Some Thoughts on the Evolution (Revolution?) of the Use of Satellite Data in Numerical Weather/Climate Prediction

Dr. Louis W. Uccellini

Director, National Centers for Environmental Prediction

June 17, 2005

25th Anniversary of the Cooperative Institute
For Meteorological Satellite Studies
Madison, WI
July 11-13, 2005

"Where America's Climate, Weather and Ocean Services Begin"

Overview

- Historical Aspects
- Today's Model Situation: Operational Reliance on Satellite Data
- Convergence of Research and Operational Requirements and Implications for Both Communities
- Current Research to Operations – Where Does CIMSS Fit?
- Summary

Historical Aspects
The Development and Applications of Numerical Models

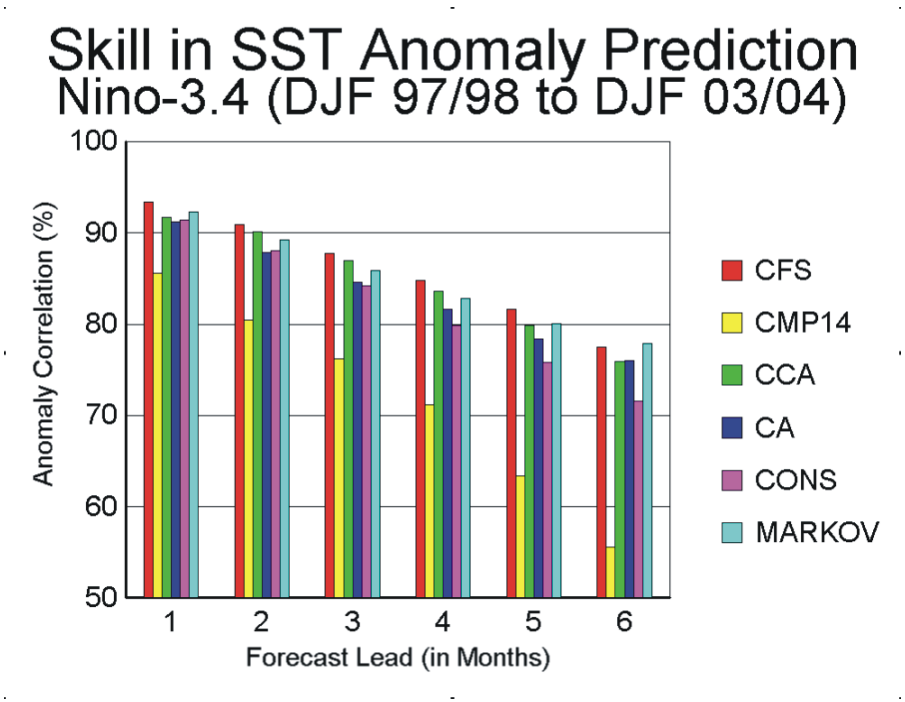
- Real-time models for weather prediction introduced in 1954
- General acceptance of numerical models as a genuine basis for weather prediction ==> Mid 1980s
  - First global observing system (from FGGE, satellite emphasis begins…hats off to SSEC)
  - First global prediction system
  - First "high" resolution regional model

It took 30 years!

- Produces consistent prediction of large-scale waves, cyclones,…, weather

Historical Aspects Climate Prediction Commenced in the 1970s – 80s

- Mainly based on statistical techniques and persistence
- First dynamical based operational prediction (2001)
- First global operational atmosphere-ocean coupled dynamic model (2004)
  - Climate Forecast System (CFS)
  - First climate forecast system to beat statistical approaches

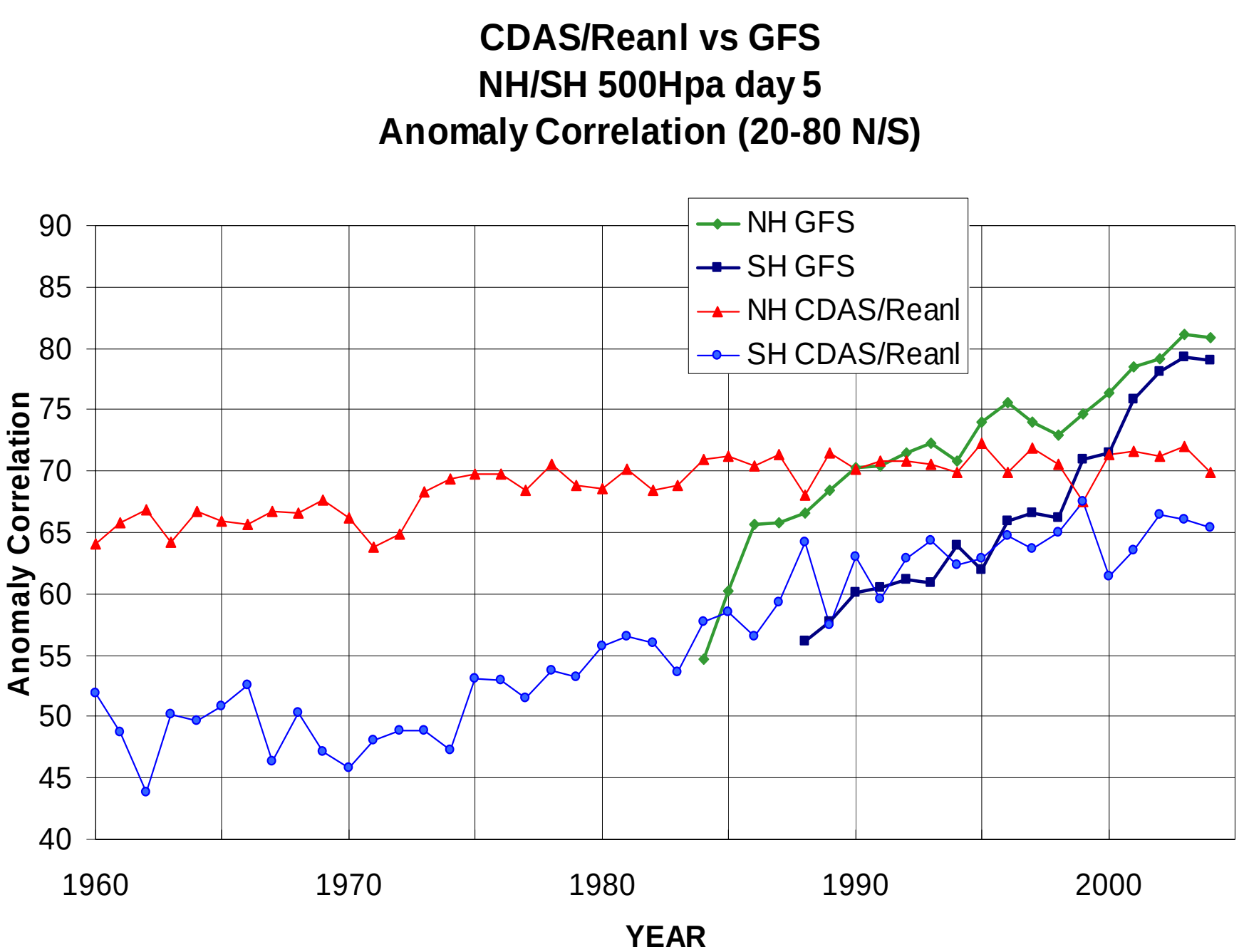


Historical Aspects
Application of Satellite Data to Numerical Weather Prediction Models

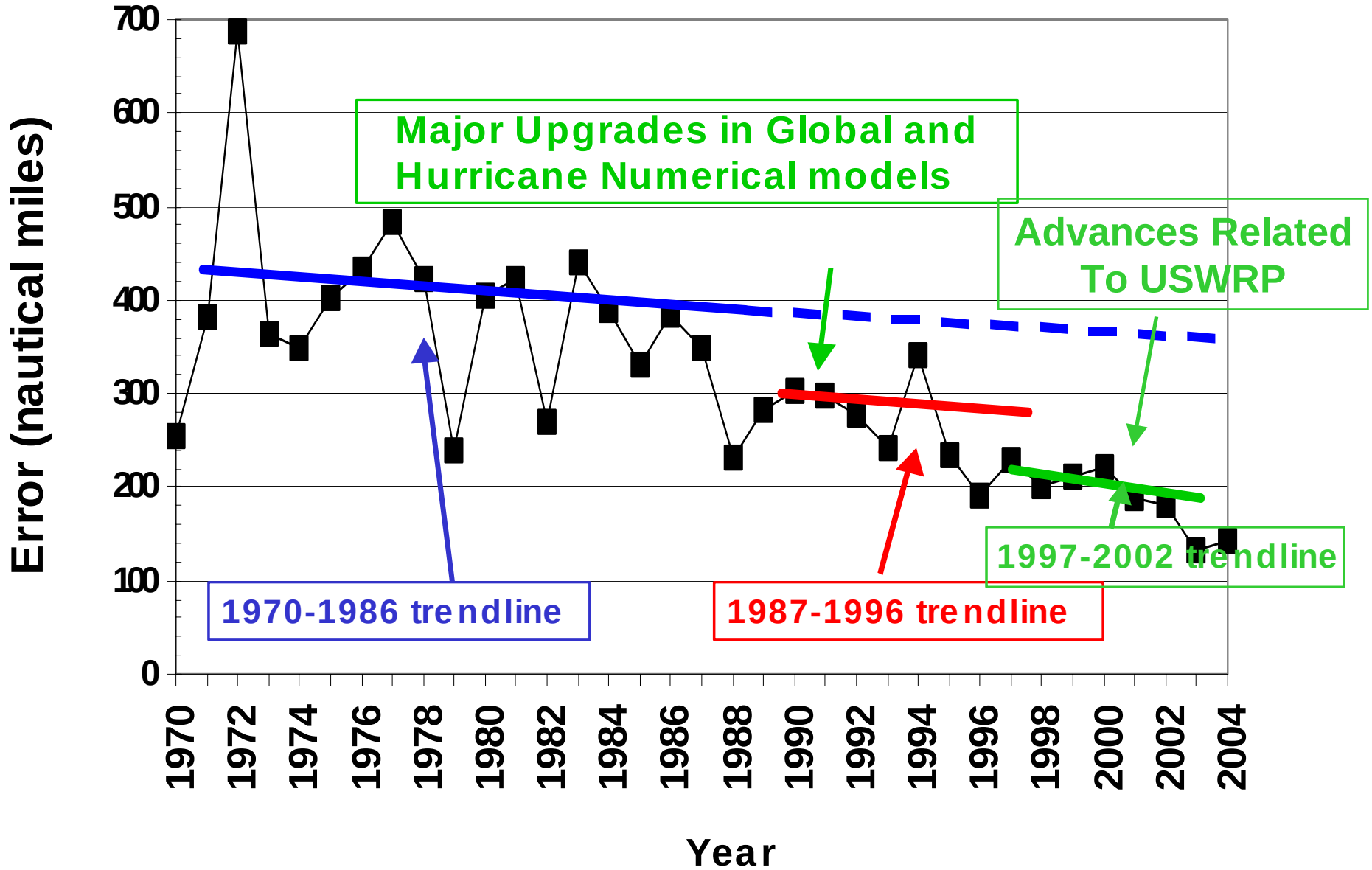
- Satellite input generally from LEO
- Work to develop satellite derived T and Td profiles started in mid to late 1960s (hats off to SSEC and Dept of Meteorology)
- Initial results in using satellite profiles in operational models: mixed
- Was not until the 1990s that satellite radiance data used directly in operational models had significant positive impact

It took 30+ years!

- High resolution winds finally incorporated in operational models in the late 1990s through 2003
- GEO data used starting in mid to late 90s


CDAS/Reanl vs GFS
NH/SH 500Hpa day 5
Anomaly Correlation (20-80 N/S)
NH GFS
SH GFS
NH CDAS/Reanl
SH CDAS/Reanl
Anomaly Correlation
90
85
80
75
70
65
60
55
50
45
40
1960
1970
1980
1990
2000
YEAR

NHC Atlantic 72 hr Track Forecast Errors



Historical Aspects
Use of Satellite Data in Climate Models

- Whereas weather prediction is viewed as an initial value problem and relies on vertical profiles of initial data sets, climate prediction is related to boundary forcing
  - Land
  - Ocean
  - Cryosphere

Historical Aspects

Thirty-Plus Years to Breakthroughs – Why?

- Difficult problem to solve
- Research “versus” Operational Communities
  - Perceived differences in requirements regarding accuracy of measurements, timeliness,… etc.
- Imbalances among the “three pillars” required for operational utilization of satellite data dominated the 1960s – 2000
- Three pillars
  - Observations
  - Science
  - Computer power for data assimilation and prediction

Today's Model Situation: Operational Reliance on Satellite Data

- Today's situation may actually represent the first instance of an existing balance among the three pillars
- Results have been:
  - Over 123 million satellite observations received/day
  - Data assimilation geared toward satellite data
  - Computer capacity geared to accommodate current research and operational satellite data stream and global to regional model prediction systems

Computing Capability

$26.4M/Year Investment

Commissioned/Operational IBM Supercomputer in Gaithersburg, MD (June 6, 2003)

- Receives Over 123 Million Global Observations Daily
- Sustained Computational Speed: 1.485 Trillion Calculations/Sec
- Generates More Than 5.7 Million Model Fields Each Day
- Global Models (Weather, Ocean, Climate)
- Regional Models (Aviation, Severe Weather, Fire Weather)
- Hazards Models (Hurricane, Volcanic Ash, Dispersion)
- 3.2x upgrade operational on January 25, 2005
- Backup in Fairmont, WV operational January 25, 2005

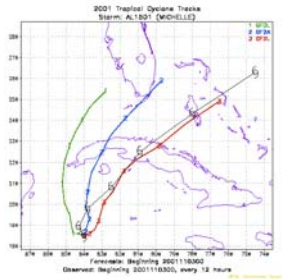
Model Dependencies:
Basis for How Predictions are Made

GLOBAL DATA

Global Forecast System
Ocean

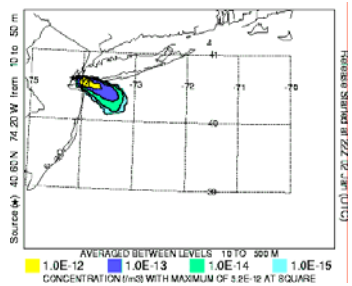
Climate Forecast System
Ocean

GFDL Hurricane

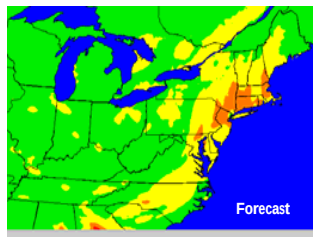


Regional Weather Forecast Models
Ocean

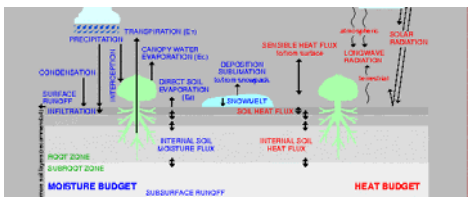
Dispersion



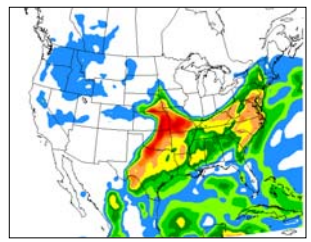
Air Quality



NOAH Land Surface Model

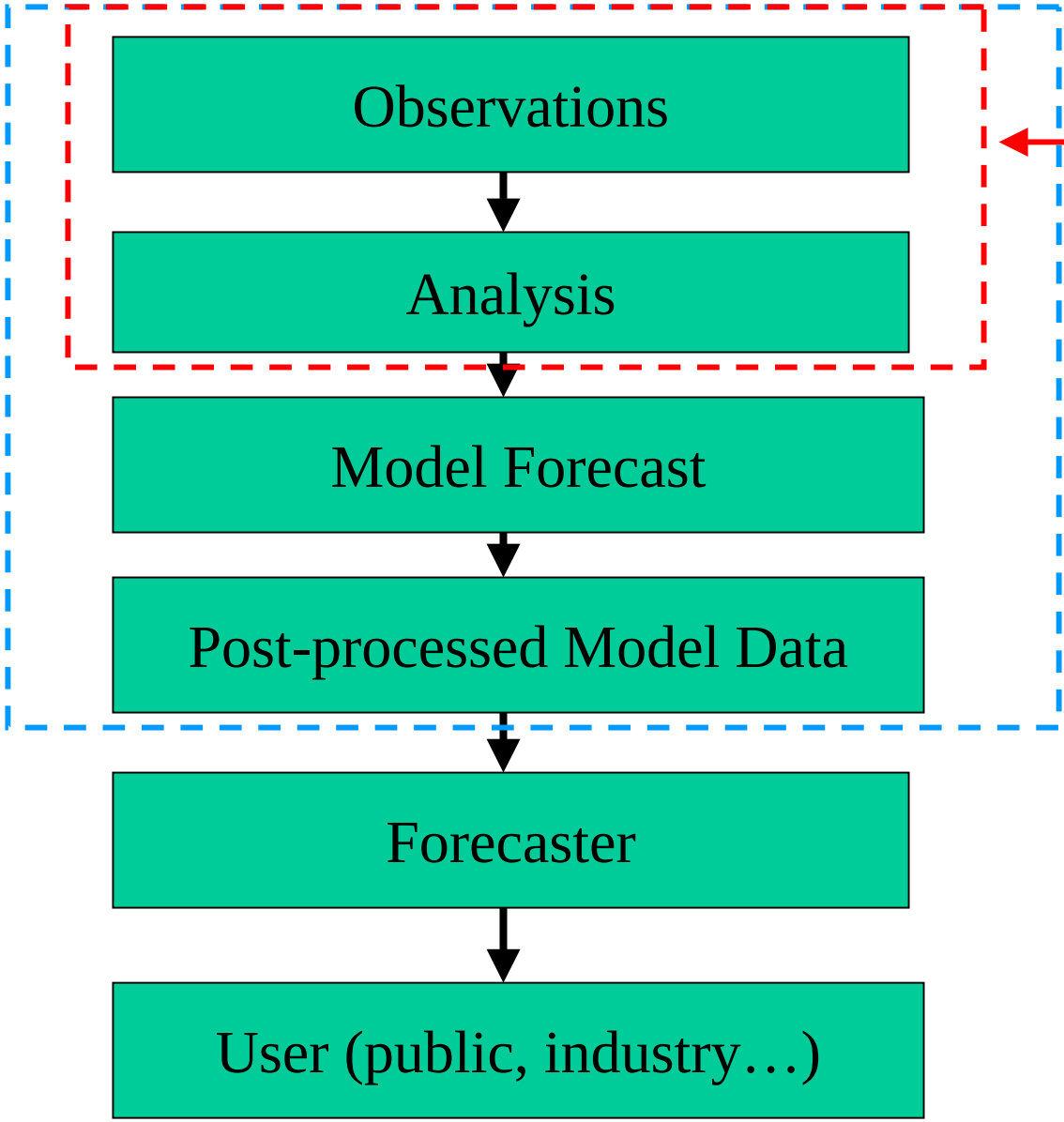


Aviation Hourly Forecast

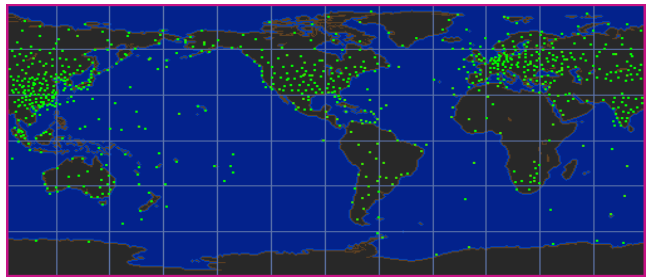


Prediction system starts with global observing system dominated by satellites

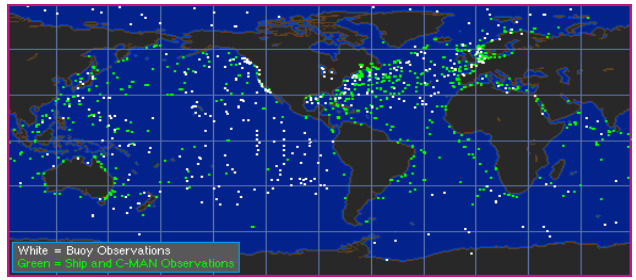
The Environmental Forecast Process



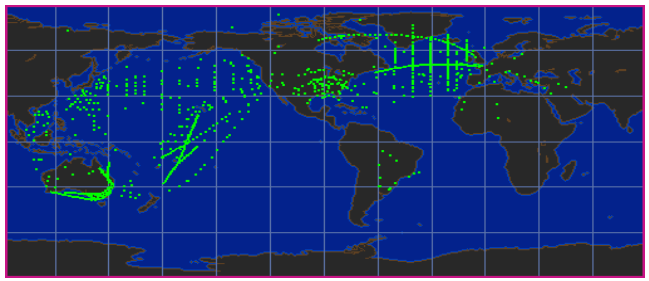
Global Observations 12 UTC
6 hour window



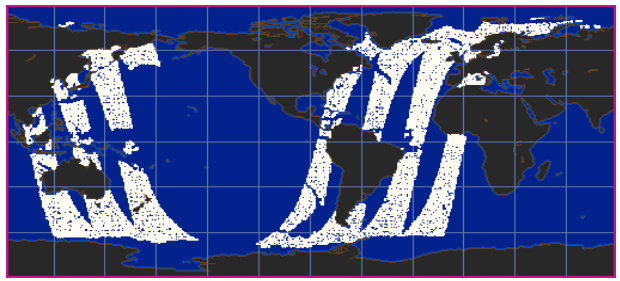
Global Rawinsondes



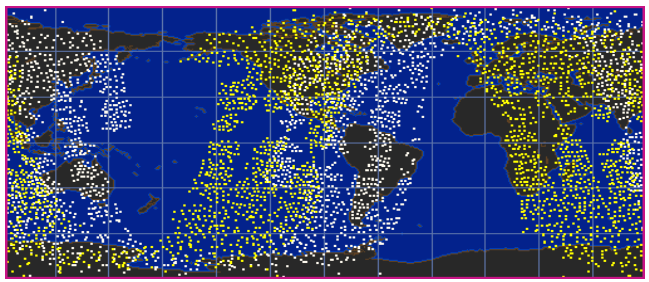
Marine Obs -- 12 Hour Total



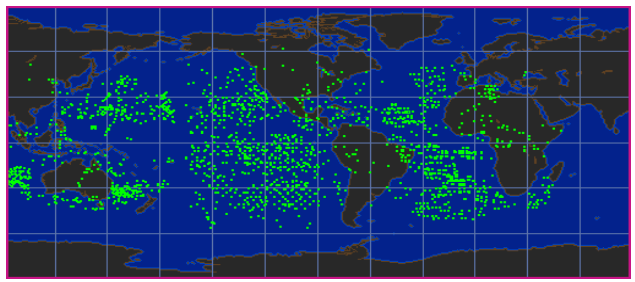
Aircraft Wind/Temp Reports



DMSP Imager – Sfc winds/PW



Polar Satellite Radiances (2 sat)



Satellite Winds

99.99% of data derived from satellites

Convergence of Research and Operational Requirements and Implications for Both Communities

The Research Community

- Is increasingly interested in seeing results influence operational prediction models and forecasters
- Finds it more cost effective to work with data in real-time
- Works with a larger number of cases for any specific study
- Has a shorter period of time to show relevancy of results (GPRA!)

This evolution in the research community demands a reliable real-time infrastructure for data access, data assimilation, model prediction, information extraction and product delivery

The Operational Community

- Is facing an onslaught of a new global observation system
  - High spectral, increased vertical and horizontal resolutions
- Is facing increased requirements for observations over land, water, ice, …
- Has absolute need to resolve the Earth System in real-time (it is not an academic problem anymore)
- Cannot take 3,4, or 5 years to figure out how to use new observing systems

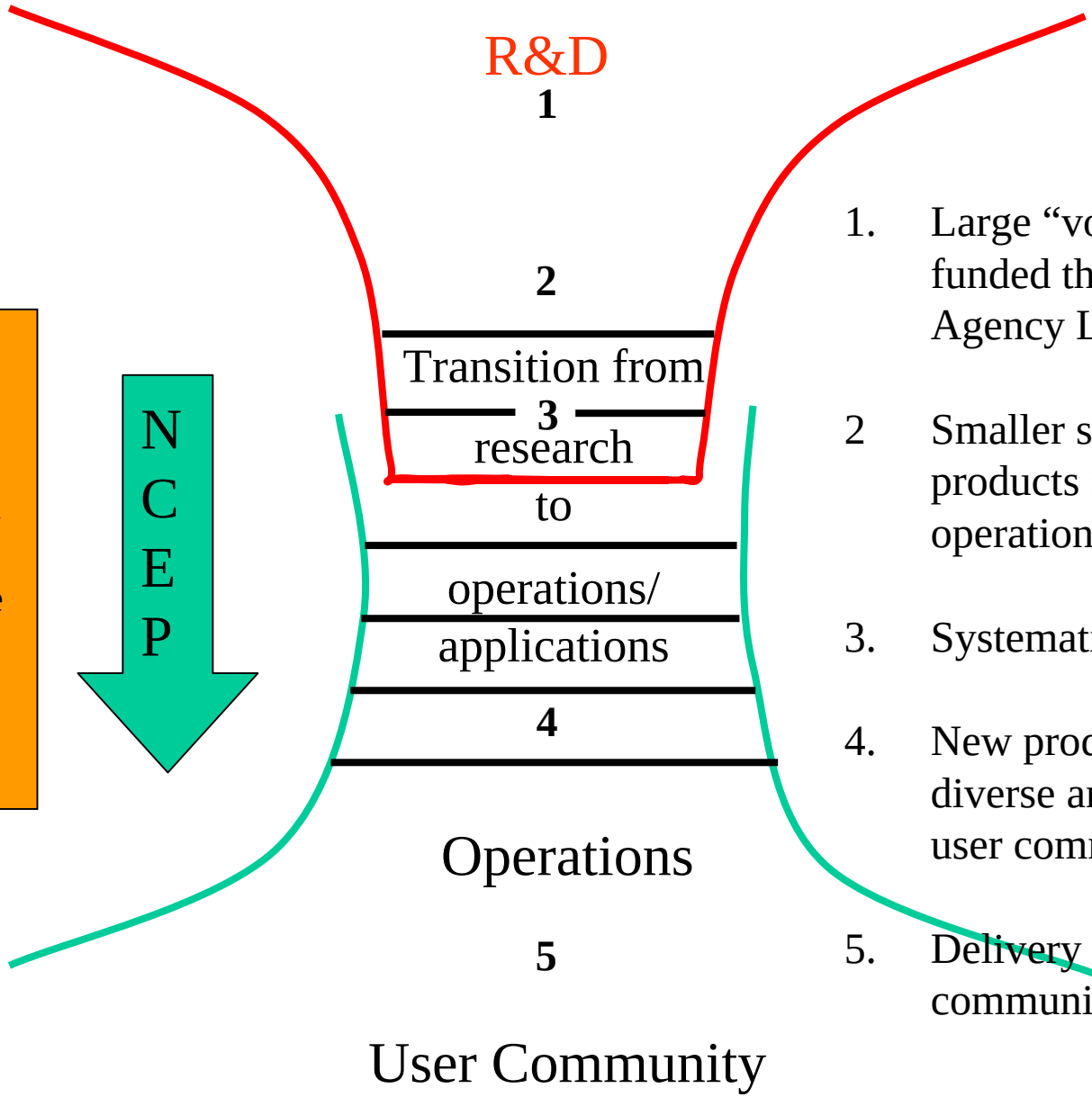
These requirements demand a close reliance on the research community

The Research and Operational Communities are Converging!!

- The operational community has secured the data access, data assimilation and model prediction system that the research community needs
- The research community is interested in addressing key science problems that face the operational community in their need to advance
- WRF ⟷ ESMF: The days of Eta vs. MM5 are over.

Current Research to Operations: Where does CIMSS fit?

Applying the "Funnel" to the Transition Process



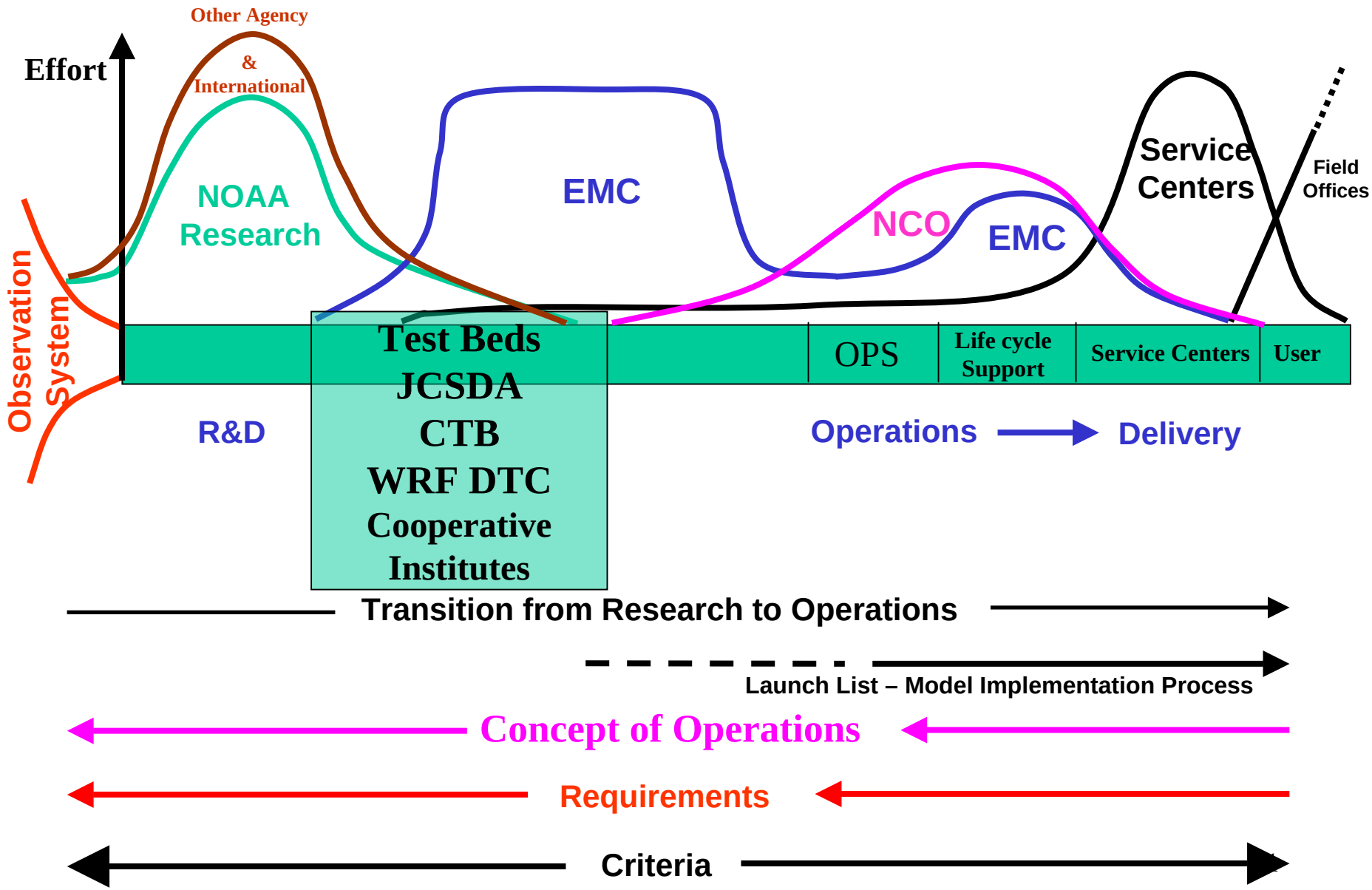
NCEP is uniquely positioned to provide an operational infrastructure for the transition process

NCEP

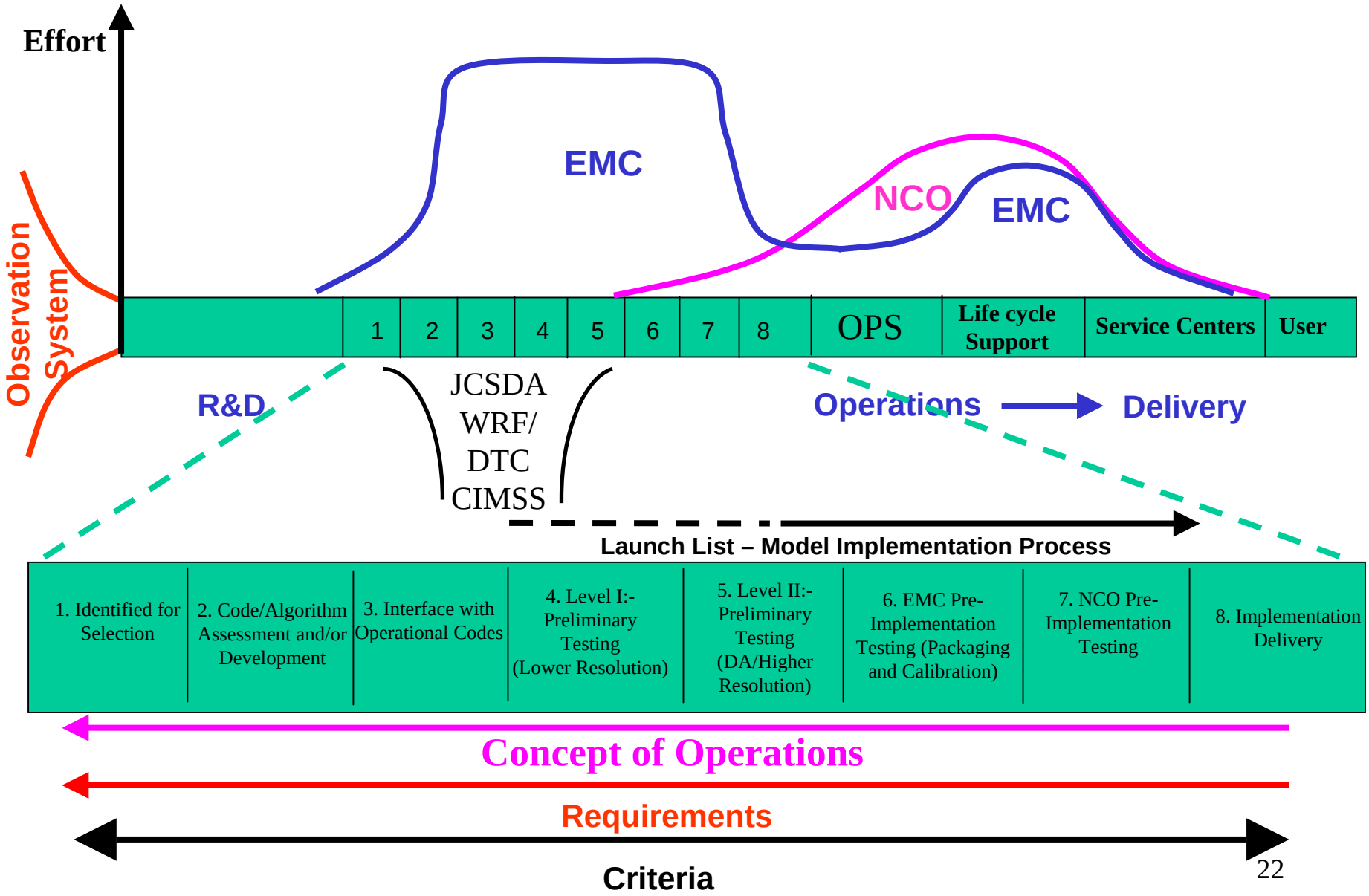
1. Large "volume" of R&D, funded through AOs, Agency Labs…
2. Smaller set of R&D products suitable for operations.
3. Systematic transition steps.
4. New products can serve diverse and expanding user community.
5. Delivery to diverse USER community

NCEP's Role in the Model Transition Process

EMC and NCO have critical roles in the transition from NOAA R&D to operations



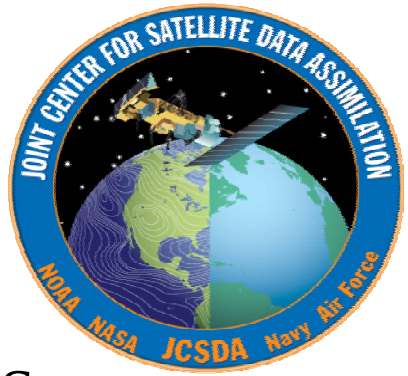
NCEP's (Modeling) Transition to Operations: Focus on EMC and NCO



CIMSS

- Important for R2O transition process
  - Data assimilation (GEO, MODIS winds, AIRS,…, passive microwave…)
  - Global/Regional data denial studies
- Has increased linkage to test beds (JCSDA, WRF/DTC, JHT, CTB,…)
- Could become even more effective if CIMSS scientists increase reliance on operational infrastructure, especially that associated with JCSDA

The Joint Center for Satellite Data Assimilation



- Formed in 2001
- Infrastructure for real-time access to operational and research satellite data from GOES, AMSU, Quikscat, AIRS, MODIS,…
- Community fast forward radiative transfer scheme … operational data assimilation and model forecast systems available to research and forecast communities
- Supports “internal” and “external research” and data assessments on NOAA/NCEP computers

The Research Community is now using the operational infrastructure.

The Operational Community is now accelerating use of satellite data.

Summary

- A long glorious history has brought the satellite, numerical modeling, research and operational forecast communities together – the results have been amazing!
- Satellite dominated global observing systems now support:
  - Operational weather forecasts to day 7
  - Operational week 2 ➔ seasonal climate prediction increasingly reliant on dynamically-based model system
- Research and operational communities are facing enormous challenges with planned upgrades to LEO and GEO (NPOESS, GOES R, GIFTS,…)
- The success of the U.S. in capitalizing on the billion dollar plus investment and accelerating the use of new data sets depends on continued convergence of the research and operational communities
- CIMSS is strategically positioned to continue to build on this legacy and contribute to future advances

Background Slides

Model vs. Forecaster Applications

Models

- Generally Quantitative
- Reliant on global observing databases
- Focus on LEO
- Only now getting into GEO world

Model vs. Forecaster Applications

Forecasters:

- Generally qualitative
- Initial reliance on imaging, focus on GEO
- "The greatest single advancement in observing tools for tropical meteorology was unquestionably the advent of the geosynchronous meteorological satellite. If there was a choice of only one observing tool for use in meeting the responsibilities of the NHC, the author would clearly choose the geosynchronous satellite with its present day associated accessing, processing and displaying systems available at NHC." - Robert C. Sheets, Director, National Hurricane Center, 1990, The National Hurricane Center – Past, Present, and Future. *Wea. Forecasting* **5**: 185-232.
- McIDAS ➔ VDUC made it possible – " …like taking a drink from a fire hose…" – Suomi
- Only now getting into the LEO world: Quikscat, TRMM, …