4.4 REAL-TIME MESO-β AND -γ SCALE ANALYSES AND FORECASTS OVER COASTAL REGIONS USING THE NCAR/ATEC FOUR-DIMENSIONAL DATA ASSIMILATION AND FORECAST SYSTEM

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1. INTRODUCTION

High-resolution weather analyses, forecasts and climatologies over coastal regions are very valuable for many applications, including economic development, environmental control and homeland-security campaigns. However, analyzing and forecasting weather in these regions can be challenging because 1) flows can be very complicated, especially in regions of complex terrain; 2) local circulations are multi-scale processes forced in part by sea-land contrasts and land-use property variations, and 3) observations are normally too sparse, especially over water, to properly resolve either the macro- or micro-scale aspects of local circulations.

In the last three years, NCAR, in collaboration with the Army Test and Evaluation Command (ATEC), has developed a multi-scale weather analysis and forecast (RTFDDA) system. The system employs a Four-Dimensional Data Assimilation (FDDA) method with which observations are dynamically combined into a full-physics mesoscale model (MM5) to generate real-time analyses and short-term forecasts on multi-scale domains. The grid increments of the model domains vary from a few hundred meters to tens of kilometers. By incorporating detailed terrain, coastline masks, and land-use information, and using synoptic-scale model analyses from the NWS and real-time mesoscale observations, the RTFDDA system has proven capable of forecasting realistic local circulations. As of August, 2004, the NCAR/ATEC RTFDDA system has been implemented at about 20 sites/regions globally, supporting various DoD projects and missions. In this paper, cases will be presented from the recent RTFDDA operations over coastal regions, including the US Army Aberdeen Proving Ground (APG) in the Chesapeake Bay areas, the 2004-Athens Olympics area, the Hawaii islands, and California coastal regions. Statistical averages of the analyses on the finest meshes of these RTFDDA systems are used to depict overall capacities of the modeling technique. On the other hand, micro-climatologies of local, coastal circulations are derived with the high-resolution dynamic analyses at each region mentioned above. The diurnal variations of these microclimatological features in response to the corresponding dominant weather regimes and specific local-scale underlying forcing are discussed.

2. MODEL AND DATA ASSIMILATION

The RTFDDA system is built around the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) mesoscale model (MM5V3). The first system started operation in October, 2000, at Dugway Proving Ground (DPG, Utah. Cram et al., 2001). Since then, many refinements and improvements have been carried out onto the data assimilation scheme and model physics (Liu et al. 2002, 2004). The model configuration used in the current RTFDDA systems can be summarized as following:

* Non-hydrostatic dynamics
* Two-way interactive nesting procedure
* Radiative upper boundary condition
* Time-dependent lateral boundary conditions relaxing toward large-scale models
* Grell cumulus parameterization on 10+ km grids.
* Reisner mixing-phase ice moisture scheme
* Modified MRF (or Hong-Pan) PBL scheme
* Cloud radiation schemes (Dudhia for shortwave and RRTM for long wave)
* Noah land-surface soil model

To simulate multi-scale weather interaction, a two-way nested-grid approach was employed. The grid increments of the model domains vary from a few hundred meters to tens of kilometers. As an example, Fig.1 shows the domain configuration and the terrain and land-use on the finest mesh of the RTFDDA system that was operated in the support of the 2004 Athens Olympics. It can be seen that the high-resolution fine meshes are able to incorporate detailed terrain and land use information. With a full-physics mesoscale model, physical forcing processes forced by these underlying heterogeneities, that control the local circulations, can be realistically simulated. To effectively combine these model advantages with all available observation, a Newtonian-relaxation-based continuous data assimilation technique, termed “observation-nudging”, (Stauffer et al. 1994), is employed. With the “observation-nudging

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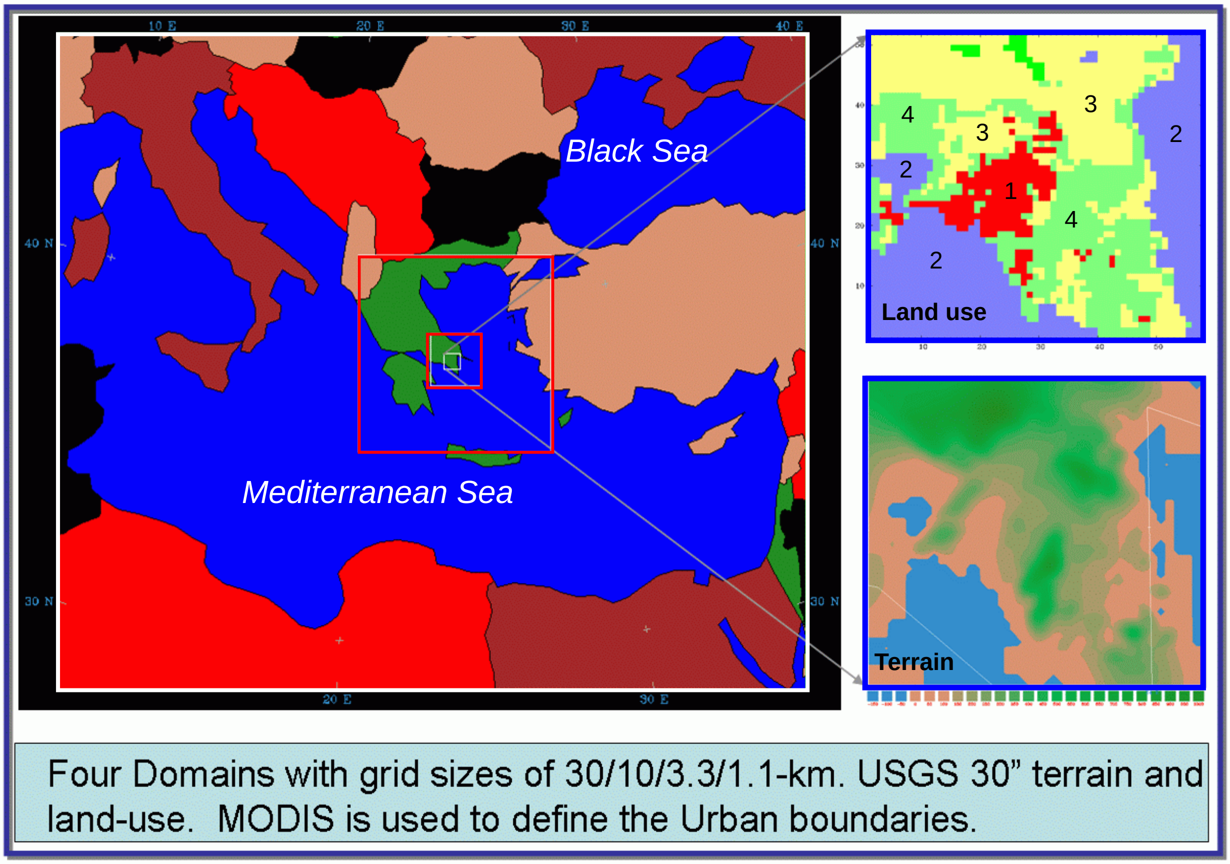

Fig.1 Domain configuration, and the terrain and landuse distribution on the finest mesh (1.1-km grids) of the 2004-Athens RTFDDA system. (Land use types: 1. Urban; 2. Water; 3. Crops; 4. Crop-wood lands).

approach, an extra term is added to the model prediction equation(s) in order to keep the model solution close to the observations. Because of the complex forcing and evolution of local circulations over complex terrain, the spatial correlation can decrease very quickly with distance. Thus, the FDDA scheme is designed to allow the model to adjust toward observations at and near the observation time and location, and let the model to spread the observation information to other regions according to the model dynamics. When the system is set up for a specific region, it will start to run continuously, producing four-dimensional dynamically and physically consistent analyses, and in many cases, high-quality short-term forecasts are also produced at a selected cycling interval of 1 - 12 hours based on application needs and availability of computer capacity.

The lack of sufficient observations on meso-β and γ scales make it particularly important to incorporate both conventional and non-conventional observations that are measured at both synoptic and asynoptic times. The data assimilation approach used in the RTFDDA system has the ability to fully use these data. The data incorporated in the current system includes: the conventional twice-daily radiosondes; hourly surface, ship and buoy observations, and special observations from GTS/WMO; NOAA/NESDIS satellite winds derived from cloud, water vapor and IR imageries; NOAA/FSL aircraft reports of ACARS, AMDAR and others; NOAA/FSL NPN (NOAA Profiler Network) and CAP (Corporative Agencies Profilers) profilers; the 3-hourly cloud-drifting winds and water-vapor-derived winds from NOAA/NESDIS; and high-density, high-frequency observations from various mesonets, in particular, those from the local coastal areas within the fine mesh domains of the model.

3. STATISTICS AND MICROCLIMATOLOGIES

Local-scale (meso-β and γ scale) circulations are controlled by two major forcing factors: 1). synoptic control flows and their interactions with local mesoscale terrain, and 2). development of local circulations driven by uneven surface heating/cooling processes due to the heterogeneous land surface properties and land-water

Table 1: RTFDDA operational systems for the six coastal regions discussed in this paper

Regions	Domains	Grid increments	The finest-mesh sizes	Operation periods
ATC	3	30/10/3.33km	180x180 km^2	2004.04
Athens (Greece)	4	30/10/3.33/1.11km	57x64 km^2	2004.08
Point Mugu	3	30/10/3.33km	77x77 km^2	2004.08
San Francisco	3	30/10/3.33km	77x77 km^2	2004.07
Monterey Bay	3	30/10/3.33km	77x77 km^2	2004.07
Quai (Hawaii)	4	36/12/4/1.33km	85x85 km^2	2004.07

contrasts. Mesoscale weather on a particular day and the time of the days is determined by the relative forcing strength and dominance of these two factors, which can lead to dramatically different weather and changes. Historically, to study the effect of local forcings, either idealized modeling or weather cases dominated by one forcing components, such as flows over and/or surrounding mountains, mountain-valley breezes, sea breezes and others, were selected for detailed analyses. On the other hand, regional climate models and simulations were also carried out by modelers to study the local climate by nesting a mesoscale model in a GCM. The daily weather and circulation details from these models may not be accurate, but some climate features can be inferred.

The real-time (and/or retrospective) accurate high-resolution continuous 4-D analyses from the RTFDDA systems provided a unique dataset for studying the roles of the local forcings and the overall ability of the model system of simulating these forcings to accurately generate daily local weather and the local climate. Since the RTFDDA systems are operated in an “on-demand” mode, it was operated in the aforementioned coastal regions for about two weeks to 2 years, which are not sufficient for computing multi-year-based climates. Instead, we study the regional “climate” by computing averages of the RTFDDA analyses for “similar weather” as classified for each region we studied. Regional climates may vary with seasons. However, it is not the intention of this paper to describe a complete local climate of selected regions. Instead, we are focusing on a few controlling factors that are responsible for the local climate formation and the capability of the high-resolution model to reproduce those features. Examples from a total of six different coastal regions will be discussed and as can be seen below, the forcing regimes and the micro-climatologies for the selected periods are distinctly different. The model configuration and operation durations of the RTFDDA systems at these six regions are summarized in Table 1. Only the results on finest mesh is discussed in this paper.

3.1 Chesapeake Bay ATC (MD) regions

The Army Aberdeen Test Center (ATC) is located over the northern coastal region of the Chesapeake Bay within Maryland. The fine mesh of the ATC RTFDDA system is characterized by relatively flat terrain with large land-water contrasts (Fig. 3a). The northwest half of the domain features with small hills of a few hundred meters height, while in the southeast half, two bays, the Chesapeake Bay and the Delaware Bay, protrude toward the northwest into the flat lower land.

Two local forcing regimes affect the formation of the mesoscale circulations in the region. One is the thermal forcing of the hilly terrain and the other is the land water contrasts. Statistical averages of RTFDDA analyses in this region for April 2004 exhibits a dominant role of the prevailing large-scale flows for the development of the local circulations. The local forcing is secondary and mostly acts to modulate the impinging large scale flows.

The monthly average surface winds at 12Z (early morning of local time) in the region (Fig.2) display a rather uniform large-scale flow pattern, with wind speeds of 3 - 5 m/s over land and up to 7 - 9 m/s over the bays. The prevailing wind blows mostly from the west, with slightly northern components in the north hilly regions and south components in the south flat region between the two bays. The northern components in the hilly regions are mostly associated with drainage downslope flows (Fig.3a). The variation of winds in the bay areas warrant more discussion. Essentially, the interaction between the prevailing flows and the warm bay water bodies is mostly responsible for the local wind variations. First, the prevailing winds tend to shift the warm and moist air above the bays downwind. Fig, 2a and b show evident warm and moist bay air cores located close to the east shore of the Chesapeake Bay. Second, due to much smaller friction over water surface, the incoming large-scale winds accelerate as they cross the water regions and decelerate sharply while exiting the bays. These processes lead to a formation of stronger winds over the bays and the downwind-side shore regions (Fig. 3b). The sharp change of winds across the bay leads to the development of significant divergence and convergence zones along the upwind shores and downwind shores respectively (Fig.3c). To

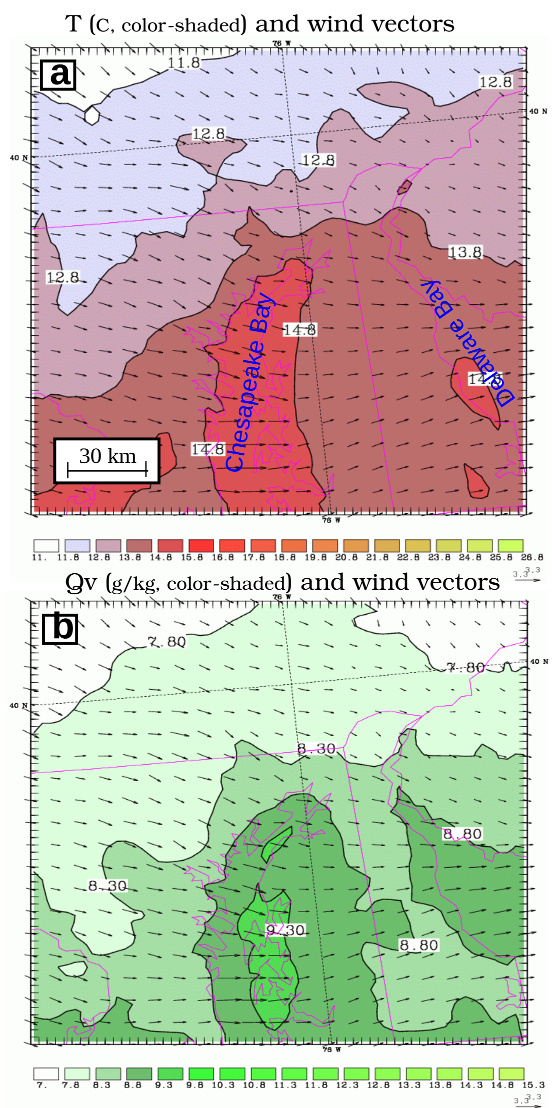

Fig.2 Monthly averaged surface temperature and moisture mixing ratio on the domain 3 of the ATC RTFDDA system for the April of 2004, valid at 1200 UTC. The averaged wind vectors are superposed.

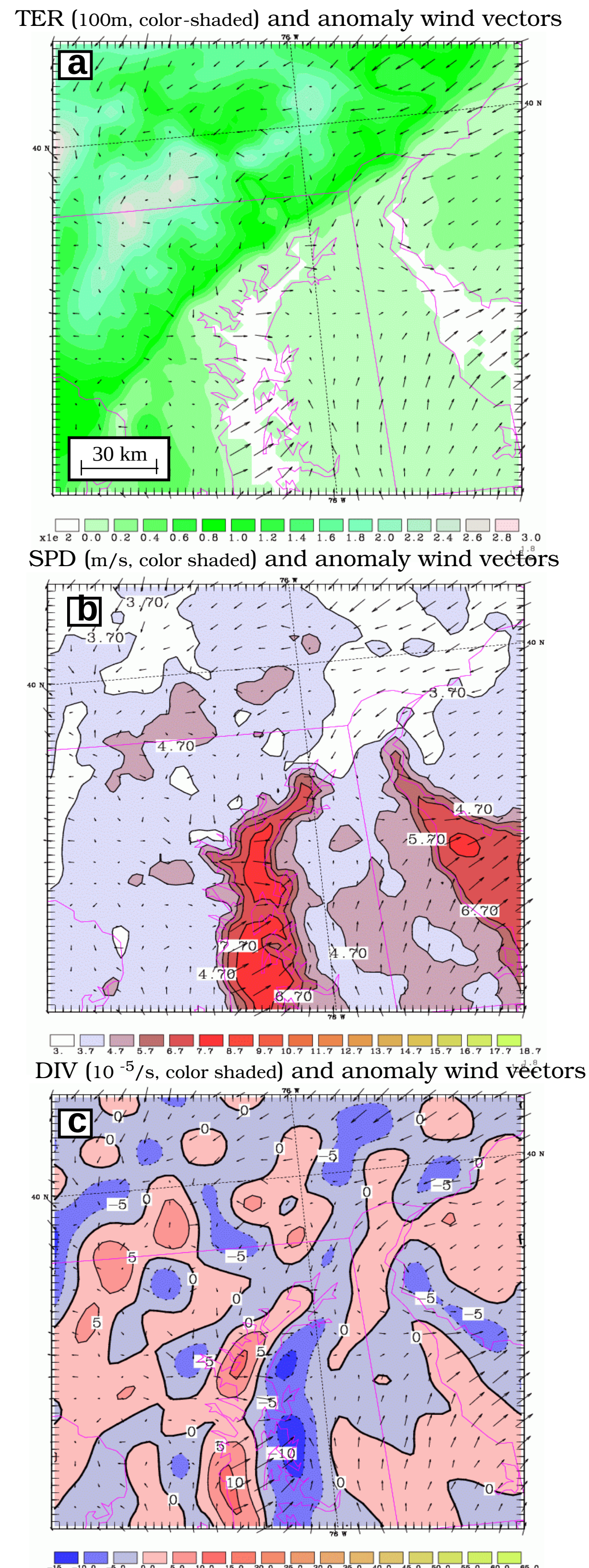

Fig.3 Same as Fig.2, but for terrain height, monthly averaged surface wind speed and divergence fields. Note that superposed are anomaly wind vectors.

further study the forcing mechanisms of the local forcing, the anomaly wind vectors -- the total wind vectors (at each grid point) minus the domain-average of surface wind vector -- are calculated and plotted in Fig.3. Obviously, the acceleration of the prevailing winds over the bays produce significant extra momentum residues. The anomaly wind vectors surrounding the Chesapeake Bay shows a trend of the flow convergence toward the warm moist bay air bubbles. More interestingly and importantly, an evident broad south stream appears to flow into the domain from the south boundary of the domain, extending to the whole bay and surrounding regions. This wind component is forced by a large-scale circulation in association with the large-scale stationary high pressure system centered over the Atlantic Ocean near 30 degrees north latitude in the vicinity of Bermuda. The smooth and broad bay surface opens a channel for this wind to travel deeply in-land along the bays. It is this wind component that, in combination with the “sped-up” residue of the prevailing west wind, produces the southwest winds over the bay.

3.2 Greece (Athens) regions

In support of the security during the Athens Olympics, 2004, the RTFDDA system were configured to run for the Athens region. It was operated for a two-month period from mid July to mid September. Only the analyses of August for which one full month was available are discussed here. As shown in FIg.1, the finest domain of the system, with a resolution of 1.11-km, covers most of Greece. The USGS 30” terrain and land use archive are used to define the land surface properties of the model and the Athens’ urban area are further refined with the recent MODIS survey. In August, Greece is characterized by dry, windy weather. A synoptic low pressure system was preferably developed and maintained in the eastern part of the Mediterranean Sea, which imposes northeastern flows (e.g. Etesian Flows) over the Greece area throughout the month. Local circulations over Athens are controlled by the oscillations of the low and the Etesian flows, the thermal contrast of the sea, land and urban, and the orographic effect of steep mountain peaks to its north, east and south.

Three weather regimes can be classified for Athens’ meteorological conditions in August: dominant Etesian flows (EF, 13 days), well-developed land-sea breezes (SB, 11 days) and weakly-developed land-sea breezes (WKSB, 5 days). Fig. 4 shows the surface winds for the three weather regimes, each averaged over all occurring days with the regime. Two times, 12Z and 00Z, roughly corresponding to the maximum daytime sea-breezes and night-time land-breezes are plotted. It is evident that the Etesian flows exist in all three weather situations. The occurrences and the properties of sea breezes will depend on the relative intensity of the Etesian flows. In the case of strong Etesian flows (Fig.4a), the northeast flows are obvious over all of Greece. The role of local forcings are secondary. As can be observed from Fig.4a, the main local forcing influence is the orographic distortion of the large-scale dominant flows by the three major mountain ranges, which causes the northeast flows over Athens. Another subtle feature is the slowing-down of the Etesian flow over Athens city, due partially to the increased friction of the urban canopies and partially to the pressure gradient formed by land-sea thermal contrast.

In the weak Etesian flow days (Fig.4b), the thermal forcing generated by the land-sea contrasts are capable of developing sea-breezes in Athens and the nearby coastal regions. The sea-breezes are able to overcome the weak Etesian flows, penetrate deep inland and finally stop at the foothills of the three mountains to the north and east of Athens. Interestingly, the three mountain ranges appear to act as natural divides that block/separate the sea breezes coming from the southwest and Etesian flows from northeast. Due to this blocking effect, Athens city areas, under this weather regime, are dominated by weak winds, and relative warm oceanic air mass. A warm bubble tends to be generated by the “urban-heat-island” of the Athens, and it is gradually shifted toward the northeast as the sea breezes intensify.

Apart from the cases of dominant Etesian flow and well-developed sea-breezes, five other days are identified as WKSB days in the month. As expected, the WKSB situation wedges between the above two -- the Etesian flows are moderate and sea breezes are able to develop but not capable of penetrating deep inland. Fig.4b depicts the scenario of weak sea-breezes. At its maximum, the sea breeze front reaches close to the middle of the Athens city, and together with the Etesian flows from northeast, produces a broad convergence zone over most of Athens.

Unlike the daytime scenarios, the local surface flows at the nighttime (00Z), plotted in Fig.4e-f for the three classified weather regimes respectively, display strikingly similar structures for all three weather regimes. The flows are mainly dominated by three forcing components: Etesian flows, land-sea contrast (land

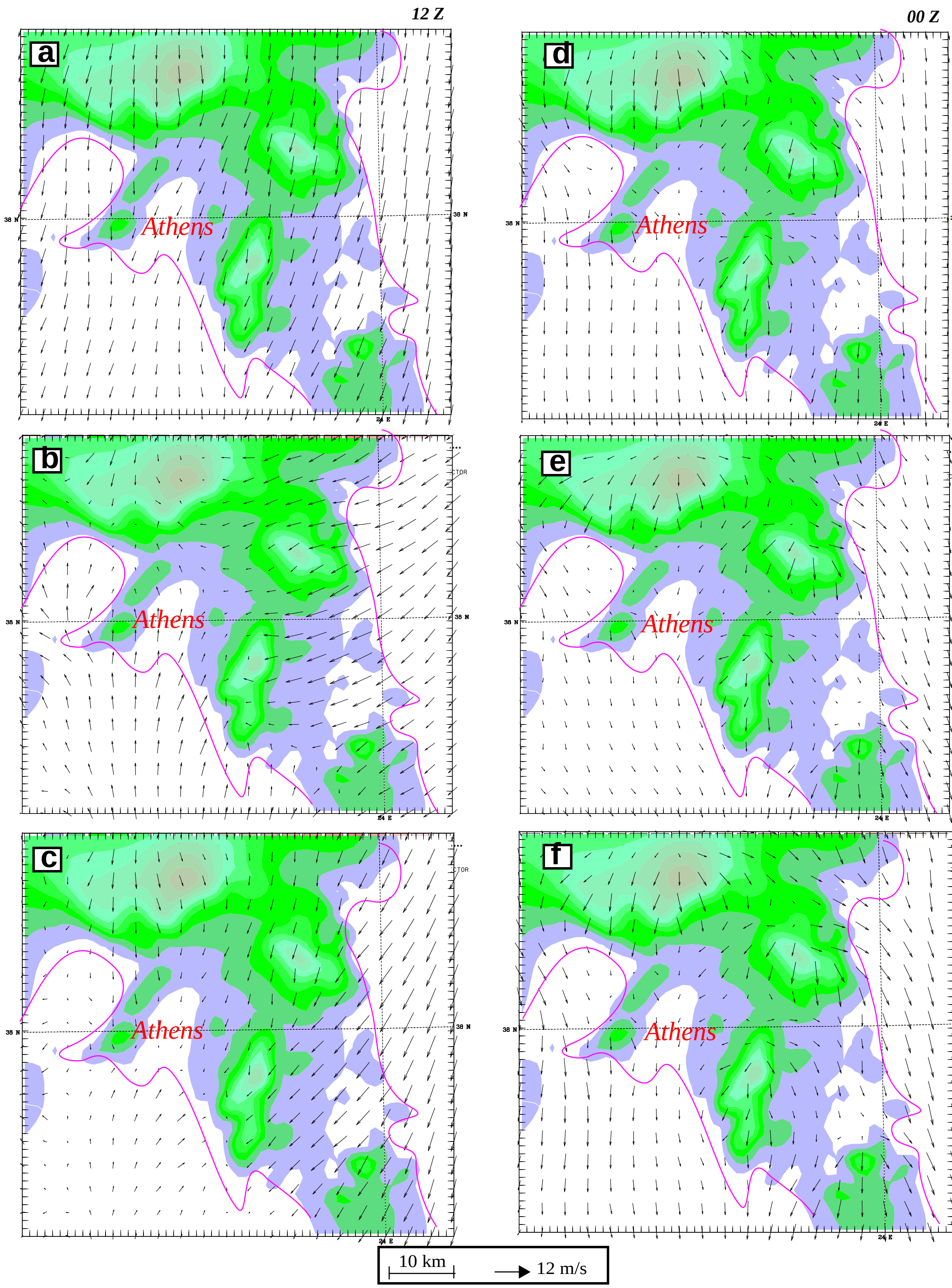

Fig.4 Mean surface winds, averaged for the Etesian winds (a and d), sea-breezes (b and e) and weak sea-breezes (c and f) cases of the Athens RTFDDA analyses on Domain 4 in August, 2004. The left panels are for 12Z (afternoon) and the right are for 00Z (nighttime). Terrain is shaded at increments of 100 m. Coastline are represented with magenta color.

breezes) and the mountain blocking and mountain breezes. The less distinctive night flow patterns between the remarkably different daytime regimes indicated that the stable PBL plays a major role in controlling the flow in the region during the nighttime. The stable PBL forces more flows going around the mountain obstacles than crossing over. This can be seen clearly from the flow vectors around each mountain peak. Meanwhile, the drainage mountain breezes appear to block (speed up) the incoming (leaving) flows in the upwind (downwind) side and causes divergences on both flank sides. Land breezes and the Etesian flows appears to join together to affect the weather in the Athens coastal areas.

Finally, it is remarkable that the Etesian flows over the water to the east of the Greece peninsula are evidently bent toward the land in the daytime and toward water at nights. The weaker the Etesian flows, the more the flows bend. This is obviously caused by the pressure gradient built by the land-sea thermal contrasts. The warmer lands in daytime induce overall convergence flows toward the land, and conversely, diverging flows from the land develop in response to the cooling of the land at night. This demonstrates another scenario of the interaction between local underlying forcings and the synoptic-driven flows.

3.3 Hawaii region -- Kauai Island

The RTFDDA system were operated in the Hawaii regions to support missile-launching tests by the Pacific Missile Range Facility (PMRF) in the summer of 2004. A fine mesh with a grid size of 1.3 km is employed, which covers the Kauai island and the surrounding regions. The model ran from June 10 to August 9. Only the model outputs from July are analyzed here. The interaction between the isolated island and the central mountains with relatively stationary large-scale flows and less-diurnally varying marine PBL makes an interesting local circulation case and associated forcing mechanisms.

Fig. 5 shows surface wind and temperature on the finest mesh of the PMRF RTFDDA system, averaged between July 1 and July 31, 2004. During this period, the large-scale prevailing flows are mostly easterlies with some northernly component. Since the diurnal variations in the marine PBL and in the large-scale prevailing flows are fairly small, the diurnal evolution of the local-scale circulations over the island and the neighboring regions are mostly controlled by the thermal variation of the island land surfaces. Averages at 00Z and 12Z, representing typical daytime and nighttime situations (02 pm and 02 am HST, respectively) are presented.

In a general view, Fig. 5 a and c indicate that the island and the steep mountains tend to block the large-scale flows in both day and night times. Flows start to diverge as they approach the island from the east, then split and move around the island, and finally converge at the lee (west) side of the Kauai island. However, closer examination shows that many details of the flows over the land are dramatically different between the daytime and the nighttime, and interactions between the local forcings and large-scale flow can be readily identified. It is known that sea-breezes (in this case, converging flows to the island) will develop in daytime in response to the excessive land surface heating, and land-breezes (in this case, diverging flows from the island) develop in the nighttime in response to the excessive cooling of the island. Similarly, the differential heating over high-terrains can drive upslope (valley) breezes in daytime and downslope (mountain) breezes in nighttime. The unique island and mountain distributions of the Kauai island appears to align the land-sea breezes and mountain-valley breezes into the same phases and jointly contribute to the development of convergence and divergence pattern over the island.

These land-forced convergence and divergence patterns take a significant role in deflecting the large scale flows around the island. It can be seen clearly that the flows surrounding the island are attracted to island in the daytime (Fig.5a) and repelled by the island in the nighttime (Fig.5b). Generally, in the daytime, the flank flows are able to converge at the near lee side of the island, whereas in the night, these flows barely converge. Furthermore, in the daytime, in spite of increased friction over the land the incoming large-scale flows combine with the local sea-breezes to extend westward as they reach the island from east, and then they further combine with the valley breezes as they move upslope. As they move further west, they are heading against the valley breezes and sea-breezes in the downwind slope, leading to the formation of the lee-side convergence centers. In contrast, in the nighttime, as the incoming flows reach the island from east, they first encounter the land breezes and then the mountain breezes that flow against them. These flows finally collapse along the foothills of the mountains and diverged to the north and south flanks of the mountains. On the lee (west) side, flows are generally divergent in the nighttime.

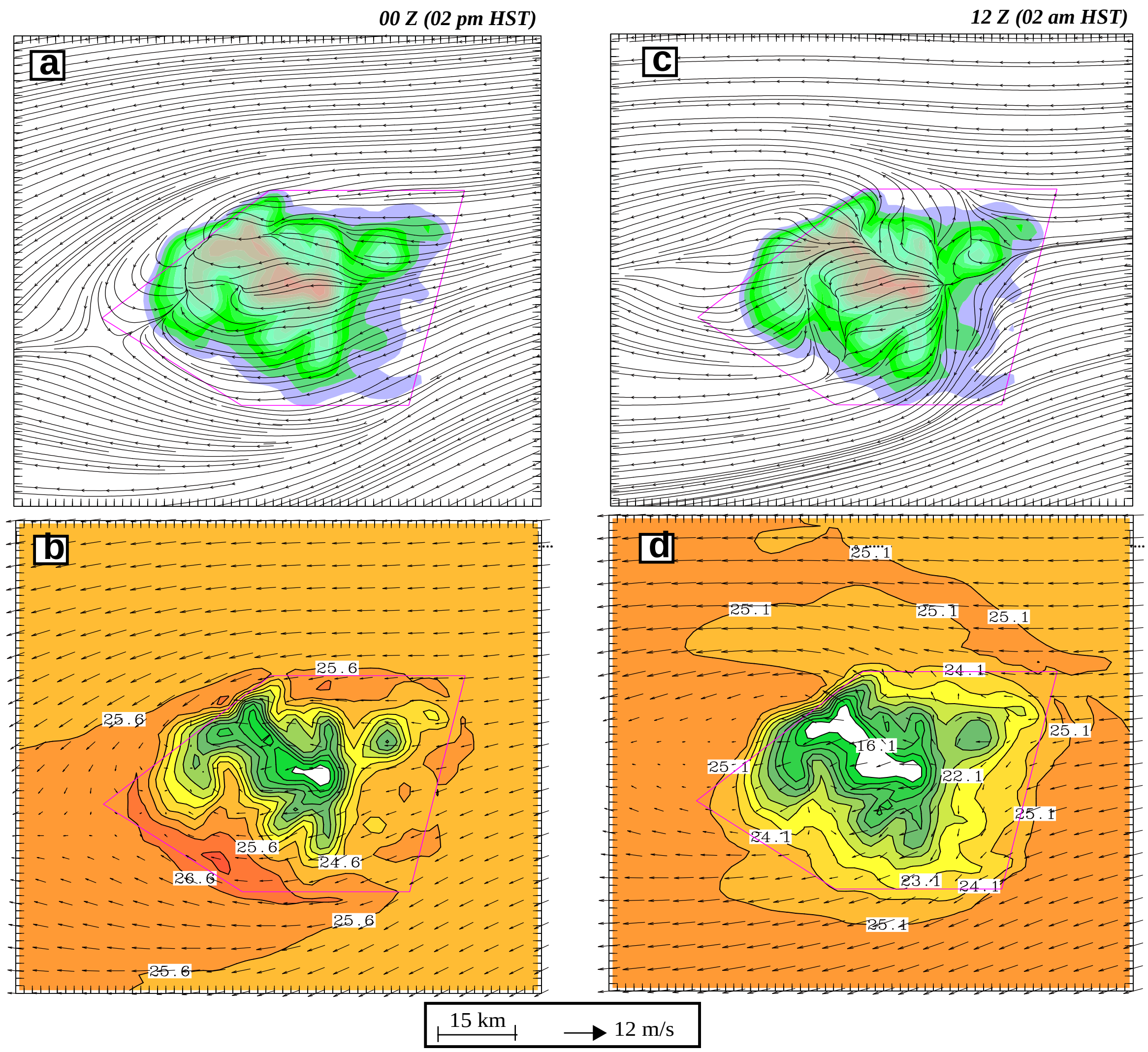

Fig.5 Mean surface wind streamlines and vectors of the PMRF RTFDDA fine mesh analyses, averaged for July, 2004. The Quai Island and terrain is shaded in (a) and (c) at increments of 100 m. The contours and shading in (b) and (d) are for mean temperature. The left panels are for 00 Z (02 pm HST) and the right are for 12Z (02 am HST).

The diurnal variations of the convergence and divergence patterns over the island not only affect the local flow structures, but also the thermal and moisture properties. Fig. 5 c and d presents the surface mean temperature for the same period and times (00Z and 12Z, respectively). Mean wind vectors are superposed. Evidently, the divergence flows develop at night and tend to spread the cool air (due to the radiative cooling of land/mountain surfaces) to relatively larger regions (Fig.5d). Conversely, the daytime convergence appears to sharpen the temperature gradient along the mountain slopes, leaving negligible air temperature gradient between lower terrain and the sea surface. An interesting feature is the formation of a belt-shaped warm anomaly located to the southwest coast of the island. They are formed by the descending branch of the mountain wave that mixes and brings down air heated by the slope of the mountains in the daytime.

3.3 California coastal regions

Between June 16 and August 22, 2004, an RTFDDA system was run over the California coastal regions to provide real-time weather analyses and forecasts for a military test operation. The operation regions shifted with the time. Accordingly, the fine mesh grids (Domain 3 with a grid size of 3.3-km) of the RTFDDA model were moved during the operation, to keep the focus on the center of operations. Collectively, we are able to produce a suite of RTFDDA analyses on the finest meshes over each of San Francisco Bay, Monterey Bay and Point Mugu regions, for durations

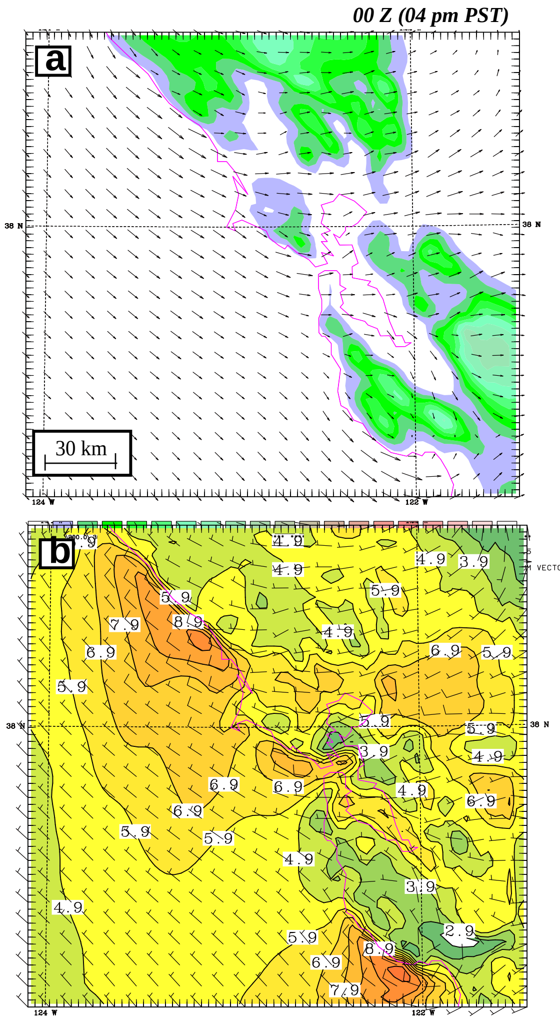

Fig.6 Mean surface winds of the RTFDDA fine mesh analyses over San Francisco Bay area, averaged between July 14 and 22, 2004. The terrain is shaded in (a) and (c) at increments of 100 m. The contours and shading in (b) and (d) are for mean wind speed. The left panels are for 00 Z (04 pm PST) and the right are for 12Z (04 am PST).

from a week to a month. It should be noted that during the RTFDDA operation period, the synoptic pattern are fairly stationary due to the dominance of the Pacific High and the overall weather processes appear generally repetitive day by day. We also note that during these periods, the prevailing large-scale winds are mostly northwesterly over all the three coastal regions. Therefore, the differences in coastal circulations between these regions largely reflect varying local forcing effects, especially the curvature of the coastlines, the terrain distribution and differential surface heating and friction between the land and sea.

3.3a San Francisco Bay regions

A nine-day average of surface winds of the RTFDDA analyses over the San Francisco Bay area between July 14 and July 22 are plotted in Fig. 6. Both daytime (00Z, 04pm PST) and nighttime (12Z; 04am PST) are included. Interestingly, the large-scale prevailing winds are roughly parallel to the coastline. Cyclonic vorticities are generated by the contrast in surface friction between the land and water in the coastal flows, which steer the flow toward the left, i.e. inland. The overall left-bending flows over the land in both daytime and nighttime suggests a primary role of this mechanism on the local circulation at all times.

Although thermal processes and orographic effects are secondary, they do play a significant role in defining many details and intensities of the local winds. First, the friction-induced left-turning flows are obviously channelled along the valleys and blocked by the mountain ranges. One broad branch of the channelled flow is able to penetrate through the San Francisco Bay, bypass the Vallejo valley and terminate in the San Joaquin Valley. Second, the daytime land-surface

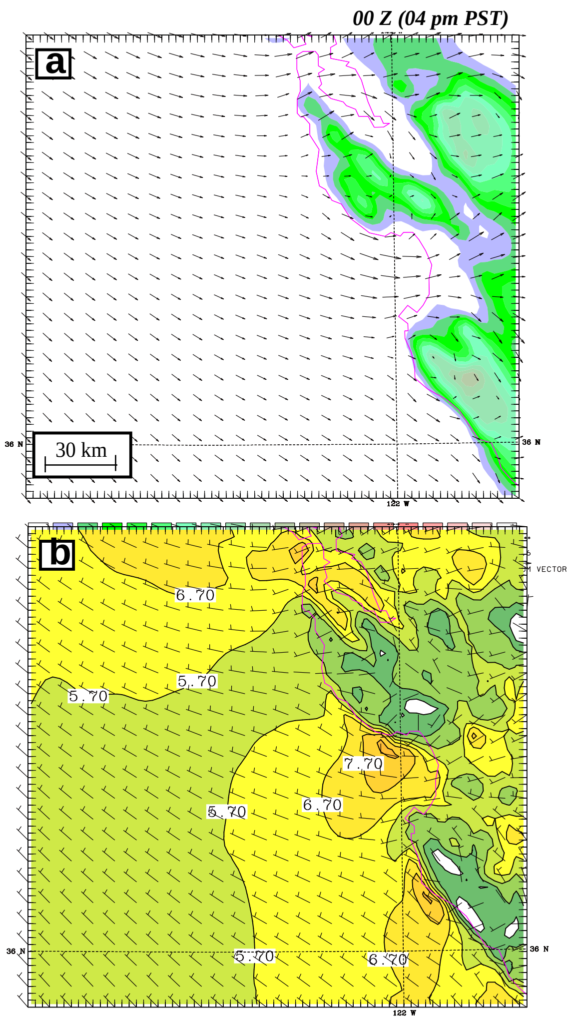

Fig.7 The same as Fig.6, but for Monterey Bay area, which is averaged from June 17 to July 13, 2004.

heatup apparently helps to speed up the inland flows (Fig.6a,c), and conversely the land-surface cooling slows down the flows (Fig.6b,d) during the nighttime. It should be pointed out that the relatively cold water in these areas is even cooler than the land in the nights. Therefore, land breezes do not develop during the nighttime. Most of the resistance on the channelled, invading flows are from the mountain breezes that drain down along the slopes and merge toward the valleys. Third, the complex terrain features are the driving force to shape the extremely rich-structured flows over the mountains. In the daytime, the mountains diverge the sea-breeze streams, whereas, in the nighttime, the mountain breezes become dominant, causing very weak winds over the land and nearly calm winds in the valleys.

Another interesting and remarkable feature in the surface winds (in Fig. 6c and d) is the occurrence of patches of strong winds over the water close to the coast. The maximum wind speeds in the core can be double those of the large-scale prevailing winds. Some common properties of these wind zones are observed: they all locate in the regions where the prevailing winds are nearly parallel to the coastline where coastal steep mountains inhibit inland penetration. The consistent orientation of wind directions and coastlines are favorable for producing cyclonic vorticity through differential friction, and the steep terrain lead to accumulation of vorticity. These enhanced vorticities may speed up the flows over the water.

3.3b Monterey Bay region

The RTFDDA system was run over the Monterey Bay area for a total of 27 days, from June 17 to July 13. The mean surface winds of the RTFDDA analyses averaged in the period are plotted in Fig.7. Amazingly, almost all findings from the San Francisco Bay regions, discussed above, can be applied here in spite of the differences in the length and dates between the average periods. Thus no more discussion is necessary.

3.3c Point Mugu region

The last stage (4 - 22, Agu. 2004) of summer RTFDDA operation over the California coastal regions were in the Point Mugu area, which spans from Santa Barbara to the San Pedro, including the bay area covering major islands, bounded by San Clemente at the south. This segment of the coast features sharp curvature of coastlines and the nearly west-east-oriented high Santa Barbara ranges to the north. Under typical large-scale situations in which northern winds exist, these two geographic features favor generation of strong cyclonic vorticity over the bay area, which frequently leads to development of various mesoscale eddies. The sizes of the eddies vary from tens to 300 kilometers and the intensities and locations of the eddies also change greatly from day to day. The well-known Catalina eddy is one of them, which develops when strong northerly winds extend over the Santa Barbara ranges and descend with hot air to produce a low pressure system. Due to the large variations of the eddy properties in the region, averages over entire time period would mask many interesting details. Instead, we pick 8 days (Aug. 4, 7, 8, 10, 11, 13, 14 and 16) on which the large-scale forcing and local eddy development are similar, to conduct averages to discuss the RTFDDA simulations of the roles of the local control forcing.

The averaged surface winds and sea-level pressure for 00Z (04pm PST) and 12Z (04am PST) are shown in

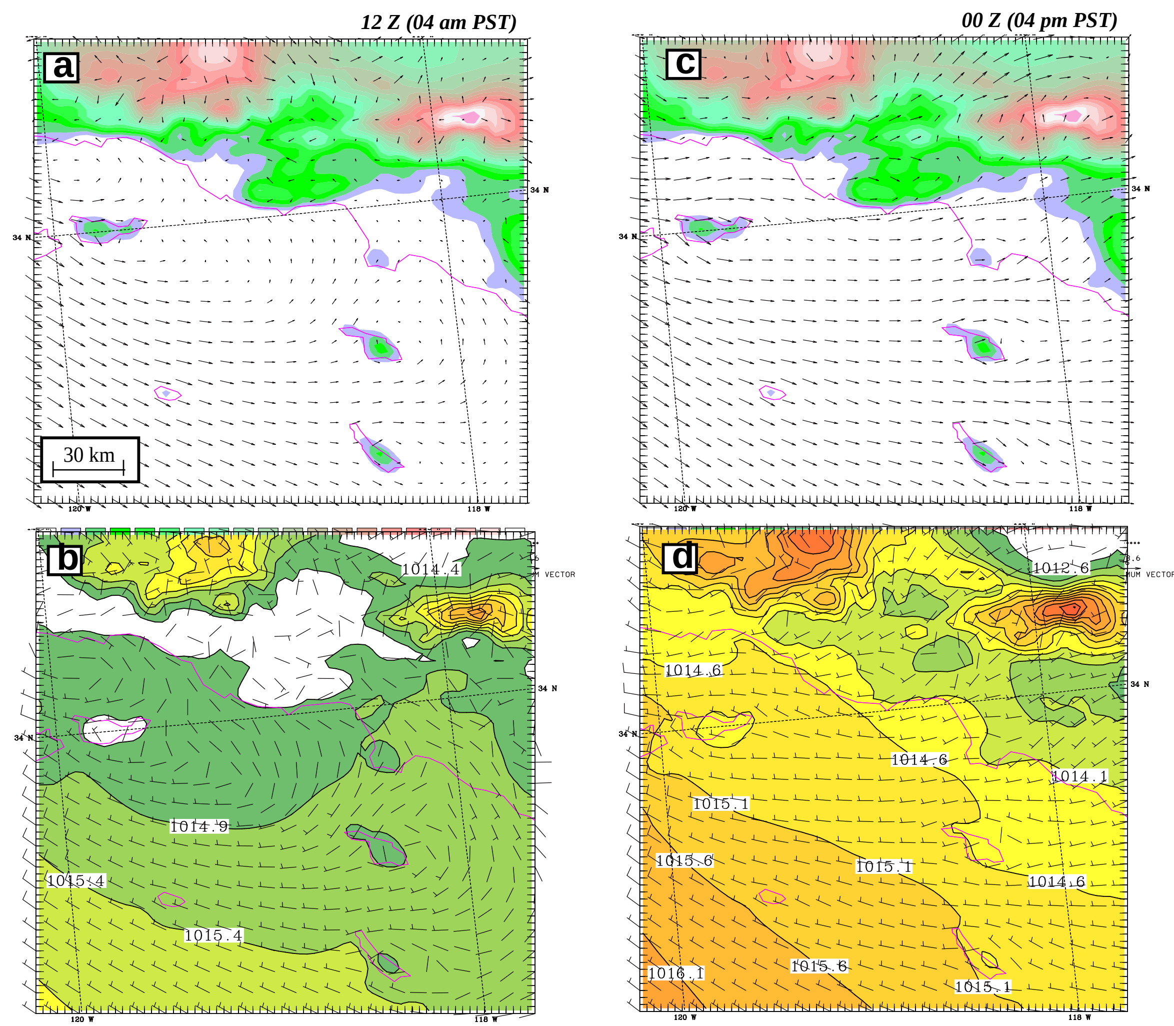

Fig.8 Mean surface winds of the RTFDDA fine mesh analyses over Point Mugu (south California coastal) area, averaged for 8 days selected in August 2004, on which eddy occurrences are similar. The terrain is shaded in (a) and (c) at increments of 100 m. The contours and shading in (b) and (d) are for mean sea-level pressure. The left panels are for 12 Z (04 am PST) and the right are for 00Z (04 pm PST).

Fig. 8. Obviously, the local forcing due to the terrain and land-sea contrasts play a critical role on the local circulation developments. An enlongated low pressure region can be observed in the northern portion of the bay area and shores in the early morning (Fig.8c). This low gradually builds up during the nighttime and starts weakening during the daytime. Up to 00Z (Fig.8d), the low can hardly be identified. Instead, an overall pressure gradient, normal to the coastlines is built up due to the uneven heating between the sea and land. The crossing-over air flows, combined with the drainage flows over Sta Barbara mountains are responsible for formation of the low. A warm band of about 5 C warmer than the neighboring regions can be seen right in the lee side of the mountain at 12Z (Fig. not shown).

The local circulations in the region are significantly affected by the pressure gradients. In the early morning, associated which the low pressure system is the large eddy circulations. The main center of the eddy is collocated with that of the low and the eddy circulations extend southeastward broadly over water along the coast. Similar to the San Francisco regions, the relatively cool ocean water is cooler than the land even in the nighttime. Thus no land-breezes develop. The drainage flows (mountain breezes) running downslope from the mountain ridges and the crossing-mountain descents over the land are able to confine the eddy circulations mostly over water.

From sunrise, the land is heated up, the low pressure is weakening and an overall pressure gradient from the sea toward the land is built up. As a result, the wind circulations adjust correspondingly. The flow pattern at 00Z (Fig.8b,d) is dramatically different from that in the early morning. The flows over water are much smoother, except for some minor distortions by the small islands. Sea-breezes are well developed over the land and penetrate deep inland along the valleys. Upslope valley-breezes are evident over all mountain regions, which further refined the structures of the complex flow pattern over the land.

4. SUMMARY

Mesoscale circulations in coastal regions are controlled by large-scale flow, land-water thermal and dynamic contrasts, and distribution and steepness of terrain over the land. Accurate simulations of the details of various local forcing factors, such as refined terrain and land use representations and coastlines, are essential to simulate locally thermally-forced circulations and the modulation of the local forcing on the large-scale flows. The change of relative strength of the forcing components, and the diurnal evolution of the forcing properties, including the PBL stabilities can dramatically change the local circulation features. It is found that the full-physics multi-scale high-resolution RTFDDA system appears to be able to simulate reasonably-well the controlling factors that affect the microclimatologies of different coastal regions and to discriminate the relative roles of the controlling forcing factors. The RTFDDA system is able to provide rich and informative details of spatial distributions of winds, and thermal features and moisture in a local region under specific large scale control scenarios or seasons, and time of day.

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