**Prudent Observations Necessary to Address**

**Wildland Fire Science and Applications Grand Challenges:**

**Critical Feedbacks with the Climate System**

A Soja (NIA/NASA LaRC), D Schimel (NASA JPL), L Giglio (UMD), T Loboda (UMD), N French (MTU), J Dibb (UNH), T Moore (WRAP/WESTAR), J McCarty (MTU), A da Silva, Jr. (NASA GSFC), S Conard (USFS retired, GMU), J Douglas (DOI), R Kahn (GFSC), R Sohlberg (UMD), A Pankratz (EnviCan), R Swap (UVA, NASA), C Ichoku (GSFC), D Hamilton (NW Nazarene U), V Ambrosia (ARC-SGE), C Rodriguez-Franco (USFS), B Stocks (CFS retired), Z Holden (USFS), M Carroll (NASA GSFC), K Weber, T Harbour (USFS), J Schnase (NASA GSFC), E Hinkley (USFS), M Miller (MTU), M Rollins (USFS), S Goodrick (USFS), A Watts (DRI), S Goetz (WHRC), B Peterson (USGS), R Ziebart (FEMA), B Barnard (AMECFW), J Coen (NCAR), J Cissel (JFSP), T Brown (DRI), C Wiedinmyer (NCAR), C Justice (UMD), J Vogelman (USGS), J Brass (ARC-SGE), J Randerson (UCI), B Quayle (USFS), B Schichtel (CO State), S Hook (NASA JPL), S Phillips (USGS), D Roy (SDSU)

An interagency Task Force was established two years ago to identify Grand Challenges for Wildland Fire (WF) communities and to suggest critical scientific and applications gaps for tractable improvement. Accordingly, several national and international conferences and workshops have included extensive community consultation (e.g., university, state, private, non-profits), focused on identifying critical scientific and applicable WF community requirements to advance knowledge to benefit both science and society. We, as an interconnected WF community, are poised to use space-based observations with complementary aircraft, UAV and ground measurements to address fundamental questions to rapidly advance WF science, applications, operations and decision-support systems to serve science and society.

**Key Challenges:**

1. **Ensuring space-based research-quality data essential to WF research, operations and applications collected from current and future satellites is compatible with existing data records. This includes research-quality algorithms, validated products, science, training and delivery mechanisms.**
2. **Given the integral nature of fire and evidence of its intensification and feedbacks, it is essential we develop and maintain space-based instrumentation focused on improving understanding of WF and its connections to the biosphere, atmosphere, hydrosphere, climate and society. This includes developing higher quality and higher spatial/temporal resolution satellite fire products with known accuracy to meet requirements.**
3. **There is inadequate understanding of WF in the context of baseline conditions in vegetation (species composition/health), fuels (3-D structure/moisture dynamics) and climate (fire weather). As climate and ecosystems change, identifying vegetation/fuel conditions and understanding the resultant changing fire regimes becomes increasingly complex and necessary.**
4. **Accurate and complete accounting of: available fuel, emissions (smoke/aerosols/trace gases/carbon), injection heights, transport and deposition are critical to understanding fire-mediated feedbacks in the climate system. While interdisciplinary approaches are necessary, action is hindered by disciplinary silos and intense competition for limited resources.**

**Timeliness:** Intensification of extreme WF behavior threatens the lives and health of responders and citizens and has increased property losses, wildlife habitat loss, and response and recovery cost. Changes in fire regimes (frequency, extent, intensity, severity, increase in catastrophic events and fire season length) are predicted to be an initial sign of climate change, and fire-climate researchers argue that change is already discernable.

Fire has never been considered an explicit priority in terms of remote observations, even though fire is an integral, consistent and primary link connecting terrestrial, atmospheric, and hydrologic systems to each other and the climate. WF encompasses numerous interacting and complex physical, ecological, and social factors, a thorough understanding of which is essential to climate, WF science and applications.

**Challenge I and II:** In most regions, it is feasible to develop a 35-year satellite-based, continuous vegetation and fire dataset [frequency and/or burned area (BA)], so patterns of fire can be identified, feedbacks to and from the climate system can be quantified (severity, aerosol source, albedo change, pyrogenic carbon on snow/ice, pollution-health), and future fire regimes can be forecast. Fire-induced ecosystem change is a key climate indicator and without global fire products, this would be impossible.

As one example of the applied use of these data (NIR, SWIR), burn severity is required by BAER teams (Burned Area Emergency Rehabilitation) to understand where rapid response is needed to mitigate post-fire hazards (e.g., erosion control/flood management). However, Landsat and MODIS often do not have cloud-free data available in the < 14-days BAER is allotted to make critical decisions. Rehabilitation is only one of many applied uses of these data.

MODIS coarse-resolution BA products are available to characterize large fires consistently, however, the spatial resolution is inadequate to meet WF applied and operational requirements. Landsat data are of sufficient spatial resolution, however the repeat frequency is insufficient. The community looks towards Sentinel for augmentation, however Sentinel lacks the SWIR band required to calculate severity.

For active fire detection (FD), there are currently 2 operational MODIS (am/pm) instruments that are past their planned lifetimes. Research-quality VIIRS (pm/launched 2011) FD data will be globally available at a higher resolution soon. However, there is only one VIIRS instrument, leaving a potential gap in data continuity for applied science users (e.g., EPA National Emission Inventory, WF operations). There is hope for augmentation with Sentinel active fire (SLSTR), however there is no firm plan to acquire and produce a consistent research-quality product.

Pre-launch consideration of research-quality FD/BA products, data continuity and sensor improvement has been and is deficient (dynamic range, on-board aggregation, temporal resolution, research-quality products). Fire Radiative Power (FRP) is retrievable but complicated by unanticipated differences in spectral response. FD/BA products will likely become globally available in 2016/2017.

Currently, no improvements to the fire capability of future VIIRS/JPSS instruments are foreseen. As widely as these BA/FD/severity data are used, both globally and in the US [Universities, Forest Services (fire suppression, identification), NOAA, EPA (emissions inventory, rules and regulatory setting), states, DOI, NPS, FEMA etc.], it is imperative new instruments have design characteristics that make them explicitly consistent with continuous records, and better in key aspects.

Future instruments should be designed and launched to avoid gaps in critical observations and products, however this will only be possible if there is combined community and political will.

**Challenge III-IV** Vegetation Conditions: Stand dynamics such as species composition, age distribution, and 3-D structure influence fire behavior, and these are not currently well quantified. As climate changes, ecosystems are likely to become increasingly unhealthy and/or migrate northward or to higher altitudes. Fire is expected to be a key process driving or facilitating change.

Technology exists to **quantify above-ground fuels using active sensors, such as LiDAR and SAR**. These are challenging technologies (processing, storage, pre-processed products and training), however resultant data have the potential for high returns.

Measurement of vegetation health including vegetation stressed by insects, drought, disease, invasive species and legacy management are critical to understanding the amount of fuel that is ‘available’ to burn, and these data are rarely available in the timeframe required. As a fire burns, it is imperative to know what is burning, however pre-burn stand-structure data are rarely available (e.g., Juniper forest location) and neither is cloud-free 30-m imagery, which is used to determine relative ecosystem health.

Detection of smaller (rangeland, agricultural, cropland) and understory fire (peatland, surface, silviculture) becomes possible with increased temporal/spatial resolution. These fires often burn near population centers, where human health is substantially affected, with direct links to increased respiratory illnesses, heart attacks, and death - recently quantified with associated societal and monetary costs.

**Specific requirements include increased temporal/spatial resolution (~ 30-meter resolution 2-4 times daily; visible, NIR, SWIR~2.1μm, ~3.9μm, thermal)** for pre-fire ecosystem health assessments (fuel availability, vegetation indices), active fire identification and forecast modeling, and post-fire BA and severity assessments for timely rehabilitation, and climate indicator assessments. Any improvement would be helpful (**8-day acquisition of Landsat 9**). An **enhanced fire product** is needed that could benefit multiple science disciplines, similar to **FRP with explicit consideration of instrument saturation and realistic fire temperatures**.

**Challenge II-IV:** Fire regimes are largely under the control of weather and climate, with anthropogenic landscape alteration often magnifying negative outcomes. Fuel and soil moisture is critical to estimating fuel availability/loading and fire potential. Antecedent and current fire weather (temperature, precipitation, wind speed, relative humidity) drives fire intensity and severity, hence fire dynamics, smoke emissions and carbon release. Weather and climate data are indispensable to: quantifying vegetative fuel moisture (living and dead); duff and soil fuel moisture; initializing active fire forecasts; and forecasting smoke injection and transport, particularly in diverse terrain.

Heat penetration is strongly related to pre-fire vegetation moisture content. If soil and surface layer fuel moisture is high, temperatures at or below ground are minimal, even in high-fire intensities (translates to severity and depth of fuel burned). Post-fire soil moisture is an essential parameter for modeling post-fire erosion (run-off).

The WF community strongly supports improved instrument development that provides **high-resolution soil moisture and surface tension, similar to SMAP’s radar**.

This community call is also for **3-hourly, 250-500m meteorological data** to enhance and simulate: (1) smoke transport (used in prescribed burn Go/No-Go decisions, small- and large-scale Air Quality (AQ) models); (2) state-of-the-art coupled atmosphere-wildland fire models that forecast active fire movement and have the realistic potential to save lives; and (3) drive detailed fire weather models that estimate the amount of fuel ‘available’ to burn and potential severity.

In support of defining smoke structure in the atmosphere for prescribed burning and large-scale transport for AQ, chemistry and climate, there is a call for **product development based on existing lidar profiles (e.g., CALIOP)** and/or **improved space-based instruments (e.g., HSRL)** capable of detecting atmospheric structure to complete feedback loop analyses (e.g., smoke layers, density, clouds).

**\* Training** and applied sciences are strategic to make full societal and applied use of data. The amount of data is overwhelming. Users are interested in knowing what information is available, not masses of data, and how to process/use products (gaining applicable knowledge).

**Space-based observations are fundamental** to address essential WF research, science, applications and operations, because large-scale effects can only be described and understood with space-based observations, complemented by other observations (UAVs, ground-based, aircraft). This group strongly and continually links space-based research with other observations to increase value to scientific research and society (human and ecosystem health).

Fire is a critical global process, one that is an integral, consistent and primary link connecting terrestrial, atmospheric, and hydrologic systems to each other and to the climate system, in terms of carbon cycling, biospheric and atmospheric health, and energy exchange. Fires can produce their own weather; fire emissions immediately alter patterns of precipitation; and post-fire debris flows and landslides pollute and dam waterways. Major fire-induced emissions and landscape change feedbacks have been largely neglected but are becoming increasingly recognized. Fire-induced feedbacks are crucial to consider in future climate assessments.

**Anticipated Scientific and Societal Benefits**: Unlike other climate indicators, humankind has the opportunity to moderate, regulate and/or direct WF and related ecosystem change by managing fuels, efficient wildfire suppression and response, ecosystem recovery and landscape management. As climate changes, some environments will no longer be able to sustain the vegetation that previously existed (vegetation-climate envelope), which is a challenging supposition but one that must be considered.

Technical capability exists to address key challenges and questions for WF Earth Science. Key science challenges span Terrestrial Ecology and Atmospheric Chemistry/Dynamics domains, with clear implications for feedbacks to and from regional-global climate. With relatively minor consideration in instrument design, key WF requirements could also be met to address fundamental WF Science, Applications, Operations and Management challenges.