Ultra-High Resolution, Observation-Driven Land Modeling is Needed to Enable the Development of Global Cloud Resolving Earth System Models

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Vision

Cloud parameterizations are a primary source of uncertainty in climate prediction models. Complex land surface phenomena have significant influence on atmospheric boundary layer turbulence. Neglecting the considerable spatial and temporal variability in terrain topography, surface properties, rainfall, and net surface radiation constitute an organic weakness of current climate models and cause substantial errors near-surface climate simulation over land.

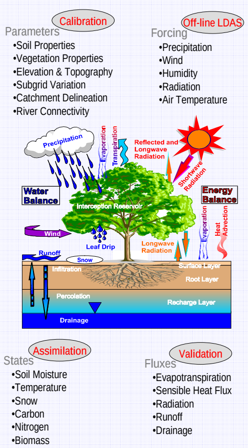
Therefore, we must progress toward a fully process-scale resolving model of land surface hydrology, atmospheric dynamics, and cloud processes over the global domain. We must integrate all obviously interdependent land-atmosphere processes into a common ultra-resolution (100's of meters) framework for Earth system modeling, through fusion of traditional land surface hydrology modules with boundary-layer turbulence and cloud process modules. Decisions regarding the model formulations must be guided to the greatest extent possible by the use of observations, as prescribed input, assimilation constraints, or validation.

We envision two, eventually convergent paths toward global land-atmosphere coupling:

1) Implement traditional cloud parameterization and atmospheric turbulence schemes and implicitly couple those to patch-based land models at highest possible resolution;
2) Develop true global process-resolving coupled land-atmosphere models in a phased approach:
   (a) off-line land-cloud process resolving studies
   (b) land-cloud super-parameterizations based on sampling the relevant process scales
   (c) nested land-cloud resolving models in a GCM framework
   (d) true global ultra-high-resolution global cloud-land process resolving model

Observations

The unprecedented availability of new global land-surface remote sensing data over the past decade should be a fundamental driver for the development of new scientific understanding and modeling innovations. Therefore, we identify the current and potential future observational systems that can guide the development of improved land-surface model physics, parameters, forcing, validation, and assimilation constraints below.



Land Parameters: Characteristics that vary on timescales longer than the model time step.

Observation	Technique	Example Platform	Temporal	Spatial	Modeling Implication
Land cover and change	optical/IR	AVHRR, MODIS, NPOESS	monthly	1km	associated parameter values, subgrid variability treatment, urban treatment
Leaf area and greenness	optical/IR	AVHRR, MODIS, NPOESS	weekly	1km	vegetation dynamics
Albedo	optical/IR	MODIS, NPOESS	weekly	1km	sun angle and topography effects
Emissivity	optical/IR	MODIS, NPOESS	weekly	1km	land cover radiative effects
Vegetation structure	Lidar	ICESAT, ESSP lidar mission	weekly-monthly	100m	vegetation dynamics
Topography	in-situ survey, radar	GTOPO30, SRTM	--	30m–1km	relation to runoff, wind, radiation, catchment delineation
Soil properties	in-situ survey	IGBP	--	1km	calibration to reduce uncertainty

Land Forcings (ESM fluxes): Boundary conditions that drive model physics.

Observation	Technique	Example Platform	Temporal	Spatial	Modeling Implication
Precipitation	microwave/ IR, in-situ	TRMM, GPM, SSMI, GPCP, GEO-IR, AVHRR, MODIS, NPOESS	hourly-monthly	10km	precipitation process-scale physics, assimilation, identify precipitation type, elevation correction, downscaling
Wind profile	Radar, in-situ	--	--	--	Implicit land-atmosphere coupling, coupled land-atmosphere assimilation
Air Humidity profile	In-situ	TOVS, AIRS	hourly-weekly	40km	Implicit land-atmosphere coupling, coupled land-atmosphere assimilation, elevation correction
Air Temperature profile	IR, in-situ	TOVS, AIRS, GOES, AVHRR, MODIS, AMSR	hourly-weekly	1km	Implicit land-atmosphere coupling, coupled land-atmosphere assimilation, elevation correction
near- surface solar radiation	optical/IR	GOES, MODIS	hourly-weekly	1km	Interaction with albedo, vegetation, topography
near-surface LW radiation	IR	GOES, MODIS	Hourly-weekly	1km	Interaction with emissivity, vegetation, topography

Land States: Model storage terms that can be assimilated to constrain model physics.

Observation	Technique	Example Platform	Temporal	Spatial	Modeling Implication
Soil moisture	active/passive microwave, IR change	SSMI, AMSR, HYDROS, SMOS, NPOESS, TRMM	3-30 day	10-100 km	soil moisture variability, microwave forward modeling, vertical soil layering, observation error
Temperature	IR, in-situ	IR-GEO, MODIS, AVHRR, TOVS	hourly-monthly	10m-4km	Radiometric temperature modeling, coupled modeling and assimilation
Snow cover or water equivalent	optical, microwave	SSMI, TM, MODIS, AMSR, AVHRR, NPOESS, GEO-IR, SMMR, future ESSP	Weekly-monthly	1km	snow pack evolution, spatial variability
freeze/thaw	Radar	Quickscat, HYDROS, IceSAT, CryoSAT	weekly	3km	Topography/land use interaction, temporal/spatial variation, permafrost
Ice cover	Radar, lidar	IceSAT, GLIMS (ASTER)	Weekly-monthly	15m-90m	Ice dynamics and assimilation, glacier processes
Inundation	optical/micro wave	MODIS, ESSP Surface Water Mission	weekly-monthly	100m	runoff routing, topography, runoff generation, wetland processes
Total water storage	Gravity	GRACE	Monthly	1000km	groundwater and surface storage processes, anthropogenic use

Land Fluxes: Model outputs that can be used for evaluation and calibration.

Observation	Technique	Example Platform	Temporal	Spatial	Modeling Implication
Evapotranspiration	optical/IR, in-situ	MODIS, GOES	hourly – weekly	10m – 4km	plant/soil/water interactions
Streamflow	microwave, laser, in-situ	ERS2, TOPEX/POSEIDON, future ESSP, GRDC	weekly-monthly	100m-1km	runoff routing, topography, runoff generation
Solar radiation	optical, IR	MODIS, GOES	hourly-monthly	10m-4km	topography and plant interaction
Longwave radiation	optical, IR	MODIS, GOES	hourly-monthly	10m-4km	Surface irradiative, and emissivity treatment
Sensible heat flux	IR	MODIS, ASTER, GOES	Hourly-monthly	10m-km	Surface irradiative and emissivity treatment

Progress

Land data assimilation systems have been developed that use sophisticated land surface models to ingest satellite and ground-based observations, as parameters, forcing, and data for assimilation, in order to produce the best possible fields of land surface states and fluxes. The multi-institution North American Land Data Assimilation System (NLDAS) project was the first to embrace this concept [Mitchell et al., 1999]. Its success led to the development of GLDAS [Houser et al., 2001]. The 1/4° resolution, high quality, near-real time and retrospective output fields that have resulted from GLDAS (Figure 1), the first of their kind, are providing the basis for global scale studies of the hydrological cycle and meteorological processes. GLDAS soil moisture fields have been shown to improve the predictability of seasonal precipitation, and are being tested as input to water management decision support systems. The Land Information System (LIS) project has streamlined and parallelized the GLDAS code and has executed 1 km resolution, global simulations using 3 different land models on high performance computing platforms. LIS is currently being coupled to the Weather Research and Forecasting (WRF) and Goddard Cumulus Ensemble (GCE) models to explore surface-layer feedback effects due to assimilation.

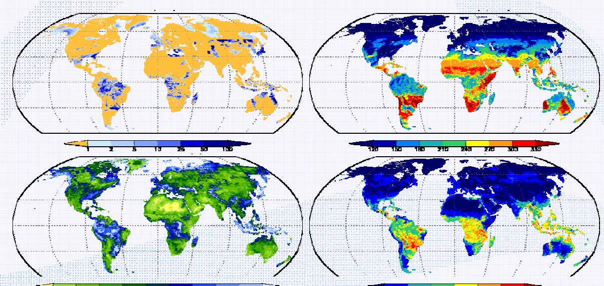


Figure 1: Sample output from GLDAS/Mosaic operational simulation, 1 March 2003. Clockwise from upper left: total precipitation [mm] (merged ADA and satellite derived data); observation based downward shortwave radiation [W/m^2]; total evapotranspiration [mm]; root zone volumetric soil water content [%].

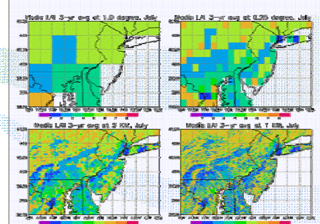


Figure 2: MODIS LAI observations degraded to the resolutions of 1°, 1/4°, 5 km, and 1 km, to illustrate the process-scale land physics requirements.

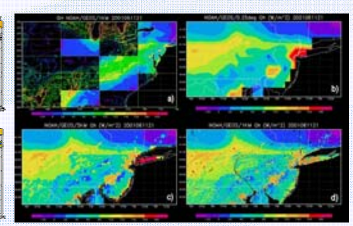


Figure 3: Sample latent heat flux snapshot from LIS/Noah simulation, 11 June 2001: (a) is a 5km simulation (contours) overlaid by a 1km slimulation (shaded), (b) is a ¼ degree simulation, (c) is a 5km simulation, and (d) is the full 1km simulation.

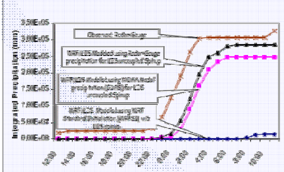


Figure 4. Comparison of the domain integrated precipitation using different coupled system simulations

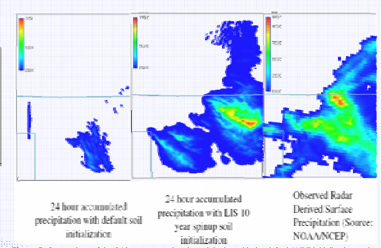
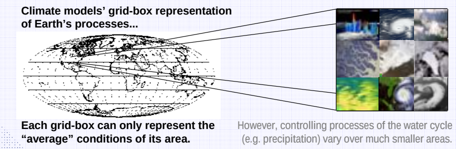


Figure 5. Comparison of the 24 hour accumulated precipitation with the default WRF initialization and with using the LIS spunup land surface states with the observed radar derived precipitation from NOAA/NCEP

Conclusions

New global remote sensing observations provide the foundation for the development of a new generation of Earth System Models that will explicitly resolve weather and climate relevant physical, chemical and biological processes, in order to improve dramatically the understanding and prediction of weather and climate. This will require, among other things, an ultra-high-resolution observation-driven land surface model with process-scale hydrology and biogeochemistry dynamics that is implicitly coupled to high-resolution boundary-layer turbulence and cloud microphysics parameterizations. These innovations will be invaluable for a wide range of applications, including satellite data assimilation, observation system design, weather forecasting and climate simulation.



Our ultimate vision is to progress toward a fully process-scale resolving coupled model of land surface hydrology, atmospheric dynamics, and cloud processes over the global domain. This requires an ultra-high-resolution land model that represents observed process-scale hydrology and biogeo-chemistry dynamics. This development must be guided by comparisons with locally to current and past observed phenomena, must bridge weather and climate prediction timescales, and partner with operational weather and climate prediction centers.

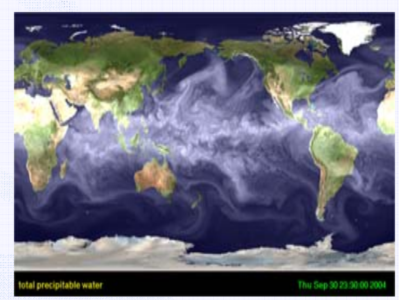


Figure 6. A ¼ degree climate model simulation, illustrating progress along the first path of producing a cloud resolving earth system model.

Literature cited

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More information

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