Evolution of Earth System Science and Earth Observations

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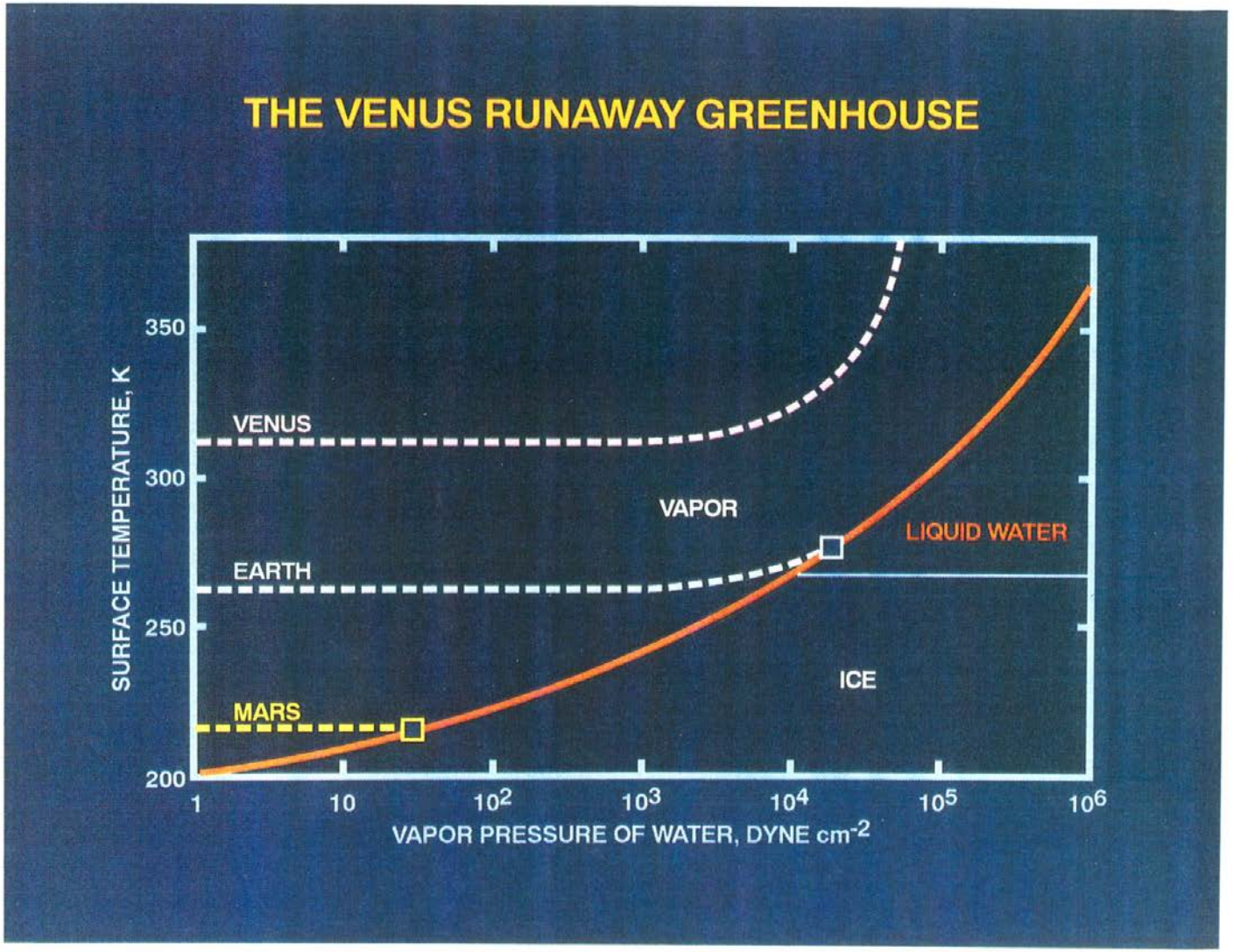
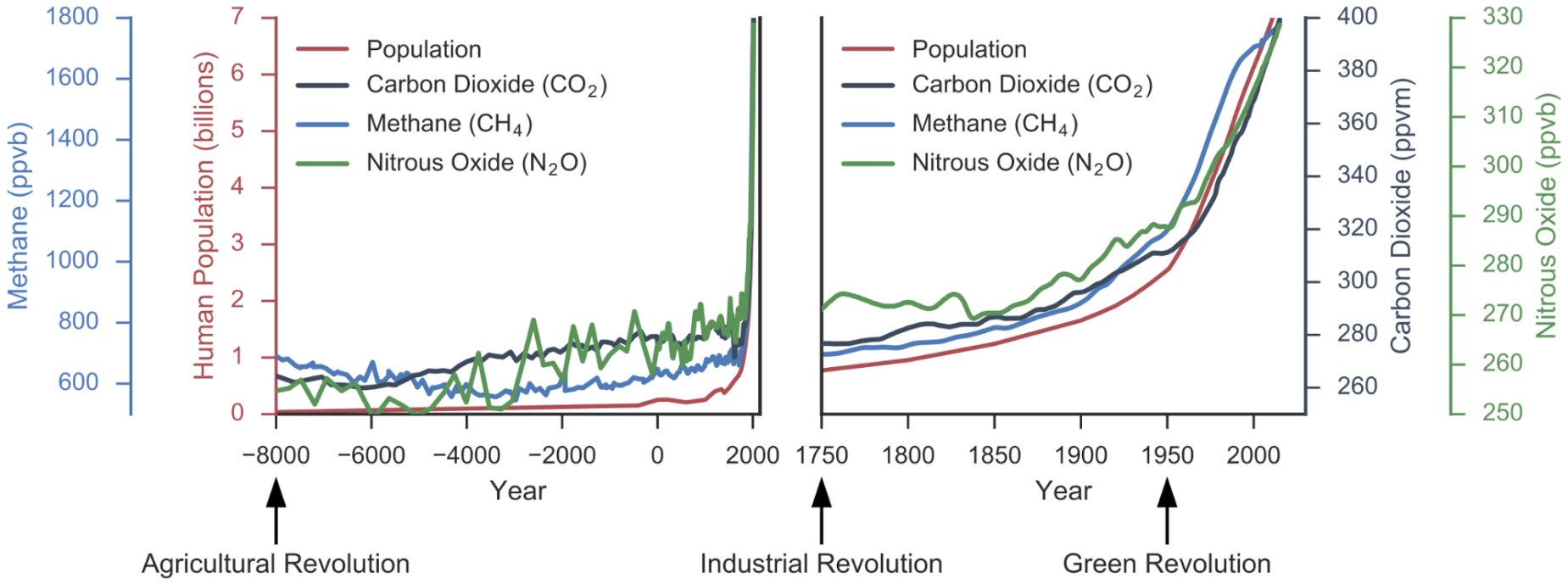
Outline

- **Motivation**
  - **Scientific Opportunity & Societal Challenge**
- **Past Practice**
  - **Scientific and Technical Innovations**
  - **National and International Capabilities**
  - **Education and Training of Scientists & Engineers**
- **Future Prospect**
  - **Earth system predictability and prediction**
  - **Mission innovation and technology**
- **Discussion**

Motivation: Scientific Opportunity

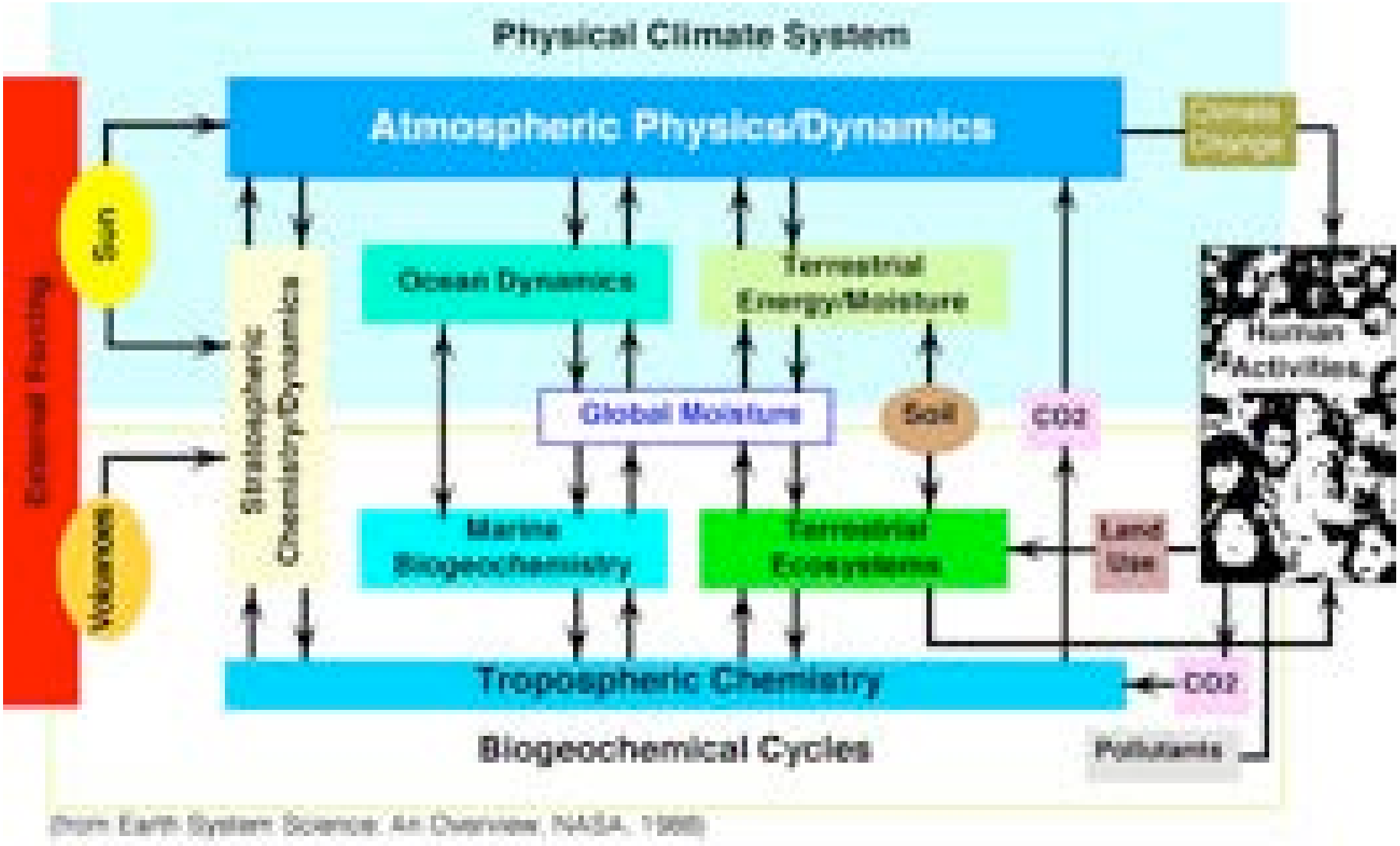


Motivation: Societal Challenge



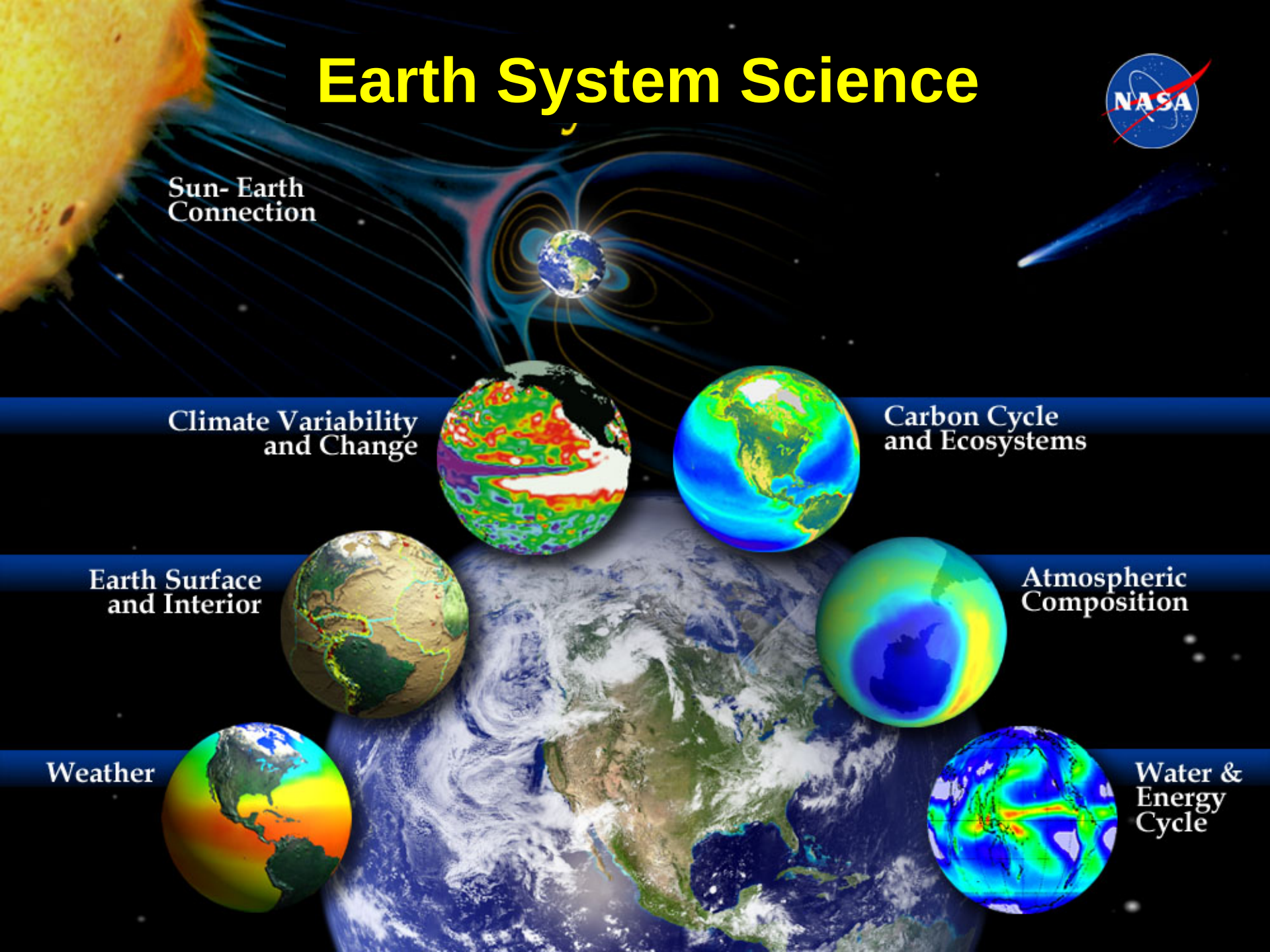
The similar evolution of human population and the atmospheric concentrations of the greenhouse gases strongly suggests that population is the driver. Note the abrupt acceleration around mid-20th century, especially with the Green Revolution and the massive use of fossil fuels.

Earth System Science

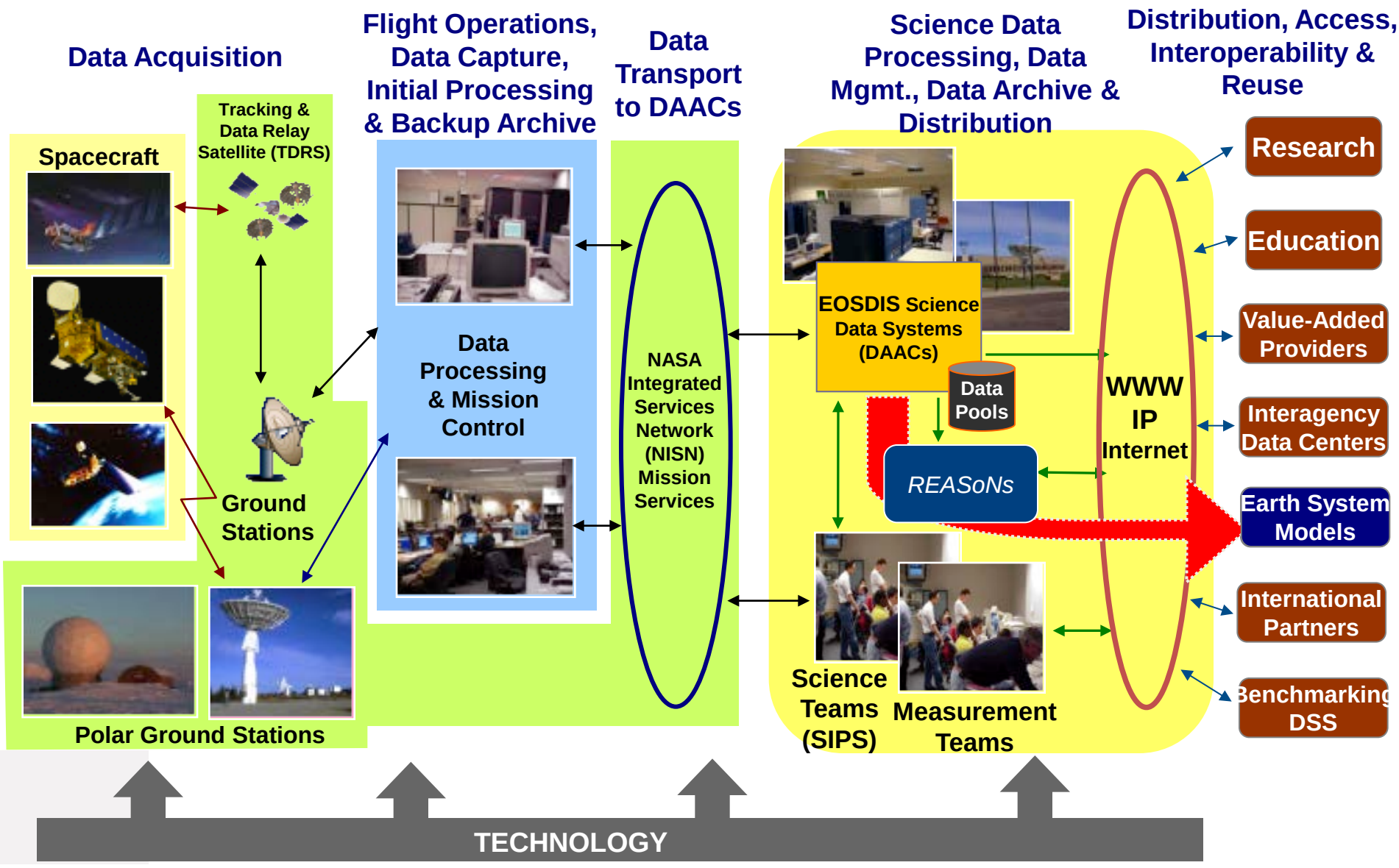


(from Earth System Science: An Overview, NASA, 1988)

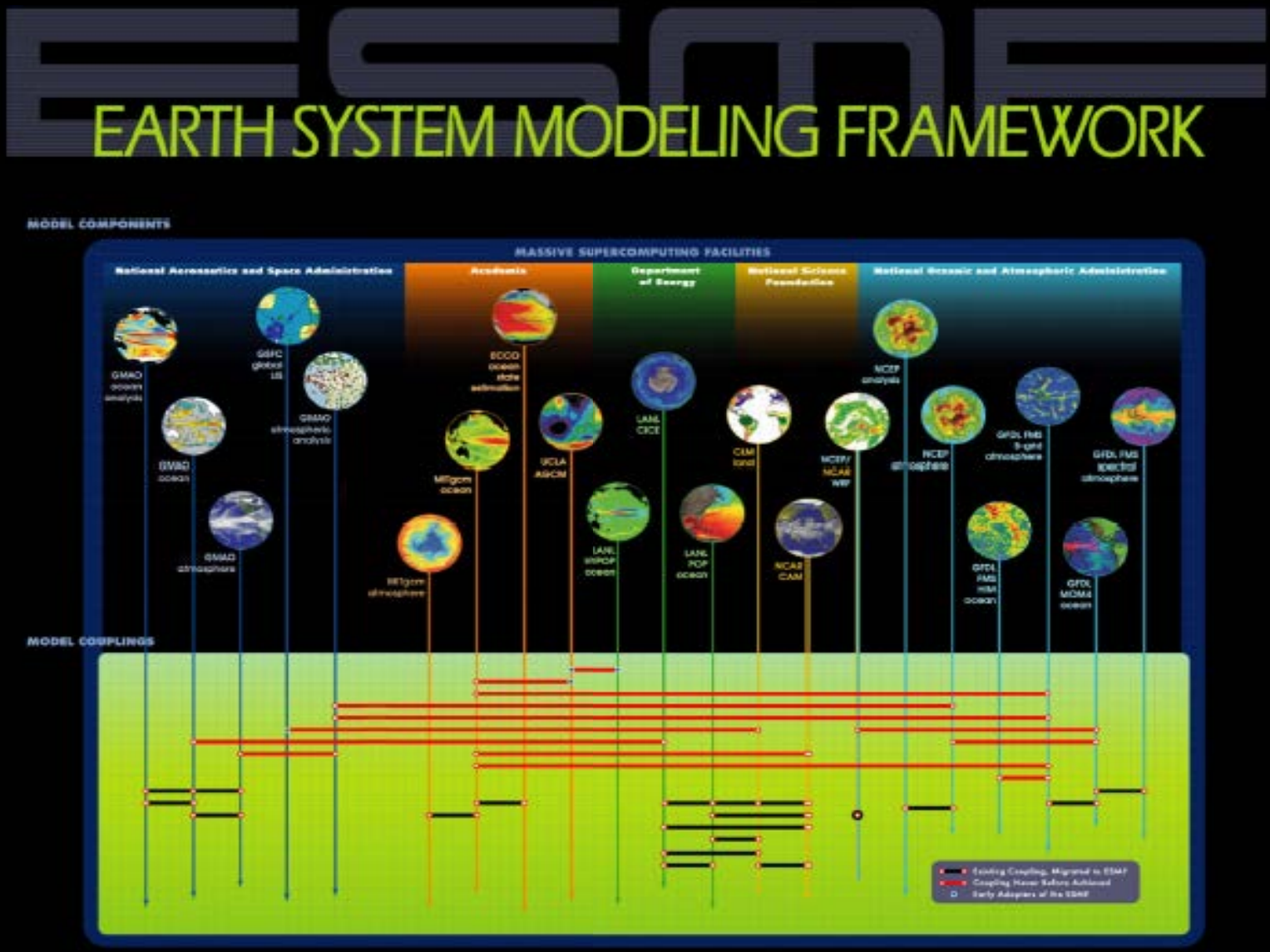
Earth System Science



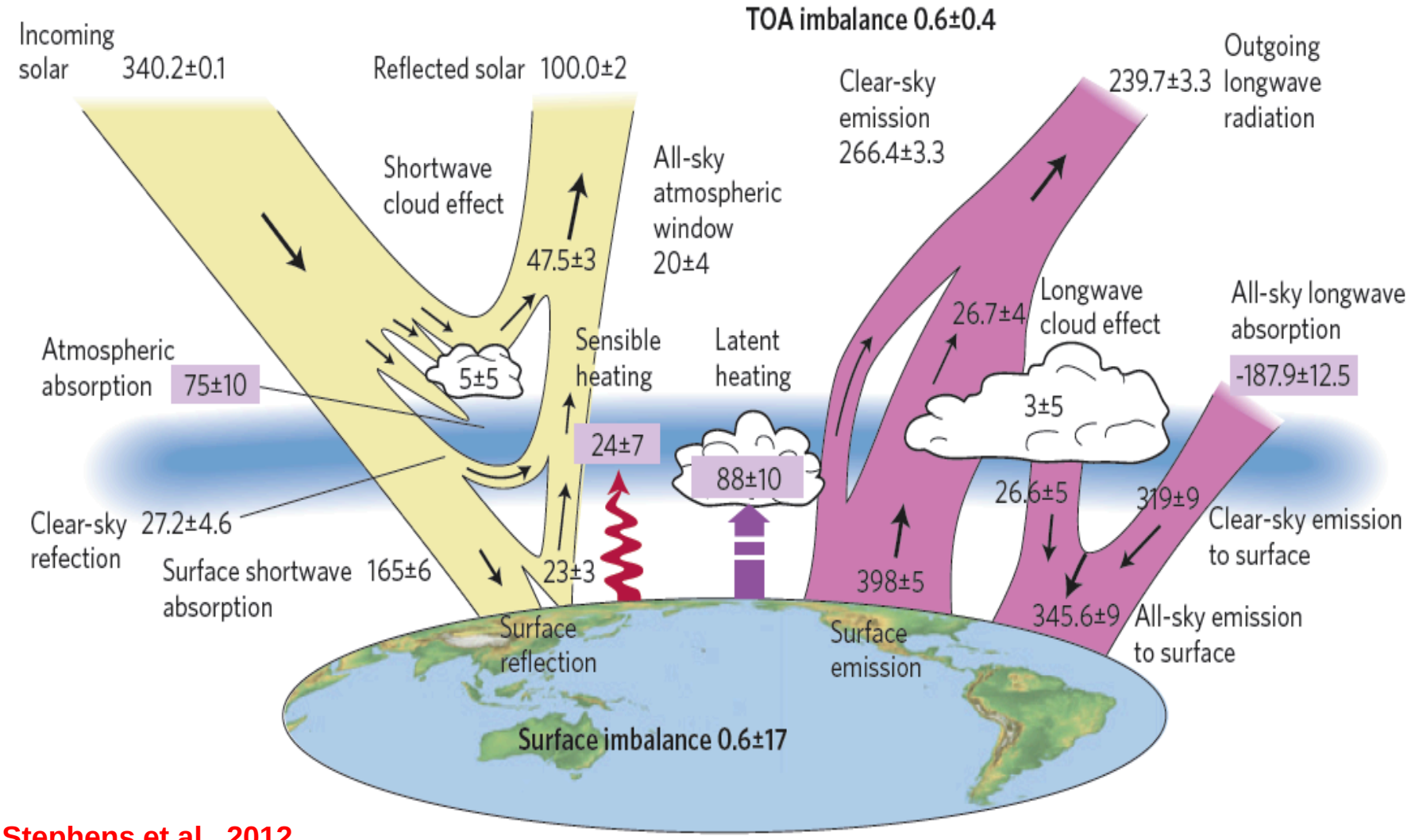
Data Management & Access



Earth System Models



Example: Earth's Global Energy Budget



Stephens et al., 2012

Earth Energy Budget: Observations & Models

Global Multi-Year Averages

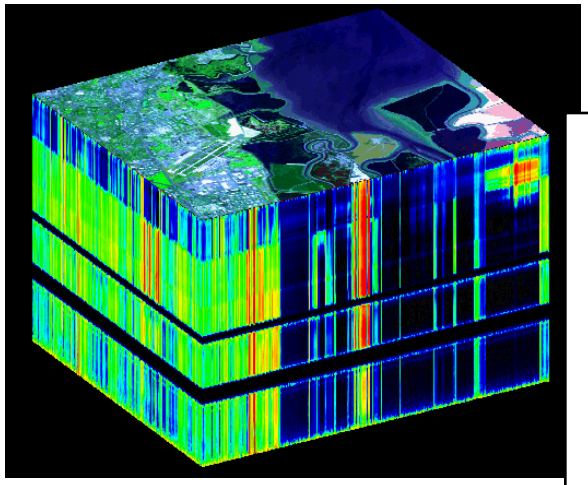
Parameter	Ohmura & Gilgen (1993) *GEBA Surf. Obs.*		Trenberth et al. (2009) CERES and Models		Zhang & Rossow (2004) *21-Year Mean (1984-2004)*		NASA/GEWEX SRB Release 3.0/2.5* (NASA LaRC) *24-Year Mean (July 1983 - June 2007)*			
							SW, LW		SW, LW QC	
	Flux	% F_0	Flux	% F_0	Flux	% F_0	Flux	% F_0	Flux	% F_0
SW Down	**169.0**	**49.4**	**184**	**53.9**	**189.2**	**55.4**	**188.7**	**55.2**	**182.2**	**53.3**
SW Net	**142.0**	**41.6**	**161**	**47.2**	**165.9**	**48.5**	**166.6**	**48.7**	**159.7**	**46.7**
LW Down	**345**	**100.9**	**333**	**97.6**	**343.8**	**100.6**	**343.2**	**100.4**	**347.5**	**101.7**
LW Net	**-40.0**	**-11.7**	**-63**	**-18.5**	**-49.6**	**-14.5**	**-52.8**	**-15.4**	**-51.2**	**-15.0**
Total Net	**102.0**	**29.8**	**98**	**28.7**	**116.3**	**34.0**	**113.8**	**33.3**	**108.5**	**31.7**
SW CRF	--	--	--	--	**-53.0**	**-15.5**	**-58.8**	**-17.2**	**-60.9**	**-17.8**
LW CRF	--	--	**46**	**13.5**	**29.5**	**8.6**	**35.3**	**10.3**	**34.3**	**10.0**
Total CRF	--	--	--	--	**-23.5**	**-6.9**	**-23.5**	**-6.9**	**-26.6**	**-7.8**

S_0 = 1365 Wm^{-2} for Trenberth et al. and 1367 Wm^{-2} for all others

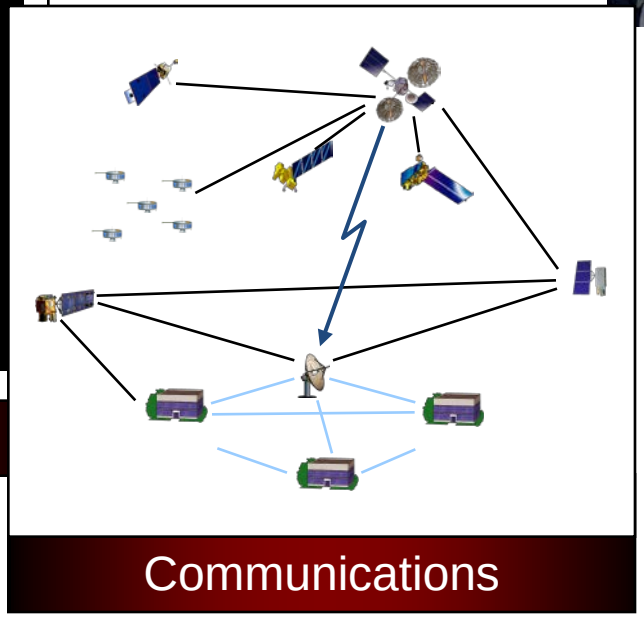
**GEWEX LW values are Rel.-2.5 and 23-year averages (Jul1983-Jun2006)*

Enabling Technologies

Earth Science Information Systems of the future will leverage three ongoing technology revolutions:



Geospatial



Communications

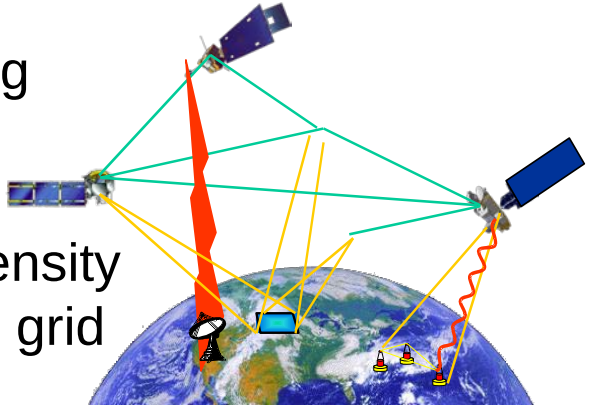
Computing

...To enable seamless, timely, and affordable delivery of Earth science data and information to users.

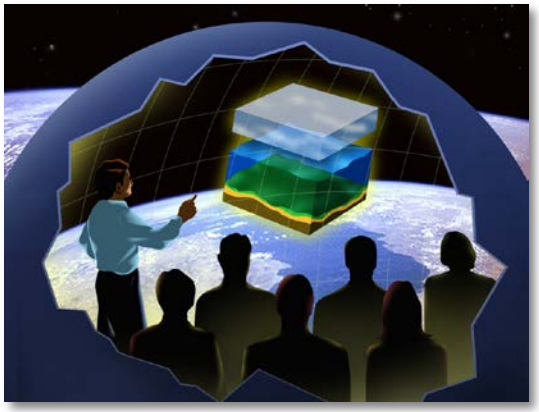
Enabling Technologies

- **Information Synthesis: Distributed, Reconfigurable, Autonomous**
- **Information Infrastructure: Standards, Formats, Protocols**
- **Access to Knowledge: On-orbit Processing, High Speed Networks**

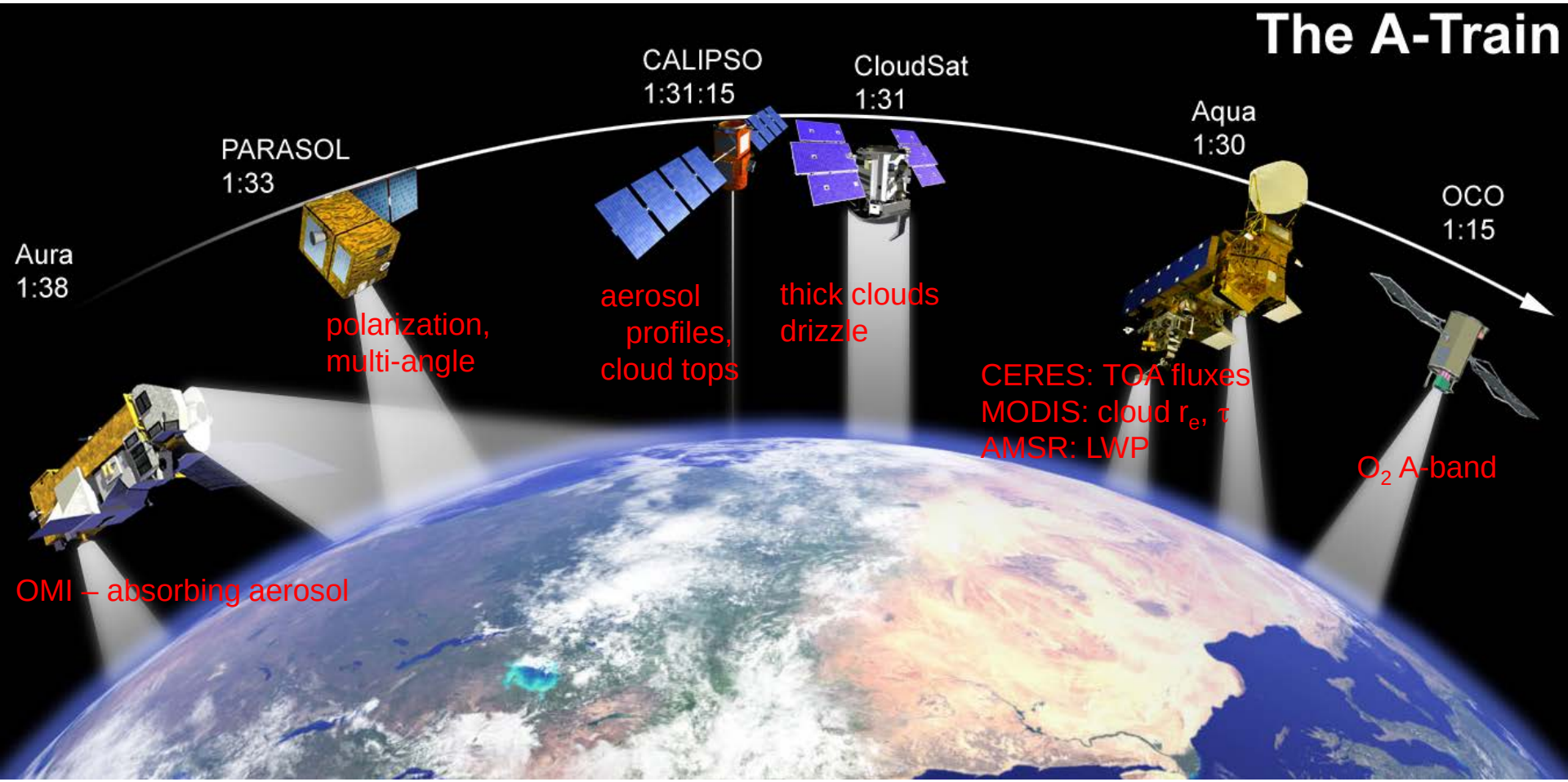
• Intelligent Distributed Systems using optical communication, on-board reprogrammable processors, autonomous network control, high density storage, automated data distribution, grid computing and virtual organizations



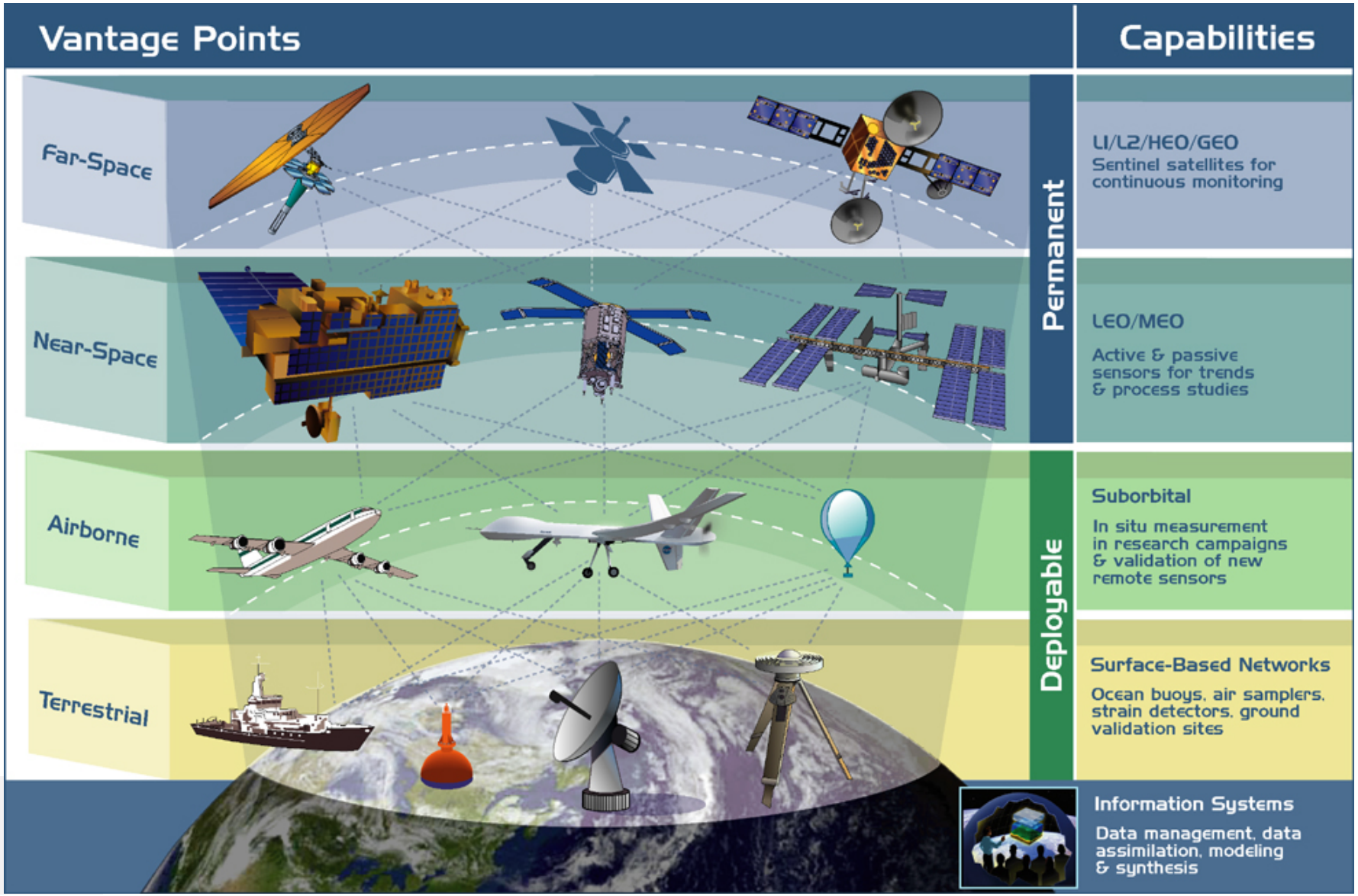
• Information Knowledge Capture through 3-D Visualization, holographic memory, seamlessly linked models, science tools, multi-panel visualization walls



Earth Observation System A-Train: Aerosol/Clouds/Radiation



Global Earth Observing System



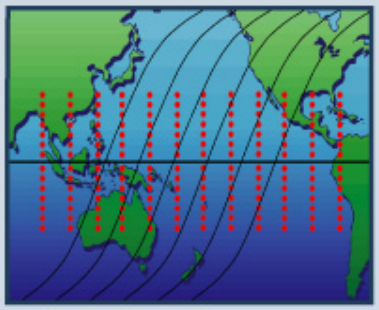
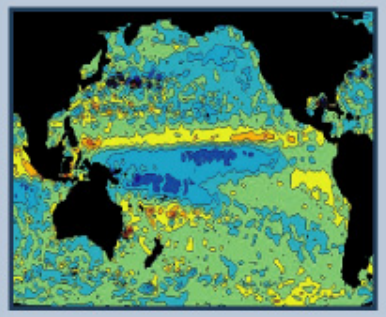
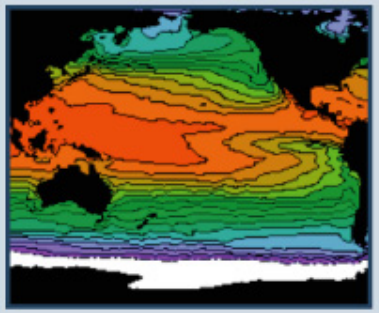
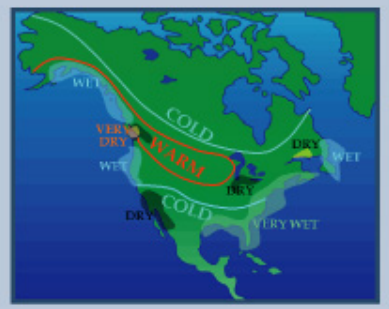
Turning Observations into Knowledge Products

Downlink Speed

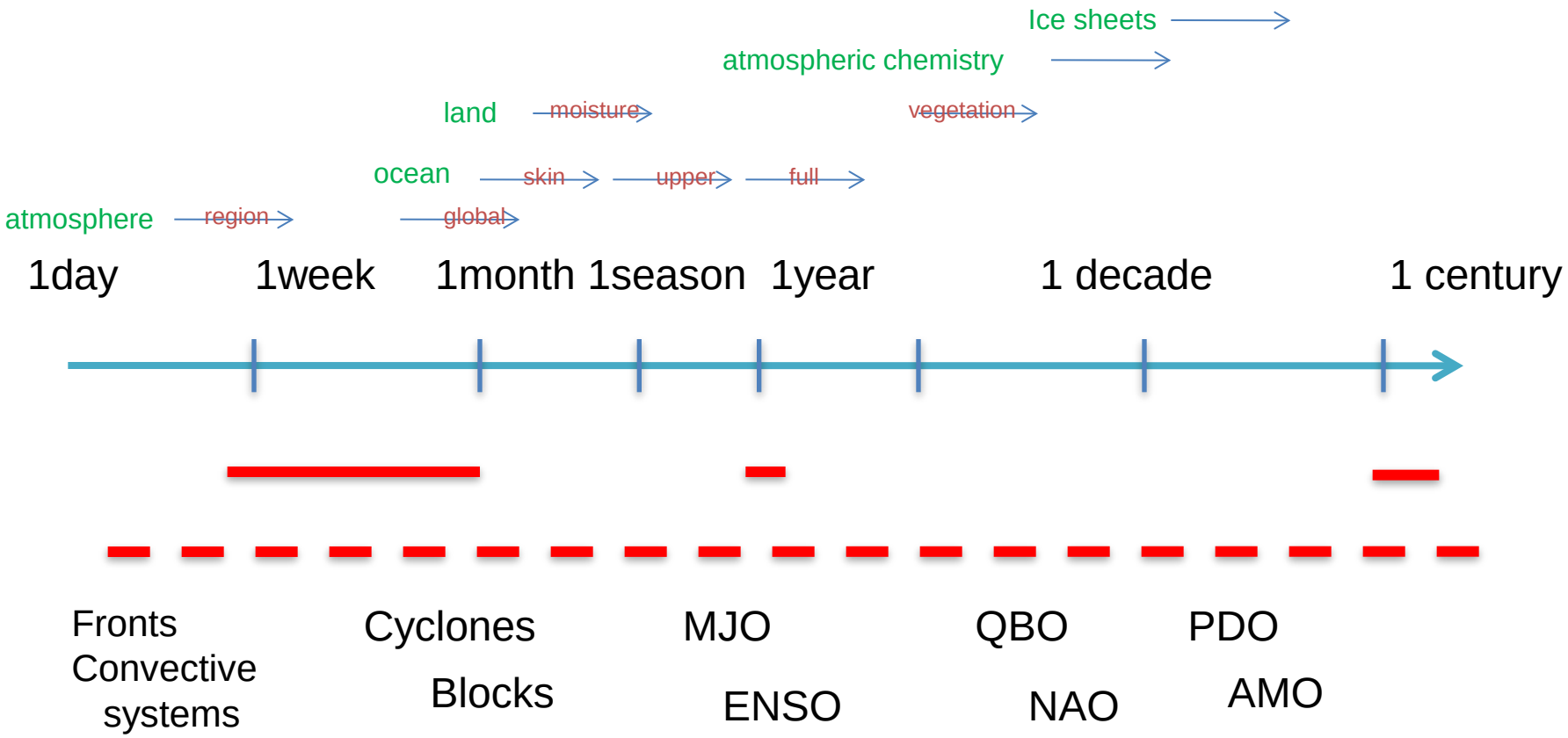
Petabytes 10^{15}	Terabytes 10^{12}	Gigabytes 10^{9}	Megabytes 10^{6}
Multi-platform, multiparameter, high spatial and temporal resolution, remote & in-situ sensing	Calibration, Transformation To Characterized Geo-physical Parameters	Interaction Between Modeling/Forecasting and Observation Systems	Interactive Dissemination and Predictions
Advanced Sensors	**Data Processing & Analysis**	**Information Synthesis**	**Access to Knowledge**





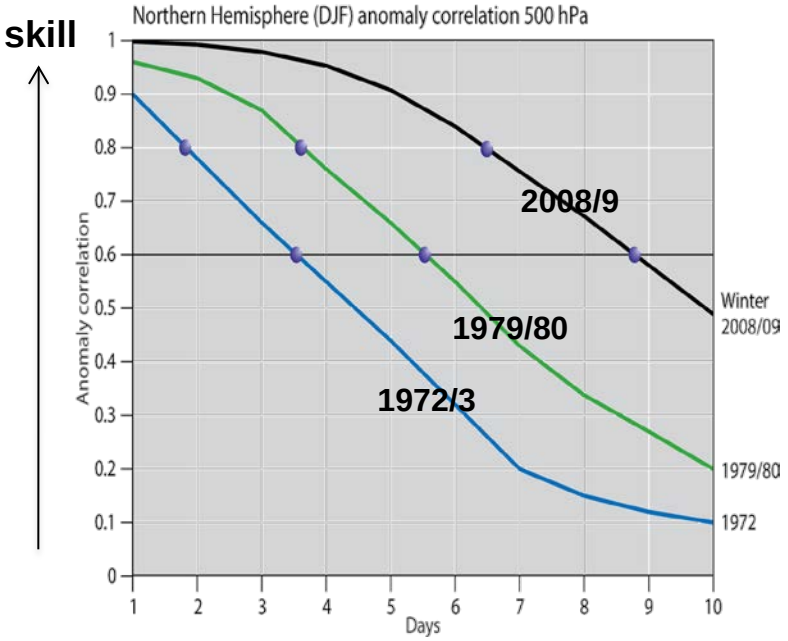
The Seamless Prediction of Earth System



Improved Weather Forecast Skill

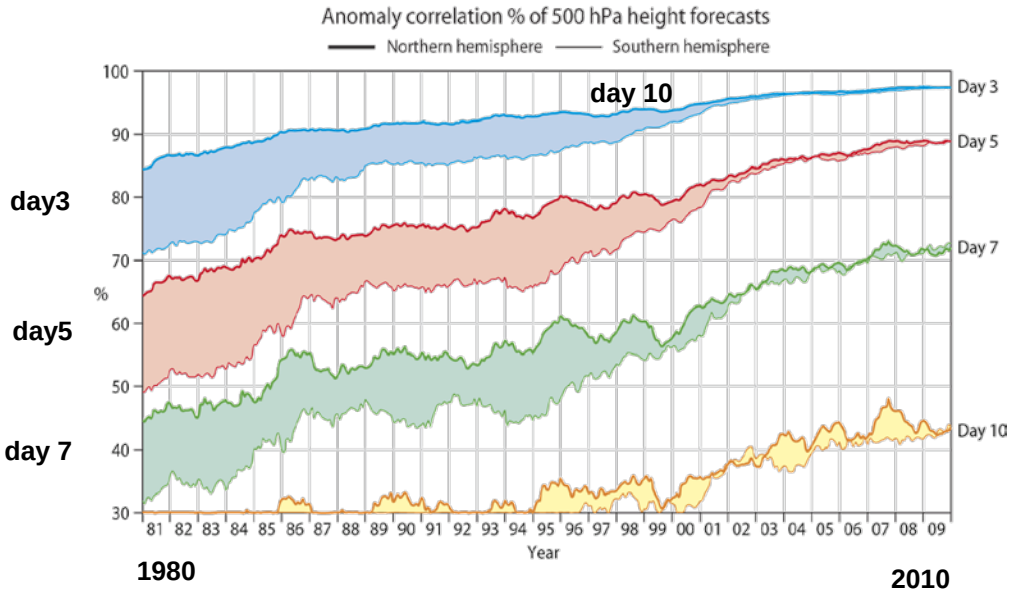
Week 1: Forecast skill

NH winter 500Z anomaly correlation



Day of forecast

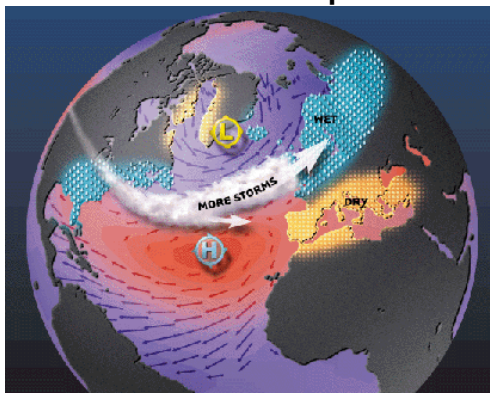
NH & SH 500Z ACC through the years



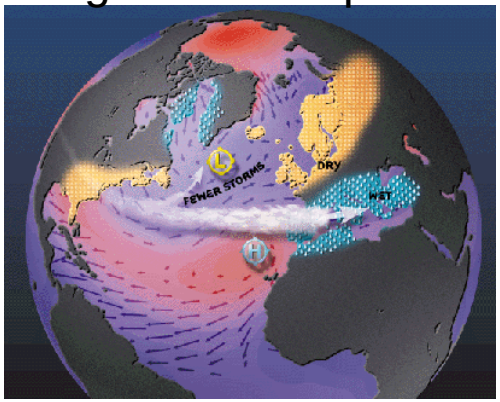
Year

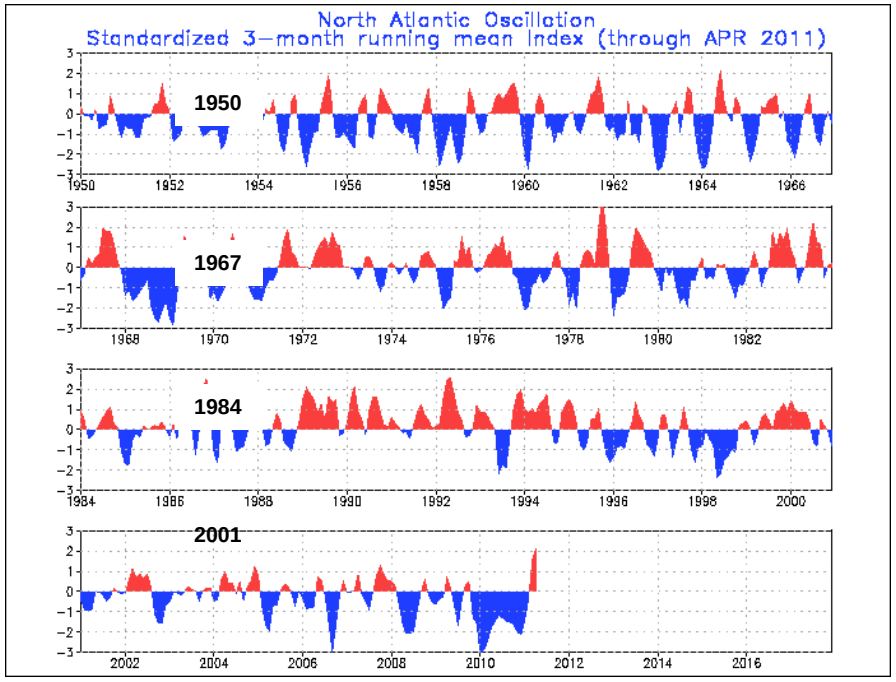
Seamless Prediction: Months to Seasons

Positive NAO phase

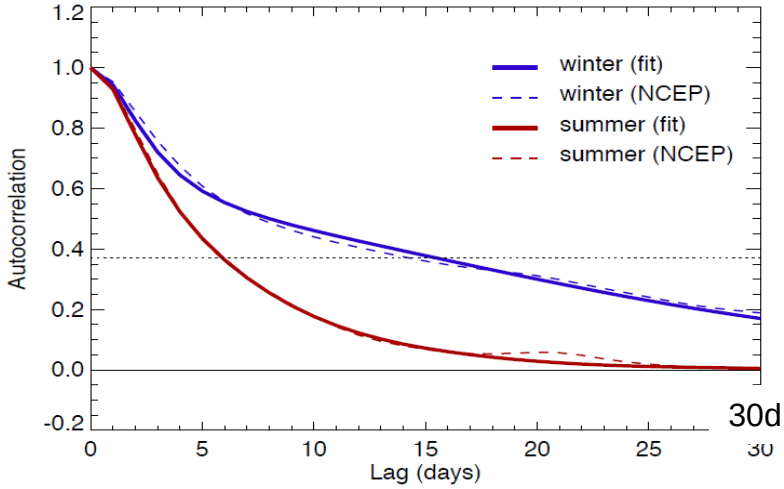


Negative NAO phase





Autocorrelation



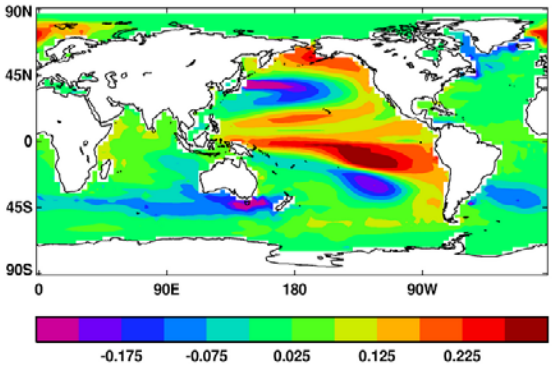
Lag

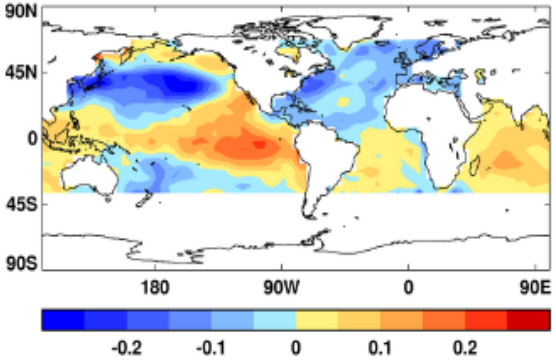
3-month running mean of NAO index 1950-date

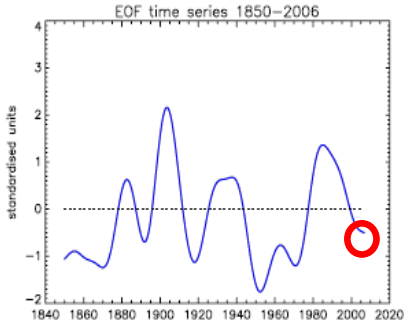
Seamless Prediction: Natural Decadal Variability

Model **Observation**

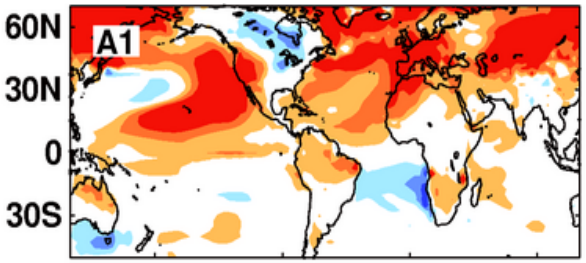
Pacific Decadal Oscillation

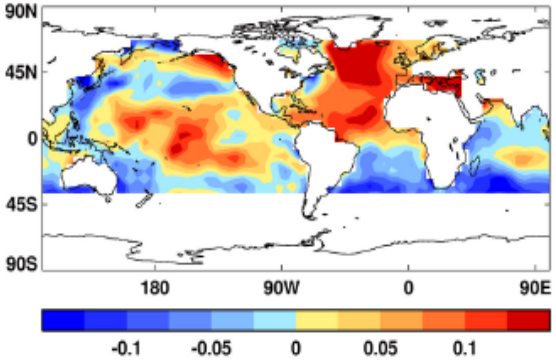


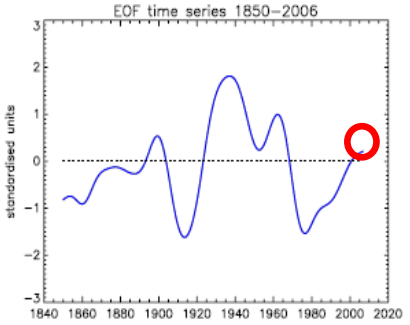




Atlantic Multidecadal Oscillation



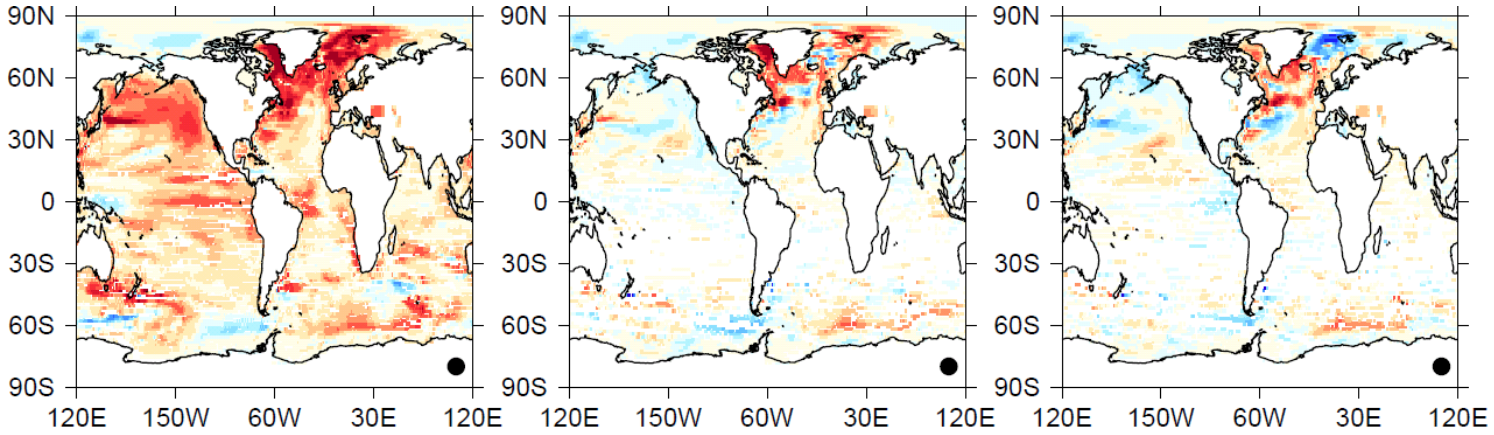




Knight et al 2005, Parker et al 2007

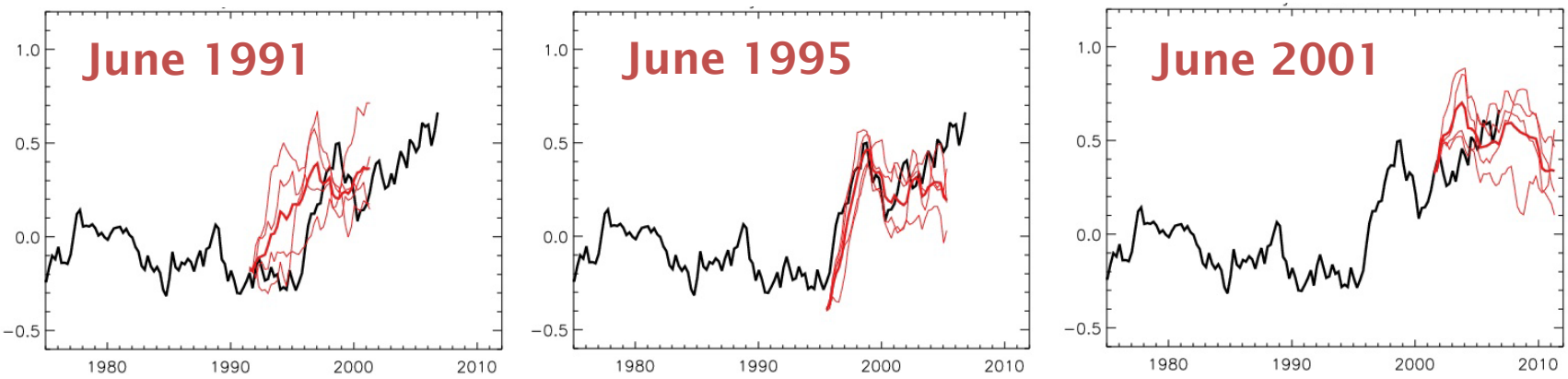
Seamless Prediction: Skill on 1-10 Year Time-scale

Heat in top 100m ocean: Improvement in Skill from intialisation



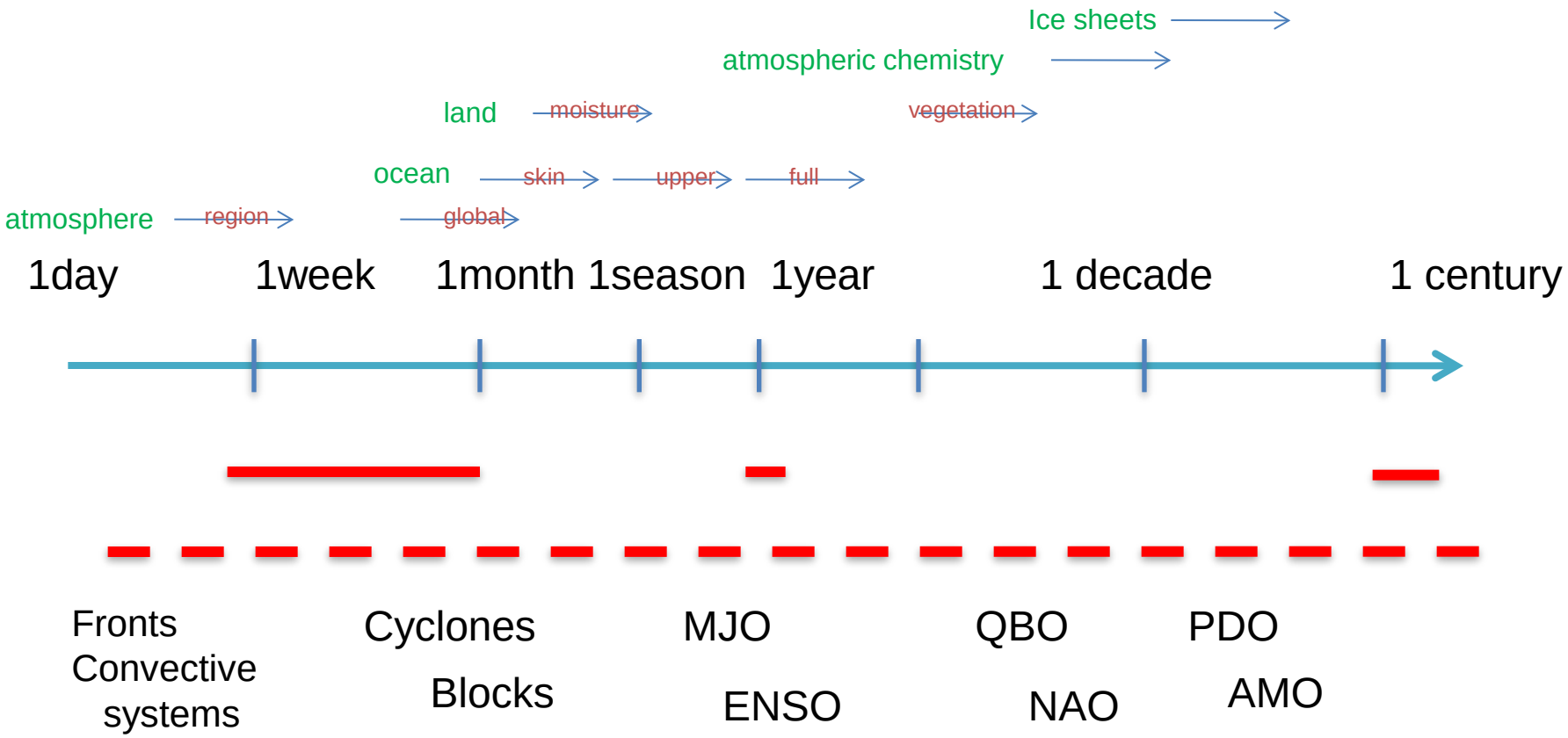
1-2y 3-4y 5-6y

Hindcast predictions of 500m heat content in Atlantic subpolar gyre

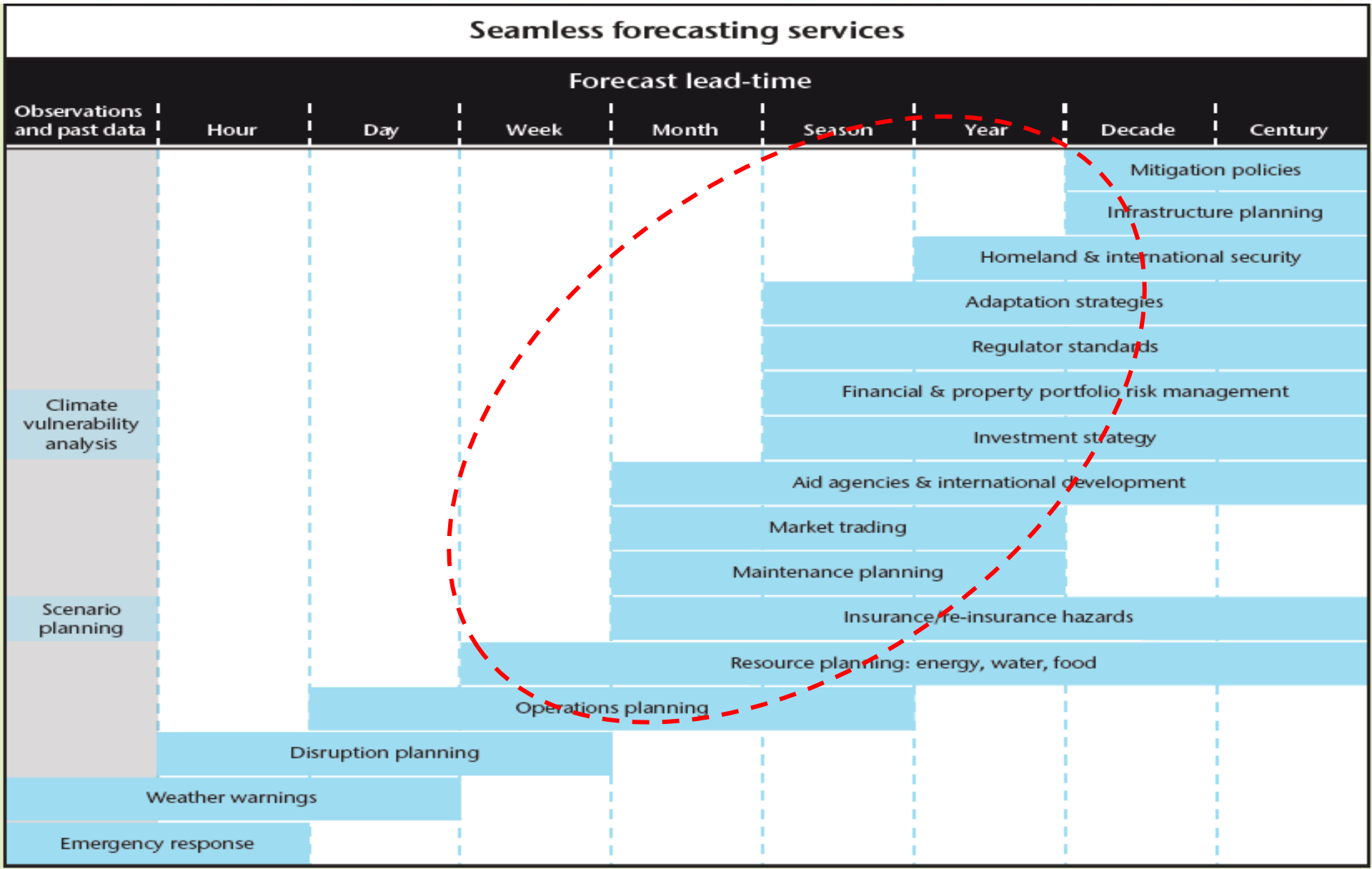


UKMET WCRP

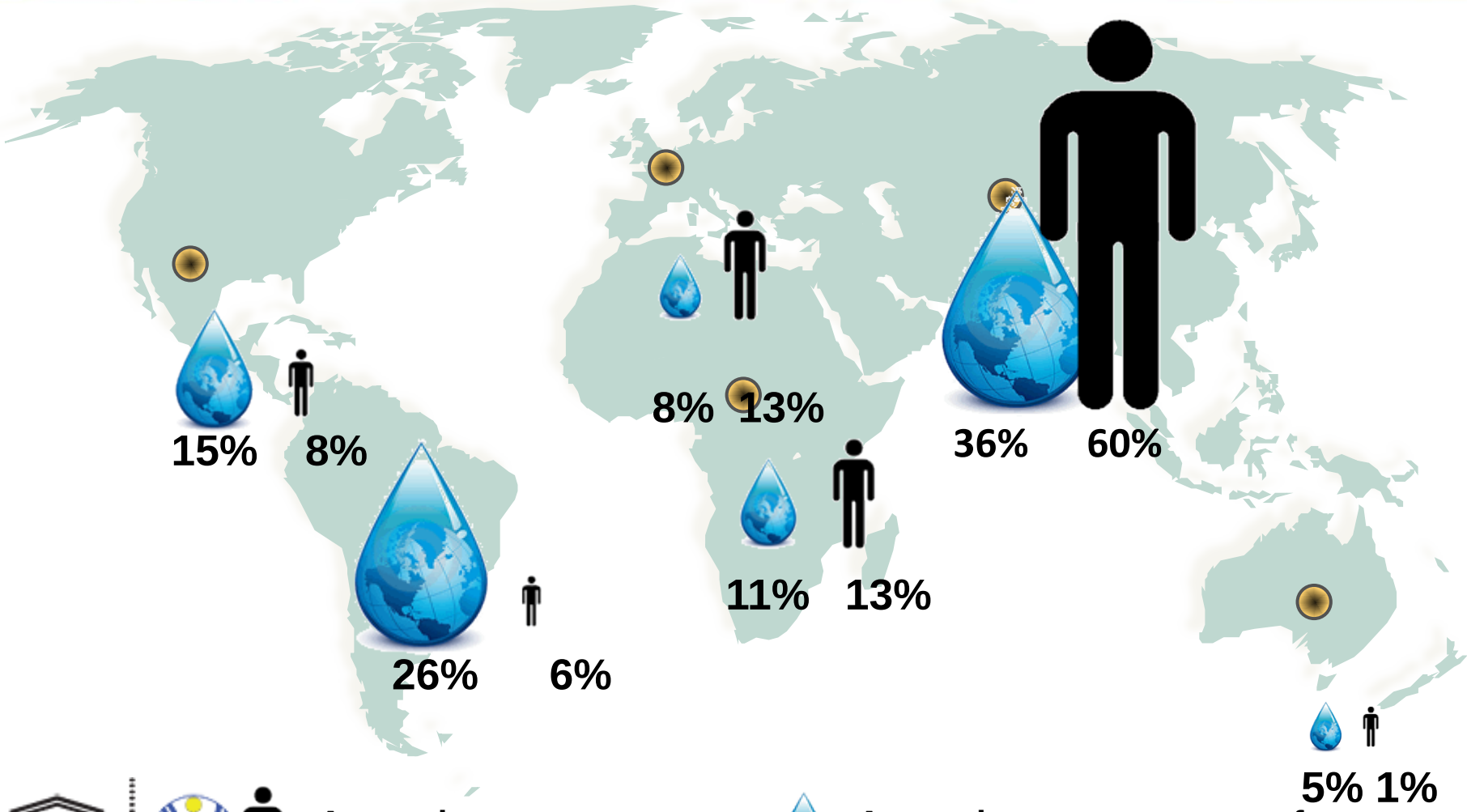
The Seamless Prediction of Earth System



Seamless forecasting services



Water Quantity, Quality and Distribution; water is not available everywhere!



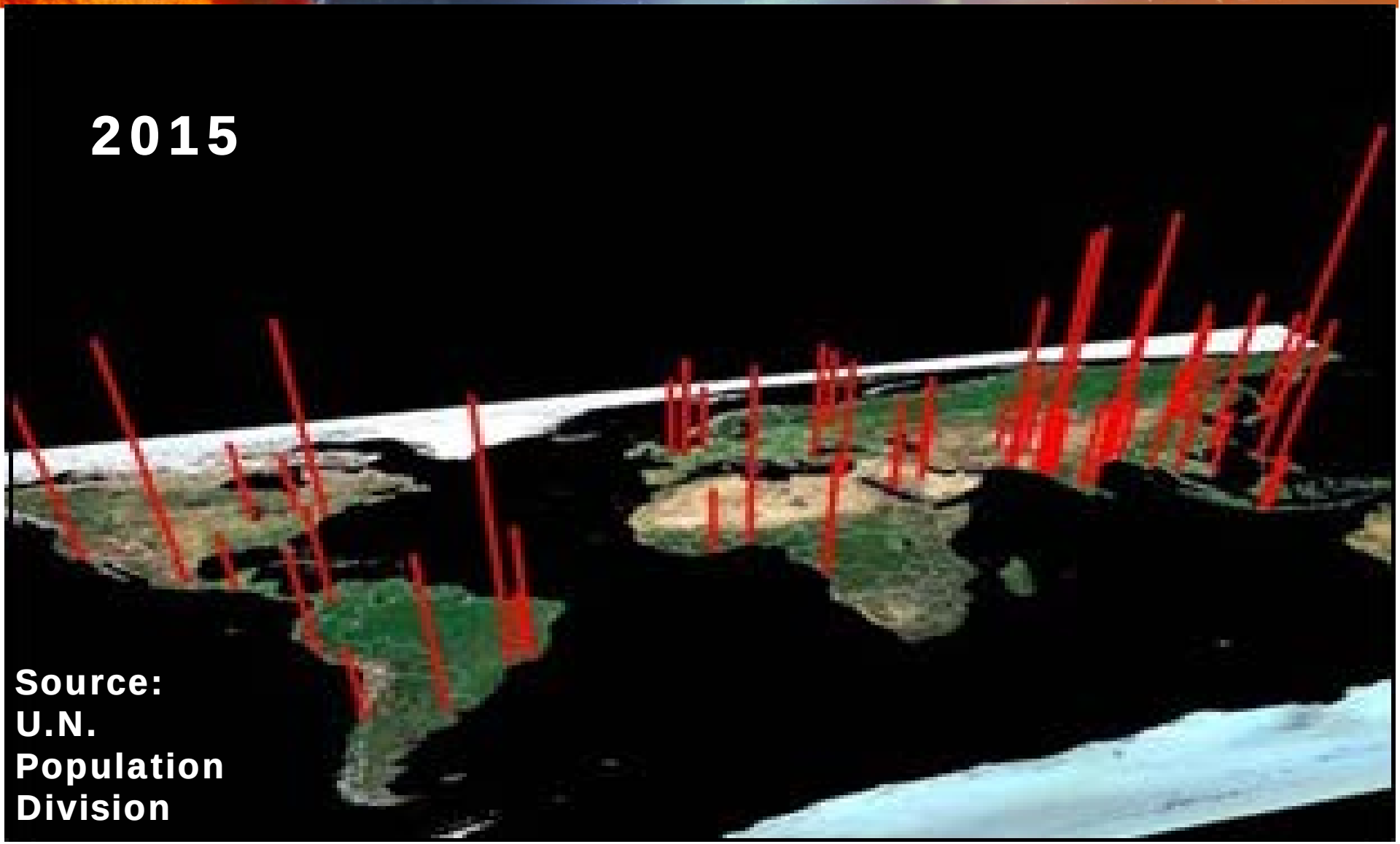
Approximate percentage of global population

Approximate percentage of global water supply

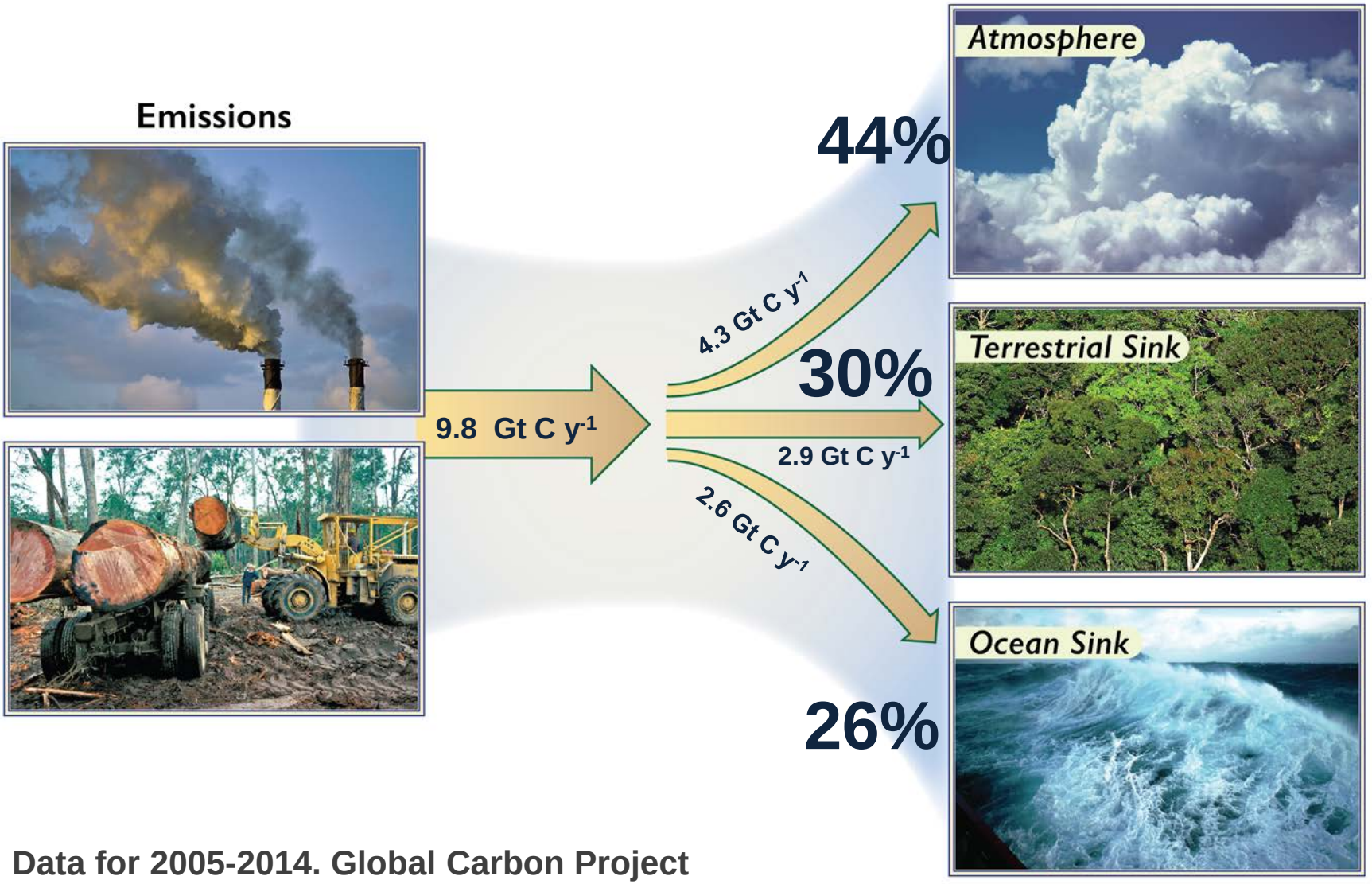
Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura

Programa Hidrológico Internacional

World Cities at Risk



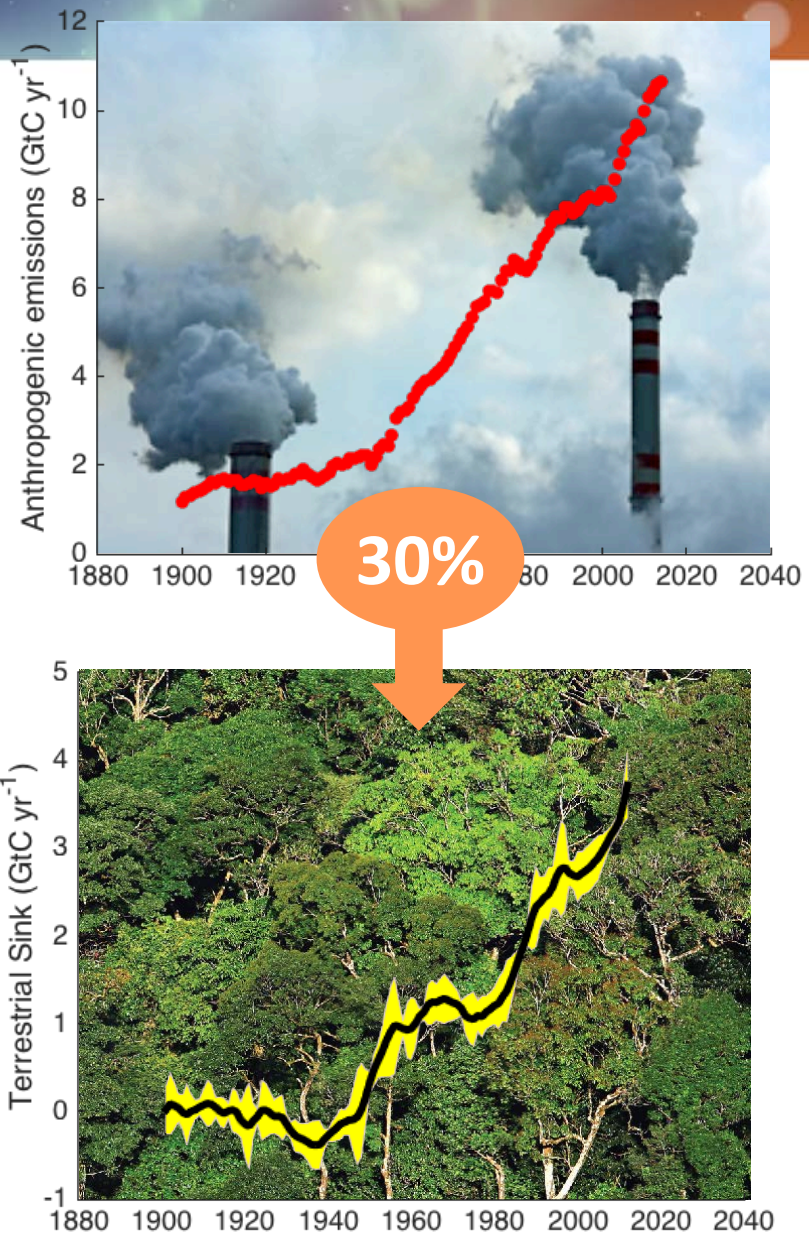
The Global "Sink" for CO_2 Emissions



Data for 2005-2014. Global Carbon Project

Source: Enhancing the Global Carbon Sink. Presented at the Big Ideas Summit April 2

The land component of carbon sink has doubled in the last decades!

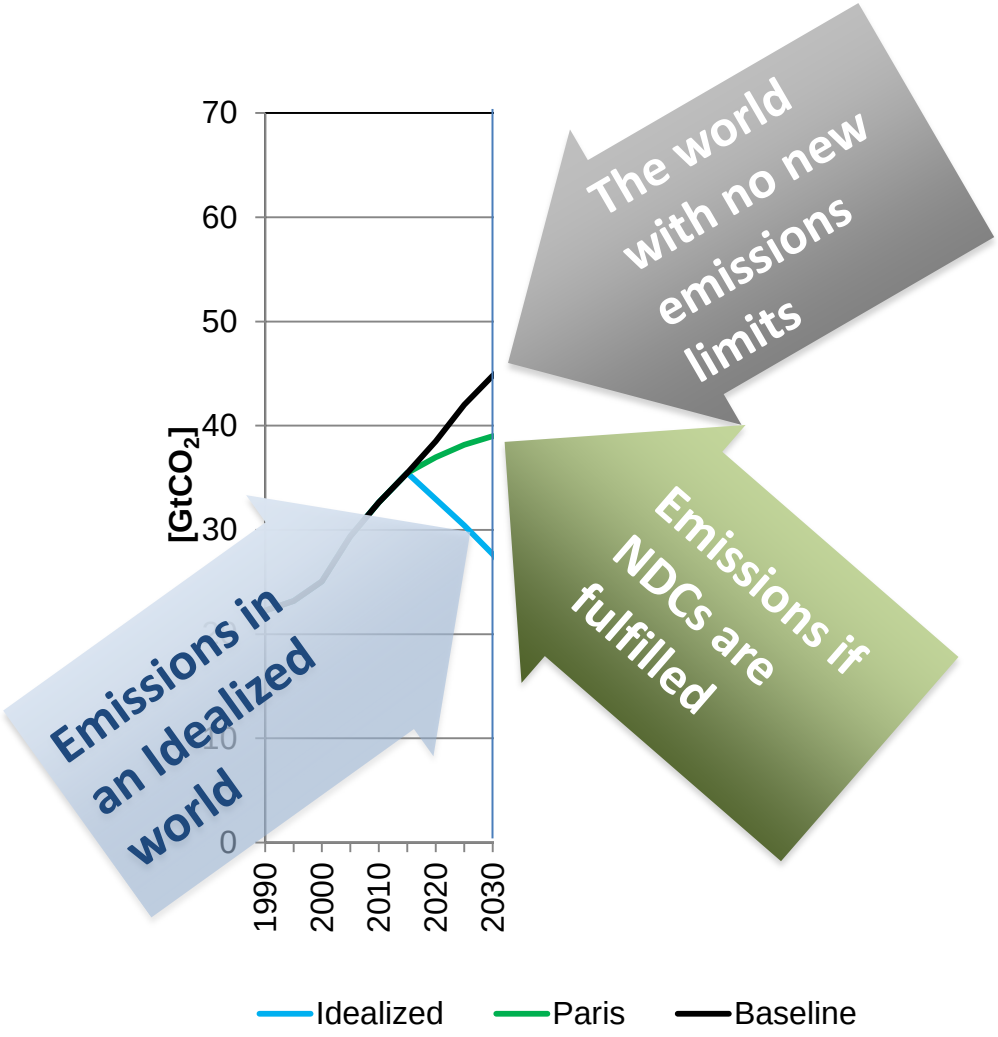


Data from the Global Carbon Project 2015

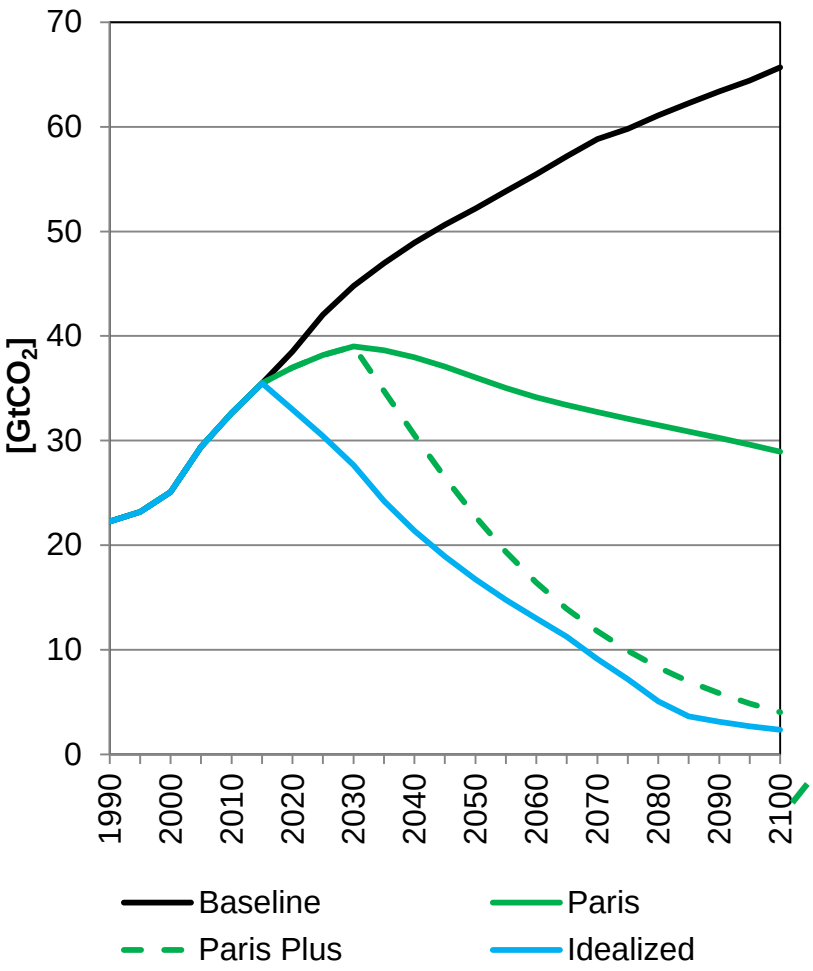
Source: Enhancing the Global Carbon Sink. Presented at the Big Ideas Summit April 22 2016

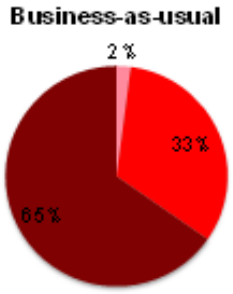
Challenge & Opportunity: Paris Agreement

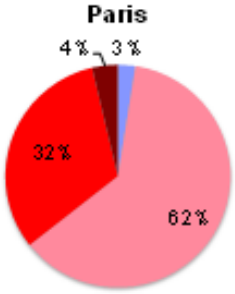
- **Baseline** emissions ~600GtCO$_2$
- Nationally Determined Contributions (**Paris**) reduce emissions ~41GtCO$_2$ (~7%)
- In an **Idealized** case focused on limiting global mean surface temperature change to 2ºC, emissions should decline ~87GtCO$_2$ by 2030

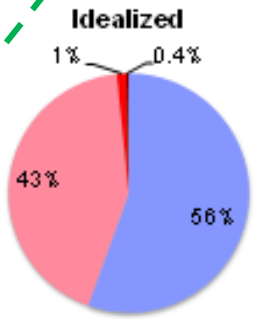


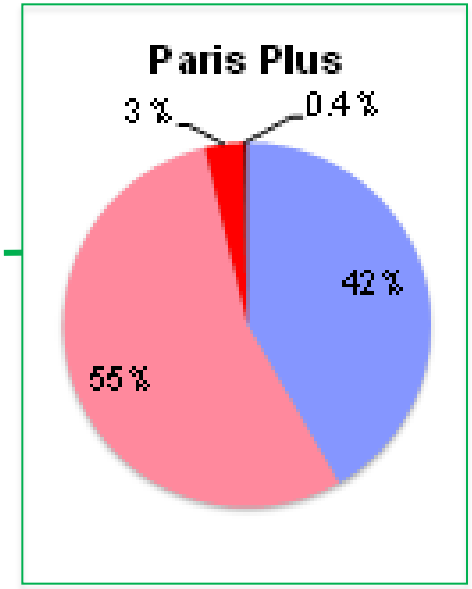
Challenge & Opportunity: Paris Agreement





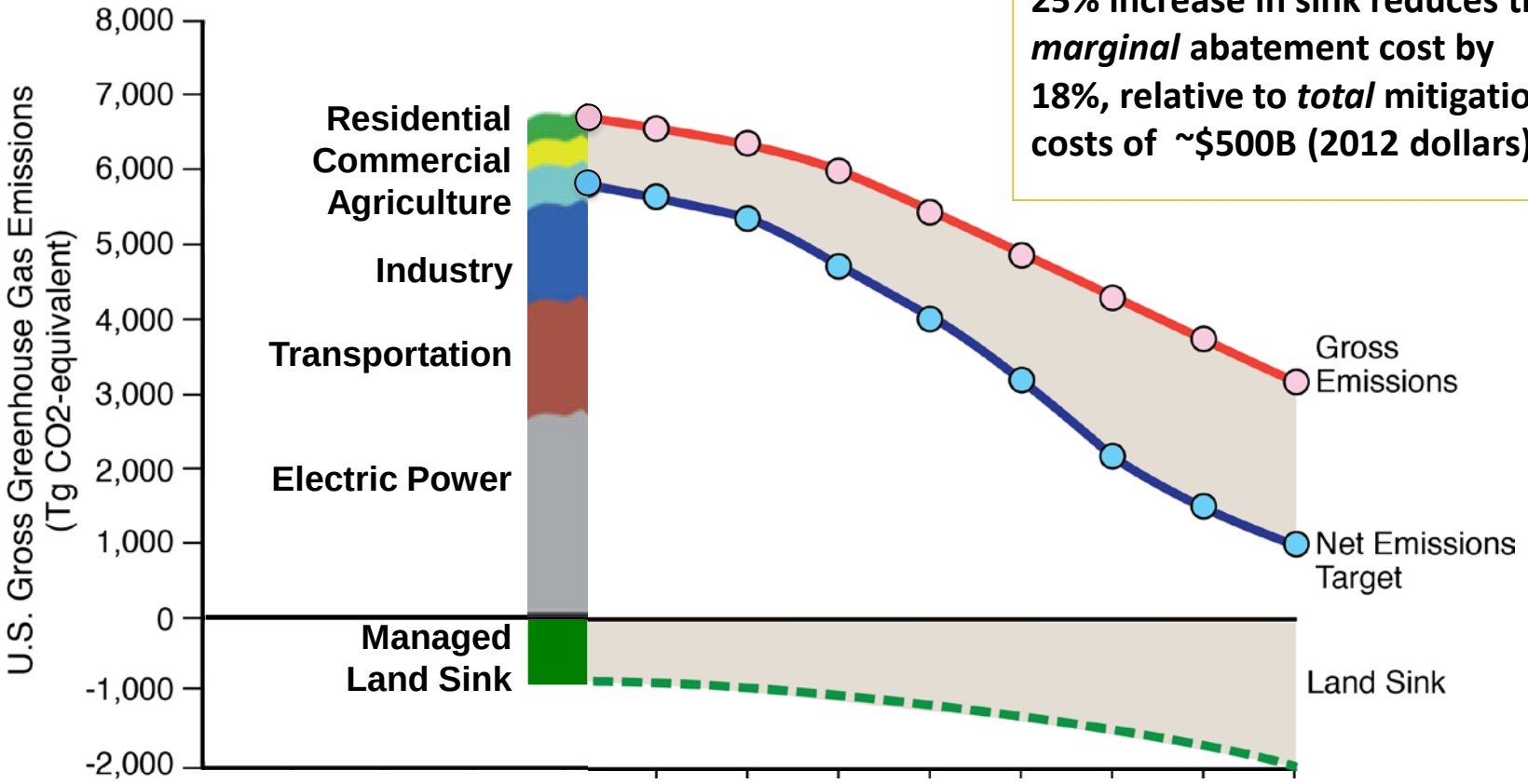






- Leaves open the door to a greater likelihood of achieving ΔGMST<2ºC.

Example: The carbon land sink is critical to U.S. carbon management options!



Williams et al., Pathways for Deep Decarbonization for the U.S., 2014

Historic land sink for AFOLU (Agriculture, Forestry, Other Land Use, Wetlands): US EPA Inventory of U.S. GHG Emissions and Sinks: 1990 – 2011

Slide: Enhancing the Global Carbon Sink. Presented at the Big Ideas Summit April 22 2016

Summary

- **Scientific exploration and discovery**: Observing, understanding & predicting the modes of variability of Earth system to enable predictability across time and space scales (i.e. seamless prediction).
- **Maturity and readiness of enabling technologies**: Evolving strategically the current Earth observing and information technologies, and required Earth system modeling capabilities.
- **Societal befits and impact**: Information resulting from seamless prediction of Earth system will enable a wide range of new applications and services to the nation, and the world.
- **Capacity development**: Education and training of next generation of scientists, engineers and technology experts who maintain US leadership in Earth science, engineering and technology.
- **Potential partnerships**: Forging the potential domestic and international partnerships to enable mission innovation, implementation and maximum use of resulting data.

Thank you.

Past Experience: Small Satellites

- According to internal NASA reports, for 786 small satellite proposals submitted to NASA over about 15 years, 253 (32%) judged not to have major risks for implementation with respect to technical, management and cost criteria.
- 130 proposals had one major weakness, 94 had two and 182 had five or more major weaknesses.
- A general increasing trend of increasing number of major weaknesses for the small missions during this period!

Even small missions could have high risk, cost and major delays!