CQ4. Ecosystem Function and Diversity
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CQ4: Overarching Question

- **How do species, functional type, and biodiversity composition within ecosystems influence the energy, water and biogeochemical cycles under varying climatic conditions?**

CQ4a: How can we enhance phenological & stress characterization through synergy between reflective and emitted radiation with higher frequency temporal sampling? [DS194, 195]

$$ESI = 1 - \frac{AET}{PET}$$

ΔESI

ΔZ

2005

2006

2007

Dry ▬▬▬▬▬▬ Wet
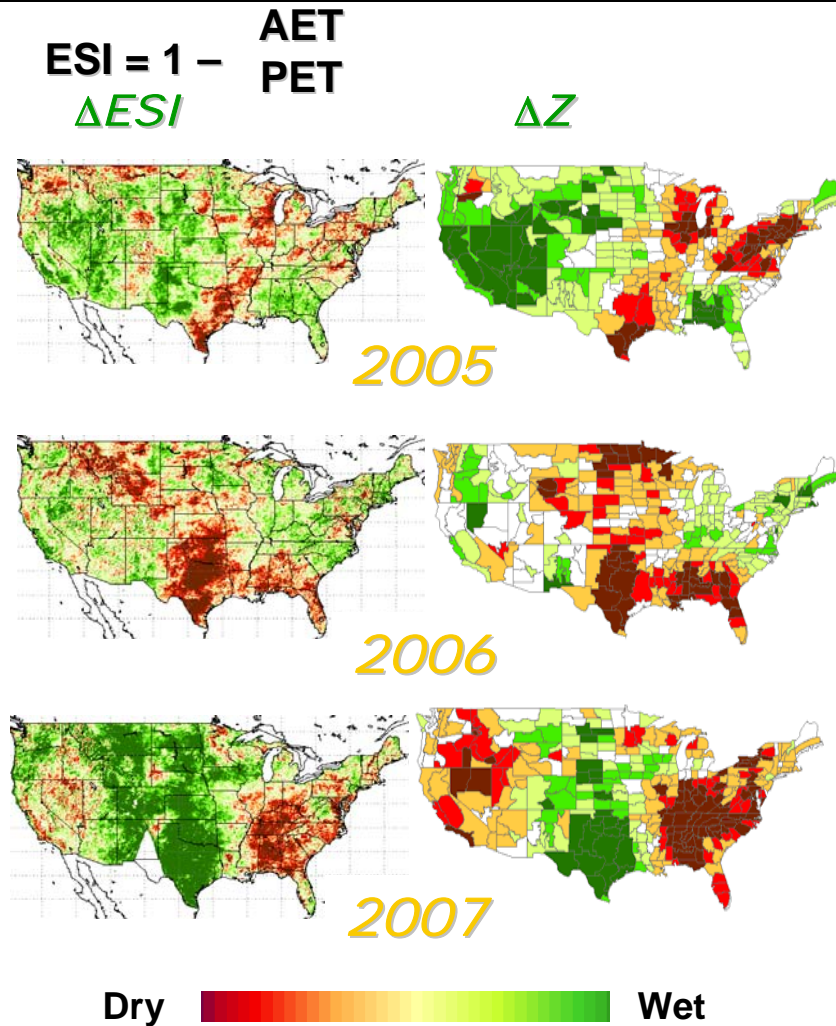
Seasonal changes in environmental stress (ratio of Actual to Potential ET) estimated from satellite (left) and meteorological (right) observations. From Anderson et al., 2007

Science Issue:

•**Plant stress** is often expressed by changes in leaf **physiological/chemical properties** or canopy biophysical attributes, notably **leaf temperatures and leaf orientations** (wilting). Seasonal changes in water availability and air temperatures are also major factors controlling plant phenology. **High frequency temperature** observations, and **less frequent VNIR-SWIR** observations provide synergies which may improve overall observations of plant stress.

•*Tools:*

•Satellite observations from HyspIRI VNIR-SWIR to **enable atmospheric correction, retrieve bi-directional reflectance and calculate suites of established stress indices.** Requires **fine temporal sampling, with multiple observations within each season** preferred. Requires fine **spatial resolution, sufficiently fine to resolve agricultural fields**.

•Requires simultaneous temperature observations in **multiple TIR wavelengths coregistered at less than one pixel** with **VNIR-SWIR** observations

•*Approach:*

•Retrieve **bi-directional reflectance and surface spectral radiance** using atmospheric radiative transfer. Estimate **surface albedo**.

•Calculate **suites of VNIR-SWIR stress indices** from surface reflectance

•Estimate sub-pixel fractions of **photosynthetic vegetation, non-photosynthetic vegetation and bare soil** to **improve ET** estimates from thermal.

•Apply established algorithms to **estimate surface emissivity and temperature from TIR.**

•**Develop linkages approaches that leverage high frequency TIR** observations to **improve analysis using coarser temporal sampling of the VNIR-SWIR.**

CQ4b: How is energy partitioned between latent and sensible heat fluxes as a function of different plant types and fractional cover and how does this impact hydrology? [DS 203]
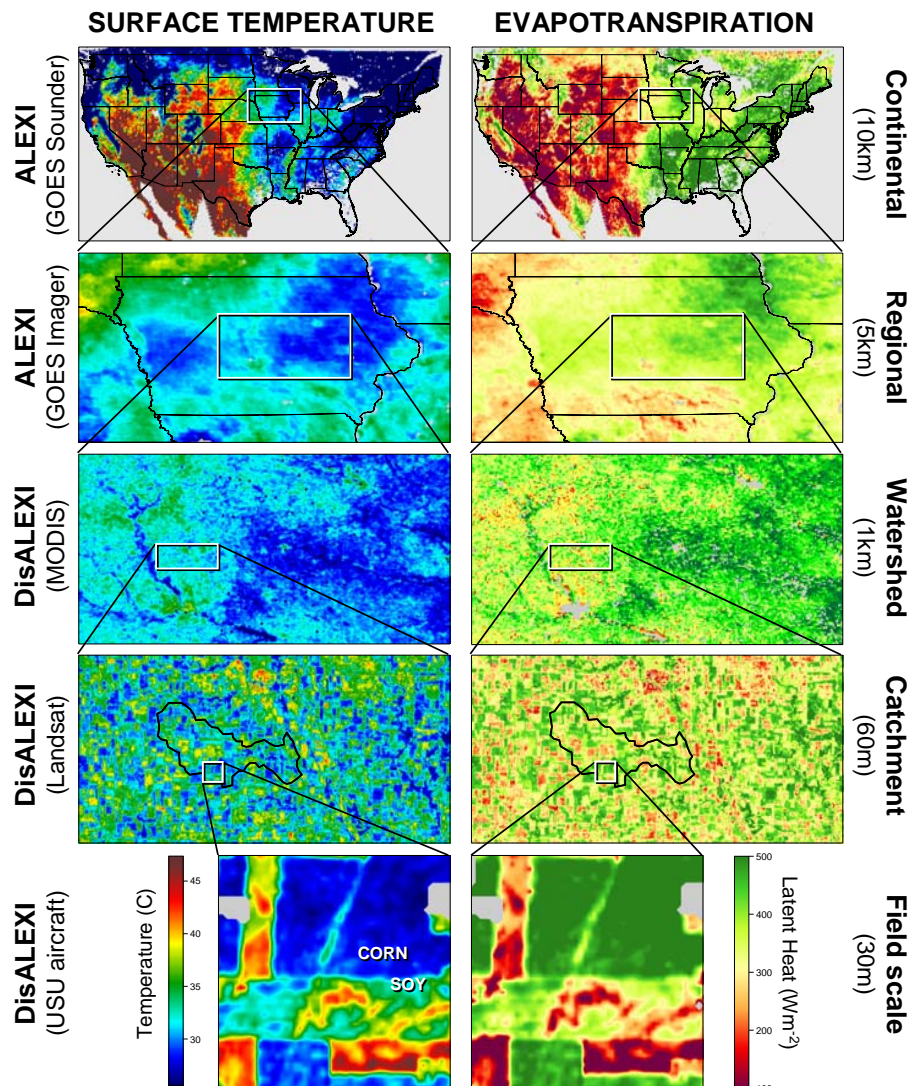
Map showing surface temperature and ET estimated at several scales using GOES, MODIS and ETM. Anderson et al., 2007.

Science Issue:

- Calculations of **surface energy balance**, a critical component of the hydrological cycle, require **accurate partitioning of radiative, latent and sensible heat components** of the surface energy budget. **VNIR-SWIR** observations **complement TIR** measurements by providing **improved discrimination of land-cover classes**, improved estimates of **surface albedo and of plant cover** required to partition **sensible and latent heat fluxes between soils and plants**. **TIR estimates of AET** compliment **VNIR-SWIR physiology**.

Tools:

- Satellite observations from HyspIRI VNIR-SWIR to enable atmospheric correction, retrieve of bi-directional reflectance and calculate suites of established stress indices. Requires fine temporal sampling, with multiple observations within each season preferred. Requires fine spatial resolution, sufficiently fine to resolve agricultural fields.
- Simultaneous temperature observations in multiple TIR wavelengths coregistered at less than one pixel with VNIR-SWIR observations
- **Hourly observations of temperature and humidity from Geostationary satellites.**

Approach:

- Retrieve bi-directional reflectance and surface spectral radiance using atmospheric radiative transfer. Estimate surface albedo.
- Estimate sub-pixel fractions of photosynthetic vegetation, non-photosynthetic vegetation and bare soil to improve ET estimates from thermal.
- Apply established algorithms to estimate surface emissivity and temperature from TIR.
- **Classify land-cover in the VNIR-SWIR data for natural and managed ecosystems**.
- **Export satellite products into appropriate hydrological models.**

CQ4c: How is physiological function affecting water and carbon exchange expressed at the ecosystem scale, especially seasonal down-regulation due to environmental stress factors? [DS 166, 196, 203, 206, 368]

Plots of net and gross carbon dioxide flux measured at 7 Boreas flux tower sites compared to estimates of FPAR (NDVI) and quantum efficiency (PRI) from AVIRIS. From Rahman et al., 2001
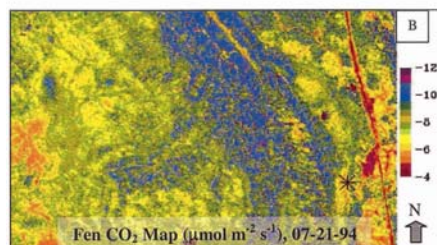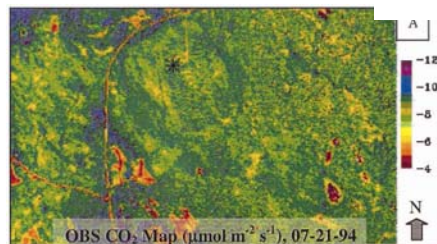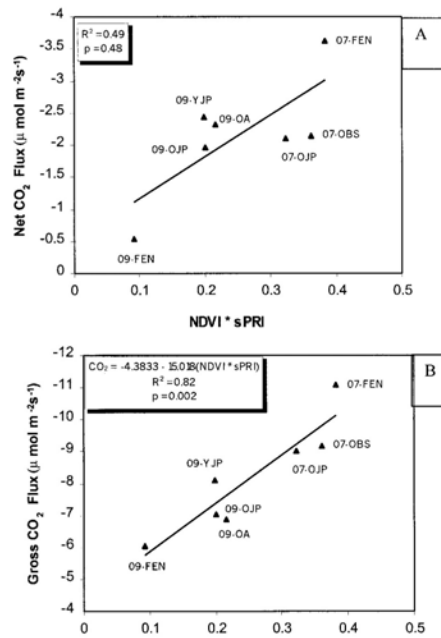
Maps of carbon dioxide uptake estimated from scaled PRI and NDVI, calibrated to eddy flux data. From Rahman et al., 2001.

Science Issue:

•Carbon uptake and evapotranspiration vary diurnally and seasonally in forests as plants adjust stomatal conductance to maximize carbon uptake and reduce water loss. These canopy responses to water stress are expressed physiologically, such as changes in the xanthophyll cycle (to protect against photoinhibition) and through changes in canopy temperature (associated with ET). Improved remotely sensed measures of physiology and temperature are required to improve regional estimates of carbon and water exchange from models.

•Tools:

•Satellite observations from HyspIRI VNIR-SWIR to enable atmospheric correction, retrieve of bi-directional reflectance and calculate specific indices, such as the Photochemical reflectance index. Requires fine temporal sampling, with multiple observations within each season preferred. Requires fine spatial resolution, sufficiently fine to resolve agricultural fields. Requires accurate wavelength calibration and wavelength stability for stability in wavelength sensitive measures such as PRI.
•Requires simultaneous temperature observations in multiple TIR wavelengths coregistered at less than one pixel with VNIR-SWIR observations

•Approach:

•Retrieve bi-directional reflectance and surface spectral radiance using atmospheric radiative transfer. Estimate surface albedo.
•Calculate suites of VNIR-SWIR stress indices from surface reflectance
•Estimate sub-pixel fractions of photosynthetic vegetation, non-photosynthetic vegetation.
•Apply established algorithms to estimate surface emissivity and temperature from TIR.

CQ4d: What is the vegetation phenological response to seasonal and interannual changes in temperature and moisture due to climate change and how does this response vary at the community/species level? [DS 196, 203, 206]

Long-term changes in high latitude greennes observed using AVHRR time series. From Myneni et al., 1997 and Tucker et al 2001.
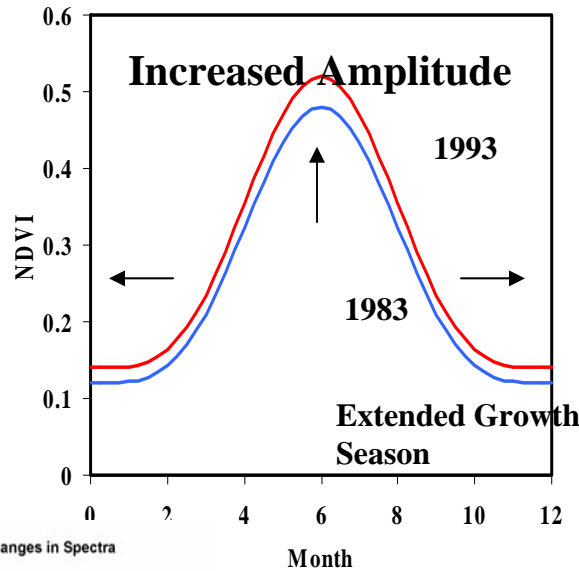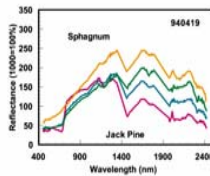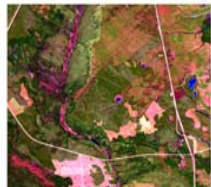
AVIRIS images acquired during the 1994 Boreas campaign in April, July and September, showing images on the left and spectra to the right. Spectra show ecosystem-dependent differences in phenology that cannot be resolved by coarse resolution sensors, yet impact the greenness signal. Roberts et al., 1999
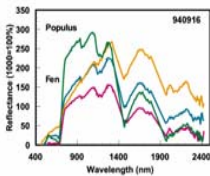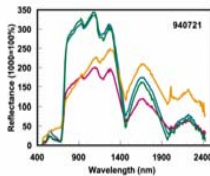
Science Issue:

•Some of the **clearest, earliest evidence for global climate change** has been high latitude **changes in the growth season**, evidence by **changes in the amplitude and width of annual greenness of NDVI time series** from AVHRR. **Finer scale ecosystem changes**, **such as succession following disturbance** and ecosystem dependent temperature or moisture responses, however, **cannot be** accurately quantified **by measures such as the NDVI**, although they may be critical in defining how ecosystems respond to future climate or disturbance regimes.

•*Tools:*

•Satellite observations from HyspIRI VNIR-SWIR to enable atmospheric correction and retrieve of bi-directional reflectance. Requires fine temporal sampling, with multiple observations within each season preferred.

***Requires fine spatial resolution, sufficient to resolve patches < 100 m.**
•**HyspIRI temperature observations to provide alternate measures of phenology and direct measures of surface temperature from multiple TIR wavelengths.**

•*Approach:*

•Retrieve bi-directional reflectance and surface spectral radiance using atmospheric radiative transfer. Estimate surface albedo.
•Calculate suites of VNIR-SWIR stress indices from surface reflectance
•Estimate sub-pixel fractions of photosynthetic vegetation, non-photosynthetic vegetation.
•Apply established algorithms to estimate surface emissivity and temperature from TIR.

CQ4e: What are the feedbacks between changes in canopy composition, mortality and retrieved canopy temperatures resulting from disturbances (e.g., disease, moisture deficiency, insect attack, fire, land degradation, fragmentation) in natural and managed ecosystems? [DS 166, 196, 203, 206]

True color image showing Multiple stages of canopy mortality. From Wulder et al,. 2005.
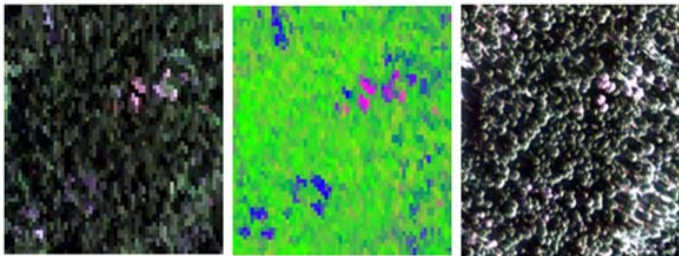
Hymap image showing map of grey and red phase beetle attack in conifers in Yellowstone. From Halligan, 2007.
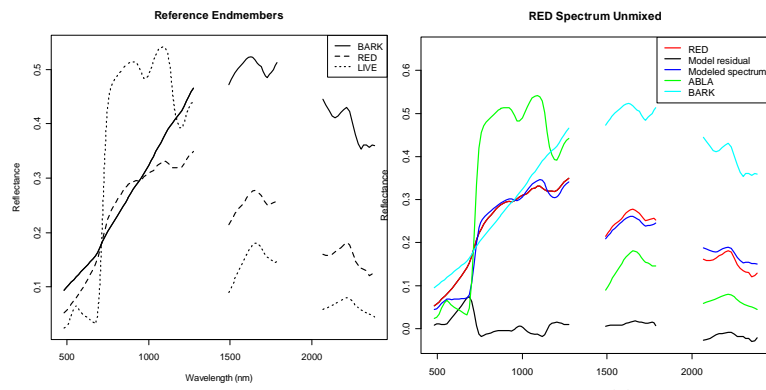
Hymap spectra showing grey phase and red phase attack. From Halligan, 2007.

Science Issue:

•**Disturbance,** either through insect attack, disease, drought, fragmentation or fire, is having an **increasingly detrimental** impact on forests worldwide. In many cases **disturbance impacts are either facilitated by large scale changes in temperature (ie, beetle attacks) or create feedbacks that promote further degradation (ie, reduced evapotranspiration raising air temperatures).**

•*Tools:*

•Satellite observations from HyspIRI VNIR-SWIR to enable atmospheric correction, retrieve of bi-directional reflectance and calculate suites of established stress indices. Requires fine temporal sampling, with multiple observations within each season preferred. Requires fine spatial resolution, sufficiently fine to patches < 100 m. .

•Requires simultaneous temperature observations in multiple TIR wavelengths coregistered at less than one pixel with VNIR-SWIR observations

•*Approach:*

•Retrieve bi-directional reflectance and surface spectral radiance using atmospheric radiative transfer..

•Calculate suites of VNIR-SWIR stress indices from surface reflectance

•Estimate sub-pixel fractions of photosynthetic vegetation and non-photosynthetic vegetation **as measures of crown mortality. Establish detection thresholds for detecting impacted crowns.**

•**Improved estimates of emissivity that account for the impact of non-photosynthetic components.** Improved canopy temperature estimates.

CQ4f: How do climate-induced temperature and moisture changes impact the distribution and spread of invasive and native species? [DS 196, 203]
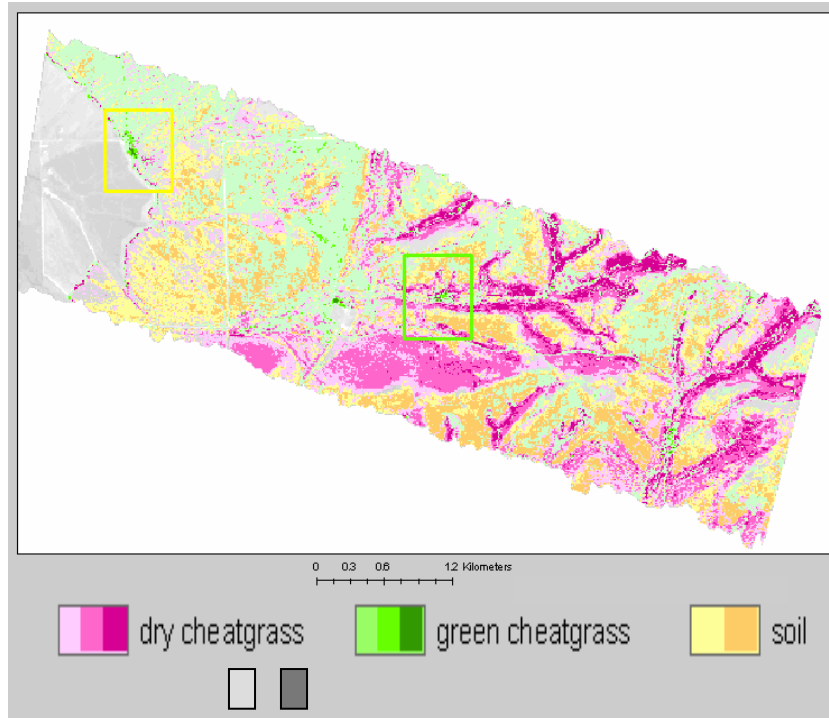
Map of Bromus tectorum (Cheat Grass) generated using imaging spectrometry. Cheat grass spreads through a combination disturbance and strategic use of soil moisture. It alters fire regimes, promoting its spread while early germination of Cheat grass enables it to produce seed in advance of native plants while reducing available water for competitors. From Ustin.

Science Issue:

• Invasive organisms are increasingly modifying terrestrial and aquatic ecosystems and are anticipated to become a leading cause of species extinction and ecosystem change in the future. Invasive species can, and often do modify disturbance regimes in a way that promotes their spread. Early detection and monitoring of the spread of invasive species is critical for mitigation and improving our knowledge of mechanisms that facilitate spread.

• Tools:

Satellite observations from HyspIRI VNIR-SWIR to enable atmospheric correction, retrieve of bi-directional reflectance and calculate suites of established stress indices. Requires fine temporal sampling, with multiple observations within each season preferred. Requires fine spatial resolution, sufficiently fine to resolve agricultural fields. Simultaneous temperature observations in multiple TIR wavelengths coregistered at less than one pixel with VNIR-SWIR observations required to estimate ET.

• Requires supplemental spectral libraries to inform mapping.
• Requires regional knowledge of important invasive organisms and a knowledge of conditions/attributes that facilitate their spread.

• Approach:

• Retrieve bi-directional reflectance and surface spectral radiance using atmospheric radiative transfer
• Develop new tools that leverage phenological information for species/functional group discrimination.
• Develop approaches for mapping sub-pixel abundance of a specific species or functional group including detection thresholds.
• TIR estimates of ET to provide complimentary measures of phenology and measures of water use.

Level 3 Products

- **Classified maps of dominant natural or agricultural land cover**
- **Presence/absence of invasive species**
  - Measures of confidence?
- **Estimates of fractional cover and confidence (i.e. MCU)**
  - Compositional (i.e., PV, NPV, soil, shadow)
  - Crop type/lifeform
- **Surface albedo**
- **Standard suite of biophysical/physiological narrow-band indices (i.e. PRI, EVI, MCARI, EWT, NDVI)**
- **Surface temperature and emissivity**
- **Partitioned estimates of sensible and latent heat**

L3 Validation

- **Leverage existing core validation sites**
  - LTERs
  - NEON
  - Flux networks (i.e. Euroflux, Ameriflux)
  - EOS Validation Core Sites
  - USDA/Foreign Agricultural Research Sites
- **Comparison to existing surface energy products**
- **Supporting sub-orbital missions/field campaigns**
  - Intensive field campaign involving airborne flux measurements (carbon, sensible & latent heat), timed with HyspIRI overpasses to validate flux estimates at the landscape scale
- **International collaborations**

Precursor Science

- Evaluation/development of current/new approaches for invasive species mapping in terrestrial ecosystems
- Classification/algorithm development and assessment across natural and agricultural land cover, leveraging phenological/seasonal information
- Evaluation of potential synergies between VNIR/SWIR and TIR for AET and plant stress
  - MASTER/AVIRIS acquisitions
- Evaluation of temporal fusion between 5 day TIR and 19 day VNIR/SWIR

Discussion/Questions