EARTH OBSERVING SYSTEM

Follow-Up Meeting to MODIS Follow On Hyperspectral Concept for EOS-AM2

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Briefing to MODIS Technical Team

Introduction

- Presentation is follow-up to briefing presented to MODIS Technical Team: *MODIS Follow On Hyperspectral Concept for EOS-AM2*, June 8, 1995
- Science and Technical Team responses to briefing were solicited and compiled (M. Herring/920 emails of 8/28/95 and 9/8/95) and forwarded to me.
- In absence of set agenda for today, presentation will consist of summary of responses comments on them.

Today will review Science Team and Technical Team responses to June 8, 1995 briefing and associated comments.

Science and Technical Team Responses

- 17 sets of responses (mostly anonymous except for P. Menzel's, E. Waluschka's, and P. Slater's).
- These fell into rougly four categories:
  1. Calibration approach (i.e. use of hyperspectral transfer radiometer and vicarious earth/lunar calibration and minimization of on-board calibration hardware)
  2. System specifications
  3. System optical and radiometric performance questions
  4. Miscellaneous (ranging from general observations on the concept to specific responses on the oversampling/coregistration scheme presented by P. Westmeyer)
- In addition, concern was raised at the June 8. 1995 briefing on the 1235 km (+/- 40 degree) swath. A 1500 km (+/-) 45 degree) could be readily incorporated into the design. A greater swath width (e.g. the 2330 km, +/- 55 degree) could also be incoporated into the design but with commensurate mass, volume, and power increases.

Calibration Approach Responses (1/2)

- There is no demonstration of which I am aware to justify the calibration philosophy of using intermittant data from a separate instrument rather than integral black body(ies), nor even for visible calibration over all the time scales of concern.
- There is concern about the complete lack of ANY on-board calibration. The design is VERY immature and many potential problems have not been studied. Westmeyer's and Neeck's conclusion that a MODIS-light is feasible may be premature.
- What about calibration? We don't trust anything without on-board blackbodies. Relying solely on vicarious calibration is expensive and thus not guaranteed.
- I presume that the HSI or HTR is only included on the payload as a calibrator and not, for example, like HIRIS which was principally for scientific not engineering purposes. If this is the case, then we are adding, in my opinion, a substantial on-board calibrator. The weight, size, cost, power, data rate etc. must be added to that of the sensor being calibrated. (Or divided among the several sensors that it might calibrate, but see following paragraph.) The claim that MODIS-light would not have an on-board calibrator, with all that that implies, is simply false advertizing. In fact there are probably several better on-board calibrators that could be designed and used that would be of smaller size, weight, cost, power and data rate. A HSI or HTR cannot be thought of as a universal calibrator as an argument for its cost effectiveness. It is unlikely to be used for more than one sensor on a future EOS platform. Although it might work well for a MODIS-like sensor, it is not suitable for the calibration of others, e.g. MISR and CERES.
- An accurate calibrating system must be radiometrically highly stable. At least it must be better in this regard than the sensor it is to calibrate. By radiometrically stable I mean it must have: A) highly stable, preferably linear detectors, which are temperature insensitive; B) high spectral out-of-band rejection; C) well defined passbands,

Calibration Approach Responses (2/2)

preferably rectangular, without cross-talk; D) well-defined instantaneous field of view, without a 'skirt' due to aberrations and/or scattered light, preferably several times smaller than that of the sensor to be calibrated.

- An imaging spectrometer is a high performance sensor, but its design entails many compromises. For example only a single spectrometer (or monochromator) can be used. For accurate spectral measurements in the laboratory, a double monochromator is always used. This is because of the stray (spectral) light present in a single instrument. The first monochromator selects a narrow spectral interval that is incident on the entrance slit of the second monochromator. Such an arrangement provides a very high spectral out-of-band rejection -- to the degree necessary for accurate radiometry. I expect this will be a very serious problem with a linear-wedge instrument. (Incidentally, this is the design of Peter Abel's ER-2 spectrometer used for satellite sensor calibration, but this is not an imaging system.) Another problem is that the bandpasses of an imaging spectrometer are not nearly rectangular as for MODIS. This is going to cause problems especially in regions of sharp absorption. With any high performance sensor such as an imaging spectrometer, we are going to encounter problems due to scatter, aberrations, cross-talk, etc. If an approach using a ground-viewing sensor is to be considered, then emphasis should be on the simplest design possible. A single detector, filter wheel instrument is probably most desirable from a radiometric standpoint. However, there are limitations to its operational utility that are immediately obvious. I am yet to be convinced that there is a good solution to the calibration problem using an earth-viewing radiometer.
- Finally the imaging spectrometer itself will need to be calibrated inflight. This, in turn, will require some form of on-board calibrator, at least for intra-orbit calibration purposes. Why not apply this directly to MODIS-light?

Calibration Approach Comments

- The calibration approach is a radical one. As far as I know, this comment is true. There has been no prior demonstration of a hyperspectral transfer radiometer.
- The design is very immature and highly conceptual. Many potential problems have not been studied and need to be in a proper Phase A effort. This would also involve necessary breadboarding and test bedding to demonstrate concept feasibility.
- Vicarious calibration can certainly not be relied upon solely (this was never stated to be the case in the earlier presentation). It is indeed expensive and lacks high temporal frequency. An intra-orbit stability monitor and inter-orbit stability monitor and calibration device/hardware (whether transfer radiometer or diffuser panel, blackbody, etc.) is necessary. Spectral and spatial monitoring/calibration methods and hardware may also be necessary.
- The HTR (hyperspectral transfer radiometer) is indeed an on-board calibrator and should be included as part of the total instrument payload mass, volume, power, etc. allocations. The HTR was originally envisoned as having a science capability but this may add excessively difficult requirements. It was envisioned that the HTR would have adequate pointing capability and spatial resolution to be used with AMISR and LATI. The comments on imaging spectrometer deficiencies are useful and spectral rejection, bandpass shape and width, and crosstalk, scattering, etc. must be evaluated in an HTR design. The single detector filter wheel radiometer idea is interesting and merits further study. The HTR does indeed require its own calibration hardware. An intra-orbit stability monitor was part of the original concept briefed in June.
- A HTR that satisfies the needs of the AMODIS, AMISR, and LATI instruments is a large, complex, and challenging instrument in itself and a number of potential difficulties in its implementation have been identified. In any event, blackbody calibrators will need to be flown to provide TIR calibration.

System Specification Responses

- There have been painful lessons learned in how to write specs. Simply using the existing MODIS spec to indicate adequate performance is entirely inappropriate. This is especially true in reponse to bright targets, lack of any spec on spectral or geometric crosstalk, and band pass performance as well a calibration.
- Many of the specs which MODIS, SeaWiFS, and, apparently, MERIS have found exceedingly difficult to meet (and indeed fail to meet) have not even been applied to the conceptual model yet, so it is way too early to declare that a viable approach has been identified, even considering how much pressure is being applied to prove this is a viable approach.
- Since many algorithms make use of band ratios, better specs must be written for band-to-band stability, location, radiometery, and spectral content.
- Let me just add that the first thing to do before we start designing a new instrument is to quantify the specs. The imaging sciences are very well established. There is no excuse for loose specs. Having well defined consistent specs in a unambigious mathematical form greatly simplifies the design task.

System Specification Comments

- The existing MDOIS specs were used merely as a starting point. We will be happy to work with the Technical and Science Teams to develop more appropriate specs.
- We did not state that "a viable approach has been identified" in the June briefing. We stated that "no show stoppers have been identified to date" and that a "smaller, MODIS -like (in data content) instrument suited to spacecraft may be feasible".
- Improvement of specs to reflect band to band ratio algorithms is a good suggestion and we welcome suggestions here.
- We also agree that specs need to be quantified before designing. That is why we used the MODIS specs. Again, we will be pleased to work with you to refine the specs.

System Optical and Radiometric Performance Responses

- With 10 nm band quantization it will be impossible to optimize band spectral position for geophysical parameters, and to avoid fraunhoefer and telluric spectral features. This will severely degrade performance. MODIS-T faced similar problems, but was canceled before the optimization studies of were completed, and they never were completed. There was hope, with principally one use driving the high spectral resolution positions (land needs were broader spectrally than oceans, and even then oceans relied on MODIS-N to do the fluorescence). I do not think this can be done where multiple tight spectral requirements exist. This argues for going to much smaller spectral resulution--say 1 nm.
- The spectral consistency of a given band along the array is relatively poor. Even if it turns out to be within spec of SeaWiFS or MODIS, the fact that the errors will be systematic within an array scan needs to be considered. I recall that MODIS-T had some specs related to this. A similar argument for the "smile" effect that troubled MODIS-T.
- The SNR in the fluorescence bands is poor. There is also concern that the proposed configuration does not build on existing infrastructure in terms of algorithms, etc., so costs may be significantly higher.
- Paul Menzel considers MTF response marginal beyond 10 microns, which is a problem since most of his science is in this spectral region.
- It is not clear how well narrow visible bands would be achieved. Some of these bands are extremely sensitive to spectral location.

System Optical and Radiometric Performance Comments

- A <5 nm spectral resolution in the visible/near infrared was proposed in the June briefing. The current MODIS has a 10 nm bandwidth band (Band 14) in the vicinity of chlorophyll a flouresence (682.5 nm). We are interested in hearing more about your narrow bandwith suggestions.
- Some level of "smile" or "frown" is inherent in all imaging spectrometers (prism, grating, or wedge filter). In a wedge filter, the radius of curvature is a function of the coating equipment and filter size. Manufacturers (e.g. OCLI) have been consulted on this problem and indicate that modest investments in modifying coating chambers can significantly improve this (i.e. decrease the "smile"). This will have to be an area of developmental activity in future work. Of course, this effect must be taken into account and appropriately "spec'ed".
- We do not understand the basis for this comment. Calculated SNR's in this spectral region (682.5 nm) are equivalent to MODIS at 1000 m spatial resolution. We agree with the comment on algorithms. In the June briefing we stated that "implications of pushbroom and linear wedge filter geometries on science data processing algorithms need to be studied".
- The MTF performance in the LWIR at >10 um is marginal for the 500 m spatial resolution for the Rflective Design. This is not a problem at 1000 m spatial resolution (equivalent to present MDOIS) and this is not a problem with the Refractive Design at 500 m spatial resolution due to its faster f-number (F/1 versus F/3).
- Spectral bandwidth and stability performance needs to be demonstrated with wedge filters. The LEWIS LEISA instrument , its successor (LEISA II), and the SBRC WIS airborne instrument may provide some answers here. This should also be the subject of Phase A laboratory breadboarding.

Miscellaneous Responses

- Related to the above, if spatial registration of ground IFOVs is to be achieved by oversampling data from different focal planes and geometries, then the oversampling should be at least a factor of 10 higher in order to assure that all bands measure their radiance from the same piece of the earth to within 10%. Current rate of oversampling at the nyquist frequency is clearly inadequate for precision, and is just enough to resolve half pixel overlap. I think this would especially concern land surface data users, but it is also very important for oceans. For example, it becomes convolved with bright target effects.
- The entire concept of attaining coincident spacial/spectral sampling by oversampling places a tremendous burden on the data rate, and data system, which is already extremely burdened and may be the critical item. It also requires that there be no relative movement in boresighting over the life of the mission if this is to be done in an operational manner. I do not believe that oversampling is a solution.
- *There are some real positive aspects of Westmeyer's and Neeck's original MODIS-light presentation. I like the use of many cameras across track. ROSIS and MERIS use this approach, and it appears to be a good way to keep distortions down, as well as to limit off angle stray light effects.
- We are interested in the concept, but would need a lot more information to be reassured that the MODIS science could be achieved with the hyper-spectral instrument.
- On another front, we have recently seen the SBRC concept for MODIS-Lite. This is also very sketchy but based on familiar MODIS designs. The interest from NOAA for NPOESS is likely to be very high. Most of the EOS and all of the NOAA science can probably be achieved with 24 spectral bands. This is a good way to take advantage of EOS developments and transfer them to NOAA. Dialogue on which spectral bands should be included is necessary.

Miscellaneous Comments

- I refer questions on spatial oversampling, coregistration , and data handling to P. Westmeyer as they pertain to his portion of the June briefing.
- Thank you for the qualified positive comments! Certainly, more work is required to demonstrate feasibility.
- Although not applied to the June briefing, the NPOESS requirements may be worth considering in design a MODIS Follow On.

Conclusions

- Thank you for your constructive comments. We appreciate your input and wish to continue this dialogue.

PAUL WESTMEYER'S COMMENTS ON SELECTED ITEMS IN MODIS TEAM MEMO ABOUT PAUL AND STEVE'S CONCEPTS 9/14/95

1. RELATED TO OVERSAMPLING CONCERNS:

SPATIAL REGISTRATION IS A MORE COMPLEX MATTER THAN JUST OVERSAMPLING. THE CONCERNS APPEARS TO BE; FIRST A CONCERN OF ALL SPECTRAL DATA COMING FROM THE SAME SCENE, WHICH WE CONSIDER AS A PARAMOUNT REQUIREMENT, AND SECOND OF LOCATING EACH SCENE IN SOME COORDINATE SYSTEM.

SPATIAL KNOWLEDGE OF EACH FOCAL PLANE RELATIVE TO ALL OTHER FOCAL PLANES IS A CONCERN, BUT, ONE THAT CAN BE WORKED. THESE SYSTEMS ARE CONCEPTS THAT DO PROVIDE KNOWLEDGE OF WHERE EACH FOCAL PLANE IS LOCATED IN THE INSTRUMENT AND THE BORESIGHTS OF THE INSTRUMENTS RELATIVE TO THE SPACECRAFT REFERENCE (STANDARD GROUND MEASUREMENTS). WITH THESE CONCEPTS THE DATA ARE MORE DIFICULT TO RELATE TO EACH OTHER WHEN COMPARED TO A SINGLE OPTICAL SYSTEM WITH A RIDIG FOCAL PLANE LAYOUT (SUCH AS MODIS), HOWEVER, THE RELATIONSHIPS CAN BE MADE AND EVEN MONITORED.

THE OVERSAMPLING WAS NOT INTENDED AS A COMPLETE SOLUTION BUT IS CONSIDERED AS A MITIGATING FACTOR. OFFSET ERRORS ASSOCIATED WITH THE ALIGNMENT COMPLEXITY OF MULTIPLE FOCAL PLANES, IN POTENTIALLY MULTIPLE OPTICAL TRAINS THAT ARE NOT INTIMATELY CONNECTED TO EACH OTHER, MUST BE ADDRESSED IN THE OVERALL ALIGNMENT PLAN OF THE SPACECRAFT. THIS IS THE NORMAL APPROACH, JUST MORE ITEMS TO ALIGN.

AS FOR COORDINATE SYSTEM ERRORS, ALL THE ITEMS NEEDED TO REGISTER A SCENE ARE NOT INCLUDED IN ANY INSTRUMENT DESIGN. GROUND PROCESSING ERRORS, AND KNOWLEDGE ERRORS IN GROUND SLOPE, AND OTHER PARAMETERS, ARE ACTUALLY BIGGER CONTRIBUTERS TO THE OVERALL LOCATION ERROR OF ANY SCENE.

2. AS FOR DATA SUBSYSTEM LIMITATIONS-- DON'T WORRY BE HAPPY. THIS PROBLEM HAS AT LEAST TWO ELEMENTS THAT MUST BE ADDRESSED; SPACE ASSETS (RECORDER AND COMMUNICATIONS) AND GROUND ASSETS (STORAGE AND PROCESSING, AND MAYBE PRODUCT DISTRIBUTION).

THE SPACE ASSETS ARE FACTORED INTO THE OVERALL CONCEPT AND THE REQUIREMENTS THAT WOULD BE PLACED ON THE SPACECRAFT VENDOR. THE SIZE OF THE RECORDER IS NOT A CONCERN, THE COMMUNICATIONS LINKS ARE NOT CONSIDERED A CONCERN, BUT LACK THE DEVELOPMENT MATURITY OF THE DATA SYSTEM.

GROUND ASSETS ARE NOT CONSIDERED A CONCERN, BUT, THAT IS NOT A UNIVERSALLY SHARED POSITION WITHIN THE GROUND SYSTEM. THESE NUMBERS ARE KNOWN TO THE GROUND SYSTEM, WERE USED IN THE RESHAPE EXERISE, AND HAVE NOT CREATED ANY SIGNIFICANT NEGATIVE RESPONSE. THE NEGATIVE RESPONSES ARE CENTERED ON BUDGET ISSUES, SUCH AS WHAT IS EXPECTED IN STORAGE DENSITY IN THE YEAR 2004 AND HOW MUCH WILL THAT TECHNOLOGY COST. IN GENERAL THE TREND DATA IN STORAGE TECHNOLOGY SUPPORT THE EXPECTATIONS USED IN THE CONCEPT STUDY. PROCESSING TRENDS ARE OF LIKE STATUS -- YOUR GUESS IS AS GOOD AS ANY OTHER.

NOTE THAT ALL OF THESE ISSUES ARE NO LONGER DRIVEN BY THE AEROSPACE USERS, COMMERCIAL USES NOW CONTROL THE FATE OF DATA STORAGE AND PROCESSING CAPABILITIES.

3. CORRESTRATION IN ORBIT BY ACTUATORS IS REAL AND A WORKING PROTOTYPE EXIST AT DRAPER LABS. THE DEVICE IS OPTICAL, NON LINE-OF-SIGHT DESIGN, WHICH CAN BE USED TO MEASURE RELATIVE ALIGNMENT OF ABOUT 1 SECOND OF ARC, WITH A DYNAMIC RANGE OF ABOUT 30 SECONDS OF ARC. THIS MEANS THAT THE GROUND ALIGNMENT MUST GET US IN THE DYNAMIC RANGE BEFORE LAUNCH. THIS DESIGN CAN BE USED TO CAPTURE DATA ABOUT ORBITAL VARIATIONS (SECONDARY DATA FROM THE SPACECRAFT FOR POST PROCESSING USE).

4. PROPOSED CONCEPTS DO NOT BUILD ON EXISTING ALGORITHMS IS NOT ACCURATE; ALGORITHMS YES, CODE PROBABLY

NOT. THERE IS NOTHING IN THESE DESIGNS THAT PROHIBITS THE GENERATION OF DATA THAT LOOKS LIKE THE EXISTING SYSTEM OUTPUTS. THE CODE MAY NEED TO BE CHANGED TO REFLECT HIGHER SAMPLE RATES ETC...

5. NOAA's INTEREST IN ANY SYSTEM NASA BUILDS IS ALWAYS TIED TO MONEY. IN THIS CASE MONEY HAS MANY ATTRIBUTES, INCLUDING SIZE, MASS AND POWER REQUIREMENTS ON THE SPACECRAFT BUS. OUR PROPOSAL IS SMALLER WHICH HAS A COST LOWER INFLUENCE FROM THE BUS PROSPECTIVE, WHILE THE INSTRUMENT MAY COST MORE THAN A MODIS-LITE FROM SBRC. THESE FACTORS ARE ALL UNKNOWN.