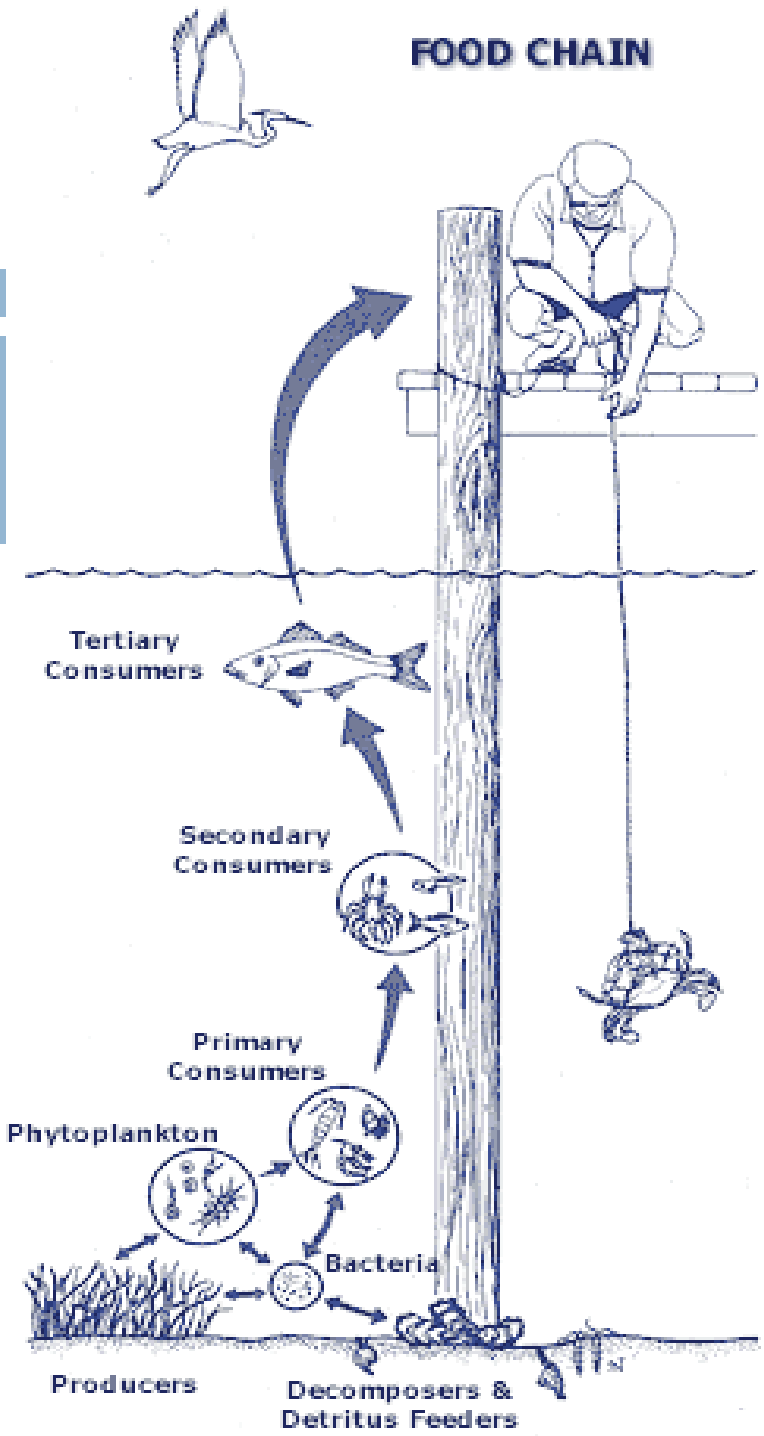
Regional Earth System Predictions for Actionable Information for Decision-Making

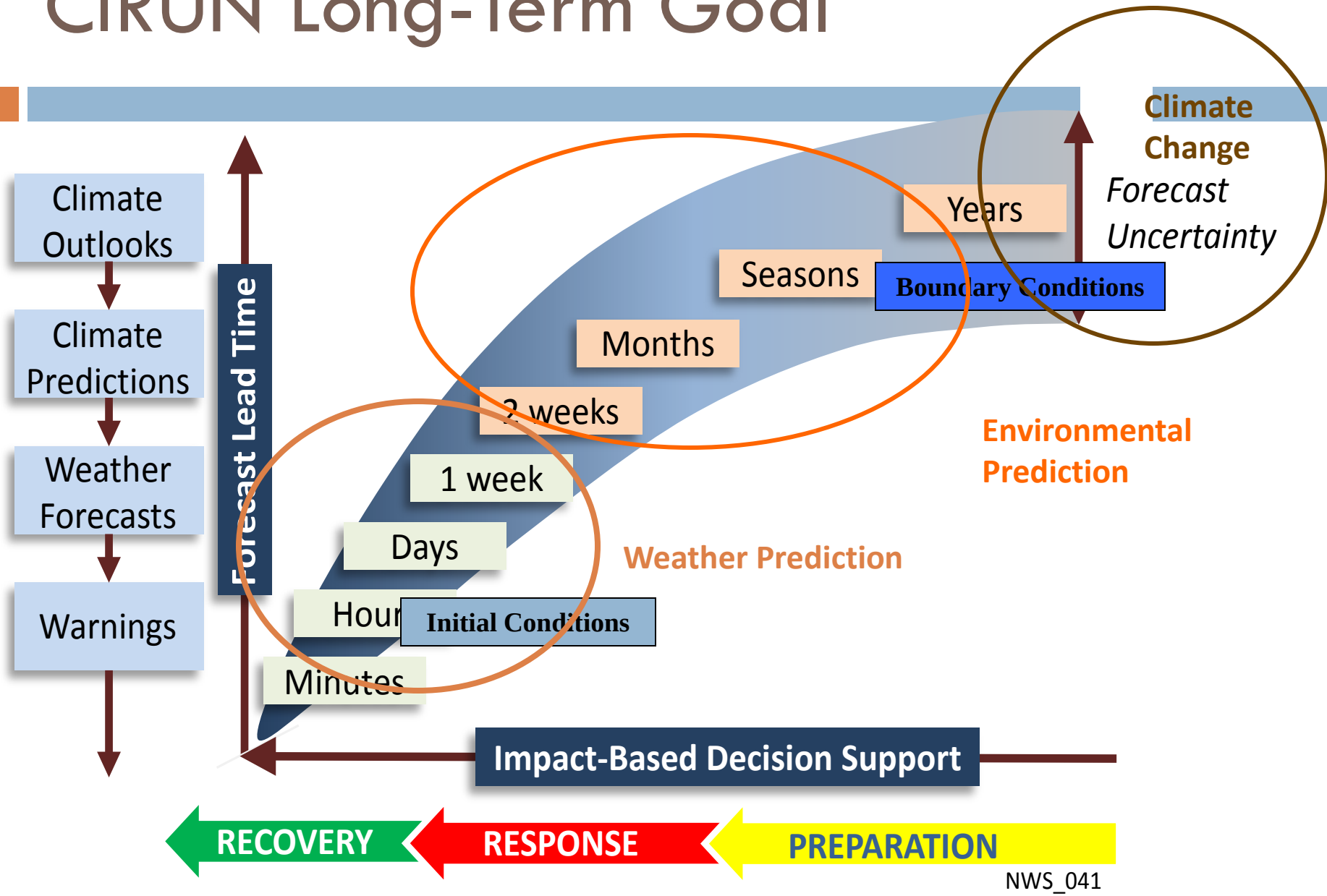
Raghu Murtugudde



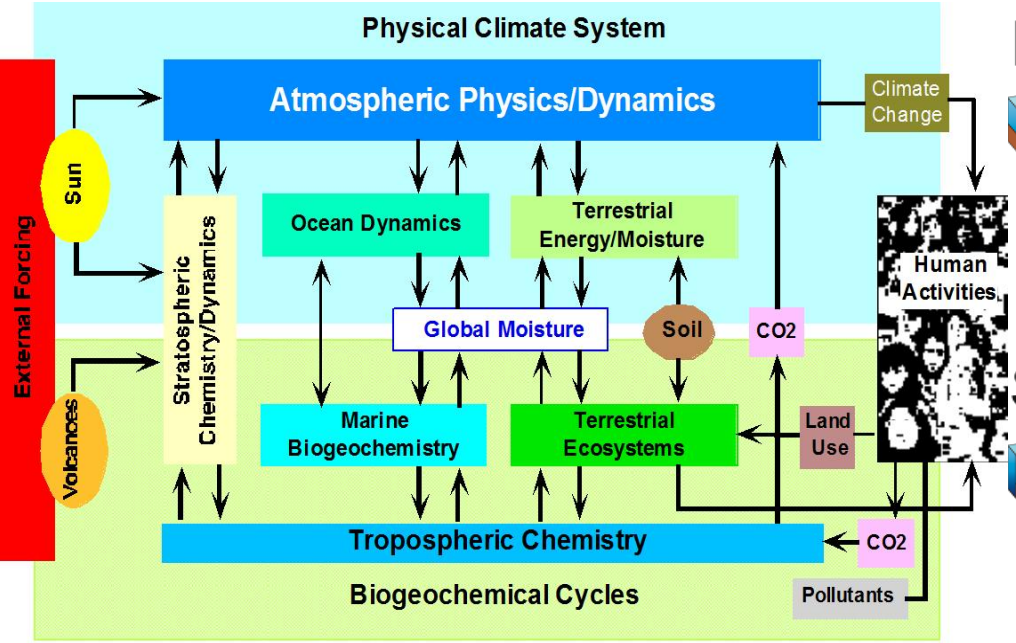
What can we learn from Weather Forecasting?

http://www.piqued.us/

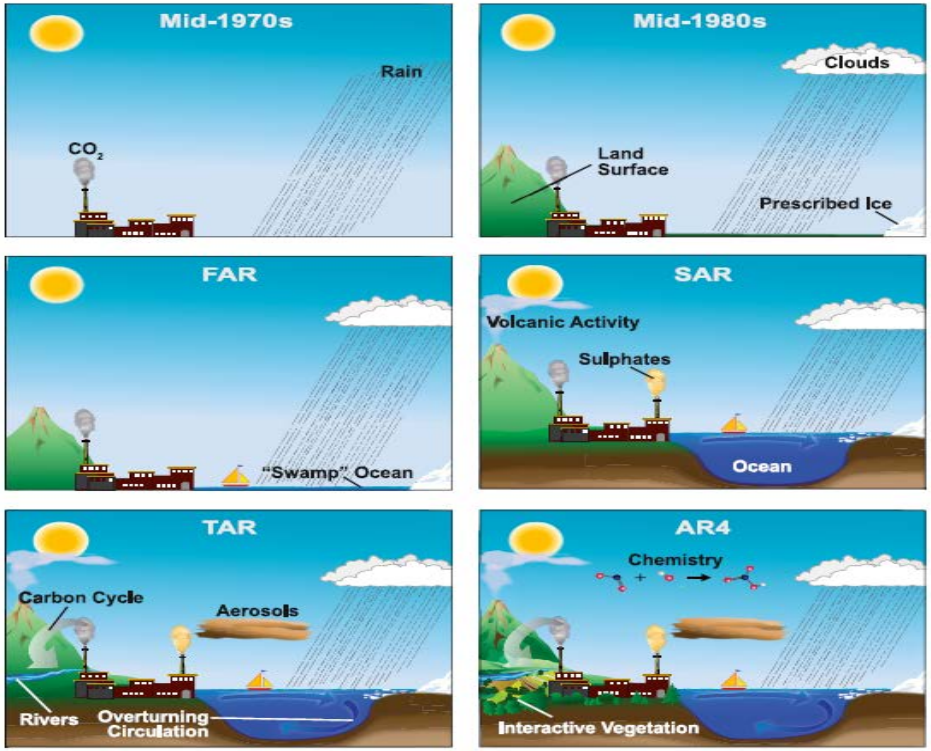
CIRUN Long-Term Goal

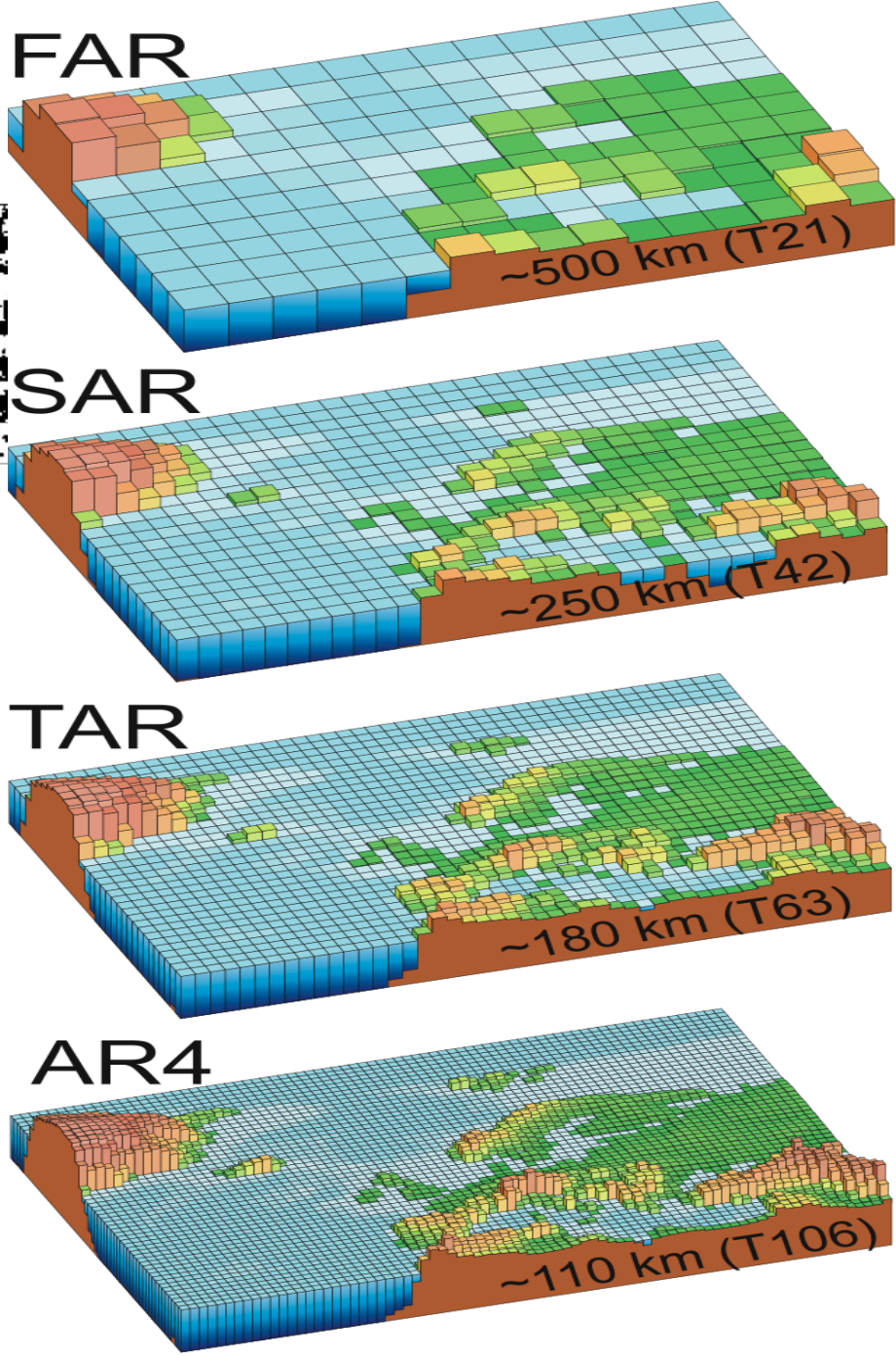


Courtesy: Dr. Wayne Higgins, NOAA

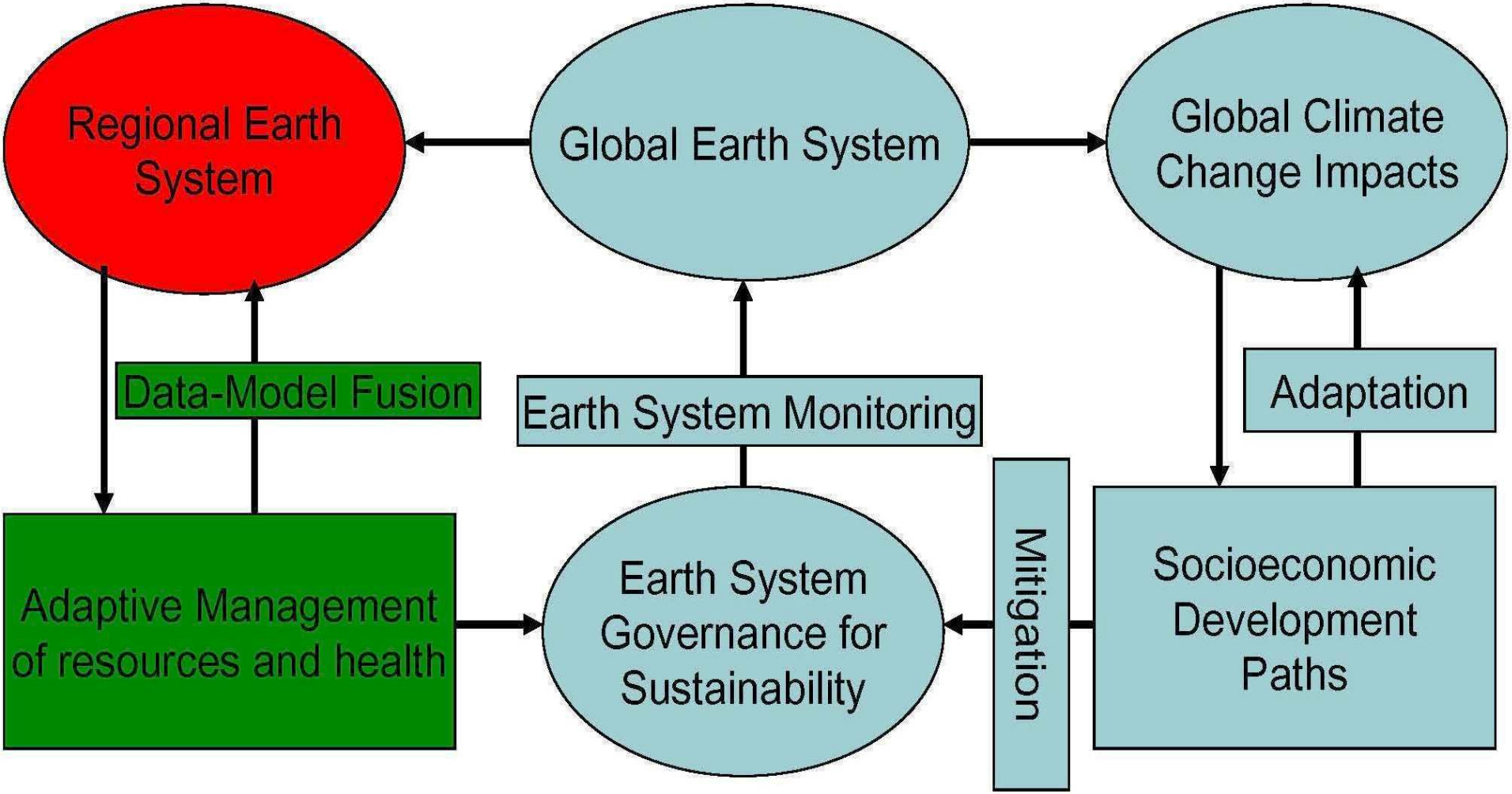


(from Earth System Science: An Overview, NASA, 1988)





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

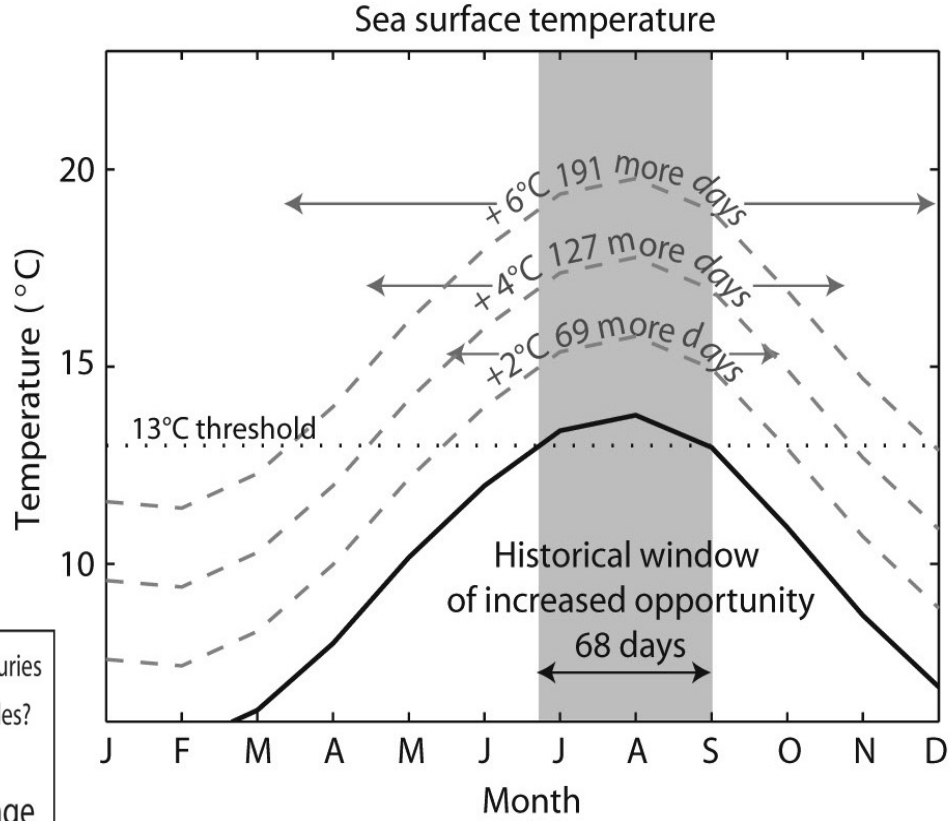
Infectious disease	Known effects of weather and climate	Possible impact of climate change
Zoonotic and vector-borne diseases (e.g., Lyme disease, West Nile virus, dengue, malaria, chikungunya, tularemia, rabies)	• Increased temperature shortens pathogen development time in vectors. This increases the 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.

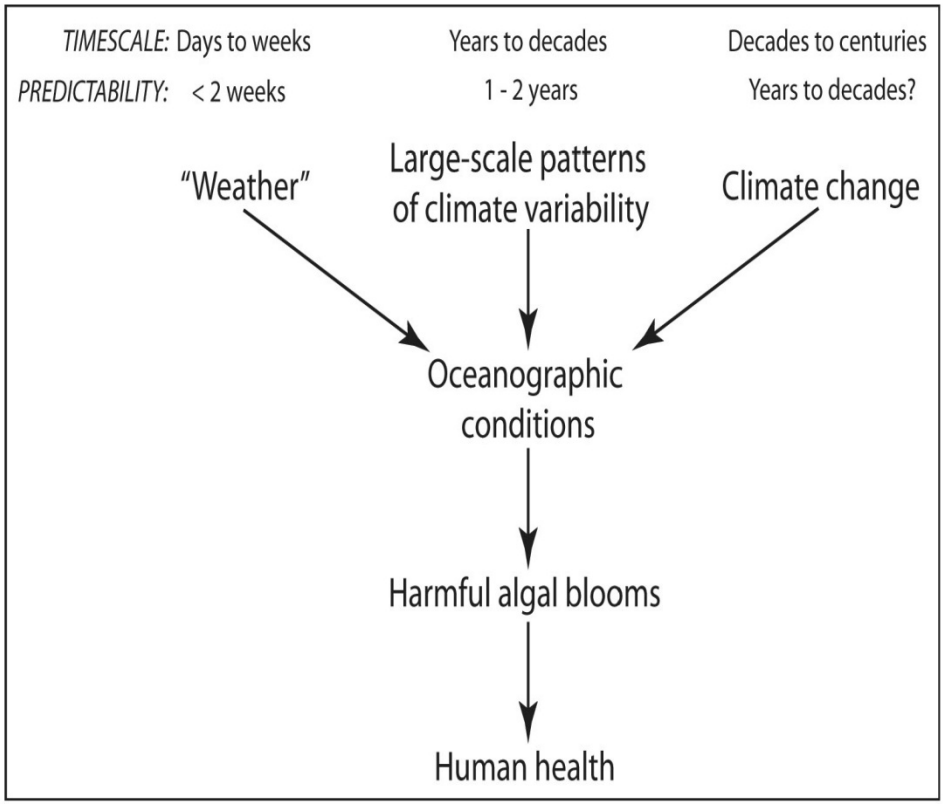
Hippocrates (~400 BC)

Environment and Health

Greer et al. 2008

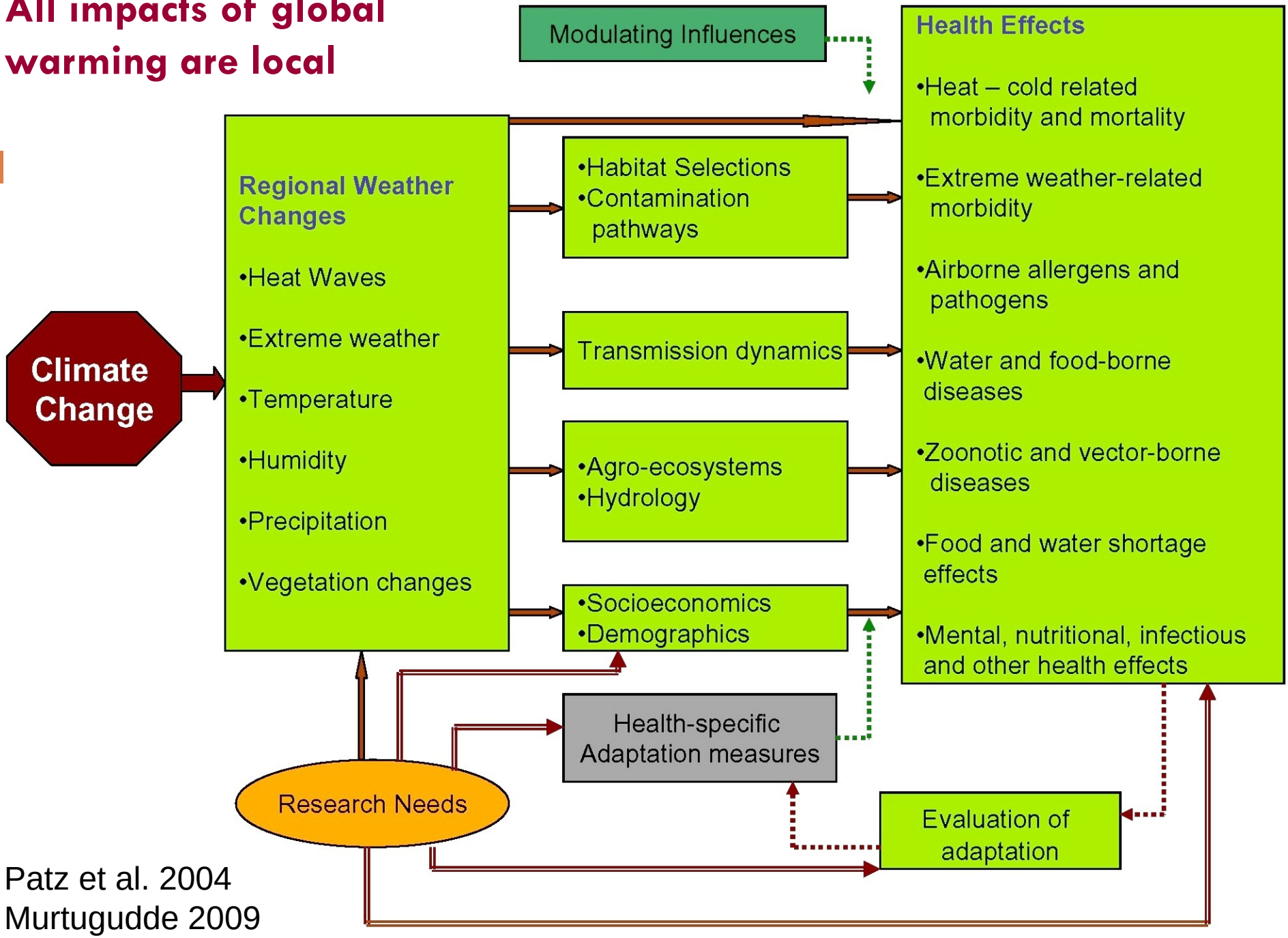
Old Paradigm





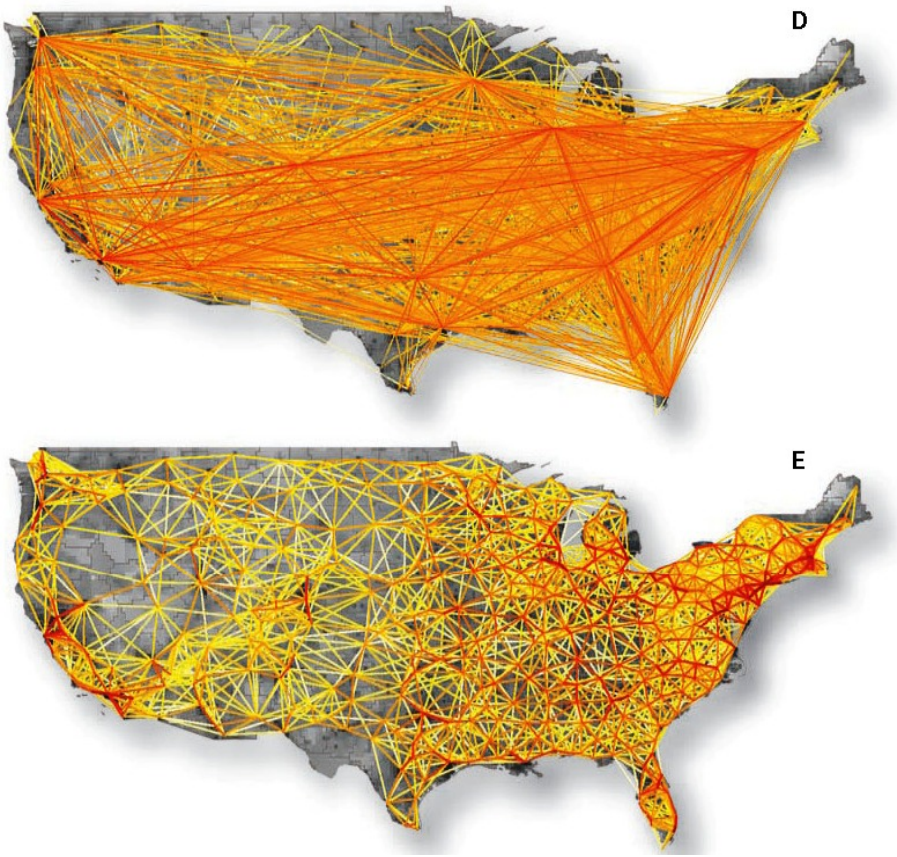
Moore et al. 2008

All impacts of global warming are local

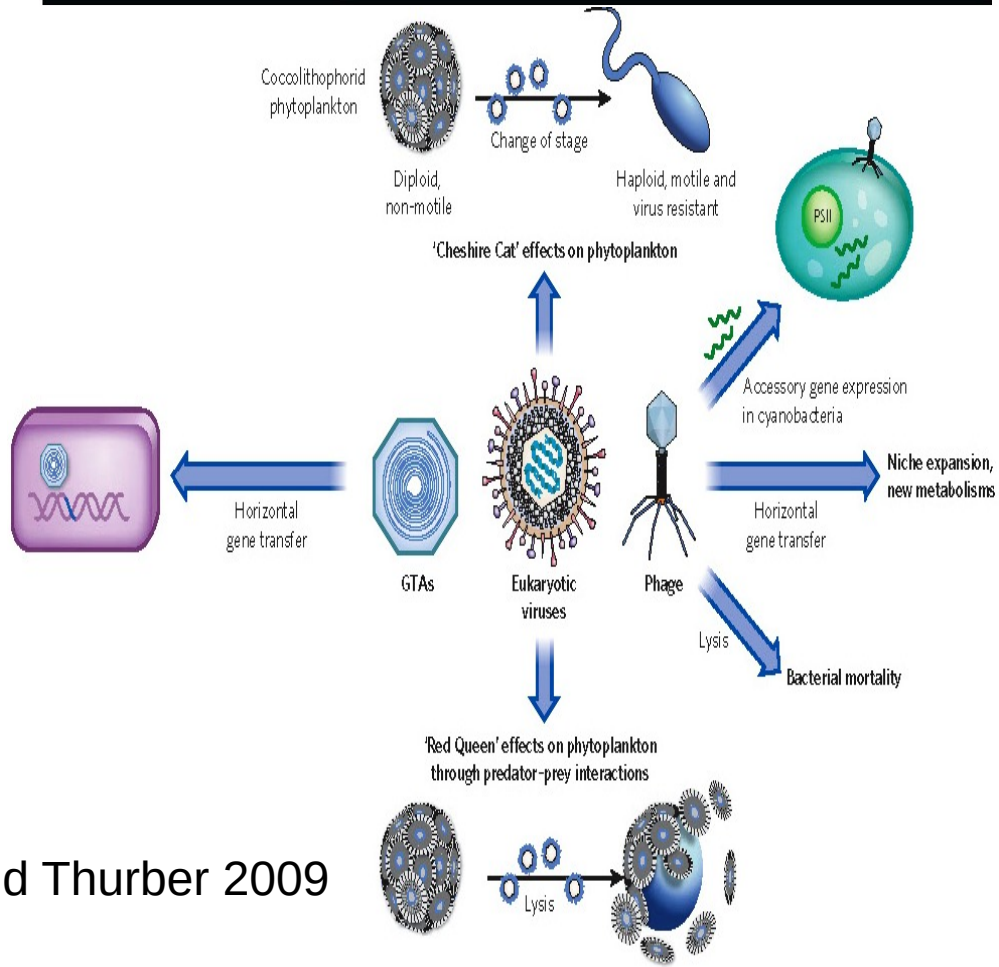


Patz et al. 2004
Murtugudde 2009

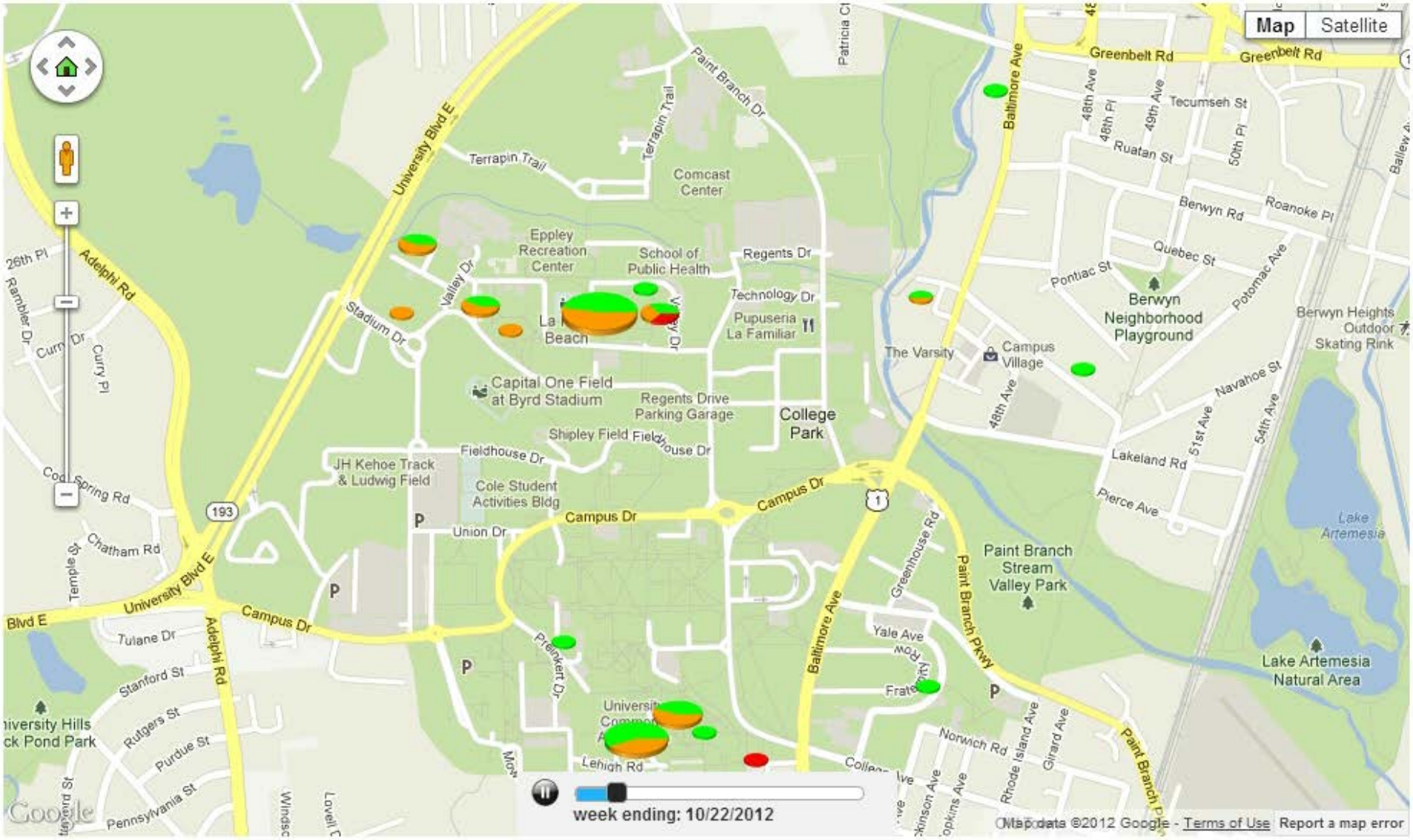
Computational social science: How things spread



Vespignani et al. 2009



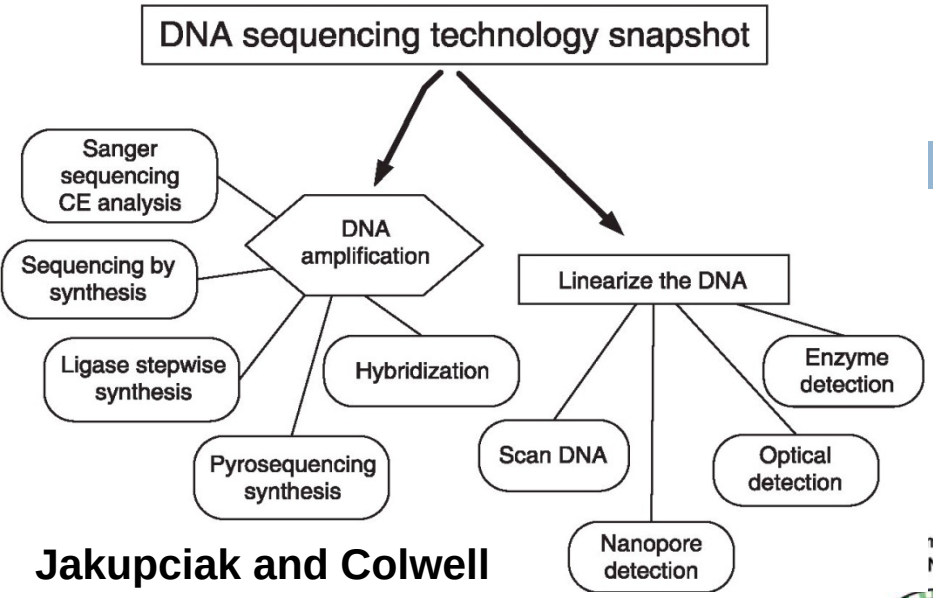
Rohwer and Thurber 2009



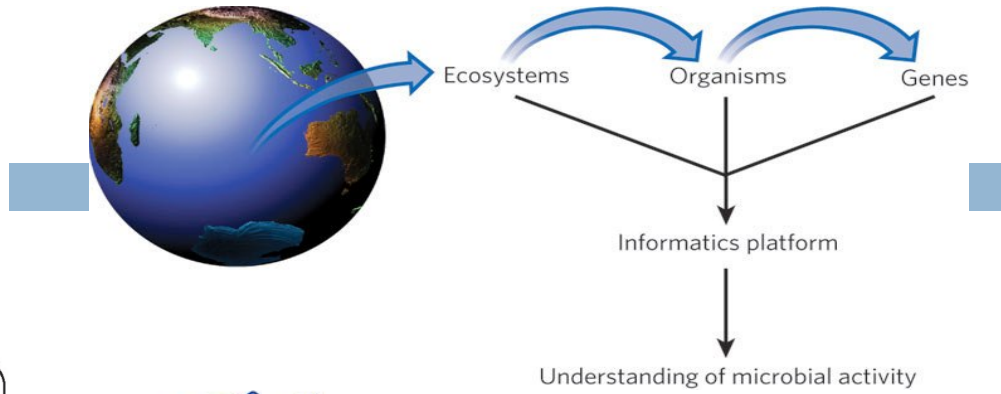
No symptoms reported | Some symptoms reported | Influenza-like illness reported

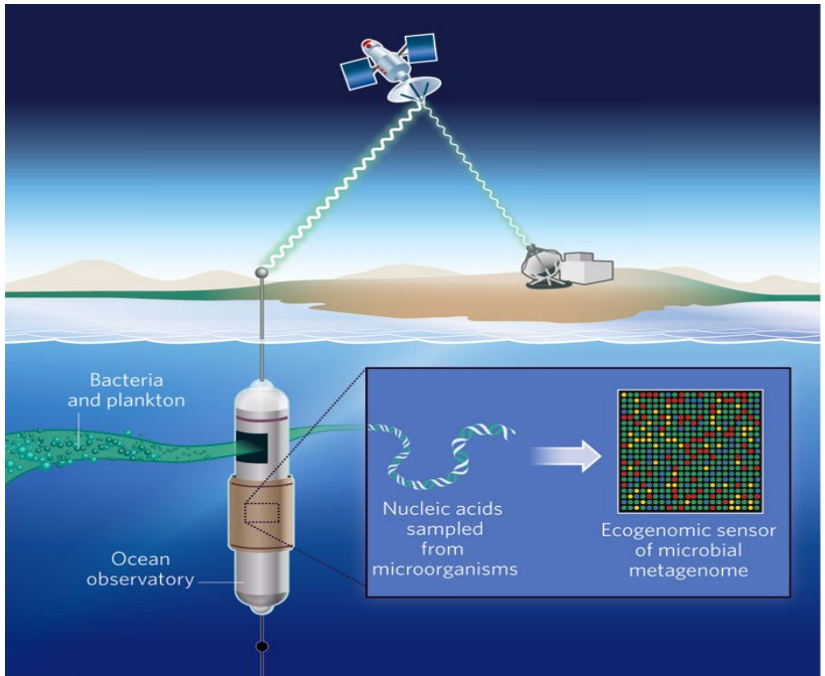
<= 2 participants | >=3 and <=5 participants | >=6 and <= 10 participants | >= 11 and <= 14 participants | >= 15 participants

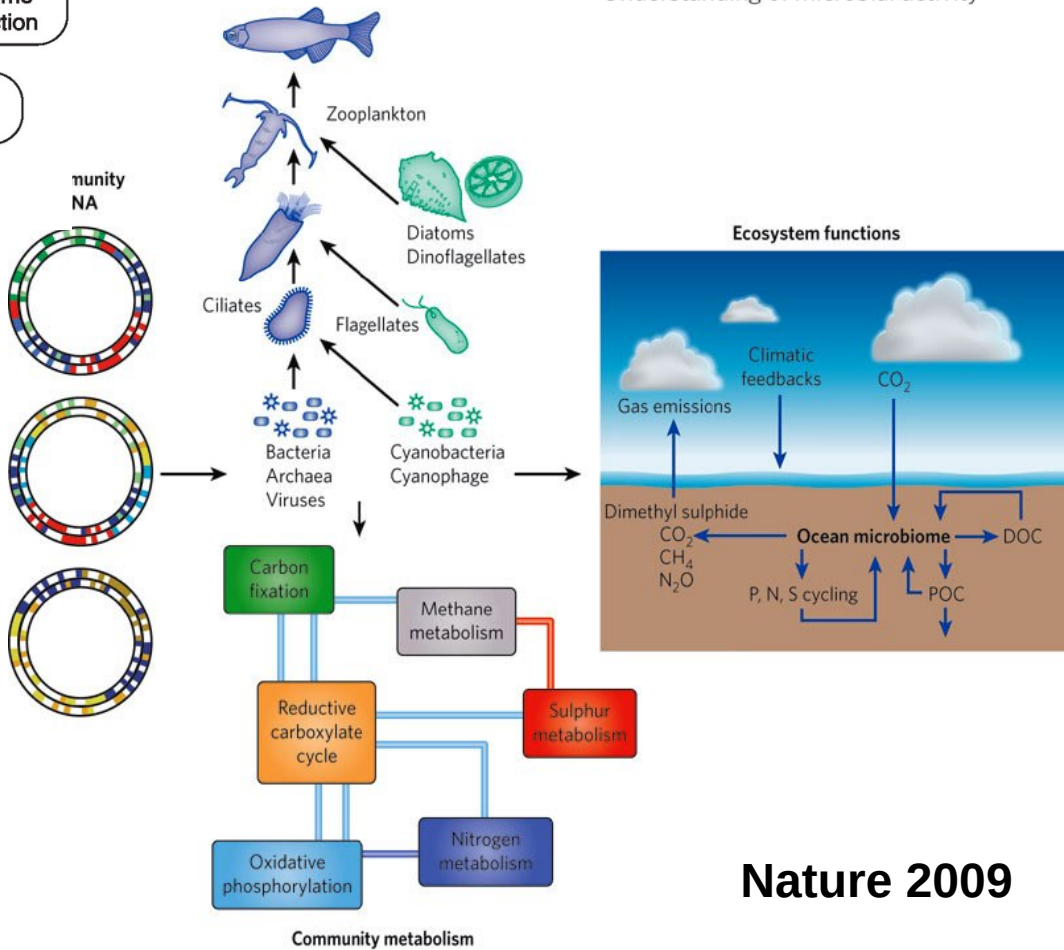
New science and new technologies



Jakupciak and Colwell 2009

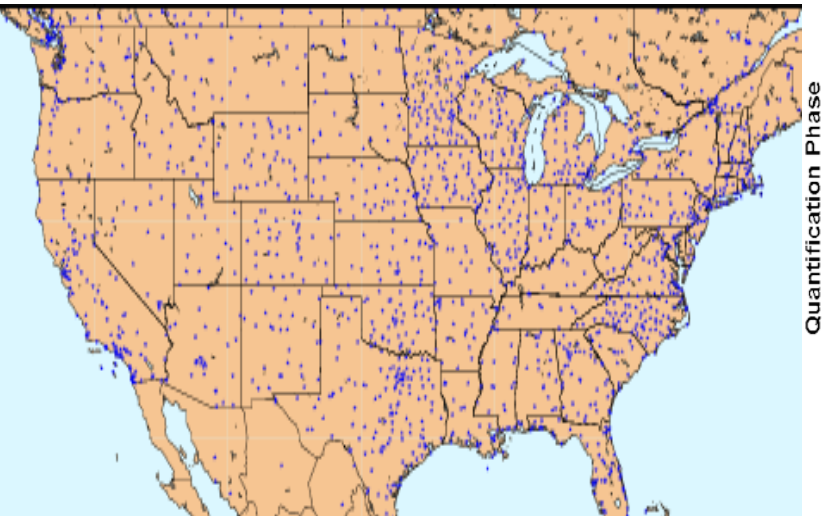


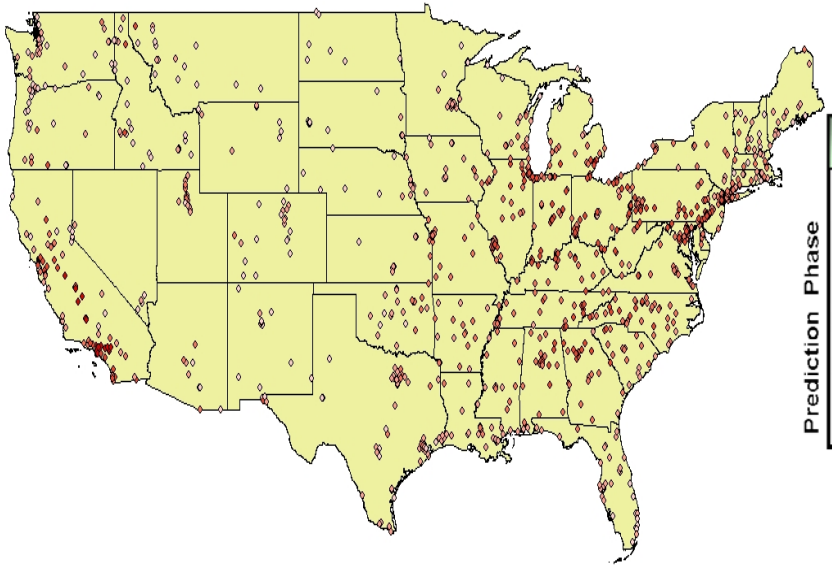


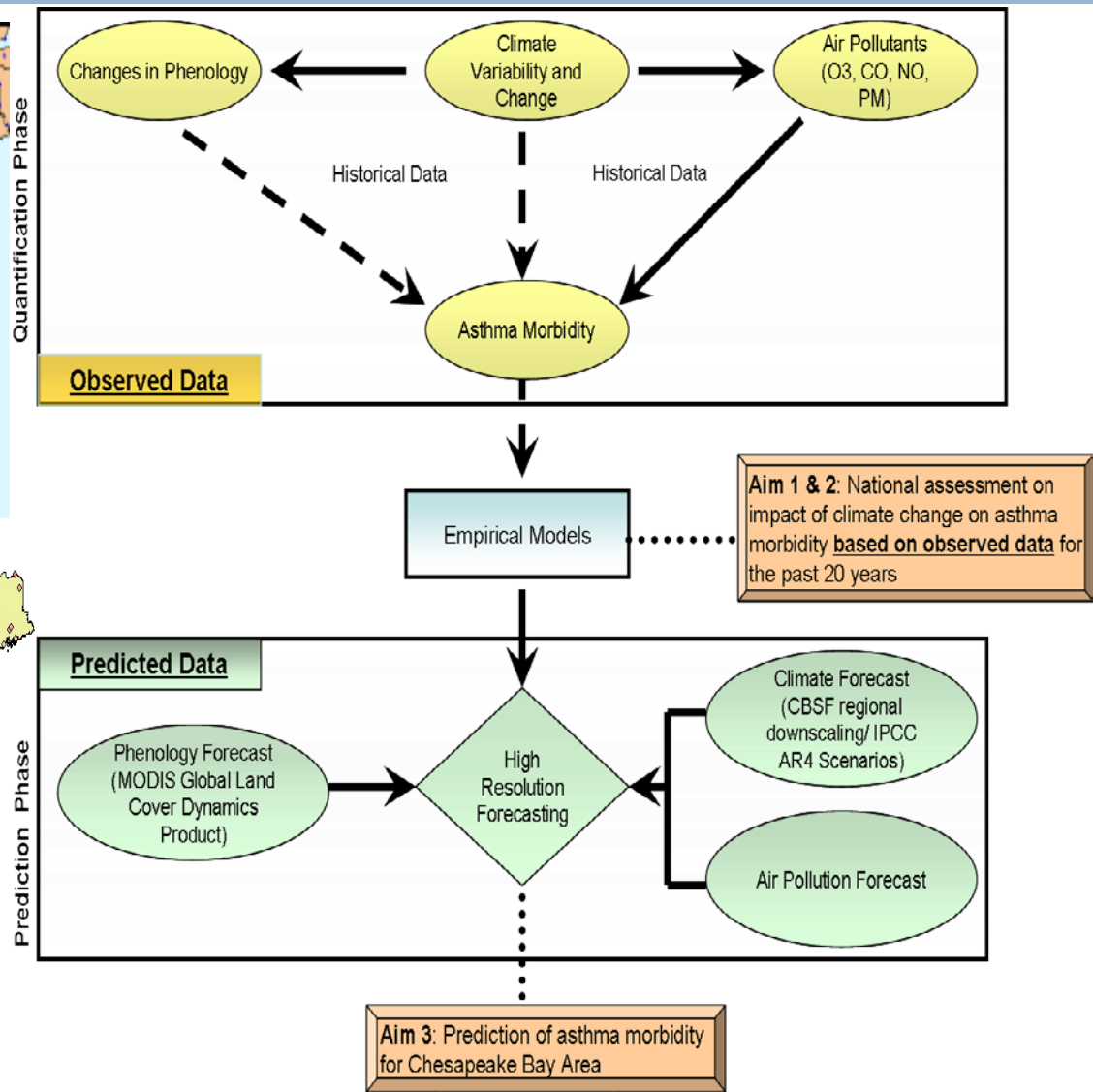


Nature 2009

Meteorological and air-quality data:







Partners

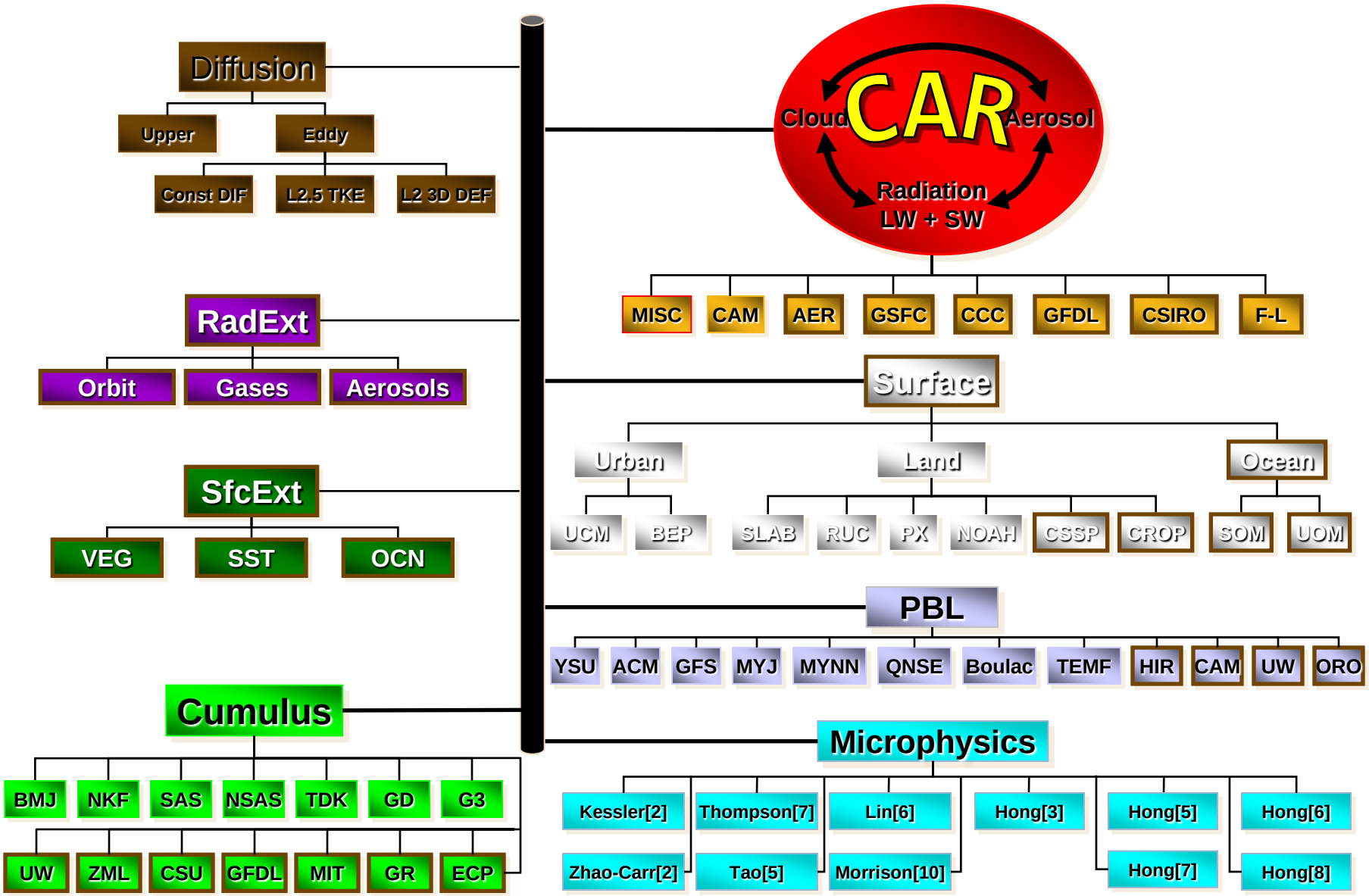
- UMCP: J. Strack, M. Bala Prasad, C. Anderson, A. Sood, G. Constantin de Magny, X. Liang and Gang
- NOAA: H. Meng, F. Aikman
- UMIACS: D. Zotkin, A. Srinivasan, B. Vasan, T. Dubois
- SPH: A. Sapkota; CDC: Jennifer Parker
- NASA: G. McConaughy, M. Seablom, H. Mitchell
- NOAA Oxford Lab: B. Wood, X. Zhang, J. Jacobs
- EPA: G. Shenk, L Linker
- DNR: C. Wazniak, B. Michael, P. Tango, COG, ICPRB

Future Partners

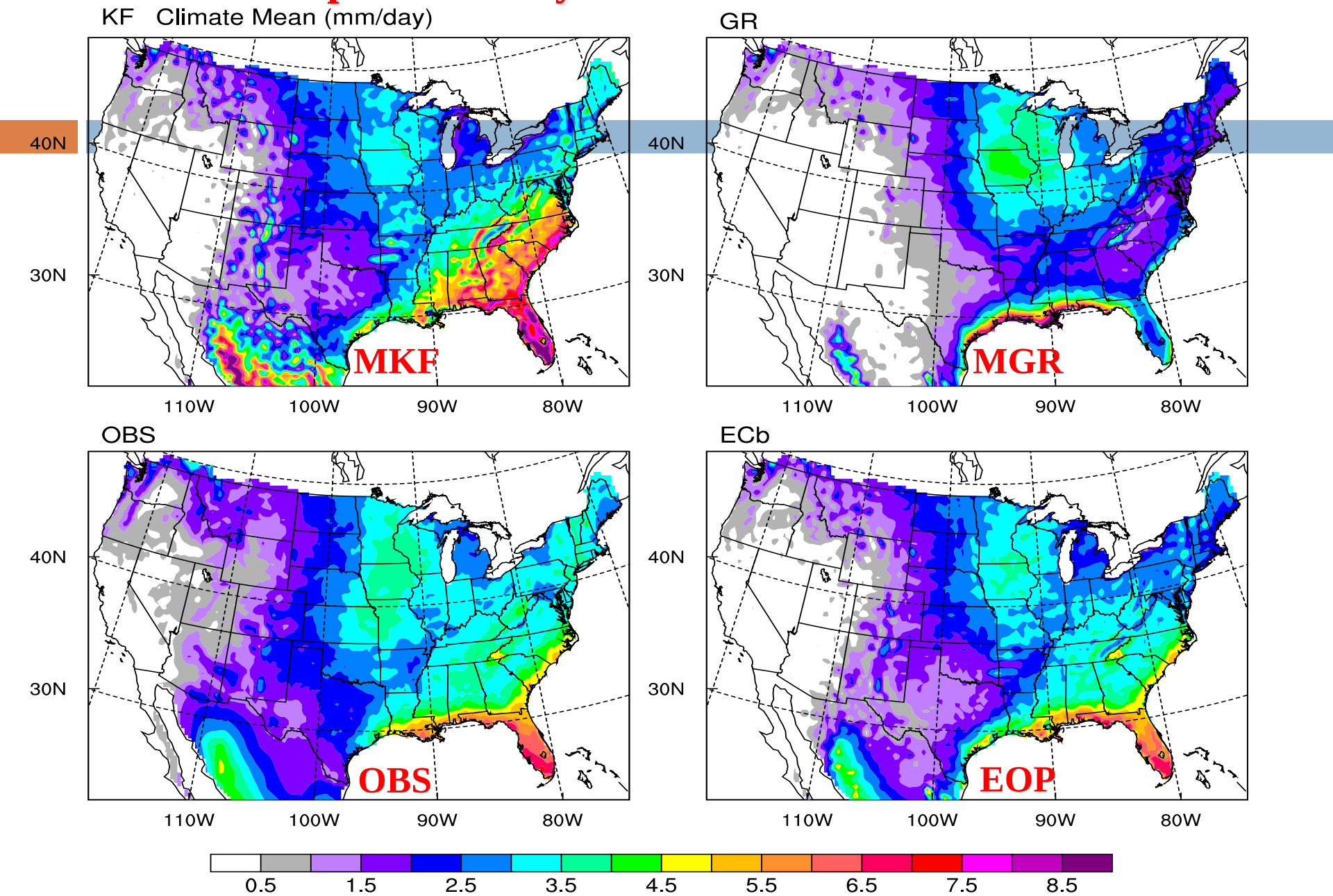
Users, Superusers, Governments, People

CWRF Physics Options

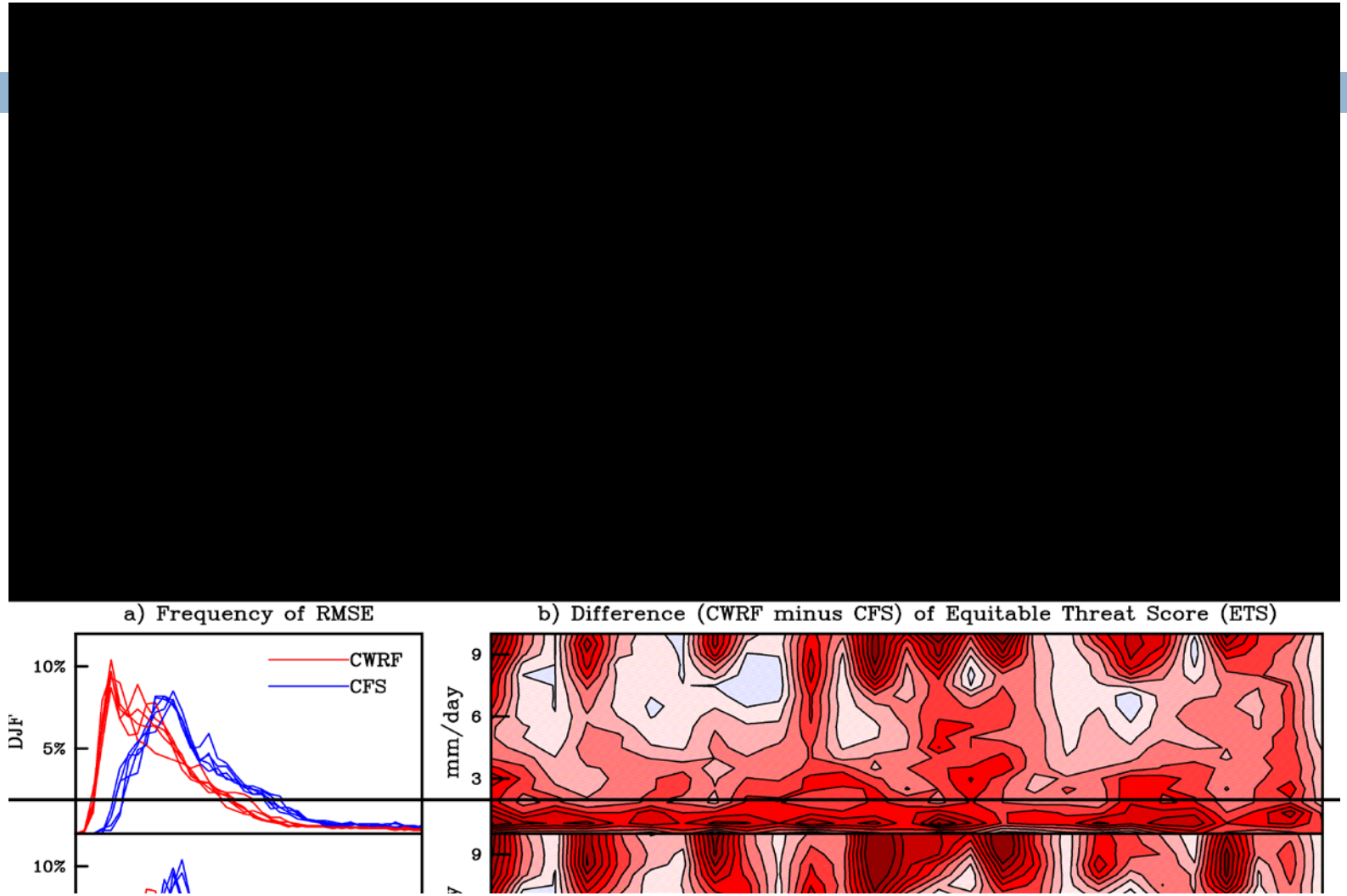
http://cwrf.umd.edu



Optimized Physics-Ensemble Prediction

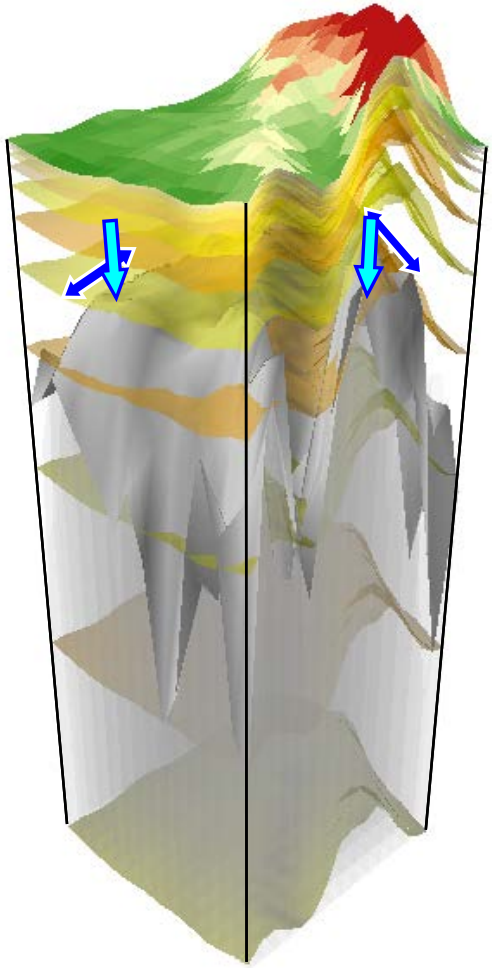


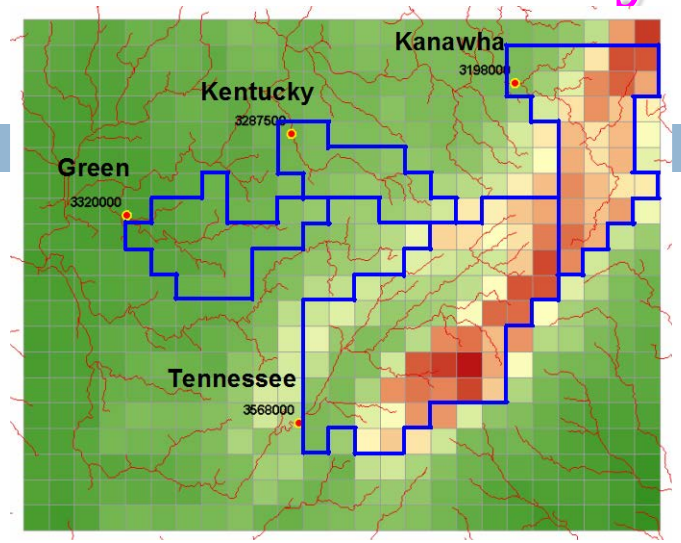
CWRF Improves Seasonal Climate Prediction

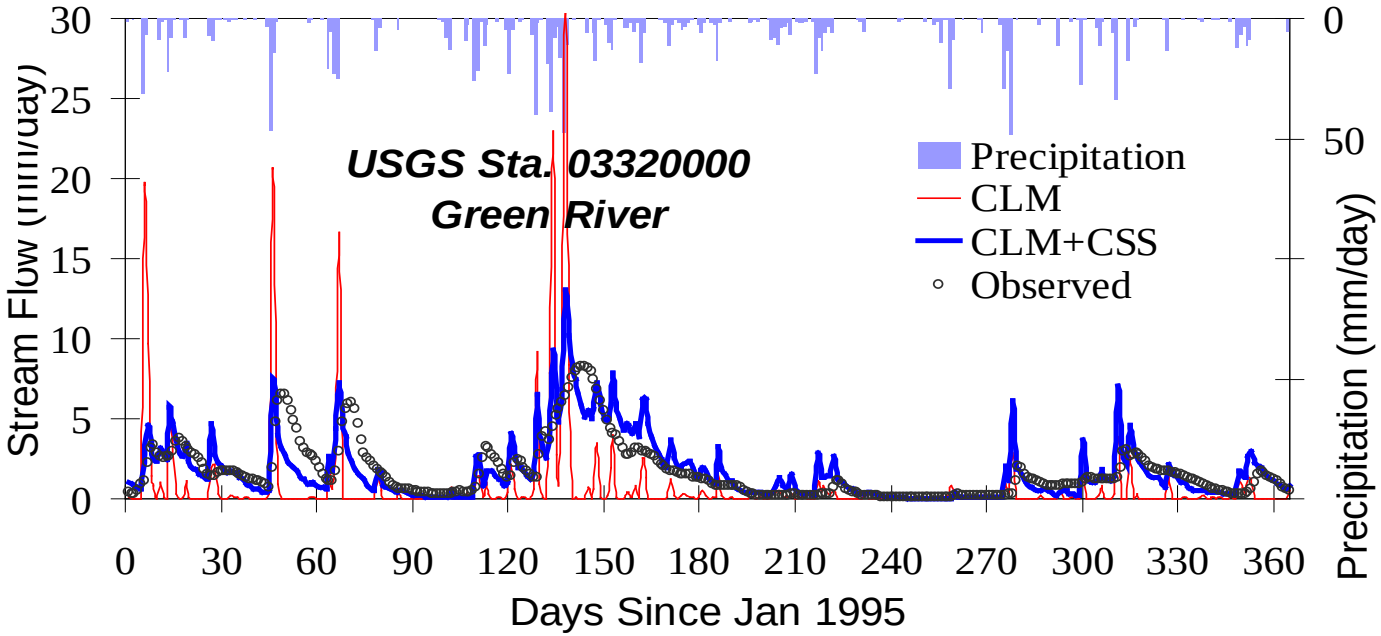


a) Spatial frequency distributions of root mean square errors (*RMSE*, mm/day) predicted by the CFS and downscaled by the CWRF and **b)** CWRF minus CFS differences in the equitable threat score (*ETS*) for seasonal mean precipitation interannual variations. The statistics are based on all land grids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

CWRF Terrestrial Hydrology

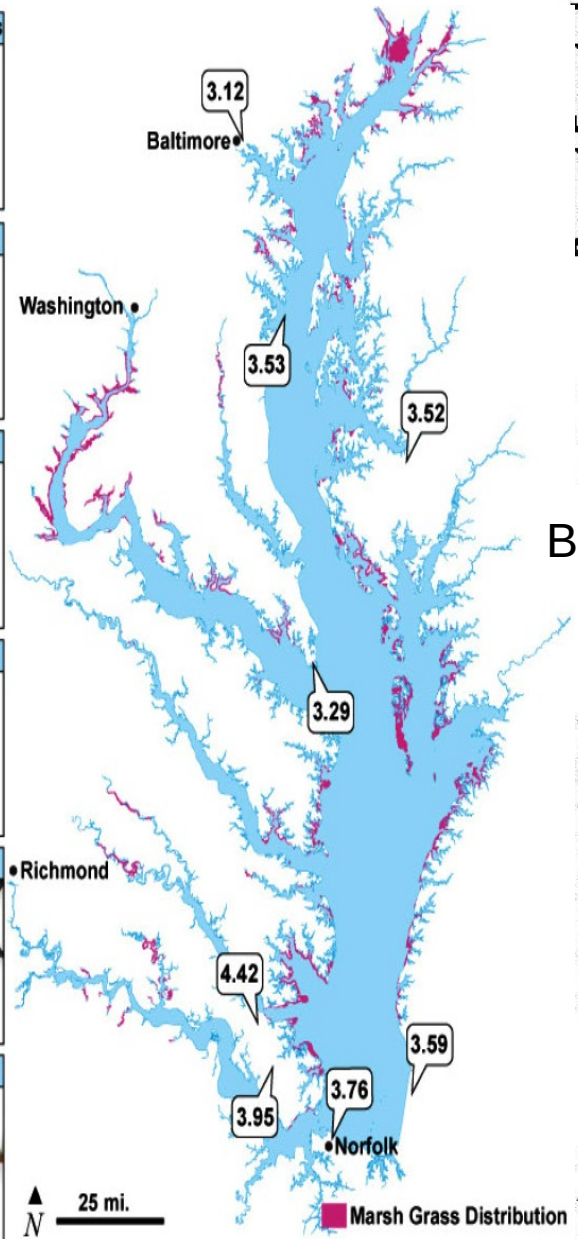






Choi 2006; Choi et al. 2007; Choi and Liang 2010; Yuan and Liang 2010; Liang et al. 2010d

Why Chesapeake Bay?



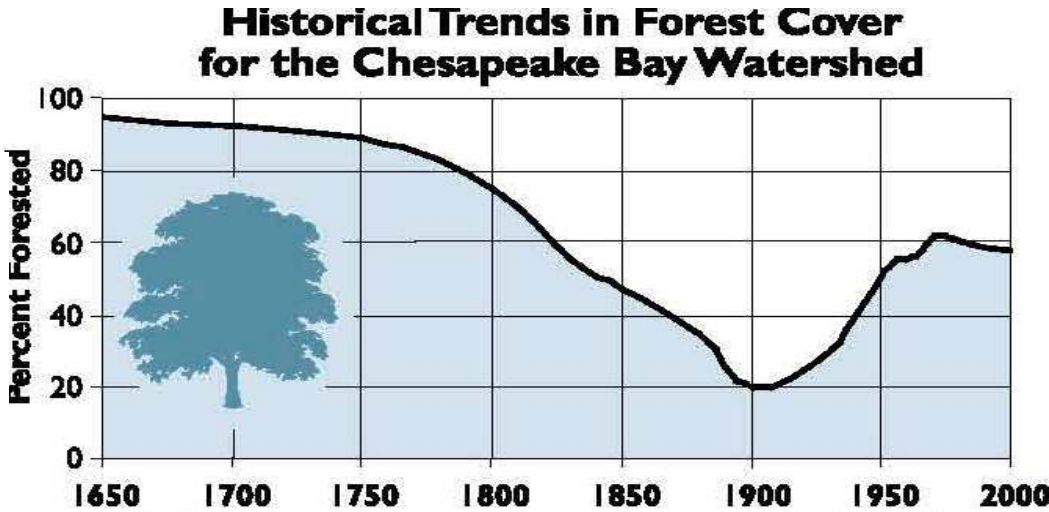


Figure 6-1. After bottoming out in the early 1900s, forest cover regained acreage throughout much of the last century. Recent decades show a slight decline.

Boesch and Greer 2003

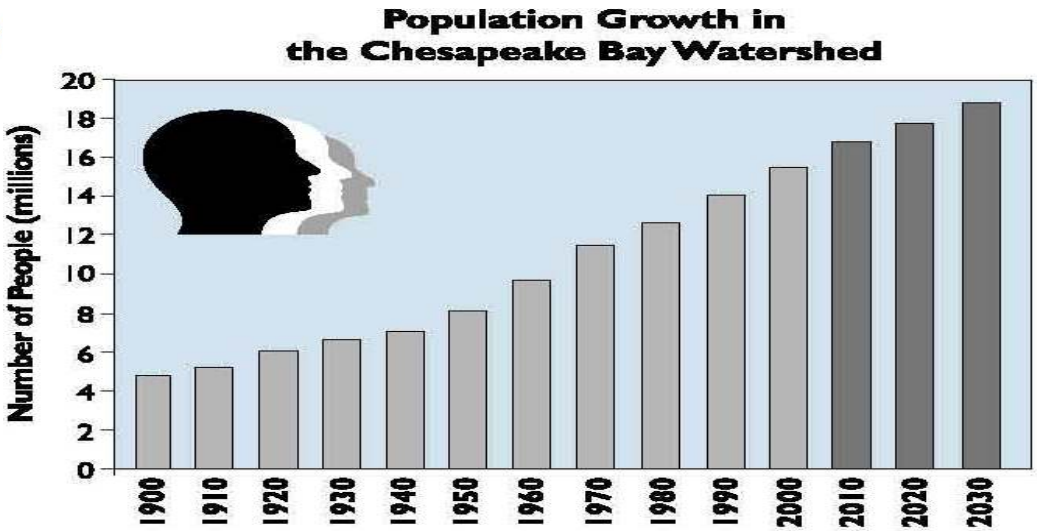
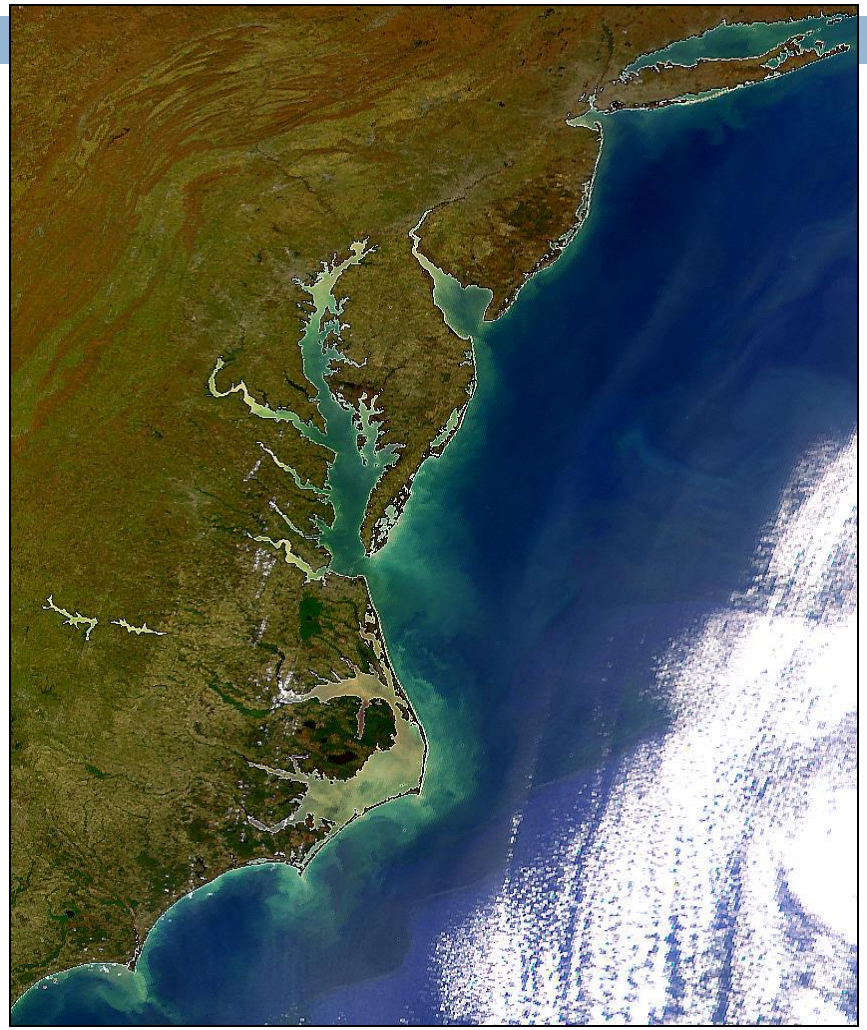


Figure 2-1. Since the beginning of the last century, population levels have shown a steady increase in the Bay watershed. Experts predict that numbers will continue to rise through the next three decades.

Chesapeake Bay Forecast System

- **Objective:** Develop a fully integrated model of the Chesapeake Bay and its air and watershed
- **Purpose:**
  - Near-Real Time Applications: Nowcasting and forecasting of the Bay circulation, ecosystem, pathogens, harmful algal blooms, waves and inundation.
  - Climate Projections: Estimating effect of climate change, between now and 2050, on the health of the Bay and its watershed.
  - Provide a decision making tool for users



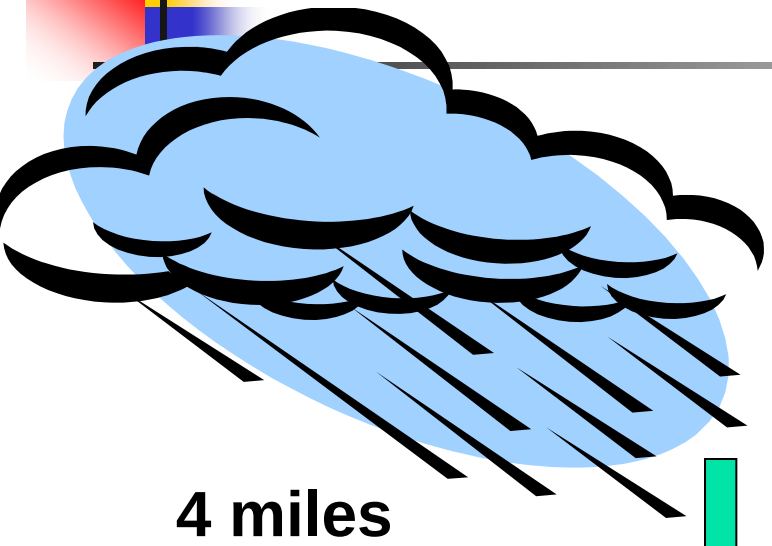
SeaWiFS true-color image of Mid-Atlantic Region from April 12, 1998.

Image provided by the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE

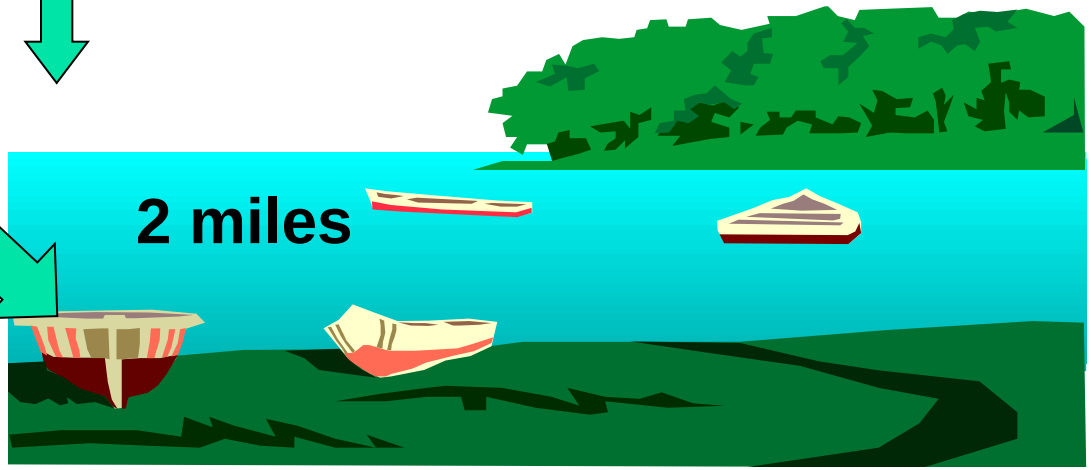
What we can predict

- Harmful algal blooms
- Sea Nettles
- Human Pathogens
- Anoxia
- Insect Infestation
- Personalized-Preemptive-Predictive Health Information
- Sea level rise, inundation, storm-surge
- Future scenarios for Policy, Agriculture, Population, Health of the Bay

Dynamic Downscaling: Scales that matter



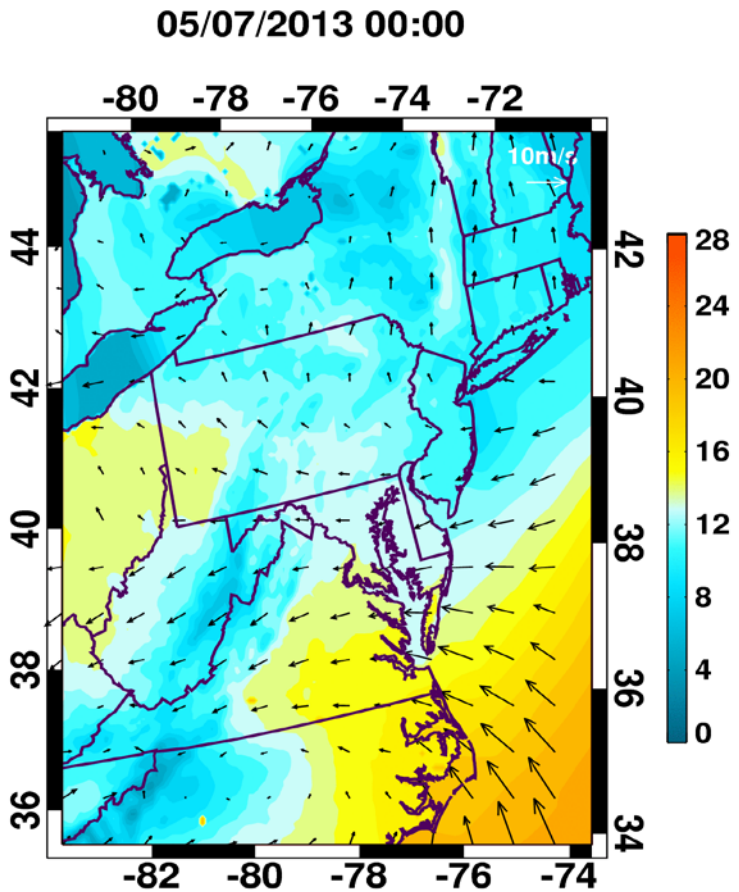
- Climate information at meter-scale
- What are the rivers and streams carrying?
- Water quality, ecosystems, crabs, clams, sea grasses, oxygen.
- Agriculture, livestock, poultry, eutrophication



WRF 14 Days Forecasts from 2013/05/07

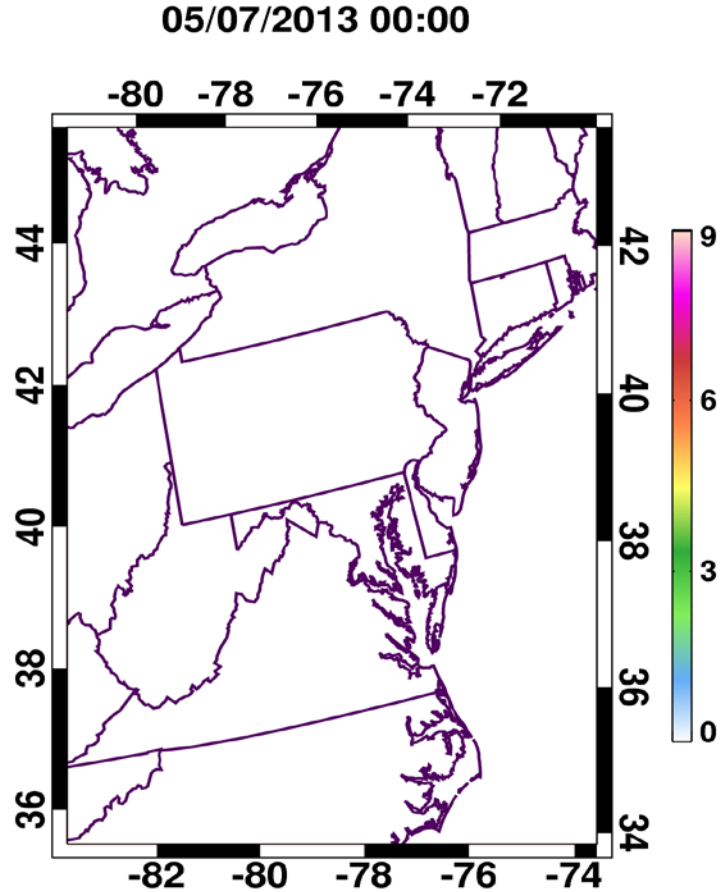
2-m Air Temperature (^{o}C) with 10-m winds(m/s)

Initialize 05/07/2013 00:00 UTC



3-hr Precipitation (mm)

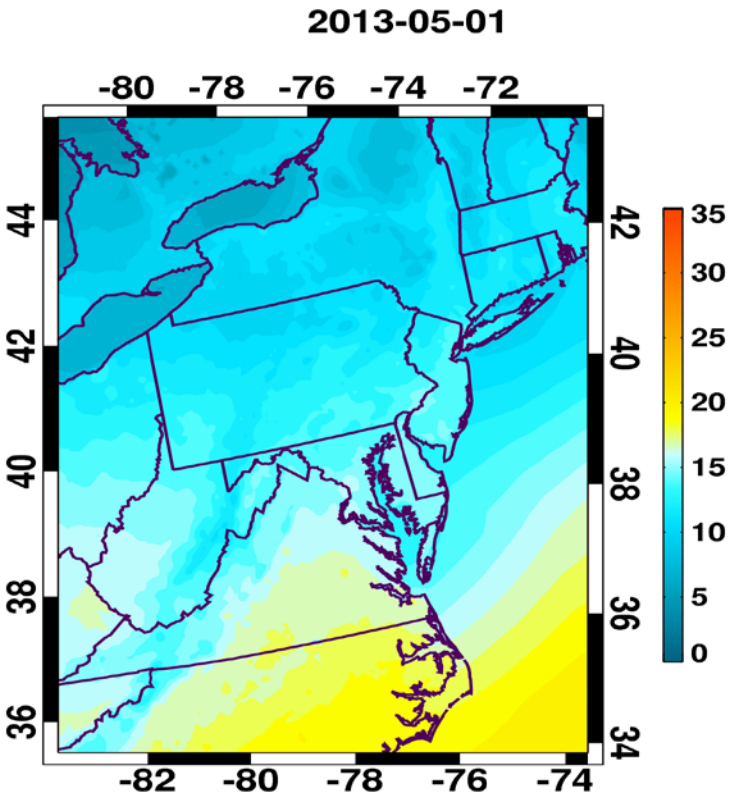
Initialize 05/07/2013 00:00 UTC



WRF Seasonal Forecasts from 2013/05/01-2013/08/31

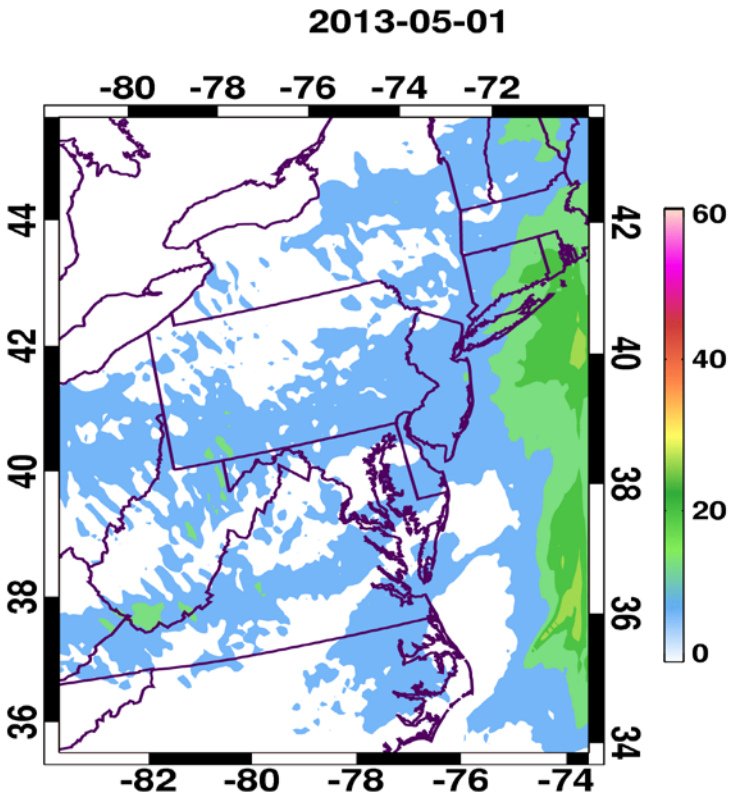
Daily Mean 2-m Air Temperature (°C)

Initialize 05/01/2013 00:00 UTC

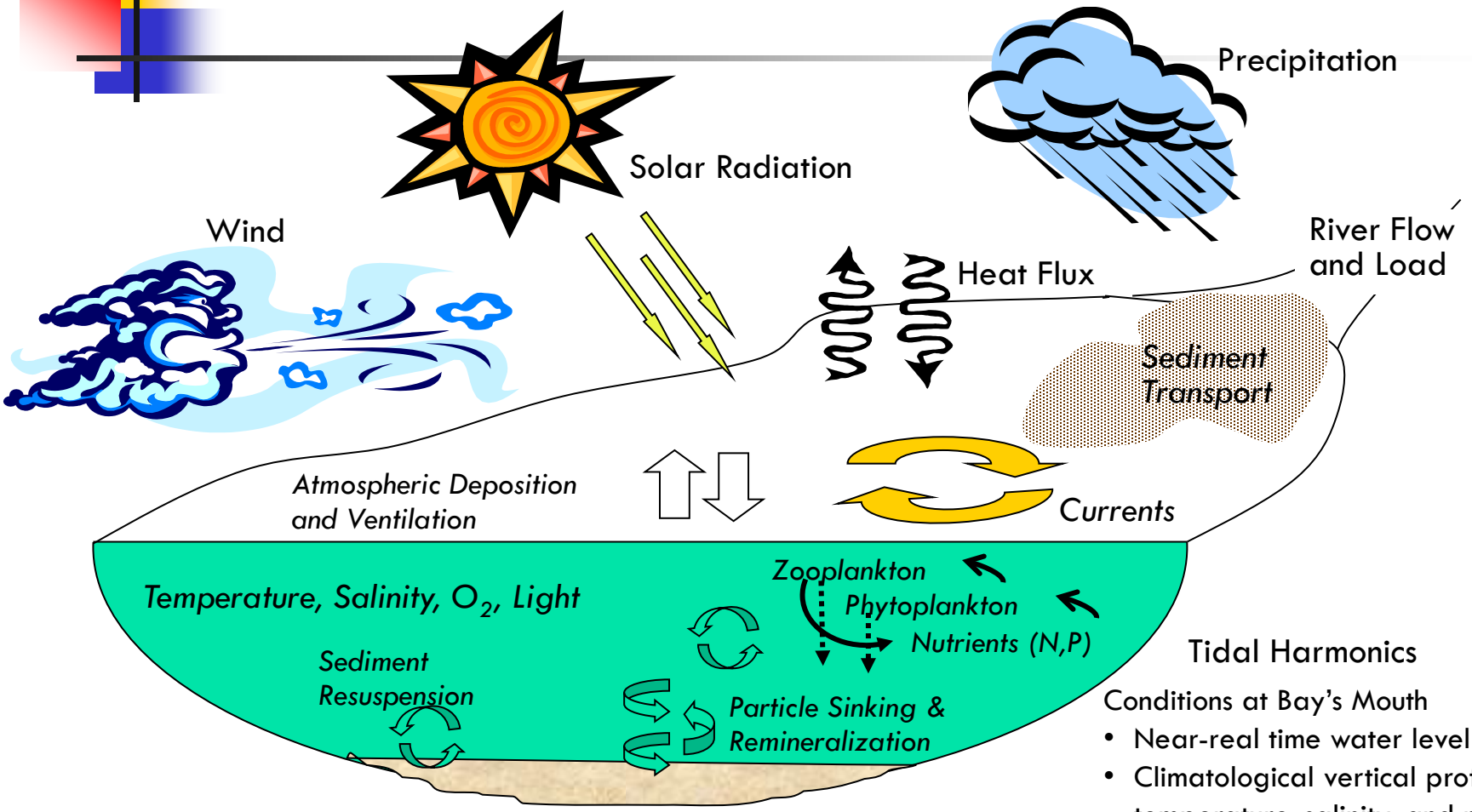


Daily Mean Rain (mm)

Initialize 05/01/2013 00:00 UTC



ROMS: Regional Ocean Modeling System

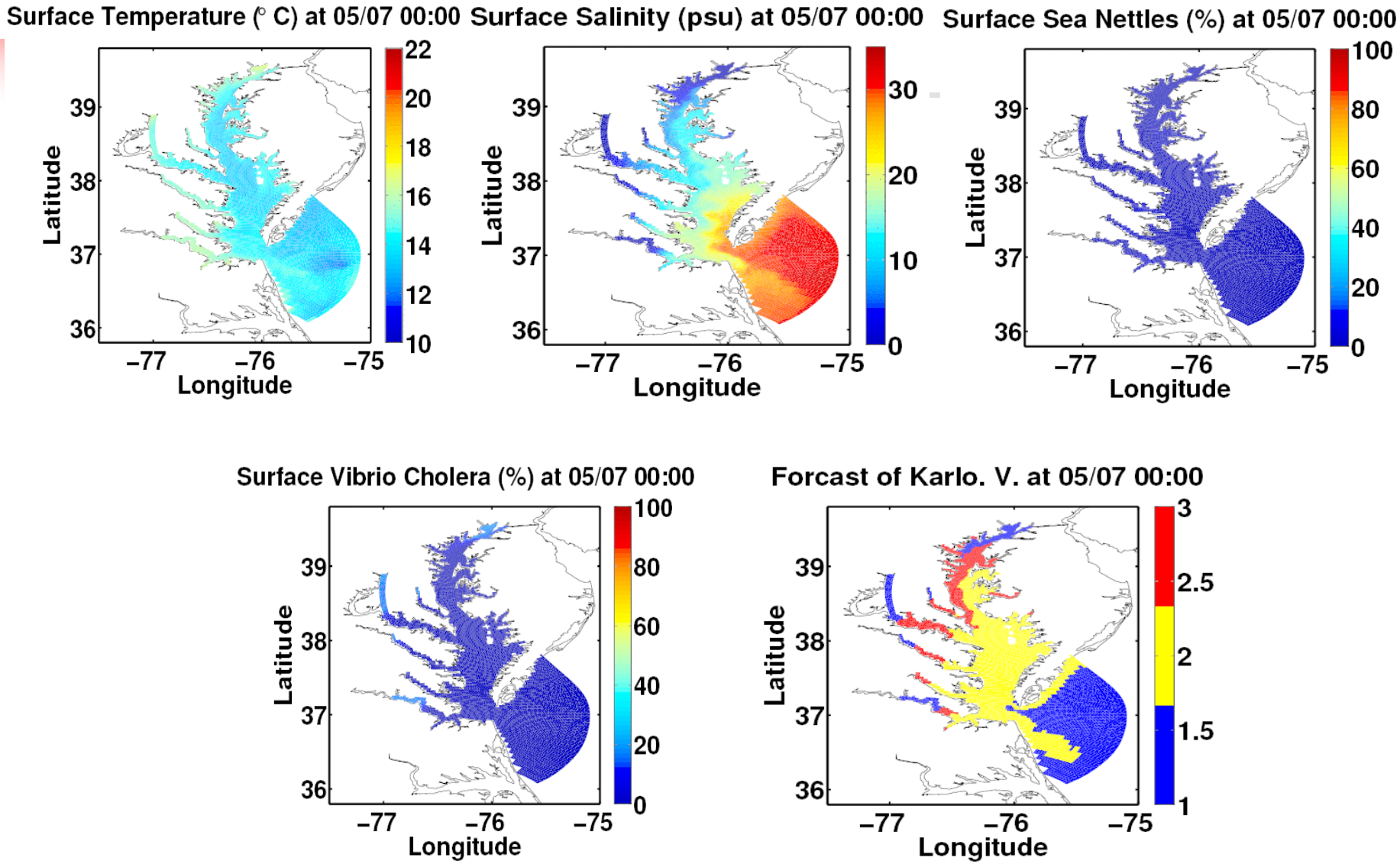


Tidal Harmonics

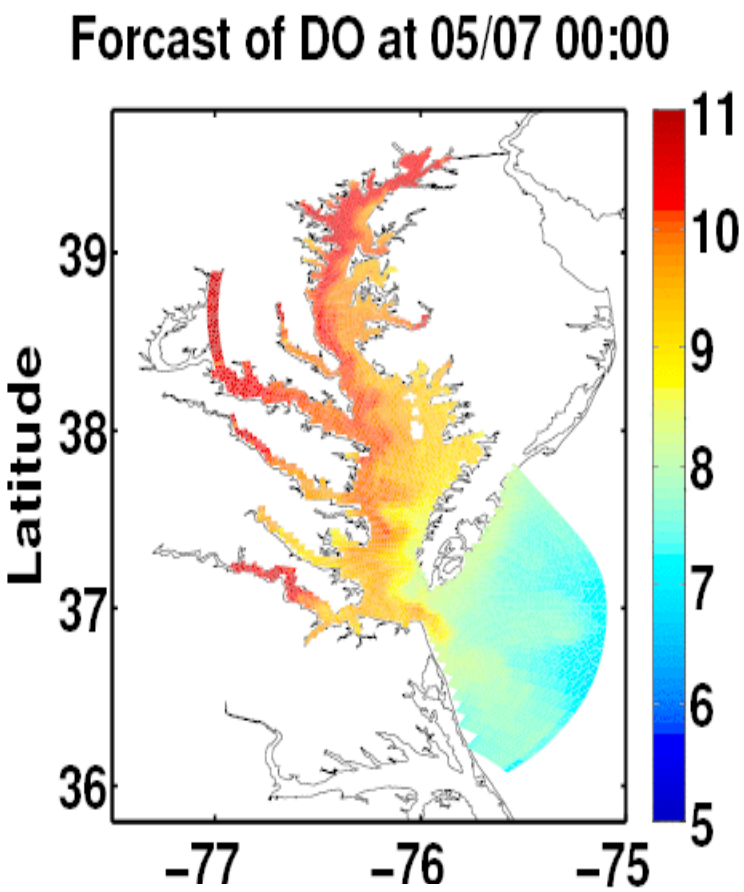
Conditions at Bay's Mouth

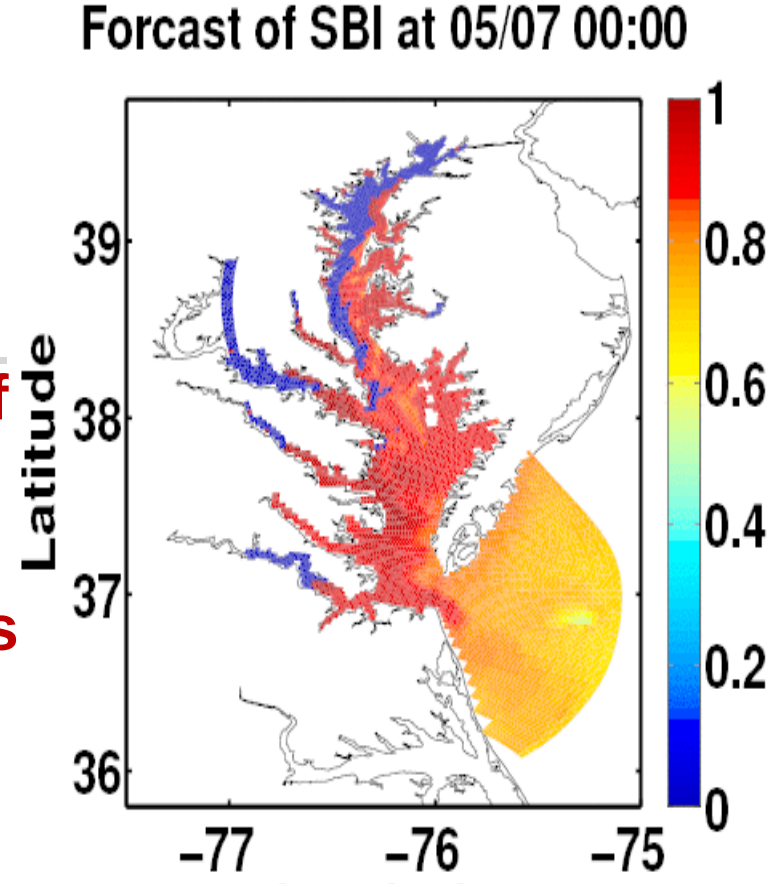
- Near-real time water level
- Climatological vertical profiles of temperature, salinity, and nutrients and chemicals

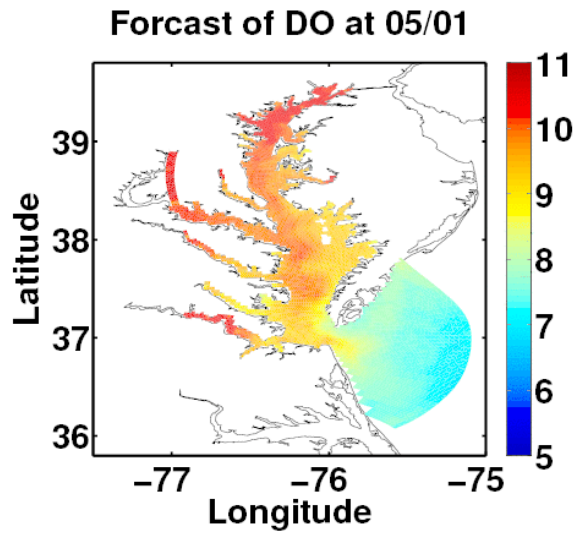
14 Days Ocean Forecasts (2013/05/07-2013/05/21)

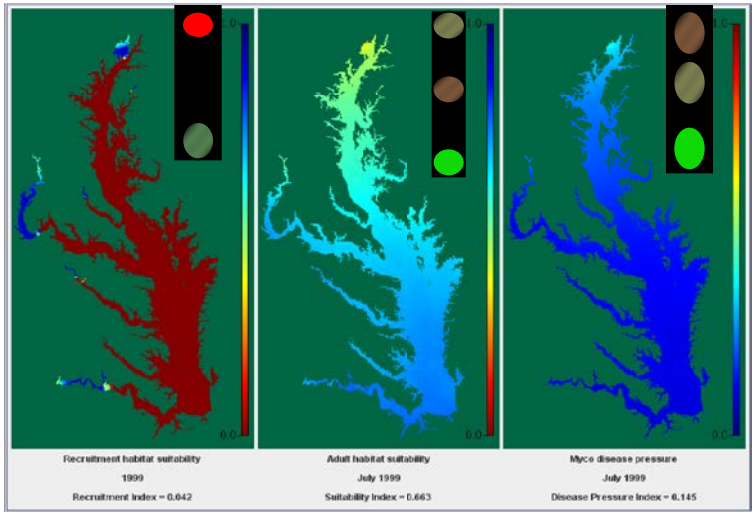


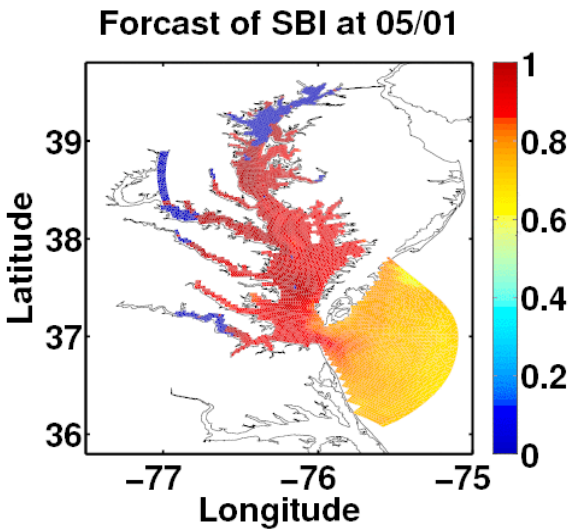
14-day and Seasonal Forecasts of Dissolved Oxygen and Striped Bass Index

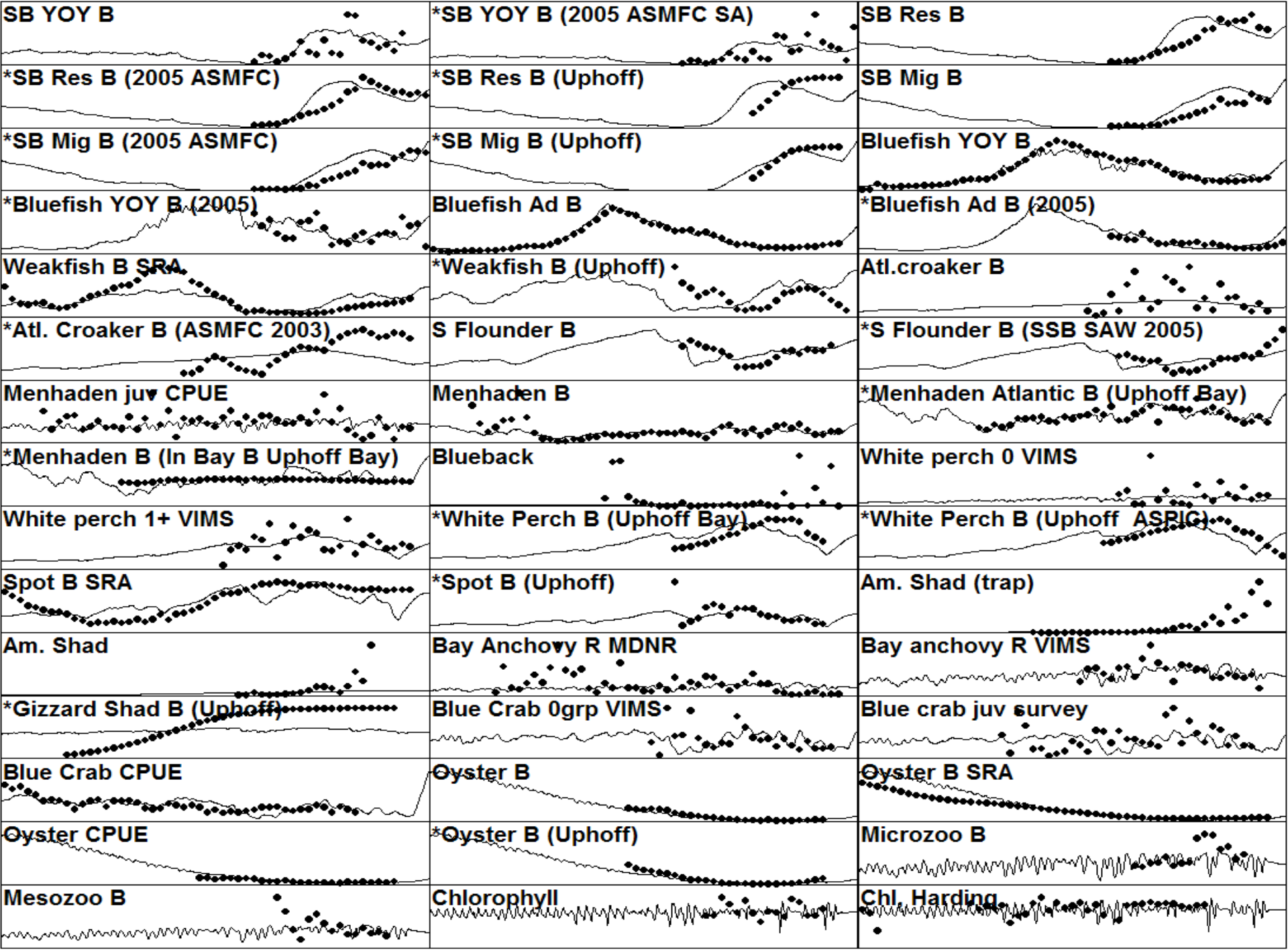






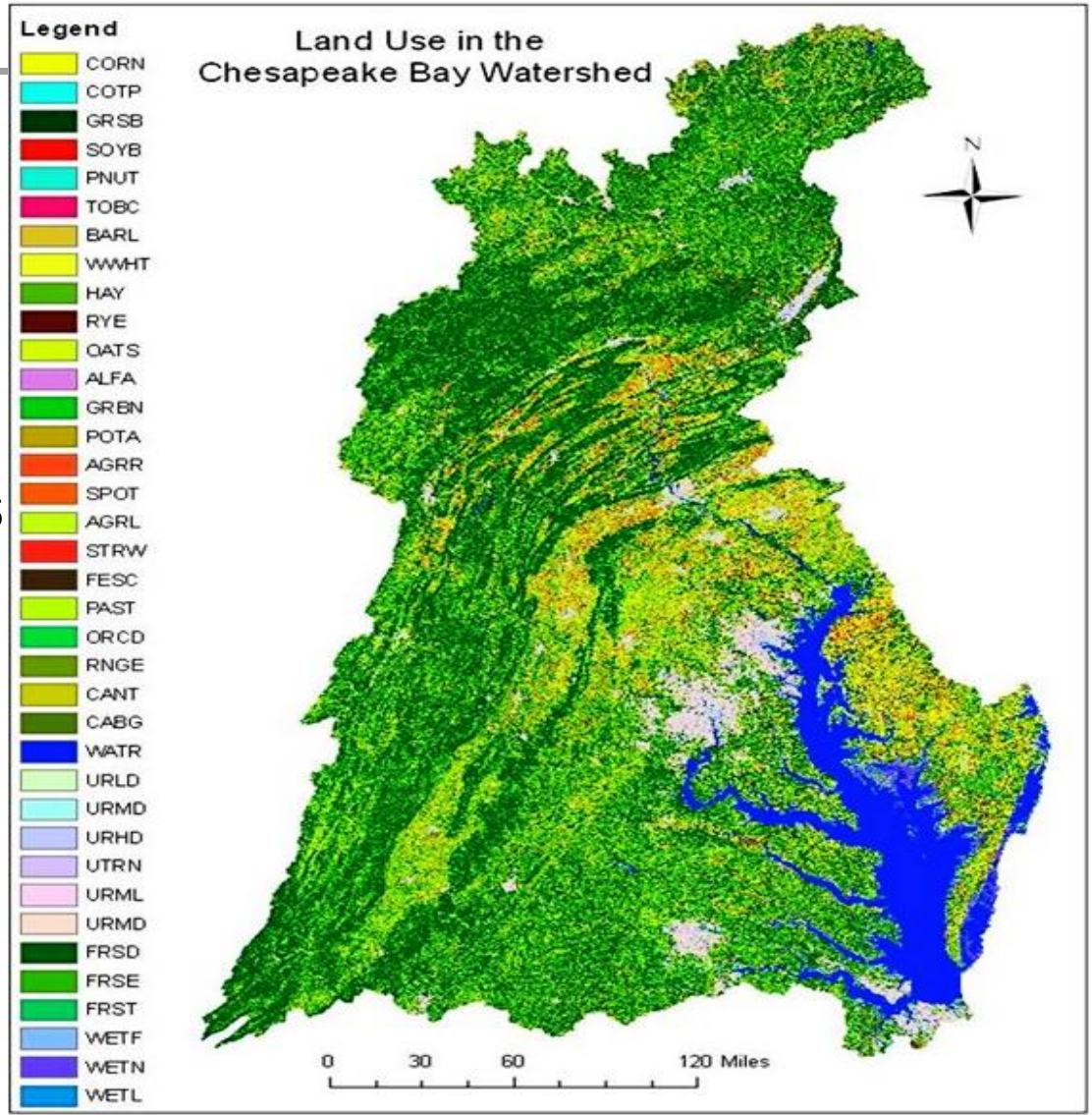





SB YOY B
*SB YOY B (2005 ASMFC SA)
SB Res B
*SB Res B (2005 ASMFC)
*SB Res B (Uphoff)
SB Mig B
*SB Mig B (2005 ASMFC)
*SB Mig B (Uphoff)
Bluefish YOY B
*Bluefish YOY B (2005)
Bluefish Ad B
*Bluefish Ad B (2005)
Weakfish B SRA
*Weakfish B (Uphoff)
Atl.croaker B
*Atl. Croaker B (ASMFC 2003)
S Flounder B
*S Flounder B (SSB SAW 2005)
Menhaden juv CPUE
Menhaden B
*Menhaden Atlantic B (Uphoff Bay)
*Menhaden B (In Bay B Uphoff Bay)
Blueback
White perch 0 VIMS
White perch 1+ VIMS
*White Perch B (Uphoff Bay)
*White Perch B (Uphoff ASPIC)
Spot B SRA
*Spot B (Uphoff)
Am. Shad (trap)
Am. Shad
Bay Anchovy R MDNR
Bay anchovy R VIMS
*Gizzard Shad B (Uphoff)
Blue Crab 0grp VIMS
Blue crab juv survey
Blue Crab CPUE
Oyster B
Oyster B SRA
Oyster CPUE
*Oyster B (Uphoff)
Microzoo B
Mesozoo B
Chlorophyll
Chl. Harding
1950
1963
1976
1989
1950
1963
1976
1989
1950
1963
1976
1989

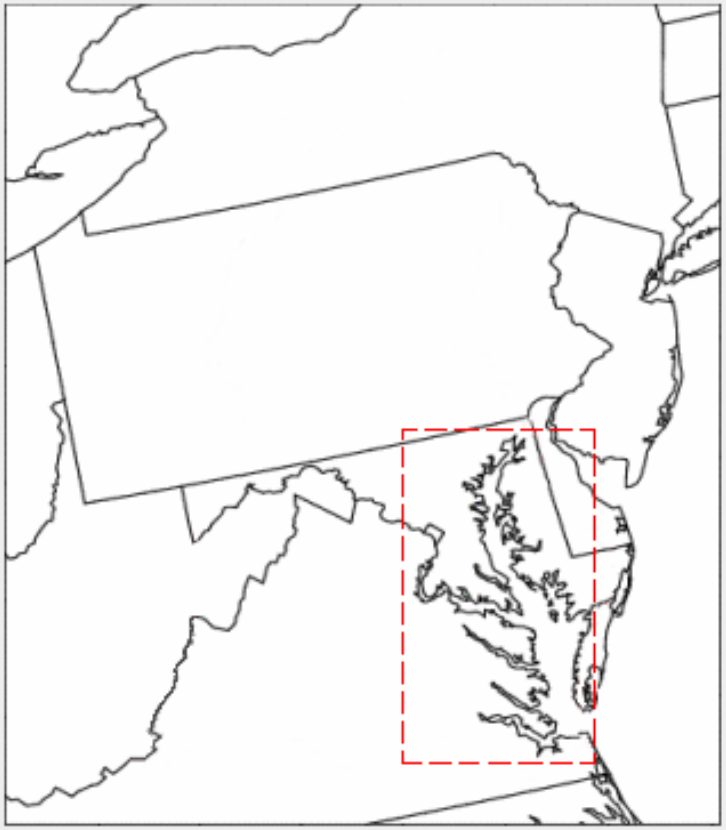
Watershed: Streamflow, loadings

- 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



Set the region

Time Scale

0 months

20 years

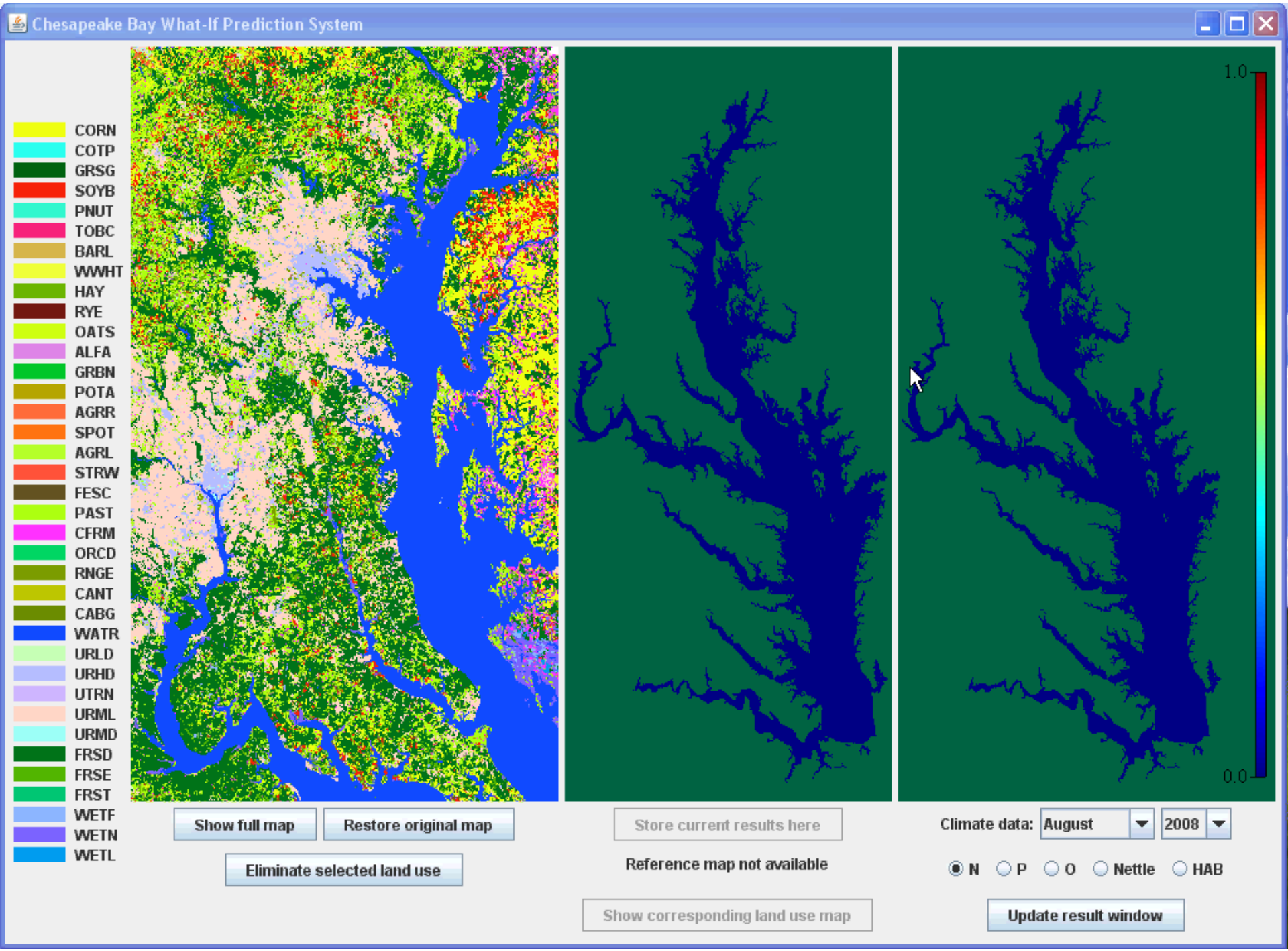
Compute

Output Variables

- [ ] Sealevel
- [ ] Storm surge
- [ ] Land coverage
- [ ] Fish / Crabs
- [ ] Air quality
- [ ] Winds
- [ ] Precipitation
- [x] Phosphorus
- [x] Oxygen
- [x] Nitrogen
- [ ] Temperature
- [ ] Salinity
- [x] Algae bloom
- [x] Sea nettles

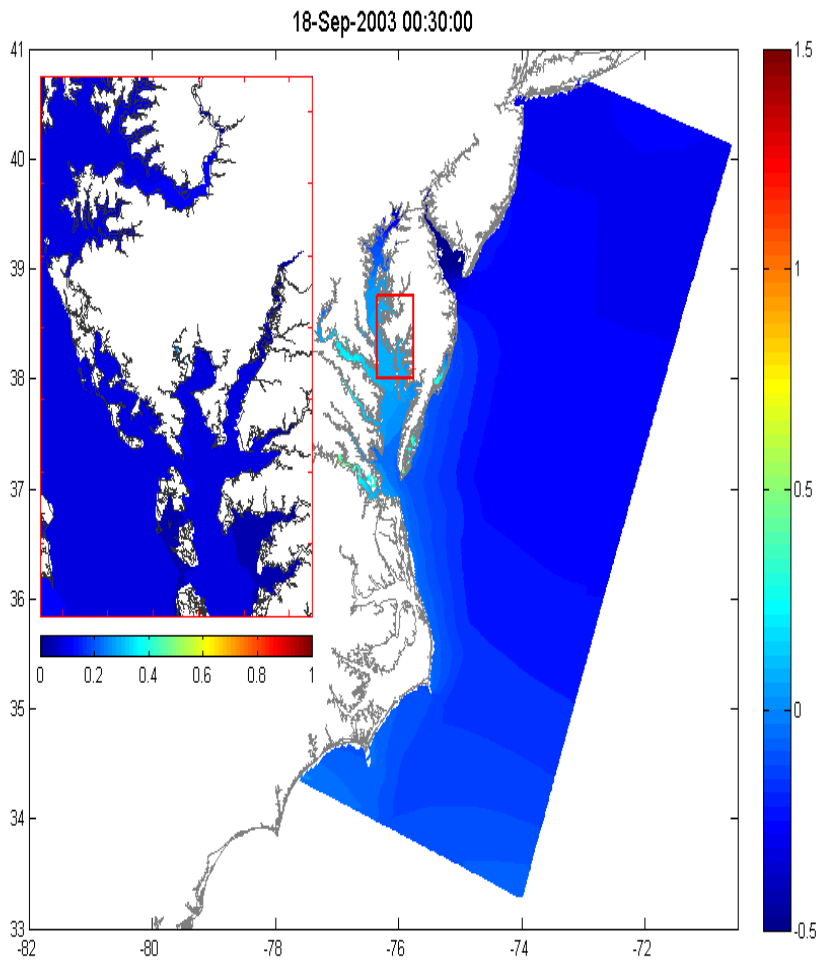
Input Variables

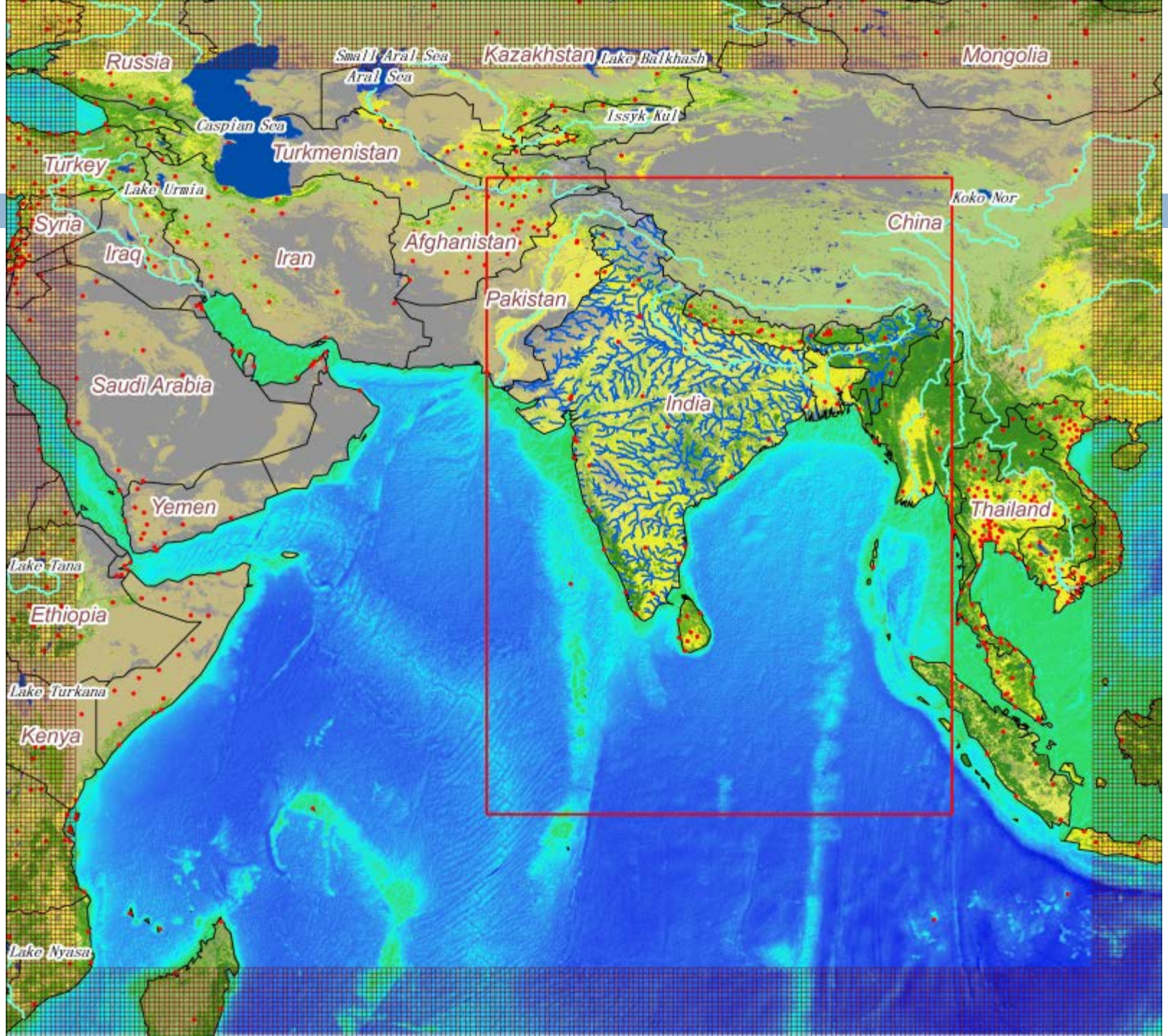
- ( ) Population density
- ( ) CO2 pollution
- ( ) Hi/low prognosis
- (•) Land use
- ( ) Stream runoff
- ( ) Agricultural mix


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

Inundation predictions

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




Russia
Small Aral Sea
Aral Sea
Kazakhstan
Lake Balkhash
Mongolia
Issyk Kul
Caspian Sea
Turkmenistan
Turkey
Lake Urmia
Koko Nor
Syria
China
Afghanistan
Iraq
Iran
Pakistan
Saudi Arabia
India
Yemen
Thailand
Lake Tana
Ethiopia
Lake Turkana
Kenya
Lake Nyasa

http://cwrf.umd.edu

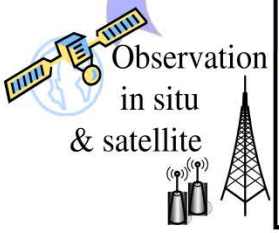
A Regional Earth System Model (RESM) for Predictive Understanding Climate Impacts on Human Health in the Chesapeake Bay

Global drivers

Increasing CO_2
Global warming
Sea level rise

Petascale computing

Optimization



Observation in situ & satellite

Model

CWRF

NA (36km) => CBay (4km)
Climate-Atmosphere
Land
Hydrology -CSSP/CLM
Lake
Upper ocean -UOM
Crop -DSSAT
Air quality -Chem/CMAQ
Water quality -SWAT,GLM
River discharge

ROMS

Coastal Ocean (4 – ½ km)
Circulations, tides, waves
Sea level & inundation
Marine ecosystem

LIS

Land Information System
LETKF data assimilation
Ocean + land initialization

Historical reconstruction
Understanding the past records of climate impacts on human health

Nowcast-forecast (<14 days)
Early warning for environmental events hazardous to human health

Subseasonal-interannual outlook
Actionable practice or real-time evaluation of decision making & system response for human health

Decadal-beyond projection
Scenario-based assessment of human health risk & vulnerability to climate change

1960 → 2010 → 2050

Science Drivers:

Application & demonstration

Sea level rise & inundation
Land use & chemical loading
Extreme weather & contamination

Prediction

Climate

Heat waves
Floods, droughts
Storm surges, sea level rise

Chemical Cascade

Chemical & pollutant loading
Atmospheric deposition
Chemical transport
Sediment exchange

Water Quality

Mercury, Arsenic
Polychlorinated biphenyls
Pathogen & sea nettle outbreaks
Harmful algae blooms

Human Health

Early warning system and Strategic decision support tool to contain risks of extreme weathers, climate change and direct/indirect exposure to toxins