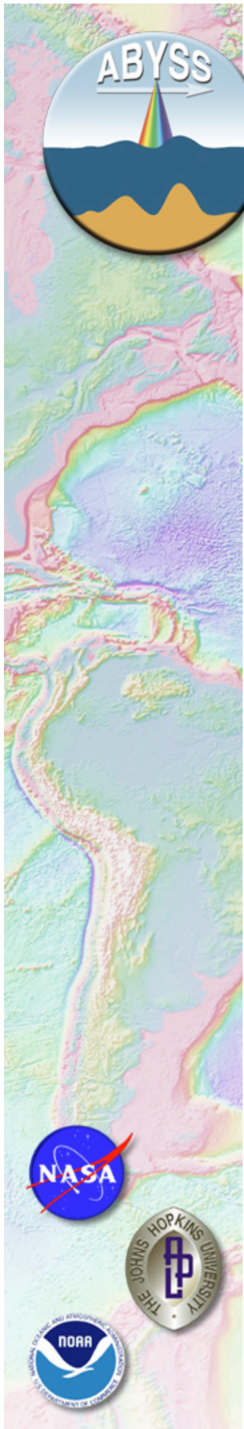

Science Overview

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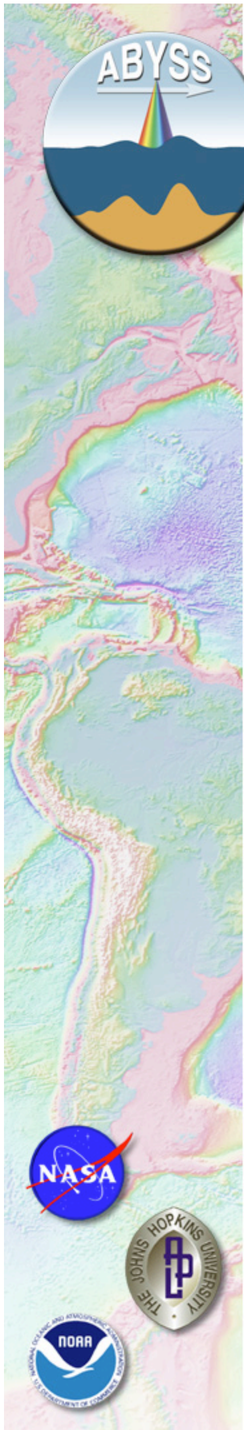


Outline of ABYSS Science Overview

- Why bathymetry?
- Why altimetric bathymetry?
- Why from surface slopes?
- What are mission design requirements?
- How is ABYSS right for NASA?
- Why should ABYSS be done now?

Bathymetry Controls Ocean's Role in Climate

- Water, heat, and greenhouse gases are moved by
  - Advection (currents)
  - Diffusion (mixing)
- Seawater is mostly stratified, so that
  - Horizontal movement is primarily by currents
  - Vertical movement is primarily by mixing
- Bathymetry is a control on both currents & mixing
  - Depth variations steer currents (Fig. F-1)
  - Bottom roughness enhances mixing (Fig. F-2, bottom)

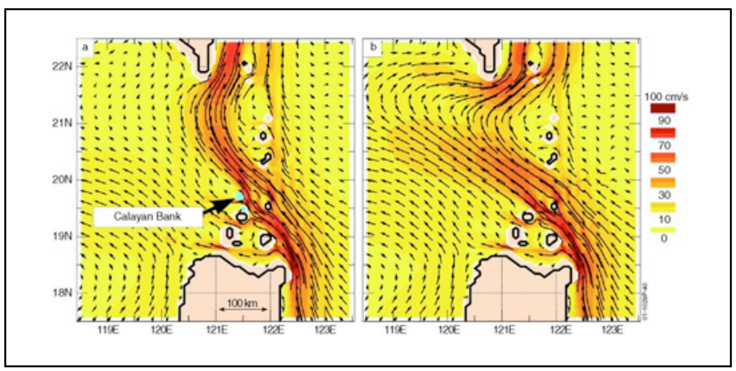


Fig. F-1

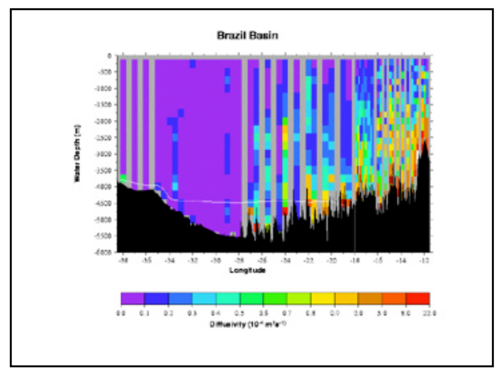


Fig. F-2, bottom

Ocean Currents Move Heat, Controlling Climate

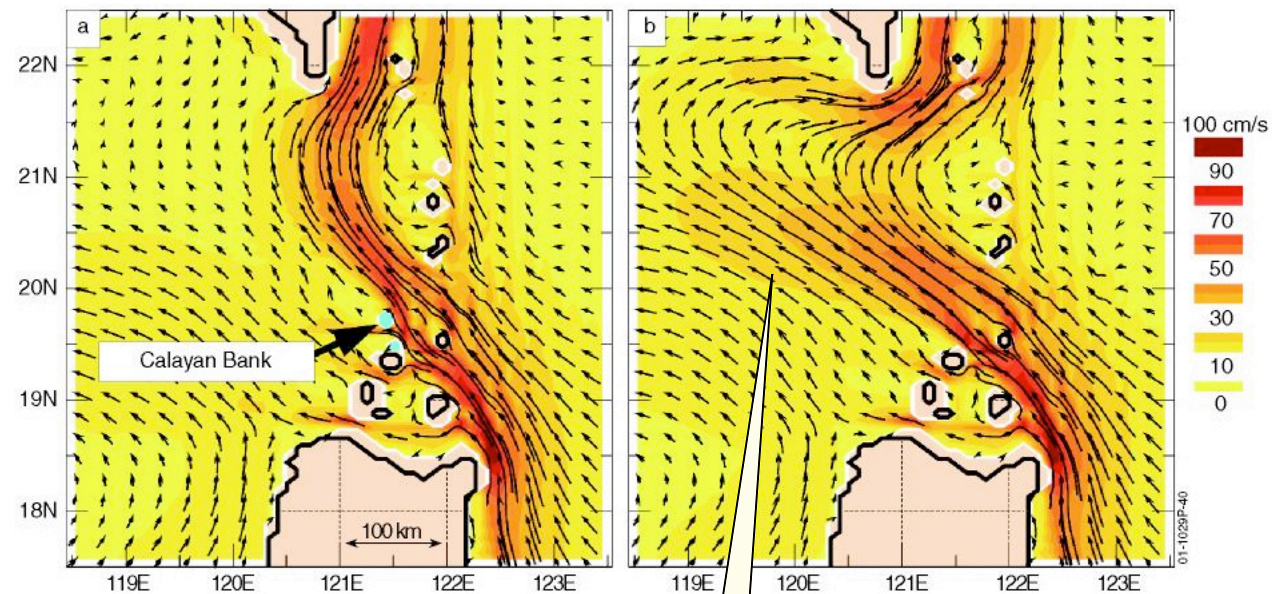
Gyre-scale circulation carries heat from tropics to mid- and higher latitudes.

The western boundaries of the basins have the most intense flow, e.g., Gulf Stream and Kuroshio.

Kuroshio Current in West Pacific

20-km-Scale Bathymetry Steers Ocean Currents

Forecast models require correct global bathymetry



Approximates nature

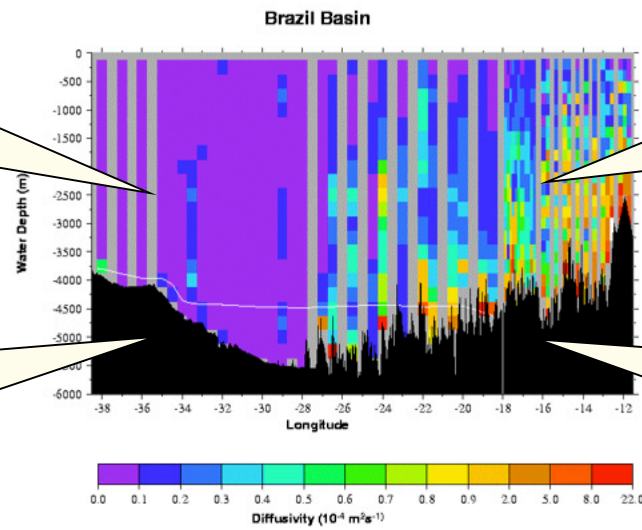
Intrudes unnaturally

ABYSS is needed because a single seamount as small as 20 km across can steer a major current (Kuroshio mean flow in U.S. Navy model at 1/16°).

Bottom Roughness Controls Mixing Rates, Thus Also Heat & Greenhouse Gas Uptake Rates

Less mixed water

Smoother bottom



More mixed water

Rougher bottom

Spatial variations in bottom roughness change mixing rates by orders of magnitude (vertical diffusivity < 10^{-5} at left and > 10^{-4} at right; actual in situ data shown).

10–30 km → bathymetry controls mixing.

Seafloor spreading shapes bathymetry at these scales.

Recent Climate Change Publications Call for Better Models of Deep Ocean Mixing

Global Warming Projections: Sensitivity to Deep Ocean Mixing

Andrei P. Sokolov and Peter H. Stone

Center for Global Change Science, Massachusetts Institute of Technology
77 Massachusetts Ave., Room 54-1312, Cambridge, MA 02139, USA

GEOPHYSICAL RESEARCH LETTERS, VOL. 25, NO. 19, PAGES 3603-3606, OCTOBER 1, 1998

Uncertainty in the oceanic heat and carbon uptake and its impact on climate projections

A. Sokolov, C. Wang, G. Holian, P. Stone and R. Prinn

Joint Program on the Science and Policy of Global Change. MIT, Cambridge, Massachusetts

Must Understand Mixing to Predict Sea Level Rise

- **Ocean mass changing?**
  - –Must calculate mixing of fresh and salt water
- **Total heat storage changing?**
  - –Mixing governs heat transfer rate
- **Mass and total heat could be steady!**
  - –SL can be changed by changing mixing alone!

Mixing seawater does NOT conserve volume (sea level) due to complexity of equation of state

Only 1/2 the SL rise has been explained

0.4 mm/yr due to melting ice
0.7 mm/yr due to warming
~1 mm/yr unexplained

The Ocean Floor Is the Key to Global Change

- Bathymetry controls currents & mixing throughout the entire water column
- Entire volume is 40–200 times mixed layer volume
- Sub-mixed-layer processes buffer climate at annual and longer time scales
- Work (energy dissipation) rates at the bottom (tide-driven) equal or exceed work rates at the surface (wind-driven)

Why Bathymetry?

Bathymetry to □ = 10 to 30 km scales is needed

- **To model ocean and its role in climate**
  - **Steering of currents** (ABYSS Objective #1)
  - **Control of mixing rates** (ABYSS Objective #2)

- **To understand plate tectonics**
  - **This scale reveals seafloor spreading process variations, fault geometry, volcano distribution, transition from non-fractal to fractal bathymetry, etc.** (ABYSS Objective #3)

Why Altimetric Bathymetry? Why Not Use Ships?

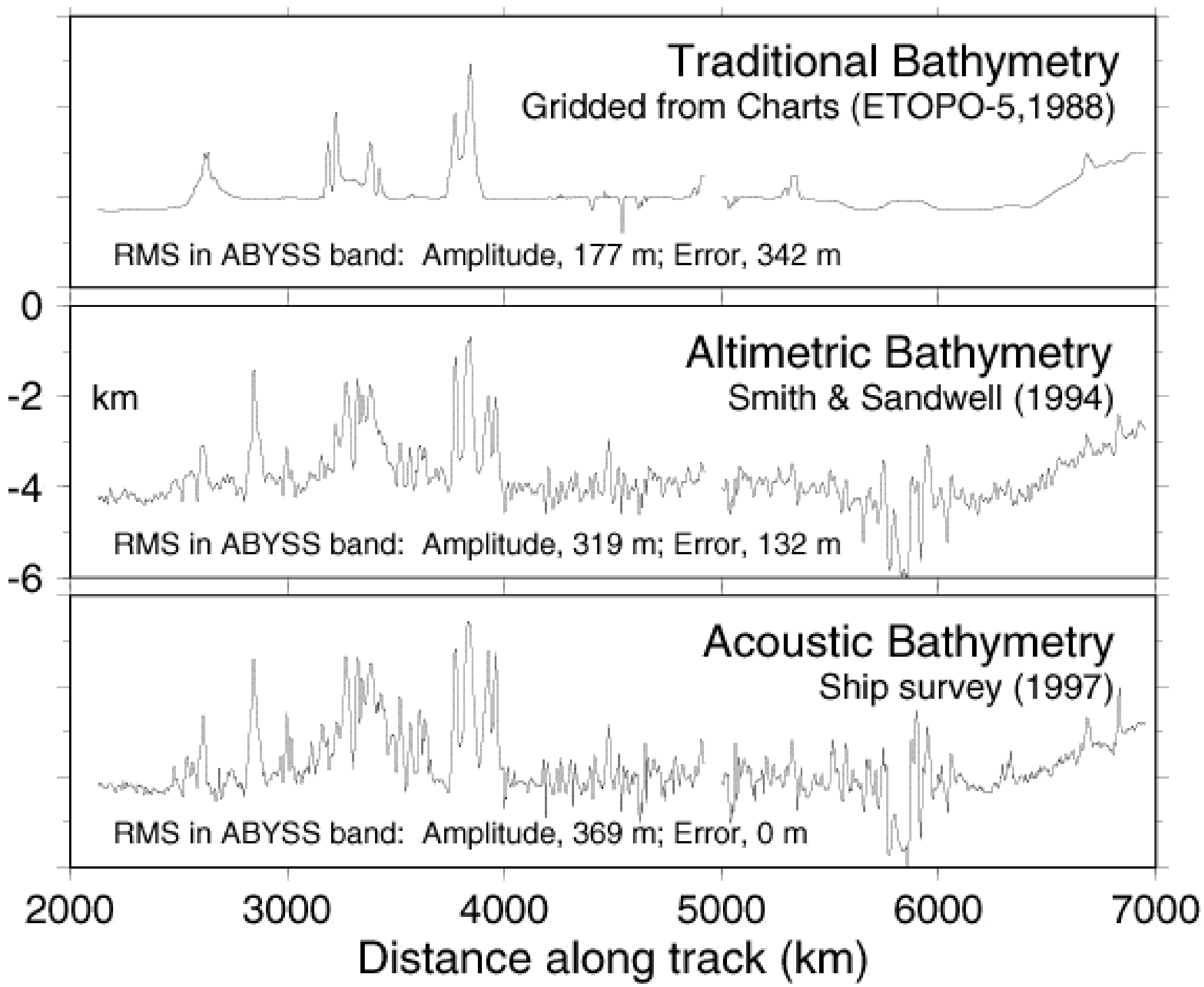
Altimetric Bathymetry

- **Ships fail to get the signal**
  - **Spatial coverage is sparse and irregular; quality often poor**
  - **Too slow (>100 ship-years)**
  - **Too expensive (~$1 billion)**
- **A space mission can do it**
  - **With uniform quality and coverage**
  - **Faster and cheaper**
  - **Only one mission needed**
  - **Concept is proven**
  - **No theory/algorithm risk**

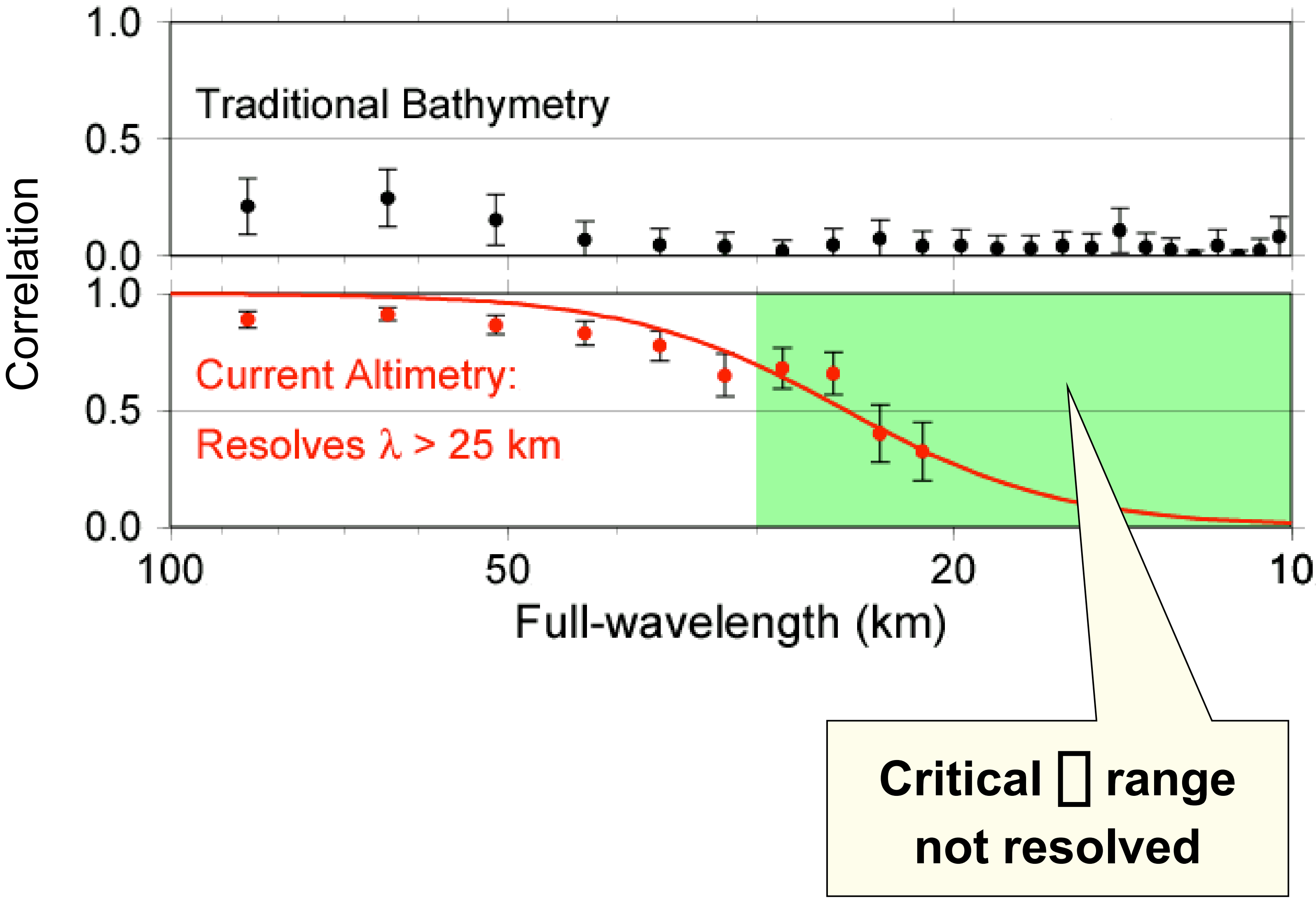
Hasn’t it been done?

**Not at the critical **

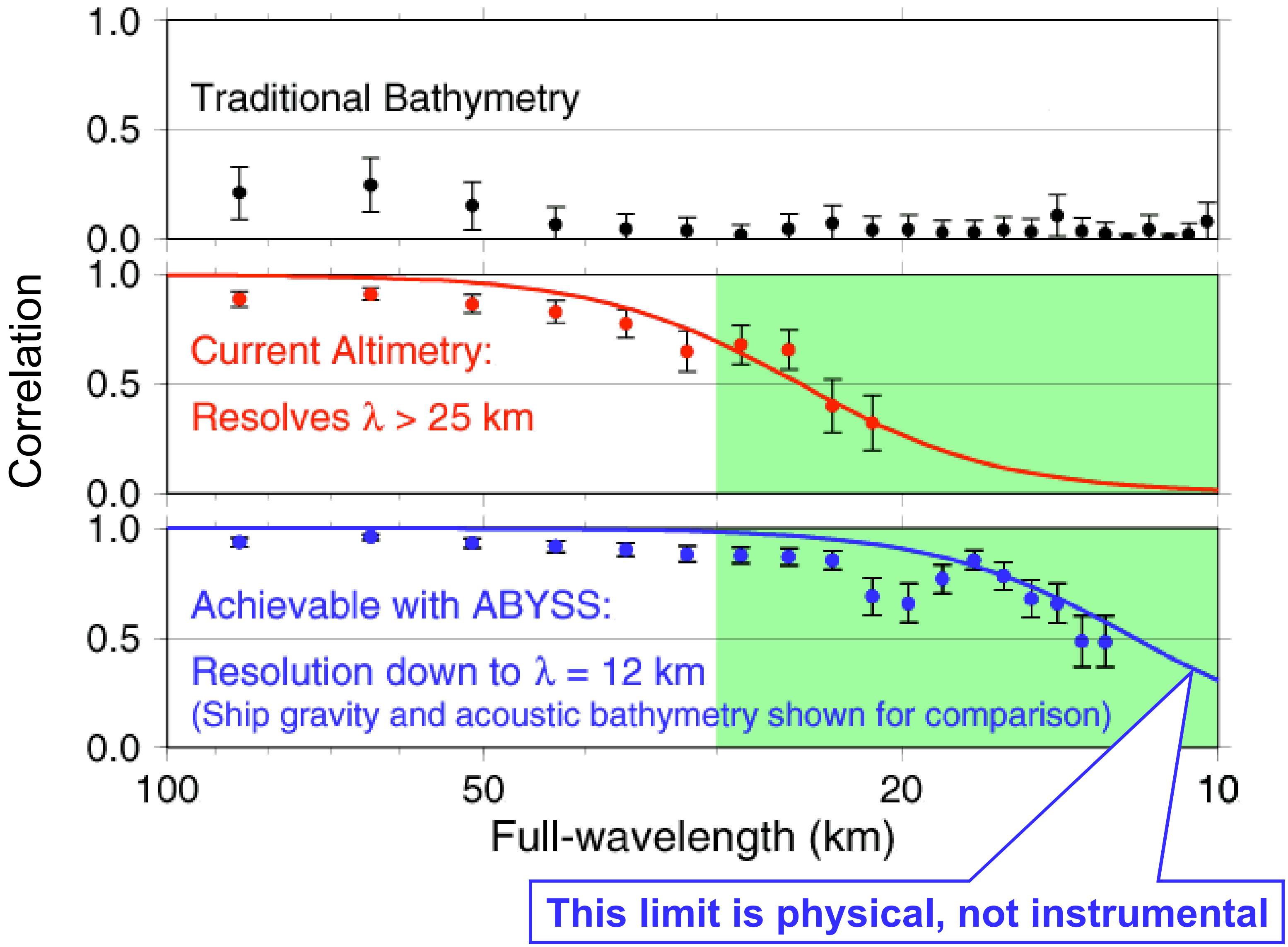
South Pacific Profile: Traditional, Altimetric, and Acoustic Ship Survey Bathymetry



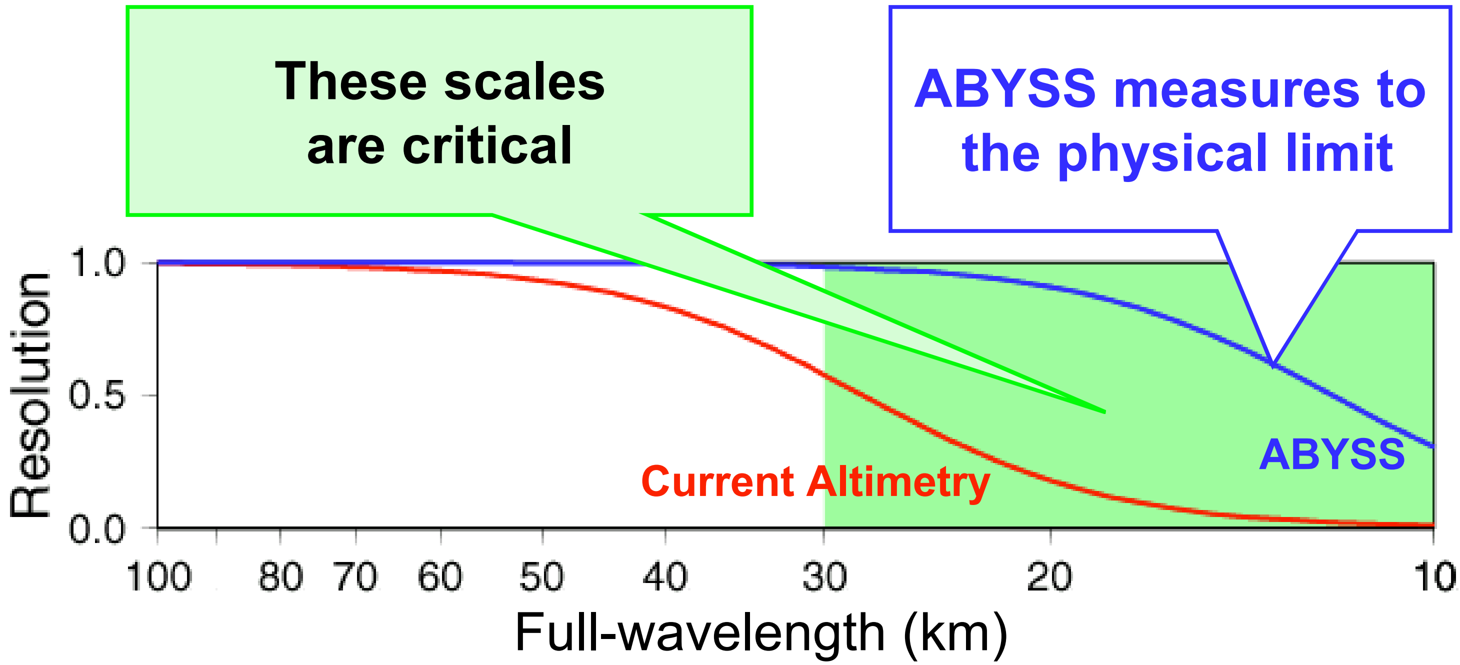
Correlation by Wavelength: Current Altimetry Beats Traditional but Doesn't Get the Critical □s



ABYSS Will Achieve Best Possible Resolution by Measuring Gravity as Well as a Ship Can



ABYSS Resolves Critical Scales for the First Time, a New Capability and Breakthrough “Pathfinder”

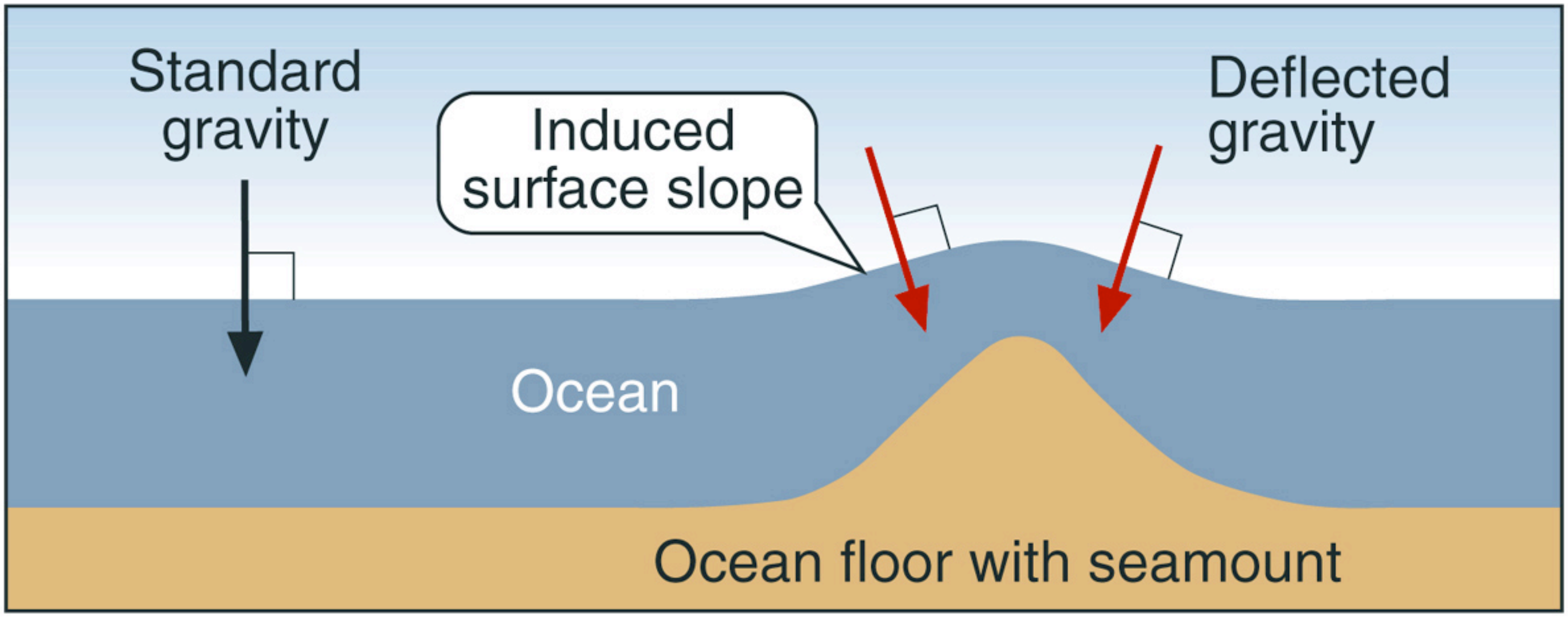


This resolution improvement is sufficient to characterize nearly all the important bottom roughness because it captures the transition to fractal topography in most cases.

Summary of Altimetric Bathymetry

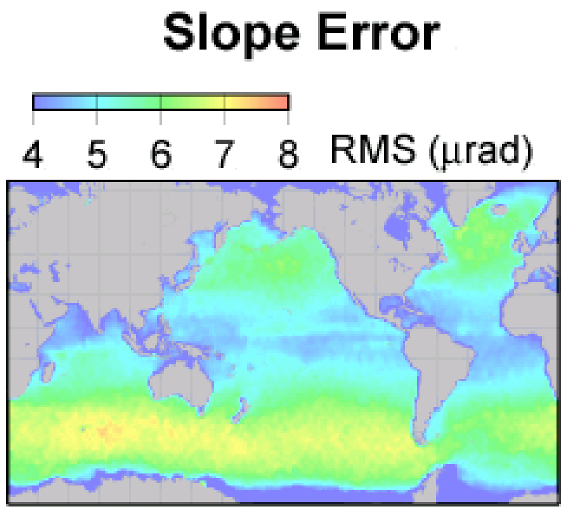
Current resolution	~25 km
Fundamental limit (physics)	~12 km
ABYSS	~12 km
Critically needed band	To ~12 km
Global ship survey?	Not feasible
Precision requirements:	
Gravity	1 mGal
Slope	1 μrad

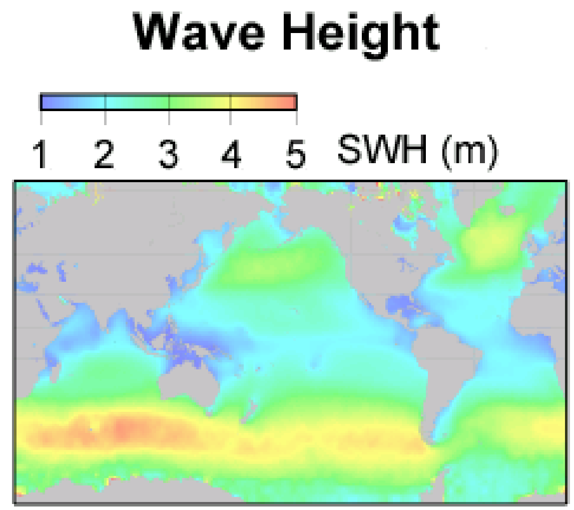
Why Surface Slopes? Best for Signal-to-Noise and Short-λ Gravity Resolution *(See Table F-3)*



- Altimeter measures ocean surface height + errors; errors are both systematic (long-λ) and random (wave-induced)
- Ocean surface height = gravity potential height (geoid) + oceanographic dynamic height, tide, etc. (mostly long-λ)
- Long-λ height errors and oceanography are time-varying
- Short-λ sea surface slope is (nearly) time-invariant and usually within 1 μrad of short-λ geoid slope (gravity deflection)

Slope Precision Is Limited Only by Wave-induced Noise





Map pattern of RMS slope error looks like map of wave height, but does not resemble pattern of variability of currents, ionosphere, etc., confirming that other error sources yield negligible slope in the ABYSS band *(Table F-3)*.

Higher precision requires an altimeter less prone to random noise induced by ocean surface waves.

What Science Requirements Dictate Mission Design? Only Two: Precise Slope, Optimal Orbit

- More precise slope
  - Less noise from waves
- Orbit which optimally samples slope
  - Dense (~6 km) ground-tracks
  - Good projection of slope errors into N and E components
  - Good coverage

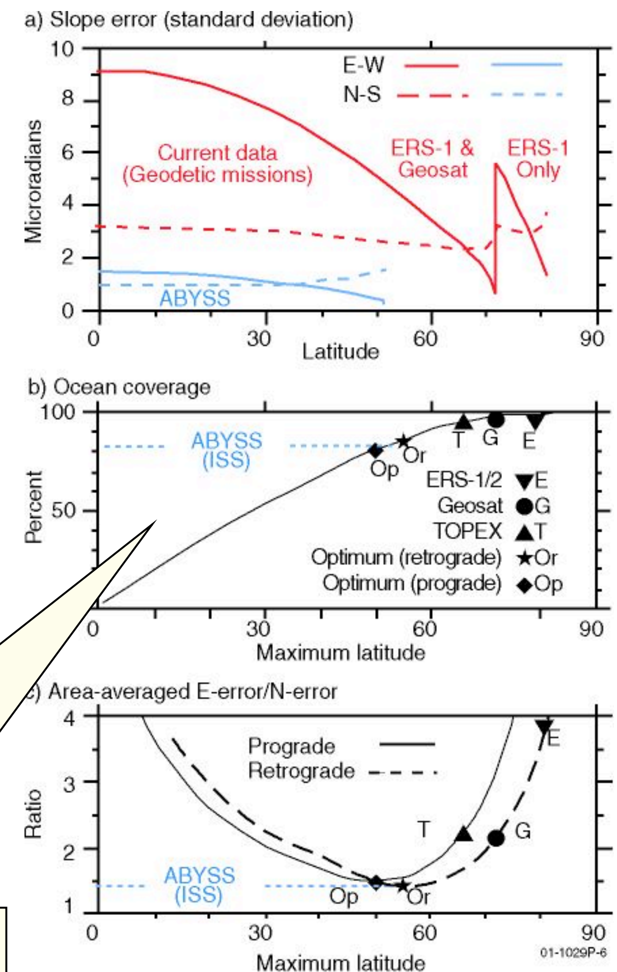
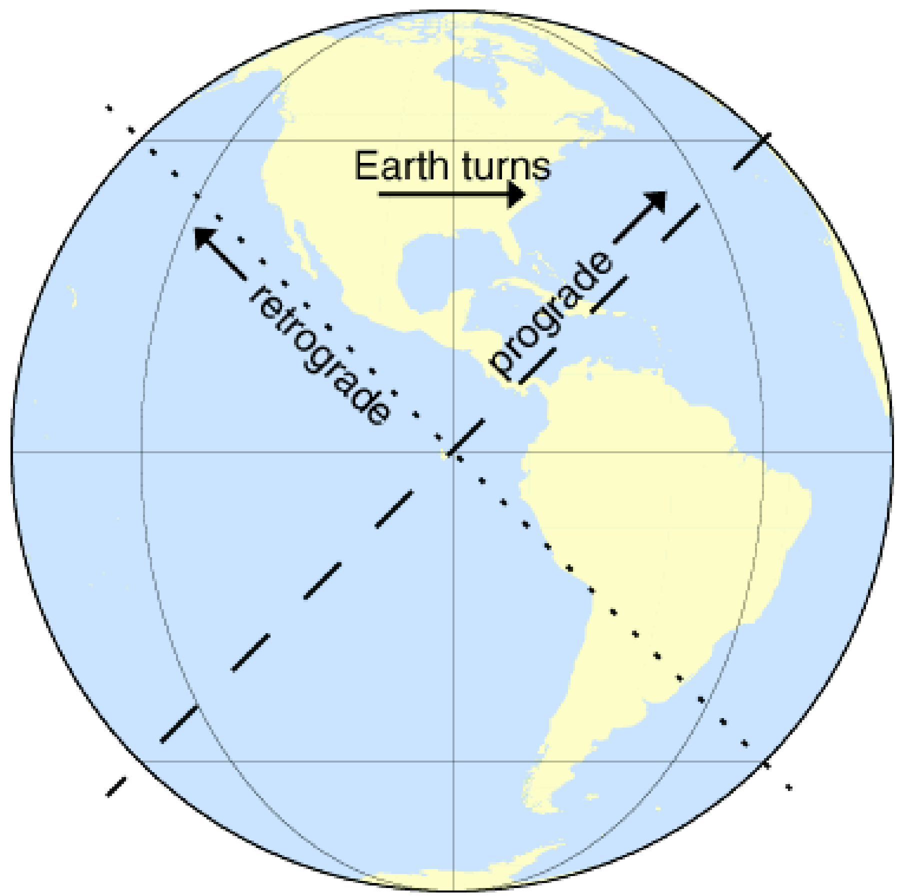


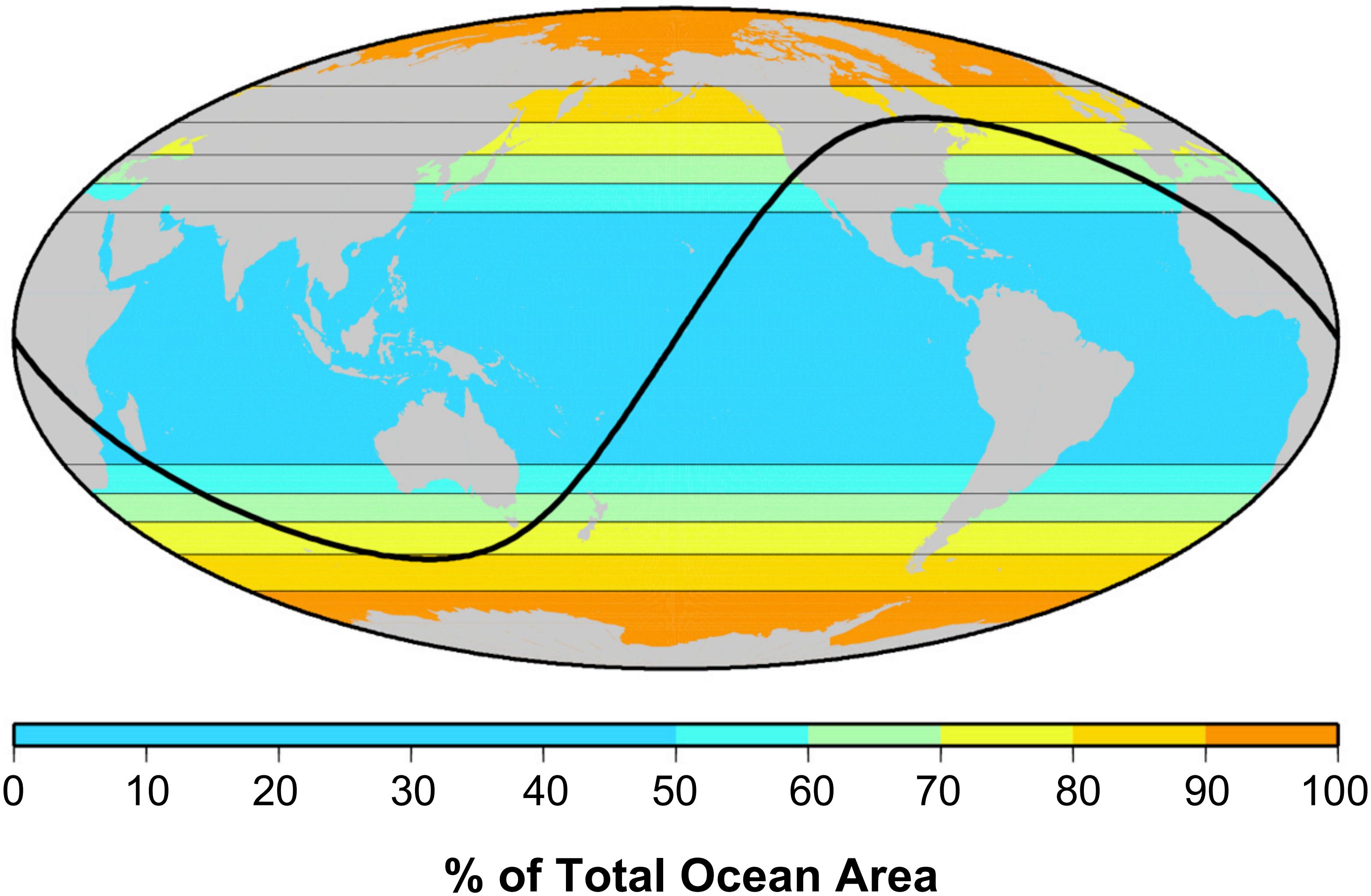
Fig. F-10 explores trade-offs in orbit optimization

Inclination Sets Area Covered and Track Crossing Angle, for Crossings at All Latitudes Covered

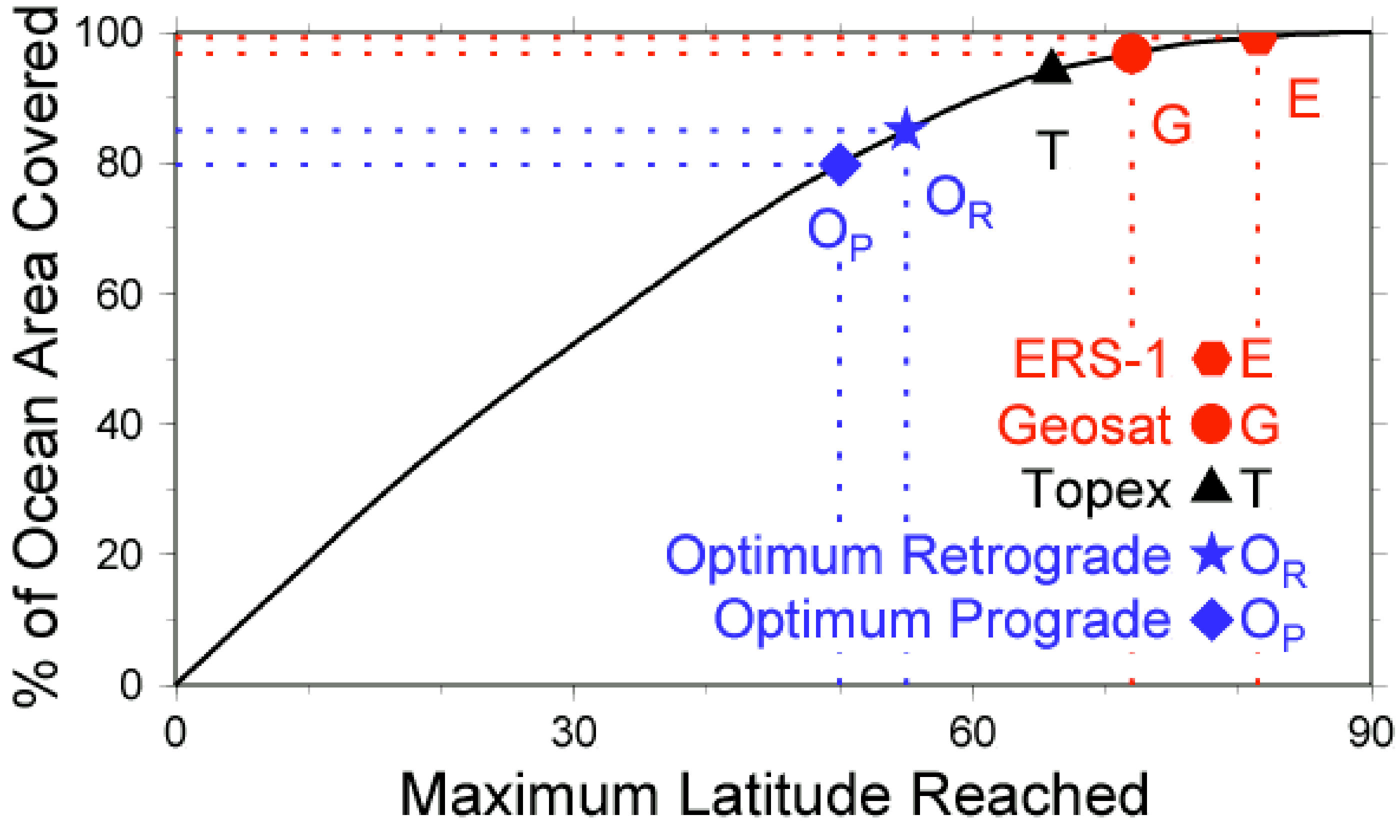


For a fixed maximum latitude, 1 retrograde and 1 prograde orbit can get there, but their angles of attack are not equivalent because of Earth's rotation

Most of Earth's Ocean Area Is at Low to Mid-Latitudes Covered by Moderate Inclinations

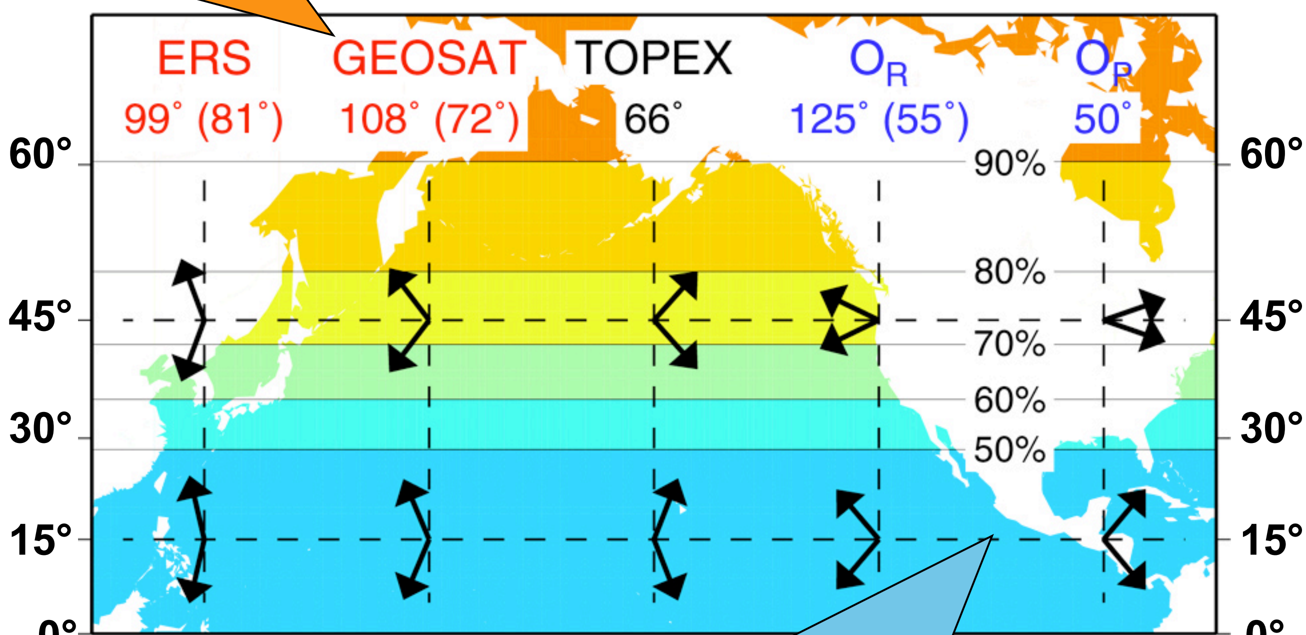


Ocean Area Coverage versus Latitude Coverage



Track Crossing Angle Depends on Inclination and Latitude

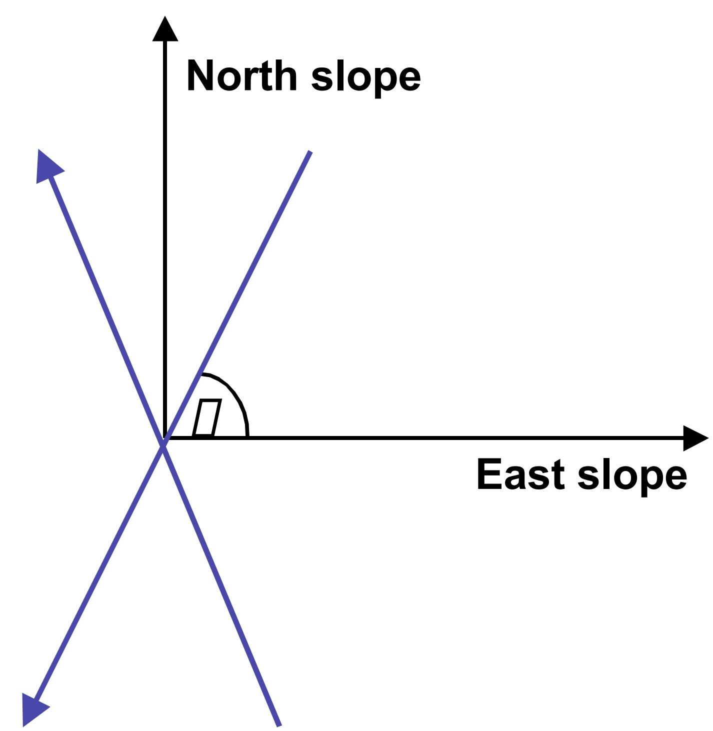
Nearly orthogonal in a small area of ocean



Nearly orthogonal over a large area of ocean

Orbit Inclination Controls North vs East Error Anisotropy, through Track Intersection Angle

- Error propagation
  - θ - local inclination of track
  - σ - error in along-track slope
  - σ_x - error in east slope
  - σ_y - error in north slope

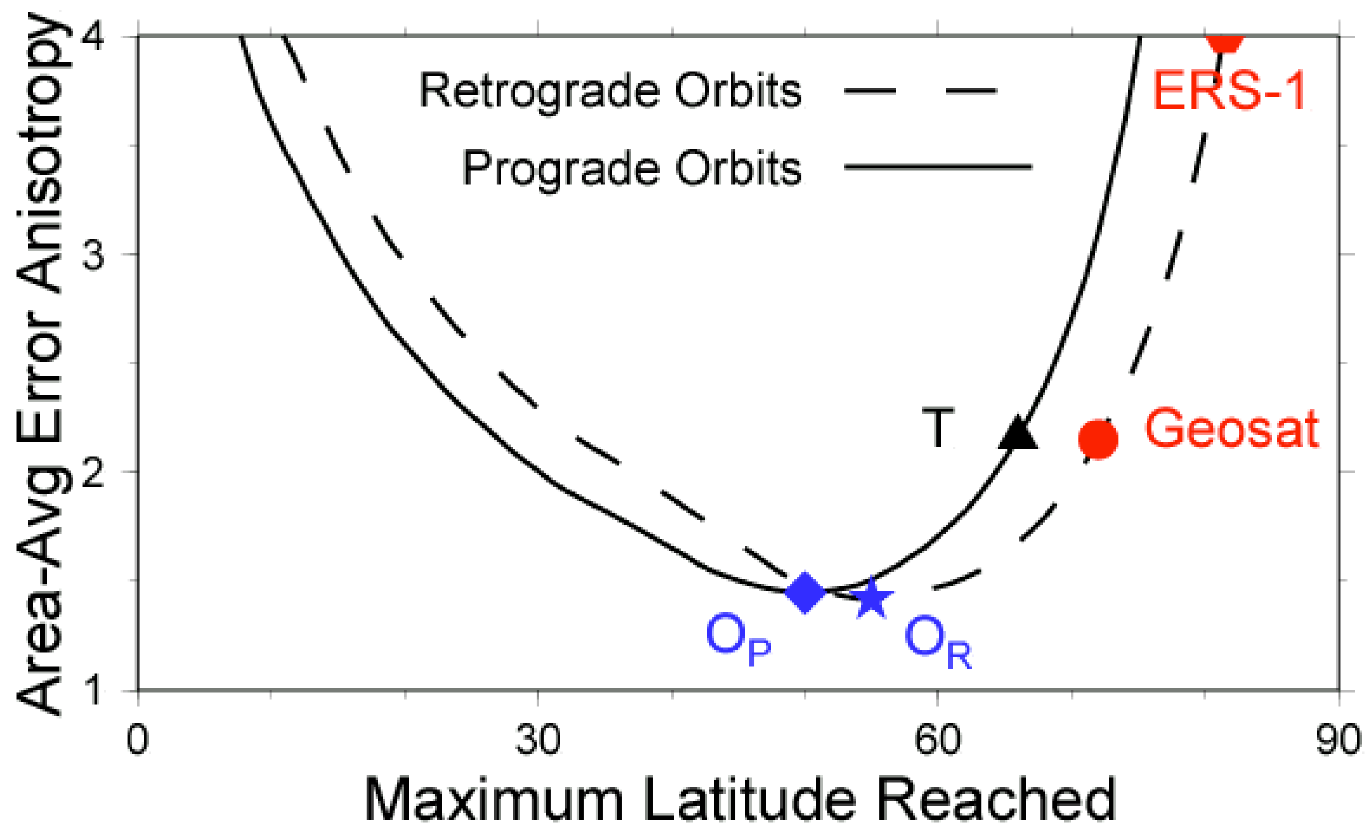


$$\sigma_x = \frac{\sigma}{\sqrt{2}\cos\theta}$$

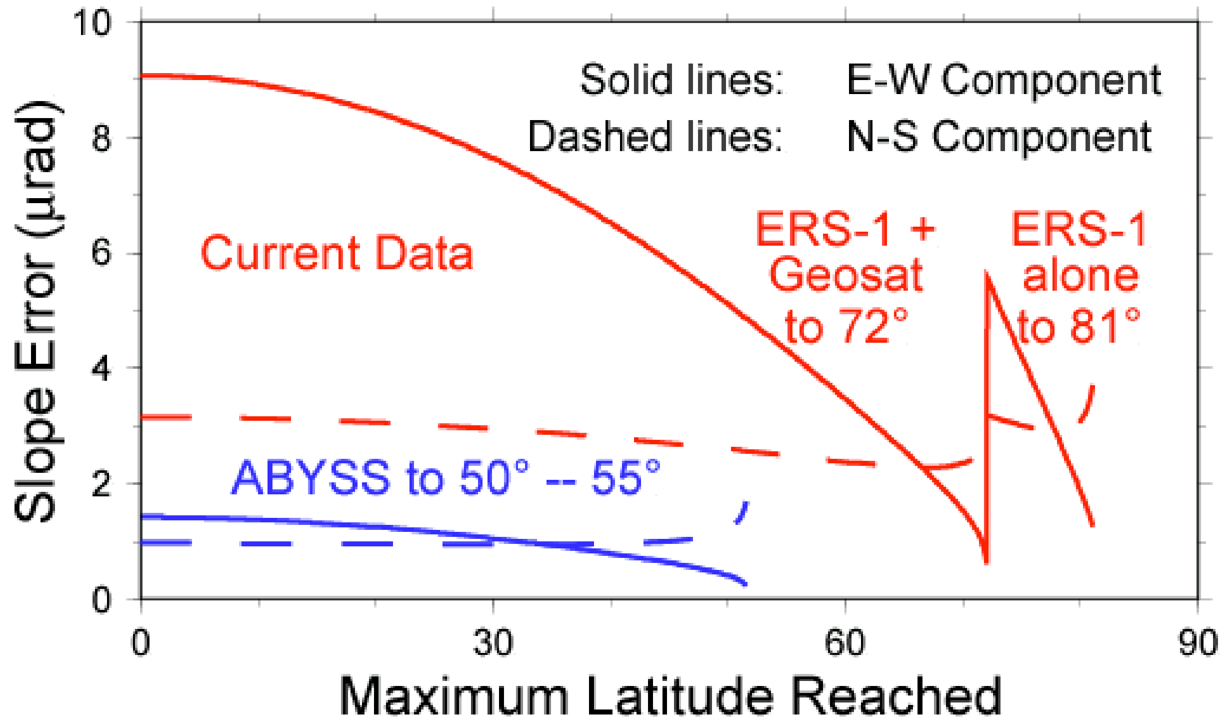
$$\sigma_y = \frac{\sigma}{\sqrt{2}\sin\theta}$$

Orthogonal tracks are optimal

Each Inclination Has an Associated Ocean-Area-Averaged Anisotropy in N-S vs E-W Slopes



The Right Inclination Makes ABYSS Resolution More Isotropic and Covers the Important Areas



ABYSS gets more precise slopes, and more nearly equalizes N and E errors, in the band of latitudes where existing data are poor (80% of ocean area), optimizing resolution.

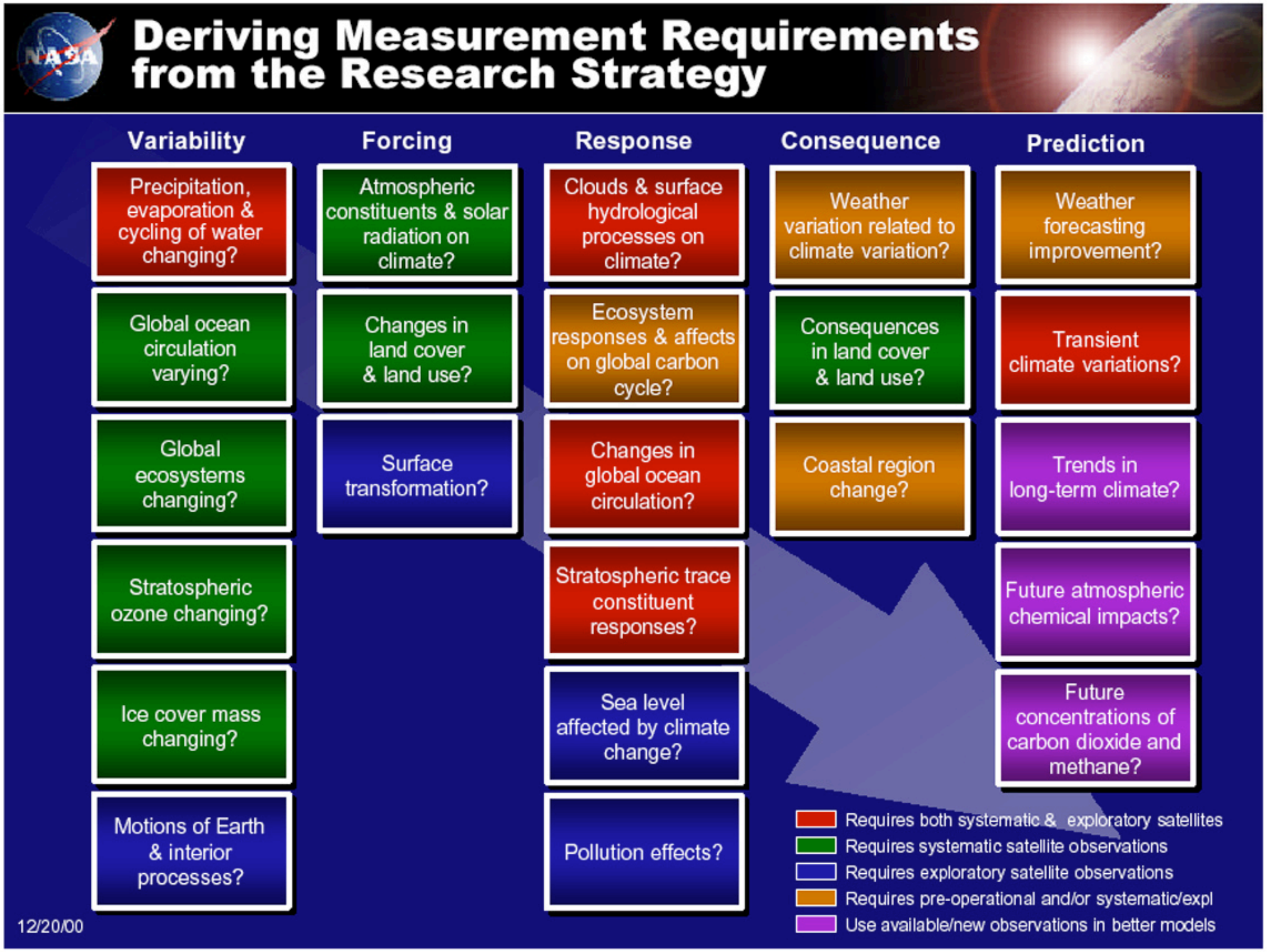
ABYSS Requirements Are Few and Simple

- **A precise altimeter**
  - Less wave-induced noise
- **Dense ground tracks**
  - ~6 km node spacing; repeat period > 1.2 years
- **A moderate inclination orbit**
  - 125° retrograde is optimal
  - 50° prograde is nearly optimal
- **A moderately long mission duration**
  - Baseline: 4 data collection cycles (6 yr w 25% reserve)
  - Minimum: 2 cycles (3 yr w 25% reserve, less precise)

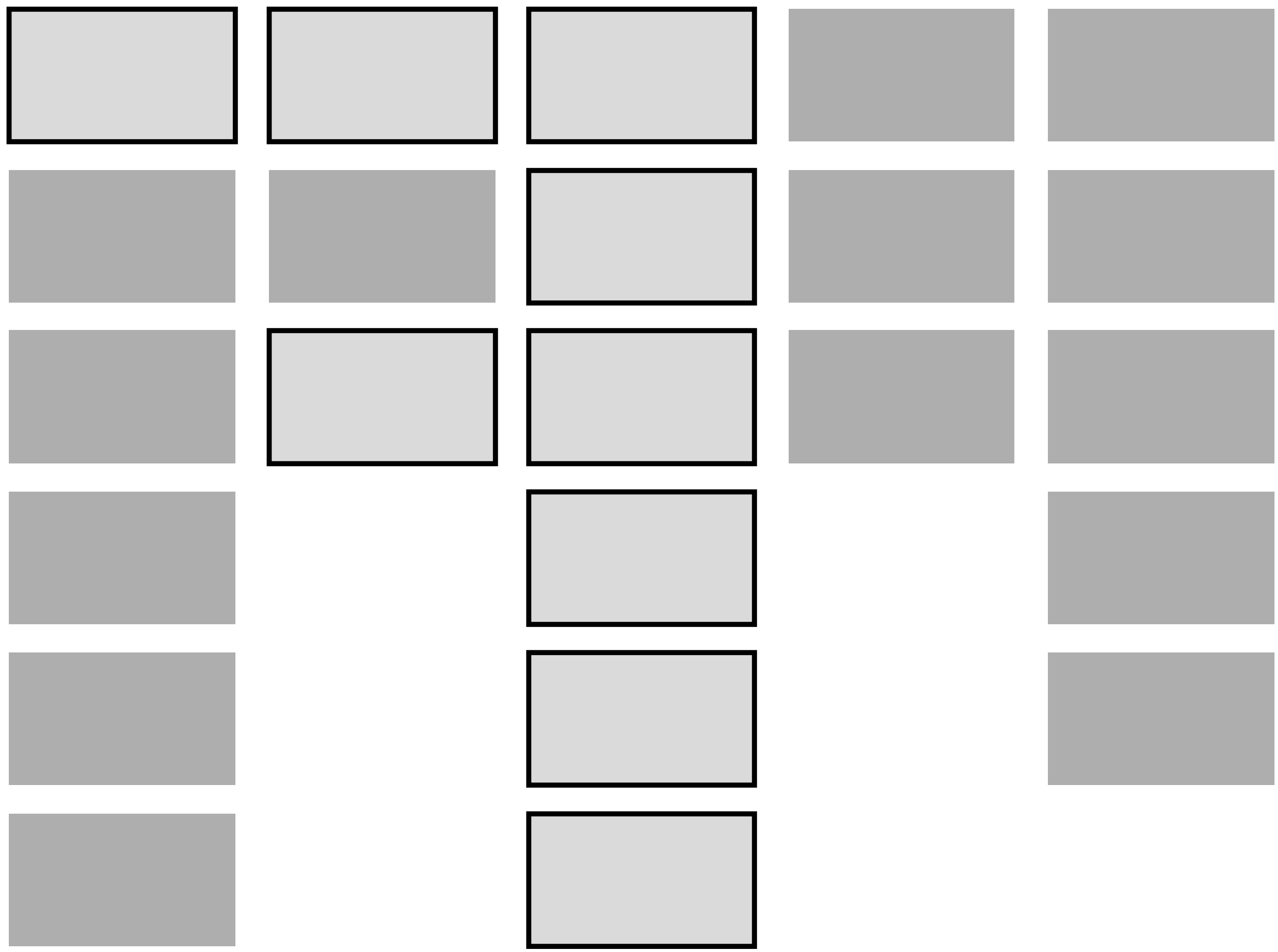
Through the Virtues of Surface Slopes, ABYSS Does NOT Require:

- **Auxiliary in situ measurements of radar path delays**
  - Dual-frequency ionosphere measurements
  - Water vapor radiometry
- **Precision orbit determination**
  - This will be done anyway, supported by NOAA, to serve secondary objectives and other customers
- **Long-wavelength (> 400 km, or 10 c.p.r.) absolute accuracy, or long-term stability of accuracy**

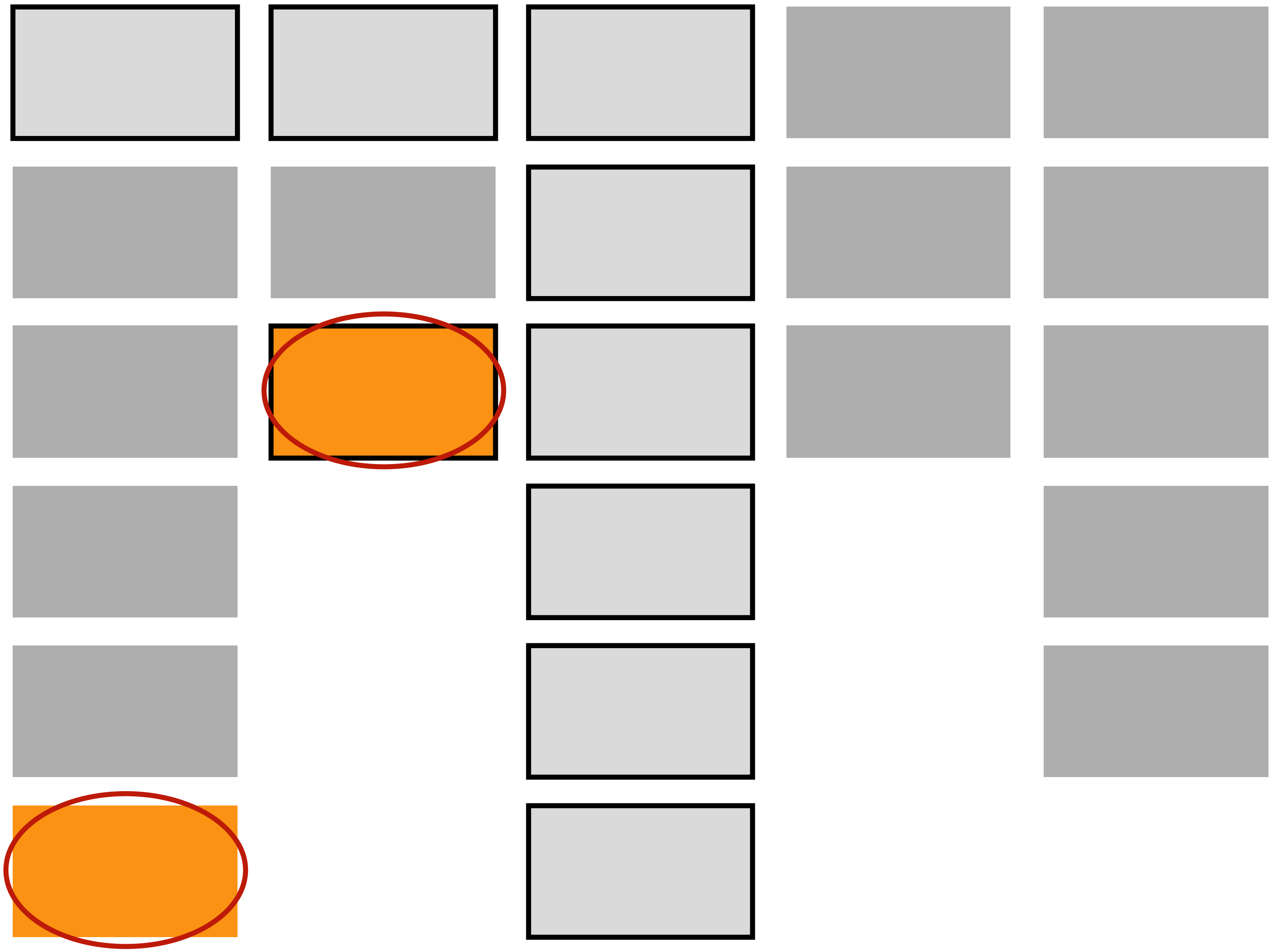
The ESE Research Strategy Science Questions: Where Does ABYSS Bathymetry Fit?



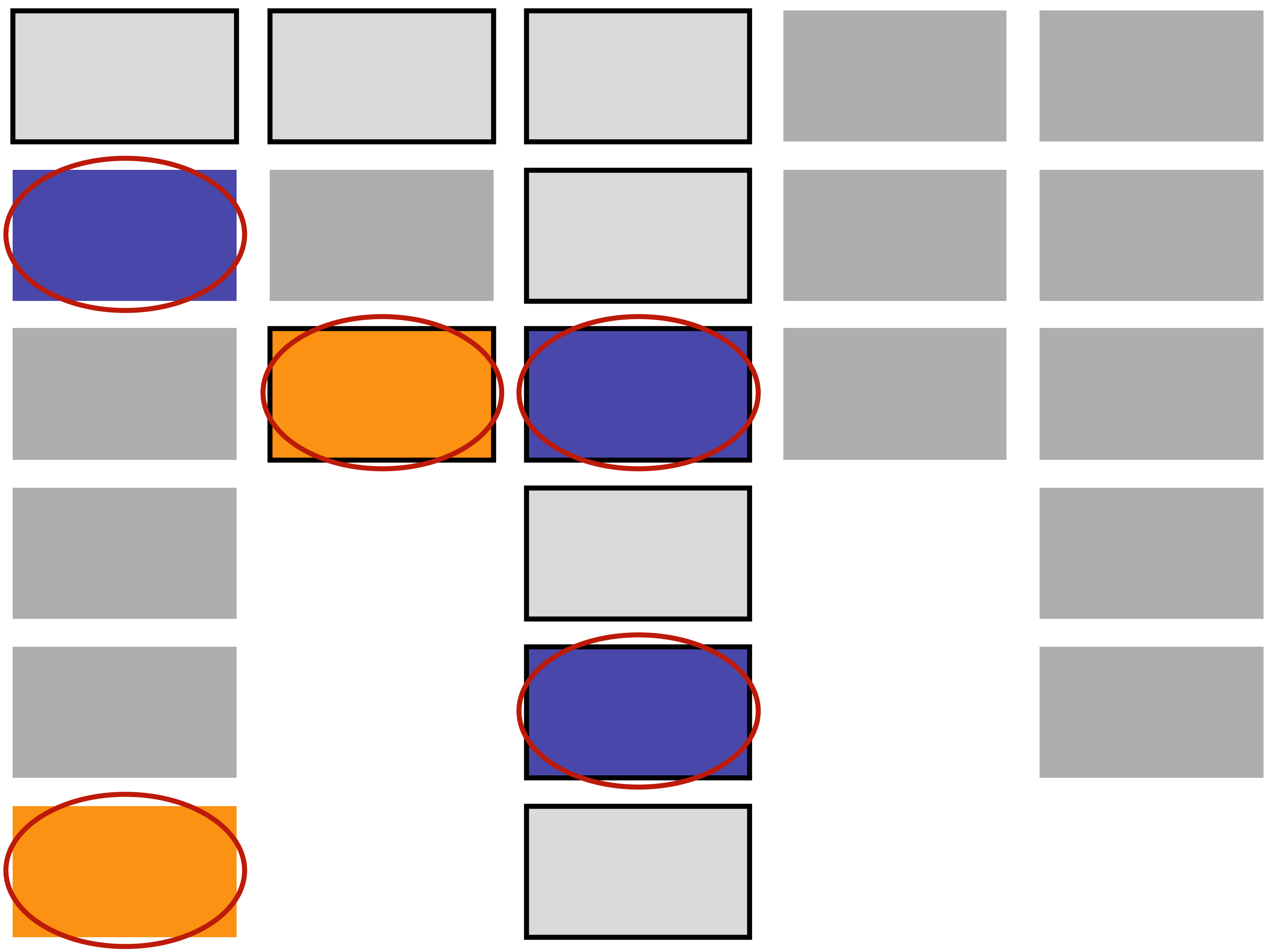
ESE has 23 Research Questions *(Dark Boxes)* with 9 Highlighted for ESSP-3 *(Light, Outlined)*



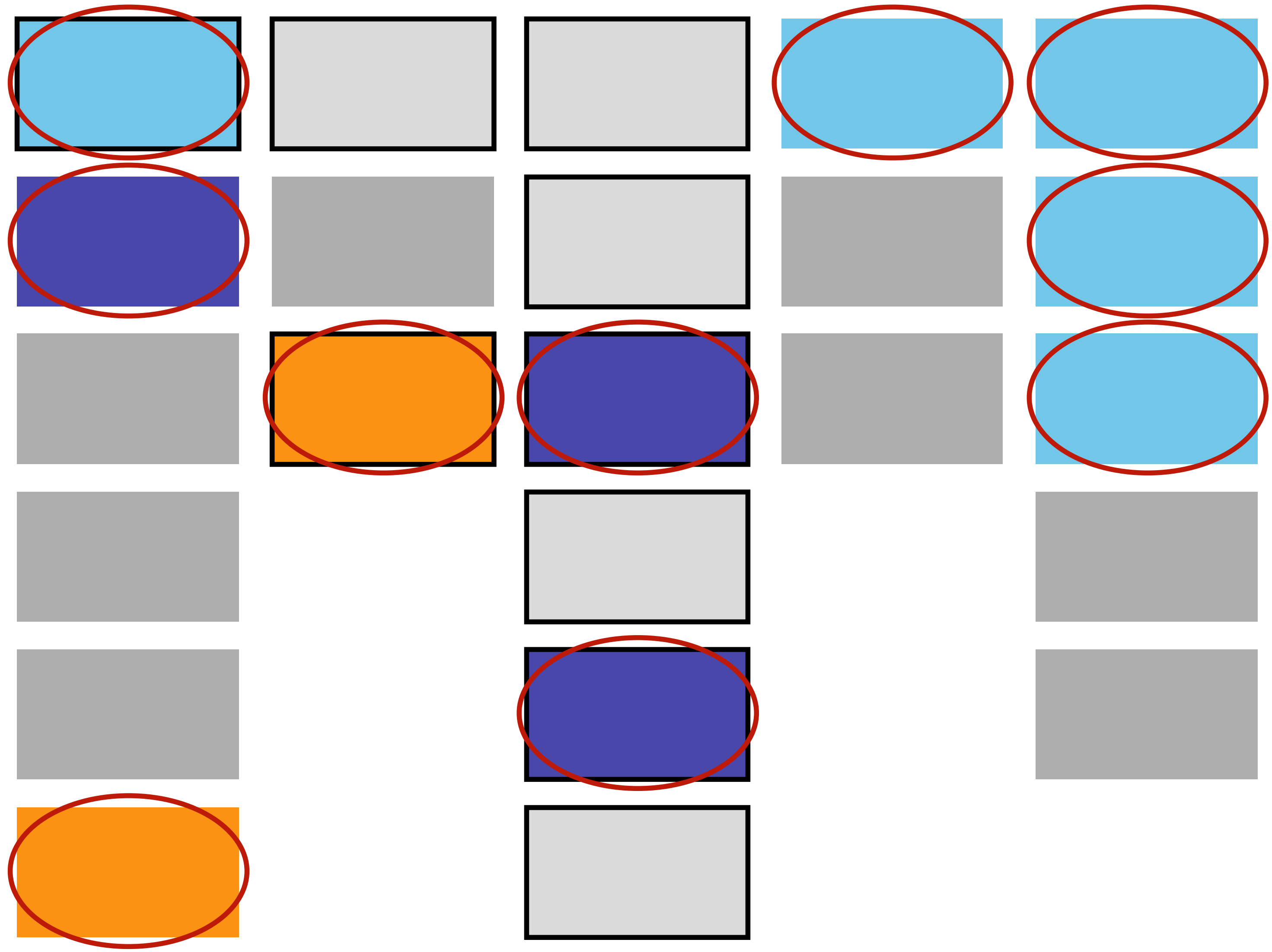
Surface Change, Earth Motion, Interior Process Qs Require Ocean Floor Tectonic Mapping



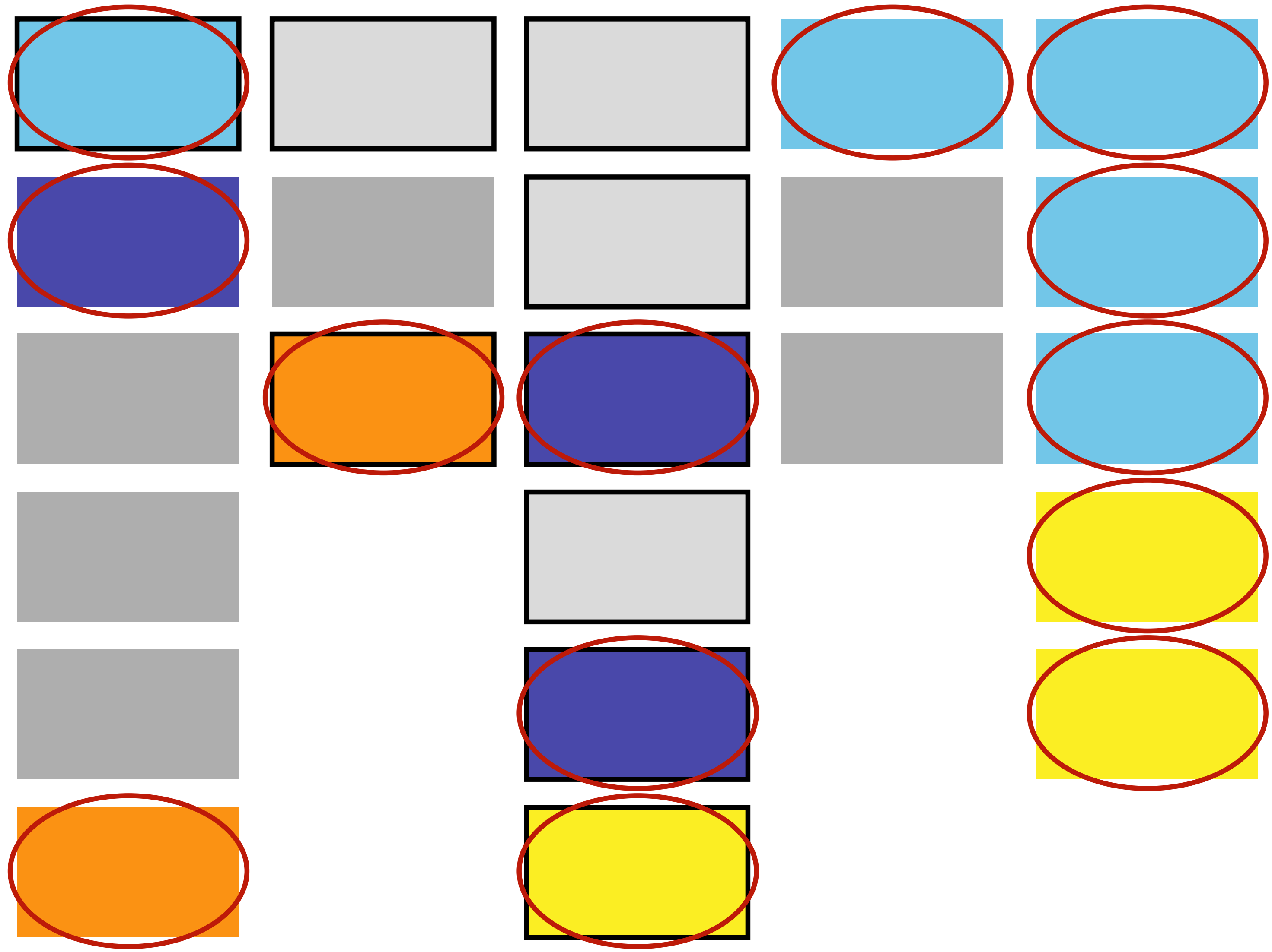
Ocean Circulation and Sea Level Qs Require an Ocean Model With Current Steering and Mixing



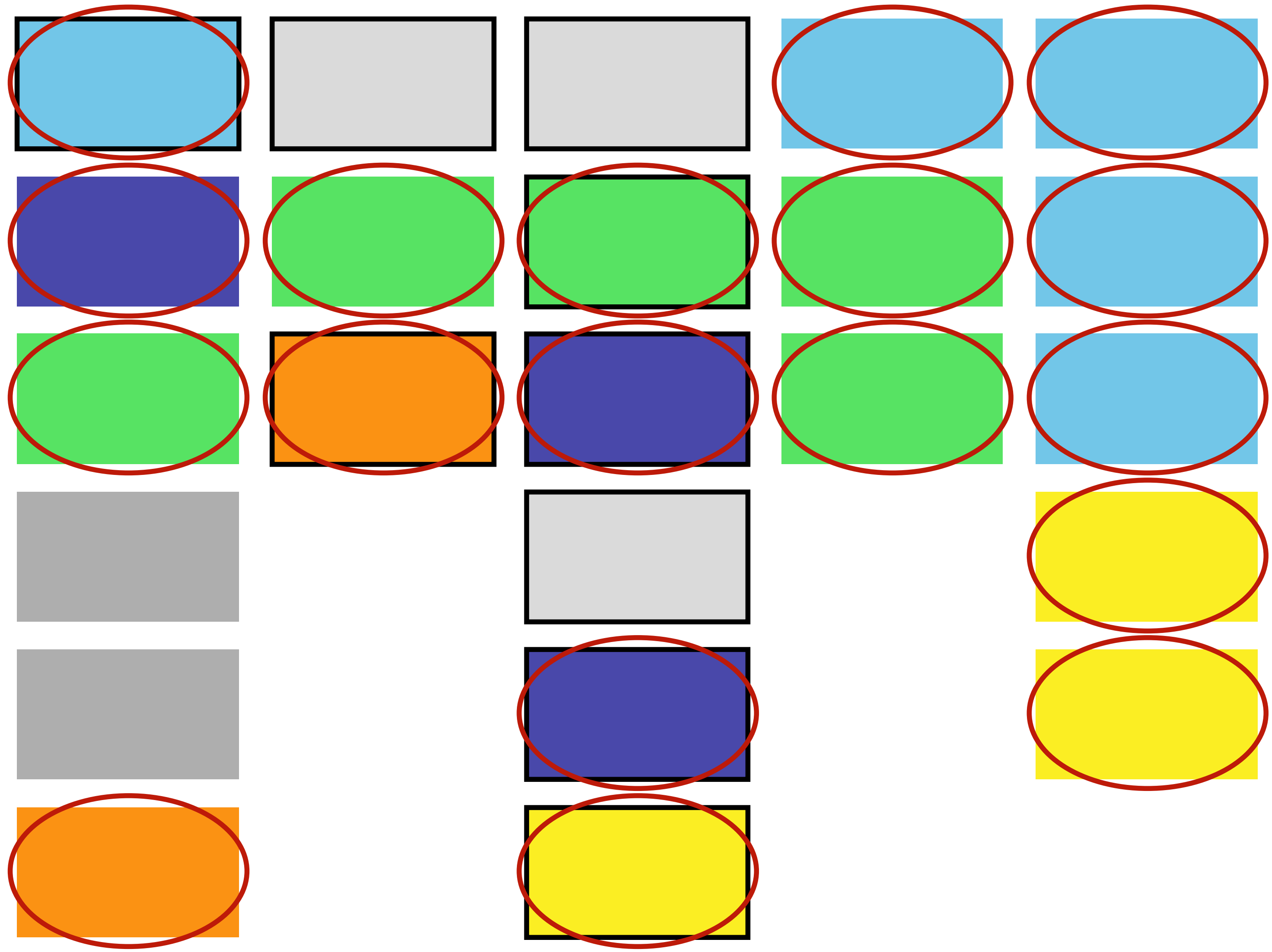
Weather and Climate Qs Require a Realistic Coupled Ocean-Atmosphere (O-A) Model



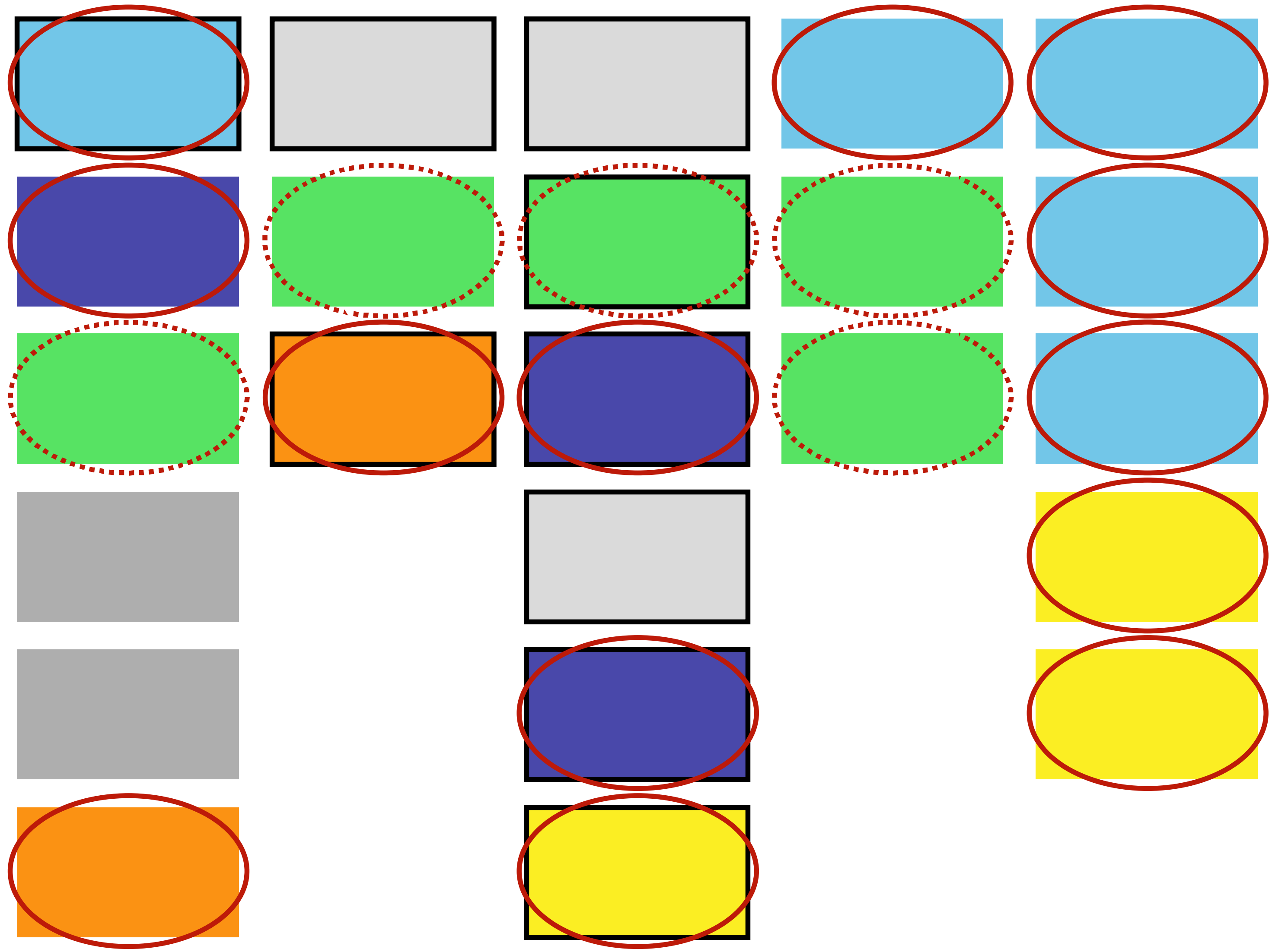
Atmos. Chem., Greenhouse Gas, and Pollution Qs Must Account for Ocean Mixing (Uptake) Rate



Ecology, Environ., Carbon Cycle, Land Use Qs Should Benefit from Realistic O-A Models



ABYSS is Required (Solid, 5 of 9 and 13 of 23) or Useful (Dashed, 1 of 9 and 5 of 23) Program-wide



ABYSS is Perfect for the ESE & ESSP-3 Because:

- **ABYSS fits all ESE Goals**
  - Science, Societal Benefit, Public Curiosity, Education, New Technology, National Priorities.
- **ABYSS covers all ESE Science Goal areas**
  - Climate, Weather, Natural Hazards; 13 to 18 of 23 ESE questions; and 5 or 6 of 9 ESSP-3 AO questions.
- **ABYSS is a pathfinder**
  - It creates a fundamental new scientific capability: realistic modeling of ocean's role in climate.
  - It needs to be done only once, and can only be done from space.
- **ABYSS is low risk and readily implemented**
  - Instrument Incubator heritage; existing, proven algorithms.
- **ABYSS leverages partner contributions**

ABYSS Should Begin NOW Because:

- Most of the ESE strategy requires a realistic model of ocean’s role in climate, greenhouse, ecology, etc.
- Lack of bathymetry is now a limiting factor in understanding and modeling ocean climate processes.
- Nothing is gained by waiting. ABYSS can’t get better in the future. The resolution limitations now are physical (upward continuation, fractal seafloor) not technological (altimeter instrument precision).
- Public curiosity and policy debate are now focused on ocean exploration, sea level rise, and ocean’s role in climate change.

Public Prefers to Explore Oceans Over Space

"Which do you consider to be a more important priority: Funding for space exploration or funding for ocean exploration?"

	Before Mars May 10–15, 1996 900 Adults	After Mars August 21–24, 1997 1014 Adults
Space	17%	35%
Ocean	72%	55%
Not Sure	11%	10%

ABYSS should stimulate public curiosity far more than any other NASA mission.

Altimetric Bathymetry from Surface Slopes

ABYSS