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Integrated modeling of aerosol, cloud, precipitation and land processes at satellite-resolved scales

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ABSTRACT

With support from NASA's Modeling and Analysis Program, we have recently developed the NASA Unified-Weather Research and Forecasting model (NU-WRF). NU-WRF is an observation-driven integrated modeling system that represents aerosol, cloud, precipitation and land processes at satellite-resolved scales. "Satellite-resolved" scales (roughly 1–25 km), bridge the continuum between local (microscale), regional (mesoscale) and global (synoptic) processes. NU-WRF is a superset of the National Center for Atmospheric Research (NCAR) Advanced Research WRF (ARW) dynamical core model, achieved by fully integrating the GSFC Land Information System (LIS, already coupled to WRF), the WRF/Chem enabled version of the GOddard Chemistry Aerosols Radiation Transport (GOCART) model, the Goddard Satellite Data Simulation Unit (G-SDSU), and custom boundary/initial condition preprocessors into a single software release, with source code available by agreement with NASA/GSFC. Full coupling between aerosol, cloud, precipitation and land processes is critical for predicting local and regional water and energy cycles.

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Software availability

Name of software: NU-WRF
Developers: NASA GSFC and affiliates
Contact address: Dr Toshihisa Matsui, NASA Goddard Space Flight Center, Mail Code 612; Greenbelt, MD, 20171, USA.
Email: toshihisa.matsui-1@nasa.gov
Availability and Online Documentation: Restricted to US Government and NASA collaborators via Software Usage Agreement; Manual available at: http://nuwrf.gsfc.nasa.gov/sites/default/files/docs/nuwrf_userguide.pdf
Year first available: 2011
Hardware required: Intel/AMD (tested on Intel Xeon), IBM Power
Software required: Linux (tested on SLES 11.1), other Unix variants
Programming language: Fortran 90, C, C++, Bash, Tcsh, Python, Perl
Program size: 1.6G (source code)

1. Introduction

The NASA Unified-Weather Research and Forecasting (NU-WRF) modeling system has been developed at NASA's Goddard Space Flight Center (GSFC), in collaboration with NASA's Marshall Space Flight Center (MSFC) and university partners, as an observation-driven integrated modeling system that represents aerosol, cloud, precipitation and land processes at satellite-resolved scales. We define "satellite-resolved" scales as being within a typical mesoscale atmospheric modeling grid (roughly 1–25 km), although this work is designed to bridge the continuum between local (microscale), regional (mesoscale) and global (synoptic) processes. We assert that representing the full coupling between aerosol, cloud, precipitation and land processes is critical for predicting local, regional, and global water and energy cycles associated with high-impact phenomena such as floods, hurricanes, mesoscale convective systems, droughts, and monsoon circulations. The philosophy of NU-WRF development is to provide a NASA-oriented superset of the community WRF model that unifies and incorporates NASA's unique experience and capabilities in validating, simulating and assimilating current earth science satellite observations into models to support observationally-based improvements of Earth system model components. NU-WRF is built upon the Advanced Research WRF (ARW; Skamarock et al., 2008) dynamical core model, with additional components that include the GSFC Land Information System (LIS; Kumar et al., 2006; Peters-Lidard et al., 2007), the WRF/Chem enabled version of the Goddard Chemistry Aerosols Radiation Transport (GOCART; Chin et al., 2000a, b) model, GSFC radiation and microphysics schemes including revised couplings to the aerosols (Tao et al., 2003; Lang et al., 2007, 2011; Shi et al., 2014), and the Goddard Satellite Data Simulator Unit (G-SDSU; Matsui et al., 2013, 2014). NU-WRF now provides the community (via a source code release process at NASA/GSFC) with an observation-driven regional Earth system modeling and assimilation system at satellite-resolved scales.

The following sections describe the coupling between atmospheric physics, land surface models and aerosol-chemistry models in NU-WRF, the interoperable features and adoption of Earth system modeling standards, and the application of NU-WRF in modeling coupled aerosol-cloud-and land surface processes.

2. NU-WRF components

As shown in Fig. 1, NU-WRF consists of 6 main components: the ARW model, LIS, GOCART, GSFC radiation and microphysics schemes, and G-SDSU. Below we describe each of these components in more detail.

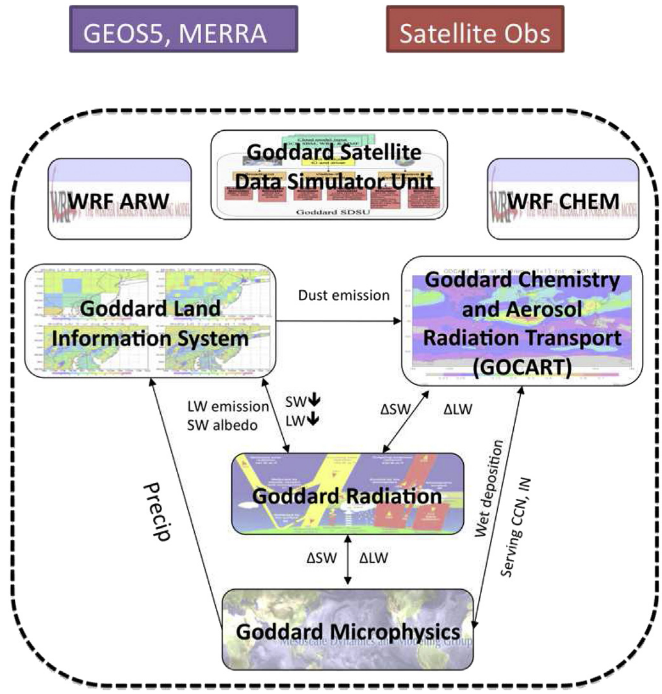

Fig. 1. A schematic representation of NU-WRF components and their interfaces.

2.1. Advanced Research WRF (ARW) model

The ARW is a mesoscale/microscale modeling and assimilation system developed by the National Center for Atmospheric Research (NCAR) with National Oceanographic and Atmospheric Administration (NOAA) and Department of Defense (DoD) partners. First released in November 2000, the model incorporates advanced numerics and data assimilation techniques, a multiple relocatable nesting capability, and numerous physics packages from the operational and research communities. The ARW is designed for flexibility and easy portability to multiple computing environments, and has been used for a wide range of applications (e.g., simulations of thunderstorms, orographic precipitation, tropical cyclones, turbulence and gravity waves, large eddy simulations, air quality, regional climate, general circulation studies). NOAA and the Air Force Weather Agency (AFWA) have transitioned the ARW to operations, replacing the legacy Rapid Update Cycle and Pennsylvania State University/NCAR Mesoscale Model version 5 forecast models.

The ARW dynamical core uses an Arakawa-C horizontal grid; a dry, hydrostatic pressure-based terrain-following vertical coordinate (Laprise, 1992); time-split integration of flux-form, fully compressible non-hydrostatic equations using a 3rd-order Runge-Kutta scheme (Klemp et al., 2007); a choice of 2nd-to 6th-order advection schemes including positive-definite and monotonic selections; options for observational, gridded and spectral nudging; several choices for upper boundary absorption and Rayleigh damping; several variants of digital filter initialization; and numerous choices for land surface, surface layer, Planetary Boundary Layer (PBL), radiation, microphysics (single- and double-moment), and cumulus (deep and shallow) parameterizations. The most recent ARW releases also include simple mixed-layer ocean and lake models. A plug-in library (WRF/Chem; ESRL, 2012) provides aerosol, gas-phase chemistry, photolysis, and dry deposition parameterizations. A companion data assimilation library (WRFDA, formerly WRF-Var; Barker et al., 2012) provides 3D Variational (3DVAR; Barker et al., 2004), hybrid Ensemble-3DVAR (Wang et al., 2008a, b), and 4DVAR (Huang et al., 2009) assimilation capabilities.