Tidal Energy and the 18.6 Year Cycle in the Bering Sea

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Outline:

- *Background*
- *Tidal model & inverse*
- *Energy fluxes and dissipation*
- *18.6 year cycle*
- *Summary*

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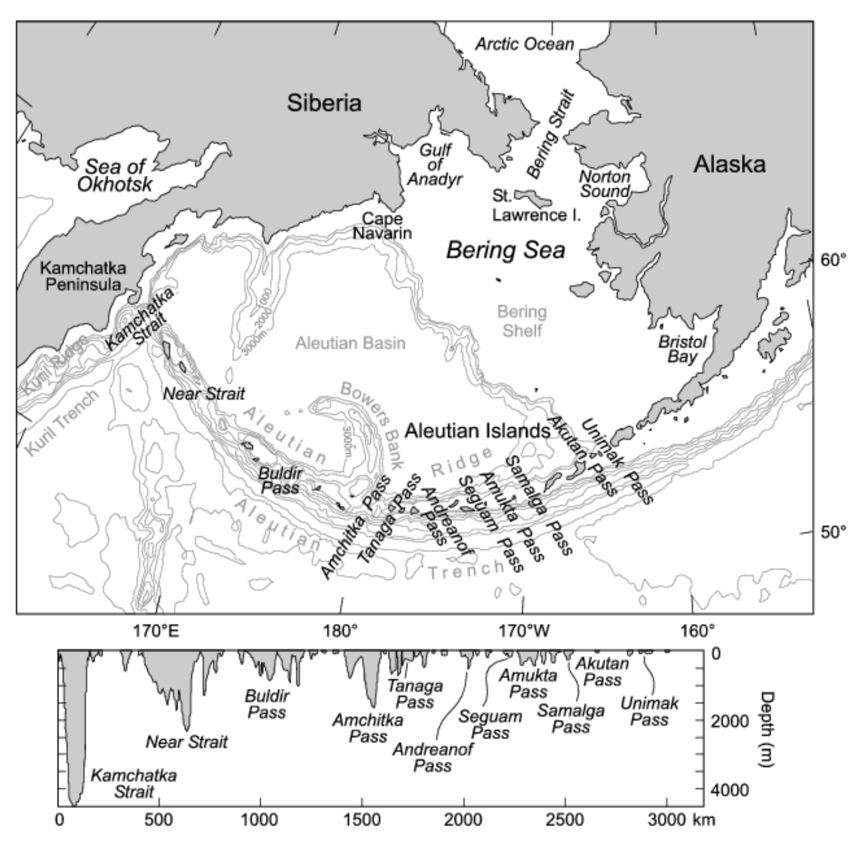
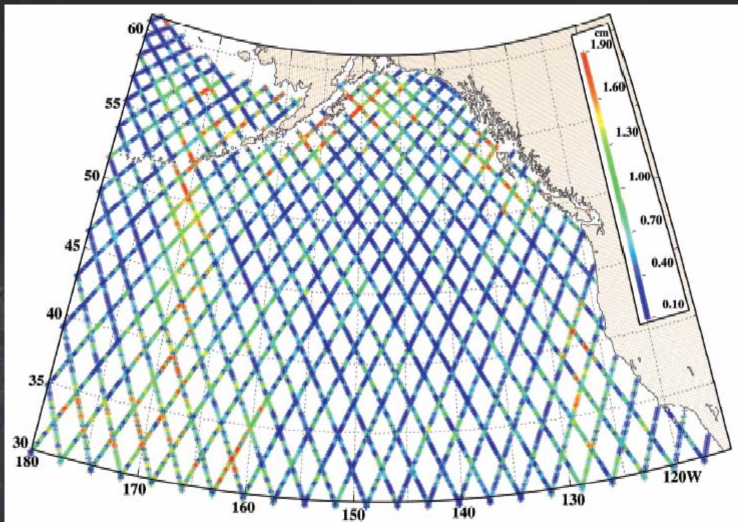
IOS

Background & Motivation

- complex tidal elevations & flows in the Bering Sea
  - ➢ Large elevation ranges in Bristol Bay
  - ➢ Large currents in the Aleutian Passes
  - ➢ both diurnal & semi-diurnal amphidromes
  - ➢ Large energy dissipation (Egbert & Ray, 2000)
  - ➢ Interactions with seasonal ice cover
  - ➢ Internal tide generation from Aleutian passes (Cummins et al., 2001)

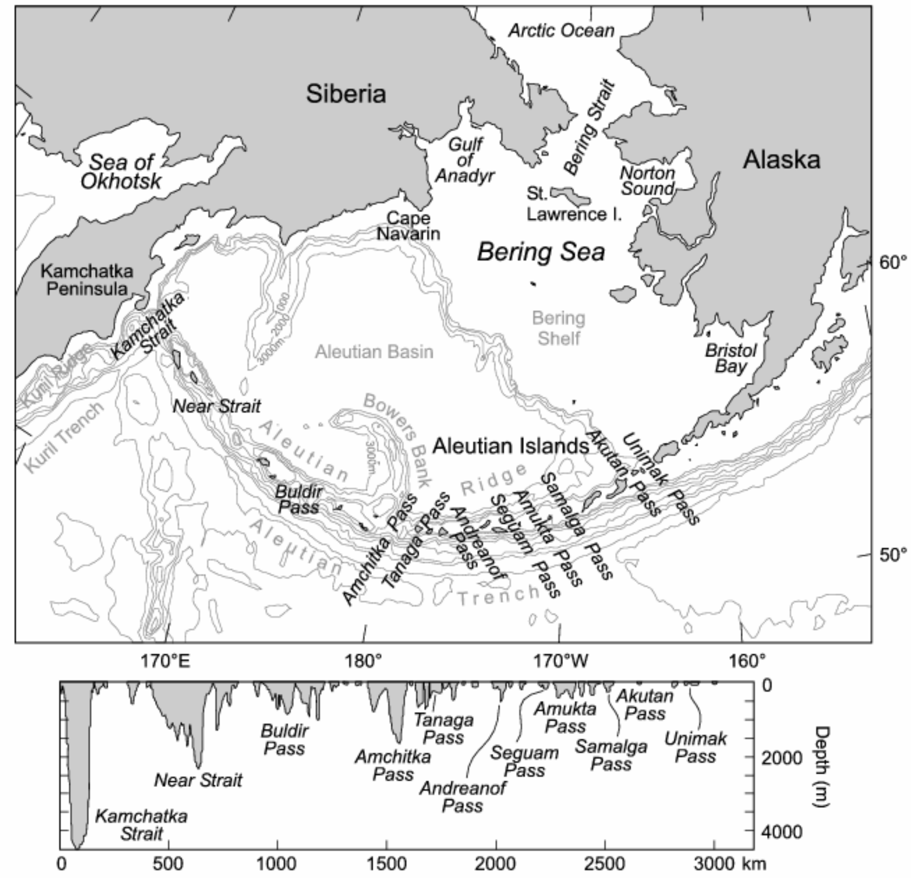




Background & Motivation

- Wide shelf, complex bathymetry, narrow entrances
- Relatively large diurnal currents that will have 18.6 year modulations

- Difficult to get currents & energy balance right with only a forward model
- Need to incorporate observations
    - Data assimilation



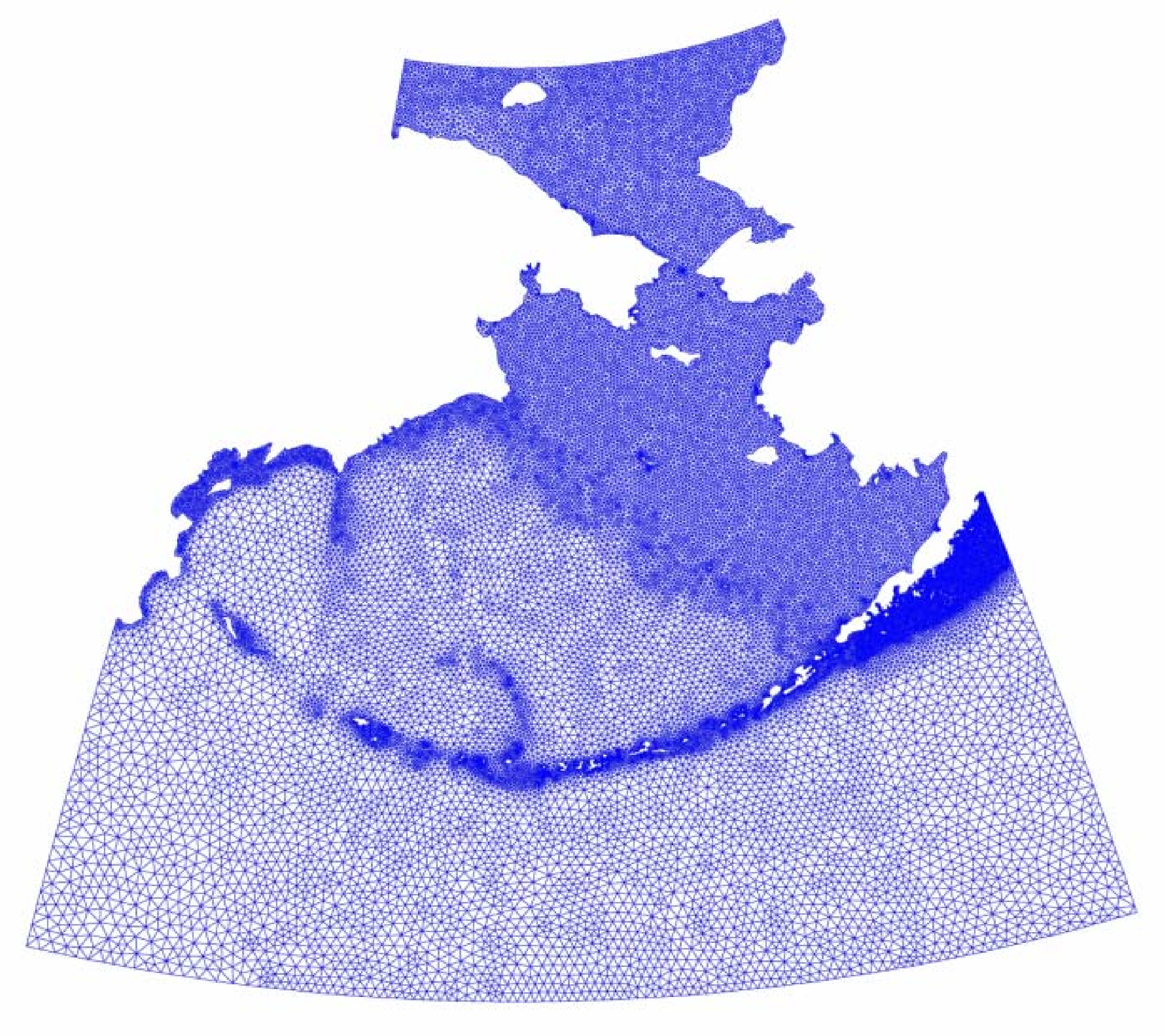
The Numerical Techniques

- Barotropic finite element method FUNDY5SP (Greenberg et al., 1998):
  - linear basis functions, triangular elements
  - $e^{-i\omega t}$ time dependency, ω = constituent frequency
  - solutions (η,u,v) have form Ae^{ig}
  - Provides an initial solution

- FUNDY5SP adjoint model
  - development parallels Egbert & Erofeeva (2002)
  - representers: Bennett (1992, 2002)
  - allows improvement of initial solution by assimilating observations

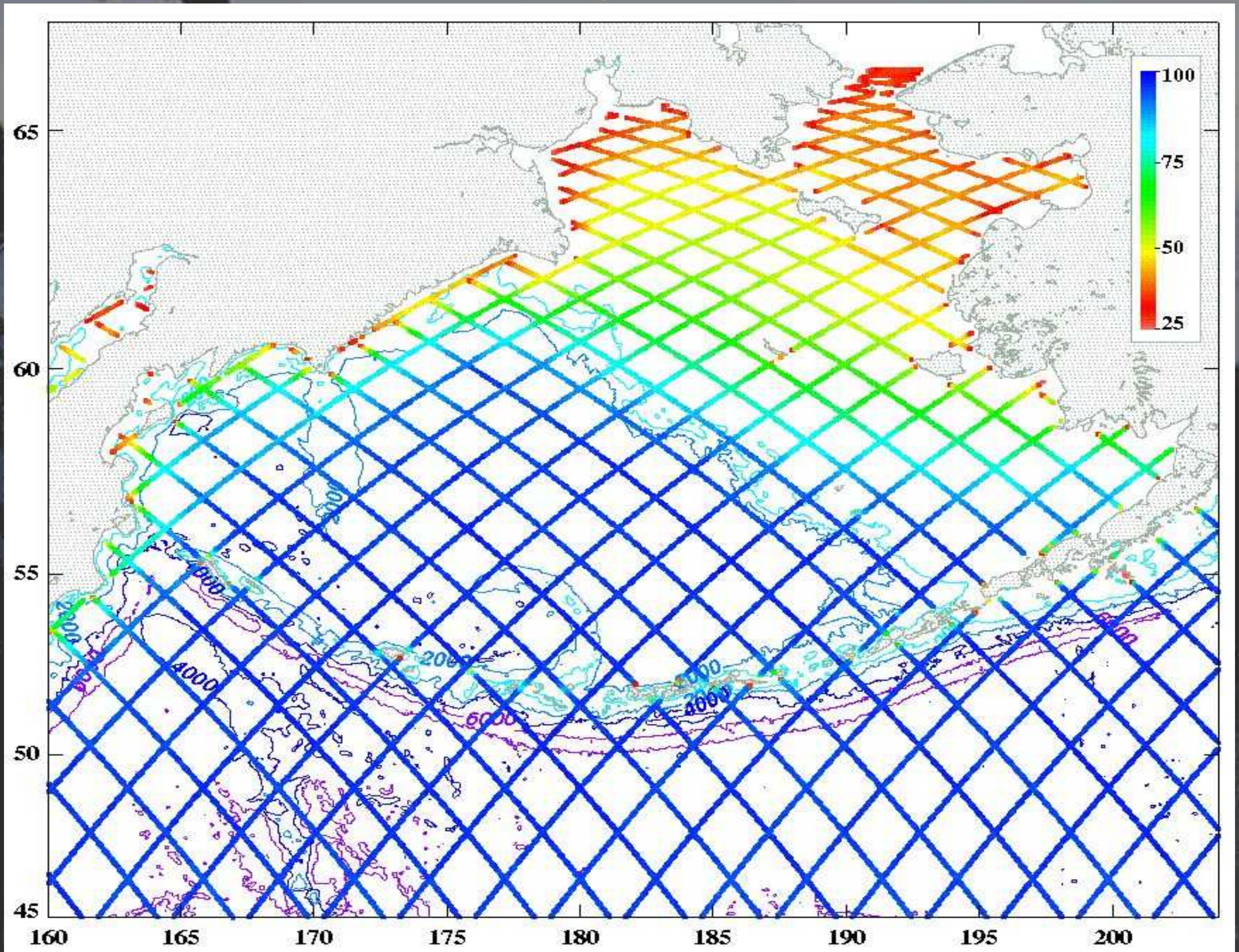
Grid & Forcing

- **variable resolution:**
  - **50km to less than 1.5km**
  - **29,645 nodes, 56,468 triangles**
- **Forcing:**
  - **Tidal elevation boundary conditions from Topex Poseidon crossover analysis**
  - **Tidal potential, earth tide, self-attraction & loading**



Assimilated Tidal Observations

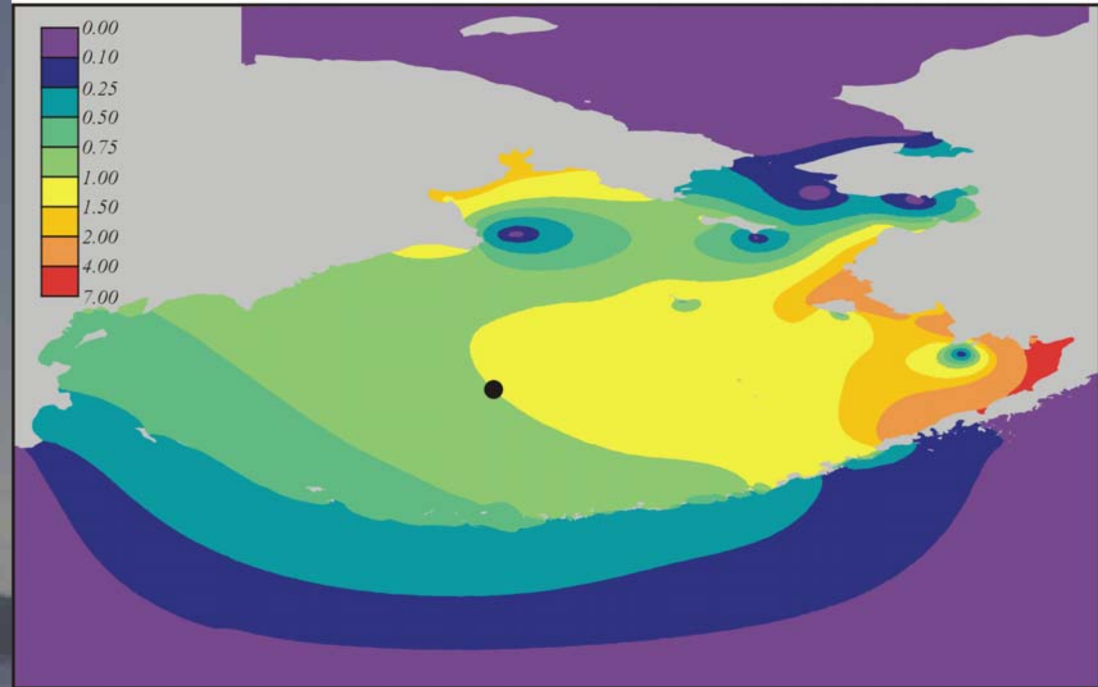
- from tidal analysis at T/P crossover sites (Cherniawsky et al. 2001)

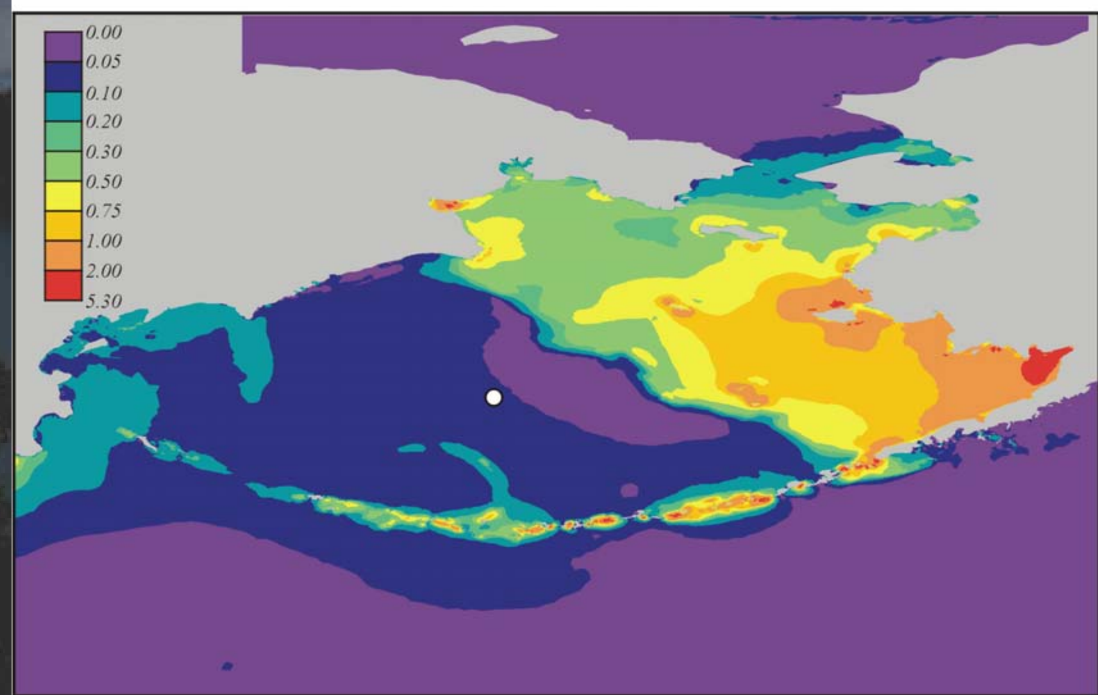


Elevation Amplitude & Major Semi-axis of a sample M_2 Representer

(amplitude normalized to 1 cm)

- these fields are used to correct initial model calculation





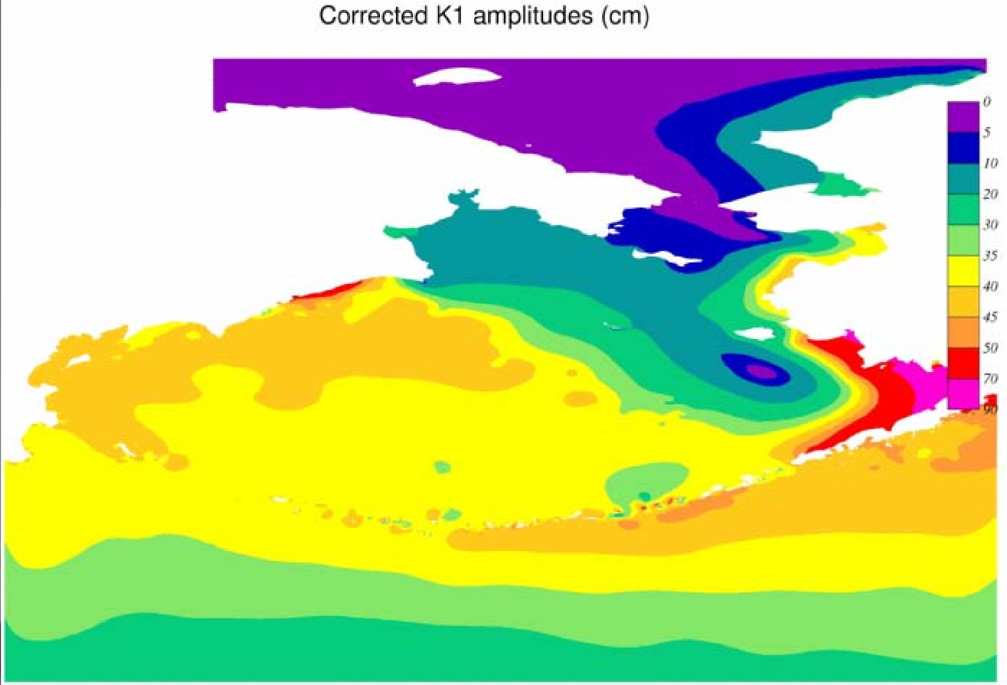
Model Accuracy Assessment:

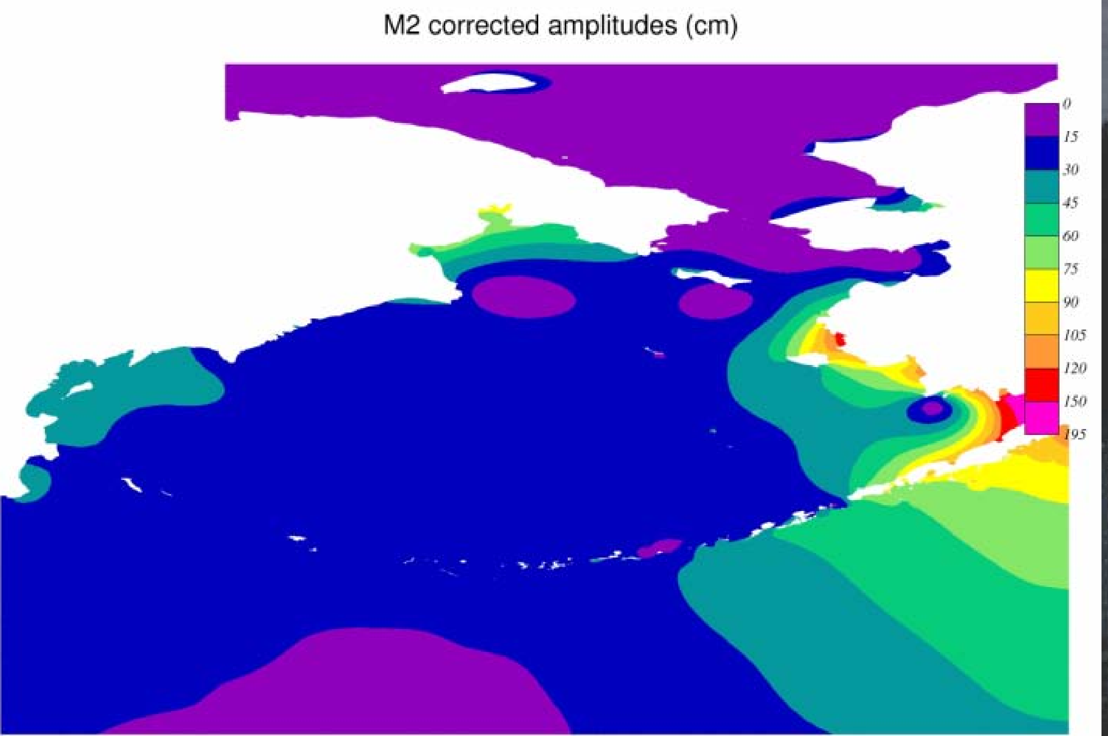
average *D (cm)* at 288 T/P crossover sites

$$D = \left\{ (A_0 \cos g_0 - A_m \cos g_m)^2 + (A_0 \sin g_0 - A_m \sin g_m)^2 \right\}^{1/2}$$

	M_2	K_1	N_2	O_1	S_2	P_1
Prior model	5.4	3.8	1.8	2.9	4.0	1.3
With T/P assimilation	2.6	2.1	1.1	1.6	1.0	1.0

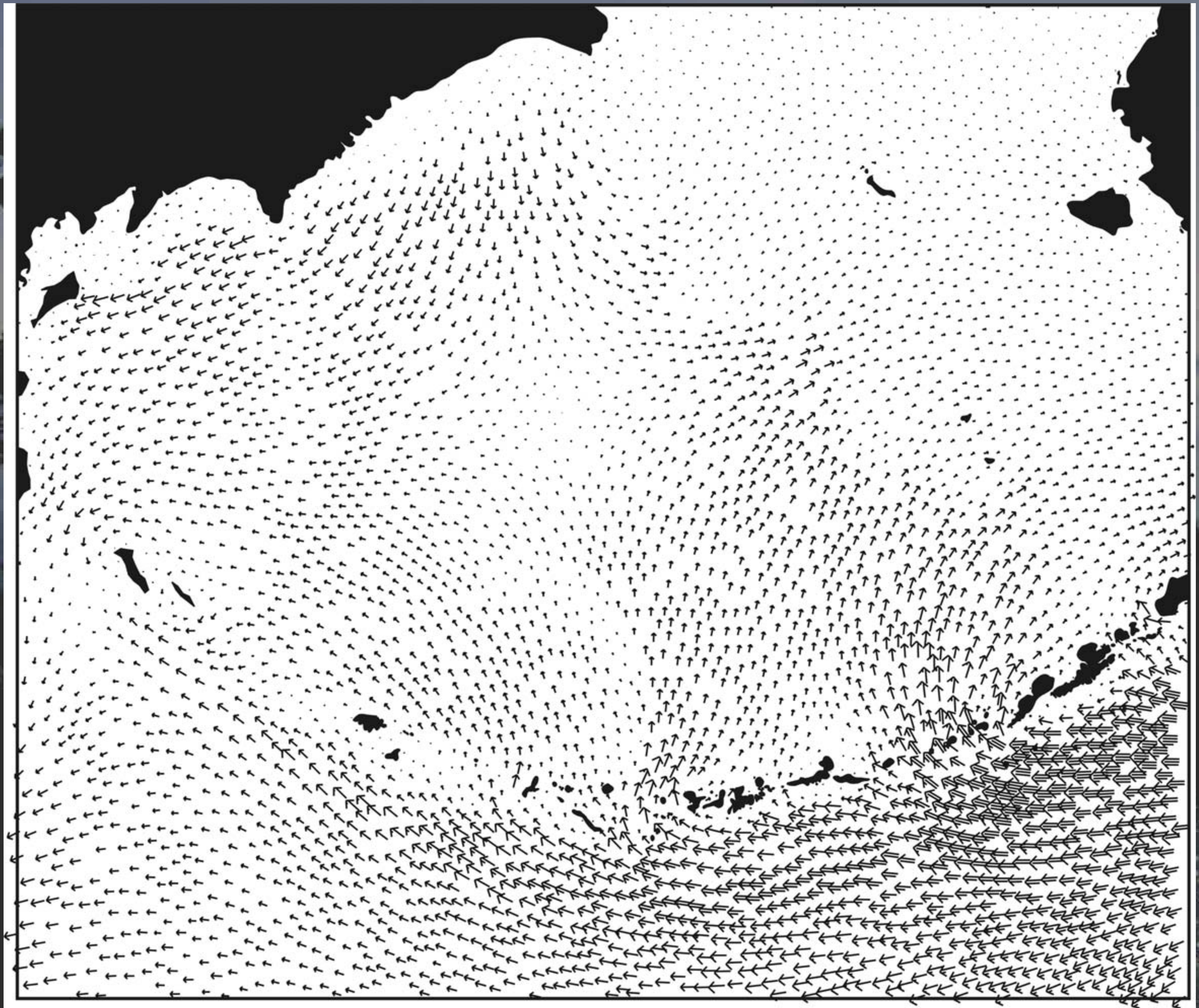
Corrected Elevation Amplitudes





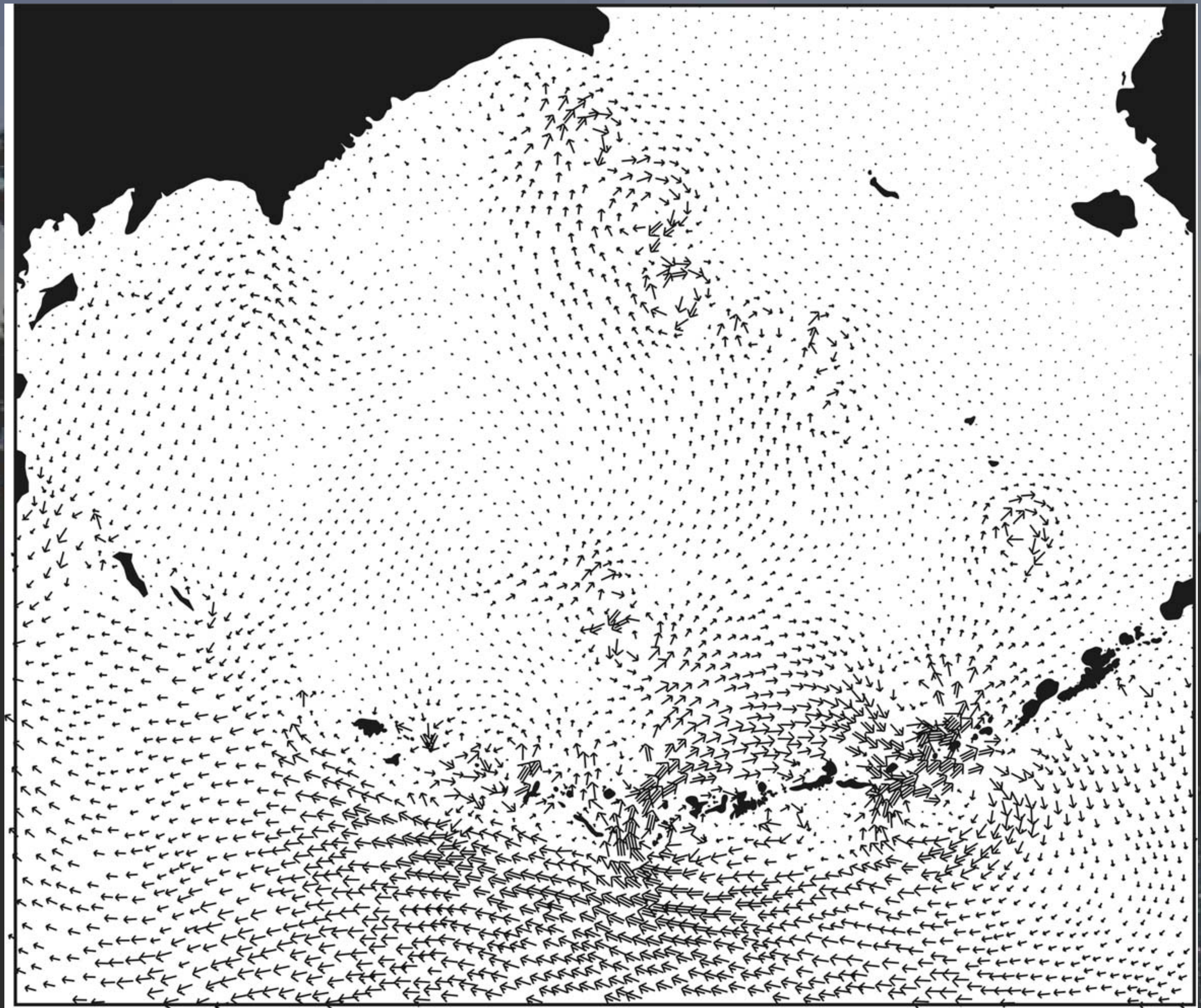
M_2 vertically-integrated energy flux

(each full shaft in multi-shafted vector represents 100KW/m)



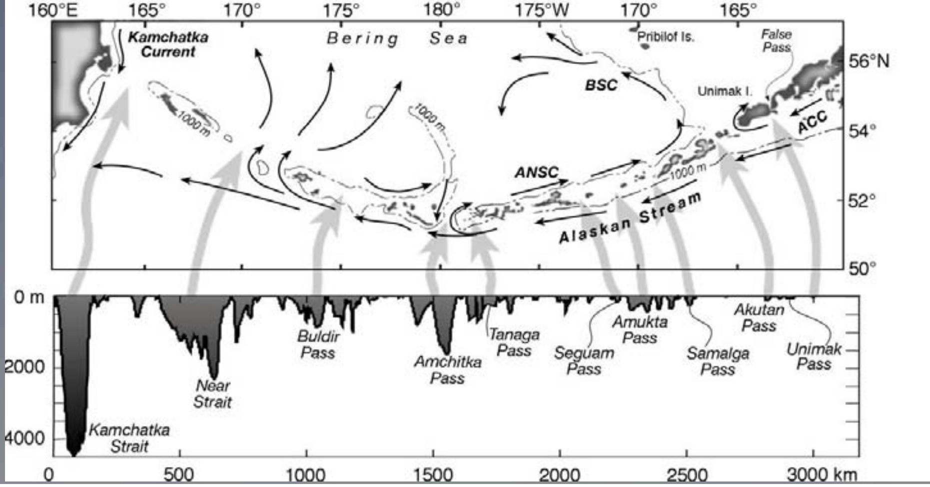
K_1 vertically-integrated energy flux

(each full shaft in multi-shafted vector represents 100KW/m)



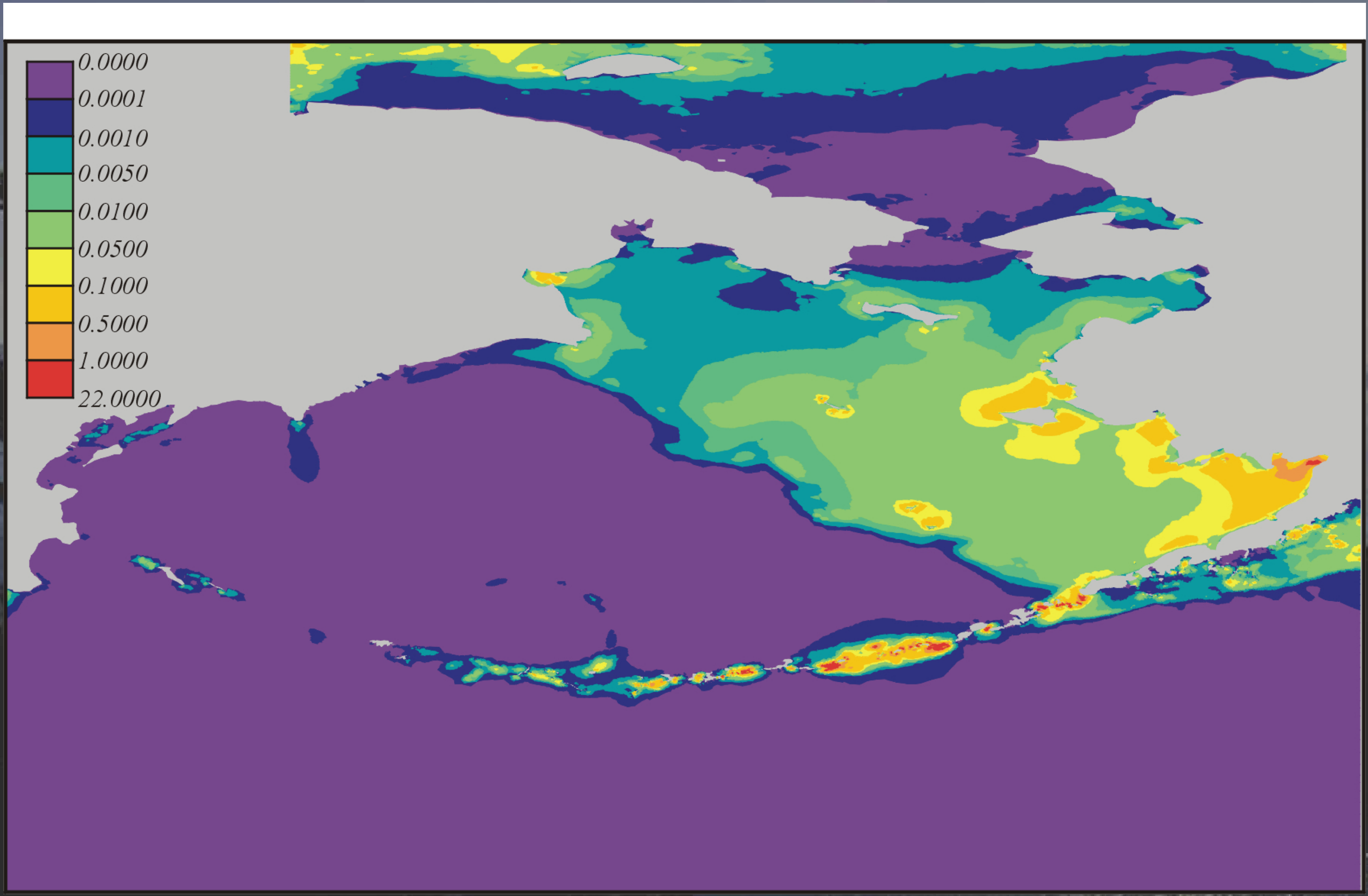
Energy Flux Through the Aleutian Passes & Bering Strait

(Vertically integrated tidal power (GW) normal to transects)



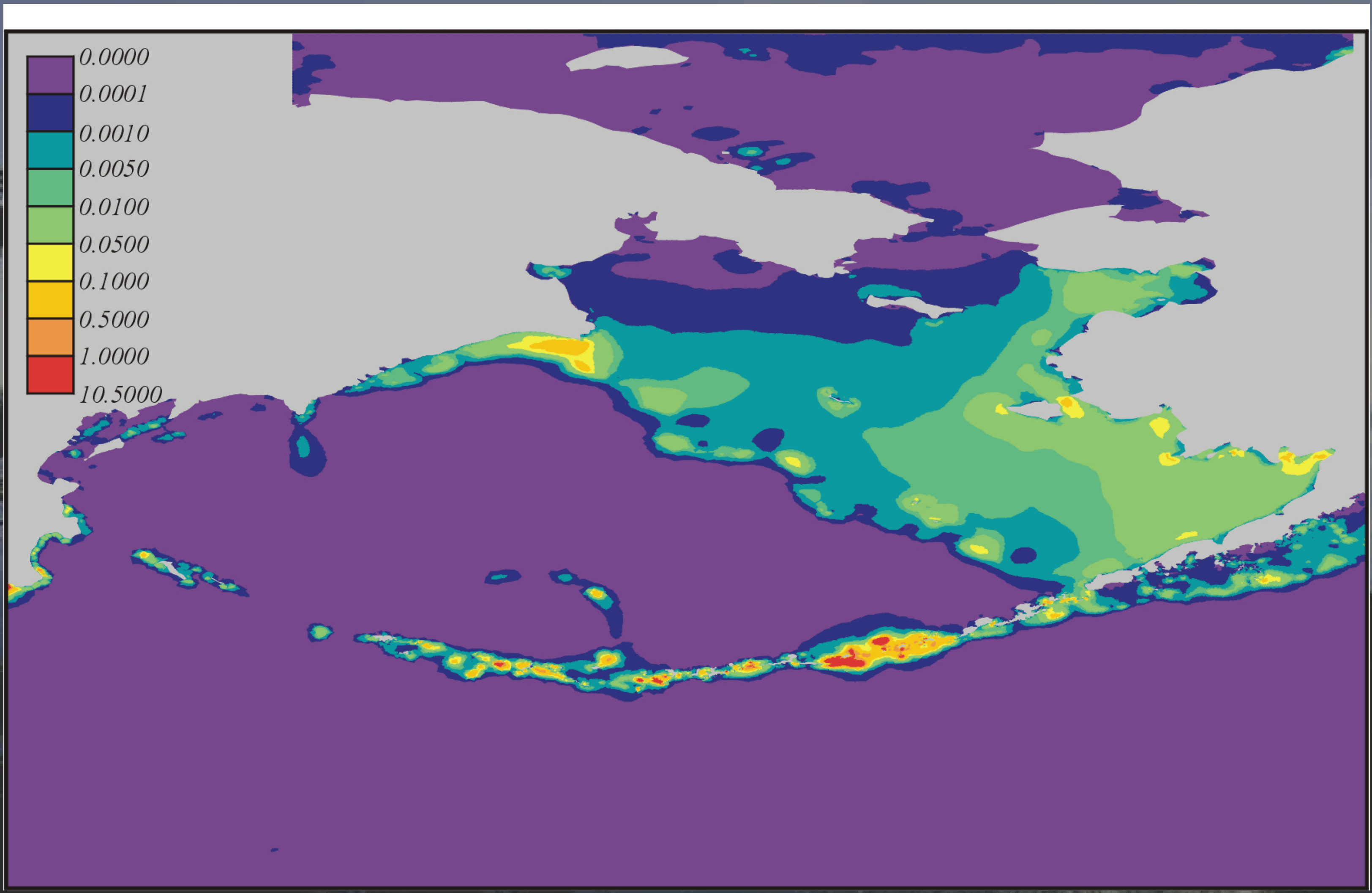
Pass(es)	M_2	N_2	S_2	K_1	O_1	P_1
Unimak	2.7	0.2	0.0	0.4	0.4	0.0
Akutan	1.0	0.1	0.0	0.1	0.1	0.0
Samalga	10.0	0.8	0.0	3.4	1.3	0.4
Amukta	12.5	1.1	-0.4	7.3	1.2	0.8
Seguam	1.6	0.1	-0.1	-2.7	-1.8	-0.2
Andreanof	2.1	0.2	-0.1	0.2	0.1	0.0
Tanaga	4.2	0.3	0.0	-.3	-0.4	0.0
Amchitka	8.0	0.6	-0.1	22.9	12.2	2.3
Buldir	5.8	0.4	0.2	7.9	1.6	0.9
Near	-8.4	-0.2	0.0	-4.8	0.2	-0.6
Kamchatka	-8.3	-0.3	-0.4	-9.5	-1.9	-1.3
Bering Strait	0.0	0.0	0.0	0.0	0.0	0.0
Total	**31.2**	**3.3**	**-0.9**	**24.9**	**13.0**	**2.3**

M_2 Dissipation from Bottom Friction (W/m^2)



- Mostly in Aleutian Passes & shallow regions like Bristol Bay
- Bering Sea accounts for about 1% of global total of 2500 GW

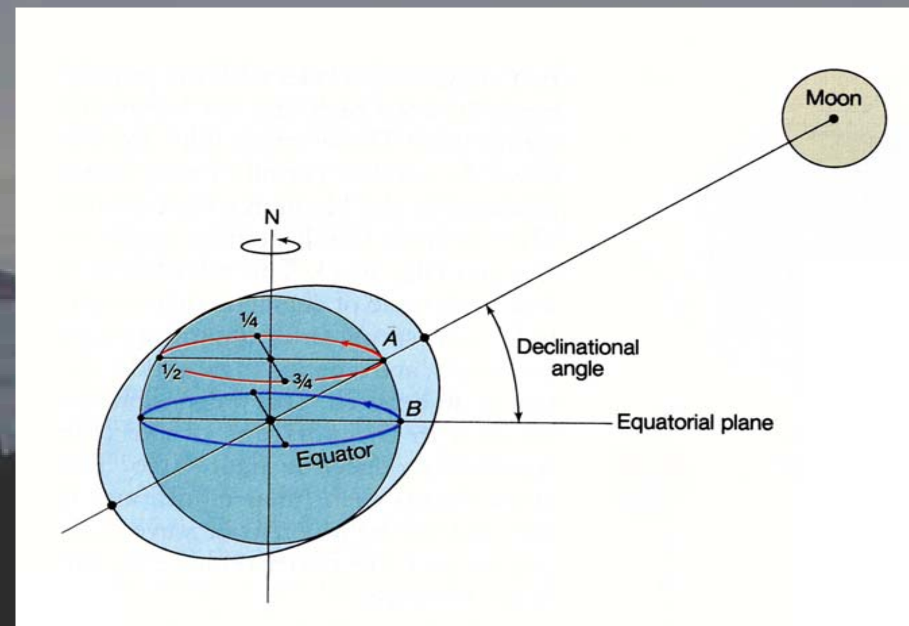
K_1 Dissipation from Bottom Friction (W/m^2)



- K_1 dissipation mostly in Aleutian Passes, along shelf break, & in shallow regions
  - Strong dissipation off Cape Navarin as shelf waves try to turn corner
  - enhances mixing and nutrient supply → biological implications
- Bering K_1 dissipation accounts for about 7% of global total of 343GW

18.6 Year Nodal Cycle

- **Declination of moons' orbit to equator varies between 18.3° and 28.6° over 18.61 year period**



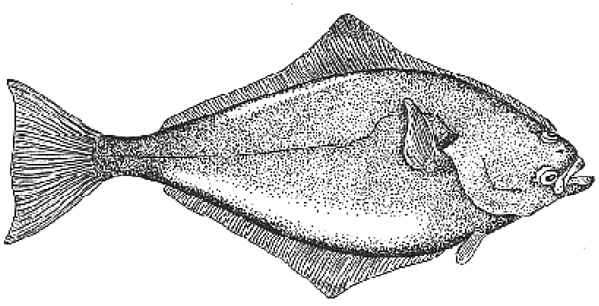
- **leads to a small tidal constituent with 18.6 yr period & modulation of most major constituents**
  - **~ ±4% for M_2**
  - **~ ±13% for K_1**
  - **~ ±19% for O_1**

- **K_1/O_1 modulations synchronous but out of phase with M_2**

- **K_1/O_1 modulations: max in 2006, min in 1997**

18.6 Year Nodal Cycle

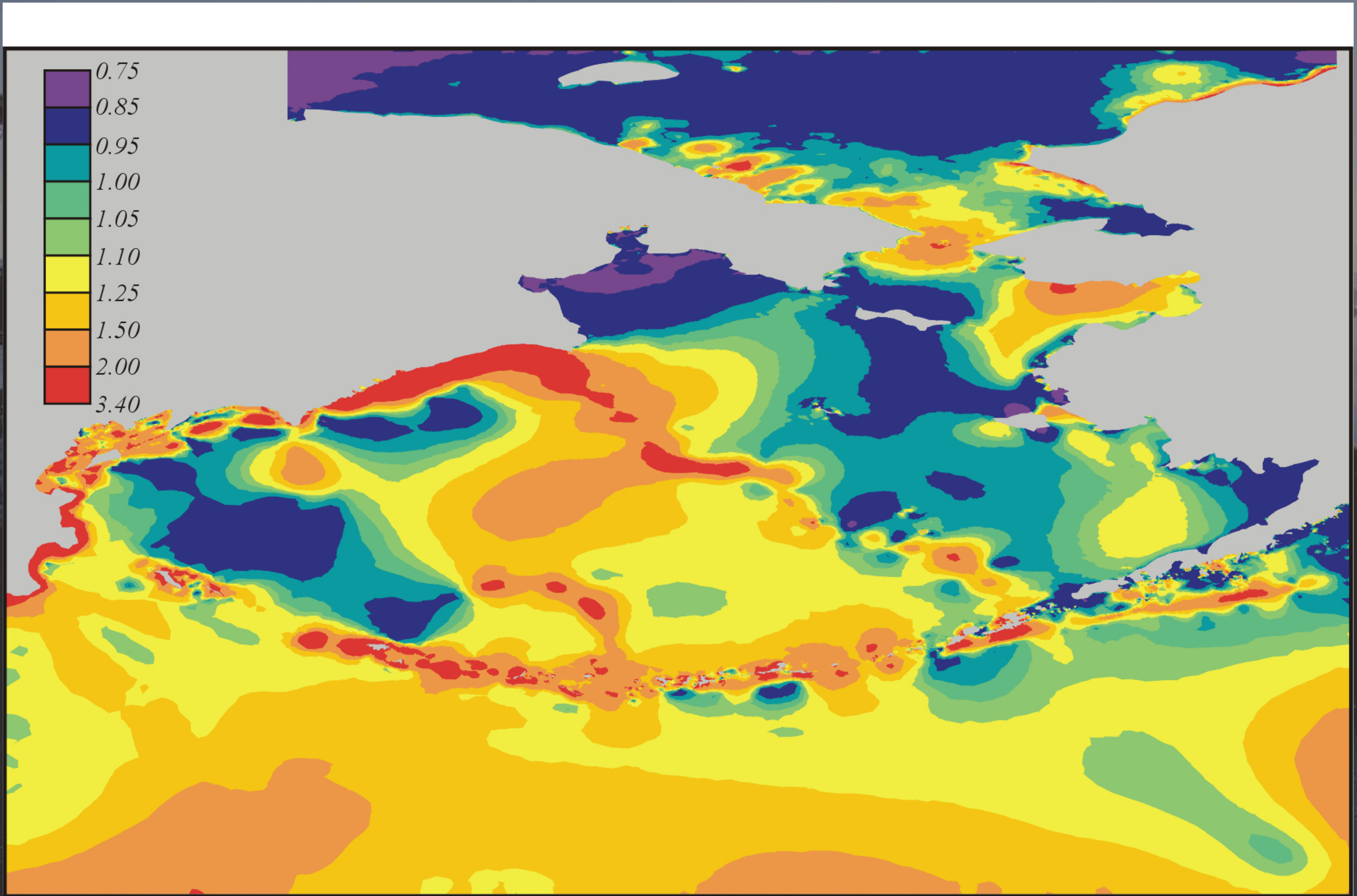
- Model estimates 19% increase in incoming tidal energy flux to Bering Sea from 1997 to 2006
  - Regional variations with relative magnitude of constituent amplitudes
  - 36% increase in Amchitka Pass
- Expect variations in energy dissipation, mixing, ice cover, and biological productivity
  - dissipation varies as cube of velocity
  - Parker et al. (1995) found correlation with Pacific halibut recruitment



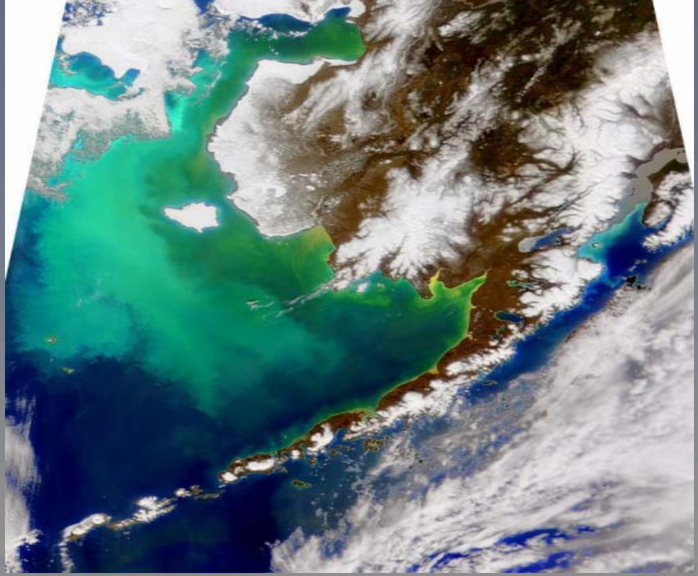
Pacific Halibut

Hippoglossus stenolepis

Ratio of average bottom friction dissipation in April 2006 to that in April 1997



Summary



- **many interesting physical & numerical problems associated with tides in the Bering Sea**
- **representer approach is instructive way to solve the inverse problem**
- **18.6 year nodal cycle**
  - **significant variation in energy dissipation in regions where diurnal tides dominate**
  - **should correlate with water properties (next speaker) & biological productivity**
- **More details in Foreman et al., Nov 2006 issue of *Journal of Marine Research***