Why the HyspIRI Mission is Critical to the Future of Global Climate Science

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With special thanks to Tom Painter, Susan Ustin and the HyspIRI community

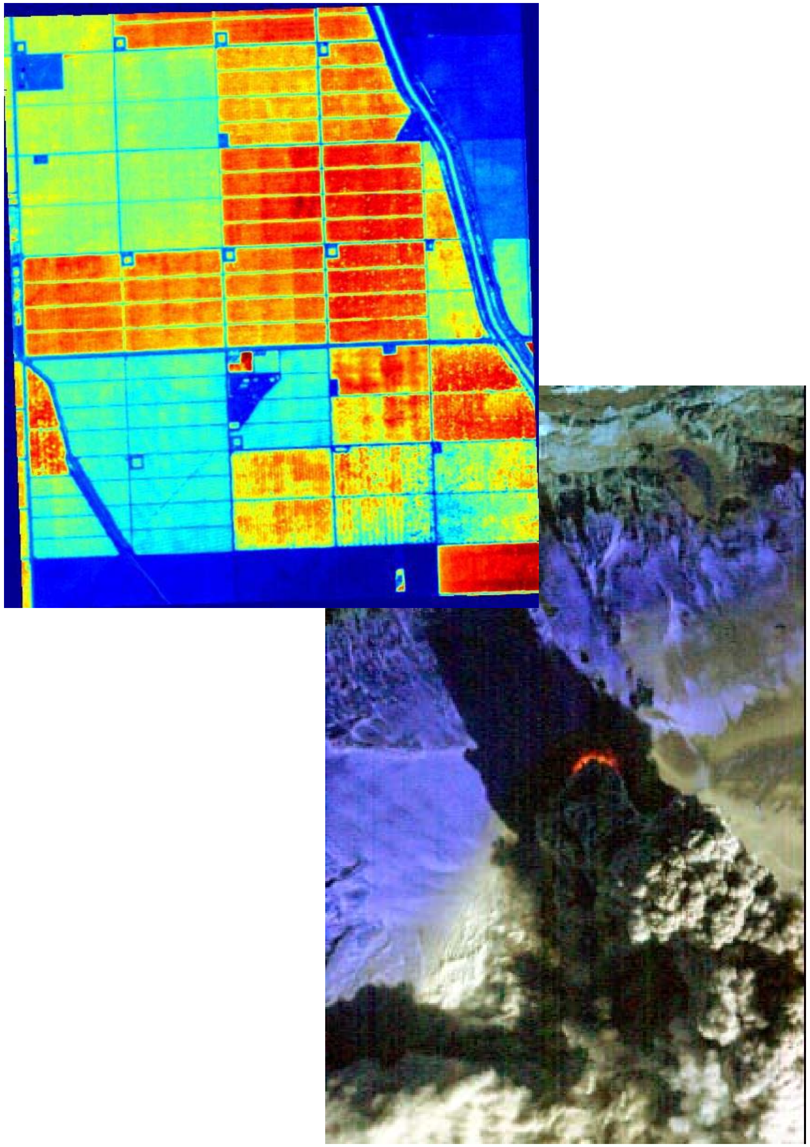
Key Issues

- The big uncertainties in predicting future climate
- The biospheric feedback
- The cryospheric feedback
- Why HyspIRI and not something else

- **Imaging spectroscopy has literally hundreds of applications**. I could put up slide after slide collected from our community showing an astounding array of applications, **from agriculture to volcanoes**.

- Our community has articulated this kaleidoscope of applications time after time, from HIRIS to HyspIRI, and all mission concepts in between.

- Many of the applications are **directly linked to regional climate and, if integrated over space and time, global climate**. But this comes off as contrived to mission decision-makers, and thus our message about the climate relevance of HyspIRI has been confused and unheard.



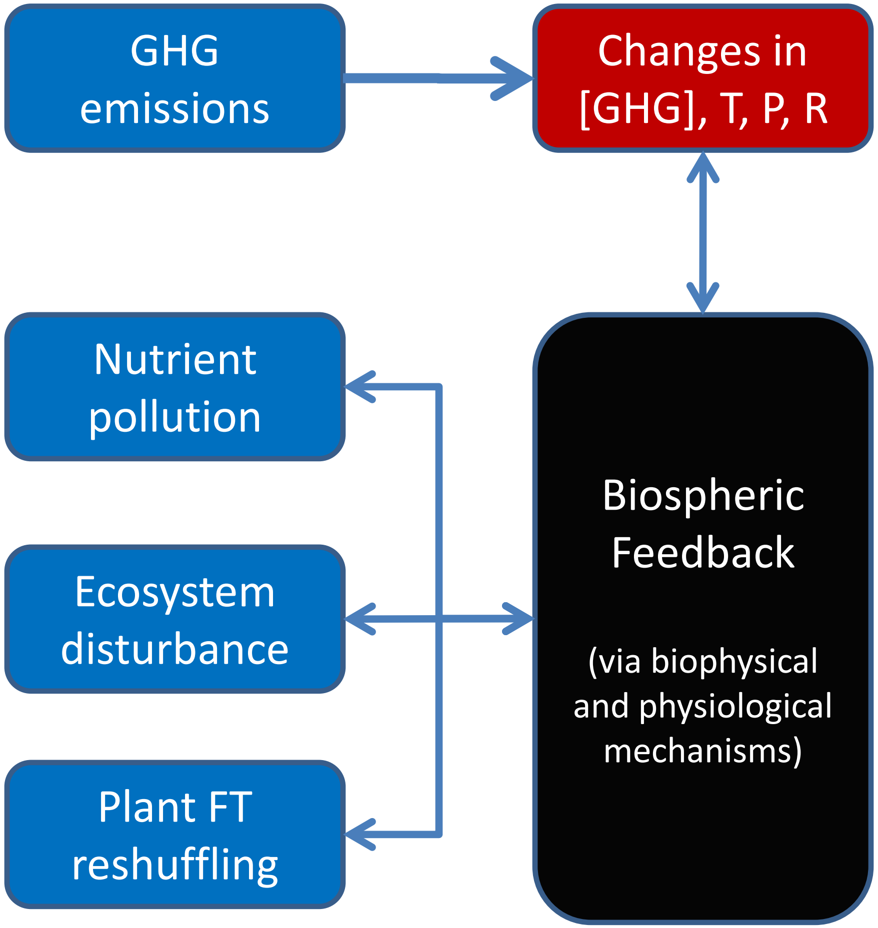
What are the big climate issues calling for the HyspIRI mission?

The biospheric feedback

1. A major uncertainty in predicting future climate lies in a biospheric feedback to a rapidly evolving climate.

2. This biospheric feedback interacts with changes in temperature, precipitation, CO_2, radiation, nutrients, ecological disturbance and plant (autotroph) distributions.

3. CRITICALLY: Although we understand many of the processes underpinning the biospheric feedback, we do not know the relative strength of these processes, spatially or temporally.



A hands-on example of a biospheric feedback

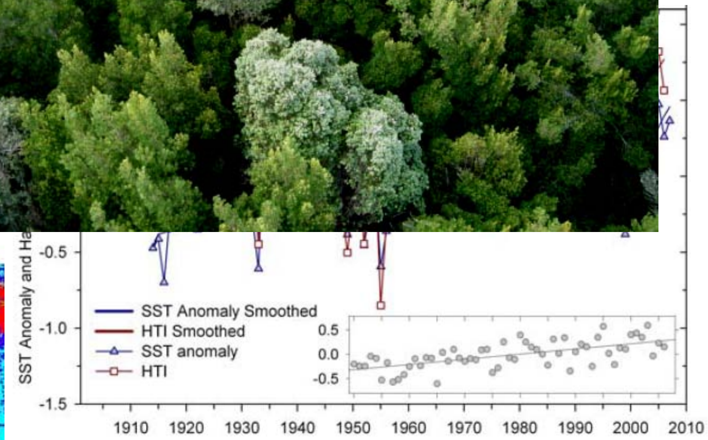
Background

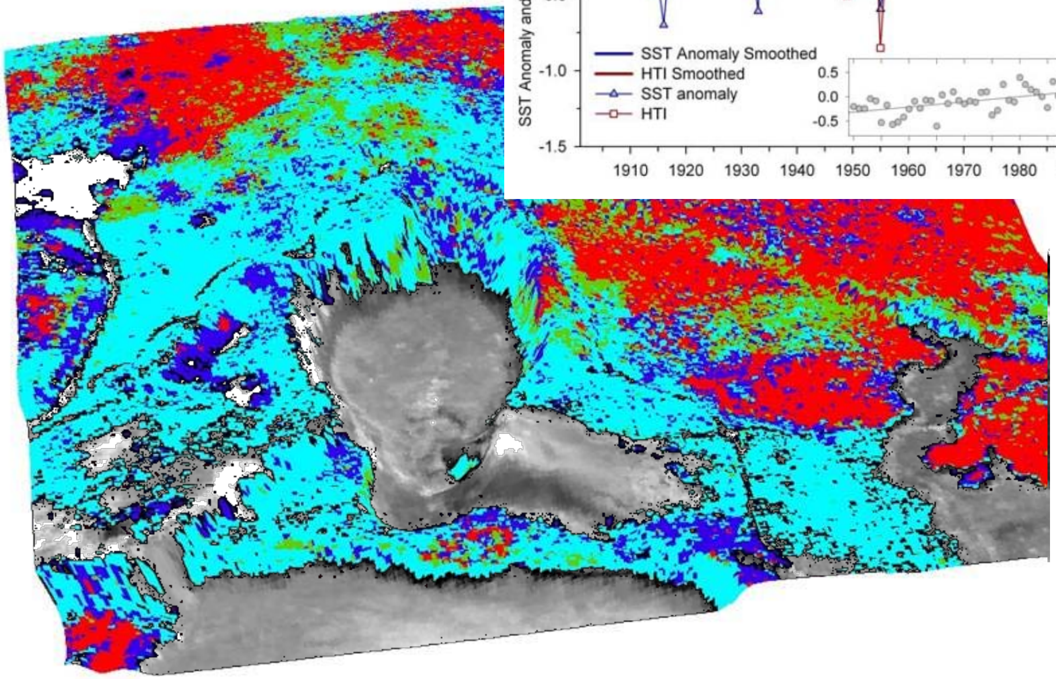
Since 1950, we have witnessed a non-linear increase in the coverage of a nitrogen-fixing invasive tree in Hawaiian forests. The spread of this tree (*Morella faya*) is just a tiny example of the global reshuffling of species caused by people.

At the same time, atmospheric [GHG] has increased non-linearly, with a measureable increase in solar radiation and temperature in Hawaiian forests.

GHG emissions

Plant FT reshuffling





Vitousek et al. 1988, Giambelluca 2009

Four components of this biospheric feedback:

1. PFT switch → more invasion during warming/drying
2. Nutrient pollution → more GHG
3. Forest carbon loss → more GHG
4. Increased albedo → cooling

Here's how:

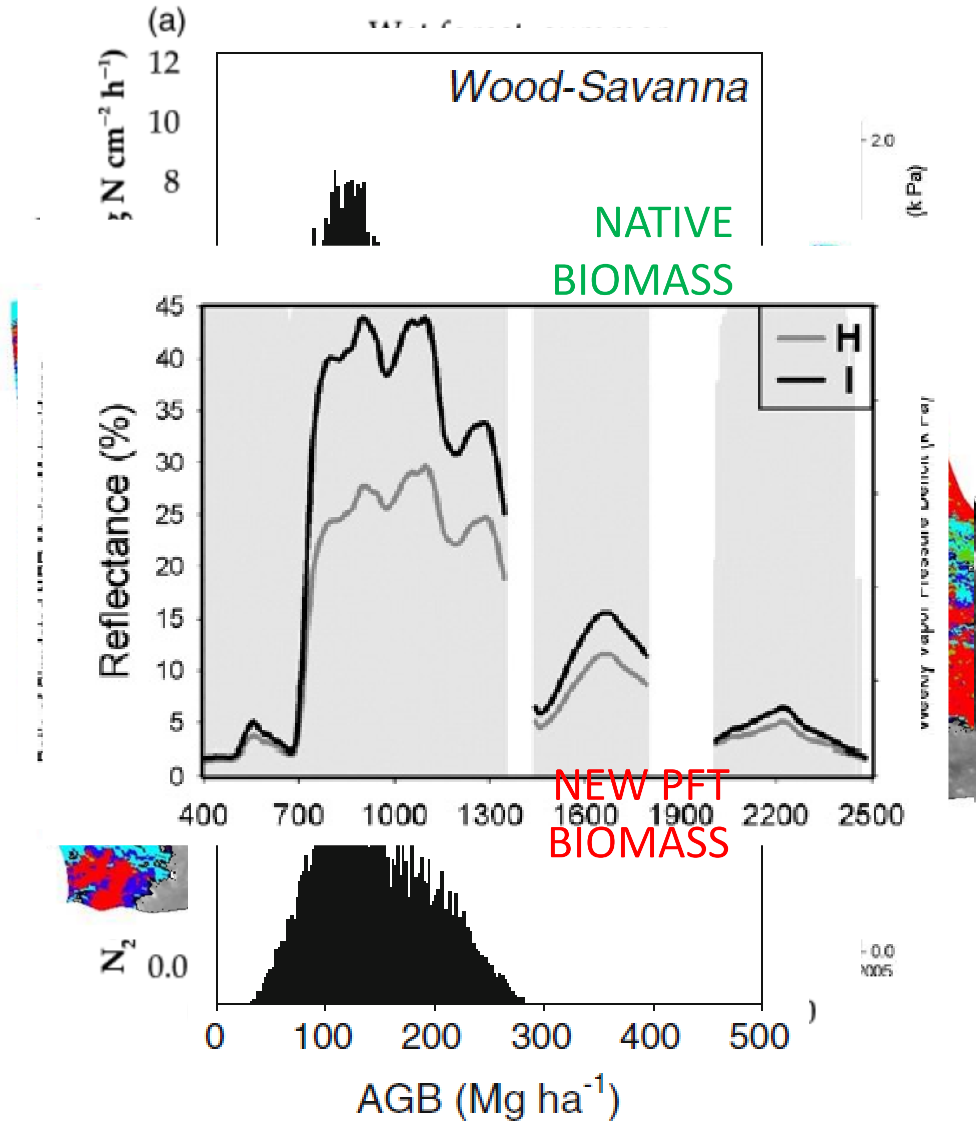
1. The invasive PFT grows faster and spreads more widely than all of the native PFTs combined, but only during periods of anomalously high radiation and temperature levels associated with climate change.

2. The invasive tree outcompetes native trees for light, eliminating the natives, and changing the entire makeup of the forest (a major change in PFT has occurred).

3. The new PFT increases nitrogen oxide gas emissions from soils by 16-times over background levels. This includes the super-GHG N_2O.

4. The physiological factors that allow the invader PFT to win, also cause it to store less carbon than the natives it replaces. This increases net GHG emissions.

5. The physiological factors that allow the invader to steal light also cause a 40% increase in forest albedo. This has a gross cooling effect on climate.

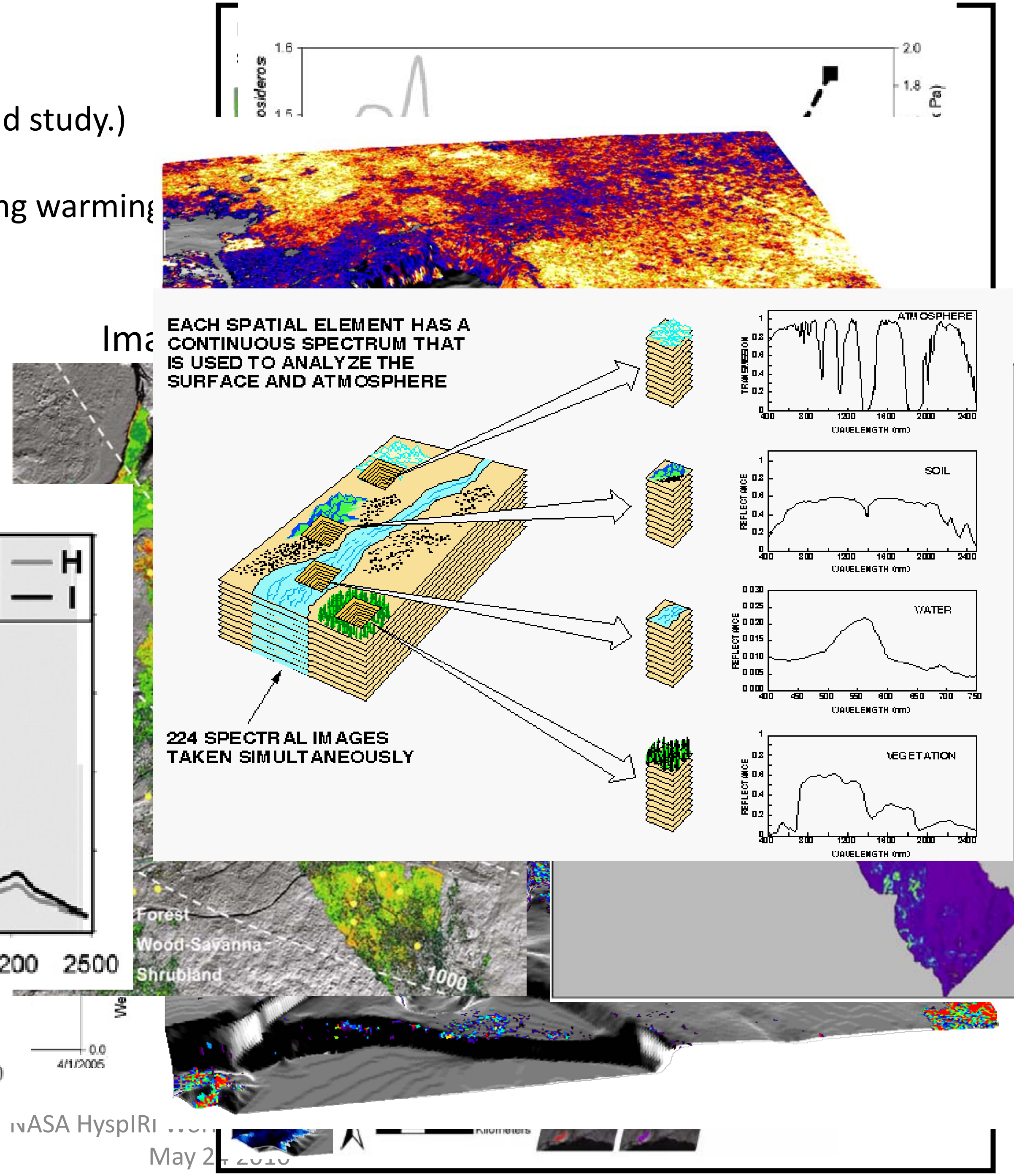


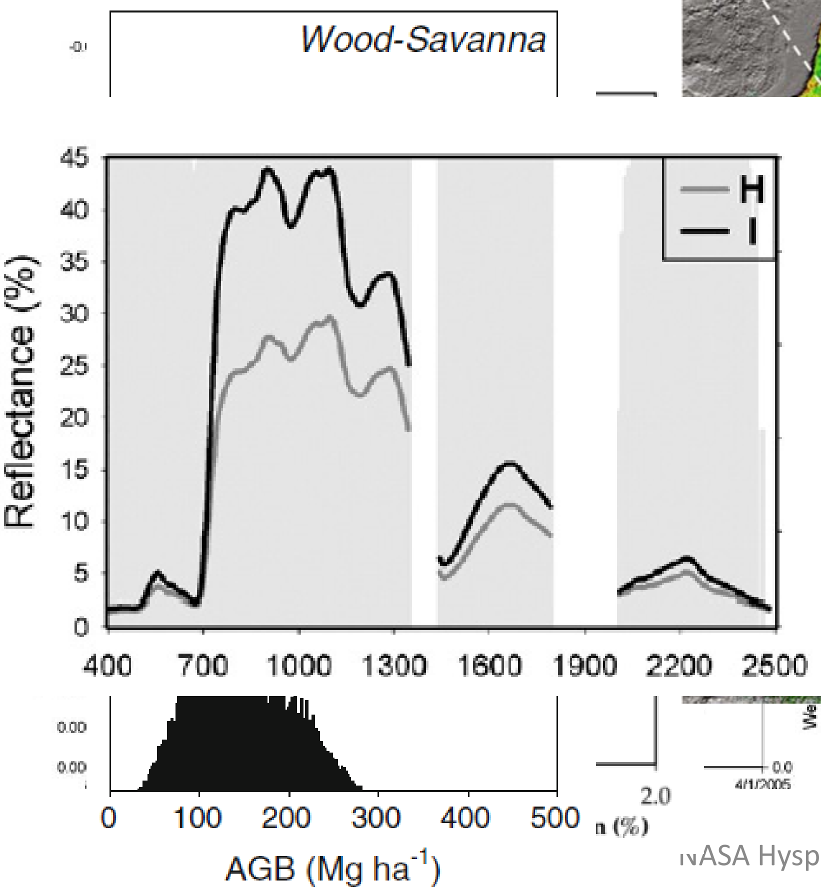
Asner et al. 2006, 2008
Asner & Vitousek 2005, Hall & Asner 2007

How did we figure this out?

(Hint: Not in 15 years of intensive field study.)

1. PFT switch → more invasion during warming and drying events
2. Nutrient pollution → more GHG
3. Forest carbon loss → more GHG
4. Increased albedo → cooling





Can it be done with other technologies?

Observation	Approach	Method	Other attempts	Report card
PFT change	Chemo-spectral analysis	Spectroscopic RT inversion, PLSR, and SMA with AVIRIS	MODIS-500, Landsat veg. indices and SMA (CLASlite)	MODIS: D (spatial/spectral) Landsat: C (spectral)
Growth response to climate change	Physiological analysis	Narrowband indices with Hyperion	ALI veg. Indices	D (weak greenness effect, no other pattern)
Nitrogen increase	Chemo-spectral analysis	Spectroscopic RT inversion, PLSR with AVIRIS	Hyperion	D (way too noisy)
Carbon decrease	Species detection, then 3-D structure	AVIRIS-guided LiDAR	Landsat veg. indices	D (vague pattern in forests)
Albedo increase	Spectral	Spectral BRDF with AVIRIS	MODIS and Landsat NIR	MODIS: D (spatial) Landsat: B (11% diff in spectral)

Do biospheric feedbacks matter at the global climate scale?

The Amazon story…without an ending

Climate is changing. We are seeing an increasing in nighttime temperatures and a 0.3% per year decrease in mean annual precipitation.

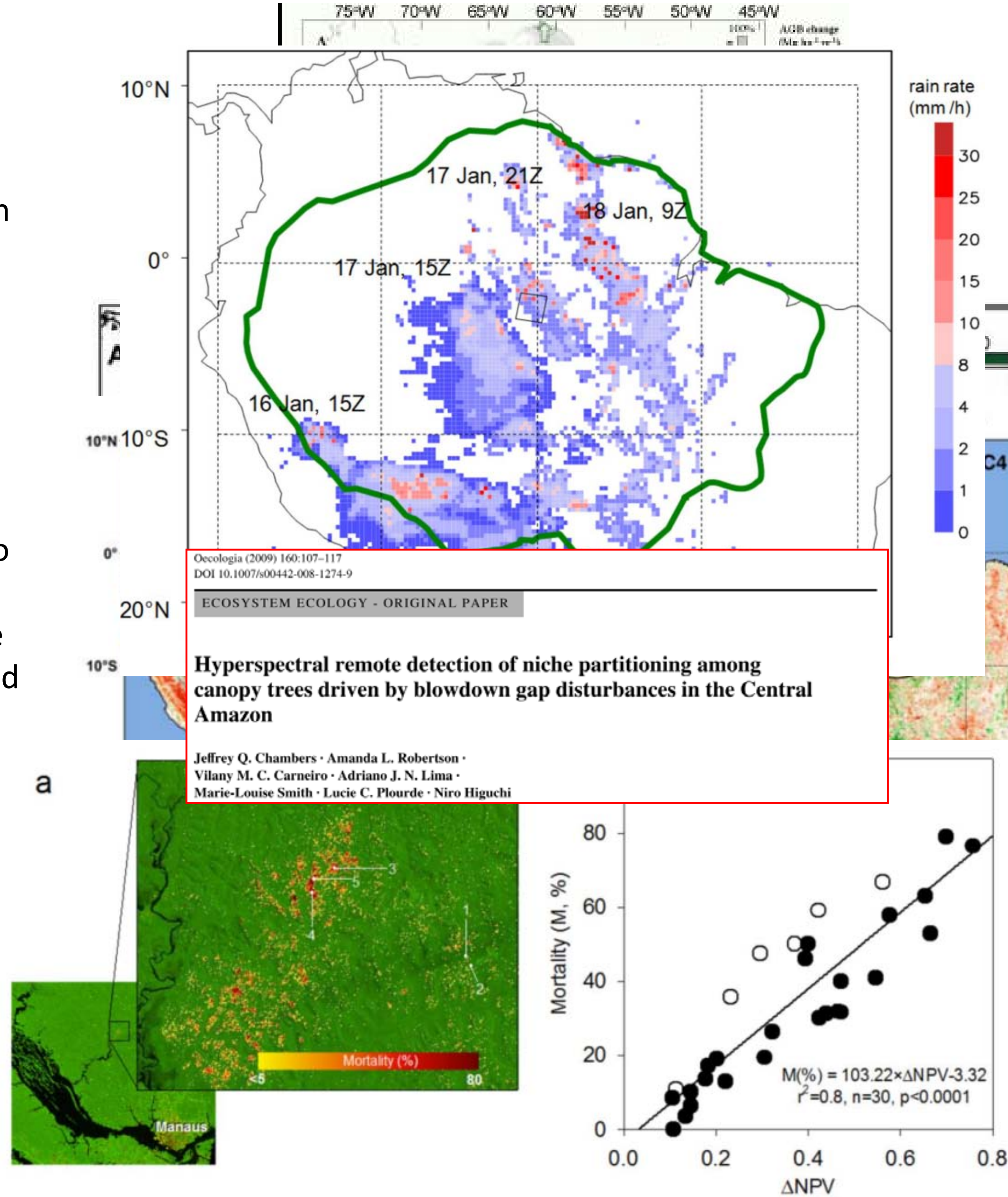
A major climate change effect is drought, both ENSO and non-ENSO related. Take the 2005 Amazon mega-drought as an example.

Saleska et al. 2007 (Science) used the MODIS EVI to assess biospheric response. They observed apparent "green up". If true, then CO_2 uptake is a negative feedback response to drought and to climate warming. Was it true?

Samanta et al. 2009 (GRL) shows that a reprocessi of the MODIS data yield no apparent green u response to drought. MODIS is not the technology for quantitative detection of biospheric feedback in this case.

Meanwhile, all field indications were that mortalit actually increased enormously across the Amazon (Phillips et al. Science)

Are there other feedbacks? (Chambers et al. 2009)

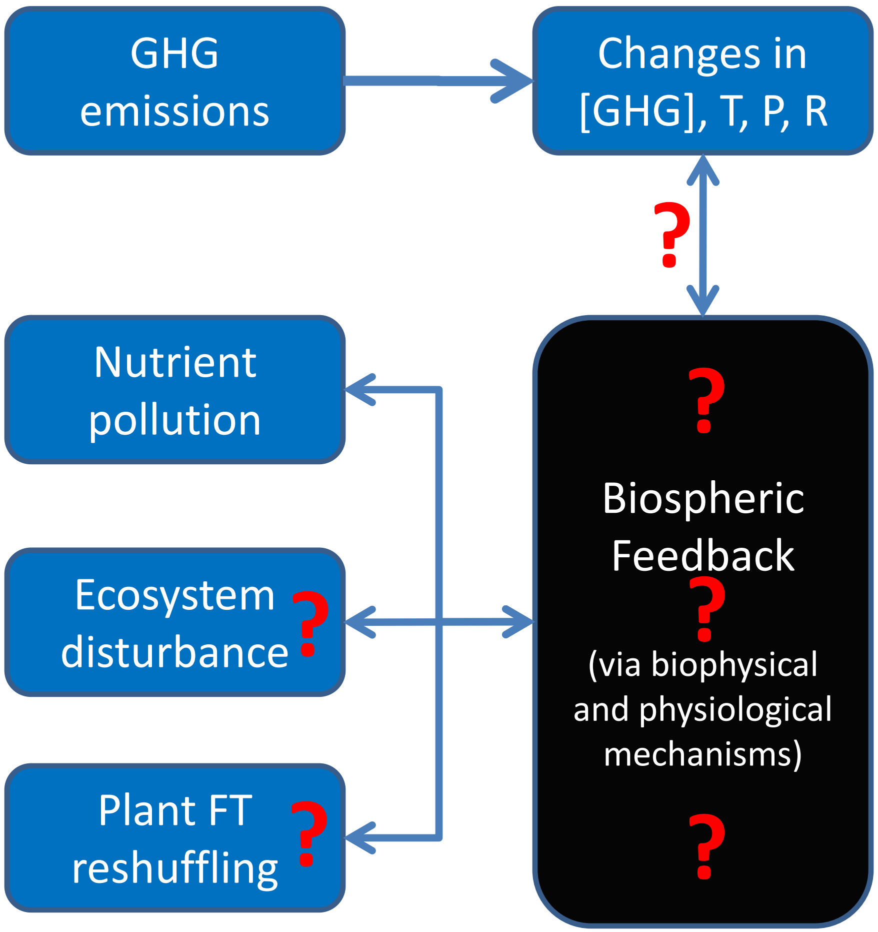


So what can HyspIRI do to address the Amazon (and global) tropical feedback challenge?

1. Physiological response to drought – whether positive or negative – is a HUGE uncertainty in the biospheric feedback to climate variability and change. HyspIRI is the only technology to deliver **global quantitative physiological measurements** needed to constrain estimates of GHG fluxes and the models used to simulate them.

2. Diffuse disturbance patterns are the spatially dominant type of change that occurs in global ecosystems (not deforestation). HyspIRI offers both **quantitative disturbance detection and physiological response globally**.

3. PFT changes underpin CO_2 and other GHG fluxes in the biospheric feedback. HyspIRI offers **quantitative mapping of PFT changes globally**.



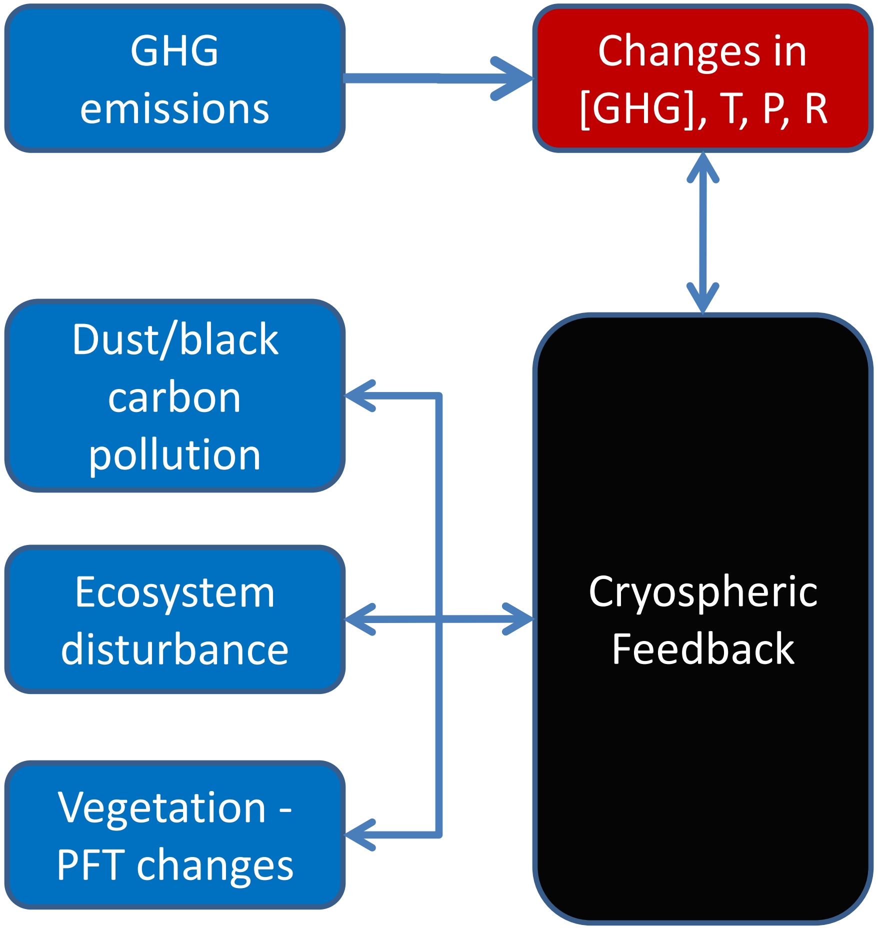
What are the big climate issues calling for the HyspIRI mission?

The cryospheric feedback

1. Another major uncertainty in predicting future climate rests in the cryospheric feedback (IPCC 2007).

2. The cryospheric feedback is determined by changes in albedo caused by changes in temperature (melt), precipitation (accumulation), and dust and black carbon deposition.

3. The cryospheric feedback is linked to the biospheric feedback.



2.9.1 Uncertainties in Radiative Forcing

< >

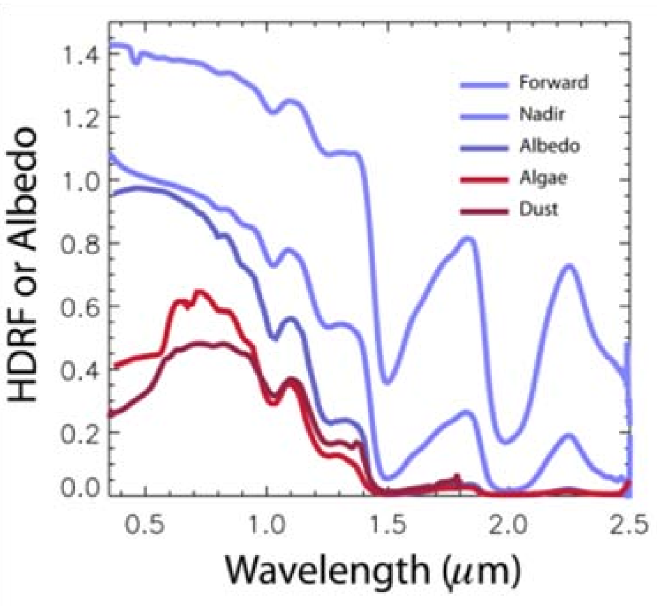
The TAR assessed uncertainties in global mean RF by attaching an error bar to each RF term that was 'guided by the range of published values and physical understanding'. It also quoted a level of scientific understanding (LOSU) for each RF, which was a subjective judgment of the estimate's reliability.

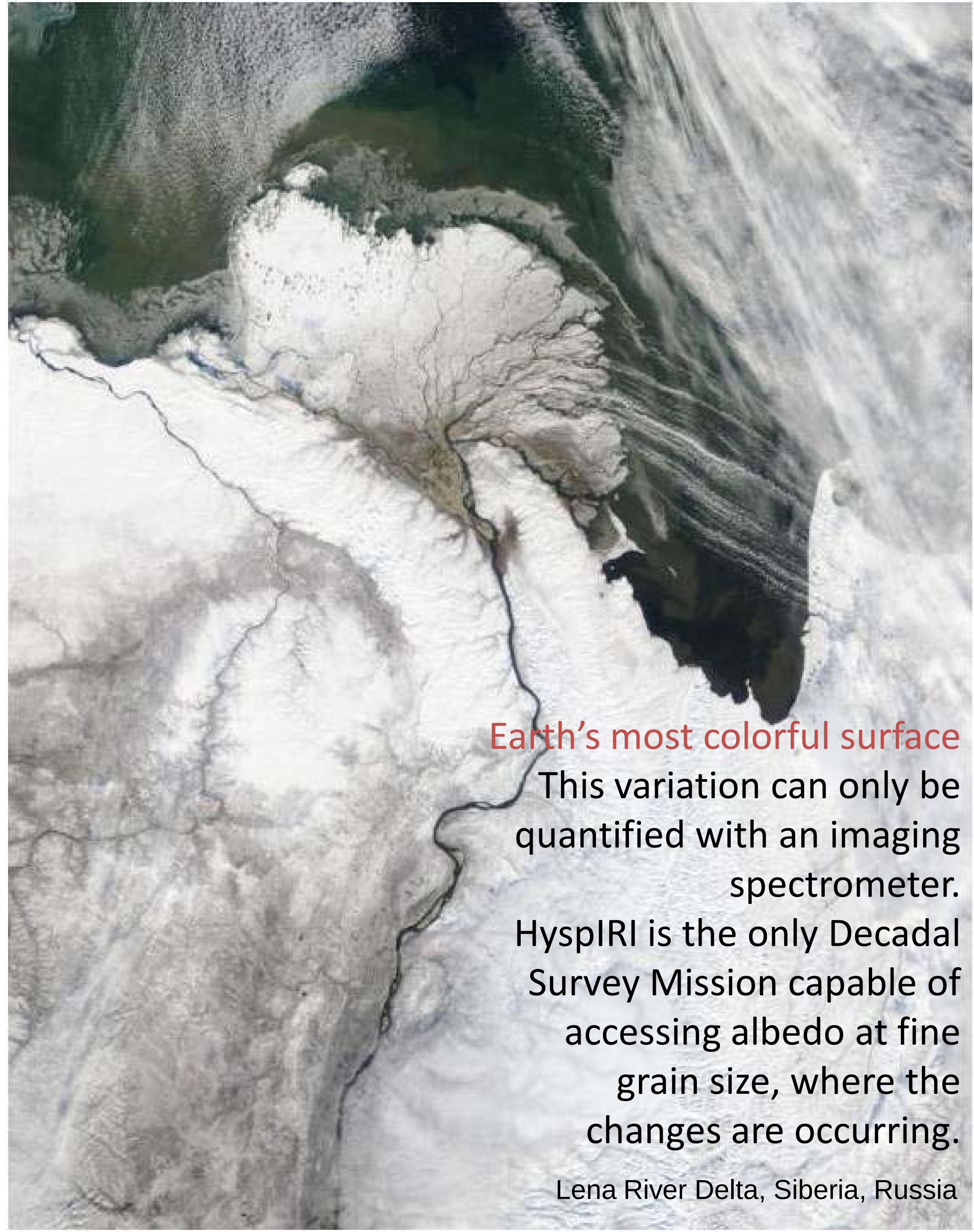
	Evidence	Consensus	LOSU	Certainties	Uncertainties	Basis of RF range
LLGHGs	A	1	High	Past and present concentrations; spectroscopy	Pre-industrial concentrations of some species; vertical profile in stratosphere; spectroscopic strength of minor gases	Uncertainty assessment of measured trends from different observed data sets and differences between radiative transfer models
Surface albedo (land use)	A	2 to 3	Medium to Low	Some quantification of deforestation and desertification	Separation of anthropogenic changes from natural	Based on range of published estimates and published uncertainty analyses
Surface albedo (BC aerosol on snow)	B	3	Low	Estimates of BC aerosol on snow; some model studies suggest link	Separation of anthropogenic changes from natural; mixing of snow and BC aerosol; quantification of RF	Estimates based on a few published model studies

*level of scientific understanding" (*LOSU)*

Climate sensitivity of the Earth system is modulated by the response of the cryosphere to radiative forcings – primarily through the *snow-albedo feedback*

Hansen and Nazarenko 2004, *PNAS*
Ramanathan and Carmichael 2008, *Nature Geosci*
Flanner et al 2009, *ACP*





Earth's most colorful surface

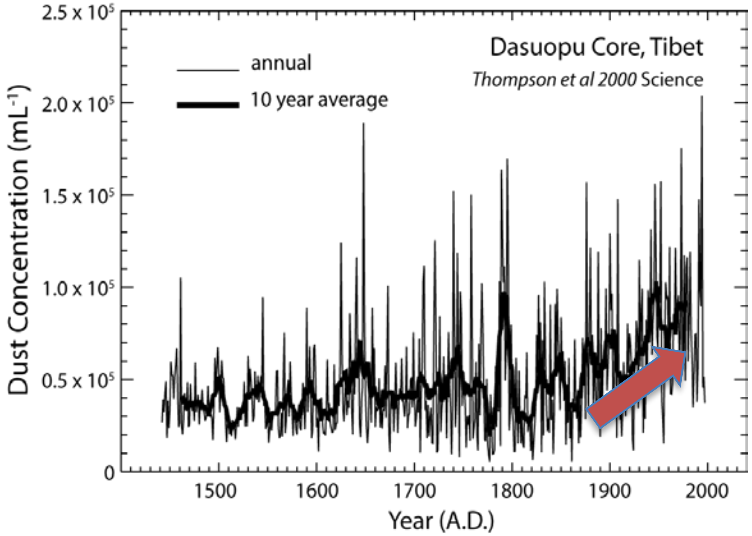
This variation can only be quantified with an imaging spectrometer.

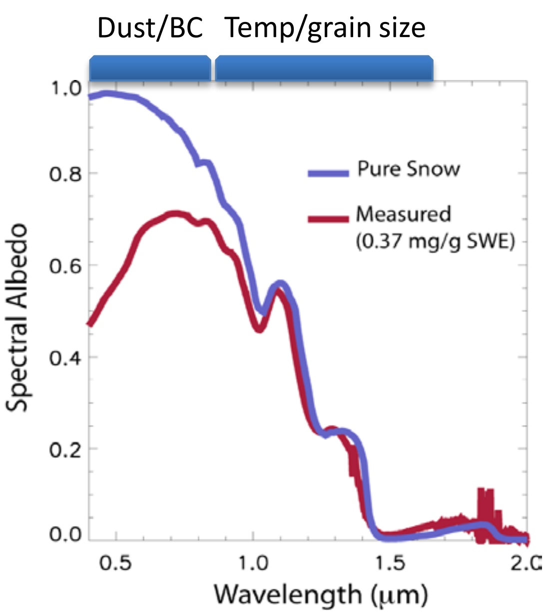
HyspIRI is the only Decadal Survey Mission capable of accessing albedo at fine grain size, where the changes are occurring.

Lena River Delta, Siberia, Russia

What is causing the downwasting and retreat of Himalayan glaciers?

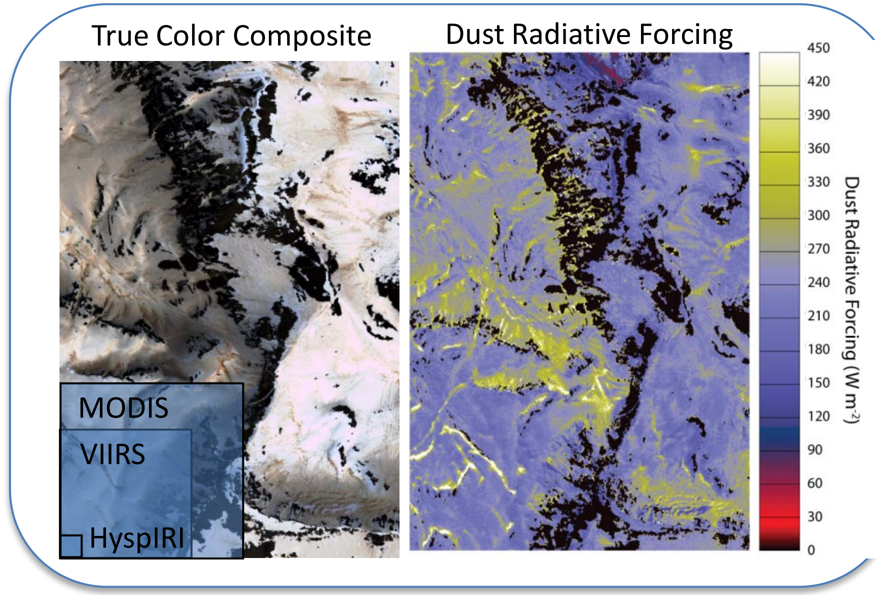
Increasing temperatures and increasing dust and soot combine in unknown proportions to accelerate melt through changes in albedo. HyspIRI is the only sensor that allows us to attribute changes in albedo into effects from temperature and dust/black carbon and at a fine enough spatial resolution that heterogeneous terrain can be resolved. Multi-band sensors such as NPOESS VIIRS have neither capacity.





Impact of dust radiative forcing on snowpack

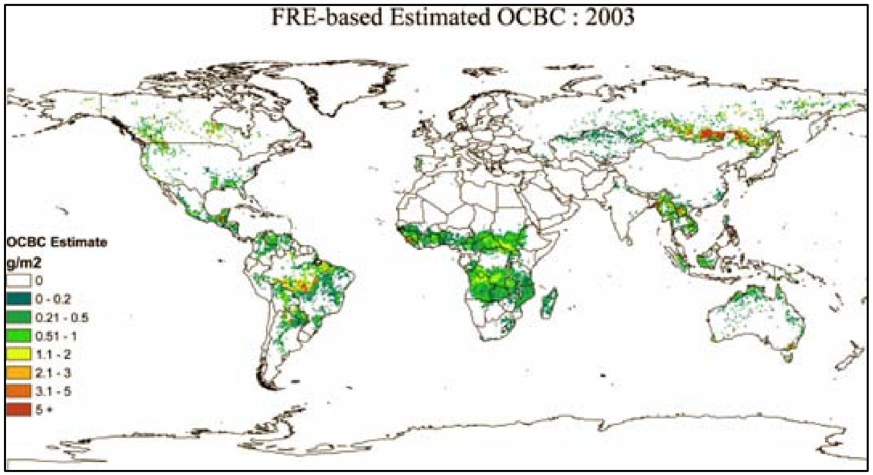
Land use and vegetation changes in globe's arid and semi-arid lands in the mid to late 1800s has led to 5-fold increase in dust loading to mountain snow cover in the Colorado River Basin (CRB) and other ranges of the globe. In the CRB, radiative forcing by this increased dust shortens snow cover duration by 3-5 weeks, intensifies spring runoff, and reduces total runoff. **Painter et al 2010, *PNAS***

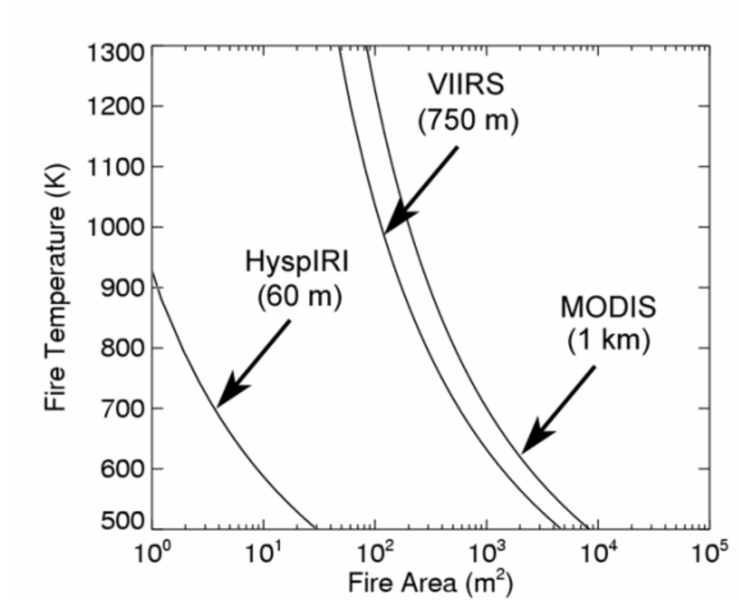


The spectral sampling of an imaging spectrometer is required to move beyond detection to quantification and attribution. The proposed spatial sampling of HyspIRI accesses entirely snow covered slopes whereas the spatial sampling of multispectral sensors MODIS and VIIRS most often is contaminated by spatial/spectral mixing of rock cliffs.

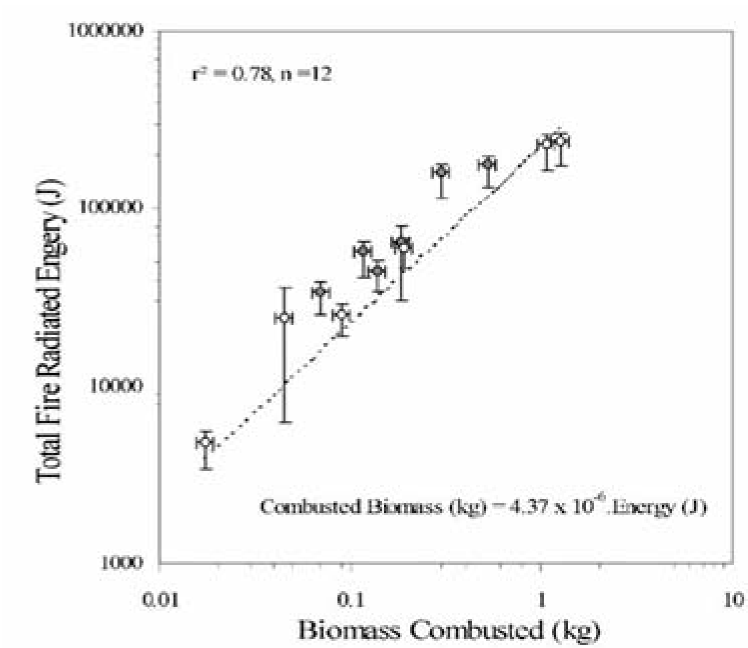
Painter et al. 2010, PNAS

Many other feedbacks are mediated by many other processes that HyspIRI uniquely measures or vastly improves measurement for:





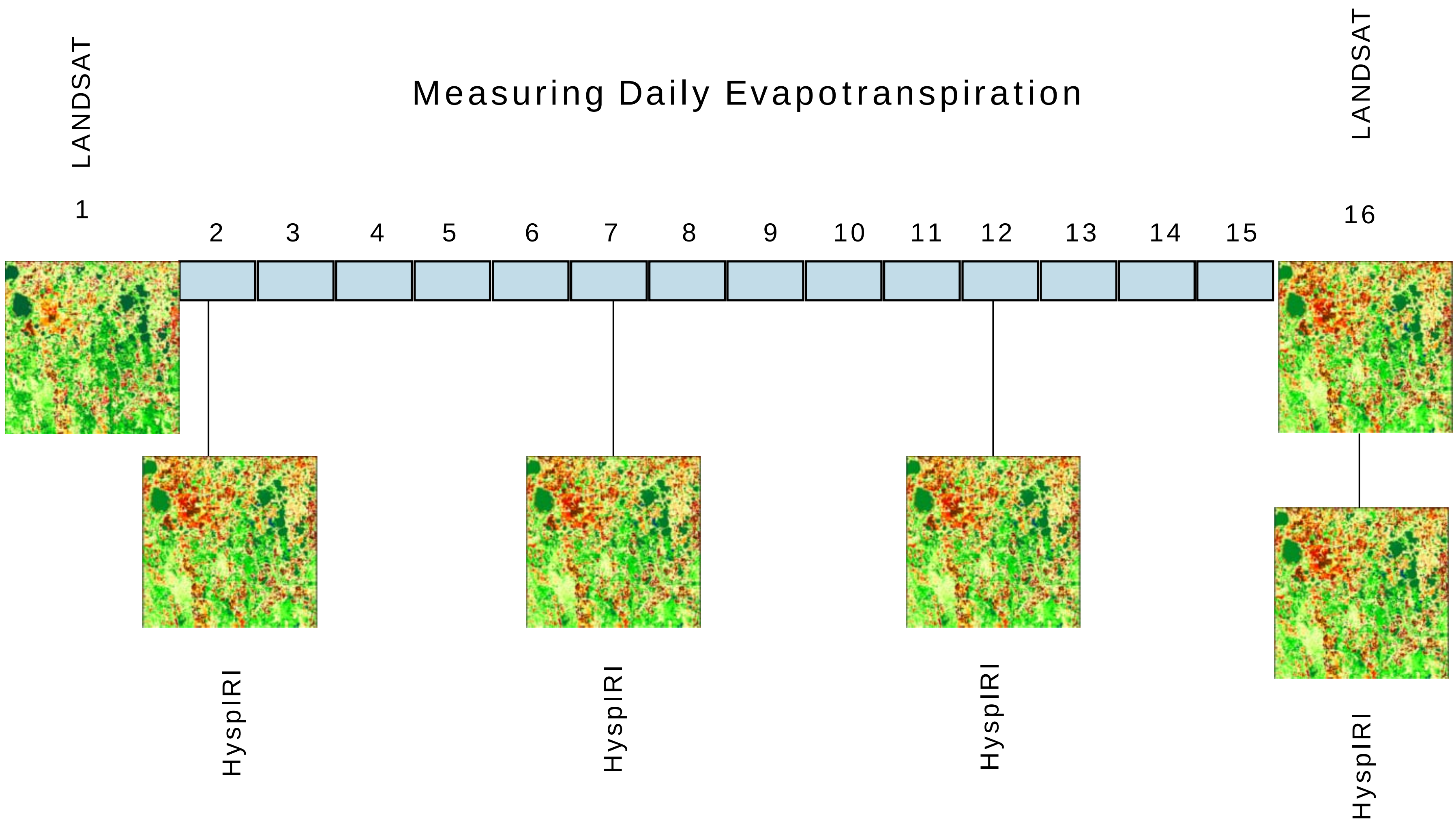
90% probability of detection; boreal forest; nadir view



Fire Radiative Energy to estimate combusted biomass: Need 3-5 um data

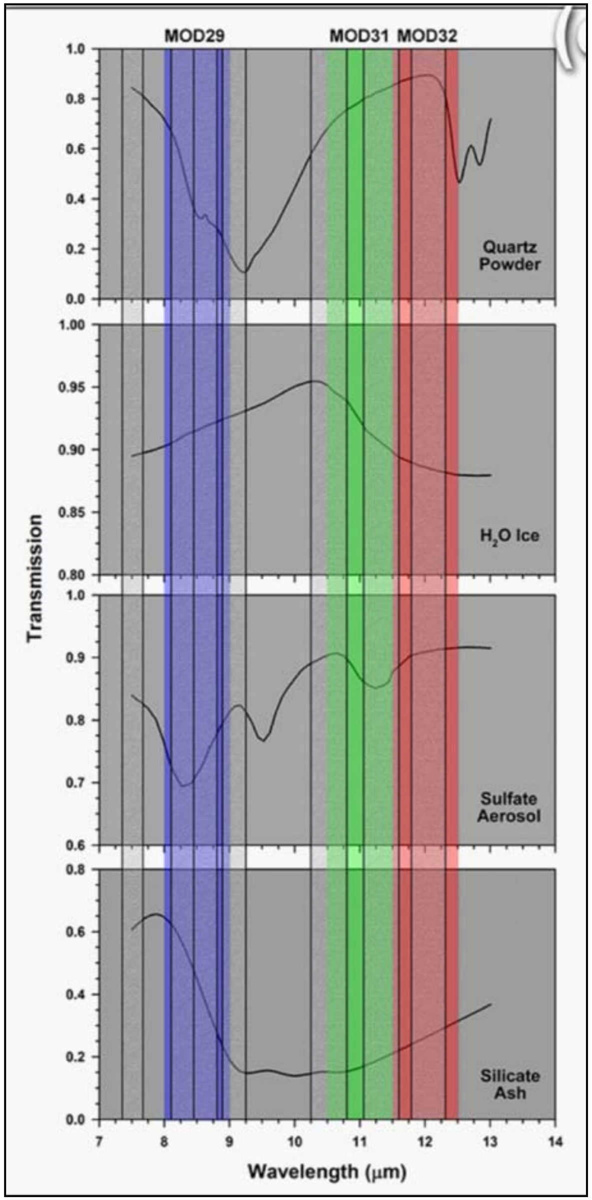
Ellicott et al 2009
Wooster et al 2002 and 2003

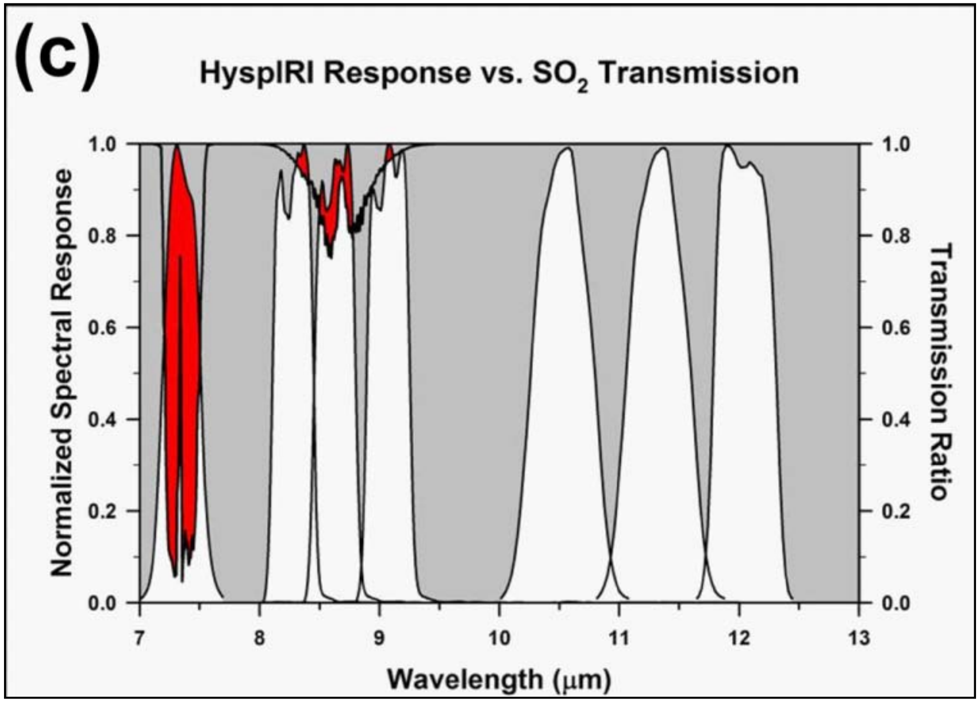
Latent/sensible heat flux: Evapotranspiration



Radiative forcing: Volcanic eruptions

Eyjafjallajökull Iceland Volcano Eruption

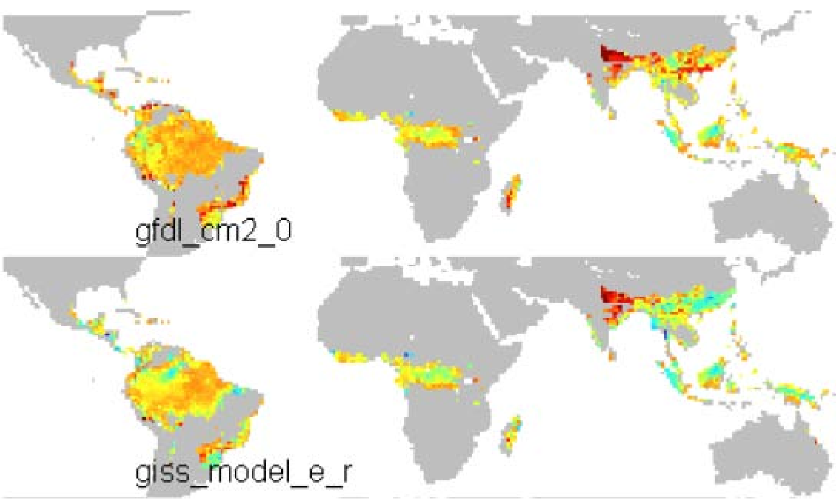




Are these “just” regional phenomena, or are these truly global, climate-relevant processes?
Footprint of the biospheric feedback in the humid tropics

Table 2 Percentage of the humid tropical forest biome with current major land use (LU) as expressed by deforestation and selective logging, predicted major climate change causing a reshuffling of vegetation types (C), a combination of climate change and land use (C+LU), and neither climate change nor land use (N)

Region	C	LU	C + LU	N
C. America	66	2	15	16
S. America	63	3	24	9
Africa	51	6	14	29
Asia-Oceania	37	19	21	23



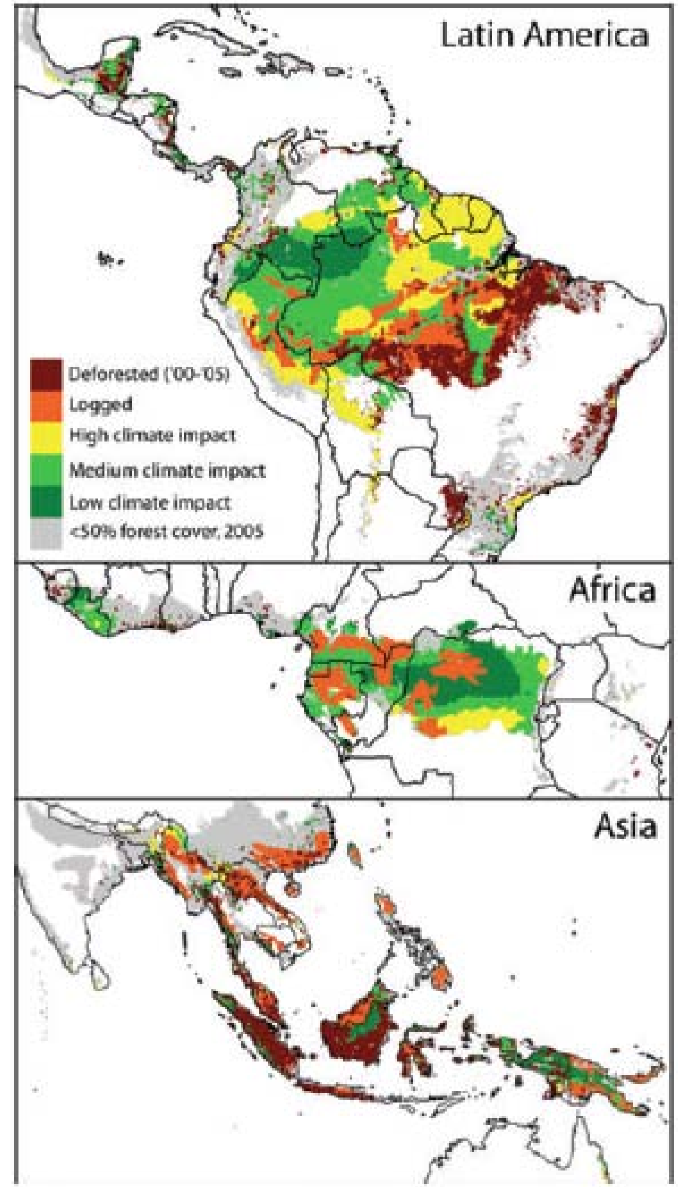


Figure 6 The footprint of deforestation, selective logging, and climate change in the humid tropical forest biome.

Asner et al. 2010

Footprint of the cryospheric feedback

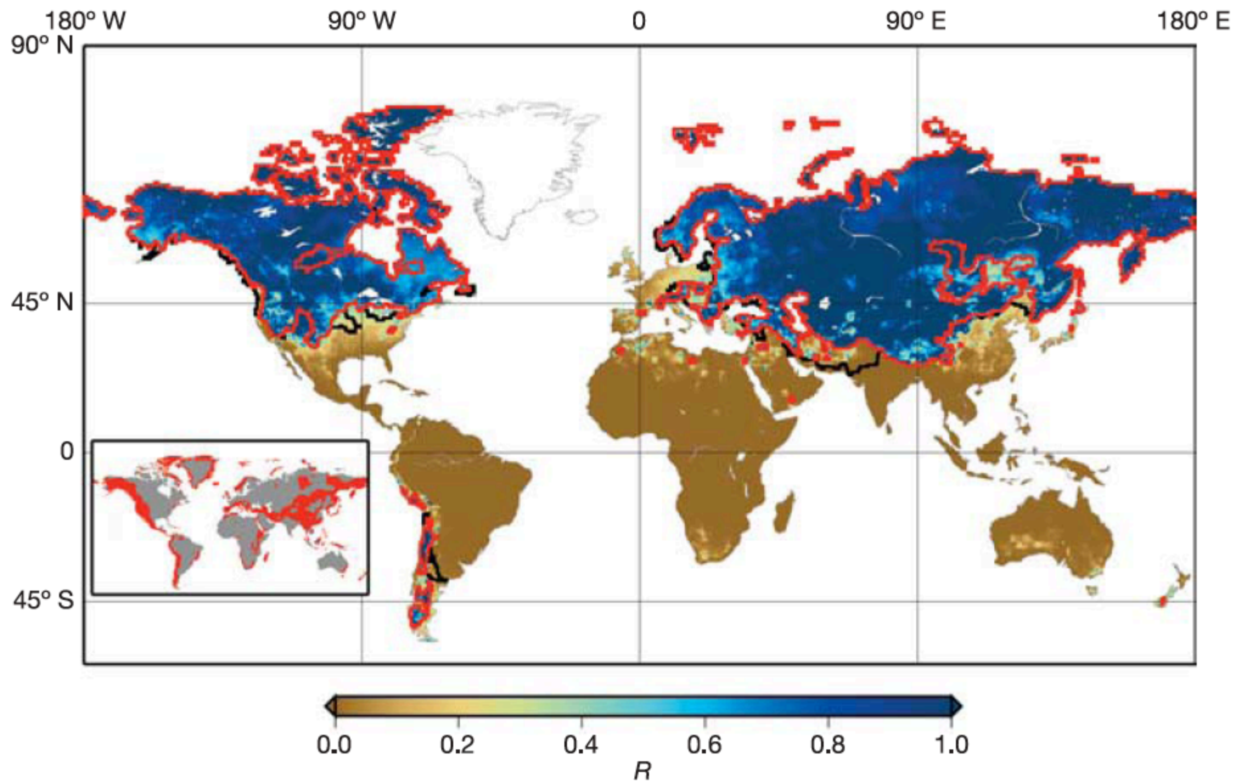
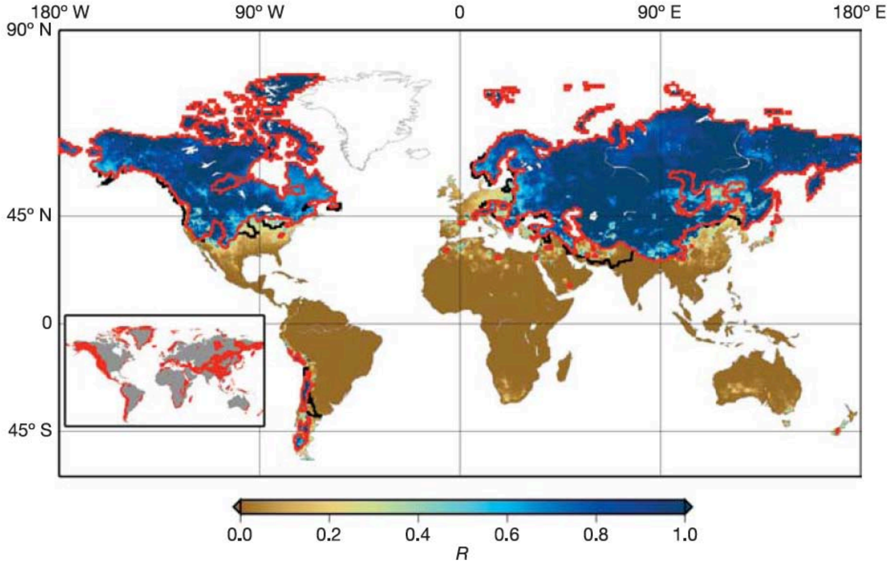
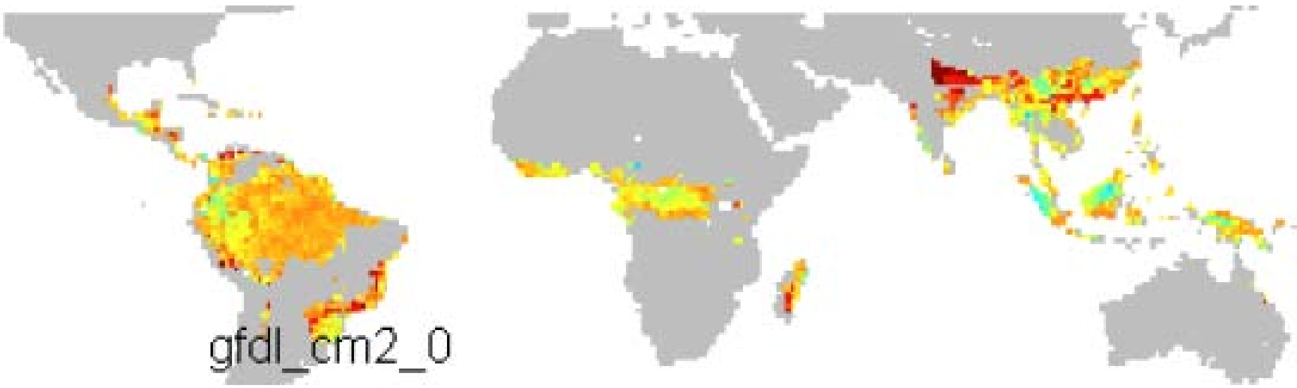


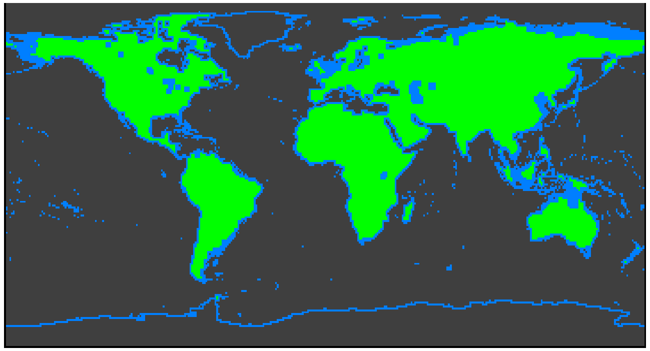
Figure 1 | Accumulated annual snowfall divided by annual runoff over the global land regions. The value of this dimensionless ratio lies between 0 and 1 and is given by the colour scale, *R*. The red lines indicate the regions where streamflow is snowmelt-dominated, and where there is not adequate reservoir storage capacity to buffer shifts in the seasonal hydrograph. The black lines indicate additional areas where water availability is predominantly influenced by snowmelt generated upstream (but runoff generated within these areas is not snowmelt-dominated). The inset shows regions of the globe that have complex topography using the criterion of ref. 17.

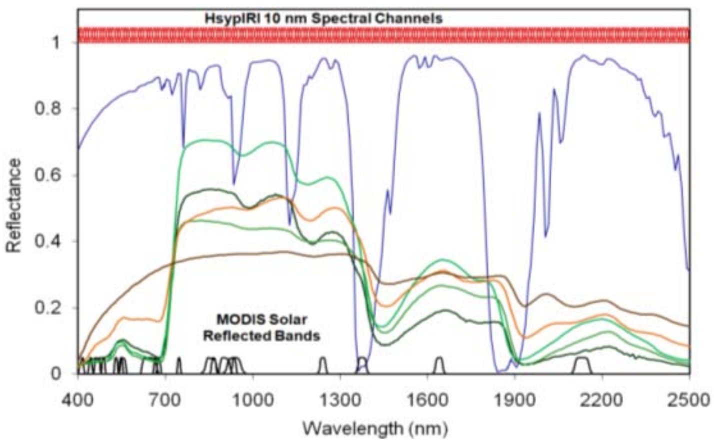
Barnett et al. 2005

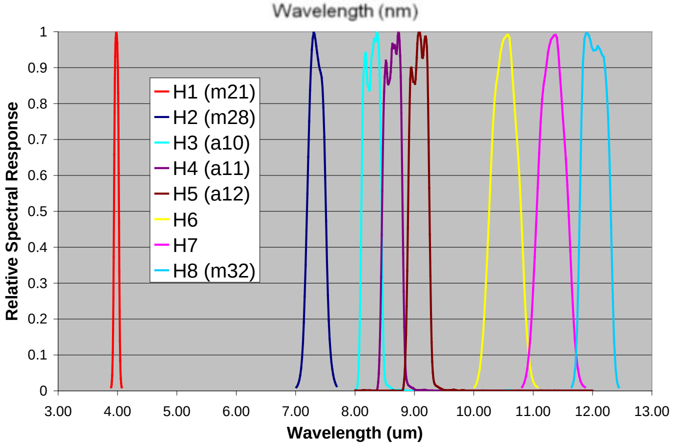
Can HyspIRI deliver?







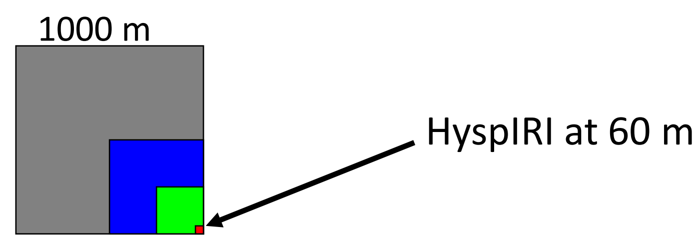




HyspIRI is a global mission, measuring land and shallow aquatic habitats at 60m and deep oceans at 1km every 5 days (TIR) and every 19 days (VSWIR)

HyspIRI's VSWIR imaging spectrometer directly measures the full solar reflected spectrum of the Earth from 380 – 2500nm at 10 nm.

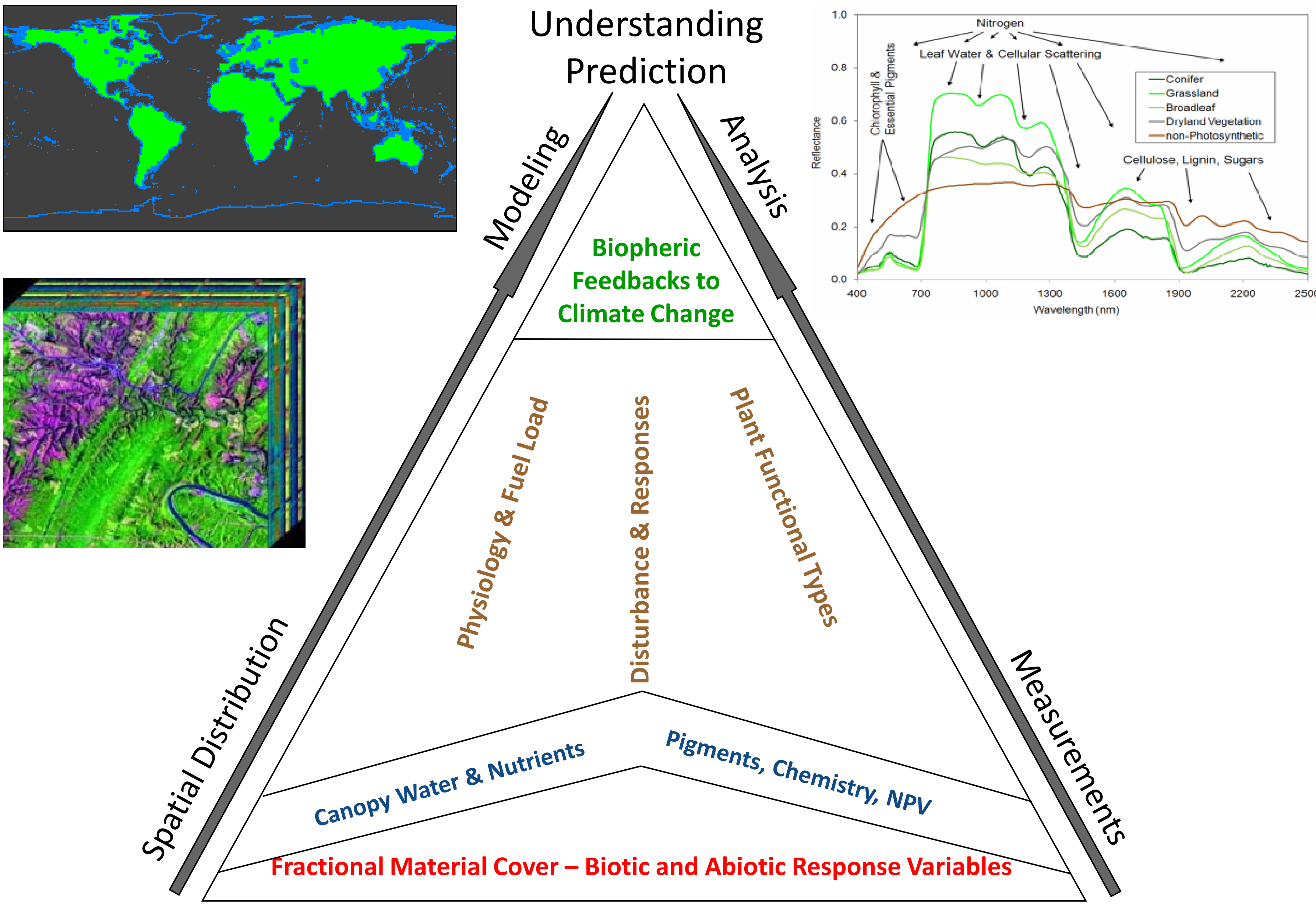
HyspIRI's TIR directly samples the Earth's emitted thermal energy in 7 bands between 7.5-12 µm, & 1 band between 3-5 µm



Why HyspIRI and not something else?

Country	Instrument	Swath km	~Dates	Terrestrial Coverage in 19 days	Mission Type	Repeat interval, days	TIR capability
USA	Hyperion	7.5	2000-	<0.5%	Demo/Sampling/Application	--	none
USA	HyspIRI	150	TBD	100%	Global/Climate	19	8 TIR bands
Germany	EnMAP	30	2014	<1%	Sampling/Application/Process	--	none
Italy	PRISMA	30	2013	~1%	Demo/Sampling/Application/Process	--	none
Japan	ALOS3	30	2014	~1%	Sampling/Application/Process	--	none
India	IMS Resource Sat-3	25	2013	~1%	Sampling/Application/Process	--	1 TIR band

HyspIRI Global Climate Science – Biosphere Component



Three top land models serving as the lower boundary for GCM work

Major Model Inputs	**CASA-3D**	**SiB3**	**Ecosystem Demography**
Vegetation Type	General Land Cover	General Land Cover	Prescribed
Plant Functional Types	Prescribed	Prescribed	Prescribed
Fractional Carbon Cover	---	---	---
Vegetation Greenness	NDVI	NDVI	NDVI
Fractional PAR Absorption	NDVI	NDVI	NDVI
Leaf Area Index (0-4 LAI units)	NDVI	NDVI	NDVI
Leaf Area Index (4-10 LAI units)	---	---	---
Canopy Gap Frequency and Size	Prescribed	---	Prescribed
Light-use Efficiency (leaf water, N)	Prescribed	Prescribed	Prescribed
Live vs. Senescent Biomass	---	---	Prescribed
Woody vs. Leaf Biomass	Prescribed	Prescribed	Prescribed
Canopy Allometry	Prescribed	Prescribed	Prescribed
Disturbance Type and Intensity	Landsat-SMA	---	Prescribed

Improvements with HyspIRI

Major Model Inputs	CASA	SiB3	Ecosystem Demography
Vegetation Type	HyspIRI	HyspIRI	HyspIRI
Plant Functional Types	HyspIRI	HyspIRI	HyspIRI
Fractional Carbon Cover	HyspIRI	HyspIRI	HyspIRI
Vegetation Greenness	HyspIRI	HyspIRI	HyspIRI
Fractional PAR Absorption	HyspIRI	HyspIRI	HyspIRI
Leaf Area Index (0-4 LAI units)	HyspIRI	HyspIRI	HyspIRI
Leaf Area Index (4-10 LAI units)	HyspIRI	HyspIRI	HyspIRI
Canopy Gap Frequency and Size	HyspIRI	HyspIRI	HyspIRI
Light-use Efficiency (leaf water, N)	HyspIRI	HyspIRI	HyspIRI
Live vs. Senescent Biomass	DesdynI	DesdynI	DesdynI
Woody vs. Leaf Biomass	DesdynI	DesdynI	DesdynI
Canopy Allometry	Prescribed	Prescribed	Prescribed
Disturbance Type and Intensity	HyspIRI	HyspIRI	HyspIRI

Final Notes

- We need to articulate the precise reasons HyspIRI is a highly relevant climate mission.
- The biospheric feedback (on land and in the sea) is central to understanding current climate and especially to predicting future climate.
- The cryospheric feedback is also critical at a very fundamental level to climate prediction.
- HyspIRI is the only global mission that can serve these and other climate-relevant observations.

Acknowledgements

Amazonia: LBA colleagues

Hawaii: Tom Giambelluca, Sharon Hall, Robin Martin, Peter Vitousek

Cryosphere: Tom Painter

Remote sensing: AVIRIS, Hyperion and HyspIRI teams

Funding: NASA Terrestrial Ecology/Biodiversity, MacArthur Foundation, Moore Foundation