4. REMOTE SENSING

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Introduction

Remote sensing has an important role in the NEESPI science program, providing up to date and historical, spatially explicit information to inventory and quantify changes in the land surface and in the coastal zone for use in process and modeling studies. Priority within the NEESPI remote sensing research community is to provide quality, validated data products to enable the science goals to be met. In addition, remote sensing will continue to play a role in monitoring the resources of the region. NEESPI science and observations will provide the opportunity for improved resource management and decision-making.

The following characteristics of the Northern Eurasia region place the research and development of satellite remote sensing capabilities among the key elements of the NEESPI Science Plan:

- Extensive and remote territories, large areas of land which are poorly inventoried and monitored
- Lack of uniform data sets across the region and restricted access to the existing more traditional data sets
- Rapid recent socio-economic change coupled with climate variability and change increases the variability of observed environmental conditions and natural hazards
- Science and resource management requirements for uniform and comprehensive data sets and integrated databases gives increasing emphasis on the generation of new data products

Satellite remote sensing provides a unique opportunity to obtain up-to-date information for global change science, natural resources management, and early warning for disaster management in the NEESPI region. Recent advances in satellite monitoring, provide a number of new data sets and tools for researchers and resource managers alike. Demonstrating current satellite monitoring capabilities and transitioning them from research to the operational domain within the region will be an important goal for NEESPI. A primary NEESPI program objective is to integrate satellite and in-situ observations and information technologies to obtain up-to-date information on the status and dynamics of the region and make it available to a wide range of public entities.

The functional structure of such an integrated observing system will consist of the following components:

- Satellite and in-situ data collection and management
- Geospatial data processing and analysis
- Spatial analysis and modeling (including GIS tools)
- Data distribution, user interfaces, and data archives

In addition to the provision and dissemination of satellite data from outside the region by satellite data providers, e.g., NASA, NOAA, ESA, and NASDA, the NEESPI satellite data collection module should help establish a network of satellite receiving stations, dedicated data processing and distribution centers within the region to provide customized products and near real-time data to meet regional needs (Loupian et al., 1999). Generation, processing and archiving of data will need to be undertaken in a distributed way, taking advantage of the expertise of various NEESPI participants within and outside the region. It will be important to maintain an open dialogue between data providers and data users, particularly from the modeling and monitoring communities, to ensure that priority data requirements are met. A culture of open data sharing will need to be fostered amongst the NEESPI scientists and an acceptable data policy established at the outset of the program.

The following satellite instruments will contribute to the NEESPI research and applications goals:

- Coarse to moderate spatial resolution data (8km-250m), e.g., NOAA-AVHRR, SPOT-Vegetation, Terra and Aqua MODIS, Envisat-MERIS, SeaWiFS. These data will provide daily observations and temporally composited products
- High spatial resolution data (c. 30m), e.g., SPOT, Landsat-ETM, ASTER, Meteor-3M, EO-1, and IRS high-resolution.
- Very high spatial resolution data (<1-4 m), e.g., IKONOS, Quick-Bird. These commercial products will be subject to copyright restrictions.
- Multi-view angle optical data, e.g., from Terra-MISR
- Moderate to high spatial resolution (500m-15m) Synthetic Aperture Radar data and products, e.g. Envisat-ASAR, ERS-1+2, JERS, Radarsat, SIR-C, SRTM
- Very coarse spatial resolution (25km) microwave radiometer data, e.g., Aqua-AMSR-E, DMSP-SSM/I, DMSP-SMMR
- Historical optical data, e.g. MSU-SK/RESURS-O1, KFA-1000, DISP-CORONA

In addition, opportunities will be sought for ad-hoc targeting of high-resolution observations from manned spacecrafts e.g. in framework of “Uragan” program on the board of International Space Station.

The following sections outline priorities for research and development of various aspects of remote sensing techniques, methods and applications in order to provide observations and products in response to the needs of the main scientific goals of the NEESPI. The sections are divided into remote sensing of terrestrial systems, remote sensing of coastal zones and inland waters, remote sensing of the cryosphere, remote sensing of energy and water balance.

4.1. Remote Sensing of Terrestrial Ecosystems

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In general terms we can distinguish four focus areas when developing and applying remote sensing to northern Eurasian terrestrial ecosystems: land cover mapping and characterization; large-scale vegetation dynamic processes; biophysical properties of the vegetation; and forest and rangeland management.

4.1.1. Land cover mapping and characterization

Northern Eurasia includes a wide range of ecosystem types, e.g., tundra, forest, steppe, wetlands, and agricultural lands, and their status and dynamics play profoundly significant roles in environmental and economic processes. A number of existing terrestrial products derived from coarse to moderate resolution satellite data (8km – 250m) have been developed including the NOAA-AVHRR land cover (Loveland et al., 1999), MODIS land cover and percent tree cover (Friedl et al., 2002; DeFries et al., 2002) and the SPOT-Vegetation data GLC 2000 land cover map (Bartalev et al., 2003). These products provide a description of the current pattern of terrestrial ecosystems for Northern Eurasia. Future land cover mapping efforts will be focused on the production of regional higher spatial resolution land cover datasets from optical sensors, e.g., MODIS 500m and 250m, Landsat-TM/ETM+, SPOT-HRV (30m). The SIBERIA-I project has generated a Central Siberia Forest Cover Map using ERS and JERS-1 radar satellite data at a scale of 1:200 000 (Schmullius et al., 2001: Balzter et al., 2002). New MODIS products for detecting land cover change are also under development for this region (e.g., Zhang et al., 2003). However, for quantifying land cover change and, in particular, for measuring land use related change, high spatial resolution data is needed. Future land cover products for Northern Eurasia would benefit from the application of a common approach to classification system, e.g. the FAO Land Cover Classification System (Di Gregorio and Jansen, 2000).

Remote sensing of vegetation cover and structure provides information on lifeform/species composition, age/successional status, phenology, and characteristics of 3D structure of trees, such as cover/crown density and forest stand height. Such parameters are used in ecosystem and biogeochemical process models. Optical satellite sensors currently provide the primary source for these parameters. Development of improved moderate resolution vegetation cover products at the regional scale should continue to exploit multi-spectral and multi-temporal data to provide direct parameterization and classification of vegetation types. This characterization should take into account lifeform (e.g. trees, shrubs, grasses, mosses and lichens), leaf types (broadleaf and needleleaf) and phenological attributes (deciduous/evergreen, annual/biennial/perennial, moisture-limited/temperature-limited). The composition of vegetation types at the sub-pixel level can be characterized using advanced algorithms, based on spectral unmixing (Adams and Smith, 1986). Multi-angular satellite observation, for example from Terra-MISR, combined with BRDF models provides a unique opportunity to develop methods to characterize 3D structure of the forest cover (Widlowski et al., 2001; Pinty et al., 2002).

4.1.2. Large Scale Vegetation Dynamics

Vegetation is dynamic, experiencing changes in the phenological tempo, species composition, biophysical and structural characteristics that are driven by successional and anthropogenic processes as well as by variation in climatic regimes as a variety of time scales. The large-scale vegetation dynamics focus includes the study of rapid vegetation changes including extensive forest clearcutting, conversion of forest or grasslands to agriculture, land abandonment following institutional changes, or short term disturbances to vegetation condition from drought, flood, fire, or pests, as well as longer term interannual and decadal trends in vegetation cover, including forest and grassland degradation, desertification, and changes in phenology or biome distribution resulting from regional climate change.

Large forest clear-cuts, which is the main type of forest logging in Russia, can be identified using 250 m resolution satellite data from Terra-MODIS (Chan et al., 2002). Whereas more fine scale clearance and selective logging can be quantified by applying change detection methods to Landsat-TM imagery (Bartalev et al., 1997).

For the last few decades, time series of NDVI derived from NOAA AVHRR sensors have been widely used to investigate vegetation phenology in response to interannual climate variability (Justice et al., 1985; Myneni et al., 2001) and to the collapse of the Soviet Union (de Beurs and Henebry, 2004). For deciduous forest, time-series of NDVI reflects largely leaf-on and leaf-off phases and, to a lesser extent, leaf area index. Recently, some progress has been made in using the MODIS Enhanced Vegetation Index (Zhang et al., 2003) and LSWI (Boles et al., 2004; Xiao et al., 2002). Alternative vegetation indices provide an opportunity for improved characterization of the seasonal dynamics of vegetation phenology and structure, particularly in croplands and grasslands (e.g., Gitelson et al., 2003; Viña et al., 2004).

4.1.3. Vegetation biophysical characteristics

Research is being undertaken to provide satellite estimates of leaf area index (LAI), the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) and Net Primary Production (NPP) (e.g., Myneni et al., 2002). These products are important variables for biogeochemical cycle and energy flux modeling. The LAI and NPP products generated from MODIS are currently being validated using ground based measurements independent ground based measurements including data from flux towers (Cohen et al. 2003; Morisette et al. 2004). As these new products are being used in quantitative models, it is critical that their precision, accuracy, and uncertainty be determined for the NEESPI region. New indices from vegetation monitoring and new methods for satellite estimation of primary production are being adapted for assessing semi-arid land degradation (De Beurs and Henebry, 2004).

As the science community develops an improved understanding of land - atmosphere interactions, advances are being made in the area of weather and climate modeling and land data assimilation (Dickinson et al., 1998). Improving the mesoscale climate modeling for northern Eurasia will be important for science goals of NEESPI and which will have a number of practical applications as well, viz., in terms of the impact on vegetation distribution, disturbance regimes, and agricultural production. Monitoring and modeling of agricultural production is improving with the wider availability of computational resources and improved moderate resolution satellite monitoring. Satellite methods are also available for early warning of droughts and agricultural blights. These tools, although tested in various locations, have yet to be evaluated over large regions and transitioned to operational datastreams for use by agricultural agencies.

4.1.4. Forest and Rangeland Management

Forests, which cover a large part of the Northern Eurasian region, are under varying degrees of management. Up to date information on the state and extent of forest cover and improved forest inventories are necessary components for effective management (Isaev and Sukhikh, 1991). Satellite remote sensing has a role to play in keeping information on forest extent and change current.

Industrial pollution is having a serious impact on forest productivity in European parts of the region and the extent of these effects and effectiveness of legislation aimed at reducing this impact and various mitigation efforts will need to be monitored (Butusov et al., 1996). Illegal logging is purported to be extensive and is proving to be a large forest management problem. The location and extent of logging is poorly quantified but can be monitored by a combination of satellite and ground based monitoring (Breido and Sukhikh, 1995). Insect infestations are extensive, covering millions of hectares and requiring early warning, if they are to be managed effectively (Isaev et al. 1991). Eurasian forests provide a large carbon sink and an opportunity for carbon management and accounting (Isaev et al., 1995), though independent verification will be necessary for carbon accounting.

Monitoring of rangeland (steppes and semi-deserts) is essential part of NEESPI program. The importance of studying vegetation dynamics of rangeland has been recognized for decades. A key driver has been the interest in understanding the patterns of rangeland productivity and its relationships with global biogeochemical cycles of carbon and nitrogen (e.g. Cao and Woodward, 1998). The main challenges for remote sensing of regional rangelands are (1) characterization of vegetation dynamics in ecosystems with high spatio-temporal variation in aboveground biomass, and (2) estimation of range condition (available forage) by synoptic sensors at scales relevant to animal use. Development of techniques for accurate estimation of vegetation dynamics would be a focus of NEESPI program.

Moderate-resolution data from optical satellite sensors, such as NOAA-AVHRR (Grégoire and Pinnock, 2000) and Terra-MODIS (Justice et al., 2002), provide an opportunity to collect information about active vegetation fires on the global scale with daily time frequency. The possibility to map vegetation burned area at the global scale from the SPOT-VEGETATION satellite data has been recently demonstrated by GBA 2000 project (Grégoire et al., 2003). High spatial resolution imagery (20-30 m) can be effectively applied at local scale to estimate burn severity in forests, which is essential for assessment of carbon emissions caused by fires (Isaev et al., 2002). Emphasis is needed on the validation of these new data products (Justice et al., 2003). Wildfires and insect infestations are natural disturbances in the boreal forests that have important economic implications for forest management. Where fires intersect with human population, anthropogenic ignitions augment lightning ignitions requiring more active management of fires and fuels. New and improved methods for fire danger rating and early detection of fires have been developed by the science community and are being made available for the fire management community (Ahern et al. 2001: Korovin et al., 1998). Similarly, methods are being developed by the research community for automated mapping of burned area, providing annual measures of the area burned, allowing monitoring of trends in fire extent and providing an input to national annual emission inventories (e.g., Roy et al., 2002). Smoke from extensive fires cause regional air pollution and smoke palls are lofted and transported great distances from their source. Direct measurement of the energy released from fires is being explored in the NEESPI region using data from the BIRD and MODIS satellites (Wooster et al. 2003) The trace gas emissions from the extensive forest, peat and grassland fires in the region are poorly quantified for Eurasia, but initial estimates indicate that they are globally significant (Kasischke and Stocks, 2000). The impacts of projected climate change on fire regimes and future forest and fire management in the region have yet to be assessed, although regional climate modeling for the boreal regions of Canada would suggest increasing frequency of fire and an associated increase in emissions (Stocks et al., 1998). Potential linkages of disturbance regimes with climate modes (Wang and Schimel, 2003) need to be evaluated within Eurasia.

Improved climate modeling will enable study of the linkages between climate and human health. Satellite monitoring of land cover change and vegetation condition are being used to identify insect breeding sites and study disease vectors. A combination of ground sampling and remote sensing of water bodies could be used for early warning of the potential for diseases such as cholera. Climate and land cover predictions can be used to study the potential spread of diseases.

Integrated Terrestrial Observing System. While most current research projects use one particular sensor system for land cover and vegetation monitoring, it is recognized that a more integrated approach is needed. To meet the NEESPI science objectives, a multi-sensor approach based on the best combination of available satellite data will be pursued. The move towards integrated observing systems is being promoted by the international community (Justice et al., 2003). To ensure continuous vegetation change detection using coarse and moderate spatial resolution satellite data, new approaches to the analysis of image time series will be investigated to provide a common methodological framework to detect a wide range of change types, including rapid changes in the vegetation, and trends in the status of vegetation. These new methods for deriving quantitative information regarding the vegetation changes have to be investigated and developed. In particular the following approaches may be considered:

i. Multi-resolution validation of measurements derived from the sequentially sampled satellite data along with coarser to finer spatial resolution imagery (e.g., ranging from <4m to 1000m);
ii. Model-based approach (spectral mixing, BRDF and light-canopy interaction models) to estimate structural changes in the vegetation cover based on measured changes in spatio-spectral heterogeneity;

In addition to multi-source data fusion, world space agencies are currently exploring sensor web technology using high frequency satellite observations to direct sampling with higher spatial resolution systems.

4.2. Remote Sensing of Coastal Zone and Inland Water Bodies

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Remote sensing in this area include the study of estuarine and coastal phytoplankton and dissolved organic matter for atmospheric carbon dioxide estimation; water quality, geomorphology and sedimentology, and coast evolution among others. To address these areas of study, comprehensive data on water quality are required. *In situ* measurements of water constituents provide accurate information for a point in time and space, but these measurements are difficult, expensive, and often inaccurate for understanding either the spatial or temporal patterns of optically active constituents needed for accurate assessment of their distributions (e.g. Curran and Novo, 1988). Assessment of the magnitude of these problems and the formulation of effective monitoring strategies require more reliable data, an improved understanding of the spatial and temporal patterns involved, and faster retrieval of information. Remote sensing techniques provide spatial and temporal data on water parameters, thus making it possible to monitor the landscape effectively and efficiently by identifying and quantifying distributions of optically active constituents such as phytoplankton, dissolved organic matter and suspended matter (e.g., Cracknell, 1999). New satellites and sensors (SeaWiFS, MODIS, MERIS, HYPERION) provide the improved spectral and spatial resolution needed to monitor coastal and inland water quality parameters from space platforms. However, there may be, in many cases, a requirement of the use of airborne or even hand held sensors to thematic calibration of algorithms.

There has been considerable success in optical remote sensing of chlorophyll concentrations (Chl) in ocean waters where the variation of optical properties is dominated by phytoplankton and associated material, and some consensus is emerging with regard to appropriate algorithms (http://seawifs.gsfc.nasa.gov/SEAWIFS.html). In contrast, Chl retrieval in turbid productive waters is still a matter of intense research activity and few convincing examples are available of satellite-derived Chl concentrations for such waters. However, the demand for detailed monitoring of Chl in such waters is very high because of the importance of estuarine and coastal phytoplankton in the balance of atmospheric carbon dioxide (Frankignoulle et al., 1998) and hence, possible climate change. It is also important due to the need to manage inland and coastal eutrophication.

Constituent concentrations in turbid productive waters are independent, thus, the blue-green two-band ratio algorithm (Gordon and Morel, 1983) used for ocean waters is not appropriate and alternative approaches must be sought. The data of the Coastal Zone Colour Scanner (CZCS), operated from 1978 to 1986, and the Sea-viewing Wide Field of View Sensor (SeaWiFS), which was launched in 1997 and is still operational, should be analysed to retrieve Chl and CDOM. CZCS did not have the ability to separate CDOM from phytoplankton. New algorithms are able to distinguish between these constituents (Carder et al., 1999) and have to be tested.

In the case of Northern Asian lakes, in reservoirs and rivers in the 400-500 nm spectral range, the absorption by tripton (particulate matter after removal of phytoplankton pigments) is generally greater than phytoplankton absorption. Considering that the satellite-based sensor sees only the effect of the total absorption coefficient (particulate plus dissolved matter plus pure water), it is clearly important to at least be able to distinguish phytoplankton related features in the total particulate absorption spectrum. A number of analytical algorithms have been developed for case 2 waters (e.g., Doerffer and Fischer, 1994; Vasilkov, 1997) that should be tested using satellite data.

For assessment of Chl*a* concentration, a specific Chl spectral feature (peak near 700 nm) has been used (e.g., Gitelson 1992; Gons, 1999; Dall'Olmo et al., 2003). There are numerous successful examples of chlorophyll retrieval using these algorithms in productive turbid water using hand held and aircraft sensors. Now, when MERIS data (channels around 670 and 6700 nm - http://wdc.dlr.de/sensors/meris/main.html), are available, these algorithms will play a significant role in estimation of Chl distributions. However, accuracy and robustness of chlorophyll retrieval, as well as a range of conditions in which concentration retrievals are reliable, have to be the main focus of NEESPI research.

One of the most exciting advances in recent remote sensing is estimation of chlorophyll *a* fluorescence from space using MODIS and MERIS systems (http://picasso.oce.orst.edu/ and http://wdc.dlr.de/sensors/meris/main.html). This is the first time scientists have been able to measure physiological changes in phytoplankton communities rather than just population increases. It can help to accurately estimate the primary productivity (the amount of organic carbon phytoplankton produces). However, only the first steps have been done in MODIS and MERIS data interpretation. Future research of the effect of constituents other than chlorophyll fluorescence on reflectance around 685 nm is required. It is especially important in turbid productive waters where scattering by suspended material, as well as absorption by chlorophyll, can greatly affect the reflectance signal in this spectral range.

4.3. Remote Sensing of the Cryosphere

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Remote sensing provides the spatial and temporal observing capabilities needed to investigate and understand cryospheric processes over Northern Eurasia.

4.3.1. Remote Sensing of Glaciers

NEESPI glacier investigations will include studies of glacier/ice cap mass change, 2D and 3D glacier geometry, glacier velocity fields, monitoring of transient snow lines, radio-echo sounding studies, deep ice-core drilling, ground truth observations, and special studies in poorly known regions. Remote sensing will play an important role in these studies. Remote sensing technologies such as GPS, geodetic airborne or satellite laser altimetry/LIDAR, high-resolution imagery, and InSAR are revolutionizing the observation of glacier mass balance. Geodetic and photogrammetric measurements are also being improved. The current and emerging methods will facilitate repeated observations of glacier volume changes over larger spatial scales and for longer observational periods while index-stake measurements will provide high temporal resolution and allow calibration of remotely sensed data. New technologies are also enabling the production of digital-based inventories over large glacierized areas. In NEESPI, these global and continental level inventories will further benefit from continuing acquisition of Landsat ETM+ and ASTER data, ASTER stereo capabilities, and data products from missions such as ICESat and data products from CryoSat. The use of a combination or of separate spectral bands of ASTER images allows for investigation of accumulation and ablation areas of the glaciers, which have different reflective characteristics. For open ice surfaces, the range 0.78-0.86 µm works more effectively, and for debris surfaces, the range 0.52-0.60 µm is more informative. The geometrical resolution of space images determines opportunities for the studying of morphology elements of a surface and glacier boundaries extraction. These opportunities also depend on the glacier size and morphological type of glacier. Radar images, despite a number of obvious advantages, are less effective for studying montane glaciation because of topography, which produces significant noise. The high-resolution optical remote sensing data from a number of space platforms can be used for assessment of modern Northern Eurasia glaciation. The following data can be used for studying individual glaciers: the PAN and LISS-3 (the I R S- 1C, the I R S - 1D), the ASTER (Terra), ETM + (Landsat7), and the MSU-A (Meteor - 3M). For retrospective analysis, it is necessary to use comparisons of the resolution of historical images: KFS-1000 (Resource - F1), MK-4 (Resource - F2), TK-350 (Comet). For study proxies and mechanisms of catastrophic glacier processes (such as Karmadon Ice-rock avalanche) images of more detail resolution provided by IKONOS (0.61

m) are required. Additionally, the RADARSAT images can be used for studying physical characteristics of glaciers.

4.3.2. Remote Sensing of Snow

DEM of the region can be used to define the altitude of glacier boundaries, which are important characteristics for glacio-hydrological calculations. For example, the position of a glacier's equilibrium line is a very informative index which could then be approximately recalculated in the solid and total precipitation (Krenke, 1982). This method is used in the World Atlas of Snow and Ice Resources (1997) created in Russia that is now available in digital form (Kotlyakov and Khromova 2002). The use of satellite images in the visual band for snow, firn, and superimposed ice lines on the glaciers at the end of ablation season together with air temperature data of the same year summer would permit evaluation of precipitation of the given year or even organization of the alpine zone precipitation monitoring.

Remote sensing will be essential for investigation of the hydrological properties of snow within the NEESPI study area because traditional in situ data collection in this region is both sparse and non-uniform, depends heavily on human observers, and data verification is almost impossible. Snow remote sensing efforts will focus on developing, validating, and refining empirical and theoretical algorithms for snow cover properties (extent, water equivalent, wet/dry state) in varying climatic regions and landscapes using passive and active microwave data. Optical (visible and near-infrared) remote sensing data will also be used, but their use is constrained by cloud cover and darkness, which is common in the study area during winter. Data from passive microwave sensors (including SSM/I and AMSR-E) allow daily coverage through thick clouds and during darkness (Armstrong et al., 1997; Krenke et al., 1997). Automated algorithms permit objective observations that are important for the development of modeling and data assimilation capabilities. The spatial resolution of these data varies from 12.5 - 25 km for SSM/I and MTVZA-OK to 5 km for AMSR-E. Of particular importance would be regular remotely sensed observation of snow water equivalent (SWE). The product of snow depth (or snow cover height) and snow density, SWE is fundamentally important to the terrestrial hydrology and ecosystem dynamics of the region. Passive microwave radiometry (e.g. SSM/I and AMSR) is the only remote sensing method available today for retrieving estimates of SWE, but with mixed results. Further, studies are needed to address well-known limitations of this approach to improve the estimation of SWE for NEESPI (Armstrong and Brodzik, 2001). All SSM/I algorithms tend to underestimate SWE and snow extent, especially during early winter and in forested areas. SWE cannot be determined when the snow pack is wet, although the presence of wet snow can be detected.

Remote sensing science goals for NEESPI include development and validation of new regional SWE algorithms for passive microwave data in the NEESPI study area and the development of multi-sensor (e.g. combined with optical and in situ data) and modelling approaches to overcome problems in shallow-snow and forested areas. The relatively low resolution of passive microwave sensors is inadequate for many regional hydrological studies. The use of active microwave sensors (radars) is emerging as the cutting edge of snow remote sensing. Radars have strong capabilities to measure snow properties, including wet-snow (complimenting passive radiometry, which typically only measures dry snow), and provide excellent resolution for hydrological studies. The major limitation to progress in this area has been the radar frequencies available on past and current satellites – primarily L- and C-band. Higher frequencies (e.g. Ku-band) are needed to measure SWE using polarimetric methods. There has been recent progress in using L-band interferometry to determine SWE. Development of improved radar remote sensing techniques for snow properties will be an important task for NEESPI. Studies using ground-based and airborne instruments under different conditions in NEESPI will be essential for advancing snow remote sensing capabilities. Finally, there are modeling approaches that combine land cover and meteorological data, digital cartographic information, and remote sensing data both in optical and microwave bands with regional algorithms for snow characteristics retrieval and techniques for joint processing of various space- and time-distributed data.

4.3.3. Remote Sensing of Frozen Ground and Permafrost

NEESPI cryosphere remote sensing efforts will include development of methods for mapping seasonally and perennially frozen ground and associated features, thereby facilitating the assessment of its changes. Supporting ground truth data collection programs need to be established at a number of locations. The programs will provide baseline data for developing satellite-based mapping methods and for validating and improving spatially distributed heat transfer models that are needed to investigate the effect of changes in air temperature and surface conditions on the active layer and permafrost. Multidimensional SAR configurations (i.e. multi-frequency, -temporal, -polarization, -incidence angle) also need to be investigated to improve the present approaches so that permafrost maps can be produced in the discontinuous and continuous permafrost zones. The multi-temporal SAR data (ERS-1/2 and RADARSAT) for monitoring the seasonal freeze/thaw cycle of sub arctic tundra and forest are available. For mapping the surface heat balance in permafrost terrain, NOAA AVHRR data can be used. Many important landscape features in permafrost regions are small in scale, but provide important indication of changes occurring to the permafrost in the region, e.g. pingos and ice-wedge polygons. Very-high-resolution IKONOS and high-resolution Landsat satellite data will be used to map and analyze these changes in selected parts of the NEESPI study area. Ground-based remote sensing methods, including ground-penetrating radars, will also be used to help evaluate permafrost conditions within the study area (e.g., Liu, 2000; Yakurov and Yakurov, 2003).

Remote sensing will be used to map the seasonal and interannual variations of seasonally frozen soils. Recent progress in using passive microwave data together with a simple numerical heat transfer model to distinguish near-surface soil freeze/thaw status over snow-free land (Zhang and Armstrong, 2001) allow a preliminary determination of frozen ground extent and variability within the NEESPI study area. Further development of this capability will be one of the foci of the NEESPI remote sensing development.

4.4. Remote Sensing of Surface Energy and Water Balance Components

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Estimates of radiative, turbulent heat fluxes, precipitation, and soil moisture are required to describe the water and energy budgets over the NEESPI region. Satellite remote sensing provides the only way to observe some of these variables and operational weather forecast models, as well as climatic and ecological models, are dependent on the large-scale satellite-based datasets that are currently available. These data sets provide cloud forcing, longwave radiation, short-wave radiation, radiative flux, solar irradiance, solar radiation, photosynthetically active radiation, direct and diffuse solar radiation, albedo, ice, ozone, precipitable water, pressure, reflectance, snow, and temperature.

4.4.1. Radiative components of the surface energy balance

The radiative components most important for climate and climate processes involve the fluxes of radiative energy exchange between space, the atmosphere, and the surface in the short-wave (SW) (direct and diffuse) and long-wave (LW) (emitted and reflected) wavelengths. The exchange of this radiative energy at the surface constitutes a significant portion of the surface energy balance. The WCRP GEWEX Surface Radiation Budget (SRB) project has produced a long-term surface radiative energy dataset containing SW and LW fluxes (Stackhouse et al. 2000; 2002; 2004). The dataset uses the GEWEX International Satellite Cloud Climatology Project (ISCCP) (Rossow and Schiffer, 1999) as input to produce a 3-hourly, ~100-km resolution time series of radiative fluxes. Other data sets covering Northern Eurasia over parts of the last 20 years include the SW and LW ISCCP Flux Data (Zhang et al., 2004) and The University of Maryland SW only (Laszlo and Pinker, 2001) datasets. These data sets have a nominal 280-km resolution. Other radiative flux data sets exist at higher resolution but for shorted time periods, including the SW and LW fluxes from the European ERS satellite (ATSR data are used), retrieving with the resolution of ~ 1km (Xue et al., 1998, Xue et al., 2000a). Despite the successes of these projects, large uncertainties in the derivation of the surface radiative fluxes remain due to complexities of the Northern Eurasia region. These include uncertainties due to (a) nonuniform temporal sampling of the entire region by polar orbiting and geosynchronous satellites, (b) the retrieval of solar fluxes at very low sun angles and high viewing angles, (c) difficulties in distinguishing cloud over snow and ice surfaces, (d) the retrieval of the spectra surface albedo due to terrain complexity, varying snow cover, and atmospheric constituents such as aerosols, (e) the retrieval LW fluxes during times of a cold inversion over ice surfaces, and (f) the determination of surface emissivity in time. These and other uncertainties remain an impetus for study of radiation balance with the NEESPI region.

4.4.2. Turbulent heat fluxes and water balance components

There are no reliable methods for the direct remote measurements of these heat and mass fluxes over the land areas, but there are numerous efforts to address the problem. The most promising are those that use information on the rate of changes in brightness temperatures within the diurnal cycle to infer the thermal inertia of the surface that can be linked to the fraction of the available surface radiation budget released in the form of the latent heat flux (Watson et al., 1971; Watson, 1974; Miller and Watson, 1977; Ho, 1986; Moran et al., 1989; Vidal and Perrier, 1989; Thunnissen and Nieuwenhuis, 1990; Caselles et al., 1992; Cracknell and Xue, 1996a.,b; Xue et al, 2000b; Diak et al., 2004).

Some of the surface water balance components could be determined remotely with the different confidence level. These include evapotranspiration (latent heat flux), precipitation, and soil moisture. Several techniques are used to determine precipitation rates over land from space. They are based on passive microwave, active microwave (precipitation radar), infrared, outgoing longwave radiation (OLR) measurements, and TIROS Operational Vertical Sounder (TOVS) data. In practice, the measurements from different platforms are combined, used jointly, and frequently calibrated and re-adjusted with the help of in-situ gauge measurements (Kummerow et al., 1998, 2000, 2001; Ferraro et al., 1996; Ferraro, 1997; Hou et al., 2001; Adler et al., 2001, 2003; Huffman et al., 1997, 2001; Joyce et al., 2003; Hsu et al., 2003). The retrieving algorithms have two different objectives. The first objective is to have the most reliable near – real time product linked to an operational weather forecast scheme (Hou et al., 2001; Janowiak et al., 2000). The second objective is a construction of long-term homogeneous, "combined" time series with near-global coverage for global climate change studies (e.g., Global Precipitation Climatology Project, GPCP[57], Adler et al.

[57] The GPCP dataset contains the monthly precipitation data since 1979 at the 2.5° x 2.5° grid cell resolution with a global coverage. For Northern Eurasia, the "blended remote" GPCP product heavily relies on the monthly rain gauge data that have a preference versus the remote sensing information. Generally, in the GPCP product over land, the scaled-down pattern derived from the remote sensing data, is used to fill in gaps in the

2003). The quality of all satellite retrievals is better when they are a part of the data assimilation scheme in a regional atmospheric model with sophisticated land surface block (Susskind et al., 1997; Kummerow et al., 1998; Hou et al., 2001; Mitchell et al., 2000; 2003). That is why this approach may be recommended for the NEESPI project. Because of a long period of snow cover in the NEESPI region, the radar method of snow equivalent determination in the boreal forest using active and passive microwave methods (Goita et al., 2003) seems to potentially be quite operationally accurate.

The use of microwave sensors (both passive and active techniques) for soil moisture retrieval have been investigated since the 1970s (Ulaby et al., 1982; 1986) and now practical methods for mapping soil moisture from local to global scales are emerging. The first global, multi-year (1992-2000) has been derived from ERS scatterometer data (C-band, 50 km spatial resolution) and is available from http://www.ipf.tuwien.ac.at/radar/ers-home.htm (Wagner et al., 1999; Scipal et al., 2002). Global passive microwave data in C-band (AMSR-E) is currently available and L-band (SMOS) will become available in the near future (Jackson et al., 2002; Kerr et al., 2004). For local scale mapping, Synthetic Aperture Radar (SAR) data, as well as passive microwave multichannel survey, are used with increasing success (Jackson et al., 2002; Wickel et al., 2001). All of these microwave techniques have been best tested for agricultural and grassland regions of temperate, tropical, and arid zones. Very little work in the area has yet been carried out over cold regions (e.g. French et al., 1995; Kasischke et al. 1995), which constitute the major part of the NEESPI area of interest. A much better understanding of the impact of wetlands, peat, humus, freeze-thaw, active layer depth, and shallow surface water on passive and active microwave data needs to be obtained before reliable soil moisture data can be obtained over boreal forest and tundra regions.

Accuracy of the retrieval of characteristics is the main problem of the remote sensing observations of the surface energy and water cycles. Comparisons to surface radiative measurements available from in the Northern Eurasia region give seasonally averaged mean bias that varies from 0.2 to 4.4 W m^{-2} and route mean square difference that varies from 8.2 to 17.7 W m^{-2} for the LW and SW fluxes respectively. Accuracy of the turbulent heat flux estimates is comparable with the natural variability, i.e., it is unacceptably high. The relative errors (or biases) for *strictly satellite* precipitation products in the tropics are on the order of 30% in terms of the annual mean (Kummerow et al. 2000). The estimates of relative random errors of similar products should be expected to be higher in the regions with predominantly light precipitation, i.e., in Northern Eurasia. These problems could be addressed by (a) using an additional number of observations, i.e., new satellite launches; (b) more thorough validation routines with the help of the in situ observations inside each ecosystem; and (c) combination of different remote sensing methodologies even with the help of in situ observations.

4.4.3. New satellite systems.

The Clouds and Earth's Radiant Energy System (CERES) instrument on board several Earth Observing System (EOS) satellites from NASA's Earth Science Enterprise (ESE) program provides a direct measurement of TOA broadband reflectance and convolves this measurement with higher resolution retrievals of atmospheric, cloud, and aerosol properties from the MODIS instrument to estimate radiative fluxes. The Surface and Atmospheric Radiation Budget (SARB) component of CERES computes the surface and atmospheric fluxes by iterating retrieved atmospheric properties with the measured TOA fluxes. Surface and atmospheric fluxes are available at the footprint level with a nominal resolution of 20 km. Time and space averaged data products are being produced with ~100-km resolution. Two

gauge data. Re-adjustment to the monthly rain gauge totals is also used in several other retrieval algorithms (e.g., Xie et al. 2003).

CERES instruments were launched aboard the EOS Terra satellite in December 1999 and on the EOS Aqua spacecraft in 2002. SARB data after July 2002 will include fluxes from both Aqua and Terra polar orbiters to improve sampling. Equatorward of 60°N, CERES SARB also uses geosynchronous data for time interpolation, improving the time and space averages of fluxes at these latitudes. Other proposed satellite systems that will effect the retrieval and inference of surface radiative fluxes by improving the retrieval of cloud and atmospheric properties. The Clouds-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) and the CloudSat missions will provide cloud and aerosol information from active lidar and cloud radar systems. These and other measurements from both microwave, visible, and infrared remote sensing platforms will provide new opportunities to improve the understanding of temperature, water vapor, clouds, aerosol, and surface properties of the Northern Eurasia region.