INTEGRATED ASSESSMENT MODELING

13th Annual CCSM Workshop

The Village at Breckenridge, Breckenridge, Colorado

Jae Edmonds and Steve Smith

June 18, 2008

GTSP Global Energy Technology Strategy Program

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OVERVIEW

- What is Integrated Assessment Modeling (IAM)?
- How is the IAM community interacting with the Climate Modeling Community (CMC)?
- What does the future hold for IAMs?

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WHAT IS INTEGRATED ASSESSMENT MODELING?

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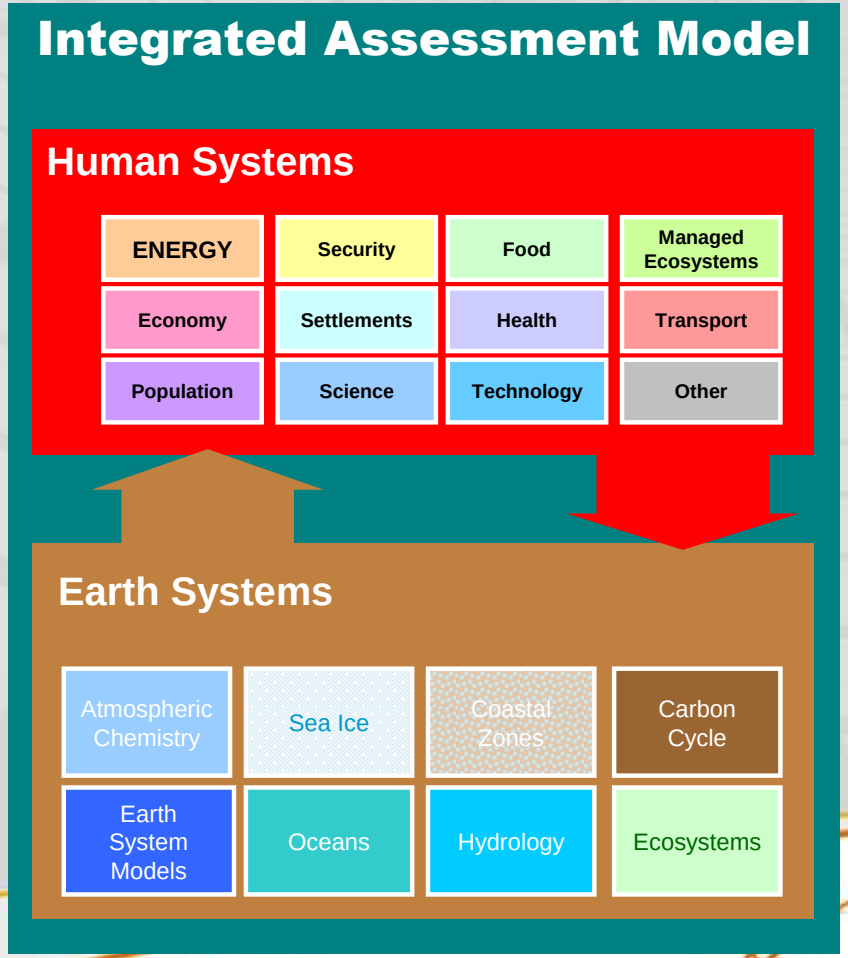
Integrated assessment modeling describes the interactions between human and natural earth systems

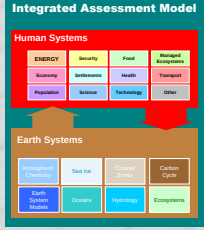
IAMs conduct **human systems research,** historically focused on the energy-emissions interface**.**

IAMs integrate human and natural Earth systems.

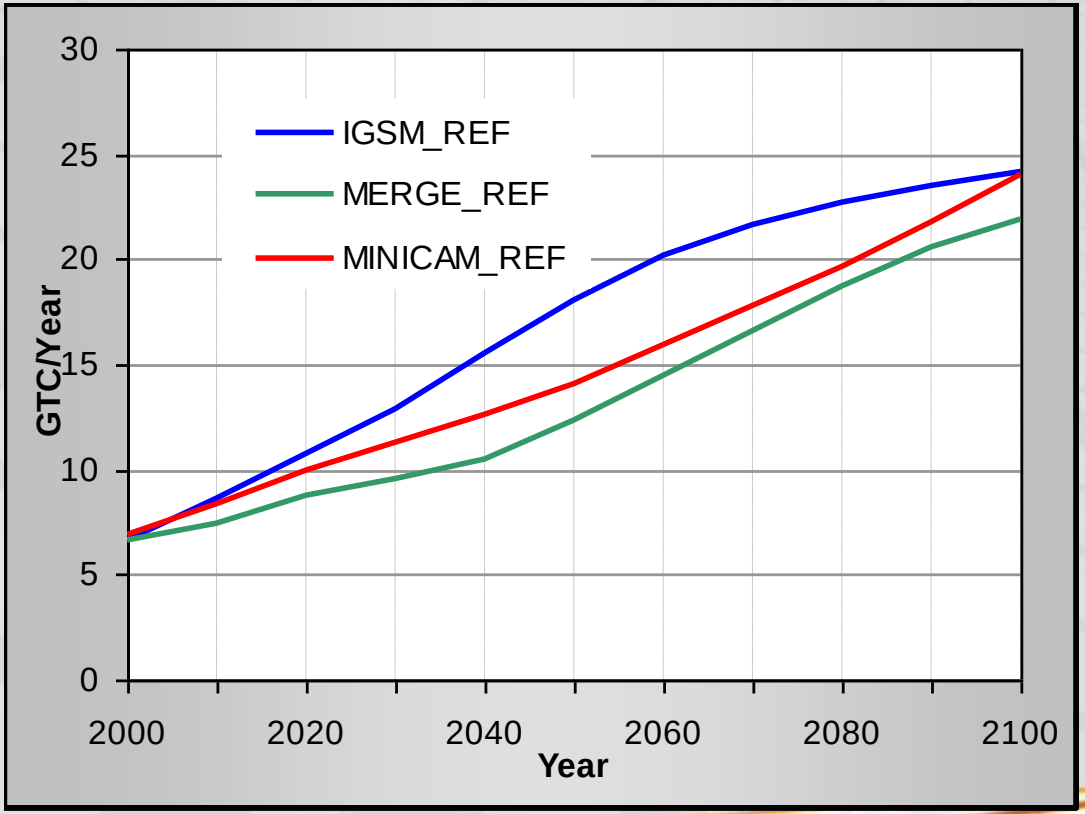
The future challenge is to extend IAMs ability to describe climate impacts and adaptations.



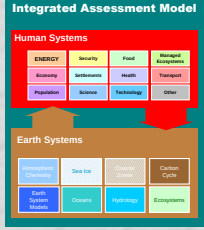
Integrated Assessment Modeling Has Four Roles In Climate Change Research



1. IAMs historical role has been to provide data and models, grounded in **human systems research,** relevant to understanding the scale and timing of the drivers of climate change over decades to century time scales. (A major interface with the climate modeling community CMC.)

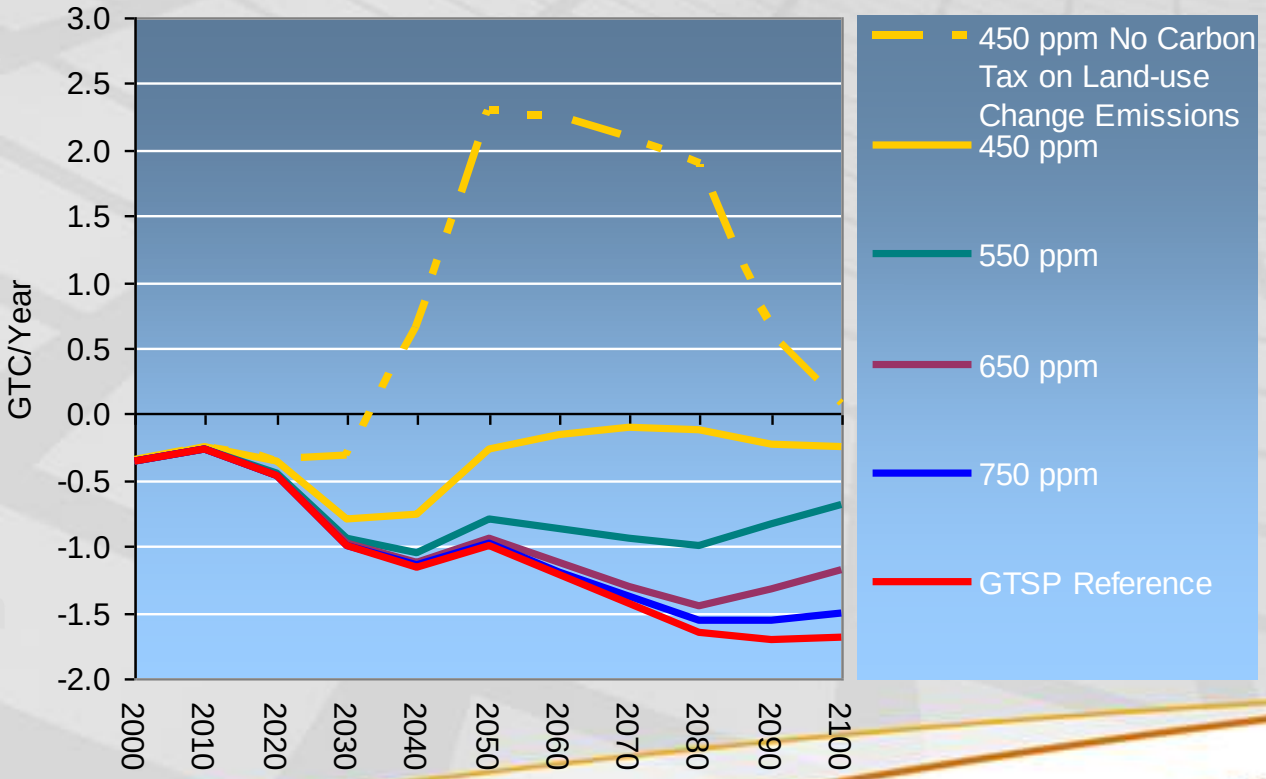


Integrated Assessment Modeling Has Three Roles In Climate Change Research



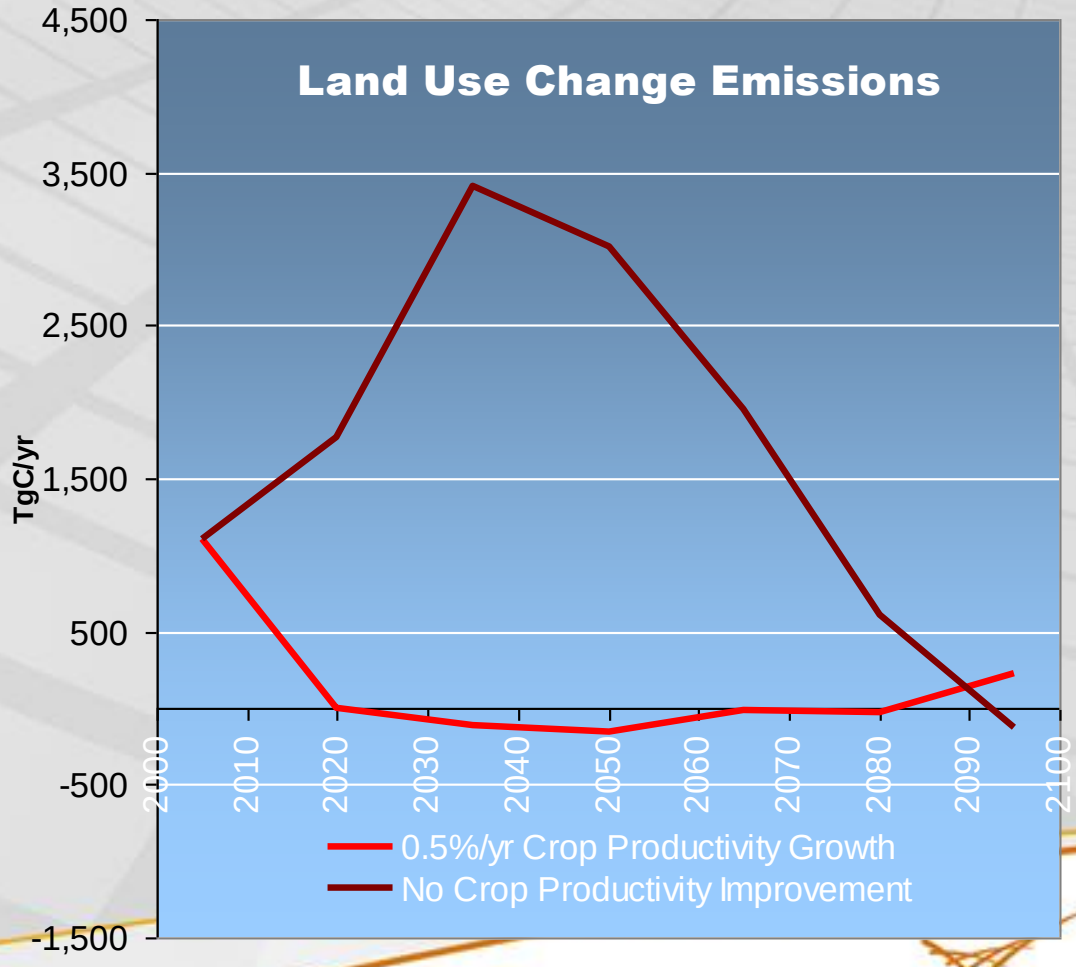
2. IAMs have also combine knowledge derived from multiple fields of climate research—**human and natural Earth systems**—in a way that can provide insights that would otherwise be unavailable from the pursuit of focused disciplinary research.

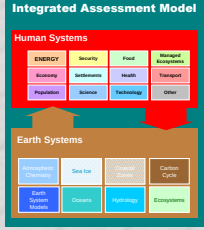
Energy, the Economy, Terrestrial Carbon Cycle, Agriculture, Land use, & Land Cover



Land Use Change Emissions and Crop Productivity

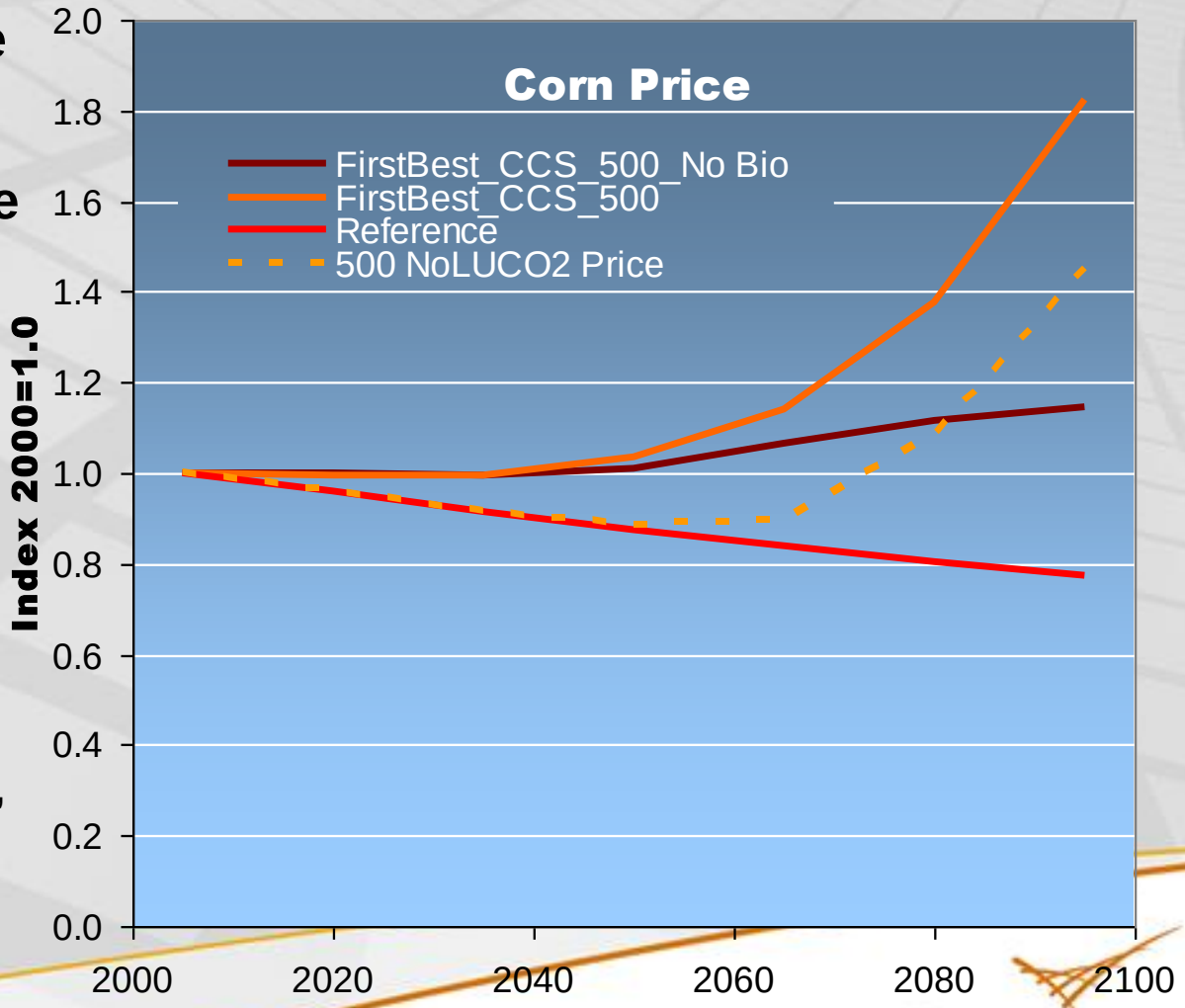
- Cumulative Emissions 2005 to 2095
  - 0.5%/yr crop productivity growth:
    - **5.2 PgC**
  - No crop productivity growth:
    - **169 PgC**



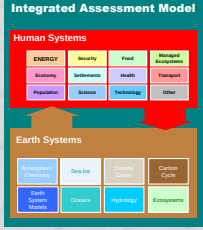


Corn Price When Carbon Is Valued But No Bioenergy Is Produced

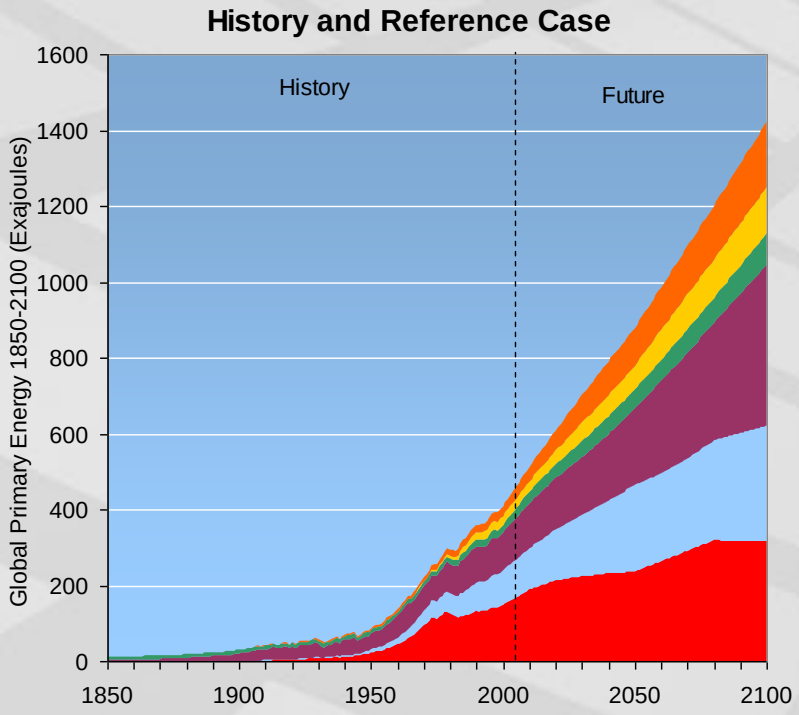
- Significant crop price escalation occurs if carbon is valued, **even in the absence of purpose grown bioenergy production.**
  - Prior to 2040 the influence of bioenergy is negligible.
  - Prior to 2040 crop price escalation, relative to the reference scenario, is predominantly driven by the value of carbon.

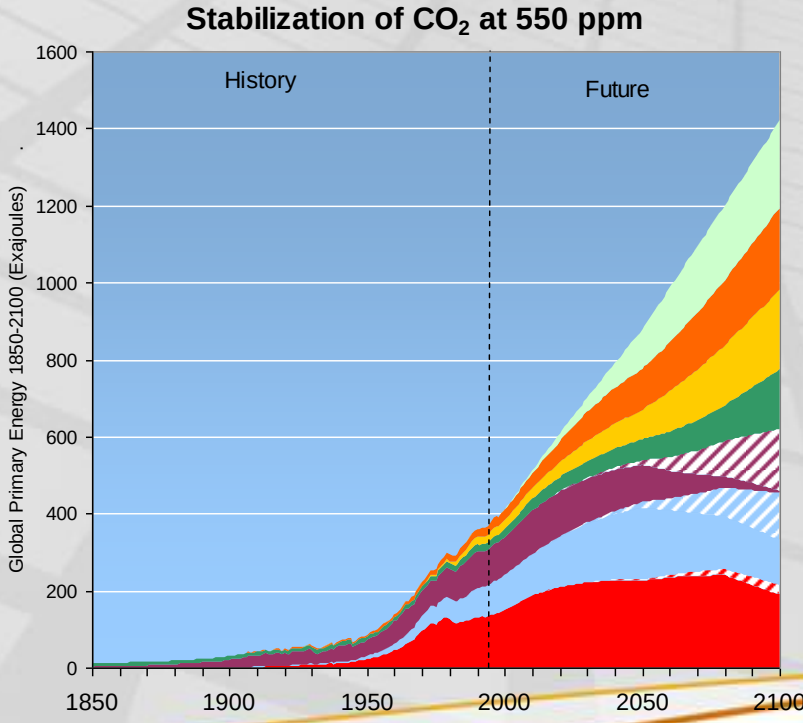


Integrated Assessment Modeling



3. IAMs provide decision makers in both the public and private sectors, e.g. the CCTP, with science-based decision support tools to help them manage risk.





- Oil
- Natural Gas
- Coal
- Biomass Energy
- Non-Biomass Renewable Energy
- Oil + CCS
- Natural Gas + CCS
- Coal + CCS
- Nuclear Energy
- End-use Energy

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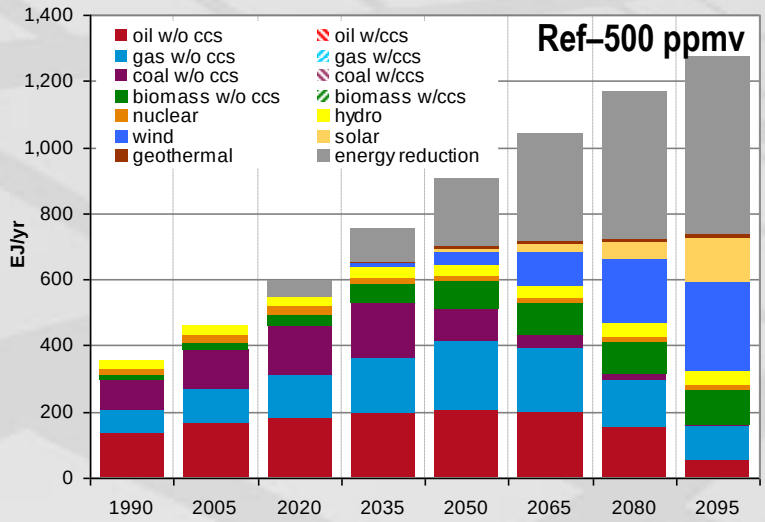
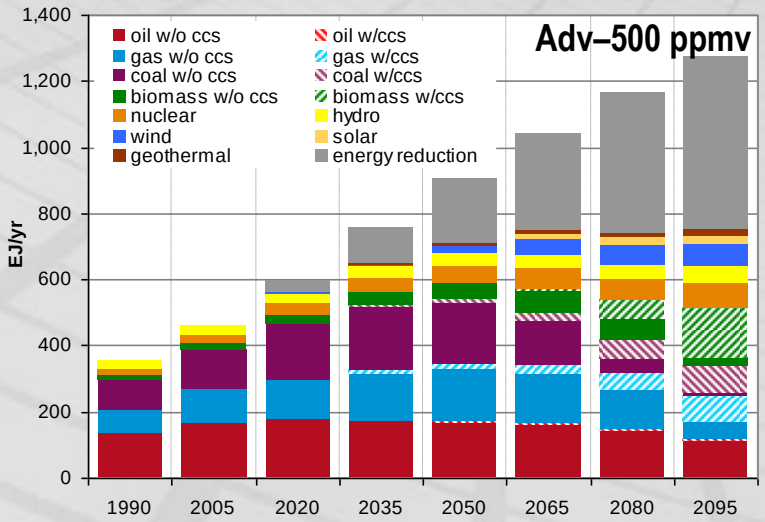
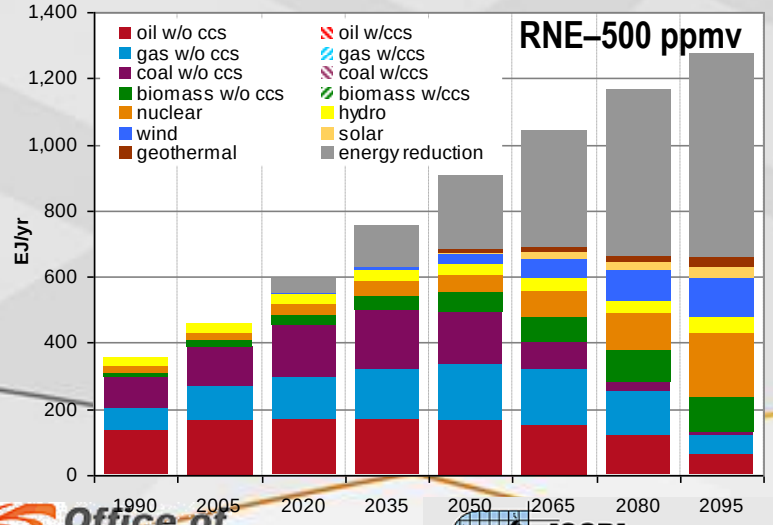
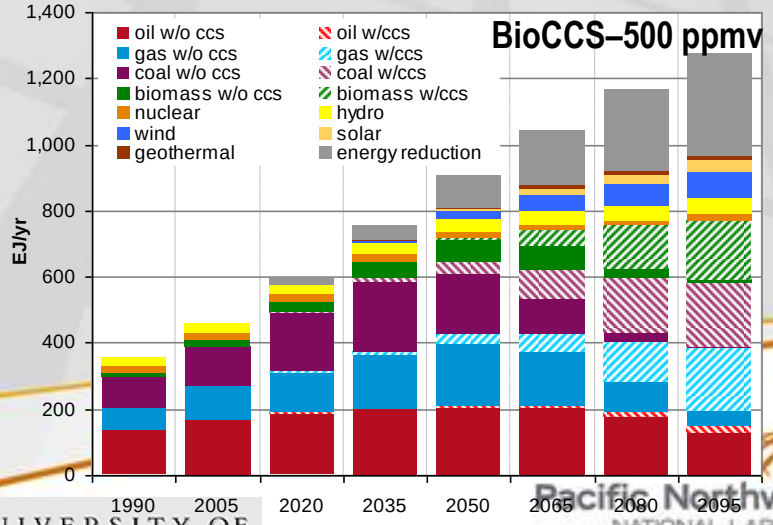
The Global Energy System
Four Evolutionary Technology Pathways



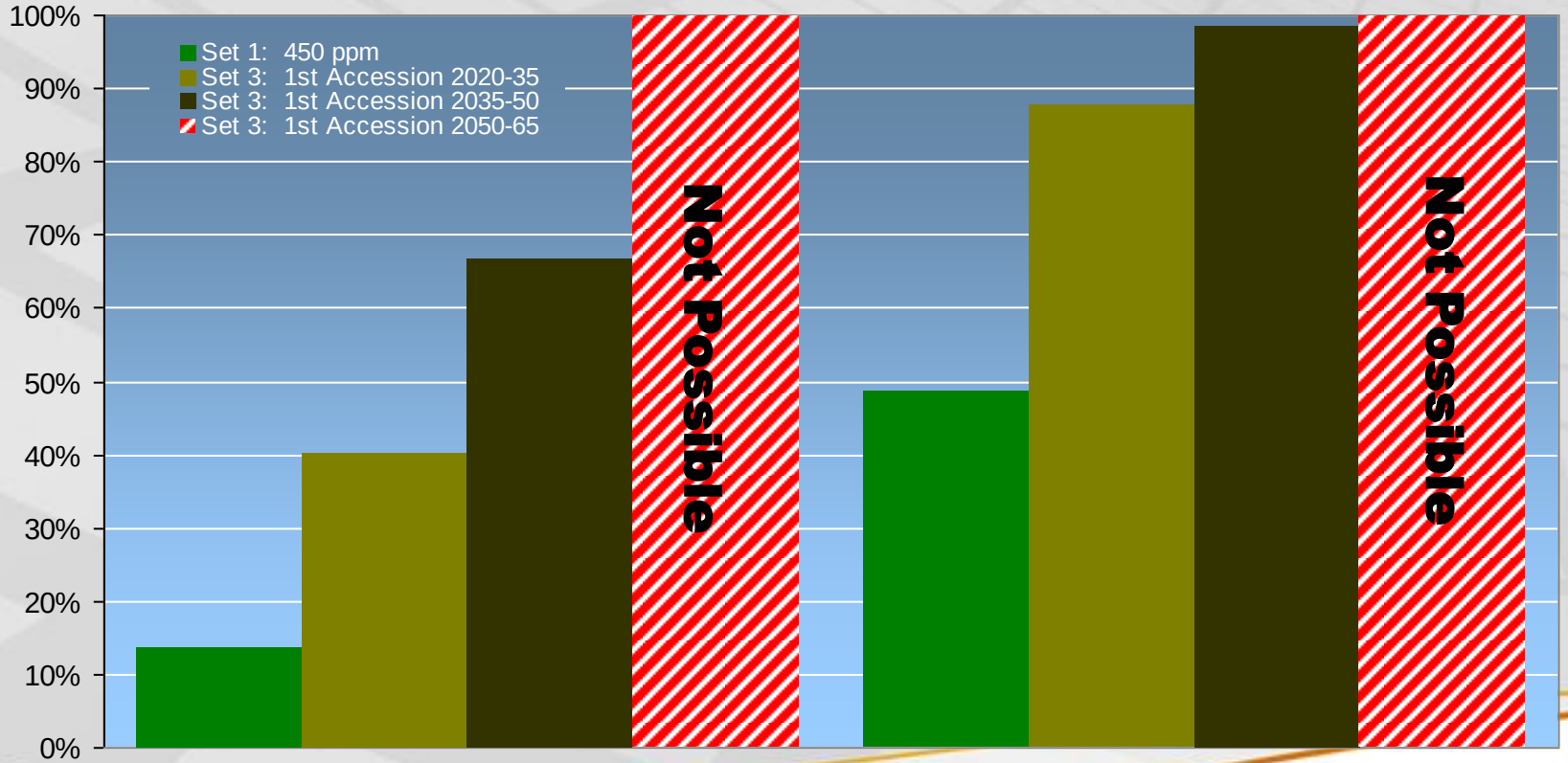






International Participation in Emissions Mitigation

Year 2020 Annex I emissions mitigation, relative to 2005, for different accession assumptions: 450 ppm



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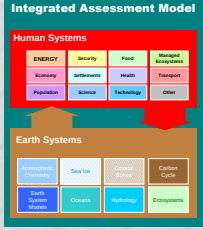
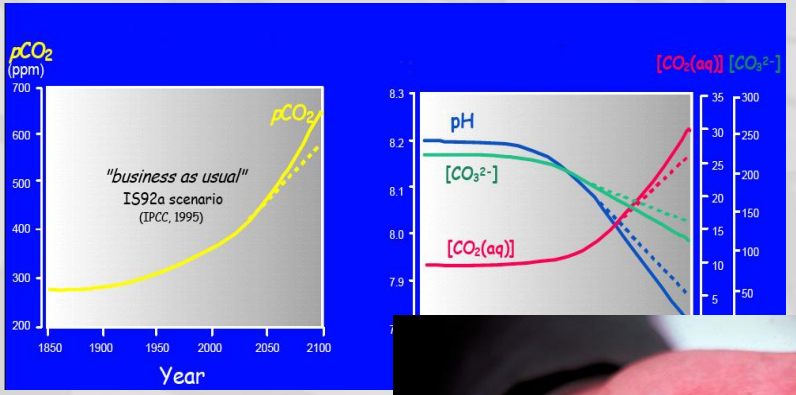
Major Future Challenges for IAMs (After Janetos)



- **One of the major challenges for IAMs in the coming decade: Land Use, Land Cover, Water, Ecosystems, Terrestrial Carbon Cycle, and the Interface with the Global Energy System Including Bioenergy**
  - IPCC WG2 in the AR4 used land to adapt to climate change.
  - IPCC WG3 in the AR4 assumed that land would be available to mitigate emissions producing bioenergy.
- **But also (emphasized in Summer 2007 DOE workshops)**
  - Ocean acidification
  - Coastal systems and sea level
  - Extreme events
  - Energy and transport
  - Health and demographics



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HOW IS THE IAM COMMUNITY INTERACTING WITH THE CLIMATE MODELING (CMC) COMMUNITY?

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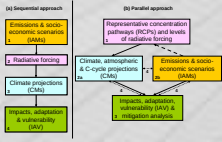
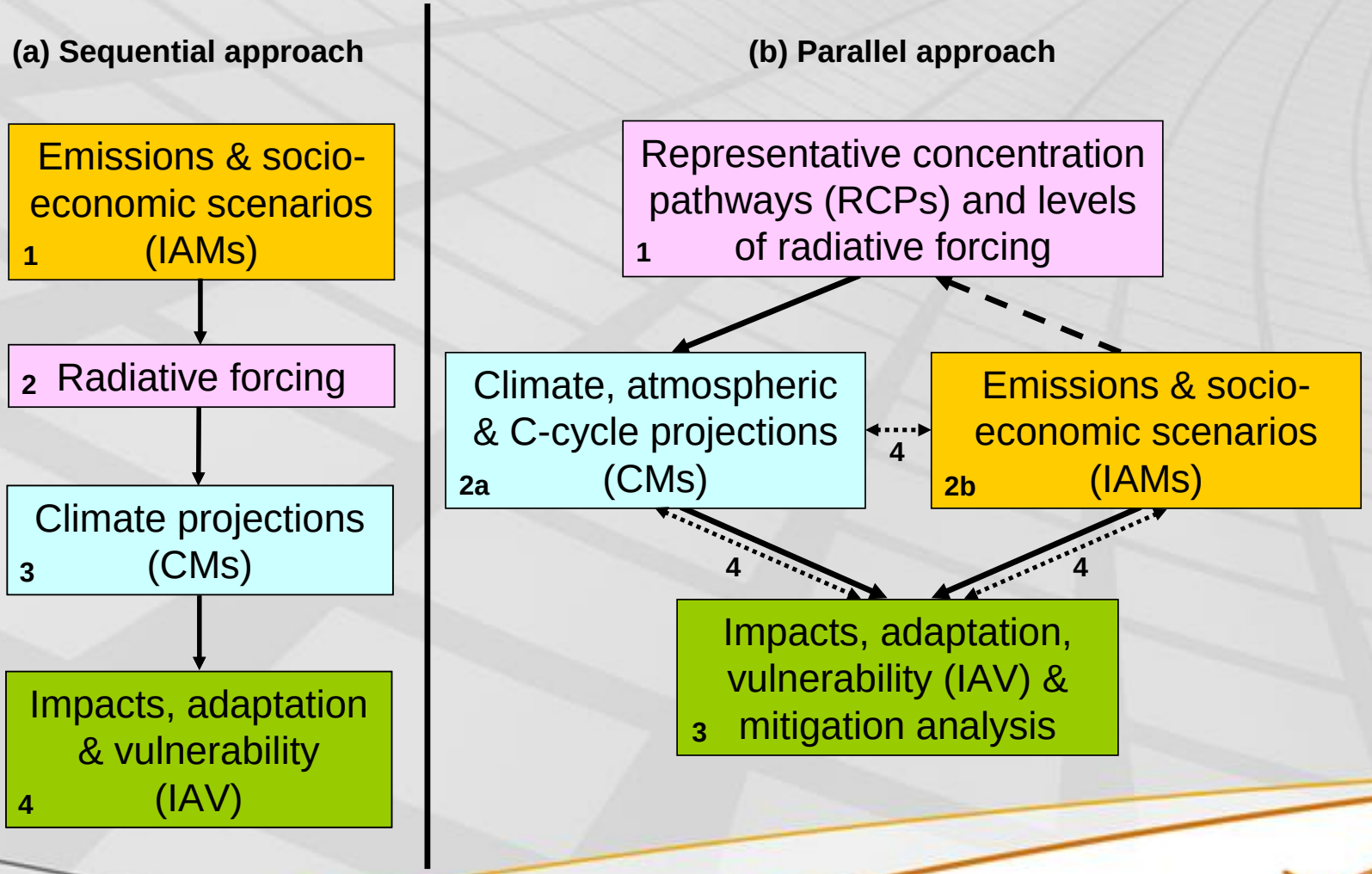
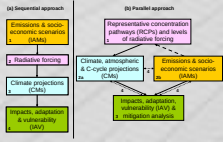
A "Parallel Approach" Implies Much More Interaction Between the IAM and CMC



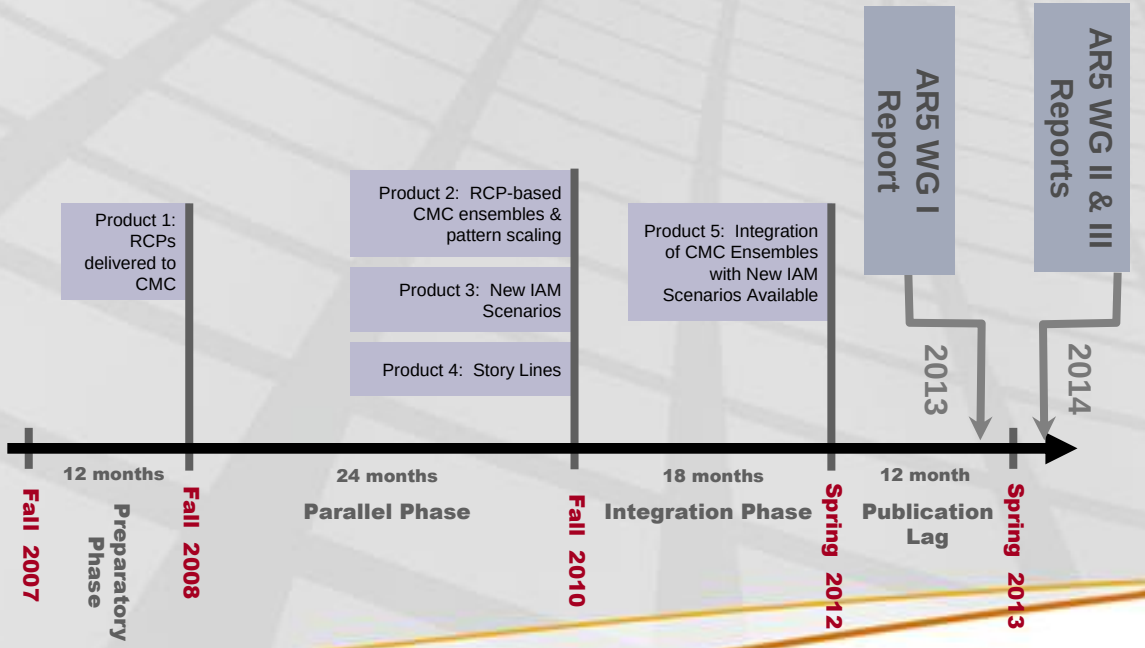


Work Plan for an Anticipated Major Assessment in the 2013-14 Time Frame



FOUR PHASES

- **The Preparatory Phase** and **Representative Concentration Pathways (RCPs)**
- **Parallel Phase:** Prepare climate and socio-economic scenarios in parallel
- **Integration Phase:**
  - "Pair up" climate scenarios with new socio-economic scenarios; and scaling for IAV research;
  - IAV-IAM "teaming to more fully integrate representation of impacts in IAMs and IAV research.
- **Publication Phase**



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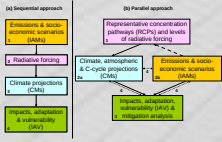
Scenarios by Whom?



For the first time scenarios are being organized by the modeling community and **NOT** the IPCC.

- The IAM community has organized itself via the IAMC.
- The CM community has organized it self via the WCRP/IGBP.

International Institute for Applied Systems Analysis (IIASA)	Energy Modeling Forum (EMF) Stanford University	National Institute for Environmental Studies (NIES)
➢Australian Bureau of Agricultural and Resource Economics (ABARE) - *Hom Pant* ➢Business Council for Sustainable Development – Argentina - *Virginia Vilariño* ➢CEA-LERNA, University of Social Sciences - *Marc Vielle* ➢Centre for International Climate and Energy Research (CICERO), University of Oslo - *H.Asbjorn Aaheim* ➢Argonne National Laboratory - *Donald Hanson* ➢Centre International de Recherche sur l'Environnement et le Developpement, EHESS - U.A. CNRS 940 (CIRED) - *Jean-Charles Hourcade* ➢CRA International - *Brian Fischer* ➢Dept. of Energy, Transport, Environment, DIW Berlin - *Claudia Kemfert* ➢Electric Power Research Institute (EPRI) - *Richard Richels* ➢Energy Research Institute, National Development and Reform Commission (NDRC) - *Kejun Jiang*	➢Freelance Professional Economist - *Thomas Rutherford* ➢Hamburg University and Economic and Social Research Institute (ESRI) - *Richard Tol* ➢Indian Institute of Management - *Priyadarshi Shukla* ➢Institut d'Economie et de Politique de l'Energie, IEPE-CNRS - *Patrick Criqui* ➢International Institute for Applied Systems Analysis (IIASA) - *Nebojsa Nakicenovic, Keywan Riahi* ➢IPCC and San Marcos University - *Eduardo Calvo* ➢National Institute for Environment Studies (NIES) - Mikiko Kainuma ➢Ohio State University - Brent Sohngen ➢Pacific Northwest National Laboratory, Joint Global Change Research Institute at the University of Maryland - *Jae Edmonds, Hugh Pitcher, Ronald Sands, Steve Smith* ➢Programa de Planejamento Energético - PPE/COPPE/UFRJ - *Emilio Lèbre La Rovere*	➢Purdue University - *Thomas Hertel* ➢RAND - *Rob Lempert* ➢Research Institute of Innovative Technology for the Earth (RITE) - *Keigo Akimoto* ➢Stanford University - *John Weyant* ➢Texas A&M University - *Bruce McCarl* ➢The Institute of Applied Energy - *Atsushi Kurosawa* ➢The Netherlands Environmental Assessment Agency (MNP) - *Detlef van Vuuren* ➢Universidad de Los Andes / Universidad Nacional de Colombia - *Jose Eddy Torres* ➢Universidad Iberoamericana Puebla - *Maria Eugenia Ibarraran Viniegra* ➢US Environmental Protection Agency - *Francisco de la Chesnaye, Allen Fawcett, Steven Rose*

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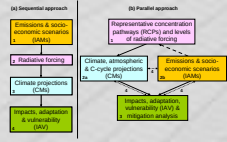
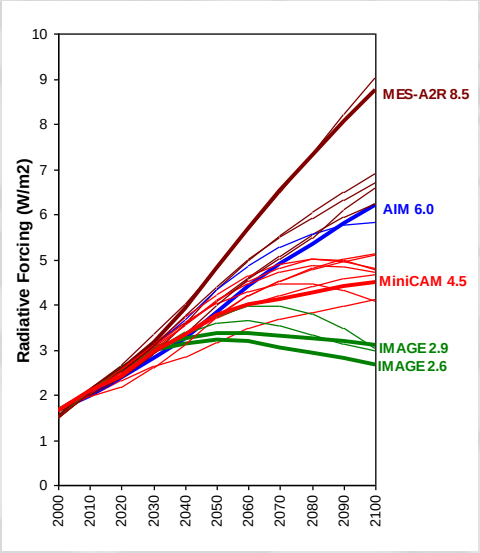
PRODUCT 1
Representative Concentration Pathways

From the Existing Literature, Already Underway



RCPs
Selection,
Extension to 2300,
Downscaling

- 8.5 W/m2
- 6 W/m2
- 4.5 W/m2
- <3 W/m2



CMC Develops RCP-based Ensemble Runs

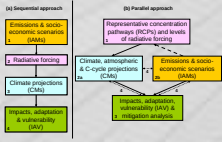
RCP8.5
- >8.5 W/m^2 in 2100,
- Rising

RCP6
- ~6 W/m^2 at stabilization after 2100
- Stabilization without exceeding target

RCP4.5
- ~4.5 W/m^2 at stabilization after 2100
- Stabilization without exceeding target

RCP3-PD
- <3 W/m^2 in 2100
- peak & decline stabilization

Representative Concentration Pathways (RCPs)



FORCING AGENTS

GHG Emissions and Concentrations from IAMs

- Greenhouse gases: CO_2, CH_4, N_2O, CFCs, HFC's, PFC's, SF_6
- Emissions of chemically active gases: CO, NO_x, NH_4, VOCs
- Derived GHG's: tropospheric O_3
- Emissions of aerosols: SO_2, BC, OC
- **Land use and land cover [NEW]**

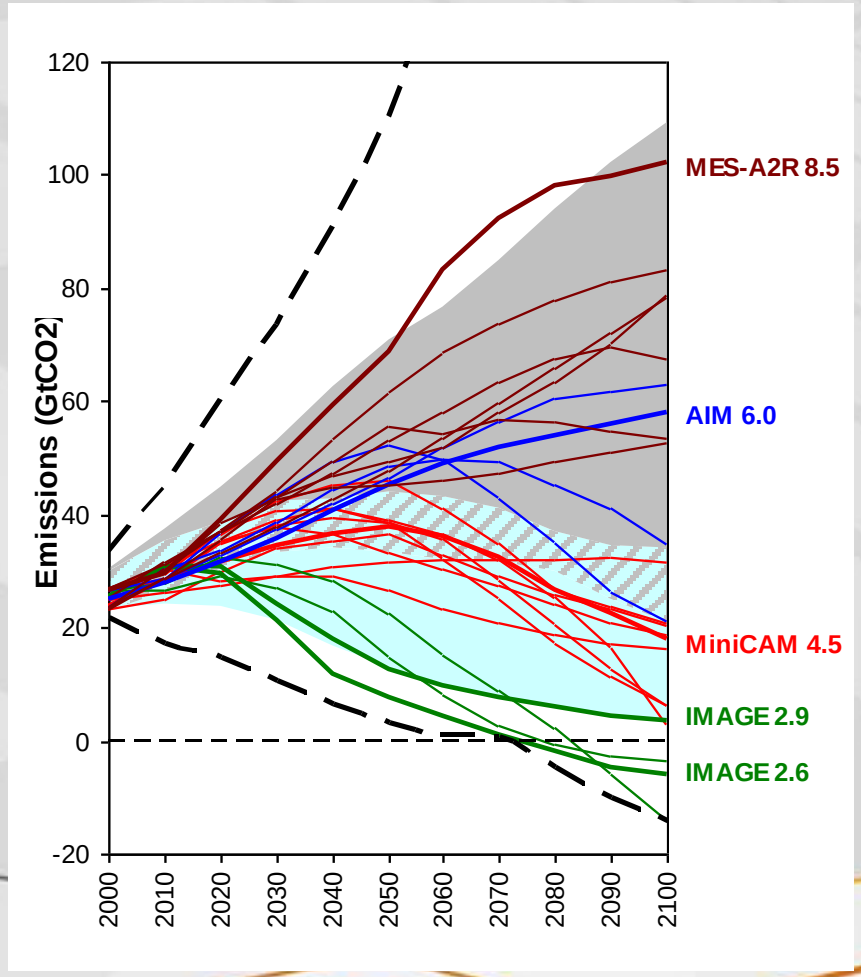
EXTENSIONS

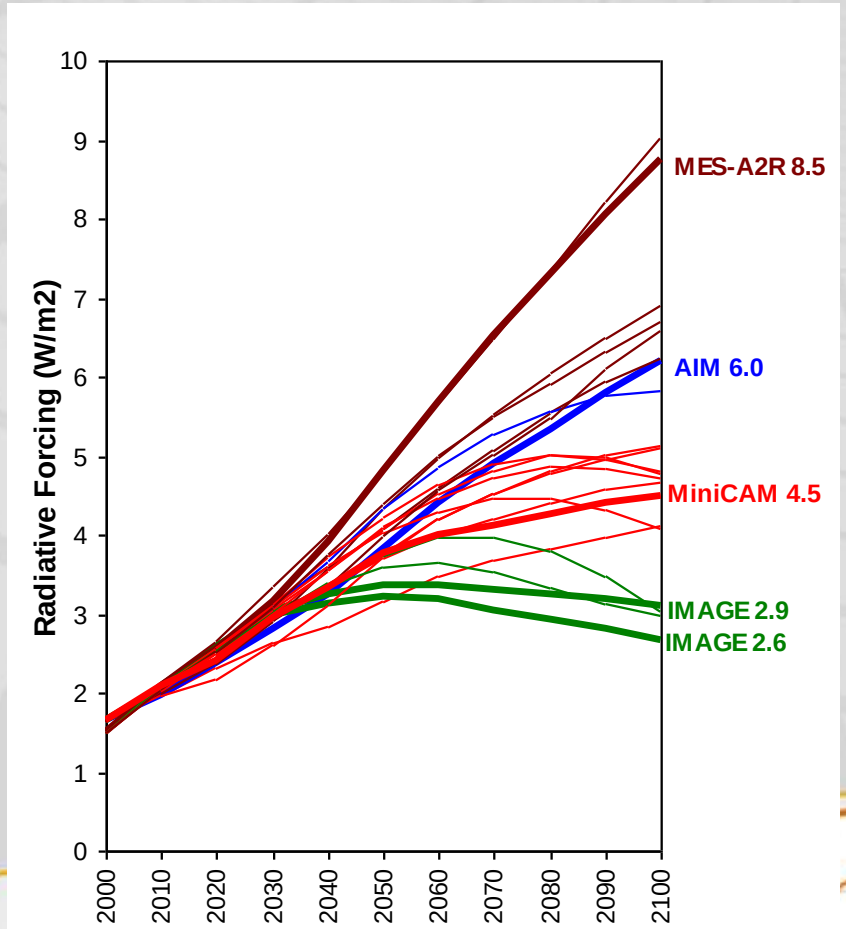
- Downscaling of **SHORT LIVED SPECIES** and **LAND USE/LAND COVER** to appropriate geographic resolution, perhaps as fine as ½° x ½° grid scale for both the near-term and long-term climate experiments.

- **Extension of scenarios to 2300.**

The RCP Scenarios

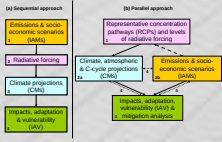
CO_2 Emissions and Total Radiative Forcing





Graphs: Detlef van Vuuren

2.6 W/m2 or 2.9 W/m2?



Which scenario for the low (<3W/m^2) RCP?

Noordwijkerhout debate over what it means to be:

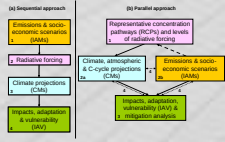
"compatible with the full range of stabilization, mitigation, and baseline emissions scenarios available in the current literature"

Van Vuuren *et al.* published a 2.9 W/m^2 and explored the potential of bioenergy with CCS to reduce 2100 radiative forcing to still lower levels.

- *The authors emphasized the experimental nature of the 2.6 W/m^2 scenario and indicated that they were uncomfortable with providing it as an RCP absent further review on their part.*
- *Some members of the policy user community argued strongly that 2.6 W/m^2 was absolutely essential.*

The IAMC is conducting a process to review the robustness of a revised 2.6 W/m^2 scenario.

RCP "Handoff"



- There is a "Handshake" document.
- *Work plan for data exchange between the Integrated Assessment and Climate Modeling community in support of Phase-0 of scenario analysis for climate change assessment (Representative Community Pathways).*

Work plan for data exchange between the Integrated Assessment and Climate Modeling community in support of Phase-0 of scenario analysis for climate change assessment (Representative Community Pathways).

Authors: Detlef P. van Vuuren, Johannes Feddema, Jean-Francois Lamarque, Keywan Riahi, Steven Rose, Steve Smith, Kathy Hibbard

1. Background

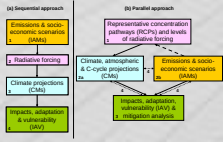
During its 26th meeting in Bangkok in May 2007, the IPCC requested the preparation of a new set of scenarios to facilitate future assessment of climate change. This new set (that is intended to replace and extend the scenarios used in earlier IPCC assessments) should be compatible with the full range of stabilization, mitigation and baseline emission scenarios available in the current scientific literature. The IPCC also decided that, in part because of the growing number of scenarios developed within the research community, and the research communities organizational structure, the research community itself would undertake development of scenarios for assessment in a possible AR5, while the IPCC's role would be that of catalyzing and assessing such work.

The research community has subsequently outlined three phases of scenario development: a preparatory phase and two main phases of scenario development—a parallel product development phase and an integration, dissemination, and application phase. In the preparatory phase, four integrated assessment (IA) concentration and emissions scenarios will be chosen from the existing literature and provided to climate modelers. These scenarios are referred to as "*representative concentration pathways*" (RCPs). These scenarios will be used to produce a new set of climate model simulations that will subsequently used for mitigation, impacts, adaptation, and vulnerability analysis. The primary goal of the RCPs is to provide, in a timely manner, the most up to date scenarios possible to be used to produce these new climate model simulations.

The identification of RCPs up-front is done to expedite the development of integrated scenarios by enabling climate modeling to proceed in parallel to emission and socio-economic scenario development. In the past, scenario development has been carried out as a sequential process (from socio-economics and emissions to climate projections and finally impact assessment). This sequential process prolonged the integration of information across the three research communities. The identification of RCPs will thus enable the climate modeling community to proceed with new climate change projections at the same time that new work is carried out in the Integrated Assessment Model (IAM) and Impact, Adaptation and Vulnerability (IAV) communities. The RCPs will be used for simulations by the Climate Modeling (CM) community, including Earth System Models (ESMs), Coupled Ocean Atmosphere Global Circulation Models (AOGCMs) and Earth System Models of Intermediate Complexity (EMICS

At an IPCC Expert meeting on New Scenarios, held 19–22 September 2007 in Noordwijkerhout, The Netherlands, a set of RCPs was identified. Following the Expert meeting, the CM and IAM communities began coordination on the resolution details of the RCP data that is to be exchanged. The rationale for choosing RCPs, the actual RCPs relative to the literature, guidelines on the use of the RCPs, and the overall new scenarios development timeline and products are described in the Noordwijkerhout report (Moss et al., 2008). The set of four RCPs is summarized in Table 1.1.

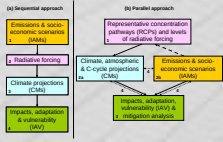
RCP "Handoff"



The four IAM teams who have agreed to supply RCP scenarios are currently preparing scenario data, to be delivered in September 2008.

- IAM teams are **updating historical data** and producing additional information requested by Earth System Models (ESM), particularly regarding land-use.
- A draft "handshake" protocol has been developed detailing the data to be delivered to the earth-system modeling community
- The development of a **consensus set of base year 2000 emissions and historical emissions from at least 1850 forward**.
  - IAM, emissions inventory, and chemical modeling communities
  - **Goal: Seamless transition between history and future scenario**

RCP "Handoff"

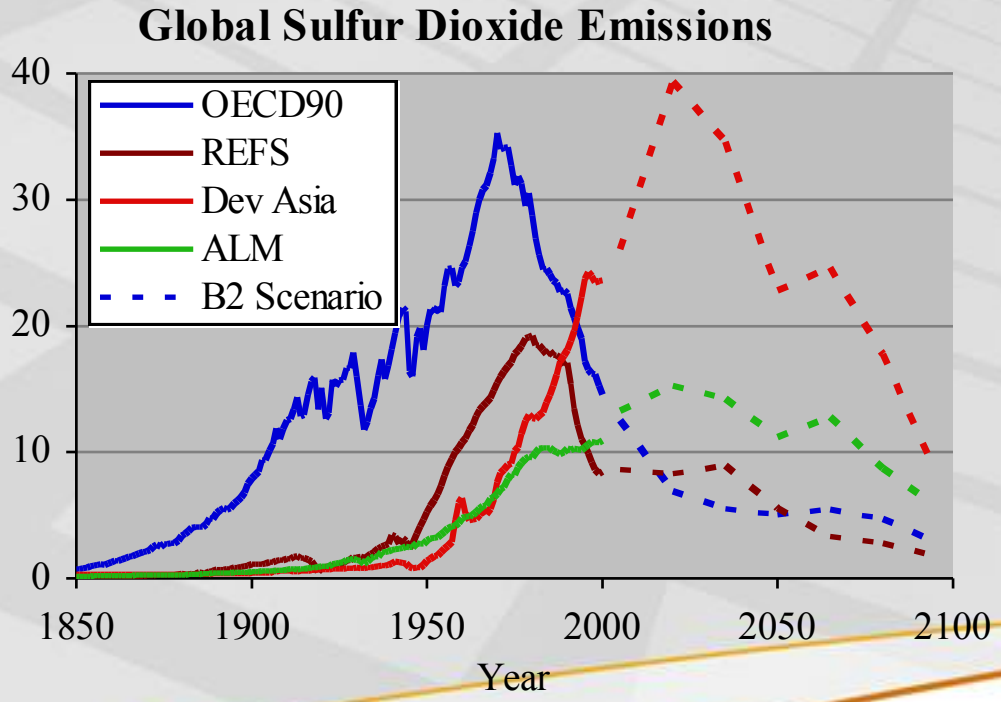


The IAM data will be used by chemistry models to produce future scenarios for atmospheric chemistry (oxidants, ozone, and, in some cases, aerosols) in preparation for ESM model runs starting in early 2009.

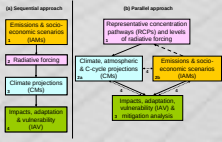
Future and Historical Emissions

A goal of the RCP development process is to produce a consistent estimate of historical emissions along with four future RCP projections that start from a common year 2000 data set.

A similar process is taking place for land-use and land-use change



RCP Sectoral Detail



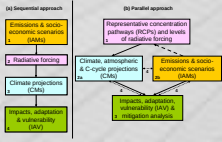
The RCP emissions data will be provided in greater **sectoral detail** than for previous scenario exercises:

- Ground Transportation
- International Shipping
- Aviation
- Power Plants, Energy Conversion, Extraction, and Distribution
- Solvents
- Waste (landfills, wastewater, non-energy incineration)
- Industry (combustion & processing)
- Residential and Commercial

- Ag waste burning on Fields
- Agriculture (e.g. Animals, Rice, & Soil)
- Savannah Burning
- Land-Use Change (Deforestation)

Greater detail is due to spatial, chemical, temporal, and differing sectoral coverage within ESM models

RCP Land-Use



Land-use and land-use change data will also be provided on a gridded basis:

- Cropland
- Harvested forest area (secondary forests)
- Deforested area (primary forests)
- Pasture and grazing land
- Urban land

Supplementary data that has also been requested includes:

- Irrigated area
- Timber and wood harvest amounts (and disposition)
- Standard of living indicator
- Fertilizer use

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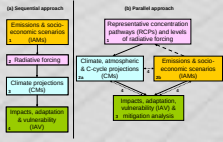
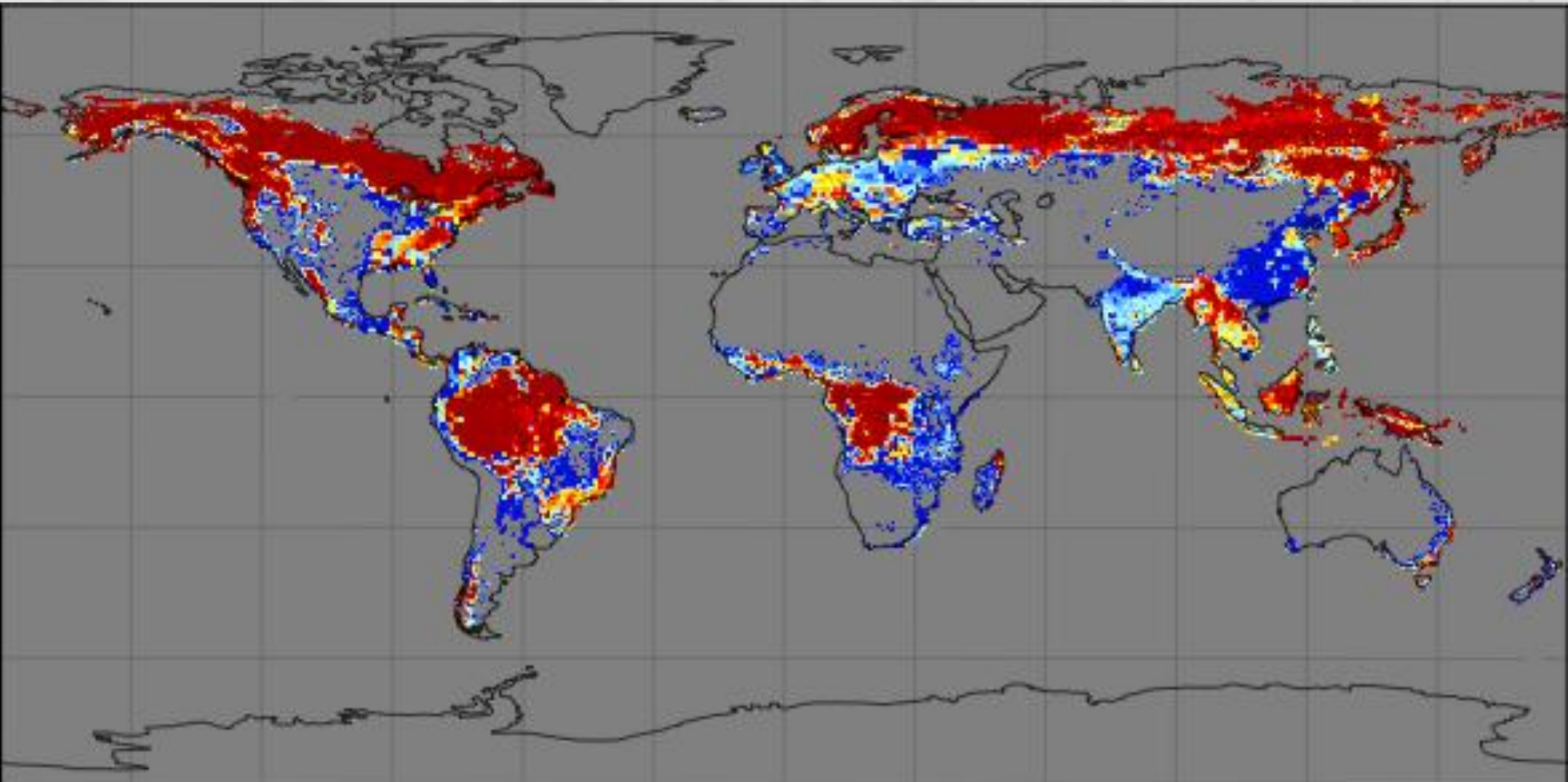
RCP Land-Use

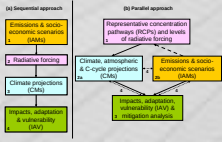


Spatially distributed information will be a fundamental part of new scenarios.

Forest Cover



RCP Extension to 2300



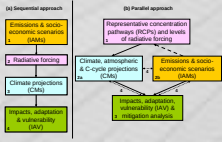
Emissions and land-use for the RCP scenarios will be extended to 2300 to allow for long-term climate simulations.

- Emissions (RCP 2.9/2.6 and 8.5) or concentrations (RCP 4.5 & 6) past 2100 will be held constant (consistent with forcing stabilization in 4.5 and 6 scenarios).
- Cropland and pasture areas past 2100 will be scaled with global population.

The extension procedure is very simple, and is intended to produce a consistent data set for ESM modeling.

These are not full 300-year scenarios!

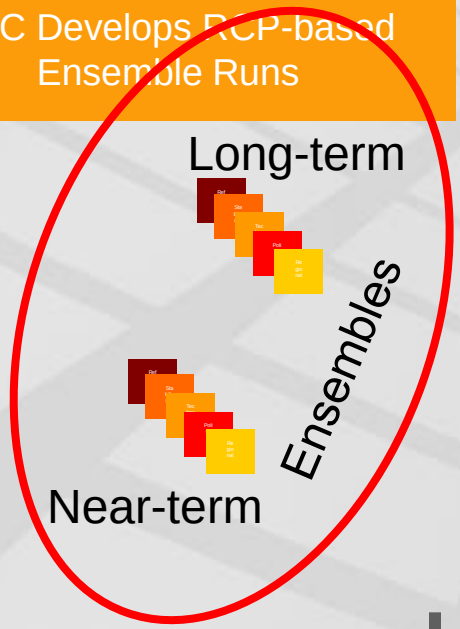
PRODUCT 2
Ensemble Climate Change Scenarios



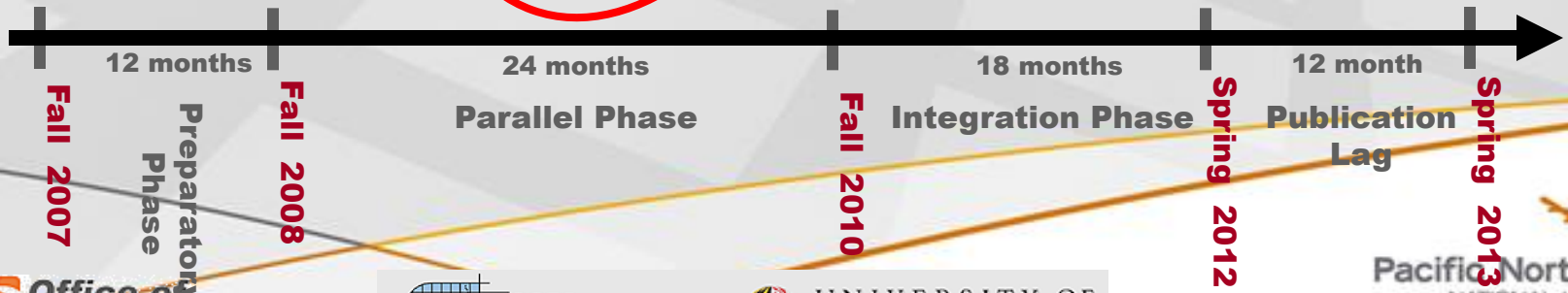
RCPs
Selection,
Extension to 2300,
Downscaling

- 8.5 W/m2
- 6 W/m2
- 4.5 W/m2
- <3 W/m2

CMC Develops RCP-based Ensemble Runs



- Time to produce: <24 months
- Product: Ensembles of gridded, time dependent projections of climate change produced by multiple climate models for the four long-term RCPs and
  - High resolution, near-term projections to 2030 (4.5W/m2 stabilization only).
  - Long-term scenarios extended to the year 2300.



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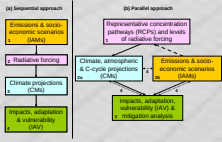
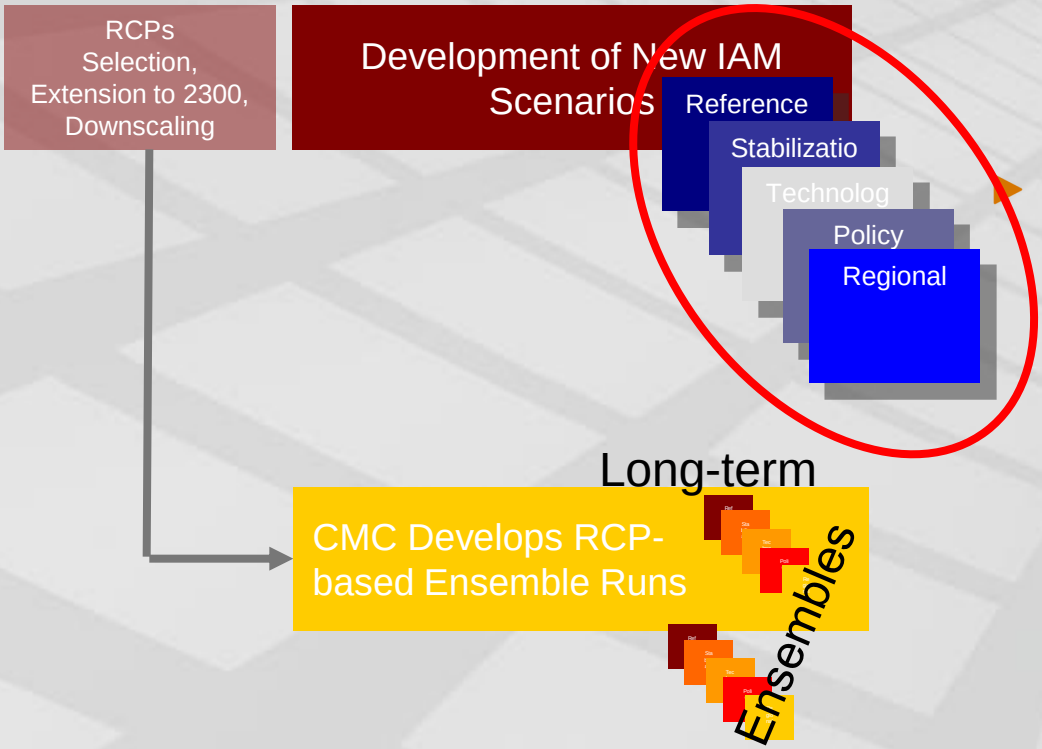
PRODUCT 3
New IAM Scenario Pathways



- Time to produce: 24 months
- Product: Groups of new scenario pathways developed by the IAM research community exploring a wide range of dimensions associated with anthropogenic climate forcing.
- Anticipated outputs include
  - alternative socio-economic backgrounds,
  - alternative technology availability regimes,
  - alternative realizations of Earth system science research,
  - alternative stabilization scenario pathways including traditional, “not-to-exceed” scenario pathways,
  - “overshoot” scenario pathways, and
  - alternative representations of regionally heterogeneous mitigation policies and measures, as well as regional societies, economies and policies.



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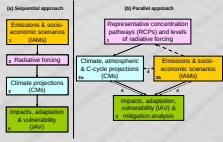
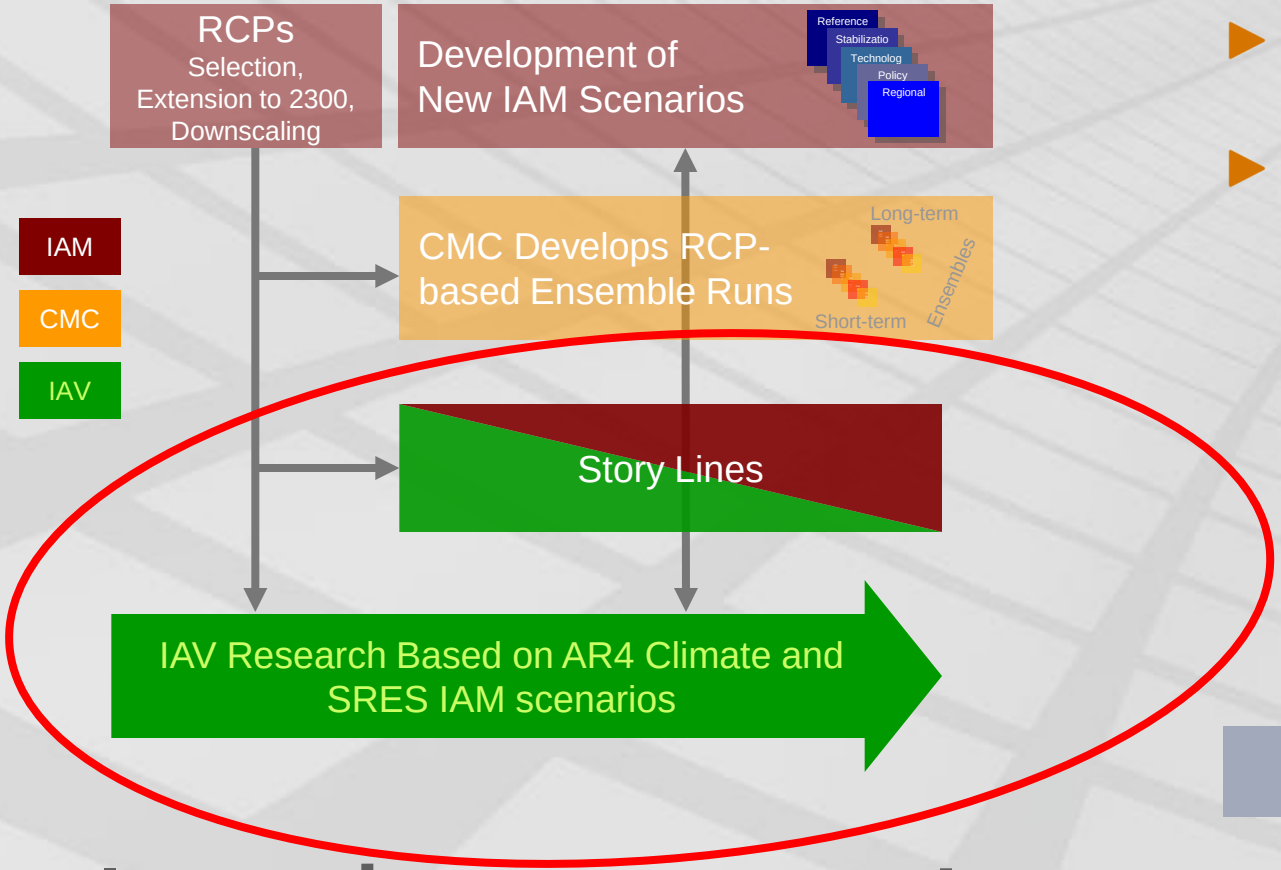
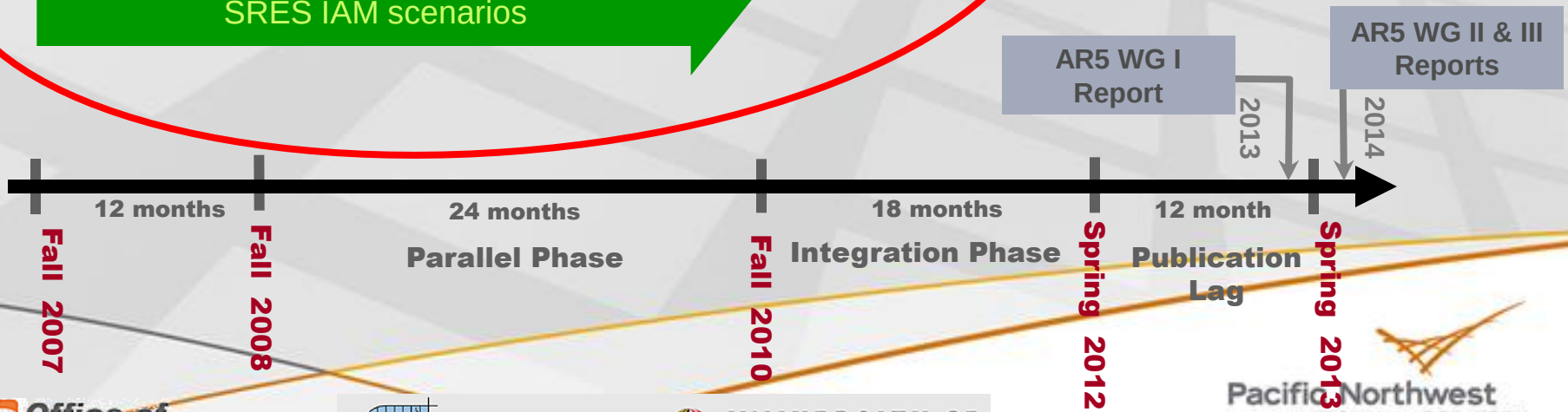
PRODUCT 4
Global Narrative Storylines

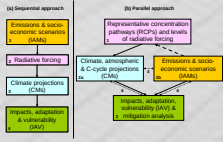




- Time to produce: 24 months
- Product: Detailed descriptions to be associated with the four RCPs produced in the Preparatory Phase and such pathways developed as part of Product 3 as selected by IAM and IAV communities.



IAMs Combine New Scenarios With New CMC Ensembles



RCPs
Selection, Extension to 2300, Downscaling

Development of New IAM Scenarios

Reference
Stabilizatio
Technolog
Policy
Regional

CMC Develops RCP-based Ensemble Runs

Story Lines

Integration of CMC Ensembles with IAM NEW Scenarios

IAV Research Based on AR4 Climate and SRES IAM scenarios

IAM
CMC
IAV

AR5 WG I Report

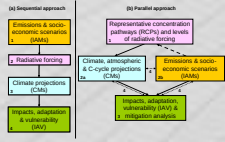
AR5 WG II & III Reports

2013

2014

Fall 2007	12 months	Fall 2008	24 months Parallel Phase	Fall 2010	18 months Integration Phase	Spring 2012	12 month Publication Lag	Spring 2013

IAV Research Community Combine New Scenarios With New CMC Ensembles



RCPs
Selection, Extension to 2300, Downscaling

Development of New IAM Scenarios

Reference
Stabilizatio
Technolog
Policy
Regional

Continued Development and Application of IAM Scenarios

CMC Develops RCP-based Ensemble Runs

Story Lines

Integration of CMC Ensembles with IAM NEW Scenarios

IAM
CMC
IAV

IAV Research Based on AR4 Climate and SRES IAM scenarios

IAV research based on new CM and IAM scenarios

Fall 2007	12 months	Fall 2008	24 months Parallel Phase	Fall 2010	18 months Integration Phase	Spring 2012	12 month Publication Lag	Spring 2013

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WHAT DOES THE FUTURE HOLD FOR INTEGRATED ASSESSMENT MODELING AND ESMS?

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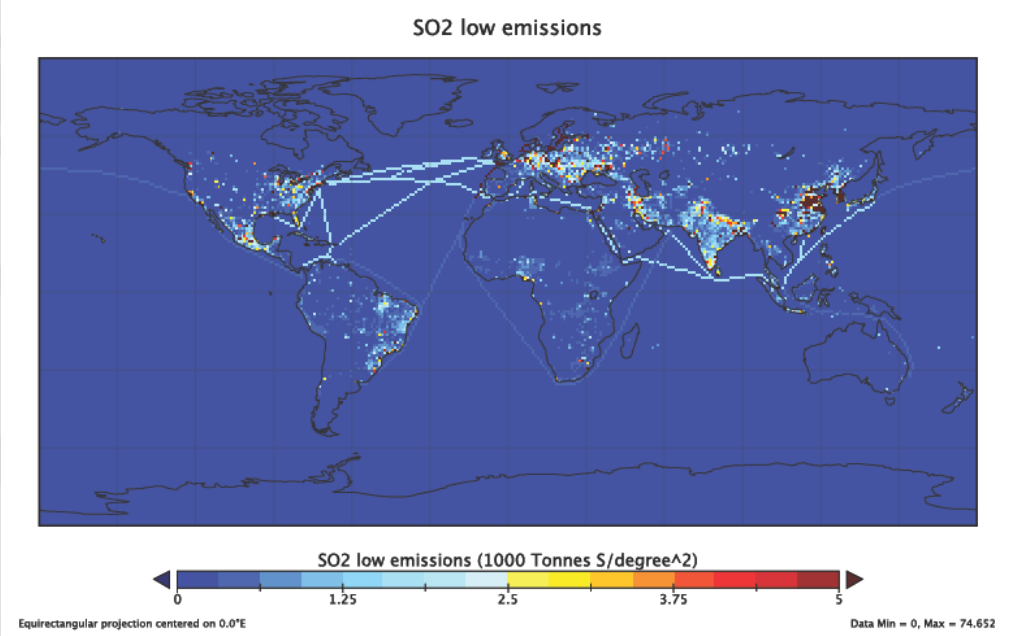
Future Challenges for IAMs

- Increased geographic specificity—for both land use and emissions of short-lived species.
- Shorter time steps.
- Longer time horizons—2300.
- Closer interface with the CMC.

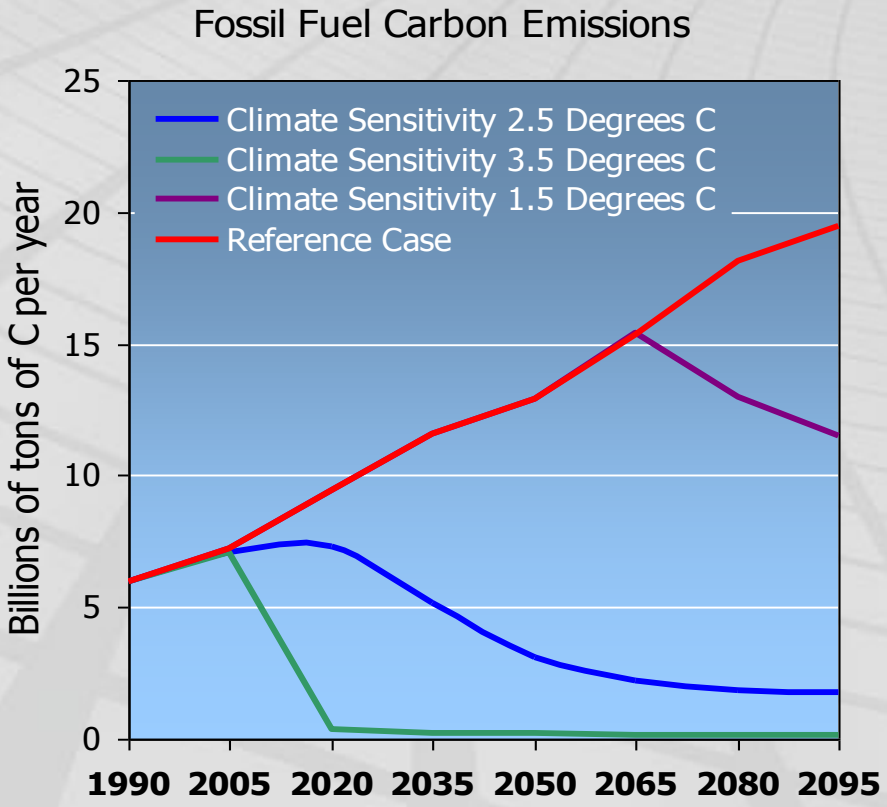


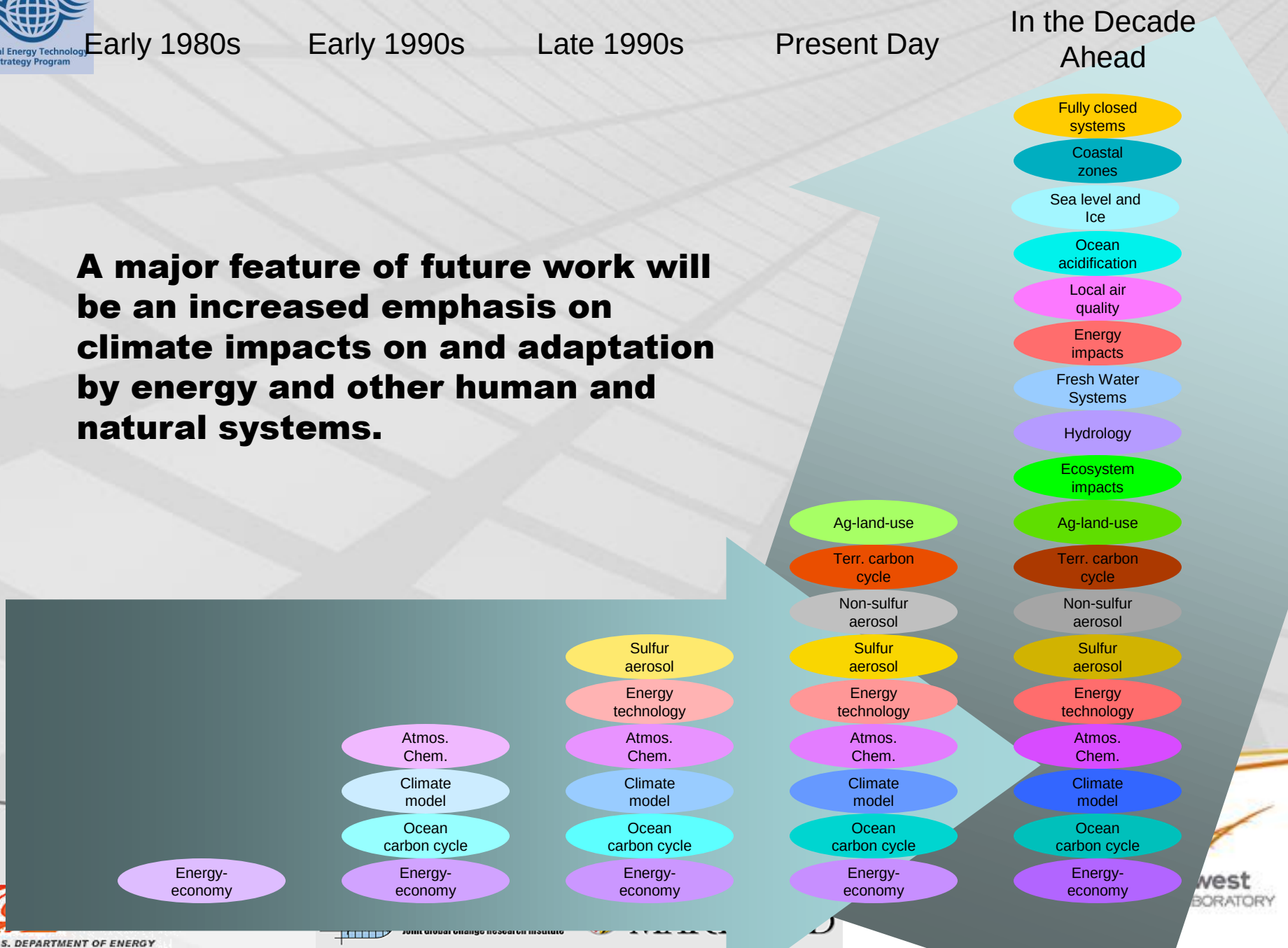
Two Parallel Development Directions

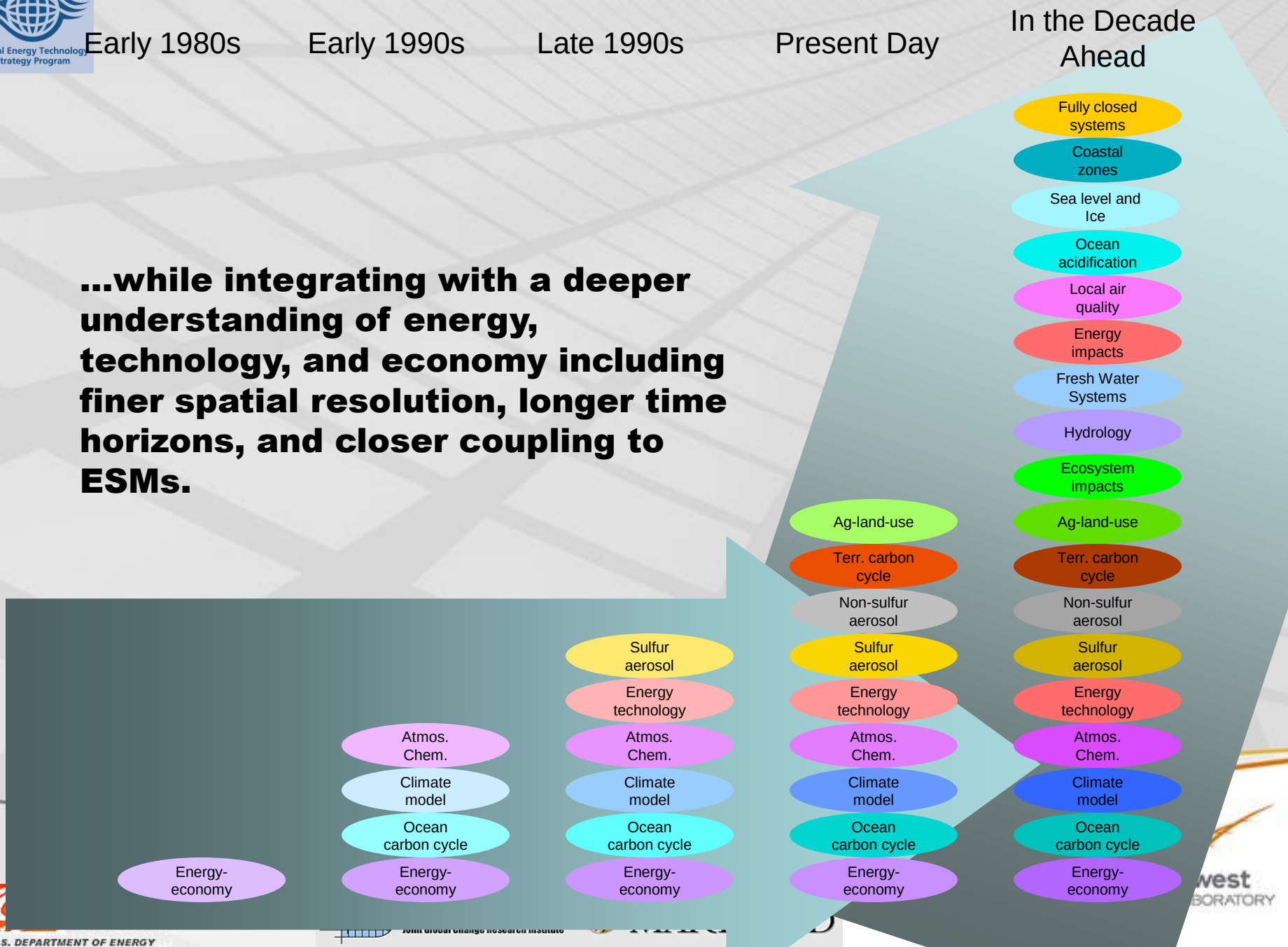
- **IAM in future ESMs.**
  - ESMs are incorporating ever more Earth system processes.
  - Overlap with IAMs which produce land use and land cover and emissions of greenhouse gases and short-lived species.
  - Obvious benefit to ESMs to incorporating the human and terrestrial systems components of IAMs.
  - This will require close collaboration because just as great mischief is possible when social scientists try to run ESMs, similarly great mischief is possible when natural scientists try to run the human system components of IAMs.

Two Parallel Development Directions

- IAM as the home of **human systems research and EMICs** for rapid exploration of the systems implication of new science.
  - Noordwijkerhout-Snowmass-Aspen “parallel approach” to faster development of scenario-ensembles for use by the IAV community.
  - Importance of improved science.
  - A tool for understanding the Earth system implications of climate change for human and natural systems—impacts and adaptation.
  - A tool for understanding the implications of emissions mitigation on climate and climate on emissions mitigation, including the potential role of transformational science and technology.




Early 1980s
Early 1990s
Late 1990s
Present Day
In the Decade Ahead
A major feature of future work will be an increased emphasis on climate impacts on and adaptation by energy and other human and natural systems.
Energy-economy
Atmos. Chem.
Climate model
Ocean carbon cycle
Energy-economy
Sulfur aerosol
Energy technology
Atmos. Chem.
Climate model
Ocean carbon cycle
Energy-economy
Ag-land-use
Terr. carbon cycle
Non-sulfur aerosol
Sulfur aerosol
Energy technology
Atmos. Chem.
Climate model
Ocean carbon cycle
Energy-economy
Fully closed systems
Coastal zones
Sea level and Ice
Ocean acidification
Local air quality
Energy impacts
Fresh Water Systems
Hydrology
Ecosystem impacts
Ag-land-use
Terr. carbon cycle
Non-sulfur aerosol
Sulfur aerosol
Energy technology
Atmos. Chem.
Climate model
Ocean carbon cycle
Energy-economy


Early 1980s
Early 1990s
Late 1990s
Present Day
In the Decade Ahead
...while integrating with a deeper understanding of energy, technology, and economy including finer spatial resolution, longer time horizons, and closer coupling to ESMs.
Energy-economy
Atmos. Chem.
Climate model
Ocean carbon cycle
Energy-economy
Sulfur aerosol
Energy technology
Atmos. Chem.
Climate model
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Energy-economy
Ag-land-use
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Local air quality
Energy impacts
Fresh Water Systems
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Climate model
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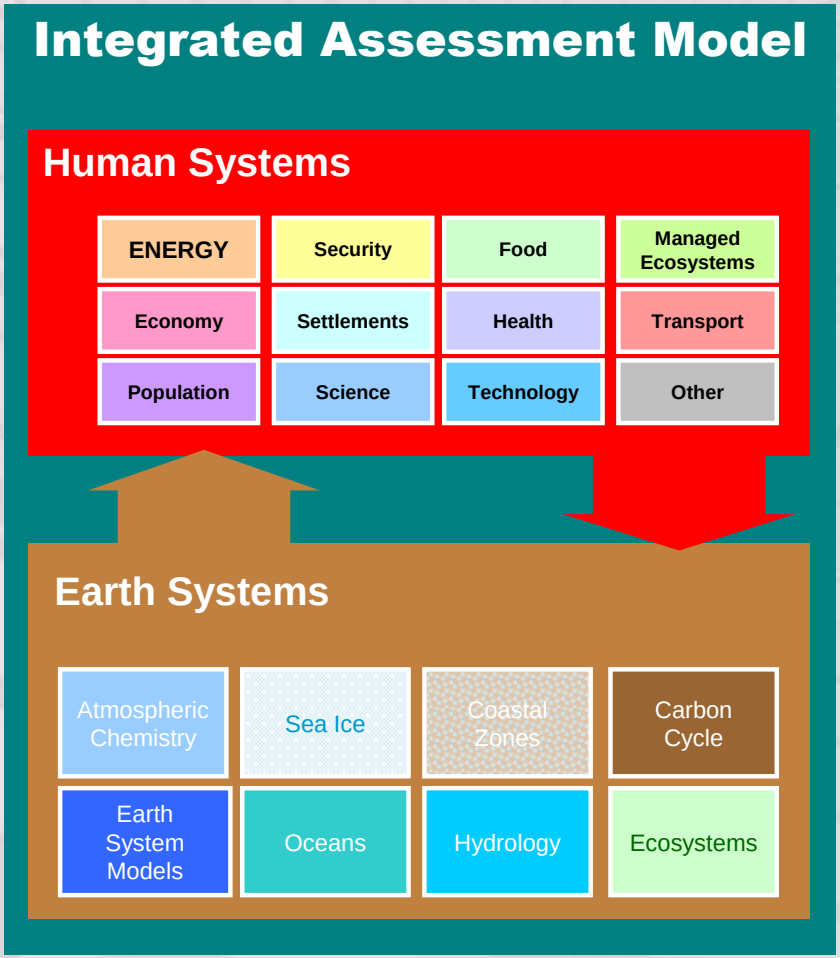

DISCUSSION

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