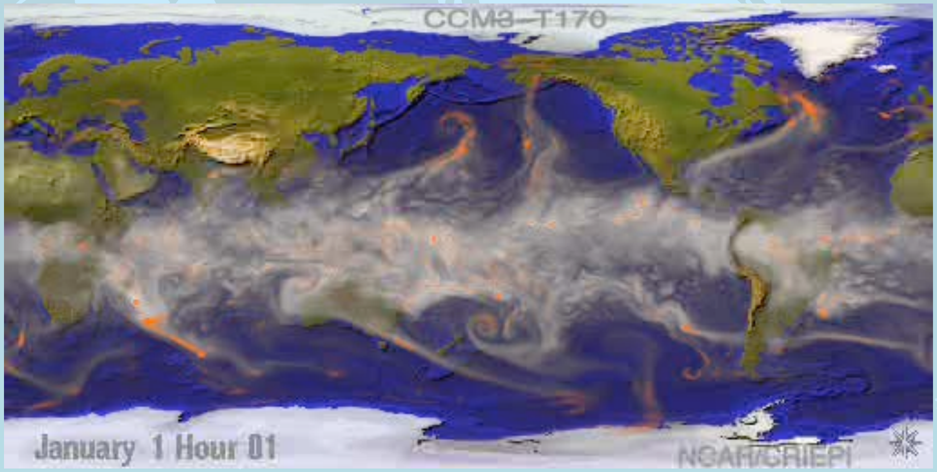
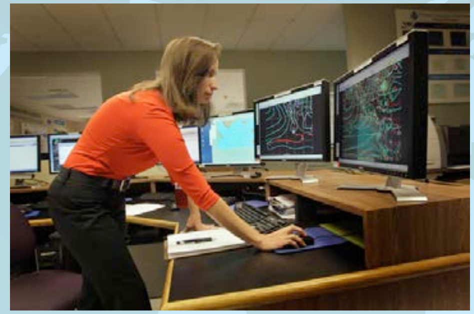
MET 200 Lecture 22
Weather Forecasting



Lecture 22 Weather Forecasting

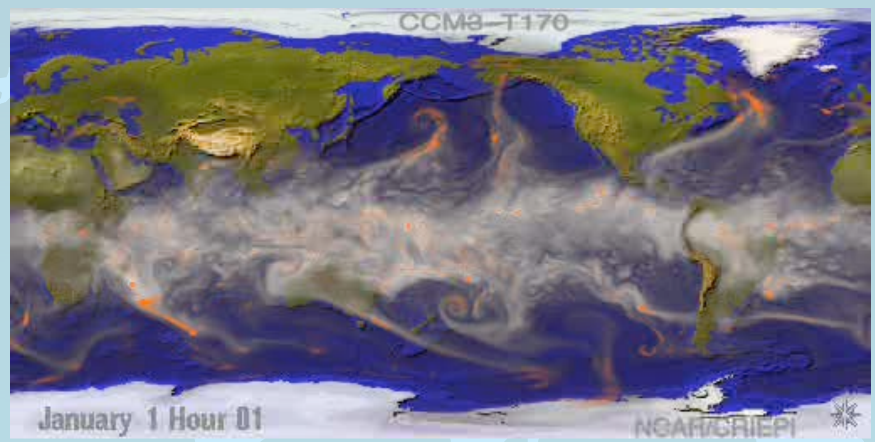


– Motivation and history
– Collect observations
– Run numerical weather prediction models
– Construct Forecasts
– Issue advisories, watches and warnings

Motivation

- The U.S. arguably has the world's worst weather: hurricanes, tornados, large hail, blizzards, droughts, heat waves….
- Hazardous weather is the reason the National Weather Service (NWS) was founded.
- The mission of the NWS is to reduce the loss of life and the loss of property associated with weather related hazards, and to mitigate the economic impact of disruptive weather.
- Weather forecasters look at current state of the weather and forecast maps and add their personal experience to come up with a forecast and to issue warnings.

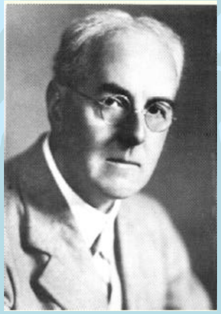
Numerical Weather Prediction (NWP)



The atmosphere is a fluid. The basic idea of numerical weather prediction is to sample the state of the fluid at a given time and use the equations of fluid dynamics and thermodynamics to estimate the state of the fluid at some time in the future.

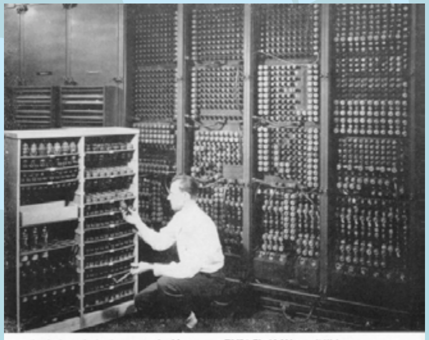
History of NWP

- British mathematician Lewis Fry Richardson first proposed numerical weather prediction in 1922.
- Richardson attempted to perform a numerical forecast but it was not successful. The cause was a failure to apply smoothing techniques to the data, which rule out unphysical surges in pressure.



History of NWP

- The first successful numerical prediction was performed in 1950 by a team composed of the American meteorologist Jule Charney, Norwegian meteorologist Ragnar Fjörtoft and applied mathematician John von Neumann, using the ENIAC digital computer.
- They used a simplified form of atmospheric dynamics to reduce the demands on computer time and memory, so that the computations could be performed on the relatively primitive computers available at the time.



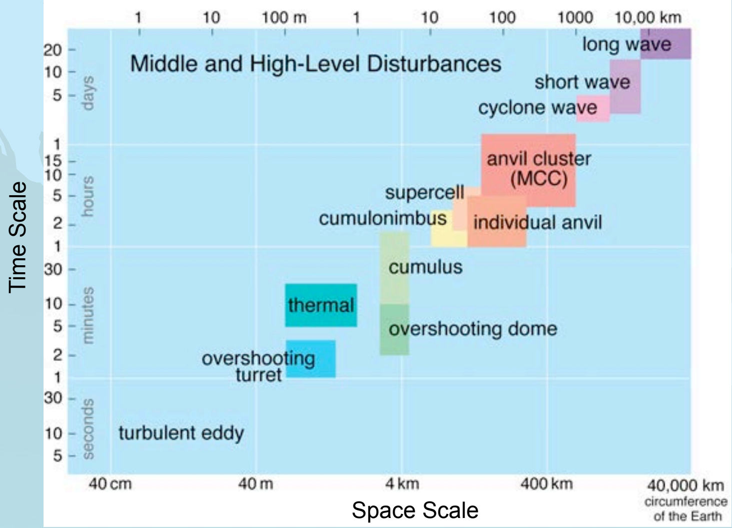
Replacing a bad tube meant checking among ENIAC's 19,000 possibilities.

History of NWP

Operational numerical weather prediction (i.e., routine predictions for practical use) began in 1955 under a joint project by the U.S. Air Force, Navy, and Weather Bureau.

Slow NCEP IBM machine: only 1.3 trillion calculations per second. No wonders the Europeans are ahead.

Forecasting Phenomena over Four Orders of Magnitude – Need Fast Computer

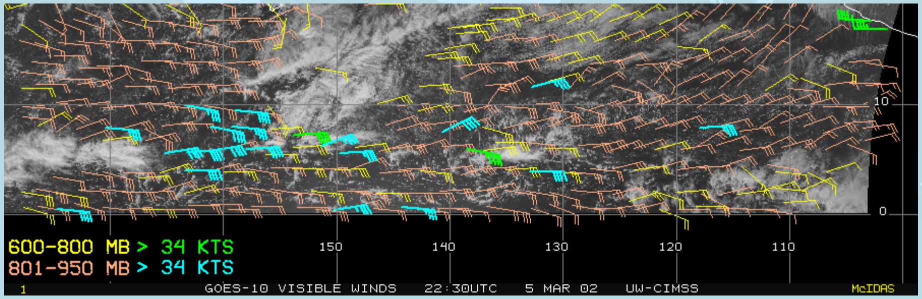


The Four Steps of NWP

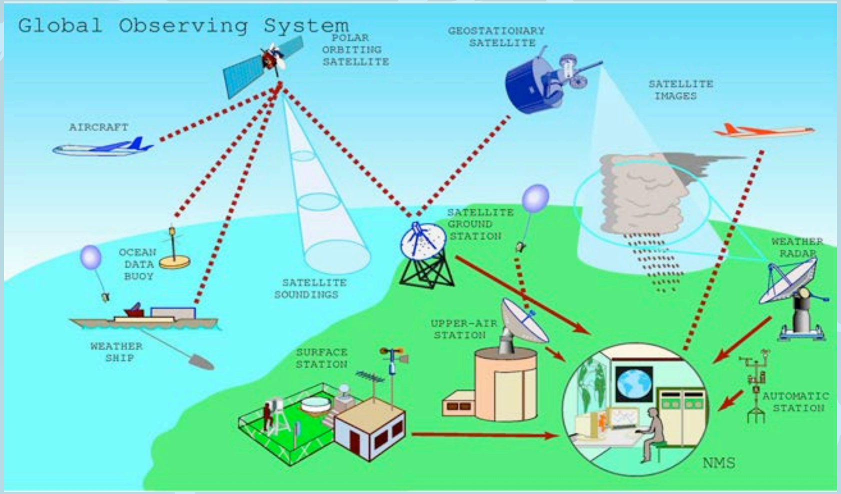
1. Collect all available observations.
2. Interpolate observations to a grid (apply boundary conditions).
3. Apply laws of physics, including parameterization of surface and cloud processes too small for the model to directly include - integrate equations forward in time.
4. Output resulting forecast as contoured maps for easy interpretation.

1. Collect All Weather Data

- Surface observations - surface pressure, wind, temp., and dew point, current weather
- Doppler radar - rainfall rate, winds
- Satellite data - clouds, precipitation, winds, aerosols
- Radiosonde and aircraft soundings - vertical profiles of wind, temperature, and dew point

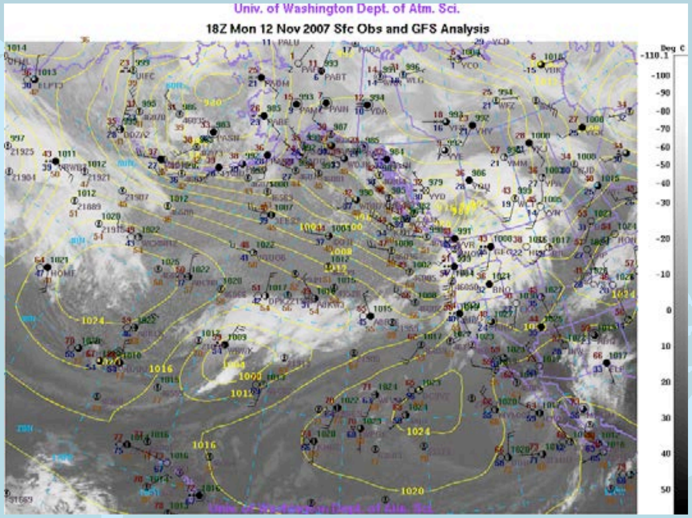


Global Observing System



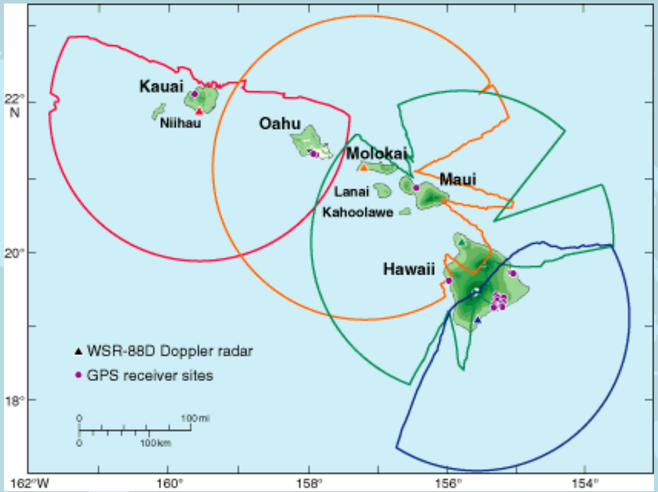
Input all available observations: surface, ship, buoy, radiosonde, aircraft, radar, satellite, etc...

1. Collect All Weather Data



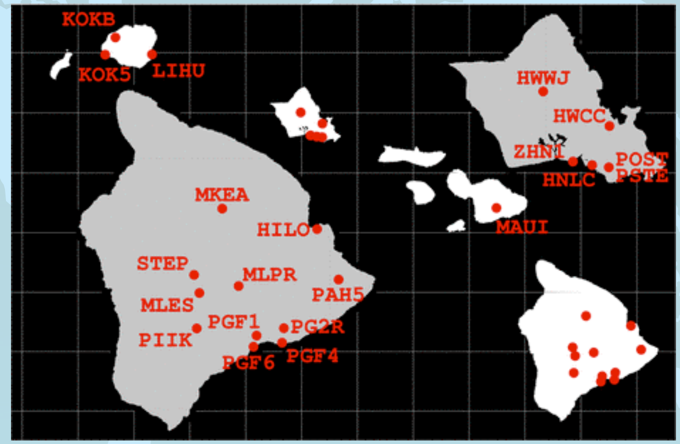
Input all available observations: surface, ship, buoy, radiosonde, aircraft, radar, satellite, etc...

Radar Observations



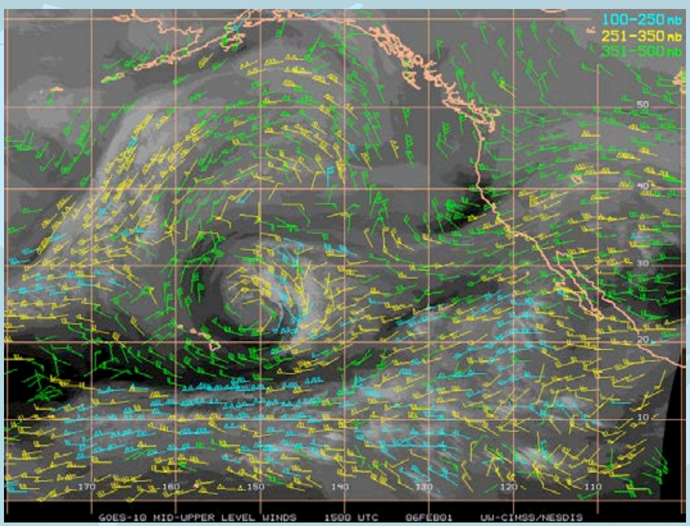
Four radars provide rain rates and wind data for near vicinity of Hawaii. Important for nowcasting of thunderstorms and flooding.

GPS Precipitable Water Observations



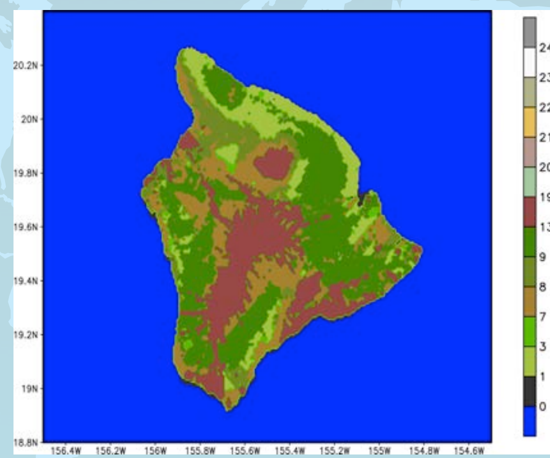
GPS sites maintained by the Pacific GPS Facility at UH (courtesy of Dr. James Foster).

Satellite Observations



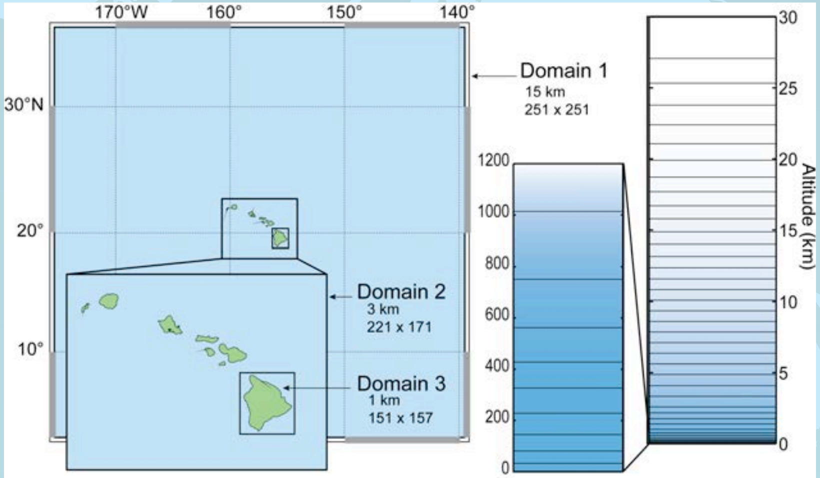
Satellite observations provide information on cloud distribution and winds. Key for data sparse Hawaii.

Apply Hawaii Land-use Categories



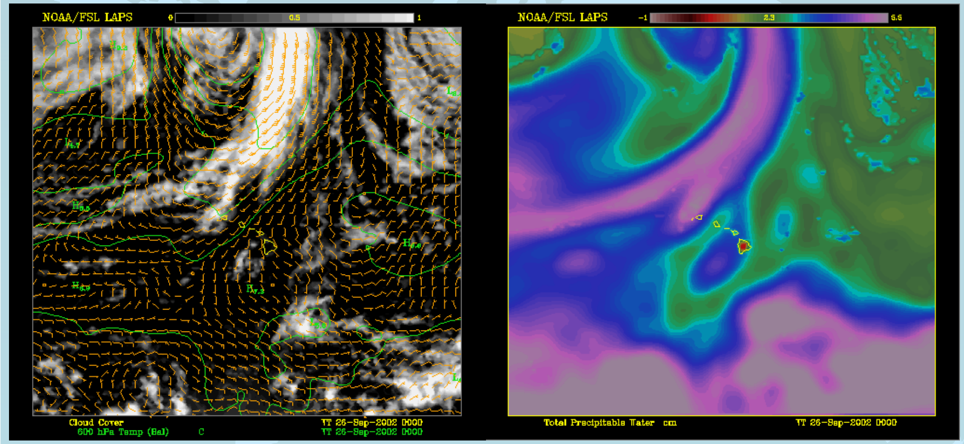
Brown indicates bare lava or soil, dark green is rainforest, and light green is agricultural land, etc.

3. Interpolate Observations to Grid



WRF configuration showing domains and grid resolution

Assimilation of Satellite Observations



Satellite Data over the ocean are interpolated to a grid.

3. Apply laws of physics, including parameterization of surface and cloud processes too small for the model to directly include - integrate equations forward in time.

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - \omega\frac{\partial u}{\partial p} + fv - \frac{\partial \phi}{\partial x} + F_x$$

$$\frac{\partial v}{\partial t} = -u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - \omega\frac{\partial v}{\partial p} - fu - \frac{\partial \phi}{\partial y} + F_y$$

$$\frac{\partial \phi}{\partial p} = -\frac{RT}{p}$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial p} = 0$$

$$\frac{\partial T}{\partial t} = -u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} + \omega\left(\frac{RT}{c_p p} - \frac{\partial T}{\partial P}\right) + \frac{H}{c_p}$$

$$\frac{\partial q}{\partial t} = -u\frac{\partial q}{\partial x} - v\frac{\partial q}{\partial y} - \omega\frac{\partial q}{\partial p} + E - P$$

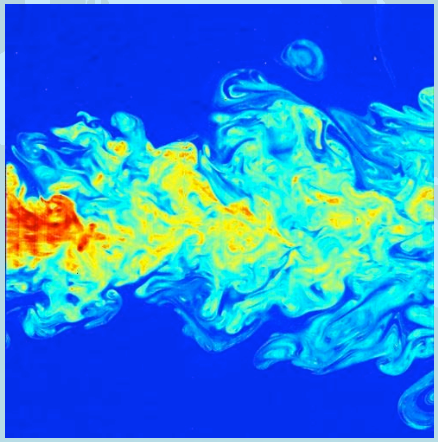
These six equations are called *primitive*, because they are fundamental or basic.

Primitive Equations

- Eqs. (1) and (2) are the horizontal momentum equations for the ‘u’ and ‘v’ components of the wind, respectively. Note that (via scale analysis), the curvature terms and the Coriolis term [$2\Omega\omega\cos\theta$] have been neglected.
- Eq. (3) is the vertical momentum equation under the assumption of hydrostatic balance (diagnoses z).
- The continuity equation (4) expresses the conservation of mass (diagnoses ω).
- The First Law of Thermodynamics yields an “energy” equation for temperature (5).
- Eqn. (6) is the conservation of moisture equation where q is specific humidity.

What is Parameterized?

- Cloud Microphysics
- Turbulence - (surface roughness)
- Radiation
- Convection
- Soil Moisture



Primitive Equations

We can say we have a <u>closed system</u> if:

1) we can find expressions (parameterizations) for F_x, F_y, H, E, and P in terms of the known dependent variables

2) we have suitable initial conditions over the domain

3) suitable lateral boundary conditions for the dependent variables are formulated (for regional models); all models need boundary conditions at the top and bottom levels

Operational NWP models

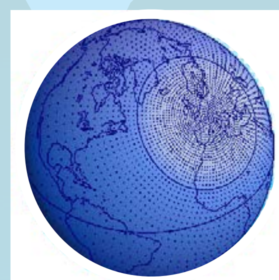
Models 1-7 are run daily at the National Centers for Environmental Prediction (NCEP)

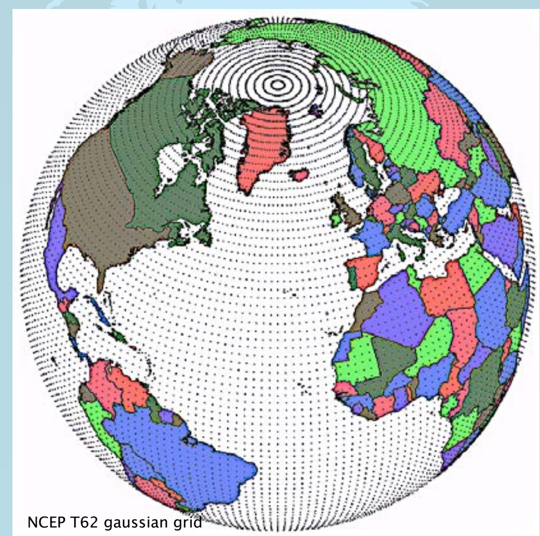
1. Eta (named after vertical coordinate)
2. RUC (Rapid Update Cycle)
3. MM5 (Mesoscale Model 5) phasing out
4. WRF (Weather Research and Forecast Model)
5. NAM (North American Model)
6. GFS, AVN, MRF (Global Forecast System, Aviation, Medium Range Forecast)
7. NOGAPS and COAMPS are run at NRL in Monterey (Navy Operational Global Atmospheric Prediction System, Coupled Ocean-Atmosphere Prediction System)
8. ECMWF model run at ECMWF in England (European Center for Medium Range Weather Forecasting)

Regional models (1-5), Global Spectral Models (6-8)

Global-spectral models

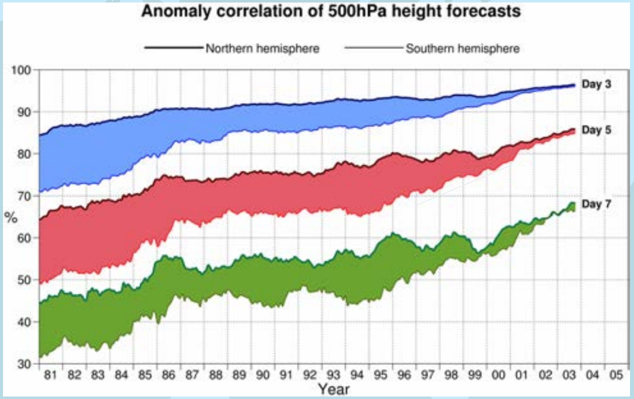
Gaussian Grids
AVN, MRF,
GSF, ECMWF





NCEP T62 gaussian grid

Skill Improvements (ECMWF)



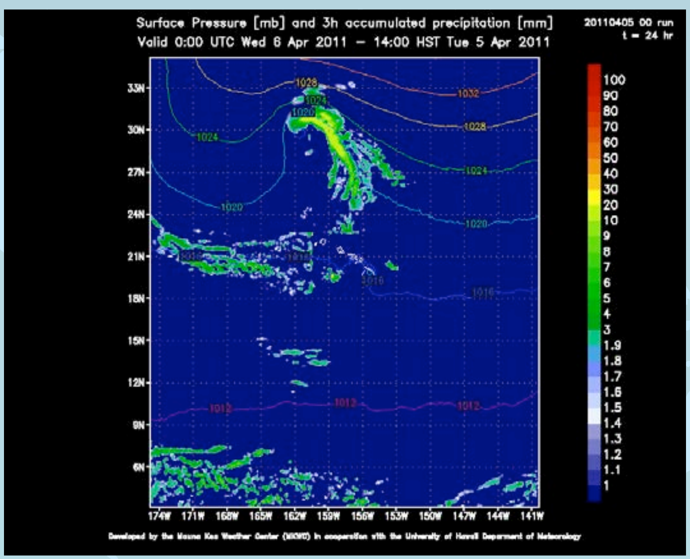
Useful skill until:
1 - day 5
2000 - day 7
2003 - day 8

Improvements from 1980 to 2001 result from:
Northern hemi. – obs. system 23% model+DA 77%
Southern hemi. – obs. system 45% model+DA 55%

Challenges in Weather Modeling

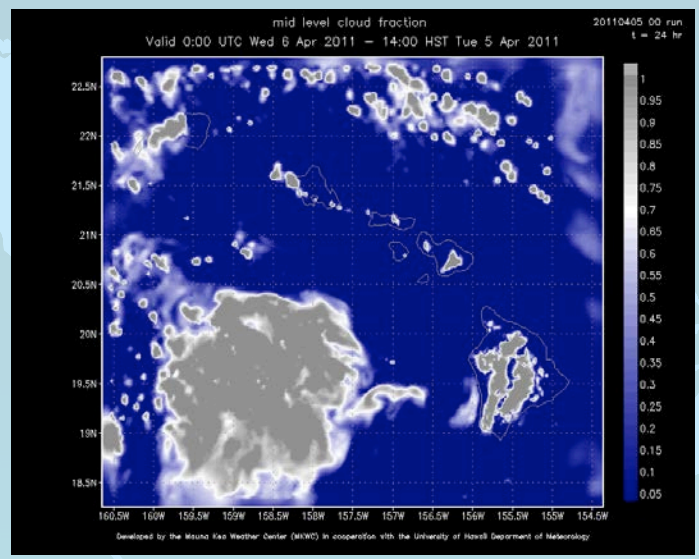
- Observations are often lacking, especially over the oceans, or there are mistakes in reporting.
- The grid scale of the model is not fine enough to fully capture the physics of clouds, terrain, or air-sea interaction. A faster computer helps.
- There are difficulties with the equations of motion at the boundary of the air and the surface, where the equations become nonlinear.

Regional Model: Maps for Interpretation



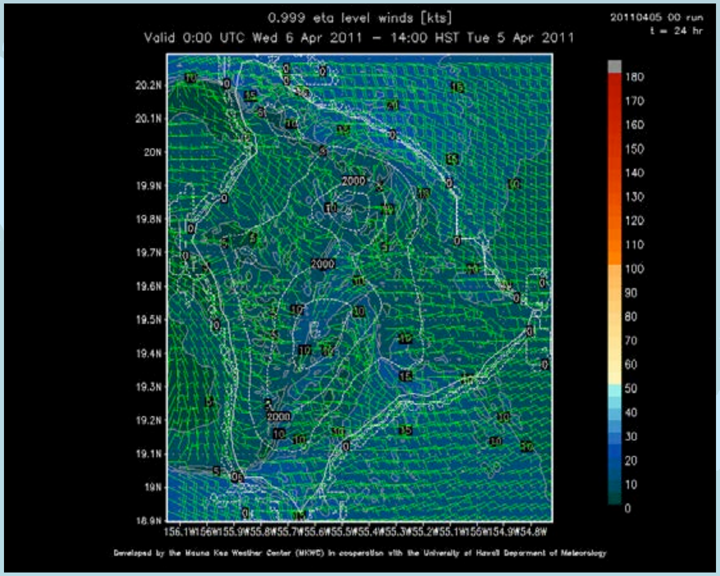
Precipitation forecast on domain D1: 15 km resolution.

Model Output to Maps for Interpretation



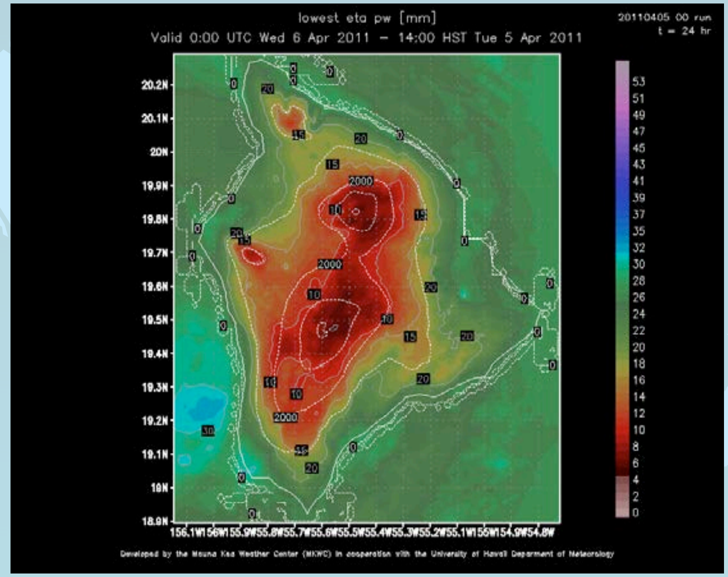
Cloud fraction forecast on domain D1: 3 km resolution.

Model Output to Maps for Interpretation



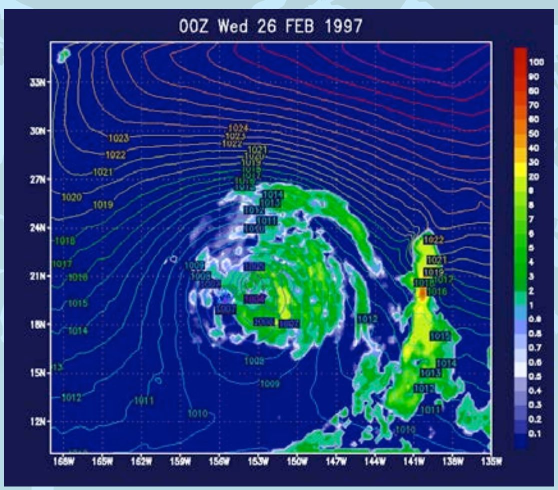
Wind forecast on domain D2: 1 km resolution.

Model Output to Maps for Interpretation



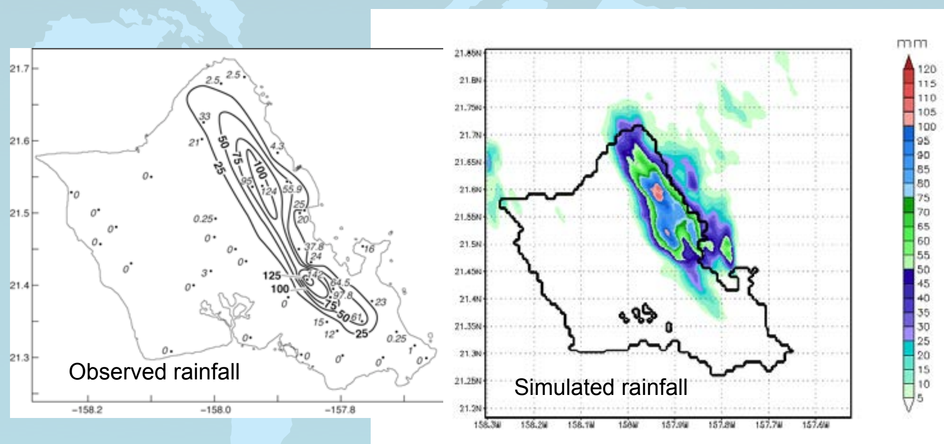
Temperature forecast on domain D3: 1 km resolution.

4. Output to Forecast Maps



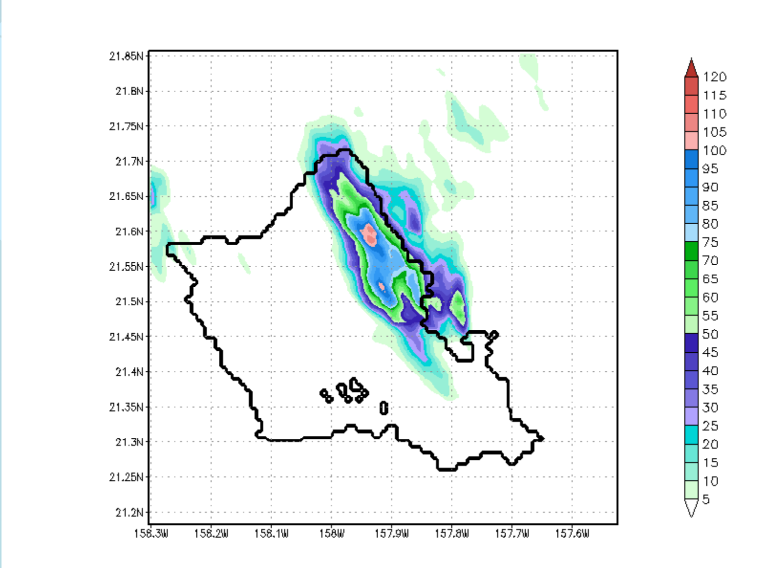
Kona Low Simulation showing pressure and rainfall.

High Resolution WRF Rainfall

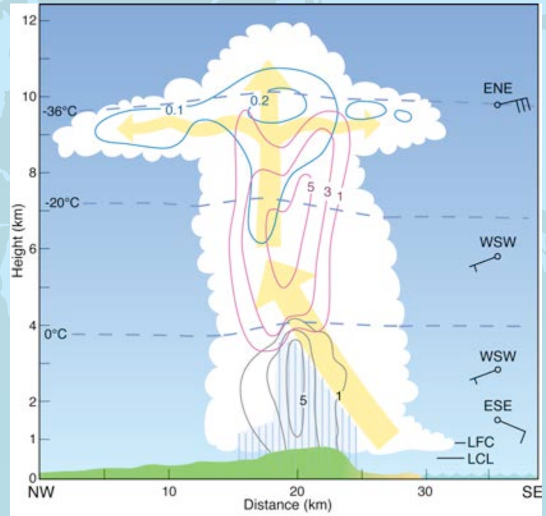


High resolution (250-m grid spacing) simulation of rainfall using the Weather Research and Forecasting (WRF) model

High Resolution WRF Rainfall



Conceptual Diagram of Koolau Flooding



NWS Flash Flood Advisories

- Flood Potential Outlook (36 hr in advance)
  - Event is possible within 36 hr
- Flood Watch (36 hr in advance)
  - Event is likely within 36 hr
- Flash Flood Warning (updated every 3 hr)
  - Threat to life and property is imminent or occurring



NWS Watches and Warnings

The NWS issues advisories to warn the public.

- Winter Storm Watch
  - Heavy snow or a blizzard is possible, but the exact timing, location, or occurrence of the storm is still uncertain. A watch means to get prepared for a storm.
- Winter Storm Warning
  - A life-threatening storm is likely with 6 inches of snow or more in 12 hours or less; or 8 inches or more in 24 hours,
  - Heavy ice accumulations that cause extremely dangerous conditions and significant damage,
  - Strong winds, and/or
  - Wind chills indices -40˚F or colder
- Blizzard Warning
  - A storm with winds 35 mph or greater AND significant snow or blowing snow with visibilities less than 1/4 mile.

Questions?

Coming up flooding and severe weather in Hawaii