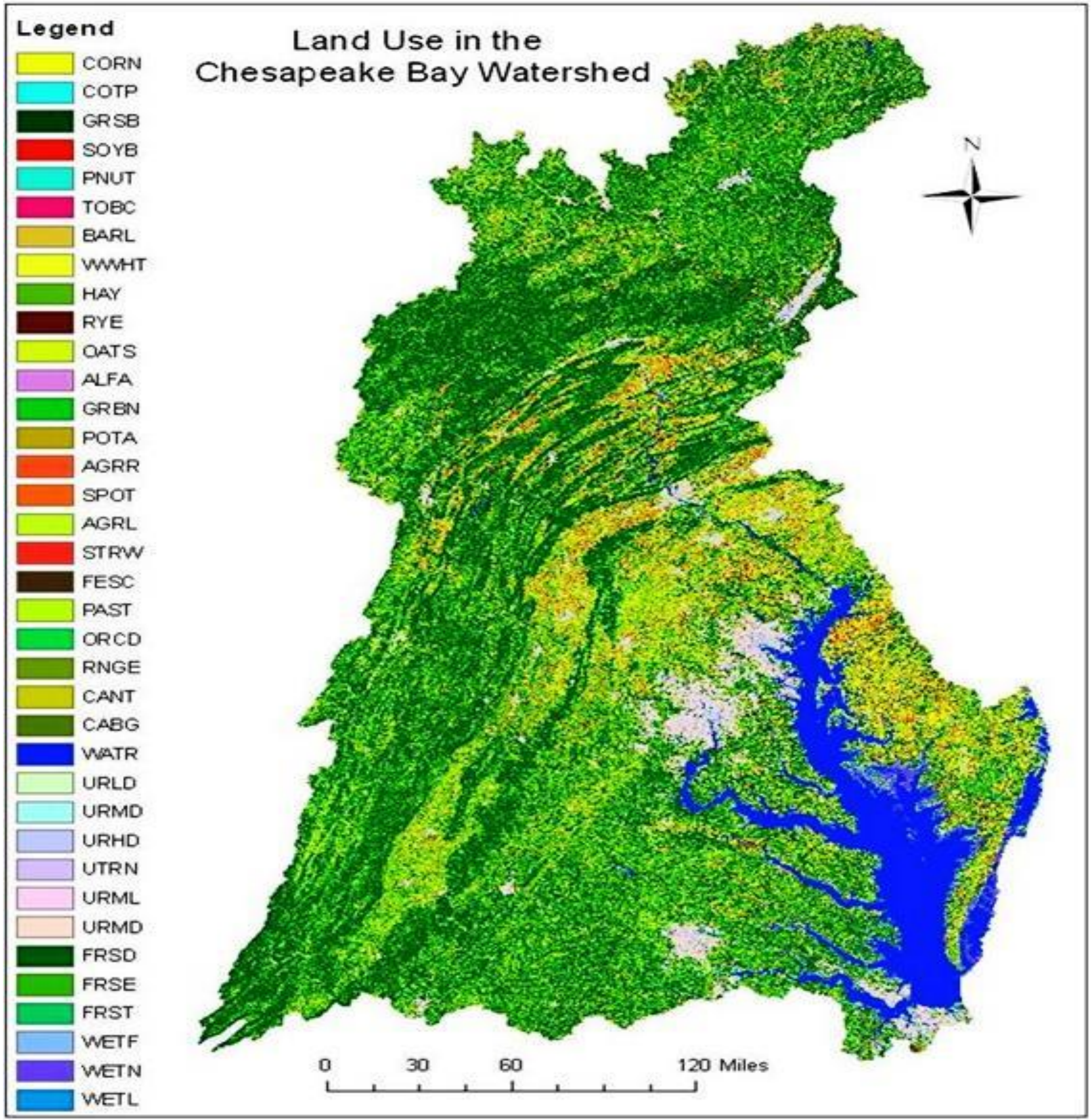


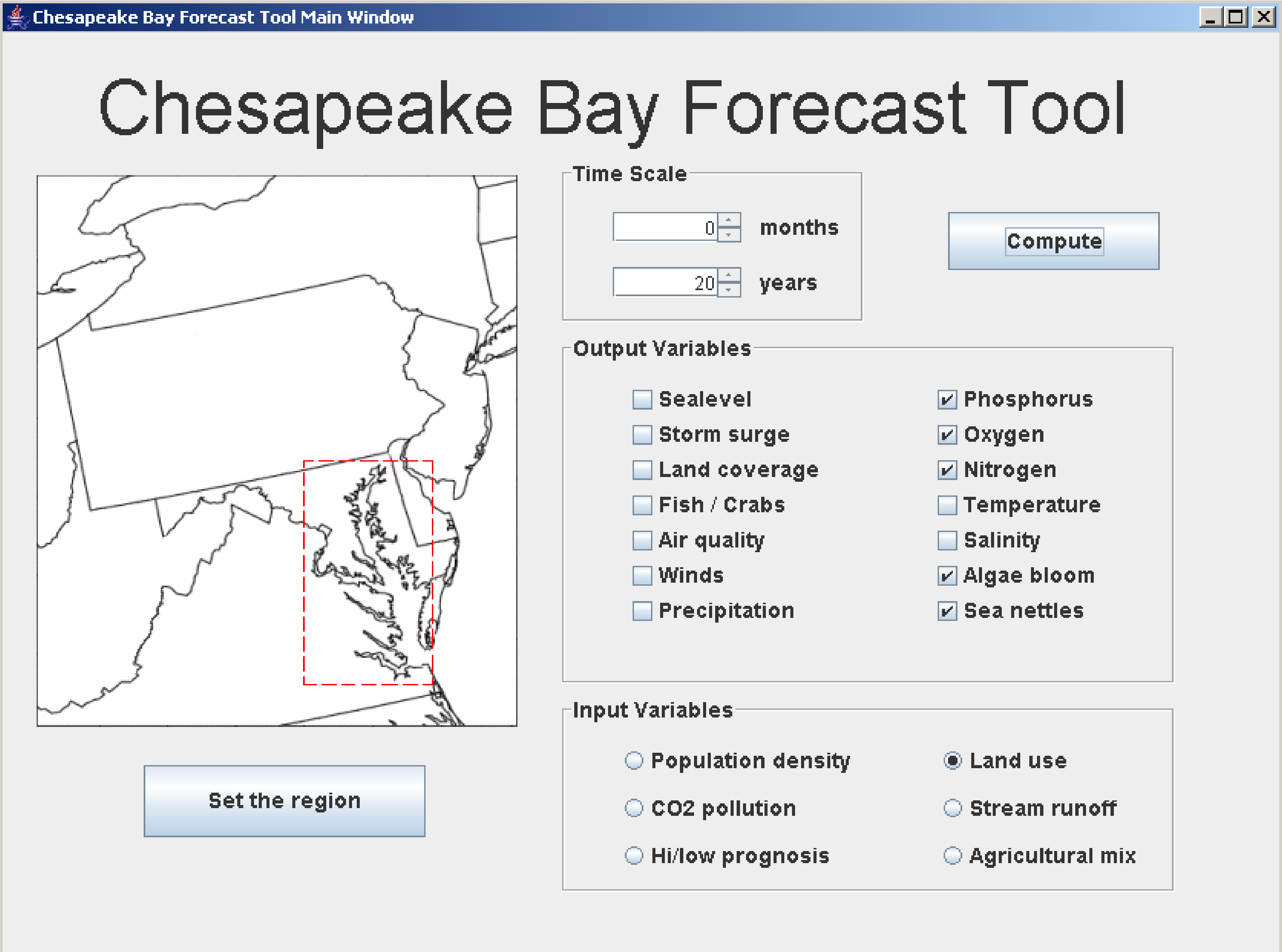
Complexity, Productivity, and Resilience – Impact of Global Monsoon

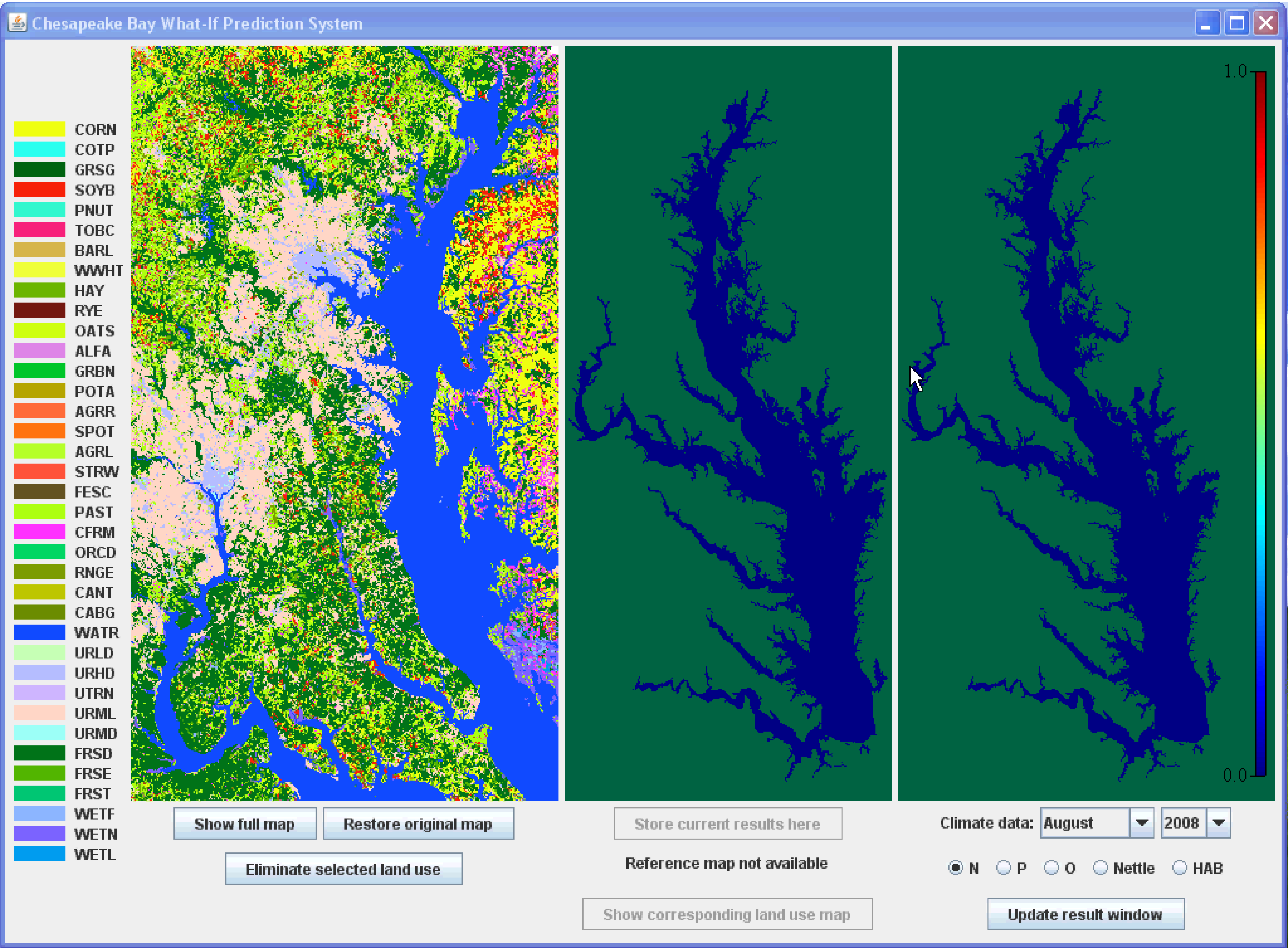


Hydrologic Modeling, Predictions and Projections: Probably the MOST Critical

- On a 30 m square!
- Soil look up tables, manure/fertilizer applications, water withdrawals, crop types, wetlands, riparian buffers, forests, Best Management Practices
- Data from EPA, USGS, DNR, MDE, USDA
- Can provide details needed for effective policy and management




Chesapeake Bay Forecast Tool Main Window
Chesapeake Bay Forecast Tool
Time Scale
0
months
20
years
Compute
Output Variables
Sealevel
Storm surge
Land coverage
Fish / Crabs
Air quality
Winds
Precipitation
Phosphorus
Oxygen
Nitrogen
Temperature
Salinity
Algae bloom
Sea nettles
Input Variables
Population density
CO2 pollution
Hi/low prognosis
Land use
Stream runoff
Agricultural mix
Set the region



Chesapeake Bay What-If Prediction System
CORN
COTP
GRSG
SOYB
PNUT
TOBC
BARL
WWHT
HAY
RYE
OATS
ALFA
GRBN
POTA
AGRR
SPOT
AGRL
STRW
FESC
PAST
CFRM
ORCD
RNGE
CANT
CABG
WATR
URLD
URHD
UTRN
URML
URMD
FRSD
FRSE
FRST
WETF
WETN
WETL
1.0
0.0
Show full map
Restore original map
Eliminate selected land use
Store current results here
Reference map not available
Show corresponding land use map
Climate data:
August
2008
N
P
O
Nettle
HAB
Update result window

Too much water or Too little water: Guidance needed for both issues

Diseases related to flooding:

Water- and food-borne

- Cholera
- Typhoid
- Hepatitis A
- Diarrhoea
- Dysentery

Vector-borne

- Malaria
- Dengue/dengue haemorrhagic fever

Due to direct contact with contaminated water

- Dermatitis
- Conjunctivitis
- Ear, nose and throat infections
- Wound infections
- Leptospirosis

Due to exposure to water/rain

- Hypothermia
- Respiratory tract infections

Effects on mental health

- Sleep disorders
- Excessive grief and depression
- Exacerbation of existing illnesses

Major floods in the SEA Region 2003-2007

YEAR	COUNTRY	IMPACT
2003	Nepal	239 Killed 284 injured 15 575 homeless 43 395 affected
	Indonesia	241 killed 30 injured 1468 affected
	Sri Lanka	235 killed 695 000 affected US$ 29 000 damage
2004	Bangladesh	730 killed 36 000 000 affected US$ 2 200 000 000 damage
	Nepal	185 killed 15 injured 800 000 affected
2005	India	1200 killed 55 injured 20 000 000 affected US$ 3 330 000 000 damage
2006	Thailand	116 killed 342 895 affected US$ 25 000 000 damage
	Indonesia	236 killed 56 injured 670 homeless 28 505 affected US$ 55 200 000 damage
	Thailand	164 killed 2 212 413 affected US$ 9 940 000 damage
	Sri Lanka	25 killed 2 injured 333 000 affected US$ 3 000 000 damage
	India	350 killed 65 injured 4 000 000 homeless US$ 3 390 000 000 damage
2007	Indonesia	40 killed 1 injured 400 000 affected US$ 695 000 000 damage

DOs & DONT's

Water-Borne Diseases

DO's

- Drink water from a safe source or water that has been disinfected preferably boiled or chlorinated.
- Store water in narrow-mouthed containers.
- Cook food or reheat it thoroughly and eat while it is still hot.
- Keep food items covered.
- Wash hands before preparing or eating food and after defecation.
- Increase fluid intake in case of diarrhoea. Use ORS solution or home-made fluids as soon as diarrhoea is detected.
- Refer diarrhoea case to a health facility in case of the following:
  - Child is irritable, restless or lethargic or unconscious.
  - Child is eating or drinking poorly.
  - Child has marked thirst.
  - Child has fever or blood in stool.

DON'Ts

- Don't drink water from unsafe sources.
- Don't eat uncooked food unless it is freshly peeled or shelled.
- Don't eat cut fruits.
- Don't defecate indiscriminately.

Vector Borne Diseases

DO's

- Use insecticide-treated mosquito nets (ITN) or insect repellents while sleeping to keep mosquitoes away.
- Wear clothing that cover arms and legs.
- Keep patients protected from mosquito bites in the acute phase.
- Empty water containers at least once a week. Cover and seal septic tanks and soak-away pits.
- Remove water from coolers and other places where water remains stagnant.
- All cases of fever to be given presumptive treatment for malaria.

DON'Ts

- Don't allow water to stagnate.
- Don't allow discarded items such as tyres, tubes, empty coconut shells, and household objects where water may collect to accumulate.
- Discourage children from wearing shorts and half-sleeved clothes.

Food-borne diseases

KEEP FOOD AT SAFE TEMPERATURES (prevent growth of microorganisms)

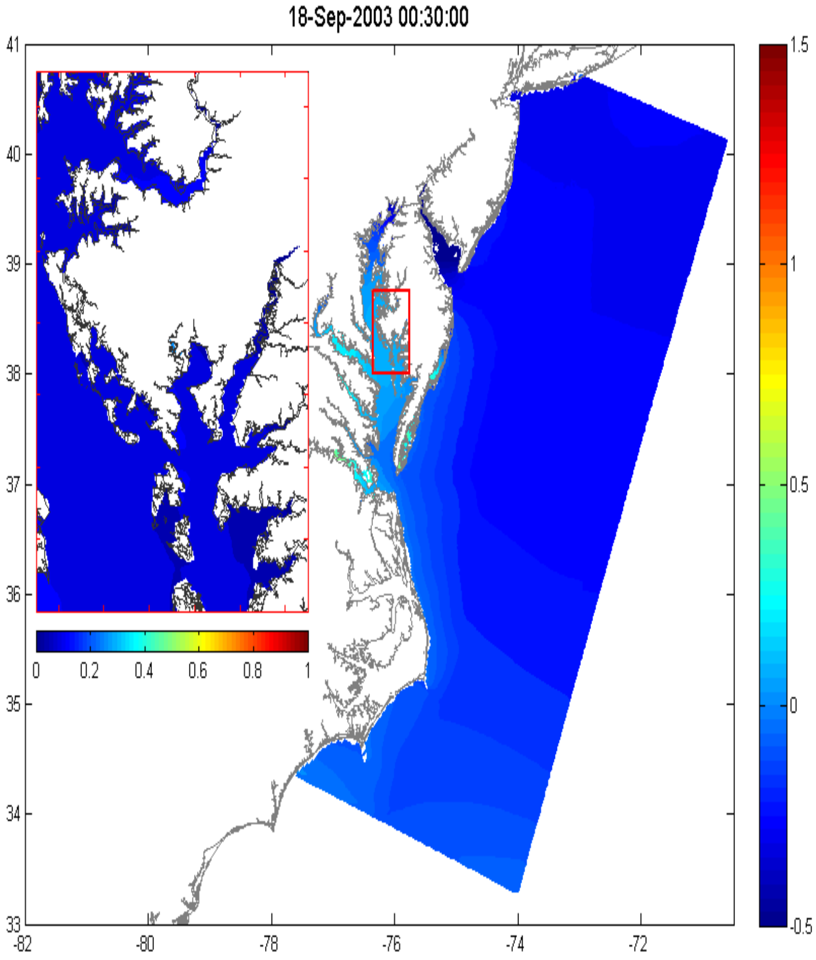
- Eat cooked food immediately and do not leave cooked food at room temperatures for longer than two hours.
- Cooked food must be steaming hot (more than 60°C) prior to serving.
- Cooked and perishable food that cannot be refrigerated (below 5°C) should be discarded.

COOK THOROUGHLY (kill dangerous microorganisms)

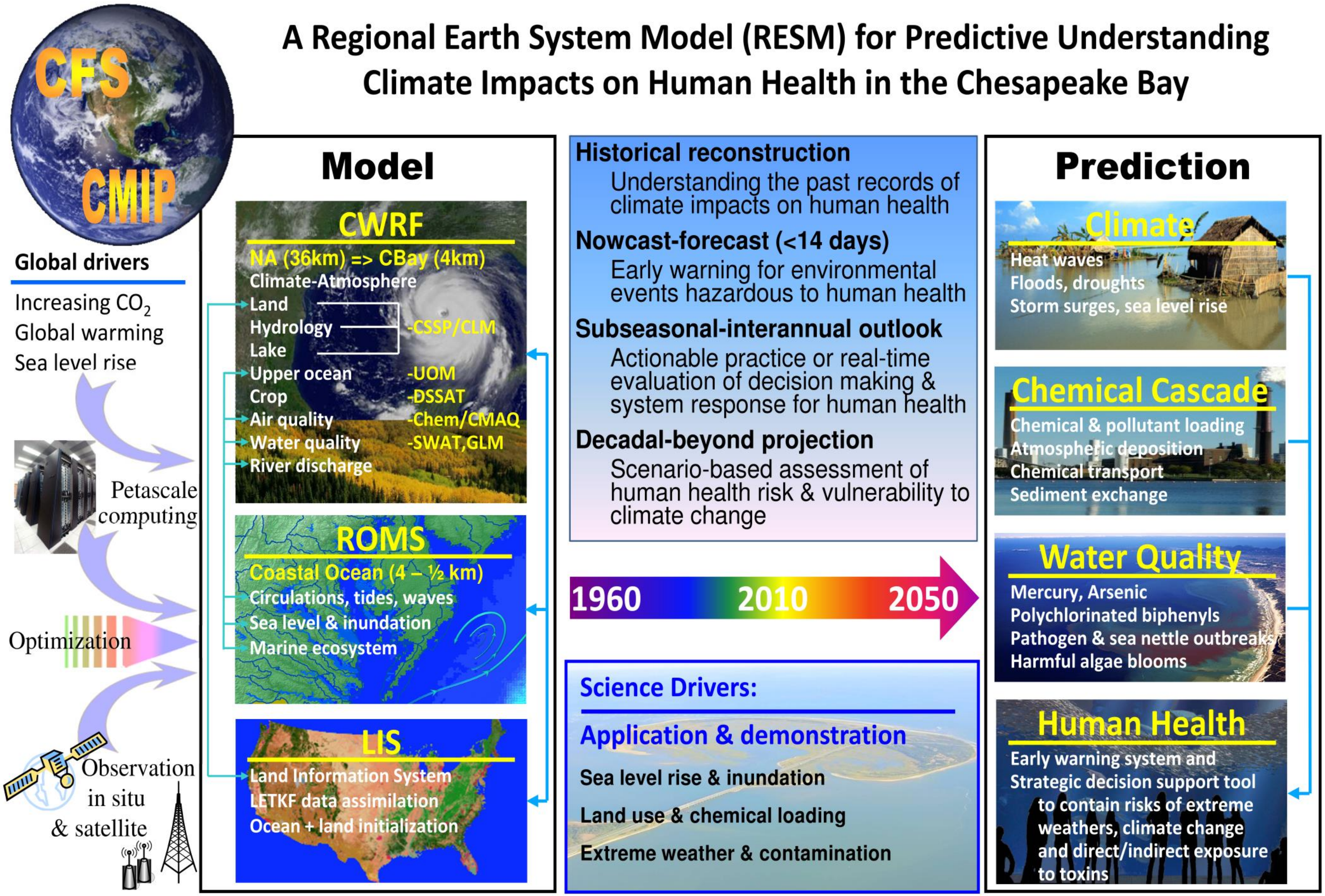
- Cook food, especially meat, poultry, eggs and seafood thoroughly until it is steaming hot throughout.
- For cooked meat and poultry to be safe their juices must run clear and no part of the meat should be visibly red or pink
- Bring soups and stews to boiling and continue to boil for at least 15 minutes
- Eat food immediately after it has been cooked. If it is necessary to eat later, reheat cooked food until it is steaming hot.

Usability and Timeliness

- Accessible streets, Hospital evacuations, resource allocations
- User Interfaces and rapid responses to special requests



Propagation of Errors and Uncertainties in Complex Systems



2. A Summary of Requirements for a Useful Forecast

It is now possible to list the general requirements for predictions to be useful to a user community.

(i) The forecasts must match the time scales of the major phenomenological time periods in the particular region. For example in the monsoon regions forecasts should be of seasonal anomalies, intraseasonal variability, and weather. It is understood that spatial resolution for a forecast is inversely proportional to the time scale.

(ii) The forecasts should be overlapping in order to allow strategic decisions to be made at the longest time period and tactical decisions to be made at the shorter time scales.

(iii) The forecasts must be probabilistic. Only in this manner can a user of the forecast make a reasoned cost-loss analysis.

(iv) The forecast should be user specific or can be rendered into information that is useful to the user, and;

(v) User information should be included into the forecast process.

Subsequently, we will address these latter two points in the creation of a User Metric in section x.

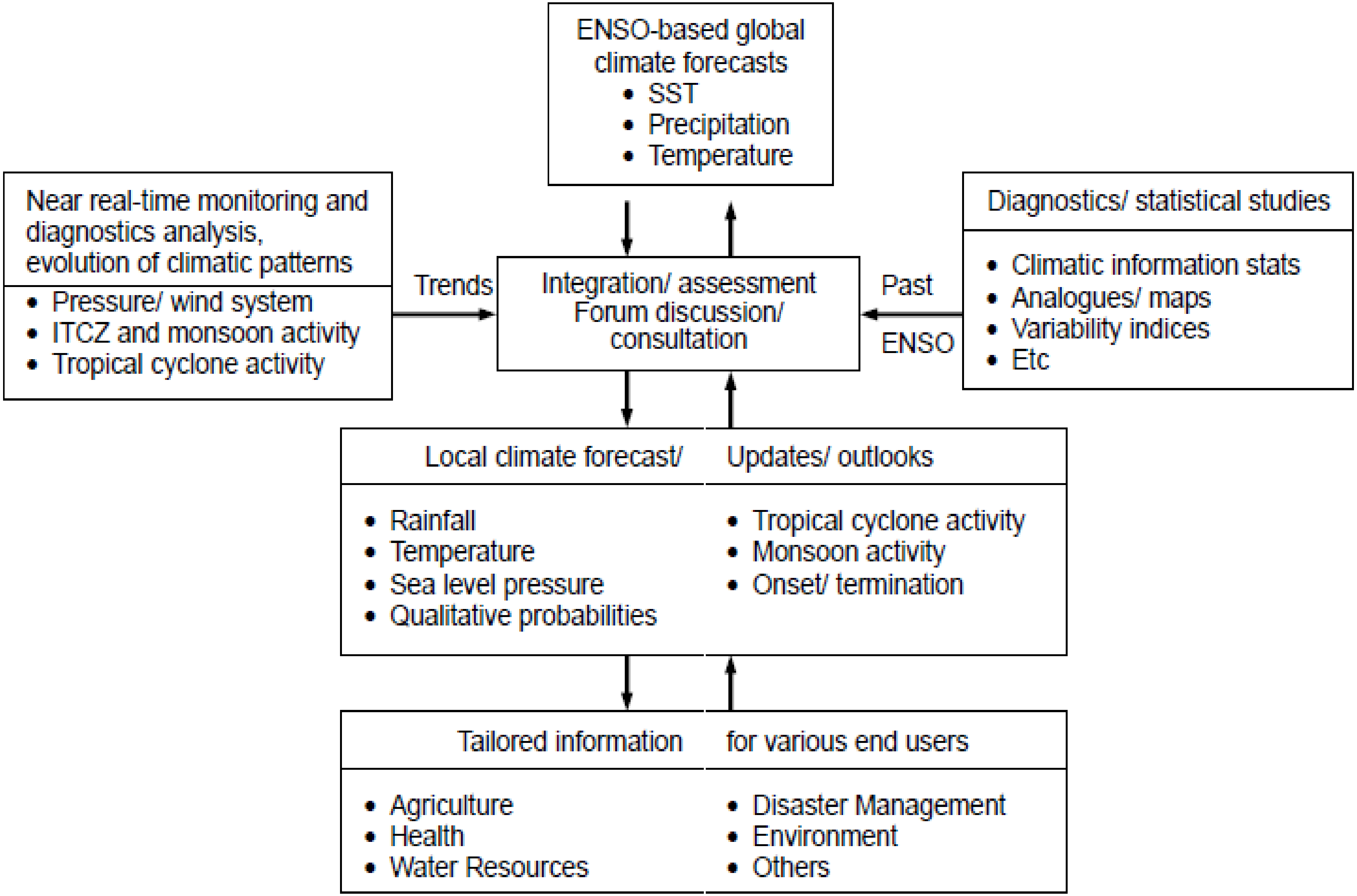


Figure 3. Translation of ENSO-based global climate forecasts into local climate forecast

(i) The generation of a river discharge and precipitation operational forecasting system available in real-time with forecasts provided on a three-tier time system: seasonal outlooks (1-6 months), intermediate (20-30 days) and short term (1-10 days) using state-of-the-art models or with models developed specifically for the Bangladesh problem;

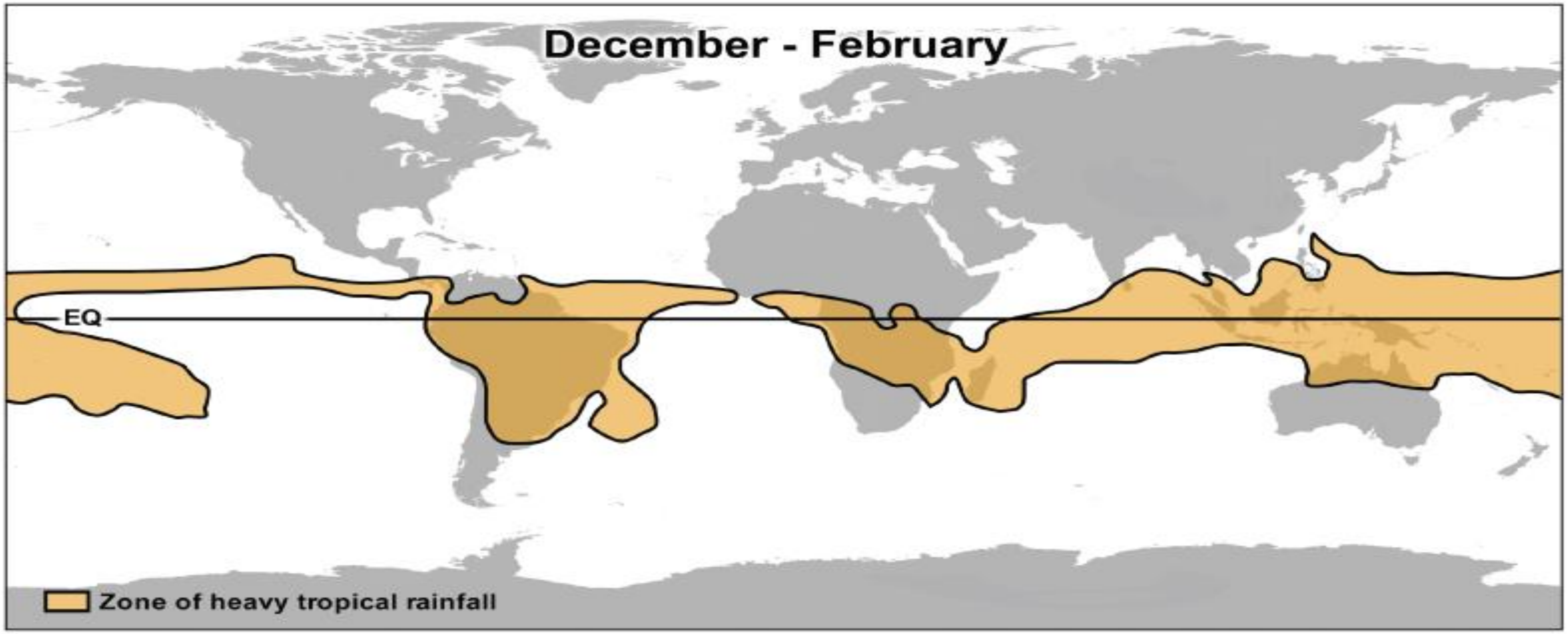
(ii) Creation of a collaborative enterprise between international (US and Europe) and Bangladeshi partners for the forecasting of the probability of floods on time scales of days to months leading to the transfer of the techniques and technology to the appropriate Bangladeshi partners;

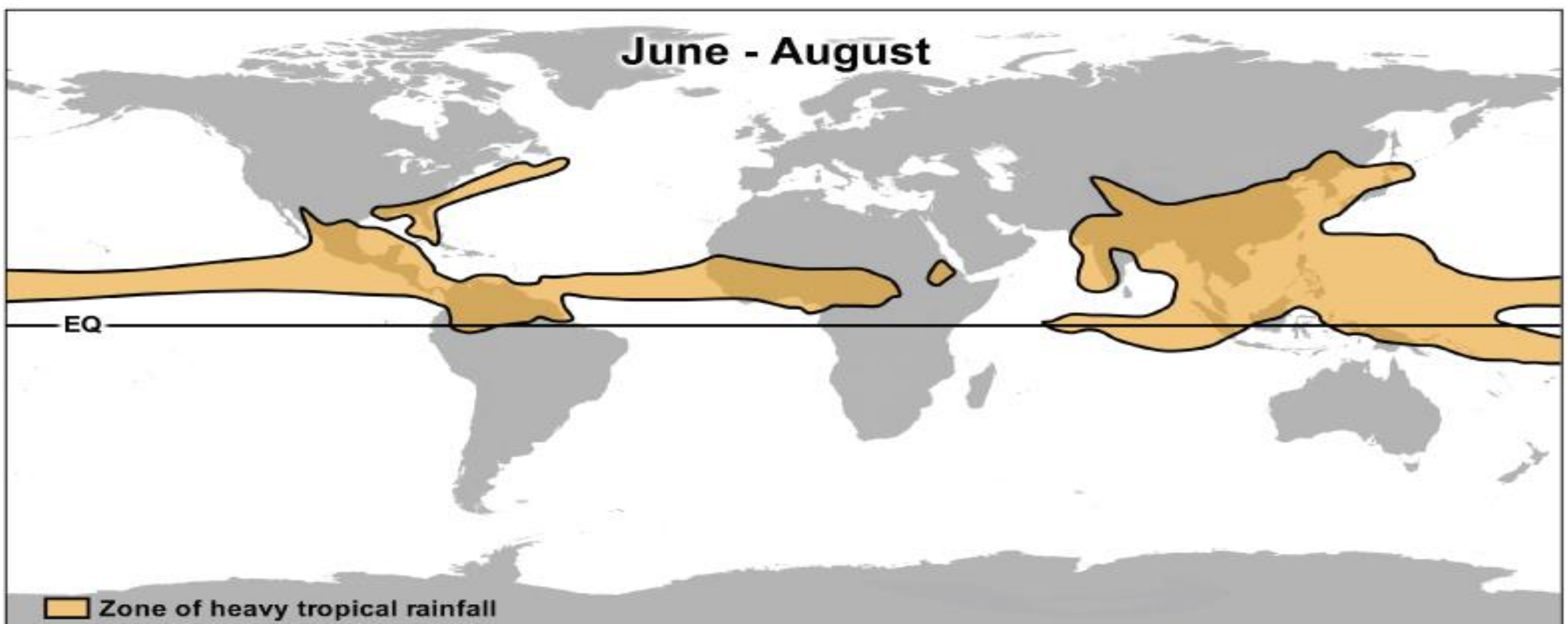
(iii) The development of an infrastructure that allows the application of the forecasts by Bangladeshi scientists, engineers, agricultural extension, disaster relief organizations and other user groups;

(iv) The development of methods and tools for the transfer of forecast information to the user community, and;

(v) The transfer of the forecasting technology to the Bangladeshis in a form that is immediately useable in an operational sense and modifiable for other uses and eventually to the larger monsoon community of Asia and Africa.

How do we advance Global and Regional Process Understanding?





Is the Global Monsoon responding as one system? If not, then what?

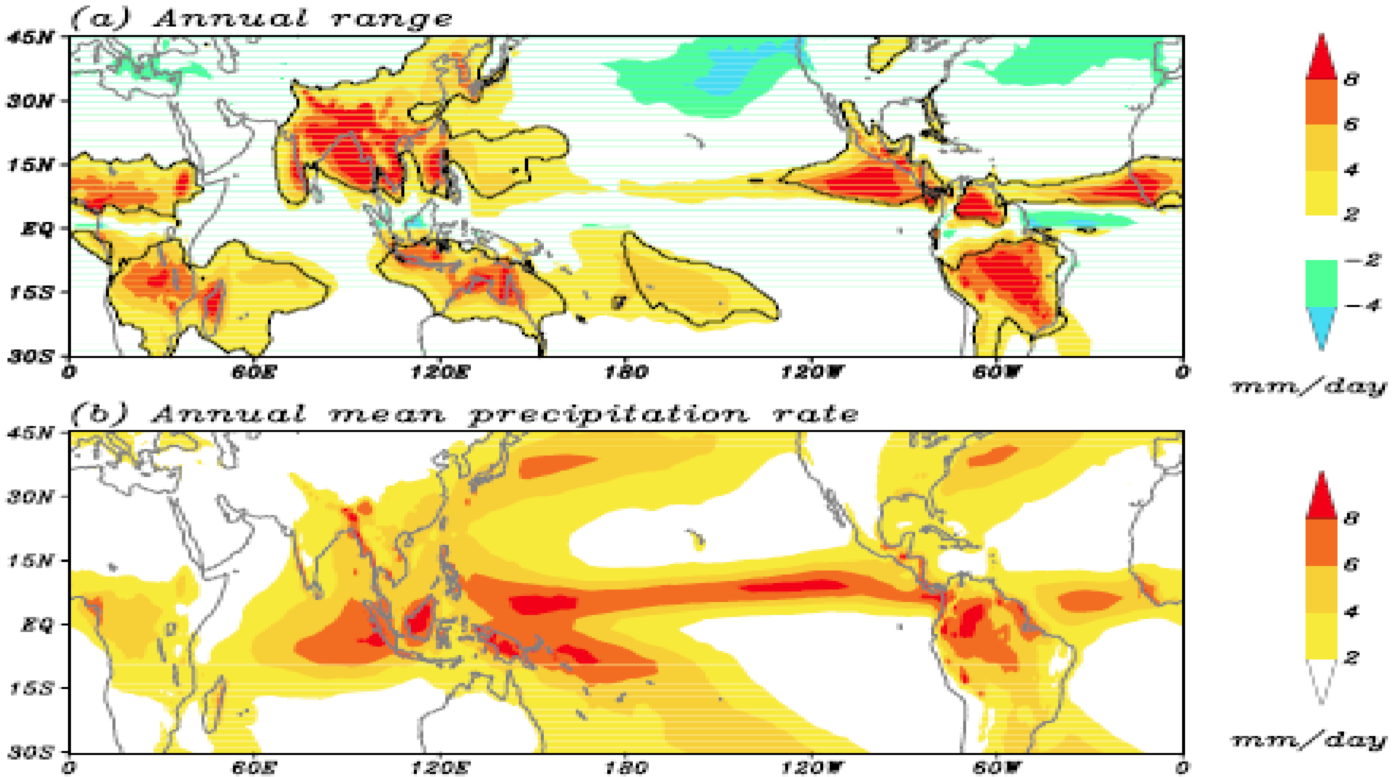


Figure 1. (a) The climatological mean for the annual range of precipitation, defined by the local summer mean precipitation rate (June to August in the Northern Hemisphere, and December to February in the Southern Hemisphere) minus the local winter mean precipitation rate. The bold lines delineate the global monsoon domain. (b) The long-term mean for total annual precipitation. The data used are a blended GPCP data (1979–2003) and the means of the four precipitation data sets (described in the text) for the period of 1948–2003.

What really are the advantages of defining a 'Global Monsoon'

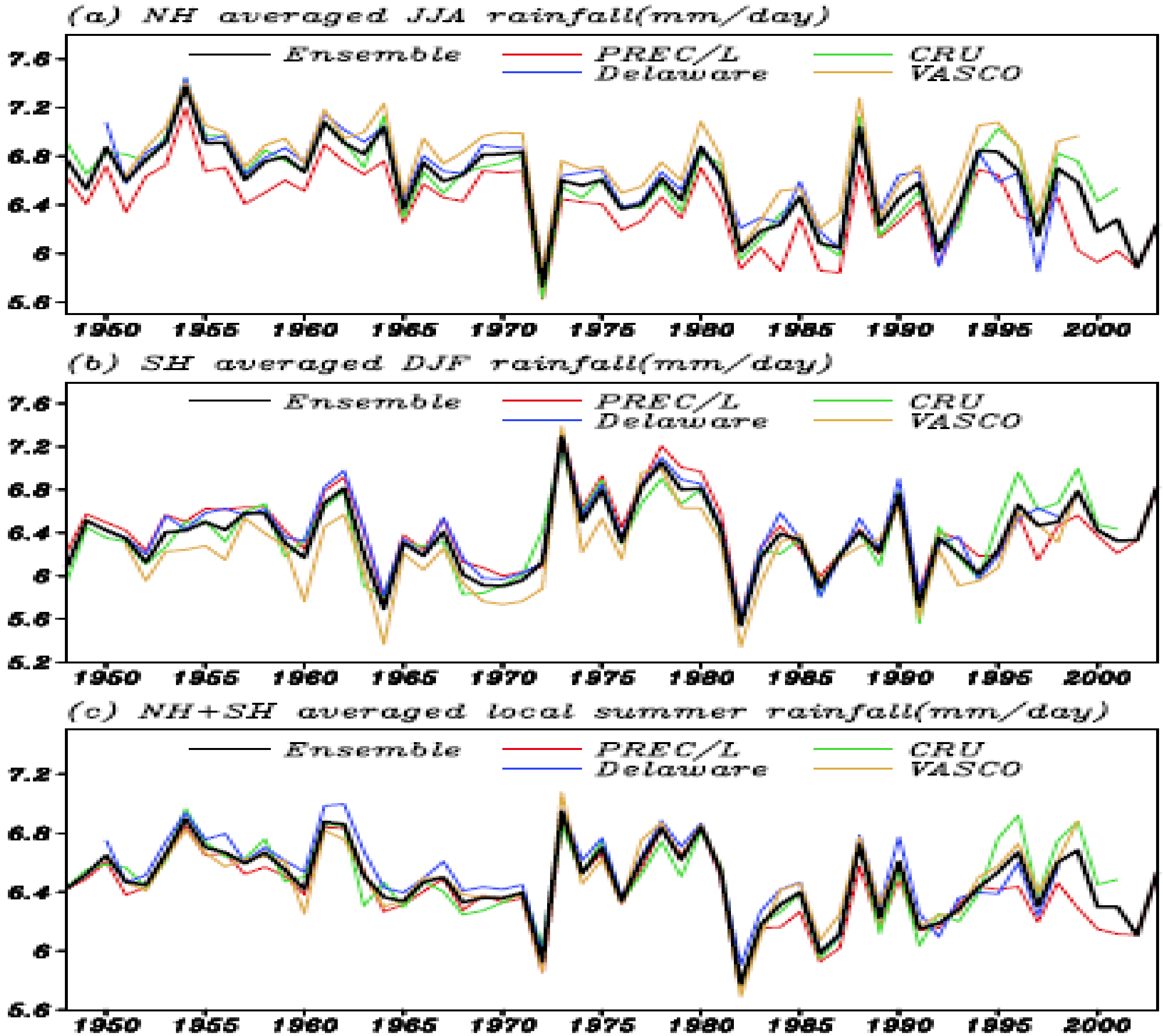


Figure 2. Time series of (a) the Northern Hemisphere-averaged June-July-August precipitation, (b) the Southern Hemisphere-averaged December-January-February precipitation, and (c) the global monsoon index (GMI), or the sum of Figures 1a and 1b.

Impacts on land can influence coastal regions. And there are multiple timescales

Sub-Seasonal Scale

- Rescheduling/postponement of seed broadcasting (deepwater *B. Aman* rice)/ transplanting (*Aman* rice)
- Undertaking mid-season corrections and crop life-saving measures wherever possible
- Reducing harvest/ storage losses
- Protection of young seedlings/ crops from flood
- Protective measures to save assets and livestock
- Enabling farmers to preserve investments and retain capacity to undertake next cropping
- Planning flood response activities
- Precautionary measures to protect infrastructure (e.g. growth centers, food silos, embankments, etc.)

Seasonal Scale

<u>*Communication of seasonal forecast: El Niño 1997 experience*</u>

During 1997-98, the Ministry of Agriculture, on receipt of the information from BMG on the likely impact of El Niño, processed the information and disseminated it to provincial agencies in a routine manner:

Day 0:	BMG press release of the seasonal forecast
Day 7-10:	Official receipt of BMG forecast by the Ministry of Agriculture
Day 10-15:	Ministry of Agriculture forwarded the information to the provincial agriculture extension services, indicating the potential impacts and the broad brush of contingency measures to be taken
Day 23-30:	Receipt of communication by provincial agricultural services. The climate working team met for deliberations about the impending drought at the provincial level.
Day 30-40:	Dissemination of information by provincial government to districts and sub-districts, with general recommendations about the need for taking possible actions

Can this paradigm work for climate projections?

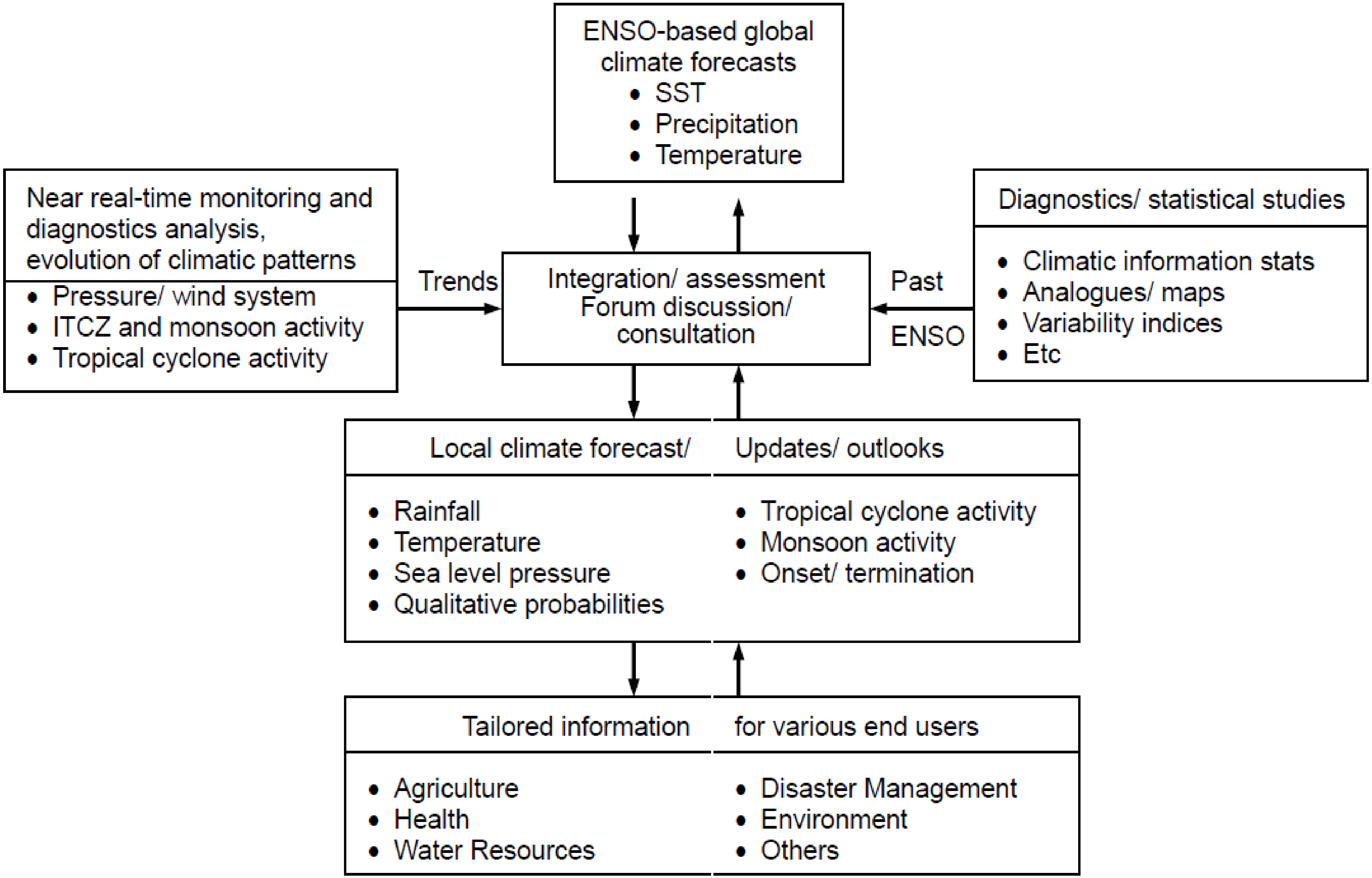


Figure 3. Translation of ENSO-based global climate forecasts into local climate forecast

How do you account for uncertainties in the Projections?

Table 1. Interpretation of rainfall accumulation

Percentile Rank	Interpretation
>90	Severe flood damage
81-90	Potential flood damage
61-80	Way above normal rainfall condition
41-60	Near normal to above normal rainfall condition
21-40	Below normal rainfall condition
11-20	Potential drought impact
≤ 10	Severe drought impact

Source: Amadore et al, 2002

Will we ever have the Regional-Specificity needed for action? No-Regret Decision vs Infrastructure Investments

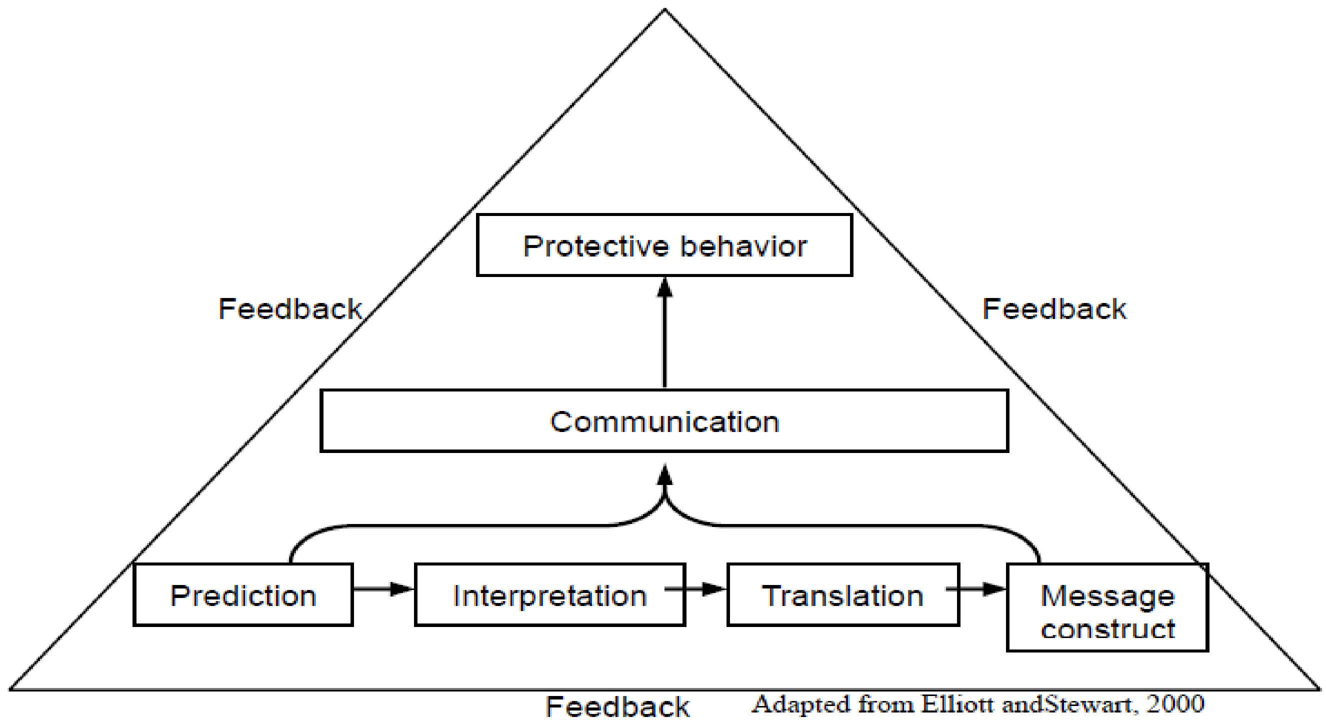


Figure 4. The warning system

Dear Villagers,

Asalamalaikum. As per the news we have heard in the ……, the water of Jamuna River is likely to run at a very high level in the next 10 days. Based on the information provided by Block supervising officers, it is likely that the following fields …… will be inundated fully in the next few days. You are all requested to harvest your crops immediately, and withhold seedbed operations for 10 more days. Please watch the flood post established in the village.

Table 2. Acceptance of probabilistic forecasts by various categories of farmers in risk-prone regions

Farmer category	High flood/drought-risk area	Medium flood/drought-risk area	Low flood/drought-risk area
High risk-taking farmers	High acceptance of probabilistic forecast indicating slight shifts of climate/flood situation. Acceptable forecast: 50-60% probability	Moderate acceptance of probabilistic forecast indicating moderate shifts of climate/flood situation. Acceptable forecast: 60-70% probability	Low acceptance of probabilistic forecast indicating decisive shifts of climate/flood situation. Acceptable forecast: More than 80% probability
Risk-neutral farmers	Moderate acceptance of probabilistic forecast indicating moderate shifts of climate/flood situation. Acceptable forecast: 60-70% probability	Low acceptance of probabilistic forecast indicating decisive shifts of climate/flood situation. Acceptable forecast: More than 80% probability	Acceptable forecast: Deterministic forecast
Risk-averse farmers	Low acceptance of probabilistic forecast indicating decisive shifts of climate/flood situation. Acceptable forecast: More than 80% probability	Acceptable forecast: Deterministic forecast	Acceptable forecast: Deterministic forecast

Data will never be sufficient to capture decadal variability Even at Global Scales. Mechanistic Understanding is LOW

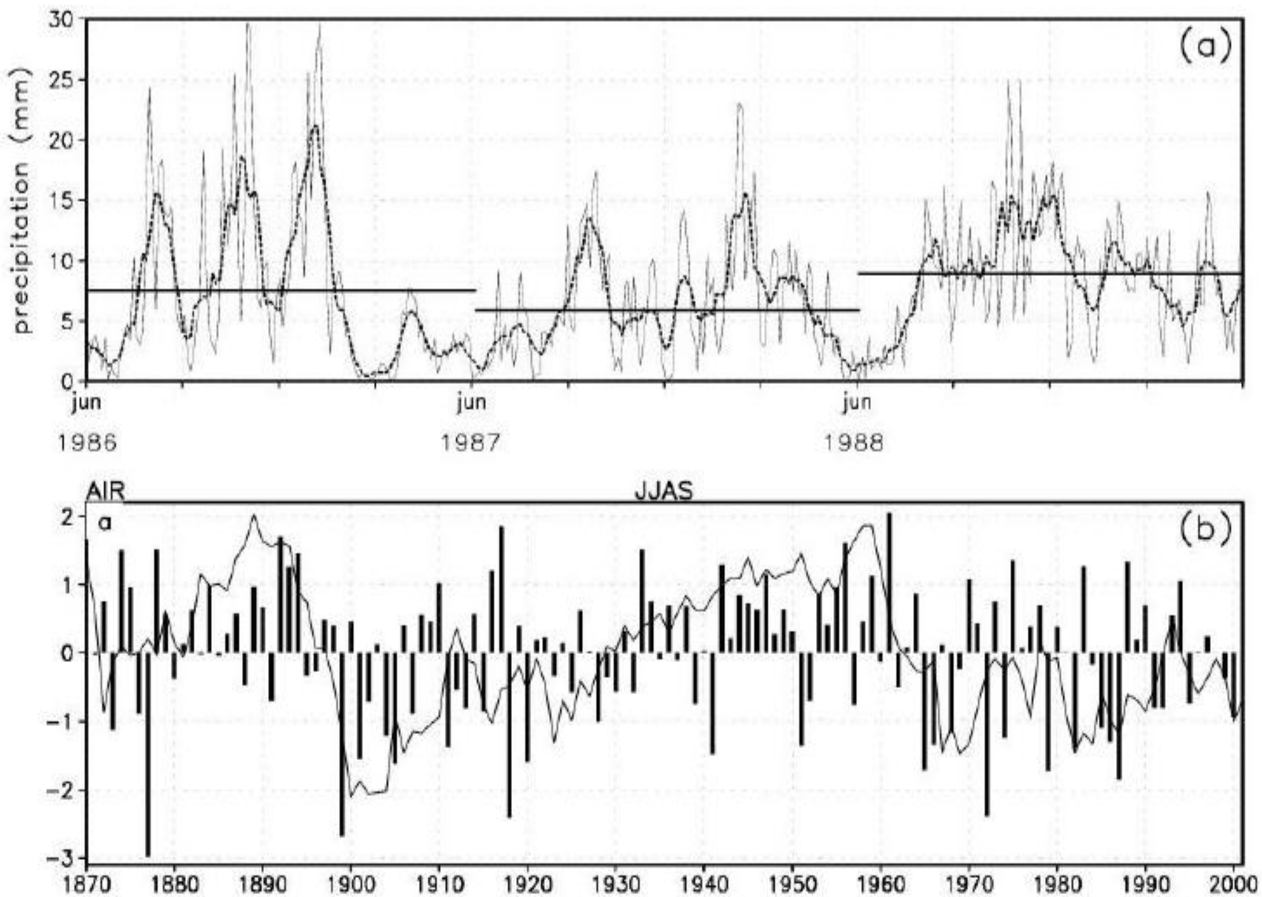
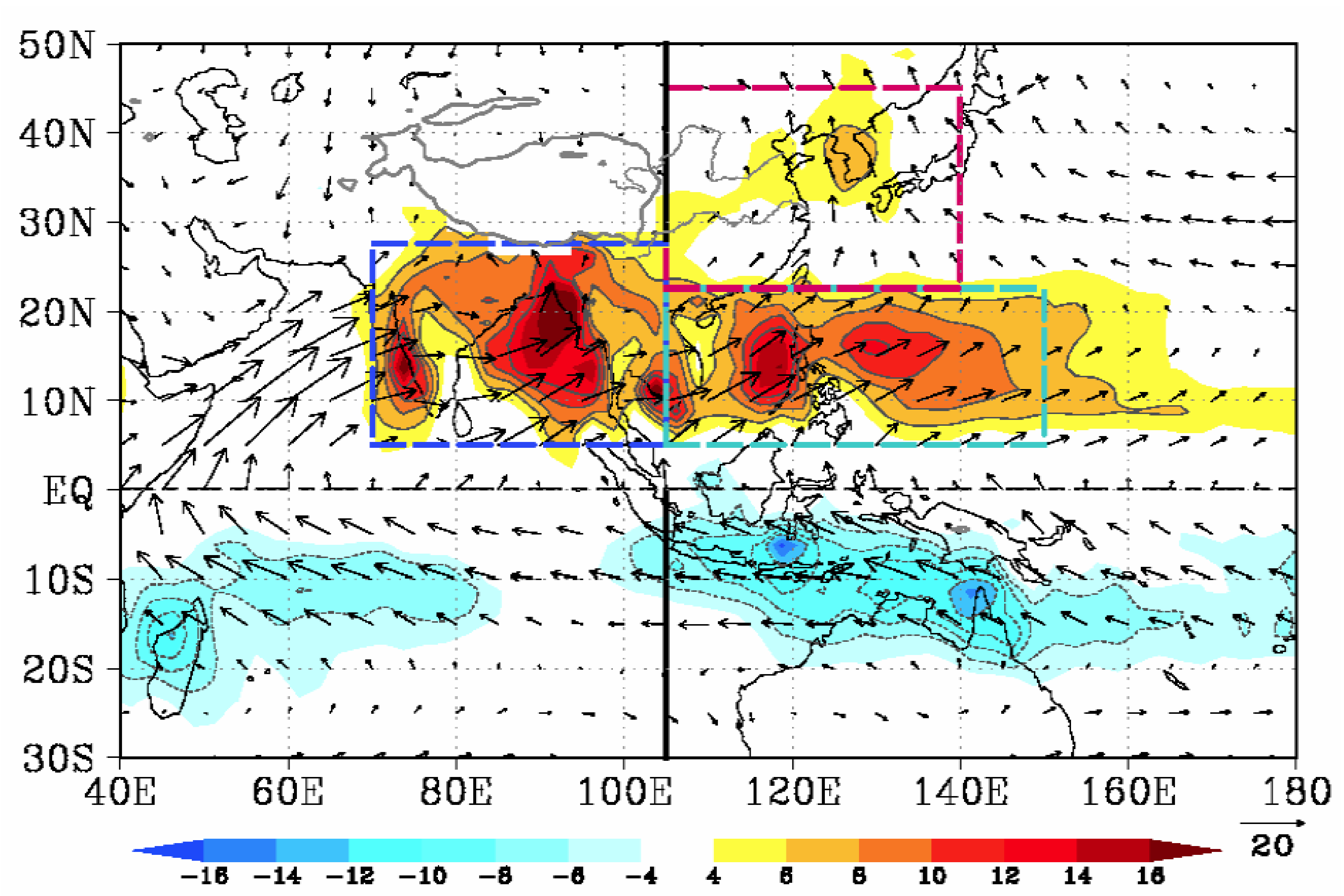
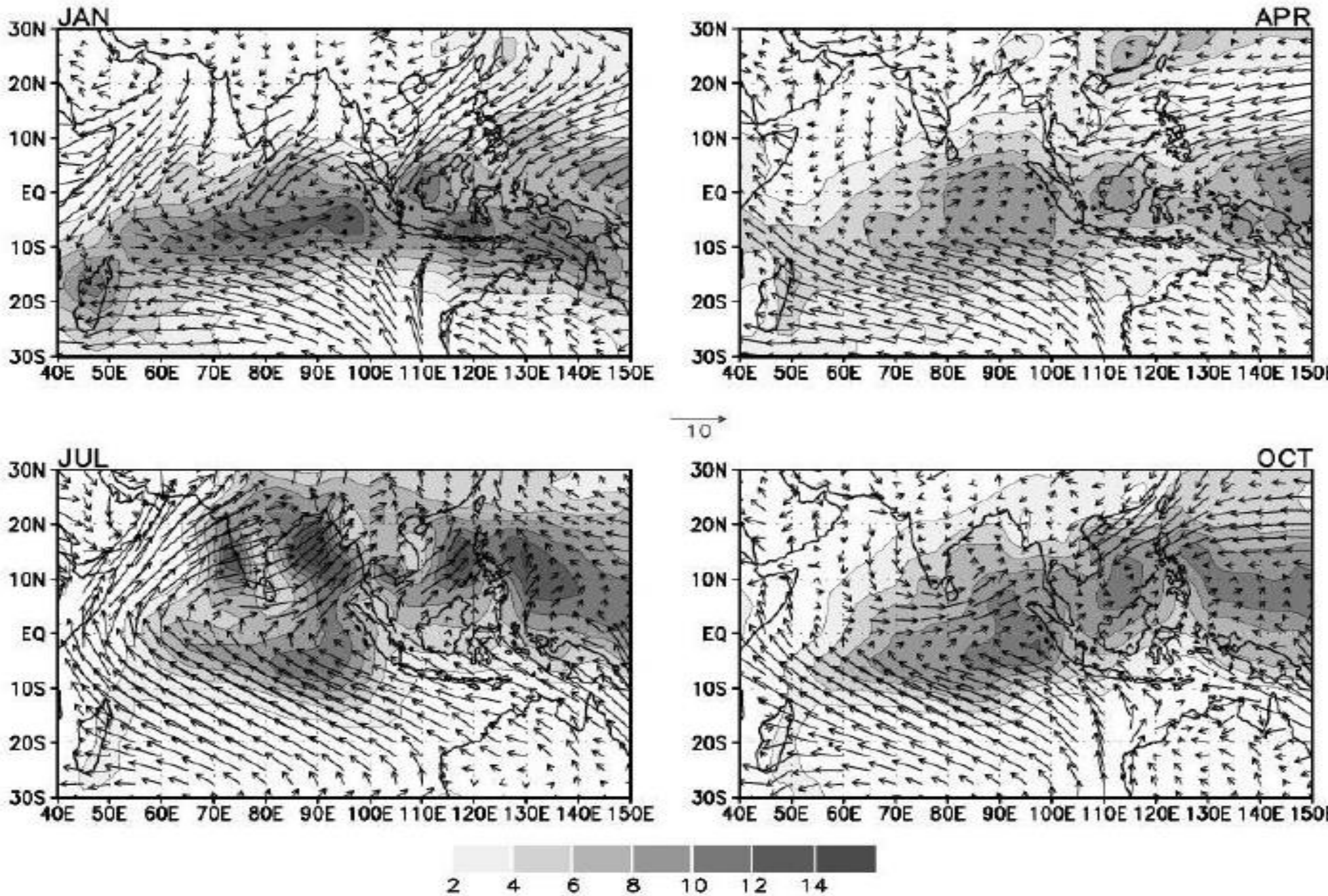


Figure 4. (a) Illustration of synoptic , intraseasonal and interannual variability with daily rainfall between June 1 and September 30 for three years over central India. (b) Interannual variability of seasonal mean all India rainfall (AIR) over a longer period normalized by its own standard deviation (bar). Normalized interdecadal variability of AIR (solid line).

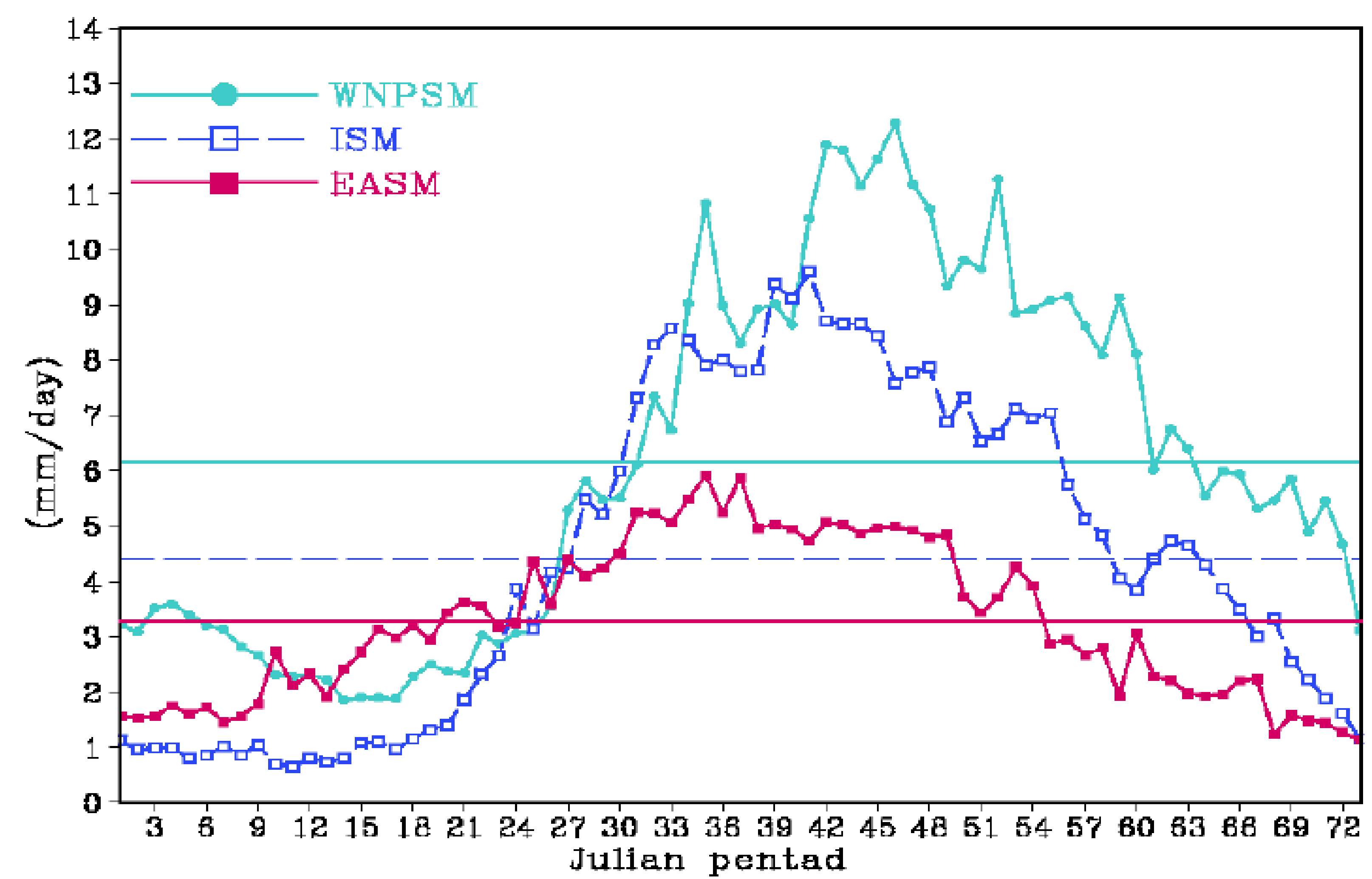
Relations are hard enough to understand – especially with warming and non-stationarity of the relations: Does it Matter for Decisions?



Easier to collect data at local coasts – but how do we downscale projections to local scales reliably?



Will phenologies remain the same? How will they interact at the coasts – for ex., spring melts, runoff and monsoons?



Extremes: Which timescales will be affected most? Local vs Nonlocal forcing of extremes? Will there be compensations in linked monsoons?

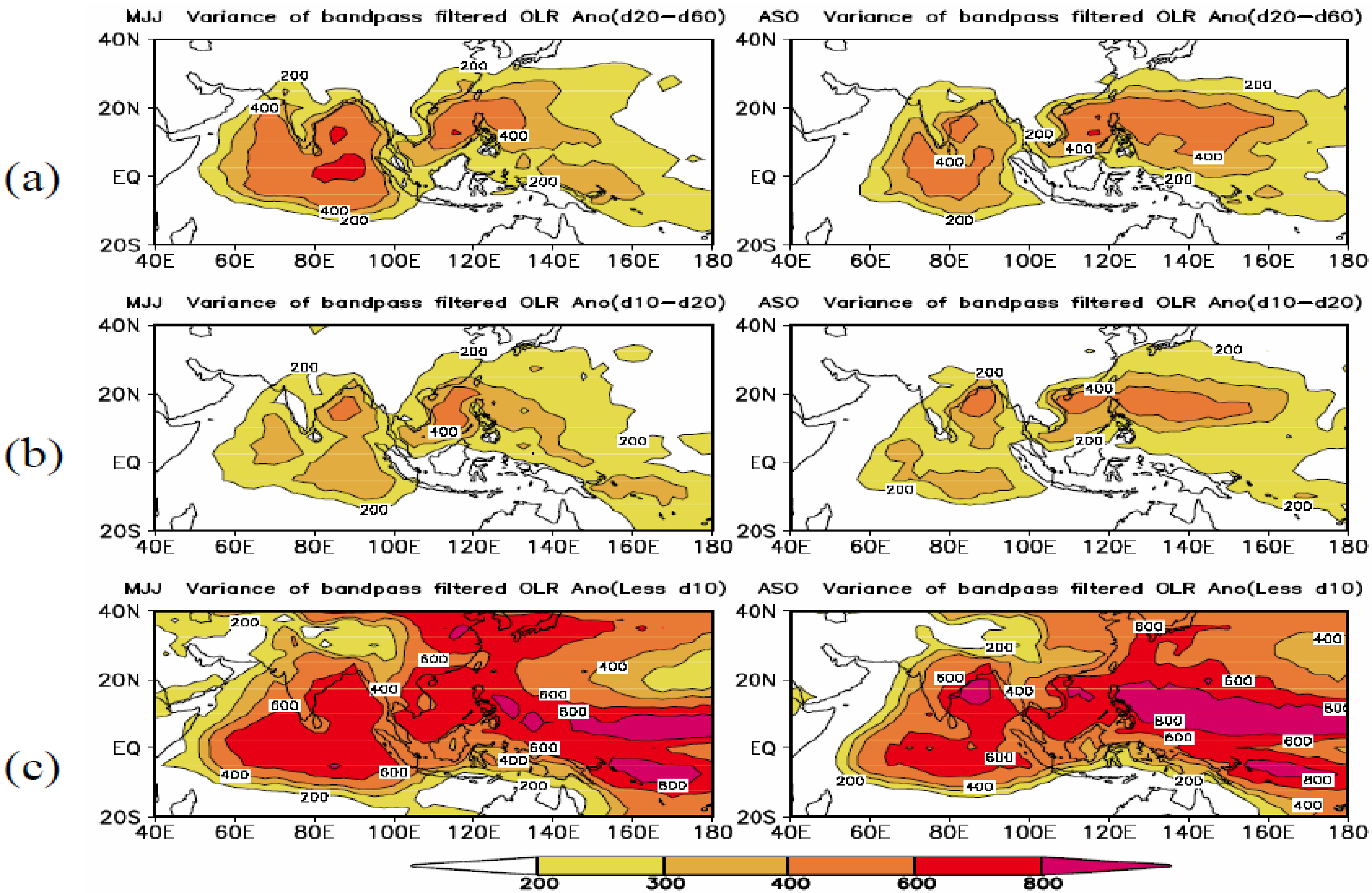
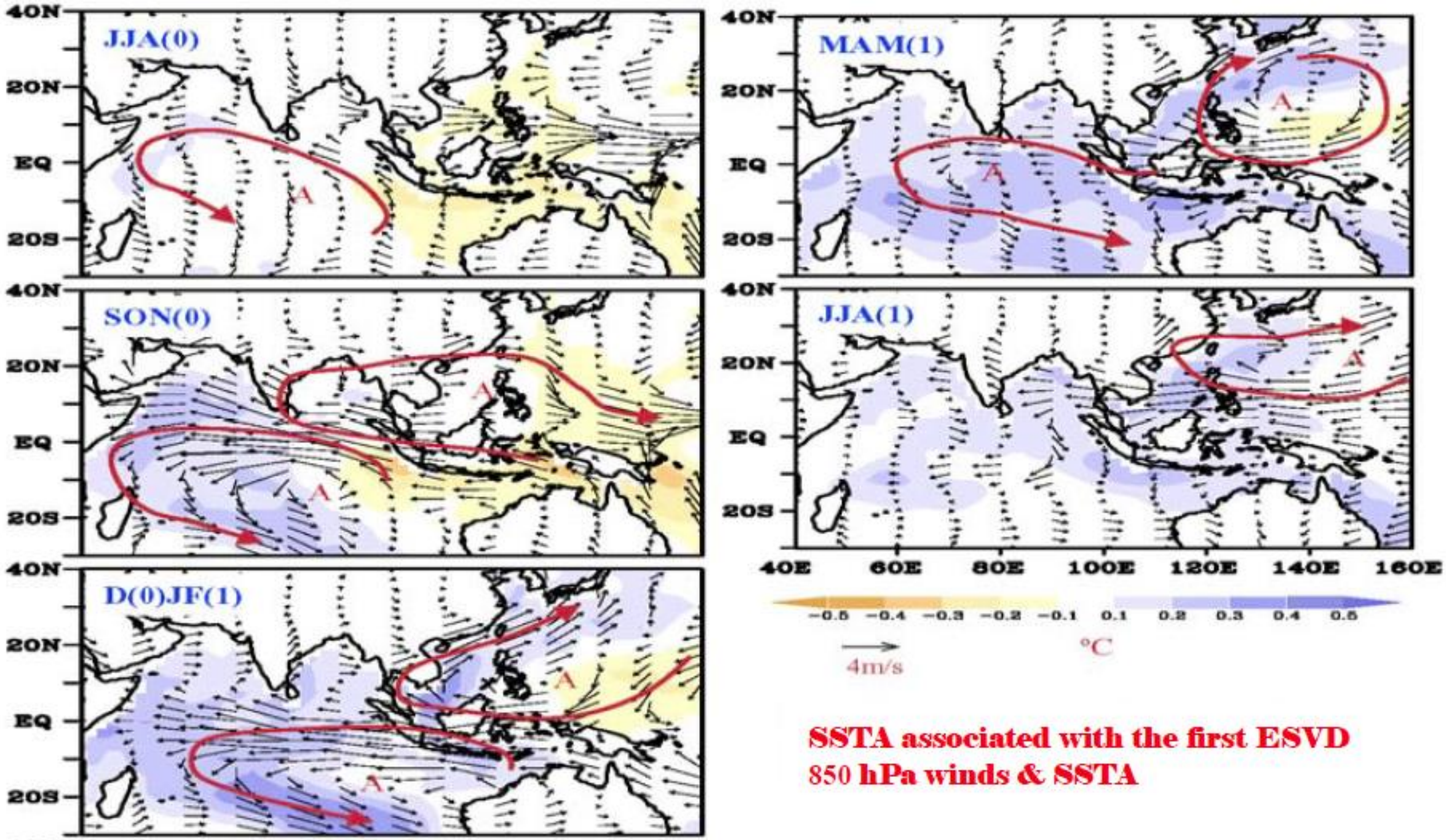


Figure 6. The OLR variances on time scales of (a) 20-60 days, (b) 10-20 day, and (c) less than 10 days.

If models do not represent ISVs accurately, will they capture seasonal-to-interannual variability correctly? How do the different errors affect coastal impacts? Subseasonal-to-seasonal predictions SHOULD be used as guides for future projections



Annual Cycle

- Why is the EA-WNP SM characterized by sudden changes (singularities) at various geographic locations?
- How important are the East-Asian marginal seas in determining the mean monsoon structure and seasonal cycle?
- Why do the most AGCMs have great difficulty in correct simulation of the summer rainfall in the WNP and the Western Pacific Subtropical High and the Meiyu/Baiu front regions?

What do we really know in terms of monsoon impacts on coastal regions at the annual timescale?

Intraseasonal Oscillation

- What are the mechanisms that give rise to the 10-20 day variability in the WNP and EA region?
- What are the dynamical relationship between the 20-60 day, 10-20 day and synoptic disturbances?
- What is the potential and practical predictability of the 10-20 day and 20-60 day oscillations?
- How does the air-sea interaction influence the 10-20 day and 20-60 day oscillations?

How do regional warmings affect the sea level rise and the monsoon impacts on the coasts? Cyclones, typhoons and hurricanes?

Interdecadal variability

- What is the dominant mode of the Interdecadal variation of the EA-WNP monsoons? What give rise to this variability?
- Are the interdecadal variations in the EA-WNP region linked to that over the ISM? If not how different they are and why they are different?

How do we translate model biases and deficiencies at these timescales to uncertainties in multi/decadal projections?

Vulnerability and Resilience vary significantly among coasts impacted by the global monsoons

Where will the largest impacts on monsoons and coasts come from? Tropics, Subtropics, or higher latitudes? From below or above?

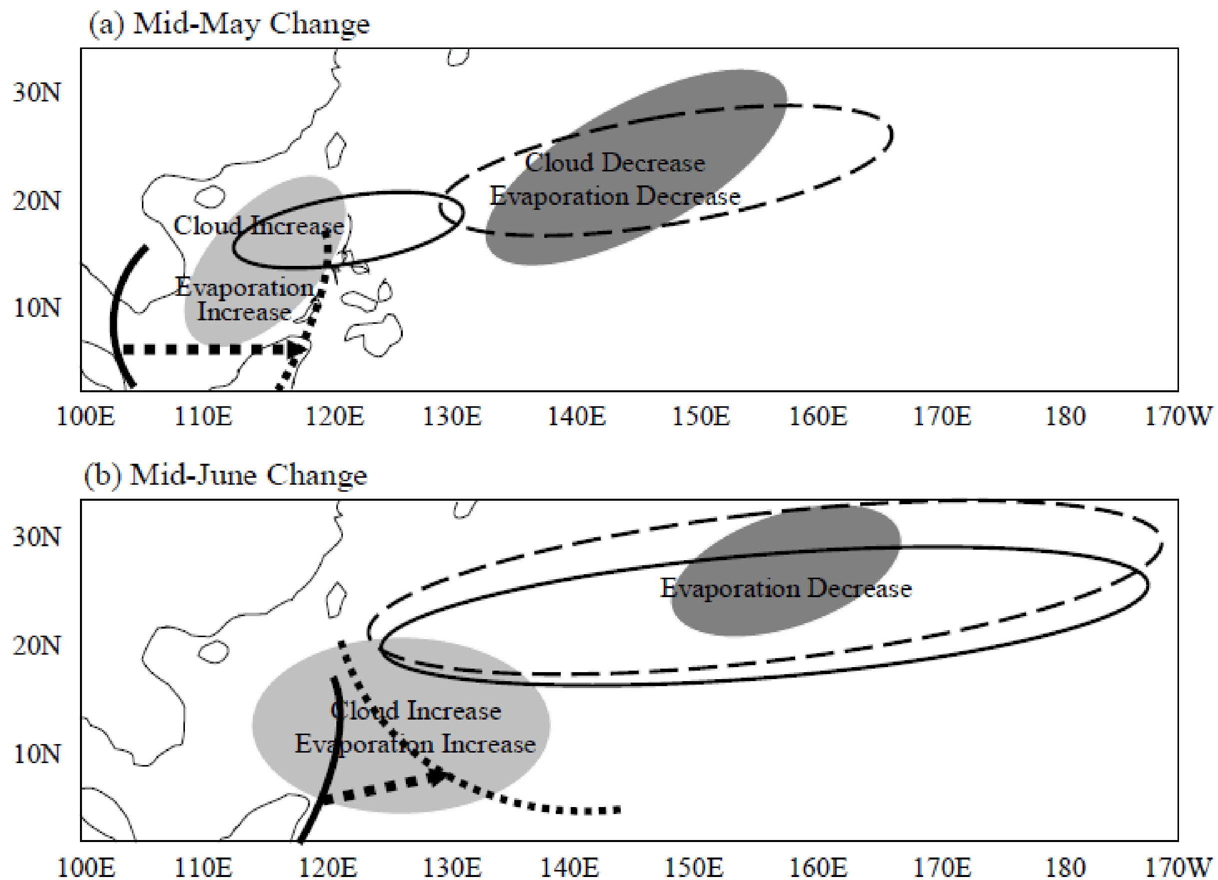


Figure 2.1. Schematic diagrams for major changes at the mid-May (a) and mid-June (b) onset. The solid (dashed) lines denote the location of the monsoon trough before (after) the onset. The closed solid (dashed) curves indicate the subtropical high before (after) the onset. The light (heavy) shadings signify region of increase (decrease) of cloud and/or evaporation. The dashed arrows indicate the direction for the extension of low-level westerly winds. (From Wu 2002).

How are the non-homogeneous ocean-atmosphere warmings affecting different pieces of diabatic heat sources? What can we learn from 2012, 2014-15?

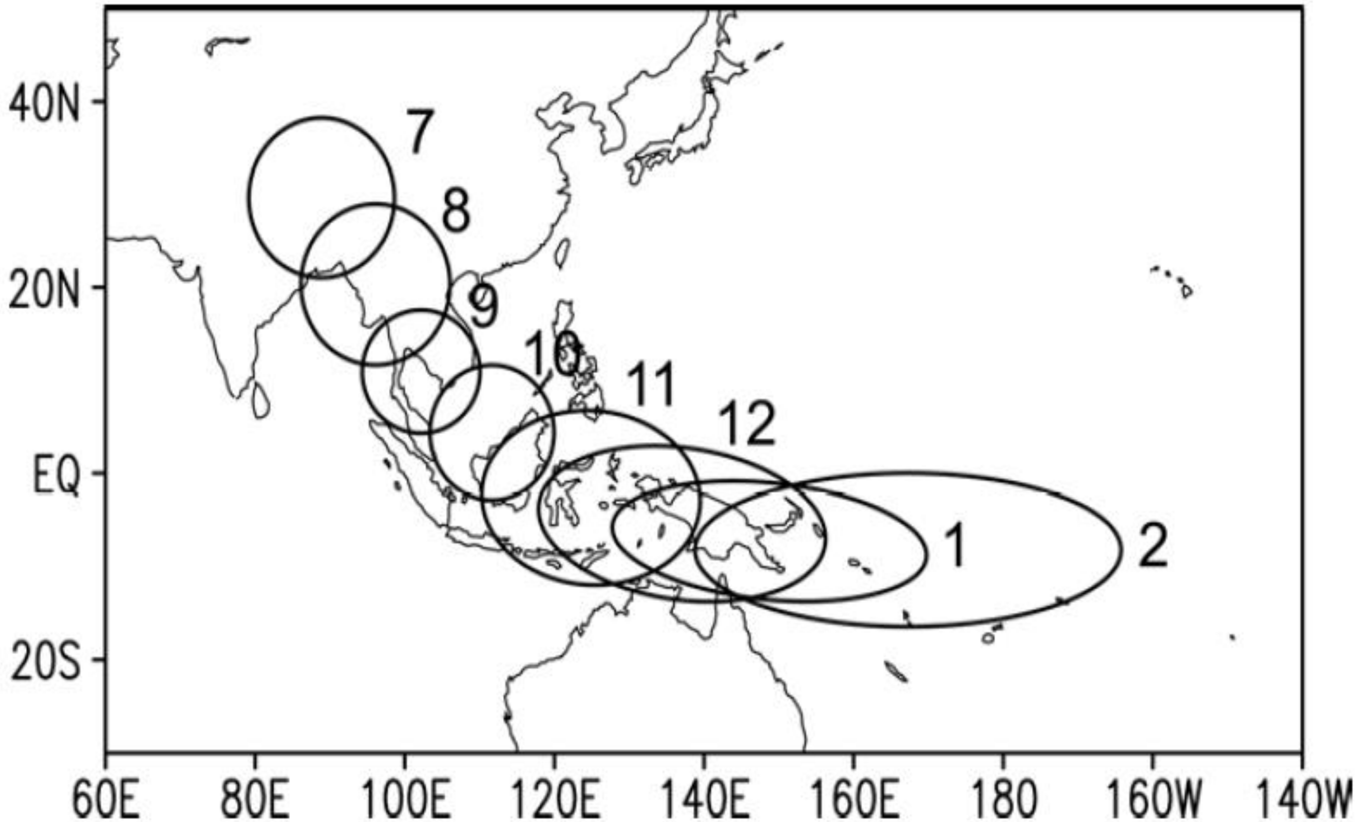


Figure 1. Seasonal migration of the monsoon diabatic heat sources during July-February (denoted by marching numerals). The extent of the diabatic heat sources is determined from the area with OLR < 225 W m^{-2} from monthly OLR climatology and is approximately proportional to the size and orientation of the schematic drawings. (Adapted from Lau and Chan 1983).

GMI: Does this help advance process/predictive understanding?

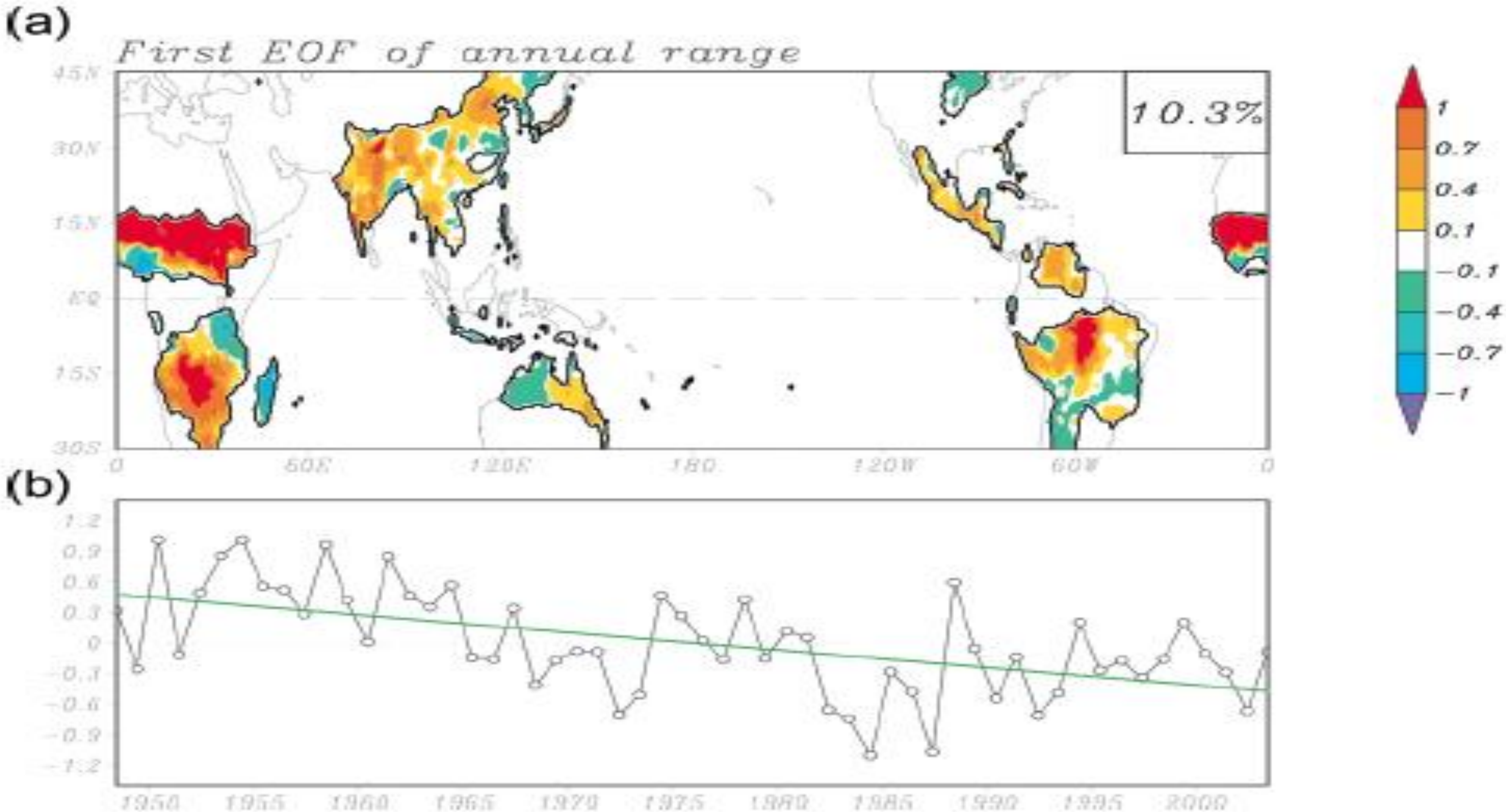


Figure 3. (a) The spatial pattern of the leading Empirical Orthogonal Function (EOF) mode of the normalized annual range anomalies over the global continental monsoon regions; (b) the corresponding principle component or annual range index (ARI). The bold contour indicates the boundaries of the monsoon domain.

What does the spatially variability of SNR really tell us about GM?

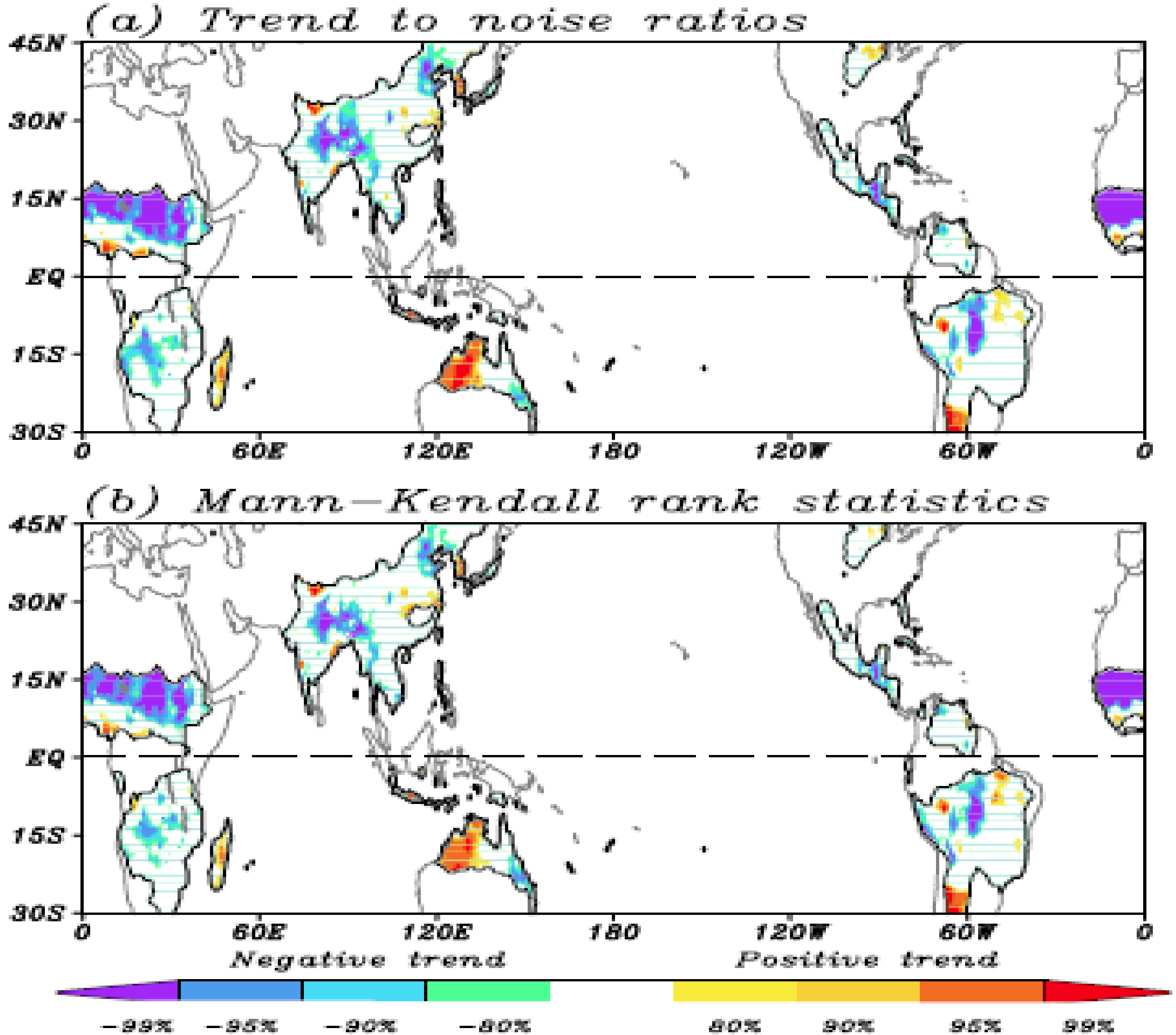


Figure 4. Statistical significance of the linear trends in summer monsoon precipitation at each grid point. (a) Trend-to-noise ratio and (b) Mann-Kendall rank statistics.

Detection & Attribution: Not easy, especially at regional scales

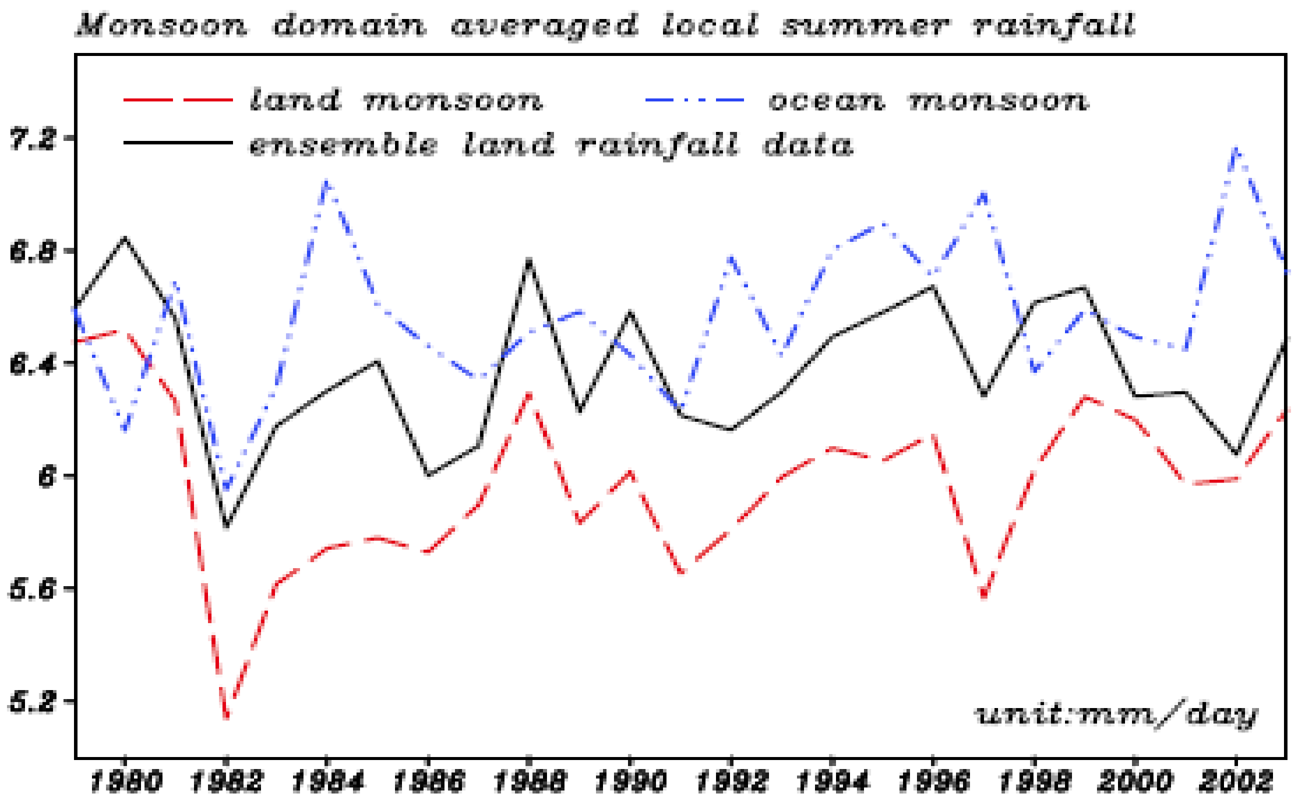


Figure 5. The GPCP global monsoon index (GMI) over land area and ocean area, respectively. Also shown is the GMI over land regions, derived from the ensemble land-based rain-gauge data.

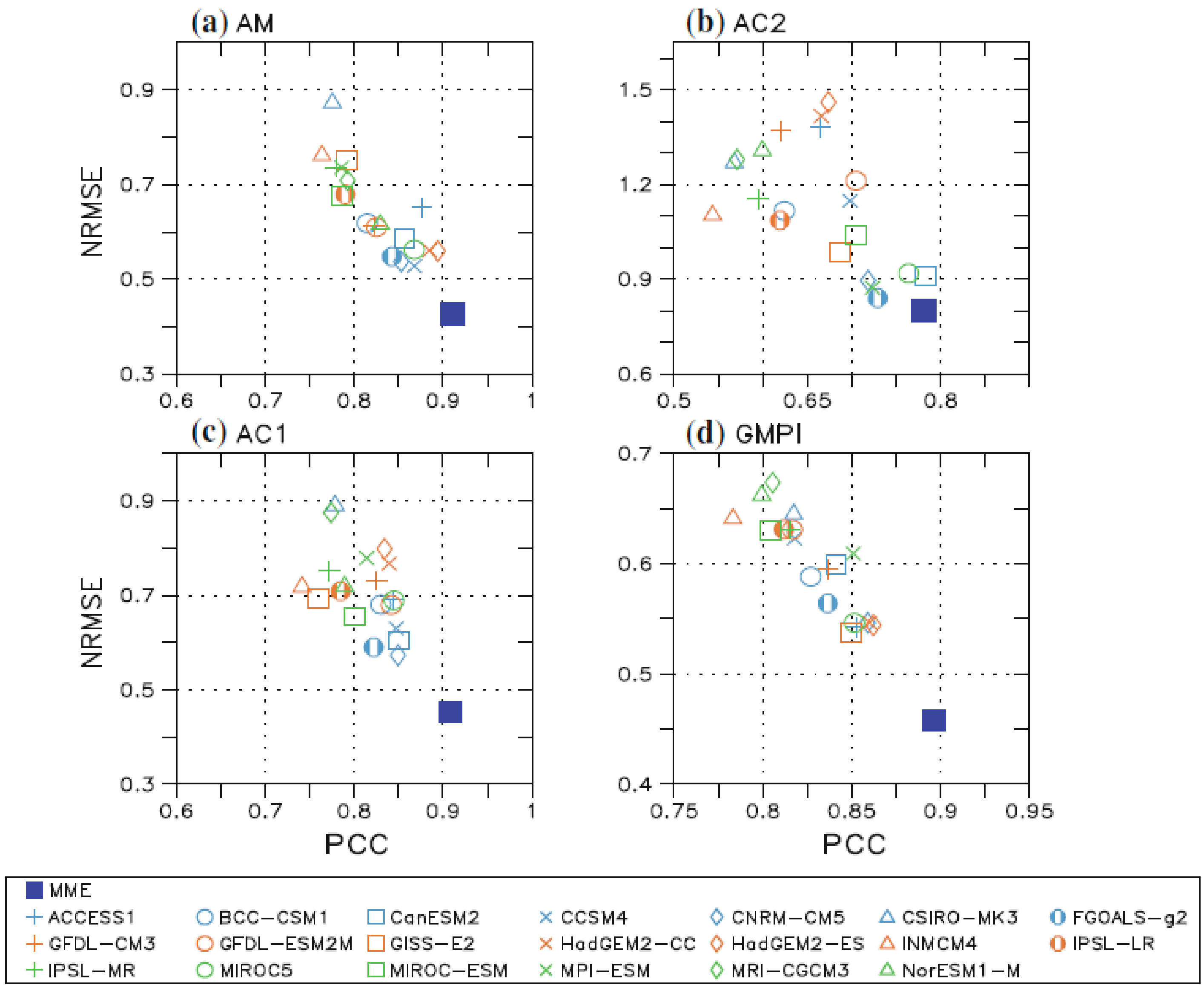


Fig. 2 Performance of CGCMs and their MME on precipitation climatology (1980–2005): **a** annual mean precipitation, **b** the solstice mode (AC1, JJAS minus DJFM), **c** the equinoctial asymmetric mode (AC2, AM minus ON), and **d** global monsoon precipitation intensity (GMPI). The abscissa and ordinates are pattern correlation coefficient (PCC) and domain-averaged RMSE normalized by the observed spatial standard deviation (NRMSE), respectively. The domain used is 60°S–60°N, 0°–360°E. The observed precipitation data were obtained from the merged CMAP and GPCP data

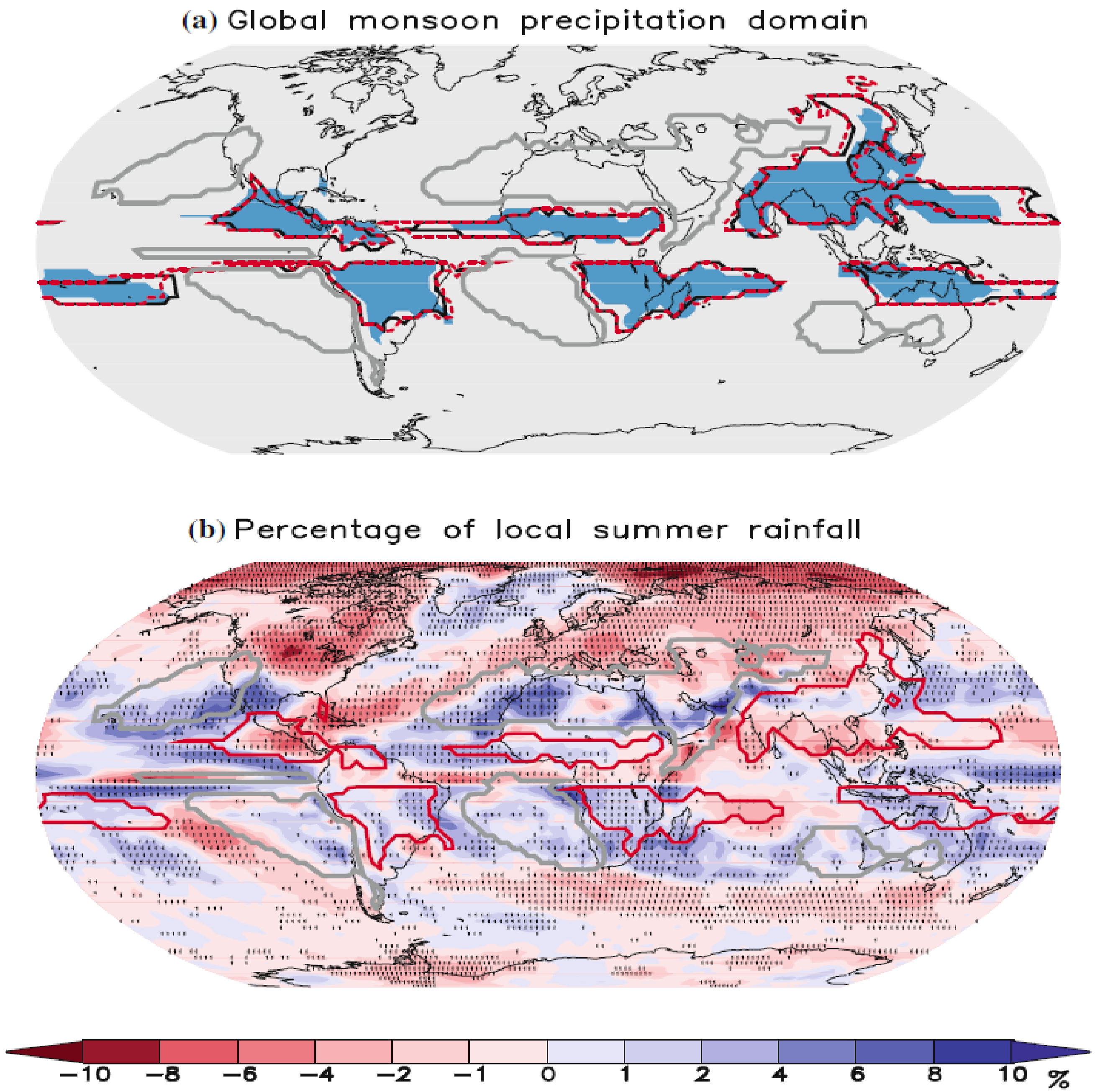
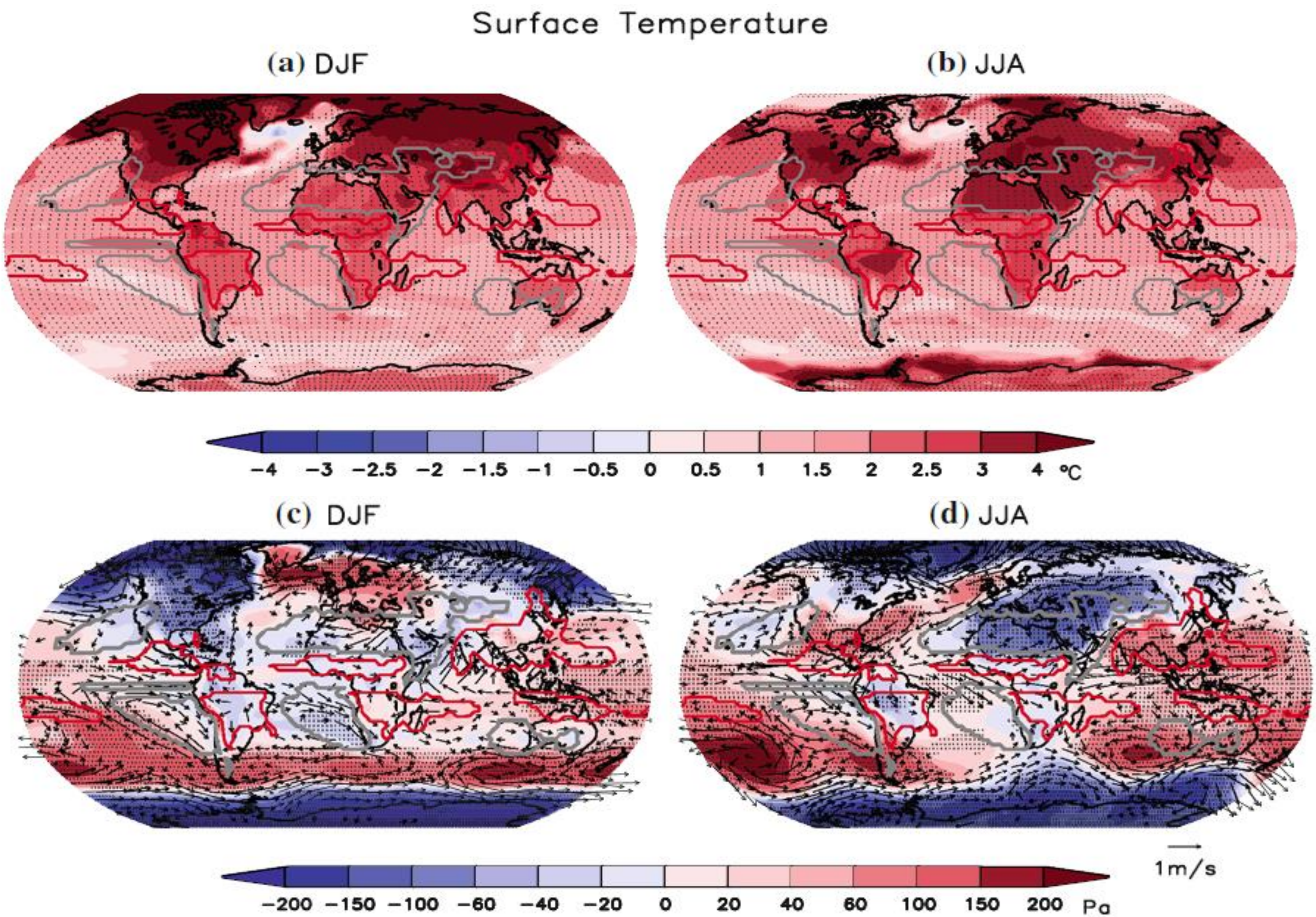


Fig. 4 Change of GM precipitation domain and percentage of local summer rainfall: **a** the monsoon domain in the observation (*mid-blue shading*), the B4MME historical simulation (*black solid line*), and RCP45 simulation (*red dashed line*). The period used to determine the monsoon domain is from 1980 to 2005 for the observation and historically simulation and from 2070 to 2095 for the RCP45 simulation. The definition of monsoon domain is the same as in Fig. 1 and the dry regions (outlined by *grey*) have summer precipitation rate <1 mm day^{-1}. The merged Global Precipitation Climatology Project/Climate Prediction Center Merged Analysis of Precipitation data were used to determine the monsoon and dry regions. **b** The corresponding future changes of percentage of local summer rainfall. Changes are given for the RCP 45 simulation for the period 2070–2095 relative to historical simulation for the period 1980–2005 in CMIP5. *Stippling* denotes areas where the magnitude of the B4MME exceeds the standard deviation of inter-model spread

Decorrelation scales and Skills for Temp and Precip are very different



Reliability of Projections – Will they all be deficient if one is deficient?

Winds and Precip changes have to be combined with sea level, extremes, land use, etc.

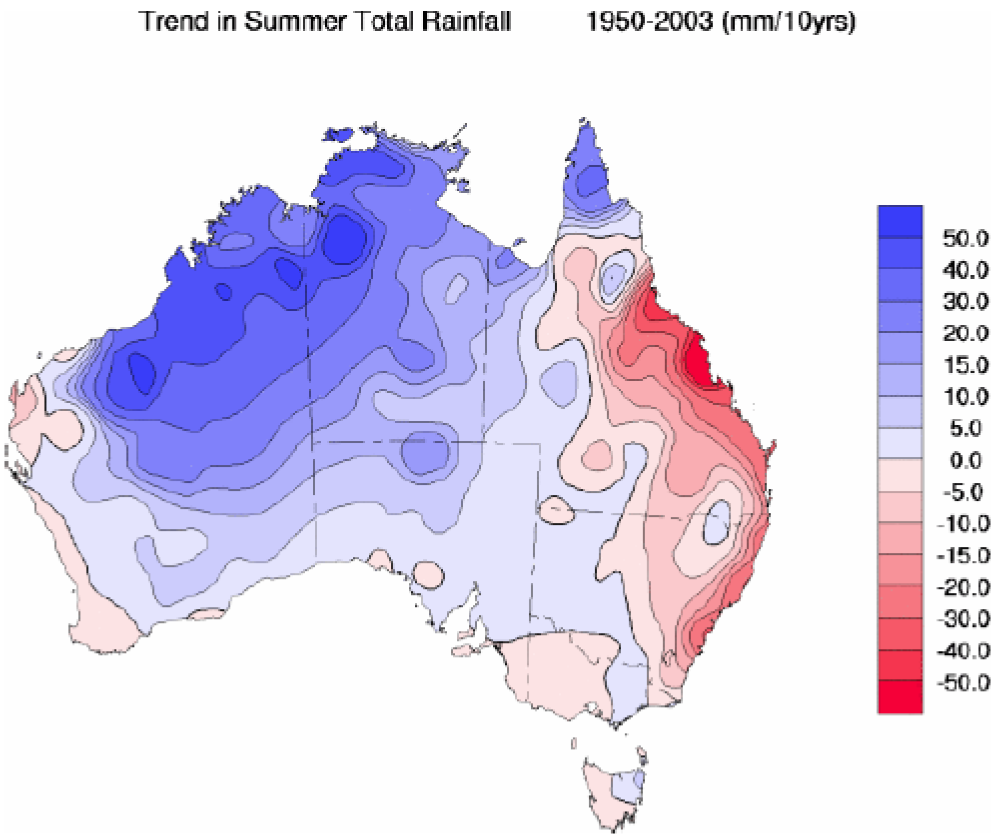
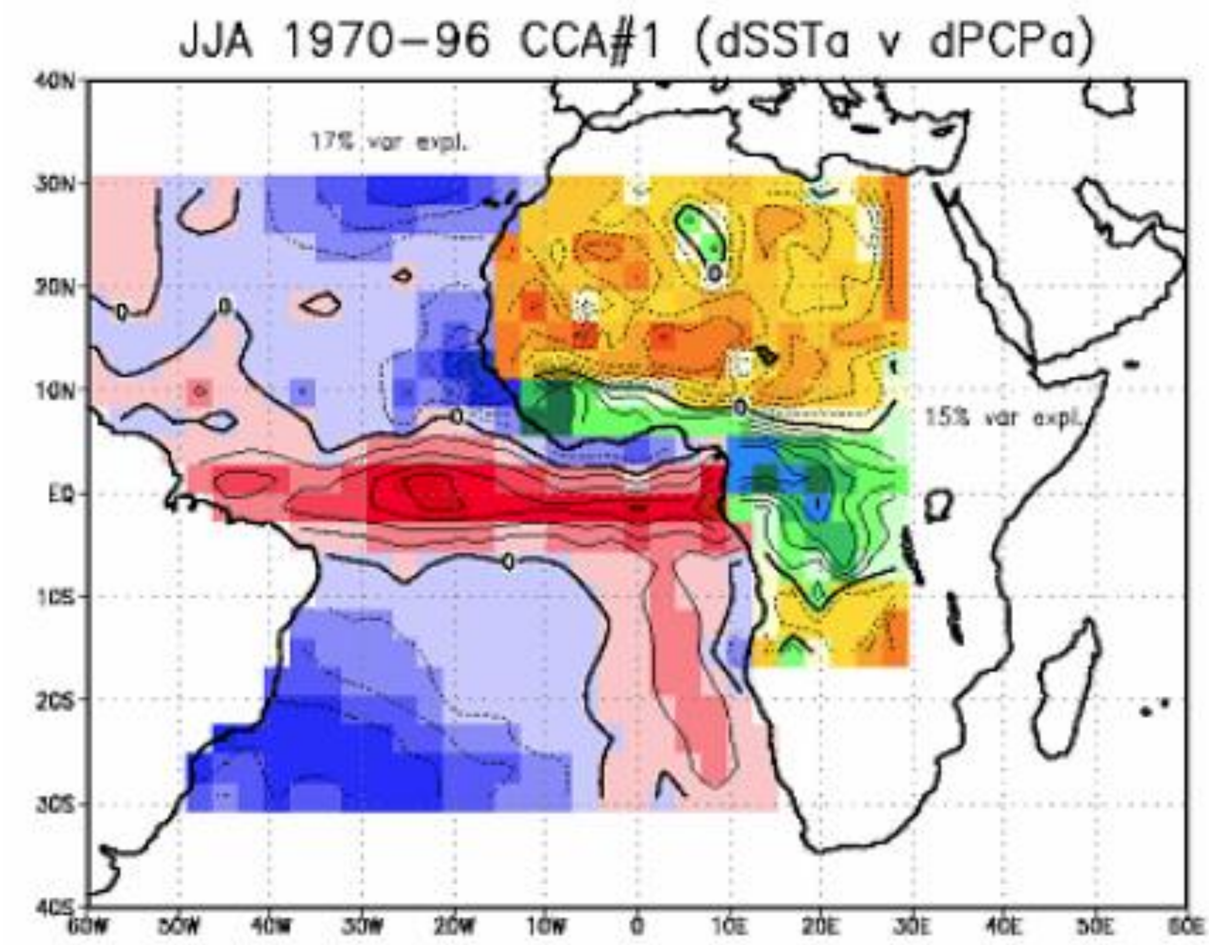


Figure 16. Summertime (DJF) rainfall trend for the period 1950-2003)

Coupling strengths and SST-P relations are a huge challenge for models. Impact of Global Warming on coupling and SST-P?



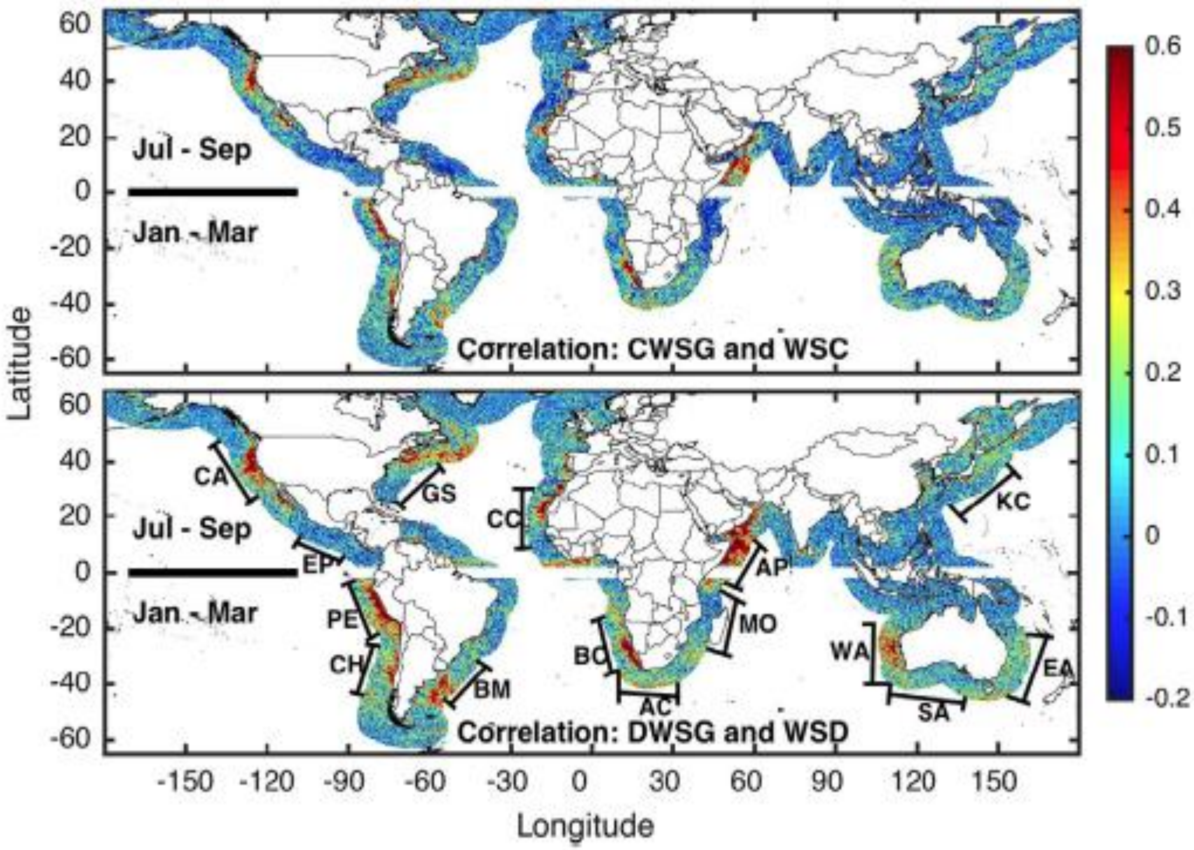


Fig. 1. Global maps of correlation between (top) crosswind SST gradient (CWSG) and wind stress curl (WSC) and between (bottom) downwind SST gradient (DWSG) and wind stress divergence (WSD). Only observations during summer (July to September in northern hemisphere, January to March in the southern hemisphere) were used for computing the correlations. CA: California Current System; EP: Eastern Tropical Pacific; PE: Humboldt Current off Peru; CH: Humboldt Current off Chile; BM: Brazil-Malvinas Confluence Zone; GS: Gulf Stream; CC: Canary Current; BC: Benguela Current; AC: Agulhas Current; MO: Mozambique Channel; AP: Arabian Peninsula; WA/SA/EA: Western/Southern/Eastern Australia; KC: Kuroshio Current.

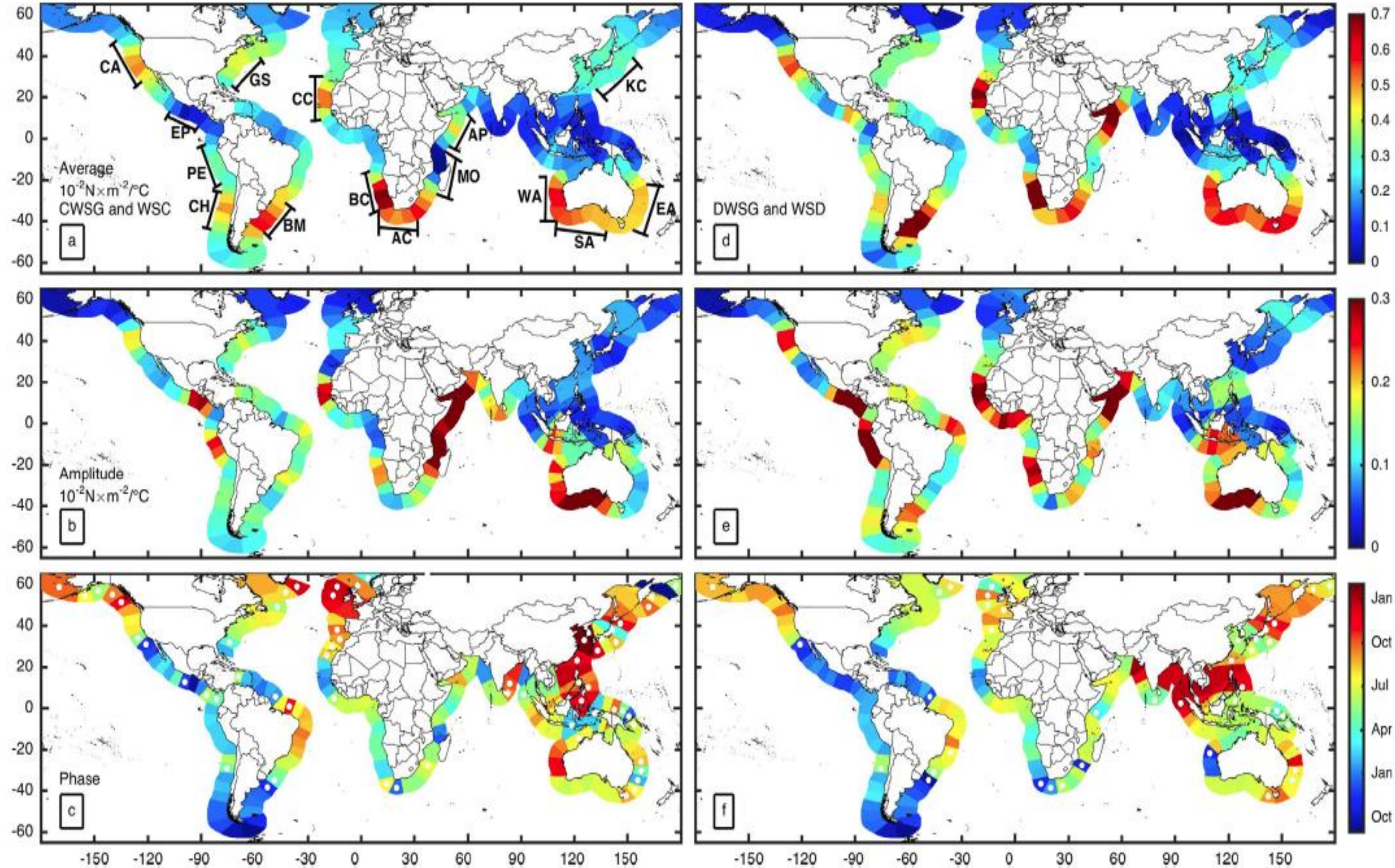


Fig. 4. Overall average (a, d) and amplitude (b,e) and phase (c, f) of the seasonal cycle calculated from monthly time series of coupling coefficients. The color scale of the phase map (c, f) is repeated from October to January in order to avoid discontinuities in the figure. White dots show regions where seasonal cycle is not statistically significant. CA: California Current System; EP: Eastern Tropical Pacific; PE: Humboldt Current off Peru; CH: Humboldt Current off Chile; BM: Brazil-Malvinas Confluence Zone; GS: Gulf Stream; CC: Canary Current; BC: Benguela Current; AC: Agulhas Current; MO: Mozambique Channel; AP: Arabian Peninsula; WA/SA/EA: Western/Southern/Eastern Australia; KC: Kuroshio Current; CWSG: crosswind SST gradients; DWSG: downwind SST gradients; WSC: wind stress curl; WSD: wind stress divergence. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

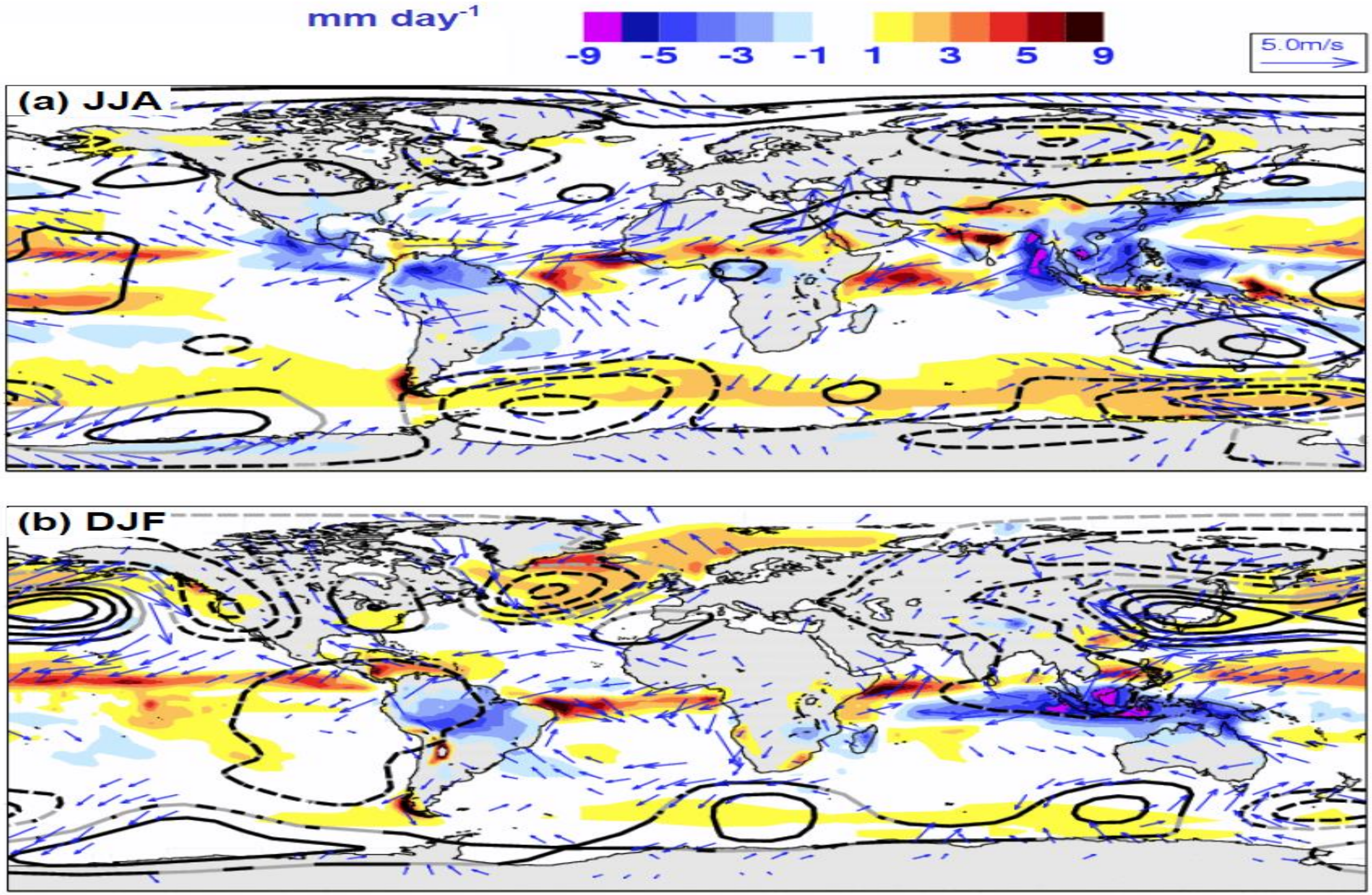


Figure 4. ECMWF climate hindcast biases in precipitation (shaded), 925 hPa horizontal winds (vectors) and 500 hPa geopotential heights (contours with interval 2 dam). The integrations are made with model version CY26R3 at a horizontal spectral resolution of T95 and incorporate the "old" (Tanre *et al.* 1984) model aerosol climatology. Hindcasts are for the period 1962-2001. Biases are relative to the observational data shown in Fig. 1. The data used from the hindcasts is that coincident with the observations. Wind vectors are only plotted when the windspeed change is significant at the 10% level and grey geopotential height contours indicate lack of statistical significance at the 10% level. Positive contours are solid, negative contours are dashed and the zero contour is omitted.

Aerosols remain the biggest monkey wrench. Knowledge and Uncertainty are NOT related!!

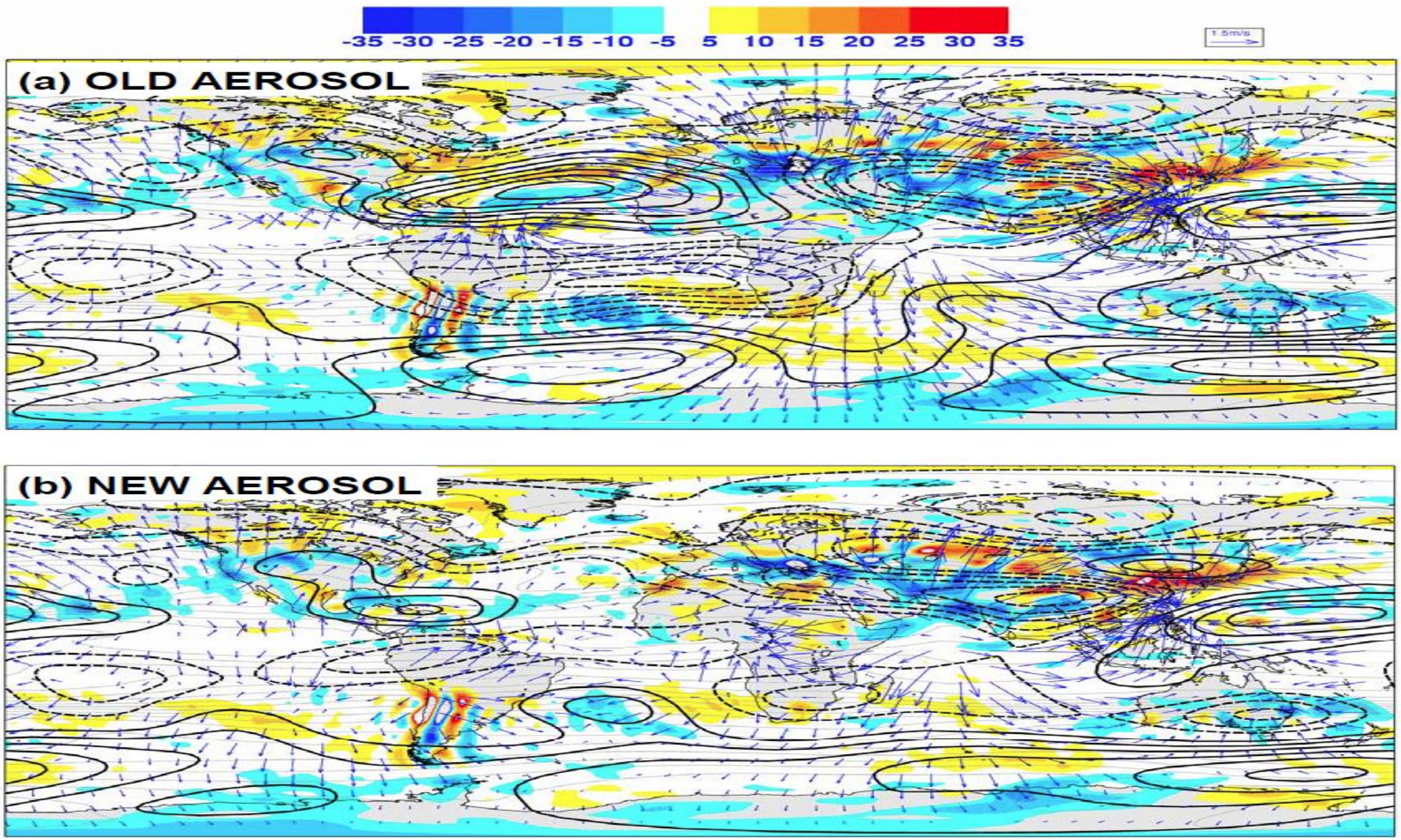
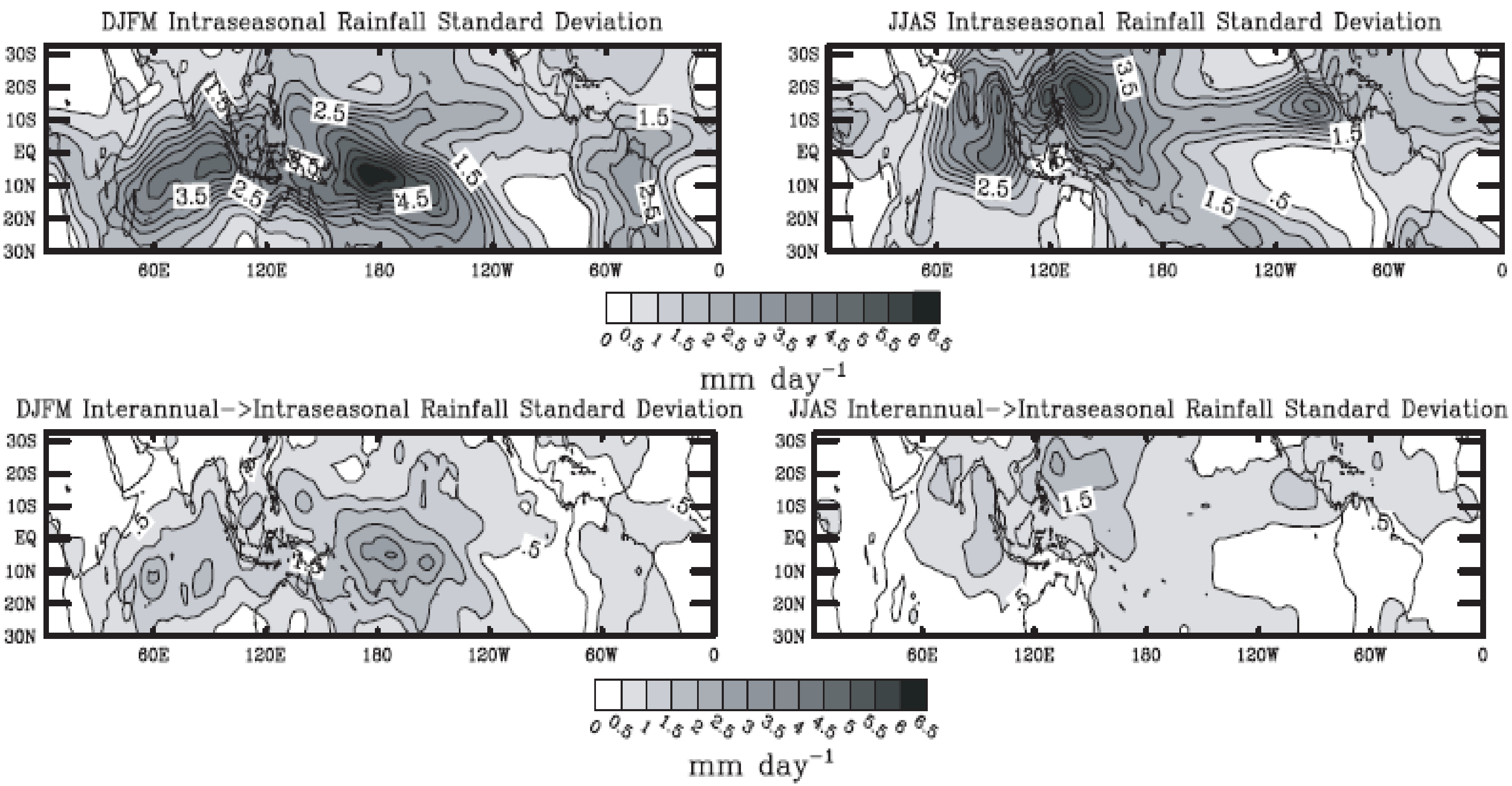


Figure 8. Biases in 150 hPa streamfunction (black contours with interval $2x10^6$ m^2 s^{-1}, positive values solid and negative values dashed), divergent wind (vectors) and Rossby wave source (shaded with units $5x10^{-11}s^{-2}$). Biases are relative to ERA40 climatology. Also shown is the mean absolute vorticity (grey contours with interval $10^{-5}s^{-1}$). Model data comes from seasonal hindcasts initiated on 1 April for each year 1962-2001. Integrations are made with ECMWF model version CY26R3 using (a) the old Tanre *et al.* (1984) aerosol climatology and (b) the new Tegen *et al.* (1997) aerosol climatology.

More robust metrics are needed to test accuracy at all timescales



A great challenge to project these into the future – but present needs to be accurate

How will warming affect convective and stratiform rain? What will have a bigger impact on the coastal regions?

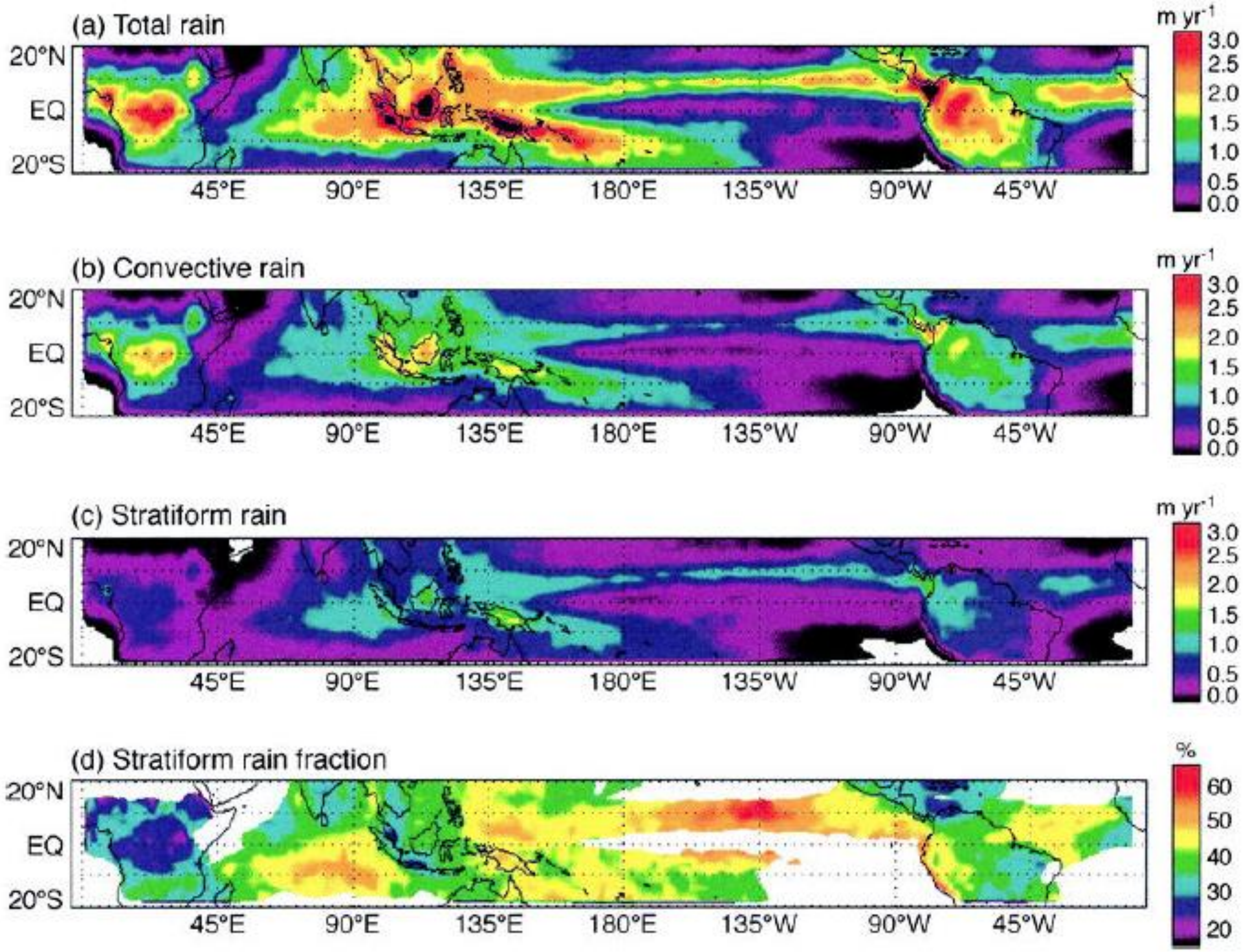


Figure 5. TRMM PR (a) total rain, (b) convective rain, (c) stratiform rain, and (d) stratiform rain fraction based on 2.5° grid averages for 1998-2000 (Schumacher and Houze 2003).

Will models achieve high enough resolutions to capture such multiscale interactions? Even if they do, will that translate to accurate depiction of coastal impacts?

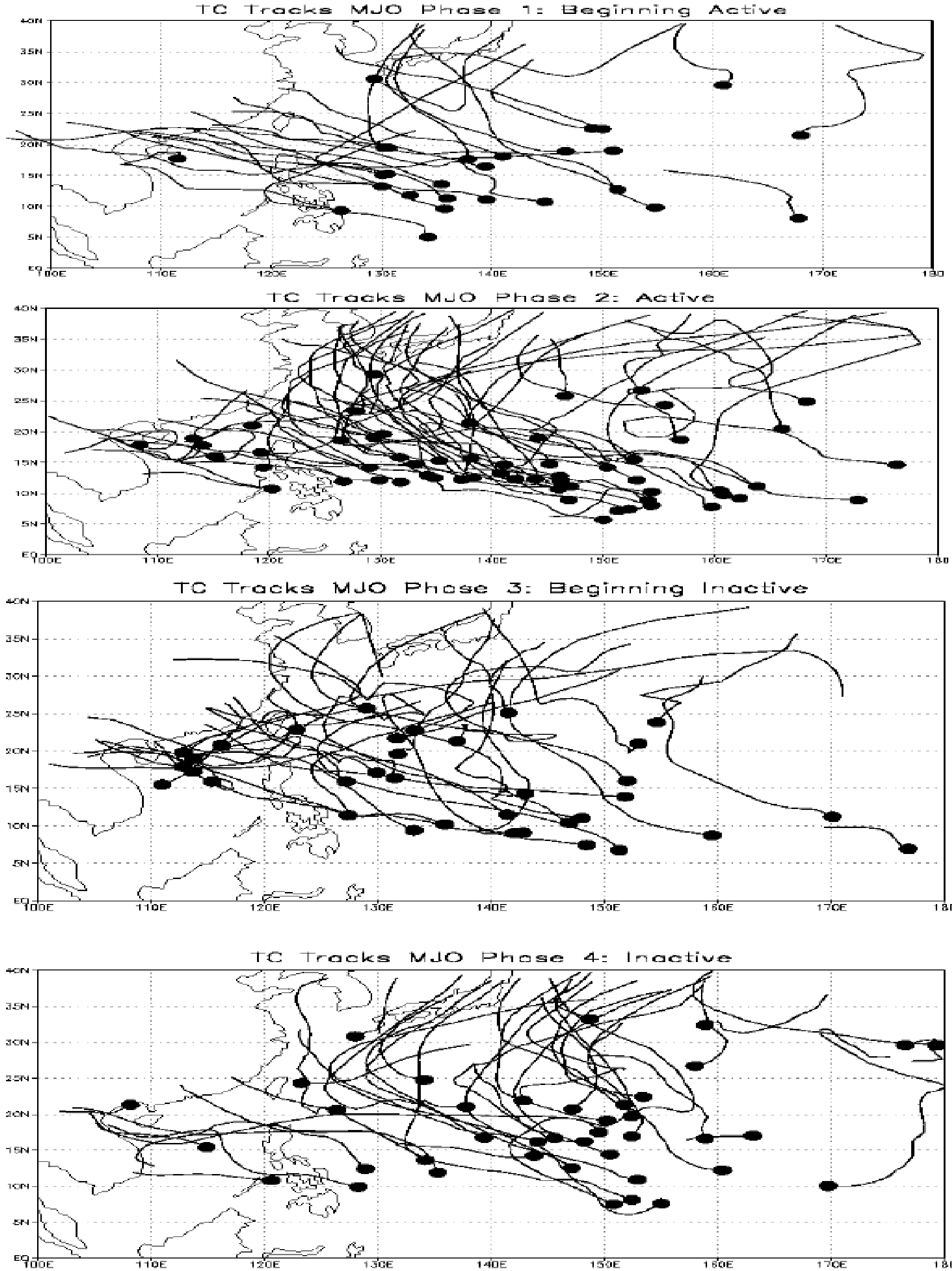


Figure 19. Tropical cyclone tracks during four phases of the MJO during June-October 1979-2000. From Harr *et al.* (2004).

How will these respond to atmospheric and oceanic warming? And interact with sea level change?

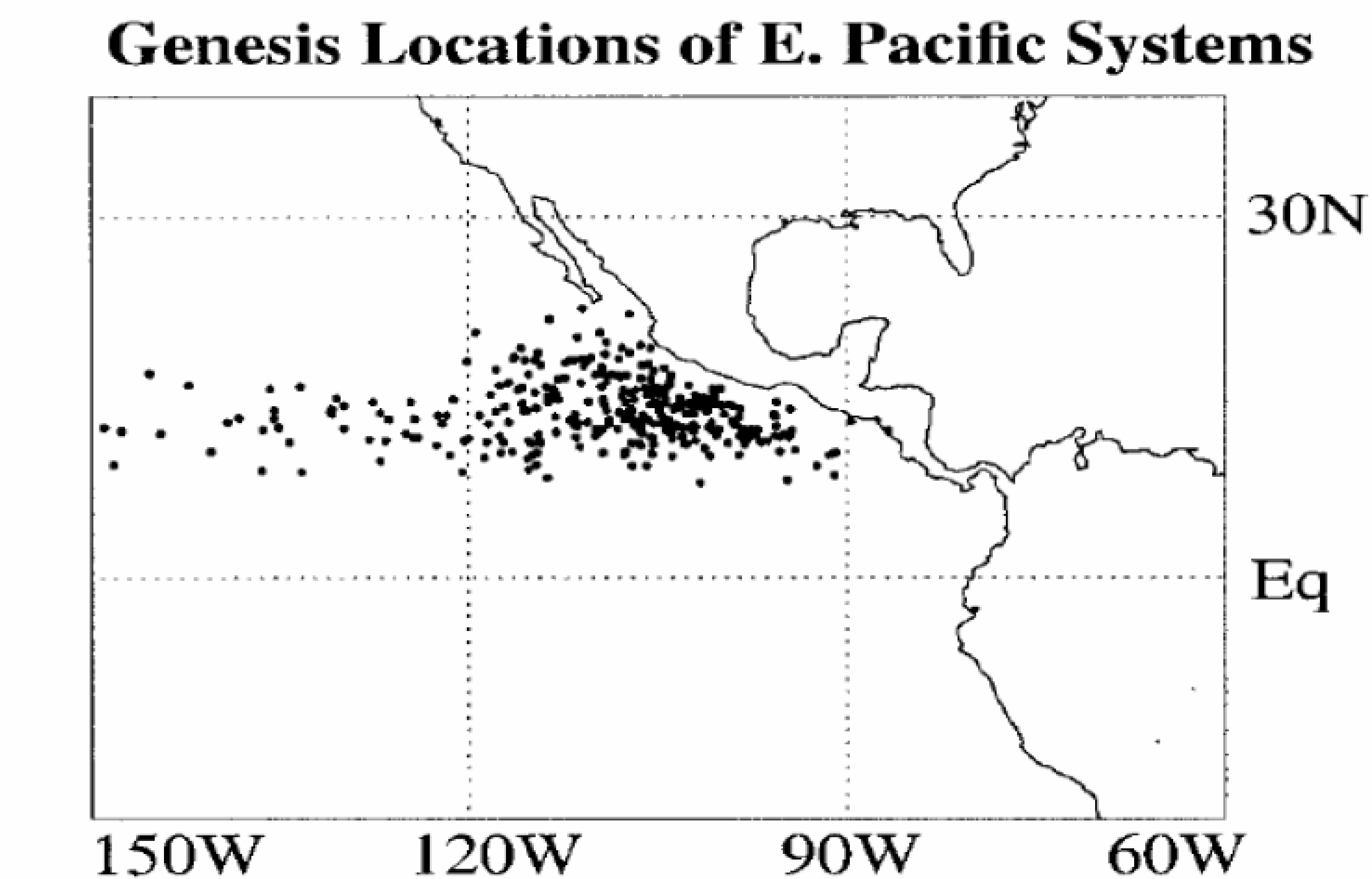


Figure 20. Tropical cyclone formation locations between May-November 1979-1995. From Maloney and Hartmann (2000).

Impacts of warming?

Feedbacks?

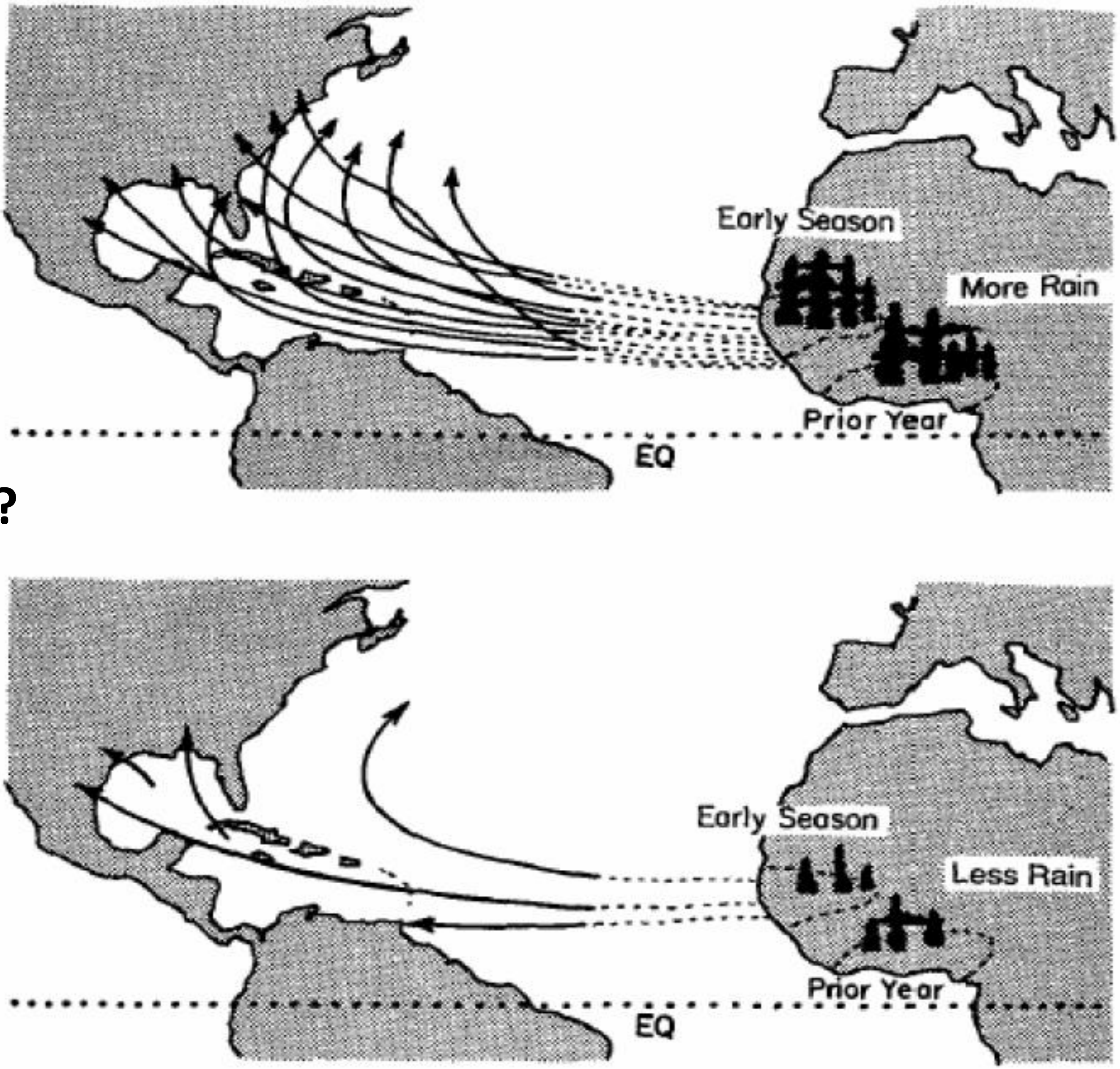


Figure 23. Schematic of the difference in hurricane activity during years with (top) above-, and (bottom) below-normal monsoon rainfall over the Sahel region of western Africa. From Landsea and Gray (1992).