Dynamical Downscaling of Global Reanalysis

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Need for higher resolution reanalysis

- Climatology has small spatial scales (due to complex mountains, surface characteristics, coast lines and islands).
- Most of the applications (water management, agriculture, wind energy, etc.) require high spatial resolution.
- Based on climatological distribution of precipitation, desirable horizontal resolution is of the order of 10km or less.
月降水量 6月（1971〜2000年の平年値）
Monthly total precipitation for June
(Normals for the period 1971-2000)
## Relevant Notable Reanalyses

<table>
<thead>
<tr>
<th></th>
<th>Resolution</th>
<th>Period</th>
<th>Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>NNR</td>
<td>T62L28</td>
<td>1948-</td>
<td>Global</td>
</tr>
<tr>
<td>ER40</td>
<td>T159L60</td>
<td>1957-2001</td>
<td>Global</td>
</tr>
<tr>
<td>JRE20</td>
<td>T106L40</td>
<td>1979-</td>
<td>Global</td>
</tr>
<tr>
<td>NARR</td>
<td>35km</td>
<td>1979-</td>
<td>North America</td>
</tr>
</tbody>
</table>
Possible approaches

• Hi-resolution data assimilation
  – Expensive
  – Possible problems (to be discussed in this talk)

• Dynamical downscaling
  – Simple
  – Some track record
    • Giorgi (1989)
    • PIRCS
    • NARCCAP
California Reanalysis Downscaling at 10km (CaRD10)

- Scripps Experimental Climate Prediction Center Hydrostatic Global to Regional Spectral Model (G-RSM).
  - Max possible resolution of ~10km.
- NCEP/NCAR Global Reanalysis as a large-scale forcing.
  - Only analysis that goes back to 1948.
- Apply Scale Selective Bias Correction technique to preserve the large-scale forcing field within the domain.
  - Global downscaling application (next talk by Dr. Yoshimura)
- No other observations, except SST and land conditions, are used.
  - Does not incorporate change in land use.
  - Response due to change in large scale atmospheric circulation and SST.
- Hourly output.
Figure 4 Santa Ana event at 00 UTC 26 October 2003. Arrows are 10 m wind vectors (m s⁻¹). Shades are temperature anomaly (K) 00 UTC October 2003 mean.
Approximate location of lateral boundary
Validation of daily mean buoy wind speed

Buoy 2-b42
Monthly averaged precipitation verification against PRISM
Correlation

CaRD10

NCEP/DOE Reanalysis
Figure 11. Comparison of the 1950-97 trend in January mean precipitation rate. a) PRISM and b) CaRD10. Unit is in mm day$^{-1}$ decade$^{-1}$. 

Linear trend
US10

Run made on Earth Simulator
US10; Extreme Weather

- Hurricanes can be tracked well in downscaling. Figure shows low pressure center for 1992 Hurricane Andrew at the time of landfall in Louisiana.
- The US10 simulation of one of the largest snowstorms in the decade (1993 superstorm) agrees well with GOES-7 image.
JP10

1948-
Taken over by W. Ohfuchi at ESC
JP10 10meter winds

JP10 10m Wind(m/s) 1959 Jan

JP10 10m Wind(m/s) 1959 Jul
Implication of dynamical downscaling to regional high resolution reanalysis
Data Assimilation

\[ A = w_o O + w_g G \]

A: Analysis  
O: Observation  
G: Guess (Forecast)  
\( w_o \): Weight for Observation  
Observational error  
Representativeness error  
Retrieval error  
\( w_g \): Weight for Guess  
Forecast error (which can be a function of space as well as of state)

Under some constraints (such as balance equation, etc)
Difficulties of objective analysis over complex terrain

Collection of comments from various variational analysis experts

1. Extreme inhomogeneity and situation dependence of observation error and forecast error. (not well handled in the current analysis scheme).
2. Poor spatial representativeness of observation. Inadequate observations over region with rapid changes and short correlation lengths. (uncertainties in observational error. Situation dependent observational error has not been used extensively).
3. Strong nonlinearities (e.g., large sensitivity to surface temperatures to small changes in the cloud cover, etc.), which leads to poor analysis guess. (model physics deficiency)
4. Lack of the knowledge of dynamical and thermodynamical balance. (Lack of the knowledge of boundary layer dynamics).
5. Large diurnal variation. (difficult in time interpolation of observations)
6. Large errors in forward model (transforming analysis variables in to form of observations). (Satellite retrievals)
7. Significant non-random (biases) errors in background fields over these areas (model physics and dynamics problems)
Consequences for reanalysis

- The spatial scale of near surface observations information is treated as too large, both horizontally and vertically, influencing the analysis too much and making the (large scale) analysis worse.
- The uncertainties in the spatial characteristics of observation and forecast guess errors may wrongly place too much emphasis on observation or initial guess.
- The dynamical and thermodynamical imbalance (due to unknown physical balance in complex terrain area) makes the analysis “increments” to disappear as soon as the forecast starts, resulting in inferior guess.
Near-surface wind (10 m) and moisture (2 m) over land. Extensive tests were conducted on the impact of assimilating near-surface ("surface") atmospheric observations in addition to surface pressure. "Off time" observations were found to be detrimental and were turned off by applying a narrow time window of 30 min centered on the analysis time to all surface observations over land.

The assimilation of surface wind and moisture observations over land was found to be marginally helpful, and thus was used in our production runs. Assimilation of 2-m temperature over land was found to be significantly detrimental to our forecast fits to tropospheric rawinsondes, and therefore was not used. It is our belief that this latter problem stems from the inability of the Eta model 3DVAR to limit the vertical influence of surface mass observations.
Implications

- In order to reduce the effect of near surface observations on free atmospheric analysis, observational errors are increased, and as a result, initial guess is weighed more for final analysis.
- The use of inappropriate dynamical constraints in the boundary layer also tends to lessen the weight placed on near surface observation.
- Thus, the resulting near surface analysis is considered to be largely coming from the model forecast guess. If this is really the case, the high resolution reanalysis can be replaced by dynamical downscaling, provided that the downscale can keep the large scale features of the reanalysis within the regional domain.
<table>
<thead>
<tr>
<th></th>
<th>January</th>
<th>August</th>
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<tbody>
<tr>
<td></td>
<td>CaRD10</td>
<td>NNR</td>
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<tr>
<td>BFL</td>
<td>2.33</td>
<td>2.85</td>
</tr>
<tr>
<td>BIH</td>
<td>3.45</td>
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<tr>
<td>CQT</td>
<td>2.29</td>
<td>3.25</td>
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<tr>
<td>FAT</td>
<td>2.94</td>
<td>3.63</td>
</tr>
<tr>
<td>LAX</td>
<td>2.81</td>
<td>3.58</td>
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<tr>
<td>LGB</td>
<td>2.63</td>
<td>4.07</td>
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<tr>
<td>RDD</td>
<td>4.18</td>
<td>5.35</td>
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<tr>
<td>SAC</td>
<td>3.52</td>
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<tr>
<td>SAN</td>
<td>2.94</td>
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<tr>
<td>SCK</td>
<td>3.73</td>
<td>4.44</td>
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<tr>
<td>SFO</td>
<td>4.12</td>
<td>4.25</td>
</tr>
<tr>
<td>SMX</td>
<td>4.01</td>
<td>4.02</td>
</tr>
<tr>
<td>All station average</td>
<td>3.24</td>
<td>3.90</td>
</tr>
</tbody>
</table>

Vector RMSE of winds of two analyses and twelve land station observations during 2000. Smaller RMSE is indicated in **bold**.
NARR 1st Guess fit of 10-m Wind

Estimated fit of 10km resolution
Recommendations

- The downscaling results seems to indicate that the model guess is probably much more accurate than the observation.
- Higher the model resolution, better fit to station observation (at least up to 10km resolution).
- Thus, downscaling with high resolution model and improving the model is the fastest approach to improve regional analysis.
- The research to improve the analysis scheme itself should continue, but it is a very complex problem, and may not be easy to improve analysis from this direction. The lack of good observation also make this approach difficult.
July 10m Wind
Climatological Diurnal Variation
Supplemental slides
JP10 Precipitation
What is the required resolution?

• The downscaling (and analysis) is strongly dependent on the resolution over the areas of complex terrain.

• Higher the better or is there an optimum resolution?
  – 10km and 2.5km solutions seem to be very different.
  – If high resolution analysis is averaged over the domain, does it agree with the coarse resolution analysis?

• Does the spectrum power of earth topography decrease monotonically or are there any spectral peaks?
  – Can we define minimum model resolution for given topography?
French model, difference in 10km and 2.5 km resolution

Wind forecast at resolution 10km (left) and 2.5km (right) (shading=windspeed)
French model, difference in 10km and 2.5 km resolution

Precipitation forecast at 10km (left) and 2.5km (right) resolution

convective cells = local flooding
The spectrum was computed using 4minutes global topography from GTOPO30. Note that the spectrum is continuous, indicating that there is no characteristic minimum Scale on topography (at least up to about 30km resolution).
Fig. 4. Topographic profiles from five sample areas. About three-quarters of each original traverse is shown. All profiles are drawn to the same scale with 5:1 vertical exaggeration. For location and descriptive details, see Table 1. Source: U.S. Geological Survey 1:24,000 quadrangles.

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SPECTRAL ANALYSIS OF LANDFORMS*

RICHARD J. PIKE AND WESLEY J. ROZEMA

Fig. 6. Spectral density functions, or variance spectra, of the five filtered profiles (Fig. 5). Overall height of each spectrum reflects the absolute roughness of its topographic profile; prominent peaks in spectra indicate periodicities in the topography; and slope of the spectrum expresses relative prominence of large- and small-scale topographic features (see text). Source: calculated by authors.