2023 PDC Exercise: Global Tsunami from Land or Ocean Impact

Mark Boslough
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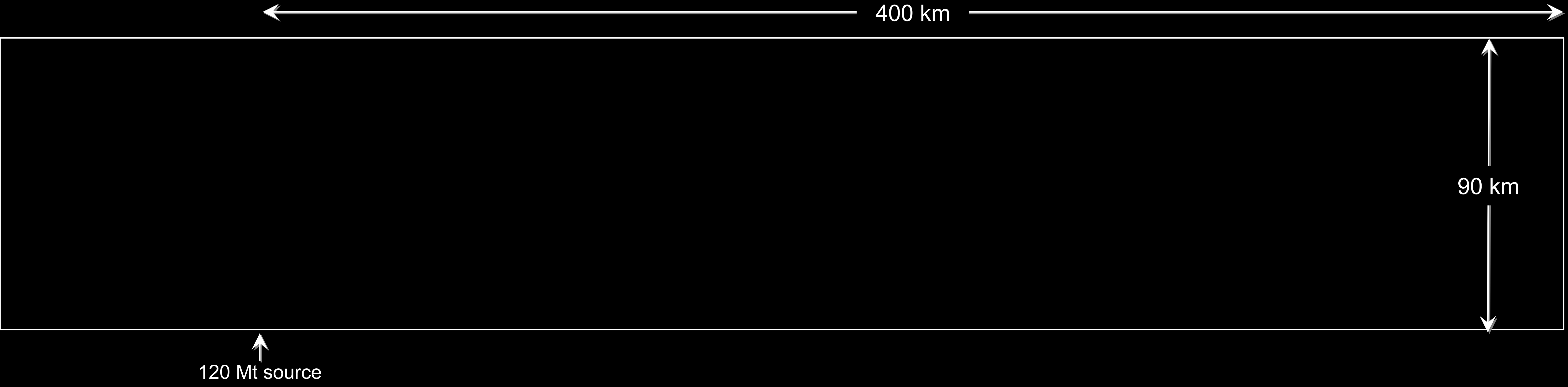
University of New Mexico

Vasily Titov
NOAA/Pacific Marine Environmental Laboratory

Hunga Tonga–Hunga Ha'apai January 15, 2022 explosion simulation (120 Mt yield)



IAA Planetary Defense Conference, Vienna, Austria, 3-7 April, 2023

LANL work was supported by the US Department of Energy through the Los Alamos National Laboratory. Los Alamos National Laboratory is operated by Triad National Security, LLC, for the National Nuclear Security Administration of U.S. Department of Energy (Contract No. 89233218CNA000001).

Notional Global Effects Taxonomy

Source

Airburst
Airburst/impact
Small impact
Medium impact
Large Impact

Coupling Mechanism

Atmos wave
Atmos chemistry
Ejecta reentry
Ejecta in orbit
Ballistic plume
Secondary impacts
Thermal radiation
Seismic
Human response

Global Effect

Tsunami
Ground motion
Blast wave
Temperature
Blackout
Volcanos
Hypernados (?)
Climate
Biosphere
Agriculture
Infrastructure
Economy
Conflict
Black swans

Time Scale
(initiation or duration)

Pre-impact
Immediate
Hours
Days
Months
Years
Geologic time

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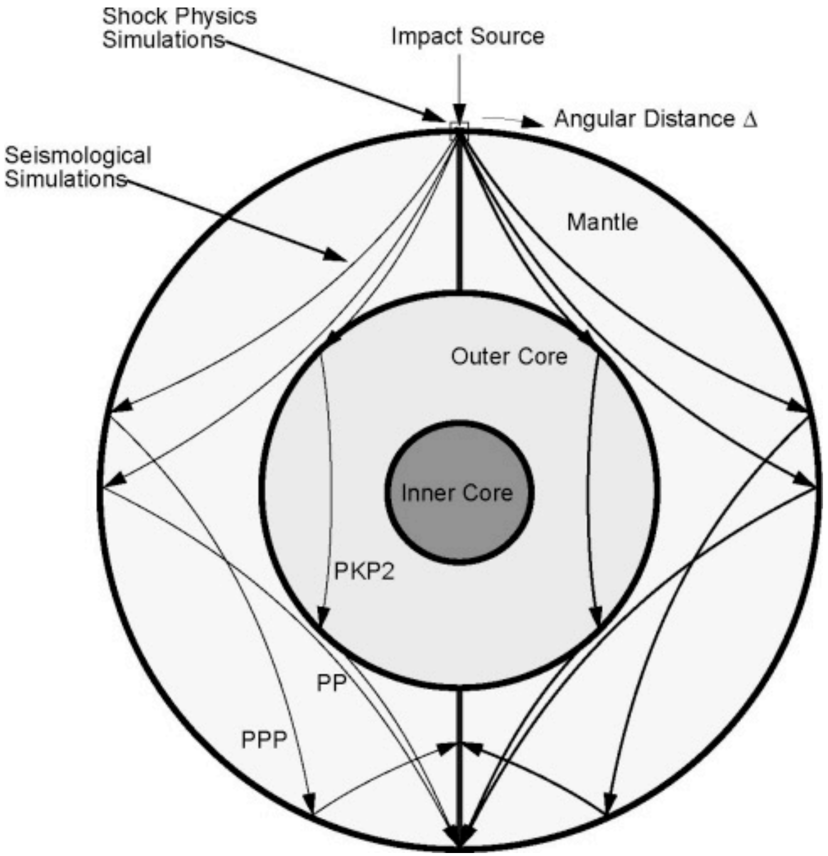
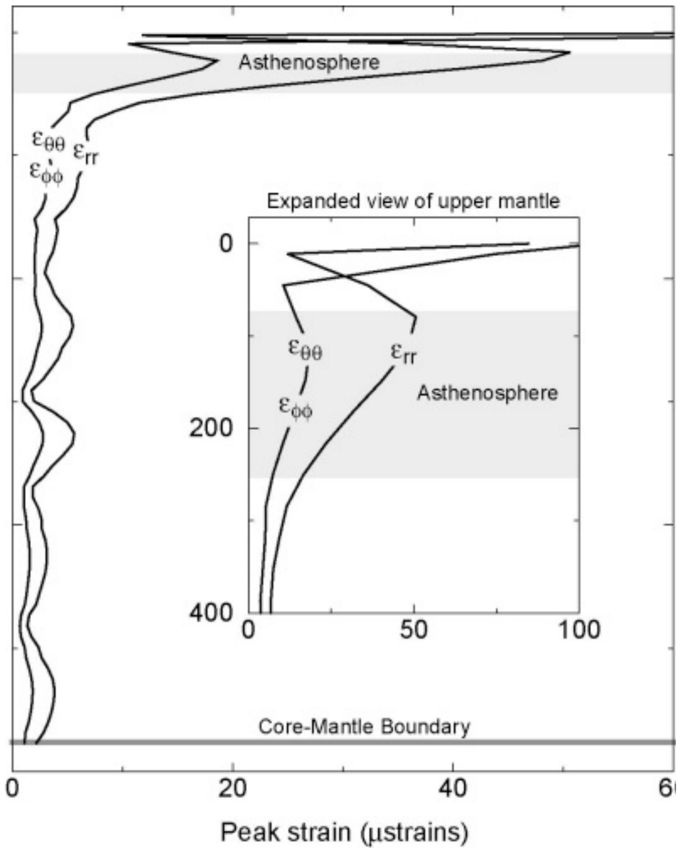
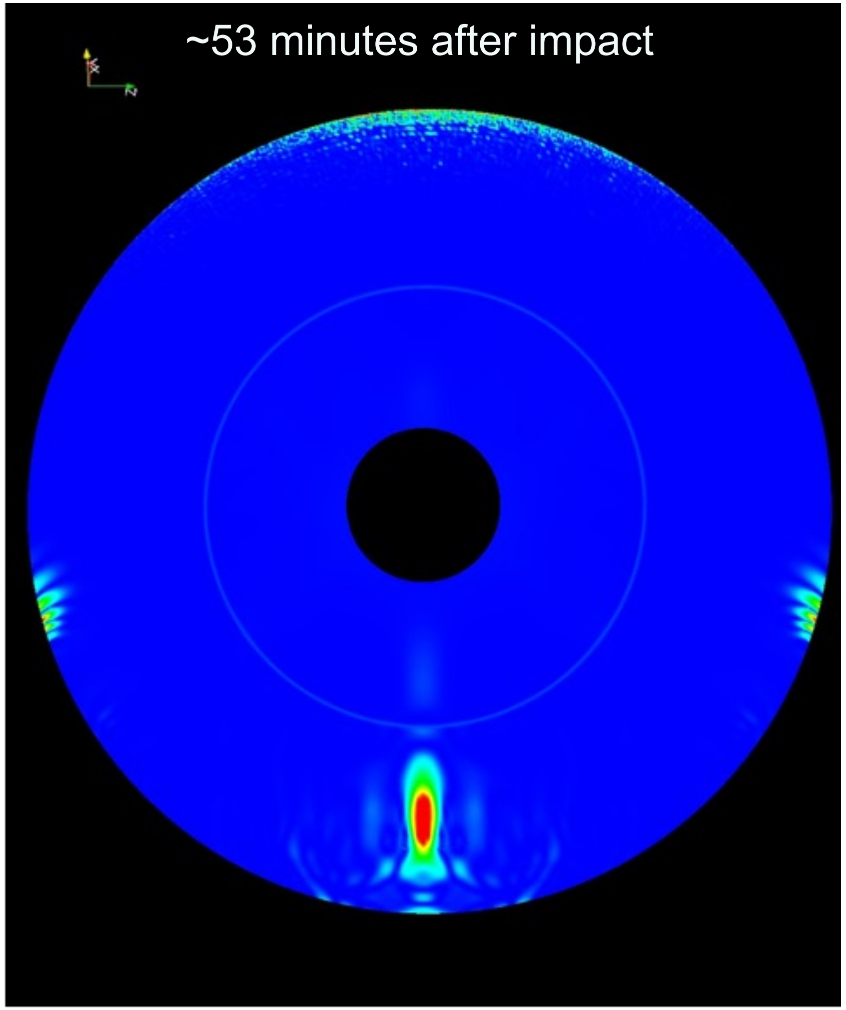
Boslough, MB, et al. (1995) Axial focusing of impact energy in the Earth's interior: a possible link to flood basalts and hotspots, In G. Ryder *et al.*, Eds., **Proceedings of the Conference on New Developments Regarding the KT Event and Other Catastrophes in Earth History**, pp. 541-550.

Boslough, MB, Taylor, MA, (2006) Supercomputer simulations of 3D seismic waves from a giant impact, Sandia Report. SAND2006-1542A.






~53 minutes after impact

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S. Monserrat et al.,
"Meteotsunamis: atmospherically induced destructive
ocean waves in the tsunami frequency band.”
Nat. Hazards Earth Syst. Sci., 6, 1035–1051, 2006

> “Consequently, these atmospheric fluctuations can produce a significant sea level response only when some form of resonance occurs between the ocean and the atmospheric forcing.”

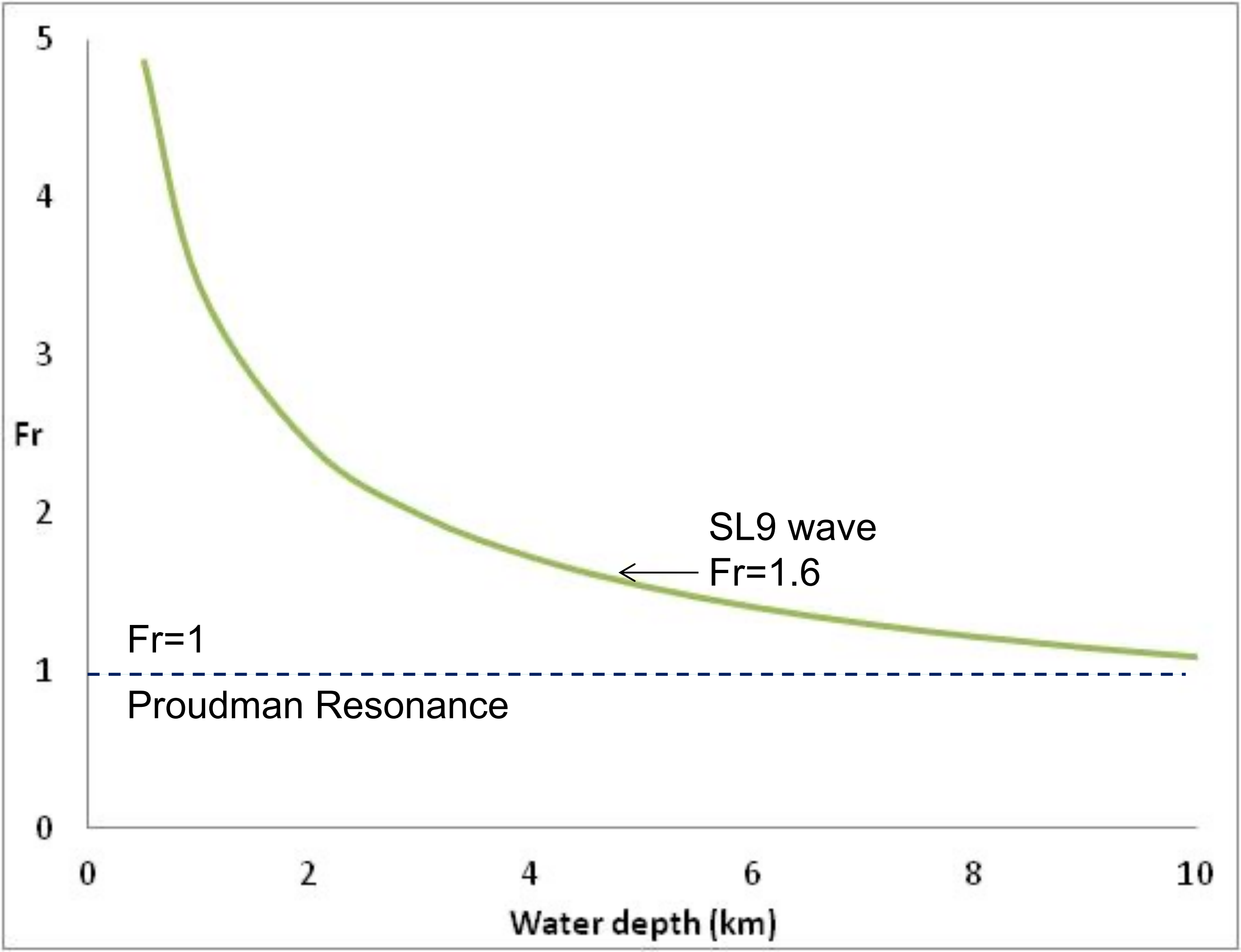
Proudman resonance

U=c, i.e. the atmospheric disturbance translational speed (U) equals the longwave phase speed $c=\sqrt{gh}$ of ocean waves

Froude number ($Fr = U/c$)

Coupling is strong when $Fr \approx 1.0$

4.6-km deep ocean has same Fr as Jupiter



Conclusion

- Tunguska-scale plume-forming impact can generate reaction impulse that raises atmospheric pressure over a large area on time scale sufficiently close to the Proudman resonance in deep water (>4 km) to produce dangerous meteotsunami.

- This effect needs to be quantified and included in NEO hazard assessment.

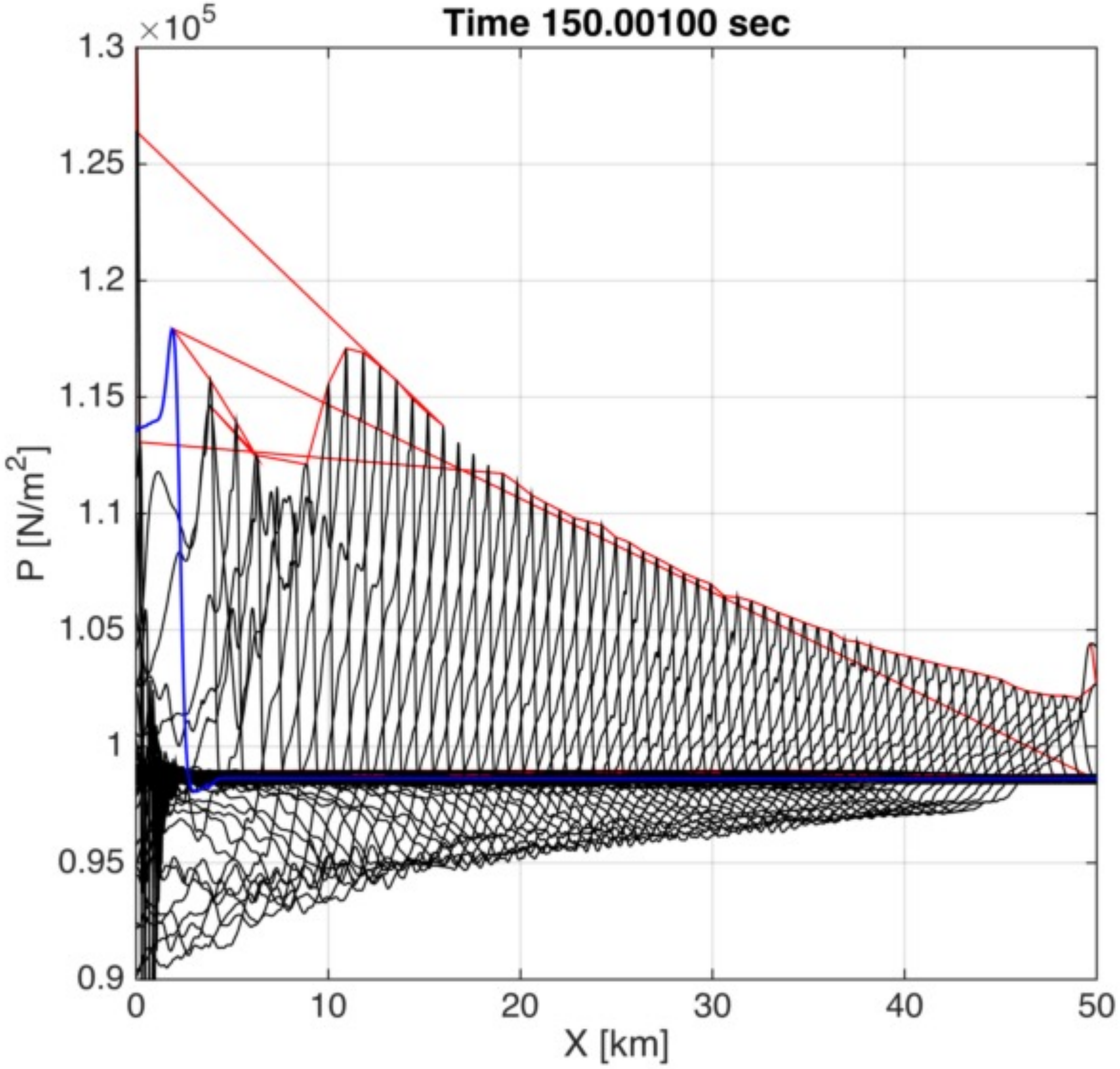
Surface pressure profiles from 5 Mt airburst

with Christopher Moore & Vasily Titov (NOAA Center for Tsunami Research)

Computational Modelling of Asteroid Airbursts

AIAA SciTech 2016

San Diego, CA
Jan 4-8, 2016



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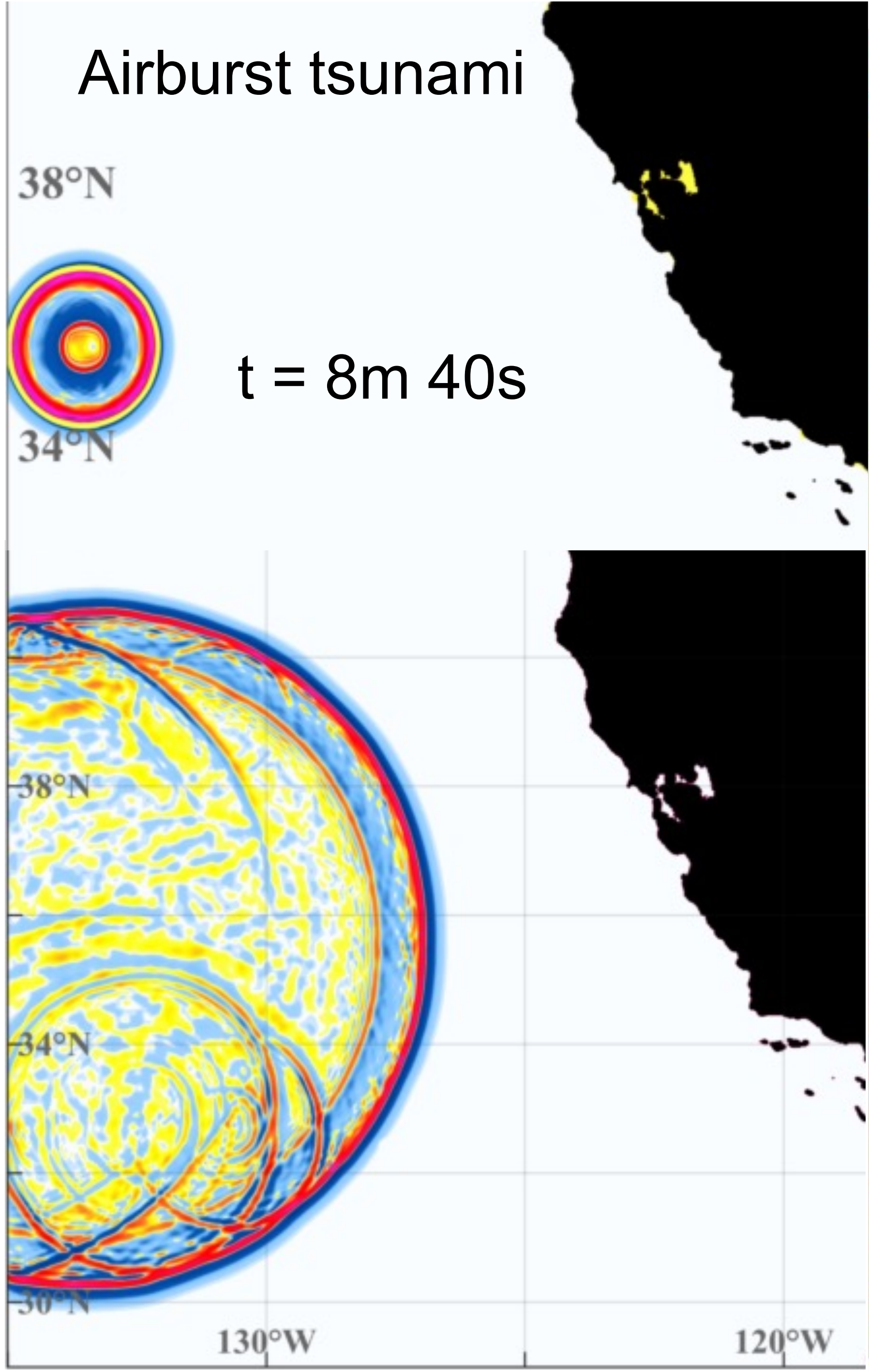
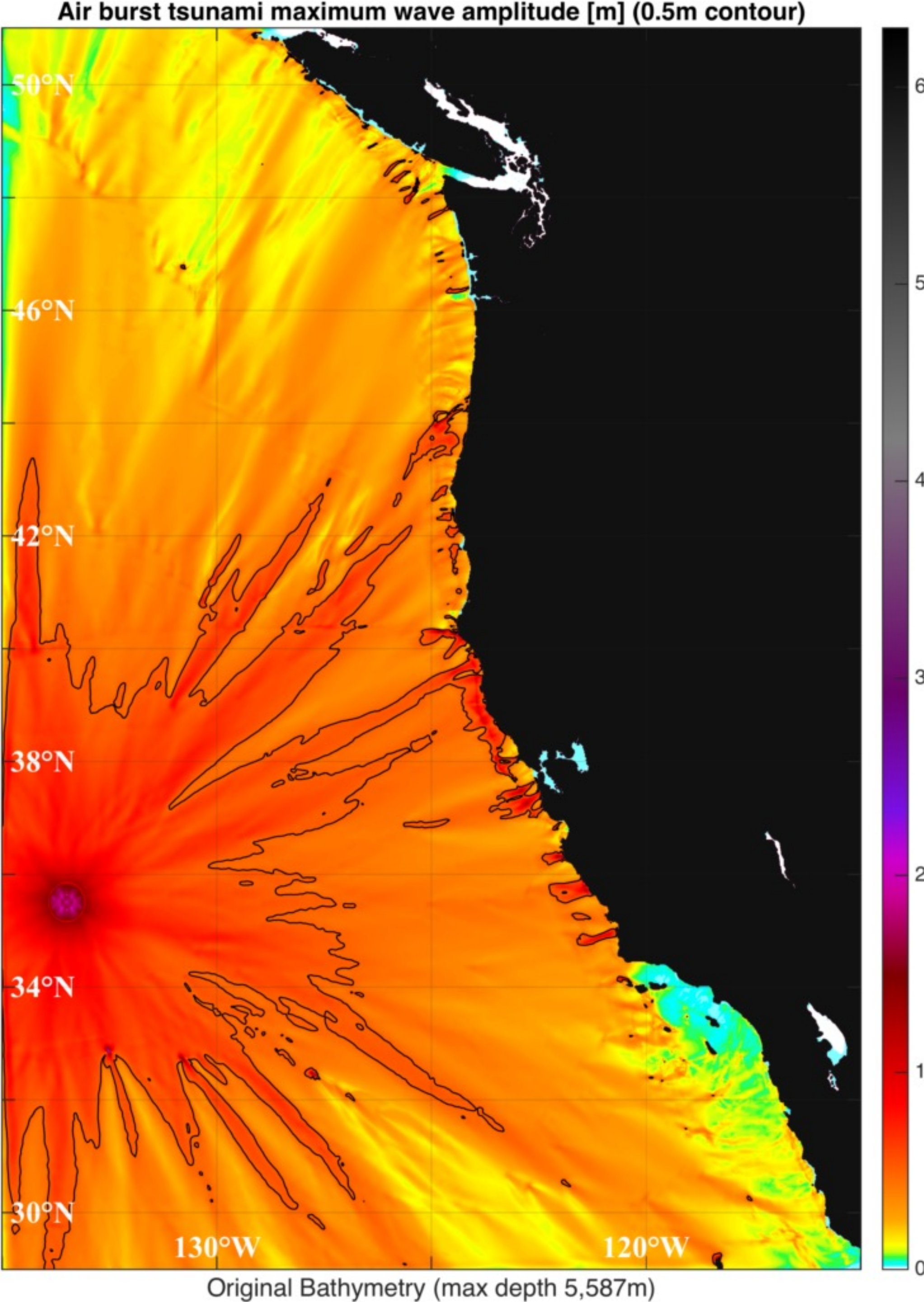
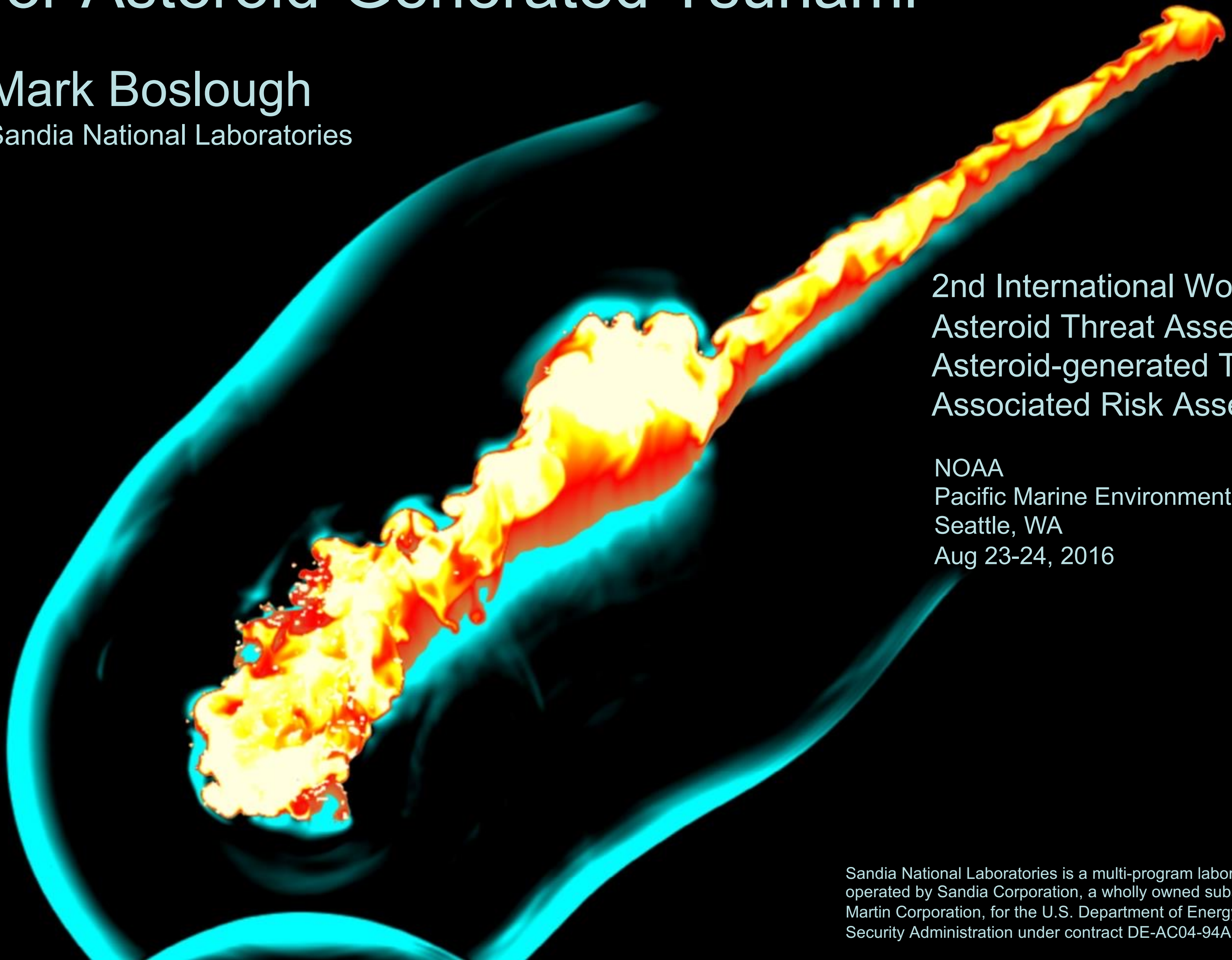




Computational Modeling of Airbursts for Asteroid-Generated Tsunami

Mark Boslough
Sandia National Laboratories



2nd International Workshop on Asteroid Threat Assessment: Asteroid-generated Tsunami and Associated Risk Assessment

NOAA
Pacific Marine Environmental Laboratory
Seattle, WA
Aug 23-24, 2016

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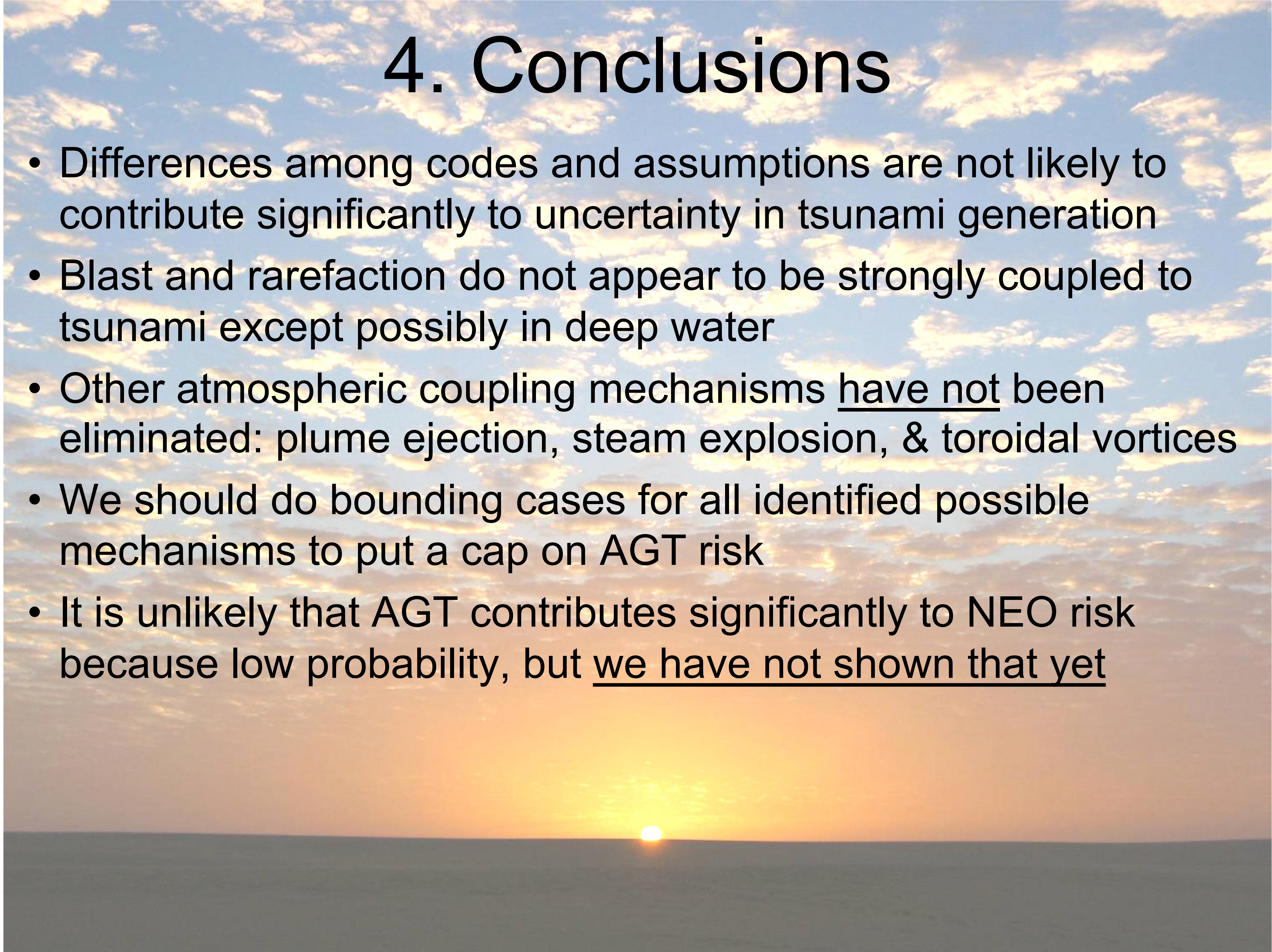


4. Conclusions

- Differences among codes and assumptions are not likely to contribute significantly to uncertainty in tsunami generation
- Blast and rarefaction do not appear to be strongly coupled to tsunami except possibly in deep water
- Other atmospheric coupling mechanisms have not been eliminated: plume ejection, steam explosion, & toroidal vortices
- We should do bounding cases for all identified possible mechanisms to put a cap on AGT risk
- It is unlikely that AGT contributes significantly to NEO risk because low probability, but we have not shown that yet

Airburst-Generated Tsunami by Various Coupling Mechanisms

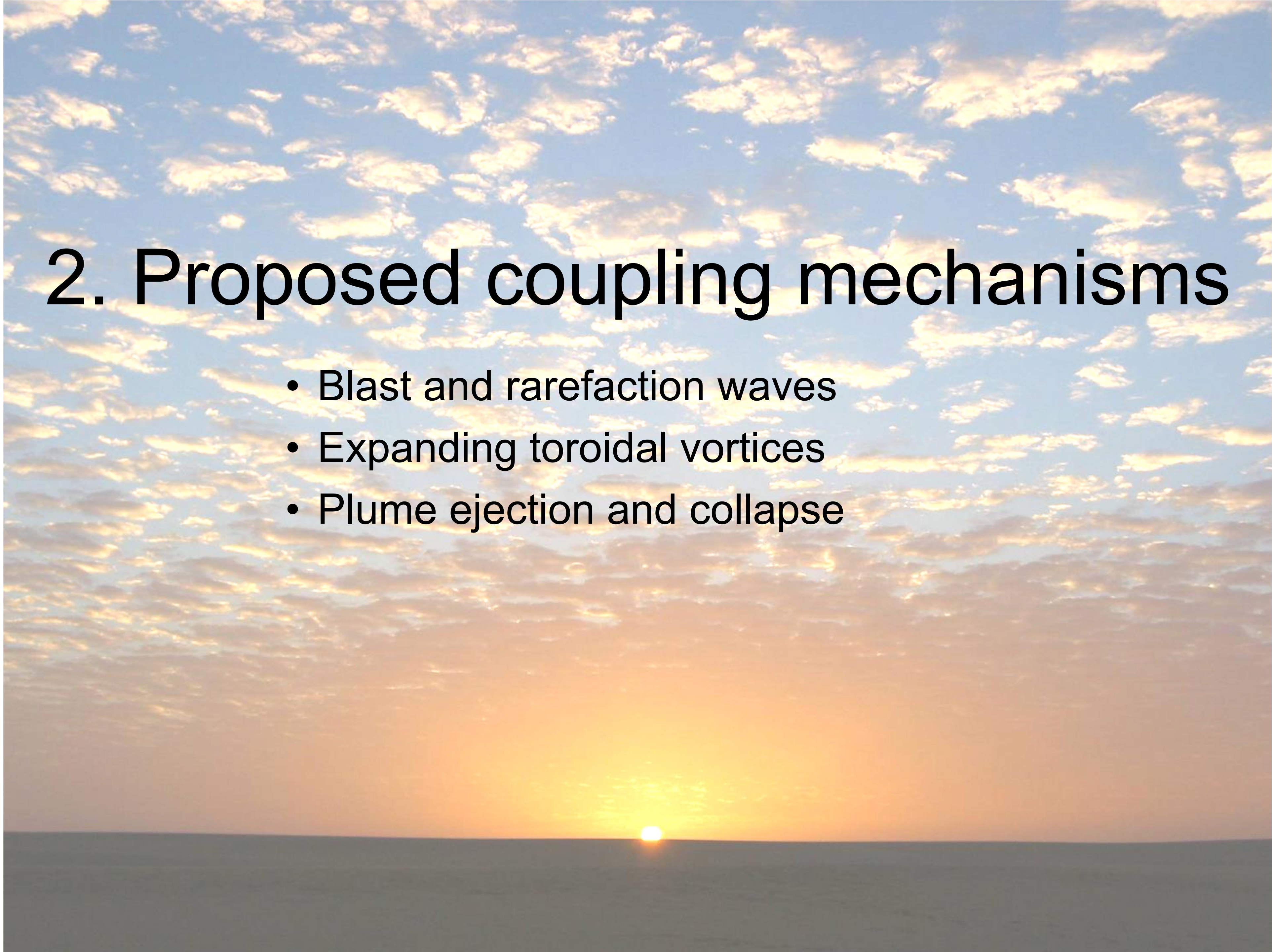
Mark Boslough
Sandia National Laboratories

Vasily Titov
NOAA Center for Tsunami Research

2017 IAA Planetary Defense Conference

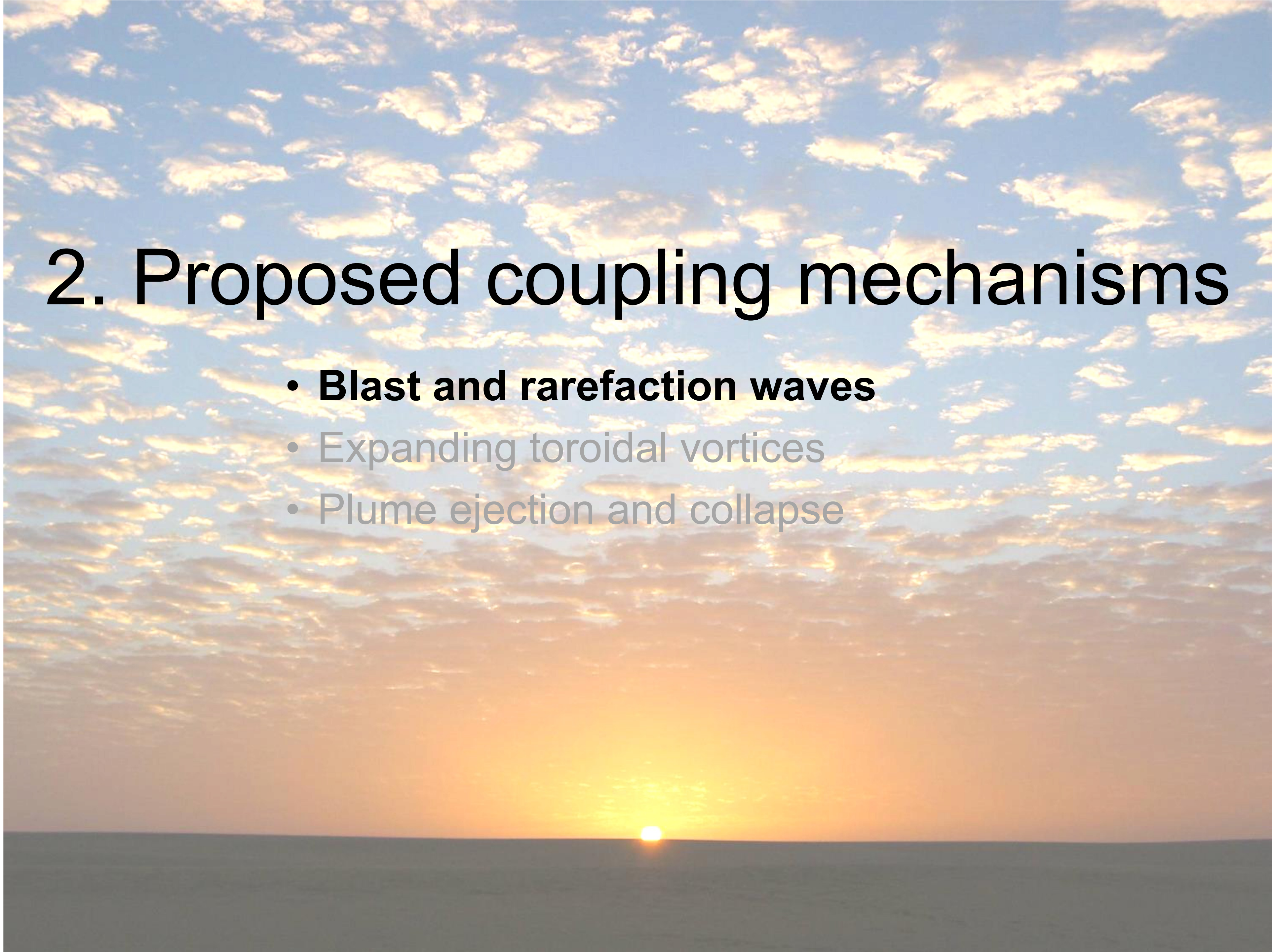
Tokyo, Japan, May 15-19, 2017

This project was funded by NASA, NNSA, and NOAA



2. Proposed coupling mechanisms

- Blast and rarefaction waves
- Expanding toroidal vortices
- Plume ejection and collapse



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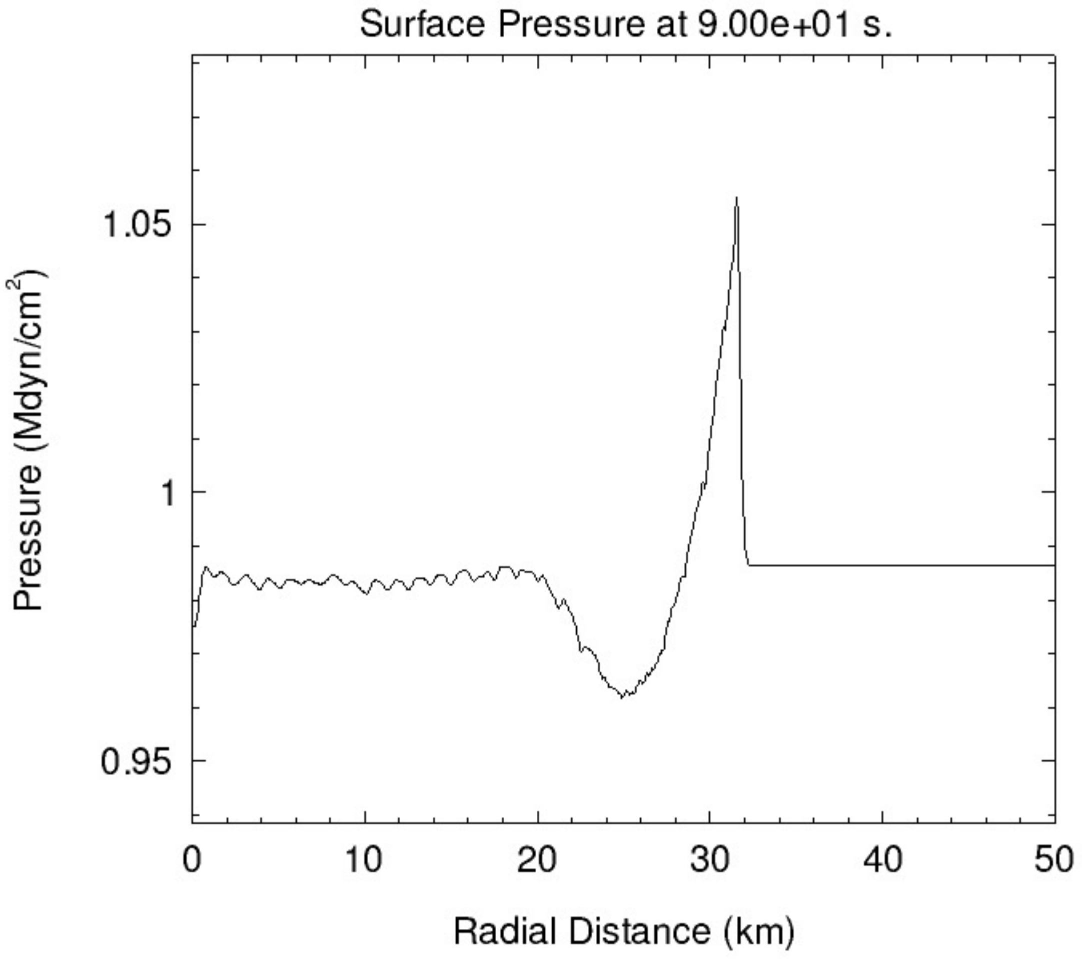
Planetary Defense Conference

Tokyo, Japan, May 15-19, 2017

Blast and rarefaction waves



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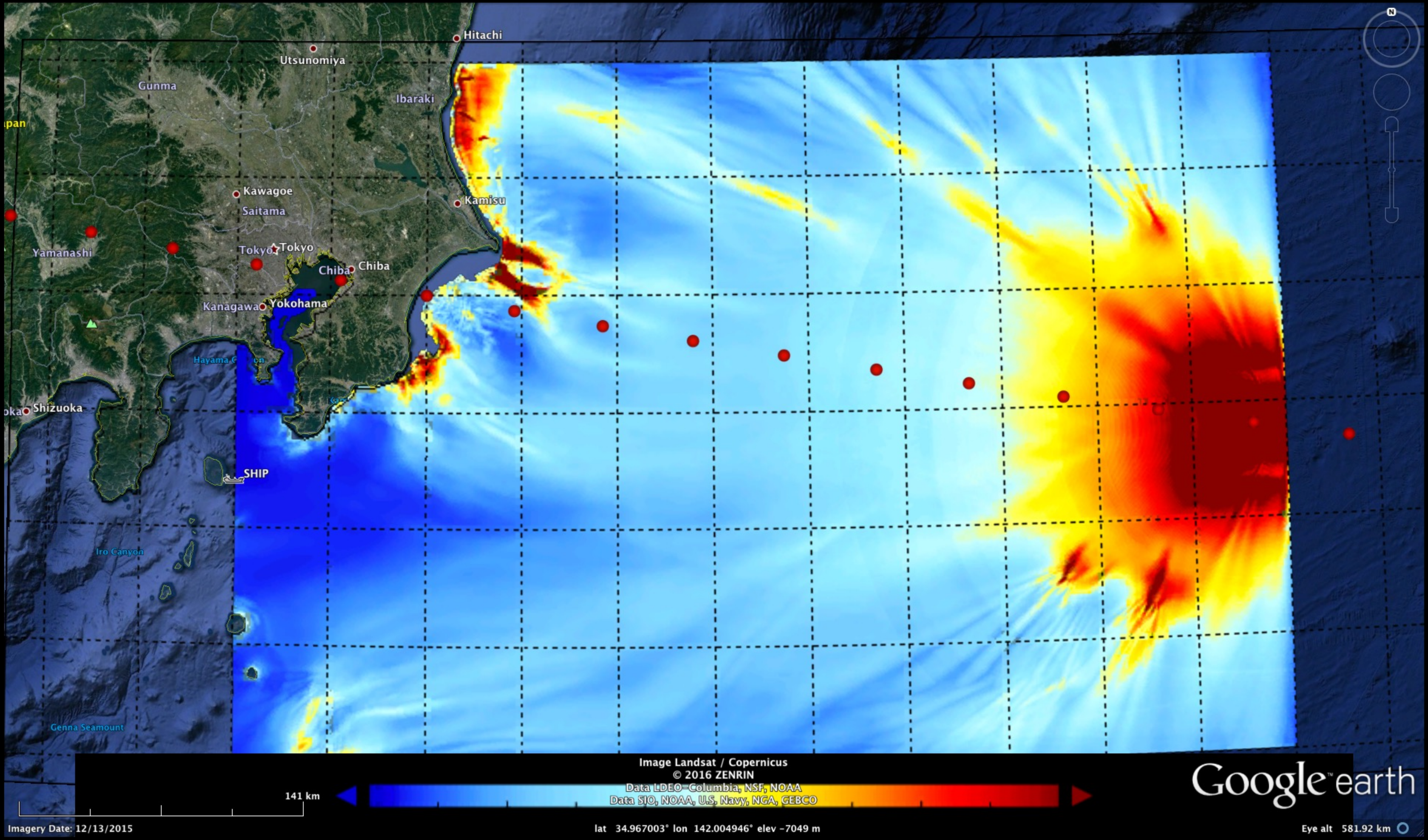
Tokyo, Japan, May 15-19, 2017

Maximum wave heights
Impact 400 km away in middle of oceanic plane

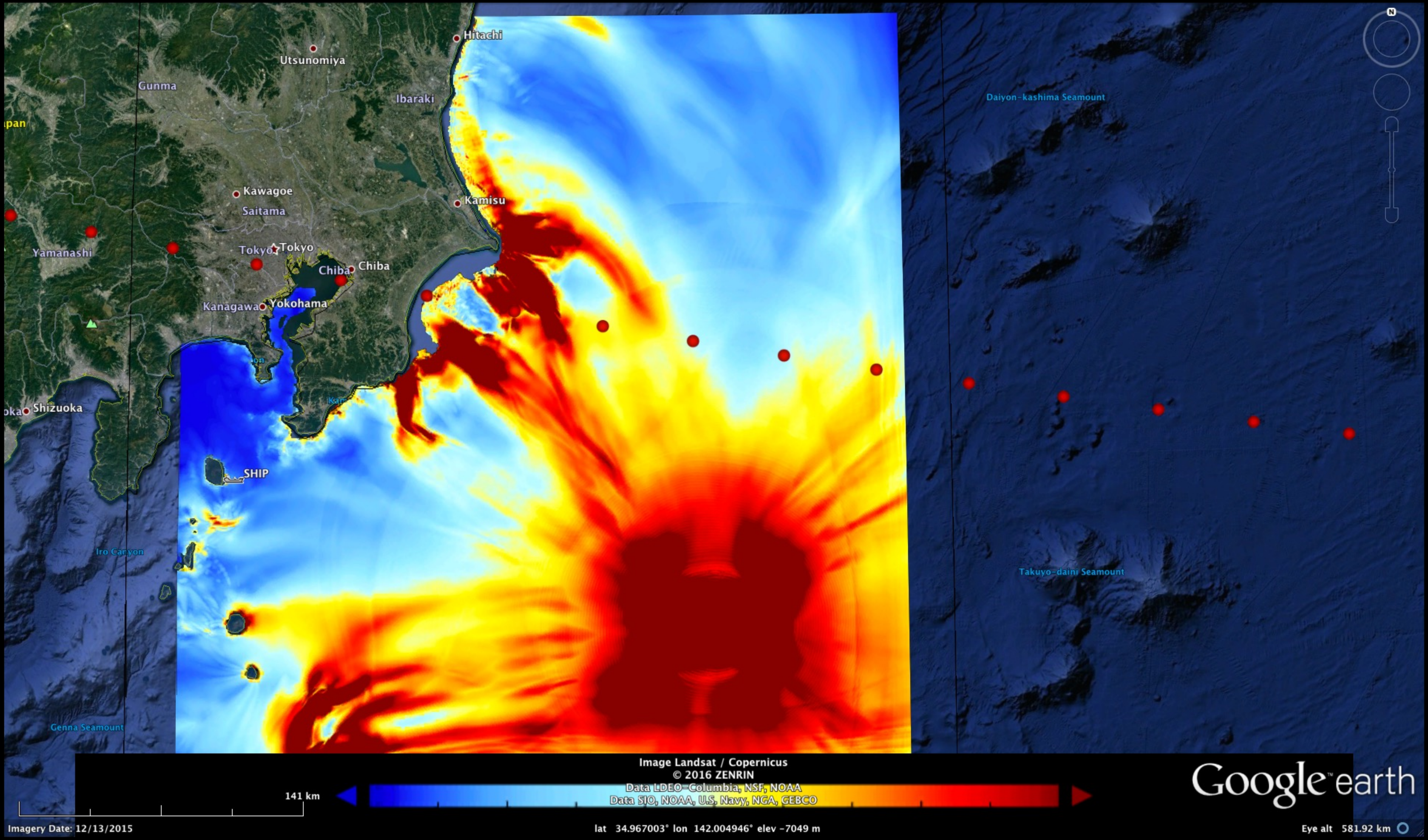


Max depth at shore = 25 m, Flooded area = 46.5 km^2

Planetary Defense Conference

Tokyo, Japan, May 15-19, 2017

Maximum wave heights
Impact on deepest part of Japan Trench



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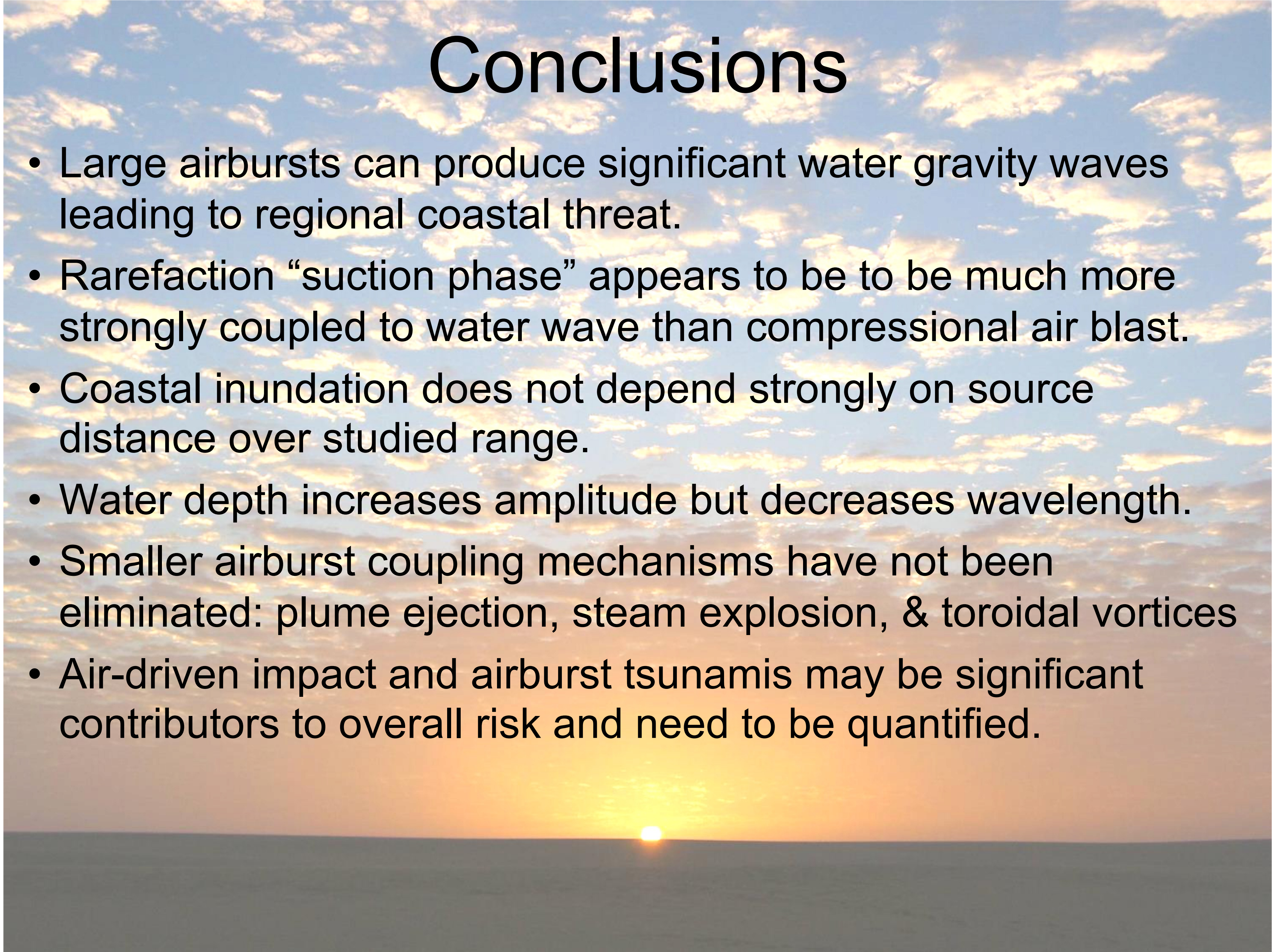
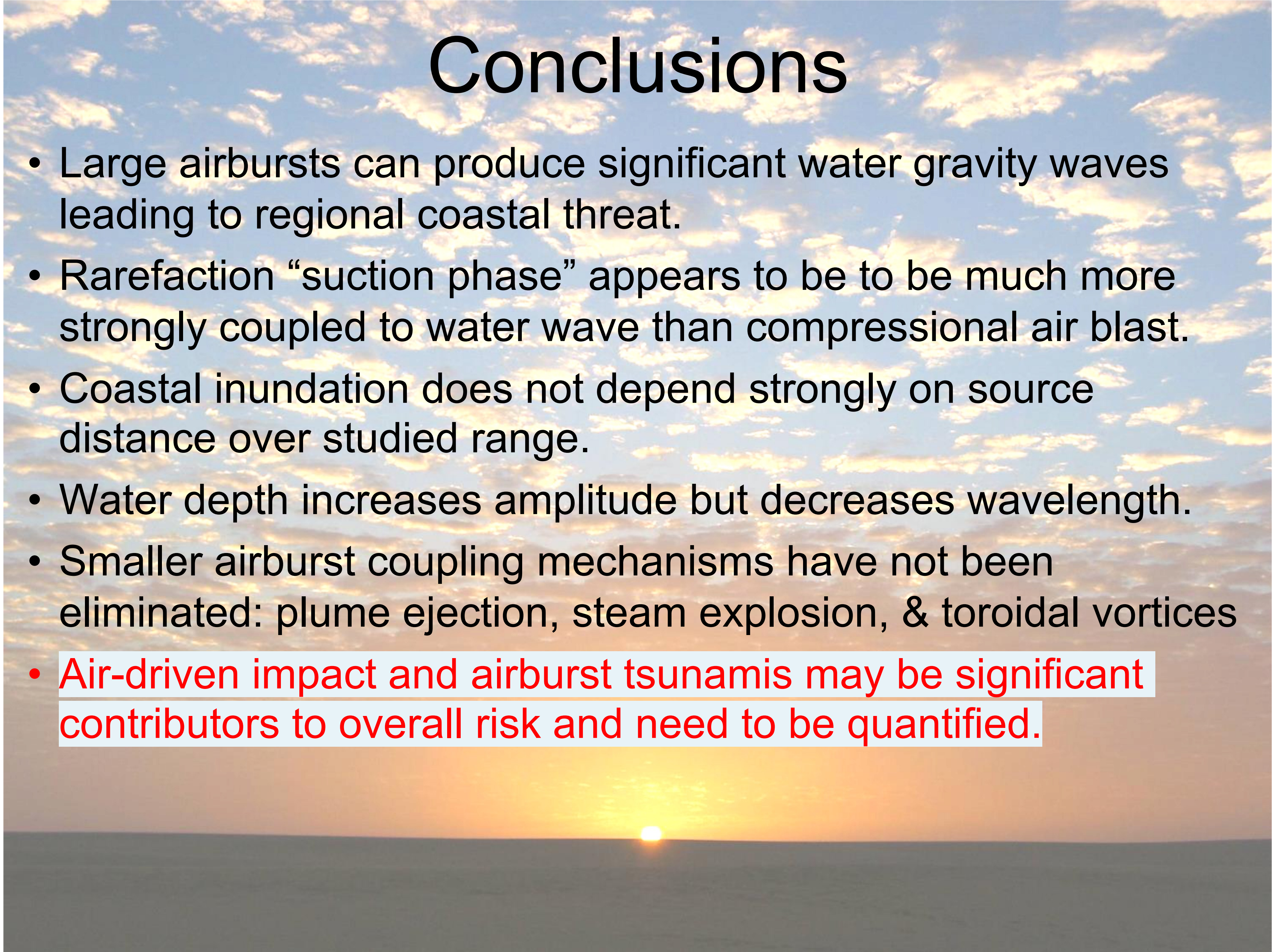


Conclusions

- Large airbursts can produce significant water gravity waves leading to regional coastal threat.
- Rarefaction “suction phase” appears to be to be much more strongly coupled to water wave than compressional air blast.
- Coastal inundation does not depend strongly on source distance over studied range.
- Water depth increases amplitude but decreases wavelength.
- Smaller airburst coupling mechanisms have not been eliminated: plume ejection, steam explosion, & toroidal vortices
- Air-driven impact and airburst tsunamis may be significant contributors to overall risk and need to be quantified.



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90 km

120 Mt airburst simulation

80 km

Hunga Tonga–Hunga Ha'apai January 15, 2022 explosion simulation (120 Mt yield)

400 km

90 km

120 Mt source

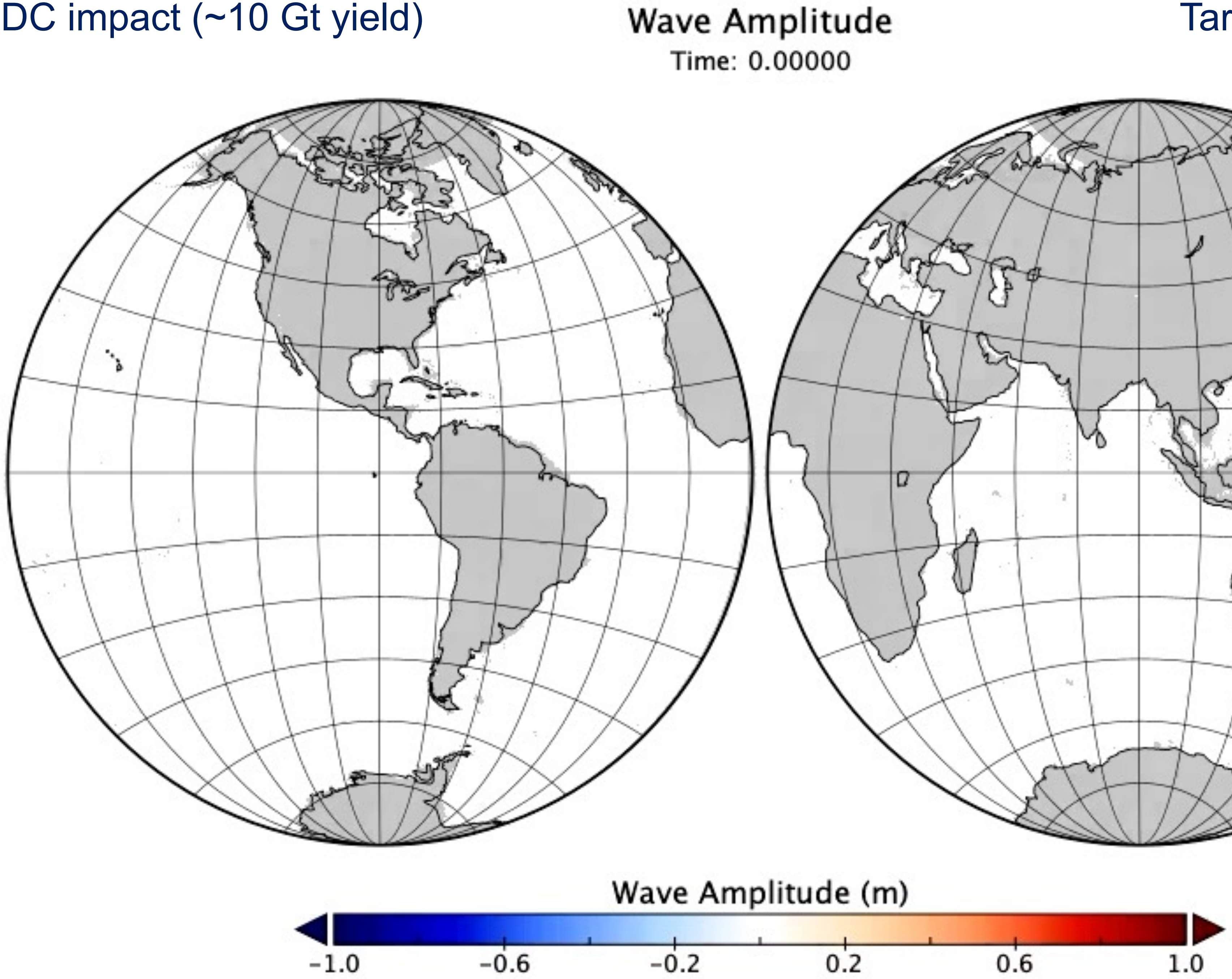
2023 PDC asteroid impact simulation (~10 Gt yield)

Dallas

Houston

2023 PDC impact (~10 Gt yield)

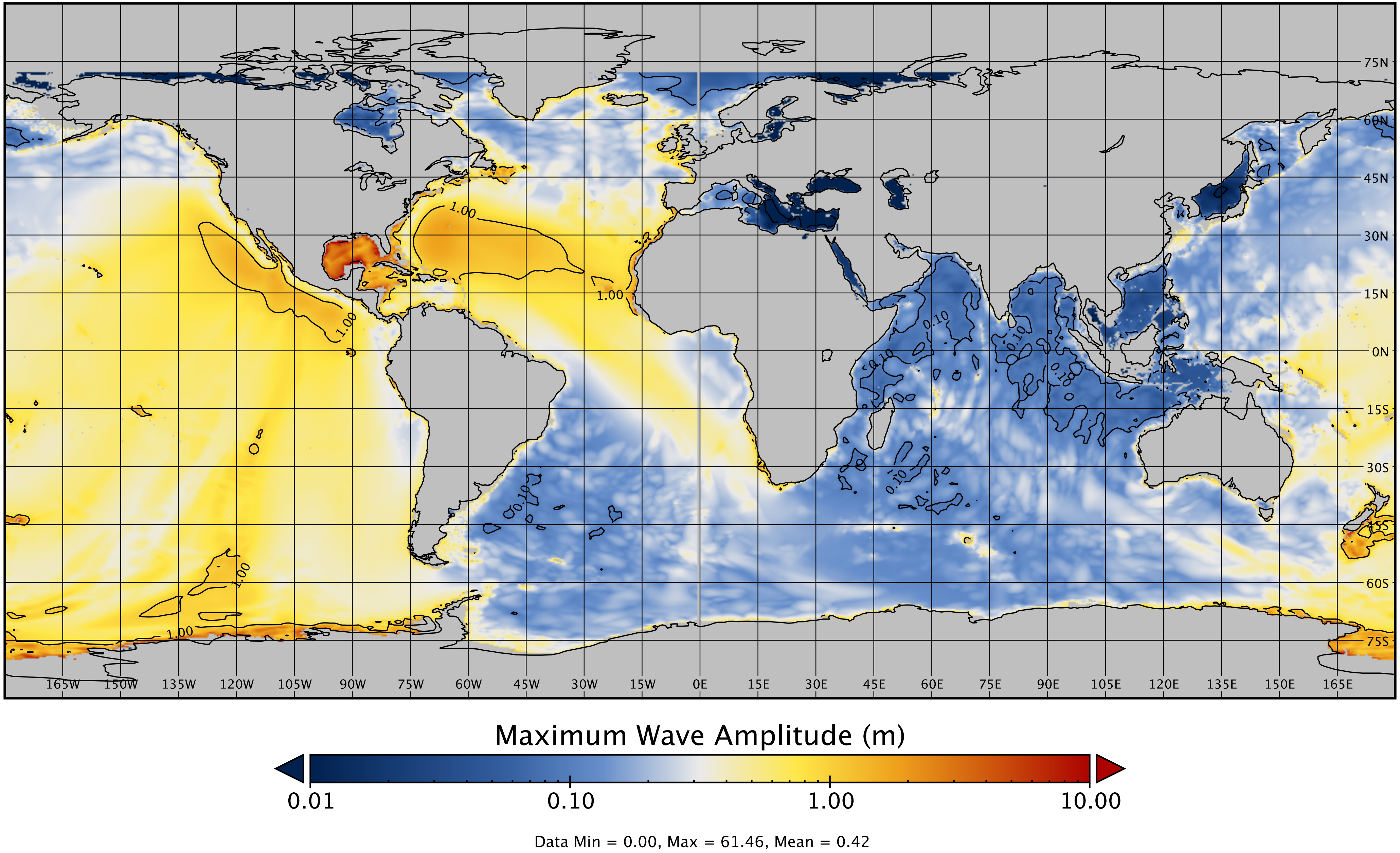
Target: Dallas, Texas, USA



2023 PDC impact (~10 Gt yield)

Target: Dallas, Texas, USA

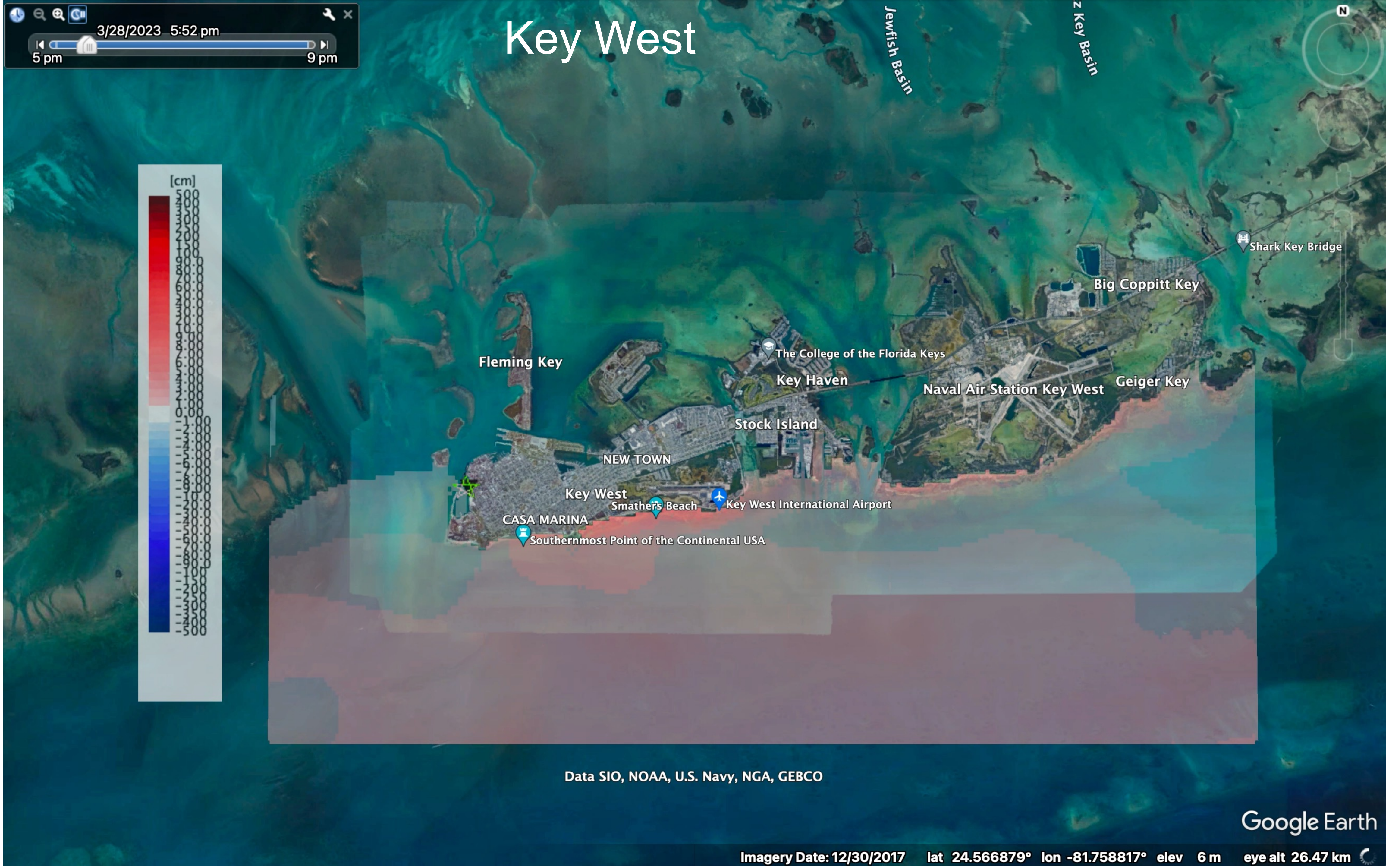
Maximum Tsunami Amplitude



Data Min = 0.00, Max = 61.46, Mean = 0.42

2023 PDC impact (~10 Gt yield)

Key West



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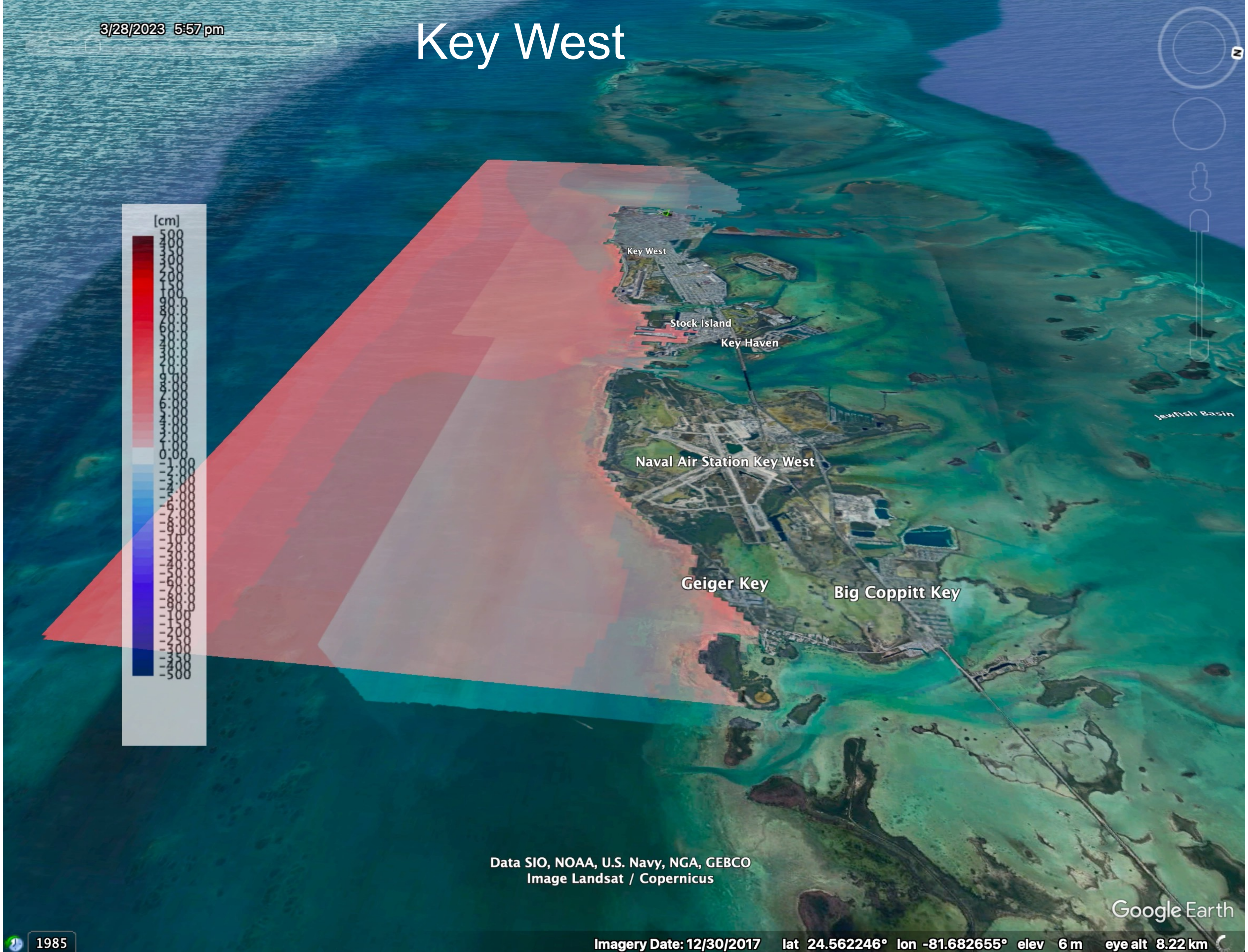

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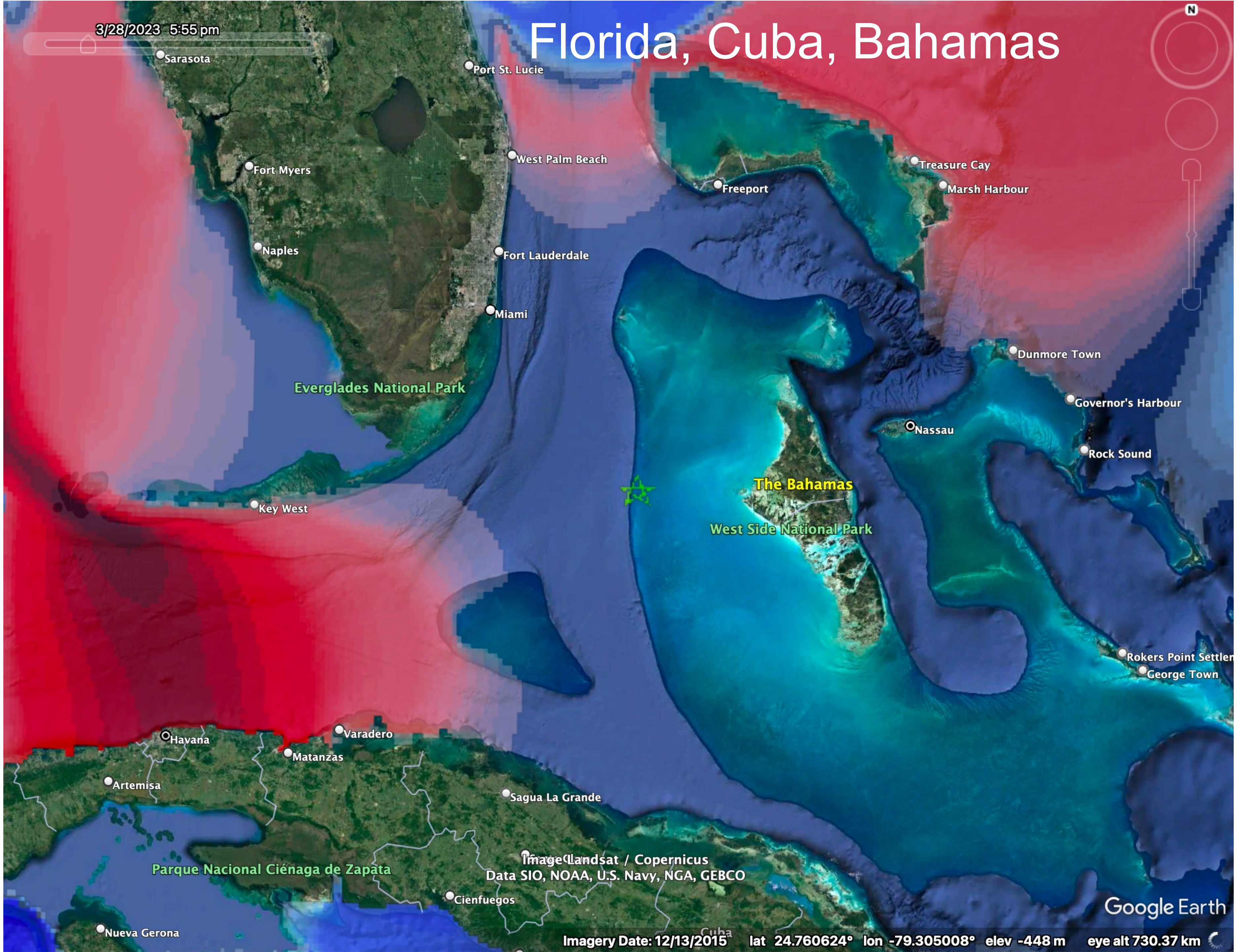
2023 PDC impact (~10 Gt yield)

Florida, Cuba, Bahamas



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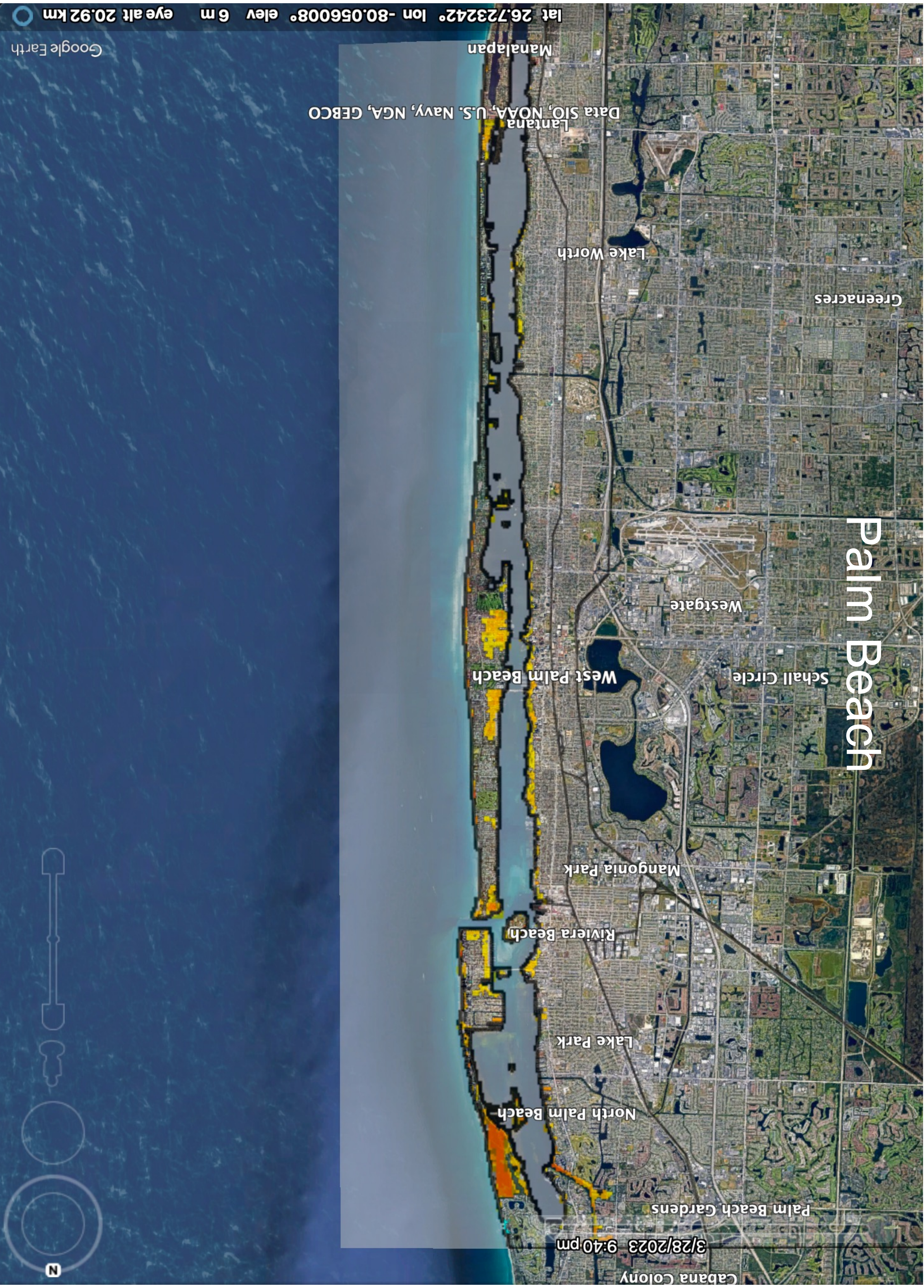


Target: Dallas, Texas, USA

2023 PDC impact (~10 Gt yield)

Hatteras

Target: Dallas, Texas, USA

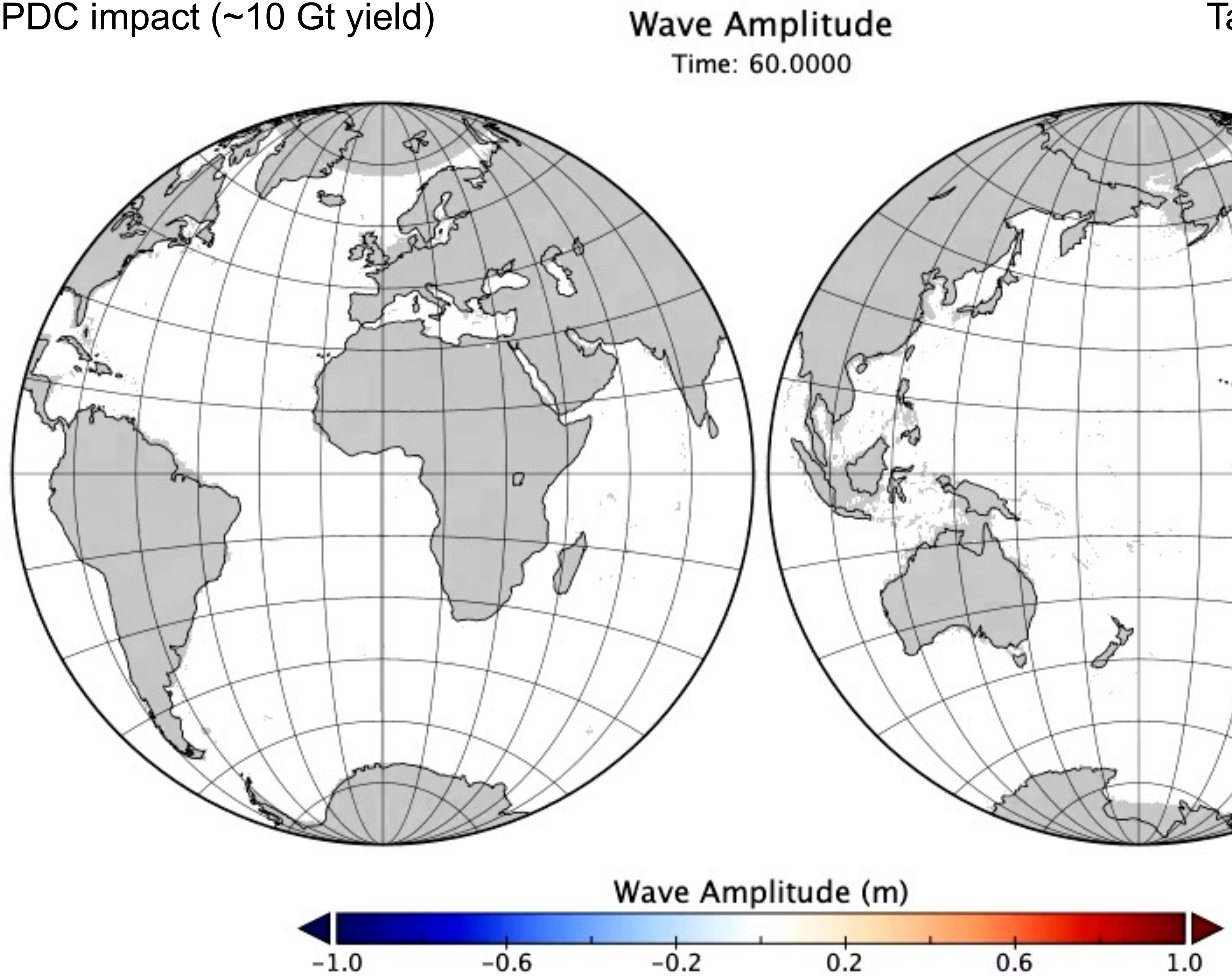
Atlantic City

2023 PDC impact (~10 Gt yield)

Target: Dallas, Texas, USA

2023 PDC impact (~10 Gt yield)

Target: Jebba, Nigeria



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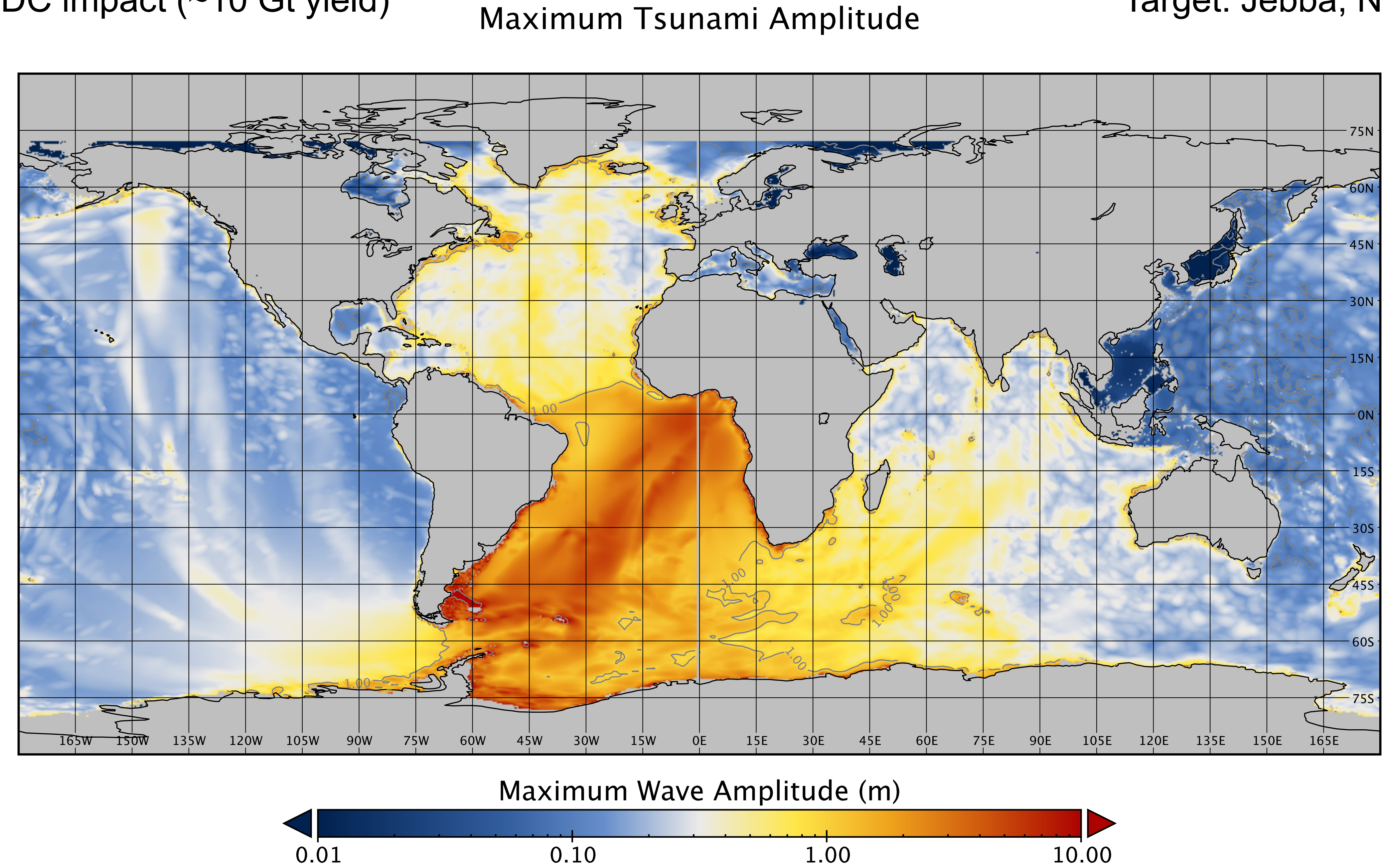
Target: Jebba, Nigeria



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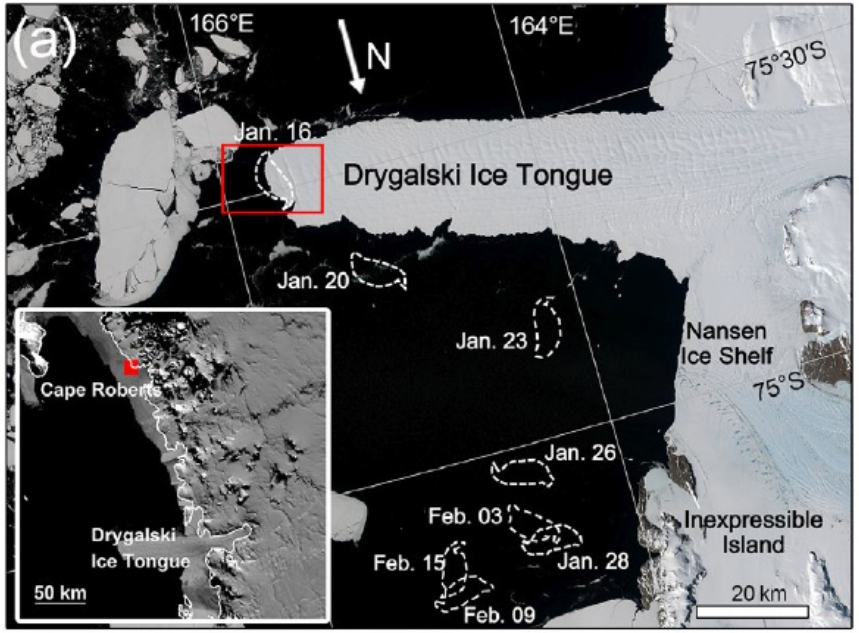
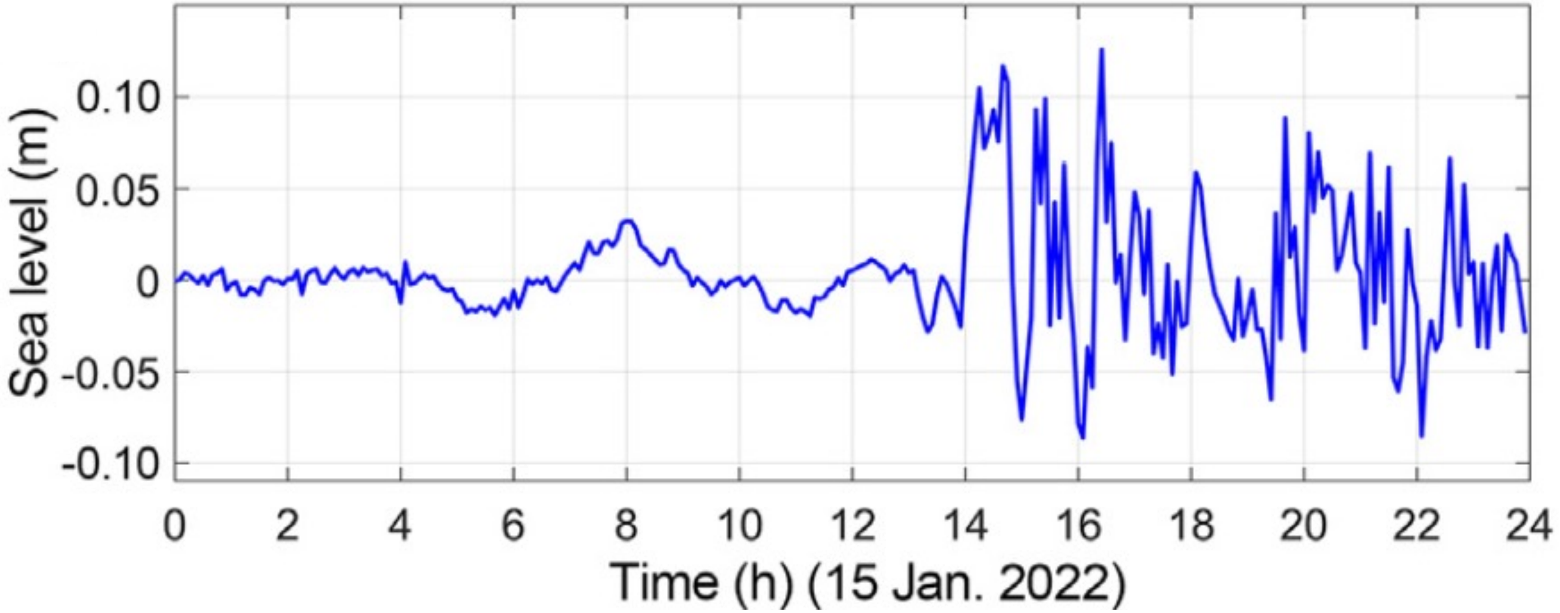
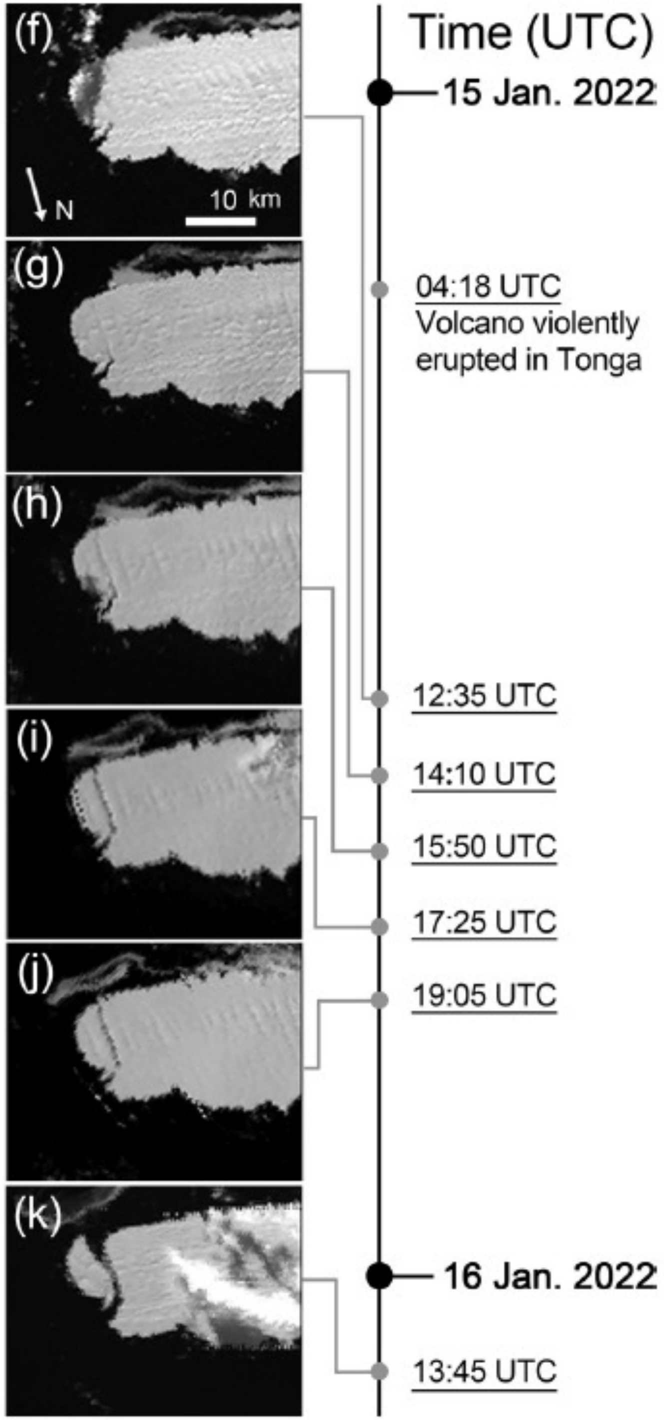
Black Swan example: Unexpected catastrophe cascade







Liang et al, (2023), Ice tongue calving in Antarctica triggered by the Hunga Tonga volcanic tsunami, January 2022, *Science Bulletin* (2023).

2023 PDC impact (~10 Gt yield)

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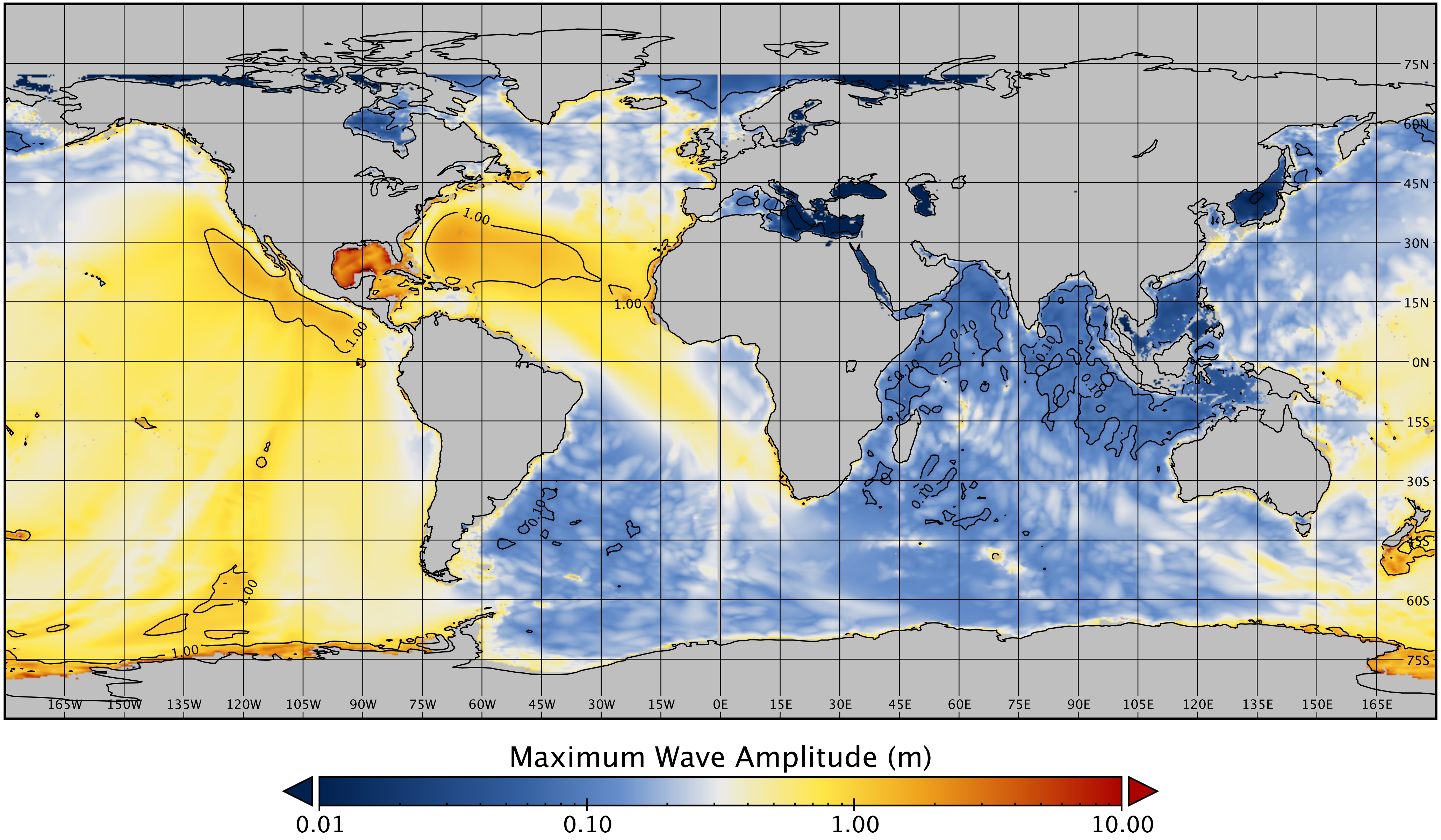
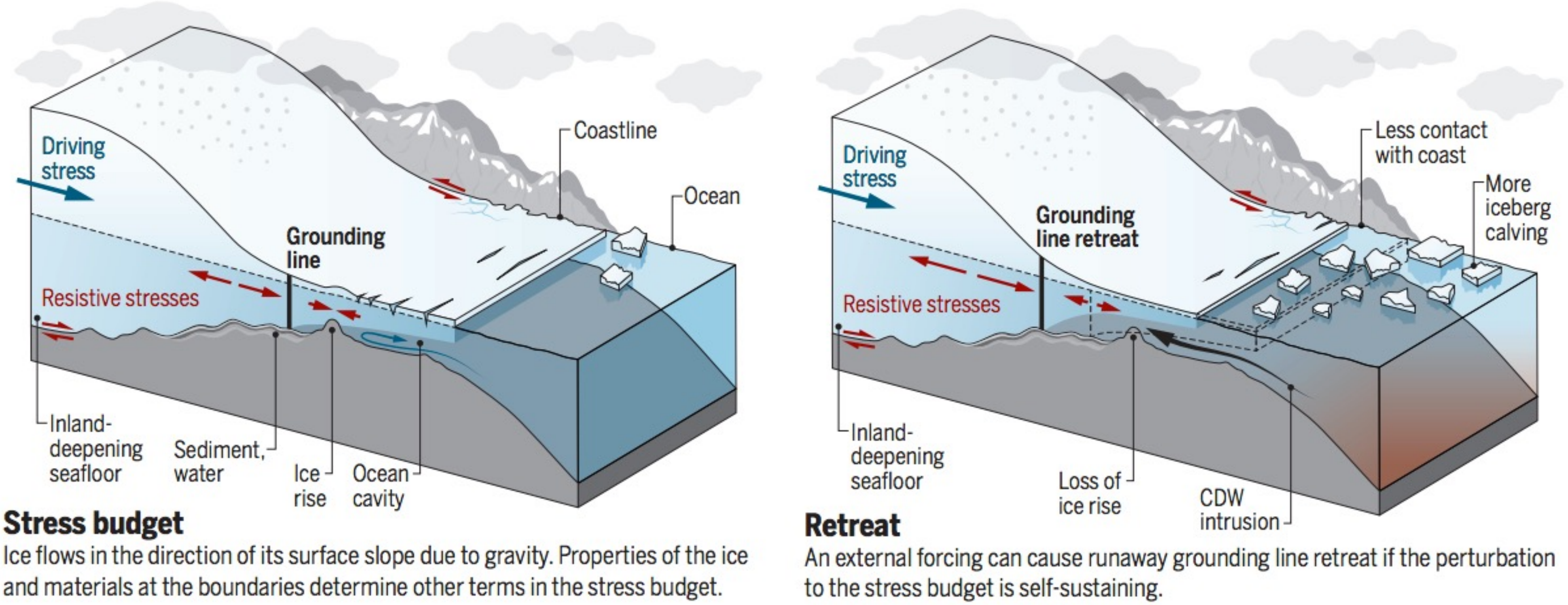
Maximum Tsunami Amplitude



Data Min = 0.00, Max = 61.46, Mean = 0.42

Possible catastrophe cascade scenario:
1) Impact, 2) Lamb wave, 3) Tsunami, 4) Bathometric focusing, 5) Ice shelf fracture 6) Loss of buttressing, 7) Runaway grounding line retreat, 8) Ice sheet collapse, 9) Abrupt sea level rise



Stress budget
Ice flows in the direction of its surface slope due to gravity. Properties of the ice and materials at the boundaries determine other terms in the stress budget.

Retreat
An external forcing can cause runaway grounding line retreat if the perturbation to the stress budget is self-sustaining.

Global warming releases the safety, asteroid impact pulls the trigger

Hulbe, C (2017) Is ice sheet collapse in West Antarctica unstoppable? Science, doi:10.1126/science.aam9728

Conclusions

- Impacts and airbursts generate global tsunamis even if they strike on land.
- The threshold for dangerous tsunami generation is smaller than we thought.
- The Hunga Tonga-Hunga Ha’apai explosion provides an existence proof.
- Global warming is a threat multiplier for impact risk.
- We have identified a “black swan”. But what haven’t we thought of yet?

Future work and recommendations

- Full sensitivity analysis and uncertainty quantification.
- Development of warning systems (Lamb wave tsunami may be first to arrive).
- Seek collaboration with volcanic hazards and tsunami hazards communities.
- Seek validation opportunities by predicting paleotsunami deposit locations.