REQUIREMENTS FOR EARTH OBSERVATION IN TROPICAL AND SUBTROPICAL ZONES FROM LOW INCLINATION ORBIT

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ABSTRACT:

Earth observation requirements in the tropical and subtropical zones addressing present and future science questions with regard to atmosphere, land and ocean are discussed. Low inclination orbits offer unique possibilities for the study of processes on different spatial and temporal scales. The high radiation input and high dynamics, e.g., in precipitation, plant productivity, gas exchange and land cover have a strong influence on global circulation and their feedback on climate and living conditions. The understanding of global models will therefore need support from specific investigations in the tropics. Processes should be studied by remote sensing on different spatial scales, sometimes up to local scales by the measurements of diurnal, seasonal and interannual variations as a complement to polar missions.

Based on a study for the use of Columbus or other platforms on low inclination orbit core optical and microwave instruments for priority science investigations are suggested. Further mission objectives can be realized by the choice of additional instruments.

KEYWORDS:

Global change, earth observation, tropics and subtropics, low inclination orbit, optical and microwave sensors, synergy in measurements.

1. GENERAL ASPECTS

For the time horizon 2000 - 2030 it is expected that remote sensing measurement needs are still going to be global but with varying temporal and spatial scales for data which characterize the atmosphere, land and oceans as part of the coupled global system. Future measurements of a large number of variables should maintain long-term monitoring of known phenomena with prominent influence over selected areas and short-process studies in experimental sites for the understanding of global evolution and change. For the monitoring of global change on large scales, key variables shall be evaluated to assess in which way our planet is evolving in time. Long term trends in forcing functions shall be measured. Interactive processes will be able to be studied by simultaneous measurements of relevant parameters which control the system on different scales.

Earth observation from space platforms, supported by airborne and ground measurements, offers the potential of continuously viewing large portions of the Earth, so documenting the current state and occuring changes. Key requirements for the earth observations of main parameters are the suitability of sensors and viewing conditions, simultaneity, accuracy, long term consistency and continuity of measurements. One challenge will be to combine relevant data from different space platforms to provide the global study context. It appears reasonable to concentrate measurements on near polar orbits for global coverage and to address further problems and the validation of models on regional or continental scale by measurements on specific orbits (Barron and Battnick, 1991).

The study, presented in this paper, is part of an investigation concerning the use of the Columbus-Attached Laboratory (CAL) in a low inclination orbit for earth remote sensing at the beginning of the next century (Beran et al., 1992). The CAL itself is the European modul of the International Space Station Freedom and part of the overall Columbus programme. It includes the Man Tended Freeflyer and Polar Platforms.

The Columbus low inclination orbit covers regions of vital influence with regard to climate and global change. More than two thirds of the global precipitation falls in the tropical region between 30° North and 30° South. The latent heat released by tropical precipitation plays an important role in the atmospheric circulation. To an increasing extent the high population density in the tropics will challenge mankind to cope with increasing food demands, urbanisation pressure, pollution and other human induced impacts. In the tropics land use changes are currently most rapid, partly as a result of the disproportionate share of the world's population growth. This results in larger land clearing - mostly forest - and substantial conversion losses of carbon, nitrogen, sulphur, and phosphorus from cleared sites. Massive amounts of material, resulting in losses of elements in solution by erosion and by gaseous emissions, are in motion over comparatively short periods of time.

In the subtropics, which are partly covered, semi-arid areas or areas between woody and grassland vegetation are widespread. Human activity and climatic changes have strong effects on vegetation distribution, land use, and soil with further climatological and biogeochemical consequences.

Within the selected "Columbus" low inclination orbit repeat cycle of appr. 45 days, the selected orbit allows nadir measurements of time dependent phenomena as a function of daytime and varying illumination and viewing geometry in the tropic and subtropic belt between 28.5° N and 28.5° S with high repetition. Variations for a complete day and night diurnal interval can be measured. For periods with smaller seasonal changes a representative day cycle can be recorded. These are the main advantages in comparison to polar orbiting platforms having usually fixed equatorial crossing times.

The orbit is well suited for time dependent investigations of photochemical processes, of the radiation budget, of air and surface temperature, of wind fields, of humidity and precipitation, of cloud cover, and of dynamic land and sea surface features like tides, sea wave spectra, currents, and catastrophic impacts (fire, storms, flooding). In addition, the state of vegetation or land cover (type, extension, height, feature, density, biomass, vitality, permanence, direction of change), the coastal and ocean biogeochemical processes, droughts, and flooding, which all evolve on a longer time scale, can be investigated.

2. MISSION OBJECTIVES

Several questions in Earth science have emerged over the last decade which require multidisciplinary approaches. Examples are the increase of atmospheric carbon dioxide, the depletion of the ozone layer, El Niño related modifications, and acid precipitation. The key to progress on these and other issues will address those questions which concern the integrated function of the Earth as a system. The fundamental processes, which govern and integrate this system, are the hydrological cycle, the biochemical cycles, and climate processes. Each of these processes include physical, chemical, and biological phenomena. Research on the integrating themes will be built upon the progress in research of the established disciplines. A number of parameters of the natural system must be measured including the composition and dynamics of the atmosphere, the dynamics and biological activity of the ocean, and the distribution of biological and geological features and characteristics over the land surface. Since many of the important changes have time scales of seasons to years, persistent observations are needed which provide data records beyond a decade or more (IGBP, 1990).

2.1 Atmosphere

From our present knowledge of the Earth system, it is obvious that the atmosphere plays a key role in the interaction between the various components. It is primarily in the atmosphere that solar heating is converted to kinetic energy. It is the atmosphere that carries water from the oceans to the land. The prediction of atmospheric behaviour has obvious scientific interest. The predictability of the atmosphere is however limited by its intrinsic nature as a nonlinear dynamic system. Current prediction capabilities are further constrained by the accuracy and coverage of measurements.

2.1.1 Atmospheric chemistry

Concentrations of several atmospheric trace gases are increasing rapidly, mainly due to human activities. Increases of the greenhouse gases and other trace gases affect the physical aspects of the climate system and also change the chemical composition, radiation, and dynamics in the atmosphere and even the biotic system by modulations of the solar UV-B radiation.

The chemical composition of the atmosphere is to a large degree determined by the uptake and release of a great variety of trace gases by the biosphere. In turn, the climate and the deposition of chemical compounds are of critical importance for the biosphere. Climate, biospheric conditions, and atmospheric composition form a strong interactive system. The biospheric production of relatively small amounts of greenhouse gases such as CO_2, CH_4 and N_2O plays a key role in atmospheric chemistry.

In the tropical atmosphere anthropogenic disturbances of the chemistry are especially important, as the removal of many trace gases is determined by high concentrations of hydroxyl radicals caused by the strong penetration of solar UV radiation through the relatively thin stratospheric ozone shield. Large natural emission of biogenic trace gases occurs from tropical forests and savannas. These trace gases can be rapidly transported to the free troposphere by convective processes and subsequently carried to other regions of the atmosphere, thus influencing global chemistry outside the tropics as well.

Especially in the tropics the rapid rate of land-use changes due to human population growth is contributing to the perturbation of interaction between biosphere and atmosphere. For example, the emission of carbon monoxid, hydrocarbons and nitrogen oxides from biomass burning results in the photochemical production of large amounts of ozone. Increased rice production contributes significantly to increasing CH_4 concentrations. Increased application of fertilizers and tropical deforestation activities lead to enhanced N_2O and NO_2 releases. These and other anthropogenic emissions affect the atmosphere over a wide range of spatial scales.

2.1.2 Atmospheric structure and dynamics

The tropical atmosphere and the underlying ocean are part of the heat engine that drives the atmospheric circulation. Differences of temperature, created by the gradients of energy input, induce large-scale atmospheric and oceanic motions which carry energy, momentum and chemical substances, and by that redistribute energy and trace substances all over the planet (BEST, 1988).

The tropical energy budget plays an important role in determining seasonal, interannual and decadal variations of the global general circulation. There is strong evidence of correlations between anomalies in the global atmospheric circulation on seasonal and interannual time scales and sea surface temperature (SST) anomalies in the tropical oceans. For example, droughts in north-east Brazil are found to be correlated with SST anomalies in the tropical Atlantic ocean and variations in the intensities of Indian monsoon rainfall, heavy rains in Peru, and droughts in China and India with anomalies in the tropical Indian and Pacific oceans. On the other hand, the occurrence of unusually warm and cold surface waters in the tropical oceans is linked to changes in the surface wind regime thus indicating the complex interaction of the coupled system of ocean, land and atmosphere. Especially the Pacific ocean shows such behaviour leading to the southern oscillation and the related El Niño phenomena.

In order to improve our current understanding and modelling of the climate system and its variability, a better knowledge of tropical atmospheric processes is needed. Many open questions are closely related to the tropical energy budget and especially to the water budget since most of the energy is delivered to the atmosphere in the form of latent heat through cloud condensation and rainfall. The latent heat is set free mainly by convective activity which itself is linked to the large scale tropical dynamics. Multiannual oscillations like El Niño are also forced by cloud convection. Over the ocean, precipitation influences surface salinity and affects ocean mixing processes as well as deep oceanic convection. Over land on the other hand, precipitation influences ecological systems and habitability.

2.1.3 Greenhouse effect and cloud/radiation feedback

Recent observations, made during the 1987 El Niño indicate that in areas with high sea surface temperature large areas of highly reflective cirrus clouds are produced by deep convection that shield the ocean from solar radiation. Thus, cirrus clouds could act as negative feedback during a possible surface heating due to the greenhouse effect of which the first signal is expected to emerge from natural variability by the end of the century. Up to now it is not clear how these radiative effects respond to a climate change, nor do we understand the feedback effects in detail. Therefore, more observations of the relevant components of the tropical energy budget are needed in regions that exhibit strong coupling between surface temperatures and radiative fluxes. The tropical Pacific shows such behaviour. Especially during El Niño events, which occur once every 2-6 years, the equatorial Pacific warms by as much as 2-4 K, and the warming is accompanied by marked variations in the radiation fluxes at the top of the atmosphere.

2.2 Land

The characteristics of the land surface play a fundamental role in the interaction between the biotic system and the climate. They are closely linked to climate, as the balance of thermal and radiative energy at the surface has a major influence on the atmospheric circulation and the distribution of surface energy. This balance is influenced by the net radiation flux at the surface, which determines the transport of heat and humidity into the atmosphere by turbulence and convection, the evaporation of water from vegetation, and heat conduction into the soil.

The nature of vegetation cover, which determines evaporation, surface albedo and surface roughness, affects the transfer of energy at the earth's surface. They are key parameters in climate models. Major changes in vegetation cover will affect the hydrological cycle and thus the water transport to the atmosphere. It will thus have a feedback on the entire climate system.

2.2.1 The hydrological cycle

One of the most important links for understanding the present nature of the biosphere is the hydrological cycle. It is modulated by the biological characteristics of the Earth surface. Precipitation over land feeds back again by means of latent heat release, soil moisture, evaporation, water vapour transport, and water run-off to the atmosphere. The conversion of energy in the tropical belt is considered to be a major term in the global energy budget. Roughly two thirds of the global precipitation fall in the tropical region. The latent heat released by condensation of water vapour in tropical rainfalls is a main source of energy for the global circulation, such shaping also weather and climate in the middle and high latitudes. Variations in tropical rainfall pattern affect life and living conditions worldwide. Economic progress and prosperity largely depend on rainfall and therefore on the variability of precipitation processes (Simpson et al., 1988).

2.2.2 The tropical forest

The knowledge of vegetation and vegetation change is important. Tropical forests and atmosphere behave in some aspects like a regional water and energy regulating system. Most of the water received as rainfall is returned to the atmosphere by the large standing biomasss such promoting heat release which generates further air motion. In tropical and subtropical regions land use change is rapidly increasing for socioeconomic reasons. For food supply, clearing and land transformation of large areas cause enormous losses of biomass and soil, a rapid change in element pool, heavy sediment transport, and pollution on land and in coastal zones with important ecological impacts. Presently, its consequences are clearly visible and measurable as far as surface parameters are concerned. For the future, consequences are not yet predictable, but they may evolve dramatically on a short time basis.

2.2.3 Desertification

The principal human impacts that produce desertification, are the cutting of forests, unwise ploughing and farming practise including agrochemicals, overgrazing, in addition pests and diseases. For semi-arid areas or transition zones between woodland and grassland or grassland and desert, changes in the atmospheric chemistry, land use, and weather will result in change of biogeochemical dynamics. They will feed back again and produce climatological and biogeochemical consequences for vegetation, soil, erosion, and water quality. Prairies are turned into desert such changing albedo, vegetation, biomass, soil, soil moisture, evaporation, water quality, and water run-off. Increase in fire frequency may favour grasses, intensified grazing may increase the patchy distribution of certain soil and soil erosion, and set in motion a positive feedback toward shrub invasion. Land cleared in dry-forest areas is often converted to self-maintaining grassland, with potential climatological and biogeochemical consequences.

2.3 Ocean

Athough they are also closely interlinked, the various mission objectives with regard to remote sensing of the ocean have been grouped according to three main topics.

2.3.1 Energy exchange

The climate on Earth is influenced in many ways by the heat exchange at the ocean atmosphere boundary layer, the ocean's heat capacity, and by ocean circulation. However, in spite of this importance, the general understanding of these processes and of the properties of the oceans, is much less advanced in comparison to that of the atmosphere.

With the exception of the visible light, the ocean is almost opaque to electromagnetic radiation, i.e., the direct radiative transfer of solar radiation into the deeper layers of the water body can take place only in the wavelength region between 400 nm to 700 nm. Heating and cooling at the surface layer occurs essentially through net radiant heating or cooling and through convection. In addition, heat exchange, ocean circulation, and all other dynamic processes are strongly affected by winds. Over large parts of the oceans the currents are driven by surface wind stress and form the well-known patterns of ocean gyres with their meandering western boundary currents and the near-zonal Antarctic circumpolar currents.

On the other hand, the ocean influences atmospheric circulation through the transfer of heat and moisture to the lower layers of the atmosphere. Any change of the water temperature will strongly affect this exchange. Because ocean flow and ocean diffusion transport heat from one place to another, the thermal energy, which the ocean absorbs in one place, may be given back to the atmosphere at a very different place and at a different time. The global transport of heat from tropical regions towards the poles contributes to the temperature balance between low and high latitudes. At high latitudes the cooling leads to the formation of cold deep and bottom water that moves back towards the equator. This in turn has a strong effect on the global temperature.

Furthermore, the extent of climate changes is affected to a large extent by the processes within the oceans which take place in different time scales. For many dynamic investigations, knowledge of the displacement of certain water masses from one day to another is very important. The near-surface water and its heat capacity is involved in exchange processes within time scales of weeks or months.

The heat capacity of the entire ocean and large-scale transport processes also play an important role in climate changes which take place at time scales in the order of tens of years and more. The heat capacity coupled with the exchange of heat and moisture with the atmosphere causes a smoothing of regional temperature extremes between the summer and the winter hemispheres. The heat capacity is most probably the reason for a delay of the global warming on behalf of the anthropogenic greenhouse effect which has been predicted by means of climate modelling.

2.3.2 Ocean dynamics

Dynamic processes such as tides, circulations, currents, upwellings, different types of waves are closely coupled to the energy exchange and to horizontal and vertical transport processes. Depending on the size of the phenomena, the temporal scales for observations may be quite different ranging from hours to months and up to years. Vertical mixing is important with regard to the heat removal from the atmosphere into the deeper layers of the oceans. Because of this effect the water temperature above the thermocline is lowest in areas of strong vertical mixing. On the other hand, prevailing off-shore winds in the shelf zones stimulate upwelling processes by moving cold bottom water to the surface with resulting changes in the atmospheric heat transfer. Ocean eddies are of similar importance with regard to their energy, but also with regard to the different water masses and the respective marine life systems involved.

Remote sensing plays a major role in studying the causes of the permanent and variable circulations, in particular the heat transfer, tidal forcing and the coupling between wind fields and the sea surface. Because of the differences in temperature and water colour, optical methods in the thermal infrared and in the visible are important. On the other hand, relevant changes in sea surface topography, which are superimposed on the geoid, can be measured quantitatively only through accurate altimetry. Also surface roughness (all kinds of waves) is conveniently monitored by suitable microwave sensors. Surface roughness also affects the exchange of heat, gases (CO_2, O_2, N_2 and others), water and aerosols.

2.3.3 Marine biology and ecology

Marine phytoplankton is the first link in the marine food chain. Thus, all organisms in the sea depend directly or indirectly on the primary production of phytoplankton. The growth of phytoplankton depends on various parameters such as the abundance of nutrients, the amount of light and the stability of the upper water column. Under given circumstances a massive growth of algae may occur which again gives raise to the subsequent growth of zoo plankton, fish and other species. The existence of most species depends on a critical balance of certain biochemical and physical parameters. These parameters and subsequently the balance of the marine food chain can be easily disturbed either by natural events or by anthropogenic influences. In coastal zones the entire ecosystem also strongly depends on the distribution and concentration of suspended matter. Organic particles are taken up as food. Without suspended matter, life in the sea would not be possible. Management of the resources in the sea has become of vital importance. Monitoring by the aid of remote sensing will play an increasingly important role in the future.

Marine organisms and their skeletons in the form of dissolved and particulate organic carbon and calcium carbonate, constitute the major reservoirs of carbon in the biosphere. The amount of carbon in sediments alone is very much higher than that presently circulating in the atmosphere, terrestrial biosphere and the ocean together. Plankton plays an important role in the global exchange of matter between the marine biosphere, the terrestrial biosphere and the atmosphere. By photosynthesis marine plankton fixes about 65 % of the carbon taken up by all plants on earth. As a result, the oceans are a major sink of atmospheric carbon dioxide through the sedimentation of organic detritus. Relatively small changes in the fluxes of carbon either to or from these reservoirs can have substantial implications for the comparatively small atmospheric reservoir. Although the capacity of the ocean to absorb carbon dioxide from the atmosphere is primarily determined by the temperature and salinity of the surface water, plankton in the upper layers enhance the transfer of carbon dioxide through photosynthesis. Estimates based on modelling indicate that about half the carbon dioxide being introduced into the atmosphere via fossil-fuel combustion is absorbed by the ocean.

Future research will concentrate on the characterization of the carbon cycle and associated links with cycles of other elements affecting biological productivity and climate, on an assessment of anthropogenic effects especially on coastal and estuarine biological system, and on a characterization of linkages between biogeochemical cycles and the physical climate system.

3. PAYLOAD

Within the scope of this study a core scientific payload, the so-called model payload, was identified. It covers the important spectrum from optical to microwave bands. Long-term measurement which will be performed by the model payload instruments will be supplemented by measurements on short-term missions with additional sensors, following the science plan and new evolving science needs. Concrete and detailed measurement quantities for the payload instruments would expand our view over its given limit. Therefore they are not presented here. They can be found in the references Barren and Battrick, 1991, Beran et al., 1992, and NASA, 1986.

3.1 Selection criteria

The following criteria were applied for the model payload selection.

- Core instrument measurements of atmosphere, land and ocean shall have a high priority in respect to main problem areas in tropical and subtropical zones. These measurements shall support long-term observations for the monitoring of status and development of processes and the understanding and prediction of change.
- Measurement objectives are the generation of information for the development and validation of regional and continental models and the improvement of global models with varying temporal and spatial scales.
- Tropical and subtropical zones shall be intensively covered in the range of minimum local and temporal coverage by polar missions, in addition to geostationary missions.
- Specific measurements of diurnal cycles, seasonal and interanual variations in support of temperature, precipitation, heat flux, atmospheric chemistry, atmospheric circulation and biochemical measurements and calculation shall be emphasized.
- Passive and active optical and microwave data shall be complementary used, to overcome frequent cloud cover in the humid tropics and to obtain synergy in measurements of different sensors and supporting systems.
- Compatibility with instruments on polar/equatorial orbiting platforms at the time horizon 2000 - 2030, mainly with respect to data and calibration, must be secured. Provision shall be made for basic sets of well calibrated data (NASA, 1990).

3.2 Model payload and additional instruments

For priority measurements with the same payload for atmosphere, land, and ocean a model payload is been identified which includes instruments with measuring capabilities from the visible to the microwave band of the spectrum. It is assumed that the instruments are of the same type as those on polar orbiting platforms. The model payload instruments are listed in Table 1, the additional strawman instruments in Table 2.

Optical sensors:	
ISMM	Imaging Spectrometer of Medium Resolution
OLNS	Optical Limb/Nadir Sounder
RBI	Radiation Budget Instrument
WLID	Wind Lidar
Microwave sensors:	
ALT	Altimeter
RR	Rain Radar
SAR	Synthetic Aperture Radar

Table 1: List of model payload sensors. The ISMM includes spectral bands in the thermal IR region.

Optical sensors:	
ALID	Absorption Lidar
ISMH	Imaging Spectrometer of High Resolution
LRR	Low Resolution Radiometer
TIR	Thermal Infrared Radiometer
Microwave sensors:	
MLS	Microwave Limb Sounder
MRAD	Microwave Radiometer
SCAT	Scatterometer

Table 2: List of additional strawman instruments

To avoid direct identification with existing instruments, neutral strawman names have been used. However, an identification can be found under the corresponding heritage instruments, see Beran et al., 1992.

4. CONCLUSION

Earth observation from space platforms, supported by airborne and ground measurements, offers the potential of continuously viewing large portions of the Earth thus documenting the current state and occuring changes. Key requirements for earth observations are the suitability of sensors and of viewing conditions, simultaneity, accuracy, long-term consistency, and continuity of measurements. Especially the tropical belt with its high radiative input, high dynamics of precipitation, plant productivity, and gas exchange has a strong influence on global circulation and their feedback on climate and living conditions. Intensive research is of vital importance for the understanding of changes and their consequences worldwide. In addition, in a few decades more than half of the human population will live in the tropical and subtropical regions (Hoeke and Irsyam, 1984).

4.1 Advantages of a Low-inclination orbit

One challenge will also be to combine relevant data from different platforms to provide the global study context. It appears reasonable to concentrate measurements on near-polar orbits for global coverage and to address further problems and the validation of models on regional or continental scales by additional measurements on specific orbits.

Many environmental processes in the tropics occur at spatial and temporal scales that cannot be adequately resolved by measurements from polar orbits. Some of these processes should be studied on regional and even local scales with high spatial resolution and high repetition rates to investigate diurnal cycles, seasonal and interannual variations. It is therefore one of the main advantages of the low-inclination orbit to allow this type of measurements. As a complement to polar orbiting platforms, the low-inclination orbit provides

- a high repetition rate (3 days) on a shift orbit (45 days),
- a variety of local solar times (illumination conditions) and viewing geometries for measurement of dynamic features
- improved spatial resolution from the lower altitude orbit and reduced power demands for active sensors.

4.2 Main Scientific objectives

The scientific objectives for Earth Observation should concentrate on the following topics:

- Observation of the atmospheric structure in the tropics, measurement of physical properties in the complex interactions of the coupled system ocean-land-atmosphere,
- Vegetation, natural and human-forced land cover change, their impact on climate, and biosphere-atmosphere exchange in a coupled system,
- Observation of ocean dynamics and marine biology and measurement of dynamic features and processes in conjunction with primary productivity and the carbon cycle.

4.3 Investigation of dynamic processes

Time and illumination dependent basic variables and phenomena for the measurement of the diurnal cycle, seasonal and interannual variations should include:

- Photochemical processes,
- Wind and water vapour fields,
- Cloud characteristics and cover,
- Surface, air and cloud top temperature,
- Radiation budget,
- Precipitation profile, rate and distribution,
- Evaporation, soil moisture,
- Photosynthesis, plant vitality and biomass production,
- Vegetation index,
- Dynamic features in coastal regions and the ocean.

For these measurements core instruments were choosen and integrated to a model payload, see Table 1, which must be supplemented for dedicated missions by extra sensors, as listed in Table 2.

4.4 Flight on the Columbus-Attached Laboratory

For the case of integration on the external platform of the Columbus-Attached Laboratory with an orbit inclination of 28,5° core and dedicated measurements of dynamic processes can performed. By grouping of instruments and variable measurement sequences high flexibility in operation is obtainable. Instruments and components can be maintained, replaced, supplemented, and calibrated, thus ensuring high mission success. Manned interaction can be restricted to a few short time periods. A further aspect is the development, test and application of new technologies or critical components in adaption to growing experience and science needs.

5. RECOMMENDATION

In conclusion the study recommends

- dedicated earth observation missions in the tropics and subtropics on low-inclination orbits for the understanding of regional and global processes as complement to polar orbiting missions,
- a further interdisciplinary study to prove the mission, instrument selection, and accommodation from the scientific and application point of view and its technical and logistic consequences.

  Special emphasis should be placed on:

  - Monitoring of tropical forests and of desertification
  - Early warning for catastrophic events
  - Atmosphere/ocean/land interaction processes.

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