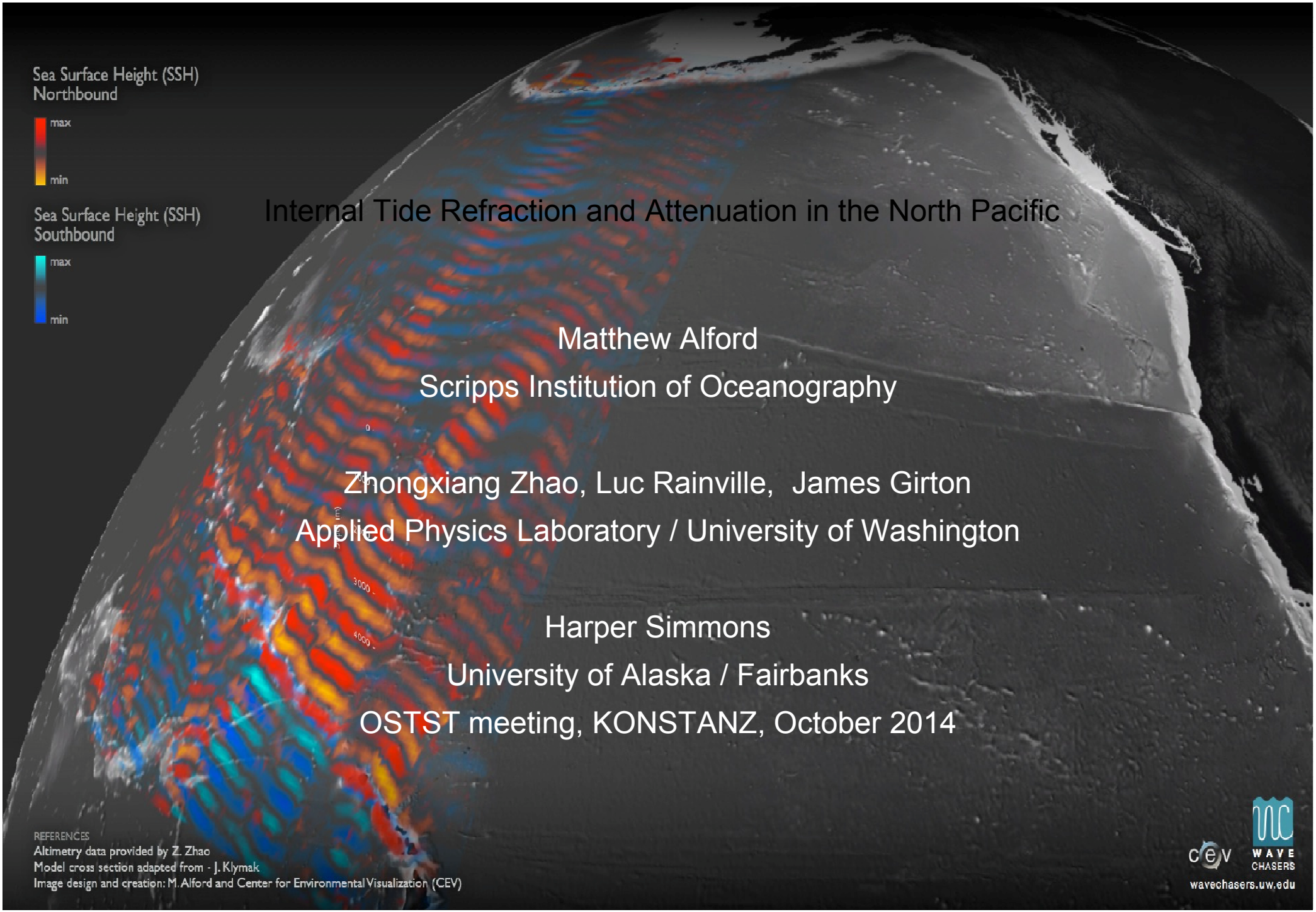


Internal Tide Refraction and Attenuation in the North Pacific

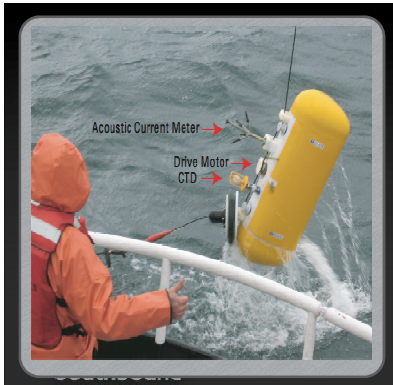
Matthew Alford
Scripps Institution of Oceanography

Zhongxiang Zhao, Luc Rainville, James Girton
Applied Physics Laboratory / University of Washington

Harper Simmons
University of Alaska / Fairbanks

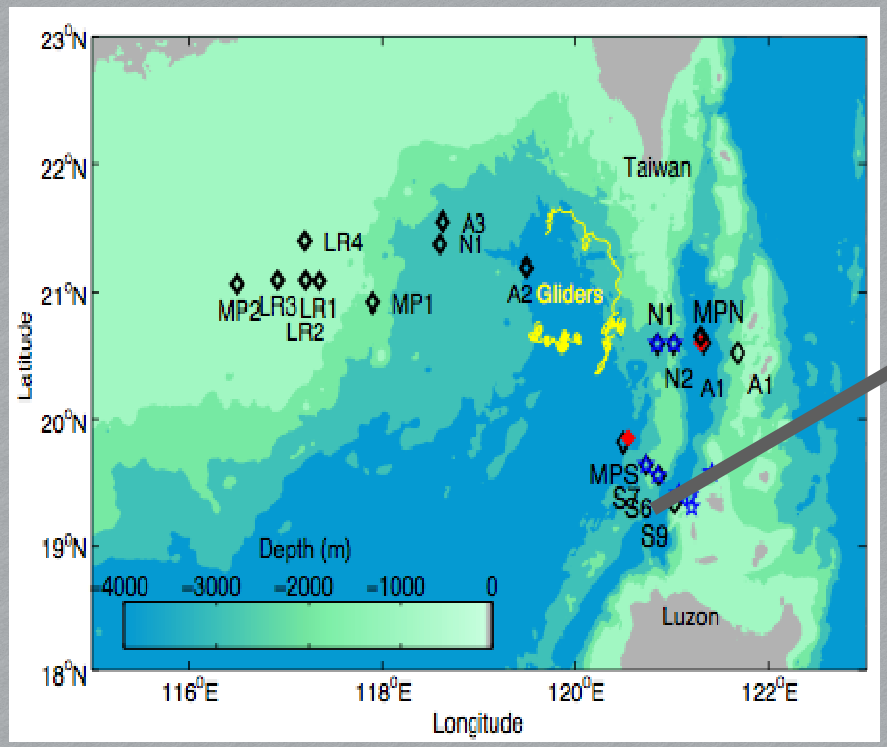
OSTST meeting, KONSTANZ, October 2014

The ocean beneath



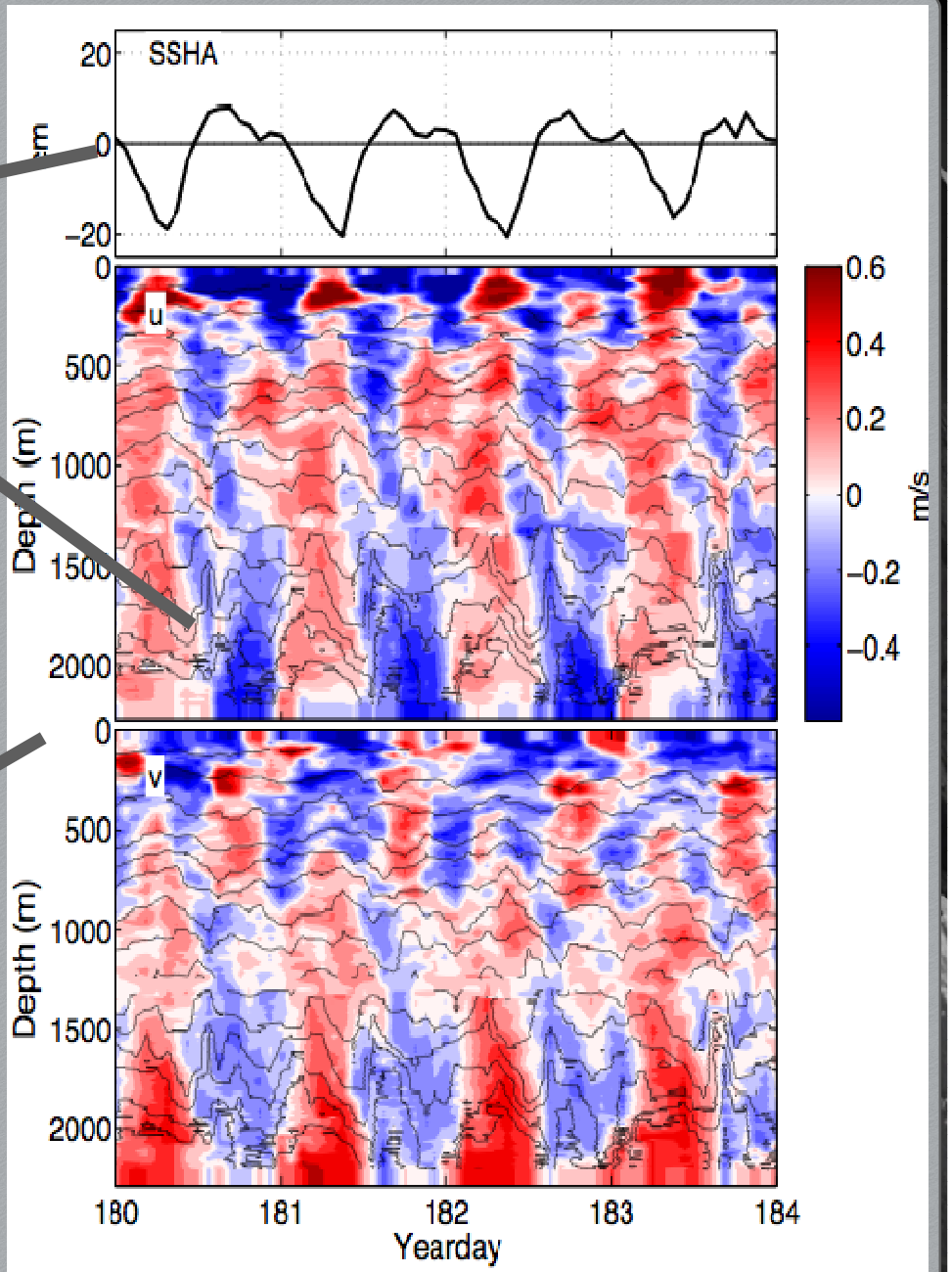
SSHA: 25 cm peak-peak!

isopycnals: 500-m peak-peak



Internal Waves in Straits Experiment

Alford et al, JPO 2010



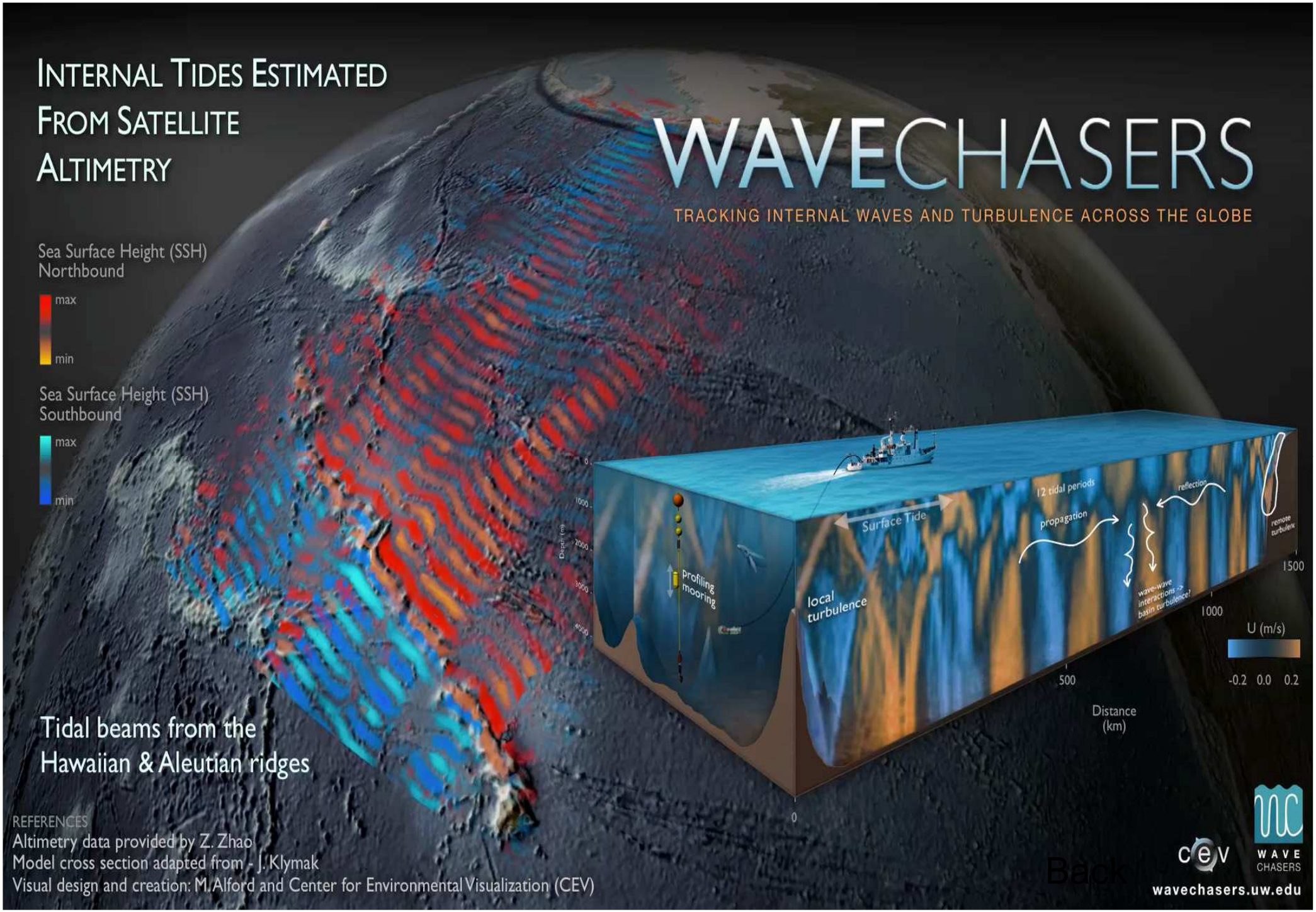
Breaking internal lee waves at Kaena Ridge

Pickering et al, in prep JPO 2013

INTERNAL TIDES ESTIMATED FROM SATELLITE ALTIMETRY

WAVECHASERS

TRACKING INTERNAL WAVES AND TURBULENCE ACROSS THE GLOBE



Tidal beams from the Hawaiian & Aleutian ridges

REFERENCES
Altimetry data provided by Z. Zhao
Model cross section adapted from - J. Klymak
Visual design and creation: M. Alford and Center for Environmental Visualization (CEV)

Back

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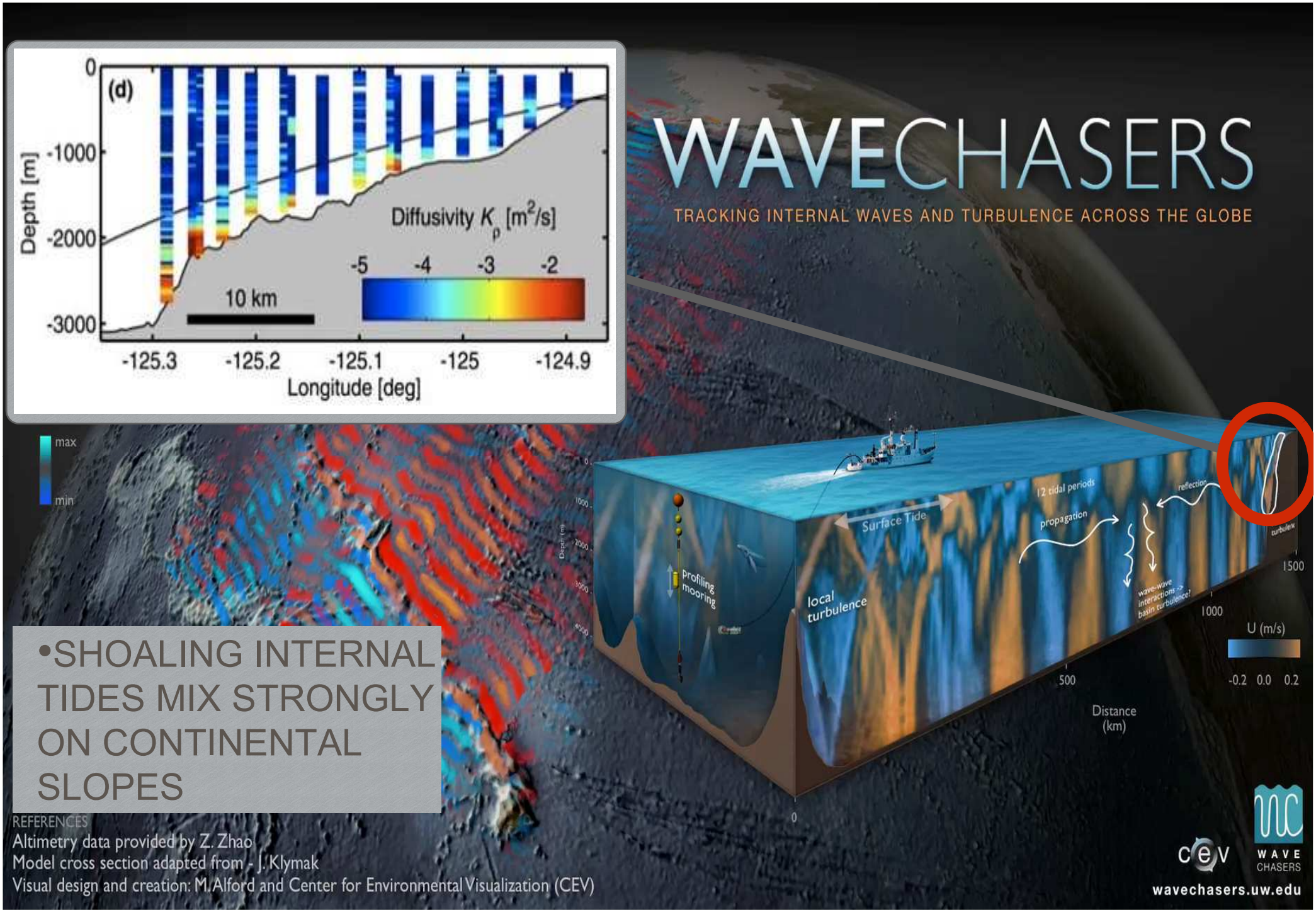
WAVECHASERS
TRACKING INTERNAL WAVES AND TURBULENCE ACROSS THE GLOBE
(d)
Depth [m]
0
-1000
-2000
-3000
Diffusivity K_ρ [m^2/s]
-5 -4 -3 -2
10 km
-125.3 -125.2 -125.1 -125 -124.9
Longitude [deg]
max
min
Surface Tide
12 tidal periods
propagation
reflection
turbulent
Profiling mooring
local turbulence
wave-wave interactions -> basin turbulence?
1500
1000
500
0
Distance (km)
U (m/s)
-0.2 0.0 0.2
•SHOALING INTERNAL TIDES MIX STRONGLY ON CONTINENTAL SLOPES
REFERENCES
Altimetry data provided by Z. Zhao
Model cross section adapted from - J. Klymak
Visual design and creation: M. Alford and Center for Environmental Visualization (CEV)
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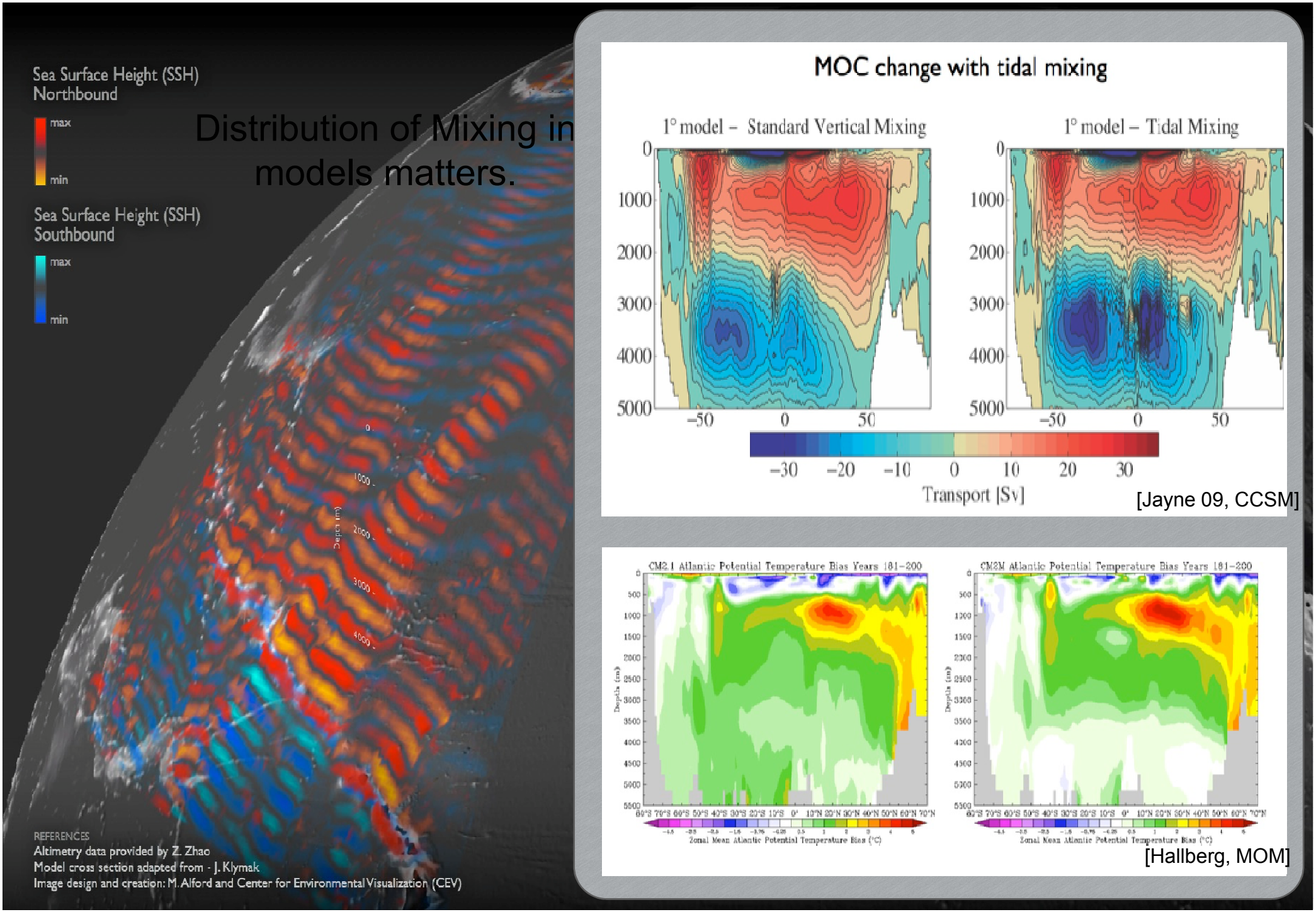
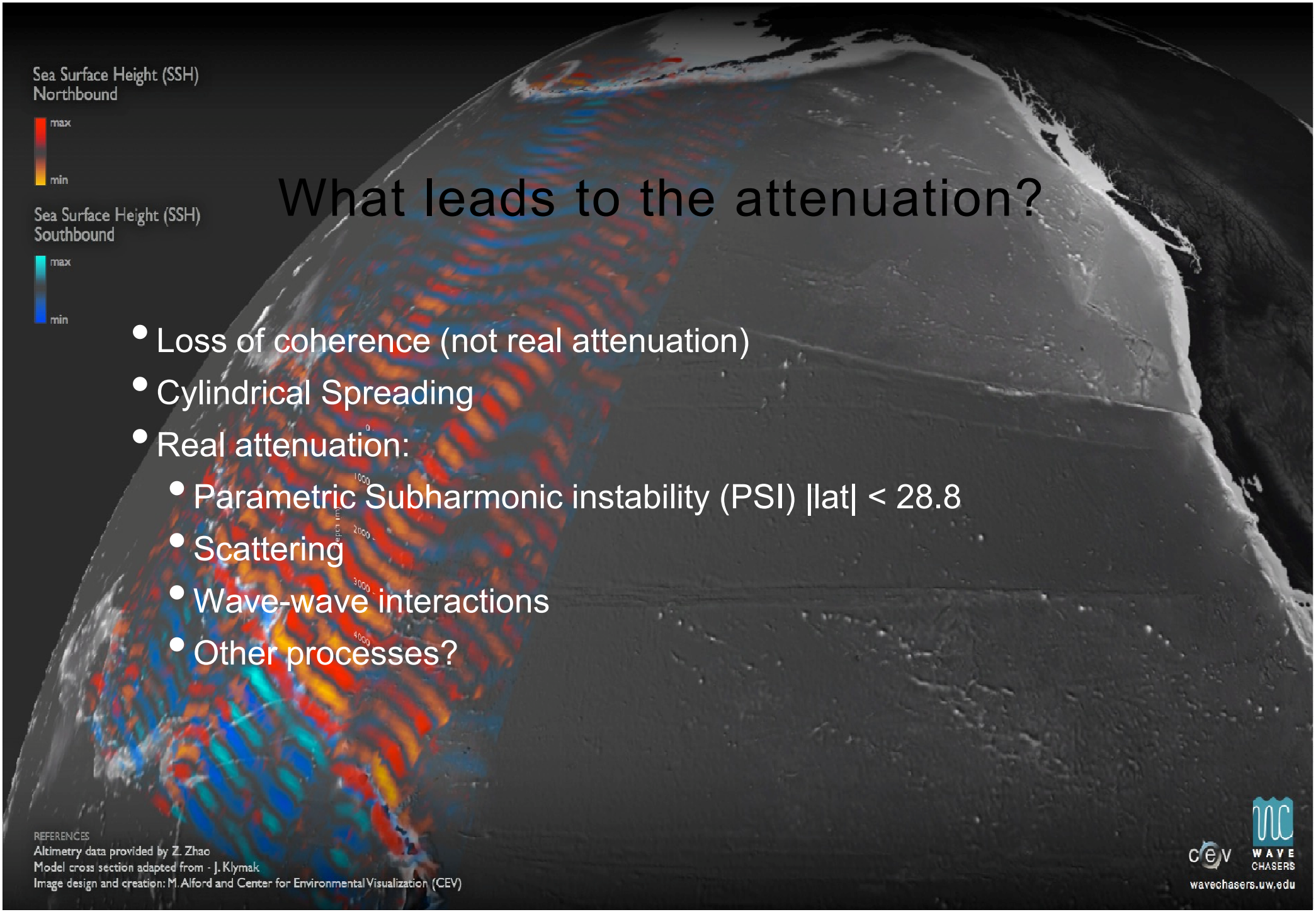
WAVE CHASERS
wavechasers.uw.edu



[Jayne 09, CCSM]

[Hallberg, MOM]



What leads to the attenuation?

- Loss of coherence (not real attenuation)
- Cylindrical Spreading
- Real attenuation:
  - Parametric Subharmonic instability (PSI) |lat| < 28.8
  - Scattering
  - Wave-wave interactions
  - Other processes?

REFERENCES
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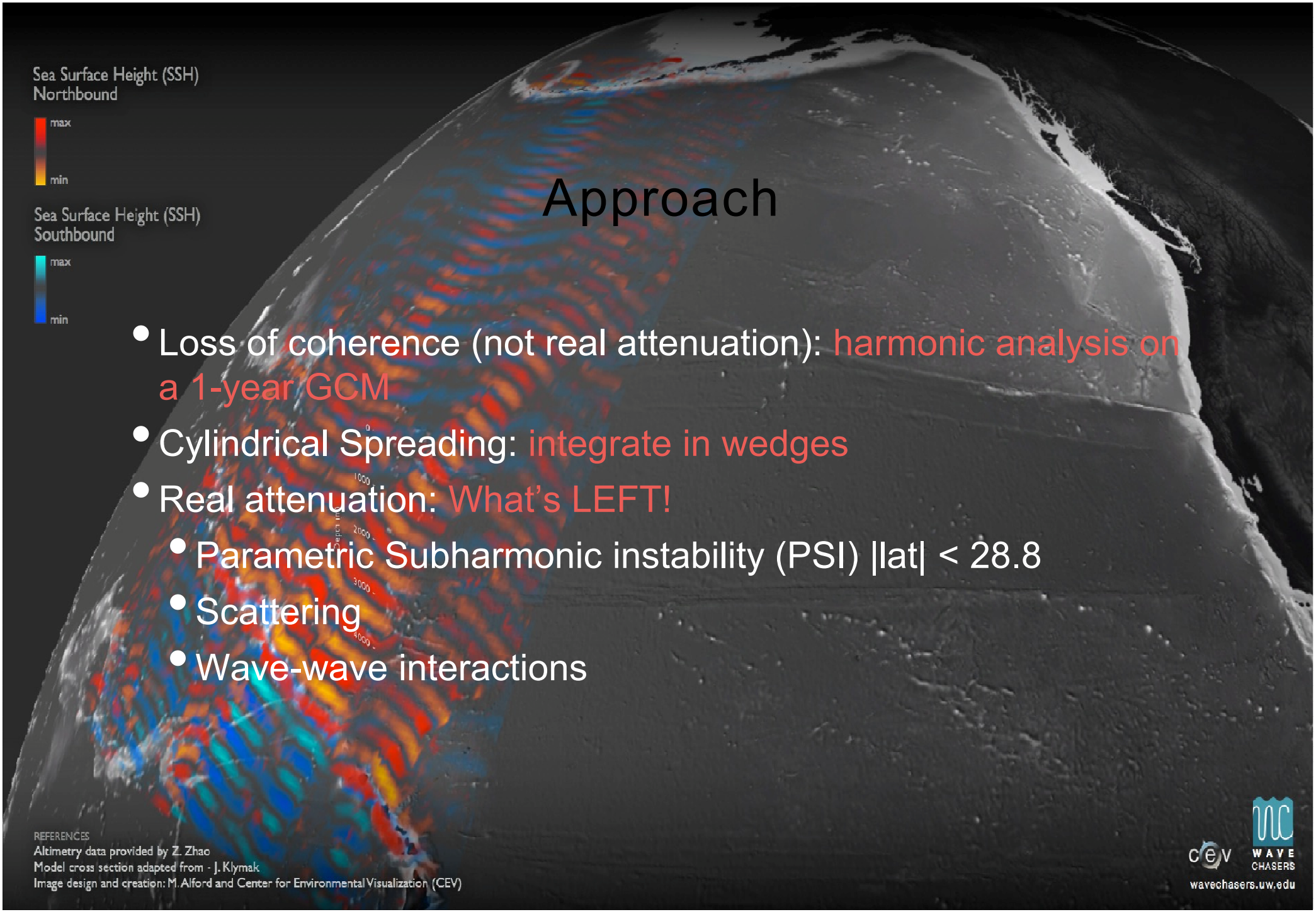

Approach

- Loss of coherence (not real attenuation): harmonic analysis on a 1-year GCM
- Cylindrical Spreading: integrate in wedges
- Real attenuation: What's LEFT!
  - Parametric Subharmonic instability (PSI) |lat| < 28.8
  - Scattering
  - Wave-wave interactions

REFERENCES
Altimetry data provided by Z. Zhao
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Model

Sea Surface Height (SSH)
Northbound

max

min

1/8º GCM with tides (GOLD; Harper Simmons)

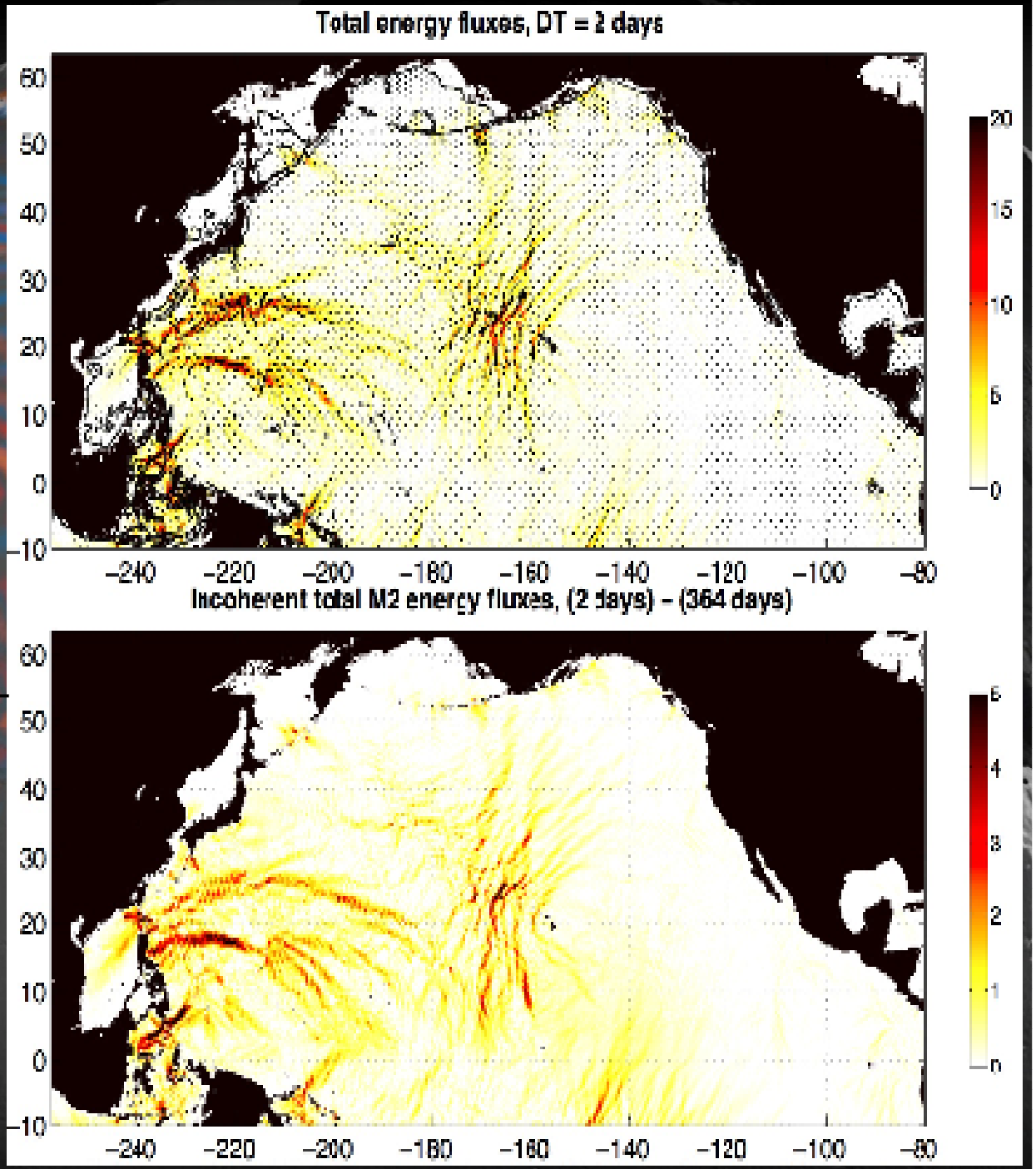
Sea Surface Height (SSH)
Southbound

max

min

TOTAL: 2-day harmonic fits

INCOHERENT: subtract 365-day harmonic fits



REFERENCES

Altimetry data provided by Z. Zhao

Model cross section adapted from - J. Klymak

Image design and creation: M. Alford and Center for Environmental Visualization (CEV)

Define beams

Altimetry

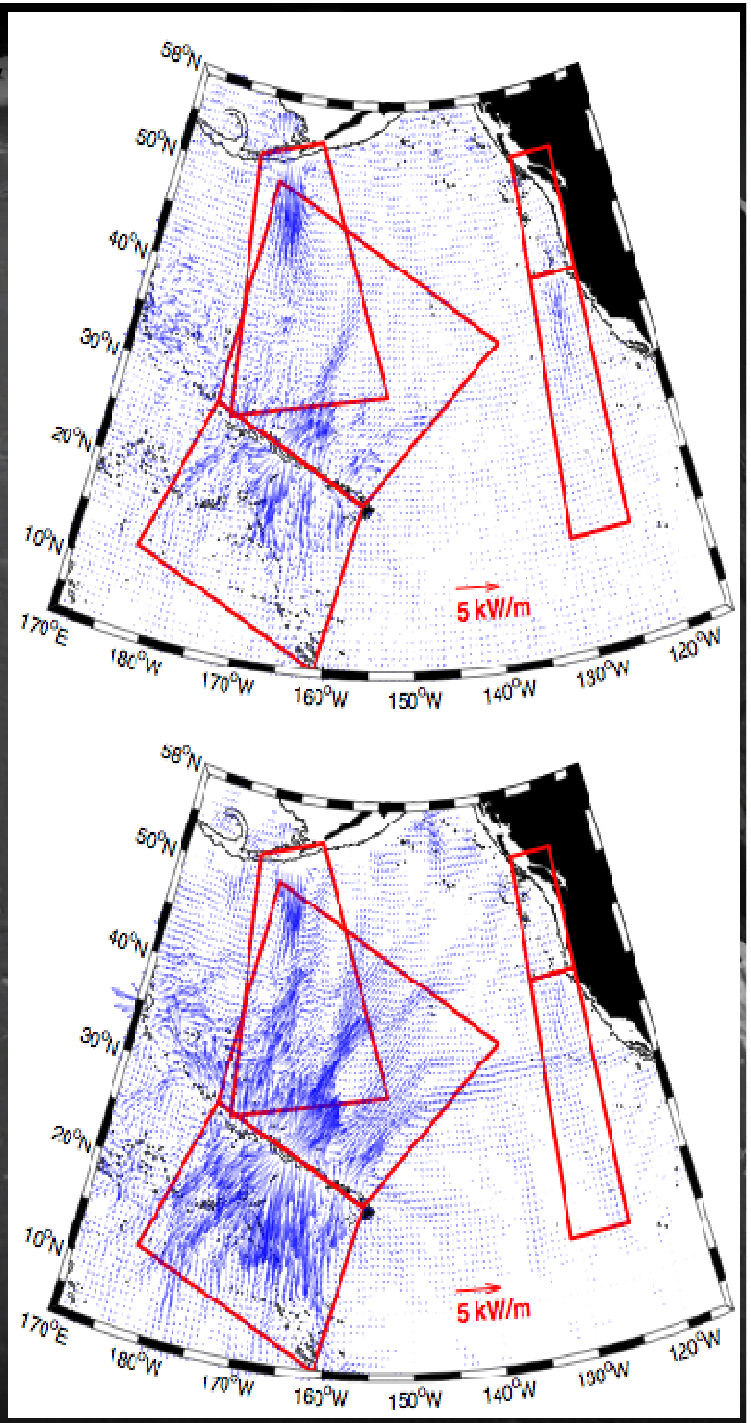
Sea Surface Height (SSH)
Northbound
max
min

Sea Surface Height (SSH)
Southbound
max
min

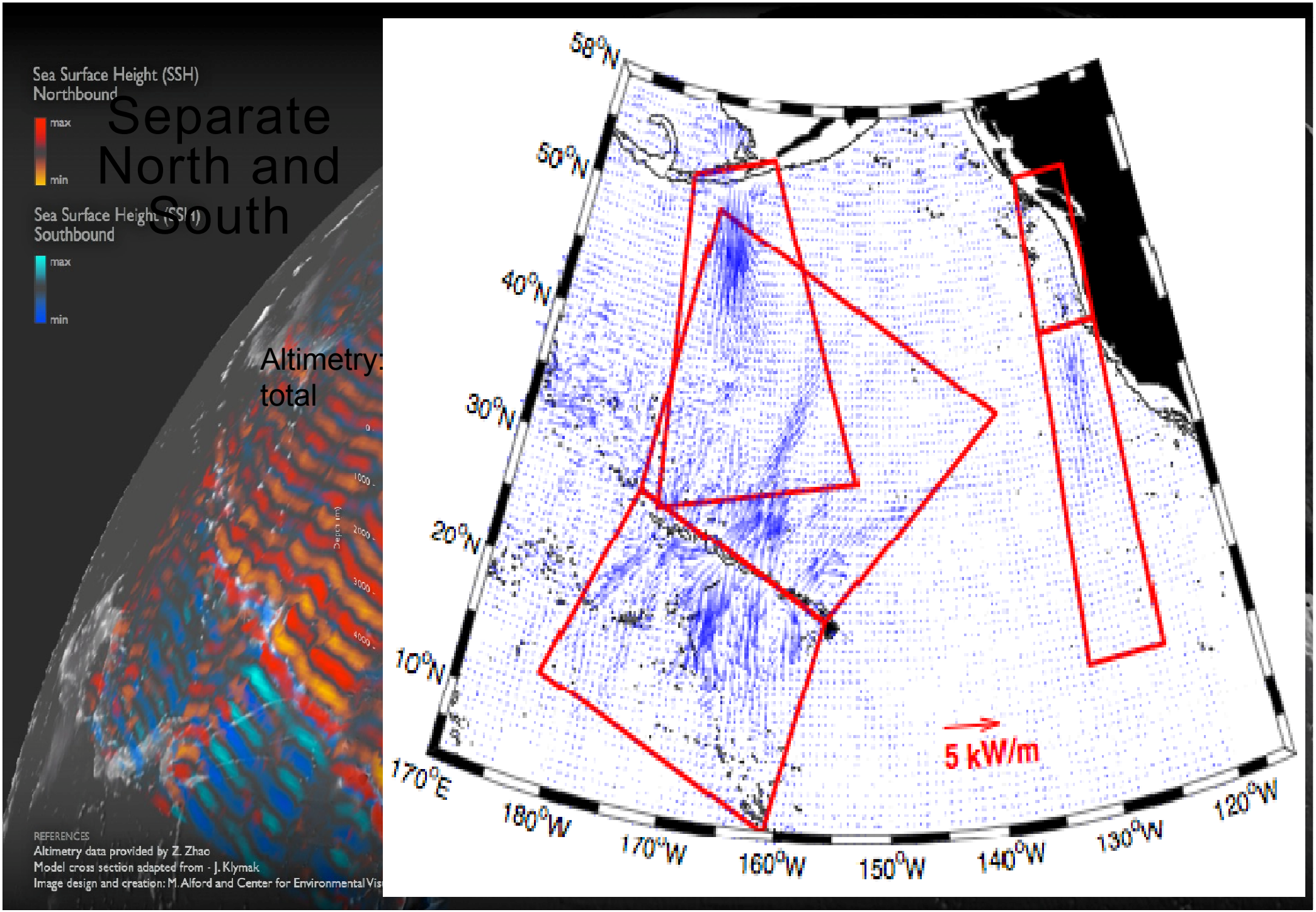
- Aleutians
- Hawaii North
- Hawaii South
- Mendocino North
- Mendocino South

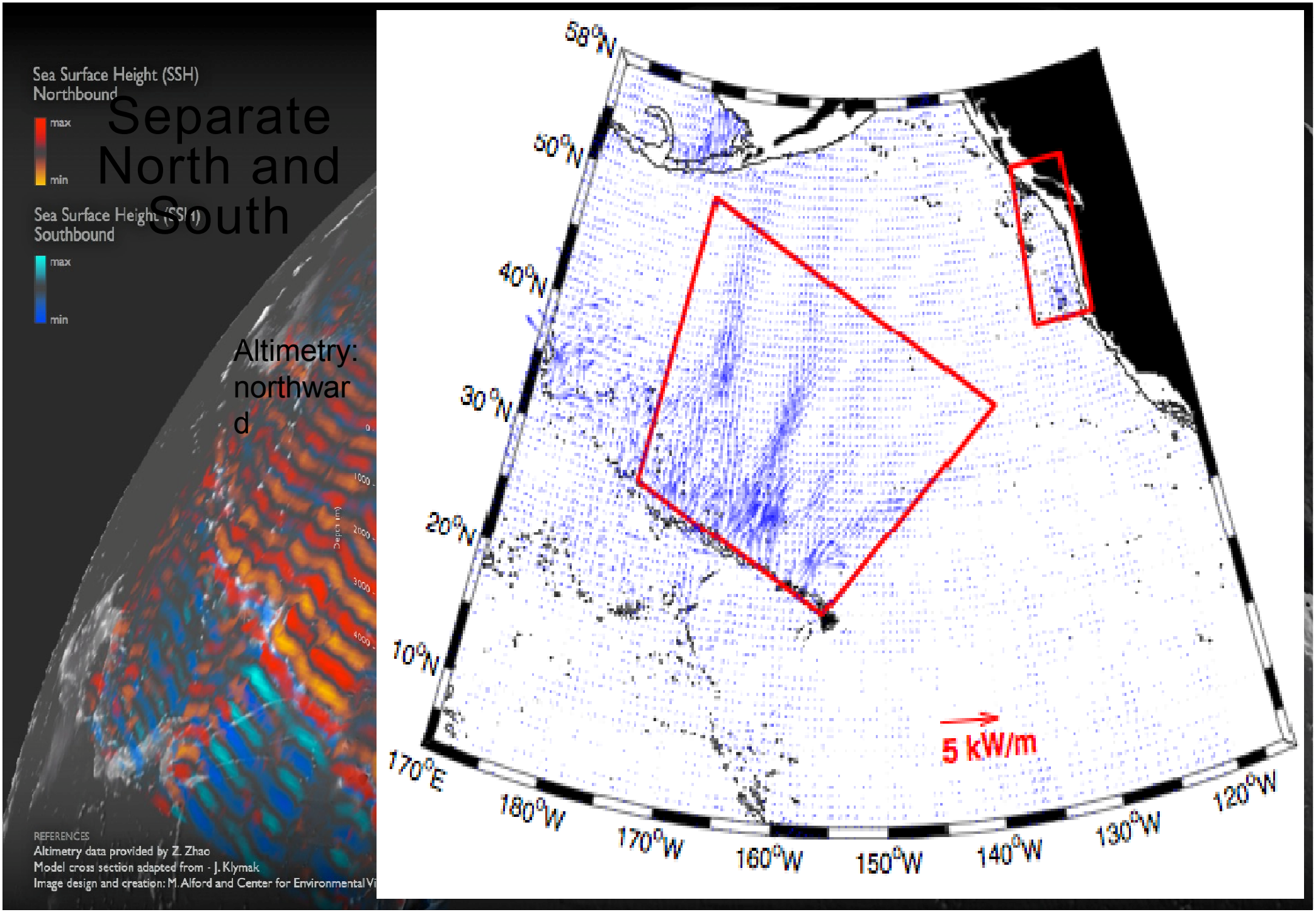
- NO PSI, SMOOTH
- NO PSI > 500 KM, SMOOTH
- PSI, ROUGH
- NO PSI, ROUGH
- NO PSI, SMOOTH

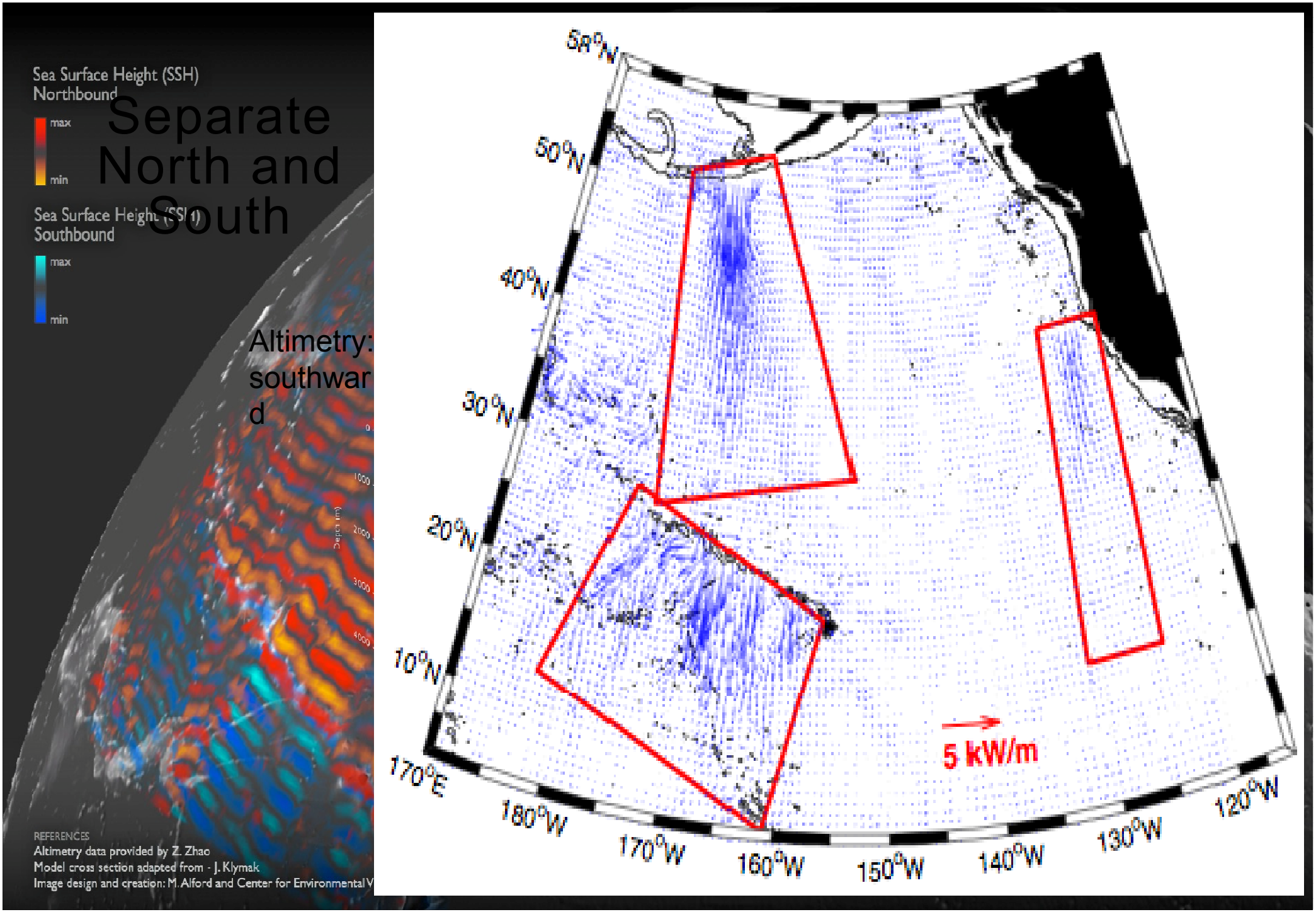
Model



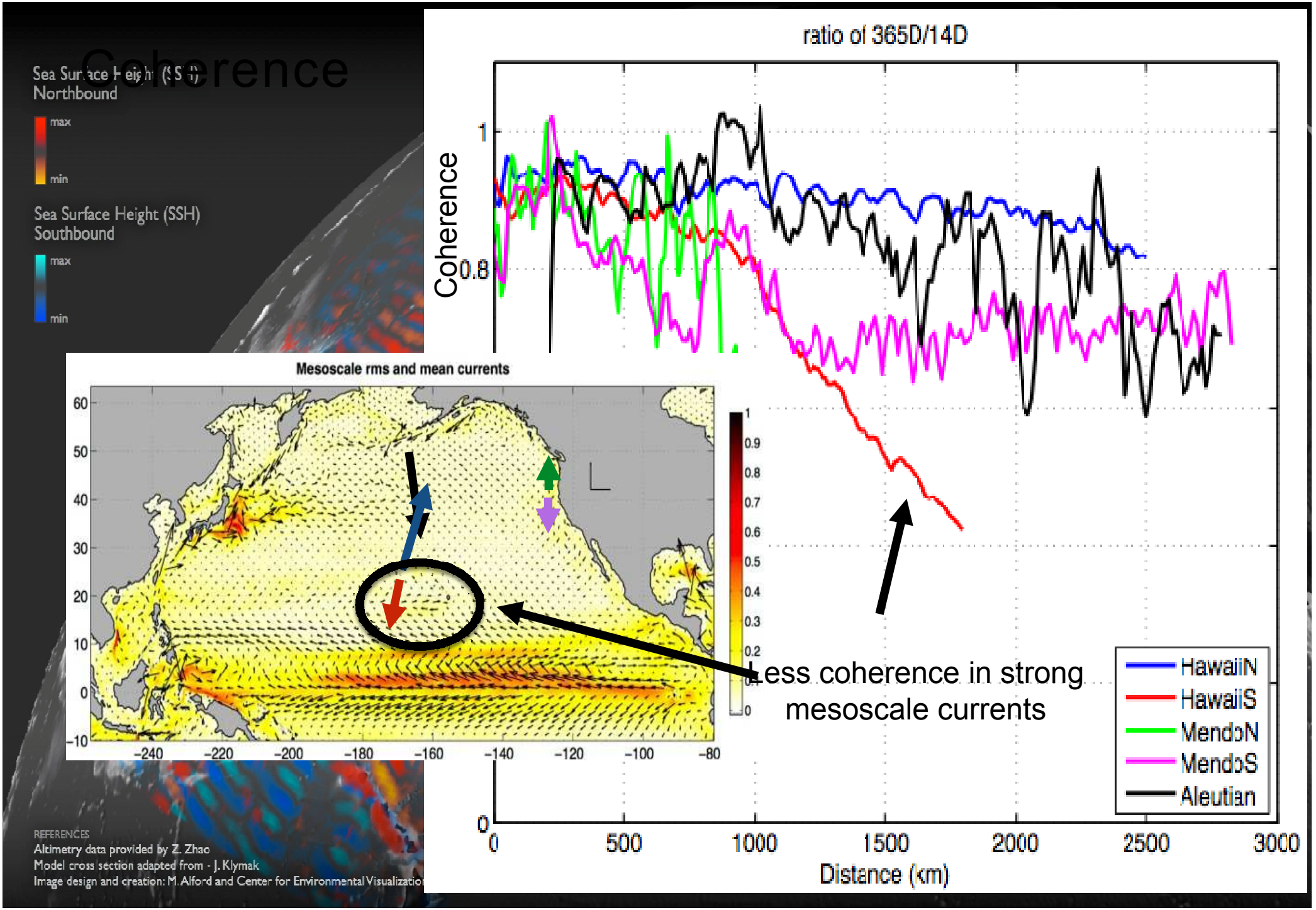
REFERENCES
Altimetry data provided by Z. Zhao
Model cross section adapted from - J. Klymak
Image design and creation: M. Alford and Center for Environmental Visualization (CEV)


Sea Surface Height (SSH)
Northbound
max
min
Separate North and South
Sea Surface Height (SSH)
Southbound
max
min
Altimetry: total
REFERENCES
Altimetry data provided by Z. Zhao
Model cross section adapted from - J. Klymak
Image design and creation: M. Alford and Center for Environmental Vis
58°N
50°N
40°N
30°N
20°N
10°N
170°E
180°W
170°W
160°W
150°W
140°W
130°W
120°W
5 kW/m


Sea Surface Height (SSH)
Northbound
max
min
Separate North and South
Sea Surface Height (SSH)
Southbound
max
min
Altimetry: northward
58°N
50°N
40°N
30°N
20°N
10°N
170°E
180°W
170°W
160°W
150°W
140°W
130°W
120°W
5 kW/m
REFERENCES
Altimetry data provided by Z. Zhao
Model cross section adapted from - J. Klymak
Image design and creation: M. Alford and Center for Environmental Vi


Sea Surface Height (SSH)
Northbound
max
min
Separate North and South
Sea Surface Height (SSH)
Southbound
max
min
Altimetry: southward
REFERENCES
Altimetry data provided by Z. Zhao
Model cross section adapted from - J. Klymak
Image design and creation: M. Alford and Center for Environmental V
50°N
40°N
30°N
20°N
10°N
170°E
180°W
170°W
160°W
150°W
140°W
130°W
120°W
5 kW/m

Coherence


Sea Surface Height (SSH)
Northbound
max
min
Sea Surface Height (SSH)
Southbound
max
min
ratio of 365D/14D
Coherence
1
0.8
0
0
500
1000
1500
2000
2500
3000
Distance (km)
HawaiiN
HawaiiS
MendoN
MendoS
Aleutian
Mesoscale rms and mean currents
60
50
40
30
20
10
0
-10
-240
-220
-200
-180
-160
-140
-120
-100
-80
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
Less coherence in strong mesoscale currents
REFERENCES
Altimetry data provided by Z. Zhao
Model cross section adapted from - J. Klymak
Image design and creation: M. Alford and Center for Environmental Visualizatio

Final result: attenuation

Sea Surface Height (SSH)
Northbound

max

min

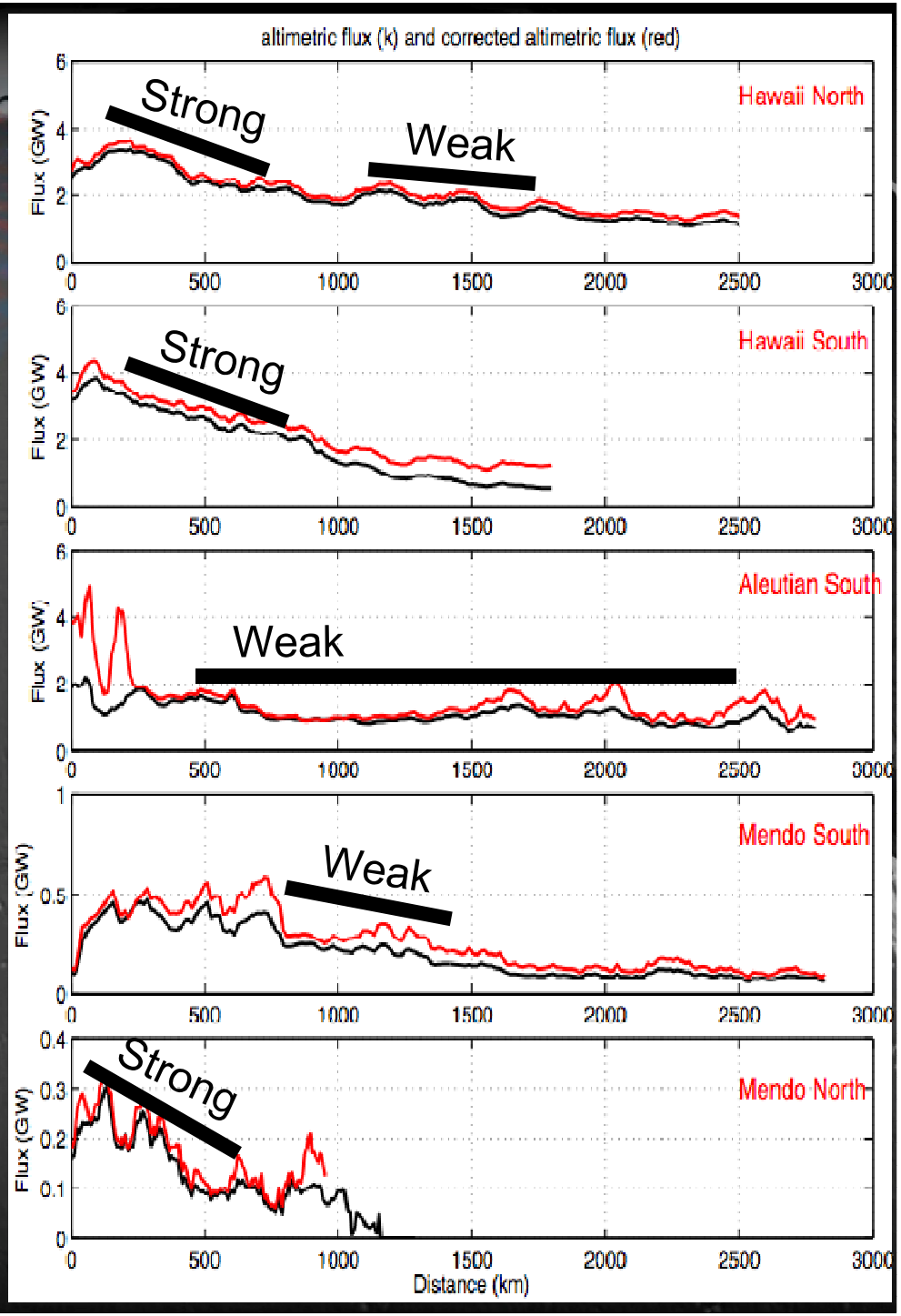
Sea Surface Height (SSH)
Southbound

max

min

- Aleutians
- Hawaii North
- Hawaii South
- Mendocino North
- Mendocino South

- NO PSI, SMOOTH
- NO PSI > 500 KM, SMOOTH
- PSI, ROUGH
- NO PSI, ROUGH
- NO PSI, SMOOTH



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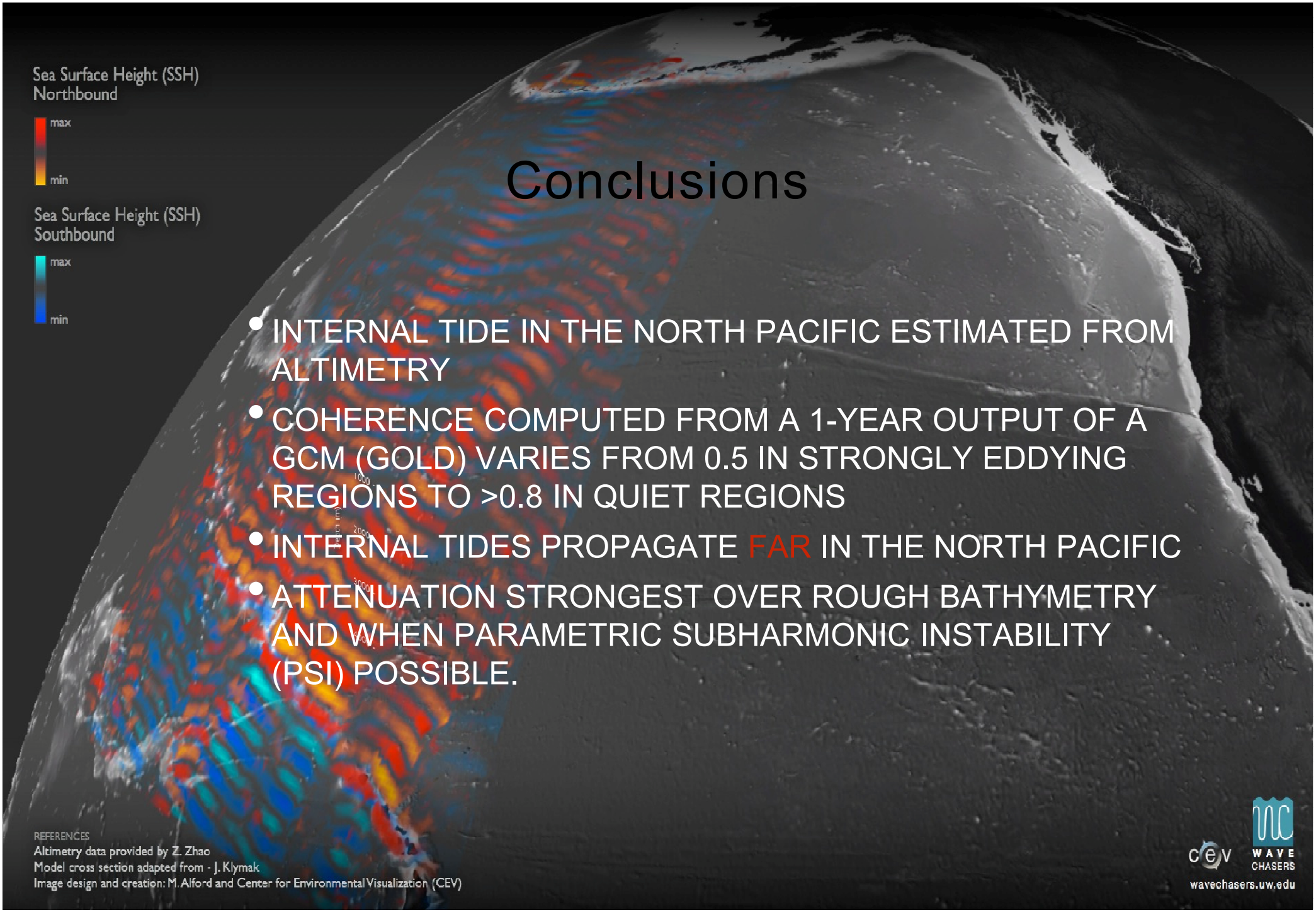

Conclusions

- INTERNAL TIDE IN THE NORTH PACIFIC ESTIMATED FROM ALTIMETRY
- COHERENCE COMPUTED FROM A 1-YEAR OUTPUT OF A GCM (GOLD) VARIES FROM 0.5 IN STRONGLY EDDYING REGIONS TO >0.8 IN QUIET REGIONS
- INTERNAL TIDES PROPAGATE FAR IN THE NORTH PACIFIC
- ATTENUATION STRONGEST OVER ROUGH BATHYMETRY AND WHEN PARAMETRIC SUBHARMONIC INSTABILITY (PSI) POSSIBLE.

REFERENCES
Altimetry data provided by Z. Zhao
Model cross section adapted from - J. Klymak
Image design and creation: M. Alford and Center for Environmental Visualization (CEV)

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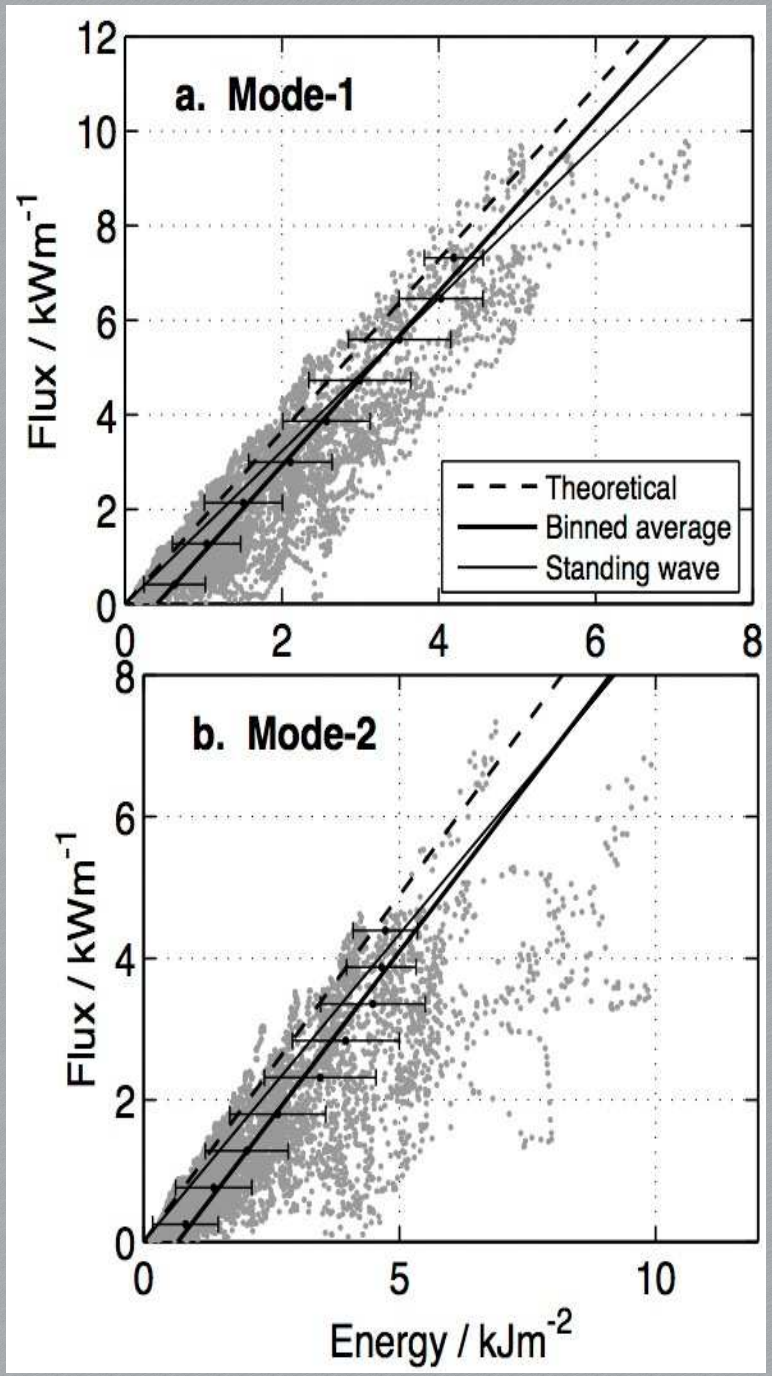

WAVECHASERS

TRACKING INTERNAL WAVES AND TURBULENCE ACROSS THE GLOBE

- FREE AND STANDING WAVES

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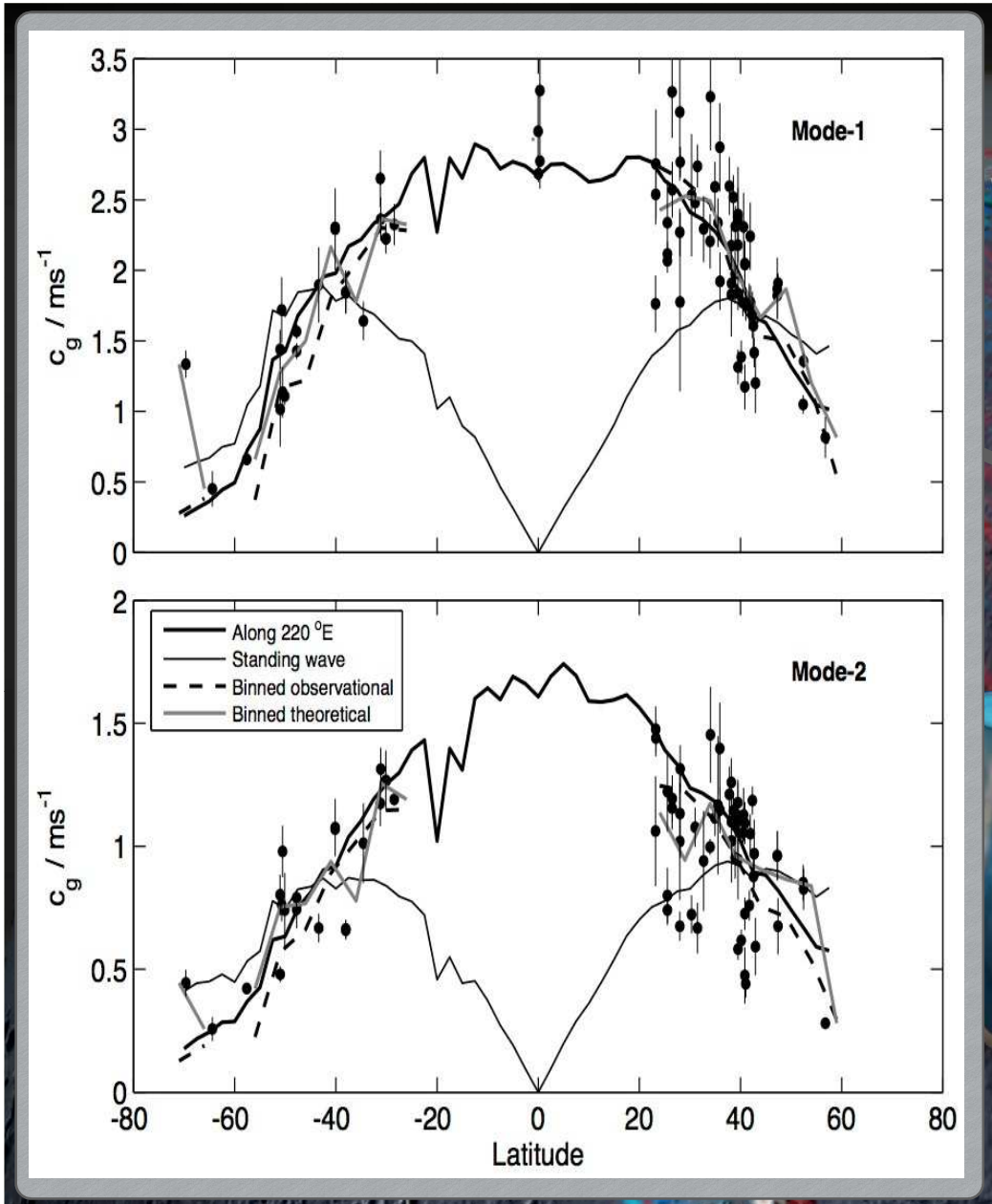

WAVECHASERS

TRACKING INTERNAL WAVES AND TURBULENCE ACROSS THE GLOBE

REFERENCES
Altimetry data provided by Z. Zhao
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Visual design and creation: M. Alford and Center for Environmental Visualization (CEV)

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WAVE CHASERS

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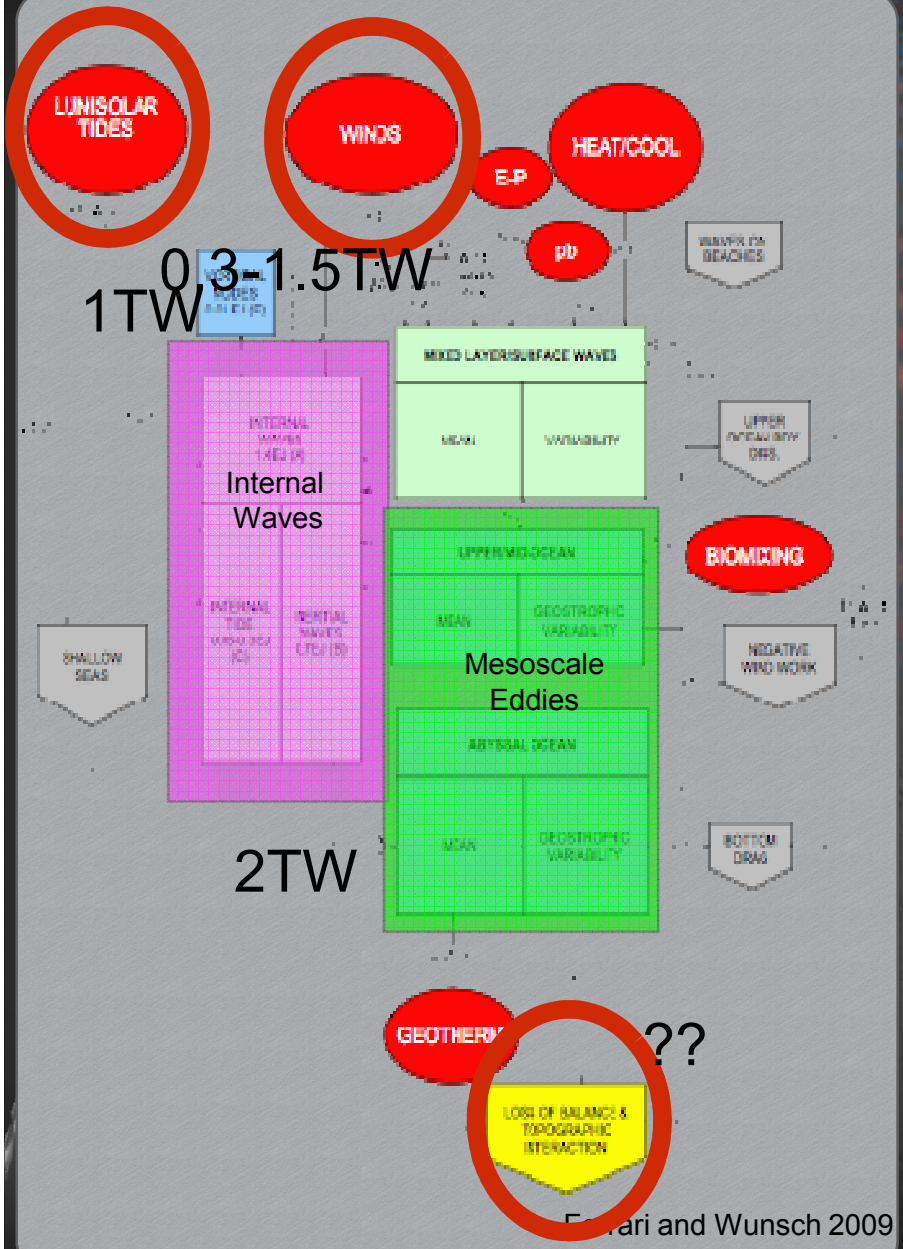
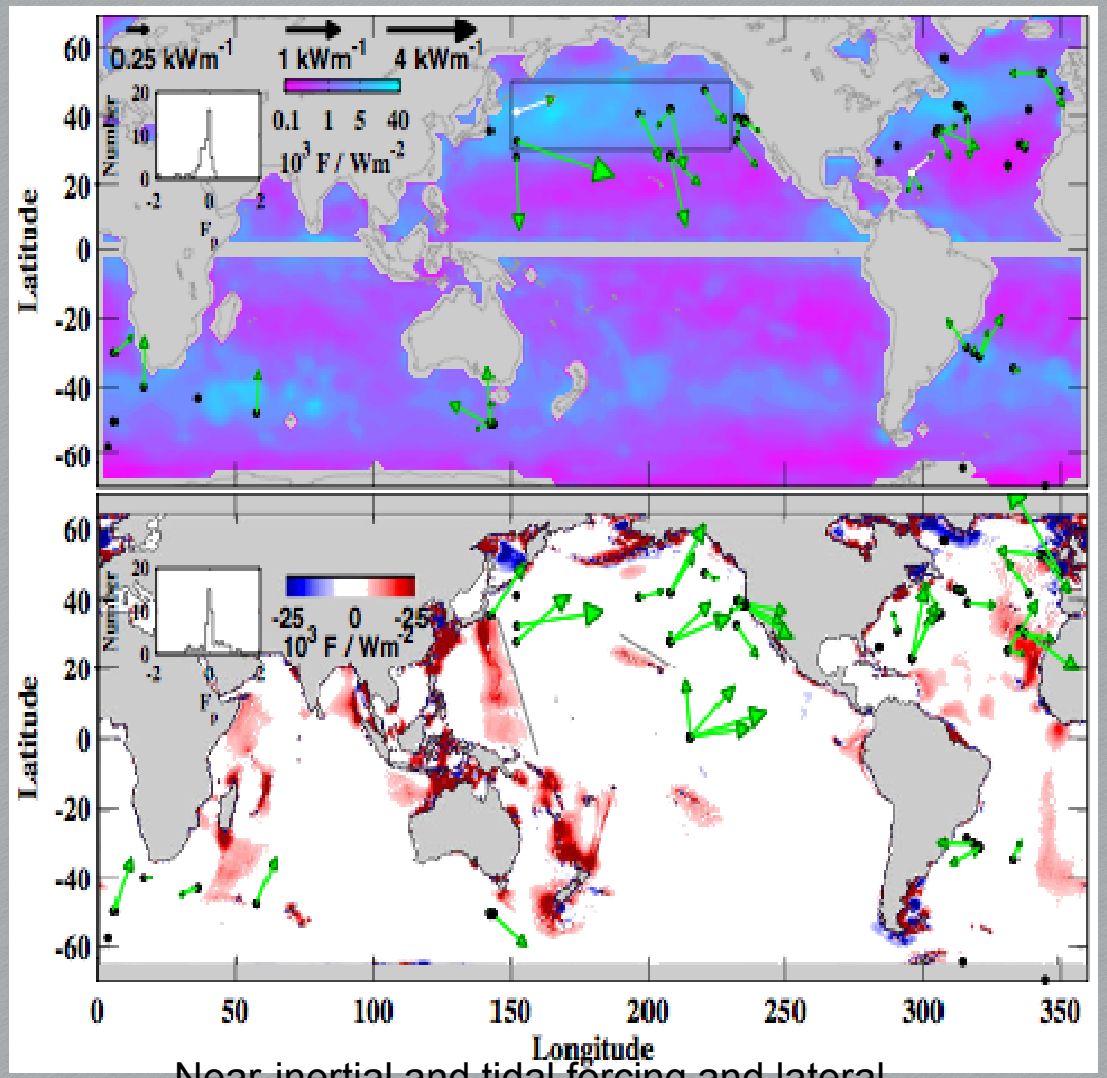
Sea Surface Height (SSH)

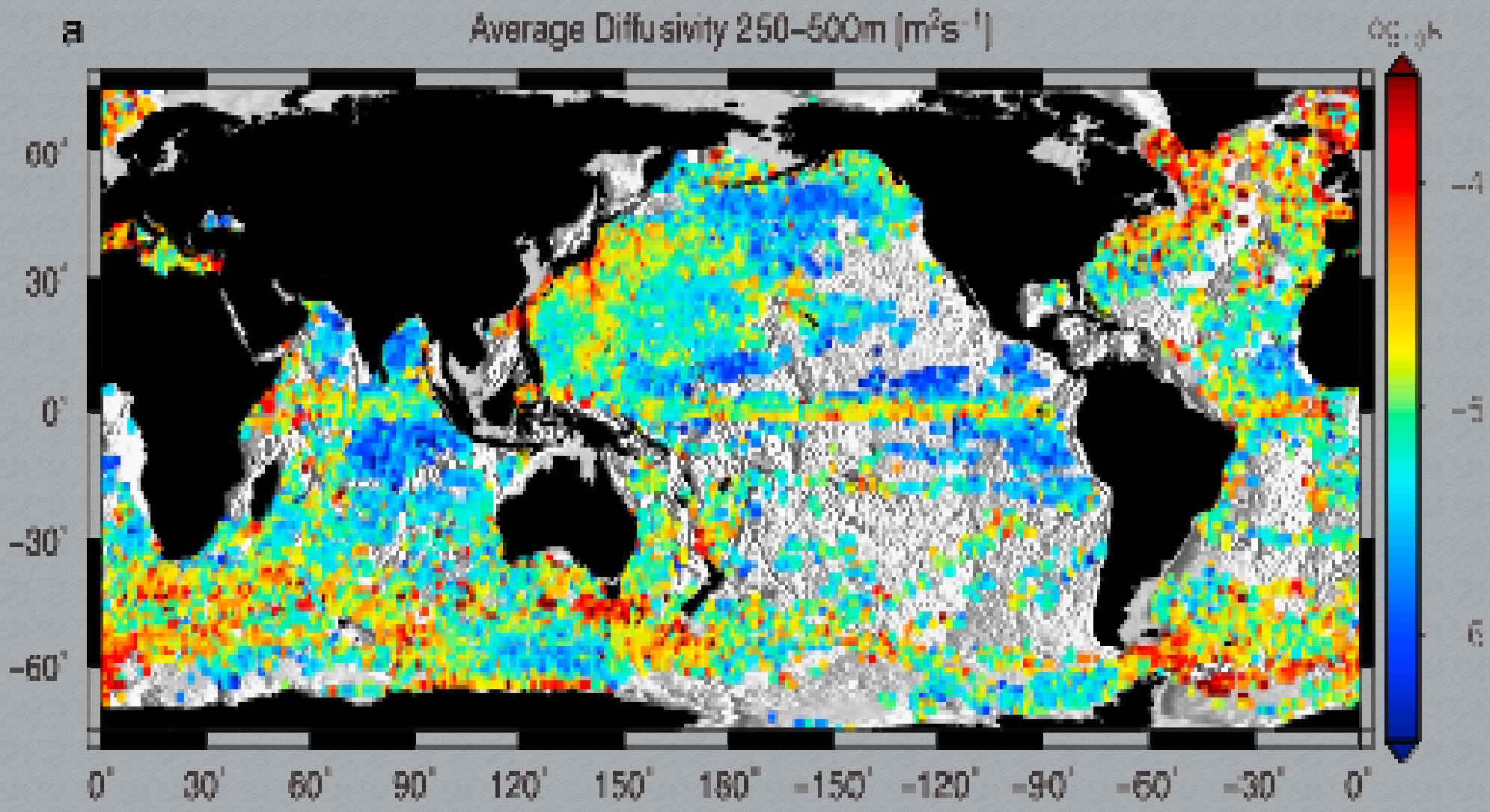


Ferrari and Wunsch 2009



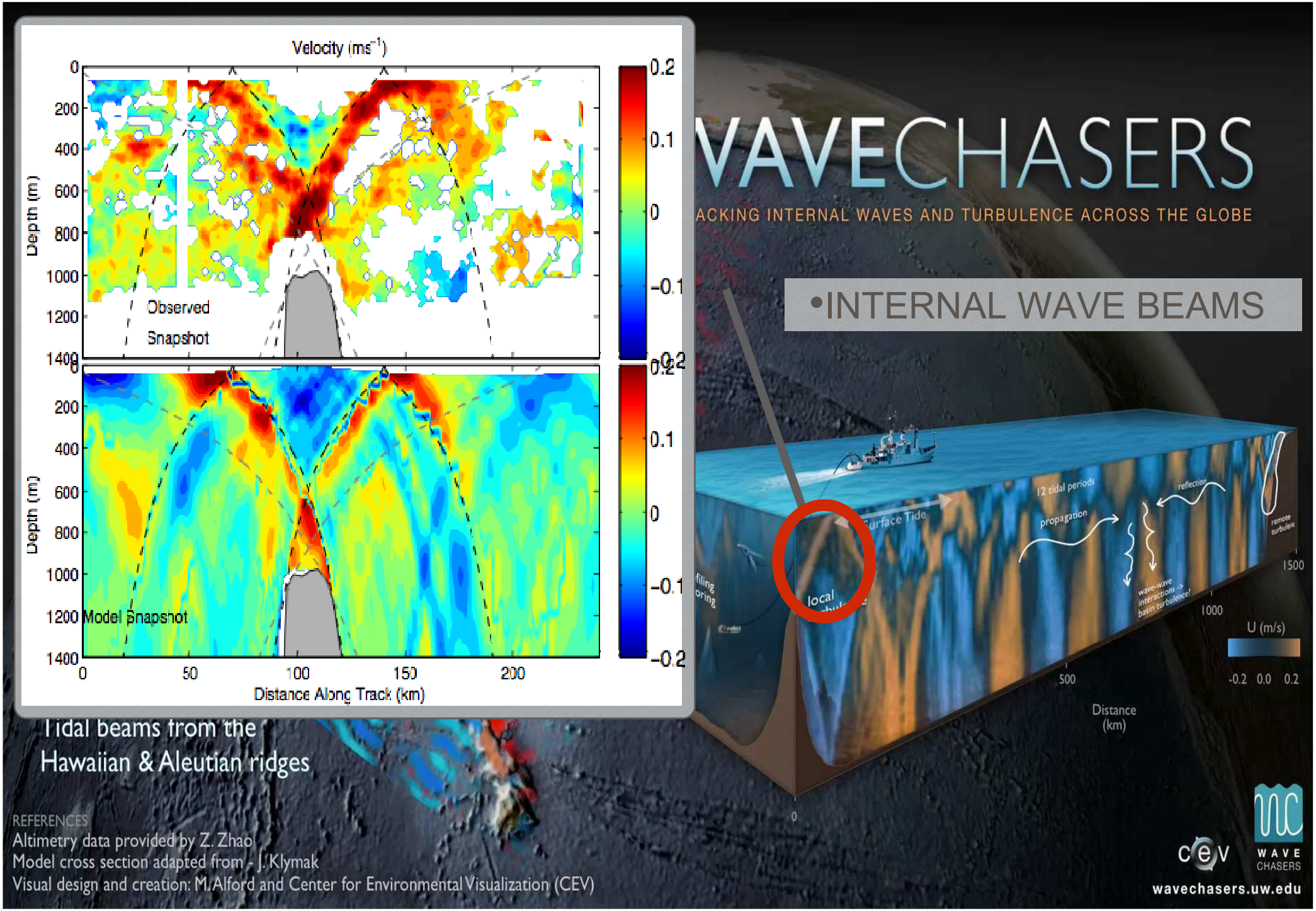
Near-inertial and tidal forcing and lateral energy flux

Alford, Nature 2003



Diffusivity and dissipation rate inferred from Argo vertical strain using a finescale parameterization

Whalen, Talley and MacKinnon, GRL 2012


Velocity (ms^{-1})
Depth (m)
Observed
Snapshot
Model Snapshot
Distance Along Track (km)
0.2
0.1
0
−0.1
−0.2
VAVECHASERS
ACKING INTERNAL WAVES AND TURBULENCE ACROSS THE GLOBE
•INTERNAL WAVE BEAMS
12 tidal periods
propagation
reflection
wave-wave interactions -> basin turbulence?
remote turbulence
local
Distance (km)
U (m/s)
-0.2 0.0 0.2
Tidal beams from the Hawaiian & Aleutian ridges
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CEV
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