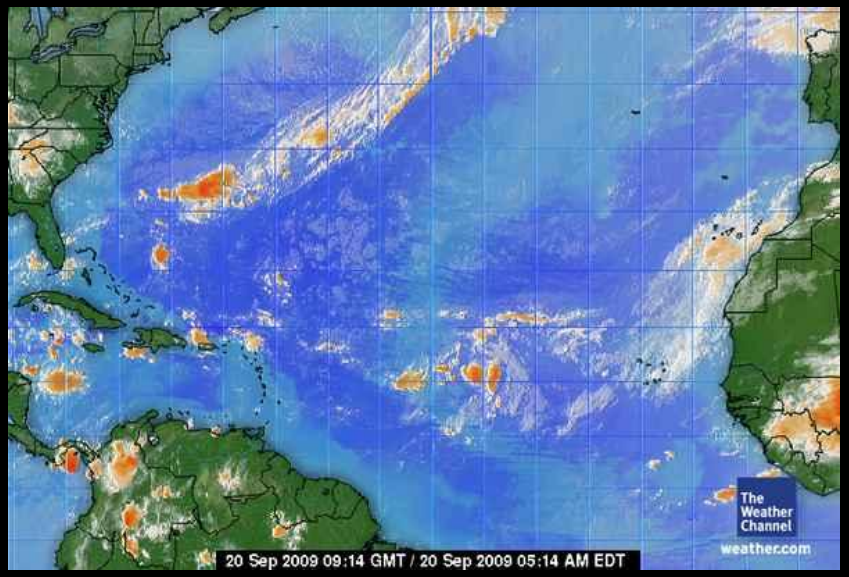
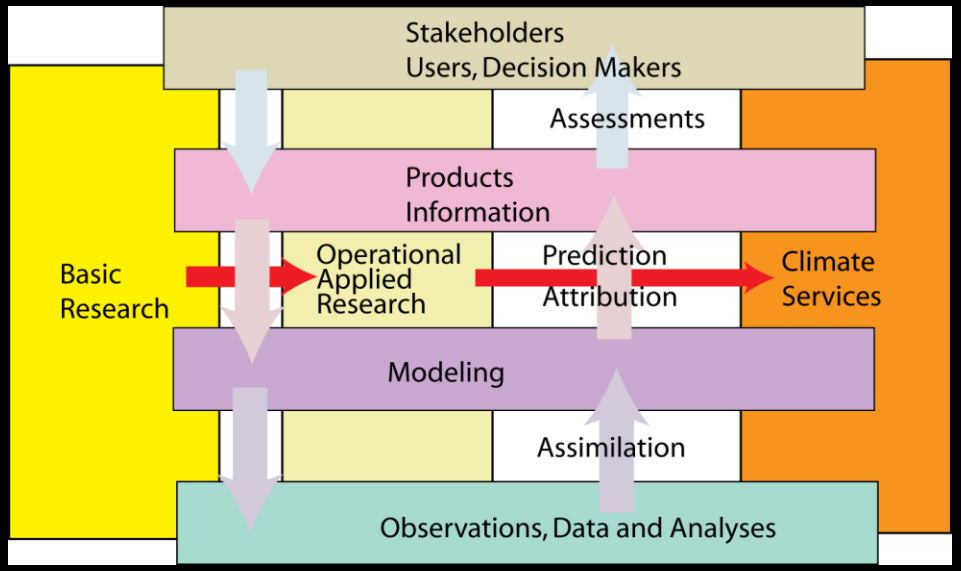




CLIMATE MODELING AND DATA ASSIMILATION ARE KEY FOR CLIMATE SERVICES

Guy P. Brasseur
Climate Service Center-Germany
GKSS, Hamburg, Germany
and
National Center for Atmospheric Research
Boulder, Colorado, USA

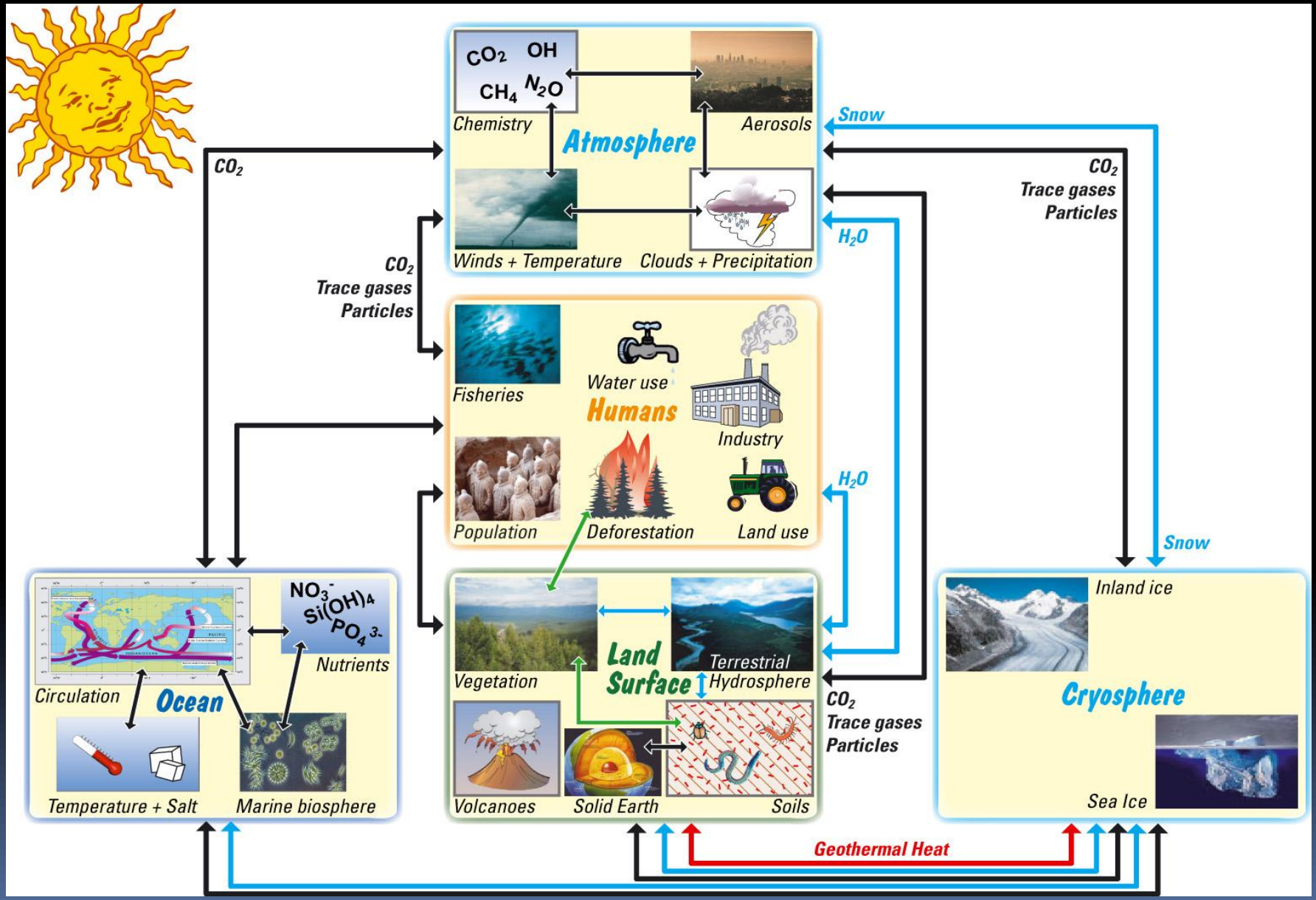
Major Planetary Issues

- **Energy and Carbon (Alternative sources)**
- **Water Scarcity**
- **Food Availability**
- **High Impact Weather Events**
- **Air and Water Quality**
- **Human Health**
- **Urbanization and Population Migration**
- **Poverty and Education**
- The need to understand interactions and feedbacks in the entire Earth System. The role of the ocean is immense.
- The need to develop integrated regional studies to assess the two-way coupling between the biophysical and social systems across scales.

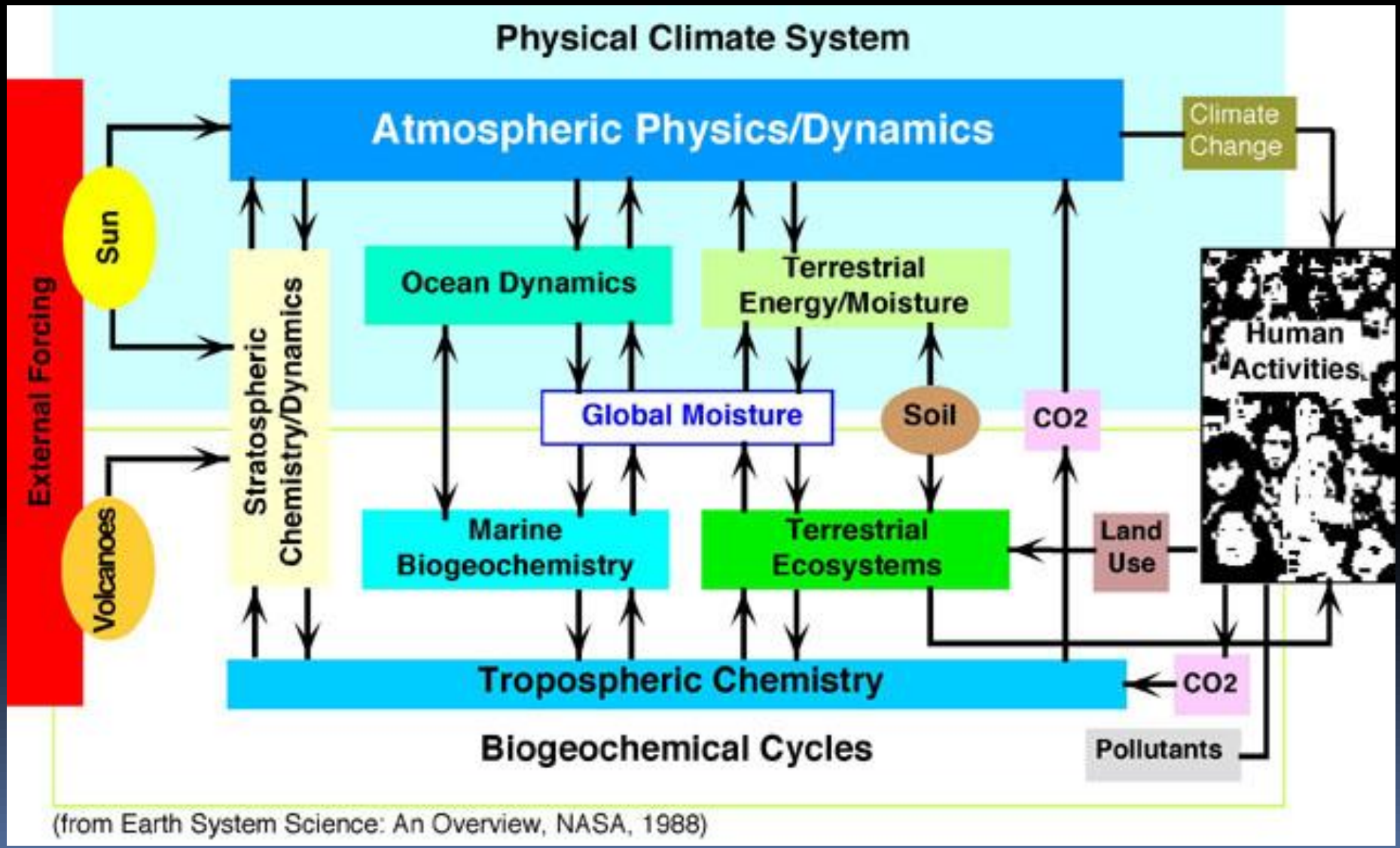
Advances in the last decade

- Better understanding of the drivers (i.e. cause and effect)
- Better understanding and parameterization of scale interactions
- Better understanding of systemic interactions and feedbacks
- Improved global datasets (climate, atmosphere, land and oceans) and historic coverage
- Integration natural and human processes: a wealth of global change scenarios was developed

The Earth System



Linking the Physical Climate System with the Biogeochemical and Human Systems

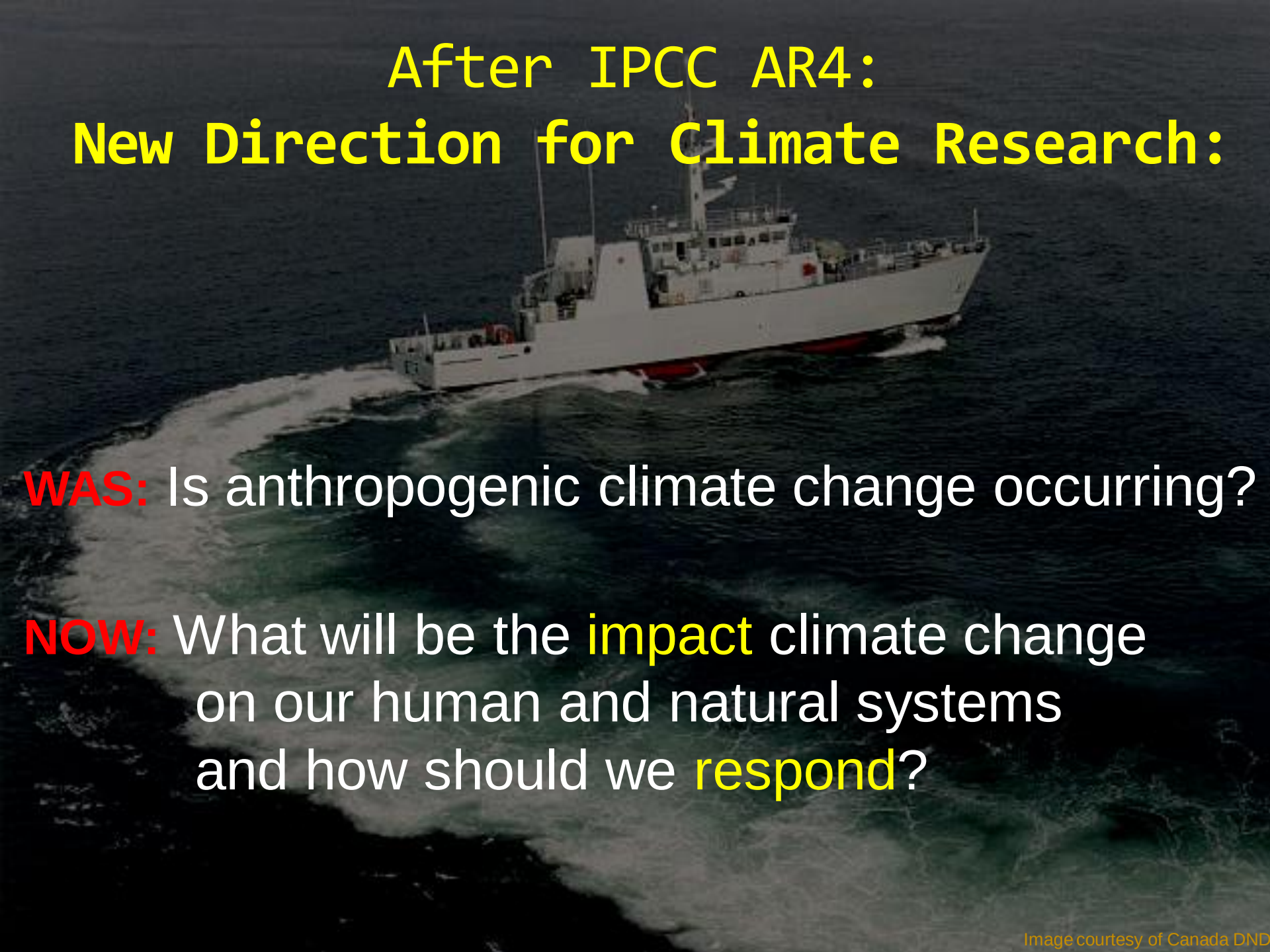


(from Earth System Science: An Overview, NASA, 1988)

From Physical Oceanography to Marine Ecosystems

- What are the key marine biogeochemical cycles and related ecosystem processes that will be impacted by global change?
- What are the responses of key biogeochemical cycles, ecosystems and their interactions, to global change?
- What is the role of ocean biogeochemistry and ecosystems in regulating climate?

After IPCC AR4:
New Direction for Climate Research:



WAS: Is anthropogenic climate change occurring?

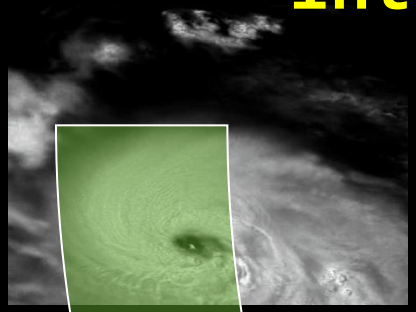
NOW: What will be the impact climate change on our human and natural systems and how should we respond?

Image courtesy of Canada DND

The Challenges

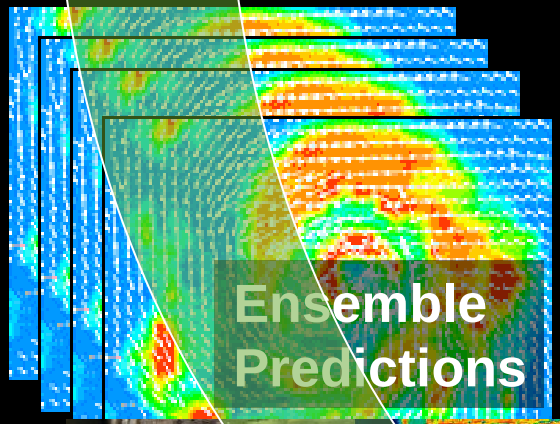
- Climate science has made major advances during the last two decades, yet climate information is neither routinely useful for nor used in planning.
- Climate science has to be connected to decision-relevant questions. It must build capacity to anticipate, plan for, and adapt to climate fluctuations.

Integrating Research Model and Data into end-use Knowledge Systems

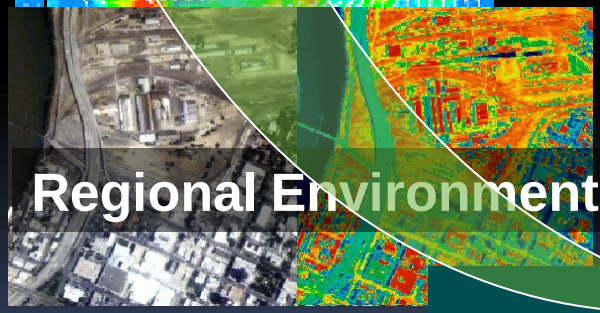


Weather/Climate Data
Assimilation Models

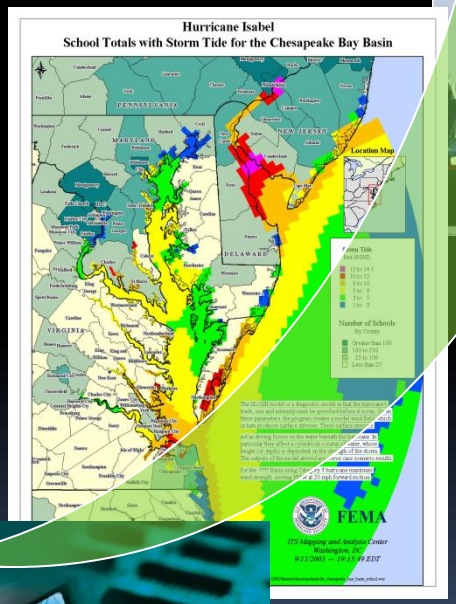
Reliable Information
Delivery



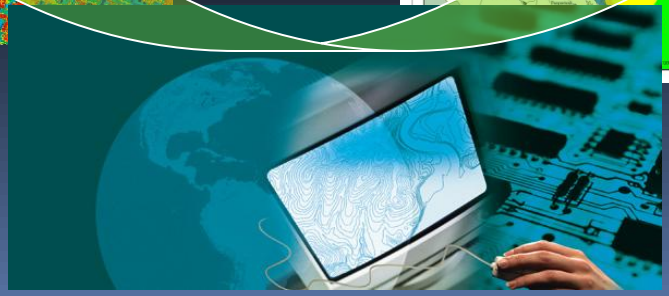
Ensemble
Predictions



Regional Environments



Operational
Implementation



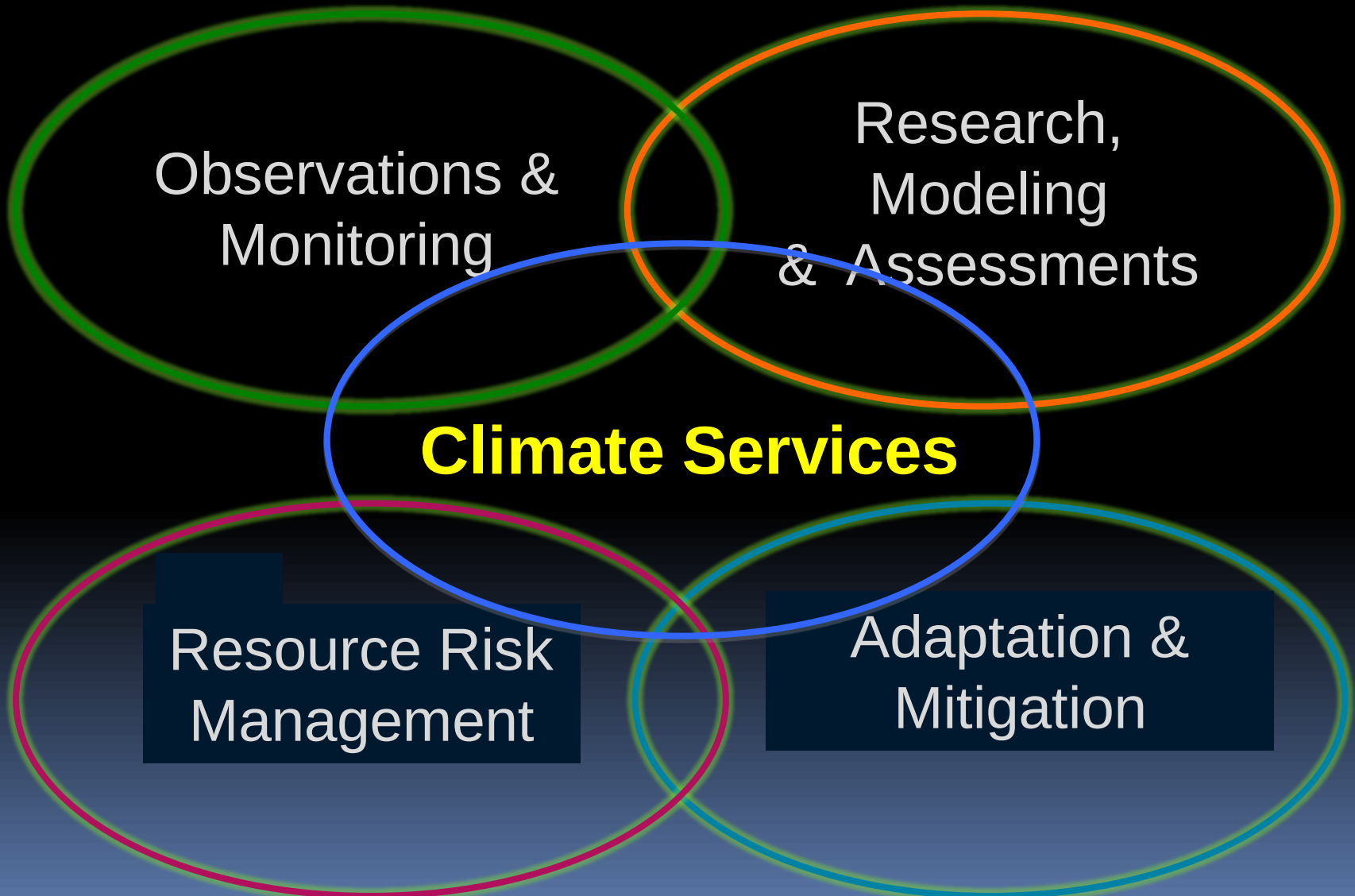
Decision Tools

Climate Services

- Provide reliable, well documented, authoritative and easily used information and develop the most effective approaches to mitigation and adaptation strategies.

- Develop sustained, nationally and regionally-based interactions with users in different economic sectors.

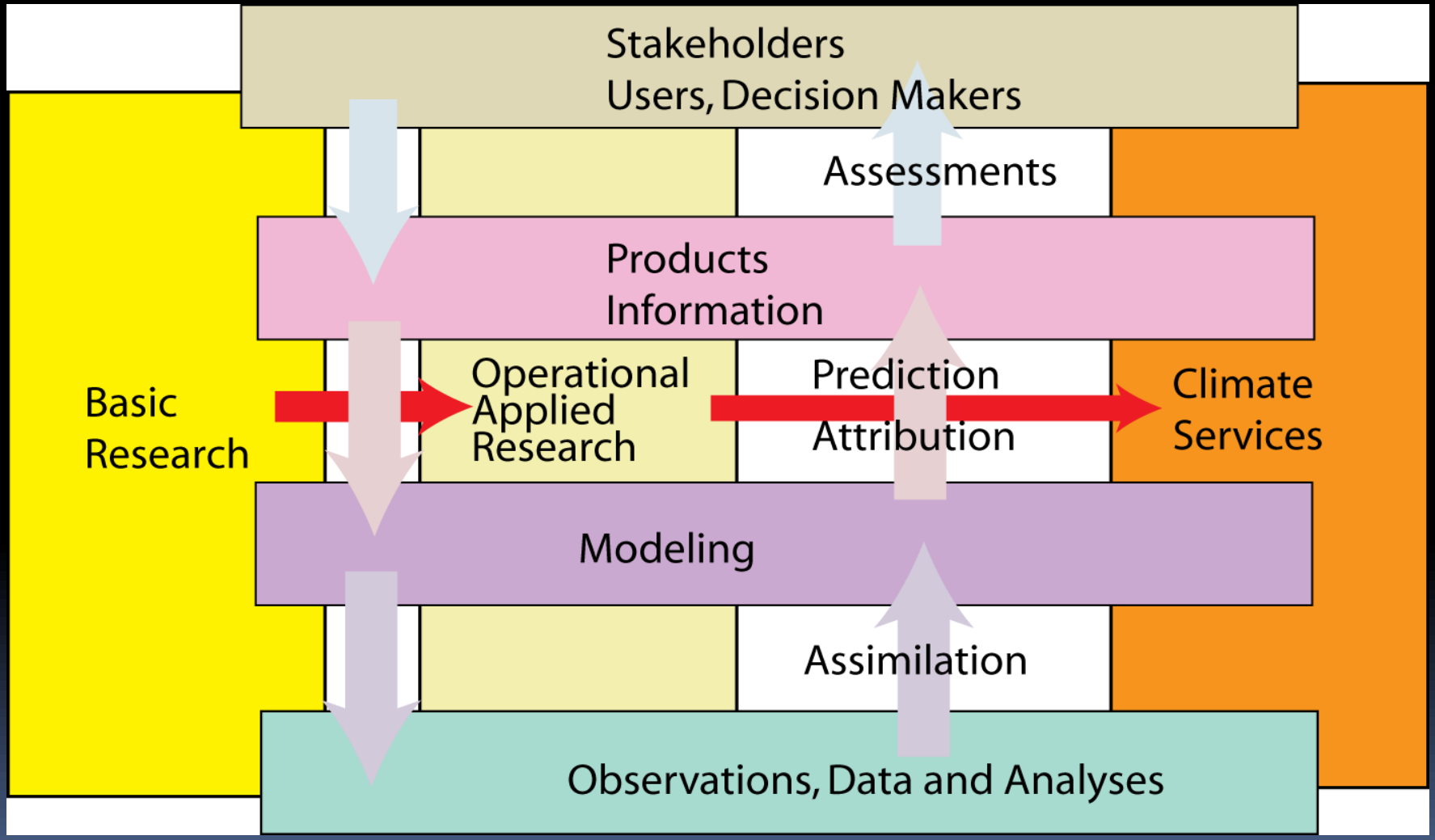
Climate Services will build Bridges between Research and Decision-makers



Important Attributes of a Climate Service

- Provide balanced, credible, cutting edge scientific and technical information
- Engage a diversity of users in meaningful ways to ensure their needs are being met
- Provide and contribute to science-based products and services to minimize climate-related risks
- Strengthen observations, standards, and data stewardship
- Improve regional and local projections of climate change
- Inform policy options
- Must be strongly linked to research

From Fundamental Research to Climate Services



From K. Trenberth

WCC-3

HIGH-LEVEL DECLARATION

We, Heads of State and Government, Ministers and Heads of Delegationpresent at the High-level Segment of the World Climate Conference-3 (WCC-3) in Geneva

Decide **to establish a Global Framework for Climate Services** to strengthen production, availability, delivery and application of science-based climate prediction and services;

The Need for a Systems Approach to Climate Observations

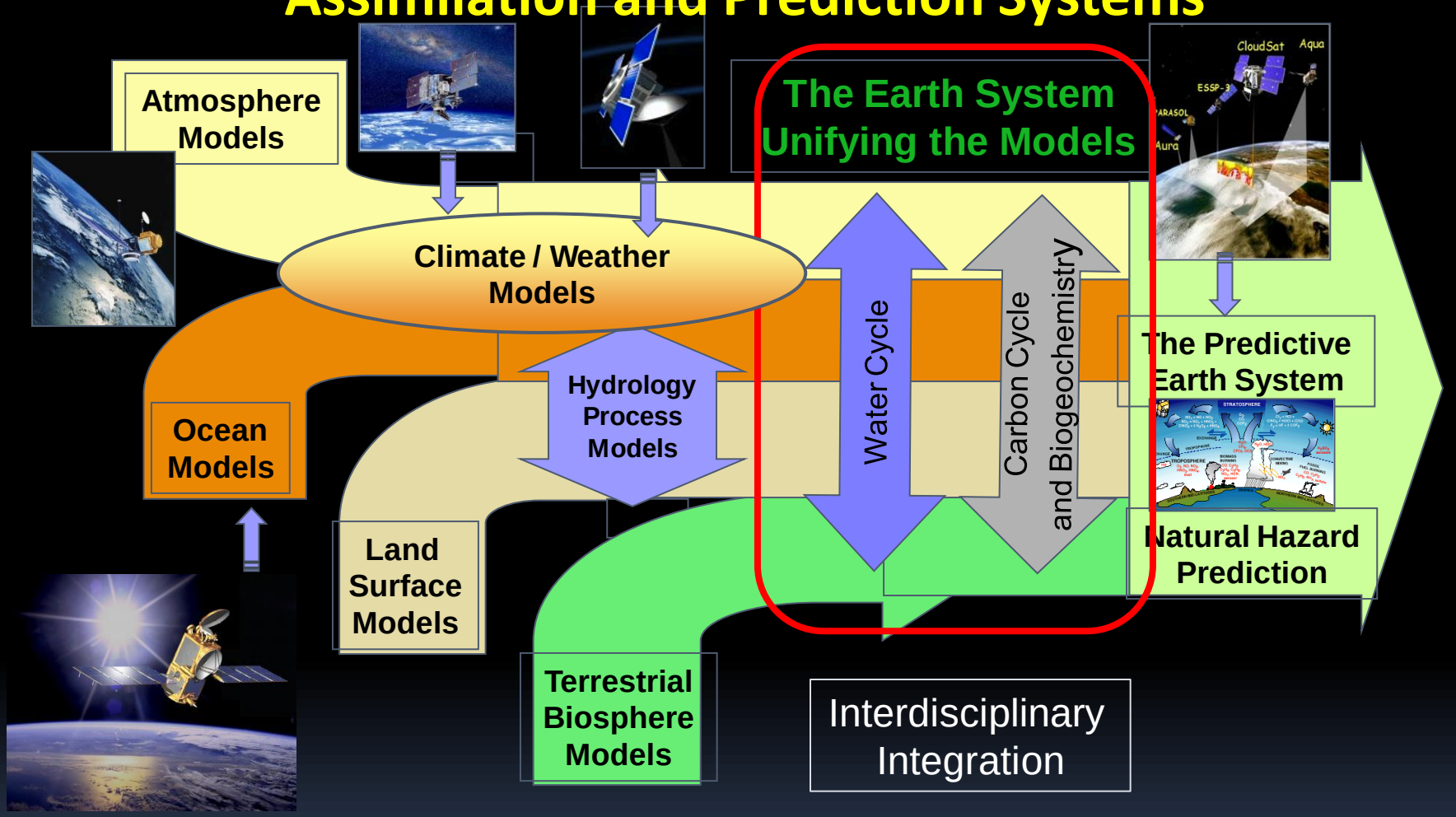
The **imperative** is to build an **observing and information system** to better plan for the future.

A climate information system

- Observations: forcings, atmosphere, ocean, land
- Analysis: comprehensive, integrated, products
- Assimilation: model based, initialization
- Attribution: understanding, causes
- Assessment: global, regions, impacts, planning
- Predictions: multiple time scales
- Decision Making: impacts, adaptation

Trenberth et al. (2002; 2006)

Towards Operational Earth System Monitoring, Assimilation and Prediction Systems



Decadal Climate Prediction

- Decadal predictions will prove invaluable for many sectors of society and for prevention of possible disasters:
  - Spread of viruses and diseases
  - Forest fires
  - Heat waves, droughts
  - Storms, hurricanes and flooding
  - Damage to agriculture, forestry, fisheries, water resources
- Important for tourism, financial and insurance sectors
- Decadal forecasting is still in its infancy

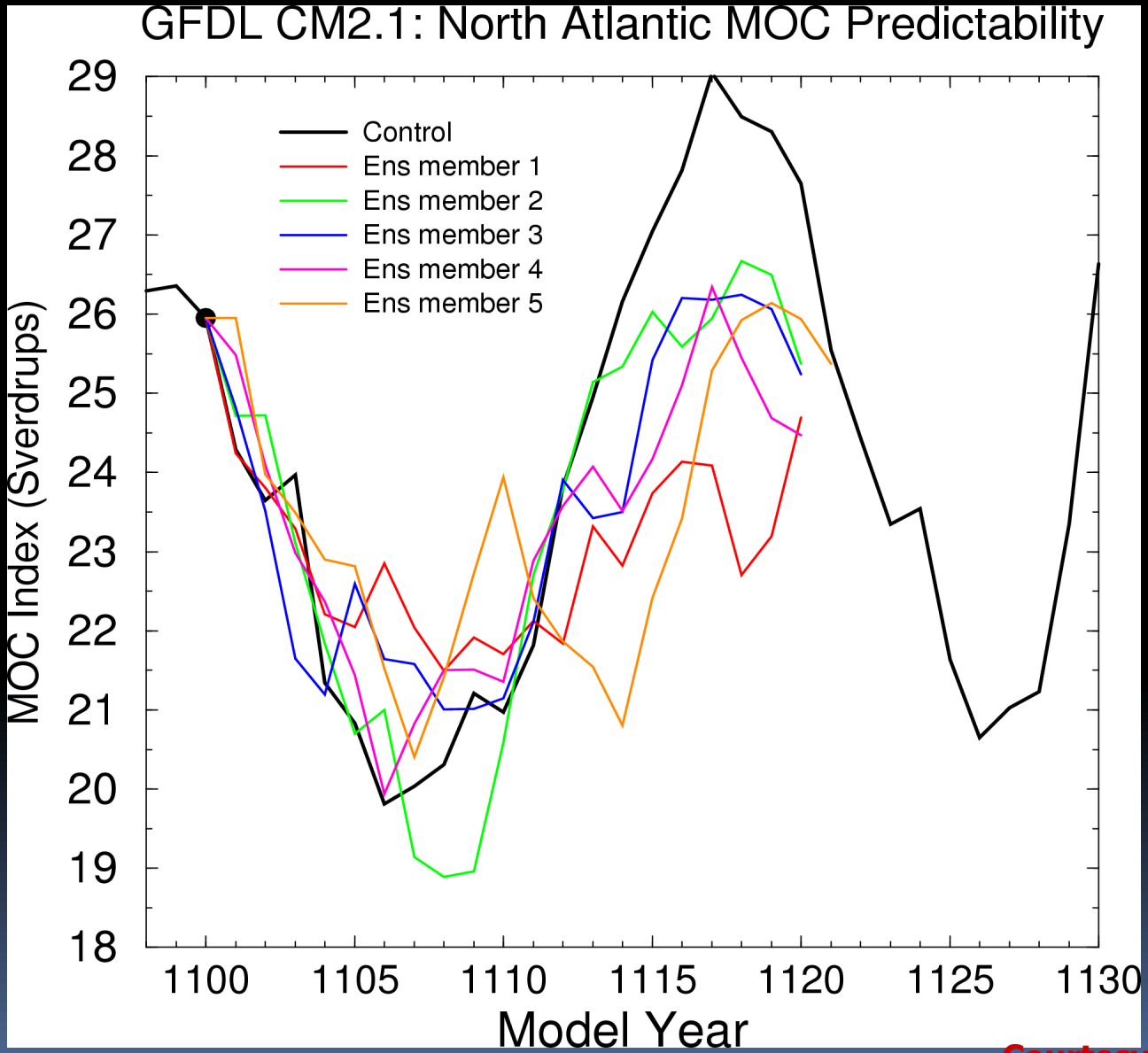
Decadal Climate Prediction
[Paper by Latif et al., 2009]

- Decadal climate prediction is a joint initial and boundary value problem. (initialization of climate state AND climate forcing)
- Decadal to multi-decadal variability still not well understood.
- Could be improved by long-term intensive observations in key regions of the ocean (Kurohio Oyashio Extension, interface between mid-latitude and tropical ocean, North Atlantic MOC)

Decadal Climate Prediction
[Paper by Hurrell et al. 2009]

- Ocean will be at heart of decadal climate predictions.
- Some level of predictability is provided by the overturning circulation of the ocean
- Full water column observations are therefore needed to initialized decadal prediction models.
- Sustained time series observations will be key for model verification and for fundamental understanding.

Scientific Basis for Decadal Prediction



Perturbed ensemble members evolve coherently for two decades

Courtesy of Tom Delworth

Decadal Climate Prediction
[Paper by Heimbach et al., 2009]

- The ocean remains substantially under-sampled.
- We need a suitable climate observing system to initialize our models
- Maintenance of the current global system (Argo, satellites)
- Inclusion of a deep ocean component
- Improvement of coverage at high latitudes
- Forcing fluxes at the air sea-and land sea boundaries

Decadal Climate Prediction
[Paper by Le Quere et al., 2009]

- For Green ocean model we need:
  - Global and regional biomass (carbon) concentrations for the important plankton types
  - Growth rates for all phytoplankton types as a function of temperature, light and nutrient concentrations
  - Export of particulate organic carbon
  - Decadal trends in surface ocean pCO_2
  - Decadal trends in sub-surface O_2 concentration

Decadal Climate Prediction

- We need to improve climate models
  - Reduction in biases leads to better prediction skills
  - Higher resolution is key to improve models; more computing capability is needed
- We need improved data assimilation systems
  - Simultaneous observations and assimilation of quantities in *coupled* compartments of the Earth system remains a challenge, but is a necessity

We have some Global Earth Observations We don't have:

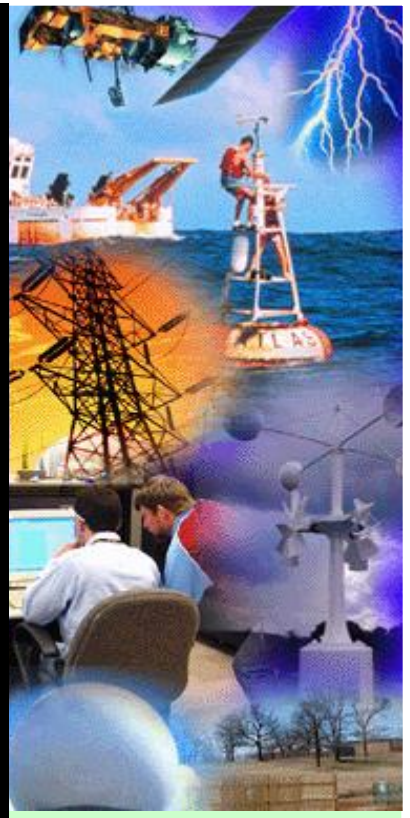
Discipline Specific View Whole System View

Atmospheric Observations

Data Systems

Ocean Observations

Space Observations



Technology Development

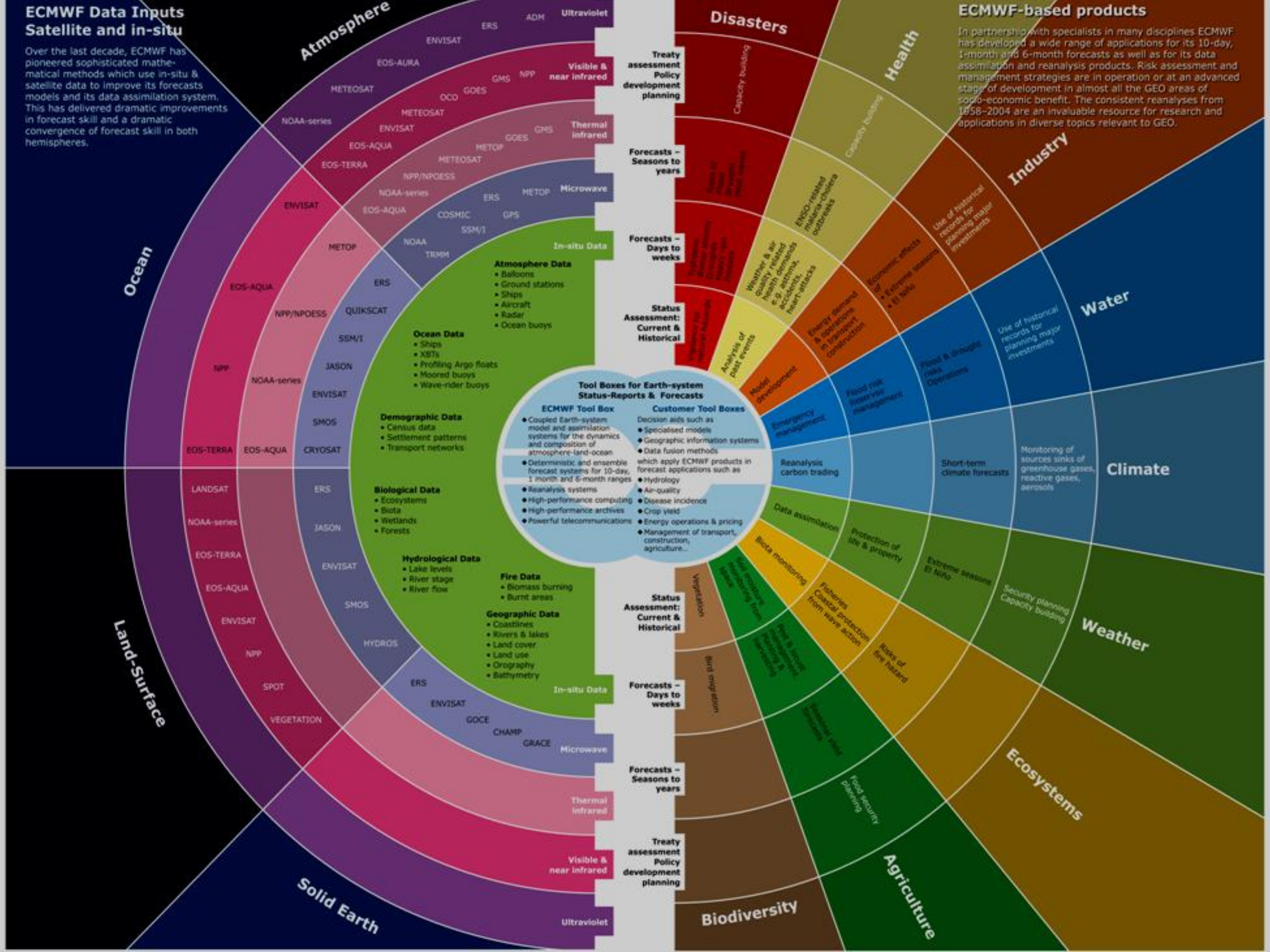
Innovations
Breakthrough
Efficiencies
Cost
Mass Productions

Breakthrough
Innovations
Efficiencies Cost
Mass Productions

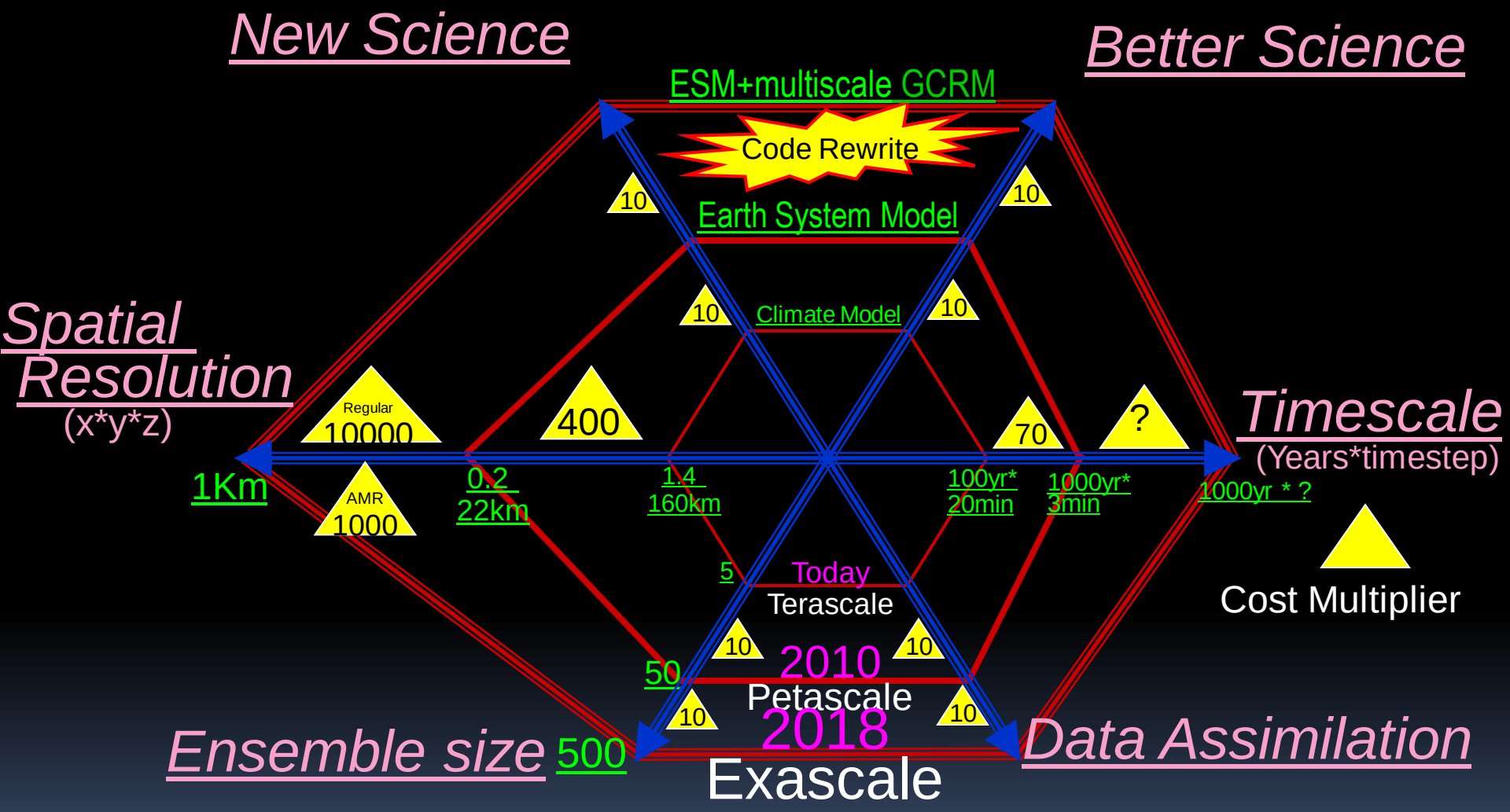
20th Century 21st Century

OBSERVING SYSTEM TIMELINE

From Tom Karl


ECMWF Data Inputs
Satellite and in-situ
Over the last decade, ECMWF has pioneered sophisticated mathematical methods which use in-situ & satellite data to improve its forecasts models and its data assimilation system. This has delivered dramatic improvements in forecast skill and a dramatic convergence of forecast skill in both hemispheres.
Atmosphere
Ocean
Land-Surface
Solid Earth
Ultraviolet
Visible & near infrared
Thermal infrared
Microwave
In-situ Data
ADM
ERS
ENVISAT
EOS-AURA
METEOSAT
NOAA-series
GMS
NPP
GOES
OCO
EOS-AQUA
EOS-TERRA
METOP
NPP/NPOESS
COSMIC
GPS
SSM/I
NOAA
TRMM
QUIKSCAT
JASON
SMOS
CRYOSAT
LANDSAT
SPOT
VEGETATION
HYDROS
GOCE
CHAMP
GRACE
Atmosphere Data
• Balloons
• Ground stations
• Ships
• Aircraft
• Radar
• Ocean buoys
Ocean Data
• Ships
• XBTs
• Profiling Argo floats
• Moored buoys
• Wave-rider buoys
Demographic Data
• Census data
• Settlement patterns
• Transport networks
Biological Data
• Ecosystems
• Biota
• Wetlands
• Forests
Hydrological Data
• Lake levels
• River stage
• River flow
Fire Data
• Biomass burning
• Burnt areas
Geographic Data
• Coastlines
• Rivers & lakes
• Land cover
• Land use
• Orography
• Bathymetry
Tool Boxes for Earth-system Status-Reports & Forecasts
ECMWF Tool Box
• Coupled Earth-system model and assimilation systems for the dynamics and composition of atmosphere-land-ocean
• Deterministic and ensemble forecast systems for 10-day, 1 month and 6-month ranges
• Reanalysis systems
• High-performance computing
• High-performance archives
• Powerful telecommunications
Customer Tool Boxes
Decision aids such as
• Specialised models
• Geographic information systems
• Data fusion methods
which apply ECMWF products in forecast applications such as
• Hydrology
• Air-quality
• Disease incidence
• Crop yield
• Energy operations & pricing
• Management of transport, construction, agriculture...
Treaty assessment Policy development planning
Forecasts – Seasons to years
Forecasts – Days to weeks
Status Assessment: Current & Historical
ECMWF-based products
In partnership with specialists in many disciplines ECMWF has developed a wide range of applications for its 10-day, 1-month and 6-month forecasts as well as for its data assimilation and reanalysis products. Risk assessment and management strategies are in operation or at an advanced stage of development in almost all the GEO areas of socio-economic benefit. The consistent reanalyses from 1958–2004 are an invaluable resource for research and applications in diverse topics relevant to GEO.
Disasters
Health
Industry
Water
Climate
Weather
Ecosystems
Agriculture
Biodiversity
Capacity building
ENSO-related malaria-cholera outbreaks
Weather & air quality related health demands e.g. asthma, accidents, heart-attacks
Analysis of past events
Use of historical records for planning major investments
Economic effects of • Extreme seasons • El Niño
Energy demand & operations in transport construction
Model development
Flood & drought risks Operations
Flood risk Reservoir management
Emergency management
Reanalysis carbon trading
Short-term climate forecasts
Monitoring of sources sinks of greenhouse gases, reactive gases, aerosols
Data assimilation
Protection of life & property
Extreme seasons El Niño
Security planning Capacity building
Biota monitoring
Fisheries Coastal protection from wave action
Risks of fire hazard
Vegetation
Bird migration
Food security planning

HPC Dimensions of Climate Prediction



Lawrence Buja (NCAR)

Conclusions (1)

- No medium or long-term forecast of the physical climate system and of the Earth system is possible without incorporating the ocean.
- Observations are also essential to understand the relations between ocean biogeochemistry, ecosystems and living marine resources.
- Forecasting require initial conditions, whose quality will depend on the quality of observations and (coupled) data assimilation systems

Conclusions (2)

- The ocean remains under-sampled in spite of progress made in the last years.
- A well-designed integrated ocean observing system is essential for climate prediction on decadal timescales and will support societal needs.
- Climate Services will make use of such observational data.

Thank You