Two long-period swell partitions meet at 90° angle in the Bay of Biscay

https://commons.wikimedia.org/wiki/File%3Alle_de_r%C3%A9.JPG

National Wave Energy Resource Refinement Using 30-year Hindcast

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National Wave Energy Resource Refinement Using 30-year Hindcast

The Challenge: DOE's first national wave energy resource assessment published five years ago (Dec 2011) was based on only 51 months of wave data that were available at the time for all coastal regions, and it did not include directional analyses critical to site selection and project layout.

Partners:

- National Renewable Energy Laboratory (NREL)
  - Project oversight, dissemination of final results
- Virginia Tech (subcontractor)
  - Technical methodology and data processing
- NOAA/NCEP (National Ocean Partnership Program, Phase II)
  - WaveWatch III 30-year reanalysis with improved swell physics

Program Strategic Priorities

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Technology Maturity

- Test and demonstrate prototypes
- Develop cost effective approaches for installation, grid integration, operations and maintenance
- Conduct R&D for innovative MHK systems & components
- Develop tools to optimize device and array performance and reliability
- Develop and apply quantitative metrics to advance MHK technologies

Deployment Barriers

- Identify potential improvements to regulatory processes and requirements
- Support research focused on retiring or mitigating environmental risks and reducing costs
- Build awareness of MHK technologies
- Ensure MHK interests are considered in coastal and marine planning processes
- Evaluate deployment infrastructure needs and possible approaches to bridge gaps

Market Development

- Support project demonstrations to reduce risk and build investor confidence
- Assess and communicate potential MHK market opportunities, including off-grid and non-electric
- Inform incentives and policy measures
- Develop, maintain and communicate our national strategy
- Support development of standards
- Expand MHK technical and research community

Crosscutting Approaches

- Enable access to testing facilities that help accelerate the pace of technology development
- **Improve resource characterization to optimize technologies, reduce deployment risks and identify promising markets**
- Exchange of data information and expertise

Project Strategic Alignment

Crosscutting Approaches

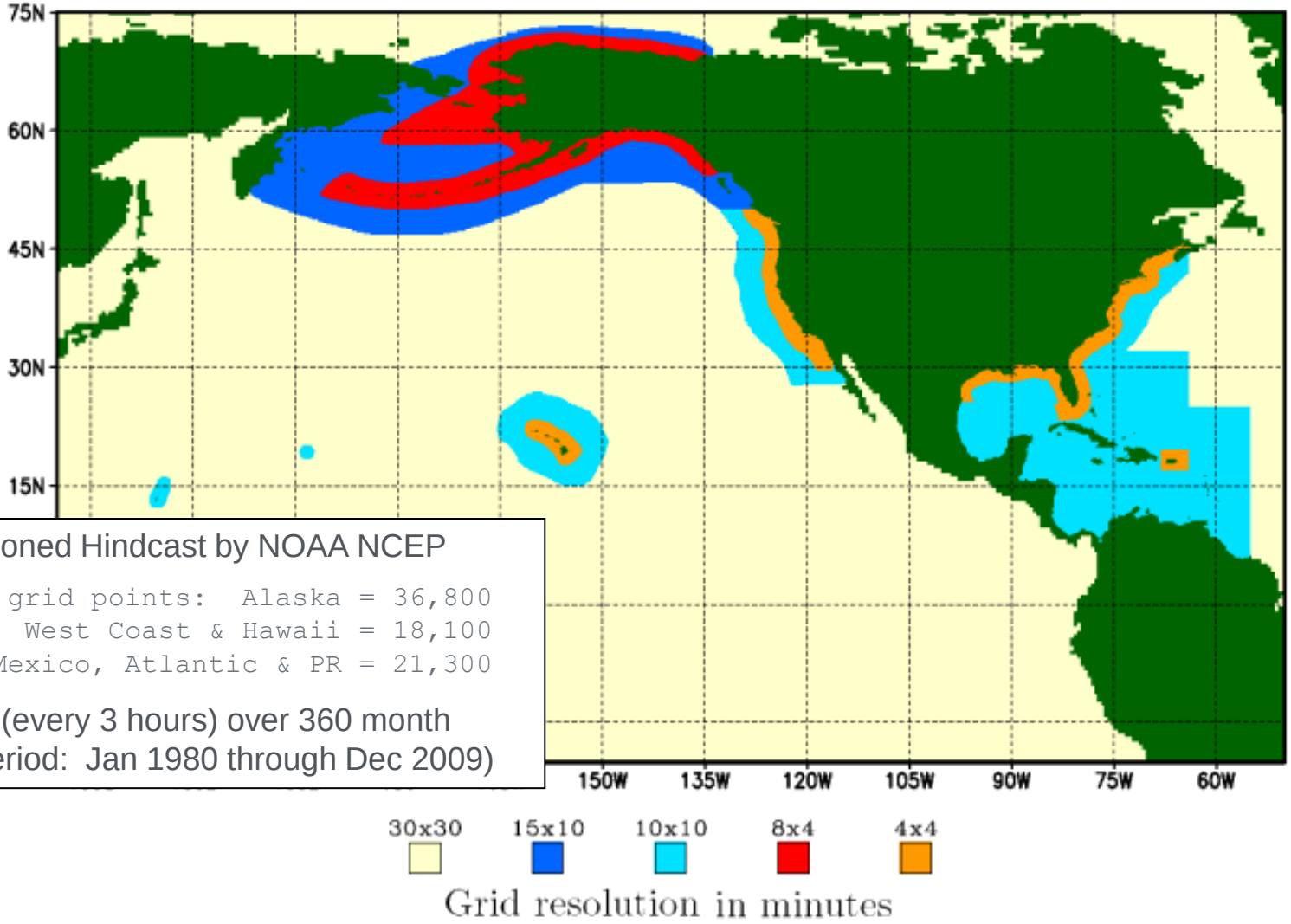
- Enable access to testing facilities that help accelerate the pace of technology development
- **Improve resource characterization to optimize technologies, reduce deployment risks and identify promising markets**
- Exchange of data information and expertise

The Impact

- **Reduction in resource uncertainty**
  - 360-month vs. 51-month dataset better represents long-term conditions
  - More accurate swell modeling
  - More accurate sea state reconstruction
- **Detailed datasets at industry-relevant points**
  - MHK device test sites
  - Remote military installations
  - Full directional spectra archived
- **Directional wave data now provide input to shallow-water wave modeling**
- **NREL Renewable Energy Atlas mapping of International Electrotechnical Commission (IEC)-specified wave resource parameters (annual average and 12 monthly averages)**
- **Revised estimation of theoretical and technical wave energy resource**

Technical Approach

Nested Multi-grid Wavewatch III



Fully Partitioned Hindcast by NOAA NCEP

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Number of grid points:  Alaska = 36,800
           West Coast & Hawaii = 18,100
 Gulf of Mexico, Atlantic & PR = 21,300
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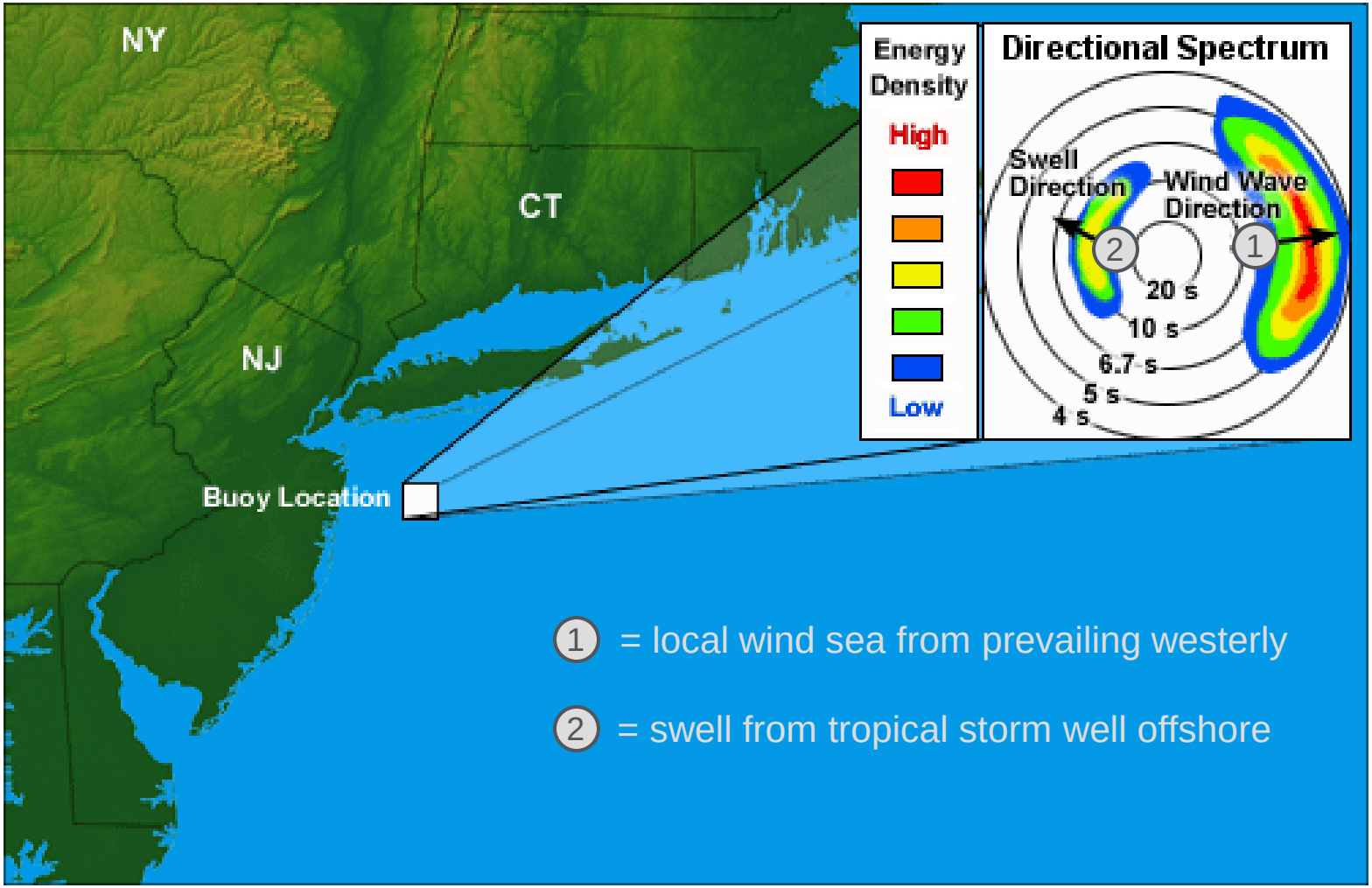
Frequency (every 3 hours) over 360 month hindcast period: Jan 1980 through Dec 2009)

Technical Approach

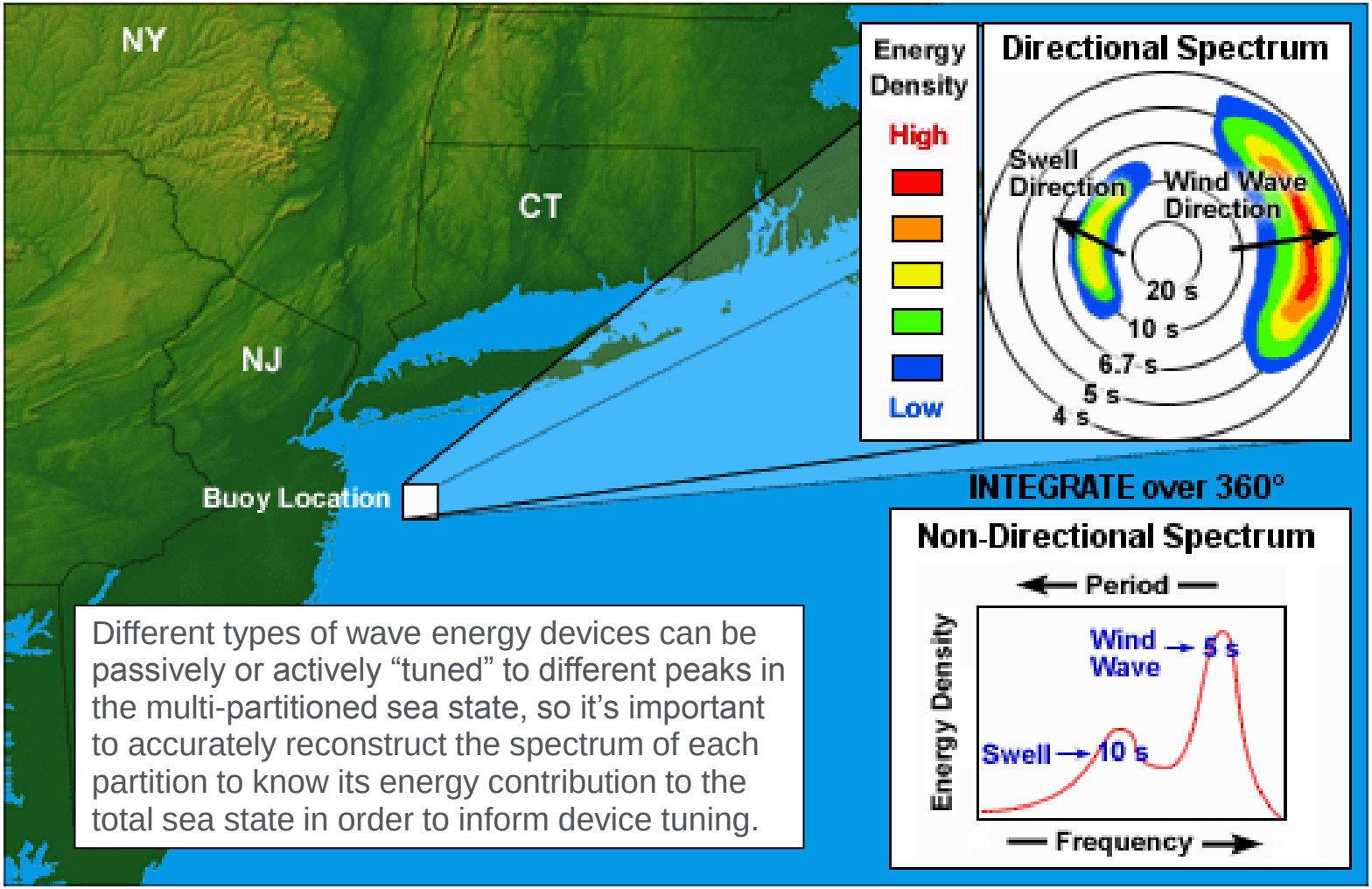
Partition Primer



1 = local wind sea from prevailing westerly

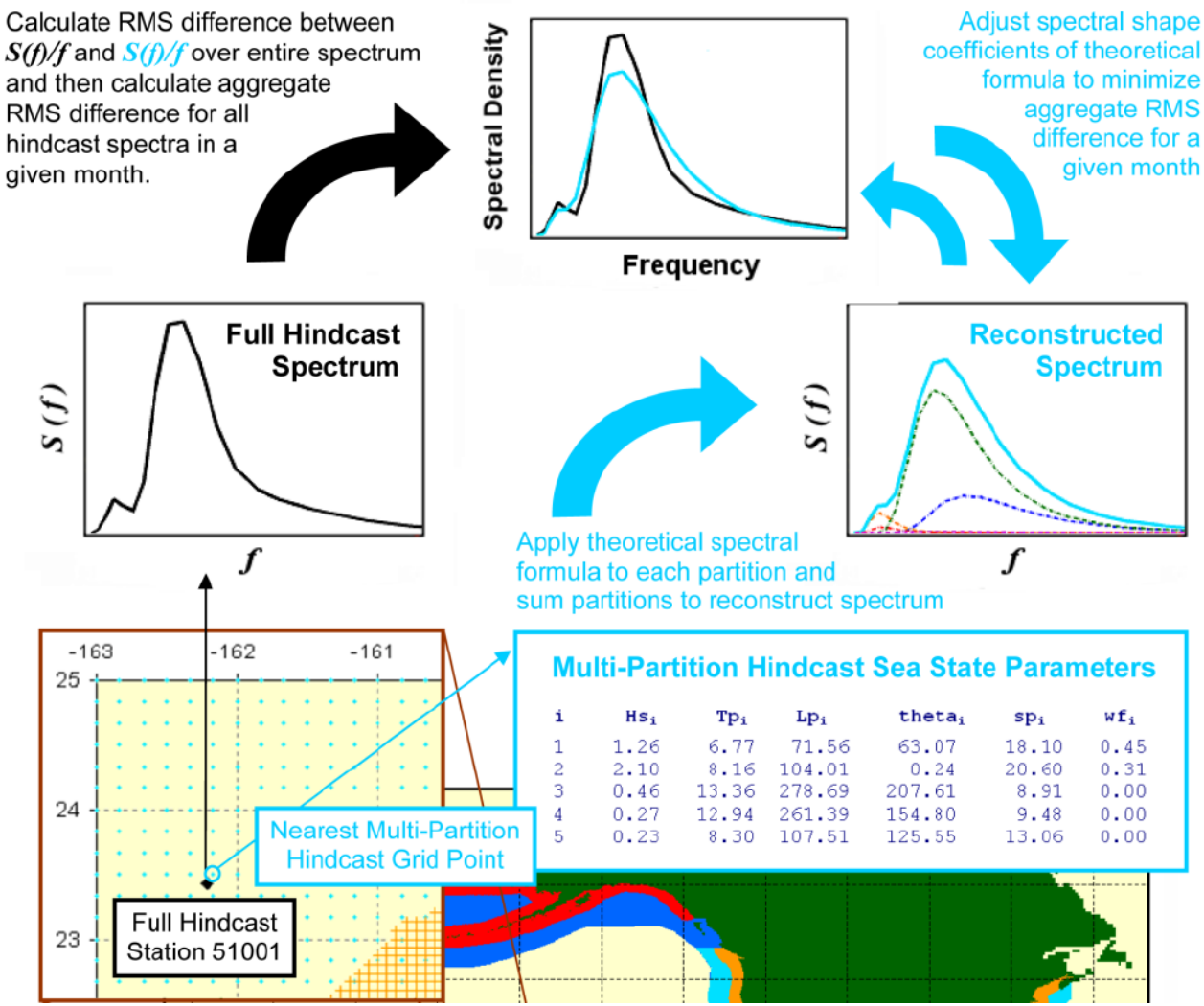
2 = swell from tropical storm well offshore

Partition Primer

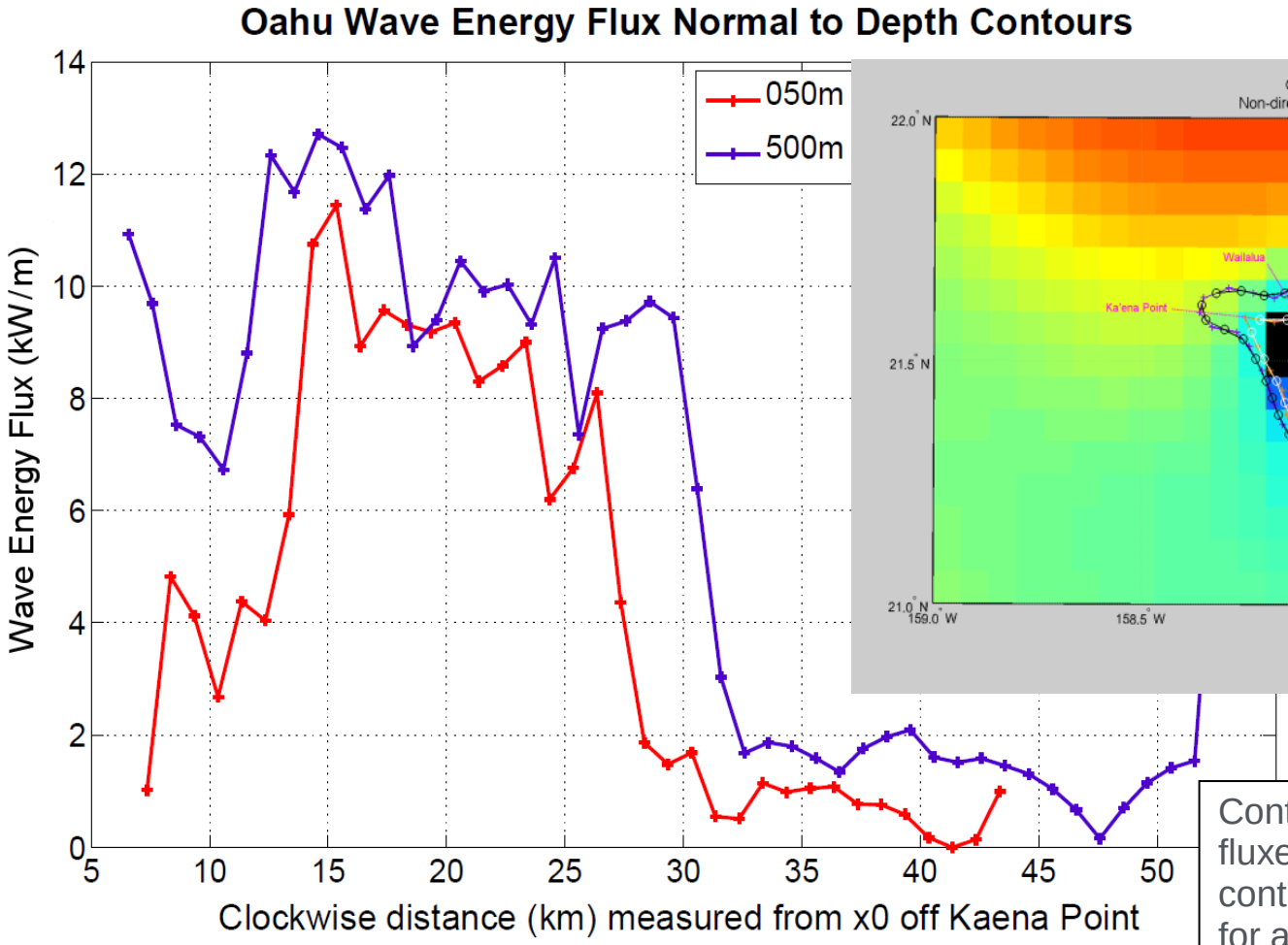


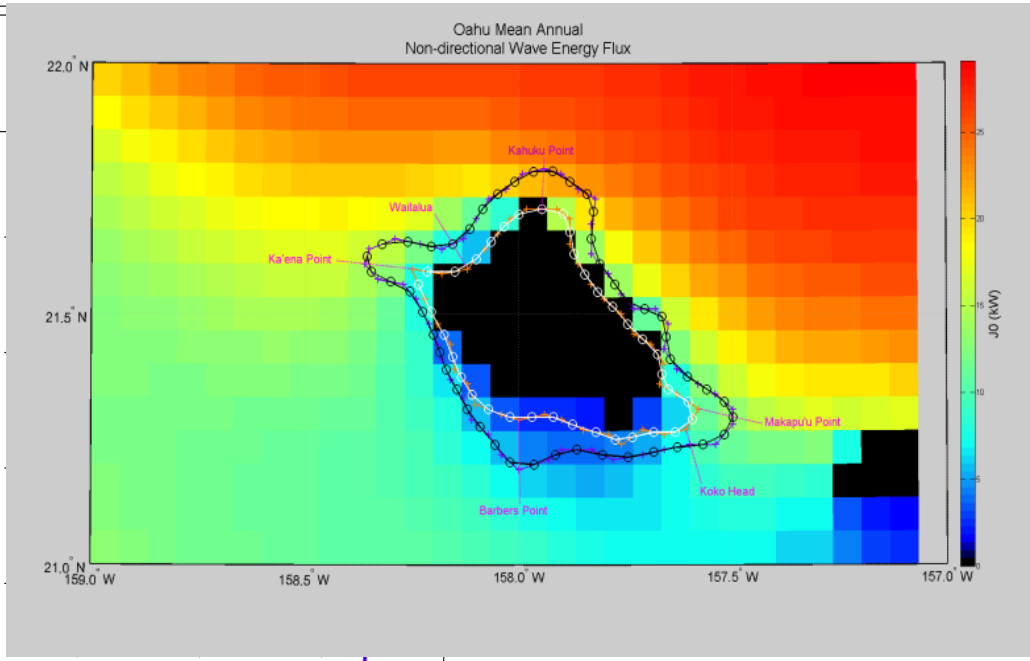
Different types of wave energy devices can be passively or actively "tuned" to different peaks in the multi-partitioned sea state, so it's important to accurately reconstruct the spectrum of each partition to know its energy contribution to the total sea state in order to inform device tuning.

Reconstruction of Full Spectrum at Each Grid Point



Example of Wave Energy Flux Normal to Depth Contours





Contour-normal wave energy fluxes are summed along depth contours to estimate total resource for a state or coastal region.

Accomplishments and Progress

- **FY 2014 accomplishments**
  - Completed identification of bathymetric contour vectors for accumulating contour-normal “Deep-Water” wave energy flux and “Project Depth” flux
  - Completed and validated algorithms for reconstructing ***directional*** spectra
  - Catalogued and verified “virtual buoy” stations archiving full directional spectra, including ocean test sites and military bases and sent to National Centers for Environmental Prediction (NCEP)
  - Developed and validated algorithm for interpolating contour-normal wave energy fluxes from mapping results
- **FY 2015 accomplishments**
  - Completed end-to-end testing of all algorithms using National Centers for Environmental Prediction (EPRI) 51-month Phase I grids while still waiting for NCEP production of 360-month Phase II grids
  - Based on “virtual buoy” data, prepared European Wave and Tidal Energy Conference *EWTEC-2015* paper identifying suitably scaled “nursery sites” for Northwest National Marine Renewable Energy Center (NNMREC) fully energetic site off Newport, OR, and proposed CalWave fully energetic site off Point Arguello, CA
- **FY 2016 accomplishments**
  - Successfully produced all mapping data, only to discover mapping shift errors due to NCEP-produced NetCDF files not supporting sparse arrays resulting from dead calms and ice; NCEP produced new NetCDF files

Project Plan & Schedule

- **Project Initiation Date**: 25 Nov 2013
- **Original Planned Completion Date**: 30 Nov 2014
- **Reasons for Delays in Completion**
  - NCEP revised Phase II dataset completion date to March–April 2015
  - NCEP computing resource constraints and hard disk crashes delayed completion of Phase II dataset until April 2016
  - NCEP errors in NetCDF conversion program—new dataset June 2016
  - VT algorithms for West Coast grids failed in other regions—corrected July 2016
  - NCEP revised NetCDF conversion—produced new dataset 17 October 2016
- **Virginia Tech successfully produced mapping data in November**
- **Final no-cost time extension to 31 December 2017**

Project Budget

Budget History					
FY2014		FY2015		FY2016	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$350k	$0	$50k	$0	$0	$0

- 96% of funding was costed by the end of FY16
- Subcontract with Virginia Tech for $217,705

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators:

Virginia Tech (subcontractor): George Hagerman (technical direction), Philip Balitsky (data processing and analysis)

National Oceanic Atmospheric Administration/NCEP: Arun Chawla (National Ocean Partnership Program lead for WaveWatch III re-analysis project; DOE is a contributing federal agency to National Oceanographic Partnership Program (NOPP) project, along with the U.S. Navy and Army Corps of Engineers)

Research Integration & Collaboration

Communications and Technology Transfer:

Project implements recommendations of National Academy of Sciences "Evaluation of the U.S. Department of Energy's Marine and Hydrokinetic Resource Assessments" report published in 2013

Papers and posters demonstrate how results of this study can be used to aid selection of wave energy test sites:

Papers: Balitsky, P. and G. Hagerman. "Wave climate analysis for scaled test sites off the US West Coast". Proceedings 11th European Wave and Tidal Energy Conference (EWTEC2015), Nantes, France, 6-11 Sep 2015.

Posters: Balitsky, P., and G. Hagerman. "Preliminary Assessment of Wave Energy Resources and Design Conditions at Four Proposed U.S. Test Sites." 5th International Conference on Ocean Energy, Halifax, Nova Scotia, Canada, 04-06 November 2014.

Balitsky, P. "The Case for 'Nursery' Sites to Support WEC Testing on the U.S. West Coast." Presented at the 10th INORE European Symposium (International Network on Offshore Renewable Energy), 23-29 May 2015, Naples, Italy.

Posters presented by P. Balitsky, who personally paid all travel costs

Next Steps and Future Research

FY17/Current research: Project to be completed in December 2016

Deliverables:

- Mapping data for NREL Renewable Energy Atlas (https://maps.nrel.gov/**mhk_atlas**) - annual average and 12 monthly averages of six IEC-specified wave energy resource characterization parameters
- Final report documenting methodology and tabulating theoretical and technical resources for fifty U.S. states

Proposed future research:

- NOPP re-analysis project, biggest improvement needed in Phase III is new physics package for wind sea source term in WW3, which would increase resource estimates on East Coast and windward coasts of Hawaii and Puerto Rico
- Lesson learned: Wait for NCEP-verified production of results before funding mapping and analysis effort