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Monitoring and Verification of Carbon Capture and Storage

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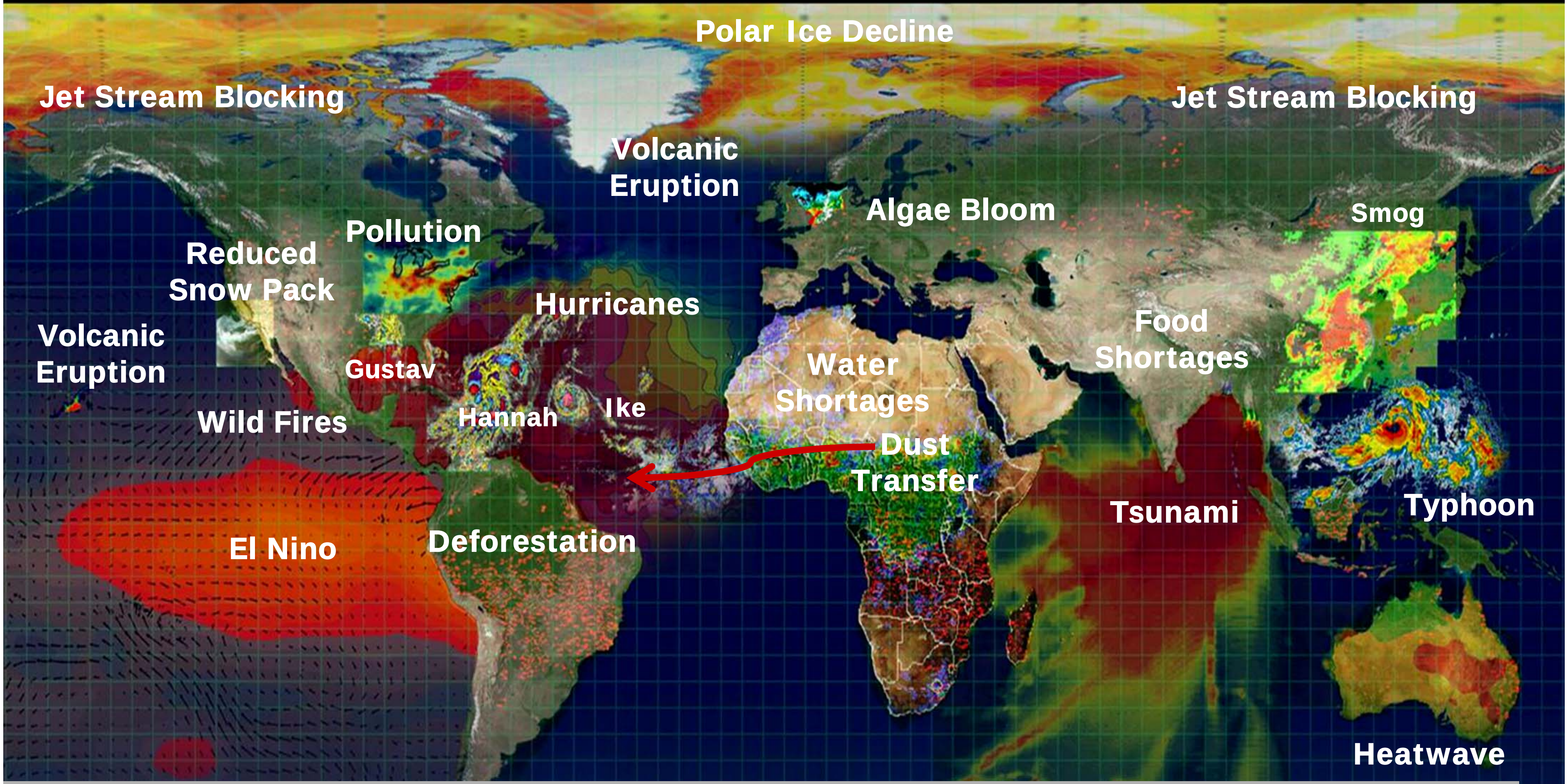
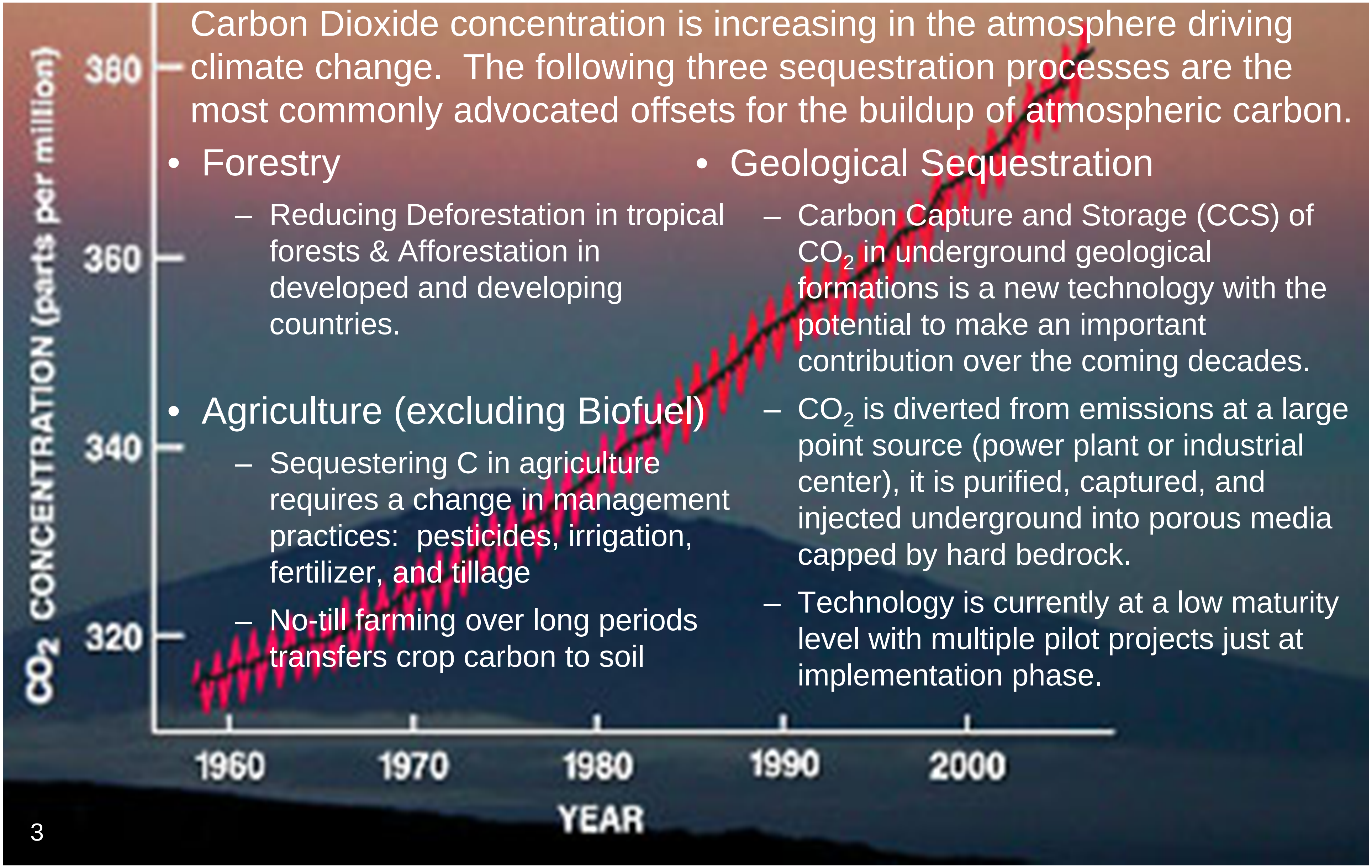
GCMS Assertion: Climate, Energy and Water Are Inextricably Linked



Decision-making tools and expertise coupled with an information architecture that answers questions such as:

- How will climate change impact the risk profile of homeowners and businesses? How should insurance policies in high risk areas be priced?
- Will the fresh water in the Great Lakes and St. Lawrence Seaway become micromanaged to the extent the Colorado River is?
- What are the energy delivery needs of developing countries? Similar to mobile phones?

Carbon Sequestration Basics



Carbon Dioxide concentration is increasing in the atmosphere driving climate change. The following three sequestration processes are the most commonly advocated offsets for the buildup of atmospheric carbon.

- Forestry
  - Reducing Deforestation in tropical forests & Afforestation in developed and developing countries.
- Agriculture (excluding Biofuel)
  - Sequestering C in agriculture requires a change in management practices: pesticides, irrigation, fertilizer, and tillage
  - No-till farming over long periods transfers crop carbon to soil
- Geological Sequestration
  - Carbon Capture and Storage (CCS) of CO_2 in underground geological formations is a new technology with the potential to make an important contribution over the coming decades.
  - CO_2 is diverted from emissions at a large point source (power plant or industrial center), it is purified, captured, and injected underground into porous media capped by hard bedrock.
  - Technology is currently at a low maturity level with multiple pilot projects just at implementation phase.

Carbon Sequestration Capacity and Cost

Carbon sequestration is targeted to reducing anthropogenic emissions of carbon dioxide, which dominantly come from burning fossil fuels and deforestation. The potential capacity and the cost differ for each sequestration method.

Forests

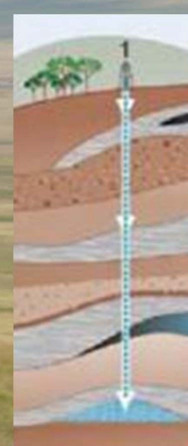
- Forestry
  - Forest-related mitigation activities can considerably reduce emissions from sources and increase CO_2 sequestration at low costs
  - Capacity: ~20% of emissions
  - Synergies with adaptation and sustainable development

Cropland

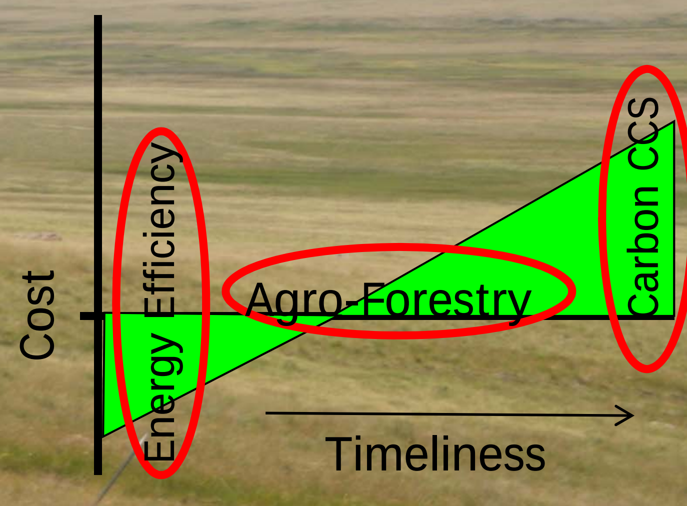
- Agriculture (excluding Biofuel)
  - Agricultural practices collectively can make a significant contribution at low cost through increasing soil carbon sinks and reductions in GHG emission
  - Capacity: ~ 2-5% of emissions

- Geological Sequestration
  - Implementation of CCS has the potential to eliminate all large stationary sources emissions
  - Capacity: 1/3 of emissions by 2100

Underground Storage



Projected Costs of Carbon Abatement



Measurement, Monitoring, and Verification Requirements

Measurement, long-term Monitoring, and Verification (MMV) of carbon sequestration amounts takes on multiple forms depending on the sequestering process. Primary carbon reservoirs consider the principle physical form in which the carbon is sequestered, but not necessarily the end state, as some carbon migrates to secondary forms and can be leaked from the primary reservoir.

- Primary Carbon Reservoirs
  - Forestry: Tree size/volume, forest soil composition
  - Ag: Soil carbon composition, decreased resource consumption
  - Geological: Carbon dioxide mass flow

All solid measurements –
easy to document and visualize!

- Secondary Carbon Reservoirs
  - Forestry: respiration, annual growth/decay (detritus), migration
  - Ag: Crop output, respiration, leaching
  - Geological: aquifer migration, dilution in resource recovery and venting, leak to atmosphere

Mostly trace gas and liquid measurements –
difficult to constrain and quantify!

Geological Storage Observations

- **Injection locations**
  - **In-situ measurement of CO_2 concentrations**
    - **Gas at drill holes & fractures**
    - **Aqueous in fresh and saline aquifers**
- **Surface area monitoring**
  - **Monitoring for gross leaks from fissures or wellheads**
  - **Network of surface monitors**
  - **Airborne, UAV, or Satellite based observations of ambient concentrations over wide area**

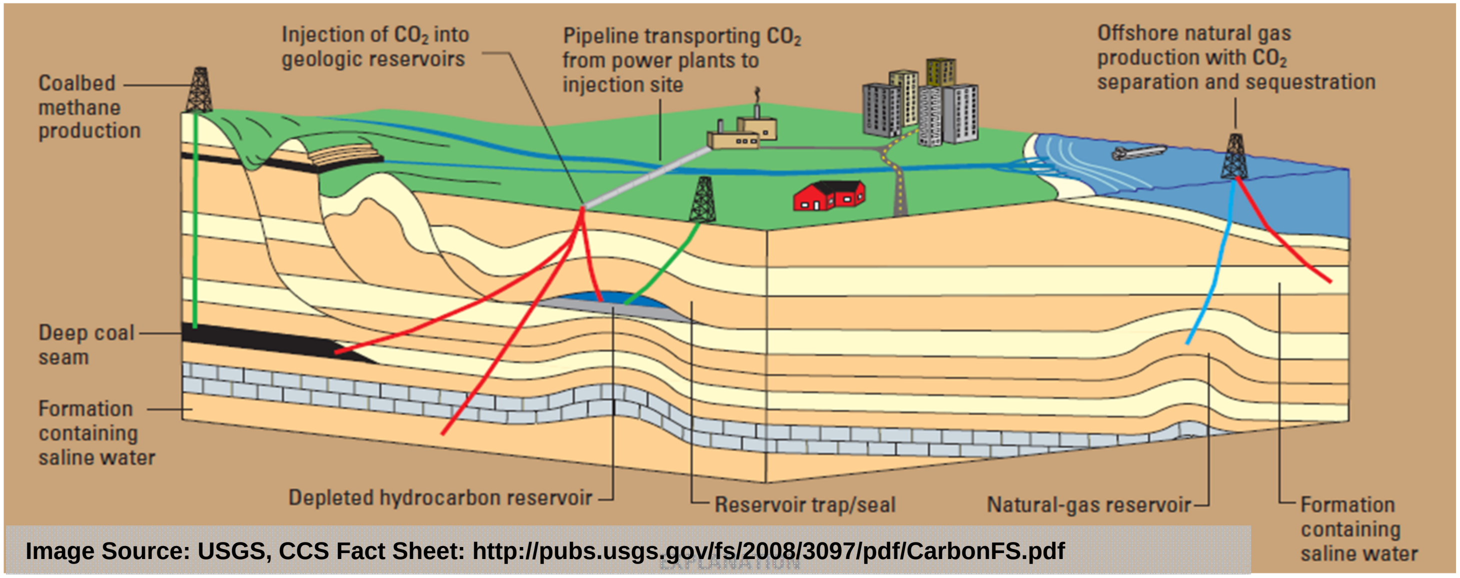


Image Source: USGS, CCS Fact Sheet: http://pubs.usgs.gov/fs/2008/3097/pdf/CarbonFS.pdf

Agriculture and Forestry Observation

- **Biomass Observations**
  - **Multispectral imagery – used to image vegetation health and type of crop or tree species. Can also feed agricultural yield forecasting.**
  - **Lidar and SAR – images differential surface and terrain elevation allowing volumetric computation of biomass.**
- **Trace-Gas Observations**
  - **Field Plot Scale**
    - **in-situ and remote sensing from ground and towers of CH_4 and CO_2**
      - **Upward looking and open path passive optical remote sensing**
      - **This captures fluxes of Carbon in/out of fields**
  - **Regional Scale**
    - **Spectral Imaging from airborne and satellite platforms to capture regional CH_4 and CO_2**
    - **Active differential Lidar systems**
    - **Large (10-1000 km) area coverage**

CONOPS for Global Carbon Monitoring and Verification Architecture

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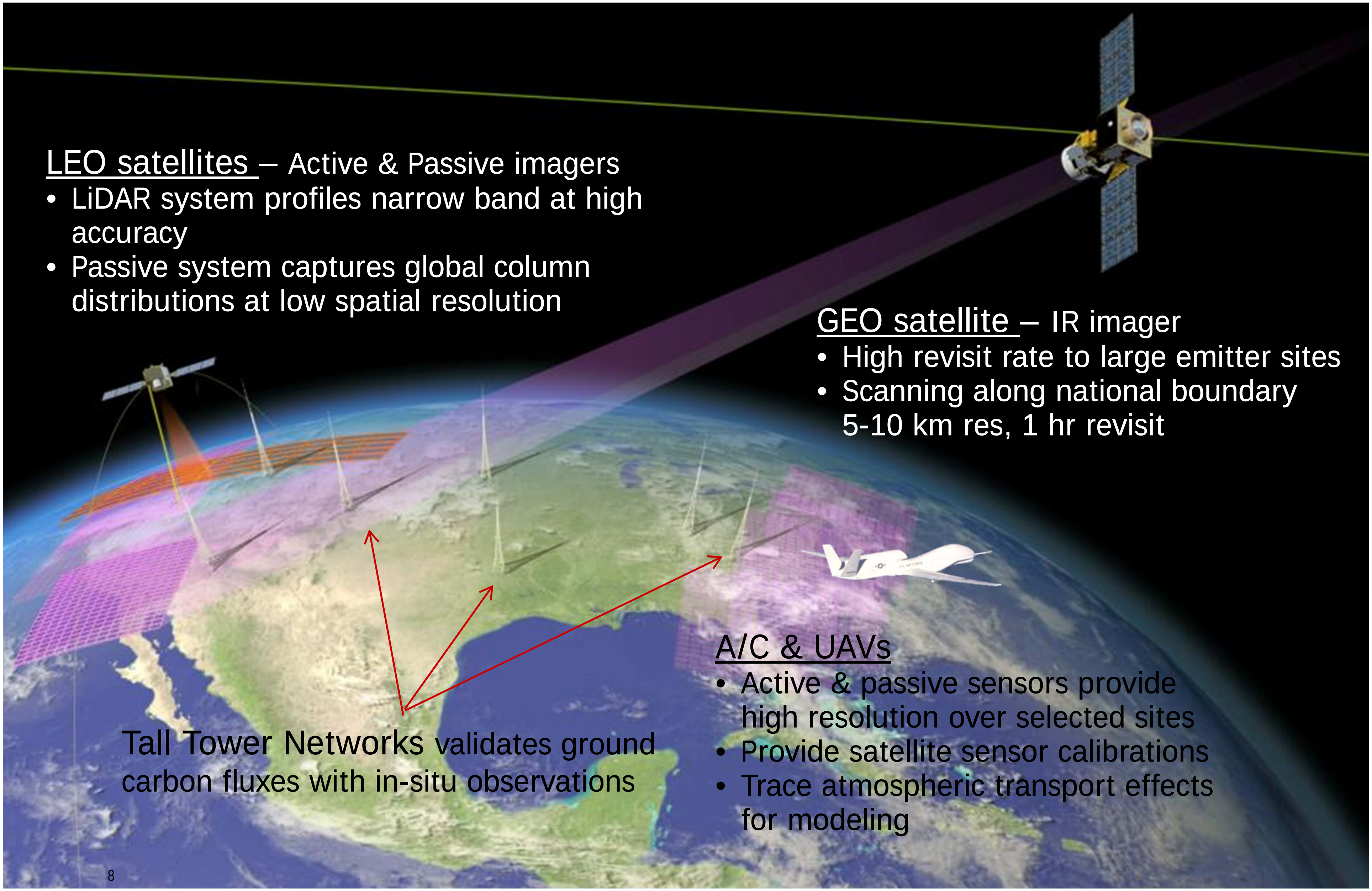
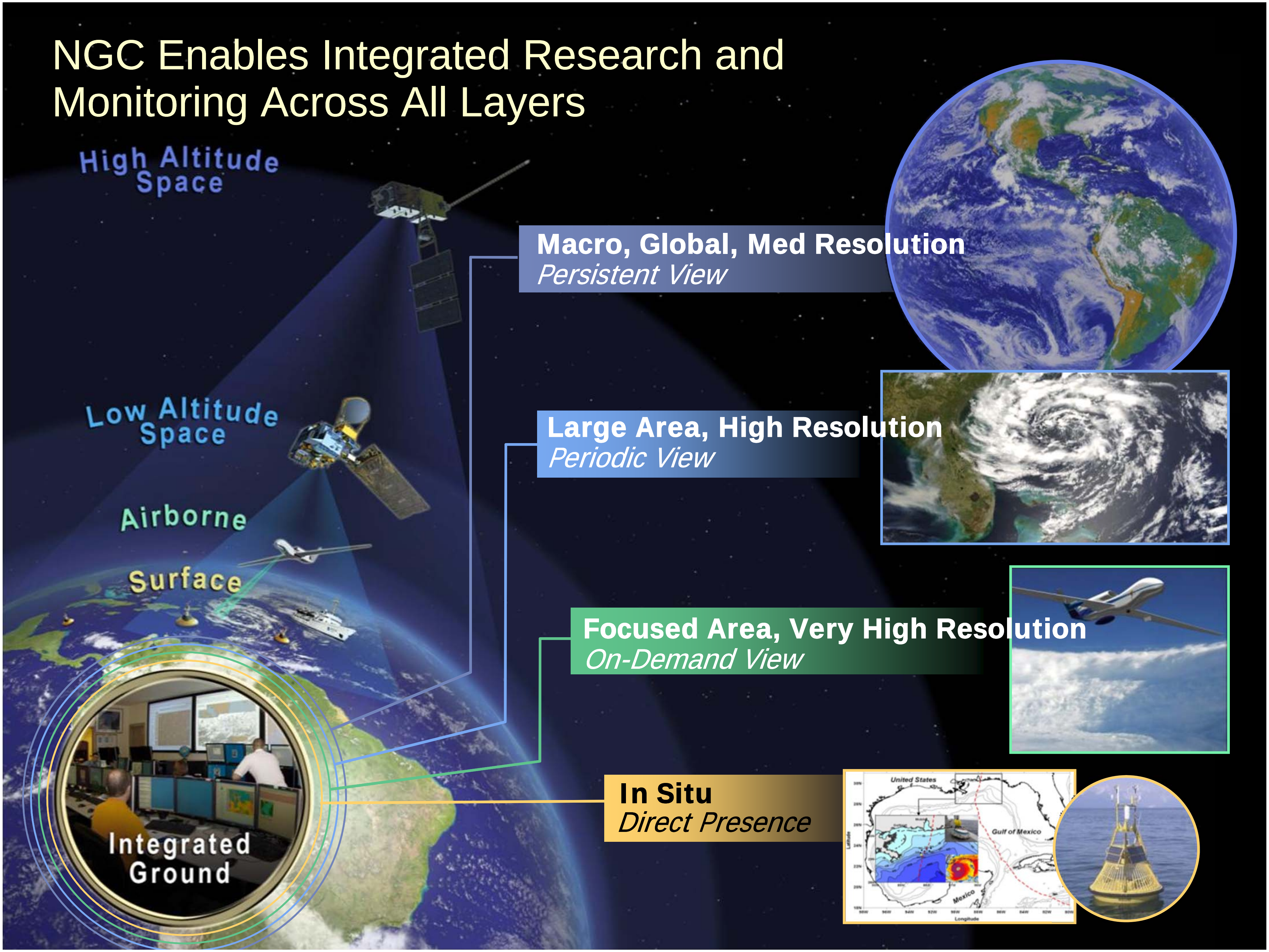
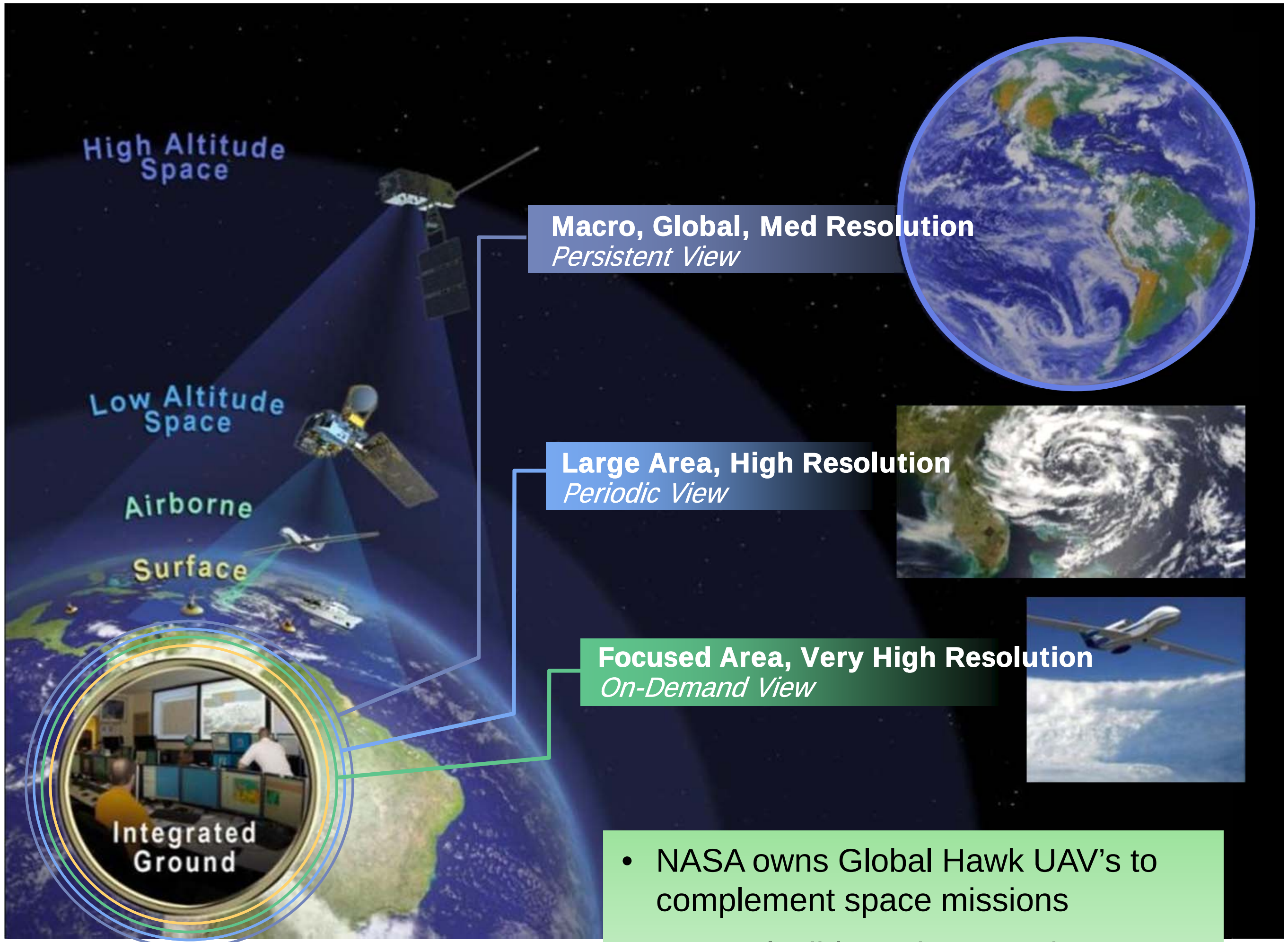
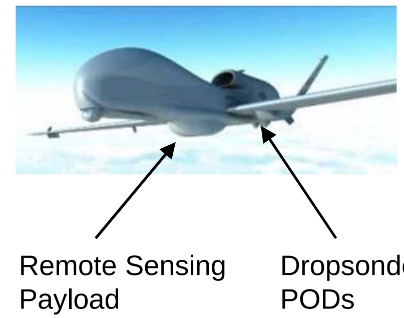



NGC Enables Integrated Research and Monitoring Across All Layers
High Altitude Space
Low Altitude Space
Airborne
Surface
Integrated Ground
Macro, Global, Med Resolution
Persistent View
Large Area, High Resolution
Periodic View
Focused Area, Very High Resolution
On-Demand View
In Situ
Direct Presence
United States
Gulf of Mexico
Mexico

Global Hawk Complements Satellites for Environmental Monitoring





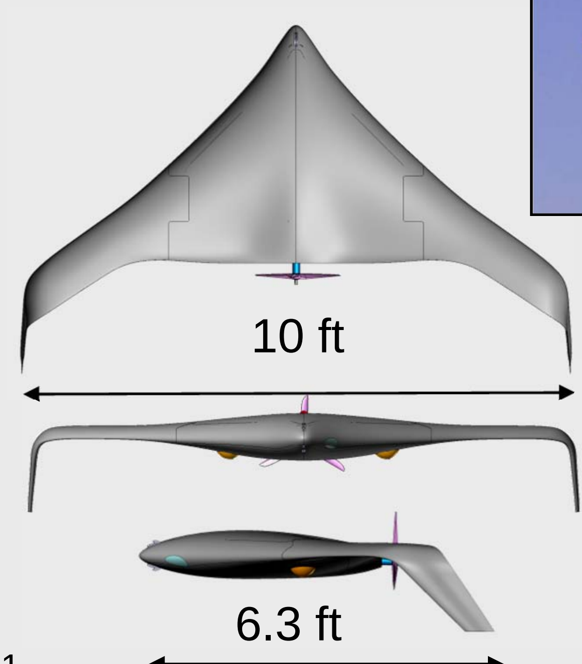
- **36 hour flight endurance**
  - Long dwell measurements
  - Extended range
- **High altitude (18,000 meters)**
  - Broader sensor coverage
  - Avoid traffic coordination requirement
  - Avoid weather & icing issues

- NASA owns Global Hawk UAV's to complement space missions
  - Flexible and responsive
- NGC provides support to NASA for Global Hawk operations

Overview

- Wingspan = 10 ft
- Gross Weight = 164 lbs
- Payload Weight = 13 - 56 lbs
- Payload Power = 600 Watts
- Endurance = 4 - 24hrs
- Max Speed = 125 kts
- Max Altitude = 20,000 ft +
- Runway Independent
    - Pneumatic Rail Launch
    - Net Recovery
- Fully Autonomous

- Organic Class-II UAV
- ISO-20 / C-130 / H-60 / CH-53 / CH-47 Transportable
- HMMWV Deployable
- EO/IR, Communications Relay
- STANAG Compliant
- 50 nm Comms
- 2-Man Operable
- Single Trailer Logistics:
    - Launcher / Net Recovery / 3 Air Vehicles
- 1 Hour Set-up / 30 Minute Teardown



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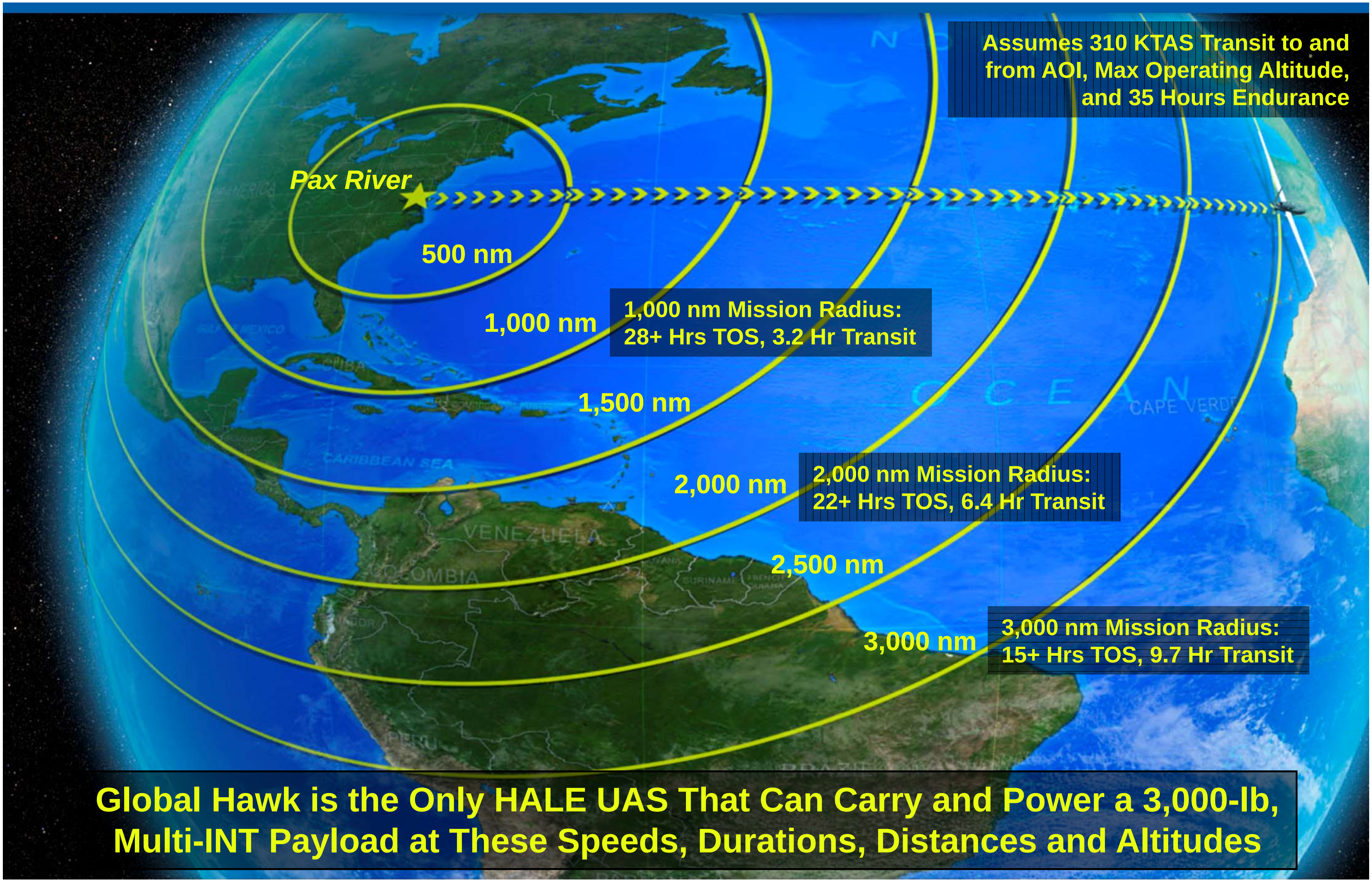
High Speed and “Persistence from a Distance”



High Speed and "Persistence from a Distance"

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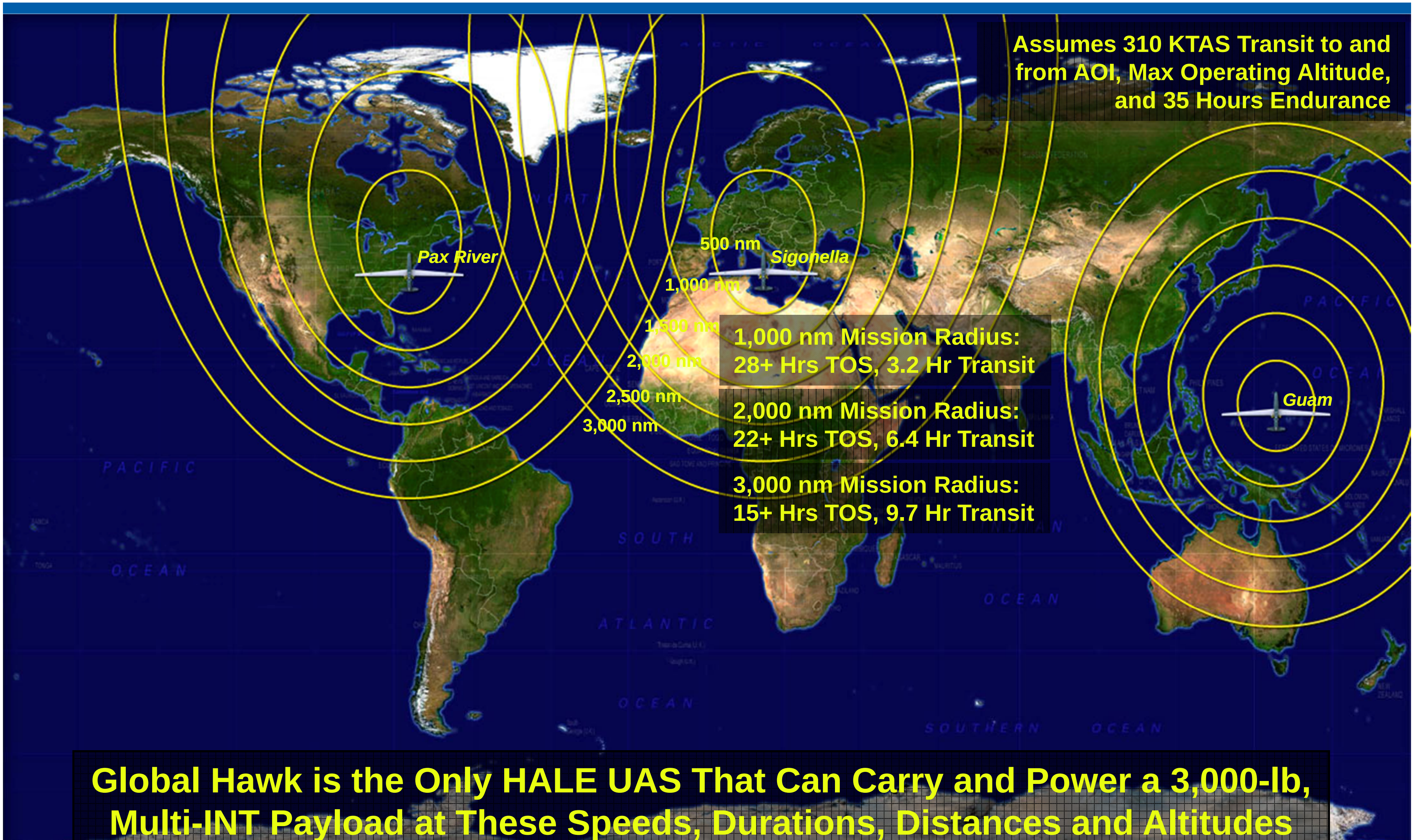

Global Hawk – Biomass Sensing CONOPS

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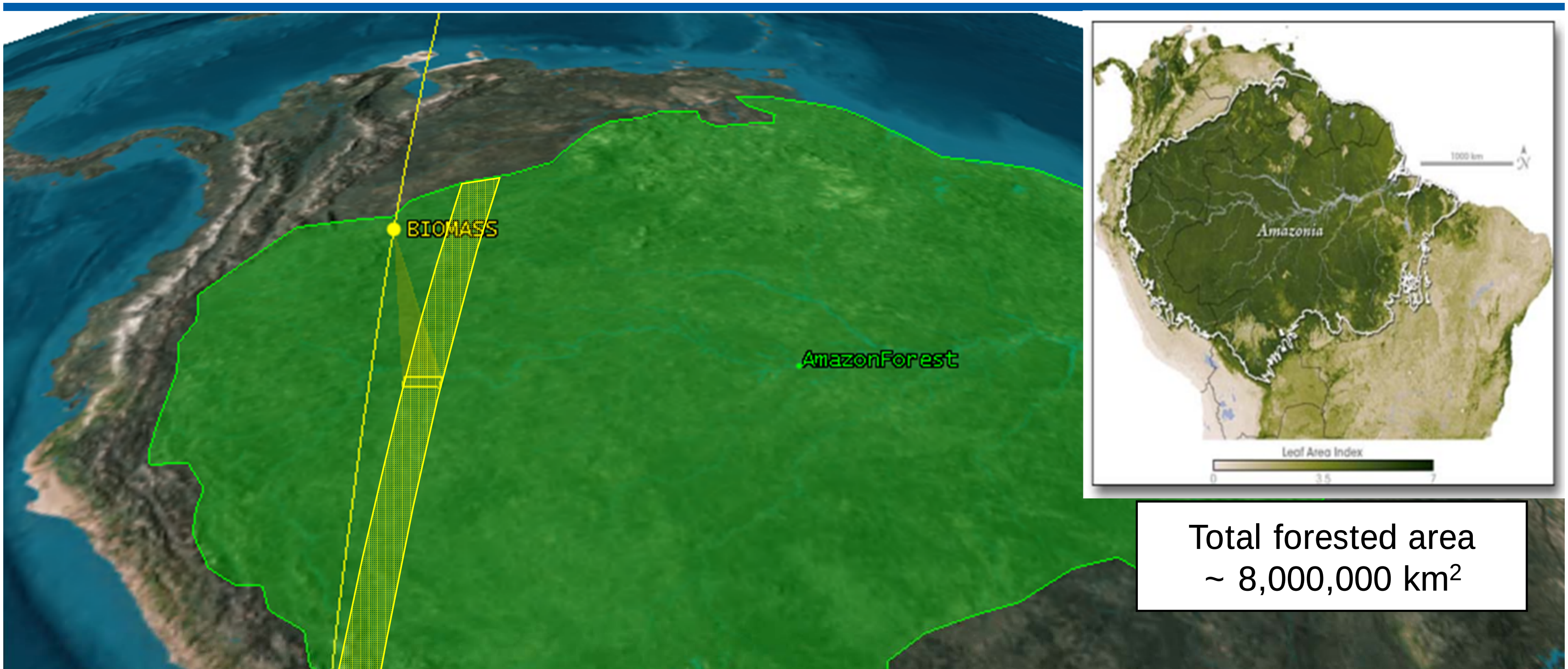

Total forested area
~ 8,000,000 km^2

If Global Hawk missions are flown, from Florida (~14hr round-trip) to Amazon around mid-day, to capture hyperspectral data, flying for ~6 hrs (at 172 ms^{-1}) with 3.45km swath from 65kft this would require 1,000 days (~2.5 yrs) to cover the entire ~ 8,000,000 km2.

In comparison a low altitude aircraft, using conventional lidar technology, from 3kft with a swath of 225m, flying 8 hrs/day (at 60 ms^{-1}), would require ~349 years.

Biomass Mapping with multispectral Imagery and Lidar Elevation Models

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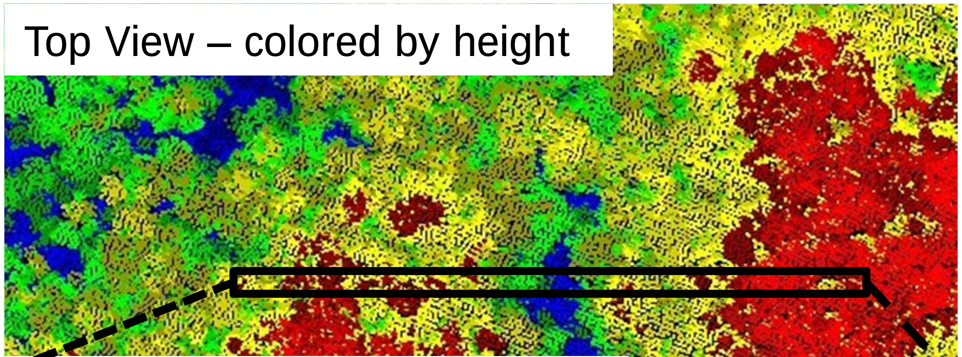
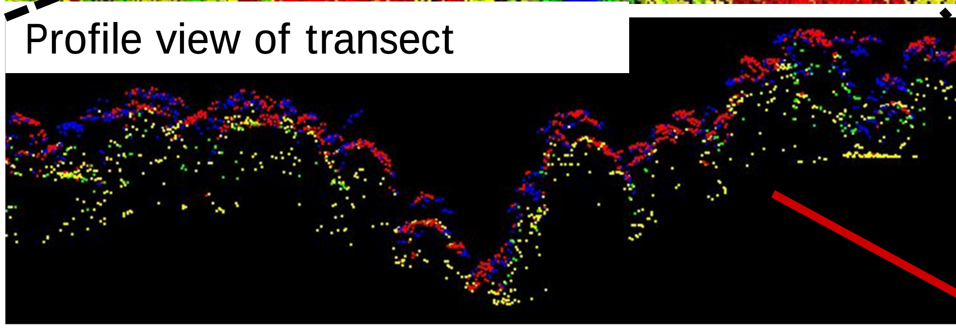
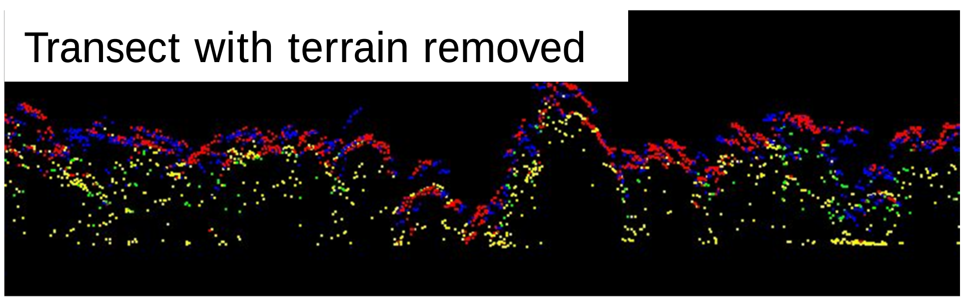
Top View – colored by height



Profile view of transect



Transect with terrain removed



Full canopy lidar, swath 150 m x 6.5 m wide, enables accurate estimate of canopy height and biomass

High Resolution Digital Photography

Imagery draped onto lidar DEM

Summary

- Carbon sequestration will require broad scale implementation across the globe to sequester Carbon at significant quantities.
- The Global scale of Carbon Sequestration will require Measurement, Monitoring, and Verification over large areas covering international boundaries and providing a consistent and uniform output.
- Northrop Grumman has the expertise and capabilities to provide Carbon Sequestration Monitoring and Verification across all environments from sea to space.

Questions

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