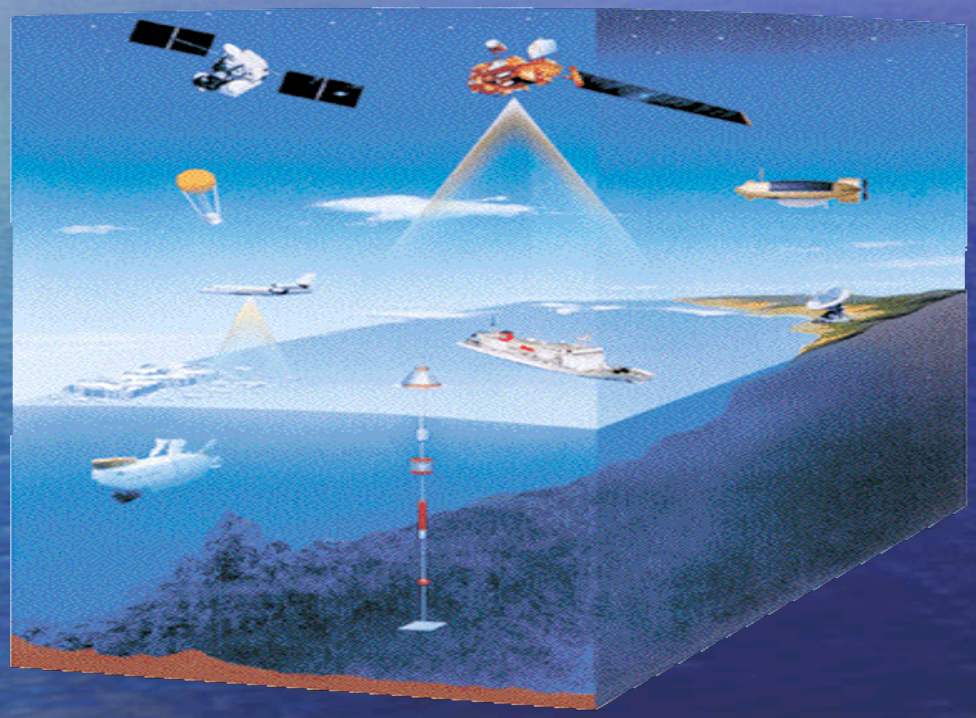
Suborbital Science Missions of the Future
Carbon Cycle Focus Area



NASA Suborbital Science Missions of the Future

Matt Fladeland, Research Scientist, NASA Ames Research Center

NASA's Vision

- To improve life here
- To extend life to there
- To find life beyond

NASA's Mission

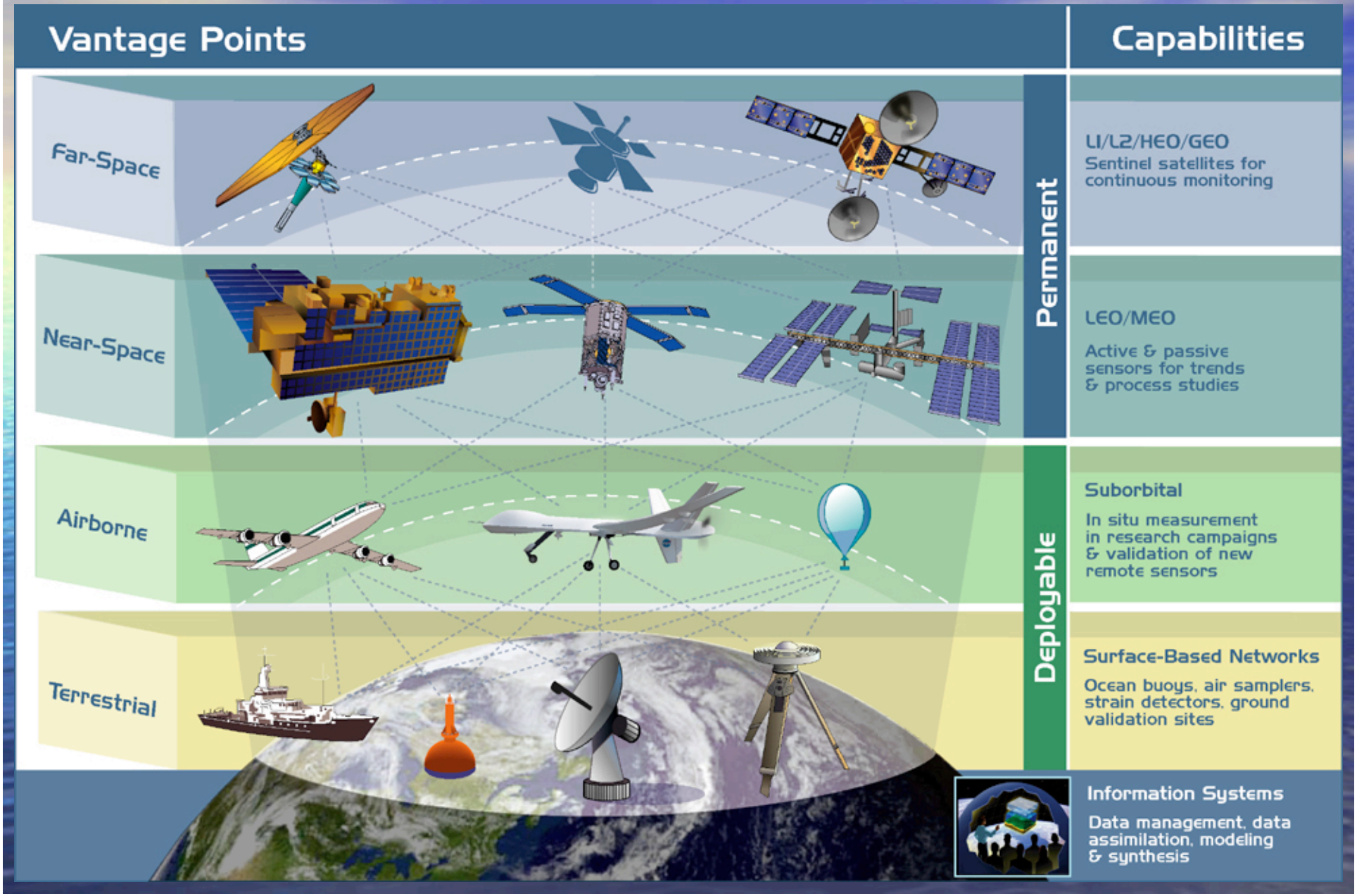
- To understand and protect our home planet
- To explore the Universe and search for life
- To inspire the next generation of explorers

...as only NASA can.

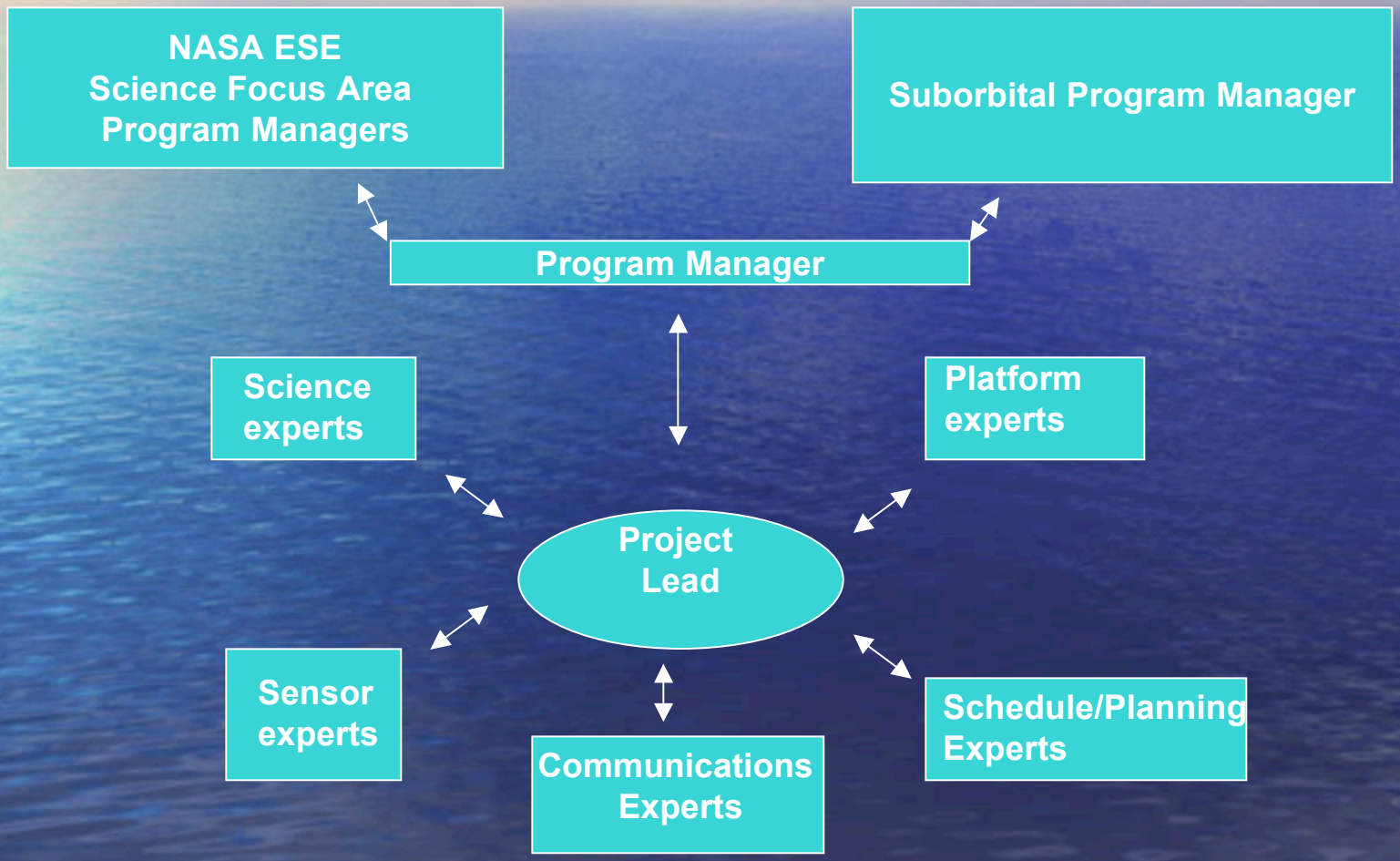
Why NASA?

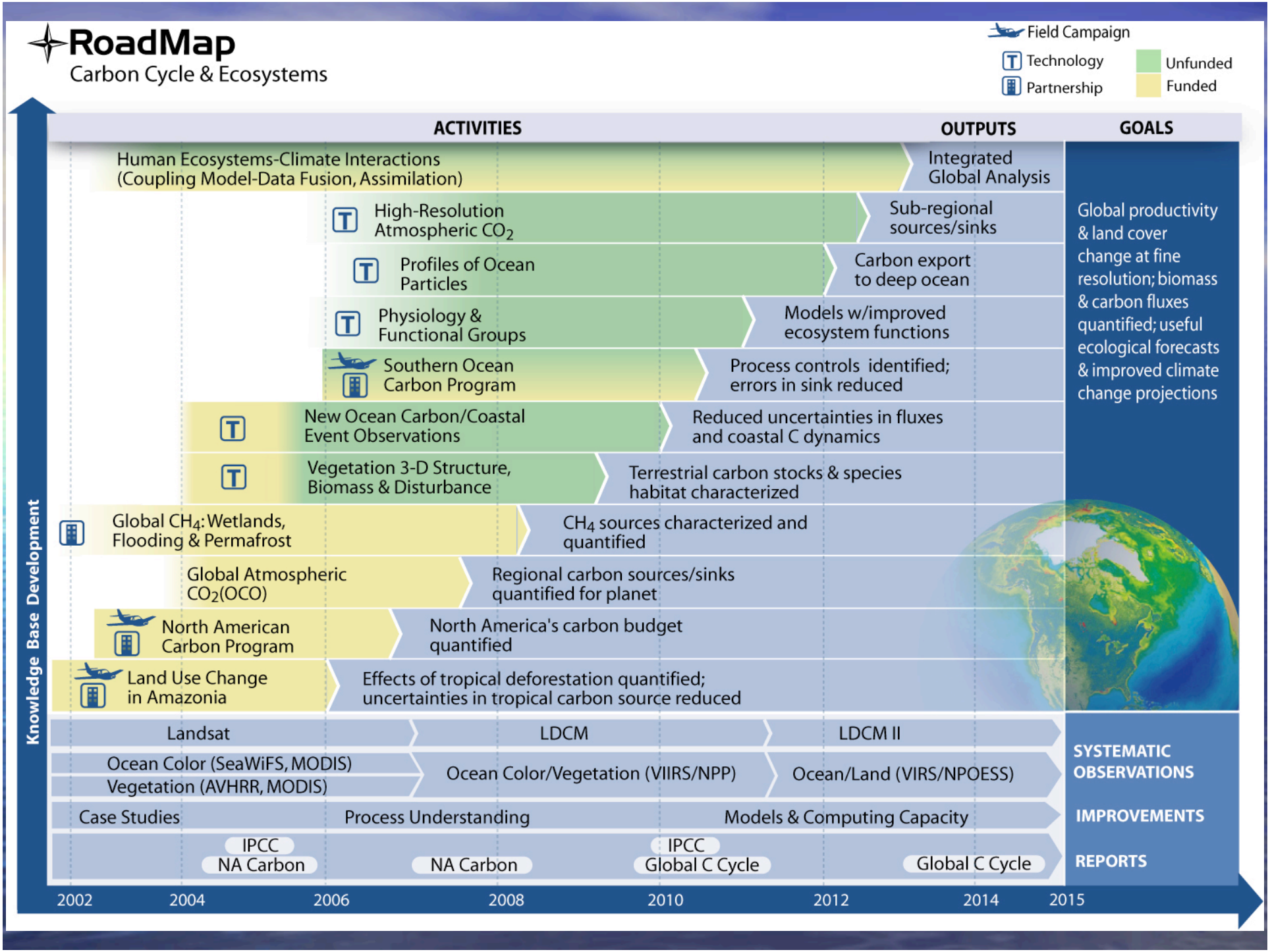
- Develop new technologies to understand how planets like earth evolve.
- Benchmark new technologies and systems for solar system exploration.
- Provide tools for future human explorers.

Components of a Future Global System for Earth Observation

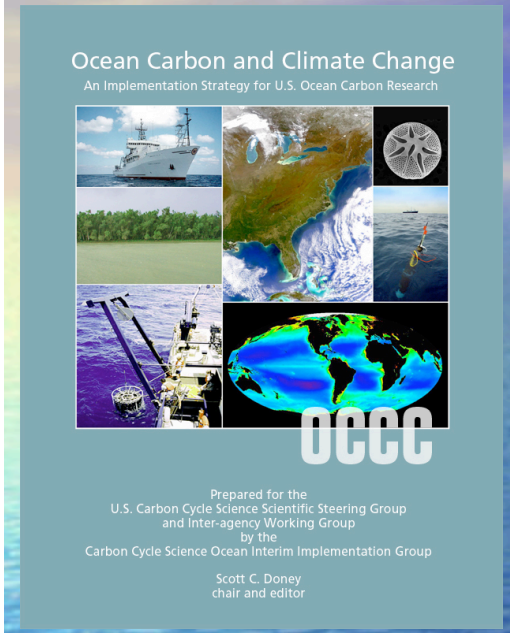


Project Architecture




RoadMap
Carbon Cycle & Ecosystems
Field Campaign
Technology
Partnership
Unfunded
Funded
ACTIVITIES
OUTPUTS
GOALS
Human Ecosystems-Climate Interactions (Coupling Model-Data Fusion, Assimilation)
Integrated Global Analysis
High-Resolution Atmospheric CO_2
Sub-regional sources/sinks
Profiles of Ocean Particles
Carbon export to deep ocean
Physiology & Functional Groups
Models w/improved ecosystem functions
Southern Ocean Carbon Program
Process controls identified; errors in sink reduced
New Ocean Carbon/Coastal Event Observations
Reduced uncertainties in fluxes and coastal C dynamics
Vegetation 3-D Structure, Biomass & Disturbance
Terrestrial carbon stocks & species habitat characterized
Global CH_4: Wetlands, Flooding & Permafrost
CH_4 sources characterized and quantified
Global Atmospheric CO_2(OCO)
Regional carbon sources/sinks quantified for planet
North American Carbon Program
North America's carbon budget quantified
Land Use Change in Amazonia
Effects of tropical deforestation quantified; uncertainties in tropical carbon source reduced
Global productivity & land cover change at fine resolution; biomass & carbon fluxes quantified; useful ecological forecasts & improved climate change projections
Landsat
LDCM
LDCM II
Ocean Color (SeaWiFS, MODIS)
Vegetation (AVHRR, MODIS)
Ocean Color/Vegetation (VIIRS/NPP)
Ocean/Land (VIRS/NPOESS)
SYSTEMATIC OBSERVATIONS
Case Studies
Process Understanding
Models & Computing Capacity
IMPROVEMENTS
IPCC
NA Carbon
NA Carbon
IPCC
Global C Cycle
Global C Cycle
REPORTS
Knowledge Base Development
2002
2004
2006
2008
2010
2012
2014
2015

Critical Science Questions:

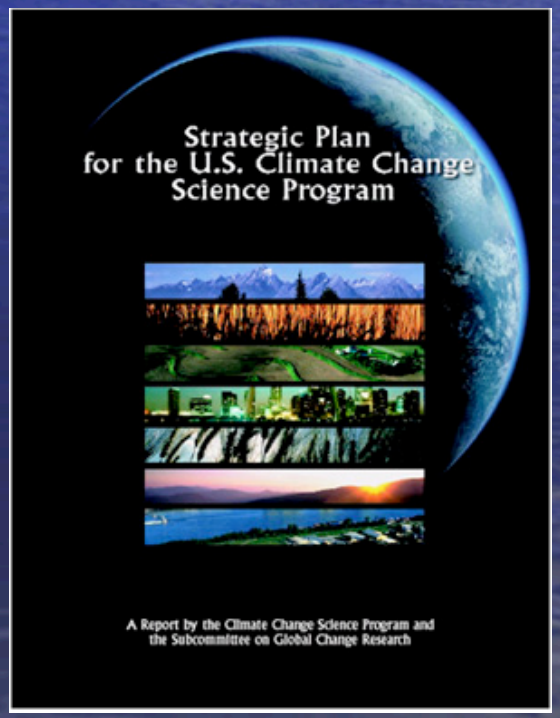


What are the global inventory, geographic distribution, and temporal evolution of anthropogenic CO2 in the oceans?

What are the magnitude, spatial pattern, and variability of air-sea CO2 flux?

What are the major physical, chemical, biological feedback mechanisms and climate sensitivities for ocean organic/inorganic carbon storage?

- What is the scientific basis for ocean carbon mitigation strategies?
- What are the magnitudes and distributions of ocean carbon sources and sinks on seasonal to centennial time scales, and
- What are the processes controlling their dynamics?



What is the role of Southern Ocean in the Global Carbon Cycle

- Does the Southern Ocean act as a net source or sink for atmospheric CO2?
  - net CO2 flux into the ocean of roughly 2.1 Pg C/year
- What are the limiting factors for primary productivity,
- How does biological variability affect the upper ocean's heat budget?

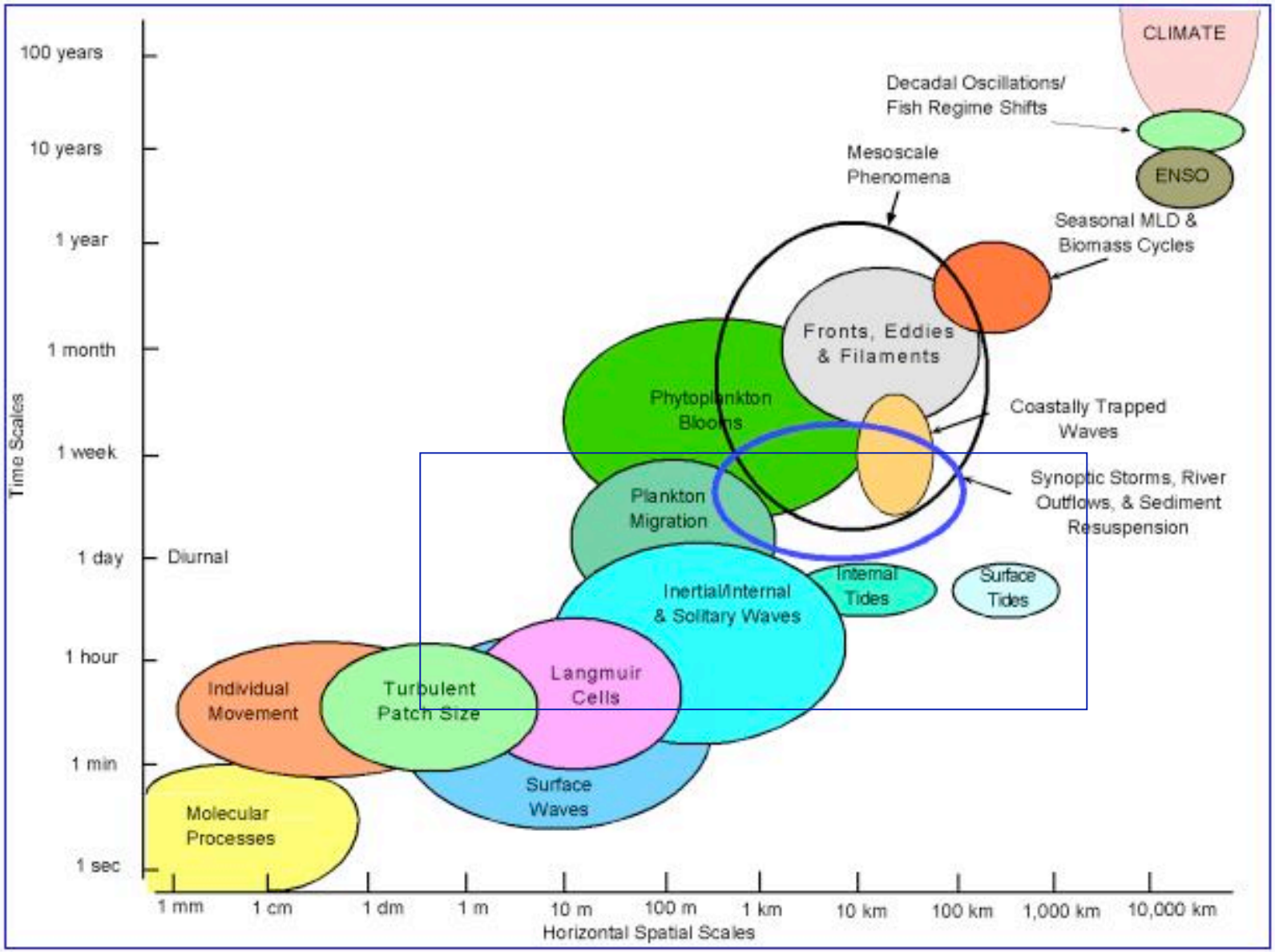
Remote Sensing of oceanic carbon cycle

Variable	Sensor
Sea-surface temperature (SST)	AVHRR, MODIS, TMI, ATSR
Sea-surface salinity	Aquarius (proposed)
Sea-surface height (SSH)	TOPEX/POSEIDON, ERS2
Wind speed and direction	QuickScat, ERS2, SSM/I (speed only)
Chlorophyll concentration	SeaWiFS, MODIS
Fluorescence	MODIS
Aerosols	AVHRR, TOMS, SeaWiFS, MODIS, MISR, ATSR

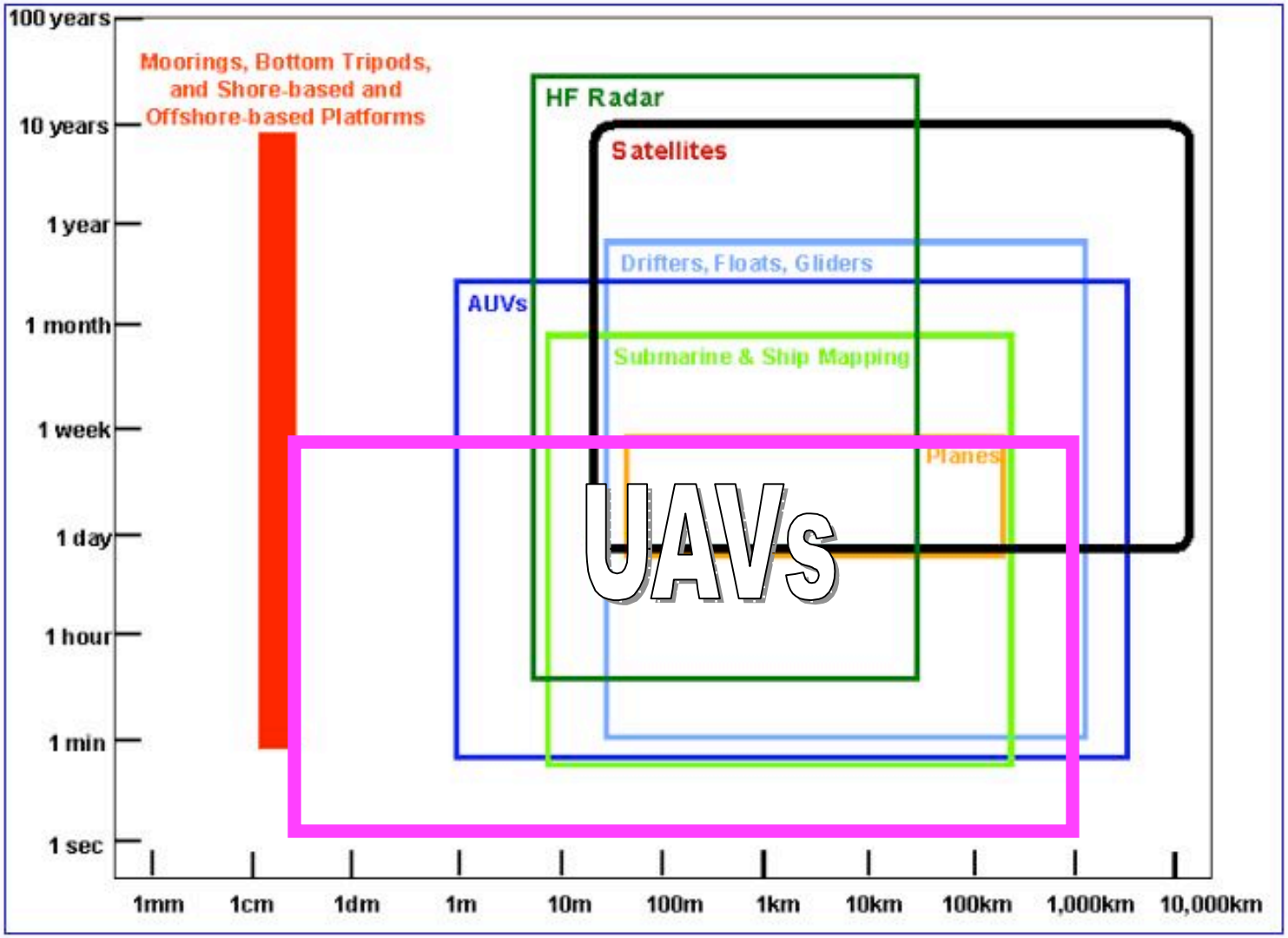
Modified from Yoder et al 2001

GASEX *Southern Ocean Air-Sea CO2 Flux Experiment*

Research Project Component Process	Method Components
1 Biological Measurements	Primary production; New production
2 Surface pCO2 Variability	Surface CO2 and O2 variability; carbon modeling; SAMI; CARIOCA; free rising temperature profiler
3 Core CO2 and Hydrographic	DIC; pCO2; CTD, spatial and temporal CO2 flux Measurements, footprint.
4 Sea Surface Roughness	Ship board Radars. Buoy based small scale waves.
5 Bulk Meteorology and Turbulent Fluxes	Atmospheric boundary layer physics/meteorology; turbulent fluxes of momentum, Water vapor, temperature, IR, Solar
6 IR Remote Sensing	IR heat flux; ocean skin temperature; microbreaking processes. Active Infrared techniques
7 Shipboard CO2 Fluxes	Air-sea gas flux systems; ship mast
8 Surface Ocean Processes	Directional wave field; currents; atmospheric CO2 gradients; oceanic surface turbulence, oceanic shear, oceanic stratification, bubbles, large waves, Langmuir, cells, aerosols.
9 Nutrients	Nutrient and oxygen
10 Deliberate Tracers	SF6 and 3He

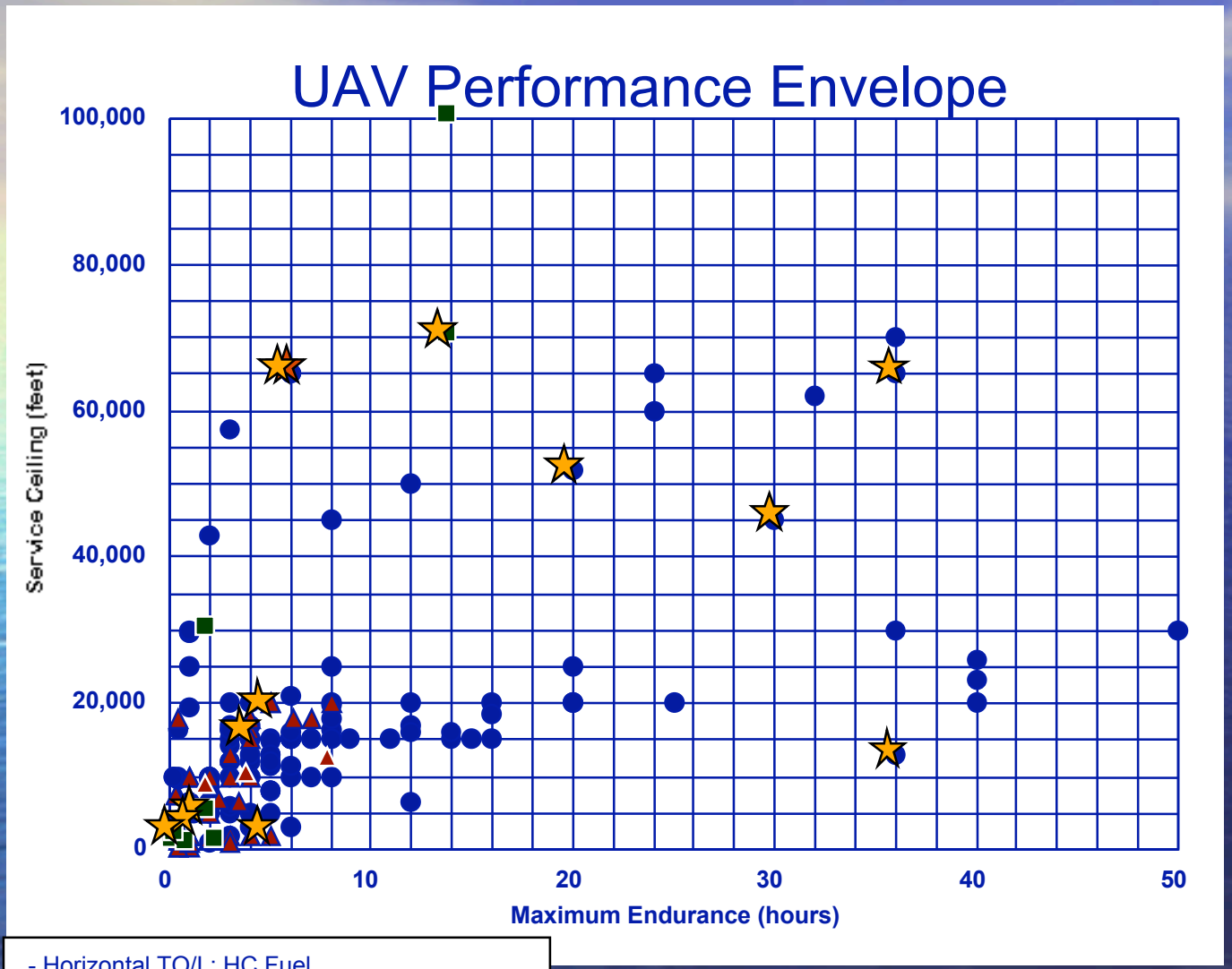


Courtesy Tommy Dickey, UCSB



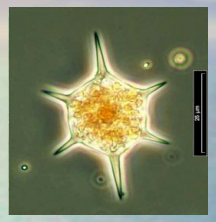
Courtesy Tommy Dickey, UCSB

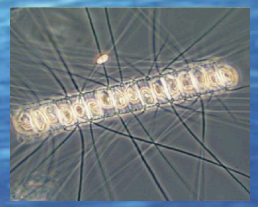
UAVs Today



- Horizontal TO/L; HC Fuel
- VSTOL; HC Fuel
- Electric (incl. Solar) Propulsion; HTOL

Observation Goal 1:
Identify ocean species to quantify ocean biological carbon cycle.

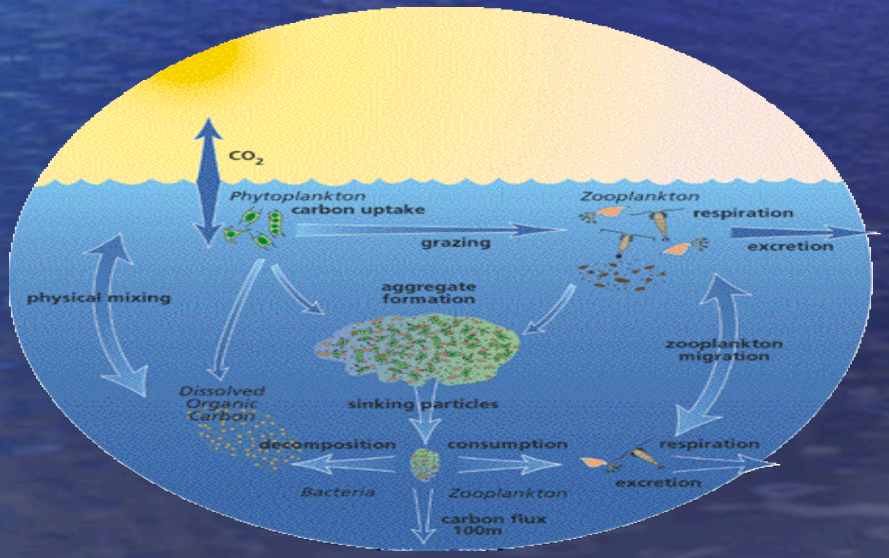




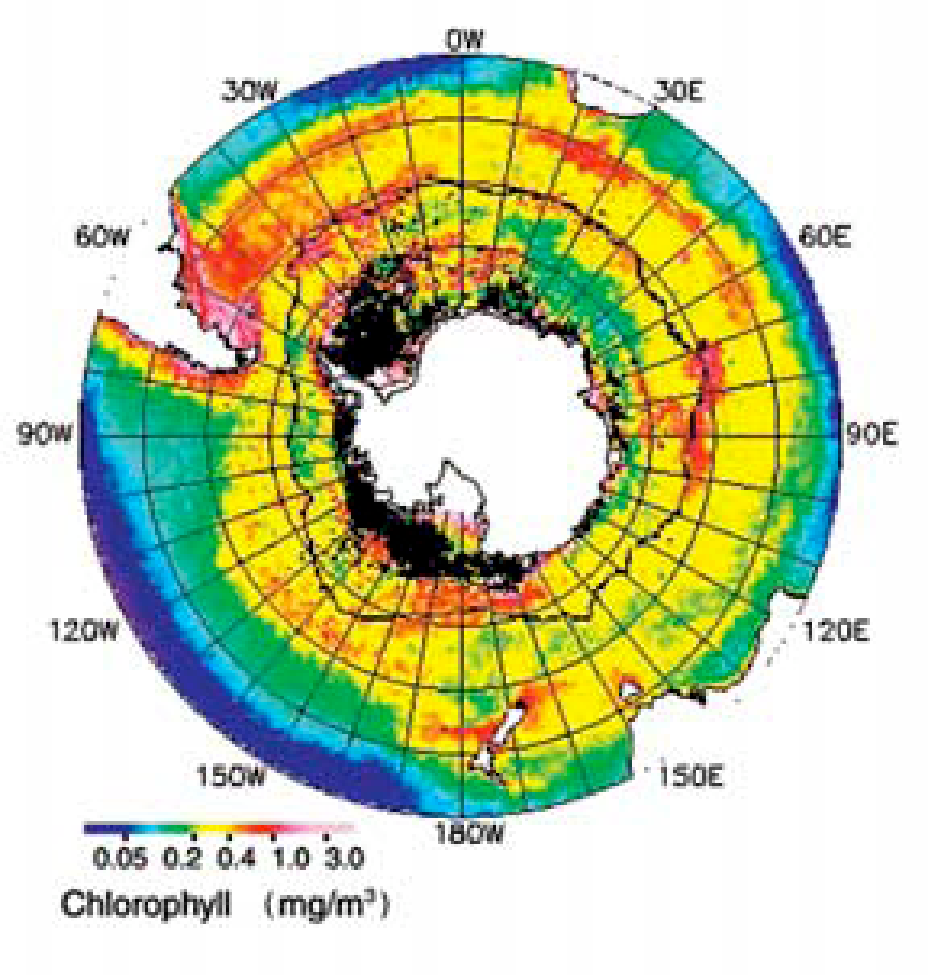
- Modern ocean color datasets from MODIS provide information on location and coarse scale estimates of ocean productivity

- Better information on species composition in blooms might aid in resolving

- Blooms detected by space observations as well as future iron fertilization experiments will inform scheduling and deployment



Patterns in Southern Ocean Productivity



SeaWifs 4-yr (1997–2000) average of mean chlorophyll a concentrations in the Southern Ocean for the month of December.

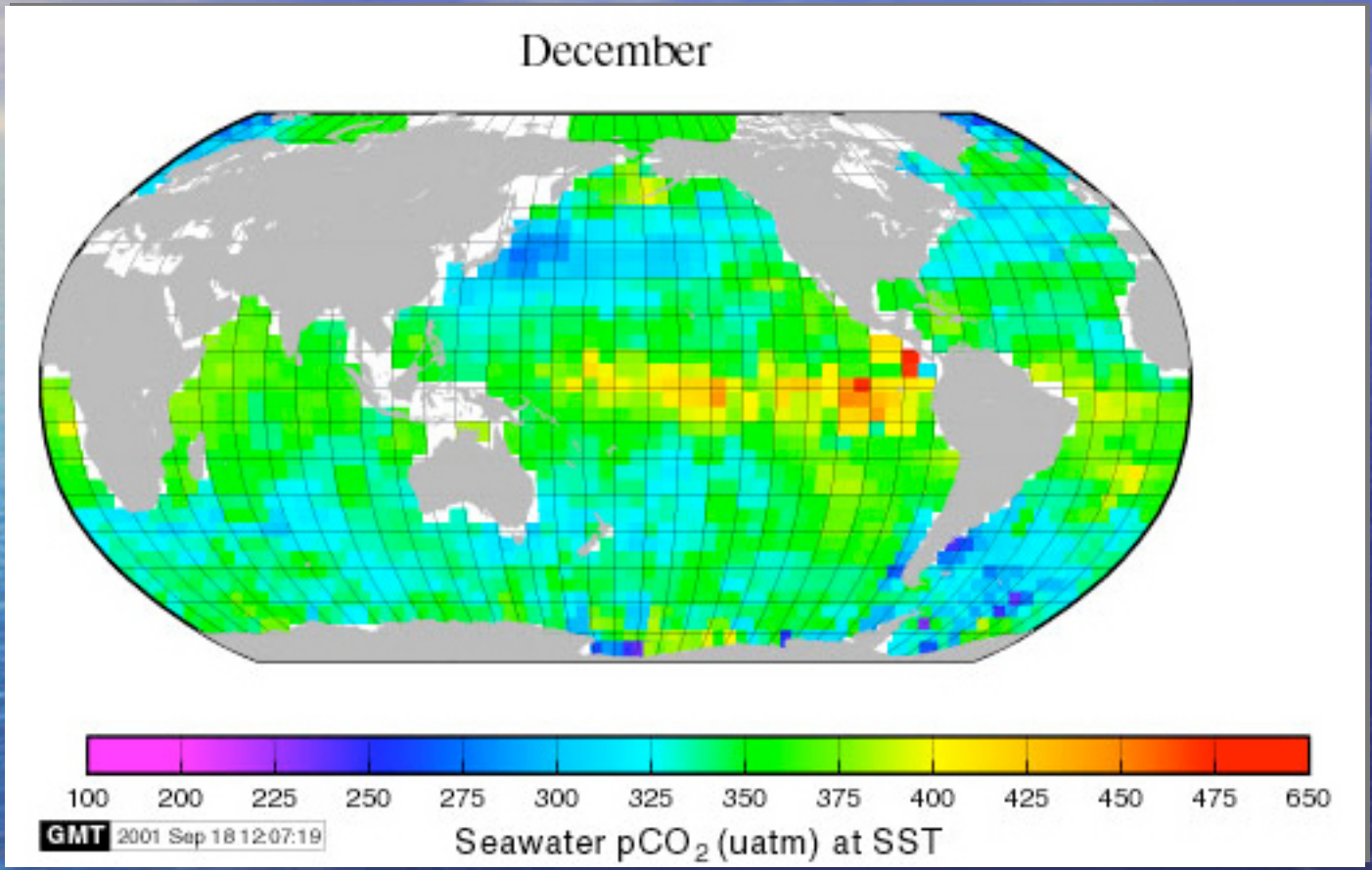
Areas of elevated chlorophyll a occur in coastal waters, in areas of sea-ice retreat and along some parts of the polar front.

The band of high chlorophyll concentrations along 40°S south of Africa is also associated with frontal systems and high kinetic energy.

(adapted from Moore and Abbott, 2000).

Mission Concept #2:
Quantify air-sea fluxes of atmospheric constituents such as CO2 over time concurrent with observations of sea surface temperature and height.

- **NASA's planned Orbiting Carbon Observatory will provide the first global measurements of column CO_2 concentrations**
- **Algorithm development and inter sensor comparisons require strict on-orbit sensor characterization.**
- **Suborbital assets can be used to improve spatial and temporal resolution, improving models of air-sea flux**



ΔpCO_2 fields:Takahashi climatology

Monthly changes in pCO_{2w}

Ocean carbon cycle missions

- Air-Sea Exchange -- **Aura, TRMM, QuikScat, OCO**
  - Column measurements at various altitudes
  - Air-sea gas flux measurements
  - Gas Spectrometry eg. O:N ratios
  - Wind speed and vectors
  - Surface roughness
  - Sea surface temperature
- Bio-optics -- **MODIS, NPP, NPOESS**
  - Ocean plume id and analysis dynamics
  - Functional group id
  - Optical depth measurements
  - Fluroscence

Considerations on Potential Flight Configurations

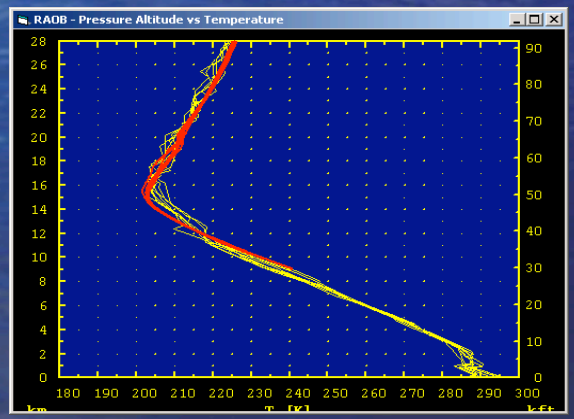
- Type and number of platforms:
  - ships, planes, dropsondes, satellites
- Number and sort of sensors
  - Eg. Clone simulator sensors for intercalibration and algorithm development
- Timing
  - Current and future satellite schedules
  - Important for resolving dependencies between measurements (both for platform control and image acquisition)
- Degrees or levels of autonomy
  - Why autonomy?
  - Closed vs. open loop systems
  - Mission planning issues

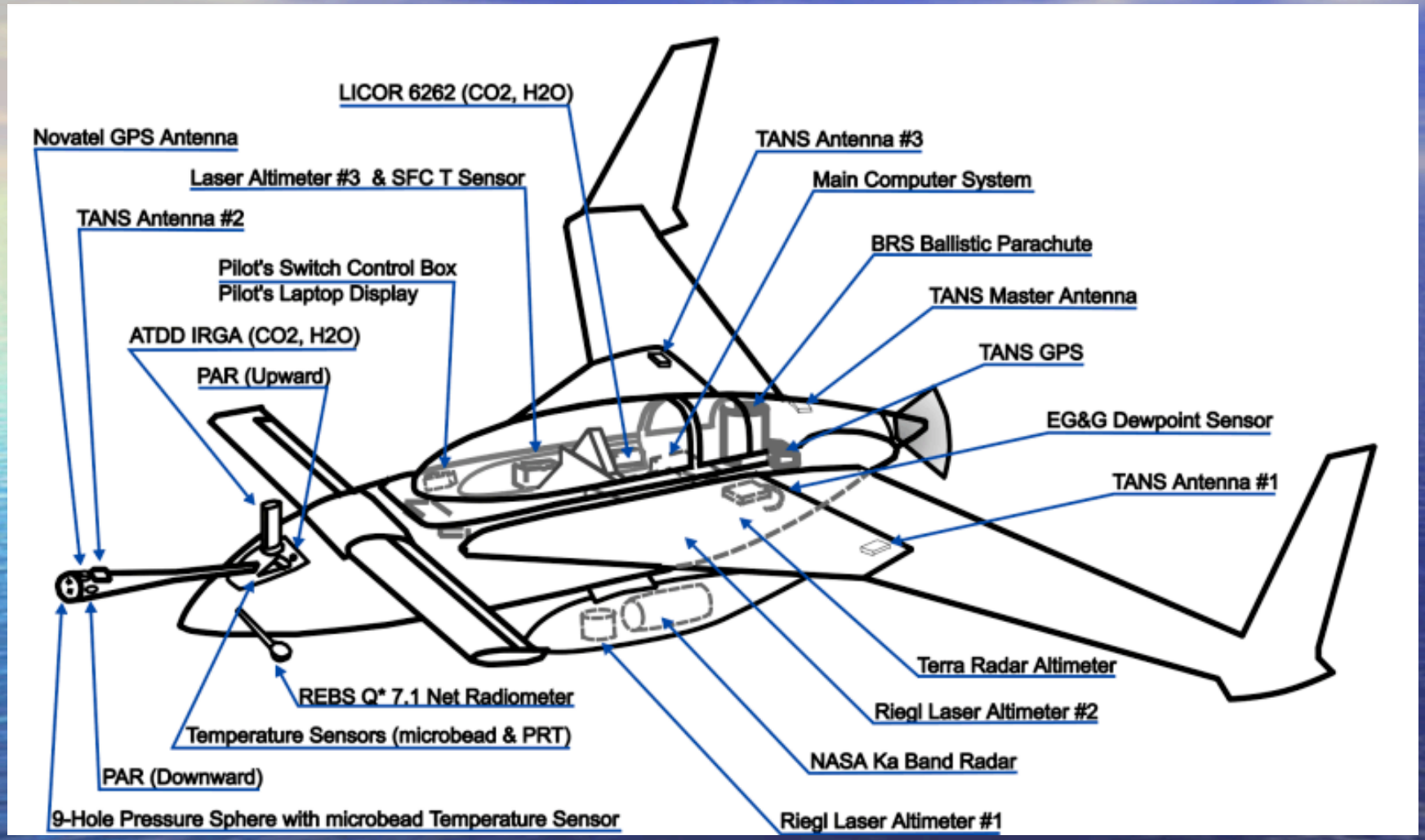
Candidate Sensor Systems

- Atmospheric chemistry
  - Isotope ratio mass spectrometers
  - Non-Dispersive IR Analyzer
  - Fabry-Perot Interferometer
- Bio-optics
  - CRiS
  - Duncantech Hyperspectral

NCAR GPS Dropsonde Sensors Specs

	Range	Accuracy	Resolution
Pressure	1080-100 hPa	± 1.0 hPa	0.1 hPa
Temperature	-90 to +60 C	± 0.2 C	0.1 C
Humidity	0-100%	± 5%	1.0%
Horiz Wind	0-200 m/s	± 0.5 m/s	0.1 m/s




LICOR 6262 (CO2, H2O)
Novatel GPS Antenna
Laser Altimeter #3 & SFC T Sensor
TANS Antenna #2
Pilot's Switch Control Box
Pilot's Laptop Display
ATDD IRGA (CO2, H2O)
PAR (Upward)
TANS Antenna #3
Main Computer System
BRS Ballistic Parachute
TANS Master Antenna
TANS GPS
EG&G Dewpoint Sensor
TANS Antenna #1
Terra Radar Altimeter
Riegl Laser Altimeter #2
NASA Ka Band Radar
Riegl Laser Altimeter #1
REBS Q* 7.1 Net Radiometer
Temperature Sensors (microbead & PRT)
PAR (Downward)
9-Hole Pressure Sphere with microbead Temperature Sensor

UAV Image Data Flow Diagram

(ASF, DRAFT Concept, 6/04)

Airborne Element

Line Scanner/ Gas Analyzer

POS/AV IMU/DGPS

Digitizer

Functions:

- Image Data Capture (ADC)
- NAV Data MUX

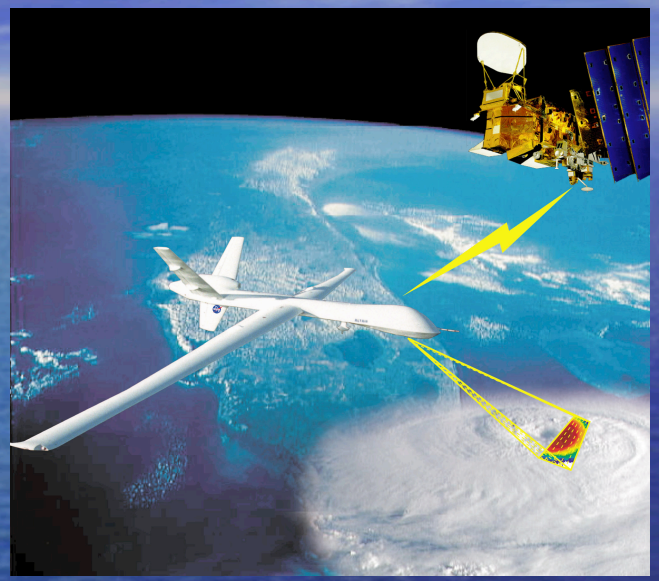
Shared Disk

Flight Computer

Functions:

- Primary Algorithm Processing
- Thumbnail Generation
- On-Demand Image Subsetting

Full Res. 200Hz Data (RS-232)



Sat Com Link

High Speed (1Mbs) Full Res. 4-Band Data

Low Speed (9.6Kbs) Thumbnails, C&C

Ground Element

End User

Web Server

Functions:

- GIS User Interface
- Image Server: Level-2 GEOTIF Thumbnails
- Track Map Server

Shared Disk

Ground Computer

Functions:

- Geo-Correction Processing
- Query Handling
- Science Algorithm Processing
- Sensor C&C

Product QA/QC

DEM/DOQ Database

ARC Earth Science Div.
Airborne Sensor Facility

Systems Engineering: Some advice during mission planning

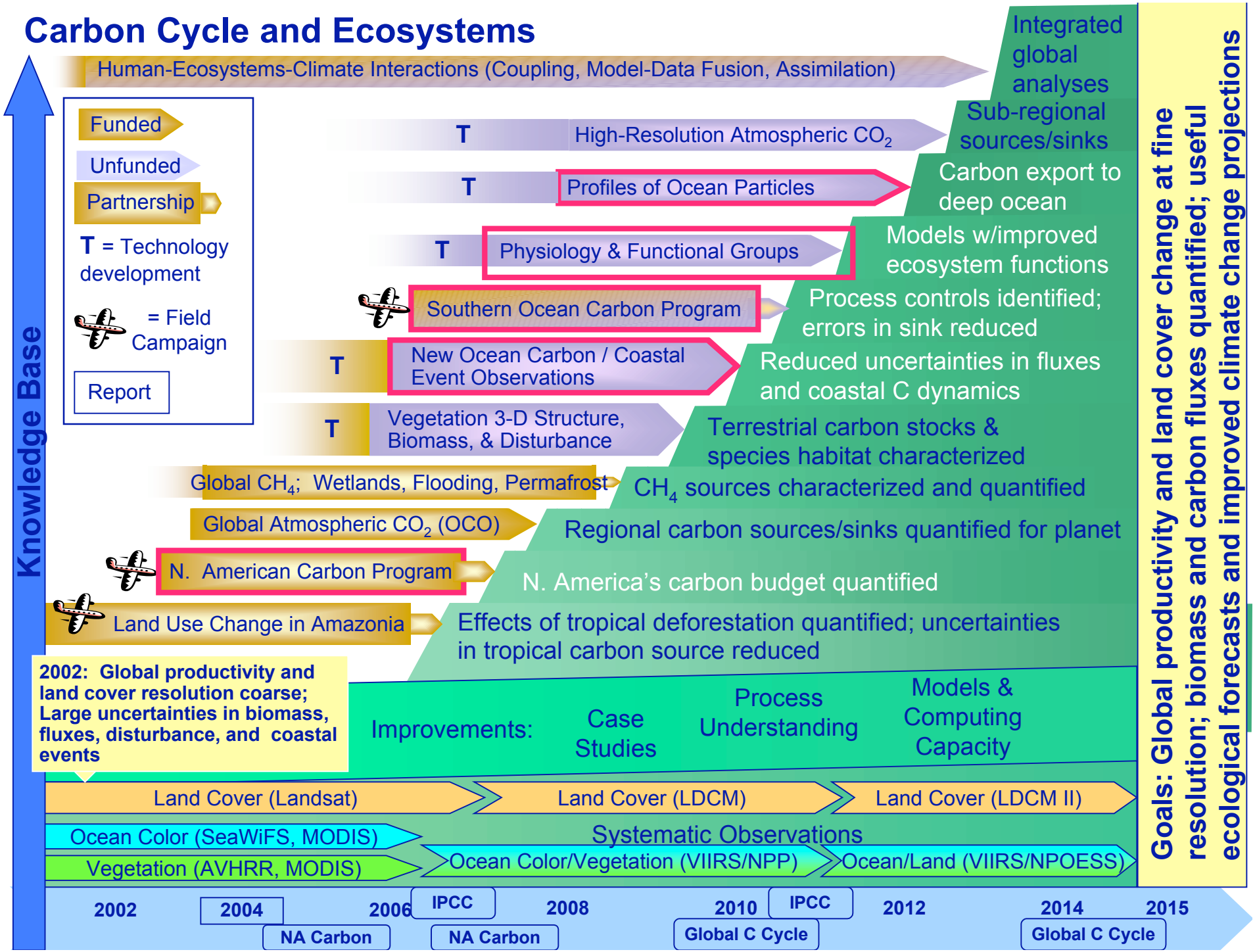
Optimizing UAV Applications:

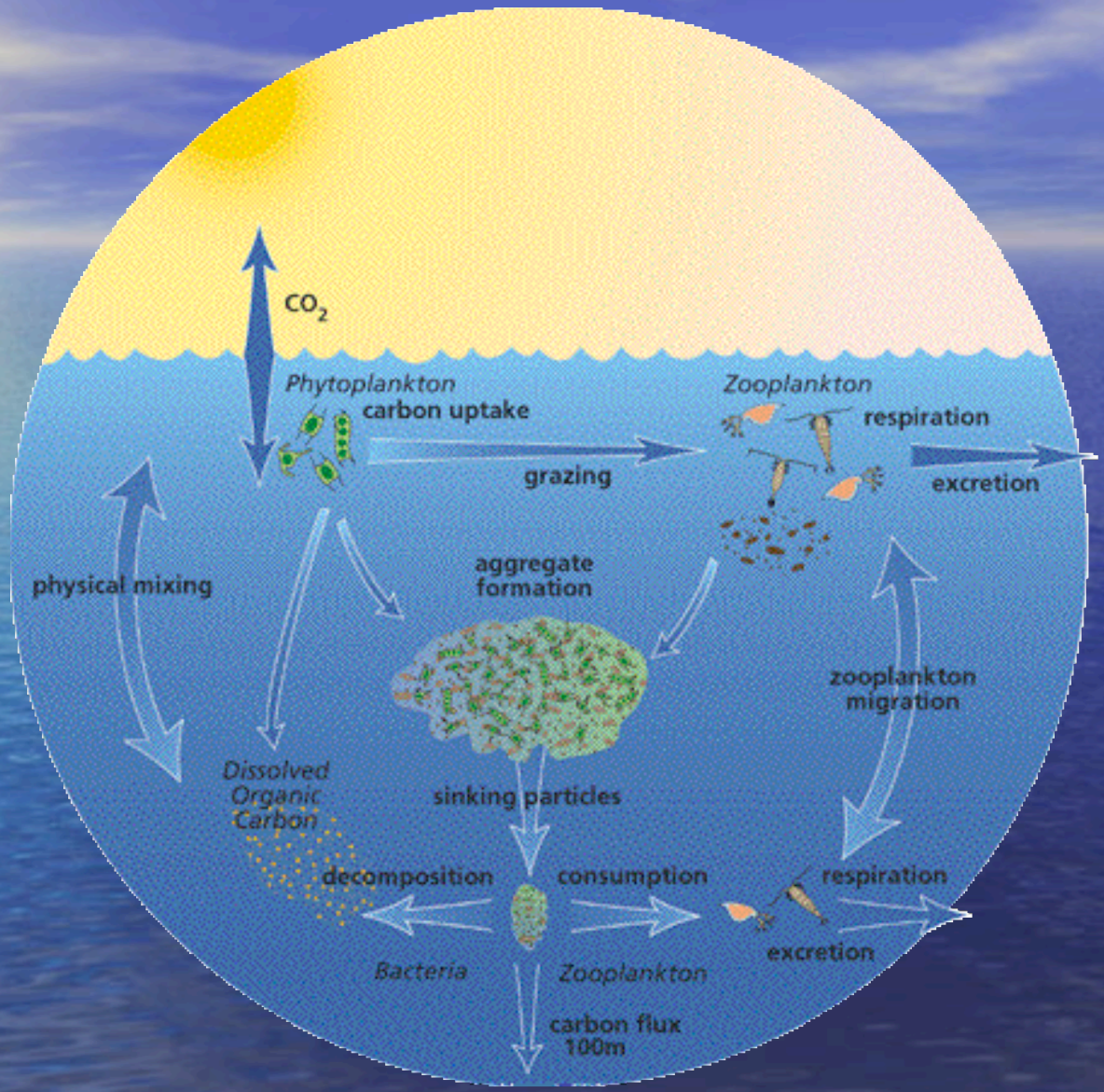
- Defining mission requirements
- Sensor selection/development and testing
- Flight planning and airspace management
- Platform selection
- Data telemetry
- Task dependent processing
- Defining risk mitigation strategies
- System, platform and payload safety reviews
- Deployment and implementation
- Organizing ground-based site logistics
- Finalizing operational procedures and checklists

Thank you!

Backup Slides

Carbon Cycle and Ecosystems





Source: JGOFS

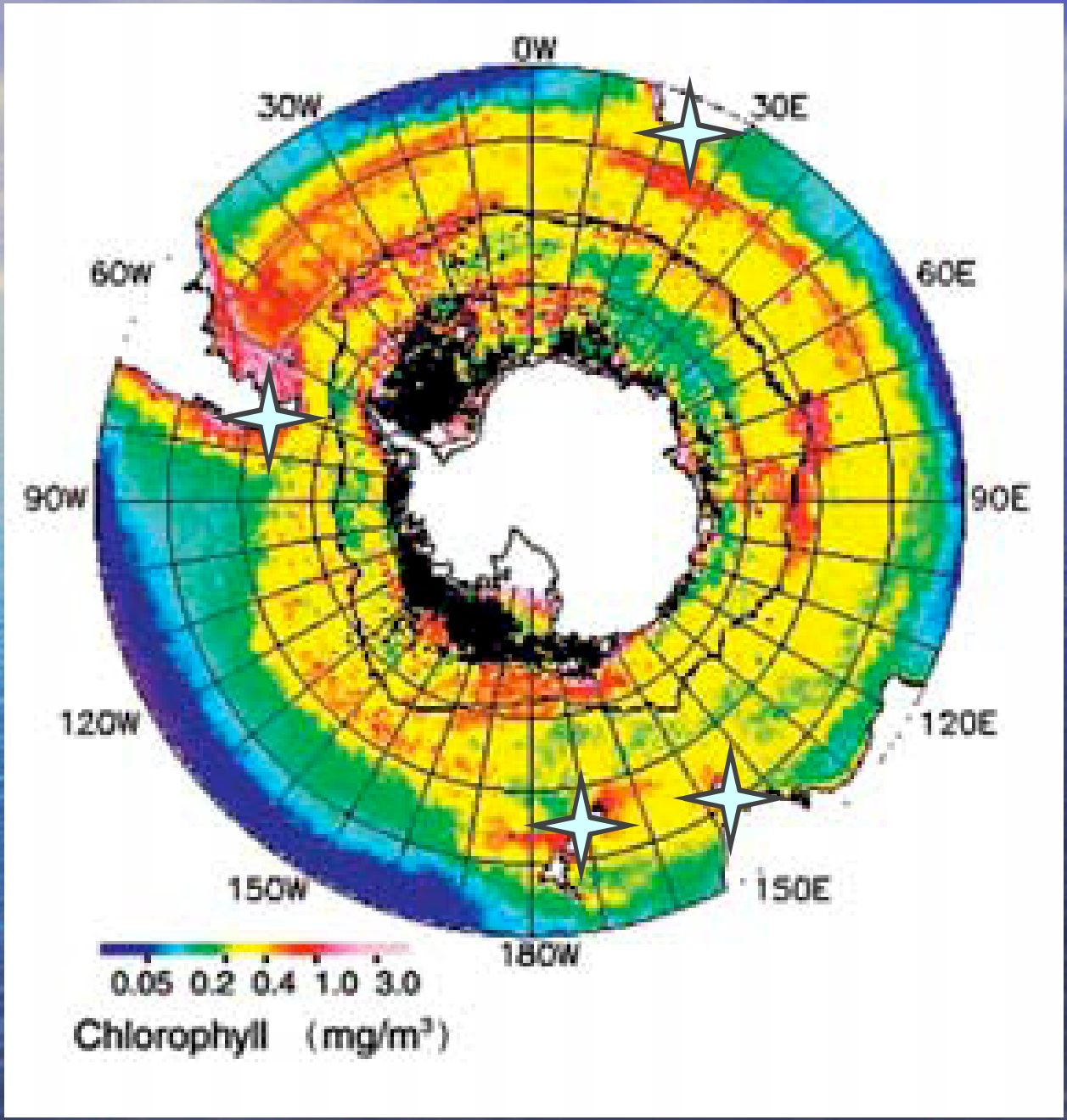
Remote sensing data for Ocean carbon cycle studies - JGOFS

Circulation, mixed-layer depth, geostrophic currents	SSH
Air-sea exchange of CO_2 pCO_2 of ocean	SST, salinity, chlorophyll concentration
gas exchange coefficient	wind speed, surface roughness
Photosynthesis	chlorophyll concentration irradiance, SST, fluorescence
New and export production	SST, primary production, NO_3 chlorophyll concentration
f-ratio	heat flux, precipitation
supply of new nutrients	oxygen, heat flux
new nutrient uptake	heat storage, SST
plankton community structure	ocean color, compound
(N_2 fixation, calification)	remote sensing
Carbon species (POC, DOC)	ocean color
Production of radiatively active	ocean color
gases (photochemistry)	irradiance
Variability, unresolved processes	variability in SSH, SST, color,
eddies	wind vector
forcing events (storms etc.)	wind vector
coastal processes	multispectral ocean color

Ocean Science Program Derives from Enterprise Strategy

Variability	Forcing	Response	Consequence	Prediction
Precipitation, evaporation & cycling of water changing?	Atmospheric constituents & solar radiation on climate?	Clouds & surface hydrological processes on climate?	Weather variation related to climate variation?	Weather Forecasting Improvement?
Global ocean circulation varying?	Changes in land cover & land use?		Consequences in land cover & land use?	**Transient climate variations?**
	Surface transformation?	**Changes in global ocean circulation?**	**Coastal region change?**	Trends in long term climate?
Stratospheric ozone changing?		Stratospheric trace constituent responses?		Future atmospheric chemical impacts?
Ice cover mass changing?		**Sea level affected by climate change?**		
Motions of Earth & interior processes?		Pollution effects?		

Ocean Biology Program


0W
30W
30E
60W
60E
90W
90E
120W
120E
150W
150E
180W
0.05 0.2 0.4 1.0 3.0
Chlorophyll (mg/m³)