Overview of
The Environmental Modeling Center
(with a focus on data assimilation)

Stephen J. Lord
Director
NCEP Environmental Modeling Center

NCEP: “where America’s climate, weather, and ocean services begin”
NATIONAL CENTERS for ENVIRONMENTAL PREDICTION

OFFICE OF THE DIRECTOR
10 FTE

TROPICAL PREDICTION CENTER
Tropical Weather Guidance and Forecasts
NATIONAL HURRICANE CENTER
Tropical Cyclone Watches & Warnings
0-5 Days
Atlantic and Pacific, 0-30°N
46 FTE

HYDROMeteorological PREDICTION CENTER
Hydrometeorological Forecasts
0-7 Days – Weather
0-5 Days – QPF
US
43 FTE

STORM PREDICTION CENTER
Hazardous Weather Guidance
0-72 Hours – Severe Weather
0-48 Hours – Fire Weather
Continental US
32 FTE

ENVIRONMENTAL MODELING CENTER
Numerical Weather and Ocean
Automated Analysis and Prediction
0-16 Days
Global
Numerical Climate Prediction
Months
Global
48 FTE

SPACE ENVIRONMENT CENTER
Space Weather Monitoring,
Warning and Forecasting
0-3 Days
Global
50 FTE

OCEAN PREDICTION CENTER
Marine Boundary Layer and Ocean
Surface Guidance, Warning and
Forecasts
0-5 Days
Atlantic and Pacific,
North of 30°N
26 FTE

AVIATION WEATHER CENTER
Weather Guidance, Warning and
Forecasts for Domestic and
International Aviation
0-2 Days
Global
54 FTE

Total FTE: 430
Contractors: 161
Visitors: 47
NOAA Seamless Suite of Forecast Products Spanning Climate and Weather

Forecast Lead Time

- Minutes
- Hours
- Days
- 1 Week
- 2 Week
- Months
- Seasons
- Years

Forecast Uncertainty

Climate Prediction Products

Weather Prediction Products

Benefits

Protection of Life & Property
Flood Mitigation & Navigation
Space Operation
Transportation
Fire Weather
Hydropower
Agriculture
Reservoir Control
Recreation
Ecosystem
Energy
Health
Commerce
State/Local Planning
Environment

Outlook
Guidance
Threats Assessments
Forecasts
Watches
Warnings & Alert Coordination

Assessments
Forecasts
Threats
Watches
Warnings & Alert Coordination
Coordination

Initial Condition Sensitivity
Boundary Condition Sensitivity

NOAA Seamless Suite of Forecast Products Spanning Climate and Weather

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EMC Support for the U. S. Economy

- Nation's Wx Sensitive Economy: $3,000,000
- NOAA: $4,000
- NWS: $800
- NCEP: $88
- EMC Base: $9
- EMC Soft: $9.5

All values in millions of dollars ($M).
Prediction Requires “Coupling” of Basic Earth “Systems” within Global Numerical Forecast Models

- Atmosphere
- Ocean
- Cryosphere
- Land

- Predictions Driven by Global Observing Systems
- Real-time operations require world’s largest computers
The Environmental Forecast Process

- Observations
- Analysis
- Model Forecast
- Post-processed Model Data
- Forecaster
- User (public, industry…)

Data Assimilation

Numerical Forecast System
Why Models?

“As go the models, so go the forecasts”
Impact of Models on Day 1 Precipitation Scores
(DOC GPRA goal)

Correlations Of HPC with:
Eta: 0.99
GFS: 0.74
NGM: 0.85
NOAH LAND-SURFACE MODEL
NCEP • OSU • Air Force • Office Of Hydrology

MOISTURE BUDGET
- Precipitation
- Transpiration (ET)
- Canopy Water Evaporation (Ec)
- Direct Soil Evaporation (Ed)
- Surface Runoff
- Infiltration

ROOT ZONE
- Subsurface Runoff

Heat Budget
- Sensible Heat Flux
- Longwave Radiation
- Solar Radiation

STATE VARIABLES
- Skin Temperature
- Soil Temperature
- Soil Water
- Soil Ice

SURFACE PARAMETERS
- Canopy Water
- Snow Water
- Snow Density
- Vegetation Type
- Green Vegetation Fraction
- Soil Texture
- Roughness
- Albedo
- Slope Factor
Why Data Assimilation?
- Model initial condition known everywhere
- Insufficient observations
- Observations and model both have errors

Must Initialize at:
4536 grid points at 64 levels (sfc to 50 km)

Number of Upper Air Observations: 10

Typical Number of Satellite Obs (over Water only): 600
NCEP Global Forecast System
6 hr Forecast and WV Imagery

6.8 micron IR (water vapor)/gfs ges 6hr—accum total precipitation (mm)
18Z 07 SEP 2002
EMC Mission

**In response to operational requirements:**

- **Maintain** the scientific correctness and integrity of operational forecast systems
  - Adapt to format changes and other changing operational requirements
  - Adapt to new computing hardware
  - Monitor and ensure the integrity of operational observing systems
- **Enhance** (Test & Improve) Numerical Forecasts Through Advanced
  - Data assimilation techniques
  - Model physics (parameterizations)
  - Numerical methods
  - Computational efficiency
- **Transition and Develop** Operational Numerical Forecast Systems for:
  - Weather prediction (domestic, global, 1-15 days)
  - Ocean prediction (daily to annual, coastal to global)
  - Climate prediction (seasonal to inter-annual)

**Maintain**: Modify current operational system to adapt to ever-present external changes

**Enhance**: Test and improve NCEP’s numerical forecast systems via scientific upgrades, tuning, additional observations, in response to user requirements

**Transition and Develop**: transform & integrate code, algorithms, techniques from research status to operational status on NCEP computers
## Mission Requirements & Forecast Suite Elements

<table>
<thead>
<tr>
<th>Suite Elements</th>
<th>Global NWP</th>
<th>Reg. NWP</th>
<th>Fire Wx Rapid Update Reg. Hurricane</th>
<th>Air Quality</th>
<th>Global Ensembles</th>
<th>Regional Ensembles</th>
<th>Real Time Ocean</th>
<th>S/I Climate</th>
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<tbody>
<tr>
<td>NCEP</td>
<td>X</td>
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<td>X</td>
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<td>ECMWF</td>
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</table>
Transition Steps (Modeling)

1. Identification for Selection
2. Code/Algorithm Assessment and/or Development
3. Interface with Operational Codes
4. Level I: Preliminary Testing (Lower Resolution)
5. Level II: Preliminary Testing (DA/Higher Resolution)
6. EMC Pre-Implementation Testing (Packaging/Calibration)
7. NCO Pre-Implementation Testing
8. Implementation/Delivery
EMC and NCO have critical roles in the transition from NOAA R&D to operations.
Ingredients for Improved Numerical Forecast Systems

• Primary ingredients
  – Observations
  – Data Assimilation & Model technology
  – Computing resources

• Secondary ingredients
  – Post-processing and dissemination
  – Research to Operations (R2O) process
Impact of Observations and Numerical Forecast System Technology Growth on Global Forecasts

NFS Tech Growth: Computing, Data Assim., Models, Ensembles

Contribution: Tech growth: 70%, Improved Obs: 30%
NOAA’s NWS Model Production Suite

- Global Ensemble Forecast System (w/ Canada)
- Hurricane Forecasts
- Dispersion
- Real-Time Ocean Forecast System
- Severe Weather
- Air Quality With EPA
- Rapid Update for Aviation
- Climate Forecast System
- Regional Analysis
- Regional Forecasts
- Short-Range Ensemble Forecast
- Global Analysis
- Global Forecasts
- Global Observations
NCEP Production Suite
Weather, Ocean, Land & Climate Forecast Systems

Current - 2007

6 Hour Cycle: Four Times/Day
Global Observations 12 UTC
6 hour window

Global Rawinsondes

Marine Obs -- 12 Hour Total

Aircraft Wind/Temp Reports

DMSP Imager – Sfc winds/PW

Polar Satellite Radiances (2 sat)

Satellite Winds
<table>
<thead>
<tr>
<th>Product/Instrument</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jason Altimeter</td>
<td>Implemented into NCEP GODAS</td>
</tr>
<tr>
<td>AIRS with All Fields of View</td>
<td>Implemented – 1 May</td>
</tr>
<tr>
<td>MODIS Winds</td>
<td>Implemented – 1 May</td>
</tr>
<tr>
<td>NOAA-18 AMSU-A</td>
<td>Implemented – 1 May</td>
</tr>
<tr>
<td>NOAA-18 MHS</td>
<td>Implemented – 1 May</td>
</tr>
<tr>
<td>NOAA-17 SBUV Total Ozone</td>
<td>Implemented – ???</td>
</tr>
<tr>
<td>NOAA-17 SBUV Ozone Profile</td>
<td>Implemented – ???</td>
</tr>
<tr>
<td>SSMI/S Radiances</td>
<td>Preliminary forecast assessment completed</td>
</tr>
<tr>
<td>GOES 1xa imagery</td>
<td>Forecast Assessment in progress</td>
</tr>
<tr>
<td>METOP AMSU-A, MHS, HIRS</td>
<td>Forecast Assessment in progress</td>
</tr>
<tr>
<td>COSMIC/CHAMP</td>
<td>Implemented (COSMIC – 1 May) CHAMP Data in prep.</td>
</tr>
<tr>
<td>MODIS Winds v2.</td>
<td>Test and Development</td>
</tr>
<tr>
<td>WINDSAT</td>
<td>Preliminary forecast assessment completed</td>
</tr>
<tr>
<td>AMSR/E Radiances</td>
<td>Preliminary forecast assessment completed</td>
</tr>
<tr>
<td>AIRS/MODIS Sounding Channels Assim.</td>
<td>Data in Preparation</td>
</tr>
<tr>
<td>GOES – SW Winds</td>
<td>To be Tested</td>
</tr>
<tr>
<td>GOES Hourly Winds</td>
<td>To be Tested</td>
</tr>
<tr>
<td>GOES 11 and 12 Clear Sky Rad. Assim(6.7µm)</td>
<td>To be Tested</td>
</tr>
<tr>
<td>MTSAT 1R Wind Assim.</td>
<td>Data in Preparation</td>
</tr>
<tr>
<td>AURA OMI</td>
<td>Test and Development</td>
</tr>
<tr>
<td>TOPEX, ERS-2 ENVISAT ALTIMETER</td>
<td>Test and Development (Envisat) ERS-2 (dead)</td>
</tr>
<tr>
<td>TOPEX implemented in NCEP GODAS</td>
<td>TOPEX implemented in NCEP GODAS</td>
</tr>
<tr>
<td>FY – 2C</td>
<td>Data in Preparation</td>
</tr>
</tbody>
</table>
Integration and Testing of New Observations

- Data Access (routine, real time) 3 months
- Formatting and establishing operational data base 1 month
- Extraction from data base 1 month
- Analysis development (I) 6-18 months
- Preliminary evaluation 2 months
- Quality control 3 months
- Analysis development (II) 6-18 months
- Assimilation testing and forecast evaluation 1 month
- Operational implementation 6 months
- Maintain system* 1 person “till death do us part”

Total Effort: 29-53 person months per instrument

* Scientific improvements, monitoring and quality assurance
Rawinsonde Delivery

Raob Receipts for 20040804 12 UTC (time window: 2004080409 to 2004080415)
Quality Monitoring of Satellite Data

AIRS Channel 453 26 March 2007

platform: airs.049
region: global (180W–180E, 90S–90N)
variable: ges (w/o bias cor) – obs (K)
valid: 00Z11MAR2007 to 00Z10APR2007

channel 375
\[ x = 0.3328 \]
\[ f = 22771.43 \text{ GHz} \]
\[ \lambda = 13.17 \text{ \mu m} \]
avg: -1.254
sdev: 1.010

channel 453
\[ x = 0.8282 \]
\[ f = 23778.66 \text{ GHz} \]
\[ \lambda = 19.01 \text{ \mu m} \]
avg: -0.688
sdev: 1.247

channel 475
\[ x = 0.2532 \]
\[ f = 24616.41 \text{ GHz} \]
\[ \lambda = 12.48 \text{ \mu m} \]
avg: -0.678
sdev: 0.918

channel 454
\[ x = 0.2982 \]
\[ f = 24114.80 \text{ GHz} \]
\[ \lambda = 12.43 \text{ \mu m} \]
avg: -0.714
sdev: 0.927

Increase in SD
Fits to Guess
Satellite Data Ingest

Daily Satellite & Radar Observation Count

- Level 2 Radar
  - 210 M obs
  - 125 M obs
  - 100 M obs

Daily Percentage of Data Ingested into Models

- Received Data: 239.5M
- Selected Data: 17.3M
- Assimilated Data: 5.2M

*2005 Data

Five Order of Magnitude Increases in Satellite Data Over Fifteen Years (2000-2015)

Received = All observations received operationally from providers
Selected = Observations selected as suitable for use
Assimilated = Observations actually used by models
NCEP 42 Level Model and HIRS Radiance Response Functions

[Graph showing atmospheric pressure and radiance response functions for CO₂ and CO₂/N₂O channels]
NASA-NOAA-DOD Joint Center for Satellite Data Assimilation (JCSDA)

- NOAA, NASA, DOD partnership

- Mission
  - Accelerate and improve the quantitative use of research and operational satellite data in weather and climate prediction models
    - Current generation data
    - Prepare for next-generation (NPOESS, METOP, research) instruments

- Supports applied research
  - Partners
  - University, Government and Commercial Labs
JCSDA Scientific Priorities
2006-2009

• Improve radiative transfer model
• Prepare for advanced instruments
• Advance techniques for assimilating cloud and precipitation information
• Improve land and sea ice surface emissivity models and land surface and sea ice products
• Improve use of satellite data in ocean and land data assimilation
• Air quality (aerosols, ozone and trace gases)
AMSU and “All Conventional” data provide nearly the same amount of improvement to the Northern Hemisphere.
Observing System Experiments (ECMWF - G. Kelly et al.)

NoSAT = no satellite radiances or winds

Control = like operations

NoUpper = no radiosondes, no pilot winds, no wind profilers
Inhomogeneous data set

N. Hemisphere 500 mb ht
anomaly correlation

AMSU: 0.5 day improvement at 5 days

N. Hemisphere 500 mb AC Z
20N - 80N Waves 1-20
15 Jan - 15 Feb '03

N. Hemisphere 500 mb AC Z
20N - 80N Waves 1-20
1 Jan - 27 Jan '04

AIRS

Forecast [days]

Anomaly Correlation
Impact of Removing AMSU, HIRS, GOES Wind, Quikscat Surface Wind Data on Hurricane Track Forecasts in the Atlantic Basin - 2003 (34 cases)

Impact of Removing AMSU, HIRS, GOES Wind, Quikscat Surface Wind Data on Hurricane Track Forecasts in the East Pacific Basin - 2003 (24 cases)

Satellite data ~ 10-15% impact
JCSDA AIRS Testing

- NCEP operational system
  - Includes first AIRS data use
- Enhanced AIRS data use
  - Data ingest includes all AIRS footprints
  - 1 month at 55 km resolution
  - Standard data selection procedure
EMC-GMAO-STAR Code Management for Atmospheric Data Assimilation

Process: similar to ECMWF & Météo-France who have annual code mergers
But, to promote collaboration, EMC and GMAO use same repository and mergers are more frequent (3 months)

GSI & CRTM supported

Protocols
1 – EMC, GMAO take (agreed-upon) merged code from repository to begin work
2 – EMC, GMAO incorporate developments into repository
3 – Code mergers, repository changes and timing are NCEP’s decision

Accepted changes
* * EMC, GMAO System change
* * Repository change
+ Repository Merger (new tag)

Time

EMC

Repository

GMAO
**Observations**

- **Satellite** (AVHRR, JASON, QuikSCAT)
- **In situ** (ARGO, Buoys, Ships)

**Data Cutoff**
- CFS: 2 week data cutoff
- RTOFS: 24 hour data cutoff

**OCEAN DATA ASSIMILATION**

- **CFS-GODAS**
  - NCO/ODA - $446 K
  - EMC - $170 K
  - NOPP-JPL (ECCO) - $34 K
- **RT-OFS-GODAE**
  - NOPP - $285 K
  - EMC - $350 K

**CLIMATE FORECAST**

- MOM-3 → MOM-4 → HOME

**OCEAN FORECAST**

- OPNL OCEAN FORECASTS
- HYCOM → HOME

**Advanced ODA Techniques**

- NASA-NOAA-DOD
- JCSDA
- AMSR, GOES, AIRS, JASON, WindSat, MODIS

- $1451 K (total)
- $341 K (direct)

**Climate Forecast System**

- http://cfs.ncep.noaa.gov/

**Real-Time Ocean Forecast System**

- http://polar.ncep.noaa.gov/of5/
US GODAE: Global Ocean Prediction with HYCOM

- Goal: to develop and demonstrate real-time, operational, high resolution ocean prediction systems for the Global Oceans and Basins
- NCEP Partners with
  - University of Miami/RSMAS
  - NRL Stennis, NRL Monterey, FNMOC
  - NOAA PMEL, AOML
  - Los Alamos National Laboratory
  - Others (international, commercial)
- Hybrid isopycnal-sigma-pressure ocean model (called Hybrid Coordinate Ocean Model – HYCOM)
- Funded FY 2003-2007 by NOPP
Adding TOPEX/Jason-1 satellite altimetry to NCEP GODAS

Larger correlations between GODAS and Altimeter data in Indian and Atlantic Oceans

Smaller RMS errors

No assimilated data

In situ data Assimilated (operational)

Operational Plus altimeter
Seasonal to Interannual Prediction at NCEP

Ocean Model
MOMv3
quasi-global
1°x1° (1/3° in tropics)
40 levels

Climate Forecast System (CFS)

Atmospheric Model
GFS (2003)
T62
64 levels

GODAS
3DVAR
XBT
TAO etc
Argo
Salinity (syn.)
(TOPEX/Jason-1)

Reanalysis-2
3DVAR
T62L28
update of the NCEP-NCAR R1

D. Behringer
Standard vs. Deep assimilation

Two long (1980-2005) experiments

Standard or operational GODAS

• Temperature profiles from Argo, XBTs, TAO moorings
• Depth of assimilation is 750 m.

Deep GODAS-X

• Temperature profiles from Argo (2200), XBTs (750), TAO (500) moorings
• Depth of assimilation is 2200 m. Shallow profiles (XBT, TAO) are augmented with climatology.
Independent WOCE CTD section completed in 1988 & 1989 …

Standard vs. Deep assimilation

…and repeated in 2003 & 2005 by PMEL. Shallow assimilation has a strong cold bias of 1-3°C below 750 m. Deep assimilation eliminates the cold bias.
Assimilating Argo Salinity

Two 2005 experiments

Standard or operational GODAS

• Temperature profiles from Argo, XBTs, TAO moorings
• Salinity profiles are 100% synthetic (via TS-relationship)

Argo salinity in GODAS-A/S

• Temperature profiles from Argo and XBTs only
• Salinity profiles are 75% observed (Argo) and 25% synthetic (XBTs)
In the east, assimilating Argo salinity reduces the bias at the surface and sharpens the profile below the thermocline at 110°W.

In the west, assimilating Argo salinity corrects the bias at the surface and the depth of the undercurrent core and captures the complex structure at 165°E.

**Assimilating Argo Salinity**

Comparison with independent ADCP currents.

![Equatorial Mean Zonal Velocity](image1)

- **TAO ADCP**
- **GODAS**
- **GODAS A/S**

![Equatorial Mean Zonal Velocity](image2)

- **TAO ADCP**
- **GODAS**
- **GODAS A/S**
NOAH LAND-SURFACE MODEL

STATE VARIABLES
- Skin temperature
- Soil temperature
- Soil water
- Soil ice

SURFACE PARAMETERS
- Canopy water
- Snow water
- Snow density
- Vegetation type
- Green vegetation fraction
- Soil texture
- Roughness
- Albedo
- Slope factor
Improving coupled NCEP NWP Forecasts via Land-Surface Influences

- **NWP prediction improvement goals**
  - air temperature and humidity
    -- especially near-surface
  - wind vector
    -- especially near-surface via improved surface drag
  - PBL T and Td vertical profiles
  - convective stability indices (CAPE)
  - integrated moisture flux convergence
  - precipitation and cloud cover
LAND-SURFACE IMPROVEMENTS FOR CFS

- NCEP LSM models
  - OSU model (1990’s)
    - Current LSM in CFS
  - Noah (supported by NOAA Climate Office CPPA)
    - Tested in operational regional model (North American Model)
    - Applied to Global Forecast System (2005)
      - Improved global precipitation and surface fluxes
    - Tested for seasonal prediction (2006)

- Future
  - NASA Land Information System
    - Includes 4 LSMs
      - Noah
      - VIC (Princeton, U. Washington)
      - MOSAIC (NASA)
      - Sacramento (NWS/OHD)
    - ESMF compliant component
      - Run offline with observed forcing to determine land surface states
      - Noah run as forecast module

K. Mitchell
LAND DATA ASSIMILATION SYSTEMS:

• Three Broad Approaches

− 1) **Coupled** Land/Atmosphere 4DDA
  • precipitation forcing at land surface is from parent atmospheric model
  • **Precipitation may have large bias: >large soil moisture bias**
  • Soil moisture may be nudged to reduce impact of precipitation bias

− 2) **Uncoupled** Land 4DDA (land model only)
  • observed precipitation used directly in land surface forcing
  • should execute same LSM on same grid & terrain as coupled model
    − **Exp: EMC uncoupled GLDAS**
      » **GLDAS provides initial land states for CTB tests of CFS/Noah**

− 3) **Hybrid** Land 4DDA  e.g. Regional Reanalysis
  • Coupled land/atmosphere, but:
    − **observed precipitation is assimilated for driving the land surface**
N-LDAS Design
(The Uncoupled Approach)

1. Force models with 4DDA surface meteorology (Eta/EDAS), except use actual observed precipitation (gage-only daily precip analysis disaggregated to hourly by radar product) and hourly downward solar insolation (derived from GOES satellites).

2. Use 4 different land surface models:
   - NOAH (NOAA/NWS/NCEP)
   - MOSAIC (NASA/GSFC)
   - VIC (Princeton U./ U. Washington)
   - Sacramento (NOAA/OHD)

3. Evaluate results with all available observations, including soil moisture, soil temperature, surface fluxes, satellite skin temperature, snow cover and runoff.
LDAS Run Modes: 1) Realtime, 2) Retrospective

- **REALTIME**: 15 Apr 1999 to 15 Dec 2001
  -- NCEP realtime forcing
- **RETROSPECTIVE**: 01 Oct 1996 to 30 Sep 99
  -- Mandated largely by spin-up issues
  -- NASA-assembled retrospective forcing
    --- Higgins NCEP/CPC reprocessed precipitation forcing:
      ---- more gages obs, more QC
    --- Pinker U.Md reprocessed solar insolation forcing
      ---- better cloud screening, more QC

Rutgers University compared the soil moisture, soil temperature, surface flux results from the retrospective LDAS runs to observations over Oklahoma/Kansas for last retro year.
LDAS Model Mean Annual Evaporation (mm) over Oct 97 – Sep 99
Seasonal change of total column soil moisture: 30Apr minus 30Sep, 99, at 23Z
Large intermodel differences in transpiration through the vegetation cover (canopy conductance, root density/depth/seasonality).
Fig. 22  SGP ARM/CART Monthly Mean Diurnal Cycle of Surface Energy Fluxes
Monthly Mean Diurnal Cycle of Surface Skin Temperature of the four NLDAS Land Models.
Large inter-model differences in land surface temperature (LST) shown in previous slide turned out to emerge more from inter-model differences in aerodynamic conductance than from inter-model differences in surface sensible and latent heat fluxes (Bowen ratio).

This cast doubt into the expectation of using validations of land model LST with satellite-retrieved LST as a measure of goodness of model Bowen ratio over large scales.
Testing Impact of Replacing OSU LSM with Noah LSM in the NCEP Medium-range Global Forecast System (GFS)
Noah LSM versus OSU LSM in NCEP Global Model

- **4 soil layers** (10, 30, 60, 100 cm) vs. 2 soil layers (10, 190 cm)
- **land surface evaporation**: *reduced high bias in warm-season*
- **vegetation cover**: *improved properties and seasonality*
  - improved seasonal cycle of green vegetation fraction
  - spatially varying root depth (1-2 m) vs. constant 2 m
- **add frozen soil physics** (freeze/thaw latent heat, limit infiltration)
- **snowpack physics improvements**: *greatly reduced early melt bias*
  - add snow density state variable (retain SWE)
  - retain some snowmelt in snowpack and allow refreezing
  - refine functions for snow cover fraction and snow albedo
  - add patchy snow cover treatments to
    - snow sublimation, sensible & ground heat flux, skin temp
  - improved numerics/robustness for very shallow snow
- **transpiration**: refine soil moisture threshold for stress onset
- **direct soil evaporation**: revise dependence on soil moisture
- **smaller ground heat flux bias**
  - especially: wet soil, under snowpack, under dense vegetation
  - new functions for soil thermal diffusivity and soil heat capacity
Impact of Noah LSM implementation in GFS: example of warm season forecasts
Noah LSM changes reduce longstanding high bias in GFS surface evaporation over east half of CONUS

Noah LSM implemented in NCEP GFS in late May 2005
Impact of Noah LSM improvements in GFS warm season forecasts:
Noah LSM changes reduce longstanding high bias in GFS precipitation
over east half of CONUS

Precipitation Validation Scores:
East half of CONUS
60-84 hour GFS fcst from 00Z
12-31 May 2005

Equitable Threat Score

**Ops GFS: solid line**
(uses old OSU LSM)

**Test GFS: dashed line**
(uses new Noah LSM)

Bias
Ratio of forecast amount to Observed amount (Y-axis) as Function of amount of 24-hour Precipitation (X-axis)

Desired Target
Improving CFS Land Physics

• Current Ops CFS applies OSU LSM
  – OSU LSM

• Next-Generation CFS in NCEP-CPO Climate Test Bed
  – Applies Noah LSM
  – Applies GLDAS-Noah initial conditions
2-m total soil moisture [%]: 01 May Climatology (climo in each frame based on 27-years of its given system)
Illinois 2-meter Soil Moisture [mm]
1985-2004
Progress of CTB Transition Project Team for Land Data Assimilation:

Impact on CFS of: A) new land model (Noah LSM)
B) new land initial conditions (from 27-year T126 GLDAS/Noah)

10-year 10-member 6-month T126 CFS runs (GFS-OP3T3,MOM-3)

- Four configurations of T126 CFS:
  - A) CFS/OSU/GR2: OSU LSM, initial land states from GR2 (CONTROL)
  - B) CFS/Noah/GR2: Noah LSM, initial land states from GR2
  - C) CFS/Noah/GLDAS: Noah LSM, initial land states from T126 GLDAS/Noah
  - D) CFS/Noah/GLDAS-Climo: Noah LSM, initial land states from GLDAS/Noah climo

- 10 summers: (88, 90, 91, 93, 99, 01, 02, 03, 04)
  - Initial conditions: 00Z daily from Apr 19-23, Apr 29-30, May 1-3
- 10 winters: (83, 88, 89, 90, 98, 00, 01, 02, 03, 04)
  - Initial conditions: 00Z daily from Nov 29-30, Dec 1-3, Dec 19-23

For summers 1999 & 2000 only
- Ensemble size test (Case B only, 5 added members from April 9-13 I.C.s for total of 15)
- Lead time test (Cases B & C, 10 added members run from May 30-31, Jun1-3, Jun 19-23 I.C.s)
  - Also for test of CFS version (in FY06 CTB, we tested current ops CFS with Noah at T126)

For summer 2003 only (to compare with Augustin’s CTB CFS tests)
- 7 members, 2-month fcstst (same July initial dates as Augustin, for Aug fcst)

10-year 10-member runs just finished on CTB/HAZE on April 8
- Only time thus far for evaluation of 1999 summer ensemble over U.S. for precip
- Results of above pilot evaluation of CFS experiments shown in next frame
- Plus 3 additional frames comparing GLDAS/Noah and GR2/OSU soil moisture
Impact of Upgrading Land Surface Model and Land Surface Initial Conditions in Seasonal 3-Month Forecasts of the Experimental NCEP Climate Forecast System

CFS Predicted July 1999 Precipitation Anomaly (mm)

With respect to 10-year climate of given CFS model from 10-member ensemble of CFS forecasts from April initial conditions

CFS Test A: Control
- old OSU LSM
- GR2 initial land states

CFS Test B:
- new Noah LSM
- GR2 initial land states

CFS Test C: Most successful configuration
- new Noah LSM
- GLDAS initial land states

CFS Test D:
New Noah LSM
GLDAS climo initial land states

July 99 Observed Anomaly
Departure from Normal (mm)

Black Circles: Worse than Case C
White Circles: Best or decent

CFS Test B:
T126 CFS / Noah / GR2

CFS Test D:
T126 CFS / Noah / GLDAS-climo
Potomac River
A Medium Sized Basin

NCEP global model ensemble predictions of streamflow.
Anatomy of an Implementation

Global Forecast System
May 2005
Focus of the implementation

• Inferior GFS winter scores
• Set the stage for improved AIRS assimilation with a conservative implementation
• Transition JCSDA work to operations
• Include technology upgrades for
  – Land surface
    • Another step in unifying LSM in NCEP’s models
  – Sea ice model
    • First in a series of upgrades
    • Replaces ultra-crude 1980’s code
• Improved resolution affordable due to computer upgrade (T254 implemented 2 ½ years ago)
• Major changes in model structure and efficiency (+ 15%), allowing work on hybrid vertical coordinate and prototype ESMF compatibility
List of Upgrades

• Model
  – Increase resolution from T254 (55 km) to T382 (35 km)
    • Old: T254/L64 (0-84 h) T170/L42 (84-180h, T126/L28 to 384h
    • New: T382/L64 (0-180 h) T190/L64 (180-364 h)
  – Modified vertical diffusion
  – Enhanced mountain blocking
  – New sea ice model
    • Fractional sea ice & leads
    • Impacts surface fluxes
  – New code structure
    • Increased computational efficiency
    • ESMF compatible superstructure
    • “Hybrid (sigma-pressure) ready”
List of Upgrades (cont)

• Model (cont)
  – Upgrade to Noah Land Surface Model
    • 2-4 soil layers
    • Reduction of early bias in snow pack depletion
    • Improved treatment of
      – Frozen soil
      – Ground heat flux
      – Energy and water balance at surface
    • Reformulated infiltration and runoff functions
    • Upgraded vegetation fraction (NESDIS)
    • Improved, plug-compatible, code structure
List of Upgrades (cont)

• Analysis
  – Increase resolution to T382
  – Surface emissivity model for snow and ice (JCSDA)
    • 3 X data used in NH polar latitudes
    • 1.3 X in SH polar latitudes
  – AQUA AIRS and AMSU-A (new data)
  – Upgraded thinning algorithm for radiances
  – QC algorithm for clouds
List of Upgrades (cont)

• NCEP Service Center Product changes to Master File
  – Increased stratospheric products at 7, 5, 3, 2, and 1 mb
  – New format (added records) to accommodate the NOAH land surface model ADDED 15 records: Clear & All-sky UV-B downward SW flux, Soil moisture/Temperature for deep soil layers (10-40cm, 40-100cm, 100-200cm), Liquid soil moisture for all 4 soil layers, Plant canopy surface water, Snow depth (frozen not water equiv), Sea Ice thickness.
  – . DROPPED 12 records and ADDED 24 records: Potential Vorticity in corrected units (500, 1000, 1500, 2000 PV units), each contains 6 records: geopotential height, temperature, pressure, vertical wind shear, u, v wind.
  – . DROPPED 2 records: Soil moisture/Temperature for the single 10-200cm layer.
  – . CHANGED 5 records: Maximum wind level 500-100mb (not 500-70mb): pressure, temperature, geopotential height, u, v wind

• For external users
  – Minor change to units
  – Additional soil moisture levels corresponding to levels in new Noal LSM
Testing

• Winter
  – 1 December – 28 February
  – Statistics and case study requests from field (HPC, NWS Regions)

• Summer
  – 20 August – 30 September
  – GFS Hurricane tracks
  – GFDL runs (2005 system)

• Real time
  – 1 April – present
  – N-AWIPS Products to Service Centers
Performance Results - Winter

NH 500 hPa Geopotential Height at day 5
for 00Z 06DEC2004 – 00Z 22FEB2005

AC +2%
RMS - 8%

Consistent day-to-day performance
Performance Results – Winter (cont)

NH Z500 AC

SH Z500 AC

Clear positive impact in for all wave categories

Neutral impact
Fits to Rawinsondes

North

TEMPERATURE

South

Upper Trop & Lower Strat.

Ops – solid
Par. - dashed

24 h
48 h

Major Improvement

Fits to Rawinsondes

North

TEMPERATURE

South

Upper Trop & Lower Strat.

Ops – solid
Par. - dashed

24 h
48 h

Major Improvement
Performance Results – Summer & Hurricanes (cont)

NH 500 hPa Geopotential Height at day 5 for 00Z26AUG2004 – 00Z30SEP2004

AC +3%
RMS - 8%
Consistent day-to-day performance
Performance Results – Summer & Hurricanes (cont)

Hurricane Track

Improved Skill for both GFS and GFDL in Atlantic Neutral in EPAC (focus of current work)