Marine Energy Technology Advancement Partnership Webinar

Project Status Update & Briefing on DOE MHK Resource Assessments

March 29, 2012

Hosted by Mark Sinclair, CESA

Clean Energy States Alliance

Housekeeping

- You can connect to the audio portion of the webinar using your computer's speakers or a headset. You can also connect by telephone. If using the telephone, please enter your "PIN" number shown on the audio box on the webinar console.
- All participants will be in listen-only mode. You can click on the "Raised Hand" icon tab on the webinar console to indicate you have a question and need to be un-muted.
- You can also submit questions for today's event by typing them into the "Question Box" on the webinar console. Questions about today's topic will be answered, as time allows, following the presentation.
- This webinar is being recorded and will be made available after today's broadcast on the CESA website at

  http://www.cleanenergystates.org/projects/marine-energy-technology-advancement-project/

CleanEnergy States Alliance

About the METAP Project

- The purpose of this project is to accelerate the overall pace of development and commercialization of marine renewable energy in the United States through a strategic, collaborative approach between state and federal agencies.
- METAP aims to link and coordinate the MHK technology support activities in states with the DOE Wind and Water Program's MHK activities. Specifically, METAP's goals are to accelerate support for the MHK industry in the U.S. and increase and leverage public funding for the most promising wave, current, and tidal devices through a collaborative State-Federal funding process. METAP was led by the Clean Energy States Alliance (CESA), with funding by the U.S. Department of Energy (via a contract with NREL).
- Link to the project webpage: http://www.cleanenergystates.org/projects/marine-energy-technology-advancement-project/

Agenda

This webinar will (1) summarize the status of the METAP Project and (2) provide a briefing on recent MHK technology resource assessments, commissioned by DOE.

- Welcome and Introduction to Webinar, Mark Sinclair
- Project Review and "Hand-Off" to DOE, Mark Sinclair
- Wave Resource Assessment Report Briefing
  - **Paul Jacobson, EPRI**
  - **George Hagerman, Virginia Tech**
- Tidal Current Resource Assessment Report Briefing
  - **Kevin Hass, Georgia Institute of Technology**
- Open Discussion and Q&A, Mark Sinclair

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METAP Scope of Work

- **Establish cooperation** among DOE/NREL and state agencies.
- **Assess** state MHK support activities and interest in partnering with DOE on a joint solicitation.
- Provide state **feedback on the NREL/OREC MHK Technology Roadmap**.
- **Inform** states on the opportunities that MHK technologies present, DOE programs and promising support programs in other states. Inform DOE and industry on MHK support activities in states.
- Learn from **international experiences in MHK technology and identify opportunities for collaboration.**
- Establish a **coordinated or joint funding** mechanism of marine energy projects to better leverage state and federal investments.
- Provide recommendations for state/federal/industry collaboration in the establishment and support of dedicated **test facilities**.
- **Evaluate and document the METAP project** as a prototype to demonstrate the value of state/federal technology cooperation, and how it can be applied to other emerging technologies.

Surveying State Interest in MHK

CESA survey findings:

- Many coastal states are involved in supporting MHK technologies through funding and policy
- Ten states investing some level of funding in MHK-related activities: demonstration projects, feasibility studies, environmental studies, test facilities, etc.
- Eight states have some type of test facilities in their state's waters.

International Experience & Collaboration Recommendations: CESA Report

- The UK has emphasized joint-funding and collaboration among local, regional and national agencies.
- The Carbon Trust's Technology Accelerator programs provide good examples of innovative collaboratively-funded projects, including pooled industry funding and sharing of technical expertise among prototype projects.
- Opportunities for international collaboration:
  - Test Facilities lessons learned
  - Device and component performance and cost data
  - Environmental and regulatory risk management

Test Facility Recommendations

- The METAP team researched existing US MHK test facilities, other technology testing models, and international approaches to develop recommendations for DOE:
  - A non-profit collaborative, **consortia model** of development, ownership and operations. The NEES consortium provides an excellent example.
  - U.S. individual test facilities should be planned and developed to be **complementary rather** than competing
  - Funding for test facilities should be **combined from federal, state and local agency sources.**
  - Opportunities for **multi-state co-funding** within regions may be available and should be pursued- "shared" infrastructure concepts such as mobile test berths could be supported by multiple states.
  - Look for cost sharing opportunities with the **Department of Defense** or **other technologies**, such as **offshore wind**.
  - DOE should establish a national advisory group to develop specific recommendations and enlist support for a test facility development deployment plan.
  - Information sharing across test facilities should be encouraged or required.

Joint Procurement
LONG-TERM OPTIONS

State Matching Grant Funding	OR	State-Issued Cost Share RFP	OR	DOE-Issued RFP with State Matching Funds
State automatically provides matching funds to awardees of DOE-issued FOA within their state, without agreement with DOE		*State issues RFP in response to DOE FOA; commits matching funds to in-state applicants meeting state criteria and selected by DOE*		*DOE and states enter into agreement prior to issuing FOA; DOE FOA lists participating states and match for projects selected in their state or region*

Joint Funded RFP

DOE-Issued Collaborative RFP

- DOE and states sign MOU, that would include state's selection criteria requirements for cost share and amount of matching funds available.
- In its FOA, DOE would inform applicants about the states that are partnering with DOE, and the amounts each state would contribute.
- States have the authority to require all successful applicants that receive awards in the DOE FOA process for projects in their states' or regions' waters to also meet state-specific Terms and Conditions for matching state funds.
- *The state funds will be used to offset both DOE and the project developer's cost-share, most likely in a 50/50 split. For example, if $6 million project is selected for which DOE requires a 50% developer cost share, and in a state that has offered $1m in cost share, the state would provide $1m, with $500,000 going to offset part of DOE's $3m cost share and $500,000 offsetting the project developers $3m cost share.*

States Status with MOU

- Five states interested in signing the MOU and providing joint funding in 2012:
  - New York, Massachusetts, Oregon, Alaska and New Hampshire.
- Four states have considered the opportunity in depth, cannot participate with matching funds in 2012:
  - Maryland, California, Hawaii and New Jersey.

METAP Going Forward

- MOU under review by DOE legal team
- DOE FOA during 2012 unlikely, but DOE very interested in co-funding as future budget allows
- DOE's Wind & Water Program now will take responsibility for METAP efforts going forward
- CESA contract ends 3/31/12, but interested in helping as useful in supporting METAP efforts
- DOE primary contact: Hoyt Battey

Lessons Learned

- It is important to develop a faster process from initial engagement of interested states to issuance of DOE funding announcement opportunities to ensure state interest and ability to commit available funds during any given state fiscal year.
- There are significant competing demands for state RE funding by technologies in the current economic downturn. States need to see a clear benefit – such as an increased chance of obtaining DOE funding for demonstration projects – to commit scarce dollars to a particular technology area.
- Current DOE FOA processes, or their interpretation by DOE legal teams, significantly limit the opportunities for state input and meaningful procurement partnerships with states.
- DOE should consider implementing a comprehensive program for states to partner with DOE as a part of all technology advancement efforts within EERE.

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Clean Energy States Alliance

Mapping and Assessment of the US Ocean Wave Energy Resource

METAP Webinar

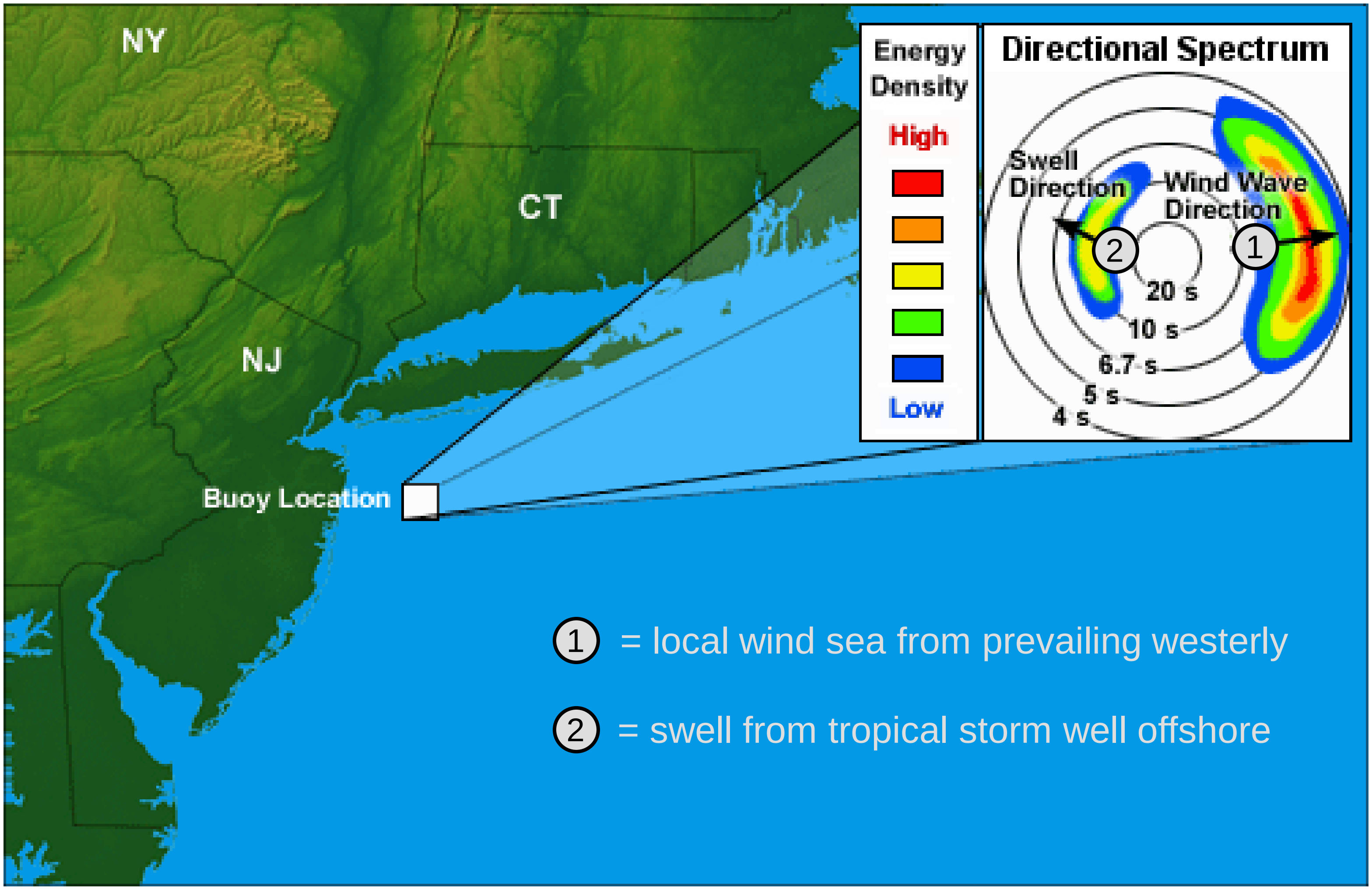
Clean Energy States Alliance

29 March 2012

Paul Jacobson
EPRI Project Manager

George Hagerman
Virginia Tech Principal Investigator

Directional Wave Spectrum off New Jersey with Two Component Partitions



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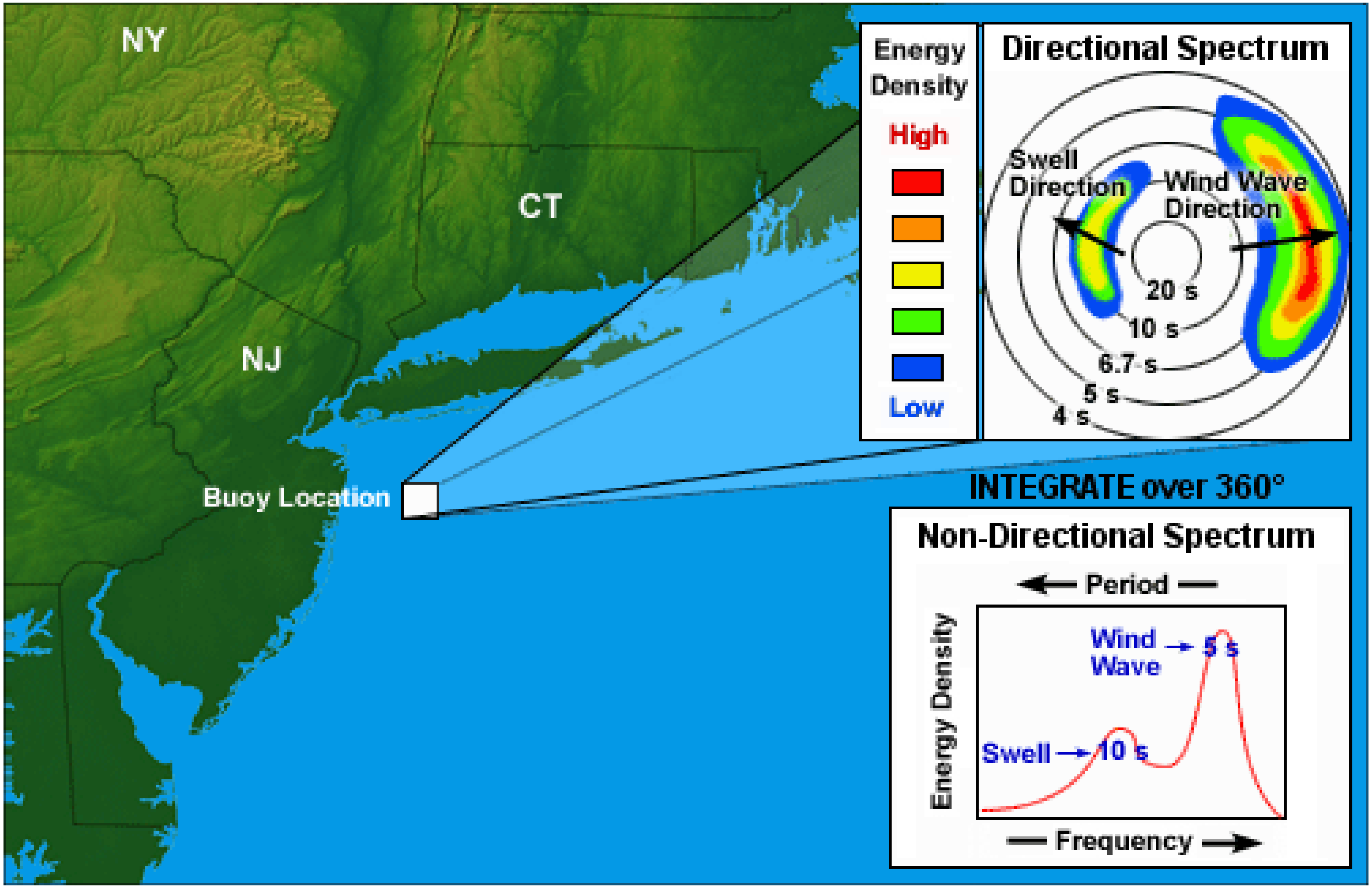
Integrating Directional Spectrum over 360° Yields Non-directional Spectrum



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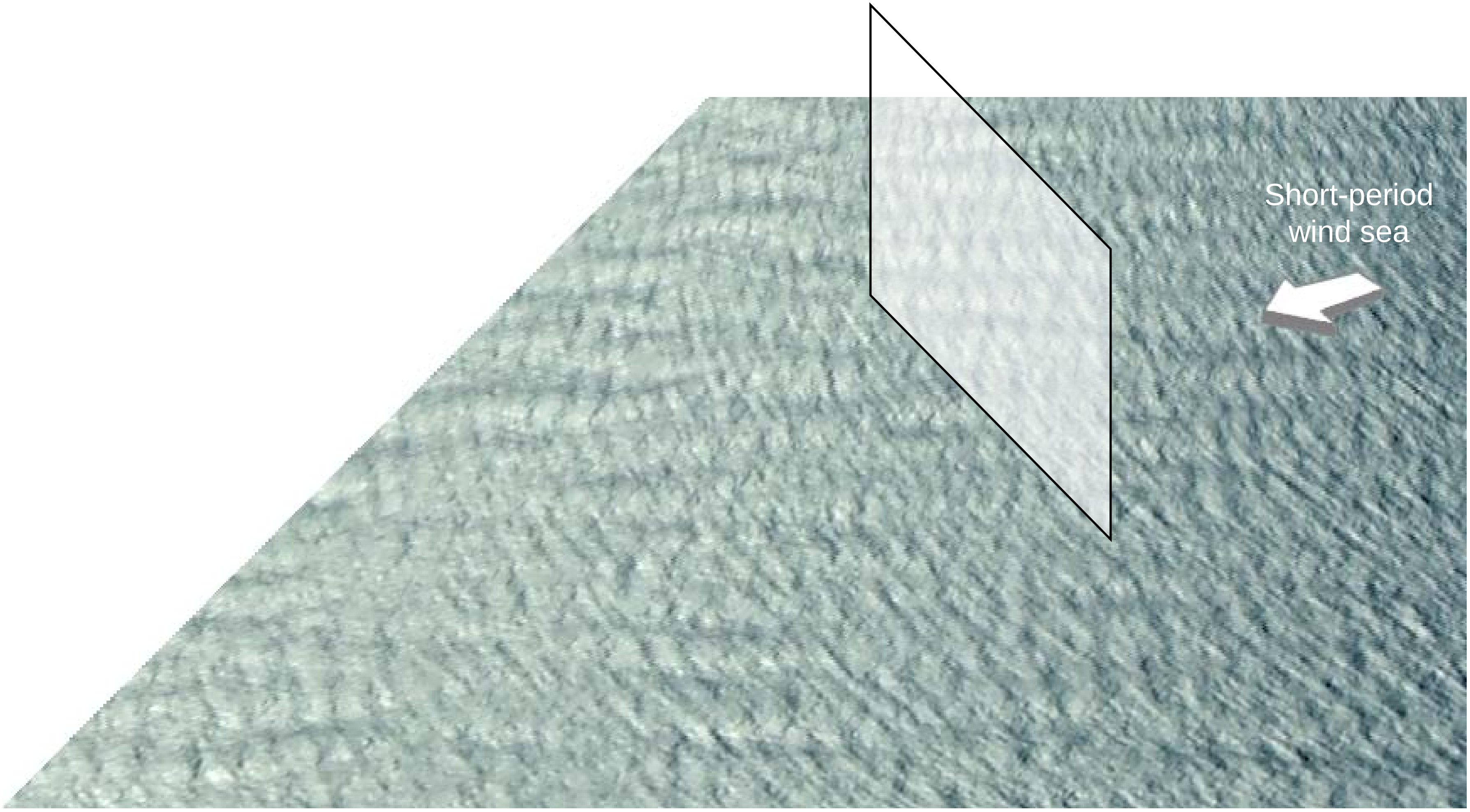
Definition Sketch for Ocean Wave Energy Flux in Multi-Partition Sea State



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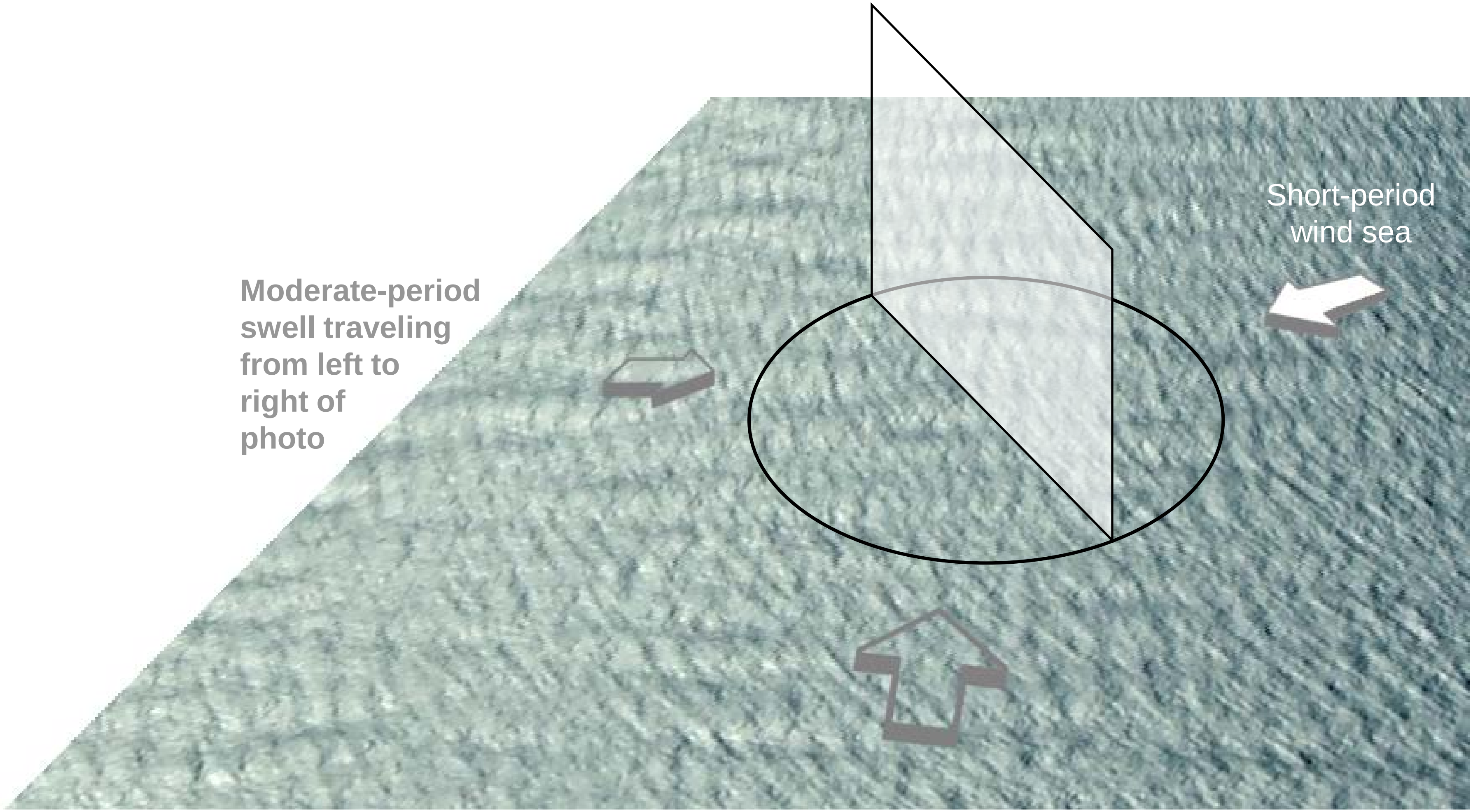
Definition Sketch for Ocean Wave Energy Flux in Multi-Partition Sea State



Long-period swell traveling from bottom to top of photo

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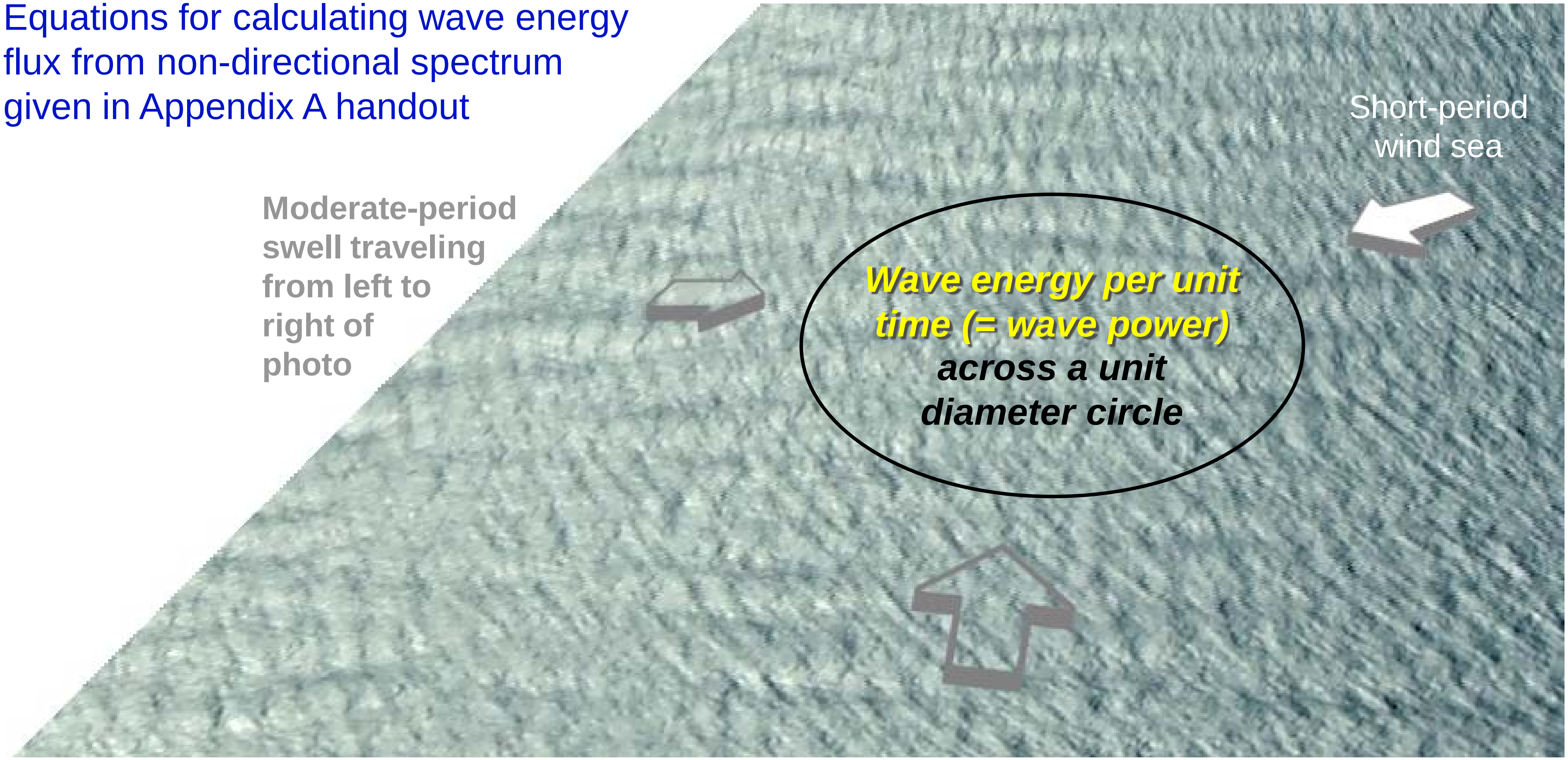
Definition Sketch for Ocean Wave Energy Flux in Multi-Partition Sea State

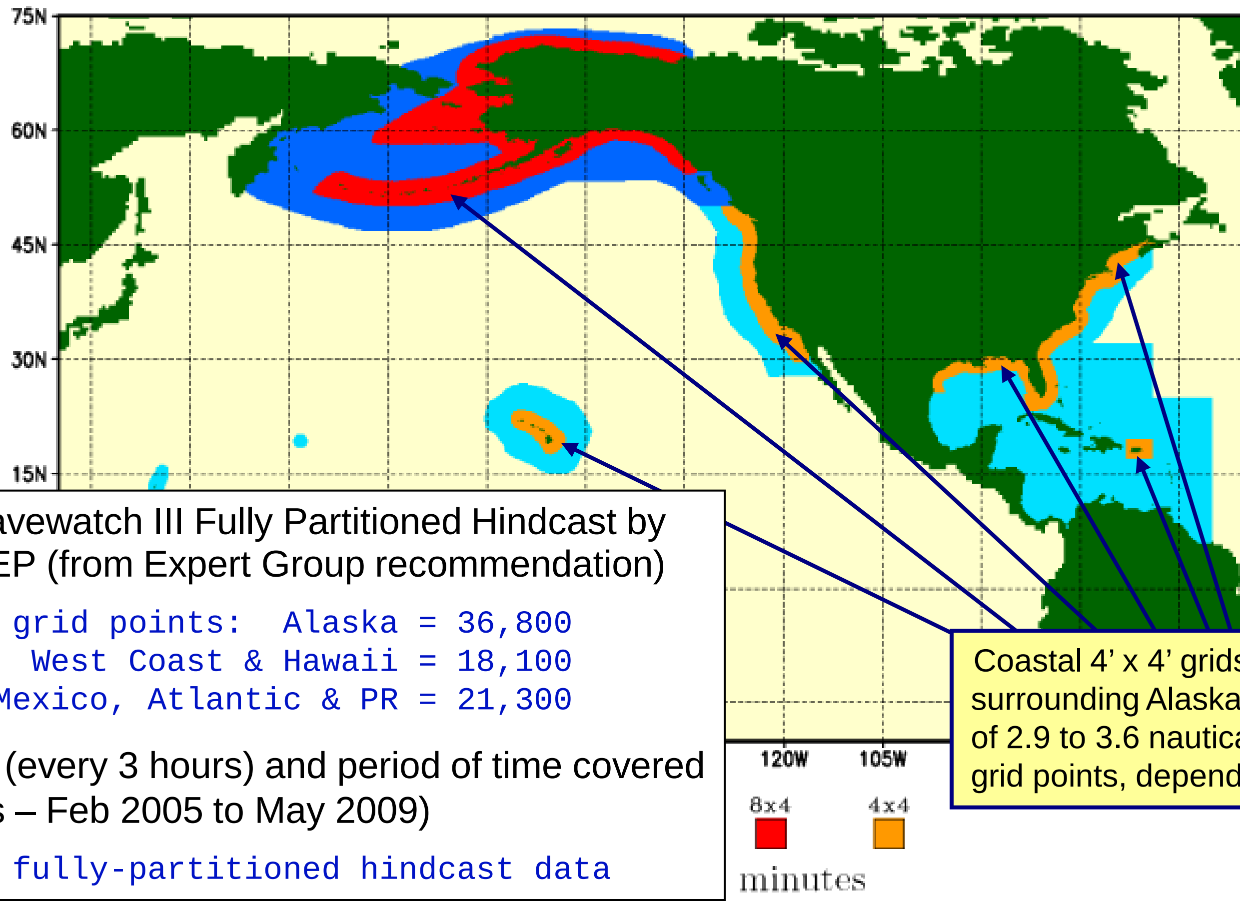
Equations for calculating wave energy flux from non-directional spectrum given in Appendix A handout



Long-period swell traveling from bottom to top of photo

Key Expert Group Outcome: July 2009 Wavewatch III Hindcast Archiving ALL Component Wave Partitions

Nested multi-grid Wavewatch III (NMWW3) provides high-resolution, uniform grid spacing over broad regions off U.S. coastlines



Special Wavewatch III Fully Partitioned Hindcast by NOAA NCEP (from Expert Group recommendation)

```
Number of grid points:  Alaska = 36,800
           West Coast & Hawaii = 18,100
 Gulf of Mexico, Atlantic & PR = 21,300
```

Frequency (every 3 hours) and period of time covered (52 months – Feb 2005 to May 2009)

`350 GB of fully-partitioned hindcast data`

Coastal 4' x 4' grids (and 8' x 4' grid surrounding Alaska) provide resolution of 2.9 to 3.6 nautical miles between grid points, depending on latitude

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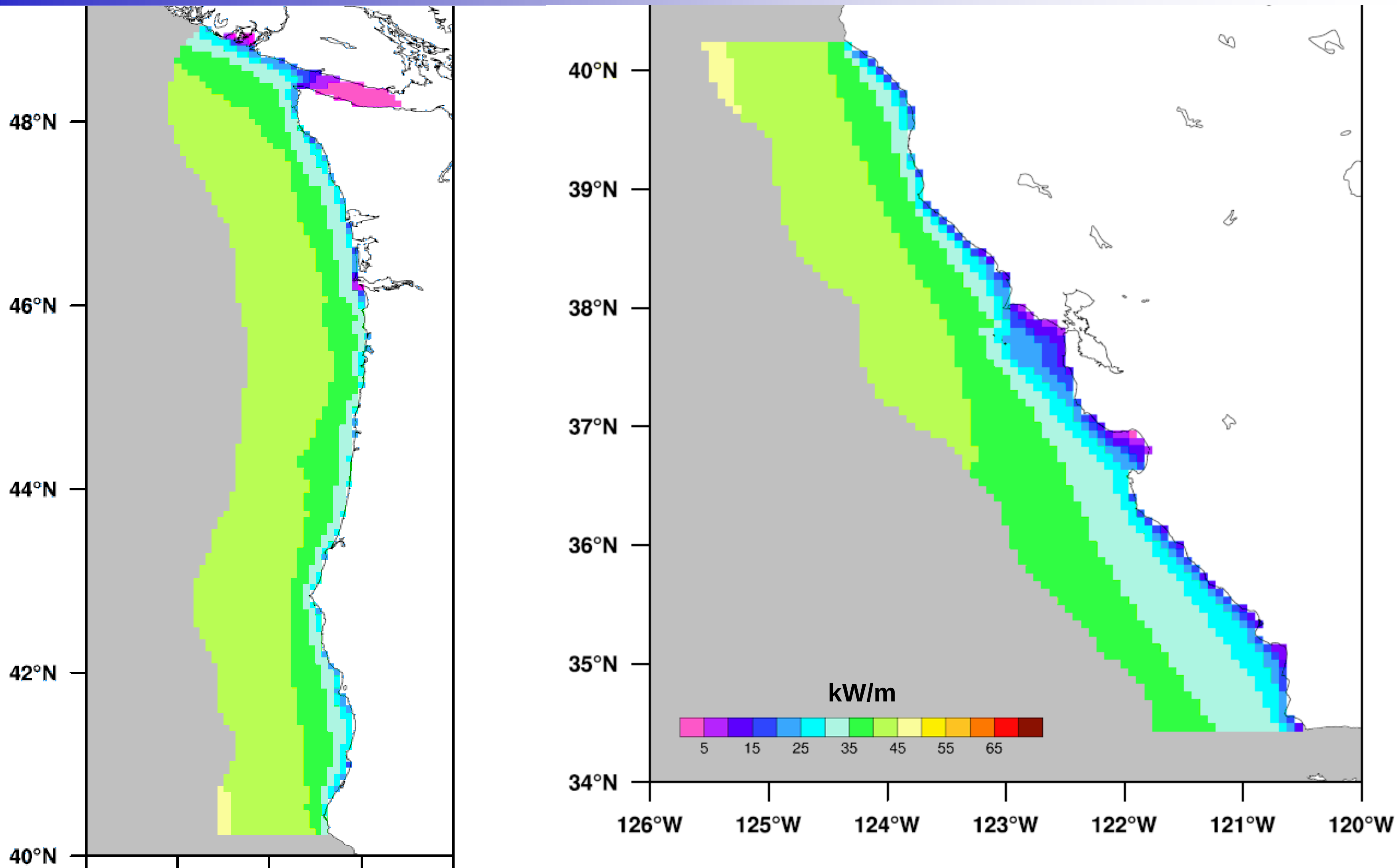
Mean Annual Wave Power Density – Pacific Northwest and Central California



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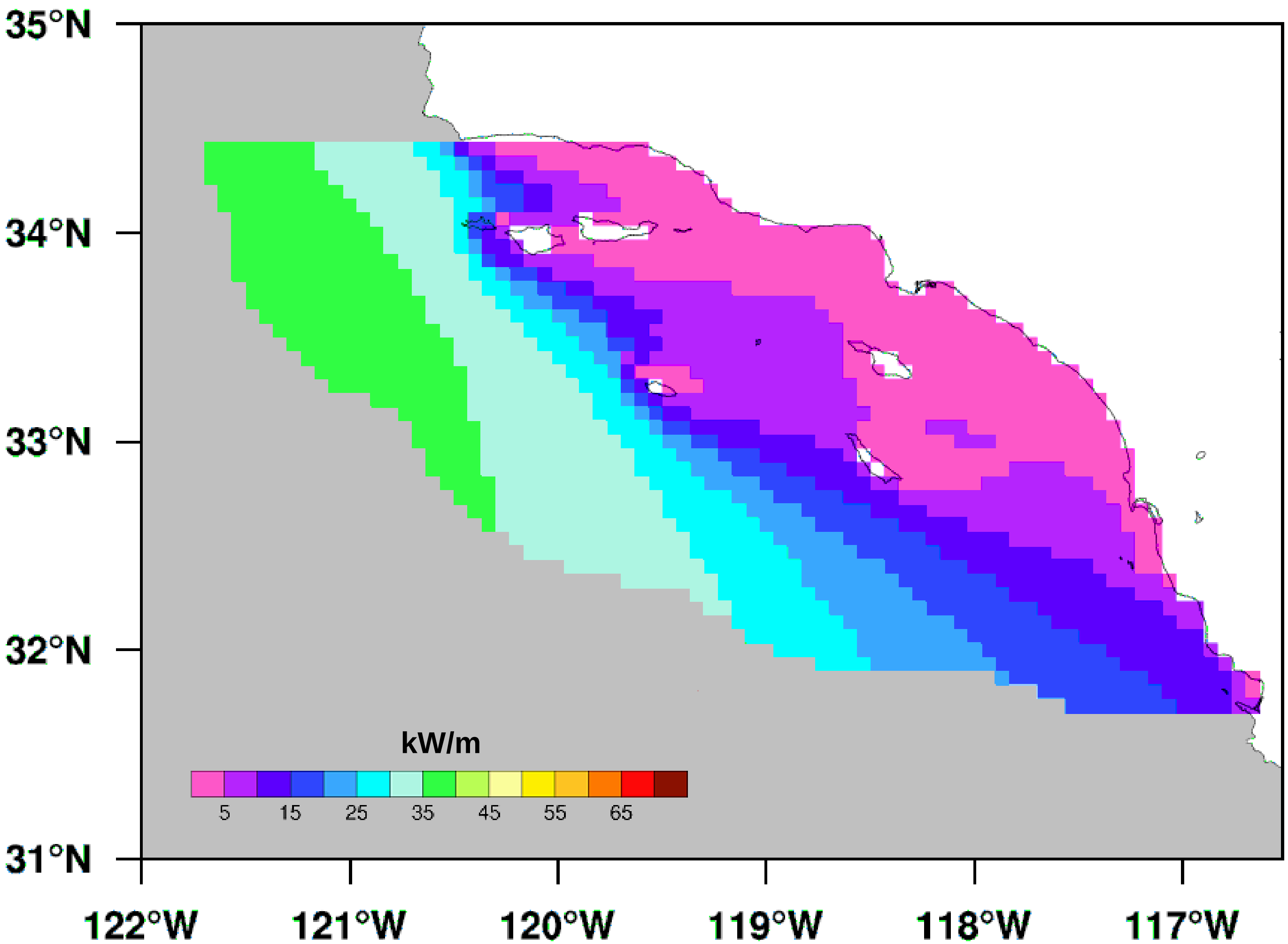
Mean Annual Wave Power Density – Southern California



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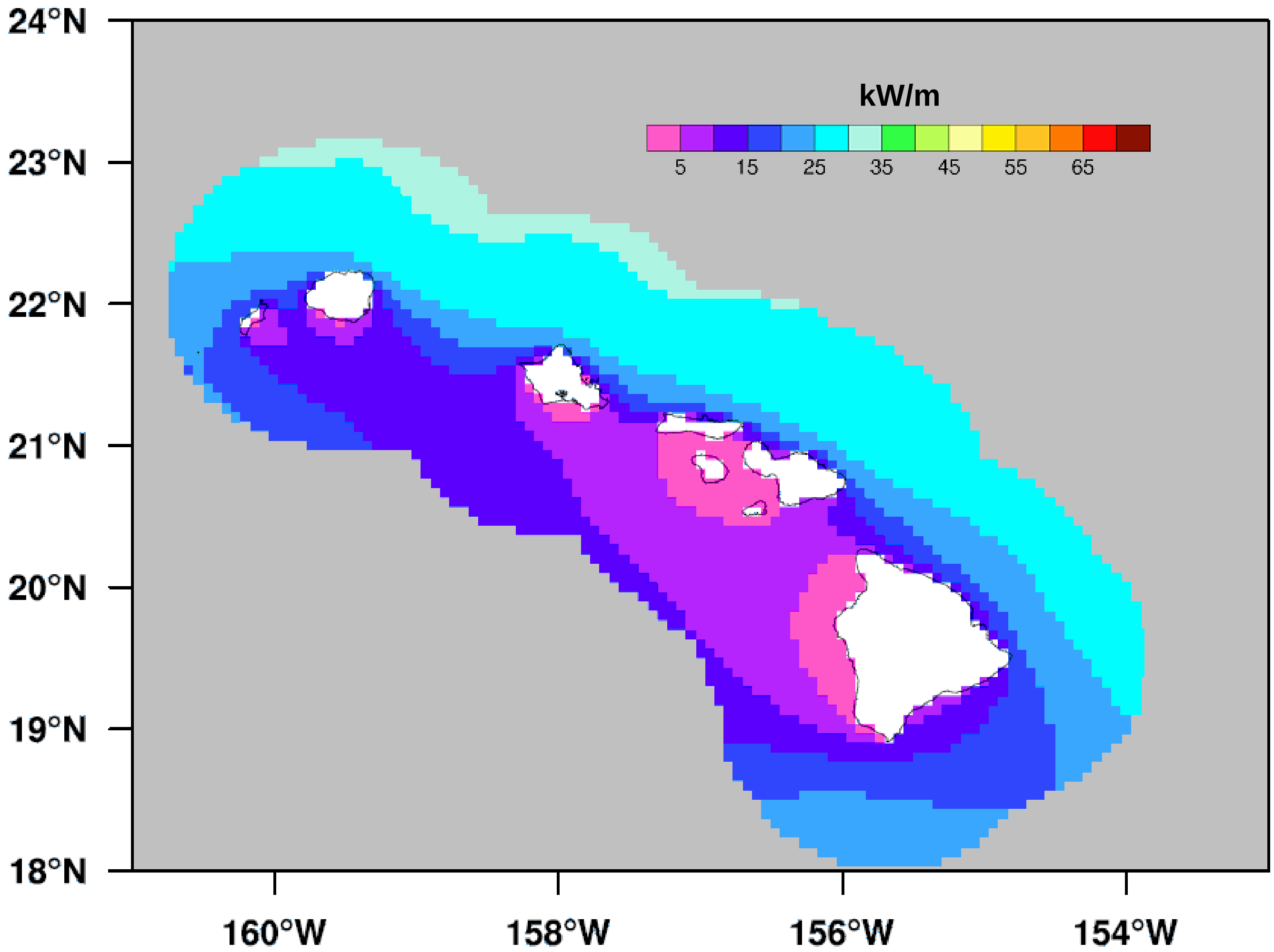
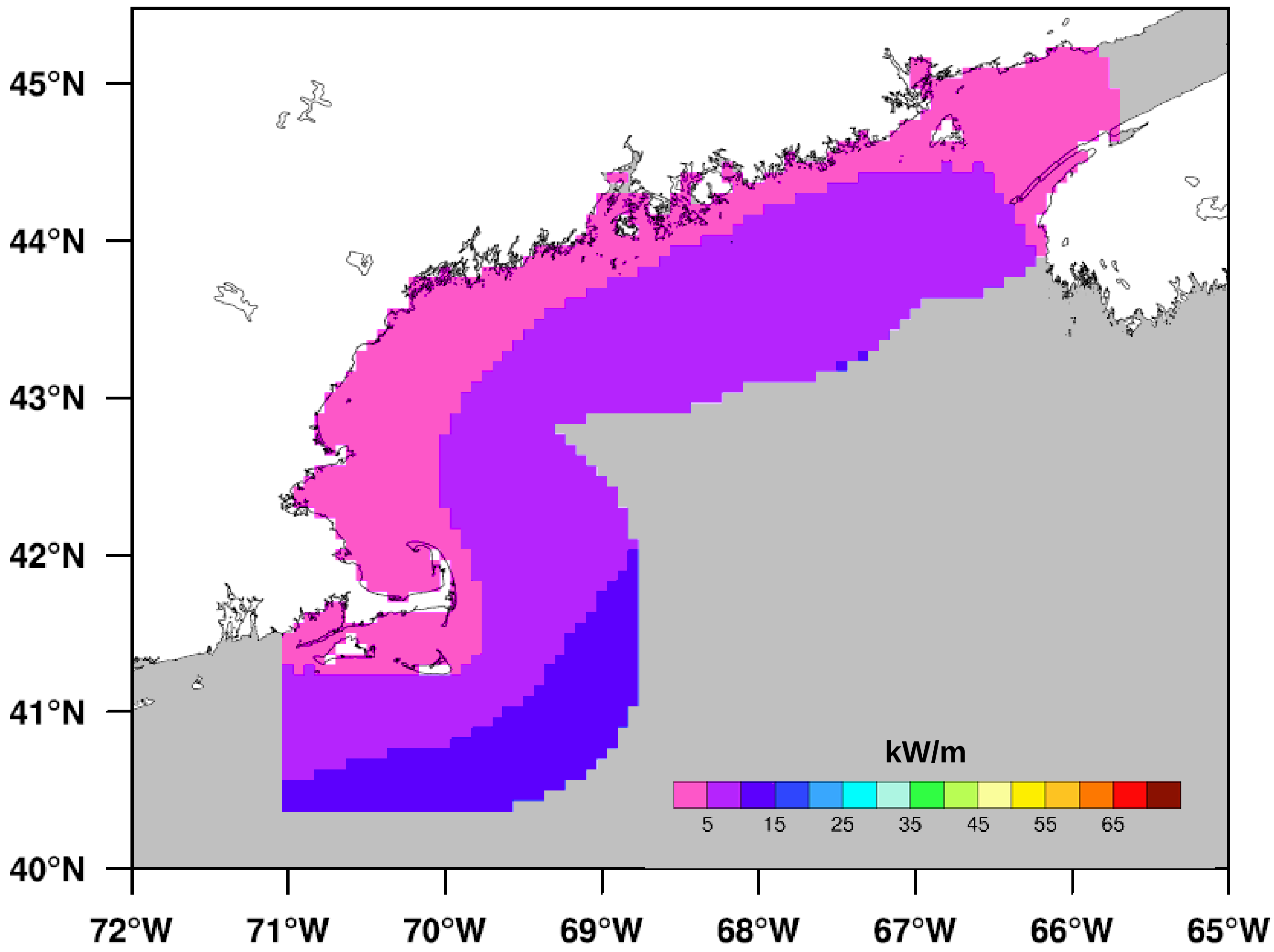
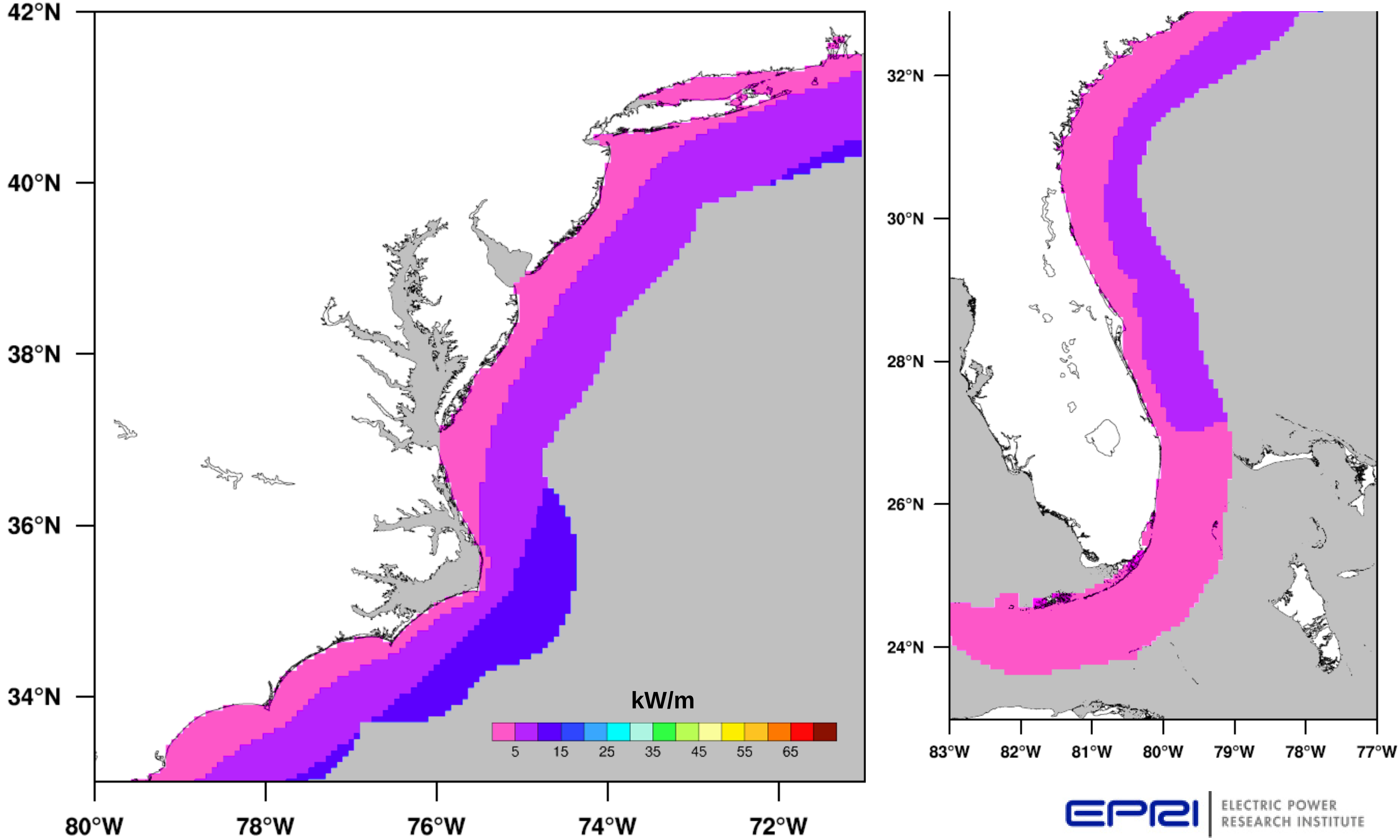
Mean Annual Wave Power Density – Hawaii



Mean Annual Wave Power Density – North Atlantic



Mean Annual Wave Power Density – Mid-Atlantic and South Atlantic



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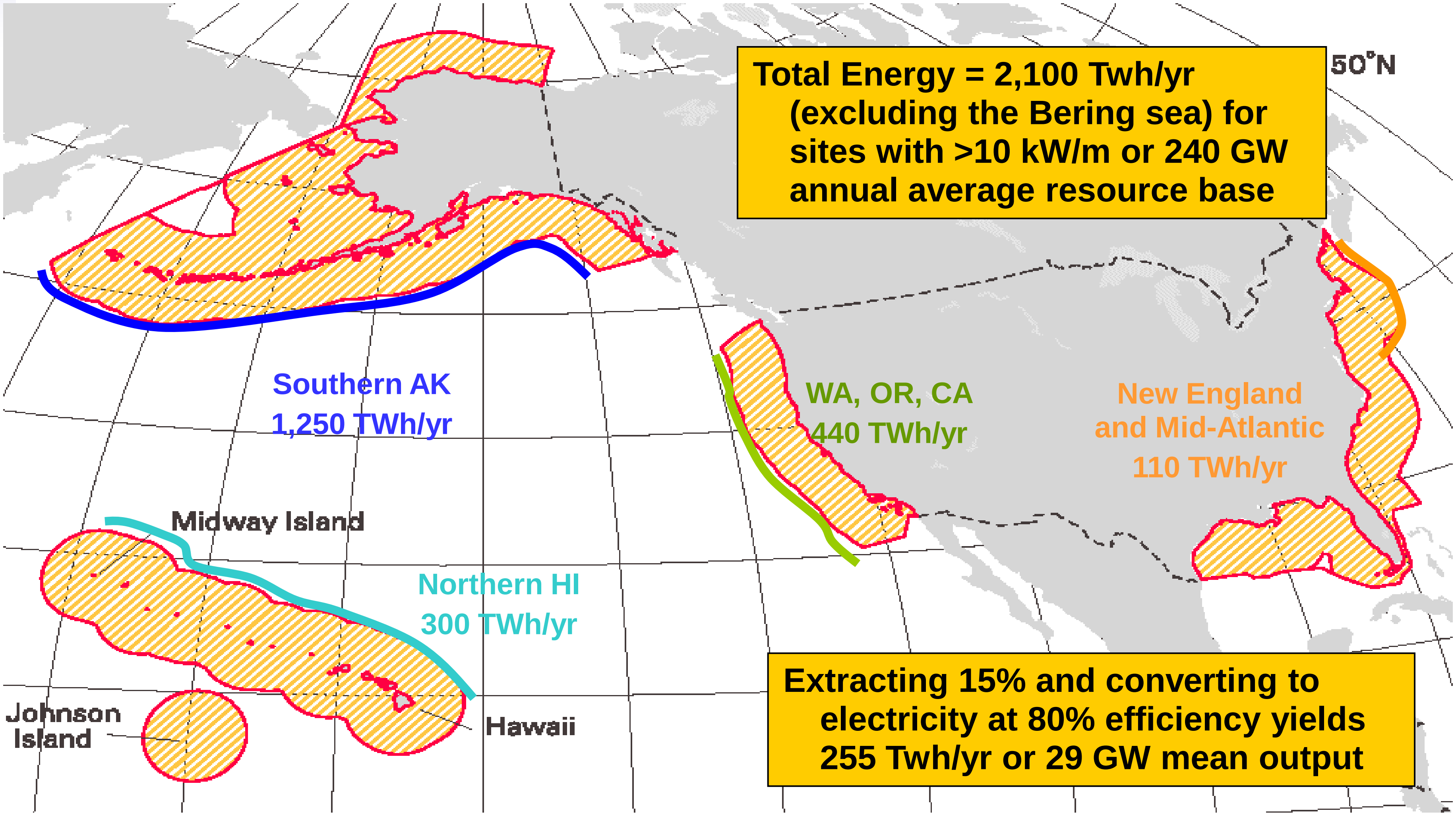
Available Resource – EPRI 2004 Map



Available Wave Energy Resource

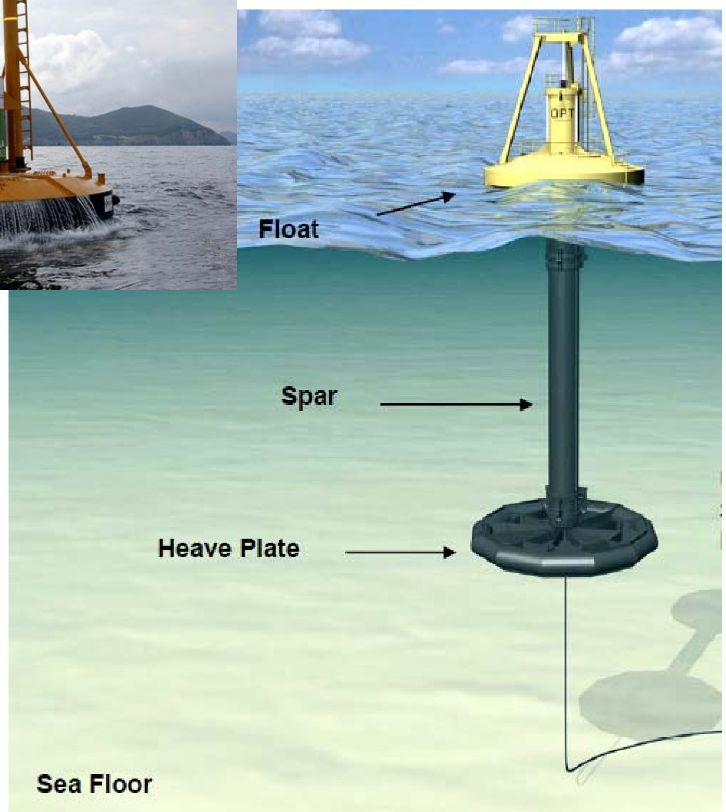
Coastline	EPRI 2004 Estimate	Present Estimate, Outer Shelf
West Coast (WA,OR,CA)	440 TWh/yr	590 TWh/yr (34% greater)
East Coast (ME thru NC)	110 TWh/yr	200 TWh/yr (82% greater)
East Coast (SC thru FL-Atlantic)	NOT ESTIMATED	40 TWh/yr
Gulf of Mexico	NOT ESTIMATED	80 TWh/yr
Alaska (Pacific only)	1,250 TWh/yr	1,360 TWh/yr (9% greater)
Alaska (Bering Sea)	NOT ESTIMATED	210 TWh/yr
Hawaii	300 TWh/yr	130 TWh/yr (not comparable *)
Puerto Rico	NOT ESTIMATED	30 TWh/yr
TOTAL	**2,100 TWh/yr**	**2,640 TWh/yr (26% greater)**

* Rounded to nearest 10 TWh/yr for consistent comparison with EPRI 2004 estimate.

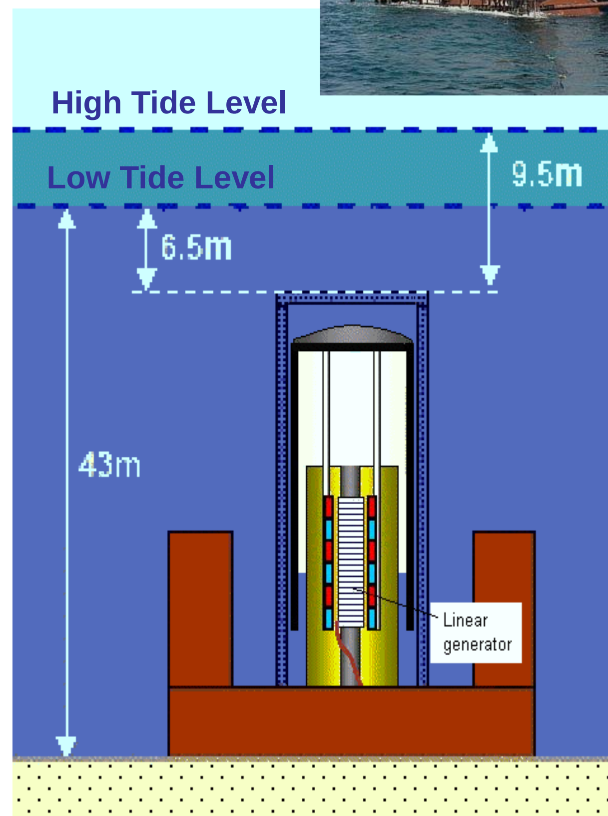
** EPRI's 2004 estimate for Hawaii was along the northern boundary of the U.S. EEZ, as far west as the Midway Islands. The present estimate extends only as far west as Kauai, and encompassed the entire islands (not just their northern exposures).

Omni-Directional Wave Energy Devices can Capture Wave Energy Flux from all Directions

OPT PowerBuoy



Archimedes Wave Swing (AWS)



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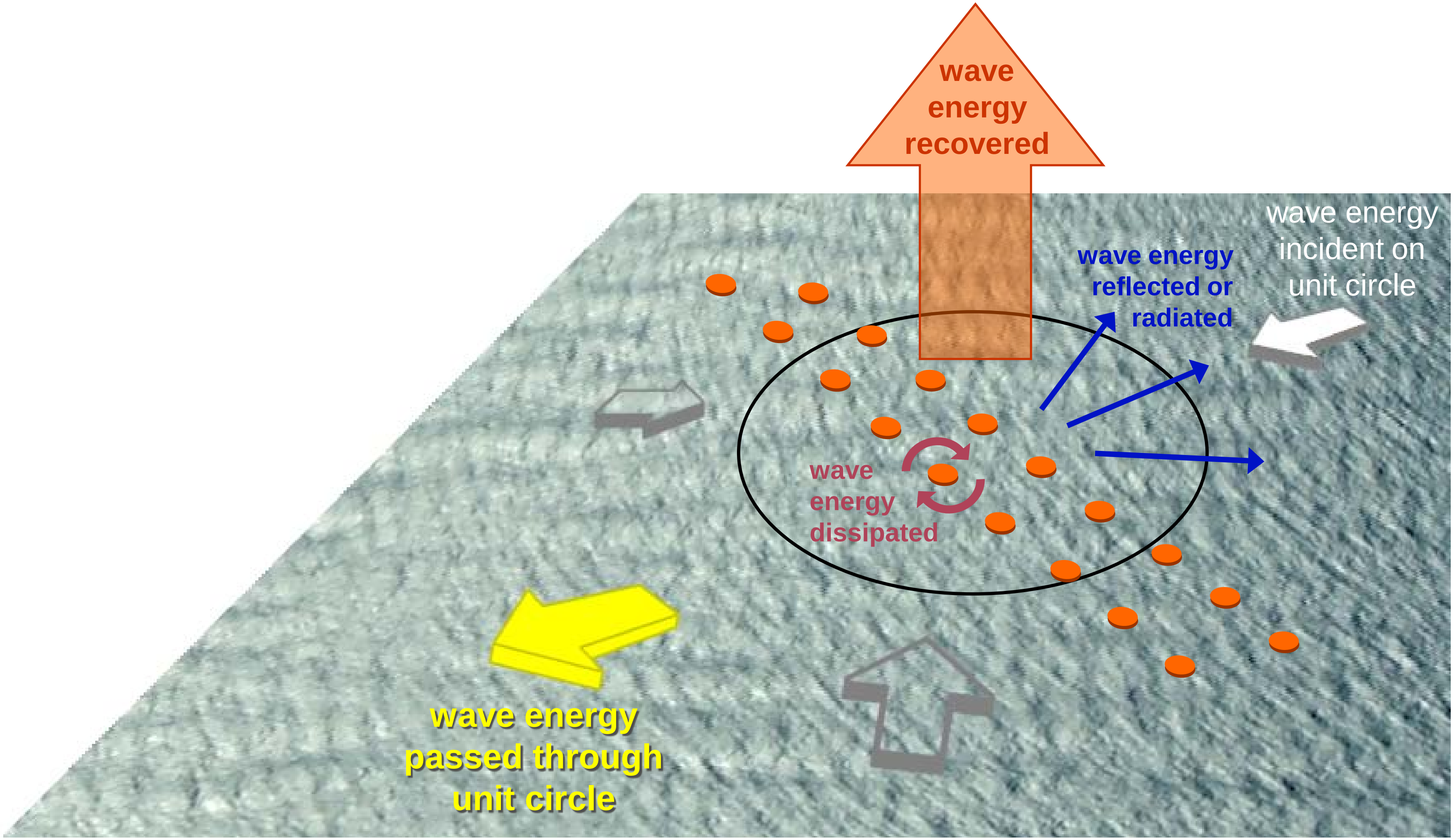
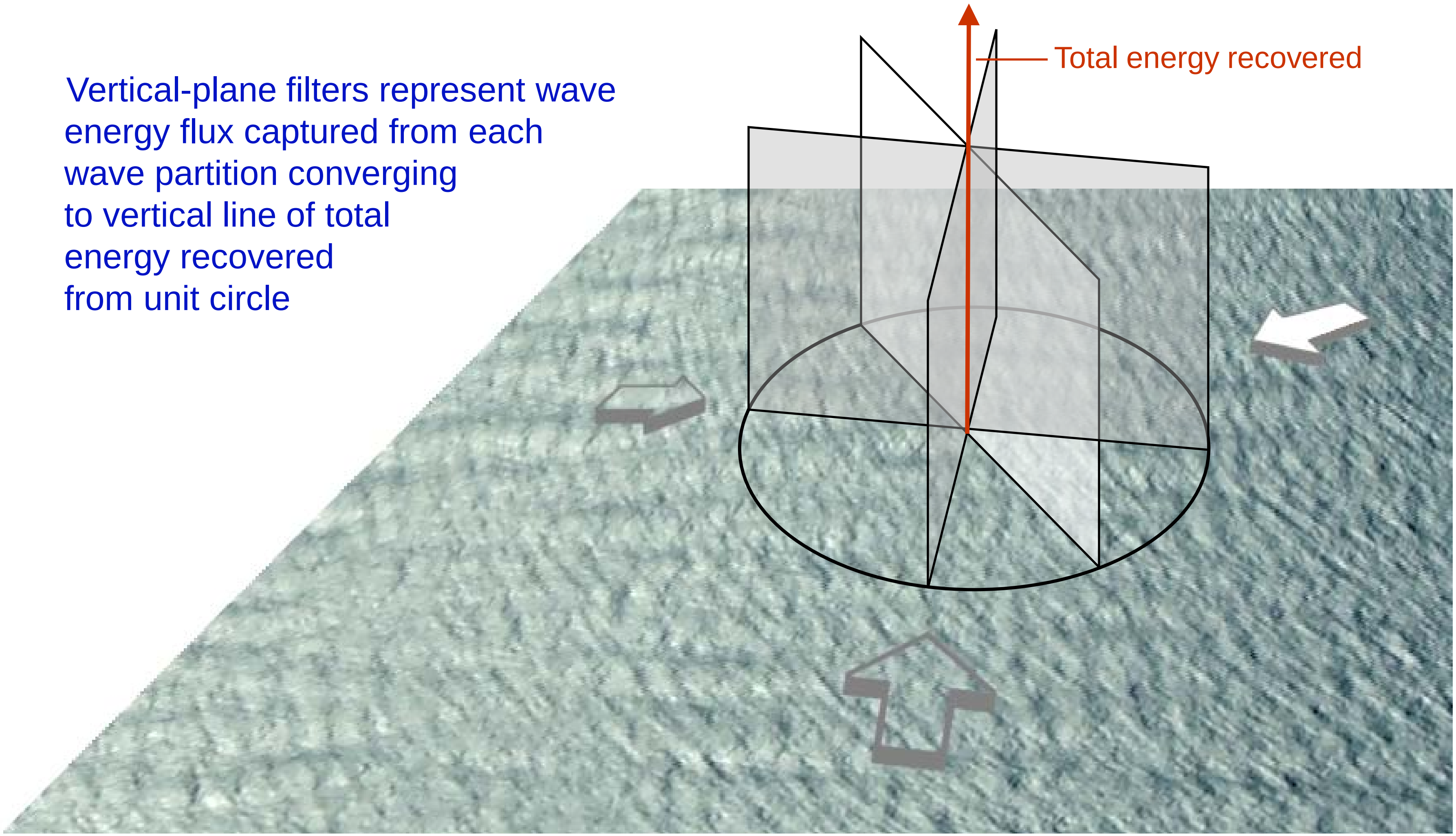
Wave Energy Flux Pathways for an Array of Omni-Directional Wave Energy Devices



Definition Sketch for Ocean Wave Energy Flux in Multi-Partition Sea State

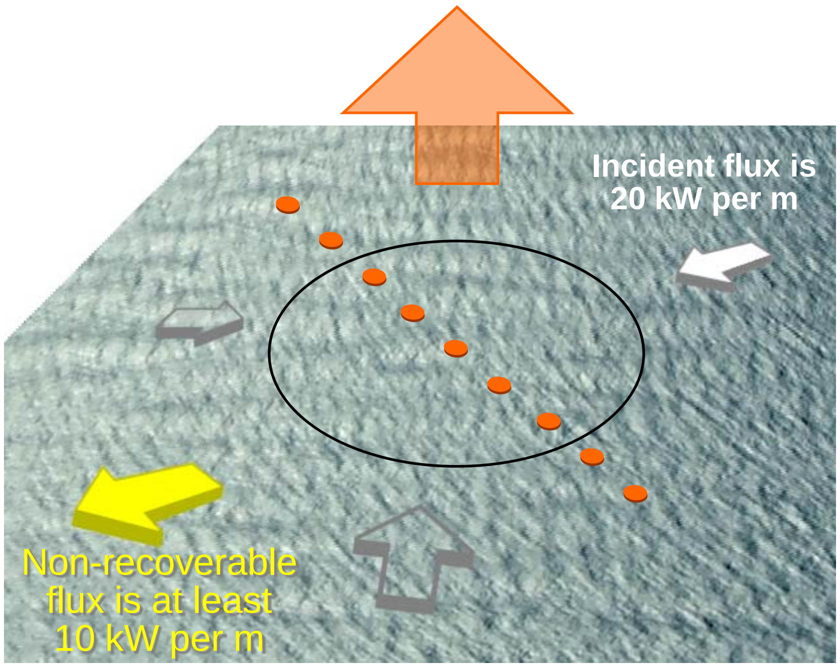
Vertical-plane filters represent wave energy flux captured from each wave partition converging to vertical line of total energy recovered from unit circle



Rated Capacity Constraint at Array Level is Capacity in MW per km Unit Circle Diameter

Recoverable flux = 10 MW per km

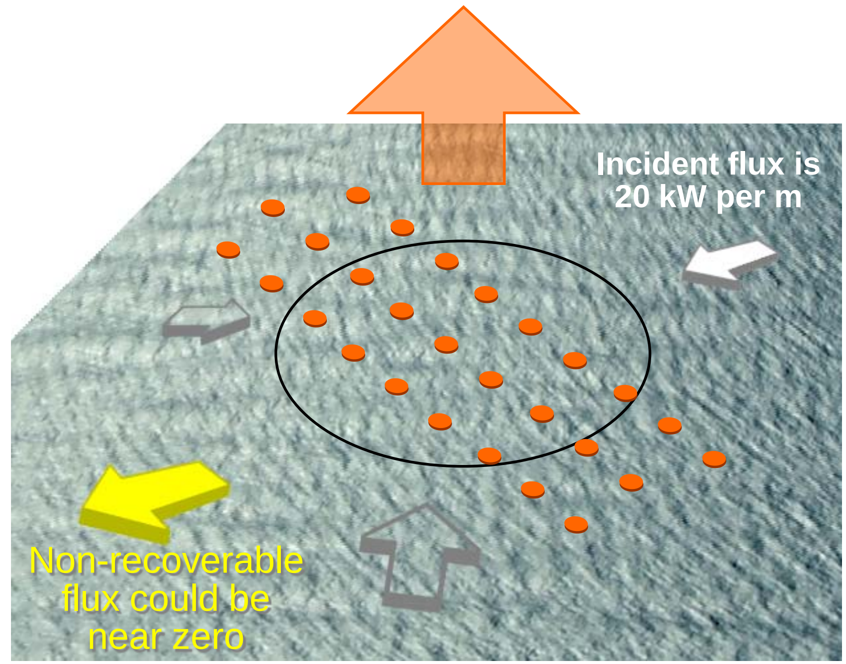
Devices in unit circle can capture no more than 10 MW



Capacity density = 10 MW per km

Recoverable flux = 20 MW per km

Devices in unit circle can capture up to 20 MW



Capacity density = 30 MW per km

Unit circle contains devices rated at 2 MW each, dimensions and efficiency of device unknown

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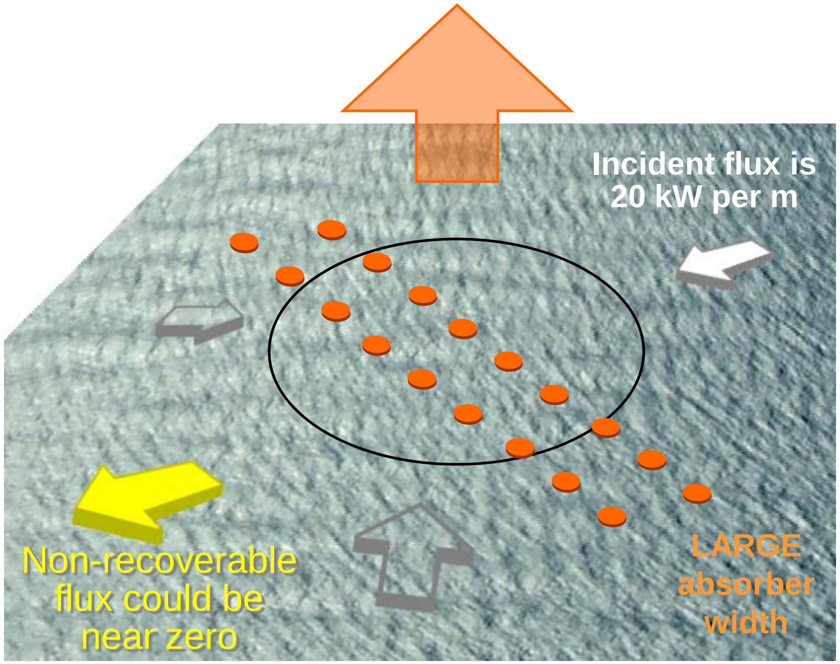
Rated Capacity Constraint at Array Level Does NOT Depend on Device-Level ROC

Recoverable flux = 20 MW per km

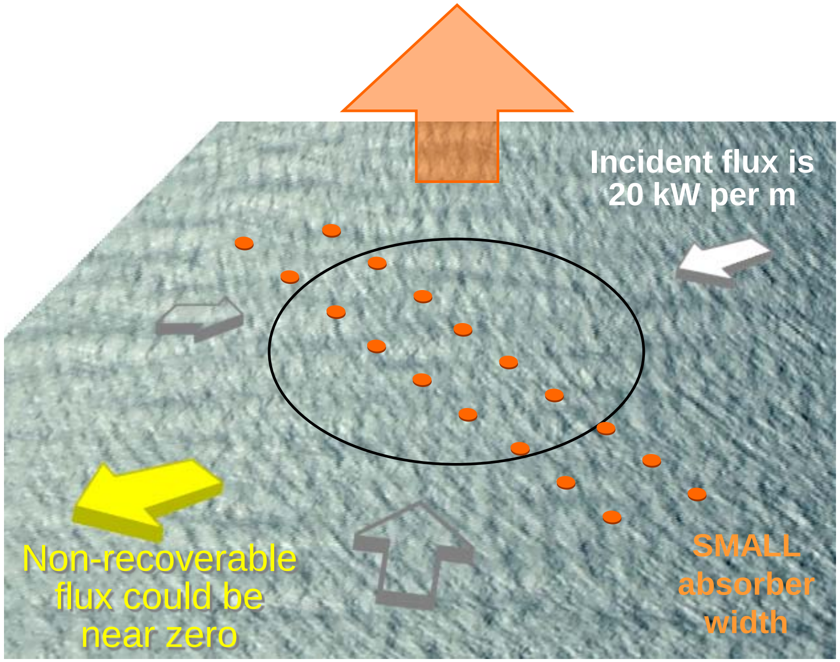
Devices in unit circle are all operating at rated capacity, recovering 20 MW



Device ROC = 10 kW per m

Recoverable flux = 20 MW per km

Buoys in unit circle can capture up to 20 MW

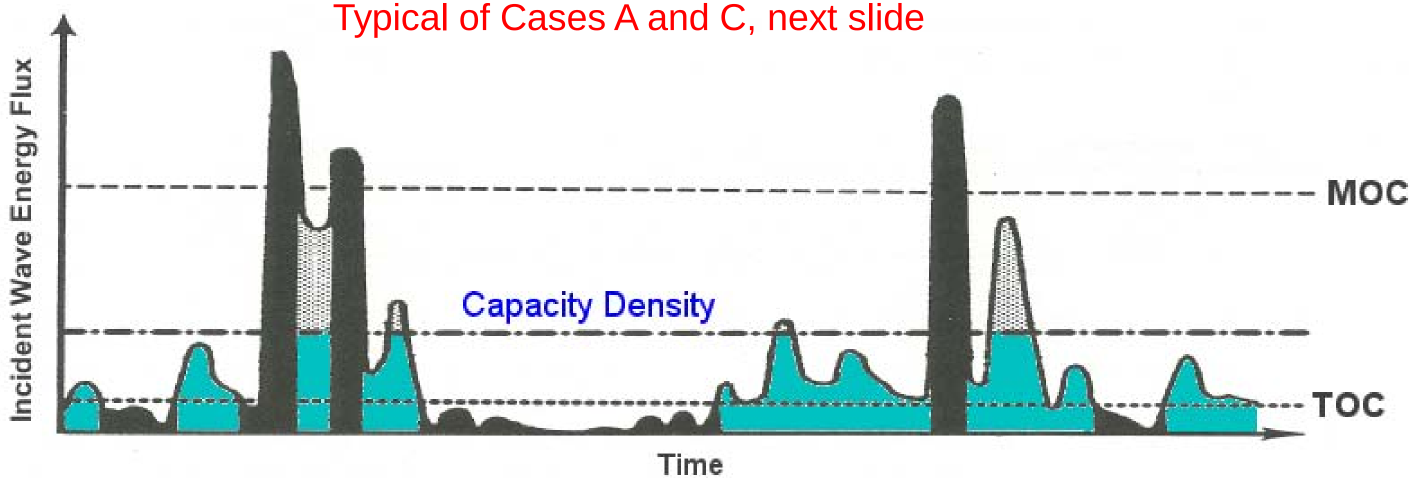


Device ROC = 30 kW per m

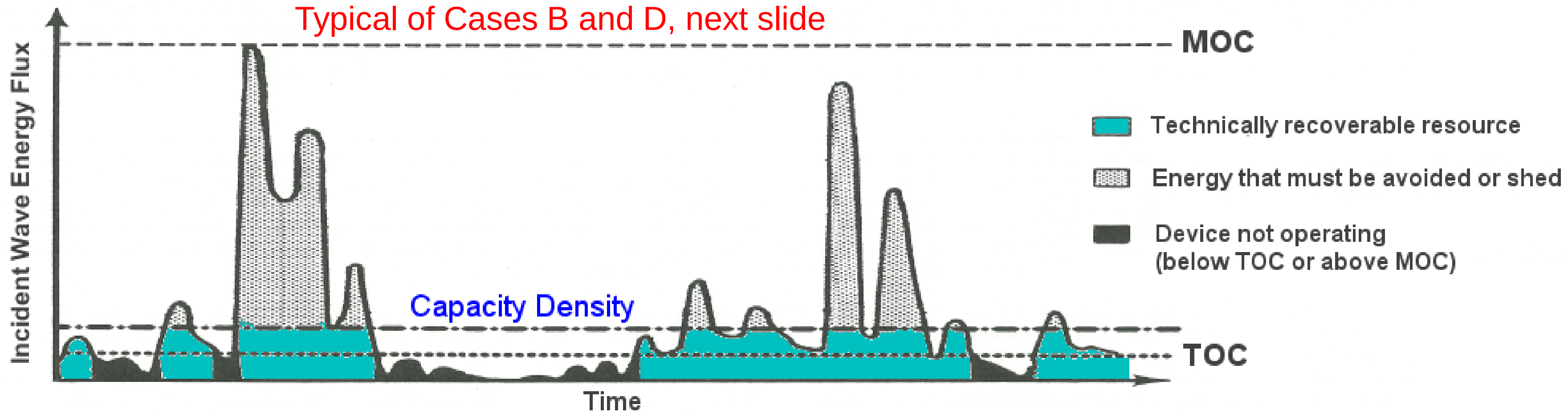
Unit circle contains devices rated at 2 MW each, dimensions and efficiency of device unknown

Recoverable Resource IS Influenced by Device-Level TOC and MOC

Typical of Cases A and C, next slide



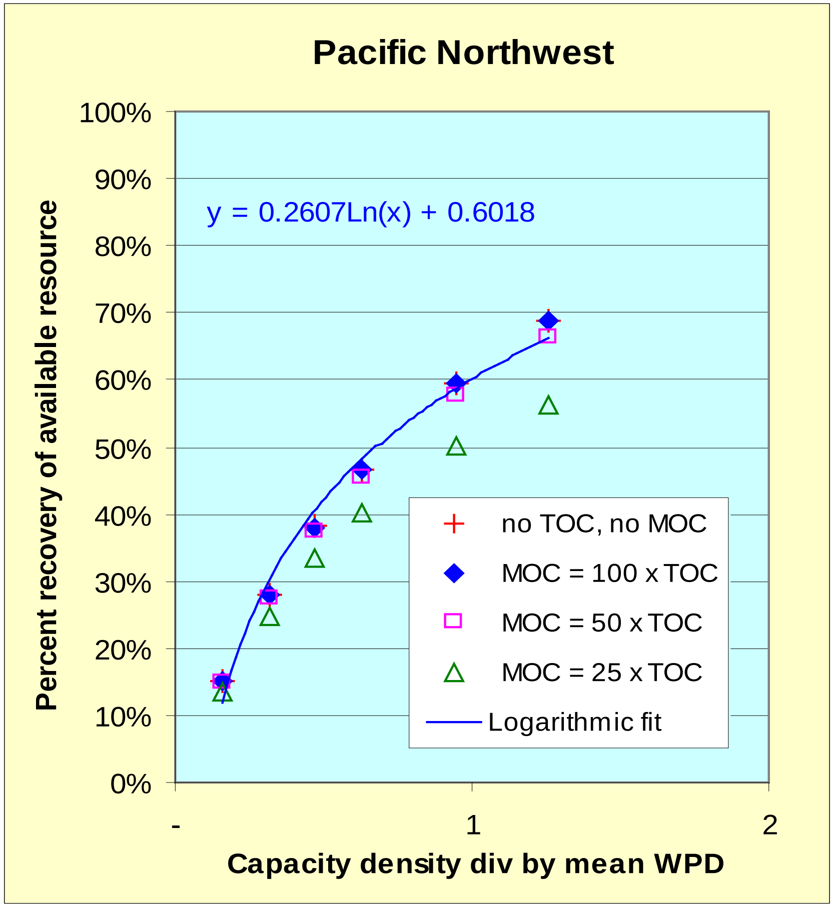
Typical of Cases B and D, next slide

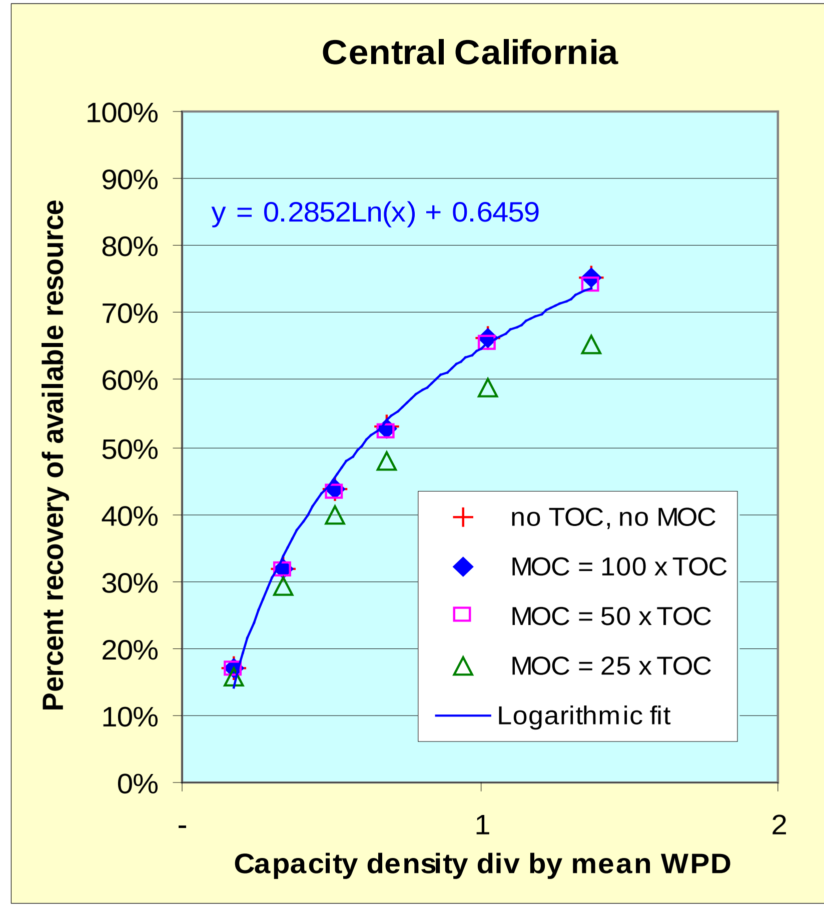


Value of Technically Recoverable Wave Energy Resource Characterization Curves

- Guidance for regulatory and resource agencies on capacity density levels associated with different levels of resource recovery
- Quantitative information for coastal and marine spatial planning
- Input for developers estimating lease areas needed for projects
- Input for industry in understanding trade-off between having several classes of a given device based on wave climate vs. fewer classes with more variable array capacity density
- Guidance for device designers on the minimum and maximum wave power densities over which a device must reliably operate
- Objective basis for developing R&D programs or evaluating R&D proposals to expand bandwidth of device operating conditions

Recoverable Resource vs. Array Capacity Density for Highly Energetic Regions (AAWPD* ≥ 20 kW/m)





* AAWPD = Annual Average Wave Power Density, in kW per meter of wave crest across a unit- diameter circle

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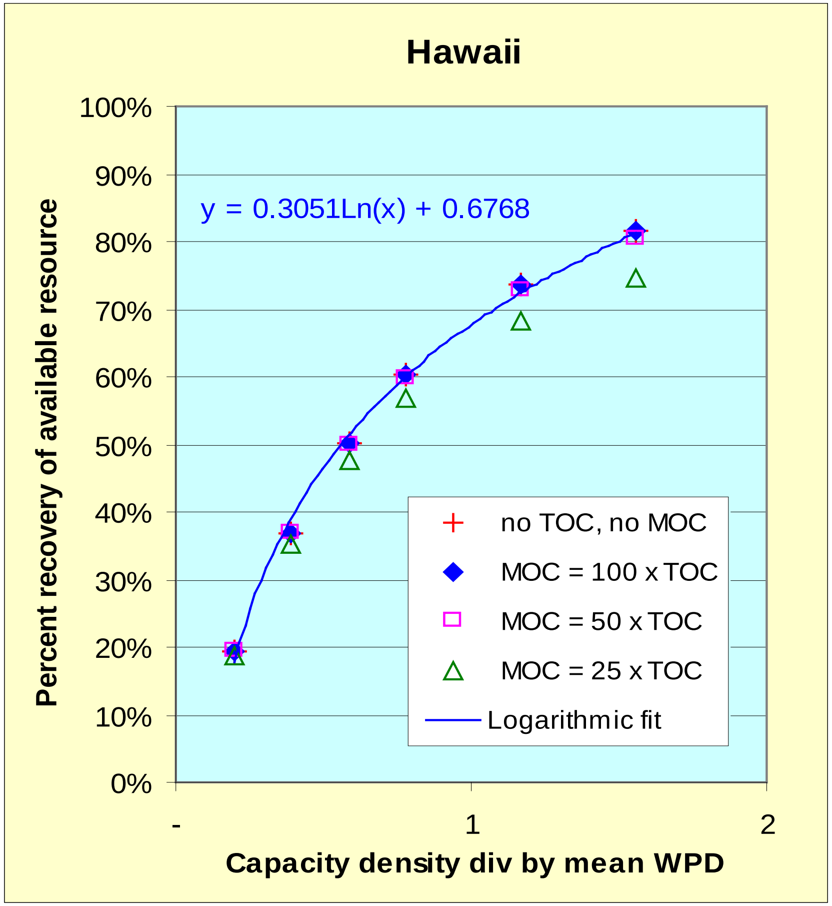
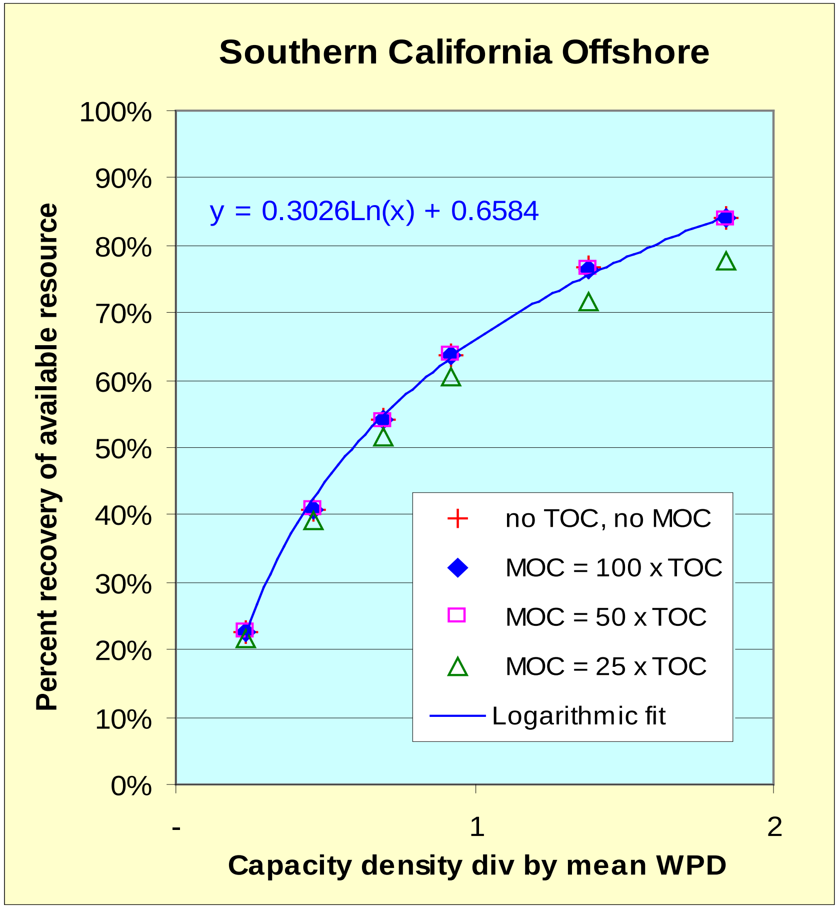
Recoverable Resource vs. Array Capacity Density for Highly Energetic Regions (AAWPD* ≥ 20 kW/m)





* AAWPD = Annual Average Wave Power Density, in kW per meter of wave crest across a unit- diameter circle

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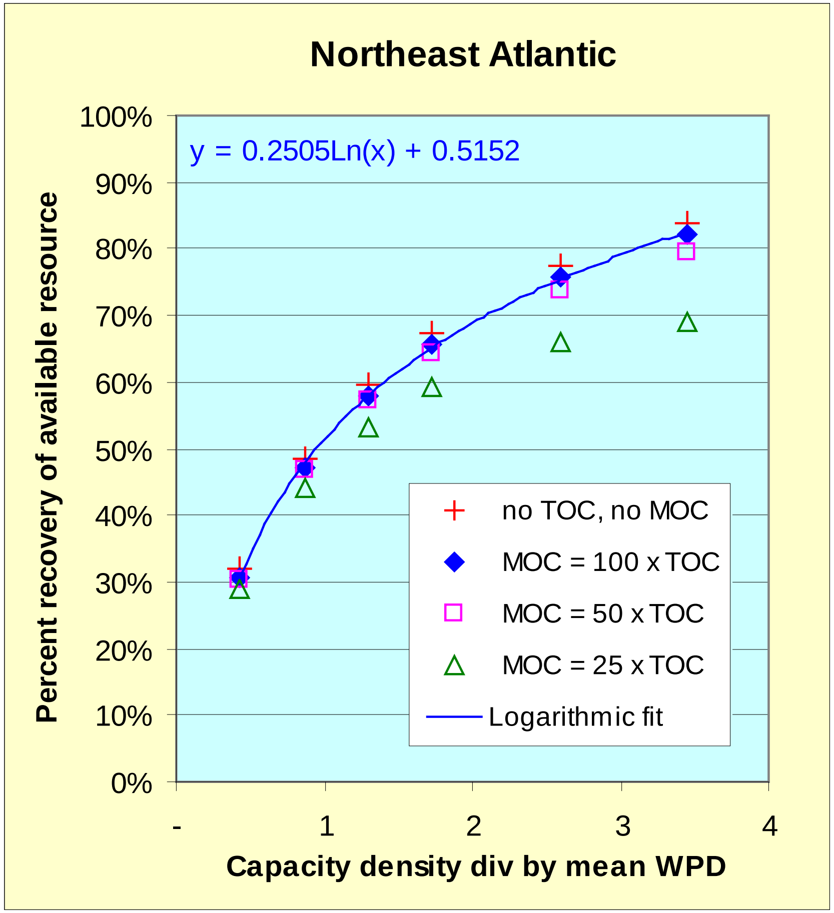
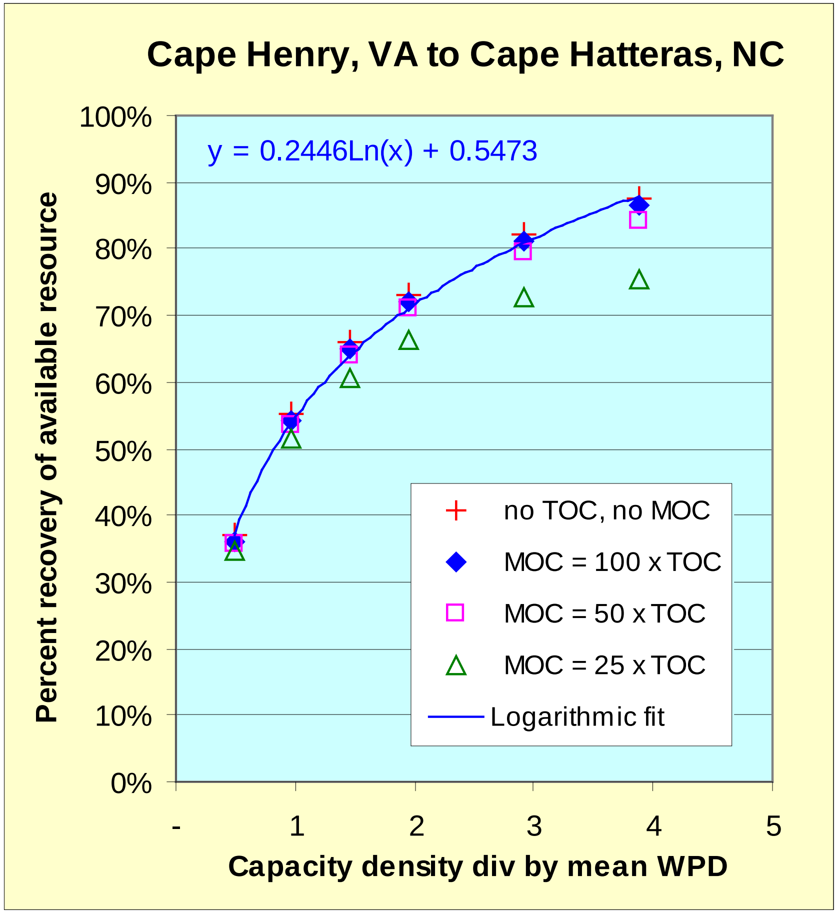
Recoverable Resource vs. Array Capacity Density for Moderately Energetic Regions (AAWPD* = 10 to 20 kW/m)





* AAWPD = Annual Average Wave Power Density, in kW per meter of wave crest across a unit- diameter circle

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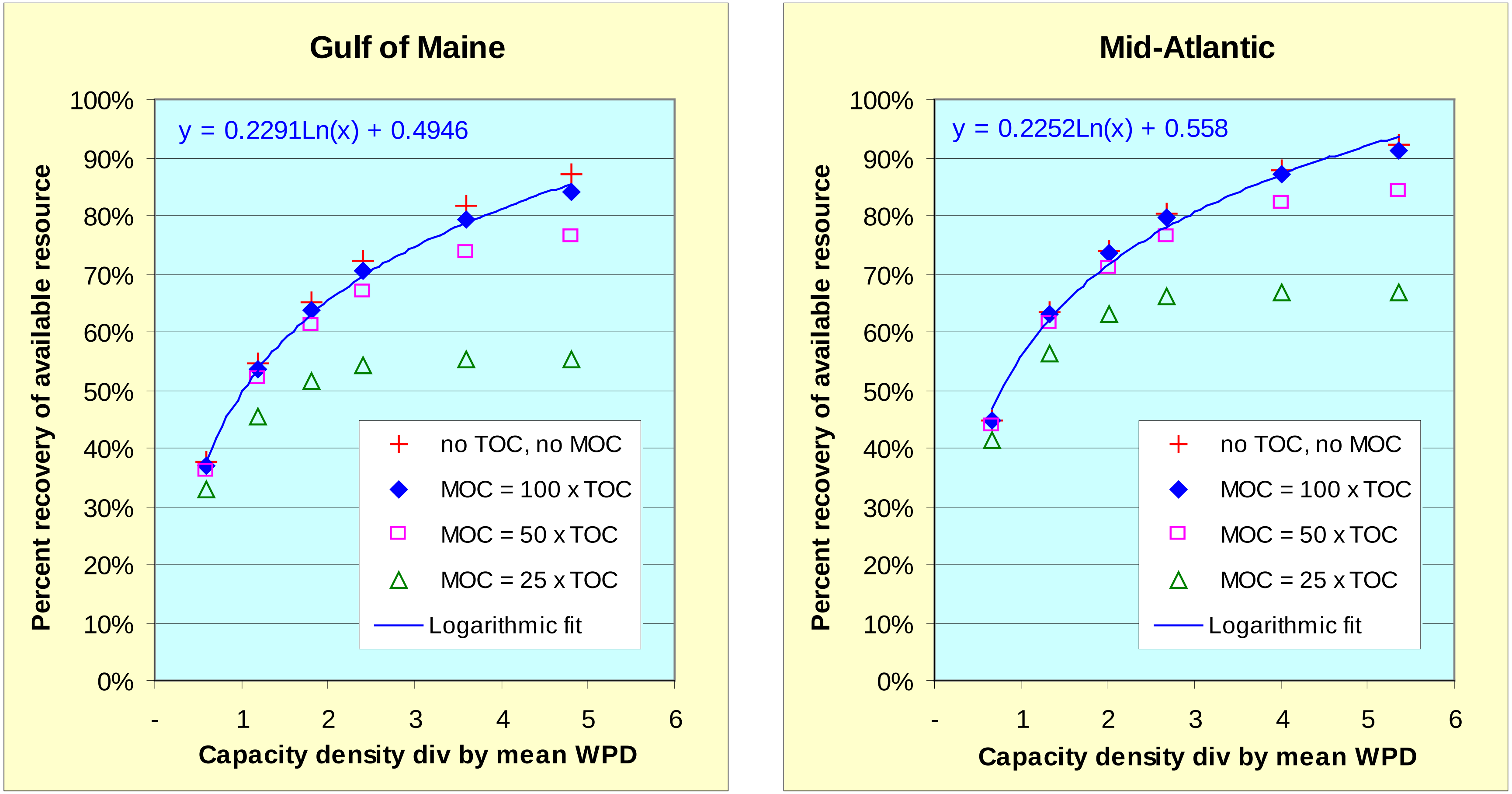
Recoverable Resource vs. Array Capacity Density for Mildly Energetic Regions (AAWPD* < 10 kW/m)



* AAWPD = Annual Average Wave Power Density, in kW per meter of wave crest across a unit- diameter circle

Recoverable Wave Energy Resource at Array Capacity Packing Density of 15 MW per km *

Coastline	Available Resource	Recoverable Resource
West Coast (WA,OR,CA)	587 TWh/yr	247 TWh/yr (42% of available)
East Coast (ME thru NC)	197 TWh/yr	128 TWh/yr (65% of available)
East Coast (SC thru FL-Atlantic)	42 TWh/yr	32 TWh/yr (76% of available)
Gulf of Mexico	83 TWh/yr	64 TWh/yr (77% of available)
Alaska (Pacific only)	1,356 TWh/yr	529 TWh/yr (39% of available)
Alaska (Bering Sea)	194 TWh/yr	95 TWh/yr (49% of available)
Hawaii	130 TWh/yr	83 TWh/yr (64% of available)
Puerto Rico	28 TWh/yr	21 TWh/yr (76% of available)
TOTAL	**2,617 TWh/yr**	**1,199 TWh/yr** (46% of available)

* Three packing densities that were evaluated: 10 MW, 15 MW, and 20 MW per kilometer, with the two lower values bracketing the current state of technology, and the upper value representing an achievable improvement.

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Summary of EPRI Wave Energy Resource Study Products

- **Time series (51 months at 3-hr interval) of sea state parameters**
  - Accessible by lat-long coordinates, sorted into five depth zone sub-folders within 15 U.S. coastal region folders
  - Spectral reconstruction equations documented in Appendix A of final report
- **Annual and monthly U.S. offshore maps** (http://maps.nrel.gov/re_atlas)
  - On-line map views of both annual and monthly statistics, as follows:
    - Significant wave height (H_{m0})
    - Mean zero crossing wave period (T_z)
    - Peak wave direction
    - Wave power density
  - Bathymetry
  - Distance from shore
- **Naturally available and technically recoverable resource estimates**
  - Range reflecting continental shelf resource (50 m to 200 m depth contours on West Coast, Hawaii, Puerto Rico, and New England; (20 m to 200 m depth contours on Mid-Atlantic and South Atlantic coastlines and in Gulf of Mexico)
  - Technically recoverable resource characterization curves

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Thank You!

Assessment of Energy Production Potential from Tidal Streams in the United States

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Hermann M. Fritz Ph.D.
Lide Jiang Ph.D.
Zafer Defne Ph.D.

Civil and Environmental Engineering
Georgia Institute of Technology
Savannah Campus (GTS)

Steven P. French Ph.D.
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Center for Geographic Information Systems
Georgia Institute of Technology
Atlanta Campus (GTA)

Brennan T. Smith Ph.D.
Vincent Neary Ph.D.
Kevin Stewart

Oak Ridge National Laboratory (ORNL)
Environmental Sciences Division

METAP Webinar: Resource Assessments of Wave Energy and Tidal Streams in the U.S. March 29, 2012

How to Assess the Resource

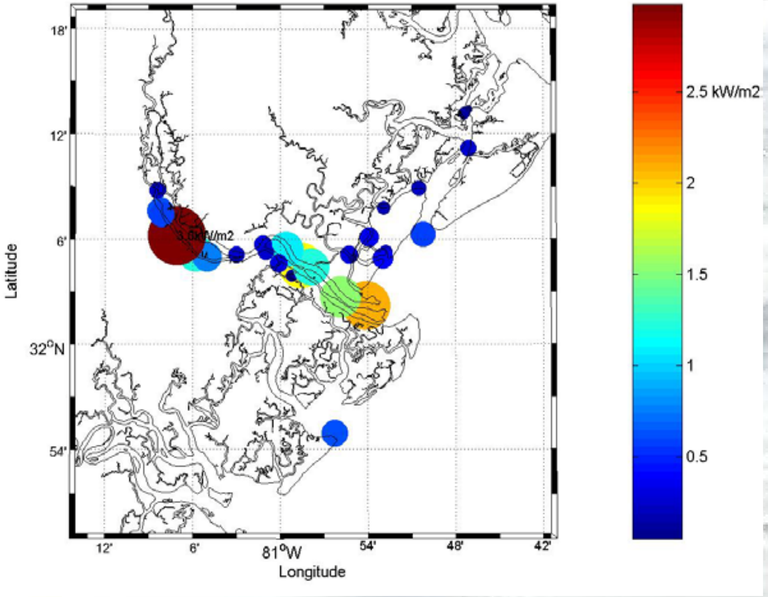
Theoretical Resource: Power contained in the tidal flows that could be extracted excluding considerations of any constraints

Technical Resource: Portion of the theoretical resource that can be captured with particular technology

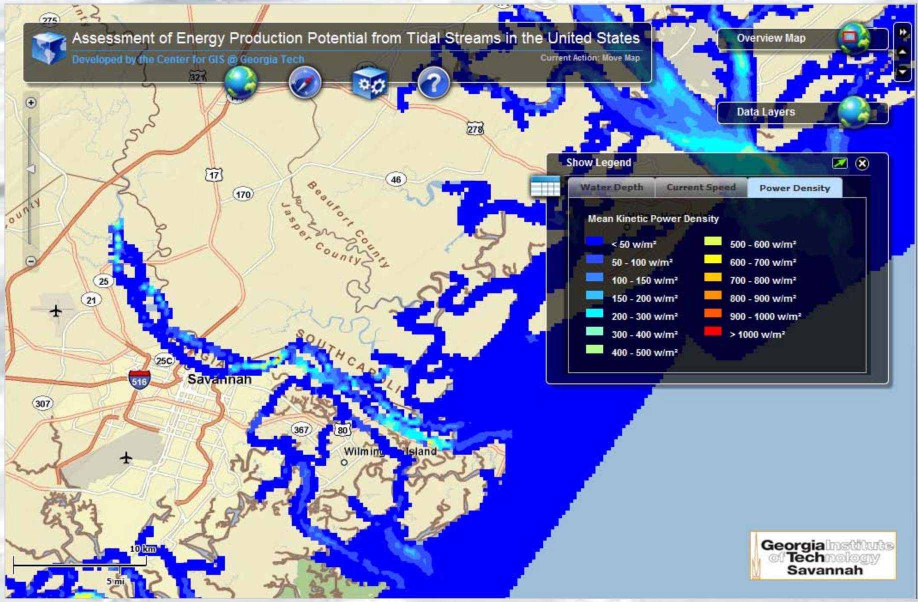
Practical Resource: Portion of the resource that can be captured considering all constraints such as environmental or economic etc.

Computing the National Theoretical Resource

Measurements or predictions are too sparse or unreliable



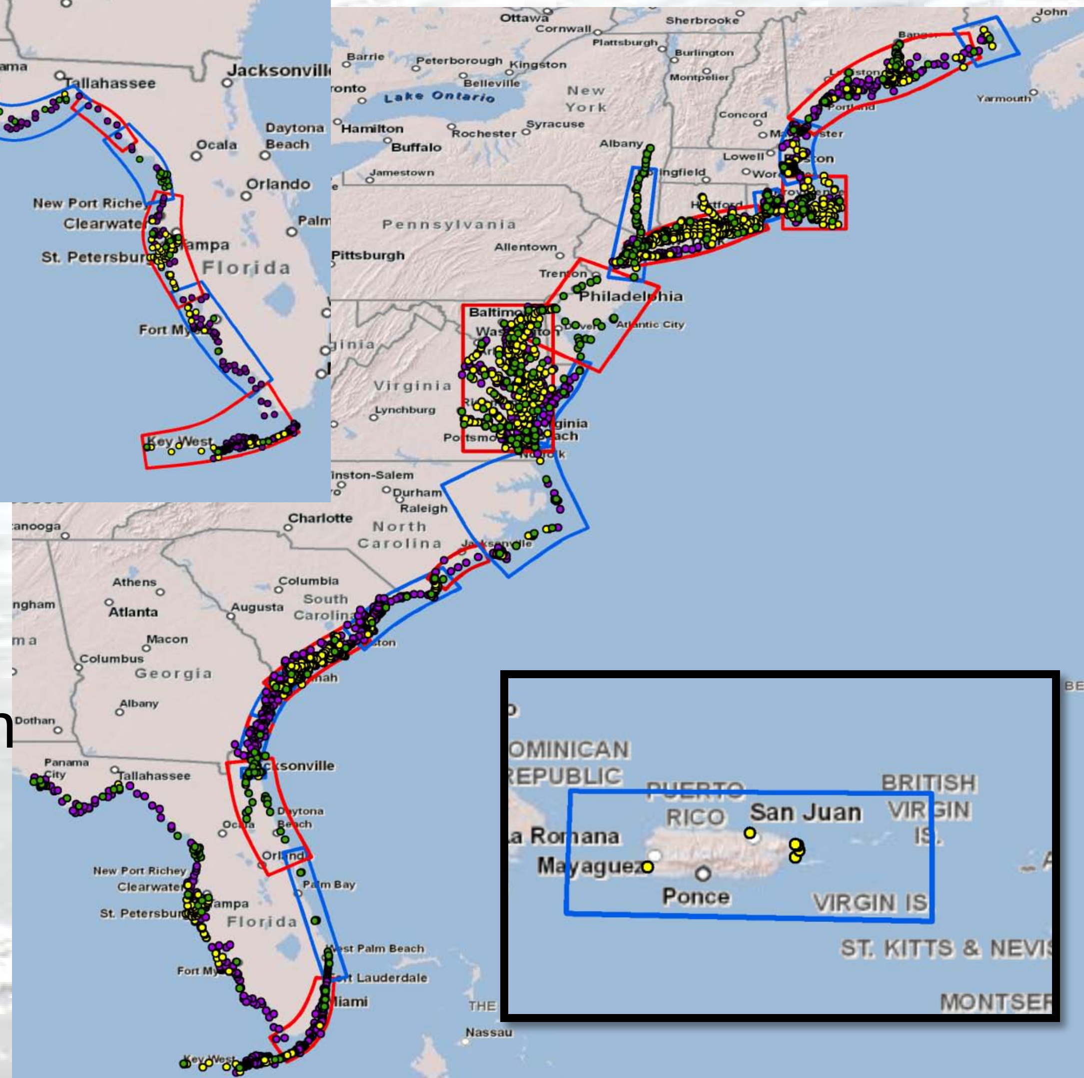
Used the numerical model ROMS to provide predictions of tidal flows at high resolution



Velocity and water level constituents computed from the model simulations are used to represent the resource

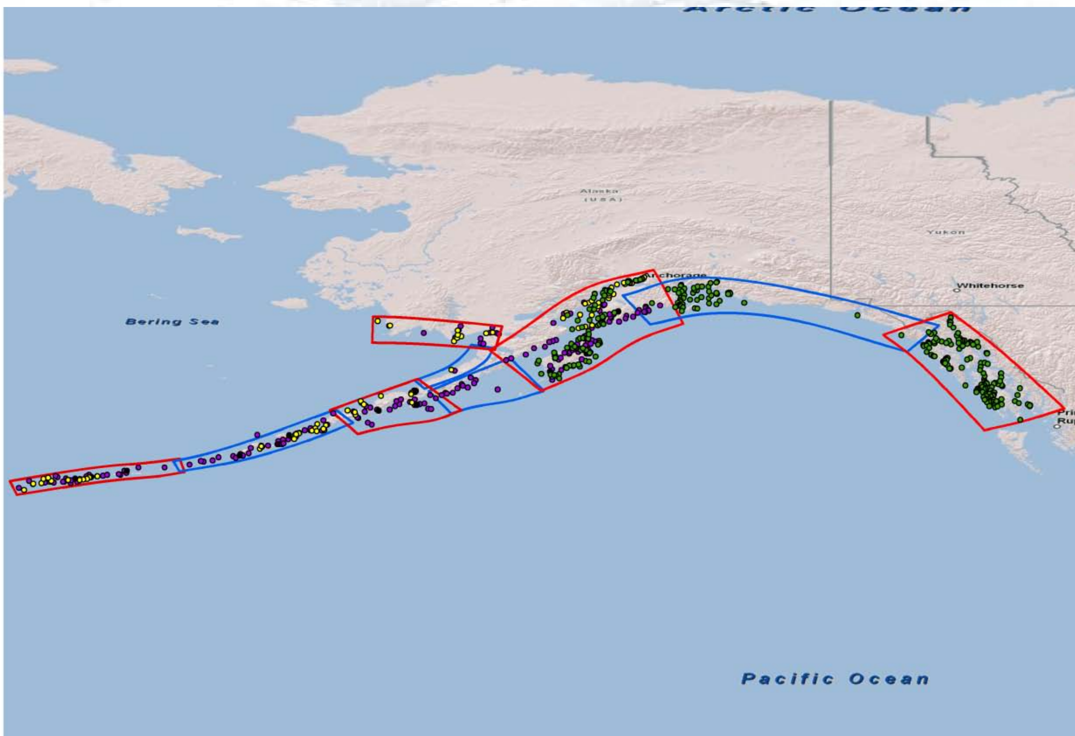
Numerical Model - ROMS

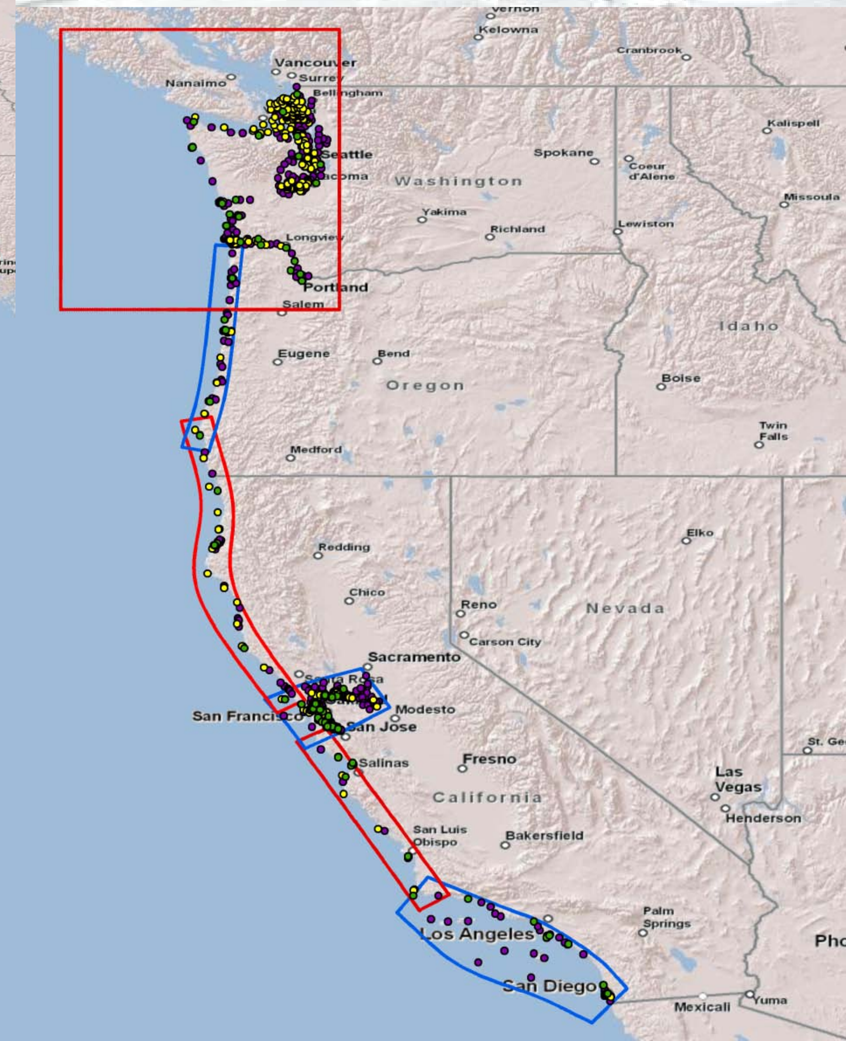
Regional Ocean Model System



Yellow: Current prediction
Purple: Water level prediction
Green: ADCP
Black: Harmonic Constituent

Numerical Model - ROMS
Regional Ocean Model System





Yellow: Current prediction
Purple: Water level prediction
Green: ADCP
Black: Harmonic Constituent

- Tidal constituents
  - East/Gulf coast – ADCIRC tidal database
  - West/Alaska – TPXO
- 32 days are simulated
  - Calibrate the model
    - Use available data and existing predictions
    - Use shorter model runs 7-10 days
    - Redo 32 day simulations
  - Compute the harmonic constituents
    - Use forced constituents only
    - T_Tide harmonic analysis toolbox for Matlab

Model Calibration Procedure

- Data Sources
  - Tidal Water Level Predictions
  - Tidal Water Level Harmonics
  - Tidal Current Predictions
  - ADCP Measurements
- Calibrate the model
  - Use measurements where possible and if none exist then use predictions
  - Modify the friction factor for whole domain
  - Use shorter model runs 7-10 days
  - Redo 32 day simulation

National Tidal Stream Power Database

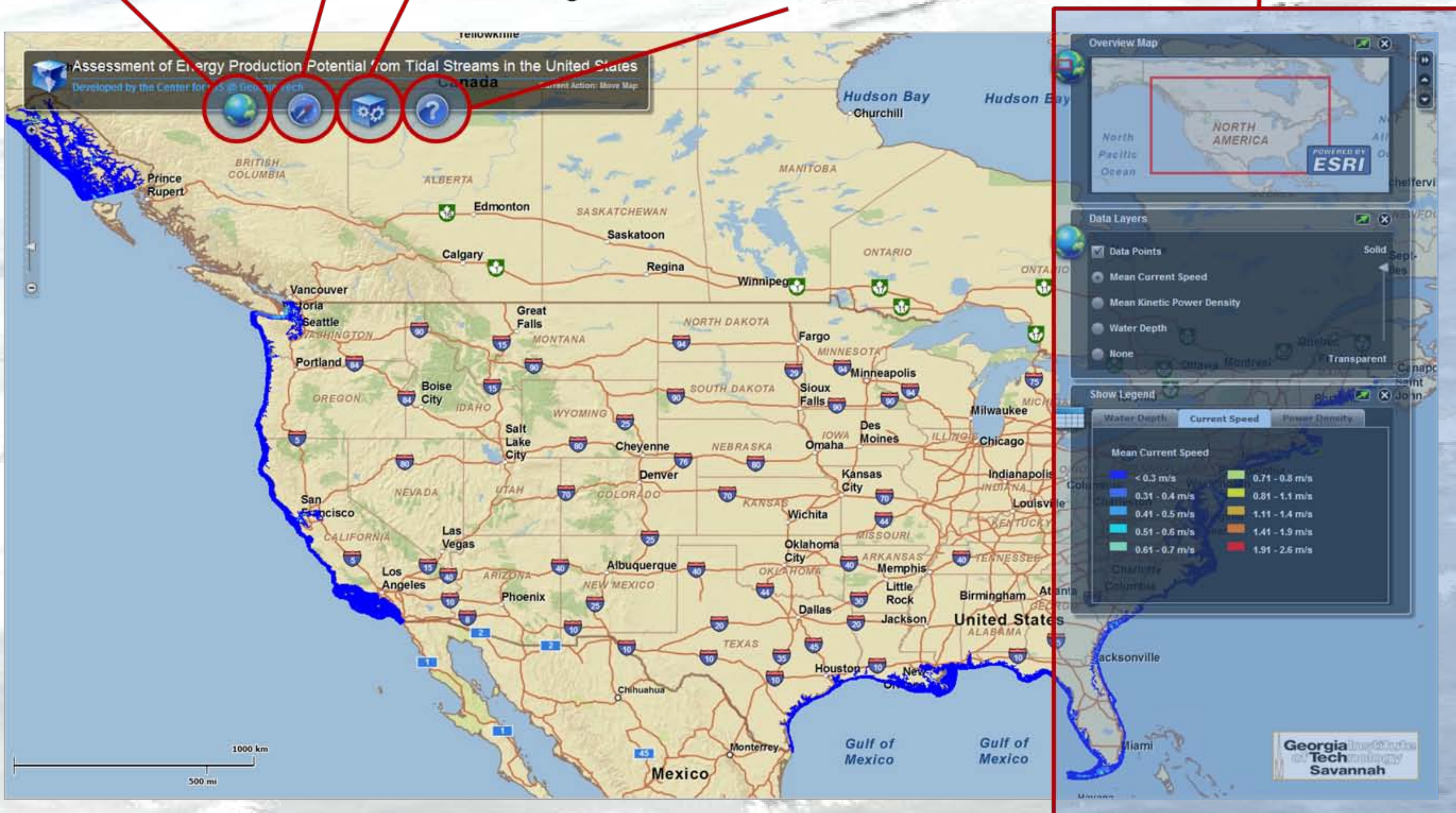
View
Street Map
Aerial Map
Overview Map

Navigation
Zoom
Pan

Tools
Data Layers
Identify
Select/Export Feature
View Legend

Help
Instructions
Project Information
Model Documentation
Contact

Interactive Widgets

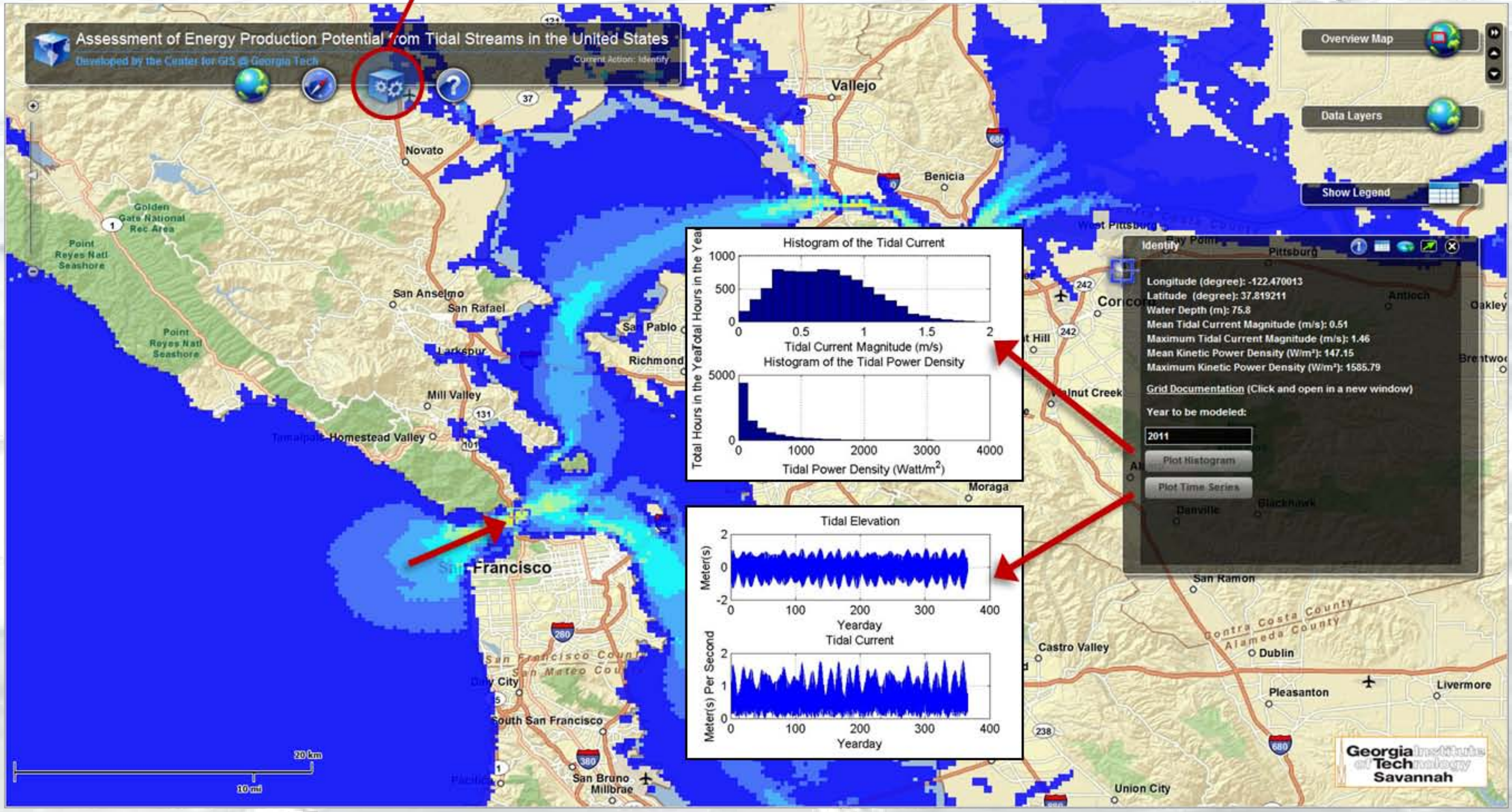


www.tidalstreampower.gatech.edu

Tools for Viewing the Data

Tools
Data Layers
Identify
Select/Export Feature
View Legend

Single data point
Select year
Plot histogram
Plot time series
Access model documentation



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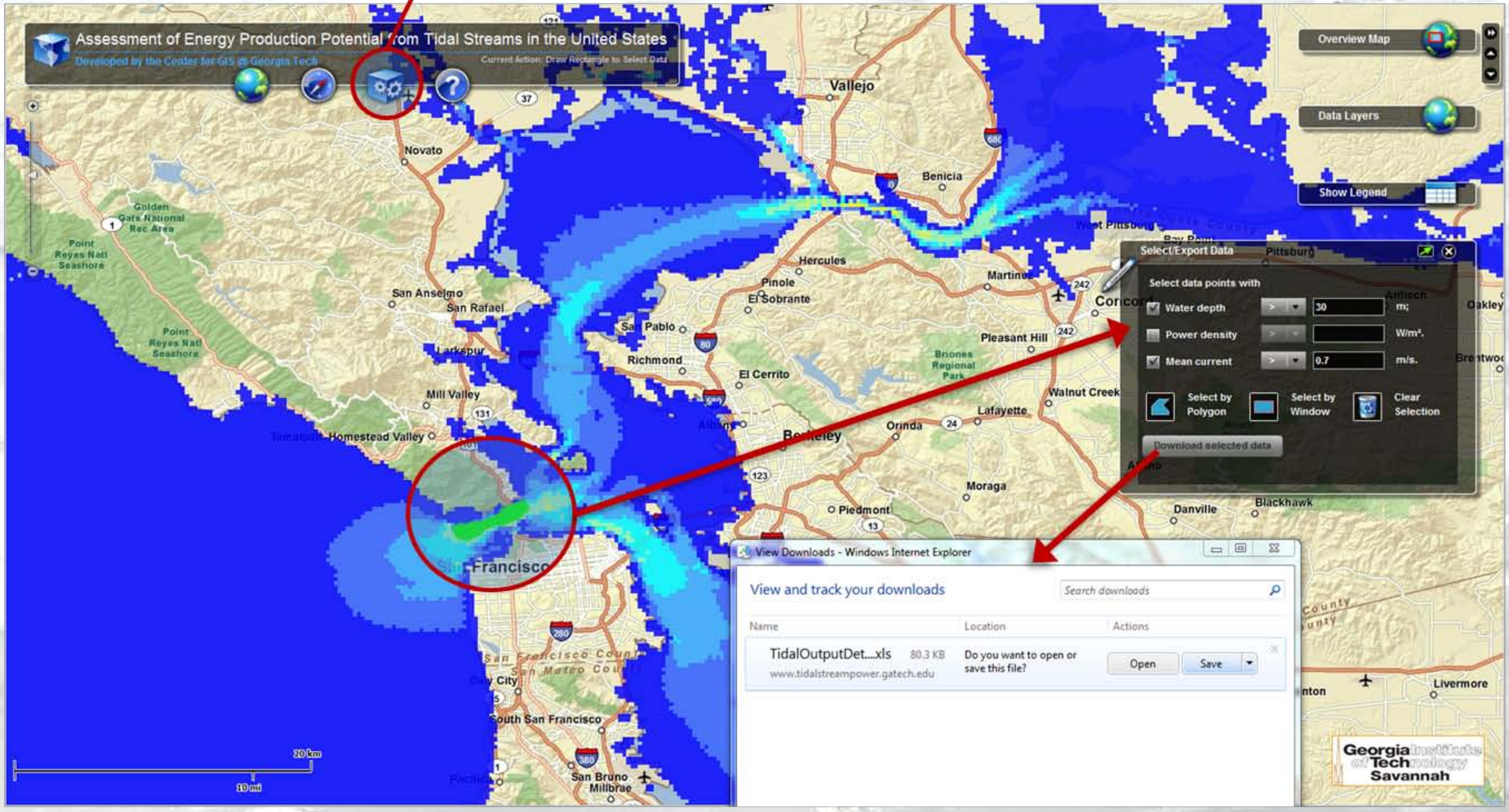
Tools for Extracting the Data

Tools
Data Layers
Identify
Select/Export Feature
View Legend

Select extent
Select area
Apply filters
Download constituents



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Grid Documentation

Model input parameters, map of the computational grid and calibration statistics

DOCUMENTATION FOR THE COMPUTATIONAL GRID: sfb

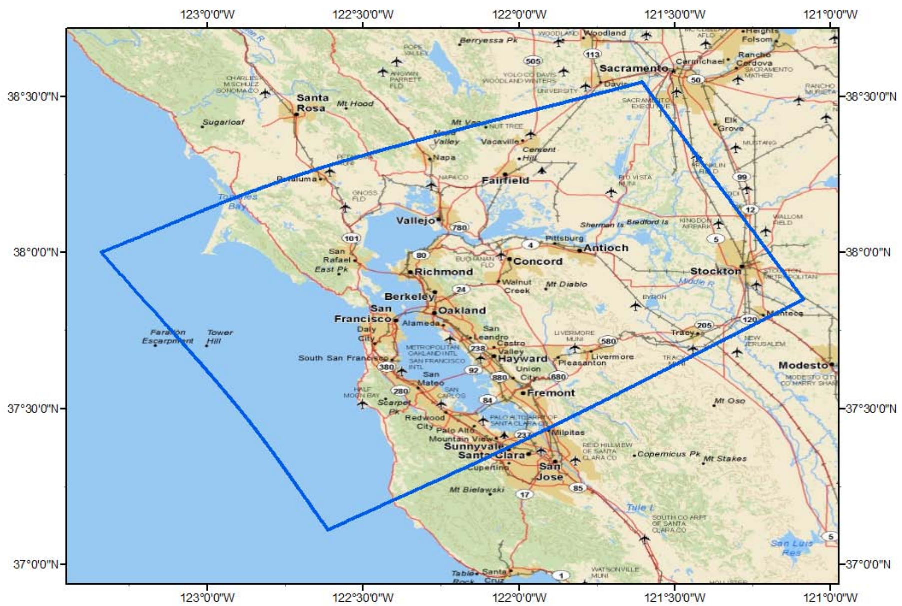
Last update on 3/24/2011 2:19 PM

For additional information on the model setup and calibration please refer to the General Documentation.

MODEL INPUT PARAMETERS: ROMS/TOMS VERSION 3.0

ACTIVATED MODULES

DOE_TIDE	San Francisco Bay Tides
ANA_BSFLUX	Analytical kinematic bottom salinity flux.
ANA_BTFLUX	Analytical kinematic bottom temperature flux.
ANA_FSOBC	Analytical free-surface boundary conditions.
ANA_INITIAL	Analytical initial conditions.
ANA_M2OBC	Analytical 2D momentum boundary conditions.
ANA_SMFLUX	Analytical kinematic surface momentum flux.
ANA_SSFLUX	Analytical kinematic surface salinity flux.
ANA_STFLUX	Analytical kinematic surface temperature flux.
ASSUMED_SHAPE	Using assumed-shape arrays.
CURVGRID	Orthogonal curvilinear grid.
DJ_GRADPS	Parabolic Splines density Jacobian (Shchepetkin, 2002).
DOUBLE_PRECISION	Double precision arithmetic.
EAST_FSCHAPMAN	Eastern edge, free-surface, Chapman condition.
EAST_M2FLATHER	Eastern edge, 2D momentum, Flather condition.
EAST_M3GRADIENT	Eastern edge, 3D momentum, gradient condition.
EAST_TGRADIENT	Eastern edge, tracers, gradient condition.
GLS_MIXING	Generic Length-Scale turbulence closure.
KANTHA_CLAYSON	Kantha and Clayson stability function formulation.
MASKING	Land/Sea masking.
MPI	MPI distributed-memory configuration.
NONLINEAR	Nonlinear Model.
!NONLIN_EOS	Linear Equation of State for seawater.
NORTH_FSCHAPMAN	Northern edge, free-surface, Chapman condition.
NORTH_M2FLATHER	Northern edge, 2D momentum, Flather condition.
NORTH_M3GRADIENT	Northern edge, 3D momentum, gradient condition.
NORTH_TGRADIENT	Northern edge, tracers, gradient condition.
N2S2_HORAVG	Horizontal smoothing of buoyancy and shear.
POWER_LAW	Power-law shape time-averaging barotropic filter.
PROFILE	Time profiling activated .
K_GSCHEME	Third-order upstream advection of TKE fields.
!RST_SINGLE	Double precision fields in restart NetCDF file.
SOLVE3D	Solving 3D Primitive Equations.
SOUTH_FSCHAPMAN	Southern edge, free-surface, Chapman condition.
SOUTH_M2FLATHER	Southern edge, 2D momentum, Flather condition.
SOUTH_M3GRADIENT	Southern edge, 3D momentum, gradient condition.
SOUTH_TGRADIENT	Southern edge, tracers, gradient condition.
SPLINES	Conservative parabolic spline reconstruction.
SSH_TIDES	Add tidal elevation to SSH climatology.
STATIONS	Writing out station data.
TS_C4HADVECTION	Fourth-order centered horizontal advection of tracers.



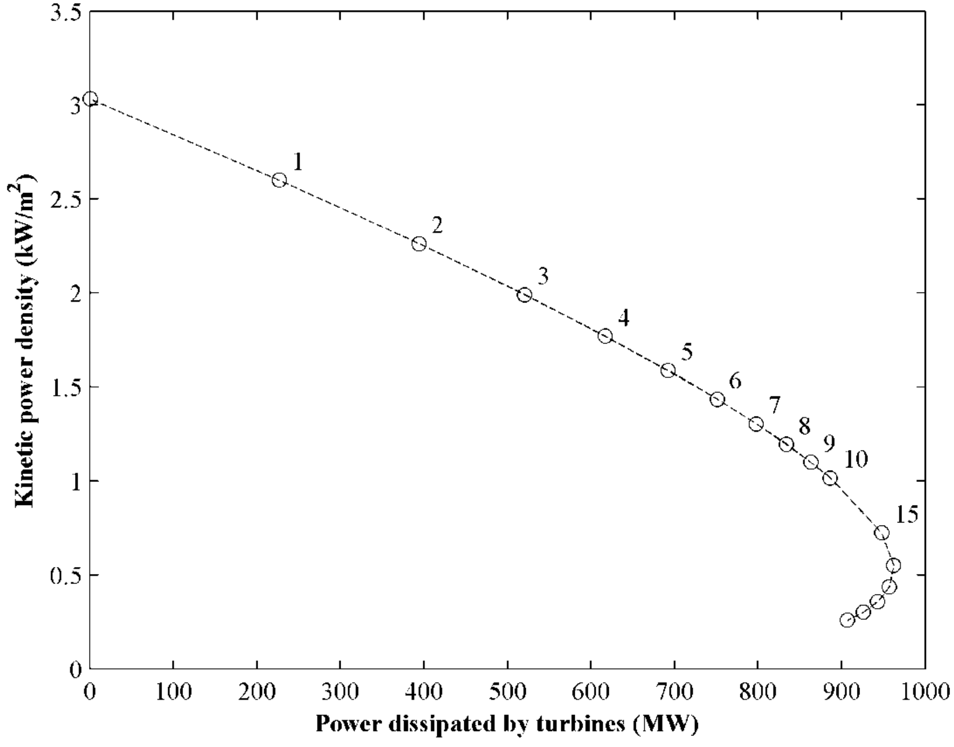
Tidal Power Resource Assessment
How do we provide information about the resource?

- The database provides the distribution of the **theoretical available kinetic power density**
  - $P = \frac{1}{2} \cdot \rho \cdot V^3$ (watts/m^2)
  - Time series can be computed
  - Map of the 30 day average
  - Does not include any technology assumptions or flow field effects
  - Provides information on an individual device scale
  - Does not apply for device arrays

Tidal Power Resource Assessment
How do we provide information about the resource?

- Performed an estimate of the **theoretical total available power** (Gigawatts)
  - Upper bound on the total power that can be dissipated
  - Does not include any technology assumptions
  - Accounts for the cumulative effect of dissipating energy
  - Provides information on an estuary scale
  - Uses undisturbed flow field from the model with simple analytical methods

From Polagye (2009)



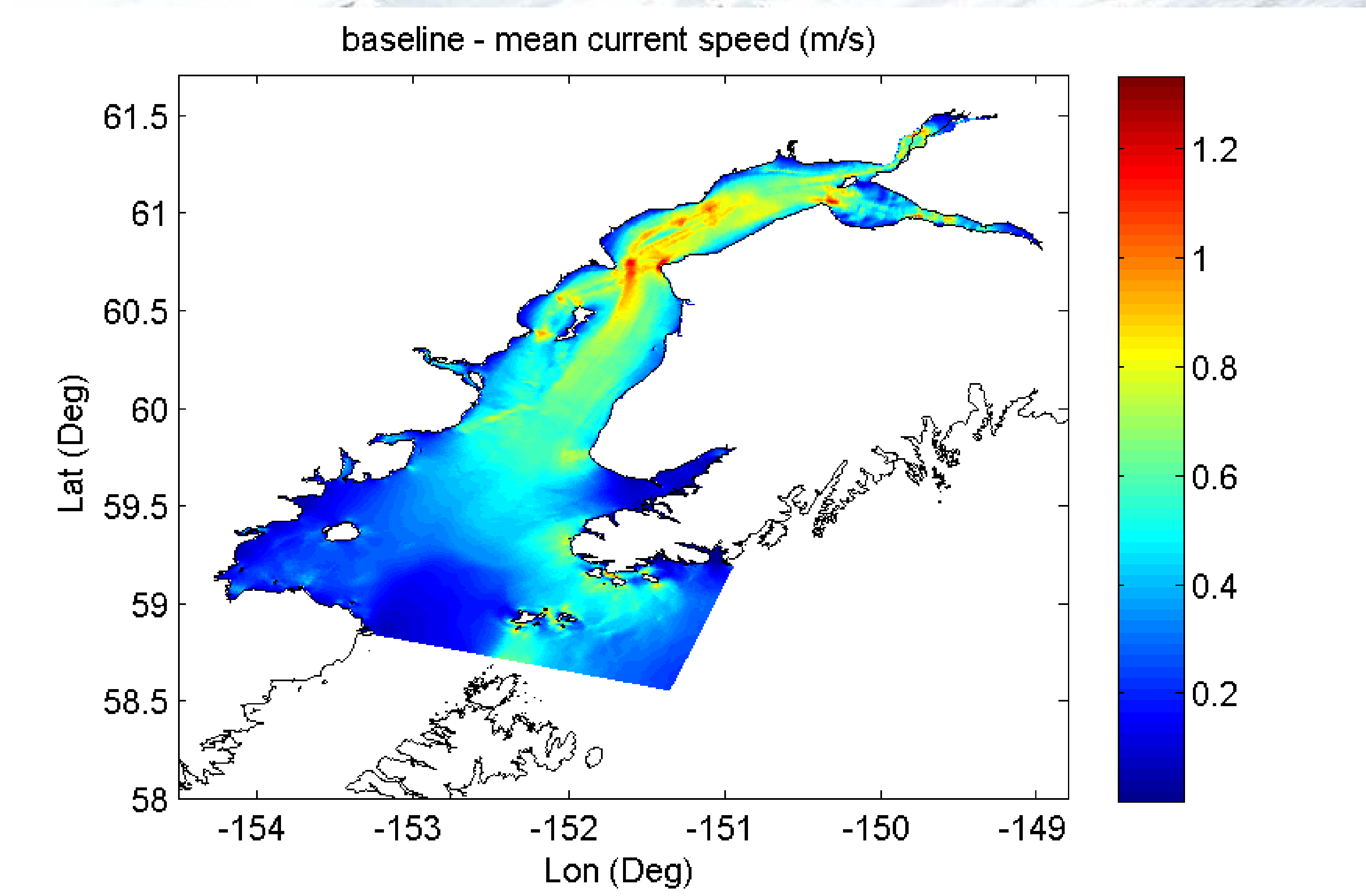
Estimate of the theoretical total available power

- Following Garrett and Cummins (2005)

$$P_{\max} = \gamma \rho g a Q_{\max}$$

γ	Parameter ~ 0.22
ρ	Water density
g	Gravity
a	Tidal water level amplitude
$Q_{\max}$	Maximum tidal flowrate

Cook Inlet P_{max} = 18.2 GW



Breakdown of the theoretical total available power

State	Maximum Power (MW)
ME	675
NH	21
MA	45
RI	16
NY	280
NJ	191.5
DE	165.5
MD	35
VA	133
NC	61
SC	388

State	Maximum Power (MW)
GA	219
FL	166
AL	7
LA	2
TX	6
CA	204
OR	118
WA	613
AK	47437
USA	**50783**

Access the Web page at:

www.tidalstreampower.gatech.edu

Access the Final Report at:

http://www1.eere.energy.gov/water/pdfs/1023527.pdf

Published Journal Article

Defne et al. National geodatabase of tidal stream power resource in USA. Renewable and Sustainable Energy Reviews 16 (2012) 3326–3338, doi:10.1016/j.rser.2012.02.061