Space Elevator Tether Atmospheric Wind Loading and a Cable Lift Concept

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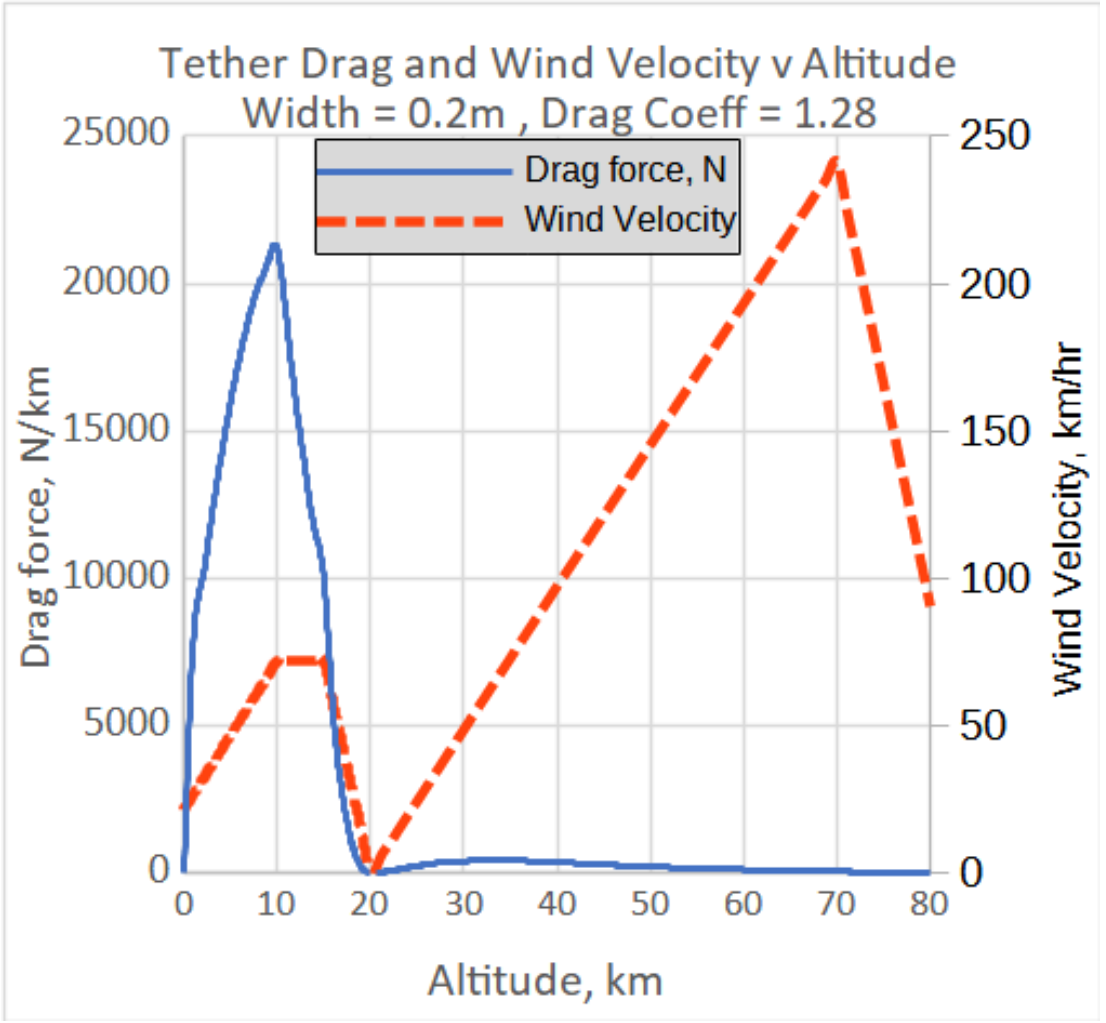
Why is Wind Loading an issue ?

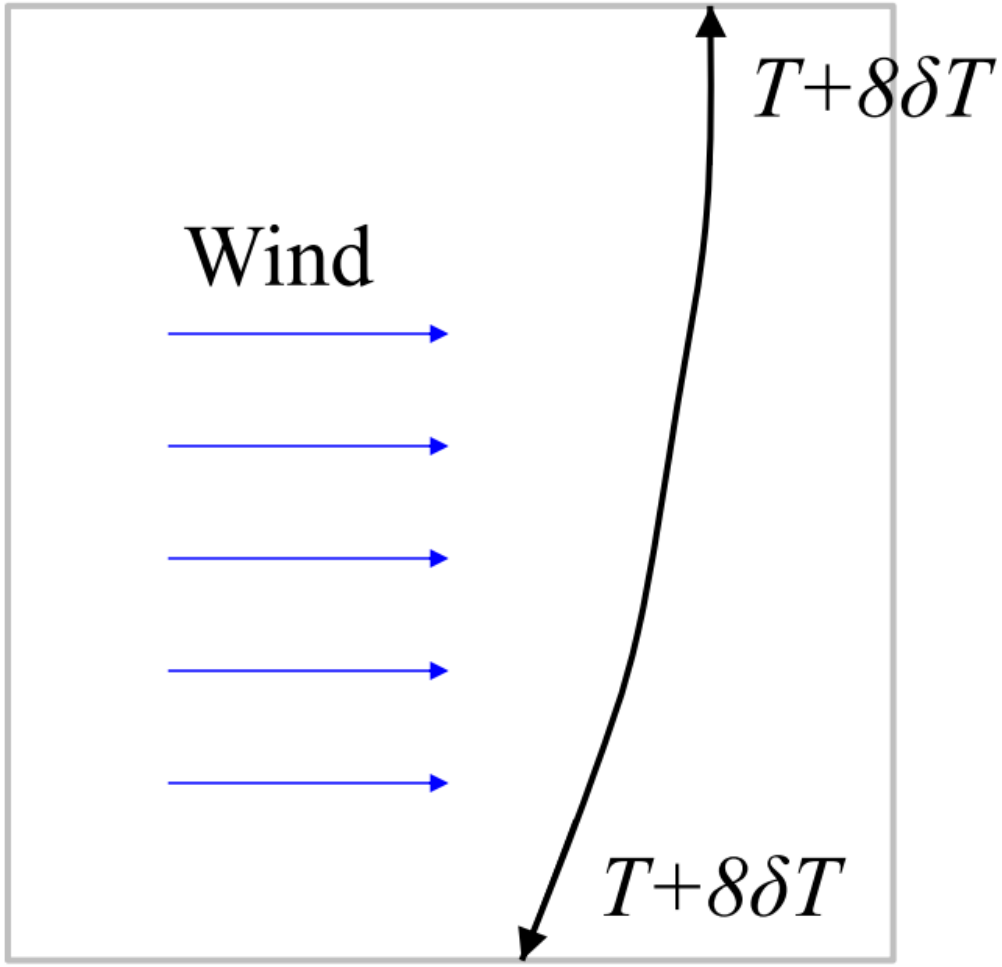
- **The section of the Space Elevator Tether in the atmosphere is subject to significant lateral wind forces**
- **The force on a 20cm tether in a 'Moderate Breeze' (Force 4) can be of the order of 250 kN**
- **In a 'Strong Breeze' (Force 6) this could rise to 1.3 MN (= 134 tonne-f)**



Why is Wind Loading an issue ?

- **On a 20cm tether in a 'Strong Breeze' the Lateral Load 'F_w' ≈ 134 tonne-f**
- **This must be countered by extra tension force 'T_w' in the tether**
  - for a 10° base inclination from the vertical force, $F_w = T_w * \sin(10°)$
  - Hence **Tw ≈ 769 tonne-f**
- A tether sized for one 20-tonne climber per day will typically have a working strength at the Earth Port of **35 tonne-f.**

Another solution is needed



Wind Loading Mitigation [1]

- **On a 20cm tether in a 'Strong Breeze' a Tension Force ≈ 769 tonne-f is needed**
- **OPTION 1 : a heavier tether**
  NOT FEASIBLE FOR INITIAL SYSTEM
- **OPTION 2 : a narrower tether**
  A WIDTH < 2CM WOULD BE REQUIRED.
  THIS COULD NOT BE ASCENDED BY A MULTI-TONNE FRICTION-DRIVE CLIMBER
- **OPTION 3 :** ASCEND THROUGH ATMOSPHERE USING A DIFFERENT CONCEPT, NOT A RIBBON TETHER

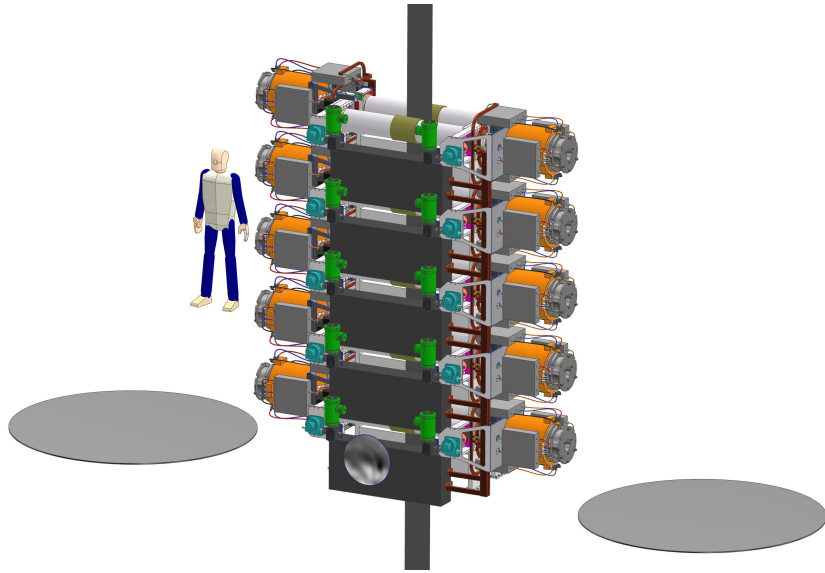
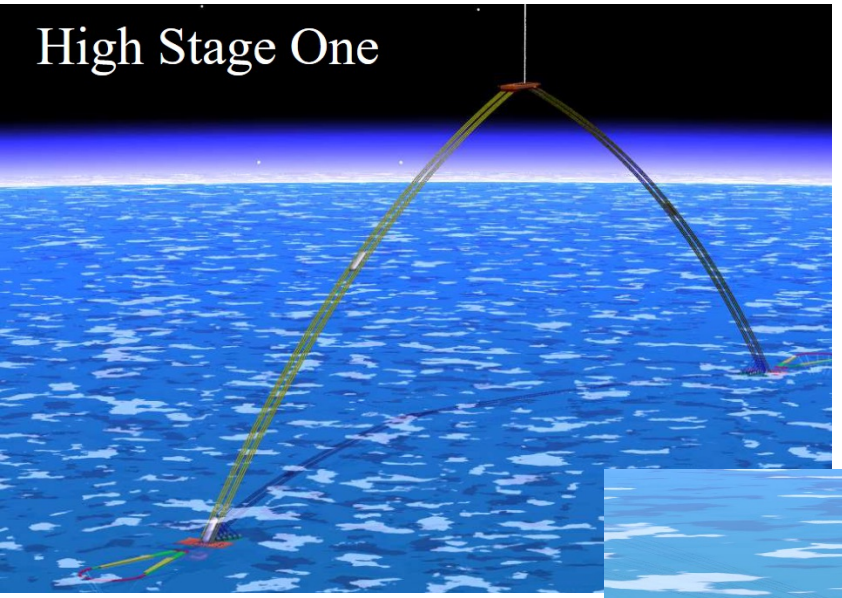


Image : L.Bartoszek

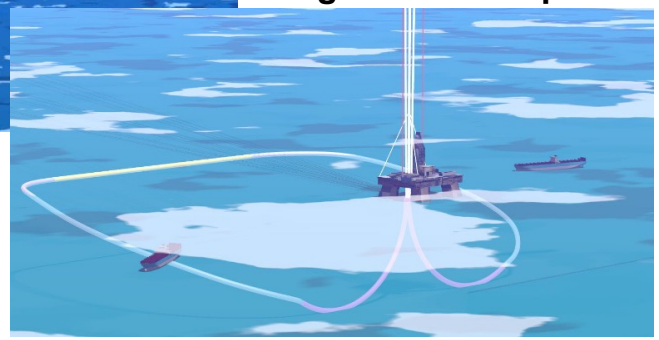
Wind Loading Mitigation [2]

Alternative Atmosphere Ascent Options



ofstrom Loop

Image : K.Lofstrom



Multi-Stage Elevator

Images : J.M.Knapman

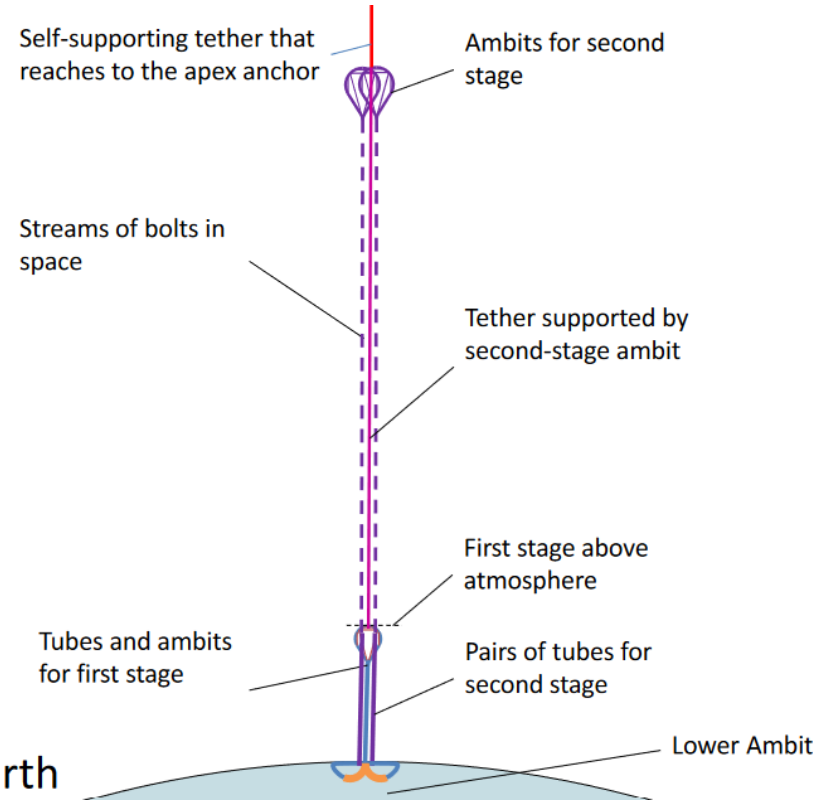


Image : Thoth Technologies

These solutions do not primarily address the Wind Loading Issue

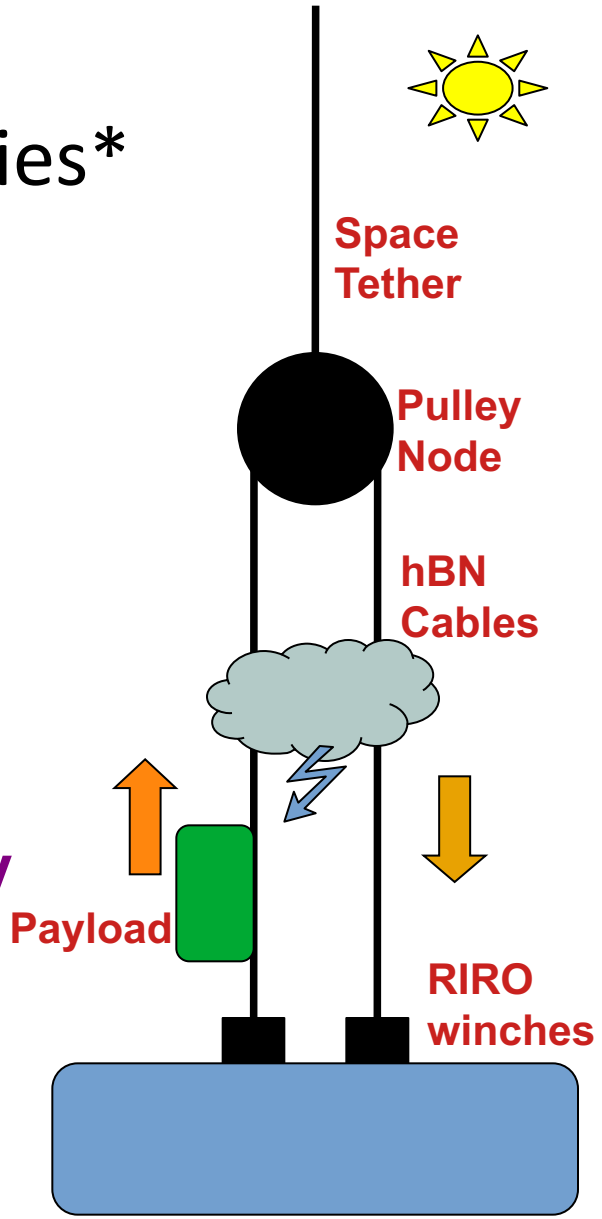
Wind Loading Mitigation [3]

A Proposal Based on Existing Technologies*

The Cable Lift

- **'Pulley Node' suspended on Space Tether at 60km or less**
  - Cable Material : ultra-high specific strength (hBN or GSL)
  - Cable diameter ≈ 2mm, total cable mass 852 kg *(2 x 60km, hBN)*
  - Earth Port retention force : 10 tonne-f
  - Load on SE Space Tether : 209 kN *(for 500kg Pulley Node mass)*
  - Operation in Moderate winds (up to Force 6 ?)
- **Payload transferred robotically from cable to above Pulley**
  - Space Climber attached to tether & cargo loaded

Other Options in Calm or Extreme Conditions...

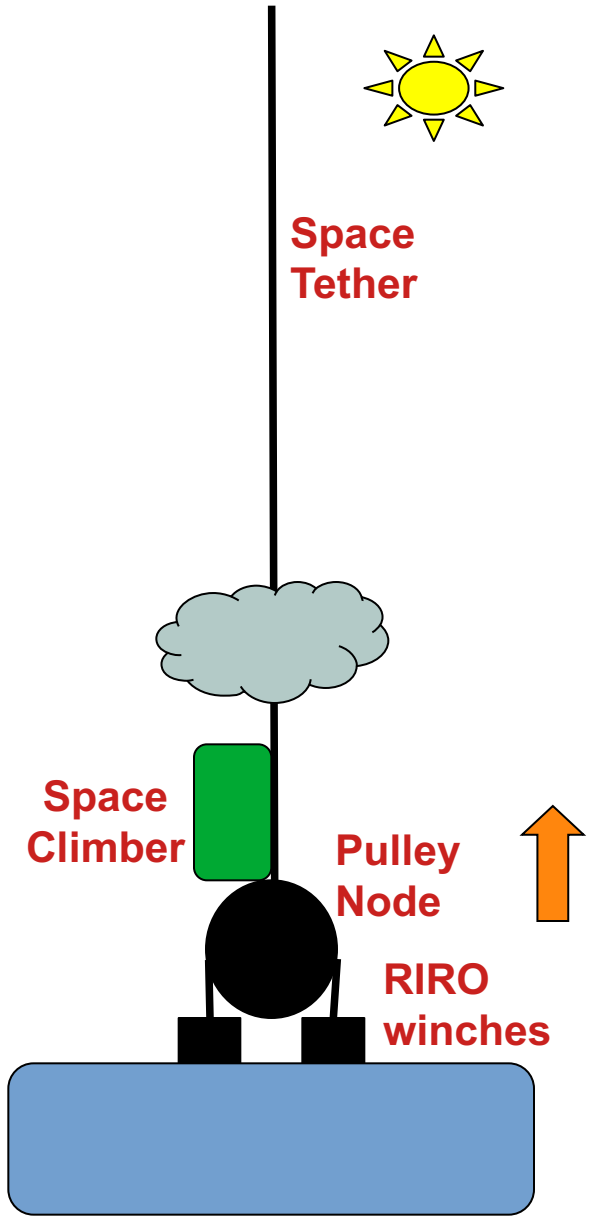


* 'Existing Technologies' except the cable material

Wind Loading Mitigation [3]

The Cable Lift : CALM CONDITIONS

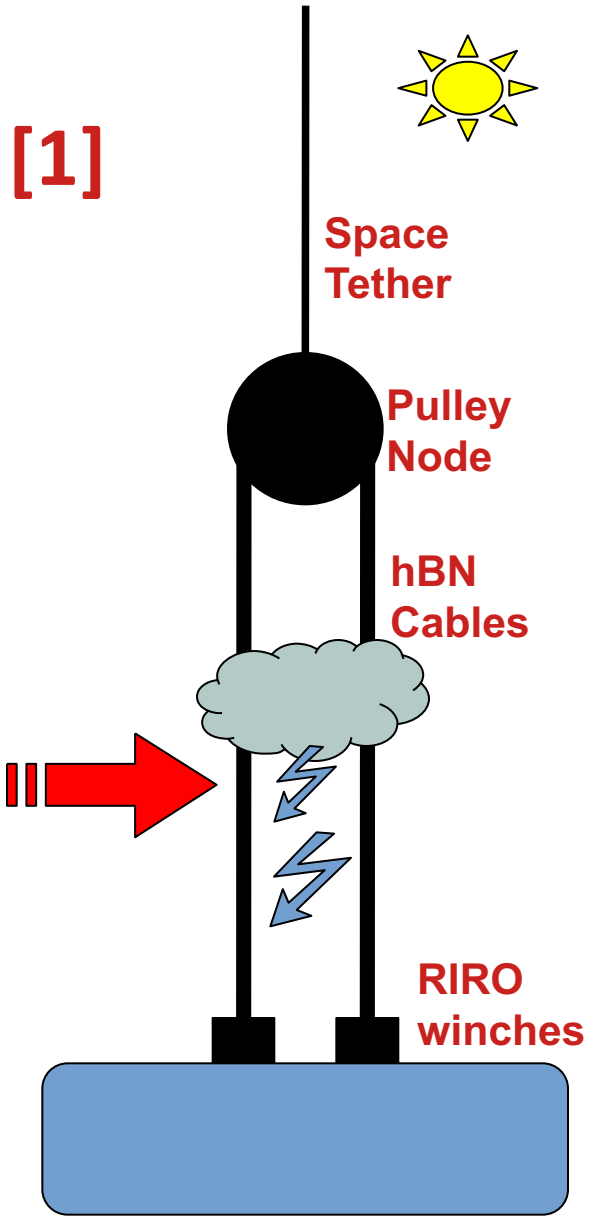
- **'Pulley Node' winched down to Earth Port by RIRO units**
- **Climber attached direct to Space Tether**
  - Also an opportunity for Pulley Node maintenance, etc
- **Pulley Node raised to above atmosphere**
  - Climber then ascends in normal 'Space' mode
  - Ascent achieved by RIRO units winching out…
  - … Pulley and Climber raised by tension in Space Tether
  - **Effectively the 'Spring Forward' launch as earlier studies**



Wind Loading Mitigation [3]

The Cable Lift : EXTREME CONDITIONS [1]

- **When high wind are forecast, cargo ascent paused**
  - higher inclination from vertical then possible
- **Climber above Pulley ascends towards GEO as usual**
  - Reducing suspended weight on tether
- **Cables replaced, diameter increased**
  - able to withstand required higher retention forces
  - extra cable weight and tension offset by lower suspended climber weight



Wind Loading Mitigation [3]

The Cable Lift : EXTREME CONDITIONS [1]

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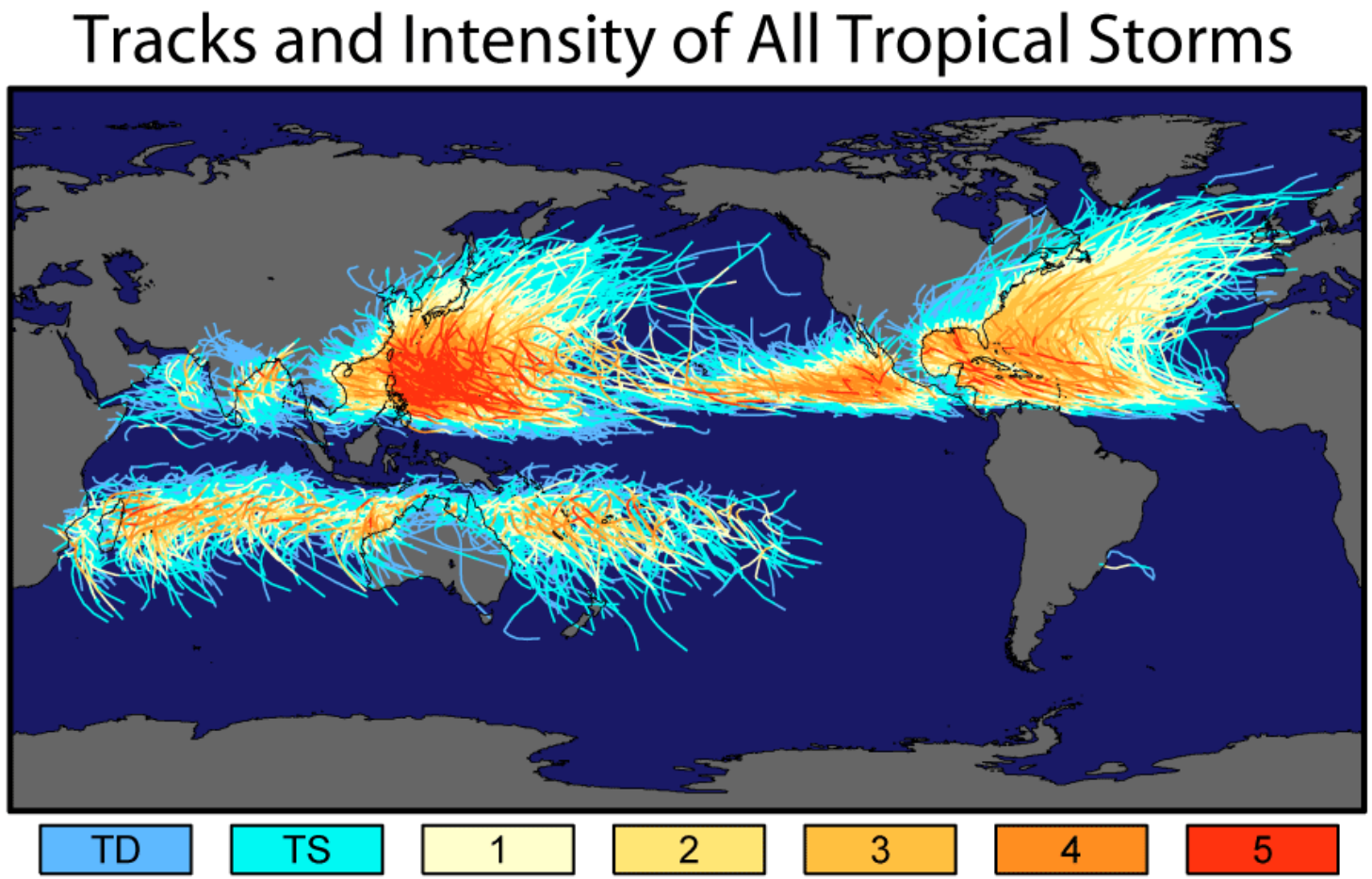
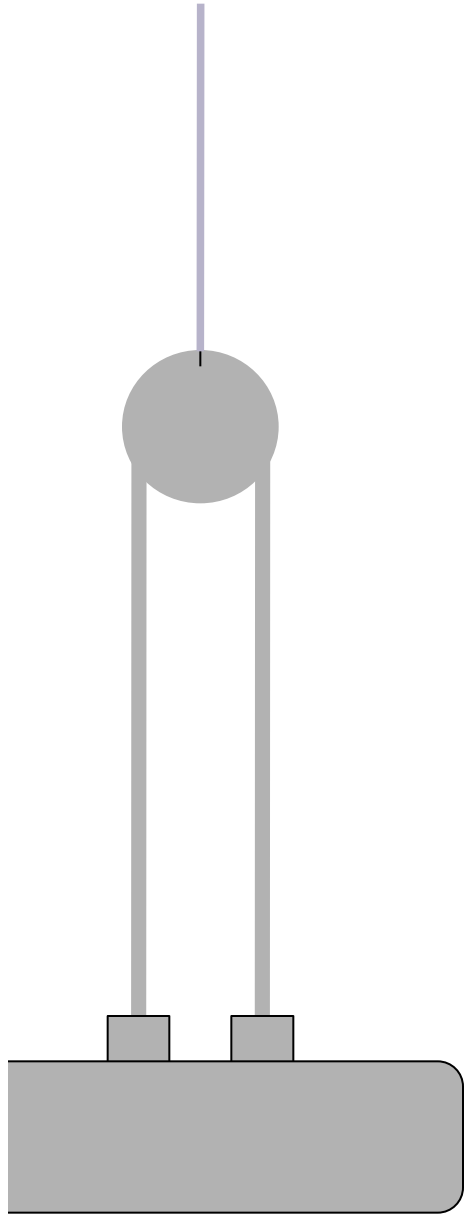


Source : NASA Earth Observatories



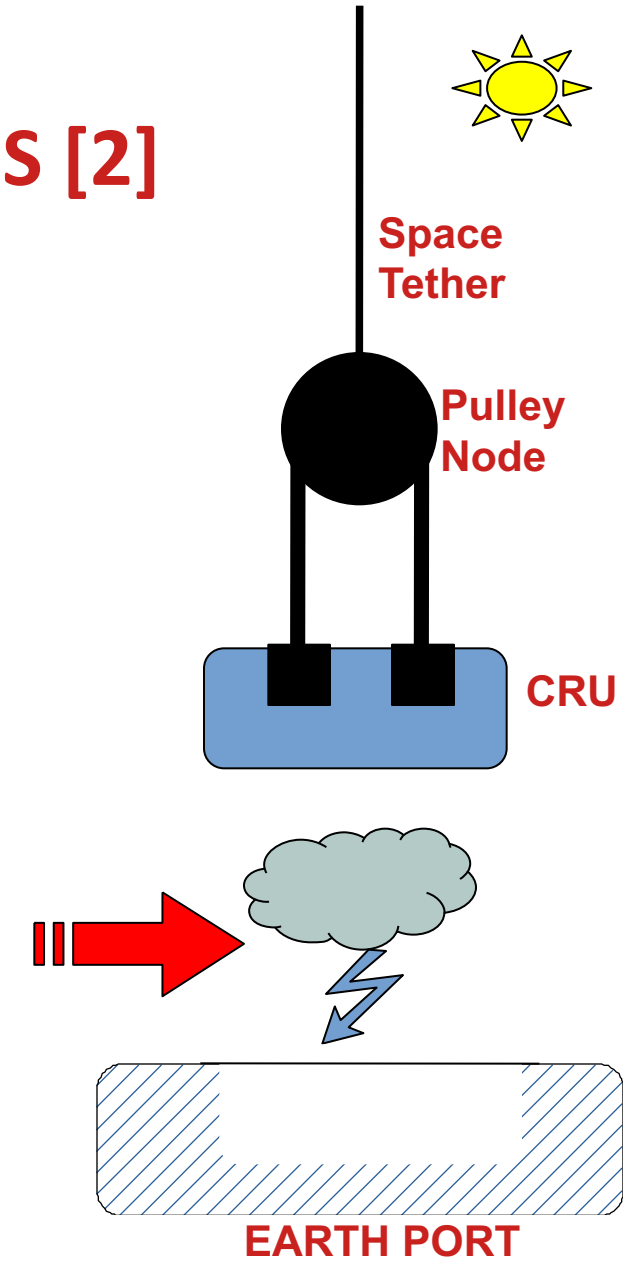
Wind Loading Mitigation [3]

The Cable Lift : EXTREME CONDITIONS [2]

- **With very high winds or some other emergency, detachment could be the only option**

- **RIRO Units and other systems would detach from the Earth Port as a 'Cable Recovery Unit' (CRU)**

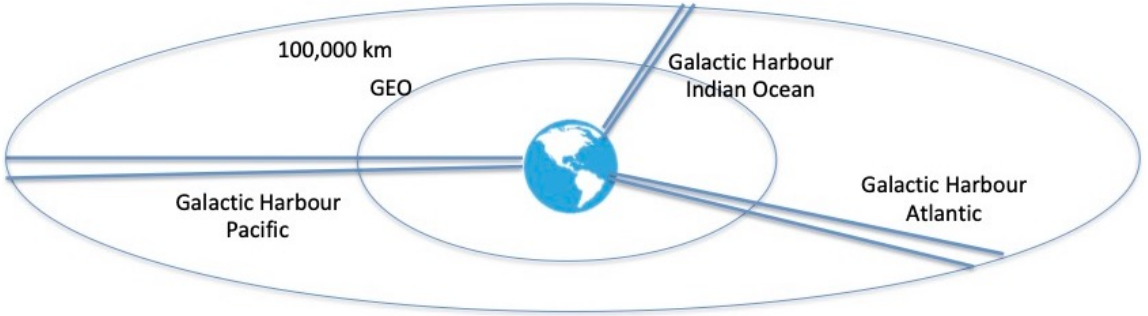
- **The CRU would then winch itself to a safe altitude and await reattachment opportunity**
  - CRU mass would be enough to maintain Space Tether tension
  - CRU systems would include power supplies, thrusters, etc
  - The CRU could be a safe haven for Earth Port crew



Wind Loading Implication

Architecture Proposal

- **Current (2022) Medium-Term Plan**
  - Build one 20-tonne/day system
  - Use it to raise more tether mass
  - Build five more 20-tonne systems



- **BUT : Wind Loading means all six will need Cable Lift system**

- and will all be susceptible to occasional operational delays

- **PROPOSAL : use first system to build one 100-tonne system**
  - Same Tether and Apex Anchor mass as 5 x 20-tonne systems
  - Able to launch 5 x 20-tonne climbers per day with more potential payload
  - Reduced need for Cable Lift operation
    - *More frequent 'Spring Forward' or direct climb from surface*

CONCLUSIONS

- A Space Elevator Tether with nominal 20-tonne/day climber capacity cannot be climbed in atmosphere AND survive possible wind loads
- Other atmospheric ascent concepts are costly and technically challenging
- An atmospheric Cable Lift concept would require no new technologies apart from a cable material similar in strength to the main ‘space’ tether
- Cable Lift operational options cover all wind strengths
- After the first ‘20-tonne’ tether system, tethers should be heavier to reduce the reliance on ‘Cable Lift’ and facilitate climber ascent from the surface

The Cable Lift

QUESTIONS ?