Satellite Imagery and Virtual Global Cloud Layer Simulation from NWP Model Fields

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Overview

• **Purpose**
  – Use NWP imbedded in global reanalyses to create detailed environment representations for:
    • Simulation-based training exercises (e.g., DoD, FEMA)
    • Sensor performance studies (e.g., remote sensing, tactical)

• **Products**
  1. Simulated operational imagery including:
     • GEO satellite: Visible, thermal infrared, and water vapor bands
     • Precipitation radar
  2. Cloud layer visualizations for virtual globes
     • Google Earth examples are presented here
Requirements

• **EDCSS – Environmental Data Cube Support System (DoD)**
  – Consistent environment representations for simulation community
    • See Holdzkom et al., 26IIPS 5A.1
  – Satellite imagery – common weather product for situational awareness
    • Goal is to match look and formats of operational imagery
  – Virtual globes – integrated situational awareness tools
    • Initial goal is to include realistic cloud representations

• **Imagery generated from NWP model fields …**
  – Must be consistent with other EDCSS products
    • e.g., METAR, charts, grib, graphics – up to 5000 per exercise
  – Must be self-consistent
    • e.g., between imagery types and temporally, spatially, spectrally
  – Must be convincingly real to end-users AND completely consistent
    with underlying model representation
    • e.g., allow cloud top height to be interpreted from temperature
Simulated operational imagery (from hourly WRF model fields)
Interpretation of NWP fields

• **Source models used (to date)**
  – WRF, COAMPS, MASS in NCEP & ERA-40 reanalyses

• **Typical parameter set (input or derived)**
  – 2D: Skin temperature, precipitable water column, wind vector, convective and total precipitation, 2 m dew point, 2 m air temperature
  – 3D: Temperature, water vapor, geopotential height, hydrometeors (total of liquid, ice, snow, & graupel)

• **Consistency check — WRF example**
  – Problem: Subgrid convective processes in WRF can produce precipitation where cloud water fields are zero
  – Solution:
    1. Compute an *ad hoc* alternative cloud water profile based on temperature, pressure, and convective precipitation rate
    2. Compute a second *ad hoc* alternative cloud water profile for areas where RH is very high (i.e., cloud margins)
    3. Use maximum of WRF cloud water fields and *ad hoc* alternatives
WRF clouds vs. *ad hoc* solution

WRF clouds only

WRF clouds + *ad hoc* clouds

Closer to operational imagery from the same time period
Clouds vs. total precipitation

WRF clouds only

WRF clouds + ad hoc clouds

More consistent with rain extent
Radiative transfer methods

• **Visible** – Solar-illuminated window band
  – OSS/Charts: 4-streams, Weinreb & Hill WV model, molecular scattering
  • Uses cloud scattering/absorption profile
  – Water: Cox & Munk wind-dependent sun glint
  – Land: MODIS land surface reflectance

• **Window IR** – Thermal emission window band (no sun)
  – OSS/Charts: 4-streams, Weinreb & Hill WV model
  • Uses cloud absorption/emission profile (scattering neglected)
  – Simple ocean/land LUT emissivities

• **Water Vapor IR** – Thermal emission absorption band (no sun)
  – Optical thickness profile LUT tabulated offline for 3 atmospheres
  • Subarctic, mid-latitude, tropic
  – Interpolate on LUT by precipitable water inputs
  – Add cloud absorption/emission profile (scattering neglected)
  – Simple 2-stream radiative transfer
  – Simple ocean/land LUT emissivities
### Satellite imagery vs. virtual global visualization

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| Constant viewing geometry (top-of-atmosphere only) | Omni-directional viewing possible within & above atmosphere | • 2-sided cloud layers (separate up & down views)  
• High clouds shadow low clouds  
• Parallax gives quasi-3D effect |
| Sensor response: image brightness scale is known | Eye-response: brightness scale is relative*   | • Constant solar zenith angle except near terminator  
• Add twilight illumination  
• Scale images relative to top-of-atmosphere brightness |
| Earth background can be modeled from remote sensing data | VG base imagery background is variable | • RT uses constant earth reflectivity  
• Terrain overlay “shadow” is included with cloud layers in VG |

* Google Earth sun affects overlay image appearance near terminator and at night
VG visualization approach

WRF: 36 levels

3-level VG visualization

Pre-selected VG layer levels (MSL)

Overview image visible only from high-altitude view (KML-controlled)

Top-side image

Bottom-side image

Viewer

Top-side image

Bottom-side image

Top-side image

Bottom-side image

Terrain overlay shadow

8 images, 1 KML file
VG visualization approach

Image brightness

Illumination attenuated by layers above

Top-side image: up-welling brightness at top of layer

Bottom-side image: down-welling brightness at bottom of layer

Constant earth surface reflectivity

Image transparency

- Layer transmittance/extinction controls image transparency
- For transparent layers (e.g., cloud-free) image brightness is moot

For a two-image VG layer:

- Image extinction = \sqrt{\text{layer extinction}}
- Image transparency = 1 – (image extinction)

Compute layer extinction (loss factor)
3-level VG visualization images

- Bottom side views
- Top side views

Terrain overlay shadow

8 km

4 km

1 km
Top-of-atmosphere view
Oblique view facing W, 6 km altitude
Oblique view facing W, 2.5 km altitude
Oblique view facing W, 900 m altitude

With terrain shadow

Without terrain shadow

Spathades, Greece
Potential areas for VG cloud visualization improvement

• Calibrate image brightness to virtual globe base imagery

• Use objective eye-response function

• More than 3 visualization layers
  – Impact on VG refresh performance

• Include fog in terrain overlay (i.e., obscure base imagery)

• Higher resolution NWP model grid
  – e.g., at ~3 km convective processes can be resolved (subgrid convective parameterizations turned off)

• Use alternative WRF physics packages (in implementation)
  – WRF double-moment bulk microphysics scheme
  – Grell-Devenyi convective scheme (vs. Kain-Fritsch)
Summary

• It is feasible to place quasi-3D cloud visualizations in virtual globe applications that are both physically consistent with NWP model fields and visually realistic

• Adaptations are required for non-physical aspects of the VG environment

• For the future: Cloud visualizations within the Google Earth platform that are closer to true 3D while meeting physical-consistency requirements
The EDCSS program is sponsored by Air Force Weather and the DoD Modeling and Simulation Coordinating Office (MSCO)

Environmental Data Cube Support System (EDCSS)

1. Build an Integrated Environment Representation ...

2. Produce a full suite of support products ...

3. Distribute during event execution

Access National Providers of ...

- Data, Models, Effects, Expertise

Simulation Domain

Control Domain

User Domain