4.6 ON USE OF HYDROSTATIC APPROXIMATION OVER GREENLAND

Abha Sood and Peter Lemke
Alfred Wegener Institute for Polar and Marine Research, Bussestrae 24, D-27570 Bremerhaven, Germany.

1 Introduction

The modern numerical weather prediction and regional climate simulation models frequently use the hydrostatic approximation in the basic primitive equations. However with increasing horizontal and vertical resolution of the simulations, the validity of this approximation is questionable. In the numerical investigations presented in this paper, the impact of resolution, vertical coordinate and the hydrostatic approximation on precipitation patterns in a domain over Greenland is addressed using the same physical parameterizations in all simulations.

Some of the previous studies on Greenland dealt with the interaction of orography with mean flow at sypnotic to planetary scales [1] and mesoscale regional features such as the Greenland tip flow [2] or gravity wave breaking [3]. The focus of this study is to ascertain in the context of climate modelling, the validity of the hydrostatic approximation used in describing the atmospheric flow at high resolutions, especially with regard to precipitation. The hydrostatic regional climate model (REMO) simulations will be performed at $1/8^\circ$ resolution in a following study, to compute the precipitation and evaporation/sublimation distributions over Greenland. Thus an estimate of the change in elevation of the ice sheets and of the fresh water discharge into the adjoining ocean can be computed.

The numerical weather prediction nonhydrostatic ETA model of NCEP is formulated as an extention of the hydrostatic version, enabling direct comparison by simply switching off an extra term in the governing essentially hydrostatic equations [4]. The vertical coordinates σ and η of the ETA model are introduced in Section 2 including a short description of this approach. The domain of the model, the synoptic conditions of the study and some results are described in Section 3 followed by a brief discussion in Section 4.

2 The ETA Model

The three dimensional primitive equation mesoscale grid-point ETA model on a semi-staggered Arakawa E-grid in the horizontal and a Lorenz grid in the vertical is the operational limited area numerical weather prediction model at NCEP/EMC. The nonhydrostatic and hydrostatic versions of this model are used for this study. The terrain following σ and step mountain η vertical coordinates are defined as

$$\sigma = \frac{\pi - \pi_t}{\pi_s - \pi_t} \qquad \text{and} \qquad \eta = \sigma \frac{\pi_{ref}(z_s) - \pi_t}{\pi_{ref}(0) - \pi_t} ,$$

where π is the hydrostatic pressure, the subscripts s and t refer to surface and top of the model layers, whereas the subscript ref refers to the standard atmosphere. The vertical coordinate η is especially designed for domains with steep orography [5] with nearly horizontal model layers, thereby reducing errors in computing the pressure gradient term.

The governing equations are decomposed into two energy conserving subsystems. The solutions of a part of the first subsystem are determined from the solutions of the previous time step with additionally computing the term $\epsilon = \frac{1}{g}\frac{dw}{dt}$, which describes the nonhydrostatic correction. These results are then substituted back into the coupled equations obtaining a final set of solutions [4] for the new time step. This method only allows for a correction to be determined for the hydrostatic solution. Explicit nonhydrostatic solutions cannot be computed since in that case, an additional equation for the vertical velocity will be required.

3 Case Study

An episode from 12 to 15 July 2002, featuring a configuration with a low south west of Greenland, a high over northern Scandinavia with a ridge extending from south of Svalbard to the Greenland Sea and a low to the north east of Iceland causes persistent warm and moist easterly winds almost perpendicular to the east coast of Greenland bringing in precipitation to the coast and to the inland ice sheet. Another low lying over N-NW of Greenland migrates along the west coast and merges with the low lying further south. The low from Iceland moves west towards the steep south east coast of Greenland also merging later in the upper (500 hPa) levels with the low coming from the west and advecting warm air over Greenland.

The same physical parameterizations are used in all simulations and thus they do not contribute to the observed differences in the two runs. The equator and the prime meridian intersection lies in the center of the domain of interest by suitably rotating the geographical grid. The initial and lateral boundary conditions are taken from the NCEP's short range AVN runs of the global weather forecast spectral

(T170L42) model GSM [6] in terrain following σ vertical coordinates.

A number of test simulations are performed to identify sources and estimate errors involved in the hydrostatic simulations. The center of the domain lies in the middle of Greenland at 72N/38W with 13° zonal and 30.5° meridional extent. The hydrostatic and nonhydrostatic simulations are run at $1/4^\circ$, $1/8^\circ$ and $1/16^\circ$ horizontal and 38 and 45 layers vertical resolutions using σ and η coordinates.

A comparison of simulation runs with increasing resolution shows many more resolved features, especially along the steep orography for both vertical coordinates and a weakening of some of the features over the ocean [7]. On increasing the horizontal resolution, better resolved feature are seen only if the vertical resolution is also improved accordingly. The differences are most pronounced along the steep coast where the simulations with the same resolution for different vertical coordinates are compared. This results from a different treatement of orography in the two approaches indicating a large impact.

The accumulated precipitation at the end of the 72 hr simulation period is presented in Fig 1(a) for the nonhydrostatic run at $1/8^\circ$ and 45 layer resolution using σ coordinates and the difference to the hydrostatic run is shown in Fig 1(b). This resolution will later be used for longer climate studies. A shift in precipitation distribution along the east coast and in the convective zones above the ocean is observed. This shift may induce a difference of about 25 % locally. This is larger than expected since it is caused by only a small correction term in the governing equations, which may primarily have an impact on the small scale dynamics and should remain negligible for hydrostatically balanced flow.

The difference in relative vorticity at 850 hPa between the nonhydrostatic and the hydrostatic case with the η vertical coordinate again depicts band-like structures which indicates a shift of flow in addition to an interaction with the orography (Fig 2(a)). The vertical zonal crosssection of the potential temperature at about mid domain also shows small deviation of about ± 0.5 K between the nonhydrostatic and hydrostatic runs (Fig 2(b)) which seem to be associated with the gravity waves over Greenland. The σ coordinates show much more fluctuation in both cases especially near steep orography.

4 Discussion

The effect of the hydrostatic approximation on precipitation amount and its distribution with respect

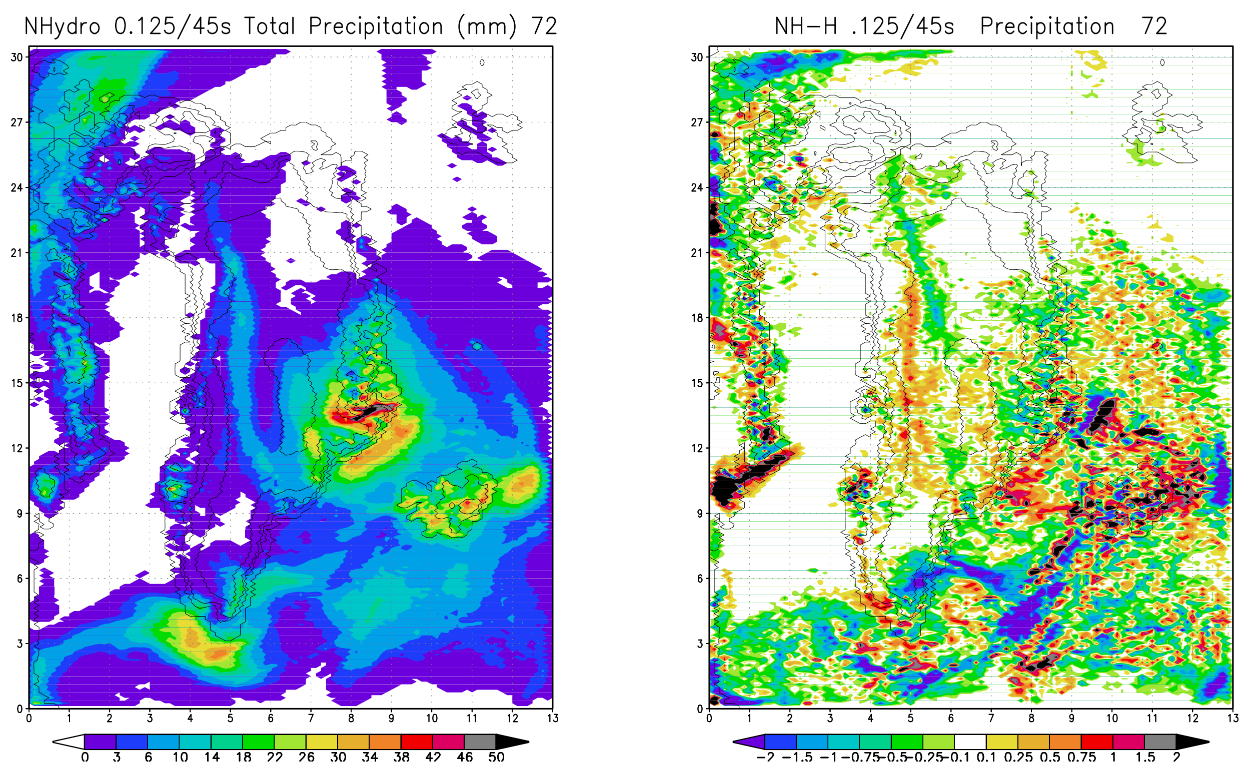

Figure 1: (a) Accumulated precipitation over Greenland using the nonhydrostatic (NH) model, and (b) difference in accumulated precipitation between nonhydrostatic(NH) and hydrostatic (H) simulations after 72 hr.

to the model resolution is examined. A rigorous explanation for the differences in precipitation distribution and magnitude remains lacking since complex parameterization of cloud physics and precipitation processes are involved. The band-like structure (Fig 1(b) & Fig 2(a)) indicates a shift in circulation. If systematic, it can produce consistently erroneous results, e.g. by causing accumulation over adjacent catchment areas. However a marginal shift in patterns will not significantly influence predictions and may simply average out. A detailed analysis will follow [7]. Ensemble and longer runs are necesary to obtain a reasonble estimate of these impacts in climate studies.

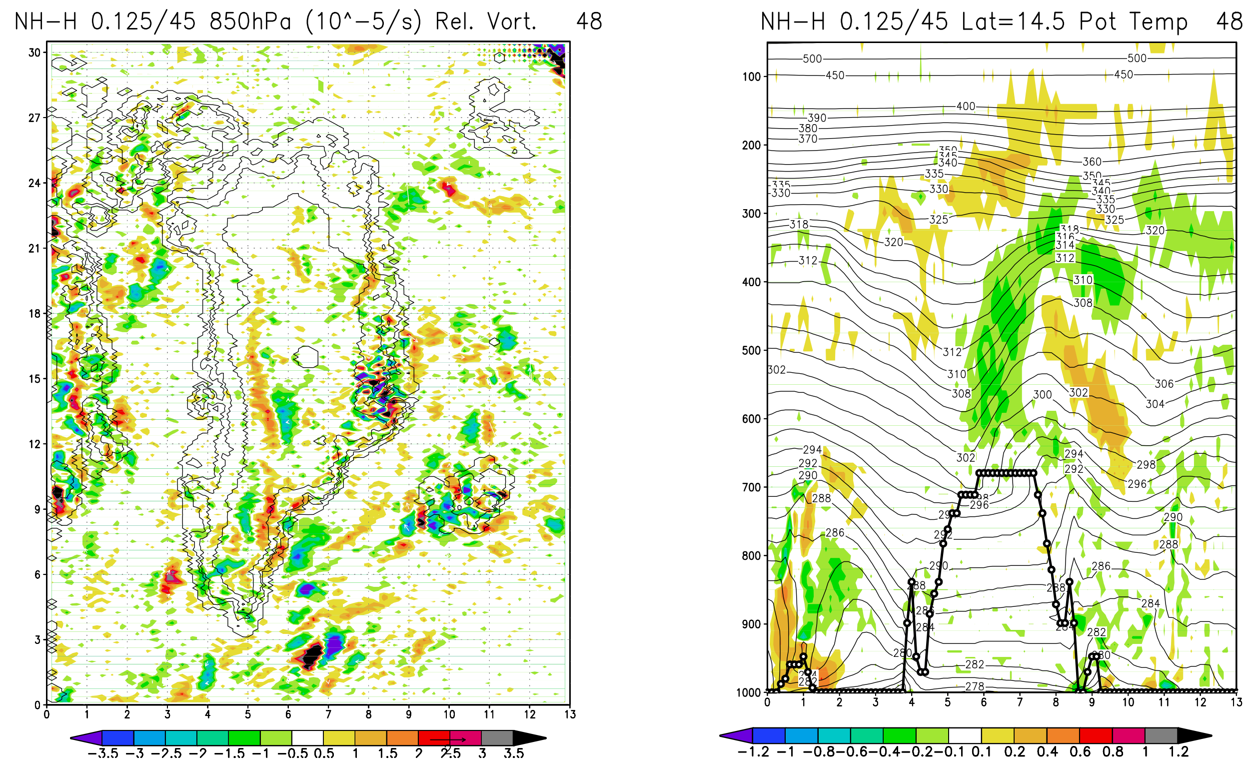

Figure 2: (a) Difference in relative vorticity between nonhydrostatic(NH) and hydrostatic (H) simulations after 48 hr, (b) Potential temperature crossection along the 14.5 latitude for the nonhydrostatic run is shown by contour lines, and the difference (NH-H) between the runs is shaded.

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