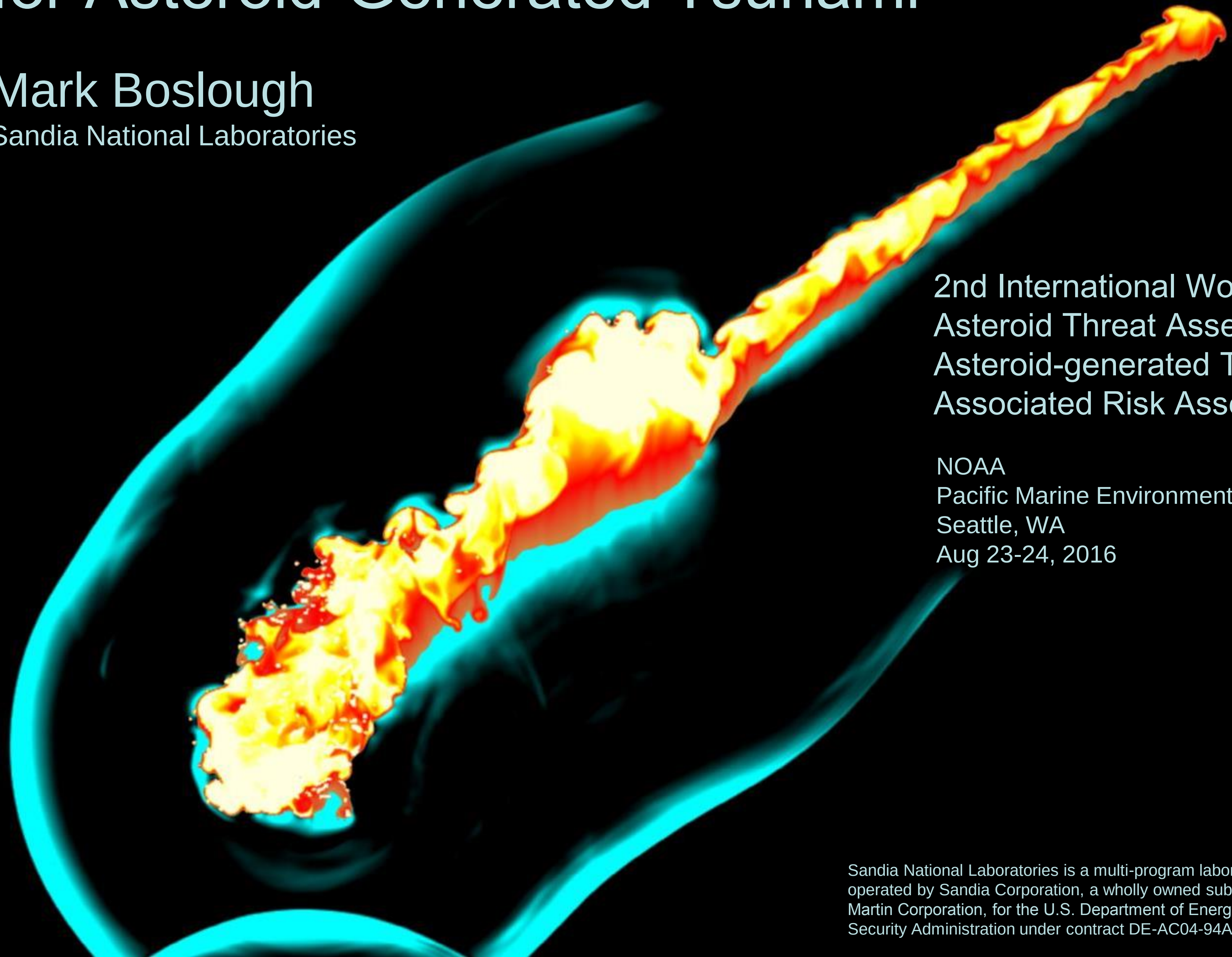
Computational Modeling of Airbursts for Asteroid-Generated Tsunami

SAND2016-9152C

Mark Boslough
Sandia National Laboratories



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

NOAA
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Group 1: Tsunami Creation (Airburst and Direct Impact)
Goal: Seek answers to the following questions:

1) Is an airburst more efficient at generating a tsunami than a surface impact of the same yield?
2) How does airburst/tsunami coupling depend on yield, height of burst, and water depth?
3) What is the “optimal” height of burst for a given yield and does it depend on water depth?
4) Does a collisional event (line source) differ from that of a stationary event (point source)?
5) Does plume ejection from an airburst enhance the coupling?

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7) Do they add significantly to the overall impact risk?

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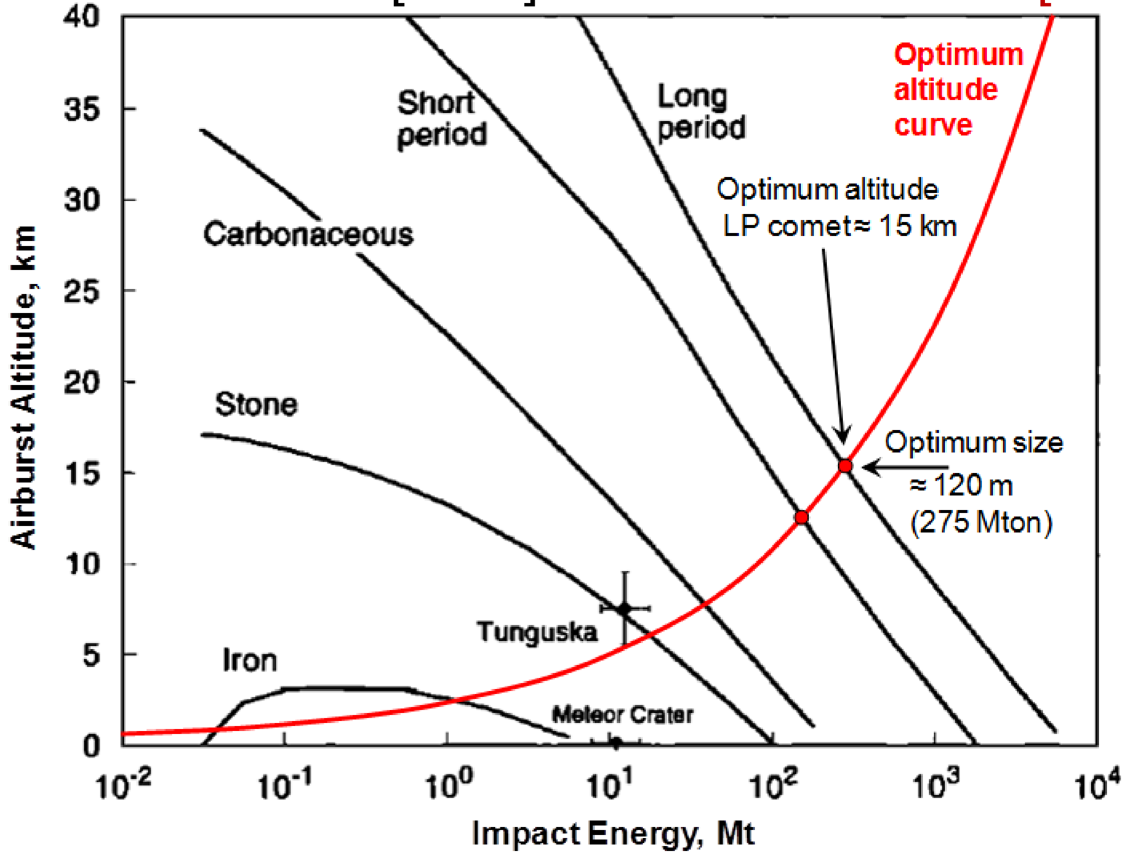
7) Do they add significantly to overall impact risk? OPEN QUESTION

A note on “optimum” height of burst and size

Toon et al. [1997]   Glasstone & Dolan [1977]



Group 1: Tsunami Creation (Airburst and Direct Impact)

Coordinated tasks

- Run 5 & 100 Mt static spherical charge cases (0, 5, & 10km burst height)
- Run 5 & 100 Mt line-source cases (include mass and momentum deposition)
- Develop and distribute line-source models for Session 1
- Compare surface overpressure and wind footprints with other hydrocodes
- Compare point source results with Glasstone & Dolan
- Convergence studies to ensure sufficient resolution
- 3D simulations of oblique impacts

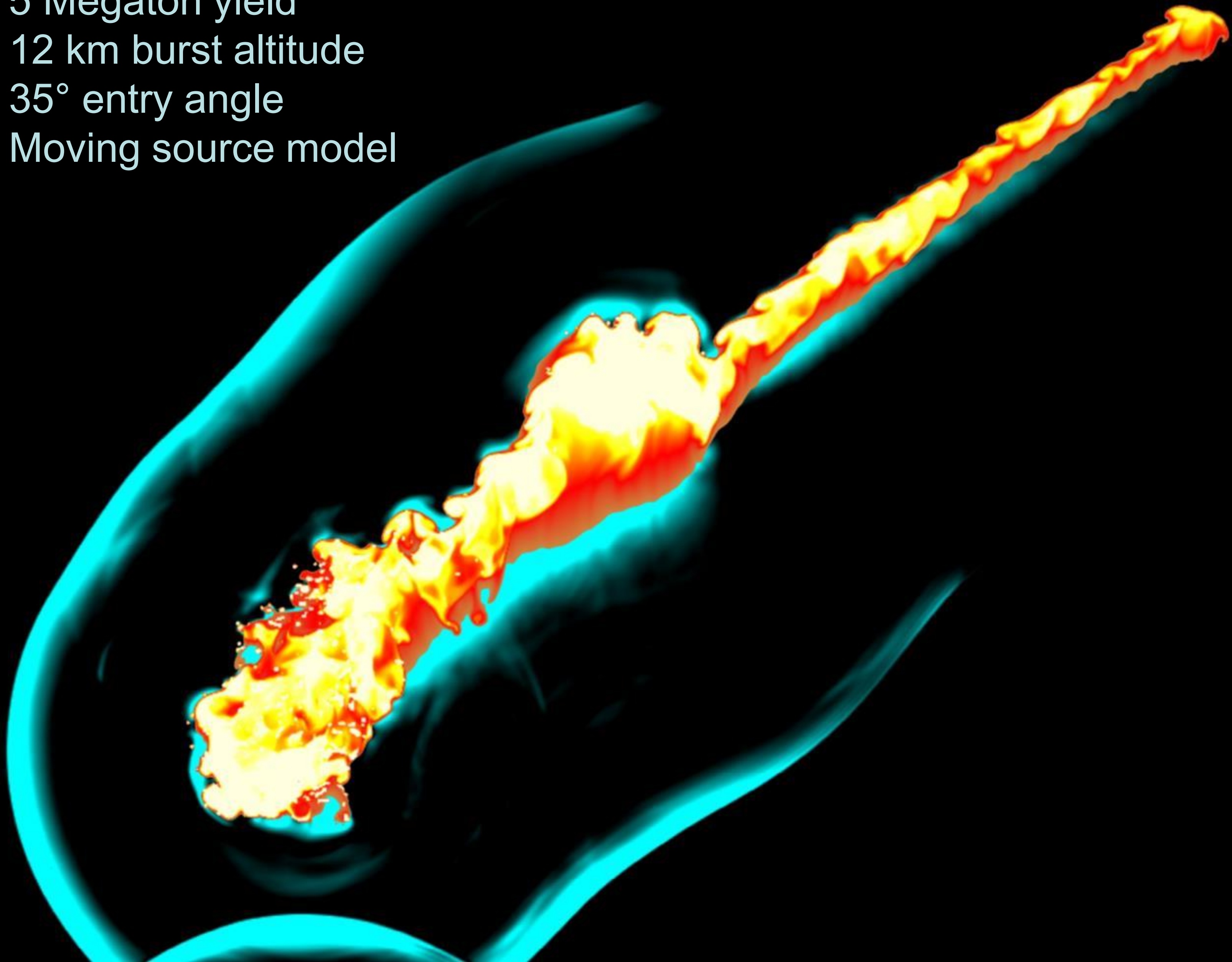
Outline

1. Review: Airbursts are different than explosions
2. Review: Airburst-generated “meteotsunami”
3. Proposed coupling mechanisms:
   - Blast wave
   - Plume ejection and collapse
   - Steam ablation and explosion
   - Expanding toroidal vortex
4. Conclusions
5. Group #1 coordinated tasks (supplemental)
   - Static point sources (5,100,250 Mt)
   - Vertical line sources (5,100,250 Mt)
   - Inclined line sources (2017 PDC)

1. Review: Airbursts vs. explosions

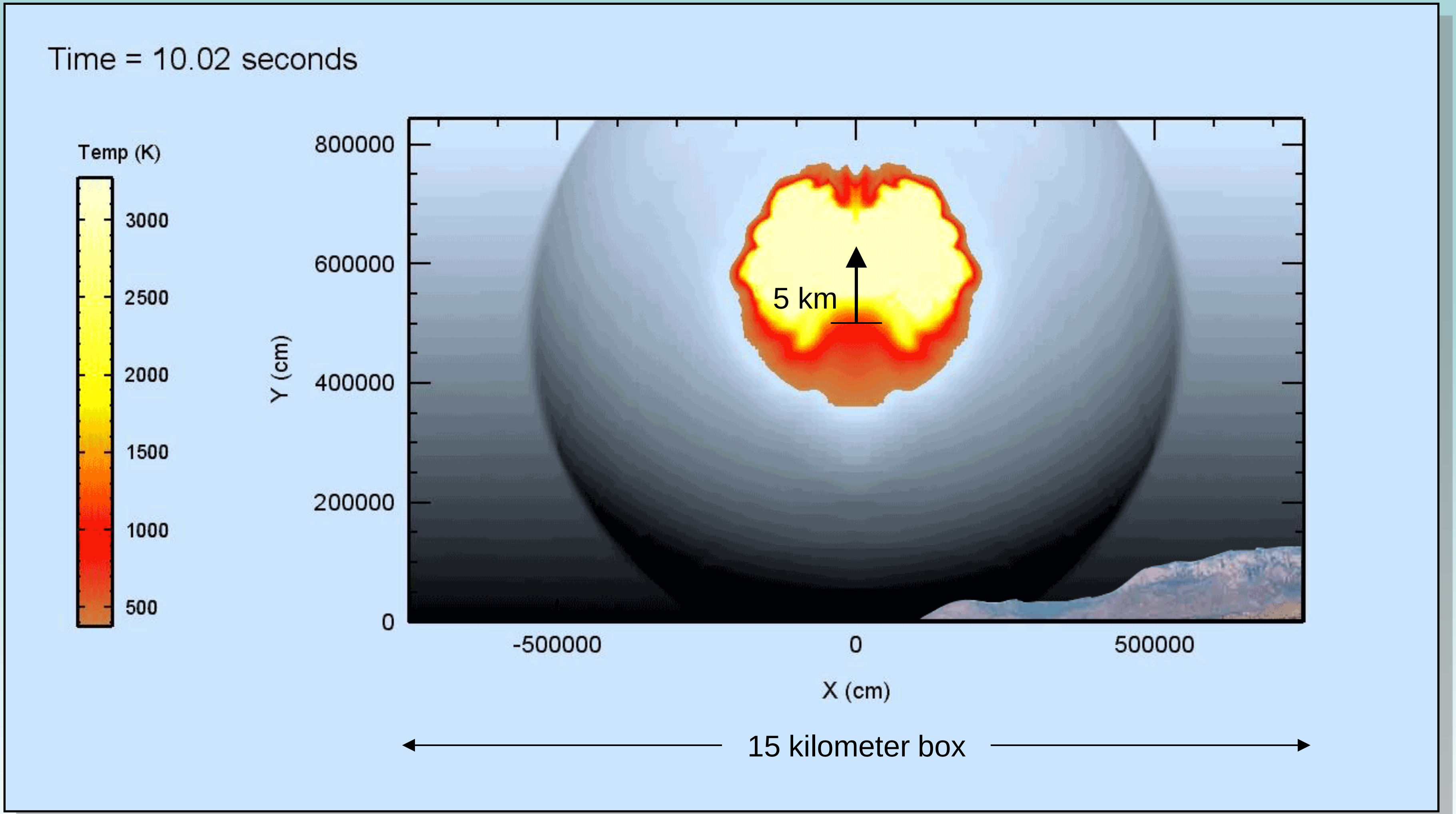
Tunguska

- 5 Megaton yield
- 12 km burst altitude
- 35° entry angle
- Moving source model



Movies: Difference between explosion and impact

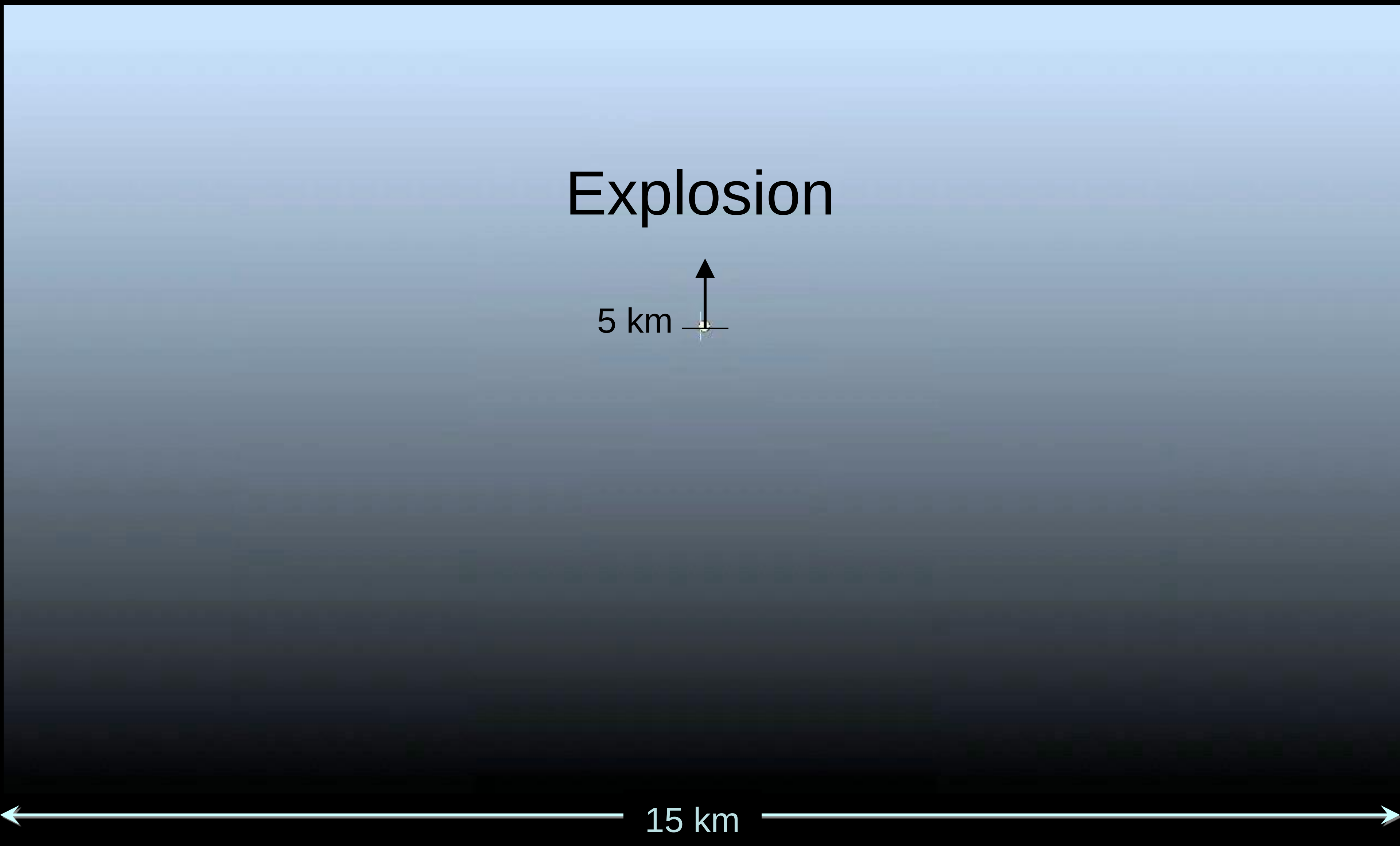
5 megaton point explosion at 5 km altitude: first 20 seconds



Difference between explosion and impact

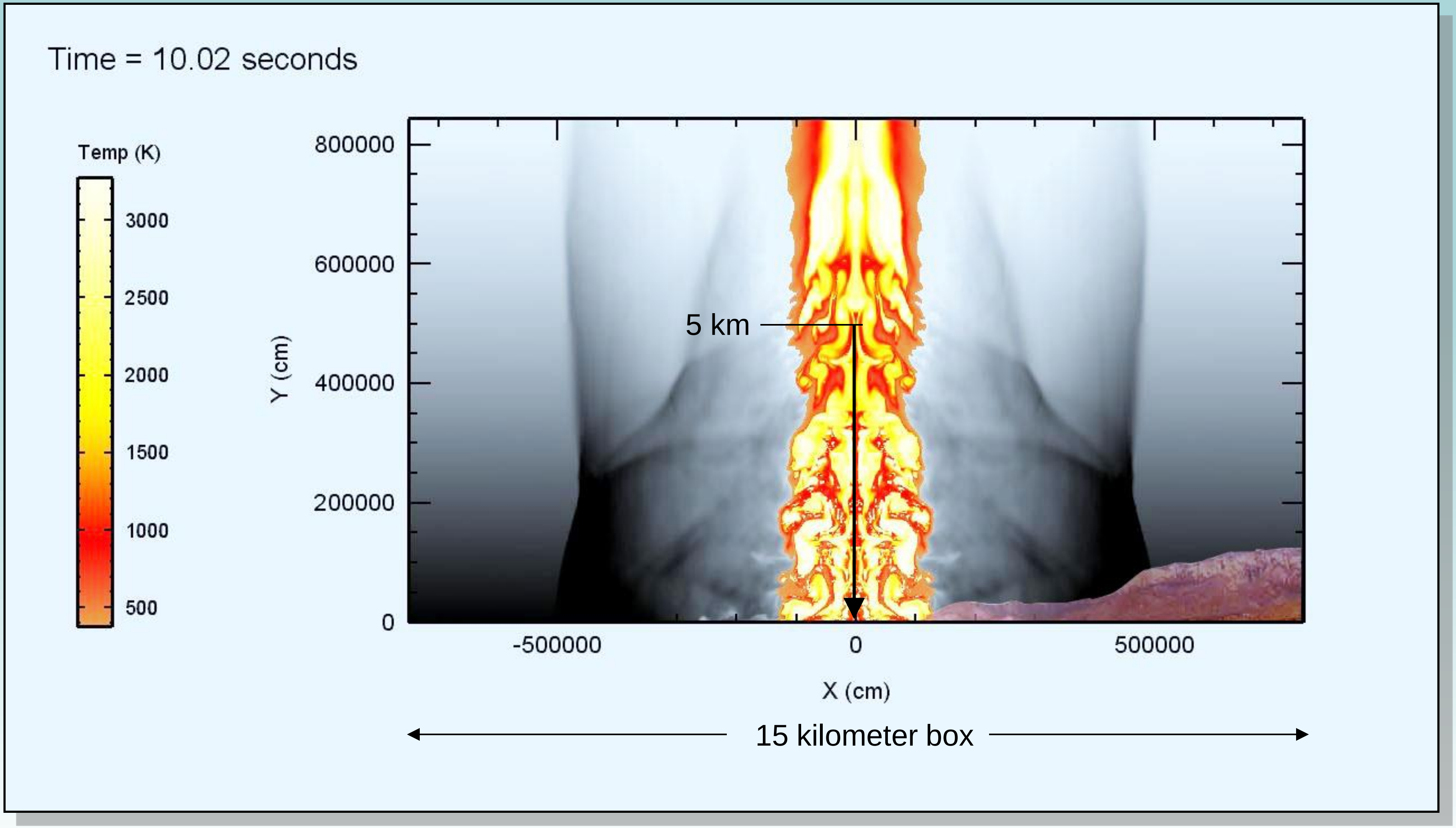
Temperature: 500 K — 3000 K

5 megatons: first 20 seconds



Movies: Difference between explosion and impact

5 megaton impact airburst at 5 km altitude: first 20 seconds



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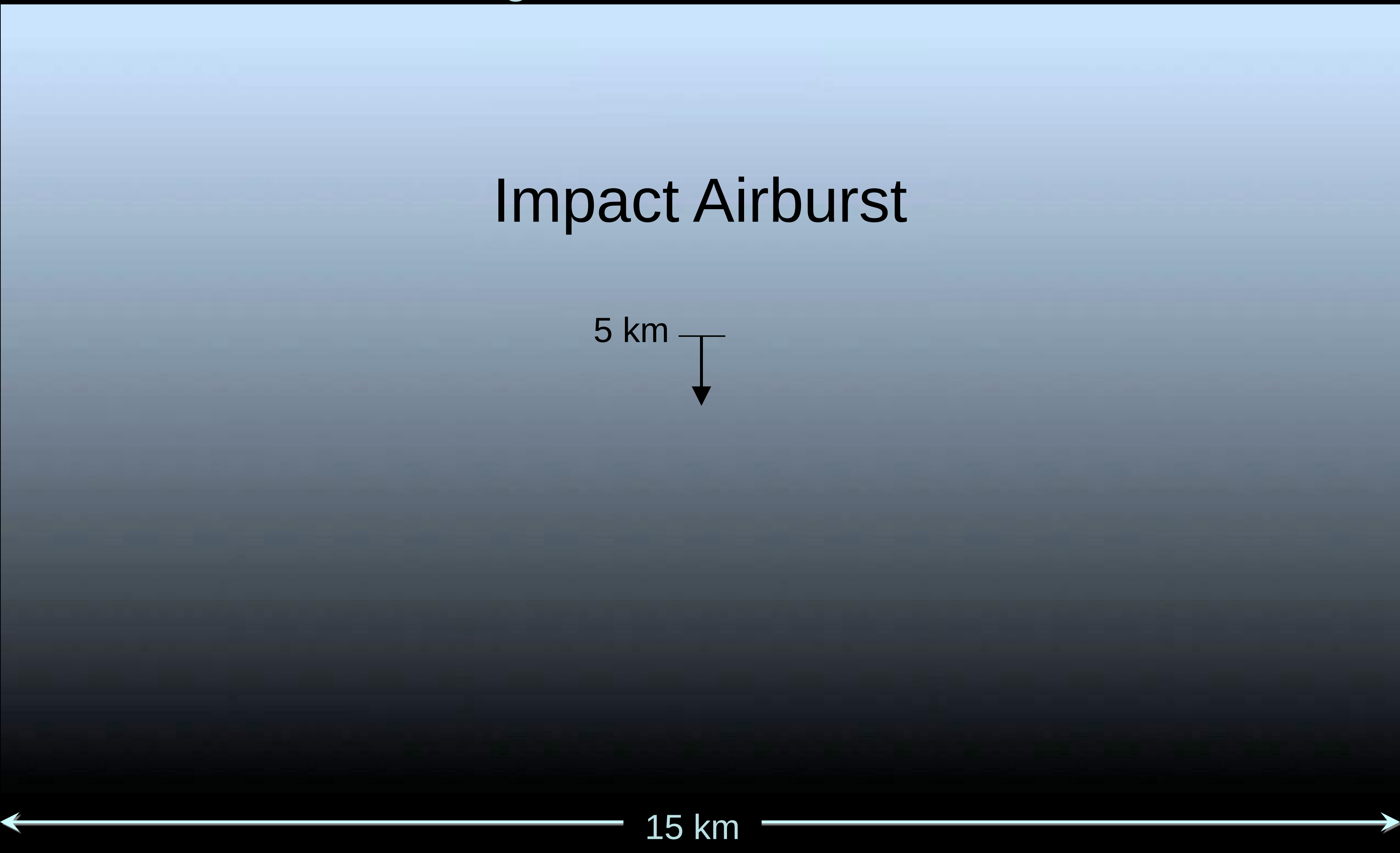
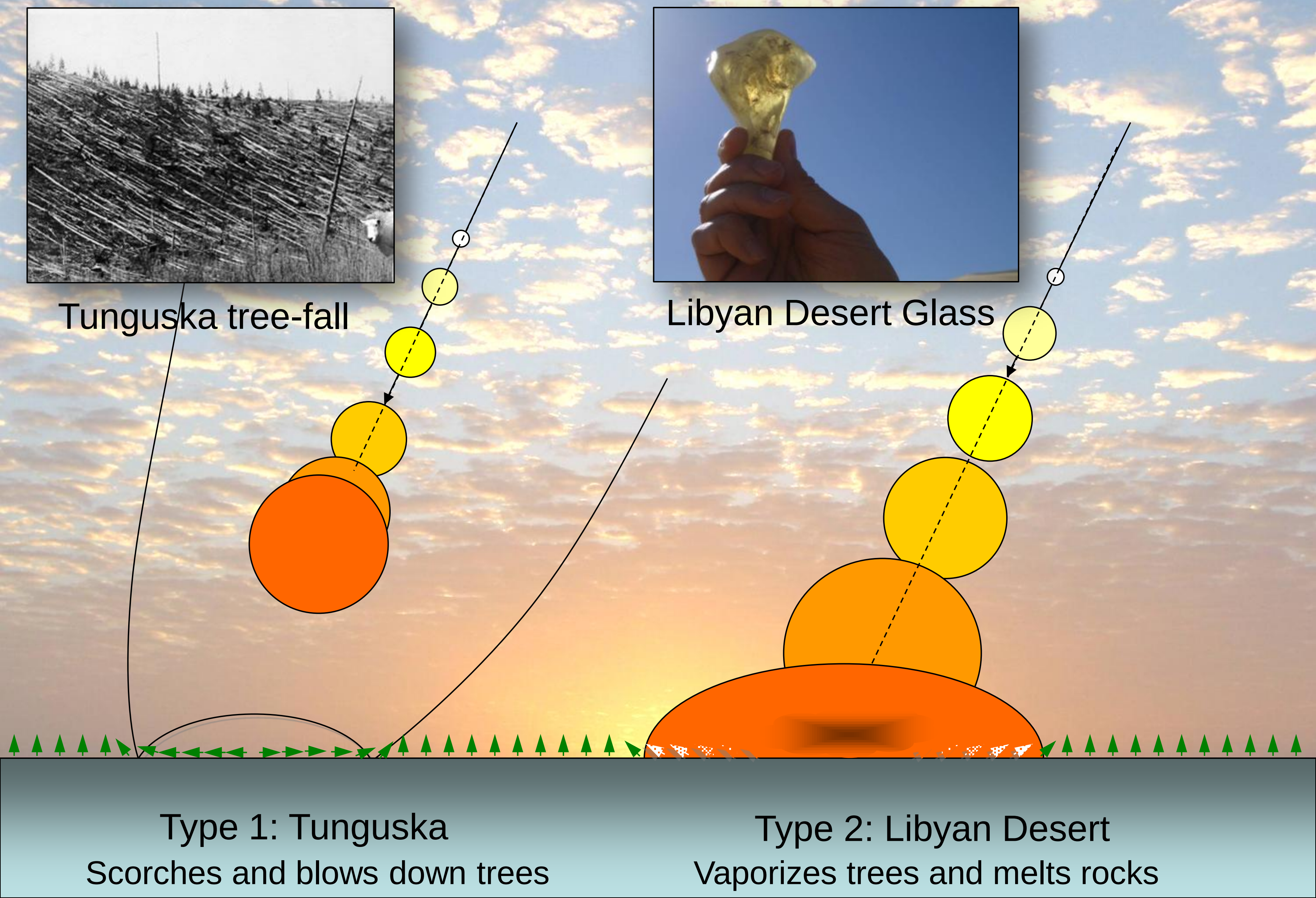


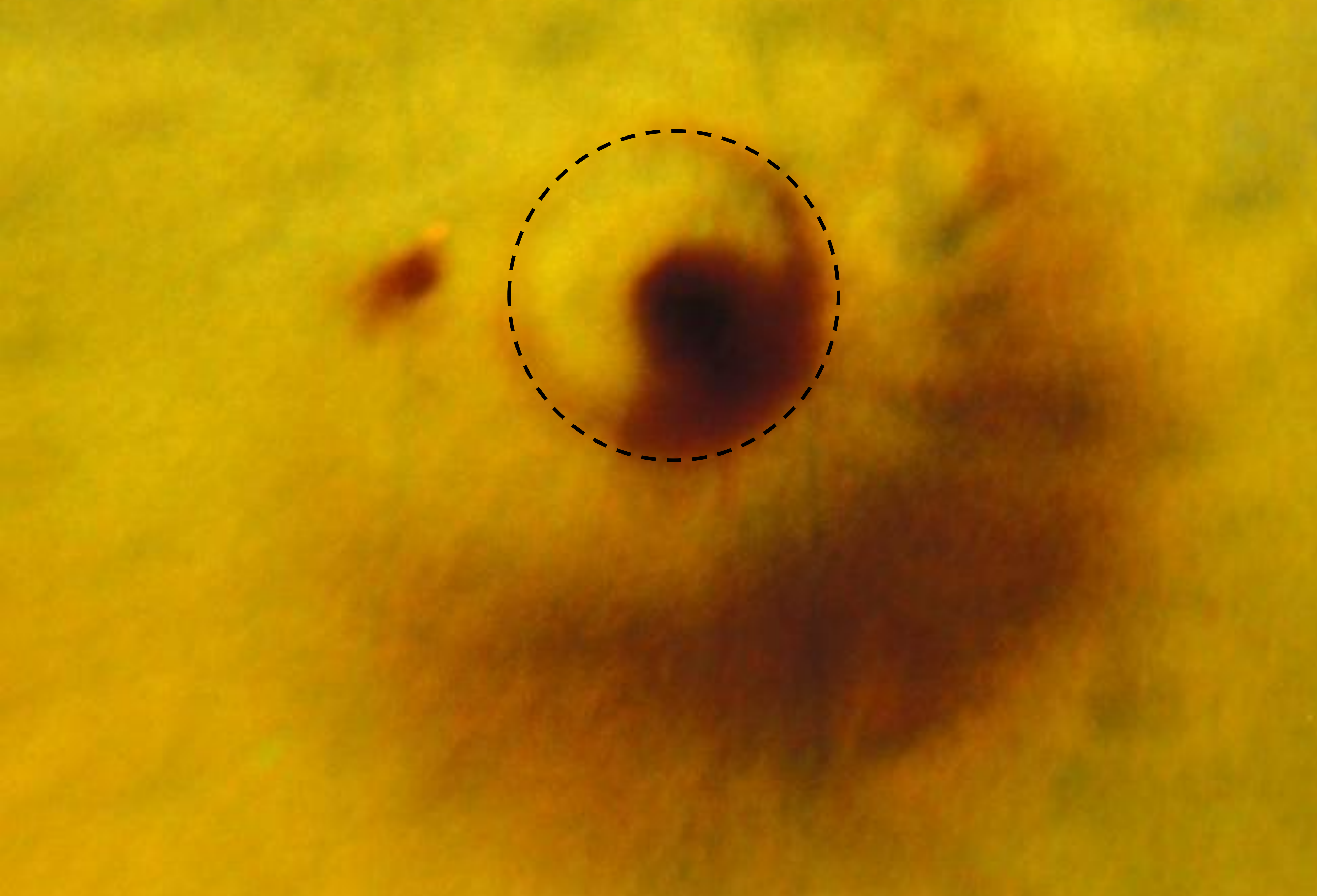
Two types of Low-Altitude Airburst



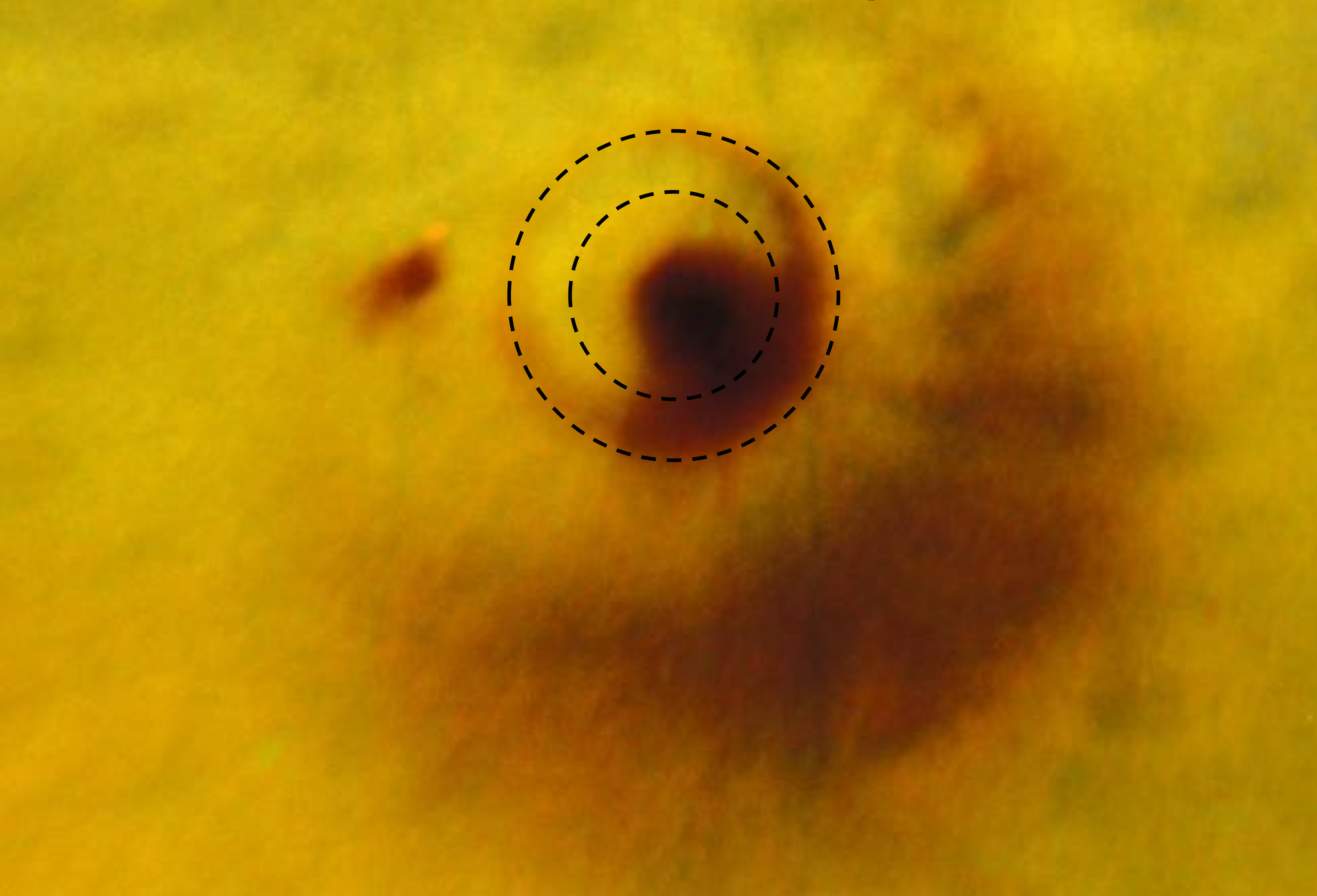
2. Review: Airburst “meteotsunami”

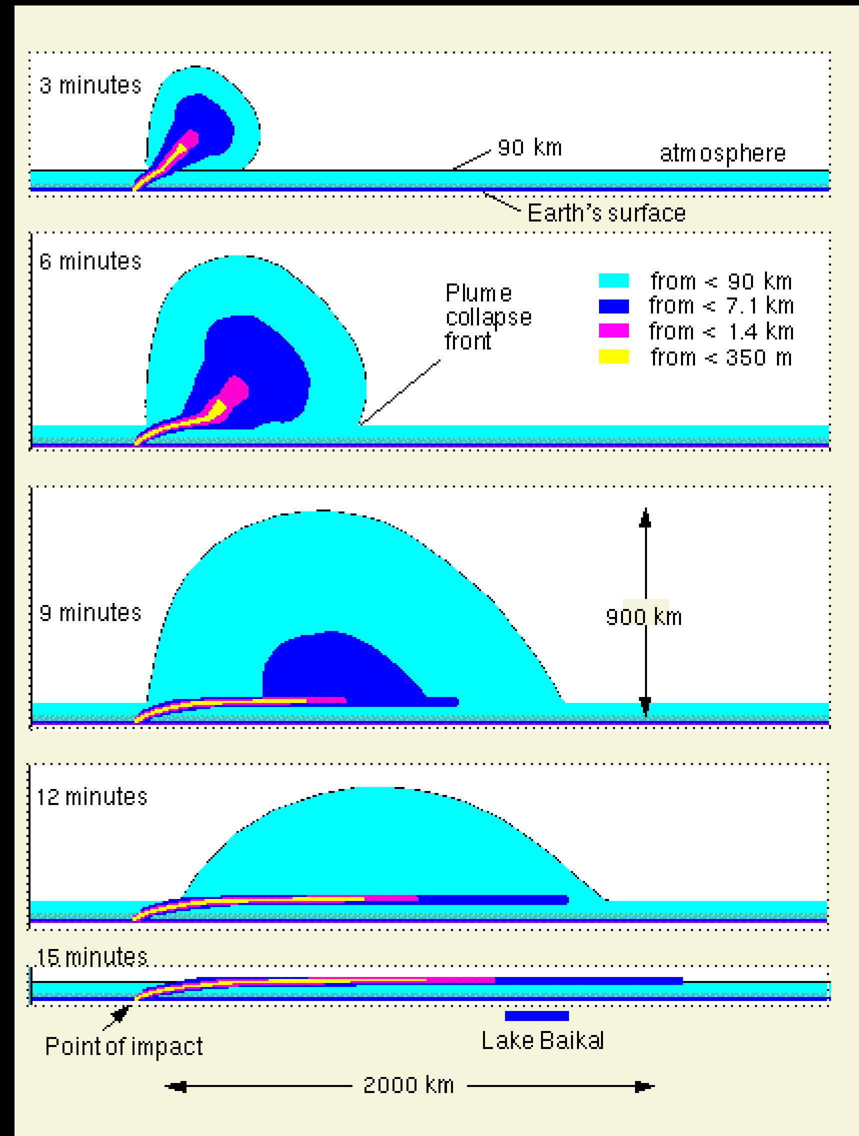
“Tsunami” on Jupiter

“Tsunami” on Jupiter



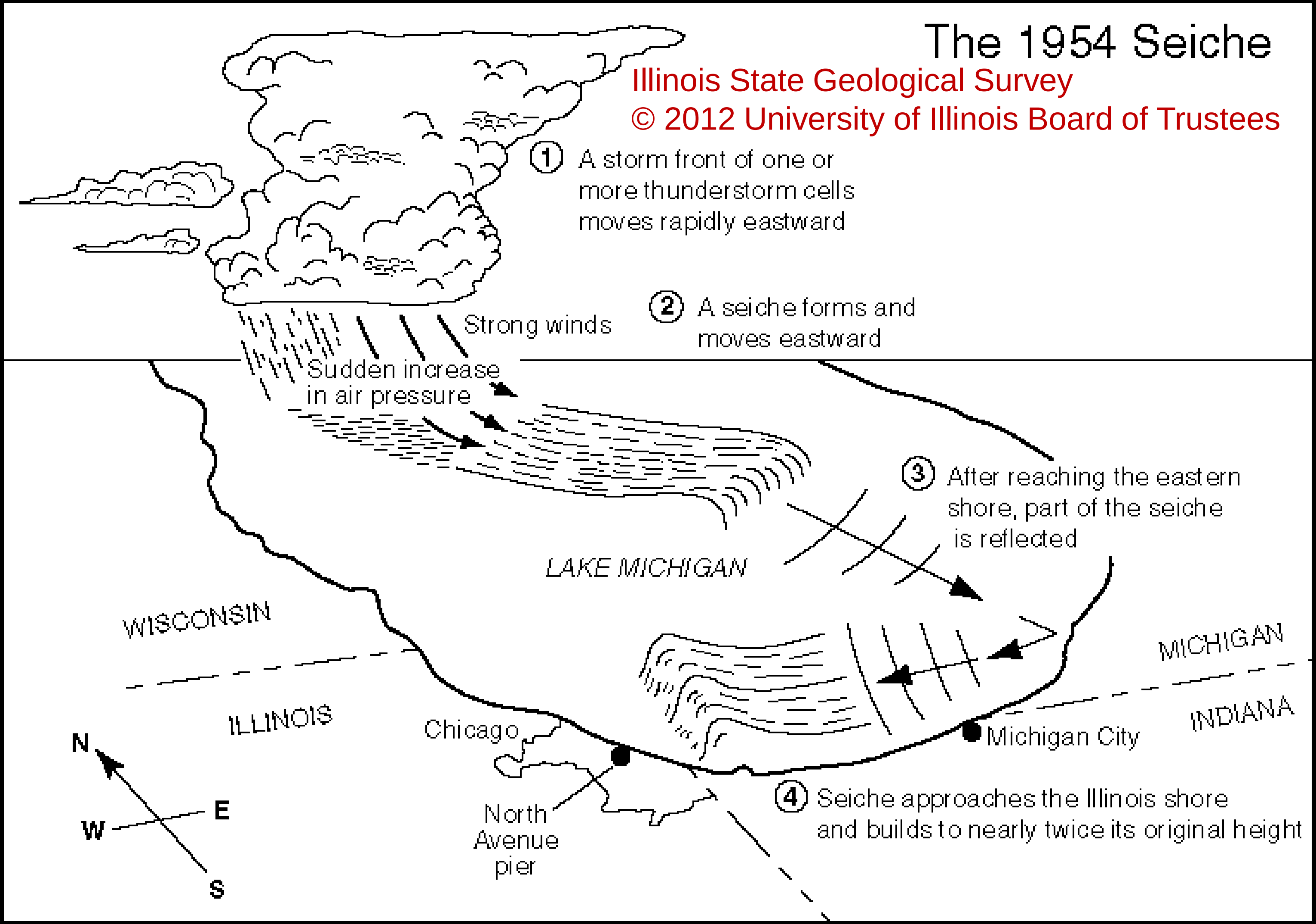
“Tsunami” on Jupiter





Distribution of bright night skies,
June 30 – July 1, 1908
(I.T Zotkin & A.L. Tchijevsky)

Meteotsunami

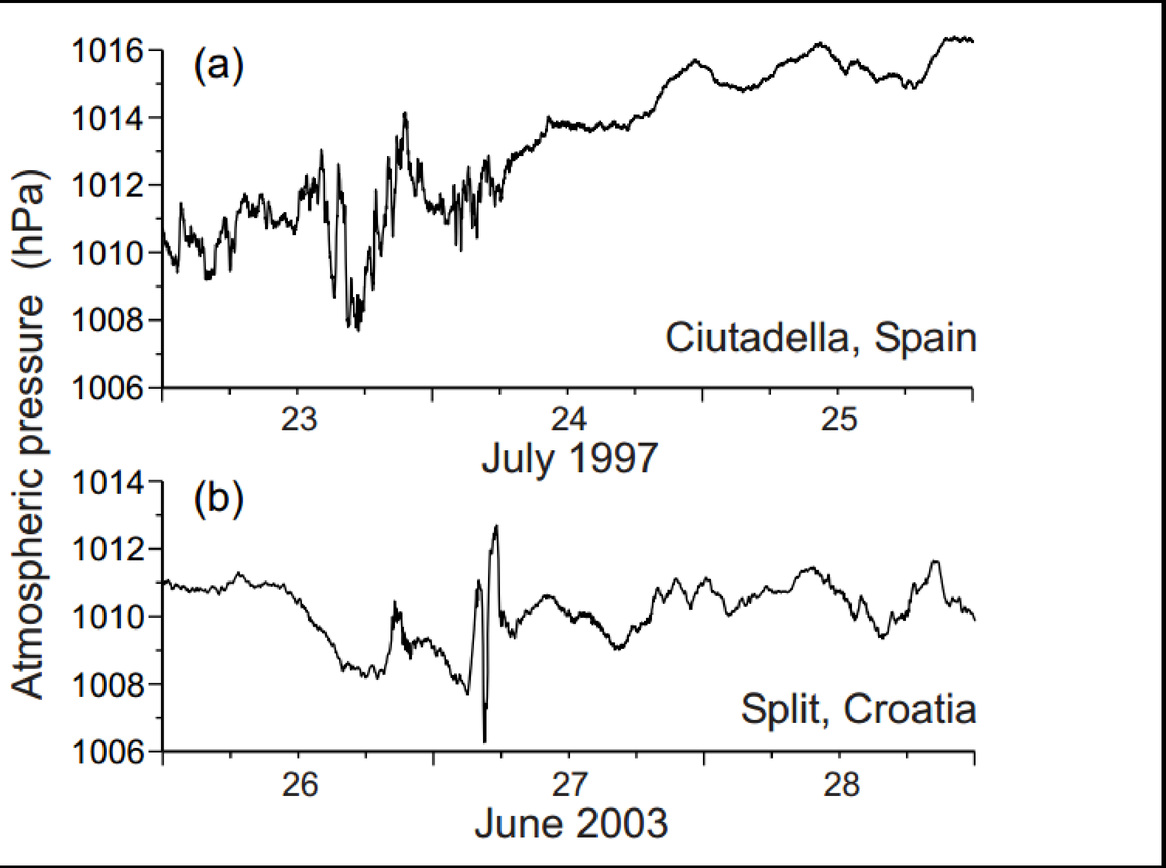


The coast was inundated up to 50 meters inland and unexpectedly swept many fishermen off of the Montrose Harbor piers, killing seven.

Rissaga a Ciutadella (2006)

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

"…even during the strongest events, the atmospheric pressure oscillations at these scales typically reach only a few hPa that correspond only to a few cm of sea level change."



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3 Mton Tunguska-scale impact

Plume impulse = $7 \cdot 10^{18}$ dyne-s within 1 minute
(Boslough & Crawford, (1997)

Mean force for 60 s = $1.2 \cdot 10^{17}$ dynes

Area within sound speed of epicenter at 60 s = 1200 km^2

Mean overpressure = 10 mbar = 10 hPa

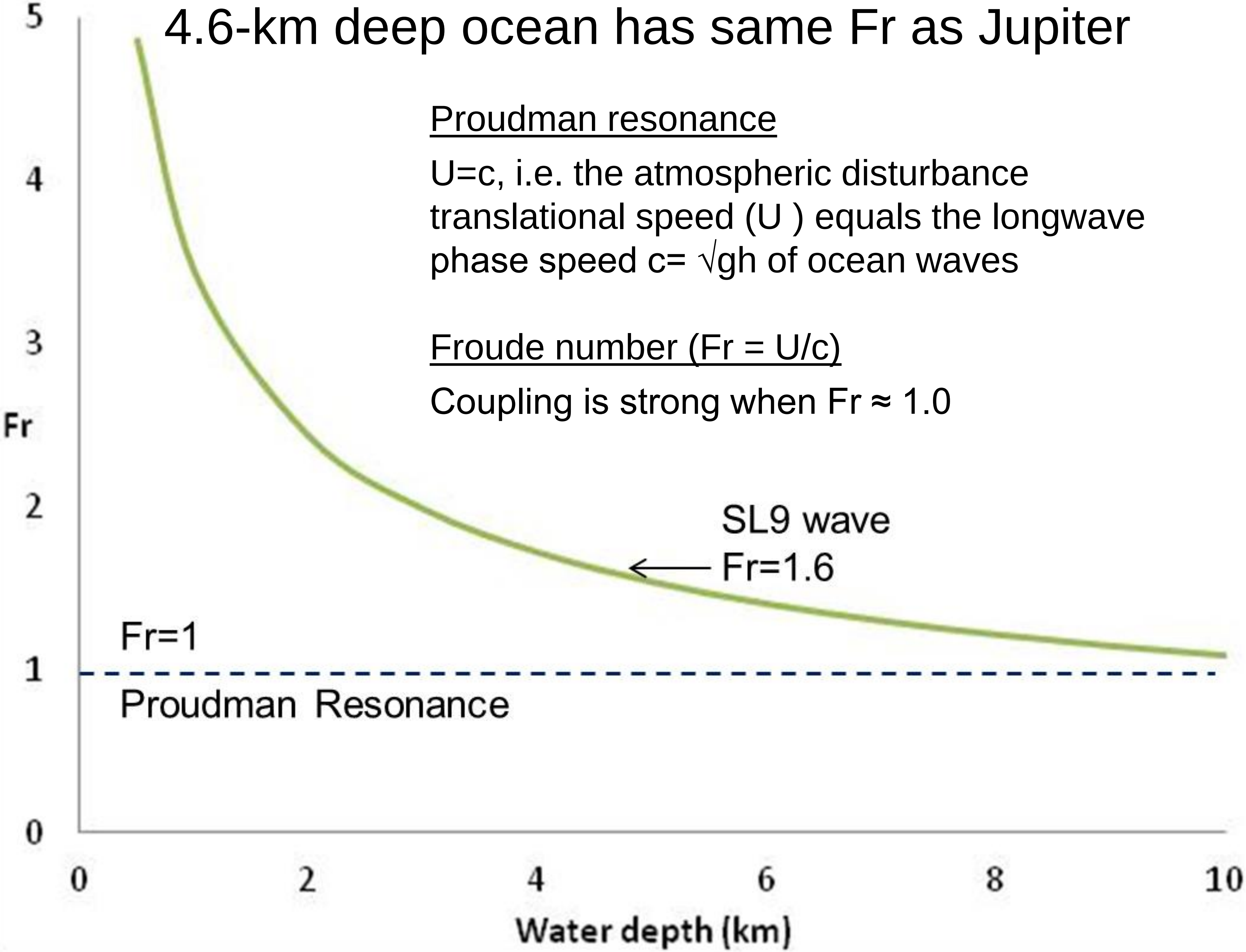
4.6-km deep ocean has same Fr as Jupiter

<ins>Proudman resonance</ins>

U=c, i.e. the atmospheric disturbance translational speed (U) equals the longwave phase speed c= √gh of ocean waves

<ins>Froude number (Fr = U/c)</ins>

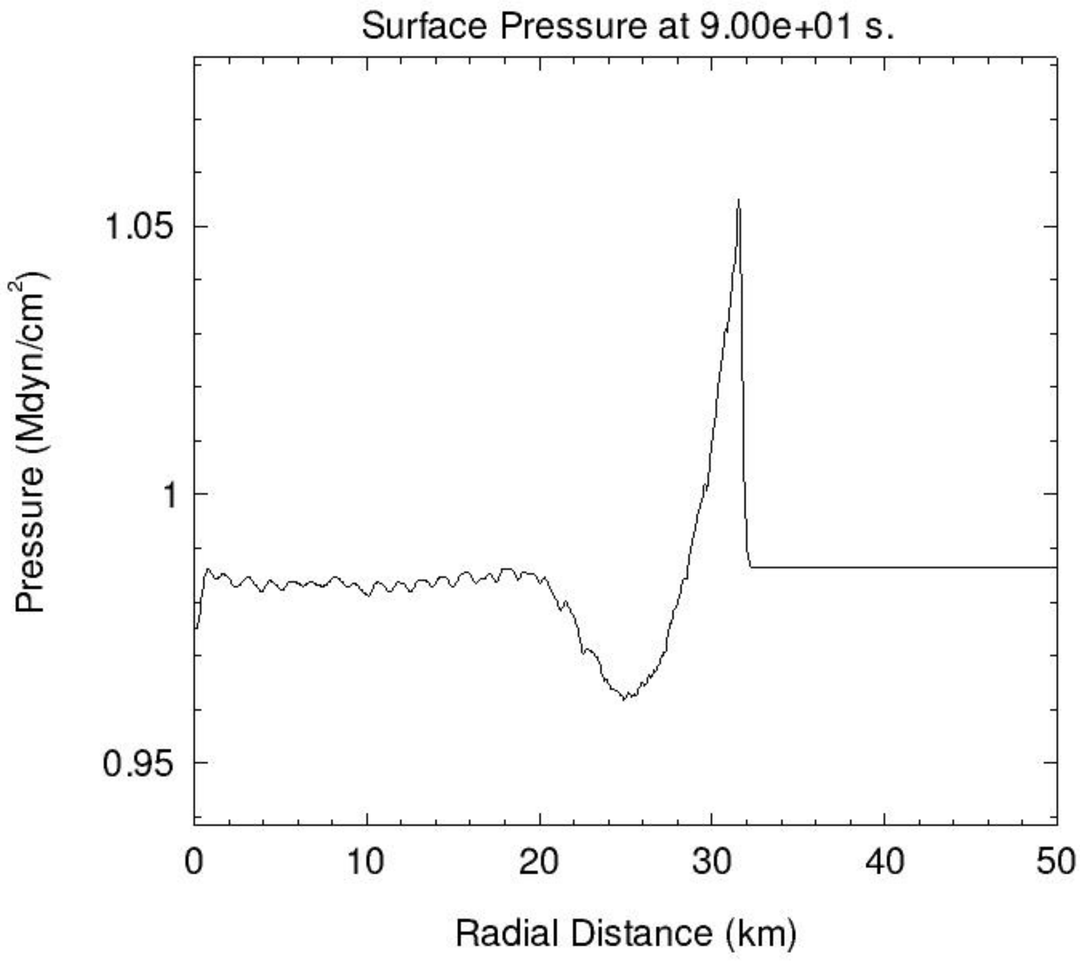
Coupling is strong when Fr ≈ 1.0



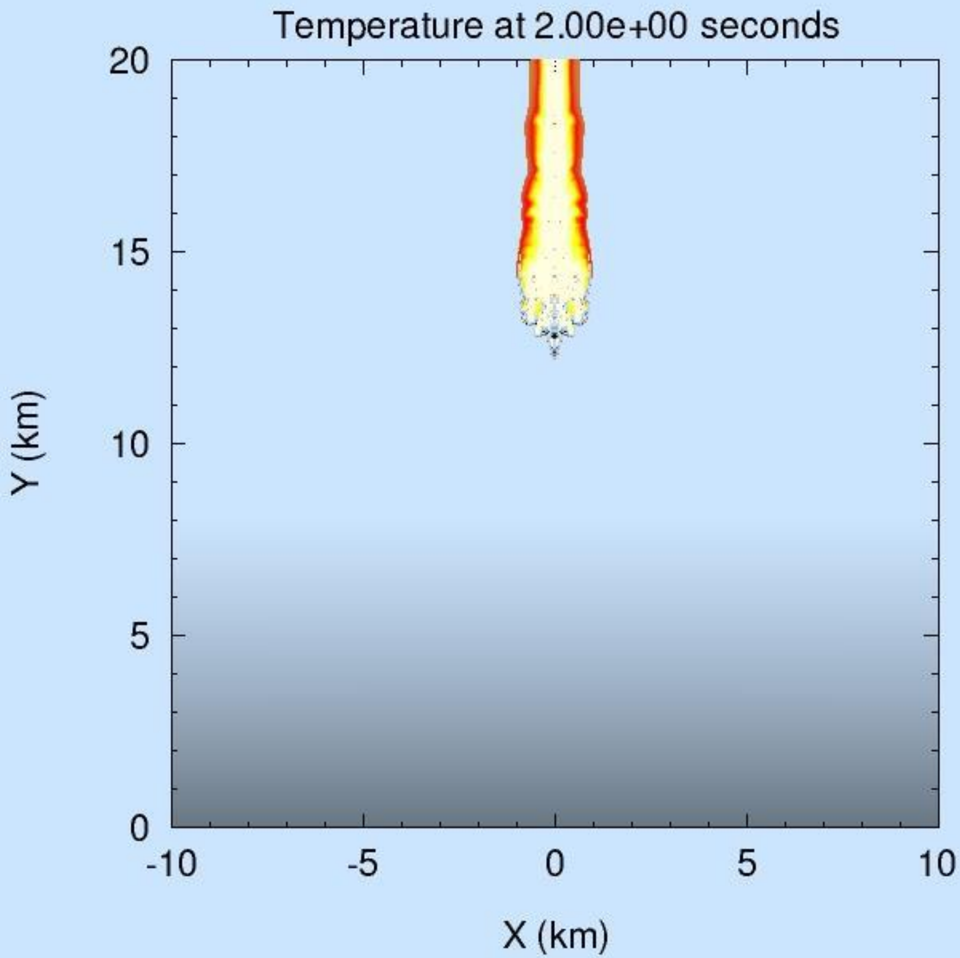
3. Proposed coupling mechanisms

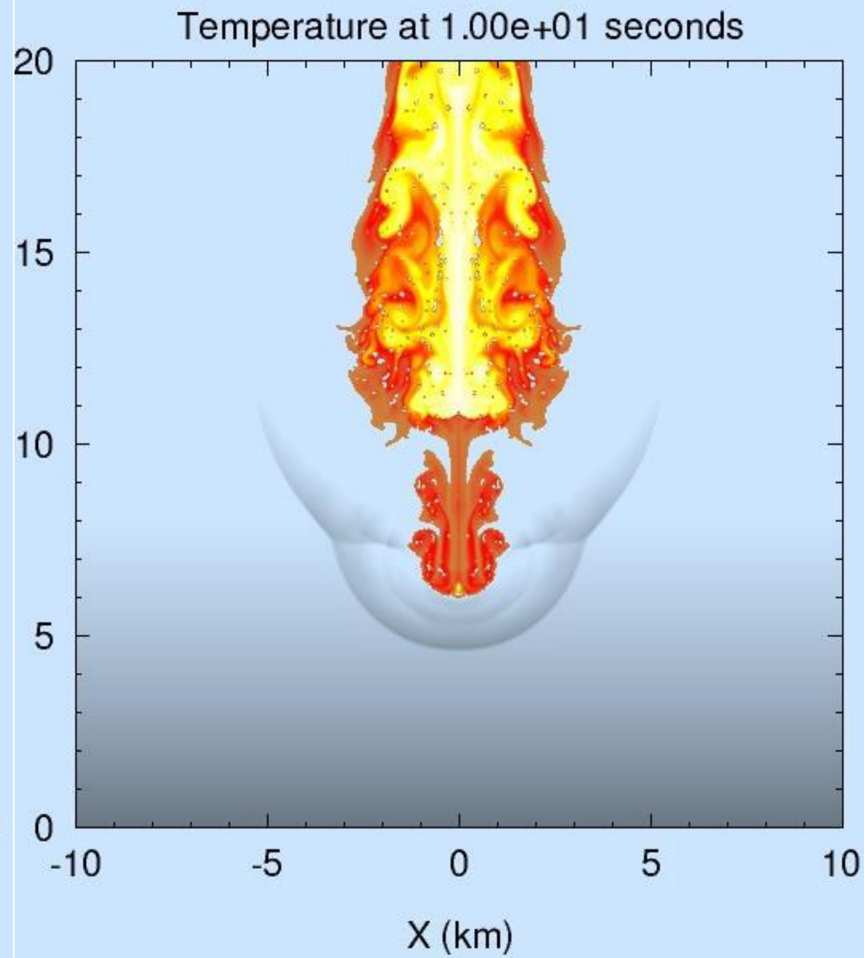
- Blast and rarefaction waves
- Plume ejection and collapse
- Ablation and steam explosion
- Expanding toroidal vortex

Blast and rarefaction waves

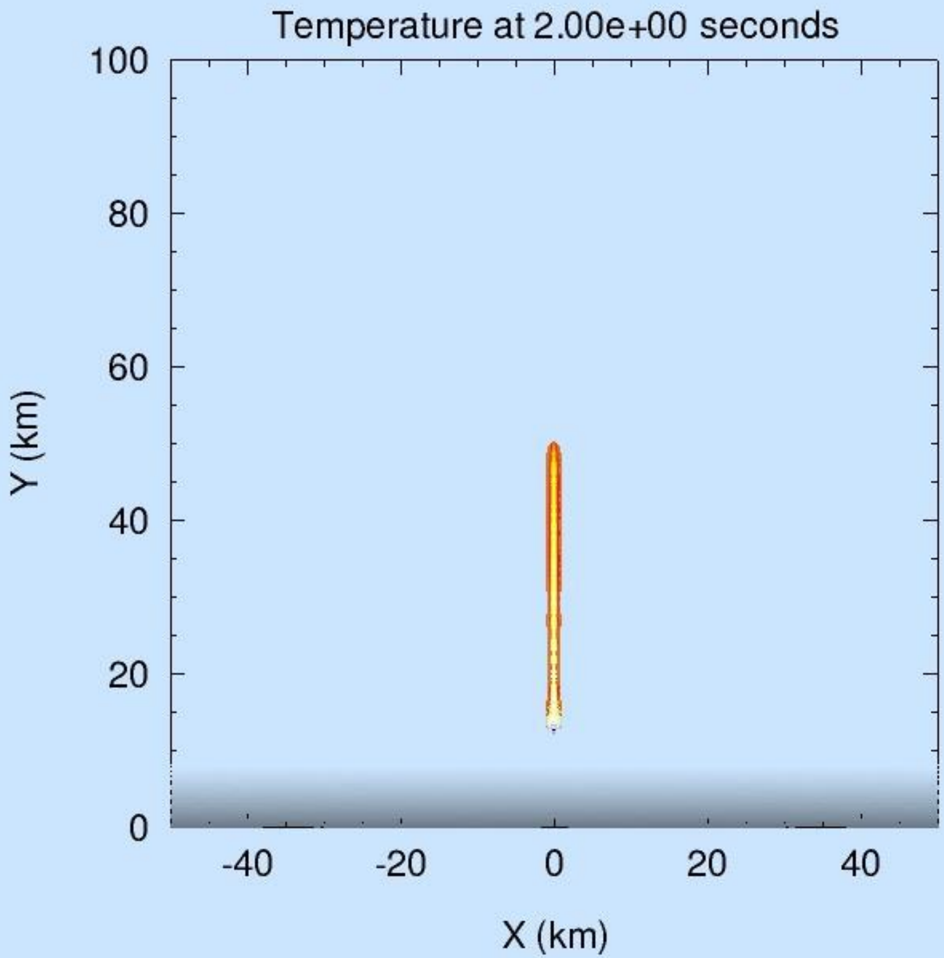


Plume ejection and collapse

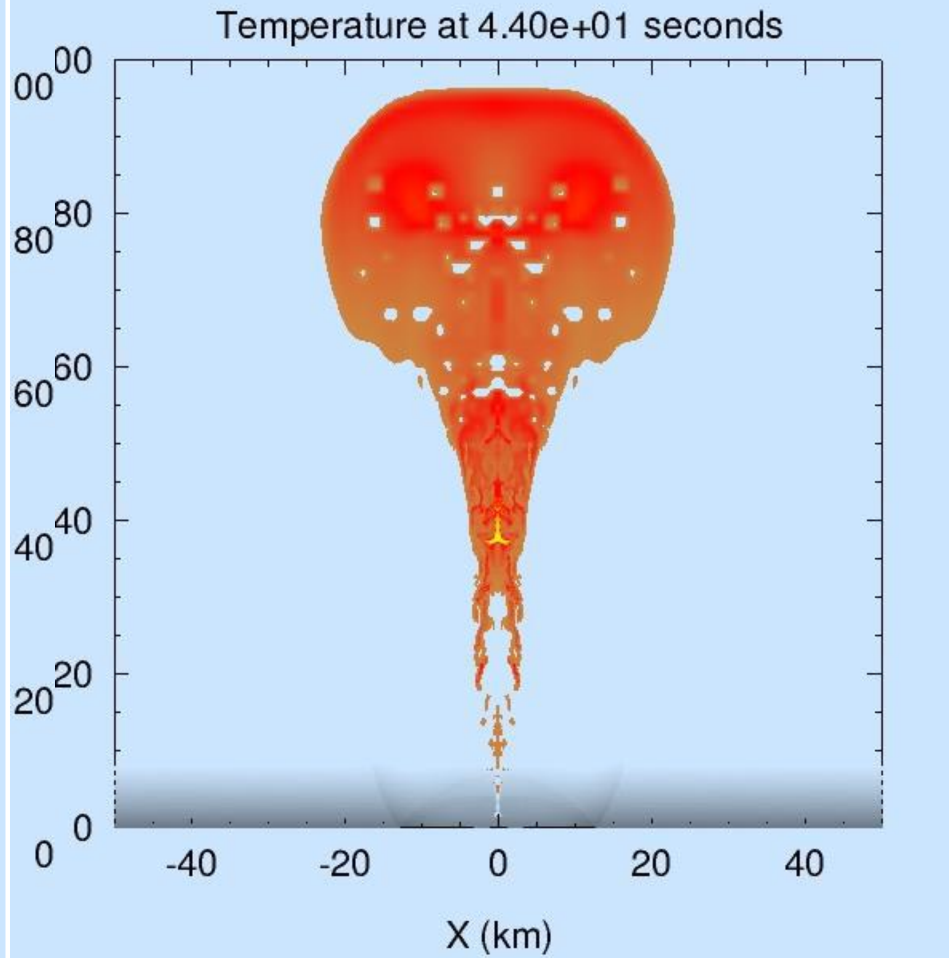

Temperature at 2.00e+00 seconds
Y (km)
X (km)
20
15
10
5
0
-10
-5
0
5
10


Temperature at 1.00e+01 seconds
X (km)
20
15
10
5
0
-10
-5
0
5
10

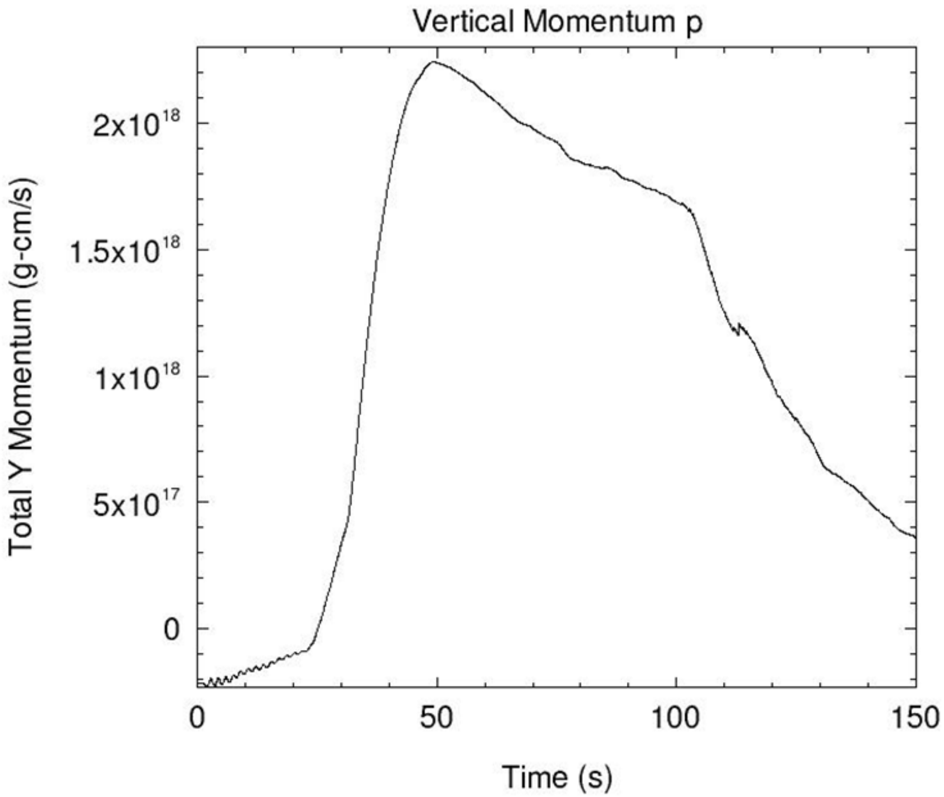
X (km)



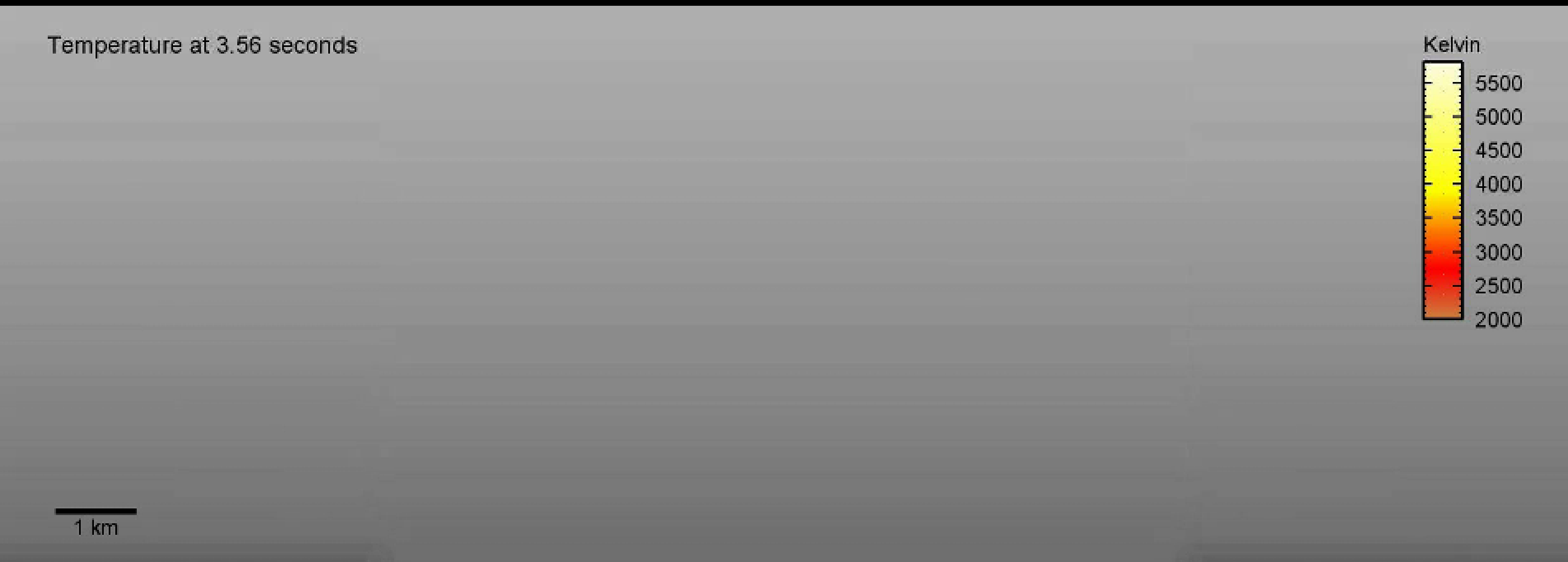
Temperature at 2.00e+00 seconds
Y (km)
100
80
60
40
20
0
-40
-20
0
20
40
X (km)



Temperature at 4.40e+01 seconds
00
80
60
40
20
0
-40
-20
0
20
40
X (km)


Vertical Momentum p
Total Y Momentum (g-cm/s)
2x10^18
1.5x10^18
1x10^18
5x10^17
0
0
50
100
150
Time (s)

Ablation and steam explosion

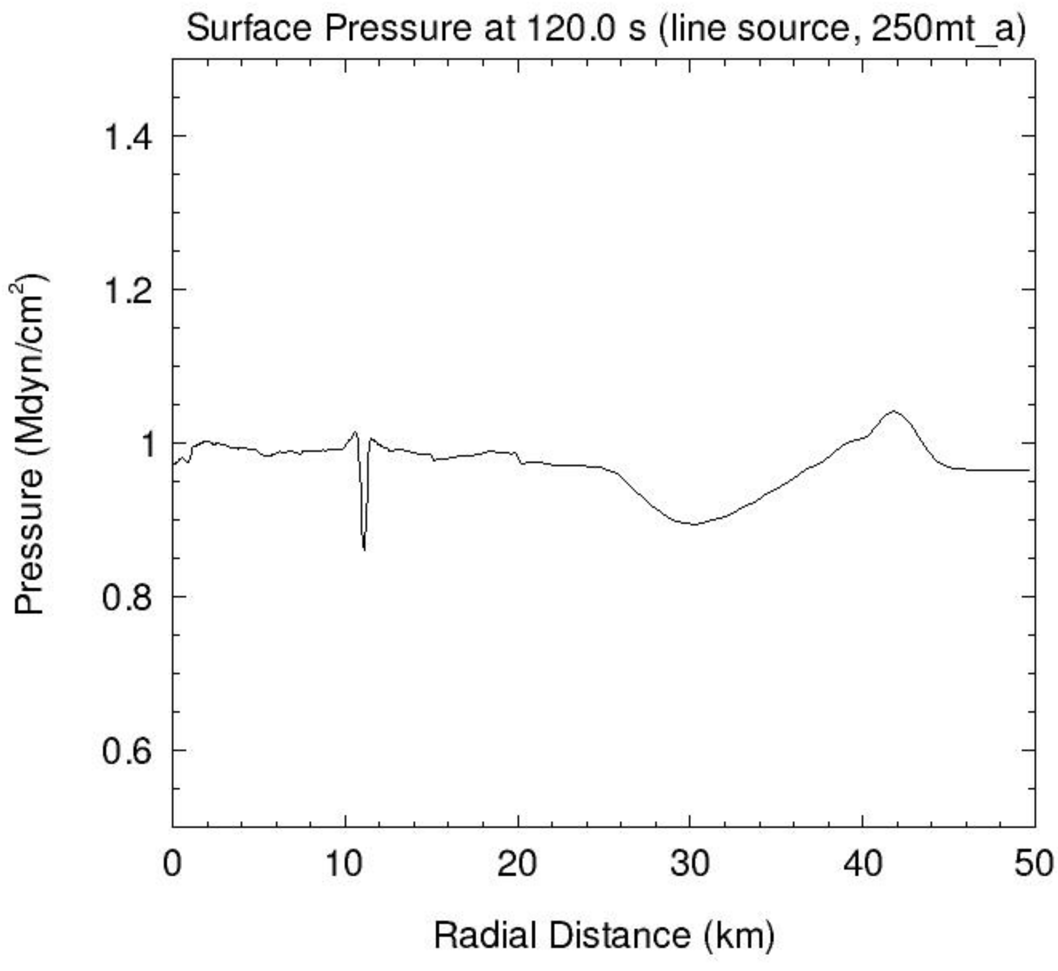

Temperature at 3.56 seconds
Kelvin
5500
5000
4500
4000
3500
3000
2500
2000
1 km

Expanding toroidal vortices

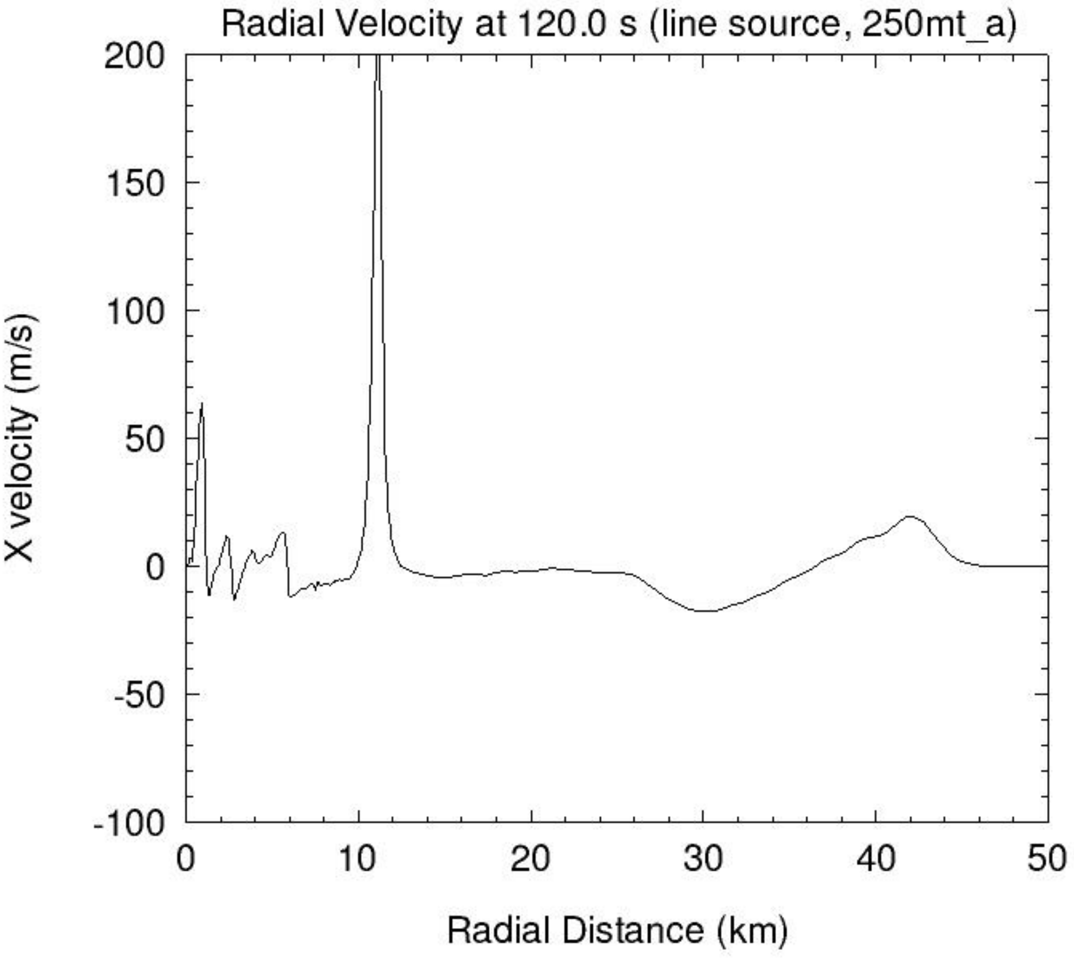
250 megaton line source simulation matrix

- a: 2dc maxl=4 ~62 m 90 deg < 100 km
- b: 2dc maxl=6 ~16 m 90 deg < 100 km
- d: 3dr maxl=4 ~62 m 90 deg < 100 km
- c: 3dr maxl=5 ~31 m 90 deg < 100 km
- f 3dr maxl=4 ~62 m 90 deg only below 26 km 105s
- g 3dr maxl=5 ~31 m 90 deg only below 26 km 120s
- h 3dr maxl=6 ~16 m 90 deg only below 26 km 120s
- e 3dr maxl=4 ~62 m 75 deg 160s below 26 km 105s
- i 3dr maxl=6 ~31 m 75 deg only below 26 km 120s
- j 3dr maxl=6 ~16 m 75 deg only below 26 km 120s

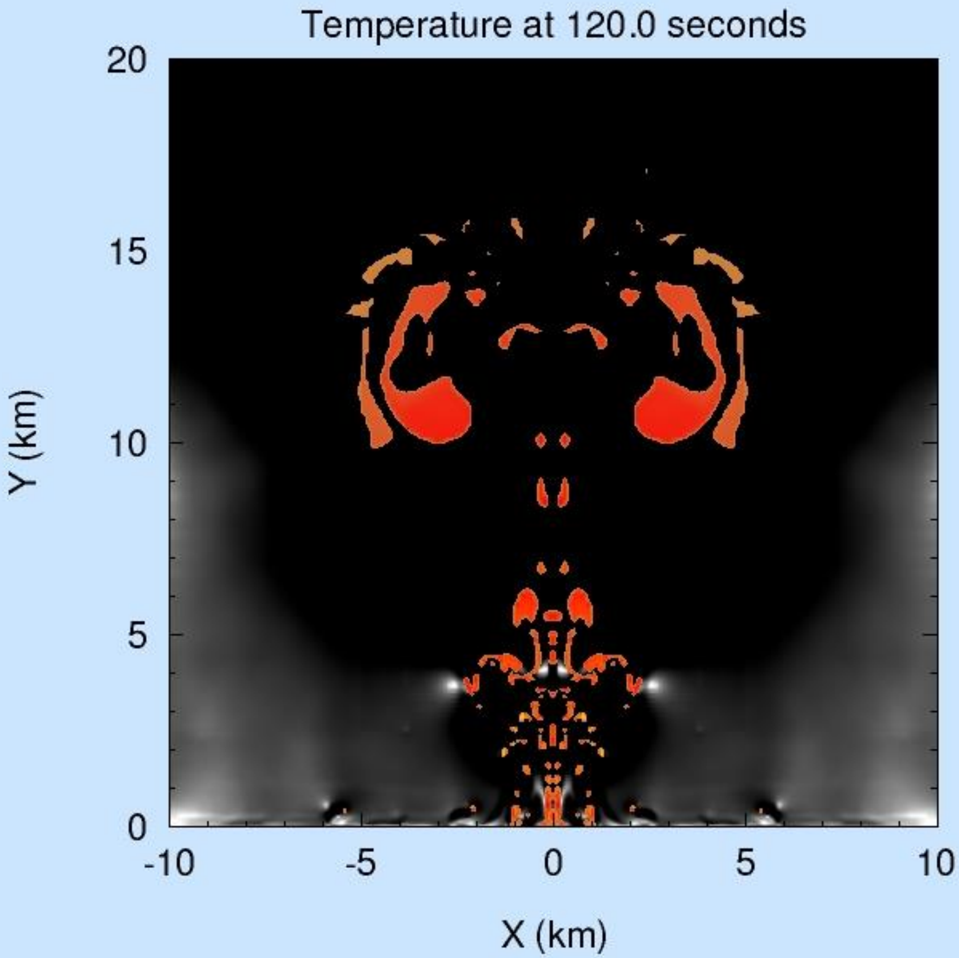
Pressure history movie (a): 250mt 2dc maxl=4 ~62 m 90° Edep<100 km



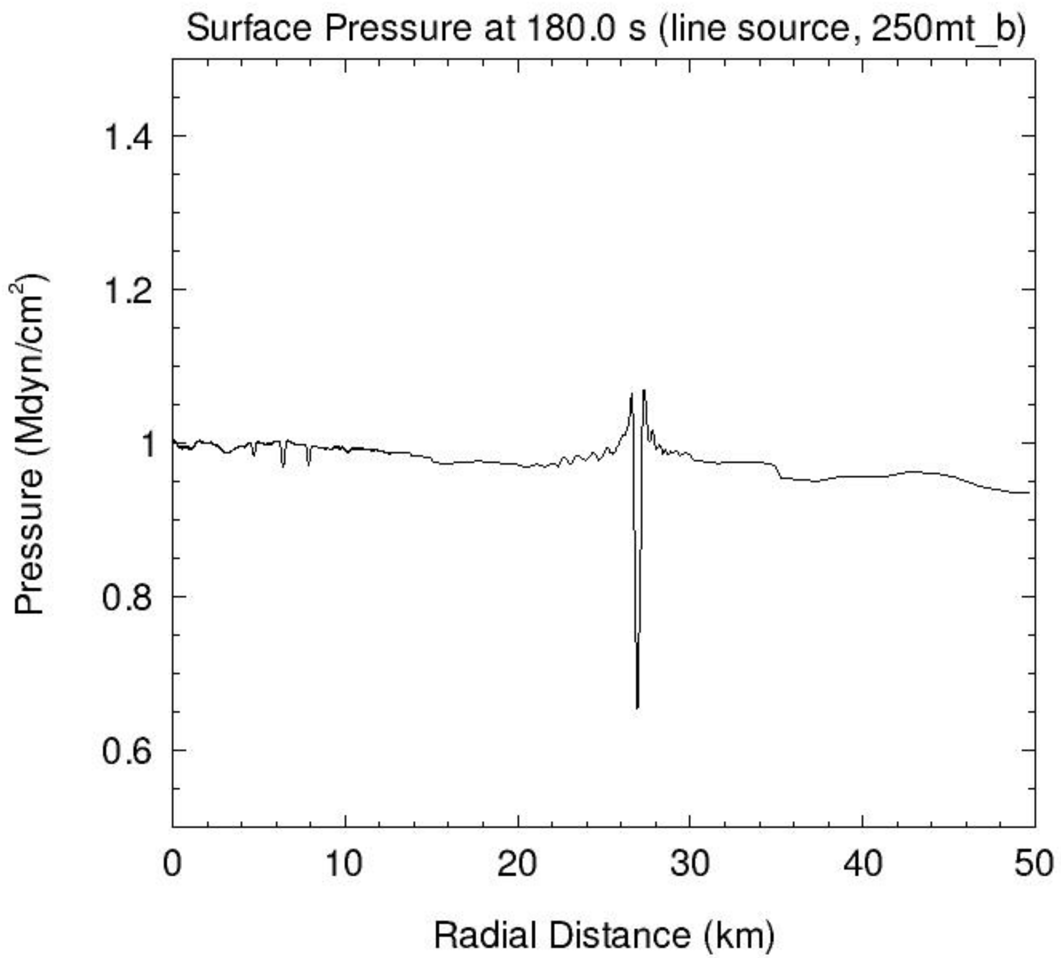
Wind history movie (a): 250mt 2dc maxl=4 ~62 m 90° Edep<100 km



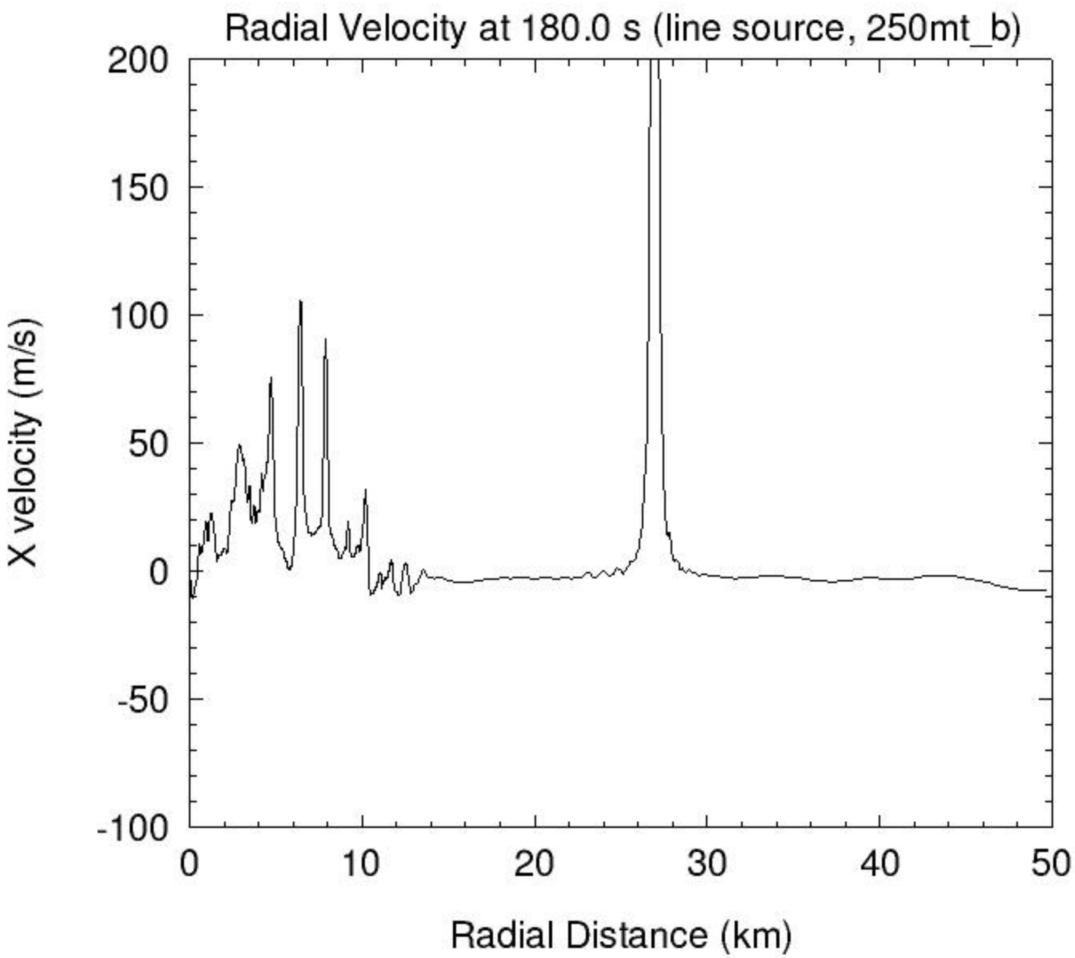
Cross-section movie (a): 250mt 2dc maxl=4 ~62 m 90° Edep<100 km



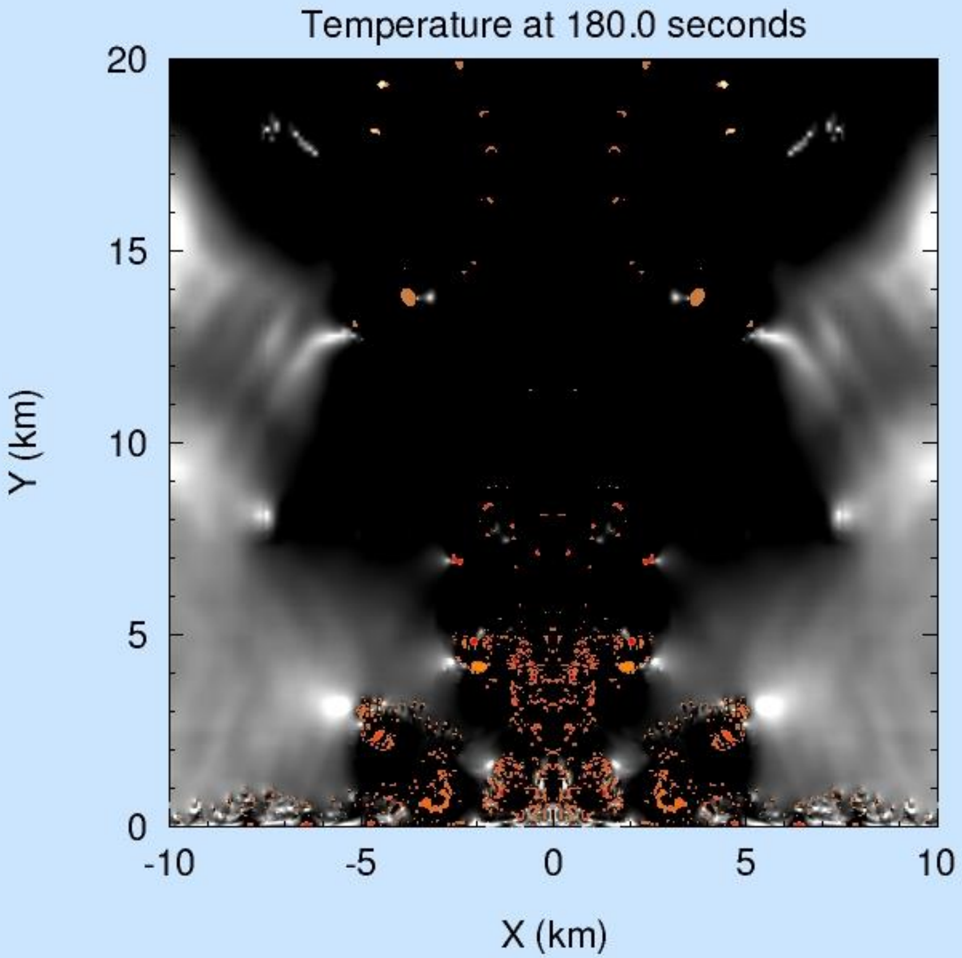
Pressure history movie (b): 250mt 2dc maxl=5 ~31m 90° Edep<100 km



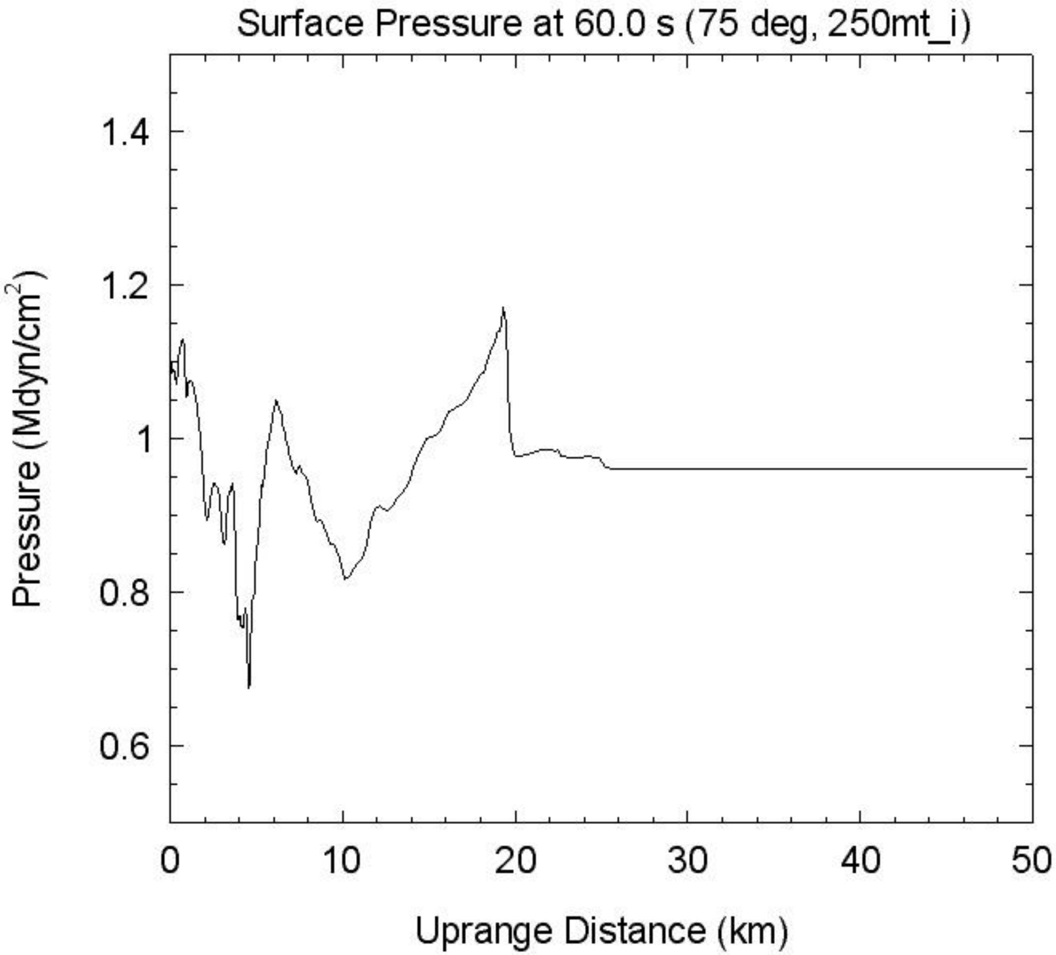
Wind history movie (b): 250mt 2dc maxl=5 ~31m 90° Edep<100 km



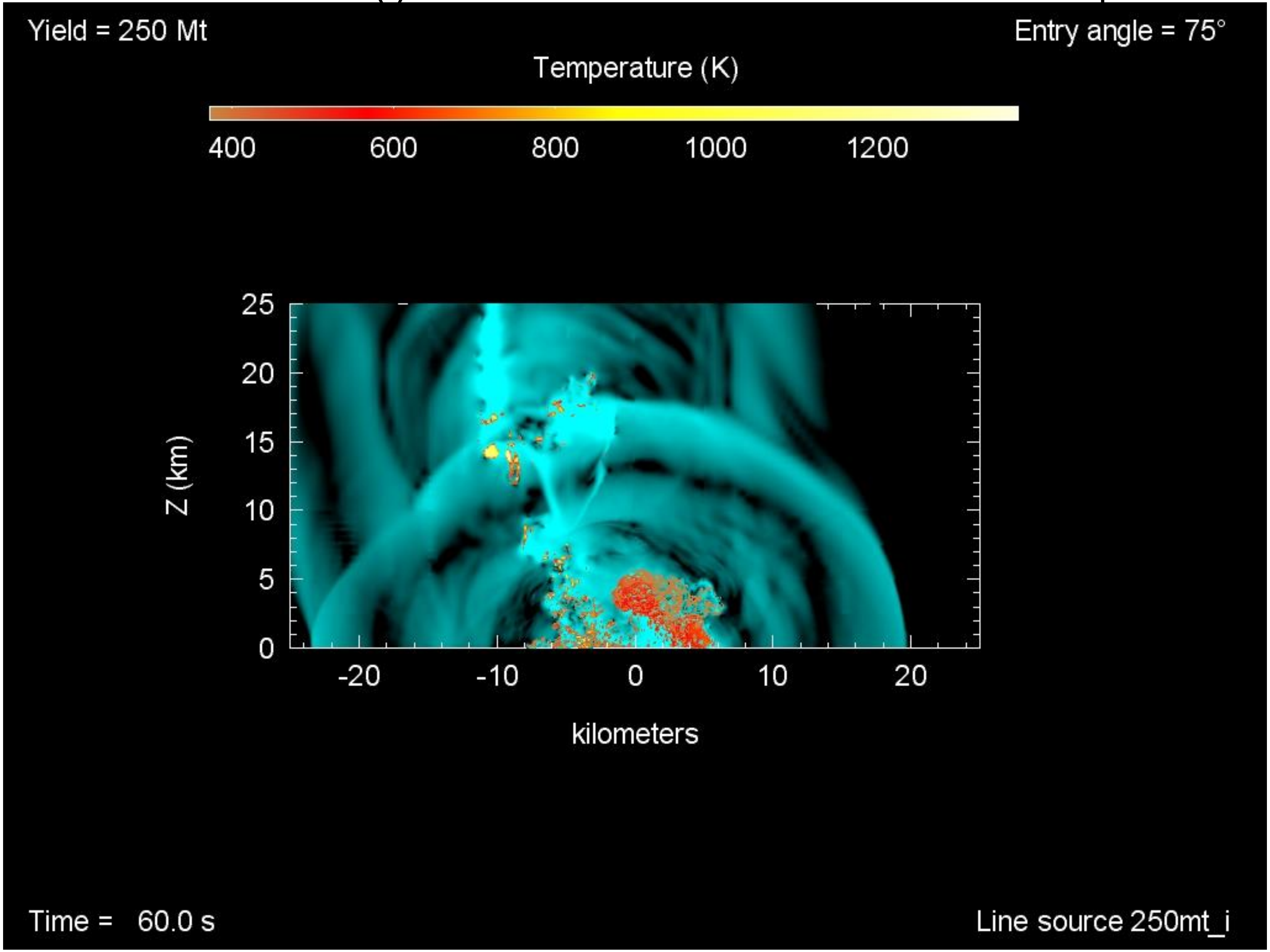
Cross-section movie (b): 250mt 2dc maxl=5 ~31 m 90° Edep<100 km



Pressure history movie (i): 250mt 2dc maxl=5 ~31 m 75° Edep<26 km



Cross-section movie (i): 250mt 2dc maxl=5 ~31 m 75° Edep<26 km



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

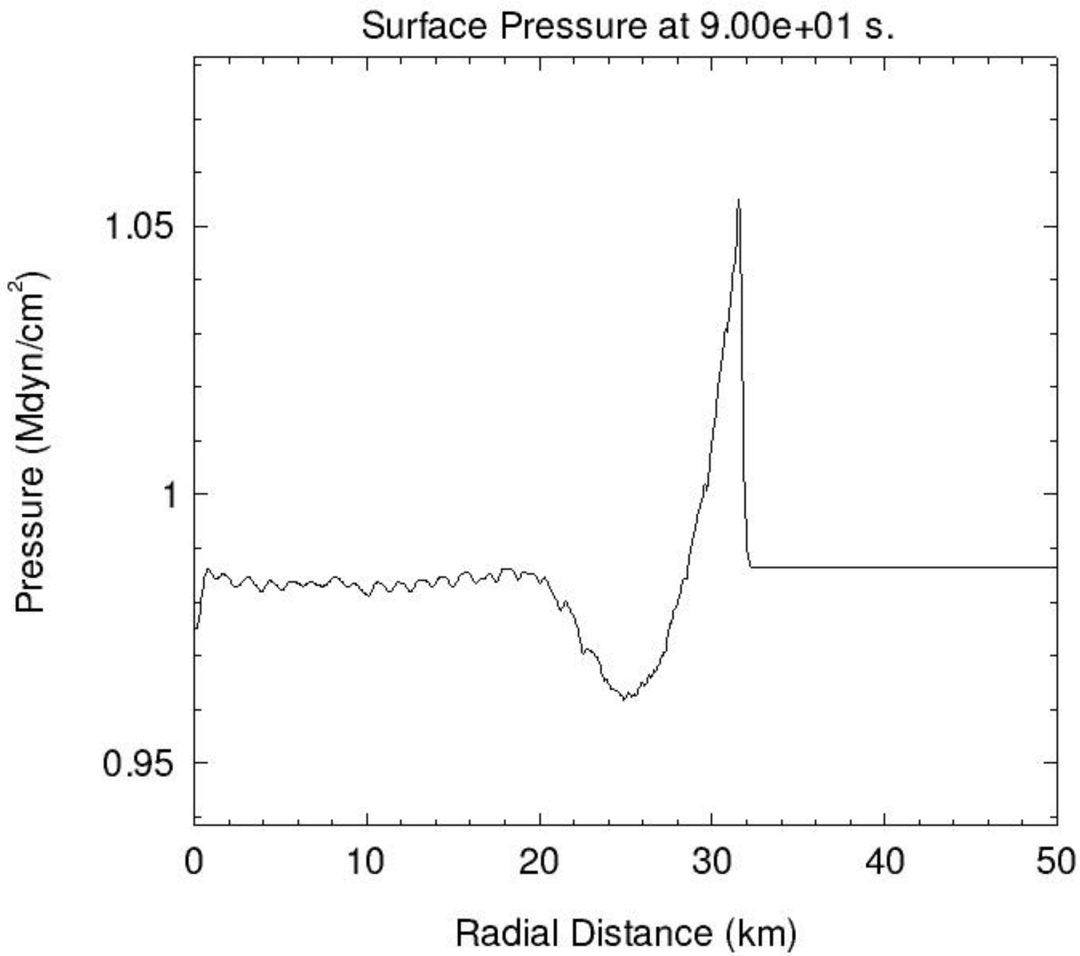
5. Coordinated tasks

- Ancillary questions: boundary conditions & resolution
- Static point source (5,100,250 Mt)
- Vertical line source (5,100,250 Mt)
- Inclined line source (2017 PDC scenario, Japan Trench)

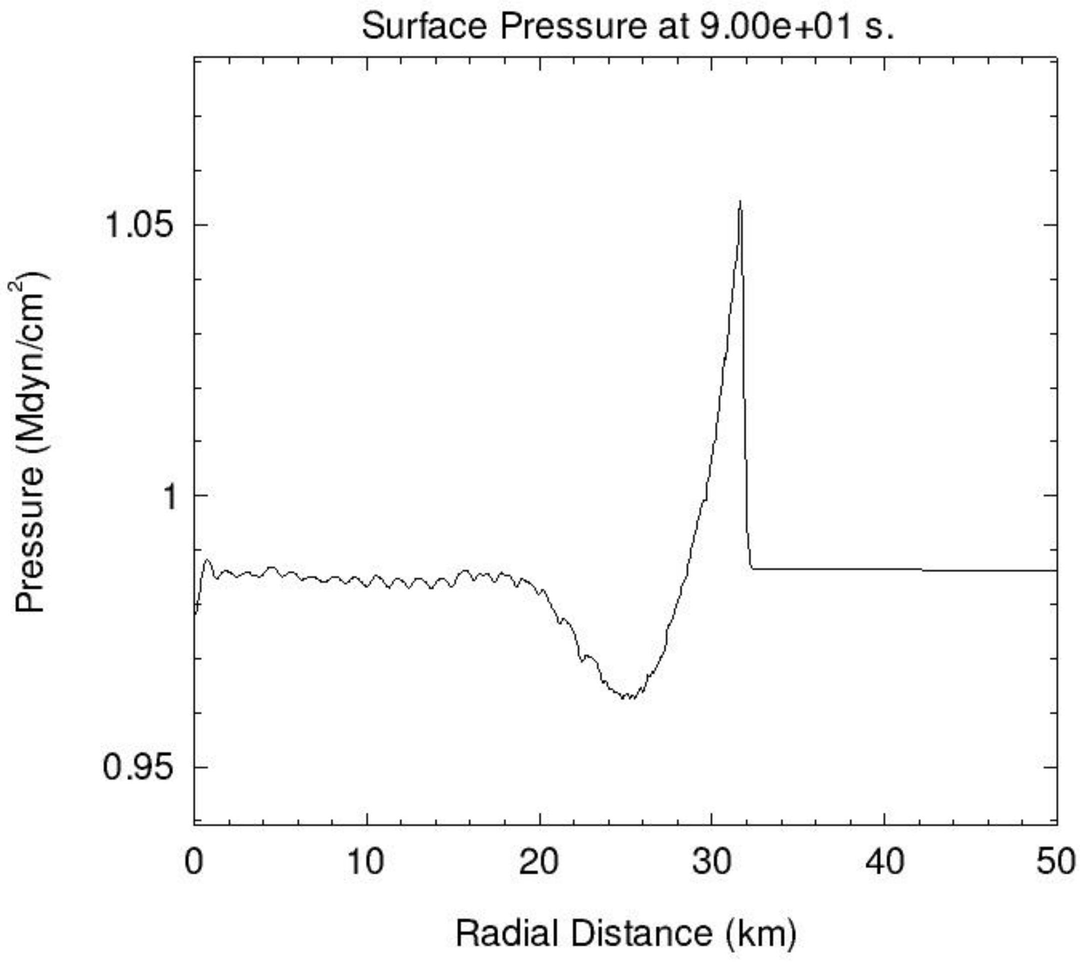
Ancillary questions:

1) Can surface be modeled as reflective boundary?
2) What resolution is sufficient for airburst sim?

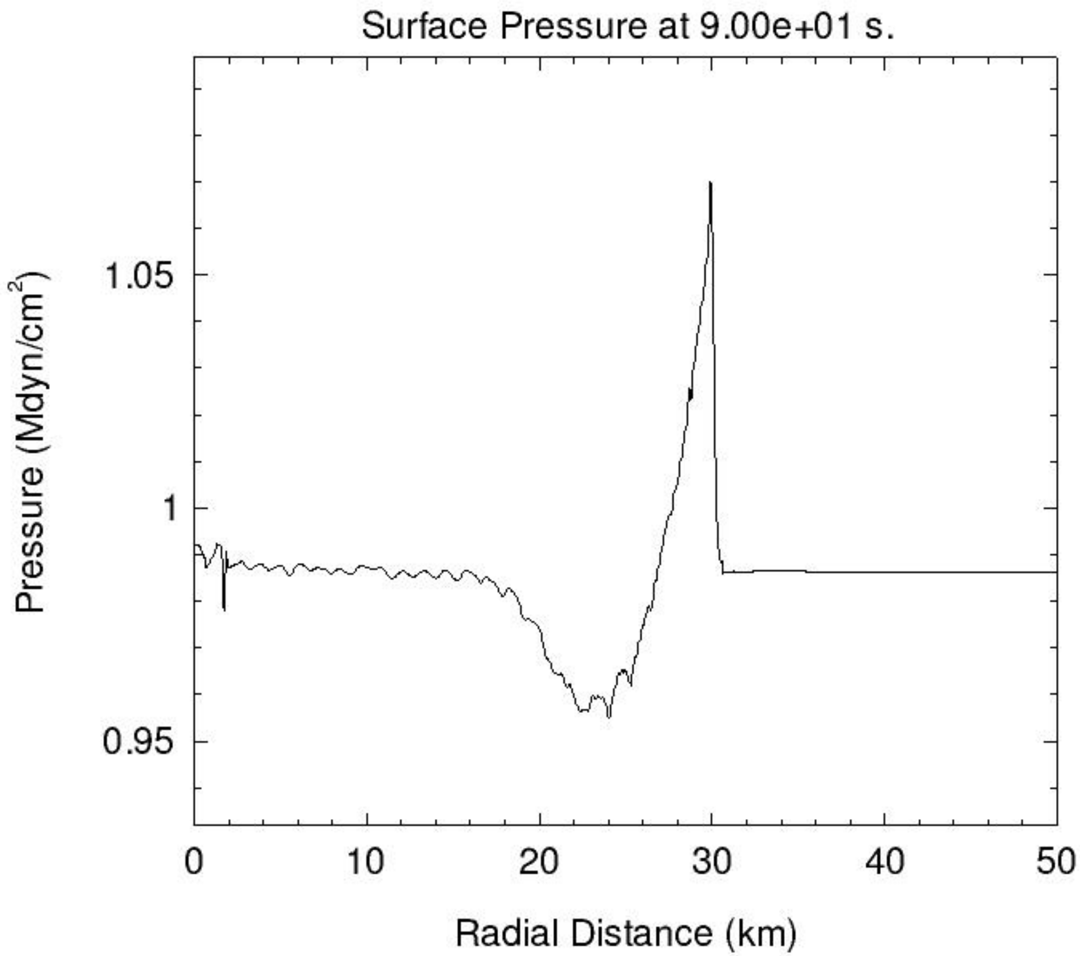
Over reflecting bc, 8 meter resolution



Over reflecting bc, 32 meter resolution



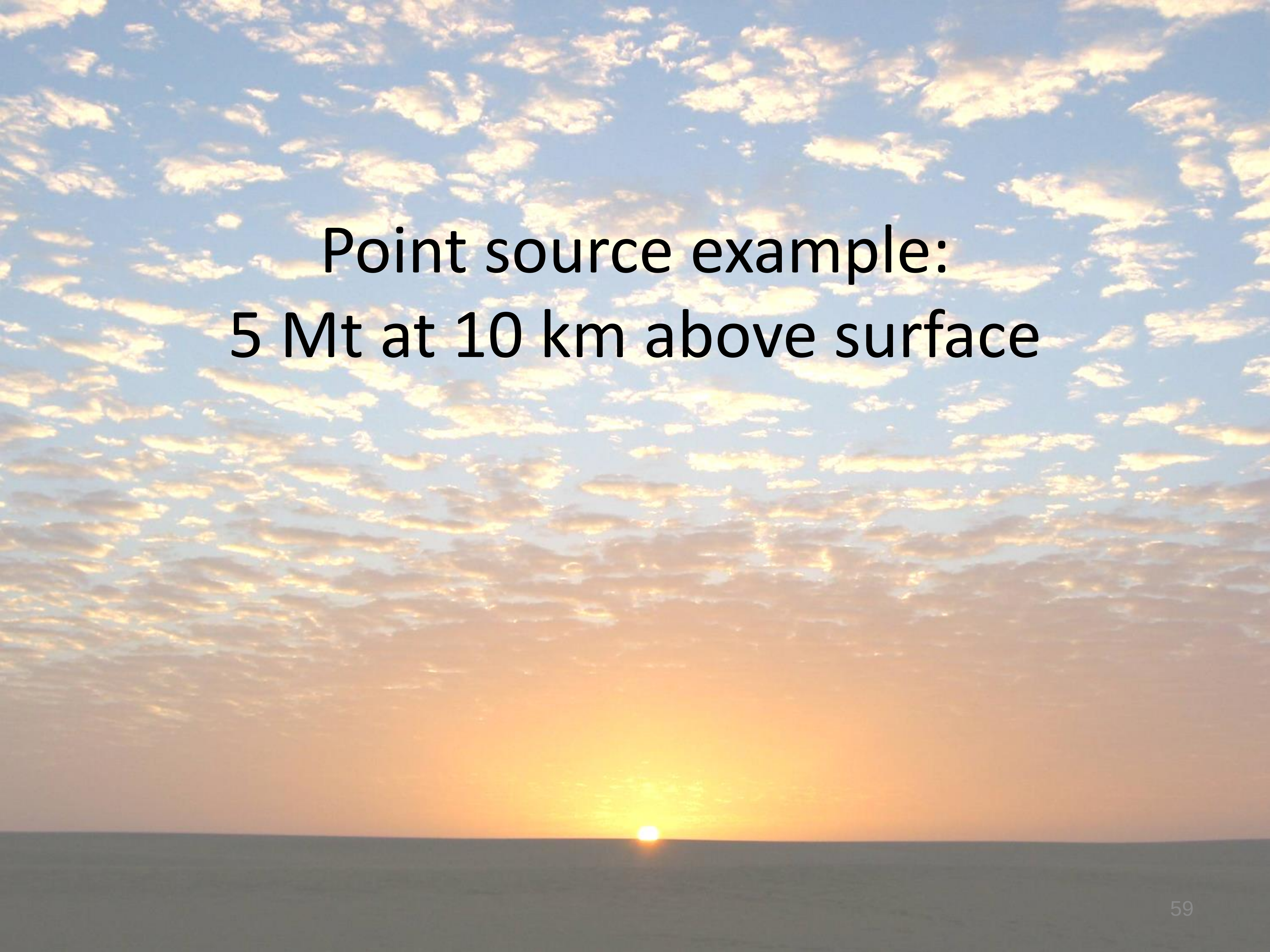
Over water, 32 meter resolution



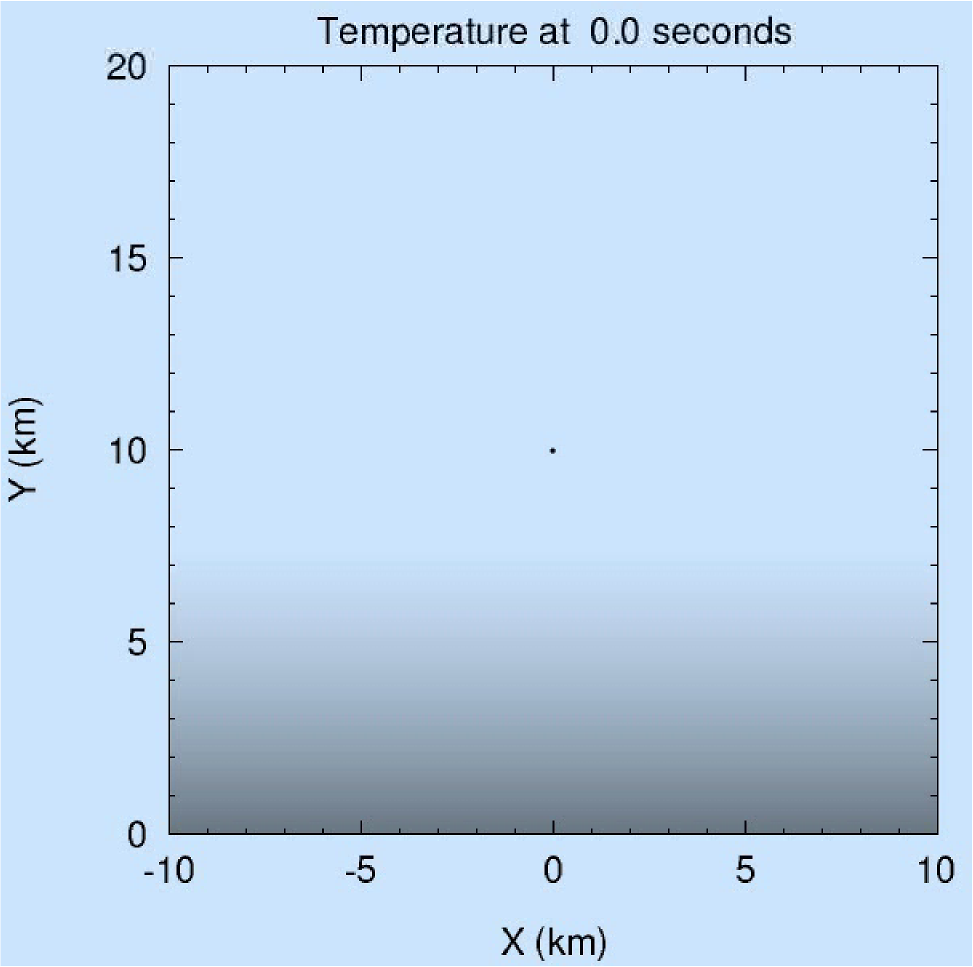
Conclusion:
For high-altitude "type 1" airbursts, reflecting boundary is preferable because…

1) Simulations are easier to set up (fewer things to go wrong that need troubleshooting).
2) They run faster (not much is happening in the water but it makes the time step smaller and increases the domain size.
3) For present purposes, the pressure difference does not seem significant and the shape of the wave is the same.
4) For cross-code comparisons, there are fewer ways to be inconsistent in assumptions (no H_2O equation of state, ocean temperature profile, etc. is needed).

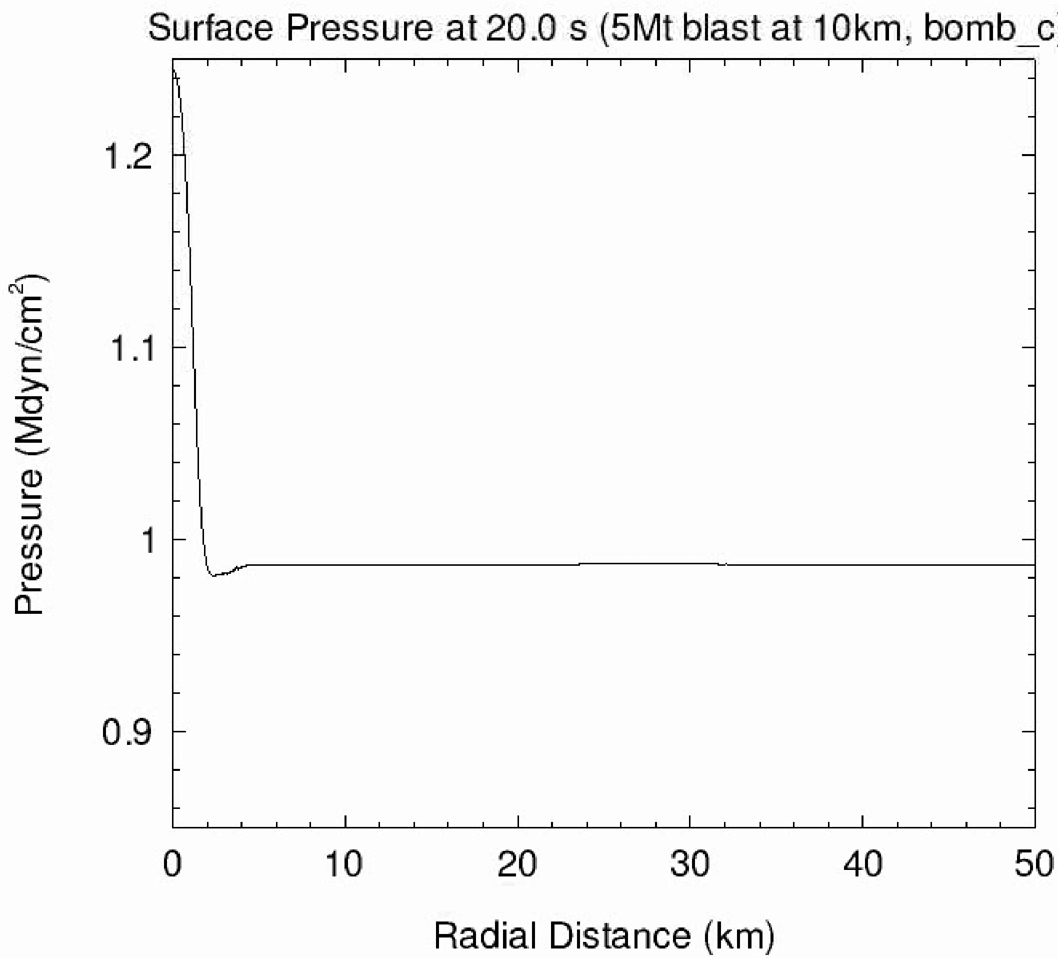
Code-to-code comparisons

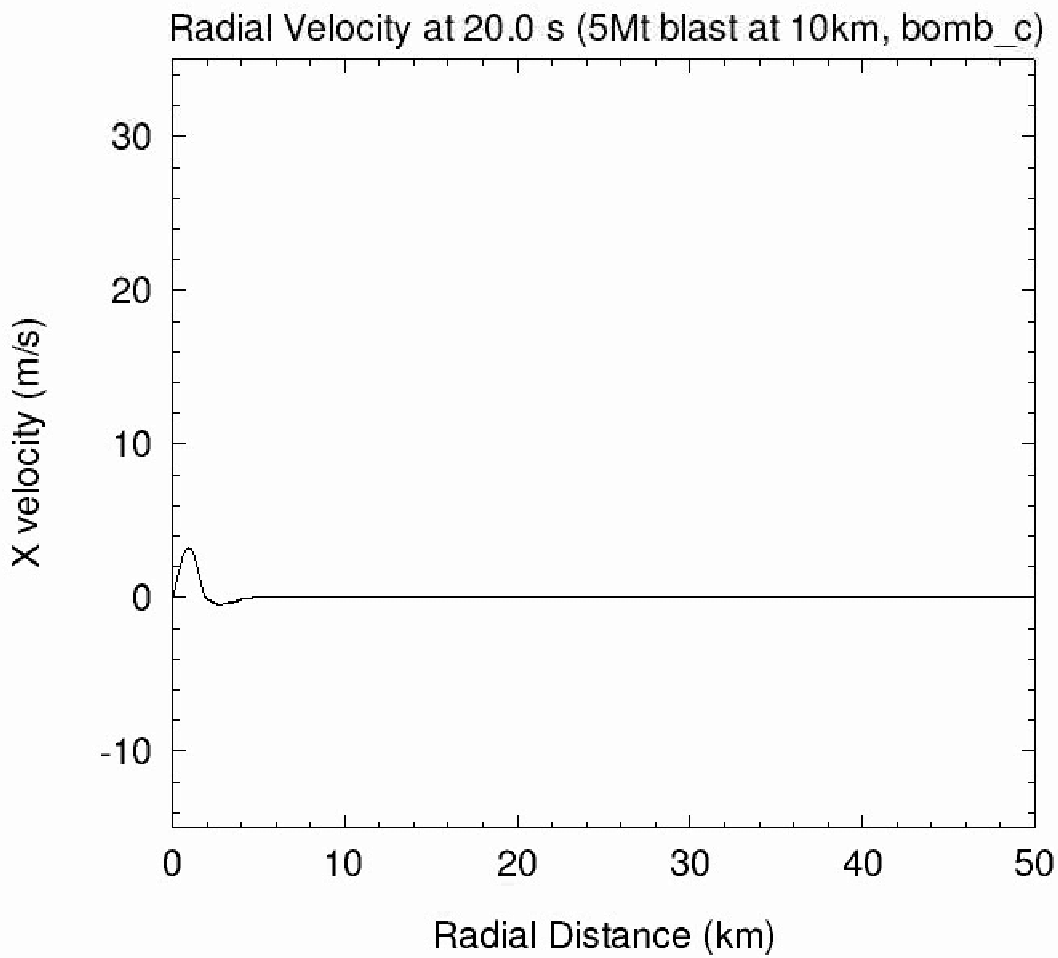


Point source example:
5 Mt at 10 km above surface

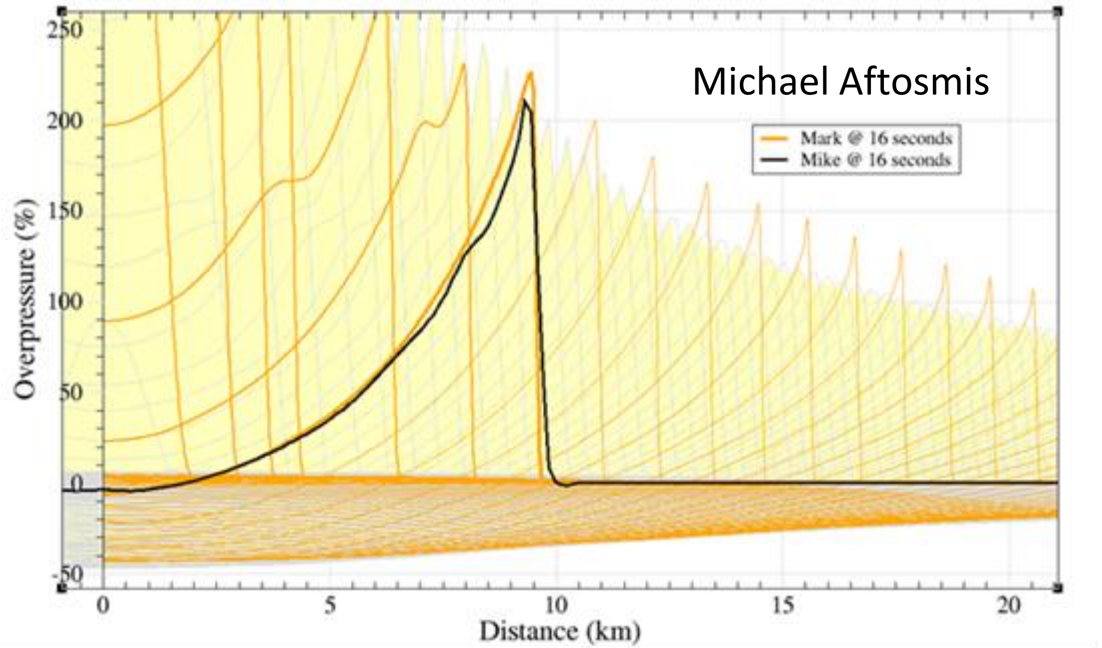


Temperature at 0.0 seconds
20
15
10
5
0
Y (km)
-10
-5
0
5
10
X (km)

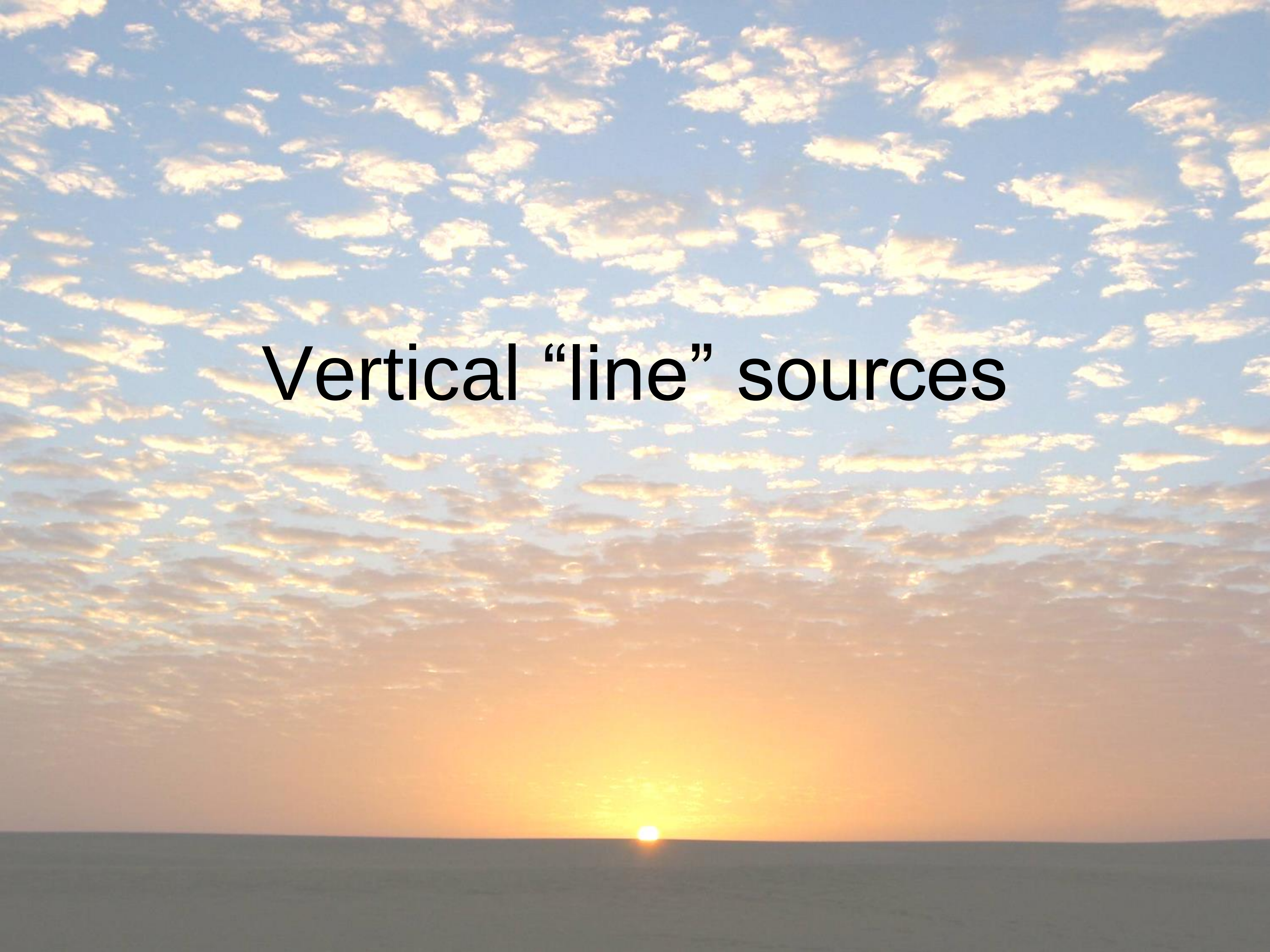

Surface Pressure at 20.0 s (5Mt blast at 10km, bomb_c)
1.2
1.1
1
0.9
Pressure (Mdyn/cm^2)
0
10
20
30
40
50
Radial Distance (km)


Radial Velocity at 20.0 s (5Mt blast at 10km, bomb_c)
X velocity (m/s)
30
20
10
0
-10
0
10
20
30
40
50
Radial Distance (km)

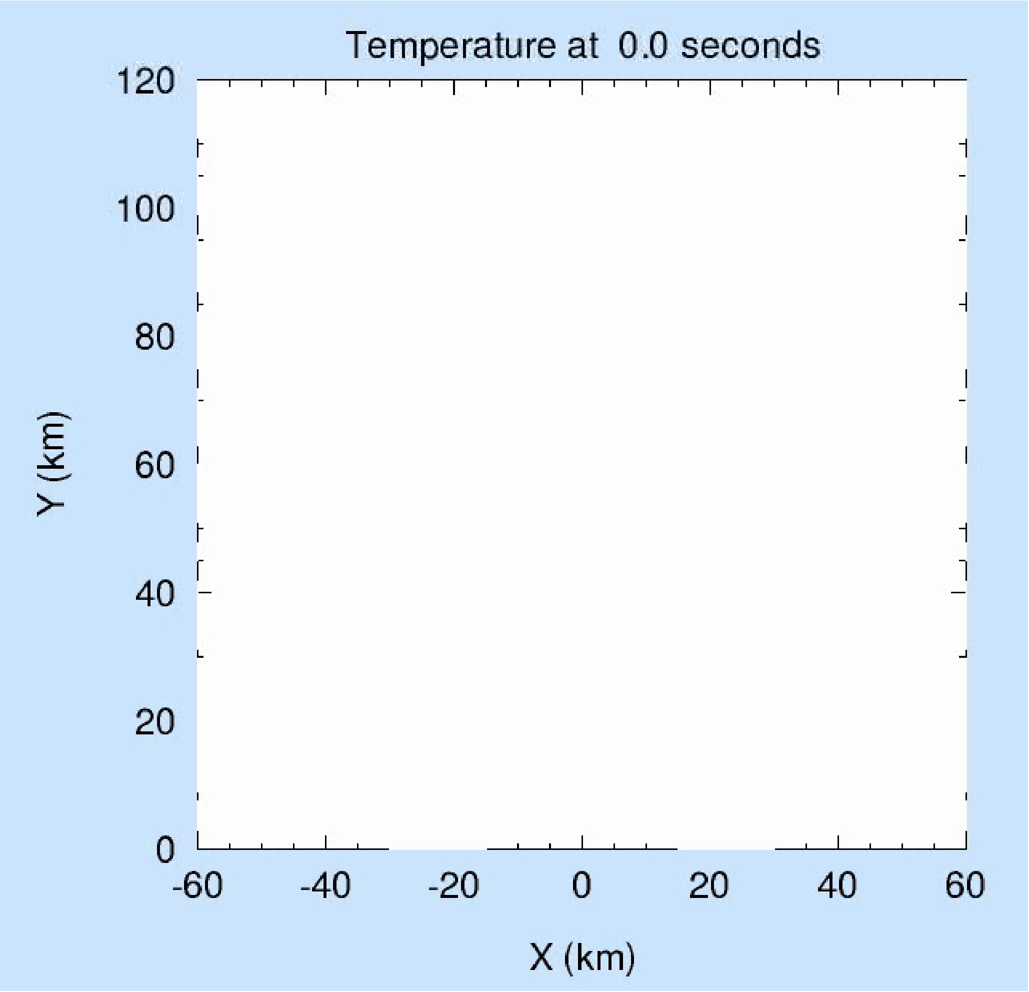
250 Mton, 10 km code comparison



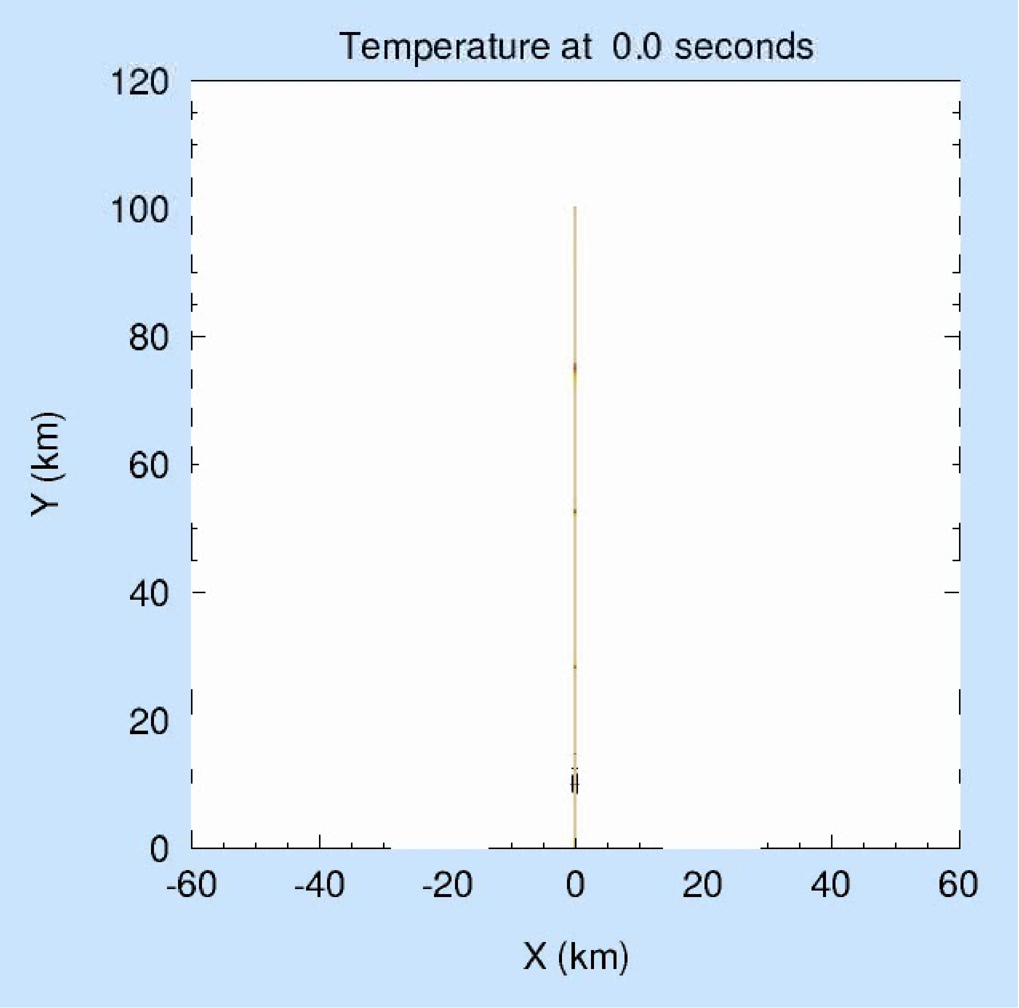
Vertical “line” sources



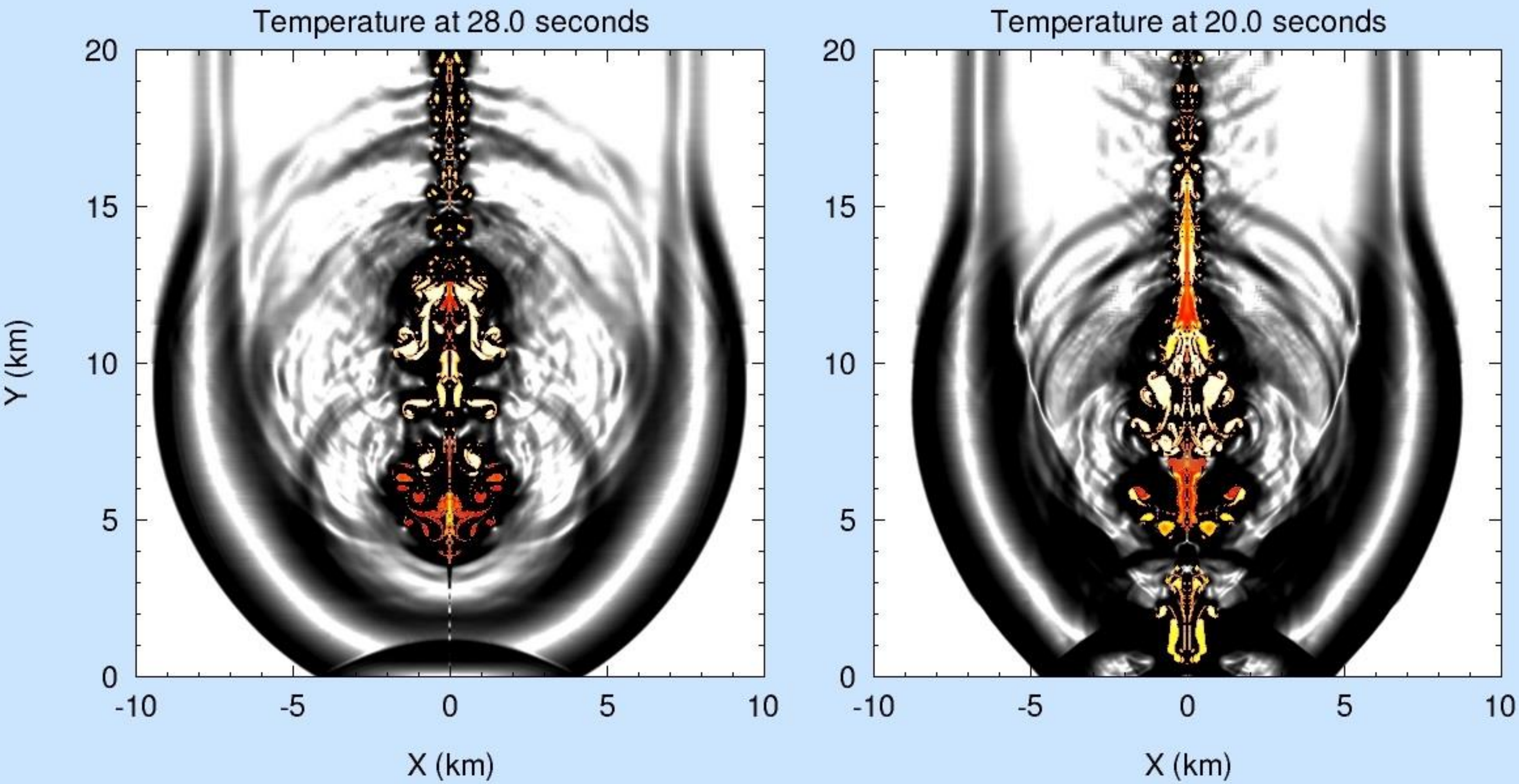
Line source:
5 Mt sequential insertion


Temperature at 0.0 seconds
120
100
80
60
40
20
0
Y (km)
-60
-40
-20
0
20
40
60
X (km)

Line source:
5 Mt simultaneous insertion


Temperature at 0.0 seconds
120
100
80
60
40
20
0
Y (km)
-60
-40
-20
0
20
40
60
X (km)

Comparison of sourcing method

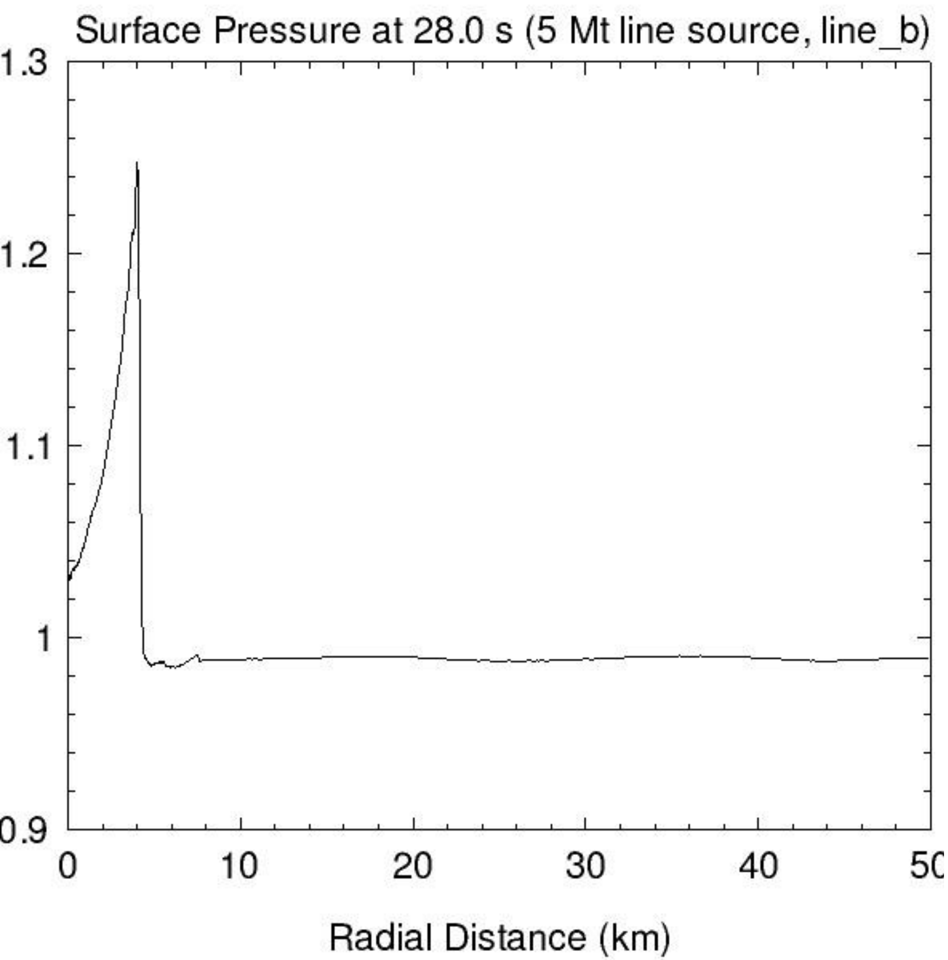


Sequential

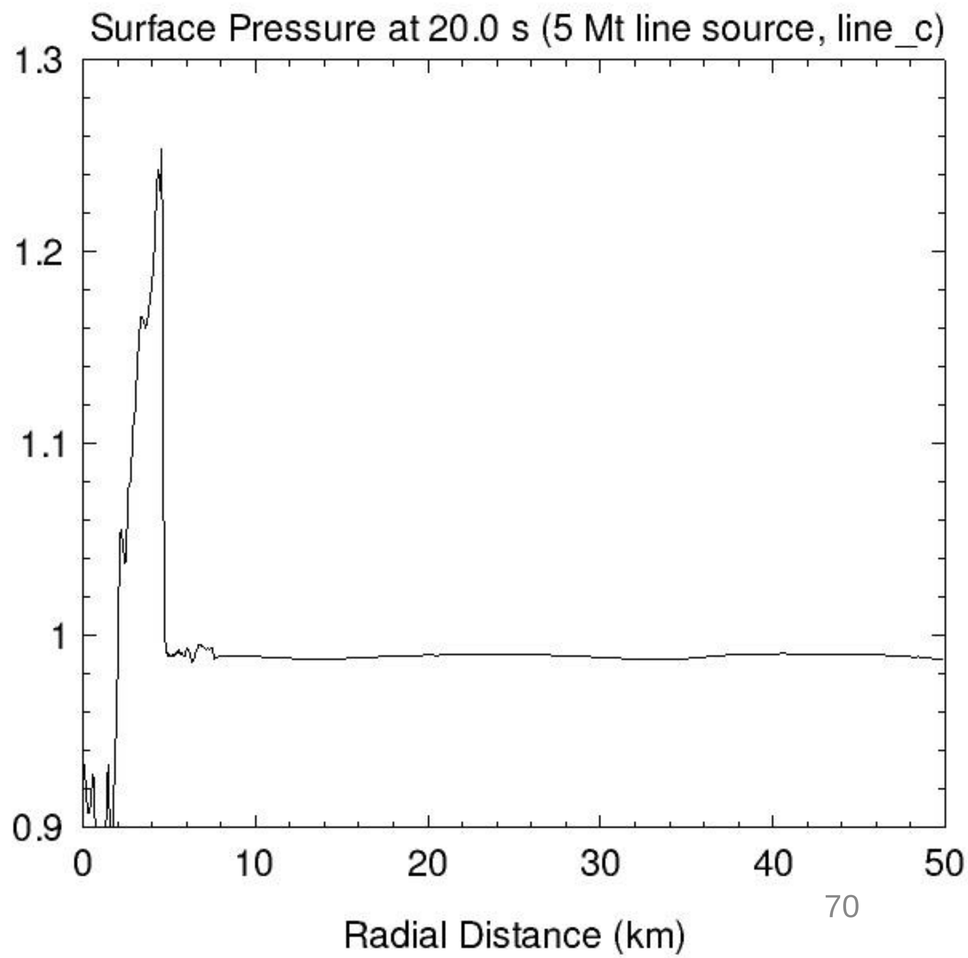
Simultaneous

Comparison of sourcing method

Sequential

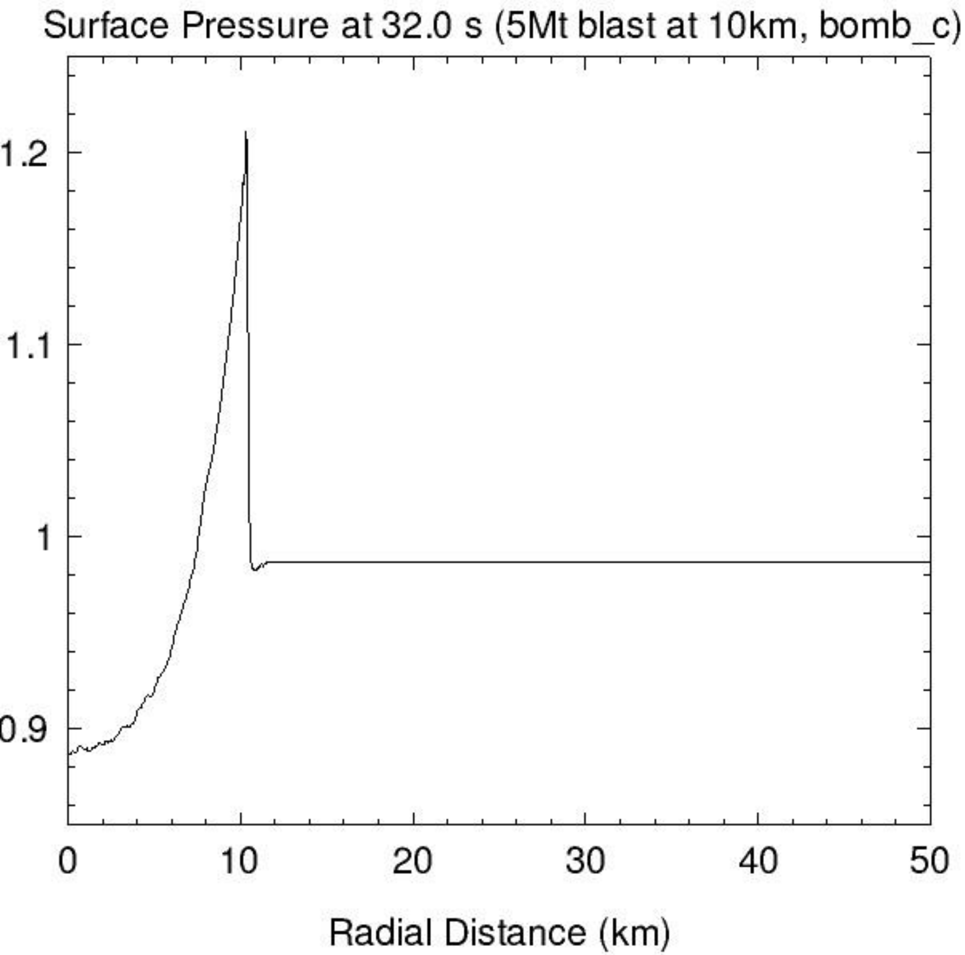


Simultaneous

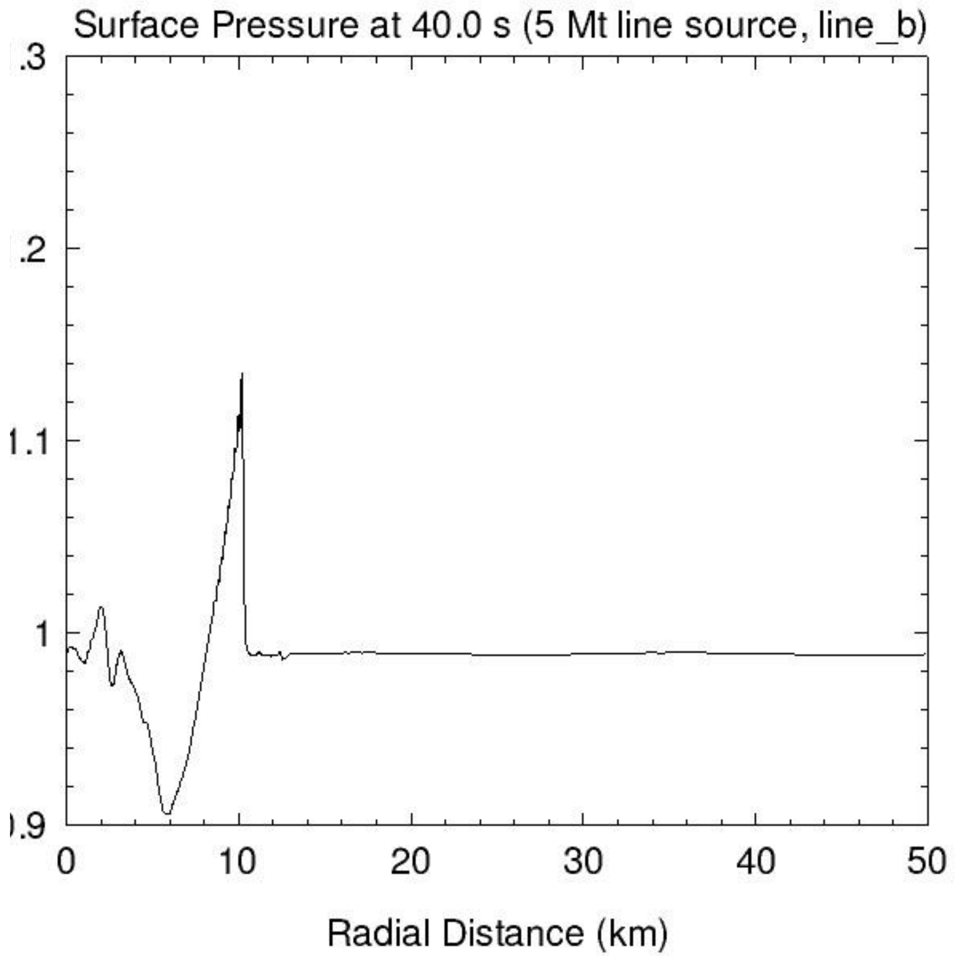


Comparison point to line source

5 Mt point source (10 km)

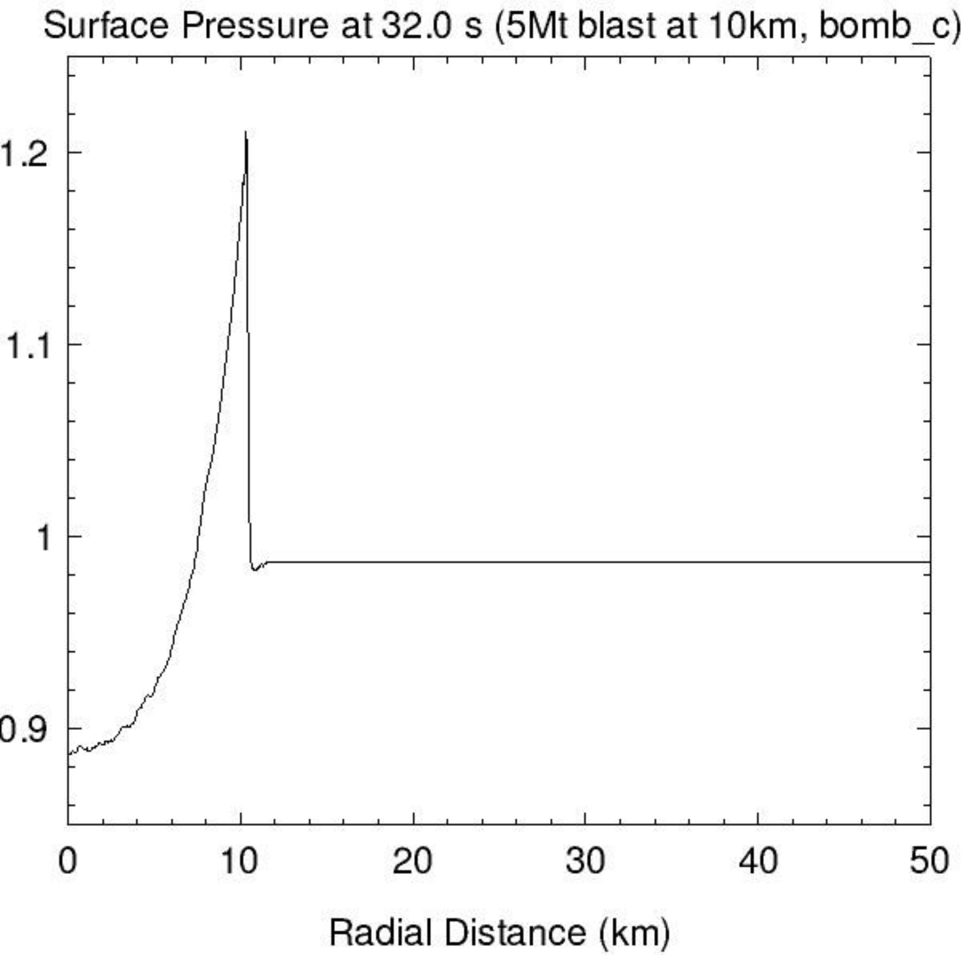


5 Mt line source (sequential)

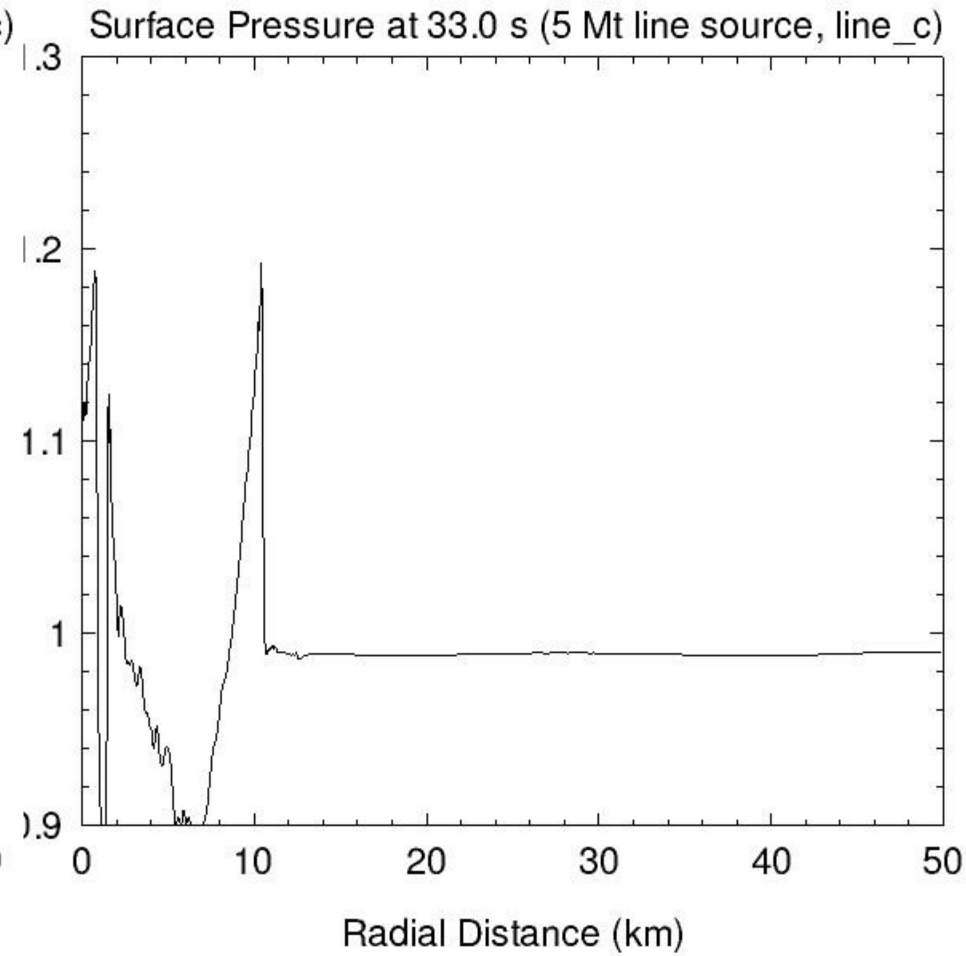


Comparison point to line source

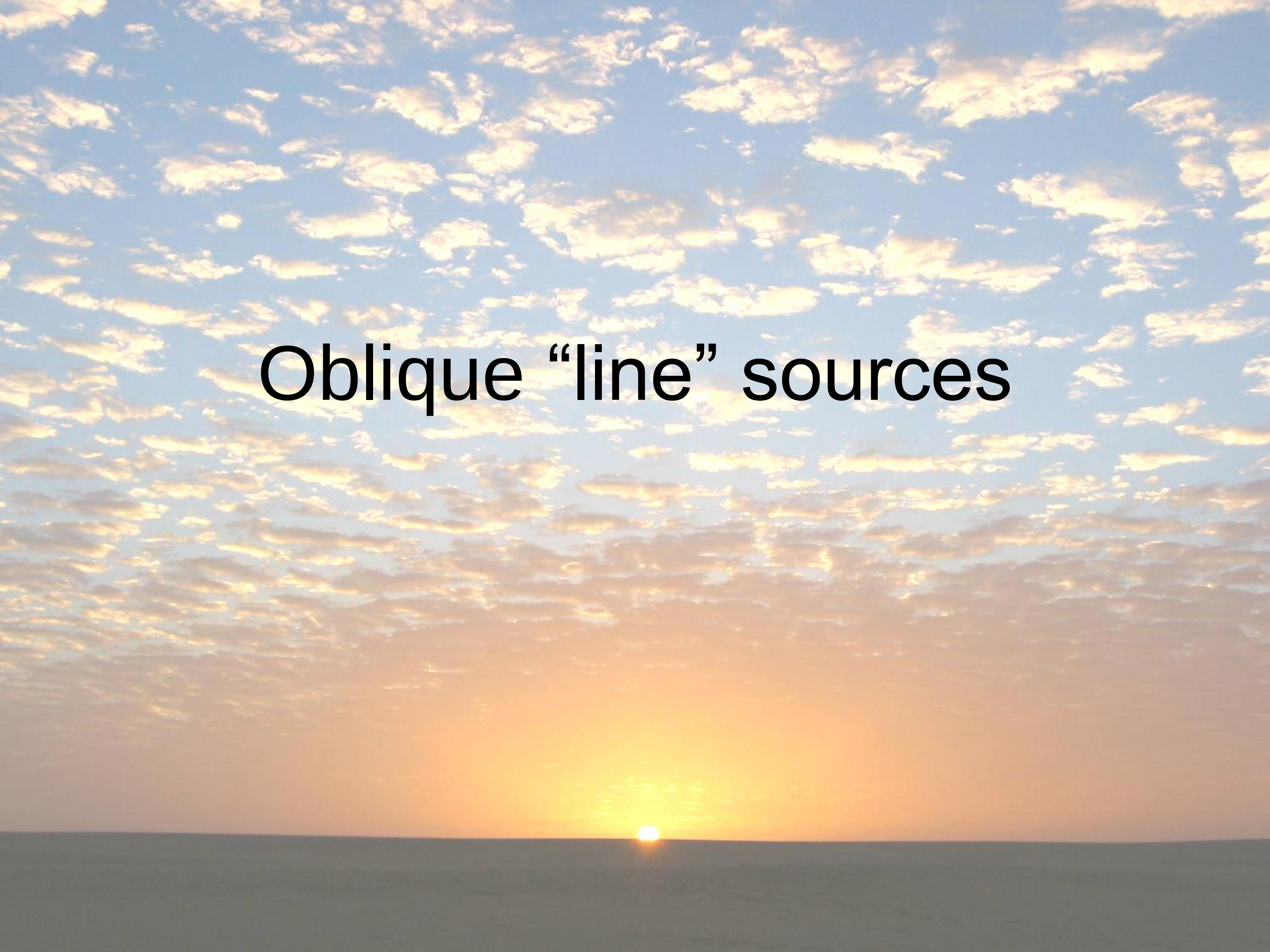
5 Mt point source (10 km)



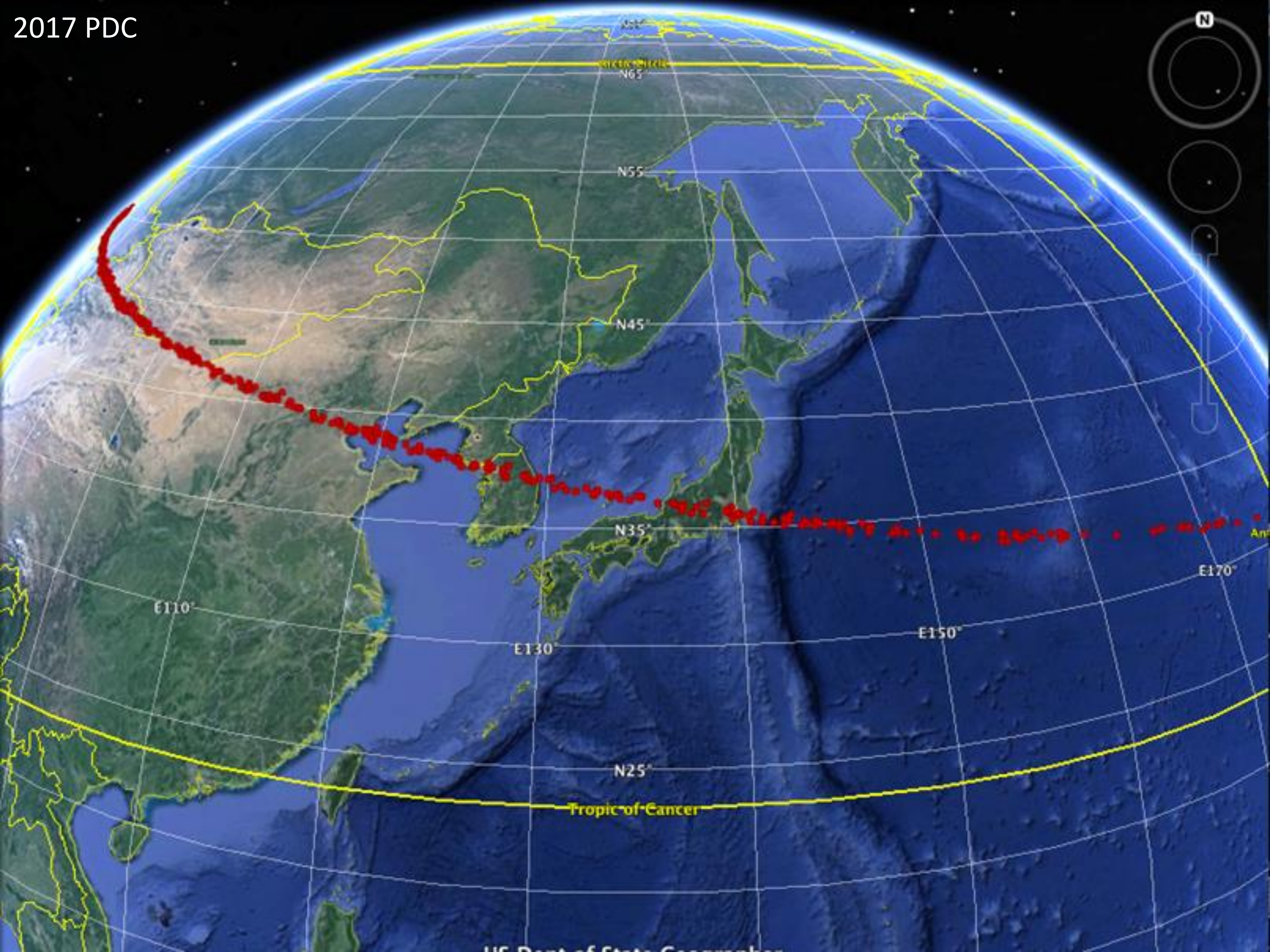
5 Mt line source (sequential)



Oblique “line” sources



2017 PDC


N65°
N55°
N45°
N35°
N25°
Tropic of Cancer
E110°
E130°
E150°
E170°
US Dept of State Geographer